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Measurement of the inclusive $t\bar{t}$ production cross section in proton-proton collisions at $\sqrt{s} = 5.02\,\text{TeV}$

The CMS Collaboration*

Abstract

The top quark pair production cross section is measured in proton-proton collisions at a center-of-mass energy of 5.02 TeV. The data were collected in a special LHC low-energy and low-intensity run in 2017, and correspond to an integrated luminosity of $302\,\text{pb}^{-1}$. The measurement is performed using events with one electron and one muon of opposite charge, and at least two jets. The measured cross section is $60.7 \pm 5.0\,(\text{stat}) \pm 2.8\,(\text{syst}) \pm 1.1\,(\text{lumi})\,\text{pb}$. To reduce the statistical uncertainty, a combination with the result in the single lepton + jets channel, based on data collected in 2015 at the same center-of-mass energy and corresponding to an integrated luminosity of $27.4\,\text{pb}^{-1}$, is then performed. The resulting measured value is $63.0 \pm 4.1\,(\text{stat}) \pm 3.0\,(\text{syst+lumi})\,\text{pb}$, in agreement with the standard model prediction of $66.8^{+2.9}_{-3.1}\,\text{pb}$.

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*See Appendix A for the list of collaboration members

1 Introduction

The top quark is the most massive elementary particle in the standard model (SM). The study of its production and properties is one of the core elements of the CERN LHC physics program. At the LHC, top quarks are primarily produced in pairs ($\mathrm{t\bar{t}}$), and the $\mathrm{t\bar{t}}$ production cross section is sensitive to the gluon parton distribution function (PDF) of the proton [1] and to the top quark pole mass [2]. The ATLAS and CMS Collaborations have performed several cross section measurements with increasing precision in a variety of decay channels at four proton-proton (pp) collision energies [3–12], as well as in proton-nucleus [13] and nucleus-nucleus [14] collisions.

The first measurement of the $\mathrm{t\bar{t}}$ production cross section, $\sigma_{\mathrm{t\bar{t}}}$, in pp collisions at a center-of-mass energy of 5.02 TeV, was performed by the CMS experiment analyzing events with one or two leptons (ℓ = electron or muon) and at least two jets, using a data sample taken in 2015 that corresponds to an integrated luminosity of $27.4\,\mathrm{pb}^{-1}$. The measurement of $\sigma_{\mathrm{t\bar{t}}} = 69.5 \pm 6.1\,(\mathrm{stat}) \pm 5.6\,(\mathrm{syst}) \pm 1.6\,(\mathrm{lumi})\,\mathrm{pb}$ was obtained from the combination of the results in the individual decay channels [3].

During the year 2017, the LHC delivered a subset of pp collisions at $\sqrt{s} = 5.02\,\mathrm{TeV}$ and CMS collected a data sample corresponding to $302\,\mathrm{pb}^{-1}$, an increase in integrated luminosity of more than an order of magnitude compared to the data set recorded in 2015. A distinct feature of this data sample is the low number of additional interactions per bunch crossing (pileup) with respect to the standard operating conditions of the LHC. We present here a measurement of $\sigma_{\mathrm{t\bar{t}}}$ using events with two opposite-charge different-flavor leptons, i.e., one electron and one muon ($\mathrm{e}^{\pm}\mu^{\mp}$), and at least two jets. The cross section is extracted using a counting experiment and the result is then combined with the measurement in the ℓ+jets final state contained in Ref. [3].

This paper is organized as follows. A brief description of the CMS detector, and of the Monte Carlo (MC) simulation samples, are given in Section 2, followed by the object and event selection in Section 3. The background estimation methods are covered in Section 4 and the systematic uncertainties in Section 5. Results are discussed in Section 6 and the summary is given in Section 7. Tabulated results are provided in HEPData [15].

2 The CMS detector and Monte Carlo simulation

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and two endcap sections. Forward calorimeters extend the pseudorapidity (η) coverage provided by the barrel and endcap detectors. Muons are detected in gas-ionization chambers embedded in the steel flux-return yoke outside the solenoid. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [16].

Simulated event samples are used to define the analysis strategy, to estimate the background contribution, and to evaluate efficiencies and uncertainties. The samples used in the analysis are summarized in Table 1. The propagation of the generated particles through the CMS detector and the modeling of the detector response are performed using GEANT4 [17].

Simulated $\mathrm{t\bar{t}}$ events are generated at next-to-leading order (NLO) in quantum chromodynamics (QCD) using POWHEG (v2) [18–20], assuming a top quark mass m_{t} of 172.5 GeV. The events are then interfaced with PYTHIA 8 (v230) [21] with the "CP5" tune [22] for parton showering, hadronization, and the underlying event description. For the study of the acceptance dependence on m_t, alternative generator-level samples have been used with $m_t = 166.5$ and 178.5 GeV. The NNPDF3.1 [23] next-to-next-to-leading-order (NNLO) PDFs are used. A similar setup is used for the simulation of the single top quark production in association with a W boson (tW).

The MADGRAPH5_aMC@NLO (v2.4.2) generator [24], interfaced with PYTHIA 8 for parton showering, is used to simulate W boson production with additional jets (W+jets), and Drell–Yan (DY) quark-antiquark annihilation into lepton-antilepton pairs through Z boson or virtual-photon exchange at NLO. The simulation is performed at NLO in QCD and includes up to two extra partons at the matrix element (ME) level. The FxFx matching scheme [25] is used to merge jets from the ME calculations and the parton shower (PS). Diboson (VV, with V = W or Z) events are simulated at NLO in QCD with POWHEG (v2). When available, higher-order cross sections are used instead of those of the generator, as shown in Table 1.

Table 1: Summary of MC samples used to model the signal and background processes. The column "Cross section order" corresponds to the QCD or electroweak (EW) precision used to normalize the distributions provided by the generators. Where no reference is given, the precision of the MC simulation is kept.

Process	Generator + parton shower	Cross section order
$t\bar{t}$	POWHEG + PYTHIA 8	NNLO+NNLL [26, 27]
tW	POWHEG + PYTHIA 8	Approximate NNLO [28]
W+jets	MADGRAPH5_aMC@NLO + PYTHIA 8	NNLO[QCD]+NLO[EW] [29]
DY	MADGRAPH5_aMC@NLO + PYTHIA 8	NNLO[QCD]+NLO[EW] [29]
VV	POWHEG + PYTHIA 8	NLO

The SM prediction for $\sigma_{t\bar{t}}$ at 5.02 TeV is $66.8^{+1.9}_{-2.3}\,(\text{scale}) \pm 1.7\,(\text{PDF})^{+1.4}_{-1.3}\,(\alpha_S(m_Z))$ pb for $m_t = 172.5$ GeV and a strong coupling at the Z boson mass, $\alpha_S(m_Z)$, of 0.118 ± 0.001 [30]. This prediction is calculated with the TOP++ program [26] at NNLO in perturbative QCD including soft-gluon resummation at next-to-next-to-leading-log (NNLL) approximation [27]. The first uncertainty reflects variations in the factorization (μ_F) and renormalization (μ_R) scales. The second and third uncertainties are associated with possible choices of PDFs and the α_S value respectively, using the NNPDF3.1 [23] NNLO PDF sets that include top quark measurements. The expected integrated event yields for signal in all figures and tables are normalized to the predicted cross section.

The simulated samples include multiple pp collisions occurring in the same bunch crossing (pileup), with a distribution that matches that observed in data, with an average of about two pileup collisions per bunch crossing.

3 Object reconstruction and event selection

Events of interest are selected online using a two-tiered trigger system [31, 32]. The first level (L1), composed of custom hardware processors, uses information from the calorimeters and muon detectors to select events at a rate of around 100 kHz within a fixed latency of less than 4 μs. The second level, known as the high-level trigger, consists of a farm of processors running a version of the full event reconstruction software optimized for fast processing, and reduces the event rate to around 1 kHz before data storage. Only events that fired at least one of the single-lepton triggers with transverse momentum (p_T) thresholds greater than 17 (12) GeV in the case of electrons (muons) are considered.

Events may contain multiple primary vertices, corresponding to pileup collisions. The candidate vertex with the largest value of summed physics-object p_{T}^2 is taken to be the primary pp interaction vertex. The physics objects are the jets, clustered using the jet finding algorithm [33, 34] using tracks assigned to candidate vertices as inputs, and the associated missing transverse momentum, taken as the negative vector sum of the p_{T} of those jets.

The particle-flow algorithm [35] aims to reconstruct and identify each individual particle in an event, with an optimized combination of information from the various elements of the CMS detector. The energy of electrons is determined from a combination of the electron momentum as measured by the tracker, the energy of the corresponding ECAL cluster, and the energy sum of all bremsstrahlung photons spatially compatible with originating from the electron track. The energy of muons is obtained from the curvature of the corresponding track. The energy of charged hadrons is determined from a combination of their momentum measured in the tracker and the matching ECAL and HCAL energy deposits, corrected for the response function of the calorimeters to hadronic showers. Finally, the energy of neutral hadrons is obtained from the corresponding corrected ECAL and HCAL energies.

Jets are clustered from these reconstructed particles using the anti-k_{T} algorithm [33, 34] with a distance parameter of 0.4. The jet momentum is determined as the vectorial sum of all particle momenta in the jet, and is found from simulation to be, on average, within 5 to 10% of the true momentum over the whole p_{T} spectrum and detector acceptance. Jet energy corrections are derived from simulation studies so that the average measured energy of jets becomes identical to that of particle-level jets. Measurements of the momentum balance are used to determine any residual differences between the jet energy scale in data and in simulation, and appropriate corrections are made [36]. Additional selection criteria are applied to remove jets potentially dominated by instrumental effects or reconstruction failures [37].

Electron candidates are required to satisfy $|\eta| < 2.5$ and $p_{\mathrm{T}} > 10\,\mathrm{GeV}$. To identify electrons, requirements are placed on a multivariate discriminant based on the shower shape and track quality of the electron candidates [38]. Electron candidates that are matched to a secondary vertex consistent with a photon conversion, or have a missing hit in the inner layer of the tracker are vetoed.

Reconstructed muon candidates are required to have $|\eta| < 2.4$ and $p_{\mathrm{T}} > 10\,\mathrm{GeV}$, and must fulfill criteria on the geometrical matching between the tracks reconstructed by the silicon tracker and the muon system, and on the quality of the global fit [39].

Lepton candidates must be consistent with originating from the primary vertex which is ensured by requiring that the transverse (longitudinal) impact parameter should not exceed 0.05 (0.10) cm. Furthermore, the significance of the three-dimensional impact parameter must be smaller than 8. Electrons and muons must also satisfy a requirement on their relative isolation (I_{rel}), defined as the scalar p_{T} sum of all the particles inside a cone around the lepton direction, excluding the lepton itself, divided by the lepton p_{T}. The cone size, defined as $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, where ϕ is the azimuthal angle, changes as a function of the lepton p_{T} as $\Delta R(p_{\mathrm{T}}) = 10\,\mathrm{GeV}/p_{\mathrm{T}}$ if $50\,\mathrm{GeV} < p_{\mathrm{T}} < 200\,\mathrm{GeV}$, $\Delta R = 0.2$ if $p_{\mathrm{T}} \leq 50\,\mathrm{GeV}$ and $\Delta R = 0.05$ otherwise. Electrons (muons) must satisfy the condition $I_{\mathrm{rel}} < 0.085\,(0.325)$.

To reject leptons originating from hadron decays, or misidentified leptons, also referred to as "nonprompt" leptons, from those produced in the decay of the electroweak bosons ("prompt"), a gradient boosted decision tree (BDT) is used, trained using MC simulation, to distinguish prompt from nonprompt leptons [40]. This BDT uses the properties of the jet containing the lepton, as returned by the jet clustering algorithm: its b tagging score, the ratio of the lepton

p_T to that of the jet, and the momentum of the jet transverse to the lepton direction. Other input variables are the lepton p_T, η, I_{rel}, longitudinal and transverse impact parameters, and the significance of the three-dimensional impact parameter. In addition, the previously mentioned multivariate discriminant for electrons and the muon segment compatibility for muons are used as input variables [39]. To further suppress nonprompt leptons originating from b quark decays, leptons associated with a jet satisfying the loose working point of the DeepCSV b tagging algorithm [41] are rejected.

The $t\bar{t}$ candidate events are required to have at least two leptons (one electron and one muon) with opposite charge and at least two jets. Only jets with $p_T > 25\,GeV$, $|\eta| < 2.4$, and containing no selected leptons are considered. To ensure efficient triggering of the events, the leading lepton is required to have $p_T > 20\,GeV$. In addition, events must have a dilepton invariant mass above 20 GeV to reduce the background from photon conversions and low-mass resonances.

4 Background estimation

Background events arise mainly from tW, DY, and VV production in which at least two prompt leptons emerge from the Z or W boson decays. The tW and VV contributions are estimated from simulation.

The DY event yield is estimated from data using the $R_{out/in}$ method [6], where events with same-flavor leptons are used to normalize the yield of different-flavor pairs from DY production of τ lepton pairs. A data-to-simulation normalization factor is estimated from the number of events in data within a 15 GeV window around the Z boson mass and extrapolated to the number of events outside the Z boson mass window with corrections applied using control regions enriched in DY events in data. This factor is measured to be 0.91 ± 0.01. The stability of the method against a potential mismodeling of the jet multiplicity is checked and found to be within 30%, which will be considered as an extra systematic uncertainty in this background estimation.

Other residual background sources, such as $t\bar{t}$ where only one of the W bosons decay leptonically or W+jets events, may contaminate the signal sample when a jet is misreconstructed as a lepton, or contains a lepton from a b/c hadron decay, incorrectly identified as a prompt lepton. These events are grouped into the nonprompt lepton category, together with meson decays and photon conversions; their contribution is estimated with simulated $t\bar{t}$ events with at least one W boson decaying into jets and W+jets events.

Figure 1 shows the p_T of the two leptons and of the leading jet, and the jet multiplicity of the selected events. The data are compared to the sum of the expected signal and background distributions for the $t\bar{t}$ signal and individual backgrounds, which are derived either from simulated samples or from data, as described above. The expected distributions describe the data within the experimental uncertainties.

5 Systematic uncertainties

The measurement of $\sigma_{t\bar{t}}$ is affected by sources of systematic uncertainty related to detector effects or theoretical assumptions. Each source of systematic uncertainty is evaluated by repeating the $\sigma_{t\bar{t}}$ extraction with variations of the input parameters by ± 1 standard deviations (experimental uncertainty) or from dedicated simulation samples with different settings (theoretical uncertainty). The total uncertainty is calculated by adding the effects of all the individual systematic components in quadrature, assuming they are independent. The sources of systematic

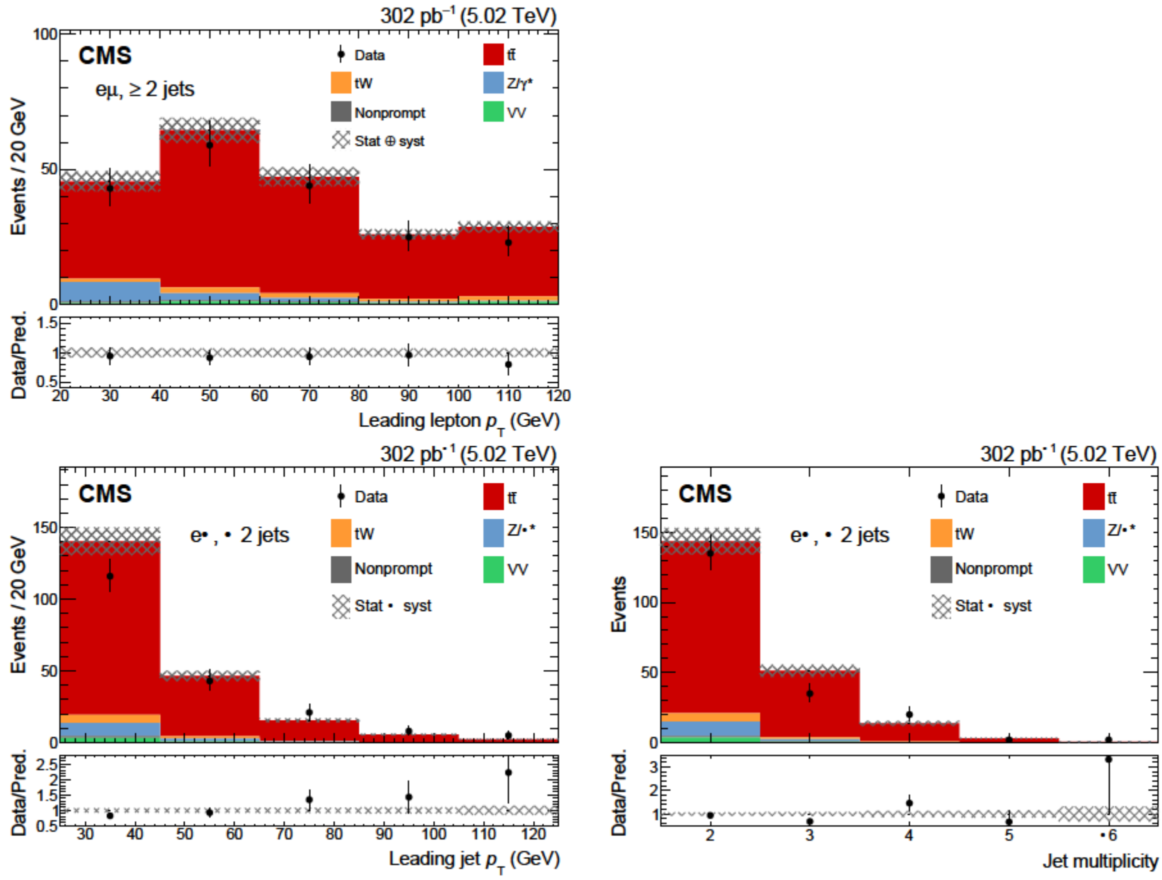

Figure 1: Leading lepton p_T (upper left), sub-leading lepton p_T (upper right), leading jet p_T (lower left), and jet multiplicity (lower right) in the selected events. The hatched band corresponds to systematic and statistical uncertainties summed in quadrature. The lower panels show the data-to-prediction ratio. The last bin in each distribution includes overflow events.

uncertainty are described in detail below:

Lepton-related uncertainty: Lepton reconstruction and identification efficiencies, as well as energy scale and resolution, are measured using Z boson events in data and simulation. Correction factors are then applied to the simulation to improve the agreement with the data. The uncertainty in these corrections is propagated to the $\sigma_{t\bar{t}}$ measurement. For the selected events, the trigger efficiency is very close to 1, as the trigger conditions are satisfied redundantly by both leptons in most of the events. The deviation of the efficiency from unity, obtained from a $t\bar{t}$ simulated sample, is used as the associated uncertainty in $\sigma_{t\bar{t}}$.

Jet-related uncertainty: The impact of the uncertainty in jet energy scale (JES) is estimated from the change in the number of simulated $t\bar{t}$ events selected after changing the jet momenta within the JES uncertainties. The effect of the jet energy resolution (JER) is determined by an η-dependent variation of the JER scale factors within their uncertainty.

L1 prefiring: During the 2017 data taking, a gradual shift in the timing of the inputs of the ECAL L1 trigger in the region $|\eta| > 2.0$ caused a trigger inefficiency. Simulations are corrected to mimic this behavior in data and the uncertainty in these corrections is propagated to $\sigma_{t\bar{t}}$ by varying the correction within the associated uncertainty.

Scale choice: The uncertainty related to the missing higher-order diagrams in POWHEG is estimated by varying the default μ_F and μ_R choices independently by a factor of 2 and 1/2. As uncertainty in the signal acceptance is assigned the maximum difference of each variation from the nominal values, excluding variations of the scales in opposite directions.

Parton shower scale: The effect of the choice of PS scale is studied by changing the scale used for the initial- and final-state radiation by a factor 2 and 1/2 with respect to its default value. The maximum variation with respect to the central sample is taken as the uncertainty.

Matrix element and PS matching (h_{damp}): The impact of the ME and PS matching, which is parameterized by the POWHEG generator as h_{damp}, with a nominal value of $(1.379^{+0.926}_{-0.505})m_t$, is calculated by varying this parameter within the uncertainties, using dedicated samples. The variation with respect to the central value of the signal acceptance at particle level is considered as the uncertainty in the $\sigma_{t\bar{t}}$ extraction.

Parton distribution functions: The uncertainty due to the proton PDFs is evaluated by reweighting simulated signal events using the replicas of the NNPDF3.1 set [23]. The variations consist of a central PDF and 100 replicas, for which the root mean square of all differences of the resulting $\sigma_{t\bar{t}}$ with respect to the central value is taken as the uncertainty. Two extra variations corresponding to different $\alpha_S(m_Z)$ choices are added in quadrature [42].

Underlying event tune: The parameters of PYTHIA are adjusted to model the measured underlying event tune [22]. The uncertainty is calculated by varying these parameters within their uncertainties in dedicated simulated samples. The variation with respect to the central value of the signal acceptance is taken as the uncertainty.

Background normalization: The uncertainty in the tW and VV cross sections is taken to be 20 and 30%, respectively, based on the theoretical uncertainties and the effect of finite size of the simulated samples. To the nonprompt background estimation is assigned a 50% uncertainty to account for possible mismodeling of the data in simulation. As explained in Section 4, a 30% uncertainty is considered for the DY background normalization.

Pileup and integrated luminosity: The uncertainty assigned to the number of pileup events in simulation is calculated by varying the total inelastic pp cross section by 4.6% [43]. The impact of this uncertainty on the result is expected to be very small, as the number of pileup events is also small. The uncertainty in the measurement of the integrated luminosity is estimated to be 1.9% [44].

Table 2 summarizes the sources of systematic and statistical uncertainties in the measured $\sigma_{t\bar{t}}$, as obtained using Eq. (1), explained in the next section. The result is dominated by the statistical uncertainty, while the uncertainty in the JES and the DY background estimate constitute the largest systematic uncertainties.

6 Results

The $t\bar{t}$ production cross section is extracted via the expression

$$\sigma_{t\bar{t}} = \frac{N - N_{bkg}}{\varepsilon \mathcal{A} \mathcal{B} \mathcal{L}}, \tag{1}$$

Table 2: Summary of the systematic and statistical relative uncertainties for the $t\bar{t}$ cross section measurement.

Source	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Electron efficiency	1.6
Muon efficiency	0.6
Trigger efficiency	1.3
JES	2.2
JER	1.2
L1 prefiring	1.4
μ_R, μ_F scales	0.2
Final-state radiation	1.1
Initial-state radiation	< 0.1
h_{damp}	1.0
PDF$\oplus\alpha_S(m_Z)$	0.3
Underlying event tune	0.7
tW	1.0
Nonprompt leptons	0.4
Drell–Yan	1.8
VV	0.8
Total systematic uncertainty	4.3
Integrated luminosity	1.9
Statistical uncertainty	8.2

where N is the number of observed events, N_{bkg} is the number of estimated background events, $\mathcal{L}$ is the integrated luminosity, $\mathcal{B}$ is the branching fraction of a W boson pair to $e^{\pm}\mu^{\mp}$, including decays through τ leptons, measured to be 3.194% [30], $\mathcal{A}$ is the total acceptance, defined as the fraction of all generated $t\bar{t} \rightarrow e^{\pm}\mu^{\mp}$ events fulfilling the aforementioned kinematic selection criteria, and ε is the reconstruction efficiency. The acceptance is estimated from simulation and is found to be 0.54 ± 0.01. The efficiency is estimated from simulation, after applying all the correction factors for leptons and jets to match the performance of the data, and is measured to be 0.53 ± 0.02. Table 3 shows the total number of events observed in data together with the total number of expected signal and background events.

Table 3: Event yields for all the processes at the final level of selection. The uncertainty corresponds to the quadratic sum of the statistical and systematic sources.

Process	Event yield
tW	8 ± 2
Nonprompt leptons	2 ± 1
DY	10 ± 4
VV	4 ± 1
Total background	24 ± 4
$t\bar{t}$	187 ± 9
Data	194

The measured inclusive cross section for a top quark mass of 172.5 GeV is

$$\sigma_{t\bar{t}} = 60.7 \pm 5.0\,(\text{stat}) \pm 2.8\,(\text{syst}) \pm 1.1\,(\text{lumi})\,\text{pb}.$$

The fiducial cross section ($\sigma_{t\bar{t}}^{fid}$) is measured for events containing one electron and one muon with $p_T > 10$ GeV and $|\eta| < 2.4$, invariant mass of the pair of at least 20 GeV, a leading lepton p_T of at least 20 GeV, and at least two jets with $p_T > 25$ GeV and $|\eta| < 2.4$. The resulting value is $\sigma_{t\bar{t}}^{fid} = 32.8 \pm 2.7\,(stat) \pm 1.5\,(syst) \pm 0.6\,(lumi)$ pb.

The acceptance has been measured for $m_t = 166.5$ and 178.5 GeV and is parameterized as a linear function of m_t. The cross section varies by ∓ 0.30 pb when the top quark mass changes by ± 0.5 GeV.

To reduce the statistical limitation of the presented measurement, the result is combined with that obtained in the ℓ+jets decay channel of Ref. [3], corresponding to an integrated luminosity of 27.4 pb^{-1}. We determine the combined $\sigma_{t\bar{t}}$ using the best linear unbiased estimator (BLUE) method [45, 46]. The 2015 measurement in the ℓ+jets channel yielded a cross section of $\sigma_{t\bar{t}} = 68.9$ pb with a total uncertainty of 13%, dominated by the statistical uncertainty. Most sources of experimental uncertainty are considered as uncorrelated, given that the data sets and background estimation methods are different, with the exception of the uncertainties on the tW background and the scale choice, which are considered as fully correlated. The modeling uncertainties are taken as fully correlated. The resulting cross section is

$$\sigma_{t\bar{t}}^{comb} = 63.0 \pm 4.1\,(stat) \pm 3.0\,(syst{+}lumi)\,pb,$$

where the total uncertainty of 8.0% is the quadrature sum of the individual sources of uncertainty. The weights of the individual measurements, to be understood in the sense of Ref. [46], are 27 and 73% for the ℓ+jets [3] and the measurement presented in this paper, respectively. This result is in agreement with the SM prediction.

The combined result is found to be robust by performing an iterative variant of the BLUE method [47] and varying some assumptions on the correlations of different combinations of systematic uncertainties. Also, the correlations between the nuisance parameters in both channels have been checked and found to have a negligible impact.

Figure 2 presents a summary of the CMS measurements [2, 6, 7, 10, 11] of $\sigma_{t\bar{t}}$ in pp collisions at different $\sqrt{s}$ in the ℓ+jets and dilepton channels, compared to the NNLO+NNLL prediction using the NNPDF3.0 NNLO PDF set with $\alpha_S(m_Z) = 0.118$ and $m_t = 172.5$ GeV. In the inset, the results from this analysis at $\sqrt{s} = 5.02$ TeV are also compared to the predictions from the MSHT20 [48], CT18 [49], and ABMP16 [50] NNLO PDF sets, with the latter using $\alpha_S(m_Z) = 0.115$ and $m_t = 170.4$ GeV. Theoretical predictions using different PDF sets have comparable values and uncertainties, once consistent values of $\alpha_S(m_Z)$ and m_t are associated with the respective PDF set.

The impact of the combined $\sigma_{t\bar{t}}$ measurement at $\sqrt{s} = 5.02$ TeV on the knowledge of the proton PDFs is tested following the MC methodology of Ref. [3]. Similar improvement with respect to the previous result is observed.

7 Summary

A measurement of the top quark pair production cross section at a center-of-mass energy of 5.02 TeV is presented for events with one electron and one muon of opposite charge, and at least two jets, using proton-proton collisions collected by the CMS experiment in 2017 and corresponding to an integrated luminosity of 302 pb^{-1}. The measured cross section is found

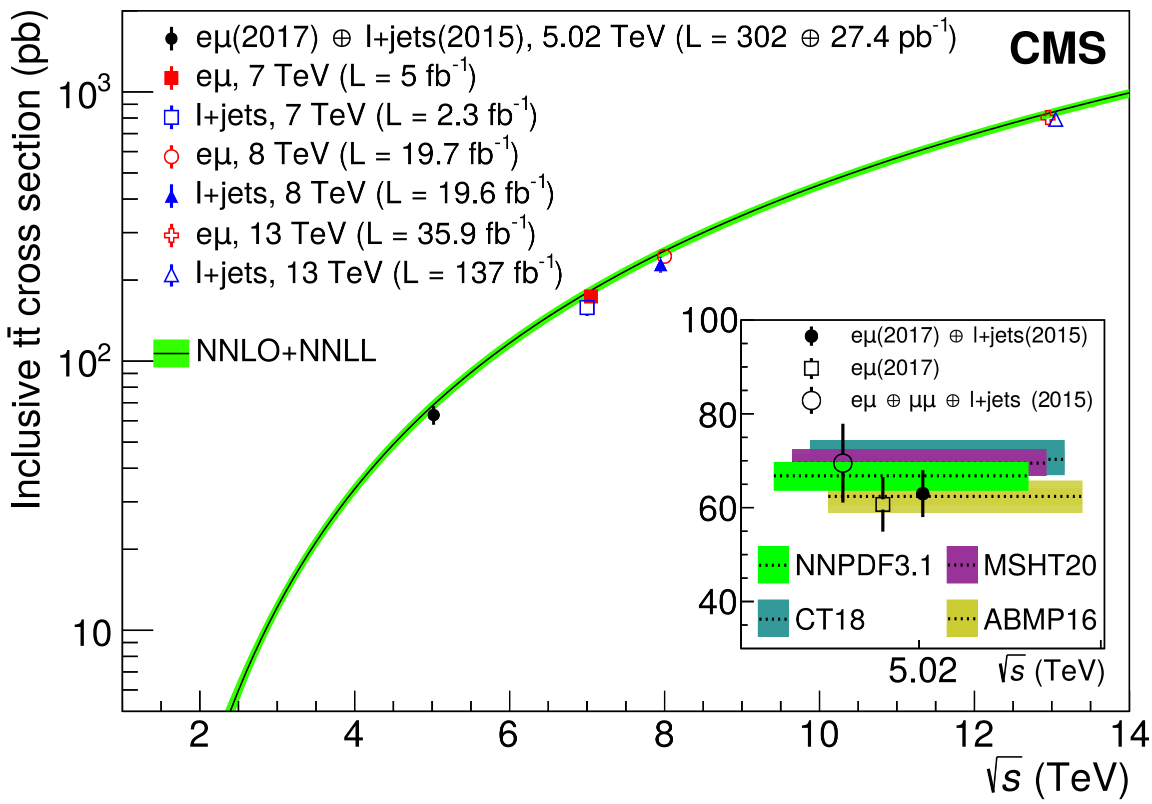

Figure 2: Inclusive $t\bar{t}$ cross section in pp collisions as a function of the center-of-mass energy in the separate ℓ+jets and dilepton channels along with the combined measurement at 5.02 TeV presented in this analysis are displayed. Some of the previous CMS measurements at $\sqrt{s} = 7$, 8 [6, 7], and 13 TeV [2, 11] are also shown. The NNLO+NNLL theoretical prediction [27] using the NNPDF3.1 [23] PDF set with $\alpha_S(m_Z) = 0.118$ and $m_t = 172.5$ GeV is shown in the main plot. In the inset, predictions at 5.02 TeV using the MSHT20 [48], CT18 [49], and ABMP16 [50] NNLO PDF sets, the latter with $\alpha_S(m_Z) = 0.115$ and $m_t = 170.4$ GeV, are compared, along with the NNPDF3.1 NNLO prediction, to the individual and combined results from this analysis. The vertical bars and bands represent the total uncertainties in the data and in the predictions, respectively. Points corresponding to measurements at the same $\sqrt{s}$ are horizontally shifted for better readability.

to be $\sigma_{t\bar{t}} = 60.7 \pm 5.0\,(\text{stat}) \pm 2.8\,(\text{syst}) \pm 1.1\,(\text{lumi})$ pb. To reduce the statistical uncertainty in the result, a combination with the single lepton + jets measurement, using a data set collected in 2015 at the same center-of-mass energy and corresponding to an integrated luminosity of $27.4\,\text{pb}^{-1}$, is performed. A measurement of $63.0 \pm 4.1\,(\text{stat}) \pm 3.0\,(\text{syst+lumi})$ pb is obtained, in agreement with the prediction from the standard model of $66.8^{+2.9}_{-3.1}$ pb.

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A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia
A. Tumasyan

Institut für Hochenergiephysik, Vienna, Austria
W. Adam, J.W. Andrejkovic, T. Bergauer, S. Chatterjee, M. Dragicevic, A. Escalante Del Valle, R. Frühwirth[1], M. Jeitler[1], N. Krammer, L. Lechner, D. Liko, I. Mikulec, P. Paulitsch, F.M. Pitters, J. Schieck[1], R. Schöfbeck, M. Spanring, S. Templ, W. Waltenberger, C.-E. Wulz[1]

Institute for Nuclear Problems, Minsk, Belarus
V. Chekhovsky, A. Litomin, V. Makarenko

Universiteit Antwerpen, Antwerpen, Belgium
M.R. Darwish[2], E.A. De Wolf, T. Janssen, T. Kello[3], A. Lelek, H. Rejeb Sfar, P. Van Mechelen, S. Van Putte, N. Van Remortel

Vrije Universiteit Brussel, Brussel, Belgium
F. Blekman, E.S. Bols, J. D'Hondt, M. Delcourt, H. El Faham, S. Lowette, S. Moortgat, A. Morton, D. Müller, A.R. Sahasransu, S. Tavernier, W. Van Doninck, P. Van Mulders

Université Libre de Bruxelles, Bruxelles, Belgium
D. Beghin, B. Bilin, B. Clerbaux, G. De Lentdecker, L. Favart, A. Grebenyuk, A.K. Kalsi, K. Lee, M. Mahdavikhorrami, I. Makarenko, L. Moureaux, L. Pétré, A. Popov, N. Postiau, E. Starling, L. Thomas, M. Vanden Bemden, C. Vander Velde, P. Vanlaer, D. Vannerom, L. Wezenbeek

Ghent University, Ghent, Belgium
T. Cornelis, D. Dobur, J. Knolle, L. Lambrecht, G. Mestdach, M. Niedziela, C. Roskas, A. Samalan, K. Skovpen, M. Tytgat, W. Verbeke, B. Vermassen, M. Vit

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
A. Bethani, G. Bruno, F. Bury, C. Caputo, P. David, C. Delaere, I.S. Donertas, A. Giammanco, K. Jaffel, Sa. Jain, V. Lemaitre, K. Mondal, J. Prisciandaro, A. Taliercio, M. Teklishyn, T.T. Tran, P. Vischia, S. Wertz

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
G.A. Alves, C. Hensel, A. Moraes

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
W.L. Aldá Júnior, M. Alves Gallo Pereira, M. Barroso Ferreira Filho, H. BRANDAO MALBOUISSON, W. Carvalho, J. Chinellato[4], E.M. Da Costa, G.G. Da Silveira[5], D. De Jesus Damiao, S. Fonseca De Souza, D. Matos Figueiredo, C. Mora Herrera, K. Mota Amarilo, L. Mundim, H. Nogima, P. Rebello Teles, A. Santoro, S.M. Silva Do Amaral, A. Sznajder, M. Thiel, F. Torres Da Silva De Araujo, A. Vilela Pereira

Universidade Estadual Paulista (a), Universidade Federal do ABC (b), São Paulo, Brazil
C.A. Bernardes[5], L. Calligaris, T.R. Fernandez Perez Tomei, E.M. Gregores, D.S. Lemos, P.G. Mercadante, S.F. Novaes, Sandra S. Padula

Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria
A. Aleksandrov, G. Antchev, R. Hadjiiska, P. Iaydjiev, M. Misheva, M. Rodozov, M. Shopova,

G. Sultanov

University of Sofia, Sofia, Bulgaria
A. Dimitrov, T. Ivanov, L. Litov, B. Pavlov, P. Petkov, A. Petrov

Beihang University, Beijing, China
T. Cheng, Q. Guo, T. Javaid[6], M. Mittal, H. Wang, L. Yuan

Department of Physics, Tsinghua University, Beijing, China
M. Ahmad, G. Bauer, C. Dozen[7], Z. Hu, J. Martins[8], Y. Wang, K. Yi[9,10]

Institute of High Energy Physics, Beijing, China
E. Chapon, G.M. Chen[6], H.S. Chen[6], M. Chen, F. Iemmi, A. Kapoor, D. Leggat, H. Liao, Z.-A. Liu[6], V. Milosevic, F. Monti, R. Sharma, J. Tao, J. Thomas-Wilsker, J. Wang, H. Zhang, S. Zhang[6], J. Zhao

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
A. Agapitos, Y. An, Y. Ban, C. Chen, A. Levin, Q. Li, X. Lyu, Y. Mao, S.J. Qian, D. Wang, Q. Wang, J. Xiao

Sun Yat-Sen University, Guangzhou, China
M. Lu, Z. You

Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) - Fudan University, Shanghai, China
X. Gao[3], H. Okawa

Zhejiang University, Hangzhou, China, Zhejiang, China
Z. Lin, M. Xiao

Universidad de Los Andes, Bogota, Colombia
C. Avila, A. Cabrera, C. Florez, J. Fraga

Universidad de Antioquia, Medellin, Colombia
J. Mejia Guisao, F. Ramirez, J.D. Ruiz Alvarez, C.A. Salazar González

University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia
D. Giljanovic, N. Godinovic, D. Lelas, I. Puljak

University of Split, Faculty of Science, Split, Croatia
Z. Antunovic, M. Kovac, T. Sculac

Institute Rudjer Boskovic, Zagreb, Croatia
V. Brigljevic, D. Ferencek, D. Majumder, M. Roguljic, A. Starodumov[11], T. Susa

University of Cyprus, Nicosia, Cyprus
A. Attikis, K. Christoforou, E. Erodotou, A. Ioannou, G. Kole, M. Kolosova, S. Konstantinou, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis, H. Rykaczewski, H. Saka

Charles University, Prague, Czech Republic
M. Finger[12], M. Finger Jr.[12], A. Kveton

Escuela Politecnica Nacional, Quito, Ecuador
E. Ayala

Universidad San Francisco de Quito, Quito, Ecuador
E. Carrera Jarrin

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
H. Abdalla[13], E. Salama[14,15]

Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt
A. Lotfy, M.A. Mahmoud

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
S. Bhowmik, R.K. Dewanjee, K. Ehataht, M. Kadastik, S. Nandan, C. Nielsen, J. Pata, M. Raidal, L. Tani, C. Veelken

Department of Physics, University of Helsinki, Helsinki, Finland
P. Eerola, L. Forthomme, H. Kirschenmann, K. Osterberg, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland
S. Bharthuar, E. Brücken, F. Garcia, J. Havukainen, M.S. Kim, R. Kinnunen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, M. Lotti, L. Martikainen, M. Myllymäki, J. Ott, H. Siikonen, E. Tuominen, J. Tuominiemi

Lappeenranta University of Technology, Lappeenranta, Finland
P. Luukka, H. Petrow, T. Tuuva

IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
C. Amendola, M. Besancon, F. Couderc, M. Dejardin, D. Denegri, J.L. Faure, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, B. Lenzi, E. Locci, J. Malcles, J. Rander, A. Rosowsky, M.Ö. Sahin, A. Savoy-Navarro[16], M. Titov, G.B. Yu

Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France
S. Ahuja, F. Beaudette, M. Bonanomi, A. Buchot Perraguin, P. Busson, A. Cappati, C. Charlot, O. Davignon, B. Diab, G. Falmagne, S. Ghosh, R. Granier de Cassagnac, A. Hakimi, I. Kucher, J. Motta, M. Nguyen, C. Ochando, P. Paganini, J. Rembser, R. Salerno, J.B. Sauvan, Y. Sirois, A. Tarabini, A. Zabi, A. Zghiche

Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France
J.-L. Agram[17], J. Andrea, D. Apparu, D. Bloch, G. Bourgatte, J.-M. Brom, E.C. Chabert, C. Collard, D. Darej, J.-C. Fontaine[17], U. Goerlach, C. Grimault, A.-C. Le Bihan, E. Nibigira, P. Van Hove

Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France
E. Asilar, S. Beauceron, C. Bernet, G. Boudoul, C. Camen, A. Carle, N. Chanon, D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, I.B. Laktineh, H. Lattaud, A. Lesauvage, M. Lethuillier, L. Mirabito, S. Perries, K. Shchablo, V. Sordini, L. Torterotot, G. Touquet, M. Vander Donckt, S. Viret

Georgian Technical University, Tbilisi, Georgia
I. Lomidze, T. Toriashvili[18], Z. Tsamalaidze[12]

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
L. Feld, K. Klein, M. Lipinski, D. Meuser, A. Pauls, M.P. Rauch, N. Röwert, J. Schulz, M. Teroerde

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
A. Dodonova, D. Eliseev, M. Erdmann, P. Fackeldey, B. Fischer, S. Ghosh, T. Hebbeker, K. Hoepfner, F. Ivone, H. Keller, L. Mastrolorenzo, M. Merschmeyer,

A. Meyer, G. Mocellin, S. Mondal, S. Mukherjee, D. Noll, A. Novak, T. Pook, A. Pozdnyakov, Y. Rath, H. Reithler, J. Roemer, A. Schmidt, S.C. Schuler, A. Sharma, L. Vigilante, S. Wiedenbeck, S. Zaleski

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
C. Dziwok, G. Flügge, W. Haj Ahmad[19], O. Hlushchenko, T. Kress, A. Nowack, C. Pistone, O. Pooth, D. Roy, H. Sert, A. Stahl[20], T. Ziemons

Deutsches Elektronen-Synchrotron, Hamburg, Germany
H. Aarup Petersen, M. Aldaya Martin, P. Asmuss, I. Babounikau, S. Baxter, O. Behnke, A. Bermúdez Martínez, S. Bhattacharya, A.A. Bin Anuar, K. Borras[21], V. Botta, D. Brunner, A. Campbell, A. Cardini, C. Cheng, F. Colombina, S. Consuegra Rodríguez, G. Correia Silva, V. Danilov, L. Didukh, G. Eckerlin, D. Eckstein, L.I. Estevez Banos, O. Filatov, E. Gallo[22], A. Geiser, A. Giraldi, A. Grohsjean, M. Guthoff, A. Jafari[23], N.Z. Jomhari, H. Jung, A. Kasem[21], M. Kasemann, H. Kaveh, C. Kleinwort, D. Krücker, W. Lange, J. Lidrych, K. Lipka, W. Lohmann[24], R. Mankel, I.-A. Melzer-Pellmann, M. Mendizabal Morentin, J. Metwally, A.B. Meyer, M. Meyer, J. Mnich, A. Mussgiller, Y. Otarid, D. Pérez Adán, D. Pitzl, A. Raspereza, B. Ribeiro Lopes, J. Rübenach, A. Saggio, A. Saibel, M. Savitskyi, M. Scham, V. Scheurer, P. Schütze, C. Schwanenberger[22], A. Singh, R.E. Sosa Ricardo, D. Stafford, N. Tonon, O. Turkot, M. Van De Klundert, R. Walsh, D. Walter, Y. Wen, K. Wichmann, L. Wiens, C. Wissing, S. Wuchterl

University of Hamburg, Hamburg, Germany
R. Aggleton, S. Albrecht, S. Bein, L. Benato, A. Benecke, P. Connor, K. De Leo, M. Eich, F. Feindt, A. Fröhlich, C. Garbers, E. Garutti, P. Gunnellini, J. Haller, A. Hinzmann, G. Kasieczka, R. Klanner, R. Kogler, T. Kramer, V. Kutzner, J. Lange, T. Lange, A. Lobanov, A. Malara, A. Nigamova, K.J. Pena Rodriguez, O. Rieger, P. Schleper, M. Schröder, J. Schwandt, D. Schwarz, J. Sonneveld, H. Stadie, G. Steinbrück, A. Tews, B. Vormwald, I. Zoi

Karlsruher Institut fuer Technologie, Karlsruhe, Germany
J. Bechtel, T. Berger, E. Butz, R. Caspart, T. Chwalek, W. De Boer[†], A. Dierlamm, A. Droll, K. El Morabit, N. Faltermann, M. Giffels, J.o. Gosewisch, A. Gottmann, F. Hartmann[20], C. Heidecker, U. Husemann, P. Keicher, R. Koppenhöfer, S. Maier, M. Metzler, S. Mitra, Th. Müller, M. Neukum, A. Nürnberg, G. Quast, K. Rabbertz, J. Rauser, D. Savoiu, M. Schnepf, D. Seith, I. Shvetsov, H.J. Simonis, R. Ulrich, J. Van Der Linden, R.F. Von Cube, M. Wassmer, M. Weber, S. Wieland, R. Wolf, S. Wozniewski, S. Wunsch

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece
G. Anagnostou, G. Daskalakis, T. Geralis, A. Kyriakis, D. Loukas, A. Stakia

National and Kapodistrian University of Athens, Athens, Greece
M. Diamantopoulou, D. Karasavvas, G. Karathanasis, P. Kontaxakis, C.K. Koraka, A. Manousakis-Katsikakis, A. Panagiotou, I. Papavergou, N. Saoulidou, K. Theofilatos, E. Tziaferi, K. Vellidis, E. Vourliotis

National Technical University of Athens, Athens, Greece
G. Bakas, K. Kousouris, I. Papakrivopoulos, G. Tsipolitis, A. Zacharopoulou

University of Ioánnina, Ioánnina, Greece
I. Evangelou, C. Foudas, P. Gianneios, P. Katsoulis, P. Kokkas, N. Manthos, I. Papadopou-

los, J. Strologas

MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
M. Csanad, K. Farkas, M.M.A. Gadallah[25], S. Lökös[26], P. Major, K. Mandal, A. Mehta, G. Pasztor, A.J. Rádl, O. Surányi, G.I. Veres

Wigner Research Centre for Physics, Budapest, Hungary
M. Bartók[27], G. Bencze, C. Hajdu, D. Horvath[28], F. Sikler, V. Veszpremi, G. Vesztergombi[†]

Institute of Nuclear Research ATOMKI, Debrecen, Hungary
S. Czellar, J. Karancsi[27], J. Molnar, Z. Szillasi, D. Teyssier

Institute of Physics, University of Debrecen, Debrecen, Hungary
P. Raics, Z.L. Trocsanyi[29], G. Zilizi

Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary
T. Csorgo[30], F. Nemes[30], T. Novak

Indian Institute of Science (IISc), Bangalore, India
J.R. Komaragiri, D. Kumar, L. Panwar, P.C. Tiwari

National Institute of Science Education and Research, HBNI, Bhubaneswar, India
S. Bahinipati[31], C. Kar, P. Mal, T. Mishra, V.K. Muraleedharan Nair Bindhu[32], A. Nayak[32], P. Saha, N. Sur, S.K. Swain, D. Vats[32]

Panjab University, Chandigarh, India
S. Bansal, S.B. Beri, V. Bhatnagar, G. Chaudhary, S. Chauhan, N. Dhingra[33], R. Gupta, A. Kaur, M. Kaur, S. Kaur, P. Kumari, M. Meena, K. Sandeep, J.B. Singh, A.K. Virdi

University of Delhi, Delhi, India
A. Ahmed, A. Bhardwaj, B.C. Choudhary, M. Gola, S. Keshri, A. Kumar, M. Naimuddin, P. Priyanka, K. Ranjan, A. Shah

Saha Institute of Nuclear Physics, HBNI, Kolkata, India
M. Bharti[34], R. Bhattacharya, S. Bhattacharya, D. Bhowmik, S. Dutta, S. Dutta, B. Gomber[35], M. Maity[36], P. Palit, P.K. Rout, G. Saha, B. Sahu, S. Sarkar, M. Sharan, B. Singh[34], S. Thakur[34]

Indian Institute of Technology Madras, Madras, India
P.K. Behera, S.C. Behera, P. Kalbhor, A. Muhammad, R. Pradhan, P.R. Pujahari, A. Sharma, A.K. Sikdar

Bhabha Atomic Research Centre, Mumbai, India
D. Dutta, V. Jha, V. Kumar, D.K. Mishra, K. Naskar[37], P.K. Netrakanti, L.M. Pant, P. Shukla

Tata Institute of Fundamental Research-A, Mumbai, India
T. Aziz, S. Dugad, M. Kumar, U. Sarkar

Tata Institute of Fundamental Research-B, Mumbai, India
S. Banerjee, R. Chudasama, M. Guchait, S. Karmakar, S. Kumar, G. Majumder, K. Mazumdar, S. Mukherjee

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

K. Alpana, S. Dube, B. Kansal, A. Laha, S. Pandey, A. Rane, A. Rastogi, S. Sharma

Isfahan University of Technology, Isfahan, Iran
H. Bakhshiansohi[38], E. Khazaie, M. Zeinali[39]

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
S. Chenarani[40], S.M. Etesami, M. Khakzad, M. Mohammadi Najafabadi

University College Dublin, Dublin, Ireland
M. Grunewald

INFN Sezione di Bari [a], Bari, Italy, Università di Bari [b], Bari, Italy, Politecnico di Bari [c], Bari, Italy
M. Abbrescia[a,b], R. Aly[a,b,41], C. Aruta[a,b], A. Colaleo[a], D. Creanza[a,c], N. De Filippis[a,c], M. De Palma[a,b], A. Di Florio[a,b], A. Di Pilato[a,b], W. Elmetenawee[a,b], L. Fiore[a], A. Gelmi[a,b], M. Gul[a], G. Iaselli[a,c], M. Ince[a,b], S. Lezki[a,b], G. Maggi[a,c], M. Maggi[a], I. Margjeka[a,b], V. Mastrapasqua[a,b], J.A. Merlin[a], S. My[a,b], S. Nuzzo[a,b], A. Pellecchia[a,b], A. Pompili[a,b], G. Pugliese[a,c], A. Ranieri[a], G. Selvaggi[a,b], L. Silvestris[a], F.M. Simone[a,b], R. Venditti[a], P. Verwilligen[a]

INFN Sezione di Bologna [a], Bologna, Italy, Università di Bologna [b], Bologna, Italy
G. Abbiendi[a], C. Battilana[a,b], D. Bonacorsi[a,b], L. Borgonovi[a], L. Brigliadori[a], R. Campanini[a,b], P. Capiluppi[a,b], A. Castro[a,b], F.R. Cavallo[a], M. Cuffiani[a,b], G.M. Dallavalle[a], T. Diotalevi[a,b], F. Fabbri[a], A. Fanfani[a,b], P. Giacomelli[a], L. Giommi[a,b], C. Grandi[a], L. Guiducci[a,b], S. Lo Meo[a,42], L. Lunerti[a,b], S. Marcellini[a], G. Masetti[a], F.L. Navarria[a,b], A. Perrotta[a], F. Primavera[a,b], A.M. Rossi[a,b], T. Rovelli[a,b], G.P. Siroli[a,b]

INFN Sezione di Catania [a], Catania, Italy, Università di Catania [b], Catania, Italy
S. Albergo[a,b,43], S. Costa[a,b,43], A. Di Mattia[a], R. Potenza[a,b], A. Tricomi[a,b,43], C. Tuve[a,b]

INFN Sezione di Firenze [a], Firenze, Italy, Università di Firenze [b], Firenze, Italy
G. Barbagli[a], A. Cassese[a], R. Ceccarelli[a,b], V. Ciulli[a,b], C. Civinini[a], R. D'Alessandro[a,b], E. Focardi[a,b], G. Latino[a,b], P. Lenzi[a,b], M. Lizzo[a,b], M. Meschini[a], S. Paoletti[a], R. Seidita[a,b], G. Sguazzoni[a], L. Viliani[a]

INFN Laboratori Nazionali di Frascati, Frascati, Italy
L. Benussi, S. Bianco, D. Piccolo

INFN Sezione di Genova [a], Genova, Italy, Università di Genova [b], Genova, Italy
M. Bozzo[a,b], F. Ferro[a], R. Mulargia[a,b], E. Robutti[a], S. Tosi[a,b]

INFN Sezione di Milano-Bicocca [a], Milano, Italy, Università di Milano-Bicocca [b], Milano, Italy
A. Benaglia[a], F. Brivio[a,b], F. Cetorelli[a,b], V. Ciriolo[a,b,20], F. De Guio[a,b], M.E. Dinardo[a,b], P. Dini[a], S. Gennai[a], A. Ghezzi[a,b], P. Govoni[a,b], L. Guzzi[a,b], M. Malberti[a], S. Malvezzi[a], A. Massironi[a], D. Menasce[a], L. Moroni[a], M. Paganoni[a,b], D. Pedrini[a], S. Ragazzi[a,b], N. Redaelli[a], T. Tabarelli de Fatis[a,b], D. Valsecchi[a,b,20], D. Zuolo[a,b]

INFN Sezione di Napoli [a], Napoli, Italy, Università di Napoli 'Federico II' [b], Napoli, Italy, Università della Basilicata [c], Potenza, Italy, Università G. Marconi [d], Roma, Italy
S. Buontempo[a], F. Carnevali[a,b], N. Cavallo[a,c], A. De Iorio[a,b], F. Fabozzi[a,c], A.O.M. Iorio[a,b], L. Lista[a,b], S. Meola[a,d,20], P. Paolucci[a,20], B. Rossi[a], C. Sciacca[a,b]

INFN Sezione di Padova [a], Padova, Italy, Università di Padova [b], Padova, Italy, Università di Trento [c], Trento, Italy
P. Azzi[a], N. Bacchetta[a], D. Bisello[a,b], P. Bortignon[a], A. Bragagnolo[a,b], R. Carlin[a,b], P. Checchia[a], T. Dorigo[a], U. Dosselli[a], F. Gasparini[a,b], U. Gasparini[a,b], G. Grosso, S.Y. Hoh[a,b], L. Layer[a,44], E. Lusiani, M. Margoni[a,b], A.T. Meneguzzo[a,b], J. Pazzini[a,b], M. Presilla[a,b], P. Ronchese[a,b], R. Rossin[a,b], F. Simonetto[a,b], G. Strong[a], M. Tosi[a,b], H. YARAR[a,b], M. Zanetti[a,b], P. Zotto[a,b], A. Zucchetta[a,b], G. Zumerle[a,b]

INFN Sezione di Pavia [a], Pavia, Italy, Università di Pavia [b], Pavia, Italy
C. Aime'[a,b], A. Braghieri[a], S. Calzaferri[a,b], D. Fiorina[a,b], P. Montagna[a,b], S.P. Ratti[a,b], V. Re[a], C. Riccardi[a,b], P. Salvini[a], I. Vai[a], P. Vitulo[a,b]

INFN Sezione di Perugia [a], Perugia, Italy, Università di Perugia [b], Perugia, Italy
P. Asenov[a,45], G.M. Bilei[a], D. Ciangottini[a,b], L. Fanò[a,b], P. Lariccia[a,b], M. Magherini[b], G. Mantovani[a,b], V. Mariani[a,b], M. Menichelli[a], F. Moscatelli[a,45], A. Piccinelli[a,b], A. Rossi[a,b], A. Santocchia[a,b], D. Spiga[a], T. Tedeschi[a,b]

INFN Sezione di Pisa [a], Pisa, Italy, Università di Pisa [b], Pisa, Italy, Scuola Normale Superiore di Pisa [c], Pisa, Italy, Università di Siena [d], Siena, Italy
P. Azzurri[a], G. Bagliesi[a], V. Bertacchi[a,c], L. Bianchini[a], T. Boccali[a], E. Bossini[a,b], R. Castaldi[a], M.A. Ciocci[a,b], V. D'Amante[a,d], R. Dell'Orso[a], M.R. Di Domenico[a,d], S. Donato[a], A. Giassi[a], F. Ligabue[a,c], E. Manca[a,c], G. Mandorli[a,c], A. Messineo[a,b], F. Palla[a], S. Parolia[a,b], G. Ramirez-Sanchez[a,c], A. Rizzi[a,b], G. Rolandi[a,c], S. Roy Chowdhury[a,c], A. Scribano[a], N. Shafiei[a,b], P. Spagnolo[a], R. Tenchini[a], G. Tonelli[a,b], N. Turini[a,d], A. Venturi[a], P.G. Verdini[a]

INFN Sezione di Roma [a], Rome, Italy, Sapienza Università di Roma [b], Rome, Italy
M. Campana[a,b], F. Cavallari[a], D. Del Re[a,b], E. Di Marco[a], M. Diemoz[a], E. Longo[a,b], P. Meridiani[a], G. Organtini[a,b], F. Pandolfi[a], R. Paramatti[a,b], C. Quaranta[a,b], S. Rahatlou[a,b], C. Rovelli[a], F. Santanastasio[a,b], L. Soffi[a], R. Tramontano[a,b]

INFN Sezione di Torino [a], Torino, Italy, Università di Torino [b], Torino, Italy, Università del Piemonte Orientale [c], Novara, Italy
N. Amapane[a,b], R. Arcidiacono[a,c], S. Argiro[a,b], M. Arneodo[a,c], N. Bartosik[a], R. Bellan[a,b], A. Bellora[a,b], J. Berenguer Antequera[a,b], C. Biino[a], N. Cartiglia[a], S. Cometti[a], M. Costa[a,b], R. Covarelli[a,b], N. Demaria[a], B. Kiani[a,b], F. Legger[a], C. Mariotti[a], S. Maselli[a], E. Migliore[a,b], E. Monteil[a,b], M. Monteno[a], M.M. Obertino[a,b], G. Ortona[a], L. Pacher[a,b], N. Pastrone[a], M. Pelliccioni[a], G.L. Pinna Angioni[a,b], M. Ruspa[a,c], K. Shchelina[a,b], F. Siviero[a,b], V. Sola[a], A. Solano[a,b], D. Soldi[a,b], A. Staiano[a], M. Tornago[a,b], D. Trocino[a,b], A. Vagnerini

INFN Sezione di Trieste [a], Trieste, Italy, Università di Trieste [b], Trieste, Italy
S. Belforte[a], V. Candelise[a,b], M. Casarsa[a], F. Cossutti[a], A. Da Rold[a,b], G. Della Ricca[a,b], G. Sorrentino[a,b], F. Vazzoler[a,b]

Kyungpook National University, Daegu, Korea
S. Dogra, C. Huh, B. Kim, D.H. Kim, G.N. Kim, J. Kim, J. Lee, S.W. Lee, C.S. Moon, Y.D. Oh, S.I. Pak, B.C. Radburn-Smith, S. Sekmen, Y.C. Yang

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
H. Kim, D.H. Moon

Hanyang University, Seoul, Korea
B. Francois, T.J. Kim, J. Park

Korea University, Seoul, Korea
S. Cho, S. Choi, Y. Go, B. Hong, K. Lee, K.S. Lee, J. Lim, J. Park, S.K. Park, J. Yoo

Kyung Hee University, Department of Physics, Seoul, Republic of Korea, Seoul, Korea
J. Goh, A. Gurtu

Sejong University, Seoul, Korea
H.S. Kim, Y. Kim

Seoul National University, Seoul, Korea
J. Almond, J.H. Bhyun, J. Choi, S. Jeon, J. Kim, J.S. Kim, S. Ko, H. Kwon, H. Lee, S. Lee, B.H. Oh, M. Oh, S.B. Oh, H. Seo, U.K. Yang, I. Yoon

University of Seoul, Seoul, Korea
W. Jang, D.Y. Kang, Y. Kang, S. Kim, B. Ko, J.S.H. Lee, Y. Lee, I.C. Park, Y. Roh, M.S. Ryu, D. Song, I.J. Watson, S. Yang

Yonsei University, Department of Physics, Seoul, Korea
S. Ha, H.D. Yoo

Sungkyunkwan University, Suwon, Korea
M. Choi, Y. Jeong, H. Lee, Y. Lee, I. Yu

College of Engineering and Technology, American University of the Middle East (AUM), Egaila, Kuwait, Dasman, Kuwait
T. Beyrouthy, Y. Maghrbi

Riga Technical University, Riga, Latvia
T. Torims, V. Veckalns[46]

Vilnius University, Vilnius, Lithuania
M. Ambrozas, A. Carvalho Antunes De Oliveira, A. Juodagalvis, A. Rinkevicius, G. Tamulaitis

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
N. Bin Norjoharuddeen, W.A.T. Wan Abdullah, M.N. Yusli, Z. Zolkapli

Universidad de Sonora (UNISON), Hermosillo, Mexico
J.F. Benitez, A. Castaneda Hernandez, M. León Coello, J.A. Murillo Quijada, A. Sehrawat, L. Valencia Palomo

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
G. Ayala, H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz[47], R. Lopez-Fernandez, C.A. Mondragon Herrera, D.A. Perez Navarro, A. Sánchez Hernández

Universidad Iberoamericana, Mexico City, Mexico
S. Carrillo Moreno, C. Oropeza Barrera, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
I. Pedraza, H.A. Salazar Ibarguen, C. Uribe Estrada

University of Montenegro, Podgorica, Montenegro
J. Mijuskovic[48], N. Raicevic

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand
S. Bheesette, P.H. Butler

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
A. Ahmad, M.I. Asghar, A. Awais, M.I.M. Awan, H.R. Hoorani, W.A. Khan, M.A. Shah, M. Shoaib, M. Waqas

AGH University of Science and Technology Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland
V. Avati, L. Grzanka, M. Malawski

National Centre for Nuclear Research, Swierk, Poland
H. Bialkowska, M. Bluj, B. Boimska, M. Górski, M. Kazana, M. Szleper, P. Zalewski

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
K. Bunkowski, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Walczak

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
M. Araujo, P. Bargassa, D. Bastos, A. Boletti, P. Faccioli, M. Gallinaro, J. Hollar, N. Leonardo, T. Niknejad, M. Pisano, J. Seixas, O. Toldaiev, J. Varela

Joint Institute for Nuclear Research, Dubna, Russia
S. Afanasiev, D. Budkouski, I. Golutvin, I. Gorbunov, V. Karjavine, V. Korenkov, A. Lanev, A. Malakhov, V. Matveev[49,50], V. Palichik, V. Perelygin, M. Savina, D. Seitova, V. Shalaev, S. Shmatov, S. Shulha, V. Smirnov, O. Teryaev, N. Voytishin, B.S. Yuldashev[51], A. Zarubin, I. Zhizhin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
G. Gavrilov, V. Golovtcov, Y. Ivanov, V. Kim[52], E. Kuznetsova[53], V. Murzin, V. Oreshkin, I. Smirnov, D. Sosnov, V. Sulimov, L. Uvarov, S. Volkov, A. Vorobyev

Institute for Nuclear Research, Moscow, Russia
Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, A. Karneyeu, D. Kirpichnikov, M. Kirsanov, N. Krasnikov, A. Pashenkov, G. Pivovarov, D. Tlisov[†], A. Toropin

Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC 'Kurchatov Institute', Moscow, Russia
V. Epshteyn, V. Gavrilov, N. Lychkovskaya, A. Nikitenko[54], V. Popov, A. Spiridonov, A. Stepennov, M. Toms, E. Vlasov, A. Zhokin

Moscow Institute of Physics and Technology, Moscow, Russia
T. Aushev

National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
R. Chistov[55], M. Danilov[55], A. Oskin, P. Parygin, S. Polikarpov[55]

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

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
A. Belyaev, E. Boos, V. Bunichev, M. Dubinin[56], L. Dudko, A. Ershov, V. Klyukhin, N. Korneeva, I. Lokhtin, S. Obraztsov, M. Perfilov, V. Savrin, P. Volkov

Novosibirsk State University (NSU), Novosibirsk, Russia
V. Blinov[57], T. Dimova[57], L. Kardapoltsev[57], A. Kozyrev[57], I. Ovtin[57], Y. Skovpen[57]

Institute for High Energy Physics of National Research Centre 'Kurchatov Institute', Protvino, Russia
I. Azhgirey, I. Bayshev, D. Elumakhov, V. Kachanov, D. Konstantinov, P. Mandrik, V. Petrov, R. Ryutin, S. Slabospitskii, A. Sobol, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

National Research Tomsk Polytechnic University, Tomsk, Russia
A. Babaev, V. Okhotnikov

Tomsk State University, Tomsk, Russia
V. Borshch, V. Ivanchenko, E. Tcherniaev

University of Belgrade: Faculty of Physics and VINCA Institute of Nuclear Sciences, Belgrade, Serbia
P. Adzic[58], M. Dordevic, P. Milenovic, J. Milosevic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
M. Aguilar-Benitez, J. Alcaraz Maestre, A. Álvarez Fernández, I. Bachiller, M. Barrio Luna, Cristina F. Bedoya, C.A. Carrillo Montoya, M. Cepeda, M. Cerrada, N. Colino, B. De La Cruz, A. Delgado Peris, J.P. Fernández Ramos, J. Flix, M.C. Fouz, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, J. León Holgado, D. Moran, Á. Navarro Tobar, C. Perez Dengra, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, I. Redondo, L. Romero, S. Sánchez Navas, L. Urda Gómez, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain
J.F. de Trocóniz, R. Reyes-Almanza

Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain
B. Alvarez Gonzalez, J. Cuevas, C. Erice, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, J.R. González Fernández, E. Palencia Cortezon, C. Ramón Álvarez, V. Rodríguez Bouza, A. Trapote, N. Trevisani

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, J. Duarte Campderros, M. Fernandez, C. Fernandez Madrazo, P.J. Fernández Manteca, A. García Alonso, G. Gomez, C. Martinez Rivero, P. Martinez Ruiz del Arbol, F. Matorras, P. Matorras Cuevas, J. Piedra Gomez, C. Prieels, T. Rodrigo, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, J.M. Vizan Garcia

University of Colombo, Colombo, Sri Lanka
M.K. Jayananda, B. Kailasapathy[59], D.U.J. Sonnadara, D.D.C. Wickramarathna

University of Ruhuna, Department of Physics, Matara, Sri Lanka
W.G.D. Dharmaratna, K. Liyanage, N. Perera, N. Wickramage

CERN, European Organization for Nuclear Research, Geneva, Switzerland
T.K. Aarrestad, D. Abbaneo, J. Alimena, E. Auffray, G. Auzinger, J. Baechler, P. Baillon[†], D. Barney, J. Bendavid, M. Bianco, A. Bocci, T. Camporesi, M. Capeans Garrido, G. Cerminara, S.S. Chhibra, M. Cipriani, L. Cristella, D. d'Enterria, A. Dabrowski, A. David, A. De Roeck, M.M. Defranchis, M. Deile, M. Dobson, M. Dünser, N. Dupont, A. Elliott-Peisert, N. Emriskova, F. Fallavollita[60], D. Fasanella, A. Florent,

G. Franzoni, W. Funk, S. Giani, D. Gigi, K. Gill, F. Glege, L. Gouskos, M. Haranko, J. Hegeman, Y. Iiyama, V. Innocente, T. James, P. Janot, J. Kaspar, J. Kieseler, M. Komm, N. Kratochwil, C. Lange, S. Laurila, P. Lecoq, K. Long, C. Lourenço, L. Malgeri, S. Mallios, M. Mannelli, A.C. Marini, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, M. Mulders, S. Orfanelli, L. Orsini, F. Pantaleo, L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, D. Piparo, M. Pitt, H. Qu, T. Quast, D. Rabady, A. Racz, G. Reales Gutiérrez, M. Rieger, M. Rovere, H. Sakulin, J. Salfeld-Nebgen, S. Scarfi, C. Schäfer, C. Schwick, M. Selvaggi, A. Sharma, P. Silva, W. Snoeys, P. Sphicas[61], S. Summers, K. Tatar, V.R. Tavolaro, D. Treille, A. Tsirou, G.P. Van Onsem, J. Wanczyk[62], K.A. Wozniak, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland
L. Caminada[63], A. Ebrahimi, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, D. Kotlinski, U. Langenegger, M. Missiroli, T. Rohe

ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
K. Androsov[62], M. Backhaus, P. Berger, A. Calandri, N. Chernyavskaya, A. De Cosa, G. Dissertori, M. Dittmar, M. Donegà, C. Dorfer, F. Eble, K. Gedia, F. Glessgen, T.A. Gómez Espinosa, C. Grab, D. Hits, W. Lustermann, A.-M. Lyon, R.A. Manzoni, C. Martin Perez, M.T. Meinhard, F. Nessi-Tedaldi, J. Niedziela, F. Pauss, V. Perovic, S. Pigazzini, M.G. Ratti, M. Reichmann, C. Reissel, T. Reitenspiess, B. Ristic, D. Ruini, D.A. Sanz Becerra, M. Schönenberger, V. Stampf, J. Steggemann[62], R. Wallny, D.H. Zhu

Universität Zürich, Zurich, Switzerland
C. Amsler[64], P. Bärtschi, C. Botta, D. Brzhechko, M.F. Canelli, K. Cormier, A. De Wit, R. Del Burgo, J.K. Heikkilä, M. Huwiler, W. Jin, A. Jofrehei, B. Kilminster, S. Leontsinis, S.P. Liechti, A. Macchiolo, P. Meiring, V.M. Mikuni, U. Molinatti, I. Neutelings, A. Reimers, P. Robmann, S. Sanchez Cruz, K. Schweiger, Y. Takahashi

National Central University, Chung-Li, Taiwan
C. Adloff[65], C.M. Kuo, W. Lin, A. Roy, T. Sarkar[36], S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan
L. Ceard, Y. Chao, K.F. Chen, P.H. Chen, W.-S. Hou, Y.y. Li, R.-S. Lu, E. Paganis, A. Psallidas, A. Steen, H.y. Wu, E. Yazgan, P.r. Yu

Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand
B. Asavapibhop, C. Asawatangtrakuldee, N. Srimanobhas

Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
F. Boran, S. Damarseckin[66], Z.S. Demiroglu, F. Dolek, I. Dumanoglu[67], E. Eskut, Y. Guler, E. Gurpinar Guler[68], I. Hos[69], C. Isik, O. Kara, A. Kayis Topaksu, U. Kiminsu, G. Onengut, K. Ozdemir[70], A. Polatoz, A.E. Simsek, B. Tali[71], U.G. Tok, S. Turkcapar, I.S. Zorbakir, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey
B. Isildak[72], G. Karapinar[73], K. Ocalan[74], M. Yalvac[75]

Bogazici University, Istanbul, Turkey
B. Akgun, I.O. Atakisi, E. Gülmez, M. Kaya[76], O. Kaya[77], Ö. Özçelik, S. Tekten[78], E.A. Yetkin[79]

Istanbul Technical University, Istanbul, Turkey

A. Cakir, K. Cankocak[67], Y. Komurcu, S. Sen[80]

Istanbul University, Istanbul, Turkey
S. Cerci[71], B. Kaynak, S. Ozkorucuklu, D. Sunar Cerci[71]

Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine
B. Grynyov

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

University of Bristol, Bristol, United Kingdom
D. Anthony, E. Bhal, S. Bologna, J.J. Brooke, A. Bundock, E. Clement, D. Cussans, H. Flacher, J. Goldstein, G.P. Heath, H.F. Heath, M.-L. Holmberg[81], L. Kreczko, B. Krikler, S. Paramesvaran, S. Seif El Nasr-Storey, V.J. Smith, N. Stylianou[82], K. Walkingshaw Pass, R. White

Rutherford Appleton Laboratory, Didcot, United Kingdom
K.W. Bell, A. Belyaev[83], C. Brew, R.M. Brown, D.J.A. Cockerill, C. Cooke, K.V. Ellis, K. Harder, S. Harper, J. Linacre, K. Manolopoulos, D.M. Newbold, E. Olaiya, D. Petyt, T. Reis, T. Schuh, C.H. Shepherd-Themistocleous, I.R. Tomalin, T. Williams

Imperial College, London, United Kingdom
R. Bainbridge, P. Bloch, S. Bonomally, J. Borg, S. Breeze, O. Buchmuller, V. Cepaitis, G.S. Chahal[84], D. Colling, P. Dauncey, G. Davies, M. Della Negra, S. Fayer, G. Fedi, G. Hall, M.H. Hassanshahi, G. Iles, J. Langford, L. Lyons, A.-M. Magnan, S. Malik, A. Martelli, D.G. Monk, J. Nash[85], M. Pesaresi, D.M. Raymond, A. Richards, A. Rose, E. Scott, C. Seez, A. Shtipliyski, A. Tapper, K. Uchida, T. Virdee[20], M. Vojinovic, N. Wardle, S.N. Webb, D. Winterbottom

Brunel University, Uxbridge, United Kingdom
K. Coldham, J.E. Cole, A. Khan, P. Kyberd, I.D. Reid, L. Teodorescu, S. Zahid

Baylor University, Waco, Texas, USA
S. Abdullin, A. Brinkerhoff, B. Caraway, J. Dittmann, K. Hatakeyama, A.R. Kanuganti, B. McMaster, N. Pastika, M. Saunders, S. Sawant, C. Sutantawibul, J. Wilson

Catholic University of America, Washington, DC, USA
R. Bartek, A. Dominguez, R. Uniyal, A.M. Vargas Hernandez

The University of Alabama, Tuscaloosa, Alabama, USA
A. Buccilli, S.I. Cooper, D. Di Croce, S.V. Gleyzer, C. Henderson, C.U. Perez, P. Rumerio[86], C. West

Boston University, Boston, Massachusetts, USA
A. Akpinar, A. Albert, D. Arcaro, C. Cosby, Z. Demiragli, E. Fontanesi, D. Gastler, J. Rohlf, K. Salyer, D. Sperka, D. Spitzbart, I. Suarez, A. Tsatsos, S. Yuan, D. Zou

Brown University, Providence, Rhode Island, USA
G. Benelli, B. Burkle, X. Coubez[21], D. Cutts, M. Hadley, U. Heintz, J.M. Hogan[87], G. Landsberg, K.T. Lau, M. Lukasik, J. Luo, M. Narain, S. Sagir[88], E. Usai, W.Y. Wong, X. Yan, D. Yu, W. Zhang

University of California, Davis, Davis, California, USA

J. Bonilla, C. Brainerd, R. Breedon, M. Calderon De La Barca Sanchez, M. Chertok, J. Conway, P.T. Cox, R. Erbacher, G. Haza, F. Jensen, O. Kukral, R. Lander, M. Mulhearn, D. Pellett, B. Regnery, D. Taylor, Y. Yao, F. Zhang

University of California, Los Angeles, California, USA
M. Bachtis, R. Cousins, A. Datta, D. Hamilton, J. Hauser, M. Ignatenko, M.A. Iqbal, T. Lam, W.A. Nash, S. Regnard, D. Saltzberg, B. Stone, V. Valuev

University of California, Riverside, Riverside, California, USA
K. Burt, Y. Chen, R. Clare, J.W. Gary, M. Gordon, G. Hanson, G. Karapostoli, O.R. Long, N. Manganelli, M. Olmedo Negrete, W. Si, S. Wimpenny, Y. Zhang

University of California, San Diego, La Jolla, California, USA
J.G. Branson, P. Chang, S. Cittolin, S. Cooperstein, N. Deelen, D. Diaz, J. Duarte, R. Gerosa, L. Giannini, D. Gilbert, J. Guiang, R. Kansal, V. Krutelyov, R. Lee, J. Letts, M. Masciovecchio, S. May, M. Pieri, B.V. Sathia Narayanan, V. Sharma, M. Tadel, A. Vartak, F. Würthwein, Y. Xiang, A. Yagil

University of California, Santa Barbara - Department of Physics, Santa Barbara, California, USA
N. Amin, C. Campagnari, M. Citron, A. Dorsett, V. Dutta, J. Incandela, M. Kilpatrick, J. Kim, B. Marsh, H. Mei, M. Oshiro, M. Quinnan, J. Richman, U. Sarica, F. Setti, J. Sheplock, D. Stuart, S. Wang

California Institute of Technology, Pasadena, California, USA
A. Bornheim, O. Cerri, I. Dutta, J.M. Lawhorn, N. Lu, J. Mao, H.B. Newman, T.Q. Nguyen, M. Spiropulu, J.R. Vlimant, C. Wang, S. Xie, Z. Zhang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, Pennsylvania, USA
J. Alison, S. An, M.B. Andrews, P. Bryant, T. Ferguson, A. Harilal, C. Liu, T. Mudholkar, M. Paulini, A. Sanchez, W. Terrill

University of Colorado Boulder, Boulder, Colorado, USA
J.P. Cumalat, W.T. Ford, A. Hassani, E. MacDonald, R. Patel, A. Perloff, C. Savard, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, New York, USA
J. Alexander, S. Bright-Thonney, Y. Cheng, D.J. Cranshaw, S. Hogan, J. Monroy, J.R. Patterson, D. Quach, J. Reichert, M. Reid, A. Ryd, W. Sun, J. Thom, P. Wittich, R. Zou

Fermi National Accelerator Laboratory, Batavia, Illinois, USA
M. Albrow, M. Alyari, G. Apollinari, A. Apresyan, A. Apyan, S. Banerjee, L.A.T. Bauerdick, D. Berry, J. Berryhill, P.C. Bhat, K. Burkett, J.N. Butler, A. Canepa, G.B. Cerati, H.W.K. Cheung, F. Chlebana, M. Cremonesi, K.F. Di Petrillo, V.D. Elvira, Y. Feng, J. Freeman, Z. Gecse, L. Gray, D. Green, S. Grünendahl, O. Gutsche, R.M. Harris, R. Heller, T.C. Herwig, J. Hirschauer, B. Jayatilaka, S. Jindariani, M. Johnson, U. Joshi, T. Klijnsma, B. Klima, K.H.M. Kwok, S. Lammel, D. Lincoln, R. Lipton, T. Liu, C. Madrid, K. Maeshima, C. Mantilla, D. Mason, P. McBride, P. Merkel, S. Mrenna, S. Nahn, J. Ngadiuba, V. O'Dell, V. Papadimitriou, K. Pedro, C. Pena[56], O. Prokofyev, F. Ravera, A. Reinsvold Hall, L. Ristori, B. Schneider, E. Sexton-Kennedy, N. Smith, A. Soha, W.J. Spalding, L. Spiegel, S. Stoynev, J. Strait, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, H.A. Weber

University of Florida, Gainesville, Florida, USA
D. Acosta, P. Avery, D. Bourilkov, L. Cadamuro, V. Cherepanov, F. Errico, R.D. Field, D. Guerrero, B.M. Joshi, M. Kim, E. Koenig, J. Konigsberg, A. Korytov, K.H. Lo, K. Matchev, N. Menendez, G. Mitselmakher, A. Muthirakalayil Madhu, N. Rawal, D. Rosenzweig, S. Rosenzweig, K. Shi, J. Sturdy, J. Wang, E. Yigitbasi, X. Zuo

Florida State University, Tallahassee, Florida, USA
T. Adams, A. Askew, R. Habibullah, V. Hagopian, K.F. Johnson, R. Khurana, T. Kolberg, G. Martinez, H. Prosper, C. Schiber, O. Viazlo, R. Yohay, J. Zhang

Florida Institute of Technology, Melbourne, Florida, USA
M.M. Baarmand, S. Butalla, T. Elkafrawy[15], M. Hohlmann, R. Kumar Verma, D. Noonan, M. Rahmani, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, Illinois, USA
M.R. Adams, H. Becerril Gonzalez, R. Cavanaugh, X. Chen, S. Dittmer, O. Evdokimov, C.E. Gerber, D.A. Hangal, D.J. Hofman, A.H. Merrit, C. Mills, G. Oh, T. Roy, S. Rudrabhatla, M.B. Tonjes, N. Varelas, J. Viinikainen, X. Wang, Z. Wu, Z. Ye

The University of Iowa, Iowa City, Iowa, USA
M. Alhusseini, K. Dilsiz[89], R.P. Gandrajula, O.K. Köseyan, J.-P. Merlo, A. Mestvirishvili[90], J. Nachtman, H. Ogul[91], Y. Onel, A. Penzo, C. Snyder, E. Tiras[92]

Johns Hopkins University, Baltimore, Maryland, USA
O. Amram, B. Blumenfeld, L. Corcodilos, J. Davis, M. Eminizer, A.V. Gritsan, S. Kyriacou, P. Maksimovic, J. Roskes, M. Swartz, T.Á. Vámi

The University of Kansas, Lawrence, Kansas, USA
A. Abreu, J. Anguiano, C. Baldenegro Barrera, P. Baringer, A. Bean, A. Bylinkin, Z. Flowers, T. Isidori, S. Khalil, J. King, G. Krintiras, A. Kropivnitskaya, M. Lazarovits, C. Lindsey, J. Marquez, N. Minafra, M. Murray, M. Nickel, C. Rogan, C. Royon, R. Salvatico, S. Sanders, E. Schmitz, C. Smith, J.D. Tapia Takaki, Q. Wang, Z. Warner, J. Williams, G. Wilson

Kansas State University, Manhattan, Kansas, USA
S. Duric, A. Ivanov, K. Kaadze, D. Kim, Y. Maravin, T. Mitchell, A. Modak, K. Nam

Lawrence Livermore National Laboratory, Livermore, California, USA
F. Rebassoo, D. Wright

University of Maryland, College Park, Maryland, USA
E. Adams, A. Baden, O. Baron, A. Belloni, S.C. Eno, N.J. Hadley, S. Jabeen, R.G. Kellogg, T. Koeth, A.C. Mignerey, S. Nabili, C. Palmer, M. Seidel, A. Skuja, L. Wang, K. Wong

Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
D. Abercrombie, G. Andreassi, R. Bi, S. Brandt, W. Busza, I.A. Cali, Y. Chen, M. D'Alfonso, J. Eysermans, C. Freer, G. Gomez Ceballos, M. Goncharov, P. Harris, M. Hu, M. Klute, D. Kovalskyi, J. Krupa, Y.-J. Lee, B. Maier, C. Mironov, C. Paus, D. Rankin, C. Roland, G. Roland, Z. Shi, G.S.F. Stephans, J. Wang, Z. Wang, B. Wyslouch

University of Minnesota, Minneapolis, Minnesota, USA
R.M. Chatterjee, A. Evans, P. Hansen, J. Hiltbrand, Sh. Jain, M. Krohn, Y. Kubota,

J. Mans, M. Revering, R. Rusack, R. Saradhy, N. Schroeder, N. Strobbe, M.A. Wadud

University of Nebraska-Lincoln, Lincoln, Nebraska, USA
K. Bloom, M. Bryson, S. Chauhan, D.R. Claes, C. Fangmeier, L. Finco, F. Golf, C. Joo, I. Kravchenko, M. Musich, I. Reed, J.E. Siado, G.R. Snow†, W. Tabb, F. Yan, A.G. Zecchinelli

State University of New York at Buffalo, Buffalo, New York, USA
G. Agarwal, H. Bandyopadhyay, L. Hay, I. Iashvili, A. Kharchilava, C. McLean, D. Nguyen, J. Pekkanen, S. Rappoccio, A. Williams

Northeastern University, Boston, Massachusetts, USA
G. Alverson, E. Barberis, Y. Haddad, A. Hortiangtham, J. Li, G. Madigan, B. Marzocchi, D.M. Morse, V. Nguyen, T. Orimoto, A. Parker, L. Skinnari, A. Tishelman-Charny, T. Wamorkar, B. Wang, A. Wisecarver, D. Wood

Northwestern University, Evanston, Illinois, USA
S. Bhattacharya, J. Bueghly, Z. Chen, A. Gilbert, T. Gunter, K.A. Hahn, Y. Liu, N. Odell, M.H. Schmitt, M. Velasco

University of Notre Dame, Notre Dame, Indiana, USA
R. Band, R. Bucci, A. Das, N. Dev, R. Goldouzian, M. Hildreth, K. Hurtado Anampa, C. Jessop, K. Lannon, J. Lawrence, N. Loukas, D. Lutton, N. Marinelli, I. Mcalister, T. McCauley, C. Mcgrady, F. Meng, K. Mohrman, Y. Musienko[49], R. Ruchti, P. Siddireddy, A. Townsend, M. Wayne, A. Wightman, M. Wolf, M. Zarucki, L. Zygala

The Ohio State University, Columbus, Ohio, USA
B. Bylsma, B. Cardwell, L.S. Durkin, B. Francis, C. Hill, M. Nunez Ornelas, K. Wei, B.L. Winer, B.R. Yates

Princeton University, Princeton, New Jersey, USA
F.M. Addesa, B. Bonham, P. Das, G. Dezoort, P. Elmer, A. Frankenthal, B. Greenberg, N. Haubrich, S. Higginbotham, A. Kalogeropoulos, G. Kopp, S. Kwan, D. Lange, M.T. Lucchini, D. Marlow, K. Mei, I. Ojalvo, J. Olsen, D. Stickland, C. Tully

University of Puerto Rico, Mayaguez, Puerto Rico, USA
S. Malik, S. Norberg

Purdue University, West Lafayette, Indiana, USA
A.S. Bakshi, V.E. Barnes, R. Chawla, S. Das, L. Gutay, M. Jones, A.W. Jung, S. Karmarkar, M. Liu, G. Negro, N. Neumeister, G. Paspalaki, C.C. Peng, S. Piperov, A. Purohit, J.F. Schulte, M. Stojanovic[16], J. Thieman, F. Wang, R. Xiao, W. Xie

Purdue University Northwest, Hammond, Indiana, USA
J. Dolen, N. Parashar

Rice University, Houston, Texas, USA
A. Baty, M. Decaro, S. Dildick, K.M. Ecklund, S. Freed, P. Gardner, F.J.M. Geurts, A. Kumar, W. Li, B.P. Padley, R. Redjimi, W. Shi, A.G. Stahl Leiton, S. Yang, L. Zhang, Y. Zhang

University of Rochester, Rochester, New York, USA
A. Bodek, P. de Barbaro, R. Demina, J.L. Dulemba, C. Fallon, T. Ferbel, M. Galanti, A. Garcia-Bellido, O. Hindrichs, A. Khukhunaishvili, E. Ranken, R. Taus

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

B. Chiarito, J.P. Chou, A. Gandrakota, Y. Gershtein, E. Halkiadakis, A. Hart, M. Heindl, O. Karacheban[24], I. Laflotte, A. Lath, R. Montalvo, K. Nash, M. Osherson, S. Salur, S. Schnetzer, S. Somalwar, R. Stone, S.A. Thayil, S. Thomas, H. Wang

University of Tennessee, Knoxville, Tennessee, USA
H. Acharya, A.G. Delannoy, S. Fiorendi, S. Spanier

Texas A&M University, College Station, Texas, USA
O. Bouhali[93], M. Dalchenko, A. Delgado, R. Eusebi, J. Gilmore, T. Huang, T. Kamon[94], H. Kim, S. Luo, S. Malhotra, R. Mueller, D. Overton, D. Rathjens, A. Safonov

Texas Tech University, Lubbock, Texas, USA
N. Akchurin, J. Damgov, V. Hegde, S. Kunori, K. Lamichhane, S.W. Lee, T. Mengke, S. Muthumuni, T. Peltola, I. Volobouev, Z. Wang, A. Whitbeck

Vanderbilt University, Nashville, Tennessee, USA
E. Appelt, S. Greene, A. Gurrola, W. Johns, A. Melo, H. Ni, K. Padeken, F. Romeo, P. Sheldon, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, Virginia, USA
M.W. Arenton, B. Cox, G. Cummings, J. Hakala, R. Hirosky, M. Joyce, A. Ledovskoy, A. Li, C. Neu, B. Tannenwald, S. White, E. Wolfe

Wayne State University, Detroit, Michigan, USA
N. Poudyal

University of Wisconsin - Madison, Madison, WI, Wisconsin, USA
K. Black, T. Bose, C. Caillol, S. Dasu, I. De Bruyn, P. Everaerts, F. Fienga, C. Galloni, H. He, M. Herndon, A. Hervé, U. Hussain, A. Lanaro, A. Loeliger, R. Loveless, J. Madhusudanan Sreekala, A. Mallampalli, A. Mohammadi, D. Pinna, A. Savin, V. Shang, V. Sharma, W.H. Smith, D. Teague, S. Trembath-Reichert, W. Vetens

†: Deceased
1: Also at TU Wien, Wien, Austria
2: Also at Institute of Basic and Applied Sciences, Faculty of Engineering, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt
3: Also at Université Libre de Bruxelles, Bruxelles, Belgium
4: Also at Universidade Estadual de Campinas, Campinas, Brazil
5: Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil
6: Also at University of Chinese Academy of Sciences, Beijing, China
7: Also at Department of Physics, Tsinghua University, Beijing, China
8: Also at UFMS, Nova Andradina, Brazil
9: Also at Nanjing Normal University Department of Physics, Nanjing, China
10: Now at The University of Iowa, Iowa City, Iowa, USA
11: Also at Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC ‘Kurchatov Institute’, Moscow, Russia
12: Also at Joint Institute for Nuclear Research, Dubna, Russia
13: Also at Cairo University, Cairo, Egypt
14: Also at British University in Egypt, Cairo, Egypt
15: Now at Ain Shams University, Cairo, Egypt
16: Also at Purdue University, West Lafayette, Indiana, USA
17: Also at Université de Haute Alsace, Mulhouse, France
18: Also at Tbilisi State University, Tbilisi, Georgia

19: Also at Erzincan Binali Yildirim University, Erzincan, Turkey
20: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
21: Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
22: Also at University of Hamburg, Hamburg, Germany
23: Also at Isfahan University of Technology, Isfahan, Iran
24: Also at Brandenburg University of Technology, Cottbus, Germany
25: Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt
26: Also at Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary
27: Also at Institute of Physics, University of Debrecen, Debrecen, Hungary
28: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
29: Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
30: Also at Wigner Research Centre for Physics, Budapest, Hungary
31: Also at IIT Bhubaneswar, Bhubaneswar, India
32: Also at Institute of Physics, Bhubaneswar, India
33: Also at G.H.G. Khalsa College, Punjab, India
34: Also at Shoolini University, Solan, India
35: Also at University of Hyderabad, Hyderabad, India
36: Also at University of Visva-Bharati, Santiniketan, India
37: Also at Indian Institute of Technology (IIT), Mumbai, India
38: Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany
39: Also at Sharif University of Technology, Tehran, Iran
40: Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran
41: Now at INFN Sezione di Bari, Università di Bari, Politecnico di Bari, Bari, Italy
42: Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy
43: Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy
44: Also at Università di Napoli 'Federico II', Napoli, Italy
45: Also at Consiglio Nazionale delle Ricerche - Istituto Officina dei Materiali, Perugia, Italy
46: Also at Riga Technical University, Riga, Latvia
47: Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico
48: Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
49: Also at Institute for Nuclear Research, Moscow, Russia
50: Now at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
51: Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan
52: Also at St. Petersburg Polytechnic University, St. Petersburg, Russia
53: Also at University of Florida, Gainesville, Florida, USA
54: Also at Imperial College, London, United Kingdom
55: Also at P.N. Lebedev Physical Institute, Moscow, Russia
56: Also at California Institute of Technology, Pasadena, California, USA
57: Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia
58: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
59: Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka
60: Also at INFN Sezione di Pavia, Università di Pavia, Pavia, Italy
61: Also at National and Kapodistrian University of Athens, Athens, Greece
62: Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland

63: Also at Universität Zürich, Zurich, Switzerland
64: Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria
65: Also at Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France
66: Also at Şırnak University, Sirnak, Turkey
67: Also at Near East University, Research Center of Experimental Health Science, Nicosia, Turkey
68: Also at Konya Technical University, Konya, Turkey
69: Also at Istanbul University - Cerrahpasa, Faculty of Engineering, Istanbul, Turkey
70: Also at Piri Reis University, Istanbul, Turkey
71: Also at Adiyaman University, Adiyaman, Turkey
72: Also at Ozyegin University, Istanbul, Turkey
73: Also at Izmir Institute of Technology, Izmir, Turkey
74: Also at Necmettin Erbakan University, Konya, Turkey
75: Also at Bozok Universitetesi Rektörlügü, Yozgat, Turkey
76: Also at Marmara University, Istanbul, Turkey
77: Also at Milli Savunma University, Istanbul, Turkey
78: Also at Kafkas University, Kars, Turkey
79: Also at Istanbul Bilgi University, Istanbul, Turkey
80: Also at Hacettepe University, Ankara, Turkey
81: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
82: Also at Vrije Universiteit Brussel, Brussel, Belgium
83: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
84: Also at IPPP Durham University, Durham, United Kingdom
85: Also at Monash University, Faculty of Science, Clayton, Australia
86: Also at Università di Torino, Torino, Italy
87: Also at Bethel University, St. Paul, Minneapolis, USA
88: Also at Karamanoğlu Mehmetbey University, Karaman, Turkey
89: Also at Bingol University, Bingol, Turkey
90: Also at Georgian Technical University, Tbilisi, Georgia
91: Also at Sinop University, Sinop, Turkey
92: Also at Erciyes University, Kayseri, Turkey
93: Also at Texas A&M University at Qatar, Doha, Qatar
94: Also at Kyungpook National University, Daegu, Korea