EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2024-293
2024/12/04

CMS-SMP-24-005

Measurement of the inclusive WZ production cross section in pp collisions at $\sqrt{s} = 13.6\,\text{TeV}$

The CMS Collaboration*

Abstract

The inclusive WZ production cross section is measured in proton-proton collisions at a centre-of-mass energy of 13.6 TeV, using data collected during 2022 with the CMS detector, corresponding to an integrated luminosity of $34.7\,\text{fb}^{-1}$. The measurement uses multileptonic final states and a simultaneous likelihood fit to the number of events in four different lepton flavour categories: eee, eeμ, $\mu\mu$e, and $\mu\mu\mu$. The selection is optimized to minimize the number of background events, and relies on an efficient prompt lepton discrimination strategy. The WZ production cross section is measured in a phase space defined within a 30 GeV window around the Z boson mass, as $\sigma_{\text{total}}(\text{pp} \to \text{WZ}) = 55.2 \pm 1.2\,(\text{stat}) \pm 1.2\,(\text{syst}) \pm 0.8\,(\text{lumi}) \pm 0.1\,(\text{theo})\,\text{pb}$. In addition, the cross section is measured in a fiducial phase space closer to the detector-level requirements. All the measurements presented in this paper are in agreement with standard model predictions.

Submitted to the Journal of High Energy Physics

*See Appendix A for the list of collaboration members

1 Introduction

Diboson production cross sections are interesting physical observables at the LHC. With relatively large event yields, high-purity multileptonic final states, and sensitivity to deviations of the trilinear gauge couplings (TGCs) from their standard-model (SM) predictions, diboson production is one of the best experimental channels to study the properties of the electroweak (EW) sector of the SM.

The simultaneous production of a W and a Z boson (WZ) in proton-proton (pp) collisions is dominated by quark-antiquark annihilation at tree level, as can be seen in Fig. 1. As a result, the process is sensitive to TGCs that could modify the WZ production cross section and thus provide evidence of beyond-the-SM (BSM) physics. Additionally, this process is one of the main backgrounds for many SM measurements and BSM searches in multileptonic final states.

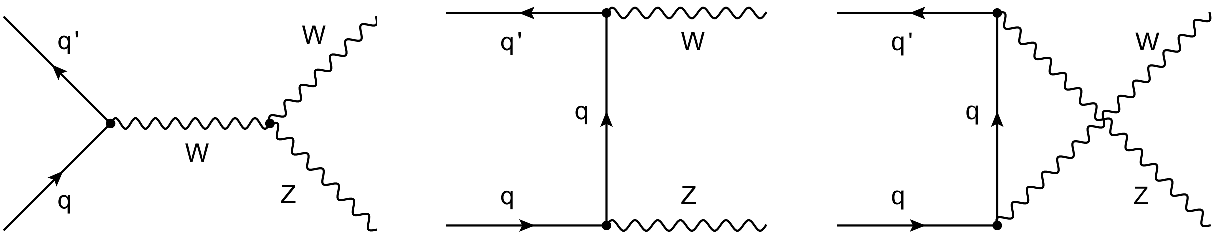

Figure 1: Leading-order Feynman diagrams for WZ production in pp collisions from the s channel (left), t channel (centre), and u channel (right).

The WZ production cross section was measured at the LHC in pp collisions at centre-of-mass energies of 5, 7, 8, and 13 TeV [1–7] by the CMS and ATLAS Collaborations. All these measurements are in good agreement with the SM predictions within uncertainties. In this paper, a new measurement of the inclusive WZ production cross section in final states with three leptons that can be either electrons (e) or muons (μ) is presented. The analysed data were collected by the CMS experiment in pp collisions at a centre-of-mass energy of 13.6 TeV during the first data-taking year of the Run 3 of the LHC, and correspond to a total integrated luminosity of 34.7 fb^{-1}. The measurement is performed by classifying events according to the number of leptons of a given flavour. The cross section is determined via a simultaneous maximum likelihood fit to the event counts in all categories, as well as via fits to each category individually.

This paper is organized as follows. Section 2 describes the CMS detector. Section 3 enumerates the simulated samples used in the measurement. Section 4 details the event reconstruction and the data sample used in this analysis. Section 5 presents the event selection and signal region definition. Section 6 explains the main SM background processes and the techniques used for their estimation. Section 7 includes a summary of the sources of uncertainty and their impact on the measurement. Section 8 presents the measurement strategy for signal extraction and the results. Finally, a summary is presented in Section 9.

Tabulated results are provided in the HEPData record for this analysis [8].

2 The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, 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), each composed of a barrel and two endcap sections. Forward calorimeters extend the pseudorapidity (η) coverage provided by the barrel and endcap detectors. Muons are detected in gas-ionization chambers embedded in the steel flux-return yoke outside the solenoid. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Refs. [9, 10].

Events of interest are selected using a two-tiered trigger system. The first level, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select events at a rate of around 100 kHz within a fixed latency of about 4 μs [11]. The second level, known as the high-level trigger, consists of a farm of processors running a version of the full event reconstruction software optimized for fast processing, and reduces the event rate to around 5 kHz before data storage [12, 13].

3 Simulated samples

Signal WZ events are generated using POWHEG BOX (v2.0) [14–18] at next-to-leading order (NLO) in quantum chromodynamics (QCD), considering only the charged lepton decays of the WZ system. Renormalization (μ_{R}) and factorization (μ_{F}) scales in the signal prediction are computed dynamically based on the invariant mass of the WZ system in the generated event, according to the POWHEG method [15]. The SM background processes are simulated at NLO in QCD using POWHEG for several diboson processes (WW, ZZ), and with MADGRAPH5_aMC@NLO [19] (v2.9.13) for the remaining diboson processes (Zγ, Wγ, and VH; where V stands for W and Z), triboson production (WWW, WWZ, WZZ, ZZZ, WZγ), and associated production of top quarks with other SM particles ($\mathrm{t\bar{t}W}$, $\mathrm{t\bar{t}Z}$, $\mathrm{t\bar{t}H}$, $\mathrm{t\bar{t}}\gamma$, tZq). In all cases the NNPDF3.1_nnlo_hessian_pdfas [20] parton distribution function (PDF) set is used for the matrix element generation, and is interfaced with PYTHIA 8 (v3.0.6) [21] for the showering, hadronization, and underlying-event modelling with the CP5 tune [22] for all the samples used in the analysis.

The propagation of the generated particles through the CMS detector and the modelling of the detector response are performed using GEANT4 [23] using the alignment and calibration from the collision data. The simulated events are processed with the same reconstruction algorithms used for the collision data.

4 Event reconstruction

The particle-flow (PF) algorithm [24] reconstructs and identifies each individual particle in an event with an optimized combination of information from the various elements of the CMS detector. The energy of photons is obtained from the ECAL measurement. The energy of electrons is determined from a combination of the electron momentum at the primary interaction vertex as determined by the tracker, the energy of the corresponding ECAL cluster, and the energy sum of all bremsstrahlung photons spatially compatible with originating from the electron track. The primary vertex (PV) is taken to be the vertex corresponding to the hardest scattering in the event, evaluated using tracking information alone, as described in Section 9.4.1 of Ref. [25]. The energy of muons is obtained from the curvature of the corresponding track, both inside the solenoid and in the return yoke. The energy of charged hadrons is determined from a combination of their momentum measured in the tracker and the matching ECAL and HCAL energy deposits, corrected for the response function of the calorimeters to hadronic showers. Finally, the energy of neutral hadrons is obtained from the corresponding corrected ECAL and HCAL energies.

All electrons in the analysis must have a transverse momentum (p_{T}) greater than 10 GeV and $|\eta| < 2.5$. The electron identification is based on a multivariate analysis (MVA) discriminant that combines observables describing the matching of the measurements in the tracker and the ECAL, the description of energy clusters in the ECAL, and the amount of bremsstrahlung radiation emitted during the propagation through the detector. The presence of electrons resulting from asymmetric photon conversions is reduced by requiring that their associated track have no missing hits in the innermost layers of the silicon tracker. An additional criterion that requires consistency among three measurements of the electron charge [26, 27] is applied to ensure a reliable charge determination. Muons are reconstructed by combining the information from the tracking system and the muon spectrometers in a global fit [28] that identifies the quality of the matching between the tracker and muon systems, and imposes minimal requirements in the track-related quantities. Muons are required to pass the kinematic selection requirements of $p_{\mathrm{T}} > 5$ GeV and $|\eta| < 2.4$. As in the case of electrons, an additional identification requirement is imposed to reduce the probability of charge misassignment in muons by requiring the measured curvature to have an uncertainty smaller than 20%.

An additional set of identification and isolation criteria are applied to define the restricted set of light leptons (e, μ) used in the analysis. These additional requirements target a high selection efficiency for leptons from W or Z bosons or from τ lepton decays, while rejecting those coming from other sources, such as leptons from hadron decays (non-prompt leptons). Lepton isolation requirements are imposed following the same approach as in Ref. [7]. The isolation of each lepton is defined as the scalar p_{T} sum of all photons and charged and neutral hadrons in a cone around the lepton direction. The contributions from neutral particles originating from additional pp interactions, within the same or nearby bunch crossings (pileup) are estimated based on their average spatial energy density and the effective area covered by an isolation cone that is placed around the position of a given neutral particle in the detector. Charged particles identified to be originating from pileup vertices are discarded for this computation. A requirement on the lepton isolation relative to its p_{T} to be smaller than 0.4 is applied. Leptons that pass the above identification and isolation criteria are referred to as “loose” leptons.

An MVA discriminant that aims to separate the prompt and non-prompt contributions is further used to select high-quality prompt leptons [29]. Its inputs are the charged and neutral components of the lepton isolation as previously described, the properties of particles reconstructed in close proximity to the lepton, and the impact parameter with respect to the PV of the reconstructed lepton track in two and three dimensions. These selection criteria are more relevant for electrons and hence the requirements on the MVA discriminant are tighter than for muons.

For each event, hadronic jets are clustered from the PF candidates using the anti-k_{T} algorithm [30, 31] with a distance parameter of 0.4. Jet momentum is determined as the vectorial sum of all particle momenta in the jet, and is found from simulation to be, on average, within 5 to 10% of the true momentum over the whole p_{T} spectrum and detector acceptance. Pileup interactions can contribute additional tracks and calorimetric energy deposits, increasing the apparent jet momentum. The pileup-per-particle identification algorithm [32, 33] is used to mitigate the effect of pileup, making use of local shape information, event pileup properties, and tracking information. For each neutral particle, a local shape variable is computed using the surrounding charged particles compatible with the PV within $|\eta| < 2.5$, and using both charged and neutral particles in the region outside of the tracker coverage. This variable is used to distinguish between collinear and soft diffuse distributions of other objects surrounding the particle under consideration. Charged particles identified to be originating from pileup vertices are discarded. The momenta of the neutral particles are then rescaled according to their probability to originate from the PV deduced from the local shape variable, superseding the need for jet-based pileup corrections. Jets produced by the hadronization of b quarks with $p_{\mathrm{T}} > 25\,\mathrm{GeV}$ and $|\eta| < 2.5$ are identified using the DEEPJET algorithm [34, 35], which is based on a deep neural network that combines information from the reconstructed tracks and secondary vertices associated with the jet. The working point used in this analysis corresponds to a b tagging efficiency of 70% and a mistagging rate of 1% for light-flavoured jets and gluon jets.

The missing transverse momentum is computed as the negative sum of the p_{T} of all the PF candidates weighted by their probability to originate from the PV [36], and its magnitude is denoted as $p_{\mathrm{T}}^{\text{miss}}$. The $p_{\mathrm{T}}^{\text{miss}}$ is modified to account for corrections to the energy scale of the reconstructed jets in the event. Anomalous high-$p_{\mathrm{T}}^{\text{miss}}$ events can be due to a variety of reconstruction failures, detector malfunctions, or noncollision backgrounds. Such events are rejected by event filters designed to identify more than 85–90% of the spurious high-$p_{\mathrm{T}}^{\text{miss}}$ events with a mistagging rate smaller than 0.1% [37].

5 Event selection

The data are recorded with a combination of single- and double-lepton triggers requiring the presence of one or two isolated electrons or muons with loose identification and isolation criteria. The p_{T} requirement of the single-lepton trigger is 32 GeV for electrons and 24 GeV for muons. The double-lepton triggers require the leading lepton to have a p_{T} greater than 23 (18) GeV, and the subleading lepton to have a p_{T} greater than 12 (8) GeV for electrons (muons).

Events are required to fulfil strict requirements designed to achieve a pure WZ signal region (SR) while keeping a high signal efficiency. The selection of events entering the SR is based on the presence of exactly three isolated leptons, with at least two leptons with electric charges of opposite sign and same flavour (OSSF). In order to exploit the kinematic properties of the WZ production, a simple assignment algorithm is used to tag each of the leptons originating from the W and Z boson decays. The algorithm works as follows: if only one OSSF lepton pair is found, the leptons are assumed to arise from the Z boson decay and, therefore, are labelled as ℓ_{Z}^{1} and ℓ_{Z}^{2}. In case two OSSF lepton pairs are found, the leptons of the pair with dilepton invariant mass closest to the nominal Z boson mass are selected as ℓ_{Z}^{1} and ℓ_{Z}^{2}. In either case, the hardest lepton not associated with the best Z boson candidate is referred to as ℓ_{W}. After assigning the origin of the leptons, the following additional p_{T} requirements are imposed in a consistent manner with the trigger requirements: $p_{\mathrm{T}}(\ell_{\mathrm{Z}}^{1}) > 25\,\mathrm{GeV}$, $p_{\mathrm{T}}(\ell_{\mathrm{Z}}^{2}) > 15\,\mathrm{GeV}$, and $p_{\mathrm{T}}(\ell_{\mathrm{W}}) > 25\,\mathrm{GeV}$. After this minimal preselection, ℓ_{Z}^{1} and ℓ_{Z}^{2} are properly tagged to the corresponding Z boson with 97% efficiency, and ℓ_{W} is found to be properly tagged to the W boson (when present) with a 94% efficiency. On top of this baseline selection, four channels based on the possible flavour combinations of the tagged leptons (ℓ_{Z}^{1}, ℓ_{Z}^{2}, ℓ_{W}): eee, eeμ, $\mu\mu$e, and $\mu\mu\mu$ are considered for the classification of events.

To increase the purity of WZ events, we require that the invariant mass of the ℓ_{Z}^{1} and ℓ_{Z}^{2} to be consistent with the Z boson mass $|m(\ell_{\mathrm{Z}}^{1}, \ell_{\mathrm{Z}}^{2}) - m_{\mathrm{Z}}| < 15\,\mathrm{GeV}$, which removes contributions from nonresonant processes. The value of m_{Z} is taken from the Z mass world average given by the PDG [38]. A minimal requirement of $p_{\mathrm{T}}^{\text{miss}} > 35\,\mathrm{GeV}$ is included to reduce the presence of dileptonic Z production with an associated jet that can be misidentified as a lepton. Events with at least one b-tagged jets are vetoed from the SR in order to reduce contributions from top quark processes. Infrared safety in the same-flavour final states is ensured by rejecting events containing an OSSF lepton pair with invariant mass below 4 GeV. The invariant mass of the three lepton system is required to be $m(\ell_Z^1, \ell_Z^2, \ell_W) > 100\,\text{GeV}$, effectively rejecting most of the contribution from $Z\gamma$ production in which the photon undergoes asymmetric conversion producing an additional final-state electron. All these requirements define the SR.

Several control regions (CRs) are defined to estimate the contribution of the main background processes. Each CR is designed to be dominated by one background process and is used to estimate its normalization including the CR into the analysis likelihood fit. The CR definitions are obtained by inverting SR requirements, effectively increasing the purity of a given background without selecting events that pass the SR selection. In particular, the ZZ CR is defined by inverting the fourth-lepton veto and dropping the $p_T^{miss} > 35\,\text{GeV}$ requirement from the SR definition. The hardest lepton not belonging to the best OSSF pair is then refered to as ℓ_3 instead of ℓ_W in this CR, yet the requirements that are imposed are the same as the ones considered in the case with three leptons. The fourth lepton is also required to pass tight identification criteria and to have $p_T > 15\,\text{GeV}$. The $t\bar{t}Z$ CR is obtained by inverting the b-tagged jet are vetoed. Finally, the conversions CR ($X\gamma$ CR) is defined by removing the $|m(\ell_Z^1, \ell_Z^2) - m_Z| < 15\,\text{GeV}$ requirement and inverting the trilepton invariant mass requirement to $m(\ell_Z^1, \ell_Z^2, \ell_W) < 100\,\text{GeV}$. Both modifications increase the presence of the process in which a photon is radiated by one of the final-state leptons in dileptonic Z boson decays, producing a typical trilepton resonance around the Z boson peak. To further increase the purity of $Z\gamma$ events in this phase space, p_T^{miss} is required to be smaller than 35 GeV. A summary of the definition of the SR and CRs can be found in Table 1.

Table 1: Requirements for the definition of the signal and control regions of the analysis. Objects in parentheses relate to the ZZ CR.

Region	N_ℓ	$p_T\{\ell_Z^1, \ell_Z^2, \ell_W(\ell_3), (\ell_4)\}$ (GeV)	N_{OSSF}	$\lvert m(\ell_Z^1, \ell_Z^2) - m_Z\rvert$ (GeV)	p_T^{miss} (GeV)	$N_{b\,tag}$	$\min(m(\ell, \ell'))$ (GeV)	$m(\ell_Z^1, \ell_Z^2, \ell_W(\ell_3))$ (GeV)
SR	=3	$>\{25, 15, 25\}$	≥1	<15	>35	=0	>4	>100
ZZ CR	=4	$>\{25, 15, 25, 15\}$	≥1	<15	—	=0	>4	>100
$t\bar{t}Z$ CR	=3	$>\{25, 15, 25\}$	≥1	<15	>35	>0	>4	>100
$X\gamma$ CR	=3	$>\{25, 15, 25\}$	≥1	—	≤35	=0	>4	<100

6 Background estimation

The background processes in the SR can be grouped into two different categories. The first category includes the reducible backgrounds that originate mainly due to the presence of non-prompt leptons, as defined in Section 4, typically arising from Z+jets or $t\bar{t}$ production in which either a jet is misidentified as a lepton or a lepton is produced in the decay of a heavy-flavour hadron. The second category groups all the irreducible backgrounds including SM processes that naturally produce three or more leptons, such as boson pair production, triboson production, and associated production of top quarks with a W, Z, or H boson.

6.1 Reducible backgrounds

The SM processes with non-prompt leptons can contribute as well in the SR. Due to the requirement on the invariant mass of the (ℓ_Z^1, ℓ_Z^2) pair described in Section 5, which largely reduces the presence of $t\bar{t}$ in the final selection, the main background is Z+jets events in which a jet from initial-state radiation is misidentified as a lepton. The contribution of the non-prompt component in the final selection is 3% of the total yield in the SR, smaller than the ZZ contribution. This is attributed to a lepton identification criteria that have been optimized to reduce the non-prompt rate to the order of a few percent. For these reasons, the non-prompt background is modelled considering the shapes and normalizations directly from MC simulation.

6.2 Irreducible backgrounds

The main irreducible backgrounds are ZZ production, amounting to ~5% of the total yield in the SR, $t\bar{t}Z$ production, that contributes ~2% of the yield in the SR, and the associated production of a photon and other SM particles, $X\gamma$, that represents 1% of the selected events. The normalization of each background is considered as an unconstrained parameter in the fit to the data, and the shape is obtained from the simulation. To constrain the major backgrounds, information from each of the CRs defined in the analysis is included in the likelihood fit. All the uncertainties included in the total inclusive cross section measurement described in Section 7 also apply to these CRs.

The purity of the ZZ contribution in the ZZ CR is about 98% of the total yield, with 90% of this contribution coming from $q\bar{q}$ annihilation ($q\bar{q} \rightarrow ZZ$), and the remaining 10% coming from gluon fusion mechanisms ($gg \rightarrow ZZ$). The distributions of several observables in this CR are shown in Fig. 2. Distributions of the reconstructed Z boson peak considering the two leptons tagged as ℓ_Z^1 and ℓ_Z^2 are also shown separately for electrons and muons in Fig. 3. All distributions show relatively good modelling of the ZZ background.

The $t\bar{t}Z$ CR is especially sensitive to both $t\bar{t}Z$ and tZq production. Residual contributions from $t\bar{t}W$ and $t\bar{t}H$ production are a factor of 20 smaller than the $t\bar{t}Z$ contribution and are grouped with $t\bar{t}Z$ into a group labelled $t\bar{t}X$. Good agreement between the observed data and predictions from simulation in this region is demonstrated in Fig. 4 for several variables.

The $X\gamma$ background includes processes with a prompt photon that proceeds through an asymmetric conversion due to the interaction with the detector to produce a single detected final-state lepton, or with a virtual photon that converts into a lepton pair. This background is dominated by associated $Z\gamma$ production (around 99% of the expected events), with residual contributions from $W\gamma$, $t\bar{t}\gamma$, and $WZ\gamma$ production. The distributions of several relevant observables in the $X\gamma$ CR are shown in Fig. 5. Good agreement is also observed in this CR.

For all CRs, the number of events in flavour categories is included in the fit described in Section 8, treating each background normalization as an unconstrained parameter.

Other irreducible backgrounds contribute less than 1% to the yields in the SR and are directly estimated from simulation. These include the associated production of a vector boson and a Higgs boson (VH) and the triboson production (VVV). These backgrounds are estimated using MC simulation. Contributions from WZ produced through vector boson scattering have not been considered. This background is expected to contribute as 1% of the total yield in the SR.

7 Systematic uncertainties

The sources of systematic uncertainties can be grouped into four categories:

- Uncertainties associated with the normalization of the background sources. These are treated as uncorrelated among backgrounds.
- Uncertainties related to the modelling of instrumental effects in the simulation such as those arising from the object identification, reconstruction, and energy scales. These are typically correlated across all processes.
- Uncertainties in the measurement of the integrated luminosity collected by CMS that

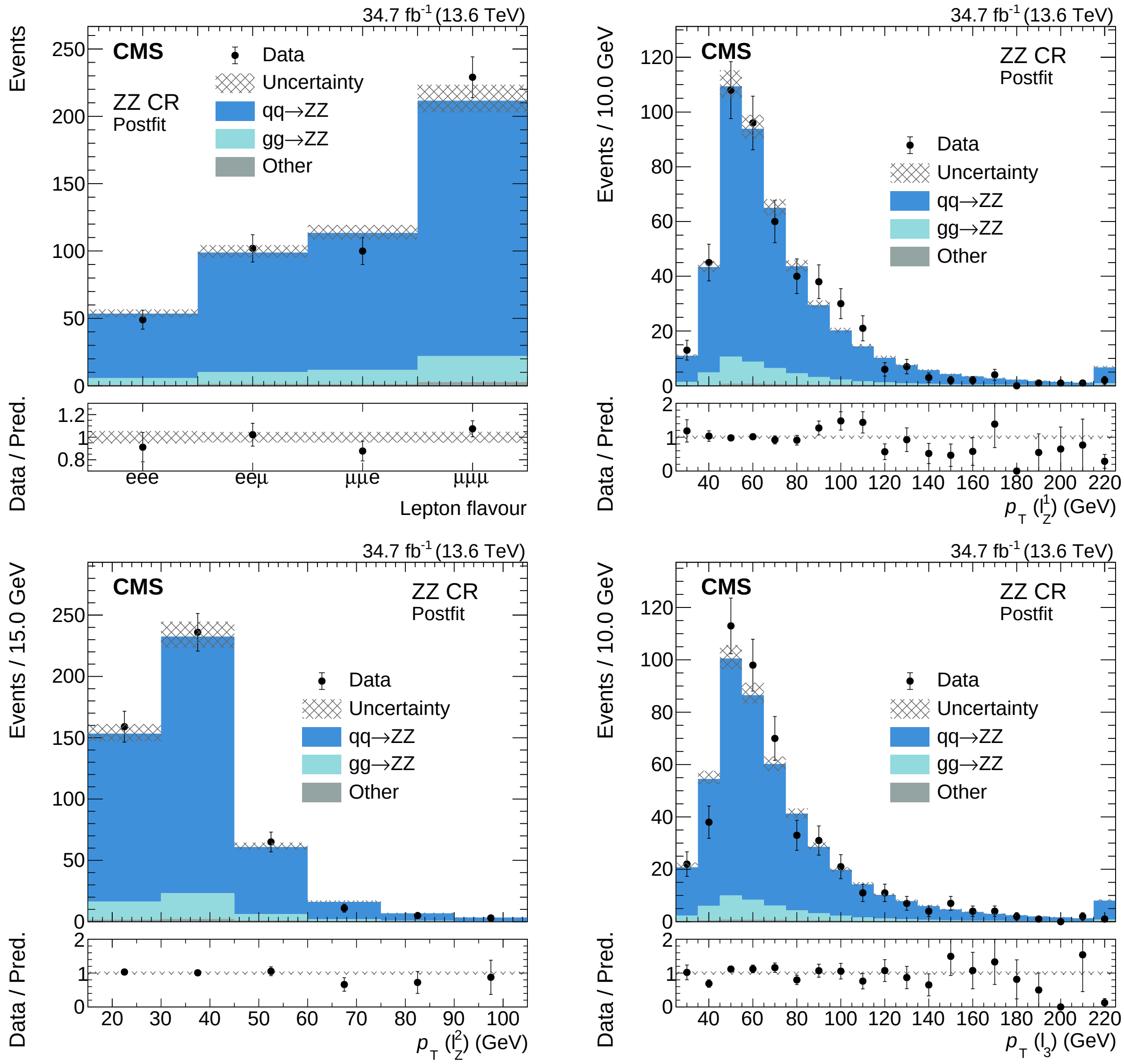

Figure 2: Distribution of observables in the ZZ CR accounting for the fit to data, described in Section 8. Clockwise from upper left to lower right: flavour composition, p_T of ℓ_Z^1, p_T of ℓ_Z^2, and p_T of ℓ_3. The hatched bands show the total uncertainty in the MC prediction. The vertical bars of the data account for the statistical uncertainty. When present, overflow events are included in the last bin of the observables. The ratio panels show the ratio between data (black markers) with respect to the total prediction after the fit to data. Processes with a small contribution to this region are grouped in the "Other" category.

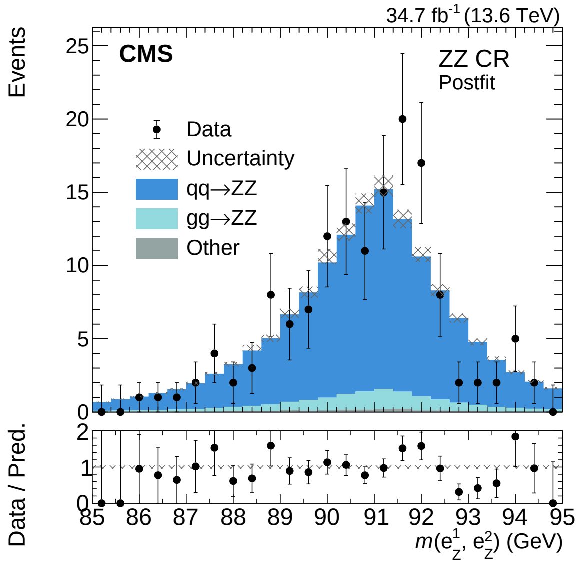

Figure 3: Distribution of the invariant mass of ℓ_Z^1 and ℓ_Z^2 in the ZZ CR accounting for the fit to data. The left (right) distribution shows the case in which the leptons are electrons (muons). The hatched bands show the total uncertainty in the MC prediction. The vertical bars of the data account for the statistical uncertainty. The ratio panels show the ratio between data (black markers) with respect to the total prediction after the fit to data. Processes with a small contribution to this region are grouped in the "Other" category.

are also correlated among all processes estimated from simulation.

- Theoretical and modelling uncertainties that affect only the WZ process.

For those backgrounds that have a significant contribution to the SR (ZZ, $t\bar{t}X$, and $X\gamma$), no additional normalization uncertainty is included, as it is treated as an unconstrained parameter in the fit. As the remaining irreducible backgrounds are small and the uncertainty in their estimation contributes negligibly to the total uncertainty of the measurement, we use the experimentally measured uncertainties on each to reduce theoretical contributions to the final uncertainty: 15% for tZq [39], 50% for VVV [40], and 25% for VH [41]. Finally, a normalization uncertainty of 30% is assigned for the non-prompt lepton background, that covers any possible normalization effect observed in a non-prompt enriched region.

The uncertainties related to the mismodelling of instrumental effects in the simulation are estimated by varying the relevant parameters within their uncertainties and recomputing the event yields. The following sources of systematic uncertainties are considered: lepton identification and isolation efficiencies, jet energy scale and resolution, b tagging efficiency, p_T^{miss} scale and resolution, and pileup modelling.

The lepton identification and isolation efficiencies are estimated using the tag-and-probe technique [42] and are affected by the size of the data set in $Z \to \ell^+\ell^-$ enriched regions, where the efficiencies are derived. Both efficiencies and their uncertainties are estimated separately for electrons and muons, with the average uncertainties of $\sim$1% per electron and $\sim$0.5% per muon. The statistical component of these uncertainties, corresponding to the size of the data set in which the tag-and-probe technique has been applied, is also included. Uncertainties in the energy scale of electrons introduce a smaller effect that induces variations in the lepton p_T. This effect is negligible for muons.

The efficiency of the trigger selection is measured in data selected using an independent set of

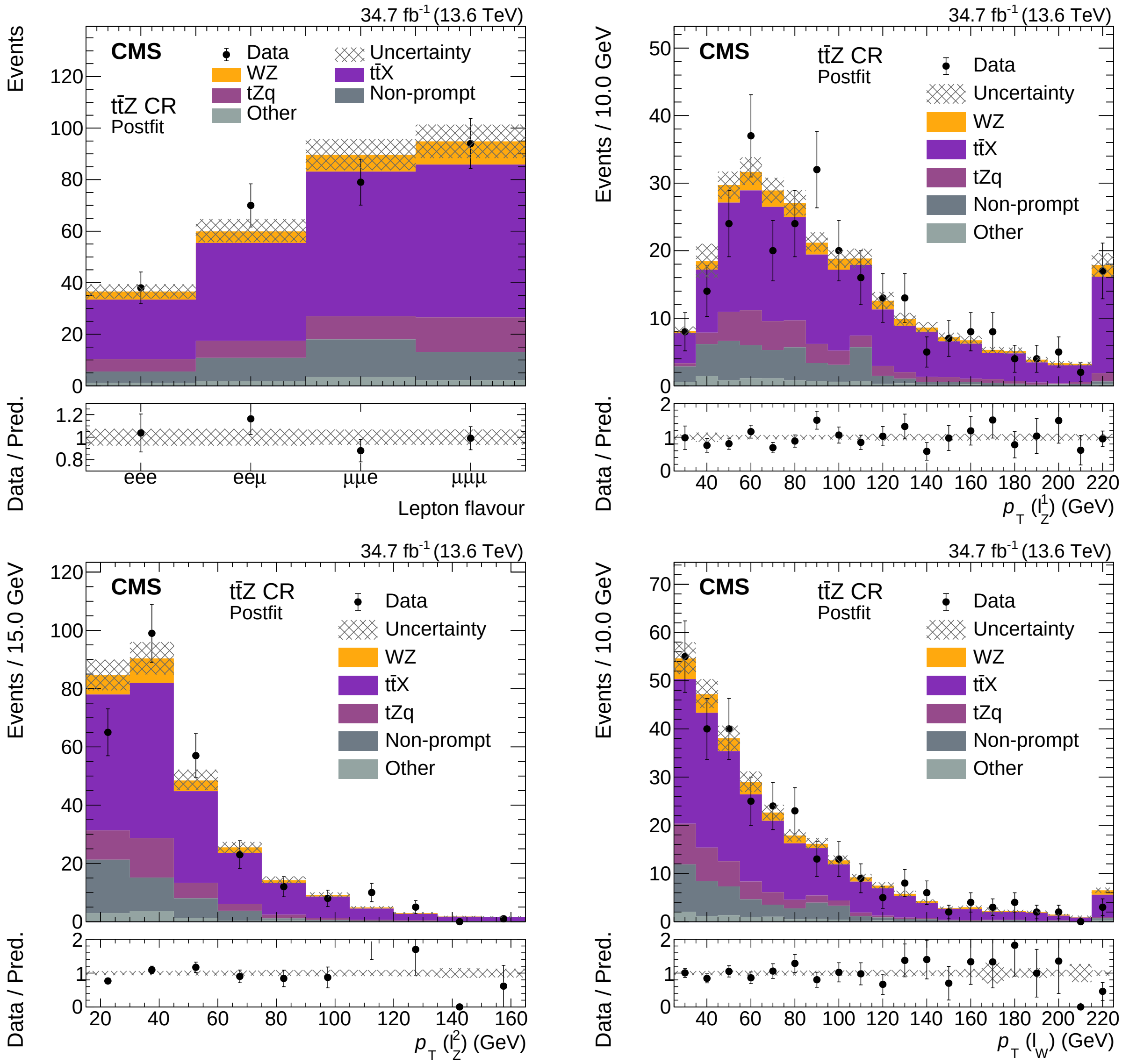

Figure 4: Distribution of observables in the $t\bar{t}Z$ CR accounting for the fit to data, described in Section 8. Clockwise from upper left to lower right: flavour composition, p_T of ℓ_Z^1, p_T of ℓ_Z^2, and p_T of ℓ_W. The hatched bands show the total uncertainty in the MC prediction. The vertical bars of the data account for the statistical uncertainty. When present, overflow events are included in the last bin of the observables. The ratio panels show the ratio between data (black markers) with respect to the total prediction after the fit to data. Processes with a small contribution to this region are grouped in the "Other" category.

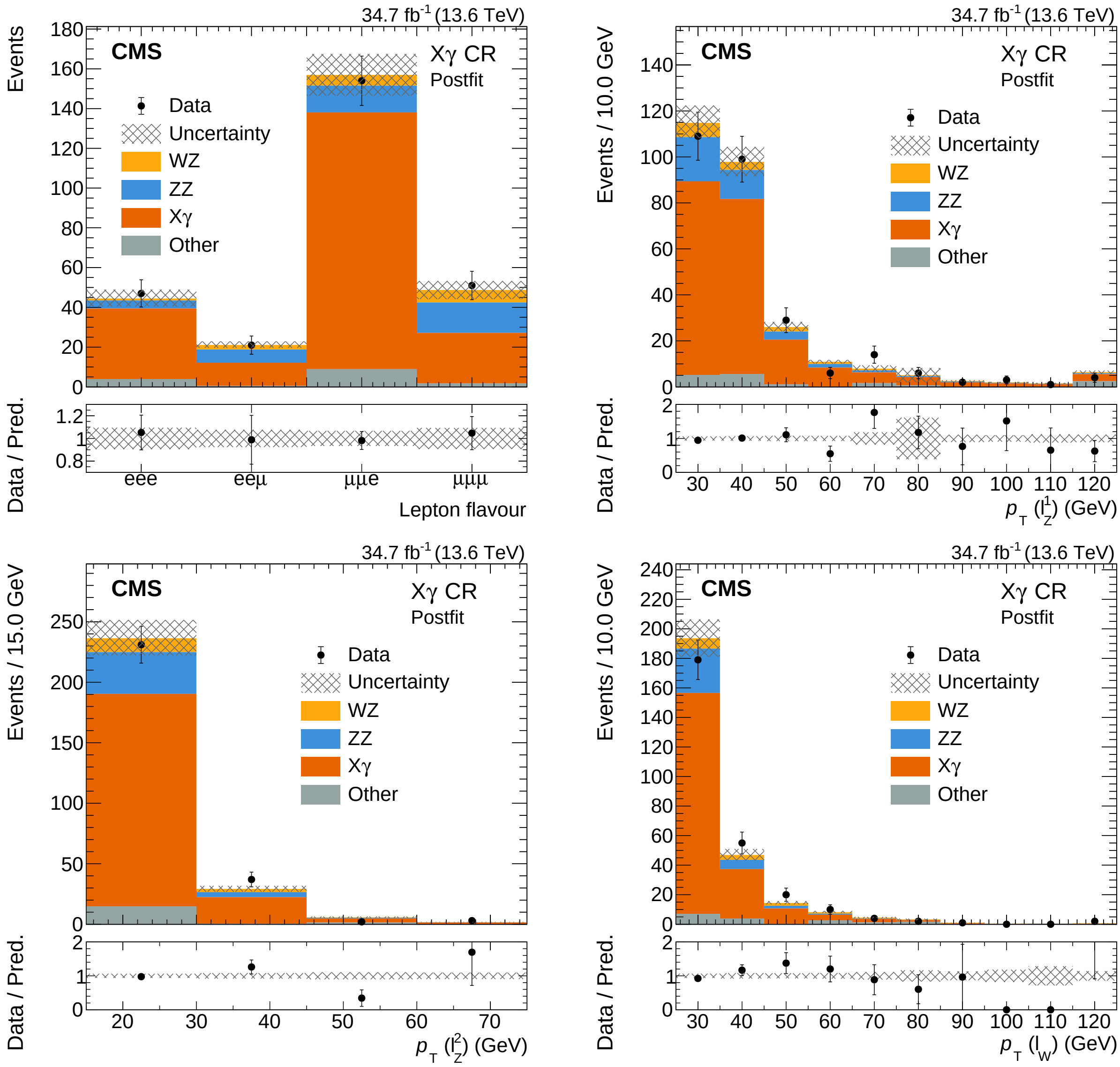

Figure 5: Distribution of observables in the Xγ CR accounting for the fit to data, described in Section 8. Clockwise from upper left to lower right: flavour composition, p_{T} of ℓ_{Z}^{1}, p_{T} of ℓ_{Z}^{2}, and p_{T} of ℓ_{W}. The hatched bands show the total uncertainty in the MC prediction. The vertical bars of the data account for the statistical uncertainty. When present, overflow events are included in the last bin of the observables. The ratio panels show the ratio between data (black markers) with respect to the total prediction after the fit to data. Processes with a small contribution to this region are grouped in the "Other" category.

$p_{\mathrm{T}}^{\mathrm{miss}}$ triggers and only the requirement of three tight leptons passing the p_{T} requirements of the SR described in Section 5. The total uncertainty in the trigger efficiency measurement is split into a 1.0% component for the estimated measurement bias in the selection of the data set, and an additional statistical component of 1.6% originating from the limited size of this data set. Since the central estimation of the trigger efficiency is high (over 99%), the Clopper–Pearson estimation [43] of the associated confidence interval leads to slightly asymmetric effects that slightly increase the uncertainty on the downward variations.

The energy scale and resolution of the reconstructed jets has an associated uncertainty, which is propagated to the $p_{\mathrm{T}}^{\mathrm{miss}}$, causing a small effect in the total cross section. The b tag veto requirement is affected by the uncertainties in the efficiency of the b tagging procedure and the mistagging rate. The effect of these uncertainties is minimized by choosing a tight working point of the b tagging algorithm. They are split into the uncertainties in the tagging of heavy-flavour, and light-flavour and gluon jets as two decorrelated sources.

The uncertainty assigned to the number of pileup events in simulation is obtained by modifying the inelastic pp cross section up and down by 4.6% [44] around its nominal value and propagating the effect to all simulated samples. The measurement of the integrated luminosity recorded by CMS introduces an additional uncertainty of 1.4% [45, 46] into the analysis. Uncertainties due to the variations of the PDFs and the missing higher order corrections in QCD, are also included in the fits. Effects due to the choice of μ_{F} and μ_{R} are evaluated by varying the parameters up and down independently by a factor of two around the nominal POWHEG μ_0 value under the constraint $0.5 \leq \mu_{\mathrm{F}}/\mu_{\mathrm{R}} \leq 2$. The envelope of these six variations is taken as the estimated uncertainty for the missing higher order QCD corrections. Parametric (PDF+α_{S}) uncertainties are estimated using the NNPDF3.1 set. Uncertainties related to the modelling of the parton shower for the WZ signal have been estimated separately for the initial- and final-state radiation (ISR and FSR) contributions by varying the associated energy scales in simulation. Finally the uncertainty coming from the finite size of the MC samples is estimated using the Barlow–Beeston method [47]. A summary of all the input uncertainties considered in the analysis is shown in Table 2.

8 Fit strategy and results

The WZ production cross section is measured in the detector-level phase space defined as SR in Section 5 in each of the four flavour-exclusive channels (eee, eeμ, $\mu\mu$e, and $\mu\mu\mu$), and in the flavour-inclusive channel. This is motivated by the fact that final states with three leptons of the same-flavour (eee and $\mu\mu\mu$) include additional contributions to the production modes due to interference contributions from diagrams exchanging same flavour final-state leptons. The additional combinatorics of the two same-charged leptons result in slightly larger cross sections. At the same time, further splitting the final states into different lepton flavour compositions leads to both the possibility of analysing deviations in the lepton flavour universality in the W and Z boson decays, and of studying possible experimental biases in the determination of electron and muon efficiencies.

The observed WZ cross section at the detector-level is extrapolated to two different particle-level phase spaces, refered to as "fiducial" (FR) and "total" (TR) regions, respectively. The TR is designed to provide a more inclusive measurement of the WZ cross section, with fewer requirements on the properties of the process. In contrast, the FR is motivated by the aim to reduce as comprehensively as possible the detector acceptance effects on the theoretical uncertainties that affect the measurement. As a result, the FR closely mirrors the SR selection criteria outlined in Section 5, including lepton kinematic requirements and the exclusion of WZ $\rightarrow \tau\tau$.

Table 2: Summary of the input relative uncertainties. Numbers are presented in percentages over the total yields of the associated process on which they have an effect. All uncertainties are treated as shape variations on the templates used for the fit, with the exception of the normalization uncertainties in the backgrounds that are treated as flat variations of the corresponding yield.

Source	Uncertainty (%)	Processes
Integrated luminosity	1.4	All MC
Trigger efficiencies	1.6	All MC
b tagging (heavy)	1	All MC
b tagging (light/gluon)	1	All MC
Pileup	1.7	All MC
Jet energy scale	1.1	All MC
Electron reconstruction	3.8	All MC
Electron ident. efficiency	3.5	All MC
Electron energy scale	0.3	All MC
Muon efficiencies	1.1	All MC
Non-prompt bkg. normalization	30	Non-prompt
VVV normalization	50	VVV
tZq normalization	15	tZq
VH normalization	25	VH
ISR	0.1	WZ
FSR	0.8	WZ
WZ theory (μ_{R}, μ_{F}, PDF)	0.2	WZ

Both these regions are defined after hadronization and parton shower using generator-level quantities. Leptons at this level are "dressed" by adding the transverse momenta of generator-level photons within a cone of $\Delta R(\ell,\gamma) < 0.1$ to their own momenta. In addition, dressed leptons are associated to the W and Z bosons using the same tagging algorithm described in Section 5. The proportion of non-FR events in the WZ sample that pass detector-level requirements is approximately 5% in all the different decay channels as well as in the inclusive channel, and it is mainly attributed to leptonic decays of WZ $\rightarrow \tau\tau$. The proportion of FR events inside the TR, known as the acceptance, is about 17% in the inclusive channel, or equivalently 4% per decay channel. These numbers have been computed considering the WZ POWHEG signal sample, and cross-checked with an alternative WZ MADGRAPH5_aMC@NLO sample. Nevertheless, they are not directly used as an input of the analysis. Instead, the non-FR events are estimated by treating them as background contributions in the extraction of the fiducial results, and as part of the signal in the TR results. The acceptance factor between the TR and FR on the other hand is measured directly in the maximum likelihood fit detailed below, as it directly impacts the normalization of the WZ sample. The requirements of the FR and TR selections are summarised in Table 3.

Results at the fiducial- and total-level are obtained from two separate maximum likelihood fits to the number of events in different flavour channels, considering the SR and all the CRs described in Section 6, using the COMBINE tool [48]. In the fits, the normalization of the signal contribution to the WZ process and the ZZ, $\mathrm{t\bar{t}Z}$, and Xγ backgrounds are considered unconstrained parameters in the fit. The systematic uncertainties described in Section 7 are included as nuisance parameters with gaussian constraints correlated across SR and CRs for all shape

Table 3: Definition of the fiducial and total regions. The lepton related quantities refer to "dressed" leptons. A dash symbol is used in cases the selection is not considered for the corresponding phase space.

Region	Fiducial	Total
Lepton definition	Dressed (e, μ)	Dressed (e, μ, τ)
$N_\ell = 3$	✓	✓
$p_T\{\ell_Z^1, \ell_Z^2, \ell_W\} > \{25, 15, 25\}$ GeV	✓	—
$\lvert\eta\rvert\{\ell_Z^1, \ell_Z^2, \ell_W\} < \{2.5, 2.5, 2.5\}$	✓	—
$N_{OSSF} = 1$	✓	✓
$\lvert m(\ell_Z^1, \ell_Z^2) - m_Z\rvert < 30$ GeV	✓	✓
$\min(m(\ell, \ell')) > 4$ GeV	✓	✓
$m(\ell_Z^1, \ell_Z^2, \ell_W) > 100$ GeV	✓	—

variations, and as log-normal functions for those sources that only have a normalization effect. In the following, all presented results consider the fit results using the TR definitions unless stated otherwise. In both fits the shape for the variations originating from theoretical sources of uncertainty are normalized in a way that ensures that the sample cross section of the WZ process is the same in both the nominal templates and all the variations. This ensures that normalization effects on the theoretical uncertainties of the WZ variations do not have an effect in the measurement, keeping only the contribution that changes the overall acceptance of the FR and TR selections. The same procedure for the extraction of the cross section results is used as well for the flavour-exclusive measurements.

Figures 6 and 7 show several relevant distributions in the SR accounting for the fit to data, including the distribution used in the fit as well as other kinematic properties of the selected leptons. Observables that do not enter the fit are obtained by propagating the fit results to the observables before the fit. The event yields per process and flavour channel after the fit are shown in Table 4. Good agreement after the fit is observed in all the observables.

Table 4: Number of selected events and their total uncertianty (by flavour channel) for the relevant processes in the signal region of the analysis accounting for the fit to data. The "Background" yield is the sum of all processes that are not WZ signal, and "Prediction" is the sum of all the processes, including WZ.

Process	eee	eeμ	$\mu\mu$e	$\mu\mu\mu$	Inclusive
Non-prompt	25 ± 7	13 ± 5	24 ± 7	30 ± 10	93 ± 15
ZZ	25 ± 2	37 ± 1	49 ± 3	75 ± 3	186 ± 5
Xγ	12 ± 2	2.5 ± 0.3	24 ± 2	3.2 ± 0.5	41 ± 3
$t\bar{t}$X	8.0 ± 0.8	11 ± 1	14 ± 1	21 ± 2	54 ± 3
VVV	4 ± 1	5 ± 2	7 ± 3	10 ± 4	27 ± 5
VH	3.0 ± 0.5	3.8 ± 0.7	5 ± 1	9 ± 2	20 ± 2
tZq	4.2 ± 0.5	5.3 ± 0.6	7.5 ± 0.9	11 ± 1	28 ± 2
Background	82 ± 8	78 ± 5	130 ± 9	160 ± 11	450 ± 17
WZ	410 ± 10	556 ± 12	768 ± 14	1096 ± 22	2830 ± 31
Prediction	491 ± 13	634 ± 13	898 ± 16	1256 ± 24	3280 ± 34
Data	491	643	869	1276	3279

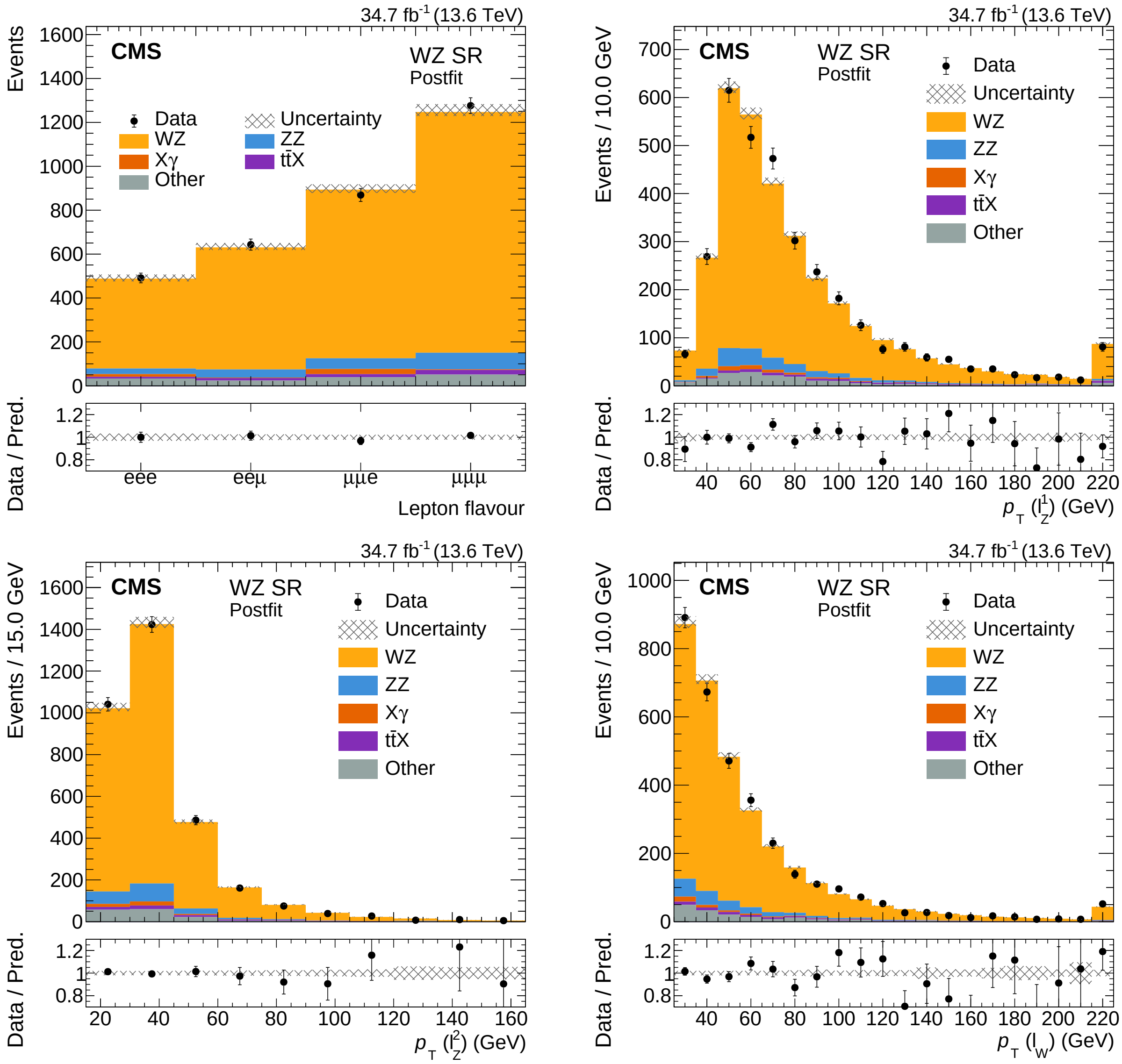

Figure 6: Distributions of several observables in the SR accounting for the fit to data. Clockwise from upper left to lower right: flavour composition, p_T of ℓ_Z^1, p_T of ℓ_Z^2, and p_T of ℓ_W. The hatched band includes all systematic uncertainties in the MC prediction. The vertical bars of the data account for the statistical uncertainty. When present, overflow events are included in the last bin of the observables. The ratio panels show the ratio between data (black markers) with respect to the total prediction after the fit to data. Processes with a small contribution to this region are grouped in the “Other” category.

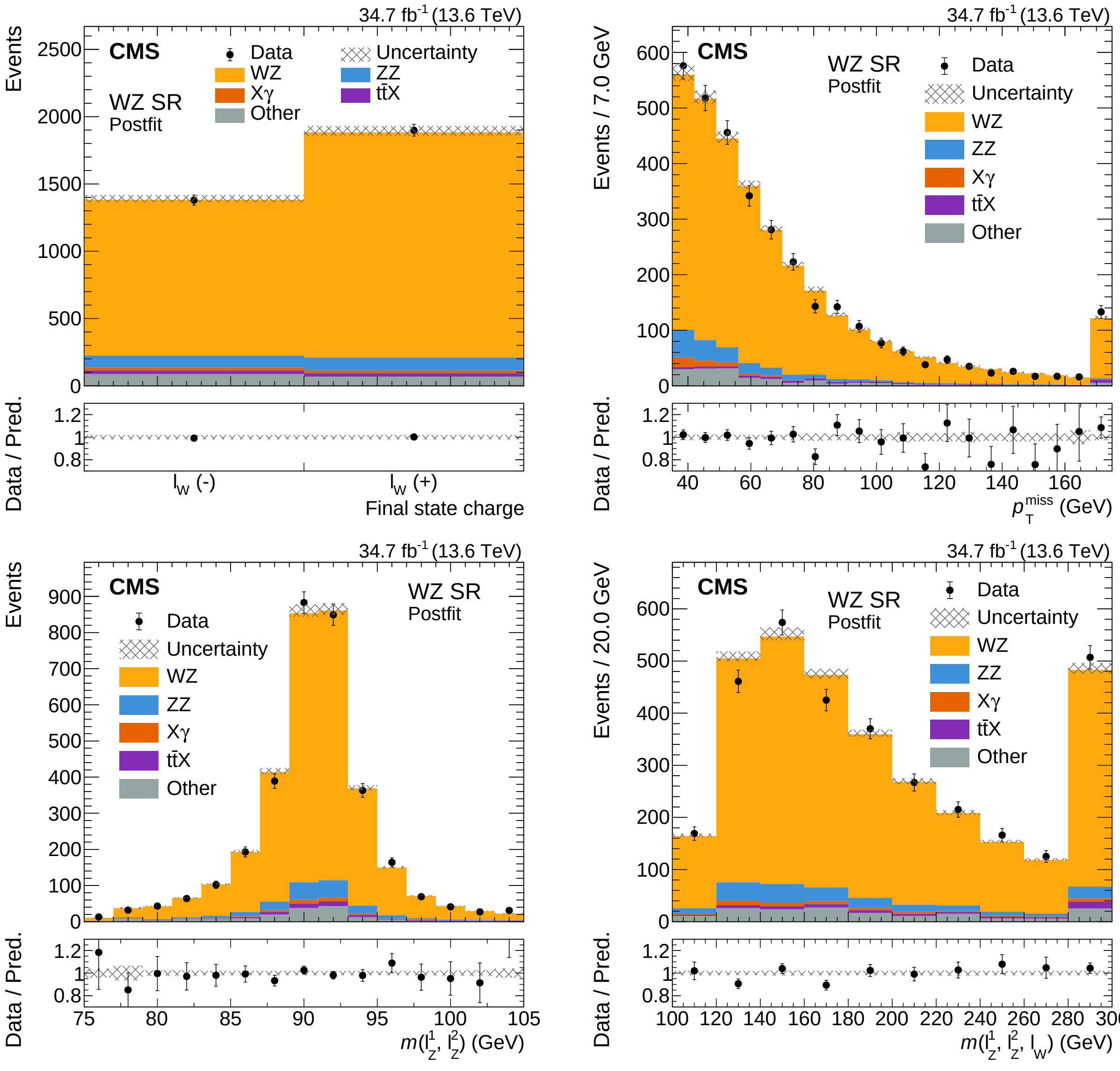

Figure 7: Distributions of several observables in the SR accounting for the fit to data. Clockwise from upper left to lower right: sum of charge of the final-state leptons, missing transverse momentum, invariant mass of the two leptons assigned to the Z boson decay, and that of the trilepton system. The hatched band includes all systematic uncertainties. When present, overflow events are included in the last bin of the observables. The ratio panels show the ratio between data (black markers) with respect to the total prediction after the fit to data. Processes with a small contribution to this region are grouped in the "Other" category.

The measured fiducial cross sections are reported in Table 5 for the different flavour channels, including a comparison with theoretical predictions computed from the signal POWHEG sample, as well as the next-to-NLO (NNLO) QCD and NNLO QCD $\times$ NLO EW prediction from MATRIX [49]. Similarly, results for the total cross section measurement and their comparison to different predictions at different orders of the QCD and EW expansion can be found in Table 6 and Fig. 8. The relative uncertainty in the measurement in the inclusive category of about 3.3% is compatible between the fiducial-level and total-level results. A breakdown of the different sources of systematic uncertainty and their impact in the result can be found in Table 7. The measurements presented in this paper, as well as all previous WZ measurements by CMS at different centre-of-mass energies, are compatible with the NNLO QCD $\times$ NLO EW predictions, as summarised in Fig. 9.

Table 5: Measured fiducial cross sections and their corresponding uncertainties for the flavour-exclusive and flavour-inclusive categories. The predictions from both POWHEG at NLO in QCD and LO EW as well as several ones obtained from MATRIX (NLO QCD, NNLO QCD, NNLO QCD $\times$ NLO EW) are also included.

Category	Accuracy	Fiducial cross section (fb)
eee	POWHEG, NLO QCD	$68.0^{+2.3}_{-2.1}$ (scale) $\pm$ 1.0 (PDF)
	MATRIX, NLO QCD	$69.9^{+3.9}_{-3.1}$ (scale)
	MATRIX, NNLO QCD	$77.0^{+1.8}_{-1.7}$ (scale)
	MATRIX, NNLO QCD $\times$ NLO EW	$75.4^{+1.7}_{-1.6}$ (scale)
	Measured	72.0 ± 4.0 (stat) $\pm$ 4.5 (syst) $\pm$ 1.0 (lumi) $\pm$ 0.1 (theo)
eeμ	POWHEG, NLO QCD	$68.0^{+2.3}_{-2.1}$ (scale) $\pm$ 1.0 (PDF)
	MATRIX, NLO QCD	$68.7^{+3.8}_{-3.0}$ (scale)
	MATRIX, NNLO QCD	$75.0^{+1.8}_{-1.6}$ (scale)
	MATRIX, NNLO QCD $\times$ NLO EW	$73.4^{+1.7}_{-1.5}$ (scale)
	Measured	73.9 ± 3.5 (stat) $\pm$ 3.1 (syst) $\pm$ 1.1 (lumi) $\pm$ 0.3 (theo)
$\mu\mu$e	POWHEG, NLO QCD	$68.0^{+2.3}_{-2.1}$ (scale) $\pm$ 1.0 (PDF)
	MATRIX, NLO QCD	$68.7^{+3.8}_{-3.0}$ (scale)
	MATRIX, NNLO QCD	$75.0^{+1.8}_{-1.6}$ (scale)
	MATRIX, NNLO QCD $\times$ NLO EW	$73.4^{+1.7}_{-1.5}$ (scale)
	Measured	71.2 ± 2.9 (stat) $\pm$ 2.0 (syst) $\pm$ 1.0 (lumi) $\pm$ 0.1 (theo)
$\mu\mu\mu$	POWHEG, NLO QCD	$68.0^{+2.3}_{-2.1}$ (scale) $\pm$ 1.0 (PDF)
	MATRIX, NLO QCD	$69.9^{+3.9}_{-3.1}$ (scale)
	MATRIX, NNLO QCD	$77.0^{+1.8}_{-1.7}$ (scale)
	MATRIX, NNLO QCD $\times$ NLO EW	$75.4^{+1.7}_{-1.6}$ (scale)
	Measured	75.3 ± 2.5 (stat) $\pm$ 1.5 (syst) $\pm$ 1.1 (lumi) $\pm$ 0.1 (theo)
Inclusive	POWHEG, NLO QCD	$271.9^{+9.0}_{-8.5}$ (scale) $\pm$ 3.8 (PDF)
	MATRIX, NLO QCD	$277.1^{+15.3}_{-12.3}$ (scale)
	MATRIX, NNLO QCD	$304.0^{+7.1}_{-6.6}$ (scale)
	MATRIX, NNLO QCD $\times$ NLO EW	$298.1^{+6.9}_{-6.3}$ (scale)
	Measured	297.6 ± 6.4 (stat) $\pm$ 6.4 (syst) $\pm$ 4.2 (lumi) $\pm$ 0.5 (theo)

Table 6: Flavour-inclusive total cross section result. The predictions from both POWHEG at NLO in QCD and LO EW as well as several ones obtained from MATRIX (NLO QCD, NNLO QCD, NNLO QCD × NLO EW) are also included.

Accuracy	Total cross section (pb)
POWHEG, NLO QCD	$50.5\,^{+2.6}_{-2.1}$ (scale) $\pm$ 1.1 (PDF)
MATRIX, NLO QCD	$50.4\,^{+2.3}_{-2.0}$ (scale)
MATRIX, NNLO QCD	$55.0\,^{+1.2}_{-1.1}$ (scale)
MATRIX, NNLO QCD × NLO EW	$54.7\,^{+1.2}_{-1.1}$ (scale)
Inclusive (Measured)	55.2 $\pm$ 1.2 (stat) $\pm$ 1.2 (syst) $\pm$ 0.8 (lumi) $\pm$ 0.1 (theo)

Table 7: Breakdown of different sources of systematic uncertainties and their relative impact in each channel, as well as in the inclusive measurement; as a percentage of the total uncertainty. The dash symbol indicates that the specific uncertainty does not apply.

Source	Inclusive (%)	eee (%)	eeμ (%)	$\mu\mu$e (%)	$\mu\mu\mu$ (%)
Integrated luminosity	1.5	1.5	1.4	1.4	1.5
Trigger efficiencies	0.5	1.0	1.0	1.0	0.7
b tagging	0.1	0.1	0.1	0.1	0.1
Pileup	0.4	0.6	0.8	0.2	0.4
Jet energy scales	0.9	1.3	0.7	1.1	0.7
Electron reconstruction	1.2	4.0	2.9	1.1	—
Electron ident. efficiencies	0.7	3.6	2.4	1.1	—
Electron energy scale	0.1	0.1	0.1	0.0	—
Muon efficiencies	0.7	—	0.3	0.8	1.2
Non-prompt bkg. normalization	0.7	1.6	0.5	0.7	0.7
VVV normalization	0.4	0.4	0.4	0.4	0.4
tZq normalization	0.1	0.1	0.1	0.1	0.1
ZZ normalization	0.3	0.8	0.7	0.5	0.5
$t\bar{t}$Z normalization	0.3	0.7	0.6	0.4	0.5
Xγ normalization	0.2	0.7	0.3	0.4	0.2
VH normalization	0.2	0.2	0.2	0.1	0.2
ISR/FSR	0.3	0.5	0.2	0.4	0.3
WZ theory (μ_R, μ_F, PDF)	0.2	0.2	0.2	0.2	0.2
MC statistical	0.5	1.9	0.9	1.0	0.9
Statistical	2.0	5.3	4.6	3.8	3.3
Total	3.3	8.4	6.4	5.0	4.2

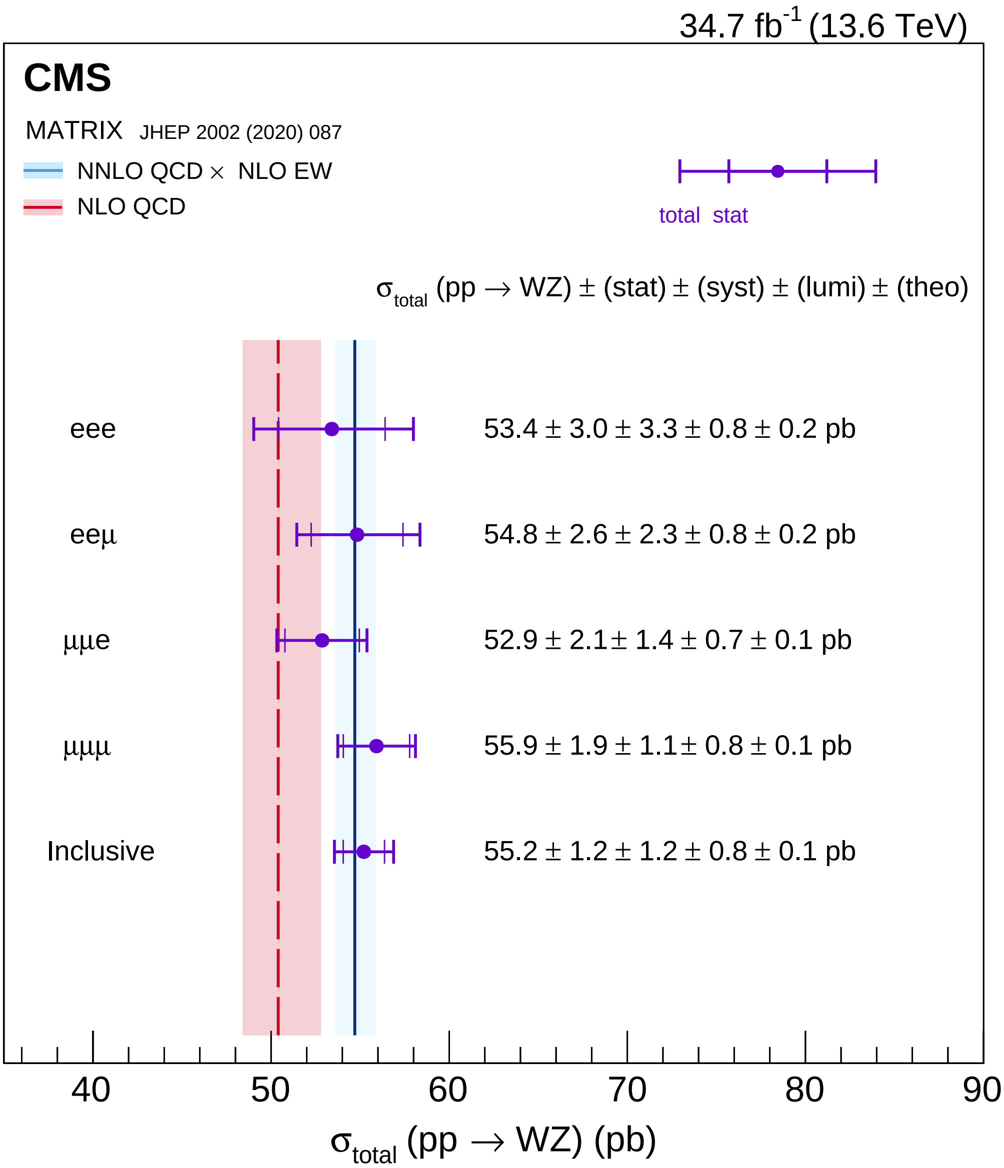

Figure 8: Total WZ production cross section for each of the flavour-exclusive and for the flavour-inclusive categories. The vertical bands show different theoretical predictions for the WZ cross section at NLO in QCD (red dashed line) and NNLO QCD × NLO EW (blue solid line), as well as their corresponding scale uncertainties. For each measurement, the best fit value is denoted with a purple point, with two delimiters on the error bars that account for the statistical and total uncertainties.

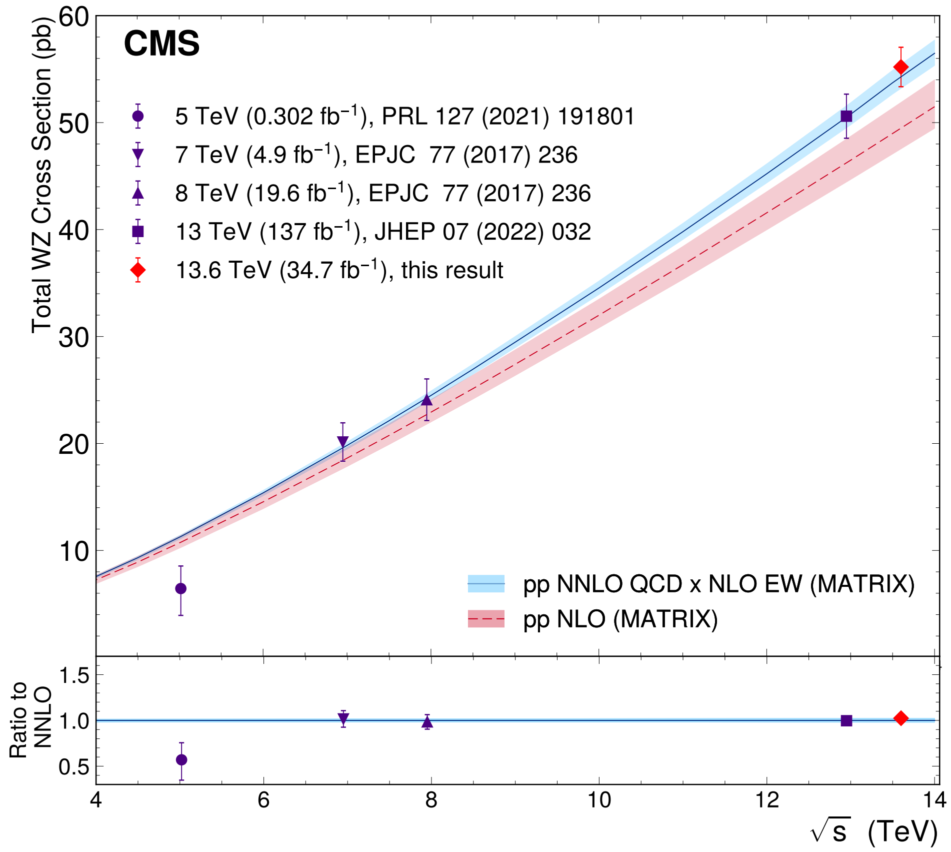

Figure 9: Measurement obtained in this analysis (red filled marker) together with other WZ production cross section measurements at different centre-of-mass energies by the CMS [1, 6, 7] Collaboration, compared to the NNLO QCD × NLO EW predictions, as well as the pure NLO prediction, computed in all cases with MATRIX.

9 Summary

The inclusive WZ production cross section is measured in proton-proton collisions at a centre-of-mass energy of 13.6 TeV, using data collected during 2022 with the CMS detector, corresponding to an integrated luminosity of 34.7 fb^{-1}. The production cross sections in the total and fiducial phase spaces are measured in the inclusive case as well as in four combinations of final state flavour composition. The cross sections are measured in a fiducial phase space as $\sigma_{\text{fiducial}}(\mathrm{pp} \to \mathrm{WZ}) = 297.6 \pm 6.4\,(\text{stat}) \pm 6.4\,(\text{syst}) \pm 4.2\,(\text{lumi}) \pm 0.5\,(\text{theo})\,\text{fb}$, and in a less restricted phase space as $\sigma_{\text{total}}(\mathrm{pp} \to \mathrm{WZ}) = 55.2 \pm 1.2\,(\text{stat}) \pm 1.2\,(\text{syst}) \pm 0.8\,(\text{lumi}) \pm 0.1\,(\text{theo})\,\text{pb}$. All these measurements are shown to be in good agreement with the SM predictions at NNLO QCD × NLO EW.

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 and other centres 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, the CMS detector, and the supporting computing infrastructure provided by the following funding agencies: SC (Armenia), BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES and BNSF (Bulgaria); CERN; CAS, MoST, and NSFC (China); MINCIENCIAS (Colombia); MSES and CSF (Croatia); RIF (Cyprus); SENESCYT (Ecuador); ERC PRG, RVTT3 and MoER TK202 (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); SRNSF (Georgia); BMBF, DFG, and HGF (Germany); GSRI (Greece); NKFIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); MES (Latvia); LMTLT (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MOS (Montenegro); MBIE (New Zealand); PAEC (Pakistan); MES and NSC (Poland); FCT (Portugal); MESTD (Serbia); MCIN/AEI and PCTI (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); MHESI and NSTDA (Thailand); TUBITAK and TENMAK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

Individuals have received support from the Marie-Curie programme and the European Research Council and Horizon 2020 Grant, contract Nos. 675440, 724704, 752730, 758316, 765710, 824093, 101115353, 101002207, and COST Action CA16108 (European Union); the Leventis Foundation; the Alfred P. Sloan Foundation; the Alexander von Humboldt Foundation; the Science Committee, project no. 22rl-037 (Armenia); the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the F.R.S.-FNRS and FWO (Belgium) under the "Excellence of Science – EOS" – be.h project n. 30820817; the Beijing Municipal Science & Technology Commission, No. Z191100007219010 and Fundamental Research Funds for the Central Universities (China); the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Shota Rustaveli National Science Foundation, grant FR-22-985 (Georgia); the Deutsche Forschungsgemeinschaft (DFG), among others, under Germany's Excellence Strategy – EXC 2121 "Quantum Universe" – 390833306, and under project number 400140256 - GRK2497; the Hellenic Foundation for Research and Innovation (HFRI), Project Number 2288 (Greece); the Hungarian Academy of Sciences, the New National Excellence Program - ÚNKP, the NKFIH research grants K 131991, K 133046, K 138136, K 143460, K 143477, K 146913, K 146914, K 147048, 2020-2.2.1-ED-2021-00181, TKP2021-NKTA-64, and 2021-4.1.2-NEMZ_KI (Hungary); the Council of Science and Industrial Research, India; ICSC – National Research Centre for High Performance Computing, Big Data and Quantum Computing and FAIR – Future Artificial Intelligence Research, funded by the NextGenerationEU program (Italy); the Latvian Council of Science; the Ministry of Education and Science, project no. 2022/WK/14, and the National Science Center, contracts Opus 2021/41/B/ST2/01369 and 2021/43/B/ST2/01552 (Poland); the Fundação para a Ciência e a Tecnologia, grant CEECIND/01334/2018 (Portugal); the National Priorities Research Program by Qatar National Research Fund; MCIN/AEI/10.13039/501100011033, ERDF "a way of making Europe", and the Programa Estatal de Fomento de la Investigación Científica y Técnica de Excelencia María de Maeztu, grant MDM-2017-0765 and Programa Severo Ochoa del Principado de Asturias (Spain); the Chulalongkorn Academic into Its 2nd Century Project Advancement Project, and the National Science, Research and Innovation Fund via the Program Management Unit for Human Resources & Institutional Development, Research and Innovation, grant B39G670016 (Thailand); the Kavli Foundation; the Nvidia Corporation; the SuperMicro Corporation; the Welch Foundation, contract C-1845; and the Weston Havens Foundation

(USA).

References

[1] CMS Collaboration, "Measurement of the WZ production cross section in pp collisions at $\sqrt{s} = 7$ and 8 TeV and search for anomalous triple gauge couplings at $\sqrt{s} = 8$ TeV", *Eur. Phys. J. C* **77** (2017) 236, doi:10.1140/epjc/s10052-017-4730-z, arXiv:1609.05721.

[2] ATLAS Collaboration, "Measurements of $W^{\pm}Z$ production cross sections in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector and limits on anomalous gauge boson self-couplings", *Phys. Rev. D* **93** (2016) 092004, doi:10.1103/PhysRevD.93.092004, arXiv:1603.02151.

[3] CMS Collaboration, "Measurement of the WZ production cross section in pp collisions at $\sqrt{s} = 13$ TeV", *Phys. Lett. B* **766** (2017) 268, doi:10.1016/j.physletb.2017.01.011, arXiv:1607.06943.

[4] ATLAS Collaboration, "Measurement of the $W^{\pm}Z$ boson pair-production cross section in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector", *Phys. Lett. B* **762** (2016) 1, doi:10.1016/j.physletb.2016.08.052, arXiv:1606.04017.

[5] ATLAS Collaboration, "Measurement of $W^{\pm}Z$ production cross sections and gauge boson polarisation in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector", *Eur. Phys. J. C* **79** (2019) 535, doi:10.1140/epjc/s10052-019-7027-6, arXiv:1902.05759.

[6] CMS Collaboration, "Measurements of the electroweak diboson production cross sections in proton-proton collisions at $\sqrt{s} = 5.02$ TeV using leptonic decays", *Phys. Rev. Lett.* **127** (2021) 191801, doi:10.1103/PhysRevLett.127.191801, arXiv:2107.01137.

[7] CMS Collaboration, "Measurement of the inclusive and differential WZ production cross sections, polarization angles, and triple gauge couplings in pp collisions at $\sqrt{s} = 13$ TeV", *JHEP* **07** (2022) 032, doi:10.1007/JHEP07(2022)032, arXiv:2110.11231.

[8] HEPData record for this analysis, 2024. doi:10.17182/hepdata.155693.

[9] CMS Collaboration, "The CMS experiment at the CERN LHC", *JINST* **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.

[10] CMS Collaboration, "Development of the CMS detector for the CERN LHC Run 3", *JINST* **19** (2024) P05064, doi:10.1088/1748-0221/19/05/P05064, arXiv:2309.05466.

[11] CMS Collaboration, "Performance of the CMS Level-1 trigger in proton-proton collisions at $\sqrt{s} = 13$ TeV", *JINST* **15** (2020) P10017, doi:10.1088/1748-0221/15/10/P10017, arXiv:2006.10165.

[12] CMS Collaboration, "The CMS trigger system", *JINST* **12** (2017) P01020, doi:10.1088/1748-0221/12/01/P01020, arXiv:1609.02366.

[13] CMS Collaboration, "Performance of the CMS high-level trigger during LHC Run 2", *JINST* **19** (2024) P11021, doi:10.1088/1748-0221/19/11/P11021, arXiv:2410.17038.

[14] P. Nason, "A new method for combining NLO QCD with shower Monte Carlo algorithms", *JHEP* **11** (2004) 040, doi:10.1088/1126-6708/2004/11/040, arXiv:hep-ph/0409146.

[15] S. Frixione, P. Nason, and C. Oleari, "Matching NLO QCD computations with parton shower simulations: the POWHEG method", *JHEP* **11** (2007) 070, doi:10.1088/1126-6708/2007/11/070, arXiv:0709.2092.

[16] S. Alioli, P. Nason, C. Oleari, and E. Re, "A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX", *JHEP* **06** (2010) 043, doi:10.1007/JHEP06(2010)043, arXiv:1002.2581.

[17] T. Melia, P. Nason, R. Röntsch, and G. Zanderighi, "W^+W^-, WZ and ZZ production in the POWHEG BOX", *JHEP* **11** (2011) 078, doi:10.1007/JHEP11(2011)078, arXiv:1107.5051.

[18] P. Nason and G. Zanderighi, "W^+W^-, WZ and ZZ production in the POWHEG-BOX-V2", *Eur. Phys. J. C* **74** (2014) 2702, doi:10.1140/epjc/s10052-013-2702-5, arXiv:1311.1365.

[19] J. Alwall et al., "The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations", *JHEP* **07** (2014) 079, doi:10.1007/JHEP07(2014)079, arXiv:1405.0301.

[20] NNPDF Collaboration, "Parton distributions from high-precision collider data", *Eur. Phys. J. C* **77** (2017) 663, doi:10.1140/epjc/s10052-017-5199-5, arXiv:1706.00428.

[21] C. Bierlich et al., "A comprehensive guide to the physics and usage of PYTHIA 8.3", *SciPost Phys. Codeb.* **8** (2022) doi:10.21468/SciPostPhysCodeb.8, arXiv:2203.11601.

[22] CMS Collaboration, "Extraction and validation of a new set of CMS PYTHIA 8 tunes from underlying-event measurements", *Eur. Phys. J. C* **80** (2020) 4, doi:10.1140/epjc/s10052-019-7499-4, arXiv:1903.12179.

[23] GEANT4 Collaboration, "GEANT4—a simulation toolkit", *Nucl. Instrum. Meth. A* **506** (2003) 250, doi:10.1016/S0168-9002(03)01368-8.

[24] CMS Collaboration, "Particle-flow reconstruction and global event description with the CMS detector", *JINST* **12** (2017) P10003, doi:10.1088/1748-0221/12/10/P10003, arXiv:1706.04965.

[25] CMS Collaboration, "Technical proposal for the Phase-II upgrade of the Compact Muon Solenoid", CMS Technical Proposal CERN-LHCC-2015-010, CMS-TDR-15-02, 2015. doi:10.17181/CERN.VU8I.D59J.

[26] CMS Collaboration, "Electron and photon reconstruction and identification with the CMS experiment at the CERN LHC", *JINST* **16** (2021) P05014, doi:10.1088/1748-0221/16/05/P05014, arXiv:2012.06888.

[27] CMS Collaboration, "Performance of electron reconstruction and selection with the CMS detector in proton-proton collisions at $\sqrt{s} = 8\,\text{TeV}$", *JINST* **10** (2015) P06005, doi:10.1088/1748-0221/10/06/P06005, arXiv:1502.02701.

[28] CMS Collaboration, "Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s} = 13$ TeV", *JINST* **13** (2018) P06015, doi:10.1088/1748-0221/13/06/P06015, arXiv:1804.04528.

[29] CMS Collaboration, "Muon identification using multivariate techniques in the CMS experiment in proton-proton collisions at $\sqrt{s} = 13$ TeV", *JINST* **19** (2024) P02031, doi:10.1088/1748-0221/19/02/P02031, arXiv:2310.03844.

[30] M. Cacciari, G. P. Salam, and G. Soyez, "The anti-k_{T} jet clustering algorithm", *JHEP* **04** (2008) 063, doi:10.1088/1126-6708/2008/04/063, arXiv:0802.1189.

[31] M. Cacciari, G. P. Salam, and G. Soyez, "FASTJET user manual", *Eur. Phys. J. C* **72** (2012) 1896, doi:10.1140/epjc/s10052-012-1896-2, arXiv:1111.6097.

[32] CMS Collaboration, "Pileup mitigation at CMS in 13 TeV data", *JINST* **15** (2020) P09018, doi:10.1088/1748-0221/15/09/P09018, arXiv:2003.00503.

[33] D. Bertolini, P. Harris, M. Low, and N. Tran, "Pileup per particle identification", *JHEP* **10** (2014) 059, doi:10.1007/JHEP10(2014)059, arXiv:1407.6013.

[34] CMS Collaboration, "Identification of heavy-flavour jets with the CMS detector in pp collisions at 13 TeV", *JINST* **13** (2018) P05011, doi:10.1088/1748-0221/13/05/P05011, arXiv:1712.07158.

[35] E. Bols et al., "Jet flavour classification using DeepJet", *JINST* **15** (2020) P12012, doi:10.1088/1748-0221/15/12/P12012, arXiv:2008.10519.

[36] CMS Collaboration, "Performance of missing transverse momentum reconstruction in proton-proton collisions at $\sqrt{s} = 13$ TeV using the CMS detector", *JINST* **14** (2019) P07004, doi:10.1088/1748-0221/14/07/P07004, arXiv:1903.06078.

[37] CMS Collaboration, "Mitigation of anomalous missing transverse momentum measurements in data collected by CMS at $\sqrt{s} = 13$ TeV during the LHC Run 2", Technical Report CMS-DP-2020-018, 2020.

[38] ALEPH, DELPHI, L3, OPAL, and SLD Collaborations, LEP Electroweak Working Group, and SLD Electroweak and Heavy Flavour Groups, "Precision electroweak measurements on the Z resonance", *Phys. Rept.* **427** (2006) 257, doi:10.1016/j.physrep.2005.12.006, arXiv:hep-ex/0509008.

[39] CMS Collaboration, "Observation of single top quark production in association with a Z boson in proton-proton collisions at $\sqrt{s} = 13$ TeV", *Phys. Rev. Lett.* **122** (2019) 132003, doi:10.1103/PhysRevLett.122.132003, arXiv:1812.05900.

[40] CMS Collaboration, "Observation of the production of three massive gauge bosons at $\sqrt{s} = 13$ TeV", *Phys. Rev. Lett.* **125** (2020) 151802, doi:10.1103/PhysRevLett.125.151802, arXiv:2006.11191.

[41] CMS Collaboration, "Observation of Higgs boson decay to bottom quarks", *Phys. Rev. Lett.* **121** (2018) 121801, doi:10.1103/PhysRevLett.121.121801, arXiv:1808.08242.

[42] CMS Collaboration, "Measurements of inclusive W and Z cross sections in pp collisions at $\sqrt{s} = 7$ TeV", *JHEP* **01** (2011) 080, doi:10.1007/JHEP01(2011)080, arXiv:1012.2466.

[43] C. J. Clopper and E. S. Pearson, “The use of confidence or fiducial limits illustrated in the case of the binomial”, *Biometrika* **26** (1934) 404, doi:10.1093/biomet/26.4.404.

[44] ATLAS Collaboration, “Measurement of the inelastic proton-proton cross section at $\sqrt{s} = 13$ TeV with the ATLAS setector at the LHC”, *Phys. Rev. Lett.* **117** (2016) 182002, doi:10.1103/PhysRevLett.117.182002, arXiv:1606.02625.

[45] CMS Collaboration, “Luminosity measurement in proton-proton collisions at 13.6 TeV in 2022 at CMS”, CMS Physics Analysis Summary CMS-PAS-LUM-22-001, 2024.

[46] CMS Collaboration, “Precision luminosity measurement in proton-proton collisions at $\sqrt{s} = 13$ TeV in 2015 and 2016 at CMS”, *Eur. Phys. J. C* **81** (2021) 800, doi:10.1140/epjc/s10052-021-09538-2, arXiv:2104.01927.

[47] R. Barlow and C. Beeston, “Fitting using finite Monte Carlo samples”, *Comput. Phys. Commun.* **77** (1993) 219, doi:10.1016/0010-4655(93)90005-W.

[48] CMS Collaboration, “The CMS statistical analysis and combination tool: COMBINE”, *Comput. Softw. Big Sci.* **8** (2024) 19, doi:10.1007/s41781-024-00121-4, arXiv:2404.06614.

[49] M. Grazzini et al., “NNLO QCD + NLO EW with MATRIX+OPENLOOPS: precise predictions for vector-boson pair production”, *JHEP* **02** (2020) 087, doi:10.1007/JHEP02(2020)087, arXiv:1912.00068.

A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia
A. Hayrapetyan, A. Tumasyan[1]

Institut für Hochenergiephysik, Vienna, Austria
W. Adam, J.W. Andrejkovic, L. Benato, T. Bergauer, S. Chatterjee, K. Damanakis, M. Dragicevic, P.S. Hussain, M. Jeitler[2], N. Krammer, A. Li, D. Liko, I. Mikulec, J. Schieck[2], R. Schöfbeck[2], D. Schwarz, M. Sonawane, W. Waltenberger, C.-E. Wulz[2]

Universiteit Antwerpen, Antwerpen, Belgium
T. Janssen, T. Van Laer, P. Van Mechelen

Vrije Universiteit Brussel, Brussel, Belgium
N. Breugelmans, J. D'Hondt, S. Dansana, A. De Moor, M. Delcourt, F. Heyen, S. Lowette, I. Makarenko, D. Müller, S. Tavernier, M. Tytgat[3], G.P. Van Onsem, S. Van Putte, D. Vannerom

Université Libre de Bruxelles, Bruxelles, Belgium
B. Bilin, B. Clerbaux, A.K. Das, I. De Bruyn, G. De Lentdecker, H. Evard, L. Favart, P. Gianneios, J. Jaramillo, A. Khalilzadeh, F.A. Khan, K. Lee, A. Malara, M.A. Shahzad, L. Thomas, M. Vanden Bemden, C. Vander Velde, P. Vanlaer

Ghent University, Ghent, Belgium
M. De Coen, D. Dobur, G. Gokbulut, Y. Hong, J. Knolle, L. Lambrecht, D. Marckx, K. Mota Amarilo, K. Skovpen, N. Van Den Bossche, J. van der Linden, L. Wezenbeek

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
A. Benecke, A. Bethani, G. Bruno, C. Caputo, J. De Favereau De Jeneret, C. Delaere, I.S. Donertas, A. Giammanco, A.O. Guzel, Sa. Jain, V. Lemaitre, J. Lidrych, P. Mastrapasqua, T.T. Tran, S. Turkcapar

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
G.A. Alves, E. Coelho, G. Correia Silva, C. Hensel, T. Menezes De Oliveira, C. Mora Herrera[4], P. Rebello Teles, M. Soeiro, E.J. Tonelli Manganote[5], A. Vilela Pereira[4]

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
W.L. Aldá Júnior, M. Barroso Ferreira Filho, H. Brandao Malbouisson, W. Carvalho, J. Chinellato[6], E.M. Da Costa, G.G. Da Silveira[7], D. De Jesus Damiao, S. Fonseca De Souza, R. Gomes De Souza, T. Laux Kuhn[7], M. Macedo, J. Martins, L. Mundim, H. Nogima, J.P. Pinheiro, A. Santoro, A. Sznajder, M. Thiel

Universidade Estadual Paulista, Universidade Federal do ABC, São Paulo, Brazil
C.A. Bernardes[7], L. Calligaris, T.R. Fernandez Perez Tomei, E.M. Gregores, I. Maietto Silverio, P.G. Mercadante, S.F. Novaes, B. Orzari, Sandra S. Padula

Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria
A. Aleksandrov, G. Antchev, R. Hadjiiska, P. Iaydjiev, M. Misheva, M. Shopova, G. Sultanov

University of Sofia, Sofia, Bulgaria
A. Dimitrov, L. Litov, B. Pavlov, P. Petkov, A. Petrov, E. Shumka

Instituto De Alta Investigación, Universidad de Tarapacá, Casilla 7 D, Arica, Chile
S. Keshri, D. Laroze, S. Thakur

Beihang University, Beijing, China
T. Cheng, T. Javaid, L. Yuan

Department of Physics, Tsinghua University, Beijing, China
Z. Hu, Z. Liang, J. Liu

Institute of High Energy Physics, Beijing, China
G.M. Chen[8], H.S. Chen[8], M. Chen[8], F. Iemmi, C.H. Jiang, A. Kapoor[9], H. Liao, Z.-A. Liu[10], R. Sharma[11], J.N. Song[10], J. Tao, C. Wang[8], J. Wang, Z. Wang[8], H. Zhang, J. Zhao

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
A. Agapitos, Y. Ban, A. Carvalho Antunes De Oliveira, S. Deng, B. Guo, C. Jiang, A. Levin, C. Li, Q. Li, Y. Mao, S. Qian, S.J. Qian, X. Qin, X. Sun, D. Wang, H. Yang, L. Zhang, Y. Zhao, C. Zhou

Guangdong Provincial Key Laboratory of Nuclear Science and Guangdong-Hong Kong Joint Laboratory of Quantum Matter, South China Normal University, Guangzhou, China
S. Yang

Sun Yat-Sen University, Guangzhou, China
Z. You

University of Science and Technology of China, Hefei, China
K. Jaffel, N. Lu

Nanjing Normal University, Nanjing, China
G. Bauer[12], B. Li[13], K. Yi[14], J. Zhang

Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) - Fudan University, Shanghai, China
Y. Li

Zhejiang University, Hangzhou, Zhejiang, China
Z. Lin, C. Lu, M. Xiao

Universidad de Los Andes, Bogota, Colombia
C. Avila, D.A. Barbosa Trujillo, A. Cabrera, C. Florez, J. Fraga, J.A. Reyes Vega

Universidad de Antioquia, Medellin, Colombia
C. Rendón, M. Rodriguez, A.A. Ruales Barbosa, J.D. Ruiz Alvarez

University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia
D. Giljanovic, N. Godinovic, D. Lelas, A. Sculac

University of Split, Faculty of Science, Split, Croatia
M. Kovac, A. Petkovic, T. Sculac

Institute Rudjer Boskovic, Zagreb, Croatia
P. Bargassa, V. Brigljevic, B.K. Chitroda, D. Ferencek, K. Jakovcic, A. Starodumov[15],

T. Susa

University of Cyprus, Nicosia, Cyprus
A. Attikis, K. Christoforou, A. Hadjiagapiou, C. Leonidou, J. Mousa, C. Nicolaou, L. Paizanos, F. Ptochos, P.A. Razis, H. Rykaczewski, H. Saka, A. Stepennov

Charles University, Prague, Czech Republic
M. Finger, M. Finger Jr., A. Kveton

Escuela Politecnica Nacional, Quito, Ecuador
E. Ayala

Universidad San Francisco de Quito, Quito, Ecuador
E. Carrera Jarrin

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
A.A. Abdelalim[16,17], S. Elgammal[18], A. Ellithi Kamel[19]

Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt
M. Abdullah Al-Mashad, M.A. Mahmoud

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
K. Ehataht, M. Kadastik, T. Lange, S. Nandan, C. Nielsen, J. Pata, M. Raidal, L. Tani, C. Veelken

Department of Physics, University of Helsinki, Helsinki, Finland
H. Kirschenmann, K. Osterberg, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland
S. Bharthuar, N. Bin Norjoharuddeen, E. Brücken, F. Garcia, P. Inkaew, K.T.S. Kallonen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, M. Myllymäki, M.m. Rantanen, H. Siikonen, J. Tuominiemi

Lappeenranta-Lahti University of Technology, Lappeenranta, Finland
P. Luukka, H. Petrow

IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
M. Besancon, F. Couderc, M. Dejardin, D. Denegri, J.L. Faure, F. Ferri, S. Ganjour, P. Gras, G. Hamel de Monchenault, M. Kumar, V. Lohezic, J. Malcles, F. Orlandi, L. Portales, A. Rosowsky, M.Ö. Sahin, A. Savoy-Navarro[20], P. Simkina, M. Titov, M. Tornago

Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France
F. Beaudette, G. Boldrini, P. Busson, A. Cappati, C. Charlot, M. Chiusi, T.D. Cuisset, F. Damas, O. Davignon, A. De Wit, I.T. Ehle, B.A. Fontana Santos Alves, S. Ghosh, A. Gilbert, R. Granier de Cassagnac, A. Hakimi, B. Harikrishnan, L. Kalipoliti, G. Liu, M. Nguyen, C. Ochando, R. Salerno, J.B. Sauvan, Y. Sirois, L. Urda Gómez, E. Vernazza, A. Zabi, A. Zghiche

Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France
J.-L. Agram[21], J. Andrea, D. Apparu, D. Bloch, J.-M. Brom, E.C. Chabert, C. Collard, S. Falke, U. Goerlach, R. Haeberle, A.-C. Le Bihan, M. Meena, O. Poncet, G. Saha, M.A. Sessini, P. Van Hove, P. Vaucelle

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

Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France
D. Amram, S. Beauceron, B. Blancon, G. Boudoul, N. Chanon, D. Contardo, P. Depasse, C. Dozen[22], H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, C. Greenberg, G. Grenier, B. Ille, E. Jourd'huy, I.B. Laktineh, M. Lethuillier, L. Mirabito, S. Perries, A. Purohit, M. Vander Donckt, P. Verdier, J. Xiao

Georgian Technical University, Tbilisi, Georgia
I. Lomidze, T. Toriashvili[23], Z. Tsamalaidze[24]

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
V. Botta, S. Consuegra Rodríguez, L. Feld, K. Klein, M. Lipinski, D. Meuser, A. Pauls, D. Pérez Adán, N. Röwert, M. Teroerde

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
S. Diekmann, A. Dodonova, N. Eich, D. Eliseev, F. Engelke, J. Erdmann, M. Erdmann, P. Fackeldey, B. Fischer, T. Hebbeker, K. Hoepfner, F. Ivone, A. Jung, M.y. Lee, F. Mausolf, M. Merschmeyer, A. Meyer, S. Mukherjee, D. Noll, F. Nowotny, A. Pozdnyakov, Y. Rath, W. Redjeb, F. Rehm, H. Reithler, V. Sarkisovi, A. Schmidt, C. Seth, A. Sharma, J.L. Spah, A. Stein, F. Torres Da Silva De Araujo[25], S. Wiedenbeck, S. Zaleski

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
C. Dziwok, G. Flügge, T. Kress, A. Nowack, O. Pooth, A. Stahl, T. Ziemons, A. Zotz

Deutsches Elektronen-Synchrotron, Hamburg, Germany
H. Aarup Petersen, M. Aldaya Martin, J. Alimena, S. Amoroso, Y. An, J. Bach, S. Baxter, M. Bayatmakou, H. Becerril Gonzalez, O. Behnke, A. Belvedere, F. Blekman[26], K. Borras[27], A. Campbell, A. Cardini, C. Cheng, F. Colombina, G. Eckerlin, D. Eckstein, L.I. Estevez Banos, E. Gallo[26], A. Geiser, V. Guglielmi, M. Guthoff, A. Hinzmann, L. Jeppe, B. Kaech, M. Kasemann, C. Kleinwort, R. Kogler, M. Komm, D. Krücker, W. Lange, D. Leyva Pernia, K. Lipka[28], W. Lohmann[29], F. Lorkowski, R. Mankel, I.-A. Melzer-Pellmann, M. Mendizabal Morentin, A.B. Meyer, G. Milella, K. Moral Figueroa, A. Mussgiller, L.P. Nair, J. Niedziela, A. Nürnberg, Y. Otarid, J. Park, E. Ranken, A. Raspereza, D. Rastorguev, J. Rübenach, L. Rygaard, A. Saggio, M. Scham[30,27], S. Schnake[27], P. Schütze, C. Schwanenberger[26], D. Selivanova, K. Sharko, M. Shchedrolosiev, D. Stafford, F. Vazzoler, A. Ventura Barroso, R. Walsh, D. Wang, Q. Wang, K. Wichmann, L. Wiens[27], C. Wissing, Y. Yang, A. Zimermmane Castro Santos

University of Hamburg, Hamburg, Germany
A. Albrecht, S. Albrecht, M. Antonello, S. Bein, S. Bollweg, M. Bonanomi, P. Connor, K. El Morabit, Y. Fischer, E. Garutti, A. Grohsjean, J. Haller, D. Hundhausen, H.R. Jabusch, G. Kasieczka, P. Keicher, R. Klanner, W. Korcari, T. Kramer, C.c. Kuo, V. Kutzner, F. Labe, J. Lange, A. Lobanov, C. Matthies, L. Moureaux, M. Mrowietz, A. Nigamova, Y. Nissan, A. Paasch, K.J. Pena Rodriguez, T. Quadfasel, B. Raciti, M. Rieger, D. Savoiu, J. Schindler, P. Schleper, M. Schröder, J. Schwandt, M. Sommerhalder, H. Stadie, G. Steinbrück, A. Tews, B. Wiederspan, M. Wolf

Karlsruher Institut fuer Technologie, Karlsruhe, Germany
S. Brommer, E. Butz, T. Chwalek, A. Dierlamm, A. Droll, U. Elicabuk, N. Faltermann, M. Giffels, A. Gottmann, F. Hartmann[31], R. Hofsaess, M. Horzela, U. Husemann, J. Kieseler, M. Klute, O. Lavoryk, J.M. Lawhorn, M. Link, A. Lintuluoto, S. Maier, S. Mitra, M. Mormile, Th. Müller, M. Neukum, M. Oh, E. Pfeffer, M. Presilla, G. Quast, K. Rabbertz, B. Regnery, N. Shadskiy, I. Shvetsov, H.J. Simonis, L. Sowa, L. Stockmeier, K. Tauqeer, M. Toms, N. Trevisani, R.F. Von Cube, M. Wassmer, S. Wieland, F. Wittig, R. Wolf, X. Zuo

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece
G. Anagnostou, G. Daskalakis, A. Kyriakis, A. Papadopoulos[31], A. Stakia

National and Kapodistrian University of Athens, Athens, Greece
G. Melachroinos, Z. Painesis, I. Paraskevas, N. Saoulidou, K. Theofilatos, E. Tziaferi, K. Vellidis, I. Zisopoulos

National Technical University of Athens, Athens, Greece
G. Bakas, T. Chatzistavrou, G. Karapostoli, K. Kousouris, I. Papakrivopoulos, E. Siamarkou, G. Tsipolitis, A. Zacharopoulou

University of Ioánnina, Ioánnina, Greece
I. Bestintzanos, I. Evangelou, C. Foudas, C. Kamtsikis, P. Katsoulis, P. Kokkas, P.G. Kosmoglou Kioseoglou, N. Manthos, I. Papadopoulos, J. Strologas

HUN-REN Wigner Research Centre for Physics, Budapest, Hungary
C. Hajdu, D. Horvath[32,33], K. Márton, A.J. Rádl[34], F. Sikler, V. Veszpremi

MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
M. Csanád, K. Farkas, A. Fehérkuti[35], M.M.A. Gadallah[36], Á. Kadlecsik, P. Major, G. Pásztor, G.I. Veres

Faculty of Informatics, University of Debrecen, Debrecen, Hungary
B. Ujvari, G. Zilizi

HUN-REN ATOMKI - Institute of Nuclear Research, Debrecen, Hungary
G. Bencze, S. Czellar, J. Molnar, Z. Szillasi

Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary
T. Csorgo[35], F. Nemes[35], T. Novak

Panjab University, Chandigarh, India
S. Bansal, S.B. Beri, V. Bhatnagar, G. Chaudhary, S. Chauhan, N. Dhingra[37], A. Kaur, A. Kaur, H. Kaur, M. Kaur, S. Kumar, T. Sheokand, J.B. Singh, A. Singla

University of Delhi, Delhi, India
A. Ahmed, A. Bhardwaj, A. Chhetri, B.C. Choudhary, A. Kumar, A. Kumar, M. Naimuddin, K. Ranjan, M.K. Saini, S. Saumya

Saha Institute of Nuclear Physics, HBNI, Kolkata, India
S. Baradia, S. Barman[38], S. Bhattacharya, S. Das Gupta, S. Dutta, S. Dutta, S. Sarkar

Indian Institute of Technology Madras, Madras, India
M.M. Ameen, P.K. Behera, S.C. Behera, S. Chatterjee, G. Dash, P. Jana,

P. Kalbhor, S. Kamble, J.R. Komaragiri[39], D. Kumar[39], T. Mishra, B. Parida[40], P.R. Pujahari, N.R. Saha, A. Sharma, A.K. Sikdar, R.K. Singh, P. Verma, S. Verma, A. Vijay

Tata Institute of Fundamental Research-A, Mumbai, India
S. Dugad, G.B. Mohanty, M. Shelake, P. Suryadevara

Tata Institute of Fundamental Research-B, Mumbai, India
A. Bala, S. Banerjee, R.M. Chatterjee, M. Guchait, Sh. Jain, A. Jaiswal, S. Kumar, G. Majumder, K. Mazumdar, S. Parolia, A. Thachayath

National Institute of Science Education and Research, An OCC of Homi Bhabha National Institute, Bhubaneswar, Odisha, India
S. Bahinipati[41], C. Kar, D. Maity[42], P. Mal, K. Naskar[42], A. Nayak[42], S. Nayak, K. Pal, P. Sadangi, S.K. Swain, S. Varghese[42], D. Vats[42]

Indian Institute of Science Education and Research (IISER), Pune, India
S. Acharya[43], A. Alpana, S. Dube, B. Gomber[43], P. Hazarika, B. Kansal, A. Laha, B. Sahu[43], S. Sharma, K.Y. Vaish

Isfahan University of Technology, Isfahan, Iran
H. Bakhshiansohi[44], A. Jafari[45], M. Zeinali[46]

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
S. Bashiri, S. Chenarani[47], S.M. Etesami, Y. Hosseini, M. Khakzad, E. Khazaie, M. Mohammadi Najafabadi, S. Tizchang[48]

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], A. Colaleo[a,b], D. Creanza[a,c], B. D'Anzi[a,b], N. De Filippis[a,c], M. De Palma[a,b], W. Elmetenawee[a,b,16], N. Ferrara[a,b], L. Fiore[a], G. Iaselli[a,c], L. Longo[a], M. Louka[a,b], G. Maggi[a,c], M. Maggi[a], I. Margjeka[a], V. Mastrapasqua[a,b], S. My[a,b], S. Nuzzo[a,b], A. Pellecchia[a,b], A. Pompili[a,b], G. Pugliese[a,c], R. Radogna[a,b], D. Ramos[a], A. Ranieri[a], L. Silvestris[a], F.M. Simone[a,c], Ü. Sözbilir[a], A. Stamerra[a,b], D. Troiano[a,b], R. Venditti[a,b], P. Verwilligen[a], A. Zaza[a,b]

INFN Sezione di Bologna[a], Università di Bologna[b], Bologna, Italy
G. Abbiendi[a], C. Battilana[a,b], D. Bonacorsi[a,b], P. Capiluppi[a,b], A. Castro[†a,b], F.R. Cavallo[a], M. Cuffiani[a,b], G.M. Dallavalle[a], T. Diotalevi[a,b], F. Fabbri[a], A. Fanfani[a,b], D. Fasanella[a], P. Giacomelli[a], L. Giommi[a,b], C. Grandi[a], L. Guiducci[a,b], S. Lo Meo[a,49], M. Lorusso[a,b], L. Lunerti[a], S. Marcellini[a], G. Masetti[a], F.L. Navarria[a,b], G. Paggi[a,b], A. Perrotta[a], F. Primavera[a,b], A.M. Rossi[a,b], S. Rossi Tisbeni[a,b], T. Rovelli[a,b], G.P. Siroli[a,b]

INFN Sezione di Catania[a], Università di Catania[b], Catania, Italy
S. Costa[a,b,50], A. Di Mattia[a], A. Lapertosa[a], R. Potenza[a,b], A. Tricomi[a,b,50], C. Tuve[a,b]

INFN Sezione di Firenze[a], Università di Firenze[b], Firenze, Italy
P. Assiouras[a], G. Barbagli[a], G. Bardelli[a,b], B. Camaiani[a,b], A. Cassese[a], R. Ceccarelli[a], V. Ciulli[a,b], C. Civinini[a], R. D'Alessandro[a,b], E. Focardi[a,b], T. Kello[a], G. Latino[a,b], P. Lenzi[a,b], M. Lizzo[a], M. Meschini[a], S. Paoletti[a],

A. Papanastassiou[a,b], G. Sguazzoni[a], L. Viliani[a]

INFN Laboratori Nazionali di Frascati, Frascati, Italy
L. Benussi, S. Bianco, S. Meola[51], D. Piccolo

INFN Sezione di Genova[a], Università di Genova[b], Genova, Italy
M. Alves Gallo Pereira[a], F. Ferro[a], E. Robutti[a], S. Tosi[a,b]

INFN Sezione di Milano-Bicocca[a], Università di Milano-Bicocca[b], Milano, Italy
A. Benaglia[a], F. Brivio[a], F. Cetorelli[a,b], F. De Guio[a,b], M.E. Dinardo[a,b], P. Dini[a], S. Gennai[a], R. Gerosa[a,b], A. Ghezzi[a,b], P. Govoni[a,b], L. Guzzi[a], M.T. Lucchini[a,b], M. Malberti[a], S. Malvezzi[a], A. Massironi[a], D. Menasce[a], L. Moroni[a], M. Paganoni[a,b], S. Palluotto[a,b], D. Pedrini[a], A. Perego[a,b], B.S. Pinolini[a], G. Pizzati[a,b], S. Ragazzi[a,b], 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; Scuola Superiore Meridionale (SSM)[d], Napoli, Italy
S. Buontempo[a], A. Cagnotta[a,b], F. Carnevali[a,b], N. Cavallo[a,c], F. Fabozzi[a,c], A.O.M. Iorio[a,b], L. Lista[a,b,52], P. Paolucci[a,31], B. Rossi[a]

INFN Sezione di Padova[a], Università di Padova[b], Padova, Italy; Università di Trento[c], Trento, Italy
R. Ardino[a], P. Azzi[a], N. Bacchetta[a,53], D. Bisello[a,b], P. Bortignon[a], G. Bortolato[a,b], A. Bragagnolo[a,b], A.C.M. Bulla[a], R. Carlin[a,b], P. Checchia[a], T. Dorigo[a,54], U. Gasparini[a,b], S. Giorgetti[a], E. Lusiani[a], M. Margoni[a,b], M. Michelotto[a], M. Migliorini[a,b], F. Montecassiano[a], J. Pazzini[a,b], P. Ronchese[a,b], R. Rossin[a,b], F. Simonetto[a,b], M. Tosi[a,b], A. Triossi[a,b], S. Ventura[a], M. Zanetti[a,b], P. Zotto[a,b], A. Zucchetta[a,b], G. Zumerle[a,b]

INFN Sezione di Pavia[a], Università di Pavia[b], Pavia, Italy
A. Braghieri[a], S. Calzaferri[a], D. Fiorina[a], P. Montagna[a,b], V. Re[a], C. Riccardi[a,b], P. Salvini[a], I. Vai[a,b], P. Vitulo[a,b]

INFN Sezione di Perugia[a], Università di Perugia[b], Perugia, Italy
S. Ajmal[a,b], M.E. Ascioti[a,b], G.M. Bilei[a], C. Carrivale[a,b], D. Ciangottini[a,b], L. Fanò[a,b], M. Magherini[a,b], V. Mariani[a,b], M. Menichelli[a], F. Moscatelli[a,55], A. Rossi[a,b], A. Santocchia[a,b], D. Spiga[a], T. Tedeschi[a,b]

INFN Sezione di Pisa[a], Università di Pisa[b], Scuola Normale Superiore di Pisa[c], Pisa, Italy; Università di Siena[d], Siena, Italy
C. Aimè[a], C.A. Alexe[a,c], P. Asenov[a,b], P. Azzurri[a], G. Bagliesi[a], R. Bhattacharya[a], L. Bianchini[a,b], T. Boccali[a], E. Bossini[a], D. Bruschini[a,c], R. Castaldi[a], M.A. Ciocci[a,b], M. Cipriani[a,b], V. D'Amante[a,d], R. Dell'Orso[a], S. Donato[a], A. Giassi[a], F. Ligabue[a,c], A.C. Marini[a], D. Matos Figueiredo[a], A. Messineo[a,b], S. Mishra[a], V.K. Muraleedharan Nair Bindhu[a,b,42], M. Musich[a,b], F. Palla[a], A. Rizzi[a,b], G. Rolandi[a,c], S. Roy Chowdhury[a], T. Sarkar[a], A. Scribano[a], P. Spagnolo[a], R. Tenchini[a], G. Tonelli[a,b], N. Turini[a,d], F. Vaselli[a,c], A. Venturi[a], P.G. Verdini[a]

INFN Sezione di Roma[a], Sapienza Università di Roma[b], Roma, Italy
C. Baldenegro Barrera[a,b], P. Barria[a], C. Basile[a,b], F. Cavallari[a], L. Cunqueiro Mendez[a,b], D. Del Re[a,b], E. Di Marco[a,b], M. Diemoz[a], F. Errico[a,b], R. Gargiulo[a,b], E. Longo[a,b], L. Martikainen[a,b], J. Mijuskovic[a,b], G. Organtini[a,b], F. Pandolfi[a], R. Paramatti[a,b], C. Quaranta[a,b], S. Rahatlou[a,b], C. Rovelli[a],

F. Santanastasio[a,b], L. Soffi[a], V. Vladimirov[a,b]

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], S. Argiro[a,b], M. Arneodo[a,c], N. Bartosik[a], R. Bellan[a,b], A. Bellora[a,b], C. Biino[a], C. Borca[a,b], N. Cartiglia[a], M. Costa[a,b], R. Covarelli[a,b], N. Demaria[a], L. Finco[a], M. Grippo[a,b], B. Kiani[a,b], F. Legger[a], F. Luongo[a,b], C. Mariotti[a], L. Markovic[a,b], S. Maselli[a], A. Mecca[a,b], L. Menzio[a,b], P. Meridiani[a], E. Migliore[a,b], M. Monteno[a], R. Mulargia[a], M.M. Obertino[a,b], G. Ortona[a], L. Pacher[a,b], N. Pastrone[a], M. Pelliccioni[a], M. Ruspa[a,c], F. Siviero[a,b], V. Sola[a,b], A. Solano[a,b], A. Staiano[a], C. Tarricone[a,b], D. Trocino[a], G. Umoret[a,b], R. White[a,b]

INFN Sezione di Trieste[a], Università di Trieste[b], Trieste, Italy
J. Babbar[a,b], S. Belforte[a], V. Candelise[a,b], M. Casarsa[a], F. Cossutti[a], K. De Leo[a], G. Della Ricca[a,b]

Kyungpook National University, Daegu, Korea
S. Dogra, J. Hong, B. Kim, J. Kim, D. Lee, H. Lee, S.W. Lee, C.S. Moon, Y.D. Oh, M.S. Ryu, S. Sekmen, B. Tae, Y.C. Yang

Department of Mathematics and Physics - GWNU, Gangneung, Korea
M.S. Kim

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
G. Bak, P. Gwak, H. Kim, D.H. Moon

Hanyang University, Seoul, Korea
E. Asilar, J. Choi[56], D. Kim, T.J. Kim, J.A. Merlin, Y. Ryou

Korea University, Seoul, Korea
S. Choi, S. Han, B. Hong, K. Lee, K.S. Lee, S. Lee, J. Yoo

Kyung Hee University, Department of Physics, Seoul, Korea
J. Goh, S. Yang

Sejong University, Seoul, Korea
H. S. Kim, Y. Kim, S. Lee

Seoul National University, Seoul, Korea
J. Almond, J.H. Bhyun, J. Choi, J. Choi, W. Jun, J. Kim, Y.W. Kim, S. Ko, H. Kwon, H. Lee, J. Lee, J. Lee, B.H. Oh, S.B. Oh, H. Seo, U.K. Yang, I. Yoon

University of Seoul, Seoul, Korea
W. Jang, D.Y. Kang, Y. Kang, S. Kim, B. Ko, J.S.H. Lee, Y. Lee, I.C. Park, Y. Roh, I.J. Watson

Yonsei University, Department of Physics, Seoul, Korea
S. Ha, K. Hwang, H.D. Yoo

Sungkyunkwan University, Suwon, Korea
M. Choi, M.R. Kim, H. Lee, Y. Lee, I. Yu

College of Engineering and Technology, American University of the Middle East (AUM), Dasman, Kuwait

T. Beyrouthy, Y. Gharbia

Kuwait University - College of Science - Department of Physics, Safat, Kuwait
F. Alazemi

Riga Technical University, Riga, Latvia
K. Dreimanis, A. Gaile, C. Munoz Diaz, D. Osite, G. Pikurs, A. Potrebko, M. Seidel, D. Sidiropoulos Kontos

University of Latvia (LU), Riga, Latvia
N.R. Strautnieks

Vilnius University, Vilnius, Lithuania
M. Ambrozas, A. Juodagalvis, A. Rinkevicius, G. Tamulaitis

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
I. Yusuff[57], Z. Zolkapli

Universidad de Sonora (UNISON), Hermosillo, Mexico
J.F. Benitez, A. Castaneda Hernandez, H.A. Encinas Acosta, L.G. Gallegos Maríñez, M. León Coello, J.A. Murillo Quijada, A. Sehrawat, L. Valencia Palomo

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
G. Ayala, H. Castilla-Valdez, H. Crotte Ledesma, E. De La Cruz-Burelo, I. Heredia-De La Cruz[58], R. Lopez-Fernandez, J. Mejia Guisao, C.A. Mondragon Herrera, A. Sánchez Hernández

Universidad Iberoamericana, Mexico City, Mexico
C. Oropeza Barrera, D.L. Ramirez Guadarrama, M. Ramírez García

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
I. Bautista, F.E. Neri Huerta, I. Pedraza, H.A. Salazar Ibarguen, C. Uribe Estrada

University of Montenegro, Podgorica, Montenegro
I. Bubanja, N. Raicevic

University of Canterbury, Christchurch, New Zealand
P.H. Butler

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
A. Ahmad, M.I. Asghar, A. Awais, M.I.M. Awan, H.R. Hoorani, W.A. Khan

AGH University of Krakow, Krakow, Poland
V. Avati, L. Grzanka, M. Malawski

National Centre for Nuclear Research, Swierk, Poland
H. Bialkowska, M. Bluj, M. Górski, M. Kazana, M. Szleper, P. Zalewski

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
K. Bunkowski, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, A. Muhammad

Warsaw University of Technology, Warsaw, Poland
P. Fokow, K. Pozniak, W. Zabolotny

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
M. Araujo, D. Bastos, C. Beirão Da Cruz E Silva, A. Boletti, M. Bozzo, T. Camporesi, G. Da Molin, P. Faccioli, M. Gallinaro, J. Hollar, N. Leonardo,

G.B. Marozzo, A. Petrilli, M. Pisano, J. Seixas, J. Varela, J.W. Wulff

Faculty of Physics, University of Belgrade, Belgrade, Serbia
P. Adzic, P. Milenovic

VINCA Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
D. Devetak, M. Dordevic, J. Milosevic, L. Nadderd, V. Rekovic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
J. Alcaraz Maestre, Cristina F. Bedoya, J.A. Brochero Cifuentes, Oliver M. Carretero, M. Cepeda, M. Cerrada, N. Colino, B. De La Cruz, A. Delgado Peris, A. Escalante Del Valle, D. Fernández Del Val, J.P. Fernández Ramos, J. Flix, M.C. Fouz, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, J. Llorente Merino, C. Martin Perez, E. Martin Viscasillas, D. Moran, C. M. Morcillo Perez, Á. Navarro Tobar, C. Perez Dengra, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, I. Redondo, S. Sánchez Navas, J. Sastre, J. Vazquez Escobar

Universidad Autónoma de Madrid, Madrid, Spain
J.F. de Trocóniz

Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain
B. Alvarez Gonzalez, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, P. Leguina, M. Obeso Menendez, E. Palencia Cortezon, J. Prado Pico, C. Ramón Álvarez, V. Rodríguez Bouza, A. Soto Rodríguez, A. Trapote, C. Vico Villalba, P. Vischia

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
S. Bhowmik, S. Blanco Fernández, I.J. Cabrillo, A. Calderon, J. Duarte Campderros, M. Fernandez, G. Gomez, C. Lasaosa García, R. Lopez Ruiz, C. Martinez Rivero, P. Martinez Ruiz del Arbol, F. Matorras, P. Matorras Cuevas, E. Navarrete Ramos, J. Piedra Gomez, L. Scodellaro, I. Vila, J.M. Vizan Garcia

University of Colombo, Colombo, Sri Lanka
B. Kailasapathy[59], D.D.C. Wickramarathna

University of Ruhuna, Department of Physics, Matara, Sri Lanka
W.G.D. Dharmaratna[60], K. Liyanage, N. Perera

CERN, European Organization for Nuclear Research, Geneva, Switzerland
D. Abbaneo, C. Amendola, E. Auffray, G. Auzinger, J. Baechler, D. Barney, A. Bermúdez Martínez, M. Bianco, A.A. Bin Anuar, A. Bocci, L. Borgonovi, C. Botta, E. Brondolin, C. Caillol, G. Cerminara, N. Chernyavskaya, D. d'Enterria, A. Dabrowski, A. David, A. De Roeck, M.M. Defranchis, M. Deile, M. Dobson, G. Franzoni, W. Funk, S. Giani, D. Gigi, K. Gill, F. Glege, J. Hegeman, J.K. Heikkilä, B. Huber, V. Innocente, T. James, P. Janot, O. Kaluzinska, O. Karacheban[29], S. Laurila, P. Lecoq, E. Leutgeb, C. Lourenço, L. Malgeri, M. Mannelli, M. Matthewman, A. Mehta, F. Meijers, S. Mersi, E. Meschi, V. Milosevic, F. Monti, F. Moortgat, M. Mulders, I. Neutelings, S. Orfanelli, F. Pantaleo, G. Petrucciani, A. Pfeiffer, M. Pierini, H. Qu, D. Rabady, B. Ribeiro Lopes, F. Riti, M. Rovere, H. Sakulin, R. Salvatico, S. Sanchez Cruz, S. Scarfi, C. Schwick, M. Selvaggi, A. Sharma, K. Shchelina, P. Silva, P. Sphicas[61], A.G. Stahl Leiton, A. Steen, S. Summers, D. Treille, P. Tropea, D. Walter,

J. Wanczyk[62], J. Wang, S. Wuchterl, P. Zehetner, P. Zejdl, W.D. Zeuner

PSI Center for Neutron and Muon Sciences, Villigen, Switzerland
T. Bevilacqua[63], L. Caminada[63], A. Ebrahimi, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, D. Kotlinski, C. Lange, M. Missiroli[63], L. Noehte[63], T. Rohe, A. Samalan

ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
T.K. Aarrestad, M. Backhaus, G. Bonomelli, A. Calandri, C. Cazzaniga, K. Datta, P. De Bryas Dexmiers D'archiac[62], A. De Cosa, G. Dissertori, M. Dittmar, M. Donegà, F. Eble, M. Galli, K. Gedia, F. Glessgen, C. Grab, N. Härringer, T.G. Harte, D. Hits, W. Lustermann, A.-M. Lyon, R.A. Manzoni, M. Marchegiani, L. Marchese, A. Mascellani[62], F. Nessi-Tedaldi, F. Pauss, V. Perovic, S. Pigazzini, B. Ristic, R. Seidita, J. Steggemann[62], A. Tarabini, D. Valsecchi, R. Wallny

Universität Zürich, Zurich, Switzerland
C. Amsler[64], P. Bärtschi, M.F. Canelli, K. Cormier, M. Huwiler, W. Jin, A. Jofrehei, B. Kilminster, S. Leontsinis, S.P. Liechti, A. Macchiolo, P. Meiring, F. Meng, J. Motta, A. Reimers, P. Robmann, M. Senger, E. Shokr, F. Stäger, R. Tramontano

National Central University, Chung-Li, Taiwan
C. Adloff[65], D. Bhowmik, C.M. Kuo, W. Lin, P.K. Rout, P.C. Tiwari[39]

National Taiwan University (NTU), Taipei, Taiwan
L. Ceard, K.F. Chen, Z.g. Chen, A. De Iorio, W.-S. Hou, T.h. Hsu, Y.w. Kao, S. Karmakar, G. Kole, Y.y. Li, R.-S. Lu, E. Paganis, X.f. Su, J. Thomas-Wilsker, L.s. Tsai, D. Tsionou, H.y. Wu, E. Yazgan

High Energy Physics Research Unit, Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand
C. Asawatangtrakuldee, N. Srimanobhas, V. Wachirapusitanand

Tunis El Manar University, Tunis, Tunisia
Y. Maghrbi

Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
D. Agyel, F. Boran, F. Dolek, I. Dumanoglu[66], E. Eskut, Y. Guler[67], E. Gurpinar Guler[67], C. Isik, O. Kara, A. Kayis Topaksu, Y. Komurcu, G. Onengut, K. Ozdemir[68], A. Polatoz, B. Tali[69], U.G. Tok, E. Uslan, I.S. Zorbakir

Middle East Technical University, Physics Department, Ankara, Turkey
G. Sokmen, M. Yalvac[70]

Bogazici University, Istanbul, Turkey
B. Akgun, I.O. Atakisi, E. Gülmez, M. Kaya[71], O. Kaya[72], S. Tekten[73]

Istanbul Technical University, Istanbul, Turkey
A. Cakir, K. Cankocak[66,74], G.G. Dincer[66], S. Sen[75]

Istanbul University, Istanbul, Turkey
O. Aydilek[76], B. Hacisahinoglu, I. Hos[77], B. Kaynak, S. Ozkorucuklu, O. Potok, H. Sert, C. Simsek, C. Zorbilmez

Yildiz Technical University, Istanbul, Turkey
S. Cerci, B. Isildak[78], D. Sunar Cerci, T. Yetkin

Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkiv, Ukraine
A. Boyaryntsev, B. Grynyov

National Science Centre, Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine
L. Levchuk

University of Bristol, Bristol, United Kingdom
D. Anthony, J.J. Brooke, A. Bundock, F. Bury, E. Clement, D. Cussans, H. Flacher, M. Glowacki, J. Goldstein, H.F. Heath, M.-L. Holmberg, L. Kreczko, S. Paramesvaran, L. Robertshaw, V.J. Smith, K. Walkingshaw Pass

Rutherford Appleton Laboratory, Didcot, United Kingdom
A.H. Ball, K.W. Bell, A. Belyaev[79], C. Brew, R.M. Brown, D.J.A. Cockerill, C. Cooke, A. Elliot, K.V. Ellis, K. Harder, S. Harper, J. Linacre, K. Manolopoulos, D.M. Newbold, E. Olaiya, D. Petyt, T. Reis, A.R. Sahasransu, G. Salvi, T. Schuh, C.H. Shepherd-Themistocleous, I.R. Tomalin, K.C. Whalen, T. Williams

Imperial College, London, United Kingdom
I. Andreou, R. Bainbridge, P. Bloch, C.E. Brown, O. Buchmuller, C.A. Carrillo Montoya, G.S. Chahal[80], D. Colling, J.S. Dancu, I. Das, P. Dauncey, G. Davies, M. Della Negra, S. Fayer, G. Fedi, G. Hall, A. Howard, G. Iles, C.R. Knight, P. Krueper, J. Langford, K.H. Law, J. León Holgado, L. Lyons, A.-M. Magnan, B. Maier, S. Mallios, M. Mieskolainen, J. Nash[81], M. Pesaresi, P.B. Pradeep, B.C. Radburn-Smith, A. Richards, A. Rose, K. Savva, C. Seez, R. Shukla, A. Tapper, K. Uchida, G.P. Uttley, T. Virdee[31], M. Vojinovic, N. Wardle, D. Winterbottom

Brunel University, Uxbridge, United Kingdom
J.E. Cole, A. Khan, P. Kyberd, I.D. Reid

Baylor University, Waco, Texas, USA
S. Abdullin, A. Brinkerhoff, E. Collins, M.R. Darwish, J. Dittmann, K. Hatakeyama, V. Hegde, J. Hiltbrand, B. McMaster, J. Samudio, S. Sawant, C. Sutantawibul, J. Wilson

Catholic University of America, Washington, DC, USA
R. Bartek, A. Dominguez, A.E. Simsek, S.S. Yu

The University of Alabama, Tuscaloosa, Alabama, USA
B. Bam, A. Buchot Perraguin, R. Chudasama, S.I. Cooper, C. Crovella, S.V. Gleyzer, E. Pearson, C.U. Perez, P. Rumerio[82], E. Usai, R. Yi

Boston University, Boston, Massachusetts, USA
A. Akpinar, C. Cosby, G. De Castro, Z. Demiragli, C. Erice, C. Fangmeier, C. Fernandez Madrazo, E. Fontanesi, D. Gastler, F. Golf, S. Jeon, J. O'cain, I. Reed, J. Rohlf, K. Salyer, D. Sperka, D. Spitzbart, I. Suarez, A. Tsatsos, A.G. Zecchinelli

Brown University, Providence, Rhode Island, USA
G. Barone, G. Benelli, D. Cutts, L. Gouskos, M. Hadley, U. Heintz, K.W. Ho, J.M. Hogan[83], T. Kwon, G. Landsberg, K.T. Lau, J. Luo, S. Mondal, T. Russell, S. Sagir[84], X. Shen, F. Simpson, M. Stamenkovic, N. Venkatasubramanian

University of California, Davis, Davis, California, USA

S. Abbott, B. Barton, C. Brainerd, R. Breedon, H. Cai, M. Calderon De La Barca Sanchez, M. Chertok, M. Citron, J. Conway, P.T. Cox, R. Erbacher, F. Jensen, O. Kukral, G. Mocellin, M. Mulhearn, S. Ostrom, W. Wei, S. Yoo, F. Zhang

University of California, Los Angeles, California, USA
K. Adamidis, M. Bachtis, D. Campos, R. Cousins, A. Datta, G. Flores Avila, J. Hauser, M. Ignatenko, M.A. Iqbal, T. Lam, Y.f. Lo, E. Manca, A. Nunez Del Prado, D. Saltzberg, V. Valuev

University of California, Riverside, Riverside, California, USA
R. Clare, J.W. Gary, G. Hanson

University of California, San Diego, La Jolla, California, USA
A. Aportela, A. Arora, J.G. Branson, S. Cittolin, S. Cooperstein, D. Diaz, J. Duarte, L. Giannini, Y. Gu, J. Guiang, R. Kansal, V. Krutelyov, R. Lee, J. Letts, M. Masciovecchio, F. Mokhtar, S. Mukherjee, M. Pieri, D. Primosch, M. Quinnan, V. Sharma, M. Tadel, E. Vourliotis, F. Würthwein, Y. Xiang, A. Yagil

University of California, Santa Barbara - Department of Physics, Santa Barbara, California, USA
A. Barzdukas, L. Brennan, C. Campagnari, K. Downham, C. Grieco, M.M. Hussain, J. Incandela, J. Kim, A.J. Li, P. Masterson, H. Mei, J. Richman, S.N. Santpur, U. Sarica, R. Schmitz, F. Setti, J. Sheplock, D. Stuart, T.Á. Vámi, X. Yan, D. Zhang

California Institute of Technology, Pasadena, California, USA
S. Bhattacharya, A. Bornheim, O. Cerri, A. Latorre, J. Mao, H.B. Newman, G. Reales Gutiérrez, M. Spiropulu, J.R. Vlimant, C. Wang, S. Xie, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, Pennsylvania, USA
J. Alison, S. An, P. Bryant, M. Cremonesi, V. Dutta, T. Ferguson, T.A. Gómez Espinosa, A. Harilal, A. Kallil Tharayil, C. Liu, T. Mudholkar, S. Murthy, P. Palit, K. Park, M. Paulini, A. Roberts, A. Sanchez, W. Terrill

University of Colorado Boulder, Boulder, Colorado, USA
J.P. Cumalat, W.T. Ford, A. Hart, A. Hassani, G. Karathanasis, N. Manganelli, J. Pearkes, C. Savard, N. Schonbeck, K. Stenson, K.A. Ulmer, S.R. Wagner, N. Zipper, D. Zuolo

Cornell University, Ithaca, New York, USA
J. Alexander, S. Bright-Thonney, X. Chen, D.J. Cranshaw, J. Dickinson, J. Fan, X. Fan, S. Hogan, P. Kotamnives, J. Monroy, M. Oshiro, J.R. Patterson, M. Reid, A. Ryd, J. Thom, P. Wittich, R. Zou

Fermi National Accelerator Laboratory, Batavia, Illinois, USA
M. Albrow, M. Alyari, O. Amram, G. Apollinari, A. Apresyan, L.A.T. Bauerdick, D. Berry, J. Berryhill, P.C. Bhat, K. Burkett, J.N. Butler, A. Canepa, G.B. Cerati, H.W.K. Cheung, F. Chlebana, G. Cummings, I. Dutta, V.D. Elvira, Y. Feng, J. Freeman, A. Gandrakota, Z. Gecse, L. Gray, D. Green, A. Grummer, S. Grünendahl, D. Guerrero, O. Gutsche, R.M. Harris, T.C. Herwig, J. Hirschauer, B. Jayatilaka, S. Jindariani, M. Johnson, U. Joshi, T. Klijnsma, B. Klima, K.H.M. Kwok, S. Lammel, C. Lee, D. Lincoln, R. Lipton, T. Liu,

C. Madrid, K. Maeshima, C. Mantilla, D. Mason, P. McBride, P. Merkel, S. Mrenna, S. Nahn, J. Ngadiuba, D. Noonan, S. Norberg, V. Papadimitriou, N. Pastika, K. Pedro, C. Pena[85], F. Ravera, A. Reinsvold Hall[86], L. Ristori, M. Safdari, E. Sexton-Kennedy, N. Smith, A. Soha, L. Spiegel, S. Stoynev, J. Strait, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, I. Zoi

University of Florida, Gainesville, Florida, USA
C. Aruta, P. Avery, D. Bourilkov, P. Chang, V. Cherepanov, R.D. Field, C. Huh, E. Koenig, M. Kolosova, J. Konigsberg, A. Korytov, K. Matchev, N. Menendez, G. Mitselmakher, K. Mohrman, A. Muthirakalayil Madhu, N. Rawal, S. Rosenzweig, Y. Takahashi, J. Wang

Florida State University, Tallahassee, Florida, USA
T. Adams, A. Al Kadhim, A. Askew, S. Bower, R. Hashmi, R.S. Kim, S. Kim, T. Kolberg, G. Martinez, H. Prosper, P.R. Prova, M. Wulansatiti, R. Yohay, J. Zhang

Florida Institute of Technology, Melbourne, Florida, USA
B. Alsufyani, S. Butalla, S. Das, T. Elkafrawy[87], M. Hohlmann, E. Yanes

University of Illinois Chicago, Chicago, Illinois, USA
M.R. Adams, A. Baty, C. Bennett, R. Cavanaugh, R. Escobar Franco, O. Evdokimov, C.E. Gerber, M. Hawksworth, A. Hingrajiya, D.J. Hofman, J.h. Lee, D. S. Lemos, A.H. Merrit, C. Mills, S. Nanda, G. Oh, B. Ozek, D. Pilipovic, R. Pradhan, E. Prifti, T. Roy, S. Rudrabhatla, N. Singh, M.B. Tonjes, N. Varelas, M.A. Wadud, Z. Ye, J. Yoo

The University of Iowa, Iowa City, Iowa, USA
M. Alhusseini, D. Blend, K. Dilsiz[88], L. Emediato, G. Karaman, O.K. Köseyan, J.-P. Merlo, A. Mestvirishvili[89], O. Neogi, H. Ogul[90], Y. Onel, A. Penzo, C. Snyder, E. Tiras[91]

Johns Hopkins University, Baltimore, Maryland, USA
B. Blumenfeld, L. Corcodilos, J. Davis, A.V. Gritsan, L. Kang, S. Kyriacou, P. Maksimovic, M. Roguljic, J. Roskes, S. Sekhar, M. Swartz

The University of Kansas, Lawrence, Kansas, USA
A. Abreu, L.F. Alcerro Alcerro, J. Anguiano, S. Arteaga Escatel, P. Baringer, A. Bean, Z. Flowers, D. Grove, J. King, G. Krintiras, M. Lazarovits, C. Le Mahieu, J. Marquez, M. Murray, M. Nickel, M. Pitt, S. Popescu[92], C. Rogan, C. Royon, S. Sanders, C. Smith, G. Wilson

Kansas State University, Manhattan, Kansas, USA
B. Allmond, R. Gujju Gurunadha, A. Ivanov, K. Kaadze, Y. Maravin, J. Natoli, D. Roy, G. Sorrentino

University of Maryland, College Park, Maryland, USA
A. Baden, A. Belloni, J. Bistany-riebman, Y.M. Chen, S.C. Eno, N.J. Hadley, S. Jabeen, R.G. Kellogg, T. Koeth, B. Kronheim, Y. Lai, S. Lascio, A.C. Mignerey, S. Nabili, C. Palmer, C. Papageorgakis, M.M. Paranjpe, E. Popova[93], A. Shevelev, L. Wang

Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
J. Bendavid, I.A. Cali, P.c. Chou, M. D'Alfonso, J. Eysermans, C. Freer, G. Gomez-Ceballos, M. Goncharov, G. Grosso, P. Harris, D. Hoang, D. Kovalskyi,

J. Krupa, L. Lavezzo, Y.-J. Lee, K. Long, C. Mcginn, A. Novak, M.I. Park, C. Paus, C. Reissel, C. Roland, G. Roland, S. Rothman, G.S.F. Stephans, Z. Wang, B. Wyslouch, T. J. Yang

University of Minnesota, Minneapolis, Minnesota, USA
B. Crossman, B.M. Joshi, C. Kapsiak, M. Krohn, D. Mahon, J. Mans, B. Marzocchi, M. Revering, R. Rusack, R. Saradhy, N. Strobbe

University of Nebraska-Lincoln, Lincoln, Nebraska, USA
K. Bloom, D.R. Claes, G. Haza, J. Hossain, C. Joo, I. Kravchenko, A. Rohilla, J.E. Siado, W. Tabb, A. Vagnerini, A. Wightman, F. Yan, D. Yu

State University of New York at Buffalo, Buffalo, New York, USA
H. Bandyopadhyay, L. Hay, H.w. Hsia, I. Iashvili, A. Kalogeropoulos, A. Kharchilava, M. Morris, D. Nguyen, S. Rappoccio, H. Rejeb Sfar, A. Williams, P. Young

Northeastern University, Boston, Massachusetts, USA
G. Alverson, E. Barberis, J. Bonilla, B. Bylsma, M. Campana, J. Dervan, Y. Haddad, Y. Han, I. Israr, A. Krishna, J. Li, M. Lu, R. Mccarthy, D.M. Morse, V. Nguyen, T. Orimoto, A. Parker, L. Skinnari, E. Tsai, D. Wood

Northwestern University, Evanston, Illinois, USA
J. Bueghly, S. Dittmer, K.A. Hahn, D. Li, Y. Liu, M. Mcginnis, Y. Miao, D.G. Monk, M.H. Schmitt, A. Taliercio, M. Velasco

University of Notre Dame, Notre Dame, Indiana, USA
G. Agarwal, R. Band, R. Bucci, S. Castells, A. Das, R. Goldouzian, M. Hildreth, K. Hurtado Anampa, T. Ivanov, C. Jessop, K. Lannon, J. Lawrence, N. Loukas, L. Lutton, J. Mariano, N. Marinelli, I. Mcalister, T. McCauley, C. Mcgrady, C. Moore, Y. Musienko[24], H. Nelson, M. Osherson, A. Piccinelli, R. Ruchti, A. Townsend, Y. Wan, M. Wayne, H. Yockey, M. Zarucki, L. Zygala

The Ohio State University, Columbus, Ohio, USA
A. Basnet, M. Carrigan, L.S. Durkin, C. Hill, M. Joyce, M. Nunez Ornelas, K. Wei, D.A. Wenzl, B.L. Winer, B. R. Yates

Princeton University, Princeton, New Jersey, USA
H. Bouchamaoui, K. Coldham, P. Das, G. Dezoort, P. Elmer, A. Frankenthal, B. Greenberg, N. Haubrich, K. Kennedy, G. Kopp, S. Kwan, D. Lange, A. Loeliger, D. Marlow, I. Ojalvo, J. Olsen, D. Stickland, C. Tully, L.H. Vage

University of Puerto Rico, Mayaguez, Puerto Rico, USA
S. Malik, R. Sharma

Purdue University, West Lafayette, Indiana, USA
A.S. Bakshi, S. Chandra, R. Chawla, A. Gu, L. Gutay, M. Jones, A.W. Jung, A.M. Koshy, M. Liu, G. Negro, N. Neumeister, G. Paspalaki, S. Piperov, V. Scheurer, J.F. Schulte, M. Stojanovic, J. Thieman, A. K. Virdi, F. Wang, A. Wildridge, W. Xie, Y. Yao

Purdue University Northwest, Hammond, Indiana, USA
J. Dolen, N. Parashar, A. Pathak

Rice University, Houston, Texas, USA

D. Acosta, T. Carnahan, K.M. Ecklund, P.J. Fernández Manteca, S. Freed, P. Gardner, F.J.M. Geurts, I. Krommydas, W. Li, J. Lin, O. Miguel Colin, B.P. Padley, R. Redjimi, J. Rotter, E. Yigitbasi, Y. Zhang

University of Rochester, Rochester, New York, USA
A. Bodek, P. de Barbaro, R. Demina, J.L. Dulemba, A. Garcia-Bellido, O. Hindrichs, A. Khukhunaishvili, N. Parmar, P. Parygin[93], R. Taus

Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA
B. Chiarito, J.P. Chou, S.V. Clark, D. Gadkari, Y. Gershtein, E. Halkiadakis, M. Heindl, C. Houghton, D. Jaroslawski, S. Konstantinou, I. Laflotte, A. Lath, R. Montalvo, K. Nash, J. Reichert, P. Saha, S. Salur, S. Schnetzer, S. Somalwar, R. Stone, S.A. Thayil, S. Thomas, J. Vora, H. Wang

University of Tennessee, Knoxville, Tennessee, USA
D. Ally, A.G. Delannoy, S. Fiorendi, S. Higginbotham, T. Holmes, A.R. Kanuganti, N. Karunarathna, L. Lee, E. Nibigira, S. Spanier

Texas A&M University, College Station, Texas, USA
D. Aebi, M. Ahmad, T. Akhter, K. Androsov[62], O. Bouhali[94], R. Eusebi, J. Gilmore, T. Huang, T. Kamon[95], H. Kim, S. Luo, R. Mueller, D. Overton, D. Rathjens, A. Safonov

Texas Tech University, Lubbock, Texas, USA
N. Akchurin, J. Damgov, N. Gogate, A. Hussain, Y. Kazhykarim, K. Lamichhane, S.W. Lee, A. Mankel, T. Peltola, I. Volobouev

Vanderbilt University, Nashville, Tennessee, USA
E. Appelt, Y. Chen, S. Greene, A. Gurrola, W. Johns, R. Kunnawalkam Elayavalli, A. Melo, F. Romeo, P. Sheldon, S. Tuo, J. Velkovska, J. Viinikainen

University of Virginia, Charlottesville, Virginia, USA
B. Cardwell, H. Chung, B. Cox, J. Hakala, R. Hirosky, A. Ledovskoy, C. Neu

Wayne State University, Detroit, Michigan, USA
S. Bhattacharya, P.E. Karchin

University of Wisconsin - Madison, Madison, Wisconsin, USA
A. Aravind, S. Banerjee, K. Black, T. Bose, E. Chavez, S. Dasu, P. Everaerts, C. Galloni, H. He, M. Herndon, A. Herve, C.K. Koraka, A. Lanaro, R. Loveless, J. Madhusudanan Sreekala, A. Mallampalli, A. Mohammadi, S. Mondal, G. Parida, L. Pétré, D. Pinna, A. Savin, V. Shang, V. Sharma, W.H. Smith, D. Teague, H.F. Tsoi, W. Vetens, A. Warden

Authors affiliated with an international laboratory covered by a cooperation agreement with CERN
S. Afanasiev, V. Alexakhin, D. Budkouski, I. Golutvin†, I. Gorbunov, V. Karjavine, V. Korenkov, A. Lanev, A. Malakhov, V. Matveev[96], V. Palichik, V. Perelygin, M. Savina, V. Shalaev, S. Shmatov, S. Shulha, V. Smirnov, O. Teryaev, N. Voytishin, B.S. Yuldashev[97], A. Zarubin, I. Zhizhin, Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, A. Karneyeu, D. Kirpichnikov, M. Kirsanov, N. Krasnikov, I. Tlisova, A. Toropin

Authors affiliated with an institute formerly covered by a cooperation agreement with CERN
G. Gavrilov, V. Golovtcov, Y. Ivanov, V. Kim[98], P. Levchenko[99], V. Murzin,

V. Oreshkin, D. Sosnov, V. Sulimov, L. Uvarov, A. Vorobyev†, T. Aushev, K. Ivanov, V. Gavrilov, N. Lychkovskaya, A. Nikitenko[100,101], V. Popov, A. Zhokin, M. Chadeeva[98], R. Chistov[98], S. Polikarpov[98], V. Andreev, M. Azarkin, M. Kirakosyan, A. Terkulov, E. Boos, V. Bunichev, M. Dubinin[85], L. Dudko, A. Gribushin, V. Klyukhin, O. Kodolova[101], O. Lukina, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev, V. Blinov[98], T. Dimova[98], A. Kozyrev[98], O. Radchenko[98], Y. Skovpen[98], V. Kachanov, S. Slabospitskii, A. Uzunian, A. Babaev, V. Borshch, D. Druzhkin

†: Deceased
[1]Also at Yerevan State University, Yerevan, Armenia
[2]Also at TU Wien, Vienna, Austria
[3]Also at Ghent University, Ghent, Belgium
[4]Also at Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
[5]Also at FACAMP - Faculdades de Campinas, Sao Paulo, Brazil
[6]Also at Universidade Estadual de Campinas, Campinas, Brazil
[7]Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil
[8]Also at University of Chinese Academy of Sciences, Beijing, China
[9]Also at China Center of Advanced Science and Technology, Beijing, China
[10]Also at University of Chinese Academy of Sciences, Beijing, China
[11]Also at China Spallation Neutron Source, Guangdong, China
[12]Now at Henan Normal University, Xinxiang, China
[13]Also at University of Shanghai for Science and Technology, Shanghai, China
[14]Now at The University of Iowa, Iowa City, Iowa, USA
[15]Also at an institute formerly covered by a cooperation agreement with CERN
[16]Also at Helwan University, Cairo, Egypt
[17]Now at Zewail City of Science and Technology, Zewail, Egypt
[18]Now at British University in Egypt, Cairo, Egypt
[19]Now at Cairo University, Cairo, Egypt
[20]Also at Purdue University, West Lafayette, Indiana, USA
[21]Also at Université de Haute Alsace, Mulhouse, France
[22]Also at Istinye University, Istanbul, Turkey
[23]Also at Tbilisi State University, Tbilisi, Georgia
[24]Also at an international laboratory covered by a cooperation agreement with CERN
[25]Also at The University of the State of Amazonas, Manaus, Brazil
[26]Also at University of Hamburg, Hamburg, Germany
[27]Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
[28]Also at Bergische University Wuppertal (BUW), Wuppertal, Germany
[29]Also at Brandenburg University of Technology, Cottbus, Germany
[30]Also at Forschungszentrum Jülich, Juelich, Germany
[31]Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
[32]Also at HUN-REN ATOMKI - Institute of Nuclear Research, Debrecen, Hungary
[33]Now at Universitatea Babes-Bolyai - Facultatea de Fizica, Cluj-Napoca, Romania
[34]Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
[35]Also at HUN-REN Wigner Research Centre for Physics, Budapest, Hungary
[36]Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt
[37]Also at Punjab Agricultural University, Ludhiana, India
[38]Also at University of Visva-Bharati, Santiniketan, India
[39]Also at Indian Institute of Science (IISc), Bangalore, India

[40]Also at Amity University Uttar Pradesh, Noida, India
[41]Also at IIT Bhubaneswar, Bhubaneswar, India
[42]Also at Institute of Physics, Bhubaneswar, India
[43]Also at University of Hyderabad, Hyderabad, India
[44]Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany
[45]Also at Isfahan University of Technology, Isfahan, Iran
[46]Also at Sharif University of Technology, Tehran, Iran
[47]Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran
[48]Also at Department of Physics, Faculty of Science, Arak University, ARAK, Iran
[49]Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy
[50]Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy
[51]Also at Università degli Studi Guglielmo Marconi, Roma, Italy
[52]Also at Scuola Superiore Meridionale, Università di Napoli 'Federico II', Napoli, Italy
[53]Also at Fermi National Accelerator Laboratory, Batavia, Illinois, USA
[54]Also at Lulea University of Technology, Lulea, Sweden
[55]Also at Consiglio Nazionale delle Ricerche - Istituto Officina dei Materiali, Perugia, Italy
[56]Also at Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France
[57]Also at Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Malaysia
[58]Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico
[59]Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka
[60]Also at Saegis Campus, Nugegoda, Sri Lanka
[61]Also at National and Kapodistrian University of Athens, Athens, Greece
[62]Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland
[63]Also at Universität Zürich, Zurich, Switzerland
[64]Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria
[65]Also at Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France
[66]Also at Near East University, Research Center of Experimental Health Science, Mersin, Turkey
[67]Also at Konya Technical University, Konya, Turkey
[68]Also at Izmir Bakircay University, Izmir, Turkey
[69]Also at Adiyaman University, Adiyaman, Turkey
[70]Also at Bozok Universitetesi Rektörlügü, Yozgat, Turkey
[71]Also at Marmara University, Istanbul, Turkey
[72]Also at Milli Savunma University, Istanbul, Turkey
[73]Also at Kafkas University, Kars, Turkey
[74]Now at Istanbul Okan University, Istanbul, Turkey
[75]Also at Hacettepe University, Ankara, Turkey
[76]Also at Erzincan Binali Yildirim University, Erzincan, Turkey
[77]Also at Istanbul University - Cerrahpasa, Faculty of Engineering, Istanbul, Turkey
[78]Also at Yildiz Technical University, Istanbul, Turkey
[79]Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
[80]Also at IPPP Durham University, Durham, United Kingdom
[81]Also at Monash University, Faculty of Science, Clayton, Australia
[82]Also at Università di Torino, Torino, Italy

[83]Also at Bethel University, St. Paul, Minnesota, USA
[84]Also at Karamanoğlu Mehmetbey University, Karaman, Turkey
[85]Also at California Institute of Technology, Pasadena, California, USA
[86]Also at United States Naval Academy, Annapolis, Maryland, USA
[87]Also at Ain Shams University, Cairo, Egypt
[88]Also at Bingol University, Bingol, Turkey
[89]Also at Georgian Technical University, Tbilisi, Georgia
[90]Also at Sinop University, Sinop, Turkey
[91]Also at Erciyes University, Kayseri, Turkey
[92]Also at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania
[93]Now at another institute formerly covered by a cooperation agreement with CERN
[94]Also at Texas A&M University at Qatar, Doha, Qatar
[95]Also at Kyungpook National University, Daegu, Korea
[96]Also at another international laboratory covered by a cooperation agreement with CERN
[97]Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan
[98]Also at another institute formerly covered by a cooperation agreement with CERN
[99]Also at Northeastern University, Boston, Massachusetts, USA
[100]Also at Imperial College, London, United Kingdom
[101]Now at Yerevan Physics Institute, Yerevan, Armenia