



Measurement of the inelastic cross section in proton-lead collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV

The CMS Collaboration*

Abstract

The inelastic hadronic cross section in proton-lead collisions at a centre-of-mass energy per nucleon pair of 5.02 TeV is measured with the CMS detector at the LHC. The data sample, corresponding to an integrated luminosity of $\mathcal{L} = 12.6 \pm 0.4 \text{ nb}^{-1}$, has been collected with an unbiased trigger for inclusive particle production. The cross section is obtained from the measured number of proton-lead collisions with hadronic activity produced in the pseudorapidity ranges $3 < \eta < 5$ and/or $-5 < \eta < -3$, corrected for photon-induced contributions, experimental acceptance, and other instrumental effects. The inelastic cross section is measured to be $\sigma_{\text{inel}}(\text{pPb}) = 2061 \pm 3(\text{stat}) \pm 34(\text{syst}) \pm 72(\text{lumi}) \text{ mb}$. Various Monte Carlo generators, commonly used in heavy ion and cosmic ray physics, are found to reproduce the data within uncertainties. The value of $\sigma_{\text{inel}}(\text{pPb})$ is compatible with that expected from the proton-proton cross section at 5.02 TeV scaled up within a simple Glauber approach to account for multiple scatterings in the lead nucleus, indicating that further net nuclear corrections are small.

Published in Physics Letters B as doi:10.1016/j.physletb.2016.06.027.

1 Introduction

The measurement of the inelastic cross section in proton-lead collisions, $\sigma_{\text{inel}}(\text{pPb})$, at a centre-of-mass energy per nucleon pair of 5.02 TeV performed by the CMS experiment at the CERN LHC is presented. The inelastic cross section (also called “particle-production” [1] or “absorption” [2] cross section in previous studies) is defined to include all hadronic events, including contributions from diffractive processes, except those from the quasi-elastic excitation of the lead nucleus—estimated to amount to about 100 mb for the pPb system [3]. Inelastic electromagnetic (photon-proton) collisions are also excluded from the measurement.

While being one of the most inclusive observables in hadronic collisions, the inelastic cross section is one of the least theoretically accessible quantities, as it cannot be determined from first-principles calculations of the theory of the strong interaction, quantum chromodynamics. In proton-proton (pp) and nucleus-nucleus collisions at the LHC, particles produced in hadronic interactions come mostly from the hadronisation of quarks and gluons, either produced in semi-hard scatterings (“minijets”) [4] or emitted at very forward rapidities from “spectator” partons, as well as from soft diffractive processes in “peripheral” interactions. From the measured inelastic proton-proton (or nucleon-nucleon) cross section at a given collision energy, one can theoretically derive the corresponding proton-nucleus and nucleus-nucleus cross sections by means of Glauber [5, 6] or Gribov–Regge [7] multiple-scattering approaches that take into account the known transverse matter profile of nuclei. Key quantities for the experimental comparison between nucleus-nucleus and pp collisions—such as the nuclear overlap function, the number of nucleon-nucleon collisions and of participant nucleons [8, 9]—are also commonly computed through such approaches. Validating the Glauber and Gribov-Regge predictions with proton-nucleus collisions at LHC energies has important implications beyond collider physics. Such approaches constitute crucial ingredients in the Monte Carlo modelling of cosmic ray air showers at the highest energies [10], for which the inelastic cross sections measured in the laboratory must be extrapolated over a wide energy range. In fact, the inelastic proton-air (mostly proton-nitrogen and proton-oxygen) cross section introduces one of the largest uncertainties for air shower simulations [11, 12].

The Glauber multiple-collision model, based on the eikonal limit (i.e. straight-line trajectories of the colliding nucleons), is the simplest and most economical approach often used to derive inclusive proton-nucleus quantities from the pp cross sections and, vice versa, to obtain pp cross sections from the cosmic ray measurements [13]. However, some of the approximations applied in the model—foremost the absence of short-range nucleon correlations [14] and of inelastic screening [15]—impact the computed cross section values. This is observed for fixed-target proton-carbon data [16–20] and estimated for collider [21, 22] as well as ultra-high cosmic ray [13] energies, where corrections to the proton-air cross section of the order of 10% have been obtained. Short-range correlations increase the number of nucleon-nucleon collisions at small impact parameters yielding a larger nucleus-nucleus cross section. On the other hand, screening affects the number of nucleons that are diffractively excited in the multiple collisions but revert back to their ground state before the scattering process is completed, thereby reducing the nuclear cross section. Different implementations of such effects exist in the current hadronic interaction models [15, 23–29]. A measurement of σ_{inel} in pPb collisions at the LHC can test if the precision of the standard Glauber calculation is sufficient, and at which energies corrections to the Glauber approach may become relevant.

2 Experimental setup and Monte Carlo simulations

The measurement presented here is based on pPb data taken with the CMS experiment at the LHC at the beginning of 2013. A detailed description of the apparatus can be found in [30]. The main detector used in this analysis is the hadron forward (HF) calorimeter that covers the pseudorapidity interval $3 < |\eta| < 5$. The calorimeter is composed of quartz fibres in a steel matrix with a 0.175×0.175 segmentation in the azimuthal angle ϕ (in radians) and pseudorapidity η . The quartz fibres pick up the Cherenkov light produced by the charged component of showers. This light is then measured by photodetector tubes. The hadronic and electromagnetic signals of each segment, as derived from fibres of two different lengths and depths, are combined to form a *tower* signal.

The data used in this analysis comprise an integrated luminosity of $\mathcal{L} = 12.6 \pm 0.4 \text{ nb}^{-1}$. This dataset combines the integrated luminosities of the two possible directions of the proton and lead beams: $5.0 \pm 0.2 \text{ nb}^{-1}$ and $7.6 \pm 0.3 \text{ nb}^{-1}$, for the proton beam going respectively in the clockwise (negative η) and anticlockwise (positive η) direction. The events are collected using an unbiased trigger, only requiring the presence of both beams in the interaction point, as determined by the “Beam Pickup Timing for the eXperiments” (BPTX) devices. Detector noise is studied with events that are randomly read out in the absence of both beams in the detector. The luminosity determination technique was calibrated by means of a van der Meer scan [31] for both beam directions independently, with an uncertainty of 3.5% [32].

A Monte Carlo event simulation based on a GEANT4 detector description [33] is used to model the experimental response and derive the reconstruction efficiencies. Different event generators are used to simulate hadronic proton-nucleus collisions. Three models are based on the Gribov-Regge formalism: DPMJET 3.06 [34], EPOS-LHC [25], and QGSJETII-04 [26]; and a fourth one is based on a minijet+Glauber approach: HIJING 1.383 [35]. In addition, particle production from photon-proton (γp) interactions in “ultraperipheral” collisions, at impact parameters larger than the sum of proton and lead radii, needs to be taken into account [36]. Given the large Pb ion charge, and the associated large “equivalent photon flux” of its electromagnetic field [36], inelastic photon-proton collisions result in a non-negligible particle production contribution. Pure photon-photon interactions, mostly producing exclusive electron-positron pairs, and photon-nucleus interactions (where the photon emitted from the proton collides with the Pb ion) have orders-of-magnitude smaller visible cross sections and are neglected. Photon-proton processes are generated with the STARLIGHT programme [37] combined either with DPMJET 3.05 or PYTHIA 6.4.26 [38].

3 Event selection and analysis

In this analysis three types of cross sections are measured: (i) σ_{obs} after removal of noise and correction for pileup, (ii) σ_{vis} after further removal of electromagnetic contributions and translation into a hadron-level quantity, and (iii) σ_{inel} including the final extrapolation to the total inelastic hadronic cross section. Two different approaches are used to determine the number of inelastic events: (1) a **single-arm** event selection that requires a localised calorimetric energy signal above a given threshold in the HF detector either at positive or negative pseudorapidities, and (2) a **double-arm** event selection that requires a localised signal above threshold in both HF detectors. The advantage of using these two event selections is that they have very different sensitivities to diffractive and photon-proton events as well as to detector noise. Denoting by $E_{\text{HF}+}$ ($E_{\text{HF}-}$) the highest energy measured in an HF tower at positive (negative) pseudorapidity,

an event is tagged as a candidate for an inelastic collision if it has a value of

$$E_{\text{HF}} = \begin{cases} \max(E_{\text{HF}+}, E_{\text{HF}-}) & \text{for single-arm selection} \\ \min(E_{\text{HF}+}, E_{\text{HF}-}) & \text{for double-arm selection} \end{cases} \quad (1)$$

above a given threshold.

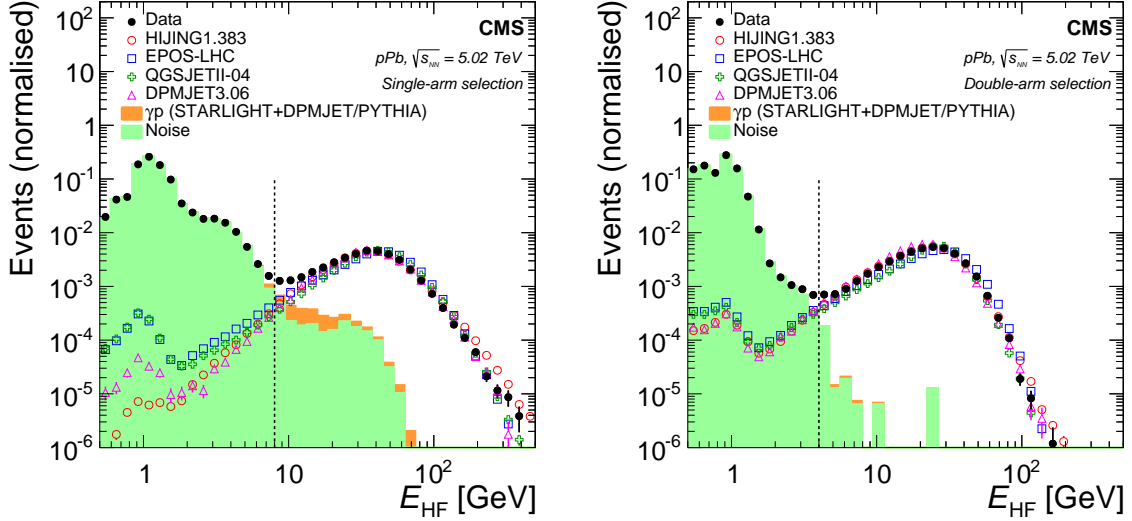


Figure 1: Distribution of the energy deposited in the HF calorimeter (E_{HF}) for the single-arm (left) and double-arm (right) event selections. The data sample, shown exemplarily for one period with stable run conditions, comprises 1.31 nb^{-1} recorded with an unbiased trigger. The contribution from noise is obtained from a random trigger normalised to the same number of triggers as that in the collision data. The average number of photon-proton processes simulated with STARLIGHT+DPMJET and STARLIGHT+PYTHIA is treated as background and stacked on top. Four hadronic interaction models (EPOS, DPMJET, HIJING, and QGSJETII) are overlaid and normalised to the number of data events with $E_{\text{HF}} > 10 \text{ GeV}$, where the contribution from the background is small. The vertical line represents the threshold energy of 8 GeV (4 GeV) for the single-arm (double-arm) selection used in this analysis.

The observed distribution of E_{HF} is well reproduced by the combined hadronic inelastic, photon-proton, and detector noise contributions as shown in the left (right) panel of Fig. 1 for the single-arm (double-arm) selection. The size of the various contributions to the HF energy deposition is determined from data and simulations. The signal is identified as that coming from hadronic collisions whereas the backgrounds arise from electromagnetic photon-proton interactions and detector noise. The expected number of photon-proton collisions is $N_{\gamma p} = f_{\gamma p} \sigma_{\gamma p} \mathcal{L}$, where $f_{\gamma p}$ is the fraction of simulated photon-proton events passing the selection and $\sigma_{\gamma p}$ is the predicted STARLIGHT cross section. The number of misidentified events produced by electronic noise in the detector is $N_{\text{noise}} = N f_{\text{noise}}$, where f_{noise} is the fraction of events read out randomly in the absence of beams that pass the selection criteria, and N is the number of events recorded with the unbiased trigger. The estimate of N_{noise} includes $N_{\text{obs+noise}} = N_{\text{obs}} f_{\text{noise}}$ events that contain also an observed inelastic collision, where N_{obs} is the number of observed inelastic events. The double-counted events are explicitly subtracted from N_{noise} . The uncertainty on N_{noise} is derived from variations in different data-taking periods. The background induced by beam-gas collisions is found to be negligible deduced from the fraction of events selected with the trigger indicating the presence of a single beam in the interaction point.

Of the number of inelastic hadronic collisions, N_{inel} , the ones that are observed by the detector and pass the event selection are defined as N_{had} . The purity of the event selection is $N_{\text{had}} / (N_{\text{had}} + N_{\gamma p} + N_{\text{noise}})$, and the acceptance is given by the ratio $\epsilon_{\text{acc}} = N_{\text{had}} / N_{\text{inel}}$. Both the purity and the acceptance depend on the energy threshold used for the selection. Higher purity is achieved for the double-arm selection, since photon-proton interactions lead to a typical final state where most of the secondary products are asymmetrically emitted towards the direction of the proton beam. Noise events are also suppressed by the coincidence requirement. The acceptance is in general smaller for the double-arm selection due to the smaller chance of selecting diffractive events characterised by large rapidity gaps devoid of activity in one or both HF sides.

The dependence of ϵ_{acc} on the HF tower energy threshold is shown in Fig. 2. For the single-arm selection the working point is chosen to be $E_{\text{HF}} > 8 \text{ GeV}$. This value is the result of a compromise between acceptance (about 93–94%) and contamination, while the probability to have a tower above the threshold does not depend much on the beam direction. The double-arm selection uses $E_{\text{HF}} > 4 \text{ GeV}$ yielding 99% purity and 91% acceptance. The value ϵ_{acc} for

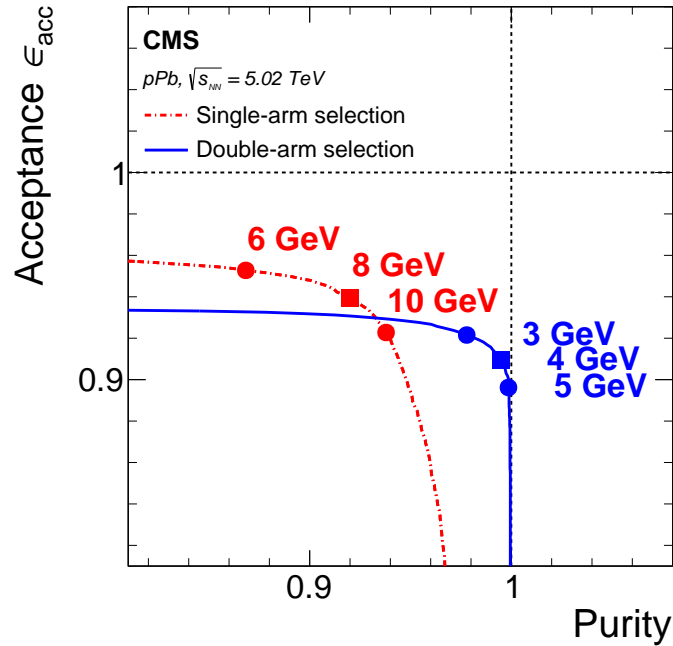


Figure 2: Acceptance versus purity of the two event selections, as derived from the EPOS and QGSJETII generators. The symbols indicate different values of the E_{HF} thresholds. The chosen thresholds are marked with squares.

a specific E_{HF} threshold is determined by averaging over the results of the EPOS and QGSJETII models. The results of HIJING and DPMJET, which do not include nuclear effects for diffraction, are not considered for this purpose. Indeed, we have verified that both latter models are unable to describe the very-forward energy spectra measured with the CASTOR detector ($-6.6 < \eta < -5.2$) in events with large rapidity gaps, which are particularly sensitive to diffractive interactions.

The uncertainties on the ϵ_{acc} and $N_{\gamma p}$ values are estimated from the maximum absolute differences obtained from the results of different event generators, averaged over a wide E_{HF} interval between 2 and 10 GeV. The uncertainties on ϵ_{acc} are 0.005 (0.014) and of $N_{\gamma p} / \mathcal{L}$ are 11 mb (0.05 mb) for the single-arm (double-arm) event selections.

In this analysis no vertex reconstruction is performed and the impact of contributions from additional pileup (PU) collisions recorded in any given event is consistently evaluated with the HF detector. The number of simultaneous collisions is Poisson-distributed with an expectation value corresponding to the interaction probability λ . If one collision is selected with probability ϵ_{acc} , then i simultaneous collisions are selected with probability $P_i \approx 1 - (1 - \epsilon_{\text{acc}})^i$. The approximation assumed in the equation, which does not account for energy deposits of multiple events in the HF towers, was verified to be valid by means of a toy Monte Carlo simulation.

The number of collisions is then corrected with the factor $f_{\text{PU}} = \epsilon_{\text{acc}} \lambda / \sum_{i=1}^{\infty} P_i \text{Poisson}(i; \lambda)$. The interaction probability λ , which amounts to 2–8% depending on the data-taking period, is calculated recursively from the ratio of the number of inelastic events to the number of unbiased triggers. The pileup correction increases the measured cross section by 2% for both event selections, and introduces an uncertainty on the final pPb cross section that is smaller than 0.1%.

To facilitate the direct comparison of the results to model predictions, detector level quantities, such as E_{HF} , are translated to hadron-level quantities. For this purpose, p_{HF} is defined equivalently to Eq. (1) but replacing E_{HF} by the largest absolute value among the momenta, $|\vec{p}|$, of all generated final-state particles (with lifetimes above 1 cm/c), within the pseudorapidity intervals of the HF calorimeters ($3 < |\eta| < 5$), excluding muons and neutrinos. A correction factor c_{vis} , obtained from simulations, is used to translate the measured cross section into a hadron-level quantity, defined by the ratio of the number of visible events, which fulfil a given requirement on p_{HF} , to the number of observed events, which pass the selection on E_{HF} . Thus, c_{vis} is larger than unity for requiring $p_{\text{HF}} > 0$, but will approach zero for very high thresholds. The threshold can be chosen freely, and for the present analysis the requirement on the minimal value of p_{HF} is chosen such that the fractions of events passing this selection and passing that on E_{HF} are equal. The factor c_{vis} then becomes equal to unity and has no numerical effect on the central value of the derived cross section. This procedure leads to the choice of selecting events that fulfil the requirement $p_{\text{HF}} > 21.3 \text{ GeV}/c$ ($11.3 \text{ GeV}/c$) for the single-arm (double-arm) analysis. For the chosen thresholds, the mean of the c_{vis} values of all four hadronic interaction models is unity and the slight dependence on models is taken into account as a systematic uncertainty on c_{vis} equal to the standard deviation of the four values.

The values of the acceptance, backgrounds, and correction factors are summarised in Table 1.

Table 1: Central values and uncertainties for the two event selections for noise cross section contribution ($N_{\text{noise}}/\mathcal{L}$) and the fraction of noise events (f_{noise}) as derived from data. Additionally, the quantities acceptance (ϵ_{acc}), electromagnetic cross section contribution ($N_{\gamma\text{p}}/\mathcal{L}$), and hadron-level correction factor (c_{vis}) as derived from simulations are listed.

Selection	$N_{\text{noise}}/\mathcal{L}$ [mb]	f_{noise}	ϵ_{acc}	$N_{\gamma\text{p}}/\mathcal{L}$ [mb]	c_{vis}
Single-arm	102 ± 25	$(2.0 \pm 0.5) \times 10^{-3}$	0.939 ± 0.005	63 ± 11	1.000 ± 0.004
Double-arm	9 ± 3	$(1.8 \pm 0.8) \times 10^{-4}$	0.910 ± 0.014	0.33 ± 0.05	1.000 ± 0.002

The number of observed inelastic events, N_{obs} , is derived from the number of events passing the event selection, N_{sel} , and is corrected for noise (N_{noise}), double counting ($N_{\text{obs+noise}}$), and pileup (f_{PU}). Dividing this number by the integrated luminosity yields the *observed* cross section:

$$\sigma_{\text{obs}} = \frac{N_{\text{obs}}}{\mathcal{L}} = (N_{\text{sel}} - N_{\text{noise}} + N_{\text{obs+noise}}) \frac{f_{\text{PU}}}{\mathcal{L}}. \quad (2)$$

Using the relation $N_{\text{obs+noise}} = N_{\text{obs}} f_{\text{noise}}$ one obtains

$$\sigma_{\text{obs}} = \frac{1}{\mathcal{L}} \frac{N_{\text{sel}} - N_{\text{noise}}}{1/f_{\text{PU}} - f_{\text{noise}}}. \quad (3)$$

The *visible* cross section for hadronic collisions is derived by subtracting the photon-proton contamination and applying the correction factor c_{vis} . Its numerical value is, by definition, equal to the part of the observed cross section related to hadronic collisions:

$$\sigma_{\text{vis}} = \frac{1}{\mathcal{L}} \frac{N_{\text{sel}} - N_{\text{noise}} - N_{\gamma\text{p}}}{1/f_{\text{PU}} - f_{\text{noise}}} c_{\text{vis}}. \quad (4)$$

The *inelastic* cross section is obtained by correcting for the limited detector acceptance (ϵ_{acc}):

$$\sigma_{\text{inel}} = \frac{1}{\mathcal{L}} \frac{N_{\text{sel}} - N_{\text{noise}} - N_{\gamma\text{p}}}{1/f_{\text{PU}} - f_{\text{noise}}} \frac{1}{\epsilon_{\text{acc}}}. \quad (5)$$

The ratio of the visible hadronic cross section obtained with the single-arm selection to the one obtained with the double-arm selection is sensitive to the fraction of diffractive pPb events. The measured value of this ratio allows one to constrain the diffractive cross section, σ_{diff} , in the models. In order to be compatible within 2 standard deviations of the data, the EPOS diffractive cross section cannot be scaled up or down by more than $\pm 13\%$ from its default value, while for QGSJETII those limits are $\pm 20\%$. This propagates into an $\epsilon_{\text{acc}}(\sigma_{\text{diff}})$ uncertainty on σ_{inel} , conservatively assumed to be symmetric, of 0.8% (1.1%). For this and the following uncertainties, the first number is related to the single-arm selection and the bracketed one to the double-arm selection. The model-dependence of the acceptance corrections results in an uncertainty for $\epsilon_{\text{acc}}(\text{models})$ of 0.5% (1.6%) for the two selections, respectively.

Since less than half of the diffractive events, mostly with a high-mass diffractive system, pass the hadron-level selection, the uncertainty on c_{vis} is smaller than that on ϵ_{acc} . The 1 standard deviation differences found among the four hadronic interaction models on the hadron-level correction, c_{vis} , propagate into uncertainties on σ_{vis} of 0.4% (0.2%) for the single-arm (double-arm) selection. The subtraction of photon-proton events (with the $N_{\gamma\text{p}}$ uncertainty shown in Table 1), results in an uncertainty of 0.6% ($< 0.1\%$) on σ_{inel} and σ_{vis} . The uncertainty on N_{noise} propagates into a 1.3% (0.2%) uncertainty in the final cross sections. The effect on the event selection of the radiation damage in the HF fibres is assessed by rescaling the signals of the simulated HF response to match data in segments of pseudorapidity. The rescaling factors are calculated using the average response produced by EPOS, HIJING, and QGSJETII. These scaling factors are found to be consistent with the observed radiation damage of HF and range from 1 to 0.67, depending on pseudorapidity. The amount of radiation damage is estimated from a comparison of $dE/d\eta$ distributions measured in proton-proton collisions at $\sqrt{s} = 2.76$ TeV recorded in 2013 and in 2010. The systematic uncertainty induced on the cross section by this approach is estimated by repeating the measurement without the radiation damage correction, which introduces an effect of 1.7% (0.8%) on the cross section. As a further check of the HF tower energy resolution, the cross sections are computed by increasing the selection thresholds to $E_{\text{HF}} > 10$ GeV (5 GeV). To account for both effects, a systematic uncertainty on the cross section of 0.6% (0.4%) is added. The cross sections measured for the two beam directions are found to be consistent. Consequently, no dedicated systematic uncertainty is assigned to this effect.

All the different sources of uncertainty of the measurement are listed in Table 2 for the single-arm and double-arm event selections. The three derived cross sections have different systematic uncertainties since not all contributions are relevant to each of them. For σ_{inel} , all uncertainties but the one due to the hadron-level correction contribute. The total uncorrelated systematic uncertainty is therefore 2.5% (2.2%) for the single-arm (double-arm) selection. For σ_{vis} , the dominant uncertainty is due to the hadron-level correction instead of the correction

Table 2: List of the systematic uncertainties, propagated into the final pPb cross sections, for the two event selections.

Source of uncertainty	Single-arm	Double-arm
Noise subtraction (N_{noise})	1.3%	0.2%
Pileup correction (f_{PU})	<0.1%	<0.1%
Acceptance ($\epsilon_{\text{acc}}(\text{models})$)	0.5%	1.6%
Acceptance ($\epsilon_{\text{acc}}(\sigma_{\text{diff}})$)	0.8%	1.1%
Hadron-level correction (c_{vis})	0.4%	0.2%
Photon-proton subtraction ($N_{\gamma\text{p}}$)	0.6%	<0.1%
Detector simulation	1.7%	0.8%
HF energy thresholds	0.6%	0.4%
Integrated luminosity (\mathcal{L})	3.5%	3.5%

for ϵ_{acc} . The value of the uncertainty is therefore reduced to 2.3% (0.9%). The uncertainties for detector simulation and photon-proton correction do not contribute to σ_{obs} and, hence, its uncertainty becomes 1.4% (0.5%). For all cross sections, a (dominant) integrated luminosity uncertainty of 3.5% is added. The main contributions to the latter arise from the model used to describe the beam profile, the length scale of the beam displacement, and the bunch-to-bunch variations [32].

4 Results and summary

The measured cross sections for the single-arm and double-arm event selections are listed in Table 3, compared to the predictions of the hadronic interaction models DPMJET, EPOS, and QGSJETII. Due to the different acceptance, the extrapolations from the hadron-level to the inelastic cross section are of different magnitude, but the models reproduce well the approximately 65 mb difference between the two selections. The values of the inelastic cross sections obtained from the single-arm and double-arm methods agree well within the uncertainties.

Table 3: Summary of cross sections obtained from the two different event selections. The acceptance definition for σ_{vis} is based on the production of stable particles within $3 < |\eta| < 5$ with momentum $p_{\text{HF}} > 21.3 \text{ GeV}/c$ (11.3 GeV/c) for the single-arm (double-arm) event selections.

	Selection	σ_{obs} (mb)	σ_{vis} (mb)	σ_{inel} (mb)
Data	Single-arm	2003±76	1937±82	2063±89
	Double-arm	1873±66	1872±68	2059±85
EPOS-LHC	Single-arm	—	1947	2082
	Double-arm	—	1883	
QGSJETII-04	Single-arm	—	2059	2181
	Double-arm	—	1998	
DPMJET 3.06	Single-arm	—	2116	2166
	Double-arm	—	2055	

The final σ_{inel} value is obtained by taking the weighted average of the measured values in the two event selections. The statistical uncertainties and the uncertainty on the luminosity are correlated between the selections. The degree of correlation among the remaining systematic uncertainties is much smaller and they are taken as uncorrelated. This yields a final result for the inelastic hadronic cross section of

$$\sigma_{\text{inel}}(\text{pPb}) = 2061 \pm 3 (\text{stat}) \pm 34 (\text{syst}) \pm 72 (\text{lumi}) \text{ mb.}$$

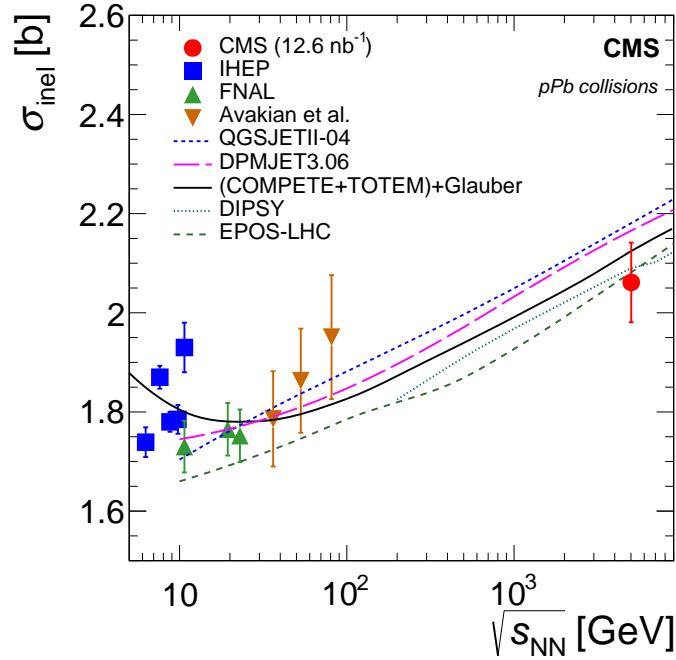


Figure 3: Inelastic hadronic cross sections for pPb collisions as a function of the centre-of-mass energy. The measurement described here (circle, with error bars obtained from the quadratic sum of all uncertainties) is compared to lower energy data (squares and triangles) [2, 39, 40] and to different model predictions (curves).

This result is shown in Fig. 3 compared to other measurements at different centre-of-mass energies and to various theoretical predictions. A pPb cross section was also measured by the ALICE Collaboration, amounting to 2090–2120 mb with an uncertainty of 70 mb [41]. A direct comparison of this observed cross section to the one measured in the present analysis is not possible due to the unknown to us ALICE detector acceptance and possible contamination from noise and photon-proton interactions.

The inelastic cross section measured by the CMS experiment is compared to the Glauber-model prediction (solid curve in Fig. 3) obtained using a pp inelastic cross section at $\sqrt{s} = 5.02$ TeV of 70.0 ± 1.5 mb, derived from the COMPETE parametrisation [42] including the measurement of the TOTEM Collaboration at $\sqrt{s} = 7$ TeV [43] (where the assigned uncertainty is that measured by the latter). The Glauber calculation yields 2130 ± 40 mb and is compatible with the measurement presented here indicating that effects neglected by the calculation (such as nucleon correlations and screening) are either small or approximately cancel out. The experimental result is also consistent with the prediction of the DIPSY model [44, 45] based on a dipole-model approach including parton saturation and multiple-scattering. Among the Gribov–Regge models, the EPOS prediction is compatible with the measurement within uncertainties, whereas DPMJET and QGSJETII predict a value more than 1 standard deviation above the data, with a larger discrepancy appearing for the σ_{vis} cross sections (Table 3). The EPOS and QGSJETII models are commonly used for cosmic ray air shower simulations. Thus, at the corresponding cosmic ray proton energies of $E_{\text{cr}} = s/(2m_p) = 10^{16.1}$ eV, where m_p is the mass of the proton, there are no indications for data-model deviations above $\approx 5\%$ in the proton-lead collisions studied here. Note, however, that our measurement deals with an ion much heavier than those involved in proton-air interactions. Corrections to the Glauber model are possibly larger in the latter case [3, 13]. In summary, the measurement of the cross sections in pPb collisions presented

here is the first such fully corrected measurement at multi-TeV energies and, thus, provides important constraints on hadronic interaction models commonly used in high-energy heavy ion and cosmic ray physics.

Acknowledgments

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centres and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWFW and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES and CSF (Croatia); RPF (Cyprus); MoER, ERC IUT and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); LAS (Lithuania); MOE and UM (Malaysia); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS and RFBR (Russia); MESTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU and SFFR (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

Individuals have received support from the Marie-Curie programme and the European Research Council and EPLANET (European Union); the Leventis Foundation; the A. P. Sloan Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Council of Science and Industrial Research, India; the HOMING PLUS programme of the Foundation for Polish Science, cofinanced from European Union, Regional Development Fund; the OPUS programme of the National Science Center (Poland); the Compagnia di San Paolo (Torino); the Consorzio per la Fisica (Trieste); MIUR project 20108T4XTM (Italy); the Thalys and Aristeia programmes cofinanced by EU-ESF and the Greek NSRF; the National Priorities Research Program by Qatar National Research Fund; the Rachadapisek Sompot Fund for Postdoctoral Fellowship, Chulalongkorn University (Thailand); and the Welch Foundation, contract C-1845.

References

- [1] R. Engel, T. K. Gaisser, P. Lipari, and T. Stanev, "Proton proton cross-section at \sqrt{s} similar to 30 TeV", *Phys. Rev. D* **58** (1998) 014019, doi:10.1103/PhysRevD.58.014019, arXiv:hep-ph/9802384.
- [2] A. S. Carroll et al., "Absorption cross-sections of π^\pm , K^\pm , p and \bar{p} on nuclei between 60 GeV/c and 280 GeV/c", *Phys. Lett. B* **80** (1979) 319, doi:10.1016/0370-2693(79)90226-0.

- [3] M. Alvioli et al., “Diffraction on nuclei: effects of nucleon correlations”, *Phys. Rev. C* **81** (2010) 025204, doi:10.1103/PhysRevC.81.025204, arXiv:0911.1382.
- [4] I. Sarcevic, S. D. Ellis, and P. Carruthers, “QCD minijet cross-sections”, *Phys. Rev. D* **40** (1989) 1446, doi:10.1103/PhysRevD.40.1446.
- [5] R. J. Glauber, “Cross-sections in deuterium at high-energies”, *Phys. Rev.* **100** (1955) 242, doi:10.1103/PhysRev.100.242.
- [6] R. J. Glauber and G. Matthiae, “High-energy scattering of protons by nuclei”, *Nucl. Phys. B* **21** (1970) 135, doi:10.1016/0550-3213(70)90511-0.
- [7] V. N. Gribov, “A reggeon diagram technique”, *Sov. Phys. JETP* **26** (196) 414.
- [8] D. d’Enterria, “Hard scattering cross-sections at LHC in the Glauber approach: From pp to pA and AA collisions”, (2003). arXiv:nucl-ex/0302016. Originally published in CERN Yellow Report on “Hard probes in heavy ion collisions at the LHC”, (2003).
- [9] M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, “Glauber modeling in high energy nuclear collisions”, *Ann. Rev. Nucl. Part. Sci.* **57** (2007) 205, doi:10.1146/annurev.nucl.57.090506.123020, arXiv:nucl-ex/0701025.
- [10] D. d’Enterria et al., “Constraints from the first LHC data on hadronic event generators for ultra-high energy cosmic-ray physics”, *Astropart. Phys.* **35** (2011) 98, doi:10.1016/j.astropartphys.2011.05.002, arXiv:1101.5596.
- [11] R. Ulrich, R. Engel, and M. Unger, “Hadronic multiparticle production at ultra-high energies and extensive air showers”, *Phys. Rev. D* **83** (2011) 054026, doi:10.1103/PhysRevD.83.054026, arXiv:1010.4310.
- [12] R. D. Parsons, C. Bleve, S. S. Ostapchenko, and J. Knapp, “Systematic uncertainties in air shower measurements from high-energy hadronic interaction models”, *Astropart. Phys.* **34** (2011) 832, doi:10.1016/j.astropartphys.2011.02.007, arXiv:1102.4603.
- [13] Pierre Auger Collaboration, “Measurement of the proton-air cross-section at $\sqrt{s} = 57$ TeV with the Pierre Auger Observatory”, *Phys. Rev. Lett.* **109** (2012) 062002, doi:10.1103/PhysRevLett.109.062002, arXiv:1208.1520.
- [14] L. L. Frankfurt, M. I. Strikman, D. B. Day, and M. Sargsian, “Evidence for short range correlations from high Q^2 (e, e') reactions”, *Phys. Rev. C* **48** (1993) 2451, doi:10.1103/PhysRevC.48.2451.
- [15] M. L. Good and W. D. Walker, “Diffraction dissociation of beam particles”, *Phys. Rev.* **120** (1960) 1857, doi:10.1103/PhysRev.120.1857.
- [16] SELEX Collaboration, “Total cross section measurements with π^- , Σ^- and protons on nuclei and nucleons around 600 GeV/c”, *Nucl. Phys. B* **579** (2000) 277, doi:10.1016/S0550-3213(00)00204-2, arXiv:hep-ex/9910052.
- [17] G. Bellettini et al., “Proton-nuclei cross sections at 20 GeV”, *Nucl. Phys.* **79** (1966) 609, doi:10.1016/0029-5582(66)90267-7.
- [18] R. P. V. Murthy et al., “Neutron total cross-sections on nuclei at Fermilab energies”, *Nucl. Phys. B* **92** (1975) 269, doi:10.1016/0550-3213(75)90182-0.

- [19] J. Engler et al., “Neutron-nucleus total cross-sections between 8 GeV/c and 21 GeV/c”, *Phys. Lett. B* **32** (1970) 716, doi:10.1016/0370-2693(70)90453-3.
- [20] A. Babaev et al., “The neutron total cross section measurements on protons and nuclei in the energy range of 28-54 GeV”, *Phys. Lett. B* **51** (1974) 501, doi:10.1016/0370-2693(74)90321-9.
- [21] C. Ciofi degli Atti et al., “Number of collisions in the Glauber model and beyond”, *Phys. Rev. C* **84** (2011) 025205, doi:10.1103/PhysRevC.84.025205, arXiv:1105.1080.
- [22] M. Alvioli et al., “Nucleon momentum distributions, their spin-isospin dependence and short-range correlations”, *Phys. Rev. C* **87** (2013) 034603, doi:10.1103/PhysRevC.87.034603, arXiv:1211.0134.
- [23] N. N. Kalmykov and S. S. Ostapchenko, “The nucleus-nucleus interaction, nuclear fragmentation, and fluctuations of extensive air showers”, *Phys. Atom. Nucl.* **56** (1993) 346.
- [24] V. Guzey and M. Strikman, “Proton-nucleus scattering and cross section fluctuations at RHIC and LHC”, *Phys. Lett. B* **633** (2006) 245, doi:10.1016/j.physletb.2008.04.010, arXiv:hep-ph/0505088.
- [25] K. Werner, F.-M. Liu, and T. Pierog, “Parton ladder splitting and the rapidity dependence of transverse momentum spectra in deuteron-gold collisions at RHIC”, *Phys. Rev. C* **74** (2006) 044902, doi:10.1103/PhysRevC.74.044902, arXiv:hep-ph/0506232.
- [26] S. Ostapchenko, “Total and diffractive cross sections in enhanced Pomeron scheme”, *Phys. Rev. D* **81** (2010) 114028, doi:10.1103/PhysRevD.81.114028, arXiv:1003.0196.
- [27] S. Ostapchenko, “Monte Carlo treatment of hadronic interactions in enhanced Pomeron scheme: I. QGSJET-II model”, *Phys. Rev. D* **83** (2011) 014018, doi:10.1103/PhysRevD.83.014018, arXiv:1010.1869.
- [28] L. Frankfurt, G. A. Miller, and M. Strikman, “Evidence for color fluctuations in hadrons from coherent nuclear diffraction”, *Phys. Rev. Lett.* **71** (1993) 2859, doi:10.1103/PhysRevLett.71.2859, arXiv:hep-ph/9309285.
- [29] D. R. Harrington, “Triple pomeron matrix model for dispersive corrections to nucleon nucleus total cross-section”, *Phys. Rev. C* **67** (2003) 064904, doi:10.1103/PhysRevC.67.064904, arXiv:nucl-th/0206032.
- [30] CMS Collaboration, “The CMS experiment at the CERN LHC”, *JINST* **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
- [31] S. van der Meer, “Calibration of the effective beam height in the ISR”, Technical Report CERN-ISR-PO-68-31. ISR-PO-68-31, CERN, 1968.
- [32] CMS Collaboration, “Luminosity calibration for the 2013 proton-lead and proton-proton data taking”, CMS Physics Analysis Summary CMS-PAS-LUM-13-002, CERN, 2014.
- [33] GEANT4 Collaboration, “GEANT4—a simulation toolkit”, *Nucl. Instrum. Meth. A* **506** (2003) 250, doi:10.1016/S0168-9002(03)01368-8.

- [34] F. W. Bopp, J. Ranft, R. Engel, and S. Roesler, "Antiparticle to particle production ratios in hadron-hadron and d-Au collisions in the DPMJET-III Monte Carlo", *Phys. Rev. C* **77** (2008) 014904, doi:10.1103/PhysRevC.77.014904, arXiv:hep-ph/0505035.
- [35] X.-N. Wang and M. Gyulassy, "HIJING: A Monte Carlo model for multiple jet production in pp, pA and AA collisions", *Phys. Rev. D* **44** (1991) 3501, doi:10.1103/PhysRevD.44.3501.
- [36] A. J. Baltz et al., "The physics of ultraperipheral collisions at the LHC", *Phys. Rept.* **458** (2008) 1, doi:10.1016/j.physrep.2007.12.001, arXiv:0706.3356.
- [37] O. Djuvsland and J. Nystrand, "Single and double photonuclear excitations in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at the CERN Large Hadron Collider", *Phys. Rev. C* **83** (2011) 041901, doi:10.1103/PhysRevC.83.041901, arXiv:1011.4908.
- [38] T. Sjöstrand, S. Mrenna, and P. Skands, "PYTHIA 6.4 physics and manual", *JHEP* **05** (2006) 026, doi:10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.
- [39] S. P. Denisov et al., "Absorption cross-sections for pions, kaons, protons and anti-protons on complex nuclei in the 6 to 60 GeV/c momentum range", *Nucl. Phys. B* **61** (1973) 62, doi:10.1016/0550-3213(73)90351-9.
- [40] V. V. Avakian et al., "Determining inelastic interaction cross-sections for nucleons and pions incident on carbon and lead nuclei at 0.5 TeV–5 TeV", *Bull. Acad. Sci. USSR, Phys. Ser.* **50** (1986) 4.
- [41] ALICE Collaboration, "Measurement of visible cross sections in proton-lead collisions at $\sqrt{s_{NN}} = 5.02$ TeV in van der Meer scans with the ALICE detector", *JINST* **9** (2014) P11003, doi:10.1088/1748-0221/9/11/P11003, arXiv:1405.1849.
- [42] COMPETE Collaboration, "Benchmarks for the forward observables at RHIC, the Tevatron Run II and the LHC", *Phys. Rev. Lett.* **89** (2002) 201801, doi:10.1103/PhysRevLett.89.201801, arXiv:hep-ph/0206172.
- [43] TOTEM Collaboration, "Luminosity-independent measurements of total, elastic and inelastic cross-sections at $\sqrt{s} = 7$ TeV", *Europhys. Lett.* **101** (2013) 21004, doi:10.1209/0295-5075/101/21004.
- [44] E. Avsar, G. Gustafson, and L. Lonnblad, "Energy conservation and saturation in small-x evolution", *JHEP* **07** (2005) 062, doi:10.1088/1126-6708/2005/07/062, arXiv:hep-ph/0503181.
- [45] C. Flensburg, G. Gustafson, and L. Lonnblad, "Inclusive and exclusive observables from dipoles in high energy collisions", *JHEP* **08** (2011) 103, doi:10.1007/JHEP08(2011)103, arXiv:1103.4321.

A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia

V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, M. Flechl, M. Friedl, R. Frühwirth¹, V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler¹, V. Knünz, A. König, M. Krammer¹, I. Krätschmer, D. Liko, T. Matsushita, I. Mikulec, D. Rabady², B. Rahbaran, H. Rohringer, J. Schieck¹, R. Schöfbeck, J. Strauss, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz¹

National Centre for Particle and High Energy Physics, Minsk, Belarus

V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium

S. Alderweireldt, T. Cornelis, E.A. De Wolf, X. Janssen, A. Knutsson, J. Lauwers, S. Luyckx, S. Ochesanu, R. Rougny, M. Van De Klundert, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeek

Vrije Universiteit Brussel, Brussel, Belgium

S. Abu Zeid, F. Blekman, J. D'Hondt, N. Daci, I. De Bruyn, K. Deroover, N. Heracleous, J. Keaveney, S. Lowette, L. Moreels, A. Olbrechts, Q. Python, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Van Parijs

Université Libre de Bruxelles, Bruxelles, Belgium

P. Barria, C. Caillol, B. Clerboux, G. De Lentdecker, H. Delannoy, G. Fasanella, L. Favart, A.P.R. Gay, A. Grebenyuk, T. Lenzi, A. Léonard, T. Maerschalk, A. Marinov, L. Perniè, A. Randle-conde, T. Reis, T. Seva, C. Vander Velde, P. Vanlaer, R. Yonamine, F. Zenoni, F. Zhang³

Ghent University, Ghent, Belgium

K. Beernaert, L. Benucci, A. Cimmino, S. Crucy, D. Dobur, A. Fagot, G. Garcia, M. Gul, J. Mccartin, A.A. Ocampo Rios, D. Poyraz, D. Ryckbosch, S. Salva, M. Sigamani, N. Strobbe, M. Tytgat, W. Van Driessche, E. Yazgan, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium

S. Basegmez, C. Beluffi⁴, O. Bondu, S. Brochet, G. Bruno, R. Castello, A. Caudron, L. Ceard, G.G. Da Silveira, C. Delaere, D. Favart, L. Forthomme, A. Giammanco⁵, J. Hollar, A. Jafari, P. Jez, M. Komm, V. Lemaître, A. Mertens, C. Nuttens, L. Perrini, A. Pin, K. Piotrkowski, A. Popov⁶, L. Quertenmont, M. Selvaggi, M. Vidal Marono

Université de Mons, Mons, Belgium

N. Beliy, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

W.L. Aldá Júnior, G.A. Alves, L. Brito, M. Correa Martins Junior, C. Hensel, C. Mora Herrera, A. Moraes, M.E. Pol, P. Rebello Teles

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

E. Belchior Batista Das Chagas, W. Carvalho, J. Chinellato⁷, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, L.M. Huertas Guativa, H. Malbouisson, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, A. Santoro, A. Sznajder, E.J. Tonelli Manganote⁷, A. Vilela Pereira

Universidade Estadual Paulista ^a, Universidade Federal do ABC ^b, São Paulo, Brazil

S. Ahuja^a, C.A. Bernardes^b, A. De Souza Santos^b, S. Dogra^a, T.R. Fernandez Perez Tomei^a, E.M. Gregores^b, P.G. Mercadante^b, C.S. Moon^{a,8}, S.F. Novaes^a, Sandra S. Padula^a, D. Romero Abad, J.C. Ruiz Vargas

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

A. Aleksandrov, V. Genchev[†], R. Hadjiiska, P. Iaydjiev, S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

University of Sofia, Sofia, Bulgaria

A. Dimitrov, I. Glushkov, L. Litov, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China

M. Ahmad, J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, T. Cheng, R. Du, C.H. Jiang, R. Plestina⁹, F. Romeo, S.M. Shaheen, J. Tao, C. Wang, Z. Wang, H. Zhang

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

C. Asawatrangkuldee, Y. Ban, Q. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, Z. Xu, W. Zou

Universidad de Los Andes, Bogota, Colombia

C. Avila, A. Cabrera, L.F. Chaparro Sierra, C. Florez, J.P. Gomez, B. Gomez Moreno, J.C. Sanabria

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

N. Godinovic, D. Lelas, D. Polic, I. Puljak, P.M. Ribeiro Cipriano

University of Split, Faculty of Science, Split, Croatia

Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

V. Brigljevic, K. Kadija, J. Luetic, S. Micanovic, L. Sudic

University of Cyprus, Nicosia, Cyprus

A. Attikis, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis, H. Rykaczewski

Charles University, Prague, Czech Republic

M. Bodlak, M. Finger¹⁰, M. Finger Jr.¹⁰

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt

A.A. Abdelalim¹¹, A. Mahrous¹², A. Radi^{13,14}

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

B. Calpas, M. Kadastik, M. Murumaa, M. Raidal, A. Tiko, C. Veelken

Department of Physics, University of Helsinki, Helsinki, Finland

P. Eerola, J. Pekkanen, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

J. Härkönen, V. Karimäki, R. Kinnunen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, L. Wendland

Lappeenranta University of Technology, Lappeenranta, Finland

J. Talvitie, T. Tuuva

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France

M. Besancon, F. Couderc, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, C. Favaro, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, M. Machet, J. Malcles, J. Rander, A. Rosowsky, M. Titov, A. Zghiche

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France

I. Antropov, S. Baffioni, F. Beaudette, P. Busson, L. Cadamuro, E. Chapon, C. Charlot, T. Dahms, O. Davignon, N. Filipovic, A. Florent, R. Granier de Cassagnac, S. Lisniak, L. Mastrolorenzo, P. Miné, I.N. Naranjo, M. Nguyen, C. Ochando, G. Ortona, P. Paganini, S. Regnard, R. Salerno, J.B. Sauvan, Y. Sirois, T. Strebler, Y. Yilmaz, A. Zabi

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

J.-L. Agram¹⁵, J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, M. Buttignol, E.C. Chabert, N. Chanon, C. Collard, E. Conte¹⁵, X. Coubez, J.-C. Fontaine¹⁵, D. Gelé, U. Goerlach, C. Goetzmann, A.-C. Le Bihan, J.A. Merlin², K. Skovpen, P. Van Hove

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France

S. Gadrat

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France

S. Beauceron, C. Bernet, G. Boudoul, E. Bouvier, C.A. Carrillo Montoya, J. Chasserat, R. Chierici, D. Contardo, B. Courbon, P. Depasse, H. El Mamouni, J. Fan, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, F. Lagarde, I.B. Laktineh, M. Lethuillier, L. Mirabito, A.L. Pequegnot, S. Perries, J.D. Ruiz Alvarez, D. Sabes, L. Sgandurra, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret, H. Xiao

Georgian Technical University, Tbilisi, Georgia

T. Toriashvili¹⁶

Tbilisi State University, Tbilisi, Georgia

I. Bagaturia¹⁷

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany

C. Autermann, S. Beranek, M. Edelhoff, L. Feld, A. Heister, M.K. Kiesel, K. Klein, M. Lipinski, A. Ostapchuk, M. Preuten, F. Raupach, S. Schael, J.F. Schulte, T. Verlage, H. Weber, B. Wittmer, V. Zhukov⁶

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany

M. Ata, M. Brodski, E. Dietz-Laursonn, D. Duchardt, M. Endres, M. Erdmann, S. Erdweg, T. Esch, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, S. Knutzen, P. Kreuzer, M. Merschmeyer, A. Meyer, P. Millet, M. Olschewski, K. Padeken, P. Papacz, T. Pook, M. Radziej, H. Reithler, M. Rieger, F. Scheuch, L. Sonnenschein, D. Teyssier, S. Thüer

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany

V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Künsken, J. Lingemann², A. Nehr Korn, A. Nowack, I.M. Nugent, C. Pistone, O. Pooth, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, I. Asin, N. Bartosik, O. Behnke, U. Behrens, A.J. Bell, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, S. Choudhury, F. Costanza, C. Diez

Pardos, G. Dolinska, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, E. Gallo, J. Garay Garcia, A. Geiser, A. Gizhko, P. Gunnellini, J. Hauk, M. Hempel¹⁸, H. Jung, A. Kalogeropoulos, O. Karacheban¹⁸, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, I. Korol, W. Lange, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann¹⁸, R. Mankel, I. Marfin¹⁸, I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, S. Naumann-Emme, A. Nayak, E. Ntomari, H. Perrey, D. Pitzl, R. Placakyte, A. Raspereza, B. Roland, M.Ö. Sahin, P. Saxena, T. Schoerner-Sadenius, M. Schröder, C. Seitz, S. Spannagel, K.D. Trippkewitz, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

V. Blobel, M. Centis Vignali, A.R. Draeger, J. Erfle, E. Garutti, K. Goebel, D. Gonzalez, M. Görner, J. Haller, M. Hoffmann, R.S. Höing, A. Junkes, R. Klanner, R. Kogler, T. Lapsien, T. Lenz, I. Marchesini, D. Marconi, D. Nowatschin, J. Ott, F. Pantaleo², T. Peiffer, A. Perieanu, N. Pietsch, J. Poehlsen, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, J. Schwandt, M. Seidel, V. Sola, H. Stadie, G. Steinbrück, H. Tholen, D. Troendle, E. Usai, L. Vanelderden, A. Vanhoefer

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

M. Akbiyik, C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, F. Colombo, W. De Boer, A. Descroix, A. Dierlamm, S. Fink, F. Frensch, M. Giffels, A. Gilbert, F. Hartmann², S.M. Heindl, U. Husemann, F. Kassel², I. Katkov⁶, A. Kornmayer², P. Lobelle Pardo, B. Maier, H. Mildner, M.U. Mozer, T. Müller, Th. Müller, M. Plagge, G. Quast, K. Rabbertz, S. Röcker, F. Roscher, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, M. Weber, T. Weiler, C. Wöhrmann, R. Wolf

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece

G. Anagnostou, G. Daskalakis, T. Gerasis, V.A. Giakoumopoulou, A. Kyriakis, D. Loukas, A. Psallidas, I. Topsis-Giotis

University of Athens, Athens, Greece

A. Agapitos, S. Kesisoglou, A. Panagiotou, N. Saoulidou, E. Tziaferi

University of Ioánnina, Ioánnina, Greece

I. Evangelou, G. Flouris, C. Foudas, P. Kokkas, N. Loukas, N. Manthos, I. Papadopoulos, E. Paradas, J. Strologas

Wigner Research Centre for Physics, Budapest, Hungary

G. Bencze, C. Hajdu, A. Hazi, P. Hidas, D. Horvath¹⁹, F. Sikler, V. Veszpremi, G. Vesztergombi²⁰, A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

N. Beni, S. Czellar, J. Karancsi²¹, J. Molnar, Z. Szillasi

University of Debrecen, Debrecen, Hungary

M. Bartók²², A. Makovec, P. Raics, Z.L. Trocsanyi, B. Ujvari

National Institute of Science Education and Research, Bhubaneswar, India

P. Mal, K. Mandal, N. Sahoo, S.K. Swain

Panjab University, Chandigarh, India

S. Bansal, S.B. Beri, V. Bhatnagar, R. Chawla, R. Gupta, U. Bhawandeep, A.K. Kalsi, A. Kaur, M. Kaur, R. Kumar, A. Mehta, M. Mittal, N. Nishu, J.B. Singh, G. Walia

University of Delhi, Delhi, India

Ashok Kumar, Arun Kumar, A. Bhardwaj, B.C. Choudhary, R.B. Garg, A. Kumar, S. Malhotra, M. Naimuddin, K. Ranjan, R. Sharma, V. Sharma

Saha Institute of Nuclear Physics, Kolkata, India

S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dey, S. Dutta, Sa. Jain, N. Majumdar, A. Modak, K. Mondal, S. Mukherjee, S. Mukhopadhyay, A. Roy, D. Roy, S. Roy Chowdhury, S. Sarkar, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India

A. Abdulsalam, R. Chudasama, D. Dutta, V. Jha, V. Kumar, A.K. Mohanty², L.M. Pant, P. Shukla, A. Topkar

Tata Institute of Fundamental Research, Mumbai, India

T. Aziz, S. Banerjee, S. Bhowmik²³, R.M. Chatterjee, R.K. Dewanjee, S. Dugad, S. Ganguly, S. Ghosh, M. Guchait, A. Gurtu²⁴, G. Kole, S. Kumar, B. Mahakud, M. Maity²³, G. Majumder, K. Mazumdar, S. Mitra, G.B. Mohanty, B. Parida, T. Sarkar²³, K. Sudhakar, N. Sur, B. Sutar, N. Wickramage²⁵

Indian Institute of Science Education and Research (IISER), Pune, India

S. Chauhan, S. Dube, S. Sharma

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran

H. Bakhshiansohi, H. Behnamian, S.M. Etesami²⁶, A. Fahim²⁷, R. Goldouzian, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, F. Rezaei Hosseinabadi, B. Safarzadeh²⁸, M. Zeinali

University College Dublin, Dublin, Ireland

M. Felcini, M. Grunewald

INFN Sezione di Bari ^a, Università di Bari ^b, Politecnico di Bari ^c, Bari, Italy

M. Abbrescia^{a,b}, C. Calabria^{a,b}, C. Caputo^{a,b}, S.S. Chhibra^{a,b}, A. Colaleo^a, D. Creanza^{a,c}, L. Cristella^{a,b}, N. De Filippis^{a,c}, M. De Palma^{a,b}, L. Fiore^a, G. Iaselli^{a,c}, G. Maggi^{a,c}, M. Maggi^a, G. Miniello^{a,b}, S. My^{a,c}, S. Nuzzo^{a,b}, A. Pompili^{a,b}, G. Pugliese^{a,c}, R. Radogna^{a,b}, A. Ranieri^a, G. Selvaggi^{a,b}, L. Silvestris^{a,2}, R. Venditti^{a,b}, P. Verwilligen^a

INFN Sezione di Bologna ^a, Università di Bologna ^b, Bologna, Italy

G. Abbiendi^a, C. Battilana², A.C. Benvenuti^a, D. Bonacorsi^{a,b}, S. Braibant-Giacomelli^{a,b}, L. Brigliadori^{a,b}, R. Campanini^{a,b}, P. Capiluppi^{a,b}, A. Castro^{a,b}, F.R. Cavallo^a, G. Codispoti^{a,b}, M. Cuffiani^{a,b}, G.M. Dallavalle^a, F. Fabbri^a, A. Fanfani^{a,b}, D. Fasanella^{a,b}, P. Giacomelli^a, C. Grandi^a, L. Guiducci^{a,b}, S. Marcellini^a, G. Masetti^a, A. Montanari^a, F.L. Navarria^{a,b}, A. Perrotta^a, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G.P. Siroli^{a,b}, N. Tosi^{a,b}, R. Travaglini^{a,b}

INFN Sezione di Catania ^a, Università di Catania ^b, CSFNSM ^c, Catania, Italy

G. Cappello^a, M. Chiorboli^{a,b}, S. Costa^{a,b}, F. Giordano^a, R. Potenza^{a,b}, A. Tricomi^{a,b}, C. Tuve^{a,b}

INFN Sezione di Firenze ^a, Università di Firenze ^b, Firenze, Italy

G. Barbagli^a, V. Ciulli^{a,b}, C. Civinini^a, R. D'Alessandro^{a,b}, E. Focardi^{a,b}, S. Gonzi^{a,b}, V. Gori^{a,b}, P. Lenzi^{a,b}, M. Meschini^a, S. Paoletti^a, G. Sguazzoni^a, A. Tropiano^{a,b}, L. Viliani^{a,b}

INFN Laboratori Nazionali di Frascati, Frascati, Italy

L. Benussi, S. Bianco, F. Fabbri, D. Piccolo

INFN Sezione di Genova ^a, Università di Genova ^b, Genova, Italy

V. Calvelli^{a,b}, F. Ferro^a, M. Lo Vetere^{a,b}, M.R. Monge^{a,b}, E. Robutti^a, S. Tosi^{a,b}

INFN Sezione di Milano-Bicocca ^a, Università di Milano-Bicocca ^b, Milano, Italy

L. Brianza, M.E. Dinardo^{a,b}, S. Fiorendi^{a,b}, S. Gennai^a, R. Gerosa^{a,b}, A. Ghezzi^{a,b}, P. Govoni^{a,b}, S. Malvezzi^a, R.A. Manzoni^{a,b}, B. Marzocchi^{a,b,2}, D. Menasce^a, L. Moroni^a, M. Paganoni^{a,b}, D. Pedrini^a, S. Ragazzi^{a,b}, N. Redaelli^a, T. Tabarelli de Fatis^{a,b}

INFN Sezione di Napoli ^a, Università di Napoli 'Federico II' ^b, Napoli, Italy, Università della Basilicata ^c, Potenza, Italy, Università G. Marconi ^d, Roma, Italy

S. Buontempo^a, N. Cavallo^{a,c}, S. Di Guida^{a,d,2}, M. Esposito^{a,b}, F. Fabozzi^{a,c}, A.O.M. Iorio^{a,b}, G. Lanza^a, L. Lista^a, S. Meola^{a,d,2}, M. Merola^a, P. Paolucci^{a,2}, C. Sciacca^{a,b}, F. Thyssen

INFN Sezione di Padova ^a, Università di Padova ^b, Padova, Italy, Università di Trento ^c, Trento, Italy

P. Azzi^{a,2}, N. Bacchetta^a, M. Bellato^a, L. Benato^{a,b}, A. Boletti^{a,b}, A. Branca^{a,b}, M. Dall'Osso^{a,b,2}, T. Dorigo^a, F. Fanzago^a, F. Gonella^a, A. Gozzelino^a, K. Kanishchev^{a,c}, S. Lacaprara^a, M. Margoni^{a,b}, G. Maron^{a,29}, A.T. Meneguzzo^{a,b}, M. Michelotto^a, F. Montecassiano^a, M. Passaseo^a, J. Pazzini^{a,b}, M. Pegoraro^a, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{a,b}, M. Zanetti, P. Zotto^{a,b}, A. Zucchetta^{a,b,2}

INFN Sezione di Pavia ^a, Università di Pavia ^b, Pavia, Italy

A. Braghieri^a, A. Magnani^a, P. Montagna^{a,b}, S.P. Ratti^{a,b}, V. Re^a, C. Riccardi^{a,b}, P. Salvini^a, I. Vai^a, P. Vitulo^{a,b}

INFN Sezione di Perugia ^a, Università di Perugia ^b, Perugia, Italy

L. Alunni Solestizi^{a,b}, M. Biasini^{a,b}, G.M. Bilei^a, D. Ciangottini^{a,b,2}, L. Fanò^{a,b}, P. Lariccia^{a,b}, G. Mantovani^{a,b}, M. Menichelli^a, A. Saha^a, A. Santocchia^{a,b}, A. Spiezia^{a,b}

INFN Sezione di Pisa ^a, Università di Pisa ^b, Scuola Normale Superiore di Pisa ^c, Pisa, Italy

K. Androsov^{a,30}, P. Azzurri^a, G. Bagliesi^a, J. Bernardini^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, M.A. Ciocci^{a,30}, R. Dell'Orso^a, S. Donato^{a,c,2}, G. Fedi, L. Foà^{a,c†}, A. Giassi^a, M.T. Grippo^{a,30}, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,b}, A. Messineo^{a,b}, F. Palla^a, A. Rizzi^{a,b}, A. Savoy-Navarro^{a,31}, A.T. Serban^a, P. Spagnolo^a, P. Squillacioti^{a,30}, R. Tenchini^a, G. Tonelli^{a,b}, A. Venturi^a, P.G. Verdini^a

INFN Sezione di Roma ^a, Università di Roma ^b, Roma, Italy

L. Barone^{a,b}, F. Cavallari^a, G. D'imperio^{a,b,2}, D. Del Re^{a,b}, M. Diemoz^a, S. Gelli^{a,b}, C. Jorda^a, E. Longo^{a,b}, F. Margaroli^{a,b}, P. Meridiani^a, F. Micheli^{a,b}, G. Organtini^{a,b}, R. Paramatti^a, F. Preiato^{a,b}, S. Rahatlou^{a,b}, C. Rovelli^a, F. Santanastasio^{a,b}, P. Traczyk^{a,b,2}

INFN Sezione di Torino ^a, Università di Torino ^b, Torino, Italy, Università del Piemonte Orientale ^c, Novara, Italy

N. Amapane^{a,b}, R. Arcidiacono^{a,c,2}, S. Argiro^{a,b}, M. Arneodo^{a,c}, R. Bellan^{a,b}, C. Biino^a, N. Cartiglia^a, M. Costa^{a,b}, R. Covarelli^{a,b}, A. Degano^{a,b}, N. Demaria^a, L. Finco^{a,b,2}, C. Mariotti^a, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b}, E. Monteil^{a,b}, M. Musich^a, M.M. Obertino^{a,b}, L. Pacher^{a,b}, N. Pastrone^a, M. Pelliccioni^a, G.L. Pinna Angioni^{a,b}, F. Ravera^{a,b}, A. Romero^{a,b}, M. Ruspa^{a,c}, R. Sacchi^{a,b}, A. Solano^{a,b}, A. Staiano^a, U. Tamponi^a, P.P. Trapani^{a,b}

INFN Sezione di Trieste ^a, Università di Trieste ^b, Trieste, Italy

S. Belforte^a, V. Candelise^{a,b,2}, M. Casarsa^a, F. Cossutti^a, G. Della Ricca^{a,b}, B. Gobbo^a, C. La Licata^{a,b}, M. Marone^{a,b}, A. Schizzi^{a,b}, T. Umer^{a,b}, A. Zanetti^a

Kangwon National University, Chunchon, Korea

S. Chang, A. Kropivnitskaya, S.K. Nam

Kyungpook National University, Daegu, Korea

D.H. Kim, G.N. Kim, M.S. Kim, D.J. Kong, S. Lee, Y.D. Oh, A. Sakharov, D.C. Son

Chonbuk National University, Jeonju, Korea

J.A. Brochero Cifuentes, H. Kim, T.J. Kim, M.S. Ryu

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea

S. Song

Korea University, Seoul, Korea

S. Choi, Y. Go, D. Gyun, B. Hong, M. Jo, H. Kim, Y. Kim, B. Lee, K. Lee, K.S. Lee, S. Lee, S.K. Park, Y. Roh

Seoul National University, Seoul, Korea

H.D. Yoo

University of Seoul, Seoul, Korea

M. Choi, H. Kim, J.H. Kim, J.S.H. Lee, I.C. Park, G. Ryu

Sungkyunkwan University, Suwon, Korea

Y. Choi, Y.K. Choi, J. Goh, D. Kim, E. Kwon, J. Lee, I. Yu

Vilnius University, Vilnius, Lithuania

A. Juodagalvis, J. Vaitkus

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia

I. Ahmed, Z.A. Ibrahim, J.R. Komaragiri, M.A.B. Md Ali³², F. Mohamad Idris³³, W.A.T. Wan Abdullah, M.N. Yusli

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico

E. Casimiro Linares, H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz³⁴, A. Hernandez-Almada, R. Lopez-Fernandez, A. Sanchez-Hernandez

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

S. Carpinteyro, I. Pedraza, H.A. Salazar Ibarguen

Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico

A. Morelos Pineda

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand

P.H. Butler, S. Reucroft

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan

A. Ahmad, M. Ahmad, Q. Hassan, H.R. Hoorani, W.A. Khan, T. Khurshid, M. Shoaib

National Centre for Nuclear Research, Swierk, Poland

H. Bialkowska, M. Bluj, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, P. Zalewski

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
G. Brona, K. Bunkowski, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, M. Walczak

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
P. Bargassa, C. Beirão Da Cruz E Silva, A. Di Francesco, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, N. Leonardo, L. Lloret Iglesias, F. Nguyen, J. Rodrigues Antunes, J. Seixas, O. Toldaiev, D. Vadrucio, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia
S. Afanasiev, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, V. Konoplyanikov, A. Lanev, A. Malakhov, V. Matveev³⁵, P. Moisezenz, V. Palichik, V. Perelygin, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
V. Golovtsov, Y. Ivanov, V. Kim³⁶, E. Kuznetsova, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev

Institute for Nuclear Research, Moscow, Russia
Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, A. Karneyeu, M. Kirsanov, N. Krasnikov, A. Pashenkov, D. Tlisov, A. Toropin

Institute for Theoretical and Experimental Physics, Moscow, Russia
V. Epshteyn, V. Gavrilov, N. Lychkovskaya, V. Popov, I. Pozdnyakov, G. Safronov, A. Spiridonov, E. Vlasov, A. Zhokin

National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
A. Bylinkin

P.N. Lebedev Physical Institute, Moscow, Russia
V. Andreev, M. Azarkin³⁷, I. Dremin³⁷, M. Kirakosyan, A. Leonidov³⁷, G. Mesyats, S.V. Rusakov, A. Vinogradov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
A. Baskakov, A. Belyaev, E. Boos, A. Ershov, A. Gribushin, L. Khein, V. Klyukhin, O. Kodolova, I. Lokhtin, O. Lukina, I. Myagkov, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia
I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkin, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
P. Adzic³⁸, M. Ekmedzic, J. Milosevic, V. Rekovic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
J. Alcaraz Maestre, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, A. Escalante Del Valle, C. Fernandez Bedoya, J.P. Fernández Ramos, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, E. Navarro De Martino, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, M.S. Soares

Universidad Autónoma de Madrid, Madrid, Spain

C. Albajar, J.F. de Trocóniz, M. Missiroli, D. Moran

Universidad de Oviedo, Oviedo, Spain

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, E. Palencia Cortezon, J.M. Vizan Garcia

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain

I.J. Cabrillo, A. Calderon, J.R. Castiñeiras De Saa, P. De Castro Manzano, J. Duarte Campderros, M. Fernandez, G. Gomez, A. Graziano, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, J. Piedra Gomez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, A. Benaglia, J. Bendavid, L. Benhabib, J.F. Benitez, G.M. Berruti, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, S. Colafranceschi³⁹, M. D'Alfonso, D. d'Enterria, A. Dabrowski, V. Daponte, A. David, M. De Gruttola, F. De Guio, A. De Roeck, S. De Visscher, E. Di Marco, M. Dobson, M. Dordevic, T. du Pree, N. Dupont, A. Elliott-Peisert, G. Franzoni, W. Funk, D. Gigi, K. Gill, D. Giordano, M. Girone, F. Glege, R. Guida, S. Gundacker, M. Guthoff, J. Hammer, M. Hansen, P. Harris, J. Hegeman, V. Innocente, P. Janot, H. Kirschenmann, M.J. Kortelainen, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, M.T. Lucchini, N. Magini, L. Malgeri, M. Mannelli, A. Martelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, S. Morovic, M. Mulders, M.V. Nemallapudi, H. Neugebauer, S. Orfanelli⁴⁰, L. Orsini, L. Pape, E. Perez, A. Petrilli, G. Petrucciani, A. Pfeiffer, D. Piparo, A. Racz, G. Rolandi⁴¹, M. Rovere, M. Ruan, H. Sakulin, C. Schäfer, C. Schwick, A. Sharma, P. Silva, M. Simon, P. Sphicas⁴², D. Spiga, J. Steggemann, B. Stieger, M. Stoye, Y. Takahashi, D. Treille, A. Triossi, A. Tsirou, G.I. Veres²⁰, N. Wardle, H.K. Wöhri, A. Zagozdinska⁴³, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

W. Bertl, K. Deiters, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, D. Kotlinski, U. Langenegger, D. Renker, T. Rohe

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

F. Bachmair, L. Bäni, L. Bianchini, M.A. Buchmann, B. Casal, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, C. Grab, C. Heidegger, D. Hits, J. Hoss, G. Kasieczka, W. Lustermann, B. Mangano, A.C. Marini, M. Marionneau, P. Martinez Ruiz del Arbol, M. Masciovecchio, D. Meister, P. Musella, F. Nessi-Tedaldi, F. Pandolfi, J. Pata, F. Pauss, L. Perrozzi, M. Peruzzi, M. Quittnat, M. Rossini, A. Starodumov⁴⁴, M. Takahashi, V.R. Tavolaro, K. Theofilatos, R. Wallny

Universität Zürich, Zurich, Switzerland

T.K. Aarrestad, C. Amsler⁴⁵, L. Caminada, M.F. Canelli, V. Chiochia, A. De Cosa, C. Galloni, A. Hinzmann, T. Hreus, B. Kilminster, C. Lange, J. Ngadiuba, D. Pinna, P. Robmann, F.J. Ronga, D. Salerno, S. Taroni, Y. Yang

National Central University, Chung-Li, Taiwan

M. Cardaci, K.H. Chen, T.H. Doan, C. Ferro, Sh. Jain, R. Khurana, M. Konyushikhin, C.M. Kuo, W. Lin, Y.J. Lu, R. Volpe, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

R. Bartek, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, P.H. Chen, C. Dietz, F. Fiori,

U. Grundler, W.-S. Hou, Y. Hsiung, Y.F. Liu, R.-S. Lu, M. Miñano Moya, E. Petrakou, J.F. Tsai, Y.M. Tzeng

Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand

B. Asavapibhop, K. Kovitanggoon, G. Singh, N. Srimanobhas, N. Suwonjandee

Cukurova University, Adana, Turkey

A. Adiguzel, S. Cerci⁴⁶, C. Dozen, I. Dumanoglu, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E.E. Kangal⁴⁷, A. Kayis Topaksu, G. Onengut⁴⁸, K. Ozdemir⁴⁹, S. Ozturk⁵⁰, B. Tali⁴⁶, H. Topakli⁵⁰, M. Vergili, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey

I.V. Akin, B. Bilin, S. Bilmis, B. Isildak⁵¹, G. Karapinar⁵², U.E. Surat, M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey

E.A. Albayrak⁵³, E. Gülmez, M. Kaya⁵⁴, O. Kaya⁵⁵, T. Yetkin⁵⁶

Istanbul Technical University, Istanbul, Turkey

K. Cankocak, S. Sen⁵⁷, F.I. Vardarli

Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine

B. Grynyov

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine

L. Levchuk, P. Sorokin

University of Bristol, Bristol, United Kingdom

R. Aggleton, F. Ball, L. Beck, J.J. Brooke, E. Clement, D. Cussans, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D.M. Newbold⁵⁸, S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, S. Senkin, D. Smith, V.J. Smith

Rutherford Appleton Laboratory, Didcot, United Kingdom

K.W. Bell, A. Belyaev⁵⁹, C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, L. Thomas, I.R. Tomalin, T. Williams, W.J. Womersley, S.D. Worm

Imperial College, London, United Kingdom

M. Baber, R. Bainbridge, O. Buchmuller, A. Bundock, D. Burton, S. Casasso, M. Citron, D. Colling, L. Corpe, N. Cripps, P. Dauncey, G. Davies, A. De Wit, M. Della Negra, P. Dunne, A. Elwood, W. Ferguson, J. Fulcher, D. Futyan, G. Hall, G. Iles, G. Karapostoli, M. Kenzie, R. Lane, R. Lucas⁵⁸, L. Lyons, A.-M. Magnan, S. Malik, J. Nash, A. Nikitenko⁴⁴, J. Pela, M. Pesaresi, K. Petridis, D.M. Raymond, A. Richards, A. Rose, C. Seez, A. Tapper, K. Uchida, M. Vazquez Acosta⁶⁰, T. Virdee, S.C. Zenz

Brunel University, Uxbridge, United Kingdom

J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leggat, D. Leslie, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

Baylor University, Waco, USA

A. Borzou, K. Call, J. Dittmann, K. Hatakeyama, A. Kasmi, H. Liu, N. Pastika

The University of Alabama, Tuscaloosa, USA

O. Charaf, S.I. Cooper, C. Henderson, P. Rumerio

Boston University, Boston, USA

A. Avetisyan, T. Bose, C. Fantasia, D. Gastler, P. Lawson, D. Rankin, C. Richardson, J. Rohlf, J. St. John, L. Sulak, D. Zou

Brown University, Providence, USA

J. Alimena, E. Berry, S. Bhattacharya, D. Cutts, N. Dhingra, A. Ferapontov, A. Garabedian, U. Heintz, E. Laird, G. Landsberg, Z. Mao, M. Narain, S. Sagir, T. Sinthuprasith

University of California, Davis, Davis, USA

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, M. Gardner, W. Ko, R. Lander, M. Mulhearn, D. Pellett, J. Pilot, F. Ricci-Tam, S. Shalhout, J. Smith, M. Squires, D. Stolp, M. Tripathi, S. Wilbur, R. Yohay

University of California, Los Angeles, USA

R. Cousins, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, D. Saltzberg, E. Takasugi, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA

K. Burt, R. Clare, J. Ellison, J.W. Gary, G. Hanson, J. Heilman, M. Ivova PANEVA, P. Jandir, E. Kennedy, F. Lacroix, O.R. Long, A. Luthra, M. Malberti, M. Olmedo Negrete, A. Shrinivas, H. Wei, S. Wimpenny

University of California, San Diego, La Jolla, USA

J.G. Branson, G.B. Cerati, S. Cittolin, R.T. D'Agnolo, A. Holzner, R. Kelley, D. Klein, J. Letts, I. Macneill, D. Olivito, S. Padhi, M. Pieri, M. Sani, V. Sharma, S. Simon, M. Tadel, A. Vartak, S. Wasserbaech⁶¹, C. Welke, F. Würthwein, A. Yagil, G. Zevi Della Porta

University of California, Santa Barbara, Santa Barbara, USA

D. Barge, J. Bradmiller-Feld, C. Campagnari, A. Dishaw, V. Dutta, K. Flowers, M. Franco Sevilla, P. Geffert, C. George, F. Golf, L. Gouskos, J. Gran, J. Incandela, C. Justus, N. Mccoll, S.D. Mullin, J. Richman, D. Stuart, I. Suarez, W. To, C. West, J. Yoo

California Institute of Technology, Pasadena, USA

D. Anderson, A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, J. Duarte, A. Mott, H.B. Newman, C. Pena, M. Pierini, M. Spiropulu, J.R. Vlimant, S. Xie, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA

V. Azzolini, A. Calamba, B. Carlson, T. Ferguson, Y. Iiyama, M. Paulini, J. Russ, M. Sun, H. Vogel, I. Vorobiev

University of Colorado Boulder, Boulder, USA

J.P. Cumalat, W.T. Ford, A. Gaz, F. Jensen, A. Johnson, M. Krohn, T. Mulholland, U. Nauenberg, J.G. Smith, K. Stenson, S.R. Wagner

Cornell University, Ithaca, USA

J. Alexander, A. Chatterjee, J. Chaves, J. Chu, S. Dittmer, N. Eggert, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Rinkevicius, A. Ryd, L. Skinnari, L. Soffi, W. Sun, S.M. Tan, W.D. Teo, J. Thom, J. Thompson, J. Tucker, Y. Weng, P. Wittich

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, G. Bolla, K. Burkett, J.N. Butler, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, J. Hanlon, D. Hare, R.M. Harris, J. Hirschauer, B. Hooberman, Z. Hu, S. Jindariani, M. Johnson, U. Joshi, A.W. Jung, B. Klima, B. Kreis, S. Kwan[†], S. Lammel, J. Linacre, D. Lincoln, R. Lipton,

T. Liu, R. Lopes De Sá, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, P. Merkel, K. Mishra, S. Mrenna, S. Nahn, C. Newman-Holmes, V. O'Dell, K. Pedro, O. Prokofyev, G. Rakness, E. Sexton-Kennedy, A. Soha, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, C. Vernieri, M. Verzocchi, R. Vidal, H.A. Weber, A. Whitbeck, F. Yang, H. Yin

University of Florida, Gainesville, USA

D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, A. Carnes, M. Carver, D. Curry, S. Das, G.P. Di Giovanni, R.D. Field, M. Fisher, I.K. Furic, J. Hugon, J. Konigsberg, A. Korytov, J.F. Low, P. Ma, K. Matchev, H. Mei, P. Milenovic⁶², G. Mitselmakher, L. Muniz, D. Rank, R. Rossin, L. Shchutska, M. Snowball, D. Sperka, J. Wang, S. Wang, J. Yelton

Florida International University, Miami, USA

S. Hewamanage, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, USA

A. Ackert, J.R. Adams, T. Adams, A. Askew, J. Bochenek, B. Diamond, J. Haas, S. Hagopian, V. Hagopian, K.F. Johnson, A. Khatiwada, H. Prosper, V. Veeraraghavan, M. Weinberg

Florida Institute of Technology, Melbourne, USA

V. Bhopatkar, M. Hohlmann, H. Kalakhety, D. Mareskas-palcek, T. Roy, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, USA

M.R. Adams, L. Apanasevich, D. Berry, R.R. Betts, I. Bucinskaite, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, P. Kurt, C. O'Brien, I.D. Sandoval Gonzalez, C. Silkworth, P. Turner, N. Varelas, Z. Wu, M. Zakaria

The University of Iowa, Iowa City, USA

B. Bilki⁶³, W. Clarida, K. Dilsiz, S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya⁶⁴, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok⁵³, A. Penzo, C. Snyder, P. Tan, E. Tiras, J. Wetzel, K. Yi

Johns Hopkins University, Baltimore, USA

I. Anderson, B.A. Barnett, B. Blumenfeld, D. Fehling, L. Feng, A.V. Gritsan, P. Maksimovic, C. Martin, K. Nash, M. Osherson, M. Swartz, M. Xiao, Y. Xin

The University of Kansas, Lawrence, USA

P. Baringer, A. Bean, G. Benelli, C. Bruner, J. Gray, R.P. Kenny III, D. Majumder, M. Malek, M. Murray, D. Noonan, S. Sanders, R. Stringer, Q. Wang, J.S. Wood

Kansas State University, Manhattan, USA

I. Chakaberia, A. Ivanov, K. Kaadze, S. Khalil, M. Makouski, Y. Maravin, A. Mohammadi, L.K. Saini, N. Skhirtladze, I. Svintradze, S. Toda

Lawrence Livermore National Laboratory, Livermore, USA

D. Lange, F. Rebassoo, D. Wright

University of Maryland, College Park, USA

C. Anelli, A. Baden, O. Baron, A. Belloni, B. Calvert, S.C. Eno, C. Ferraioli, J.A. Gomez, N.J. Hadley, S. Jabeen, R.G. Kellogg, T. Kolberg, J. Kunkle, Y. Lu, A.C. Mignerey, Y.H. Shin, A. Skuja, M.B. Tonjes, S.C. Tonwar

Massachusetts Institute of Technology, Cambridge, USA

A. Apyan, R. Barbieri, A. Baty, K. Bierwagen, S. Brandt, W. Busza, I.A. Cali, Z. Demiragli, L. Di Matteo, G. Gomez Ceballos, M. Goncharov, D. Gulhan, G.M. Innocenti, M. Klute, D. Kovalskyi,

Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, C. McGinn, C. Mironov, X. Niu, C. Paus, D. Ralph, C. Roland, G. Roland, J. Salfeld-Nebgen, G.S.F. Stephans, K. Sumorok, M. Varma, D. Velicanu, J. Veverka, J. Wang, T.W. Wang, B. Wyslouch, M. Yang, V. Zhukova

University of Minnesota, Minneapolis, USA

B. Dahmes, A. Finkel, A. Gude, P. Hansen, S. Kalafut, S.C. Kao, K. Klapoetke, Y. Kubota, Z. Lesko, J. Mans, S. Nourbakhsh, N. Ruckstuhl, R. Rusack, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, USA

J.G. Acosta, S. Oliveros

University of Nebraska-Lincoln, Lincoln, USA

E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, C. Fangmeier, R. Gonzalez Suarez, R. Kamalieddin, J. Keller, D. Knowlton, I. Kravchenko, J. Lazo-Flores, F. Meier, J. Monroy, F. Ratnikov, J.E. Siado, G.R. Snow

State University of New York at Buffalo, Buffalo, USA

M. Alyari, J. Dolen, J. George, A. Godshalk, I. Iashvili, J. Kaisen, A. Kharchilava, A. Kumar, S. Rappoccio

Northeastern University, Boston, USA

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, A. Hortiangtham, A. Massironi, D.M. Morse, D. Nash, T. Orimoto, R. Teixeira De Lima, D. Trocino, R.-J. Wang, D. Wood, J. Zhang

Northwestern University, Evanston, USA

K.A. Hahn, A. Kubik, N. Mucia, N. Odell, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, K. Sung, M. Trovato, M. Velasco, S. Won

University of Notre Dame, Notre Dame, USA

A. Brinkerhoff, N. Dev, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, S. Lynch, N. Marinelli, F. Meng, C. Mueller, Y. Musienko³⁵, T. Pearson, M. Planer, A. Reinsvold, R. Ruchti, G. Smith, N. Valls, M. Wayne, M. Wolf, A. Woodard

The Ohio State University, Columbus, USA

L. Antonelli, J. Brinson, B. Bylsma, L.S. Durkin, S. Flowers, A. Hart, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, B. Liu, W. Luo, D. Puigh, M. Rodenburg, B.L. Winer, H.W. Wulsin

Princeton University, Princeton, USA

O. Driga, P. Elmer, J. Hardenbrook, P. Hebda, S.A. Koay, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, C. Palmer, P. Piroué, X. Quan, H. Saka, D. Stickland, C. Tully, J.S. Werner, A. Zuranski

University of Puerto Rico, Mayaguez, USA

S. Malik

Purdue University, West Lafayette, USA

V.E. Barnes, D. Benedetti, D. Bortoletto, L. Gutay, M.K. Jha, M. Jones, K. Jung, M. Kress, D.H. Miller, N. Neumeister, F. Primavera, B.C. Radburn-Smith, X. Shi, I. Shipsey, D. Silvers, J. Sun, A. Svyatkovskiy, F. Wang, W. Xie, L. Xu, J. Zablocki

Purdue University Calumet, Hammond, USA

N. Parashar, J. Stupak

Rice University, Houston, USA

A. Adair, B. Akgun, Z. Chen, K.M. Ecklund, F.J.M. Geurts, M. Guilbaud, W. Li, B. Michlin, M. Northup, B.P. Padley, R. Redjimi, J. Roberts, J. Rorie, Z. Tu, J. Zabel

University of Rochester, Rochester, USA

B. Betchart, A. Bodek, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, M. Galanti, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, O. Hindrichs, A. Khukhunaishvili, G. Petrillo, M. Verzetti

The Rockefeller University, New York, USA

L. Demortier

Rutgers, The State University of New Jersey, Piscataway, USA

S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, E. Hughes, S. Kaplan, R. Kunnawalkam Elayavalli, A. Lath, S. Panwalkar, M. Park, S. Salur, S. Schnetzer, D. Sheffield, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

University of Tennessee, Knoxville, USA

M. Foerster, G. Riley, K. Rose, S. Spanier, A. York

Texas A&M University, College Station, USA

O. Bouhali⁶⁵, A. Castaneda Hernandez, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon⁶⁶, V. Krutelyov, R. Montalvo, R. Mueller, I. Osipenkov, Y. Pakhotin, R. Patel, A. Perloff, J. Roe, A. Rose, A. Safonov, A. Tatarinov, K.A. Ulmer²

Texas Tech University, Lubbock, USA

N. Akchurin, C. Cowden, J. Damgov, C. Dragoiu, P.R. Duerdo, J. Faulkner, S. Kunori, K. Lamichhane, S.W. Lee, T. Libeiro, S. Undleeb, I. Volobouev

Vanderbilt University, Nashville, USA

E. Appelt, A.G. Delannoy, S. Greene, A. Gurrola, R. Janjam, W. Johns, C. Maguire, Y. Mao, A. Melo, P. Sheldon, B. Snook, S. Tuo, J. Velkovska, Q. Xu

University of Virginia, Charlottesville, USA

M.W. Arenton, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, H. Li, C. Lin, C. Neu, E. Wolfe, J. Wood, F. Xia

Wayne State University, Detroit, USA

C. Clarke, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, J. Sturdy

University of Wisconsin, Madison, USA

D.A. Belknap, D. Carlsmith, M. Cepeda, A. Christian, S. Dasu, L. Dodd, S. Duric, E. Friis, B. Gomber, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, A. Lanaro, A. Levine, K. Long, R. Loveless, A. Mohapatra, I. Ojalvo, T. Perry, G.A. Pierro, G. Polese, I. Ross, T. Ruggles, T. Sarangi, A. Savin, A. Sharma, N. Smith, W.H. Smith, D. Taylor, N. Woods

†: Deceased

1: Also at Vienna University of Technology, Vienna, Austria

2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland

3: Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

4: Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

-
- 5: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
 - 6: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
 - 7: Also at Universidade Estadual de Campinas, Campinas, Brazil
 - 8: Also at Centre National de la Recherche Scientifique (CNRS) - IN2P3, Paris, France
 - 9: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
 - 10: Also at Joint Institute for Nuclear Research, Dubna, Russia
 - 11: Also at Zewail City of Science and Technology, Zewail, Egypt
 - 12: Also at Helwan University, Cairo, Egypt
 - 13: Also at British University in Egypt, Cairo, Egypt
 - 14: Now at Ain Shams University, Cairo, Egypt
 - 15: Also at Université de Haute Alsace, Mulhouse, France
 - 16: Also at Tbilisi State University, Tbilisi, Georgia
 - 17: Also at Ilia State University, Tbilisi, Georgia
 - 18: Also at Brandenburg University of Technology, Cottbus, Germany
 - 19: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
 - 20: Also at Eötvös Loránd University, Budapest, Hungary
 - 21: Also at University of Debrecen, Debrecen, Hungary
 - 22: Also at Wigner Research Centre for Physics, Budapest, Hungary
 - 23: Also at University of Visva-Bharati, Santiniketan, India
 - 24: Now at King Abdulaziz University, Jeddah, Saudi Arabia
 - 25: Also at University of Ruhuna, Matara, Sri Lanka
 - 26: Also at Isfahan University of Technology, Isfahan, Iran
 - 27: Also at University of Tehran, Department of Engineering Science, Tehran, Iran
 - 28: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
 - 29: Also at Laboratori Nazionali di Legnaro dell'INFN, Legnaro, Italy
 - 30: Also at Università degli Studi di Siena, Siena, Italy
 - 31: Also at Purdue University, West Lafayette, USA
 - 32: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
 - 33: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia
 - 34: Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico
 - 35: Also at Institute for Nuclear Research, Moscow, Russia
 - 36: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
 - 37: Also at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
 - 38: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
 - 39: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
 - 40: Also at National Technical University of Athens, Athens, Greece
 - 41: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
 - 42: Also at University of Athens, Athens, Greece
 - 43: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
 - 44: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
 - 45: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
 - 46: Also at Adiyaman University, Adiyaman, Turkey
 - 47: Also at Mersin University, Mersin, Turkey
 - 48: Also at Cag University, Mersin, Turkey
 - 49: Also at Piri Reis University, Istanbul, Turkey
 - 50: Also at Gaziosmanpasa University, Tokat, Turkey

- 51: Also at Ozyegin University, Istanbul, Turkey
- 52: Also at Izmir Institute of Technology, Izmir, Turkey
- 53: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
- 54: Also at Marmara University, Istanbul, Turkey
- 55: Also at Kafkas University, Kars, Turkey
- 56: Also at Yildiz Technical University, Istanbul, Turkey
- 57: Also at Hacettepe University, Ankara, Turkey
- 58: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
- 59: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
- 60: Also at Instituto de Astrofísica de Canarias, La Laguna, Spain
- 61: Also at Utah Valley University, Orem, USA
- 62: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- 63: Also at Argonne National Laboratory, Argonne, USA
- 64: Also at Erzincan University, Erzincan, Turkey
- 65: Also at Texas A&M University at Qatar, Doha, Qatar
- 66: Also at Kyungpook National University, Daegu, Korea