

Measurement of the underlying event activity using charged-particle jets in proton-proton collisions at $\sqrt{s} = 2.76$ TeV



The CMS collaboration

E-mail: cms-publication-committee-chair@cern.ch

ABSTRACT: A measurement of the underlying event (UE) activity in proton-proton collisions is performed using events with charged-particle jets produced in the central pseudorapidity region ($|\eta^{\text{jet}}| < 2$) and with transverse momentum $1 \leq p_{\text{T}}^{\text{jet}} < 100$ GeV. The analysis uses a data sample collected at a centre-of-mass energy of 2.76 TeV with the CMS experiment at the LHC. The UE activity is measured as a function of $p_{\text{T}}^{\text{jet}}$ in terms of the average multiplicity and scalar sum of transverse momenta (p_{T}) of charged particles, with $|\eta| < 2$ and $p_{\text{T}} > 0.5$ GeV, in the azimuthal region transverse to the highest p_{T} jet direction. By further dividing the transverse region into two regions of smaller and larger activity, various components of the UE activity are separated. The measurements are compared to previous results at 0.9 and 7 TeV, and to predictions of several Monte Carlo event generators, providing constraints on the modelling of the UE dynamics.

KEYWORDS: Hadron-Hadron Scattering, Particle correlations and fluctuations

ARXIV EPRINT: [1507.07229](https://arxiv.org/abs/1507.07229)

Contents

1	Introduction	1
2	Monte Carlo event generators	2
3	Experimental methods	3
3.1	The CMS detector	3
3.2	Event and track selection	4
3.3	Observables	5
3.4	Corrections and systematic uncertainties	6
4	Results	7
5	Summary	10
	The CMS collaboration	14

1 Introduction

Hadron production in high-energy proton-proton (pp) collisions originates from multiple scatterings of the partonic constituents of the protons at central rapidities, and from “spectator” (noncolliding) partons emitted in the very forward direction. The produced partons reduce their virtuality through gluon radiation and quark-antiquark splittings, and finally fragment into hadrons at scales approaching 0.2 GeV (Λ_{QCD}). Usually, one separates the produced hadrons into two classes: those coming directly from the fragmentation of partons resulting from the scattering with the largest momentum transfer (hard scattering) in the event, and the rest (underlying event, or UE). The UE thus consists of hadrons coming from (i) initial- and final-state radiation (ISR, FSR) from the hard scattering, (ii) softer partonic scatters in the same pp collision (multiple parton interactions, or MPI) possibly with their own initial- and final-state radiation, and (iii) proton remnants concentrated along the beam direction.

An accurate understanding of the UE is required for precise measurements of standard model processes at high energies and searches for new physics. Indeed, the UE affects measurements of isolated high transverse momentum p_T leptons or photons, and it dominates most of the hadronic activity from the overlapping pp collisions taking place in a given bunch crossing (pileup) at the high luminosities achieved by the CERN LHC. The semi-hard and low-momentum partonic processes, which dominate the UE, cannot be adequately calculated with perturbative Quantum Chromodynamics (pQCD) methods alone, and require a phenomenological description containing parameters that must be tuned to data.

The topological structure of pp interactions with a hard scattering can be used to define experimental observables sensitive to the UE. One example is the study of particle properties in regions away from the direction of the products of the hard scattering. At the Tevatron, the CDF experiment measured UE observables using inclusive jet and Drell-Yan (DY) events in $p\bar{p}$ collisions at centre-of-mass energies $\sqrt{s} = 0.63, 1.8,$ and 1.96 TeV [1–3]. In pp collisions at the LHC, the ALICE, ATLAS, and CMS experiments have carried out UE measurements at $\sqrt{s} = 0.9$ and 7 TeV using events containing a leading (highest p_T) charged-particle jet [4–6] or a leading charged particle [7, 8], or a DY lepton pair [9]. In this paper, we study the UE activity in pp collisions at $\sqrt{s} = 2.76$ TeV by measuring the average multiplicity and scalar transverse momentum sum (Σp_T) densities of charged particles in the azimuthal region orthogonal to the direction of the leading charged-particle jet, referred to as the transverse region.

At a given centre-of-mass energy, the UE activity is expected to increase with the momentum transfer between the interacting partons (hard scale). On average, increasingly hard parton interactions result from pp collisions with decreasing impact parameters between the two protons, which in turn enhance the overall hadronic activity originating from MPI until a saturation is reached for central collisions with maximum overlap [10, 11]. At the same time, the activity related to the ISR and FSR components also increases with the hard scale. For events with the same hard scale, probed by the p_T of jets or DY pairs, the MPI activity rises with \sqrt{s} , as more partons are expected in the protons at increasingly smaller parton fractional momenta $x \sim 2p_T/\sqrt{s}$ [10, 11]. Hence, studying the UE as a function of the hard scale at several centre-of-mass energies provides an insight into the UE dynamics and its evolution with the collision energy, further constraining the model parameters.

The paper is organised as follows. Section 2 presents the main features of the Monte Carlo (MC) event generators used in this study to provide a description of the UE properties. Section 3 briefly describes the experimental methods, observables, event and track selection, as well as the corrections and systematic uncertainties of the measurements. The results are presented in section 4, and summarised in section 5.

2 Monte Carlo event generators

In this analysis, the PYTHIA6 [12], PYTHIA8 [13], and HERWIG++ [14] MC event generators are used with various tunes that are described below. In PYTHIA, the $2 \rightarrow 2$ parton scatterings, including MPI, are described by leading-order pQCD, with the $1/p_T^4$ cross section divergence regularised by introducing a low- p_T infrared cutoff (p_{T0}), such that the diverging term is replaced by $1/(p_T^2 + p_{T0}^2)^2$. There are various tunable parameters that control the behaviour of this regularisation, the matter distribution of partons in the transverse plane within the hadrons, and the final-state colour reconnection effects among the produced partons. When QCD radiation is modelled via a p_T -ordered evolution, the MPI and parton showers are interleaved in one common sequence of decreasing p_T values [15]. For the latest version of PYTHIA6 only ISR showers and MPI are interleaved, while in PYTHIA8 FSR showers are also included. The final nonperturbative transition of partons to hadrons is described by the Lund string fragmentation model [16].

Another general-purpose generator, HERWIG++, is similar to PYTHIA, but uses angular-ordered parton showers and the cluster model [14] for hadronisation. It has an MPI model similar to the one used by PYTHIA, with tunable parameters for regularising the partonic cross sections at low momentum transfer, but does not include the interleaved evolution with ISR and FSR.

Both MC models incorporate multiple parton collisions “perturbatively” — i.e. based on a “regularisation” of the underlying pQCD subprocesses’ cross sections — but require a nonperturbative ansatz for the impact parameter profile of the colliding protons. The frequency of MPI is then generated by assuming a Poissonian distribution of the number of elementary partonic interactions over the overlapping pp volume, with the average number depending on the impact parameter of the hadronic collision [10, 11]. The MPI cross section is dominated by scatterings with semi-hard momentum transfers, $O(1\text{--}2\text{ GeV})$, involving low- x partons, and thus shows a stronger dependence on the evolution of the low- p_T infrared cutoff, and on the incoming parton densities than the single hard-scattering interactions [10, 11]. In PYTHIA6, PYTHIA8 and HERWIG++, the energy dependence of MPI is mostly controlled by the energy evolution of the low- p_T infrared cutoff parameter, which follows a (tunable) power law dependence on the centre-of-mass energy [12–14]. The UE activity accompanying various types of hard scattering processes is well described by MC event generators, [4, 5, 7–9], illustrating the universality of MPI in different event topologies and hard-scattering production processes. Such a universality is confirmed by the similarity between the UE activity measured in DY [9] and jet-dominated events [4, 5, 7, 8], despite their different underlying parton radiation patterns.

In this analysis, several event generator tunes are used. These are the PYTHIA6 (version 6.426 [12]) tunes Z2, Z2*, and CUETP6S1 [17], PYTHIA8 (version 8.175 [13]) tunes 4C [18] and CUETP8S1 [17], and HERWIG++ 2.7 with tune UE-EE-5C [14, 19]. All of these tunes use the CTEQ6L1 [20] parton density function. The energy dependence of p_{T0} in these tunes is parameterised as $p_{T0}(\sqrt{s}) = p_{T0}^{\text{REF}} \times (\sqrt{s}/E_0)^\epsilon$, where p_{T0}^{REF} , E_0 , and ϵ are tune parameters summarised in table 1. These parameters were obtained by tuning to different data sets. The 4C tune was derived from early LHC data on charged particle multiplicities [18]. Z2, Z2*, CUETP6S1 and CUETP8S1 were tuned to the previous UE results from CMS at 0.9 and 7 TeV [5]. In addition, CUETP6S1 tune also included CDF data [21] at 0.3, 0.9, and 1.96 TeV, while CUETP8S1 tune used 0.9 and 1.96 TeV data for tuning. The UE-EE-5C was tuned with the ATLAS UE data at 0.9 and 7 TeV [7] and CDF UE data at 0.3, 0.9, and 1.96 TeV [21]. None of the tunes make use of data at 2.76 TeV, making this a good test of interpolation between other centre-of-mass energies. The detector response was simulated in detail by using the GEANT4 package [22], and simulated events were processed and reconstructed in the same manner as collision data.

3 Experimental methods

3.1 The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume there are several

Tune	p_{T0}^{REF} (GeV)	E_0 (GeV)	ϵ
Z2	1.832	1800	0.275
Z2*	1.921	1800	0.227
CUETP6S1	1.9096	1800	0.2479
4C	2.085	1800	0.19
CUETP8S1	2.1006	1800	0.2106
UE-EE-5C	3.91	7000	0.33

Table 1. Summary of the parameters of the Monte Carlo generator tunes.

complementary detectors: a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two endcap sections. The silicon tracker measures charged particles within the pseudorapidity range $|\eta| < 2.5$. For non-isolated particles of $1 < p_T < 10$ GeV and $|\eta| < 1.4$, the track resolutions are typically 1.5% in p_T , and 25–90 (45–150) μm in the transverse (longitudinal) impact parameter [23]. Two of the CMS subdetectors acting as LHC beam monitors, the Beam Scintillation Counters (BSC) and the Beam Pick-up Timing for the eXperiments (BPTX) devices, are used to trigger the detector readout. The BSC are located along the beam line on each side of the Interaction Point (IP) at a distance of 10.86 m and cover the range $3.23 < |\eta| < 4.65$. The two BPTX devices, located inside the beam pipe at distances of 175 m from the IP, are designed to provide precise information on the bunch structure and timing of the incoming beams, with a time resolution better than 0.2 ns. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in ref. [24].

3.2 Event and track selection

The present analysis is performed with a data sample of proton-proton collisions collected with the CMS detector at $\sqrt{s} = 2.76$ TeV during a dedicated run in March 2011, corresponding to an integrated luminosity of 0.3 nb^{-1} . In 6.2% of the events there is an extra (pileup) pp collision, corresponding to an average of 0.12 overlapping pp collisions. Minimum bias events were recorded by requiring activity in both BSC counters in coincidence with signals from both BPTX devices (in contrast to ref. [5], where only one of the BPTX devices is required). To reduce the statistical uncertainty for the highly prescaled minimum bias trigger at large p_T^{jet} , single-jet triggers based on information from the calorimeters, with p_T thresholds at 20 and 40 GeV, were also used to collect data (differently from ref. [5], where thresholds of 30 and 50 GeV are used). Events identified as originating from beam-halo background were removed from the sample [25]. The event selection requires exactly one primary vertex with more than four degrees of freedom (approximately 4 particles) and located no more than ± 10 cm from the centre of the luminous region (beamspot) in the z -direction.

For each selected event, the reconstructed track collection needs to be freed from undesired tracks, namely secondaries and background from track combinatorics and beam halo tracks. Tracks not corresponding to actual charged particles (misreconstructed tracks) are suppressed by imposing the *high-purity* selection criteria [23]. Secondary decays are suppressed by requiring that the impact parameter significance $d_0/\sigma(d_0)$ (measure of the distance between the track and the primary vertex in the xy -plane) and the significance in the z -direction $d_z/\sigma(d_z)$ to be each less than 3. In order to remove tracks with poor momentum measurement, we require the relative uncertainty in the momentum measurement $\sigma(p_T)/p_T$ to be less than 5%. The average reconstruction efficiency for the selected tracks is about 85% and drops to 75% for tracks with $p_T \approx 0.5$ GeV and $|\eta| \approx 2$, while the track misreconstruction rate is about 2%, increasing to about 8% for tracks with $p_T \approx 0.5$ GeV and $|\eta| \approx 2$. Track efficiencies are determined by matching the generated level and reconstructed level tracks.

The event hard scale and reference direction, for the identification of the UE sensitive region, are defined using leading “track jets” [26] or charged-particle jets. The use of track jets makes the transition of leading tracks to leading jets more continuous and extends the p_T coverage to larger values. These jets are reconstructed from tracks with $p_T > 0.5$ GeV and $|\eta| < 2.5$ using the Seedless Infrared-Safe Cone (SISCone) [27] algorithm with distance parameter of 0.5. Although anti- k_T [28] is now the preferred algorithm at the LHC, the SISCone algorithm is chosen in this analysis for compatibility with previous results [5]. Furthermore, a comparison of the UE activity obtained at generator level using SISCone and anti- k_T algorithms has been performed, finding differences of only a few percent for $p_T^{\text{jet}} \leq 20$ GeV. From all reconstructed track jets with $|\eta| < 2$ and $p_T > 1.0$ GeV, the one with the largest p_T^{jet} is selected. Only events containing at least one track jet fulfilling these criteria are considered for this analysis. Jets are reconstructed with a matching efficiency of 80% at $p_T^{\text{jet}} \approx 1$ GeV and up to 95% for $p_T^{\text{jet}} > 20$ GeV. Trigger conditions are chosen to keep the trigger efficiency as uniform as possible and close to 100%. For the p_T^{jet} ranges in [1, 25), [25, 50), and [50, 100) GeV, we use the minimum-bias and the two single-jet samples, respectively, corresponding to about 11M, 50k, and 23k selected events.

3.3 Observables

In this analysis we follow the same methodology as in the previous studies of the UE activity in events with a leading charged-particle jet, carried out at $\sqrt{s} = 0.9$ and 7 TeV [5]. Charged-particle jets and charged particles produced at central pseudorapidity ($|\eta| < 2$) with $p_T > 1$ and 0.5 GeV, respectively, are used to study the UE properties. The direction of the leading charged-particle jet in the event is used to select charged particles in the transverse region defined by $60^\circ < |\Delta\phi| < 120^\circ$, where $\Delta\phi$ is the relative azimuthal distance between a charged particle and the leading jet. The UE is measured in terms of particle and Σp_T densities, as a function of the leading p_T^{jet} , which is used as an estimate for the hard scale of the interaction. The particle density ($\langle N_{\text{ch}} \rangle / [\Delta\eta\Delta(\Delta\phi)]$) and Σp_T density ($\langle \Sigma p_T \rangle / [\Delta\eta\Delta(\Delta\phi)]$) are computed, respectively, as the average number of primary charged particles, and the average of their scalar p_T sum, each per unit of η and of $\Delta\phi$.

As suggested in ref. [29], the transverse region can be studied in detail by separating — independently for the particle multiplicity and for the p_T sum — the $60^\circ < \Delta\phi < 120^\circ$ and the $-120^\circ < \Delta\phi < -60^\circ$ ranges, and identifying the regions with higher and lower activities, referred to as transMAX and transMIN, respectively. The two regions should have roughly equal activities for most events since the dominant production channel, two-jet production, is topologically symmetrical. In a three-jet topology, the transMAX side will capture the activity from the third jet. The difference between the measured densities in the transMAX and transMIN regions is called the transDIF density. The resulting particle and Σp_T densities are expected to be sensitive to different components of the UE activity.

Since the transMAX region contains the third jet, while both transMAX and transMIN regions receive contributions from MPI and beam remnants, the transMIN activity is sensitive to MPI and beam remnants, and the transDIF activity is sensitive to harder initial- and final-state radiation. The present approach extends the methodology employed in ref. [5]

3.4 Corrections and systematic uncertainties

The UE observables ($\langle N_{\text{ch}} \rangle / [\Delta\eta\Delta(\Delta\phi)]$ and $\langle \sum p_T \rangle / [\Delta\eta\Delta(\Delta\phi)]$) described in section 3.3 are reconstructed from selected tracks, with $p_T > 0.5 \text{ GeV}$ and $|\eta| < 2$, in the region transverse to the leading track-jet. These measured observables are corrected for detector effects and selection efficiencies to reflect the primary charged-particle activity using a 2-dimensional, iterative unfolding technique [30] based on response matrices that correlate the generated and reconstructed level observables. These matrices are constructed from the generator level and reconstructed level UE and p_T^{jet} observables for PYTHIA6 Z2 events; this procedure accounts for detector effects and inefficiencies. The unfolding matrices are applied to a PYTHIA8 4C sample to estimate the systematic uncertainties related to the correction procedure. These vary between 0.2% and 4%, depending on the observable, region and p_T^{jet} .

Several other sources of systematic uncertainties may affect the results. These include the implementation of the simulation of the track and vertex selection criteria, tracker alignment and material content, background contamination, trigger conditions, and pileup contributions. The uncertainty in the simulation of the track selection is evaluated by applying various sets of selection criteria and comparing their effects on the data and on the simulated events. The impact parameter significance ranges are varied by one unit around the nominal window resulting in an effect on the densities of 0.6–4%. Replacing the *high-purity* selection by the simpler requirement $N_{\text{layers}} \geq 4$ and $N_{\text{pixel layers}} \geq 2$ for the silicon strip and pixel detector layers, respectively, has an effect of up to 0.8%. Varying the fraction of misreconstructed tracks by 50% affects the densities by 0.4–0.6%. The description of inactive tracker material in the simulation is adequate within 5% [4], and increasing the material densities by 5% in the simulation induces a change in the observables of 1%. The effects of tracker misalignment, precision in the IP position, and dead channels, evaluated by varying the detector conditions in the MC simulation, are each found to change the results by 0.1–0.3%. The effect of varying the trigger and vertex efficiencies within their uncertainties, as well as the effect of pileup contributions, all lead to a negligible effect.

Source	Systematic (%)
Unfolding procedure	0.2–4
Impact parameter significance	0.6–4
Fraction of misreconstructed tracks	0.4–0.6
Track selection	0.1–0.8
Material density	1
Dead channels	0.1
Tracker alignment	0.2–0.3
Interaction point position	0.2
Total	1.9–5.8

Table 2. Summary of the systematic uncertainties (in percentage) due to various sources. The values range from the minimum to maximum from all regions, observables, and across different p_T^{jet} values.

Systematic uncertainties are largely independent of one another, but they are correlated among data points in each experimental distribution. They are added in quadrature to the statistical uncertainties and are shown in all figures. Systematic uncertainties mostly dominate the statistical ones, which are often smaller than the data points. Table 2 shows a summary of the systematic uncertainties as a range from the minimum to maximum values as they vary across region, observable and p_T^{jet} . The transMAX and transMIN regions tend to have a larger total systematic uncertainty than the other regions and the $\langle \sum p_T \rangle / [\Delta\eta\Delta(\Delta\phi)]$ observable tends to have a slightly larger total systematic uncertainty by about 0.2% compared to the $\langle N_{\text{ch}} \rangle / [\Delta\eta\Delta(\Delta\phi)]$ observable. The total systematic uncertainty is large at low p_T^{jet} and decreases to a minimum at $p_T^{\text{jet}} \approx 3$ GeV and then rises again up to a plateau for $p_T^{\text{jet}} > 20$ GeV.

4 Results

In figure 1, the (a) particle and (b) Σp_T densities, after unfolding, are shown in the transverse region, relative to the leading charged-particle jet, as a function of p_T^{jet} . A steep rise of the underlying event activity in the transverse region is seen up to $p_T^{\text{jet}} \approx 8$ GeV, followed by a “saturation” (plateau-like) region, with nearly constant multiplicity and small Σp_T density increase. In figure 2, the (left panes) particle and (right panes) Σp_T densities after unfolding are shown as a function of p_T^{jet} in the transverse region with maximum and minimum activities (transMAX and transMIN), respectively. In the transMIN region, the amount of UE activity is roughly half that in the transMAX region. The p_T^{jet} dependences observed in the two regions are also quite different. At high p_T , the distributions show a slow rise in the transMAX region, while for transMIN the flattening of the UE activity as a function of p_T^{jet} is more pronounced. The corresponding distributions in the difference

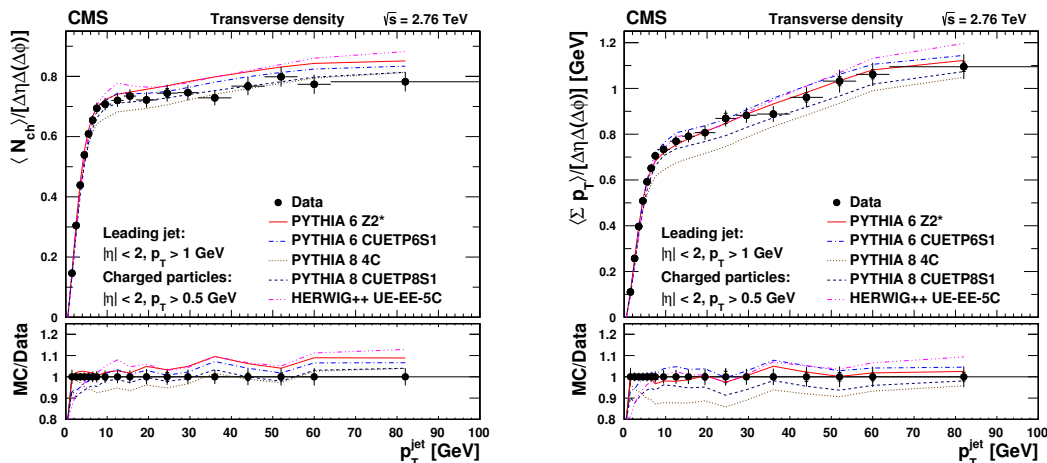


Figure 1. Measured (left) particle density, and (right) Σp_T density, in the transverse region relative to the leading charged-particle jet in the event ($|\eta| < 2$, $60^\circ < |\Delta\varphi| < 120^\circ$), as a function p_T^{jet} . The data (symbols) are compared to various MC simulations (curves). The ratios of MC simulations to the measurements are shown in the bottom panels. The inner error bars correspond to the statistical uncertainties, and the outer error bars represent the statistical and systematic uncertainties added in quadrature.

between the transMAX and transMIN regions (transDIF) are presented in figure 3. The particle and Σp_T densities both show a rise with p_T^{jet} , and the plateau-like region above $p_T^{\text{jet}} \approx 8$ GeV—seen for distributions in the individual transMAX and transMIN regions—is replaced by an increase as a function of p_T^{jet} .

The rapid increase of the UE activity with p_T^{jet} in the region below ~ 8 GeV is mainly attributed to the increase of MPI activity as the hard scale of the interaction increases [11]. This fast rise is followed by a saturation region (for the transverse and especially transMIN distributions), with nearly constant multiplicity and small Σp_T density increase. This behaviour is expected as a consequence of a nearly full overlap of the colliding protons in interactions yielding the hardest parton-parton scatterings. When pp collisions occur for very small impact parameter, the amount of MPI activity saturates [10, 11]. Such a distinct p_T^{jet} -dependent pattern in the amount of UE activity (sharp rise followed by a plateau above the $p_T^{\text{jet}} \approx 8$ GeV transition) is clearly seen for all the observables presented, especially in the transMIN region. In contrast, the transMAX and transDIF distributions show a continuous rise with p_T^{jet} also in the high- p_T regime. This is expected to be caused by contributions from initial- and final-state radiation in the transverse region [29]. Following such an interpretation, the present results provide constraints on the modelling of the different UE components.

The results are compared to recent tunes of the PYTHIA and HERWIG++ event generators. All PYTHIA6 and PYTHIA8 tunes predict the distinctive change in the amount of activity as a function of the leading jet p_T within 5–10%. The HERWIG++ UE-EE-5C tune also provides a fair description of the data. In general, the data-model agreement improves for the transDIF densities. The continuous increase observed at high- p_T^{jet} in the transDIF distributions is well reproduced by all MC tunes, corroborating the hypothesis of increased

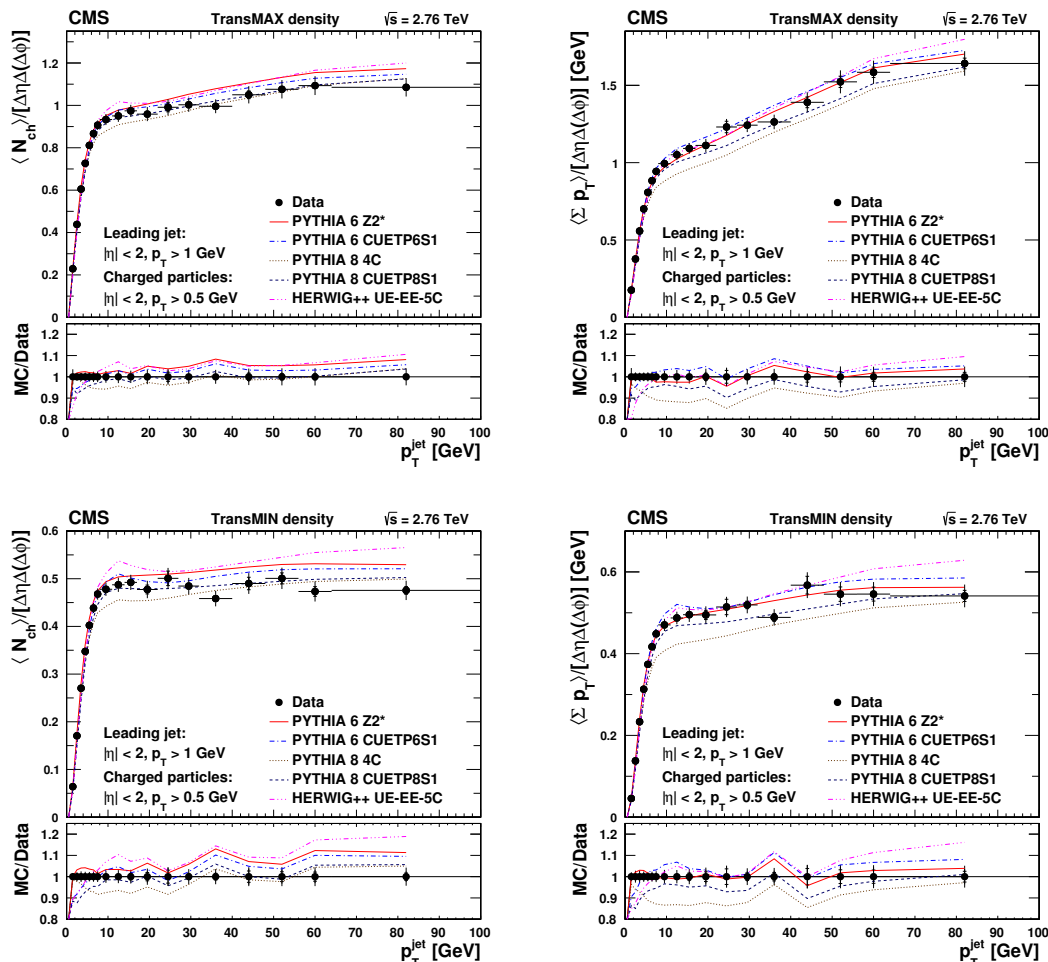


Figure 2. Measured (left panes) particle density, and (right panes) Σp_T density, in the transMAX and transMIN regions ($60^\circ < |\Delta\phi| < 120^\circ$, relative to the leading charged-particle jet in the event, with maximum/minimum UE activity), as a function of p_T^{jet} . The definitions of the symbols and error bars are the same as for figure 1.

contributions of QCD radiation from the hardest scattered partons. The same trend is observed in $p\bar{p}$ collisions at 1.96 TeV [3]. The latest PYTHIA6 (PYTHIA8) tune CUETP6S1 (CUETP8S1) improves the description of the data in comparison to the results obtained with the parameters of the previous Z2* (4C) tune.

The centre-of-mass energy dependence of the UE activity in the transverse region is presented in figure 4 as a function of p_T^{jet} for $\sqrt{s} = 0.9, 2.76,$ and 7 TeV [4, 5]. A fast rise with increasing centre-of-mass energy of the activity in the transverse region is observed for the same value of the leading charged-particle p_T^{jet} . This is expected from the higher parton densities probed at low- x in the protons, and the larger phase space available for parton radiation. All tunes predict a centre-of-mass energy dependence of the UE activity which is consistent with that of the data.

The measurements presented here provide constraints for the development and tuning of the underlying event description implemented in MC models. In particular, they may

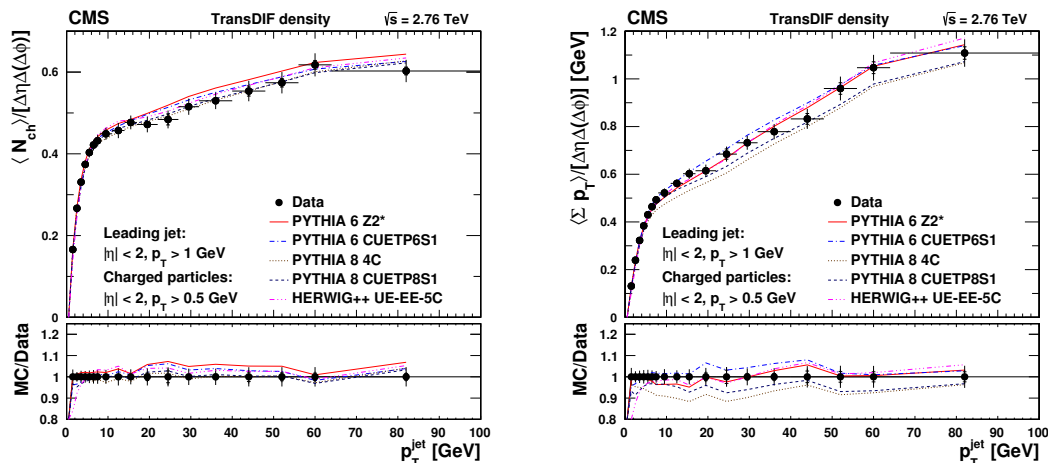


Figure 3. Measured transDIF activity (see text for its definition) for (left) particle density, and (right) Σp_T density, as a function of p_T^{jet} . The definitions of the symbols and error bars are the same as for figure 1.

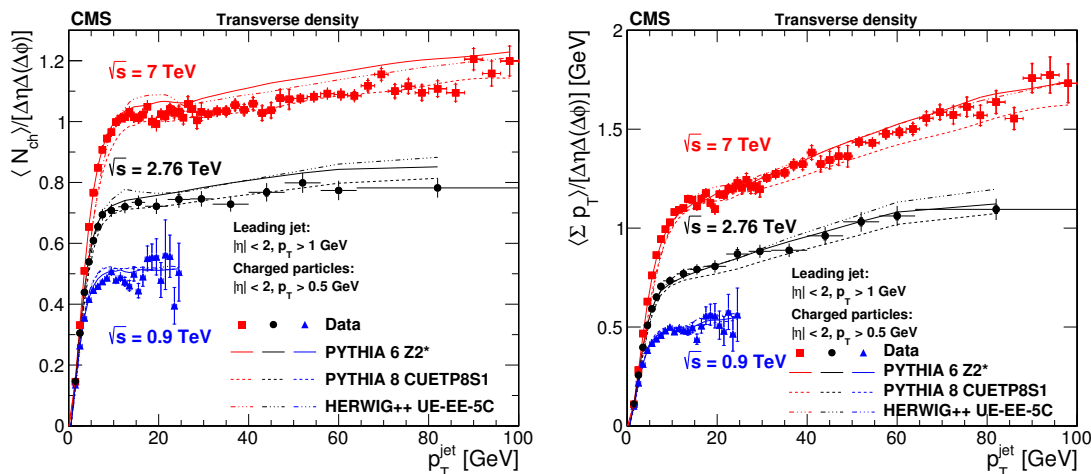


Figure 4. Comparison of UE activity at $\sqrt{s} = 0.9, 2.76,$ and 7 TeV for (left) particle density, and (right) Σp_T density, as a function of p_T^{jet} [4, 5]. The data (symbols) are compared to various MC simulations (curves). The definition of the error bars is the same as for figure 1.

allow improving the modelling of key ingredients — such as multiparton interactions, QCD radiation, energy evolution of the transverse proton profile, etc. — which will play an increasing role at higher proton-proton collision energies.

5 Summary

The measurement of the underlying event (UE) activity in proton-proton collisions at $\sqrt{s} = 2.76$ TeV has been presented using events with a charged-particle jet produced at central pseudorapidity ($|\eta^{\text{jet}}| < 2$) with transverse momenta $1 \leq p_T^{\text{jet}} < 100$ GeV. This analysis complements the results of previous similar measurements at $\sqrt{s} = 0.9$ and 7 TeV.

The UE activity is measured in the transverse region and further studied in terms of the transMAX, transMIN and transDIF activities. A step rise of the underlying activity

in the transverse region is seen with increasing leading jet p_T . This fast rise is followed by a leveling above $p_T^{\text{jet}} \approx 8$ GeV, with nearly constant particle density and small Σp_T density increase. Such a distinct pattern (fast rise followed by a leveling of the UE hadronic activity) is clearly seen for all the observables in the various regions, and is compatible with the impact parameter picture of pp collisions featuring an increasing number of MPI for increasing overlap followed by a saturation of hadron production once the hardest most-central collisions are reached. The transDIF density distributions show an increase of the activity as a function of p_T^{jet} , corroborating the hypothesis of more intense ISR and FSR from the increasingly harder parton-parton scatter.

The results are compared to recent tunes of PYTHIA and HERWIG++ Monte Carlo event generators. The PYTHIA6, PYTHIA8, and HERWIG++ tunes describe the data within 5 to 10%. All MC tunes predict a collision energy dependence of the hadronic activity similar to that observed in the data. The ability of the latest Monte Carlo generator tunes to describe the data confirms the validity of the tunes and lends confidence to the predictions of UE activity for higher collision energies.

Acknowledgments

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

Individuals have received support from the Marie-Curie programme and the European Research Council and EPLANET (European Union); the Leventis Foundation; the A. P. Sloan Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the Ministry of Education, Youth and Sports (MEYS) of

the Czech Republic; the Council of Science and Industrial Research, India; the HOMING PLUS programme of the Foundation for Polish Science, cofinanced from European Union, Regional Development Fund; the Compagnia di San Paolo (Torino); the Consorzio per la Fisica (Trieste); MIUR project 20108T4XTM (Italy); the Thalys and Aristeia programmes cofinanced by EU-ESF and the Greek NSRF; the National Priorities Research Program by Qatar National Research Fund; the Rachadapisek Sompot Fund for Postdoctoral Fellowship, Chulalongkorn University (Thailand); and the Welch Foundation.

Open Access. This article is distributed under the terms of the Creative Commons Attribution License ([CC-BY 4.0](https://creativecommons.org/licenses/by/4.0/)), which permits any use, distribution and reproduction in any medium, provided the original author(s) and source are credited.

References

- [1] CDF collaboration, T. Affolder et al., *Charged jet evolution and the underlying event in $p\bar{p}$ collisions at 1.8 TeV*, *Phys. Rev. D* **65** (2002) 092002 [[INSPIRE](#)].
- [2] CDF collaboration, D. Acosta et al., *The underlying event in hard interactions at the Tevatron $p\bar{p}$ collider*, *Phys. Rev. D* **70** (2004) 072002 [[hep-ex/0404004](#)] [[INSPIRE](#)].
- [3] CDF collaboration, T. Aaltonen et al., *Studying the underlying event in Drell-Yan and high transverse momentum jet production at the Tevatron*, *Phys. Rev. D* **82** (2010) 034001 [[arXiv:1003.3146](#)] [[INSPIRE](#)].
- [4] CMS collaboration, *First measurement of the underlying event activity at the LHC with $\sqrt{s} = 0.9$ TeV*, *Eur. Phys. J. C* **70** (2010) 555 [[arXiv:1006.2083](#)] [[INSPIRE](#)].
- [5] CMS collaboration, *Measurement of the underlying event activity at the LHC with $\sqrt{s} = 7$ TeV and comparison with $\sqrt{s} = 0.9$ TeV*, *JHEP* **09** (2011) 109 [[arXiv:1107.0330](#)] [[INSPIRE](#)].
- [6] CMS collaboration, *Study of the underlying event at forward rapidity in pp collisions at $\sqrt{s} = 0.9, 2.76$ and 7 TeV*, *JHEP* **04** (2013) 072 [[arXiv:1302.2394](#)] [[INSPIRE](#)].
- [7] ATLAS collaboration, *Measurement of underlying event characteristics using charged particles in pp collisions at $\sqrt{s} = 900$ GeV and 7 TeV with the ATLAS detector*, *Phys. Rev. D* **83** (2011) 112001 [[arXiv:1012.0791](#)] [[INSPIRE](#)].
- [8] ALICE collaboration, *Underlying Event measurements in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV with the ALICE experiment at the LHC*, *JHEP* **07** (2012) 116 [[arXiv:1112.2082](#)] [[INSPIRE](#)].
- [9] CMS collaboration, *Measurement of the underlying event in the Drell-Yan process in proton-proton collisions at $\sqrt{s} = 7$ TeV*, *Eur. Phys. J. C* **72** (2012) 2080 [[arXiv:1204.1411](#)] [[INSPIRE](#)].
- [10] T. Sjöstrand and M. van Zijl, *Multiple parton-parton interactions in an impact parameter picture*, *Phys. Lett. B* **188** (1987) 149 [[INSPIRE](#)].
- [11] L. Frankfurt, M. Strikman and C. Weiss, *Transverse nucleon structure and diagnostics of hard parton-parton processes at LHC*, *Phys. Rev. D* **83** (2011) 054012 [[arXiv:1009.2559](#)] [[INSPIRE](#)].
- [12] T. Sjöstrand, S. Mrenna and P.Z. Skands, *PYTHIA 6.4 physics and manual*, *JHEP* **05** (2006) 026 [[hep-ph/0603175](#)] [[INSPIRE](#)].

- [13] T. Sjöstrand, S. Mrenna and P.Z. Skands, *A brief introduction to PYTHIA 8.1*, *Comput. Phys. Commun.* **178** (2008) 852 [[arXiv:0710.3820](#)] [[INSPIRE](#)].
- [14] M. Bähr et al., *Herwig++ physics and manual*, *Eur. Phys. J. C* **58** (2008) 639 [[INSPIRE](#)].
- [15] T. Sjöstrand and P.Z. Skands, *Transverse-momentum-ordered showers and interleaved multiple interactions*, *Eur. Phys. J. C* **39** (2005) 129 [[hep-ph/0408302](#)] [[INSPIRE](#)].
- [16] B. Andersson, G. Gustafson, G. Ingelman and T. Sjöstrand, *Parton fragmentation and string dynamics*, *Phys. Rept.* **97** (1983) 31 [[INSPIRE](#)].
- [17] CMS collaboration, *Underlying event tunes and double parton scattering*, [CMS-PAS-GEN-14-001](#) (2014).
- [18] R. Corke and T. Sjöstrand, *Interleaved parton showers and tuning prospects*, *JHEP* **03** (2011) 032 [[arXiv:1011.1759](#)] [[INSPIRE](#)].
- [19] M.H. Seymour and A. Siodmok, *Constraining MPI models using σ_{eff} and recent Tevatron and LHC Underlying Event data*, *JHEP* **10** (2013) 113 [[arXiv:1307.5015](#)] [[INSPIRE](#)].
- [20] J. Pumplin, D.R. Stump, J. Huston, H.L. Lai, P.M. Nadolsky and W.K. Tung, *New generation of parton distributions with uncertainties from global QCD analysis*, *JHEP* **07** (2002) 012 [[hep-ph/0201195](#)] [[INSPIRE](#)].
- [21] R. Field, *Early LHC underlying event data — Findings and surprises*, [arXiv:1010.3558](#) [[INSPIRE](#)].
- [22] J. Allison et al., *GEANT4 developments and applications*, *IEEE Trans. Nucl. Sci.* **53** (2006) 270.
- [23] CMS collaboration, *Description and performance of track and primary-vertex reconstruction with the CMS tracker*, [2014 JINST 9 P10009](#) [[arXiv:1405.6569](#)] [[INSPIRE](#)].
- [24] CMS collaboration, *The CMS experiment at the CERN LHC*, [2008 JINST 3 S08004](#) [[INSPIRE](#)].
- [25] CMS collaboration, *CMS tracking performance results from early LHC operation*, *Eur. Phys. J. C* **70** (2010) 1165 [[arXiv:1007.1988](#)] [[INSPIRE](#)].
- [26] CMS Collaboration, *Performance of jet reconstruction with charged tracks only*, [CMS-PAS-JME-08-001](#) (2008).
- [27] G.P. Salam and G. Soyez, *A practical seedless infrared-safe cone jet algorithm*, *JHEP* **05** (2007) 086 [[arXiv:0704.0292](#)] [[INSPIRE](#)].
- [28] M. Cacciari, G.P. Salam and G. Soyez, *The anti- k_t jet clustering algorithm*, *JHEP* **04** (2008) 063 [[arXiv:0802.1189](#)] [[INSPIRE](#)].
- [29] J. Pumplin, *Hard underlying event correction to inclusive jet cross-sections*, *Phys. Rev. D* **57** (1998) 5787 [[hep-ph/9708464](#)] [[INSPIRE](#)].
- [30] G. D’Agostini, *A multidimensional unfolding method based on Bayes’ theorem*, *Nucl. Instrum. Meth. A* **362** (1995) 487 [[INSPIRE](#)].

The CMS collaboration

Yerevan Physics Institute, Yerevan, Armenia

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

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, M. Flechl, M. Friedl, R. Frühwirth¹, V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler¹, V. Knünz, A. König, M. Krammer¹, I. Krätschmer, D. Liko, T. Matsushita, I. Mikulec, D. Rabady², B. Rahbaran, H. Rohringer, J. Schieck¹, R. Schöfbeck, J. Strauss, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz¹

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

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

Universiteit Antwerpen, Antwerpen, Belgium

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

Vrije Universiteit Brussel, Brussel, Belgium

S. Abu Zeid, F. Blekman, J. D'Hondt, N. Daci, I. De Bruyn, K. Deroover, N. Heracleous, J. Keaveney, S. Lowette, L. Moreels, A. Olbrechts, Q. Python, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Van Parijs

Université Libre de Bruxelles, Bruxelles, Belgium

P. Barria, C. Caillol, B. Clerbaux, G. De Lentdecker, H. Delannoy, D. Dobur, G. Fasanella, L. Favart, A.P.R. Gay, A. Grebenyuk, T. Lenzi, A. Léonard, T. Maerschalk, A. Mohammadi, L. Perniè, A. Randle-conde, T. Reis, T. Seva, C. Vander Velde, P. Vanlaer, J. Wang, R. Yonamine, F. Zenoni, F. Zhang³

Ghent University, Ghent, Belgium

K. Beernaert, L. Benucci, A. Cimmino, S. Crucy, A. Fagot, G. Garcia, M. Gul, J. Mccartin, A.A. Ocampo Rios, D. Poyraz, D. Ryckbosch, S. Salva, M. Sigamani, N. Strobbe, M. Tytgat, W. Van Driessche, E. Yazgan, N. Zaganidis

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

S. Basesmez, C. Beluffi⁴, O. Bondu, G. Bruno, R. Castello, A. Caudron, L. Ceard, G.G. Da Silveira, C. Delaere, D. Favart, L. Forthomme, A. Giammanco⁵, J. Hollar, A. Jafari, P. Jez, M. Komm, V. Lemaitre, A. Mertens, C. Nuttens, L. Perrini, A. Pin, K. Piotrkowski, A. Popov⁶, L. Quertenmont, M. Selvaggi, M. Vidal Marono

Université de Mons, Mons, Belgium

N. Belyi, T. Caebergs, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

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

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

E. Belchior Batista Das Chagas, W. Carvalho, J. Chinellato⁷, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, L.M. Huertas Guativa, H. Malbouisson, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, A. Santoro, A. Sznajder, E.J. Tonelli Manganote⁷, A. Vilela Pereira

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

S. Ahuja^a, C.A. Bernardes^b, A. De Souza Santos^b, S. Dogra^a, T.R. Fernandez Perez Tomei^a, E.M. Gregores^b, P.G. Mercadante^b, C.S. Moon^{a,8}, S.F. Novaes^a, Sandra S. Padula^a, D. Romero Abad, J.C. Ruiz Vargas

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

A. Aleksandrov, V. Genchev[†], R. Hadjiiska, P. Iaydjiev, A. Marinov, S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

University of Sofia, Sofia, Bulgaria

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

Institute of High Energy Physics, Beijing, China

M. Ahmad, J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, T. Cheng, R. Du, C.H. Jiang, R. Plestina⁹, F. Romeo, S.M. Shaheen, J. Tao, C. Wang, Z. Wang, H. Zhang

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

C. Asawatangtrakuldee, Y. Ban, Q. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, Z. Xu, W. Zou

Universidad de Los Andes, Bogota, Colombia

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

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

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

University of Split, Faculty of Science, Split, Croatia

Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

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

University of Cyprus, Nicosia, Cyprus

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

Charles University, Prague, Czech Republic

M. Bodlak, M. Finger¹⁰, M. Finger Jr.¹⁰

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

R. Aly¹¹, S. Aly¹¹, Y. Assran¹², S. Elgammal¹³, A. Ellithi Kamel¹⁴, A. Lotfy¹⁵,
M.A. Mahmoud¹⁵, A. Radi^{13,16}, A. Sayed^{16,13}

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

B. Calpas, M. Kadastik, M. Murumaa, M. Raidal, A. Tiko, C. Veelken

Department of Physics, University of Helsinki, Helsinki, Finland

P. Eerola, J. Pekkanen, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

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

Lappeenranta University of Technology, Lappeenranta, Finland

J. Talvitie, T. Tuuva

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

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

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

S. Baffioni, F. Beaudette, P. Busson, L. Cadamuro, E. Chapon, C. Charlot, T. Dahms,
O. Davignon, N. Filipovic, A. Florent, R. Granier de Cassagnac, S. Lisniak, L. Mas-
trotolorenzo, P. Miné, I.N. Naranjo, M. Nguyen, C. Ochando, G. Ortona, P. Paganini,
S. Regnard, R. Salerno, J.B. Sauvan, Y. Sirois, T. Strebler, Y. Yilmaz, A. Zabi

**Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Univer-
sité de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France**

J.-L. Agram¹⁷, J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, M. Buttignol, E.C. Chabert,
N. Chanon, C. Collard, E. Conte¹⁷, X. Coubez, J.-C. Fontaine¹⁷, D. Gelé, U. Goerlach,
C. Goetzmann, A.-C. Le Bihan, J.A. Merlin², K. Skovpen, P. Van Hove

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

S. Gadrat

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

S. Beauceron, C. Bernet, G. Boudoul, E. Bouvier, S. Brochet, C.A. Carrillo Montoya,
J. Chasserat, R. Chierici, D. Contardo, B. Courbon, P. Depasse, H. El Mamouni, J. Fan,
J. Fay, S. Gascon, M. Gouzevitch, B. Ille, I.B. Laktineh, M. Lethuillier, L. Mirabito,
A.L. Pequegnot, S. Perries, J.D. Ruiz Alvarez, D. Sabes, L. Sgandurra, V. Sordini,
M. Vander Donckt, P. Verdier, S. Viret, H. Xiao

Georgian Technical University, Tbilisi, GeorgiaT. Toriashvili¹⁸**Tbilisi State University, Tbilisi, Georgia**I. Bagaturia¹⁹**RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany**C. Autermann, S. Beranek, M. Edelhoff, L. Feld, A. Heister, M.K. Kiesel, K. Klein, M. Lipinski, A. Ostapchuk, M. Preuten, F. Raupach, J. Sammet, S. Schael, J.F. Schulte, T. Verlage, H. Weber, B. Wittmer, V. Zhukov⁶**RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany**

M. Ata, M. Brodski, E. Dietz-Laursonn, D. Duchardt, M. Endres, M. Erdmann, S. Erdweg, T. Esch, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, S. Knutzen, P. Kreuzer, M. Merschmeyer, A. Meyer, P. Millet, M. Olschewski, K. Padeken, P. Papacz, T. Pook, M. Radziej, H. Reithler, M. Rieger, F. Scheuch, L. Sonnenschein, D. Teysier, S. Thier

RWTH Aachen University, III. Physikalisches Institut B, Aachen, GermanyV. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Künsken, J. Lingemann², A. Nehr Korn, A. Nowack, I.M. Nugent, C. Pistone, O. Pooth, A. Stahl**Deutsches Elektronen-Synchrotron, Hamburg, Germany**M. Aldaya Martin, I. Asin, N. Bartosik, O. Behnke, U. Behrens, A.J. Bell, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, S. Choudhury, F. Costanza, C. Diez Pardos, G. Dolinska, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, E. Gallo, J. Garay Garcia, A. Geiser, A. Gizhko, P. Gunnellini, J. Hauk, M. Hempel²⁰, H. Jung, A. Kalogeropoulos, O. Karacheban²⁰, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, I. Korol, W. Lange, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann²⁰, R. Mankel, I. Marfin²⁰, I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, S. Naumann-Emme, A. Nayak, E. Ntomari, H. Perrey, D. Pitzl, R. Placakyte, A. Raspereza, P.M. Ribeiro Cipriano, B. Roland, M.Ö. Sahin, J. Salfeld-Nebgen, P. Saxena, T. Schoerner-Sadenius, M. Schröder, C. Seitz, S. Spannagel, K.D. Trippkewitz, C. Wissing**University of Hamburg, Hamburg, Germany**V. Blobel, M. Centis Vignali, A.R. Draeger, J. Erfle, E. Garutti, K. Goebel, D. Gonzalez, M. Görner, J. Haller, M. Hoffmann, R.S. Höing, A. Junkes, R. Klanner, R. Kogler, T. Lapsien, T. Lenz, I. Marchesini, D. Marconi, D. Nowatschin, J. Ott, F. Pantaleo², T. Peiffer, A. Perieanu, N. Pietsch, J. Poehlsen, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, J. Schwandt, M. Seidel, V. Sola, H. Stadie, G. Steinbrück, H. Tholen, D. Troendle, E. Usai, L. Vanelderen, A. Vanhoefer**Institut für Experimentelle Kernphysik, Karlsruhe, Germany**

M. Akbiyik, C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, F. Colombo, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, F. Frensch, M. Giffels, A. Gilbert,

F. Hartmann², U. Husemann, F. Kassel², I. Katkov⁶, A. Kornmayer², P. Lobelle Pardo, M.U. Mozer, T. Müller, Th. Müller, M. Plagge, G. Quast, K. Rabbertz, S. Röcker, F. Roscher, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, C. Wöhrmann, R. Wolf

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

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

University of Athens, Athens, Greece

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

University of Ioánnina, Ioánnina, Greece

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

Wigner Research Centre for Physics, Budapest, Hungary

G. Bencze, C. Hajdu, A. Hazi, P. Hidas, D. Horvath²¹, F. Sikler, V. Veszpremi, G. Vesztergombi²², A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

N. Beni, S. Czellar, J. Karancsi²³, J. Molnar, Z. Szillasi

University of Debrecen, Debrecen, Hungary

M. Bartók²⁴, A. Makovec, P. Raics, Z.L. Trocsanyi, B. Ujvari

National Institute of Science Education and Research, Bhubaneswar, India

P. Mal, K. Mandal, N. Sahoo, S.K. Swain

Panjab University, Chandigarh, India

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

University of Delhi, Delhi, India

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

Saha Institute of Nuclear Physics, Kolkata, India

S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dey, S. Dutta, Sa. Jain, Sh. Jain, R. Khurana, N. Majumdar, A. Modak, K. Mondal, S. Mukherjee, S. Mukhopadhyay, A. Roy, D. Roy, S. Roy Chowdhury, S. Sarkar, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India

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

Tata Institute of Fundamental Research, Mumbai, India

T. Aziz, S. Banerjee, S. Bhowmik²⁵, R.M. Chatterjee, R.K. Dewanjee, S. Dugad, S. Ganguly, S. Ghosh, M. Guchait, A. Gurtu²⁶, G. Kole, S. Kumar, B. Mahakud, M. Maity²⁵,

G. Majumder, K. Mazumdar, S. Mitra, G.B. Mohanty, B. Parida, T. Sarkar²⁵, K. Sudhakar, N. Sur, B. Sutar, N. Wickramage²⁷

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

S. Sharma

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

H. Bakhshiansohi, H. Behnamian, S.M. Etesami²⁸, A. Fahim²⁹, R. Goldouzian, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, F. Rezaei Hosseinabadi, B. Safarzadeh³⁰, M. Zeinali

University College Dublin, Dublin, Ireland

M. Felcini, M. Grunewald

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

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

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

G. Abbiendi^a, C. Battilana², A.C. Benvenuti^a, D. Bonacorsi^{a,b}, S. Braibant-Giacomelli^{a,b}, L. Brigliadori^{a,b}, R. Campanini^{a,b}, P. Capiluppi^{a,b}, A. Castro^{a,b}, F.R. Cavallo^a, G. Codispoti^{a,b}, M. Cuffiani^{a,b}, G.M. Dallavalle^a, F. Fabbri^a, A. Fanfani^{a,b}, D. Fasanella^{a,b}, P. Giacomelli^a, C. Grandi^a, L. Guiducci^{a,b}, S. Marcellini^a, G. Masetti^a, A. Montanari^a, F.L. Navarria^{a,b}, A. Perrotta^a, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G.P. Siroli^{a,b}, N. Tosi^{a,b}, R. Travaglini^{a,b}

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

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

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

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

INFN Laboratori Nazionali di Frascati, Frascati, Italy

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

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

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

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

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

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

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

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

P. Azzi^{a,2}, N. Bacchetta^a, M. Bellato^a, D. Bisello^{a,b}, R. Carlin^{a,b}, A. Carvalho Antunes De Oliveira^{a,b}, P. Checchia^a, M. Dall'Osso^{a,b,2}, T. Dorigo^a, S. Fantinel^a, F. Fanzago^a, F. Gasparini^{a,b}, U. Gasparini^{a,b}, A. Gozzelino^a, S. Lacaprara^a, M. Margoni^{a,b}, A.T. Meneguzzo^{a,b}, J. Pazzini^{a,b}, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{a,b}, M. Zanetti, P. Zotto^{a,b}, A. Zucchetta^{a,b,2}, G. Zumerle^{a,b}

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

A. Braghieri^a, M. Gabusi^{a,b}, A. Magnani^a, S.P. Ratti^{a,b}, V. Re^a, C. Riccardi^{a,b}, P. Salvini^a, I. Vai^a, P. Vitulo^{a,b}

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

L. Alunni Solestizi^{a,b}, M. Biasini^{a,b}, G.M. Bilei^a, D. Ciangottini^{a,b,2}, L. Fanò^{a,b}, P. Lariccia^{a,b}, G. Mantovani^{a,b}, M. Menichelli^a, A. Saha^a, A. Santocchia^{a,b}, A. Spiezia^{a,b}

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

K. Androsov^{a,31}, P. Azzurri^a, G. Bagliesi^a, J. Bernardini^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, M.A. Ciocci^{a,31}, R. Dell'Orso^a, S. Donato^{a,c,2}, G. Fedi, L. Foà^{a,c†}, A. Giassi^a, M.T. Grippo^{a,31}, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,b}, A. Messineo^{a,b}, F. Palla^a, A. Rizzi^{a,b}, A. Savoy-Navarro^{a,32}, A.T. Serban^a, P. Spagnolo^a, P. Squillacioti^{a,31}, R. Tenchini^a, G. Tonelli^{a,b}, A. Venturi^a, P.G. Verdini^a

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

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

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

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

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

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

Kangwon National University, Chunchon, Korea

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

Kyungpook National University, Daegu, Korea

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

Chonbuk National University, Jeonju, Korea

J.A. Brochero Cifuentes, H. Kim, T.J. Kim, M.S. Ryu

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

S. Song

Korea University, Seoul, Korea

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

Seoul National University, Seoul, Korea

H.D. Yoo

University of Seoul, Seoul, Korea

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

Sungkyunkwan University, Suwon, Korea

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

Vilnius University, Vilnius, Lithuania

A. Juodagalvis, J. Vaitkus

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

I. Ahmed, Z.A. Ibrahim, J.R. Komaragiri, M.A.B. Md Ali³³, F. Mohamad Idris³⁴,
W.A.T. Wan Abdullah

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

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

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

S. Carpinteyro, I. Pedraza, H.A. Salazar Ibarguen

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

A. Morelos Pineda

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand

P.H. Butler, S. Reucroft

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

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

National Centre for Nuclear Research, Swierk, Poland

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

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

G. Brona, K. Bunkowski, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Mis-iura, M. Olszewski, M. Walczak

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

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

Joint Institute for Nuclear Research, Dubna, Russia

S. Afanasiev, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, V. Konoplyanikov, A. Lanev, A. Malakhov, V. Matveev³⁶, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, A. Zarubin

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

V. Golovtsov, Y. Ivanov, V. Kim³⁷, E. Kuznetsova, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev

Institute for Nuclear Research, Moscow, Russia

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

Institute for Theoretical and Experimental Physics, Moscow, Russia

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

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

A. Bylinkin

P.N. Lebedev Physical Institute, Moscow, Russia

V. Andreev, M. Azarkin³⁸, I. Dremin³⁸, M. Kirakosyan, A. Leonidov³⁸, G. Mesyats, S.V. Rusakov, A. Vinogradov

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

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

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

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

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

P. Adzic³⁹, M. Ekmedzic, J. Milosevic, V. Rekovic

National University of Singapore, Singapore, Singapore

W.Y. Wang

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

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

Universidad Autónoma de Madrid, Madrid, Spain

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

Universidad de Oviedo, Oviedo, Spain

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, E. Palencia Cortezon, J.M. Vizan Garcia

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

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

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, A. Benaglia, J. Bendavid, L. Benhabib, J.F. Benitez, G.M. Berruti, G. Bianchi, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, S. Colafranceschi⁴⁰, M. D'Alfonso, D. d'Enterria, A. Dabrowski, V. Daponte, A. David, M. De Gruttola, F. De Guio, A. De Roeck, S. De Visscher, E. Di Marco, M. Dobson,

M. Dordevic, T. du Pree, N. Dupont, A. Elliott-Peisert, J. Eugster, G. Franzoni, W. Funk, D. Gigi, K. Gill, D. Giordano, M. Girone, F. Glege, R. Guida, S. Gundacker, M. Guthoff, J. Hammer, M. Hansen, P. Harris, J. Hegeman, V. Innocente, P. Janot, H. Kirschenmann, M.J. Kortelainen, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, M.T. Lucchini, N. Magini, L. Malgeri, M. Mannelli, J. Marrouche, A. Martelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, S. Morovic, M. Mulders, M.V. Nemallapudi, H. Neugebauer, S. Orfanelli⁴¹, L. Orsini, L. Pape, E. Perez, A. Petrilli, G. Petrucciani, A. Pfeiffer, D. Piparo, A. Racz, G. Rolandi⁴², M. Rovere, M. Ruan, H. Sakulin, C. Schäfer, C. Schwick, A. Sharma, P. Silva, M. Simon, P. Sphicas⁴³, D. Spiga, J. Steggemann, B. Stieger, M. Stoye, Y. Takahashi, D. Treille, A. Tsirou, G.I. Veres²², N. Wardle, H.K. Wöhri, A. Zagodzinska⁴⁴, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

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

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

F. Bachmair, L. Bäni, L. Bianchini, M.A. Buchmann, B. Casal, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, C. Grab, C. Heidegger, D. Hits, J. Hoss, G. Kasieczka, W. Lustermann, B. Mangano, A.C. Marini, M. Marionneau, P. Martinez Ruiz del Arbol, M. Masciovecchio, D. Meister, P. Musella, F. Nessi-Tedaldi, F. Pandolfi, J. Pata, F. Pauss, L. Perrozzi, M. Peruzzi, M. Quittnat, M. Rossini, A. Starodumov⁴⁵, M. Takahashi, V.R. Tavolaro, K. Theofilatos, R. Wallny, H.A. Weber

Universität Zürich, Zurich, Switzerland

T.K. Aarrestad, C. AMSler⁴⁶, M.F. Canelli, V. Chiochia, A. De Cosa, C. Galloni, A. Hinzmann, T. Hreus, B. Kilminster, C. Lange, J. Ngadiuba, D. Pinna, P. Robmann, F.J. Ronga, D. Salerno, S. Taroni, Y. Yang

National Central University, Chung-Li, Taiwan

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

National Taiwan University (NTU), Taipei, Taiwan

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

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

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

Cukurova University, Adana, Turkey

A. Adiguzel, S. Cerci⁴⁷, C. Dozen, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E.E. Kangal⁴⁸, A. Kayis Topaksu, G. Onengut⁴⁹, K. Ozdemir⁵⁰, S. Ozturk⁵¹, B. Tali⁴⁷, H. Topakli⁵¹, M. Vergili, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey

I.V. Akin, B. Bilin, S. Bilmis, B. Isildak⁵², G. Karapinar⁵³, U.E. Surat, M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey

E.A. Albayrak⁵⁴, E. Gülmez, M. Kaya⁵⁵, O. Kaya⁵⁶, T. Yetkin⁵⁷

Istanbul Technical University, Istanbul, Turkey

K. Cankocak, S. Sen⁵⁸, F.I. Vardarli

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

B. Grynyov

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

L. Levchuk, P. Sorokin

University of Bristol, Bristol, United Kingdom

R. Aggleton, F. Ball, L. Beck, J.J. Brooke, E. Clement, D. Cussans, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D.M. Newbold⁵⁹, S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, S. Senkin, D. Smith, V.J. Smith

Rutherford Appleton Laboratory, Didcot, United Kingdom

K.W. Bell, A. Belyaev⁶⁰, C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, L. Thomas, I.R. Tomalin, T. Williams, W.J. Womersley, S.D. Worm

Imperial College, London, United Kingdom

M. Baber, R. Bainbridge, O. Buchmuller, A. Bundock, D. Burton, S. Casasso, M. Citron, D. Colling, L. Corpe, N. Cripps, P. Dauncey, G. Davies, A. De Wit, M. Della Negra, P. Dunne, A. Elwood, W. Ferguson, J. Fulcher, D. Futyan, G. Hall, G. Iles, G. Karapostoli, M. Kenzie, R. Lane, R. Lucas⁵⁹, L. Lyons, A.-M. Magnan, S. Malik, J. Nash, A. Nikitenko⁴⁵, J. Pela, M. Pesaresi, K. Petridis, D.M. Raymond, A. Richards, A. Rose, C. Seez, P. Sharp[†], A. Tapper, K. Uchida, M. Vazquez Acosta⁶¹, T. Virdee, S.C. Zenz

Brunel University, Uxbridge, United Kingdom

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

Baylor University, Waco, USA

A. Borzou, J. Dittmann, K. Hatakeyama, A. Kasmi, H. Liu, N. Pastika

The University of Alabama, Tuscaloosa, USA

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

Boston University, Boston, USA

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

Brown University, Providence, USA

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

University of California, Davis, Davis, USA

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

University of California, Los Angeles, USA

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

University of California, Riverside, Riverside, USA

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

University of California, San Diego, La Jolla, USA

J.G. Branson, G.B. Cerati, S. Cittolin, R.T. D'Agnolo, A. Holzner, R. Kelley, D. Klein, J. Letts, I. Macneill, D. Olivito, S. Padhi, M. Pieri, M. Sani, V. Sharma, S. Simon, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech⁶², C. Welke, F. Würthwein, A. Yagil, G. Zevi Della Porta

University of California, Santa Barbara, Santa Barbara, USA

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

California Institute of Technology, Pasadena, USA

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

Carnegie Mellon University, Pittsburgh, USA

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

University of Colorado Boulder, Boulder, USA

J.P. Cumalat, W.T. Ford, A. Gaz, F. Jensen, A. Johnson, M. Krohn, T. Mulholland, U. Nauenberg, J.G. Smith, K. Stenson, S.R. Wagner

Cornell University, Ithaca, USA

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

Fermi National Accelerator Laboratory, Batavia, USA

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

University of Florida, Gainesville, USA

D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, A. Carnes, M. Carver, D. Curry, S. Das, G.P. Di Giovanni, R.D. Field, M. Fisher, I.K. Furic, J. Hugon, J. Konigsberg, A. Korytov, J.F. Low, P. Ma, K. Matchev, H. Mei, P. Milenovic⁶³, G. Mitselmakher, L. Muniz, D. Rank, L. Shchutska, M. Snowball, D. Sperka, S. Wang, J. Yelton

Florida International University, Miami, USA

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

Florida State University, Tallahassee, USA

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

Florida Institute of Technology, Melbourne, USA

V. Bhopatkar, M. Hohlmann, H. Kalakhety, D. Mareskas-palcek, T. Roy, F. Yumiceva

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

M.R. Adams, L. Apanasevich, D. Berry, R.R. Betts, I. Bucinskaite, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, P. Kurt, C. O'Brien, I.D. Sandoval Gonzalez, C. Silkworth, P. Turner, N. Varelas, Z. Wu, M. Zakaria

The University of Iowa, Iowa City, USA

B. Bilki⁶⁴, W. Clarida, K. Dilsiz, S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya⁶⁵, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok⁵⁴, A. Penzo, C. Snyder, P. Tan, E. Tiras, J. Wetzel, K. Yi

Johns Hopkins University, Baltimore, USA

I. Anderson, B.A. Barnett, B. Blumenfeld, D. Fehling, L. Feng, A.V. Gritsan, P. Maksimovic, C. Martin, K. Nash, M. Osherson, M. Swartz, M. Xiao, Y. Xin

The University of Kansas, Lawrence, USA

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

Kansas State University, Manhattan, USA

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

Lawrence Livermore National Laboratory, Livermore, USA

D. Lange, F. Rebassoo, D. Wright

University of Maryland, College Park, USA

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

Massachusetts Institute of Technology, Cambridge, USA

A. Apyan, R. Barbieri, A. Baty, K. Bierwagen, S. Brandt, W. Busza, I.A. Cali, Z. Demiragli, L. Di Matteo, G. Gomez Ceballos, M. Goncharov, D. Gulhan, G.M. Innocenti, M. Klute, D. Kovalskyi, Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, C. McGinn, X. Niu, C. Paus, D. Ralph, C. Roland, G. Roland, G.S.F. Stephans, K. Sumorok, M. Varma, D. Velicanu, J. Veverka, J. Wang, T.W. Wang, B. Wyslouch, M. Yang, V. Zhukova

University of Minnesota, Minneapolis, USA

B. Dahmes, A. Finkel, A. Gude, P. Hansen, S. Kalafut, S.C. Kao, K. Klapoetke, Y. Kubota, Z. Lesko, J. Mans, S. Nourbakhsh, N. Ruckstuhl, R. Rusack, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, USA

J.G. Acosta, S. Oliveros

University of Nebraska-Lincoln, Lincoln, USA

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

State University of New York at Buffalo, Buffalo, USA

M. Alyari, J. Dolen, J. George, A. Godshalk, I. Iashvili, J. Kaisen, A. Kharchilava, A. Kumar, S. Rappoccio

Northeastern University, Boston, USA

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

Northwestern University, Evanston, USA

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

University of Notre Dame, Notre Dame, USA

A. Brinkerhoff, N. Dev, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, S. Lynch, N. Marinelli, F. Meng, C. Mueller, Y. Musienko³⁶, T. Pearson, M. Planer, R. Ruchti, G. Smith, N. Valls, M. Wayne, M. Wolf, A. Woodard

The Ohio State University, Columbus, USA

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

Princeton University, Princeton, USA

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

University of Puerto Rico, Mayaguez, USA

S. Malik

Purdue University, West Lafayette, USA

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

Purdue University Calumet, Hammond, USA

N. Parashar, J. Stupak

Rice University, Houston, USA

A. Adair, B. Akgun, Z. Chen, K.M. Ecklund, F.J.M. Geurts, M. Guilbaud, W. Li, B. Michlin, M. Northup, B.P. Padley, R. Redjimi, J. Roberts, J. Rorie, Z. Tu, J. Zabel

University of Rochester, Rochester, USA

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

The Rockefeller University, New York, USA

L. Demortier

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

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

University of Tennessee, Knoxville, USA

M. Foerster, G. Riley, K. Rose, S. Spanier, A. York

Texas A&M University, College Station, USA

O. Bouhali⁶⁶, A. Castaneda Hernandez, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon⁶⁷, V. Krutelyov, R. Montalvo, R. Mueller, I. Osipenkov, Y. Pakhotin, R. Patel, A. Perloff, J. Roe, A. Rose, A. Safonov, A. Tatarinov, K.A. Ulmer²

Texas Tech University, Lubbock, USA

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

Vanderbilt University, Nashville, USA

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

University of Virginia, Charlottesville, USA

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

Wayne State University, Detroit, USA

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

University of Wisconsin, Madison, USA

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

†: Deceased

- 1: Also at Vienna University of Technology, Vienna, Austria
- 2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
- 3: Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
- 4: Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
- 5: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
- 6: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
- 7: Also at Universidade Estadual de Campinas, Campinas, Brazil
- 8: Also at Centre National de la Recherche Scientifique (CNRS) - IN2P3, Paris, France
- 9: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
- 10: Also at Joint Institute for Nuclear Research, Dubna, Russia
- 11: Now at Helwan University, Cairo, Egypt
- 12: Also at Suez University, Suez, Egypt
- 13: Also at British University in Egypt, Cairo, Egypt
- 14: Also at Cairo University, Cairo, Egypt
- 15: Now at Fayoum University, El-Fayoum, Egypt
- 16: Now at Ain Shams University, Cairo, Egypt
- 17: Also at Université de Haute Alsace, Mulhouse, France
- 18: Also at Tbilisi State University, Tbilisi, Georgia
- 19: Also at Ilia State University, Tbilisi, Georgia
- 20: Also at Brandenburg University of Technology, Cottbus, Germany

- 21: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- 22: Also at Eötvös Loránd University, Budapest, Hungary
- 23: Also at University of Debrecen, Debrecen, Hungary
- 24: Also at Wigner Research Centre for Physics, Budapest, Hungary
- 25: Also at University of Visva-Bharati, Santiniketan, India
- 26: Now at King Abdulaziz University, Jeddah, Saudi Arabia
- 27: Also at University of Ruhuna, Matara, Sri Lanka
- 28: Also at Isfahan University of Technology, Isfahan, Iran
- 29: Also at University of Tehran, Department of Engineering Science, Tehran, Iran
- 30: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
- 31: Also at Università degli Studi di Siena, Siena, Italy
- 32: Also at Purdue University, West Lafayette, USA
- 33: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
- 34: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia
- 35: Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico
- 36: Also at Institute for Nuclear Research, Moscow, Russia
- 37: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
- 38: Also at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
- 39: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
- 40: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
- 41: Also at National Technical University of Athens, Athens, Greece
- 42: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
- 43: Also at University of Athens, Athens, Greece
- 44: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
- 45: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
- 46: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
- 47: Also at Adiyaman University, Adiyaman, Turkey
- 48: Also at Mersin University, Mersin, Turkey
- 49: Also at Cag University, Mersin, Turkey
- 50: Also at Piri Reis University, Istanbul, Turkey
- 51: Also at Gaziosmanpasa University, Tokat, Turkey
- 52: Also at Ozyegin University, Istanbul, Turkey
- 53: Also at Izmir Institute of Technology, Izmir, Turkey
- 54: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
- 55: Also at Marmara University, Istanbul, Turkey
- 56: Also at Kafkas University, Kars, Turkey
- 57: Also at Yildiz Technical University, Istanbul, Turkey
- 58: Also at Hacettepe University, Ankara, Turkey
- 59: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
- 60: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
- 61: Also at Instituto de Astrofísica de Canarias, La Laguna, Spain
- 62: Also at Utah Valley University, Orem, USA
- 63: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- 64: Also at Argonne National Laboratory, Argonne, USA

65: Also at Erzincan University, Erzincan, Turkey

66: Also at Texas A&M University at Qatar, Doha, Qatar

67: Also at Kyungpook National University, Daegu, Korea