CERN-EP-2021-023
2022/01/24

CMS-HIN-19-005

Evidence for X(3872) in PbPb collisions and studies of its prompt production at $\sqrt{s_{\text{NN}}} = 5.02$ TeV

The CMS Collaboration*

Abstract

The first evidence for X(3872) production in relativistic heavy ion collisions is reported. The X(3872) production is studied in lead-lead (PbPb) collisions at a center-of-mass energy of $\sqrt{s_{\text{NN}}} = 5.02$ TeV per nucleon pair, using the decay chain $X(3872) \rightarrow J/\psi \pi^+ \pi^- \rightarrow \mu^+ \mu^- \pi^+ \pi^-$. The data were recorded with the CMS detector in 2018 and correspond to an integrated luminosity of 1.7 nb^{-1} . The measurement is performed in the rapidity and transverse momentum ranges $|y| < 1.6$ and $15 < p_T < 50 \text{ GeV}/c$. The significance of the inclusive X(3872) signal is 4.2 standard deviations. The prompt X(3872) to $\psi(2S)$ yield ratio is found to be $\rho^{\text{PbPb}} = 1.08 \pm 0.49 (\text{stat}) \pm 0.52 (\text{syst})$, to be compared with typical values of 0.1 for pp collisions. This result provides a unique experimental input to theoretical models of the X(3872) production mechanism, and of the nature of this exotic state.

Published in Physical Review Letters as doi:10.1103/PhysRevLett.128.032001.

The $X(3872)$, also known as $\chi_{c1}(3872)$, is an exotic particle that was first observed by the Belle Collaboration [1], and then confirmed and studied by other experiments at electron-positron [2, 3] and hadron colliders [4–8]. The quantum numbers of the $X(3872)$ have been narrowed down by the CDF [9], and later determined to be $J^{PC} = 1^{++}$ by the LHCb [10] Collaborations. However, the nature of this particle is still not fully understood and interpretations in terms of conventional charmonium (a bound state of charm-anticharm quarks), $D^*(2010)^0 \bar{D}^0$ molecules [11], tetraquark states [12], and their admixture [13] have been proposed. The production and survival of the $X(3872)$ in a quark-gluon plasma (QGP), a deconfined state of quarks and gluons [14, 15], or after the QGP, in a hadronic phase, is expected to depend upon the $X(3872)$'s internal structure [16, 17]. Thus, the recent large data set of lead-lead (PbPb) collisions at a center-of-mass energy of $\sqrt{s_{NN}} = 5.02$ TeV per nucleon pair, delivered by the Large Hadron Collider (LHC) at CERN at the end of 2018, opened new opportunities to probe the nature of this exotic state [18–20].

It is expected that in relativistic heavy ion collisions, the formation of the QGP could enhance or suppress the production of the $X(3872)$ particle. Coalescence mechanisms could enhance the $X(3872)$ production yield [16, 19]. These mechanisms can be modeled via the overlap of the density matrix of the constituents in an emission source with the Wigner function of the produced particle [21]. Therefore, the enhancement of the $X(3872)$ production in the QGP would depend on the spatial configuration of the exotic state. Moreover, a longer distance between the quarks and antiquarks that constitute the state could also lead to a higher $X(3872)$ dissociation rate, similar to that from the mechanism of quarkonium suppression in heavy ion collisions [22]. Therefore, the study of the $X(3872)$ state in the QGP may be used as a tool to distinguish a compact tetraquark configuration with a radius ~ 0.3 fm from a molecular state with a radius greater than 1.5 fm [23]. Such a measurement would be complementary to the recent evidence for the radiative decay $X(3872) \rightarrow \psi(2S)\gamma$ in proton-proton (pp) collisions reported by LHCb Collaboration [24], which does not support a pure $D^*(2010)^0 \bar{D}$ molecular interpretation. In addition, measurements of prompt $X(3872)$ production could provide an interesting test of the statistical hadronization model, which assumes that the produced matter is in thermodynamic equilibrium at the phase transition to hadrons [25, 26].

In this Letter, the first evidence for $X(3872)$ production in PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV is reported. The PbPb sample corresponds to an integrated luminosity of 1.7 nb^{-1} . The $X(3872)$ candidates are reconstructed through the decay chain $X(3872) \rightarrow J/\psi \pi^+ \pi^- \rightarrow \mu^+ \mu^- \pi^+ \pi^-$, and are measured in the $15 < p_T < 50 \text{ GeV}/c$ and $|y| < 1.6$ kinematic region. At the LHC energies, the inclusive $X(3872)$ yields in pp and PbPb collisions contain a significant nonprompt contribution coming from b hadron decays [8]. The nonprompt $X(3872)$ component is related to the medium-modified beauty hadron production in heavy ion collisions, which is out of the scope of this paper. Here, we focus on the prompt component, from charm quark fragmentation, for which the ratio ρ^i (i is pp or PbPb) between the corrected yields of $X(3872)$ and $\psi(2S)$ mesons (where the $\psi(2S)$ is reconstructed with the same final-state particles in order to reduce systematic uncertainties) is presented:

$$\rho^i = \frac{N_i^{X(3872) \rightarrow J/\psi \pi \pi}}{N_i^{\psi(2S) \rightarrow J/\psi \pi \pi}}. \quad (1)$$

The ratios in pp and PbPb collisions are connected to the nuclear modification factors $R_{AA}^{X(3872)}$ and $R_{AA}^{\psi(2S)}$ (the meson yield ratio in nucleus-nucleus and pp interactions normalized by the

number of inelastic nucleon-nucleon collisions) via the following relation:

$$\rho^{\text{PbPb}} = \rho^{\text{PP}} \frac{R_{\text{AA}}^{\text{X}(3872)}}{R_{\text{AA}}^{\psi(2\text{S})}}. \quad (2)$$

The CMS apparatus [27] is a multipurpose, nearly hermetic detector, designed to trigger on [28, 29] and identify electrons, muons, photons, and (charged and neutral) hadrons [30–33]. A global reconstruction algorithm [34] combines the information provided by the all-silicon inner tracker and by the crystal electromagnetic and brass-scintillator hadron calorimeters, operating inside a 3.8 T superconducting solenoid, with data from gas-ionization muon detectors interleaved with the solenoid return yoke. Information from the hadron forward (HF) calorimeter is used for performing offline event selection and determining centrality (the degree of overlap between the two colliding nuclei). The results refer to the collisions with 0–90% centrality, i.e., the top 90% events based on the total transverse energy deposition in both HF detectors [35], which corresponds to the 90% of collisions having the largest overlap of the two nuclei.

Events of interest were selected in real-time using the CMS two-tiered trigger system: the first level (L1), composed of custom hardware processors [28], and the high-level trigger (HLT), consisting of a farm of processors running a version of the full event reconstruction software optimized for fast processing [29]. The selection required the presence of two muon candidates, with at least one muon reconstructed in the outer muon spectrometer, and one muon reconstructed using information from both the outer muon spectrometer and the inner tracker. The dimuon candidate invariant mass is required to be $1 < m_{\mu\mu} < 5 \text{ GeV}/c^2$. For the offline analysis, events have to pass a set of selection criteria designed to reject events from background processes (beam-gas collisions, beam scraping events and electromagnetic interactions) as described in Ref. [36]. Events are required to have at least one reconstructed primary interaction vertex formed by two or more tracks, with a distance from the center of the nominal interaction point of less than 15 cm along the beam axis. The shapes of the clusters in the pixel detector have to be compatible with those expected from particles produced by a PbPb collision [37]. In order to select hadronic collisions, the PbPb events are also required to have at least two towers (i.e., a geometrically defined group of calorimeter cells) in each of the HF detectors with total energy deposits of more than 4 GeV per tower. This analysis is restricted to events within centrality 0–90%, for which the hadronic event selection is fully efficient. Multiple-collision events (pileup) have a negligible effect on the measurement, since the average number of additional collisions per bunch crossing is approximately 0.002.

Dedicated PbPb X(3872) and $\psi(2\text{S})$ Monte Carlo (MC) simulated samples were generated in order to estimate the acceptance and selection efficiencies, to study the background components, and to evaluate systematic uncertainties. The PYTHIA 8 v212 [38] Tune CP5 [39] was used to generate the X(3872) and $\psi(2\text{S})$ signals at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$. It was assumed that X(3872) and $\psi(2\text{S})$ are unpolarized. Since the X(3872) cannot be generated by PYTHIA, the $\chi_{\text{c1}}(1\text{P})$ particle is used, with a modified mass of $3.8716 \text{ GeV}/c^2$ [40]. The $\chi_{\text{c1}}(1\text{P})$ has the quantum numbers $J^{PC} = 1^{++}$, identical to those of the X(3872). The X(3872) particle was forced to decay into $J/\psi \pi^+ \pi^-$ (assuming the ρ resonance dominates the pion pair spectrum [7, 8]), followed by the J/ψ meson decaying into two muons. Final-state radiation was generated using PHOTOS 2.0 [41]. The $\chi_{\text{c1}}(1\text{P}) \rightarrow J/\psi \pi^+ \pi^-$ decay is generated with EVTGEN. The samples with prompt (fragmenting in charm quarks) and nonprompt (originating from b hadron decays) $\psi(2\text{S})/\text{X}(3872)$ production are generated separately. Each PYTHIA event is embedded in a PbPb collision event generated with HYDJET 1.8 [42], which is tuned to reproduce global event properties such as the charged-hadron p_{T} spectrum and particle multiplicity.

The $X(3872)$ signal is extracted in the following steps. Each muon candidate must be matched to a triggered muon and have $p_T^\mu > 3.5 \text{ GeV}/c$ in the interval $|\eta^\mu| < 1.2$, $p_T^\mu > (5.47 - 1.89|\eta^\mu|) \text{ GeV}/c$ in the interval $1.2 < |\eta^\mu| < 2.1$, or $p_T^\mu > 1.5 \text{ GeV}/c$ in the forward region $2.1 < |\eta^\mu| < 2.4$. Two muons of opposite sign, with an invariant mass within $\pm 150 \text{ MeV}/c^2$ of the world-average J/ψ meson mass [40] are selected to reconstruct a J/ψ candidate. The opposite-sign muon pairs are fitted with a common vertex constraint and are kept if the χ^2 probability of the fit is greater than 1%, thus reducing the background from charm and beauty hadron semileptonic decays. The $X(3872)$ and $\psi(2S)$ candidates are built by combining the J/ψ candidates with two additional tracks, which have $p_T > 0.9 \text{ GeV}/c$, $|\eta| < 2.4$ and pass a high purity selection, assumed to be produced by two pions. Only candidates that have $15 < p_T < 50 \text{ GeV}/c$ and $|y| < 1.6$ are considered. Then, a kinematic fit to the $J/\psi \pi^+ \pi^-$ system is performed, requiring that the four tracks originate from a common vertex and forcing the mass of the dimuon pair to be equal to the nominal J/ψ mass [40]. The selection is further optimized, using a boosted decision tree (BDT) algorithm [43]. The $X(3872)$ decay vertex probability, the radial distance between the pion and the J/ψ candidate momentum vectors ($\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, where ϕ is the azimuthal angle), and the p_T of each pion are used in the BDT algorithm to distinguish signal and combinatorial background formed by random combinations of tracks. For the multivariate training, the $X(3872)$ signal sample is taken from simulation, and the background sample consists of data from the sidebands of the $X(3872)$ meson peak (i.e., $0.07 < |m - m_{X(3872)}| < 0.128 \text{ GeV}/c^2$). The nominal BDT selection is chosen in order to maximize the statistical significance of $X(3872)$, defined as $S/\sqrt{(S+B)}$ where S and B are the numbers of $X(3872)$ and background in the signal region, respectively. Because there is no reliable theoretical calculation available for the $X(3872)$ production, an estimation of the $X(3872)$ cross-section is obtained from data, by extracting the signal yield in data when applying a tight BDT cut. This is used in conjunction with the MC-calculated efficiency to obtain the yield for each BDT cutoff value. The BDT selection determined in this way is applied to entries in the whole invariant mass range from 3.62 to $4 \text{ GeV}/c^2$ in data.

The raw inclusive yields of $X(3872)$ and $\psi(2S)$ are extracted by an extended unbinned maximum-likelihood fit. A double-Gaussian function with a common mean but independent widths is used to model the signal component for each of the $X(3872)$ and $\psi(2S)$ peaks. This was preferred to a single-Gaussian or a Breit-Wigner function since it described better (i.e., superior χ^2 of the fit) the signal shape in MC simulations. For describing the combinatorial background, mostly produced by the random combination of a J/ψ candidate with tracks that are not coming from $X(3872)$ or $\psi(2S)$ decay, a 4th-order polynomial is used, which gives the best fit in terms of χ^2 per degrees of freedom and stability during all studies. For the signal, only the magnitude of the two peaks is left free in the fit, the rest (the mean and widths of the two Gaussian functions, as well as their relative contribution to the signal yield in either $X(3872)$ or $\psi(2S)$ peaks) are set to the values derived from simulation. The five parameters of the combinatorial background are all allowed to float. The invariant mass range considered for the fit is 3.62 to $4 \text{ GeV}/c^2$. The invariant mass fits for both the inclusive and nonprompt samples, with BDT selection optimized for $X(3872)$, are shown in Fig. 1. The significance of the inclusive $X(3872)$ signal against background-only hypothesis is 4.2 standard deviations. The systematic uncertainty (described below) contributing to this significance is the one related to the $X(3872)$ invariant mass fit. After performing a likelihood scan for each alternative signal and background shape considered, the significance was calculated as the square root of the logarithm of the profile likelihood ratio where the signal is zero, with the smallest value obtained being chosen among all scans.

The contribution from b hadron decays is subtracted from the inclusive result using the

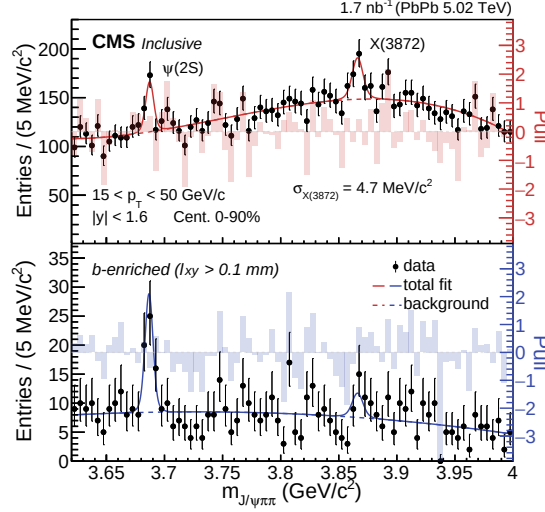


Figure 1: Invariant mass distribution of $m_{\mu\mu\pi\pi}$ in PbPb collisions, for the inclusive (upper) and b-enriched (bottom) samples. The vertical lines represent statistical uncertainties in the data. The results of the unbinned maximum-likelihood fits for the signal+background and background alone are also shown by the solid and dashed lines, respectively. The pull distribution is represented by the shaded bars. The X(3872) peak mass resolution, $\sigma_{X(3872)}$, calculated at the half-maximum of the signal-shape distribution, is also listed for reference.

“pseudo-proper” decay length l_{xy} , defined as the distance in the transverse plane, L_{xy} , between the vertex formed by the 4-tracks and the primary vertex, corrected by the transverse Lorentz boost of the candidate: $l_{xy} = L_{xy} m_{J/\psi\pi\pi} c / |\vec{p}_T|$. The prompt-component fraction (f_{prompt}) is estimated using a cutoff-based method in the following way. Since the l_{xy} of the prompt component was found in MC studies to be smaller than 0.1 mm, the prompt fraction, f_{prompt} , can be derived from: i) the raw inclusive yield, N_{incl} , obtained from the fit to the invariant mass distributions of all candidates, shown in Fig. 1, and ii) $N_{\text{b-enr}}$, the “b-enriched” yield, obtained from a fit to the invariant mass distribution only containing candidates that passed the selection $l_{xy} > 0.1$ mm, also shown in Fig. 1. In addition, $N_{\text{b-enr}}$ has to be corrected to account for nonprompt candidates, with $l_{xy} < 0.1$ mm, that have been missed: $f_{\text{nonprompt}}^{\text{b-enr}} = N_{\text{nonprompt}}(l_{xy} > 0.1 \text{ mm}) / N_{\text{nonprompt}}$. The correction was obtained from simulation. The raw prompt fraction is then calculated as:

$$f_{\text{prompt}} = 1 - \frac{N_{\text{b-enr}} / f_{\text{nonprompt}}^{\text{b-enr}}}{N_{\text{incl}}}, \quad (3)$$

separately for X(3872) and $\psi(2S)$ states. The corrected yield of the prompt component can then be derived as:

$$N^{i \rightarrow J/\psi\pi\pi} = N_{\text{raw}}^i f_{\text{prompt}}^i / (\alpha \epsilon_{\text{reco}} \epsilon_{\text{sel}})^i, \quad (4)$$

where i is X(3872) or $\psi(2S)$, α is the acceptance, ϵ_{reco} is the candidate reconstruction efficiency and ϵ_{sel} is the candidate selection efficiency. Since the two states are reconstructed in the same decay channel and are relatively close in mass, their corresponding $\alpha \epsilon_{\text{reco}}$ values are similar. The choice of the BDT optimization criteria results in ϵ_{sel} being higher for the X(3872) than for the $\psi(2S)$.

The measurement of ρ^{PbPb} is affected by several sources of systematic uncertainty, arising from the candidate selection, invariant mass fit, and efficiency corrections. To estimate the systematic uncertainty associated with the BDT selection, the BDT cutoff values are varied within a range

that allows a robust invariant mass fit procedure (i.e., signal statistical significance larger than 2), and for each variation all factors in Eq. (4) are recalculated, separately for $X(3872)$ and $\psi(2S)$. The maximum difference of the final ρ^{PbPb} value from the nominal result (40%) is quoted as the systematic uncertainty. The relatively large ρ^{PbPb} uncertainty associated with BDT cutoff value is the convolution of mainly two causes: the BDT variables distribution differences in data and MC samples for the $X(3872)$ meson, and the statistical limitation of the signal in data. The largest differences (~ 2 standard deviations) between data and MC samples are in the distributions of the p_T of the pions, and the radial distance between the pion and the J/ψ candidate momentum vectors.

The uncertainty in the invariant mass fit (8.0%) is calculated by adding in quadrature the maximum deviations from the nominal result to that found using two alternative fitting functions for both signal and background. For the signal, one variation consists of using a triple-Gaussian function, while for the other the signal width of the nominal fit is allowed to float to account for the resolution difference between data and MC. Other choices for the signal shape (e.g., one-Gaussian function) were not considered because of their poor-quality fits. For the background, the fit function is changed once to a third-order polynomial (as an exponential function or lower-order polynomials could not describe the data), and the fit range is also changed from $3.62\text{--}4\text{ GeV}/c^2$ to $3.62\text{--}3.9\text{ GeV}/c^2$ to exclude the right-hand shoulder.

The efficiency corrections obtained from simulation are sensitive to how well the p_T spectrum of the $X(3872)$ and $\psi(2S)$ candidates is modeled. The uncertainty related to the simulated p_T shape is evaluated by comparing the reconstruction and selection efficiencies calculated using the default PYTHIA MC sample, with another MC sample in which the p_T distributions of $X(3872)$ and $\psi(2S)$ are tuned to reproduce the extracted $X(3872)$ and $\psi(2S)$ p_T and y spectra obtained in data, by performing mass fits in bins of $X(3872)$ and $\psi(2S)$ p_T and y . The p_T and y spectra of the alternative MC samples are allowed to vary within the statistical uncertainties in data. The mean of the differences between efficiencies from the alternative MC samples and the default PYTHIA MC due to the variation of p_T and y spectra, which is 13%, is quoted as the systematic uncertainty.

The uncertainties in the trigger efficiency, in the muon reconstruction and identification are evaluated using single muons from J/ψ meson decays in both simulated and collision data, with the tag-and-probe method [44, 45]. This combined uncertainty is found to be negligible, below 1%. Scale factors, calculated as the ratio of data to simulated efficiencies as a function of p_T^μ and η^μ , are applied to each dimuon pair on a muon-by-muon basis. The uncertainties of the scaling factors from tag-and-probe studies are quoted as systematic uncertainties.

To estimate the uncertainty in the prompt fraction arising from potential differences between the resolution in data and simulation, a template fit of the l_{xy} distribution in data is performed using prompt and nonprompt l_{xy} templates from simulation. Data are binned in l_{xy} , and an invariant mass fit is performed to extract the inclusive yield in each l_{xy} bin. This background-subtracted l_{xy} distribution is then fitted using a two component fit, which includes the prompt and nonprompt l_{xy} templates from simulation. The widths of the simulated DCA distributions are varied by a floating scale factor, and the best simulated smearing scale factor to match data is determined by minimizing the χ^2 of the two-component fit. The difference between the ratio of the prompt fractions of $X(3872)$ to $\psi(2S)$ using the template fit method and the nominal result (8.1%) is quoted as a systematic uncertainty.

When calculating the uncertainties in the ratio of the acceptance-corrected yields of prompt $X(3872)$ production over prompt $\psi(2S)$ production, the uncertainties of $X(3872)$ and $\psi(2S)$ yields are assumed to be independent except for the systematic uncertainties from muon re-

construction, efficiencies, and prompt fractions.

The ratio ρ^{PbPb} between the prompt $X(3872)$ and $\psi(2S)$ mesons is shown in Fig. 2, together with ρ^{PP} measured as a function of p_T . The pp data were measured at $\sqrt{s} = 7$ and 8 TeV, in the $|y| < 1.2$ and $|y| < 0.75$ intervals, respectively [7, 8, 10]. The 7 TeV result was derived using the CMS Collaboration published ratio of the inclusive yields [7] and prompt fractions [7, 46]. From Fig. 2 it is clear that the prompt ρ^{PP} does not depend significantly on collision energy or rapidity. In pp collisions at $\sqrt{s} = 8$ TeV, in the kinematic range of $16 < p_T < 22$ GeV/c, the ρ^{PP} measured by the ATLAS Collaboration is 0.106 ± 0.008 (stat) ± 0.004 (syst) [8]. This is to be compared to the prompt ρ^{PbPb} measured in this Letter, $\rho^{\text{PbPb}} = 1.08 \pm 0.49$ (stat) ± 0.52 (syst).

In the interval $15 < p_T < 20$ GeV/c, the yield of the prompt $\psi(2S)$ in PbPb collisions was reported to be significantly suppressed with respect to pp collisions, $R_{\text{AA}}^{\psi(2S)} = 0.142 \pm 0.061$ (stat) ± 0.020 (syst) [47]. This leads, using Eq. (2), to an $R_{\text{AA}}^{X(3872)}$ central value larger than 1 (i.e., enhancement of the prompt $X(3872)$ yield in PbPb compared to pp collisions). However, the uncertainties are such that $R_{\text{AA}}^{X(3872)}$ is compatible with 1 within ~ 1 standard deviation, and with $R_{\text{AA}}^{\psi(2S)}$ within ~ 2 standard deviations. Thus, it is possible that in PbPb collisions, the prompt $X(3872)$ yield has either no suppression with respect to pp collisions, or as much suppression as the $\psi(2S)$ state. The much larger data sample expected in Run 3 at the LHC will answer whether $R_{\text{AA}}^{X(3872)}$ is different from $R_{\text{AA}}^{\psi(2S)}$ and significantly above unity. It may answer whether the $\psi(2S)$ meson production (a bound state of a c and $\bar{c}$ quarks, with $r \sim 0.9$ fm) [48], is affected differently by the medium produced in PbPb collisions than the $X(3872)$ state (that could be made of c, $\bar{c}$, u, and $\bar{u}$ quarks, with a radius of $r \sim 0.3$ fm or $r > 1.5$ fm), the difference in both size and quark content playing a role into their production mechanisms. It will also answer whether the $X(3872)$ prompt state production is different in PbPb collisions compared to pp collisions. The question whether $X(3872)$ is a tetraquark or a molecule cannot yet be answered, because of the statistical limitation of the data, and the disagreement among models. For example, while the AMPT transport model [16] predicts $R_{\text{AA}}^{\text{molecule}} \gg R_{\text{AA}}^{\text{tetraquark}}$ with $R_{\text{AA}}^{\text{molecule}} > 1$, the TAMU transport model [17] predicts $R_{\text{AA}}^{\text{molecule}} \sim R_{\text{AA}}^{\text{tetraquark}}/2$ (albeit, considering only the $X(3872)$ from regeneration processes).

In summary, the first evidence for $X(3872)$ production in heavy ion collisions is presented using lead-lead collisions at a center-of-mass energy of $\sqrt{s_{\text{NN}}} = 5.02$ TeV per nucleon pair, recorded with the CMS detector. The $X(3872)$ state is reconstructed using the decay chain $X(3872) \rightarrow J/\psi \pi^+ \pi^- \rightarrow \mu^+ \mu^- \pi^+ \pi^-$. The measurement is performed for transverse momentum values of the $X(3872)$ of $15 < p_T < 50$ GeV/c and rapidity $|y| < 1.6$. The significance of the inclusive $X(3872)$ signal is 4.2 standard deviations. The ratio ρ^{PbPb} between the prompt $X(3872)$ and $\psi(2S)$ yields times their branching fractions into $J/\psi \pi^+ \pi^-$ is found to be 1.08 ± 0.49 (stat) ± 0.52 (syst), to be compared with typical values of 0.1 for pp collisions. This result provides a unique experimental input to theoretical models of the $X(3872)$ production mechanism, and of the nature of this exotic state.

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 centers and personnel of the Worldwide LHC Computing Grid and other centers for delivering so effectively the computing infrastructure essential to our

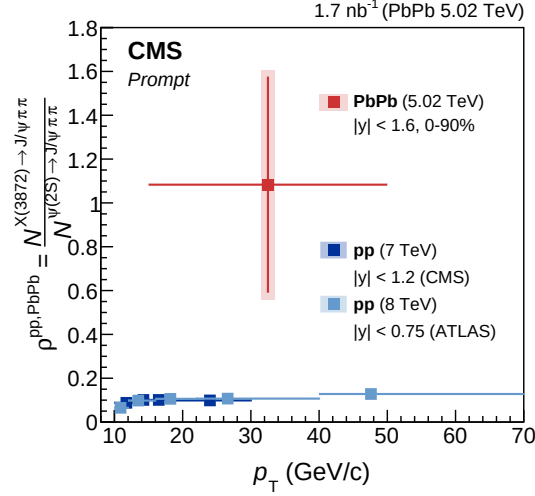


Figure 2: The yield ratio ρ^{PbPb} of prompt $X(3872)$ over $\psi(2S)$ production in PbPb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV. The vertical bars (boxes) correspond to statistical (systematic) uncertainties. The yield ratios ρ^{pp} of prompt $X(3872)$ over $\psi(2S)$ production in pp collisions at $\sqrt{s} = 8$ TeV, measured by ATLAS [8], and at $\sqrt{s} = 7$ TeV, measured by CMS [7] are also shown.

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: BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES and CSF (Croatia); RIF (Cyprus); SENESCYT (Ecuador); MoER, ERC PUT and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); NK-FIA (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); MES (Latvia); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MOS (Montenegro); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, RFBR, and NRC KI (Russia); MESTD (Serbia); SEIDI, CPAN, PCTI, and FEDER (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

Individuals have received support from the Marie-Curie program and the European Research Council and Horizon 2020 Grant, contract Nos. 675440, 724704, 752730, and 765710 (European Union); the Leventis Foundation; the Alfred P. Sloan Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the 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; the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Deutsche Forschungsgemeinschaft (DFG), under Germany’s Excellence Strategy – EXC 2121 “Quantum Universe” – 390833306, and under project number 400140256 - GRK2497; the Lendület (“Momentum”) Program and the János Bolyai Research Scholarship of the Hungarian Academy of Sciences, the New National Excellence Program ÚNKP, the NKFI research grants 123842, 123959, 124845, 124850, 125105, 128713, 128786, and 129058 (Hungary); the Council of Science and Industrial Research, In-

dia; the Ministry of Science and Higher Education and the National Science Center, contracts Opus 2014/15/B/ST2/03998 and 2015/19/B/ST2/02861 (Poland); the National Priorities Research Program by Qatar National Research Fund; the Ministry of Science and Higher Education, project no. 0723-2020-0041 (Russia); the Programa Estatal de Fomento de la Investigación Científica y Técnica de Excelencia María de Maeztu, grant MDM-2015-0509 and the Programa Severo Ochoa del Principado de Asturias; the Thalís and Aristeia programs cofinanced by EU-ESF and the Greek NSRF; the Rachadapisek Sompot Fund for Postdoctoral Fellowship, Chulalongkorn University and the Chulalongkorn Academic into Its 2nd Century Project Advancement Project (Thailand); the Kavli Foundation; the Nvidia Corporation; the SuperMicro Corporation; the Welch Foundation, contract C-1845; and the Weston Havens Foundation (USA).

References

- [1] Belle Collaboration, “Observation of a narrow charmonium-like state in exclusive $B^\pm \rightarrow K^\pm \pi^+ \pi^- J/\psi$ decays”, *Phys. Rev. Lett.* **91** (2003) 262001, doi:10.1103/PhysRevLett.91.262001, arXiv:hep-ex/0309032.
- [2] BaBar Collaboration, “Study of the $B \rightarrow J/\psi K^- \pi^+ \pi^-$ decay and measurement of the $B \rightarrow X(3872) K^-$ branching fraction”, *Phys. Rev. D* **71** (2005) 071103, doi:10.1103/PhysRevD.71.071103, arXiv:hep-ex/0406022.
- [3] BESIII Collaboration, “Observation of $e^+ e^- \rightarrow X(3872)$ at BESIII”, *Phys. Rev. Lett.* **112** (2014) 092001, doi:10.1103/PhysRevLett.112.092001, arXiv:1310.4101.
- [4] CDF Collaboration, “Observation of the narrow state $X(3872) \rightarrow J/\psi \pi^+ \pi^-$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV”, *Phys. Rev. Lett.* **93** (2004) 072001, doi:10.1103/PhysRevLett.93.072001, arXiv:hep-ex/0312021.
- [5] D0 Collaboration, “Observation and properties of the $X(3872)$ decaying to $J/\psi \pi^+ \pi^-$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV”, *Phys. Rev. Lett.* **93** (2004) 162002, doi:10.1103/PhysRevLett.93.162002, arXiv:hep-ex/0405004.
- [6] LHCb Collaboration, “Observation of $X(3872)$ production in pp collisions at $\sqrt{s} = 7$ TeV”, *Eur. Phys. J. C* **72** (2012) 1972, doi:10.1140/epjc/s10052-012-1972-7, arXiv:1112.5310.
- [7] CMS Collaboration, “Measurement of the $X(3872)$ production cross section via decays to $J/\psi \pi^+ \pi^-$ in pp collisions at $\sqrt{s} = 7$ TeV”, *JHEP* **04** (2013) 154, doi:10.1007/JHEP04(2013)154, arXiv:1302.3968.
- [8] ATLAS Collaboration, “Measurements of $\psi(2S)$ and $X(3872) \rightarrow J/\psi \pi^+ \pi^-$ production in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector”, *JHEP* **01** (2017) 117, doi:10.1007/JHEP01(2017)117, arXiv:1610.09303.
- [9] CDF Collaboration, “Analysis of the quantum numbers J^{PC} of the $X(3872)$ ”, *Phys. Rev. Lett.* **98** (2007) 132002, doi:10.1103/PhysRevLett.98.132002, arXiv:hep-ex/0612053.
- [10] LHCb Collaboration, “Determination of the $X(3872)$ meson quantum numbers”, *Phys. Rev. Lett.* **110** (2013) 222001, doi:10.1103/PhysRevLett.110.222001, arXiv:1302.6269.

- [11] N. A. Tornqvist, “Isospin breaking of the narrow charmonium state of Belle at 3872 MeV as a deuson”, *Phys. Lett. B* **590** (2004) 209, doi:10.1016/j.physletb.2004.03.077, arXiv:hep-ph/0402237.
- [12] L. Maiani, F. Piccinini, A. D. Polosa, and V. Riquer, “Diquark-antidiquarks with hidden or open charm and the nature of X(3872)”, *Phys. Rev. D* **71** (2005) 014028, doi:10.1103/PhysRevD.71.014028, arXiv:hep-ph/0412098.
- [13] C. Hanhart, Yu. S. Kalashnikova, and A. V. Nefediev, “Interplay of quark and meson degrees of freedom in a near-threshold resonance: multi-channel case”, *Eur. Phys. J. A* **47** (2011) 101, doi:10.1140/epja/i2011-11101-9, arXiv:1106.1185.
- [14] J. C. Collins and M. J. Perry, “Superdense matter: neutrons or asymptotically free quarks?”, *Phys. Rev. Lett.* **34** (1975) 1353, doi:10.1103/PhysRevLett.34.1353.
- [15] E. V. Shuryak, “Quark-gluon plasma and hadronic production of leptons, photons and pions”, *Phys. Lett. B* **78** (1978) 150, doi:10.1016/0370-2693(78)90370-2. [*Yad. Fiz.* **28** (1978) 796].
- [16] H. Zhang et al., “Deciphering the nature of X(3872) in heavy ion collisions”, *Phys. Rev. Lett.* **126** (2021) 012301, doi:10.1103/PhysRevLett.126.012301, arXiv:2004.00024.
- [17] B. Wu, X. Du, M. Sibila, and R. Rapp, “X(3872) transport in heavy-ion collisions”, 2021. arXiv:2006.09945. [Erratum: doi:https://doi.org/10.1140/epja/s10050-021-00623-4].
- [18] ExHIC Collaboration, “Identifying multi-quark hadrons from heavy ion collisions”, *Phys. Rev. Lett.* **106** (2011) 212001, doi:10.1103/PhysRevLett.106.212001, arXiv:1011.0852.
- [19] ExHIC Collaboration, “Exotic hadrons in heavy ion collisions”, *Phys. Rev. C* **84** (2011) 064910, doi:10.1103/PhysRevC.84.064910, arXiv:1107.1302.
- [20] A. Martinez Torres et al., “X(3872) production in high energy heavy ion collisions”, *Phys. Rev. D* **90** (2014) 114023, doi:10.1103/PhysRevD.90.114023, arXiv:1405.7583. [Erratum: doi:10.1103/PhysRevD.93.059902].
- [21] H. Sato and K. Yazaki, “On the coalescence model for high energy nuclear reactions”, *Physics Letters B* **98** (1981) 153, doi:10.1016/0370-2693(81)90976-X.
- [22] T. Matsui and H. Satz, “ J/ψ suppression by quark-gluon plasma formation”, *Phys. Lett. B* **178** (1986) 416, doi:10.1016/0370-2693(86)91404-8.
- [23] L. M. Abreu et al., “X(3872) production and absorption in a hot hadron gas”, *Phys. Lett. B* **761** (2016) 303, doi:10.1016/j.physletb.2016.08.050, arXiv:1604.07716.
- [24] LHCb Collaboration, “Evidence for the decay $X(3872) \rightarrow \psi(2S)\gamma$ ”, *Nucl. Phys. B* **886** (2014) 665, doi:10.1016/j.nuclphysb.2014.06.011, arXiv:1404.0275.
- [25] A. Andronic, P. Braun-Munzinger, and J. Stachel, “Hadron production in central nucleus-nucleus collisions at chemical freeze-out”, *Nucl. Phys. A* **772** (2006) 167, doi:10.1016/j.nuclphysa.2006.03.012, arXiv:nucl-th/0511071.

-
- [26] A. Andronic, P. Braun-Munzinger, K. Redlich, and J. Stachel, “Decoding the phase structure of QCD via particle production at high energy”, *Nature* **561** (2018), no. 7723, 321, doi:10.1038/s41586-018-0491-6, arXiv:1710.09425.
- [27] CMS Collaboration, “The CMS experiment at the CERN LHC”, *JINST* **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
- [28] 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.
- [29] CMS Collaboration, “The CMS trigger system”, *JINST* **12** (2017) P01020, doi:10.1088/1748-0221/12/01/P01020, arXiv:1609.02366.
- [30] CMS Collaboration, “Performance of electron reconstruction and selection with the CMS detector in proton-proton collisions at $\sqrt{s} = 8$ TeV”, *JINST* **10** (2015) P06005, doi:10.1088/1748-0221/10/06/P06005, arXiv:1502.02701.
- [31] 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.
- [32] CMS Collaboration, “Performance of photon reconstruction and identification with the CMS detector in proton-proton collisions at $\sqrt{s} = 8$ TeV”, *JINST* **10** (2015) P08010, doi:10.1088/1748-0221/10/08/P08010, arXiv:1502.02702.
- [33] CMS Collaboration, “Description and performance of track and primary-vertex reconstruction with the CMS tracker”, *JINST* **9** (2014) P10009, doi:10.1088/1748-0221/9/10/P10009, arXiv:1405.6569.
- [34] 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.
- [35] CMS Collaboration, “Observation and studies of jet quenching in PbPb collisions at nucleon-nucleon center-of-mass energy = 2.76 TeV”, *Phys. Rev. C* **84** (2011) 024906, doi:10.1103/PhysRevC.84.024906, arXiv:1102.1957.
- [36] CMS Collaboration, “Charged-particle nuclear modification factors in PbPb and pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV”, *JHEP* **04** (2017) 039, doi:10.1007/JHEP04(2017)039, arXiv:1611.01664.
- [37] CMS Collaboration, “Transverse momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s} = 0.9$ and 2.36 TeV”, *JHEP* **02** (2010) 041, doi:10.1007/JHEP02(2010)041, arXiv:1002.0621.
- [38] T. Sjöstrand et al., “An introduction to PYTHIA 8.2”, *Comput. Phys. Commun.* **191** (2015) 159, doi:10.1016/j.cpc.2015.01.024, arXiv:1410.3012.
- [39] 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.
- [40] Particle Data Group, P. A. Zyla et al., “Review of particle physics”, *Prog. Theor. Exp. Phys.* **2020** (2020) 083C01, doi:10.1093/ptep/ptaa104.

- [41] E. Barberio, B. van Eijk, and Z. Was, “Photos — a universal Monte Carlo for QED radiative corrections in decays”, *Comput. Phys. Commun.* **66** (1991) 115, doi:10.1016/0010-4655(91)90012-A.
- [42] I. P. Lokhtin and A. M. Snigirev, “A model of jet quenching in ultrarelativistic heavy ion collisions and high- p_T hadron spectra at RHIC”, *Eur. Phys. J. C* **45** (2006) 211, doi:10.1140/epjc/s2005-02426-3, arXiv:hep-ph/0506189.
- [43] H. Voss, A. Höcker, J. Stelzer, and F. Tegenfeldt, “TMVA, the toolkit for multivariate data analysis with ROOT”, in *XIth International Workshop on Advanced Computing and Analysis Techniques in Physics Research (ACAT)*, p. 40. 2007. arXiv:physics/0703039. [PoS(ACAT)040]. doi:10.22323/1.050.0040.
- [44] 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.
- [45] CMS Collaboration, “Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV”, *JINST* **7** (2012) P10002, doi:10.1088/1748-0221/7/10/P10002, arXiv:1206.4071.
- [46] CMS Collaboration, “ J/ψ and $\psi(2S)$ production in pp collisions at $\sqrt{s} = 7$ TeV”, *JHEP* **02** (2012) 011, doi:10.1007/JHEP02(2012)011, arXiv:1111.1557.
- [47] CMS Collaboration, “Measurement of prompt and nonprompt charmonium suppression in PbPb collisions at 5.02 TeV”, *Eur. Phys. J. C* **78** (2018) 509, doi:10.1140/epjc/s10052-018-5950-6, arXiv:1712.08959.
- [48] L. Kluberg and H. Satz, “Color deconfinement and charmonium production in nuclear collisions”, in *Springer Materials - The Landolt-Börnstein Database*, R. Stock, ed., volume 23: Relativistic Heavy Ion Physics. Springer-Verlag, 2010. arXiv:0901.3831. doi:10.1007/978-3-642-01539-7_13.

A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia

A.M. Sirunyan[†], A. Tumasyan

Institut für Hochenergiephysik, Wien, Austria

W. Adam, F. Ambrogio, T. Bergauer, M. Dragicevic, J. Erö, A. Escalante Del Valle, M. Flechl, R. Frühwirth¹, M. Jeitler¹, N. Krammer, I. Krätschmer, D. Liko, T. Madlener, I. Mikulec, N. Rad, J. Schieck¹, R. Schöfbeck, M. Spanring, W. Waltenberger, C.-E. Wulz¹, M. Zarucki

Institute for Nuclear Problems, Minsk, Belarus

V. Drugakov, V. Mossolov, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium

M.R. Darwish, E.A. De Wolf, D. Di Croce, X. Janssen, T. Kello², A. Lelek, M. Pieters, H. Rejeb Sfar, H. Van Haevermaet, P. Van Mechelen, S. Van Putte, N. Van Remortel

Vrije Universiteit Brussel, Brussel, Belgium

F. Blekman, E.S. Bols, S.S. Chhibra, J. D'Hondt, J. De Clercq, D. Lontkovskyi, S. Lowette, I. Marchesini, S. Moortgat, Q. Python, S. Tavernier, W. Van Doninck, P. Van Mulders

Université Libre de Bruxelles, Bruxelles, Belgium

D. Beghin, B. Bilin, B. Clerbaux, G. De Lentdecker, H. Delannoy, B. Dorney, L. Favart, A. Grebenyuk, A.K. Kalsi, L. Moureaux, A. Popov, N. Postiau, E. Starling, L. Thomas, C. Vander Velde, P. Vanlaer, D. Vannerom

Ghent University, Ghent, Belgium

T. Cornelis, D. Dobur, I. Khvastunov³, M. Niedziela, C. Roskas, K. Skovpen, M. Tytgat, W. Verbeke, B. Vermassen, M. Vit

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

G. Bruno, C. Caputo, P. David, C. Delaere, M. Delcourt, A. Giammanco, V. Lemaitre, J. Prisciandaro, A. Saggio, P. Vischia, J. Zobec

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

G.A. Alves, G. Correia Silva, C. Hensel, A. Moraes

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

E. Belchior Batista Das Chagas, W. Carvalho, J. Chinellato⁴, E. Coelho, E.M. Da Costa, G.G. Da Silveira⁵, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, J. Martins⁶, D. Matos Figueiredo, M. Medina Jaime⁷, M. Melo De Almeida, C. Mora Herrera, L. Mundim, H. Nogima, W.L. Prado Da Silva, P. Rebello Teles, L.J. Sanchez Rosas, A. Santoro, A. Sznajder, M. Thiel, E.J. Tonelli Manganote⁴, F. Torres Da Silva De Araujo, A. Vilela Pereira

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

C.A. Bernardes^a, L. Calligaris^a, T.R. Fernandez Perez Tomei^a, E.M. Gregores^b, D.S. Lemos^a, P.G. Mercadante^b, S.F. Novaes^a, Sandra S. Padula^a

Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria

A. Aleksandrov, G. Antchev, R. Hadjiiska, P. Iaydjiev, M. Misheva, M. Rodozov, M. Shopova, G. Sultanov

University of Sofia, Sofia, Bulgaria

M. Bonchev, A. Dimitrov, T. Ivanov, L. Litov, B. Pavlov, P. Petkov, A. Petrov

Beihang University, Beijing, China

W. Fang², X. Gao², L. Yuan

Department of Physics, Tsinghua University, Beijing, China

M. Ahmad, Z. Hu, Y. Wang

Institute of High Energy Physics, Beijing, China

G.M. Chen⁸, H.S. Chen⁸, M. Chen, C.H. Jiang, D. Leggat, H. Liao, Z. Liu, A. Spiezia, J. Tao, E. Yazgan, H. Zhang, S. Zhang⁸, J. Zhao

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

A. Agapitos, Y. Ban, G. Chen, A. Levin, J. Li, L. Li, Q. Li, Y. Mao, S.J. Qian, D. Wang, Q. Wang

Zhejiang University, Hangzhou, China

M. Xiao

Universidad de Los Andes, Bogota, Colombia

C. Avila, A. Cabrera, C. Florez, C.F. González Hernández, M.A. Segura Delgado

Universidad de Antioquia, Medellin, Colombia

J. Mejia Guisao, J.D. Ruiz Alvarez, C.A. Salazar González, N. Vanegas Arbelaez

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

D. Giljanović, N. Godinovic, D. Lelas, I. Puljak, T. Sculac

University of Split, Faculty of Science, Split, Croatia

Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

V. Brigljevic, D. Ferencek, K. Kadija, B. Mesic, M. Roguljic, A. Starodumov⁹, T. Susa

University of Cyprus, Nicosia, Cyprus

M.W. Ather, A. Attikis, E. Erodotou, A. Ioannou, M. Kolosova, S. Konstantinou, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis, H. Rykaczewski, H. Saka, D. Tsiakkouri

Charles University, Prague, Czech Republic

M. Finger¹⁰, M. Finger Jr.¹⁰, A. Kveton, J. Tomsa

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

M.A. Mahmoud^{11,12}, Y. Mohammed¹¹

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

S. Bhowmik, A. Carvalho Antunes De Oliveira, R.K. Dewanjee, K. Ehataht, M. Kadastik, M. Raidal, C. Veelken

Department of Physics, University of Helsinki, Helsinki, Finland

P. Eerola, L. Forthomme, H. Kirschenmann, K. Osterberg, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

F. Garcia, J. Havukainen, J.K. Heikkilä, V. Karimäki, M.S. Kim, R. Kinnunen, T. Lampén, K. Lassila-Perini, S. Laurila, S. Lehti, T. Lindén, H. Siikonen, E. Tuominen, J. Tuominiemi

Lappeenranta University of Technology, Lappeenranta, Finland

P. Luukka, T. Tuuva

IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France

M. Besancon, F. Couderc, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, C. Leloup, B. Lenzi, E. Locci, J. Malcles, J. Rander, A. Rosowsky, M.Ö. Sahin, A. Savoy-Navarro¹³, M. Titov, G.B. Yu

Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France

S. Ahuja, C. Amendola, F. Beaudette, M. Bonanomi, P. Busson, C. Charlot, B. Diab, G. Falmagne, R. Granier de Cassagnac, I. Kucher, A. Lobanov, C. Martin Perez, M. Nguyen, C. Ochando, P. Paganini, J. Rembser, R. Salerno, J.B. Sauvan, Y. Sirois, A. Zabi, A. Zghiche

Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France

J.-L. Agram¹⁴, J. Andrea, D. Bloch, G. Bourgatte, J.-M. Brom, E.C. Chabert, C. Collard, E. Conte¹⁴, J.-C. Fontaine¹⁴, D. Gelé, U. Goerlach, C. Grimault, A.-C. Le Bihan, N. Tonon, P. Van Hove

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

S. Gadrat

Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France

S. Beauceron, C. Bernet, G. Boudoul, C. Camen, A. Carle, N. Chanon, R. Chierici, D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, Sa. Jain, I.B. Laktineh, H. Lattaud, A. Lesauvage, M. Lethuillier, L. Mirabito, S. Perries, V. Sordini, L. Tarterotot, G. Touquet, M. Vander Donckt, S. Viret

Georgian Technical University, Tbilisi, Georgia

T. Toriashvili¹⁵

Tbilisi State University, Tbilisi, Georgia

Z. Tsamalaidze¹⁰

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

C. Autermann, L. Feld, K. Klein, M. Lipinski, D. Meuser, A. Pauls, M. Preuten, M.P. Rauch, J. Schulz, M. Teroerde

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

M. Erdmann, B. Fischer, S. Ghosh, T. Hebbeker, K. Hoepfner, H. Keller, L. Mastrolorenzo, M. Merschmeyer, A. Meyer, P. Millet, G. Mocellin, S. Mondal, S. Mukherjee, D. Noll, A. Novak, T. Pook, A. Pozdnyakov, T. Quast, M. Radziej, Y. Rath, H. Reithler, J. Roemer, A. Schmidt, S.C. Schuler, A. Sharma, S. Wiedenbeck, S. Zaleski

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

G. Flügge, W. Haj Ahmad¹⁶, O. Hlushchenko, T. Kress, T. Müller, A. Nowack, C. Pistone, O. Pooth, D. Roy, H. Sert, A. Stahl¹⁷

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, P. Asmuss, I. Babounikau, H. Bakhshiansohi, K. Beernaert, O. Behnke,

A. Bermúdez Martínez, A.A. Bin Anuar, K. Borrás¹⁸, V. Botta, A. Campbell, A. Cardini, P. Connor, S. Consuegra Rodríguez, C. Contreras-Campana, V. Danilov, A. De Wit, M.M. Defranchis, C. Diez Pardos, D. Domínguez Damiani, G. Eckerlin, D. Eckstein, T. Eichhorn, A. Elwood, E. Eren, L.I. Estevez Banos, E. Gallo¹⁹, A. Geiser, A. Grohsjean, M. Guthoff, M. Haranko, A. Harb, A. Jafari, N.Z. Jomhari, H. Jung, A. Kasem¹⁸, M. Kasemann, H. Kaveh, J. Keaveney, C. Kleinwort, J. Knolle, D. Krücker, W. Lange, T. Lenz, J. Lidrych, K. Lipka, W. Lohmann²⁰, R. Mankel, I.-A. Melzer-Pellmann, A.B. Meyer, M. Meyer, M. Missiroli, J. Mnich, A. Mussgiller, V. Myronenko, D. Pérez Adán, S.K. Pflitsch, D. Pitzl, A. Raspereza, A. Saibel, M. Savitskyi, V. Scheurer, P. Schütze, C. Schwanenberger, R. Shevchenko, A. Singh, R.E. Sosa Ricardo, H. Tholen, O. Turkot, A. Vagnerini, M. Van De Klundert, R. Walsh, Y. Wen, K. Wichmann, C. Wissing, O. Zenaiev, R. Zlebcik

University of Hamburg, Hamburg, Germany

R. Aggleton, S. Bein, L. Benato, A. Benecke, T. Dreyer, A. Ebrahimi, F. Feindt, A. Fröhlich, C. Garbers, E. Garutti, D. Gonzalez, P. Gunnellini, J. Haller, A. Hinzmann, A. Karavdina, G. Kasieczka, R. Klanner, R. Kogler, N. Kovalchuk, S. Kurz, V. Kutzner, J. Lange, T. Lange, A. Malara, J. Multhaupt, C.E.N. Niemeyer, A. Reimers, O. Rieger, P. Schleper, S. Schumann, J. Schwandt, J. Sonneveld, H. Stadie, G. Steinbrück, B. Vormwald, I. Zoi

Karlsruher Institut fuer Technologie, Karlsruhe, Germany

M. Akbiyik, M. Baselga, S. Baur, T. Berger, E. Butz, R. Caspart, T. Chwalek, W. De Boer, A. Dierlamm, K. El Morabit, N. Faltermann, M. Giffels, A. Gottmann, F. Hartmann¹⁷, C. Heidecker, U. Husemann, M.A. Iqbal, S. Kudella, S. Maier, S. Mitra, M.U. Mozer, D. Müller, Th. Müller, M. Musich, A. Nürnberg, G. Quast, K. Rabbertz, D. Savoie, D. Schäfer, M. Schnepf, M. Schröder, I. Shvetsov, H.J. Simonis, R. Ulrich, M. Wassmer, M. Weber, C. Wöhrmann, R. Wolf, S. Wozniowski

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

G. Anagnostou, P. Asenov, G. Daskalakis, T. Gerasis, A. Kyriakis, D. Loukas, G. Paspalaki, A. Stakia

National and Kapodistrian University of Athens, Athens, Greece

M. Diamantopoulou, G. Karathanasis, P. Kontaxakis, A. Manousakis-katsikakis, A. Panagiotou, I. Papavergou, N. Saoulidou, K. Theofilatos, K. Vellidis, E. Vourliotis

National Technical University of Athens, Athens, Greece

G. Bakas, K. Kousouris, I. Papakrivopoulos, G. Tsipolitis, A. Zacharopoulou

University of Ioánnina, Ioánnina, Greece

I. Evangelou, C. Foudas, P. Giannios, P. Katsoulis, P. Kokkas, S. Mallios, K. Manitaras, N. Manthos, I. Papadopoulos, J. Strolagos, F.A. Triantis, D. Tsitsonis

MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary

M. Bartók²¹, R. Chudasama, M. Csanad, P. Major, K. Mandal, A. Mehta, G. Pasztor, O. Surányi, G.I. Veres

Wigner Research Centre for Physics, Budapest, Hungary

G. Bencze, C. Hajdu, D. Horvath²², F. Sikler, V. Veszpremi, G. Vesztergombi[†]

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

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

Institute of Physics, University of Debrecen, Debrecen, Hungary

P. Raics, D. Teyssier, Z.L. Trocsanyi, B. Ujvari

Eszterhazy Karoly University, Karoly Robert Campus, Gyongyos, Hungary

T. Csorgo, W.J. Metzger, F. Nemes, T. Novak

Indian Institute of Science (IISc), Bangalore, India

S. Choudhury, J.R. Komaragiri, P.C. Tiwari

National Institute of Science Education and Research, HBNI, Bhubaneswar, India

S. Bahinipati²⁴, C. Kar, G. Kole, P. Mal, V.K. Muraleedharan Nair Bindhu, A. Nayak²⁵, D.K. Sahoo²⁴, S.K. Swain

Panjab University, Chandigarh, India

S. Bansal, S.B. Beri, V. Bhatnagar, S. Chauhan, N. Dhingra²⁶, R. Gupta, A. Kaur, M. Kaur, S. Kaur, P. Kumari, M. Lohan, M. Meena, K. Sandeep, S. Sharma, J.B. Singh, A.K. Viridi, G. Walia

University of Delhi, Delhi, India

A. Bhardwaj, B.C. Choudhary, R.B. Garg, M. Gola, S. Keshri, Ashok Kumar, M. Naimuddin, P. Priyanka, K. Ranjan, Aashaq Shah, R. Sharma

Saha Institute of Nuclear Physics, HBNI, Kolkata, India

R. Bhardwaj²⁷, M. Bharti²⁷, R. Bhattacharya, S. Bhattacharya, U. Bhawandeep²⁷, D. Bhowmik, S. Dutta, S. Ghosh, B. Gomber²⁸, M. Maity²⁹, K. Mondal, S. Nandan, A. Purohit, P.K. Rout, G. Saha, S. Sarkar, M. Sharan, B. Singh²⁷, S. Thakur²⁷

Indian Institute of Technology Madras, Madras, India

P.K. Behera, S.C. Behera, P. Kalbhor, A. Muhammad, P.R. Pujahari, A. Sharma, A.K. Sikdar

Bhabha Atomic Research Centre, Mumbai, India

D. Dutta, V. Jha, D.K. Mishra, P.K. Netrakanti, L.M. Pant, P. Shukla

Tata Institute of Fundamental Research-A, Mumbai, India

T. Aziz, M.A. Bhat, S. Dugad, G.B. Mohanty, N. Sur, Ravindra Kumar Verma

Tata Institute of Fundamental Research-B, Mumbai, India

S. Banerjee, S. Bhattacharya, S. Chatterjee, P. Das, M. Guchait, S. Karmakar, S. Kumar, G. Majumder, K. Mazumdar, N. Sahoo, S. Sawant

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

S. Dube, B. Kansal, A. Kapoor, K. Kothekar, S. Pandey, A. Rane, A. Rastogi, S. Sharma

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

S. Chenarani, S.M. Etesami, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, F. Rezaei Hosseinabadi

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}, R. Aly^{a,b,30}, C. Calabria^{a,b}, A. Colaleo^a, D. Creanza^{a,c}, L. Cristella^{a,b}, N. De Filippis^{a,c}, M. De Palma^{a,b}, A. Di Florio^{a,b}, W. Elmetenawee^{a,b}, L. Fiore^a, A. Gelmi^{a,b}, G. Iaselli^{a,c}, M. Ince^{a,b}, S. Lezki^{a,b}, G. Maggi^{a,c}, M. Maggi^a, J.A. Merlin^a, G. Miniello^{a,b}, S. My^{a,b}, S. Nuzzo^{a,b}, A. Pompili^{a,b}, G. Pugliese^{a,c}, R. Radogna^a, A. Ranieri^a, G. Selvaggi^{a,b}, L. Silvestris^a, F.M. Simone^{a,b}, R. Venditti^a, P. Verwilligen^a

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

G. Abbiendi^a, C. Battilana^{a,b}, D. Bonacorsi^{a,b}, L. Borgonovi^{a,b}, S. Braibant-Giacomelli^{a,b}, R. Campanini^{a,b}, P. Capiluppi^{a,b}, A. Castro^{a,b}, F.R. Cavallo^a, G. Codispoti^{a,b}, M. Cuffiani^{a,b}, G.M. Dallavalle^a, F. Fabbri^a, A. Fanfani^{a,b}, E. Fontanesi^{a,b}, P. Giacomelli^a, L. Giommi^{a,b}, C. Grandi^a, L. Guiducci^{a,b}, F. Iemmi^{a,b}, S. Lo Meo^{a,31}, S. Marcellini^a, G. Masetti^a, F.L. Navarria^{a,b}, A. Perrotta^a, F. Primavera^{a,b}, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G.P. Siroli^{a,b}, N. Tosi^a

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

S. Albergo^{a,b,32}, S. Costa^{a,b,32}, A. Di Mattia^a, R. Potenza^{a,b}, A. Tricomi^{a,b,32}, C. Tuve^{a,b}

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

G. Barbagli^a, A. Cassese^a, R. Ceccarelli^{a,b}, V. Ciulli^{a,b}, C. Civinini^a, R. D'Alessandro^{a,b}, F. Fiori^a, E. Focardi^{a,b}, G. Latino^{a,b}, P. Lenzi^{a,b}, M. Meschini^a, S. Paoletti^a, G. Sguazzoni^a, L. Viliani^a

INFN Laboratori Nazionali di Frascati, Frascati, Italy

L. Benussi, S. Bianco, D. Piccolo

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

M. Bozzo^{a,b}, F. Ferro^a, R. Mulargia^{a,b}, E. Robutti^a, S. Tosi^{a,b}

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

A. Benaglia^a, A. Beschi^{a,b}, F. Brivio^{a,b}, V. Ciriolo^{a,b,17}, M.E. Dinardo^{a,b}, P. Dini^a, S. Gennai^a, A. Ghezzi^{a,b}, P. Govoni^{a,b}, L. Guzzi^{a,b}, M. Malberti^a, S. Malvezzi^a, D. Menasce^a, F. Monti^{a,b}, L. Moroni^a, M. Paganoni^{a,b}, D. Pedrini^a, S. Ragazzi^{a,b}, T. Tabarelli de Fatis^{a,b}, D. Valsecchi^{a,b,17}, D. Zuolo^{a,b}

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

S. Buontempo^a, N. Cavallo^{a,c}, A. De Iorio^{a,b}, A. Di Crescenzo^{a,b}, F. Fabozzi^{a,c}, F. Fienga^a, G. Galati^a, A.O.M. Iorio^{a,b}, L. Layer^{a,b}, L. Lista^{a,b}, S. Meola^{a,d,17}, P. Paolucci^{a,17}, B. Rossi^a, C. Sciacca^{a,b}, E. Voevodina^{a,b}

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

P. Azzi^a, N. Bacchetta^a, D. Bisello^{a,b}, A. Boletti^{a,b}, A. Bragagnolo^{a,b}, R. Carlin^{a,b}, P. Checchia^a, P. De Castro Manzano^a, T. Dorigo^a, U. Dosselli^a, F. Gasparini^{a,b}, U. Gasparini^{a,b}, A. Gozzelino^a, S.Y. Hoh^{a,b}, M. Margoni^{a,b}, A.T. Meneguzzo^{a,b}, J. Pazzini^{a,b}, M. Presilla^b, P. Ronchese^{a,b}, R. Rossin^{a,b}, F. Simonetto^{a,b}, A. Tiko^a, M. Tosi^{a,b}, 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, D. Fiorina^{a,b}, P. Montagna^{a,b}, S.P. Ratti^{a,b}, V. Re^a, M. Ressegotti^{a,b}, C. Riccardi^{a,b}, P. Salvini^a, I. Vai^a, P. Vitulo^{a,b}

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

M. Biasini^{a,b}, G.M. Bilei^a, D. Ciangottini^{a,b}, L. Fanò^{a,b}, P. Lariccia^{a,b}, R. Leonardi^{a,b}, E. Manoni^a, G. Mantovani^{a,b}, V. Mariani^{a,b}, M. Menichelli^a, A. Rossi^{a,b}, A. Santocchia^{a,b}, D. Spiga^a

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

K. Androsov^a, P. Azzurri^a, G. Bagliesi^a, V. Bertacchi^{a,c}, L. Bianchini^a, T. Boccali^a, R. Castaldi^a, M.A. Ciocci^{a,b}, R. Dell'Orso^a, S. Donato^a, L. Giannini^{a,c}, A. Giassi^a, M.T. Grippo^a, F. Ligabue^{a,c}, E. Manca^{a,c}, G. Mandorli^{a,c}, A. Messineo^{a,b}, F. Palla^a, A. Rizzi^{a,b}, G. Rolandi^{a,c}

S. Roy Chowdhury^{a,c}, A. Scribano^a, P. Spagnolo^a, R. Tenchini^a, G. Tonelli^{a,b}, N. Turini^{a,d}, A. Venturi^a, P.G. Verдини^a

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

F. Cavallari^a, M. Cipriani^{a,b}, D. Del Re^{a,b}, E. Di Marco^a, M. Diemoz^a, E. Longo^{a,b}, P. Meridiani^a, 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,b}, R. Tramontano^{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, A. Cappati^{a,b}, N. Cartiglia^a, S. Cometti^a, M. Costa^{a,b}, R. Covarelli^{a,b}, N. Demaria^a, J.R. González Fernández^a, B. Kiani^{a,b}, F. Legger^a, C. Mariotti^a, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b}, E. Monteil^{a,b}, M. Monteno^a, M.M. Obertino^{a,b}, G. Ortona^a, L. Pacher^{a,b}, N. Pastrone^a, M. Pelliccioni^a, G.L. Pinna Angioni^{a,b}, A. Romero^{a,b}, M. Ruspa^{a,c}, R. Salvatico^{a,b}, V. Sola^a, A. Solano^{a,b}, D. Soldi^{a,b}, A. Staiano^a, D. Trocino^{a,b}

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

S. Belforte^a, V. Candelise^{a,b}, M. Casarsa^a, F. Cossutti^a, A. Da Rold^{a,b}, G. Della Ricca^{a,b}, F. Vazzoler^{a,b}, A. Zanetti^a

Kyungpook National University, Daegu, Korea

B. Kim, D.H. Kim, G.N. Kim, J. Lee, S.W. Lee, C.S. Moon, Y.D. Oh, S.I. Pak, S. Sekmen, D.C. Son, Y.C. Yang

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

H. Kim, D.H. Moon

Hanyang University, Seoul, Korea

B. Francois, T.J. Kim, J. Park

Korea University, Seoul, Korea

S. Cho, S. Choi, Y. Go, S. Ha, B. Hong, K. Lee, K.S. Lee, J. Lim, J. Park, S.K. Park, Y. Roh, J. Yoo

Kyung Hee University, Department of Physics, Seoul, Republic of Korea

J. Goh

Sejong University, Seoul, Korea

H.S. Kim

Seoul National University, Seoul, Korea

J. Almond, J.H. Bhyun, J. Choi, S. Jeon, J. Kim, J.S. Kim, H. Lee, K. Lee, S. Lee, K. Nam, M. Oh, S.B. Oh, B.C. Radburn-Smith, U.K. Yang, H.D. Yoo, I. Yoon

University of Seoul, Seoul, Korea

D. Jeon, J.H. Kim, J.S.H. Lee, I.C. Park, I.J. Watson

Sungkyunkwan University, Suwon, Korea

Y. Choi, C. Hwang, Y. Jeong, J. Lee, Y. Lee, I. Yu

Riga Technical University, Riga, Latvia

V. Veckalns³³

Vilnius University, Vilnius, Lithuania

V. Dudenas, A. Juodagalvis, A. Rinkevicius, G. Tamulaitis, J. Vaitkus

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

F. Mohamad Idris³⁴, W.A.T. Wan Abdullah, M.N. Yusli, Z. Zolkapli

Universidad de Sonora (UNISON), Hermosillo, Mexico

J.F. Benitez, A. Castaneda Hernandez, J.A. Murillo Quijada, L. Valencia Palomo

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

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz³⁵, R. Lopez-Fernandez, A. Sanchez-Hernandez

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, C. Oropeza Barrera, M. Ramirez-Garcia, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

J. Eysermans, I. Pedraza, H.A. Salazar Ibarguen, C. Uribe Estrada

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

A. Morelos Pineda

University of Montenegro, Podgorica, Montenegro

J. Mijuskovic³, N. Raicevic

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand

S. Bheesette, P.H. Butler, P. Lujan

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

A. Ahmad, M. Ahmad, M.I.M. Awan, Q. Hassan, H.R. Hoorani, W.A. Khan, M.A. Shah, M. Shoaib, M. Waqas

AGH University of Science and Technology Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland

V. Avati, L. Grzanka, M. Malawski

National Centre for Nuclear Research, Swierk, Poland

H. Bialkowska, M. Bluj, B. Boimska, M. Górski, M. Kazana, M. Szleper, P. Zalewski

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

K. Bunkowski, A. Byszk³⁶, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Olszewski, M. Walczak

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

M. Araujo, P. Bargassa, D. Bastos, A. Di Francesco, P. Faccioli, B. Galinhas, M. Gallinaro, J. Hollar, N. Leonardo, T. Niknejad, J. Seixas, K. Shchelina, G. Strong, O. Toldaiev, J. Varela

Joint Institute for Nuclear Research, Dubna, Russia

S. Afanasiev, P. Bunin, Y. Ershov, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavine, V. Korenkov, A. Lanev, A. Malakhov, V. Matveev^{37,38}, V.V. Mitsyn, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, N. Skatchkov, B.S. Yuldashev³⁹, A. Zarubin, V. Zhiltsov

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

L. Chtchipounov, V. Golovtcov, Y. Ivanov, V. Kim⁴⁰, E. Kuznetsova⁴¹, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, D. Sosnov, V. Sulimov, L. Uvarov, A. Vorobyev

Institute for Nuclear Research, Moscow, Russia

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

Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC 'Kurchatov Institute', Moscow, Russia

V. Epshteyn, V. Gavrilov, N. Lychkovskaya, A. Nikitenko⁴², V. Popov, I. Pozdnyakov, G. Safronov, A. Spiridonov, A. Stepenov, M. Toms, E. Vlasov, A. Zhokin

Moscow Institute of Physics and Technology, Moscow, Russia

T. Aushev

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

O. Bychkova, R. Chistov⁴³, M. Danilov⁴³, S. Polikarpov⁴³, E. Tarkovskii

P.N. Lebedev Physical Institute, Moscow, Russia

V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Terkulov

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

A. Belyaev, E. Boos, A. Demijanov, A. Ershov, A. Gribushin, O. Kodolova, V. Korotkikh, I. Lokhtin, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev, I. Vardanyan

Novosibirsk State University (NSU), Novosibirsk, Russia

A. Barnyakov⁴⁴, V. Blinov⁴⁴, T. Dimova⁴⁴, L. Kardapol'tsev⁴⁴, Y. Skovpen⁴⁴

Institute for High Energy Physics of National Research Centre 'Kurchatov Institute', Protvino, Russia

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, D. Konstantinov, P. Mandrik, V. Petrov, R. Ryutin, S. Slabospitskii, A. Sobol, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

National Research Tomsk Polytechnic University, Tomsk, Russia

A. Babaev, A. Iuzhakov, V. Okhotnikov

Tomsk State University, Tomsk, Russia

V. Borchsh, V. Ivanchenko, E. Tcherniaev

University of Belgrade: Faculty of Physics and VINCA Institute of Nuclear Sciences, Belgrade, Serbia

P. Adzic⁴⁵, P. Cirkovic, M. Dordevic, P. Milenovic, J. Milosevic, M. Stojanovic

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

M. Aguilar-Benitez, J. Alcaraz Maestre, A. Álvarez Fernández, I. Bachiller, M. Barrio Luna, Cristina F. Bedoya, J.A. Brochero Cifuentes, C.A. Carrillo Montoya, M. Cepeda, M. Cerrada, N. Colino, B. De La Cruz, A. Delgado Peris, J.P. Fernández Ramos, J. Flix, M.C. Fouz, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, D. Moran, Á. Navarro Tobar, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, I. Redondo, L. Romero, S. Sánchez Navas, M.S. Soares, A. Triossi, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain

C. Albajar, J.F. de Trocóniz, R. Reyes-Almanza

Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain

B. Alvarez Gonzalez, J. Cuevas, C. Erice, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, E. Palencia Cortezon, C. Ramón Álvarez, V. Rodríguez Bouza, S. Sanchez Cruz

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

I.J. Cabrillo, A. Calderon, B. Chazin Quero, J. Duarte Campderros, M. Fernandez, P.J. Fernández Manteca, A. García Alonso, G. Gomez, C. Martinez Rivero, P. Martinez Ruiz del Arbol, F. Matorras, J. Piedra Gomez, C. Prieels, F. Ricci-Tam, T. Rodrigo, A. Ruiz-Jimeno, L. Russo⁴⁶, L. Scodellaro, I. Vila, J.M. Vizan Garcia

University of Colombo, Colombo, Sri Lanka

D.U.J. Sonnadara

University of Ruhuna, Department of Physics, Matara, Sri Lanka

W.G.D. Dharmaratna, N. Wickramage

CERN, European Organization for Nuclear Research, Geneva, Switzerland

T.K. Aarrestad, D. Abbaneo, B. Akgun, E. Auffray, G. Auzinger, J. Baechler, P. Baillon, A.H. Ball, D. Barney, J. Bendavid, M. Bianco, A. Bocci, P. Bortignon, E. Bossini, E. Brondolin, T. Camporesi, A. Caratelli, G. Cerminara, E. Chapon, G. Cucciati, D. d'Enterria, A. Dabrowski, N. Daci, V. Daponte, A. David, O. Davignon, A. De Roeck, M. Deile, R. Di Maria, M. Dobson, M. Dünser, N. Dupont, A. Elliott-Peisert, N. Emriskova, F. Fallavollita⁴⁷, D. Fasanella, S. Fiorendi, G. Franzoni, J. Fulcher, W. Funk, S. Giani, D. Gigi, K. Gill, F. Glege, L. Gouskos, M. Gruchala, M. Guilbaud, D. Gulhan, J. Hegeman, C. Heidegger, Y. Iiyama, V. Innocente, T. James, P. Janot, O. Karacheban²⁰, J. Kaspar, J. Kieseler, M. Krammer¹, N. Kratochwil, C. Lange, P. Lecoq, K. Long, C. Lourenço, L. Malgeri, M. Mannelli, A. Massironi, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, M. Mulders, J. Ngadiuba, J. Niedziela, S. Nourbakhsh, S. Orfanelli, L. Orsini, F. Pantaleo¹⁷, L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, F.M. Pitters, D. Rabady, A. Racz, M. Rieger, M. Rovere, H. Sakulin, J. Salfeld-Nebgen, S. Scarfi, C. Schäfer, C. Schwick, M. Selvaggi, A. Sharma, P. Silva, W. Snoeys, P. Sphicas⁴⁸, J. Steggemann, S. Summers, V.R. Tavolaro, D. Treille, A. Tsirou, G.P. Van Onsem, A. Vartak, M. Verzetti, K.A. Wozniak, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

L. Caminada⁴⁹, K. Deiters, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, D. Kotlinski, U. Langenegger, T. Rohe

ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland

M. Backhaus, P. Berger, A. Calandri, N. Chernyavskaya, G. Dissertori, M. Dittmar, M. Donegà, C. Dorfer, T.A. Gómez Espinosa, C. Grab, D. Hits, W. Lustermann, R.A. Manzoni, M.T. Meinhard, F. Micheli, P. Musella, F. Nessi-Tedaldi, F. Pauss, V. Perovic, G. Perrin, L. Perrozzi, S. Pigazzini, M.G. Ratti, M. Reichmann, C. Reissel, T. Reitenspiess, B. Ristic, D. Ruini, D.A. Sanz Becerra, M. Schönenberger, L. Shchutska, M.L. Vesterbacka Olsson, R. Wallny, D.H. Zhu

Universität Zürich, Zurich, Switzerland

C. Amsler⁵⁰, C. Botta, D. Brzhechko, M.F. Canelli, A. De Cosa, R. Del Burgo, B. Kilminster, S. Leontsinis, V.M. Mikuni, I. Neutelings, G. Rauco, P. Robmann, K. Schweiger, Y. Takahashi, S. Wertz

National Central University, Chung-Li, Taiwan

C.M. Kuo, W. Lin, A. Roy, T. Sarkar²⁹, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

P. Chang, Y. Chao, K.F. Chen, P.H. Chen, W.-S. Hou, Y.y. Li, R.-S. Lu, E. Paganis, A. Psallidas, A. Steen

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

B. Asavapibhop, C. Asawatangtrakuldee, N. Srimanobhas, N. Suwonjandee

Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey

A. Bat, F. Boran, A. Celik⁵¹, S. Damarseckin⁵², Z.S. Demiroglu, F. Dolek, C. Dozen⁵³, I. Dumanoglu⁵⁴, G. Gokbulut, Emine Gurpınar Guler⁵⁵, Y. Guler, I. Hos⁵⁶, C. Isik, E.E. Kangal⁵⁷, O. Kara, A. Kayis Topaksu, U. Kiminsu, G. Onengut, K. Ozdemir⁵⁸, A.E. Simsek, U.G. Tok, S. Turkcapar, I.S. Zorbakir, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey

B. Isildak⁵⁹, G. Karapınar⁶⁰, M. Yalvac⁶¹

Bogazici University, Istanbul, Turkey

I.O. Atakisi, E. Gülmez, M. Kaya⁶², O. Kaya⁶³, Ö. Özçelik, S. Tekten⁶⁴, E.A. Yetkin⁶⁵

Istanbul Technical University, Istanbul, Turkey

A. Cakir, K. Cankocak⁵⁴, Y. Komurcu, S. Sen⁶⁶

Istanbul University, Istanbul, Turkey

S. Cerci⁶⁷, B. Kaynak, S. Ozkorucuklu, D. Sunar Cerci⁶⁷

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

B. Grynyov

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

L. Levchuk

University of Bristol, Bristol, United Kingdom

E. Bhal, S. Bologna, J.J. Brooke, D. Burns⁶⁸, E. Clement, D. Cussans, H. Flacher, J. Goldstein, G.P. Heath, H.F. Heath, L. Kreczko, B. Krikler, S. Paramesvaran, T. Sakuma, S. Seif El Nasr-Storey, V.J. Smith, J. Taylor, A. Titterton

Rutherford Appleton Laboratory, Didcot, United Kingdom

K.W. Bell, A. Belyaev⁶⁹, C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Linacre, K. Manolopoulos, D.M. Newbold, E. Olaiya, D. Petyt, T. Reis, T. Schuh, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams

Imperial College, London, United Kingdom

R. Bainbridge, P. Bloch, S. Bonomally, J. Borg, S. Breeze, O. Buchmuller, A. Bundock, Gurpreet Singh CHAHAL⁷⁰, D. Colling, P. Dauncey, G. Davies, M. Della Negra, P. Everaerts, G. Hall, G. Iles, M. Komm, J. Langford, L. Lyons, A.-M. Magnan, S. Malik, A. Martelli, V. Milosevic, A. Morton, J. Nash⁷¹, V. Palladino, M. Pesaresi, D.M. Raymond, A. Richards, A. Rose, E. Scott, C. Seez, A. Shtipliyski, M. Stoye, T. Strebler, A. Tapper, K. Uchida, T. Virdee¹⁷, N. Wardle, S.N. Webb, D. Winterbottom, A.G. Zecchinelli, S.C. Zenz

Brunel University, Uxbridge, United Kingdom

J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, C.K. Mackay, I.D. Reid, L. Teodorescu, S. Zahid

Baylor University, Waco, USA

A. Brinkerhoff, K. Call, B. Caraway, J. Dittmann, K. Hatakeyama, C. Madrid, B. McMaster, N. Pastika, C. Smith

Catholic University of America, Washington, DC, USA

R. Bartek, A. Dominguez, R. Uniyal, A.M. Vargas Hernandez

The University of Alabama, Tuscaloosa, USA

A. Buccilli, S.I. Cooper, S.V. Gleyzer, C. Henderson, P. Rumerio, C. West

Boston University, Boston, USA

A. Albert, D. Arcaro, Z. Demiragli, D. Gastler, C. Richardson, J. Rohlf, D. Sperka, D. Spitzbart, I. Suarez, L. Sulak, D. Zou

Brown University, Providence, USA

G. Benelli, B. Burkle, X. Coubez¹⁸, D. Cutts, Y.t. Duh, M. Hadley, U. Heintz, J.M. Hogan⁷², K.H.M. Kwok, E. Laird, G. Landsberg, K.T. Lau, J. Lee, M. Narain, S. Sagir⁷³, R. Syarif, E. Usai, W.Y. Wong, D. Yu, W. Zhang

University of California, Davis, Davis, USA

R. Band, C. Brainerd, R. Breedon, M. Calderon De La Barca Sanchez, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, C. Flores, G. Funk, F. Jensen, W. Ko[†], O. Kukral, R. Lander, M. Mulhearn, D. Pellett, J. Pilot, M. Shi, D. Taylor, K. Tos, M. Tripathi, Z. Wang, F. Zhang

University of California, Los Angeles, USA

M. Bachtis, C. Bravo, R. Cousins, A. Dasgupta, A. Florent, J. Hauser, M. Ignatenko, N. Mccoll, W.A. Nash, S. Regnard, D. Saltzberg, C. Schnaible, B. Stone, V. Valuev

University of California, Riverside, Riverside, USA

K. Burt, Y. Chen, R. Clare, J.W. Gary, S.M.A. Ghiasi Shirazi, G. Hanson, G. Karapostoli, O.R. Long, N. Manganelli, M. Olmedo Negrete, M.I. Paneva, W. Si, S. Wimpenny, B.R. Yates, Y. Zhang

University of California, San Diego, La Jolla, USA

J.G. Branson, P. Chang, S. Cittolin, S. Cooperstein, N. Deelen, M. Derdzinski, J. Duarte, R. Gerosa, D. Gilbert, B. Hashemi, D. Klein, V. Krutelyov, J. Letts, M. Masciovecchio, S. May, S. Padhi, M. Pieri, V. Sharma, M. Tadel, F. Würthwein, A. Yagil, G. Zevi Della Porta

University of California, Santa Barbara - Department of Physics, Santa Barbara, USA

N. Amin, R. Bhandari, C. Campagnari, M. Citron, V. Dutta, J. Incandela, B. Marsh, H. Mei, A. Ovcharova, H. Qu, J. Richman, U. Sarica, D. Stuart, S. Wang

California Institute of Technology, Pasadena, USA

D. Anderson, A. Bornheim, O. Cerri, I. Dutta, J.M. Lawhorn, N. Lu, J. Mao, H.B. Newman, T.Q. Nguyen, J. Pata, M. Spiropulu, J.R. Vlimant, S. Xie, Z. Zhang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA

J. Alison, M.B. Andrews, T. Ferguson, T. Mudholkar, M. Paulini, M. Sun, I. Vorobiev, M. Weinberg

University of Colorado Boulder, Boulder, USA

J.P. Cumalat, W.T. Ford, E. MacDonald, T. Mulholland, R. Patel, A. Perloff, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, USA

J. Alexander, Y. Cheng, J. Chu, A. Datta, A. Frankenthal, K. Mcdermott, J.R. Patterson, D. Quach, A. Ryd, S.M. Tan, Z. Tao, J. Thom, P. Wittich, M. Zientek

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, M. Alyari, G. Apollinari, A. Apresyan, A. Apyan, S. Banerjee,

L.A.T. Bauerdick, A. Beretvas, D. Berry, J. Berryhill, P.C. Bhat, K. Burkett, J.N. Butler, A. Canepa, G.B. Cerati, H.W.K. Cheung, F. Chlebana, M. Cremonesi, V.D. Elvira, J. Freeman, Z. Gecse, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, J. Hanlon, R.M. Harris, S. Hasegawa, R. Heller, J. Hirschauer, B. Jayatilaka, S. Jindariani, M. Johnson, U. Joshi, T. Klijnsma, B. Klima, M.J. Kortelainen, B. Kreis, S. Lammel, J. Lewis, D. Lincoln, R. Lipton, M. Liu, T. Liu, J. Lykken, K. Maeshima, J.M. Marraffino, D. Mason, P. McBride, P. Merkel, S. Mrenna, S. Nahn, V. O'Dell, V. Papadimitriou, K. Pedro, C. Pena⁷⁴, F. Ravera, A. Reinsvold Hall, L. Ristori, B. Schneider, E. Sexton-Kennedy, N. Smith, A. Soha, W.J. Spalding, L. Spiegel, S. Stoynev, J. Strait, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, M. Wang, H.A. Weber, A. Woodard

University of Florida, Gainesville, USA

D. Acosta, P. Avery, D. Bourilkov, L. Cadamuro, V. Cherepanov, F. Errico, R.D. Field, D. Guerrero, B.M. Joshi, M. Kim, J. Konigsberg, A. Korytov, K.H. Lo, K. Matchev, N. Menendez, G. Mitselmakher, D. Rosenzweig, K. Shi, J. Wang, S. Wang, X. Zuo

Florida International University, Miami, USA

Y.R. Joshi

Florida State University, Tallahassee, USA

T. Adams, A. Askew, S. Hagopian, V. Hagopian, K.F. Johnson, R. Khurana, T. Kolberg, G. Martinez, T. Perry, H. Prosper, C. Schiber, R. Yohay, J. Zhang

Florida Institute of Technology, Melbourne, USA

M.M. Baarmand, M. Hohlmann, D. Noonan, M. Rahmani, M. Saunders, F. Yumiceva

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

M.R. Adams, L. Apanasevich, R.R. Betts, R. Cavanaugh, X. Chen, S. Dittmer, O. Evdokimov, C.E. Gerber, D.A. Hangal, D.J. Hofman, V. Kumar, C. Mills, G. Oh, T. Roy, M.B. Tonjes, N. Varelas, J. Viinikainen, H. Wang, X. Wang, Z. Wu

The University of Iowa, Iowa City, USA

M. Alhusseini, B. Bilki⁵⁵, K. Dilsiz⁷⁵, S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, O.K. Köseyan, J.-P. Merlo, A. Mestvirishvili⁷⁶, A. Moeller, J. Nachtman, H. Ogul⁷⁷, Y. Onel, F. Ozok⁷⁸, A. Penzo, C. Snyder, E. Tiras, J. Wetzel, K. Yi⁷⁹

Johns Hopkins University, Baltimore, USA

B. Blumenfeld, A. Cocoros, N. Eminizer, A.V. Gritsan, W.T. Hung, S. Kyriacou, P. Maksimovic, C. Mantilla, J. Roskes, M. Swartz, T.Á. Vámi

The University of Kansas, Lawrence, USA

C. Baldenegro Barrera, P. Baringer, A. Bean, S. Boren, A. Bylinkin, T. Isidori, S. Khalil, J. King, G. Krintras, A. Kropivnitskaya, C. Lindsey, D. Majumder, W. Mcbrayer, N. Minafra, M. Murray, C. Rogan, C. Royon, S. Sanders, E. Schmitz, J.D. Tapia Takaki, Q. Wang, J. Williams, G. Wilson

Kansas State University, Manhattan, USA

S. Duric, A. Ivanov, K. Kaadze, D. Kim, Y. Maravin, D.R. Mendis, T. Mitchell, A. Modak, A. Mohammadi

Lawrence Livermore National Laboratory, Livermore, USA

F. Rebassoo, D. Wright

University of Maryland, College Park, USA

A. Baden, O. Baron, A. Belloni, S.C. Eno, Y. Feng, N.J. Hadley, S. Jabeen, G.Y. Jeng, R.G. Kellogg, A.C. Mignerey, S. Nabili, M. Seidel, A. Skuja, S.C. Tonwar, L. Wang, K. Wong

Massachusetts Institute of Technology, Cambridge, USA

D. Abercrombie, B. Allen, R. Bi, S. Brandt, W. Busza, I.A. Cali, M. D'Alfonso, G. Gomez Ceballos, M. Goncharov, P. Harris, D. Hsu, M. Hu, M. Klute, D. Kovalskyi, Y.-J. Lee, P.D. Luckey, B. Maier, A.C. Marini, C. McGinn, C. Mironov, S. Narayanan, X. Niu, C. Paus, D. Rankin, C. Roland, G. Roland, Z. Shi, G.S.F. Stephans, K. Sumorok, K. Tatar, D. Velicanu, J. Wang, T.W. Wang, B. Wyslouch

University of Minnesota, Minneapolis, USA

R.M. Chatterjee, A. Evans, S. Guts[†], P. Hansen, J. Hiltbrand, Sh. Jain, Y. Kubota, Z. Lesko, J. Mans, M. Revering, R. Rusack, R. Saradhy, N. Schroeder, N. Strobbe, M.A. Wadud

University of Mississippi, Oxford, USA

J.G. Acosta, S. Oliveros

University of Nebraska-Lincoln, Lincoln, USA

K. Bloom, S. Chauhan, D.R. Claes, C. Fangmeier, L. Finco, F. Golf, R. Kamalieddin, I. Kravchenko, J.E. Siado, G.R. Snow[†], B. Stieger, W. Tabb

State University of New York at Buffalo, Buffalo, USA

G. Agarwal, C. Harrington, I. Iashvili, A. Kharchilava, C. McLean, D. Nguyen, A. Parker, J. Pekkanen, S. Rappoccio, B. Roozbahani

Northeastern University, Boston, USA

G. Alverson, E. Barberis, C. Freer, Y. Haddad, A. Hortiangtham, G. Madigan, B. Marzocchi, D.M. Morse, V. Nguyen, T. Orimoto, L. Skinnari, A. Tishelman-Charny, T. Wamorkar, B. Wang, A. Wisecarver, D. Wood

Northwestern University, Evanston, USA

S. Bhattacharya, J. Bueghly, G. Fedi, A. Gilbert, T. Gunter, K.A. Hahn, N. Odell, M.H. Schmitt, K. Sung, M. Velasco

University of Notre Dame, Notre Dame, USA

R. Bucci, N. Dev, R. Goldouzian, M. Hildreth, K. Hurtado Anampa, C. Jessop, D.J. Karmgard, K. Lannon, W. Li, N. Loukas, N. Marinelli, I. Mcalister, F. Meng, Y. Musienko³⁷, R. Ruchti, P. Siddireddy, G. Smith, S. Taroni, M. Wayne, A. Wightman, M. Wolf

The Ohio State University, Columbus, USA

J. Alimena, B. Bylsma, B. Cardwell, L.S. Durkin, B. Francis, C. Hill, W. Ji, A. Lefeld, T.Y. Ling, B.L. Winer

Princeton University, Princeton, USA

G. Dezoort, P. Elmer, J. Hardenbrook, N. Haubrich, S. Higginbotham, A. Kalogeropoulos, S. Kwan, D. Lange, M.T. Lucchini, J. Luo, D. Marlow, K. Mei, I. Ojalvo, J. Olsen, C. Palmer, P. Piroué, D. Stickland, C. Tully

University of Puerto Rico, Mayaguez, USA

S. Malik, S. Norberg

Purdue University, West Lafayette, USA

A. Barker, V.E. Barnes, R. Chawla, S. Das, L. Gutay, M. Jones, A.W. Jung, B. Mahakud, D.H. Miller, G. Negro, N. Neumeister, C.C. Peng, S. Piperov, H. Qiu, J.F. Schulte, N. Trevisani, F. Wang, R. Xiao, W. Xie

Purdue University Northwest, Hammond, USA

T. Cheng, J. Dolen, N. Parashar

Rice University, Houston, USA

A. Baty, U. Behrens, S. Dildick, K.M. Ecklund, S. Freed, F.J.M. Geurts, M. Kilpatrick, Arun Kumar, W. Li, B.P. Padley, R. Redjimi, J. Roberts, J. Rorie, W. Shi, A.G. Stahl Leiton, Z. Tu, A. Zhang

University of Rochester, Rochester, USA

A. Bodek, P. de Barbaro, R. Demina, J.L. Dulemba, C. Fallon, T. Ferbel, M. Galanti, A. Garcia-Bellido, O. Hindrichs, A. Khukhunaishvili, E. Ranken, R. Taus

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

B. Chiarito, J.P. Chou, A. Gandrakota, Y. Gershtein, E. Halkiadakis, A. Hart, M. Heindl, E. Hughes, S. Kaplan, I. Laflotte, A. Lath, R. Montalvo, K. Nash, M. Osherson, S. Salur, S. Schnetzer, S. Somalwar, R. Stone, S. Thomas

University of Tennessee, Knoxville, USA

H. Acharya, A.G. Delannoy, S. Spanier

Texas A&M University, College Station, USA

O. Bouhali⁸⁰, M. Dalchenko, M. De Mattia, A. Delgado, R. Eusebi, J. Gilmore, T. Huang, T. Kamon⁸¹, H. Kim, S. Luo, S. Malhotra, D. Marley, R. Mueller, D. Overton, L. Perniè, D. Rathjens, A. Safonov

Texas Tech University, Lubbock, USA

N. Akchurin, J. Damgov, F. De Guio, V. Hegde, S. Kunori, K. Lamichhane, S.W. Lee, T. Mengke, S. Muthumuni, T. Peltola, S. Undleeb, I. Volobouev, Z. Wang, A. Whitbeck

Vanderbilt University, Nashville, USA

S. Greene, A. Gurrola, R. Janjam, W. Johns, C. Maguire, A. Melo, H. Ni, K. Padeken, F. Romeo, P. Sheldon, S. Tuo, J. Velkovska, M. Verweij

University of Virginia, Charlottesville, USA

M.W. Arenton, P. Barria, B. Cox, G. Cummings, J. Hakala, R. Hirosky, M. Joyce, A. Ledovskoy, C. Neu, B. Tannenwald, Y. Wang, E. Wolfe, F. Xia

Wayne State University, Detroit, USA

R. Harr, P.E. Karchin, N. Poudyal, J. Sturdy, P. Thapa

University of Wisconsin - Madison, Madison, WI, USA

K. Black, T. Bose, J. Buchanan, C. Caillol, D. Carlsmith, S. Dasu, I. De Bruyn, L. Dodd, C. Galloni, H. He, M. Herndon, A. Hervé, U. Hussain, A. Lanaro, A. Loeliger, R. Loveless, J. Madhusudan Sreekala, A. Mallampalli, D. Pinna, T. Ruggles, A. Savin, V. Sharma, W.H. Smith, D. Teague, S. Trembath-reichert

†: Deceased

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

2: Also at Université Libre de Bruxelles, Bruxelles, Belgium

3: Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France

4: Also at Universidade Estadual de Campinas, Campinas, Brazil

5: Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil

6: Also at UFMS, Nova Andradina, Brazil

7: Also at Universidade Federal de Pelotas, Pelotas, Brazil

8: Also at University of Chinese Academy of Sciences, Beijing, China

9: Also at Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC 'Kurchatov Institute', Moscow, Russia

- 10: Also at Joint Institute for Nuclear Research, Dubna, Russia
- 11: Also at Fayoum University, El-Fayoum, Egypt
- 12: Now at British University in Egypt, Cairo, Egypt
- 13: Also at Purdue University, West Lafayette, USA
- 14: Also at Université de Haute Alsace, Mulhouse, France
- 15: Also at Tbilisi State University, Tbilisi, Georgia
- 16: Also at Erzincan Binali Yildirim University, Erzincan, Turkey
- 17: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
- 18: Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
- 19: Also at University of Hamburg, Hamburg, Germany
- 20: Also at Brandenburg University of Technology, Cottbus, Germany
- 21: Also at Institute of Physics, University of Debrecen, Debrecen, Hungary, Debrecen, Hungary
- 22: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- 23: Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary, Budapest, Hungary
- 24: Also at IIT Bhubaneswar, Bhubaneswar, India, Bhubaneswar, India
- 25: Also at Institute of Physics, Bhubaneswar, India
- 26: Also at G.H.G. Khalsa College, Punjab, India
- 27: Also at Shoolini University, Solan, India
- 28: Also at University of Hyderabad, Hyderabad, India
- 29: Also at University of Visva-Bharati, Santiniketan, India
- 30: Now at INFN Sezione di Bari ^a, Università di Bari ^b, Politecnico di Bari ^c, Bari, Italy
- 31: Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy
- 32: Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy
- 33: Also at Riga Technical University, Riga, Latvia, Riga, Latvia
- 34: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia
- 35: Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico
- 36: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
- 37: Also at Institute for Nuclear Research, Moscow, Russia
- 38: Now at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
- 39: Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan
- 40: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
- 41: Also at University of Florida, Gainesville, USA
- 42: Also at Imperial College, London, United Kingdom
- 43: Also at P.N. Lebedev Physical Institute, Moscow, Russia
- 44: Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia
- 45: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
- 46: Also at Università degli Studi di Siena, Siena, Italy, Siena, Italy
- 47: Also at INFN Sezione di Pavia ^a, Università di Pavia ^b, Pavia, Italy, Pavia, Italy
- 48: Also at National and Kapodistrian University of Athens, Athens, Greece
- 49: Also at Universität Zürich, Zurich, Switzerland
- 50: Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria, Vienna, Austria
- 51: Also at Burdur Mehmet Akif Ersoy University, BURDUR, Turkey
- 52: Also at Şırnak University, Sirnak, Turkey
- 53: Also at Department of Physics, Tsinghua University, Beijing, China, Beijing, China

-
- 54: Also at Near East University, Research Center of Experimental Health Science, Nicosia, Turkey
- 55: Also at Beykent University, Istanbul, Turkey, Istanbul, Turkey
- 56: Also at Istanbul Aydin University, Application and Research Center for Advanced Studies (App. & Res. Cent. for Advanced Studies), Istanbul, Turkey
- 57: Also at Mersin University, Mersin, Turkey
- 58: Also at Piri Reis University, Istanbul, Turkey
- 59: Also at Ozyegin University, Istanbul, Turkey
- 60: Also at Izmir Institute of Technology, Izmir, Turkey
- 61: Also at Bozok Universitetesi Rektörlüğü, Yozgat, Turkey, Yozgat, Turkey
- 62: Also at Marmara University, Istanbul, Turkey
- 63: Also at Milli Savunma University, Istanbul, Turkey
- 64: Also at Kafkas University, Kars, Turkey
- 65: Also at Istanbul Bilgi University, Istanbul, Turkey
- 66: Also at Hacettepe University, Ankara, Turkey
- 67: Also at Adiyaman University, Adiyaman, Turkey
- 68: Also at Vrije Universiteit Brussel, Brussel, Belgium
- 69: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
- 70: Also at IPPP Durham University, Durham, United Kingdom
- 71: Also at Monash University, Faculty of Science, Clayton, Australia
- 72: Also at Bethel University, St. Paul, Minneapolis, USA, St. Paul, USA
- 73: Also at Karamanoğlu Mehmetbey University, Karaman, Turkey
- 74: Also at California Institute of Technology, Pasadena, USA
- 75: Also at Bingol University, Bingol, Turkey
- 76: Also at Georgian Technical University, Tbilisi, Georgia
- 77: Also at Sinop University, Sinop, Turkey
- 78: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
- 79: Also at Nanjing Normal University Department of Physics, Nanjing, China
- 80: Also at Texas A&M University at Qatar, Doha, Qatar
- 81: Also at Kyungpook National University, Daegu, Korea, Daegu, Korea