Published for SISSA by Springer

Received: April 14, 2012
Accepted: June 8, 2012
Published: June 27, 2012

Shape, transverse size, and charged-hadron multiplicity of jets in pp collisions at $\sqrt{s} = 7$ TeV

JHEP06(2012)160

The CMS collaboration

Abstract: Measurements of jet characteristics from inclusive jet production in proton-proton collisions at a centre-of-mass energy of 7 TeV are presented. The data sample was collected with the CMS detector at the LHC during 2010 and corresponds to an integrated luminosity of $36\,\mathrm{pb}^{-1}$. The mean charged-hadron multiplicity, the differential and integral jet shape distributions, and two independent moments of the shape distributions are measured as functions of the jet transverse momentum for jets reconstructed with the anti-k_T algorithm. The measured observables are corrected to the particle level and compared with predictions from various QCD Monte Carlo generators.

Keywords: Hadron-Hadron Scattering

doi:10.1007/JHEP06(2012)160

Contents

1 Introduction

The jet transverse momentum profile (shape) [1, 2], transverse size, and charged-hadron multiplicity in jets are sensitive to multiple parton emissions from the primary outgoing parton and provide a powerful test of the parton showering approximation of quantum chromodynamics (QCD), the theory of strong interactions. Recently, there have been many methods proposed to search for heavy particles by studying the substructure of jets formed by their decay products, as these particles can be highly boosted and thus their decay products are well collimated [3–6]. Jets arising from the fragmentation of a single parton, hereafter referred to as QCD jets, contribute to backgrounds in searches for such boosted-object jets. A good understanding of the QCD jet structure is very important for these searches to be successful. The structures of gluon-initiated and quark-initiated jets are different due to their different fragmentation properties. QCD predicts gluon-initiated jets to have a higher average particle multiplicity and a broader distribution of particle transverse momentum with respect to the jet direction compared to quark-initiated jets. Jet structure measurements test these predictions and can be used to develop techniques to discriminate between gluon and quark jets. Such discrimination techniques can enhance both standard model measurements and the ability to search for physics beyond the standard model.

Historically the jet shape has been used to test perturbative QCD (pQCD) calculations up to the third power in the coupling constant α_s [7, 8]. These leading-order calculations, with only one additional parton in a jet, showed reasonable agreement with the observed jet shapes. While confirming the validity of pQCD calculations, jet shape studies also indicated that jet clustering, underlying event contributions, and hadronization effects must be considered. Currently, these effects are modelled within the framework of Monte Carlo (MC) event generators, which use QCD parton shower models, in conjunction with hadronization and underlying event models, to generate final-state particles. These MC event generators are used extensively to model the signal and background events for a variety of standard model studies and searches for new physics at hadron colliders. Jet shapes are used to tune phenomenological parameters in the event generators. Jet shapes have been measured previously in $\mathrm{p\overline{p}}$ collisions at the Tevatron [7–10] and ep collisions at HERA [11–15].

We present measurements of the charged-hadron multiplicity, shape, and transverse size for jets with transverse momentum up to 1 TeV and rapidity up to 3 using $36\,\mathrm{pb}^{-1}$ of pp collisions at a centre-of-mass energy of 7 TeV collected by the CMS experiment at the Large Hadron Collider (LHC). A similar measurement has been performed by the ATLAS Collaboration [16].

This paper is organised as follows. Section 2 contains a brief description of the CMS detector. In section 3 we present the event selection and reconstruction. The jet observables are defined in section 4 and the results are given in section 5. The conclusions are summarized in section 6.

2 The CMS detector

CMS uses a right-handed coordinate system in which the z axis points in the anticlockwise beam direction, the x axis points towards the centre of the LHC ring, and the y axis points up, perpendicular to the plane of the LHC ring. The azimuthal angle ϕ is measured in radians with respect to the x axis, and the polar angle θ is measured with respect to the z axis. A particle with energy E and momentum $\vec{p}$ is characterized by transverse momentum $p_{\mathrm{T}} = |\vec{p}|\sin\theta$, rapidity $y = \frac{1}{2}\ln\left[(E+p_z)/(E-p_z)\right]$, and pseudorapidity $\eta = -\ln\left[\tan(\theta/2)\right]$.

The CMS superconducting solenoid, 12.5 m long with an internal diameter of 6 m, provides a uniform magnetic field of 3.8 T. The inner tracking system is composed of a pixel detector with three barrel layers at radii between 4.4 and 10.2 cm and a silicon strip tracker with 10 barrel detection layers extending outwards to a radius of 1.1 m. This system is complemented by two endcaps, extending the acceptance up to $|\eta| = 2.5$. The momentum resolution for reconstructed tracks in the central region is about 1% at $p_{\mathrm{T}} = 100\,\mathrm{GeV}/c$.

The calorimeters inside the magnet coil consist of a lead tungstate crystal electromagnetic calorimeter (ECAL) and a brass-scintillator hadron calorimeter (HCAL) with coverage up to $|\eta| = 3$. The quartz/steel forward hadron calorimeters extend the calorimetry coverage up to $|\eta| = 5$. Muons are measured in gas-ionization detectors embedded in the steel return yoke of the magnet. The calorimeter cells are grouped in projective towers of granularity $\Delta\eta \times \Delta\phi = 0.087 \times 0.087$ for the central rapidities considered in this paper. The ECAL was initially calibrated using test beam electrons and then, *in situ*, with photons from π^0 and η meson decays and electrons from Z boson decays [17]. The

JHEP06(2012)160

energy scale in data agrees with that in the simulation to better than 1% in the barrel region ($|\eta| < 1.5$) and better than 3% in the endcap region ($1.3 < |\eta| < 3.0$) [18]. Hadron calorimeter cells in the $|\eta| < 3$ region are calibrated primarily with test-beam data and radioactive sources [19, 20]. A detailed description of the CMS detector may be found in [21].

3 Event selection and reconstruction

The data were recorded using a set of inclusive single-jet high-level triggers [22] requiring at least one jet in the event to have an online jet p_{T} of at least 15, 30, 50, 70, 100, or 140 GeV/c. These jets are reconstructed only from energy deposits in the calorimeters using an iterative cone algorithm. In addition, a minimum-bias trigger, defined as a signal from at least one of two beam scintillator counters in coincidence with a signal from one of two beam pickup timing devices, was used to collect low p_{T} jets. These datasets are combined to measure the jet characteristics in bins spanning the range $20\,\mathrm{GeV}/c < p_{\mathrm{T}} < 1\,\mathrm{TeV}/c$, so that the trigger contributing to each bin is fully efficient. Only a fraction of events satisfying the lower threshold jet triggers were recorded because of limited data acquisition system bandwidth. Thus the effective integrated luminosity for jets with $p_{\mathrm{T}} < 140\,\mathrm{GeV}/c$ is less than 36 pb^{-1}.

Jets are reconstructed offline using the anti-k_{T} jet clustering algorithm [23–25]. This algorithm is similar to the well-known k_{T} algorithm, except that it uses $1/p_{\mathrm{T}}$ instead of p_{T} as the weighting factor for the scaled distance. The algorithm is collinear- and infrared-safe, and it produces circular jets in y-ϕ space except when jets overlap. Two different types of inputs are used with this algorithm. In the first method, individually calibrated particle candidates are used as inputs to the jet clustering algorithm. These particle candidates, photons, electrons, muons, charged hadrons, and neutral hadrons, are reconstructed using the CMS particle flow (PF) algorithm [26]. This algorithm combines the information from all the subdetectors including the silicon tracking system, the electromagnetic calorimeter, the hadron calorimeter, and the muon system in order to reconstruct and identify individual particles in an event. The charged-particle information is primarily derived from the tracking system, and the photons are reconstructed using information from the electromagnetic calorimeter. The neutral hadrons, e.g. neutrons and $\mathrm{K}^0_{\mathrm{L}}$ mesons, carry on average about 15% of the jet momentum, and are reconstructed using information from the hadron calorimeter. Jets reconstructed from these inputs are referred to as PF jets.

In the second method, called the jet-plus-track (JPT) algorithm [27], the energy deposits in the electromagnetic and hadron calorimeter cells, which are combined into calorimeter towers, are used as inputs to the clustering algorithm to form calorimeter jets. Tracks originating from the interaction vertex [28] are associated with these calorimeter jets based on the separation in η-ϕ space between the jet direction and track direction at the interaction vertex. In the case of partially overlapping jets, tracks are assigned to the jet with the minimum p_{T}-weighted distance between each track and the jet axis. These tracks are categorized as muon, charged pion, and electron candidates, and the jet momentum is corrected by substituting their expected particle energy deposition in the calorimeter with their momentum. These track-corrected jets are referred to as JPT jets.

JHEP06(2012)160

The p_{T} of both types of jets are corrected to the particle-level jet p_{T} [29]. In both cases, the ratio of the reconstructed jet p_{T} to the particle jet p_{T} is close to unity, and only small additional corrections to the jet energy scale, of the order of 5–10%, are needed. These corrections are derived from GEANT4-based [30] CMS simulations, based on the p_{T} ratio of the particle jet formed from all stable ($c\tau > 1$ cm) particles to the reconstructed jet, and also *in situ* measurements using dijet and photon + jet events [29]. The uncertainty on the absolute jet energy scale is studied using both data and MC events and is found to be less than 5% for all values of jet p_{T} and η. In order to remove jets coming from instrumental noise, jet quality requirements are applied [31].

The JPT jets are reconstructed with the anti-k_{T} jet clustering algorithm and distance parameter $D = 0.5$ [23]. The tracks associated with JPT jets are used to measure the charged-hadron multiplicity and the transverse size of the jets in the jet p_{T} range $50\,\mathrm{GeV}/c < p_{\mathrm{T}} < 1\,\mathrm{TeV}/c$. The PF jets reconstructed with a distance parameter $D = 0.7$ are used to measure the jet shapes in the jet p_{T} range $20\,\mathrm{GeV}/c < p_{\mathrm{T}} < 1\,\mathrm{TeV}/c$. Owing to the larger jet size, jet shape measurements evaluate a larger fraction of the momentum from the originating parton and are relatively more sensitive to momentum deposited by multiple-parton interactions (MPIs), thus providing important information to tune both the parton showering and MPI models in the event generators. To minimize the contribution from additional pp interactions in a triggered event (pileup), events with only one reconstructed primary vertex are selected for jet shape measurements, as the measurements use both charged and neutral particles. For charged-hadron multiplicity and jet transverse size studies, the events with multiple vertices are also considered as these studies use only those tracks that are associated with the primary vertex. The primary vertex is defined as the vertex with the highest sum of transverse momenta of all reconstructed tracks pointing to it.

4 Jet observables

We have studied several observables to characterize the jet structure. These observables are complementary and they can provide a more comprehensive picture of the composition of jets. In order to compare the resulting measurements with theoretical predictions, all the observables are corrected back to the particle level by taking into account detector effects using MC simulations.

4.1 Jet shapes

The differential jet shape $\rho(r)$ is defined as the average fraction of the transverse momentum contained inside an annulus of inner radius $r_{\mathrm{a}} = r - \delta r/2$ and outer radius $r_{\mathrm{b}} = r + \delta r/2$ as illustrated in figure 1:

$$\rho(r) = \frac{1}{\delta r} \frac{\sum\limits_{r_{\mathrm{a}}<r_i<r_{\mathrm{b}}} p_{\mathrm{T},i}}{\sum\limits_{r_i<R} p_{\mathrm{T},i}},$$

where $\delta r = 0.1$.

JHEP06(2012)160

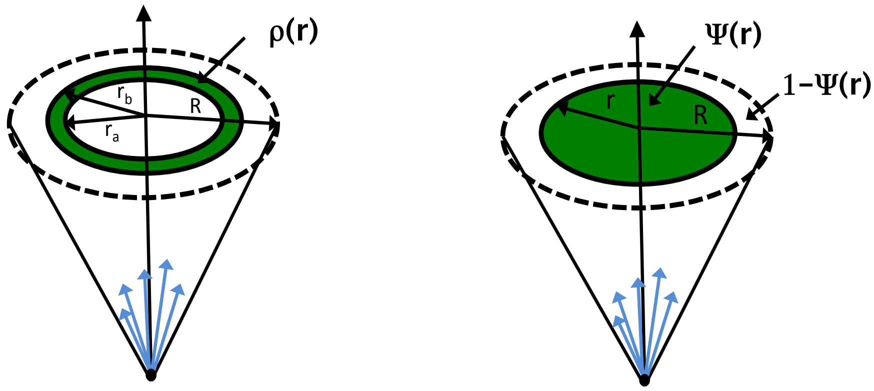

Figure 1. Pictorial definition of the differential (top) and integrated (bottom) jet shape quantities. Analytical definitions of these quantities are given in the text.

The integrated jet shape $\Psi(r)$ is defined as the average fraction of the transverse momentum of particles inside a cone of radius r around the jet axis:

$$\Psi(r) = \frac{\sum\limits_{r_i<r} p_{\mathrm{T},i}}{\sum\limits_{r_i<R} p_{\mathrm{T},i}}.$$

The sums run over the reconstructed particles, with the distance $r_i = \sqrt{(y_i - y_{\mathrm{jet}})^2 + (\phi_i - \phi_{\mathrm{jet}})^2}$ relative to the jet axis described by y_{jet} and ϕ_{jet}, and $R = 0.7$.

The observed detector-level jet shapes and true particle-level jet shapes differ because of jet energy resolution effects, detector response to individual particles, smearing of the jet directions, smearing of the individual particle directions, and inefficiency of particle reconstruction, especially at low p_{T}. The data are unfolded to the particle level using bin-by-bin corrections derived from the CMS simulation based on the PYTHIA 6.4 (PYTHIA6) MC generator [32] tuned to the CMS data (tune Z2). The Z2 tune is identical to the Z1 tune described in [33], except that Z2 uses the CTEQ6L [34] parton distribution function (PDF), while Z1 uses CTEQ5L [35] PDF. The correction factors are determined as functions of r for each jet p_{T} and rapidity bin and vary between 0 and 20%. Since the MC model affects the momentum and angular distributions and flavour composition of particles in a jet, and therefore the simulated detector response to the jet, the unfolding factors depend on the MC model. In order to estimate the systematic uncertainty due to the fragmentation model, the corrections are also derived using PYTHIA8 [36], PYTHIA6 tune D6T [32], and HERWIG++ [37]. The largest difference of these three sets of correction factors from those of PYTHIA6 tune Z2 is assigned as the uncertainty on the correction. This uncertainty is typically 2–3% in the region where the bulk of the jet energy is deposited and increases to as high as 15% at large radii where the momentum of particles is very small. For very high p_{T} jets where the fraction of jet momentum deposited at large radii is extremely small, the uncertainty is less than 1% at $r = 0.1$ and reaches 25% at high radii.

JHEP06(2012)160

The impact of the calibration uncertainties for particles used to measure the jet shapes is studied separately for charged hadrons, neutral hadrons, and photons. The calibration of each type of particle is varied within its measurement uncertainty, depending on its p_{T} and η. The resulting change in the jet shape distributions is negligible as expected since the effect is largely cancelled out in the jet shapes, which are defined as p_{T} sum ratios.

The jet energy scale uncertainty has a larger impact on the jet shape measurements because it affects the migration of jets between different jet p_{T} bins. The jet energy scale uncertainty is estimated to be less than 5% for all jet p_{T} and η bins [29] and results in a maximum uncertainty of 2–3% in both the differential and integrated jet shape distributions.

4.2 The charged-hadron multiplicity and the transverse size of jets

In addition to the study of $\rho(r)$ and $\Psi(r)$, we have measured characteristics of the charged components of jets, namely, the mean charged-hadron multiplicity per jet, $\langle N_{\mathrm{ch}}\rangle$, and the second moments of the transverse jet size, defined by

$$\left\langle \delta\eta^2 \right\rangle = \frac{\sum\limits_{i\in \mathrm{jet}} (\eta_i - \eta_{\mathrm{C}})^2 \cdot p_{\mathrm{T},i}}{\sum\limits_{i\in \mathrm{jet}} p_{\mathrm{T},i}} , \qquad \left\langle \delta\phi^2 \right\rangle = \frac{\sum\limits_{i\in \mathrm{jet}} (\phi_i - \phi_{\mathrm{C}})^2 \cdot p_{\mathrm{T},i}}{\sum\limits_{i\in \mathrm{jet}} p_{\mathrm{T},i}} ,$$

where

$$\eta_C = \frac{\sum\limits_{i\in \mathrm{jet}} \eta_i \cdot p_{\mathrm{T},i}}{\sum\limits_{i\in \mathrm{jet}} p_{\mathrm{T},i}} , \qquad \phi_C = \frac{\sum\limits_{i\in \mathrm{jet}} \phi_i \cdot p_{\mathrm{T},i}}{\sum\limits_{i\in \mathrm{jet}} p_{\mathrm{T},i}} ,$$

and $p_{\mathrm{T},i}$, η_i, and ϕ_i are the transverse momentum, pseudorapidity, and azimuthal direction of a particle i in the jet. These moments are combined to obtain the second moment of the jet transverse width:

$$\left\langle \delta R^2 \right\rangle = \left\langle \delta\eta^2 \right\rangle + \left\langle \delta\phi^2 \right\rangle .$$

We measure $\langle N_{\mathrm{ch}}\rangle$ and $\left\langle \delta R^2 \right\rangle$ using tracks with $p_{\mathrm{T}} > 0.5\,\mathrm{GeV}/c$ associated with JPT jets. The tracks identified as electrons or muons are explicitly removed. As the tracks are required to be attached to the primary vertex, the tracks resulting from photon conversions are not used either.

The particle-level $\langle N_{\mathrm{ch}}\rangle$ and $\left\langle \delta R^2 \right\rangle$ values, defined to correspond to all stable charged hadrons with $p_{\mathrm{T}} > 0.5\,\mathrm{GeV}/c$, are obtained by separately correcting the measured observables for the tracking inefficiency and the jet energy resolution. The corrections to the track detection efficiency are applied in two steps: first, corrections for the tracker acceptance and for losses due to interactions in the detector material are determined for isolated charged pions as functions of p_{T} and η using CMS simulation and applied as a weight assigned to each track [38]. Next, residual corrections for both the tracking inefficiency and misidentified tracks inside the dense high-p_{T} jet environment are calculated for $\langle N_{\mathrm{ch}}\rangle$ and $\left\langle \delta R^2 \right\rangle$ as functions of jet p_{T} in two jet rapidity ranges: $|y| < 1$ and $1 < |y| < 2$. These corrections are derived from MC by comparing the detector-level and particle-level $\langle N_{\mathrm{ch}}\rangle$

JHEP06(2012)160

and $\langle \delta R^2 \rangle$ for each jet p_T bin. The correction factors for $\langle N_{ch} \rangle$ increase from about 2% for jets with $p_T = 40\,\text{GeV}/c$ to 5% for jets with $p_T = 200\,\text{GeV}/c$. The corrections increase to 20% for a jet with p_T of $800\,\text{GeV}/c$. For $\langle \delta R^2 \rangle$, the corrections increase from 3 to 8% as the jet p_T goes from $40\,\text{GeV}/c$ to $200\,\text{GeV}/c$, and rise to 20% for $800\,\text{GeV}/c$ p_T jets. The uncertainty on $\langle N_{ch} \rangle$ due to these residual corrections is 1%, while the uncertainty on $\langle \delta R^2 \rangle$ is 2–5%.

The jet energy resolution corrections are extracted bin by bin from the CMS simulation based on the PYTHIA6 tune Z2 MC samples. The uncertainty on $\langle N_{ch} \rangle$ ($\langle \delta R^2 \rangle$) due to jet energy resolution is 1–2% (2–5%). A cross-check of the correction procedure is performed using the Tikhonov regularization method with a quasi-optimal solution [39, 40]. The results obtained with these two methods are consistent to within 2%.

5 Results

In this section, data results are compared to MC simulations using the PYTHIA6 [32], PYTHIA8 [36], and HERWIG++ [37] event generators. Three different tunes of the PYTHIA 6.4 generator are considered: tune D6T, tune Z2, and the Perugia2010 tune [41]. Tune D6T uses virtuality-ordered parton showers, while tune Z2 and the Perugia2010 tune use p_T-ordered parton showers. Generator input parameters controlling the underlying event, radiation, and hadronization are tuned in order to provide a better description of collider data. Tune D6T was developed using previous hadron and lepton collider data, while tune Z2 also uses CMS soft p_T data [42]. The Perugia2010 tune [41] was tuned using LEP and Tevatron data, notably the CDF jet shape results [9]. Tunes D6T and Z2 are simulated with PYTHIA 6.4.22, and the Perugia2010 tune is simulated with PYTHIA 6.4.24. The CTEQ6L1 [34] parton distribution function (PDF) of the proton is used with tunes D6T and Z2, while the CTEQ5L [35] PDF is used with the Perugia2010 tune. The PYTHIA 8.145 generator, tune 2C, uses an improved diffraction model, and the HERWIG++ 2.4.2 generator uses angular-ordered parton showers and a cluster-based fragmentation model. For HERWIG++ 2.4.2, the default underlying event tune is used together with the MRST2001 [43] PDF.

The differential jet shape measurements for central jets ($|y| < 1$) for representative bins in jet p_T, along with their statistical and systematic uncertainties, compared with predictions from different MC generators and tunes are presented in figures 2 and 3.

Larger values of $\rho(r)$ denote larger transverse momentum fraction in a particular annulus. At high jet p_T, the data are peaked at low radius r, indicating that jets are highly collimated with most of their p_T close to the jet axis while they widen at lower jet p_T. For the lowest jet p_T bins, the p_T distribution within the jet flattens considerably. For $20\,\text{GeV}/c$ jets in the central rapidity region, approximately 15% of the jet p_T is within a radius of $r = 0.1$ around the jet axis, whereas at $600\,\text{GeV}/c$ this fraction increases to about 90%. This behaviour is illustrated in figures 4 and 5 where the amount of jet energy deposited outside a cone of $r = 0.3$, $1 - \Psi(r = 0.3)$, is shown as a function of jet p_T for central jets and also in six different jet rapidity regions up to $|y| = 3$. These figures also show comparisons of the data with the PYTHIA6, PYTHIA8, and HERWIG++ generators.

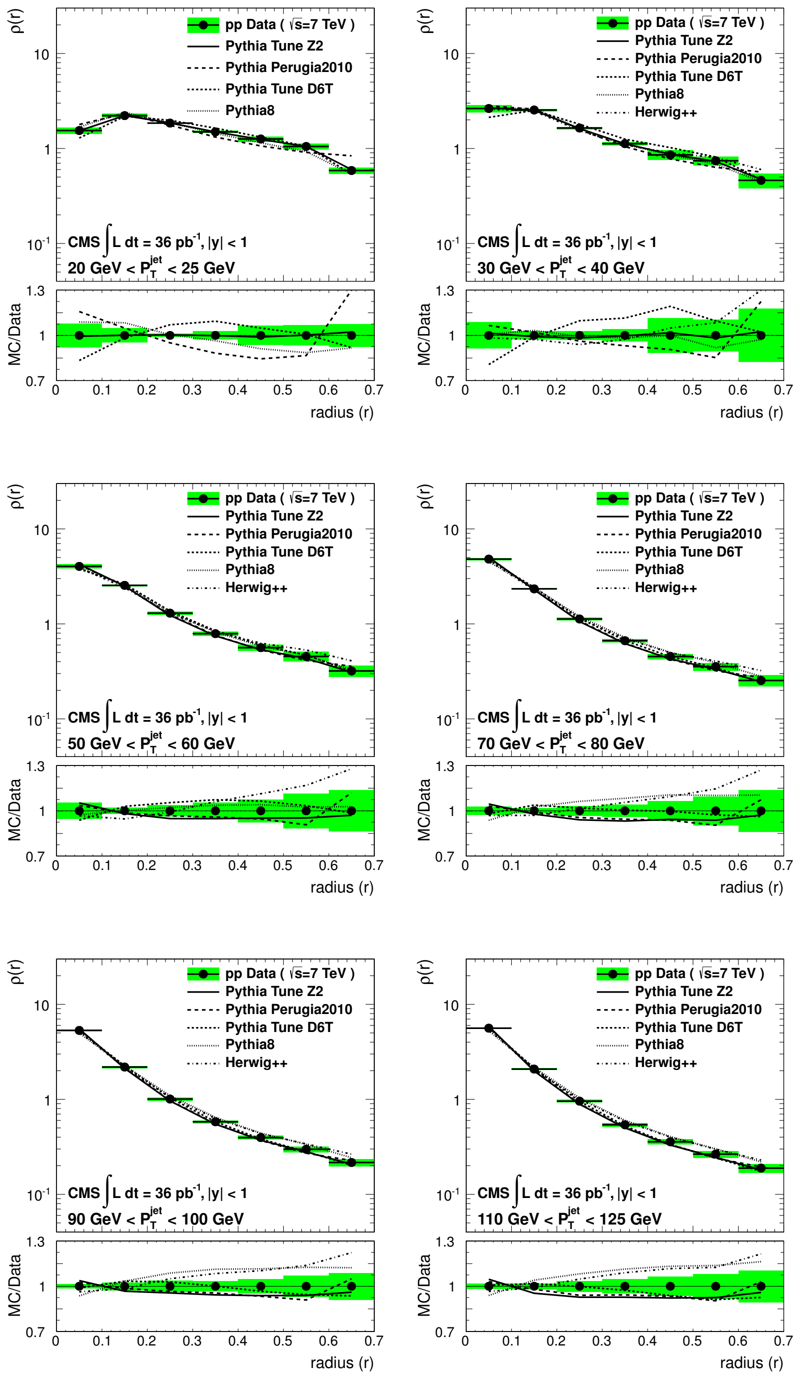

Figure 2. Differential jet shape as a function of the distance from the jet axis for central jets ($|y| < 1$) with jet transverse momentum ranging from 20 to 125 GeV/c for representative jet $p_{\rm T}$ bins. The data are compared to particle-level HERWIG++, PYTHIA8, and PYTHIA6 predictions with various tunes. Statistical uncertainties are shown as error bars on the data points and the shaded region represents the total systematic uncertainty of the measurement. Data points are placed at the bin centre; the horizontal bars show the size of the bin. The ratio of each MC prediction to the data is also shown in the lower part of each plot.

JHEP06(2012)160

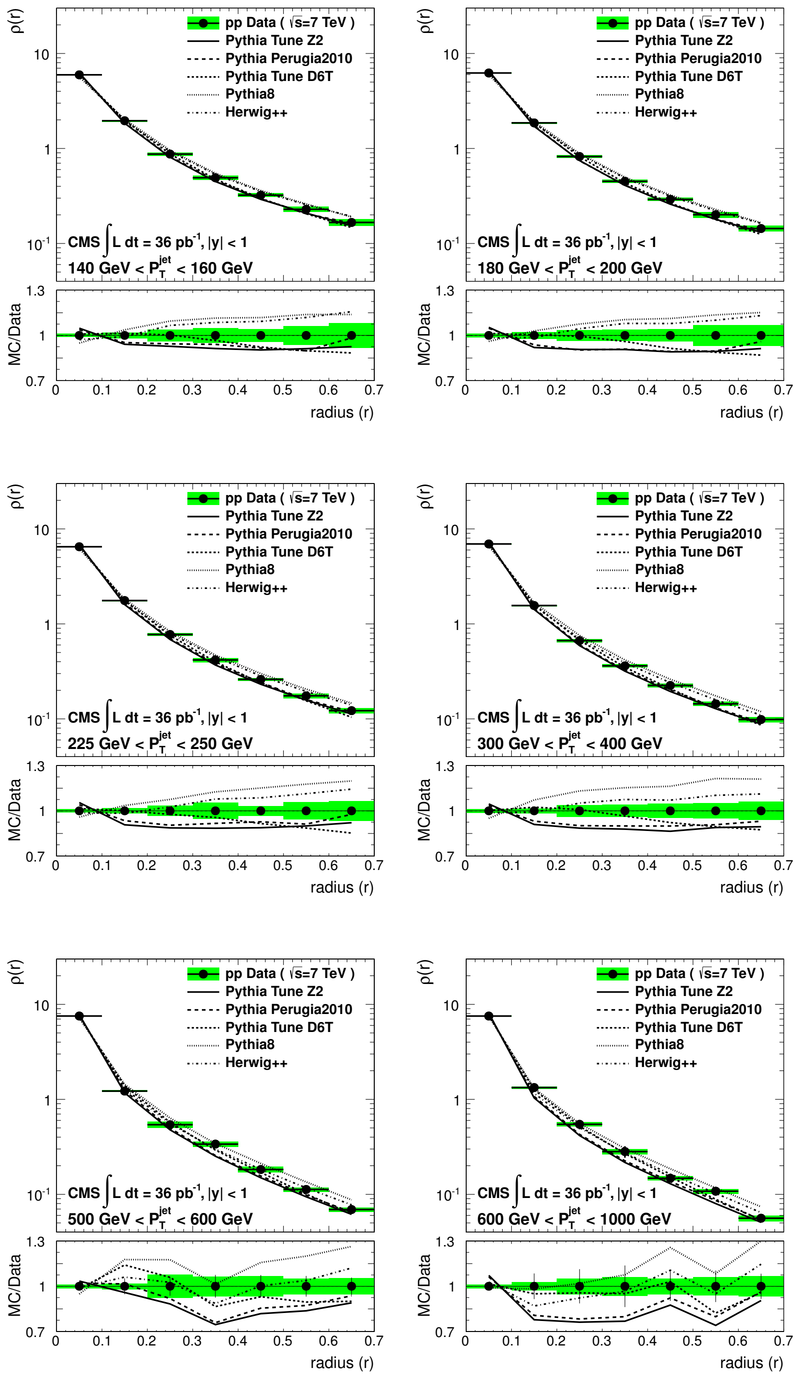

Figure 3. Differential jet shape as a function of the distance from the jet axis for central jets ($|y| < 1$) with jet transverse momentum ranging from 140 to 1000 GeV/c for representative jet p_{T} bins. The data are compared to particle-level HERWIG++, PYTHIA8, and PYTHIA6 predictions with various tunes. Statistical uncertainties are shown as error bars on the data points and the shaded region represents the total systematic uncertainty of the measurement. Data points are placed at the bin centre; the horizontal bars show the size of the bin. The ratio of each MC prediction to the data is also shown in the lower part of each plot.

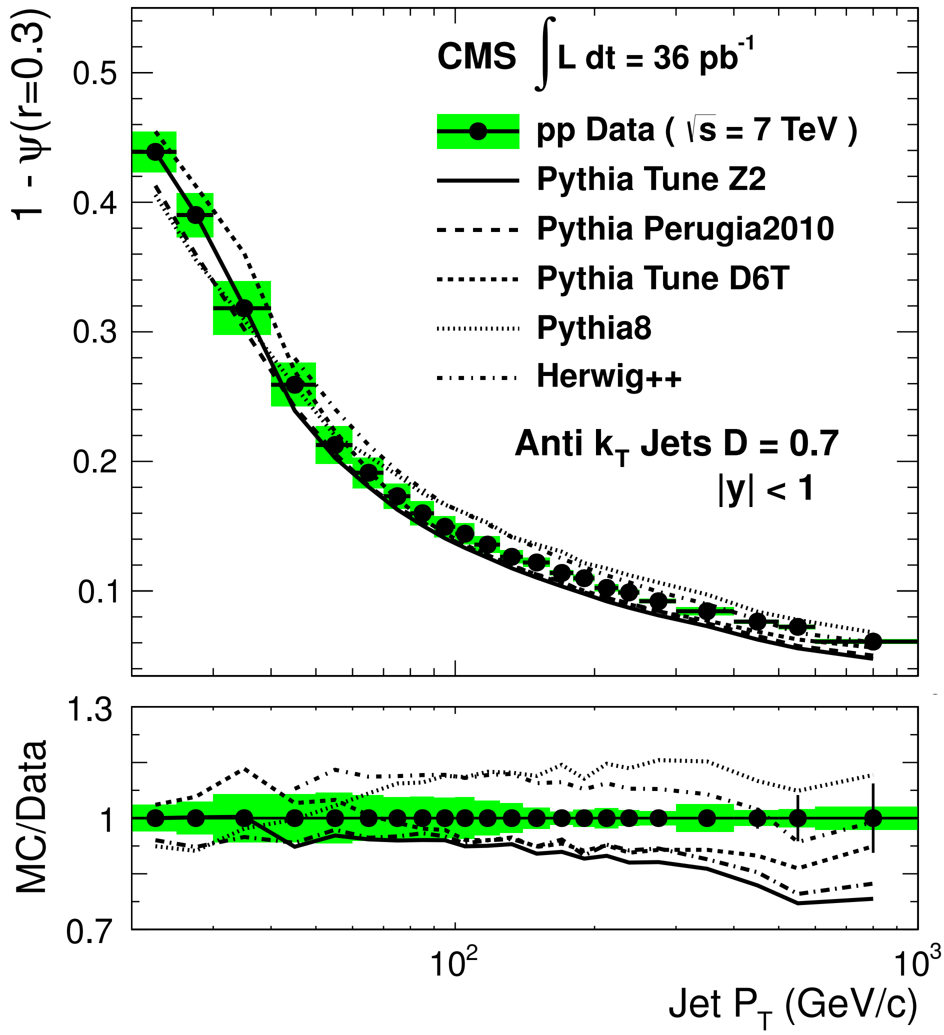

Figure 4. Measured integrated jet shape, $1 - \Psi(r = 0.3)$, as a function of jet p_T in the central rapidity region $|y| < 1$, compared to HERWIG++, PYTHIA8, and PYTHIA6 predictions with various tunes. Statistical uncertainties are shown as uncertainties on the data points and the shaded region represents the total systematic uncertainty of the measurement. Data points are placed at the bin centre; the horizontal bars show the size of the bin. The ratio of each MC prediction to the data is also shown in the lower part of each plot.

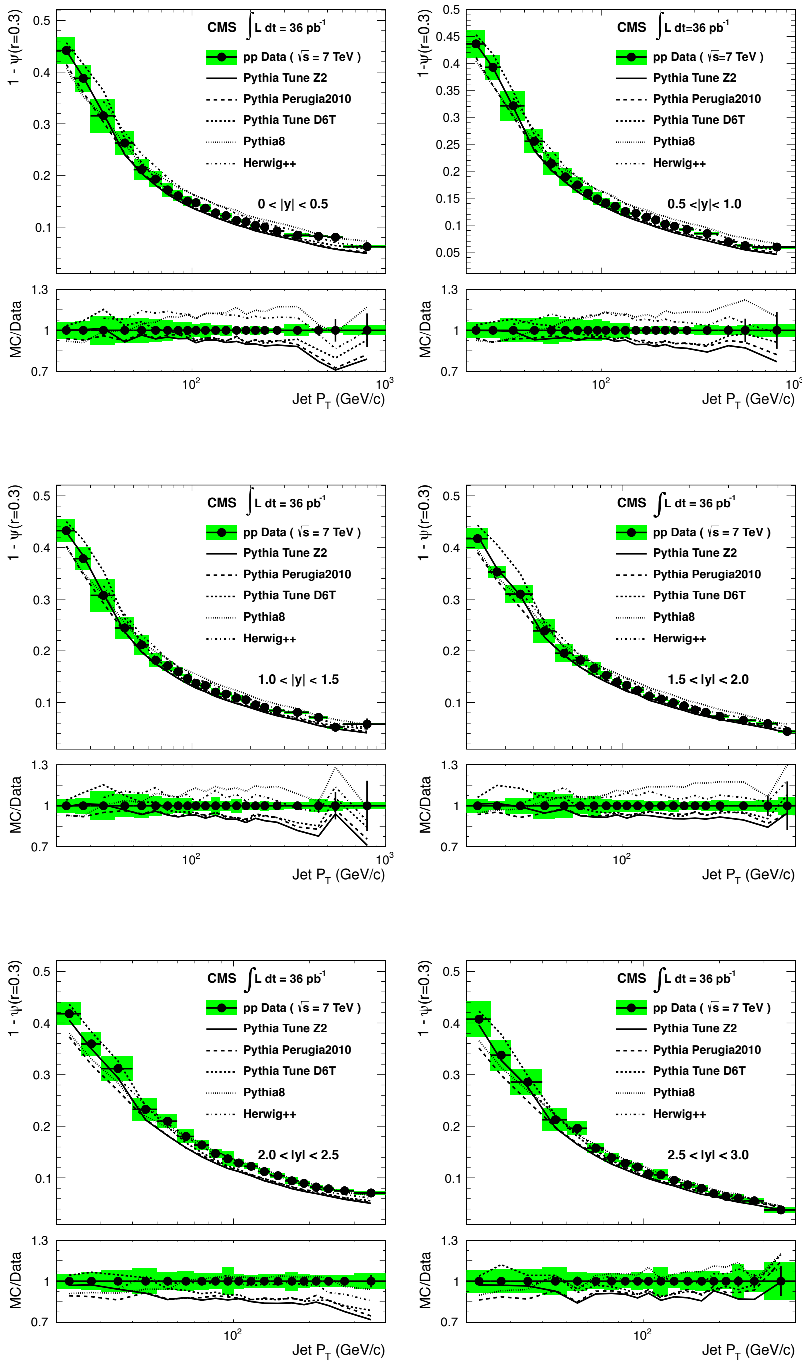

Figure 5. Measured integrated jet shape, $1 - \Psi(r = 0.3)$, as a function of jet p_T in different jet rapidity regions, compared to HERWIG++, PYTHIA8, and PYTHIA6 predictions with various tunes. Statistical uncertainties are shown as error bars on the data points and the shaded region represents the total systematic uncertainty of the measurement. Data points are placed at the bin centre; the horizontal bars show the size of the bin. The ratio of each MC prediction to the data is also shown in the lower part of each plot.

As depicted in figures 4 and 5, at low jet $p_{\rm T}$ the PYTHIA8 generator predicts somewhat narrower jets than those found in data, while PYTHIA6 tune D6T predicts wider jets. Tune Z2 provides a good description of data at low jet $p_{\rm T}$. At jet $p_{\rm T} \gtrsim 40\,\mathrm{GeV}/c$ the Perugia2010 and D6T tunes describe the data better than tune Z2. This trend holds for all rapidity ranges. HERWIG++ predicts wider jets than observed in data over most of the jet $p_{\rm T}$ region except at the forward rapidity regions where the agreement is better. The measurement is presented as a function of jet rapidity for different $p_{\rm T}$ regions in figure 6, which shows that jets become somewhat narrower with increasing $|y|$ in both data and simulation.

The measured $\langle N_{\rm ch}\rangle$ and $\langle \delta R^2\rangle$ as functions of jet $p_{\rm T}$ are presented in figures 7 and 8 for two different rapidity intervals, $|y| < 1$ and $1 < |y| < 2$, along with their statistical and systematic uncertainties. The total systematic uncertainty includes the uncertainty on the jet energy scale, jet energy resolution, tracking inefficiency, jet unsmearing procedure, and pileup contribution. The ratios of the MC predictions to data, corrected to the particle level, of these two observables are shown at the bottom of the figures. The measured values of $\langle N_{\rm ch}\rangle$ are systematically lower than the values predicted by both PYTHIA6 and HERWIG++. In the case of $\langle \delta R^2\rangle$ the predicted values are in agreement with the measured values with the exception of some disagreement observed with PYTHIA6 tune Z2 at $|y| < 1$.

The ratio of the second moments in the η and ϕ directions is shown as a function of jet $p_{\rm T}$ for $|y| < 1$ in figure 9. Systematic uncertainties largely cancel in this ratio. The measured jet width in the η direction is slightly wider than in the ϕ direction. These results agree with PYTHIA6 predictions, while HERWIG++ predicts a larger difference of the jet width in the η and ϕ directions.

A comparison of the $\langle N_{\rm ch}\rangle$ and $\langle \delta R^2\rangle$ values obtained from the data as functions of jet $p_{\rm T}$ in two ranges of jet rapidity is shown in figure 10. The data are in good agreement with the hypothesis that the fraction of quark-induced jets increases with increasing jet $p_{\rm T}$ and jet rapidity.

Tables containing the measured jet shape, charged-hadron multiplicity, and transverse size data are available as a supplement to the online version of this article.

6 Summary

We have presented measurements of jet shapes, mean charged-hadron multiplicity, and transverse width for jets produced in proton-proton collisions at a centre-of-mass energy of 7 TeV, collected by the CMS detector at the LHC. Jets become narrower with increasing jet $p_{\rm T}$, and they also show a mild rapidity dependence in which jets become somewhat narrower with increasing $|y|$, in the manner predicted by various QCD Monte Carlo models. At low jet $p_{\rm T}$, the PYTHIA6 Z2 model tuned to the initial CMS soft $p_{\rm T}$ data [42] provides a fair description of the measured jet shapes. At jet $p_{\rm T} \gtrsim 40\,\mathrm{GeV}/c$, the tune Z2 predicts slightly narrower jets than those observed in data whereas the D6T and Perugia2010 tunes describe the data better. The measurements may be used to further improve these Monte Carlo models.

The mean charged-hadron multiplicity and the second moment of the jet width are compared with predictions from the PYTHIA6 (tunes D6T and Z2) and HERWIG++ gen-

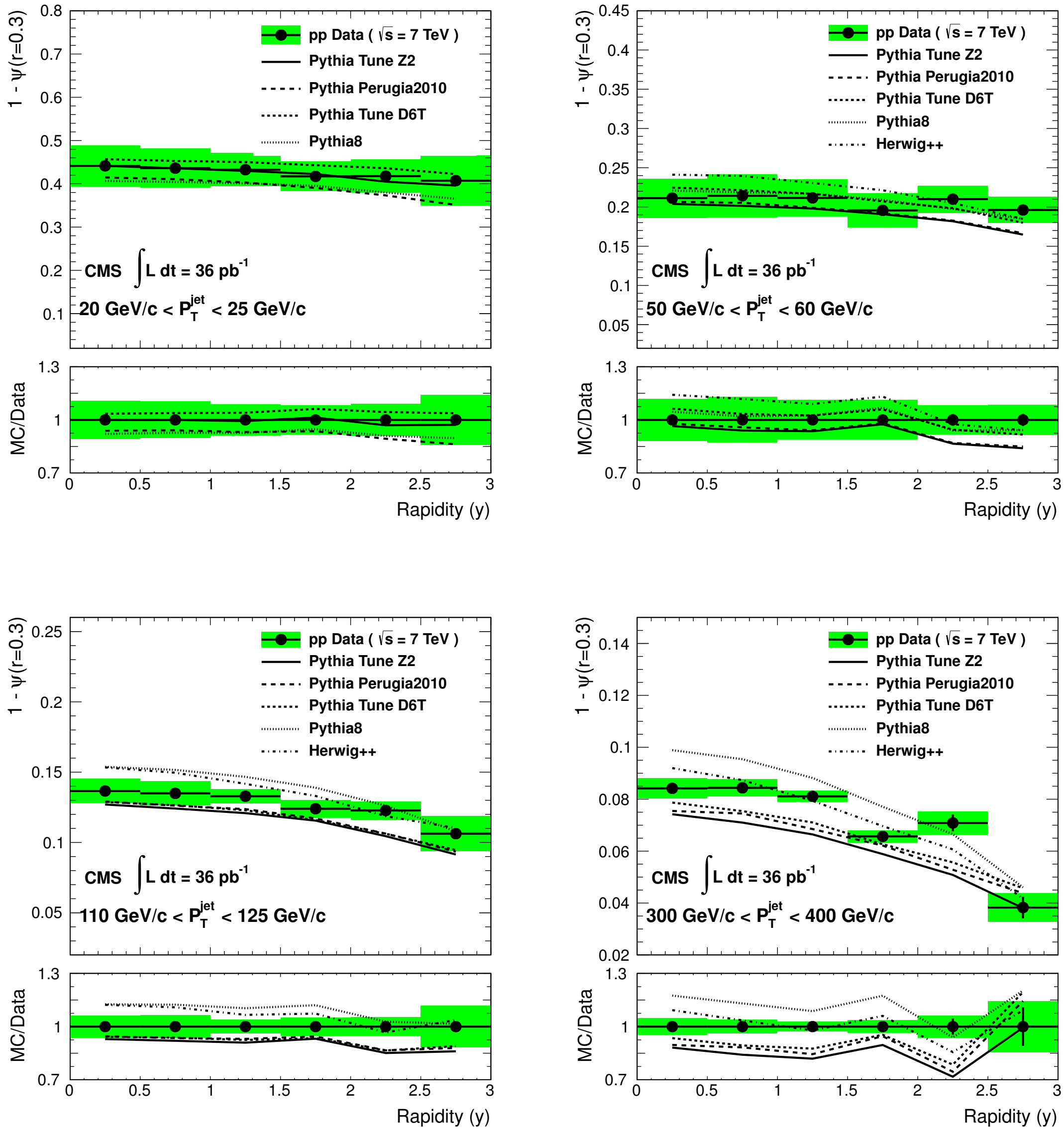

Figure 6. Measured integrated jet shape, $1 - \Psi(r = 0.3)$, as a function of jet rapidity for representative jet p_T bins. The data (points) are compared to particle-level HERWIG++, PYTHIA8, and PYTHIA6 predictions with various tunes. Statistical uncertainties are shown as error bars on the data points and the shaded region represents the total systematic uncertainty of the measurement. Data points are placed at the bin centre; the horizontal bars show the size of the bin. The ratio of each MC prediction to the data is also shown in the lower part of each plot.

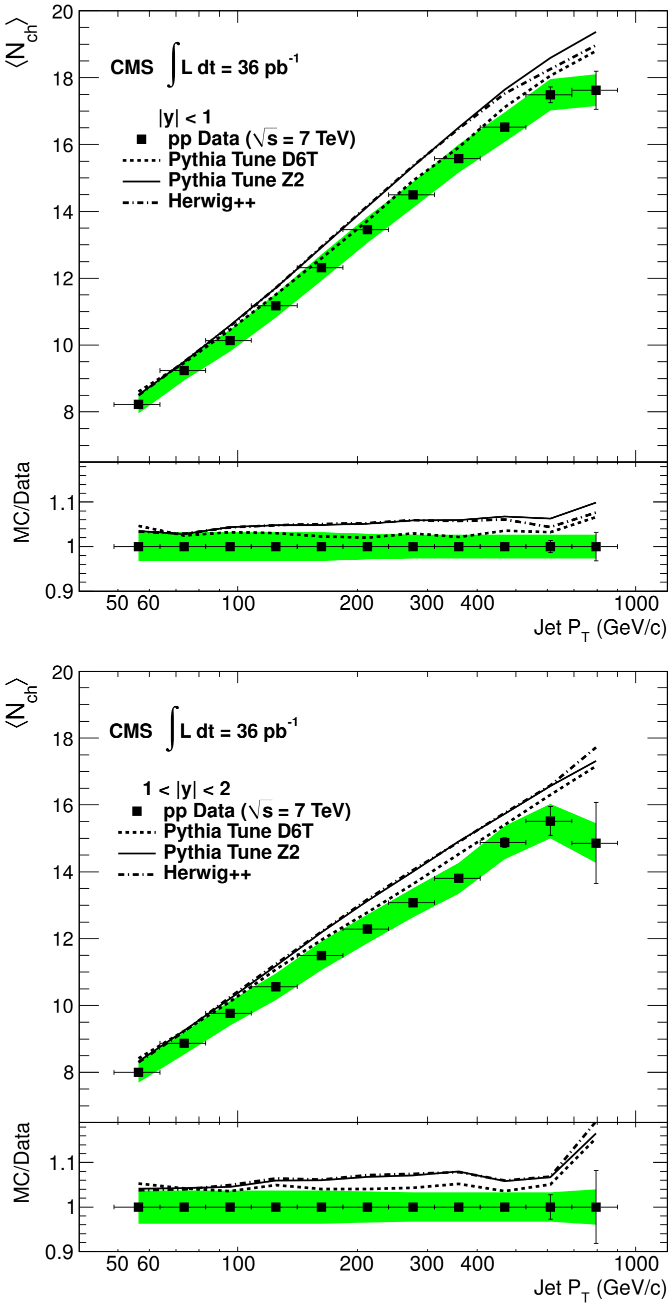

Figure 7. The average charged-particle multiplicity $\langle N_{\rm ch}\rangle$ as a function of jet $p_{\rm T}$ for jets with $0 < |y| < 1$ (top) and $1 < |y| < 2$ (bottom). Data are shown with statistical error bars and a band denoting the systematic uncertainty. Also shown are predictions based on the PYTHIA6 tune D6T (dashed line) and tune Z2 (solid line) and HERWIG++ (dot-dashed line) event generators. The bottom of each plot shows the ratio of the MC simulations to data with statistical error bars and a band denoting the systematic uncertainties on the data measurement.

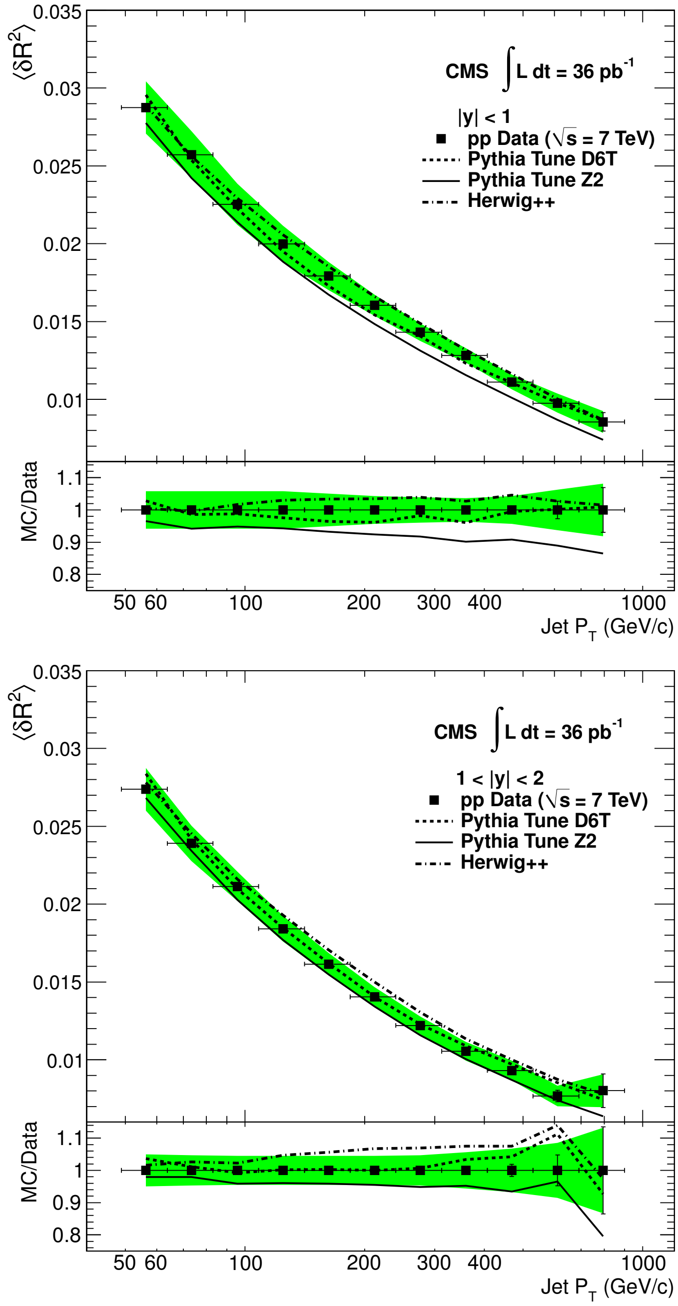

Figure 8. The average transverse jet size $\langle \delta R^2 \rangle$ as a function of jet p_{T} for jets with $0 < |y| < 1$ (top) and $1 < |y| < 2$ (bottom). Data are shown with statistical error bars and a band denoting the systematic uncertainty. Predictions are shown based on the PYTHIA6 tune D6T (dashed line), tune Z2 (solid line), and HERWIG++ (dot-dashed line) event generators. The bottom of each plot shows the ratio of the MC simulations to data with statistical error bars and a band denoting the systematic uncertainties on the data measurement.

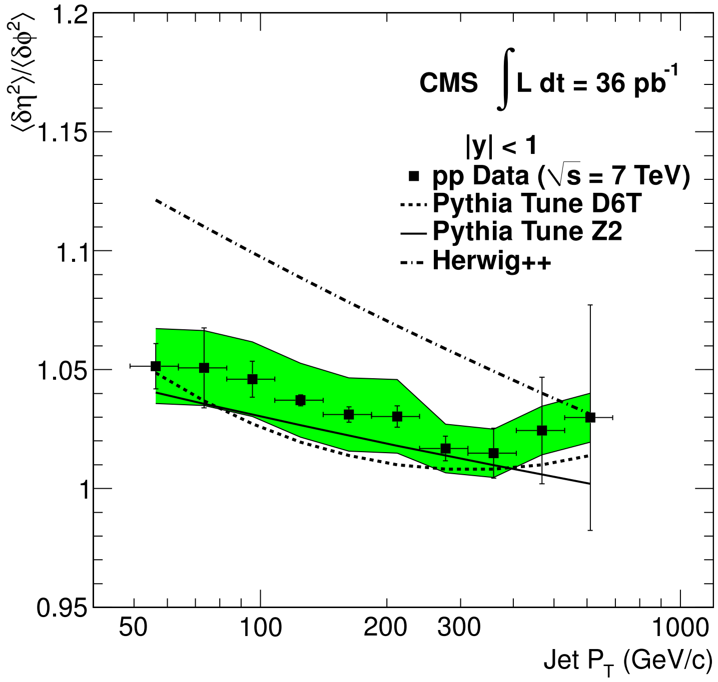

Figure 9. The ratio of the jet transverse width second moments in the η and ϕ directions as a function of jet p_{T} for jets with $|y| < 1$. The systematic uncertainty is shown as a band around the data points. Also shown are predictions based on the PYTHIA6 tune D6T (dot-dashed line), tune Z2 (solid line), and HERWIG++ (dashed line) event generators.

erators. All these models predict slightly higher mean charged-hadron multiplicities than found in the data; however, good agreement is observed between the models and the measured second moment of the jet transverse width. The observed behaviour of the mean multiplicity and jet transverse width agrees with the predicted increase in the fraction of quark-induced jets at higher jet transverse momentum and rapidity. Decomposition of the transverse width second moment into second moments for η and ϕ demonstrates that jets are slightly wider in the η direction than in the ϕ direction. This observation is in good quantitative agreement with PYTHIA6 predictions, while HERWIG++ predicts a larger difference between jet widths in the η and ϕ directions.

Acknowledgments

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC machine. We thank the technical and administrative staff at CERN and other CMS institutes. This work was supported by the Austrian Federal Ministry of Science and Research; the Belgium Fonds de la Recherche Scientifique, and Fonds voor Wetenschappelijk Onderzoek; the Brazilian Funding Agencies (CNPq, CAPES, FAPERJ, and FAPESP); the Bulgarian Ministry of Education and Science; CERN; the Chinese Academy of Sciences, Ministry of Science and Technology, and National Natural Science

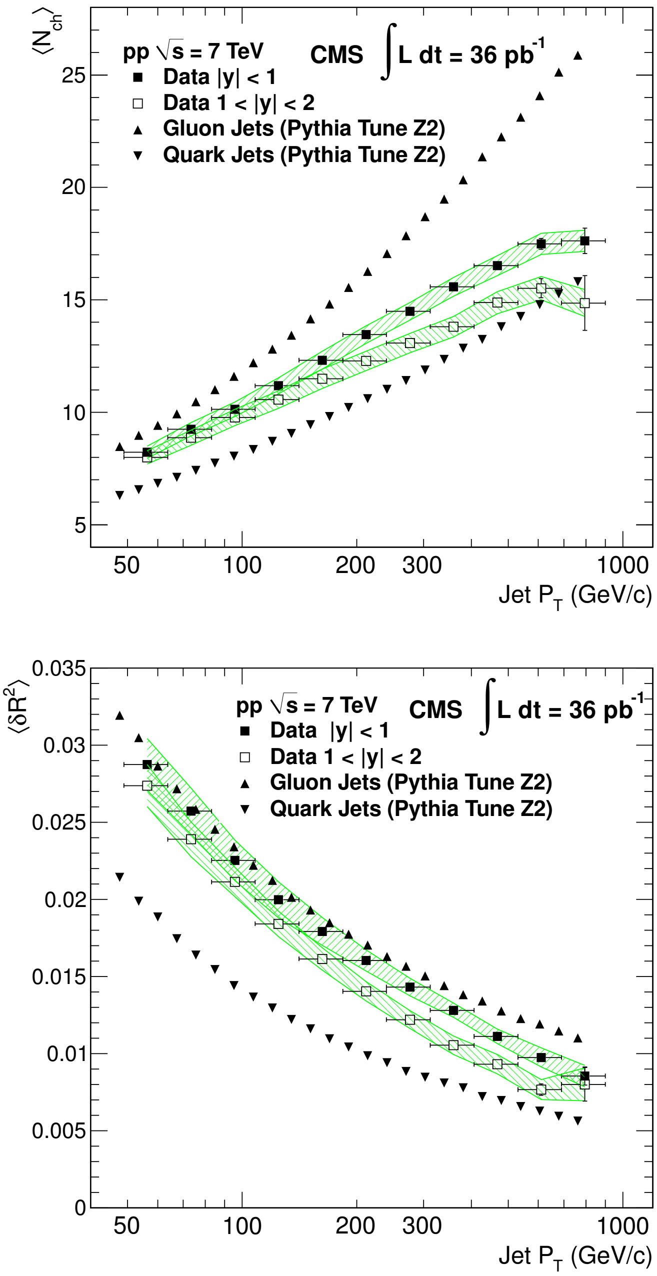

Figure 10. Average charged-particle multiplicity $\langle N_{\mathrm{ch}}\rangle$ (top) and average transverse jet size $\langle \delta R^2 \rangle$ (bottom) as functions of jet p_{T} for jets with $0 < |y| < 1$ (solid squares) and with $1 < |y| < 2$ (open squares). Data are shown with statistical error bars and a band denoting the systematic uncertainty. Also shown are predictions for quark-induced and gluon-induced jets for $|y| < 1$ based on the PYTHIA6 tune Z2 event generator.

Foundation of China; the Colombian Funding Agency (COLCIENCIAS); the Croatian Ministry of Science, Education and Sport; the Research Promotion Foundation, Cyprus; the Ministry of Education and Research, Recurrent financing contract SF0690030s09 and European Regional Development Fund, Estonia; the Academy of Finland, Finnish Ministry of Education and Culture, and Helsinki Institute of Physics; the Institut National de Physique Nucléaire et de Physique des Particules / CNRS, and Commissariat à l'Énergie Atomique et aux Énergies Alternatives / CEA, France; the Bundesministerium für Bildung und Forschung, Deutsche Forschungsgemeinschaft, and Helmholtz-Gemeinschaft Deutscher Forschungszentren, Germany; the General Secretariat for Research and Technology, Greece; the National Scientific Research Foundation, and National Office for Research and Technology, Hungary; the Department of Atomic Energy and the Department of Science and Technology, India; the Institute for Studies in Theoretical Physics and Mathematics, Iran; the Science Foundation, Ireland; the Istituto Nazionale di Fisica Nucleare, Italy; the Korean Ministry of Education, Science and Technology and the World Class University program of NRF, Korea; the Lithuanian Academy of Sciences; the Mexican Funding Agencies (CINVESTAV, CONACYT, SEP, and UASLP-FAI); the Ministry of Science and Innovation, New Zealand; the Pakistan Atomic Energy Commission; the Ministry of Science and Higher Education and the National Science Centre, Poland; the Fundação para a Ciência e a Tecnologia, Portugal; JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); the Ministry of Education and Science of the Russian Federation, the Federal Agency of Atomic Energy of the Russian Federation, Russian Academy of Sciences, and the Russian Foundation for Basic Research; the Ministry of Science and Technological Development of Serbia; the Ministerio de Ciencia e Innovación, and Programa Consolider-Ingenio 2010, Spain; the Swiss Funding Agencies (ETH Board, ETH Zurich, PSI, SNF, UniZH, Canton Zurich, and SER); the National Science Council, Taipei; the Scientific and Technical Research Council of Turkey, and Turkish Atomic Energy Authority; the Science and Technology Facilities Council, U.K.; the US Department of Energy, and the US National Science Foundation.

Individuals have received support from the Marie-Curie programme and the European Research Council (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 Council of Science and Industrial Research, India; and the HOMING PLUS programme of Foundation for Polish Science, cofinanced from European Union, Regional Development Fund.

References

[1] S.D. Ellis, Z. Kunszt and D.E. Soper, *Jets at hadron colliders at order α_s^3: A Look inside*, *Phys. Rev. Lett.* **69** (1992) 3615 [hep-ph/9208249] [INSPIRE].

[2] M. Seymour, *Jet shapes in hadron collisions: Higher orders, resummation and hadronization*, *Nucl. Phys.* **B 513** (1998) 269 [hep-ph/9707338] [INSPIRE].

[3] M.H. Seymour, *Searches for new particles using cone and cluster jet algorithms: A Comparative study*, *Z. Phys.* **C 62** (1994) 127 [INSPIRE].

[4] J.M. Butterworth, A.R. Davison, M. Rubin and G.P. Salam, *Jet substructure as a new Higgs search channel at the LHC*, *Phys. Rev. Lett.* **100** (2008) 242001 [arXiv:0802.2470] [INSPIRE].

[5] D.E. Kaplan, K. Rehermann, M.D. Schwartz and B. Tweedie, *Top Tagging: A Method for Identifying Boosted Hadronically Decaying Top Quarks*, *Phys. Rev. Lett.* **101** (2008) 142001 [arXiv:0806.0848] [INSPIRE].

[6] S.D. Ellis, C.K. Vermilion and J.R. Walsh, *Techniques for improved heavy particle searches with jet substructure*, *Phys. Rev.* **D 80** (2009) 051501 [arXiv:0903.5081] [INSPIRE].

[7] CDF collaboration, F. Abe et al., *A Measurement of jet shapes in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV*, *Phys. Rev. Lett.* **70** (1993) 713 [INSPIRE].

[8] D0 collaboration, S. Abachi et al., *Transverse energy distributions within jets in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV*, *Phys. Lett.* **B 357** (1995) 500 [INSPIRE].

[9] CDF collaboration, D. Acosta et al., *Study of jet shapes in inclusive jet production in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV*, *Phys. Rev.* **D 71** (2005) 112002 [hep-ex/0505013] [INSPIRE].

[10] CDF collaboration, T. Aaltonen et al., *Measurement of b-jet Shapes in Inclusive Jet Production in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.96-TeV*, *Phys. Rev.* **D 78** (2008) 072005 [arXiv:0806.1699] [INSPIRE].

[11] H1 collaboration, S. Aid et al., *Jets and energy flow in photon-proton collisions at HERA*, *Z. Phys.* **C 70** (1996) 17 [hep-ex/9511012] [INSPIRE].

[12] H1 collaboration, C. Adloff et al., *Measurement of event shape variables in deep inelastic ep scattering*, *Phys. Lett.* **B 406** (1997) 256 [hep-ex/9706002] [INSPIRE].

[13] ZEUS collaboration, J. Breitweg et al., *Measurement of jet shapes in photoproduction at HERA*, *Eur. Phys. J.* **C 2** (1998) 61 [hep-ex/9710002] [INSPIRE].

[14] H1 collaboration, C. Adloff et al., *Measurement of internal jet structure in dijet production in deep inelastic scattering at HERA*, *Nucl. Phys.* **B 545** (1999) 3 [hep-ex/9901010] [INSPIRE].

[15] ZEUS collaboration, J. Breitweg et al., *Measurement of jet shapes in high Q^2 deep inelastic scattering at HERA*, *Eur. Phys. J.* **C 8** (1999) 367 [hep-ex/9804001] [INSPIRE].

[16] ATLAS collaboration, G. Aad et al., *Study of Jet Shapes in Inclusive Jet Production in pp Collisions at $\sqrt{s} = 7$ TeV using the ATLAS Detector*, *Phys. Rev.* **D 83** (2011) 052003 [arXiv:1101.0070] [INSPIRE].

[17] CMS collaboration, *ECAL 2010 performance results*, CMS-DP-2011-008 (2011).

[18] CMS collaboration, *Electromagnetic calorimeter calibration with 7 TeV data*, PAS-EGM-10-003.

[19] CMS collaboration, S. Chatrchyan et al., *Performance of the CMS Hadron Calorimeter with Cosmic Ray Muons and LHC Beam Data*, 2010 *JINST* **5** T03012 [arXiv:0911.4991] [INSPIRE].

JHEP06(2012)160

[20] CMS ECAL/HCAL collaborations, S. Abdullin et al., *The CMS barrel calorimeter response to particle beams from 2-GeV/c to 350-GeV/c*, *Eur. Phys. J.* **C 60** (2009) 359 [*Erratum ibid.* **C 61** (2009) 353] [INSPIRE].

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

[22] CMS Trigger and Data Acquisition Group collaboration, W. Adam et al., *The CMS high level trigger*, *Eur. Phys. J.* **C 46** (2006) 605 [hep-ex/0512077] [INSPIRE].

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

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

[25] 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].

[26] CMS collaboration, *Particle-Flow Event Reconstruction in CMS and Performance for Jets, Taus and MET*, PAS-PFT-09-001.

[27] CMS collaboration, *The Jet Plus Tracks Algorithm for Calorimeter Jet Energy Corrections in CMS*, PAS-JME-09-002.

[28] CMS collaboration, *Tracking and Primary Vertex Results in First 7 TeV Collisions*, PAS-TRK-10-005.

[29] CMS collaboration, S. Chatrchyan et al., *Determination of Jet Energy Calibration and Transverse Momentum Resolution in CMS*, 2011 *JINST* **6** P11002 [arXiv:1107.4277] [INSPIRE].

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

[31] CMS collaboration, *Jet Performance in pp Collisions at 7 TeV*, PAS-JME-10-003.

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

[33] R. Field, *Early LHC Underlying Event Data - Findings and Surprises*, arXiv:1010.3558 [INSPIRE].

[34] J. Pumplin, D.R. Stump, J. Huston, H.-L. Lai, P. Nadolsky and W.-K. Tung, *New generation of parton distributions with uncertainties from global QCD analysis*, *JHEP* **07** (2002) 012 [hep-ph/0201195] [INSPIRE].

[35] 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].

[36] 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].

[37] M. Bahr et al., *HERWIG++ Physics and Manual*, *Eur. Phys. J.* **C 58** (2008) 639 [arXiv:0803.0883] [INSPIRE].

[38] CMS collaboration, *Measurement of Tracking Efficiency*, PAS-TRK-10-002.

[39] M.Y. Bogolyubsky et al., *Characteristics of the groups of charged particles in $\bar{p}p$, $p\,p$ and $K^- p$ interactions at 32-GeV/c*, *Phys. Atom. Nucl.* **58** (1995) 1877 [INSPIRE].

JHEP06(2012)160

[40] V. Glasko, *Inverse Problems of Mathematical Physics*, American Institute of Physics Translations Series, Springer Verlag (1989).

[41] P.Z. Skands, *Tuning Monte Carlo Generators: The Perugia Tunes*, Phys. Rev. **D 82** (2010) 074018 [arXiv:1005.3457] [INSPIRE].

[42] 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].

[43] A.D. Martin, R. Roberts, W. Stirling and R. Thorne, *MRST2001: Partons and α_s from precise deep inelastic scattering and Tevatron jet data*, Eur. Phys. J. **C 23** (2002) 73 [hep-ph/0110215] [INSPIRE].

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], M. Hoch, N. Hörmann, J. Hrubec, M. Jeitler, W. Kiesenhofer, 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, L. Benucci, 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, G.H. Hammad, T. Hreus, A. Léonard, P.E. Marage, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wickens

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

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
S. Basegmez, G. Bruno, J. Caudron, L. Ceard, J. De Favereau De Jeneret, C. Delaere, D. Favart, L. Forthomme, A. Giammanco[2], G. Grégoire, J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrzkowski, N. Schul

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

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

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
W.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, A. Sznajder

JHEP06(2012)160

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
N. Darmenov[1], 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
Y. Ban, S. Guo, Y. Guo, W. Li, Y. Mao, S.J. Qian, H. Teng, S. Wang, B. Zhu, W. Zou

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

Technical University of Split, Split, Croatia
N. Godinovic, D. Lelas, R. Plestina[5], D. Polic, I. Puljak

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

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
A. Hektor, 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, E. Tuominen, J. Tuominiemi, E. Tuovinen, D. Ungaro, L. Wendland

JHEP06(2012)160

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

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

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

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, S. Elgammal, R. Granier de Cassagnac, M. Haguenauer, P. Miné, C. Mironov, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Thiebaux, 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, S. Greder, 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, 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
D. Lomidze

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
G. Anagnostou, S. Beranek, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, M. Weber, B. Wittmer, V. Zhukov[13]

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
M. Ata, E. Dietz-Laursonn, M. Erdmann, T. Hebbeker, C. Heidemann, A. Hinzmann, K. Hoepfner, T. Klimkovich, D. Klingebiel, P. Kreuzer, D. Lanske[†], J. Lingemann,

JHEP06(2012)160

C. Magass, M. Merschmeyer, A. Meyer, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier

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

M. Bontenackels, V. Cherepanov, M. Davids, G. Flügge, H. Geenen, 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, D. Tornier, M.H. Zoeller

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, W. Behrenhoff, U. Behrens, M. Bergholz[14], A. Bethani, K. Borras, A. Cakir, A. Campbell, E. Castro, D. Dammann, G. Eckerlin, D. Eckstein, A. Flossdorf, G. Flucke, A. Geiser, J. Hauk, H. Jung[1], M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann[14], B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, J. Olzem, A. Petrukhin, D. Pitzl, A. Raspereza, M. Rosin, J. Salfeld-Nebgen, R. Schmidt[14], T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, J. Tomaszewska, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

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

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, J. Berger, T. Chwalek, W. De Boer, A. Dierlamm, G. Dirkes, M. Feindt, J. Gruschke, M. Guthoff[1], C. Hackstein, F. Hartmann, M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, I. Katkov[13], J.R. Komaragiri, T. Kuhr, D. Martschei, S. Mueller, Th. Müller, M. Niegel, O. Oberst, A. Oehler, J. Ott, T. Peiffer, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, M. Renz, S. Röcker, C. Saout, A. Scheurer, P. Schieferdecker, F.-P. Schilling, M. Schmanau, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, J. Wagner-Kuhr, 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, E. Petrakou

University of Athens, Athens, Greece

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

University of Ioánnina, Ioánnina, Greece

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

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

A. Aranyi, G. Bencze, L. Boldizsar, C. Hajdu[1], P. Hidas, D. Horvath[15], A. Kapusi, K. Krajczar[16], F. Sikler[1], G.I. Veres[16], G. Vesztergombi[16]

JHEP06(2012)160

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

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
S. Ahuja, B.C. Choudhary, A. Kumar, A. Kumar, S. Malhotra, M. Naimuddin, K. Ranjan, 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
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, M. Guchait[17], A. Gurtu[18], M. Maity[19], D. Majumder, G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, A. Saha, K. Sudhakar, N. Wickramage

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

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
H. Arfaei, H. Bakhshiansohi[20], S.M. Etesami[21], A. Fahim[20], M. Hashemi, H. Hesari, A. Jafari[20], M. Khakzad, A. Mohammadi[22], M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh[23], M. Zeinali[21]

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

INFN Sezione di Bologna [a], Università di Bologna [b], Bologna, Italy
G. Abbiendi[a], A.C. Benvenuti[a], D. Bonacorsi[a], S. Braibant-Giacomelli[a,b], L. Brigliadori[a], P. Capiluppi[a,b], A. Castro[a,b], F.R. Cavallo[a], M. Cuffiani[a,b], G.M. Dallavalle[a], F. Fabbri[a], A. Fanfani[a,b], D. Fasanella[a,1], P. Giacomelli[a], C. Grandi[a], S. Marcellini[a], G. Masetti[a], M. Meneghelli[a,b], A. Montanari[a], F.L. Navarria[a,b], F. Odorici[a], A. Perrotta[a], F. Primavera[a], A.M. Rossi[a,b], T. Rovelli[a,b], G. Siroli[a,b], R. Travaglini[a,b]

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

JHEP06(2012)160

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[24], 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], S. Gennai[a,1], A. Ghezzi[a,b], S. Malvezzi[a], 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,25], A. De Cosa[a,b], O. Dogangun[a,b], F. Fabozzi[a,25], A.O.M. Iorio[a,1], L. Lista[a], M. Merola[a,b], P. Paolucci[a]

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

P. Azzi[a], N. Bacchetta[a,1], P. Bellan[a,b], D. Bisello[a,b], A. Branca[a], R. Carlin[a,b], P. Checchia[a], T. Dorigo[a], U. Dosselli[a], F. Gasparini[a,b], U. Gasparini[a,b], A. Gozzelino[a], M. Gulmini[a,26], S. Lacaprara[a,26], I. Lazzizzera[a,c], M. Margoni[a,b], A.T. Meneguzzo[a,b], M. Nespolo[a,1], M. Passaseo[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], G. Zumerle[a,b]

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

P. Baesso[a,b], U. Berzano[a], S.P. Ratti[a,b], C. Riccardi[a,b], P. Torre[a,b], P. Vitulo[a,b], C. Viviani[a,b]

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

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

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

P. Azzurri[a,c], G. Bagliesi[a], 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,27], A. Messineo[a,b], F. Palla[a], F. Palmonari[a], A. Rizzi[a,b], G. Segneri[a], A.T. Serban[a], P. Spagnolo[a], R. Tenchini[a], G. Tonelli[a,b,1], A. Venturi[a,1], P.G. Verdini[a]

INFN Sezione di Roma [a], Università di Roma "La Sapienza" [b], Roma, Italy

L. Barone[a,b], F. Cavallari[a], D. Del Re[a,b,1], M. Diemoz[a], D. Franci[a,b], M. Grassi[a,1], E. Longo[a,b], P. Meridiani[a], S. Nourbakhsh[a], G. Organtini[a,b], F. Pandolfi[a,b], R. Paramatti[a], S. Rahatlou[a,b], M. Sigamani[a]

JHEP06(2012)160

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], S. Maselli[a], E. Migliore[a,b], V. Monaco[a,b], M. Musich[a], 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], D. Montanino[a,b,1], A. Penzo[a]

Kangwon National University, Chunchon, Korea

S.G. Heo, S.K. Nam

Kyungpook National University, Daegu, Korea

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

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, D. Martisiute, P. Petrov, M. Polujanskas, T. Sabonis

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

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz, R. Lopez-Fernandez, R. Magaña Villalba, 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

JHEP06(2012)160

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

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

University of Canterbury, Christchurch, New Zealand
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, P.G. Ferreira Parracho, M. Gallinaro, P. Musella, A. Nayak, J. Pela[1], P.Q. Ribeiro, J. Seixas, J. Varela

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

Petersburg Nuclear Physics Institute, Gatchina (St Petersburg), Russia
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, A. Toropin, S. Troitsky

Institute for Theoretical and Experimental Physics, Moscow, Russia
V. Epshteyn, M. Erofeeva, V. Gavrilov, M. Kossov[1], A. Krokhotin, 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, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushanko, L. Sarycheva, V. Savrin, A. Snigirev

JHEP06(2012)160

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[28], M. Djordjevic, M. Ekmedzic, D. Krpic[28], 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.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[29], M. Fernandez, G. Gomez, J. Gonzalez Sanchez, C. Jorda, P. Lobelle Pardo, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, J. Piedra Gomez[30], 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], W. Bialas, P. Bloch, A. Bocci, H. Breuker, K. Bunkowski, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, B. Curé, D. D'Enterria, A. De Roeck, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, B. Frisch, W. Funk, A. Gaddi, G. Georgiou, H. Gerwig, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Giunta, F. Glege, R. Gomez-Reino Garrido, M. Gouzevitch, P. Govoni, S. Gowdy, R. Guida, L. Guiducci, S. Gundacker, M. Hansen, C. Hartl, J. Harvey, J. Hegeman, B. Hegner, H.F. Hoffmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, P. Lecoq, P. Lenzi, C. Lourenço, T. Mäki, M. Malberti,

L. Malgeri, M. Mannelli, L. Masetti, G. Mavromanolakis, 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[31], T. Rommerskirchen, C. Rovelli[32], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[33], D. Spiga, M. Spiropulu[4], M. Stoye, A. Tsirou, P. Vichoudis, H.K. Wöhri, S.D. Worm[34], 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[35]

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

L. Bäni, P. Bortignon, B. Casal, N. Chanon, Z. Chen, S. Cittolin, A. Deisher, G. Dissertori, M. Dittmar, J. Eugster, K. Freudenreich, C. Grab, P. Lecomte, W. Lustermann, C. Marchica[36], P. Martinez Ruiz del Arbol, P. Milenovic[37], N. Mohr, F. Moortgat, C. Nägeli[36], 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[38], B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli, J. Weng

Universität Zürich, Zurich, Switzerland

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

National Central University, Chung-Li, Taiwan

Y.H. Chang, K.H. Chen, C.M. Kuo, S.W. Li, W. Lin, Z.K. Liu, Y.J. Lu, D. Mekterovic, R. Volpe, 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, J.G. Shiu, Y.M. Tzeng, X. Wan, M. Wang

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci[39], S. Cerci[40], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, I. Hos, E.E. Kangal, A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk[41], A. Polatoz, K. Sogut[42], D. Sunar Cerci[40], B. Tali[40], H. Topakli[39], D. Uzun, L.N. Vergili, M. Vergili

Middle East Technical University, Physics Department, Ankara, Turkey

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

Bogazici University, Istanbul, Turkey

M. Deliomeroglu, E. Gülmez, B. Isildak, M. Kaya[43], O. Kaya[43], M. Özbek, S. Ozkorucuklu[44], N. Sonmez[45]

JHEP06(2012)160

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, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold[34], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith

Rutherford Appleton Laboratory, Didcot, United Kingdom

L. Basso[46], K.W. Bell, A. Belyaev[46], C. Brew, R.M. Brown, B. Camanzi, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley

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[38], A. Papageorgiou, M. Pesaresi, K. Petridis, M. Pioppi[47], D.M. Raymond, S. Rogerson, N. Rompotis, A. Rose, M.J. Ryan, C. Seez, P. Sharp, A. Sparrow, A. Tapper, S. Tourneur, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, D. Wardrope, T. Whyntie

Brunel University, Uxbridge, United Kingdom

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

Baylor University, Waco, U.S.A.

K. Hatakeyama, H. Liu, T. Scarborough

The University of Alabama, Tuscaloosa, U.S.A.

C. Henderson

Boston University, Boston, U.S.A.

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

Brown University, Providence, U.S.A.

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, U.S.A.

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, R. Houtz, W. Ko, A. Kopecky, R. Lander, O. Mall, S. Maruyama, T. Miceli, D. Pellett, J. Robles, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra

JHEP06(2012)160

University of California, Los Angeles, Los Angeles, U.S.A.
V. Andreev, K. Arisaka, 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, U.S.A.
J. Babb, R. Clare, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng[48], S.C. Kao, 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, U.S.A.
W. Andrews, J.G. Branson, G.B. Cerati, D. Evans, F. Golf, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, B. Mangano, S. Padhi, C. Palmer, G. Petrucciani, H. Pi, M. Pieri, R. Ranieri, M. Sani, I. Sfiligoi, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech[49], F. Würthwein, A. Yagil, J. Yoo

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

California Institute of Technology, Pasadena, U.S.A.
A. Apresyan, A. Bornheim, J. Bunn, 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, U.S.A.
B. Akgun, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, S.Y. Jun, Y.F. Liu, M. Paulini, J. Russ, H. Vogel, I. Vorobiev

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

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

Fairfield University, Fairfield, U.S.A.
A. Biselli, G. Cirino, D. Winn

Fermi National Accelerator Laboratory, Batavia, U.S.A.
S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, M. Atac, J.A. Bakken, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, I. Bloch, K. Burkett, J.N. But-

ler, V. Chetluru, H.W.K. Cheung, F. Chlebana, S. Cihangir, W. Cooper, D.P. Eartly, V.D. Elvira, S. Esen, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, D. Green, O. Gutsche, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, H. Jensen, S. Jindariani, M. Johnson, U. Joshi, B. Klima, K. Kousouris, S. Kunori, S. Kwan, C. Leonidopoulos, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, D. Mason, P. McBride, T. Miao, K. Mishra, S. Mrenna, Y. Musienko[50], C. Newman-Holmes, V. O'Dell, J. Pivarski, R. Pordes, O. Prokofyev, T. Schwarz, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, P. Tan, L. Taylor, S. Tkaczyk, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, F. Yumiceva, J.C. Yun

University of Florida, Gainesville, U.S.A.

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, S. Goldberg, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, G. Mitselmakher, L. Muniz, M. Park, R. Remington, A. Rinkevicius, M. Schmitt, B. Scurlock, P. Sellers, N. Skhirtladze, M. Snowball, D. Wang, J. Yelton, M. Zakaria

Florida International University, Miami, U.S.A.

V. Gaultney, L.M. Lebolo, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, U.S.A.

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, S. Sekmen, V. Veeraraghavan

Florida Institute of Technology, Melbourne, U.S.A.

M.M. Baarmand, B. Dorney, M. Hohlmann, H. Kalakhety, I. Vodopiyanov

University of Illinois at Chicago (UIC), Chicago, U.S.A.

M.R. Adams, I.M. Anghel, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, J. Callner, R. Cavanaugh, C. Dragoiu, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, G.J. Kunde[51], F. Lacroix, M. Malek, C. O'Brien, C. Silkworth, C. Silvestre, D. Strom, N. Varelas

The University of Iowa, Iowa City, U.S.A.

U. Akgun, E.A. Albayrak, B. Bilki, W. Clarida, F. Duru, S. Griffiths, C.K. Lae, E. McCliment, J.-P. Merlo, H. Mermerkaya[52], 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, U.S.A.

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

JHEP06(2012)160

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

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

Lawrence Livermore National Laboratory, Livermore, U.S.A.
J. Gronberg, D. Lange, D. Wright

University of Maryland, College Park, U.S.A.
A. Baden, M. Boutemeur, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, M. Kirn, Y. Lu, A.C. Mignerey, A. Peterman, K. Rossato, P. Rumerio, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar, E. Twedt

Massachusetts Institute of Technology, Cambridge, U.S.A.
B. Alver, G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, G. Gomez Ceballos, M. Goncharov, K.A. Hahn, P. Harris, 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, U.S.A.
S.I. Cooper, P. Cushman, B. Dahmes, A. De Benedetti, G. Franzoni, A. Gude, J. Haupt, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, V. Rekovic, R. Rusack, M. Sasseville, A. Singovsky, N. Tambe, J. Turkewitz

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

University of Nebraska-Lincoln, Lincoln, U.S.A.
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, U.S.A.
U. Baur, A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, K. Smith, Z. Wan

Northeastern University, Boston, U.S.A.
G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, D. Trocino, D. Wood, J. Zhang

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

JHEP06(2012)160

The Ohio State University, Columbus, U.S.A.

B. Bylsma, L.S. Durkin, C. Hill, P. Killewald, K. Kotov, T.Y. Ling, M. Rodenburg, C. Vuosalo, G. Williams

Princeton University, Princeton, U.S.A.

N. Adam, E. Berry, P. Elmer, D. Gerbaudo, V. Halyo, P. Hebda, 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, U.S.A.

J.G. Acosta, X.T. Huang, A. Lopez, H. Mendez, S. Oliveros, J.E. Ramirez Vargas, A. Zatserklyaniy

Purdue University, West Lafayette, U.S.A.

E. Alagoz, V.E. Barnes, D. Benedetti, G. Bolla, L. Borrello, D. Bortoletto, M. De Mattia, A. Everett, L. Gutay, 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, U.S.A.

S. Guragain, N. Parashar

Rice University, Houston, U.S.A.

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, U.S.A.

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

The Rockefeller University, New York, U.S.A.

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

Rutgers, the State University of New Jersey, Piscataway, U.S.A.

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, K. Rose, S. Salur, S. Schnetzer, S. Somalwar, R. Stone, S. Thomas

University of Tennessee, Knoxville, U.S.A.

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

Texas A&M University, College Station, U.S.A.

R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[53], V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback

JHEP06(2012)160

Texas Tech University, Lubbock, U.S.A.

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

Vanderbilt University, Nashville, U.S.A.

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

University of Virginia, Charlottesville, U.S.A.

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

Wayne State University, Detroit, U.S.A.

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

University of Wisconsin, Madison, U.S.A.

M. Anderson, M. Bachtis, D. Belknap, J.N. Bellinger, J. Bernardini, D. Carlsmith, M. Cepeda, S. Dasu, J. Efron, E. Friis, 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, M. Weinberg

†: 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: Also at Moscow State University, Moscow, Russia
14: Also at Brandenburg University of Technology, Cottbus, Germany
15: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
16: Also at Eötvös Loránd University, Budapest, Hungary
17: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
18: Now at King Abdulaziz University, Jeddah, Saudi Arabia
19: Also at University of Visva-Bharati, Santiniketan, India
20: Also at Sharif University of Technology, Tehran, Iran

JHEP06(2012)160

21: Also at Isfahan University of Technology, Isfahan, Iran
22: Also at Shiraz University, Shiraz, Iran
23: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Teheran, Iran
24: Also at Facoltà Ingegneria Università di Roma, Roma, Italy
25: Also at Università della Basilicata, Potenza, Italy
26: Also at Laboratori Nazionali di Legnaro dell' INFN, Legnaro, Italy
27: Also at Università degli studi di Siena, Siena, Italy
28: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
29: Also at University of California, Los Angeles, Los Angeles, U.S.A.
30: Also at University of Florida, Gainesville, U.S.A.
31: Also at Scuola Normale e Sezione dell' INFN, Pisa, Italy
32: Also at INFN Sezione di Roma; Università di Roma "La Sapienza", Roma, Italy
33: Also at University of Athens, Athens, Greece
34: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
35: Also at The University of Kansas, Lawrence, U.S.A.
36: Also at Paul Scherrer Institut, Villigen, Switzerland
37: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
38: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
39: Also at Gaziosmanpasa University, Tokat, Turkey
40: Also at Adiyaman University, Adiyaman, Turkey
41: Also at The University of Iowa, Iowa City, U.S.A.
42: Also at Mersin University, Mersin, Turkey
43: Also at Kafkas University, Kars, Turkey
44: Also at Suleyman Demirel University, Isparta, Turkey
45: Also at Ege University, Izmir, Turkey
46: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
47: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
48: Also at University of Sydney, Sydney, Australia
49: Also at Utah Valley University, Orem, U.S.A.
50: Also at Institute for Nuclear Research, Moscow, Russia
51: Also at Los Alamos National Laboratory, Los Alamos, U.S.A.
52: Also at Erzincan University, Erzincan, Turkey
53: Also at Kyungpook National University, Daegu, Korea

JHEP06(2012)160