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Search for R-parity violating decays of a top squark in proton-proton collisions at $\sqrt{s} = 8$ TeV

The CMS Collaboration*

Abstract

The results of a search for a supersymmetric partner of the top quark (top squark), pair-produced in proton-proton collisions at $\sqrt{s} = 8$ TeV, are presented. The search, which focuses on R-parity violating, chargino-mediated decays of the top squark, is performed in final states with low missing transverse momentum, two oppositely charged electrons or muons, and at least five jets. The analysis uses a data sample corresponding to an integrated luminosity of 19.7 fb^{-1} collected with the CMS detector at the LHC in 2012. The data are found to be in agreement with the standard model expectation, and upper limits are placed on the top squark pair production cross section at 95% confidence level. Assuming a 100% branching fraction for the top squark decay chain, $\tilde{t} \rightarrow t\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \rightarrow \ell^\pm + \text{jj}$, top squark masses less than 890 (1000) GeV for the electron (muon) channel are excluded for the first time in models with a single nonzero R-parity violating coupling λ'_{ijk} ($i, j, k \leq 2$), where i, j, k correspond to the three generations.

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1 Introduction

Supersymmetry (SUSY) [1, 2] is an extension of the standard model (SM) that may provide a solution to the hierarchy problem [3, 4]. In the SUSY framework, quadratically divergent radiative corrections to the Higgs boson mass, dominated by loops involving the top quark, are canceled by loops with a supersymmetric partner of the top quark (top squark). The mass of the top squark is expected to be within a few hundred GeV of the top quark mass, and the supersymmetric Higgs boson partners are also expected to have masses less than 1 TeV [5, 6].

Searches for SUSY are performed in many decay channels and are classified into R-parity conserving (RPC) and R-parity violating (RPV) scenarios. The quantum number, R-parity, $P_R = (-1)^{3B+L+2s}$ has a value +1 for SM particles and -1 for superpartners, where B , L , and s are baryon number, lepton number, and spin, respectively [7]. In RPC models the top squark is expected to decay into the lightest SUSY particle, which escapes detection. This results in an event signature with substantial missing transverse momentum. Recent searches performed at the LHC at CERN in events with high missing transverse momentum have reduced the parameter space available for a low mass top squark [8–13]. However, R-parity may not be conserved, in which case searches for SUSY particle decaying to SM particles without substantial missing transverse momentum are important.

The superpotential terms that result in R-parity violation are given by:

$$W_{\text{RPV}} = \frac{1}{2} \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2} \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + \mu_i L_i H_u; \quad (1)$$

where λ_{ijk} , λ'_{ijk} , and λ''_{ijk} are three trilinear Yukawa couplings; $i, j, k = 1, 2, 3$ are generation indices; L and Q are the $SU(2)_L$ doublet superfields of the lepton and quark; H_u is the Higgs field that gives mass to the up-type quarks; μ_i are the bilinear terms that mix lepton and Higgs superfields, and \bar{E} , \bar{D} , and \bar{U} are the $SU(2)_L$ singlet superfields of the charged lepton, down-type quark, and up-type quark. The third term violates the conservation of baryon number, while the first two violate the conservation of lepton number. If baryon number and lepton number were both violated, proton decay would proceed at a rate excluded by experimental observations [14, 15]. To avoid these experimental constraints and to simplify the interpretation of results, it is commonly assumed that only one of the λ_{ijk} , λ'_{ijk} , or λ''_{ijk} couplings is different from zero. In this analysis only λ'_{ijk} couplings with $(i, j, k) \leq 2$ are considered.

In RPV SUSY models with the chargino $\tilde{\chi}_1^\pm$ lighter than the top squark and nonzero λ'_{ijk} , the top squark \tilde{t} can decay via $\tilde{t} \rightarrow b\tilde{\chi}_1^\pm$, with subsequent decay of the chargino to a lepton and two jets via an off-shell sneutrino ($\tilde{\chi}_1^\pm \rightarrow \ell^\pm + jj$) [16], as depicted in Fig. 1. The branching fraction of decay $\tilde{\chi}_1^\pm \rightarrow \nu + jj$ via an off-shell slepton will be negligible unless the slepton and sneutrino masses are comparable. The decay $\tilde{\chi}_1^\pm \rightarrow W^\pm \tilde{\chi}_1^0$ is suppressed for models with $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ almost degenerate in mass.

We perform a search for top squark decays, as depicted in Fig. 1, using proton-proton (pp) collisions at a center-of-mass energy of 8 TeV, corresponding to an integrated luminosity of 19.7 fb^{-1} , collected with the CMS detector at the LHC in 2012. As top squarks are expected to be dominantly pair-produced at the LHC [17], the search is performed using events with exactly two oppositely charged electrons ($e^\pm e^\mp$) or muons ($\mu^\pm \mu^\mp$), at least five jets of which one or more jet is identified as arising from hadronization of a bottom quark (b-tagged jet), and high S_T , where S_T is defined as the scalar sum of the transverse momenta of leptons and jets. As a consequence of the assumption that only one of the λ'_{ijk} couplings is nonzero, the two leptons must have opposite charge and the same flavor. Details of the event selection are described in

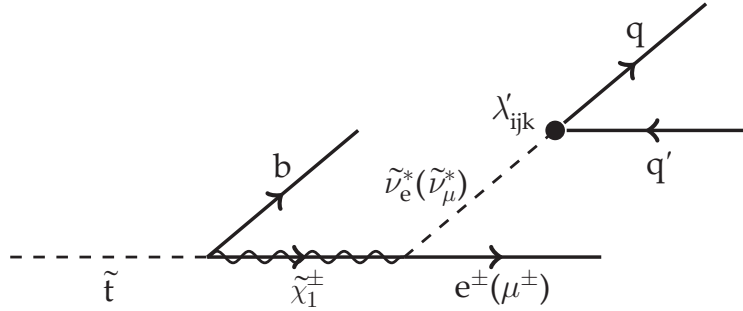


Figure 1: Diagram for the R-parity violating, chargino-mediated decay of a top squark. The chargino decays to a lepton and two jets via an off-shell sneutrino with nonzero λ'_{ijk} coupling.

Section 3.

The sensitivity of the $e^\pm e^\mp (\mu^\pm \mu^\mp)$ search does not depend on which of the four RPV couplings associated with the second operator LQD ($L_i Q_j \bar{D}_k$) in Eq. (1): λ'_{111} , λ'_{112} , λ'_{121} , and λ'_{122} (λ'_{211} , λ'_{212} , λ'_{221} , and λ'_{222}) is non-zero, because the final states and kinematic distributions are the same in each case. We expect that the searches have some sensitivity to models with third-generation couplings λ'_{311} , λ'_{312} , λ'_{321} , and λ'_{322} , via leptonic τ decays; however, we do not include this possible extra contribution in this paper. The difference $\Delta M_{\tilde{t}, \tilde{\chi}_1^\pm}$ between top squark mass $M_{\tilde{t}}$, and chargino mass $M_{\tilde{\chi}_1^\pm}$, is chosen to be 100 GeV, since this value is representative of the bulk of the $M_{\tilde{t}}-M_{\tilde{\chi}_1^\pm}$ parameter space where the signal reconstruction efficiency is slowly varying. This analysis does not attempt to quantify the decrease in efficiency (and signal sensitivity) in the regions of parameter space where either $\Delta M_{\tilde{t}, \tilde{\chi}_1^\pm}$ or $M_{\tilde{\chi}_1^\pm}$ is very small (< 100 GeV).

Several searches for R-parity violating top squark decays via LQD couplings have been performed by the CMS [18–20] and ATLAS [21] collaborations. These searches have focused on top squark pairs decaying via λ'_{i32} couplings into final states of two leptons (e^\pm or μ^\pm) and two jets or two leptons (e^\pm or μ^\pm) and six jets, four of which are b-tagged jets [20, 21]; via λ'_{3jk} couplings into a final state including two tau leptons and two b-tagged jets [19]; and via the λ'_{233} coupling into a final state including three leptons and additional jets [18]. The analysis described in this paper is the first search for R-parity violating top squark decays via purely first- or second-generation LQD couplings; in this case, the final states are two leptons (e^\pm or μ^\pm) and six jets, two of which are b-tagged jets.

2 The CMS detector

A detailed description of the CMS detector, together with a definition of the coordinate system used, can be found elsewhere [22]. A notable feature of the CMS detector is its 6 m internal diameter superconducting solenoid magnet that provides a field of 3.8 T. Within the field volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter. Muon detectors based on gas ionization chambers are embedded in a steel flux-return yoke located outside the solenoid. Events are collected by a two-layer trigger system based on a hardware level-1 trigger, followed by a software-based high-level trigger.

The pseudorapidity range covered by the tracking system is $|\eta| < 2.5$, the muon detector extends up to $|\eta| < 2.4$, and the calorimeters cover a region with $|\eta| < 3.0$. The region of $3 < |\eta| < 5$ is instrumented with steel and quartz fiber forward calorimeters. The hermeticity of

the detector up to large values of $|\eta|$ permits accurate measurement of the momentum balance transverse to the beam direction.

3 Trigger and event selection

Events are selected using a trigger that requires at least one electron (muon) with a transverse momentum (p_T) threshold of 27 (24) GeV, and $|\eta| < 2.5$ (2.1). All objects are reconstructed using a particle-flow (PF) algorithm [23, 24], which uses information from all subsystems to reconstruct photons, electrons, muons, charged hadrons, and neutral hadrons.

To reduce the background from jets containing leptons, we impose isolation constraints on the transverse energy $E_{T,\text{cone}}$ from charged-particle tracks or deposits in the calorimeter within a cone $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.3$ (0.4) around the trajectory of the electron (muon), where ϕ is azimuthal angle, and η is the pseudorapidity. The energy from the reconstructed lepton and the average transverse energy density from pileup are subtracted from $E_{T,\text{cone}}$, where pileup is defined as additional inelastic ppcollisions within the same LHC bunch crossing. Tracking information together with calorimeter information is used to identify and subtract hadronic energy depositions from charged particles originating from pileup. The contributions to the neutral hadron and photon energy components due to pileup are also computed and subtracted. In electron channel, the contributions to the neutral hadron and photon energy components due to pileup interactions are subtracted from $E_{T,\text{cone}}$ using the jet area technique [25], which computes the transverse energy density of neutral particles from the median of the neutral energy distribution in jets with $p_T > 3$ GeV on an event-by-event basis. In muon channel, the method assumes the pileup energy density from neutral particles to be half of that from charged hadrons, based on measurements performed in jets [24].

Electrons are reconstructed by matching an energy cluster in the ECAL with a track reconstructed using a Gaussian sum filter [26]. Electrons are required to have $p_T > 50$ GeV and $|\eta| < 2.5$. The transition region between the ECAL barrel and endcap is excluded ($1.444 < |\eta| < 1.566$) because the calorimeter is not well modeled in this region. Electrons are identified using a multivariate identification algorithm [26], whose input variables are sensitive to bremsstrahlung along the electron path, matching between tracks and ECAL energy deposits, and shower-shape variables. The algorithm is trained with a sample of simulated Drell–Yan (DY) events that contains true electrons and a data sample enriched in misidentified electrons. In addition, the transverse impact parameter of the electron track is required to be less than 2 mm. To reduce backgrounds that arise from photon conversions in the inner pixel detector, at least one pixel hit in the innermost pixel layer is required and the electron must be inconsistent with the hypothesis that it resulted from photon pair creation. We ensure that the electron is isolated from other activity in the event by requiring that $E_{T,\text{cone}}$ be less than 10% of the electron p_T .

Muons are required to have $p_T > 50$ GeV and $|\eta| < 2.1$. Most cosmic ray muons are rejected by requiring that the transverse (longitudinal) impact parameter be less than 2 (5) mm relative to the primary vertex, defined as the vertex with the largest sum of the p_T^2 from all tracks associated with it. Only muons with at least ten hits in the silicon strip tracker and at least one hit in the pixel detector are considered, which ensures a precise momentum measurement. Isolation is imposed by the requirement that $E_{T,\text{cone}}$ be less than 12% of the muon p_T [27].

The differences in lepton reconstruction and trigger efficiencies between data and simulation are corrected in simulation in bins of p_T and η , using a tag-and-probe method [28].

Jets are reconstructed from PF objects [29] using the anti- k_T clustering algorithm [30] with a distance parameter of 0.5. The tracker and ECAL granularity are exploited to precisely measure the charged particles, and hence to determine jet directions at the production vertex. To remove jets arising from instrumental and non-collision backgrounds, additional criteria on charged and neutral hadron energy is applied.

The energy and momentum of each jet are corrected as a function of the jet p_T and η to account for the combined response function of the calorimeters. The average energy from pileup is subtracted from the jet [31]. Only jets within $|\eta| < 2.4$ are considered. The corrected jet p_T must be at least 100 GeV for the leading jet, 50 GeV for the second-leading jet, and 30 GeV for the remaining jets. At least five jets are required in the event.

Events with at least one b-tagged jet are selected. The combined secondary-vertex algorithm [32] uses information from the track impact parameter and vertex information to discriminate between jets that originate from b quarks and jets from light-flavor quarks and gluons. The algorithm correctly identifies jets produced by the hadronization of a b quark (b jets) with an efficiency of approximately 70% and misidentifies jets from light-flavor quarks or gluons (charm quarks) at a rate of approximately 1% (20%) [32]. The b-tagging efficiency in the simulation is scaled to match the measured efficiency in data as a function of p_T , η , and the flavor of the jet.

The missing transverse momentum \vec{p}_T^{miss} in the event is defined as the projection of the negative vector sum of the momenta of all reconstructed PF candidates on the plane perpendicular to the beams. The magnitude of \vec{p}_T^{miss} in the event is referred to as E_T^{miss} . To suppress leptonic $t\bar{t}$ decays that often have significant E_T^{miss} because of the presence of neutrinos in the final state, E_T^{miss} is required to be less than 100 GeV. The dilepton mass $M_{\ell\ell}$, computed from the two lepton four-momenta, is required to be greater than 130 GeV, based on an optimization to reduce the contribution from low-mass resonances and Z boson decays.

To enhance the statistical significance, for each lepton flavor the sample is divided into three exclusive categories of jet multiplicity: $N_{\text{jets}} = 5, 6, \text{ or } 7$. To improve the sensitivity to signal decays, we compute an S_T threshold S_T^{min} optimized for each top squark mass hypothesis and for each N_{jets} bin. The S_T^{min} is determined by maximizing the value of $S/\sqrt{S+B}$, where S and B are the number of expected signal and background events above S_T^{min} , respectively.

4 Simulation of background and signal events

Monte Carlo (MC) simulations of background and signal events are used to optimize the selection criteria for maximum signal sensitivity and to estimate backgrounds. The simulation of the hard-scattering event is performed using the leading-order (LO) matrix element event generator MADGRAPH 5 [33], unless noted otherwise. The CTEQ6L1 [34] set of parton distribution functions (PDF) is used to describe the proton structure. The simulation of the hard-scattering event is then passed to PYTHIA 6.426 [35] with the Z2* tune [36] to model the parton shower, hadronization, and the underlying event. A full simulation of the response of the CMS detector is performed using GEANT4 [37]. Additional simulated minimum bias events are overlaid to reproduce the effects of pileup.

The main SM backgrounds for this search are DY and $t\bar{t}$ pair production. Additional SM backgrounds, which include diboson (WW, WZ, and ZZ) and single top quark production, are small. The $t\bar{t}$ sample is generated with up to three additional partons, the DY events are produced with up to four additional partons, and the diboson samples are generated with up to two additional partons. Single top quark production (t -, s -, and tW -channels) is simulated

with POWHEG v1.0 [38–42]. Simulated samples of $t\bar{t}$ and DY are normalized using cross sections computed at next-to-next-to-leading-order (NNLO) [43, 44]. Cross sections computed at next-to-leading-order (NLO) [45, 46] are used to normalize the single top quark and diboson samples.

The signal samples are generated using MADGRAPH 5, PYTHIA 6.426, and the CTEQ6L1 PDF set. The top squark pair production cross section is computed at NLO as a function of $M_{\tilde{t}}$, including soft gluon resummation at next-to-leading logarithm (NLL) [47–50]. The uncertainty in the cross section includes uncertainties associated with the renormalization and factorization scale, and the PDF set [51].

5 Background estimation

Corrections to the normalization of $t\bar{t}$ and DY simulations are estimated by examining background enriched samples in data. A summary of the selection criteria for the signal search region and the control regions, including selections on the dilepton mass, is presented in Table 1. Diboson and single top quark production yield small contributions to the background and are estimated from simulation. In simulated $t\bar{t}$ sample, events are reweighted so that the p_T of the top quark matches the data in a dedicated control sample [52].

Table 1: Summary of the selection criteria for the signal region and the control regions. Data in the control regions described as $t\bar{t}$, DY normalization, and DY shape are used to estimate SM backgrounds in the signal region.

		Lepton selection	N_{jets}	$N_{\text{b-tags}}$
Signal region		$e^\pm e^\mp(\mu^\pm \mu^\mp), M_{\ell\ell} > 130 \text{ GeV}$	≥ 5	≥ 1
	$t\bar{t}$ shape	$e^\pm \mu^\mp$	≥ 5	≥ 1
Control regions	DY normalization	$e^\pm e^\mp(\mu^\pm \mu^\mp), 50 < M_{\ell\ell} < 130 \text{ GeV}$	≥ 2	≥ 1
	DY shape	$e^\pm e^\mp(\mu^\pm \mu^\mp), 50 < M_{\ell\ell} < 130 \text{ GeV}$	≥ 2	0

The leptonic $t\bar{t}$ decays contribute to 89% of the total background. Since the signal produces only same-flavor leptons, we estimate the $t\bar{t}$ background from a control sample of $e^\pm \mu^\mp$ events after correcting it for the small contributions of DY, diboson, and single top events using simulations. We use this control sample to compute correction factors for the $t\bar{t}$ simulation for different jet multiplicities in the signal region. The $e^\pm \mu^\mp$ control sample is well modeled by the simulation, thus correction factors are statistically consistent with unity.

The Drell–Yan production constitutes approximately 8% of the SM background in the signal region, and is reduced by requiring at least one b-tagged jet. The contribution from this source is estimated using a control sample of two oppositely charge same-flavor leptons, which have an invariant mass $M_{\ell\ell}$ in the range 50–130 GeV. We perform a fit to the $M_{\ell\ell}$ distribution to estimate the number of DY events. The DY shape is obtained from background-subtracted data using a DY-enriched sample with no b-tagged jets. The background from diboson decays including leptonic Z boson decays is estimated from simulation and is constrained in the fit. The $M_{\ell\ell}$ shape for the remaining backgrounds does not exhibit a Z boson mass peak, and is described by a linear function. The fit determines the number N_{DY} of DY events and the number of all other background events. To check that the procedure is insensitive to a potential signal contamination, we performed a fit with signal events included, and observed that the obtained N_{DY} is independent of the presence of the potential signal in the control sample. The ratio of N_{DY} from the fit to the simulated number of DY events is calculated for each value of N_{jets} and is used to correct the simulation. This correction factor ranges from 1.2 ± 0.1 to

2.1 ± 0.6 and increases with jet multiplicity.

We checked that the corrections to the DY normalization are valid in the signal region with $M_{\ell\ell} > 130 \text{ GeV}$. We compared the numbers of events in different mass ranges using a DY-enriched sample with at least five jets and no b-tagged jets. The ratio of the number of events with $M_{\ell\ell}$ in the Z-peak (normalization region) to the number with $M_{\ell\ell}$ in the high-mass tail (signal region) is predicted from simulation to be 11.8 ± 0.4 and observed to be 14.0 ± 3.5 in data, in reasonable agreement.

6 Systematic uncertainties

We evaluate systematic uncertainties related to each background and to the signal reconstruction efficiency; these are summarized in Table 2.

Table 2: Systematic uncertainties for background and expected signal yields.

	Source	Uncertainty (%)
Background estimates	$t\bar{t}$ +jets	10–50
	Drell–Yan	50–100
	Diboson	30
	Single top quark	30
	MC statistics	10–30
Expected signal yield	Jet energy scale	5
	b tagging scale factor	1–3
	Integrated luminosity	2.6
	Lepton identification	3
	Electron energy scale	2
	Muon momentum scale	0.9
	Trigger efficiency	1
	Lepton isolation	5
	MC statistics	2–7

Since the $t\bar{t}$ correction factor for the simulated sample is estimated from a control sample of $e^\pm\mu^\mp$ events in data, the systematic uncertainty in this background is given by the statistical uncertainty in the control sample. This uncertainty ranges from 10 to 50%, depending on the value of N_{jets} and of S_T^{min} . For the small DY background, we take 50 (100)% of correction factor as the systematic uncertainty on the correction in 5 (≥ 6) jet bin(s). We assign a 30% uncertainty to the diboson and single top quark background contributions to account for the difference between the NLO theoretical calculation and the CMS measurements of the WW and ZZ cross sections [53] and the single top cross sections [54]. The statistical uncertainty due to the finite size of the simulated background samples is 10–30%, depending on the N_{jets} bin and S_T^{min} value.

The following systematic uncertainties in the signal efficiency are included: jet energy scale (5%) [31], jet b-tagging efficiencies (3%), integrated luminosity (2.6%) [55], lepton identification and reconstruction efficiency (3%), electron energy scale (2%), muon momentum scale (0.9%), and trigger efficiency (1%). Noting the effect of the b-tagging uncertainty on the signal prediction is evaluated by varying the efficiency and misidentification rates by their uncertainties [32, 56], and the effect on the signal prediction. The uncertainty related to the lepton isolation requirement for signal events with many jets is estimated using a $t\bar{t}$ control sample selected as shown in Table 1, but with ≥ 7 jets, and is determined to be 5%. The uncertainty due to the limited size of the simulated signal sample varies from 2 to 7%. The impact of un-

certainties related to the PDF set choice, modeling of the top quark p_T spectrum, and pileup modeling is determined to be negligible.

7 Results

Figure 2 shows the observed distributions of jet multiplicity, the estimated background distributions, and the expected distributions for signals with a mass $M_{\tilde{t}}$ of either 300 GeV or 900 GeV. In Tables 3 and 4 we present the numbers of expected and observed events for each value of N_{jets} , for each $M_{\tilde{t}}$ hypothesis and corresponding $S_{\text{T}}^{\text{min}}$ value. The signal expectations are based on NLO cross sections [51]. The data are in agreement with the SM expectation in each bin.

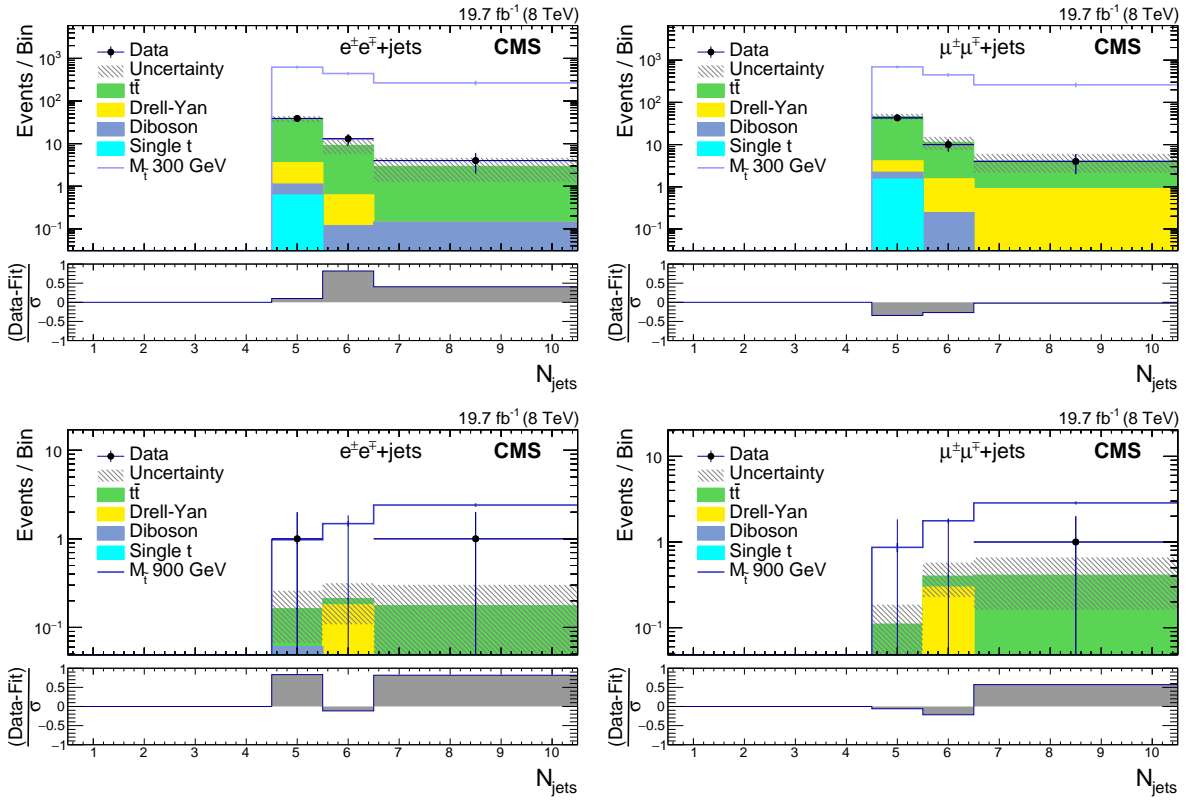


Figure 2: Jet multiplicity distributions for $e^{\pm}e^{\mp}$ (left) and $\mu^{\pm}\mu^{\mp}$ (right) for selections optimized for $M_{\tilde{t}}$ hypotheses of 300 GeV (top) and 900 GeV (bottom). The expected signal is shown by an open histogram superimposed on the expected SM background. For bins with no data observation, an upper limit on Poisson uncertainty is added to the bin. The systematic uncertainties for the SM contributions are indicated by hatched bands. Under each histogram is shown a plot in gray as the ratio of difference of data from background expectation to the sum of their uncertainties, including the systematic uncertainties in background expectation.

We use these results to determine 95% confidence level (CL) limits, as a function of $M_{\tilde{t}}$, on the product of the top-squark pair-production cross section and the square of the branching fraction \mathcal{B} for the decay $\tilde{t} \rightarrow b\ell^{\pm}qq$. We use the modified frequentist CL_s method [57] with profiling of nuisance parameters. For each $M_{\tilde{t}}$ hypothesis, the Poisson likelihoods of the three N_{jets} bins are combined. Systematic uncertainties are incorporated into the test statistic as nuisance parameters. The nuisance parameter probability density function (pdf) for the $t\bar{t}$ background normalization, which is estimated from background control regions containing limited numbers of events in high N_{jets} bins, is described by a gamma function. All other uncertainties are

treated with log-normal pdfs. With the exception of uncertainties related to the finite size of a control sample, we assume the systematic uncertainties are fully correlated across different N_{jets} bins.

The observed and expected limits on the product of the cross section and the branching fraction squared are shown in Fig. 3. The green (yellow) band corresponds to a variation of one (two) standard deviation(s) on the expected limit. The dotted curve shows the signal cross section, with the width of the associated band showing the sensitivity to uncertainties in the renormalization and factorization scales and the PDF uncertainties [51]. Comparing the observed cross section limits to the signal cross section, we exclude top squarks with masses less than 890 (1000) GeV for the electron (muon) channel. The expected mass exclusion is 950 (970) GeV for the electron (muon) channel.

These cross section limits strictly apply to models with mass difference $\Delta M_{\tilde{t}, \tilde{\chi}_1^\pm} = 100$ GeV; however, the sensitivities for models with $\Delta M_{\tilde{t}, \tilde{\chi}_1^\pm} > 50$ GeV are similar. The mass exclusions assume $\mathcal{B} = 100\%$. As described earlier, the limits for the electron channel apply equally to models with nonzero $\lambda'_{111}, \lambda'_{112}, \lambda'_{121},$ or λ'_{122} and the limits for the muon channel apply equally to models with nonzero $\lambda'_{211}, \lambda'_{212}, \lambda'_{221},$ or λ'_{222} . Because the coupling strength does not affect the production cross section and the branching fraction is assumed to be 100%, the value of λ'_{ijk} is not important as long as it is sufficiently large to ensure that the sneutrino decays promptly. For coupling values smaller than 10^{-5} , the decay lengths are of order 1 mm or greater, resulting in a decreased signal reconstruction efficiency and sensitivity. These are the first limits on chargino-mediated top squark decays via a single LQD coupling λ'_{ijk} with $(i, j, k \leq 2)$.

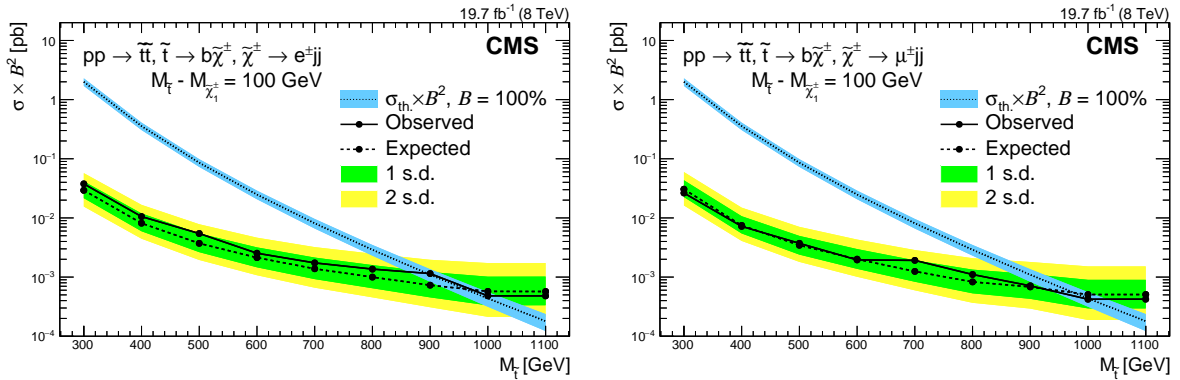


Figure 3: Observed and expected 95% CL upper limits on the cross section on the product of the cross section and the branching (\mathcal{B}) squared, for $e^\pm e^\mp$ (left) and $\mu^\pm \mu^\mp$ (right). The green (inner) and yellow (outer) bands show the 1 s.d. (2 s.d.) uncertainty ranges in the expected limits, respectively. The dotted curve shows the expected top squark cross section computed at NLO+NLL. The difference $M_{\tilde{t}} - M_{\tilde{\chi}_1^\pm}$ is assumed to be 100 GeV for the signal model.

8 Summary

A search for new phenomena using events with two oppositely charged electrons or muons, at least five jets, with at least one b-tagged jet, and low missing transverse momentum has been performed. No excess over the estimated background is observed. The results are interpreted in the framework of chargino-mediated, R-parity violating top squark decays, assuming a 100% branching fraction for the top squark decay chain, $\tilde{t} \rightarrow b\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \rightarrow \ell^\pm + jj$. In models with a single nonzero λ'_{ijk} coupling with $(i, j, k \leq 2)$, the results exclude top squarks with mass less

than 890 (1000) GeV for the electron (muon) channel at 95% confidence level. These limits are the first obtained for this model.

Table 3: Observed events, estimated background, and expected signal yields, for $N_{\text{jets}} = 5, 6,$ and ≥ 7 , along with the optimized value of $S_{\text{T}}^{\text{min}}$, for different $M_{\tilde{\tau}}$ in the electron channel. The signal and background uncertainties include both statistical and systematic contributions.

$M_{\tilde{\tau}}$ (GeV)	N_{jets}	$S_{\text{T}}^{\text{min}}$ (GeV)	Data	Estimated background	Expected signal	Signal efficiency(%)
300	5	325	39	38.1 ± 5.9	622 ± 49	2.4 ± 0.2
300	6	325	13	9.0 ± 3.3	442 ± 41	1.8 ± 0.1
300	≥ 7	325	4	2.9 ± 1.7	266 ± 33	0.9 ± 0.1
400	5	525	27	28.7 ± 5.6	256 ± 14	5.6 ± 0.2
400	6	325	13	9.0 ± 3.3	245 ± 13	5.3 ± 0.2
400	≥ 7	325	4	2.9 ± 1.7	180 ± 11	3.8 ± 0.2
500	5	725	12	14.1 ± 3.3	69.2 ± 3.3	6.0 ± 0.2
500	6	675	9	5.3 ± 2.5	88.1 ± 3.7	7.9 ± 0.3
500	≥ 7	675	4	2.2 ± 1.4	89.7 ± 3.8	8.1 ± 0.3
600	5	925	1	3.4 ± 1.1	19.0 ± 0.9	5.8 ± 0.2
600	6	875	3	2.7 ± 1.0	28.8 ± 1.1	8.9 ± 0.3
600	≥ 7	825	4	1.8 ± 0.9	38.7 ± 1.3	11.6 ± 0.3
700	5	1025	1	1.6 ± 0.5	7.1 ± 0.3	6.6 ± 0.2
700	6	975	2	1.3 ± 0.5	10.5 ± 0.4	9.6 ± 0.3
700	≥ 7	975	2	1.1 ± 0.6	14.8 ± 0.5	13.6 ± 0.3
800	5	1225	1	0.4 ± 0.2	2.7 ± 0.1	7.0 ± 0.2
800	6	1175	0	0.4 ± 0.2	3.6 ± 0.2	9.5 ± 0.3
800	≥ 7	1075	2	0.7 ± 0.4	5.7 ± 0.2	15.1 ± 0.4
900	5	1325	1	0.2 ± 0.1	1.0 ± 0.1	6.7 ± 0.3
900	6	1375	0	0.2 ± 0.1	1.5 ± 0.1	10.1 ± 0.3
900	≥ 7	1375	1	0.2 ± 0.1	2.4 ± 0.1	16.4 ± 0.4
1000	5	1475	0	0.06 ± 0.07	0.34 ± 0.10	5.7 ± 0.2
1000	6	1425	0	0.18 ± 0.10	0.61 ± 0.09	10.6 ± 0.3
1000	≥ 7	1525	0	0.05 ± 0.06	0.98 ± 0.09	16.6 ± 0.4
1100	5	1475	0	0.06 ± 0.07	0.12 ± 0.04	5.3 ± 0.2
1100	6	1425	0	0.18 ± 0.10	0.26 ± 0.04	11.2 ± 0.3
1100	≥ 7	1525	0	0.05 ± 0.06	0.42 ± 0.04	17.6 ± 0.4

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Table 4: Observed events, estimated background, and expected signal yields, for $N_{\text{jets}} = 5, 6,$ and ≥ 7 , along with the optimized value of $S_{\text{T}}^{\text{min}}$, for different $M_{\tilde{\tau}}$ in the muon channel. The signal and background uncertainties include both statistical and systematic contributions.

$M_{\tilde{\tau}}$ (GeV)	N_{jets}	$S_{\text{T}}^{\text{min}}$ (GeV)	Data	Estimated background	Expected signal	Signal efficiency(%)
300	5	475	43	46.4 ± 7.2	696 ± 52	2.5 ± 0.2
300	6	475	10	11.3 ± 3.8	450 ± 43	1.7 ± 0.1
300	≥ 7	325	4	4.1 ± 1.9	261 ± 33	0.9 ± 0.1
400	5	525	39	36.8 ± 7.2	266 ± 13	5.4 ± 0.2
400	6	525	10	10.8 ± 3.9	281 ± 14	5.3 ± 0.2
400	≥ 7	325	4	4.1 ± 1.9	223 ± 12	4.3 ± 0.2
500	5	725	16	16.0 ± 3.8	81.1 ± 4.0	6.3 ± 0.3
500	6	675	9	7.3 ± 3.2	114.4 ± 4.8	8.8 ± 0.3
500	≥ 7	675	3	3.1 ± 1.6	101.8 ± 4.5	8.3 ± 0.3
600	5	875	5	5.2 ± 1.5	23.7 ± 1.1	6.6 ± 0.3
600	6	825	5	4.6 ± 1.6	36.0 ± 1.3	10.0 ± 0.3
600	≥ 7	825	2	2.4 ± 1.0	44.2 ± 1.5	12.3 ± 0.3
700	5	1075	2	1.3 ± 0.4	7.7 ± 0.4	6.3 ± 0.2
700	6	975	4	2.4 ± 0.8	13.2 ± 0.5	11.2 ± 0.3
700	≥ 7	975	2	1.0 ± 0.5	17.8 ± 0.5	14.9 ± 0.4
800	5	1175	0	0.9 ± 0.3	2.9 ± 0.2	6.8 ± 0.3
800	6	1175	2	0.8 ± 0.3	4.5 ± 0.2	10.6 ± 0.3
800	≥ 7	1125	1	0.4 ± 0.3	7.3 ± 0.2	17.6 ± 0.4
900	5	1475	0	0.1 ± 0.1	0.9 ± 0.1	5.6 ± 0.2
900	6	1325	0	0.4 ± 0.2	1.8 ± 0.1	11.0 ± 0.3
900	≥ 7	1175	1	0.4 ± 0.3	2.9 ± 0.1	18.1 ± 0.4
1000	5	1575	0	0.07 ± 0.06	0.4 ± 0.1	5.9 ± 0.2
1000	6	1525	0	0.01 ± 0.04	0.6 ± 0.1	10.0 ± 0.3
1000	≥ 7	1425	0	0.25 ± 0.16	1.2 ± 0.1	18.9 ± 0.4
1100	5	1575	0	0.07 ± 0.06	0.13 ± 0.04	5.2 ± 0.3
1100	6	1525	0	0.01 ± 0.04	0.25 ± 0.04	9.9 ± 0.3
1100	≥ 7	1425	0	0.25 ± 0.16	0.50 ± 0.04	19.7 ± 0.4

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A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia

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

Institut für Hochenergiephysik der OeAW, Wien, Austria

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

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

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

Universiteit Antwerpen, Antwerpen, Belgium

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

Vrije Universiteit Brussel, Brussel, Belgium

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

Université Libre de Bruxelles, Bruxelles, Belgium

P. Barria, H. Brun, C. Caillol, B. Clerboux, G. De Lentdecker, G. Fasanella, L. Favart, A. Grebenyuk, G. Karapostoli, T. Lenzi, A. Léonard, T. Maerschalk, A. Marinov, L. Perniè, A. Randle-conde, T. Seva, C. Vander Velde, P. Vanlaer, R. Yonamine, F. Zenoni, F. Zhang³

Ghent University, Ghent, Belgium

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

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

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

Université de Mons, Mons, Belgium

N. Belyi, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

W.L. Aldá Júnior, F.L. Alves, G.A. Alves, L. Brito, M. Correa Martins Junior, M. Hamer, C. Hensel, A. Moraes, M.E. Pol, P. Rebello Teles

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

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

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

S. Ahuja^a, C.A. Bernardes^b, A. De Souza Santos^b, S. Dogra^a, T.R. Fernandez Perez Tomei^a,

E.M. Gregores^b, P.G. Mercadante^b, C.S. Moon^{a,8}, S.F. Novaes^a, Sandra S. Padula^a, D. Romero Abad, J.C. Ruiz Vargas

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

A. Aleksandrov, R. Hadjiiska, P. Iaydjiev, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

University of Sofia, Sofia, Bulgaria

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

Institute of High Energy Physics, Beijing, China

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

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

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

Universidad de Los Andes, Bogota, Colombia

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

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

N. Godinovic, D. Lelas, I. Puljak, P.M. Ribeiro Cipriano

University of Split, Faculty of Science, Split, Croatia

Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

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

University of Cyprus, Nicosia, Cyprus

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

Charles University, Prague, Czech Republic

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

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

Y. Assran^{11,12}, S. Elgammal¹¹, A. Ellithi Kamel^{13,13}, M.A. Mahmoud^{14,14}

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

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

Department of Physics, University of Helsinki, Helsinki, Finland

P. Eerola, J. Pekkanen, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

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

Lappeenranta University of Technology, Lappeenranta, Finland

J. Talvitie, T. Tuuva

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

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

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

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

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

J.-L. Agram¹⁵, J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, M. Buttignol, E.C. Chabert, N. Chanon, C. Collard, E. Conte¹⁵, X. Coubez, J.-C. Fontaine¹⁵, D. Gelé, U. Goerlach, C. Goetzmann, A.-C. Le Bihan, J.A. Merlin², K. Skovpen, P. Van Hove

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

S. Gadrat

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

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

Georgian Technical University, Tbilisi, Georgia

T. Toriashvili¹⁶

Tbilisi State University, Tbilisi, Georgia

L. Rurua

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

C. Autermann, S. Beranek, L. Feld, A. Heister, M.K. Kiesel, K. Klein, M. Lipinski, A. Ostapchuk, M. Preuten, F. Raupach, S. Schael, J.F. Schulte, T. Verlage, H. Weber, V. Zhukov⁶

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

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

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

V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Künsken, J. Lingemann, A. Nehr Korn, A. Nowack, I.M. Nugent, C. Pistone, O. Pooth, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, I. Asin, N. Bartosik, O. Behnke, U. Behrens, A.J. Bell, K. Borras¹⁷, A. Burgmeier, A. Campbell, F. Costanza, C. Diez Pardos, G. Dolinska, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, E. Gallo¹⁸, J. Garay Garcia, A. Geiser, A. Gizhko, P. Gunnellini, J. Hauk, M. Hempel¹⁹, H. Jung, A. Kalogeropoulos, O. Karacheban¹⁹, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, I. Korol, W. Lange, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann¹⁹, R. Mankel, I. Marfin¹⁹, I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, S. Naumann-Emme, A. Nayak, E. Ntomari, H. Perrey, D. Pitzl, R. Placakyte, A. Raspereza, B. Roland, M.Ö. Sahin, P. Saxena, T. Schoerner-Sadenius, M. Schröder, C. Seitz, S. Spannagel, K.D. Trippkewitz, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

V. Blobel, M. Centis Vignali, A.R. Draeger, J. Erfle, E. Garutti, K. Goebel, D. Gonzalez, M. Görner, J. Haller, M. Hoffmann, R.S. Höing, A. Junkes, R. Klanner, R. Kogler, N. Kovalchuk, T. Lapsien, T. Lenz, I. Marchesini, D. Marconi, M. Meyer, D. Nowatschin, J. Ott, F. Pantaleo², T. Peiffer, A. Perieanu, N. Pietsch, J. Poehlsen, D. Rathjens, C. Sander, C. Scharf, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, J. Schwandt, V. Sola, H. Stadie, G. Steinbrück, H. Tholen, D. Troendle, E. Usai, L. Vanelderen, A. Vanhoefer, B. Vormwald

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, F. Colombo, W. De Boer, A. Descroix, A. Dierlamm, S. Fink, F. Frensch, R. Friese, M. Giffels, A. Gilbert, D. Haitz, F. Hartmann², S.M. Heindl, U. Husemann, I. Katkov⁶, A. Kornmayer², P. Lobelle Pardo, B. Maier, H. Mildner, M.U. Mozer, T. Müller, Th. Müller, M. Plagge, G. Quast, K. Rabbertz, S. Röcker, F. Roscher, G. Sieber, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, M. Weber, T. Weiler, S. Williamson, C. Wöhrmann, R. Wolf

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

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

National and Kapodistrian University of Athens, Athens, Greece

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

University of Ioánnina, Ioánnina, Greece

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

Wigner Research Centre for Physics, Budapest, Hungary

G. Bencze, C. Hajdu, A. Hazi, P. Hidas, D. Horvath²⁰, F. Sikler, V. Veszpremi, G. Vesztergombi²¹, A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

N. Beni, S. Czellar, J. Karancsi²², J. Molnar, Z. Szillasi²

University of Debrecen, Debrecen, Hungary

M. Bartók²³, A. Makovec, P. Raics, Z.L. Trocsanyi, B. Ujvari

National Institute of Science Education and Research, Bhubaneswar, India

S. Choudhury²⁴, P. Mal, K. Mandal, D.K. Sahoo, N. Sahoo, S.K. Swain

Panjab University, Chandigarh, India

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

University of Delhi, Delhi, India

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

Saha Institute of Nuclear Physics, Kolkata, India

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

Bhabha Atomic Research Centre, Mumbai, India

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

Tata Institute of Fundamental Research, Mumbai, India

T. Aziz, S. Banerjee, S. Bhowmik²⁵, R.M. Chatterjee, R.K. Dewanjee, S. Dugad, S. Ganguly, S. Ghosh, M. Guchait, A. Gurtu²⁶, G. Kole, S. Kumar, B. Mahakud, M. Maity²⁵, G. Majumder, K. Mazumdar, S. Mitra, G.B. Mohanty, B. Parida, T. Sarkar²⁵, N. Sur, B. Sutar, N. Wickramage²⁷

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

S. Chauhan, S. Dube, A. Kapoor, K. Kothekar, S. Sharma

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

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

University College Dublin, Dublin, Ireland

M. Felcini, M. Grunewald

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

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

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

G. Abbiendi^a, C. Battilana², A.C. Benvenuti^a, D. Bonacorsi^{a,b}, S. Braibant-Giacomelli^{a,b}, L. Brigliadori^{a,b}, R. Campanini^{a,b}, P. Capiluppi^{a,b}, A. Castro^{a,b}, F.R. Cavallo^a, S.S. Chhibra^{a,b}, G. Codispoti^{a,b}, M. Cuffiani^{a,b}, G.M. Dallavalle^a, F. Fabbri^a, A. Fanfani^{a,b}, D. Fasanella^{a,b}, P. Giacomelli^a, C. Grandi^a, L. Guiducci^{a,b}, S. Marcellini^a, G. Masetti^a, A. Montanari^a, F.L. Navarria^{a,b}, A. Perrotta^a, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G.P. Siroli^{a,b}, N. Tosi^{a,b,2}, R. Travaglini^{a,b}

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

G. Cappello^a, M. Chiorboli^{a,b}, S. Costa^{a,b}, A. Di Mattia^a, F. Giordano^{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}, V. Gori^{a,b}, P. Lenzi^{a,b}, M. Meschini^a, S. Paoletti^a, G. Sguazzoni^a, L. Viliani^{a,b,2}

INFN Laboratori Nazionali di Frascati, Frascati, Italy

L. Benussi, S. Bianco, F. Fabbri, D. Piccolo, F. Primavera²

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

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

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

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

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

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

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

P. Azzi^{a,2}, N. Bacchetta^a, L. Benato^{a,b}, D. Bisello^{a,b}, A. Boletti^{a,b}, R. Carlin^{a,b}, P. Checchia^a, M. Dall'Osso^{a,b,2}, T. Dorigo^a, U. Dosselli^a, F. Gasparini^{a,b}, U. Gasparini^{a,b}, F. Gonella^a, A. Gozzelino^a, M. Gulmini^{a,31}, S. Lacaprara^a, M. Margoni^{a,b}, A.T. Meneguzzo^{a,b}, F. Montecassiano^a, J. Pazzini^{a,b,2}, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{a,b}, M. Zanetti, P. Zotto^{a,b}, A. Zucchetta^{a,b,2}, G. Zumerle^{a,b}

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

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

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

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

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

K. Androsov^{a,32}, P. Azzurri^{a,2}, G. Bagliesi^a, J. Bernardini^a, T. Boccali^a, R. Castaldi^a, M.A. Ciocci^{a,32}, R. Dell'Orso^a, S. Donato^{a,c,2}, G. Fedi, L. Foà^{a,c†}, A. Giassi^a, M.T. Grippo^{a,32}, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,b}, A. Messineo^{a,b}, F. Palla^a, A. Rizzi^{a,b}, A. Savoy-Navarro^{a,33}, A.T. Serban^a, P. Spagnolo^a, R. Tenchini^a, G. Tonelli^{a,b}, A. Venturi^a, P.G. Verdini^a

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

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

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

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

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, C. La Licata^{a,b}, M. Marone^{a,b}, A. Schizzi^{a,b}, A. Zanetti^a

Kangwon National University, Chunchon, Korea

A. Kropivnitskaya, S.K. Nam

Kyungpook National University, Daegu, Korea

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

Chonbuk National University, Jeonju, Korea

J.A. Brochero Cifuentes, H. Kim, T.J. Kim

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

S. Song

Korea University, Seoul, Korea

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

Seoul National University, Seoul, Korea

H.D. Yoo

University of Seoul, Seoul, Korea

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

Sungkyunkwan University, Suwon, Korea

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

Vilnius University, Vilnius, Lithuania

V. Dudenas, A. Juodagalvis, J. Vaitkus

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

I. Ahmed, Z.A. Ibrahim, J.R. Komaragiri, M.A.B. Md Ali³⁴, F. Mohamad Idris³⁵, W.A.T. Wan Abdullah, M.N. Yusli

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

E. Casimiro Linares, H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz³⁶, A. Hernandez-Almada, R. Lopez-Fernandez, A. Sanchez-Hernandez

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

I. Pedraza, H.A. Salazar Ibarguen

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

A. Morelos Pineda

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand

P.H. Butler

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

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

National Centre for Nuclear Research, Swierk, Poland

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

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

G. Brona, K. Bunkowski, A. Byszuk³⁷, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, M. Walczak

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

P. Bargassa, C. Beirão Da Cruz E Silva, A. Di Francesco, P. Faccioli, P.G. Ferreira Parracho,

M. Gallinaro, N. Leonardo, L. Lloret Iglesias, F. Nguyen, J. Rodrigues Antunes, J. Seixas, O. Toldaiev, D. Vadrucio, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia

S. Afanasiev, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, A. Lanev, A. Malakhov, V. Matveev^{38,39}, P. Moiseenz, V. Palichik, V. Perelygin, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, A. Zarubin

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

V. Golovtsov, Y. Ivanov, V. Kim⁴⁰, E. Kuznetsova, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev

Institute for Nuclear Research, Moscow, Russia

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

Institute for Theoretical and Experimental Physics, Moscow, Russia

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

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

A. Bylinkin

P.N. Lebedev Physical Institute, Moscow, Russia

V. Andreev, M. Azarkin³⁹, I. Dremin³⁹, M. Kirakosyan, A. Leonidov³⁹, G. Mesyats, S.V. Rusakov

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

A. Baskakov, A. Belyaev, E. Boos, M. Dubinin⁴¹, L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, I. Myagkov, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

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

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkin, 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. Adzic⁴², P. Cirkovic, J. Milosevic, V. Rekovic

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

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

Universidad Autónoma de Madrid, Madrid, Spain

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

Universidad de Oviedo, Oviedo, Spain

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

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

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

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, A. Benaglia, J. Bendavid, L. Benhabib, J.F. Benitez, G.M. Berruti, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, R. Castello, G. Cerminara, M. D'Alfonso, D. d'Enterria, A. Dabrowski, V. Daponte, A. David, M. De Gruttola, F. De Guio, A. De Roeck, S. De Visscher, E. Di Marco⁴³, M. Dobson, M. Dordevic, B. Dorney, T. du Pree, D. Duggan, M. Dünser, N. Dupont, A. Elliott-Peisert, G. Franzoni, J. Fulcher, W. Funk, D. Gigi, K. Gill, D. Giordano, M. Girone, F. Glege, R. Guida, S. Gundacker, M. Guthoff, J. Hammer, P. Harris, J. Hegeman, V. Innocente, P. Janot, H. Kirschenmann, M.J. Kortelainen, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, M.T. Lucchini, N. Magini, L. Malgeri, M. Mannelli, A. Martelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, S. Morovic, M. Mulders, M.V. Nemallapudi, H. Neugebauer, S. Orfanelli⁴⁴, L. Orsini, L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, D. Piparo, A. Racz, T. Reis, G. Rolandi⁴⁵, M. Rovere, M. Ruan, H. Sakulin, C. Schäfer, C. Schwick, M. Seidel, A. Sharma, P. Silva, M. Simon, P. Sphicas⁴⁶, J. Steggemann, B. Stieger, M. Stoye, Y. Takahashi, D. Treille, A. Triossi, A. Tsiros, G.I. Veres²¹, N. Wardle, H.K. Wöhri, A. Zagozdinska³⁷, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

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

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

F. Bachmair, L. Bäni, L. Bianchini, B. Casal, G. Dissertori, M. Dittmar, M. Donegà, P. Eller, C. Grab, C. Heidegger, D. Hits, J. Hoss, G. Kasieczka, W. Luster, B. Mangano, M. Marionneau, P. Martinez Ruiz del Arbol, M. Masciovecchio, D. Meister, F. Micheli, P. Musella, F. Nessi-Tedaldi, F. Pandolfi, J. Pata, F. Pauss, L. Perrozzi, M. Quittnat, M. Rossini, M. Schönenberger, A. Starodumov⁴⁷, M. Takahashi, V.R. Tavolaro, K. Theofilatos, R. Wallny

Universität Zürich, Zurich, Switzerland

T.K. Aarrestad, C. AMSLER⁴⁸, L. Caminada, M.F. Canelli, V. Chiochia, A. De Cosa, C. Galloni, A. Hinzmann, T. Hreus, B. Kilminster, C. Lange, J. Ngadiuba, D. Pinna, G. Rauco, P. Robmann, F.J. Ronga, D. Salerno, Y. Yang

National Central University, Chung-Li, Taiwan

M. Cardaci, K.H. Chen, T.H. Doan, Sh. Jain, R. Khurana, M. Konyushikhin, C.M. Kuo, W. Lin, Y.J. Lu, A. Pozdnyakov, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

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

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

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

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci⁴⁹, Z.S. Demiroglu, C. Dozen, E. Eskut, F.H. Gecit, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E.E. Kangal⁵⁰, G. Onengut⁵¹, M. Ozcan, K. Ozdemir⁵², S. Ozturk⁴⁹, D. Sunar Cerci⁵³, B. Tali⁵³, H. Topakli⁴⁹, M. Vergili, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey

I.V. Akin, B. Bilin, S. Bilmis, B. Isildak⁵⁴, G. Karapinar⁵⁵, M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey

E. Gülmez, M. Kaya⁵⁶, O. Kaya⁵⁷, E.A. Yetkin⁵⁸, T. Yetkin⁵⁹

Istanbul Technical University, Istanbul, Turkey

A. Cakir, K. Cankocak, S. Sen⁶⁰, F.I. Vardarli

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

B. Grynyov

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

L. Levchuk, P. Sorokin

University of Bristol, Bristol, United Kingdom

R. Aggleton, F. Ball, L. Beck, J.J. Brooke, E. Clement, D. Cussans, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D.M. Newbold⁶¹, S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, S. Senkin, D. Smith, V.J. Smith

Rutherford Appleton Laboratory, Didcot, United Kingdom

K.W. Bell, A. Belyaev⁶², C. Brew, R.M. Brown, L. Calligaris, D. Cieri, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams, S.D. Worm

Imperial College, London, United Kingdom

M. Baber, R. Bainbridge, O. Buchmuller, A. Bundock, D. Burton, S. Casasso, M. Citron, D. Colling, L. Corpe, P. Dauncey, G. Davies, A. De Wit, M. Della Negra, P. Dunne, A. Elwood, D. Futyan, G. Hall, G. Iles, R. Lane, R. Lucas⁶¹, L. Lyons, A.-M. Magnan, S. Malik, J. Nash, A. Nikitenko⁴⁷, J. Pela, M. Pesaresi, K. Petridis, D.M. Raymond, A. Richards, A. Rose, C. Seez, A. Tapper, K. Uchida, M. Vazquez Acosta⁶³, T. Virdee, S.C. Zenz

Brunel University, Uxbridge, United Kingdom

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

Baylor University, Waco, USA

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

The University of Alabama, Tuscaloosa, USA

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

Boston University, Boston, USA

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

Brown University, Providence, USA

J. Alimena, E. Berry, S. Bhattacharya, D. Cutts, A. Ferapontov, A. Garabedian, J. Hakala, U. Heintz, E. Laird, G. Landsberg, Z. Mao, M. Narain, S. Piperov, S. Sagir, R. Syarif

University of California, Davis, Davis, USA

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

University of California, Los Angeles, USA

R. Cousins, P. Everaerts, A. Florent, J. Hauser, M. Ignatenko, D. Saltzberg, E. Takasugi, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA

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

University of California, San Diego, La Jolla, USA

J.G. Branson, G.B. Cerati, S. Cittolin, R.T. D'Agnolo, M. Derdzinski, A. Holzner, R. Kelley, D. Klein, J. Letts, I. Macneill, D. Olivito, S. Padhi, M. Pieri, M. Sani, V. Sharma, S. Simon, M. Tadel, A. Vartak, S. Wasserbaech⁶⁴, C. Welke, F. Würthwein, A. Yagil, G. Zevi Della Porta

University of California, Santa Barbara, Santa Barbara, USA

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

California Institute of Technology, Pasadena, USA

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

Carnegie Mellon University, Pittsburgh, USA

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

University of Colorado Boulder, Boulder, USA

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

Cornell University, Ithaca, USA

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

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, G. Apollinari, S. Banerjee, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, G. Bolla, K. Burkett, J.N. Butler, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, J. Hanlon, D. Hare, R.M. Harris, S. Hasegawa, J. Hirschauer, Z. Hu, B. Jayatilaka, S. Jindariani, M. Johnson, U. Joshi, B. Klima, B. Kreis, S. Lammel, J. Linacre, D. Lincoln, R. Lipton, T. Liu, R. Lopes De Sá, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, P. Merkel, S. Mrenna, S. Nahn, C. Newman-Holmes[†], V. O'Dell, K. Pedro, O. Prokofyev, G. Rakness,

E. Sexton-Kennedy, A. Soha, W.J. Spalding, L. Spiegel, N. Strobbe, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, C. Vernieri, M. Verzocchi, R. Vidal, H.A. Weber, A. Whitbeck

University of Florida, Gainesville, USA

D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, A. Carnes, M. Carver, D. Curry, S. Das, R.D. Field, I.K. Furic, S.V. Gleyzer, J. Konigsberg, A. Korytov, K. Kotov, P. Ma, K. Matchev, H. Mei, P. Milenovic⁶⁵, G. Mitselmakher, D. Rank, R. Rossin, L. Shchutska, M. Snowball, D. Sperka, N. Terentyev, L. Thomas, J. Wang, S. Wang, J. Yelton

Florida International University, Miami, USA

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

Florida State University, Tallahassee, USA

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

Florida Institute of Technology, Melbourne, USA

M.M. Baarmand, V. Bhopatkar, S. Colafranceschi⁶⁶, M. Hohlmann, H. Kalakhety, D. Noonan, T. Roy, F. Yumiceva

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

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

The University of Iowa, Iowa City, USA

B. Bilki⁶⁷, W. Clarida, K. Dilsiz, S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya⁶⁸, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok⁶⁹, A. Penzo, C. Snyder, E. Tiras, J. Wetzel, K. Yi

Johns Hopkins University, Baltimore, USA

I. Anderson, B.A. Barnett, B. Blumenfeld, N. Eminizer, D. Fehling, L. Feng, A.V. Gritsan, P. Maksimovic, C. Martin, M. Osherson, J. Roskes, A. Sady, U. Sarica, M. Swartz, M. Xiao, Y. Xin, C. You

The University of Kansas, Lawrence, USA

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

Kansas State University, Manhattan, USA

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

Lawrence Livermore National Laboratory, Livermore, USA

D. Lange, F. Rebassoo, D. Wright

University of Maryland, College Park, USA

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

Massachusetts Institute of Technology, Cambridge, USA

A. Apyan, R. Barbieri, A. Baty, K. Bierwagen, S. Brandt, W. Busza, I.A. Cali, Z. Demiragli, L. Di Matteo, G. Gomez Ceballos, M. Goncharov, D. Gulhan, Y. Iiyama, G.M. Innocenti, M. Klute,

D. Kovalskiy, Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, A.C. Marini, C. McGinn, C. Mironov, S. Narayanan, X. Niu, C. Paus, C. Roland, G. Roland, J. Salfeld-Nebgen, G.S.F. Stephans, K. Sumorok, M. Varma, D. Velicanu, J. Veverka, J. Wang, T.W. Wang, B. Wyslouch, M. Yang, V. Zhukova

University of Minnesota, Minneapolis, USA

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

University of Mississippi, Oxford, USA

J.G. Acosta, S. Oliveros

University of Nebraska-Lincoln, Lincoln, USA

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

State University of New York at Buffalo, Buffalo, USA

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

Northeastern University, Boston, USA

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

Northwestern University, Evanston, USA

K.A. Hahn, A. Kubik, J.F. Low, N. Mucia, N. Odell, B. Pollack, M. Schmitt, S. Stoynev, K. Sung, M. Trovato, M. Velasco

University of Notre Dame, Notre Dame, USA

A. Brinkerhoff, N. Dev, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, N. Marinelli, F. Meng, C. Mueller, Y. Musienko³⁸, M. Planer, A. Reinsvold, R. Ruchti, G. Smith, S. Taroni, N. Valls, M. Wayne, M. Wolf, A. Woodard

The Ohio State University, Columbus, USA

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

Princeton University, Princeton, USA

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

University of Puerto Rico, Mayaguez, USA

S. Malik

Purdue University, West Lafayette, USA

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

Purdue University Calumet, Hammond, USA

N. Parashar, J. Stupak

Rice University, Houston, USA

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

University of Rochester, Rochester, USA

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

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

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

University of Tennessee, Knoxville, USA

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

Texas A&M University, College Station, USA

O. Bouhali⁷⁰, A. Castaneda Hernandez⁷⁰, A. Celik, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, J. Gilmore, T. Huang, T. Kamon⁷¹, V. Krutelyov, R. Mueller, I. Osipenkov, Y. Pakhotin, R. Patel, A. Perloff, A. Rose, A. Safonov, A. Tatarinov, K.A. Ulmer²

Texas Tech University, Lubbock, USA

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

Vanderbilt University, Nashville, USA

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

University of Virginia, Charlottesville, USA

M.W. Arenton, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, H. Li, C. Lin, C. Neu, T. Sinthuprasith, X. Sun, Y. Wang, E. Wolfe, J. Wood, F. Xia

Wayne State University, Detroit, USA

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

University of Wisconsin - Madison, Madison, WI, USA

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

†: Deceased

1: Also at Vienna University of Technology, Vienna, Austria

2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland

3: Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

4: Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

5: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

6: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

7: Also at Universidade Estadual de Campinas, Campinas, Brazil

-
- 8: Also at Centre National de la Recherche Scientifique (CNRS) - IN2P3, Paris, France
 - 9: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
 - 10: Also at Joint Institute for Nuclear Research, Dubna, Russia
 - 11: Also at British University in Egypt, Cairo, Egypt
 - 12: Now at Suez University, Suez, Egypt
 - 13: Also at Cairo University, Cairo, Egypt
 - 14: Also at Fayoum University, El-Fayoum, Egypt
 - 15: Also at Université de Haute Alsace, Mulhouse, France
 - 16: Also at Tbilisi State University, Tbilisi, Georgia
 - 17: Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
 - 18: Also at University of Hamburg, Hamburg, Germany
 - 19: Also at Brandenburg University of Technology, Cottbus, Germany
 - 20: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
 - 21: Also at Eötvös Loránd University, Budapest, Hungary
 - 22: Also at University of Debrecen, Debrecen, Hungary
 - 23: Also at Wigner Research Centre for Physics, Budapest, Hungary
 - 24: Also at Indian Institute of Science Education and Research, Bhopal, India
 - 25: Also at University of Visva-Bharati, Santiniketan, India
 - 26: Now at King Abdulaziz University, Jeddah, Saudi Arabia
 - 27: Also at University of Ruhuna, Matara, Sri Lanka
 - 28: Also at Isfahan University of Technology, Isfahan, Iran
 - 29: Also at University of Tehran, Department of Engineering Science, Tehran, Iran
 - 30: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
 - 31: Also at Laboratori Nazionali di Legnaro dell'INFN, Legnaro, Italy
 - 32: Also at Università degli Studi di Siena, Siena, Italy
 - 33: Also at Purdue University, West Lafayette, USA
 - 34: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
 - 35: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia
 - 36: Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico
 - 37: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
 - 38: Also at Institute for Nuclear Research, Moscow, Russia
 - 39: Now at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
 - 40: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
 - 41: Also at California Institute of Technology, Pasadena, USA
 - 42: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
 - 43: Also at INFN Sezione di Roma; Università di Roma, Roma, Italy
 - 44: Also at National Technical University of Athens, Athens, Greece
 - 45: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
 - 46: Also at National and Kapodistrian University of Athens, Athens, Greece
 - 47: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
 - 48: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
 - 49: Also at Gaziosmanpasa University, Tokat, Turkey
 - 50: Also at Mersin University, Mersin, Turkey
 - 51: Also at Cag University, Mersin, Turkey
 - 52: Also at Piri Reis University, Istanbul, Turkey
 - 53: Also at Adiyaman University, Adiyaman, Turkey
 - 54: Also at Ozyegin University, Istanbul, Turkey

- 55: Also at Izmir Institute of Technology, Izmir, Turkey
- 56: Also at Marmara University, Istanbul, Turkey
- 57: Also at Kafkas University, Kars, Turkey
- 58: Also at Istanbul Bilgi University, Istanbul, Turkey
- 59: Also at Yildiz Technical University, Istanbul, Turkey
- 60: Also at Hacettepe University, Ankara, Turkey
- 61: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
- 62: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
- 63: Also at Instituto de Astrofísica de Canarias, La Laguna, Spain
- 64: Also at Utah Valley University, Orem, USA
- 65: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- 66: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
- 67: Also at Argonne National Laboratory, Argonne, USA
- 68: Also at Erzincan University, Erzincan, Turkey
- 69: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
- 70: Also at Texas A&M University at Qatar, Doha, Qatar
- 71: Also at Kyungpook National University, Daegu, Korea