Year: 2011

Inclusive b-hadron production cross section with muons in pp collisions at $\sqrt{s} = 7$ TeV

CMS Collaboration ; Amsler, C ; Chiochia, V ; Snoek, H ; Favaro, C ; Verzetti, M ; De Visscher, S ; Aguiló, E ; Schmitt, A ; Otyugova, P ; Ivova, M ; Millan, B ; Storey, J

Abstract: A measurement of the b-hadron production cross section in proton-proton collisions at sqrt(s)=7 TeV is presented. The dataset, corresponding to 85 inverse nanobarns, was recorded with the CMS experiment at the LHC using a low-threshold single-muon trigger. Events are selected by the presence of a muon with transverse momentum greater than 6 GeV with respect to the beam direction and pseudorapidity less than 2.1. The transverse momentum of the muon with respect to the closest jet discriminates events containing b hadrons from background. The inclusive b-hadron production cross section is presented as a function of muon transverse momentum and pseudorapidity. The measured total cross section in the kinematic acceptance is sigma(pp to b+X to mu + X') =1.32 +/- 0.01 (stat) +/- 0.30 (syst) +/- 0.15 (lumi) microbarns.

DOI: https://doi.org/10.1007/JHEP03(2011)090

Originally published at:
CMS Collaboration; Amsler, C; Chiochia, V; Snoek, H; Favaro, C; Verzetti, M; De Visscher, S; Aguiló, E; Schmitt, A; Otyugova, P; Ivova, M; Millan, B; Storey, J (2011). Inclusive b-hadron production cross section with muons in pp collisions at $\sqrt{s} = 7$ TeV. Journal of High Energy Physics, (3):90.
DOI: https://doi.org/10.1007/JHEP03(2011)090

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2010-088
2011/01/17

CMS-BPH-10-007

Inclusive b-hadron production cross section with muons in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$

The CMS Collaboration[*]

Abstract

A measurement of the b-hadron production cross section in proton-proton collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ is presented. The dataset, corresponding to $85\,\mathrm{nb}^{-1}$, was recorded with the CMS experiment at the LHC using a low-threshold single-muon trigger. Events are selected by the presence of a muon with transverse momentum $p_{\mathrm{T}}^{\mu} > 6\,\mathrm{GeV}$ with respect to the beam direction and pseudorapidity $|\eta^{\mu}| < 2.1$. The transverse momentum of the muon with respect to the closest jet discriminates events containing b hadrons from background. The inclusive b-hadron production cross section is presented as a function of muon transverse momentum and pseudorapidity. The measured total cross section in the kinematic acceptance is $\sigma(\mathrm{pp} \to \mathrm{b} + X \to \mu + X') = 1.32 \pm 0.01(\mathrm{stat}) \pm 0.30(\mathrm{syst}) \pm 0.15(\mathrm{lumi})\,\mu\mathrm{b}$.

Submitted to the Journal of High Energy Physics

---

[*] See Appendix A for the list of collaboration members

1 Introduction

Measurements of b-hadron production in proton-proton (pp) collisions at the Large Hadron Collider (LHC) are important tests of Quantum Chromodynamics (QCD) in a new kinematical region. Results on b-hadron production in proton-antiproton collisions at the lower center-of-mass energies, $\sqrt{s}$, of the CERN Sp$\bar{\mathrm{p}}$S Collider [1] and the Tevatron [2–5] have aroused substantial interest because of tensions between the experimental results and the theoretical expectations [6, 7]. First results at the LHC from pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ have been reported by the LHCb collaboration for the forward rapidity region using semi-inclusive decays [8] and by the CMS collaboration in the central rapidity region using fully reconstructed B^+ hadron decays [9].

The b-quark production cross section in hadron collisions has been computed at next-to-leading order (NLO) in perturbative QCD [10–12]. The observed large scale dependence of the NLO results is considered to be a symptom of large contributions from higher orders: small-x effects [13, 14], where $x \sim m_\mathrm{b}/\sqrt{s}$, are possibly relevant in the low-p_T domain, while multiple-gluon radiation leads to large logarithms of $p_\mathrm{T}/m_\mathrm{b}$ and may be important at high p_T [15]. The resummed logarithms of $p_\mathrm{T}/m_\mathrm{b}$ at next-to-leading-logarithmic accuracy have been matched to the fixed-order NLO calculation for massive quarks [16]. At the non-perturbative level, the b-hadron p_T spectrum depends strongly on the parametrization of the fragmentation function [17]. The b-quark production cross section has also been studied in the general-mass variable-flavor-number scheme [18] and the k_T factorization QCD approach [19, 20].

In this paper we present an inclusive measurement of the production of b hadrons decaying into muons and jets based on $85\,\mathrm{nb}^{-1}$ of data recorded by the CMS experiment using a low-threshold single-muon trigger. Muons from b-hadron decays are distinguished from backgrounds based on their transverse momentum relative to a nearby jet ($p_\perp^\mathrm{rel}$).

In Section 2 a brief overview of the CMS detector is given. Section 3 discusses the Monte Carlo (MC) simulation used. Section 4 describes the event selection and analysis methodology. The systematic errors are addressed in Section 5 and the results are presented in Section 6.

2 The CMS Detector

A detailed description of the CMS detector can be found in Ref. [21]. The subdetectors used for the present analysis are the inner tracker, consisting of silicon pixel and silicon strip layers, and the muon detectors. The inner tracker is immersed in a 3.8 T axial magnetic field. The pixel tracker consists of three barrel layers and two endcap disks at each barrel end. The strip tracker has 10 barrel layers and 12 end-cap disks at each barrel end. Muons are measured in gas-ionization detectors embedded in the steel return yokes. In the barrel, there is a drift tube system interspersed with resistive plate chambers (RPCs), and in the end-caps there is a cathode strip chamber system, also interspersed with RPCs. The first-level (L1) trigger used in this analysis is based on the muon system alone, while the high-level trigger (HLT) uses additional information from the inner tracker.

The CMS experiment uses a right-handed coordinate system, with the origin at the nominal LHC beam collision point, the x axis pointing towards the center of the LHC ring and the z axis pointing along the counterclockwise beam direction. The polar angle θ is measured from the positive z axis and the pseudorapidity is defined by $\eta = -\ln\tan(\theta/2)$. The azimuthal angle ϕ is measured from the positive x axis in the plane perpendicular to the beam.

3 Monte Carlo Simulation

The MC event generator PYTHIA 6.422 [22] is used (with MSEL=1) to compute efficiencies and kinematic distributions. PYTHIA and MC@NLO 3.4 [23, 24] predictions are compared with the experimental results. The programs were run with their default parameter settings, except when mentioned otherwise. The PYTHIA event sample was simulated with the CTEQ6L1 [25] PDF, a b-quark mass $m_\mathrm{b} = 4.8\,\mathrm{GeV}$, and Peterson *et al.* fragmentation functions [26] for c and quarks with parameters $\varepsilon_\mathrm{c} = 0.05$ and $\varepsilon_b = 0.005$. The underlying event is simulated with the D6T tune [27]. Pileup events were not included in the simulation and play a negligible role in the data sample used for this measurement.

For comparison, additional event samples were generated where the EVTGEN [28] program was used to decay the b hadrons. Events generated by the PYTHIA program were passed through a detailed MC simulation of the CMS detector response based on GEANT4 [29]. The MC@NLO package has a NLO matrix element calculation interfaced to the parton shower algorithms of the HERWIG [30] package. A b quark mass of $m_\mathrm{b} = 4.75\,\mathrm{GeV}$ and the CTEQ6M PDF set [25] were used. The events generated with MC@NLO are studied only at the generator level and are not passed through the detailed detector simulation.

4 Data Selection and Analysis

This analysis is based on data collected in 2010 when the collider and detector were fully operational and fulfilled the following requirements: (1) Stable beam conditions, (2) stable magnetic field inside CMS at the nominal value, (3) operational L1 and HLT, and (4) inner tracker and muon stations at their nominal high-voltage settings. The data sample used in this analysis corresponds to an integrated luminosity of $\mathcal{L} = 85 \pm 9\,\mathrm{nb}^{-1}$ [31].

The events of interest are selected by a very loose single-muon trigger path. The L1 muon trigger makes no explicit requirement on the muon momentum transverse to the z axis, p_T, although muons with $p_\mathrm{T} < 3\,\mathrm{GeV}$ do not have sufficient momentum to be reconstructed in the barrel region of the muon system.

In the HLT, a standalone muon reconstruction (with information from the muon detectors only) is seeded by the parameters of the L1 muon candidate. If the standalone muon candidate has $p_\mathrm{T} > 3\,\mathrm{GeV}$ it serves as a seed in the global muon reconstruction, where a track in the inner tracker is linked to the standalone muon, and further selection requirements are applied on the transverse momentum ($p_\mathrm{T} > 3\,\mathrm{GeV}$) and the impact parameter with respect to the beam spot in the transverse plane ($|d_0| < 2\,\mathrm{cm}$).

The offline event selection requires a reconstructed primary vertex with more than three tracks and at least one muon candidate with $p_\mathrm{T} > 6\,\mathrm{GeV}$ and pseudorapidity $|\eta| < 2.1$ that fulfills a tight muon selection similar to that in Ref. [32]. The muon candidates are required to be reconstructed by two independent algorithms, one starting from segments in the muon chambers and one starting from inner-tracker information. The inner track must be measured with at least 10 hits in the inner tracker, two of which must be on pixel layers. The inner-track fit and the global muon fit (including all inner tracker and muon detector hits) are required to have a χ^2 of less than 10 per degree of freedom and at least two muon segments matching the inner track must be found. Only muon candidates with transverse impact parameter with respect to the primary vertex $|d_0| < 2\,\mathrm{mm}$ and longitudinal impact parameter with respect to the primary vertex $|d_z| < 1\,\mathrm{cm}$ are accepted.

In events passing the trigger and event selections, all tracks including the muon are clustered into track-jets [33] by the anti-k_T jet algorithm [34] with $R = 0.5$. The tracks are selected with the following requirements: $0.3 < p_T < 500\,\mathrm{GeV}$, $|z_0| < 2\,\mathrm{cm}$, and hits in at least 2 (5) layers of the pixel (pixel and strip) detector. Only jets containing a muon are accepted as b-jet candidates.

The jet direction and jet energy E are calculated by summing the four-momenta of all tracks in the jet except the muon. The pion mass hypothesis is assumed for calculating the energy associated with a track. The jet is required to contain at least one track and to have a transverse energy $E_T = E \sin\theta_{\mathrm{jet}}$ of at least 1 GeV, where θ_{jet} is the polar angle of the jet direction.

The efficiency for identifying b jets is determined in MC simulation for events in which the muon from a b-hadron decay falls into the kinematic region of this measurement. The efficiency for finding a jet containing the muon rises with the muon p_T from 74% at 6 GeV to almost 100% for events containing a muon with $p_T > 20\,\mathrm{GeV}$. The fraction of events in which the reconstructed jet containing the muon is not matched to the b jet at the generator level is smaller than 7% in the lowest muon transverse momentum bin and asymptotically reaches a value of 2% at large p_T.

From the momenta of the selected muon ($\vec{p}_\mu$) and the associated track-jet ($\vec{p}_j$), the relative transverse momentum of the muon with respect to its track-jet is calculated as $p_\perp^{\mathrm{rel}} = |\vec{p}_\mu \times \vec{p}_j| / |\vec{p}_j|$.

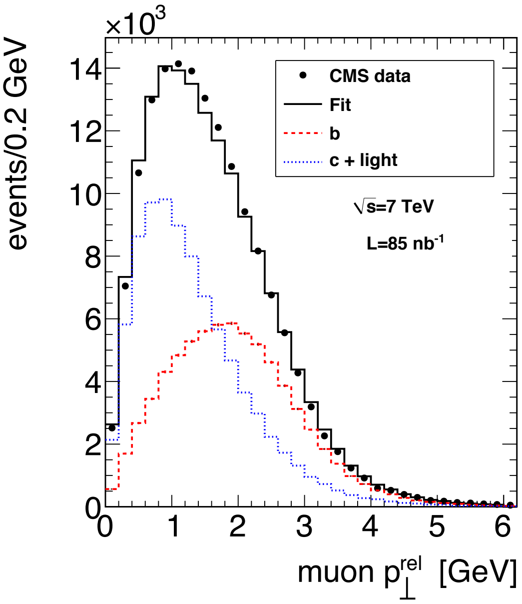

Figure 1: Distribution of muon transverse momentum $p_\perp^{\mathrm{rel}}$ with respect to the closest track-jet in data and results of the maximum likelihood fit. The black full circles correspond to the data distribution, while the black line is the result of the fitting procedure. The red dashed and the blue dotted line are the simulated b and cudsg distributions, respectively.

A total of 157 783 data events pass the selection. If an event contains more than one muon of either charge, only the muon with the largest transverse momentum p_T^μ is kept. This affects 0.5% of all data events.

4.1 Fitting Procedure

A fit to the observed $p_{\perp}^{\mathrm{rel}}$ spectrum, based on distributions obtained from simulation (signal and $\mathrm{c\bar{c}}$) and data (the remaining background), is used to determine the fraction of signal events among all events passing the event selection. A binned log-likelihood fit is performed, which takes into account the finite size of the MC simulated sample [35].

The distributions used in the fitting algorithm are determined separately for the full sample and for each bin in muon transverse momentum and pseudorapidity. Since the shape of the $p_{\perp}^{\mathrm{rel}}$ distribution in c and light-quark/gluon (udsg) events cannot be distinguished by the fit, the two background components are combined and a fit discriminating the signal component against a single background component is implemented. The udsg background is dominated by hadrons misidentified as muons (mainly in-flight decays) and is determined in data. Hadrons satisfying all muon track selection criteria (without muon detector requirements) are weighted by the misidentification probability and used instead of muons to determine $p_{\perp}^{\mathrm{rel}}$. The misidentification probability has been measured in data [36]. The c background is determined from MC simulation. Muons from sources other than b, c and udsg events are neglected. The largest contribution to the muon event sample from these sources is expected in the highest p_{T}^{μ} bin (3%, from W decays).

The result of the fit in the full sample is displayed in Fig. 1. Extensive tests to validate the fitting procedure were performed [37] with repeated fits of MC pseudo-experiments obtained by appropriate random variations. A satisfactory performance of the fit was observed: the fit result does not show a significant bias and the errors are properly calculated by the fitter. The stability of the fit was proven by repeated fits with varied binning. The signal fractions have also been determined with particle flow jets [38] and with a fit to the muon impact parameter distribution. The results are consistent with the fit using track-jets within the systematic uncertainty.

5 Systematic Uncertainties

The systematic uncertainties of this analysis are dominated by the shapes of the $p_{\perp}^{\mathrm{rel}}$ distributions used in the fitting procedure.

The signal $p_{\perp}^{\mathrm{rel}}$ distribution is validated with data through a control sample enriched in b decays. Selecting muons with a large impact parameter significance of $|d_0|/\sigma_{d_0} > 12$, where d_0 is the uncertainty of the impact parameter measurement, results in an event sample with an expected b fraction of about 85%. Small adjustments of the shape of the distributions by rescaling $p_{\perp}^{\mathrm{rel}}$ improve the agreement between data and simulation in the b-enriched region and in the full sample. They result in variations of the measured cross section of up to 21% that are taken as a systematic uncertainty.

The background consists of contributions from $\mathrm{c\bar{c}}$ events and from light-quark and gluon events, where a hadron is misidentified as a muon. Both contributions are similar in shape and magnitude. The c fraction of the background is expected to rise with increasing muon p_{T}. The fit does not separately determine the c and udsg content of the sample. Two effects can introduce a systematic uncertainty. (1) The udsg distribution determined from data could be biased. Using the PYTHIA-derived udsg background introduces a difference to the reference fit of 2–14%, depending on the muon transverse momentum and pseudorapidity bin. (2) If the c fraction of the non-b background in the data was different from the value used in combining the backgrounds, the fitted b fraction could change. The MC-simulation predicts a c fraction of

Table 1: Summary of systematic cross section uncertainties. The systematic uncertainty can vary depending on the muon transverse momentum and pseudorapidity as indicated by the range.

source	cross section uncertainty (%)
Trigger efficiency	5
Muon reconstruction efficiency	3
Hadron tracking efficiency	2
b $p_{\perp}^{\rm rel}$ shape uncertainty	≤ 21
Background $p_{\perp}^{\rm rel}$ shape uncertainty	2–14
Background composition	3–6
Production mechanism	2–5
Fragmentation	1–4
Decay	3
Underlying event	10
Luminosity	11

50–70% in the non-b background depending on the muon transverse momentum. This fraction depends on the modeling of charm semileptonic decays and on the hadron misidentificaton probability. Varying the c vs. udsg fraction by ±20% leads to a systematic uncertainty of 3–6%.

The muon trigger efficiency has been determined from data with an uncertainty of 5% using independent triggers. The muon reconstruction efficiency is known to a precision of 3%. The tracking efficiency for hadrons is known with a precision of about 4% [39], which induces a systematic uncertainty of 2% on the number of events passing the event selection.

In PYTHIA, the production of a $b\bar{b}$ pair can be separated into flavor creation (19% of the selected events), flavor excitation (56%), and gluon splitting (25%). The event selection efficiencies are 71%, 72%, and 76%, respectively. Reweighting the events from the different production processes to reflect the difference between PYTHIA and HERWIG leads to a systematic uncertainty of 2–5%, depending on the muon transverse momentum. The uncertainty of the b quark fragmentation is studied by varying the parameter $\varepsilon_{\rm b}$ between 0.003 and 0.010, which results in a systematic uncertainty of 1–4% on the reconstruction efficiency. A sample generated with EVTGEN is used to investigate the uncertainty in modeling the b-hadron decay properties. A systematic uncertainty of 3% is found. Varying the fraction of prompt $b \to \mu$ decays with respect to $b \to c \to \mu$ decays within its uncertainty [40] changes the measured cross section by 1%. Neither the muon trigger efficiency nor the track-jet finding is affected significantly by the variation of the fragmentation and decay parameters. The track-jet reconstruction can be affected by the underlying event. Using simulated event samples with different MC tunes (D6T [27], Pro-Q20 [41], and CW [42]) for the efficiency and acceptance calculation changes the cross section of the order of 10 %. At the present stage of the CMS experiment, the integrated luminosity recorded is known with an accuracy of 11% [31].

Table 1 summarizes the systematic uncertainties.

6 Results

The inclusive production cross section for b quarks decaying into muons is calculated as

$$\sigma \equiv \sigma(\mathrm{pp} \rightarrow \mathrm{b} + X \rightarrow \mu + X') = \frac{N_{\mathrm{b}}}{\mathcal{L}\,\varepsilon},$$

where N_{b} is the number of selected b events in data. No distinction is made between positive and negative muons; N_{b} includes the process $\mathrm{pp} \rightarrow \bar{\mathrm{b}} + X \rightarrow \mu + X'$. The efficiency ε includes the trigger efficiency, $(88 \pm 5)\%$, the muon reconstruction efficiency, $(94 \pm 3)\%$, and the efficiency for associating a track-jet to the reconstructed muon, $(77 \pm 8)\%$.

The result of the inclusive production cross section for b quarks decaying into muons within the kinematic range $p_{\mathrm{T}}^{\mu} > 6\,\mathrm{GeV}$ and $|\eta^{\mu}| < 2.1$ is

$$\sigma = 1.32 \pm 0.01(\mathrm{stat}) \pm 0.30(\mathrm{syst}) \pm 0.15(\mathrm{lumi})\,\mu\mathrm{b},$$

where the first uncertainty is statistical, the second is systematic, and the third is associated with the estimation of the integrated luminosity. For comparison, the inclusive b-quark production cross section predicted by MC@NLO is

$$\sigma_{\mathrm{MC@NLO}} = 0.84^{+0.36}_{-0.19}(\mathrm{scale}) \pm 0.08(m_{\mathrm{b}}) \pm 0.04(\mathrm{pdf})\,\mu\mathrm{b},$$

where the first uncertainty is due to variations in the QCD scale, the second to the b-quark mass, and the third to the parton distribution function. The value of the scale uncertainty is obtained by varying the QCD renormalization and factorization scales as described in Ref. [7]. The b-quark mass was varied between 4.5 GeV and 5.0 GeV and the uncertainty induced by the parton distribution function was evaluated using the eigenvector sets as described in Ref. [25]. The PYTHIA prediction using the parameters described in Section 3 is 1.8 μb.

The differential cross section is calculated from

$$\left.\frac{d\sigma(\mathrm{pp} \rightarrow \mathrm{b} + X \rightarrow \mu + X')}{dx}\right|_{\mathrm{bin}\ i} = \frac{N_{\mathrm{b}}^{i}}{\mathcal{L}\,\varepsilon^{i}\,\Delta x^{i}},$$

where x stands for the muon transverse momentum or the muon pseudorapidity, and Δx^{i} denotes the width of bin i. The number N_{b}^{i} of selected b events in data and the efficiency ε_{i} are determined separately for each bin.

The results of the differential b-quark production cross section as a function of the muon transverse momentum and pseudorapidity are shown in Fig. 2 and summarized in Table 2. The data lie between the PYTHIA and the MC@NLO predictions. The observed shapes of the kinematic distributions are described reasonably well by both programs. The integral of the differential cross section is consistent with the cross section determined from the full sample.

7 Conclusions

A measurement of the inclusive b-hadron production cross section in the central rapidity region in proton-proton collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ has been performed. The measurement is based on a data sample corresponding to an integrated luminosity of $85\,\mathrm{nb}^{-1}$ recorded by the CMS experiment during the first months of data taking in 2010 with a low-threshold single-muon trigger.

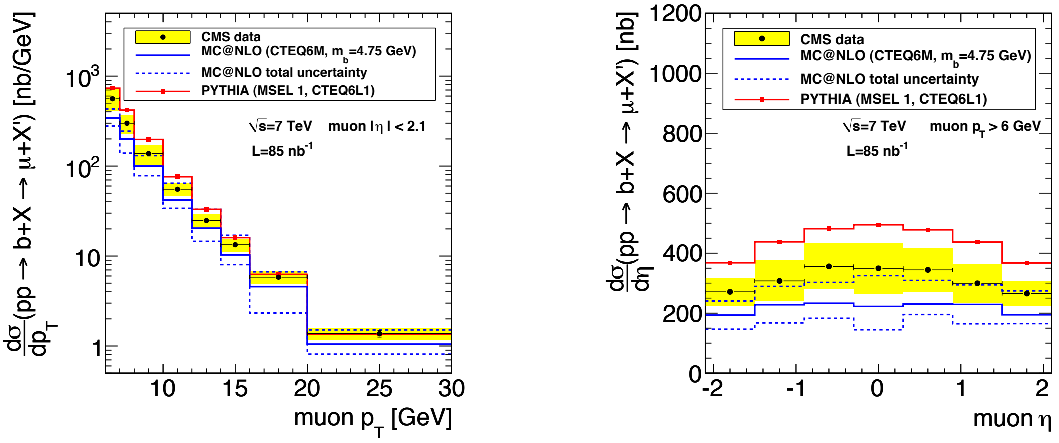

Figure 2: Differential cross section (left) $\frac{d\sigma}{dp_{\mathrm{T}}^{\mu}}(\mathrm{pp} \to \mathrm{b} + X \to \mu + X', |\eta^{\mu}| < 2.1)$, and (right) $\frac{d\sigma}{d\eta^{\mu}}(\mathrm{pp} \to \mathrm{b} + X \to \mu + X', p_{\mathrm{T}}^{\mu} > 6\,\mathrm{GeV})$. The two possible muon charges are not distinguished and the process $\mathrm{pp} \to \bar{\mathrm{b}} + X \to \mu + X'$ is included. The black points are the CMS measurements. Vertical error bars showing the statistical error are smaller than the point size in most bins, the horizontal bars indicate the bin width. The yellow band shows the quadratic sum of statistical and systematic uncertainties. The systematic uncertainty (11%) of the luminosity measurement is not included. The solid blue line shows the MC@NLO result and the dashed blue lines illustrate the theoretical uncertainty as described in the text. The solid red line with dots shows the PYTHIA result.

The result for the total inclusive production cross section of b hadrons decaying into muons within the visible kinematic range is

$$\sigma(\mathrm{pp} \to \mathrm{b} + X \to \mu + X') = 1.32 \pm 0.01(\mathrm{stat}) \pm 0.30(\mathrm{syst}) \pm 0.15(\mathrm{lumi})\,\mu\mathrm{b},$$

where $p_{\mathrm{T}}^{\mu} > 6\,\mathrm{GeV}, |\eta^{\mu}| < 2.1$. The measured cross section is approximately 1.6 times higher than the MC@NLO prediction, but the difference is less than the theoretical and experimental uncertainties. Differential cross sections have been measured as a function of muon transverse momentum and pseudorapidity. The observed shapes are reasonably well described by MC@NLO. A similar pattern was recently found by this collaboration in the measurement of b production using fully reconstructed B^{+} meson decays [9].

Acknowledgements

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

Table 2: Differential cross sections $d\sigma/dp_{\mathrm{T}}^{\mu}$ for $|\eta^{\mu}| < 2.1$ in bins of muon transverse momentum and $d\sigma/d\eta^{\mu}$ for $p_{\mathrm{T}}^{\mu} > 6\,\mathrm{GeV}$ in bins of muon pseudorapidity. The number of b events (N_{b}, including $\bar{\mathrm{b}}$ events) determined by the fit, the efficiency (ε) of the online and offline event selection, and the differential cross section, together with its relative statistical and systematic uncertainties, are given. A common uncertainty on the luminosity of 11% is not included.

p_{T}^{μ} [GeV]	N_{b}	ε	$d\sigma/dp_{\mathrm{T}}$ [nb/GeV]	stat (%)	syst (%)
6–7	26351 ± 523	0.55 ± 0.01	559	2	27
7–8	16016 ± 359	0.63 ± 0.01	299	2	23
8–10	16459 ± 332	0.70 ± 0.01	138	2	21
10–12	7136 ± 209	0.76 ± 0.02	55	3	15
12–14	3330 ± 146	0.79 ± 0.02	25	4	19
14–16	1871 ± 102	0.82 ± 0.04	13	5	15
16–20	1685 ± 99	0.85 ± 0.04	5.8	6	14
20–30	969 ± 82	0.83 ± 0.04	1.4	8	13
η^{μ}	N_{b}	ε	$d\sigma/d\eta$ [nb]	stat	syst
(-2.1,-1.5)	8452 ± 262	0.61 ± 0.02	271	3	18
(-1.5,-0.9)	9843 ± 276	0.63 ± 0.02	307	3	23
(-0.9,-0.3)	12476 ± 321	0.68 ± 0.02	356	3	23
(-0.3, 0.3)	11508 ± 315	0.64 ± 0.02	349	3	27
(0.3, 0.9)	11918 ± 312	0.68 ± 0.02	344	3	23
(0.9, 1.5)	9330 ± 272	0.61 ± 0.02	299	3	24
(1.5, 2.1)	8397 ± 255	0.62 ± 0.02	265	3	17

(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] UA1 Collaboration, "Beauty Production at the CERN Proton - anti-Proton Collider", *Phys. Lett.* **B186** (1987) 237. `doi:10.1016/0370-2693(87)90287-5`.

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

[3] D0 Collaboration, "Inclusive μ and b quark production cross-sections in $p\bar{p}$ collisions at $\sqrt{s} = 1.8\,\mathrm{TeV}$", *Phys. Rev. Lett.* **74** (1995) 3548. `doi:10.1103/PhysRevLett.74.3548`.

[4] D0 Collaboration, "The $b\bar{b}$ production cross section and angular correlations in $p\bar{p}$ collisions at $\sqrt{s} = 1.8\,\mathrm{TeV}$", *Phys. Lett.* **B487** (2000) 264. `doi:10.1016/S0370-2693(00)00844-3`.

[5] CDF Collaboration, "Measurement of the b-Hadron Production Cross Section Using Decays to $\mu^{-}D^{0}X$ Final States in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96\,\mathrm{TeV}$", *Phys. Rev.* **D79** (2009) 092003. `doi:10.1103/PhysRevD.79.092003`.

[6] M. Cacciari and P. Nason, “Is there a significant excess in bottom hadroproduction at the Tevatron?”, *Phys. Rev. Lett.* **89** (2002) 122003. `doi:10.1103/PhysRevLett.89.122003`.

[7] M. Cacciari, S. Frixione, M. L. Mangano 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`.

[8] LHCb Collaboration, “Measurement of $\sigma(pp \to b\bar{b}X)$ at $\sqrt{s} = 7$ TeV in the forward region”, *Phys. Lett.* **B694** (2010) 209. `doi:10.1016/j.physletb.2010.10.010`.

[9] CMS Collaboration, “Measurement of the B+ Production Cross Section in pp Collisions at sqrt(s) = 7 TeV”, `arXiv:1101.0131`. Submitted to *Phys. Rev. Lett.*

[10] P. Nason, S. Dawson, and R. Ellis, “The Total Cross-Section for the Production of Heavy Quarks in Hadronic Collisions”, *Nucl. Phys.* **B303** (1988) 607. `doi:10.1016/0550-3213(88)90422-1`.

[11] P. Nason, S. Dawson, and R. Ellis, “The One Particle Inclusive Differential Cross-Section for Heavy Quark Production in Hadronic Collisions”, *Nucl. Phys.* **B327** (1989) 49. `doi:10.1016/0550-3213(89)90286-1`.

[12] W. Beenakker, W. van Neerven, R. Meng et al., “QCD corrections to heavy quark production in hadron hadron collisions”, *Nucl. Phys.* **B351** (1991) 507. `doi:10.1016/S0550-3213(05)80032-X`.

[13] J. C. Collins and R. Ellis, “Heavy quark production in very high-energy hadron collisions”, *Nucl. Phys.* **B360** (1991) 3. `doi:10.1016/0550-3213(91)90288-9`.

[14] S. Catani, M. Ciafaloni, and F. Hautmann, “High-energy factorization and small-x heavy flavor production”, *Nucl. Phys.* **B366** (1991) 135. `doi:10.1016/0550-3213(91)90055-3`.

[15] M. Cacciari and M. Greco, “Large p_{T} hadroproduction of heavy quarks”, *Nucl. Phys.* **B421** (1994) 530. `doi:10.1016/0550-3213(94)90515-0`.

[16] M. Cacciari, M. Greco, and P. Nason, “The p_{T} spectrum in heavy-flavour hadroproduction”, *JHEP* **05** (1998) 007. `doi:10.1088/1126-6708/1998/05/007`.

[17] S. Frixione, M. L. Mangano, P. Nason et al., “Heavy quark production”, *Adv. Ser. Direct. High Energy Phys.* **15** (1998) 609.

[18] B. A. Kniehl, G. Kramer, I. Schienbein et al., “Finite-mass effects on inclusive B meson hadroproduction”, *Phys. Rev.* **D77** (2008) 014011. `doi:10.1103/PhysRevD.77.014011`.

[19] M. G. Ryskin, A. G. Shuvaev, and Y. M. Shabelski, “Comparison of k_T factorization approach and QCD parton model for charm and beauty hadroproduction”, *Phys. Atom. Nucl.* **64** (2001) 1995. `doi:10.1134/1.1423749`.

[20] H. Jung, “Heavy quark production at the TEVATRON and HERA using k_t factorization with CCFM evolution”, *Phys. Rev.* **D65** (2002) 034015. `doi:10.1103/PhysRevD.65.034015`.

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

[22] 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`.

[23] S. Frixione and B. R. Webber, "Matching NLO QCD computations and parton shower simulations", *JHEP* **06** (2002) 029. `doi:10.1088/1126-6708/2002/06/029`.

[24] S. Frixione, P. Nason, and B. R. Webber, "Matching NLO QCD and parton showers in heavy flavour production", *JHEP* **08** (2003) 007. `doi:10.1088/1126-6708/2003/08/007`.

[25] 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`.

[26] C. Peterson, D. Schlatter, I. Schmitt et al., "Scaling Violations in Inclusive e+ e- Annihilation Spectra", *Phys. Rev.* **D27** (1983) 105. `doi:10.1103/PhysRevD.27.105`.

[27] ATLAS, CMS, and TOTEM Collaboration, "Multiple parton interactions, underlying event and forward physics at LHC", *Proceedings of Multiple Parton Interactions at the LHC, 1st Workshop, October 27–31, 2008, DESY-PROC-2009-06* (2008). `doi:10.3204/DESY-PROC-2007-02/23`.

[28] D. J. Lange, "The EvtGen particle decay simulation package", *Nucl. Instrum. Meth.* **A462** (2001) 152. `doi:10.1016/S0168-9002(01)00089-4`.

[29] GEANT4 Collaboration, "GEANT4: A simulation toolkit", *Nucl. Instrum. Meth.* **A506** (2003) 250. `doi:10.1016/S0168-9002(03)01368-8`.

[30] G. Corcella et al., "HERWIG 6.5: an event generator for Hadron Emission Reactions With Interfering Gluons (including supersymmetric processes)", *JHEP* **01** (2001) 010.

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

[32] CMS Collaboration, "Measurements of Inclusive W and Z Cross Sections in pp Collisions at sqrt(s)=7 TeV", `arXiv:1012.2466`. Submitted to the *Journal of High Energy Physics*.

[33] CMS Collaboration, "Commissioning of TrackJets in pp Collisions at $\sqrt{s} = 7\,\mathrm{TeV}$", *CMS Physics Analysis Summary* **CMS-PAS-JME-10-006** (2010).

[34] M. Cacciari, G. P. Salam, and G. Soyez, "The anti-k_t jet clustering algorithm", *JHEP* **04** (2008) 063. `doi:10.1088/1126-6708/2008/04/063`.

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

[36] CMS Collaboration, "Performance muon identification in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$", *CMS Physics Analysis Summary* **CMS-PAS-MUO-10-002** (2010).

[37] L. Caminada, "Study of the Inclusive Beauty Production at CMS and Construction and Commissioning of the CMS Pixel Barrel Detector". PhD thesis, ETH Zürich, 2010. ETH No. 19091.

[38] CMS Collaboration, "Commissioning of the Particle-Flow reconstruction in Minimum-Bias and Jet Events from pp Collisions at 7 TeV", *CMS Physics Analysis Summary* **CMS-PAS-PFT-10-002** (2010).

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

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

[41] A. Buckley et al., “Systematic event generator tuning for the LHC”, *Eur. Phys. J.* **C65** (2010) 331. `doi:10.1140/epjc/s10052-009-1196-7`.

[42] CMS Collaboration, “Measurement of the Underlying Event Activity in Proton- Proton Collisions at 0.9 TeV”, *Eur. Phys. J.* **C70** (2010) 555. `doi:10.1140/epjc/s10052-010-1453-9`.

A 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, C. Fabjan, M. Friedl, R. Frühwirth, V.M. Ghete, J. Hammer[1], S. Hänsel, C. Hartl, M. Hoch, N. Hörmann, J. Hrubec, M. Jeitler, G. Kasieczka, 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
L. Benucci, K. Cerny, E.A. De Wolf, X. Janssen, 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
V. Adler, S. Beauceron, F. Blekman, S. Blyweert, J. D'Hondt, O. Devroede, R. Gonzalez Suarez, A. Kalogeropoulos, J. Maes, M. Maes, S. Tavernier, 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, J. Wickens

Ghent University, Ghent, Belgium
S. Costantini, M. Grunewald, B. Klein, 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, J. De Favereau De Jeneret, C. Delaere, P. Demin, D. Favart, A. Giammanco, G. Grégoire, J. Hollar, V. Lemaitre, J. Liao, O. Militaru, 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
F.A. Dias, M.A.F. Dias, T.R. Fernandez Perez Tomei, E. M. Gregores[2], F. Marinho, S.F. Novaes, Sandra S. Padula

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

University of Sofia, Sofia, Bulgaria
M. Dyulendarova, R. Hadjiiska, V. Kozhuharov, L. Litov, E. Marinova, 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, J. Wang, J. Wang, X. Wang, Z. Wang, M. Xu, M. Yang, 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, L. Zhang, 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, H. Rykaczewski

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

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

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

Helsinki Institute of Physics, Helsinki, Finland
S. Czellar, J. Härkönen, A. Heikkinen, V. Karimäki, R. Kinnunen, J. Klem, 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. 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. Bianchini, M. Bluj[6], C. Broutin, P. Busson, C. Charlot, T. Dahms, L. Dobrzynski, R. Granier de Cassagnac, M. Haguenauer, P. Miné, C. Mironov, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Thiebaux, B. Wyslouch[7], A. Zabi

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
J.-L. Agram[8], J. Andrea, A. Besson, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte[8], F. Drouhin[8], C. Ferro, J.-C. Fontaine[8], D. Gelé, U. Goerlach, S. Greder, P. Juillot, M. Karim[8], 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, N. Beaupere, M. Bedjidian, O. Bondu, G. Boudoul, D. Boumediene, H. Brun, N. Chanon, R. Chierici, D. Contardo, P. Depasse, H. El Mamouni, A. Falkiewicz, 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, H. Xiao

E. Andronikashvili Institute of Physics, Academy of Science, Tbilisi, Georgia
V. Roinishvili

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

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
G. Anagnostou, 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, W. Bender, M. Erdmann, J. Frangenheim, T. Hebbeker, A. Hinzmann, K. Hoepfner, C. Hof, T. Klimkovich, D. Klingebiel, P. Kreuzer, D. Lanske[†], C. Magass, G. Masetti, 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, 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[9], K. Borras, A. Cakir, A. Campbell, E. Castro, D. Dammann, G. Eckerlin, D. Eckstein, A. Flossdorf, G. Flucke, A. Geiser, I. Glushkov, J. Hauk, H. Jung, M. Kasemann, I. Katkov, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann[9], R. Mankel, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, J. Olzem, A. Parenti, A. Raspereza, A. Raval, R. Schmidt[9], T. Schoerner-Sadenius, N. Sen, M. Stein, J. Tomaszewska, D. Volyanskyy, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany
C. Autermann, S. Bobrovskyi, J. Draeger, H. Enderle, U. Gebbert, K. Kaschube, G. Kaussen, R. Klanner, J. Lange, B. Mura, S. Naumann-Emme, F. Nowak, N. Pietsch, C. Sander, H. Schettler, P. Schleper, M. Schröder, T. Schum, J. Schwandt, A.K. Srivastava, H. Stadie, G. Steinbrück, J. Thomsen, R. Wolf

Institut für Experimentelle Kernphysik, Karlsruhe, Germany
C. Barth, J. Bauer, V. Buege, T. Chwalek, W. De Boer, A. Dierlamm, G. Dirkes, M. Feindt, J. Gruschke, C. Hackstein, F. Hartmann, S.M. Heindl, M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, T. Kuhr, D. Martschei, S. Mueller, Th. Müller, M. Niegel, O. Oberst, A. Oehler, J. Ott, T. Peiffer, D. Piparo, G. Quast, K. Rabbertz, F. Ratnikov, M. Renz, C. Saout, A. Scheurer, P. Schieferdecker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, J. Wagner-Kuhr, M. Zeise, V. Zhukov[10], 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[1]

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, G. Debreczeni, C. Hajdu[1], D. Horvath[11], A. Kapusi, K. Krajczar[12], A. Laszlo, F. Sikler, G. Vesztergombi[12]

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. Bansal, 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, R. Sharma, A.P. Singh, J.B. Singh, S.P. Singh

University of Delhi, Delhi, India
S. Ahuja, S. Bhattacharya, B.C. Choudhary, P. Gupta, S. Jain, S. Jain, A. Kumar, R.K. Shivpuri

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

Tata Institute of Fundamental Research - EHEP, Mumbai, India
T. Aziz, M. Guchait[13], A. Gurtu, M. Maity[14], 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 Studies in Theoretical Physics & Mathematics (IPM), Tehran, Iran
H. Arfaei, H. Bakhshiansohi, S.M. Etesami, A. Fahim, M. Hashemi, A. Jafari, M. Khakzad, A. Mohammadi, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh, M. Zeinali

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], M. De Palma[a,b], A. Dimitrov[a], L. Fiore[a], G. Iaselli[a,c], L. Lusito[a,b,1], 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], S. Marcellini[a], 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]

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], C. Genta[a], 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[15], F. Fabbri, D. Piccolo

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

INFN Sezione di Milano-Biccoca [a], Università di Milano-Bicocca [b], Milano, Italy
A. Benaglia[a,b], F. De Guio[a,b,1], L. Di Matteo[a,b], A. Ghezzi[a,b,1], M. Malberti[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], V. Tancini[a,b]

INFN Sezione di Napoli [a], Università di Napoli "Federico II" [b], Napoli, Italy
S. Buontempo[a], C.A. Carrillo Montoya[a], A. Cimmino[a,b], A. De Cosa[a,b], M. De Gruttola[a,b], F. Fabozzi[a,16], A.O.M. Iorio[a], L. Lista[a], M. Merola[a,b], P. Noli[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], E. Conti[a], M. De Mattia[a,b], T. Dorigo[a], U. Dosselli[a], F. Fanzago[a], F. Gasparini[a,b], U. Gasparini[a,b], P. Giubilato[a,b], A. Gresele[a,c], S. Lacaprara[a,17], I. Lazzizzera[a,c], M. Margoni[a,b], M. Mazzucato[a], A.T. Meneguzzo[a,b], 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], 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], A. Santocchia[a,b], L. Servoli[a], S. Taroni[a,b], M. Valdata[a,b], R. Volpe[a,b,1]

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], A. Messineo[a,b], F. Palla[a], F. Palmonari[a], S. Sarkar[a,c], 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], E. Longo[a,b], G. Organtini[a,b], A. Palma[a,b], F. Pandolfi[a,b,1], R. Paramatti[a], S. Rahatlou[a,b]

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,1], A. Romero[a,b], M. Ruspa[a,c], R. Sacchi[a,b], V. Sola[a,b], A. Solano[a,b], A. Staiano[a], D. Trocino[a,b], A. Vilela Pereira[a,b,1]

INFN Sezione di Trieste [a], Università di Trieste [b], Trieste, Italy
F. Ambroglini[a,b], 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

Kyungpook National University, Daegu, Korea
S. Chang, J. Chung, D.H. Kim, G.N. Kim, J.E. Kim, D.J. Kong, H. Park, D. Son, D.C. 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, H.B. Rhee, E. Seo, S. Shin, 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, 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, R. Lopez-Fernandez, 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
P. Allfrey, D. Krofcheck

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
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 Instrumenta*c*cão e Física Experimental de Partículas, Lisboa, Portugal
N. Almeida, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, P. Martins, P. Musella, A. Nayak, P.Q. Ribeiro, J. Seixas, P. Silva, J. Varela[1], H.K. Wöhri

Joint Institute for Nuclear Research, Dubna, Russia
I. Belotelov, P. Bunin, M. Finger, M. Finger Jr., 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
N. Bondar, V. Golovtsov, Y. Ivanov, V. Kim, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev

Institute for Nuclear Research, Moscow, Russia
Yu. Andreev, 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, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

Moscow State University, Moscow, Russia
E. Boos, M. Dubinin[18], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, S. Obraztsov, S. Petrushanko, L. Sarycheva, V. Savrin

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

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia
I. Azhgirey, S. Bitioukov, V. Grishin[1], V. Kachanov, D. Konstantinov, A. Korablev, V. Krychkine, V. Petrov, R. Ryutin, S. Slabospitsky, 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[19], M. Djordjevic, D. Krpic[19], 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, N. Colino, B. De La Cruz, 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, 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, M. Chamizo Llatas, S.H. Chuang, J. Duarte Campderros, M. Felcini[20], 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[21], T. Rodrigo, 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[22], D. Benedetti, C. Bernet[3], W. Bialas, P. Bloch, A. Bocci, S. Bolognesi, H. Breuker, G. Brona, K. Bunkowski, T. Camporesi, E. Cano, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, B. Curé, D. D'Enterria, A. De Roeck, F. Duarte Ramos, A. Elliott-Peisert, B. Frisch, W. Funk, A. Gaddi, S. Gennai, 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, J. Harvey, J. Hegeman, B. Hegner, C. Henderson, G. Hesketh, H.F. Hoffmann, A. Honma, V. Innocente, P. Janot, E. Karavakis, P. Lecoq, C. Leonidopoulos, C. Lourencco, A. Macpherson, T. Mäki, L. Malgeri, M. Mannelli, L. Masetti, 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, G. Polese, A. Racz, J. Rodrigues Antunes, G. Rolandi[23], T. Rommerskirchen, C. Rovelli[24], M. Rovere, H. Sakulin, C. Schäfer, C. Schwick, I. Segoni, A. Sharma, P. Siegrist, M. Simon, P. Sphicas[25], D. Spiga, M. Spiropulu[18], F. Stöckli, M. Stoye, P. Tropea, A. Tsirou, A. Tsyganov, G.I. Veres[12], 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[26], A. Starodumov[27]

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland
P. Bortignon, L. Caminada[28], Z. Chen, S. Cittolin, G. Dissertori, M. Dittmar, J. Eugster, K. Freudenreich, C. Grab, A. Hervé, W. Hintz, P. Lecomte, W. Lustermann, C. Marchica[28], P. Martinez Ruiz del Arbol, P. Meridiani, P. Milenovic[29], F. Moortgat, 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. Aguiló, C. Amsler, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Millan Mejias, C. Regenfus, P. Robmann, A. Schmidt, H. Snoek

National Central University, Chung-Li, Taiwan
Y.H. Chang, K.H. Chen, W.T. Chen, S. Dutta, A. Go, C.M. Kuo, S.W. Li, W. Lin, M.H. Liu, Z.K. Liu, Y.J. Lu, 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[30], S. Cerci[31], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E.E. Kangal, T. Karaman, A. Kayis Topaksu, A. Nart, G. Onengut, K. Ozdemir, S. Ozturk, A. Polatoz, K. Sogut[32], B. Tali, H. Topakli[30], D. Uzun, L.N. Vergili, M. Vergili, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey
I.V. Akin, T. Aliev, 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[33], E. Gülmez, A. Halu, B. Isildak, M. Kaya[34], O. Kaya[34], S. Ozkorucuklu[35], N. Sonmez[36]

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

University of Bristol, Bristol, United Kingdom
P. Bell, 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, B. Huckvale, J. Jackson, L. Kreczko, S. Metson, D.M. Newbold[37], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, S. Ward

Rutherford Appleton Laboratory, Didcot, United Kingdom
L. Basso, K.W. Bell, A. Belyaev, C. Brew, R.M. Brown, B. Camanzi, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, 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, J. Fulcher, D. Futyan, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, G. Karapostoli, L. Lyons, A.-M. Magnan, J. Marrouche, R. Nandi, J. Nash, A. Nikitenko[27], A. Papageorgiou, M. Pesaresi, K. Petridis, M. Pioppi[38], D.M. Raymond, N. Rompotis, A. Rose, M.J. Ryan, C. Seez, P. Sharp, A. Sparrow, A. Tapper, S. Tourneur, M. Vazquez Acosta, T. Virdee, S. Wakefield, 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

Boston University, Boston, USA
T. Bose, E. Carrera Jarrin, A. Clough, 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. Narain, D. Nguyen, M. Segala, T. Speer, K.V. Tsang

University of California, Davis, Davis, USA
M.A. Borgia, R. Breedon, M. Calderon De La Barca Sanchez, D. Cebra, 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, R. Clare, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng, S.C. Kao, F. Liu, H. Liu, A. Luthra, H. Nguyen, G. Pasztor[39], A. Satpathy, 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, E. Dusinberre, D. Evans, F. Golf, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, B. Mangano, J. Muelmenstaedt, S. Padhi, C. Palmer, G. Petrucciani, H. Pi, M. Pieri, R. Ranieri, M. Sani, V. Sharma[1], S. Simon, Y. Tu, A. Vartak, F. Würthwein, A. Yagil

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. Bornheim, J. Bunn, Y. Chen, M. Gataullin, D. Kcira, V. Litvine, Y. Ma, A. Mott, H.B. Newman, C. Rogan, 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, N. Terentyev, 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, 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, A. Chatterjee, S. Das, N. Eggert, L.J. Fields, L.K. Gibbons, B. Heltsley, W. Hopkins, A. Khukhunaishvili, B. Kreis, V. Kuznetsov, G. Nicolas Kaufman, J.R. Patterson, D. Puigh, D. Riley, A. Ryd, 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, M. Demarteau, D.P. Eartly, V.D. Elvira, S. Esen, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, D. Green, K. Gunthoti, O. Gutsche, A. Hahn, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, E. James, H. Jensen, M. Johnson, U. Joshi, R. Khatiwada, B. Kilminster, B. Klima, K. Kousouris, S. Kunori, S. Kwan, P. Limon, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, D. Mason, P. McBride, T. McCauley, T. Miao, K. Mishra, S. Mrenna, Y. Musienko[40], C. Newman-Holmes, V. O'Dell, S. Popescu[41], R. Pordes, O. Prokofyev, N. Saoulidou, E. Sexton-Kennedy, S. Sharma, A. Soha, 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, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, S. Goldberg, B. Kim, S. Klimenko, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, K. Matchev, G. Mitselmakher, L. Muniz, Y. Pakhotin, C. Prescott, R. Remington, M. Schmitt, B. Scurlock, P. Sellers, N. Skhirtladze, 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, J.L. Rodriguez

Florida State University, Tallahassee, USA
T. Adams, A. Askew, D. Bandurin, 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, E.J. Garcia-Solis, C.E. Gerber, D.J. Hofman, S. Khalatyan, F. Lacroix, M. Malek, C. O'Brien, C. Silvestre, A. Smoron, D. Strom, N. Varelas

The University of Iowa, Iowa City, USA
U. Akgun, E.A. Albayrak, B. Bilki, K. Cankocak[42], W. Clarida, F. Duru, C.K. Lae, E. McCliment, J.-P. Merlo, H. Mermerkaya, 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, M. Murray, D. Noonan, V. Radicci, S. Sanders, J.S. Wood, V. Zhukova

Kansas State University, Manhattan, USA
T. Bolton, I. Chakaberia, A. Ivanov, 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, K. Sumorok, K. Sung, E.A. Wenger, S. Xie, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti

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

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, C. Lundstedt, 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, K. Kaadze, S. Reucroft, J. Swain, 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, 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, J. Warchol, 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, Z. Gecse, L. Gutay, Z. Hu, M. Jones, O. Koybasi, 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, V. Cuplov, K.M. Ecklund, F.J.M. Geurts, J.H. Liu, 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, 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, A. Richards, 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
J. Asaadi, R. Eusebi, J. Gilmore, A. Gurrola, T. Kamon, V. Khotilovich, R. Montalvo, C.N. Nguyen, I. Osipenkov, 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, 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, W. Johns, P. Kurt, C. Maguire, A. Melo, P. Sheldon, J. Velkovska

University of Virginia, Charlottesville, USA
M.W. Arenton, M. Balazs, S. Boutle, M. Buehler, S. Conetti, 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, L. Gray, K.S. Grogg, M. Grothe, R. Hall-Wilton[1], M. Herndon, P. Klabbers, J. Klukas, A. Lanaro, C. Lazaridis, J. Leonard, R. Loveless, A. Mohapatra, 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 Fayoum University, El-Fayoum, Egypt
6: Also at Soltan Institute for Nuclear Studies, Warsaw, Poland
7: Also at Massachusetts Institute of Technology, Cambridge, USA
8: Also at Université de Haute-Alsace, Mulhouse, France
9: Also at Brandenburg University of Technology, Cottbus, Germany
10: Also at Moscow State University, Moscow, Russia
11: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
12: Also at Eötvös Loránd University, Budapest, Hungary
13: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India

14: Also at University of Visva-Bharati, Santiniketan, India
15: Also at Facoltà Ingegneria Università di Roma "La Sapienza", Roma, Italy
16: Also at Università della Basilicata, Potenza, Italy
17: Also at Laboratori Nazionali di Legnaro dell' INFN, Legnaro, Italy
18: Also at California Institute of Technology, Pasadena, USA
19: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
20: Also at University of California, Los Angeles, Los Angeles, USA
21: Also at University of Florida, Gainesville, USA
22: Also at Université de Genève, Geneva, Switzerland
23: Also at Scuola Normale e Sezione dell' INFN, Pisa, Italy
24: Also at INFN Sezione di Roma; Università di Roma "La Sapienza", Roma, Italy
25: Also at University of Athens, Athens, Greece
26: Also at The University of Kansas, Lawrence, USA
27: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
28: Also at Paul Scherrer Institut, Villigen, Switzerland
29: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
30: Also at Gaziosmanpasa University, Tokat, Turkey
31: Also at Adiyaman University, Adiyaman, Turkey
32: Also at Mersin University, Mersin, Turkey
33: Also at Izmir Institute of Technology, Izmir, Turkey
34: Also at Kafkas University, Kars, Turkey
35: Also at Suleyman Demirel University, Isparta, Turkey
36: Also at Ege University, Izmir, Turkey
37: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
38: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
39: Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
40: Also at Institute for Nuclear Research, Moscow, Russia
41: Also at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania
42: Also at Istanbul Technical University, Istanbul, Turkey