



Search for dark matter produced in association with a dark Higgs boson in the $b\bar{b}$ final state using pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

The ATLAS Collaboration

A search is performed for dark matter particles produced in association with a resonantly produced pair of b -quarks with $30 < m_{bb} < 150$ GeV using 140 fb^{-1} of proton–proton collisions at a center-of-mass energy of 13 TeV recorded by the ATLAS detector at the LHC. This signature is expected in extensions of the Standard Model predicting the production of dark matter particles, in particular those containing a dark Higgs boson s that decays into $b\bar{b}$. The highly boosted $s \rightarrow b\bar{b}$ topology is reconstructed using jet reclustering and a new identification algorithm. This search places stringent constraints across regions of the dark Higgs model parameter space that satisfy the observed relic density, excluding dark Higgs bosons with masses between 30 and 150 GeV in benchmark scenarios with Z' mediator masses up to 4.8 TeV at 95% confidence level.

Multiple astrophysical observations [1–4] indicate that a large fraction of the matter density of the universe is in the form of dark matter (DM). Its nature is a major open question in physics, for the Standard Model (SM) of particle physics does not provide any suitable DM candidates. Many extensions of the SM propose DM candidates that are stable, neutral, massive weakly interacting particles [4], which determine the DM relic abundance via thermal freeze-out. The search for DM candidates is being pursued actively in direct and indirect detection experiments in addition to collider experiments [5–11]. Once produced in colliders, DM would be undetected and must be inferred from the imbalance of the transverse momentum \vec{p}_T^{miss} ¹, with magnitude E_T^{miss} , observed from the detected SM particles.

This Letter presents a novel DM search using a $X + E_T^{\text{miss}}$ signature in which X is a hypothetical particle that decays into a b -quark pair, $b\bar{b}$. This signature of large E_T^{miss} and resonant $b\bar{b}$ production has not been probed directly for invariant masses $m_{bb} < 150$ GeV, except for when X is the SM Higgs boson, h [12, 13]. Signal regions (SRs) are defined by requiring significant E_T^{miss} consistent with the presence of DM, in association with a $b\bar{b}$ decay, which is usually the dominant branching fraction for a low mass X with SM Higgs boson couplings. The background is dominated by vector-boson production in association with jets, referred to as V +jets, with top quark pair ($t\bar{t}$) production also significant at lower E_T^{miss} values. To constrain and improve the modeling of these background contributions, control regions (CRs) are defined that require either a single muon (μ) or a pair of charged leptons $\ell^\pm\ell^\mp$ ($\ell = e, \mu$) in the final state.

The optimization and interpretation of the search is based on a dark Higgs model [14] that explains mass generation for DM particles (χ) through a Higgs mechanism in the dark sector and Yukawa interactions with a new massive dark Higgs boson (s). This model satisfies the observed DM relic density as, when the dark Higgs boson s is lighter than the DM particle χ , additional annihilation channels such as $\chi\chi \rightarrow ss$ can be dominant. Thus it offers a widespread, generic ability to reproduce the observed relic density. In this two-mediator DM model, Majorana DM particles interact with the SM via the exchange of new spin-1 “mediator” particles carrying a new $U(1)'$ gauge symmetry (e.g. a new Z' gauge boson), which can be probed at colliders [14] through s -channel processes. Since large dark sector couplings usually reproduce the relic density, the probability for a Z' to radiate a dark Higgs boson can be large. Annihilation signals in these models are suppressed, as is direct detection sensitivity for Majorana DM particles; thus colliders provide unique discovery potential. The key model parameters are the Majorana DM candidate’s mass m_χ , the Z' mass $m_{Z'}$, the dark Higgs boson mass m_s , the two couplings of the Z' boson to quarks g_q and to DM g_χ , and lastly the mixing angle between the SM and dark Higgs bosons θ . In this model, the Z' decays dominantly into DM, which recoils against the dark Higgs boson and its visible decay products. If the dark Higgs boson is the lightest dark sector state, exploring the dominant decays of low-mass s bosons is vital. For $m_s < 150$ GeV, decays into a b -quark pair dominate, with the Lorentz boost and collimated decay generating a merged topology signature of a single large-radius (large- R) jet containing two b -quarks. The experimental challenges of this final state are the identification of the massive jet and its b -quarks, and maintaining sensitivity to $m_s < 50$ GeV. For $m_{Z'} < 2$ TeV and $m_s > 70$ GeV, the greater separation of the b -quark pair motivates a resolved topology of two small-radius (small- R) b -quark jets.

The analysis is performed using 140 fb⁻¹ of pp collisions at $\sqrt{s} = 13$ TeV recorded with the ATLAS detector [15, 16] in 2015–2018 during good operating conditions [17]. The ATLAS experiment is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and nearly 4π

¹ 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 upwards. Polar coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z -axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$ and is equal to the rapidity $y = \frac{1}{2} \ln \left(\frac{E+p_z c}{E-p_z c} \right)$ in the relativistic limit. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. Transverse momentum is defined by $p_T \equiv p \sin \theta$.

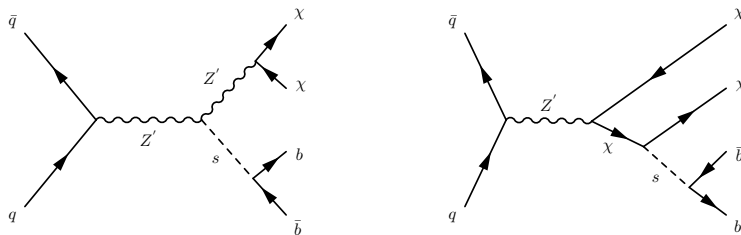


Figure 1: Signal diagrams illustrating the resonant $pp \rightarrow Z' \rightarrow s\chi\chi \rightarrow b\bar{b}\chi\chi$ process.

coverage in solid angle. It consists of an inner tracking detector (ID) surrounded by a superconducting solenoid, sampling electromagnetic (EM) and hadronic calorimeters, and a muon spectrometer (MS) with three toroidal superconducting magnets. A two-level trigger system [18] selects events for offline analysis. Events in the SR and the single-muon CR were collected by triggers on the $E_{\text{T}}^{\text{miss}}$ reconstructed from calorimeter information only [19] above a threshold that varied from 90 to 110 GeV. Events in the two-lepton CR were recorded using single-lepton triggers with p_{T} thresholds of 24–26 GeV [20, 21], depending on the data-taking period. An extensive software suite [22] is used in the experiment.

Monte Carlo (MC) simulations are used to model the kinematics of SM background processes and the $s + \chi\chi$ signal, illustrated in Figure 1. A detailed simulation of the ATLAS detector [23] based on GEANT4 [24] was used to simulate the detector response for MC event samples. Contributions from additional pp interactions in the same and neighboring bunch crossings (pileup) were simulated through the overlay of inelastic pp simulations from PYTHIA 8.186 [25] using the A3 set of tuned parameters [26] and the NNPDF2.3 leading order (LO) parton distribution function (PDF) set [27]. Details of the event simulation configurations used for signal and background processes can be found in the Appendix.

Signal simulations for the $pp \rightarrow Z' \rightarrow s\chi\chi \rightarrow b\bar{b}\chi\chi$ process in three interpretation scenarios are used to investigate interesting phase spaces of the model. Scenario 1 simulations were generated in the $(m_{Z'}, m_s)$ plane, covering 30–150 GeV in m_s and $m_{Z'}$ up to 4 TeV. Other parameter values were $m_\chi = 200$ GeV to avoid $s \rightarrow \chi\chi$ decays, $g_q = 0.25$ [28, 29], $g_\chi = 1.0$ and $\sin\theta = 0.01$ [14], defining a conventional benchmark used in previous studies in different final states [30–32]. Two other scenarios are developed, where the coupling parameter g_χ is varied (instead of being set to unity) to ensure all signal points are compatible with the observed relic density, $\Omega h^2 = 0.12$ [33], calculated using MADDM [34]. This requirement usually indicates large g_χ couplings, especially for larger $m_{Z'}$, which enhances the sensitivity of dark Higgs boson signatures and reduces that of others, e.g. where the Z' decays into quarks. Signal simulations for scenario 2 were generated in the $(m_{Z'}, m_s)$ plane, but with $m_\chi = 900$ GeV to enable a match with the relic density across the investigated parameter plane. Finally, scenario 3 explores the $(m_{Z'}, m_\chi)$ plane for a fixed dark Higgs boson mass $m_s = 70$ GeV that coincides with the highest analysis sensitivity. The other parameters (g_q and $\sin\theta$) in these scenarios match those of scenario 1.

At least one pp collision vertex reconstructed from at least two ID tracks with $p_{\text{T}} > 0.5$ GeV is required in each event. The vertex with the highest $\sum(p_{\text{T}})^2$ is designated the primary vertex (PV) [35]. Electrons are reconstructed by matching a cluster of energy in the calorimeter to an ID track. Electron candidates are identified using a likelihood-based method and must satisfy the “loose” requirement [36] and have $|\eta| < 2.47$. Muons are reconstructed by matching a track or track segment found in the MS to an ID track. Muons must satisfy “loose” requirements [37] and have $|\eta| < 2.5$. Electrons and muons must be isolated according to the track proximity criteria defined in Ref. [38]. Hadronic τ -lepton decays are identified by an

algorithm based on a boosted decision tree [39] that combines calorimeter and ID information. Events with τ -leptons satisfying $p_T > 20$ GeV and “very loose” requirements [40] within $|\eta| = 2.5$ are rejected.

Small- R jets are formed with the anti- k_t algorithm [41, 42], using a radius parameter $R = 0.4$, from ID tracks associated with the PV and three-dimensional clusters of calorimeter cells selected by a particle-flow reconstruction algorithm [43]. “Central” small- R jets satisfy $|\eta| < 2.5$ and $p_T > 20$ GeV while “forward” jets satisfy $2.5 < |\eta| < 4.5$ and $p_T > 30$ GeV. Corrections for pileup [44] and the jet energy scale (JES) and resolution (JER) [45] are applied. The PV origin of central small- R jets with $20 < p_T < 60$ GeV and $|\eta| < 2.4$ is required, using an associated-track-based discriminant [46]. Small- R jets closer than $\Delta R = 0.2$ to an e or μ are rejected. Two types of large- R jets are reconstructed using the anti- k_t algorithm with radius $R = 1.0$. “Reclustered” large- R jets (J) are derived by clustering small- R jets (j) [47]; these are used for the merged analysis with the intention of capturing the dark Higgs boson decay in full, providing sensitivity and good mass resolution across the full jet mass range (down to $m_J = 30$ GeV). Their flavor content is evaluated through their associated variable-radius (VR) track-jets [48, 49] or the D_{Xbb} discriminant score of the corresponding calorimeter large- R jet, as described below. “Calorimeter” large- R jets are clustered from topological clusters calibrated to the hadronic scale using the local hadronic cell weighting (LCW) scheme [50]. All large- R jets are trimmed [51] to minimise the impact of pileup and underlying event. The JES and jet mass scale (JMS) of trimmed jets are calibrated following techniques described in Ref. [52].

To suppress contributions from processes that involve light quarks or gluons, two multivariate algorithms are used to identify jets containing b -hadrons (b -tagging) [53]. The algorithm DL1r is used at an operating point evaluated to be 77% efficient at b -jet identification on $t\bar{t}$ simulation [54]. For $m_J < 50$ GeV, this algorithm and operating point is applied to VR track-jets with $p_T > 10$ GeV and $|\eta| < 2.5$ formed from ID tracks using the anti- k_t algorithm and a p_T -dependent radius parameter. It is also applied to the small- R jets in the resolved channel. A second, new tagging algorithm D_{Xbb} [55, 56], developed specifically for the $X \rightarrow b\bar{b}$ topology, combines the flavor information of up to three VR track-jets within the large- R jet. This mass-agnostic neural network exploits the powerful tagging capability of individual track-jets and their discriminant correlations, together with the knowledge of the large- R jet kinematics. The algorithm is trained on calorimeter large- R jets with masses above 50 GeV, where the axes of the large- R jet and the reclustered large- R jet lie within $\Delta R = 1.0$. An operating point evaluated to be 50% efficient at selecting Higgs bosons with $p_T > 250$ GeV is employed. It is calibrated using $Z(\rightarrow b\bar{b})$ +jets and $Z(\rightarrow b\bar{b})+\gamma$ data samples in four p_T regions, supported by $t\bar{t}$ and $g \rightarrow b\bar{b}$ topologies. It is estimated that the D_{Xbb} algorithm improves the sensitivity by a factor of up to 50% in expected median discovery significance compared with an $E_T^{\text{miss}} + h(b\bar{b})$ analysis [12] using VR track-jet b -tagging, neglecting systematic uncertainties.

The \vec{p}_T^{miss} is computed as the negative vector sum of the transverse momenta of the identified and calibrated physics objects in the event, plus a term accounting for low-energy charged particles, using the “tight” operating point defined in Ref. [57]. An object-based E_T^{miss} significance \mathcal{S} [57] discriminates events with genuine E_T^{miss} produced by neutrinos or possible weakly interacting exotic particles, from those events in which E_T^{miss} is caused by mismeasurements or resolution effects.

The signal is characterized by high E_T^{miss} from the DM particle production, and substantial hadronic activity from $s \rightarrow b\bar{b}$ decays that results in an invariant mass consistent with m_s . Thus events in the SR are required to have $E_T^{\text{miss}} > 150$ GeV, either two b -tagged small- R jets or a large- R jet containing two b -quarks, and no isolated e or μ . Events in the SR are rejected if a “loose” electron or muon with $p_T > 7$ GeV is present. The smallest azimuthal angle between the \vec{p}_T^{miss} and any of the three highest- p_T (leading) small- R jets is required to be at least 20° to reduce the multijet background arising from mismeasured jet momenta. For signal events the E_T^{miss} and the p_T of the reconstructed dark Higgs boson candidate (p_T^{JJ} in the resolved

region or p_T^J in the merged region) are correlated through the production process. Their ratio is required to be between 0.8 and 1.3 to reduce the contributions from $t\bar{t}$ and W +jets events.

In the merged channel, to ensure the decay products are contained in the large- R jet, a $2m_J/p_T^J < 0.6$ requirement is applied. The dark Higgs boson candidate jet is required to have at least two non-overlapping VR track-jets associated with it. Events with an additional b -tagged VR track-jet not associated with the large- R jet are rejected to suppress top quark pair production. In the resolved channel, the dominant background process is $t\bar{t}$ production. This background is reduced by the variables $m_T^{b,\min/\max} = \sqrt{2p_T^{b,\min/\max} E_T^{\text{miss}} (1 - \cos \Delta\phi(\vec{p}_T^{b,\min/\max}, \vec{p}_T^{\text{miss}}))}$, and a requirement of $m_T^{b,\min} > 170$ GeV and $m_T^{b,\max} > 200$ GeV, where $p_T^{b,\min}$ and $p_T^{b,\max}$ are defined as the p_T of the b -jet that is closer to (min) or further from (max) \vec{p}_T^{miss} in ϕ . To suppress $t\bar{t}$ processes further, the central small- R jet multiplicity is required to be ≤ 4 . An $S > 12$ requirement is also applied, and results in negligible multijet background.

The largest SR background contributions come from SM $Z(\rightarrow \nu\bar{\nu})$ +jets processes (48%–60%), increasing in higher E_T^{miss} categories. In the merged topology, SM diboson production (17%) and $W(\rightarrow \ell\nu)$ +jets (9%–13%) provide sub-leading contributions; top quark pair production (10%–30%) and $W(\rightarrow \ell\nu)$ +jets processes (13%–15%) contribute in the resolved topology. Two CRs are defined to improve the modeling of the V +jets background: the single-muon CR (1μ -CR) enriched in W +jets and $t\bar{t}$, and the two-lepton CR (2ℓ -CR) dominated by Z +jets. The 1μ -CR follows the same selection and E_T^{miss} trigger as the SR, except that events must contain exactly one “medium” muon [58] with $p_T > 27$ GeV and no “loose” electrons with $p_T > 7$ GeV. It is split into two regions depending on the muon charge to provide additional discrimination between these two backgrounds, due to the larger cross-section for W^+ boson production in pp collisions. Events in the 2ℓ -CR are selected using the same requirements as in the SR, except that events must contain exactly two “loose” electrons or oppositely charged “medium” muons, and satisfy $S > 12$, with an additional requirement that this significance be lower than 5 when considering E_T^{miss} calculated with the two visible leptons. The leading electron (muon) must fulfill $p_T > 27$ (25) GeV, while the subleading lepton must satisfy $p_T > 7$ GeV. The dilepton system mass and p_T must be consistent with the Z boson hypothesis of $|m_{\ell\ell} - m_Z| < 10$ GeV and $p_T^{\ell\ell} > 150$ GeV.

To maintain sensitivity to signals generating higher E_T^{miss} values and constrain background processes more effectively, events are further categorized in $E_T^{\text{miss}}/\text{GeV}$: [150, 200), [200, 350) and [350, 500) in the resolved category and $E_T^{\text{miss}}/\text{GeV}$: [500, 750), ≥ 750 in the merged category. The CRs in the resolved category are divided in the same way. The boundary between resolved and merged categories at 500 GeV is optimized for search sensitivity. To match the E_T^{miss} kinematics of V +jets processes in the SR, $\vec{E}_{T,\mu}^{\text{miss}} = \vec{p}_T^{\text{miss}} + \vec{p}_T^\mu$ is used in the 1μ -CR, incorporating the p_T of the W boson. Similarly, the addition of $\vec{p}_T^{\ell\ell}$ in the 2ℓ -CR provides an analog to the E_T^{miss} in the SR.

Experimental systematic uncertainties affect the reconstruction of the dark Higgs boson candidate. These include uncertainties in the JMS [52] and the JES and JER [45] of both the small- R and large- R jets, and uncertainties in the calibrations of the b -jet identification algorithms [54, 59, 60]. Uncertainties in the lepton identification efficiencies [36, 37], E_T^{miss} trigger efficiency, energy scale and resolution [57] are found to be negligible, as is the uncertainty in the luminosity [61].

Theoretical systematic uncertainties originate from the modeling of the signal and major background processes. These include uncertainties from the choice of PDFs and the factorization and renormalization scales. Additionally, uncertainties in the choice of the matrix element and parton shower generator are assessed through dedicated, alternative MC simulations as detailed in the Appendix.

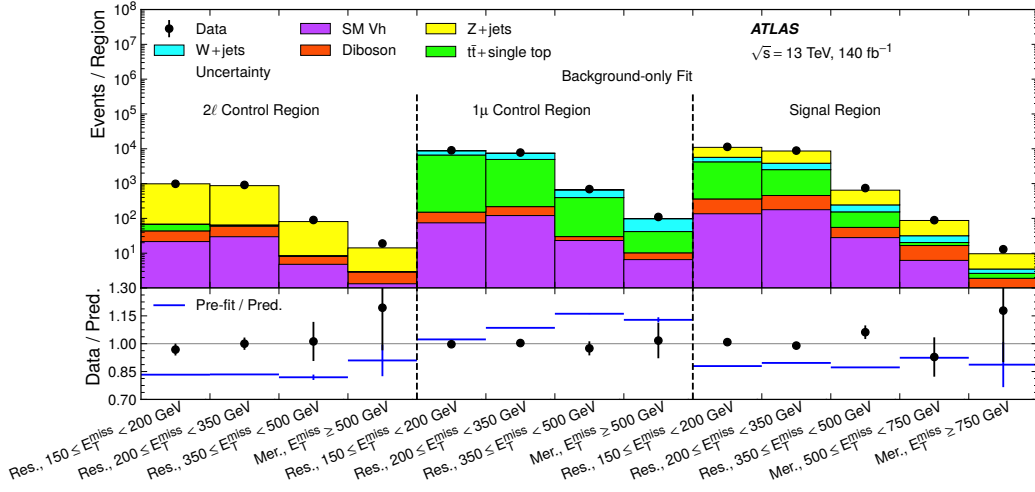


Figure 2: Data and predicted SM background yields after a simultaneous background-only fit to each resolved (Res.) and merged (Mer.) SR and CR E_T^{miss} category. The ratio of the data to the SM expectation is shown in the lower panel; the lines give the ratios of the pre-fit to the post-fit background predictions and the shaded areas indicate the total uncertainty in the predictions.

Limits on DM signals are extracted via a simultaneous maximum-likelihood fit [62, 63] of signal and background simulations to the binned candidate mass distributions in the SR and to the event yields in the CRs. The normalizations of Z +jets, $t\bar{t}$ and W +jets processes are free parameters in the fit and are constrained by the total event yields, considering each E_T^{miss} region separately in the SR and CRs. Systematic uncertainties are parameterized as nuisance parameters with Gaussian prior probabilities, and constrain the fit templates and normalizations [64]. Statistical uncertainties in the data are the largest source of uncertainty (75%–85% of the total), with systematic uncertainties, specifically those in the calibration of the large- R jet b -tagging algorithm, becoming more important at larger p_T and $m_{Z'}$ values (20%–47%). The largest theoretical uncertainties are in the modeling of Z +jets processes (15%–25%), and those associated with the normalization of V +jets processes (10%–15%). At $m_s \approx 50$ GeV and high $m_{Z'}$, the predominance of Z +jets increases the impact of its normalization uncertainty (up to 41% of total).

The observed and fitted yields in the SR and CR categories obtained after a simultaneous fit under the hypothesis that only SM contributions are present (“background-only fit”) are shown in Figure 2. The overall yields in the CRs and the SR are found to be well described by SM expectations, with the fit favoring a mild increase ($\sim 20\%$) of the Z +jets contribution. The pre-fit uncertainties cover the differences between the data and pre-fit background predictions. Figure 3 shows the mass distributions m_{bb} of the s candidate mass in the SR categories after the background-only fit. The MC simulations agree well with the data in the CRs, indicating that V +jets background processes are well modeled. The data exceed the SM expectation slightly around $m_s = 60$ GeV in the $350 \leq E_T^{\text{miss}} < 500$ GeV category. Its local significance is 1.6 standard deviations (σ). A smaller, very localized excess is also seen near $m_s = 130$ GeV in the same category, and is narrower than the resolution in m_s . The observed results in the SR indicate that the data are in agreement with SM predictions with no significant evidence of a DM signal.

Consequently, upper limits are set on the product of the $pp \rightarrow s\chi\chi$ production cross-section and branching fraction $\mathcal{B}(s \rightarrow b\bar{b})$, using a modified frequentist approach (CL_s) [65] with a test statistic based on the profile likelihood in the asymptotic approximation [66]. Exclusion contours at 95% confidence level (CL)

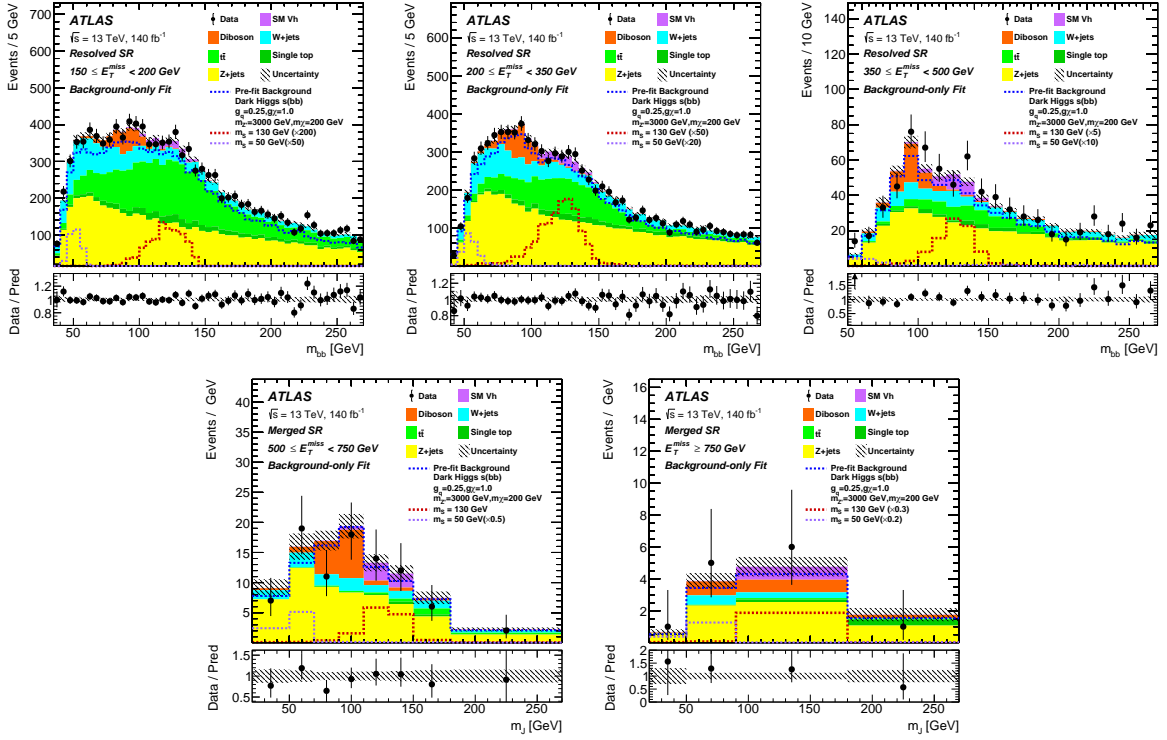


Figure 3: The m_{bb} distributions for data and SM expectations in the different E_T^{miss} regions for the resolved (top row) and merged (bottom row) topologies after a background-only simultaneous fit to data. The shaded area represents the total uncertainty in the predicted yields. Two signal distributions are overlaid, multiplied in each E_T^{miss} region by a scale factor indicated in the legend for visibility. The lower panels show the ratios of the data to the predictions.

for the dark Higgs model are presented in Figure 4. The two-dimensional $(m_{Z'}, m_s)$ plane for scenarios 1 and 2 are shown in Figures 4(a), 4(b) and 4(c). In scenario 1, with $g_\chi = 1$ and $m_\chi = 200$ GeV, $m_{Z'}$ values are excluded up to 3.4 TeV at $m_s = 70$ GeV, which are the highest mass exclusions for this conventional benchmark model. Figure 4(b) summarizes the exclusions on this model. The observed relic density is obtained for $m_{Z'} = 850$ GeV, and also for $m_s \simeq 2m_\chi = 400$ GeV where dark Higgs boson annihilation processes are greatly enhanced and deplete the relic abundance for all $m_{Z'}$ values.

In scenario 2 (Figure 4(c)), the DM coupling varies to satisfy the observed relic density throughout; thus the exclusion behavior is more complex. The increased DM mass ($m_\chi = 900$ GeV) leads to reduced cross-sections, with $m_{Z'}$ masses around $m_{Z'} = 2.5$ TeV having g_χ values near unity and lying close to the expected exclusions. The relic density constraint requires larger g_χ values for larger $m_{Z'}$ values, as the DM annihilation process $\chi\chi \rightarrow Z' \rightarrow q\bar{q}$ becomes more inefficient. The increasing coupling, and thus greater probability for the Z' to emit a dark Higgs boson and decay into DM, increases the cross-section, extending sensitivity to higher masses, where $m_{Z'}$ values can be excluded up to 4.5 TeV for $m_s = 75$ GeV. Below $m_{Z'} = 2.5$ TeV, and especially for $m_{Z'} \sim 2m_\chi$, the annihilation process above becomes very efficient, and the small g_χ couplings that match the relic density lead to cross-sections that are too small to be excluded. The observed exclusion range in $m_{Z'}$ becomes narrower than expected at higher m_s values owing to the small excesses in data near $m_{bb} = 50$ GeV and $m_{bb} = 130$ GeV discussed above.

The exclusion limits on the $m_{Z'}$ and m_χ plane for scenario 3 are shown in Figure 4(d). Again, the relic

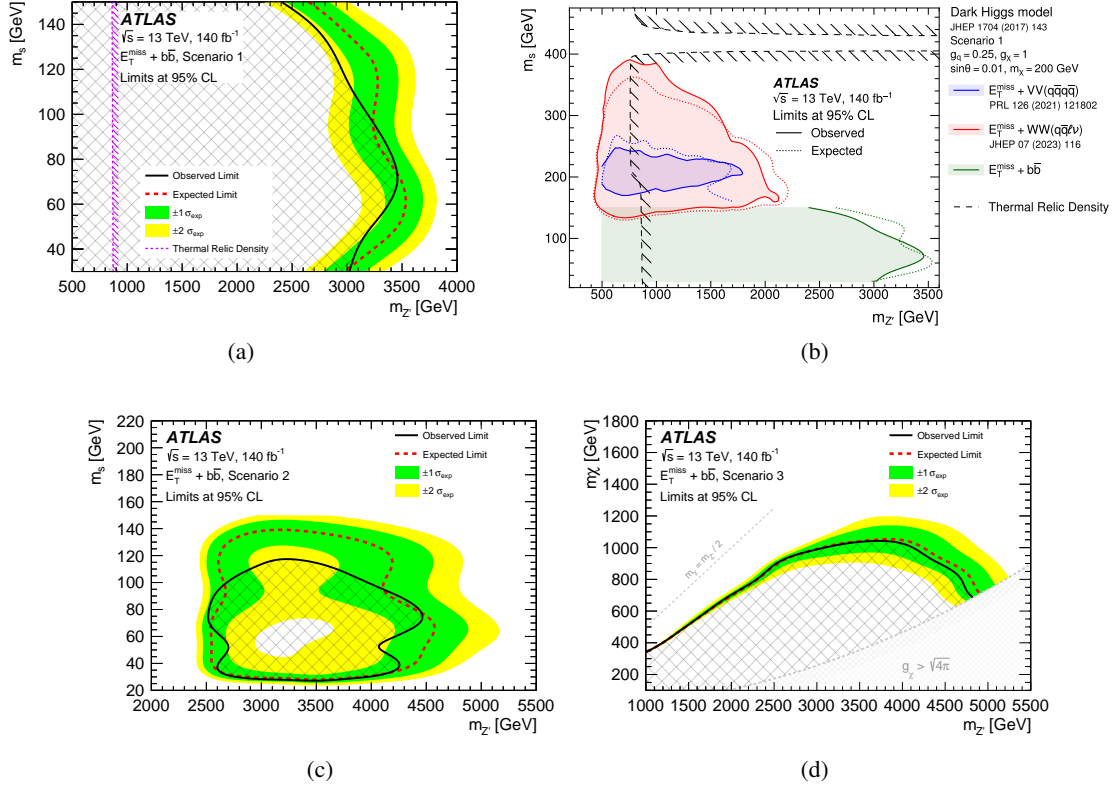


Figure 4: Observed (expected) exclusion regions at 95% CL for (a, b) scenario 1, (c) scenario 2 and (d) scenario 3. The $\pm 1\sigma$ ($\pm 2\sigma$) expected exclusion intervals are shown as the filled inner (outer) bands (a, c, d). The observed relic density is indicated with a dashed line for scenario 1 (a, b), with the diagonal lines indicating an overabundance of DM. The filled areas of (b) are excluded, with the open contours indicating regions not explored for a given signature. The lower-right shaded area indicates the region beyond the Z' -DM coupling perturbative limit for scenario 3 (d).

density depends upon the efficiency of the $\chi\chi \rightarrow Z' \rightarrow q\bar{q}$ process, resulting in increasing g_χ values for higher $m_{Z'}$ values and lower χ masses (lower right of figure). For DM masses up to 700 GeV, $m_{Z'}$ values up to the perturbative limit are excluded, reaching a maximum of 4.8 TeV at that m_χ . The merged SR dominates the sensitivity at low m_s and high $m_{Z'}$, while the resolved SR contributes for $m_{Z'} < 2$ TeV.

In conclusion, this Letter reports a novel search for dark matter in a final state with large E_T^{miss} and a resonant $b\bar{b}$ pair with $30 < m_{b\bar{b}} < 150$ GeV using 140 fb^{-1} of 13 TeV pp data collected by the ATLAS detector at the LHC. The analysis employs jet reclustering and a new $X \rightarrow b\bar{b}$ tagging algorithm to provide sensitivity to low $m_{b\bar{b}}$ and highly boosted bb -jets. No excess over the expected background prediction is observed and 95% CL exclusions are placed on dark Higgs boson models with $m_s < 150$ GeV. In this dark Higgs boson mass range, Z' mediators are excluded with masses up to 3.4 TeV, for a benchmark model with $g_\chi = 1$, $g_q = 0.25$ and $\sin \theta = 0.01$, and up to 4.8 TeV in a relic density inspired benchmark model in which couplings vary more widely. This first experimental search for this signature significantly extends existing exclusions on this model, and strongly constrains regions compatible with the observed DM relic density, which occur primarily when the dark Higgs boson is comparable or lighter in mass than the DM candidate, such that related annihilation processes dominate. These results complement other higher-mass dark Higgs boson and collider DM searches.

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

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF/SFU (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), 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. [67].

We gratefully 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; MNiSW, 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, Taipei; TENMAK, Türkiye; STFC, United Kingdom; DOE and NSF, United States of America.

Individual groups and members have received support from BCKDF, CANARIE, CRC and DRAC, Canada; CERN-CZ, FORTE and PRIMUS, Czech Republic; COST, ERC, ERDF, Horizon 2020, ICSC-NextGenerationEU 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.

In addition, individual members wish to acknowledge support from CERN: European Organization for Nuclear Research (CERN P.J.A.S.); Chile: Agencia Nacional de Investigación y Desarrollo (FONDECYT 1190886, FONDECYT 1230812, FONDECYT 1230987); China: Chinese Ministry of Science and Technology (MOST-2023YFA1605700), National Natural Science Foundation of China (NSFC - 12175119, NSFC 12275265, NSFC-12075060); Czech Republic: Czech Science Foundation (GACR - 24-11373S), Ministry of Education Youth and Sports (FORTE CZ.02.01.01/00/22_008/0004632), PRIMUS Research Programme (PRIMUS/21/SCI/017); EU: H2020 European Research Council (ERC - 101002463); European Union: European Research Council (ERC - 948254, ERC 101089007), Horizon 2020 Framework Programme (MUCCA - CHIST-ERA-19-XAI-00), European Union, Future Artificial Intelligence Research (FAIR-NextGenerationEU PE00000013), Italian Center for High Performance Computing, Big Data and Quantum Computing (ICSC, NextGenerationEU); France: Agence Nationale de la Recherche (ANR-20-CE31-0013, ANR-21-CE31-0013, ANR-21-CE31-0022), Investissements d’Avenir Labex (ANR-11-LABX-0012); Germany: Baden-Württemberg Stiftung (BW Stiftung-Postdoc Eliteprogramme), Deutsche Forschungsgemeinschaft (DFG - 469666862, DFG - CR 312/5-2); Italy: Istituto Nazionale di Fisica Nucleare (ICSC, NextGenerationEU); Japan: Japan Society for the Promotion of Science (JSPS KAKENHI JP21H05085, JSPS KAKENHI JP22H01227, JSPS KAKENHI JP22H04944, JSPS KAKENHI JP22KK0227); Netherlands: Netherlands Organisation for Scientific Research (NWO Veni 2020 - VI.Veni.202.179); Norway: Research Council of Norway (RCN-314472); Poland: Polish National Agency for Academic Exchange (PPN/PPO/2020/1/00002/U/00001), Polish National Science Centre (NCN 2021/42/E/ST2/00350, NCN

OPUS nr 2022/47/B/ST2/03059, NCN UMO-2019/34/E/ST2/00393, UMO-2020/37/B/ST2/01043, UMO-2021/40/C/ST2/00187, UMO-2022/47/O/ST2/00148, UMO-2023/49/B/ST2/04085); Slovenia: Slovenian Research Agency (ARIS grant J1-3010); Spain: Generalitat Valenciana (Artemisa, FEDER, ID-IFEDER/2018/048), Ministry of Science and Innovation (MCIN & NextGenEU PCI2022-135018-2, MICIN & FEDER PID2021-125273NB, RYC2019-028510-I, RYC2020-030254-I, RYC2021-031273-I, RYC2022-038164-I), PROMETEO and GenT Programmes Generalitat Valenciana (CIDEAGENT/2019/023, CIDEAGENT/2019/027); Sweden: Swedish Research Council (Swedish Research Council 2023-04654, VR 2018-00482, VR 2022-03845, VR 2022-04683, VR 2023-03403, VR grant 2021-03651), Knut and Alice Wallenberg Foundation (KAW 2018.0157, KAW 2018.0458, KAW 2019.0447, KAW 2022.0358); Switzerland: Swiss National Science Foundation (SNSF - PCEFP2_194658); United Kingdom: Leverhulme Trust (Leverhulme Trust RPG-2020-004), Royal Society (NIF-R1-231091); United States of America: U.S. Department of Energy (ECA DE-AC02-76SF00515), Neubauer Family Foundation.

Appendix

Simulated signal samples for the $pp \rightarrow Z' \rightarrow s\chi\chi \rightarrow b\bar{b}\chi\chi$ process were generated at LO in quantum chromodynamics (QCD) with up to one additional parton in the event, using MADGRAPH5_AMC@NLO 2.9.3 [68] interfaced to PYTHIA 8.245 [69], both using the NNPDF3.0 LO PDF set [70] with $\alpha_s = 0.13$ [70] and the A14 set of tuned parameters [71].

The V +jets background was simulated with SHERPA 2.2.11 [72], using next-to-leading-order (NLO) matrix elements for up to two partons, and LO matrix elements for up to five partons calculated with the COMIX [73] and OPENLOOPS [74–76] libraries. The matching to the SHERPA parton shower [77] used the MEPS@NLO prescription [78–81] with the set of tuned parameters developed by the SHERPA authors. The NNPDF3.0 NNLO set of PDFs [70] was used and the samples were normalized to the next-to-next-to-leading-order (NNLO) prediction [82]. Backgrounds from $t\bar{t}$ production and single top quark production were generated at NLO in QCD with POWHEG Box v2 [83–86] using the NNPDF3.0 NLO PDF set, interfaced to PYTHIA 8.230. Parton shower simulations with PYTHIA 8.230 used the A14 set of tuned parameters [71] with the NNPDF2.3 LO PDF set. The $t\bar{t}$ samples were normalized using calculations at NNLO in QCD including next-to-next-to-leading logarithmic soft-gluon terms calculated using TOP++ 2.0 [87–93]. The single-top-quark processes were normalized to cross-sections at NLO in QCD from HATHOR v2.1 [94, 95]. Samples of diboson final states (VV) were simulated with the SHERPA 2.2.1 or 2.2.2 [72] generator depending on the process and normalized using calculations at NNLO in QCD using the NNPDF3.0 NNLO PDF set. Backgrounds from associated Vh production were generated at NLO in QCD with POWHEG Box interfaced to PYTHIA 8.186 using the NNPDF3.0 NLO PDF set. The $qq \rightarrow Vh$ and $gg \rightarrow Vh$ processes were normalized using calculations at NNLO in QCD and at NLO in QCD combined with next-to-leading-logarithmic order corrections, respectively [96–102]. Top quarks were decayed at LO using MADSPIN [103, 104] to preserve all spin correlations. The decays of bottom and charm hadrons were simulated using the EVTGEN 1.6.0 program [105].

For top quark processes, uncertainties in the choice of generator were evaluated by comparison with event samples generated with MADGRAPH5_AMC@NLO 2.6.0 interfaced to PYTHIA 8.230 and the nominal POWHEG generator hadronized by HERWIG 7.04 [106, 107], using the H7UE set of tuned parameters [107] and the MMHT2014 LO PDF set [108]. For single top quark production in the tW channel, an alternative sample was generated using the diagram subtraction scheme [109, 110] to estimate the uncertainty arising from the interference with $t\bar{t}$ production. For V +jets processes, a sample generated with

MADGRAPH5_AMC@NLO 2.6.2 at LO in QCD with up to four parton emissions using the NNPDF2.3 LO PDF set and interfaced to PYTHIA 8.230 using a merging scale of $Q_{\text{cut}} = 30$ GeV was employed. Uncertainties in the matching parameter and resummation scale were also assessed.

References

- [1] J. Silk et al., *Particle Dark Matter: Observations, Models and Searches*, ed. by G. Bertone, Cambridge: Cambridge Univ. Press, 2010, ISBN: 978-1-107-65392-4.
- [2] J. L. Feng, *Dark Matter Candidates from Particle Physics and Methods of Detection*, *Ann. Rev. Astron. Astrophys.* **48** (2010) 495, arXiv: [1003.0904 \[astro-ph.CO\]](#).
- [3] T. A. Porter, R. P. Johnson, and P. W. Graham, *Dark Matter Searches with Astroparticle Data*, *Ann. Rev. Astron. Astrophys.* **49** (2011) 155, arXiv: [1104.2836 \[astro-ph.HE\]](#).
- [4] G. Bertone et al., *Identifying WIMP dark matter from particle and astroparticle data*, *JCAP* **03** (2018) 026, arXiv: [1712.04793 \[hep-ph\]](#).
- [5] XENON Collaboration, *Dark Matter Search Results from a One Ton-Year Exposure of XENON1T*, *Phys. Rev. Lett.* **121** (2018) 111302, arXiv: [1805.12562 \[astro-ph.CO\]](#).
- [6] PandaX-II Collaboration, *Dark Matter Results from First 98.7 Days of Data from the PandaX-II Experiment*, *Phys. Rev. Lett.* **117** (2016) 121303, arXiv: [1607.07400 \[hep-ex\]](#).
- [7] DarkSide Collaboration, *Low-Mass Dark Matter Search with the DarkSide-50 Experiment*, *Phys. Rev. Lett.* **121** (2018) 081307, arXiv: [1802.06994 \[astro-ph.HE\]](#).
- [8] XENON Collaboration, *Search for Light Dark Matter Interactions Enhanced by the Migdal Effect or Bremsstrahlung in XENON1T*, *Phys. Rev. Lett.* **123** (2019) 241803, arXiv: [1907.12771 \[hep-ex\]](#).
- [9] PICO Collaboration, *Dark matter search results from the complete exposure of the PICO-60 C₃F₈ bubble chamber*, *Phys. Rev. D* **100** (2019) 022001, arXiv: [1902.04031 \[astro-ph.CO\]](#).
- [10] Fermi-LAT Collaboration, *Searching for Dark Matter Annihilation from Milky Way Dwarf Spheroidal Galaxies with Six Years of Fermi Large Area Telescope Data*, *Phys. Rev. Lett.* **115** (2015) 231301, arXiv: [1503.02641 \[astro-ph.HE\]](#).
- [11] C. Pérez de los Heros, *Status, Challenges and Directions in Indirect Dark Matter Searches*, *Symmetry* **12** (2020) 1648, arXiv: [2008.11561 \[astro-ph.HE\]](#).
- [12] ATLAS Collaboration, *Search for dark matter produced in association with a Standard Model Higgs boson decaying into b -quarks using the full Run 2 dataset from the ATLAS detector*, *JHEP* **11** (2021) 209, arXiv: [2108.13391 \[hep-ex\]](#).
- [13] CMS Collaboration, *Search for dark matter produced in association with a Higgs boson decaying to a pair of bottom quarks in proton–proton collisions at $\sqrt{s} = 13$ TeV*, *Eur. Phys. J. C* **79** (2019) 280, arXiv: [1811.06562 \[hep-ex\]](#).
- [14] M. Duerr et al., *Hunting the dark Higgs*, *JHEP* **04** (2017) 143, arXiv: [1701.08780 \[hep-ph\]](#).
- [15] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.

- [16] 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>.
- [17] 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](#)].
- [18] 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](#)].
- [19] ATLAS Collaboration, *Performance of the missing transverse momentum triggers for the ATLAS detector during Run-2 data taking*, *JHEP* **08** (2020) 080, arXiv: [2005.09554](https://arxiv.org/abs/2005.09554) [[hep-ex](#)].
- [20] ATLAS Collaboration, *Performance of electron and photon triggers in ATLAS during LHC Run 2*, *Eur. Phys. J. C* **80** (2020) 47, arXiv: [1909.00761](https://arxiv.org/abs/1909.00761) [[hep-ex](#)].
- [21] ATLAS Collaboration, *Performance of the ATLAS muon triggers in Run 2*, *JINST* **15** (2020) P09015, arXiv: [2004.13447](https://arxiv.org/abs/2004.13447) [[physics.ins-det](#)].
- [22] ATLAS Collaboration, *Software and computing for Run 3 of the ATLAS experiment at the LHC*, (2024), arXiv: [2404.06335](https://arxiv.org/abs/2404.06335) [[hep-ex](#)].
- [23] ATLAS Collaboration, *The ATLAS Simulation Infrastructure*, *Eur. Phys. J. C* **70** (2010) 823, arXiv: [1005.4568](https://arxiv.org/abs/1005.4568) [[physics.ins-det](#)].
- [24] S. Agostinelli et al., *GEANT4 – a simulation toolkit*, *Nucl. Instrum. Meth. A* **506** (2003) 250.
- [25] T. Sjöstrand, S. Mrenna, and P. Skands, *A brief introduction to PYTHIA 8.1*, *Comput. Phys. Commun.* **178** (2008) 852, arXiv: [0710.3820](https://arxiv.org/abs/0710.3820) [[hep-ph](#)].
- [26] ATLAS Collaboration, *Summary of ATLAS Pythia 8 tunes*, ATL-PHYS-PUB-2012-003, 2012, URL: <https://cds.cern.ch/record/1474107>.
- [27] NNPDF Collaboration, R. D. Ball, et al., *Parton distributions with LHC data*, *Nucl. Phys. B* **867** (2013) 244, arXiv: [1207.1303](https://arxiv.org/abs/1207.1303) [[hep-ph](#)].
- [28] D. Abercrombie et al., *Dark Matter benchmark models for early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum*, *Phys. Dark Univ.* **27** (2020) 100371, arXiv: [1507.00966](https://arxiv.org/abs/1507.00966) [[hep-ex](#)].
- [29] J. Abdallah et al., *Simplified models for dark matter searches at the LHC*, *Phys. Dark Univ.* **9-10** (2015) 8, arXiv: [1506.03116](https://arxiv.org/abs/1506.03116) [[hep-ph](#)].
- [30] ATLAS Collaboration, *Search for dark matter produced in association with a dark Higgs boson decaying into W^+W^- in the one-lepton final state at $\sqrt{s} = 13$ TeV using 139fb^{-1} of pp collisions recorded with the ATLAS detector*, *JHEP* **07** (2023) 116, arXiv: [2211.07175](https://arxiv.org/abs/2211.07175) [[hep-ex](#)].
- [31] ATLAS Collaboration, *Search for Dark Matter Produced in Association with a Dark Higgs Boson Decaying into $W^\pm W^\mp$ or ZZ in Fully Hadronic Final States from $\sqrt{s} = 13$ TeV pp Collisions Recorded with the ATLAS Detector*, *Phys. Rev. Lett.* **126** (2021) 121802, arXiv: [2010.06548](https://arxiv.org/abs/2010.06548) [[hep-ex](#)].
- [32] CMS Collaboration, *Search for dark matter particles in W^+W^- events with transverse momentum imbalance in proton–proton collisions at $\sqrt{s} = 13$ TeV*, *JHEP* **03** (2024) 134, arXiv: [2310.12229](https://arxiv.org/abs/2310.12229) [[hep-ex](#)].

- [33] Planck Collaboration, *Planck 2018 results. VI. Cosmological parameters*, *Astron. Astrophys.* **641** (2020) A6, arXiv: 1807.06209 [astro-ph.CO], Erratum: *Astron. Astrophys.* **652** (2021) C4.
- [34] F. Ambrogio et al., *MadDM v.3.0: A comprehensive tool for dark matter studies*, *Phys. Dark Univ.* **24** (2019) 100249, arXiv: 1804.00044 [hep-ph].
- [35] ATLAS Collaboration, *Vertex Reconstruction Performance of the ATLAS Detector at $\sqrt{s} = 13$ TeV*, ATL-PHYS-PUB-2015-026, 2015, URL: <https://cds.cern.ch/record/2037717>.
- [36] 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].
- [37] 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].
- [38] ATLAS Collaboration, *Search for dark matter in association with a Higgs boson decaying to b -quarks in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, *Phys. Lett. B* **765** (2017) 11, arXiv: 1609.04572 [hep-ex].
- [39] ATLAS Collaboration, *Reconstruction, Energy Calibration, and Identification of Hadronically Decaying Tau Leptons in the ATLAS Experiment for Run-2 of the LHC*, ATL-PHYS-PUB-2015-045, 2015, URL: <https://cds.cern.ch/record/2064383>.
- [40] ATLAS Collaboration, *Identification of hadronic tau lepton decays using neural networks in the ATLAS experiment*, ATL-PHYS-PUB-2019-033, 2019, URL: <https://cds.cern.ch/record/2688062>.
- [41] M. Cacciari, G. P. Salam, and G. Soyez, *FastJet user manual*, *Eur. Phys. J. C* **72** (2012) 1896, arXiv: 1111.6097 [hep-ph].
- [42] M. Cacciari, G. P. Salam, and G. Soyez, *The anti- k_t jet clustering algorithm*, *JHEP* **04** (2008) 063, arXiv: 0802.1189 [hep-ph].
- [43] ATLAS Collaboration, *Jet reconstruction and performance using particle flow with the ATLAS Detector*, *Eur. Phys. J. C* **77** (2017) 466, arXiv: 1703.10485 [hep-ex].
- [44] M. Cacciari, G. P. Salam, and G. Soyez, *The catchment area of jets*, *JHEP* **04** (2008) 005, arXiv: 0802.1188 [hep-ph].
- [45] ATLAS Collaboration, *Jet energy scale and resolution measured in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, *Eur. Phys. J. C* **81** (2021) 689, arXiv: 2007.02645 [hep-ex].
- [46] ATLAS Collaboration, *Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector*, *Eur. Phys. J. C* **76** (2016) 581, arXiv: 1510.03823 [hep-ex].
- [47] ATLAS Collaboration, *Jet reclustering and close-by effects in ATLAS Run 2*, ATL-PHYS-PUB-2017-062, 2017, URL: <https://cds.cern.ch/record/2275649>.
- [48] ATLAS Collaboration, *Variable Radius, Exclusive- k_T , and Center-of-Mass Subject Reconstruction for Higgs($\rightarrow b\bar{b}$) Tagging in ATLAS*, ATL-PHYS-PUB-2017-010, 2017, URL: <https://cds.cern.ch/record/2268678>.

- [49] ATLAS Collaboration, *Optimisation and performance studies of the ATLAS b-tagging algorithms for the 2017-18 LHC run*, ATL-PHYS-PUB-2017-013, 2017, URL: <https://cds.cern.ch/record/2273281>.
- [50] 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](https://arxiv.org/abs/1603.02934) [hep-ex].
- [51] D. Krohn, J. Thaler, and L.-T. Wang, *Jet Trimming*, *JHEP* **02** (2010) 084, arXiv: [0912.1342](https://arxiv.org/abs/0912.1342) [hep-ph].
- [52] ATLAS Collaboration, *In situ calibration of large-radius jet energy and mass in 13 TeV proton–proton collisions with the ATLAS detector*, *Eur. Phys. J. C* **79** (2019) 135, arXiv: [1807.09477](https://arxiv.org/abs/1807.09477) [hep-ex].
- [53] ATLAS Collaboration, *ATLAS flavour-tagging algorithms for the LHC Run 2 pp collision dataset*, *Eur. Phys. J. C* **83** (2023) 681, arXiv: [2211.16345](https://arxiv.org/abs/2211.16345) [physics.data-an].
- [54] ATLAS Collaboration, *ATLAS b-jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at $\sqrt{s} = 13$ TeV*, *Eur. Phys. J. C* **79** (2019) 970, arXiv: [1907.05120](https://arxiv.org/abs/1907.05120) [hep-ex].
- [55] ATLAS Collaboration, *Identification of Boosted Higgs Bosons Decaying Into $b\bar{b}$ With Neural Networks and Variable Radius Subjets in ATLAS*, ATL-PHYS-PUB-2020-019, 2020, URL: <https://cds.cern.ch/record/2724739>.
- [56] ATLAS Collaboration, *Efficiency corrections for a tagger for boosted $H \rightarrow b\bar{b}$ decays in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, ATL-PHYS-PUB-2021-035, 2021, URL: <https://cds.cern.ch/record/2777811>.
- [57] ATLAS Collaboration, *The performance of missing transverse momentum reconstruction and its significance with the ATLAS detector using 140fb^{-1} of $\sqrt{s} = 13$ TeV pp collisions*, (2024), arXiv: [2402.05858](https://arxiv.org/abs/2402.05858) [hep-ex].
- [58] 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](https://arxiv.org/abs/1603.05598) [hep-ex].
- [59] ATLAS Collaboration, *Measurement of the c-jet mistagging efficiency in $t\bar{t}$ events using pp collision data at $\sqrt{s} = 13$ TeV collected with the ATLAS detector*, *Eur. Phys. J. C* **82** (2022) 95, arXiv: [2109.10627](https://arxiv.org/abs/2109.10627) [hep-ex].
- [60] ATLAS Collaboration, *Calibration of the light-flavour jet mistagging efficiency of the b-tagging algorithms with Z+jets events using 139fb^{-1} of ATLAS proton–proton collision data at $\sqrt{s} = 13$ TeV*, *Eur. Phys. J. C* **83** (2023) 728, arXiv: [2301.06319](https://arxiv.org/abs/2301.06319) [hep-ex].
- [61] ATLAS Collaboration, *Luminosity determination in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC*, *Eur. Phys. J. C* **83** (2023) 982, arXiv: [2212.09379](https://arxiv.org/abs/2212.09379) [hep-ex].
- [62] L. Moneta et al., *The RooStats Project*, PoS ACAT2010 (2010) 057, arXiv: [1009.1003](https://arxiv.org/abs/1009.1003) [physics.data-an].
- [63] W. Verkerke and D. Kirkby, *The RooFit toolkit for data modeling*, (2003), arXiv: [physics/0306116](https://arxiv.org/abs/physics/0306116).

- [64] ATLAS Collaboration, *Search for the $b\bar{b}$ decay of the Standard Model Higgs boson in associated $(W/Z)H$ production with the ATLAS detector*, *JHEP* **01** (2015) 069, arXiv: [1409.6212 \[hep-ex\]](#).
- [65] A. L. Read, *Presentation of search results: the CL_S technique*, *J. Phys. G* **28** (2002) 2693.
- [66] 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 \[physics.data-an\]](#), Erratum: *Eur. Phys. J. C* **73** (2013) 2501.
- [67] ATLAS Collaboration, *ATLAS Computing Acknowledgements*, ATL-SOFT-PUB-2023-001, 2023, URL: <https://cds.cern.ch/record/2869272>.
- [68] 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 \[hep-ph\]](#).
- [69] T. Sjöstrand et al., *An introduction to PYTHIA 8.2*, *Comput. Phys. Commun.* **191** (2015) 159, arXiv: [1410.3012 \[hep-ph\]](#).
- [70] NNPDF Collaboration, R. D. Ball, et al., *Parton distributions for the LHC run II*, *JHEP* **04** (2015) 040, arXiv: [1410.8849 \[hep-ph\]](#).
- [71] ATLAS Collaboration, *ATLAS Pythia 8 tunes to 7 TeV data*, ATL-PHYS-PUB-2014-021, 2014, URL: <https://cds.cern.ch/record/1966419>.
- [72] E. Bothmann et al., *Event generation with Sherpa 2.2*, *SciPost Phys.* **7** (2019) 034, arXiv: [1905.09127 \[hep-ph\]](#).
- [73] T. Gleisberg and S. Höche, *Comix, a new matrix element generator*, *JHEP* **12** (2008) 039, arXiv: [0808.3674 \[hep-ph\]](#).
- [74] F. Buccioni et al., *OpenLoops 2*, *Eur. Phys. J. C* **79** (2019) 866, arXiv: [1907.13071 \[hep-ph\]](#).
- [75] F. Cascioli, P. Maierhöfer, and S. Pozzorini, *Scattering Amplitudes with Open Loops*, *Phys. Rev. Lett.* **108** (2012) 111601, arXiv: [1111.5206 \[hep-ph\]](#).
- [76] A. Denner, S. Dittmaier, and L. Hofer, *COLLIER: A fortran-based complex one-loop library in extended regularizations*, *Comput. Phys. Commun.* **212** (2017) 220, arXiv: [1604.06792 \[hep-ph\]](#).
- [77] S. Schumann and F. Krauss, *A parton shower algorithm based on Catani–Seymour dipole factorisation*, *JHEP* **03** (2008) 038, arXiv: [0709.1027 \[hep-ph\]](#).
- [78] S. Höche, F. Krauss, M. Schönherr, and F. Siegert, *A critical appraisal of NLO+PS matching methods*, *JHEP* **09** (2012) 049, arXiv: [1111.1220 \[hep-ph\]](#).
- [79] S. Höche, F. Krauss, M. Schönherr, and F. Siegert, *QCD matrix elements + parton showers. The NLO case*, *JHEP* **04** (2013) 027, arXiv: [1207.5030 \[hep-ph\]](#).
- [80] S. Catani, F. Krauss, B. R. Webber, and R. Kuhn, *QCD Matrix Elements + Parton Showers*, *JHEP* **11** (2001) 063, arXiv: [hep-ph/0109231](#).
- [81] S. Höche, F. Krauss, S. Schumann, and F. Siegert, *QCD matrix elements and truncated showers*, *JHEP* **05** (2009) 053, arXiv: [0903.1219 \[hep-ph\]](#).

- [82] C. Anastasiou, L. Dixon, K. Melnikov, and F. Petriello, *High-precision QCD at hadron colliders: Electroweak gauge boson rapidity distributions at next-to-next-to leading order*, [Phys. Rev. D **69** \(2004\) 094008](#), arXiv: [hep-ph/0312266](#).
- [83] S. Frixione, G. Ridolfi, and P. Nason, *A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction*, [JHEP **09** \(2007\) 126](#), arXiv: [0707.3088 \[hep-ph\]](#).
- [84] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, [JHEP **11** \(2004\) 040](#), arXiv: [hep-ph/0409146](#).
- [85] S. Frixione, P. Nason, and C. Oleari, *Matching NLO QCD computations with parton shower simulations: the POWHEG method*, [JHEP **11** \(2007\) 070](#), arXiv: [0709.2092 \[hep-ph\]](#).
- [86] S. Alioli, P. Nason, C. Oleari, and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, [JHEP **06** \(2010\) 043](#), arXiv: [1002.2581 \[hep-ph\]](#).
- [87] M. Beneke, P. Falgari, S. Klein, and C. Schwinn, *Hadronic top-quark pair production with NNLL threshold resummation*, [Nucl. Phys. B **855** \(2012\) 695](#), arXiv: [1109.1536 \[hep-ph\]](#).
- [88] M. Cacciari, M. Czakon, M. Mangano, A. Mitov, and P. Nason, *Top-pair production at hadron colliders with next-to-next-to-leading logarithmic soft-gluon resummation*, [Phys. Lett. B **710** \(2012\) 612](#), arXiv: [1111.5869 \[hep-ph\]](#).
- [89] P. Bärnreuther, M. Czakon, and A. Mitov, *Percent-Level-Precision Physics at the Tevatron: Next-to-Next-to-Leading Order QCD Corrections to $q\bar{q} \rightarrow t\bar{t} + X$* , [Phys. Rev. Lett. **109** \(2012\) 132001](#), arXiv: [1204.5201 \[hep-ph\]](#).
- [90] M. Czakon and A. Mitov, *NNLO corrections to top-pair production at hadron colliders: the all-fermionic scattering channels*, [JHEP **12** \(2012\) 054](#), arXiv: [1207.0236 \[hep-ph\]](#).
- [91] M. Czakon and A. Mitov, *NNLO corrections to top pair production at hadron colliders: the quark-gluon reaction*, [JHEP **01** \(2013\) 080](#), arXiv: [1210.6832 \[hep-ph\]](#).
- [92] M. Czakon, P. Fiedler, and A. Mitov, *Total Top-Quark Pair-Production Cross Section at Hadron Colliders Through $O(\alpha_S^4)$* , [Phys. Rev. Lett. **110** \(2013\) 252004](#), arXiv: [1303.6254 \[hep-ph\]](#).
- [93] M. Czakon and A. Mitov, *Top++: A program for the calculation of the top-pair cross-section at hadron colliders*, [Comput. Phys. Commun. **185** \(2014\) 2930](#), arXiv: [1112.5675 \[hep-ph\]](#).
- [94] M. Aliev et al., *HATHOR – HAdronic Top and Heavy quarks crOss section calculatoR*, [Comput. Phys. Commun. **182** \(2011\) 1034](#), arXiv: [1007.1327 \[hep-ph\]](#).
- [95] P. Kant et al., *HatHor for single top-quark production: Updated predictions and uncertainty estimates for single top-quark production in hadronic collisions*, [Comput. Phys. Commun. **191** \(2015\) 74](#), arXiv: [1406.4403 \[hep-ph\]](#).
- [96] M. L. Ciccolini, S. Dittmaier, and M. Krämer, *Electroweak radiative corrections to associated WH and ZH production at hadron colliders*, [Phys. Rev. D **68** \(2003\) 073003](#), arXiv: [hep-ph/0306234](#).

- [97] O. Brein, A. Djouadi, and R. Harlander, *NNLO QCD corrections to the Higgs-strahlung processes at hadron colliders*, [Phys. Lett. B **579** \(2004\) 149](#), arXiv: [hep-ph/0307206](#).
- [98] O. Brein, R. V. Harlander, M. Wiesemann, and T. Zirke, *Top-quark mediated effects in hadronic Higgs-Strahlung*, [Eur. Phys. J. C **72** \(2012\) 1868](#), arXiv: [1111.0761 \[hep-ph\]](#).
- [99] L. Altenkamp, S. Dittmaier, R. V. Harlander, H. Rzehak, and T. J. E. Zirke, *Gluon-induced Higgs-strahlung at next-to-leading order QCD*, [JHEP **02** \(2013\) 078](#), arXiv: [1211.5015 \[hep-ph\]](#).
- [100] A. Denner, S. Dittmaier, S. Kallweit, and A. Mück, *HAWK 2.0: A Monte Carlo program for Higgs production in vector-boson fusion and Higgs strahlung at hadron colliders*, [Comput. Phys. Commun. **195** \(2015\) 161](#), arXiv: [1412.5390 \[hep-ph\]](#).
- [101] O. Brein, R. V. Harlander, and T. J. E. Zirke, *vh@nnlo – Higgs Strahlung at hadron colliders*, [Comput. Phys. Commun. **184** \(2013\) 998](#), arXiv: [1210.5347 \[hep-ph\]](#).
- [102] R. V. Harlander, A. Kulesza, V. Theeuwes, and T. Zirke, *Soft gluon resummation for gluon-induced Higgs Strahlung*, [JHEP **11** \(2014\) 082](#), arXiv: [1410.0217 \[hep-ph\]](#).
- [103] S. Frixione, E. Laenen, P. Motylinski, and B. R. Webber, *Angular correlations of lepton pairs from vector boson and top quark decays in Monte Carlo simulations*, [JHEP **04** \(2007\) 081](#), arXiv: [hep-ph/0702198](#).
- [104] P. Artoisenet, R. Frederix, O. Mattelaer, and R. Rietkerk, *Automatic spin-entangled decays of heavy resonances in Monte Carlo simulations*, [JHEP **03** \(2013\) 015](#), arXiv: [1212.3460 \[hep-ph\]](#).
- [105] D. J. Lange, *The EvtGen particle decay simulation package*, [Nucl. Instrum. Meth. A **462** \(2001\) 152](#).
- [106] M. Bähr et al., *Herwig++ physics and manual*, [Eur. Phys. J. C **58** \(2008\) 639](#), arXiv: [0803.0883 \[hep-ph\]](#).
- [107] J. Bellm et al., *Herwig 7.0/Herwig++ 3.0 release note*, [Eur. Phys. J. C **76** \(2016\) 196](#), arXiv: [1512.01178 \[hep-ph\]](#).
- [108] L. A. Harland-Lang, A. D. Martin, P. Motylinski, and R. S. Thorne, *Parton distributions in the LHC era: MMHT 2014 PDFs*, [Eur. Phys. J. C **75** \(2015\) 204](#), arXiv: [1412.3989 \[hep-ph\]](#).
- [109] S. Frixione, E. Laenen, P. Motylinski, C. White, and B. R. Webber, *Single-top hadroproduction in association with a W boson*, [JHEP **07** \(2008\) 029](#), arXiv: [0805.3067 \[hep-ph\]](#).
- [110] ATLAS Collaboration, *Studies on top-quark Monte Carlo modelling for Top2016*, ATL-PHYS-PUB-2016-020, 2016, URL: <https://cds.cern.ch/record/2216168>.

The ATLAS Collaboration

G. Aad ¹⁰⁴, E. Aakvaag ¹⁷, B. Abbott ¹²³, S. Abdelhameed ^{119a}, K. Abeling ⁵⁶, N.J. Abicht ⁵⁰, S.H. Abidi ³⁰, M. Aboeela ⁴⁵, A. Aboulhorma ^{36e}, H. Abramowicz ¹⁵⁴, H. Abreu ¹⁵³, Y. Abulaiti ¹²⁰, B.S. Acharya ^{70a,70b,k}, A. Ackermann ^{64a}, C. Adam Bourdarios ⁴, L. Adamczyk ^{87a}, S.V. Addepalli ²⁷, M.J. Addison ¹⁰³, J. Adelman ¹¹⁸, A. Adiguzel ^{22c}, T. Adye ¹³⁷, A.A. Affolder ¹³⁹, Y. Afik ⁴⁰, M.N. Agaras ¹³, J. Agarwala ^{74a,74b}, A. Aggarwal ¹⁰², C. Agheorghiesei ^{28c}, F. Ahmadov ^{39,x}, W.S. Ahmed ¹⁰⁶, S. Ahuja ⁹⁷, X. Ai ^{63e}, G. Aielli ^{77a,77b}, A. Aikot ¹⁶⁶, M. Ait Tamliah ^{36e}, B. Aitbenkikh ^{36a}, M. Akbiyik ¹⁰², T.P.A. Åkesson ¹⁰⁰, A.V. Akimov ³⁸, D. Akiyama ¹⁷¹, N.N. Akolkar ²⁵, S. Aktas ^{22a}, K. Al Houry ⁴², G.L. Alberghi ^{24b}, J. Albert ¹⁶⁸, P. Albicocco ⁵⁴, G.L. Albouy ⁶¹, S. Alderweireldt ⁵³, Z.L. Alegria ¹²⁴, M. Aleksa ³⁷, I.N. Aleksandrov ³⁹, C. Alexa ^{28b}, T. Alexopoulos ¹⁰, F. Alfonsi ^{24b}, M. Algren ⁵⁷, M. Alhroob ¹⁷⁰, B. Ali ¹³⁵, H.M.J. Ali ⁹³, S. Ali ³², S.W. Alibocus ⁹⁴, M. Aliev ^{34c}, G. Alimonti ^{72a}, W. Alkahi ⁵⁶, C. Allaire ⁶⁷, B.M.M. Allbrooke ¹⁴⁹, J.F. Allen ⁵³, C.A. Allendes Flores ^{140f}, P.P. Allport ²¹, A. Aloisio ^{73a,73b}, F. Alonso ⁹², C. Alpigiani ¹⁴¹, Z.M.K. Alsolami ⁹³, M. Alvarez Estevez ¹⁰¹, A. Alvarez Fernandez ¹⁰², M. Alves Cardoso ⁵⁷, M.G. Alvigi ^{73a,73b}, M. Aly ¹⁰³, Y. Amaral Coutinho ^{84b}, A. Ambler ¹⁰⁶, C. Amelung ³⁷, M. Amerl ¹⁰³, C.G. Ames ¹¹¹, D. Amidei ¹⁰⁸, K.J. Amirie ¹⁵⁸, S.P. Amor Dos Santos ^{133a}, K.R. Amos ¹⁶⁶, S. An ⁸⁵, V. Ananiev ¹²⁸, C. Anastopoulos ¹⁴², T. Andeen ¹¹, J.K. Anders ³⁷, A.C. Anderson ⁶⁰, S.Y. Andreev ^{48a,48b}, A. Andreatta ^{72a,72b}, S. Angelidakis ⁹, A. Angerami ⁴², A.V. Anisenkov ³⁸, A. Annovi ^{75a}, C. Antel ⁵⁷, E. Antipov ¹⁴⁸, M. Antonelli ⁵⁴, F. Anulli ^{76a}, M. Aoki ⁸⁵, T. Aoki ¹⁵⁶, M.A. Aparo ¹⁴⁹, L. Aperio Bella ⁴⁹, C. Appelt ¹⁹, A. Apyan ²⁷, S.J. Arbiol Val ⁸⁸, C. Arcangeletti ⁵⁴, A.T.H. Arce ⁵², E. Arena ⁹⁴, J-F. Arguin ¹¹⁰, S. Argyropoulos ⁵⁵, J.-H. Arling ⁴⁹, O. Arnaez ⁴, H. Arnold ¹⁴⁸, G. Artoni ^{76a,76b}, H. Asada ¹¹³, K. Asai ¹²¹, S. Asai ¹⁵⁶, N.A. Asbah ³⁷, R.A. Ashby Pickering ¹⁷⁰, K. Assamagan ³⁰, R. Astalos ^{29a}, K.S.V. Astrand ¹⁰⁰, S. Atashi ¹⁶², R.J. Atkin ^{34a}, M. Atkinson ¹⁶⁵, H. Atmani ^{36f}, P.A. Atmasiddha ¹³¹, K. Augsten ¹³⁵, S. Auricchio ^{73a,73b}, A.D. Auriol ²¹, V.A. Austrup ¹⁰³, G. Avolio ³⁷, K. Axiotis ⁵⁷, G. Azuelos ^{110,ac}, D. Babal ^{29b}, H. Bachacou ¹³⁸, K. Bachas ^{155,o}, A. Bachiu ³⁵, F. Backman ^{48a,48b}, A. Badea ⁴⁰, T.M. Baer ¹⁰⁸, P. Bagnaia ^{76a,76b}, M. Bahmani ¹⁹, D. Bahner ⁵⁵, K. Bai ¹²⁶, J.T. Baines ¹³⁷, L. Baines ⁹⁶, O.K. Baker ¹⁷⁵, E. Bakos ¹⁶, D. Bakshi Gupta ⁸, L.E. Balabram Filho ^{84b}, V. Balakrishnan ¹²³, R. Balasubramanian ¹¹⁷, E.M. Baldin ³⁸, P. Balek ^{87a}, E. Ballabene ^{24b,24a}, F. Balli ¹³⁸, L.M. Baltes ^{64a}, W.K. Balunas ³³, J. Balz ¹⁰², I. Bamwidhi ^{119b}, E. Banas ⁸⁸, M. Bandieramonte ¹³², A. Bandyopadhyay ²⁵, S. Bansal ²⁵, L. Barak ¹⁵⁴, M. Barakat ⁴⁹, E.L. Barberio ¹⁰⁷, D. Barberis ^{58b,58a}, M. Barbero ¹⁰⁴, M.Z. Barel ¹¹⁷, K.N. Barends ^{34a}, T. Barillari ¹¹², M-S. Barisits ³⁷, T. Barklow ¹⁴⁶, P. Baron ¹²⁵, D.A. Baron Moreno ¹⁰³, A. Baroncelli ^{63a}, G. Barone ³⁰, A.J. Barr ¹²⁹, J.D. Barr ⁹⁸, F. Barreiro ¹⁰¹, J. Barreiro Guimarães da Costa ¹⁴, U. Barron ¹⁵⁴, M.G. Barros Teixeira ^{133a}, S. Barsov ³⁸, F. Bartels ^{64a}, R. Bartoldus ¹⁴⁶, A.E. Barton ⁹³, P. Bartos ^{29a}, A. Basan ¹⁰², M. Baselga ⁵⁰, A. Bassalat ^{67,b}, M.J. Basso ^{159a}, S. Bataju ⁴⁵, R. Bate ¹⁶⁷, R.L. Bates ⁶⁰, S. Batlamous ¹⁰¹, B. Batool ¹⁴⁴, M. Battaglia ¹³⁹, D. Battulga ¹⁹, M. Bauce ^{76a,76b}, M. Bauer ⁸⁰, P. Bauer ²⁵, L.T. Bazzano Hurrell ³¹, J.B. Beacham ⁵², T. Beau ¹³⁰, J.Y. Beaucamp ⁹², P.H. Beauchemin ¹⁶¹, P. Bechtel ²⁵, H.P. Beck ^{20,n}, K. Becker ¹⁷⁰, A.J. Beddall ⁸³, V.A. Bednyakov ³⁹, C.P. Bee ¹⁴⁸, L.J. Beemster ¹⁶, T.A. Beermann ³⁷, M. Begalli ^{84d}, M. Begel ³⁰, A. Behera ¹⁴⁸, J.K. Behr ⁴⁹, J.F. Beirer ³⁷, F. Beisiegel ²⁵, M. Belfkir ^{119b}, G. Bella ¹⁵⁴, L. Bellagamba ^{24b}, A. Bellerive ³⁵,

P. Bellos ²¹, K. Beloborodov ³⁸, D. Benchekroun ^{36a}, F. Bendebba ^{36a}, Y. Benhammou ¹⁵⁴,
 K.C. Benkendorfer ⁶², L. Beresford ⁴⁹, M. Beretta ⁵⁴, E. Bergeaas Kuutmann ¹⁶⁴, N. Berger ⁴,
 B. Bergmann ¹³⁵, J. Beringer ^{18a}, G. Bernardi ⁵, C. Bernius ¹⁴⁶, F.U. Bernlochner ²⁵,
 F. Bernon ^{37,104}, A. Berrocal Guardia ¹³, T. Berry ⁹⁷, P. Berta ¹³⁶, A. Berthold ⁵¹, S. Bethke ¹¹²,
 A. Betti ^{76a,76b}, A.J. Bevan ⁹⁶, N.K. Bhalla ⁵⁵, S. Bhatta ¹⁴⁸, D.S. Bhattacharya ¹⁶⁹,
 P. Bhattarai ¹⁴⁶, K.D. Bhide ⁵⁵, V.S. Bhopatkar ¹²⁴, R.M. Bianchi ¹³², G. Bianco ^{24b,24a},
 O. Biebel ¹¹¹, R. Bielski ¹²⁶, M. Biglietti ^{78a}, C.S. Billingsley ⁴⁵, M. Bindi ⁵⁶, A. Bingul ^{22b},
 C. Bini ^{76a,76b}, A. Biondini ⁹⁴, G.A. Bird ³³, M. Birman ¹⁷², M. Biros ¹³⁶, S. Biryukov ¹⁴⁹,
 T. Bisanz ⁵⁰, E. Bisceglie ^{44b,44a}, J.P. Biswal ¹³⁷, D. Biswas ¹⁴⁴, I. Bloch ⁴⁹, A. Blue ⁶⁰,
 U. Blumenschein ⁹⁶, J. Blumenthal ¹⁰², V.S. Bobrovnikov ³⁸, M. Boehler ⁵⁵, B. Boehm ¹⁶⁹,
 D. Bogavac ³⁷, A.G. Bogdanchikov ³⁸, C. Bohm ^{48a}, V. Boisvert ⁹⁷, P. Bokan ³⁷, T. Bold ^{87a},
 M. Bomben ⁵, M. Bona ⁹⁶, M. Boonekamp ¹³⁸, C.D. Booth ⁹⁷, A.G. Borbély ⁶⁰,
 I.S. Bordulev ³⁸, H.M. Borecka-Bielska ¹¹⁰, G. Borissov ⁹³, D. Bortoletto ¹²⁹, D. Boscherini ^{24b},
 M. Bosman ¹³, J.D. Bossio Sola ³⁷, K. Bouaouda ^{36a}, N. Bouchhar ¹⁶⁶, L. Boudet ⁴,
 J. Boudreau ¹³², E.V. Bouhova-Thacker ⁹³, D. Boumediene ⁴¹, R. Bouquet ^{58b,58a}, A. Boveia ¹²²,
 J. Boyd ³⁷, D. Boye ³⁰, I.R. Boyko ³⁹, L. Bozianu ⁵⁷, J. Bracinek ²¹, N. Brahimi ⁴,
 G. Brandt ¹⁷⁴, O. Brandt ³³, F. Braren ⁴⁹, B. Brau ¹⁰⁵, J.E. Brau ¹²⁶, R. Brenner ¹⁷²,
 L. Brenner ¹¹⁷, R. Brenner ¹⁶⁴, S. Bressler ¹⁷², G. Brianti ^{79a,79b}, D. Britton ⁶⁰, D. Britzger ¹¹²,
 I. Brock ²⁵, G. Brooijmans ⁴², E.M. Brooks ^{159b}, E. Brost ³⁰, L.M. Brown ¹⁶⁸, L.E. Bruce ⁶²,
 T.L. Bruckler ¹²⁹, P.A. Bruckman de Renstrom ⁸⁸, B. Brüers ⁴⁹, A. Bruni ^{24b}, G. Bruni ^{24b},
 M. Bruschi ^{24b}, N. Bruscinò ^{76a,76b}, T. Buanes ¹⁷, Q. Buat ¹⁴¹, D. Buchin ¹¹², A.G. Buckley ⁶⁰,
 O. Bulekov ³⁸, B.A. Bullard ¹⁴⁶, S. Burdin ⁹⁴, C.D. Burgard ⁵⁰, A.M. Burger ³⁷,
 B. Burghgrave ⁸, O. Burlayenko ⁵⁵, J. Burleson ¹⁶⁵, J.T.P. Burr ³³, J.C. Burzynski ¹⁴⁵,
 E.L. Busch ⁴², V. Büscher ¹⁰², P.J. Bussey ⁶⁰, J.M. Butler ²⁶, C.M. Buttar ⁶⁰,
 J.M. Butterworth ⁹⁸, W. Buttinger ¹³⁷, C.J. Buxo Vazquez ¹⁰⁹, A.R. Buzykaev ³⁸,
 S. Cabrera Urbán ¹⁶⁶, L. Cadamuro ⁶⁷, D. Caforio ⁵⁹, H. Cai ¹³², Y. Cai ^{14,114c}, Y. Cai ^{114a},
 V.M.M. Cairo ³⁷, O. Cakir ^{3a}, N. Calace ³⁷, P. Calafiura ^{18a}, G. Calderini ¹³⁰, P. Calfayan ⁶⁹,
 G. Callea ⁶⁰, L.P. Caloba ^{84b}, D. Calvet ⁴¹, S. Calvet ⁴¹, M. Calvetti ^{75a,75b}, R. Camacho Toro ¹³⁰,
 S. Camarda ³⁷, D. Camarero Munoz ²⁷, P. Camarri ^{77a,77b}, M.T. Camerlingo ^{73a,73b},
 D. Cameron ³⁷, C. Camincher ¹⁶⁸, M. Campanelli ⁹⁸, A. Camplani ⁴³, V. Canale ^{73a,73b},
 A.C. Canbay ^{3a}, E. Canonero ⁹⁷, J. Cantero ¹⁶⁶, Y. Cao ¹⁶⁵, F. Capocasa ²⁷, M. Capua ^{44b,44a},
 A. Carbone ^{72a,72b}, R. Cardarelli ^{77a}, J.C.J. Cardenas ⁸, G. Carducci ^{44b,44a}, T. Carli ³⁷,
 G. Carlino ^{73a}, J.I. Carlotta ¹³, B.T. Carlson ^{132,p}, E.M. Carlson ^{168,159a}, J. Carmignani ⁹⁴,
 L. Carminati ^{72a,72b}, A. Carnelli ¹³⁸, M. Carnesale ^{76a,76b}, S. Caron ¹¹⁶, E. Carquin ^{140f},
 S. Carrá ^{72a}, G. Carratta ^{24b,24a}, A.M. Carroll ¹²⁶, T.M. Carter ⁵³, M.P. Casado ^{13,h},
 M. Caspar ⁴⁹, F.L. Castillo ⁴, L. Castillo Garcia ¹³, V. Castillo Gimenez ¹⁶⁶, N.F. Castro ^{133a,133e},
 A. Catinaccio ³⁷, J.R. Catmore ¹²⁸, T. Cavaliere ⁴, V. Cavaliere ³⁰, N. Cavalli ^{24b,24a},
 L.J. Caviedes Betancourt ^{23b}, Y.C. Cekmecelioglu ⁴⁹, E. Celebi ⁸³, S. Cella ³⁷, F. Celli ¹²⁹,
 M.S. Centonze ^{71a,71b}, V. Cepaitis ⁵⁷, K. Cerny ¹²⁵, A.S. Cerqueira ^{84a}, A. Cerri ¹⁴⁹,
 L. Cerrito ^{77a,77b}, F. Cerutti ^{18a}, B. Cervato ¹⁴⁴, A. Cervelli ^{24b}, G. Cesarini ⁵⁴, S.A. Cetin ⁸³,
 D. Chakraborty ¹¹⁸, J. Chan ^{18a}, W.Y. Chan ¹⁵⁶, J.D. Chapman ³³, E. Chapon ¹³⁸,
 B. Chargeishvili ^{152b}, D.G. Charlton ²¹, M. Chatterjee ²⁰, C. Chauhan ¹³⁶, Y. Che ^{114a},
 S. Chekanov ⁶, S.V. Chekulaev ^{159a}, G.A. Chelkov ^{39,a}, A. Chen ¹⁰⁸, B. Chen ¹⁵⁴, B. Chen ¹⁶⁸,
 H. Chen ^{114a}, H. Chen ³⁰, J. Chen ^{63c}, J. Chen ¹⁴⁵, M. Chen ¹²⁹, S. Chen ¹⁵⁶, S.J. Chen ^{114a},
 X. Chen ^{63c,138}, X. Chen ^{15,ab}, Y. Chen ^{63a}, C.L. Cheng ¹⁷³, H.C. Cheng ^{65a}, S. Cheong ¹⁴⁶,
 A. Cheplakov ³⁹, E. Cheremushkina ⁴⁹, E. Cherepanova ¹¹⁷, R. Cherkaoui El Moursli ^{36e},
 E. Cheu ⁷, K. Cheung ⁶⁶, L. Chevalier ¹³⁸, V. Chiarella ⁵⁴, G. Chiarelli ^{75a}, N. Chiedde ¹⁰⁴,

G. Chiodini ^{71a}, A.S. Chisholm ²¹, A. Chitan ^{28b}, M. Chitishvili ¹⁶⁶, M.V. Chizhov ³⁹, K. Choi ¹¹, Y. Chou ¹⁴¹, E.Y.S. Chow ¹¹⁶, K.L. Chu ¹⁷², M.C. Chu ^{65a}, X. Chu ^{14,114c}, Z. Chubinidze ⁵⁴, J. Chudoba ¹³⁴, J.J. Chwastowski ⁸⁸, D. Cieri ¹¹², K.M. Ciesla ^{87a}, V. Cindro ⁹⁵, A. Ciocio ^{18a}, F. Cirotto ^{73a,73b}, Z.H. Citron ¹⁷², M. Citterio ^{72a}, D.A. Ciubotaru ^{28b}, A. Clark ⁵⁷, P.J. Clark ⁵³, N. Clarke Hall ⁹⁸, C. Clarry ¹⁵⁸, J.M. Clavijo Columbie ⁴⁹, S.E. Clawson ⁴⁹, C. Clement ^{48a,48b}, Y. Coadou ¹⁰⁴, M. Cobal ^{70a,70c}, A. Coccaro ^{58b}, R.F. Coelho Barrue ^{133a}, R. Coelho Lopes De Sa ¹⁰⁵, S. Coelli ^{72a}, B. Cole ⁴², J. Collot ⁶¹, P. Conde Muiño ^{133a,133g}, M.P. Connell ^{34c}, S.H. Connell ^{34c}, E.I. Conroy ¹²⁹, F. Conventi ^{73a,ad}, H.G. Cooke ²¹, A.M. Cooper-Sarkar ¹²⁹, F.A. Corchia ^{24b,24a}, A. Cordeiro Oudot Choi ¹³⁰, L.D. Corpe ⁴¹, M. Corradi ^{76a,76b}, F. Corriveau ^{106,v}, A. Cortes-Gonzalez ¹⁹, M.J. Costa ¹⁶⁶, F. Costanza ⁴, D. Costanzo ¹⁴², B.M. Cote ¹²², J. Couthures ⁴, G. Cowan ⁹⁷, K. Cranmer ¹⁷³, D. Cremonini ^{24b,24a}, S. Crépe-Renaudin ⁶¹, F. Crescioli ¹³⁰, M. Cristinziani ¹⁴⁴, M. Cristoforetti ^{79a,79b}, V. Croft ¹¹⁷, J.E. Crosby ¹²⁴, G. Crosetti ^{44b,44a}, A. Cueto ¹⁰¹, H. Cui ⁹⁸, Z. Cui ⁷, W.R. Cunningham ⁶⁰, F. Curcio ¹⁶⁶, J.R. Curran ⁵³, P. Czodrowski ³⁷, M.M. Czurylo ³⁷, M.J. Da Cunha Sargedas De Sousa ^{58b,58a}, J.V. Da Fonseca Pinto ^{84b}, C. Da Via ¹⁰³, W. Dabrowski ^{87a}, T. Dado ⁵⁰, S. Dahbi ¹⁵¹, T. Dai ¹⁰⁸, D. Dal Santo ²⁰, C. Dallapiccola ¹⁰⁵, M. Dam ⁴³, G. D'amen ³⁰, V. D'Amico ¹¹¹, J. Damp ¹⁰², J.R. Dandoy ³⁵, D. Dannheim ³⁷, M. Danninger ¹⁴⁵, V. Dao ¹⁴⁸, G. Darbo ^{58b}, S.J. Das ^{30,ae}, F. Dattola ⁴⁹, S. D'Auria ^{72a,72b}, A. D'Avanzo ^{73a,73b}, C. David ^{34a}, T. Davidek ¹³⁶, I. Dawson ⁹⁶, H.A. Day-hall ¹³⁵, K. De ⁸, R. De Asmundis ^{73a}, N. De Biase ⁴⁹, S. De Castro ^{24b,24a}, N. De Groot ¹¹⁶, P. de Jong ¹¹⁷, H. De la Torre ¹¹⁸, A. De Maria ^{114a}, A. De Salvo ^{76a}, U. De Sanctis ^{77a,77b}, F. De Santis ^{71a,71b}, A. De Santo ¹⁴⁹, J.B. De Vivie De Regie ⁶¹, D.V. Dedovich ³⁹, J. Degens ⁹⁴, A.M. Deiana ⁴⁵, F. Del Corso ^{24b,24a}, J. Del Peso ¹⁰¹, F. Del Rio ^{64a}, L. Delagrangé ¹³⁰, F. Deliot ¹³⁸, C.M. Delitzsch ⁵⁰, M. Della Pietra ^{73a,73b}, D. Della Volpe ⁵⁷, A. Dell'Acqua ³⁷, L. Dell'Asta ^{72a,72b}, M. Delmastro ⁴, P.A. Delsart ⁶¹, S. Demers ¹⁷⁵, M. Demichev ³⁹, S.P. Denisov ³⁸, L. D'Eramo ⁴¹, D. Derendarz ⁸⁸, F. Derue ¹³⁰, P. Dervan ⁹⁴, K. Desch ²⁵, C. Deutsch ²⁵, F.A. Di Bello ^{58b,58a}, A. Di Ciaccio ^{77a,77b}, L. Di Ciaccio ⁴, A. Di Domenico ^{76a,76b}, C. Di Donato ^{73a,73b}, A. Di Girolamo ³⁷, G. Di Gregorio ³⁷, A. Di Luca ^{79a,79b}, B. Di Micco ^{78a,78b}, R. Di Nardo ^{78a,78b}, K.F. Di Petrillo ⁴⁰, M. Diamantopoulou ³⁵, F.A. Dias ¹¹⁷, T. Dias Do Vale ¹⁴⁵, M.A. Diaz ^{140a,140b}, F.G. Diaz Capriles ²⁵, A.R. Didenko ³⁹, M. Didenko ¹⁶⁶, E.B. Diehl ¹⁰⁸, S. Díez Cornell ⁴⁹, C. Diez Pardos ¹⁴⁴, C. Dimitriadi ¹⁶⁴, A. Dimitrievska ²¹, J. Dingfelder ²⁵, T. Dingley ¹²⁹, I-M. Dinu ^{28b}, S.J. Dittmeier ^{64b}, F. Dittus ³⁷, M. Divisek ¹³⁶, F. Djama ¹⁰⁴, T. Djobava ^{152b}, C. Doglioni ^{103,100}, A. Dohnalova ^{29a}, J. Dolejsi ¹³⁶, Z. Dolezal ¹³⁶, K. Domijan ^{87a}, K.M. Dona ⁴⁰, M. Donadelli ^{84d}, B. Dong ¹⁰⁹, J. Donini ⁴¹, A. D'Onofrio ^{73a,73b}, M. D'Onofrio ⁹⁴, J. Dopke ¹³⁷, A. Doria ^{73a}, N. Dos Santos Fernandes ^{133a}, P. Dougan ¹⁰³, M.T. Dova ⁹², A.T. Doyle ⁶⁰, M.A. Draguet ¹²⁹, E. Dreyer ¹⁷², I. Drivas-koulouris ¹⁰, M. Drnevich ¹²⁰, M. Drozdova ⁵⁷, D. Du ^{63a}, T.A. du Pree ¹¹⁷, F. Dubinin ³⁸, M. Dubovsky ^{29a}, E. Duchovni ¹⁷², G. Duckeck ¹¹¹, O.A. Ducu ^{28b}, D. Duda ⁵³, A. Dudarev ³⁷, E.R. Duden ²⁷, M. D'uffizi ¹⁰³, L. Duflost ⁶⁷, M. Dührssen ³⁷, I. Duminica ^{28g}, A.E. Dumitriu ^{28b}, M. Dunford ^{64a}, S. Dungs ⁵⁰, K. Dunne ^{48a,48b}, A. Duperrin ¹⁰⁴, H. Duran Yildiz ^{3a}, M. Düren ⁵⁹, A. Durglishvili ^{152b}, B.L. Dwyer ¹¹⁸, G.I. Dyckes ^{18a}, M. Dyndal ^{87a}, B.S. Dziedzic ³⁷, Z.O. Earnshaw ¹⁴⁹, G.H. Eberwein ¹²⁹, B. Eckerova ^{29a}, S. Eggebrecht ⁵⁶, E. Egidio Purcino De Souza ¹³⁰, L.F. Ehrke ⁵⁷, G. Eigen ¹⁷, K. Einsweiler ^{18a}, T. Ekelof ¹⁶⁴, P.A. Ekman ¹⁰⁰, S. El Farkh ^{36b}, Y. El Ghazali ^{36b}, H. El Jarrari ³⁷, A. El Moussaouy ^{36a}, V. Ellajosyula ¹⁶⁴, M. Ellert ¹⁶⁴, F. Ellinghaus ¹⁷⁴, N. Ellis ³⁷, J. Elmsheuser ³⁰, M. Elsayy ^{119a}, M. Elsing ³⁷, D. Emelianov ¹³⁷, Y. Enari ¹⁵⁶, I. Ene ^{18a}, S. Epari ¹³, P.A. Erland ⁸⁸,

D. Ernani Martins Neto [ID88](#), M. Errenst [ID174](#), M. Escalier [ID67](#), C. Escobar [ID166](#), E. Etzion [ID154](#),
 G. Evans [ID133a](#), H. Evans [ID69](#), L.S. Evans [ID97](#), A. Ezhilov [ID38](#), S. Ezzarqtouni [ID36a](#), F. Fabbri [ID24b,24a](#),
 L. Fabbri [ID24b,24a](#), G. Facini [ID98](#), V. Fadeyev [ID139](#), R.M. Fakhruddinov [ID38](#), D. Fakoudis [ID102](#),
 S. Falciano [ID76a](#), L.F. Falda Ulhoa Coelho [ID37](#), F. Fallavollita [ID112](#), G. Falsetti [ID44b,44a](#), J. Faltova [ID136](#),
 C. Fan [ID165](#), Y. Fan [ID14](#), Y. Fang [ID14,114c](#), M. Fanti [ID72a,72b](#), M. Faraj [ID70a,70b](#), Z. Farazpay [ID99](#),
 A. Farbin [ID8](#), A. Farilla [ID78a](#), T. Farooque [ID109](#), S.M. Farrington [ID53](#), F. Fassi [ID36e](#), D. Fassouliotis [ID9](#),
 M. Faucci Giannelli [ID77a,77b](#), W.J. Fawcett [ID33](#), L. Fayard [ID67](#), P. Federic [ID136](#), P. Federicova [ID134](#),
 O.L. Fedin [ID38,a](#), M. Feickert [ID173](#), L. Feligioni [ID104](#), D.E. Fellers [ID126](#), C. Feng [ID63b](#), M. Feng [ID15](#),
 Z. Feng [ID117](#), M.J. Fenton [ID162](#), L. Ferencz [ID49](#), R.A.M. Ferguson [ID93](#), S.I. Fernandez Luengo [ID140f](#),
 P. Fernandez Martinez [ID13](#), M.J.V. Fernoux [ID104](#), J. Ferrando [ID93](#), A. Ferrari [ID164](#), P. Ferrari [ID117,116](#),
 R. Ferrari [ID74a](#), D. Ferrere [ID57](#), C. Ferretti [ID108](#), D. Fiacco [ID76a,76b](#), F. Fiedler [ID102](#), P. Fiedler [ID135](#),
 A. Filipčič [ID95](#), E.K. Filmer [ID1](#), F. Filthaut [ID116](#), M.C.N. Fiolhais [ID133a,133c,c](#), L. Fiorini [ID166](#),
 W.C. Fisher [ID109](#), T. Fitschen [ID103](#), P.M. Fitzhugh [ID138](#), I. Fleck [ID144](#), P. Fleischmann [ID108](#), T. Flick [ID174](#),
 M. Flores [ID34d,z](#), L.R. Flores Castillo [ID65a](#), L. Flores Sanz De Acedo [ID37](#), F.M. Follega [ID79a,79b](#),
 N. Fomin [ID33](#), J.H. Foo [ID158](#), A. Formica [ID138](#), A.C. Forti [ID103](#), E. Fortin [ID37](#), A.W. Fortman [ID18a](#),
 M.G. Foti [ID18a](#), L. Fountas [ID9,i](#), D. Fournier [ID67](#), H. Fox [ID93](#), P. Francavilla [ID75a,75b](#), S. Francescato [ID62](#),
 S. Franchellucci [ID57](#), M. Franchini [ID24b,24a](#), S. Franchino [ID64a](#), D. Francis [ID37](#), L. Franco [ID116](#),
 V. Franco Lima [ID37](#), L. Franconi [ID49](#), M. Franklin [ID62](#), G. Frattari [ID27](#), Y.Y. Frid [ID154](#), J. Friend [ID60](#),
 N. Fritzsche [ID51](#), A. Froch [ID55](#), D. Froidevaux [ID37](#), J.A. Frost [ID129](#), Y. Fu [ID63a](#),
 S. Fuenzalida Garrido [ID140f](#), M. Fujimoto [ID104](#), K.Y. Fung [ID65a](#), E. Furtado De Simas Filho [ID84e](#),
 M. Furukawa [ID156](#), J. Fuster [ID166](#), A. Gaa [ID56](#), A. Gabrielli [ID24b,24a](#), A. Gabrielli [ID158](#), P. Gadow [ID37](#),
 G. Gagliardi [ID58b,58a](#), L.G. Gagnon [ID18a](#), S. Gaid [ID163](#), S. Galantzan [ID154](#), E.J. Gallas [ID129](#),
 B.J. Gallop [ID137](#), K.K. Gan [ID122](#), S. Ganguly [ID156](#), Y. Gao [ID53](#), F.M. Garay Walls [ID140a,140b](#), B. Garcia³⁰,
 C. García [ID166](#), A. Garcia Alonso [ID117](#), A.G. Garcia Caffaro [ID175](#), J.E. García Navarro [ID166](#),
 M. Garcia-Sciveres [ID18a](#), G.L. Gardner [ID131](#), R.W. Gardner [ID40](#), N. Garelli [ID161](#), D. Garg [ID81](#),
 R.B. Garg [ID146](#), J.M. Gargan⁵³, C.A. Garner¹⁵⁸, C.M. Garvey [ID34a](#), V.K. Gassmann¹⁶¹, G. Gaudio [ID74a](#),
 V. Gautam¹³, P. Gauzzi [ID76a,76b](#), J. Gavranovic [ID95](#), I.L. Gavrilenko [ID38](#), A. Gavriluk [ID38](#), C. Gay [ID167](#),
 G. Gaycken [ID126](#), E.N. Gazis [ID10](#), A.A. Geanta [ID28b](#), C.M. Gee [ID139](#), A. Gekow¹²², C. Gemme [ID58b](#),
 M.H. Genest [ID61](#), A.D. Gentry [ID115](#), S. George [ID97](#), W.F. George [ID21](#), T. Geralis [ID47](#),
 P. Gessinger-Befurt [ID37](#), M.E. Geyik [ID174](#), M. Ghani [ID170](#), K. Ghorbanian [ID96](#), A. Ghosal [ID144](#),
 A. Ghosh [ID162](#), A. Ghosh [ID7](#), B. Giacobbe [ID24b](#), S. Giagu [ID76a,76b](#), T. Giani [ID117](#), A. Giannini [ID63a](#),
 S.M. Gibson [ID97](#), M. Gignac [ID139](#), D.T. Gil [ID87b](#), A.K. Gilbert [ID87a](#), B.J. Gilbert [ID42](#), D. Gillberg [ID35](#),
 G. Gilles [ID117](#), L. Ginabat [ID130](#), D.M. Gingrich [ID2,ac](#), M.P. Giordani [ID70a,70c](#), P.F. Giraud [ID138](#),
 G. Giugliarelli [ID70a,70c](#), D. Giugni [ID72a](#), F. Giuli [ID37](#), I. Gkialas [ID9,i](#), L.K. Gladilin [ID38](#), C. Glasman [ID101](#),
 G.R. Gledhill [ID126](#), G. Glemža [ID49](#), M. Glisic¹²⁶, I. Gnesi [ID44b,e](#), Y. Go [ID30](#), M. Goblirsch-Kolb [ID37](#),
 B. Gocke [ID50](#), D. Godin¹¹⁰, B. Gokturk [ID22a](#), S. Goldfarb [ID107](#), T. Golling [ID57](#), M.G.D. Gololo [ID34g](#),
 D. Golubkov [ID38](#), J.P. Gombas [ID109](#), A. Gomes [ID133a,133b](#), G. Gomes Da Silva [ID144](#),
 A.J. Gomez Delegido [ID166](#), R. Gonçalo [ID133a](#), L. Gonella [ID21](#), A. Gongadze [ID152c](#), F. Gonnella [ID21](#),
 J.L. Gonski [ID146](#), R.Y. González Andana [ID53](#), S. González de la Hoz [ID166](#), R. Gonzalez Lopez [ID94](#),
 C. Gonzalez Renteria [ID18a](#), M.V. Gonzalez Rodrigues [ID49](#), R. Gonzalez Suarez [ID164](#),
 S. Gonzalez-Sevilla [ID57](#), L. Goossens [ID37](#), B. Gorini [ID37](#), E. Gorini [ID71a,71b](#), A. Gorišek [ID95](#),
 T.C. Gosart [ID131](#), A.T. Goshaw [ID52](#), M.I. Gostkin [ID39](#), S. Goswami [ID124](#), C.A. Gottardo [ID37](#),
 S.A. Gotz [ID111](#), M. Goughri [ID36b](#), V. Goumarre [ID49](#), A.G. Goussiou [ID141](#), N. Govender [ID34c](#),
 I. Grabowska-Bold [ID87a](#), K. Graham [ID35](#), E. Gramstad [ID128](#), S. Grancagnolo [ID71a,71b](#), C.M. Grant^{1,138},
 P.M. Gravila [ID28f](#), F.G. Gravili [ID71a,71b](#), H.M. Gray [ID18a](#), M. Greco [ID71a,71b](#), M.J. Green [ID1](#), C. Grefe [ID25](#),
 A.S. Grefsrud [ID17](#), I.M. Gregor [ID49](#), K.T. Greif [ID162](#), P. Grenier [ID146](#), S.G. Grewe¹¹², A.A. Grillo [ID139](#),
 K. Grimm [ID32](#), S. Grinstein [ID13,r](#), J.-F. Grivaz [ID67](#), E. Gross [ID172](#), J. Grosse-Knetter [ID56](#),

J.C. Grundy ¹²⁹, L. Guan ¹⁰⁸, J.G.R. Guerrero Rojas ¹⁶⁶, G. Guerrieri ^{70a,70c}, R. Gugel ¹⁰², J.A.M. Guhit ¹⁰⁸, A. Guida ¹⁹, E. Guilloton ¹⁷⁰, S. Guindon ³⁷, F. Guo ^{14,114c}, J. Guo ^{63c}, L. Guo ⁴⁹, Y. Guo ¹⁰⁸, R. Gupta ¹³², S. Gurbuz ²⁵, S.S. Gurdasani ⁵⁵, G. Gustavino ^{76a,76b}, P. Gutierrez ¹²³, L.F. Gutierrez Zagazeta ¹³¹, M. Gutsche ⁵¹, C. Gutschow ⁹⁸, C. Gwenlan ¹²⁹, C.B. Gwilliam ⁹⁴, E.S. Haaland ¹²⁸, A. Haas ¹²⁰, M. Habedank ⁴⁹, C. Haber ^{18a}, H.K. Hadavand ⁸, A. Hadeef ⁵¹, S. Hadzic ¹¹², A.I. Hagan ⁹³, J.J. Hahn ¹⁴⁴, E.H. Haines ⁹⁸, M. Haleem ¹⁶⁹, J. Haley ¹²⁴, J.J. Hall ¹⁴², G.D. Hallewell ¹⁰⁴, L. Halser ²⁰, K. Hamano ¹⁶⁸, M. Hamer ²⁵, G.N. Hamity ⁵³, E.J. Hampshire ⁹⁷, J. Han ^{63b}, K. Han ^{63a}, L. Han ^{114a}, L. Han ^{63a}, S. Han ^{18a}, Y.F. Han ¹⁵⁸, K. Hanagaki ⁸⁵, M. Hance ¹³⁹, D.A. Hangal ⁴², H. Hanif ¹⁴⁵, M.D. Hank ¹³¹, J.B. Hansen ⁴³, P.H. Hansen ⁴³, K. Hara ¹⁶⁰, D. Harada ⁵⁷, T. Harenberg ¹⁷⁴, S. Harkusha ³⁸, M.L. Harris ¹⁰⁵, Y.T. Harris ¹²⁹, J. Harrison ¹³, N.M. Harrison ¹²², P.F. Harrison ¹⁷⁰, N.M. Hartman ¹¹², N.M. Hartmann ¹¹¹, R.Z. Hasan ^{97,137}, Y. Hasegawa ¹⁴³, S. Hassan ¹⁷, R. Hauser ¹⁰⁹, C.M. Hawkes ²¹, R.J. Hawkings ³⁷, Y. Hayashi ¹⁵⁶, S. Hayashida ¹¹³, D. Hayden ¹⁰⁹, C. Hayes ¹⁰⁸, R.L. Hayes ¹¹⁷, C.P. Hays ¹²⁹, J.M. Hays ⁹⁶, H.S. Hayward ⁹⁴, F. He ^{63a}, M. He ^{14,114c}, Y. He ¹⁵⁷, Y. He ⁴⁹, Y. He ⁹⁸, N.B. Heatley ⁹⁶, V. Hedberg ¹⁰⁰, A.L. Heggelund ¹²⁸, N.D. Hehir ^{96,*}, C. Heidegger ⁵⁵, K.K. Heidegger ⁵⁵, J. Heilman ³⁵, S. Heim ⁴⁹, T. Heim ^{18a}, J.G. Heinlein ¹³¹, J.J. Heinrich ¹²⁶, L. Heinrich ^{112,aa}, J. Hejbal ¹³⁴, A. Held ¹⁷³, S. Hellesund ¹⁷, C.M. Helling ¹⁶⁷, S. Hellman ^{48a,48b}, R.C.W. Henderson ⁹³, L. Henkelmann ³³, A.M. Henriques Correia ³⁷, H. Herde ¹⁰⁰, Y. Hernández Jiménez ¹⁴⁸, L.M. Herrmann ²⁵, T. Herrmann ⁵¹, G. Herten ⁵⁵, R. Hertenberger ¹¹¹, L. Hervas ³⁷, M.E. Hespings ¹⁰², N.P. Hessey ^{159a}, M. Hidaoui ^{36b}, N. Hidic ¹³⁶, E. Hill ¹⁵⁸, S.J. Hillier ²¹, J.R. Hinds ¹⁰⁹, F. Hinterkeuser ²⁵, M. Hirose ¹²⁷, S. Hirose ¹⁶⁰, D. Hirschbuehl ¹⁷⁴, T.G. Hitchings ¹⁰³, B. Hiti ⁹⁵, J. Hobbs ¹⁴⁸, R. Hobincu ^{28e}, N. Hod ¹⁷², M.C. Hodgkinson ¹⁴², B.H. Hodgkinson ¹²⁹, A. Hoecker ³⁷, D.D. Hofer ¹⁰⁸, J. Hofer ⁴⁹, T. Holm ²⁵, M. Holzbock ¹¹², L.B.A.H. Hommels ³³, B.P. Honan ¹⁰³, J.J. Hong ⁶⁹, J. Hong ^{63c}, T.M. Hong ¹³², B.H. Hooberman ¹⁶⁵, W.H. Hopkins ⁶, M.C. Hoppesch ¹⁶⁵, Y. Horii ¹¹³, S. Hou ¹⁵¹, A.S. Howard ⁹⁵, J. Howarth ⁶⁰, J. Hoya ⁶, M. Hrabovsky ¹²⁵, A. Hrynevich ⁴⁹, T. Hryn'ova ⁴, P.J. Hsu ⁶⁶, S.-C. Hsu ¹⁴¹, T. Hsu ⁶⁷, M. Hu ^{18a}, Q. Hu ^{63a}, S. Huang ^{65b}, X. Huang ^{14,114c}, Y. Huang ¹⁴², Y. Huang ¹⁰², Y. Huang ¹⁴, Z. Huang ¹⁰³, Z. Hubacek ¹³⁵, M. Huebner ²⁵, F. Huegging ²⁵, T.B. Huffman ¹²⁹, C.A. Hugli ⁴⁹, M. Huhtinen ³⁷, S.K. Huiberts ¹⁷, R. Hulsken ¹⁰⁶, N. Huseynov ¹², J. Huston ¹⁰⁹, J. Huth ⁶², R. Hyneman ¹⁴⁶, G. Iacobucci ⁵⁷, G. Iakovidis ³⁰, L. Iconomidou-Fayard ⁶⁷, J.P. Iddon ³⁷, P. Iengo ^{73a,73b}, R. Iguchi ¹⁵⁶, Y. Iiyama ¹⁵⁶, T. Iizawa ¹²⁹, Y. Ikegami ⁸⁵, N. Ilic ¹⁵⁸, H. Imam ^{36a}, M. Ince Lezki ⁵⁷, T. Ingebretsen Carlson ^{48a,48b}, J.M. Inglis ⁹⁶, G. Introzzi ^{74a,74b}, M. Iodice ^{78a}, V. Ippolito ^{76a,76b}, R.K. Irwin ⁹⁴, M. Ishino ¹⁵⁶, W. Islam ¹⁷³, C. Issever ^{19,49}, S. Istin ^{22a,ag}, H. Ito ¹⁷¹, R. Iuppa ^{79a,79b}, A. Ivina ¹⁷², J.M. Izen ⁴⁶, V. Izzo ^{73a}, P. Jacka ¹³⁴, P. Jackson ¹, C.S. Jagfeld ¹¹¹, G. Jain ^{159a}, P. Jain ⁴⁹, K. Jakobs ⁵⁵, T. Jakoubek ¹⁷², J. Jamieson ⁶⁰, W. Jang ¹⁵⁶, M. Javurkova ¹⁰⁵, P. Jawahar ¹⁰³, L. Jeanty ¹²⁶, J. Jejelava ^{152a,y}, P. Jenni ^{55,f}, C.E. Jessiman ³⁵, C. Jia ^{63b}, J. Jia ¹⁴⁸, X. Jia ⁶², X. Jia ^{14,114c}, Z. Jia ^{114a}, C. Jiang ⁵³, Q. Jiang ^{65b}, S. Jiggins ⁴⁹, J. Jimenez Pena ¹³, S. Jin ^{114a}, A. Jinaru ^{28b}, O. Jinnouchi ¹⁵⁷, P. Johansson ¹⁴², K.A. Johns ⁷, J.W. Johnson ¹³⁹, D.M. Jones ¹⁴⁹, E. Jones ⁴⁹, P. Jones ³³, R.W.L. Jones ⁹³, T.J. Jones ⁹⁴, H.L. Joos ^{56,37}, R. Joshi ¹²², J. Jovicevic ¹⁶, X. Ju ^{18a}, J.J. Junggeburth ¹⁰⁵, T. Junkermann ^{64a}, A. Juste Rozas ^{13,r}, M.K. Juzek ⁸⁸, S. Kabana ^{140e}, A. Kaczmarska ⁸⁸, M. Kado ¹¹², H. Kagan ¹²², M. Kagan ¹⁴⁶, A. Kahn ¹³¹, C. Kahra ¹⁰², T. Kaji ¹⁵⁶, E. Kajomovitz ¹⁵³, N. Kakati ¹⁷², I. Kalaitzidou ⁵⁵, C.W. Kalderon ³⁰, N.J. Kang ¹³⁹, D. Kar ^{34g}, K. Karava ¹²⁹, M.J. Kareem ^{159b}, E. Karentzos ⁵⁵, O. Karkout ¹¹⁷, S.N. Karpov ³⁹, Z.M. Karpova ³⁹, V. Kartvelishvili ⁹³, A.N. Karyukhin ³⁸, E. Kasimi ¹⁵⁵, J. Katzy ⁴⁹, S. Kaur ³⁵,

K. Kawade ¹⁴³, M.P. Kawale ¹²³, C. Kawamoto ⁸⁹, T. Kawamoto ^{63a}, E.F. Kay ³⁷, F.I. Kaya ¹⁶¹,
 S. Kazakos ¹⁰⁹, V.F. Kazanin ³⁸, Y. Ke ¹⁴⁸, J.M. Keaveney ^{34a}, R. Keeler ¹⁶⁸, G.V. Kehris ⁶²,
 J.S. Keller ³⁵, A.S. Kelly ⁹⁸, J.J. Kempster ¹⁴⁹, P.D. Kennedy ¹⁰², O. Kepka ¹³⁴, B.P. Kerridge ¹³⁷,
 S. Kersten ¹⁷⁴, B.P. Kerševan ⁹⁵, L. Keszezhova ^{29a}, S. Ketabchi Haghighat ¹⁵⁸, R.A. Khan ¹³²,
 A. Khanov ¹²⁴, A.G. Kharlamov ³⁸, T. Kharlamova ³⁸, E.E. Khoda ¹⁴¹, M. Kholodenko ³⁸,
 T.J. Khoo ¹⁹, G. Khoraiuli ¹⁶⁹, J. Khubua ^{152b,*}, Y.A.R. Khwaira ¹³⁰, B. Kibirige ^{34g}, D. Kim ⁶,
 D.W. Kim ^{48a,48b}, Y.K. Kim ⁴⁰, N. Kimura ⁹⁸, M.K. Kingston ⁵⁶, A. Kirchhoff ⁵⁶, C. Kirfel ²⁵,
 F. Kirfel ²⁵, J. Kirk ¹³⁷, A.E. Kiryunin ¹¹², C. Kitsaki ¹⁰, O. Kivernyk ²⁵, M. Klassen ¹⁶¹,
 C. Klein ³⁵, L. Klein ¹⁶⁹, M.H. Klein ⁴⁵, S.B. Klein ⁵⁷, U. Klein ⁹⁴, P. Klimek ³⁷,
 A. Klimentov ³⁰, T. Klioutchnikova ³⁷, P. Kluit ¹¹⁷, S. Kluth ¹¹², E. Kneringer ⁸⁰,
 T.M. Knight ¹⁵⁸, A. Knue ⁵⁰, R. Kobayashi ⁸⁹, D. Kobylanski ¹⁷², S.F. Koch ¹²⁹,
 M. Kocian ¹⁴⁶, P. Kodyš ¹³⁶, D.M. Koeck ¹²⁶, P.T. Koenig ²⁵, T. Koffas ³⁵, O. Kolay ⁵¹,
 I. Koletsou ⁴, T. Komarek ⁸⁸, K. Köneke ⁵⁵, A.X.Y. Kong ¹, T. Kono ¹²¹, N. Konstantinidis ⁹⁸,
 P. Kontaxakis ⁵⁷, B. Konya ¹⁰⁰, R. Kopeliansky ⁴², S. Koperny ^{87a}, K. Korcyl ⁸⁸,
 K. Kordas ^{155,d}, A. Korn ⁹⁸, S. Korn ⁵⁶, I. Korolkov ¹³, N. Korotkova ³⁸, B. Kortman ¹¹⁷,
 O. Kortner ¹¹², S. Kortner ¹¹², W.H. Kostecka ¹¹⁸, V.V. Kostyukhin ¹⁴⁴, A. Kotsokechagia ¹³⁸,
 A. Kotwal ⁵², A. Koulouris ³⁷, A. Kourkoumeli-Charalampidi ^{74a,74b}, C. Kourkoumelis ⁹,
 E. Kourlitis ^{112,aa}, O. Kovanda ¹²⁶, R. Kowalewski ¹⁶⁸, W. Kozanecki ¹³⁸, A.S. Kozhin ³⁸,
 V.A. Kramarenko ³⁸, G. Kramberger ⁹⁵, P. Kramer ¹⁰², M.W. Krasny ¹³⁰, A. Krasznahorkay ³⁷,
 A.C. Kraus ¹¹⁸, J.W. Kraus ¹⁷⁴, J.A. Kremer ⁴⁹, T. Kresse ⁵¹, L. Kretschmann ¹⁷⁴,
 J. Kretschmar ⁹⁴, K. Kreul ¹⁹, P. Krieger ¹⁵⁸, S. Krishnamurthy ¹⁰⁵, M. Krivos ¹³⁶,
 K. Krizka ²¹, K. Kroeninger ⁵⁰, H. Kroha ¹¹², J. Kroll ¹³⁴, J. Kroll ¹³¹, K.S. Krowpman ¹⁰⁹,
 U. Kruchonak ³⁹, H. Krüger ²⁵, N. Krumnack ⁸², M.C. Kruse ⁵², O. Kuchinskaia ³⁸, S. Kuday ^{3a},
 S. Kuehn ³⁷, R. Kuesters ⁵⁵, T. Kuhl ⁴⁹, V. Kukhtin ³⁹, Y. Kulchitsky ^{38,a}, S. Kuleshov ^{140d,140b},
 M. Kumar ^{34g}, N. Kumari ⁴⁹, P. Kumari ^{159b}, A. Kupco ¹³⁴, T. Kupfer ⁵⁰, A. Kupich ³⁸,
 O. Kuprash ⁵⁵, H. Kurashige ⁸⁶, L.L. Kurchaninov ^{159a}, O. Kurdysh ⁶⁷, Y.A. Kurochkin ³⁸,
 A. Kurova ³⁸, M. Kuze ¹⁵⁷, A.K. Kvam ¹⁰⁵, J. Kvita ¹²⁵, T. Kwan ¹⁰⁶, N.G. Kyriacou ¹⁰⁸,
 L.A.O. Laatu ¹⁰⁴, C. Lacasta ¹⁶⁶, F. Lacava ^{76a,76b}, H. Lacker ¹⁹, D. Lacour ¹³⁰, N.N. Lad ⁹⁸,
 E. Ladygin ³⁹, A. Lafarge ⁴¹, B. Laforge ¹³⁰, T. Lagouri ¹⁷⁵, F.Z. Lahbabi ^{36a}, S. Lai ⁵⁶,
 J.E. Lambert ¹⁶⁸, S. Lammers ⁶⁹, W. Lampl ⁷, C. Lampoudis ^{155,d}, G. Lamprinoudis ¹⁰²,
 A.N. Lancaster ¹¹⁸, E. Lançon ³⁰, U. Landgraf ⁵⁵, M.P.J. Landon ⁹⁶, V.S. Lang ⁵⁵,
 O.K.B. Langrekken ¹²⁸, A.J. Lankford ¹⁶², F. Lanni ³⁷, K. Lantzsch ²⁵, A. Lanza ^{74a},
 J.F. Laporte ¹³⁸, T. Lari ^{72a}, F. Lasagni Manghi ^{24b}, M. Lassnig ³⁷, V. Latonova ¹³⁴,
 A. Laurier ¹⁵³, S.D. Lawlor ¹⁴², Z. Lawrence ¹⁰³, R. Lazaridou ¹⁷⁰, M. Lazzaroni ^{72a,72b}, B. Le ¹⁰³,
 E.M. Le Boulicaut ⁵², L.T. Le Pottier ^{18a}, B. Leban ^{24b,24a}, A. Lebedev ⁸², M. LeBlanc ¹⁰³,
 F. Ledroit-Guillon ⁶¹, S.C. Lee ¹⁵¹, S. Lee ^{48a,48b}, T.F. Lee ⁹⁴, L.L. Leeuw ^{34c}, H.P. Lefebvre ⁹⁷,
 M. Lefebvre ¹⁶⁸, C. Leggett ^{18a}, G. Lehmann Miotto ³⁷, M. Leigh ⁵⁷, W.A. Leight ¹⁰⁵,
 W. Leinonen ¹¹⁶, A. Leisos ^{155,q}, M.A.L. Leite ^{84c}, C.E. Leitgeb ¹⁹, R. Leitner ¹³⁶,
 K.J.C. Leney ⁴⁵, T. Lenz ²⁵, S. Leone ^{75a}, C. Leonidopoulos ⁵³, A. Leopold ¹⁴⁷, R. Les ¹⁰⁹,
 C.G. Lester ³³, M. Levchenko ³⁸, J. Levêque ⁴, L.J. Levinson ¹⁷², G. Levrini ^{24b,24a},
 M.P. Lewicki ⁸⁸, C. Lewis ¹⁴¹, D.J. Lewis ⁴, A. Li ⁵, B. Li ^{63b}, C. Li ^{63a}, C-Q. Li ¹¹², H. Li ^{63a},
 H. Li ^{63b}, H. Li ^{114a}, H. Li ¹⁵, H. Li ^{63b}, J. Li ^{63c}, K. Li ¹⁴¹, L. Li ^{63c}, M. Li ^{14,114c},
 S. Li ^{14,114c}, S. Li ^{63d,63c}, T. Li ⁵, X. Li ¹⁰⁶, Z. Li ¹²⁹, Z. Li ¹⁵⁶, Z. Li ^{14,114c}, S. Liang ^{14,114c},
 Z. Liang ¹⁴, M. Liberatore ¹³⁸, B. Liberti ^{77a}, K. Lie ^{65c}, J. Lieber Marin ^{84e}, H. Lien ⁶⁹,
 H. Lin ¹⁰⁸, K. Lin ¹⁰⁹, R.E. Lindley ⁷, J.H. Lindon ², J. Ling ⁶², E. Lipeles ¹³¹,
 A. Lipniacka ¹⁷, A. Lister ¹⁶⁷, J.D. Little ⁶⁹, B. Liu ¹⁴, B.X. Liu ^{114b}, D. Liu ^{63d,63c},
 E.H.L. Liu ²¹, J.B. Liu ^{63a}, J.K.K. Liu ³³, K. Liu ^{63d}, K. Liu ^{63d,63c}, M. Liu ^{63a}, M.Y. Liu ^{63a},



P. Liu ¹⁴, Q. Liu ^{63d,141,63c}, X. Liu ^{63a}, X. Liu ^{63b}, Y. Liu ^{114b,114c}, Y.L. Liu ^{63b}, Y.W. Liu ^{63a},
 J. Llorente Merino ¹⁴⁵, S.L. Lloyd ⁹⁶, E.M. Lobodzinska ⁴⁹, P. Loch ⁷, T. Lohse ¹⁹,
 K. Lohwasser ¹⁴², E. Loiacono ⁴⁹, M. Lokajicek ^{134,*}, J.D. Lomas ²¹, J.D. Long ¹⁶⁵,
 I. Longarini ¹⁶², R. Longo ¹⁶⁵, I. Lopez Paz ⁶⁸, A. Lopez Solis ⁴⁹, N. Lorenzo Martinez ⁴,
 A.M. Lory ¹¹¹, M. Losada ^{119a}, G. Löschcke Centeno ¹⁴⁹, O. Loseva ³⁸, X. Lou ^{48a,48b},
 X. Lou ^{14,114c}, A. Lounis ⁶⁷, P.A. Love ⁹³, G. Lu ^{14,114c}, M. Lu ⁶⁷, S. Lu ¹³¹, Y.J. Lu ⁶⁶,
 H.J. Lubatti ¹⁴¹, C. Luci ^{76a,76b}, F.L. Lucio Alves ^{114a}, F. Luehring ⁶⁹, I. Luise ¹⁴⁸,
 O. Lukianchuk ⁶⁷, O. Lundberg ¹⁴⁷, B. Lund-Jensen ^{147,*}, N.A. Luongo ⁶, M.S. Lutz ³⁷,
 A.B. Lux ²⁶, D. Lynn ³⁰, R. Lysak ¹³⁴, E. Lytken ¹⁰⁰, V. Lyubushkin ³⁹, T. Lyubushkina ³⁹,
 M.M. Lyukova ¹⁴⁸, M.Firdaus M. Soberi ⁵³, H. Ma ³⁰, K. Ma ^{63a}, L.L. Ma ^{63b}, W. Ma ^{63a},
 Y. Ma ¹²⁴, J.C. MacDonald ¹⁰², P.C. Machado De Abreu Farias ^{84e}, R. Madar ⁴¹, T. Madula ⁹⁸,
 J. Maeda ⁸⁶, T. Maeno ³⁰, H. Maguire ¹⁴², V. Maiboroda ¹³⁸, A. Maio ^{133a,133b,133d}, K. Maj ^{87a},
 O. Majersky ⁴⁹, S. Majewski ¹²⁶, N. Makovec ⁶⁷, V. Maksimovic ¹⁶, B. Malaescu ¹³⁰,
 Pa. Malecki ⁸⁸, V.P. Maleev ³⁸, F. Malek ^{61,m}, M. Mali ⁹⁵, D. Malito ⁹⁷, U. Mallik ⁸¹,
 S. Maltezos¹⁰, S. Malyukov³⁹, J. Mamuzic ¹³, G. Mancini ⁵⁴, M.N. Mancini ²⁷, G. Manco ^{74a,74b},
 J.P. Mandalia ⁹⁶, S.S. Mandarry ¹⁴⁹, I. Mandić ⁹⁵, L. Manhaes de Andrade Filho ^{84a},
 I.M. Maniatis ¹⁷², J. Manjarres Ramos ⁹¹, D.C. Mankad ¹⁷², A. Mann ¹¹¹, S. Manzoni ³⁷,
 L. Mao ^{63c}, X. Mapekula ^{34c}, A. Marantis ^{155,q}, G. Marchiori ⁵, M. Marcisovsky ¹³⁴,
 C. Marcon ^{72a}, M. Marinescu ²¹, S. Marium ⁴⁹, M. Marjanovic ¹²³, A. Markhoos ⁵⁵,
 M. Markovitch ⁶⁷, E.J. Marshall ⁹³, Z. Marshall ^{18a}, S. Marti-Garcia ¹⁶⁶, J. Martin ⁹⁸,
 T.A. Martin ¹³⁷, V.J. Martin ⁵³, B. Martin dit Latour ¹⁷, L. Martinelli ^{76a,76b}, M. Martinez ^{13,r},
 P. Martinez Agullo ¹⁶⁶, V.I. Martinez Outschoorn ¹⁰⁵, P. Martinez Suarez ¹³, S. Martin-Haugh ¹³⁷,
 G. Martinovicova ¹³⁶, V.S. Martoiu ^{28b}, A.C. Martyniuk ⁹⁸, A. Marzin ³⁷, D. Mascione ^{79a,79b},
 L. Masetti ¹⁰², T. Mashimo ¹⁵⁶, J. Masik ¹⁰³, A.L. Maslennikov ³⁸, P. Massarotti ^{73a,73b},
 P. Mastrandrea ^{75a,75b}, A. Mastroberardino ^{44b,44a}, T. Masubuchi ¹⁵⁶, T. Mathisen ¹⁶⁴,
 J. Matousek ¹³⁶, N. Matsuzawa¹⁵⁶, J. Maurer ^{28b}, A.J. Maury ⁶⁷, B. Maček ⁹⁵, D.A. Maximov ³⁸,
 A.E. May ¹⁰³, R. Mazini ¹⁵¹, I. Maznas ¹¹⁸, M. Mazza ¹⁰⁹, S.M. Mazza ¹³⁹, E. Mazzeo ^{72a,72b},
 C. Mc Ginn ³⁰, J.P. Mc Gowan ¹⁶⁸, S.P. Mc Kee ¹⁰⁸, C.C. McCracken ¹⁶⁷, E.F. McDonald ¹⁰⁷,
 A.E. McDougall ¹¹⁷, J.A. Mcfayden ¹⁴⁹, R.P. McGovern ¹³¹, R.P. Mckenzie ^{34g},
 T.C. McLachlan ⁴⁹, D.J. McLaughlin ⁹⁸, S.J. McMahon ¹³⁷, C.M. Mcpartland ⁹⁴,
 R.A. McPherson ^{168,v}, S. Mehlhase ¹¹¹, A. Mehta ⁹⁴, D. Melini ¹⁶⁶, B.R. Mellado Garcia ^{34g},
 A.H. Melo ⁵⁶, F. Meloni ⁴⁹, A.M. Mendes Jacques Da Costa ¹⁰³, H.Y. Meng ¹⁵⁸, L. Meng ⁹³,
 S. Menke ¹¹², M. Mentink ³⁷, E. Meoni ^{44b,44a}, G. Mercado ¹¹⁸, S. Merianos ¹⁵⁵,
 C. Merlassino ^{70a,70c}, L. Merola ^{73a,73b}, C. Meroni ^{72a,72b}, J. Metcalfe ⁶, A.S. Mete ⁶,
 E. Meuser ¹⁰², C. Meyer ⁶⁹, J-P. Meyer ¹³⁸, R.P. Middleton ¹³⁷, L. Mijović ⁵³,
 G. Mikenberg ¹⁷², M. Mikesikova ¹³⁴, M. Mikuž ⁹⁵, H. Mildner ¹⁰², A. Milic ³⁷,
 D.W. Miller ⁴⁰, E.H. Miller ¹⁴⁶, L.S. Miller ³⁵, A. Milov ¹⁷², D.A. Milstead^{48a,48b}, T. Min^{114a},
 A.A. Minaenko ³⁸, I.A. Minashvili ^{152b}, L. Mince ⁶⁰, A.I. Mincer ¹²⁰, B. Mindur ^{87a},
 M. Mineev ³⁹, Y. Mino ⁸⁹, L.M. Mir ¹³, M. Miralles Lopez ⁶⁰, M. Mironova ^{18a}, A. Mishima¹⁵⁶,
 M.C. Missio ¹¹⁶, A. Mitra ¹⁷⁰, V.A. Mitsou ¹⁶⁶, Y. Mitsumori ¹¹³, O. Miu ¹⁵⁸,
 P.S. Miyagawa ⁹⁶, T. Mkrtchyan ^{64a}, M. Mlinarevic ⁹⁸, T. Mlinarevic ⁹⁸, M. Mlynarikova ³⁷,
 S. Mobius ²⁰, P. Mogg ¹¹¹, M.H. Mohamed Farook ¹¹⁵, A.F. Mohammed ^{14,114c}, S. Mohapatra ⁴²,
 G. Mokgatitwane ^{34g}, L. Moleri ¹⁷², B. Mondal ¹⁴⁴, S. Mondal ¹³⁵, K. Mönig ⁴⁹,
 E. Monnier ¹⁰⁴, L. Monsonis Romero¹⁶⁶, J. Montejo Berlingen ¹³, M. Montella ¹²²,
 F. Montekali ^{78a,78b}, F. Monticelli ⁹², S. Monzani ^{70a,70c}, N. Morange ⁶⁷,
 A.L. Moreira De Carvalho ⁴⁹, M. Moreno Llácer ¹⁶⁶, C. Moreno Martinez ⁵⁷, P. Morettini ^{58b},
 S. Morgenstern ³⁷, M. Morii ⁶², M. Morinaga ¹⁵⁶, F. Morodei ^{76a,76b}, L. Morvaj ³⁷,

P. Moschovakos [ID37](#), B. Moser [ID37](#), M. Mosidze [ID152b](#), T. Moskalets [ID45](#), P. Moskvitina [ID116](#),
 J. Moss [ID32j](#), P. Moszkowicz [ID87a](#), A. Moussa [ID36d](#), E.J.W. Moyse [ID105](#), O. Mtintsilana [ID34g](#),
 S. Muanza [ID104](#), J. Mueller [ID132](#), D. Muenstermann [ID93](#), R. Müller [ID37](#), G.A. Mullier [ID164](#),
 A.J. Mullin [ID33](#), J.J. Mullin [ID131](#), D.P. Mungo [ID158](#), D. Munoz Perez [ID166](#), F.J. Munoz Sanchez [ID103](#),
 M. Murin [ID103](#), W.J. Murray [ID170,137](#), M. Muškinja [ID95](#), C. Mwewa [ID30](#), A.G. Myagkov [ID38,a](#),
 A.J. Myers [ID8](#), G. Myers [ID108](#), M. Myska [ID135](#), B.P. Nachman [ID18a](#), O. Nackenhorst [ID50](#), K. Nagai [ID129](#),
 K. Nagano [ID85](#), J.L. Nagle [ID30,ae](#), E. Nagy [ID104](#), A.M. Nairz [ID37](#), Y. Nakahama [ID85](#), K. Nakamura [ID85](#),
 K. Nakkalil [ID5](#), H. Nanjo [ID127](#), E.A. Narayanan [ID115](#), I. Naryshkin [ID38](#), L. Nasella [ID72a,72b](#),
 M. Naseri [ID35](#), S. Nasri [ID119b](#), C. Nass [ID25](#), G. Navarro [ID23a](#), J. Navarro-Gonzalez [ID166](#), R. Nayak [ID154](#),
 A. Nayaz [ID19](#), P.Y. Nechaeva [ID38](#), S. Nechaeva [ID24b,24a](#), F. Nechansky [ID49](#), L. Nedic [ID129](#), T.J. Neep [ID21](#),
 A. Negri [ID74a,74b](#), M. Negrini [ID24b](#), C. Nellist [ID117](#), C. Nelson [ID106](#), K. Nelson [ID108](#), S. Nemecek [ID134](#),
 M. Nessi [ID37,g](#), M.S. Neubauer [ID165](#), F. Neuhaus [ID102](#), J. Neundorf [ID49](#), P.R. Newman [ID21](#),
 C.W. Ng [ID132](#), Y.W.Y. Ng [ID49](#), B. Ngair [ID119a](#), H.D.N. Nguyen [ID110](#), R.B. Nickerson [ID129](#),
 R. Nicolaidou [ID138](#), J. Nielsen [ID139](#), M. Niemeyer [ID56](#), J. Niermann [ID56](#), N. Nikiforou [ID37](#),
 V. Nikolaenko [ID38,a](#), I. Nikolic-Audit [ID130](#), K. Nikolopoulos [ID21](#), P. Nilsson [ID30](#), I. Ninca [ID49](#),
 G. Ninio [ID154](#), A. Nisati [ID76a](#), N. Nishu [ID2](#), R. Nisius [ID112](#), J-E. Nitschke [ID51](#), E.K. Nkadimeng [ID34g](#),
 T. Nobe [ID156](#), T. Nommensen [ID150](#), M.B. Norfolk [ID142](#), B.J. Norman [ID35](#), M. Noury [ID36a](#), J. Novak [ID95](#),
 T. Novak [ID95](#), L. Novotny [ID135](#), R. Novotny [ID115](#), L. Nozka [ID125](#), K. Ntekas [ID162](#),
 N.M.J. Nunes De Moura Junior [ID84b](#), J. Ocariz [ID130](#), A. Ochi [ID86](#), I. Ochoa [ID133a](#), S. Oerdek [ID49,s](#),
 J.T. Offermann [ID40](#), A. Ogrodnik [ID136](#), A. Oh [ID103](#), C.C. Ohm [ID147](#), H. Oide [ID85](#), R. Oishi [ID156](#),
 M.L. Ojeda [ID49](#), Y. Okumura [ID156](#), L.F. Oleiro Seabra [ID133a](#), I. Oleksiyuk [ID57](#), S.A. Olivares Pino [ID140d](#),
 G. Oliveira Correa [ID13](#), D. Oliveira Damazio [ID30](#), D. Oliveira Goncalves [ID84a](#), J.L. Oliver [ID162](#),
 Ö.O. Öncel [ID55](#), A.P. O'Neill [ID20](#), A. Onofre [ID133a,133e](#), P.U.E. Onyisi [ID11](#), M.J. Oreglia [ID40](#),
 G.E. Orellana [ID92](#), D. Orestano [ID78a,78b](#), N. Orlando [ID13](#), R.S. Orr [ID158](#), L.M. Osojnak [ID131](#),
 R. Ospanov [ID63a](#), G. Otero y Garzon [ID31](#), H. Otono [ID90](#), P.S. Ott [ID64a](#), G.J. Ottino [ID18a](#), M. Ouchrif [ID36d](#),
 F. Ould-Saada [ID128](#), T. Ovsianikova [ID141](#), M. Owen [ID60](#), R.E. Owen [ID137](#), V.E. Ozcan [ID22a](#),
 F. Ozturk [ID88](#), N. Ozturk [ID8](#), S. Ozturk [ID83](#), H.A. Pacey [ID129](#), A. Pacheco Pages [ID13](#),
 C. Padilla Aranda [ID13](#), G. Padovano [ID76a,76b](#), S. Pagan Griso [ID18a](#), G. Palacino [ID69](#), A. Palazzo [ID71a,71b](#),
 J. Pampel [ID25](#), J. Pan [ID175](#), T. Pan [ID65a](#), D.K. Panchal [ID11](#), C.E. Pandini [ID117](#), J.G. Panduro Vazquez [ID137](#),
 H.D. Pandya [ID1](#), H. Pang [ID15](#), P. Pani [ID49](#), G. Panizzo [ID70a,70c](#), L. Panwar [ID130](#), L. Paolozzi [ID57](#),
 S. Parajuli [ID165](#), A. Paramonov [ID6](#), C. Paraskevopoulos [ID54](#), D. Paredes Hernandez [ID65b](#),
 A. Pareti [ID74a,74b](#), K.R. Park [ID42](#), T.H. Park [ID158](#), M.A. Parker [ID33](#), F. Parodi [ID58b,58a](#), E.W. Parrish [ID118](#),
 V.A. Parrish [ID53](#), J.A. Parsons [ID42](#), U. Parzefall [ID55](#), B. Pascual Dias [ID110](#), L. Pascual Dominguez [ID101](#),
 E. Pasqualucci [ID76a](#), S. Passaggio [ID58b](#), F. Pastore [ID97](#), P. Patel [ID88](#), U.M. Patel [ID52](#), J.R. Pater [ID103](#),
 T. Pauly [ID37](#), C.I. Pazos [ID161](#), J. Pearkes [ID146](#), M. Pedersen [ID128](#), R. Pedro [ID133a](#), S.V. Peleganchuk [ID38](#),
 O. Penc [ID37](#), E.A. Pender [ID53](#), G.D. Penn [ID175](#), K.E. Penski [ID111](#), M. Penzin [ID38](#), B.S. Peralva [ID84d](#),
 A.P. Pereira Peixoto [ID141](#), L. Pereira Sanchez [ID146](#), D.V. Perepelitsa [ID30,ae](#), G. Perera [ID105](#),
 E. Perez Codina [ID159a](#), M. Perganti [ID10](#), H. Pernegger [ID37](#), S. Perrella [ID76a,76b](#), O. Perrin [ID41](#),
 K. Peters [ID49](#), R.F.Y. Peters [ID103](#), B.A. Petersen [ID37](#), T.C. Petersen [ID43](#), E. Petit [ID104](#), V. Petousis [ID135](#),
 C. Petridou [ID155,d](#), T. Petru [ID136](#), A. Petrukhin [ID144](#), M. Pettee [ID18a](#), A. Petukhov [ID38](#), K. Petukhova [ID37](#),
 R. Pezoa [ID140f](#), L. Pezzotti [ID37](#), G. Pezzullo [ID175](#), T.M. Pham [ID173](#), T. Pham [ID107](#), P.W. Phillips [ID137](#),
 G. Piacquadio [ID148](#), E. Pianori [ID18a](#), F. Piazza [ID126](#), R. Piegai [ID31](#), D. Pietreanu [ID28b](#),
 A.D. Pilkington [ID103](#), M. Pinamonti [ID70a,70c](#), J.L. Pinfeld [ID2](#), B.C. Pinheiro Pereira [ID133a](#),
 A.E. Pinto Pinoargote [ID138,138](#), L. Pintucci [ID70a,70c](#), K.M. Piper [ID149](#), A. Pirttikoski [ID57](#), D.A. Pizzi [ID35](#),
 L. Pizzimento [ID65b](#), A. Pizzini [ID117](#), M.-A. Pleier [ID30](#), V. Pleskot [ID136](#), E. Plotnikova [ID39](#), G. Poddar [ID96](#),
 R. Poettgen [ID100](#), L. Poggioli [ID130](#), I. Pokharel [ID56](#), S. Polacek [ID136](#), G. Polesello [ID74a](#),
 A. Poley [ID145,159a](#), A. Polini [ID24b](#), C.S. Pollard [ID170](#), Z.B. Pollock [ID122](#), E. Pompa Pacchi [ID76a,76b](#),

N.I. Pond ⁹⁸, D. Ponomarenko ¹¹⁶, L. Pontecorvo ³⁷, S. Popa ^{28a}, G.A. Popeneciu ^{28d},
 A. Poreba ³⁷, D.M. Portillo Quintero ^{159a}, S. Pospisil ¹³⁵, M.A. Postill ¹⁴², P. Postolache ^{28c},
 K. Potamianos ¹⁷⁰, P.A. Potepa ^{87a}, I.N. Potrap ³⁹, C.J. Potter ³³, H. Potti ¹⁵⁰, J. Poveda ¹⁶⁶,
 M.E. Pozo Astigarraga ³⁷, A. Prades Ibanez ¹⁶⁶, J. Pretel ⁵⁵, D. Price ¹⁰³, M. Primavera ^{71a},
 M.A. Principe Martin ¹⁰¹, R. Privara ¹²⁵, T. Procter ⁶⁰, M.L. Proffitt ¹⁴¹, N. Proklova ¹³¹,
 K. Prokofiev ^{65c}, G. Proto ¹¹², J. Proudfoot ⁶, M. Przybycien ^{87a}, W.W. Przygoda ^{87b},
 A. Psallidas ⁴⁷, J.E. Puddefoot ¹⁴², D. Pudzha ⁵⁵, D. Pyatiizbyantseva ³⁸, J. Qian ¹⁰⁸,
 D. Qichen ¹⁰³, Y. Qin ¹³, T. Qiu ⁵³, A. Quadt ⁵⁶, M. Queitsch-Maitland ¹⁰³, G. Quetant ⁵⁷,
 R.P. Quinn ¹⁶⁷, G. Rabanal Bolanos ⁶², D. Rafanoharana ⁵⁵, F. Raffaelli ^{77a,77b}, F. Ragusa ^{72a,72b},
 J.L. Rainbolt ⁴⁰, J.A. Raine ⁵⁷, S. Rajagopalan ³⁰, E. Ramakoti ³⁸, I.A. Ramirez-Berend ³⁵,
 K. Ran ^{49,114c}, N.P. Rapheeha ^{34g}, H. Rasheed ^{28b}, V. Raskina ¹³⁰, D.F. Rassloff ^{64a},
 A. Rastogi ^{18a}, S. Rave ¹⁰², S. Ravera ^{58b,58a}, B. Ravina ⁵⁶, I. Ravinovich ¹⁷², M. Raymond ³⁷,
 A.L. Read ¹²⁸, N.P. Readioff ¹⁴², D.M. Rebuzzi ^{74a,74b}, G. Redlinger ³⁰, A.S. Reed ¹¹²,
 K. Reeves ²⁷, J.A. Reidelsturz ¹⁷⁴, D. Reikher ¹⁵⁴, A. Rej ⁵⁰, C. Rembser ³⁷, M. Renda ^{28b},
 F. Renner ⁴⁹, A.G. Rennie ¹⁶², A.L. Rescia ⁴⁹, S. Resconi ^{72a}, M. Ressegotti ^{58b,58a}, S. Rettie ³⁷,
 J.G. Reyes Rivera ¹⁰⁹, E. Reynolds ^{18a}, O.L. Rezanova ³⁸, P. Reznicek ¹³⁶, H. Riani ^{36d},
 N. Ribaric ⁹³, E. Ricci ^{79a,79b}, R. Richter ¹¹², S. Richter ^{48a,48b}, E. Richter-Was ^{87b},
 M. Ridel ¹³⁰, S. Ridouani ^{36d}, P. Rieck ¹²⁰, P. Riedler ³⁷, E.M. Riefel ^{48a,48b}, J.O. Rieger ¹¹⁷,
 M. Rijssenbeek ¹⁴⁸, M. Rimoldi ³⁷, L. Rinaldi ^{24b,24a}, P. Rincke ^{56,164}, T.T. Rinn ³⁰,
 M.P. Rinnagel ¹¹¹, G. Ripellino ¹⁶⁴, I. Riu ¹³, J.C. Rivera Vergara ¹⁶⁸, F. Rizatdinova ¹²⁴,
 E. Rizvi ⁹⁶, B.R. Roberts ^{18a}, S.H. Robertson ^{106,v}, D. Robinson ³³, C.M. Robles Gajardo ^{140f},
 M. Robles Manzano ¹⁰², A. Robson ⁶⁰, A. Rocchi ^{77a,77b}, C. Roda ^{75a,75b}, S. Rodriguez Bosca ³⁷,
 Y. Rodriguez Garcia ^{23a}, A. Rodriguez Rodriguez ⁵⁵, A.M. Rodríguez Vera ¹¹⁸, S. Roe ³⁷,
 J.T. Roemer ³⁷, A.R. Roepe-Gier ¹³⁹, O. Røhne ¹²⁸, R.A. Rojas ¹⁰⁵, C.P.A. Roland ¹³⁰,
 J. Roloff ³⁰, A. Romaniouk ³⁸, E. Romano ^{74a,74b}, M. Romano ^{24b}, A.C. Romero Hernandez ¹⁶⁵,
 N. Rompotis ⁹⁴, L. Roos ¹³⁰, S. Rosati ^{76a}, B.J. Rosser ⁴⁰, E. Rossi ¹²⁹, E. Rossi ^{73a,73b},
 L.P. Rossi ⁶², L. Rossini ⁵⁵, R. Rosten ¹²², M. Rotaru ^{28b}, B. Rottler ⁵⁵, C. Rougier ⁹¹,
 D. Rousseau ⁶⁷, D. Rousso ⁴⁹, A. Roy ¹⁶⁵, S. Roy-Garand ¹⁵⁸, A. Rozanov ¹⁰⁴,
 Z.M.A. Rozario ⁶⁰, Y. Rozen ¹⁵³, A. Rubio Jimenez ¹⁶⁶, A.J. Ruby ⁹⁴, V.H. Ruelas Rivera ¹⁹,
 T.A. Ruggeri ¹, A. Ruggiero ¹²⁹, A. Ruiz-Martinez ¹⁶⁶, A. Rummler ³⁷, Z. Rurikova ⁵⁵,
 N.A. Rusakovich ³⁹, H.L. Russell ¹⁶⁸, G. Russo ^{76a,76b}, J.P. Rutherford ⁷,
 S. Rutherford Colmenares ³³, M. Rybar ¹³⁶, E.B. Rye ¹²⁸, A. Ryzhov ⁴⁵, J.A. Sabater Iglesias ⁵⁷,
 P. Sabatini ¹⁶⁶, H.F-W. Sadrozinski ¹³⁹, F. Safai Tehrani ^{76a}, B. Safarzadeh Samani ¹³⁷, S. Saha ¹,
 M. Sahinsoy ¹¹², A. Saibel ¹⁶⁶, M. Saimpert ¹³⁸, M. Saito ¹⁵⁶, T. Saito ¹⁵⁶, A. Sala ^{72a,72b},
 D. Salamani ³⁷, A. Salnikov ¹⁴⁶, J. Salt ¹⁶⁶, A. Salvador Salas ¹⁵⁴, D. Salvatore ^{44b,44a},
 F. Salvatore ¹⁴⁹, A. Salzburger ³⁷, D. Sammel ⁵⁵, E. Sampson ⁹³, D. Sampsonidis ^{155,d},
 D. Sampsonidou ¹²⁶, J. Sánchez ¹⁶⁶, V. Sanchez Sebastian ¹⁶⁶, H. Sandaker ¹²⁸, C.O. Sander ⁴⁹,
 J.A. Sandesara ¹⁰⁵, M. Sandhoff ¹⁷⁴, C. Sandoval ^{23b}, L. Sanfilippo ^{64a}, D.P.C. Sankey ¹³⁷,
 T. Sano ⁸⁹, A. Sansoni ⁵⁴, L. Santi ^{37,76b}, C. Santoni ⁴¹, H. Santos ^{133a,133b}, A. Santra ¹⁷²,
 E. Sanzani ^{24b,24a}, K.A. Saoucha ¹⁶³, J.G. Saraiva ^{133a,133d}, J. Sardain ⁷, O. Sasaki ⁸⁵,
 K. Sato ¹⁶⁰, C. Sauer ^{64b}, E. Sauvan ⁴, P. Savard ^{158,ac}, R. Sawada ¹⁵⁶, C. Sawyer ¹³⁷,
 L. Sawyer ⁹⁹, C. Sbarra ^{24b}, A. Sbrizzi ^{24b,24a}, T. Scanlon ⁹⁸, J. Schaarschmidt ¹⁴¹,
 U. Schäfer ¹⁰², A.C. Schaffer ^{67,45}, D. Schaile ¹¹¹, R.D. Schamberger ¹⁴⁸, C. Scharf ¹⁹,
 M.M. Schefer ²⁰, V.A. Schegelsky ³⁸, D. Scheirich ¹³⁶, M. Schernau ¹⁶², C. Scheulen ⁵⁶,
 C. Schiavi ^{58b,58a}, M. Schioppa ^{44b,44a}, B. Schlag ^{146,1}, K.E. Schleicher ⁵⁵, S. Schlenker ³⁷,
 J. Schmeing ¹⁷⁴, M.A. Schmidt ¹⁷⁴, K. Schmieden ¹⁰², C. Schmitt ¹⁰², N. Schmitt ¹⁰²,
 S. Schmitt ⁴⁹, L. Schoeffel ¹³⁸, A. Schoening ^{64b}, P.G. Scholer ³⁵, E. Schopf ¹²⁹, M. Schott ²⁵,

J. Schovancova [ID37](#), S. Schramm [ID57](#), T. Schroer [ID57](#), H-C. Schultz-Coulon [ID64a](#), M. Schumacher [ID55](#),
 B.A. Schumm [ID139](#), Ph. Schune [ID138](#), A.J. Schuy [ID141](#), H.R. Schwartz [ID139](#), A. Schwartzman [ID146](#),
 T.A. Schwarz [ID108](#), Ph. Schwemling [ID138](#), R. Schwienhorst [ID109](#), F.G. Sciacca [ID20](#), A. Sciandra [ID30](#),
 G. Sciolla [ID27](#), F. Scuri [ID75a](#), C.D. Sebastiani [ID94](#), K. Sedlaczek [ID118](#), S.C. Seidel [ID115](#), A. Seiden [ID139](#),
 B.D. Seidlitz [ID42](#), C. Seitz [ID49](#), J.M. Seixas [ID84b](#), G. Sekhniaidze [ID73a](#), L. Selem [ID61](#),
 N. Semprini-Cesari [ID24b,24a](#), D. Sengupta [ID57](#), V. Senthilkumar [ID166](#), L. Serin [ID67](#), M. Sessa [ID77a,77b](#),
 H. Severini [ID123](#), F. Sforza [ID58b,58a](#), A. Sfyrta [ID57](#), Q. Sha [ID14](#), E. Shabalina [ID56](#), A.H. Shah [ID33](#),
 R. Shaheen [ID147](#), J.D. Shahinian [ID131](#), D. Shaked Renous [ID172](#), L.Y. Shan [ID14](#), M. Shapiro [ID18a](#),
 A. Sharma [ID37](#), A.S. Sharma [ID167](#), P. Sharma [ID81](#), P.B. Shatalov [ID38](#), K. Shaw [ID149](#), S.M. Shaw [ID103](#),
 Q. Shen [ID63c](#), D.J. Sheppard [ID145](#), P. Sherwood [ID98](#), L. Shi [ID98](#), X. Shi [ID14](#), C.O. Shimmin [ID175](#),
 J.D. Shinner [ID97](#), I.P.J. Shipsey [ID129](#), S. Shirabe [ID90](#), M. Shiyakova [ID39,t](#), M.J. Shochet [ID40](#),
 J. Shojaii [ID107](#), D.R. Shope [ID128](#), B. Shrestha [ID123](#), S. Shrestha [ID122,af](#), M.J. Shroff [ID168](#), P. Sicho [ID134](#),
 A.M. Sickles [ID165](#), E. Sideras Haddad [ID34g](#), A.C. Sidley [ID117](#), A. Sidoti [ID24b](#), F. Siegert [ID51](#),
 Dj. Sijacki [ID16](#), F. Sili [ID92](#), J.M. Silva [ID53](#), I. Silva Ferreira [ID84b](#), M.V. Silva Oliveira [ID30](#),
 S.B. Silverstein [ID48a](#), S. Simion [ID67](#), R. Simoniello [ID37](#), E.L. Simpson [ID103](#), H. Simpson [ID149](#),
 L.R. Simpson [ID108](#), N.D. Simpson [ID100](#), S. Simsek [ID83](#), S. Sindhu [ID56](#), P. Sinervo [ID158](#), S. Singh [ID158](#),
 S. Sinha [ID49](#), S. Sinha [ID103](#), M. Sioli [ID24b,24a](#), I. Siral [ID37](#), E. Sitnikova [ID49](#), J. Sjölin [ID48a,48b](#),
 A. Skaf [ID56](#), E. Skorda [ID21](#), P. Skubic [ID123](#), M. Slawinska [ID88](#), V. Smakhtin [ID172](#), B.H. Smart [ID137](#),
 S.Yu. Smirnov [ID38](#), Y. Smirnov [ID38](#), L.N. Smirnova [ID38,a](#), O. Smirnova [ID100](#), A.C. Smith [ID42](#),
 D.R. Smith [ID162](#), E.A. Smith [ID40](#), H.A. Smith [ID129](#), J.L. Smith [ID103](#), R. Smith [ID146](#), M. Smizanska [ID93](#),
 K. Smolek [ID135](#), A.A. Snesarev [ID38](#), S.R. Snider [ID158](#), H.L. Snoek [ID117](#), S. Snyder [ID30](#), R. Sobie [ID168,v](#),
 A. Soffer [ID154](#), C.A. Solans Sanchez [ID37](#), E.Yu. Soldatov [ID38](#), U. Soldevila [ID166](#), A.A. Solodkov [ID38](#),
 S. Solomon [ID27](#), A. Soloshenko [ID39](#), K. Solovieva [ID55](#), O.V. Solovyanov [ID41](#), P. Sommer [ID37](#),
 A. Sonay [ID13](#), W.Y. Song [ID159b](#), A. Sopczak [ID135](#), A.L. Soppio [ID98](#), F. Sopkova [ID29b](#), J.D. Sorenson [ID115](#),
 I.R. Sotarriva Alvarez [ID157](#), V. Sothilingam [ID64a](#), O.J. Soto Sandoval [ID140c,140b](#), S. Sottocornola [ID69](#),
 R. Soualah [ID163](#), Z. Soumami [ID36e](#), D. South [ID49](#), N. Soybelman [ID172](#), S. Spagnolo [ID71a,71b](#),
 M. Spalla [ID112](#), D. Sperlich [ID55](#), G. Spigo [ID37](#), S. Spinali [ID93](#), B. Spisso [ID73a,73b](#), D.P. Spiteri [ID60](#),
 M. Spousta [ID136](#), E.J. Staats [ID35](#), R. Stamen [ID64a](#), A. Stampekis [ID21](#), M. Standke [ID25](#), E. Stanecka [ID88](#),
 W. Stanek-Maslouska [ID49](#), M.V. Stange [ID51](#), B. Stanislaus [ID18a](#), M.M. Stanitzki [ID49](#), B. Stapf [ID49](#),
 E.A. Starchenko [ID38](#), G.H. Stark [ID139](#), J. Stark [ID91](#), P. Staroba [ID134](#), P. Starovoitov [ID64a](#), S. Stärz [ID106](#),
 R. Staszewski [ID88](#), G. Stavropoulos [ID47](#), P. Steinberg [ID30](#), B. Stelzer [ID145,159a](#), H.J. Stelzer [ID132](#),
 O. Stelzer-Chilton [ID159a](#), H. Stenzel [ID59](#), T.J. Stevenson [ID149](#), G.A. Stewart [ID37](#), J.R. Stewart [ID124](#),
 M.C. Stockton [ID37](#), G. Stoicea [ID28b](#), M. Stolarski [ID133a](#), S. Stonjek [ID112](#), A. Straessner [ID51](#),
 J. Strandberg [ID147](#), S. Strandberg [ID48a,48b](#), M. Stratmann [ID174](#), M. Strauss [ID123](#), T. Strebler [ID104](#),
 P. Strizenc [ID29b](#), R. Ströhmer [ID169](#), D.M. Strom [ID126](#), R. Stroynowski [ID45](#), A. Strubig [ID48a,48b](#),
 S.A. Stucci [ID30](#), B. Stugu [ID17](#), J. Stupak [ID123](#), N.A. Styles [ID49](#), D. Su [ID146](#), S. Su [ID63a](#), W. Su [ID63d](#),
 X. Su [ID63a](#), D. Suchy [ID29a](#), K. Sugizaki [ID156](#), V.V. Sulin [ID38](#), M.J. Sullivan [ID94](#), D.M.S. Sultan [ID129](#),
 L. Sultanliyeva [ID38](#), S. Sultansoy [ID3b](#), T. Sumida [ID89](#), S. Sun [ID173](#), O. Sunneborn Gudnadottir [ID164](#),
 N. Sur [ID104](#), M.R. Sutton [ID149](#), H. Suzuki [ID160](#), M. Svatos [ID134](#), M. Swiatlowski [ID159a](#), T. Swirski [ID169](#),
 I. Sykora [ID29a](#), M. Sykora [ID136](#), T. Sykora [ID136](#), D. Ta [ID102](#), K. Tackmann [ID49,s](#), A. Taffard [ID162](#),
 R. Tafirout [ID159a](#), J.S. Tafoya Vargas [ID67](#), Y. Takubo [ID85](#), M. Talby [ID104](#), A.A. Talyshev [ID38](#),
 K.C. Tam [ID65b](#), N.M. Tamir [ID154](#), A. Tanaka [ID156](#), J. Tanaka [ID156](#), R. Tanaka [ID67](#), M. Tanasini [ID148](#),
 Z. Tao [ID167](#), S. Tapia Araya [ID140f](#), S. Tapprogge [ID102](#), A. Tarek Abouelfadl Mohamed [ID109](#),
 S. Tarem [ID153](#), K. Tariq [ID14](#), G. Tarna [ID28b](#), G.F. Tartarelli [ID72a](#), M.J. Tartarin [ID91](#), P. Tas [ID136](#),
 M. Tasevsky [ID134](#), E. Tassi [ID44b,44a](#), A.C. Tate [ID165](#), G. Tateno [ID156](#), Y. Tayalati [ID36e,u](#), G.N. Taylor [ID107](#),
 W. Taylor [ID159b](#), R. Teixeira De Lima [ID146](#), P. Teixeira-Dias [ID97](#), J.J. Teoh [ID158](#), K. Terashi [ID156](#),
 J. Terron [ID101](#), S. Terzo [ID13](#), M. Testa [ID54](#), R.J. Teuscher [ID158,v](#), A. Thaler [ID80](#), O. Theiner [ID57](#),

N. Themistokleous ⁵³, T. Thevenaux-Pelzer ¹⁰⁴, O. Thielmann ¹⁷⁴, D.W. Thomas ⁹⁷,
 J.P. Thomas ²¹, E.A. Thompson ^{18a}, P.D. Thompson ²¹, E. Thomson ¹³¹, R.E. Thornberry ⁴⁵,
 C. Tian ^{63a}, Y. Tian ⁵⁶, V. Tikhomirov ^{38,a}, Yu.A. Tikhonov ³⁸, S. Timoshenko ³⁸,
 D. Timoshyn ¹³⁶, E.X.L. Ting ¹, P. Tipton ¹⁷⁵, A. Tishelman-Charny ³⁰, S.H. Tlou ^{34g},
 K. Todome ¹⁵⁷, S. Todorova-Nova ¹³⁶, S. Todt ⁵¹, L. Toffolin ^{70a,70c}, M. Togawa ⁸⁵, J. Tojo ⁹⁰,
 S. Tokár ^{29a}, K. Tokushuku ⁸⁵, O. Toldaiev ⁶⁹, R. Tombs ³³, M. Tomoto ^{85,113},
 L. Tompkins ^{146,1}, K.W. Topolnicki ^{87b}, E. Torrence ¹²⁶, H. Torres ⁹¹, E. Torró Pastor ¹⁶⁶,
 M. Toscani ³¹, C. Tosciri ⁴⁰, M. Tost ¹¹, D.R. Tovey ¹⁴², I.S. Trandafir ^{28b}, T. Trefzger ¹⁶⁹,
 A. Tricoli ³⁰, I.M. Trigger ^{159a}, S. Trincaz-Duvoid ¹³⁰, D.A. Trischuk ²⁷, B. Trocmé ⁶¹,
 A. Tropina ³⁹, L. Truong ^{34c}, M. Trzebinski ⁸⁸, A. Trzupiek ⁸⁸, F. Tsai ¹⁴⁸, M. Tsai ¹⁰⁸,
 A. Tsiamis ^{155,d}, P.V. Tsiarehka ³⁸, S. Tsigaridas ^{159a}, A. Tsirigotis ^{155,q}, V. Tsiskaridze ¹⁵⁸,
 E.G. Tskhadadze ^{152a}, M. Tsopoulou ¹⁵⁵, Y. Tsujikawa ⁸⁹, I.I. Tsukerman ³⁸, V. Tsulaia ^{18a},
 S. Tsuno ⁸⁵, K. Tsuri ¹²¹, D. Tsybychev ¹⁴⁸, Y. Tu ^{65b}, A. Tudorache ^{28b}, V. Tudorache ^{28b},
 A.N. Tuna ⁶², S. Turchikhin ^{58b,58a}, I. Turk Cakir ^{3a}, R. Turra ^{72a}, T. Turtuvshin ^{39,w},
 P.M. Tuts ⁴², S. Tzamarias ^{155,d}, E. Tzovara ¹⁰², F. Ukegawa ¹⁶⁰, P.A. Ulloa Poblete ^{140c,140b},
 E.N. Umaka ³⁰, G. Unal ³⁷, A. Undrus ³⁰, G. Unel ¹⁶², J. Urban ^{29b}, P. Urrejola ^{140a},
 G. Usai ⁸, R. Ushioda ¹⁵⁷, M. Usman ¹¹⁰, Z. Uysal ⁸³, V. Vacek ¹³⁵, B. Vachon ¹⁰⁶,
 T. Vafeiadis ³⁷, A. Vaitkus ⁹⁸, C. Valderanis ¹¹¹, E. Valdes Santurio ^{48a,48b}, M. Valente ^{159a},
 S. Valentinetti ^{24b,24a}, A. Valero ¹⁶⁶, E. Valiente Moreno ¹⁶⁶, A. Vallier ⁹¹, J.A. Valls Ferrer ¹⁶⁶,
 D.R. Van Arneman ¹¹⁷, T.R. Van Daalen ¹⁴¹, A. Van Der Graaf ⁵⁰, P. Van Gemmeren ⁶,
 M. Van Rijnbach ³⁷, S. Van Stroud ⁹⁸, I. Van Vulpen ¹¹⁷, P. Vana ¹³⁶, M. Vanadia ^{77a,77b},
 W. Vandelli ³⁷, E.R. Vandewall ¹²⁴, D. Vannicola ¹⁵⁴, L. Vannoli ⁵⁴, R. Vari ^{76a}, E.W. Varnes ⁷,
 C. Varni ^{18b}, T. Varol ¹⁵¹, D. Varouchas ⁶⁷, L. Varriale ¹⁶⁶, K.E. Varvell ¹⁵⁰, M.E. Vasile ^{28b},
 L. Vaslin ⁸⁵, G.A. Vasquez ¹⁶⁸, A. Vasyukov ³⁹, L.M. Vaughan ¹²⁴, R. Vavricka ¹⁰²,
 T. Vazquez Schroeder ³⁷, J. Veatch ³², V. Vecchio ¹⁰³, M.J. Veen ¹⁰⁵, I. Veliscek ³⁰,
 L.M. Veloce ¹⁵⁸, F. Veloso ^{133a,133c}, S. Veneziano ^{76a}, A. Ventura ^{71a,71b}, S. Ventura Gonzalez ¹³⁸,
 A. Verbytskyi ¹¹², M. Verducci ^{75a,75b}, C. Vergis ⁹⁶, M. Verissimo De Araujo ^{84b},
 W. Verkerke ¹¹⁷, J.C. Vermeulen ¹¹⁷, C. Vernieri ¹⁴⁶, M. Vessella ¹⁰⁵, M.C. Vetterli ^{145,ac},
 A. Vgenopoulos ¹⁰², N. Viaux Maira ^{140f}, T. Vickey ¹⁴², O.E. Vickey Boeriu ¹⁴²,
 G.H.A. Viehhauser ¹²⁹, L. Vigani ^{64b}, M. Villa ^{24b,24a}, M. Villaplana Perez ¹⁶⁶, E.M. Villhauer ⁵³,
 E. Vilucchi ⁵⁴, M.G. Vincter ³⁵, A. Visible ¹¹⁷, C. Vittori ³⁷, I. Vivarelli ^{24b,24a}, E. Voevodina ¹¹²,
 F. Vogel ¹¹¹, J.C. Voigt ⁵¹, P. Vokac ¹³⁵, Yu. Volkotrub ^{87b}, J. Von Ahnen ⁴⁹, E. Von Toerne ²⁵,
 B. Vormwald ³⁷, V. Vorobel ¹³⁶, K. Vorobev ³⁸, M. Vos ¹⁶⁶, K. Voss ¹⁴⁴, M. Vozak ¹¹⁷,
 L. Vozdecky ¹²³, N. Vranjes ¹⁶, M. Vranjes Milosavljevic ¹⁶, M. Vreeswijk ¹¹⁷, N.K. Vu ^{63d,63c},
 R. Vuillermet ³⁷, O. Vujinovic ¹⁰², I. Vukotic ⁴⁰, S. Wada ¹⁶⁰, C. Wagner ¹⁰⁵, J.M. Wagner ^{18a},
 W. Wagner ¹⁷⁴, S. Wahdan ¹⁷⁴, H. Wahlberg ⁹², M. Wakida ¹¹³, J. Walder ¹³⁷, R. Walker ¹¹¹,
 W. Walkowiak ¹⁴⁴, A. Wall ¹³¹, E.J. Wallin ¹⁰⁰, T. Wamorkar ⁶, A.Z. Wang ¹³⁹, C. Wang ¹⁰²,
 C. Wang ¹¹, H. Wang ^{18a}, J. Wang ^{65c}, P. Wang ⁹⁸, R. Wang ⁶², R. Wang ⁶, S.M. Wang ¹⁵¹,
 S. Wang ^{63b}, S. Wang ¹⁴, T. Wang ^{63a}, W.T. Wang ⁸¹, W. Wang ¹⁴, X. Wang ^{114a}, X. Wang ¹⁶⁵,
 X. Wang ^{63c}, Y. Wang ^{63d}, Y. Wang ^{114a}, Y. Wang ^{63a}, Z. Wang ¹⁰⁸, Z. Wang ^{63d,52,63c},
 Z. Wang ¹⁰⁸, A. Warburton ¹⁰⁶, R.J. Ward ²¹, N. Warrack ⁶⁰, S. Waterhouse ⁹⁷, A.T. Watson ²¹,
 H. Watson ⁶⁰, M.F. Watson ²¹, E. Watton ^{60,137}, G. Watts ¹⁴¹, B.M. Waugh ⁹⁸, J.M. Webb ⁵⁵,
 C. Weber ³⁰, H.A. Weber ¹⁹, M.S. Weber ²⁰, S.M. Weber ^{64a}, C. Wei ^{63a}, Y. Wei ⁵⁵,
 A.R. Weidberg ¹²⁹, E.J. Weik ¹²⁰, J. Weingarten ⁵⁰, C. Weiser ⁵⁵, C.J. Wells ⁴⁹, T. Wenaus ³⁰,
 B. Wendland ⁵⁰, T. Wengler ³⁷, N.S. Wenke ¹¹², N. Wermes ²⁵, M. Wessels ^{64a}, A.M. Wharton ⁹³,
 A.S. White ⁶², A. White ⁸, M.J. White ¹, D. Whiteson ¹⁶², L. Wickremasinghe ¹²⁷,
 W. Wiedenmann ¹⁷³, M. Wielers ¹³⁷, C. Wiglesworth ⁴³, D.J. Wilbern ¹²³, H.G. Wilkens ³⁷,

J.J.H. Wilkinson , D.M. Williams , H.H. Williams¹³¹, S. Williams , S. Willocq , B.J. Wilson , P.J. Windischhofer , F.I. Winkel , F. Winklmeier , B.T. Winter , J.K. Winter , M. Wittgen¹⁴⁶, M. Wobisch , T. Wojtkowski⁶¹, Z. Wolffs , J. Wollrath¹⁶², M.W. Wolter , H. Wolters ^{133a,133c}, M.C. Wong¹³⁹, E.L. Woodward , S.D. Worm , B.K. Wosiek , K.W. Woźniak , S. Wozniowski , K. Wraight , C. Wu , M. Wu ^{114b}, M. Wu , S.L. Wu ¹⁷³, X. Wu ⁵⁷, Y. Wu ^{63a}, Z. Wu ⁴, J. Wuerzinger ^{112,aa}, T.R. Wyatt ¹⁰³, B.M. Wynne , S. Xella ⁴³, L. Xia ^{114a}, M. Xia ¹⁵, M. Xie ^{63a}, S. Xin ^{14,114c}, A. Xiong ¹²⁶, J. Xiong ^{18a}, D. Xu ¹⁴, H. Xu ^{63a}, L. Xu ^{63a}, R. Xu ¹³¹, T. Xu ¹⁰⁸, Y. Xu ¹⁵, Z. Xu ⁵³, Z. Xu^{114a}, B. Yabsley ¹⁵⁰, S. Yacoob ^{34a}, Y. Yamaguchi ¹⁵⁷, E. Yamashita ¹⁵⁶, H. Yamauchi ¹⁶⁰, T. Yamazaki ^{18a}, Y. Yamazaki ⁸⁶, J. Yan^{63c}, S. Yan ⁶⁰, Z. Yan ¹⁰⁵, H.J. Yang ^{63c,63d}, H.T. Yang ^{63a}, S. Yang ^{63a}, T. Yang ^{65c}, X. Yang ³⁷, X. Yang ¹⁴, Y. Yang ⁴⁵, Y. Yang^{63a}, Z. Yang ^{63a}, W.-M. Yao ^{18a}, H. Ye ^{114a}, H. Ye ⁵⁶, J. Ye ¹⁴, S. Ye ³⁰, X. Ye ^{63a}, Y. Yeh ⁹⁸, I. Yeletsikh ³⁹, B.K. Yeo ^{18b}, M.R. Yexley ⁹⁸, T.P. Yildirim ¹²⁹, P. Yin ⁴², K. Yorita ¹⁷¹, S. Younas ^{28b}, C.J.S. Young ³⁷, C. Young ¹⁴⁶, C. Yu ^{14,114c}, Y. Yu ^{63a}, J. Yuan ^{14,114c}, M. Yuan ¹⁰⁸, R. Yuan ^{63d,63c}, L. Yue ⁹⁸, M. Zaazoua ^{63a}, B. Zabinski ⁸⁸, E. Zaid⁵³, Z.K. Zak ⁸⁸, T. Zakareishvili ¹⁶⁶, S. Zambito ⁵⁷, J.A. Zamora Saa ^{140d,140b}, J. Zang ¹⁵⁶, D. Zanzi ⁵⁵, O. Zaplatilek ¹³⁵, C. Zeitnitz ¹⁷⁴, H. Zeng ¹⁴, J.C. Zeng ¹⁶⁵, D.T. Zenger Jr ²⁷, O. Zenin ³⁸, T. Ženiš ^{29a}, S. Zenz ⁹⁶, S. Zerradi ^{36a}, D. Zerwas ⁶⁷, M. Zhai ^{14,114c}, D.F. Zhang ¹⁴², J. Zhang ^{63b}, J. Zhang ⁶, K. Zhang ^{14,114c}, L. Zhang ^{63a}, L. Zhang ^{114a}, P. Zhang ^{14,114c}, R. Zhang ¹⁷³, S. Zhang ¹⁰⁸, S. Zhang ⁹¹, T. Zhang ¹⁵⁶, X. Zhang ^{63c}, X. Zhang ^{63b}, Y. Zhang ^{63c}, Y. Zhang ⁹⁸, Y. Zhang ^{114a}, Z. Zhang ^{18a}, Z. Zhang ^{63b}, Z. Zhang ⁶⁷, H. Zhao ¹⁴¹, T. Zhao ^{63b}, Y. Zhao ¹³⁹, Z. Zhao ^{63a}, Z. Zhao ^{63a}, A. Zhemchugov ³⁹, J. Zheng ^{114a}, K. Zheng ¹⁶⁵, X. Zheng ^{63a}, Z. Zheng ¹⁴⁶, D. Zhong ¹⁶⁵, B. Zhou ¹⁰⁸, H. Zhou ⁷, N. Zhou ^{63c}, Y. Zhou¹⁵, Y. Zhou ^{114a}, Y. Zhou⁷, C.G. Zhu ^{63b}, J. Zhu ¹⁰⁸, X. Zhu^{63d}, Y. Zhu ^{63c}, Y. Zhu ^{63a}, X. Zhuang ¹⁴, K. Zhukov ³⁸, N.I. Zimine ³⁹, J. Zinsser ^{64b}, M. Ziolkowski ¹⁴⁴, L. Živković ¹⁶, A. Zoccoli ^{24b,24a}, K. Zoch ⁶², T.G. Zorbas ¹⁴², O. Zormpa ⁴⁷, W. Zou ⁴², L. Zwalinski ³⁷.

¹Department of Physics, University of Adelaide, Adelaide; Australia.

²Department of Physics, University of Alberta, Edmonton AB; Canada.

³(*a*) Department of Physics, Ankara University, Ankara; (*b*) Division of Physics, TOBB University of Economics and Technology, Ankara; Türkiye.

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

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

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

⁷Department of Physics, University of Arizona, Tucson AZ; United States of America.

⁸Department of Physics, University of Texas at Arlington, Arlington TX; United States of America.

⁹Physics Department, National and Kapodistrian University of Athens, Athens; Greece.

¹⁰Physics Department, National Technical University of Athens, Zografou; Greece.

¹¹Department of Physics, University of Texas at Austin, Austin TX; United States of America.

¹²Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.

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

¹⁴Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; China.

¹⁵Physics Department, Tsinghua University, Beijing; China.

¹⁶Institute of Physics, University of Belgrade, Belgrade; Serbia.

¹⁷Department for Physics and Technology, University of Bergen, Bergen; Norway.

- ^{18(a)}Physics Division, Lawrence Berkeley National Laboratory, Berkeley CA;^(b)University of California, Berkeley CA; United States of America.
- ¹⁹Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany.
- ²⁰Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland.
- ²¹School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom.
- ^{22(a)}Department of Physics, Bogazici University, Istanbul;^(b)Department of Physics Engineering, Gaziantep University, Gaziantep;^(c)Department of Physics, Istanbul University, Istanbul; Türkiye.
- ^{23(a)}Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogotá;^(b)Departamento de Física, Universidad Nacional de Colombia, Bogotá; Colombia.
- ^{24(a)}Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna;^(b)INFN Sezione di Bologna; Italy.
- ²⁵Physikalisches Institut, Universität Bonn, Bonn; Germany.
- ²⁶Department of Physics, Boston University, Boston MA; United States of America.
- ²⁷Department of Physics, Brandeis University, Waltham MA; United States of America.
- ^{28(a)}Transilvania University of Brasov, Brasov;^(b)Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest;^(c)Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi;^(d)National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca;^(e)National University of Science and Technology Politehnica, Bucharest;^(f)West University in Timisoara, Timisoara;^(g)Faculty of Physics, University of Bucharest, Bucharest; Romania.
- ^{29(a)}Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava;^(b)Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice; Slovak Republic.
- ³⁰Physics Department, Brookhaven National Laboratory, Upton NY; United States of America.
- ³¹Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires; Argentina.
- ³²California State University, CA; United States of America.
- ³³Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom.
- ^{34(a)}Department of Physics, University of Cape Town, Cape Town;^(b)iThemba Labs, Western Cape;^(c)Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg;^(d)National Institute of Physics, University of the Philippines Diliman (Philippines);^(e)University of South Africa, Department of Physics, Pretoria;^(f)University of Zululand, KwaDlangezwa;^(g)School of Physics, University of the Witwatersrand, Johannesburg; South Africa.
- ³⁵Department of Physics, Carleton University, Ottawa ON; Canada.
- ^{36(a)}Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca;^(b)Faculté des Sciences, Université Ibn-Tofail, Kénitra;^(c)Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech;^(d)LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda;^(e)Faculté des sciences, Université Mohammed V, Rabat;^(f)Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
- ³⁷CERN, Geneva; Switzerland.
- ³⁸Affiliated with an institute covered by a cooperation agreement with CERN.
- ³⁹Affiliated with an international laboratory covered by a cooperation agreement with CERN.
- ⁴⁰Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America.
- ⁴¹LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France.
- ⁴²Nevis Laboratory, Columbia University, Irvington NY; United States of America.
- ⁴³Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark.
- ^{44(a)}Dipartimento di Fisica, Università della Calabria, Rende;^(b)INFN Gruppo Collegato di Cosenza,

Laboratori Nazionali di Frascati; Italy.

⁴⁵Physics Department, Southern Methodist University, Dallas TX; United States of America.

⁴⁶Physics Department, University of Texas at Dallas, Richardson TX; United States of America.

⁴⁷National Centre for Scientific Research "Demokritos", Agia Paraskevi; Greece.

⁴⁸(^a) Department of Physics, Stockholm University; (^b) Oskar Klein Centre, Stockholm; Sweden.

⁴⁹Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany.

⁵⁰Fakultät Physik, Technische Universität Dortmund, Dortmund; Germany.

⁵¹Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany.

⁵²Department of Physics, Duke University, Durham NC; United States of America.

⁵³SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom.

⁵⁴INFN e Laboratori Nazionali di Frascati, Frascati; Italy.

⁵⁵Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.

⁵⁶II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany.

⁵⁷Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.

⁵⁸(^a) Dipartimento di Fisica, Università di Genova, Genova; (^b) INFN Sezione di Genova; Italy.

⁵⁹II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany.

⁶⁰SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom.

⁶¹LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France.

⁶²Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America.

⁶³(^a) Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei; (^b) Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao; (^c) School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai; (^d) Tsung-Dao Lee Institute, Shanghai; (^e) School of Physics and Microelectronics, Zhengzhou University; China.

⁶⁴(^a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; (^b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany.

⁶⁵(^a) Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong; (^b) Department of Physics, University of Hong Kong, Hong Kong; (^c) Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong; China.

⁶⁶Department of Physics, National Tsing Hua University, Hsinchu; Taiwan.

⁶⁷IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France.

⁶⁸Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona; Spain.

⁶⁹Department of Physics, Indiana University, Bloomington IN; United States of America.

⁷⁰(^a) INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine; (^b) ICTP, Trieste; (^c) Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine; Italy.

⁷¹(^a) INFN Sezione di Lecce; (^b) Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy.

⁷²(^a) INFN Sezione di Milano; (^b) Dipartimento di Fisica, Università di Milano, Milano; Italy.

⁷³(^a) INFN Sezione di Napoli; (^b) Dipartimento di Fisica, Università di Napoli, Napoli; Italy.

⁷⁴(^a) INFN Sezione di Pavia; (^b) Dipartimento di Fisica, Università di Pavia, Pavia; Italy.

⁷⁵(^a) INFN Sezione di Pisa; (^b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy.

⁷⁶(^a) INFN Sezione di Roma; (^b) Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy.

⁷⁷(^a) INFN Sezione di Roma Tor Vergata; (^b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy.

⁷⁸(^a) INFN Sezione di Roma Tre; (^b) Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy.

- ^{79(a)}INFN-TIFPA;^(b)Università degli Studi di Trento, Trento; Italy.
- ⁸⁰Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck; Austria.
- ⁸¹University of Iowa, Iowa City IA; United States of America.
- ⁸²Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America.
- ⁸³Istinye University, Sariyer, Istanbul; Türkiye.
- ^{84(a)}Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora;^(b)Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro;^(c)Instituto de Física, Universidade de São Paulo, São Paulo;^(d)Rio de Janeiro State University, Rio de Janeiro;^(e)Federal University of Bahia, Bahia; Brazil.
- ⁸⁵KEK, High Energy Accelerator Research Organization, Tsukuba; Japan.
- ⁸⁶Graduate School of Science, Kobe University, Kobe; Japan.
- ^{87(a)}AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow;^(b)Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland.
- ⁸⁸Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland.
- ⁸⁹Faculty of Science, Kyoto University, Kyoto; Japan.
- ⁹⁰Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka ; Japan.
- ⁹¹L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse; France.
- ⁹²Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina.
- ⁹³Physics Department, Lancaster University, Lancaster; United Kingdom.
- ⁹⁴Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom.
- ⁹⁵Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia.
- ⁹⁶School of Physics and Astronomy, Queen Mary University of London, London; United Kingdom.
- ⁹⁷Department of Physics, Royal Holloway University of London, Egham; United Kingdom.
- ⁹⁸Department of Physics and Astronomy, University College London, London; United Kingdom.
- ⁹⁹Louisiana Tech University, Ruston LA; United States of America.
- ¹⁰⁰Fysiska institutionen, Lunds universitet, Lund; Sweden.
- ¹⁰¹Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain.
- ¹⁰²Institut für Physik, Universität Mainz, Mainz; Germany.
- ¹⁰³School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom.
- ¹⁰⁴CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.
- ¹⁰⁵Department of Physics, University of Massachusetts, Amherst MA; United States of America.
- ¹⁰⁶Department of Physics, McGill University, Montreal QC; Canada.
- ¹⁰⁷School of Physics, University of Melbourne, Victoria; Australia.
- ¹⁰⁸Department of Physics, University of Michigan, Ann Arbor MI; United States of America.
- ¹⁰⁹Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.
- ¹¹⁰Group of Particle Physics, University of Montreal, Montreal QC; Canada.
- ¹¹¹Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany.
- ¹¹²Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany.
- ¹¹³Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan.
- ^{114(a)}Department of Physics, Nanjing University, Nanjing;^(b)School of Science, Shenzhen Campus of Sun Yat-sen University;^(c)University of Chinese Academy of Science (UCAS), Beijing; China.
- ¹¹⁵Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America.
- ¹¹⁶Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen;

Netherlands.

¹¹⁷Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands.

¹¹⁸Department of Physics, Northern Illinois University, DeKalb IL; United States of America.

¹¹⁹(^a)New York University Abu Dhabi, Abu Dhabi;(^b)United Arab Emirates University, Al Ain; United Arab Emirates.

¹²⁰Department of Physics, New York University, New York NY; United States of America.

¹²¹Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan.

¹²²Ohio State University, Columbus OH; United States of America.

¹²³Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America.

¹²⁴Department of Physics, Oklahoma State University, Stillwater OK; United States of America.

¹²⁵Palacký University, Joint Laboratory of Optics, Olomouc; Czech Republic.

¹²⁶Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America.

¹²⁷Graduate School of Science, Osaka University, Osaka; Japan.

¹²⁸Department of Physics, University of Oslo, Oslo; Norway.

¹²⁹Department of Physics, Oxford University, Oxford; United Kingdom.

¹³⁰LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris; France.

¹³¹Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America.

¹³²Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America.

¹³³(^a)Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa;(^b)Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa;(^c)Departamento de Física, Universidade de Coimbra, Coimbra;(^d)Centro de Física Nuclear da Universidade de Lisboa, Lisboa;(^e)Departamento de Física, Universidade do Minho, Braga;(^f)Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain);(^g)Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal.

¹³⁴Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic.

¹³⁵Czech Technical University in Prague, Prague; Czech Republic.

¹³⁶Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic.

¹³⁷Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom.

¹³⁸IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.

¹³⁹Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America.

¹⁴⁰(^a)Departamento de Física, Pontificia Universidad Católica de Chile, Santiago;(^b)Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago;(^c)Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena;(^d)Universidad Andres Bello, Department of Physics, Santiago;(^e)Instituto de Alta Investigación, Universidad de Tarapacá, Arica;(^f)Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile.

¹⁴¹Department of Physics, University of Washington, Seattle WA; United States of America.

¹⁴²Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.

¹⁴³Department of Physics, Shinshu University, Nagano; Japan.

¹⁴⁴Department Physik, Universität Siegen, Siegen; Germany.

¹⁴⁵Department of Physics, Simon Fraser University, Burnaby BC; Canada.

¹⁴⁶SLAC National Accelerator Laboratory, Stanford CA; United States of America.

¹⁴⁷Department of Physics, Royal Institute of Technology, Stockholm; Sweden.

- ¹⁴⁸Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America.
- ¹⁴⁹Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom.
- ¹⁵⁰School of Physics, University of Sydney, Sydney; Australia.
- ¹⁵¹Institute of Physics, Academia Sinica, Taipei; Taiwan.
- ¹⁵²^(a)E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi;^(b)High Energy Physics Institute, Tbilisi State University, Tbilisi;^(c)University of Georgia, Tbilisi; Georgia.
- ¹⁵³Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel.
- ¹⁵⁴Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel.
- ¹⁵⁵Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece.
- ¹⁵⁶International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan.
- ¹⁵⁷Department of Physics, Tokyo Institute of Technology, Tokyo; Japan.
- ¹⁵⁸Department of Physics, University of Toronto, Toronto ON; Canada.
- ¹⁵⁹^(a)TRIUMF, Vancouver BC;^(b)Department of Physics and Astronomy, York University, Toronto ON; Canada.
- ¹⁶⁰Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan.
- ¹⁶¹Department of Physics and Astronomy, Tufts University, Medford MA; United States of America.
- ¹⁶²Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America.
- ¹⁶³University of Sharjah, Sharjah; United Arab Emirates.
- ¹⁶⁴Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden.
- ¹⁶⁵Department of Physics, University of Illinois, Urbana IL; United States of America.
- ¹⁶⁶Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain.
- ¹⁶⁷Department of Physics, University of British Columbia, Vancouver BC; Canada.
- ¹⁶⁸Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.
- ¹⁶⁹Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany.
- ¹⁷⁰Department of Physics, University of Warwick, Coventry; United Kingdom.
- ¹⁷¹Waseda University, Tokyo; Japan.
- ¹⁷²Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel.
- ¹⁷³Department of Physics, University of Wisconsin, Madison WI; United States of America.
- ¹⁷⁴Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
- ¹⁷⁵Department of Physics, Yale University, New Haven CT; United States of America.
- ^a Also Affiliated with an institute covered by a cooperation agreement with CERN.
- ^b Also at An-Najah National University, Nablus; Palestine.
- ^c Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.
- ^d Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki; Greece.
- ^e Also at Centro Studi e Ricerche Enrico Fermi; Italy.
- ^f Also at CERN, Geneva; Switzerland.
- ^g Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
- ^h Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona; Spain.
- ⁱ Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.
- ^j Also at Department of Physics, California State University, Sacramento; United States of America.

- ^k Also at Department of Physics, King's College London, London; United Kingdom.
- ^l Also at Department of Physics, Stanford University, Stanford CA; United States of America.
- ^m Also at Department of Physics, Stellenbosch University; South Africa.
- ⁿ Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
- ^o Also at Department of Physics, University of Thessaly; Greece.
- ^p Also at Department of Physics, Westmont College, Santa Barbara; United States of America.
- ^q Also at Hellenic Open University, Patras; Greece.
- ^r Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
- ^s Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
- ^t Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia; Bulgaria.
- ^u Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
- ^v Also at Institute of Particle Physics (IPP); Canada.
- ^w Also at Institute of Physics and Technology, Mongolian Academy of Sciences, Ulaanbaatar; Mongolia.
- ^x Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
- ^y Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
- ^z Also at National Institute of Physics, University of the Philippines Diliman (Philippines); Philippines.
- ^{aa} Also at Technical University of Munich, Munich; Germany.
- ^{ab} Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
- ^{ac} Also at TRIUMF, Vancouver BC; Canada.
- ^{ad} Also at Università di Napoli Parthenope, Napoli; Italy.
- ^{ae} Also at University of Colorado Boulder, Department of Physics, Colorado; United States of America.
- ^{af} Also at Washington College, Chestertown, MD; United States of America.
- ^{ag} Also at Yeditepe University, Physics Department, Istanbul; Türkiye.
- * Deceased