EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2011-063
2011/06/22

CMS-BPH-10-013

Measurement of the B_s^0 Production Cross Section with $B_s^0 \to J/\psi\,\phi$ Decays in pp Collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration*

Abstract

The B_s^0 differential production cross section is measured as functions of the transverse momentum and rapidity in pp collisions at $\sqrt{s} = 7$ TeV, using the $B_s^0 \to J/\psi\,\phi$ decay, and compared with predictions based on perturbative QCD calculations at next-to-leading order. The data sample, collected by the CMS experiment at the LHC, corresponds to an integrated luminosity of $40\,\mathrm{pb}^{-1}$. The B_s^0 is reconstructed from the decays $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$. The integrated B_s^0 cross section times $B_s^0 \to J/\psi\,\phi$ branching fraction in the range $8 < p_T^B < 50$ GeV/c and $|y^B| < 2.4$ is measured to be $6.9 \pm 0.6 \pm 0.6$ nb, where the first uncertainty is statistical and the second is systematic.

Submitted to Physical Review D (Rapid Communications)

*See Appendix A for the list of collaboration members

The measurements of differential cross sections for heavy-quark production in high-energy hadronic interactions are critical input for the underlying next-to-leading order (NLO) Quantum Chromodynamics (QCD) calculations [1]. While progress has been achieved in the understanding of heavy-quark production at Tevatron energies [2–10], large theoretical uncertainties remain due to the dependence on the renormalization and factorization scales. Measurements of b-hadron production at the higher energies provided by the LHC represent an important new test of theoretical approaches that aim to reduce the scale dependence of NLO QCD calculations [11, 12]. The Compact Muon Solenoid (CMS) experiment, that covers a rapidity range complementary to the specialised b-physics experiment LHCb [13], recently measured the cross sections for production of B^+ [14] and B^0 [15] in pp collisions at $\sqrt{s} = 7$ TeV. This paper presents the first measurement of the production of B_s^0, with B_s^0 decaying into $J/\psi\ \phi$, and adds information to improve the understanding of b-quark production at this energy. Data and theoretical predictions are compared at the level of NLO heavy-quark production.

The decay channel $B_s^0 \to J/\psi\ \phi$ is of wide interest for the indirect search of physics beyond the standard model at the LHC. This decay proceeds via the $b \to c\bar{c}s$ transition that probes the CP-violating phase related to B_s^0-$\overline{B}_s^0$ mixing. The standard model predicts this phase to be close to zero [16] while new phenomena may alter the observed phase [17]. The differential production cross section analysis prototypes the signal extraction towards time-dependent measurements in this final state.

A sample of exclusive $B_s^0 \to J/\psi\ \phi$ decays, with $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$, is reconstructed in the data collected in 2010 by the CMS experiment, corresponding to an integrated luminosity of $39.6 \pm 1.6\,\mathrm{pb}^{-1}$. The differential production cross sections, $d\sigma/dp_T^B$ and $d\sigma/dy^B$, are determined as functions of the transverse momentum p_T^B and rapidity $|y^B|$ of the reconstructed B_s^0 candidate. Here, the rapidity y^B is defined as $\frac{1}{2}\ln\frac{E+cp_L}{E-cp_L}$, where E is the particle's energy and p_L is the particle's momentum along the counterclockwise beam direction. The differential cross sections are calculated from the measured signal yields (n_{sig}), corrected for the overall efficiency (ϵ), bin size (Δx, with $x = p_T^B, |y^B|$), and integrated luminosity (L),

$$\frac{d\sigma(pp \to B_s^0 \to J/\psi\ \phi)}{dx} = \frac{n_{sig}}{2 \cdot \epsilon \cdot \mathcal{B} \cdot L \cdot \Delta x}\,, \tag{1}$$

where $\mathcal{B}$ is the product of the branching fractions for the decays of the J/ψ and ϕ mesons. In each bin the signal yield is extracted with an unbinned maximum likelihood fit to the $J/\psi\ \phi$ invariant mass and proper decay length ct of the B_s^0 candidates. The factor of 2 in Eq. (1) accounts for the choice of quoting the cross section for B_s^0 production, while n_{sig} includes both B_s^0 and $\overline{B}_s^0$ states. The size of the bins is chosen such that the statistical uncertainty on n_{sig} is comparable in each of them.

A detailed description of the CMS detector can be found elsewhere [18]. The primary components used in this analysis are the silicon tracker and the muon systems. The tracker operates in a 3.8 T axial magnetic field generated by a superconducting solenoid having an internal diameter of 6 m. The tracker consists of three cylindrical layers of pixel detectors complemented by two disks in the forward and backward directions. The radial region between 20 and 116 cm is occupied by several layers of silicon strip detectors in barrel and disk configurations, ensuring at least nine hits in the pseudorapidity range $|\eta| < 2.4$, where $\eta = -\ln[\tan(\theta/2)]$ and θ is the polar angle of the track relative to the counterclockwise beam direction. An impact parameter resolution around 15 μm and a p_T resolution around 1.5 % are achieved for charged particles with transverse momenta up to 100 GeV/c. Muons are identified in the range $|\eta| < 2.4$, with detection planes made of drift tubes, cathode strip chambers, and resistive plate chambers, embedded in the steel return yoke.

The first level of the CMS trigger system uses information from the crystal electromagnetic calorimeter, the brass/scintillator hadron calorimeter, and the muon detectors to select the most interesting events in less than 1 μs. The high level trigger (HLT) employs software algorithms and a farm of commercial processors to further decrease the event rate using information from all detector subsystems. The events used in the measurement reported in this paper were collected with a trigger requiring the presence of two muons at the HLT, with no explicit momentum threshold.

Reconstruction of $B_s^0 \to J/\psi\ \phi$ candidates begins by identifying $J/\psi \to \mu^+\mu^-$ decays. The muon candidates must have one or more reconstructed segments in the muon system that match the extrapolated position of a track reconstructed in the tracker. Furthermore, the muons are required to lie within a kinematic acceptance region defined as: $p_T^\mu > 3.3$ GeV/c for $|\eta^\mu| < 1.3$; total momentum $p^\mu > 2.9$ GeV/c for $1.3 < |\eta^\mu| < 2.2$; and $p_T^\mu > 0.8$ GeV/c for $2.2 < |\eta^\mu| < 2.4$. Two oppositely charged muon candidates are paired and are required to originate from a common vertex using a Kalman vertex fit. The muon pair is required to have a transverse momentum $p_T > 0.5$ GeV/c and an invariant mass within 150 MeV/c^2 of the world average J/ψ mass value [19], which corresponds to more than three times the measured dimuon invariant mass resolution [20].

Candidate ϕ mesons are reconstructed from pairs of oppositely charged tracks with $p_T > 0.7$ GeV/c that are selected from a sample with the muon candidate tracks removed. The tracks are required to have at least five hits in the silicon tracker detectors, and a track χ^2 per degree of freedom less than five. Each track is assumed to be a kaon and the invariant mass of a track pair has to be within 10 MeV/c^2 of the world average ϕ-meson mass [19].

The B_s^0 candidates are formed by combining a J/ψ with a ϕ candidate. The two muons and the two kaons are subjected to a combined vertex and kinematic fit [21], where in addition the dimuon invariant mass is constrained to the nominal J/ψ mass. The selected candidates must have a resulting χ^2 vertex probability greater than 2%, an invariant mass between 5.20 and 5.65 GeV/c^2, and be in the kinematic range $8 < p_T^B < 50$ GeV/c and $|y^B| < 2.4$. For events with more than one candidate, the one with the highest vertex-fit probability is selected, which results in the correct choice 97% of the time, as determined from simulated signal events.

The proper decay length of each selected B_s^0 candidate is calculated using the formula $ct = c(M_B/p_T^B)L_{xy}$, where the transverse decay length L_{xy} is the length of the vector $\vec{s}$ pointing from the primary vertex [22] to the secondary vertex projected onto the B_s^0 transverse momentum: $L_{xy} = (\vec{s} \cdot \vec{p}_T^B)/p_T^B$, with M_B being the reconstructed mass of the B_s^0 candidate. Candidate B_s^0 mesons are accepted within the range $-0.05 < ct < 0.35$ cm.

A total of 6200 events pass all the selection criteria. The efficiency of the B_s^0 reconstruction is computed with a combination of techniques using the data and large samples of simulated signal events generated using PYTHIA 6.422 [23]. The decays of unstable particles are described by the EVTGEN [24] simulation. Long-lived particles are then propagated through a detailed description of the CMS detector based on the GEANT4 [25] package. The trigger and muon-reconstruction efficiencies are obtained from a large sample of inclusive $J/\psi \to \mu^+\mu^-$ decays in data using a (tag-and-probe) technique similar to that described in Ref. [20], where one muon (the tag) is identified with stringent quality requirements, and the second muon (the probe) is identified using information either exclusively from the tracker (to measure the trigger and muon-identification efficiencies), or from the muon system (to measure the silicon tracking efficiency). The dimuon efficiencies are calculated as the product of the single-muon efficiencies obtained with this method. Corrections to account for correlations between the two muons (1–3%) are obtained from simulation studies. The correction factors are determined in bins of single muon p_{T}^{μ} and η^{μ}, and are applied independently to each muon from a $\mathrm{B_s^0} \to \mathrm{J}/\psi\ \phi$ decay in the simulation to determine the total corrected efficiency. The probabilities for the muons to lie within the kinematic acceptance region and for the ϕ and $\mathrm{B_s^0}$ candidates to pass the selection requirements are determined from the simulated events. The efficiencies for hadronic track reconstruction [26] and the vertex-quality requirement are found to be consistent between real data and simulated events within their uncertainties (up to 5%). The total efficiency of this selection, defined as the fraction of $\mathrm{B_s^0} \to \mathrm{J}/\psi\ \phi$ decays produced with $8 < p_{\mathrm{T}}^{\mathrm{B}} < 50\ \mathrm{GeV}/c$ and $|y^{\mathrm{B}}| < 2.4$ that pass all criteria, ranges from 1.3% for $p_{\mathrm{T}}^{\mathrm{B}} \approx\ 8\ \mathrm{GeV}/c$ to 19.6% for $p_{\mathrm{T}}^{\mathrm{B}} > 23\ \mathrm{GeV}/c$.

Backgrounds are dominated by prompt and non-prompt J/ψ production. The latter background is dominated by B^+ and B^0 mesons that decay to a J/ψ and a higher-mass K-meson state (such as the $\mathrm{K^+}_1$). Such events tend to contribute to the low-mass side of the M_{B} mass distribution. Inspection of a large variety of potential background channels confirms that there is no single dominant component and that the channel $\mathrm{B}^0 \to \mathrm{J}/\psi\ \mathrm{K}^*(892)$ (with $\mathrm{K}^*(892)^0 \to \mathrm{K}^+\pi^-$), which *a priori* is kinematically similar to the signal decay and more abundantly produced, is strongly suppressed by the restriction on the $\mathrm{K^+K^-}$ invariant mass. A study of the sidebands of the dimuon invariant mass distribution confirms that the contamination from events without a J/ψ decay to two muons is negligible after all selection criteria have been applied.

The signal yields in each $p_{\mathrm{T}}^{\mathrm{B}}$ and $|y^{\mathrm{B}}|$ bin, given in Table 1, are obtained using an unbinned extended maximum-likelihood fit to M_{B} and ct. The likelihood for event j is obtained by summing the product of the yield n_i and the probability density functions (PDF) $\mathcal{P}_i$ and $\mathcal{Q}_i$ for each of the signal and background hypotheses i. Three individual components are considered: signal, non-prompt $\mathrm{b} \to \mathrm{J}/\psi\ \mathrm{X}$, and prompt J/ψ. The extended likelihood function is then the product of likelihoods for each event j:

$$\mathcal{L} = \exp\left(-\sum_{i=1}^{3} n_i\right) \prod_j \left[\sum_{i=1}^{3} n_i \mathcal{P}_i(M_{\mathrm{B}};\ \vec{\alpha}_i)\,\mathcal{Q}_i(ct;\ \vec{\beta}_i)\right]. \tag{2}$$

The PDFs $\mathcal{P}_i$ and $\mathcal{Q}_i$ are parameterized separately for each fit component with shape parameters $\vec{\alpha}_i$ for M_{B} and $\vec{\beta}_i$ for ct. The yields n_i are then determined by minimizing the quantity $-\ln\mathcal{L}$ with respect to the signal yields and a subset of the PDF parameters [27]. Possible correlations between M_{B} and ct are found to be less than 2%. Therefore, they are assumed to have a negligible impact on the fit, and potential biases arising from this assumption are accounted for in the systematic uncertainty on the fitted signal yield as described below.

The PDFs are constructed from basic analytical functions that satisfactorily describe the variable distributions from simulated events. Shape parameters are obtained from data when possible. The M_{B} PDF is the sum of two Gaussian functions for the signal, a second-order polynomial for the non-prompt J/ψ that allows for possible curvature in the shape, and a first-order polynomial for prompt J/ψ. The resolution on M_{B} is approximately 20 MeV/c^2 near the $\mathrm{B_s^0}$ mass.

For the signal, the ct PDF is a single exponential parameterized in terms of a proper decay length $c\tau$. It is convolved with a resolution function that is a combination of two Gaussian functions to account for a dominant core and small outlier distribution; the core fraction is varied in the fit and found to be consistently larger than 95%. The ct distribution for the non-prompt J/ψ background is described by a sum of two exponentials, with effective lifetimes that are allowed to be different. The "long-lifetime exponential" corresponds to decays of b-hadrons to a J/ψ plus some charged particles that survive the ϕ selection, while the "short-lifetime exponential"

Table 1: Signal yield $n_{\rm sig}$, efficiency ϵ (%), and measured differential cross sections $d\sigma/dp_{\rm T}^{\rm B}$ and $d\sigma/dy^{\rm B}$, compared to the MC@NLO and PYTHIA predictions, in different $p_{\rm T}^{\rm B}$ and $|y^{\rm B}|$ intervals. The uncertainties on the measured cross sections are statistical and systematic, respectively, excluding the common luminosity of 4% and the 1.4% from the J/ψ and ϕ branching fractions.

$p_{\rm T}^{\rm B}$ (GeV/c)	$n_{\rm sig}$	ϵ (%)	$d\sigma/dp_{\rm T}^{\rm B}$ (nb/ GeV/c)		
			Data	MC@NLO	PYTHIA
8–12	138 ± 16	1.28 ± 0.05	$1.172 \pm 0.136 \pm 0.113$	0.719	1.513
12–16	176 ± 17	5.26 ± 0.23	$0.364 \pm 0.035 \pm 0.034$	0.240	0.515
16–23	162 ± 16	11.9 ± 0.6	$0.085 \pm 0.008 \pm 0.008$	0.074	0.144
23–50	86 ± 11	19.6 ± 1.1	$0.007 \pm 0.001 \pm 0.001$	0.008	0.010
$\lvert y^{\rm B}\rvert$	$n_{\rm sig}$	ϵ (%)	$d\sigma/dy^{\rm B}$ (nb)		
			Data	MC@NLO	PYTHIA
0.00–0.80	151 ± 15	2.75 ± 0.09	$1.484 \pm 0.147 \pm 0.148$	1.040	2.281
0.80–1.40	144 ± 15	4.65 ± 0.18	$1.123 \pm 0.117 \pm 0.102$	1.023	2.051
1.40–1.70	129 ± 15	5.68 ± 0.31	$1.634 \pm 0.190 \pm 0.160$	0.929	1.833
1.70–2.40	139 ± 17	3.26 ± 0.20	$1.316 \pm 0.161 \pm 0.139$	0.801	1.559

accounts for events where the muons from the J/ψ decay are wrongly combined with hadron tracks originating from the pp collision point. The exponential functions are convolved with a resolution function with the same parameters as the signal. For the prompt J/ψ component the pure resolution function is used. The core resolution in ct is measured in data to be 45 μm.

All background shapes are obtained directly from data, while the signal shape in $M_{\rm B}$ is taken from a fit to reconstructed signal events from the simulation. The effective lifetime and resolution function parameters for prompt and non-prompt backgrounds are extracted, using the full data sample irrespectively of $p_{\rm T}^{\rm B}$ and $|y^{\rm B}|$, from regions in $M_{\rm B}$ that are separated by more than four times the width of the observed $\rm B_s^0$ signal from the mean $\rm B_s^0$ peak position ($M_{\rm B}$ sidebands): $5.20 < M_{\rm B} < 5.29\,{\rm GeV}/c^2$ and $5.45 < M_{\rm B} < 5.65\,{\rm GeV}/c^2$. A comparison of the PDF shapes for the different sideband regions in simulated events confirms that their average over the signal-free regions is a good representation of the background in the signal region. With the lifetimes for signal and non-prompt background fixed from this first step, the resolution function parameters are then determined separately in each $p_{\rm T}^{\rm B}$ and $|y^{\rm B}|$ bin, from the $M_{\rm B}$ sidebands. The signal and background yields in each $p_{\rm T}^{\rm B}$ and $|y^{\rm B}|$ bin are determined in a final iteration, using the full $M_{\rm B}$ range, with all parameters floating except the background lifetimes and the lifetime resolution functions, which are fixed to the results of the fit to the $M_{\rm B}$ sidebands. It has been verified that leaving all parameters floating changes the signal yield by an amount smaller than the systematic uncertainty assigned to the fit procedure.

Many detailed studies have been conducted to validate the accuracy and robustness of the fit procedure. A large number of pseudo-experiments were performed, each corresponding to the yields observed in each $p_{\rm T}^{\rm B}$ and $|y^{\rm B}|$ bin for a data sample corresponding to an integrated luminosity of $40\,{\rm pb}^{-1}$, where signal and background events were generated randomly from the PDFs in each bin. The fit yields were found to be unbiased and their uncertainties estimated properly. The effects of residual correlations between $M_{\rm B}$ and ct were studied by mixing fully simulated signal and background events to produce pseudo-experiments. The observed deviations between the fitted and generated yields (1–2%) are taken as the systematic uncertainty due to potential biases in the fit method.

Figure 1 shows the fit projections for M_B and ct from the inclusive sample with $8 < p_T^B < 50$ GeV/c and $|y^B| < 2.4$. When plotting M_B, the selection $ct > 0.01$ cm is applied for better visibility of the individual contributions. The number of signal events in the entire data sample is 549 ± 32, where the uncertainty is statistical only. The obtained proper decay length of the signal, $c\tau = 478 \pm 26$ μm, is within 1.4 standard deviations of the world average value [19], even though this analysis was not optimized for lifetime measurements.

Table 1 summarizes the fitted signal yield in each bin of p_T^B and $|y^B|$. The differential cross section is calculated according to Eq. (1), using the product of the branching fractions $\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-) = (5.93 \pm 0.06) \times 10^{-2}$ and $\mathcal{B}(\phi \rightarrow K^+K^-) = (48.9 \pm 0.5) \times 10^{-2}$ [19]. All efficiencies are calculated separately in each bin, and account for bin-to-bin migrations (less than 1%) due to the finite resolution of the measured momentum and rapidity.

The cross section measurement is affected by several sources of systematic uncertainty arising from uncertainties on the fit, efficiencies, branching fractions, and integrated luminosity. In every bin the total uncertainty is about 11%. Uncertainties on the muon efficiencies from the trigger, identification, and tracking are determined directly from data (3–5%). The uncertainty of the method employed to measure the efficiency in the data has been estimated from a large sample of full-detector simulated events (1–3%). The tracking efficiency for the charged kaons has been shown to be consistent with simulation. A conservative uncertainty of at most 9% in each bin has been assigned for the hadronic track reconstruction (adding linearly the uncertainties on the two kaon tracks [26]), which includes the uncertainty due to misalignment of the silicon detectors. The uncertainty on the fit procedure arising from potential biases and imperfect knowledge of the PDF parameters is estimated by varying the parameters by one standard deviation (2–4%). The contribution related to the B_s^0 momentum spectrum (1–3%) is evaluated by reweighting the shape of the p_T^B distribution generated with PYTHIA to match the spectrum predicted by MC@NLO [28]. An uncertainty of 1% is assigned to the variation of the selection criteria applied to the vertex fit probability, the transverse momentum of the kaons, the B_s^0 transverse momentum, and the K^+K^- invariant mass window. An uncertainty is added to account for the limited number of simulated events (at most 3% in the highest p_T^B bin). The total uncorrelated systematic uncertainty on the cross-section measurement is computed in each bin as the sum in quadrature of the individual uncertainties, and is summarized in Table 1. In addition, there are common uncertainties of 4% from the integrated luminosity measurement [29] and 1.4% from the J/ψ and ϕ branching fractions. As the reported result is a measurement of the B_s^0 cross section times the $B_s^0 \rightarrow J/\psi\, \phi$ branching fraction, the 30% uncertainty on the $B_s^0 \rightarrow J/\psi\, \phi$ branching fraction [19] is not included in the result.

The differential cross sections times branching fraction as functions of p_T^B and $|y^B|$ are listed in Table 1 and plotted in Fig. 2, together with predictions from MC@NLO and PYTHIA. The predictions of MC@NLO use the renormalization and factorization scales $\mu = \sqrt{m_b^2 c^4 + p_T^2 c^2}$, where p_T is the transverse momentum of the b quark, a b-quark mass of $m_b = 4.75$ GeV/c^2, and the CTEQ6M parton distribution functions [30]. The uncertainty on the MC@NLO cross section is obtained simultaneously varying the renormalization and factorization scales by factors of two, varying m_b by ± 0.25 GeV/c^2, and using the CTEQ6.6 parton distribution function set. The prediction of PYTHIA uses the CTEQ6L1 parton distribution functions [30], a b-quark mass of 4.8 GeV/c^2, and the Z2 tune [31] to simulate the underlying event. The total integrated B_s^0 cross section times $B_s^0 \rightarrow J/\psi\, \phi$ branching fraction for the range $8 < p_T^B < 50$ GeV/c and $|y^B| < 2.4$ is measured to be $6.9 \pm 0.6 \pm 0.6$ nb, where the first uncertainty is statistical and the second is systematic. The statistical and systematic uncertainties are derived from the bin-by-bin uncer-

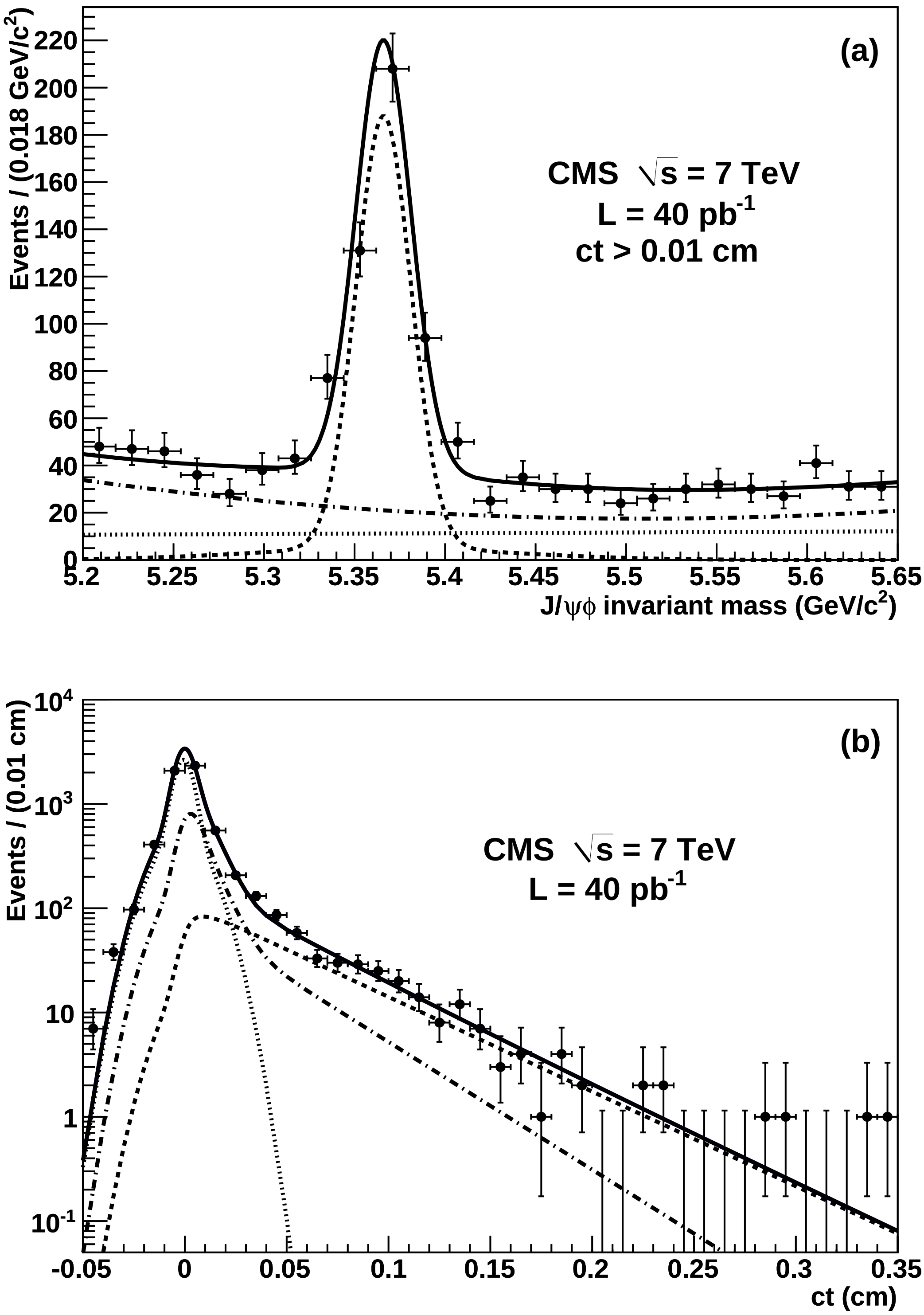
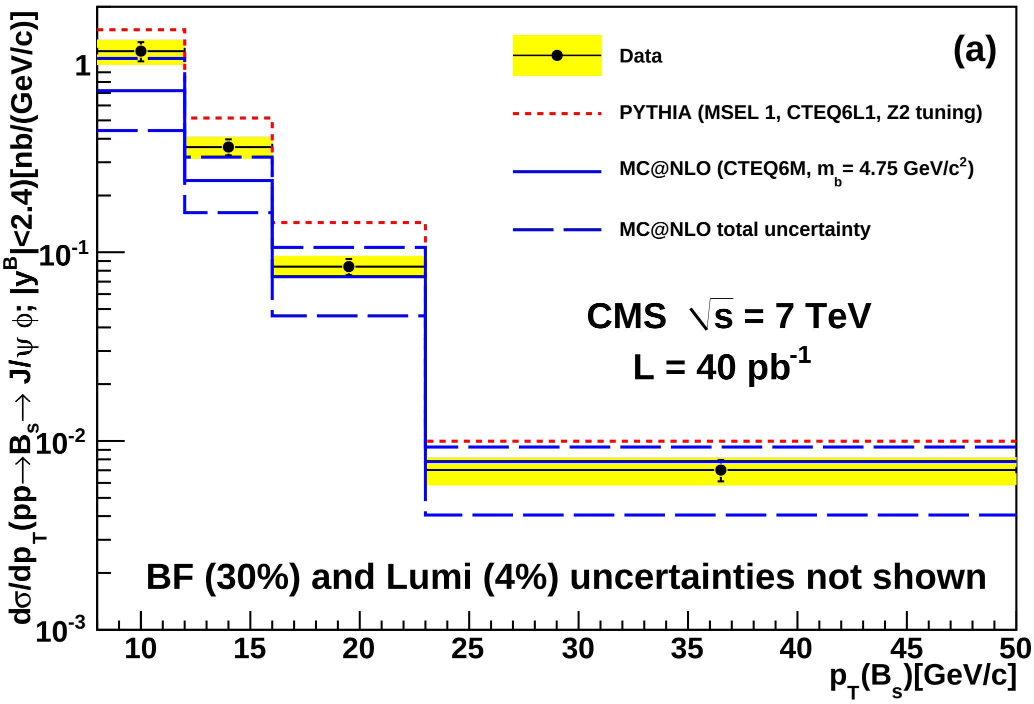


Figure 1: Projections of the fit results in M_{B} (a) and ct (b) for $8 < p_{\mathrm{T}}^{\mathrm{B}} < 50\,\mathrm{GeV}/c$ and $|y^{\mathrm{B}}| < 2.4$. The curves in each plot are: the sum of all contributions (solid line); signal (dashed); prompt J/ψ (dotted); and non-prompt J/ψ (dot-dashed). For better visibility of the individual contributions, plot (a) includes the requirement $ct > 0.01$ cm.



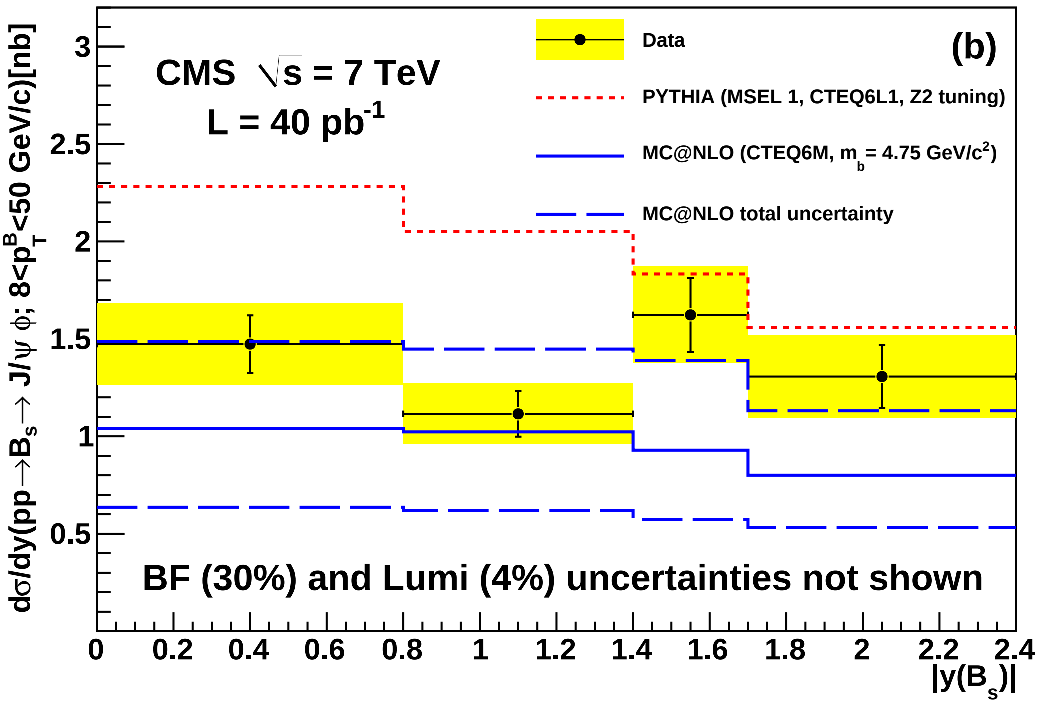


Figure 2: Measured differential cross sections $d\sigma/dp_T^B$ (a) and $d\sigma/dy^B$ (b) compared with theoretical predictions. The (yellow) band represents the sum in quadrature of statistical and systematic uncertainties. The dotted (red) line is the PYTHIA prediction; the solid and dashed (blue) lines are the MC@NLO prediction and its uncertainty, respectively. The common uncertainties of 4% on the data points, due to the integrated luminosity, and of 30% on the theory curves, due to the $B_s^0 \to J/\psi\,\phi$ branching fraction, are not shown.

tainties and propagated through the sum. The result lies between the theoretical predictions of MC@NLO ($4.6^{+1.9}_{-1.7} \pm 1.4$ nb) and PYTHIA (9.4 ± 2.8 nb), where the last uncertainty is from the $B^0_s \to J/\psi\ \phi$ branching fraction [19]. Also the previous CMS cross-section measurements of B^+ [14] and B^0 [15] production in pp collisions at $\sqrt{s} = 7$ TeV, gave values between the two theory predictions, indicating internal consistency amongst the three different B-meson results.

In summary, the first measurements of the B^0_s differential cross sections $d\sigma/dp^B_T$ and $d\sigma/dy^B$, in the decay channel $B^0_s \to J/\psi\ \phi$ and in pp collisions at $\sqrt{s} = 7$ TeV, have been presented. The results cover the kinematical window $|y^B| < 2.4$ and $8 < p^B_T < 50$ GeV/c. They add complementary information to previous results in moving towards a comprehensive description of b-hadron production at $\sqrt{s} = 7$ TeV.

We wish to congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC machine. We thank the technical and administrative staff at CERN and other CMS institutes, and acknowledge support from: FMSR (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); Academy of Sciences and NICPB (Estonia); Academy of Finland, ME, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); PAEC (Pakistan); SCSR (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MST and MAE (Russia); MSTD (Serbia); MICINN and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); TUBITAK and TAEK (Turkey); STFC (United Kingdom); DOE and NSF (USA).

References

[1] P. Nason et al., "The Total Cross-Section for the Production of Heavy Quarks in Hadronic Collisions", *Nucl. Phys. B* **303** (1988) 607. doi:10.1016/0550-3213(88)90422-1.

[2] CDF Collaboration, "Measurement of the bottom quark production cross-section using semileptonic decay electrons in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. Lett.* **71** (1993) 500. doi:10.1103/PhysRevLett.71.500.

[3] CDF Collaboration, "Measurement of the B meson differential cross-section, $d\sigma/dp_T$, in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. Lett.* **75** (1995) 1451. doi:10.1103/PhysRevLett.75.1451.

[4] CDF Collaboration, "Measurement of the B^+ total cross section and B^+ differential cross section $d\sigma/dp_T$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. D* **65** (2002) 052005. doi:10.1103/PhysRevD.65.052005.

[5] D0 Collaboration, "Inclusive μ and b-quark Production Cross Sections in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. Lett.* **74** (1995) 3548. doi:10.1103/PhysRevLett.74.3548.

[6] D0 Collaboration, "Small angle muon and bottom quark production in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. Lett.* **84** (2000) 5478. doi:10.1103/PhysRevLett.84.5478.

[7] D0 Collaboration, "Cross section for b jet production in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. Lett.* **85** (2000) 5068. doi:10.1103/PhysRevLett.85.5068.

[8] CDF Collaboration, “Measurement of the J/ψ meson and b-hadron production cross sections in p$\bar{\text{p}}$ collisions at $\sqrt{s} = 1960\,\text{GeV}$”, *Phys. Rev. D* **71** (2005) 032001. doi:10.1103/PhysRevD.71.032001.

[9] CDF Collaboration, “Measurement of the B^+ production cross section in p$\bar{\text{p}}$ collisions at $\sqrt{s} = 1960\,\text{GeV}$”, *Phys. Rev. D* **75** (2007) 012010. doi:10.1103/PhysRevD.75.012010.

[10] M. Cacciari et al., “QCD analysis of first b cross-section data at 1.96 *TeV*”, *JHEP* **07** (2004) 033. doi:10.1088/1126-6708/2004/07/033.

[11] M. Cacciari et al., “The p_{T} spectrum in heavy-flavour hadroproduction”, *JHEP* **05** (1998) 007. doi:10.1088/1126-6708/1998/05/007.

[12] B. A. Kniehl et al., “Finite-mass effects on inclusive B-meson hadroproduction”, *Phys. Rev. D* **77** (2008) 014011. doi:10.1103/PhysRevD.77.014011.

[13] LHCb Collaboration, “Measurement of $\sigma(\text{pp} \to \text{b}\bar{\text{b}}X)$ at $\sqrt{(s)} = 7\,\text{TeV}$ in the forward region”, *Phys. Lett. B* **694** (2010) 209. doi:10.1016/j.physletb.2010.10.010.

[14] CMS Collaboration, “Measurement of the B^+ production cross section in pp collisions at $\sqrt{s} = 7\,\text{TeV}$”, *Phys. Rev. Lett.* **106** (2011) 112001. doi:10.1103/PhysRevLett.106.112001.

[15] CMS Collaboration, “Measurement of the B^0 production cross section in pp collisions at $\sqrt{s} = 7\,\text{TeV}$”, (2011). arXiv:1104.2892. Submitted to Phys. Rev. Lett.

[16] A. Lenz et al., “Theoretical update of $B_s\bar{B}_s$ mixing”, *JHEP* **0706** (2007) 072. doi:10.1088/1126-6708/2007/06/072.

[17] I. Dunietz et al., “In Pursuit of New Physics with B_s Decays”, *Phys. Rev. D* **63** (2001) 114015. doi:10.1103/PhysRevD.63.114015.

[18] CMS Collaboration, “The CMS experiment at the CERN LHC”, *JINST* **0803** (2008) S08004. doi:10.1088/1748-0221/3/08/S08004.

[19] Particle Data Group Collaboration, “Review of particle physics”, *J. Phys.* **G37** (2010) 075021. doi:10.1088/0954-3899/37/7A/075021.

[20] CMS Collaboration, “Prompt and non-prompt J/ψ production in pp collisions at $\sqrt{s} = 7\,\text{TeV}$”, *Eur. Phys. J. D* **71** (2011) 1575. doi:10.1140/epjc/s10052-011-1575-8.

[21] K. Prokofiev and T. Speer, “A kinematic and a decay chain reconstruction library”, in *Proceedings of Computing in High Energy Physics and Nuclear Physics*, p. 411. Interlaken, Switzerland, September, 2004.

[22] CMS Collaboration, “Tracking and Primary Vertex Results in First 7 TeV Collisions”, *CMS Physics Analysis Summary* **CMS-PAS-TRK-10-005** (2010).

[23] T. Sjöstrand et al., “PYTHIA 6.4 physics and manual”, *JHEP* **05** (2006) 026. doi:10.1088/1126-6708/2006/05/026.

[24] D. J. Lange, “The EvtGen particle decay simulation package”, *Nucl. Instrum. Meth. A* **462** (2001) 152. doi:10.1016/S0168-9002(01)00089-4.

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

[26] CMS Collaboration, "Measurement of Tracking Efficiency", *CMS Physics Analysis Summary* **CMS-PAS-TRK-10-002** (2010).

[27] I. Antcheva et al., "ROOT – A C++ framework for petabyte data storage, statistical analysis and visualization", *Comput. Phys. Commun.* **180** (2009) 2499. doi:10.1016/j.cpc.2009.08.005.

[28] S. Frixione et al., "Matching NLO QCD and parton showers in heavy flavour production", *JHEP* **08** (2003) 007. doi:10.1088/1126-6708/2003/08/007.

[29] CMS Collaboration, "Measurement of CMS Luminosity", *CMS Physics Analysis Summary* **CMS-PAS-EWK-10-004** (2010).

[30] J. Pumplin et al., "New generation of parton distributions with uncertainties from global QCD analysis", *JHEP* **07** (2002) 012. doi:10.1088/1126-6708/2002/07/012.

[31] R. Field, "Early LHC Underlying Event Data–Findings and Surprises", in *Proceedings of the Hadron Collider Physics Symposium*. 2010. arXiv:1010.3558.

A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia
S. Chatrchyan, V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Institut für Hochenergiephysik der OeAW, Wien, Austria
W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan, M. Friedl, R. Frühwirth, V.M. Ghete, J. Hammer[1], S. Hänsel, M. Hoch, N. Hörmann, J. Hrubec, M. Jeitler, W. Kiesenhofer, M. Krammer, D. Liko, I. Mikulec, M. Pernicka, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, F. Teischinger, P. Wagner, W. Waltenberger, G. Walzel, E. Widl, C.-E. Wulz

National Centre for Particle and High Energy Physics, Minsk, Belarus
V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium
S. Bansal, L. Benucci, E.A. De Wolf, X. Janssen, J. Maes, T. Maes, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel

Vrije Universiteit Brussel, Brussel, Belgium
F. Blekman, S. Blyweert, J. D'Hondt, O. Devroede, R. Gonzalez Suarez, A. Kalogeropoulos, M. Maes, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

Université Libre de Bruxelles, Bruxelles, Belgium
O. Charaf, B. Clerbaux, G. De Lentdecker, V. Dero, A.P.R. Gay, G.H. Hammad, T. Hreus, P.E. Marage, L. Thomas, C. Vander Velde, P. Vanlaer

Ghent University, Ghent, Belgium
V. Adler, A. Cimmino, S. Costantini, M. Grunewald, B. Klein, J. Lellouch, A. Marinov, J. Mccartin, D. Ryckbosch, F. Thyssen, M. Tytgat, L. Vanelderen, P. Verwilligen, S. Walsh, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
S. Basegmez, G. Bruno, J. Caudron, L. Ceard, E. Cortina Gil, J. De Favereau De Jeneret, C. Delaere[1], D. Favart, A. Giammanco, G. Grégoire, J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, S. Ovyn, D. Pagano, A. Pin, K. Piotrzkowski, N. Schul

Université de Mons, Mons, Belgium
N. Beliy, T. Caebergs, E. Daubie

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
G.A. Alves, D. De Jesus Damiao, M.E. Pol, M.H.G. Souza

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
W. Carvalho, E.M. Da Costa, C. De Oliveira Martins, S. Fonseca De Souza, L. Mundim, H. Nogima, V. Oguri, W.L. Prado Da Silva, A. Santoro, S.M. Silva Do Amaral, A. Sznajder

Instituto de Fisica Teorica, Universidade Estadual Paulista, Sao Paulo, Brazil
C.A. Bernardes[2], F.A. Dias, T.R. Fernandez Perez Tomei, E. M. Gregores[2], C. Lagana, F. Marinho, P.G. Mercadante[2], S.F. Novaes, Sandra S. Padula

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
N. Darmenov[1], V. Genchev[1], P. Iaydjiev[1], S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov

University of Sofia, Sofia, Bulgaria
A. Dimitrov, R. Hadjiiska, A. Karadzhinova, V. Kozhuharov, L. Litov, M. Mateev, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China
J.G. Bian, G.M. Chen, H.S. Chen, C.H. Jiang, D. Liang, S. Liang, X. Meng, J. Tao, J. Wang, J. Wang, X. Wang, Z. Wang, H. Xiao, M. Xu, J. Zang, Z. Zhang

State Key Lab. of Nucl. Phys. and Tech., Peking University, Beijing, China
Y. Ban, S. Guo, Y. Guo, W. Li, Y. Mao, S.J. Qian, H. Teng, B. Zhu, W. Zou

Universidad de Los Andes, Bogota, Colombia
A. Cabrera, B. Gomez Moreno, A.A. Ocampo Rios, A.F. Osorio Oliveros, J.C. Sanabria

Technical University of Split, Split, Croatia
N. Godinovic, D. Lelas, K. Lelas, R. Plestina[3], D. Polic, I. Puljak

University of Split, Split, Croatia
Z. Antunovic, M. Dzelalija

Institute Rudjer Boskovic, Zagreb, Croatia
V. Brigljevic, S. Duric, K. Kadija, S. Morovic

University of Cyprus, Nicosia, Cyprus
A. Attikis, M. Galanti, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis

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

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
Y. Assran[4], S. Khalil[5], M.A. Mahmoud[6]

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
A. Hektor, M. Kadastik, M. Müntel, M. Raidal, L. Rebane

Department of Physics, University of Helsinki, Helsinki, Finland
V. Azzolini, P. Eerola, G. Fedi

Helsinki Institute of Physics, Helsinki, Finland
S. Czellar, J. Härkönen, A. Heikkinen, V. Karimäki, R. Kinnunen, M.J. Kortelainen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, E. Tuominen, J. Tuominiemi, E. Tuovinen, D. Ungaro, L. Wendland

Lappeenranta University of Technology, Lappeenranta, Finland
K. Banzuzi, A. Karjalainen, A. Korpela, T. Tuuva

Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France
D. Sillou

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France
M. Besancon, S. Choudhury, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, S. Ganjour, F.X. Gentit, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, M. Marionneau, L. Millischer, J. Rander, A. Rosowsky, I. Shreyber, M. Titov, P. Verrecchia

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj[7], C. Broutin, P. Busson, C. Charlot, T. Dahms, L. Dobrzynski, S. Elgammal, R. Granier de Cassagnac, M. Haguenauer, P. Miné, C. Mironov, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Thiebaux, B. Wyslouch[8], A. Zabi

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
J.-L. Agram[9], J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte[9], F. Drouhin[9], C. Ferro, J.-C. Fontaine[9], D. Gelé, U. Goerlach, S. Greder, P. Juillot, M. Karim[9], A.-C. Le Bihan, Y. Mikami, P. Van Hove

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules (IN2P3), Villeurbanne, France
F. Fassi, D. Mercier

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France
C. Baty, S. Beauceron, N. Beaupere, M. Bedjidian, O. Bondu, G. Boudoul, D. Boumediene, H. Brun, J. Chasserat, R. Chierici, D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, B. Ille, T. Kurca, T. Le Grand, M. Lethuillier, L. Mirabito, S. Perries, V. Sordini, S. Tosi, Y. Tschudi, P. Verdier

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

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
G. Anagnostou, S. Beranek, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, N. Mohr, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, M. Weber, B. Wittmer

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
M. Ata, E. Dietz-Laursonn, M. Erdmann, T. Hebbeker, A. Hinzmann, K. Hoepfner, T. Klimkovich, D. Klingebiel, P. Kreuzer, D. Lanske[†], C. Magass, M. Merschmeyer, A. Meyer, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
M. Bontenackels, M. Davids, M. Duda, G. Flügge, H. Geenen, M. Giffels, W. Haj Ahmad, D. Heydhausen, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Linn, A. Nowack, L. Perchalla, O. Pooth, J. Rennefeld, P. Sauerland, A. Stahl, M. Thomas, D. Tornier, M.H. Zoeller

Deutsches Elektronen-Synchrotron, Hamburg, Germany
M. Aldaya Martin, W. Behrenhoff, U. Behrens, M. Bergholz[10], A. Bethani, K. Borras, A. Cakir, A. Campbell, E. Castro, D. Dammann, G. Eckerlin, D. Eckstein, A. Flossdorf, G. Flucke, A. Geiser, J. Hauk, H. Jung[1], M. Kasemann, I. Katkov[11], P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann[10], R. Mankel, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, J. Olzem, A. Petrukhin, D. Pitzl, A. Raspereza, A. Raval, M. Rosin, R. Schmidt[10], T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, J. Tomaszewska, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany
C. Autermann, V. Blobel, S. Bobrovskyi, J. Draeger, H. Enderle, U. Gebbert, M. Görner, K. Kaschube, G. Kaussen, H. Kirschenmann, R. Klanner, J. Lange, B. Mura, S. Naumann-Emme,

F. Nowak, N. Pietsch, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, M. Schröder, T. Schum, J. Schwandt, H. Stadie, G. Steinbrück, J. Thomsen

Institut für Experimentelle Kernphysik, Karlsruhe, Germany
C. Barth, J. Bauer, J. Berger, V. Buege, T. Chwalek, W. De Boer, A. Dierlamm, G. Dirkes, M. Feindt, J. Gruschke, C. Hackstein, F. Hartmann, M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, J.R. Komaragiri, T. Kuhr, D. Martschei, S. Mueller, Th. Müller, M. Niegel, O. Oberst, A. Oehler, J. Ott, T. Peiffer, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, M. Renz, C. Saout, A. Scheurer, P. Schieferdecker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, J. Wagner-Kuhr, T. Weiler, M. Zeise, V. Zhukov[11], E.B. Ziebarth

Institute of Nuclear Physics "Demokritos", Aghia Paraskevi, Greece
G. Daskalakis, T. Geralis, S. Kesisoglou, A. Kyriakis, D. Loukas, I. Manolakos, A. Markou, C. Markou, C. Mavrommatis, E. Ntomari, E. Petrakou

University of Athens, Athens, Greece
L. Gouskos, T.J. Mertzimekis, A. Panagiotou, E. Stiliaris

University of Ioánnina, Ioánnina, Greece
I. Evangelou, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos, V. Patras, F.A. Triantis

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
A. Aranyi, G. Bencze, L. Boldizsar, C. Hajdu[1], P. Hidas, D. Horvath[12], A. Kapusi, K. Krajczar[13], F. Sikler[1], G.I. Veres[13], G. Vesztergombi[13]

Institute of Nuclear Research ATOMKI, Debrecen, Hungary
N. Beni, J. Molnar, J. Palinkas, Z. Szillasi, V. Veszpremi

University of Debrecen, Debrecen, Hungary
P. Raics, Z.L. Trocsanyi, B. Ujvari

Panjab University, Chandigarh, India
S.B. Beri, V. Bhatnagar, N. Dhingra, R. Gupta, M. Jindal, M. Kaur, J.M. Kohli, M.Z. Mehta, N. Nishu, L.K. Saini, A. Sharma, A.P. Singh, J. Singh, S.P. Singh

University of Delhi, Delhi, India
S. Ahuja, B.C. Choudhary, B. Gomber, P. Gupta, S. Jain, S. Jain, R. Khurana, A. Kumar, M. Naimuddin, K. Ranjan, R.K. Shivpuri

Saha Institute of Nuclear Physics, Kolkata, India
S. Bhattacharya, S. Dutta, S. Sarkar

Bhabha Atomic Research Centre, Mumbai, India
R.K. Choudhury, D. Dutta, S. Kailas, V. Kumar, P. Mehta, A.K. Mohanty[1], L.M. Pant, P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India
T. Aziz, M. Guchait[14], A. Gurtu, M. Maity[15], D. Majumder, G. Majumder, K. Mazumdar, G.B. Mohanty, A. Saha, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research - HECR, Mumbai, India
S. Banerjee, S. Dugad, N.K. Mondal

Institute for Research and Fundamental Sciences (IPM), Tehran, Iran
H. Arfaei, H. Bakhshiansohi[16], S.M. Etesami, A. Fahim[16], M. Hashemi, A. Jafari[16], M. Khakzad, A. Mohammadi[17], M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh, M. Zeinali[18]

INFN Sezione di Bari [a], Università di Bari [b], Politecnico di Bari [c], Bari, Italy
M. Abbrescia[a,b], L. Barbone[a,b], C. Calabria[a,b], A. Colaleo[a], D. Creanza[a,c], N. De Filippis[a,c,1], M. De Palma[a,b], L. Fiore[a], G. Iaselli[a,c], L. Lusito[a,b], G. Maggi[a,c], M. Maggi[a], N. Manna[a,b], B. Marangelli[a,b], S. My[a,c], S. Nuzzo[a,b], N. Pacifico[a,b], G.A. Pierro[a], A. Pompili[a,b], G. Pugliese[a,c], F. Romano[a,c], G. Roselli[a,b], G. Selvaggi[a,b], L. Silvestris[a], R. Trentadue[a], S. Tupputi[a,b], G. Zito[a]

INFN Sezione di Bologna [a], Università di Bologna [b], Bologna, Italy
G. Abbiendi[a], A.C. Benvenuti[a], D. Bonacorsi[a], S. Braibant-Giacomelli[a,b], L. Brigliadori[a], P. Capiluppi[a,b], A. Castro[a,b], F.R. Cavallo[a], M. Cuffiani[a,b], G.M. Dallavalle[a], F. Fabbri[a], A. Fanfani[a,b], D. Fasanella[a], P. Giacomelli[a], M. Giunta[a], C. Grandi[a], S. Marcellini[a], G. Masetti[b], M. Meneghelli[a,b], A. Montanari[a], F.L. Navarria[a,b], F. Odorici[a], A. Perrotta[a], F. Primavera[a], A.M. Rossi[a,b], T. Rovelli[a,b], G. Siroli[a,b], R. Travaglini[a,b]

INFN Sezione di Catania [a], Università di Catania [b], Catania, Italy
S. Albergo[a,b], G. Cappello[a,b], M. Chiorboli[a,b,1], S. Costa[a,b], A. Tricomi[a,b], C. Tuve[a,b]

INFN Sezione di Firenze [a], Università di Firenze [b], Firenze, Italy
G. Barbagli[a], V. Ciulli[a,b], C. Civinini[a], R. D'Alessandro[a,b], E. Focardi[a,b], S. Frosali[a,b], E. Gallo[a], S. Gonzi[a,b], P. Lenzi[a,b], M. Meschini[a], S. Paoletti[a], G. Sguazzoni[a], A. Tropiano[a,1]

INFN Laboratori Nazionali di Frascati, Frascati, Italy
L. Benussi, S. Bianco, S. Colafranceschi[19], F. Fabbri, D. Piccolo

INFN Sezione di Genova, Genova, Italy
P. Fabbricatore, R. Musenich

INFN Sezione di Milano-Bicocca [a], Università di Milano-Bicocca [b], Milano, Italy
A. Benaglia[a,b], F. De Guio[a,b,1], L. Di Matteo[a,b], S. Gennai[1], A. Ghezzi[a,b], S. Malvezzi[a], A. Martelli[a,b], A. Massironi[a,b], D. Menasce[a], L. Moroni[a], M. Paganoni[a,b], D. Pedrini[a], S. Ragazzi[a,b], N. Redaelli[a], S. Sala[a], T. Tabarelli de Fatis[a,b]

INFN Sezione di Napoli [a], Università di Napoli "Federico II" [b], Napoli, Italy
S. Buontempo[a], C.A. Carrillo Montoya[a,1], N. Cavallo[a,20], A. De Cosa[a,b], F. Fabozzi[a,20], A.O.M. Iorio[a,1], L. Lista[a], M. Merola[a,b], P. Paolucci[a]

INFN Sezione di Padova [a], Università di Padova [b], Università di Trento (Trento) [c], Padova, Italy
P. Azzi[a], N. Bacchetta[a], P. Bellan[a,b], D. Bisello[a,b], A. Branca[a], R. Carlin[a,b], P. Checchia[a], M. De Mattia[a,b], T. Dorigo[a], U. Dosselli[a], F. Fanzago[a], F. Gasparini[a,b], U. Gasparini[a,b], A. Gozzelino, S. Lacaprara[a,21], I. Lazzizzera[a,c], M. Margoni[a,b], M. Mazzucato[a], A.T. Meneguzzo[a,b], M. Nespolo[a,1], L. Perrozzi[a,1], N. Pozzobon[a,b], P. Ronchese[a,b], F. Simonetto[a,b], E. Torassa[a], M. Tosi[a,b], S. Vanini[a,b], P. Zotto[a,b], G. Zumerle[a,b]

INFN Sezione di Pavia [a], Università di Pavia [b], Pavia, Italy
P. Baesso[a,b], U. Berzano[a], S.P. Ratti[a,b], C. Riccardi[a,b], P. Torre[a,b], P. Vitulo[a,b], C. Viviani[a,b]

INFN Sezione di Perugia [a], Università di Perugia [b], Perugia, Italy
M. Biasini[a,b], G.M. Bilei[a], B. Caponeri[a,b], L. Fanò[a,b], P. Lariccia[a,b], A. Lucaroni[a,b,1], G. Mantovani[a,b], M. Menichelli[a], A. Nappi[a,b], F. Romeo[a,b], A. Santocchia[a,b], S. Taroni[a,b,1], M. Valdata[a,b]

INFN Sezione di Pisa [a], Università di Pisa [b], Scuola Normale Superiore di Pisa [c], Pisa, Italy
P. Azzurri[a,c], G. Bagliesi[a], J. Bernardini[a,b], T. Boccali[a,1], G. Broccolo[a,c], R. Castaldi[a], R.T. D'Agnolo[a,c], R. Dell'Orso[a], F. Fiori[a,b], L. Foà[a,c], A. Giassi[a], A. Kraan[a], F. Ligabue[a,c],

T. Lomtadze[a], L. Martini[a,22], A. Messineo[a,b], F. Palla[a], G. Segneri[a], A.T. Serban[a], P. Spagnolo[a], R. Tenchini[a], G. Tonelli[a,b,1], A. Venturi[a,1], P.G. Verdini[a]

INFN Sezione di Roma [a], Università di Roma "La Sapienza" [b], Roma, Italy
L. Barone[a,b], F. Cavallari[a], D. Del Re[a,b], E. Di Marco[a,b], M. Diemoz[a], D. Franci[a,b], M. Grassi[a,1], E. Longo[a,b], P. Meridiani, S. Nourbakhsh[a], G. Organtini[a,b], F. Pandolfi[a,b,1], R. Paramatti[a], S. Rahatlou[a,b], C. Rovelli[1]

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], C. Biino[a], C. Botta[a,b,1], N. Cartiglia[a], R. Castello[a,b], M. Costa[a,b], N. Demaria[a], A. Graziano[a,b,1], C. Mariotti[a], M. Marone[a,b], S. Maselli[a], E. Migliore[a,b], G. Mila[a,b], V. Monaco[a,b], M. Musich[a,b], M.M. Obertino[a,c], N. Pastrone[a], M. Pelliccioni[a,b], A. Potenza[a,b], A. Romero[a,b], M. Ruspa[a,c], R. Sacchi[a,b], V. Sola[a,b], A. Solano[a,b], A. Staiano[a], A. Vilela Pereira[a]

INFN Sezione di Trieste [a], Università di Trieste [b], Trieste, Italy
S. Belforte[a], F. Cossutti[a], G. Della Ricca[a,b], B. Gobbo[a], D. Montanino[a,b], A. Penzo[a]

Kangwon National University, Chunchon, Korea
S.G. Heo, S.K. Nam

Kyungpook National University, Daegu, Korea
S. Chang, J. Chung, D.H. Kim, G.N. Kim, J.E. Kim, D.J. Kong, H. Park, S.R. Ro, D. Son, D.C. Son, T. Son

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
Zero Kim, J.Y. Kim, S. Song

Korea University, Seoul, Korea
S. Choi, B. Hong, M. Jo, H. Kim, J.H. Kim, T.J. Kim, K.S. Lee, D.H. Moon, S.K. Park, K.S. Sim

University of Seoul, Seoul, Korea
M. Choi, S. Kang, H. Kim, C. Park, I.C. Park, S. Park, G. Ryu

Sungkyunkwan University, Suwon, Korea
Y. Choi, Y.K. Choi, J. Goh, M.S. Kim, E. Kwon, J. Lee, S. Lee, H. Seo, I. Yu

Vilnius University, Vilnius, Lithuania
M.J. Bilinskas, I. Grigelionis, M. Janulis, D. Martisiute, P. Petrov, T. Sabonis

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz, R. Lopez-Fernandez, R. Magaña Villalba, A. Sánchez-Hernández, L.M. Villasenor-Cendejas

Universidad Iberoamericana, Mexico City, Mexico
S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
H.A. Salazar Ibarguen

Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
E. Casimiro Linares, A. Morelos Pineda, M.A. Reyes-Santos

University of Auckland, Auckland, New Zealand
D. Krofcheck, J. Tam

University of Canterbury, Christchurch, New Zealand
P.H. Butler, R. Doesburg, H. Silverwood

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
M. Ahmad, I. Ahmed, M.I. Asghar, H.R. Hoorani, W.A. Khan, T. Khurshid, S. Qazi

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
G. Brona, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski

Soltan Institute for Nuclear Studies, Warsaw, Poland
T. Frueboes, R. Gokieli, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
N. Almeida, P. Bargassa, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, P. Musella, A. Nayak, J. Pela[1], P.Q. Ribeiro, J. Seixas, J. Varela

Joint Institute for Nuclear Research, Dubna, Russia
S. Afanasiev, I. Belotelov, P. Bunin, I. Golutvin, A. Kamenev, V. Karjavin, G. Kozlov, A. Lanev, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, V. Smirnov, A. Volodko, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St Petersburg), Russia
V. Golovtsov, Y. Ivanov, V. Kim, 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, V. Matveev, A. Pashenkov, A. Toropin, S. Troitsky

Institute for Theoretical and Experimental Physics, Moscow, Russia
V. Epshteyn, V. Gavrilov, V. Kaftanov[†], M. Kossov[1], A. Krokhotin, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

Moscow State University, Moscow, Russia
E. Boos, M. Dubinin[23], L. Dudko, A. Ershov, A. Gribushin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushanko, L. Sarycheva, V. Savrin, A. Snigirev

P.N. Lebedev Physical Institute, Moscow, Russia
V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Leonidov, S.V. Rusakov, A. Vinogradov

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia
I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin[1], V. Kachanov, D. Konstantinov, A. Korablev, 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. Adzic[24], M. Djordjevic, D. Krpic[24], J. Milosevic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
M. Aguilar-Benitez, J. Alcaraz Maestre, P. Arce, C. Battilana, E. Calvo, M. Cepeda, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, C. Diez Pardos, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz,

P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, J. Puerta Pelayo, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain
C. Albajar, G. Codispoti, J.F. de Trocóniz

Universidad de Oviedo, Oviedo, Spain
J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J.M. Vizan Garcia

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Felcini[25], M. Fernandez, G. Gomez, J. Gonzalez Sanchez, C. Jorda, P. Lobelle Pardo, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, J. Piedra Gomez[26], T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, M. Sobron Sanudo, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland
D. Abbaneo, E. Auffray, G. Auzinger, P. Baillon, A.H. Ball, D. Barney, A.J. Bell[27], D. Benedetti, C. Bernet[3], W. Bialas, P. Bloch, A. Bocci, S. Bolognesi, M. Bona, H. Breuker, K. Bunkowski, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, B. Curé, D. D'Enterria, A. De Roeck, S. Di Guida, N. Dupont-Sagorin, A. Elliott-Peisert, B. Frisch, W. Funk, A. Gaddi, G. Georgiou, H. Gerwig, D. Gigi, K. Gill, D. Giordano, F. Glege, R. Gomez-Reino Garrido, M. Gouzevitch, P. Govoni, S. Gowdy, L. Guiducci, M. Hansen, C. Hartl, J. Harvey, J. Hegeman, B. Hegner, H.F. Hoffmann, A. Honma, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, P. Lecoq, C. Lourenço, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, A. Maurisset, F. Meijers, S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, E. Nesvold[1], M. Nguyen, T. Orimoto, L. Orsini, E. Perez, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, A. Racz, J. Rodrigues Antunes, G. Rolandi[28], T. Rommerskirchen, M. Rovere, H. Sakulin, C. Schäfer, C. Schwick, I. Segoni, A. Sharma, P. Siegrist, M. Simon, P. Sphicas[29], M. Spiropulu[23], M. Stoye, P. Tropea, A. Tsirou, P. Vichoudis, M. Voutilainen, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland
W. Bertl, K. Deiters, W. Erdmann, K. Gabathuler, R. Horisberger, Q. Ingram, H.C. Kaestli, S. König, D. Kotlinski, U. Langenegger, F. Meier, D. Renker, T. Rohe, J. Sibille[30], A. Starodumov[31]

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland
L. Bäni, P. Bortignon, L. Caminada[32], N. Chanon, Z. Chen, S. Cittolin, G. Dissertori, M. Dittmar, J. Eugster, K. Freudenreich, C. Grab, W. Hintz, P. Lecomte, W. Lustermann, C. Marchica[32], P. Martinez Ruiz del Arbol, P. Milenovic[33], F. Moortgat, C. Nägeli[32], P. Nef, F. Nessi-Tedaldi, L. Pape, F. Pauss, T. Punz, A. Rizzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, M.-C. Sawley, B. Stieger, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, M. Weber, L. Wehrli, J. Weng

Universität Zürich, Zurich, Switzerland
E. Aguilo, C. Amsler, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Millan Mejias, P. Otiougova, C. Regenfus, P. Robmann, A. Schmidt, H. Snoek

National Central University, Chung-Li, Taiwan
Y.H. Chang, K.H. Chen, C.M. Kuo, S.W. Li, W. Lin, Z.K. Liu, Y.J. Lu, D. Mekterovic, R. Volpe, J.H. Wu, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan
P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, R.-S. Lu, J.G. Shiu, Y.M. Tzeng, M. Wang

Cukurova University, Adana, Turkey
A. Adiguzel, M.N. Bakirci[34], S. Cerci[35], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, I. Hos, E.E. Kangal, A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk[36], A. Polatoz, K. Sogut[37], D. Sunar Cerci[35], B. Tali[35], H. Topakli[34], D. Uzun, L.N. Vergili, M. Vergili

Middle East Technical University, Physics Department, Ankara, Turkey
I.V. Akin, T. Aliev, B. Bilin, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, E. Yildirim, M. Zeyrek

Bogazici University, Istanbul, Turkey
M. Deliomeroglu, D. Demir[38], E. Gülmez, B. Isildak, M. Kaya[39], O. Kaya[39], M. Özbek, S. Ozkorucuklu[40], N. Sonmez[41]

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine
L. Levchuk

University of Bristol, Bristol, United Kingdom
F. Bostock, J.J. Brooke, T.L. Cheng, E. Clement, D. Cussans, R. Frazier, J. Goldstein, M. Grimes, M. Hansen, D. Hartley, G.P. Heath, H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold[42], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, S. Ward

Rutherford Appleton Laboratory, Didcot, United Kingdom
L. Basso[43], K.W. Bell, A. Belyaev[43], C. Brew, R.M. Brown, B. Camanzi, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley, S.D. Worm

Imperial College, London, United Kingdom
R. Bainbridge, G. Ball, J. Ballin, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, L. Lyons, B.C. MacEvoy, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko[31], A. Papageorgiou, M. Pesaresi, K. Petridis, M. Pioppi[44], D.M. Raymond, S. Rogerson, N. Rompotis, A. Rose, M.J. Ryan, C. Seez, P. Sharp, A. Sparrow, A. Tapper, S. Tourneur, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, D. Wardrope, T. Whyntie

Brunel University, Uxbridge, United Kingdom
M. Barrett, M. Chadwick, J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leslie, W. Martin, I.D. Reid, L. Teodorescu

Baylor University, Waco, USA
K. Hatakeyama, H. Liu

The University of Alabama, Tuscaloosa, USA
C. Henderson

Boston University, Boston, USA
T. Bose, E. Carrera Jarrin, C. Fantasia, A. Heister, J. St. John, P. Lawson, D. Lazic, J. Rohlf, D. Sperka, L. Sulak

Brown University, Providence, USA
A. Avetisyan, S. Bhattacharya, J.P. Chou, D. Cutts, A. Ferapontov, U. Heintz, S. Jabeen,

G. Kukartsev, G. Landsberg, M. Luk, M. Narain, D. Nguyen, M. Segala, T. Sinthuprasith, T. Speer, K.V. Tsang

University of California, Davis, Davis, USA
R. Breedon, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, P.T. Cox, J. Dolen, R. Erbacher, E. Friis, W. Ko, A. Kopecky, R. Lander, H. Liu, S. Maruyama, T. Miceli, M. Nikolic, D. Pellett, J. Robles, S. Salur, T. Schwarz, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra, C. Veelken

University of California, Los Angeles, Los Angeles, USA
V. Andreev, K. Arisaka, D. Cline, R. Cousins, A. Deisher, J. Duris, S. Erhan, C. Farrell, J. Hauser, M. Ignatenko, C. Jarvis, C. Plager, G. Rakness, P. Schlein[†], J. Tucker, V. Valuev

University of California, Riverside, Riverside, USA
J. Babb, A. Chandra, R. Clare, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng, S.C. Kao, F. Liu, H. Liu, O.R. Long, A. Luthra, H. Nguyen, B.C. Shen[†], R. Stringer, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

University of California, San Diego, La Jolla, USA
W. Andrews, J.G. Branson, G.B. Cerati, D. Evans, F. Golf, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, B. Mangano, S. Padhi, C. Palmer, G. Petrucciani, H. Pi, M. Pieri, R. Ranieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech[45], F. Würthwein, A. Yagil, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA
D. Barge, R. Bellan, C. Campagnari, M. D'Alfonso, T. Danielson, K. Flowers, P. Geffert, J. Incandela, C. Justus, P. Kalavase, S.A. Koay, D. Kovalskyi, V. Krutelyov, S. Lowette, N. Mccoll, V. Pavlunin, F. Rebassoo, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, J.R. Vlimant

California Institute of Technology, Pasadena, USA
A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, M. Gataullin, Y. Ma, A. Mott, H.B. Newman, C. Rogan, K. Shin, V. Timciuc, P. Traczyk, J. Veverka, R. Wilkinson, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA
B. Akgun, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, S.Y. Jun, Y.F. Liu, M. Paulini, J. Russ, H. Vogel, I. Vorobiev

University of Colorado at Boulder, Boulder, USA
J.P. Cumalat, M.E. Dinardo, B.R. Drell, C.J. Edelmaier, W.T. Ford, A. Gaz, B. Heyburn, E. Luiggi Lopez, U. Nauenberg, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner, S.L. Zang

Cornell University, Ithaca, USA
L. Agostino, J. Alexander, D. Cassel, A. Chatterjee, S. Das, N. Eggert, L.K. Gibbons, B. Heltsley, W. Hopkins, A. Khukhunaishvili, B. Kreis, G. Nicolas Kaufman, J.R. Patterson, D. Puigh, A. Ryd, E. Salvati, X. Shi, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Vaughan, Y. Weng, L. Winstrom, P. Wittich

Fairfield University, Fairfield, USA
A. Biselli, G. Cirino, D. Winn

Fermi National Accelerator Laboratory, Batavia, USA
S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, M. Atac, J.A. Bakken, S. Banerjee, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, I. Bloch, F. Borcherding, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, S. Cihangir, W. Cooper, D.P. Eartly, V.D. Elvira, S. Esen, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, D. Green, K. Gunthoti,

O. Gutsche, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, H. Jensen, M. Johnson, U. Joshi, R. Khatiwada, B. Klima, K. Kousouris, S. Kunori, S. Kwan, C. Leonidopoulos, P. Limon, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, D. Mason, P. McBride, T. Miao, K. Mishra, S. Mrenna, Y. Musienko[46], C. Newman-Holmes, V. O'Dell, R. Pordes, O. Prokofyev, N. Saoulidou, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, P. Tan, L. Taylor, S. Tkaczyk, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, F. Yumiceva, J.C. Yun

University of Florida, Gainesville, USA
D. Acosta, P. Avery, D. Bourilkov, M. Chen, M. De Gruttola, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, K. Matchev, G. Mitselmakher, L. Muniz, C. Prescott, R. Remington, M. Schmitt, B. Scurlock, P. Sellers, N. Skhirtladze, M. Snowball, D. Wang, J. Yelton, M. Zakaria

Florida International University, Miami, USA
C. Ceron, V. Gaultney, L. Kramer, L.M. Lebolo, S. Linn, P. Markowitz, G. Martinez, D. Mesa, J.L. Rodriguez

Florida State University, Tallahassee, USA
T. Adams, A. Askew, J. Bochenek, J. Chen, B. Diamond, S.V. Gleyzer, J. Haas, S. Hagopian, V. Hagopian, M. Jenkins, K.F. Johnson, H. Prosper, L. Quertenmont, S. Sekmen, V. Veeraraghavan

Florida Institute of Technology, Melbourne, USA
M.M. Baarmand, B. Dorney, S. Guragain, M. Hohlmann, H. Kalakhety, R. Ralich, I. Vodopiyanov

University of Illinois at Chicago (UIC), Chicago, USA
M.R. Adams, I.M. Anghel, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, J. Callner, R. Cavanaugh, C. Dragoiu, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, G.J. Kunde[47], F. Lacroix, M. Malek, C. O'Brien, C. Silkworth, C. Silvestre, A. Smoron, D. Strom, N. Varelas

The University of Iowa, Iowa City, USA
U. Akgun, E.A. Albayrak, B. Bilki, W. Clarida, F. Duru, C.K. Lae, E. McCliment, J.-P. Merlo, H. Mermerkaya[48], A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, J. Olson, Y. Onel, F. Ozok, S. Sen, J. Wetzel, T. Yetkin, K. Yi

Johns Hopkins University, Baltimore, USA
B.A. Barnett, B. Blumenfeld, A. Bonato, C. Eskew, D. Fehling, G. Giurgiu, A.V. Gritsan, Z.J. Guo, G. Hu, P. Maksimovic, S. Rappoccio, M. Swartz, N.V. Tran, A. Whitbeck

The University of Kansas, Lawrence, USA
P. Baringer, A. Bean, G. Benelli, O. Grachov, R.P. Kenny Iii, M. Murray, D. Noonan, S. Sanders, J.S. Wood, V. Zhukova

Kansas State University, Manhattan, USA
A.F. Barfuss, T. Bolton, I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, S. Shrestha, I. Svintradze, Z. Wan

Lawrence Livermore National Laboratory, Livermore, USA
J. Gronberg, D. Lange, D. Wright

University of Maryland, College Park, USA
A. Baden, M. Boutemeur, S.C. Eno, D. Ferencek, J.A. Gomez, N.J. Hadley, R.G. Kellogg, M. Kirn,

Y. Lu, A.C. Mignerey, K. Rossato, P. Rumerio, F. Santanastasio, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar, E. Twedt

Massachusetts Institute of Technology, Cambridge, USA
B. Alver, G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, P. Everaerts, G. Gomez Ceballos, M. Goncharov, K.A. Hahn, P. Harris, Y. Kim, M. Klute, Y.-J. Lee, W. Li, C. Loizides, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, M. Rudolph, G.S.F. Stephans, F. Stöckli, K. Sumorok, K. Sung, E.A. Wenger, R. Wolf, S. Xie, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti

University of Minnesota, Minneapolis, USA
S.I. Cooper, P. Cushman, B. Dahmes, A. De Benedetti, P.R. Dudero, G. Franzoni, J. Haupt, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, V. Rekovic, R. Rusack, M. Sasseville, A. Singovsky, N. Tambe

University of Mississippi, University, USA
L.M. Cremaldi, R. Godang, R. Kroeger, L. Perera, R. Rahmat, D.A. Sanders, D. Summers

University of Nebraska-Lincoln, Lincoln, USA
K. Bloom, S. Bose, J. Butt, D.R. Claes, A. Dominguez, M. Eads, J. Keller, T. Kelly, I. Kravchenko, J. Lazo-Flores, H. Malbouisson, S. Malik, G.R. Snow

State University of New York at Buffalo, Buffalo, USA
U. Baur, A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S.P. Shipkowski, K. Smith

Northeastern University, Boston, USA
G. Alverson, E. Barberis, D. Baumgartel, O. Boeriu, M. Chasco, S. Reucroft, J. Swain, D. Trocino, D. Wood, J. Zhang

Northwestern University, Evanston, USA
A. Anastassov, A. Kubik, N. Odell, R.A. Ofierzynski, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, M. Velasco, S. Won

University of Notre Dame, Notre Dame, USA
L. Antonelli, D. Berry, A. Brinkerhoff, M. Hildreth, C. Jessop, D.J. Karmgard, J. Kolb, T. Kolberg, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, R. Ruchti, J. Slaunwhite, N. Valls, M. Wayne, J. Ziegler

The Ohio State University, Columbus, USA
B. Bylsma, L.S. Durkin, J. Gu, C. Hill, P. Killewald, K. Kotov, T.Y. Ling, M. Rodenburg, G. Williams

Princeton University, Princeton, USA
N. Adam, E. Berry, P. Elmer, D. Gerbaudo, V. Halyo, P. Hebda, A. Hunt, J. Jones, E. Laird, D. Lopes Pegna, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, H. Saka, D. Stickland, C. Tully, J.S. Werner, A. Zuranski

University of Puerto Rico, Mayaguez, USA
J.G. Acosta, X.T. Huang, A. Lopez, H. Mendez, S. Oliveros, J.E. Ramirez Vargas, A. Zatserklyaniy

Purdue University, West Lafayette, USA
E. Alagoz, V.E. Barnes, G. Bolla, L. Borrello, D. Bortoletto, A. Everett, A.F. Garfinkel, L. Gutay, Z. Hu, M. Jones, O. Koybasi, M. Kress, A.T. Laasanen, N. Leonardo, C. Liu, V. Maroussov,

P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA
P. Jindal, N. Parashar

Rice University, Houston, USA
C. Boulahouache, K.M. Ecklund, F.J.M. Geurts, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

University of Rochester, Rochester, USA
B. Betchart, A. Bodek, Y.S. Chung, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, H. Flacher, A. Garcia-Bellido, P. Goldenzweig, Y. Gotra, J. Han, A. Harel, D.C. Miner, D. Orbaker, G. Petrillo, D. Vishnevskiy, M. Zielinski

The Rockefeller University, New York, USA
A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, S. Malik, C. Mesropian, M. Yan

Rutgers, the State University of New Jersey, Piscataway, USA
O. Atramentov, A. Barker, D. Duggan, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, D. Hits, A. Lath, S. Panwalkar, R. Patel, K. Rose, S. Schnetzer, S. Somalwar, R. Stone, S. Thomas

University of Tennessee, Knoxville, USA
G. Cerizza, M. Hollingsworth, S. Spanier, Z.C. Yang, A. York

Texas A&M University, College Station, USA
R. Eusebi, W. Flanagan, J. Gilmore, A. Gurrola, T. Kamon, V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, J. Pivarski, A. Safonov, S. Sengupta, A. Tatarinov, D. Toback, M. Weinberger

Texas Tech University, Lubbock, USA
N. Akchurin, C. Bardak, J. Damgov, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, P. Mane, Y. Roh, A. Sill, I. Volobouev, R. Wigmans, E. Yazgan

Vanderbilt University, Nashville, USA
E. Appelt, E. Brownson, D. Engh, C. Florez, W. Gabella, M. Issah, W. Johns, P. Kurt, C. Maguire, A. Melo, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, USA
M.W. Arenton, M. Balazs, S. Boutle, B. Cox, B. Francis, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, R. Yohay

Wayne State University, Detroit, USA
S. Gollapinni, R. Harr, P.E. Karchin, P. Lamichhane, M. Mattson, C. Milstène, A. Sakharov

University of Wisconsin, Madison, USA
M. Anderson, M. Bachtis, J.N. Bellinger, D. Carlsmith, S. Dasu, J. Efron, K. Flood, L. Gray, K.S. Grogg, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, J. Klukas, A. Lanaro, C. Lazaridis, J. Leonard, R. Loveless, A. Mohapatra, F. Palmonari, D. Reeder, I. Ross, A. Savin, W.H. Smith, J. Swanson, M. Weinberg

†: Deceased
1: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
2: Also at Universidade Federal do ABC, Santo Andre, Brazil
3: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
4: Also at Suez Canal University, Suez, Egypt
5: Also at British University, Cairo, Egypt

6: Also at Fayoum University, El-Fayoum, Egypt
7: Also at Soltan Institute for Nuclear Studies, Warsaw, Poland
8: Also at Massachusetts Institute of Technology, Cambridge, USA
9: Also at Université de Haute-Alsace, Mulhouse, France
10: Also at Brandenburg University of Technology, Cottbus, Germany
11: Also at Moscow State University, Moscow, Russia
12: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
13: Also at Eötvös Loránd University, Budapest, Hungary
14: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
15: Also at University of Visva-Bharati, Santiniketan, India
16: Also at Sharif University of Technology, Tehran, Iran
17: Also at Shiraz University, Shiraz, Iran
18: Also at Isfahan University of Technology, Isfahan, Iran
19: Also at Facoltà Ingegneria Università di Roma "La Sapienza", Roma, Italy
20: Also at Università della Basilicata, Potenza, Italy
21: Also at Laboratori Nazionali di Legnaro dell' INFN, Legnaro, Italy
22: Also at Università degli studi di Siena, Siena, Italy
23: Also at California Institute of Technology, Pasadena, USA
24: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
25: Also at University of California, Los Angeles, Los Angeles, USA
26: Also at University of Florida, Gainesville, USA
27: Also at Université de Genève, Geneva, Switzerland
28: Also at Scuola Normale e Sezione dell' INFN, Pisa, Italy
29: Also at University of Athens, Athens, Greece
30: Also at The University of Kansas, Lawrence, USA
31: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
32: Also at Paul Scherrer Institut, Villigen, Switzerland
33: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
34: Also at Gaziosmanpasa University, Tokat, Turkey
35: Also at Adiyaman University, Adiyaman, Turkey
36: Also at The University of Iowa, Iowa City, USA
37: Also at Mersin University, Mersin, Turkey
38: Also at Izmir Institute of Technology, Izmir, Turkey
39: Also at Kafkas University, Kars, Turkey
40: Also at Suleyman Demirel University, Isparta, Turkey
41: Also at Ege University, Izmir, Turkey
42: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
43: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
44: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
45: Also at Utah Valley University, Orem, USA
46: Also at Institute for Nuclear Research, Moscow, Russia
47: Also at Los Alamos National Laboratory, Los Alamos, USA
48: Also at Erzincan University, Erzincan, Turkey