

Measurement of the $t\bar{t}$ production cross section in the all-jet final state in pp collisions at $\sqrt{s} = 7$ TeV



The CMS collaboration

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

ABSTRACT: A measurement is presented of the $t\bar{t}$ production cross section ($\sigma_{t\bar{t}}$) in proton-proton collisions at a centre-of-mass energy of 7 TeV, in the all-jet final state that contains at least six jets, two of which are tagged as originating from b quarks. The data correspond to an integrated luminosity of 3.54 fb^{-1} , collected with the CMS detector at the LHC. The cross section is determined through an unbinned maximum likelihood fit of background and $t\bar{t}$ signal to the reconstructed mass spectrum of $t\bar{t}$ candidates in the data, in which events are subjected to a kinematic fit assuming a $t\bar{t} \rightarrow W^+bW^- \bar{b} \rightarrow 6$ jets hypothesis. The measurement yields $\sigma_{t\bar{t}} = 139 \pm 10$ (stat.) ± 26 (syst.) ± 3 (lum.) pb, a result consistent with those obtained in other $t\bar{t}$ decay channels, as well as with predictions of the standard model.

KEYWORDS: Hadron-Hadron Scattering

ARXIV EPRINT: [1302.0508](https://arxiv.org/abs/1302.0508)

Contents

1	Introduction	1
2	The CMS detector	2
3	Data and simulation	2
4	Event selection	3
4.1	Kinematic fit	4
5	Extraction of $t\bar{t}$ signal	4
5.1	Estimate of background from multijet events	5
6	Systematic uncertainties	6
7	Results	8
8	Alternative analysis using a neural-network-based selection	9
9	Summary	11
	The CMS collaboration	15

1 Introduction

Precise measurements of the top-quark pair ($t\bar{t}$) production cross section ($\sigma_{t\bar{t}}$), especially in different final states, in proton-proton (pp) collisions at the Large Hadron Collider (LHC) provide important checks of perturbative quantum chromodynamics (QCD) and therefore of the standard model (SM). Such studies are also of value in estimating backgrounds in searches for new physics. First measurements from pp collisions in 2010 at a centre-of-mass energy of $\sqrt{s} = 7$ TeV, based on an integrated luminosity of 3 pb^{-1} , were reported by the CMS [1] and ATLAS [2] experiments. Subsequent measurements, based on all the data collected in 2010, corresponding to an integrated luminosity of approximately 36 pb^{-1} were performed in the dilepton ($t\bar{t} \rightarrow W^+bW^-\bar{b} \rightarrow \ell^+\nu_\ell b\ell^-\bar{\nu}_\ell\bar{b}$) [3, 4] and in the lepton+jets channels ($W^+bW^-\bar{b} \rightarrow \ell^+\nu_\ell b\bar{q}q'\bar{b} + \text{charge conjugate states}$), both with [5, 6] and without [6, 7] the use of b tagging. Measurements using data collected in 2011, corresponding to integrated luminosities between 0.7 and 2.3 fb^{-1} , were also reported in lepton+jets and dilepton channels for contributions from $\tau \rightarrow \text{hadrons} + \nu_\tau$ decays [8–10], as well as from final states containing just electrons or muons [11–13].

This Letter presents the first measurement of the $t\bar{t}$ production cross section in proton-proton collisions at $\sqrt{s} = 7$ TeV in the all-jet decay channel ($W^+bW^-\bar{b} \rightarrow \bar{q}q'bq''\bar{q}''\bar{b}$) by the CMS collaboration. The measurement is complementary to the previous measurements

of $\sigma_{t\bar{t}}$, and is therefore interesting in its own right. The all-jet final state has a far larger yield of $t\bar{t}$ events than the dilepton or lepton+jets channels. Moreover, it does not suffer from the presence of neutrinos of large transverse momentum p_T that escape detection. However, with only jets in the final state, this channel is dominated by background from generic multijet (MJ) production. The main analysis is based on a reconstruction of the candidate events through a kinematic fit to the $t\bar{t}$ hypothesis. An alternative measurement is performed using a neural-network-based selection and a different model for background.

2 The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an axial magnetic field of 3.8 T. The bore of the solenoid is outfitted with various particle detection systems. Charged-particle trajectories are measured with silicon pixel and strip trackers, covering $0 < \phi < 2\pi$ in azimuth and $|\eta| < 2.5$ in pseudorapidity, where η is defined as $-\ln(\tan\theta/2)$, with θ being the polar angle of the trajectory of the particle with respect to the anticlockwise beam direction. A lead tungstate crystal electromagnetic calorimeter and a brass/scintillator hadronic calorimeter surround the tracking volume. The calorimetry provides excellent resolution in energy for electrons and jets of hadrons within $|\eta| < 3.0$. Muons are measured up to $|\eta| < 2.4$ using gas-ionisation detectors embedded in the steel return yoke outside the solenoid. The detector is nearly hermetic, providing accurate measurements of any imbalance in momentum in the plane transverse to the beam direction. A two-level trigger system selects the pp final states pertinent to this analysis. A detailed description of the CMS detector is available in ref. [14].

3 Data and simulation

The data correspond to an integrated luminosity of 3.54 fb^{-1} collected in 2011. Two multijet triggers are used in this analysis. The first requires the presence of at least four jets in the calorimeter, each with $p_T > 50 \text{ GeV}/c$, and a fifth jet with $p_T > 40 \text{ GeV}/c$. The second trigger, intended for coping with the higher instantaneous luminosities in the latter stages of the data taking period, requires an additional sixth jet with $p_T > 30 \text{ GeV}/c$. Data taken beyond the initial 3.54 fb^{-1} in 2011 are not used in this analysis because a more-restrictive trigger implemented for highest luminosities greatly reduced the gain in the number of selected $t\bar{t}$ events. The efficiencies for the two triggers are determined from events that pass a prescaled trigger with a less-restrictive requirement of at least four jets with $p_T > 40 \text{ GeV}/c$ that is highly efficient for $t\bar{t}$ signal, as estimated from $t\bar{t}$ Monte Carlo (MC) simulation. Trigger efficiencies are defined by the number of such events that pass the two tighter trigger requirements for the offline selection criteria described in section 4, relative to the number that pass just the offline selections. The combined trigger efficiency for $t\bar{t}$ signal for data is $96^{+4}_{-5}\%$, and $99.7^{+0.3}_{-0.4}\%$ for the MC simulation described below, where the uncertainties are purely statistical for the MC, and mainly systematic for the data (see section 6).

The simulated $t\bar{t}$ events are generated considering QCD matrix elements with up to three additional final-state partons, using MADGRAPH v5.1.1.0 [15] interfaced to the PYTHIA v6.424 MC generator [16] for providing perturbative quantum-chromodynamic parton showering. The value of the top-quark mass in the MC is $m_t = 172.5 \text{ GeV}/c^2$, and the proton structure is described by the parton distribution functions (PDF) CTEQ6L1 [17]. The Z2 tune¹ is used to characterise the underlying event. The simulation includes the effects of the presence of additional, overlapping minimum-bias pp interactions (pileup) and a weighting procedure ensures that the pileup profile in the simulated events matches the one inferred from data with an average number of eight additional pileup events. Multijet events are simulated using the leading-order (LO) QCD PYTHIA MC, and are used to check the validity of the method of analysis. However, the background from such generic multijet events is estimated from data through events in the sidebands of the signal to represent better the multijet component within the signal-dominated region.

4 Event selection

Offline collections of reconstructed particles are produced using a particle-flow (PF) algorithm [18, 19]. Jets are clustered together from the PF particles using the anti- k_T jet algorithm [20], implemented through FASTJET v2.4.2 [21] with a distance parameter of $R = 0.5$. The PF particles can be charged or neutral hadrons, electrons, photons, or muons. By combining information from all subdetectors, the PF technique reduces considerably the size of energy corrections required for otherwise reconstructed jets. Another advantage of this technique is that it also reduces the impact of event pileup at large luminosities by discarding contributions from charged particles associated with other than the primary and secondary vertices of the most energetic pp interaction, defined by the largest value of the sum of $\sum p_T^2$ over all the associated tracks. Effects from pileup, including that of energy deposition from neutral hadrons, are reduced further by using the FASTJET pileup subtraction procedure [22, 23]. To minimise contamination from jet candidates generated through electronics noise or from electrons reconstructed as jets, evidence must be present of energy deposition in the calorimeter that can be attributed to charged hadrons originating from the jet, and no more than 99% of the jet energy can be attributed to a combination of photons, electrons, and neutral hadrons.

Since this analysis focuses on purely hadronic decays of the $t\bar{t}$ system, with each top quark producing a minimum of three jets ($t \rightarrow bW \rightarrow b\bar{q}q'$) in the final state, candidate events are required to have at least four jets with $p_T > 60 \text{ GeV}/c$, a fifth jet with $p_T > 50 \text{ GeV}/c$, and a sixth jet with $p_T > 40 \text{ GeV}/c$. All jets must be observed within $|\eta| < 2.4$, which corresponds to a fiducial region in the inner tracker acceptance. Additional jets are considered for use in the kinematic fit described later (section 4.1) if they have $p_T > 30 \text{ GeV}/c$ and $|\eta| < 2.4$.

Jets originating from bottom quarks are classified as b-tagged jets through an algorithm based on the reconstruction of secondary vertices [24]. Only secondary vertices with at

¹The PYTHIA6 Z2 tune is identical to the Z1 tune described in [30] except that Z2 uses the CTEQ6L1 parton distribution functions while Z1 uses CTEQ5L.

least three tracks are considered for designation as b jets. A discriminant d_B reflects the significance of the decay length (the distance between the primary and secondary vertices) in each event. A restrictive working point chosen for this algorithm, with discriminant value of $d_B > 2.0$, provides an efficiency of $47 \pm 1\%$ for tagging b quarks (as determined from data), and a ‘mistag’ rate of $0.12 \pm 0.01\%$ for misidentifying all lighter (up, down, and strange) quarks and gluons, as b jets. The misidentification rate for charm-quark induced jets is higher than for jets induced by lighter quarks or gluons, and treated separately in the evaluation of systematic uncertainty in the tagging of b jets, with at least two b-tagged jets required in each event.

4.1 Kinematic fit

For the final selection of candidate $t\bar{t}$ events, a kinematic least-squares (χ^2) fit [25, 26] is performed to the $t\bar{t}$ hypothesis. It exploits the characteristic topology of top-quark events, i.e. the presence of two W bosons that are each reconstructed from the untagged jets and constrained to their accepted mass of $80.4 \text{ GeV}/c^2$ [27], and two top quarks reconstructed from the W bosons and the b-tagged jets. The masses (m_t) of the two top quarks are assumed to be equal, but are not fixed to a specific value so as to use the m_t distribution to extract an unbiased $t\bar{t}$ signal, as discussed in section 5.

To find the most likely combination of six jets, their four-momenta are fitted to the $t\bar{t}$ final state for each experimentally distinguishable permutation, using all jets in each event that pass the above selection criteria. All b-tagged jets are taken as bottom-quark candidates, and the remaining jets as light-quark candidates. At least two b-tagged and four untagged jets are needed for the fit. For events containing just six jets, two of which are b-tagged, there are six distinguishable jet combinations. When there are more than six jets present in an event, all possible combinations are considered in the kinematic fitting procedure. If the fit converges for more than one of the possible jet permutations, the one with smallest χ^2 is chosen to represent that event. After the kinematic fit, all events with a fit probability of $P(\chi^2) > 0.09$ are accepted for further consideration. This cutoff is chosen as it is found to give the smallest combined systematic and statistical uncertainty in simulation.

The kinematic fit to the $t\bar{t}$ hypothesis assumes Gaussian resolutions for jet energies, pseudorapidities, and azimuthal angles, that are determined separately for jets originating from light and bottom quarks in MC simulated $t\bar{t}$ events. The resolutions depend on jet energy and pseudorapidity, and are corrected for any differences observed between the data and MC simulation [28].

The number of events remaining in the data after each consecutive selection, and the expected fraction of $t\bar{t}$ signal, for a $t\bar{t}$ production cross section of 163 pb [29], are given in table 1.

5 Extraction of $t\bar{t}$ signal

The number of $t\bar{t}$ events remaining after final selections is determined through an unbinned maximum likelihood fit of contributions from $t\bar{t}$ signal and MJ background (obtained from

Selection	Events	Fraction of $t\bar{t}$
At least 6 jets	786 741	0.02
At least two b-tags	21 783	0.18
Kinematic fit	3 136	0.41

Table 1. Number of events and the expected fraction of $t\bar{t}$ events in the data for $\sigma_{t\bar{t}} = 163$ pb, following each consecutive selection. The expected $t\bar{t}$ fractions are taken from simulation.

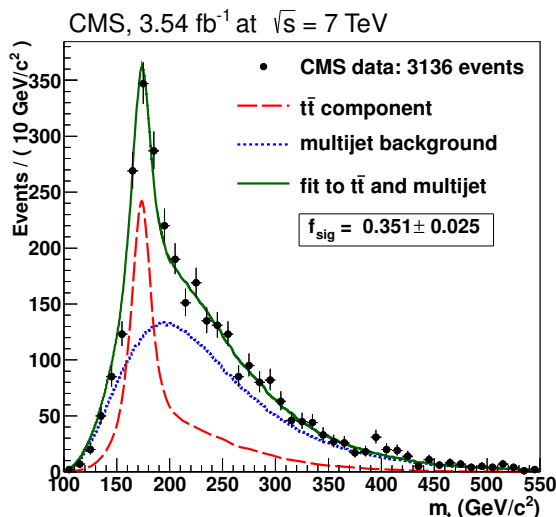


Figure 1. Results of a fit of contributions from a MC $t\bar{t}$ component (dashed line) and MJ background estimated from data (dotted line) to the distribution of the reconstructed top-quark mass in the data. The uncertainty in the signal fraction represents just the statistical uncertainty obtained from the fit.

the MC $t\bar{t}$ simulation and the multijet data as described in section 5.1, respectively) to the distribution in reconstructed m_t obtained from the kinematic fits. The result, shown in figure 1, corresponds to a signal fraction (f_{sig}) of 0.351 ± 0.025 , where the uncertainty is purely statistical. Section 6 provides a discussion of the systematic uncertainties on the MJ background.

5.1 Estimate of background from multijet events

The background from multijet production is estimated from data containing ≥ 6 jets using the same criteria as detailed in section 4 except for the b-tagging requirement (786 741 events, as indicated in table 1). However, as properties of b-tagged and untagged jets differ, those events in this sample that do not have b-tagged jets are weighted to reproduce the distributions appropriate for b-tagged jets from MJ background in the b-tagged $t\bar{t}$ -candidate data sample. This is done through the jet-tag-rate ratio:

$$\mathcal{R}(p_T, |\eta|) = \frac{N(p_T, |\eta|, d_B > 2)}{N(p_T, |\eta|, d_B < 2)}, \tag{5.1}$$

which indicates the relative dependence on jet p_T and jet $|\eta|$ of b-tagged jets and untagged jets in ≥ 6 -jet MJ events. The numerator reflects the number of b-tagged jets in the MJ data, and the denominator is the number of untagged jets in the same MJ data. The jet-tag-rate ratio \mathcal{R} is not corrected for contamination of the MJ sample by $t\bar{t}$ events, as the effect on the signal fraction is below the percent level.

The kinematic fit to the $t\bar{t}$ hypothesis is then implemented in the ≥ 6 -jet MJ events that do not have b-tagged jets, assuming each jet to be a candidate for a b quark, and an event weight is calculated for each fitted permutation of jets with $P(\chi^2) > 0.09$:

$$w = \mathcal{R}(p_T^b, |\eta^b|) \times \mathcal{R}(p_T^{\bar{b}}, |\eta^{\bar{b}}|) \tag{5.2}$$

for the two jets assigned as b and \bar{b} quarks in the kinematic fit. This method yields a total of 1 276 204 combinations, which after the weighting with w , provides an estimate of the background from MJ events that contain two jets that pass the b-tagging requirement for selection as $t\bar{t}$ candidates. This is the distribution for the MJ background shown in figure 1. The correction to the distribution due to the application of event weights is typically smaller than the systematic uncertainty assigned to it (see section 6).

As the above method is based on properties of single jets, it does not account for any correlations in the background from gluons splitting into b and \bar{b} quarks. Nevertheless, it appears that these correlations may be negligible as, after subtracting the $t\bar{t}$ component from the $t\bar{t}$ candidate sample, there are no significant correlations observed between the fitted top-quark mass for the remaining reconstructed events and the weighted kinematic distributions for the bottom quarks.

The method is checked by extracting the dependence of $\mathcal{R}(p_T, |\eta|)$ in MC-generated multijet events. Proceeding as before, new weights are applied to simulated events that contain ≥ 6 jets, but no b-tagged jets. A comparison of the distributions for m_t reconstructed in kinematic fits of such MC-weighted events with results of kinematic fits to MJ MC events that pass $t\bar{t}$ selections is given in figure 2(left). The two distributions are in agreement, thereby confirming the consistency of the method chosen to estimate multijet background in $t\bar{t}$ candidate events.

6 Systematic uncertainties

To determine the systematic uncertainties in the measured cross section, modified samples of simulated events are reanalysed to gauge the impact of changes in the modified parameters. Using MC pseudo-experiments based on the fitted fractions of $t\bar{t}$ signal and background, we determine the impact on $\sigma_{t\bar{t}}$ of a change in the value of each parameter (e.g. efficiency, signal fraction, or scale of QCD) as described below.

Jet energy scale. The uncertainty from ambiguities in jet energy scale is assessed by shifting the jet energy by ± 1 standard deviation (SD) relative to the nominal value, as a function of jet p_T and η . The method is described in ref. [28], and is applied with updated values appropriate for these data. The uncertainties in jet energy scale per jet range from 2.0% to 3.4%.

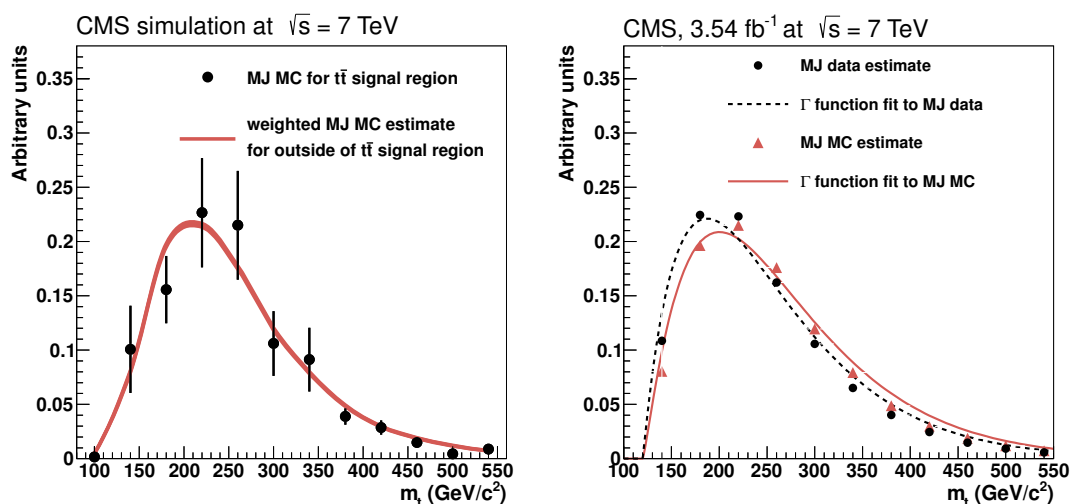


Figure 2. (Left) Comparison of the distribution in reconstructed m_t for MJ MC events that pass selections for $t\bar{t}$ candidates (black circles) to weighted events that fail $t\bar{t}$ selections (thick line). The width of the (narrow) band indicates the 68% CL of statistical uncertainty. (Right) Comparison of the distributions in m_t for MJ background estimated from the data and from the simulation, with Γ functions fitted to each set of points.

Background contribution. The systematic uncertainty associated with the normalisation of the background is well within the statistical uncertainty of the fit in figure 1. The uncertainty from the distribution of the background as a function of m_t is determined using a Γ function fitted to the background distribution estimated from the MJ data. The parameters of the Γ function are changed by half of the difference in the fitted parameters of the Γ functions for the background estimates obtained from the MJ data and that from the MC simulation, both shown in figure 2(right).

Tagging of b jets. To evaluate the impact of the uncertainty in b tagging on the efficiency of the event selection, the b-tagging efficiency and mistag rate are changed by ± 1 SD, corresponding to changes of $\approx 2\%$ and $\approx 9\%$ in their values respectively [24]. When propagated to $\sigma_{t\bar{t}}$, they change the cross section by $\pm 6\%$ (cf. table 2).

Renormalisation and factorisation scale. To study the dependence of the analysis on the renormalisation and factorisation scales (μ) used in the $t\bar{t}$ MC simulation, the nominal common value $\mu = Q$ for the hard scattering ($Q^2 = m_t^2 + \sum p_T^2$, where the sum is over all additional final state partons) and for parton showering are simultaneously changed by a factor 0.5 and 2.0. This also reflects the uncertainty in the amount of initial and final-state radiation for changes in the strong coupling constant α_s in parton showering by a factor 0.5 and 2.0.

Tune for underlying event. The uncertainty in the modeling of the underlying event is based on a comparison of the two PYTHIA tunes Z2 and D6T [30], with Z2 as the

default tune for this measurement. The uncertainty is defined by half of the difference between the values obtained with these two tunes.

Trigger. The trigger efficiency of 96% observed in the data (section 3) is changed by -5% and $+4\%$. These standard deviations are determined by emulating the two triggers used in the subsequent data-taking periods. The energy of the jets reconstructed at the trigger level is also changed by ± 1 SD, which reflects the absolute uncertainty in the jet energy scale for calorimeter jets [28], and provides the ± 1 SD limits of uncertainty for trigger efficiencies. Using this procedure, the uncertainties in trigger efficiency are determined in both data and simulation, and are propagated to $\sigma_{t\bar{t}}$.

Jet energy resolution. The jet energy resolution in simulated events is changed by $\pm 10\%$ for $|\eta| < 1.5$, $\pm 15\%$ for $1.5 < |\eta| < 2.0$, and $\pm 20\%$ for $|\eta| > 2.0$. The uncertainty is defined by the difference in $\sigma_{t\bar{t}}$ for the ± 1 SD excursions in resolution relative to the nominal values [28].

Matching of parton showers to matrix elements. The threshold of the matching scale used for interfacing the matrix elements generated with MADGRAPH and PYTHIA parton showering in simulating $t\bar{t}$ events is changed from the default value of 20 GeV to 10 GeV and to 40 GeV, and propagated to $\sigma_{t\bar{t}}$.

Mass of the top quark. The influence of the value of m_t is estimated by shifting m_t in the $t\bar{t}$ simulation from the nominal $172.5 \text{ GeV}/c^2$ by $\pm 0.9 \text{ GeV}/c^2$, the uncertainty in the currently accepted value of m_t [31].

Pileup. The effect of pileup from simultaneous pp interactions is evaluated by superimposing additional minimum-bias events on the simulated signal (on average, ≈ 8 observed in the data). To account for uncertainties associated with the measured total inelastic pp cross section, the mean number of observed interactions, and the weighting procedure, the average number of additional pileup events is changed by $\pm 8\%$, and the impact of the changes extrapolated to $\sigma_{t\bar{t}}$.

Luminosity. The total integrated luminosity is determined with a precision of $\pm 2.2\%$ [32].

An overview of the different uncertainties contributing to $\sigma_{t\bar{t}}$ is given in table 2. All uncertainties are reasonably symmetric around the mean value of $\sigma_{t\bar{t}}$. They are therefore averaged and presented as symmetrical excursions about the extracted value of $\sigma_{t\bar{t}}$. The total uncertainty is obtained by summing the individual uncertainties in quadrature.

7 Results

The $t\bar{t}$ production cross section, as measured in the all-jet final state, is given by:

$$\sigma_{t\bar{t}} = \frac{f_{\text{sig}} \cdot N}{\epsilon \cdot L_{\text{int}}}, \tag{7.1}$$

where f_{sig} is estimated from the fit in figure 1. The total number of candidate events is $N = 3136$, as given in table 1. The efficiency for selecting $t\bar{t}$ events as determined

Source	Relative uncertainty (%)
Jet energy scale	10.1
Background contribution	9.0
Tagging of b jets	6.0
Renormalisation and factorisation scale	5.8
Tune for underlying event	5.5
Trigger	5.0
Jet energy resolution	4.0
Matching of parton showers to matrix elements	4.0
Mass of the top quark	2.1
Pileup	0.8
Total systematic	18.6
Total statistical	7.0
Luminosity	2.2
Total uncertainty	20.0

Table 2. List of all non-negligible uncertainties contributing to the measurement of $\sigma_{t\bar{t}}$.

from simulation is $\epsilon = 0.22\%$ and refers to all possible $t\bar{t}$ final states. The latter, which is small mainly due to the restrictive jet- p_T selection criteria, includes correction factors for b-tagging efficiency, mistag rate, and trigger efficiency, all obtained from data. The integrated luminosity of the data sample is $L_{\text{int}} = 3.54 \text{ fb}^{-1}$. These values yield a $t\bar{t}$ production cross section for an assumed top-quark mass of $m_t = 172.5 \text{ GeV}/c^2$ of:

$$\sigma_{t\bar{t}} = 139 \pm 10 \text{ (stat.)} \pm 26 \text{ (syst.)} \pm 3 \text{ (lum.) pb}, \tag{7.2}$$

which corresponds to a total uncertainty of $\pm 20\%$, with the individual contributions listed in table 2.

8 Alternative analysis using a neural-network-based selection

A separate measurement of $\sigma_{t\bar{t}}$ is also performed as a cross-check. The kinematic properties of signal and background events are used to develop selection criteria based on a neural-network (NN) procedure, which is expected to be less sensitive to the jet energy scale (JES). In addition, the MJ background is estimated using a model that takes account of correlations between jets that pass b-tagging criteria.

The NN is trained on a set of simulated $t\bar{t}$ events with jet multiplicities of $6 \leq N_{\text{jet}} \leq 8$ (using the same criteria of section 4) and an equal number of MJ events of same range in jet multiplicity that have a greatly reduced $t\bar{t}$ component relative to background. Six variables are used to train the neural network. One, called centrality, is defined as the ratio of the scalar sum of the transverse energies ($E_T = E \sin \theta$) of the jets to the invariant mass of the multijet system (MJS). Another variable is the aplanarity, defined as $\frac{3}{2} \mathcal{Q}_1$, where \mathcal{Q}_1 is the smallest of the three normalised eigenvalues of the sphericity tensor $M_{ab} = \sum_j p_j^a p_j^b$, calculated in the centre-of-mass of the MJS, where a and b reflect the three spatial

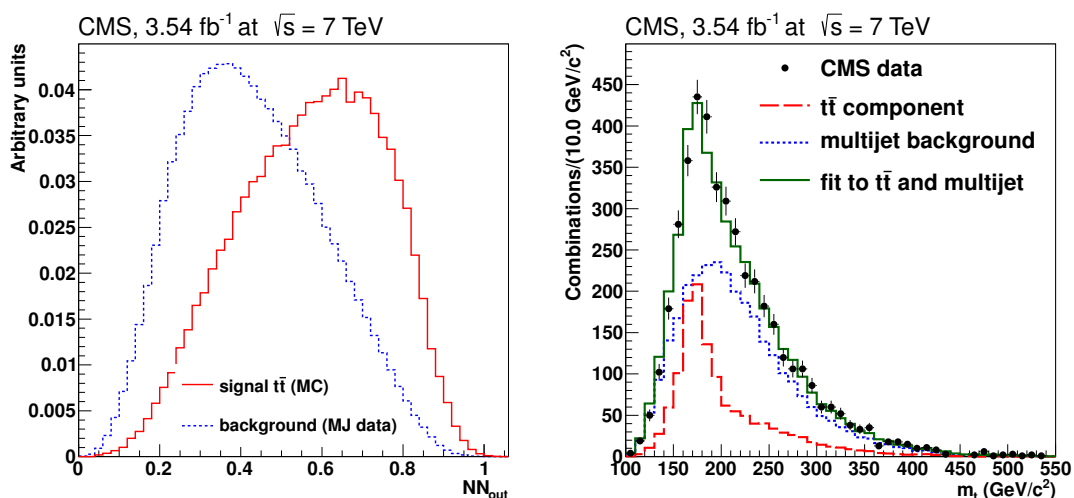


Figure 3. (Left) Neural network output for the $t\bar{t}$ MC and multijet background components shown normalised to unity. (Right) Result of a fit of contributions from a MC $t\bar{t}$ component (dashed line) and MJ background estimated from data (dotted line) to the distribution of the reconstructed top-quark mass in the data.

components of the momentum of each jet p_j . The remaining variables are defined by the ratio of E_T values of the two jets of largest E_T to the scalar sum of the transverse energies of all jets, the transverse energies of these jets multiplied by $\sin^2 \theta^*$ (θ^* being the angle between the jet and the beam axis in the centre-of-mass of the MJS), and the average of the scalar quantity $E_T \sin^2 \theta^*$ for the remaining jets. The output of the neural network (NN_{out}), shown in figure 3(left), is used to enhance the $t\bar{t}$ signal purity by requiring $NN_{out} > 0.65$. To compensate for this restrictive selection, a more efficient b-tagging algorithm is used [24] in this analysis, requiring the b-jet discriminant d'_B for the track in the jet with an impact parameter of next-to-highest significance to be $d'_B > 3.3$, which improves by about 30% the b-tagging efficiency. Candidate events are required to have at least two such b-tagged jets.

The multijet background estimate is obtained from the data, inferring it from a sample of events with just five jets. The probability of any two jets in the background sample to pass the b-tag condition for the $t\bar{t}$ candidate selection is defined relative to pairs of jets that both pass a looser b-tag requirement ($d'_B > 1.7$). This probability is defined by the ratio

$$\mathcal{R}_{LL}^{MM}(\langle p_T \rangle, \langle |\eta| \rangle, \Delta R) = \frac{N(\langle p_T \rangle, \langle |\eta| \rangle, \Delta R, d'_B > 3.3)}{N(\langle p_T \rangle, \langle |\eta| \rangle, \Delta R, d'_B > 1.7)}, \quad (8.1)$$

parameterised in terms of the average transverse momentum $\langle p_T \rangle$ of the two jets, the average of the absolute values of the two pseudorapidities $\langle |\eta| \rangle$, and the $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ separation between the two jets. The expected background from pairs of b-tagged jets is obtained by weighting each pair of less restrictive b-tags with the corresponding \mathcal{R}_{LL}^{MM} .

The top-quark mass is reconstructed from a kinematic fit, with minor modifications with respect to the one described in section 4.1. All permutations where two b-tagged jets are associated to the b quarks are considered. To increase $t\bar{t}$ purity and reduce false

permutations, a cut is made on the quality of the fit and on the separation between the two b-tagged jets, $\Delta R > 1.5$. Following event selection, 3571 events remain in the sample, corresponding to 4329 fitted m_t values. The expectation for m_t in $t\bar{t}$ events is acquired directly from simulation, while the MJ background is obtained from data, as described above, but correcting for the presence of $t\bar{t}$ events in the background sample. Finally, the cross section is extracted from a binned maximum likelihood fit of these two contributions to the data, see figure 3(right). The measured cross section is $\sigma_{t\bar{t}} = 114 \pm 15$ (stat.) ± 27 (syst.) ± 3 (lum.) pb, with a signal fraction of $30 \pm 4\%$.

The obtained value for the cross section is well within 2SD of that measured in the main analysis. Considering the difference in event selections, the two measurements can be regarded as compatible. However, the results are also partly independent, which implies that they could be combined to improve the uncertainty on the cross section. For instance, the uncertainty associated with JES is about 40% smaller for the alternative method. However, the statistical uncertainty on the second result is larger, which reflects the fact that this analysis has more background and less difference in the distributions of m_t for signal and background events. Because of that poorer statistical significance, the second result is not combined with that from the main analysis.

9 Summary

Assuming a top-quark mass of $172.5 \text{ GeV}/c^2$, a first measurement of the $t\bar{t}$ production cross section in the all-jet channel at $\sqrt{s} = 7 \text{ TeV}$ yields $\sigma_{t\bar{t}} = 139 \pm 10$ (stat.) ± 26 (syst.) ± 3 (lum.) pb.

This result is consistent within 2SD of an alternative analysis using a neural-network-based selection, and with previous CMS measurements in dilepton and lepton+jets final states, as well as with the predictions of the standard model. The most precise single CMS measurement is currently in the dilepton channel and provides $\sigma_{t\bar{t}} = 161.9 \pm 2.5$ (stat.) $^{+5.1}_{-5.0}$ (syst.) ± 3.6 (lum.) pb [12]. Two predictions of the SM based on approximate next-to-next-to-leading-order calculations yield $\sigma_{t\bar{t}} = 164^{+10}_{-13}$ pb [33] and $\sigma_{t\bar{t}} = 163^{+11}_{-10}$ pb [29].

This measurement complements the set of CMS measurements of $t\bar{t}$ production at the LHC.

Acknowledgments

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centres and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP

(Brazil); MEYS (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); MoER, SF0690030s09 and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MSI (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MON, RosAtom, RAS and RFBR (Russia); MSTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); ThEP, IPST and NECTEC (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (U.S.A.). 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 Ministry of Education, Youth and Sports (MEYS) of Czech Republic; the Council of Science and Industrial Research, India; the Compagnia di San Paolo (Torino); and the HOMING PLUS programme of Foundation for Polish Science, cofinanced from European Union, Regional Development Fund.

Open Access. This article is distributed under the terms of the Creative Commons Attribution License which permits any use, distribution and reproduction in any medium, provided the original author(s) and source are credited.

References

- [1] CMS collaboration, *First measurement of the cross section for top-quark pair production in proton-proton collisions at $\sqrt{s} = 7$ TeV*, *Phys. Lett. B* **695** (2011) 424 [[arXiv:1010.5994](#)] [[INSPIRE](#)].
- [2] ATLAS collaboration, *Measurement of the top quark-pair production cross section with ATLAS in pp collisions at $\sqrt{s} = 7$ TeV*, *Eur. Phys. J. C* **71** (2011) 1577 [[arXiv:1012.1792](#)] [[INSPIRE](#)].
- [3] CMS collaboration, *Measurement of the $t\bar{t}$ production cross section and the top quark mass in the dilepton channel in pp collisions at $\sqrt{s} = 7$ TeV*, *JHEP* **07** (2011) 049 [[arXiv:1105.5661](#)] [[INSPIRE](#)].
- [4] ATLAS collaboration, *Measurement of the top quark pair production cross section in pp collisions at $\sqrt{s} = 7$ TeV in dilepton final states with ATLAS*, *Phys. Lett. B* **707** (2012) 459 [[arXiv:1108.3699](#)] [[INSPIRE](#)].
- [5] CMS collaboration, *Measurement of the $t\bar{t}$ production cross section in pp collisions at 7 TeV in lepton + jets events using b-quark jet identification*, *Phys. Rev. D* **84** (2011) 092004 [[arXiv:1108.3773](#)] [[INSPIRE](#)].
- [6] ATLAS collaboration, *Measurement of the top quark pair production cross-section with ATLAS in the single lepton channel*, *Phys. Lett. B* **711** (2012) 244 [[arXiv:1201.1889](#)] [[INSPIRE](#)].

- [7] CMS collaboration, *Measurement of the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s} = 7$ TeV using the kinematic properties of events with leptons and jets*, *Eur. Phys. J. C* **71** (2011) 1721 [[arXiv:1106.0902](#)] [[INSPIRE](#)].
- [8] ATLAS collaboration, *Measurement of the $t\bar{t}$ production cross section in the tau+jets channel using the ATLAS detector*, *Eur. Phys. J. C* **73** (2013) 2328 [[arXiv:1211.7205](#)] [[INSPIRE](#)].
- [9] CMS collaboration, *Measurement of the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s} = 7$ TeV in dilepton final states containing a τ* , *Phys. Rev. D* **85** (2012) 112007 [[arXiv:1203.6810](#)] [[INSPIRE](#)].
- [10] ATLAS collaboration, *Measurement of the top quark pair cross section with ATLAS in pp collisions at $\sqrt{s} = 7$ TeV using final states with an electron or a muon and a hadronically decaying τ lepton*, *Phys. Lett. B* **717** (2012) 89 [[arXiv:1205.2067](#)] [[INSPIRE](#)].
- [11] ATLAS collaboration, *Measurement of the cross section for top-quark pair production in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector using final states with two high- p_T leptons*, *JHEP* **05** (2012) 059 [[arXiv:1202.4892](#)] [[INSPIRE](#)].
- [12] CMS collaboration, *Measurement of the $t\bar{t}$ production cross section in the dilepton channel in pp collisions at $\sqrt{s} = 7$ TeV*, *JHEP* **11** (2012) 067 [[arXiv:1208.2671](#)] [[INSPIRE](#)].
- [13] CMS collaboration, *Measurement of the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s} = 7$ TeV with lepton + jets final states*, *Phys. Lett. B* **720** (2013) 83 [[arXiv:1212.6682](#)] [[INSPIRE](#)].
- [14] CMS collaboration, *The CMS experiment at the CERN LHC*, *JINST* **3** (2008) S08004 [[INSPIRE](#)].
- [15] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer and T. Stelzer, *MadGraph 5: going beyond*, *JHEP* **06** (2011) 128 [[arXiv:1106.0522](#)] [[INSPIRE](#)].
- [16] T. Sjöstrand, S. Mrenna and P.Z. Skands, *PYTHIA 6.4 physics and manual*, *JHEP* **05** (2006) 026 [[hep-ph/0603175](#)] [[INSPIRE](#)].
- [17] 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](#)].
- [18] CMS collaboration, *Particle-flow event reconstruction in CMS and performance for jets, taus and MET*, *CMS-PAS-PFT-09-001* (2009).
- [19] CMS collaboration, *Commissioning of the particle-flow reconstruction in minimum-bias and jet events from pp collisions at 7 TeV*, *CMS-PAS-PFT-10-002* (2010).
- [20] M. Cacciari, G.P. Salam and G. Soyez, *The anti- k_t jet clustering algorithm*, *JHEP* **04** (2008) 063 [[arXiv:0802.1189](#)] [[INSPIRE](#)].
- [21] 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](#)].
- [22] M. Cacciari and G.P. Salam, *Pileup subtraction using jet areas*, *Phys. Lett. B* **659** (2008) 119 [[arXiv:0707.1378](#)] [[INSPIRE](#)].
- [23] M. Cacciari, G.P. Salam and G. Soyez, *The catchment area of jets*, *JHEP* **04** (2008) 005 [[arXiv:0802.1188](#)] [[INSPIRE](#)].

- [24] CMS collaboration, *Identification of b-quark jets with the CMS experiment*, *JINST* **8** (2013) P04013 [[arXiv:1211.4462](#)] [[INSPIRE](#)].
- [25] V. Blobel and E. Lohrmann, *Statistische und numerische Methoden der Datenanalyse*, Teubner Studienbücher, B.G. Teubner (1998).
- [26] J. D'Hondt et al., *Fitting of event topologies with external kinematic constraints in CMS*, *CMS-NOTE-2006-023* (2006).
- [27] PARTICLE DATA GROUP, J. Beringer et al., *Review of particle physics (RPP)*, *Phys. Rev. D* **86** (2012) 010001 [[INSPIRE](#)].
- [28] CMS collaboration, *Determination of jet energy calibration and transverse momentum resolution in CMS*, *JINST* **6** (2011) P11002 [[arXiv:1107.4277](#)] [[INSPIRE](#)].
- [29] N. Kidonakis, *Next-to-next-to-leading soft-gluon corrections for the top quark cross section and transverse momentum distribution*, *Phys. Rev. D* **82** (2010) 114030 [[arXiv:1009.4935](#)] [[INSPIRE](#)].
- [30] R. Field, *Early LHC underlying event data - Findings and surprises*, [arXiv:1010.3558](#) [[INSPIRE](#)].
- [31] CDF and D0 collaborations, *Combination of the top-quark mass measurements from the Tevatron collider*, *Phys. Rev. D* **86** (2012) 092003 [[arXiv:1207.1069](#)] [[INSPIRE](#)].
- [32] CMS collaboration, *Absolute calibration of the luminosity measurement at CMS: winter 2012 update*, *CMS-PAS-SMP-12-008* (2012).
- [33] M. Aliev, H. Lacker, U. Langenfeld, S. Moch, P. Uwer et al., *HATHOR: hadronic top and heavy quarks cross section calculator*, *Comput. Phys. Commun.* **182** (2011) 1034 [[arXiv:1007.1327](#)] [[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, E. Aguilo, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan¹, M. Friedl, R. Frühwirth¹, V.M. Ghete, J. Hammer, N. Hörmann, J. Hrubec, M. Jeitler¹, W. Kiesenhofer, V. Knünz, M. Krammer¹, I. Krätschmer, D. Liko, I. Mikulec, M. Pernicka[†], B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Waltenberger, G. Walzel, E. Widl, C.-E. Wulz¹

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

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

Universiteit Antwerpen, Antwerpen, Belgium

M. Bansal, S. Bansal, T. Cornelis, E.A. De Wolf, X. Janssen, S. Luyckx, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, Z. Staykova, H. Van Haeveermaet, 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. Vilella

Université Libre de Bruxelles, Bruxelles, Belgium

B. Clerbaux, G. De Lentdecker, V. Dero, A.P.R. Gay, T. Hreus, A. Léonard, P.E. Marage, A. Mohammadi, T. Reis, L. Thomas, G. Vander Marcken, C. Vander Velde, P. Vanlaer, J. Wang

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, P. Verwilligen, S. Walsh, E. Yazgan, N. Zaganidis

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

S. Basegmez, G. Bruno, R. Castello, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco², J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrkowski, N. Schul, J.M. Vizan Garcia

Université de Mons, Mons, Belgium

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

Centro Brasileiro de Pesquisas Físicas, 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, L. Soares Jorge, A. Sznajder

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

T.S. Anjos^b, C.A. Bernardes^b, F.A. Dias^{a,3}, T.R. Fernandez Perez Tomei^a, E.M. Gregores^b, C. Lagana^a, F. Marinho^a, P.G. Mercadante^b, S.F. Novaes^a, Sandra S. Padula^a

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

V. Genchev⁴, P. Iaydjiev⁴, S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, M. Vutova

University of Sofia, Sofia, Bulgaria

A. Dimitrov, R. Hadjiiska, 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, X. Wang, Z. Wang, H. Xiao, M. Xu, J. Zang, Z. Zhang

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

C. Asawatrangkuldee, Y. Ban, Y. Guo, Q. Li, W. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, L. Zhang, W. Zou

Universidad de Los Andes, Bogota, Colombia

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

Technical University of Split, Split, Croatia

N. Godinovic, D. Lelas, R. Plestina⁵, D. Polic, I. Puljak⁴

University of Split, Split, Croatia

Z. Antunovic, 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. Assran⁶, S. Elgammal⁷, A. Ellithi Kamel⁸, M.A. Mahmoud⁹, A. Radi^{10,11}

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

P. Eerola, G. Fedi, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

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. Karjalainen, A. Korpela, T. Tuuva

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, A. Nayak, 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. Bluj¹², C. Broutin, P. Busson, C. Charlot, N. Daci, T. Dahms, L. Dobrzynski, R. Granier de Cassagnac, M. Haguenaer, P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, 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. Agram¹³, J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte¹³, F. Drouhin¹³, C. Ferro, J.-C. Fontaine¹³, D. Gelé, U. Goerlach, P. Juillot, A.-C. Le Bihan, P. Van Hove

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/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

S. Beauceron, N. Beaupere, O. Bondu, G. Boudoul, J. Chasserat, R. Chierici⁴, D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, L. Sgandurra, V. Sordini, Y. Tschudi, P. Verdier, S. Viret

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

Z. Tsamalaidze¹⁴

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

G. Anagnostou, C. Autermann, 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. Zhukov¹⁵

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, D. Klingebiel, P. Kreuzer, M. Merschmeyer, A. Meyer, M. Olschewski, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teysier, M. Weber

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

M. Bontenackels, V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, J. Lingemann⁴, A. Nowack, L. Perchalla, O. Pooth, P. Sauerland, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz¹⁶, A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, E. Castro, F. Costanza, D. Dammann, C. Diez Pardos, G. Eckerlin, D. Eckstein, G. Flucke, A. Geiser, I. Glushkov, P. Gunnellini, S. Habib, J. Hauk, G. Hellwig, H. Jung, M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann¹⁶, B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, O. Novgorodova, J. Olzem, H. Perrey, A. Petrukhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M. Rosin, J. Salfeld-Nebgen, R. Schmidt¹⁶, T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

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

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, J. Berger, C. Böser, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff⁴, C. Hackstein, F. Hartmann, T. Hauth⁴, M. Heinrich, H. Held, K.H. Hoffmann, U. Husemann, I. Katkov¹⁵, J.R. Komaragiri, P. Lobelle Pardo, D. Martschei, S. Mueller, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, A. Oehler, J. Ott, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, S. Röcker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, M. Zeise

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, P. Kokkas, N. Manthos, I. Papadopoulos, V. Patras

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

G. Bencze, C. Hajdu, P. Hidas, D. Horvath¹⁷, F. Sikler, V. Veszpremi, G. Vesztergombi¹⁸

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

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

University of Debrecen, Debrecen, Hungary

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

Panjab University, Chandigarh, India

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

University of Delhi, Delhi, India

Ashok Kumar, Arun Kumar, S. Ahuja, A. Bhardwaj, 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, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India

A. Abdulsalam, R.K. Choudhury, D. Dutta, S. Kailas, V. Kumar, P. Mehta, A.K. Mohanty⁴, L.M. Pant, P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India

T. Aziz, S. Ganguly, M. Guchait¹⁹, M. Maity²⁰, 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. Arfaei²¹, H. Bakhshiansohi, S.M. Etesami²², A. Fahim²¹, M. Hashemi, H. Hesari, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh²³, M. Zeinali

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

M. Abbrescia^{a,b}, L. Barbone^{a,b}, C. Calabria^{a,b,4}, S.S. Chhibra^{a,b}, A. Colaleo^a, D. Creanza^{a,c}, N. De Filippis^{a,c,4}, 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^{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,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,4}, P. Giacomelli^a, C. Grandi^a, L. Guiducci^{a,b}, S. Marcellini^a, G. Masetti^a, M. Meneghelli^{a,b,4}, 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.P. 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. Gozzi^{a,b}, M. Meschini^a, S. Paoletti^a, G. Sguazzoni^a, A. Tropiano^a

INFN Laboratori Nazionali di Frascati, Frascati, ItalyL. Benussi, S. Bianco, S. Colafranceschi²⁴, F. Fabbri, D. Piccolo**INFN Sezione di Genova^a, Università di Genova^b, Genova, Italy**P. Fabbricatore^a, R. Musenich^a, S. Tosi^{a,b}**INFN Sezione di Milano-Bicocca^a, Università di Milano-Bicocca^b, Milano, Italy**A. Benaglia^{a,b}, F. De Guio^{a,b}, L. Di Matteo^{a,b,4}, S. Fiorendi^{a,b}, S. Gennai^{a,4}, A. Ghezzi^{a,b}, S. Malvezzi^a, R.A. Manzoni^{a,b}, A. Martelli^{a,b}, A. Massironi^{a,b,4}, 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, Università della Basilicata (Potenza)^c, Università G. Marconi (Roma)^d, Napoli, Italy**S. Buontempo^a, C.A. Carrillo Montoya^a, N. Cavallo^{a,c}, A. De Cosa^{a,b,4}, O. Dogangun^{a,b}, F. Fabozzi^{a,c}, A.O.M. Iorio^{a,b}, L. Lista^a, S. Meola^{a,d,25}, M. Merola^a, P. Paolucci^{a,4}**INFN Sezione di Padova^a, Università di Padova^b, Università di Trento (Trento)^c, Padova, Italy**P. Azzi^a, N. Bacchetta^{a,4}, D. Bisello^{a,b}, A. Branca^{a,b,4}, R. Carlin^{a,b}, P. Checchia^a, T. Dorigo^a, U. Dosselli^a, F. Gasparini^{a,b}, U. Gasparini^{a,b}, A. Gozzelino^a, K. Kanishchev^{a,c}, S. Lacaprara^a, I. Lazzizzera^{a,c}, M. Margoni^{a,b}, A.T. Meneguzzo^{a,b}, J. Pazzini^{a,b}, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{a,b,4}, S. Vanini^{a,b}, P. Zotto^{a,b}, 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**M. Biasini^{a,b}, G.M. Bilei^a, L. Fanò^{a,b}, P. Lariccia^{a,b}, G. Mantovani^{a,b}, M. Menichelli^a, A. Nappi^{a,b†}, F. Romeo^{a,b}, A. Saha^a, A. Santocchia^{a,b}, A. Spiezia^{a,b}, S. Taroni^{a,b}**INFN Sezione di Pisa^a, Università di Pisa^b, Scuola Normale Superiore di Pisa^c, Pisa, Italy**P. Azzurri^{a,c}, G. Bagliesi^a, J. Bernardini^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, R.T. D'Agnolo^{a,c,4}, R. Dell'Orso^a, F. Fiori^{a,b,4}, L. Foà^{a,c}, A. Giassi^a, A. Kraan^a, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,26}, A. Messineo^{a,b}, F. Palla^a, A. Rizzi^{a,b}, A.T. Serban^{a,27}, P. Spagnolo^a, P. Squillacioti^{a,4}, R. Tenchini^a, G. Tonelli^{a,b}, A. Venturi^a, P.G. Verdini^a

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

L. Barone^{a,b}, F. Cavallari^a, D. Del Re^{a,b}, M. Diemoz^a, C. Fanelli^{a,b}, M. Grassi^{a,b,4},
E. Longo^{a,b}, P. Meridiani^{a,4}, F. Micheli^{a,b}, S. Nourbakhsh^{a,b}, G. Organtini^{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, N. Cartiglia^a,
M. Costa^{a,b}, N. Demaria^a, C. Mariotti^{a,4}, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b},
M. Musich^{a,4}, 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}, 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, V. Candelise^{a,b}, M. Casarsa^a, F. Cossutti^a, G. Della Ricca^{a,b}, B. Gobbo^a,
M. Marone^{a,b,4}, D. Montanino^{a,b,4}, 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, D.H. Kim, G.N. 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

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

University of Seoul, Seoul, Korea

M. Choi, 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, E. Kwon, 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. Sanchez-Hernandez, 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 Ibarquen

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

National Centre for Nuclear Research, Swierk, Poland

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

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

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

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

N. Almeida, P. Bargassa, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, 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, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

P.N. Lebedev Physical Institute, Moscow, Russia

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

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

A. Belyaev, E. Boos, V. Bunichev, M. Dubinin³, L. Dudko, A. Ershov, V. Klyukhin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushanko, A. Popov, L. Sarycheva[†], V. Savrin, A. Snigirev

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

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin⁴, V. Kachanov, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

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

P. Adzic²⁸, M. Djordjevic, M. Ekmedzic, D. Krpic²⁸, 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, 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, A. Quintario Olmeda, 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

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez

**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. Felcini²⁹, M. Fernandez, G. Gomez, J. Gonzalez Sanchez, A. Graziano, C. Jorda, 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, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, J.F. Benitez, C. Bernet⁵, G. Bianchi, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, D. D'Enterria, A. Dabrowski, 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. Girone, 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, Y.-J. Lee, P. Lenzi, C. Lourenço, N. Magini, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, P. Musella, E. Nesvold, T. Orimoto, L. Orsini, E. Palencia Cortezon, E. Perez, L. Perrozzi, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, L. Quertenmont, A. Racz, W. Reece, J. Rodrigues Antunes, G. Rolandi³⁰, C. Rovelli³¹, M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas³², D. Spiga, A. Tsirou, G.I. Veres¹⁸, J.R. Vlimant, H.K. Wöhri, S.D. Worm³³, 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. Sibille³⁴

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, J. Eugster, K. Freudenreich, C. Grab, D. Hits, P. Lecomte, W. Lustermann, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli³⁵, P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov³⁶, 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

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, C.M. Kuo, S.W. Li, W. Lin, Z.K. Liu, Y.J. Lu, D. Mekterovic, A.P. Singh, 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, X. Wan, M. Wang

Chulalongkorn University, Bangkok, Thailand

B. Asavapibhop, N. Srimanobhas

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci³⁷, S. Cerci³⁸, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, T. Karaman, G. Karapinar³⁹, A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk⁴⁰, A. Polatoz, K. Sogut⁴¹, D. Sunar Cerci³⁸, B. Tali³⁸, H. Topakli³⁷, 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

E. Gülmez, B. Isildak⁴², M. Kaya⁴³, O. Kaya⁴³, S. Ozkorucuklu⁴⁴, N. Sonmez⁴⁵

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. Newbold³³, K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom

L. Basso⁴⁶, K.W. Bell, A. Belyaev⁴⁶, 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. Nikitenko³⁶, A. Papageorgiou, J. Pela, M. Pesaresi, K. Petridis, M. Pioppi⁴⁷, D.M. Raymond, S. Rogerson, A. Rose, M.J. Ryan, C. Seez, P. Sharp[†], A. Sparrow, M. Stoye, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

Brunel University, Uxbridge, United Kingdom

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, U.S.A.

K. Hatakeyama, H. Liu, T. Scarborough

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

O. Charaf, C. Henderson, P. Rumerio

Boston University, Boston, U.S.A.

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

Brown University, Providence, U.S.A.

J. Alimena, S. Bhattacharya, D. Cutts, A. Ferapontov, U. Heintz, S. Jabeen, G. Kukartsev, E. Laird, 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, M. Gardner, R. Houtz, W. Ko, A. Kopecky, R. Lander, O. Mall, T. Miceli, D. Pellett, F. Ricci-Tam, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra

University of California, Los Angeles, U.S.A.

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[†], P. Traczyk, V. Valuev, M. Weber

University of California, Riverside, Riverside, U.S.A.

J. Babb, R. Clare, M.E. Dinardo, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng⁴⁸, 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, S. Cittolin, D. Evans, F. Golf, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, S. Padhi, C. Palmer, G. Petrucciani, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech⁴⁹, 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, J. Incandela, C. Justus, P. Kalavase, S.A. Koay, D. Kovalskyi, V. Krutelyov, S. Lowette, N. Mccoll, V. Pavlunin, F. Rebassoo, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, 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, D. Kcira, Y. Ma, A. Mott, H.B. Newman, C. Rogan, M. Spiropulu, V. Timciuc, J. Veverka, R. Wilkinson, S. Xie, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, U.S.A.

B. Akgun, V. Azzolini, A. Calamba, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, Y.F. Liu, M. Paulini, H. Vogel, I. Vorobiev

University of Colorado at Boulder, Boulder, U.S.A.

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

Cornell University, Ithaca, U.S.A.

J. Alexander, A. Chatterjee, N. Eggert, L.K. Gibbons, B. Heltsley, 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. Tucker, J. Vaughan, Y. Weng, L. Winstrom, P. Wittich

Fairfield University, Fairfield, U.S.A.

D. Winn

Fermi National Accelerator Laboratory, Batavia, U.S.A.

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, 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, S. Cihangir, 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, C. Leonidopoulos, J. Linacre, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko⁵⁰, C. Newman-Holmes, V. O'Dell, E. Sexton-Kennedy,

S. Sharma, W.J. Spalding, L. Spiegel, 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, U.S.A.

D. Acosta, P. Avery, D. Bourilkov, M. Chen, T. Cheng, 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. Milenovic⁵¹, G. Mitselmakher, L. Muniz, M. Park, R. Remington, A. Rinkevicius, P. Sellers, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

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

V. Gaultney, S. Hewamanage, 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, V. Veeraraghavan, M. Weinberg

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

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

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, I. Bucinskaite, J. Callner, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, F. Lacroix, M. Malek, C. O'Brien, C. Silkworth, D. Strom, P. Turner, N. Varelas

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

U. Akgun, E.A. Albayrak, B. Bilki⁵², W. Clarida, F. Duru, J.-P. Merlo, H. Mermerkaya⁵³, A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, Y. Onel, F. Ozok⁵⁴, S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin, K. Yi

Johns Hopkins University, Baltimore, U.S.A.

B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, G. Giurgiu, A.V. Gribsan, Z.J. Guo, G. Hu, P. Maksimovic, S. Rappoccio, M. Swartz, A. Whitbeck

The University of Kansas, Lawrence, U.S.A.

P. Baringer, A. Bean, G. Benelli, R.P. Kenny Iii, M. Murray, D. Noonan, S. Sanders, R. Stringer, G. Tinti, 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. Boutemour, 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,
A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar, E. Twedt

Massachusetts Institute of Technology, Cambridge, U.S.A.

A. Apyan, 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, K. Krajczar⁵⁵,
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, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti

University of Minnesota, Minneapolis, U.S.A.

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

University of Mississippi, Oxford, U.S.A.

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

University of Nebraska-Lincoln, Lincoln, U.S.A.

E. Avdeeva, K. Bloom, S. Bose, J. Butt, D.R. Claes, A. Dominguez, M. Eads, 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, S.P. Shipkowski,
K. Smith

Northeastern University, Boston, U.S.A.

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, D. Nash, 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, K.M. Chan, M. Hildreth, C. Jessop, D.J. Karmgard, J. Kolb, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, M. Planer, R. Ruchti, J. Slaunwhite, N. Valls, M. Wayne, M. Wolf

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

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

Princeton University, Princeton, U.S.A.

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

University of Puerto Rico, Mayaguez, U.S.A.

E. Brownson, A. Lopez, H. Mendez, J.E. Ramirez Vargas

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

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, U.S.A.

S. Guragain, N. Parashar

Rice University, Houston, U.S.A.

A. Adair, C. Boulahouache, K.M. Ecklund, F.J.M. Geurts, W. Li, 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, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, D.C. Miner, D. Vishnevskiy, M. Zielinski

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

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

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

S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, J. Robles, K. Rose, S. Salur, S. Schnetzer, C. Seitz, 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. Kamon⁵⁶, 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, U.S.A.

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

Vanderbilt University, Nashville, U.S.A.

E. Appelt, A.G. Delannoy, C. Florez, S. Greene, A. Gurrola, W. Johns, P. Kurt, C. Maguire, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

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

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, U.S.A.

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

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

M. Anderson, D.A. Belknap, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, 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, F. Palmonari, G.A. Pierro, I. Ross, A. Savin, W.H. Smith, J. Swanson

- †: Deceased
- 1: Also at Vienna University of Technology, Vienna, Austria
 - 2: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
 - 3: Also at California Institute of Technology, Pasadena, U.S.A.
 - 4: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
 - 5: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
 - 6: Also at Suez Canal University, Suez, Egypt
 - 7: Also at Zewail City of Science and Technology, Zewail, Egypt
 - 8: Also at Cairo University, Cairo, Egypt
 - 9: Also at Fayoum University, El-Fayoum, Egypt
 - 10: Also at British University in Egypt, Cairo, Egypt
 - 11: Now at Ain Shams University, Cairo, Egypt
 - 12: Also at National Centre for Nuclear Research, Swierk, Poland
 - 13: Also at Université de Haute Alsace, Mulhouse, France
 - 14: Now at Joint Institute for Nuclear Research, Dubna, Russia
 - 15: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
 - 16: Also at Brandenburg University of Technology, Cottbus, Germany
 - 17: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
 - 18: Also at Eötvös Loránd University, Budapest, Hungary
 - 19: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
 - 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 Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
 - 24: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
 - 25: Also at Università degli Studi Guglielmo Marconi, Roma, Italy
 - 26: Also at Università degli Studi di Siena, Siena, Italy
 - 27: Also at University of Bucharest, Faculty of Physics, Bucuresti-Magurele, Romania
 - 28: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
 - 29: Also at University of California, Los Angeles, U.S.A.
 - 30: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
 - 31: Also at INFN Sezione di Roma; Università di Roma, Roma, Italy
 - 32: Also at University of Athens, Athens, Greece
 - 33: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
 - 34: Also at The University of Kansas, Lawrence, U.S.A.
 - 35: Also at Paul Scherrer Institut, Villigen, Switzerland
 - 36: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
 - 37: Also at Gaziosmanpasa University, Tokat, Turkey
 - 38: Also at Adiyaman University, Adiyaman, Turkey
 - 39: Also at Izmir Institute of Technology, Izmir, Turkey
 - 40: Also at The University of Iowa, Iowa City, U.S.A.
 - 41: Also at Mersin University, Mersin, Turkey
 - 42: Also at Ozyegin University, Istanbul, 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 University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- 52: Also at Argonne National Laboratory, Argonne, U.S.A.
- 53: Also at Erzincan University, Erzincan, Turkey
- 54: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
- 55: Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
- 56: Also at Kyungpook National University, Daegu, Korea