



# Observation of the $\gamma\gamma \rightarrow \tau\tau$ process in Pb+Pb collisions and constraints on the $\tau$ -lepton anomalous magnetic moment with the ATLAS detector

The ATLAS Collaboration

This Letter reports the observation of  $\tau$ -lepton pair production in ultraperipheral lead–lead collisions,  $\text{Pb+Pb} \rightarrow \text{Pb}(\gamma\gamma \rightarrow \tau\tau)\text{Pb}$ , and constraints on the  $\tau$ -lepton anomalous magnetic moment,  $a_\tau$ . The dataset corresponds to an integrated luminosity of  $1.44 \text{ nb}^{-1}$  of LHC Pb+Pb collisions at  $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$  recorded by the ATLAS experiment in 2018. Selected events contain one muon from a  $\tau$ -lepton decay, an electron or charged-particle track(s) from the other  $\tau$ -lepton decay, little additional central-detector activity, and no forward neutrons. The  $\gamma\gamma \rightarrow \tau\tau$  process is observed in Pb+Pb collisions with a significance exceeding 5 standard deviations, and a signal strength of  $\mu_{\tau\tau} = 1.03^{+0.06}_{-0.05}$  assuming the Standard Model value for  $a_\tau$ . To measure  $a_\tau$ , a template fit to the muon transverse-momentum distribution from  $\tau$ -lepton candidates is performed, using a dimuon ( $\gamma\gamma \rightarrow \mu\mu$ ) control sample to constrain systematic uncertainties. The observed 95% confidence-level interval for  $a_\tau$  is  $-0.057 < a_\tau < 0.024$ .

Measurements of the anomalous magnetic moment,  $a_\ell = \frac{1}{2}(g_\ell - 2)$ , of charged leptons  $\ell$  (electrons, muons, and  $\tau$ -leptons) are cornerstone tests of the Standard Model (SM) with unique sensitivity to beyond-the-SM (BSM) phenomena. The leading contribution to  $a_\ell$  in the SM is the one-loop Schwinger term  $\alpha_{\text{EM}}/2\pi \simeq 0.00116$  [1, 2], where  $\alpha_{\text{EM}}$  is the electromagnetic (EM) fine-structure constant. For the electron (muon),  $a_e$  ( $a_\mu$ ) is tested to parts per  $10^{10}$  [3–8] ( $10^7$  [9–11]) precision. Measurements of  $a_\mu$  report tensions with the SM expectation [12–16], which may suggest BSM dynamics. Specific BSM scenarios such as supersymmetry [17] predict enhancements that scale quadratically with lepton mass  $m_\ell$ , i.e.  $\delta a_\ell \propto m_\ell^2$ , resulting in a  $(m_\tau/m_\mu)^2 \simeq 280$  times larger effect for  $\tau$ -leptons. However, the short  $\tau$ -lepton lifetime precludes precise spin-precession measurements of  $a_\tau$  to test the SM prediction of  $a_\tau^{\text{SM}} = 0.001\,177\,21(5)$  [18] and potential BSM contributions.

Photon-induced events arise from interactions between the EM fields surrounding the beam particles at colliders. Observing photon-induced  $\tau$ -lepton pairs ( $\gamma\gamma \rightarrow \tau\tau$ ) predicted to occur at the Large Hadron Collider (LHC) [19–26] would open the way to hadron-collider probes of  $a_\tau$ . Currently, the most precise single-experiment measurement is  $a_\tau = -0.018(17)$  by the DELPHI Collaboration [27, 28] using  $\gamma\gamma \rightarrow \tau\tau$  events at the Large Electron Positron (LEP) collider. The OPAL [29] and L3 [30] Collaborations also set constraints using radiative  $\tau$ -lepton decays [31]. At the LHC, photon-induced dilepton production has only been measured in the dielectron ( $ee$ ) and dimuon ( $\mu\mu$ ) channels, using proton–proton ( $pp$ ) [32–37] and lead–lead (Pb+Pb) collisions [38–43]. The  $\tau\tau$  channel is challenging due to hadronic backgrounds and neutrinos in  $\tau$ -lepton decays diluting visible final-state kinematics. This renders triggering and reconstruction more difficult, especially in high-luminosity  $pp$  collisions. Strategies to overcome these experimental obstacles using heavy-ion collisions were proposed in Refs. [44–46].

This Letter presents the observation of the Pb+Pb  $\rightarrow$  Pb( $\gamma\gamma \rightarrow \tau\tau$ )Pb process and measurement of  $a_\tau$  using  $1.44\text{ nb}^{-1}$  of  $\sqrt{s_{\text{NN}}} = 5.02\text{ TeV}$  Pb+Pb data recorded by ATLAS in 2018. The EM fields accompanying the ions coherently create photons that interact to produce  $\tau$ -lepton pairs. The cross-section is enhanced by  $Z^4$  relative to  $pp$  collisions, where  $Z$  is the atomic number ( $Z = 82$  for lead). The ions can remain intact, enabling selection of low-multiplicity events with one muon originating from one of the  $\tau$ -leptons, while the other  $\tau$ -lepton decay is reconstructed as either an electron or one or three charged-particle tracks with low transverse momentum.

The ATLAS experiment [47–49] is a multipurpose particle detector with cylindrical geometry [50], comprising an inner detector (ID) tracker, EM and hadronic calorimeters, and a muon spectrometer (MS). The zero-degree calorimeters (ZDC) [51] are located at  $z = \pm 140\text{ m}$  from the interaction point, and detect neutral particles such as neutrons emitted from interacting nuclei. A two-level trigger system [52, 53] was used to select events containing one muon with  $p_T > 4\text{ GeV}$ , and at most 50 GeV (3 GeV) of transverse energy deposited in the whole (forward  $3.2 < |\eta| < 4.9$ ) calorimeter [54]. An extensive software suite [55] is used in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems. Standard data-quality requirements are imposed [56]. The average number of hadronic interactions per bunch crossing was 0.003.

Samples of simulated  $\gamma\gamma \rightarrow \tau\tau$  signal events were produced at leading order in QED using the STARLIGHT 2.0 [57] Monte Carlo (MC) generator, interfaced with TAUOLA [58, 59] for  $\tau$ -lepton decays. Final-state radiation (FSR) from the  $\tau$ -leptons and charged decay products of  $\tau$ -leptons was simulated using PYTHIA 8.245 [60] and PHOTOS++ 3.61 [61], respectively. One of the dominant background sources is the  $\gamma\gamma \rightarrow \mu\mu$  process, and its contribution is estimated with the aid of MC samples generated using STARLIGHT; PYTHIA 8 was used to model EM FSR from the muons. The photon-flux distribution in simulated  $\gamma\gamma \rightarrow \tau\tau$  and  $\gamma\gamma \rightarrow \mu\mu$  events was reweighted to that of SUPERCHIC 3.05 [62], differentially in

dilepton invariant mass and dilepton rapidity. In the STARLIGHT and SUPERCHIC simulations, no restriction on the Coulomb breakup of either nucleus was imposed. Dijet samples from photon-induced diquark production,  $\gamma\gamma \rightarrow q\bar{q}$ , were generated using PYTHIA 8. Nondiffractive photonuclear events ( $\gamma A \rightarrow X$ ) were simulated with STARLIGHT interfaced with DPMJET-III [63]. All MC samples were passed through a detailed detector simulation based on GEANT4 [64, 65].

Charged-particle tracks reconstructed in the ID must satisfy  $p_T > 100$  MeV,  $|\eta| < 2.5$ , transverse impact parameter  $|d_0| < 1.5$  mm, and the ‘‘Loose Primary’’ track selection criterion [66–68]. Electrons must satisfy  $p_T > 4$  GeV,  $|\eta| < 2.47$  (excluding the calorimeter transition region, i.e.  $|\eta| \notin [1.37, 1.52]$ ),  $|d_0| < 0.5$  mm, and ‘‘Loose’’ [69] likelihood-based identification criteria. Muons must satisfy  $p_T > 4$  GeV,  $|\eta| < 2.4$ ,  $|d_0| < 0.3$  mm, and ‘‘LowPt’’ [70] identification criteria. Small corrections, derived using tag-and-probe methods similar to those in Refs. [40, 71, 72], are applied to simulated reconstruction and trigger efficiencies of electrons and muons. Clusters of topologically connected calorimeter cells called topoclusters [73] must satisfy  $|\eta| < 4.9$ ,  $p_T > 0.1$  GeV ( $p_T > 1$  GeV) for  $2.5 < |\eta| < 4.9$  ( $|\eta| < 2.5$ ), and the cell significance criteria for measured energies outlined in Ref. [74]. Topoclusters from calorimeter regions with an abnormal noise distribution are removed using a data-driven procedure based on analyzing  $\eta$ – $\phi$  distributions of topocluster activity for each calorimeter layer. Reconstructed photons must satisfy  $E_T > 1.5$  GeV,  $|\eta| < 2.37 \notin [1.37, 1.52]$ , and dedicated identification criteria defined in Ref. [72].

Selected events must contain exactly one muon, which targets a muonic decay of one of the  $\tau$ -leptons while reducing backgrounds from  $\gamma\gamma \rightarrow \mu\mu$  and  $\gamma\gamma \rightarrow q\bar{q}$ . Three signal regions (SR) then categorize events by the decay signature of the other  $\tau$ -lepton. The  $\mu e$ -SR category additionally requires one electron, and no additional tracks separated from the muon (electron) by  $\Delta R_{\mu(e),\text{trk}} > 0.1$ , which targets fully leptonic decays of both  $\tau$ -leptons. The different-flavor ( $\mu e$ ) requirement suppresses same-flavor backgrounds dominated by  $\gamma\gamma \rightarrow \mu\mu/ee$ . The  $\mu 1\text{T}$ -SR ( $\mu 3\text{T}$ -SR) category requires exactly one track (three tracks) separated from the muon by  $\Delta R_{\mu,\text{trk}} > 0.1$ , which targets  $\tau$ -lepton decays to one or three charged hadrons. The one-track requirement also captures leptonic  $\tau$ -lepton decays that fail electron or muon reconstruction. The electric charges of the muon, electron, and tracks must sum to zero.

For both  $\mu 1\text{T}$ -SR and  $\mu 3\text{T}$ -SR, events must contain no additional muons satisfying looser criteria and no electrons to reject  $\gamma\gamma \rightarrow \mu\mu/ee$  backgrounds. The looser requirements on muons comprise matched tracks in the ID and MS satisfying  $p_T > 2$  GeV and  $|\eta| < 2.5$ . To suppress hadronic backgrounds such as photonuclear processes, there must be no topoclusters separated from the muon (track or three-track system [75]) by  $\Delta R_{\text{clust},\mu} > 0.3$  ( $\Delta R_{\text{clust},\text{trk}(s)} > 1.0$ ); this requirement is referred to as the topocluster veto. To further reduce photonuclear backgrounds, the acoplanarity between the muon and the track (three-track system) must satisfy  $A_\phi^{\mu,\text{trk}(s)} \equiv 1 - |\Delta\phi_{\mu,\text{trk}(s)}|/\pi < 0.4$  (0.2). The signal has a narrower  $A_\phi^{\mu,\text{trk}(s)}$  distribution in  $\mu 3\text{T}$ -SR than  $\mu 1\text{T}$ -SR, motivating the tighter requirement.

For  $\mu 1\text{T}$ -SR, the  $p_T$  of the muon–track pair must satisfy  $p_T^{\mu,\text{trk}} > 1$  GeV to reject  $p_T$ -balanced backgrounds, such as  $\gamma\gamma \rightarrow \mu\mu$ . To further reduce the  $\gamma\gamma \rightarrow \mu\mu\gamma$  background, the  $p_T$  of the muon, track, and photon (topocluster) system must fulfill  $p_T^{\mu,\text{trk},\gamma(\text{clust})} > 1$  GeV for events containing a photon (topocluster) within  $\Delta R_{\gamma(\text{clust}),\text{trk}} = 1$  of the track. If there are multiple nearby photons (topoclusters), the highest- $p_T$  photon (topocluster) is used. The topoclusters considered here must have  $p_T > 2$  GeV and not be track-matched; these criteria avoid track-induced topoclusters from, e.g., charged-pion energy deposits. Topoclusters within  $\Delta R_{\text{clust},\text{trk}} = 0.1$  of a track with  $p_T > 0.7$  GeV extrapolated to the calorimeter are considered track-matched. Low-multiplicity events in minimum-bias data are used to correct for the bending due to the magnetic field, such that the  $\Delta R_{\text{clust},\text{trk}}$  distribution of topoclusters associated with a track peaks at

zero. Tracks with  $p_T < 0.7$  GeV are not considered in the track–cluster matching as they typically do not deposit significant energy in the calorimeter.

For  $\mu 3\text{T-SR}$ , the three-track system mass must fulfill  $m_{3\text{trk}} < 1.7$  GeV, assuming each track has the charged-pion mass of 140 MeV. This requirement retains three-prong hadronic  $\tau$ -lepton decays and suppresses background from exclusive  $\rho^0$  mesons ( $\gamma A \rightarrow \rho^0 \rightarrow \pi\pi$ ) produced simultaneously with  $\gamma\gamma \rightarrow \mu\mu$  events. In this background process, neither muon is correlated with the  $\pi\pi$  system and  $m_{\pi\pi\mu}$  typically exceeds 1.7 GeV for a muon with  $p_T$  of several GeV.

To constrain the  $\gamma\gamma \rightarrow \mu\mu$  background, a control region (CR) of dimuon events called  $2\mu\text{-CR}$  is defined. It requires exactly two muons with invariant mass above 11 GeV to suppress quarkonia ( $Y(nS) \rightarrow \mu\mu$ ) backgrounds and no additional tracks separated from the muons by  $\Delta R_{\mu,\text{trk}} > 0.1$ .

Events must additionally not have ZDC energies satisfying  $E_{\text{ZDC}} > 1$  TeV on each side, mainly to suppress photonuclear backgrounds where ion dissociation typically occurs. This class of events with no forward neutrons detected ( $0n0n$ ) corresponds to the absence of Coulomb breakup of either nucleus. Such breakup typically proceeds through the giant dipole resonance and induces the emission of one or more neutrons [40]. This requirement also fully suppresses lepton-pair production in which the initial photon emission results in the dissociation of one or both nuclei [40]. The SRs and  $2\mu\text{-CR}$  are all statistically independent. Since the extra forward neutron emissions are not simulated, the  $\gamma\gamma \rightarrow \ell\ell$  MC samples are corrected using data-driven probabilities for the  $0n0n$  event topology, which are found to be between 0.4 and 0.7. These are extracted from  $2\mu\text{-CR}$  without the  $E_{\text{ZDC}}$  requirement, differentially in dilepton invariant mass and dilepton rapidity.

The dominant sources of background after event selection are radiative dimuon ( $\gamma\gamma \rightarrow \mu\mu\gamma$ ) and photonuclear events with low central-detector activity.

The  $\gamma\gamma \rightarrow \mu\mu\gamma$  background is estimated with the aid of MC samples. This process enters  $\mu 1\text{T-SR}$  when FSR photons substantially modify the dimuon kinematics so as to mimic the signal kinematics, and enters  $\mu 3\text{T-SR}$  and  $\mu e\text{-SR}$  primarily when photons convert to  $e^+e^-$  in detector material. To improve the modeling of high- $p_T$  ( $p_T^\gamma \gtrsim p_T^\mu$ ) photon emissions for  $t$ - and  $u$ -channel  $\gamma\gamma \rightarrow \mu\mu$  processes, an additional  $\gamma\gamma \rightarrow \mu\mu\gamma$  MC sample generated using MADGRAPH5\_AMC@NLO [76] with the photon flux reweighted to SUPERCHIC is used instead of STARLIGHT+PYTHIA 8 if a leading photon has  $p_T^\gamma > 2$  GeV. Comparing the  $\gamma\gamma \rightarrow \mu\mu(\gamma)$  simulated events with data in  $2\mu\text{-CR}$  shows reasonable data-to-MC agreement in differential distributions, and normalization to within 5%. The simulated  $\gamma\gamma \rightarrow \mu\mu(\gamma)$  event yield in  $2\mu\text{-CR}$  is 15% lower than data if STARLIGHT photon-flux calculations are used due to known limitations of STARLIGHT [40, 77]. Before the fit to data, this method estimates 70, 6.5, and 2.8  $\gamma\gamma \rightarrow \mu\mu(\gamma)$  events enter  $\mu 1\text{T-SR}$ ,  $\mu 3\text{T-SR}$ , and  $\mu e\text{-SR}$ , respectively.

Diffraction photonuclear backgrounds with low particle activity are estimated using fully data-driven methods. Dedicated CRs are introduced, called  $\mu 2\text{T-CR}$  ( $\mu 4\text{T-CR}$ ), which apply the same selection as  $\mu 1\text{T-SR}$  ( $\mu 3\text{T-SR}$ ), but require an additional track satisfying  $p_T < 0.5$  GeV. Furthermore, the  $E_{\text{ZDC}} < 1$  TeV requirement is removed on either side to enrich the sample with events from photonuclear processes. To suppress the  $\gamma\gamma \rightarrow \tau\tau$  signal contamination in  $\mu 2\text{T-CR}$ , the two-track system mass must fulfill  $m_{2\text{trk}} > 1$  GeV; if  $m_{2\text{trk}} < 1$  GeV, the acoplanarity of the muon and highest- $p_T$  track is required to exceed 0.2. The event yields in CRs are extrapolated to SRs by loosening the veto on topoclusters not matched to the muon or tracks from  $n_{\text{TC}}^{\text{unmatch}} = 0$  to  $n_{\text{TC}}^{\text{unmatch}} \leq 8$ , both in CRs and SRs. The  $\mu 2\text{T-CR}$  ( $\mu 4\text{T-CR}$ ) templates for  $n_{\text{TC}}^{\text{unmatch}}$  distributions are normalized to the event yield in  $\mu 1\text{T-SR}$  ( $\mu 3\text{T-SR}$ ) in the region  $4 \leq n_{\text{TC}}^{\text{unmatch}} \leq 8$ . In this region, the signal and dimuon background contributions are found to be

negligible, and events exhibit properties that suggest nonexclusive diffractive production, such as a small or no rapidity gap [78]. As the additional track in  $\mu 2\text{T-CR}$  and  $\mu 4\text{T-CR}$  is soft ( $p_T < 0.5$  GeV), its possible correlation with topocluster activity is very small. This method estimates that 13 (2.8) photonuclear events enter  $\mu 1\text{T-SR}$  ( $\mu 3\text{T-SR}$ ); photonuclear events are expected to be negligible in  $\mu e\text{-SR}$ .

Other sources of background are predicted to be negligible in the SRs. Nondiffractive photonuclear interactions are estimated using the STARLIGHT+DPMJET-III sample and are found to be negligible in all three SRs. The PYTHIA 8 simulation of  $\gamma\gamma \rightarrow q\bar{q}$  estimates dijet backgrounds contribute less than 0.3 events in both  $\mu 1\text{T-SR}$  and  $\mu 3\text{T-SR}$ . Similarly, the contribution from resolved  $\gamma\gamma$  interactions, as estimated with PYTHIA 8 [79], is found to be negligible. Exclusive  $\rho^0$ -meson production with simultaneous  $\gamma\gamma \rightarrow \mu\mu$  production in  $\mu 3\text{T-SR}$  is studied using a data-driven method. Template distributions for this process are built from events with two muons and two additional charged-particle tracks. The acoplanarities of both the muon pair and the track pair must be below 0.05. All events in these templates are found to have  $m_{3\text{trk}} > 1.7$  GeV, so this background is expected to be negligible in  $\mu 3\text{T-SR}$ .

Systematic uncertainties affecting the measurement arise from the reconstruction of leptons, photons, charged-particle tracks and topoclusters, the signal and background modeling, and integrated luminosity.

Uncertainties in the muon momentum scale and resolution follow those in Ref. [80]. The analysis includes uncertainties in the data-to-MC correction factors applied to simulated samples for the muon trigger and reconstruction efficiencies. Uncertainties in the reconstruction, identification, and energy calibration of electrons and photons are evaluated in accord with Ref. [72]. The uncertainty in the inclusive track reconstruction efficiency is dominated by the uncertainty in the amount of ID material [67]. This uncertainty is applied in the simulation by randomly removing tracks with a  $p_T$ - and  $\eta$ -dependent probability corresponding to the material uncertainty. Uncertainties in the topocluster reconstruction efficiency and energy calibration are estimated using  $\gamma\gamma \rightarrow ee$  events where one of the electrons emits a hard bremsstrahlung photon due to its interaction with detector material [72].

Uncertainties in the photonuclear background evaluation are estimated by repeating the procedure with alternative requirements for CRs. These resemble the  $\mu 1\text{T-SR}$  ( $\mu 3\text{T-SR}$ ) selection except that the track (three-track system) has the same electric charge as the muon candidate. The difference between the photonuclear background contribution evaluated with alternative and nominal CRs defines the uncertainties, affecting both the normalization and differential distributions. Uncertainties in modeling the photon flux are estimated by using the STARLIGHT MC samples without reweighting to SUPERCHIC. This affects the normalization and differential distributions of the signal and  $\gamma\gamma \rightarrow \mu\mu$  background. Uncertainties in modeling  $\tau$ -lepton decays are estimated using PYTHIA 8 [81] as an alternative MC simulation to TAUOLA. The effect of  $\tau$ -lepton spin correlations in TAUOLA is implemented using helicity amplitudes from the  $\gamma^* \rightarrow \tau\tau$  process. This modeling is therefore cross-checked by comparing signal events simulated using two versions of PYTHIA 8: v8.245 uses helicity amplitudes from the  $\gamma^* \rightarrow \tau\tau$  process, whereas v8.305 uses the  $\gamma\gamma \rightarrow \tau\tau$  elementary process. The difference between the two implementations is found to be negligible, and no further systematic uncertainty is assigned.

The uncertainty in the integrated luminosity is 1.9%, obtained with the LUCID-2 detector [82] using methods similar to Ref. [83] for the primary luminosity measurements.

After applying the event selection, a total of 532, 85, and 39 data events are observed, compared with  $84 \pm 19$ ,  $9 \pm 3$ , and  $2.8 \pm 0.7$  expected background events in  $\mu 1\text{T-SR}$ ,  $\mu 3\text{T-SR}$ , and  $\mu e\text{-SR}$ , respectively. The background-only hypothesis is rejected with significance exceeding  $5\sigma$ , establishing the observation of the  $\gamma\gamma \rightarrow \tau\tau$  process at ATLAS. The signal significance is highest in  $\mu 1\text{T-SR}$ , while  $\mu e\text{-SR}$  has the

largest signal-to-background ratio. The pre-fit signal-plus-background hypothesis predicts  $543 \pm 111$ ,  $93 \pm 20$ , and  $35 \pm 8$  events in  $\mu 1\text{T-SR}$ ,  $\mu 3\text{T-SR}$ , and  $\mu e\text{-SR}$ , respectively, which is compatible with the observed data. The signal strength  $\mu_{\tau\tau}$ , defined as the ratio of the observed signal yield to the SM expectation assuming the SM value for  $a_\tau$ , is measured using a profile-likelihood fit [84, 85] to be  $\mu_{\tau\tau} = 1.03^{+0.06}_{-0.05}$  (tot) =  $1.03^{+0.05}_{-0.05}$  (stat)  $^{+0.03}_{-0.03}$  (syst). The fit uses the  $p_{\text{T}}^\mu$  distribution in the three SRs and  $2\mu\text{-CR}$  with  $\mu_{\tau\tau}$  being the only parameter of interest.

Approximately 80 nuisance parameters representing the systematic uncertainties are included in the fit. Many systematic uncertainties are correlated between the SRs and  $2\mu\text{-CR}$ , so their impact on the measurement precision is minimized since they are constrained by  $2\mu\text{-CR}$ . The dominant pre-fit contribution is the photon-flux uncertainty, which mainly affects the signal yield (by approximately 20%), with a significantly smaller impact on the signal shape found upon decorrelation from the normalization component. After the fit, the photon-flux uncertainty becomes subdominant and luminosity uncertainty becomes negligible relative to other sources. The leading contributions to the total systematic uncertainty are the estimation of the muon trigger efficiency,  $\tau$ -lepton decay modeling, and track reconstruction efficiency.

To measure  $a_\tau$ , an alternative fit is performed where  $a_\tau$  is the only free parameter using the  $p_{\text{T}}^\mu$  distribution in the three SRs and  $2\mu\text{-CR}$ ;  $p_{\text{T}}^\mu$  is chosen because of its high sensitivity to  $a_\tau$  [46]. Simulated signal samples with various  $a_\tau$  values are employed. In the nominal sample,  $a_\tau$  is set to its SM value. Signal templates for alternative  $a_\tau$  hypotheses are obtained by reweighting the nominal sample in three dimensions, differentially in  $\tau\tau$  invariant mass,  $\tau\tau$  rapidity, and rapidity difference between the two  $\tau$ -leptons, according to calculations from Ref. [46]. These calculations parameterize the  $\tau\tau\gamma$  coupling by  $F_1(q^2)\gamma^\mu + F_2(q^2)\frac{i}{2m_\tau}\sigma^{\mu\nu}q_\nu$ , where  $q_\nu$  is the photon four-momentum,  $\sigma^{\mu\nu} = i[\gamma^\mu, \gamma^\nu]/2$  the spin tensor, and the form factors satisfy  $F_1(q^2 \rightarrow 0) = 1$  and  $F_2(q^2 \rightarrow 0) = a_\tau$ . A similar parameterization was used in previous LEP measurements [27, 29, 30], which exploits the near-zero virtuality of initial-state photons. A total of 14 templates for different  $a_\tau$  values are created to model the dependence of the  $p_{\text{T}}^\mu$  distribution on  $a_\tau$  in the three SRs.

Figure 1 shows the  $p_{\text{T}}^\mu$  distributions of the four analysis regions for the data and post-fit expectation. The fit describes the data well.

The best-fit value of  $a_\tau$  is  $a_\tau = -0.041$ , with the corresponding 68% CL and 95% CL intervals being  $(-0.050, -0.029)$  and  $(-0.057, 0.024)$ , respectively. The higher-than-expected observed yields lead to the highly asymmetric 95% CL interval. This arises from the nearly quadratic signal cross-section dependence on  $a_\tau$ , caused by the interference of the SM and BSM amplitudes [29, 30, 46]. The expected 95% CL interval is  $-0.039 < a_\tau < 0.020$ . The impact of systematic uncertainties on the final results is small relative to statistical uncertainties. Figure 2 shows the  $a_\tau$  measurement alongside previous results obtained at LEP. The precision of this measurement is similar to the most precise single-experiment measurement by the DELPHI Collaboration.

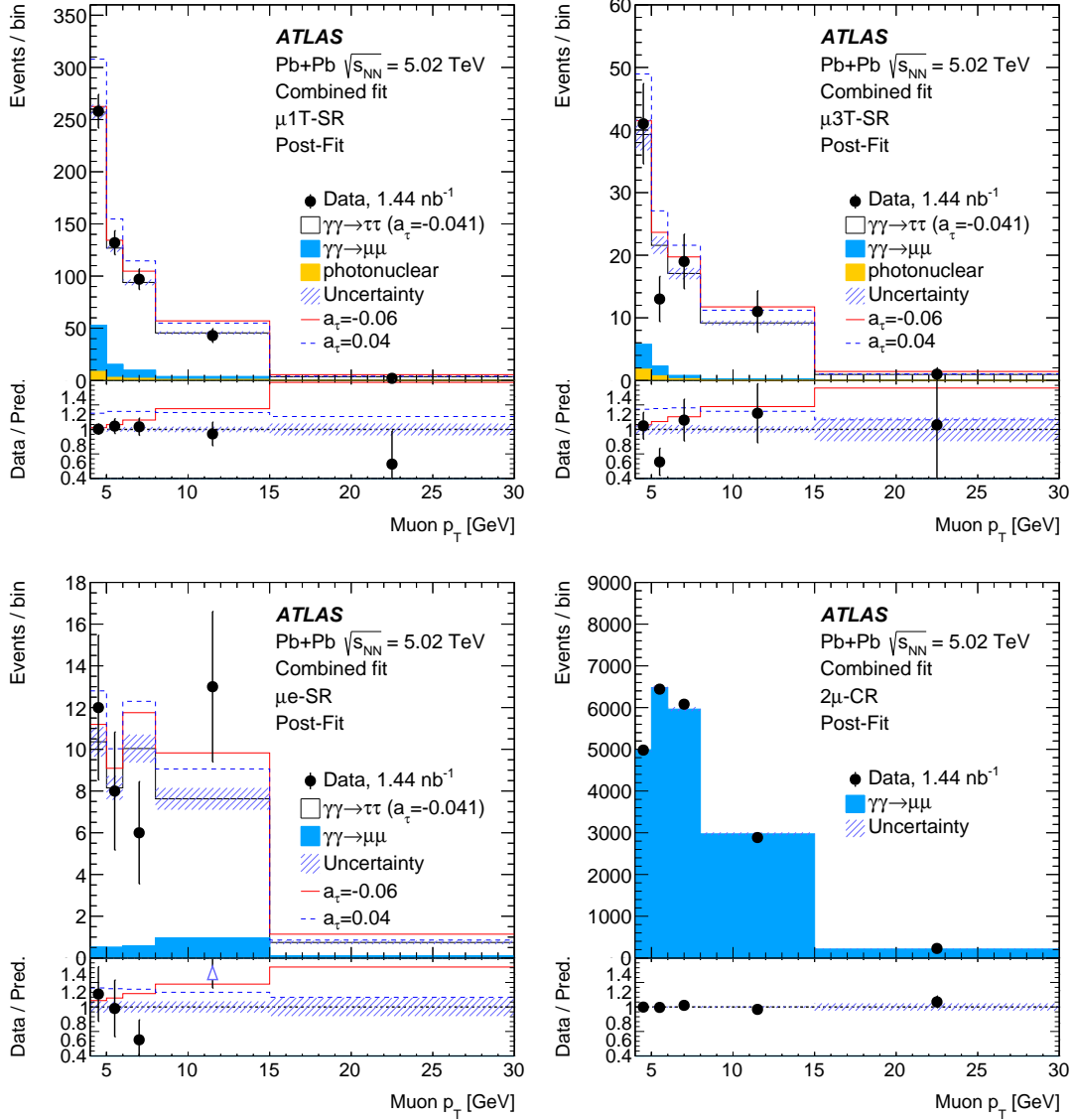


Figure 1: Muon transverse momentum distributions in the (top-left)  $\mu 1T$ -SR, (top-right)  $\mu 3T$ -SR, (bottom-left)  $\mu e$ -SR, and (bottom-right)  $2\mu$ -CR categories. Black markers denote data and stacked histograms indicate the different components contributing to the regions. Post-fit distributions are shown with the signal contribution corresponding to the best-fit  $a_\tau$  value ( $a_\tau = -0.041$ ). For comparison, signal contributions with alternative  $a_\tau$  values are shown as solid red ( $a_\tau = -0.06$ ) or dashed blue ( $a_\tau = 0.04$ ) lines. The bottom panel shows the ratio of the data to post-fit predictions. Vertical bars denote uncertainties from the finite number of data events. Hatched bands represent  $\pm 1\sigma$  systematic uncertainties of the prediction with the constraints from the fit applied.

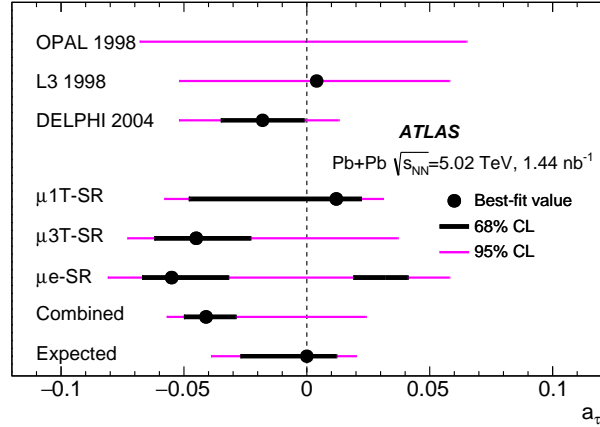


Figure 2: Measurements of  $a_\tau$  from fits to individual signal regions (including the dimuon control region), and from the combined fit. These are compared with existing measurements from the OPAL [29], L3 [30] and DELPHI [27] experiments at LEP. A point denotes the best-fit  $a_\tau$  value for each measurement if available, while thick black (thin magenta) lines show 68% CL (95% CL) intervals. The expected interval from the ATLAS combined fit is also shown.

In summary,  $\tau$ -lepton pair production in ultraperipheral heavy-ion collisions,  $\text{Pb}+\text{Pb} \rightarrow \text{Pb}(\gamma\gamma \rightarrow \tau\tau)\text{Pb}$ , is observed by ATLAS with a significance exceeding  $5\sigma$  in  $1.44 \text{ nb}^{-1}$  of  $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$  data at the LHC. The observed event yield is compatible with that expected from the SM prediction within uncertainties. The events are used to set constraints on the  $\tau$ -lepton anomalous magnetic moment, corresponding to  $-0.057 < a_\tau < 0.024$  at 95% CL. The measurement precision is limited by statistical uncertainties. This result introduces the use of hadron-collider data to test electromagnetic properties of the  $\tau$ -lepton, and the results are competitive with existing lepton-collider constraints.

## Acknowledgments

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; ANID, Chile; CAS, MOST and NSFC, China; Minciencias, Colombia; MEYS CR, Czech Republic; DNRf and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ISF and Benozziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MEiN, Poland; FCT, Portugal; MNE/IFA, Romania; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DSI/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TENMAK, Türkiye; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada and CRC, Canada; PRIMUS 21/SCI/017 and UNCE SCI/013, Czech Republic; COST, ERC, ERDF, Horizon 2020 and Marie Skłodowska-Curie



Actions, European Union; Investissements d’Avenir Labex, Investissements d’Avenir Idex and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and MINERVA, Israel; Norwegian Financial Mechanism 2014-2021, Norway; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [86].

## References

- [1] J. Schwinger, *On Quantum-Electrodynamics and the Magnetic Moment of the Electron*, [Phys. Rev. \*\*73\*\* \(1948\) 416](#).
- [2] P. Kusch and H. M. Foley, *The Magnetic Moment of the Electron*, [Phys. Rev. \*\*74\*\* \(1948\) 250](#).
- [3] B. Odom, D. Hanneke, B. D’Urso, and G. Gabrielse, *New Measurement of the Electron Magnetic Moment Using a One-Electron Quantum Cyclotron*, [Phys. Rev. Lett. \*\*97\*\* \(2006\) 030801](#).
- [4] D. Hanneke, S. Fogwell Hoogerheide, and G. Gabrielse, *Cavity control of a single-electron quantum cyclotron: Measuring the electron magnetic moment*, [Phys. Rev. A \*\*83\*\* \(2011\) 052122](#), arXiv: [1009.4831 \[physics.atom-ph\]](#).
- [5] R. Bouchendira, P. Cladé, S. Guellati-Khélifa, F. Nez, and F. Biraben, *New Determination of the Fine Structure Constant and Test of the Quantum Electrodynamics*, [Phys. Rev. Lett. \*\*106\*\* \(2011\) 080801](#).
- [6] T. Aoyama, M. Hayakawa, T. Kinoshita, and M. Nio, *Tenth-Order QED Contribution to the Electron  $g-2$  and an Improved Value of the Fine Structure Constant*, [Phys. Rev. Lett. \*\*109\*\* \(2012\) 111807](#), arXiv: [1205.5368 \[hep-ph\]](#).
- [7] R. H. Parker, C. Yu, W. Zhong, B. Estey, and H. Müller, *Measurement of the fine-structure constant as a test of the Standard Model*, [Science \*\*360\*\* \(2018\) 191](#), arXiv: [1812.04130 \[physics.atom-ph\]](#).
- [8] L. Morel, Z. Yao, P. Cladé, and S. Guellati-Khélifa, *Determination of the fine-structure constant with an accuracy of 81 parts per trillion*, [Nature \*\*588\*\* \(2020\) 61](#).
- [9] G. W. Bennett et al., *Final report of the E821 muon anomalous magnetic moment measurement at BNL*, [Phys. Rev. D \*\*73\*\* \(2006\) 072003](#), arXiv: [hep-ex/0602035 \[hep-ex\]](#).
- [10] B. Abi et al., *Measurement of the Positive Muon Anomalous Magnetic Moment to 0.46 ppm*, [Phys. Rev. Lett. \*\*126\*\* \(2021\) 141801](#), arXiv: [2104.03281 \[hep-ex\]](#).
- [11] T. Albahri et al., *Measurement of the anomalous precession frequency of the muon in the Fermilab Muon  $g-2$  Experiment*, [Phys. Rev. D \*\*103\*\* \(2021\) 072002](#), arXiv: [2104.03247 \[hep-ex\]](#).
- [12] T. Aoyama, M. Hayakawa, T. Kinoshita, and M. Nio, *Complete Tenth-Order QED Contribution to the Muon  $g-2$* , [Phys. Rev. Lett. \*\*109\*\* \(2012\) 111808](#), arXiv: [1205.5370 \[hep-ph\]](#).

- [13] A. Keshavarzi, D. Nomura, and T. Teubner, *Muon  $g - 2$  and  $\alpha(M_Z^2)$ : A new data-based analysis*, *Phys. Rev. D* **97** (2018) 114025, arXiv: [1802.02995 \[hep-ph\]](#).
- [14] M. Davier, A. Hoecker, B. Malaescu, and Z. Zhang, *A new evaluation of the hadronic vacuum polarisation contributions to the muon anomalous magnetic moment and to  $\alpha(m_Z^2)$* , *Eur. Phys. J. C* **80** (2020) 241, arXiv: [1908.00921 \[hep-ph\]](#).
- [15] T. Aoyama et al., *The anomalous magnetic moment of the muon in the Standard Model*, *Phys. Rept.* **887** (2020) 1, arXiv: [2006.04822 \[hep-ph\]](#).
- [16] Sz. Borsanyi et al., *Leading hadronic contribution to the muon magnetic moment from lattice QCD*, *Nature* **593** (2021) 51, arXiv: [2002.12347 \[hep-lat\]](#).
- [17] S. P. Martin and J. D. Wells, *Muon anomalous magnetic dipole moment in supersymmetric theories*, *Phys. Rev. D* **64** (2001) 035003, arXiv: [hep-ph/0103067 \[hep-ph\]](#).
- [18] S. Eidelman and M. Passera, *Theory of the tau lepton anomalous magnetic moment*, *Mod. Phys. Lett. A* **22** (2007) 159, arXiv: [hep-ph/0701260 \[hep-ph\]](#).
- [19] G. Breit and J. A. Wheeler, *Collision of Two Light Quanta*, *Phys. Rev.* **46** (1934) 1087.
- [20] W. Heisenberg and H. Euler, *Folgerungen aus der Diracschen Theorie des Positrons*, *Z. Physik* **98** (1936) 714, arXiv: [physics/0605038](#).
- [21] J. Schwinger, *On Gauge Invariance and Vacuum Polarization*, *Phys. Rev.* **82** (1951) 664.
- [22] M.-S. Chen, I. J. Muzinich, H. Terazawa, and T. P. Cheng, *Lepton Pair Production from Two-Photon Processes*, *Phys. Rev. D* **7** (1973) 3485.
- [23] S. R. Klein and P. Steinberg, *Photonuclear and Two-Photon Interactions at High-Energy Nuclear Colliders*, *Ann. Rev. Nucl. Part. Sci.* **70** (2020) 323, arXiv: [2005.01872 \[nucl-ex\]](#).
- [24] V. M. Budnev, I. F. Ginzburg, G. V. Meledin, and V. G. Serbo, *The two-photon particle production mechanism. Physical problems. Applications. Equivalent photon approximation*, *Phys. Rept.* **15** (1975) 181.
- [25] A. J. Baltz et al., *The physics of ultraperipheral collisions at the LHC*, *Phys. Rept.* **458** (2008) 1, arXiv: [0706.3356 \[nucl-ex\]](#).
- [26] J. de Favereau de Jeneret et al., *High energy photon interactions at the LHC*, (2009), arXiv: [0908.2020 \[hep-ph\]](#).
- [27] DELPHI Collaboration, *Study of tau-pair production in photon-photon collisions at LEP and limits on the anomalous electromagnetic moments of the tau lepton*, *Eur. Phys. J. C* **35** (2004) 159, arXiv: [hep-ex/0406010 \[hep-ex\]](#).
- [28] Particle Data Group, *Review of Particle Physics*, *Phys. Rev. D* **98** (2018) 030001.
- [29] OPAL Collaboration, *An upper limit on the anomalous magnetic moment of the  $\tau$  lepton*, *Phys. Lett. B* **431** (1998) 188, arXiv: [hep-ex/9803020 \[hep-ex\]](#).
- [30] L3 Collaboration, *Measurement of the anomalous magnetic and electric dipole moments of the tau lepton*, *Phys. Lett. B* **434** (1998) 169.
- [31] S. S. Gau, T. Paul, J. Swain, and L. Taylor, *Radiative tau lepton pair production as a probe of anomalous electromagnetic couplings of the tau*, *Nucl. Phys. B* **523** (1998) 439, arXiv: [hep-ph/9712360 \[hep-ph\]](#).

- [32] ATLAS Collaboration, *Measurement of exclusive  $\gamma\gamma \rightarrow \ell^+\ell^-$  production in proton–proton collisions at  $\sqrt{s} = 7$  TeV with the ATLAS detector*, *Phys. Lett. B* **749** (2015) 242, arXiv: [1506.07098 \[hep-ex\]](#).
- [33] ATLAS Collaboration, *Measurement of the exclusive  $\gamma\gamma \rightarrow \mu^+\mu^-$  process in proton–proton collisions at  $\sqrt{s} = 13$  TeV with the ATLAS detector*, *Phys. Lett. B* **777** (2018) 303, arXiv: [1708.04053 \[hep-ex\]](#).
- [34] ATLAS Collaboration, *Observation and Measurement of Forward Proton Scattering in Association with Lepton Pairs Produced via the Photon Fusion Mechanism at ATLAS*, *Phys. Rev. Lett.* **125** (2020) 261801, arXiv: [2009.14537 \[hep-ex\]](#).
- [35] CMS Collaboration, *Observation of proton-tagged, central (semi)exclusive production of high-mass lepton pairs in pp collisions at 13 TeV with the CMS-TOTEM precision proton spectrometer*, *JHEP* **07** (2018) 153, arXiv: [1803.04496 \[hep-ex\]](#).
- [36] CMS Collaboration, *Search for exclusive or semi-exclusive  $\gamma\gamma$  production and observation of exclusive and semi-exclusive  $e^+e^-$  production in pp collisions at  $\sqrt{s} = 7$  TeV*, *JHEP* **11** (2012) 080, arXiv: [1209.1666 \[hep-ex\]](#).
- [37] CMS Collaboration, *Exclusive  $\gamma\gamma \rightarrow \mu^+\mu^-$  production in proton–proton collisions at  $\sqrt{s} = 7$  TeV*, *JHEP* **01** (2012) 052, arXiv: [1111.5536 \[hep-ex\]](#).
- [38] ATLAS Collaboration, *Observation of Centrality-Dependent Acoplanarity for Muon Pairs Produced via Two-Photon Scattering in Pb+Pb Collisions at  $\sqrt{s_{NN}} = 5.02$  TeV with the ATLAS Detector*, *Phys. Rev. Lett.* **121** (2018) 212301, arXiv: [1806.08708 \[hep-ex\]](#).
- [39] ATLAS Collaboration, *Observation of Light-by-Light Scattering in Ultrapерipheral Pb+Pb Collisions with the ATLAS Detector*, *Phys. Rev. Lett.* **123** (2019) 052001, arXiv: [1904.03536 \[hep-ex\]](#).
- [40] ATLAS Collaboration, *Exclusive dimuon production in ultraperipheral Pb+Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV with ATLAS*, *Phys. Rev. C* **104** (2020) 024906, arXiv: [2011.12211 \[hep-ex\]](#).
- [41] CMS Collaboration, *Evidence for light-by-light scattering and searches for axion-like particles in ultraperipheral PbPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV*, *Phys. Lett. B* **797** (2019) 134826, arXiv: [1810.04602 \[hep-ex\]](#).
- [42] CMS Collaboration, *Observation of Forward Neutron Multiplicity Dependence of Dimuon Acoplanarity in Ultrapерipheral PbPb Collisions at  $\sqrt{s_{NN}} = 5.02$  TeV*, *Phys. Rev. Lett.* **127** (2020) 122001, arXiv: [2011.05239 \[hep-ex\]](#).
- [43] ALICE Collaboration, *Charmonium and  $e^+e^-$  pair photoproduction at mid-rapidity in ultraperipheral Pb-Pb collisions at  $\sqrt{s_{NN}}=2.76$  TeV*, *Eur. Phys. J. C* **73** (2013) 2617, arXiv: [1305.1467 \[nucl-ex\]](#).
- [44] F. del Aguila, F. Cornet, and J. I. Illana, *The possibility of using a large heavy-ion collider for measuring the electromagnetic properties of the tau lepton*, *Phys. Lett. B* **271** (1991) 256.
- [45] L. Beresford and J. Liu, *New physics and tau  $g - 2$  using LHC heavy ion collisions*, *Phys. Rev. D* **102** (2020) 113008, arXiv: [1908.05180 \[hep-ph\]](#).
- [46] M. Dyndal, M. Klusek-Gawenda, A. Szczurek, and M. Schott, *Anomalous electromagnetic moments of  $\tau$  lepton in  $\gamma\gamma \rightarrow \tau^+\tau^-$  reaction in Pb+Pb collisions at the LHC*, *Phys. Lett. B* **809** (2020) 135682, arXiv: [2002.05503 \[hep-ph\]](#).

- [47] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, **JINST** **3** (2008) S08003.
- [48] ATLAS Collaboration, *ATLAS Insertable B-Layer Technical Design Report*, ATLAS-TDR-19; CERN-LHCC-2010-013, 2010, URL: <https://cds.cern.ch/record/1291633>, Addendum: ATLAS-TDR-19-ADD-1; CERN-LHCC-2012-009, 2012, URL: <https://cds.cern.ch/record/1451888>.
- [49] B. Abbott et al., *Production and integration of the ATLAS Insertable B-Layer*, **JINST** **13** (2018) T05008, arXiv: [1803.00844](https://arxiv.org/abs/1803.00844) [[physics.ins-det](https://arxiv.org/abs/1803.00844)].
- [50] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the  $z$  axis along the beam pipe. The  $x$  axis points from the IP to the center of the LHC ring, and the  $y$  axis points upward. Cylindrical coordinates  $(r, \phi)$  are used in the transverse plane,  $\phi$  being the azimuthal angle around the  $z$  axis. The pseudorapidity is defined in terms of the polar angle  $\theta$  as  $\eta = -\ln \tan(\theta/2)$ . The transverse momentum (energy) is denoted by  $p_T$  ( $E_T$ ). Angular distances are measured in units of  $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ . Rapidity is defined as  $y = \frac{1}{2} \ln[(E + p_z)/(E - p_z)]$ , where  $E$  is the energy and  $p_z$  is the longitudinal component of the momentum of the particle.
- [51] ATLAS Collaboration, *Zero Degree Calorimeters for ATLAS*, CERN-LHCC-2007-001, 2007, URL: <https://cds.cern.ch/record/1009649>.
- [52] ATLAS Collaboration, *Performance of the ATLAS trigger system in 2015*, **Eur. Phys. J. C** **77** (2017) 317, arXiv: [1611.09661](https://arxiv.org/abs/1611.09661) [[hep-ex](https://arxiv.org/abs/1611.09661)].
- [53] ATLAS Collaboration, *Operation of the ATLAS trigger system in Run 2*, **JINST** **15** (2020) P10004, arXiv: [2007.12539](https://arxiv.org/abs/2007.12539) [[hep-ex](https://arxiv.org/abs/2007.12539)].
- [54] ATLAS Collaboration, *Trigger menu in 2018*, ATL-DAQ-PUB-2019-001, 2019, URL: <https://cds.cern.ch/record/2693402>.
- [55] ATLAS Collaboration, *The ATLAS Collaboration Software and Firmware*, ATL-SOFT-PUB-2021-001, 2021, URL: <https://cds.cern.ch/record/2767187>.
- [56] ATLAS Collaboration, *ATLAS data quality operations and performance for 2015–2018 data-taking*, **JINST** **15** (2020) P04003, arXiv: [1911.04632](https://arxiv.org/abs/1911.04632) [[physics.ins-det](https://arxiv.org/abs/1911.04632)].
- [57] S. R. Klein, J. Nystrand, J. Seger, Y. Gorbunov, and J. Butterworth, *STARlight: A Monte Carlo simulation program for ultra-peripheral collisions of relativistic ions*, **Comput. Phys. Commun.** **212** (2017) 258, arXiv: [1607.03838](https://arxiv.org/abs/1607.03838) [[hep-ph](https://arxiv.org/abs/1607.03838)].
- [58] S. Jadach, Z. Was, R. Decker, and J. H. Kühn, *The  $\tau$  decay library TAUOLA, version 2.4*, **Comput. Phys. Commun.** **76** (1993) 361.
- [59] N. Davidson, G. Nanava, T. Przedzinski, E. Richter-Was, and Z. Was, *Universal interface of TAUOLA: Technical and physics documentation*, **Comput. Phys. Commun.** **183** (2012) 821, arXiv: [1002.0543](https://arxiv.org/abs/1002.0543) [[hep-ph](https://arxiv.org/abs/1002.0543)].
- [60] T. Sjöstrand et al., *An introduction to PYTHIA 8.2*, **Comput. Phys. Commun.** **191** (2015) 159, arXiv: [1410.3012](https://arxiv.org/abs/1410.3012) [[hep-ph](https://arxiv.org/abs/1410.3012)].
- [61] N. Davidson, T. Przedzinski, and Z. Was, *PHOTOS interface in C++: Technical and physics documentation*, **Comput. Phys. Commun.** **199** (2016) 86, arXiv: [1011.0937](https://arxiv.org/abs/1011.0937) [[hep-ph](https://arxiv.org/abs/1011.0937)].
- [62] L. A. Harland-Lang, V. A. Khoze, and M. G. Ryskin, *Exclusive LHC physics with heavy ions: SuperChic 3*, **Eur. Phys. J. C** **79** (2019) 39, arXiv: [1810.06567](https://arxiv.org/abs/1810.06567) [[hep-ph](https://arxiv.org/abs/1810.06567)].

- [63] S. Roesler, R. Engel, and J. Ranft, “The Monte Carlo Event Generator DPMJET-III,” *International Conference on Advanced Monte Carlo for Radiation Physics, Particle Transport Simulation and Applications (MC 2000)*, 2000 1033, arXiv: [hep-ph/0012252](#).
- [64] S. Agostinelli et al., *GEANT4 – a simulation toolkit*, *Nucl. Instrum. Meth. A* **506** (2003) 250.
- [65] ATLAS Collaboration, *The ATLAS Simulation Infrastructure*, *Eur. Phys. J. C* **70** (2010) 823, arXiv: [1005.4568 \[physics.ins-det\]](#).
- [66] ATLAS Collaboration, *Early Inner Detector Tracking Performance in the 2015 Data at  $\sqrt{s} = 13$  TeV*, ATL-PHYS-PUB-2015-051, 2015, URL: <https://cds.cern.ch/record/2110140>.
- [67] ATLAS Collaboration, *Study of the material of the ATLAS inner detector for Run 2 of the LHC*, *JINST* **12** (2017) P12009, arXiv: [1707.02826 \[hep-ex\]](#).
- [68] ATLAS Collaboration, *Performance of the ATLAS track reconstruction algorithms in dense environments in LHC Run 2*, *Eur. Phys. J. C* **77** (2017) 673, arXiv: [1704.07983 \[hep-ex\]](#).
- [69] ATLAS Collaboration, *Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton–proton collision data*, *JINST* **14** (2019) P12006, arXiv: [1908.00005 \[hep-ex\]](#).
- [70] ATLAS Collaboration, *Muon reconstruction and identification efficiency in ATLAS using the full Run 2  $pp$  collision data set at  $\sqrt{s} = 13$  TeV*, *Eur. Phys. J. C* **81** (2021) 578, arXiv: [2012.00578 \[hep-ex\]](#).
- [71] ATLAS Collaboration, *Performance of the ATLAS muon triggers in Run 2*, *JINST* **15** (2020) P09015, arXiv: [2004.13447 \[physics.ins-det\]](#).
- [72] ATLAS Collaboration, *Measurement of light-by-light scattering and search for axion-like particles with  $2.2 \text{ nb}^{-1}$  of  $Pb+Pb$  data with the ATLAS detector*, *JHEP* **03** (2021) 243, arXiv: [2008.05355 \[hep-ex\]](#), Erratum: *JHEP* **11** (2021) 050.
- [73] ATLAS Collaboration, *Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1*, *Eur. Phys. J. C* **77** (2017) 490, arXiv: [1603.02934 \[hep-ex\]](#).
- [74] ATLAS Collaboration, *Rapidity gap cross sections measured with the ATLAS detector in  $pp$  collisions at  $\sqrt{s} = 7$  TeV*, *Eur. Phys. J. C* **72** (2012) 1926, arXiv: [1201.2808 \[hep-ex\]](#).
- [75] The momentum of the track system is defined as the vectorial sum of the momentum of each track considered:  $p_{\text{trk}}^{\text{syst}} = \sum_i p_{\text{trk}}^i$ .
- [76] J. Alwall et al., *The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations*, *JHEP* **07** (2014) 079, arXiv: [1405.0301 \[hep-ph\]](#).
- [77] L. A. Harland-Lang, V. A. Khoze, and M. G. Ryskin, *Elastic photon-initiated production at the LHC: the role of hadron-hadron interactions*, *SciPost Phys.* **11** (2021) 064, arXiv: [2104.13392 \[hep-ph\]](#).
- [78] Rapidity gaps are defined as regions in rapidity with few or no topoclusters or tracks.
- [79] I. Helenius, *Photon-photon and photon-hadron processes in Pythia 8*, *CERN Proc.* **1** (2018) 119, arXiv: [1708.09759 \[hep-ph\]](#).
- [80] ATLAS Collaboration, *Muon reconstruction performance of the ATLAS detector in proton–proton collision data at  $\sqrt{s} = 13$  TeV*, *Eur. Phys. J. C* **76** (2016) 292, arXiv: [1603.05598 \[hep-ex\]](#).

- [81] P. Ilten, *Pythia 8: Simulating Tau-Lepton Decays*, *Nucl. Part. Phys. Proc.* **260** (2015) 56.
- [82] G. Avoni et al., *The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS*, *JINST* **13** (2018) P07017.
- [83] ATLAS Collaboration, *Luminosity determination in pp collisions at  $\sqrt{s} = 13$  TeV using the ATLAS detector at the LHC*, ATLAS-CONF-2019-021, 2019, URL: <https://cds.cern.ch/record/2677054>.
- [84] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, *Asymptotic formulae for likelihood-based tests of new physics*, *Eur. Phys. J. C* **71** (2011) 1554, arXiv: [1007.1727](https://arxiv.org/abs/1007.1727) [[physics.data-an](https://arxiv.org/archive/physics)], Erratum: *Eur. Phys. J. C* **73** (2013) 2501.
- [85] K. Cranmer, G. Lewis, L. Moneta, A. Shibata, and W. Verkerke, *HistFactory: A tool for creating statistical models for use with RooFit and RooStats*, tech. rep., New York U., 2012, URL: <https://cds.cern.ch/record/1456844>.
- [86] ATLAS Collaboration, *ATLAS Computing Acknowledgements*, ATL-SOFT-PUB-2023-001, 2023, URL: <https://cds.cern.ch/record/2869272>.

## The ATLAS Collaboration

G. Aad <sup>101</sup>, B. Abbott <sup>119</sup>, D.C. Abbott <sup>102</sup>, K. Abeling <sup>55</sup>, S.H. Abidi <sup>29</sup>, A. Abouhorma <sup>35e</sup>,  
H. Abramowicz <sup>150</sup>, H. Abreu <sup>149</sup>, Y. Abulaiti <sup>116</sup>, A.C. Abusleme Hoffman <sup>136a</sup>,  
B.S. Acharya <sup>68a,68b,p</sup>, B. Achkar <sup>55</sup>, L. Adam <sup>99</sup>, C. Adam Bourdarios <sup>4</sup>, L. Adamczyk <sup>84a</sup>,  
L. Adamek <sup>154</sup>, S.V. Addepalli <sup>26</sup>, J. Adelman <sup>114</sup>, A. Adiguzel <sup>21c</sup>, S. Adorni <sup>56</sup>, T. Adye <sup>133</sup>,  
A.A. Affolder <sup>135</sup>, Y. Afik <sup>36</sup>, M.N. Agaras <sup>13</sup>, J. Agarwala <sup>72a,72b</sup>, A. Aggarwal <sup>99</sup>,  
C. Agheorghiesei <sup>27c</sup>, J.A. Aguilar-Saavedra <sup>129f</sup>, A. Ahmad <sup>36</sup>, F. Ahmadov <sup>38,z</sup>,  
W.S. Ahmed <sup>103</sup>, S. Ahuja <sup>94</sup>, X. Ai <sup>48</sup>, G. Aielli <sup>75a,75b</sup>, I. Aizenberg <sup>168</sup>, M. Akbiyik <sup>99</sup>,  
T.P.A. Åkesson <sup>97</sup>, A.V. Akimov <sup>37</sup>, K. Al Houry <sup>41</sup>, G.L. Alberghi <sup>23b</sup>, J. Albert <sup>164</sup>,  
P. Albicocco <sup>53</sup>, M.J. Alconada Verzini <sup>89</sup>, S. Alderweireldt <sup>52</sup>, M. Aleksa <sup>36</sup>,  
I.N. Aleksandrov <sup>38</sup>, C. Alexa <sup>27b</sup>, T. Alexopoulos <sup>10</sup>, A. Alfonsi <sup>113</sup>, F. Alfonsi <sup>23b</sup>,  
M. Alhroob <sup>119</sup>, B. Ali <sup>131</sup>, S. Ali <sup>147</sup>, M. Aliev <sup>37</sup>, G. Alimonti <sup>70a</sup>, C. Allaire <sup>36</sup>,  
B.M.M. Allbrooke <sup>145</sup>, P.P. Allport <sup>20</sup>, A. Aloisio <sup>71a,71b</sup>, F. Alonso <sup>89</sup>, C. Alpigiani <sup>137</sup>,  
E. Alunno Camelia <sup>75a,75b</sup>, M. Alvarez Estevez <sup>98</sup>, M.G. Alvigi <sup>71a,71b</sup>, Y. Amaral Coutinho <sup>81b</sup>,  
A. Ambler <sup>103</sup>, C. Amelung <sup>36</sup>, C.G. Ames <sup>108</sup>, D. Amidei <sup>105</sup>, S.P. Amor Dos Santos <sup>129a</sup>,  
S. Amoroso <sup>48</sup>, K.R. Amos <sup>162</sup>, C.S. Amrouche <sup>56</sup>, V. Ananiev <sup>124</sup>, C. Anastopoulos <sup>138</sup>,  
N. Andari <sup>134</sup>, T. Andeen <sup>11</sup>, J.K. Anders <sup>19</sup>, S.Y. Andrean <sup>47a,47b</sup>, A. Andreatta <sup>70a,70b</sup>,  
S. Angelidakis <sup>9</sup>, A. Angerami <sup>41,ac</sup>, A.V. Anisenkov <sup>37</sup>, A. Annovi <sup>73a</sup>, C. Antel <sup>56</sup>,  
M.T. Anthony <sup>138</sup>, E. Antipov <sup>120</sup>, M. Antonelli <sup>53</sup>, D.J.A. Antrim <sup>17a</sup>, F. Anulli <sup>74a</sup>,  
M. Aoki <sup>82</sup>, T. Aoki <sup>152</sup>, J.A. Aparisi Pozo <sup>162</sup>, M.A. Aparo <sup>145</sup>, L. Aperio Bella <sup>48</sup>,  
C. Appelt <sup>18</sup>, N. Aranzabal <sup>36</sup>, V. Araujo Ferraz <sup>81a</sup>, C. Arcangeletti <sup>53</sup>, A.T.H. Arce <sup>51</sup>,  
E. Arena <sup>91</sup>, J-F. Arguin <sup>107</sup>, S. Argyropoulos <sup>54</sup>, J.-H. Arling <sup>48</sup>, A.J. Armbruster <sup>36</sup>,  
O. Arnaez <sup>154</sup>, H. Arnold <sup>113</sup>, Z.P. Arrubarrena Tame <sup>108</sup>, G. Artoni <sup>74a,74b</sup>, H. Asada <sup>110</sup>,  
K. Asai <sup>117</sup>, S. Asai <sup>152</sup>, N.A. Asbah <sup>61</sup>, E.M. Asimakopoulou <sup>160</sup>, J. Assahsah <sup>35d</sup>,  
K. Assamagan <sup>29</sup>, R. Astalos <sup>28a</sup>, R.J. Atkin <sup>33a</sup>, M. Atkinson <sup>161</sup>, N.B. Atlay <sup>18</sup>, H. Atmani <sup>62b</sup>,  
P.A. Atmasiddha <sup>105</sup>, K. Augsten <sup>131</sup>, S. Auricchio <sup>71a,71b</sup>, A.D. Auriol <sup>20</sup>, V.A. Austrup <sup>170</sup>,  
G. Avner <sup>149</sup>, G. Avolio <sup>36</sup>, K. Axiotis <sup>56</sup>, M.K. Ayoub <sup>14c</sup>, G. Azuelos <sup>107,ag</sup>, D. Babal <sup>28a</sup>,  
H. Bachacou <sup>134</sup>, K. Bachas <sup>151,s</sup>, A. Bachi <sup>34</sup>, F. Backman <sup>47a,47b</sup>, A. Badea <sup>61</sup>,  
P. Bagnaia <sup>74a,74b</sup>, M. Bahmani <sup>18</sup>, A.J. Bailey <sup>162</sup>, V.R. Bailey <sup>161</sup>, J.T. Baines <sup>133</sup>,  
C. Bakalis <sup>10</sup>, O.K. Baker <sup>171</sup>, P.J. Bakker <sup>113</sup>, E. Bakos <sup>15</sup>, D. Bakshi Gupta <sup>8</sup>, S. Balaji <sup>146</sup>,  
R. Balasubramanian <sup>113</sup>, E.M. Baldin <sup>37</sup>, P. Balek <sup>132</sup>, E. Ballabene <sup>70a,70b</sup>, F. Balli <sup>134</sup>,  
L.M. Baltes <sup>63a</sup>, W.K. Balunas <sup>32</sup>, J. Balz <sup>99</sup>, E. Banas <sup>85</sup>, M. Bandieramonte <sup>128</sup>,  
A. Bandyopadhyay <sup>24</sup>, S. Bansal <sup>24</sup>, L. Barak <sup>150</sup>, E.L. Barberio <sup>104</sup>, D. Barberis <sup>57b,57a</sup>,  
M. Barbero <sup>101</sup>, G. Barbour <sup>95</sup>, K.N. Barends <sup>33a</sup>, T. Barillari <sup>109</sup>, M-S. Barisits <sup>36</sup>,  
J. Barkeloo <sup>122</sup>, T. Barklow <sup>142</sup>, R.M. Barnett <sup>17a</sup>, P. Baron <sup>121</sup>, D.A. Baron Moreno <sup>100</sup>,  
A. Baroncelli <sup>62a</sup>, G. Barone <sup>29</sup>, A.J. Barr <sup>125</sup>, L. Barranco Navarro <sup>47a,47b</sup>, F. Barreiro <sup>98</sup>,  
J. Barreiro Guimarães da Costa <sup>14a</sup>, U. Barron <sup>150</sup>, M.G. Barros Teixeira <sup>129a</sup>, S. Barsov <sup>37</sup>,  
F. Bartels <sup>63a</sup>, R. Bartoldus <sup>142</sup>, A.E. Barton <sup>90</sup>, P. Bartos <sup>28a</sup>, A. Basalae <sup>48</sup>, A. Basan <sup>99</sup>,  
M. Baselga <sup>49</sup>, I. Bashta <sup>76a,76b</sup>, A. Bassalat <sup>66,b</sup>, M.J. Basso <sup>154</sup>, C.R. Basson <sup>100</sup>,  
R.L. Bates <sup>59</sup>, S. Batlamous <sup>35e</sup>, J.R. Batley <sup>32</sup>, B. Batool <sup>140</sup>, M. Battaglia <sup>135</sup>, M. Baucé <sup>74a,74b</sup>,  
P. Bauer <sup>24</sup>, A. Bayirli <sup>21a</sup>, J.B. Beacham <sup>51</sup>, T. Beau <sup>126</sup>, P.H. Beauchemin <sup>157</sup>, F. Becherer <sup>54</sup>,  
P. Bechtel <sup>24</sup>, H.P. Beck <sup>19,r</sup>, K. Becker <sup>166</sup>, C. Becot <sup>48</sup>, A.J. Beddall <sup>21d</sup>, V.A. Bednyakov <sup>38</sup>,  
C.P. Bee <sup>144</sup>, L.J. Beemster <sup>15</sup>, T.A. Beermann <sup>36</sup>, M. Begalli <sup>81d</sup>, M. Begel <sup>29</sup>, A. Behera <sup>144</sup>,  
J.K. Behr <sup>48</sup>, C. Beirao Da Cruz E Silva <sup>36</sup>, J.F. Beirer <sup>55,36</sup>, F. Beisiegel <sup>24</sup>, M. Belfkir <sup>158</sup>,  
G. Bella <sup>150</sup>, L. Bellagamba <sup>23b</sup>, A. Bellerive <sup>34</sup>, P. Bellos <sup>20</sup>, K. Beloborodov <sup>37</sup>,

K. Belotskiy [id<sup>37</sup>](#), N.L. Belyaev [id<sup>37</sup>](#), D. Benchekroun [id<sup>35a</sup>](#), F. Bendebba [id<sup>35a</sup>](#), Y. Benhammou [id<sup>150</sup>](#),  
 D.P. Benjamin [id<sup>29</sup>](#), M. Benoit [id<sup>29</sup>](#), J.R. Bensingier [id<sup>26</sup>](#), S. Bentvelsen [id<sup>113</sup>](#), L. Beresford [id<sup>36</sup>](#),  
 M. Beretta [id<sup>53</sup>](#), D. Berge [id<sup>18</sup>](#), E. Bergeaas Kuutmann [id<sup>160</sup>](#), N. Berger [id<sup>4</sup>](#), B. Bergmann [id<sup>131</sup>](#),  
 J. Beringer [id<sup>17a</sup>](#), S. Berlendis [id<sup>7</sup>](#), G. Bernardi [id<sup>5</sup>](#), C. Bernius [id<sup>142</sup>](#), F.U. Bernlochner [id<sup>24</sup>](#), T. Berry [id<sup>94</sup>](#),  
 P. Berta [id<sup>132</sup>](#), A. Berthold [id<sup>50</sup>](#), I.A. Bertram [id<sup>90</sup>](#), S. Bethke [id<sup>109</sup>](#), A. Betti [id<sup>74a,74b</sup>](#), A.J. Bevan [id<sup>93</sup>](#),  
 M. Bhamjee [id<sup>33c</sup>](#), S. Bhatta [id<sup>144</sup>](#), D.S. Bhattacharya [id<sup>165</sup>](#), P. Bhattarai [id<sup>26</sup>](#), V.S. Bhopatkar [id<sup>6</sup>](#), R. Bi<sup>128</sup>,  
 R. Bi<sup>29,aj</sup>, R.M. Bianchi [id<sup>128</sup>](#), O. Biebel [id<sup>108</sup>](#), R. Bielski [id<sup>122</sup>](#), M. Biglietti [id<sup>76a</sup>](#), T.R.V. Billoud [id<sup>131</sup>](#),  
 M. Bindi [id<sup>55</sup>](#), A. Bingul [id<sup>21b</sup>](#), C. Bini [id<sup>74a,74b</sup>](#), S. Biondi [id<sup>23b,23a</sup>](#), A. Biondini [id<sup>91</sup>](#),  
 C.J. Birch-sykes [id<sup>100</sup>](#), G.A. Bird [id<sup>20,133</sup>](#), M. Birman [id<sup>168</sup>](#), T. Bisanz [id<sup>36</sup>](#), E. Bisceglie [id<sup>43b,43a</sup>](#),  
 D. Biswas [id<sup>169,1</sup>](#), A. Bitadze [id<sup>100</sup>](#), K. Bjørke [id<sup>124</sup>](#), I. Bloch [id<sup>48</sup>](#), C. Blocker [id<sup>26</sup>](#), A. Blue [id<sup>59</sup>](#),  
 U. Blumenschein [id<sup>93</sup>](#), J. Blumenthal [id<sup>99</sup>](#), G.J. Bobbink [id<sup>113</sup>](#), V.S. Bobrovnikov [id<sup>37</sup>](#), M. Boehler [id<sup>54</sup>](#),  
 D. Bogavac [id<sup>36</sup>](#), A.G. Bogdanchikov [id<sup>37</sup>](#), C. Bohm [id<sup>47a</sup>](#), V. Boisvert [id<sup>94</sup>](#), P. Bokan [id<sup>48</sup>](#), T. Bold [id<sup>84a</sup>](#),  
 M. Bomben [id<sup>5</sup>](#), M. Bona [id<sup>93</sup>](#), M. Boonekamp [id<sup>134</sup>](#), C.D. Booth [id<sup>94</sup>](#), A.G. Borbély [id<sup>59</sup>](#),  
 H.M. Borecka-Bielska [id<sup>107</sup>](#), L.S. Borgna [id<sup>95</sup>](#), G. Borissov [id<sup>90</sup>](#), D. Bortoletto [id<sup>125</sup>](#), D. Boscherini [id<sup>23b</sup>](#),  
 M. Bosman [id<sup>13</sup>](#), J.D. Bossio Sola [id<sup>36</sup>](#), K. Bouaouda [id<sup>35a</sup>](#), J. Boudreau [id<sup>128</sup>](#), E.V. Bouhova-Thacker [id<sup>90</sup>](#),  
 D. Boumediene [id<sup>40</sup>](#), R. Bouquet [id<sup>5</sup>](#), A. Boveia [id<sup>118</sup>](#), J. Boyd [id<sup>36</sup>](#), D. Boye [id<sup>29</sup>](#), I.R. Boyko [id<sup>38</sup>](#),  
 J. Bracinik [id<sup>20</sup>](#), N. Brahimy [id<sup>62d</sup>](#), G. Brandt [id<sup>170</sup>](#), O. Brandt [id<sup>32</sup>](#), F. Braren [id<sup>48</sup>](#), B. Brau [id<sup>102</sup>](#),  
 J.E. Brau [id<sup>122</sup>](#), W.D. Breaden Madden [id<sup>59</sup>](#), K. Brendlinger [id<sup>48</sup>](#), R. Brenner [id<sup>168</sup>](#), L. Brenner [id<sup>36</sup>](#),  
 R. Brenner [id<sup>160</sup>](#), S. Bressler [id<sup>168</sup>](#), B. Brickwedde [id<sup>99</sup>](#), D. Britton [id<sup>59</sup>](#), D. Britzger [id<sup>109</sup>](#), I. Brock [id<sup>24</sup>](#),  
 G. Brooijmans [id<sup>41</sup>](#), W.K. Brooks [id<sup>136f</sup>](#), E. Brost [id<sup>29</sup>](#), P.A. Bruckman de Renstrom [id<sup>85</sup>](#), B. Brüers [id<sup>48</sup>](#),  
 D. Bruncko [id<sup>28b,\\*</sup>](#), A. Bruni [id<sup>23b</sup>](#), G. Bruni [id<sup>23b</sup>](#), M. Bruschi [id<sup>23b</sup>](#), N. Bruscinò [id<sup>74a,74b</sup>](#),  
 L. Bryngemark [id<sup>142</sup>](#), T. Buanes [id<sup>16</sup>](#), Q. Buat [id<sup>137</sup>](#), P. Buchholz [id<sup>140</sup>](#), A.G. Buckley [id<sup>59</sup>](#),  
 I.A. Budagov [id<sup>38,\\*</sup>](#), M.K. Bugge [id<sup>124</sup>](#), O. Bulekov [id<sup>37</sup>](#), B.A. Bullard [id<sup>61</sup>](#), S. Burdin [id<sup>91</sup>](#),  
 C.D. Burgard [id<sup>48</sup>](#), A.M. Burger [id<sup>40</sup>](#), B. Burghgrave [id<sup>8</sup>](#), J.T.P. Burr [id<sup>32</sup>](#), C.D. Burton [id<sup>11</sup>](#),  
 J.C. Burzynski [id<sup>141</sup>](#), E.L. Busch [id<sup>41</sup>](#), V. Büscher [id<sup>99</sup>](#), P.J. Bussey [id<sup>59</sup>](#), J.M. Butler [id<sup>25</sup>](#),  
 C.M. Buttar [id<sup>59</sup>](#), J.M. Butterworth [id<sup>95</sup>](#), W. Buttinger [id<sup>133</sup>](#), C.J. Buxo Vazquez [id<sup>106</sup>](#), A.R. Buzykaev [id<sup>37</sup>](#),  
 G. Cabras [id<sup>23b</sup>](#), S. Cabrera Urbán [id<sup>162</sup>](#), D. Caforio [id<sup>58</sup>](#), H. Cai [id<sup>128</sup>](#), Y. Cai [id<sup>14a,14d</sup>](#), V.M.M. Cairo [id<sup>36</sup>](#),  
 O. Cakir [id<sup>3a</sup>](#), N. Calace [id<sup>36</sup>](#), P. Calafiura [id<sup>17a</sup>](#), G. Calderini [id<sup>126</sup>](#), P. Calfayan [id<sup>67</sup>](#), G. Callea [id<sup>59</sup>](#),  
 L.P. Caloba [id<sup>81b</sup>](#), D. Calvet [id<sup>40</sup>](#), S. Calvet [id<sup>40</sup>](#), T.P. Calvet [id<sup>101</sup>](#), M. Calvetti [id<sup>73a,73b</sup>](#),  
 R. Camacho Toro [id<sup>126</sup>](#), S. Camarda [id<sup>36</sup>](#), D. Camarero Munoz [id<sup>98</sup>](#), P. Camarri [id<sup>75a,75b</sup>](#),  
 M.T. Camerlingo [id<sup>76a,76b</sup>](#), D. Cameron [id<sup>124</sup>](#), C. Camincher [id<sup>164</sup>](#), M. Campanelli [id<sup>95</sup>](#), A. Camplani [id<sup>42</sup>](#),  
 V. Canale [id<sup>71a,71b</sup>](#), A. Canesse [id<sup>103</sup>](#), M. Cano Bret [id<sup>79</sup>](#), J. Cantero [id<sup>162</sup>](#), Y. Cao [id<sup>161</sup>](#), F. Capocasa [id<sup>26</sup>](#),  
 M. Capua [id<sup>43b,43a</sup>](#), A. Carbone [id<sup>70a,70b</sup>](#), R. Cardarelli [id<sup>75a</sup>](#), J.C.J. Cardenas [id<sup>8</sup>](#), F. Cardillo [id<sup>162</sup>](#),  
 T. Carli [id<sup>36</sup>](#), G. Carlino [id<sup>71a</sup>](#), B.T. Carlson [id<sup>128,t</sup>](#), E.M. Carlson [id<sup>164,155a</sup>](#), L. Carminati [id<sup>70a,70b</sup>](#),  
 M. Carnesale [id<sup>74a,74b</sup>](#), S. Caron [id<sup>112</sup>](#), E. Carquin [id<sup>136f</sup>](#), S. Carrá [id<sup>70a,70b</sup>](#), G. Carratta [id<sup>23b,23a</sup>](#),  
 F. Carri Argos [id<sup>33g</sup>](#), J.W.S. Carter [id<sup>154</sup>](#), T.M. Carter [id<sup>52</sup>](#), M.P. Casado [id<sup>13,i</sup>](#), A.F. Casha [id<sup>154</sup>](#),  
 E.G. Castiglia [id<sup>171</sup>](#), F.L. Castillo [id<sup>63a</sup>](#), L. Castillo Garcia [id<sup>13</sup>](#), V. Castillo Gimenez [id<sup>162</sup>](#),  
 N.F. Castro [id<sup>129a,129e</sup>](#), A. Catinaccio [id<sup>36</sup>](#), J.R. Catmore [id<sup>124</sup>](#), V. Cavaliere [id<sup>29</sup>](#), N. Cavalli [id<sup>23b,23a</sup>](#),  
 V. Cavasinni [id<sup>73a,73b</sup>](#), E. Celebi [id<sup>21a</sup>](#), F. Celli [id<sup>125</sup>](#), M.S. Centonze [id<sup>69a,69b</sup>](#), K. Cerny [id<sup>121</sup>](#),  
 A.S. Cerqueira [id<sup>81a</sup>](#), A. Cerri [id<sup>145</sup>](#), L. Cerrito [id<sup>75a,75b</sup>](#), F. Cerutti [id<sup>17a</sup>](#), A. Cervelli [id<sup>23b</sup>](#),  
 S.A. Cetin [id<sup>21d</sup>](#), Z. Chadi [id<sup>35a</sup>](#), D. Chakraborty [id<sup>114</sup>](#), M. Chala [id<sup>129f</sup>](#), J. Chan [id<sup>169</sup>](#), W.S. Chan [id<sup>113</sup>](#),  
 W.Y. Chan [id<sup>152</sup>](#), J.D. Chapman [id<sup>32</sup>](#), B. Chargeishvili [id<sup>148b</sup>](#), D.G. Charlton [id<sup>20</sup>](#), T.P. Charman [id<sup>93</sup>](#),  
 M. Chatterjee [id<sup>19</sup>](#), S. Chekanov [id<sup>6</sup>](#), S.V. Chekulaev [id<sup>155a</sup>](#), G.A. Chelkov [id<sup>38,a</sup>](#), A. Chen [id<sup>105</sup>](#),  
 B. Chen [id<sup>150</sup>](#), B. Chen [id<sup>164</sup>](#), C. Chen [id<sup>62a</sup>](#), H. Chen [id<sup>14c</sup>](#), H. Chen [id<sup>29</sup>](#), J. Chen [id<sup>62c</sup>](#), J. Chen [id<sup>26</sup>](#),  
 S. Chen [id<sup>152</sup>](#), S.J. Chen [id<sup>14c</sup>](#), X. Chen [id<sup>62c</sup>](#), X. Chen [id<sup>14b,af</sup>](#), Y. Chen [id<sup>62a</sup>](#), C.L. Cheng [id<sup>169</sup>](#),  
 H.C. Cheng [id<sup>64a</sup>](#), A. Cheplakov [id<sup>38</sup>](#), E. Cheremushkina [id<sup>48</sup>](#), E. Cherepanova [id<sup>113</sup>](#),



R. Cherkaoui El Moursli [id](#)<sup>35e</sup>, E. Cheu [id](#)<sup>7</sup>, K. Cheung [id](#)<sup>65</sup>, L. Chevalier [id](#)<sup>134</sup>, V. Chiarella [id](#)<sup>53</sup>, G. Chiarelli [id](#)<sup>73a</sup>, N. Chiedde [id](#)<sup>101</sup>, G. Chiodini [id](#)<sup>69a</sup>, A.S. Chisholm [id](#)<sup>20</sup>, A. Chitan [id](#)<sup>27b</sup>, Y.H. Chiu [id](#)<sup>164</sup>, M.V. Chizhov [id](#)<sup>38</sup>, K. Choi [id](#)<sup>11</sup>, A.R. Chomont [id](#)<sup>74a,74b</sup>, Y. Chou [id](#)<sup>102</sup>, E.Y.S. Chow [id](#)<sup>113</sup>, T. Chowdhury [id](#)<sup>33g</sup>, L.D. Christopher [id](#)<sup>33g</sup>, K.L. Chu [id](#)<sup>64a</sup>, M.C. Chu [id](#)<sup>64a</sup>, X. Chu [id](#)<sup>14a,14d</sup>, J. Chudoba [id](#)<sup>130</sup>, J.J. Chwastowski [id](#)<sup>85</sup>, D. Cieri [id](#)<sup>109</sup>, K.M. Ciesla [id](#)<sup>84a</sup>, V. Cindro [id](#)<sup>92</sup>, A. Ciocio [id](#)<sup>17a</sup>, F. Citroto [id](#)<sup>71a,71b</sup>, Z.H. Citron [id](#)<sup>168,m</sup>, M. Citterio [id](#)<sup>70a</sup>, D.A. Ciubotaru [id](#)<sup>27b</sup>, B.M. Ciungu [id](#)<sup>154</sup>, A. Clark [id](#)<sup>56</sup>, P.J. Clark [id](#)<sup>52</sup>, J.M. Clavijo Columbie [id](#)<sup>48</sup>, S.E. Clawson [id](#)<sup>100</sup>, C. Clement [id](#)<sup>47a,47b</sup>, J. Clercx [id](#)<sup>48</sup>, L. Clissa [id](#)<sup>23b,23a</sup>, Y. Coadou [id](#)<sup>101</sup>, M. Cobal [id](#)<sup>68a,68c</sup>, A. Coccaro [id](#)<sup>57b</sup>, R.F. Coelho Barrue [id](#)<sup>129a</sup>, R. Coelho Lopes De Sa [id](#)<sup>102</sup>, S. Coelli [id](#)<sup>70a</sup>, H. Cohen [id](#)<sup>150</sup>, A.E.C. Coimbra [id](#)<sup>70a,70b</sup>, B. Cole [id](#)<sup>41</sup>, J. Collot [id](#)<sup>60</sup>, P. Conde Muñio [id](#)<sup>129a,129g</sup>, M.P. Connell [id](#)<sup>33c</sup>, S.H. Connell [id](#)<sup>33c</sup>, I.A. Connelly [id](#)<sup>59</sup>, E.I. Conroy [id](#)<sup>125</sup>, F. Conventi [id](#)<sup>71a,ah</sup>, H.G. Cooke [id](#)<sup>20</sup>, A.M. Cooper-Sarkar [id](#)<sup>125</sup>, F. Cormier [id](#)<sup>163</sup>, L.D. Corpe [id](#)<sup>36</sup>, M. Corradi [id](#)<sup>74a,74b</sup>, E.E. Corrigan [id](#)<sup>97</sup>, F. Corriveau [id](#)<sup>103,y</sup>, A. Cortes-Gonzalez [id](#)<sup>18</sup>, M.J. Costa [id](#)<sup>162</sup>, F. Costanza [id](#)<sup>4</sup>, D. Costanzo [id](#)<sup>138</sup>, B.M. Cote [id](#)<sup>118</sup>, G. Cowan [id](#)<sup>94</sup>, J.W. Cowley [id](#)<sup>32</sup>, K. Cranmer [id](#)<sup>116</sup>, S. Crépe-Renaudin [id](#)<sup>60</sup>, F. Crescioli [id](#)<sup>126</sup>, M. Cristinziani [id](#)<sup>140</sup>, M. Cristoforetti [id](#)<sup>77a,77b,d</sup>, V. Croft [id](#)<sup>157</sup>, G. Crosetti [id](#)<sup>43b,43a</sup>, A. Cueto [id](#)<sup>36</sup>, T. Cuhadar Donszelmann [id](#)<sup>159</sup>, H. Cui [id](#)<sup>14a,14d</sup>, Z. Cui [id](#)<sup>7</sup>, A.R. Cukierman [id](#)<sup>142</sup>, W.R. Cunningham [id](#)<sup>59</sup>, F. Curcio [id](#)<sup>43b,43a</sup>, P. Czodrowski [id](#)<sup>36</sup>, M.M. Czurylo [id](#)<sup>63b</sup>, M.J. Da Cunha Sargedas De Sousa [id](#)<sup>62a</sup>, J.V. Da Fonseca Pinto [id](#)<sup>81b</sup>, C. Da Via [id](#)<sup>100</sup>, W. Dabrowski [id](#)<sup>84a</sup>, T. Dado [id](#)<sup>49</sup>, S. Dahbi [id](#)<sup>33g</sup>, T. Dai [id](#)<sup>105</sup>, C. Dallapiccola [id](#)<sup>102</sup>, M. Dam [id](#)<sup>42</sup>, G. D'amen [id](#)<sup>29</sup>, V. D'Amico [id](#)<sup>76a,76b</sup>, J. Damp [id](#)<sup>99</sup>, J.R. Dandoy [id](#)<sup>127</sup>, M.F. Daneri [id](#)<sup>30</sup>, M. Danninger [id](#)<sup>141</sup>, V. Dao [id](#)<sup>36</sup>, G. Darbo [id](#)<sup>57b</sup>, S. Darmora [id](#)<sup>6</sup>, S.J. Das [id](#)<sup>29,aj</sup>, A. Dattagupta [id](#)<sup>122</sup>, S. D'Auria [id](#)<sup>70a,70b</sup>, C. David [id](#)<sup>155b</sup>, T. Davidek [id](#)<sup>132</sup>, D.R. Davis [id](#)<sup>51</sup>, B. Davis-Purcell [id](#)<sup>34</sup>, I. Dawson [id](#)<sup>93</sup>, K. De [id](#)<sup>8</sup>, R. De Asmundis [id](#)<sup>71a</sup>, M. De Beurs [id](#)<sup>113</sup>, S. De Castro [id](#)<sup>23b,23a</sup>, N. De Groot [id](#)<sup>112</sup>, P. de Jong [id](#)<sup>113</sup>, H. De la Torre [id](#)<sup>106</sup>, A. De Maria [id](#)<sup>14c</sup>, A. De Salvo [id](#)<sup>74a</sup>, U. De Sanctis [id](#)<sup>75a,75b</sup>, A. De Santo [id](#)<sup>145</sup>, J.B. De Vivie De Regie [id](#)<sup>60</sup>, D.V. Dedovich [id](#)<sup>38</sup>, J. Degens [id](#)<sup>113</sup>, A.M. Deiana [id](#)<sup>44</sup>, F. Del Corso [id](#)<sup>23b,23a</sup>, J. Del Peso [id](#)<sup>98</sup>, F. Del Rio [id](#)<sup>63a</sup>, F. Deliot [id](#)<sup>134</sup>, C.M. Delitzsch [id](#)<sup>49</sup>, M. Della Pietra [id](#)<sup>71a,71b</sup>, D. Della Volpe [id](#)<sup>56</sup>, A. Dell'Acqua [id](#)<sup>36</sup>, L. Dell'Asta [id](#)<sup>70a,70b</sup>, M. Delmastro [id](#)<sup>4</sup>, P.A. Delsart [id](#)<sup>60</sup>, S. Demers [id](#)<sup>171</sup>, M. Demichev [id](#)<sup>38</sup>, S.P. Denisov [id](#)<sup>37</sup>, L. D'Eramo [id](#)<sup>114</sup>, D. Derendarz [id](#)<sup>85</sup>, F. Derue [id](#)<sup>126</sup>, P. Dervan [id](#)<sup>91</sup>, K. Desch [id](#)<sup>24</sup>, K. Dette [id](#)<sup>154</sup>, C. Deutsch [id](#)<sup>24</sup>, P.O. Deviveiros [id](#)<sup>36</sup>, F.A. Di Bello [id](#)<sup>74a,74b</sup>, A. Di Ciaccio [id](#)<sup>75a,75b</sup>, L. Di Ciaccio [id](#)<sup>4</sup>, A. Di Domenico [id](#)<sup>74a,74b</sup>, C. Di Donato [id](#)<sup>71a,71b</sup>, A. Di Girolamo [id](#)<sup>36</sup>, G. Di Gregorio [id](#)<sup>73a,73b</sup>, A. Di Luca [id](#)<sup>77a,77b</sup>, B. Di Micco [id](#)<sup>76a,76b</sup>, R. Di Nardo [id](#)<sup>76a,76b</sup>, C. Diaconu [id](#)<sup>101</sup>, F.A. Dias [id](#)<sup>113</sup>, T. Dias Do Vale [id](#)<sup>141</sup>, M.A. Diaz [id](#)<sup>136a,136b</sup>, F.G. Diaz Capriles [id](#)<sup>24</sup>, M. Didenko [id](#)<sup>162</sup>, E.B. Diehl [id](#)<sup>105</sup>, L. Diehl [id](#)<sup>54</sup>, S. Díez Cornell [id](#)<sup>48</sup>, C. Diez Pardos [id](#)<sup>140</sup>, C. Dimitriadi [id](#)<sup>24,160</sup>, A. Dimitrievska [id](#)<sup>17a</sup>, W. Ding [id](#)<sup>14b</sup>, J. Dingfelder [id](#)<sup>24</sup>, I-M. Dinu [id](#)<sup>27b</sup>, S.J. Dittmeier [id](#)<sup>63b</sup>, F. Dittus [id](#)<sup>36</sup>, F. Djama [id](#)<sup>101</sup>, T. Djobava [id](#)<sup>148b</sup>, J.I. Djuvsland [id](#)<sup>16</sup>, D. Dodsworth [id](#)<sup>26</sup>, C. Doglioni [id](#)<sup>100,97</sup>, J. Dolejsi [id](#)<sup>132</sup>, Z. Dolezal [id](#)<sup>132</sup>, K. Domijan [id](#)<sup>84a</sup>, M. Donadelli [id](#)<sup>81c</sup>, B. Dong [id](#)<sup>62c</sup>, J. Donini [id](#)<sup>40</sup>, A. D'Onofrio [id](#)<sup>14c</sup>, M. D'Onofrio [id](#)<sup>91</sup>, J. Dopke [id](#)<sup>133</sup>, A. Doria [id](#)<sup>71a</sup>, M.T. Dova [id](#)<sup>89</sup>, A.T. Doyle [id](#)<sup>59</sup>, M.A. Draguet [id](#)<sup>125</sup>, E. Drechsler [id](#)<sup>141</sup>, E. Dreyer [id](#)<sup>168</sup>, I. Drivas-koulouris [id](#)<sup>10</sup>, A.S. Drobac [id](#)<sup>157</sup>, D. Du [id](#)<sup>62a</sup>, T.A. du Pree [id](#)<sup>113</sup>, F. Dubinin [id](#)<sup>37</sup>, M. Dubovsky [id](#)<sup>28a</sup>, E. Duchovni [id](#)<sup>168</sup>, G. Duckeck [id](#)<sup>108</sup>, O.A. Ducu [id](#)<sup>36</sup>, D. Duda [id](#)<sup>109</sup>, A. Dudarev [id](#)<sup>36</sup>, M. D'uffizi [id](#)<sup>100</sup>, L. Duflost [id](#)<sup>66</sup>, M. Dührssen [id](#)<sup>36</sup>, C. Dülsen [id](#)<sup>170</sup>, A.E. Dumitriu [id](#)<sup>27b</sup>, M. Dunford [id](#)<sup>63a</sup>, S. Dungs [id](#)<sup>49</sup>, K. Dunne [id](#)<sup>47a,47b</sup>, A. Duperrin [id](#)<sup>101</sup>, H. Duran Yildiz [id](#)<sup>3a</sup>, M. Düren [id](#)<sup>58</sup>, A. Durglishvili [id](#)<sup>148b</sup>, B.L. Dwyer [id](#)<sup>114</sup>, G.I. Dyckes [id](#)<sup>17a</sup>, M. Dyndal [id](#)<sup>84a</sup>, S. Dysch [id](#)<sup>100</sup>, B.S. Dziedzic [id](#)<sup>85</sup>, Z.O. Earnshaw [id](#)<sup>145</sup>, B. Eckerova [id](#)<sup>28a</sup>, M.G. Eggleston [id](#)<sup>51</sup>, E. Egidio Purcino De Souza [id](#)<sup>81b</sup>, L.F. Ehrke [id](#)<sup>56</sup>, G. Eigen [id](#)<sup>16</sup>, K. Einsweiler [id](#)<sup>17a</sup>,

T. Ekelof [id](#)<sup>160</sup>, P.A. Ekman [id](#)<sup>97</sup>, Y. El Ghazali [id](#)<sup>35b</sup>, H. El Jarrari [id](#)<sup>35e,147</sup>, A. El Moussaouy [id](#)<sup>35a</sup>,  
 V. Ellajosyula [id](#)<sup>160</sup>, M. Ellert [id](#)<sup>160</sup>, F. Ellinghaus [id](#)<sup>170</sup>, A.A. Elliot [id](#)<sup>93</sup>, N. Ellis [id](#)<sup>36</sup>, J. Elmsheuser [id](#)<sup>29</sup>,  
 M. Elsing [id](#)<sup>36</sup>, D. Emeliyanov [id](#)<sup>133</sup>, A. Emerman [id](#)<sup>41</sup>, Y. Enari [id](#)<sup>152</sup>, I. Ene [id](#)<sup>17a</sup>, S. Epari [id](#)<sup>13</sup>,  
 J. Erdmann [id](#)<sup>49</sup>, A. Ereditato [id](#)<sup>19</sup>, P.A. Erland [id](#)<sup>85</sup>, M. Errenst [id](#)<sup>170</sup>, M. Escalier [id](#)<sup>66</sup>, C. Escobar [id](#)<sup>162</sup>,  
 E. Etzion [id](#)<sup>150</sup>, G. Evans [id](#)<sup>129a</sup>, H. Evans [id](#)<sup>67</sup>, M.O. Evans [id](#)<sup>145</sup>, A. Ezhilov [id](#)<sup>37</sup>, S. Ezzarqtouni [id](#)<sup>35a</sup>,  
 F. Fabbri [id](#)<sup>59</sup>, L. Fabbri [id](#)<sup>23b,23a</sup>, G. Facini [id](#)<sup>95</sup>, V. Fadeyev [id](#)<sup>135</sup>, R.M. Fakhruddinov [id](#)<sup>37</sup>,  
 S. Falciano [id](#)<sup>74a</sup>, P.J. Falke [id](#)<sup>24</sup>, S. Falke [id](#)<sup>36</sup>, J. Faltova [id](#)<sup>132</sup>, Y. Fan [id](#)<sup>14a</sup>, Y. Fang [id](#)<sup>14a,14d</sup>,  
 G. Fanourakis [id](#)<sup>46</sup>, M. Fanti [id](#)<sup>70a,70b</sup>, M. Faraj [id](#)<sup>68a,68b</sup>, A. Farbin [id](#)<sup>8</sup>, A. Farilla [id](#)<sup>76a</sup>, T. Farooque [id](#)<sup>106</sup>,  
 S.M. Farrington [id](#)<sup>52</sup>, F. Fassi [id](#)<sup>35e</sup>, D. Fassouliotis [id](#)<sup>9</sup>, M. Faucci Giannelli [id](#)<sup>75a,75b</sup>, W.J. Fawcett [id](#)<sup>32</sup>,  
 L. Fayard [id](#)<sup>66</sup>, O.L. Fedin [id](#)<sup>37,a</sup>, G. Fedotov [id](#)<sup>37</sup>, M. Feickert [id](#)<sup>161</sup>, L. Feligioni [id](#)<sup>101</sup>, A. Fell [id](#)<sup>138</sup>,  
 D.E. Fellers [id](#)<sup>122</sup>, C. Feng [id](#)<sup>62b</sup>, M. Feng [id](#)<sup>14b</sup>, Z. Feng [id](#)<sup>113</sup>, M.J. Fenton [id](#)<sup>159</sup>, A.B. Fenyuk [id](#)<sup>37</sup>,  
 L. Ferencz [id](#)<sup>48</sup>, S.W. Ferguson [id](#)<sup>45</sup>, J. Ferrando [id](#)<sup>48</sup>, A. Ferrari [id](#)<sup>160</sup>, P. Ferrari [id](#)<sup>113</sup>, R. Ferrari [id](#)<sup>72a</sup>,  
 D. Ferrere [id](#)<sup>56</sup>, C. Ferretti [id](#)<sup>105</sup>, F. Fiedler [id](#)<sup>99</sup>, A. Filipčič [id](#)<sup>92</sup>, E.K. Filmer [id](#)<sup>1</sup>, F. Filthaut [id](#)<sup>112</sup>,  
 M.C.N. Fiolhais [id](#)<sup>129a,129c,c</sup>, L. Fiorini [id](#)<sup>162</sup>, F. Fischer [id](#)<sup>140</sup>, W.C. Fisher [id](#)<sup>106</sup>, T. Fitschen [id](#)<sup>20,66</sup>,  
 I. Fleck [id](#)<sup>140</sup>, P. Fleischmann [id](#)<sup>105</sup>, T. Flick [id](#)<sup>170</sup>, L. Flores [id](#)<sup>127</sup>, M. Flores [id](#)<sup>33d,ad</sup>,  
 L.R. Flores Castillo [id](#)<sup>64a</sup>, F.M. Follega [id](#)<sup>77a,77b</sup>, N. Fomin [id](#)<sup>16</sup>, J.H. Foo [id](#)<sup>154</sup>, B.C. Forland [id](#)<sup>67</sup>,  
 A. Formica [id](#)<sup>134</sup>, A.C. Forti [id](#)<sup>100</sup>, E. Fortin [id](#)<sup>101</sup>, A.W. Fortman [id](#)<sup>61</sup>, M.G. Foti [id](#)<sup>17a</sup>, L. Fountas [id](#)<sup>9,j</sup>,  
 D. Fournier [id](#)<sup>66</sup>, H. Fox [id](#)<sup>90</sup>, P. Francavilla [id](#)<sup>73a,73b</sup>, S. Francescato [id](#)<sup>61</sup>, M. Franchini [id](#)<sup>23b,23a</sup>,  
 S. Franchino [id](#)<sup>63a</sup>, D. Francis [id](#)<sup>36</sup>, L. Franco [id](#)<sup>112</sup>, L. Franconi [id](#)<sup>19</sup>, M. Franklin [id](#)<sup>61</sup>, G. Frattari [id](#)<sup>26</sup>,  
 A.C. Freegard [id](#)<sup>93</sup>, P.M. Freeman [id](#)<sup>20</sup>, W.S. Freund [id](#)<sup>81b</sup>, N. Fritzsche [id](#)<sup>50</sup>, A. Froch [id](#)<sup>54</sup>,  
 D. Froidevaux [id](#)<sup>36</sup>, J.A. Frost [id](#)<sup>125</sup>, Y. Fu [id](#)<sup>62a</sup>, M. Fujimoto [id](#)<sup>117</sup>, E. Fullana Torregrosa [id](#)<sup>162,\*</sup>,  
 J. Fuster [id](#)<sup>162</sup>, A. Gabrielli [id](#)<sup>23b,23a</sup>, A. Gabrielli [id](#)<sup>36</sup>, P. Gadow [id](#)<sup>48</sup>, G. Gagliardi [id](#)<sup>57b,57a</sup>,  
 L.G. Gagnon [id](#)<sup>17a</sup>, G.E. Gallardo [id](#)<sup>125</sup>, E.J. Gallas [id](#)<sup>125</sup>, B.J. Gallop [id](#)<sup>133</sup>, R. Gamboa Goni [id](#)<sup>93</sup>,  
 K.K. Gan [id](#)<sup>118</sup>, S. Ganguly [id](#)<sup>152</sup>, J. Gao [id](#)<sup>62a</sup>, Y. Gao [id](#)<sup>52</sup>, F.M. Garay Walls [id](#)<sup>136a,136b</sup>, B. Garcia [id](#)<sup>29,aj</sup>,  
 C. García [id](#)<sup>162</sup>, J.E. García Navarro [id](#)<sup>162</sup>, J.A. García Pascual [id](#)<sup>14a</sup>, M. Garcia-Sciveres [id](#)<sup>17a</sup>,  
 R.W. Gardner [id](#)<sup>39</sup>, D. Garg [id](#)<sup>79</sup>, R.B. Garg [id](#)<sup>142,q</sup>, S. Gargiulo [id](#)<sup>54</sup>, C.A. Garner [id](#)<sup>154</sup>, V. Garonne [id](#)<sup>29</sup>,  
 S.J. Gasirowski [id](#)<sup>137</sup>, P. Gaspar [id](#)<sup>81b</sup>, G. Gaudio [id](#)<sup>72a</sup>, V. Gautam [id](#)<sup>13</sup>, P. Gauzzi [id](#)<sup>74a,74b</sup>,  
 I.L. Gavrilenko [id](#)<sup>37</sup>, A. Gavriluk [id](#)<sup>37</sup>, C. Gay [id](#)<sup>163</sup>, G. Gaycken [id](#)<sup>48</sup>, E.N. Gazis [id](#)<sup>10</sup>,  
 A.A. Geanta [id](#)<sup>27b,27e</sup>, C.M. Gee [id](#)<sup>135</sup>, J. Geisen [id](#)<sup>97</sup>, M. Geisen [id](#)<sup>99</sup>, C. Gemme [id](#)<sup>57b</sup>, M.H. Genest [id](#)<sup>60</sup>,  
 S. Gentile [id](#)<sup>74a,74b</sup>, S. George [id](#)<sup>94</sup>, W.F. George [id](#)<sup>20</sup>, T. Gerialis [id](#)<sup>46</sup>, L.O. Gerlach [id](#)<sup>55</sup>,  
 P. Gessinger-Befurt [id](#)<sup>36</sup>, M. Ghasemi Bostanabad [id](#)<sup>164</sup>, M. Ghneimat [id](#)<sup>140</sup>, A. Ghosal [id](#)<sup>140</sup>,  
 A. Ghosh [id](#)<sup>159</sup>, A. Ghosh [id](#)<sup>7</sup>, B. Giacobbe [id](#)<sup>23b</sup>, S. Giagu [id](#)<sup>74a,74b</sup>, N. Giangiacomi [id](#)<sup>154</sup>,  
 P. Giannetti [id](#)<sup>73a</sup>, A. Giannini [id](#)<sup>62a</sup>, S.M. Gibson [id](#)<sup>94</sup>, M. Gignac [id](#)<sup>135</sup>, D.T. Gil [id](#)<sup>84b</sup>,  
 A.K. Gilbert [id](#)<sup>84a</sup>, B.J. Gilbert [id](#)<sup>41</sup>, D. Gillberg [id](#)<sup>34</sup>, G. Gilles [id](#)<sup>113</sup>, N.E.K. Gillwald [id](#)<sup>48</sup>,  
 L. Ginabat [id](#)<sup>126</sup>, D.M. Gingrich [id](#)<sup>2,ag</sup>, M.P. Giordani [id](#)<sup>68a,68c</sup>, P.F. Giraud [id](#)<sup>134</sup>, G. Giugliarelli [id](#)<sup>68a,68c</sup>,  
 D. Giugni [id](#)<sup>70a</sup>, F. Giuli [id](#)<sup>36</sup>, I. Gkialas [id](#)<sup>9,j</sup>, L.K. Gladilin [id](#)<sup>37</sup>, C. Glasman [id](#)<sup>98</sup>, G.R. Gledhill [id](#)<sup>122</sup>,  
 M. Glisic [id](#)<sup>122</sup>, I. Gnesi [id](#)<sup>43b,f</sup>, Y. Go [id](#)<sup>29,aj</sup>, M. Goblirsch-Kolb [id](#)<sup>26</sup>, D. Godin [id](#)<sup>107</sup>, S. Goldfarb [id](#)<sup>104</sup>,  
 T. Golling [id](#)<sup>56</sup>, M.G.D. Gololo [id](#)<sup>33g</sup>, D. Golubkov [id](#)<sup>37</sup>, J.P. Gombas [id](#)<sup>106</sup>, A. Gomes [id](#)<sup>129a,129b</sup>,  
 G. Gomes Da Silva [id](#)<sup>140</sup>, A.J. Gomez Delegido [id](#)<sup>162</sup>, R. Goncalves Gama [id](#)<sup>55</sup>, R. Gonçalves [id](#)<sup>129a,129c</sup>,  
 G. Gonella [id](#)<sup>122</sup>, L. Gonella [id](#)<sup>20</sup>, A. Gongadze [id](#)<sup>38</sup>, F. Gonnella [id](#)<sup>20</sup>, J.L. Gonski [id](#)<sup>41</sup>,  
 R.Y. González Andana [id](#)<sup>52</sup>, S. González de la Hoz [id](#)<sup>162</sup>, S. Gonzalez Fernandez [id](#)<sup>13</sup>,  
 R. Gonzalez Lopez [id](#)<sup>91</sup>, C. Gonzalez Renteria [id](#)<sup>17a</sup>, R. Gonzalez Suarez [id](#)<sup>160</sup>, S. Gonzalez-Sevilla [id](#)<sup>56</sup>,  
 G.R. Gonzalvo Rodriguez [id](#)<sup>162</sup>, L. Goossens [id](#)<sup>36</sup>, N.A. Gorasia [id](#)<sup>20</sup>, P.A. Gorbounov [id](#)<sup>37</sup>,  
 B. Gorini [id](#)<sup>36</sup>, E. Gorini [id](#)<sup>69a,69b</sup>, A. Gorišek [id](#)<sup>92</sup>, A.T. Goshaw [id](#)<sup>51</sup>, M.I. Gostkin [id](#)<sup>38</sup>,  
 C.A. Gottardo [id](#)<sup>36</sup>, M. Gouighri [id](#)<sup>35b</sup>, V. Goumarre [id](#)<sup>48</sup>, A.G. Goussiou [id](#)<sup>137</sup>, N. Govender [id](#)<sup>33c</sup>,  
 C. Goy [id](#)<sup>4</sup>, I. Grabowska-Bold [id](#)<sup>84a</sup>, K. Graham [id](#)<sup>34</sup>, E. Gramstad [id](#)<sup>124</sup>, S. Grancagnolo [id](#)<sup>18</sup>,

M. Grandi [id](#)<sup>145</sup>, V. Gratchev<sup>37,\*</sup>, P.M. Gravila [id](#)<sup>27f</sup>, F.G. Gravili [id](#)<sup>69a,69b</sup>, H.M. Gray [id](#)<sup>17a</sup>,  
M. Greco [id](#)<sup>69a,69b</sup>, C. Grefe [id](#)<sup>24</sup>, I.M. Gregor [id](#)<sup>48</sup>, P. Grenier [id](#)<sup>142</sup>, C. Grieco [id](#)<sup>13</sup>, A.A. Grillo [id](#)<sup>135</sup>,  
K. Grimm [id](#)<sup>31,n</sup>, S. Grinstein [id](#)<sup>13,v</sup>, J.-F. Grivaz [id](#)<sup>66</sup>, E. Gross [id](#)<sup>168</sup>, J. Grosse-Knetter [id](#)<sup>55</sup>, C. Grud<sup>105</sup>,  
A. Grummer [id](#)<sup>111</sup>, J.C. Grundy [id](#)<sup>125</sup>, L. Guan [id](#)<sup>105</sup>, W. Guan [id](#)<sup>169</sup>, C. Gubbels [id](#)<sup>163</sup>,  
J.G.R. Guerrero Rojas [id](#)<sup>162</sup>, G. Guerrieri [id](#)<sup>68a,68b</sup>, F. Guescini [id](#)<sup>109</sup>, R. Gugel [id](#)<sup>99</sup>, J.A.M. Guhit [id](#)<sup>105</sup>,  
A. Guida [id](#)<sup>48</sup>, T. Guillemain [id](#)<sup>4</sup>, E. Guilloton [id](#)<sup>166,133</sup>, S. Guindon [id](#)<sup>36</sup>, F. Guo [id](#)<sup>14a,14d</sup>, J. Guo [id](#)<sup>62c</sup>,  
L. Guo [id](#)<sup>66</sup>, Y. Guo [id](#)<sup>105</sup>, R. Gupta [id](#)<sup>48</sup>, S. Gurbuz [id](#)<sup>24</sup>, S.S. Gurdasani [id](#)<sup>54</sup>, G. Gustavino [id](#)<sup>36</sup>,  
M. Guth [id](#)<sup>56</sup>, P. Gutierrez [id](#)<sup>119</sup>, L.F. Gutierrez Zagazeta [id](#)<sup>127</sup>, C. Gutschow [id](#)<sup>95</sup>, C. Guyot [id](#)<sup>134</sup>,  
C. Gwenlan [id](#)<sup>125</sup>, C.B. Gwilliam [id](#)<sup>91</sup>, E.S. Haaland [id](#)<sup>124</sup>, A. Haas [id](#)<sup>116</sup>, M. Habedank [id](#)<sup>48</sup>,  
C. Haber [id](#)<sup>17a</sup>, H.K. Hadavand [id](#)<sup>8</sup>, A. Hadeb [id](#)<sup>99</sup>, S. Hadzic [id](#)<sup>109</sup>, M. Haleem [id](#)<sup>165</sup>, J. Haley [id](#)<sup>120</sup>,  
J.J. Hall [id](#)<sup>138</sup>, G.D. Hallelwell [id](#)<sup>101</sup>, L. Halser [id](#)<sup>19</sup>, K. Hamano [id](#)<sup>164</sup>, H. Hamdaoui [id](#)<sup>35e</sup>, M. Hamer [id](#)<sup>24</sup>,  
G.N. Hamity [id](#)<sup>52</sup>, J. Han [id](#)<sup>62b</sup>, K. Han [id](#)<sup>62a</sup>, L. Han [id](#)<sup>14c</sup>, L. Han [id](#)<sup>62a</sup>, S. Han [id](#)<sup>17a</sup>, Y.F. Han [id](#)<sup>154</sup>,  
K. Hanagaki [id](#)<sup>82</sup>, M. Hance [id](#)<sup>135</sup>, D.A. Hangal [id](#)<sup>41,ac</sup>, M.D. Hank [id](#)<sup>39</sup>, R. Hankache [id](#)<sup>100</sup>,  
J.B. Hansen [id](#)<sup>42</sup>, J.D. Hansen [id](#)<sup>42</sup>, P.H. Hansen [id](#)<sup>42</sup>, K. Hara [id](#)<sup>156</sup>, D. Harada [id](#)<sup>56</sup>, T. Harenberg [id](#)<sup>170</sup>,  
S. Harkusha [id](#)<sup>37</sup>, Y.T. Harris [id](#)<sup>125</sup>, N.M. Harrison [id](#)<sup>118</sup>, P.F. Harrison<sup>166</sup>, N.M. Hartman [id](#)<sup>142</sup>,  
N.M. Hartmann [id](#)<sup>108</sup>, Y. Hasegawa [id](#)<sup>139</sup>, A. Hasib [id](#)<sup>52</sup>, S. Haug [id](#)<sup>19</sup>, R. Hauser [id](#)<sup>106</sup>,  
M. Havranek [id](#)<sup>131</sup>, C.M. Hawkes [id](#)<sup>20</sup>, R.J. Hawkins [id](#)<sup>36</sup>, S. Hayashida [id](#)<sup>110</sup>, D. Hayden [id](#)<sup>106</sup>,  
C. Hayes [id](#)<sup>105</sup>, R.L. Hayes [id](#)<sup>163</sup>, C.P. Hays [id](#)<sup>125</sup>, J.M. Hays [id](#)<sup>93</sup>, H.S. Hayward [id](#)<sup>91</sup>, F. He [id](#)<sup>62a</sup>,  
Y. He [id](#)<sup>153</sup>, Y. He [id](#)<sup>126</sup>, M.P. Heath [id](#)<sup>52</sup>, V. Hedberg [id](#)<sup>97</sup>, A.L. Heggelund [id](#)<sup>124</sup>, N.D. Hehir [id](#)<sup>93</sup>,  
C. Heidegger [id](#)<sup>54</sup>, K.K. Heidegger [id](#)<sup>54</sup>, W.D. Heidorn [id](#)<sup>80</sup>, J. Heilman [id](#)<sup>34</sup>, S. Heim [id](#)<sup>48</sup>, T. Heim [id](#)<sup>17a</sup>,  
J.G. Heinlein [id](#)<sup>127</sup>, J.J. Heinrich [id](#)<sup>122</sup>, L. Heinrich [id](#)<sup>109,ae</sup>, J. Hejbal [id](#)<sup>130</sup>, L. Helary [id](#)<sup>48</sup>, A. Held [id](#)<sup>169</sup>,  
S. Hellesund [id](#)<sup>124</sup>, C.M. Helling [id](#)<sup>163</sup>, S. Hellman [id](#)<sup>47a,47b</sup>, C. Helsens [id](#)<sup>36</sup>, R.C.W. Henderson<sup>90</sup>,  
L. Henkelmann [id](#)<sup>32</sup>, A.M. Henriques Correia<sup>36</sup>, H. Herde [id](#)<sup>142</sup>, L. Hermann [id](#)<sup>54</sup>,  
Y. Hernández Jiménez [id](#)<sup>144</sup>, H. Herr<sup>99</sup>, M.G. Herrmann [id](#)<sup>108</sup>, T. Herrmann [id](#)<sup>50</sup>, G. Herten [id](#)<sup>54</sup>,  
R. Hertenberger [id](#)<sup>108</sup>, L. Hervas [id](#)<sup>36</sup>, N.P. Hessey [id](#)<sup>155a</sup>, H. Hibi [id](#)<sup>83</sup>, E. Higón-Rodríguez [id](#)<sup>162</sup>,  
S.J. Hillier [id](#)<sup>20</sup>, I. Hinchliffe [id](#)<sup>17a</sup>, F. Hinterkeuser [id](#)<sup>24</sup>, M. Hirose [id](#)<sup>123</sup>, S. Hirose [id](#)<sup>156</sup>,  
D. Hirschbuehl [id](#)<sup>170</sup>, T.G. Hitchings [id](#)<sup>100</sup>, B. Hiti [id](#)<sup>92</sup>, J. Hobbs [id](#)<sup>144</sup>, R. Hobincu [id](#)<sup>27e</sup>, N. Hod [id](#)<sup>168</sup>,  
M.C. Hodgkinson [id](#)<sup>138</sup>, B.H. Hodgkinson [id](#)<sup>32</sup>, A. Hoecker [id](#)<sup>36</sup>, J. Hofer [id](#)<sup>48</sup>, D. Hohn [id](#)<sup>54</sup>, T. Holm [id](#)<sup>24</sup>,  
M. Holzbock [id](#)<sup>109</sup>, L.B.A.H. Hommels [id](#)<sup>32</sup>, B.P. Honan [id](#)<sup>100</sup>, J. Hong [id](#)<sup>62c</sup>, T.M. Hong [id](#)<sup>128</sup>,  
Y. Hong [id](#)<sup>55</sup>, J.C. Honig [id](#)<sup>54</sup>, A. Hönlé [id](#)<sup>109</sup>, B.H. Hooberman [id](#)<sup>161</sup>, W.H. Hopkins [id](#)<sup>6</sup>, Y. Horii [id](#)<sup>110</sup>,  
S. Hou [id](#)<sup>147</sup>, A.S. Howard [id](#)<sup>92</sup>, J. Howarth [id](#)<sup>59</sup>, J. Hoya [id](#)<sup>89</sup>, M. Hrabovsky [id](#)<sup>121</sup>, A. Hrynevich [id](#)<sup>37</sup>,  
T. Hryn'ova [id](#)<sup>4</sup>, P.J. Hsu [id](#)<sup>65</sup>, S.-C. Hsu [id](#)<sup>137</sup>, Q. Hu [id](#)<sup>41,ac</sup>, Y.F. Hu [id](#)<sup>14a,14d,ai</sup>, D.P. Huang [id](#)<sup>95</sup>,  
S. Huang [id](#)<sup>64b</sup>, X. Huang [id](#)<sup>14c</sup>, Y. Huang [id](#)<sup>62a</sup>, Y. Huang [id](#)<sup>14a</sup>, Z. Huang [id](#)<sup>100</sup>, Z. Hubacek [id](#)<sup>131</sup>,  
M. Huebner [id](#)<sup>24</sup>, F. Huegging [id](#)<sup>24</sup>, T.B. Huffman [id](#)<sup>125</sup>, M. Huhtinen [id](#)<sup>36</sup>, S.K. Huiberts [id](#)<sup>16</sup>,  
R. Hulsken [id](#)<sup>103</sup>, N. Huseynov [id](#)<sup>12,a</sup>, J. Huston [id](#)<sup>106</sup>, J. Huth [id](#)<sup>61</sup>, R. Hyneman [id](#)<sup>142</sup>, S. Hyrych [id](#)<sup>28a</sup>,  
G. Iacobucci [id](#)<sup>56</sup>, G. Iakovidis [id](#)<sup>29</sup>, I. Ibragimov [id](#)<sup>140</sup>, L. Iconomidou-Fayard [id](#)<sup>66</sup>, P. Iengo [id](#)<sup>71a,71b</sup>,  
R. Iguchi [id](#)<sup>152</sup>, T. Iizawa [id](#)<sup>56</sup>, Y. Ikegami [id](#)<sup>82</sup>, A. Ilg [id](#)<sup>19</sup>, N. Ilic [id](#)<sup>154</sup>, H. Imam [id](#)<sup>35a</sup>,  
T. Ingebretsen Carlson [id](#)<sup>47a,47b</sup>, G. Introzzi [id](#)<sup>72a,72b</sup>, M. Iodice [id](#)<sup>76a</sup>, V. Ippolito [id](#)<sup>74a,74b</sup>, M. Ishino [id](#)<sup>152</sup>,  
W. Islam [id](#)<sup>169</sup>, C. Issever [id](#)<sup>18,48</sup>, S. Istin [id](#)<sup>21a,al</sup>, H. Ito [id](#)<sup>167</sup>, J.M. Iturbe Ponce [id](#)<sup>64a</sup>, R. Iuppa [id](#)<sup>77a,77b</sup>,  
A. Ivina [id](#)<sup>168</sup>, J.M. Izen [id](#)<sup>45</sup>, V. Izzo [id](#)<sup>71a</sup>, P. Jacka [id](#)<sup>130,131</sup>, P. Jackson [id](#)<sup>1</sup>, R.M. Jacobs [id](#)<sup>48</sup>,  
B.P. Jaeger [id](#)<sup>141</sup>, C.S. Jagfeld [id](#)<sup>108</sup>, G. Jäkel [id](#)<sup>170</sup>, K. Jakobs [id](#)<sup>54</sup>, T. Jakoubek [id](#)<sup>168</sup>, J. Jamieson [id](#)<sup>59</sup>,  
K.W. Janas [id](#)<sup>84a</sup>, G. Jarlskog [id](#)<sup>97</sup>, A.E. Jaspán [id](#)<sup>91</sup>, T. Javůrek [id](#)<sup>36</sup>, M. Javurkova [id](#)<sup>102</sup>,  
F. Jeanneau [id](#)<sup>134</sup>, L. Jeanty [id](#)<sup>122</sup>, J. Jejelava [id](#)<sup>148a,aa</sup>, P. Jenni [id](#)<sup>54,g</sup>, C.E. Jessiman [id](#)<sup>34</sup>, S. Jézéquel [id](#)<sup>4</sup>,  
J. Jia [id](#)<sup>144</sup>, X. Jia [id](#)<sup>61</sup>, X. Jia [id](#)<sup>14a,14d</sup>, Z. Jia [id](#)<sup>14c</sup>, Y. Jiang [id](#)<sup>62a</sup>, S. Jiggins [id](#)<sup>52</sup>, J. Jimenez Pena [id](#)<sup>109</sup>,  
S. Jin [id](#)<sup>14c</sup>, A. Jinaru [id](#)<sup>27b</sup>, O. Jinnouchi [id](#)<sup>153</sup>, H. Jivan [id](#)<sup>33g</sup>, P. Johansson [id](#)<sup>138</sup>, K.A. Johns [id](#)<sup>7</sup>,  
C.A. Johnson [id](#)<sup>67</sup>, D.M. Jones [id](#)<sup>32</sup>, E. Jones [id](#)<sup>166</sup>, P. Jones [id](#)<sup>32</sup>, R.W.L. Jones [id](#)<sup>90</sup>, T.J. Jones [id](#)<sup>91</sup>,

J. Jovicevic [id](#)<sup>15</sup>, X. Ju [id](#)<sup>17a</sup>, J.J. Junggeburth [id](#)<sup>36</sup>, A. Juste Rozas [id](#)<sup>13,v</sup>, S. Kabana [id](#)<sup>136e</sup>,  
 A. Kaczmarek [id](#)<sup>85</sup>, M. Kado [id](#)<sup>74a,74b</sup>, H. Kagan [id](#)<sup>118</sup>, M. Kagan [id](#)<sup>142</sup>, A. Kahn<sup>41</sup>, A. Kahn [id](#)<sup>127</sup>,  
 C. Kahra [id](#)<sup>99</sup>, T. Kaji [id](#)<sup>167</sup>, E. Kajomovitz [id](#)<sup>149</sup>, N. Kakati [id](#)<sup>168</sup>, C.W. Kalderon [id](#)<sup>29</sup>,  
 A. Kamenshchikov [id](#)<sup>154</sup>, N.J. Kang [id](#)<sup>135</sup>, Y. Kano [id](#)<sup>110</sup>, D. Kar [id](#)<sup>33g</sup>, K. Karava [id](#)<sup>125</sup>,  
 M.J. Kareem [id](#)<sup>155b</sup>, E. Karentzos [id](#)<sup>54</sup>, I. Karkanias [id](#)<sup>151</sup>, S.N. Karpov [id](#)<sup>38</sup>, Z.M. Karpova [id](#)<sup>38</sup>,  
 V. Kartvelishvili [id](#)<sup>90</sup>, A.N. Karyukhin [id](#)<sup>37</sup>, E. Kasimi [id](#)<sup>151</sup>, C. Kato [id](#)<sup>62d</sup>, J. Katzy [id](#)<sup>48</sup>, S. Kaur [id](#)<sup>34</sup>,  
 K. Kawade [id](#)<sup>139</sup>, K. Kawagoe [id](#)<sup>88</sup>, T. Kawaguchi [id](#)<sup>110</sup>, T. Kawamoto [id](#)<sup>134</sup>, G. Kawamura<sup>55</sup>,  
 E.F. Kay [id](#)<sup>164</sup>, F.I. Kaya [id](#)<sup>157</sup>, S. Kazakos [id](#)<sup>13</sup>, V.F. Kazanin [id](#)<sup>37</sup>, Y. Ke [id](#)<sup>144</sup>, J.M. Keaveney [id](#)<sup>33a</sup>,  
 R. Keeler [id](#)<sup>164</sup>, G.V. Kehris [id](#)<sup>61</sup>, J.S. Keller [id](#)<sup>34</sup>, A.S. Kelly<sup>95</sup>, D. Kelsey [id](#)<sup>145</sup>, J.J. Kempster [id](#)<sup>20</sup>,  
 J. Kendrick [id](#)<sup>20</sup>, K.E. Kennedy [id](#)<sup>41</sup>, O. Kepka [id](#)<sup>130</sup>, B.P. Kerridge [id](#)<sup>166</sup>, S. Kersten [id](#)<sup>170</sup>,  
 B.P. Kerševan [id](#)<sup>92</sup>, L. Keszeghova [id](#)<sup>28a</sup>, S. Ketabchi Haghighat [id](#)<sup>154</sup>, M. Khandoga [id](#)<sup>126</sup>,  
 A. Khanov [id](#)<sup>120</sup>, A.G. Kharlamov [id](#)<sup>37</sup>, T. Kharlamova [id](#)<sup>37</sup>, E.E. Khoda [id](#)<sup>137</sup>, T.J. Khoo [id](#)<sup>18</sup>,  
 G. Khoraiuli [id](#)<sup>165</sup>, J. Khubua [id](#)<sup>148b</sup>, Y.A.R. Khwaira [id](#)<sup>66</sup>, M. Kiehn [id](#)<sup>36</sup>, A. Kilgallon [id](#)<sup>122</sup>,  
 D.W. Kim [id](#)<sup>47a,47b</sup>, E. Kim [id](#)<sup>153</sup>, Y.K. Kim [id](#)<sup>39</sup>, N. Kimura [id](#)<sup>95</sup>, A. Kirchhoff [id](#)<sup>55</sup>, D. Kirchmeier [id](#)<sup>50</sup>,  
 C. Kirfel [id](#)<sup>24</sup>, J. Kirk [id](#)<sup>133</sup>, A.E. Kiryunin [id](#)<sup>109</sup>, T. Kishimoto [id](#)<sup>152</sup>, D.P. Kisliuk<sup>154</sup>, C. Kitsaki [id](#)<sup>10</sup>,  
 O. Kivernyk [id](#)<sup>24</sup>, M. Klassen [id](#)<sup>63a</sup>, C. Klein [id](#)<sup>34</sup>, L. Klein [id](#)<sup>165</sup>, M.H. Klein [id](#)<sup>105</sup>, M. Klein [id](#)<sup>91</sup>,  
 U. Klein [id](#)<sup>91</sup>, P. Klimek [id](#)<sup>36</sup>, A. Klimentov [id](#)<sup>29</sup>, F. Klimpel [id](#)<sup>109</sup>, T. Klingl [id](#)<sup>24</sup>, T. Klioutchnikova [id](#)<sup>36</sup>,  
 F.F. Klitzner [id](#)<sup>108</sup>, P. Kluit [id](#)<sup>113</sup>, S. Kluth [id](#)<sup>109</sup>, E. Kneringer [id](#)<sup>78</sup>, T.M. Knight [id](#)<sup>154</sup>, A. Knue [id](#)<sup>54</sup>,  
 D. Kobayashi<sup>88</sup>, R. Kobayashi [id](#)<sup>86</sup>, M. Kocian [id](#)<sup>142</sup>, T. Kodama<sup>152</sup>, P. Kodyš [id](#)<sup>132</sup>, D.M. Koeck [id](#)<sup>145</sup>,  
 P.T. Koenig [id](#)<sup>24</sup>, T. Koffas [id](#)<sup>34</sup>, N.M. Köhler [id](#)<sup>36</sup>, M. Kolb [id](#)<sup>134</sup>, I. Koletsou [id](#)<sup>4</sup>, T. Komarek [id](#)<sup>121</sup>,  
 K. Köneke [id](#)<sup>54</sup>, A.X.Y. Kong [id](#)<sup>1</sup>, T. Kono [id](#)<sup>117</sup>, N. Konstantinidis [id](#)<sup>95</sup>, B. Konya [id](#)<sup>97</sup>,  
 R. Kopeliansky [id](#)<sup>67</sup>, S. Koperny [id](#)<sup>84a</sup>, K. Korcyl [id](#)<sup>85</sup>, K. Kordas [id](#)<sup>151</sup>, G. Koren [id](#)<sup>150</sup>, A. Korn [id](#)<sup>95</sup>,  
 S. Korn [id](#)<sup>55</sup>, I. Korolkov [id](#)<sup>13</sup>, N. Korotkova [id](#)<sup>37</sup>, B. Kortman [id](#)<sup>113</sup>, O. Kortner [id](#)<sup>109</sup>, S. Kortner [id](#)<sup>109</sup>,  
 W.H. Kostecka [id](#)<sup>114</sup>, V.V. Kostyukhin [id](#)<sup>140</sup>, A. Kotsokechagia [id](#)<sup>66</sup>, A. Kotwal [id](#)<sup>51</sup>, A. Koulouris [id](#)<sup>36</sup>,  
 A. Kourkoumeli-Charalampidi [id](#)<sup>72a,72b</sup>, C. Kourkoumelis [id](#)<sup>9</sup>, E. Kourlitis [id](#)<sup>6</sup>, O. Kovanda [id](#)<sup>145</sup>,  
 R. Kowalewski [id](#)<sup>164</sup>, W. Kozanecki [id](#)<sup>134</sup>, A.S. Kozhin [id](#)<sup>37</sup>, V.A. Kramarenko [id](#)<sup>37</sup>, G. Kramberger [id](#)<sup>92</sup>,  
 P. Kramer [id](#)<sup>99</sup>, M.W. Krasny [id](#)<sup>126</sup>, A. Krasznahorkay [id](#)<sup>36</sup>, J.A. Kremer [id](#)<sup>99</sup>, T. Kresse [id](#)<sup>50</sup>,  
 J. Kretschmar [id](#)<sup>91</sup>, K. Kreul [id](#)<sup>18</sup>, P. Krieger [id](#)<sup>154</sup>, F. Krieter [id](#)<sup>108</sup>, S. Krishnamurthy [id](#)<sup>102</sup>,  
 A. Krishnan [id](#)<sup>63b</sup>, M. Krivos [id](#)<sup>132</sup>, K. Krizka [id](#)<sup>17a</sup>, K. Kroeninger [id](#)<sup>49</sup>, H. Kroha [id](#)<sup>109</sup>, J. Kroll [id](#)<sup>130</sup>,  
 J. Kroll [id](#)<sup>127</sup>, K.S. Krowpman [id](#)<sup>106</sup>, U. Kruchonak [id](#)<sup>38</sup>, H. Krüger [id](#)<sup>24</sup>, N. Krumnack<sup>80</sup>,  
 M.C. Kruse [id](#)<sup>51</sup>, J.A. Krzysiak [id](#)<sup>85</sup>, A. Kubota [id](#)<sup>153</sup>, O. Kuchinskaia [id](#)<sup>37</sup>, S. Kuday [id](#)<sup>3a</sup>,  
 D. Kuechler [id](#)<sup>48</sup>, J.T. Kuechler [id](#)<sup>48</sup>, S. Kuehn [id](#)<sup>36</sup>, T. Kuhl [id](#)<sup>48</sup>, V. Kukhtin [id](#)<sup>38</sup>, Y. Kulchitsky [id](#)<sup>37,a</sup>,  
 S. Kuleshov [id](#)<sup>136d,136b</sup>, M. Kumar [id](#)<sup>33g</sup>, N. Kumari [id](#)<sup>101</sup>, M. Kuna [id](#)<sup>60</sup>, A. Kupco [id](#)<sup>130</sup>, T. Kupfer<sup>49</sup>,  
 A. Kupich [id](#)<sup>37</sup>, O. Kuprash [id](#)<sup>54</sup>, H. Kurashige [id](#)<sup>83</sup>, L.L. Kurchaninov [id](#)<sup>155a</sup>, Y.A. Kurochkin [id](#)<sup>37</sup>,  
 A. Kurova [id](#)<sup>37</sup>, E.S. Kuwertz [id](#)<sup>36</sup>, M. Kuze [id](#)<sup>153</sup>, A.K. Kvam [id](#)<sup>102</sup>, J. Kvita [id](#)<sup>121</sup>, T. Kwan [id](#)<sup>103</sup>,  
 K.W. Kwok [id](#)<sup>64a</sup>, N.G. Kyriacou [id](#)<sup>105</sup>, L.A.O. Laatu [id](#)<sup>101</sup>, C. Lacasta [id](#)<sup>162</sup>, F. Lacava [id](#)<sup>74a,74b</sup>,  
 H. Lacker [id](#)<sup>18</sup>, D. Lacour [id](#)<sup>126</sup>, N.N. Lad [id](#)<sup>95</sup>, E. Ladygin [id](#)<sup>38</sup>, B. Laforge [id](#)<sup>126</sup>, T. Lagouri [id](#)<sup>136e</sup>,  
 S. Lai [id](#)<sup>55</sup>, I.K. Lakomic [id](#)<sup>84a</sup>, N. Lalloue [id](#)<sup>60</sup>, J.E. Lambert [id](#)<sup>119</sup>, S. Lammers [id](#)<sup>67</sup>, W. Lampl [id](#)<sup>7</sup>,  
 C. Lampoudis [id](#)<sup>151</sup>, A.N. Lancaster [id](#)<sup>114</sup>, E. Lançon [id](#)<sup>29</sup>, U. Landgraf [id](#)<sup>54</sup>, M.P.J. Landon [id](#)<sup>93</sup>,  
 V.S. Lang [id](#)<sup>54</sup>, R.J. Langenberg [id](#)<sup>102</sup>, A.J. Lankford [id](#)<sup>159</sup>, F. Lanni [id](#)<sup>29</sup>, K. Lantzsck [id](#)<sup>24</sup>,  
 A. Lanza [id](#)<sup>72a</sup>, A. Lapertosa [id](#)<sup>57b,57a</sup>, J.F. Laporte [id](#)<sup>134</sup>, T. Lari [id](#)<sup>70a</sup>, F. Lasagni Manghi [id](#)<sup>23b</sup>,  
 M. Lassnig [id](#)<sup>36</sup>, V. Latonova [id](#)<sup>130</sup>, T.S. Lau [id](#)<sup>64a</sup>, A. Laudrain [id](#)<sup>99</sup>, A. Laurier [id](#)<sup>34</sup>, S.D. Lawlor [id](#)<sup>94</sup>,  
 Z. Lawrence [id](#)<sup>100</sup>, M. Lazzaroni [id](#)<sup>70a,70b</sup>, B. Le<sup>100</sup>, B. Leban [id](#)<sup>92</sup>, A. Lebedev [id](#)<sup>80</sup>, M. LeBlanc [id](#)<sup>36</sup>,  
 T. LeCompte [id](#)<sup>6</sup>, F. Ledroit-Guillon [id](#)<sup>60</sup>, A.C.A. Lee<sup>95</sup>, G.R. Lee [id](#)<sup>16</sup>, L. Lee [id](#)<sup>61</sup>, S.C. Lee [id](#)<sup>147</sup>,  
 S. Lee [id](#)<sup>47a,47b</sup>, T.F. Lee [id](#)<sup>91</sup>, L.L. Leeuw [id](#)<sup>33c</sup>, H.P. Lefebvre [id](#)<sup>94</sup>, M. Lefebvre [id](#)<sup>164</sup>, C. Leggett [id](#)<sup>17a</sup>,  
 K. Lehmann [id](#)<sup>141</sup>, G. Lehmann Miotto [id](#)<sup>36</sup>, W.A. Leight [id](#)<sup>102</sup>, A. Leisos [id](#)<sup>151,u</sup>, M.A.L. Leite [id](#)<sup>81c</sup>,

C.E. Leitgeb <sup>48</sup>, R. Leitner <sup>132</sup>, K.J.C. Leney <sup>44</sup>, T. Lenz <sup>24</sup>, S. Leone <sup>73a</sup>, C. Leonidopoulos <sup>52</sup>,  
 A. Leopold <sup>143</sup>, C. Leroy <sup>107</sup>, R. Les <sup>106</sup>, C.G. Lester <sup>32</sup>, M. Levchenko <sup>37</sup>, J. Levêque <sup>4</sup>,  
 D. Levin <sup>105</sup>, L.J. Levinson <sup>168</sup>, M.P. Lewicki <sup>85</sup>, D.J. Lewis <sup>20</sup>, B. Li <sup>14b</sup>, B. Li <sup>62b</sup>, C. Li <sup>62a</sup>,  
 C-Q. Li <sup>62c,62d</sup>, H. Li <sup>62a</sup>, H. Li <sup>62b</sup>, H. Li <sup>14c</sup>, H. Li <sup>62b</sup>, J. Li <sup>62c</sup>, K. Li <sup>137</sup>, L. Li <sup>62c</sup>,  
 M. Li <sup>14a,14d</sup>, Q.Y. Li <sup>62a</sup>, S. Li <sup>62d,62c,e</sup>, T. Li <sup>62b</sup>, X. Li <sup>103</sup>, Z. Li <sup>62b</sup>, Z. Li <sup>125</sup>, Z. Li <sup>103</sup>,  
 Z. Li <sup>91</sup>, Z. Liang <sup>14a</sup>, M. Liberatore <sup>48</sup>, B. Liberti <sup>75a</sup>, K. Lie <sup>64c</sup>, J. Lieber Marin <sup>81b</sup>,  
 K. Lin <sup>106</sup>, R.A. Linck <sup>67</sup>, R.E. Lindley <sup>7</sup>, J.H. Lindon <sup>2</sup>, A. Linss <sup>48</sup>, E. Lipeles <sup>127</sup>,  
 A. Lipniacka <sup>16</sup>, A. Lister <sup>163</sup>, J.D. Little <sup>4</sup>, B. Liu <sup>14a</sup>, B.X. Liu <sup>141</sup>, D. Liu <sup>62d,62c</sup>,  
 J.B. Liu <sup>62a</sup>, J.K.K. Liu <sup>32</sup>, K. Liu <sup>62d,62c</sup>, M. Liu <sup>62a</sup>, M.Y. Liu <sup>62a</sup>, P. Liu <sup>14a</sup>,  
 Q. Liu <sup>62d,137,62c</sup>, X. Liu <sup>62a</sup>, X. Liu <sup>62b</sup>, Y. Liu <sup>48</sup>, Y. Liu <sup>14c,14d</sup>, Y.L. Liu <sup>105</sup>, Y.W. Liu <sup>62a</sup>,  
 M. Livan <sup>72a,72b</sup>, J. Llorente Merino <sup>141</sup>, S.L. Lloyd <sup>93</sup>, E.M. Lobodzinska <sup>48</sup>, P. Loch <sup>7</sup>,  
 S. Loffredo <sup>75a,75b</sup>, T. Lohse <sup>18</sup>, K. Lohwasser <sup>138</sup>, M. Lokajicek <sup>130,\*</sup>, J.D. Long <sup>161</sup>,  
 I. Longarini <sup>74a,74b</sup>, L. Longo <sup>69a,69b</sup>, R. Longo <sup>161</sup>, I. Lopez Paz <sup>36</sup>, A. Lopez Solis <sup>48</sup>,  
 J. Lorenz <sup>108</sup>, N. Lorenzo Martinez <sup>4</sup>, A.M. Lory <sup>108</sup>, A. Lösle <sup>54</sup>, X. Lou <sup>47a,47b</sup>,  
 X. Lou <sup>14a,14d</sup>, A. Lounis <sup>66</sup>, J. Love <sup>6</sup>, P.A. Love <sup>90</sup>, J.J. Lozano Bahilo <sup>162</sup>, G. Lu <sup>14a,14d</sup>,  
 M. Lu <sup>79</sup>, S. Lu <sup>127</sup>, Y.J. Lu <sup>65</sup>, H.J. Lubatti <sup>137</sup>, C. Luci <sup>74a,74b</sup>, F.L. Lucio Alves <sup>14c</sup>,  
 A. Lucotte <sup>60</sup>, F. Luehring <sup>67</sup>, I. Luise <sup>144</sup>, O. Lukianchuk <sup>66</sup>, O. Lundberg <sup>143</sup>,  
 B. Lund-Jensen <sup>143</sup>, N.A. Luongo <sup>122</sup>, M.S. Lutz <sup>150</sup>, D. Lynn <sup>29</sup>, H. Lyons <sup>91</sup>, R. Lysak <sup>130</sup>,  
 E. Lytken <sup>97</sup>, F. Lyu <sup>14a</sup>, V. Lyubushkin <sup>38</sup>, T. Lyubushkina <sup>38</sup>, H. Ma <sup>29</sup>, L.L. Ma <sup>62b</sup>,  
 Y. Ma <sup>95</sup>, D.M. Mac Donell <sup>164</sup>, G. Maccarrone <sup>53</sup>, J.C. MacDonald <sup>138</sup>, R. Madar <sup>40</sup>,  
 W.F. Mader <sup>50</sup>, J. Maeda <sup>83</sup>, T. Maeno <sup>29</sup>, M. Maerker <sup>50</sup>, V. Magerl <sup>54</sup>, J. Magro <sup>68a,68c</sup>,  
 H. Maguire <sup>138</sup>, D.J. Mahon <sup>41</sup>, C. Maidantchik <sup>81b</sup>, A. Maio <sup>129a,129b,129d</sup>, K. Maj <sup>84a</sup>,  
 O. Majersky <sup>28a</sup>, S. Majewski <sup>122</sup>, N. Makovec <sup>66</sup>, V. Maksimovic <sup>15</sup>, B. Malaescu <sup>126</sup>,  
 Pa. Malecki <sup>85</sup>, V.P. Maleev <sup>37</sup>, F. Malek <sup>60</sup>, D. Malito <sup>43b,43a</sup>, U. Mallik <sup>79</sup>, C. Malone <sup>32</sup>,  
 S. Maltezos <sup>10</sup>, S. Malyukov <sup>38</sup>, J. Mamuzic <sup>13</sup>, G. Mancini <sup>53</sup>, G. Manco <sup>72a,72b</sup>, J.P. Mandalia <sup>93</sup>,  
 I. Mandić <sup>92</sup>, L. Manhaes de Andrade Filho <sup>81a</sup>, I.M. Maniatis <sup>151</sup>, M. Manisha <sup>134</sup>,  
 J. Manjarres Ramos <sup>50</sup>, D.C. Mankad <sup>168</sup>, K.H. Mankinen <sup>97</sup>, A. Mann <sup>108</sup>, A. Manousos <sup>78</sup>,  
 B. Mansoulie <sup>134</sup>, S. Manzoni <sup>36</sup>, A. Marantis <sup>151,u</sup>, G. Marchiori <sup>5</sup>, M. Marcisovsky <sup>130</sup>,  
 L. Marcoccia <sup>75a,75b</sup>, C. Marcon <sup>70a,70b</sup>, M. Marinescu <sup>20</sup>, M. Marjanovic <sup>119</sup>, Z. Marshall <sup>17a</sup>,  
 S. Marti-Garcia <sup>162</sup>, T.A. Martin <sup>166</sup>, V.J. Martin <sup>52</sup>, B. Martin dit Latour <sup>16</sup>,  
 L. Martinelli <sup>74a,74b</sup>, M. Martinez <sup>13,v</sup>, P. Martinez Agullo <sup>162</sup>, V.I. Martinez Outschoorn <sup>102</sup>,  
 P. Martinez Suarez <sup>13</sup>, S. Martin-Haugh <sup>133</sup>, V.S. Martoiu <sup>27b</sup>, A.C. Martyniuk <sup>95</sup>, A. Marzin <sup>36</sup>,  
 S.R. Maschek <sup>109</sup>, L. Masetti <sup>99</sup>, T. Mashimo <sup>152</sup>, J. Masik <sup>100</sup>, A.L. Maslennikov <sup>37</sup>,  
 L. Massa <sup>23b</sup>, P. Massarotti <sup>71a,71b</sup>, P. Mastrandrea <sup>73a,73b</sup>, A. Mastroberardino <sup>43b,43a</sup>,  
 T. Masubuchi <sup>152</sup>, T. Mathisen <sup>160</sup>, A. Matic <sup>108</sup>, N. Matsuzawa <sup>152</sup>, J. Maurer <sup>27b</sup>, B. Maček <sup>92</sup>,  
 D.A. Maximov <sup>37</sup>, R. Mazini <sup>147</sup>, I. Maznas <sup>151</sup>, M. Mazza <sup>106</sup>, S.M. Mazza <sup>135</sup>,  
 C. Mc Ginn <sup>29</sup>, J.P. Mc Gowan <sup>103</sup>, S.P. Mc Kee <sup>105</sup>, T.G. McCarthy <sup>109</sup>, W.P. McCormack <sup>17a</sup>,  
 E.F. McDonald <sup>104</sup>, A.E. McDougall <sup>113</sup>, J.A. MCFayden <sup>145</sup>, G. Mchedlidze <sup>148b</sup>,  
 R.P. McKenzie <sup>33g</sup>, T.C. Mclachlan <sup>48</sup>, D.J. Mclaughlin <sup>95</sup>, K.D. McLean <sup>164</sup>, S.J. McMahan <sup>133</sup>,  
 P.C. McNamara <sup>104</sup>, R.A. McPherson <sup>164,y</sup>, J.E. Mdhluli <sup>33g</sup>, S. Meehan <sup>36</sup>, T. Megy <sup>40</sup>,  
 S. Mehlhase <sup>108</sup>, A. Mehta <sup>91</sup>, B. Meirose <sup>45</sup>, D. Melini <sup>149</sup>, B.R. Mellado Garcia <sup>33g</sup>,  
 A.H. Melo <sup>55</sup>, F. Meloni <sup>48</sup>, E.D. Mendes Gouveia <sup>129a</sup>, A.M. Mendes Jacques Da Costa <sup>20</sup>,  
 H.Y. Meng <sup>154</sup>, L. Meng <sup>90</sup>, S. Menke <sup>109</sup>, M. Mentink <sup>36</sup>, E. Meoni <sup>43b,43a</sup>, C. Merlassino <sup>125</sup>,  
 L. Merola <sup>71a,71b</sup>, C. Meroni <sup>70a,70b</sup>, G. Merz <sup>105</sup>, O. Meshkov <sup>37</sup>, J.K.R. Meshreki <sup>140</sup>,  
 J. Metcalfe <sup>6</sup>, A.S. Mete <sup>6</sup>, C. Meyer <sup>67</sup>, J-P. Meyer <sup>134</sup>, M. Michetti <sup>18</sup>, R.P. Middleton <sup>133</sup>,  
 L. Mijović <sup>52</sup>, G. Mikenberg <sup>168</sup>, M. Mikesstikova <sup>130</sup>, M. Mikuž <sup>92</sup>, H. Mildner <sup>138</sup>,

A. Milic <sup>154</sup>, C.D. Milke <sup>44</sup>, D.W. Miller <sup>39</sup>, L.S. Miller <sup>34</sup>, A. Milov <sup>168</sup>, D.A. Milstead <sup>47a,47b</sup>,  
 T. Min <sup>14c</sup>, A.A. Minaenko <sup>37</sup>, I.A. Minashvili <sup>148b</sup>, L. Mince <sup>59</sup>, A.I. Mincer <sup>116</sup>, B. Mindur <sup>84a</sup>,  
 M. Mineev <sup>38</sup>, Y. Minegishi <sup>152</sup>, Y. Mino <sup>86</sup>, L.M. Mir <sup>13</sup>, M. Miralles Lopez <sup>162</sup>,  
 M. Mironova <sup>125</sup>, T. Mitani <sup>167</sup>, A. Mitra <sup>166</sup>, V.A. Mitsou <sup>162</sup>, O. Miu <sup>154</sup>, P.S. Miyagawa <sup>93</sup>,  
 Y. Miyazaki <sup>88</sup>, A. Mizukami <sup>82</sup>, J.U. Mjörnmark <sup>97</sup>, T. Mkrtchyan <sup>63a</sup>, M. Mlynarikova <sup>114</sup>,  
 T. Moa <sup>47a,47b</sup>, S. Mobius <sup>55</sup>, K. Mochizuki <sup>107</sup>, P. Moder <sup>48</sup>, P. Mogg <sup>108</sup>,  
 A.F. Mohammed <sup>14a,14d</sup>, S. Mohapatra <sup>41</sup>, G. Mokgatitswane <sup>33g</sup>, B. Mondal <sup>140</sup>, S. Mondal <sup>131</sup>,  
 K. Mönig <sup>48</sup>, E. Monnier <sup>101</sup>, L. Monsonis Romero <sup>162</sup>, J. Montejo Berlingen <sup>36</sup>, M. Montella <sup>118</sup>,  
 F. Monticelli <sup>89</sup>, N. Morange <sup>66</sup>, A.L. Moreira De Carvalho <sup>129a</sup>, M. Moreno Llácer <sup>162</sup>,  
 C. Moreno Martinez <sup>13</sup>, P. Morettini <sup>57b</sup>, S. Morgenstern <sup>166</sup>, M. Morii <sup>61</sup>, M. Morinaga <sup>152</sup>,  
 V. Morisbak <sup>124</sup>, A.K. Morley <sup>36</sup>, F. Morodej <sup>74a,74b</sup>, L. Morvaj <sup>36</sup>, P. Moschovakos <sup>36</sup>,  
 B. Moser <sup>36</sup>, M. Mosidze <sup>148b</sup>, T. Moskalets <sup>54</sup>, P. Moskvitina <sup>112</sup>, J. Moss <sup>31,o</sup>, E.J.W. Moyse <sup>102</sup>,  
 S. Muanza <sup>101</sup>, J. Mueller <sup>128</sup>, D. Muenstermann <sup>90</sup>, R. Müller <sup>19</sup>, G.A. Mullier <sup>97</sup>,  
 J.J. Mullin <sup>127</sup>, D.P. Mungo <sup>70a,70b</sup>, J.L. Munoz Martinez <sup>13</sup>, D. Munoz Perez <sup>162</sup>,  
 F.J. Munoz Sanchez <sup>100</sup>, M. Murin <sup>100</sup>, W.J. Murray <sup>166,133</sup>, A. Murrone <sup>70a,70b</sup>, J.M. Muse <sup>119</sup>,  
 M. Muškinja <sup>17a</sup>, C. Mwewa <sup>29</sup>, A.G. Myagkov <sup>37,a</sup>, A.J. Myers <sup>8</sup>, A.A. Myers <sup>128</sup>, G. Myers <sup>67</sup>,  
 M. Myska <sup>131</sup>, B.P. Nachman <sup>17a</sup>, O. Nackenhorst <sup>49</sup>, A. Nag <sup>50</sup>, K. Nagai <sup>125</sup>, K. Nagano <sup>82</sup>,  
 J.L. Nagle <sup>29,aj</sup>, E. Nagy <sup>101</sup>, A.M. Nairz <sup>36</sup>, Y. Nakahama <sup>82</sup>, K. Nakamura <sup>82</sup>, H. Nanjo <sup>123</sup>,  
 R. Narayan <sup>44</sup>, E.A. Narayanan <sup>111</sup>, I. Naryshkin <sup>37</sup>, M. Naseri <sup>34</sup>, C. Nass <sup>24</sup>, G. Navarro <sup>22a</sup>,  
 J. Navarro-Gonzalez <sup>162</sup>, R. Nayak <sup>150</sup>, P.Y. Nechaeva <sup>37</sup>, F. Nechansky <sup>48</sup>, T.J. Neep <sup>20</sup>,  
 A. Negri <sup>72a,72b</sup>, M. Negrini <sup>23b</sup>, C. Nellist <sup>112</sup>, C. Nelson <sup>103</sup>, K. Nelson <sup>105</sup>, S. Nemecek <sup>130</sup>,  
 M. Nessi <sup>36,h</sup>, M.S. Neubauer <sup>161</sup>, F. Neuhaus <sup>99</sup>, J. Neundorf <sup>48</sup>, R. Newhouse <sup>163</sup>,  
 P.R. Newman <sup>20</sup>, C.W. Ng <sup>128</sup>, Y.S. Ng <sup>18</sup>, Y.W.Y. Ng <sup>159</sup>, B. Ngair <sup>35e</sup>, H.D.N. Nguyen <sup>107</sup>,  
 R.B. Nickerson <sup>125</sup>, R. Nicolaidou <sup>134</sup>, J. Nielsen <sup>135</sup>, M. Niemeyer <sup>55</sup>, N. Nikiforou <sup>36</sup>,  
 V. Nikolaenko <sup>37,a</sup>, I. Nikolic-Audit <sup>126</sup>, K. Nikolopoulos <sup>20</sup>, P. Nilsson <sup>29</sup>, H.R. Nindhito <sup>56</sup>,  
 A. Nisati <sup>74a</sup>, N. Nishu <sup>2</sup>, R. Nisius <sup>109</sup>, J-E. Nitschke <sup>50</sup>, E.K. Nkadimeng <sup>33g</sup>,  
 S.J. Noacco Rosende <sup>89</sup>, T. Nobe <sup>152</sup>, D.L. Noel <sup>32</sup>, Y. Noguchi <sup>86</sup>, T. Nommensen <sup>146</sup>,  
 M.A. Nomura <sup>29</sup>, M.B. Norfolk <sup>138</sup>, R.R.B. Norisam <sup>95</sup>, B.J. Norman <sup>34</sup>, J. Novak <sup>92</sup>,  
 T. Novak <sup>48</sup>, O. Novgorodova <sup>50</sup>, L. Novotny <sup>131</sup>, R. Novotny <sup>111</sup>, L. Nozka <sup>121</sup>, K. Ntekas <sup>159</sup>,  
 E. Nurse <sup>95</sup>, F.G. Oakham <sup>34,ag</sup>, J. Ocariz <sup>126</sup>, A. Ochi <sup>83</sup>, I. Ochoa <sup>129a</sup>, S. Oerdek <sup>160</sup>,  
 A. Ogrodnik <sup>84a</sup>, A. Oh <sup>100</sup>, C.C. Ohm <sup>143</sup>, H. Oide <sup>153</sup>, R. Oishi <sup>152</sup>, M.L. Ojeda <sup>48</sup>,  
 Y. Okazaki <sup>86</sup>, M.W. O'Keefe <sup>91</sup>, Y. Okumura <sup>152</sup>, A. Olariu <sup>27b</sup>, L.F. Oleiro Seabra <sup>129a</sup>,  
 S.A. Olivares Pino <sup>136e</sup>, D. Oliveira Damazio <sup>29</sup>, D. Oliveira Goncalves <sup>81a</sup>, J.L. Oliver <sup>159</sup>,  
 M.J.R. Olsson <sup>159</sup>, A. Olszewski <sup>85</sup>, J. Olszowska <sup>85,\*</sup>, Ö.O. Öncel <sup>54</sup>, D.C. O'Neil <sup>141</sup>,  
 A.P. O'Neill <sup>19</sup>, A. Onofre <sup>129a,129e</sup>, P.U.E. Onyisi <sup>11</sup>, M.J. Oreglia <sup>39</sup>, G.E. Orellana <sup>89</sup>,  
 D. Orestano <sup>76a,76b</sup>, N. Orlando <sup>13</sup>, R.S. Orr <sup>154</sup>, V. O'Shea <sup>59</sup>, R. Ospanov <sup>62a</sup>,  
 G. Otero y Garzon <sup>30</sup>, H. Otono <sup>88</sup>, P.S. Ott <sup>63a</sup>, G.J. Ottino <sup>17a</sup>, M. Ouchrif <sup>35d</sup>,  
 J. Ouellette <sup>29,aj</sup>, F. Ould-Saada <sup>124</sup>, M. Owen <sup>59</sup>, R.E. Owen <sup>133</sup>, K.Y. Oyulmaz <sup>21a</sup>,  
 V.E. Ozcan <sup>21a</sup>, N. Ozturk <sup>8</sup>, S. Ozturk <sup>21d</sup>, J. Pacalt <sup>121</sup>, H.A. Pacey <sup>32</sup>, A. Pacheco Pages <sup>13</sup>,  
 C. Padilla Aranda <sup>13</sup>, G. Padovano <sup>74a,74b</sup>, S. Pagan Griso <sup>17a</sup>, G. Palacino <sup>67</sup>, A. Palazzo <sup>69a,69b</sup>,  
 S. Palazzo <sup>52</sup>, S. Palestini <sup>36</sup>, M. Palka <sup>84b</sup>, J. Pan <sup>171</sup>, T. Pan <sup>64a</sup>, D.K. Panchal <sup>11</sup>,  
 C.E. Pandini <sup>113</sup>, J.G. Panduro Vazquez <sup>94</sup>, H. Pang <sup>14b</sup>, P. Pani <sup>48</sup>, G. Panizzo <sup>68a,68c</sup>,  
 L. Paolozzi <sup>56</sup>, C. Papadatos <sup>107</sup>, S. Parajuli <sup>44</sup>, A. Paramonov <sup>6</sup>, C. Paraskevopoulos <sup>10</sup>,  
 D. Paredes Hernandez <sup>64b</sup>, T.H. Park <sup>154</sup>, M.A. Parker <sup>32</sup>, F. Parodi <sup>57b,57a</sup>, E.W. Parrish <sup>114</sup>,  
 V.A. Parrish <sup>52</sup>, J.A. Parsons <sup>41</sup>, U. Parzefall <sup>54</sup>, B. Pascual Dias <sup>107</sup>, L. Pascual Dominguez <sup>150</sup>,  
 V.R. Pascuzzi <sup>17a</sup>, F. Pasquali <sup>113</sup>, E. Pasqualucci <sup>74a</sup>, S. Passaggio <sup>57b</sup>, F. Pastore <sup>94</sup>,

P. Pasuwan [id](#)<sup>47a,47b</sup>, J.R. Pater [id](#)<sup>100</sup>, J. Patton<sup>91</sup>, T. Pauly [id](#)<sup>36</sup>, J. Pearkes [id](#)<sup>142</sup>, M. Pedersen [id](#)<sup>124</sup>,  
 R. Pedro [id](#)<sup>129a</sup>, S.V. Peleganchuk [id](#)<sup>37</sup>, O. Penc [id](#)<sup>36</sup>, C. Peng [id](#)<sup>64b</sup>, H. Peng [id](#)<sup>62a</sup>, K.E. Penski [id](#)<sup>108</sup>,  
 M. Penzin [id](#)<sup>37</sup>, B.S. Peralva [id](#)<sup>81d</sup>, A.P. Pereira Peixoto [id](#)<sup>60</sup>, L. Pereira Sanchez [id](#)<sup>47a,47b</sup>,  
 D.V. Perepelitsa [id](#)<sup>29,aj</sup>, E. Perez Codina [id](#)<sup>155a</sup>, M. Perganti [id](#)<sup>10</sup>, L. Perini [id](#)<sup>70a,70b,\*</sup>, H. Pernegger [id](#)<sup>36</sup>,  
 A. Perrevoort [id](#)<sup>112</sup>, O. Perrin [id](#)<sup>40</sup>, K. Peters [id](#)<sup>48</sup>, R.F.Y. Peters [id](#)<sup>100</sup>, B.A. Petersen [id](#)<sup>36</sup>,  
 T.C. Petersen [id](#)<sup>42</sup>, E. Petit [id](#)<sup>101</sup>, V. Petousis [id](#)<sup>131</sup>, C. Petridou [id](#)<sup>151</sup>, A. Petrukhin [id](#)<sup>140</sup>, M. Pettee [id](#)<sup>17a</sup>,  
 N.E. Pettersson [id](#)<sup>36</sup>, A. Petukhov [id](#)<sup>37</sup>, K. Petukhova [id](#)<sup>132</sup>, A. Peyaud [id](#)<sup>134</sup>, R. Pezoa [id](#)<sup>136f</sup>,  
 L. Pezzotti [id](#)<sup>36</sup>, G. Pezzullo [id](#)<sup>171</sup>, T. Pham [id](#)<sup>104</sup>, P.W. Phillips [id](#)<sup>133</sup>, M.W. Phipps [id](#)<sup>161</sup>,  
 G. Piacquadio [id](#)<sup>144</sup>, E. Pianori [id](#)<sup>17a</sup>, F. Piazza [id](#)<sup>70a,70b</sup>, R. Piegaia [id](#)<sup>30</sup>, D. Pietreanu [id](#)<sup>27b</sup>,  
 A.D. Pilkington [id](#)<sup>100</sup>, M. Pinamonti [id](#)<sup>68a,68c</sup>, J.L. Pinfold [id](#)<sup>2</sup>, B.C. Pinheiro Pereira [id](#)<sup>129a</sup>,  
 C. Pitman Donaldson<sup>95</sup>, D.A. Pizzi [id](#)<sup>34</sup>, L. Pizzimento [id](#)<sup>75a,75b</sup>, A. Pizzini [id](#)<sup>113</sup>, M.-A. Pleier [id](#)<sup>29</sup>,  
 V. Plesanovs<sup>54</sup>, V. Pleskot [id](#)<sup>132</sup>, E. Plotnikova<sup>38</sup>, G. Poddar [id](#)<sup>4</sup>, R. Poettgen [id](#)<sup>97</sup>, L. Poggioli [id](#)<sup>126</sup>,  
 I. Pogrebnyak [id](#)<sup>106</sup>, D. Pohl [id](#)<sup>24</sup>, I. Pokharel [id](#)<sup>55</sup>, S. Polacek [id](#)<sup>132</sup>, G. Polesello [id](#)<sup>72a</sup>, A. Poley [id](#)<sup>141,155a</sup>,  
 R. Polifka [id](#)<sup>131</sup>, A. Polini [id](#)<sup>23b</sup>, C.S. Pollard [id](#)<sup>125</sup>, Z.B. Pollock [id](#)<sup>118</sup>, V. Polychronakos [id](#)<sup>29</sup>,  
 D. Ponomarenko [id](#)<sup>37</sup>, L. Pontecorvo [id](#)<sup>36</sup>, S. Popa [id](#)<sup>27a</sup>, G.A. Popeneciu [id](#)<sup>27d</sup>,  
 D.M. Portillo Quintero [id](#)<sup>155a</sup>, S. Pospisil [id](#)<sup>131</sup>, P. Postolache [id](#)<sup>27c</sup>, K. Potamianos [id](#)<sup>125</sup>, I.N. Potrap [id](#)<sup>38</sup>,  
 C.J. Potter [id](#)<sup>32</sup>, H. Potti [id](#)<sup>1</sup>, T. Poulsen [id](#)<sup>48</sup>, J. Poveda [id](#)<sup>162</sup>, G. Pownall [id](#)<sup>48</sup>, M.E. Pozo Astigarraga [id](#)<sup>36</sup>,  
 A. Prades Ibanez [id](#)<sup>162</sup>, M.M. Prapa [id](#)<sup>46</sup>, J. Pretel [id](#)<sup>54</sup>, D. Price [id](#)<sup>100</sup>, M. Primavera [id](#)<sup>69a</sup>,  
 M.A. Principe Martin [id](#)<sup>98</sup>, M.L. Proffitt [id](#)<sup>137</sup>, N. Proklova [id](#)<sup>37</sup>, K. Prokofiev [id](#)<sup>64c</sup>, G. Proto [id](#)<sup>75a,75b</sup>,  
 S. Protopopescu [id](#)<sup>29</sup>, J. Proudfoot [id](#)<sup>6</sup>, M. Przybycien [id](#)<sup>84a</sup>, J.E. Puddefoot [id](#)<sup>138</sup>, D. Pudzha [id](#)<sup>37</sup>,  
 P. Puzo<sup>66</sup>, D. Pyatiizbyantseva [id](#)<sup>37</sup>, J. Qian [id](#)<sup>105</sup>, Y. Qin [id](#)<sup>100</sup>, T. Qiu [id](#)<sup>93</sup>, A. Quadt [id](#)<sup>55</sup>,  
 M. Queitsch-Maitland [id](#)<sup>100</sup>, G. Rabanal Bolanos [id](#)<sup>61</sup>, D. Rafanoharana [id](#)<sup>54</sup>, F. Ragusa [id](#)<sup>70a,70b</sup>,  
 J.L. Rainbolt [id](#)<sup>39</sup>, J.A. Raine [id](#)<sup>56</sup>, S. Rajagopalan [id](#)<sup>29</sup>, E. Ramakoti [id](#)<sup>37</sup>, K. Ran [id](#)<sup>48,14d</sup>,  
 V. Raskina [id](#)<sup>126</sup>, D.F. Rassloff [id](#)<sup>63a</sup>, S. Rave [id](#)<sup>99</sup>, B. Ravina [id](#)<sup>59</sup>, I. Ravinovich [id](#)<sup>168</sup>, M. Raymond [id](#)<sup>36</sup>,  
 A.L. Read [id](#)<sup>124</sup>, N.P. Radioff [id](#)<sup>138</sup>, D.M. Rebuzzi [id](#)<sup>72a,72b</sup>, G. Redlinger [id](#)<sup>29</sup>, K. Reeves [id](#)<sup>45</sup>,  
 J.A. Reidelsturz [id](#)<sup>170</sup>, D. Reikher [id](#)<sup>150</sup>, A. Reiss<sup>99</sup>, A. Rej [id](#)<sup>140</sup>, C. Rembser [id](#)<sup>36</sup>, A. Renardi [id](#)<sup>48</sup>,  
 M. Renda [id](#)<sup>27b</sup>, M.B. Rendel<sup>109</sup>, A.G. Rennie [id](#)<sup>59</sup>, S. Resconi [id](#)<sup>70a</sup>, M. Ressegotti [id](#)<sup>57b,57a</sup>,  
 E.D. Resseguie [id](#)<sup>17a</sup>, S. Rettie [id](#)<sup>95</sup>, B. Reynolds<sup>118</sup>, E. Reynolds [id](#)<sup>17a</sup>, M. Rezaei Estabragh [id](#)<sup>170</sup>,  
 O.L. Rezanova [id](#)<sup>37</sup>, P. Reznicek [id](#)<sup>132</sup>, E. Ricci [id](#)<sup>77a,77b</sup>, R. Richter [id](#)<sup>109</sup>, S. Richter [id](#)<sup>47a,47b</sup>,  
 E. Richter-Was [id](#)<sup>84b</sup>, M. Ridel [id](#)<sup>126</sup>, P. Rieck [id](#)<sup>116</sup>, P. Riedler [id](#)<sup>36</sup>, M. Rijssenbeek [id](#)<sup>144</sup>,  
 A. Rimoldi [id](#)<sup>72a,72b</sup>, M. Rimoldi [id](#)<sup>48</sup>, L. Rinaldi [id](#)<sup>23b,23a</sup>, T.T. Rinn [id](#)<sup>29</sup>, M.P. Rinnagel [id](#)<sup>108</sup>,  
 G. Ripellino [id](#)<sup>143</sup>, I. Riu [id](#)<sup>13</sup>, P. Rivadeneira [id](#)<sup>48</sup>, J.C. Rivera Vergara [id](#)<sup>164</sup>, F. Rizatdinova [id](#)<sup>120</sup>,  
 E. Rizvi [id](#)<sup>93</sup>, C. Rizzi [id](#)<sup>56</sup>, B.A. Roberts [id](#)<sup>166</sup>, B.R. Roberts [id](#)<sup>17a</sup>, S.H. Robertson [id](#)<sup>103,y</sup>, M. Robin [id](#)<sup>48</sup>,  
 D. Robinson [id](#)<sup>32</sup>, C.M. Robles Gajardo<sup>136f</sup>, M. Robles Manzano [id](#)<sup>99</sup>, A. Robson [id](#)<sup>59</sup>, A. Rocchi [id](#)<sup>75a,75b</sup>,  
 C. Roda [id](#)<sup>73a,73b</sup>, S. Rodriguez Bosca [id](#)<sup>63a</sup>, Y. Rodriguez Garcia [id](#)<sup>22a</sup>, A. Rodriguez Rodriguez [id](#)<sup>54</sup>,  
 A.M. Rodríguez Vera [id](#)<sup>155b</sup>, S. Roe<sup>36</sup>, J.T. Roemer [id](#)<sup>159</sup>, A.R. Roepe-Gier [id](#)<sup>119</sup>, J. Roggel [id](#)<sup>170</sup>,  
 O. Røhne [id](#)<sup>124</sup>, R.A. Rojas [id](#)<sup>164</sup>, B. Roland [id](#)<sup>54</sup>, C.P.A. Roland [id](#)<sup>67</sup>, J. Roloff [id](#)<sup>29</sup>, A. Romaniouk [id](#)<sup>37</sup>,  
 E. Romano [id](#)<sup>72a,72b</sup>, M. Romano [id](#)<sup>23b</sup>, A.C. Romero Hernandez [id](#)<sup>161</sup>, N. Rompotis [id](#)<sup>91</sup>, L. Roos [id](#)<sup>126</sup>,  
 S. Rosati [id](#)<sup>74a</sup>, B.J. Rosser [id](#)<sup>39</sup>, E. Rossi [id](#)<sup>4</sup>, E. Rossi [id](#)<sup>71a,71b</sup>, L.P. Rossi [id](#)<sup>57b</sup>, L. Rossini [id](#)<sup>48</sup>,  
 R. Rosten [id](#)<sup>118</sup>, M. Rotaru [id](#)<sup>27b</sup>, B. Rottler [id](#)<sup>54</sup>, D. Rousseau [id](#)<sup>66</sup>, D. Rousso [id](#)<sup>32</sup>, G. Rovelli [id](#)<sup>72a,72b</sup>,  
 A. Roy [id](#)<sup>161</sup>, A. Rozanov [id](#)<sup>101</sup>, Y. Rozen [id](#)<sup>149</sup>, X. Ruan [id](#)<sup>33g</sup>, A. Rubio Jimenez [id](#)<sup>162</sup>, A.J. Ruby [id](#)<sup>91</sup>,  
 V.H. Ruelas Rivera [id](#)<sup>18</sup>, T.A. Ruggeri [id](#)<sup>1</sup>, F. Rühr [id](#)<sup>54</sup>, A. Ruiz-Martinez [id](#)<sup>162</sup>, A. Rummler [id](#)<sup>36</sup>,  
 Z. Rurikova [id](#)<sup>54</sup>, N.A. Rusakovich [id](#)<sup>38</sup>, H.L. Russell [id](#)<sup>164</sup>, J.P. Rutherford [id](#)<sup>7</sup>, E.M. Rüttinger [id](#)<sup>138</sup>,  
 K. Rybacki<sup>90</sup>, M. Rybar [id](#)<sup>132</sup>, E.B. Rye [id](#)<sup>124</sup>, A. Ryzhov [id](#)<sup>37</sup>, J.A. Sabater Iglesias [id](#)<sup>56</sup>, P. Sabatini [id](#)<sup>162</sup>,  
 L. Sabetta [id](#)<sup>74a,74b</sup>, H.F.-W. Sadrozinski [id](#)<sup>135</sup>, F. Safai Tehrani [id](#)<sup>74a</sup>, B. Safarzadeh Samani [id](#)<sup>145</sup>,  
 M. Safdari [id](#)<sup>142</sup>, S. Saha [id](#)<sup>103</sup>, M. Sahinsoy [id](#)<sup>109</sup>, M. Saimpert [id](#)<sup>134</sup>, M. Saito [id](#)<sup>152</sup>, T. Saito [id](#)<sup>152</sup>,

D. Salamani <sup>36</sup>, G. Salamanna <sup>76a,76b</sup>, A. Salnikov <sup>142</sup>, J. Salt <sup>162</sup>, A. Salvador Salas <sup>13</sup>,  
 D. Salvatore <sup>43b,43a</sup>, F. Salvatore <sup>145</sup>, A. Salzburger <sup>36</sup>, D. Sammel <sup>54</sup>, D. Sampsonidis <sup>151</sup>,  
 D. Sampsonidou <sup>62d,62c</sup>, J. Sánchez <sup>162</sup>, A. Sanchez Pineda <sup>4</sup>, V. Sanchez Sebastian <sup>162</sup>,  
 H. Sandaker <sup>124</sup>, C.O. Sander <sup>48</sup>, J.A. Sandesara <sup>102</sup>, M. Sandhoff <sup>170</sup>, C. Sandoval <sup>22b</sup>,  
 D.P.C. Sankey <sup>133</sup>, A. Sansoni <sup>53</sup>, L. Santi <sup>74a,74b</sup>, C. Santoni <sup>40</sup>, H. Santos <sup>129a,129b</sup>,  
 S.N. Santpur <sup>17a</sup>, A. Santra <sup>168</sup>, K.A. Saoucha <sup>138</sup>, J.G. Saraiva <sup>129a,129d</sup>, J. Sardain <sup>7</sup>,  
 O. Sasaki <sup>82</sup>, K. Sato <sup>156</sup>, C. Sauer <sup>63b</sup>, F. Sauerburger <sup>54</sup>, E. Sauvan <sup>4</sup>, P. Savard <sup>154,ag</sup>,  
 R. Sawada <sup>152</sup>, C. Sawyer <sup>133</sup>, L. Sawyer <sup>96</sup>, I. Sayago Galvan <sup>162</sup>, C. Sbarra <sup>23b</sup>,  
 A. Sbrizzi <sup>23b,23a</sup>, T. Scanlon <sup>95</sup>, J. Schaarschmidt <sup>137</sup>, P. Schacht <sup>109</sup>, D. Schaefer <sup>39</sup>,  
 U. Schäfer <sup>99</sup>, A.C. Schaffer <sup>66</sup>, D. Schaile <sup>108</sup>, R.D. Schamberger <sup>144</sup>, E. Schanet <sup>108</sup>,  
 C. Scharf <sup>18</sup>, V.A. Schegelsky <sup>37</sup>, D. Scheirich <sup>132</sup>, F. Schenck <sup>18</sup>, M. Schernau <sup>159</sup>,  
 C. Scheulen <sup>55</sup>, C. Schiavi <sup>57b,57a</sup>, Z.M. Schillaci <sup>26</sup>, E.J. Schioppa <sup>69a,69b</sup>, M. Schioppa <sup>43b,43a</sup>,  
 B. Schlag <sup>99</sup>, K.E. Schleicher <sup>54</sup>, S. Schlenker <sup>36</sup>, K. Schmieden <sup>99</sup>, C. Schmitt <sup>99</sup>,  
 S. Schmitt <sup>48</sup>, L. Schoeffel <sup>134</sup>, A. Schoening <sup>63b</sup>, P.G. Scholer <sup>54</sup>, E. Schopf <sup>125</sup>, M. Schott <sup>99</sup>,  
 J. Schovancova <sup>36</sup>, S. Schramm <sup>56</sup>, F. Schroeder <sup>170</sup>, H-C. Schultz-Coulon <sup>63a</sup>,  
 M. Schumacher <sup>54</sup>, B.A. Schumm <sup>135</sup>, Ph. Schune <sup>134</sup>, A. Schwartzman <sup>142</sup>, T.A. Schwarz <sup>105</sup>,  
 Ph. Schwemling <sup>134</sup>, R. Schwienhorst <sup>106</sup>, A. Sciandra <sup>135</sup>, G. Sciolla <sup>26</sup>, F. Scuri <sup>73a</sup>,  
 F. Scutti <sup>104</sup>, C.D. Sebastiani <sup>91</sup>, K. Sedlaczek <sup>49</sup>, P. Seema <sup>18</sup>, S.C. Seidel <sup>111</sup>, A. Seiden <sup>135</sup>,  
 B.D. Seidlitz <sup>41</sup>, T. Seiss <sup>39</sup>, C. Seitz <sup>48</sup>, J.M. Seixas <sup>81b</sup>, G. Sekhniaidze <sup>71a</sup>, S.J. Sekula <sup>44</sup>,  
 L. Selem <sup>4</sup>, N. Semprini-Cesari <sup>23b,23a</sup>, S. Sen <sup>51</sup>, D. Sengupta <sup>56</sup>, V. Senthilkumar <sup>162</sup>,  
 L. Serin <sup>66</sup>, L. Serkin <sup>68a,68b</sup>, M. Sessa <sup>76a,76b</sup>, H. Severini <sup>119</sup>, S. Sevova <sup>142</sup>, F. Sforza <sup>57b,57a</sup>,  
 A. Sfyrla <sup>56</sup>, E. Shabalina <sup>55</sup>, R. Shaheen <sup>143</sup>, J.D. Shahinian <sup>127</sup>, N.W. Shaikh <sup>47a,47b</sup>,  
 D. Shaked Renous <sup>168</sup>, L.Y. Shan <sup>14a</sup>, M. Shapiro <sup>17a</sup>, A. Sharma <sup>36</sup>, A.S. Sharma <sup>163</sup>,  
 P. Sharma <sup>79</sup>, S. Sharma <sup>48</sup>, P.B. Shatalov <sup>37</sup>, K. Shaw <sup>145</sup>, S.M. Shaw <sup>100</sup>, Q. Shen <sup>62c</sup>,  
 P. Sherwood <sup>95</sup>, L. Shi <sup>95</sup>, C.O. Shimmin <sup>171</sup>, Y. Shimogama <sup>167</sup>, J.D. Shinner <sup>94</sup>,  
 I.P.J. Shipsey <sup>125</sup>, S. Shirabe <sup>60</sup>, M. Shiyakova <sup>38,x</sup>, J. Shlomi <sup>168</sup>, M.J. Shochet <sup>39</sup>,  
 J. Shojaii <sup>104</sup>, D.R. Shope <sup>143</sup>, S. Shrestha <sup>118,ak</sup>, E.M. Shrif <sup>33g</sup>, M.J. Shroff <sup>164</sup>, P. Sicho <sup>130</sup>,  
 A.M. Sickles <sup>161</sup>, E. Sideras Haddad <sup>33g</sup>, O. Sidiropoulou <sup>36</sup>, A. Sidoti <sup>23b</sup>, F. Siegert <sup>50</sup>,  
 Dj. Sijacki <sup>15</sup>, R. Sikora <sup>84a</sup>, F. Sili <sup>89</sup>, J.M. Silva <sup>20</sup>, M.V. Silva Oliveira <sup>36</sup>,  
 S.B. Silverstein <sup>47a</sup>, S. Simion <sup>66</sup>, R. Simoniello <sup>36</sup>, E.L. Simpson <sup>59</sup>, N.D. Simpson <sup>97</sup>,  
 S. Simsek <sup>21d</sup>, S. Sindhu <sup>55</sup>, P. Sinervo <sup>154</sup>, V. Sinetckii <sup>37</sup>, S. Singh <sup>141</sup>, S. Singh <sup>154</sup>,  
 S. Sinha <sup>48</sup>, S. Sinha <sup>33g</sup>, M. Sioli <sup>23b,23a</sup>, I. Siral <sup>122</sup>, S.Yu. Sivoklokov <sup>37,\*</sup>, J. Sjölin <sup>47a,47b</sup>,  
 A. Skaf <sup>55</sup>, E. Skorda <sup>97</sup>, P. Skubic <sup>119</sup>, M. Slawinska <sup>85</sup>, V. Smakhtin <sup>168</sup>, B.H. Smart <sup>133</sup>,  
 J. Smiesko <sup>132</sup>, S.Yu. Smirnov <sup>37</sup>, Y. Smirnov <sup>37</sup>, L.N. Smirnova <sup>37,a</sup>, O. Smirnova <sup>97</sup>,  
 A.C. Smith <sup>41</sup>, E.A. Smith <sup>39</sup>, H.A. Smith <sup>125</sup>, J.L. Smith <sup>91</sup>, R. Smith <sup>142</sup>, M. Smizanska <sup>90</sup>,  
 K. Smolek <sup>131</sup>, A. Smykiewicz <sup>85</sup>, A.A. Snesarev <sup>37</sup>, H.L. Snoek <sup>113</sup>, S. Snyder <sup>29</sup>,  
 R. Sobie <sup>164,y</sup>, A. Soffer <sup>150</sup>, C.A. Solans Sanchez <sup>36</sup>, E.Yu. Soldatov <sup>37</sup>, U. Soldevila <sup>162</sup>,  
 A.A. Solodkov <sup>37</sup>, S. Solomon <sup>54</sup>, A. Soloshenko <sup>38</sup>, K. Solovieva <sup>54</sup>, O.V. Solovyanov <sup>37</sup>,  
 V. Solovyev <sup>37</sup>, P. Sommer <sup>36</sup>, A. Sonay <sup>13</sup>, W.Y. Song <sup>155b</sup>, A. Sopczak <sup>131</sup>, A.L. Soppio <sup>95</sup>,  
 F. Sopkova <sup>28b</sup>, V. Sothilingam <sup>63a</sup>, S. Sottocornola <sup>72a,72b</sup>, R. Soualah <sup>115b</sup>, Z. Soumami <sup>35e</sup>,  
 D. South <sup>48</sup>, S. Spagnolo <sup>69a,69b</sup>, M. Spalla <sup>109</sup>, F. Spanò <sup>94</sup>, D. Sperlich <sup>54</sup>, G. Spigo <sup>36</sup>,  
 M. Spina <sup>145</sup>, S. Spinali <sup>90</sup>, D.P. Spiteri <sup>59</sup>, M. Spousta <sup>132</sup>, E.J. Staats <sup>34</sup>, A. Stabile <sup>70a,70b</sup>,  
 R. Stamen <sup>63a</sup>, M. Stamenkovic <sup>113</sup>, A. Stampekis <sup>20</sup>, M. Standke <sup>24</sup>, E. Stanecka <sup>85</sup>,  
 B. Stanislaus <sup>17a</sup>, M.M. Stanitzki <sup>48</sup>, M. Stankaityte <sup>125</sup>, B. Stapf <sup>48</sup>, E.A. Starchenko <sup>37</sup>,  
 G.H. Stark <sup>135</sup>, J. Stark <sup>101,ab</sup>, D.M. Starko <sup>155b</sup>, P. Staroba <sup>130</sup>, P. Starovoitov <sup>63a</sup>, S. Stärz <sup>103</sup>,  
 R. Staszewski <sup>85</sup>, G. Stavropoulos <sup>46</sup>, J. Steentoft <sup>160</sup>, P. Steinberg <sup>29</sup>, A.L. Steinhebel <sup>122</sup>,



B. Stelzer [id<sup>141,155a</sup>](#), H.J. Stelzer [id<sup>128</sup>](#), O. Stelzer-Chilton [id<sup>155a</sup>](#), H. Stenzel [id<sup>58</sup>](#), T.J. Stevenson [id<sup>145</sup>](#),  
 G.A. Stewart [id<sup>36</sup>](#), M.C. Stockton [id<sup>36</sup>](#), G. Stoicea [id<sup>27b</sup>](#), M. Stolarski [id<sup>129a</sup>](#), S. Stonjek [id<sup>109</sup>](#),  
 A. Straessner [id<sup>50</sup>](#), J. Strandberg [id<sup>143</sup>](#), S. Strandberg [id<sup>47a,47b</sup>](#), M. Strauss [id<sup>119</sup>](#), T. Strebler [id<sup>101</sup>](#),  
 P. Strizenec [id<sup>28b</sup>](#), R. Ströhmer [id<sup>165</sup>](#), D.M. Strom [id<sup>122</sup>](#), L.R. Strom [id<sup>48</sup>](#), R. Stroynowski [id<sup>44</sup>](#),  
 A. Strubig [id<sup>47a,47b</sup>](#), S.A. Stucci [id<sup>29</sup>](#), B. Stugu [id<sup>16</sup>](#), J. Stupak [id<sup>119</sup>](#), N.A. Styles [id<sup>48</sup>](#), D. Su [id<sup>142</sup>](#),  
 S. Su [id<sup>62a</sup>](#), W. Su [id<sup>62d,137,62c</sup>](#), X. Su [id<sup>62a,66</sup>](#), K. Sugizaki [id<sup>152</sup>](#), V.V. Sulin [id<sup>37</sup>](#), M.J. Sullivan [id<sup>91</sup>](#),  
 D.M.S. Sultan [id<sup>77a,77b</sup>](#), L. Sultanaliev [id<sup>37</sup>](#), S. Sultansoy [id<sup>3b</sup>](#), T. Sumida [id<sup>86</sup>](#), S. Sun [id<sup>105</sup>](#),  
 S. Sun [id<sup>169</sup>](#), O. Sunneborn Gudnadottir [id<sup>160</sup>](#), M.R. Sutton [id<sup>145</sup>](#), M. Svatos [id<sup>130</sup>](#), M. Swiatlowski [id<sup>155a</sup>](#),  
 T. Swirski [id<sup>165</sup>](#), I. Sykora [id<sup>28a</sup>](#), M. Sykora [id<sup>132</sup>](#), T. Sykora [id<sup>132</sup>](#), D. Ta [id<sup>99</sup>](#), K. Tackmann [id<sup>48,w</sup>](#),  
 A. Taffard [id<sup>159</sup>](#), R. Tafirout [id<sup>155a</sup>](#), J.S. Tafoya Vargas [id<sup>66</sup>](#), R.H.M. Taibah [id<sup>126</sup>](#), R. Takashima [id<sup>87</sup>](#),  
 K. Takeda [id<sup>83</sup>](#), E.P. Takeva [id<sup>52</sup>](#), Y. Takubo [id<sup>82</sup>](#), M. Talby [id<sup>101</sup>](#), A.A. Talyshev [id<sup>37</sup>](#), K.C. Tam [id<sup>64b</sup>](#),  
 N.M. Tamir [id<sup>150</sup>](#), A. Tanaka [id<sup>152</sup>](#), J. Tanaka [id<sup>152</sup>](#), R. Tanaka [id<sup>66</sup>](#), M. Tanasini [id<sup>57b,57a</sup>](#), J. Tang [id<sup>62c</sup>](#),  
 Z. Tao [id<sup>163</sup>](#), S. Tapia Araya [id<sup>80</sup>](#), S. Tapprogge [id<sup>99</sup>](#), A. Tarek Abouelfadl Mohamed [id<sup>106</sup>](#), S. Tarem [id<sup>149</sup>](#),  
 K. Tariq [id<sup>62b</sup>](#), G. Tarna [id<sup>27b</sup>](#), G.F. Tartarelli [id<sup>70a</sup>](#), P. Tas [id<sup>132</sup>](#), M. Tasevsky [id<sup>130</sup>](#), E. Tassi [id<sup>43b,43a</sup>](#),  
 A.C. Tate [id<sup>161</sup>](#), G. Tateno [id<sup>152</sup>](#), Y. Tayalati [id<sup>35e</sup>](#), G.N. Taylor [id<sup>104</sup>](#), W. Taylor [id<sup>155b</sup>](#), H. Teagle [id<sup>91</sup>](#),  
 A.S. Tee [id<sup>169</sup>](#), R. Teixeira De Lima [id<sup>142</sup>](#), P. Teixeira-Dias [id<sup>94</sup>](#), J.J. Teoh [id<sup>154</sup>](#), K. Terashi [id<sup>152</sup>](#),  
 J. Terron [id<sup>98</sup>](#), S. Terzo [id<sup>13</sup>](#), M. Testa [id<sup>53</sup>](#), R.J. Teuscher [id<sup>154,y</sup>](#), A. Thaler [id<sup>78</sup>](#), O. Theiner [id<sup>56</sup>](#),  
 N. Themistokleous [id<sup>52</sup>](#), T. Theveneaux-Pelzer [id<sup>18</sup>](#), O. Thielmann [id<sup>170</sup>](#), D.W. Thomas [id<sup>94</sup>](#),  
 J.P. Thomas [id<sup>20</sup>](#), E.A. Thompson [id<sup>48</sup>](#), P.D. Thompson [id<sup>20</sup>](#), E. Thomson [id<sup>127</sup>](#), E.J. Thorpe [id<sup>93</sup>](#),  
 Y. Tian [id<sup>55</sup>](#), V. Tikhomirov [id<sup>37,a</sup>](#), Yu.A. Tikhonov [id<sup>37</sup>](#), S. Timoshenko [id<sup>37</sup>](#), E.X.L. Ting [id<sup>1</sup>](#),  
 P. Tipton [id<sup>171</sup>](#), S. Tisserant [id<sup>101</sup>](#), S.H. Tlou [id<sup>33g</sup>](#), A. Tnourji [id<sup>40</sup>](#), K. Todome [id<sup>23b,23a</sup>](#),  
 S. Todorova-Nova [id<sup>132</sup>](#), S. Todt [id<sup>50</sup>](#), M. Togawa [id<sup>82</sup>](#), J. Tojo [id<sup>88</sup>](#), S. Tokár [id<sup>28a</sup>](#), K. Tokushuku [id<sup>82</sup>](#),  
 R. Tombs [id<sup>32</sup>](#), M. Tomoto [id<sup>82,110</sup>](#), L. Tompkins [id<sup>142,q</sup>](#), K.W. Topolnicki [id<sup>84b</sup>](#), P. Tornambe [id<sup>102</sup>](#),  
 E. Torrence [id<sup>122</sup>](#), H. Torres [id<sup>50</sup>](#), E. Torró Pastor [id<sup>162</sup>](#), M. Toscani [id<sup>30</sup>](#), C. Tosciri [id<sup>39</sup>](#), D.R. Tovey [id<sup>138</sup>](#),  
 A. Traet [id<sup>16</sup>](#), I.S. Trandafir [id<sup>27b</sup>](#), T. Trefzger [id<sup>165</sup>](#), A. Tricoli [id<sup>29</sup>](#), I.M. Trigger [id<sup>155a</sup>](#),  
 S. Trincaz-Duvoid [id<sup>126</sup>](#), D.A. Trischuk [id<sup>163</sup>](#), B. Trocmé [id<sup>60</sup>](#), A. Trofymov [id<sup>66</sup>](#), C. Troncon [id<sup>70a</sup>](#),  
 L. Truong [id<sup>33c</sup>](#), M. Trzebinski [id<sup>85</sup>](#), A. Trzupek [id<sup>85</sup>](#), F. Tsai [id<sup>144</sup>](#), M. Tsai [id<sup>105</sup>](#), A. Tsiamis [id<sup>151</sup>](#),  
 P.V. Tsiarshka [id<sup>37</sup>](#), S. Tsigaridas [id<sup>155a</sup>](#), A. Tsigaridis [id<sup>151,u</sup>](#), V. Tsiskaridze [id<sup>144</sup>](#), E.G. Tskhadadze [id<sup>148a</sup>](#),  
 M. Tsopoulou [id<sup>151</sup>](#), Y. Tsujikawa [id<sup>86</sup>](#), I.I. Tsukerman [id<sup>37</sup>](#), V. Tsulaia [id<sup>17a</sup>](#), S. Tsuno [id<sup>82</sup>](#), O. Tsur [id<sup>149</sup>](#),  
 D. Tsybychev [id<sup>144</sup>](#), Y. Tu [id<sup>64b</sup>](#), A. Tudorache [id<sup>27b</sup>](#), V. Tudorache [id<sup>27b</sup>](#), A.N. Tuna [id<sup>36</sup>](#),  
 S. Turchikhin [id<sup>38</sup>](#), I. Turk Cakir [id<sup>3a</sup>](#), R. Turra [id<sup>70a</sup>](#), T. Turtuvshin [id<sup>38</sup>](#), P.M. Tuts [id<sup>41</sup>](#), S. Tzamarias [id<sup>151</sup>](#),  
 P. Tzani [id<sup>10</sup>](#), E. Tzovara [id<sup>99</sup>](#), K. Uchida [id<sup>152</sup>](#), F. Ukegawa [id<sup>156</sup>](#), P.A. Ulloa Poblete [id<sup>136c</sup>](#), G. Unal [id<sup>36</sup>](#),  
 M. Unal [id<sup>11</sup>](#), A. Undrus [id<sup>29</sup>](#), G. Unel [id<sup>159</sup>](#), K. Uno [id<sup>152</sup>](#), J. Urban [id<sup>28b</sup>](#), P. Urquijo [id<sup>104</sup>](#), G. Usai [id<sup>8</sup>](#),  
 R. Ushioda [id<sup>153</sup>](#), M. Usman [id<sup>107</sup>](#), Z. Uysal [id<sup>21b</sup>](#), V. Vacek [id<sup>131</sup>](#), B. Vachon [id<sup>103</sup>](#), K.O.H. Vadla [id<sup>124</sup>](#),  
 T. Vafeiadis [id<sup>36</sup>](#), C. Valderanis [id<sup>108</sup>](#), E. Valdes Santurio [id<sup>47a,47b</sup>](#), M. Valente [id<sup>155a</sup>](#),  
 S. Valentini [id<sup>23b,23a</sup>](#), A. Valero [id<sup>162</sup>](#), A. Vallier [id<sup>101,ab</sup>](#), J.A. Valls Ferrer [id<sup>162</sup>](#), T.R. Van Daalen [id<sup>137</sup>](#),  
 P. Van Gemmeren [id<sup>6</sup>](#), M. Van Rijnbach [id<sup>124,36</sup>](#), S. Van Stroud [id<sup>95</sup>](#), I. Van Vulpen [id<sup>113</sup>](#),  
 M. Vanadia [id<sup>75a,75b</sup>](#), W. Vandelli [id<sup>36</sup>](#), M. Vandenbroucke [id<sup>134</sup>](#), E.R. Vandewall [id<sup>120</sup>](#), D. Vannicola [id<sup>150</sup>](#),  
 L. Vannoli [id<sup>57b,57a</sup>](#), R. Vari [id<sup>74a</sup>](#), E.W. Varnes [id<sup>7</sup>](#), C. Varni [id<sup>17a</sup>](#), T. Varol [id<sup>147</sup>](#), D. Varouchas [id<sup>66</sup>](#),  
 L. Varriale [id<sup>162</sup>](#), K.E. Varvell [id<sup>146</sup>](#), M.E. Vasile [id<sup>27b</sup>](#), L. Vaslin [id<sup>40</sup>](#), G.A. Vasquez [id<sup>164</sup>](#), F. Vazeille [id<sup>40</sup>](#),  
 T. Vazquez Schroeder [id<sup>36</sup>](#), J. Veatch [id<sup>31</sup>](#), V. Vecchio [id<sup>100</sup>](#), M.J. Veen [id<sup>113</sup>](#), I. Veliscek [id<sup>125</sup>](#),  
 L.M. Veloce [id<sup>154</sup>](#), F. Veloso [id<sup>129a,129c</sup>](#), S. Veneziano [id<sup>74a</sup>](#), A. Ventura [id<sup>69a,69b</sup>](#), A. Verbitskyi [id<sup>109</sup>](#),  
 M. Verducci [id<sup>73a,73b</sup>](#), C. Vergis [id<sup>24</sup>](#), M. Verissimo De Araujo [id<sup>81b</sup>](#), W. Verkerke [id<sup>113</sup>](#),  
 J.C. Vermeulen [id<sup>113</sup>](#), C. Vernieri [id<sup>142</sup>](#), P.J. Verschuur [id<sup>94</sup>](#), M. Vessella [id<sup>102</sup>](#), M.L. Vesterbacka [id<sup>116</sup>](#),  
 M.C. Vetterli [id<sup>141,ag</sup>](#), A. Vgenopoulos [id<sup>151</sup>](#), N. Viaux Maira [id<sup>136f</sup>](#), T. Vickey [id<sup>138</sup>](#),  
 O.E. Vickey Boeriu [id<sup>138</sup>](#), G.H.A. Viehhauser [id<sup>125</sup>](#), L. Vigani [id<sup>63b</sup>](#), M. Villa [id<sup>23b,23a</sup>](#),

M. Villaplana Perez [id](#)<sup>162</sup>, E.M. Villhauer<sup>52</sup>, E. Vilucchi [id](#)<sup>53</sup>, M.G. Vincter [id](#)<sup>34</sup>, G.S. Virdee [id](#)<sup>20</sup>, A. Vishwakarma [id](#)<sup>52</sup>, C. Vittori [id](#)<sup>23b,23a</sup>, I. Vivarelli [id](#)<sup>145</sup>, V. Vladimirov<sup>166</sup>, E. Voevodina [id](#)<sup>109</sup>, F. Vogel [id](#)<sup>108</sup>, P. Vokac [id](#)<sup>131</sup>, J. Von Ahnen [id](#)<sup>48</sup>, E. Von Toerne [id](#)<sup>24</sup>, B. Vormwald [id](#)<sup>36</sup>, V. Vorobel [id](#)<sup>132</sup>, K. Vorobev [id](#)<sup>37</sup>, M. Vos [id](#)<sup>162</sup>, J.H. Vosseveld [id](#)<sup>91</sup>, M. Vozak [id](#)<sup>113</sup>, L. Vozdecky [id](#)<sup>93</sup>, N. Vranjes [id](#)<sup>15</sup>, M. Vranjes Milosavljevic [id](#)<sup>15</sup>, M. Vreeswijk [id](#)<sup>113</sup>, R. Vuillermet [id](#)<sup>36</sup>, O. Vujanovic [id](#)<sup>99</sup>, I. Vukotic [id](#)<sup>39</sup>, S. Wada [id](#)<sup>156</sup>, C. Wagner<sup>102</sup>, W. Wagner [id](#)<sup>170</sup>, S. Wahdan [id](#)<sup>170</sup>, H. Wahlberg [id](#)<sup>89</sup>, R. Wakasa [id](#)<sup>156</sup>, M. Wakida [id](#)<sup>110</sup>, V.M. Walbrecht [id](#)<sup>109</sup>, J. Walder [id](#)<sup>133</sup>, R. Walker [id](#)<sup>108</sup>, W. Walkowiak [id](#)<sup>140</sup>, A.M. Wang [id](#)<sup>61</sup>, A.Z. Wang [id](#)<sup>169</sup>, C. Wang [id](#)<sup>62a</sup>, C. Wang [id](#)<sup>62c</sup>, H. Wang [id](#)<sup>17a</sup>, J. Wang [id](#)<sup>64a</sup>, P. Wang [id](#)<sup>44</sup>, R.-J. Wang [id](#)<sup>99</sup>, R. Wang [id](#)<sup>61</sup>, R. Wang [id](#)<sup>6</sup>, S.M. Wang [id](#)<sup>147</sup>, S. Wang [id](#)<sup>62b</sup>, T. Wang [id](#)<sup>62a</sup>, W.T. Wang [id](#)<sup>79</sup>, W.X. Wang [id](#)<sup>62a</sup>, X. Wang [id](#)<sup>14c</sup>, X. Wang [id](#)<sup>161</sup>, X. Wang [id](#)<sup>62c</sup>, Y. Wang [id](#)<sup>62d</sup>, Y. Wang [id](#)<sup>14c</sup>, Z. Wang [id](#)<sup>105</sup>, Z. Wang [id](#)<sup>62d,51,62c</sup>, Z. Wang [id](#)<sup>105</sup>, A. Warburton [id](#)<sup>103</sup>, R.J. Ward [id](#)<sup>20</sup>, N. Warrack [id](#)<sup>59</sup>, A.T. Watson [id](#)<sup>20</sup>, M.F. Watson [id](#)<sup>20</sup>, G. Watts [id](#)<sup>137</sup>, B.M. Waugh [id](#)<sup>95</sup>, A.F. Webb [id](#)<sup>11</sup>, C. Weber [id](#)<sup>29</sup>, M.S. Weber [id](#)<sup>19</sup>, S.A. Weber [id](#)<sup>34</sup>, S.M. Weber [id](#)<sup>63a</sup>, C. Wei [id](#)<sup>62a</sup>, Y. Wei [id](#)<sup>125</sup>, A.R. Weidberg [id](#)<sup>125</sup>, J. Weingarten [id](#)<sup>49</sup>, M. Weirich [id](#)<sup>99</sup>, C. Weiser [id](#)<sup>54</sup>, C.J. Wells [id](#)<sup>48</sup>, T. Wenaus [id](#)<sup>29</sup>, B. Wendland [id](#)<sup>49</sup>, T. Wengler [id](#)<sup>36</sup>, N.S. Wenke<sup>109</sup>, N. Vermes [id](#)<sup>24</sup>, M. Wessels [id](#)<sup>63a</sup>, K. Whalen [id](#)<sup>122</sup>, A.M. Wharton [id](#)<sup>90</sup>, A.S. White [id](#)<sup>61</sup>, A. White [id](#)<sup>8</sup>, M.J. White [id](#)<sup>1</sup>, D. Whiteson [id](#)<sup>159</sup>, L. Wickremasinghe [id](#)<sup>123</sup>, W. Wiedenmann [id](#)<sup>169</sup>, C. Wiel [id](#)<sup>50</sup>, M. Wielers [id](#)<sup>133</sup>, N. Wieseotte<sup>99</sup>, C. Wiglesworth [id](#)<sup>42</sup>, L.A.M. Wiik-Fuchs [id](#)<sup>54</sup>, D.J. Wilbern<sup>119</sup>, H.G. Wilkens [id](#)<sup>36</sup>, D.M. Williams [id](#)<sup>41</sup>, H.H. Williams<sup>127</sup>, S. Williams [id](#)<sup>32</sup>, S. Willocq [id](#)<sup>102</sup>, P.J. Windischhofer [id](#)<sup>125</sup>, F. Winklmeier [id](#)<sup>122</sup>, B.T. Winter [id](#)<sup>54</sup>, M. Wittgen<sup>142</sup>, M. Wobisch [id](#)<sup>96</sup>, A. Wolf [id](#)<sup>99</sup>, R. Wölker [id](#)<sup>125</sup>, J. Wollrath<sup>159</sup>, M.W. Wolter [id](#)<sup>85</sup>, H. Wolters [id](#)<sup>129a,129c</sup>, V.W.S. Wong [id](#)<sup>163</sup>, A.F. Wongel [id](#)<sup>48</sup>, S.D. Worm [id](#)<sup>48</sup>, B.K. Wosiek [id](#)<sup>85</sup>, K.W. Woźniak [id](#)<sup>85</sup>, K. Wraight [id](#)<sup>59</sup>, J. Wu [id](#)<sup>14a,14d</sup>, M. Wu [id](#)<sup>64a</sup>, S.L. Wu [id](#)<sup>169</sup>, X. Wu [id](#)<sup>56</sup>, Y. Wu [id](#)<sup>62a</sup>, Z. Wu [id](#)<sup>134,62a</sup>, J. Wuerzinger [id](#)<sup>125</sup>, T.R. Wyatt [id](#)<sup>100</sup>, B.M. Wynne [id](#)<sup>52</sup>, S. Xella [id](#)<sup>42</sup>, L. Xia [id](#)<sup>14c</sup>, M. Xia [id](#)<sup>14b</sup>, J. Xiang [id](#)<sup>64c</sup>, X. Xiao [id](#)<sup>105</sup>, M. Xie [id](#)<sup>62a</sup>, X. Xie [id](#)<sup>62a</sup>, J. Xiong [id](#)<sup>17a</sup>, I. Xiotidis<sup>145</sup>, D. Xu [id](#)<sup>14a</sup>, H. Xu [id](#)<sup>62a</sup>, H. Xu [id](#)<sup>62a</sup>, L. Xu [id](#)<sup>62a</sup>, R. Xu [id](#)<sup>127</sup>, T. Xu [id](#)<sup>105</sup>, W. Xu [id](#)<sup>105</sup>, Y. Xu [id](#)<sup>14b</sup>, Z. Xu [id](#)<sup>62b</sup>, Z. Xu [id](#)<sup>142</sup>, B. Yabsley [id](#)<sup>146</sup>, S. Yacoob [id](#)<sup>33a</sup>, N. Yamaguchi [id](#)<sup>88</sup>, Y. Yamaguchi [id](#)<sup>153</sup>, H. Yamauchi [id](#)<sup>156</sup>, T. Yamazaki [id](#)<sup>17a</sup>, Y. Yamazaki [id](#)<sup>83</sup>, J. Yan [id](#)<sup>62c</sup>, S. Yan [id](#)<sup>125</sup>, Z. Yan [id](#)<sup>25</sup>, H.J. Yang [id](#)<sup>62c,62d</sup>, H.T. Yang [id](#)<sup>17a</sup>, S. Yang [id](#)<sup>62a</sup>, T. Yang [id](#)<sup>64c</sup>, X. Yang [id](#)<sup>62a</sup>, X. Yang [id](#)<sup>14a</sup>, Y. Yang [id](#)<sup>44</sup>, Z. Yang [id](#)<sup>62a,105</sup>, W.-M. Yao [id](#)<sup>17a</sup>, Y.C. Yap [id](#)<sup>48</sup>, H. Ye [id](#)<sup>14c</sup>, J. Ye [id](#)<sup>44</sup>, S. Ye [id](#)<sup>29</sup>, X. Ye [id](#)<sup>62a</sup>, Y. Yeh [id](#)<sup>95</sup>, I. Yeletsikh [id](#)<sup>38</sup>, M.R. Yexley [id](#)<sup>90</sup>, P. Yin [id](#)<sup>41</sup>, K. Yorita [id](#)<sup>167</sup>, C.J.S. Young [id](#)<sup>54</sup>, C. Young [id](#)<sup>142</sup>, M. Yuan [id](#)<sup>105</sup>, R. Yuan [id](#)<sup>62b,k</sup>, L. Yue [id](#)<sup>95</sup>, X. Yue [id](#)<sup>63a</sup>, M. Zaazoua [id](#)<sup>35e</sup>, B. Zabinski [id](#)<sup>85</sup>, E. Zaid<sup>52</sup>, T. Zakareishvili [id](#)<sup>148b</sup>, N. Zakharchuk [id](#)<sup>34</sup>, S. Zambito [id](#)<sup>56</sup>, J.A. Zamora Saa [id](#)<sup>136d</sup>, J. Zang [id](#)<sup>152</sup>, D. Zanzi [id](#)<sup>54</sup>, O. Zaplatilek [id](#)<sup>131</sup>, S.V. Zeißner [id](#)<sup>49</sup>, C. Zeitnitz [id](#)<sup>170</sup>, J.C. Zeng [id](#)<sup>161</sup>, D.T. Zenger Jr [id](#)<sup>26</sup>, O. Zenin [id](#)<sup>37</sup>, T. Ženiš [id](#)<sup>28a</sup>, S. Zenz [id](#)<sup>93</sup>, S. Zerradi [id](#)<sup>35a</sup>, D. Zerwas [id](#)<sup>66</sup>, B. Zhang [id](#)<sup>14c</sup>, D.F. Zhang [id](#)<sup>138</sup>, G. Zhang [id](#)<sup>14b</sup>, J. Zhang [id](#)<sup>6</sup>, K. Zhang [id](#)<sup>14a,14d</sup>, L. Zhang [id](#)<sup>14c</sup>, P. Zhang [id](#)<sup>14a,14d</sup>, R. Zhang [id](#)<sup>169</sup>, S. Zhang [id](#)<sup>105</sup>, T. Zhang [id](#)<sup>152</sup>, X. Zhang [id](#)<sup>62c</sup>, X. Zhang [id](#)<sup>62b</sup>, Z. Zhang [id](#)<sup>17a</sup>, Z. Zhang [id](#)<sup>66</sup>, H. Zhao [id](#)<sup>137</sup>, P. Zhao [id](#)<sup>51</sup>, T. Zhao [id](#)<sup>62b</sup>, Y. Zhao [id](#)<sup>135</sup>, Z. Zhao [id](#)<sup>62a</sup>, A. Zhemchugov [id](#)<sup>38</sup>, Z. Zheng [id](#)<sup>142</sup>, D. Zhong [id](#)<sup>161</sup>, B. Zhou<sup>105</sup>, C. Zhou [id](#)<sup>169</sup>, H. Zhou [id](#)<sup>7</sup>, N. Zhou [id](#)<sup>62c</sup>, Y. Zhou<sup>7</sup>, C.G. Zhu [id](#)<sup>62b</sup>, C. Zhu [id](#)<sup>14a,14d</sup>, H.L. Zhu [id](#)<sup>62a</sup>, H. Zhu [id](#)<sup>14a</sup>, J. Zhu [id](#)<sup>105</sup>, Y. Zhu [id](#)<sup>62c</sup>, Y. Zhu [id](#)<sup>62a</sup>, X. Zhuang [id](#)<sup>14a</sup>, K. Zhukov [id](#)<sup>37</sup>, V. Zhulanov [id](#)<sup>37</sup>, N.I. Zimine [id](#)<sup>38</sup>, J. Zinsser [id](#)<sup>63b</sup>, M. Ziolkowski [id](#)<sup>140</sup>, L. Živković [id](#)<sup>15</sup>, A. Zoccoli [id](#)<sup>23b,23a</sup>, K. Zoch [id](#)<sup>56</sup>, T.G. Zorbas [id](#)<sup>138</sup>, O. Zormpa [id](#)<sup>46</sup>, W. Zou [id](#)<sup>41</sup>, L. Zwalinski [id](#)<sup>36</sup>.

<sup>1</sup>Department of Physics, University of Adelaide, Adelaide; Australia.

<sup>2</sup>Department of Physics, University of Alberta, Edmonton AB; Canada.

<sup>3(a)</sup>Department of Physics, Ankara University, Ankara; <sup>(b)</sup>Division of Physics, TOBB University of

Economics and Technology, Ankara; Türkiye.

<sup>4</sup>LAPP, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy; France.

<sup>5</sup>APC, Université Paris Cité, CNRS/IN2P3, Paris; France.

<sup>6</sup>High Energy Physics Division, Argonne National Laboratory, Argonne IL; United States of America.

<sup>7</sup>Department of Physics, University of Arizona, Tucson AZ; United States of America.

<sup>8</sup>Department of Physics, University of Texas at Arlington, Arlington TX; United States of America.

<sup>9</sup>Physics Department, National and Kapodistrian University of Athens, Athens; Greece.

<sup>10</sup>Physics Department, National Technical University of Athens, Zografou; Greece.

<sup>11</sup>Department of Physics, University of Texas at Austin, Austin TX; United States of America.

<sup>12</sup>Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.

<sup>13</sup>Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona; Spain.

<sup>14</sup>(<sup>a</sup>)Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; (<sup>b</sup>)Physics Department, Tsinghua University, Beijing; (<sup>c</sup>)Department of Physics, Nanjing University, Nanjing; (<sup>d</sup>)University of Chinese Academy of Science (UCAS), Beijing; China.

<sup>15</sup>Institute of Physics, University of Belgrade, Belgrade; Serbia.

<sup>16</sup>Department for Physics and Technology, University of Bergen, Bergen; Norway.

<sup>17</sup>(<sup>a</sup>)Physics Division, Lawrence Berkeley National Laboratory, Berkeley CA; (<sup>b</sup>)University of California, Berkeley CA; United States of America.

<sup>18</sup>Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany.

<sup>19</sup>Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland.

<sup>20</sup>School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom.

<sup>21</sup>(<sup>a</sup>)Department of Physics, Bogazici University, Istanbul; (<sup>b</sup>)Department of Physics Engineering, Gaziantep University, Gaziantep; (<sup>c</sup>)Department of Physics, Istanbul University, Istanbul; (<sup>d</sup>)Istinye University, Sariyer, Istanbul; Türkiye.

<sup>22</sup>(<sup>a</sup>)Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogotá; (<sup>b</sup>)Departamento de Física, Universidad Nacional de Colombia, Bogotá; Colombia.

<sup>23</sup>(<sup>a</sup>)Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna; (<sup>b</sup>)INFN Sezione di Bologna; Italy.

<sup>24</sup>Physikalisches Institut, Universität Bonn, Bonn; Germany.

<sup>25</sup>Department of Physics, Boston University, Boston MA; United States of America.

<sup>26</sup>Department of Physics, Brandeis University, Waltham MA; United States of America.

<sup>27</sup>(<sup>a</sup>)Transilvania University of Brasov, Brasov; (<sup>b</sup>)Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest; (<sup>c</sup>)Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi; (<sup>d</sup>)National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca; (<sup>e</sup>)University Politehnica Bucharest, Bucharest; (<sup>f</sup>)West University in Timisoara, Timisoara; (<sup>g</sup>)Faculty of Physics, University of Bucharest, Bucharest; Romania.

<sup>28</sup>(<sup>a</sup>)Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava; (<sup>b</sup>)Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice; Slovak Republic.

<sup>29</sup>Physics Department, Brookhaven National Laboratory, Upton NY; United States of America.

<sup>30</sup>Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires; Argentina.

<sup>31</sup>California State University, CA; United States of America.

<sup>32</sup>Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom.

- <sup>33</sup>(<sup>a</sup>) Department of Physics, University of Cape Town, Cape Town; (<sup>b</sup>) iThemba Labs, Western Cape; (<sup>c</sup>) Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg; (<sup>d</sup>) National Institute of Physics, University of the Philippines Diliman (Philippines); (<sup>e</sup>) University of South Africa, Department of Physics, Pretoria; (<sup>f</sup>) University of Zululand, KwaDlangezwa; (<sup>g</sup>) School of Physics, University of the Witwatersrand, Johannesburg; South Africa.
- <sup>34</sup> Department of Physics, Carleton University, Ottawa ON; Canada.
- <sup>35</sup>(<sup>a</sup>) Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca; (<sup>b</sup>) Faculté des Sciences, Université Ibn-Tofail, Kénitra; (<sup>c</sup>) Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech; (<sup>d</sup>) LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda; (<sup>e</sup>) Faculté des sciences, Université Mohammed V, Rabat; (<sup>f</sup>) Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
- <sup>36</sup> CERN, Geneva; Switzerland.
- <sup>37</sup> Affiliated with an institute covered by a cooperation agreement with CERN.
- <sup>38</sup> Affiliated with an international laboratory covered by a cooperation agreement with CERN.
- <sup>39</sup> Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America.
- <sup>40</sup> LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France.
- <sup>41</sup> Nevis Laboratory, Columbia University, Irvington NY; United States of America.
- <sup>42</sup> Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark.
- <sup>43</sup>(<sup>a</sup>) Dipartimento di Fisica, Università della Calabria, Rende; (<sup>b</sup>) INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy.
- <sup>44</sup> Physics Department, Southern Methodist University, Dallas TX; United States of America.
- <sup>45</sup> Physics Department, University of Texas at Dallas, Richardson TX; United States of America.
- <sup>46</sup> National Centre for Scientific Research "Demokritos", Agia Paraskevi; Greece.
- <sup>47</sup>(<sup>a</sup>) Department of Physics, Stockholm University; (<sup>b</sup>) Oskar Klein Centre, Stockholm; Sweden.
- <sup>48</sup> Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany.
- <sup>49</sup> Fakultät Physik, Technische Universität Dortmund, Dortmund; Germany.
- <sup>50</sup> Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany.
- <sup>51</sup> Department of Physics, Duke University, Durham NC; United States of America.
- <sup>52</sup> SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom.
- <sup>53</sup> INFN e Laboratori Nazionali di Frascati, Frascati; Italy.
- <sup>54</sup> Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
- <sup>55</sup> II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany.
- <sup>56</sup> Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
- <sup>57</sup>(<sup>a</sup>) Dipartimento di Fisica, Università di Genova, Genova; (<sup>b</sup>) INFN Sezione di Genova; Italy.
- <sup>58</sup> II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany.
- <sup>59</sup> SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom.
- <sup>60</sup> LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France.
- <sup>61</sup> Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America.
- <sup>62</sup>(<sup>a</sup>) Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei; (<sup>b</sup>) Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao; (<sup>c</sup>) School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai; (<sup>d</sup>) Tsung-Dao Lee Institute, Shanghai; China.
- <sup>63</sup>(<sup>a</sup>) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; (<sup>b</sup>) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany.

- <sup>64</sup>(<sup>a</sup>) Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong; (<sup>b</sup>) Department of Physics, University of Hong Kong, Hong Kong; (<sup>c</sup>) Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong; China.
- <sup>65</sup>Department of Physics, National Tsing Hua University, Hsinchu; Taiwan.
- <sup>66</sup>IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France.
- <sup>67</sup>Department of Physics, Indiana University, Bloomington IN; United States of America.
- <sup>68</sup>(<sup>a</sup>) INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine; (<sup>b</sup>) ICTP, Trieste; (<sup>c</sup>) Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine; Italy.
- <sup>69</sup>(<sup>a</sup>) INFN Sezione di Lecce; (<sup>b</sup>) Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy.
- <sup>70</sup>(<sup>a</sup>) INFN Sezione di Milano; (<sup>b</sup>) Dipartimento di Fisica, Università di Milano, Milano; Italy.
- <sup>71</sup>(<sup>a</sup>) INFN Sezione di Napoli; (<sup>b</sup>) Dipartimento di Fisica, Università di Napoli, Napoli; Italy.
- <sup>72</sup>(<sup>a</sup>) INFN Sezione di Pavia; (<sup>b</sup>) Dipartimento di Fisica, Università di Pavia, Pavia; Italy.
- <sup>73</sup>(<sup>a</sup>) INFN Sezione di Pisa; (<sup>b</sup>) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy.
- <sup>74</sup>(<sup>a</sup>) INFN Sezione di Roma; (<sup>b</sup>) Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy.
- <sup>75</sup>(<sup>a</sup>) INFN Sezione di Roma Tor Vergata; (<sup>b</sup>) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy.
- <sup>76</sup>(<sup>a</sup>) INFN Sezione di Roma Tre; (<sup>b</sup>) Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy.
- <sup>77</sup>(<sup>a</sup>) INFN-TIFPA; (<sup>b</sup>) Università degli Studi di Trento, Trento; Italy.
- <sup>78</sup>Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck; Austria.
- <sup>79</sup>University of Iowa, Iowa City IA; United States of America.
- <sup>80</sup>Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America.
- <sup>81</sup>(<sup>a</sup>) Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora; (<sup>b</sup>) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; (<sup>c</sup>) Instituto de Física, Universidade de São Paulo, São Paulo; (<sup>d</sup>) Rio de Janeiro State University, Rio de Janeiro; Brazil.
- <sup>82</sup>KEK, High Energy Accelerator Research Organization, Tsukuba; Japan.
- <sup>83</sup>Graduate School of Science, Kobe University, Kobe; Japan.
- <sup>84</sup>(<sup>a</sup>) AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow; (<sup>b</sup>) Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland.
- <sup>85</sup>Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland.
- <sup>86</sup>Faculty of Science, Kyoto University, Kyoto; Japan.
- <sup>87</sup>Kyoto University of Education, Kyoto; Japan.
- <sup>88</sup>Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka ; Japan.
- <sup>89</sup>Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina.
- <sup>90</sup>Physics Department, Lancaster University, Lancaster; United Kingdom.
- <sup>91</sup>Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom.
- <sup>92</sup>Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia.
- <sup>93</sup>School of Physics and Astronomy, Queen Mary University of London, London; United Kingdom.
- <sup>94</sup>Department of Physics, Royal Holloway University of London, Egham; United Kingdom.
- <sup>95</sup>Department of Physics and Astronomy, University College London, London; United Kingdom.
- <sup>96</sup>Louisiana Tech University, Ruston LA; United States of America.
- <sup>97</sup>Fysiska institutionen, Lunds universitet, Lund; Sweden.
- <sup>98</sup>Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain.
- <sup>99</sup>Institut für Physik, Universität Mainz, Mainz; Germany.

- <sup>100</sup>School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom.
- <sup>101</sup>CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.
- <sup>102</sup>Department of Physics, University of Massachusetts, Amherst MA; United States of America.
- <sup>103</sup>Department of Physics, McGill University, Montreal QC; Canada.
- <sup>104</sup>School of Physics, University of Melbourne, Victoria; Australia.
- <sup>105</sup>Department of Physics, University of Michigan, Ann Arbor MI; United States of America.
- <sup>106</sup>Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.
- <sup>107</sup>Group of Particle Physics, University of Montreal, Montreal QC; Canada.
- <sup>108</sup>Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany.
- <sup>109</sup>Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany.
- <sup>110</sup>Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan.
- <sup>111</sup>Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America.
- <sup>112</sup>Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen; Netherlands.
- <sup>113</sup>Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands.
- <sup>114</sup>Department of Physics, Northern Illinois University, DeKalb IL; United States of America.
- <sup>115</sup><sup>(a)</sup>New York University Abu Dhabi, Abu Dhabi; <sup>(b)</sup>University of Sharjah, Sharjah; United Arab Emirates.
- <sup>116</sup>Department of Physics, New York University, New York NY; United States of America.
- <sup>117</sup>Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan.
- <sup>118</sup>Ohio State University, Columbus OH; United States of America.
- <sup>119</sup>Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America.
- <sup>120</sup>Department of Physics, Oklahoma State University, Stillwater OK; United States of America.
- <sup>121</sup>Palacký University, Joint Laboratory of Optics, Olomouc; Czech Republic.
- <sup>122</sup>Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America.
- <sup>123</sup>Graduate School of Science, Osaka University, Osaka; Japan.
- <sup>124</sup>Department of Physics, University of Oslo, Oslo; Norway.
- <sup>125</sup>Department of Physics, Oxford University, Oxford; United Kingdom.
- <sup>126</sup>LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris; France.
- <sup>127</sup>Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America.
- <sup>128</sup>Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America.
- <sup>129</sup><sup>(a)</sup>Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa; <sup>(b)</sup>Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa; <sup>(c)</sup>Departamento de Física, Universidade de Coimbra, Coimbra; <sup>(d)</sup>Centro de Física Nuclear da Universidade de Lisboa, Lisboa; <sup>(e)</sup>Departamento de Física, Universidade do Minho, Braga; <sup>(f)</sup>Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain); <sup>(g)</sup>Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal.
- <sup>130</sup>Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic.
- <sup>131</sup>Czech Technical University in Prague, Prague; Czech Republic.
- <sup>132</sup>Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic.
- <sup>133</sup>Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom.

- <sup>134</sup>IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.
- <sup>135</sup>Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America.
- <sup>136</sup>(<sup>a</sup>)Departamento de Física, Pontificia Universidad Católica de Chile, Santiago;<sup>(b)</sup>Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago;<sup>(c)</sup>Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena;<sup>(d)</sup>Universidad Andres Bello, Department of Physics, Santiago;<sup>(e)</sup>Instituto de Alta Investigación, Universidad de Tarapacá, Arica;<sup>(f)</sup>Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile.
- <sup>137</sup>Department of Physics, University of Washington, Seattle WA; United States of America.
- <sup>138</sup>Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
- <sup>139</sup>Department of Physics, Shinshu University, Nagano; Japan.
- <sup>140</sup>Department Physik, Universität Siegen, Siegen; Germany.
- <sup>141</sup>Department of Physics, Simon Fraser University, Burnaby BC; Canada.
- <sup>142</sup>SLAC National Accelerator Laboratory, Stanford CA; United States of America.
- <sup>143</sup>Department of Physics, Royal Institute of Technology, Stockholm; Sweden.
- <sup>144</sup>Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America.
- <sup>145</sup>Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom.
- <sup>146</sup>School of Physics, University of Sydney, Sydney; Australia.
- <sup>147</sup>Institute of Physics, Academia Sinica, Taipei; Taiwan.
- <sup>148</sup>(<sup>a</sup>)E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi;<sup>(b)</sup>High Energy Physics Institute, Tbilisi State University, Tbilisi;<sup>(c)</sup>University of Georgia, Tbilisi; Georgia.
- <sup>149</sup>Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel.
- <sup>150</sup>Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel.
- <sup>151</sup>Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece.
- <sup>152</sup>International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan.
- <sup>153</sup>Department of Physics, Tokyo Institute of Technology, Tokyo; Japan.
- <sup>154</sup>Department of Physics, University of Toronto, Toronto ON; Canada.
- <sup>155</sup>(<sup>a</sup>)TRIUMF, Vancouver BC;<sup>(b)</sup>Department of Physics and Astronomy, York University, Toronto ON; Canada.
- <sup>156</sup>Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan.
- <sup>157</sup>Department of Physics and Astronomy, Tufts University, Medford MA; United States of America.
- <sup>158</sup>United Arab Emirates University, Al Ain; United Arab Emirates.
- <sup>159</sup>Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America.
- <sup>160</sup>Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden.
- <sup>161</sup>Department of Physics, University of Illinois, Urbana IL; United States of America.
- <sup>162</sup>Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain.
- <sup>163</sup>Department of Physics, University of British Columbia, Vancouver BC; Canada.
- <sup>164</sup>Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.
- <sup>165</sup>Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany.
- <sup>166</sup>Department of Physics, University of Warwick, Coventry; United Kingdom.
- <sup>167</sup>Waseda University, Tokyo; Japan.

- <sup>168</sup>Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel.
- <sup>169</sup>Department of Physics, University of Wisconsin, Madison WI; United States of America.
- <sup>170</sup>Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
- <sup>171</sup>Department of Physics, Yale University, New Haven CT; United States of America.
- <sup>a</sup> Also Affiliated with an institute covered by a cooperation agreement with CERN.
- <sup>b</sup> Also at An-Najah National University, Nablus; Palestine.
- <sup>c</sup> Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.
- <sup>d</sup> Also at Bruno Kessler Foundation, Trento; Italy.
- <sup>e</sup> Also at Center for High Energy Physics, Peking University; China.
- <sup>f</sup> Also at Centro Studi e Ricerche Enrico Fermi; Italy.
- <sup>g</sup> Also at CERN, Geneva; Switzerland.
- <sup>h</sup> Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
- <sup>i</sup> Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona; Spain.
- <sup>j</sup> Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.
- <sup>k</sup> Also at Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.
- <sup>l</sup> Also at Department of Physics and Astronomy, University of Louisville, Louisville, KY; United States of America.
- <sup>m</sup> Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva; Israel.
- <sup>n</sup> Also at Department of Physics, California State University, East Bay; United States of America.
- <sup>o</sup> Also at Department of Physics, California State University, Sacramento; United States of America.
- <sup>p</sup> Also at Department of Physics, King's College London, London; United Kingdom.
- <sup>q</sup> Also at Department of Physics, Stanford University, Stanford CA; United States of America.
- <sup>r</sup> Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
- <sup>s</sup> Also at Department of Physics, University of Thessaly; Greece.
- <sup>t</sup> Also at Department of Physics, Westmont College, Santa Barbara; United States of America.
- <sup>u</sup> Also at Hellenic Open University, Patras; Greece.
- <sup>v</sup> Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
- <sup>w</sup> Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
- <sup>x</sup> Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia; Bulgaria.
- <sup>y</sup> Also at Institute of Particle Physics (IPP); Canada.
- <sup>z</sup> Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
- <sup>aa</sup> Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
- <sup>ab</sup> Also at L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse; France.
- <sup>ac</sup> Also at Lawrence Livermore National Laboratory, Livermore; United States of America.
- <sup>ad</sup> Also at National Institute of Physics, University of the Philippines Diliman (Philippines); Philippines.
- <sup>ae</sup> Also at Technical University of Munich, Munich; Germany.
- <sup>af</sup> Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
- <sup>ag</sup> Also at TRIUMF, Vancouver BC; Canada.
- <sup>ah</sup> Also at Università di Napoli Parthenope, Napoli; Italy.
- <sup>ai</sup> Also at University of Chinese Academy of Sciences (UCAS), Beijing; China.



<sup>aj</sup> Also at University of Colorado Boulder, Department of Physics, Colorado; United States of America.

<sup>ak</sup> Also at Washington College, Maryland; United States of America.

<sup>al</sup> Also at Yeditepe University, Physics Department, Istanbul; Türkiye.

\* Deceased