



First measurement of Ω_c^0 production in pp collisions at $\sqrt{s} = 13$ TeV

ALICE Collaboration*

ARTICLE INFO

Article history:

Received 24 June 2022

Received in revised form 7 December 2022

Accepted 12 December 2022

Available online 15 September 2023

Editor: M. Pierini

Dataset link: [https://](https://www.hepdata.net/record/ins2088206)

www.hepdata.net/record/ins2088206

ABSTRACT

The inclusive production of the charm–strange baryon Ω_c^0 is measured for the first time via its hadronic decay into $\Omega^- \pi^+$ at midrapidity ($|y| < 0.5$) in proton–proton (pp) collisions at the centre-of-mass energy $\sqrt{s} = 13$ TeV with the ALICE detector at the LHC. The transverse momentum (p_T) differential cross section multiplied by the branching ratio is presented in the interval $2 < p_T < 12$ GeV/c. The p_T dependence of the Ω_c^0 -baryon production relative to the prompt D^0 -meson and to the prompt Ξ_c^0 -baryon production is compared to various models that take different hadronisation mechanisms into consideration. In the measured p_T interval, the ratio of the p_T -integrated cross sections of Ω_c^0 and prompt Λ_c^+ baryons multiplied by the $\Omega^- \pi^+$ branching ratio is found to be larger by a factor of about 20 with a significance of about 4σ when compared to e^+e^- collisions.

© 2022 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>). Funded by SCOAP³.

Recent measurements of charm-baryon production at midrapidity by the ALICE Collaboration [1–5] show that the Λ_c^+/D^0 , $\Xi_c^{0,+}/D^0$, and $\Sigma_c^{0,++}/D^0$ baryon-to-meson yield ratios are higher in pp collisions at LHC energies than in e^+e^- collisions, indicating that charm hadronisation occurs via different processes in the two collision systems [6]. The ratios are found to decrease with increasing transverse momentum (p_T), a trend not expected by models based on factorisation and on the usage of the fragmentation functions extracted from e^+e^- collisions. A significant dependence of the p_T -differential Λ_c^+/D^0 ratio with the multiplicity of charged particles produced in the event was also observed in pp collisions at $\sqrt{s} = 13$ TeV [7], possibly suggesting a continuous evolution of this ratio from low-multiplicity pp collisions to the highest multiplicity of charged particles characterising Pb–Pb collisions with a small impact parameter [8].

Higher charm baryon-to-meson ratios in pp collisions with respect to e^+e^- collisions are expected by models that either include dynamical processes that are relevant in quark-and-gluon enriched systems (e.g. colour reconnection beyond leading colour approximation [9] and quark coalescence [10]), or that treat hadronisation as a statistical process [11,12].

The Lund string fragmentation model [13,14] implemented in the PYTHIA event generator [15–17], is one of the main hadronisation models used in general-purpose Monte Carlo event generators [18]. In the default version of PYTHIA 8 (Monash 2013 tune [19]), the choice of quarks and gluons that are matched to form strings, encoding colour-confining potentials, is done in the leading-colour approximation. This configuration suppresses the connection of quarks and gluons coming from independent parton

scatterings, realising heavy-quark fragmentation and hadronisation schemes very similar to those occurring in e^+e^- collisions. As a result, all of the baryon-to-meson ratios mentioned above are severely underestimated. The extension of colour reconnection beyond the leading colour (CR-BLC) approximation [9] allows the calculations to better approximate quantum chromodynamic colour algebra when matching partons to form strings and enhances the role of “junction” colour-topologies that favour the formation of baryons. The CR-BLC model reproduces the Λ_c^+/D^0 ratio, including the dependence on event multiplicity [7], and the $\Sigma_c^{0,++}/D^0$ ratio [3], but it underestimates the $\Xi_c^{0,+}/D^0$ [4,5].

In the Catania model [10], charm quarks can hadronise via “vacuum”-like fragmentation as well as recombine (coalesce) with surrounding light quarks from the underlying event. The Wigner formalism is used to calculate the probability to form a baryon (meson) given the phase-space distribution of three (two) quarks. Within uncertainties, this model reproduces the charm baryon-to-meson ratios measured so far in pp collisions, though it tends to systematically underpredict the $\Xi_c^{0,+}/D^0$ and the $\Xi_c^{0,+}/\Sigma_c^{0,++}$ ratios.

In the models implementing hadronisation on a statistical basis, the relative abundances of the various charm-hadron species are determined by statistical weights that depend on the hadron mass, spin, and on the system properties. The p_T dependence of the predicted ratios can have different origins. It derives from the feed-down from higher-mass state decays in the model of Ref. [12], in which a large set of not-yet-observed charm-baryon states is assumed, following the expectation of the relativistic quark model [20]. In the quark-recombination model (QCM) [11] it instead derives from the requirement that charm quarks form hadrons by combining with light quarks with the same velocity.

* E-mail address: alice-publications@cern.ch.

Both models describe the Λ_c^+/D^0 and $\Sigma_c^{0,++}/D^0$ ratios and underestimate the $\Xi_c^{0,+}/D^0$ ratio in pp collisions, with the QCM prediction being closer to the data, although lower by about a factor of two.

The Ω_c^0 baryon is composed of a charm quark and two strange quarks. The mentioned models can reproduce Λ_c^+ data better than $\Xi_c^{0,+}$ data. This signals a possible difficulty with charm-strange baryons and suggests that the measurement of Ω_c^0 production represents a crucial step to constrain models and understand whether strange quarks, or strange diquarks, play a peculiar role in charm-baryon formation in pp collisions. In high-energy nucleus–nucleus collisions, the production yields of strange hadrons, in particular of multiple-strange baryons, normalised to pion ones are enhanced with respect to pp collisions and are well described by statistical models using a grand canonical ensemble with strangeness production regulated by chemical equilibrium [21–27]. Measurements of Ω^- and Ξ^- production as a function of the event multiplicity suggest that the onset of such enhancement occurs progressively with increasing particle multiplicity, starting from low-multiplicity pp collisions [25]. In this context, it is however interesting to note that although current data do not exclude that the D_s^+/D^0 ratio in pp collisions could be larger than in e^+e^- collisions, they do not support an increase similar, in relative terms, to that of $\Xi_c^{0,+}/D^0$ ratio. Indeed, the analysis of charm fragmentation fractions reported in Ref. [6] suggests that the sum of the $c \rightarrow \Xi_c^0$ and $c \rightarrow \Xi_c^+$ fragmentation fractions could be larger than the $c \rightarrow D_s^+$ one. Another interesting observation is given by the fact that the $\Xi_c^{0,+}/\Sigma_c^{0,++}$ ratio is described well by the default PYTHIA 8 Monash tune [5], which significantly underestimates both $\Xi_c^{0,+}/D^0$ and $\Sigma_c^{0,++}/D^0$ ratios, suggesting that the production of the two baryons could be equally suppressed in e^+e^- collisions because of similar mechanisms. The fraction of Λ_c^+ coming from $\Sigma_c^{0,++}$ decays is larger by a factor of about two in pp collisions than in e^+e^- collisions [3]: this supports the interpretation [9,28] that in e^+e^- collisions the $\Sigma_c^{0,++}$ formation is suppressed by the need of forming in string breaking a (dd, ud, uu)-diquark with spin $S = 1$, which is heavier than the $S = 0$ (ud)-diquark needed to form a Λ_c^+ . A similar argument might be relevant in the comparison of Ω_c^0 and $\Xi_c^{0,+}$ production, possibly influenced by the different mass values of $S = 1$ (ss) and $S = 0$ (sd, su) diquarks [20]. This further highlights the importance of measuring the Ω_c^0 production cross section to understand the role played by strange quarks and diquarks in charm-quark hadronisation. The measurement of the production cross section of the Ω_c^0 baryon is also needed to quantify its possible significant contribution to the total charm cross section at midrapidity per unit of rapidity, both in pp and in Pb–Pb collisions at the LHC [6].

This Letter reports on the first measurement of the p_T -differential production cross section of the inclusive Ω_c^0 baryon multiplied by the branching ratio (BR) of the hadronic decay channel $\Omega_c^0 \rightarrow \Omega^- \pi^+$ at midrapidity ($|y| < 0.5$) in pp collisions at $\sqrt{s} = 13$ TeV. Inclusive Ω_c^0 include prompt Ω_c^0 , produced directly in the hadronisation of charm quarks or in the decay of directly produced excited charm states, as well as Ω_c^0 from decays of beauty or multiple-charm hadron decays. The ratios of the inclusive Ω_c^0 cross section to the prompt D^0 meson [3] and to the prompt charm-strange Ξ_c^0 baryon [5] are also reported. The absolute branching ratio of the decay channel used has not been measured yet. The Ω_c^0 baryon was reconstructed together with its charge conjugate in the interval $2 < p_T < 12$ GeV/c.

A description of the ALICE detector and its performance can be found in Refs. [29,30]. The main detectors used for this measurement are the Inner Tracking System (ITS), the Time Projection Chamber (TPC), and the Time-Of-Flight detector (TOF). They are located in the central barrel, which covers the pseudorapidity in-

terval ($|\eta| < 0.9$), and are embedded in a solenoidal magnet that provides a $B = 0.5$ T field parallel to the beam direction. The ITS is used for tracking, vertex reconstruction, and trigger purposes. The TPC is the main tracking detector in the central barrel and is also used for particle identification (PID) via the measurement of the particle specific energy loss (dE/dx). The TOF provides PID information via the measurement of the particle time-of-flight relative to the time of the collision [31]. The analysed data sample consists of pp collisions at $\sqrt{s} = 13$ TeV recorded with a minimum-bias (MB) trigger based on coincident signals in the two scintillator arrays (V0) located on both sides of the nominal interaction point along the beam direction. Offline selection criteria, based on the signals from the V0 and the Silicon Pixel Detector, which constitutes the two innermost ITS layers, were applied to remove background due to the interaction between one of the beams and the residual gas present in the beam vacuum tube as well as other machine-induced backgrounds [32]. Events with multiple reconstructed primary vertices, which amount to 1% of the total event sample, were rejected to reduce the contamination from the superposition of several collisions within the same colliding bunches (pile-up events). Only events with a primary vertex position within 10 cm from the nominal interaction point along the beam direction were used. After the aforementioned selections, the data sample corresponds to an integrated luminosity $\mathcal{L}_{\text{int}} = 32.08 \pm 0.51$ nb $^{-1}$ [33].

The Ω_c^0 -baryon candidates were built from $\Omega^- \pi^+$ pairs using a Kalman-Filter (KF) vertexing algorithm [34] by combining a positive charged track (π^+ candidate) originating from the primary vertex and a Ω^- -baryon candidate. The Ω^- was reconstructed from the decay chain $\Omega^- \rightarrow \Lambda K^-$, BR = $(67.8 \pm 0.7)\%$, followed by $\Lambda \rightarrow p \pi^-$, BR = $(63.9 \pm 0.5)\%$ [35]. The Ω^- and Λ baryons were reconstructed by exploiting their characteristic decay topologies as reported in Refs. [5,36]. The tracks of the charged particles involved in the decay chain were required to be in the pseudorapidity interval $|\eta| < 0.8$, to have at least 70 out of 159 crossed TPC tracking points, and to have a fit quality $\chi^2/\text{NDF} < 2$ in the TPC. Moreover, primary π^+ candidates were required to have a minimum of four (out of six) hits in the ITS. Protons, pions, and kaons were selected by requiring compatibility within four standard deviations (4σ) between the measured signal and that expected for the respective particle hypothesis for both the TPC dE/dx and the time-of-flight measurement. Tracks without signal in the TOF detector were identified using only the TPC information. In order to reduce the large combinatorial background, a machine-learning approach based on the adaptive Boosted Decision Tree (BDT) algorithm in the Toolkit for Multivariate Data Analysis (TMVA) [37] was used. The signal sample of Ω_c^0 baryons for the BDT training was obtained from a simulation based on the PYTHIA 8.243 event generator [17]. The mean proper lifetime of Ω_c^0 in the simulation was set to 80 μm according to the latest LHCb measurement [38]. The propagation of the generated particles through the detector was performed using the GEANT 3 package [39]. The luminous region distribution and the conditions of all ALICE detectors in terms of active channels, gain, noise level, and alignment, and their evolution with time during the data taking, were taken into account in the simulations. The background candidates were taken from data by selecting candidates with invariant mass in the intervals $2.39 < M < 2.62$ GeV/ c^2 and $2.77 < M < 2.99$ GeV/ c^2 , which are outside of the expected mass peak of the Ω_c^0 . Before the training, loose selections were applied on the distance, normalised to its uncertainty, between the Λ decay point and the primary vertex, and on the Λ , Ω^- , and Ω_c^0 $\chi_{\text{geo}}^2/\text{NDF}$, which is a variable calculated by the KF Particle algorithm [34] related to the intersection probability of the daughter-particle trajectories taking their uncertainties into account. The BDT model was trained independently for each p_T interval with variables related to the Ω^- decay topology, such

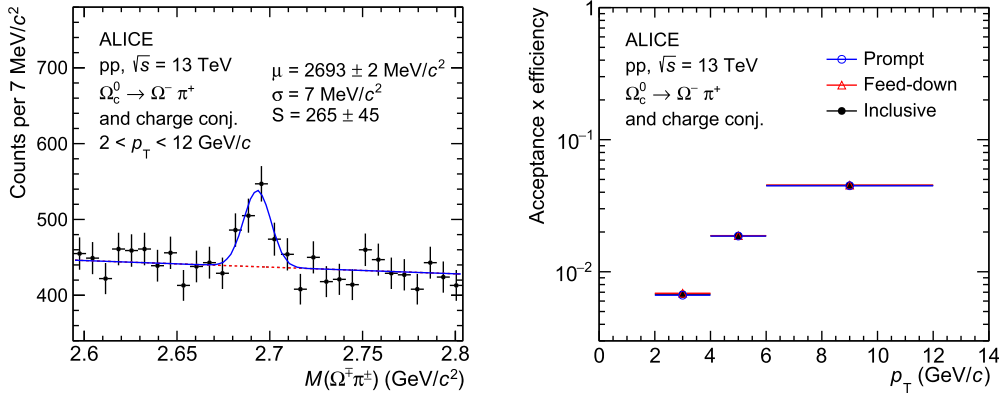


Fig. 1. (Left panel): invariant-mass distribution of $\Omega_c^0 \rightarrow \Omega^- \pi^+$ candidates and their charge conjugates integrated over the whole p_T interval 2–12 GeV/c. The blue line shows the total fit function and the red line represents the combinatorial background fit. (Right panel): acceptance-times-efficiency for prompt, feed-down, and inclusive Ω_c^0 baryons decaying into $\Omega^- \pi^+$ as a function of p_T in pp collisions at $\sqrt{s} = 13$ TeV.

as the distance of closest approach (DCA) of the decay particles, the DCA between the primary vertex and the reconstructed Ω^- candidate, the pointing angle of the reconstructed Ω^- decay vertex to the reconstructed Ω_c^0 decay vertex, the $\chi_{\text{geo}}^2/\text{NDF}$, and the $\chi_{\text{topo}}^2/\text{NDF}$. The $\chi_{\text{topo}}^2/\text{NDF}$ is calculated by the KF Particle [34] algorithm and characterises whether the Ω^- candidate points back to the reconstructed Ω_c^0 decay vertex. The output of the BDT training allows the classification of each candidate with a number related to its probability to be a Ω_c^0 baryon signal or combinatorial background.

The Ω_c^0 raw yields were obtained from the fit to the invariant-mass distribution of the candidates as shown in the left panel of Fig. 1. The signal peak was modelled with a Gaussian function and the background was described by a linear function.

The p_T and y -differential production cross section in the rapidity interval $|y| < 0.5$ of inclusive Ω_c^0 baryons multiplied by the branching ratio into the considered hadronic decay channel was calculated from the raw yields as follows

$$\text{BR} \times \frac{d^2\sigma_{\Omega_c^0}}{dp_T dy} = \frac{1}{2\Delta y \Delta p_T} \times \frac{N_{\text{raw}}^{\Omega_c^0 + \bar{\Omega}_c^0}}{(\text{Acc} \times \varepsilon)_{\text{inclusive}}} \times \frac{1}{\mathcal{L}_{\text{int}}}, \quad (1)$$

where $N_{\text{raw}}^{\Omega_c^0 + \bar{\Omega}_c^0}$ is the raw yield in a given p_T interval with width Δp_T and in the rapidity interval $\Delta y = 1.6$ assuming that the cross section does not vary significantly from $|y| < 0.5$ to $|y| < 0.8$. To confirm that this assumption has a negligible impact on the result, it was verified that by assuming the rapidity dependence expected for charm mesons in FONLL [40,41] and for charm baryons in PYTHIA 8 [17] the cross section changes by less than 1% in the measured p_T interval. Since the feed-down contribution is not subtracted, the raw yield is divided by the inclusive acceptance-times-efficiency factor, $(\text{Acc} \times \varepsilon)_{\text{inclusive}}$ and by the integrated luminosity \mathcal{L}_{int} of the data sample to obtain the production cross section. The factor 1/2 is needed to compute the average cross section of Ω_c^0 and $\bar{\Omega}_c^0$. The factor $(\text{Acc} \times \varepsilon)_{\text{inclusive}}$ is the product of the geometrical acceptance (Acc) and the reconstruction and selection efficiency (ε) for the $\Omega_c^0 \rightarrow \Omega^- \pi^+$ decay. The $(\text{Acc} \times \varepsilon)_{\text{inclusive}}$ correction was obtained from a simulation with the same configuration as the one used for the BDT training described above. The Ω_c^0 -baryon p_T distribution from the simulations was reweighted in order to use realistic momentum distributions in the determination of the acceptance and the efficiency, which depends on p_T . The weights were defined with an iterative procedure to match the p_T dependence measured for Ω_c^0 baryon in the intervals used in the analysis. In the simulation, the Ω_c^0 is unpolarized: it was assumed that the modification of the acceptance that would arise

from a non-zero polarization can be considered negligible with respect to the statistical uncertainty and the other systematic uncertainties of the measurement. The right panel of Fig. 1 shows the final $(\text{Acc} \times \varepsilon)$ correction factors of prompt, beauty feed-down, and inclusive Ω_c^0 as a function of p_T . They are consistent with each other within uncertainties because the selection variables used are not sensitive to the displacement by a few hundred micrometers of the prompt and beauty feed-down Ω_c^0 decay vertices from the collision point. The efficiency values increase with p_T from about 0.7% to about 5%.

Systematic uncertainties were estimated considering several sources. The uncertainty on the track reconstruction efficiency was evaluated by varying the track selection criteria and by comparing the probability to prolong the tracks from the TPC to the ITS hits in data and simulations. A 6% uncertainty was assigned. The systematic uncertainty on the selection efficiency derives from possible differences between the detector resolutions and alignment and their description in the simulation. This uncertainty was assessed from the comparison of the corrected yields obtained by varying the selections. In particular, the selections on the BDT outputs were varied separately in the different p_T intervals, with a corresponding variation of the efficiencies ranging from 30% to 50% depending on p_T . The assigned systematic uncertainty is 10%, which represents the largest contribution to the systematic uncertainty of the measurement. The systematic uncertainty due to the shape of the Ω_c^0 p_T spectrum used in the simulation for the calculation of the $(\text{Acc} \times \varepsilon)_{\text{inclusive}}$ factor was estimated by modifying the weights mentioned above within their uncertainties. An uncertainty of about 4% was estimated in the p_T interval $2 < p_T < 4$ GeV/c and a 2% uncertainty in $4 < p_T < 12$ GeV/c. The systematic uncertainty on the raw-yield extraction was evaluated in each p_T interval by repeating the fit to the invariant-mass distributions varying the function used to describe the background and the fit range. In order to test the sensitivity to the line-shape of the signal, a bin-counting method was used, in which the signal yield was obtained by integrating the invariant-mass distribution after subtracting the combinatorial background. A 6% uncertainty was assigned independent of p_T . The sources of systematic uncertainty are assumed to be uncorrelated among each other and the total systematic uncertainty in each p_T interval is calculated by a quadratic sum of the individual contributions, resulting in a 14% systematic uncertainty in $2 < p_T < 4$ GeV/c and 13% in $4 < p_T < 12$ GeV/c. The production cross section has an additional global normalisation uncertainty of 1.6% due to the integrated luminosity determination [33].

The p_T -differential production cross section of inclusive Ω_c^0 baryons multiplied by the branching ratio of the $\Omega^- \pi^+$ channel

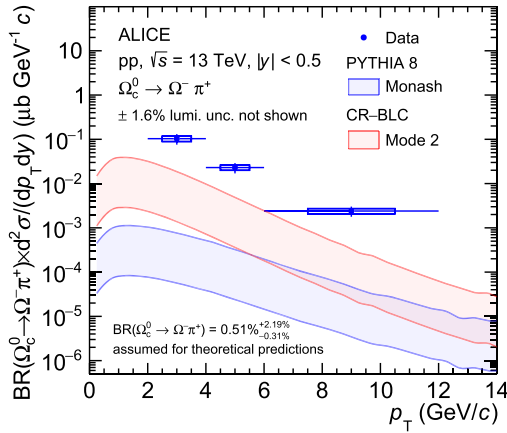


Fig. 2. The p_T -differential production cross section of inclusive Ω_c^0 baryons multiplied by the branching ratio into $\Omega^- \pi^+$ for $|y| < 0.5$ in pp collisions at $\sqrt{s} = 13$ TeV. The error bars and empty boxes represent the statistical and systematic uncertainties, respectively. The measurement is compared with PYTHIA 8.243 with Monash tune [19] and with CR beyond the leading-colour approximation [9], which are multiplied by a theoretical $\text{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+) = (0.51^{+2.19}_{-0.31})\%$ [42–47].

measured in the rapidity interval $|y| < 0.5$ and the p_T interval $2 < p_T < 12$ GeV/c are shown in Fig. 2. The feed-down contribution from Ω_b^- , e.g. $\Omega_b^- \rightarrow \Omega_c^0 + \pi^-$ [35], is not subtracted because of the lack of knowledge of the branching ratios of b-hadron decays to Ω_c^0 . Given that the efficiencies of prompt and feed-down Ω_c^0 are consistent within uncertainties, the inclusive measurement presented here preserve the original relative abundances of its prompt and feed-down components. The data are compared with the inclusive Ω_c^0 p_T -differential cross sections expected from the PYTHIA 8.243 Monash and CR-BLC tunes (Mode 2) [9,17,19] multiplied by the branching ratio, $\text{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+) = (0.51^{+2.19}_{-0.31})\%$, obtained by considering the estimate reported in Ref. [42] for the central value, and the envelope of the values (including their uncertainties) reported in Refs. [42–47] to determine the uncertainty. In the p_T interval of the measurement, the cross section from the CR-BLC tune is larger than the one from the Monash tune by factor varying between 9 and 25 depending on p_T . The Monash tune and CR-BLC tune underestimate the data by more than 3.3σ and 2.7σ , respectively, when $\text{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+) = 0.51^{+2.19}_{-0.31}\%$ is considered.

The ratios of the p_T -differential production cross section of inclusive Ω_c^0 baryons (multiplied by the branching ratio of the $\Omega_c^0 \rightarrow \Omega^- \pi^+$ decay channel) to the prompt D^0 -meson cross section [3] and to the prompt Ξ_c^0 -baryon one [5] are reported in the left and right panel of Fig. 3, respectively. The systematic uncertainties on the tracking efficiency and on the luminosity were propagated as fully correlated in the ratios. The uncertainties do not allow to draw a conclusion about the possible p_T dependence of the ratios. The data are compared with model expectations that were obtained by scaling the Ω_c^0/D^0 and Ω_c^0/Ξ_c^0 ratios predicted by the models by the BR of the $\Omega_c^0 \rightarrow \Omega^- \pi^+$ decay channel mentioned above. The uncertainty band of the models represents the BR uncertainty. For the Catania model only the specific uncertainty of the model itself are also included in the uncertainty band [10]. In the bottom panels, the ratios of the various models and the data to the Catania prediction are shown. The expectations of the models differ significantly, even by orders of magnitude, demonstrating the sensitivity of the measured ratios to the implementation of the charm hadronisation process in the models. As visible in the left panels of Fig. 3, the Monash [19] and CR-BLC [9] tunes of PYTHIA 8, as well as the QCM [11] model underestimate the data significantly. The Monash tune expects a $\text{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+) \times \Omega_c^0/D^0$ ratio increasing with p_T from about 4×10^{-7} to about 1×10^{-5} . The CR-BLC model enhances the ratio

by a factor of 12 to 34 with respect to the Monash tune. The prediction of the QCM is larger than that of the CR-BLC model, but it is lower than the data by more than 1.8σ . The Catania model [10] is consistent with the data. In particular, in the version in which additional charm resonance states on top of those listed in the PDG [35] are considered, the Ω_c^0/D^0 ratio is enhanced by a factor of 2, thus enlarging the range of possible $\text{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+)$ values that would allow the model prediction to be compatible within 1σ with the data considering only the data uncertainty. The Ω_c^0/D^0 ratio decreases with p_T in the measured p_T range in the CR-BLC, QCM, and Catania models, oppositely to what is expected by Monash. In the Ω_c^0/Ξ_c^0 baryon-to-baryon ratio, shown in the right panel of Fig. 3, a similar hierarchy among the model predictions is present, though PYTHIA 8 with CR-BLC gives an enhancement by a factor of 4 to 5 with respect to the Monash expectation, thus smaller than that of the Ω_c^0/D^0 ratio. Also for this ratio, the CR-BLC and QCM predictions are close to each other and higher than the Monash tune. The Catania model shows a good agreement with the data, whether the augmented set of charm resonance states is considered or not.

Using the ALICE Ξ_c^0 [5] and Λ_c^+ [3] data, the ratios $\text{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+) \times \sigma(\Omega_c^0)/\sigma(\Lambda_c^+)$ and $\text{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+) \times \sigma(\Omega_c^0)/\sigma(\Xi_c^0)$ of the cross sections integrated in the Ω_c^0 measured p_T interval were obtained. They are reported in Table 1. They are compared with the values measured in e^+e^- collisions at $\sqrt{s} = 10.52$ GeV by Belle, obtained from the cross sections reported in Table 1 of Ref. [28]. Though the limited p_T and rapidity ranges of the ALICE measurement do not allow for a direct comparison of the pp and e^+e^- data, the ratios observed by ALICE are larger by a factor of $8.7 \pm 2.2(\text{stat.}) \pm 0.9(\text{syst.})$ and $4.7 \pm 1.3(\text{stat.}) \pm 0.5(\text{syst.})$ for the $\text{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+) \times \sigma(\Omega_c^0)/\sigma(\Lambda_c^+)$ and $\text{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+) \times \sigma(\Omega_c^0)/\sigma(\Xi_c^0)$, respectively. The large BR uncertainties of the Ξ_c^0 are not propagated in the computation of this factor. This difference, along with the comparison of data and models in Fig. 3, represents further evidence that the hadronisation process differs in pp and e^+e^- collisions and is sensitive to the density of quarks, colour charges, and on the system size.

In summary, the inclusive p_T -differential production cross section of the charm-strange baryon Ω_c^0 multiplied by the branching ratio of the $\Omega_c^0 \rightarrow \Omega^- \pi^+$ decay channel was measured at midrapidity ($|y| < 0.5$) in pp collisions at $\sqrt{s} = 13$ TeV. The ratio of this measurement to the production cross section of the D^0 meson provides further evidence that charm quarks hadronise to Ω_c^0 baryons more frequently in pp collisions than in e^+e^- collisions, confirming the general trend observed from previous measurements of Λ_c^+ , Ξ_c^0 , and Σ_c^{++} production. The large uncertainty of the $\Omega_c^0 \rightarrow \Omega^- \pi^+$ branching ratio limits the effectiveness of the comparison with theoretical models. However, the predictions of the available models differ by large factors indicating that future measurements of the BR, which could be performed also by the LHCb or Belle 2 collaborations, will allow to exploit these data to set stringent constraints to theoretical models and obtain deep insight into the charm hadronisation and the role of strange quarks and diquarks. Moreover, despite the large uncertainties, only the Catania model, which assumes that charm-quark hadronisation proceeds via both fragmentation and coalescence, can describe the $\text{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+) \times \sigma(\Omega_c^0)/\sigma(D^0)$ ratio within uncertainties. More precise measurements with the data sample collected in Run 3 of the LHC will allow us to further investigate the p_T shape of the Ω_c^0/D^0 and Ω_c^0/Ξ_c^0 ratios.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

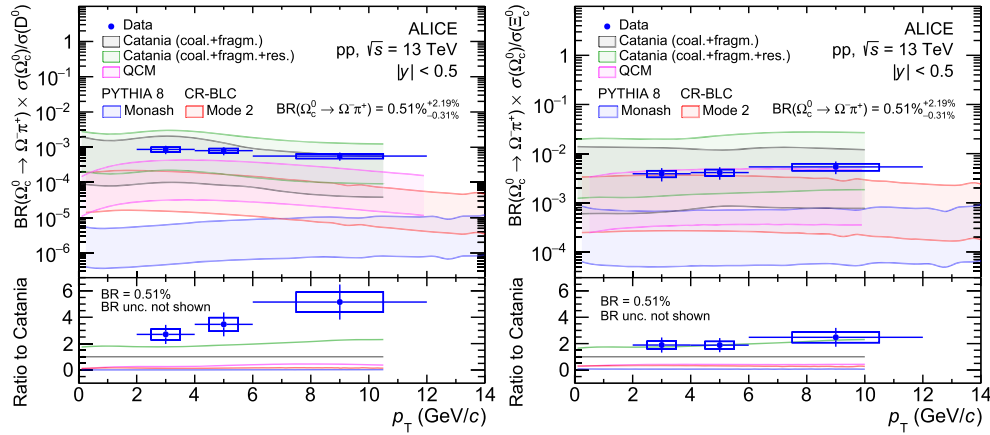


Fig. 3. Left, top panel: ratio of the p_T -differential cross section of Ω_c^0 baryons (multiplied by the branching ratio into $\Omega^- \pi^+$) to the D^0 -meson one [3] in $|y| < 0.5$ in pp collisions at $\sqrt{s} = 13$ TeV. Right, top panel: ratio of the p_T -differential cross section of Ω_c^0 baryons (multiplied by the branching ratio into $\Omega^- \pi^+$) to the Ξ_c^0 -baryon one [5] in $|y| < 0.5$ in pp collisions at $\sqrt{s} = 13$ TeV. Bottom panels: ratio of the data and models to the Catania (coalescence plus fragmentation) model [10]. The error bars and empty boxes represent the statistical and systematic uncertainties, respectively. The measurements are compared with model calculations (see text for details), which are multiplied by a theoretical $BR(\Omega_c^0 \rightarrow \Omega^- \pi^+) = (0.51^{+2.19}_{-0.31})\%$ [42–47].

Table 1

Ratio of the p_T -integrated cross section of Ω_c^0 baryon (multiplied by the branching ratio into $\Omega^- \pi^+$) in the interval $2 < p_T < 12$ GeV/c with respect to the Λ_c^+ - and Ξ_c^0 -baryon cross sections measured by the ALICE [3,5] and Belle [28] experiments in pp collisions at $\sqrt{s} = 13$ TeV and e^+e^- collisions at $\sqrt{s} = 10.52$ GeV, respectively. The first and second uncertainties represent the statistical and systematic ones. The data include the correction for the branching ratio $BR(\Omega^- \rightarrow \Lambda K^-, \Lambda \rightarrow p \pi^-) = (43.3 \pm 0.6)\%$ [35].

Ratio	ALICE (pp 13 TeV) $2 < p_T < 12$ GeV/c	Belle (e^+e^- 10.52 GeV) [28] visible
$BR(\Omega_c^0 \rightarrow \Omega^- \pi^+) \times \sigma(\Omega_c^0)/\sigma(\Lambda_c^+)$	$(1.96 \pm 0.42 \pm 0.13) \times 10^{-3}$	$(2.24 \pm 0.29 \pm 0.16) \times 10^{-4}$
$BR(\Omega_c^0 \rightarrow \Omega^- \pi^+) \times \sigma(\Omega_c^0)/\sigma(\Xi_c^0)$	$(3.99 \pm 0.96 \pm 0.96) \times 10^{-3}$	$(8.58 \pm 1.15 \pm 1.98) \times 10^{-4}$

Data availability

This manuscript has associated data in a HEPData repository at: <https://www.hepdata.net/record/ins2088206>.

Acknowledgements

The ALICE Collaboration would like to thank all its engineers and technicians for their invaluable contributions to the construction of the experiment and the CERN accelerator teams for the outstanding performance of the LHC complex. The ALICE Collaboration gratefully acknowledges the resources and support provided by all Grid centres and the Worldwide LHC Computing Grid (WLCG) collaboration. The ALICE Collaboration acknowledges the following funding agencies for their support in building and running the ALICE detector: A. I. Alikhanyan National Science Laboratory (Yerevan Physics Institute) Foundation (ANSL), State Committee of Science and World Federation of Scientists (WFS), Armenia; Austrian Academy of Sciences, Austrian Science Fund (FWF): [M 2467-N36] and Österreichische Nationalstiftung für Forschung, Technologie und Entwicklung, Austria; Ministry of Communications and High Technologies, National Nuclear Research Center, Azerbaijan; Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Financiadora de Estudos e Projetos (Finep), Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Universidade Federal do Rio Grande do Sul (UFRGS), Brazil; Bulgarian Ministry of Education and Science, within the National Roadmap for Research Infrastructures 2020–2027 (object CERN), Bulgaria; Ministry of Education of China (MOEC), Ministry of Science & Technology of China (MSTC) and National Natural Science Foundation of China (NSFC), China; Ministry of Science and Education and Croatian Science Foundation, Croatia; Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear (CEADEN), Cubaenergía,

Cuba; Ministry of Education, Youth and Sports of the Czech Republic, Czech Republic; The Danish Council for Independent Research | Natural Sciences, the Villum Fonden and Danish National Research Foundation (DNRF), Denmark; Helsinki Institute of Physics (HIP), Finland; Commissariat à l'Énergie Atomique (CEA) and Institut National de Physique Nucléaire et de Physique des Particules (IN2P3) and Centre National de la Recherche Scientifique (CNRS), France; Bundesministerium für Bildung und Forschung (BMBF) and GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany; General Secretariat for Research and Technology, Ministry of Education, Research and Religions, Greece; National Research, Development and Innovation Office, Hungary; Department of Atomic Energy Government of India (DAE), Department of Science and Technology, Government of India (DST), University Grants Commission, Government of India (UGC) and Council of Scientific and Industrial Research (CSIR), India; National Research and Innovation Agency - BRIN, Indonesia; Istituto Nazionale di Fisica Nucleare (INFN), Italy; Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) and Japan Society for the Promotion of Science (JSPS) KAKENHI, Japan; Consejo Nacional de Ciencia (CONACYT) y Tecnología, through Fondo de Cooperación Internacional en Ciencia y Tecnología (FONCICYT) and Dirección General de Asuntos del Personal Académico (DGAPA), Mexico; Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO), Netherlands; The Research Council of Norway, Norway; Commission on Science and Technology for Sustainable Development in the South (COMSATS), Pakistan; Pontificia Universidad Católica del Perú, Peru; Ministry of Education and Science, National Science Centre and WUT ID-UB, Poland; Korea Institute of Science and Technology Information and National Research Foundation of Korea (NRF), Republic of Korea; Ministry of Education and Scientific Research, Institute of Atomic Physics, Ministry of Research and Innovation and In-

stitute of Atomic Physics and University Politehnica of Bucharest, Romania; Ministry of Education, Science, Research and Sport of the Slovak Republic, Slovakia; National Research Foundation of South Africa, South Africa; Swedish Research Council (VR) and Knut & Alice Wallenberg Foundation (KAW), Sweden; European Organization for Nuclear Research, Switzerland; Suranaree University of Technology (SUT), National Science and Technology Development Agency (NSTDA) and National Science, Research and Innovation Fund (NSRF via PMU-B B05F650021), Thailand; Turkish Energy, Nuclear and Mineral Research Agency (TENMAK), Turkey; National Academy of Sciences of Ukraine, Ukraine; Science and Technology Facilities Council (STFC), United Kingdom; National Science Foundation of the United States of America (NSF) and United States Department of Energy, Office of Nuclear Physics (DOE NP), United States of America. In addition, individual groups or members have received support from: Marie Skłodowska Curie, European Research Council, Strong 2020 - Horizon 2020 (grant nos. 950692, 824093, 896850), European Union; Academy of Finland (Center of Excellence in Quark Matter) (grant nos. 346327, 346328), Finland; Programa de Apoyos para la Superación del Personal Académico, UNAM, Mexico.

References

- [1] ALICE Collaboration, S. Acharya, et al., Λ_c^+ production in pp and in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, Phys. Rev. C 104 (2021) 054905, arXiv:2011.06079 [nucl-ex].
- [2] ALICE Collaboration, S. Acharya, et al., Λ_c^+ production and baryon-to-meson ratios in pp and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV at the LHC, Phys. Rev. Lett. 127 (2021) 202301, arXiv:2011.06078 [nucl-ex].
- [3] ALICE Collaboration, S. Acharya, et al., Measurement of prompt D^0 , Λ_c^+ , and $\Sigma_c^{0,++}(2455)$ production in proton-proton collisions at $\sqrt{s} = 13$ TeV, Phys. Rev. Lett. 128 (2022) 012001, arXiv:2106.08278 [hep-ex].
- [4] ALICE Collaboration, S. Acharya, et al., Measurement of the production cross section of prompt Ξ_c^0 baryons at midrapidity in pp collisions at $\sqrt{s} = 5.02$ TeV, J. High Energy Phys. 10 (2021) 159, arXiv:2105.05616 [nucl-ex].
- [5] ALICE Collaboration, S. Acharya, et al., Measurement of the cross sections of Ξ_c^0 and Ξ_c^+ baryons and of the branching-fraction ratio $BR(\Xi_c^0 \rightarrow \Xi^- e^+ \nu_e)/BR(\Xi_c^0 \rightarrow \Xi^- \pi^+)$ in pp collisions at 13 TeV, Phys. Rev. Lett. 127 (2021) 272001, arXiv:2105.05187 [nucl-ex].
- [6] ALICE Collaboration, S. Acharya, et al., Charm-quark fragmentation fractions and production cross section at midrapidity in pp collisions at the LHC, Phys. Rev. D 105 (2022) L011103, arXiv:2105.06335 [nucl-ex].
- [7] ALICE Collaboration, S. Acharya, et al., Observation of a multiplicity dependence in the p_T -differential charm baryon-to-meson ratios in proton-proton collisions at $\sqrt{s} = 13$ TeV, Phys. Lett. B 829 (2022) 137065, arXiv:2111.11948 [nucl-ex].
- [8] ALICE Collaboration, S. Acharya, et al., Constraining hadronization mechanisms with Λ_c^+/D^0 production ratios in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, arXiv:2112.08156 [nucl-ex].
- [9] J.R. Christiansen, P.Z. Skands, String formation beyond leading colour, J. High Energy Phys. 08 (2015) 003, arXiv:1505.01681 [hep-ph].
- [10] V. Minissale, S. Plumari, V. Greco, Charm hadrons in pp collisions at LHC energy within a coalescence plus fragmentation approach, Phys. Lett. B 821 (2021) 136622, arXiv:2012.12001 [hep-ph].
- [11] J. Song, H.-h. Li, F.-l. Shao, New feature of low p_T charm quark hadronization in pp collisions at $\sqrt{s} = 7$ TeV, Eur. Phys. J. C 78 (2018) 344, arXiv:1801.09402 [hep-ph].
- [12] M. He, R. Rapp, Charm-baryon production in proton-proton collisions, Phys. Lett. B 795 (2019) 117–121, arXiv:1902.08889 [nucl-th].
- [13] B. Andersson, G. Gustafson, B. Soderberg, A general model for jet fragmentation, Z. Phys. C 20 (1983) 317.
- [14] B. Andersson, The Lund Model, vol. 7, Cambridge University Press, 2005.
- [15] T. Sjöstrand, S. Mrenna, P.Z. Skands, PYTHIA 6.4 physics and manual, J. High Energy Phys. 05 (2006) 026, arXiv:hep-ph/0603175.
- [16] T. Sjöstrand, S. Mrenna, P.Z. Skands, A brief introduction to PYTHIA 8.1, Comput. Phys. Commun. 178 (2008) 852–867, arXiv:0710.3820 [hep-ph].
- [17] T. Sjöstrand, S. Ask, J.R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C.O. Rasmussen, P.Z. Skands, An introduction to PYTHIA 8.2, Comput. Phys. Commun. 191 (2015) 159–177, arXiv:1410.3012 [hep-ph].
- [18] A. Buckley, et al., General-purpose event generators for LHC physics, Phys. Rep. 504 (2011) 145–233, arXiv:1101.2599 [hep-ph].
- [19] P. Skands, S. Carrazza, J. Rojo, Tuning PYTHIA 8.1: the Monash 2013 tune, Eur. Phys. J. C 74 (2014) 3024, arXiv:1404.5630 [hep-ph].
- [20] D. Ebert, R.N. Faustov, V.O. Galkin, Spectroscopy and Regge trajectories of heavy baryons in the relativistic quark-diquark picture, Phys. Rev. D 84 (2011) 014025, arXiv:1105.0583 [hep-ph].
- [21] J. Rafelski, B. Muller, Strangeness production in the quark - gluon plasma, Phys. Rev. Lett. 48 (1982) 1066, Erratum: Phys. Rev. Lett. 56 (1986) 2334.
- [22] WA97 Collaboration, E. Andersen, et al., Strangeness enhancement at mid-rapidity in Pb-Pb collisions at 158 A GeV/c, Phys. Lett. B 449 (1999) 401–406.
- [23] STAR Collaboration, B.I. Abelev, et al., Enhanced strange baryon production in Au + Au collisions compared to p + p at $\sqrt{s_{NN}} = 200$ GeV, Phys. Rev. C 77 (2008) 044908, arXiv:0705.2511 [nucl-ex].
- [24] C. Blume, C. Markert, Strange hadron production in heavy ion collisions from SPS to RHIC, Prog. Part. Nucl. Phys. 66 (2011) 834–879, arXiv:1105.2798 [nucl-ex].
- [25] ALICE Collaboration, J. Adam, et al., Enhanced production of multi-strange hadrons in high-multiplicity proton-proton collisions, Nat. Phys. 13 (2017) 535–539, arXiv:1606.07424 [nucl-ex].
- [26] ALICE Collaboration, B. Abelev, et al., Multi-strange baryon production at mid-rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B 728 (2014) 216–227, arXiv:1307.5543 [nucl-ex], Erratum: Phys. Lett. B 734 (2014) 409–410.
- [27] A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, Decoding the phase structure of QCD via particle production at high energy, Nature 561 (2018) 321–330, arXiv:1710.09425 [nucl-th].
- [28] Belle Collaboration, M. Niiyama, et al., Production cross sections of hyperons and charmed baryons from e^+e^- annihilation near $\sqrt{s} = 10.52$ GeV, Phys. Rev. D 97 (2018) 072005, arXiv:1706.06791 [hep-ex].
- [29] ALICE Collaboration, K. Aamodt, et al., The ALICE experiment at the CERN LHC, J. Instrum. 3 (2008) S08002.
- [30] ALICE Collaboration, B. Abelev, et al., Performance of the ALICE experiment at the CERN LHC, Int. J. Mod. Phys. A 29 (2014) 1430044, arXiv:1402.4476 [nucl-ex].
- [31] ALICE Collaboration, J. Adam, et al., Determination of the event collision time with the ALICE detector at the LHC, Eur. Phys. J. Plus 132 (2017) 99, arXiv:1610.03055 [physics.ins-det].
- [32] ALICE Collaboration, B. Abelev, et al., Performance of the ALICE experiment at the CERN LHC, Int. J. Mod. Phys. A 29 (2014) 1430044, arXiv:1402.4476 [nucl-ex].
- [33] ALICE Collaboration, S. Acharya, et al., ALICE 2016–2017–2018 luminosity determination for pp collisions at $\sqrt{s} = 13$ TeV, Tech. Rep. ALICE-PUBLIC-2021-005, CERN, 2021, <https://cds.cern.ch/record/2776672>.
- [34] I. Kisel, I. Kulakov, M. Zyzak, Standalone first level event selection package for the CBM experiment, IEEE Trans. Nucl. Sci. 60 (2013) 3703–3708.
- [35] Particle Data Group Collaboration, P.A. Zyla, et al., Review of particle physics, PTEP 2020 (2020), 083C01.
- [36] ALICE Collaboration, S. Acharya, et al., Multiplicity dependence of (multi-)strange hadron production in proton-proton collisions at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C 80 (2020) 167, arXiv:1908.01861 [nucl-ex].
- [37] A. Hocker, et al., “TMVA - toolkit for multivariate data analysis”, CERN-OPEN-2007-007, arXiv:physics/0703039.
- [38] LHCb Collaboration, R. Aaij, et al., Measurement of the Ω_c^0 baryon lifetime, Phys. Rev. Lett. 121 (2018) 092003, arXiv:1807.02024 [hep-ex].
- [39] R. Brun, F. Bruyant, F. Carminati, S. Giani, M. Maire, A. McPherson, G. Patrick, L. Urban, GEANT: Detector Description and Simulation Tool, CERN Program Library, CERN, Geneva, 1993, <https://cds.cern.ch/record/1082634>.
- [40] M. Cacciari, M. Greco, P. Nason, The p_T spectrum in heavy flavor hadroproduction, J. High Energy Phys. 05 (1998) 007, arXiv:hep-ph/9803400 [hep-ph].
- [41] M. Cacciari, S. Frixione, N. Houdeau, M.L. Mangano, P. Nason, G. Ridolfi, Theoretical predictions for charm and bottom production at the LHC, J. High Energy Phys. 10 (2012) 137, arXiv:1205.6344 [hep-ph].
- [42] Y.-K. Hsiao, L. Yang, C.-C. Lih, S.-Y. Tsai, Charmed Ω_c weak decays into Ω in the light-front quark model, Eur. Phys. J. C 80 (2020) 1066, arXiv:2009.12752 [hep-ph].
- [43] T. Gutsche, M.A. Ivanov, J.G. Körner, V.E. Lyubovitskij, Nonleptonic two-body decays of single heavy baryons Λ_Q , Ξ_Q , and Ω_Q ($Q = b, c$) induced by W emission in the covariant confined quark model, Phys. Rev. D 98 (2018) 074011, arXiv:1806.11549 [hep-ph].
- [44] H.-Y. Cheng, Nonleptonic weak decays of bottom baryons, Phys. Rev. D 56 (1997) 2799–2811, arXiv:hep-ph/9612223, Erratum: Phys. Rev. D 99 (2019) 079901.
- [45] S. Hu, G. Meng, F. Xu, Hadronic weak decays of the charmed baryon Ω_c , Phys. Rev. D 101 (2020) 094033, arXiv:2003.04705 [hep-ph].
- [46] E. Solovieva, et al., Study of Ω_c^0 and Ω_c^{*0} baryons at belle, Phys. Lett. B 672 (2009) 1–5, arXiv:0808.3677 [hep-ex].
- [47] K.-L. Wang, Q.-F. Lü, J.-J. Xie, X.-H. Zhong, Toward discovering the excited Ω baryons through nonleptonic weak decays of Ω_c , arXiv:2203.04458 [hep-ph].

ALICE Collaboration

S. Acharya^{124,132, ID}, D. Adamová^{85, ID}, A. Adler⁶⁹, G. Aglieri Rinella^{32, ID}, M. Agnello^{29, ID},
 N. Agrawal^{50, ID}, Z. Ahammed^{132, ID}, S. Ahmad^{15, ID}, S.U. Ahn^{70, ID}, I. Ahuja^{37, ID}, A. Akindinov^{140, ID},
 M. Al-Turany^{97, ID}, D. Aleksandrov^{140, ID}, B. Alessandro^{55, ID}, H.M. Alfanda^{6, ID}, R. Alfaro Molina^{66, ID},
 B. Ali^{15, ID}, Y. Ali¹³, A. Alici^{25, ID}, N. Alizadehvandchali^{113, ID}, A. Alkin^{32, ID}, J. Alme^{20, ID}, G. Alocco^{51, ID},
 T. Alt^{63, ID}, I. Altsybeev^{140, ID}, M.N. Anaam^{6, ID}, C. Andrei^{45, ID}, A. Andronic^{135, ID}, V. Anguelov^{94, ID},
 F. Antinori^{53, ID}, P. Antonioli^{50, ID}, C. Anuj^{15, ID}, N. Apadula^{73, ID}, L. Aphecetche^{103, ID},
 H. Appelshäuser^{63, ID}, C. Arata^{72, ID}, S. Arcelli^{25, ID}, R. Arnaldi^{55, ID}, I.C. Arsene^{19, ID}, M. Arslanok^{137, ID},
 A. Augustinus^{32, ID}, R. Averbeck^{97, ID}, S. Aziz^{128, ID}, M.D. Azmi^{15, ID}, A. Badalà^{52, ID}, Y.W. Baek^{40, ID},
 X. Bai^{117, ID}, R. Bailhache^{63, ID}, Y. Bailung^{47, ID}, R. Bala^{90, ID}, A. Balbino^{29, ID}, A. Baldisseri^{127, ID},
 B. Balis^{2, ID}, D. Banerjee^{4, ID}, Z. Banoo^{90, ID}, R. Barbera^{26, ID}, L. Barioglio^{95, ID}, M. Barlou⁷⁷,
 G.G. Barnaföldi^{136, ID}, L.S. Barnby^{84, ID}, V. Barret^{124, ID}, L. Barreto^{109, ID}, C. Bartels^{116, ID}, K. Barth^{32, ID},
 E. Bartsch^{63, ID}, F. Baruffaldi^{27, ID}, N. Bastid^{124, ID}, S. Basu^{74, ID}, G. Batigne^{103, ID}, D. Battistini^{95, ID},
 B. Batyunya^{141, ID}, D. Bauri⁴⁶, J.L. Bazo Alba^{101, ID}, I.G. Bearden^{82, ID}, C. Beattie^{137, ID}, P. Becht^{97, ID},
 D. Behera^{47, ID}, I. Belikov^{126, ID}, A.D.C. Bell Hechavarria^{135, ID}, F. Bellini^{25, ID}, R. Bellwied^{113, ID},
 S. Belokurova^{140, ID}, V. Belyaev^{140, ID}, G. Bencedi^{136,64, ID}, S. Beole^{24, ID}, A. Bercuci^{45, ID},
 Y. Berdnikov^{140, ID}, A. Berdnikova^{94, ID}, L. Bergmann^{94, ID}, M.G. Besoiu^{62, ID}, L. Betev^{32, ID},
 P.P. Bhaduri^{132, ID}, A. Bhasin^{90, ID}, M.A. Bhat^{4, ID}, B. Bhattacharjee^{41, ID}, L. Bianchi^{24, ID}, N. Bianchi^{48, ID},
 J. Bielčik^{35, ID}, J. Bielčíková^{85, ID}, J. Biernat^{106, ID}, A.P. Bigot^{126, ID}, A. Bilandzic^{95, ID}, G. Biro^{136, ID},
 S. Biswas^{4, ID}, N. Bize^{103, ID}, J.T. Blair^{107, ID}, D. Blau^{140, ID}, M.B. Blidaru^{97, ID}, N. Bluhme³⁸, C. Blume^{63, ID},
 G. Boca^{21,54, ID}, F. Bock^{86, ID}, T. Bodova^{20, ID}, A. Bogdanov¹⁴⁰, S. Boi^{22, ID}, J. Bok^{57, ID}, L. Boldizsár^{136, ID},
 A. Bolozdynya^{140, ID}, M. Bombara^{37, ID}, P.M. Bond^{32, ID}, G. Bonomi^{131,54, ID}, H. Borel^{127, ID},
 A. Borissov^{140, ID}, H. Bossi^{137, ID}, E. Botta^{24, ID}, L. Bratrud^{63, ID}, P. Braun-Munzinger^{97, ID}, M. Bregant^{109, ID},
 M. Broz^{35, ID}, G.E. Bruno^{96,31, ID}, M.D. Buckland^{116, ID}, D. Budnikov^{140, ID}, H. Buesching^{63, ID},
 S. Bufalino^{29, ID}, O. Bugnon¹⁰³, P. Buhler^{102, ID}, Z. Buthelezi^{67,120, ID}, J.B. Butt¹³, A. Bylinkin^{115, ID},
 S.A. Bysiak¹⁰⁶, M. Cai^{27,6, ID}, H. Caines^{137, ID}, A. Caliva^{97, ID}, E. Calvo Villar^{101, ID}, J.M.M. Camacho^{108, ID},
 P. Camerini^{23, ID}, F.D.M. Canedo^{109, ID}, M. Carabas^{123, ID}, F. Carnesecchi^{32, ID}, R. Caron^{125, ID}, J. Castillo
 Castellanos^{127, ID}, F. Catalano^{29, ID}, C. Ceballos Sanchez^{141, ID}, I. Chakaberia^{73, ID}, P. Chakraborty^{46, ID},
 S. Chandra^{132, ID}, S. Chapeland^{32, ID}, M. Chartier^{116, ID}, S. Chattopadhyay^{132, ID}, S. Chattopadhyay^{99, ID},
 T.G. Chavez^{44, ID}, T. Cheng^{6, ID}, C. Cheshkov^{125, ID}, B. Cheynis^{125, ID}, V. Chibante Barroso^{32, ID},
 D.D. Chinellato^{110, ID}, E.S. Chizzali^{95, ID, II}, J. Cho^{57, ID}, S. Cho^{57, ID}, P. Chochula^{32, ID}, P. Christakoglou^{83, ID},
 C.H. Christensen^{82, ID}, P. Christiansen^{74, ID}, T. Chujo^{122, ID}, M. Ciaccio^{29, ID}, C. Cicalo^{51, ID}, L. Cifarelli^{25, ID},
 F. Cindolo^{50, ID}, M.R. Ciupek⁹⁷, G. Clai^{50, III}, F. Colamaria^{49, ID}, J.S. Colburn¹⁰⁰, D. Colella^{96,31, ID},
 A. Collu⁷³, M. Colocci^{32, ID}, M. Concas^{55, ID, IV}, G. Conesa Balbastre^{72, ID}, Z. Conesa del Valle^{128, ID},
 G. Contin^{23, ID}, J.G. Contreras^{35, ID}, M.L. Coquet^{127, ID}, T.M. Cormier^{86, I}, P. Cortese^{130,55, ID},
 M.R. Cosentino^{111, ID}, F. Costa^{32, ID}, S. Costanza^{21,54, ID}, P. Crochet^{124, ID}, R. Cruz-Torres^{73, ID}, E. Cuautle⁶⁴,
 P. Cui^{6, ID}, L. Cunqueiro⁸⁶, A. Dainese^{53, ID}, M.C. Danisch^{94, ID}, A. Danu^{62, ID}, P. Das^{79, ID}, P. Das^{4, ID},
 S. Das^{4, ID}, A.R. Dash^{135, ID}, S. Dash^{46, ID}, R.M.H. David⁴⁴, A. De Caro^{28, ID}, G. de Cataldo^{49, ID}, L. De
 Cilladi^{24, ID}, J. de Cuveland³⁸, A. De Falco^{22, ID}, D. De Gruttola^{28, ID}, N. De Marco^{55, ID}, C. De Martin^{23, ID},
 S. De Pasquale^{28, ID}, S. Deb^{47, ID}, H.F. Degenhardt¹⁰⁹, K.R. Deja¹³³, R. Del Grande^{95, ID},
 L. Dello Stritto^{28, ID}, W. Deng^{6, ID}, P. Dhankher^{18, ID}, D. Di Bari^{31, ID}, A. Di Mauro^{32, ID}, R.A. Diaz^{141,7, ID},
 T. Dietel^{112, ID}, Y. Ding^{125,6, ID}, R. Divià^{32, ID}, D.U. Dixit^{18, ID}, Ø. Djuvsland²⁰, U. Dmitrieva^{140, ID},

A. Dobrin ^{62, [id](#)}, B. Dönigus ^{63, [id](#)}, A.K. Dubey ^{132, [id](#)}, J.M. Dubinski ^{133, [id](#)}, A. Dubla ^{97, [id](#)}, S. Dudi ^{89, [id](#)},
 P. Dupieux ^{124, [id](#)}, M. Durkac ¹⁰⁵, N. Dzalaiova ¹², T.M. Eder ^{135, [id](#)}, R.J. Ehlers ^{86, [id](#)}, V.N. Eikeland ²⁰,
 F. Eisenhut ^{63, [id](#)}, D. Elia ^{49, [id](#)}, B. Erasmus ^{103, [id](#)}, F. Ercolessi ^{25, [id](#)}, F. Erhardt ^{88, [id](#)}, M.R. Ersdal ²⁰,
 B. Espagnon ^{128, [id](#)}, G. Eulisse ^{32, [id](#)}, D. Evans ^{100, [id](#)}, S. Evdokimov ^{140, [id](#)}, L. Fabbietti ^{95, [id](#)}, M. Faggin ^{27, [id](#)},
 J. Faivre ^{72, [id](#)}, F. Fan ^{6, [id](#)}, W. Fan ^{73, [id](#)}, A. Fantoni ^{48, [id](#)}, M. Fasel ^{86, [id](#)}, P. Fedchio ²⁹, A. Feliciello ^{55, [id](#)},
 G. Feofilov ^{140, [id](#)}, A. Fernández Téllez ^{44, [id](#)}, M.B. Ferrer ^{32, [id](#)}, A. Ferrero ^{127, [id](#)}, A. Ferretti ^{24, [id](#)},
 V.J.G. Feuillard ^{94, [id](#)}, J. Figiel ^{106, [id](#)}, V. Filova ^{35, [id](#)}, D. Finogeev ^{140, [id](#)}, F.M. Fionda ^{51, [id](#)}, G. Fiorenza ⁹⁶,
 F. Flor ^{113, [id](#)}, A.N. Flores ^{107, [id](#)}, S. Foertsch ^{67, [id](#)}, I. Fokin ^{94, [id](#)}, S. Fokin ^{140, [id](#)}, E. Fragiaco ^{56, [id](#)},
 E. Frajna ^{136, [id](#)}, U. Fuchs ^{32, [id](#)}, N. Funicello ^{28, [id](#)}, C. Furget ^{72, [id](#)}, A. Furs ^{140, [id](#)}, T. Fusayasu ^{98, [id](#)},
 J.J. Gaardhøje ^{82, [id](#)}, M. Gagliardi ^{24, [id](#)}, A.M. Gago ^{101, [id](#)}, A. Gal ¹²⁶, C.D. Galvan ^{108, [id](#)},
 D.R. Gangadharan ^{113, [id](#)}, P. Ganoti ^{77, [id](#)}, C. Garabatos ^{97, [id](#)}, J.R.A. Garcia ^{44, [id](#)}, E. Garcia-Solis ^{9, [id](#)},
 K. Garg ^{103, [id](#)}, C. Gargiulo ^{32, [id](#)}, A. Garibli ⁸⁰, K. Garner ¹³⁵, A. Gautam ^{115, [id](#)}, M.B. Gay Ducati ^{65, [id](#)},
 M. Germain ^{103, [id](#)}, C. Ghosh ¹³², S.K. Ghosh ⁴, M. Giacalone ^{25, [id](#)}, P. Gianotti ^{48, [id](#)}, P. Giubellino ^{97, 55, [id](#)},
 P. Giubilato ^{27, [id](#)}, A.M.C. Glaenger ^{127, [id](#)}, P. Glässel ^{94, [id](#)}, E. Glimos ^{119, [id](#)}, D.J.Q. Goh ⁷⁵, V. Gonzalez ^{134, [id](#)},
 L.H. González-Trueba ^{66, [id](#)}, M. Gorgon ^{2, [id](#)}, L. Görlich ^{106, [id](#)}, S. Gotovac ³³, V. Grabski ^{66, [id](#)},
 L.K. Graczykowski ^{133, [id](#)}, E. Grecka ^{85, [id](#)}, L. Greiner ^{73, [id](#)}, A. Grelli ^{58, [id](#)}, C. Grigoras ^{32, [id](#)}, V. Grigoriev ^{140, [id](#)},
 S. Grigoryan ^{141, 1, [id](#)}, F. Grosa ^{32, [id](#)}, J.F. Grosse-Oetringhaus ^{32, [id](#)}, R. Grosso ^{97, [id](#)}, D. Grund ^{35, [id](#)},
 G.G. Guardiano ^{110, [id](#)}, R. Guernane ^{72, [id](#)}, M. Guilbaud ^{103, [id](#)}, K. Gulbrandsen ^{82, [id](#)}, T. Gunji ^{121, [id](#)},
 W. Guo ^{6, [id](#)}, A. Gupta ^{90, [id](#)}, R. Gupta ^{90, [id](#)}, S.P. Guzman ^{44, [id](#)}, L. Gyulai ^{136, [id](#)}, M.K. Habib ⁹⁷,
 C. Hadjidakis ^{128, [id](#)}, H. Hamagaki ^{75, [id](#)}, M. Hamid ⁶, Y. Han ^{138, [id](#)}, R. Hannigan ^{107, [id](#)}, M.R. Haque ^{133, [id](#)},
 A. Harlenderova ⁹⁷, J.W. Harris ^{137, [id](#)}, A. Harton ^{9, [id](#)}, H. Hassan ^{86, [id](#)}, D. Hatzifotiadou ^{50, [id](#)}, P. Hauer ^{42, [id](#)},
 L.B. Havener ^{137, [id](#)}, S.T. Heckel ^{95, [id](#)}, E. Hellbär ^{97, [id](#)}, H. Helstrup ^{34, [id](#)}, T. Herman ^{35, [id](#)}, G. Herrera
 Corral ^{8, [id](#)}, F. Herrmann ¹³⁵, S. Herrmann ^{125, [id](#)}, K.F. Hetland ^{34, [id](#)}, B. Heybeck ^{63, [id](#)}, H. Hillemanns ^{32, [id](#)},
 C. Hills ^{116, [id](#)}, B. Hippolyte ^{126, [id](#)}, B. Hofman ^{58, [id](#)}, B. Hohlweger ^{83, [id](#)}, J. Honermann ^{135, [id](#)},
 G.H. Hong ^{138, [id](#)}, D. Horak ^{35, [id](#)}, A. Horzyk ^{2, [id](#)}, R. Hosokawa ¹⁴, Y. Hou ^{6, [id](#)}, P. Hristov ^{32, [id](#)},
 C. Hughes ^{119, [id](#)}, P. Huhn ⁶³, L.M. Huhta ^{114, [id](#)}, C.V. Hulse ^{128, [id](#)}, T.J. Humanic ^{87, [id](#)}, H. Hushnud ⁹⁹,
 A. Hutson ^{113, [id](#)}, D. Hutter ^{38, [id](#)}, J.P. Iddon ^{116, [id](#)}, R. Ilkaev ¹⁴⁰, H. Ilyas ^{13, [id](#)}, M. Inaba ^{122, [id](#)},
 G.M. Innocenti ^{32, [id](#)}, M. Ippolitov ^{140, [id](#)}, A. Isakov ^{85, [id](#)}, T. Isidori ^{115, [id](#)}, M.S. Islam ^{99, [id](#)}, M. Ivanov ^{97, [id](#)},
 M. Ivanov ¹², V. Ivanov ^{140, [id](#)}, V. Izucheev ¹⁴⁰, M. Jablonski ^{2, [id](#)}, B. Jacak ^{73, [id](#)}, N. Jacazio ^{32, [id](#)},
 P.M. Jacobs ^{73, [id](#)}, S. Jadlovská ¹⁰⁵, J. Jadlovsky ¹⁰⁵, S. Jaelani ⁸¹, L. Jaffe ³⁸, C. Jahnke ^{110, [id](#)}, M.A. Janik ^{133, [id](#)},
 T. Janson ⁶⁹, M. Jercic ⁸⁸, O. Jevons ¹⁰⁰, A.A.P. Jimenez ^{64, [id](#)}, F. Jonas ^{86, [id](#)}, P.G. Jones ¹⁰⁰, J.M. Jowett ^{32, 97, [id](#)},
 J. Jung ^{63, [id](#)}, M. Jung ^{63, [id](#)}, A. Junique ^{32, [id](#)}, A. Jusko ^{100, [id](#)}, M.J. Kabus ^{32, 133, [id](#)}, J. Kaewjai ¹⁰⁴,
 P. Kalinak ^{59, [id](#)}, A.S. Kalteyer ^{97, [id](#)}, A. Kalweit ^{32, [id](#)}, V. Kaplin ^{140, [id](#)}, A. Karasu Uysal ^{71, [id](#)}, D. Karatovic ^{88, [id](#)},
 O. Karavichev ^{140, [id](#)}, T. Karavicheva ^{140, [id](#)}, P. Karczmarczyk ^{133, [id](#)}, E. Karpechev ^{140, [id](#)}, V. Kashyap ⁷⁹,
 A. Kazantsev ¹⁴⁰, U. Keschull ^{69, [id](#)}, R. Keidel ^{139, [id](#)}, D.L.D. Keijdener ⁵⁸, M. Keil ^{32, [id](#)}, B. Ketzer ^{42, [id](#)},
 A.M. Khan ^{6, [id](#)}, S. Khan ^{15, [id](#)}, A. Khanzadeev ^{140, [id](#)}, Y. Kharlov ^{140, [id](#)}, A. Khatun ^{15, [id](#)}, A. Khuntia ^{106, [id](#)},
 B. Kileng ^{34, [id](#)}, B. Kim ^{16, [id](#)}, C. Kim ^{16, [id](#)}, D.J. Kim ^{114, [id](#)}, E.J. Kim ^{68, [id](#)}, J. Kim ^{138, [id](#)}, J.S. Kim ^{40, [id](#)},
 J. Kim ^{94, [id](#)}, J. Kim ^{68, [id](#)}, M. Kim ^{94, [id](#)}, S. Kim ^{17, [id](#)}, T. Kim ^{138, [id](#)}, K. Kimura ^{92, [id](#)}, S. Kirsch ^{63, [id](#)},
 I. Kisel ^{38, [id](#)}, S. Kiselev ^{140, [id](#)}, A. Kisiel ^{133, [id](#)}, J.P. Kitowski ^{2, [id](#)}, J.L. Klay ^{5, [id](#)}, J. Klein ^{32, [id](#)}, S. Klein ^{73, [id](#)},
 C. Klein-Bösing ^{135, [id](#)}, M. Kleiner ^{63, [id](#)}, T. Klemenz ^{95, [id](#)}, A. Kluge ^{32, [id](#)}, A.G. Knospe ^{113, [id](#)}, C. Kobdaj ^{104, [id](#)},
 T. Kollegger ⁹⁷, A. Kondratyev ^{141, [id](#)}, E. Kondratyuk ^{140, [id](#)}, J. Konig ^{63, [id](#)}, S.A. Konigstorfer ^{95, [id](#)},
 P.J. Konopka ^{32, [id](#)}, G. Kornakov ^{133, [id](#)}, S.D. Koryciak ^{2, [id](#)}, A. Kotliarov ^{85, [id](#)}, O. Kovalenko ^{78, [id](#)},

V. Kovalenko ^{140, [ib](#)}, M. Kowalski ^{106, [ib](#)}, I. Králik ^{59, [ib](#)}, A. Kravčáková ^{37, [ib](#)}, L. Kreis ⁹⁷, M. Krivda ^{100,59, [ib](#)},
F. Krizek ^{85, [ib](#)}, K. Krizkova Gajdosova ^{35, [ib](#)}, M. Kroesen ^{94, [ib](#)}, M. Krüger ^{63, [ib](#)}, D.M. Krupova ^{35, [ib](#)},
E. Kryshen ^{140, [ib](#)}, M. Krzewicki ³⁸, V. Kučera ^{32, [ib](#)}, C. Kuhn ^{126, [ib](#)}, P.G. Kuijter ^{83, [ib](#)}, T. Kumaoka ¹²²,
D. Kumar ¹³², L. Kumar ^{89, [ib](#)}, N. Kumar ⁸⁹, S. Kundu ^{32, [ib](#)}, P. Kurashvili ^{78, [ib](#)}, A. Kurepin ^{140, [ib](#)},
A.B. Kurepin ^{140, [ib](#)}, S. Kuschpil ^{85, [ib](#)}, J. Kvapil ^{100, [ib](#)}, M.J. Kweon ^{57, [ib](#)}, J.Y. Kwon ^{57, [ib](#)}, Y. Kwon ^{138, [ib](#)}, S.L. La
Pointe ^{38, [ib](#)}, P. La Rocca ^{26, [ib](#)}, Y.S. Lai ⁷³, A. Lakrathok ¹⁰⁴, M. Lamanna ^{32, [ib](#)}, R. Langoy ^{118, [ib](#)},
P. Larionov ^{48, [ib](#)}, E. Laudi ^{32, [ib](#)}, L. Lautner ^{32,95, [ib](#)}, R. Lavicka ^{102, [ib](#)}, T. Lazareva ^{140, [ib](#)}, R. Lea ^{131,54, [ib](#)},
G. Legras ^{135, [ib](#)}, J. Lehrbach ^{38, [ib](#)}, R.C. Lemmon ^{84, [ib](#)}, I. León Monzón ^{108, [ib](#)}, M.M. Lesch ^{95, [ib](#)},
E.D. Lesser ^{18, [ib](#)}, M. Lettrich ⁹⁵, P. Lévai ^{136, [ib](#)}, X. Li ¹⁰, X.L. Li ⁶, J. Lien ^{118, [ib](#)}, R. Lietava ^{100, [ib](#)}, B. Lim ^{16, [ib](#)},
S.H. Lim ^{16, [ib](#)}, V. Lindenstruth ^{38, [ib](#)}, A. Lindner ⁴⁵, C. Lippmann ^{97, [ib](#)}, A. Liu ^{18, [ib](#)}, D.H. Liu ^{6, [ib](#)}, J. Liu ^{116, [ib](#)},
I.M. Lofnes ^{20, [ib](#)}, C. Loizides ^{86, [ib](#)}, P. Loncar ^{33, [ib](#)}, J.A. Lopez ^{94, [ib](#)}, X. Lopez ^{124, [ib](#)}, E. López Torres ^{7, [ib](#)},
P. Lu ^{97,117, [ib](#)}, J.R. Luhder ^{135, [ib](#)}, M. Lunardon ^{27, [ib](#)}, G. Luparello ^{56, [ib](#)}, Y.G. Ma ^{39, [ib](#)}, A. Maevskaya ¹⁴⁰,
M. Mager ^{32, [ib](#)}, T. Mahmoud ⁴², A. Maire ^{126, [ib](#)}, M. Malaev ^{140, [ib](#)}, G. Malfattore ^{25, [ib](#)}, N.M. Malik ^{90, [ib](#)},
Q.W. Malik ¹⁹, S.K. Malik ^{90, [ib](#)}, L. Malinina ^{141, [ib](#), VII}, D. Mal'Kevich ^{140, [ib](#)}, D. Mallick ^{79, [ib](#)}, N. Mallick ^{47, [ib](#)},
G. Mandaglio ^{30,52, [ib](#)}, V. Manko ^{140, [ib](#)}, F. Manso ^{124, [ib](#)}, V. Manzari ^{49, [ib](#)}, Y. Mao ^{6, [ib](#)}, G.V. Margagliotti ^{23, [ib](#)},
A. Margotti ^{50, [ib](#)}, A. Marín ^{97, [ib](#)}, C. Markert ^{107, [ib](#)}, M. Marquard ⁶³, P. Martinengo ^{32, [ib](#)}, J.L. Martinez ¹¹³,
M.I. Martínez ^{44, [ib](#)}, G. Martínez García ^{103, [ib](#)}, S. Masciocchi ^{97, [ib](#)}, M. Masera ^{24, [ib](#)}, A. Masoni ^{51, [ib](#)},
L. Massacrier ^{128, [ib](#)}, A. Mastroserio ^{129,49, [ib](#)}, A.M. Mathis ^{95, [ib](#)}, O. Matonoha ^{74, [ib](#)}, P.F.T. Matuoka ¹⁰⁹,
A. Matyja ^{106, [ib](#)}, C. Mayer ^{106, [ib](#)}, A.L. Mazuecos ^{32, [ib](#)}, F. Mazzaschi ^{24, [ib](#)}, M. Mazzilli ^{32, [ib](#)},
J.E. Mdhului ^{120, [ib](#)}, A.F. Mechler ⁶³, Y. Melikyan ^{140, [ib](#)}, A. Menchaca-Rocha ^{66, [ib](#)}, E. Meninno ^{102,28, [ib](#)},
A.S. Menon ^{113, [ib](#)}, M. Meres ^{12, [ib](#)}, S. Mhlanga ^{112,67}, Y. Miake ¹²², L. Micheletti ^{55, [ib](#)}, L.C. Migliorin ¹²⁵,
D.L. Mihaylov ^{95, [ib](#)}, K. Mikhaylov ^{141,140, [ib](#)}, A.N. Mishra ^{136, [ib](#)}, D. Miśkowiec ^{97, [ib](#)}, A. Modak ^{4, [ib](#)},
A.P. Mohanty ^{58, [ib](#)}, B. Mohanty ⁷⁹, M. Mohisin Khan ^{15, [ib](#), V}, M.A. Molander ^{43, [ib](#)}, Z. Moravcova ^{82, [ib](#)},
C. Mordasini ^{95, [ib](#)}, D.A. Moreira De Godoy ^{135, [ib](#)}, I. Morozov ^{140, [ib](#)}, A. Morsch ^{32, [ib](#)}, T. Mrnjavac ^{32, [ib](#)},
V. Muccifora ^{48, [ib](#)}, E. Mudnic ³³, S. Muhuri ^{132, [ib](#)}, J.D. Mulligan ^{73, [ib](#)}, A. Mulliri ²², M.G. Munhoz ^{109, [ib](#)},
R.H. Munzer ^{63, [ib](#)}, H. Murakami ^{121, [ib](#)}, S. Murray ^{112, [ib](#)}, L. Musa ^{32, [ib](#)}, J. Musinsky ^{59, [ib](#)}, J.W. Myrcha ^{133, [ib](#)},
B. Naik ^{120, [ib](#)}, R. Nair ^{78, [ib](#)}, A.I. Nambrath ^{18, [ib](#)}, B.K. Nandi ^{46, [ib](#)}, R. Nania ^{50, [ib](#)}, E. Nappi ^{49, [ib](#)},
A.F. Nassirpour ^{74, [ib](#)}, A. Nath ^{94, [ib](#)}, C. Nattrass ^{119, [ib](#)}, A. Neagu ¹⁹, A. Negru ¹²³, L. Nellen ^{64, [ib](#)},
S.V. Nesbo ³⁴, G. Neskovic ^{38, [ib](#)}, D. Nesterov ^{140, [ib](#)}, B.S. Nielsen ^{82, [ib](#)}, E.G. Nielsen ^{82, [ib](#)}, S. Nikolaev ^{140, [ib](#)},
S. Nikulin ^{140, [ib](#)}, V. Nikulin ^{140, [ib](#)}, F. Noferini ^{50, [ib](#)}, S. Noh ^{11, [ib](#)}, P. Nomokonov ^{141, [ib](#)}, J. Norman ^{116, [ib](#)},
N. Novitzky ^{122, [ib](#)}, P. Nowakowski ^{133, [ib](#)}, A. Nyanin ^{140, [ib](#)}, J. Nystrand ^{20, [ib](#)}, M. Ogino ^{75, [ib](#)}, A. Ohlson ^{74, [ib](#)},
V.A. Okorokov ^{140, [ib](#)}, J. Oleniacz ^{133, [ib](#)}, A.C. Oliveira Da Silva ^{119, [ib](#)}, M.H. Oliver ^{137, [ib](#)}, A. Onnerstad ^{114, [ib](#)},
C. Oppedisano ^{55, [ib](#)}, A. Ortiz Velasquez ^{64, [ib](#)}, A. Oskarsson ⁷⁴, J. Otwinowski ^{106, [ib](#)}, M. Oya ⁹²,
K. Oyama ^{75, [ib](#)}, Y. Pachmayer ^{94, [ib](#)}, S. Padhan ^{46, [ib](#)}, D. Pagano ^{131,54, [ib](#)}, G. Paic ^{64, [ib](#)}, A. Palasciano ^{49, [ib](#)},
S. Panebianco ^{127, [ib](#)}, H. Park ^{122, [ib](#)}, J. Park ^{57, [ib](#)}, J.E. Parkkila ^{32,114, [ib](#)}, S.P. Pathak ¹¹³, R.N. Patra ⁹⁰,
B. Paul ^{22, [ib](#)}, H. Pei ^{6, [ib](#)}, T. Peitzmann ^{58, [ib](#)}, X. Peng ^{6, [ib](#)}, M. Pennisi ^{24, [ib](#)}, L.G. Pereira ^{65, [ib](#)}, H. Pereira Da
Costa ^{127, [ib](#)}, D. Peresunko ^{140, [ib](#)}, G.M. Perez ^{7, [ib](#)}, S. Perrin ^{127, [ib](#)}, Y. Pestov ¹⁴⁰, V. Petráček ^{35, [ib](#)},
V. Petrov ^{140, [ib](#)}, M. Petrovici ^{45, [ib](#)}, R.P. Pezzi ^{103,65, [ib](#)}, S. Piano ^{56, [ib](#)}, M. Pikna ^{12, [ib](#)}, P. Pillot ^{103, [ib](#)},
O. Pinazza ^{50,32, [ib](#)}, L. Pinsky ¹¹³, C. Pinto ^{95, [ib](#)}, S. Pisano ^{48, [ib](#)}, M. Płoskoń ^{73, [ib](#)}, M. Planinic ⁸⁸, F. Pliquett ⁶³,
M.G. Poghosyan ^{86, [ib](#)}, S. Politano ^{29, [ib](#)}, N. Poljak ^{88, [ib](#)}, A. Pop ^{45, [ib](#)}, S. Porteboeuf-Houssais ^{124, [ib](#)},
J. Porter ^{73, [ib](#)}, V. Pozdniakov ^{141, [ib](#)}, S.K. Prasad ^{4, [ib](#)}, S. Prasad ^{47, [ib](#)}, R. Preghenella ^{50, [ib](#)}, F. Prino ^{55, [ib](#)},
C.A. Pruneau ^{134, [ib](#)}, I. Pshenichnov ^{140, [ib](#)}, M. Puccio ^{32, [ib](#)}, S. Pucillo ^{24, [ib](#)}, Z. Pugelova ¹⁰⁵, S. Qiu ^{83, [ib](#)},

L. Quaglia^{24, [id](#)}, R.E. Quishpe¹¹³, S. Ragoni^{100, [id](#)}, A. Rakotozafindrabe^{127, [id](#)}, L. Ramello^{130,55, [id](#)},
 F. Rami^{126, [id](#)}, S.A.R. Ramirez^{44, [id](#)}, T.A. Rancien⁷², R. Raniwala^{91, [id](#)}, S. Raniwala⁹¹, S.S. Räsänen^{43, [id](#)},
 R. Rath^{50,47, [id](#)}, I. Ravasenga^{83, [id](#)}, K.F. Read^{86,119, [id](#)}, A.R. Redelbach^{38, [id](#)}, K. Redlich^{78, [id](#), [VI](#)}, A. Rehman²⁰,
 P. Reichelt⁶³, F. Reidt^{32, [id](#)}, H.A. Reme-Ness^{34, [id](#)}, Z. Rescakova³⁷, K. Reygers^{94, [id](#)}, A. Riabov^{140, [id](#)},
 V. Riabov^{140, [id](#)}, R. Ricci^{28, [id](#)}, T. Richert⁷⁴, M. Richter^{19, [id](#)}, A.A. Riedel^{95, [id](#)}, W. Riegler^{32, [id](#)}, F. Riggi^{26, [id](#)},
 C. Ristea^{62, [id](#)}, M. Rodríguez Cahuantzi^{44, [id](#)}, K. Røed^{19, [id](#)}, R. Rogalev^{140, [id](#)}, E. Rogochaya^{141, [id](#)},
 T.S. Rogoschinski^{63, [id](#)}, D. Rohr^{32, [id](#)}, D. Röhrich^{20, [id](#)}, P.F. Rojas⁴⁴, S. Rojas Torres^{35, [id](#)}, P.S. Rokita^{133, [id](#)},
 G. Romanenko^{141, [id](#)}, F. Ronchetti^{48, [id](#)}, A. Rosano^{30,52, [id](#)}, E.D. Rosas⁶⁴, A. Rossi^{53, [id](#)}, A. Roy^{47, [id](#)},
 P. Roy⁹⁹, S. Roy^{46, [id](#)}, N. Rubini^{25, [id](#)}, D. Ruggiano^{133, [id](#)}, R. Rui^{23, [id](#)}, B. Rumyantsev¹⁴¹, P.G. Russek^{2, [id](#)},
 R. Russo^{83, [id](#)}, A. Rustamov^{80, [id](#)}, E. Ryabinkin^{140, [id](#)}, Y. Ryabov^{140, [id](#)}, A. Rybicki^{106, [id](#)}, H. Rytkonen^{114, [id](#)},
 W. Rzesza^{133, [id](#)}, O.A.M. Saarimaki^{43, [id](#)}, R. Sadek^{103, [id](#)}, S. Sadovsky^{140, [id](#)}, J. Saetre^{20, [id](#)}, K. Šafařík^{35, [id](#)},
 S. Saha^{79, [id](#)}, B. Sahoo^{46, [id](#)}, R. Sahoo^{47, [id](#)}, S. Sahoo⁶⁰, D. Sahu^{47, [id](#)}, P.K. Sahu^{60, [id](#)}, J. Saini^{132, [id](#)},
 K. Sajdakova³⁷, S. Sakai^{122, [id](#)}, M.P. Salvan^{97, [id](#)}, S. Sambyal^{90, [id](#)}, T.B. Saramela¹⁰⁹, D. Sarkar^{134, [id](#)},
 N. Sarkar¹³², P. Sarma^{41, [id](#)}, V. Sarritzu^{22, [id](#)}, V.M. Sarti^{95, [id](#)}, M.H.P. Sas^{137, [id](#)}, J. Schambach^{86, [id](#)},
 H.S. Scheid^{63, [id](#)}, C. Schiaua^{45, [id](#)}, R. Schicker^{94, [id](#)}, A. Schmah⁹⁴, C. Schmidt^{97, [id](#)}, H.R. Schmidt⁹³,
 M.O. Schmidt^{32, [id](#)}, M. Schmidt⁹³, N.V. Schmidt^{86, [id](#)}, A.R. Schmier^{119, [id](#)}, R. Schotter^{126, [id](#)},
 J. Schukraft^{32, [id](#)}, K. Schwarz⁹⁷, K. Schweda^{97, [id](#)}, G. Scioli^{25, [id](#)}, E. Scomparin^{55, [id](#)}, J.E. Seger^{14, [id](#)},
 Y. Sekiguchi¹²¹, D. Sekihata^{121, [id](#)}, I. Selyuzhenkov^{97,140, [id](#)}, S. Senyukov^{126, [id](#)}, J.J. Seo^{57, [id](#)},
 D. Serebryakov^{140, [id](#)}, L. Šerkšnytė^{95, [id](#)}, A. Sevcenco^{62, [id](#)}, T.J. Shaba^{67, [id](#)}, A. Shabetai^{103, [id](#)},
 R. Shahoyan³², A. Shangaraev^{140, [id](#)}, A. Sharma⁸⁹, D. Sharma^{46, [id](#)}, H. Sharma^{106, [id](#)}, M. Sharma^{90, [id](#)},
 N. Sharma^{89, [id](#)}, S. Sharma^{75, [id](#)}, S. Sharma^{90, [id](#)}, U. Sharma^{90, [id](#)}, A. Shatat^{128, [id](#)}, O. Sheibani¹¹³,
 K. Shigaki^{92, [id](#)}, M. Shimomura⁷⁶, S. Shirinkin^{140, [id](#)}, Q. Shou^{39, [id](#)}, Y. Sibiriak^{140, [id](#)}, S. Siddhanta^{51, [id](#)},
 T. Siemiarczuk^{78, [id](#)}, T.F. Silva^{109, [id](#)}, D. Silvermyr^{74, [id](#)}, T. Simantathammakul¹⁰⁴, R. Simeonov^{36, [id](#)},
 G. Simonetti³², B. Singh⁹⁰, B. Singh^{95, [id](#)}, R. Singh^{79, [id](#)}, R. Singh^{90, [id](#)}, R. Singh^{47, [id](#)}, S. Singh^{15, [id](#)},
 V.K. Singh^{132, [id](#)}, V. Singhal^{132, [id](#)}, T. Sinha^{99, [id](#)}, B. Sitar^{12, [id](#)}, M. Sitta^{130,55, [id](#)}, T.B. Skaali¹⁹,
 G. Skorodumovs^{94, [id](#)}, M. Slupecki^{43, [id](#)}, N. Smirnov^{137, [id](#)}, R.J.M. Snellings^{58, [id](#)}, E.H. Solheim^{19, [id](#)},
 C. Soncco¹⁰¹, J. Song^{113, [id](#)}, A. Songmoolnak¹⁰⁴, F. Soramel^{27, [id](#)}, S.P. Sorensen^{119, [id](#)}, R. Spijkers^{83, [id](#)},
 I. Sputowska^{106, [id](#)}, J. Staa^{74, [id](#)}, J. Stachel^{94, [id](#)}, I. Stan^{62, [id](#)}, P.J. Steffanic^{119, [id](#)}, S.F. Stiefelmaier^{94, [id](#)},
 D. Stocco^{103, [id](#)}, I. Storehaug^{19, [id](#)}, M.M. Storetvedt^{34, [id](#)}, P. Stratmann^{135, [id](#)}, S. Strazzi^{25, [id](#)},
 C.P. Stylianidis⁸³, A.A.P. Suaide^{109, [id](#)}, C. Suire^{128, [id](#)}, M. Sukhanov^{140, [id](#)}, M. Suljic^{32, [id](#)}, V. Sumberia^{90, [id](#)},
 S. Sumowidagdo^{81, [id](#)}, S. Swain⁶⁰, I. Szarka^{12, [id](#)}, U. Tabassam¹³, S.F. Taghavi^{95, [id](#)}, G. Tallepied^{97, [id](#)},
 J. Takahashi^{110, [id](#)}, G.J. Tambave^{20, [id](#)}, S. Tang^{124,6, [id](#)}, Z. Tang^{117, [id](#)}, J.D. Tapia Takaki^{115, [id](#)}, N. Tapus¹²³,
 L.A. Tarasovicova^{135, [id](#)}, M.G. Tarzila^{45, [id](#)}, G.F. Tassielli^{31, [id](#)}, A. Tauro^{32, [id](#)}, A. Telesca^{32, [id](#)}, L. Terlizzi^{24, [id](#)},
 C. Terrevoli^{113, [id](#)}, G. Tersimonov³, D. Thomas^{107, [id](#)}, A. Tikhonov^{140, [id](#)}, A.R. Timmins^{113, [id](#)}, M. Tkacik¹⁰⁵,
 T. Tkacik^{105, [id](#)}, A. Toia^{63, [id](#)}, R. Tokumoto⁹², N. Topilskaya^{140, [id](#)}, M. Toppi^{48, [id](#)}, F. Torales-Acosta¹⁸,
 T. Tork^{128, [id](#)}, A.G. Torres Ramos^{31, [id](#)}, A. Trifiró^{30,52, [id](#)}, A.S. Triolo^{30,52, [id](#)}, S. Tripathy^{50, [id](#)},
 T. Tripathy^{46, [id](#)}, S. Trogolo^{32, [id](#)}, V. Trubnikov^{3, [id](#)}, W.H. Trzaska^{114, [id](#)}, T.P. Trzcinski^{133, [id](#)}, R. Turrisi^{53, [id](#)},
 T.S. Tveter^{19, [id](#)}, K. Ullaland^{20, [id](#)}, B. Ulukutlu^{95, [id](#)}, A. Uras^{125, [id](#)}, M. Urioni^{54,131, [id](#)}, G.L. Usai^{22, [id](#)},
 M. Vala³⁷, N. Valle^{21, [id](#)}, S. Vallero^{55, [id](#)}, L.V.R. van Doremalen⁵⁸, M. van Leeuwen^{83, [id](#)}, C.A. van
 Veen^{94, [id](#)}, R.J.G. van Weelden^{83, [id](#)}, P. Vande Vyvre^{32, [id](#)}, D. Varga^{136, [id](#)}, Z. Varga^{136, [id](#)},
 M. Varga-Kofarago^{136, [id](#)}, M. Vasileiou^{77, [id](#)}, A. Vasiliev^{140, [id](#)}, O. Vázquez Doce^{95, [id](#)}, O. Vazquez
 Rueda^{74, [id](#)}, V. Vechernin^{140, [id](#)}, E. Vercellin^{24, [id](#)}, S. Vergara Limón⁴⁴, L. Vermunt^{97, [id](#)}, R. Vértesi^{136, [id](#)},

M. Verweij^{58, [id](#)}, L. Vickovic³³, Z. Vilakazi¹²⁰, O. Villalobos Baillie^{100, [id](#)}, G. Vino^{49, [id](#)},
 A. Vinogradov^{140, [id](#)}, T. Virgili^{28, [id](#)}, V. Vislavicius⁸², A. Vodopyanov^{141, [id](#)}, B. Volkel^{32, [id](#)}, M.A. Völkl^{94, [id](#)},
 K. Voloshin¹⁴⁰, S.A. Voloshin^{134, [id](#)}, G. Volpe^{31, [id](#)}, B. von Haller^{32, [id](#)}, I. Vorobyev^{95, [id](#)}, N. Vozniuk^{140, [id](#)},
 J. Vrláková^{37, [id](#)}, B. Wagner²⁰, C. Wang^{39, [id](#)}, D. Wang³⁹, M. Weber^{102, [id](#)}, A. Wegrzynek^{32, [id](#)},
 F.T. Weiglhofer³⁸, S.C. Wenzel^{32, [id](#)}, J.P. Wessels^{135, [id](#)}, S.L. Weyhmler^{137, [id](#)}, J. Wiechula^{63, [id](#)},
 J. Wikne^{19, [id](#)}, G. Wilk^{78, [id](#)}, J. Wilkinson^{97, [id](#)}, G.A. Willems^{135, [id](#)}, B. Windelband^{94, [id](#)}, M. Winn^{127, [id](#)},
 J.R. Wright^{107, [id](#)}, W. Wu³⁹, Y. Wu^{117, [id](#)}, R. Xu^{6, [id](#)}, A. Yadav^{42, [id](#)}, A.K. Yadav^{132, [id](#)}, S. Yalcin^{71, [id](#)},
 Y. Yamaguchi^{92, [id](#)}, K. Yamakawa⁹², S. Yang²⁰, S. Yano^{92, [id](#)}, Z. Yin^{6, [id](#)}, I.-K. Yoo^{16, [id](#)}, J.H. Yoon^{57, [id](#)},
 S. Yuan²⁰, A. Yuncu^{94, [id](#)}, V. Zaccolo^{23, [id](#)}, C. Zampolli^{32, [id](#)}, H.J.C. Zanolini⁵⁸, F. Zanone^{94, [id](#)},
 N. Zardoshti^{32, 100, [id](#)}, A. Zarochentsev^{140, [id](#)}, P. Závada^{61, [id](#)}, N. Zaviyalov¹⁴⁰, M. Zhalov^{140, [id](#)},
 B. Zhang^{6, [id](#)}, S. Zhang^{39, [id](#)}, X. Zhang^{6, [id](#)}, Y. Zhang¹¹⁷, Z. Zhang^{6, [id](#)}, M. Zhao^{10, [id](#)},
 V. Zherebchevskii^{140, [id](#)}, Y. Zhi¹⁰, N. Zhigareva¹⁴⁰, D. Zhou^{6, [id](#)}, Y. Zhou^{82, [id](#)}, J. Zhu^{6, 97, [id](#)}, Y. Zhu⁶,
 G. Zinovjev^{3, 1}, N. Zurlo^{131, 54, [id](#)}

¹ A.I. Alikhanyan National Science Laboratory (Yerevan Physics Institute) Foundation, Yerevan, Armenia

² AGH University of Krakow, Cracow, Poland

³ Bogolyubov Institute for Theoretical Physics, National Academy of Sciences of Ukraine, Kiev, Ukraine

⁴ Bose Institute, Department of Physics and Centre for Astroparticle Physics and Space Science (CAPSS), Kolkata, India

⁵ California Polytechnic State University, San Luis Obispo, CA, United States

⁶ Central China Normal University, Wuhan, China

⁷ Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear (CEADEN), Havana, Cuba

⁸ Centro de Investigación y de Estudios Avanzados (CINVESTAV), Mexico City and Mérida, Mexico

⁹ Chicago State University, Chicago, IL, United States

¹⁰ China Institute of Atomic Energy, Beijing, China

¹¹ Chungbuk National University, Cheongju, Republic of Korea

¹² Comenius University Bratislava, Faculty of Mathematics, Physics and Informatics, Bratislava, Slovak Republic

¹³ COMSATS University Islamabad, Islamabad, Pakistan

¹⁴ Creighton University, Omaha, NE, United States

¹⁵ Department of Physics, Aligarh Muslim University, Aligarh, India

¹⁶ Department of Physics, Pusan National University, Pusan, Republic of Korea

¹⁷ Department of Physics, Sejong University, Seoul, Republic of Korea

¹⁸ Department of Physics, University of California, Berkeley, CA, United States

¹⁹ Department of Physics, University of Oslo, Oslo, Norway

²⁰ Department of Physics and Technology, University of Bergen, Bergen, Norway

²¹ Dipartimento di Fisica, Università di Pavia, Pavia, Italy

²² Dipartimento di Fisica dell'Università and Sezione INFN, Cagliari, Italy

²³ Dipartimento di Fisica dell'Università and Sezione INFN, Trieste, Italy

²⁴ Dipartimento di Fisica dell'Università and Sezione INFN, Turin, Italy

²⁵ Dipartimento di Fisica e Astronomia dell'Università and Sezione INFN, Bologna, Italy

²⁶ Dipartimento di Fisica e Astronomia dell'Università and Sezione INFN, Catania, Italy

²⁷ Dipartimento di Fisica e Astronomia dell'Università and Sezione INFN, Padova, Italy

²⁸ Dipartimento di Fisica 'E.R. Caianiello' dell'Università and Gruppo Collegato INFN, Salerno, Italy

²⁹ Dipartimento DISAT del Politecnico and Sezione INFN, Turin, Italy

³⁰ Dipartimento di Scienze MIFT, Università di Messina, Messina, Italy

³¹ Dipartimento Interateneo di Fisica 'M. Merlin' and Sezione INFN, Bari, Italy

³² European Organization for Nuclear Research (CERN), Geneva, Switzerland

³³ Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, Split, Croatia

³⁴ Faculty of Engineering and Science, Western Norway University of Applied Sciences, Bergen, Norway

³⁵ Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, Czech Republic

³⁶ Faculty of Physics, Sofia University, Sofia, Bulgaria

³⁷ Faculty of Science, P.J. Šafárik University, Košice, Slovak Republic

³⁸ Frankfurt Institute for Advanced Studies, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany

³⁹ Fudan University, Shanghai, China

⁴⁰ Gangneung-Wonju National University, Gangneung, Republic of Korea

⁴¹ Gauhati University, Department of Physics, Guwahati, India

⁴² Helmholtz-Institut für Strahlen- und Kernphysik, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, Germany

⁴³ Helsinki Institute of Physics (HIP), Helsinki, Finland

⁴⁴ High Energy Physics Group, Universidad Autónoma de Puebla, Puebla, Mexico

⁴⁵ Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania

⁴⁶ Indian Institute of Technology Bombay (IIT), Mumbai, India

⁴⁷ Indian Institute of Technology Indore, Indore, India

⁴⁸ INFN, Laboratori Nazionali di Frascati, Frascati, Italy

⁴⁹ INFN, Sezione di Bari, Bari, Italy

⁵⁰ INFN, Sezione di Bologna, Bologna, Italy

⁵¹ INFN, Sezione di Cagliari, Cagliari, Italy

⁵² INFN, Sezione di Catania, Catania, Italy

⁵³ INFN, Sezione di Padova, Padova, Italy

⁵⁴ INFN, Sezione di Pavia, Pavia, Italy

⁵⁵ INFN, Sezione di Torino, Turin, Italy

- 56 INFN, Sezione di Trieste, Trieste, Italy
- 57 Inha University, Incheon, Republic of Korea
- 58 Institute for Gravitational and Subatomic Physics (GRASP), Utrecht University/Nikhef, Utrecht, Netherlands
- 59 Institute of Experimental Physics, Slovak Academy of Sciences, Košice, Slovak Republic
- 60 Institute of Physics, Homi Bhabha National Institute, Bhubaneswar, India
- 61 Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic
- 62 Institute of Space Science (ISS), Bucharest, Romania
- 63 Institut für Kernphysik, Johann Wolfgang Goethe-Universität Frankfurt, Frankfurt, Germany
- 64 Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Mexico City, Mexico
- 65 Instituto de Física, Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, Brazil
- 66 Instituto de Física, Universidad Nacional Autónoma de México, Mexico City, Mexico
- 67 iThemba LABS, National Research Foundation, Somerset West, South Africa
- 68 Jeonbuk National University, Jeonju, Republic of Korea
- 69 Johann-Wolfgang-Goethe Universität Frankfurt Institut für Informatik, Fachbereich Informatik und Mathematik, Frankfurt, Germany
- 70 Korea Institute of Science and Technology Information, Daejeon, Republic of Korea
- 71 KTO Karatay University, Konya, Turkey
- 72 Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS-IN2P3, Grenoble, France
- 73 Lawrence Berkeley National Laboratory, Berkeley, CA, United States
- 74 Lund University Department of Physics, Division of Particle Physics, Lund, Sweden
- 75 Nagasaki Institute of Applied Science, Nagasaki, Japan
- 76 Nara Women's University (NWU), Nara, Japan
- 77 National and Kapodistrian University of Athens, School of Science, Department of Physics, Athens, Greece
- 78 National Centre for Nuclear Research, Warsaw, Poland
- 79 National Institute of Science Education and Research, Homi Bhabha National Institute, Jatni, India
- 80 National Nuclear Research Center, Baku, Azerbaijan
- 81 National Research and Innovation Agency - BRIN, Jakarta, Indonesia
- 82 Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
- 83 Nikhef, National institute for subatomic physics, Amsterdam, Netherlands
- 84 Nuclear Physics Group, STFC Daresbury Laboratory, Daresbury, United Kingdom
- 85 Nuclear Physics Institute of the Czech Academy of Sciences, Husinec-Řež, Czech Republic
- 86 Oak Ridge National Laboratory, Oak Ridge, TN, United States
- 87 Ohio State University, Columbus, OH, United States
- 88 Physics department, Faculty of science, University of Zagreb, Zagreb, Croatia
- 89 Physics Department, Panjab University, Chandigarh, India
- 90 Physics Department, University of Jammu, Jammu, India
- 91 Physics Department, University of Rajasthan, Jaipur, India
- 92 Physics Program and International Institute for Sustainability with Knotted Chiral Meta Matter (SKCM2), Hiroshima University, Hiroshima, Japan
- 93 Physikalisches Institut, Eberhard-Karls-Universität Tübingen, Tübingen, Germany
- 94 Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
- 95 Physik Department, Technische Universität München, Munich, Germany
- 96 Politecnico di Bari and Sezione INFN, Bari, Italy
- 97 Research Division and ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
- 98 Saga University, Saga, Japan
- 99 Saha Institute of Nuclear Physics, Homi Bhabha National Institute, Kolkata, India
- 100 School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
- 101 Sección Física, Departamento de Ciencias, Pontificia Universidad Católica del Perú, Lima, Peru
- 102 Stefan Meyer Institut für Subatomare Physik (SMI), Vienna, Austria
- 103 SUBATECH, IMT Atlantique, Nantes Université, CNRS-IN2P3, Nantes, France
- 104 Suranaree University of Technology, Nakhon Ratchasima, Thailand
- 105 Technical University of Košice, Košice, Slovak Republic
- 106 The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Cracow, Poland
- 107 The University of Texas at Austin, Austin, TX, United States
- 108 Universidad Autónoma de Sinaloa, Culiacán, Mexico
- 109 Universidade de São Paulo (USP), São Paulo, Brazil
- 110 Universidade Estadual de Campinas (UNICAMP), Campinas, Brazil
- 111 Universidade Federal do ABC, Santo Andre, Brazil
- 112 University of Cape Town, Cape Town, South Africa
- 113 University of Houston, Houston, TX, United States
- 114 University of Jyväskylä, Jyväskylä, Finland
- 115 University of Kansas, Lawrence, KS, United States
- 116 University of Liverpool, Liverpool, United Kingdom
- 117 University of Science and Technology of China, Hefei, China
- 118 University of South-Eastern Norway, Kongsberg, Norway
- 119 University of Tennessee, Knoxville, TN, United States
- 120 University of the Witwatersrand, Johannesburg, South Africa
- 121 University of Tokyo, Tokyo, Japan
- 122 University of Tsukuba, Tsukuba, Japan
- 123 University Politehnica of Bucharest, Bucharest, Romania
- 124 Université Clermont Auvergne, CNRS/IN2P3, LPC, Clermont-Ferrand, France
- 125 Université de Lyon, CNRS/IN2P3, Institut de Physique des 2 Infinis de Lyon, Lyon, France
- 126 Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France
- 127 Université Paris-Saclay, Centre d'Etudes de Saclay (CEA), IRFU, Département de Physique Nucléaire (DPN), Saclay, France
- 128 Université Paris-Saclay, CNRS/IN2P3, IJCLab, Orsay, France
- 129 Università degli Studi di Foggia, Foggia, Italy
- 130 Università del Piemonte Orientale, Vercelli, Italy
- 131 Università di Brescia, Brescia, Italy
- 132 Variable Energy Cyclotron Centre, Homi Bhabha National Institute, Kolkata, India
- 133 Warsaw University of Technology, Warsaw, Poland
- 134 Wayne State University, Detroit, MI, United States
- 135 Westfälische Wilhelms-Universität Münster, Institut für Kernphysik, Münster, Germany

¹³⁶ Wigner Research Centre for Physics, Budapest, Hungary

¹³⁷ Yale University, New Haven, CT, United States

¹³⁸ Yonsei University, Seoul, Republic of Korea

¹³⁹ Zentrum für Technologie und Transfer (ZTT), Worms, Germany

¹⁴⁰ Affiliated with an institute covered by a cooperation agreement with CERN

¹⁴¹ Affiliated with an international laboratory covered by a cooperation agreement with CERN

^I Deceased.

^{II} Also at: Max-Planck-Institut für Physik, Munich, Germany.

^{III} Also at: Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Bologna, Italy.

^{IV} Also at: Dipartimento DET del Politecnico di Torino, Turin, Italy.

^V Also at: Department of Applied Physics, Aligarh Muslim University, Aligarh, India.

^{VI} Also at: Institute of Theoretical Physics, University of Wrocław, Poland.

^{VII} Also at: An institution covered by a cooperation agreement with CERN.