# Measurement of the underlying event activity in pp collisions at √s = 0.9 and 7 TeV with the novel jet-area/median approach

**Massachusetts Institute of Technology**

# Measurement of the underlying event activity in pp collisions at $\sqrt{s} = 0.9$ and $7\,\mathrm{TeV}$ with the novel jet-area/median approach

**The CMS collaboration**

ABSTRACT: The first measurement of the charged component of the underlying event using the novel "jet-area/median" approach is presented for proton-proton collisions at centre-of-mass energies of 0.9 and $7\,\mathrm{TeV}$. The data were recorded in 2010 with the CMS experiment at the LHC. A new observable, sensitive to soft particle production, is introduced and investigated inclusively and as a function of the event scale defined by the transverse momentum of the leading jet. Various phenomenological models are compared to data, with and without corrections for detector effects. None of the examined models describe the data satisfactorily.

# Contents

## 1   Introduction

In the theoretical description of nondiffractive inelastic proton-proton collisions, the main momentum transfer occurs between only two partons. This simple picture is refined by the inclusion of radiative effects in the form of initial- and final-state radiation. In addition, the primary interaction is accompanied by the production of further particles in multiple-parton interactions (MPIs) and in the hadronisation of the beam-beam remnants. The extra activity in a collision, which cannot be uniquely separated from initial- and final-state radiation, is referred to as the underlying event (UE).

Monte Carlo event generators simulate the UE based on phenomenological models, which have been tuned to the data of various collider experiments, taking into account the dependence of the UE on the centre-of-mass energy. The observation of substantial deviations of the predictions from the data, in particular when extrapolating to different

centre-of-mass energies, emphasises the need for measurements of the UE at different energies [1–6]. Retuned models allow for more precise measurements of observables based on jets or relying on isolation cones, for example in diphoton events from QCD processes or decays of the Higgs boson.

An unambiguous association of a specific particle to the reaction from which it originates is impossible. The investigation of the UE therefore requires a physically motivated separation of hard and soft contributions through the definition of phase-space regions that are dominated by either the hard or soft component of a collision. Traditionally, this is done by geometrically subdividing an event into different regions ("towards", "away", and "transverse") with respect to the jet or particle leading in transverse momentum $p_\mathrm{T}$. At the same time the $p_\mathrm{T}$ of the leading object is defined to be the so-called "event scale", i.e. a measure of the momentum transfer in the hard partonic scattering. Studies using this approach were performed at the Tevatron [1–3] and the Large Hadron Collider (LHC) [4–6].

A new technique based on the transverse momentum density per jet area, the jet-area/median approach, was proposed in [7]. The jet area covered by a jet, the "catchment area" [8], is determined in the plane of pseudorapidity $\eta$ versus azimuthal angle $\phi$ as defined in section 2. The exact size and shape of the area must be sensitive to the event-by-event fluctuating soft hadronic activity of the UE. The most widely used jet algorithm at the LHC, the anti-$k_\mathrm{T}$ jet algorithm [9], is unsuited for such an analysis and is replaced by the $k_\mathrm{T}$ algorithm [10–13]. The separation of the soft from the hard component of a collision is performed event by event by using the median of the distribution of transverse momentum densities of all jets in an event.

The data analysed in this study were collected with the Compact Muon Solenoid (CMS) detector at centre-of-mass energies of 0.9 and 7 TeV during the early LHC running in 2010, in which the contamination of events by additional proton-proton collisions in or close to the same bunch crossing, so-called pileup collisions, is very small. This jet area technique can be exploited to correct jet energies for pileup contamination in other measurements. The present paper is the first publication applying this new method in a collider experiment.

In the following, section 2 defines the UE-sensitive observable based on jet areas. Section 3 describes the experimental setup for data collection, triggering, vertex reconstruction, and event selection. Section 4 gives details on the phenomenological models used for event generation and on the detector simulation. The event reconstruction and the track and jet selections are explained in section 5 and are followed by a description of the unfolding technique in section 6. Sections 7 and 8 present the derivation of the measurement uncertainties and the final results, which are then summarised in section 9.

## 2 Definition of the observable

CMS uses a right-handed coordinate system, with the origin at the nominal interaction point, the $x$ axis pointing to the centre of the LHC, the $y$ axis pointing up (perpendicular to the LHC plane), and the $z$ axis along the anticlockwise-beam direction. The polar angle

$\theta$ is measured from the positive $z$ axis and the azimuthal angle $\phi$ is measured in the $x$-$y$ plane. The pseudorapidity $\eta$ is then defined as $\eta = -\ln\tan(\theta/2)$.

The adopted standard for jet clustering in the LHC experiments is the anti-$k_\mathrm{T}$ jet algorithm [9]. Although it follows a sequential recombination procedure, the jets leading in $p_\mathrm{T}$ resemble in shape the jets reconstructed using algorithms with fixed cone sizes [14] because it starts clustering with the hardest (highest $p_\mathrm{T}$) objects. Hence, it is less sensitive to details of the distribution of softer objects in an event and less suited for an investigation of the UE. In contrast, the $k_\mathrm{T}$ jet algorithm clusters the softest objects first, trying to undo the effects of parton showering [10–12]. This approach to jet clustering leads to nonuniform catchment areas of $k_\mathrm{T}$ jets, which can be evaluated by applying the active area clustering technique as described in [8]. In this analysis of the UE, jets are reconstructed using the $k_\mathrm{T}$ algorithm with a distance parameter $R$ of 0.6 as implemented in the FASTJET package [13, 15], which at the same time performs the jet-area determination. For this purpose, the event in question is overlaid with a uniform grid of artificial, extremely soft "ghost particles" in the $\eta$-$\phi$ plane as indicators of a jet's domain of influence or catchment area. They are fed into the jet algorithm together with the measured tracks or charged particles but without impact on the reconstructed physical jets. This is guaranteed by the use of an infrared- and collinear-safe jet algorithm and the smallness of the transverse momentum of the ghost particles, which is of the order of $10^{-100}\,\mathrm{GeV}$. The number of ghosts, $N_j^{\mathrm{ghosts}}$, clustered into a jet $j$ is then a measure of the jet area $A_j$:

$$A_j = \frac{N_j^{\mathrm{ghosts}}}{\rho^{\mathrm{ghosts}}} = \frac{N_j^{\mathrm{ghosts}}}{N_{\mathrm{tot}}^{\mathrm{ghosts}}} A_{\mathrm{tot}} , \qquad (2.1)$$

where $\rho^{\mathrm{ghosts}}$ is the ghost density, defined as the total number of ghosts $N_{\mathrm{tot}}^{\mathrm{ghosts}}$ divided by the total area $A_{\mathrm{tot}}$ within the acceptance. In this study, $A_{\mathrm{tot}}$ is set equal to $8\pi$ according to the ranges of $0 \le \phi < 2\pi$ and $|\eta| \le 2$. In order to limit boundary effects, the directions of the jets axes are restricted to $|\eta| < 1.8$ while tracks are used up to $|\eta| = 2.3$. The distribution of ghosts extends up to $|\eta| = 5$. Here it is important to note that empty areas within the acceptance are covered by jets which consist solely of ghost particles. These "ghost jets" have a well-defined area but vanishing transverse momentum.

A measure of the soft activity in an event is then given by the median $\rho$ of the distribution of the jet transverse momentum per jet area for all jets in an event [7]:

$$\rho = \underset{j\,\in\,\mathrm{jets}}{\mathrm{median}} \left\{ \frac{p_{\mathrm{T}j}}{A_j} \right\} . \qquad (2.2)$$

The choice of the median is motivated by its robustness to outliers in the distribution. These outliers are in particular the leading jets originated by the hard partonic interaction. The observable $\rho$ thus naturally isolates UE contributions by assuming that the majority of the event is either empty or dominated by soft contributions and that the hard component of the interaction is well contained within the leading jets. In contrast to the conventional approach, no explicit geometrical subdivision of the event is necessary. The separation of the hard and soft components is done event by event through the area clustering for the $k_\mathrm{T}$

algorithm and the use of the median. An advantage of this novel method is that it can easily be extended to event topologies other than the minimum-bias events investigated here.

In the proposal for a measurement of $\rho$ in collider experiments [7], no kinematic selection was imposed on the input particles for the jet clustering. Unfortunately, this is not realistic experimentally because of threshold effects and a limited detector acceptance. Typically in minimum-bias events with a low average charged-particle multiplicity, large parts of the detector do not contain any physical particles and are therefore covered by ghost jets. As each ghost jet contributes one entry at $p_{Tj}/A_j = 0$, events with a majority of ghost jets have $\rho = 0$, corresponding to zero UE activity. In order to increase the sensitivity to low UE activity, an adjusted observable $\rho'$ is introduced, which takes into account only jets containing at least one physical particle:

$$\rho' = \underset{j \,\in\, \text{physical jets}}{\text{median}} \left\{ \frac{p_{Tj}}{A_j} \right\} \cdot C \,. \tag{2.3}$$

Here, the event occupancy $C$, defined as the area $\sum_j A_j$ covered by physical jets divided by the total area $A_{\text{tot}}$, is a measure of the "nonemptiness" of an event. While in $\rho$ the ghost jets account for empty regions in the detector in the derivation of the median, the scaling factor $C$ has a similar effect on $\rho'$ by shifting events with low activity towards smaller values of $\rho'$. In the limit of full coverage of the detector with physical jets, $\rho$ and $\rho'$ are identical.

## 3  Detector description and event selection

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter. Within the field volume are a silicon pixel and strip tracker, a crystal electromagnetic calorimeter, and a brass/scintillator hadron calorimeter. Muons are measured in gas-ionisation detectors embedded in the steel return yoke. Extensive forward calorimetry complements the coverage provided by the barrel and endcap detectors. In the following, only the parts of the detector that are most important for this analysis will be presented. A more detailed description can be found in ref. [16].

The inner tracker measures charged particles within the pseudorapidity range $|\eta| < 2.5$. It consists of 1440 silicon pixel and 15 148 silicon strip detector modules and is located in the 3.8 T field of the superconducting solenoid. It provides an impact parameter resolution of $\sim$15 $\mu$m and a transverse momentum resolution of about 1.5% for 100 GeV particles.

Two subsystems of the first-level trigger system are used in this analysis: the Beam Pick-up Timing for eXperiments (BPTX) and the Beam Scintillator Counters (BSC). The two BPTX devices, which are installed around the beam pipe at a distance of $\pm$175 m from the interaction point, are designed to provide precise information on the structure and timing of the LHC beams with a time resolution better than 0.2 ns. The two BSCs, each consisting of a set of 16 scintillator tiles, are located along the beam line on each side of the interaction point at a distance of 10.86 m and are sensitive in the range $3.23 < |\eta| < 4.65$. They provide information on hits and coincidence signals with an average detection efficiency of 96.3% for minimum-ionising particles and a time resolution of 3 ns.

For an analysis of the UE, only data with not more than one collision per bunch crossing, i.e. without pileup, are suitable. Therefore data taken during periods with low instantaneous luminosity, between March and August 2010, at centre-of-mass energies of 0.9 and 7 TeV are used.

The high-level trigger selection requires at least one track to be reconstructed in the silicon pixel detector with a minimum transverse momentum of 0.2 GeV. This high-level trigger path is seeded by the BPTX and BSC level-1 triggers. In order to minimise the contamination caused by additional interactions within the same LHC bunch crossing, only events with exactly one reconstructed vertex are used in this analysis. The position of this vertex must be fitted from at least four tracks and its $z$ component must lie within 10 cm of the centre of the reconstructed luminous region for the given data-taking run [17]. The effect of pileup collisions that remained undetected because of inefficiencies in the primary vertex reconstruction is estimated to be negligible compared to other sources of systematic uncertainty.

Even though this analysis contains data taken at two different centre-of-mass energies, all event selection and trigger criteria are identical throughout to guarantee compatibility of the results and consistency with the conventional UE measurement [4].

## 4  Event generators and simulation

The generator predictions that are compared with the data were produced with three different tunes of the PYTHIA program version 6.4.22 [18], and one from PYTHIA version 8.145 [19]. The matrix elements chosen for the event generation reflect the minimum-bias event selection in data. A simulation of the CMS detector, based on the GEANT4 package [20], is applied. As Monte Carlo methods are used in both steps, we refer to "generator" when particle-level generator information is concerned, while "simulation" refers to a simulation of the CMS detector response.

The PYTHIA 6 tune D6T [21, 22] was the default tune within the CMS Collaboration prior to the LHC operation. It is based on the CTEQ6L1 [23] parton distribution functions (PDFs) and was tuned to describe measurements of the UA5 Collaboration at the Sp$\overline{\text{p}}$S collider and the Tevatron experiments.

As a consequence of the higher particle multiplicities observed in LHC collision data at 0.9 TeV and 7 TeV [24–28] compared to existing model predictions, the new tunes Z1 [29] and Z2 were developed. Both tunes employ a new model for MPIs and a fragmentation function derived with the PROFESSOR [30] tool, as well as $p_{\text{T}}$-ordered parton showers. The main difference between the two tunes is the usage of the CTEQ5L PDFs [31] in Z1 and the CTEQ6L1 PDFs [23] in Z2. Using different PDF sets requires the adjustment of the parameter that defines the minimal momentum transfer in MPIs in order to keep the cross section of the additional scatterings constant. Tune 4C [32] of PYTHIA version 8 also uses a new MPI model, which is interleaved with parton showering, and the CTEQ6L1 PDFs.

During simulation and reconstruction, the simulated samples take into account an imperfect alignment as well as nonoperational channels of the tracking system.

## 5 Reconstruction

For the purpose of measuring the soft activity of the UE, the data are analysed down to very small transverse momenta of 0.3 GeV, exploiting the capabilities of the CMS tracking detectors. A potential neutral component of the UE, measurable only with the calorimeters, is neglected. Consequently, the jet clustering is performed on reconstructed tracks either from data or simulated events (track jets), and also on stable charged particles in generator events (charged-particle jets). Generator particles with mean lifetimes $\tau$ such that $c\tau > 10$ mm are considered to be stable.

### 5.1 Track selection

The performance and technical details of the CMS tracking with first collision data is described in [17]. The track selection of this analysis follows that of the conventional UE measurement as discussed in [4]. In detail, the following criteria are applied:

- high-purity track quality [17];

- transverse momentum $p_T > 0.3$ GeV;

- pseudorapidity $|\eta| < 2.3$;

- transverse impact parameter $d_{xy} < 0.2$ cm;

- longitudinal impact parameter $d_z < 1$ cm;

- relative track $p_T$ uncertainty $(\sigma_{p_T}/p_T) \cdot \max(1, \chi^2/N_{\mathrm{dof}}) < 0.2$, where $N_{\mathrm{dof}}$ denotes the number of degrees of freedom in the track fit.

These impact parameters are determined with respect to the primary vertex.

### 5.2 Charged generator particles

The influence of the detector on a particular observable is estimated by comparing the predictions, as given by a particle generator, before and after detector simulation, including trigger effects. To achieve a good correspondence to the track selection, the generated stable charged particles are required to satisfy $p_T > 0.3$ GeV and $|\eta| < 2.3$. This minimum transverse momentum threshold and the restriction to charged particles significantly reduces the number of particles entering the clustering process.

### 5.3 Jet selection

No further selection on the transverse momenta of the jets is imposed. Because of the selection criteria on the input objects, however, they are implicitly restricted to be larger than 0.3 GeV. To avoid boundary effects in the jet-area determination, the absolute pseudorapidity of the jet axis is required to be smaller than 1.8, which is to be compared with $|\eta| < 2.3$ for the input objects.

## 6   Detector unfolding

In order to compare data with theoretical predictions, the measurement must be corrected for detector response and resolution effects. In abstract terms, the connection between a true and the reconstructed distribution is expressed by a folding integral, which must be inverted to correct for the detector effects. Commonly, this procedure is referred to as unfolding or deconvolution. The technique adopted here to unfold the $\rho'$ distribution is the iterative Bayesian approach [33] as implemented in the RooUnfold framework [34]. For this method the relevant distributions of a given observable are analysed before and after detector simulation and the detector response is expressed as a response matrix. To improve the statistical stability of the unfolding procedure, a wider binning and a reduced $\rho'$ range are used compared to the uncorrected distributions.

It is found that the response matrices derived from different event generator tunes yield different results after the unfolding of the data distribution, which is a consequence of the difference in track multiplicities of the tunes. The tune Z2, which yields the best description of track-based observables, is used to unfold detector effects, while the others are employed only to derive the systematic uncertainties arising from this procedure.

## 7   Systematic uncertainties

The following sources of systematic uncertainties are considered: the trigger efficiency bias, the influence of the track selection, track misreconstruction and the reconstruction efficiency, the track jet $p_T$ response, nonoperational tracker channels, and the tune dependence in the unfolding procedure.

Since most of the effects are found to be $\rho'$-dependent, suitable parametrisations are chosen to quantify them. From these parametrisations, the uncertainties are derived bin by bin by adding the different effects in quadrature. For variations in the requirements, for example from decreasing and increasing the track $p_T$ requirement, symmetrised uncertainties are derived in the form of the average of the observed absolute deviations from the baseline scenario. Representative numbers for the uncertainties are summarised in table 1 apart from the trigger efficiency bias, which is found to be negligible, since the event selection criterion of at least four tracks required for a well reconstructed primary vertex is stricter than the trigger condition.

The only track selection criterion identified to have a significant impact on the observable is the minimal track $p_T$. Varying the threshold value of 300 MeV by $\pm10\%$ induces a systematic uncertainty on the $\rho'$ distribution of about 2.0% at 7 TeV and 3.0% at 0.9 TeV. For the lowest $\rho'$ bins, the effect increases dramatically to $\pm15\%$ at 7 TeV and $\pm16\%$ at 0.9 TeV.

The potential mismatch between the number of reconstructed tracks and the number of charged particles is estimated from simulated events to be 5%. A similar number is found for the reconstruction efficiency of nonisolated muons in data [35]. To quantify the influence of the tracking efficiency on $\rho'$, a random track from an independent sample is added to the analysed sample with a probability of 5% per existing track. Thus, the kinematic variables

| Systematic effect | $\sqrt{s} = 0.9\,\mathrm{TeV}$ | | $\sqrt{s} = 7\,\mathrm{TeV}$ | |
|---|---|---|---|---|
| | typ. size | max. size | typ. size | max. size |
| Track selection | $\pm 3.0$ | $\pm 16$ (low $\rho'$) | $\pm 2.0$ | $\pm 15$ (low $\rho'$) |
| Track reconstruction | $\pm 0.5$ | $\pm 3.0$ (low $\rho'$) | $\pm 0.5$ | $\pm 2.5$ (low $\rho'$) |
| Track-jet $p_{\mathrm{T}}$ response | $\pm 4.0$ | $\pm 5.0$ (low $\rho'$) | $\pm 2.0$ | $\pm 4.0$ (low $\rho'$) |
| Nonoperational tracker channels | $\pm 2.5$ | $-3.0$ (low $\rho'$) | $\pm 1.0$ | $+1.5$ (low $\rho'$) |
| Unfolding & tune dependence | $\pm 9$ | $\pm 10$ (high $\rho'$) | $\pm 4$ | $\pm 16$ (high $\rho'$) |

**Table 1**. Summary of systematic uncertainties on the $\rho'$ distributions (in percent).

of the additional track follow the distributions predicted by the simulation. The effect of dropping each track with a probability of 5% is also studied. The total resulting influence on $\rho'$ for adding false or losing real tracks is found to be around 0.5% in most bins.

The response of the track jet $p_{\mathrm{T}}$ measurement compared to charged-particle jets is another source of uncertainty. It is studied by shifting the $p_{\mathrm{T}}$ of each jet in the events by $\pm 1.7$%. This number corresponds to the width of the transverse momentum response distribution when comparing jets from generated charged particles and their corresponding reconstructed track jets. As expected in the case of systematically increased transverse momenta, the $\rho'$ spectrum is shifted towards higher values and vice versa. The magnitude of the effect is dependent on $\rho'$ and ranges from about 4% for small $\rho'$ to about 2.0% for large $\rho'$ at $\sqrt{s} = 7\,\mathrm{TeV}$. In the case of $\sqrt{s} = 0.9\,\mathrm{TeV}$, the effect is more pronounced but it remains smaller than 5%.

Further sources of uncertainties are nonoperational tracker channels and imperfect alignment of the tracker components. These effects are studied by means of a special simulated data set, which assumes perfect alignment and all channels functional. Small values of $\rho'$ are affected most, with a total systematic uncertainty of 1.0% at 7 TeV and 2.5% at 0.9 TeV on average.

The uncertainty arising from the response matrix in the unfolding procedure is evaluated by investigating the differences in the response in the different tunes. The measured distribution is unfolded with all four response matrices, and the average deviation of the D6T, Z1, and 4C results from those obtained with the Z2 tune are taken as the systematic uncertainty, which amounts to roughly 4% at 7 TeV and 9% at 0.9 TeV, increasing for higher $\rho'$ values.

## 8 Results

As in conventional UE measurements it is possible for the $\rho'$ observable to be investigated not only inclusively but also as a function of the hardness of an event, which is given by the "event scale". In the conventional approach, this scale is usually defined by the transverse momentum of either the hardest track or hardest jet. In the present study, the natural choice for the event scale is the transverse momentum of the jet leading in $p_{\mathrm{T}}$ within the acceptance. In the next two subsections the inclusive and the event-scale-dependent results

on $\rho'$ are presented without correction for detector effects. The unfolded results follow in subsection 8.3.

## 8.1 Inclusive measurement

Figure 1 shows the uncorrected inclusive $\rho'$ distributions for data in comparison to the PYTHIA 6 tunes Z1, Z2, D6T, and the PYTHIA 8 tune 4C. The distributions are normalised to the observed number of events. All predictions deviate significantly from the measurements at both centre-of-mass energies, in particular for $\rho'$ values larger than about 0.5 GeV. At $\sqrt{s} = 0.9$ TeV PYTHIA 6 Z2 overshoots the data while PYTHIA 6 D6T and PYTHIA 8 4C are systematically too low. In comparison, PYTHIA 6 Z1 is closer to the measurement with some overestimation in the range of $\rho'$ from 0.5 to 1.5 GeV at $\sqrt{s} = 0.9$ TeV and a similar behaviour from 1.0 to 2.0 GeV at $\sqrt{s} = 7$ TeV. For higher $\rho'$, Z1 undershoots the data. While PYTHIA 8 4C continues to exhibit too little UE activity at the higher centre-of-mass energy of 7 TeV, PYTHIA 6 D6T describes the data somewhat better. PYTHIA 6 Z2 changes from severely overestimating the UE to an underestimation at 7 TeV, hinting at a problem with the energy dependence of the UE in this tune.

## 8.2 Event scale dependence

Figure 2 shows as examples the uncorrected $\rho'$ distributions in the two slices of the leading jet $p_T$ of $3 < p_{T,\text{leading}} < 6$ GeV (left) and $9 < p_{T,\text{leading}} < 12$ GeV (right) at $\sqrt{s} = 7$ TeV. Of course, the additional binning in the hardness of the events effectively limits the accessible range in $\rho'$ as well. The observed deviations of PYTHIA 6 Z2 or PYTHIA 8 4C from the measurements remain similar when going from an inclusive view to slices in event scale. In contrast to this, the comparison of PYTHIA 6 D6T and Z1 relative to the data does change. This can be seen even more clearly when concentrating on gross features of the distributions such as the peak values, means, or widths, which depend visibly on the event scale.

For completeness figure 3 presents the mean values $\langle \rho' \rangle$ for all slices possible at 0.9 and 7 TeV centre-of-mass energy versus the leading jet $p_T$ as event scale. In accordance with expectations from similar UE studies in the conventional approach, a steep rise at small event scales as well as a saturation or plateau region at high scales are exhibited. The increase of the UE activity with higher centre-of-mass energies is visible from the heights of the plateau regions, which roughly correspond to a ratio of 1.8, in agreement with observations of a ratio around 2 for conventional observables in [4].

With respect to the tune comparisons at 0.9 and 7 TeV, PYTHIA 8 4C always undershoots the average UE activity as characterised by $\langle \rho' \rangle$, PYTHIA 6 Z1 changes from agreement with data to an underestimation, Z2 from an overestimation to an underestimation, and D6T from a systematic underestimation to an overestimation for event scales larger than 10 GeV at 7 TeV centre-of-mass energy.

## 8.3 Unfolded results

Figure 4 compares the inclusive $\rho'$ distributions, unfolded with the Bayesian method, to the PYTHIA 6 tunes Z1, Z2, D6T, and the PYTHIA 8 tune 4C, but this time at the
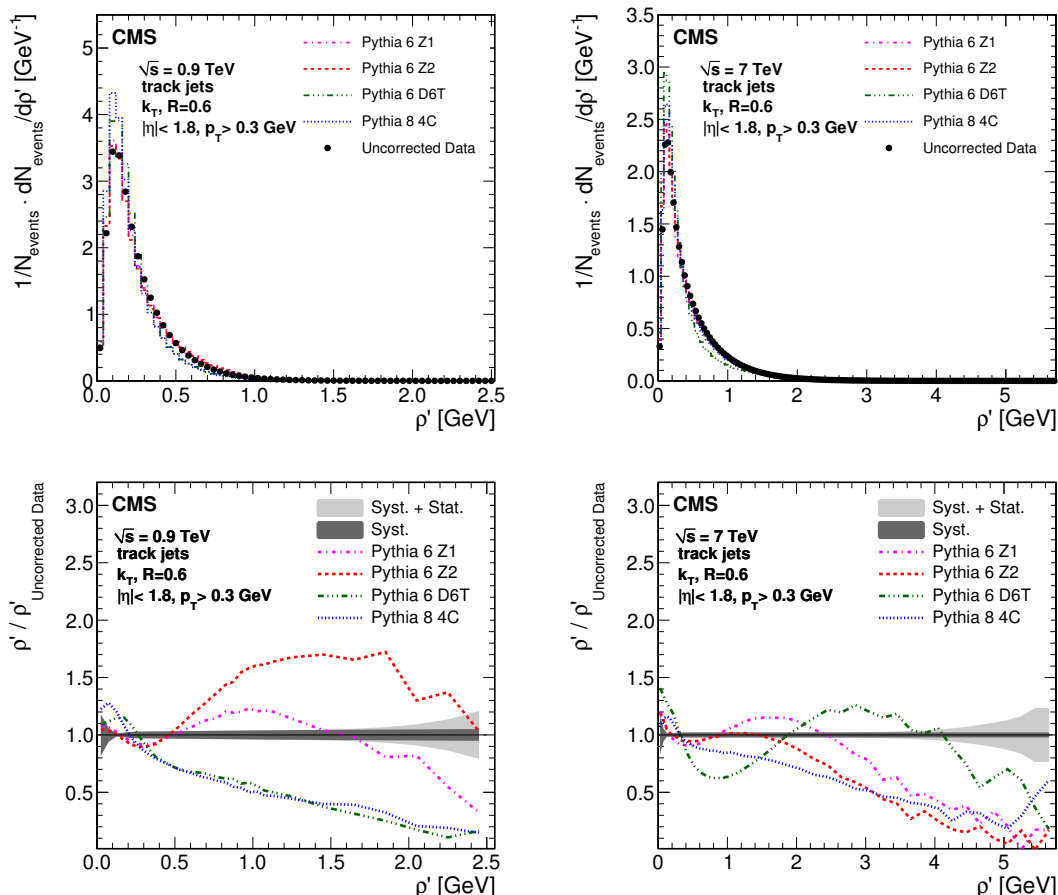
**Figure 1**. Uncorrected inclusive $\rho'$ distributions for data and simulation (upper row), and ratios of the PYTHIA 6 tunes Z1, Z2, D6T, and the PYTHIA 8 tune 4C relative to data (lower row) at $\sqrt{s} = 0.9$ TeV (left) and $\sqrt{s} = 7$ TeV (right). The dark grey shaded band corresponds to the systematic uncertainty and the light grey shaded band to the quadratic sum of the systematic and statistical uncertainty. The reach in $\rho'$ is different at the two centre-of-mass energies.

level of stable charged particles. Because of the response differences among the tunes, a substantial systematic uncertainty is introduced by the unfolding, which is indicated in figure 4 by the difference between the dark and light grey shaded bands. Also the range in $\rho'$ had to be limited to $\rho' < 2.0$ GeV for $\sqrt{s} = 0.9$ TeV and $\rho' < 3.2$ GeV for $\sqrt{s} = 7$ TeV to ensure the stability of the procedure. Nevertheless, the shape of the $\rho'$ distributions is rather well preserved during the unfolding process and the same conclusions can be drawn as from the comparison of the uncorrected observable.

For the purpose of deriving the event scale dependence of $\langle\rho'\rangle$, the $\rho'$ distribution in each slice of jet $p_T$ must be unfolded independently using separate response matrices. The result is presented in figure 5 where the error bars are dominated by the uncertainty introduced through the unfolding procedure. Again, the observations are consistent with the uncorrected case as shown in figure 3 and the ratio of the plateau heights roughly corresponds to a factor of 1.8 between 0.9 and 7 TeV centre-of-mass energy.
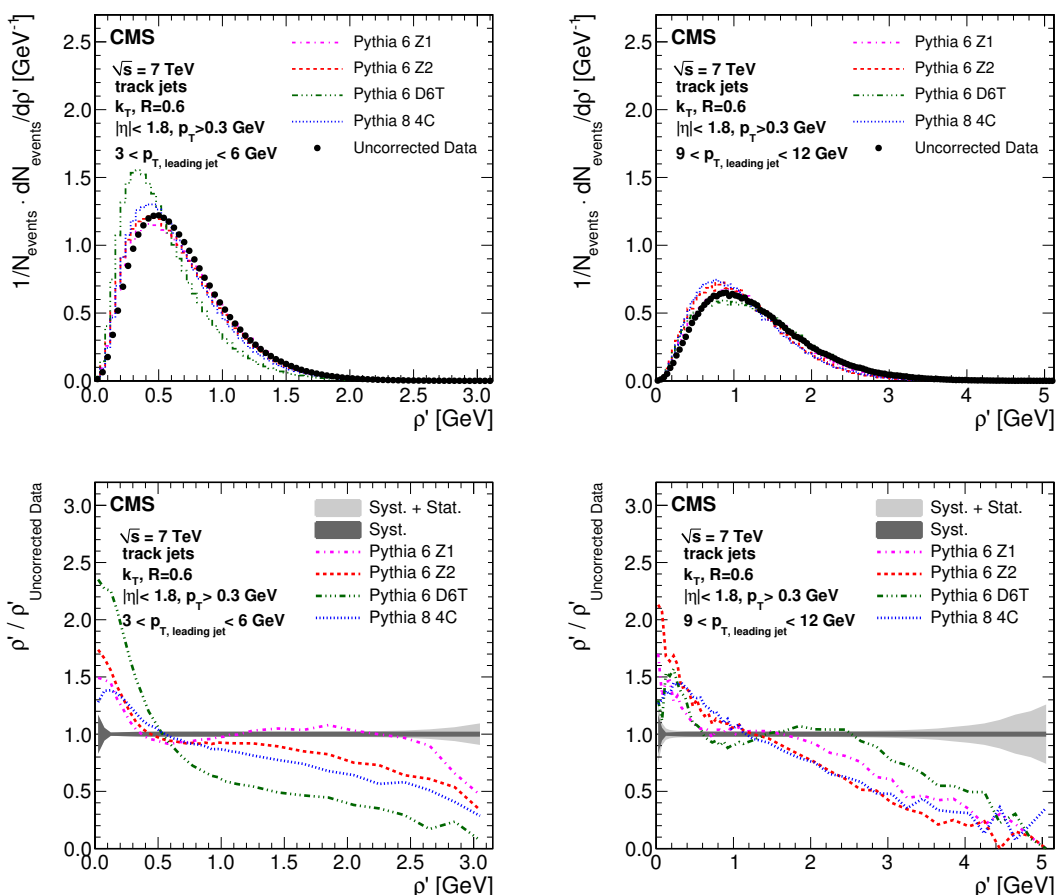
**Figure 2**. Uncorrected $\rho'$ distributions in the two slices of leading track jet transverse momentum, $3 < p_{\mathrm{T,leading}} < 6\,\mathrm{GeV}$ (left) and $9 < p_{\mathrm{T,leading}} < 12\,\mathrm{GeV}$ (right) at $\sqrt{s} = 7\,\mathrm{TeV}$. The reach in $\rho'$ is different for the two slices in leading track jet $p_{\mathrm{T}}$. The lower plots show the ratios of the different generator tunes to the reconstructed data. The dark grey shaded band corresponds to the systematic uncertainty and the light grey shaded band to the quadratic sum of the systematic and statistical uncertainty.

## 9  Summary

The jet-area/median approach to measuring the underlying event has been studied for the first time in a collider experiment at the two centre-of-mass energies of 0.9 and 7 TeV with the CMS detector. The measured distributions of the observable $\rho'$, based on this approach, are unfolded for detector effects and compared to predictions of several Monte Carlo event generator tunes before and after detector simulation. The substantial discrepancies observed among the various predictions and also between the predictions and the data demonstrate the sensitivity of the method and indicate the need for improved tunes at both centre-of-mass energies. None of the examined models describe the data satisfactorily.

Overall, PYTHIA 6 Z1 gives the best description of the data with some residual underestimation at $\sqrt{s} = 7\,\mathrm{TeV}$. PYTHIA 6 Z2 varies from severely overshooting the data at 0.9 TeV to falling short of the data at 7 TeV, hinting at an inadequate setting of the $\sqrt{s}$
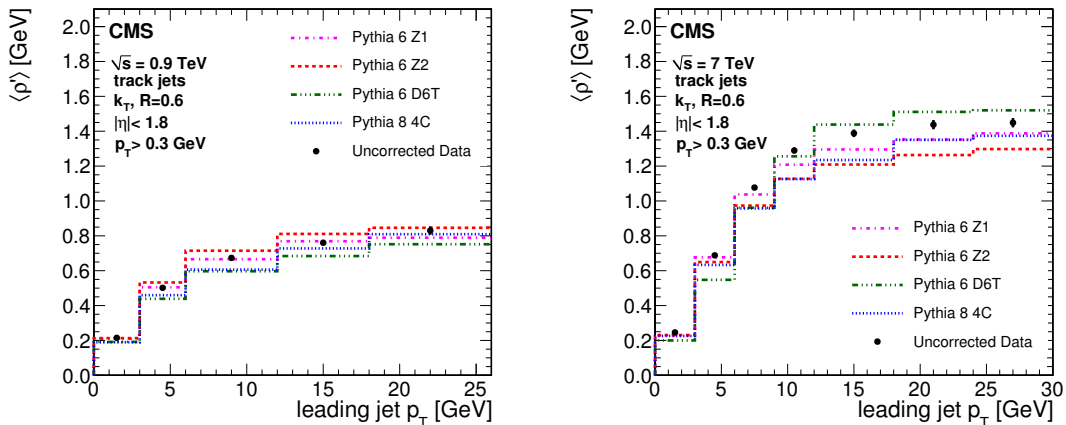
**Figure 3**. Mean values of the uncorrected $\rho'$ distributions versus leading track jet transverse momentum at $\sqrt{s} = 0.9\,\text{TeV}$ (left) and $\sqrt{s} = 7\,\text{TeV}$ (right) in comparison to the predictions by the different generator tunes. The error bars, which are mostly smaller than the symbol sizes, correspond to the quadratic sum of the systematic and statistical uncertainty.

dependence for the UE model. PYTHIA 8 4C almost always underestimates the UE activity, while PYTHIA 6 D6T does so only at $0.9\,\text{TeV}$ or at small event scales but then rises too steeply with increasing hardness of the events. The general pattern of deviations from data by the considered PYTHIA tunes is similar to that observed with the conventional approach [4].

The mean $\langle\rho'\rangle$ has also been investigated as a function of the transverse momentum of the leading jet. In agreement with the conventional analysis, a steep rise of the UE activity with increasing leading jet transverse momentum up to about $10\,\text{GeV}$ is observed. For higher transverse momenta a plateau is reached. The ratio of the UE activity in this saturation region at $7\,\text{TeV}$ to that at $0.9\,\text{TeV}$ is approximately 1.8, which is close to the ratios of around 2 measured with the conventional observables.

In conclusion, the new observable $\rho'$ based on the jet-area/median approach has been demonstrated to be sensitive to soft hadronic activity and offers an alternative view of the UE. The method is not restricted to minimum-bias events as examined here but can also be applied to different event topologies.

### Acknowledgments

**Figure 4**. Unfolded inclusive $\rho'$ distributions for data and simulation (upper row), and ratios of the PYTHIA 6 tunes Z1, Z2, D6T, and the PYTHIA 8 tune 4C relative to data (lower row) at $\sqrt{s} = 0.9\,\text{TeV}$ (left) and $\sqrt{s} = 7\,\text{TeV}$ (right). The quadratic difference between the total uncertainty, as given by the light grey band, and the dark grey band corresponds to the unfolding uncertainty, which inherently also comprises the statistical uncertainty.

**Figure 5**. Mean values of the corrected $\rho'$ distributions versus leading charged-particle jet transverse momentum at $\sqrt{s} = 0.9$ TeV (left) and $\sqrt{s} = 7$ TeV (right) in comparison to the predictions by the different ge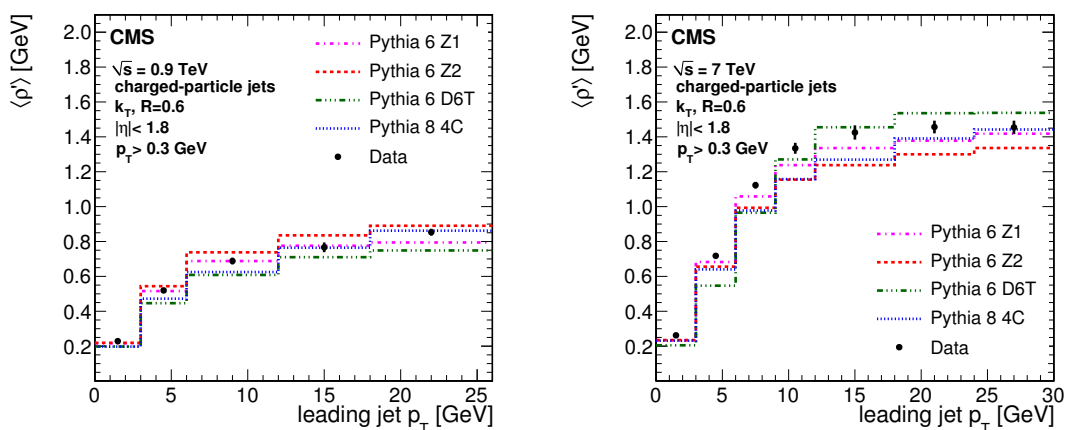nerator tunes. The $\rho'$ distributions in each slice are unfolded with the Bayesian method. The error bars, which are mostly smaller than the symbol sizes, correspond to the total uncertainty.

# References

[1] CDF collaboration, T. Affolder et al., *Charged jet evolution and the underlying event in pp̄ 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 pp̄ 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, S. Chatrchyan et al., *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].

[5] ATLAS collaboration, G. Aad et al., *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].

[6] ATLAS collaboration, G. Aad et al., *Measurements of underlying-event properties using neutral and charged particles in pp collisions at* 900 *GeV and* 7 *TeV with the ATLAS detector at the LHC*, *Eur. Phys. J.* **C 71** (2011) 1636 [arXiv:1103.1816] [INSPIRE].

[7] M. Cacciari, G.P. Salam and S. Sapeta, *On the characterisation of the underlying event*, *JHEP* **04** (2010) 065 [arXiv:0912.4926] [INSPIRE].

[8] M. Cacciari, G.P. Salam and G. Soyez, *The catchment area of jets*, *JHEP* **04** (2008) 005 [arXiv:0802.1188] [INSPIRE].

[9] M. Cacciari, G.P. Salam and G. Soyez, *The anti-$k_t$ jet clustering algorithm*, *JHEP* **04** (2008) 063 [arXiv:0802.1189] [INSPIRE].

[10] S. Catani, Y.L. Dokshitzer, M. Olsson, G. Turnock and B. Webber, *New clustering algorithm for multi-jet cross-sections in* $e^+e^-$ *annihilation*, *Phys. Lett.* **B 269** (1991) 432 [INSPIRE].

[11] S. Catani, Y.L. Dokshitzer and B. Webber, *The $k_\perp$ perpendicular clustering algorithm for jets in deep inelastic scattering and hadron collisions*, *Phys. Lett.* **B 285** (1992) 291 [INSPIRE].

[12] S.D. Ellis and D.E. Soper, *Successive combination jet algorithm for hadron collisions*, *Phys. Rev.* **D 48** (1993) 3160 [hep-ph/9305266] [INSPIRE].

[13] M. Cacciari and G.P. Salam, *Dispelling the $N^3$ myth for the $k_t$ jet-finder*, *Phys. Lett.* **B 641** (2006) 57 [hep-ph/0512210] [INSPIRE].

[14] G.F. Sterman and S. Weinberg, *Jets from quantum chromodynamics*, *Phys. Rev. Lett.* **39** (1977) 1436 [INSPIRE].

[15] M. Cacciari, G.P. Salam and G. Soyez, *FastJet user manual*, *Eur. Phys. J.* **C 72** (2012) 1896 [arXiv:1111.6097] [INSPIRE].

[16] CMS collaboration, S. Chatrchyan et al., *The CMS experiment at the CERN LHC*, 2008 *JINST* **3** S08004 [INSPIRE].

[17] CMS collaboration, V. Khachatryan et al., *CMS tracking performance results from early LHC operation*, *Eur. Phys. J.* **C 70** (2010) 1165 [arXiv:1007.1988] [INSPIRE].

[18] T. Sjöstrand, S. Mrenna and P.Z. Skands, *PYTHIA 6.4 physics and manual*, *JHEP* **05** (2006) 026 [hep-ph/0603175] [INSPIRE].

[19] 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].

[20] GEANT4 collaboration, S. Agostinelli et al., *GEANT4: a simulation toolkit*, *Nucl. Instrum. Meth.* **A 506** (2003) 250 [INSPIRE].

[21] R. Field, *Physics at the Tevatron*, Acta Phys. Polon. **B 39** (2008) 2611 [INSPIRE].

[22] P. Bartalini and L. Fano, *Multiple partonic interactions at the LHC. Proceedings of the 1st International Workshop, MPI'08, Perugia, Italy, October 27–31, 2008*, arXiv:1003.4220 [INSPIRE].

[23] J. Pumplin, D. Stump, J. Huston, H. Lai, P.M. Nadolsky, et al., *New generation of parton distributions with uncertainties from global QCD analysis*, *JHEP* **07** (2002) 012 [hep-ph/0201195] [INSPIRE].

[24] ALICE collaboration, K. Aamodt et al., *Charged-particle multiplicity measurement in proton-proton collisions at $\sqrt{s} = 0.9$ and 2.36 TeV with ALICE at LHC*, *Eur. Phys. J.* **C 68** (2010) 89 [arXiv:1004.3034] [INSPIRE].

[25] ALICE collaboration, K. Aamodt et al., *Charged-particle multiplicity measurement in proton-proton collisions at $\sqrt{s} = 7$ TeV with ALICE at LHC*, *Eur. Phys. J.* **C 68** (2010) 345 [arXiv:1004.3514] [INSPIRE].

[26] ATLAS collaboration, G. Aad et al., *Charged-particle multiplicities in pp interactions at $\sqrt{s} = 900$ GeV measured with the ATLAS detector at the LHC*, *Phys. Lett.* **B 688** (2010) 21 [arXiv:1003.3124] [INSPIRE].

[27] CMS collaboration, V. Khachatryan et al., *Transverse momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s} = 0.9$ and 2.36 TeV*, *JHEP* **02** (2010) 041 [arXiv:1002.0621] [INSPIRE].

[28] CMS collaboration, V. Khachatryan et al., *Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s} = 7$ TeV*, *Phys. Rev. Lett.* **105** (2010) 022002 [arXiv:1005.3299] [INSPIRE].

[29] R. Field, *Early LHC underlying event data-findings and surprises*, arXiv:1010.3558 [INSPIRE].

[30] A. Buckley, H. Hoeth, H. Lacker, H. Schulz and J.E. von Seggern, *Systematic event generator tuning for the LHC*, *Eur. Phys. J.* **C 65** (2010) 331 [arXiv:0907.2973] [INSPIRE].

[31] CTEQ collaboration, H. Lai et al., *Global QCD analysis of parton structure of the nucleon: CTEQ5 parton distributions*, *Eur. Phys. J.* **C 12** (2000) 375 [hep-ph/9903282] [INSPIRE].

[32] R. Corke and T. Sjöstrand, *Interleaved parton showers and tuning prospects*, *JHEP* **03** (2011) 032 [arXiv:1011.1759] [INSPIRE].

[33] G. D'Agostini, *A multidimensional unfolding method based on Bayes' theorem*, *Nucl. Instrum. Meth.* **A 362** (1995) 487 [INSPIRE].

[34] T. Adye, *Unfolding algorithms and tests using RooUnfold*, arXiv:1105.1160 [INSPIRE].

[35] CMS collaboration, *Measurement of tracking efficiency*, PAS-TRK-10-002 (2010).

## The CMS collaboration

**Yerevan Physics Institute, Yerevan, Armenia**

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

**Institut für Hochenergiephysik der OeAW, Wien, Austria**

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan, M. Friedl, R. Frühwirth, V.M. Ghete, J. Hammer[1], N. Hörmann, J. Hrubec, M. Jeitler, W. Kiesenhofer, V. Knünz, M. Krammer, D. Liko, I. Mikulec, M. Pernicka[†], B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, F. Teischinger, P. Wagner, W. Waltenberger, G. Walzel, E. Widl, C.-E. Wulz

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

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

**Universiteit Antwerpen, Antwerpen, Belgium**

S. Bansal, K. Cerny, T. Cornelis, E.A. De Wolf, X. Janssen, S. Luyckx, T. Maes, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

**Vrije Universiteit Brussel, Brussel, Belgium**

F. Blekman, S. Blyweert, J. D'Hondt, R. Gonzalez Suarez, A. Kalogeropoulos, M. Maes, A. Olbrechts, 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, T. Hreus, A. Léonard, P.E. Marage, L. Thomas, C. Vander Velde, P. Vanlaer

**Ghent University, Ghent, Belgium**

V. Adler, K. Beernaert, A. Cimmino, S. Costantini, G. Garcia, M. Grunewald, B. Klein, J. Lellouch, A. Marinov, J. Mccartin, A.A. Ocampo Rios, D. Ryckbosch, N. Strobbe, F. Thyssen, M. Tytgat, L. Vanelderen, P. Verwilligen, S. Walsh, E. Yazgan, N. Zaganidis

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

S. Basegmez, G. Bruno, A. Caudron, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco[2], J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, L. Perrini, A. Pin, K. Piotrzkowski, N. Schul

**Université de Mons, Mons, Belgium**

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

**Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil**

G.A. Alves, M. Correa Martins Junior, D. De Jesus Damiao, T. Martins, M.E. Pol, M.H.G. Souza

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

W.L. Aldá Júnior, W. Carvalho, A. Custódio, E.M. Da Costa, C. De Oliveira Martins, S. Fonseca De Souza, D. Matos Figueiredo, L. Mundim, H. Nogima, V. Oguri, W.L. Prado Da Silva, A. Santoro, S.M. Silva Do Amaral, L. Soares Jorge, A. Sznajder

**Instituto de Fisica Teorica, Universidade Estadual Paulista, Sao Paulo, Brazil**

T.S. Anjos[3], C.A. Bernardes[3], F.A. Dias[4], T.R. Fernandez Perez Tomei, E. M. Gregores[3], C. Lagana, F. Marinho, P.G. Mercadante[3], S.F. Novaes, Sandra S. Padula

**Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria**

V. Genchev[1], P. Iaydjiev[1], S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, M. Vutova

**University of Sofia, Sofia, Bulgaria**

A. Dimitrov, R. Hadjiiska, A. Karadzhinova, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

**Institute of High Energy Physics, Beijing, China**

J.G. Bian, G.M. Chen, H.S. Chen, C.H. Jiang, D. Liang, S. Liang, X. Meng, J. Tao, J. Wang, J. Wang, X. Wang, Z. Wang, H. Xiao, M. Xu, J. Zang, Z. Zhang

**State Key Lab. of Nucl. Phys. and Tech.,  Peking University, Beijing, China**

C. Asawatangtrakuldee, Y. Ban, S. Guo, Y. Guo, W. Li, S. Liu, Y. Mao, S.J. Qian, H. Teng, S. Wang, B. Zhu, W. Zou

**Universidad de Los Andes, Bogota, Colombia**

C. Avila, B. Gomez Moreno, A.F. Osorio Oliveros, J.C. Sanabria

**Technical University of Split, Split, Croatia**

N. Godinovic, D. Lelas, R. Plestina[5], D. Polic, I. Puljak[1]

**University of Split, Split, Croatia**

Z. Antunovic, M. Dzelalija, M. Kovac

**Institute Rudjer Boskovic, Zagreb, Croatia**

V. Brigljevic, S. Duric, K. Kadija, J. Luetic, S. Morovic

**University of Cyprus, Nicosia, Cyprus**

A. Attikis, M. Galanti, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis

**Charles University, Prague, Czech Republic**

M. Finger, M. Finger Jr.

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

Y. Assran[6], S. Elgammal, A. Ellithi Kamel[7], S. Khalil[8], M.A. Mahmoud[9], A. Radi[8,10]

**National Institute of Chemical Physics and Biophysics, Tallinn, Estonia**

M. Kadastik, M. Müntel, M. Raidal, L. Rebane, A. Tiko

**Department of Physics, University of Helsinki, Helsinki, Finland**

V. Azzolini, P. Eerola, G. Fedi, M. Voutilainen

**Helsinki Institute of Physics, Helsinki, Finland**

S. Czellar, J. Härkönen, A. Heikkinen, V. Karimäki, R. Kinnunen, M.J. Kortelainen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, 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, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, L. Millischer, J. Rander, A. Rosowsky, I. Shreyber, M. Titov

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

S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj[11], C. Broutin, P. Busson, C. Charlot, N. Daci, 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. Veelken, A. Zabi

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

J.-L. Agram[12], J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte[12], F. Drouhin[12], C. Ferro, J.-C. Fontaine[12], D. Gelé, U. Goerlach, P. Juillot, M. Karim[12], A.-C. Le Bihan, P. Van Hove

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

F. Fassi, D. Mercier

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

C. Baty, S. Beauceron, N. Beaupere, M. Bedjidian, O. Bondu, G. Boudoul, D. Boumediene, H. Brun, J. Chasserat, R. Chierici[1], D. Contardo, P. Depasse, H. El Mamouni, A. Falkiewicz, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, T. Le Grand, M. Lethuillier, L. Mirabito, S. Perries, V. Sordini, S. Tosi, Y. Tschudi, P. Verdier, S. Viret

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

Z. Tsamalaidze[13]

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

G. Anagnostou, S. Beranek, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov[14]

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

M. Ata, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, T. Klimkovich, D. Klingebiel, P. Kreuzer,

D. Lanske[†], J. Lingemann, C. Magass, M. Merschmeyer, A. Meyer, M. Olschewski, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier, M. Weber

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

M. Bontenackels, V. Cherepanov, M. Davids, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Linn, A. Nowack, L. Perchalla, O. Pooth, J. Rennefeld, P. Sauerland, A. Stahl

### Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz[15], A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, E. Castro, F. Costanza, D. Dammann, G. Eckerlin, D. Eckstein, G. Flucke, A. Geiser, I. Glushkov, P. Gunnellini, S. Habib, J. Hauk, G. Hellwig, H. Jung[1], M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann[15], B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, J. Olzem, H. Perrey, A. Petrukhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, M. Rosin, J. Salfeld-Nebgen, R. Schmidt[15], T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, R. Walsh, C. Wissing

### University of Hamburg, Hamburg, Germany

C. Autermann, V. Blobel, S. Bobrovskyi, J. Draeger, H. Enderle, J. Erfle, U. Gebbert, M. Görner, T. Hermanns, R.S. Höing, K. Kaschube, G. Kaussen, H. Kirschenmann, R. Klanner, J. Lange, B. Mura, F. Nowak, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Schröder, T. Schum, M. Seidel, H. Stadie, G. Steinbrück, J. Thomsen

### Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, J. Berger, C. Böser, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff[1], C. Hackstein, F. Hartmann, T. Hauth[1], M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, I. Katkov[14], D. Kernert, J.R. Komaragiri, D. Martschei, S. Mueller, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, A. Oehler, J. Ott, T. Peiffer, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, S. Riedel, S. Röcker, C. Saout, A. Scheurer, F.-P. Schilling, M. Schmanau, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, M. Zeise, 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

### University of Athens, Athens, Greece

L. Gouskos, T.J. Mertzimekis, A. Panagiotou, N. Saoulidou

### University of Ioánnina, Ioánnina, Greece

I. Evangelou, C. Foudas[1], P. Kokkas, N. Manthos, I. Papadopoulos, V. Patras

**KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary**

A. Aranyi, G. Bencze, L. Boldizsar, C. Hajdu[1], P. Hidas, D. Horvath[16], A. Kapusi, K. Krajczar[17], B. Radics, F. Sikler[1], V. Veszpremi, G. Vesztergombi[17]

**Institute of Nuclear Research ATOMKI, Debrecen, Hungary**

N. Beni, J. Molnar, J. Palinkas, Z. Szillasi

**University of Debrecen, Debrecen, Hungary**

J. Karancsi, P. Raics, Z.L. Trocsanyi, B. Ujvari

**Panjab University, Chandigarh, India**

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

**University of Delhi, Delhi, India**

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

**Saha Institute of Nuclear Physics, Kolkata, India**

S. Banerjee, S. Bhattacharya, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, S. Sarkar

**Bhabha Atomic Research Centre, Mumbai, India**

A. Abdulsalam, R.K. Choudhury, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty[1], L.M. Pant, P. Shukla

**Tata Institute of Fundamental Research - EHEP, Mumbai, India**

T. Aziz, S. Ganguly, M. Guchait[18], A. Gurtu[19], M. Maity[20], G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage

**Tata Institute of Fundamental Research - HECR, Mumbai, India**

S. Banerjee, S. Dugad

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

H. Arfaei, H. Bakhshiansohi[21], S.M. Etesami[22], A. Fahim[21], M. Hashemi, H. Hesari, A. Jafari[21], M. Khakzad, A. Mohammadi[23], M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh[24], M. Zeinali[22]

**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,1], S.S. Chhibra[a,b], A. Colaleo[a], D. Creanza[a,c], N. De Filippis[a,c,1], M. De Palma[a,b], L. Fiore[a], G. Iaselli[a,c], L. Lusito[a,b], G. Maggi[a,c], M. Maggi[a], B. Marangelli[a,b], S. My[a,c], S. Nuzzo[a,b], N. Pacifico[a,b], A. Pompili[a,b], G. Pugliese[a,c], G. Selvaggi[a,b], L. Silvestris[a], G. Singh[a,b], R. Venditti, G. Zito[a]

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

G. Abbiendi[a], A.C. Benvenuti[a], D. Bonacorsi[a,b], S. Braibant-Giacomelli[a,b], L. Brigliadori[a,b], 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,b,1], P. Giacomelli[a],

C. Grandi[a], L. Guiducci, S. Marcellini[a], G. Masetti[a], M. Meneghelli[a,b,1], A. Montanari[a], F.L. Navarria[a,b], F. Odorici[a], A. Perrotta[a], F. Primavera[a,b], 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], S. Costa[a,b], 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. Frosali[a,b], E. Gallo[a], S. Gonzi[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[25], F. Fabbri, D. Piccolo

**INFN Sezione di Genova, Genova, Italy**

P. Fabbricatore, R. Musenich

**INFN Sezione di Milano-Bicocca** [a], **Università di Milano-Bicocca** [b], **Milano, Italy**

A. Benaglia[a,b,1], F. De Guio[a,b], L. Di Matteo[a,b,1], S. Fiorendi[a,b], S. Gennai[a,1], A. Ghezzi[a,b], S. Malvezzi[a], R.A. Manzoni[a,b], A. Martelli[a,b], A. Massironi[a,b,1], D. Menasce[a], L. Moroni[a], M. Paganoni[a,b], D. Pedrini[a], S. Ragazzi[a,b], N. Redaelli[a], S. Sala[a], T. Tabarelli de Fatis[a,b]

**INFN Sezione di Napoli** [a], **Università di Napoli "Federico II"** [b], **Napoli, Italy**

S. Buontempo[a], C.A. Carrillo Montoya[a,1], N. Cavallo[a,26], A. De Cosa[a,b], O. Dogangun[a,b], F. Fabozzi[a,26], A.O.M. Iorio[a,1], L. Lista[a], S. Meola[a,27], M. Merola[a,b], P. Paolucci[a]

**INFN Sezione di Padova** [a], **Università di Padova** [b], **Università di Trento (Trento)** [c], **Padova, Italy**

P. Azzi[a], N. Bacchetta[a,1], P. Bellan[a,b], D. Bisello[a,b], A. Branca[a,1], P. Checchia[a], T. Dorigo[a], U. Dosselli[a], F. Gasparini[a,b], A. Gozzelino[a], K. Kanishchev[a,c], S. Lacaprara[a,28], I. Lazzizzera[a,c], M. Margoni[a,b], A.T. Meneguzzo[a,b], M. Nespolo[a,1], J. Pazzini[a], L. Perrozzi[a], N. Pozzobon[a,b], P. Ronchese[a,b], F. Simonetto[a,b], E. Torassa[a], M. Tosi[a,b,1], S. Vanini[a,b], P. Zotto[a,b], A. Zucchetta[a], G. Zumerle[a,b]

**INFN Sezione di Pavia** [a], **Università di Pavia** [b], **Pavia, Italy**

M. Gabusi[a,b], S.P. Ratti[a,b], C. Riccardi[a,b], P. Torre[a,b], P. Vitulo[a,b]

**INFN Sezione di Perugia** [a], **Università di Perugia** [b], **Perugia, Italy**

G.M. Bilei[a], B. Caponeri[a,b], L. Fanò[a,b], P. Lariccia[a,b], A. Lucaroni[a,b,1], G. Mantovani[a,b], M. Menichelli[a], A. Nappi[a,b], F. Romeo[a,b], A. Saha, A. Santocchia[a,b], S. Taroni[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], T. Boccali[a], 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,29], A. Messineo[a,b], F. Palla[a], F. Palmonari[a], A. Rizzi[a,b], A.T. Serban[a,30], 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,1], M. Diemoz[a], C. Fanelli[a,b], M. Grassi[a,1], E. Longo[a,b], P. Meridiani[a,1], F. Micheli[a,b], S. Nourbakhsh[a], G. Organtini[a,b], F. Pandolfi[a,b], R. Paramatti[a], S. Rahatlou[a,b], M. Sigamani[a], L. Soffi[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], N. Cartiglia[a], R. Castello[a,b], M. Costa[a,b], N. Demaria[a], A. Graziano[a,b], C. Mariotti[a,1], S. Maselli[a], E. Migliore[a,b], V. Monaco[a,b], M. Musich[a,1], M.M. Obertino[a,c], N. Pastrone[a], M. Pelliccioni[a], A. Potenza[a,b], A. Romero[a,b], M. Ruspa[a,c], R. Sacchi[a,b], V. Sola[a,b], A. Solano[a,b], A. Staiano[a], A. Vilela Pereira[a]

**INFN Sezione di Trieste** [a]**, Università di Trieste** [b]**, Trieste, Italy**

S. Belforte[a], F. Cossutti[a], G. Della Ricca[a,b], B. Gobbo[a], M. Marone[a,b,1], D. Montanino[a,b,1], A. Penzo[a], A. Schizzi[a,b]

**Kangwon National University, Chunchon, Korea**

S.G. Heo, T.Y. Kim, S.K. Nam

**Kyungpook National University, Daegu, Korea**

S. Chang, J. Chung, D.H. Kim, G.N. Kim, D.J. Kong, H. Park, S.R. Ro, D.C. Son

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

J.Y. Kim, Zero J. Kim, S. Song

**Konkuk University, Seoul, Korea**

H.Y. Jo

**Korea University, Seoul, Korea**

S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, T.J. Kim, K.S. Lee, D.H. Moon, S.K. Park, E. Seo

**University of Seoul, Seoul, Korea**

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

**Sungkyunkwan University, Suwon, Korea**

Y. Cho, Y. Choi, Y.K. Choi, J. Goh, M.S. Kim, B. Lee, J. Lee, S. Lee, H. Seo, I. Yu

**Vilnius University, Vilnius, Lithuania**

M.J. Bilinskas, I. Grigelionis, M. Janulis, A. Juodagalvis

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

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz, R. Lopez-Fernandez, R. Magaña Villalba, J. Martínez-Ortega, A. Sánchez-Hernández, L.M. Villasenor-Cendejas

**Universidad Iberoamericana, Mexico City, Mexico**

S. Carrillo Moreno, F. Vazquez Valencia

**Benemerita Universidad Autonoma de Puebla, Puebla, Mexico**

H.A. Salazar Ibarguen

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

E. Casimiro Linares, A. Morelos Pineda, M.A. Reyes-Santos

**University of Auckland, Auckland, New Zealand**

D. Krofcheck

**University of Canterbury, Christchurch, New Zealand**

A.J. Bell, P.H. Butler, R. Doesburg, S. Reucroft, H. Silverwood

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

M. Ahmad, M.I. Asghar, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi,
M.A. Shah, M. Shoaib

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

G. Brona, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski

**Soltan Institute for Nuclear Studies, Warsaw, Poland**

H. Bialkowska, B. Boimska, T. Frueboes, R. Gokieli, M. Górski, M. Kazana, K. Nawrocki,
K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

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

N. Almeida, P. Bargassa, A. David, P. Faccioli, M. Fernandes, P.G. Ferreira Parracho,
M. Gallinaro, P. Musella, A. Nayak, J. Pela[1], J. Seixas, J. Varela, P. Vischia

**Joint Institute for Nuclear Research, Dubna, Russia**

I. Belotelov, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin,
G. Kozlov, A. Lanev, A. Malakhov, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov,
V. Smirnov, A. Volodko, A. Zarubin

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

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

**Institute for Nuclear Research, Moscow, Russia**

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

**Institute for Theoretical and Experimental Physics, Moscow, Russia**

V. Epshteyn, M. Erofeeva, V. Gavrilov, M. Kossov[1], N. Lychkovskaya, V. Popov,
G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

**Moscow State University, Moscow, Russia**

A. Belyaev, E. Boos, M. Dubinin[4], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin,
O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushanko, A. Popov,
L. Sarycheva[†], V. Savrin, A. Snigirev

**P.N. Lebedev Physical Institute, Moscow, Russia**

V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Leonidov, G. Mesyats, S.V. Rusakov, A. Vinogradov

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

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin[1], V. Kachanov, D. Konstantinov, A. Korablev, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

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

P. Adzic[31], M. Djordjevic, M. Ekmedzic, D. Krpic[31], 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. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, C. Diez Pardos, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, J. Puerta Pelayo, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares, C. Willmott

**Universidad Autónoma de Madrid, Madrid, Spain**

C. Albajar, G. Codispoti, J.F. de Trocóniz

**Universidad de Oviedo, Oviedo, Spain**

J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez[32], J.M. Vizan Garcia

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

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Felcini[33], 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, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, M. Sobron Sanudo, I. Vila, R. Vilar Cortabitarte

**CERN, European Organization for Nuclear Research, Geneva, Switzerland**

D. Abbaneo, E. Auffray, G. Auzinger, P. Baillon, A.H. Ball, D. Barney, C. Bernet[5], G. Bianchi, P. Bloch, A. Bocci, A. Bonato, H. Breuker, K. Bunkowski, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, D. D'Enterria, A. De Roeck, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, B. Frisch, W. Funk, G. Georgiou, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, P. Lecoq, P. Lenzi, C. Lourenço, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti,

F. Meijers, S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, E. Nesvold, M. Nguyen, T. Orimoto, L. Orsini, E. Palencia Cortezon, E. Perez, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, L. Quertenmont, A. Racz, W. Reece, J. Rodrigues Antunes, G. Rolandi[34], T. Rommerskirchen, C. Rovelli[35], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[36], D. Spiga, M. Spiropulu[4], M. Stoye, A. Tsirou, G.I. Veres[17], J.R. Vlimant, H.K. Wöhri, S.D. Worm[37], 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[38]

**Institute for Particle Physics, ETH Zurich, Zurich, Switzerland**

L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, Z. Chen, A. Deisher, G. Dissertori, M. Dittmar, M. Dünser, J. Eugster, K. Freudenreich, C. Grab, P. Lecomte, W. Lustermann, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli[39], P. Nef, F. Nessi-Tedaldi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, M.-C. Sawley, A. Starodumov[40], B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli

**Universität Zürich, Zurich, Switzerland**

E. Aguilo, C. Amsler, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, S. Tupputi, M. Verzetti

**National Central University, Chung-Li, Taiwan**

Y.H. Chang, K.H. Chen, A. Go, C.M. Kuo, S.W. Li, W. Lin, Z.K. Liu, Y.J. Lu, D. Mekterovic, R. Volpe, S.S. Yu

**National Taiwan University (NTU), Taipei, Taiwan**

P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, C. Dietz, U. Grundler, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, R.-S. Lu, D. Majumder, E. Petrakou, X. Shi, J.G. Shiu, Y.M. Tzeng, M. Wang

**Cukurova University, Adana, Turkey**

A. Adiguzel, M.N. Bakirci[41], S. Cerci[42], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, I. Hos, E.E. Kangal, G. Karapinar, A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk[43], A. Polatoz, K. Sogut[44], D. Sunar Cerci[42], B. Tali[42], H. Topakli[41], L.N. Vergili, M. Vergili

**Middle East Technical University, Physics Department, Ankara, Turkey**

I.V. Akin, T. Aliev, B. Bilin, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, M. Yalvac, E. Yildirim, M. Zeyrek

**Bogazici University, Istanbul, Turkey**

M. Deliomeroglu, E. Gülmez, B. Isildak, M. Kaya[45], O. Kaya[45], S. Ozkorucuklu[46], N. Sonmez[47]

**Istanbul Technical University, Istanbul, Turkey**

K. Cankocak

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

L. Levchuk

**University of Bristol, Bristol, United Kingdom**

F. Bostock, J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold[37], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

**Rutherford Appleton Laboratory, Didcot, United Kingdom**

L. Basso[48], K.W. Bell, A. Belyaev[48], C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley

**Imperial College, London, United Kingdom**

R. Bainbridge, G. Ball, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko[40], A. Papageorgiou, M. Pesaresi, K. Petridis, M. Pioppi[49], D.M. Raymond, S. Rogerson, N. Rompotis, A. Rose, M.J. Ryan, C. Seez, P. Sharp, A. Sparrow, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

**Brunel University, Uxbridge, United Kingdom**

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

**Baylor University, Waco, USA**

K. Hatakeyama, H. Liu, T. Scarborough

**The University of Alabama, Tuscaloosa, USA**

C. Henderson, P. Rumerio

**Boston University, Boston, USA**

A. Avetisyan, T. Bose, C. Fantasia, A. Heister, J. St. John, P. Lawson, D. Lazic, J. Rohlf, D. Sperka, L. Sulak

**Brown University, Providence, USA**

J. Alimena, S. Bhattacharya, D. Cutts, A. Ferapontov, U. Heintz, S. Jabeen, G. Kukartsev, G. Landsberg, M. Luk, M. Narain, D. Nguyen, M. Segala, T. Sinthuprasith, T. Speer, K.V. Tsang

**University of California, Davis, Davis, USA**

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, J. Dolen, R. Erbacher, M. Gardner, R. Houtz, W. Ko,

A. Kopecky, R. Lander, O. Mall, T. Miceli, R. Nelson, D. Pellett, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra

**University of California, Los Angeles, Los Angeles, USA**

V. Andreev, D. Cline, R. Cousins, J. Duris, S. Erhan, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, C. Jarvis, C. Plager, G. Rakness, P. Schlein[†], J. Tucker, V. Valuev, M. Weber

**University of California, Riverside, Riverside, USA**

J. Babb, R. Clare, M.E. Dinardo, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng[50], H. Liu, O.R. Long, A. Luthra, H. Nguyen, S. Paramesvaran, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

**University of California, San Diego, La Jolla, USA**

W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, D. Evans, F. Golf, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, J. Muelmenstaedt, S. Padhi, C. Palmer, G. Petrucciani, M. Pieri, R. Ranieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech[51], F. Würthwein, A. Yagil, J. Yoo

**University of California, Santa Barbara, Santa Barbara, USA**

D. Barge, R. Bellan, C. Campagnari, M. D'Alfonso, T. Danielson, K. Flowers, P. Geffert, J. Incandela, C. Justus, P. Kalavase, S.A. Koay, D. Kovalskyi[1], V. Krutelyov, S. Lowette, N. Mccoll, V. Pavlunin, F. Rebassoo, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, C. West

**California Institute of Technology, Pasadena, USA**

A. Apresyan, A. Bornheim, Y. Chen, E. Di Marco, J. Duarte, M. Gataullin, 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, Y.F. Liu, M. Paulini, H. Vogel, I. Vorobiev

**University of Colorado at Boulder, Boulder, USA**

J.P. Cumalat, B.R. Drell, C.J. Edelmaier, W.T. Ford, A. Gaz, B. Heyburn, E. Luiggi Lopez, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

**Cornell University, Ithaca, USA**

L. Agostino, J. Alexander, A. Chatterjee, N. Eggert, L.K. Gibbons, B. Heltsley, W. Hopkins, A. Khukhunaishvili, B. Kreis, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Ryd, E. Salvati, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Vaughan, Y. Weng, L. Winstrom, P. Wittich

**Fairfield University, Fairfield, USA**

D. Winn

**Fermi National Accelerator Laboratory, Batavia, USA**

S. Abdullin, M. Albrow, J. Anderson, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, I. Bloch, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana,

V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, D. Green, O. Gutsche, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Kilminster, B. Klima, S. Kunori, S. Kwan, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko[52], C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, P. Tan, L. Taylor, S. Tkaczyk, N.V. Tran, 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, S. Das, M. De Gruttola, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic[53], G. Mitselmakher, L. Muniz, R. Remington, A. Rinkevicius, P. Sellers, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

### Florida International University, Miami, USA
V. Gaultney, L.M. Lebolo, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

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

### Florida Institute of Technology, Melbourne, USA
M.M. Baarmand, B. Dorney, M. Hohlmann, H. Kalakhety, 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, O. Evdokimov, E.J. Garcia-Solis, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, F. Lacroix, M. Malek, C. O'Brien, C. Silkworth, D. Strom, N. Varelas

### The University of Iowa, Iowa City, USA
U. Akgun, E.A. Albayrak, B. Bilki[54], K. Chung, W. Clarida, F. Duru, S. Griffiths, C.K. Lae, J.-P. Merlo, H. Mermerkaya[55], A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, J. Olson, Y. Onel, F. Ozok, S. Sen, E. Tiras, J. Wetzel, T. Yetkin, K. Yi

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

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

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

– 29 –

**Lawrence Livermore National Laboratory, Livermore, USA**

J. Gronberg, D. Lange, D. Wright

**University of Maryland, College Park, USA**

A. Baden, M. Boutemeur, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, M. Kirn, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, K. Pedro, A. Peterman, K. Rossato, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar, E. Twedt

**Massachusetts Institute of Technology, Cambridge, USA**

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

**University of Minnesota, Minneapolis, USA**

S.I. Cooper, P. Cushman, B. Dahmes, A. De Benedetti, G. Franzoni, A. Gude, J. Haupt, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, V. Rekovic, R. Rusack, M. Sasseville, A. Singovsky, N. Tambe, J. Turkewitz

**University of Mississippi, University, USA**

L.M. Cremaldi, R. Kroeger, L. Perera, R. Rahmat, D.A. Sanders

**University of Nebraska-Lincoln, Lincoln, USA**

E. Avdeeva, K. Bloom, S. Bose, J. Butt, D.R. Claes, A. Dominguez, M. Eads, P. Jindal, J. Keller, I. Kravchenko, J. Lazo-Flores, H. Malbouisson, S. Malik, G.R. Snow

**State University of New York at Buffalo, Buffalo, USA**

U. Baur, A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S.P. Shipkowski, K. Smith

**Northeastern University, Boston, USA**

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, D. Trocino, D. Wood, J. Zhang

**Northwestern University, Evanston, USA**

A. Anastassov, A. Kubik, N. Mucia, N. Odell, R.A. Ofierzynski, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, M. Velasco, S. Won

**University of Notre Dame, Notre Dame, USA**

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

**The Ohio State University, Columbus, USA**

B. Bylsma, L.S. Durkin, A. Hart, C. Hill, R. Hughes, P. Killewald, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, C. Vuosalo, G. Williams, B.L. Winer

**Princeton University, Princeton, USA**

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

**University of Puerto Rico, Mayaguez, USA**

J.G. Acosta, E. Brownson, 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, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M. Jones, O. Koybasi, M. Kress, A.T. Laasanen, N. Leonardo, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, M. Vidal Marono, H.D. Yoo, J. Zablocki, Y. Zheng

**Purdue University Calumet, Hammond, USA**

S. Guragain, N. Parashar

**Rice University, Houston, USA**

A. Adair, C. Boulahouache, V. Cuplov, K.M. Ecklund, F.J.M. Geurts, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

**University of Rochester, Rochester, USA**

B. Betchart, A. Bodek, Y.S. Chung, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, A. Garcia-Bellido, P. Goldenzweig, Y. Gotra, J. Han, A. Harel, S. Korjenevski, D.C. Miner, D. Vishnevskiy, M. Zielinski

**The Rockefeller University, New York, USA**

A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, S. Malik, C. Mesropian

**Rutgers, the State University of New Jersey, Piscataway, USA**

S. Arora, O. Atramentov, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, D. Hits, A. Lath, S. Panwalkar, M. Park, R. Patel, A. Richards, J. Robles, K. Rose, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas

**University of Tennessee, Knoxville, USA**

G. Cerizza, M. Hollingsworth, S. Spanier, Z.C. Yang, A. York

**Texas A&M University, College Station, USA**

R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[56], V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback

**Texas Tech University, Lubbock, USA**

N. Akchurin, J. Damgov, P.R. Dudero, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, Y. Roh, I. Volobouev

## Vanderbilt University, Nashville, USA

E. Appelt, D. Engh, C. Florez, S. Greene, A. Gurrola, W. Johns, P. Kurt, C. Maguire, A. Melo, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

## University of Virginia, Charlottesville, USA

M.W. Arenton, M. Balazs, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, J. Wood, R. Yohay

## Wayne State University, Detroit, USA

S. Gollapinni, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, A. Sakharov

## University of Wisconsin, Madison, USA

M. Anderson, M. Bachtis, D. Belknap, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, L. Gray, K.S. Grogg, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, J. Klukas, A. Lanaro, C. Lazaridis, J. Leonard, R. Loveless, A. Mohapatra, I. Ojalvo, G.A. Pierro, I. Ross, A. Savin, W.H. Smith, J. Swanson

†: Deceased
1: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
2: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
3: Also at Universidade Federal do ABC, Santo Andre, Brazil
4: Also at California Institute of Technology, Pasadena, U.S.A.
5: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
6: Also at Suez Canal University, Suez, Egypt
7: Also at Cairo University, Cairo, Egypt
8: Also at British University, Cairo, Egypt
9: Also at Fayoum University, El-Fayoum, Egypt
10: Now at Ain Shams University, Cairo, Egypt
11: Also at Soltan Institute for Nuclear Studies, Warsaw, Poland
12: Also at Université de Haute-Alsace, Mulhouse, France
13: Now at Joint Institute for Nuclear Research, Dubna, Russia
14: Also at Moscow State University, Moscow, Russia
15: Also at Brandenburg University of Technology, Cottbus, Germany
16: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
17: Also at Eötvös Loránd University, Budapest, Hungary
18: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
19: Now at King Abdulaziz University, Jeddah, Saudi Arabia
20: Also at University of Visva-Bharati, Santiniketan, India
21: Also at Sharif University of Technology, Tehran, Iran
22: Also at Isfahan University of Technology, Isfahan, Iran
23: Also at Shiraz University, Shiraz, Iran
24: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Teheran, Iran
25: Also at Facoltà Ingegneria Università di Roma, Roma, Italy
26: Also at Università della Basilicata, Potenza, Italy
27: Also at Università degli Studi Guglielmo Marconi, Roma, Italy

28: Also at Laboratori Nazionali di Legnaro dell' INFN, Legnaro, Italy
29: Also at Università degli studi di Siena, Siena, Italy
30: Also at University of Bucharest, Faculty of Physics, Bucuresti-Magurele, Romania
31: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
32: Also at University of Florida, Gainesville, U.S.A.
33: Also at University of California, Los Angeles, Los Angeles, U.S.A.
34: Also at Scuola Normale e Sezione dell' INFN, Pisa, Italy
35: Also at INFN Sezione di Roma; Università di Roma "La Sapienza", Roma, Italy
36: Also at University of Athens, Athens, Greece
37: Also at Rutherford Appleton Laboratory, Didcot, U.K.
38: Also at The University of Kansas, Lawrence, U.S.A.
39: Also at Paul Scherrer Institut, Villigen, Switzerland
40: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
41: Also at Gaziosmanpasa University, Tokat, Turkey
42: Also at Adiyaman University, Adiyaman, Turkey
43: Also at The University of Iowa, Iowa City, U.S.A.
44: Also at Mersin University, Mersin, Turkey
45: Also at Kafkas University, Kars, Turkey
46: Also at Suleyman Demirel University, Isparta, Turkey
47: Also at Ege University, Izmir, Turkey
48: Also at School of Physics and Astronomy, University of Southampton, Southampton, U.K.
49: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
50: Also at University of Sydney, Sydney, Australia
51: Also at Utah Valley University, Orem, U.S.A.
52: Also at Institute for Nuclear Research, Moscow, Russia
53: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
54: Also at Argonne National Laboratory, Argonne, U.S.A.
55: Also at Erzincan University, Erzincan, Turkey
56: Also at Kyungpook National University, Daegu, Korea