

CERN-PH-EP/2013-037
2015/05/19

CMS-BPH-14-001

Measurement of prompt J/ψ and $\psi(2S)$ double-differential cross sections in pp collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration*

Abstract

The double-differential cross sections of promptly produced J/ψ and $\psi(2S)$ mesons are measured in pp collisions at $\sqrt{s} = 7$ TeV, as a function of transverse momentum p_T and absolute rapidity $|y|$. The analysis uses J/ψ and $\psi(2S)$ dimuon samples collected by the CMS experiment, corresponding to integrated luminosities of 4.55 and 4.90 fb⁻¹, respectively. The results are based on a two-dimensional analysis of the dimuon invariant mass and decay length, and extend to $p_T = 120$ and 100 GeV for the J/ψ and $\psi(2S)$, respectively, when integrated over the interval $|y| < 1.2$. The ratio of the $\psi(2S)$ to J/ψ cross sections is also reported for $|y| < 1.2$, over the range $10 < p_T < 100$ GeV. These are the highest p_T values for which the cross sections and ratio have been measured.

Published in Physical Review Letters as doi:10.1103/PhysRevLett.114.191802.

Studies of heavy-quarkonium production are of central importance for an improved understanding of nonperturbative quantum chromodynamics (QCD) [1]. The nonrelativistic QCD (NRQCD) effective-field-theory framework [2], arguably the best formalism at this time, factorizes high- p_T quarkonium production in short-distance and long-distance scales. First a heavy quark-antiquark pair, $Q\bar{Q}$, is produced in a Fock state $^{2S+1}L_J^{[a]}$, with spin S , orbital angular momentum L , and total angular momentum J that are either identical to (color singlet, $a = 1$) or different from (color octet, $a = 8$) those of the corresponding quarkonium state. The $Q\bar{Q}$ cross sections are determined by short-distance coefficients (SDC), kinematic-dependent functions calculable perturbatively as expansions in the strong-coupling constant α_s . Then this “preresonant” $Q\bar{Q}$ pair binds into the physically observable quarkonium through a nonperturbative evolution that may change L and S , with bound-state formation probabilities proportional to long-distance matrix elements (LDME). The LDMEs are conjectured to be constant (i.e., independent of the $Q\bar{Q}$ momentum) and universal (i.e., process independent). The color-octet terms are expected to scale with powers of the heavy-quark velocity in the $Q\bar{Q}$ rest frame. In the nonrelativistic limit, an S -wave vector quarkonium state should be formed from a $Q\bar{Q}$ pair produced as a color singlet ($^3S_1^{[1]}$) or as one of three color octets ($^1S_0^{[8]}$, $^3S_1^{[8]}$, and $^3P_J^{[8]}$).

Three “global fits” to measured quarkonium data [3–5] obtained incompatible octet LDMEs, despite the use of essentially identical theory inputs: next-to-leading-order (NLO) QCD calculations of the singlet and octet SDCs. The disagreement stems from the fact that different sets of measurements were considered. In particular, the results crucially depend on the minimum p_T of the fitted measurements [6], because the octet SDCs have different p_T dependences. Fits including low- p_T cross sections lead to the conclusion that, at high p_T , quarkonium production should be dominated by transversely polarized octet terms. This prediction is in stark contradiction with the unpolarized production seen by the CDF [7, 8] and CMS [9, 10] experiments, an observation known as the “quarkonium polarization puzzle”. As shown in Ref. [6], the puzzle is seemingly solved by restricting the NRQCD global fits to high- p_T quarkonia, indicating that the presently available fixed-order calculations provide SDCs unable to reproduce reality at lower p_T values or that NRQCD factorization only holds for p_T values much larger than the quarkonium mass. The polarization measurements add a crucial dimension to the global fits because the various channels have remarkably distinct polarization properties: in the helicity frame, $^3S_1^{[1]}$ is longitudinally polarized, $^1S_0^{[8]}$ is unpolarized, $^3S_1^{[8]}$ is transversely polarized, and $^3P_J^{[8]}$ has a polarization that changes significantly with p_T . Bottomonium and prompt charmonium polarizations reaching or exceeding $p_T = 50$ GeV were measured by CMS [9, 10], using a very robust analysis framework [11, 12], on the basis of event samples collected in 2011. Instead, the differential charmonium cross sections published by CMS [13] are based on data collected in 2010 and have a much lower p_T reach. Measurements of prompt charmonium cross sections extending well beyond $p_T = 50$ GeV will trigger improved NRQCD global fits, restricted to a kinematic domain where the factorization formalism is unquestioned, and will provide more accurate and reliable LDMEs.

This Letter presents measurements of the double-differential cross sections of J/ψ and $\psi(2S)$ mesons promptly produced in pp collisions at a center-of-mass energy of 7 TeV, based on dimuon event samples collected by CMS in 2011. They complement other prompt charmonium cross sections measured at the LHC, by ATLAS [14, 15], LHCb [16, 17], and ALICE [18]. The analysis is made in four bins of absolute rapidity ($|y| < 0.3$, $0.3 < |y| < 0.6$, $0.6 < |y| < 0.9$, and $0.9 < |y| < 1.2$) and in the p_T ranges 10–95 GeV for the J/ψ and 10–75 GeV for the $\psi(2S)$. A rapidity-integrated result in the range $|y| < 1.2$ is also provided, extending the p_T reach to 120 GeV for the J/ψ and 100 GeV for the $\psi(2S)$. The corresponding $\psi(2S)$ over J/ψ cross section

ratios are also reported. The dimuon invariant mass distribution is used to separate the J/ψ and $\psi(2S)$ signals from other processes, mostly pairs of uncorrelated muons, while the dimuon decay length is used to separate the nonprompt charmonia, coming from decays of b hadrons, from the prompt component. Feed-down from decays of heavier charmonium states, approximately 33% of the prompt J/ψ cross section [19], is not distinguished from the directly produced charmonia.

The CMS apparatus is based on a superconducting solenoid of 6 m internal diameter, providing a 3.8 T field. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter. Muons are measured with three kinds of gas-ionization detectors: drift tubes, cathode strip chambers, and resistive-plate chambers. The main subdetectors used in this analysis are the silicon tracker and the muon system, which enable the measurement of muon momenta over the pseudorapidity range $|\eta| < 2.4$. 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 Ref. [20].

The events were collected using a two-level trigger system. The first level, made of custom hardware processors, uses data from the muon system to select events with two muon candidates. The high-level trigger, adding information from the silicon tracker, reduces the rate of stored events by requiring an opposite-sign muon pair of invariant mass $2.8 < M < 3.35$ GeV, $p_T > 9.9$ GeV, and $|y| < 1.25$ for the J/ψ trigger, and $3.35 < M < 4.05$ GeV and $p_T > 6.9$ GeV for the $\psi(2S)$ trigger. No p_T requirement is imposed on the single muons at trigger level. Both triggers require a dimuon vertex fit χ^2 probability greater than 0.5% and a distance of closest approach between the two muons less than 5 mm. Events where the muons bend towards each other in the magnetic field are rejected to lower the trigger rate while retaining the highest-quality dimuons. The J/ψ and $\psi(2S)$ analyses are conducted independently, using event samples separated at the trigger level. The $\psi(2S)$ sample corresponds to an integrated luminosity of 4.90 fb^{-1} , while the J/ψ sample has a reduced value, 4.55 fb^{-1} , because the p_T threshold of the J/ψ trigger was raised to 12.9 GeV in a fraction of the data-taking period; the integrated luminosities have an uncertainty of 2.2% [21].

The muon tracks are required to have hits in at least eleven tracker layers, with at least two in the silicon pixel detector, and to be matched with at least one segment in the muon system. They must have a good track fit quality (χ^2 per degree of freedom smaller than 1.8) and point to the interaction region. The selected muons must also match in pseudorapidity and azimuthal angle with the muon objects responsible for triggering the event. The analysis is restricted to muons produced within a fiducial phase-space window where the muon detection efficiencies are accurately measured: $p_T > 4.5$, 3.5, and 3.0 GeV for the regions $|\eta| < 1.2$, $1.2 < |\eta| < 1.4$, and $1.4 < |\eta| < 1.6$, respectively. The combinatorial dimuon background is reduced by requiring a dimuon vertex fit χ^2 probability larger than 1%. After applying the event selection criteria, the combined yields of prompt and nonprompt charmonia in the range $|y| < 1.2$ are 5.45 M for the J/ψ and 266 k for the $\psi(2S)$. The prompt charmonia are separated from those resulting from decays of b hadrons through the use of the dimuon pseudo-proper decay length [22], $\ell = L_{xy} M / p_T$, where L_{xy} is the transverse decay length in the laboratory frame, measured after removing the two muon tracks from the calculation of the primary vertex position. For events with multiple collision vertices, L_{xy} is calculated with respect to the vertex closest to the direction of the dimuon momentum, extrapolated towards the beam line.

For each $(|y|, p_T)$ bin, the prompt charmonium yields are evaluated through an extended unbinned maximum-likelihood fit to the two-dimensional (M, ℓ) event distribution. In the mass dimension, the shape of each signal peak is represented by a Crystal Ball (CB) function [23],

with free mean (μ_{CB}) and width (σ_{CB}) parameters. Given the strong correlation between the two CB tail parameters, α_{CB} and n_{CB} , they are fixed to values evaluated from fits to event samples integrated in broader p_T ranges. A single CB function provides a good description of the signal mass peaks, given that the dimuon mass distributions are studied in narrow ($|y|, p_T$) bins, within which the dimuon invariant mass resolution has a negligible variation. The mass distribution of the underlying continuum background is described by an exponential function. Concerning the pseudo-proper decay length variable, the prompt signal component is modeled by a resolution function, which exploits the per-event uncertainty information provided by the vertex reconstruction algorithm, while the nonprompt charmonium term is modeled by an exponential function convolved with the resolution function. The continuum background component is represented by a sum of prompt and nonprompt empirical forms. The distributions are well described with a relatively small number of free parameters.

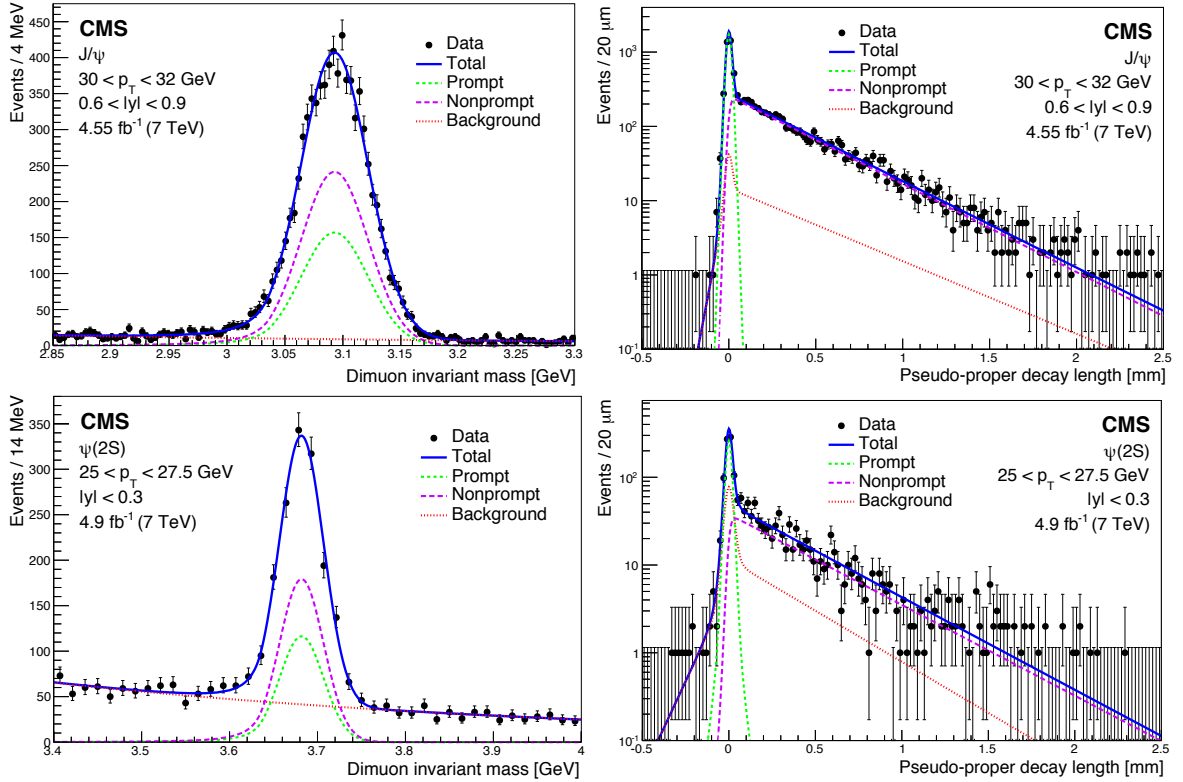


Figure 1: Projections on the dimuon invariant mass (left) and pseudo-proper decay length (right) axes, for the J/ψ (top) and $\psi(2S)$ (bottom) events in the kinematic bins given in the plots. The right panels show dimuons of invariant mass within $\pm 3\sigma_{CB}$ of the pole masses. The curves, identified in the legends, represent the result of the fits described in the text. The vertical bars on the data points show the statistical uncertainties.

Figure 1 shows the J/ψ and $\psi(2S)$ dimuon invariant mass and pseudo-proper decay length projections for two representative ($|y|, p_T$) bins. The decay length projections are shown for events with dimuon invariant mass within $\pm 3\sigma_{CB}$ of the pole mass. In the highest p_T bins, where the number of dimuons is relatively small, stable results are obtained by fixing μ_{CB} and the slope of the exponential-like function describing the nonprompt combinatorial background to values extrapolated from the trend found from the lower- p_T bins. The systematic uncertainties in the signal yields are evaluated by repeating the fit with different functional forms, varying the values of the fixed parameters, and allowing for more free parameters in the fit. The fit results are robust with respect to changes in the procedure; the corresponding systematic uncertainties are

negligible at low p_T and increase to $\approx 2\%$ for the J/ψ and $\approx 6\%$ for the $\psi(2S)$ in the highest p_T bins.

The single-muon detection efficiencies ϵ_μ are measured with a “tag-and-probe” (T&P) technique [24], using event samples collected with triggers specifically designed for this purpose, including a sample enriched in dimuons from J/ψ decays where a muon is combined with another track and the pair is required to have an invariant mass within the range 2.8–3.4 GeV. The procedure was validated in the phase-space window of the analysis with detailed Monte Carlo (MC) simulation studies. The measured efficiencies are parametrized as a function of muon p_T , in eight bins of muon $|\eta|$. Their uncertainties, reflecting the statistical precision of the T&P samples and possible imperfections of the parametrization, are $\approx 2\text{--}3\%$. The efficiency of the dimuon vertex fit χ^2 probability requirement is also measured with the T&P approach, using a sample of events collected with a dedicated (prescaled) trigger. It is around 95–97%, improving with increasing p_T , with a 2% systematic uncertainty. At high p_T , when the two muons might be emitted relatively close to each other, the efficiency of the dimuon trigger $\epsilon_{\mu\mu}$ is smaller than the product of the two single-muon efficiencies [13], $\epsilon_{\mu\mu} = \epsilon_{\mu_1} \epsilon_{\mu_2} \rho$. The correction factor ρ is evaluated with MC simulations, validated from data collected with single-muon triggers. For $p_T < 35$ GeV, ρ is consistent with being unity, within a systematic uncertainty estimated as 2%, except in the $0.9 < |y| < 1.2$ bin, where the uncertainty increases to 4.3% for the J/ψ if $p_T < 12$ GeV, and to 2.7% for the $\psi(2S)$ if $p_T < 11$ GeV. For $p_T > 35$ GeV, ρ decreases approximately linearly with p_T , reaching 60–70% for $p_T \sim 85$ GeV, with systematic uncertainties evaluated by comparing the MC simulation results with estimations made using data collected with single-muon triggers: 5% up to $p_T = 50$ (55) GeV for the J/ψ ($\psi(2S)$) and 10% for higher p_T . The total dimuon detection efficiency increases from $\epsilon_{\mu\mu} \approx 78\%$ at $p_T = 15$ GeV to $\approx 85\%$ at 30 GeV, and then decreases to $\approx 65\%$ at 80 GeV.

To obtain the charmonium cross sections in each $(|y|, p_T)$ bin without any restrictions on the kinematic variables of the two muons, we correct for the corresponding dimuon acceptance, defined as the fraction of dimuon decays having both muons emitted within the single-muon fiducial phase space. These acceptances are calculated using a detailed MC simulation of the CMS experiment. Charmonia are generated using a flat rapidity distribution and p_T distributions based on previous measurements [13]; using flat p_T distributions leads to negligible changes. The particles are decayed by EVTGEN [25] interfaced to PYTHIA 6.4 [26], while PHOTOS [27] is used to simulate final-state radiation. The fractions of J/ψ and $\psi(2S)$ dimuon events in a given $(|y|, p_T)$ bin with both muons surviving the fiducial selections depend on the decay kinematics and, in particular, on the polarization of the mother particle. Acceptances are calculated using polarization scenarios corresponding to different values of the polar anisotropy parameter in the helicity frame, $\lambda_\theta^{\text{HX}}$: 0 (unpolarized), +1 (transverse), and -1 (longitudinal). A fourth scenario, corresponding to $\lambda_\theta^{\text{HX}} = +0.10$ for the J/ψ and $+0.03$ for the $\psi(2S)$, reflects the results published by CMS [10]. The two other parameters characterizing the dimuon angular distributions [28], λ_ϕ and $\lambda_{\theta\phi}$, have been measured to be essentially zero [10] and have a negligible influence on the acceptance. The acceptances are essentially identical for the two charmonia and are almost rapidity independent for $|y| < 1.2$. The two-dimensional acceptance maps are calculated with large MC simulation samples, so that statistical fluctuations are small, and in narrow $|y|$ bins, so that variations within the bins can be neglected. Since the efficiencies and acceptances are evaluated for events where the two muons bend away from each other, a factor of two is applied to obtain the final cross sections.

The double-differential cross sections of promptly produced J/ψ and $\psi(2S)$ in the dimuon channel, $\mathcal{B} d^2\sigma/dp_T dy$, where $\mathcal{B}$ is the J/ψ or $\psi(2S)$ dimuon branching fraction, is obtained by dividing the fitted prompt-signal yields, already corrected on an event-by-event basis for efficien-

cies and acceptance, by the integrated luminosity and the widths of the p_T and $|y|$ bins. The numerical values, including the relative statistical and systematic uncertainties, are reported for both charmonia, five rapidity intervals, and four polarization scenarios in Tables A.1–A.4 of Appendix A. Figure 2 shows the results obtained in the unpolarized scenario. With respect to the $|y| < 0.3$ bin, the cross sections drop by $\approx 5\%$ for $0.6 < |y| < 0.9$ and $\approx 15\%$ for $0.9 < |y| < 1.2$. Measuring the charmonium production cross sections in the broader rapidity range $|y| < 1.2$ has the advantage that the increased statistical accuracy allows the measurement to be extended to higher- p_T values, where comparisons with theoretical calculations are particularly informative. Figure 3 compares the rapidity-integrated (unpolarized) cross sections, after rescaling with the branching fraction $\mathcal{B}$ of the dimuon decay channels [29], with results reported by ATLAS [14, 15]. The curve represents a fit of the J/ψ cross section measured in this analysis to a power-law function [30]. The band labelled FKLSW represents the result of a global fit [6] comparing SDCs calculated at NLO [3] with $\psi(2S)$ cross sections and polarizations previously reported by CMS [10, 13] and LHCb [17]. According to that fit, $\psi(2S)$ mesons are produced predominantly unpolarized. At high p_T , the values reported in this Letter tend to be higher than the band, which is essentially determined from results for $p_T < 30$ GeV.

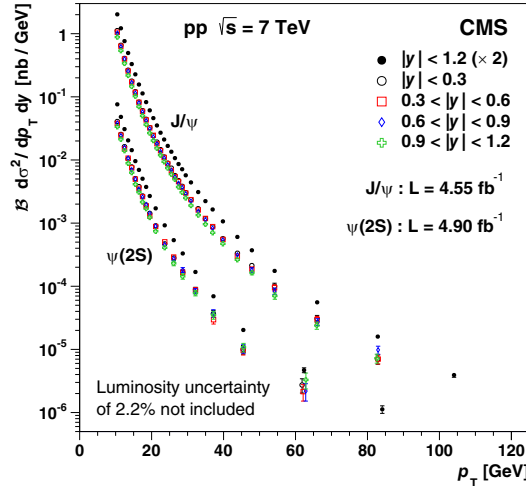


Figure 2: The J/ψ and $\psi(2S)$ differential p_T cross sections times the dimuon branching fractions for four rapidity bins and integrated over the range $|y| < 1.2$ (scaled up by a factor of 2 for presentation purposes), assuming the unpolarized scenario. The vertical bars show the statistical and systematic uncertainties added in quadrature.

The ratio of the $\psi(2S)$ to J/ψ differential cross sections is also measured in the $|y| < 1.2$ range, recomputing the J/ψ values in the p_T bins of the $\psi(2S)$ analysis. The measured values are reported in Table A.5 of Appendix A. The corrections owing to the integrated luminosity, acceptances, and efficiencies cancel to a large extent in the measurement of the ratio. The total systematic uncertainty, dominated by the ρ correction for $p_T > 30$ GeV and by the acceptance and efficiency corrections for $p_T < 20$ GeV, does not exceed 3%, except for $p_T > 75$ GeV, where it reaches 5%. Larger event samples are needed to clarify the trend of the ratio for p_T above ≈ 35 GeV.

In summary, the double-differential cross sections of the J/ψ and $\psi(2S)$ mesons promptly produced in pp collisions at $\sqrt{s} = 7$ TeV have been measured as a function of p_T in four $|y|$ bins, as well as integrated over the $|y| < 1.2$ range, extending up to or beyond $p_T = 100$ GeV. New global fits of cross sections and polarizations, including these high- p_T measurements, will probe the theoretical calculations in a kinematical region where NRQCD factorization is

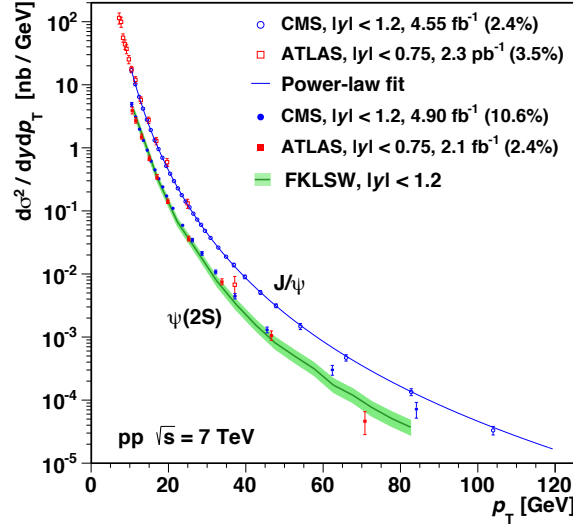


Figure 3: The J/ψ (open symbols) and $\psi(2S)$ (closed symbols) differential (unpolarized) cross sections from this analysis (circles) and from ATLAS (squares) [14, 15]. The vertical bars show the statistical and systematic uncertainties added in quadrature, not including the uncertainties from integrated luminosities and branching fractions, which are indicated by the percentages given in the legend. The curve shows a fit of the J/ψ cross section measured in this analysis to a power-law function, while the band labelled FKLSW represents a calculation of the $\psi(2S)$ cross section using LDMEs determined with lower- p_T LHC data [6].

believed to be most reliable. The new data should also provide input to stringent tests of recent theory developments, such as those described in Refs. [31–33].

Acknowledgments

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

References

- [1] N. Brambilla et al., “Heavy quarkonium: progress, puzzles, and opportunities”, *Eur. Phys. J. C* **71** (2011) 1534, doi:10.1140/epjc/s10052-010-1534-9, arXiv:1010.5827.
- [2] G. T. Bodwin, E. Braaten, and G. P. Lepage, “Rigorous QCD analysis of inclusive annihilation and production of heavy quarkonium”, *Phys. Rev. D* **51** (1995) 1125, doi:10.1103/PhysRevD.51.1125, arXiv:hep-ph/9407339.
- [3] M. Butenschoen and B. A. Kniehl, “ J/ψ Polarization at Tevatron and the LHC: Nonrelativistic-QCD Factorization at the Crossroads”, *Phys. Rev. Lett.* **108** (2012) 172002, doi:10.1103/PhysRevLett.108.172002, arXiv:1201.1872.
- [4] B. Gong, L.-P. Wan, J.-X. Wang, and H.-F. Zhang, “Polarization for Prompt J/ψ , $\psi(2S)$ Production at the Tevatron and LHC”, *Phys. Rev. Lett.* **110** (2013) 042002, doi:10.1103/PhysRevLett.110.042002, arXiv:1205.6682.
- [5] K.-T. Chao et al., “ J/ψ Polarization at Hadron Colliders in Nonrelativistic QCD”, *Phys. Rev. Lett.* **108** (2012) 242004, doi:10.1103/PhysRevLett.108.242004, arXiv:1201.2675.
- [6] P. Faccioli et al., “Quarkonium production in the LHC era: a polarized perspective”, *Phys. Lett. B* **736** (2014) 98, doi:10.1016/j.physletb.2014.07.006, arXiv:1403.3970.
- [7] CDF Collaboration, “Polarization of J/ψ and $\psi(2S)$ Mesons Produced in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV”, *Phys. Rev. Lett.* **99** (2007) 132001, doi:10.1103/PhysRevLett.99.132001, arXiv:0704.0638.
- [8] CDF Collaboration, “Measurements of Angular Distributions of Muons from Y Decays in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV”, *Phys. Rev. Lett.* **108** (2012) 151802, doi:10.1103/PhysRevLett.108.151802, arXiv:1112.1591.
- [9] CMS Collaboration, “Measurement of the $Y(1S)$, $Y(2S)$, and $Y(3S)$ Polarizations in pp Collisions at $\sqrt{s} = 7$ TeV”, *Phys. Rev. Lett.* **110** (2013) 081802, doi:10.1103/PhysRevLett.110.081802, arXiv:1209.2922.
- [10] CMS Collaboration, “Measurement of the prompt J/ψ and $\psi(2S)$ polarizations in pp collisions at $\sqrt{s} = 7$ TeV”, *Phys. Lett. B* **727** (2013) 381, doi:10.1016/j.physletb.2013.10.055, arXiv:1307.6070.
- [11] P. Faccioli, C. Lourenço, and J. Seixas, “Rotation-Invariant Relations in Vector Meson Decays into Fermion Pairs”, *Phys. Rev. Lett.* **105** (2010) 061601, doi:10.1103/PhysRevLett.105.061601, arXiv:1005.2601.
- [12] P. Faccioli, C. Lourenço, and J. Seixas, “New approach to quarkonium polarization studies”, *Phys. Rev. D* **81** (2010) 111502(R), doi:10.1103/PhysRevD.81.111502, arXiv:1005.2855.
- [13] 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.

- [14] ATLAS Collaboration, “Measurement of the differential cross-sections of inclusive, prompt and non-prompt J/ψ production in proton-proton collisions at $\sqrt{s} = 7$ TeV”, *Nucl. Phys. B* **850** (2011) 387, doi:10.1016/j.nuclphysb.2011.05.015, arXiv:1104.3038.
- [15] ATLAS Collaboration, “Measurement of the production cross-section of $\psi(2S) \rightarrow J/\psi(\rightarrow \mu^+\mu^-)\pi^+\pi^-$ in pp collisions at $\sqrt{s} = 7$ TeV at ATLAS”, *JHEP* **09** (2014) 079, doi:10.1007/JHEP09(2014)079, arXiv:1407.5532.
- [16] LHCb Collaboration, “Measurement of J/ψ production in pp collisions at $\sqrt{s} = 7$ TeV”, *Eur. Phys. J. C* **71** (2011) 1645, doi:10.1140/epjc/s10052-011-1645-y, arXiv:1103.0423.
- [17] LHCb Collaboration, “Measurement of $\psi(2S)$ meson production in pp collisions at $\sqrt{s} = 7$ TeV”, *Eur. Phys. J. C* **72** (2012) 2100, doi:10.1140/epjc/s10052-012-2100-4, arXiv:1204.1258.
- [18] ALICE Collaboration, “Measurement of prompt J/ψ and beauty hadron production cross sections at mid-rapidity in pp collisions at $\sqrt{s} = 7$ TeV”, *JHEP* **11** (2012) 065, doi:10.1007/JHEP11(2012)065, arXiv:1205.5880.
- [19] P. Faccioli, C. Lourenço, J. Seixas, and H. Wöhri, “Study of ψ' and χ_c decays as feed-down sources of J/ψ hadro-production”, *JHEP* **10** (2008) 004, doi:10.1088/1126-6708/2008/10/004, arXiv:0809.2153.
- [20] CMS Collaboration, “The CMS experiment at the CERN LHC”, *JINST* **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
- [21] CMS Collaboration, “Absolute Calibration of the Luminosity Measurement at CMS: Winter 2012 Update”, CMS Physics Analysis Summary CMS-PAS-SMP-12-008, 2012.
- [22] CMS Collaboration, “Prompt and non-prompt J/ψ production in pp collisions at $\sqrt{s} = 7$ TeV”, *Eur. Phys. J. C* **71** (2011) 1575, doi:10.1140/epjc/s10052-011-1575-8, arXiv:1011.4193.
- [23] M. J. Oreglia, “A Study of the Reactions $\psi' \rightarrow \gamma\gamma\psi$ ”. PhD thesis, Stanford University, 1980. SLAC-R-236.
- [24] 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.
- [25] D. J. Lange, “The EvtGen particle decay simulation package”, *Nucl. Instrum. Meth. A* **462** (2001) 152, doi:10.1016/S0168-9002(01)00089-4.
- [26] T. Sjöstrand, S. Mrenna, and P. Z. Skands, “PYTHIA 6.4 physics and manual”, *JHEP* **05** (2006) 026, doi:10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.
- [27] E. Barberio and Z. Was, “PHOTOS - a universal Monte Carlo for QED radiative corrections: version 2.0”, *Comput. Phys. Commun.* **79** (1994) 291, doi:10.1016/0010-4655(94)90074-4.
- [28] P. Faccioli, C. Lourenço, J. Seixas, and H. Wöhri, “Towards the experimental clarification of quarkonium polarization”, *Eur. Phys. J. C* **69** (2010) 657, doi:10.1140/epjc/s10052-010-1420-5, arXiv:1006.2738.

-
- [29] Particle Data Group, K. A. Olive et al., “Review of Particle Physics”, *Chin. Phys. C* **38** (2014) 090001, doi:10.1088/1674-1137/38/9/090001.
- [30] HERA-B Collaboration, “A measurement of the ψ' to J/ψ production ratio in 920 GeV proton-nucleus interactions”, *Eur. Phys. J. C* **49** (2007) 545, doi:10.1140/epjc/s10052-006-0139-9, arXiv:hep-ex/0607046.
- [31] Z.-B. Kang, J.-W. Qiu, and G. Sterman, “Heavy Quarkonium Production and Polarization”, *Phys. Rev. Lett.* **108** (2012) 102002, doi:10.1103/PhysRevLett.108.102002, arXiv:1109.1520.
- [32] Z.-B. Kang, Y.-Q. Ma, J.-W. Qiu, and G. Sterman, “Heavy quarkonium production at collider energies: Factorization and evolution”, *Phys. Rev. D* **90** (2014) 034006, doi:10.1103/PhysRevD.90.034006, arXiv:1401.0923.
- [33] G. T. Bodwin, H. S. Chung, U.-R. Kim, and J. Lee, “Fragmentation Contributions to J/ψ Production at the Tevatron and the LHC”, *Phys. Rev. Lett.* **113** (2014) 022001, doi:10.1103/PhysRevLett.113.022001, arXiv:1403.3612.

A Tables of cross sections

Table A.1: The J/ψ differential cross section times dimuon branching fraction $\mathcal{B} d\sigma/dp_T$ in four rapidity ranges for the unpolarized scenario. The relative uncertainties (first statistical and then systematic) are given in percent. The systematic uncertainties are to be treated as bin-to-bin correlated.

Δp_T [GeV]	$\mathcal{B} d\sigma/dp_T$ [pb/GeV]			
	$ y < 0.3$	$0.3 < y < 0.6$	$0.6 < y < 0.9$	$0.9 < y < 1.2$
10–11	1.12E+03 $\pm 0.3 \pm 7.9$	1.06E+03 $\pm 0.3 \pm 6.2$	1.02E+03 $\pm 0.3 \pm 4.6$	8.84E+02 $\pm 0.2 \pm 5.5$
11–12	6.55E+02 $\pm 0.3 \pm 5.9$	6.34E+02 $\pm 0.3 \pm 4.8$	6.20E+02 $\pm 0.3 \pm 4.1$	5.38E+02 $\pm 0.3 \pm 4.7$
12–13	4.06E+02 $\pm 0.3 \pm 5.0$	3.97E+02 $\pm 0.3 \pm 4.3$	3.97E+02 $\pm 0.3 \pm 3.9$	3.39E+02 $\pm 0.3 \pm 3.8$
13–14	2.65E+02 $\pm 0.4 \pm 4.7$	2.56E+02 $\pm 0.4 \pm 4.1$	2.54E+02 $\pm 0.4 \pm 3.9$	2.18E+02 $\pm 0.4 \pm 3.8$
14–15	1.78E+02 $\pm 0.4 \pm 4.5$	1.71E+02 $\pm 0.4 \pm 4.0$	1.67E+02 $\pm 0.4 \pm 3.9$	1.46E+02 $\pm 0.4 \pm 3.9$
15–16	1.21E+02 $\pm 0.5 \pm 4.4$	1.18E+02 $\pm 0.5 \pm 3.9$	1.14E+02 $\pm 0.5 \pm 3.9$	1.03E+02 $\pm 0.5 \pm 3.3$
16–17	8.25E+01 $\pm 0.6 \pm 4.4$	8.19E+01 $\pm 0.6 \pm 3.8$	7.97E+01 $\pm 0.6 \pm 3.9$	7.00E+01 $\pm 0.6 \pm 3.3$
17–18	6.05E+01 $\pm 0.6 \pm 4.3$	5.89E+01 $\pm 0.6 \pm 3.8$	5.76E+01 $\pm 0.6 \pm 3.8$	5.00E+01 $\pm 0.7 \pm 3.3$
18–19	4.42E+01 $\pm 0.7 \pm 4.3$	4.30E+01 $\pm 0.7 \pm 3.8$	4.18E+01 $\pm 0.7 \pm 3.8$	3.64E+01 $\pm 0.7 \pm 3.3$
19–20	3.25E+01 $\pm 0.8 \pm 4.3$	3.22E+01 $\pm 0.8 \pm 3.8$	3.11E+01 $\pm 0.8 \pm 3.8$	2.67E+01 $\pm 0.9 \pm 3.3$
20–21	2.42E+01 $\pm 0.9 \pm 4.3$	2.46E+01 $\pm 0.9 \pm 3.8$	2.31E+01 $\pm 0.9 \pm 3.8$	2.03E+01 $\pm 1.0 \pm 3.3$
21–22	1.92E+01 $\pm 1.0 \pm 4.3$	1.81E+01 $\pm 1.0 \pm 3.8$	1.80E+01 $\pm 1.0 \pm 3.8$	1.54E+01 $\pm 1.1 \pm 3.3$
22–23	1.46E+01 $\pm 1.2 \pm 4.3$	1.40E+01 $\pm 1.1 \pm 3.7$	1.35E+01 $\pm 1.2 \pm 3.8$	1.20E+01 $\pm 1.2 \pm 3.4$
23–24	1.12E+01 $\pm 1.3 \pm 4.3$	1.10E+01 $\pm 1.3 \pm 3.7$	1.07E+01 $\pm 1.3 \pm 3.8$	9.36E+00 $\pm 1.4 \pm 3.4$
24–25	8.92E+00 $\pm 1.4 \pm 4.4$	8.75E+00 $\pm 1.4 \pm 3.7$	8.39E+00 $\pm 1.4 \pm 3.8$	7.46E+00 $\pm 1.5 \pm 3.4$
25–26	7.43E+00 $\pm 1.6 \pm 4.4$	6.81E+00 $\pm 1.6 \pm 3.7$	6.86E+00 $\pm 1.6 \pm 3.8$	5.96E+00 $\pm 1.7 \pm 3.4$
26–27	5.66E+00 $\pm 1.8 \pm 4.4$	5.45E+00 $\pm 1.7 \pm 3.7$	5.35E+00 $\pm 1.8 \pm 3.8$	4.96E+00 $\pm 1.8 \pm 3.4$
27–28	4.72E+00 $\pm 1.9 \pm 4.4$	4.54E+00 $\pm 1.9 \pm 3.7$	4.26E+00 $\pm 2.0 \pm 3.8$	3.74E+00 $\pm 2.1 \pm 3.4$
28–29	3.83E+00 $\pm 2.1 \pm 4.4$	3.70E+00 $\pm 2.1 \pm 3.7$	3.65E+00 $\pm 2.1 \pm 3.8$	3.08E+00 $\pm 2.3 \pm 3.5$
29–30	3.04E+00 $\pm 2.3 \pm 4.4$	2.99E+00 $\pm 2.3 \pm 3.7$	2.91E+00 $\pm 2.4 \pm 3.8$	2.50E+00 $\pm 2.5 \pm 3.5$
30–32	2.35E+00 $\pm 1.9 \pm 4.4$	2.35E+00 $\pm 1.8 \pm 3.7$	2.22E+00 $\pm 1.9 \pm 3.9$	1.90E+00 $\pm 2.1 \pm 3.5$
32–34	1.69E+00 $\pm 2.2 \pm 4.5$	1.61E+00 $\pm 2.2 \pm 3.7$	1.53E+00 $\pm 2.3 \pm 3.9$	1.34E+00 $\pm 2.4 \pm 3.5$
34–36	1.17E+00 $\pm 2.6 \pm 4.5$	1.19E+00 $\pm 2.5 \pm 3.7$	1.13E+00 $\pm 2.6 \pm 3.9$	9.62E-01 $\pm 2.9 \pm 3.6$
36–38	8.70E-01 $\pm 3.0 \pm 6.5$	8.80E-01 $\pm 2.9 \pm 5.9$	8.32E-01 $\pm 3.0 \pm 6.1$	7.03E-01 $\pm 3.4 \pm 5.8$
38–42	5.67E-01 $\pm 2.6 \pm 6.5$	5.51E-01 $\pm 2.6 \pm 5.9$	5.39E-01 $\pm 2.6 \pm 6.1$	4.70E-01 $\pm 2.9 \pm 5.9$
42–46	3.34E-01 $\pm 3.4 \pm 6.5$	2.99E-01 $\pm 3.5 \pm 5.9$	3.13E-01 $\pm 3.4 \pm 6.1$	2.63E-01 $\pm 3.7 \pm 5.9$
46–50	2.13E-01 $\pm 4.4 \pm 6.5$	1.87E-01 $\pm 4.5 \pm 5.9$	1.80E-01 $\pm 6.5 \pm 6.1$	1.64E-01 $\pm 4.9 \pm 5.9$
50–60	1.00E-01 $\pm 4.1 \pm 11$	9.48E-02 $\pm 4.1 \pm 11$	8.37E-02 $\pm 4.3 \pm 11$	7.03E-02 $\pm 4.9 \pm 11$
60–75	3.06E-02 $\pm 6.4 \pm 11$	2.97E-02 $\pm 6.1 \pm 11$	2.72E-02 $\pm 6.5 \pm 11$	2.39E-02 $\pm 7.3 \pm 11$
75–95	7.00E-03 $\pm 13 \pm 11$	7.03E-03 $\pm 12 \pm 11$	9.80E-03 $\pm 9.6 \pm 11$	7.23E-03 $\pm 12.0 \pm 11$

Table A.2: The $\psi(2S)$ differential cross section times dimuon branching fraction $\mathcal{B} d\sigma/dp_T$ in four rapidity ranges for the unpolarized scenario. The relative uncertainties (first statistical and then systematic) are given in percent. The systematic uncertainties are to be treated as bin-to-bin correlated.

Δp_T [GeV]	$\mathcal{B} d\sigma/dp_T$ [pb/GeV]			
	$ y < 0.3$	$0.3 < y < 0.6$	$0.6 < y < 0.9$	$0.9 < y < 1.2$
10–11	4.07E+01 $\pm 1.7 \pm 7.5$	3.80E+01 $\pm 1.7 \pm 6.2$	3.82E+01 $\pm 1.6 \pm 4.4$	3.35E+01 $\pm 1.5 \pm 4.5$
11–12	2.54E+01 $\pm 1.6 \pm 5.8$	2.48E+01 $\pm 1.7 \pm 5.0$	2.42E+01 $\pm 1.7 \pm 4.1$	2.13E+01 $\pm 1.6 \pm 3.9$
12–13	1.62E+01 $\pm 1.8 \pm 5.1$	1.51E+01 $\pm 1.9 \pm 4.6$	1.58E+01 $\pm 1.8 \pm 4.1$	1.40E+01 $\pm 1.8 \pm 3.8$
13–14	1.04E+01 $\pm 2.0 \pm 4.8$	1.07E+01 $\pm 2.0 \pm 4.4$	1.07E+01 $\pm 2.0 \pm 4.0$	8.88E+00 $\pm 2.1 \pm 3.7$
14–15	7.77E+00 $\pm 2.2 \pm 4.7$	7.51E+00 $\pm 2.2 \pm 4.3$	6.98E+00 $\pm 2.3 \pm 4.0$	6.31E+00 $\pm 2.4 \pm 3.6$
15–16	5.08E+00 $\pm 2.6 \pm 4.8$	4.97E+00 $\pm 2.5 \pm 4.4$	4.96E+00 $\pm 2.6 \pm 4.3$	4.13E+00 $\pm 2.9 \pm 3.9$
16–17	3.79E+00 $\pm 2.8 \pm 4.6$	3.57E+00 $\pm 2.9 \pm 4.3$	3.42E+00 $\pm 3.1 \pm 4.1$	3.10E+00 $\pm 3.2 \pm 3.7$
17–18	2.69E+00 $\pm 3.2 \pm 4.7$	2.63E+00 $\pm 3.3 \pm 4.3$	2.58E+00 $\pm 3.4 \pm 4.3$	2.16E+00 $\pm 3.8 \pm 3.9$
18–19	1.94E+00 $\pm 3.7 \pm 4.6$	1.87E+00 $\pm 3.8 \pm 4.2$	1.96E+00 $\pm 3.7 \pm 4.1$	1.70E+00 $\pm 4.1 \pm 3.7$
19–20	1.43E+00 $\pm 4.3 \pm 4.7$	1.30E+00 $\pm 4.5 \pm 4.3$	1.42E+00 $\pm 4.3 \pm 4.2$	1.23E+00 $\pm 4.8 \pm 3.9$
20–22.5	9.07E-01 $\pm 3.2 \pm 5.1$	8.83E-01 $\pm 3.3 \pm 4.7$	8.96E-01 $\pm 3.3 \pm 4.7$	7.44E-01 $\pm 3.9 \pm 4.3$
22.5–25	4.69E-01 $\pm 4.4 \pm 5.2$	5.05E-01 $\pm 4.2 \pm 4.7$	4.57E-01 $\pm 4.5 \pm 4.7$	4.08E-01 $\pm 5.0 \pm 4.4$
25–27.5	2.81E-01 $\pm 5.6 \pm 5.8$	2.90E-01 $\pm 5.4 \pm 5.4$	2.75E-01 $\pm 5.8 \pm 5.4$	2.31E-01 $\pm 6.8 \pm 5.1$
27.5–30	1.65E-01 $\pm 7.2 \pm 5.7$	1.66E-01 $\pm 7.2 \pm 5.3$	1.81E-01 $\pm 7.1 \pm 5.3$	1.44E-01 $\pm 8.5 \pm 5.1$
30–35	8.83E-02 $\pm 6.8 \pm 6.0$	8.70E-02 $\pm 7.2 \pm 5.5$	8.40E-02 $\pm 7.3 \pm 5.6$	7.78E-02 $\pm 8.0 \pm 5.4$
35–40	3.67E-02 $\pm 10 \pm 7.8$	2.95E-02 $\pm 13 \pm 7.4$	3.74E-02 $\pm 11 \pm 7.5$	3.50E-02 $\pm 12 \pm 7.2$
40–55	9.96E-03 $\pm 13 \pm 8.2$	9.64E-03 $\pm 13 \pm 7.9$	1.03E-02 $\pm 13 \pm 8.0$	1.08E-02 $\pm 14 \pm 7.8$
55–75	2.73E-03 $\pm 22 \pm 12$	2.14E-03 $\pm 27 \pm 12$	2.19E-03 $\pm 28 \pm 12$	3.29E-03 $\pm 26 \pm 12$

Table A.3: The J/ψ differential cross section times dimuon branching fraction $\mathcal{B} d\sigma/dp_T$ for the integrated rapidity range $|y| < 1.2$, in the unpolarized scenario. The relative uncertainties (first statistical and then systematic) are given in percent. The systematic uncertainties are to be treated as bin-to-bin correlated. The average p_T values, $\langle p_T \rangle$, are calculated after acceptance and efficiency corrections. Detector smearing has a negligible effect on this value. The last three columns list the scaling factors needed to obtain the cross sections corresponding to the polarization scenarios represented by the indicated $\lambda_\theta^{\text{HX}}$ values.

Δp_T [GeV]	$\langle p_T \rangle$ [GeV]	$\mathcal{B} d\sigma/dp_T$ [pb/GeV]	$\lambda_\theta^{\text{HX}}$ scaling factors		
			+1	-1	0.10
10–11	10.5	1.01E+03 $\pm 0.1 \pm 7.9$	1.31	0.68	1.03
11–12	11.5	6.09E+02 $\pm 0.1 \pm 5.9$	1.30	0.68	1.03
12–13	12.5	3.82E+02 $\pm 0.2 \pm 5.0$	1.29	0.69	1.03
13–14	13.5	2.47E+02 $\pm 0.2 \pm 4.7$	1.28	0.70	1.03
14–15	14.5	1.65E+02 $\pm 0.2 \pm 4.5$	1.26	0.71	1.03
15–16	15.5	1.14E+02 $\pm 0.2 \pm 4.4$	1.25	0.71	1.03
16–17	16.5	7.84E+01 $\pm 0.3 \pm 4.4$	1.24	0.72	1.03
17–18	17.5	5.66E+01 $\pm 0.3 \pm 4.3$	1.23	0.73	1.02
18–19	18.5	4.13E+01 $\pm 0.4 \pm 4.3$	1.22	0.73	1.02
19–20	19.5	3.05E+01 $\pm 0.4 \pm 4.3$	1.21	0.74	1.02
20–21	20.5	2.30E+01 $\pm 0.5 \pm 4.3$	1.20	0.75	1.02
21–22	21.5	1.76E+01 $\pm 0.5 \pm 4.3$	1.19	0.75	1.02
22–23	22.5	1.35E+01 $\pm 0.6 \pm 4.3$	1.19	0.76	1.02
23–24	23.5	1.05E+01 $\pm 0.6 \pm 4.3$	1.18	0.77	1.02
24–25	24.5	8.35E+00 $\pm 0.7 \pm 4.4$	1.17	0.77	1.02
25–26	25.5	6.75E+00 $\pm 0.8 \pm 4.4$	1.17	0.78	1.02
26–27	26.5	5.35E+00 $\pm 0.9 \pm 4.4$	1.16	0.78	1.02
27–28	27.5	4.31E+00 $\pm 1.0 \pm 4.4$	1.16	0.79	1.02
28–29	28.5	3.57E+00 $\pm 1.1 \pm 4.4$	1.15	0.79	1.02
29–30	29.5	2.86E+00 $\pm 1.2 \pm 4.4$	1.15	0.80	1.02
30–32	30.9	2.21E+00 $\pm 0.9 \pm 4.4$	1.14	0.80	1.02
32–34	32.9	1.55E+00 $\pm 1.1 \pm 4.5$	1.13	0.81	1.02
34–36	35.0	1.11E+00 $\pm 1.3 \pm 4.5$	1.12	0.82	1.01
36–38	37.0	8.22E-01 $\pm 1.5 \pm 6.5$	1.12	0.83	1.01
38–42	39.8	5.33E-01 $\pm 1.3 \pm 6.5$	1.11	0.83	1.01
42–46	43.8	3.02E-01 $\pm 1.8 \pm 6.5$	1.10	0.85	1.01
46–50	47.9	1.86E-01 $\pm 2.3 \pm 6.5$	1.09	0.86	1.01
50–60	54.2	8.75E-02 $\pm 2.1 \pm 10.9$	1.08	0.87	1.01
60–75	66.0	2.78E-02 $\pm 3.2 \pm 11.1$	1.07	0.89	1.01
75–95	82.9	7.97E-03 $\pm 5.4 \pm 11.2$	1.05	0.91	1.01
95–120	104.1	1.96E-03 $\pm 10.7 \pm 11.4$	1.04	0.92	1.01

Table A.4: The $\psi(2S)$ differential cross section times dimuon branching fraction $\mathcal{B} d\sigma/dp_T$ for the integrated rapidity range $|y| < 1.2$, in the unpolarized scenario. The relative uncertainties (first statistical and then systematic) are given in percent. The systematic uncertainties are to be treated as bin-to-bin correlated. The average p_T values, $\langle p_T \rangle$, are calculated after acceptance and efficiency corrections. Detector smearing has a negligible effect on this value. The last three columns list the scaling factors needed to obtain the cross sections corresponding to the polarization scenarios represented by the indicated $\lambda_\theta^{\text{HX}}$ values.

Δp_T [GeV]	$\langle p_T \rangle$ [GeV]	$\mathcal{B} d\sigma/dp_T$ [pb/GeV]	$\lambda_\theta^{\text{HX}}$ scaling factors		
			+1	-1	0.03
10–11	10.5	$3.80\text{E}+01 \pm 0.8 \pm 7.5$	1.31	0.68	1.01
11–12	11.5	$2.41\text{E}+01 \pm 0.8 \pm 5.8$	1.30	0.69	1.01
12–13	12.5	$1.54\text{E}+01 \pm 0.9 \pm 5.1$	1.28	0.69	1.01
13–14	13.5	$1.02\text{E}+01 \pm 1.0 \pm 4.8$	1.27	0.70	1.01
14–15	14.5	$7.15\text{E}+00 \pm 1.1 \pm 4.7$	1.26	0.71	1.01
15–16	15.5	$4.79\text{E}+00 \pm 1.3 \pm 4.8$	1.25	0.72	1.01
16–17	16.5	$3.48\text{E}+00 \pm 1.5 \pm 4.6$	1.24	0.72	1.01
17–18	17.5	$2.52\text{E}+00 \pm 1.7 \pm 4.7$	1.23	0.73	1.01
18–19	18.5	$1.87\text{E}+00 \pm 1.9 \pm 4.6$	1.22	0.74	1.01
19–20	19.5	$1.34\text{E}+00 \pm 2.2 \pm 4.7$	1.21	0.74	1.01
20–22.5	21.1	$8.57\text{E}-01 \pm 1.7 \pm 5.1$	1.20	0.75	1.01
22.5–25	23.6	$4.61\text{E}-01 \pm 2.2 \pm 5.2$	1.18	0.77	1.01
25–27.5	26.1	$2.69\text{E}-01 \pm 2.9 \pm 5.8$	1.16	0.78	1.01
27.5–30	28.7	$1.65\text{E}-01 \pm 3.7 \pm 5.7$	1.15	0.79	1.01
30–35	32.2	$8.42\text{E}-02 \pm 3.6 \pm 6.0$	1.13	0.81	1.00
35–40	37.2	$3.47\text{E}-02 \pm 5.8 \pm 7.8$	1.12	0.83	1.00
40–55	45.5	$1.02\text{E}-02 \pm 6.6 \pm 8.2$	1.10	0.85	1.00
55–75	62.4	$2.35\text{E}-03 \pm 12.7 \pm 12.3$	1.07	0.88	1.00
75–100	84.1	$5.62\text{E}-04 \pm 24.4 \pm 12.6$	1.05	0.91	1.00

Table A.5: The ratio of the $\psi(2S)$ to J/ψ differential cross sections times dimuon branching fractions in percent, as a function of p_T , in the unpolarized scenario for $|y| < 1.2$. The first uncertainty is statistical and the second is systematic. The systematic uncertainties are to be treated as bin-to-bin correlated.

Δp_T [GeV]	$\langle p_T \rangle$ [GeV]	$[\mathcal{B} \sigma(\psi(2S))] / [\mathcal{B} \sigma(J/\psi)]$ [%]
10–11	10.5	$3.75 \pm 0.03 \pm 0.11$
11–12	11.5	$3.93 \pm 0.03 \pm 0.11$
12–13	12.5	$4.04 \pm 0.04 \pm 0.11$
13–14	13.5	$4.11 \pm 0.04 \pm 0.11$
14–15	14.5	$4.30 \pm 0.05 \pm 0.12$
15–16	15.5	$4.20 \pm 0.06 \pm 0.11$
16–17	16.5	$4.39 \pm 0.07 \pm 0.12$
17–18	17.5	$4.42 \pm 0.08 \pm 0.12$
18–19	18.5	$4.45 \pm 0.09 \pm 0.12$
19–20	19.5	$4.37 \pm 0.10 \pm 0.11$
20–22.5	21.1	$4.49 \pm 0.08 \pm 0.05$
22.5–25	23.6	$4.58 \pm 0.10 \pm 0.05$
25–27.5	26.1	$4.69 \pm 0.14 \pm 0.04$
27.5–30	28.7	$4.85 \pm 0.18 \pm 0.05$
30–35	32.2	$4.84 \pm 0.18 \pm 0.05$
35–40	37.2	$4.47 \pm 0.26 \pm 0.05$
40–55	45.5	$4.47 \pm 0.30 \pm 0.04$
55–75	62.3	$6.08 \pm 0.80 \pm 0.12$
75–100	82.9	$7.64 \pm 1.98 \pm 0.41$

B The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia

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

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, M. Friedl, R. Frühwirth¹, V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler¹, W. Kiesenhofer, V. Knünz, M. Krammer¹, I. Krätschmer, D. Liko, I. Mikulec, D. Rabadý², B. Rahbaran, H. Rohringer, R. Schöffbeck, J. Strauss, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz¹

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

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

Universiteit Antwerpen, Antwerpen, Belgium

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

Vrije Universiteit Brussel, Brussel, Belgium

F. Blekman, S. Blyweert, J. D'Hondt, N. Daci, N. Heracleous, J. Keaveney, S. Lowette, M. Maes, A. Olbrechts, Q. Python, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Vilella

Université Libre de Bruxelles, Bruxelles, Belgium

C. Caillol, B. Clerbaux, G. De Lentdecker, D. Dobur, L. Favart, A.P.R. Gay, A. Grebenyuk, A. Léonard, A. Mohammadi, L. Perniè², A. Randle-conde, T. Reis, T. Seva, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wang, F. Zenoni

Ghent University, Ghent, Belgium

V. Adler, K. Beernaert, L. Benucci, A. Cimmino, S. Costantini, S. Crucy, A. Fagot, G. Garcia, J. Mccartin, A.A. Ocampo Rios, D. Poyraz, D. Ryckbosch, S. Salva Diblen, M. Sigamani, N. Strobbe, F. Thyssen, M. Tytgat, E. Yazgan, N. Zaganidis

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

S. Basegmez, C. Beluffi³, G. Bruno, R. Castello, A. Caudron, L. Ceard, G.G. Da Silveira, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco⁴, J. Hollar, A. Jafari, P. Jez, M. Komm, V. Lemaître, C. Nuttens, D. Pagano, L. Perrini, A. Pin, K. Piotrkowski, A. Popov⁵, L. Quertenmont, M. Selvaggi, M. Vidal Marono, J.M. Vizan Garcia

Université de Mons, Mons, Belgium

N. Beliy, T. Caebergs, E. Daubie, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

W.L. Aldá Júnior, G.A. Alves, L. Brito, M. Correa Martins Junior, T. Dos Reis Martins, J. Molina, C. Mora Herrera, M.E. Pol, P. Rebello Teles

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

W. Carvalho, J. Chinellato⁶, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, J. Santaolalla, A. Santoro, A. Sznajder, E.J. Tonelli Manganote⁶, A. Vilela Pereira

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

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

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

A. Aleksandrov, V. Genchev², R. Hadjiiska, P. Iaydjiev, A. Marinov, S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

University of Sofia, Sofia, Bulgaria

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

Institute of High Energy Physics, Beijing, China

J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, T. Cheng, R. Du, C.H. Jiang, R. Plestina⁷, F. Romeo, J. Tao, Z. Wang

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

C. Asawatrangkuldee, Y. Ban, W. Guo, S. Liu, Y. Mao, S.J. Qian, D. Wang, Z. Xu, F. Zhang⁸, L. Zhang, W. Zou

Universidad de Los Andes, Bogota, Colombia

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

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

N. Godinovic, D. Lelas, D. Polic, I. Puljak

University of Split, Faculty of Science, Split, Croatia

Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

V. Brigljevic, K. Kadija, J. Luetic, D. Mekterovic, L. Sudic

University of Cyprus, Nicosia, Cyprus

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

Charles University, Prague, Czech Republic

M. Bodlak, M. Finger, M. Finger Jr.⁹

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

Y. Assran¹⁰, A. Ellithi Kamel¹¹, M.A. Mahmoud¹², A. Radi^{13,14}

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

M. Kadastik, M. Murumaa, M. Raidal, A. Tiko

Department of Physics, University of Helsinki, Helsinki, Finland

P. Eerola, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

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

Lappeenranta University of Technology, Lappeenranta, Finland

J. Talvitie, T. Tuuva

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

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

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

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

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

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

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

S. Gadrat

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

S. Beauceron, N. Beaupere, C. Bernet⁷, G. Boudoul², E. Bouvier, S. Brochet, C.A. Carrillo Montoya, J. Chasserat, R. Chierici, D. Contardo², B. Courbon, P. Depasse, H. El Mamouni, J. Fan, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, A.L. Pequegnot, S. Perries, J.D. Ruiz Alvarez, D. Sabes, L. Sgandurra, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret, H. Xiao

Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia

Z. Tsamalaidze⁹

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

C. Autermann, S. Beranek, M. Bontenackels, M. Edelhoff, L. Feld, A. Heister, K. Klein, M. Lipinski, A. Ostapchuk, M. Preuten, F. Raupach, J. Sammet, S. Schael, J.F. Schulte, H. Weber, B. Wittmer, V. Zhukov⁵

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

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

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

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

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, I. Asin, N. Bartosik, J. Behr, U. Behrens, A.J. Bell, A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, S. Choudhury, F. Costanza, C. Diez Pardos, G. Dolinska, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, J. Garay Garcia, A. Geiser, A. Gizhko, P. Gunnellini, J. Hauk, M. Hempel¹⁶, H. Jung, A. Kalogeropoulos, O. Karacheban¹⁶, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, I. Korol,

D. Krücker, W. Lange, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann¹⁶, B. Lutz, R. Mankel, I. Marfin¹⁶, I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, S. Naumann-Emme, A. Nayak, E. Ntomari, H. Perrey, D. Pitzl, R. Placakyte, A. Raspereza, P.M. Ribeiro Cipriano, B. Roland, E. Ron, M.Ö. Sahin, J. Salfeld-Nebgen, P. Saxena, T. Schoerner-Sadenius, M. Schröder, C. Seitz, S. Spannagel, A.D.R. Vargas Trevino, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

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

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, F. Frensch, M. Giffels, A. Gilbert, F. Hartmann², T. Hauth, U. Husemann, I. Katkov⁵, A. Kornmayer², P. Lobelle Pardo, M.U. Mozer, T. Müller, Th. Müller, A. Nürnberg, G. Quast, K. Rabbertz, S. Röcker, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, R. Wolf

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

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

University of Athens, Athens, Greece

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

University of Ioánnina, Ioánnina, Greece

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

Wigner Research Centre for Physics, Budapest, Hungary

G. Bencze, C. Hajdu, P. Hidas, D. Horvath¹⁷, F. Sikler, V. Veszpremi, G. Vesztergombi¹⁸, A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

N. Beni, S. Czellar, J. Karancsi¹⁹, J. Molnar, J. Palinkas, Z. Szillasi

University of Debrecen, Debrecen, Hungary

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

National Institute of Science Education and Research, Bhubaneswar, India

S.K. Swain

Panjab University, Chandigarh, India

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

University of Delhi, Delhi, India

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

Saha Institute of Nuclear Physics, Kolkata, India

S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, A. Modak, S. Mukherjee, D. Roy, S. Sarkar, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India

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

Tata Institute of Fundamental Research, Mumbai, India

T. Aziz, S. Banerjee, S. Bhowmik²⁰, R.M. Chatterjee, R.K. Dewanjee, S. Dugad, S. Ganguly, S. Ghosh, M. Guchait, A. Gurtu²¹, G. Kole, S. Kumar, M. Maity²⁰, G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage²²

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

S. Sharma

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

H. Bakhshiansohi, H. Behnamian, S.M. Etesami²³, A. Fahim²⁴, R. Goldouzian, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, F. Rezaei Hosseinabadi, B. Safarzadeh²⁵, M. Zeinali

University College Dublin, Dublin, Ireland

M. Felcini, M. Grunewald

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

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

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

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

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

S. Albergo^{a,b}, G. Cappello^a, M. Chiorboli^{a,b}, S. Costa^{a,b}, F. Giordano^{a,2}, R. Potenza^{a,b}, A. Tricomi^{a,b}, C. Tuve^{a,b}

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

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

INFN Laboratori Nazionali di Frascati, Frascati, Italy

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

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

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

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

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

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

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

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

P. Azzi^a, N. Bacchetta^a, D. Bisello^{a,b}, R. Carlin^{a,b}, P. Checchia^a, M. Dall'Osso^{a,b}, T. Dorigo^a, U. Dosselli^a, F. Gasparini^{a,b}, U. Gasparini^{a,b}, A. Gozzelino^a, S. Lacaprara^a, M. Margoni^{a,b}, A.T. Meneguzzo^{a,b}, F. Montecassiano^a, M. Passaseo^a, J. Pazzini^{a,b}, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{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

M. Gabusi^{a,b}, S.P. Ratti^{a,b}, V. Re^a, C. Riccardi^{a,b}, P. Salvini^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,2}, L. Fanò^{a,b}, P. Lariccia^{a,b}, G. Mantovani^{a,b}, M. Menichelli^a, A. Saha^a, A. Santocchia^{a,b}, A. Spiezia^{a,b,2}

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

K. Androsov^{a,26}, P. Azzurri^a, G. Bagliesi^a, J. Bernardini^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, M.A. Ciocci^{a,26}, R. Dell'Orso^a, S. Donato^{a,c,2}, G. Fedi^a, F. Fiori^{a,c}, L. Foà^{a,c}, A. Giassi^a, M.T. Grippo^{a,26}, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,b}, A. Messineo^{a,b}, C.S. Moon^{a,27}, F. Palla^{a,2}, A. Rizzi^{a,b}, A. Savoy-Navarro^{a,28}, A.T. Serban^a, P. Spagnolo^a, P. Squillacioti^{a,26}, R. Tenchini^a, G. Tonelli^{a,b}, A. Venturi^a, P.G. Verdini^a, C. Vernieri^{a,c}

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

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

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

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

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

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

Kangwon National University, Chunchon, Korea

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

Kyungpook National University, Daegu, Korea

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

Chonbuk National University, Jeonju, Korea

T.J. Kim, M.S. Ryu

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

J.Y. Kim, D.H. Moon, S. Song

Korea University, Seoul, Korea

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

Seoul National University, Seoul, Korea

H.D. Yoo

University of Seoul, Seoul, Korea

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

Sungkyunkwan University, Suwon, Korea

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

Vilnius University, Vilnius, Lithuania

A. Juodagalvis

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

J.R. Komaragiri, M.A.B. Md Ali²⁹, W.A.T. Wan Abdullah

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

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

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

I. Pedraza, H.A. Salazar Ibarguen

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

A. Morelos Pineda

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand

P.H. Butler, S. Reucroft

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

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

National Centre for Nuclear Research, Swierk, Poland

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

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

G. Bona, K. Bunkowski, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski

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

P. Bargassa, C. Beirão Da Cruz E Silva, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, L. Lloret Iglesias, F. Nguyen, J. Rodrigues Antunes, J. Seixas, D. Vadrucchio, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia

S. Afanasiev, I. Golutvin, V. Karjavin, V. Konoplyanikov, V. Korenkov, G. Kozlov, A. Lanev, A. Malakhov, V. Matveev³⁰, V.V. Mitsyn, P. Moisezenz, V. Palichik, V. Perelegin, S. Shmatov, N. Skatchkov, V. Smirnov, E. Tikhonenko, A. Zarubin

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

V. Golovtsov, Y. Ivanov, V. Kim³¹, E. Kuznetsova, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev, An. Vorobyev

Institute for Nuclear Research, Moscow, Russia

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

Institute for Theoretical and Experimental Physics, Moscow, Russia

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

P.N. Lebedev Physical Institute, Moscow, Russia

V. Andreev, M. Azarkin³², I. Dremin³², M. Kirakosyan, A. Leonidov³², G. Mesyats, S.V. Rusakov, A. Vinogradov

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

A. Belyaev, E. Boos, M. Dubinin³³, L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

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

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

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

P. Adzic³⁴, M. Ekmedzic, J. Milosevic, V. Rekovic

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

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

Universidad Autónoma de Madrid, Madrid, Spain

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

Universidad de Oviedo, Oviedo, Spain

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero

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

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

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, A. Benaglia, J. Bendavid, L. Benhabib, J.F. Benitez, P. Bloch, A. Bocci, A. Bonato, O. Bondu, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, S. Colafranceschi³⁵, M. D'Alfonso, D. d'Enterria, A. Dabrowski, A. David, F. De Guio, A. De Roeck, S. De Visscher, E. Di Marco, M. Dobson,

M. Dordevic, B. Dorney, N. Dupont-Sagorin, A. Elliott-Peisert, G. Franzoni, W. Funk, D. Gigi, K. Gill, D. Giordano, M. Girone, F. Glege, R. Guida, S. Gundacker, M. Guthoff, J. Hammer, M. Hansen, P. Harris, J. Hegeman, V. Innocente, P. Janot, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, N. Magini, L. Malgeri, M. Mannelli, J. Marrouche, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, S. Morovic, M. Mulders, S. Orfanelli, L. Orsini, L. Pape, E. Perez, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pimiä, D. Piparo, M. Plagge, A. Racz, G. Rolandi³⁶, M. Rovere, H. Sakulin, C. Schäfer, C. Schwick, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas³⁷, D. Spiga, J. Steggemann, B. Stieger, M. Stoye, Y. Takahashi, D. Treille, A. Tsiros, G.I. Veres¹⁸, N. Wardle, H.K. Wöhri, H. Wollny, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

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

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

F. Bachmair, L. Bäni, L. Bianchini, M.A. Buchmann, B. Casal, N. Chanon, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, C. Grab, D. Hits, J. Hoss, G. Kasieczka, W. Lustermann, B. Mangano, A.C. Marini, M. Marionneau, P. Martinez Ruiz del Arbol, M. Masciovecchio, D. Meister, N. Mohr, P. Musella, C. Nägeli³⁸, F. Nessi-Tedaldi, F. Pandolfi, F. Pauss, L. Perrozzi, M. Peruzzi, M. Quittnat, L. Rebane, M. Rossini, A. Starodumov³⁹, M. Takahashi, K. Theofilatos, R. Wallny, H.A. Weber

Universität Zürich, Zurich, Switzerland

C. AMSLER⁴⁰, M.F. Canelli, V. Chiochia, A. De Cosa, A. Hinzmann, T. Hreus, B. Kilminster, C. Lange, J. Ngadiuba, D. Pinna, P. Robmann, F.J. Ronga, S. Taroni, Y. Yang

National Central University, Chung-Li, Taiwan

M. Cardaci, K.H. Chen, C. Ferro, C.M. Kuo, W. Lin, Y.J. Lu, R. Volpe, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

P. Chang, Y.H. Chang, Y. Chao, K.F. Chen, P.H. Chen, C. Dietz, U. Grundler, W.-S. Hou, Y.F. Liu, R.-S. Lu, M. Miñano Moya, E. Petrakou, J.F. Tsai, Y.M. Tzeng, R. Wilken

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

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

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci⁴¹, S. Cerci⁴², C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E.E. Kangal⁴³, A. Kayis Topaksu, G. Onengut⁴⁴, K. Ozdemir⁴⁵, S. Ozturk⁴¹, A. Polatoz, D. Sunar Cerci⁴², B. Tali⁴², H. Topakli⁴¹, M. Vergili, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey

I.V. Akin, B. Bilin, S. Bilmis, H. Gamsizkan⁴⁶, B. Isildak⁴⁷, G. Karapinar⁴⁸, K. Ocalan⁴⁹, S. Sekmen, U.E. Surat, M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey

E.A. Albayrak⁵⁰, E. Gülmez, M. Kaya⁵¹, O. Kaya⁵², T. Yetkin⁵³

Istanbul Technical University, Istanbul, Turkey

K. Cankocak, F.I. Vardarli

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

L. Levchuk, P. Sorokin

University of Bristol, Bristol, United Kingdom

J.J. Brooke, E. Clement, D. Cussans, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D.M. Newbold⁵⁴, S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, S. Senkin, V.J. Smith

Rutherford Appleton Laboratory, Didcot, United Kingdom

K.W. Bell, A. Belyaev⁵⁵, C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams, W.J. Womersley, S.D. Worm

Imperial College, London, United Kingdom

M. Baber, R. Bainbridge, O. Buchmuller, D. Burton, D. Colling, N. Cripps, P. Dauncey, G. Davies, M. Della Negra, P. Dunne, A. Elwood, W. Ferguson, J. Fulcher, D. Futyan, G. Hall, G. Iles, M. Jarvis, G. Karapostoli, M. Kenzie, R. Lane, R. Lucas⁵⁴, L. Lyons, A.-M. Magnan, S. Malik, B. Mathias, J. Nash, A. Nikitenko³⁹, J. Pela, M. Pesaresi, K. Petridis, D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp[†], A. Tapper, M. Vazquez Acosta, T. Virdee, S.C. Zenz

Brunel University, Uxbridge, United Kingdom

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

Baylor University, Waco, USA

J. Dittmann, K. Hatakeyama, A. Kasmi, H. Liu, N. Pastika, T. Scarborough, Z. Wu

The University of Alabama, Tuscaloosa, USA

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

Boston University, Boston, USA

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

Brown University, Providence, USA

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

University of California, Davis, Davis, USA

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

University of California, Los Angeles, USA

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

University of California, Riverside, Riverside, USA

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

University of California, San Diego, La Jolla, USA

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

University of California, Santa Barbara, Santa Barbara, USA

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

California Institute of Technology, Pasadena, USA

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

Carnegie Mellon University, Pittsburgh, USA

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

University of Colorado at Boulder, Boulder, USA

J.P. Cumalat, W.T. Ford, A. Gaz, M. Krohn, E. Luiggi Lopez, U. Nauenberg, J.G. Smith, K. Stenson, S.R. Wagner

Cornell University, Ithaca, USA

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

Fairfield University, Fairfield, USA

D. Winn

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, G. Bolla, K. Burkett, J.N. Butler, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, J. Hanlon, D. Hare, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Klima, B. Kreis, S. Kwan[†], J. Linacre, D. Lincoln, R. Lipton, T. Liu, R. Lopes De Sá, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, P. Merkel, K. Mishra, S. Mrenna, S. Nahn, C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, A. Soha, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, A. Whitbeck, J. Whitmore, F. Yang

University of Florida, Gainesville, USA

D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, M. Carver, D. Curry, S. Das, M. De Gruttola, G.P. Di Giovanni, R.D. Field, M. Fisher, I.K. Furic, J. Hugon, J. Konigsberg, A. Korytov, T. Kypreos, J.F. Low, K. Matchev, H. Mei, P. Milenovic⁵⁶, G. Mitselmakher, L. Muniz, A. Rinkevicius, L. Shchutska, M. Snowball, D. Sperka, J. Yelton, M. Zakaria

Florida International University, Miami, USA

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

Florida State University, Tallahassee, USA

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

Florida Institute of Technology, Melbourne, USA

M.M. Baarmand, M. Hohlmann, H. Kalakhety, F. Yumiceva

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

M.R. Adams, L. Apanasevich, D. Berry, R.R. Betts, I. Bucinskaite, R. Cavanaugh, O. Evdokimov,

L. Gauthier, C.E. Gerber, D.J. Hofman, P. Kurt, C. O'Brien, I.D. Sandoval Gonzalez, C. Silkworth, P. Turner, N. Varelas

The University of Iowa, Iowa City, USA

B. Bilki⁵⁷, W. Clarida, K. Dilsiz, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya⁵⁸, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok⁵⁰, A. Penzo, R. Rahmat, S. Sen, P. Tan, E. Tiras, J. Wetzel, K. Yi

Johns Hopkins University, Baltimore, USA

I. Anderson, B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, A.V. Gritsan, P. Maksimovic, C. Martin, M. Swartz, M. Xiao

The University of Kansas, Lawrence, USA

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

Kansas State University, Manhattan, USA

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

Lawrence Livermore National Laboratory, Livermore, USA

J. Gronberg, D. Lange, F. Rebassoo, D. Wright

University of Maryland, College Park, USA

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

Massachusetts Institute of Technology, Cambridge, USA

A. Apyan, R. Barbieri, K. Bierwagen, W. Busza, I.A. Cali, L. Di Matteo, G. Gomez Ceballos, M. Goncharov, D. Gulhan, M. Klute, Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, C. Paus, D. Ralph, C. Roland, G. Roland, G.S.F. Stephans, K. Sumorok, D. Velicanu, J. Veverka, B. Wyslouch, M. Yang, M. Zanetti, V. Zhukova

University of Minnesota, Minneapolis, USA

B. Dahmes, A. Gude, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, S. Nourbakhsh, R. Rusack, A. Singovsky, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, USA

J.G. Acosta, S. Oliveros

University of Nebraska-Lincoln, Lincoln, USA

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

State University of New York at Buffalo, Buffalo, USA

J. Dolen, A. Godshalk, I. Iashvili, A. Kharchilava, A. Kumar, S. Rappoccio

Northeastern University, Boston, USA

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

Northwestern University, Evanston, USA

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

University of Notre Dame, Notre Dame, USA

A. Brinkerhoff, K.M. Chan, A. Drozdetskiy, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, S. Lynch, N. Marinelli, Y. Musienko³⁰, T. Pearson, M. Planer, R. Ruchti, G. Smith, N. Valls, M. Wayne, M. Wolf, A. Woodard

The Ohio State University, Columbus, USA

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

Princeton University, Princeton, USA

O. Driga, P. Elmer, J. Hardenbrook, P. Hebda, S.A. Koay, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, H. Saka, D. Stickland², C. Tully, J.S. Werner, A. Zuranski

University of Puerto Rico, Mayaguez, USA

E. Brownson, S. Malik, H. Mendez, J.E. Ramirez Vargas

Purdue University, West Lafayette, USA

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

Purdue University Calumet, Hammond, USA

N. Parashar, J. Stupak

Rice University, Houston, USA

A. Adair, B. Akgun, K.M. Ecklund, F.J.M. Geurts, W. Li, B. Michlin, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

University of Rochester, Rochester, USA

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

The Rockefeller University, New York, USA

R. Ciesielski, L. Demortier, K. Goulianos, C. Mesropian

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

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

University of Tennessee, Knoxville, USA

K. Rose, S. Spanier, A. York

Texas A&M University, College Station, USA

O. Bouhali⁵⁹, A. Castaneda Hernandez, M. Dalchenko, M. De Mattia, S. Dildick, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon⁶⁰, V. Khotilovich, V. Krutelyov, R. Montalvo, I. Osipenkov, Y. Pakhotin, R. Patel, A. Perloff, J. Roe, A. Rose, A. Safonov, I. Suarez, A. Tatarinov, K.A. Ulmer

Texas Tech University, Lubbock, USA

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

Vanderbilt University, Nashville, USA

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

University of Virginia, Charlottesville, USA

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

Wayne State University, Detroit, USA

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

University of Wisconsin, Madison, USA

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

†: Deceased

- 1: Also at Vienna University of Technology, Vienna, Austria
- 2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
- 3: Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
- 4: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
- 5: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
- 6: Also at Universidade Estadual de Campinas, Campinas, Brazil
- 7: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
- 8: Also at Université Libre de Bruxelles, Bruxelles, Belgium
- 9: Also at Joint Institute for Nuclear Research, Dubna, Russia
- 10: Also at Suez University, Suez, Egypt
- 11: Also at Cairo University, Cairo, Egypt
- 12: Also at Fayoum University, El-Fayoum, Egypt
- 13: Also at British University in Egypt, Cairo, Egypt
- 14: Now at Ain Shams University, Cairo, Egypt
- 15: Also at Université de Haute Alsace, Mulhouse, France
- 16: Also at Brandenburg University of Technology, Cottbus, Germany
- 17: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- 18: Also at Eötvös Loránd University, Budapest, Hungary
- 19: Also at University of Debrecen, Debrecen, Hungary
- 20: Also at University of Visva-Bharati, Santiniketan, India
- 21: Now at King Abdulaziz University, Jeddah, Saudi Arabia
- 22: Also at University of Ruhuna, Matara, Sri Lanka
- 23: Also at Isfahan University of Technology, Isfahan, Iran
- 24: Also at University of Tehran, Department of Engineering Science, Tehran, Iran
- 25: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
- 26: Also at Università degli Studi di Siena, Siena, Italy
- 27: Also at Centre National de la Recherche Scientifique (CNRS) - IN2P3, Paris, France
- 28: Also at Purdue University, West Lafayette, USA
- 29: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
- 30: Also at Institute for Nuclear Research, Moscow, Russia

-
- 31: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
 - 32: Also at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
 - 33: Also at California Institute of Technology, Pasadena, USA
 - 34: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
 - 35: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
 - 36: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
 - 37: Also at University of Athens, Athens, Greece
 - 38: Also at Paul Scherrer Institut, Villigen, Switzerland
 - 39: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
 - 40: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
 - 41: Also at Gaziosmanpasa University, Tokat, Turkey
 - 42: Also at Adiyaman University, Adiyaman, Turkey
 - 43: Also at Mersin University, Mersin, Turkey
 - 44: Also at Cag University, Mersin, Turkey
 - 45: Also at Piri Reis University, Istanbul, Turkey
 - 46: Also at Anadolu University, Eskisehir, Turkey
 - 47: Also at Ozyegin University, Istanbul, Turkey
 - 48: Also at Izmir Institute of Technology, Izmir, Turkey
 - 49: Also at Necmettin Erbakan University, Konya, Turkey
 - 50: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
 - 51: Also at Marmara University, Istanbul, Turkey
 - 52: Also at Kafkas University, Kars, Turkey
 - 53: Also at Yildiz Technical University, Istanbul, Turkey
 - 54: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
 - 55: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
 - 56: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
 - 57: Also at Argonne National Laboratory, Argonne, USA
 - 58: Also at Erzincan University, Erzincan, Turkey
 - 59: Also at Texas A&M University at Qatar, Doha, Qatar
 - 60: Also at Kyungpook National University, Daegu, Korea