EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: Physical Review Letters

CERN-EP-2023-184
1st September 2023

Measurements of longitudinal flow decorrelations in pp and Xe+Xe collisions with the ATLAS detector

The ATLAS Collaboration

Measurements of longitudinal flow decorrelations in 13 TeV pp and 5.44 TeV Xe+Xe collisions with the ATLAS detector are presented. The measurements are performed using the two-particle correlation method, combining charged-particle tracks within $|\eta| < 2.5$ with either calorimeter energy clusters or towers within $4.0 < |\eta| < 4.9$. A template-based subtraction procedure is used to remove non-flow effects in both the pp and the Xe+Xe analyses. The dependence of the longitudinal flow decorrelations on the pseudorapidity separation between the particles is characterized via the slope parameter F_n for the elliptic ($n = 2$) and triangular ($n = 3$) harmonic moments. The results are reported as a function of charged-particle multiplicity for the pp and Xe+Xe collision systems. Comparing the data to a color string-based model of the initial geometry indicates that in pp and peripheral Xe+Xe collisions, sub-nucleonic structure and fluctuations in longitudinal energy deposition are needed to describe the data.

Relativistic heavy-ion collisions are understood to create nucleus-sized droplets of quark-gluon plasma (QGP), where the time evolution is well described by nearly inviscid hydrodynamics [1]. This hydrodynamic modeling of collisions of large nuclei has been successfully extended to collisions of smaller nuclei and even proton-proton (pp) collisions [2]. An accurate description requires a quantitative description of the energy deposited at the earliest time of the collision. Conversely, observables sensitive to hydrodynamic behavior also allow one to learn about the nuclear geometry, nucleon fluctuations, and even sub-nucleonic structure.

In the plane transverse to the beams, an anisotropic initial state (resulting from the intrinsic nuclear geometry and fluctuations at the nucleon, sub-nucleon or even gluon field level [3–5]) evolves hydrodynamically to produce an azimuthally anisotropic final state with particle yields characterized by $dN/d\phi \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\phi - \Psi_n)]$, where the v_n are Fourier moments referred to as flow coefficients, ϕ is the azimuthal angle in the transverse plane [6], and Ψ_n is the n^{th} order event plane. If the deposited energy is boost invariant [7], the Ψ_n and v_n are rapidity independent. However, if the deposited energy is not boost invariant, i.e., not uniform along the beam direction, there may be a rapidity dependence of Ψ_n and v_n, which is referred to as longitudinal flow decorrelation. Numerous works have modeled longitudinal decorrelations and made specific predictions for experimental observables [8–13]. Other calculations, suggesting strong initial-state momentum anisotropies that may carry through to the final state, have a larger longitudinal decorrelation than ones based on longitudinally fluctuating energy deposition [14, 15].

Experiments have measured longitudinal decorrelations in Pb+Pb [16, 17] and Xe+Xe [18] collisions. Calculations based on initial-state color strings, longitudinally extended objects modeling long-range gluon fields [19], such as AMPT [20], yield a longitudinally dependent geometry from the finite length of the strings and qualitatively describe these data [11]. It is crucial to extend these measurements to pp collisions and lower-multiplicity nucleus-nucleus collisions for understanding the role of sub-nucleonic degrees of freedom where their role is expected to dominate.

In this Letter, longitudinal decorrelations are measured in 13 TeV pp and 5.44 TeV Xe+Xe collisions via the comparison of large-rapidity-gap ($\Delta\eta \approx 7$) to small-rapidity-gap ($\Delta\eta \approx 2$) correlations, similar to the previous measurements, which construct correlations between charged-particle tracks around mid rapidity and a reconstructed event-plane angle Ψ_n at very forward rapidity [16–18]. In the case of pp or low-multiplicity heavy-ion collisions, significant *non-flow* correlations, which are not arising from many-body collective motion, such as from jets and particle decays, can mimic a longitudinal decorrelation signal, and must therefore be corrected for [21]. It is also important to explore these effects in previously measured large systems [18]. Here, the two-particle correlation (2PC) method is employed using charged-particle tracks and energy deposits in the forward calorimeter, which then allows the application of non-flow subtraction (NFS) procedures [22–25]. Because the 2PC method is ubiquitous, a detailed understanding of the longitudinal dependence has great practical importance, for example, when comparing results between experiments with different η acceptances [26, 27].

The ATLAS detector [28] is a general-purpose particle detector with a nearly full solid-angle acceptance and many detector subsystems, which makes it well suited for understanding the underlying correlations between particles across a large range in pseudorapidity. The main subsystems used in this measurement are the tracking detectors, a subset of the calorimeter system, and the trigger system.

The inner detector (ID) provides charged-particle tracking within $|\eta| < 2.5$ via a combination of subsystems: a silicon-pixel detector (including the insertable B-layer [29, 30]), a silicon microstrip detector, and a straw-tube transition-radiation tracker.

The calorimeter provides full ϕ coverage within $|\eta| < 4.9$ acceptance. The forward regions, $3.2 < |\eta| < 4.9$, are instrumented with liquid-argon calorimeters (FCals) that include both electromagnetic (EM) and hadronic layers. Sets of FCal cells at similar η-ϕ positions, over its multiple layers, are combined into *towers*. Separately, FCal cells can be clustered in three dimensions into topologically connected clusters [31], referred to as topoclusters, which are more closely associated with single-particle energy depositions than the set of towers. Topoclusters cannot be reconstructed in Xe+Xe collisions due to the high occupancy in the FCal, and hence topoclusters are only reconstructed in pp data. The energy in both the towers and clusters is evaluated at the electromagnetic scale [32].

A two-level trigger system [33] is used to select events. The first trigger level is hardware-based and uses a subset of the detector information to restrict the accepted rate to be below 100 kHz. This is followed by a software-based high-level trigger (HLT) stage, which reduces the accepted event rate to a few kHz, depending on the data-taking conditions. An extensive software suite [34] is used in data simulation, in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems of the experiment.

The 13 TeV pp analysis uses 1.7 pb^{-1} of collision data recorded throughout 2015–2018 in which the average number of interactions per a crossing was less than 1.25. The collision data was recorded utilizing a variety of triggers, including minimum bias triggers and triggers enhancing the sample of high-multiplicity events [35]. The $\sqrt{s_{\mathrm{NN}}} = 5.44$ TeV Xe+Xe analysis uses 3 μb^{-1} of collision data collected in 2017, with the triggers and offline criteria initially selecting minimum-bias events as described in Ref. [18]. Xe+Xe events were further required to satisfy a reconstructed pseudo-rapidity gap requirement similar to that in Ref. [36] to reject the possible contribution of photo-nuclear processes to low-multiplicity events.

For both the pp and Xe+Xe data, the reconstructed primary vertex [37] is required to be within 100 mm of the center of the detector along the z-axis. In the pp data, events with multiple collisions are suppressed by requiring only one reconstructed vertex. Charged-particle tracks are reconstructed in the ID and must satisfy quality criteria related to the number of hits in different ID layers and their projected distance of closest approach to the primary vertex [38]. Tracks used in the correlation analysis are required to have $|\eta| < 2.5$ and $0.3 < p_{\mathrm{T}} < 5.0$ GeV. However, the reconstructed charged-particle multiplicity, $N_{\mathrm{ch}}^{\mathrm{rec}}$, is defined as the number of tracks with $|\eta| < 2.5$ and $p_{\mathrm{T}} > 0.4$ GeV in the event, to match the definition in previous measurements [18, 39].

The 2PC function measures the relative azimuthal angle between particles of type a and so-called reference particles. The a particles are charged-particle tracks with $0.3 < p_{\mathrm{T}} < 5.0$ GeV, and the correlation function is evaluated as a function of their pseudorapidity, η^a. For pp collisions, the reference particles are topoclusters with $0.5 < E_{\mathrm{T}} < 5.0$ GeV and $4.0 < \eta < 4.9$, as measured in the FCal. For Xe+Xe collisions, FCal towers with $E_{\mathrm{T}} < 5$ GeV and $4.0 < \eta < 4.9$ are utilized. As a component of the NFS in Xe+Xe data, detailed below, 5.02 TeV pp collision data, recorded in 2017, is used which utilizes FCal towers as well. Due to the symmetric nature of the collisions and ATLAS acceptance, each event was also analyzed by swapping the pseudorapidity sign and using the other FCal. The two results are compatible within uncertainties.

The track-topocluster or track-tower pair correlation functions of relative azimuthal angle, $\Delta\phi = \phi^a - \phi^{\mathrm{ref}}$, were constructed for all possible pairs as a function of charged-particle track η^a. Each entry in the distributions was weighted by $1/\varepsilon_{\mathrm{trk}}$, where $\varepsilon_{\mathrm{trk}}$ is the p_{T}- and η-dependent tracking efficiency. The efficiency applied to the pp (Xe+Xe) data was obtained using events generated with Pythia8 [19] (Hijing [40]) and passed through a Geant4 simulation [34, 41] of the ATLAS detector. For the track-tower pairs, there is an additional weighting by the calorimeter tower transverse energy to account for the energy

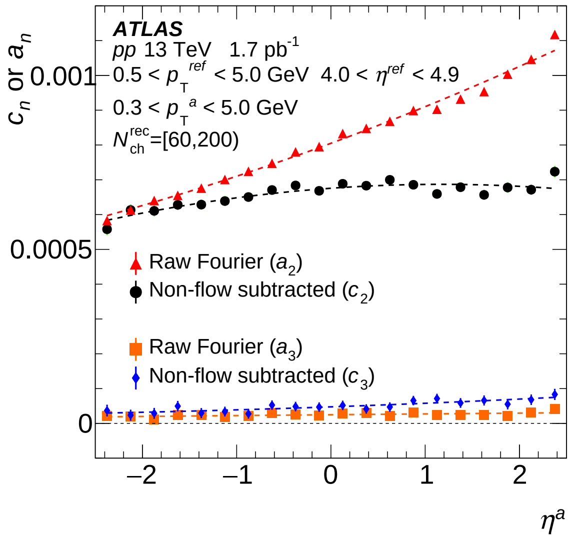

Figure 1: Coefficients a_n and c_n in high-multiplicity 13 TeV pp events for $n = 2, 3$ as a function of track pseudorapidity η^a. The c_n values are obtained from the template fitting method. The dashed lines represent a fit to a quadratic function in η^a for each set of coefficients. The pseudorapidity gap between the cluster and track pair is largest for negative η^a and decreases moving to positive η^a. Only statistical uncertainties are shown.

deposition of particles. As is standard in 2PC analyses [22, 35, 36], the correlation functions were then corrected for the impact of detector non-uniformity through a mixed-event procedure and normalized to a total integral of 2π. The resulting correlation functions, $Y(\Delta\phi, \eta^a)$, were expressed as a Fourier series, $Y = G\left\{1 + 2\sum_{n=1}^{4} a_n(\eta^a)\cos(n\Delta\phi)\right\}$, where the η^a-dependent coefficients a_n are the "raw" Fourier coefficients of order n and G is the normalization factor. An example of the $a_n(\eta^a)$ values in pp collisions is shown in Figure 1.

The contribution of non-flow to the correlation functions was removed using a template-based NFS method [22, 36, 42]. In this method, a low-multiplicity (LM) correlation function is used as a "template" that has a larger non-flow contribution, which then allows the non-flow contribution to be statistically removed from a high-multiplicity (HM) correlation function. To extract the flow coefficients, the template method relies on some assumptions, such as the Fourier a_1 term being completely due to non-flow and the shape of the non-flow correlation not changing with multiplicity. The template method and associated assumptions are standard in flow measurement, and many have been validated in data [22, 23, 26].

In the 13 TeV pp data and the 5.02 TeV pp data (used only as the Xe+Xe LM reference), the LM correlation function is constructed using events with multiplicity $10 \leq N_{ch}^{rec} < 30$. Each HM correlation function $Y^{HM}(\Delta\phi)$ was fit with a weighted sum of the analogous LM correlation function, $Y^{LM}(\Delta\phi)$, and an azimuthally modulated pedestal characterized by a set of flow coefficients c_n, i.e., $Y^{HM}(\Delta\phi) = w_1 Y^{LM}(\Delta\phi) + w_2\left(1 + 2\sum_{n=2}^{4} c_n\cos(n\Delta\phi)\right)$, where $w_{1,2}$ are the weight factors. This fitting was performed separately for each η^a selection, resulting in η^a-dependent NFS coefficients $c_n(\eta^a)$, examples of which can also be seen in Figure 1. Example 2PCs for individual η^a bins and their associated template fits can be viewed in the Appendix.

The longitudinal decorrelation effect was measured by fitting the coefficients $c_n(\eta^a)$ and $a_n(\eta^a)$ to the quadratic functional form $A_n\left(1 + F_n \cdot \eta^a + S_n \cdot (\eta^a)^2\right)$, with the following three free parameters: A_n, which accounts for the overall magnitude of the coefficients; F_n, which describes the relative decrease of c_n or a_n with η^a and thus characterizes the linear decorrelation strength; and S_n, which models any higher-order dependence on η^a. Higher order terms $(\eta^a)^n$, i.e., $n > 2$, provide negligible contributions. In previous measurements [16, 18], the decorrelation parameter F_n was defined differently. These definitions are all nearly identical in the limit of small F_n, but the definition used in this Letter is more well-suited for large raw F_n values before NFS, see the Appendix for details.

Figure 1 shows an example of the η^a-dependent correlation coefficients, measured in high-multiplicity ($60 \le N_{\mathrm{ch}}^{\mathrm{rec}} < 200$) 13 TeV pp collisions. The raw Fourier coefficients a_2 and a_3, which are sensitive to contributions from non-flow effects, decrease in magnitude as the gap between the a particles (tracks) and reference particles (clusters) increases. The correlation coefficient c_2, which has had the NFS procedure applied, shows a weaker variation with track-cluster pseudorapidity separation. The opposite is true for coefficient c_3, which has a stronger variation with separation after NFS. This is a result of contributions from non-flow to a_n, which are of opposite sign for a_2 and a_3. The η^a-dependent differences between the c_n and a_n values highlight the need to account for non-flow effects in the measurement. The results of applying the η^a-dependent fits, used to extract the values of F_n, are also shown and provide a good characterization of the data. Similar examples of correlation coefficients as a function of η^a in Xe+Xe collisions can be viewed in the Appendix.

In the track-tower measurement, since the energy in nearby towers is correlated, a bootstrapping method using pseudo-experiment sampling [43] was used to determine the statistical uncertainties. For both the track-tower and track-topocluster measurements, multiple potential sources of systematic uncertainty were evaluated, with those having a significant impact on the measurement summarized here. The uncertainty associated with the choice of low-multiplicity reference in the template method (nominally $10 \le N_{\mathrm{ch}}^{\mathrm{rec}} < 30$) was evaluated by using alternative, but partially overlapping, ranges in $N_{\mathrm{ch}}^{\mathrm{rec}}$. The uncertainty in the mixed-event correction procedure was evaluated by changing the required similarity of the mixed events in $N_{\mathrm{ch}}^{\mathrm{rec}}$ and the z-coordinate of the vertex. The sensitivity to the track selection was evaluated by varying the track quality criteria and the reconstruction efficiency ϵ^{trk} by its uncertainty [38]. The sensitivity to the trigger composition in pp data was evaluated by raising the trigger efficiency requirement of 70% to 80%. Different uncertainty sources were dominant in different $N_{\mathrm{ch}}^{\mathrm{rec}}$ ranges, collision systems, and observables, with no single one dominant. For the pp results, the statistical uncertainties are larger than systematic uncertainties in all cases.

Figure 2 presents the longitudinal decorrelation parameters F_n in pp collisions at 13 TeV and Xe+Xe collisions at 5.44 TeV as a function of $N_{\mathrm{ch}}^{\mathrm{rec}}$. The measured F_n values extracted from fits to the correlation coefficients $c_n(\eta^a)$ are shown for $n = 2, 3$, as well as raw values for $n = 1, 2, 3$ obtained from quadratic fits to the Fourier coefficients $a_n(\eta^a)$ before the application of the NFS.

In pp collisions, the raw F_2 values decrease strongly with increasing $N_{\mathrm{ch}}^{\mathrm{rec}}$, reflecting the changing relative contribution from flow and non-flow. With NFS, an $N_{\mathrm{ch}}^{\mathrm{rec}}$-independent $F_2 \approx 0.02$–0.03 is observed. The data also yields a measurement of NFS F_3, which is large and positive at ≈ 0.2. Notably, the effect of NFS is to decrease the F_2 values while increasing those of F_3.

As in pp, the raw F_2 in Xe+Xe decreases strongly with $N_{\mathrm{ch}}^{\mathrm{rec}}$, but with a small increase in the highest $N_{\mathrm{ch}}^{\mathrm{rec}}$ events. These results are similar to the previous measurement performed without NFS [18]. The NFS F_2 values are smaller than the raw ones by more than a factor of three (two) at low $N_{\mathrm{ch}}^{\mathrm{rec}}$ (large $N_{\mathrm{ch}}^{\mathrm{rec}}$), and range from ≈ 0.03 to ≈ 0.005 (note the $\times 2$ applied to the raw Fourier in the left panel of Fig. 2). The measurement of F_3 is less sensitive to the application of NFS, and the resulting values are larger than those for F_2 over most of the multiplicity range.

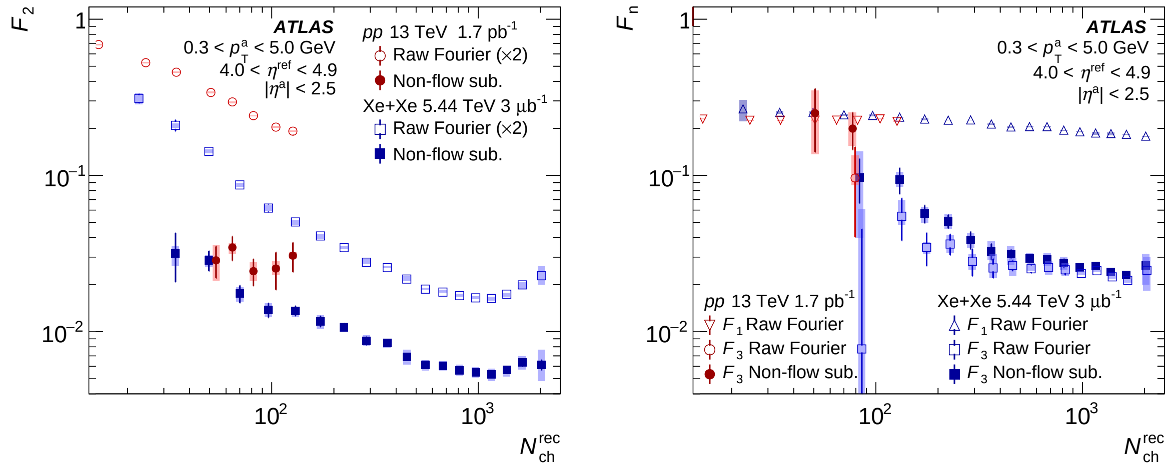

Figure 2: Longitudinal decorrelation parameters F_n for 13 TeV pp (red) and 5.44 TeV Xe+Xe (blue) for $n = 2$ (left) and $n = 1, 3$ (right) as a function of N_{ch}^{rec}. The parameters are reported after the application of the NFS to the correlation function (solid markers), and those derived from fits to the raw Fourier coefficients (open markers). The statistical (systematic) uncertainties are drawn as vertical lines (shaded boxes). Points with errors exceeding 0.15 are not shown.

Even in the highest N_{ch}^{rec} Xe+Xe collisions, there are important non-flow corrections to F_2 and F_3. However, the template fitting method assumes that there is no modification to the non-flow correlation shape as a function of N_{ch}^{rec}. Jet quenching effects, where partons lose energy in the QGP, are known to suppress the yields of jet-correlated particles and modify their angular distributions [44, 45]. Additionally, the slow change of F_1 with N_{ch}^{rec}, which reflects only non-flow, may indicate a shape modification or the presence of another source of first harmonic correlations [23, 46]. Further exploration of these possible effects, or other observables less sensitive to non-flow [21], may be required for precision data-model comparisons in this large-N_{ch}^{rec} region.

For the template fit to give an unbiased measurement of flow decorrelation, the flow decorrelation in the template and the HM data must be similar, see the Appendix for details. In the case of the pp analysis, the NFS F_2 results are consistent with an N_{ch}^{rec}-independent flow decorrelation and thus no bias is incurred. However, the Xe+Xe F_2 is not N_{ch}^{rec} independent, thus a precise calculation of the possible incurred bias has to be performed. Given a range of possible 5.02 TeV pp F_2 values of 0.00–0.07, this potential bias was determined to be at the 0 to +10% level.

At the lowest multiplicities, $N_{ch}^{rec} \approx 30$–50, where the Xe+Xe events have a large contribution from single nucleon-nucleon collision configurations, the F_2 values with NFS are similar to those in pp events. At larger multiplicities, the F_2 values remain large in pp collisions but decrease in Xe+Xe collisions, indicating that the mechanism of additional particle production is different in the two systems. These results, along with the lack of N_{ch}^{rec} dependence of azimuthal anisotropy in pp collisions [35], suggest that the correlation between the initial-state geometry and overall particle production is different at sub-nucleonic scales than at nucleonic scales. The F_3 results in pp and Xe+Xe collisions are statistically compatible, agreeing with the qualitative picture indicated by the F_2 results.

The data are further compared with calculations from the AMPT model [20] as shown in Fig. 3. AMPT is a kinetic transport model that starts from a full three-dimensional initial state of color strings, evolves partons from those strings, the partons scatter, and finally hadronize via a coalescence prescription. AMPT

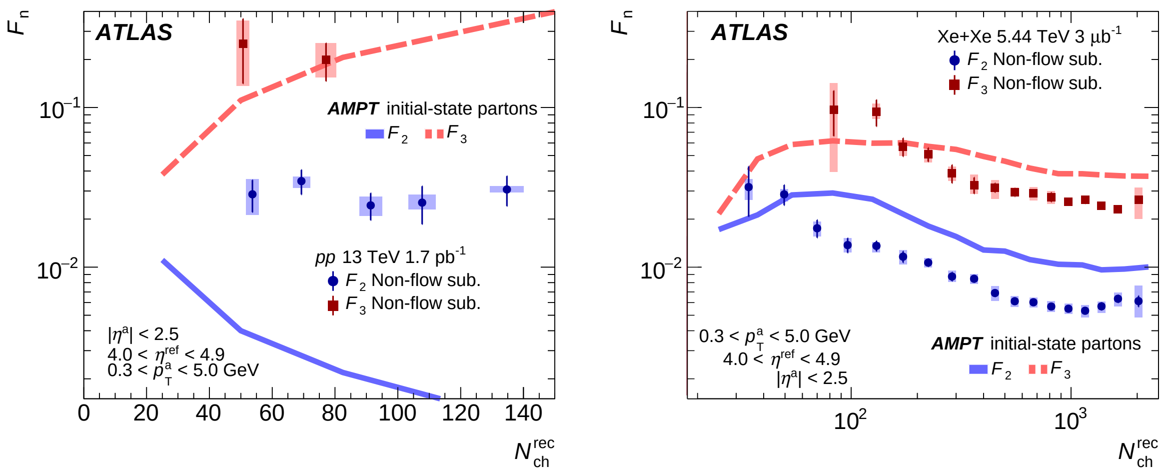

Figure 3: Comparison of AMPT theory calculations to the 13 TeV pp (left) and 5.44 TeV Xe+Xe (right) results. In data, the non-flow subtracted F_n values are shown as a function of N_{ch}^{rec}. The statistical (systematic) uncertainties are drawn as vertical lines (shaded bands).

has been shown to reproduce a broad range of observables related to bulk collectivity in nucleus-nucleus collisions [47]. Since the initial-state geometry in AMPT is known, the F_n parameters can be calculated directly via the decorrelation of the spatial eccentricity vectors [11] as a function of pseudorapidity separation, thus avoiding the non-flow effects introduced by 2PC methods. The spatial eccentricity vectors are calculated from the positions of the partons when they form via the color strings. The AMPT Xe+Xe charged particle multiplicity was scaled by a factor of 0.5, to reproduce the distribution of N_{ch}^{rec} in data. No rescaling was applied to the AMPT pp predictions.

For pp collisions, the simple geometric description in AMPT in terms of two color strings spanning a large longitudinal extent (thus resulting in small F_2) is highly disfavored by the data. In contrast the F_3 is well described and should arise primarily via geometry fluctuations. In the case of Xe+Xe, AMPT shows a qualitative agreement for the multiplicity dependence of $F_{2,3}$, though a factor of two higher than the data for $N_{ch}^{rec} > 250$. Moving to lower N_{ch}^{rec} Xe+Xe collisions, the AMPT $F_{2,3}$ values turn over and begin to decrease, which is not present in the data. This decreasing behavior is likely due to the prevalence of geometries with very few strings, including the single nucleon-nucleon (i.e., pp-like) case.

In conclusion, this paper presents the measurements of longitudinal flow decorrelation parameters F_n in 13 TeV pp and 5.44 TeV Xe+Xe collisions. These results are derived from pseudorapidity-separated two-particle correlations, after the application of a template-based non-flow subtraction. Both the systems feature large decorrelation signals in low-multiplicity events that are N_{ch}^{rec}-independent in pp and decrease with increasing N_{ch}^{rec} in Xe+Xe. The data were compared with the AMPT color-string geometry calculations, which have a good qualitative modeling for the large N_{ch}^{rec} Xe+Xe data but significantly under-predict the decorrelation effects in single nucleon-nucleon collisions, both in the pp collisions and potentially the Xe+Xe collisions. The results when compared with a color string-based model of the initial geometry indicate that in pp and low-multiplicity Xe+Xe collisions, sub-nucleonic structure and fluctuations in longitudinal energy deposition are needed to describe the data. In contrast, high-multiplicity Xe+Xe and Pb+Pb collisions have longitudinal decorrelations reasonably understood in terms of intrinsic nuclear geometry and fluctuating longitudinal energy deposition at the nucleon scale.

Acknowledgments

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

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; ANID, Chile; CAS, MOST and NSFC, China; Minciencias, Colombia; MEYS CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ISF and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MEiN, Poland; FCT, Portugal; MNE/IFA, Romania; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DSI/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TENMAK, Türkiye; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada and CRC, Canada; PRIMUS 21/SCI/017 and UNCE SCI/013, Czech Republic; COST, ERC, ERDF, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex, Investissements d'Avenir Idex and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and MINERVA, Israel; Norwegian Financial Mechanism 2014-2021, Norway; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [48].

Appendix

Correlation functions and coefficients

Examples of the 2PC functions are shown in Fig. 4 for pp in the left two panels and Xe+Xe in the right two panels for different $N_{\mathrm{ch}}^{\mathrm{rec}}$ selections. In all cases, the ID charged-particle tracks are used as a-type particles and FCal topoclusters (towers) are used as reference particles for pp collisions (Xe+Xe collisions). In all cases, there is peak-like feature centered at $\Delta\Phi = \pi$, which is dominated by contributions from non-flow correlations, specifically dijets, and is well described by the low multiplicity template $Y^{\mathrm{LM}}(\Delta\Phi)$. The residual flow-like correlation after NFS is shown in the lower panels.

The resulting correlation coefficients from the raw Fourier fit and NFS for Xe+Xe collisions in two $N_{\mathrm{ch}}^{\mathrm{rec}}$ ranges are shown in Fig. 5.

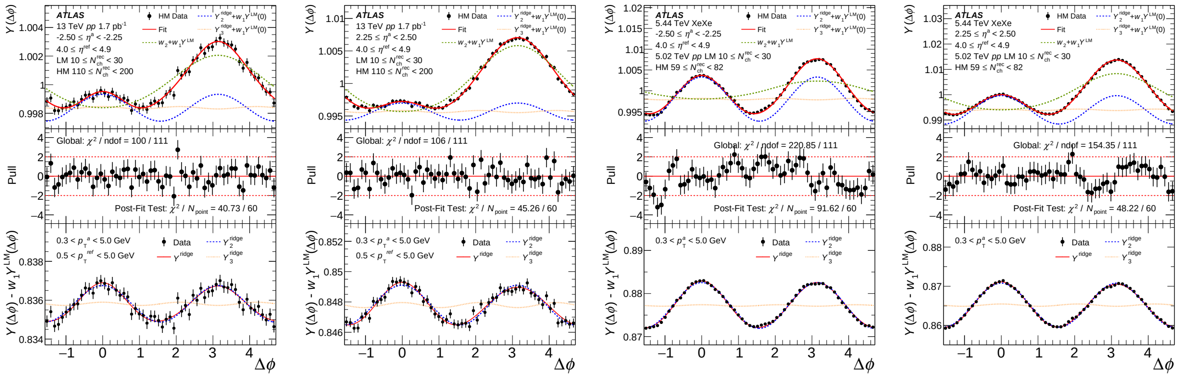

Figure 4: Selected example 2PC template fit results for two η^a intervals in 13 TeV pp collisions (left) and 5.44 TeV Xe+Xe collisions (right). In the top panels, the solid red line shows the total fit to the HM data, shown in black markers. The dashed green line shows the scaled LM reference correlation plus pedestal, while the dashed blue and dotted yellow lines indicate the two flow contributions to the fit, $Y_2^{\mathrm{ridge}} = w_2[1 + 2c_2 \cos(2\Delta\phi)]$ and $Y_3^{\mathrm{ridge}} = w_2[1 + 2c_3 \cos(3\Delta\phi)]$, shifted upwards by $w_1 Y^{\mathrm{LM}}(0)$ for visibility. The middle panels show the pull distribution for the template fits. The global χ^2/ndf is calculated from the simultaneous fit to the HM and LM correlations. The post-fit $\chi^2/N_{\mathrm{point}}$ is calculated from the pull distribution in the panel. The bottom panels show the same set of data and fit components, where the scaled LM distribution was subtracted from each to better isolate the modulation.

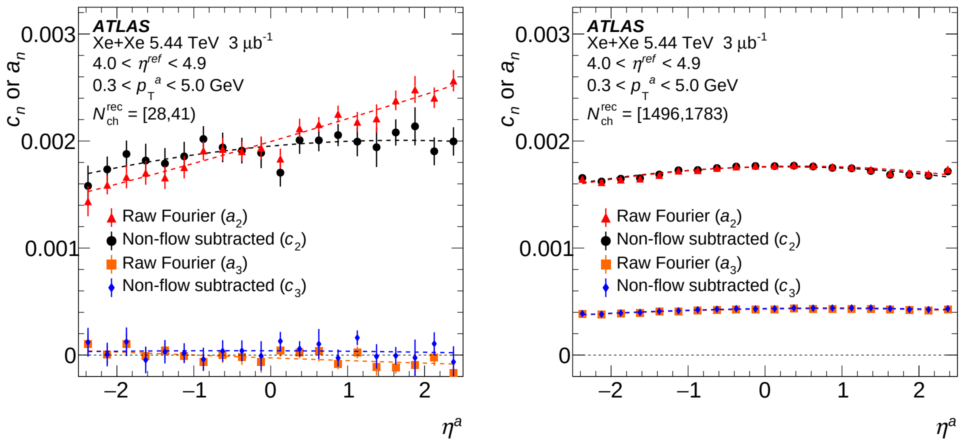

Figure 5: Coefficients a_n and c_n in low-multiplicity (high-multiplicity) 5.44 TeV Xe+Xe events are shown in the left (right) panel, for $n = 2, 3$ as a function of track pseudorapidity η^a. The c_n values are obtained from the template fitting method. The dashed lines represent a fit to a quadratic function in η^a for each set of coefficients. The pseudorapidity gap between the tower and track pair is largest for negative η^a and decreases moving to positive η^a. Only the statistical uncertainties are shown.

Further details on decorrelation extraction

There are two additional details that are important for (i) relating these results to other experimental measurements of longitudinal flow decorrelations and for (ii) understanding potential biases introduced in the template NFS procedure from one of nultiple assumptions.

First, in previous heavy-ion analyses of longitudinal decorrelations [17, 18], a set of specific ratios of correlation coefficients were taken. The r_n ratio as a function of $|\eta^a|$, is defined as

$$r_n(|\eta^a|) = \frac{c_n(-|\eta^a|)}{c_n(|\eta^a|)}, \tag{1}$$

which also applies to coefficient a_n and can be substituted for c_n. If c_n is thought of as $c_n(\eta^a) \propto 1 + F_n\eta^a$, which is the case in this paper, then the above equation yields $r_n(|\eta^a|) \approx 1 - 2F_n|\eta^a| + 2F_n^2|\eta^a|^2$. Thus a fit to $r_n(|\eta^a|)$ with $1 - 2P_0|\eta^a|$ can be used to extract F_n, where $F_n = P_0$. However, if F_n is large, the next higher-order term in $|\eta^a|$ leads to a systematically smaller extracted F_n. The decorrelations measured in large systems in the literature, as well as the coefficients with NFS in this analysis, are sufficiently small that this effect is negligible. In contrast the measured raw Fourier moments in small systems have large non-linear trends with η^a and such a method leads to underestimates of F_n.

Second, the true flow coefficients of the HM correlation, $c_n^{\mathrm{HM}}(\eta^a)$, are not measured directly by the template-based NFS. Rather, the $c_n(\eta^a)$ coefficients are measured and a set of criteria need to be met for these measured coefficients to be exactly equal to $c_n^{\mathrm{HM}}(\eta^a)$. Similarly, when measuring the linear moment of the η^a dependence of $c_n(\eta^a)$ through the methods detailed in this Letter, the resulting, F_n, has a set of criteria that must be fulfilled for this measured flow decorrelation to correspond to the true flow decorrelation in the HM selection F_n^{HM}. These criteria relate to the mid-rapidity flow $c_n^{\mathrm{LM}}|^{\eta^a=0}$ and flow decorrelation F_n^{LM} in the template LM selection. The mathematical representation of the criteria is

$$F_n \approx \frac{c_n^{\mathrm{HM}}|^{\eta^a=0} F_n^{\mathrm{HM}} - w_1 c_n^{\mathrm{LM}}|^{\eta^a=0} F_n^{\mathrm{LM}}}{c_n^{\mathrm{HM}}|^{\eta^a=0} - w_1 c_n^{\mathrm{LM}}|^{\eta^a=0}}. \tag{2}$$

One observes implicitly that if F_n^{LM} and F_n^{HM} are equal, F_n corresponds to the true flow decorrelation in the HM selection. Within uncertainties, this is the case for the F_n results in 13 TeV pp collisions. For the Xe+Xe results, because the extracted F_n values are found to vary with $N_{\mathrm{ch}}^{\mathrm{rec}}$, the above equation can be used to measure the potential bias. Inserting all the parameters and varying F_n^{LM} from 0.0–0.07, the deviation of F_n^{HM} and the reported F_n is found to be 0 to 10% level. Because F_n^{LM} is the true flow decorrelation (after NFS), with the current technique, it is impossible to know what it is because this multiplicity range is used for the NFS itself by definition. Thus the range used to quantify this specific possible bias in the template fitting procedure (0 to 0.07) is arbitrarily chosen to demonstrate that even a large range of possible F_n^{LM} produces systematic effects that are about the size of the uncertainties of the measurement.

Eq. 2 can be derived by starting with Eq. 14 from Ref. [49], introducing a linear dependence of the correlation coefficients on η^a, constructing the r_n ratio from Eq. 2, and setting it equal to $1 - 2F_n$.

References

[1] U. Heinz and R. Snellings, *Collective flow and viscosity in relativistic heavy-ion collisions*, Ann. Rev. Nucl. Part. Sci. **63** (2013) 123, arXiv: 1301.2826 [nucl-th].

[2] J. L. Nagle and W. A. Zajc,
Small System Collectivity in Relativistic Hadronic and Nuclear Collisions,
Ann. Rev. Nucl. Part. Sci. **68** (2018) 211, arXiv: 1801.03477 [nucl-ex].

[3] M. Luzum and H. Petersen,
Initial State Fluctuations and Final State Correlations in Relativistic Heavy-Ion Collisions,
J. Phys. G **41** (2014) 063102, arXiv: 1312.5503 [nucl-th].

[4] J. E. Bernhard, J. S. Moreland, S. A. Bass, J. Liu and U. Heinz,
Applying Bayesian parameter estimation to relativistic heavy-ion collisions: simultaneous characterization of the initial state and quark-gluon plasma medium,
Phys. Rev. C **94** (2016) 024907, arXiv: 1605.03954 [nucl-th].

[5] R. Snyder, M. Byres, S. H. Lim and J. L. Nagle,
Gluonic Hot Spot Initial Conditions in Heavy-Ion Collisions, Phys. Rev. C **103** (2021) 024906,
arXiv: 2008.08729 [nucl-th].

[6] 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. Cylindrical 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 $\eta = -\ln \tan(\theta/2)$.

[7] J. D. Bjorken, *Highly Relativistic Nucleus-Nucleus Collisions: The Central Rapidity Region*,
Phys. Rev. D **27** (1983) 140.

[8] P. Bozek, W. Broniowski and J. Moreira, *Torqued fireballs in relativistic heavy-ion collisions*,
Phys. Rev. C **83** (2011) 034911, arXiv: 1011.3354 [nucl-th].

[9] J. Jia and P. Huo, *Forward-backward eccentricity and participant-plane angle fluctuations and their influences on longitudinal dynamics of collective flow*, Phys. Rev. C **90** (2014) 034915,
arXiv: 1403.6077 [nucl-th].

[10] P. Bozek and W. Broniowski, *The torque effect and fluctuations of entropy deposition in rapidity in ultra-relativistic nuclear collisions*, Phys. Lett. B **752** (2016) 206, arXiv: 1506.02817 [nucl-th].

[11] L.-G. Pang, H. Petersen, G.-Y. Qin, V. Roy and X.-N. Wang,
Decorrelation of anisotropic flow along the longitudinal direction, Eur. Phys. J. A **52** (2016) 97,
arXiv: 1511.04131 [nucl-th].

[12] C. Shen and B. Schenke, *Dynamical initial state model for relativistic heavy-ion collisions*,
Phys. Rev. C **97** (2018) 024907, arXiv: 1710.00881 [nucl-th].

[13] P. Bozek and W. Broniowski, *Longitudinal decorrelation measures of flow magnitude and event-plane angles in ultrarelativistic nuclear collisions*, Phys. Rev. C **97** (2018) 034913,
arXiv: 1711.03325 [nucl-th].

[14] B. Schenke, S. Schlichting and P. Singh,
Rapidity dependence of initial state geometry and momentum correlations in p+Pb collisions,
Phys. Rev. D **105** (2022) 094023, arXiv: 2201.08864 [nucl-th].

[15] B. Schenke and S. Schlichting, *3D glasma initial state for relativistic heavy ion collisions*,
Phys. Rev. C **94** (2016) 044907, arXiv: 1605.07158 [hep-ph].

[16] CMS Collaboration, *Evidence for transverse-momentum- and pseudorapidity-dependent event-plane fluctuations in PbPb and pPb collisions*, Phys. Rev. C **92** (2015) 034911,
arXiv: 1503.01692 [hep-ex].

[17] ATLAS Collaboration, *Measurement of longitudinal flow decorrelations in Pb+Pb collisions at* $\sqrt{s_{NN}} = 2.76$ *and* 5.02 *TeV with the ATLAS detector*, Eur. Phys. J. C **78** (2018) 142, arXiv: 1709.02301 [hep-ex].

[18] ATLAS Collaboration, *Longitudinal flow decorrelations in Xe+Xe collisions at* $\sqrt{s_{NN}} = 5.44$ *TeV with the ATLAS detector*, Phys. Rev. Lett. **126** (2021) 122301, arXiv: 2001.04201 [hep-ex].

[19] T. Sjöstrand, S. Mrenna and P. Skands, *A brief introduction to PYTHIA 8.1*, Comput. Phys. Commun. **178** (2008) 852, arXiv: 0710.3820 [hep-ph].

[20] Z.-W. Lin, C. M. Ko, B.-A. Li, B. Zhang and S. Pal, *A Multi-phase transport model for relativistic heavy ion collisions*, Phys. Rev. C **72** (2005) 064901, arXiv: nucl-th/0411110.

[21] Z. Xu et al., *Flow-plane decorrelations in heavy-ion collisions with multiple-plane cumulants*, Phys. Rev. C **105** (2022) 024902, arXiv: 2012.06689 [nucl-ex].

[22] ATLAS Collaboration, *Observation of Long-Range Elliptic Azimuthal Anisotropies in* $\sqrt{s} = 13$ *and* 2.76 *TeV* pp *Collisions with the ATLAS Detector*, Phys. Rev. Lett. **116** (2016) 172301, arXiv: 1509.04776 [hep-ex].

[23] ATLAS Collaboration, *Measurement of long-range pseudorapidity correlations and azimuthal harmonics in* $\sqrt{s_{NN}} = 5.02$ *TeV proton–lead collisions with the ATLAS detector*, Phys. Rev. C **90** (2014) 044906, arXiv: 1409.1792 [hep-ex].

[24] CMS Collaboration, *Observation of long-range, near-side angular correlations in proton–proton collisions at the LHC*, JHEP **09** (2010) 091, arXiv: 1009.4122 [hep-ex].

[25] CMS Collaboration, *Evidence for collectivity in* pp *collisions at the LHC*, Phys. Lett. B **765** (2017) 193, arXiv: 1606.06198 [hep-ex].

[26] J. L. Nagle, R. Belmont, S. H. Lim and B. Seidlitz, *Checking nonflow assumptions and results via PHENIX published correlations in* $p + p$, *p+Au, d+Au, and* ^{3}*He+Au at* $\sqrt{s_{NN}}$*=200 GeV*, Phys. Rev. C **105** (2022) 024906, arXiv: 2107.07287 [nucl-th].

[27] W. Zhao, S. Ryu, C. Shen and B. Schenke, *3D structure of anisotropic flow in small collision systems at energies available at the BNL Relativistic Heavy Ion Collider*, Phys. Rev. C **107** (2023) 014904, arXiv: 2211.16376 [nucl-th].

[28] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3** (2008) S08003.

[29] 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.

[30] B. Abbott et al., *Production and integration of the ATLAS Insertable B-Layer*, JINST **13** (2018) T05008, arXiv: 1803.00844 [physics.ins-det].

[31] ATLAS Collaboration, *Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1*, Eur. Phys. J. C **77** (2017) 490, arXiv: 1603.02934 [hep-ex].

[32] ATLAS Collaboration,
Jet energy measurement with the ATLAS detector in proton–proton collisions at $\sqrt{s} = 7$ TeV,
Eur. Phys. J. C **73** (2013) 2304, arXiv: 1112.6426 [hep-ex].

[33] ATLAS Collaboration, *Performance of the ATLAS trigger system in 2015*,
Eur. Phys. J. C **77** (2017) 317, arXiv: 1611.09661 [hep-ex].

[34] ATLAS Collaboration, *The ATLAS Collaboration Software and Firmware*,
ATL-SOFT-PUB-2021-001, 2021, URL: https://cds.cern.ch/record/2767187.

[35] ATLAS Collaboration, *Measurements of long-range azimuthal anisotropies and associated Fourier coefficients for pp collisions at $\sqrt{s} = 5.02$ and 13 TeV and p+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ATLAS detector*, Phys. Rev. C **96** (2017) 024908, arXiv: 1609.06213 [hep-ex].

[36] ATLAS Collaboration, *Two-particle azimuthal correlations in photonuclear ultraperipheral Pb+Pb collisions at* 5.02 *TeV with ATLAS*, Phys. Rev. C **104** (2021) 014903,
arXiv: 2101.10771 [hep-ex].

[37] 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.

[38] ATLAS Collaboration, *Charged-particle distributions in $\sqrt{s} = 13$ TeV pp interactions measured with the ATLAS detector at the LHC*, Phys. Lett. B **758** (2016) 67, arXiv: 1602.01633 [hep-ex].

[39] ATLAS Collaboration, *Measurement of Azimuthal Anisotropy of Muons from Charm and Bottom Hadrons in pp Collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector*,
Phys. Rev. Lett. **124** (2020) 082301, arXiv: 1909.01650 [hep-ex].

[40] X.-N. Wang and M. Gyulassy,
HIJING: A Monte Carlo model for multiple jet production in p p, p A and A A collisions,
Phys. Rev. D **44** (1991) 3501.

[41] S. Agostinelli et al., *Geant4 – a simulation toolkit*, Nucl. Instrum. Meth. A **506** (2003) 250.

[42] ATLAS Collaboration, *Measurement of the azimuthal anisotropy of charged-particle production in Xe+Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV with the ATLAS detector*, Phys. Rev. C **101** (2020) 024906,
arXiv: 1911.04812 [hep-ex].

[43] G. Aad et al., *Two-particle azimuthal correlations in photonuclear ultraperipheral Pb+Pb collisions at 5.02 TeV with ATLAS*, Phys. Rev. C **104** (2021) 014903,
arXiv: 2101.10771 [nucl-ex].

[44] M. Connors, C. Nattrass, R. Reed and S. Salur, *Jet measurements in heavy ion physics*,
Rev. Mod. Phys. **90** (2018) 025005, arXiv: 1705.01974 [nucl-ex].

[45] ALICE Collaboration, *Particle-yield modification in jet-like azimuthal di-hadron correlations in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV*, Phys. Rev. Lett. **108** (2012) 092301,
arXiv: 1110.0121 [nucl-ex].

[46] E. Retinskaya, M. Luzum and J.-Y. Ollitrault,
Directed flow at midrapidity in $\sqrt{s_{NN}} = 2.76$ TeV Pb+Pb collisions,
Phys. Rev. Lett. **108** (2012) 252302, arXiv: 1203.0931 [nucl-th].

[47] Z.-W. Lin and L. Zheng,
Further developments of a multi-phase transport model for relativistic nuclear collisions,
Nucl. Sci. Tech. **32** (2021) 113, arXiv: 2110.02989 [nucl-th].

[48] ATLAS Collaboration, *ATLAS Computing Acknowledgements*, ATL-SOFT-PUB-2021-003, 2021, URL: https://cds.cern.ch/record/2776662.

[49] S. Lim et al., *Examination of flow and nonflow factorization methods in small collision systems*, Phys. Rev. C **100** (2019) 024908, arXiv: 1902.11290 [nucl-th].

The ATLAS Collaboration

G. Aad[102], B. Abbott[120], K. Abeling[55], N.J. Abicht[49], S.H. Abidi[29], A. Aboulhorma[35e], H. Abramowicz[151], H. Abreu[150], Y. Abulaiti[117], B.S. Acharya[69a,69b,q], C. Adam Bourdarios[4], L. Adamczyk[86a], S.V. Addepalli[26], M.J. Addison[101], J. Adelman[115], A. Adiguzel[21c], T. Adye[134], A.A. Affolder[136], Y. Afik[39], M.N. Agaras[13], J. Agarwala[73a,73b], A. Aggarwal[100], C. Agheorghiesei[27c], A. Ahmad[36], F. Ahmadov[38,ak], W.S. Ahmed[104], S. Ahuja[95], X. Ai[62e], G. Aielli[76a,76b], A. Aikot[163], M. Ait Tamlihat[35e], B. Aitbenchikh[35a], I. Aizenberg[169], M. Akbiyik[100], T.P.A. Åkesson[98], A.V. Akimov[37], D. Akiyama[168], N.N. Akolkar[24], K. Al Khoury[41], G.L. Alberghi[23b], J. Albert[165], P. Albicocco[53], G.L. Albouy[60], S. Alderweireldt[52], Z.L. Alegria[121], M. Aleksa[36], I.N. Aleksandrov[38], C. Alexa[27b], T. Alexopoulos[10], F. Alfonsi[23b], M. Algren[56], M. Alhroob[120], B. Ali[132], H.M.J. Ali[91], S. Ali[148], S.W. Alibocus[92], M. Aliev[145], G. Alimonti[71a], W. Alkakhi[55], C. Allaire[66], B.M.M. Allbrooke[146], J.F. Allen[52], C.A. Allendes Flores[137f], P.P. Allport[20], A. Aloisio[72a,72b], F. Alonso[90], C. Alpigiani[138], M. Alvarez Estevez[99], A. Alvarez Fernandez[100], M. Alves Cardoso[56], M.G. Alviggi[72a,72b], M. Aly[101], Y. Amaral Coutinho[83b], A. Ambler[104], C. Amelung[36], M. Amerl[101], C.G. Ames[109], D. Amidei[106], S.P. Amor Dos Santos[130a], K.R. Amos[163], V. Ananiev[125], C. Anastopoulos[139], T. Andeen[11], J.K. Anders[36], S.Y. Andrean[47a,47b], A. Andreazza[71a,71b], S. Angelidakis[9], A. Angerami[41,ao], A.V. Anisenkov[37], A. Annovi[74a], C. Antel[56], M.T. Anthony[139], E. Antipov[145], M. Antonelli[53], F. Anulli[75a], M. Aoki[84], T. Aoki[153], J.A. Aparisi Pozo[163], M.A. Aparo[146], L. Aperio Bella[48], C. Appelt[18], A. Apyan[26], N. Aranzabal[36], S.J. Arbiol Val[87], C. Arcangeletti[53], A.T.H. Arce[51], E. Arena[92], J-F. Arguin[108], S. Argyropoulos[54], J.-H. Arling[48], O. Arnaez[4], H. Arnold[114], G. Artoni[75a,75b], H. Asada[111], K. Asai[118], S. Asai[153], N.A. Asbah[61], J. Assahsah[35d], K. Assamagan[29], R. Astalos[28a], S. Atashi[160], R.J. Atkin[33a], M. Atkinson[162], H. Atmani[35f], P.A. Atmasiddha[128], K. Augsten[132], S. Auricchio[72a,72b], A.D. Auriol[20], V.A. Austrup[101], G. Avolio[36], K. Axiotis[56], G. Azuelos[108,av], D. Babal[28b], H. Bachacou[135], K. Bachas[152,w], A. Bachiu[34], F. Backman[47a,47b], A. Badea[61], P. Bagnaia[75a,75b], M. Bahmani[18], D. Bahner[54], A.J. Bailey[163], V.R. Bailey[162], J.T. Baines[134], L. Baines[94], O.K. Baker[172], E. Bakos[15], D. Bakshi Gupta[8], V. Balakrishnan[120], R. Balasubramanian[114], E.M. Baldin[37], P. Balek[86a], E. Ballabene[23b,23a], F. Balli[135], L.M. Baltes[63a], W.K. Balunas[32], J. Balz[100], E. Banas[87], M. Bandieramonte[129], A. Bandyopadhyay[24], S. Bansal[24], L. Barak[151], M. Barakat[48], E.L. Barberio[105], D. Barberis[57b,57a], M. Barbero[102], M.Z. Barel[114], K.N. Barends[33a], T. Barillari[110], M-S. Barisits[36], T. Barklow[143], P. Baron[122], D.A. Baron Moreno[101], A. Baroncelli[62a], G. Barone[29], A.J. Barr[126], J.D. Barr[96], L. Barranco Navarro[47a,47b], F. Barreiro[99], J. Barreiro Guimarães da Costa[14a], U. Barron[151], M.G. Barros Teixeira[130a], S. Barsov[37], F. Bartels[63a], R. Bartoldus[143], A.E. Barton[91], P. Bartos[28a], A. Basan[100,af], M. Baselga[49], A. Bassalat[66,b], M.J. Basso[156a], C.R. Basson[101], R.L. Bates[59], S. Batlamous[35e], J.R. Batley[32], B. Batool[141], M. Battaglia[136], D. Battulga[18], M. Bauce[75a,75b], M. Bauer[36], P. Bauer[24], L.T. Bazzano Hurrell[30], J.B. Beacham[51], T. Beau[127], J.Y. Beaucamp[90], P.H. Beauchemin[158], F. Becherer[54], P. Bechtle[24], H.P. Beck[19,u], K. Becker[167], A.J. Beddall[82], V.A. Bednyakov[38], C.P. Bee[145], L.J. Beemster[15], T.A. Beermann[36], M. Begalli[83d], M. Begel[29], A. Behera[145], J.K. Behr[48], J.F. Beirer[36], F. Beisiegel[24], M. Belfkir[159], G. Bella[151], L. Bellagamba[23b], A. Bellerive[34], P. Bellos[20], K. Beloborodov[37], D. Benchekroun[35a], F. Bendebba[35a], Y. Benhammou[151], M. Benoit[29], J.R. Bensinger[26],

S. Bentvelsen [114], L. Beresford [48], M. Beretta [53], E. Bergeaas Kuutmann [161], N. Berger [4], B. Bergmann [132], J. Beringer [17a], G. Bernardi [5], C. Bernius [143], F.U. Bernlochner [24], F. Bernon [36,102], A. Berrocal Guardia [13], T. Berry [95], P. Berta [133], A. Berthold [50], I.A. Bertram [91], S. Bethke [110], A. Betti [75a,75b], A.J. Bevan [94], N.K. Bhalla [54], M. Bhamjee [33c], S. Bhatta [145], D.S. Bhattacharya [166], P. Bhattarai [143], V.S. Bhopatkar [121], R. Bi [29,ay], R.M. Bianchi [129], G. Bianco [23b,23a], O. Biebel [109], R. Bielski [123], M. Biglietti [77a], M. Bindi [55], A. Bingul [21b], C. Bini [75a,75b], A. Biondini [92], C.J. Birch-sykes [101], G.A. Bird [20,134], M. Birman [169], M. Biros [133], S. Biryukov [146], T. Bisanz [49], E. Bisceglie [43b,43a], J.P. Biswal [134], D. Biswas [141], A. Bitadze [101], K. Bjørke [125], I. Bloch [48], A. Blue [59], U. Blumenschein [94], J. Blumenthal [100], G.J. Bobbink [114], V.S. Bobrovnikov [37], M. Boehler [54], B. Boehm [166], D. Bogavac [36], A.G. Bogdanchikov [37], C. Bohm [47a], V. Boisvert [95], P. Bokan [48], T. Bold [86a], M. Bomben [5], M. Bona [94], M. Boonekamp [135], C.D. Booth [95], A.G. Borbély [59,as], I.S. Bordulev [37], H.M. Borecka-Bielska [108], G. Borissov [91], D. Bortoletto [126], D. Boscherini [23b], M. Bosman [13], J.D. Bossio Sola [36], K. Bouaouda [35a], N. Bouchhar [163], J. Boudreau [129], E.V. Bouhova-Thacker [91], D. Boumediene [40], R. Bouquet [165], A. Boveia [119], J. Boyd [36], D. Boye [29], I.R. Boyko [38], J. Bracinik [20], N. Brahimi [62d], G. Brandt [171], O. Brandt [32], F. Braren [48], B. Brau [103], J.E. Brau [123], R. Brener [169], L. Brenner [114], R. Brenner [161], S. Bressler [169], D. Britton [59], D. Britzger [110], I. Brock [24], G. Brooijmans [41], W.K. Brooks [137f], E. Brost [29], L.M. Brown [165,n], L.E. Bruce [61], T.L. Bruckler [126], P.A. Bruckman de Renstrom [87], B. Brüers [48], A. Bruni [23b], G. Bruni [23b], M. Bruschi [23b], N. Bruscino [75a,75b], T. Buanes [16], Q. Buat [138], D. Buchin [110], A.G. Buckley [59], O. Bulekov [37], B.A. Bullard [143], S. Burdin [92], C.D. Burgard [49], A.M. Burger [40], B. Burghgrave [8], O. Burlayenko [54], J.T.P. Burr [32], C.D. Burton [11], J.C. Burzynski [142], E.L. Busch [41], V. Büscher [100], P.J. Bussey [59], J.M. Butler [25], C.M. Buttar [59], J.M. Butterworth [96], W. Buttinger [134], C.J. Buxo Vazquez [107], A.R. Buzykaev [37], S. Cabrera Urbán [163], L. Cadamuro [66], D. Caforio [58], H. Cai [129], Y. Cai [14a,14e], Y. Cai [14c], V.M.M. Cairo [36], O. Cakir [3a], N. Calace [36], P. Calafiura [17a], G. Calderini [127], P. Calfayan [68], G. Callea [59], L.P. Caloba [83b], D. Calvet [40], S. Calvet [40], T.P. Calvet [102], M. Calvetti [74a,74b], R. Camacho Toro [127], S. Camarda [36], D. Camarero Munoz [26], P. Camarri [76a,76b], M.T. Camerlingo [72a,72b], D. Cameron [36,h], C. Camincher [165], M. Campanelli [96], A. Camplani [42], V. Canale [72a,72b], A. Canesse [104], J. Cantero [163], Y. Cao [162], F. Capocasa [26], M. Capua [43b,43a], A. Carbone [71a,71b], R. Cardarelli [76a], J.C.J. Cardenas [8], F. Cardillo [163], G. Carducci [43b,43a], T. Carli [36], G. Carlino [72a], J.I. Carlotto [13], B.T. Carlson [129,x], E.M. Carlson [165,156a], L. Carminati [71a,71b], A. Carnelli [135], M. Carnesale [75a,75b], S. Caron [113], E. Carquin [137f], S. Carrá [71a,71b], G. Carratta [23b,23a], F. Carrio Argos [33g], J.W.S. Carter [155], T.M. Carter [52], M.P. Casado [13,k], M. Caspar [48], F.L. Castillo [4], L. Castillo Garcia [13], V. Castillo Gimenez [163], N.F. Castro [130a,130e], A. Catinaccio [36], J.R. Catmore [125], V. Cavaliere [29], N. Cavalli [23b,23a], V. Cavasinni [74a,74b], Y.C. Cekmecelioglu [48], E. Celebi [21a], F. Celli [126], M.S. Centonze [70a,70b], V. Cepaitis [56], K. Cerny [122], A.S. Cerqueira [83a], A. Cerri [146], L. Cerrito [76a,76b], F. Cerutti [17a], B. Cervato [141], A. Cervelli [23b], G. Cesarini [53], S.A. Cetin [82], D. Chakraborty [115], J. Chan [170], W.Y. Chan [153], J.D. Chapman [32], E. Chapon [135], B. Chargeishvili [149b], D.G. Charlton [20], M. Chatterjee [19], C. Chauhan [133], S. Chekanov [6], S.V. Chekulaev [156a], G.A. Chelkov [38,a], A. Chen [106], B. Chen [151], B. Chen [165], H. Chen [14c], H. Chen [29], J. Chen [62c], J. Chen [142], M. Chen [126], S. Chen [153], S.J. Chen [14c], X. Chen [62c,135], X. Chen [14b,au], Y. Chen [62a], C.L. Cheng [170], H.C. Cheng [64a], S. Cheong [143], A. Cheplakov [38], E. Cheremushkina [48], E. Cherepanova [114], R. Cherkaoui El Moursli [35e], E. Cheu [7], K. Cheung [65], L. Chevalier [135], V. Chiarella [53], G. Chiarelli [74a], N. Chiedde [102], G. Chiodini [70a], A.S. Chisholm [20], A. Chitan [27b], M. Chitishvili [163], M.V. Chizhov [38], K. Choi [11], A.R. Chomont [75a,75b],

Y. Chou[103], E.Y.S. Chow[113], T. Chowdhury[33g], K.L. Chu[169], M.C. Chu[64a], X. Chu[14a,14e], J. Chudoba[131], J.J. Chwastowski[87], D. Cieri[110], K.M. Ciesla[86a], V. Cindro[93], A. Ciocio[17a], F. Cirotto[72a,72b], Z.H. Citron[169,o], M. Citterio[71a], D.A. Ciubotaru[27b], A. Clark[56], P.J. Clark[52], C. Clarry[155], J.M. Clavijo Columbie[48], S.E. Clawson[48], C. Clement[47a,47b], J. Clercx[48], Y. Coadou[102], M. Cobal[69a,69c], A. Coccaro[57b], R.F. Coelho Barrue[130a], R. Coelho Lopes De Sa[103], S. Coelli[71a], A.E.C. Coimbra[71a,71b], B. Cole[41], J. Collot[60], P. Conde Muiño[130a,130g], M.P. Connell[33c], S.H. Connell[33c], I.A. Connelly[59], E.I. Conroy[126], F. Conventi[72a,aw], H.G. Cooke[20], A.M. Cooper-Sarkar[126], A. Cordeiro Oudot Choi[127], L.D. Corpe[40], M. Corradi[75a,75b], F. Corriveau[104,ai], A. Cortes-Gonzalez[18], M.J. Costa[163], F. Costanza[4], D. Costanzo[139], B.M. Cote[119], G. Cowan[95], K. Cranmer[170], D. Cremonini[23b,23a], S. Crépé-Renaudin[60], F. Crescioli[127], M. Cristinziani[141], M. Cristoforetti[78a,78b], V. Croft[114], J.E. Crosby[121], G. Crosetti[43b,43a], A. Cueto[99], T. Cuhadar Donszelmann[160], H. Cui[14a,14e], Z. Cui[7], W.R. Cunningham[59], F. Curcio[43b,43a], P. Czodrowski[36], M.M. Czurylo[63b], M.J. Da Cunha Sargedas De Sousa[57b,57a], J.V. Da Fonseca Pinto[83b], C. Da Via[101], W. Dabrowski[86a], T. Dado[49], S. Dahbi[33g], T. Dai[106], D. Dal Santo[19], C. Dallapiccola[103], M. Dam[42], G. D'amen[29], V. D'Amico[109], J. Damp[100], J.R. Dandoy[34], M.F. Daneri[30], M. Danninger[142], V. Dao[36], G. Darbo[57b], S. Darmora[6], S.J. Das[29,ay], S. D'Auria[71a,71b], C. David[156b], T. Davidek[133], B. Davis-Purcell[34], I. Dawson[94], H.A. Day-hall[132], K. De[8], R. De Asmundis[72a], N. De Biase[48], S. De Castro[23b,23a], N. De Groot[113], P. de Jong[114], H. De la Torre[115], A. De Maria[14c], A. De Salvo[75a], U. De Sanctis[76a,76b], F. De Santis[70a,70b], A. De Santo[146], J.B. De Vivie De Regie[60], D.V. Dedovich[38], J. Degens[114], A.M. Deiana[44], F. Del Corso[23b,23a], J. Del Peso[99], F. Del Rio[63a], L. Delagrange[127], F. Deliot[135], C.M. Delitzsch[49], M. Della Pietra[72a,72b], D. Della Volpe[56], A. Dell'Acqua[36], L. Dell'Asta[71a,71b], M. Delmastro[4], P.A. Delsart[60], S. Demers[172], M. Demichev[38], S.P. Denisov[37], L. D'Eramo[40], D. Derendarz[87], F. Derue[127], P. Dervan[92], K. Desch[24], C. Deutsch[24], F.A. Di Bello[57b,57a], A. Di Ciaccio[76a,76b], L. Di Ciaccio[4], A. Di Domenico[75a,75b], C. Di Donato[72a,72b], A. Di Girolamo[36], G. Di Gregorio[36], A. Di Luca[78a,78b], B. Di Micco[77a,77b], R. Di Nardo[77a,77b], C. Diaconu[102], M. Diamantopoulou[34], F.A. Dias[114], T. Dias Do Vale[142], M.A. Diaz[137a,137b], F.G. Diaz Capriles[24], M. Didenko[163], E.B. Diehl[106], L. Diehl[54], S. Díez Cornell[48], C. Diez Pardos[141], C. Dimitriadi[161,24], A. Dimitrievska[17a], J. Dingfelder[24], I-M. Dinu[27b], S.J. Dittmeier[63b], F. Dittus[36], F. Djama[102], T. Djobava[149b], J.I. Djuvsland[16], C. Doglioni[101,98], A. Dohnalova[28a], J. Dolejsi[133], Z. Dolezal[133], K.M. Dona[39], M. Donadelli[83c], B. Dong[107], J. Donini[40], A. D'Onofrio[72a,72b], M. D'Onofrio[92], J. Dopke[134], A. Doria[72a], N. Dos Santos Fernandes[130a], P. Dougan[101], M.T. Dova[90], A.T. Doyle[59], M.A. Draguet[126], E. Dreyer[169], I. Drivas-koulouris[10], M. Drnevich[117], A.S. Drobac[158], M. Drozdova[56], D. Du[62a], T.A. du Pree[114], F. Dubinin[37], M. Dubovsky[28a], E. Duchovni[169], G. Duckeck[109], O.A. Ducu[27b], D. Duda[52], A. Dudarev[36], E.R. Duden[26], M. D'uffizi[101], L. Duflot[66], M. Dührssen[36], C. Dülsen[171], A.E. Dumitriu[27b], M. Dunford[63a], S. Dungs[49], K. Dunne[47a,47b], A. Duperrin[102], H. Duran Yildiz[3a], M. Düren[58], A. Durglishvili[149b], B.L. Dwyer[115], G.I. Dyckes[17a], M. Dyndal[86a], B.S. Dziedzic[87], Z.O. Earnshaw[146], G.H. Eberwein[126], B. Eckerova[28a], S. Eggebrecht[55], E. Egidio Purcino De Souza[127], L.F. Ehrke[56], G. Eigen[16], K. Einsweiler[17a], T. Ekelof[161], P.A. Ekman[98], S. El Farkh[35b], Y. El Ghazali[35b], H. El Jarrari[36], A. El Moussaouy[108,ab], V. Ellajosyula[161], M. Ellert[161], F. Ellinghaus[171], N. Ellis[36], J. Elmsheuser[29], M. Elsing[36], D. Emeliyanov[134], Y. Enari[153], I. Ene[17a], S. Epari[13], J. Erdmann[49], P.A. Erland[87], M. Errenst[171], M. Escalier[66], C. Escobar[163], E. Etzion[151], G. Evans[130a], H. Evans[68], L.S. Evans[95], M.O. Evans[146], A. Ezhilov[37], S. Ezzarqtouni[35a], F. Fabbri[59], L. Fabbri[23b,23a], G. Facini[96], V. Fadeyev[136], R.M. Fakhrutdinov[37], D. Fakoudis[100], S. Falciano[75a], L.F. Falda Ulhoa Coelho[36], P.J. Falke[24], J. Faltova[133], C. Fan[162], Y. Fan[14a], Y. Fang[14a,14e], M. Fanti[71a,71b], M. Faraj[69a,69b], Z. Farazpay[97], A. Farbin[8], A. Farilla[77a], T. Farooque[107], S.M. Farrington[52], F. Fassi[35e], D. Fassouliotis[9], M. Faucci Giannelli[76a,76b], W.J. Fawcett[32], L. Fayard[66], P. Federic[133], P. Federicova[131], O.L. Fedin[37,a], G. Fedotov[37], M. Feickert[170], L. Feligioni[102], D.E. Fellers[123], C. Feng[62b], M. Feng[14b], Z. Feng[114], M.J. Fenton[160], A.B. Fenyuk[37], L. Ferencz[48], R.A.M. Ferguson[91], S.I. Fernandez Luengo[137f], P. Fernandez Martinez[13], M.J.V. Fernoux[102], J. Ferrando[91], A. Ferrari[161], P. Ferrari[114,113], R. Ferrari[73a], D. Ferrere[56], C. Ferretti[106], F. Fiedler[100], P. Fiedler[132], A. Filipčič[93], E.K. Filmer[1], F. Filthaut[113], M.C.N. Fiolhais[130a,130c,d], L. Fiorini[163], W.C. Fisher[107], T. Fitschen[101], P.M. Fitzhugh[135], I. Fleck[141], P. Fleischmann[106], T. Flick[171], M. Flores[33d,ap], L.R. Flores Castillo[64a], L. Flores Sanz De Acedo[36], F.M. Follega[78a,78b], N. Fomin[16], J.H. Foo[155], B.C. Forland[68], A. Formica[135], A.C. Forti[101], E. Fortin[36], A.W. Fortman[61], M.G. Foti[17a], L. Fountas[9,l], D. Fournier[66], H. Fox[91], P. Francavilla[74a,74b], S. Francescato[61], S. Franchellucci[56], M. Franchini[23b,23a], S. Franchino[63a], D. Francis[36], L. Franco[113], V. Franco Lima[36], L. Franconi[48], M. Franklin[61], G. Frattari[26], A.C. Freegard[94], W.S. Freund[83b], Y.Y. Frid[151], J. Friend[59], N. Fritzsche[50], A. Froch[54], D. Froidevaux[36], J.A. Frost[126], Y. Fu[62a], S. Fuenzalida Garrido[137f], M. Fujimoto[102], K.Y. Fung[64a], E. Furtado De Simas Filho[83b], M. Furukawa[153], J. Fuster[163], A. Gabrielli[23b,23a], A. Gabrielli[155], P. Gadow[36], G. Gagliardi[57b,57a], L.G. Gagnon[17a], E.J. Gallas[126], B.J. Gallop[134], K.K. Gan[119], S. Ganguly[153], Y. Gao[52], F.M. Garay Walls[137a,137b], B. Garcia[29,ay], C. García[163], A. Garcia Alonso[114], A.G. Garcia Caffaro[172], J.E. García Navarro[163], M. Garcia-Sciveres[17a], G.L. Gardner[128], R.W. Gardner[39], N. Garelli[158], D. Garg[80], R.B. Garg[143,t], J.M. Gargan[52], C.A. Garner[155], C.M. Garvey[33a], P. Gaspar[83b], V.K. Gassmann[158], G. Gaudio[73a], V. Gautam[13], P. Gauzzi[75a,75b], I.L. Gavrilenko[37], A. Gavrilyuk[37], C. Gay[164], G. Gaycken[48], E.N. Gazis[10], A.A. Geanta[27b], C.M. Gee[136], A. Gekow[119], C. Gemme[57b], M.H. Genest[60], S. Gentile[75a,75b], A.D. Gentry[112], S. George[95], W.F. George[20], T. Geralis[46], P. Gessinger-Befurt[36], M.E. Geyik[171], M. Ghani[167], M. Ghneimat[141], K. Ghorbanian[94], A. Ghosal[141], A. Ghosh[160], A. Ghosh[7], B. Giacobbe[23b], S. Giagu[75a,75b], T. Giani[114], P. Giannetti[74a], A. Giannini[62a], S.M. Gibson[95], M. Gignac[136], D.T. Gil[86b], A.K. Gilbert[86a], B.J. Gilbert[41], D. Gillberg[34], G. Gilles[114], N.E.K. Gillwald[48], L. Ginabat[127], D.M. Gingrich[2,av], M.P. Giordani[69a,69c], P.F. Giraud[135], G. Giugliarelli[69a,69c], D. Giugni[71a], F. Giuli[36], I. Gkialas[9,l], L.K. Gladilin[37], C. Glasman[99], G.R. Gledhill[123], G. Glemža[48], M. Glisic[123], I. Gnesi[43b,g], Y. Go[29,ay], M. Goblirsch-Kolb[36], B. Gocke[49], D. Godin[108], B. Gokturk[21a], S. Goldfarb[105], T. Golling[56], M.G.D. Gololo[33g], D. Golubkov[37], J.P. Gombas[107], A. Gomes[130a,130b], G. Gomes Da Silva[141], A.J. Gomez Delegido[163], R. Gonçalo[130a,130c], G. Gonella[123], L. Gonella[20], A. Gongadze[149c], F. Gonnella[20], J.L. Gonski[41], R.Y. González Andana[52], S. González de la Hoz[163], S. Gonzalez Fernandez[13], R. Gonzalez Lopez[92], C. Gonzalez Renteria[17a], M.V. Gonzalez Rodrigues[48], R. Gonzalez Suarez[161], S. Gonzalez-Sevilla[56], G.R. Gonzalvo Rodriguez[163], L. Goossens[36], B. Gorini[36], E. Gorini[70a,70b], A. Gorišek[93], T.C. Gosart[128], A.T. Goshaw[51], M.I. Gostkin[38], S. Goswami[121], C.A. Gottardo[36], S.A. Gotz[109], M. Gouighri[35b], V. Goumarre[48], A.G. Goussiou[138], N. Govender[33c], I. Grabowska-Bold[86a], K. Graham[34], E. Gramstad[125], S. Grancagnolo[70a,70b], M. Grandi[146], C.M. Grant[1,135], P.M. Gravila[27f], F.G. Gravili[70a,70b], H.M. Gray[17a], M. Greco[70a,70b], C. Grefe[24], I.M. Gregor[48], P. Grenier[143], S.G. Grewe[110], C. Grieco[13], A.A. Grillo[136], K. Grimm[31], S. Grinstein[13,ad], J.-F. Grivaz[66], E. Gross[169],

J. Grosse-Knetter[55], C. Grud[106], J.C. Grundy[126], L. Guan[106], W. Guan[170], C. Gubbels[164], J.G.R. Guerrero Rojas[163], G. Guerrieri[69a,69c], F. Guescini[110], R. Gugel[100], J.A.M. Guhit[106], A. Guida[18], E. Guilloton[167,134], S. Guindon[36], F. Guo[14a,14e], J. Guo[62c], L. Guo[48], Y. Guo[106], R. Gupta[48], R. Gupta[129], S. Gurbuz[24], S.S. Gurdasani[54], G. Gustavino[36], M. Guth[56], P. Gutierrez[120], L.F. Gutierrez Zagazeta[128], M. Gutsche[50], C. Gutschow[96], C. Gwenlan[126], C.B. Gwilliam[92], E.S. Haaland[125], A. Haas[117], M. Habedank[48], C. Haber[17a], H.K. Hadavand[8], A. Hadef[50], S. Hadzic[110], A.I. Hagan[91], J.J. Hahn[141], E.H. Haines[96], M. Haleem[166], J. Haley[121], J.J. Hall[139], G.D. Hallewell[102], L. Halser[19], K. Hamano[165], M. Hamer[24], G.N. Hamity[52], E.J. Hampshire[95], J. Han[62b], K. Han[62a], L. Han[14c], L. Han[62a], S. Han[17a], Y.F. Han[155], K. Hanagaki[84], M. Hance[136], D.A. Hangal[41,ao], H. Hanif[142], M.D. Hank[128], R. Hankache[101], J.B. Hansen[42], J.D. Hansen[42], P.H. Hansen[42], K. Hara[157], D. Harada[56], T. Harenberg[171], S. Harkusha[37], M.L. Harris[103], Y.T. Harris[126], J. Harrison[13], N.M. Harrison[119], P.F. Harrison[167], N.M. Hartman[143], N.M. Hartmann[109], Y. Hasegawa[140], R. Hauser[107], C.M. Hawkes[20], R.J. Hawkings[36], Y. Hayashi[153], S. Hayashida[111], D. Hayden[107], C. Hayes[106], R.L. Hayes[114], C.P. Hays[126], J.M. Hays[94], H.S. Hayward[92], F. He[62a], M. He[14a,14e], Y. He[154], Y. He[48], N.B. Heatley[94], V. Hedberg[98], A.L. Heggelund[125], N.D. Hehir[94], C. Heidegger[54], K.K. Heidegger[54], W.D. Heidorn[81], J. Heilman[34], S. Heim[48], T. Heim[17a], J.G. Heinlein[128], J.J. Heinrich[123], L. Heinrich[110,at], J. Hejbal[131], L. Helary[48], A. Held[170], S. Hellesund[16], C.M. Helling[164], S. Hellman[47a,47b], R.C.W. Henderson[91], L. Henkelmann[32], A.M. Henriques Correia[36], H. Herde[98], Y. Hernández Jiménez[145], L.M. Herrmann[24], T. Herrmann[50], G. Herten[54], R. Hertenberger[109], L. Hervas[36], M.E. Hesping[100], N.P. Hessey[156a], H. Hibi[85], E. Hill[155], S.J. Hillier[20], J.R. Hinds[107], F. Hinterkeuser[24], M. Hirose[124], S. Hirose[157], D. Hirschbuehl[171], T.G. Hitchings[101], B. Hiti[93], J. Hobbs[145], R. Hobincu[27e], N. Hod[169], M.C. Hodgkinson[139], B.H. Hodkinson[32], A. Hoecker[36], J. Hofer[48], T. Holm[24], M. Holzbock[110], L.B.A.H. Hommels[32], B.P. Honan[101], J. Hong[62c], T.M. Hong[129], B.H. Hooberman[162], W.H. Hopkins[6], Y. Horii[111], S. Hou[148], A.S. Howard[93], J. Howarth[59], J. Hoya[6], M. Hrabovsky[122], A. Hrynevich[48], T. Hryn'ova[4], P.J. Hsu[65], S.-C. Hsu[138], Q. Hu[62a], Y.F. Hu[14a,14e], S. Huang[64b], X. Huang[14c], X. Huang[14a,14e], Y. Huang[139,m], Y. Huang[14a], Z. Huang[101], Z. Hubacek[132], M. Huebner[24], F. Huegging[24], T.B. Huffman[126], C.A. Hugli[48], M. Huhtinen[36], S.K. Huiberts[16], R. Hulsken[104], N. Huseynov[12], J. Huston[107], J. Huth[61], R. Hyneman[143], G. Iacobucci[56], G. Iakovidis[29], I. Ibragimov[141], L. Iconomidou-Fayard[66], P. Iengo[72a,72b], R. Iguchi[153], T. Iizawa[126,r], Y. Ikegami[84], N. Ilic[155], H. Imam[35a], M. Ince Lezki[56], T. Ingebretsen Carlson[47a,47b], G. Introzzi[73a,73b], M. Iodice[77a], V. Ippolito[75a,75b], R.K. Irwin[92], M. Ishino[153], W. Islam[170], C. Issever[18,48], S. Istin[21a,ba], H. Ito[168], J.M. Iturbe Ponce[64a], R. Iuppa[78a,78b], A. Ivina[169], J.M. Izen[45], V. Izzo[72a], P. Jacka[131,132], P. Jackson[1], R.M. Jacobs[48], B.P. Jaeger[142], C.S. Jagfeld[109], G. Jain[156a], P. Jain[54], K. Jakobs[54], T. Jakoubek[169], J. Jamieson[59], K.W. Janas[86a], M. Javurkova[103], F. Jeanneau[135], L. Jeanty[123], J. Jejelava[149a,al], P. Jenni[54,i], C.E. Jessiman[34], S. Jézéquel[4], C. Jia[62b], J. Jia[145], X. Jia[61], X. Jia[14a,14e], Z. Jia[14c], S. Jiggins[48], J. Jimenez Pena[13], S. Jin[14c], A. Jinaru[27b], O. Jinnouchi[154], P. Johansson[139], K.A. Johns[7], J.W. Johnson[136], D.M. Jones[32], E. Jones[48], P. Jones[32], R.W.L. Jones[91], T.J. Jones[92], H.L. Joos[55,36], R. Joshi[119], J. Jovicevic[15], X. Ju[17a], J.J. Junggeburth[103,v], T. Junkermann[63a], A. Juste Rozas[13,ad], M.K. Juzek[87], S. Kabana[137e], A. Kaczmarska[87], M. Kado[110], H. Kagan[119], M. Kagan[143], A. Kahn[41], A. Kahn[128], C. Kahra[100], T. Kaji[153], E. Kajomovitz[150], N. Kakati[169], I. Kalaitzidou[54], C.W. Kalderon[29], A. Kamenshchikov[155], N.J. Kang[136], D. Kar[33g], K. Karava[126], M.J. Kareem[156b], E. Karentzos[54], I. Karkanias[152],

O. Karkout[114], S.N. Karpov[38], Z.M. Karpova[38], V. Kartvelishvili[91], A.N. Karyukhin[37], E. Kasimi[152], J. Katzy[48], S. Kaur[34], K. Kawade[140], M.P. Kawale[120], C. Kawamoto[88], T. Kawamoto[62a], E.F. Kay[36], F.I. Kaya[158], S. Kazakos[107], V.F. Kazanin[37], Y. Ke[145], J.M. Keaveney[33a], R. Keeler[165], G.V. Kehris[61], J.S. Keller[34], A.S. Kelly[96], J.J. Kempster[146], K.E. Kennedy[41], P.D. Kennedy[100], O. Kepka[131], B.P. Kerridge[167], S. Kersten[171], B.P. Kerševan[93], S. Keshri[66], L. Keszeghova[28a], S. Ketabchi Haghighat[155], A. Khanov[121], A.G. Kharlamov[37], T. Kharlamova[37], E.E. Khoda[138], M. Kholodenko[37], T.J. Khoo[18], G. Khoriauli[166], J. Khubua[149b], Y.A.R. Khwaira[66], A. Kilgallon[123], D.W. Kim[47a,47b], Y.K. Kim[39], N. Kimura[96], M.K. Kingston[55], A. Kirchhoff[55], C. Kirfel[24], F. Kirfel[24], J. Kirk[134], A.E. Kiryunin[110], C. Kitsaki[10], O. Kivernyk[24], M. Klassen[63a], C. Klein[34], L. Klein[166], M.H. Klein[44], M. Klein[92], S.B. Klein[56], U. Klein[92], P. Klimek[36], A. Klimentov[29], T. Klioutchnikova[36], P. Kluit[114], S. Kluth[110], E. Kneringer[79], T.M. Knight[155], A. Knue[49], R. Kobayashi[88], D. Kobylianskii[169], S.F. Koch[126], M. Kocian[143], P. Kodyš[133], D.M. Koeck[123], P.T. Koenig[24], T. Koffas[34], O. Kolay[50], I. Koletsou[4], T. Komarek[122], K. Köneke[54], A.X.Y. Kong[1], T. Kono[118], N. Konstantinidis[96], P. Kontaxakis[56], B. Konya[98], R. Kopeliansky[68], S. Koperny[86a], K. Korcyl[87], K. Kordas[152,f], G. Koren[151], A. Korn[96], S. Korn[55], I. Korolkov[13], N. Korotkova[37], B. Kortman[114], O. Kortner[110], S. Kortner[110], W.H. Kostecka[115], V.V. Kostyukhin[141], A. Kotsokechagia[135], A. Kotwal[51], A. Koulouris[36], A. Kourkoumeli-Charalampidi[73a,73b], C. Kourkoumelis[9], E. Kourlitis[110,at], O. Kovanda[146], R. Kowalewski[165], W. Kozanecki[135], A.S. Kozhin[37], V.A. Kramarenko[37], G. Kramberger[93], P. Kramer[100], M.W. Krasny[127], A. Krasznahorkay[36], J.W. Kraus[171], J.A. Kremer[48], T. Kresse[50], J. Kretzschmar[92], K. Kreul[18], P. Krieger[155], S. Krishnamurthy[103], M. Krivos[133], K. Krizka[20], K. Kroeninger[49], H. Kroha[110], J. Kroll[131], J. Kroll[128], K.S. Krowpman[107], U. Kruchonak[38], H. Krüger[24], N. Krumnack[81], M.C. Kruse[51], O. Kuchinskaia[37], S. Kuday[3a], S. Kuehn[36], R. Kuesters[54], T. Kuhl[48], V. Kukhtin[38], Y. Kulchitsky[37,a], S. Kuleshov[137d,137b], M. Kumar[33g], N. Kumari[48], A. Kupco[131], T. Kupfer[49], A. Kupich[37], O. Kuprash[54], H. Kurashige[85], L.L. Kurchaninov[156a], O. Kurdysh[66], Y.A. Kurochkin[37], A. Kurova[37], M. Kuze[154], A.K. Kvam[103], J. Kvita[122], T. Kwan[104], N.G. Kyriacou[106], L.A.O. Laatu[102], C. Lacasta[163], F. Lacava[75a,75b], H. Lacker[18], D. Lacour[127], N.N. Lad[96], E. Ladygin[38], B. Laforge[127], T. Lagouri[137e], F.Z. Lahbabi[35a], S. Lai[55], I.K. Lakomiec[86a], N. Lalloue[60], J.E. Lambert[165,n], S. Lammers[68], W. Lampl[7], C. Lampoudis[152,f], A.N. Lancaster[115], E. Lançon[29], U. Landgraf[54], M.P.J. Landon[94], V.S. Lang[54], R.J. Langenberg[103], O.K.B. Langrekken[125], A.J. Lankford[160], F. Lanni[36], K. Lantzsch[24], A. Lanza[73a], A. Lapertosa[57b,57a], J.F. Laporte[135], T. Lari[71a], F. Lasagni Manghi[23b], M. Lassnig[36], V. Latonova[131], A. Laudrain[100], A. Laurier[150], S.D. Lawlor[139], Z. Lawrence[101], R. Lazaridou[167], M. Lazzaroni[71a,71b], B. Le[101], E.M. Le Boulicaut[51], B. Leban[93], A. Lebedev[81], M. LeBlanc[101,ar], F. Ledroit-Guillon[60], A.C.A. Lee[96], S.C. Lee[148], S. Lee[47a,47b], T.F. Lee[92], L.L. Leeuw[33c], H.P. Lefebvre[95], M. Lefebvre[165], C. Leggett[17a], G. Lehmann Miotto[36], M. Leigh[56], W.A. Leight[103], W. Leinonen[113], A. Leisos[152,ac], M.A.L. Leite[83c], C.E. Leitgeb[48], R. Leitner[133], K.J.C. Leney[44], T. Lenz[24], S. Leone[74a], C. Leonidopoulos[52], A. Leopold[144], C. Leroy[108], R. Les[107], C.G. Lester[32], M. Levchenko[37], J. Levêque[4], D. Levin[106], L.J. Levinson[169], M.P. Lewicki[87], D.J. Lewis[4], A. Li[5], B. Li[62b], C. Li[62a], C-Q. Li[110], H. Li[62a], H. Li[62b], H. Li[14c], H. Li[14b], H. Li[62b], J. Li[62c], K. Li[138], L. Li[62c], M. Li[14a,14e], Q.Y. Li[62a], S. Li[14a,14e], S. Li[62d,62c,e], T. Li[5,c], X. Li[104], Z. Li[126], Z. Li[104], Z. Li[14a,14e], S. Liang[14a,14e], Z. Liang[14a], M. Liberatore[135,am], B. Liberti[76a], K. Lie[64c], J. Lieber Marin[83b], H. Lien[68], K. Lin[107], R.E. Lindley[7], J.H. Lindon[2], E. Lipeles[128], A. Lipniacka[16], A. Lister[164], J.D. Little [4], B. Liu [14a], B.X. Liu [142], D. Liu [62d,62c], J.B. Liu [62a], J.K.K. Liu [32], K. Liu [62d,62c], M. Liu [62a], M.Y. Liu [62a], P. Liu [14a], Q. Liu [62d,138,62c], X. Liu [62a], X. Liu [62b], Y. Liu [14d,14e], Y.L. Liu [62b], Y.W. Liu [62a], J. Llorente Merino [142], S.L. Lloyd [94], E.M. Lobodzinska [48], P. Loch [7], T. Lohse [18], K. Lohwasser [139], E. Loiacono [48], M. Lokajicek [131,*], J.D. Lomas [20], J.D. Long [162], I. Longarini [160], L. Longo [70a,70b], R. Longo [162], I. Lopez Paz [67], A. Lopez Solis [48], N. Lorenzo Martinez [4], A.M. Lory [109], O. Loseva [37], X. Lou [47a,47b], X. Lou [14a,14e], A. Lounis [66], J. Love [6], P.A. Love [91], G. Lu [14a,14e], M. Lu [80], S. Lu [128], Y.J. Lu [65], H.J. Lubatti [138], C. Luci [75a,75b], F.L. Lucio Alves [14c], A. Lucotte [60], F. Luehring [68], I. Luise [145], O. Lukianchuk [66], O. Lundberg [144], B. Lund-Jensen [144], N.A. Luongo [6], M.S. Lutz [151], A.B. Lux [25], D. Lynn [29], H. Lyons[92], R. Lysak [131], E. Lytken [98], V. Lyubushkin [38], T. Lyubushkina [38], M.M. Lyukova [145], H. Ma [29], K. Ma[62a], L.L. Ma [62b], W. Ma [62a], Y. Ma [121], D.M. Mac Donell [165], G. Maccarrone [53], J.C. MacDonald [100], P.C. Machado De Abreu Farias [83b], R. Madar [40], W.F. Mader [50], T. Madula [96], J. Maeda [85], T. Maeno [29], H. Maguire [139], V. Maiboroda [135], A. Maio [130a,130b,130d], K. Maj [86a], O. Majersky [48], S. Majewski [123], N. Makovec [66], V. Maksimovic [15], B. Malaescu [127], Pa. Malecki [87], V.P. Maleev [37], F. Malek [60], M. Mali [93], D. Malito [95,s], U. Mallik [80], S. Maltezos[10], S. Malyukov[38], J. Mamuzic [13], G. Mancini [53], G. Manco [73a,73b], J.P. Mandalia [94], I. Mandić [93], L. Manhaes de Andrade Filho [83a], I.M. Maniatis [169], J. Manjarres Ramos [102,an], D.C. Mankad [169], A. Mann [109], B. Mansoulie [135], S. Manzoni [36], L. Mao [62c], X. Mapekula [33c], A. Marantis [152,ac], G. Marchiori [5], M. Marcisovsky [131], C. Marcon [71a,71b], M. Marinescu [20], S. Marium [48], M. Marjanovic [120], E.J. Marshall [91], Z. Marshall [17a], S. Marti-Garcia [163], T.A. Martin [167], V.J. Martin [52], B. Martin dit Latour [16], L. Martinelli [75a,75b], M. Martinez [13,ad], P. Martinez Agullo [163], V.I. Martinez Outschoorn [103], P. Martinez Suarez [13], S. Martin-Haugh [134], V.S. Martoiu [27b], A.C. Martyniuk [96], A. Marzin [36], D. Mascione [78a,78b], L. Masetti [100], T. Mashimo [153], J. Masik [101], A.L. Maslennikov [37], L. Massa [23b], P. Massarotti [72a,72b], P. Mastrandrea [74a,74b], A. Mastroberardino [43b,43a], T. Masubuchi [153], T. Mathisen [161], J. Matousek [133], N. Matsuzawa[153], J. Maurer [27b], B. Maček [93], D.A. Maximov [37], R. Mazini [148], I. Maznas [152], M. Mazza [107], S.M. Mazza [136], E. Mazzeo [71a,71b], C. Mc Ginn [29], J.P. Mc Gowan [104], S.P. Mc Kee [106], C.C. McCracken [164], E.F. McDonald [105], A.E. McDougall [114], J.A. Mcfayden [146], R.P. McGovern [128], G. Mchedlidze [149b], R.P. Mckenzie [33g], T.C. Mclachlan [48], D.J. Mclaughlin [96], S.J. McMahon [134], C.M. Mcpartland [92], R.A. McPherson [165,ai], S. Mehlhase [109], A. Mehta [92], D. Melini [150], B.R. Mellado Garcia [33g], A.H. Melo [55], F. Meloni [48], A.M. Mendes Jacques Da Costa [101], H.Y. Meng [155], L. Meng [91], S. Menke [110], M. Mentink [36], E. Meoni [43b,43a], G. Mercado [115], C. Merlassino [69a,69c], L. Merola [72a,72b], C. Meroni [71a], G. Merz[106], J. Metcalfe [6], A.S. Mete [6], C. Meyer [68], J-P. Meyer [135], R.P. Middleton [134], L. Mijović [52], G. Mikenberg [169], M. Mikestikova [131], M. Mikuž [93], H. Mildner [100], A. Milic [36], C.D. Milke [44], D.W. Miller [39], L.S. Miller [34], A. Milov [169], D.A. Milstead[47a,47b], T. Min[14c], A.A. Minaenko [37], I.A. Minashvili [149b], L. Mince [59], A.I. Mincer [117], B. Mindur [86a], M. Mineev [38], Y. Mino [88], L.M. Mir [13], M. Miralles Lopez [163], M. Mironova [17a], A. Mishima[153], M.C. Missio [113], A. Mitra [167], V.A. Mitsou [163], Y. Mitsumori [111], O. Miu [155], P.S. Miyagawa [94], T. Mkrtchyan [63a], M. Mlinarevic [96], T. Mlinarevic [96], M. Mlynarikova [36], S. Mobius [19], P. Moder [48], P. Mogg [109], M.H. Mohamed Farook [112], A.F. Mohammed [14a,14e], S. Mohapatra [41], G. Mokgatitswane [33g], L. Moleri [169], B. Mondal [141], S. Mondal [132], G. Monig [146], K. Mönig [48], E. Monnier [102], L. Monsonis Romero[163], J. Montejo Berlingen [13], M. Montella [119], F. Montereali [77a,77b], F. Monticelli [90], S. Monzani [69a,69c], N. Morange [66], A.L. Moreira De Carvalho [130a], M. Moreno Llácer [163], C. Moreno Martinez [56], P. Morettini [57b],

S. Morgenstern [36], M. Morii [61], M. Morinaga [153], A.K. Morley [36], F. Morodei [75a,75b], L. Morvaj [36], P. Moschovakos [36], B. Moser [36], M. Mosidze[149b], T. Moskalets [54], P. Moskvitina [113], J. Moss [31,p], E.J.W. Moyse [103], O. Mtintsilana [33g], S. Muanza [102], J. Mueller [129], D. Muenstermann [91], R. Müller [19], G.A. Mullier [161], A.J. Mullin[32], J.J. Mullin[128], D.P. Mungo [155], D. Munoz Perez [163], F.J. Munoz Sanchez [101], M. Murin [101], W.J. Murray [167,134], A. Murrone [71a,71b], M. Muškinja [17a], C. Mwewa [29], A.G. Myagkov [37,a], A.J. Myers [8], G. Myers [68], M. Myska [132], B.P. Nachman [17a], O. Nackenhorst [49], A. Nag [50], K. Nagai [126], K. Nagano [84], J.L. Nagle [29,ay], E. Nagy [102], A.M. Nairz [36], Y. Nakahama [84], K. Nakamura [84], K. Nakkalil [5], H. Nanjo [124], R. Narayan [44], E.A. Narayanan [112], I. Naryshkin [37], M. Naseri [34], S. Nasri [159], C. Nass [24], G. Navarro [22a], J. Navarro-Gonzalez [163], R. Nayak [151], A. Nayaz [18], P.Y. Nechaeva [37], F. Nechansky [48], L. Nedic [126], T.J. Neep [20], A. Negri [73a,73b], M. Negrini [23b], C. Nellist [114], C. Nelson [104], K. Nelson [106], S. Nemecek [131], M. Nessi [36,j], M.S. Neubauer [162], F. Neuhaus [100], J. Neundorf [48], R. Newhouse [164], P.R. Newman [20], C.W. Ng [129], Y.W.Y. Ng [48], B. Ngair [35e], H.D.N. Nguyen [108], R.B. Nickerson [126], R. Nicolaidou [135], J. Nielsen [136], M. Niemeyer [55], J. Niermann [55,36], N. Nikiforou [36], V. Nikolaenko [37,a], I. Nikolic-Audit [127], K. Nikolopoulos [20], P. Nilsson [29], I. Ninca [48], H.R. Nindhito [56], G. Ninio [151], A. Nisati [75a], N. Nishu [2], R. Nisius [110], J-E. Nitschke [50], E.K. Nkadimeng [33g], T. Nobe [153], D.L. Noel [32], T. Nommensen [147], M.B. Norfolk [139], R.R.B. Norisam [96], B.J. Norman [34], M. Noury [35a], J. Novak [93], T. Novak [48], L. Novotny [132], R. Novotny [112], L. Nozka [122], K. Ntekas [160], N.M.J. Nunes De Moura Junior [83b], E. Nurse[96], J. Ocariz [127], A. Ochi [85], I. Ochoa [130a], S. Oerdek [48,y], J.T. Offermann [39], A. Ogrodnik [133], A. Oh [101], C.C. Ohm [144], H. Oide [84], R. Oishi [153], M.L. Ojeda [48], M.W. O'Keefe[92], Y. Okumura [153], L.F. Oleiro Seabra [130a], S.A. Olivares Pino [137d], D. Oliveira Damazio [29], D. Oliveira Goncalves [83a], J.L. Oliver [160], Ö.O. Öncel [54], A.P. O'Neill [19], A. Onofre [130a,130e], P.U.E. Onyisi [11], M.J. Oreglia [39], G.E. Orellana [90], D. Orestano [77a,77b], N. Orlando [13], R.S. Orr [155], V. O'Shea [59], L.M. Osojnak [128], R. Ospanov [62a], G. Otero y Garzon [30], H. Otono [89], P.S. Ott [63a], G.J. Ottino [17a], M. Ouchrif [35d], J. Ouellette [29], F. Ould-Saada [125], M. Owen [59], R.E. Owen [134], K.Y. Oyulmaz [21a], V.E. Ozcan [21a], F. Ozturk [87], N. Ozturk [8], S. Ozturk [82], H.A. Pacey [126], A. Pacheco Pages [13], C. Padilla Aranda [13], G. Padovano [75a,75b], S. Pagan Griso [17a], G. Palacino [68], A. Palazzo [70a,70b], S. Palestini [36], J. Pan [172], T. Pan [64a], D.K. Panchal [11], C.E. Pandini [114], J.G. Panduro Vazquez [95], H.D. Pandya [1], H. Pang [14b], P. Pani [48], G. Panizzo [69a,69c], L. Paolozzi [56], C. Papadatos [108], S. Parajuli [162], A. Paramonov [6], C. Paraskevopoulos [10], D. Paredes Hernandez [64b], K.R. Park [41], T.H. Park [155], M.A. Parker [32], F. Parodi [57b,57a], E.W. Parrish [115], V.A. Parrish [52], J.A. Parsons [41], U. Parzefall [54], B. Pascual Dias [108], L. Pascual Dominguez [151], E. Pasqualucci [75a], S. Passaggio [57b], F. Pastore [95], P. Pasuwan [47a,47b], P. Patel [87], U.M. Patel [51], J.R. Pater [101], T. Pauly [36], J. Pearkes [143], M. Pedersen [125], R. Pedro [130a], S.V. Peleganchuk [37], O. Penc [36], E.A. Pender [52], K.E. Penski [109], M. Penzin [37], B.S. Peralva [83d], A.P. Pereira Peixoto [60], L. Pereira Sanchez [47a,47b], D.V. Perepelitsa [29,ay], E. Perez Codina [156a], M. Perganti [10], L. Perini [71a,71b,*], H. Pernegger [36], O. Perrin [40], K. Peters [48], R.F.Y. Peters [101], B.A. Petersen [36], T.C. Petersen [42], E. Petit [102], V. Petousis [132], C. Petridou [152,f], A. Petrukhin [141], M. Pettee [17a], N.E. Pettersson [36], A. Petukhov [37], K. Petukhova [133], R. Pezoa [137f], L. Pezzotti [36], G. Pezzullo [172], T.M. Pham [170], T. Pham [105], P.W. Phillips [134], G. Piacquadio [145], E. Pianori [17a], F. Piazza [123], R. Piegaia [30], D. Pietreanu [27b], A.D. Pilkington [101], M. Pinamonti [69a,69c], J.L. Pinfold [2], B.C. Pinheiro Pereira [130a], A.E. Pinto Pinoargote [100,135], L. Pintucci [69a,69c], K.M. Piper [146], A. Pirttikoski [56], D.A. Pizzi [34], L. Pizzimento [64b], A. Pizzini [114], M.-A. Pleier [29], V. Plesanovs[54], V. Pleskot [133], E. Plotnikova[38], G. Poddar [4], R. Poettgen [98], L. Poggioli [127], I. Pokharel [55],

S. Polacek[133], G. Polesello[73a], A. Poley[142,156a], R. Polifka[132], A. Polini[23b], C.S. Pollard[167], Z.B. Pollock[119], V. Polychronakos[29], E. Pompa Pacchi[75a,75b], D. Ponomarenko[113], L. Pontecorvo[36], S. Popa[27a], G.A. Popeneciu[27d], A. Poreba[36], D.M. Portillo Quintero[156a], S. Pospisil[132], M.A. Postill[139], P. Postolache[27c], K. Potamianos[167], P.A. Potepa[86a], I.N. Potrap[38], C.J. Potter[32], H. Potti[1], T. Poulsen[48], J. Poveda[163], M.E. Pozo Astigarraga[36], A. Prades Ibanez[163], J. Pretel[54], D. Price[101], M. Primavera[70a], M.A. Principe Martin[99], R. Privara[122], T. Procter[59], M.L. Proffitt[138], N. Proklova[128], K. Prokofiev[64c], G. Proto[110], S. Protopopescu[29], J. Proudfoot[6], M. Przybycien[86a], W.W. Przygoda[86b], A. Psallidas[46], J.E. Puddefoot[139], D. Pudzha[37], D. Pyatiizbyantseva[37], J. Qian[106], D. Qichen[101], Y. Qin[101], T. Qiu[52], A. Quadt[55], M. Queitsch-Maitland[101], G. Quetant[56], R.P. Quinn[164], G. Rabanal Bolanos[61], D. Rafanoharana[54], F. Ragusa[71a,71b], J.L. Rainbolt[39], J.A. Raine[56], S. Rajagopalan[29], E. Ramakoti[37], I.A. Ramirez-Berend[34], K. Ran[48,14e], N.P. Rapheeha[33g], H. Rasheed[27b], V. Raskina[127], D.F. Rassloff[63a], A. Rastogi[17a], S. Rave[100], B. Ravina[55], I. Ravinovich[169], M. Raymond[36], A.L. Read[125], N.P. Readioff[139], D.M. Rebuzzi[73a,73b], G. Redlinger[29], A.S. Reed[110], K. Reeves[26], J.A. Reidelsturz[171,aa], D. Reikher[151], A. Rej[49,z], C. Rembser[36], A. Renardi[48], M. Renda[27b], M.B. Rendel[110], F. Renner[48], A.G. Rennie[160], A.L. Rescia[48], S. Resconi[71a], M. Ressegotti[57b,57a], S. Rettie[36], J.G. Reyes Rivera[107], E. Reynolds[17a], O.L. Rezanova[37], P. Reznicek[133], N. Ribaric[91], E. Ricci[78a,78b], R. Richter[110], S. Richter[47a,47b], E. Richter-Was[86b], M. Ridel[127], S. Ridouani[35d], P. Rieck[117], P. Riedler[36], E.M. Riefel[47a,47b], J.O. Rieger[114], M. Rijssenbeek[145], A. Rimoldi[73a,73b], M. Rimoldi[36], L. Rinaldi[23b,23a], T.T. Rinn[29], M.P. Rinnagel[109], G. Ripellino[161], I. Riu[13], P. Rivadeneira[48], J.C. Rivera Vergara[165], F. Rizatdinova[121], E. Rizvi[94], B.A. Roberts[167], B.R. Roberts[17a], S.H. Robertson[104,ai], D. Robinson[32], C.M. Robles Gajardo[137f], M. Robles Manzano[100], A. Robson[59], A. Rocchi[76a,76b], C. Roda[74a,74b], S. Rodriguez Bosca[63a], Y. Rodriguez Garcia[22a], A. Rodriguez Rodriguez[54], A.M. Rodríguez Vera[156b], S. Roe[36], J.T. Roemer[160], A.R. Roepe-Gier[136], J. Roggel[171], O. Røhne[125], R.A. Rojas[103], C.P.A. Roland[127], J. Roloff[29], A. Romaniouk[37], E. Romano[73a,73b], M. Romano[23b], A.C. Romero Hernandez[162], N. Rompotis[92], L. Roos[127], S. Rosati[75a], B.J. Rosser[39], E. Rossi[126], E. Rossi[72a,72b], L.P. Rossi[57b], L. Rossini[54], R. Rosten[119], M. Rotaru[27b], B. Rottler[54], C. Rougier[102,an], D. Rousseau[66], D. Rousso[32], A. Roy[162], S. Roy-Garand[155], A. Rozanov[102], Z.M.A. Rozario[59], Y. Rozen[150], X. Ruan[33g], A. Rubio Jimenez[163], A.J. Ruby[92], V.H. Ruelas Rivera[18], T.A. Ruggeri[1], A. Ruggiero[126], A. Ruiz-Martinez[163], A. Rummler[36], Z. Rurikova[54], N.A. Rusakovich[38], H.L. Russell[165], G. Russo[75a,75b], J.P. Rutherfoord[7], S. Rutherford Colmenares[32], K. Rybacki[91], M. Rybar[133], E.B. Rye[125], A. Ryzhov[44], J.A. Sabater Iglesias[56], P. Sabatini[163], H.F-W. Sadrozinski[136], F. Safai Tehrani[75a], B. Safarzadeh Samani[134], M. Safdari[143], S. Saha[165], M. Sahinsoy[110], A. Saibel[163], M. Saimpert[135], M. Saito[153], T. Saito[153], D. Salamani[36], A. Salnikov[143], J. Salt[163], A. Salvador Salas[151], D. Salvatore[43b,43a], F. Salvatore[146], A. Salzburger[36], D. Sammel[54], D. Sampsonidis[152,f], D. Sampsonidou[123], J. Sánchez[163], A. Sanchez Pineda[4], V. Sanchez Sebastian[163], H. Sandaker[125], C.O. Sander[48], J.A. Sandesara[103], M. Sandhoff[171], C. Sandoval[22b], D.P.C. Sankey[134], T. Sano[88], A. Sansoni[53], L. Santi[75a,75b], C. Santoni[40], H. Santos[130a,130b], S.N. Santpur[17a], A. Santra[169], K.A. Saoucha[116b], J.G. Saraiva[130a,130d], J. Sardain[7], O. Sasaki[84], K. Sato[157], C. Sauer[63b], F. Sauerburger[54], E. Sauvan[4], P. Savard[155,av], R. Sawada[153], C. Sawyer[134], L. Sawyer[97], I. Sayago Galvan[163], C. Sbarra[23b], A. Sbrizzi[23b,23a], T. Scanlon[96], J. Schaarschmidt[138], P. Schacht[110], U. Schäfer[100], A.C. Schaffer[66,44], D. Schaile[109], R.D. Schamberger[145], C. Scharf[18], M.M. Schefer[19], V.A. Schegelsky[37], D. Scheirich[133], F. Schenck[18], M. Schernau[160], C. Scheulen[55],

C. Schiavi[57b,57a], E.J. Schioppa[70a,70b], M. Schioppa[43b,43a], B. Schlag[143,t], K.E. Schleicher[54], S. Schlenker[36], J. Schmeing[171], M.A. Schmidt[171], K. Schmieden[100], C. Schmitt[100], N. Schmitt[100], S. Schmitt[48], L. Schoeffel[135], A. Schoening[63b], P.G. Scholer[54], E. Schopf[126], M. Schott[100], J. Schovancova[36], S. Schramm[56], F. Schroeder[171], T. Schroer[56], H-C. Schultz-Coulon[63a], M. Schumacher[54], B.A. Schumm[136], Ph. Schune[135], A.J. Schuy[138], H.R. Schwartz[136], A. Schwartzman[143], T.A. Schwarz[106], Ph. Schwemling[135], R. Schwienhorst[107], A. Sciandra[136], G. Sciolla[26], F. Scuri[74a], C.D. Sebastiani[92], K. Sedlaczek[115], P. Seema[18], S.C. Seidel[112], A. Seiden[136], B.D. Seidlitz[41], C. Seitz[48], J.M. Seixas[83b], G. Sekhniaidze[72a], S.J. Sekula[44], L. Selem[60], N. Semprini-Cesari[23b,23a], D. Sengupta[56], V. Senthilkumar[163], L. Serin[66], L. Serkin[69a,69b], M. Sessa[76a,76b], H. Severini[120], F. Sforza[57b,57a], A. Sfyrla[56], E. Shabalina[55], R. Shaheen[144], J.D. Shahinian[128], D. Shaked Renous[169], L.Y. Shan[14a], M. Shapiro[17a], A. Sharma[36], A.S. Sharma[164], P. Sharma[80], S. Sharma[48], P.B. Shatalov[37], K. Shaw[146], S.M. Shaw[101], A. Shcherbakova[37], Q. Shen[62c,5], D.J. Sheppard[142], P. Sherwood[96], L. Shi[96], X. Shi[14a], C.O. Shimmin[172], J.D. Shinner[95], I.P.J. Shipsey[126], S. Shirabe[56,j], M. Shiyakova[38,ag], J. Shlomi[169], M.J. Shochet[39], J. Shojaii[105], D.R. Shope[125], B. Shrestha[120], S. Shrestha[119,az], E.M. Shrif[33g], M.J. Shroff[165], P. Sicho[131], A.M. Sickles[162], E. Sideras Haddad[33g], A. Sidoti[23b], F. Siegert[50], Dj. Sijacki[15], F. Sili[90], J.M. Silva[20], M.V. Silva Oliveira[29], S.B. Silverstein[47a], S. Simion[66], R. Simoniello[36], E.L. Simpson[59], H. Simpson[146], L.R. Simpson[106], N.D. Simpson[98], S. Simsek[82], S. Sindhu[55], P. Sinervo[155], S. Singh[155], S. Sinha[48], S. Sinha[101], M. Sioli[23b,23a], I. Siral[36], E. Sitnikova[48], S.Yu. Sivoklokov[37,*], J. Sjölin[47a,47b], A. Skaf[55], E. Skorda[20,aq], P. Skubic[120], M. Slawinska[87], V. Smakhtin[169], B.H. Smart[134], S.Yu. Smirnov[37], Y. Smirnov[37], L.N. Smirnova[37,a], O. Smirnova[98], A.C. Smith[41], E.A. Smith[39], H.A. Smith[126], J.L. Smith[92], R. Smith[143], M. Smizanska[91], K. Smolek[132], A.A. Snesarev[37], S.R. Snider[155], H.L. Snoek[114], S. Snyder[29], R. Sobie[165,ai], A. Soffer[151], C.A. Solans Sanchez[36], E.Yu. Soldatov[37], U. Soldevila[163], A.A. Solodkov[37], S. Solomon[26], A. Soloshenko[38], K. Solovieva[54], O.V. Solovyanov[40], V. Solovyev[37], P. Sommer[36], A. Sonay[13], W.Y. Song[156b], J.M. Sonneveld[114], A. Sopczak[132], A.L. Sopio[96], F. Sopkova[28b], J.D. Sorenson[112], I.R. Sotarriva Alvarez[154], V. Sothilingam[63a], S. Sottocornola[68], R. Soualah[116b], Z. Soumaimi[35e], D. South[48], N. Soybelman[169], S. Spagnolo[70a,70b], M. Spalla[110], D. Sperlich[54], G. Spigo[36], S. Spinali[91], D.P. Spiteri[59], M. Spousta[133], E.J. Staats[34], A. Stabile[71a,71b], R. Stamen[63a], A. Stampekis[20], M. Standke[24], E. Stanecka[87], M.V. Stange[50], B. Stanislaus[17a], M.M. Stanitzki[48], B. Stapf[48], E.A. Starchenko[37], G.H. Stark[136], J. Stark[102,an], D.M. Starko[156b], P. Staroba[131], P. Starovoitov[63a], S. Stärz[104], R. Staszewski[87], G. Stavropoulos[46], J. Steentoft[161], P. Steinberg[29], B. Stelzer[142,156a], H.J. Stelzer[129], O. Stelzer-Chilton[156a], H. Stenzel[58], T.J. Stevenson[146], G.A. Stewart[36], J.R. Stewart[121], M.C. Stockton[36], G. Stoicea[27b], M. Stolarski[130a], S. Stonjek[110], A. Straessner[50], J. Strandberg[144], S. Strandberg[47a,47b], M. Stratmann[171], M. Strauss[120], T. Strebler[102], P. Strizenec[28b], R. Ströhmer[166], D.M. Strom[123], R. Stroynowski[44], A. Strubig[47a,47b], S.A. Stucci[29], B. Stugu[16], J. Stupak[120], N.A. Styles[48], D. Su[143], S. Su[62a], W. Su[62d], X. Su[62a,66], K. Sugizaki[153], V.V. Sulin[37], M.J. Sullivan[92], D.M.S. Sultan[78a,78b], L. Sultanaliyeva[37], S. Sultansoy[3b], T. Sumida[88], S. Sun[106], S. Sun[170], O. Sunneborn Gudnadottir[161], N. Sur[102], M.R. Sutton[146], H. Suzuki[157], M. Svatos[131], M. Swiatlowski[156a], T. Swirski[166], I. Sykora[28a], M. Sykora[133], T. Sykora[133], D. Ta[100], K. Tackmann[48,ae], A. Taffard[160], R. Tafirout[156a], J.S. Tafoya Vargas[66], E.P. Takeva[52], Y. Takubo[84], M. Talby[102], A.A. Talyshev[37], K.C. Tam[64b], N.M. Tamir[151], A. Tanaka[153], J. Tanaka[153], R. Tanaka[66], M. Tanasini[57b,57a], Z. Tao[164], S. Tapia Araya[137f],

S. Tapprogge[100], A. Tarek Abouelfadl Mohamed[107], S. Tarem[150], K. Tariq[14a], G. Tarna[102,27b], G.F. Tartarelli[71a], P. Tas[133], M. Tasevsky[131], E. Tassi[43b,43a], A.C. Tate[162], G. Tateno[153], Y. Tayalati[35e,ah], G.N. Taylor[105], W. Taylor[156b], A.S. Tee[170], R. Teixeira De Lima[143], P. Teixeira-Dias[95], J.J. Teoh[155], K. Terashi[153], J. Terron[99], S. Terzo[13], M. Testa[53], R.J. Teuscher[155,ai], A. Thaler[79], O. Theiner[56], N. Themistokleous[52], T. Theveneaux-Pelzer[102], O. Thielmann[171], D.W. Thomas[95], J.P. Thomas[20], E.A. Thompson[17a], P.D. Thompson[20], E. Thomson[128], Y. Tian[55], V. Tikhomirov[37,a], Yu.A. Tikhonov[37], S. Timoshenko[37], D. Timoshyn[133], E.X.L. Ting[1], P. Tipton[172], S.H. Tlou[33g], A. Tnourji[40], K. Todome[154], S. Todorova-Nova[133], S. Todt[50], M. Togawa[84], J. Tojo[89], S. Tokár[28a], K. Tokushuku[84], O. Toldaiev[68], R. Tombs[32], M. Tomoto[84,111], L. Tompkins[143,t], K.W. Topolnicki[86b], E. Torrence[123], H. Torres[102,an], E. Torró Pastor[163], M. Toscani[30], C. Tosciri[39], M. Tost[11], D.R. Tovey[139], A. Traeet[16], I.S. Trandafir[27b], T. Trefzger[166], A. Tricoli[29], I.M. Trigger[156a], S. Trincaz-Duvoid[127], D.A. Trischuk[26], B. Trocmé[60], C. Troncon[71a], L. Truong[33c], M. Trzebinski[87], A. Trzupek[87], F. Tsai[145], M. Tsai[106], A. Tsiamis[152,f], P.V. Tsiareshka[37], S. Tsigaridas[156a], A. Tsirigotis[152,ac], V. Tsiskaridze[155], E.G. Tskhadadze[149a], M. Tsopoulou[152,f], Y. Tsujikawa[88], I.I. Tsukerman[37], V. Tsulaia[17a], S. Tsuno[84], K. Tsuri[118], D. Tsybychev[145], Y. Tu[64b], A. Tudorache[27b], V. Tudorache[27b], A.N. Tuna[61], S. Turchikhin[57b,57a], I. Turk Cakir[3a], R. Turra[71a], T. Turtuvshin[38,aj], P.M. Tuts[41], S. Tzamarias[152,f], P. Tzanis[10], E. Tzovara[100], F. Ukegawa[157], P.A. Ulloa Poblete[137c,137b], E.N. Umaka[29], G. Unal[36], M. Unal[11], A. Undrus[29], G. Unel[160], J. Urban[28b], P. Urquijo[105], P. Urrejola[137a], G. Usai[8], R. Ushioda[154], M. Usman[108], Z. Uysal[21b], V. Vacek[132], B. Vachon[104], K.O.H. Vadla[125], T. Vafeiadis[36], A. Vaitkus[96], C. Valderanis[109], E. Valdes Santurio[47a,47b], M. Valente[156a], S. Valentinetti[23b,23a], A. Valero[163], E. Valiente Moreno[163], A. Vallier[102,an], J.A. Valls Ferrer[163], D.R. Van Arneman[114], T.R. Van Daalen[138], A. Van Der Graaf[49], P. Van Gemmeren[6], M. Van Rijnbach[125,36], S. Van Stroud[96], I. Van Vulpen[114], M. Vanadia[76a,76b], W. Vandelli[36], M. Vandenbroucke[135], E.R. Vandewall[121], D. Vannicola[151], L. Vannoli[57b,57a], R. Vari[75a], E.W. Varnes[7], C. Varni[17b], T. Varol[148], D. Varouchas[66], L. Varriale[163], K.E. Varvell[147], M.E. Vasile[27b], L. Vaslin[84], G.A. Vasquez[165], A. Vasyukov[38], F. Vazeille[40], T. Vazquez Schroeder[36], J. Veatch[31], V. Vecchio[101], M.J. Veen[103], I. Veliscek[126], L.M. Veloce[155], F. Veloso[130a,130c], S. Veneziano[75a], A. Ventura[70a,70b], S. Ventura Gonzalez[135], A. Verbytskyi[110], M. Verducci[74a,74b], C. Vergis[24], M. Verissimo De Araujo[83b], W. Verkerke[114], J.C. Vermeulen[114], C. Vernieri[143], M. Vessella[103], M.C. Vetterli[142,av], A. Vgenopoulos[152,f], N. Viaux Maira[137f], T. Vickey[139], O.E. Vickey Boeriu[139], G.H.A. Viehhauser[126], L. Vigani[63b], M. Villa[23b,23a], M. Villaplana Perez[163], E.M. Villhauer[52], E. Vilucchi[53], M.G. Vincter[34], G.S. Virdee[20], A. Vishwakarma[52], A. Visibile[114], C. Vittori[36], I. Vivarelli[146], E. Voevodina[110], F. Vogel[109], J.C. Voigt[50], P. Vokac[132], Yu. Volkotrub[86a], J. Von Ahnen[48], E. Von Toerne[24], B. Vormwald[36], V. Vorobel[133], K. Vorobev[37], M. Vos[163], K. Voss[141], J.H. Vossebeld[92], M. Vozak[114], L. Vozdecky[94], N. Vranjes[15], M. Vranjes Milosavljevic[15], M. Vreeswijk[114], N.K. Vu[62d,62c], R. Vuillermet[36], O. Vujinovic[100], I. Vukotic[39], S. Wada[157], C. Wagner[103], J.M. Wagner[17a], W. Wagner[171], S. Wahdan[171], H. Wahlberg[90], M. Wakida[111], J. Walder[134], R. Walker[109], W. Walkowiak[141], A. Wall[128], T. Wamorkar[6], A.Z. Wang[136], C. Wang[100], C. Wang[62c], H. Wang[17a], J. Wang[64a], R.-J. Wang[100], R. Wang[61], R. Wang[6], S.M. Wang[148], S. Wang[62b], T. Wang[62a], W.T. Wang[80], W. Wang[14a], X. Wang[14c], X. Wang[162], X. Wang[62c], Y. Wang[62d], Y. Wang[14c], Z. Wang[106], Z. Wang[62d,51,62c], Z. Wang[106], A. Warburton[104], R.J. Ward[20], N. Warrack[59], A.T. Watson[20], H. Watson[59], M.F. Watson[20], E. Watton[59,134], G. Watts[138], B.M. Waugh[96], C. Weber[29], H.A. Weber[18], M.S. Weber [19], S.M. Weber [63a], C. Wei[62a], Y. Wei [126], A.R. Weidberg [126], E.J. Weik [117], J. Weingarten [49], M. Weirich [100], C. Weiser [54], C.J. Wells [48], T. Wenaus [29], B. Wendland [49], T. Wengler [36], N.S. Wenke[110], N. Wermes [24], M. Wessels [63a], A.M. Wharton [91], A.S. White [61], A. White [8], M.J. White [1], D. Whiteson [160], L. Wickremasinghe [124], W. Wiedenmann [170], C. Wiel [50], M. Wielers [134], C. Wiglesworth [42], D.J. Wilbern[120], H.G. Wilkens [36], D.M. Williams [41], H.H. Williams[128], S. Williams [32], S. Willocq [103], B.J. Wilson [101], P.J. Windischhofer [39], F.I. Winkel [30], F. Winklmeier [123], B.T. Winter [54], J.K. Winter [101], M. Wittgen[143], M. Wobisch [97], Z. Wolffs [114], J. Wollrath[160], M.W. Wolter [87], H. Wolters [130a,130c], A.F. Wongel [48], E.L. Woodward [41], S.D. Worm [48], B.K. Wosiek [87], K.W. Woźniak [87], S. Wozniewski [55], K. Wraight [59], C. Wu [20], J. Wu [14a,14e], M. Wu [64a], M. Wu [113], S.L. Wu [170], X. Wu [56], Y. Wu [62a], Z. Wu [135], J. Wuerzinger [110,at], T.R. Wyatt [101], B.M. Wynne [52], S. Xella [42], L. Xia [14c], M. Xia [14b], J. Xiang [64c], M. Xie [62a], X. Xie [62a], S. Xin [14a,14e], A. Xiong [123], J. Xiong [17a], D. Xu [14a], H. Xu [62a], L. Xu [62a], R. Xu [128], T. Xu [106], Y. Xu [14b], Z. Xu [52], B. Yabsley [147], S. Yacoob [33a], Y. Yamaguchi [154], E. Yamashita [153], H. Yamauchi [157], T. Yamazaki [17a], Y. Yamazaki [85], J. Yan[62c], S. Yan [126], Z. Yan [25], H.J. Yang [62c,62d], H.T. Yang [62a], S. Yang [62a], T. Yang [64c], X. Yang [36], X. Yang [14a], Y. Yang [44], Y. Yang[62a], Z. Yang [62a], W-M. Yao [17a], Y.C. Yap [48], H. Ye [14c], H. Ye [55], J. Ye [14a], S. Ye [29], X. Ye [62a], Y. Yeh [96], I. Yeletskikh [38], B.K. Yeo [17b], M.R. Yexley [96], P. Yin [41], K. Yorita [168], S. Younas [27b], C.J.S. Young [36], C. Young [143], C. Yu [14a,14e,ax], Y. Yu [62a], M. Yuan [106], R. Yuan [62b], L. Yue [96], M. Zaazoua [62a], B. Zabinski [87], E. Zaid[52], T. Zakareishvili [149b], N. Zakharchuk [34], S. Zambito [56], J.A. Zamora Saa [137d,137b], J. Zang [153], D. Zanzi [54], O. Zaplatilek [132], C. Zeitnitz [171], H. Zeng [14a], J.C. Zeng [162], D.T. Zenger Jr [26], O. Zenin [37], T. Ženiš [28a], S. Zenz [94], S. Zerradi [35a], D. Zerwas [66], M. Zhai [14a,14e], B. Zhang [14c], D.F. Zhang [139], J. Zhang [62b], J. Zhang [6], K. Zhang [14a,14e], L. Zhang [14c], P. Zhang[14a,14e], R. Zhang [170], S. Zhang [106], S. Zhang [44], T. Zhang [153], X. Zhang [62c], X. Zhang [62b], Y. Zhang [62c,5], Y. Zhang [96], Y. Zhang [14c], Z. Zhang [17a], Z. Zhang [66], H. Zhao [138], T. Zhao [62b], Y. Zhao [136], Z. Zhao [62a], A. Zhemchugov [38], J. Zheng [14c], K. Zheng [162], X. Zheng [62a], Z. Zheng [143], D. Zhong [162], B. Zhou[106], H. Zhou [7], N. Zhou [62c], Y. Zhou[7], C.G. Zhu [62b], J. Zhu [106], Y. Zhu [62c], Y. Zhu [62a], X. Zhuang [14a], K. Zhukov [37], V. Zhulanov [37], N.I. Zimine [38], J. Zinsser [63b], M. Ziolkowski [141], L. Živković [15], A. Zoccoli [23b,23a], K. Zoch [61], T.G. Zorbas [139], O. Zormpa [46], W. Zou [41], L. Zwalinski [36].

[1]Department of Physics, University of Adelaide, Adelaide; Australia.
[2]Department 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.
[4]LAPP, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy; France.
[5]APC, Université Paris Cité, CNRS/IN2P3, Paris; France.
[6]High Energy Physics Division, Argonne National Laboratory, Argonne IL; United States of America.
[7]Department of Physics, University of Arizona, Tucson AZ; United States of America.
[8]Department of Physics, University of Texas at Arlington, Arlington TX; United States of America.
[9]Physics Department, National and Kapodistrian University of Athens, Athens; Greece.
[10]Physics Department, National Technical University of Athens, Zografou; Greece.
[11]Department of Physics, University of Texas at Austin, Austin TX; United States of America.
[12]Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
[13]Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona; Spain.

[14] [(a)] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; [(b)] Physics Department, Tsinghua University, Beijing; [(c)] Department of Physics, Nanjing University, Nanjing; [(d)] School of Science, Shenzhen Campus of Sun Yat-sen University; [(e)] University of Chinese Academy of Science (UCAS), Beijing; China.
[15] Institute of Physics, University of Belgrade, Belgrade; Serbia.
[16] Department for Physics and Technology, University of Bergen, Bergen; Norway.
[17] [(a)] Physics Division, Lawrence Berkeley National Laboratory, Berkeley CA; [(b)] University of California, Berkeley CA; United States of America.
[18] Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany.
[19] Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland.
[20] School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom.
[21] [(a)] Department of Physics, Bogazici University, Istanbul; [(b)] Department of Physics Engineering, Gaziantep University, Gaziantep; [(c)] Department of Physics, Istanbul University, Istanbul; Türkiye.
[22] [(a)] Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogotá; [(b)] Departamento de Física, Universidad Nacional de Colombia, Bogotá; [(c)] Pontificia Universidad Javeriana, Bogota; Colombia.
[23] [(a)] Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna; [(b)] INFN Sezione di Bologna; Italy.
[24] Physikalisches Institut, Universität Bonn, Bonn; Germany.
[25] Department of Physics, Boston University, Boston MA; United States of America.
[26] Department of Physics, Brandeis University, Waltham MA; United States of America.
[27] [(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)] University Politehnica Bucharest, Bucharest; [(f)] West University in Timisoara, Timisoara; [(g)] Faculty of Physics, University of Bucharest, Bucharest; Romania.
[28] [(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.
[29] Physics Department, Brookhaven National Laboratory, Upton NY; United States of America.
[30] Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires; Argentina.
[31] California State University, CA; United States of America.
[32] Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom.
[33] [(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.
[34] Department of Physics, Carleton University, Ottawa ON; Canada.
[35] [(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.
[36] CERN, Geneva; Switzerland.

[37]Affiliated with an institute covered by a cooperation agreement with CERN.
[38]Affiliated with an international laboratory covered by a cooperation agreement with CERN.
[39]Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America.
[40]LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France.
[41]Nevis Laboratory, Columbia University, Irvington NY; United States of America.
[42]Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark.
[43(a)]Dipartimento di Fisica, Università della Calabria, Rende;[(b)]INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy.
[44]Physics Department, Southern Methodist University, Dallas TX; United States of America.
[45]Physics Department, University of Texas at Dallas, Richardson TX; United States of America.
[46]National Centre for Scientific Research "Demokritos", Agia Paraskevi; Greece.
[47(a)]Department of Physics, Stockholm University;[(b)]Oskar Klein Centre, Stockholm; Sweden.
[48]Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany.
[49]Fakultät Physik , Technische Universität Dortmund, Dortmund; Germany.
[50]Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany.
[51]Department of Physics, Duke University, Durham NC; United States of America.
[52]SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom.
[53]INFN e Laboratori Nazionali di Frascati, Frascati; Italy.
[54]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
[55]II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany.
[56]Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[57(a)]Dipartimento di Fisica, Università di Genova, Genova;[(b)]INFN Sezione di Genova; Italy.
[58]II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany.
[59]SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom.
[60]LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France.
[61]Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America.
[62(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.
[63(a)]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;[(b)]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany.
[64(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.
[65]Department of Physics, National Tsing Hua University, Hsinchu; Taiwan.
[66]IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France.
[67]Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona; Spain.
[68]Department of Physics, Indiana University, Bloomington IN; United States of America.
[69(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.
[70(a)]INFN Sezione di Lecce;[(b)]Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy.
[71(a)]INFN Sezione di Milano;[(b)]Dipartimento di Fisica, Università di Milano, Milano; Italy.
[72(a)]INFN Sezione di Napoli;[(b)]Dipartimento di Fisica, Università di Napoli, Napoli; Italy.

[73(a)]INFN Sezione di Pavia;[(b)]Dipartimento di Fisica, Università di Pavia, Pavia; Italy.
[74(a)]INFN Sezione di Pisa;[(b)]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy.
[75(a)]INFN Sezione di Roma;[(b)]Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy.
[76(a)]INFN Sezione di Roma Tor Vergata;[(b)]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy.
[77(a)]INFN Sezione di Roma Tre;[(b)]Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy.
[78(a)]INFN-TIFPA;[(b)]Università degli Studi di Trento, Trento; Italy.
[79]Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck; Austria.
[80]University of Iowa, Iowa City IA; United States of America.
[81]Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America.
[82]Istinye University, Sariyer, Istanbul; Türkiye.
[83(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; Brazil.
[84]KEK, High Energy Accelerator Research Organization, Tsukuba; Japan.
[85]Graduate School of Science, Kobe University, Kobe; Japan.
[86(a)]AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow;[(b)]Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland.
[87]Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland.
[88]Faculty of Science, Kyoto University, Kyoto; Japan.
[89]Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka ; Japan.
[90]Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina.
[91]Physics Department, Lancaster University, Lancaster; United Kingdom.
[92]Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom.
[93]Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia.
[94]School of Physics and Astronomy, Queen Mary University of London, London; United Kingdom.
[95]Department of Physics, Royal Holloway University of London, Egham; United Kingdom.
[96]Department of Physics and Astronomy, University College London, London; United Kingdom.
[97]Louisiana Tech University, Ruston LA; United States of America.
[98]Fysiska institutionen, Lunds universitet, Lund; Sweden.
[99]Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain.
[100]Institut für Physik, Universität Mainz, Mainz; Germany.
[101]School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom.
[102]CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.
[103]Department of Physics, University of Massachusetts, Amherst MA; United States of America.
[104]Department of Physics, McGill University, Montreal QC; Canada.
[105]School of Physics, University of Melbourne, Victoria; Australia.
[106]Department of Physics, University of Michigan, Ann Arbor MI; United States of America.
[107]Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.
[108]Group of Particle Physics, University of Montreal, Montreal QC; Canada.
[109]Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany.
[110]Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany.
[111]Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan.

[112]Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America.
[113]Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen; Netherlands.
[114]Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands.
[115]Department of Physics, Northern Illinois University, DeKalb IL; United States of America.
[116(a)]New York University Abu Dhabi, Abu Dhabi;[(b)]University of Sharjah, Sharjah; United Arab Emirates.
[117]Department of Physics, New York University, New York NY; United States of America.
[118]Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan.
[119]Ohio State University, Columbus OH; United States of America.
[120]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America.
[121]Department of Physics, Oklahoma State University, Stillwater OK; United States of America.
[122]Palacký University, Joint Laboratory of Optics, Olomouc; Czech Republic.
[123]Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America.
[124]Graduate School of Science, Osaka University, Osaka; Japan.
[125]Department of Physics, University of Oslo, Oslo; Norway.
[126]Department of Physics, Oxford University, Oxford; United Kingdom.
[127]LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris; France.
[128]Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America.
[129]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America.
[130(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.
[131]Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic.
[132]Czech Technical University in Prague, Prague; Czech Republic.
[133]Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic.
[134]Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom.
[135]IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.
[136]Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America.
[137(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.
[138]Department of Physics, University of Washington, Seattle WA; United States of America.
[139]Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
[140]Department of Physics, Shinshu University, Nagano; Japan.
[141]Department Physik, Universität Siegen, Siegen; Germany.

[142]Department of Physics, Simon Fraser University, Burnaby BC; Canada.
[143]SLAC National Accelerator Laboratory, Stanford CA; United States of America.
[144]Department of Physics, Royal Institute of Technology, Stockholm; Sweden.
[145]Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America.
[146]Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom.
[147]School of Physics, University of Sydney, Sydney; Australia.
[148]Institute of Physics, Academia Sinica, Taipei; Taiwan.
[149](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.
[150]Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel.
[151]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel.
[152]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece.
[153]International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan.
[154]Department of Physics, Tokyo Institute of Technology, Tokyo; Japan.
[155]Department of Physics, University of Toronto, Toronto ON; Canada.
[156](a)TRIUMF, Vancouver BC;(b)Department of Physics and Astronomy, York University, Toronto ON; Canada.
[157]Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan.
[158]Department of Physics and Astronomy, Tufts University, Medford MA; United States of America.
[159]United Arab Emirates University, Al Ain; United Arab Emirates.
[160]Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America.
[161]Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden.
[162]Department of Physics, University of Illinois, Urbana IL; United States of America.
[163]Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain.
[164]Department of Physics, University of British Columbia, Vancouver BC; Canada.
[165]Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.
[166]Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany.
[167]Department of Physics, University of Warwick, Coventry; United Kingdom.
[168]Waseda University, Tokyo; Japan.
[169]Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel.
[170]Department of Physics, University of Wisconsin, Madison WI; United States of America.
[171]Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
[172]Department 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 APC, Université Paris Cité, CNRS/IN2P3, Paris; France.
[d] Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.
[e] Also at Center for High Energy Physics, Peking University; China.
[f] Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki ; Greece.
[g] Also at Centro Studi e Ricerche Enrico Fermi; Italy.
[h] Also at CERN Tier-0; Switzerland.

[i] Also at CERN, Geneva; Switzerland.
[j] Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[k] Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona; Spain.
[l] Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.
[m] Also at Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
[n] Also at Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.
[o] Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva; Israel.
[p] Also at Department of Physics, California State University, Sacramento; United States of America.
[q] Also at Department of Physics, King's College London, London; United Kingdom.
[r] Also at Department of Physics, Oxford University, Oxford; United Kingdom.
[s] Also at Department of Physics, Royal Holloway University of London, Egham; United Kingdom.
[t] Also at Department of Physics, Stanford University, Stanford CA; United States of America.
[u] Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
[v] Also at Department of Physics, University of Massachusetts, Amherst MA; United States of America.
[w] Also at Department of Physics, University of Thessaly; Greece.
[x] Also at Department of Physics, Westmont College, Santa Barbara; United States of America.
[y] Also at Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany.
[z] Also at Fakultät Physik , Technische Universität Dortmund, Dortmund; Germany.
[aa] Also at Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
[ab] Also at Group of Particle Physics, University of Montreal, Montreal QC; Canada.
[ac] Also at Hellenic Open University, Patras; Greece.
[ad] Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
[ae] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
[af] Also at Institut für Physik, Universität Mainz, Mainz; Germany.
[ag] Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia; Bulgaria.
[ah] Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
[ai] Also at Institute of Particle Physics (IPP); Canada.
[aj] Also at Institute of Physics and Technology, Ulaanbaatar; Mongolia.
[ak] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
[al] Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
[am] Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.
[an] Also at L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse; France.
[ao] Also at Lawrence Livermore National Laboratory, Livermore; United States of America.
[ap] Also at National Institute of Physics, University of the Philippines Diliman (Philippines); Philippines.
[aq] Also at School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom.
[ar] Also at School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom.
[as] Also at SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom.
[at] Also at Technical University of Munich, Munich; Germany.
[au] Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
[av] Also at TRIUMF, Vancouver BC; Canada.
[aw] Also at Università di Napoli Parthenope, Napoli; Italy.
[ax] Also at University of Chinese Academy of Sciences (UCAS), Beijing; China.
[ay] Also at University of Colorado Boulder, Department of Physics, Colorado; United States of America.
[az] Also at Washington College, Chestertown, MD; United States of America.

[ba] Also at Yeditepe University, Physics Department, Istanbul; Türkiye.
[*] Deceased