Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Study of Z boson production in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

CMS Collaboration *

CERN, Switzerland

ABSTRACT

The production of Z bosons in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV is studied by the CMS experiment via the electron and muon decay channels. The inclusive cross section is compared to pp collision predictions, and found to scale with the number of elementary nucleon–nucleon collisions. The differential cross sections as a function of the Z boson rapidity and transverse momentum are measured. Though they are found to be consistent within uncertainty with theoretical predictions both with and without nuclear effects, the forward–backward asymmetry suggests the presence of nuclear effects at large rapidities. These results provide new data for constraining nuclear parton distribution functions.

© 2016 The Author. 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.

1. Introduction

Electroweak boson production is an important benchmark process in high-energy particle physics. The production of Z and W bosons has been extensively studied at hadron and e^+e^- colliders, at various collision energies. The latest measurements in pp collisions at the LHC [1–8] are well described by the standard model using higher-order perturbative quantum chromodynamics (QCD) and parton distribution functions (PDFs).

With its large center-of-mass energy and high luminosity, the LHC enables for the first time the study of Z and W boson production in heavy ion collisions. Electroweak bosons are unmodified by the hot and dense medium created in nucleus–nucleus collisions, and their leptonic decays are of particular interest since leptons pass through the medium without being affected by the strong interaction. Both the Z and W boson production were measured by the ATLAS [9,10] and the CMS [11,12] experiments using PbPb collisions taken in 2010 and 2011 at a center-of-mass energy per nucleon pair of $\sqrt{s_{NN}} = 2.76$ TeV, confirming that the production cross section scales with the number of elementary nucleon–nucleon collisions with a precision of about 10%.

However, in nuclear collisions, the production of electroweak bosons can be affected by the initial conditions of the collision. The free-proton PDFs are expected to be modified for protons bound in the Pb nucleus, which, together with the fact that the nucleus contains neutrons as well as protons (isospin effect), can modify the observed cross sections as compared to pp collisions. Various groups have studied the nuclear modification of PDFs, and several

results are available at next-to-leading-order (NLO) precision in QCD [13–15]. These results are obtained by global fits to the available deep inelastic scattering and Drell–Yan data, which constrain the nuclear PDFs (nPDFs) in the region of parton longitudinal momentum fraction $x > 10^{-2}$ and four-momentum transfer squared $Q^2 < (10 \text{ GeV})^2$.

The production of electroweak bosons in proton–nucleus collisions at the LHC provides an opportunity to study the nPDFs at the high $Q^2 \approx (100 \text{ GeV})^2$ and lower x phase space region [16]. The CMS experiment made the first measurement of W boson production in pPb collisions [17]. Deviations from the current expectations for PDFs were observed, showing the need for including W boson data in nPDF global fits. Furthermore, the dijet pseudorapidity distribution measured in pPb collisions by CMS [18] and the Z boson production in pPb collisions measured by ATLAS [19] show better agreement with modified PDFs. Deviations from pp expectations were also seen with charged hadrons [20].

Various models predict different nuclear modifications of the Z boson production cross section (σ) as a function of transverse momentum (p_T) and rapidity in the nucleon–nucleon center-of-mass frame (y_{cm}) [21–25]. Processes mediated by a virtual photon and interference effects are also considered as part of the Z boson signal. The rapidity distribution of Z bosons is particularly sensitive to the parton content of the interacting nucleons. Consequently, the symmetric rapidity spectrum of the Z bosons in the center-of-mass frame of pp collisions is modified by nuclear effects in pPb collisions [24]. This can be quantified through measurements of the forward–backward asymmetry in the center-of-mass frame:

$$R_{FB}(y_{cm}) = \frac{d\sigma(+y_{cm})/dy_{cm}}{d\sigma(-y_{cm})/dy_{cm}}, \tag{1}$$

where by convention positive rapidity values correspond to the direction of the incoming proton.

The aim of this paper is to study the $Z \to \ell\ell$ process (where ℓ represents either muons or electrons) and to measure the production cross section as functions of rapidity and transverse momentum. The typical quark momentum fraction probed in the Pb nucleus is given by $x = M_Z/\sqrt{s_{NN}}e^{-y_{cm}}$, and thus with $0.002 < x < 0.3$ in the measured range of $-2.8 < y_{cm} < 2.0$. These measurements will help to constrain the parton content of the nucleons in the nucleus.

2. Experimental setup, data selection and reconstruction

A detailed description of the CMS detector and its coordinate system can be found elsewhere [26]. Its central feature is a superconducting solenoid with internal diameter of 6 m, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL). Muons are detected in the pseudorapidity range $|\eta_{lab}| < 2.4$ using gas-ionization detectors embedded in the steel return yoke outside the solenoid. Electrons are measured in the ECAL that consists of 75 848 lead tungstate crystals providing a coverage in the barrel region of $|\eta_{lab}| < 1.48$ and in the two endcap regions of $1.48 < |\eta_{lab}| < 3.00$. Extensive forward calorimetry complements the coverage provided by these barrel and endcap detectors. CMS has a two-level trigger system. The first level, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select the most interesting events. The high-level trigger processor farm further decreases the event rate before data storage.

The analysis is performed using the pPb collision data taken at the beginning of 2013 and corresponding to an integrated luminosity of 34.6 ± 1.2 nb^{-1} [27]. The beam energies were 4 TeV for protons and 1.58 TeV per nucleon for lead nuclei, resulting in a center-of-mass energy per nucleon pair of $\sqrt{s_{NN}} = 5.02$ TeV. As a consequence of the energy difference between the colliding beams, the nucleon–nucleon center-of-mass frame is not at rest with respect to the laboratory frame. Massless particles emitted at rapidity $y_{cm} = 0$ in the nucleon–nucleon center-of-mass frame will be detected at $y_{lab} = -0.465$ (clockwise proton beam) or $+0.465$ (counterclockwise proton beam) in the laboratory frame. The results presented here are expressed in the center-of-mass frame with the proton-going side defining the region of positive y_{cm} values, to respect the usual convention of the proton fragmentation region being probed at positive rapidity. The direction of the higher energy proton beam was initially clockwise and was then reversed, producing two comparable datasets.

During data taking, muon and electron triggers were employed to select and record all events with high-p_T leptons. The measurements in the muon final state are based on a sample obtained by requiring at least one muon with p_T greater than 12 GeV/c. The muon candidates are reconstructed with an algorithm that combines information from both the silicon tracker and the muon system [28]. Background muons from cosmic rays and heavy-quark semileptonic decays are rejected by applying a set of quality criteria to each muon, based on previous studies of the performance of the muon reconstruction [28]. The muons are selected by requiring at least two muon stations to be matched to the muon track, a low χ^2/ndf of the global fit, a minimum number of tracker layers and pixel hits, and finally, a maximum distance from the primary vertex in the transverse and longitudinal direction.

The electron measurements are based on a candidate photon or electron sample collected by requiring at least one ECAL transverse energy deposit of $E_T > 15$ GeV and online identification criteria

that are looser than the electron selection applied offline. Electrons are reconstructed by matching ECAL clusters to tracks measured in the silicon tracker. This matching is used to differentiate electrons from photons [29]. The identification criteria are chosen to match those used for pp collisions [30]. The electrons are selected by requiring a match between the η and ϕ coordinates of the track and the ECAL cluster, a narrow width of the ECAL cluster in η, a low HCAL energy measured in the ECAL cluster direction and by rejecting electrons with a partner track consistent with a photon conversion. In this measurement, no isolation requirements are imposed on the leptons.

3. Analysis procedure

The Z boson production cross section is calculated using the following equation:

$$\sigma = \frac{S - B}{\alpha \, \epsilon \, L_{\text{int}}}, \tag{2}$$

where S is the number of Z candidates, B is the estimated background, α is the acceptance, ϵ is the efficiency, including correction factors derived from data, and L_{int} is the integrated luminosity. The phase space region considered in the analysis is defined by requiring two leptons with $p_T^\ell > 20$ GeV/c and with pseudorapidity in the laboratory frame $|\eta_{lab}^\ell| < 2.4$ in order to ensure that the triggers are maximally efficient and are within the geometrical coverage of the muon detectors. This fiducial region of the measurement is extrapolated to the full phase space over p_T^ℓ and η_{lab}^ℓ by the acceptance correction. Each component of Eq. (2) is presented and systematic uncertainties summarized below.

3.1. Signal and background

The Z candidate events are selected by requiring a same-flavor, oppositely-charged lepton pair with an invariant mass in the 60–120 GeV/c^2 range, where both leptons satisfy the acceptance and quality requirements and at least one of them corresponds to the lepton that triggered the event. Fig. 1 shows the invariant mass distribution of the selected lepton pairs compared to a combination of PYTHIA 6 and HIJING (PYTHIA 6+HIJING) Monte Carlo (MC) simulations. The $pN \to Z \to \ell\ell$ process is simulated using the PYTHIA 6 [31] generator (version 6.424, tune Z2 [32]) with a mixture of pp and pn interactions corresponding to pPb collisions. Each PYTHIA 6 signal event is embedded in a minimum bias pPb background event which is produced with the HIJING event generator version 1.383 [33]. The detector response for each produced event is simulated with GEANT4 [34]. The signal and background events have the same generated vertex location and are boosted to have the correct rapidity distribution in the laboratory frame. The embedding is done at the level of detector hits and then the events are processed through the trigger emulation and the event reconstruction chains. The reconstructed longitudinal primary vertex and overall multiplicity distributions are reweighted to match those observed in data.

An electron energy scale correction is extracted by fitting the energy to momentum ratio of electrons in a very pure $W \to e\nu$ control sample [29]. After fixing the shape of the distribution from MC, the energy to momentum ratio in data is fitted to derive the difference of the energy scale between data and MC, and then the data is corrected for this difference. A correction of the electron energy resolution is applied to MC by comparing the mass distribution of electron pairs between data and MC. Such corrections are also estimated for the $Z \to \mu^+\mu^-$ channel and found to be negligible.
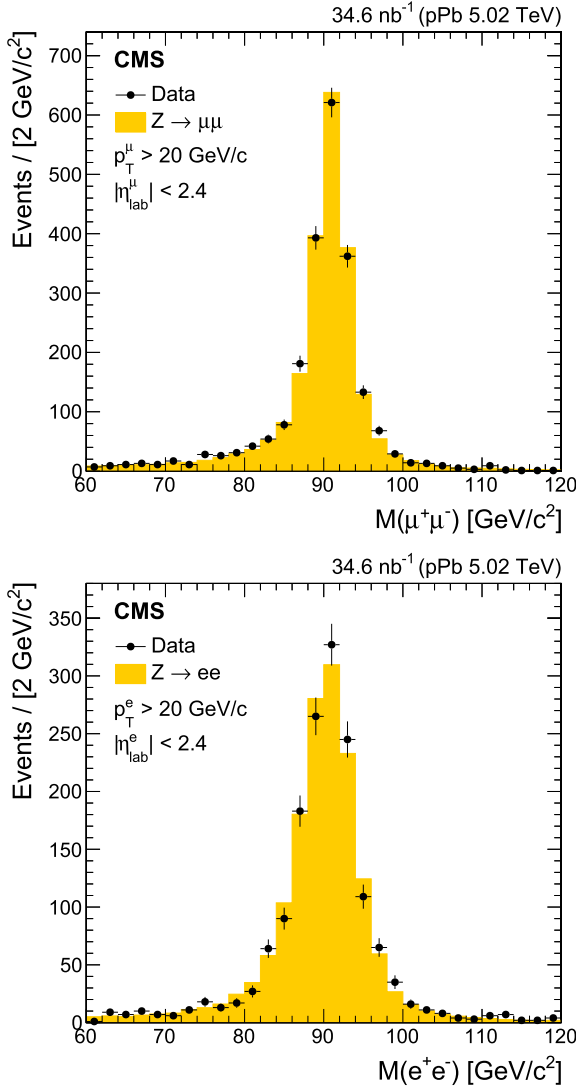
Fig. 1. Invariant mass of selected muon (top) and electron (bottom) pairs compared to PYTHIA 6+HIJING simulated pN → Z → ℓℓ events with N = (p, n) according to the number of nucleons in the Pb nucleus. The MC sample is normalized to the number of events in the data.

The raw yield, S, of Z boson candidates in the pPb sample is determined by counting the number of oppositely-charged lepton pairs in the 60–120 GeV/c^2 mass region that fulfill the acceptance and quality requirements. This number is found to be 2183 in the muon channel and 1571 in the electron channel. The difference between the two channels is due to the tighter selection criteria applied to the electrons in order to suppress the higher background. A charge misidentification correction of 1% is applied to the dielectron yields; this correction is negligible for dimuons. No events are found with more than one Z boson candidate. For the differential cross sections, the measurement is performed in the dilepton transverse momentum or rapidity bins, where the rapidity is calculated in the center-of-mass frame.

Possible background contributions to the Z → ℓℓ production are QCD multijet events, t$\bar{\text{t}}$ pairs and electroweak processes such as W+jets, diboson (WW, WZ, ZZ), and Z → $\tau\tau$ production. Although the expected background contamination is small, an estimate based on data is used to subtract its contribution from the dilepton raw yield. For t$\bar{\text{t}}$, b$\bar{\text{b}}$, WW, and Z → $\tau\tau$ processes, two electron–muon events are expected for each dimuon or dielec-

tron event, because of lepton universality. In the Z boson mass range, the oppositely-charged electron–muon pairs are counted and translated into the expected number of muon or electron pairs, taking into account the differences in the muon and electron reconstruction and selection efficiencies. This background is subtracted from the dilepton raw yield and accounts for the main electroweak and t$\bar{\text{t}}$ backgrounds, as well as for the part of QCD multijet background (such as b$\bar{\text{b}}$ decays) that produces oppositely-charged leptons. The background from random combinations of other leptons in the event is estimated by counting the same-charge pairs. Additional electroweak contributions from W+jets and diboson production are found to be negligible via MC simulations. The fraction of background events subtracted from the raw yield is 2.4% (2.9%) in the muon (electron) channel, where the dominant background contribution comes from QCD processes, since no isolation requirements are imposed on the leptons.

3.2. Efficiency and acceptance

The efficiency, ϵ, for Z bosons is defined as the number of reconstructed Z candidates, where both leptons fulfill the acceptance and quality requirements, divided by the number of generated Z bosons where both leptons fulfill the acceptance requirements. This combined reconstruction, lepton identification, and trigger efficiency is calculated from the PYTHIA 6+HIJING simulation samples so that the effects of the pPb environment are taken into account.

For the rapidly falling dilepton p_T spectrum, an unfolding technique based on the inversion of a response matrix similar to the one used in Ref. [4] is first applied to the data before applying the efficiency correction. The response matrix is constructed from the PYTHIA 6+HIJING simulation to take into account the detector resolution effects. The dilepton p_T resolution is about 0.5–1.5 GeV/c, which results in a maximum bin-to-bin spill of about 30% in the lowest p_T bins chosen for this analysis. In the measurement of the dilepton rapidity, the unfolding is not necessary as the shape of the y_{cm} spectrum is almost flat and the resolution is a small fraction of the analysis bin size. Instead, the resolution effects in rapidity are taken into account in the efficiency corrections.

In order to correct for possible differences between data and simulation, a method derived from data is used to determine correction factors to the baseline efficiency from simulation. These correction factors are determined as a function of lepton η and p_T by applying the *tag-and-probe* method to both data and simulation to calculate single lepton efficiencies for reconstruction, identification, and triggering, similar to the method described in Ref. [28]. The ratio of each efficiency from data over the corresponding efficiency in the simulation is then applied to reweight the simulation on a lepton-by-lepton basis. The efficiency for the Z bosons, after correcting for the small differences between data and simulation, is found to be 0.878 ± 0.015 in the dimuon and 0.605 ± 0.015 in the dielectron decay channel. The sources of systematic uncertainties are described in Section 3.3.

The acceptance, α, is defined as the number of generated dilepton events where both leptons fulfill the acceptance requirements ($p_T^\ell > 20$ GeV/c, $|\eta_{lab}^\ell| < 2.4$) divided by the number of all generated dilepton events in the 60–120 GeV/c^2 mass range. It is calculated using simulated events. The event generation is provided by the POWHEG generator [35–38] with the CT10 free proton PDF set [39], interfaced with PYTHIA 6 parton shower, and the events are boosted to the laboratory frame (POWHEG+PYTHIA 6). Final-state photon radiation is also simulated by PYTHIA 6. The integrated acceptance is found to be 0.516 ± 0.026 in both decay channels.

3.3. Systematic uncertainties

The total systematic uncertainty in the Z boson production cross section is calculated by adding in quadrature the different contributions from the background subtraction, acceptance and efficiency determination, and the unfolding technique. The integrated luminosity, calibrated by the van der Meer scans [27], has a systematic uncertainty of 3.5%. It is the dominant systematic uncertainty of the measurement in the fiducial region.

The signal yield of Z candidates is affected by the uncertainty in the background subtraction method. The number of subtracted background events determined by the electron–muon method is varied conservatively by ±100% to assign an uncertainty in the signal yield. The uncertainty in the signal yield from this background variation is 1.7% (1.8%) in the muon (electron) channel.

The uncertainty in the correction factor for the electron energy scale is propagated as a systematic uncertainty in the dielectron yield. It is estimated to be 0.5% in the inclusive yield and varies across the analysis p_T bins between 4 and 19%. The residual difference in the mass resolution between data and simulation is taken as the systematic uncertainty in the electron channel. After propagating to the inclusive cross section, it accounts for a 1.1% uncertainty.

The systematic uncertainty in the efficiency comes from two different sources. The first one is the uncertainty in the underlying rapidity and transverse momentum distributions reflecting the poorly known PDFs. This is estimated by applying a weight to the generated events that varies linearly between 0.7 and 1.3 over the $-3 < y_{cm} < 3$ range, and a weight that varies between 0.9 and 1.1 over the $0 < p_T < 150$ GeV/c range. These variations cover the predicted nuclear effects to the rapidity and p_T spectrum from different groups [21,22,24] as well as the statistical uncertainties in the present measurement and result in a 0.2% uncertainty in the dilepton efficiency. Second, the statistical uncertainty in the correction factors coming from the ratio of data and simulation in the tag-and-probe method is propagated to the dilepton efficiency. In addition, the tag-and-probe technique itself carries an uncertainty of about 1%, estimated from differences observed in the efficiencies by varying the functional form or the range of the fits. Finally, the uncertainties in the three different components of the efficiency are combined in quadrature, resulting in an overall uncertainty in the dimuon (dielectron) efficiency of 1.7% (2.5%).

All the uncertainties above are evaluated in bins of dilepton rapidity and transverse momentum to give uncertainties in the differential cross sections. The systematic uncertainty of the forward–backward asymmetry is calculated from the rapidity differential cross section. The uncertainties in the background, electron energy scale, and efficiency are propagated without assuming any cancellation. The uncertainty of the luminosity cancels in the ratio.

There is an additional uncertainty in the dilepton p_T spectrum coming from the matrix inversion procedure used for the unfolding. This uncertainty is determined by varying the generated dilepton p_T distribution and the single lepton p_T resolution. The reconstructed p_T distributions from PYTHIA 6+HIJING and POWHEG+PYTHIA 6, as well as the weighted p_T spectrum reflecting possible nPDF differences, are all studied and their effect on the results is directly evaluated. These two sources give a combined uncertainty in the unfolded yield of about 1–5%, depending on the p_T bin.

The uncertainty due to the acceptance correction is estimated by changing the shape of the generated rapidity and p_T distributions of the Z bosons with the same functions as described for the efficiency uncertainty in order to cover differences in PDFs and possible nuclear effects. The resulting uncertainty in the acceptance is about 5% from the extrapolation to the most forward and

Table 1
Summary of systematic uncertainties in the two decay channels.

Source	Z $\to \mu\mu$		Z $\to$ ee
Background	1.7%		1.8%
Electron energy scale	–		0.5%
Electron resolution	–		1.1%
Efficiency	1.7%		2.5%
Unfolding of p_T spectrum		1–5%	
Acceptance		5%	
Luminosity		3.5%	
Total (fiducial cross section)	4.2%		4.8%
Total (total cross section)	6.6%		6.9%

backward rapidity regions and it only affects the total cross section. Table 1 summarizes the systematic uncertainties in the two decay channels.

4. Results

The results are primarily compared to the NLO pp predictions from the POWHEG+PYTHIA 6 generator using the CT10 [39] free proton PDF set. The pN $\to$ Z $\to \ell\ell$ process is also simulated with the MCFM [40] generator (version 6.7) using the CT10 free proton PDF set, as well as the EPS09 [14] and DSSZ [13] nuclear PDF sets. Since these predictions include theoretical uncertainties, their statistical compatibility with the measurements can be tested. All predictions are scaled by the number of nucleons in the Pb nucleus ($A = 208$) as is expected in the case of elementary nucleon–nucleon collision scaling.

The cross section of Z boson production is calculated using Eq. (2) for both decay channels. The analysis of the muon channel results in a fiducial cross section ($p_T^\ell > 20$ GeV/c, $|\eta_{lab}^\ell| < 2.4$) of 70.1 ± 1.5 (stat) ± 1.7 (syst) ± 2.5 (lumi) nb and the electron channel gives 73.9 ± 1.9 (stat) ± 2.8 (syst) ± 2.6 (lumi) nb.

The muon and electron results, which agree within statistical and systematic uncertainties, are combined, separating out the uncertainty related to the integrated luminosity. The best linear unbiased estimate (BLUE) technique [41] is applied, taking the muon and electron channel cross sections and their uncertainties in each bin to be uncorrelated.

The measured inclusive Z boson production cross section in the fiducial region, where both leptons fulfill the acceptance requirements is

$$\sigma_{pPb \to Z \to \ell\ell}(p_T^\ell > 20 \text{ GeV}/c, |\eta_{lab}^\ell| < 2.4)$$
$$= 71.3 \pm 1.2 \text{ (stat)} \pm 1.5 \text{ (syst)} \pm 2.5 \text{ (lumi) nb.} \quad (3)$$

The POWHEG+PYTHIA 6 prediction gives a Z boson cross section in pp collisions at $\sqrt{s} = 5.02$ TeV of 338 ± 17 pb for Z $\to \ell\ell$ production in the 60–120 GeV/c^2 mass range after applying the acceptance requirements on the leptons. The uncertainties in the theoretical prediction in pp collisions amount to about 5% and arise from missing higher-order corrections and from the uncertainties in the PDF sets. Scaling the pp cross section by $A = 208$, results in the prediction of 70.4 ± 3.5 nb for the pPb cross section, which is consistent with the measured value.

For the acceptance-corrected total cross section, the systematic uncertainty in the acceptance is correlated between the two decay channels, which is taken into account in the BLUE method. The combined total Z boson production cross section in the 60–120 GeV/c^2 mass region is

$$\sigma_{pPb \to Z \to \ell\ell} = 138.1 \pm 2.4 \text{ (stat)} \pm 8.6 \text{ (syst)} \pm 4.8 \text{ (lumi) nb.} \quad (4)$$
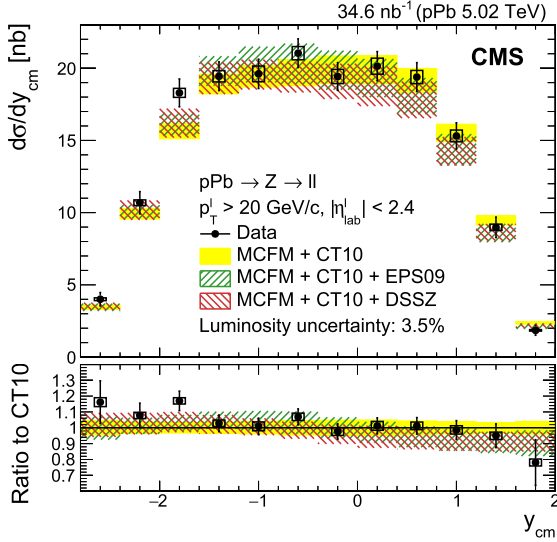
Fig. 2. Differential cross section of the Z bosons in pPb collisions as a function of rapidity in the fiducial region for the combined leptonic decay channel. Colored boxes are predictions from the MCFM generator, scaled by 208 (see text), and using nuclear (EPS09 and DSSZ) or free (CT10) PDF sets. The bottom panel shows the ratio of the data and the nPDF predictions to the CT10 PDF set. The vertical bars (boxes) represent the statistical (systematic) uncertainties.

This measurement has an uncertainty of about 5% from the extrapolation of the detector acceptance to the full phase space. The POWHEG+PYTHIA 6 generator after scaling predicts 136.1 ± 6.8 nb, which is consistent with the measured value.

Fig. 2 shows the differential cross section of the Z bosons in the fiducial region in pPb collisions as a function of rapidity. The luminosity normalization uncertainty of 3.5% is not shown. The MCFM theoretical predictions, both with and without nuclear modification, are consistent with the measured differential cross section within uncertainties. The corresponding rapidity dependence predicted by POWHEG+PYTHIA 6 for pp collisions agrees with the MCFM calculation for pN collisions using the CT10 PDF set without nuclear modification, showing that any dependences on isospin or the PDF set are within the theoretical uncertainties.

Nuclear effects are expected to modify the rapidity distribution asymmetrically and thus they can be further quantified by the forward–backward asymmetry defined in Eq. (1). This quantity is expected to be more sensitive to nuclear effects [24] because normalization uncertainties cancel both in theory and in experiment. Fig. 3 shows the measured forward–backward asymmetry as a function of $|y_{cm}|$ compared to the MCFM predictions with and without nuclear modification.

While being consistent with the three theoretical predictions shown, the data tend to favor the presence of nuclear effects in PDFs. The ATLAS collaboration reached similar conclusions from their Z boson measurement [19]. Together with the measured W boson production in pPb collisions [17], these results can reduce the nPDF uncertainties by adding new data to the global fits in a previously unexplored region of the (Q^2, x) phase space.

In order to quantify the agreement between the measurements and the predictions with the different PDF sets, a χ^2 test is performed for the rapidity-dependent differential cross section and the forward–backward asymmetry. The few correlations in the experimental uncertainties, only relevant for the cross section but not for the asymmetry, are taken into account, as well as the correlations in the theoretical uncertainties. The resulting χ^2 values and probabilities are given in Table 2. The theoretical calculations
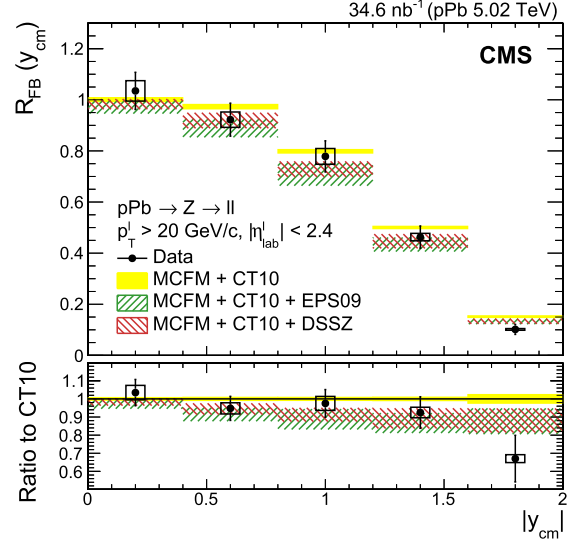

Fig. 3. Forward–backward asymmetry R_{FB} distribution of the Z bosons in pPb collisions as a function of rapidity in the fiducial region for the combined leptonic decay channel compared to the predictions from the MCFM generator with nuclear (EPS09 and DSSZ) or free (CT10) PDF sets. The bottom panel shows the ratio of the data and the nPDF predictions to the CT10 PDF set. The vertical bars (boxes) represent the statistical (systematic) uncertainties.
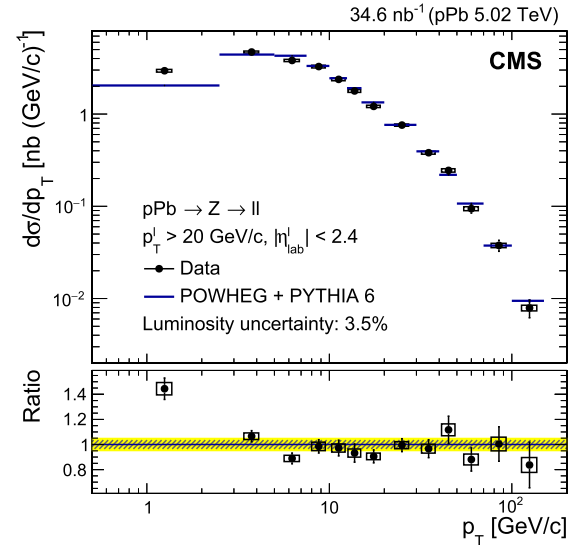

Fig. 4. Differential cross section of the Z bosons in pPb collisions as a function of transverse momentum in the fiducial region for the combined leptonic decay channel compared to the prediction from the POWHEG+PYTHIA 6 generator scaled by the number of nucleons in the Pb nucleus. The vertical bars (boxes) represent the statistical (systematic) uncertainties. The 3.5% luminosity uncertainty is shown in the ratio plot as a hashed band together with the assumed 5% theoretical uncertainty, shown as a yellow band. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

including nuclear effects provide a somewhat better description of the measurements.

Fig. 4 shows the differential cross section as a function of p_T in the fiducial region. The results are compared only to theoretical predictions from POWHEG+PYTHIA 6, because the expected nuclear modification of the p_T spectrum is small compared to the uncertainties in the theory [21,22]. No large deviations are found from the theoretical cross sections, apart from the lowest dilepton p_T bins where the differences from POWHEG+PYTHIA 6 are similar to the ones observed in the pp measurements at 7 TeV [2,4].

Table 2

Results of the χ^2 test between the measurements and the theoretical predictions with and without nuclear modification from the EPS09 or DSSZ nPDF sets. The differential cross section and the forward–backward asymmetry have twelve and five numbers of degrees of freedom (NDF), respectively.

Observable	CT10		CT10+EPS09		CT10+DSSZ	
	χ^2/NDF	Probability	χ^2/NDF	Probability	χ^2/NDF	Probability
$d\sigma/dy_{cm}$	10.8/12	54%	7.4/12	83%	6.6/12	88%
R_{FB}	7.3/5	20%	3.9/5	56%	3.4/5	64%

5. Summary

The cross section of Z boson production has been measured in the muon and electron decay channels in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The NLO pp inclusive cross section from POWHEG+PYTHIA 6 scaled by the number of elementary nucleon–nucleon collisions is in agreement with the measured pPb cross section. The pPb theoretical predictions for the differential cross section as a function of the Z boson rapidity with and without nuclear effects are compared to the measurement. Given the small differences in these predictions and their inherent theoretical uncertainties as well as the sensitivity of the data, both scenarios, presence or not of nuclear effects, are consistent with the data. A more sensitive variable, the forward–backward asymmetry, deviates from predictions assuming free proton PDFs by an amount which is compatible with both the EPS09 and the DSSZ nPDF modifications, although the statistical precision of the measurement precludes making a definitive statement. The differential cross section as a function of the Z boson transverse momentum has been measured and is found to be in agreement with pp predictions from POWHEG+PYTHIA 6, except at very low transverse momentum, where similar deviations as previously seen in pp are observed. The presented results provide new data for constraining nuclear PDF fits.

References

[1] ATLAS Collaboration, Measurement of the inclusive $W^{\pm}$ and Z/γ^* cross sections in the e and μ decay channels in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, Phys. Rev. D 85 (2012) 072004, http://dx.doi.org/10.1103/PhysRevD.85.072004, arXiv:1109.5141.

[2] ATLAS Collaboration, Measurement of the transverse momentum distribution of Z/γ^* bosons in proton–proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, Phys. Lett. B 705 (2011) 415, http://dx.doi.org/10.1016/j.physletb.2011.10.018, arXiv:1107.2381.

[3] CMS Collaboration, Measurement of the inclusive W and Z production cross sections in pp collisions at $\sqrt{s} = 7$ TeV, J. High Energy Phys. 10 (2011) 132, http://dx.doi.org/10.1007/JHEP10(2011)132, arXiv:1107.4789.

[4] CMS Collaboration, Measurement of the rapidity and transverse momentum distributions of Z bosons in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Rev. D 85 (2012) 032002, http://dx.doi.org/10.1103/PhysRevD.85.032002, arXiv:1110.4973.

[5] CMS Collaboration, Measurement of inclusive W and Z boson production cross sections in pp collisions at $\sqrt{s} = 8$ TeV, Phys. Rev. Lett. 112 (2014) 191802, http://dx.doi.org/10.1103/PhysRevLett.112.191802, arXiv:1402.0923.

[6] CMS Collaboration, Measurement of the Z boson differential cross section in transverse momentum and rapidity in proton–proton collisions at 8 TeV, Phys. Lett. B 749 (2015) 187, http://dx.doi.org/10.1016/j.physletb.2015.07.065, arXiv:1504.03511.

[7] LHCb Collaboration, Measurement of the cross-section for Z → e^+e^- production in pp collisions at $\sqrt{s} = 7$ TeV, J. High Energy Phys. 02 (2013) 106, http://dx.doi.org/10.1007/JHEP02(2013)106, arXiv:1212.4620.

[8] LHCb Collaboration, Inclusive W and Z production in the forward region at $\sqrt{s} = 7$ TeV, J. High Energy Phys. 06 (2012) 058, http://dx.doi.org/10.1007/JHEP06(2012)058, arXiv:1204.1620.

[9] ATLAS Collaboration, Measurement of Z boson production in pb–pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector, Phys. Rev. Lett. 110 (2013) 022301, http://dx.doi.org/10.1103/PhysRevLett.110.022301, arXiv:1210.6486.

[10] ATLAS Collaboration, Measurement of the production and lepton charge asymmetry of W bosons in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector, Eur. Phys. J. C 75 (2015) 23, http://dx.doi.org/10.1140/epjc/s10052-014-3231-6, arXiv:1408.4674.

[11] CMS Collaboration, Study of Z production in PbPb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV in the dimuon and dielectron decay channels, J. High Energy Phys. 03 (2015) 022, http://dx.doi.org/10.1007/JHEP03(2015)022, arXiv:1410.4825.

[12] CMS Collaboration, Study of W boson production in PbPb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B 715 (2012) 66, http://dx.doi.org/10.1016/j.physletb.2012.07.025, arXiv:1205.6334.

[13] D. de Florian, R. Sassot, P. Zurita, M. Stratmann, Global analysis of nuclear parton distributions, Phys. Rev. D 85 (2012) 074028, http://dx.doi.org/10.1103/PhysRevD.85.074028, arXiv:1112.6324.

[14] K.J. Eskola, H. Paukkunen, C.A. Salgado, EPS09 – a new generation of NLO and LO nuclear parton distribution functions, J. High Energy Phys. 04 (2009) 065, http://dx.doi.org/10.1088/1126-6708/2009/04/065, arXiv:0902.4154.

[15] M. Hirai, S. Kumano, T.-H. Nagai, Determination of nuclear parton distribution functions and their uncertainties in next-to-leading order, Phys. Rev. C 76 (2007) 065207, http://dx.doi.org/10.1103/PhysRevC.76.065207, arXiv:0709.3038.

[16] C.A. Salgado, The physics potential of proton–nucleus collisions at the TeV scale, J. Phys. G 38 (2011) 124036, http://dx.doi.org/10.1088/0954-3899/38/12/124036, arXiv:1108.5438.

[17] CMS Collaboration, Study of W boson production in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, Phys. Lett. B 750 (2015) 565, http://dx.doi.org/10.1016/j.physletb.2015.09.057, arXiv:1503.05825.

[18] CMS Collaboration, Studies of dijet transverse momentum balance and pseudorapidity distributions in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, Eur. Phys. J. C 74 (2014) 2951, http://dx.doi.org/10.1140/epjc/s10052-014-2951-y, arXiv:1401.4433.

[19] ATLAS Collaboration, Z boson production in p + Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV measured with the ATLAS detector, Phys. Rev. C 92 (2015) 044915, http://dx.doi.org/10.1103/PhysRevC.92.044915, arXiv:1507.06232.

[20] CMS Collaboration, Nuclear effects on the transverse momentum spectra of charged particles in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, Eur. Phys. J. C 75 (2015) 237, http://dx.doi.org/10.1140/epjc/s10052-015-3435-4, arXiv:1502.05387.

[21] V. Guzey, M. Guzzi, P.M. Nadolsky, M. Strikman, B. Wang, Massive neutral gauge boson production as a probe of nuclear modifications of parton distributions at the LHC, Eur. Phys. J. A 49 (2013) 35, http://dx.doi.org/10.1140/epja/i2013-13035-6, arXiv:1212.5344.

[22] Z.-B. Kang, J.-W. Qiu, Nuclear modification of vector boson production in proton–lead collisions at the LHC, Phys. Lett. B 721 (2013) 277, http://dx.doi.org/10.1016/j.physletb.2013.03.030, arXiv:1212.6541.

[23] V. Kartvelishvili, R. Kvatadze, R. Shanidze, On Z and Z+jet production in heavy ion collisions, Phys. Lett. B 356 (1995) 589, http://dx.doi.org/10.1016/0370-2693(95)00865-I, arXiv:hep-ph/9505418.

[24] H. Paukkunen, C.A. Salgado, Constraints for the nuclear parton distributions from Z and $W^{\pm}$ production at the LHC, J. High Energy Phys. 03 (2011) 071, http://dx.doi.org/10.1007/JHEP03(2011)071, arXiv:1010.5392.

[25] R. Vogt, Shadowing effects on vector boson production, Phys. Rev. C 64 (2001) 044901, http://dx.doi.org/10.1103/PhysRevC.64.044901, arXiv:hep-ph/0011242.

[26] CMS Collaboration, The CMS experiment at the CERN LHC, J. Instrum. 3 (2008) S08004, http://dx.doi.org/10.1088/1748-0221/3/08/S08004.

[27] CMS Collaboration, Luminosity calibration for the 2013 proton–lead and proton–proton data taking, CMS Physics Analysis Summary CMS-PAS-LUM-13-002, http://cds.cern.ch/record/1643269, 2014.

[28] CMS Collaboration, Performance of CMS muon reconstruction in pp collision events at $\sqrt{s}$ = 7 TeV, J. Instrum. 7 (2012) P10002, http://dx.doi.org/10.1088/1748-0221/7/10/P10002, arXiv:1206.4071.

[29] CMS Collaboration, Energy calibration and resolution of the CMS electromag-netic calorimeter in pp collisions at $\sqrt{s}$ = 7 TeV, J. Instrum. 8 (2013) P09009, http://dx.doi.org/10.1088/1748-0221/8/09/P09009, arXiv:1306.2016.

[30] CMS Collaboration, Performance of electron reconstruction and selection with the CMS detector in proton–proton collisions at $\sqrt{s}$ = 8 TeV, J. Instrum. 10 (2015) P06005, http://dx.doi.org/10.1088/1748-0221/10/06/P06005, arXiv:1502.02701.

[31] T. Sjöstrand, S. Mrenna, P. Skands, PYTHIA 6.4 physics and manual, J. High Energy Phys. 05 (2006) 026, http://dx.doi.org/10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.

[32] R. Field, Early LHC underlying event data – findings and surprises, arXiv:1010.3558, 2010.

[33] M. Gyulassy, X.-N. Wang, HIJING 1.0: a Monte Carlo program for parton and particle production in high-energy hadronic and nuclear collisions, Comput. Phys. Commun. 83 (1994) 307, http://dx.doi.org/10.1016/0010-4655(94)90057-4, arXiv:nucl-th/9502021.

[34] S. Agostinelli, et al., GEANT4, GEANT4—a simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A, Accel. Spectrom. Detect. Assoc. Equip. 506 (2003) 250, http://dx.doi.org/10.1016/S0168-9002(03)01368-8.

[35] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, J. High Energy Phys. 11 (2004) 040, http://dx.doi.org/10.1088/1126-6708/2004/11/040, arXiv:hep-ph/0409146.

[36] S. Frixione, P. Nason, C. Oleari, Matching NLO QCD computations with parton shower simulations: the POWHEG method, J. High Energy Phys. 11 (2007) 070, http://dx.doi.org/10.1088/1126-6708/2007/11/070, arXiv:0709.2092.

[37] S. Alioli, P. Nason, C. Oleari, E. Re, NLO vector-boson production matched with shower in POWHEG, J. High Energy Phys. 07 (2008) 060, http://dx.doi.org/10.1088/1126-6708/2008/07/060, arXiv:0805.4802.

[38] S. Alioli, P. Nason, C. Oleari, E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX, J. High Energy Phys. 06 (2010) 043, http://dx.doi.org/10.1007/JHEP06(2010)043, arXiv:1002.2581.

[39] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P.M. Nadolsky, J. Pumplin, C.-P. Yuan, New parton distributions for collider physics, Phys. Rev. D 82 (2010) 074024, http://dx.doi.org/10.1103/PhysRevD.82.074024, arXiv:1007.2241.

[40] J.M. Campbell, R.K. Ellis, C. Williams, Vector boson pair production at the LHC, J. High Energy Phys. 07 (2011) 018, http://dx.doi.org/10.1007/JHEP07(2011)018, arXiv:1105.0020.

[41] L. Lyons, D. Gibaut, P. Clifford, How to combine correlated estimates of a single physical quantity, Nucl. Instrum. Methods Phys. Res., Sect. A, Accel. Spectrom. Detect. Assoc. Equip. 270 (1988) 110, http://dx.doi.org/10.1016/0168-9002(88)90018-6.

CMS Collaboration

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

Yerevan Physics Institute, Yerevan, Armenia

W. Adam, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, M. Flechl, M. Friedl, R. Frühwirth [1], V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler [1], V. Knünz, A. König, M. Krammer [1], I. Krätschmer, D. Liko, T. Matsushita, I. Mikulec, D. Rabady [2], N. Rad, B. Rahbaran, H. Rohringer, J. Schieck [1], R. Schöfbeck, J. Strauss, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz [1]

Institut für Hochenergiephysik der OeAW, Wien, Austria

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

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

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

Universiteit Antwerpen, Antwerpen, 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

Vrije Universiteit Brussel, Brussel, Belgium

P. Barria, H. Brun, C. Caillol, B. Clerbaux, G. De Lentdecker, W. Fang, G. Fasanella, L. Favart, R. Goldouzian, A. Grebenyuk, G. Karapostoli, T. Lenzi, A. Léonard, T. Maerschalk, A. Marinov, L. Perniè, A. Randle-conde, T. Seva, C. Vander Velde, P. Vanlaer, R. Yonamine, F. Zenoni, F. Zhang [3]

Université Libre de Bruxelles, Bruxelles, 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, M. Tytgat, W. Van Driessche, E. Yazgan, N. Zaganidis

Ghent University, Ghent, Belgium

S. Basegmez, C. Beluffi [4], O. Bondu, S. Brochet, G. Bruno, A. Caudron, L. Ceard, C. Delaere, M. Delcourt, D. Favart, L. Forthomme, A. Giammanco, A. Jafari, P. Jez, M. Komm, V. Lemaitre, A. Mertens, M. Musich, C. Nuttens, L. Perrini, K. Piotrzkowski, A. Popov [5], L. Quertenmont, M. Selvaggi, M. Vidal Marono

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

N. Beliy, G.H. Hammad

Université de Mons, Mons, Belgium

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

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

E. Belchior Batista Das Chagas, W. Carvalho, J. Chinellato [6], 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, C. Mora Herrera, L. Mundim, H. Nogima, W.L. Prado Da Silva, A. Santoro, A. Sznajder, E.J. Tonelli Manganote [6], A. Vilela Pereira

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, 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,7], S.F. Novaes [a], Sandra S. Padula [a], D. Romero Abad [b], J.C. Ruiz Vargas

[a] *Universidade Estadual Paulista, São Paulo, Brazil*
[b] *Universidade Federal do ABC, São Paulo, Brazil*

A. Aleksandrov, R. Hadjiiska, P. Iaydjiev, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

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

University of Sofia, Sofia, Bulgaria

M. Ahmad, J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, T. Cheng, R. Du, C.H. Jiang, D. Leggat, R. Plestina [8], F. Romeo, S.M. Shaheen, A. Spiezia, J. Tao, C. Wang, Z. Wang, H. Zhang

Institute of High Energy Physics, Beijing, China

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

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

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

Universidad de Los Andes, Bogota, Colombia

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

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

Z. Antunovic, M. Kovac

University of Split, Faculty of Science, Split, Croatia

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

Institute Rudjer Boskovic, Zagreb, Croatia

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

University of Cyprus, Nicosia, Cyprus

M. Bodlak, M. Finger [9], M. Finger Jr. [9]

Charles University, Prague, Czech Republic

E. El-khateeb [10], T. Elkafrawy [10], A. Mohamed [11], E. Salama [12,10]

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

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

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

P. Eerola, J. Pekkanen, M. Voutilainen

Department of Physics, University of Helsinki, Helsinki, Finland

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

Helsinki Institute of Physics, Helsinki, Finland

J. Talvitie, T. Tuuva

Lappeenranta University of Technology, Lappeenranta, Finland

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

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

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

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

J.-L. Agram [13], J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, M. Buttignol, E.C. Chabert, N. Chanon, C. Collard, E. Conte [13], X. Coubez, J.-C. Fontaine [13], D. Gelé, U. Goerlach, C. Goetzmann, A.-C. Le Bihan, J.A. Merlin [2], K. Skovpen, P. Van Hove

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

S. Gadrat

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

S. Beauceron, C. Bernet, G. Boudoul, E. Bouvier, C.A. Carrillo Montoya, 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, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret

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

T. Toriashvili [14]

Georgian Technical University, Tbilisi, Georgia

Z. Tsamalaidze [9]

Tbilisi State University, Tbilisi, Georgia

C. Autermann, S. Beranek, 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, V. Zhukov [5]

RWTH Aachen University, I. Physikalisches Institut, 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, S. Knutzen, P. Kreuzer, M. Merschmeyer, A. Meyer, P. Millet, S. Mukherjee, 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 A, Aachen, Germany

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

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

M. Aldaya Martin, I. Asin, N. Bartosik, O. Behnke, U. Behrens, K. Borras [15], A. Burgmeier, A. Campbell, C. Contreras-Campana, F. Costanza, C. Diez Pardos, G. Dolinska, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, E. Gallo [16], J. Garay Garcia, A. Geiser, A. Gizhko, P. Gunnellini, J. Hauk, M. Hempel [17], H. Jung, A. Kalogeropoulos, O. Karacheban [17], M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, I. Korol, W. Lange, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann [17], R. Mankel, 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, C. Seitz, S. Spannagel, N. Stefaniuk, K.D. Trippkewitz, R. Walsh, C. Wissing

Deutsches Elektronen-Synchrotron, 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, N. Kovalchuk, T. Lapsien, T. Lenz, I. Marchesini, D. Marconi, M. Meyer, D. Nowatschin, J. Ott, F. Pantaleo [2], T. Peiffer, A. Perieanu, N. Pietsch, J. Poehlsen, D. Rathjens, C. Sander, C. Scharf, P. Schleper, E. Schlieckau, A. Schmidt, S. Schumann, J. Schwandt, V. Sola, H. Stadie, G. Steinbrück, F.M. Stober, H. Tholen, D. Troendle, E. Usai, L. Vanelderen, A. Vanhoefer, B. Vormwald

University of Hamburg, Hamburg, Germany

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, R. Friese, M. Giffels, A. Gilbert, D. Haitz, F. Hartmann [2], S.M. Heindl, U. Husemann, I. Katkov [5], A. Kornmayer [2], P. Lobelle Pardo, B. Maier, H. Mildner, M.U. Mozer, T. Müller, Th. Müller, M. Plagge, G. Quast, K. Rabbertz, S. Röcker, F. Roscher, M. Schröder, G. Sieber, H.J. Simonis, R. Ulrich, J. Wagner-Kuhr, S. Wayand, M. Weber, T. Weiler, S. Williamson, C. Wöhrmann, R. Wolf

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

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

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

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

National and Kapodistrian University of Athens, Athens, Greece

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

University of Ioánnina, Ioánnina, Greece

G. Bencze, C. Hajdu, A. Hazi, P. Hidas, D. Horvath [18], F. Sikler, V. Veszpremi, G. Vesztergombi [19], A.J. Zsigmond

Wigner Research Centre for Physics, Budapest, Hungary

N. Beni, S. Czellar, J. Karancsi [20], J. Molnar, Z. Szillasi [2]

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

M. Bartók [21], A. Makovec, P. Raics, Z.L. Trocsanyi, B. Ujvari

University of Debrecen, Debrecen, Hungary

S. Choudhury [22], P. Mal, K. Mandal, D.K. Sahoo, N. Sahoo, S.K. Swain

National Institute of Science Education and Research, Bhubaneswar, 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, J.B. Singh, G. Walia

Panjab University, Chandigarh, India

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

University of Delhi, Delhi, India

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

Saha Institute of Nuclear Physics, Kolkata, India

R. Chudasama, D. Dutta, V. Jha, V. Kumar, A.K. Mohanty [2], L.M. Pant, P. Shukla, A. Topkar

Bhabha Atomic Research Centre, Mumbai, India

T. Aziz, S. Banerjee, S. Bhowmik [23], R.M. Chatterjee, R.K. Dewanjee, S. Dugad, S. Ganguly, S. Ghosh, M. Guchait, A. Gurtu [24], Sa. Jain, G. Kole, S. Kumar, B. Mahakud, M. Maity [23], G. Majumder, K. Mazumdar, S. Mitra, G.B. Mohanty, B. Parida, T. Sarkar [23], N. Sur, B. Sutar, N. Wickramage [25]

Tata Institute of Fundamental Research, Mumbai, India

S. Chauhan, S. Dube, A. Kapoor, K. Kothekar, S. Sharma

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

H. Bakhshiansohi, H. Behnamian, S.M. Etesami [26], A. Fahim [27], M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, F. Rezaei Hosseinabadi, B. Safarzadeh [28], M. Zeinali

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

M. Felcini, M. Grunewald

University College Dublin, Dublin, Ireland

M. Abbrescia [a,b], C. Calabria [a,b], C. Caputo [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]

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

G. Abbiendi [a], C. Battilana [2], 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], S.S. Chhibra [a,b], 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,2]

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

G. Cappello [b], M. Chiorboli [a,b], S. Costa [a,b], A. Di Mattia [a], F. Giordano [a,b], R. Potenza [a,b], A. Tricomi [a,b], C. Tuve [a,b]

a *INFN Sezione di Catania, Catania, Italy*
b *Università di Catania, Catania, Italy*

G. Barbagli [a], V. Ciulli [a,b], C. Civinini [a], R. D'Alessandro [a,b], E. Focardi [a,b], V. Gori [a,b], P. Lenzi [a,b], M. Meschini [a], S. Paoletti [a], G. Sguazzoni [a], L. Viliani [a,b,2]

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

L. Benussi, S. Bianco, F. Fabbri, D. Piccolo, F. Primavera [2]

INFN Laboratori Nazionali di Frascati, Frascati, 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]

a *INFN Sezione di Genova, Genova, Italy*
b *Università di Genova, Genova, 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,2], B. Marzocchi [a,b], 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]

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

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

P. Azzi [a,2], N. Bacchetta [a], L. Benato [a,b], D. Bisello [a,b], A. Boletti [a,b], R. Carlin [a,b], P. Checchia [a], M. Dall'Osso [a,b,2], T. Dorigo [a], U. Dosselli [a], F. Gasparini [a,b], U. Gasparini [a,b], A. Gozzelino [a], S. Lacaprara [a], M. Margoni [a,b], A.T. Meneguzzo [a,b], M. Passaseo [a], J. Pazzini [a,b,2], M. Pegoraro [a], N. Pozzobon [a,b], P. Ronchese [a,b], F. Simonetto [a,b], E. Torassa [a], M. Tosi [a,b], S. Ventura [a], M. Zanetti, P. Zotto [a,b],

A. Zucchetta [a,b,2], G. Zumerle [a,b]

[a] *INFN Sezione di Padova, Padova, Italy*
[b] *Università di Padova, Padova, Italy*
[c] *Università di Trento, Trento, Italy*

A. Braghieri [a], A. Magnani [a,b], P. Montagna [a,b], S.P. Ratti [a,b], V. Re [a], C. Riccardi [a,b], P. Salvini [a], I. Vai [a,b], P. Vitulo [a,b]

[a] *INFN Sezione di Pavia, Pavia, Italy*
[b] *Università di Pavia, Pavia, Italy*

L. Alunni Solestizi [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] *INFN Sezione di Perugia, Perugia, Italy*
[b] *Università di Perugia, Perugia, Italy*

K. Androsov [a,29], P. Azzurri [a,2], G. Bagliesi [a], J. Bernardini [a], T. Boccali [a], R. Castaldi [a], M.A. Ciocci [a,29], R. Dell'Orso [a], S. Donato [a,c,2], G. Fedi, L. Foà [a,c,†], A. Giassi [a], M.T. Grippo [a,29], 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,30], A.T. Serban [a], P. Spagnolo [a], R. Tenchini [a], G. Tonelli [a,b], A. Venturi [a], P.G. Verdini [a]

[a] *INFN Sezione di Pisa, Pisa, Italy*
[b] *Università di Pisa, Pisa, Italy*
[c] *Scuola Normale Superiore di Pisa, Pisa, Italy*

L. Barone [a,b], F. Cavallari [a], G. D'imperio [a,b,2], D. Del Re [a,b,2], M. Diemoz [a], S. Gelli [a,b], C. Jorda [a], E. Longo [a,b], F. Margaroli [a,b], P. Meridiani [a], 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]

[a] *INFN Sezione di Roma, Roma, Italy*
[b] *Università di Roma, Roma, 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], B. Kiani [a,b], C. Mariotti [a], S. Maselli [a], E. Migliore [a,b], V. Monaco [a,b], E. Monteil [a,b], 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]

[a] *INFN Sezione di Torino, Torino, Italy*
[b] *Università di Torino, Torino, Italy*
[c] *Università del Piemonte Orientale, Novara, Italy*

S. Belforte [a], V. Candelise [a,b], 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], A. Zanetti [a]

[a] *INFN Sezione di Trieste, Trieste, Italy*
[b] *Università di Trieste, Trieste, Italy*

A. Kropivnitskaya, S.K. Nam

Kangwon National University, Chunchon, Republic of Korea

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

Kyungpook National University, Daegu, Republic of Korea

J.A. Brochero Cifuentes, H. Kim, T.J. Kim

Chonbuk National University, Jeonju, Republic of Korea

S. Song

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

S. Cho, S. Choi, Y. Go, D. Gyun, B. Hong, H. Kim, Y. Kim, B. Lee, K. Lee, K.S. Lee, S. Lee, J. Lim, S.K. Park, Y. Roh

Korea University, Seoul, Republic of Korea

H.D. Yoo

Seoul National University, Seoul, Republic of Korea

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

University of Seoul, Seoul, Republic of Korea

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

Sungkyunkwan University, Suwon, Republic of Korea

V. Dudenas, A. Juodagalvis, J. Vaitkus

Vilnius University, Vilnius, Lithuania

I. Ahmed, Z.A. Ibrahim, J.R. Komaragiri, M.A.B. Md Ali [31], F. Mohamad Idris [32], W.A.T. Wan Abdullah, M.N. Yusli, Z. Zolkapli

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

E. Casimiro Linares, H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz [33], A. Hernandez-Almada, R. Lopez-Fernandez, J. Mejia Guisao, A. Sanchez-Hernandez

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

S. Carrillo Moreno, F. Vazquez Valencia

Universidad Iberoamericana, Mexico City, Mexico

I. Pedraza, H.A. Salazar Ibarguen

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

A. Morelos Pineda

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

D. Krofcheck

University of Auckland, Auckland, New Zealand

P.H. Butler

University of Canterbury, Christchurch, New Zealand

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

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

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

National Centre for Nuclear Research, Swierk, Poland

G. Brona, K. Bunkowski, A. Byszuk [34], K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, M. Walczak

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland

P. Bargassa, C. Beirão Da Cruz E Silva, A. Di Francesco, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, J. Hollar, N. Leonardo, L. Lloret Iglesias, F. Nguyen, J. Rodrigues Antunes, J. Seixas, O. Toldaiev, D. Vadruccio, J. Varela, P. Vischia

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal

S. Afanasiev, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, A. Lanev, A. Malakhov, V. Matveev [35,36], P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, A. Zarubin

Joint Institute for Nuclear Research, Dubna, Russia

V. Golovtsov, Y. Ivanov, V. Kim [37], E. Kuznetsova, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia

Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, A. Karneyeu, M. Kirsanov, N. Krasnikov, A. Pashenkov, D. Tlisov, A. Toropin

Institute for Nuclear Research, Moscow, Russia

V. Epshteyn, V. Gavrilov, N. Lychkovskaya, V. Popov, I. Pozdnyakov, G. Safronov, A. Spiridonov, E. Vlasov, A. Zhokin

Institute for Theoretical and Experimental Physics, Moscow, Russia

M. Chadeeva, R. Chistov, M. Danilov, V. Rusinov, E. Tarkovskii

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

V. Andreev, M. Azarkin [36], I. Dremin [36], M. Kirakosyan, A. Leonidov [36], G. Mesyats, S.V. Rusakov

P.N. Lebedev Physical Institute, Moscow, Russia

A. Baskakov, A. Belyaev, E. Boos, A. Ershov, A. Gribushin, A. Kaminskiy [38], O. Kodolova, V. Korotkikh, I. Lokhtin, I. Miagkov, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev, I. Vardanyan

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia

P. Adzic [39], P. Cirkovic, D. Devetak, J. Milosevic, V. Rekovic

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia

J. Alcaraz Maestre, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, 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

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain

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

Universidad Autónoma de Madrid, Madrid, Spain

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

Universidad de Oviedo, Oviedo, Spain

I.J. Cabrillo, A. Calderon, J.R. Castiñeiras De Saa, E. Curras, P. De Castro Manzano, M. Fernandez, J. Garcia-Ferrero, G. Gomez, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, J. Piedra Gomez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, N. Trevisani, I. Vila, R. Vilar Cortabitarte

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

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, A. Benaglia, J. Bendavid, L. Benhabib, G.M. Berruti, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, R. Castello, M. Cepeda, G. Cerminara, 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 [40], M. Dobson, M. Dordevic, B. Dorney, T. du Pree, D. Duggan, M. Dünser, N. Dupont, A. Elliott-Peisert, G. Franzoni, J. Fulcher, W. Funk, D. Gigi, K. Gill, D. Giordano, M. Girone, F. Glege, R. Guida, S. Gundacker, M. Guthoff, J. Hammer, 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. Orfanelli [41], L. Orsini, L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, D. Piparo, A. Racz, T. Reis, G. Rolandi [42], M. Rovere, M. Ruan, H. Sakulin, C. Schäfer, C. Schwick, M. Seidel, A. Sharma, P. Silva, M. Simon, P. Sphicas [43], J. Steggemann, B. Stieger, M. Stoye, Y. Takahashi, D. Treille, A. Triossi, A. Tsirou, G.I. Veres [19], N. Wardle, H.K. Wöhri, A. Zagozdzinska [34], W.D. Zeuner

CERN, European Organization for Nuclear Research, Geneva, Switzerland

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

Paul Scherrer Institut, Villigen, Switzerland

F. Bachmair, L. Bäni, L. Bianchini, B. Casal, G. Dissertori, M. Dittmar, M. Donegà, P. Eller, C. Grab, C. Heidegger, D. Hits, J. Hoss, G. Kasieczka, P. Lecomte [†], W. Lustermann, B. Mangano, M. Marionneau, P. Martinez Ruiz del Arbol, M. Masciovecchio, M.T. Meinhard, D. Meister, F. Micheli, P. Musella, F. Nessi-Tedaldi, F. Pandolfi, J. Pata, F. Pauss, G. Perrin, L. Perrozzi, M. Quittnat, M. Rossini, M. Schönenberger, A. Starodumov [44], M. Takahashi, V.R. Tavolaro, K. Theofilatos, R. Wallny

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

T.K. Aarrestad, C. Amsler [45], L. Caminada, M.F. Canelli, V. Chiochia, A. De Cosa, C. Galloni, A. Hinzmann, T. Hreus, B. Kilminster, C. Lange, J. Ngadiuba, D. Pinna, G. Rauco, P. Robmann, D. Salerno, Y. Yang

Universität Zürich, Zurich, Switzerland

K.H. Chen, T.H. Doan, Sh. Jain, R. Khurana, M. Konyushikhin, C.M. Kuo, W. Lin, Y.J. Lu, A. Pozdnyakov, S.Y. Tseng, S.S. Yu

National Central University, Chung-Li, Taiwan

Arun Kumar, 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

National Taiwan University (NTU), Taipei, Taiwan

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

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

A. Adiguzel, S. Cerci [46], S. Damarseckin, Z.S. Demiroglu, C. Dozen, I. Dumanoglu, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E.E. Kangal [47], A. Kayis Topaksu, G. Onengut [48], K. Ozdemir [49], S. Ozturk [50], B. Tali [46], H. Topakli [50], C. Zorbilmez

Cukurova University, Adana, Turkey

B. Bilin, S. Bilmis, B. Isildak [51], G. Karapinar [52], M. Yalvac, M. Zeyrek

Middle East Technical University, Physics Department, Ankara, Turkey

E. Gülmez, M. Kaya [53], O. Kaya [54], E.A. Yetkin [55], T. Yetkin [56]

Bogazici University, Istanbul, Turkey

A. Cakir, K. Cankocak, S. Sen [57], F.I. Vardarlı

Istanbul Technical University, Istanbul, Turkey

B. Grynyov

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

L. Levchuk, P. Sorokin

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

R. Aggleton, F. Ball, L. Beck, J.J. Brooke, D. Burns, 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. Newbold [58], S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, S. Senkin, D. Smith, V.J. Smith

University of Bristol, Bristol, United Kingdom

A. Belyaev [59], C. Brew, R.M. Brown, L. Calligaris, D. Cieri, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams, S.D. Worm

Rutherford Appleton Laboratory, Didcot, United Kingdom

M. Baber, R. Bainbridge, O. Buchmuller, A. Bundock, D. Burton, S. Casasso, M. Citron, D. Colling, L. Corpe, P. Dauncey, G. Davies, A. De Wit, M. Della Negra, P. Dunne, A. Elwood, D. Futyan, G. Hall, G. Iles, R. Lane, R. Lucas [58], L. Lyons, A.-M. Magnan, S. Malik, J. Nash, A. Nikitenko [44], J. Pela, M. Pesaresi, D.M. Raymond, A. Richards, A. Rose, C. Seez, A. Tapper, K. Uchida, M. Vazquez Acosta [60], T. Virdee, S.C. Zenz

Imperial College, London, United Kingdom

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

Brunel University, Uxbridge, United Kingdom

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

Baylor University, Waco, USA

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

The University of Alabama, Tuscaloosa, USA

D. Arcaro, A. Avetisyan, T. Bose, D. Gastler, D. Rankin, C. Richardson, J. Rohlf, L. Sulak, D. Zou

Boston University, Boston, USA

J. Alimena, G. Benelli, E. Berry, D. Cutts, A. Ferapontov, A. Garabedian, J. Hakala, U. Heintz, O. Jesus, E. Laird, G. Landsberg, Z. Mao, M. Narain, S. Piperov, S. Sagir, R. Syarif

Brown University, Providence, USA

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, G. Funk, M. Gardner, W. Ko, R. Lander, C. Mclean, 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, Davis, Davis, USA

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

University of California, Los Angeles, 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, M. Malberti, M. Olmedo Negrete, A. Shrinivas, H. Wei, S. Wimpenny, B.R. Yates

University of California, Riverside, Riverside, USA

J.G. Branson, G.B. Cerati, S. Cittolin, R.T. D'Agnolo, M. Derdzinski, 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. Wasserbaech [61], C. Welke, F. Würthwein, A. Yagil, G. Zevi Della Porta

University of California, San Diego, La Jolla, USA

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, N. Mccoll, S.D. Mullin, J. Richman, D. Stuart, I. Suarez, C. West, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA

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

California Institute of Technology, Pasadena, USA

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

Carnegie Mellon University, Pittsburgh, USA

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

University of Colorado Boulder, Boulder, 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

Cornell University, Ithaca, USA

S. Abdullin, M. Albrow, G. Apollinari, S. Banerjee, 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, S. Hasegawa, J. Hirschauer, Z. Hu, B. Jayatilaka, S. Jindariani, M. Johnson, U. Joshi, B. Klima, B. Kreis, S. Lammel, J. Lewis, J. Linacre, D. Lincoln, R. Lipton, T. Liu, R. Lopes De Sá, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, P. Merkel, 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, S. Stoynev, N. Strobbe, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, C. Vernieri, M. Verzocchi, R. Vidal, M. Wang, H.A. Weber, A. Whitbeck

Fermi National Accelerator Laboratory, Batavia, USA

D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, A. Brinkerhoff, A. Carnes, M. Carver, D. Curry, S. Das, R.D. Field, I.K. Furic, J. Konigsberg, A. Korytov, K. Kotov, P. Ma, K. Matchev, H. Mei, P. Milenovic [62], G. Mitselmakher, D. Rank, R. Rossin, L. Shchutska, M. Snowball, D. Sperka, N. Terentyev, L. Thomas, J. Wang, S. Wang, J. Yelton

University of Florida, Gainesville, USA

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

Florida International University, Miami, USA

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

Florida State University, Tallahassee, USA

M.M. Baarmand, V. Bhopatkar, S. Colafranceschi [63], M. Hohlmann, H. Kalakhety, D. Noonan, T. Roy, F. Yumiceva

Florida Institute of Technology, Melbourne, 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, P. Turner, N. Varelas, Z. Wu, M. Zakaria, J. Zhang

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

B. Bilki [64], W. Clarida, K. Dilsiz, S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya [65], A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok [66], A. Penzo, C. Snyder, E. Tiras, J. Wetzel, K. Yi

The University of Iowa, Iowa City, USA

I. Anderson, B.A. Barnett, B. Blumenfeld, A. Cocoros, N. Eminizer, D. Fehling, L. Feng, A.V. Gritsan, P. Maksimovic, M. Osherson, J. Roskes, U. Sarica, M. Swartz, M. Xiao, Y. Xin, C. You

Johns Hopkins University, Baltimore, USA

P. Baringer, A. Bean, C. Bruner, R.P. Kenny III, D. Majumder, M. Malek, W. Mcbrayer, M. Murray, S. Sanders, R. Stringer, Q. Wang

The University of Kansas, Lawrence, USA

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

Kansas State University, Manhattan, USA

D. Lange, F. Rebassoo, D. Wright

Lawrence Livermore National Laboratory, Livermore, 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

University of Maryland, College Park, USA

A. Apyan, R. Barbieri, A. Baty, R. Bi, K. Bierwagen, S. Brandt, W. Busza, I.A. Cali, Z. Demiragli, L. Di Matteo, G. Gomez Ceballos, M. Goncharov, D. Gulhan, Y. Iiyama, G.M. Innocenti, M. Klute, D. Kovalskyi, Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, A.C. Marini, C. Mcginn, C. Mironov, S. Narayanan, X. Niu, C. Paus, C. Roland, G. Roland, J. Salfeld-Nebgen, G.S.F. Stephans, K. Sumorok, K. Tatar, M. Varma, D. Velicanu, J. Veverka, J. Wang, T.W. Wang, B. Wyslouch, M. Yang, V. Zhukova

Massachusetts Institute of Technology, Cambridge, USA

A.C. Benvenuti, B. Dahmes, A. Evans, 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 Minnesota, Minneapolis, USA

J.G. Acosta, S. Oliveros

University of Mississippi, Oxford, USA

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

University of Nebraska-Lincoln, Lincoln, USA

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

State University of New York at Buffalo, Buffalo, 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

Northeastern University, Boston, USA

S. Bhattacharya, K.A. Hahn, A. Kubik, J.F. Low, N. Mucia, N. Odell, B. Pollack, M. Schmitt, K. Sung, M. Trovato, M. Velasco

Northwestern University, Evanston, USA

N. Dev, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, N. Marinelli, F. Meng, C. Mueller, Y. Musienko [35], M. Planer, A. Reinsvold, R. Ruchti, G. Smith, S. Taroni, N. Valls, M. Wayne, M. Wolf, A. Woodard

University of Notre Dame, Notre Dame, USA

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

The Ohio State University, Columbus, 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, D. Stickland, C. Tully, A. Zuranski

Princeton University, Princeton, USA

S. Malik

University of Puerto Rico, Mayaguez, USA

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

Purdue University, West Lafayette, USA

N. Parashar, J. Stupak

Purdue University Calumet, Hammond, 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

Rice University, Houston, USA

B. Betchart, A. Bodek, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, M. Galanti, A. Garcia-Bellido, J. Han, O. Hindrichs, A. Khukhunaishvili, K.H. Lo, P. Tan, M. Verzetti

University of Rochester, Rochester, USA

J.P. Chou, E. Contreras-Campana, D. Ferencek, Y. Gershtein, E. Halkiadakis, M. Heindl, D. Hidas, E. Hughes, S. Kaplan, R. Kunnawalkam Elayavalli, A. Lath, K. Nash, H. Saka, S. Salur, S. Schnetzer, D. Sheffield, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

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

M. Foerster, G. Riley, K. Rose, S. Spanier, K. Thapa

University of Tennessee, Knoxville, USA

O. Bouhali [67], A. Castaneda Hernandez [67], A. Celik, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, J. Gilmore, T. Huang, T. Kamon [68], V. Krutelyov, R. Mueller, I. Osipenkov, Y. Pakhotin, R. Patel, A. Perloff, A. Rose, A. Safonov, A. Tatarinov, K.A. Ulmer [2]

Texas A&M University, College Station, USA

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

Texas Tech University, Lubbock, USA

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

Vanderbilt University, Nashville, USA

M.W. Arenton, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, H. Li, C. Lin, C. Neu, T. Sinthuprasith, X. Sun, Y. Wang, E. Wolfe, J. Wood, F. Xia

University of Virginia, Charlottesville, USA

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

Wayne State University, Detroit, USA

D.A. Belknap, D. Carlsmith, S. Dasu, L. Dodd, S. Duric, B. Gomber, M. Grothe, 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, T. Ruggles, T. Sarangi, A. Savin, A. Sharma, N. Smith, W.H. Smith, D. Taylor, P. Verwilligen, N. Woods

University of Wisconsin – Madison, Madison, WI, USA

---

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

[5] Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.

[6] Also at Universidade Estadual de Campinas, Campinas, Brazil.

[7] Also at Centre National de la Recherche Scientifique (CNRS) – IN2P3, Paris, France.

[8] Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France.

[9] Also at Joint Institute for Nuclear Research, Dubna, Russia.

[10] Also at Ain Shams University, Cairo, Egypt.

[11] Also at Zewail City of Science and Technology, Zewail, Egypt.

[12] Also at British University in Egypt, Cairo, Egypt.

[13] Also at Université de Haute Alsace, Mulhouse, France.

[14] Also at Tbilisi State University, Tbilisi, Georgia.

[15] Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.

[16] Also at University of Hamburg, Hamburg, Germany.

[17] Also at Brandenburg University of Technology, Cottbus, Germany.

[18] Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.

[19] Also at Eötvös Loránd University, Budapest, Hungary.

[20] Also at University of Debrecen, Debrecen, Hungary.

[21] Also at Wigner Research Centre for Physics, Budapest, Hungary.

[22] Also at Indian Institute of Science Education and Research, Bhopal, India.

[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 Università degli Studi di Siena, Siena, Italy.
[30] Also at Purdue University, West Lafayette, USA.
[31] Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia.
[32] Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia.
[33] Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico.
[34] Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland.
[35] Also at Institute for Nuclear Research, Moscow, Russia.
[36] Now at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia.
[37] Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[38] Also at INFN Sezione di Padova; Università di Padova; Università di Trento (Trento), Padova, Italy.
[39] Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
[40] Also at INFN Sezione di Roma; Università di Roma, Roma, Italy.
[41] Also at National Technical University of Athens, Athens, Greece.
[42] Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.
[43] Also at National and Kapodistrian University of Athens, Athens, Greece.
[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 Marmara University, Istanbul, Turkey.
[54] Also at Kafkas University, Kars, Turkey.
[55] Also at Istanbul Bilgi University, Istanbul, 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 Facoltà Ingegneria, Università di Roma, Roma, Italy.
[64] Also at Argonne National Laboratory, Argonne, USA.
[65] Also at Erzincan University, Erzincan, Turkey.
[66] Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
[67] Also at Texas A&M University at Qatar, Doha, Qatar.
[68] Also at Kyungpook National University, Daegu, Republic of Korea.