arXiv:1202.1997v1 [hep-ex] 9 Feb 2012

Search for the standard model Higgs boson in the decay channel H → ZZ → 4ℓ in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$

The CMS Collaboration*

Abstract

A search for a Higgs boson in the four-lepton decay channel H → ZZ, with each Z boson decaying to an electron or muon pair, is reported. The search covers Higgs boson mass hypotheses in the range $110 < m_\mathrm{H} < 600\,\mathrm{GeV}$. The analysis uses data corresponding to an integrated luminosity of $4.7\,\mathrm{fb}^{-1}$ recorded by the CMS detector in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ from the LHC. Seventy-two events are observed with four-lepton invariant mass $m_{4\ell} > 100\,\mathrm{GeV}$ (with thirteen below $160\,\mathrm{GeV}$), while 67.1 ± 6.0 (9.5 ± 1.3) events are expected from background. The four-lepton mass distribution is consistent with the expectation of standard model background production of ZZ pairs. Upper limits at 95% confidence level exclude the standard model Higgs boson in the ranges 134–158 GeV, 180–305 GeV, and 340–465 GeV. Small excesses of events are observed around masses of 119, 126, and 320 GeV, making the observed limits weaker than expected in the absence of a signal.

Submitted to Physical Review Letters

---

*See Appendix A for the list of collaboration members

The standard model (SM) of electroweak interactions [1–3] relies on a scalar particle, the Higgs boson, associated with the field responsible for the spontaneous electroweak symmetry breaking [4–9]. The existence of the Higgs boson has yet to be established experimentally, while its mass, m_H, is not fixed by the theory. Direct searches for the SM Higgs boson at the LEP e^+e^- collider and the Tevatron $p\bar{p}$ collider have led, respectively, to a lower mass bound of $m_H > 114.4\,\mathrm{GeV}$ [10], and to an exclusion in the range 162–166 GeV [11], at 95% CL. Indirect constraints from precision measurements favour the mass range $m_H < 158\,\mathrm{GeV}$ [12] at 95% CL. The inclusive Higgs boson production followed by the decay H $\rightarrow$ ZZ is expected to be one of the main discovery channels at the CERN proton-proton (pp) Large Hadron Collider (LHC) for a wide range of m_H values. Using the H $\rightarrow$ ZZ and the H $\rightarrow$ WW decay channels, the AT-LAS collaboration have excluded at 95% CL the mass ranges 145–206 GeV, 214–224 GeV, and 340–450 GeV [13–15].

In this Letter, an inclusive search in the four-lepton decay channel, H $\rightarrow$ ZZ $\rightarrow \ell^+\ell^-\ell'^+\ell'^-$ with $\ell, \ell' = $ e or μ, abbreviated as H $\rightarrow 4\ell$, is presented. The analysis is designed for a Higgs boson in the mass range $110 < m_H < 600\,\mathrm{GeV}$. It uses pp data from the LHC collected at $\sqrt{s} = 7\,\mathrm{TeV}$ by the Compact Muon Solenoid (CMS) experiment during 2010 and 2011. The data corresponds to an integrated luminosity of $4.7\,\mathrm{fb}^{-1}$. The search relies solely on the measurement of leptons, and the analysis achieves high lepton reconstruction, identification, and isolation efficiencies for a ZZ $\rightarrow 4\ell$ system composed of two pairs of same-flavour and opposite-charge isolated leptons, e^+e^- or $\mu^+\mu^-$, in the measurement range $m_{4\ell} > 100\,\mathrm{GeV}$. One or both of the Z bosons can be off-shell. The background sources include an irreducible four-lepton contribution from direct ZZ production via $q\bar{q}$ annihilation and gg fusion. Reducible contributions arise from $Zb\bar{b}$ and $t\bar{t}$ where the final states contain two isolated leptons and two b jets producing secondary leptons. Additional background of instrumental nature arises from Z + jets events where jets are misidentified as leptons.

Particles produced in the pp collisions are detected in the pseudorapidity range $|\eta| < 5$, where $\eta = -\ln\tan(\theta/2)$ and θ is the polar angle with respect to the direction of the proton beam. The CMS detector comprises a superconducting solenoid, providing a uniform magnetic field of 3.8 T in the bore, equipped with silicon pixel and strip tracking systems ($|\eta| < 2.5$) surrounded by a lead tungstate crystal electromagnetic calorimeter (ECAL) and a brass-scintillator hadronic calorimeter (HCAL) ($|\eta| < 3.0$). A steel/quartz-fiber Cherenkov calorimeter extends the coverage ($|\eta| < 5$). The steel return yoke outside the solenoid is instrumented with gas detectors used to identify muons ($|\eta| < 2.4$). A detailed description of the detector is given in Ref. [16].

Monte Carlo (MC) samples for the SM Higgs boson signal and for background processes are used to optimize the event selection and to evaluate the acceptance and systematic uncertainties. The Higgs boson signals from gluon-fusion (gg $\rightarrow$ H), and vector-boson fusion ($q\bar{q} \rightarrow q\bar{q}$H), are generated with POWHEG [17] at next-to-leading-order (NLO) and a dedicated generator from Ref. [18]. Additional samples of WH, ZH, and $t\bar{t}$H events are generated with PYTHIA [19]. Events at generator level are reweighted according to the total cross section $\sigma(\mathrm{pp} \rightarrow \mathrm{H})$, which contains contributions from gluon fusion up to next-to-next-to-leading-order (NNLO) and next-next-to-leading-log taken from Refs. [20–29] and from the weak-boson fusion contribution computed at NNLO in Refs. [22, 30–34]. The total cross section is scaled by the branching fraction $\mathcal{B}(\mathrm{H} \rightarrow 4\ell)$ [22, 35–38]. Interference effects in the 4e and 4μ channels are calculated with PROPHECY4F [22, 35, 36]. The SM background contribution from ZZ production via $q\bar{q}$ is generated at NLO with POWHEG, while other di-boson processes (WW, WZ) are generated with PYTHIA with cross sections rescaled to NLO predictions. The gg $\rightarrow$ ZZ contribution is generated with GG2ZZ [39]. The $Zb\bar{b}$, $Zc\bar{c}$, $Z\gamma$, and Z + light jets samples are generated with MADGRAPH [40] with cross sections rescaled to NNLO prediction for inclusive

Z production. The $t\bar{t}$ events are generated at NLO with POWHEG. The generation takes into account the internal initial state and final state radiation (FSR) effects which can lead to the presence of additional hard photons in an event. All events are processed through a detailed simulation of the CMS detector based on GEANT4 [41] and are reconstructed with the same algorithms that are used for data.

Collision events are selected by the trigger system that requires the presence of a pair of electrons (a pair of muons) with transverse energy (transverse momenta) for the first and second lepton above 17 and 8 GeV respectively. The trigger efficiency within the acceptance of this analysis is greater than 99% for signal in the 4e and 4μ channels, and rises from about 97.5% at $m_H = 120$ GeV to above 99% at $m_H > 140$ GeV in the 2e2μ channel, within the acceptance of this analysis.

Electrons are reconstructed within the geometrical acceptance, $|\eta^e| < 2.5$, and with $p_T^e > 7$ GeV, by combining information from the ECAL and inner tracker [42, 43]. Electron identification selection requirements rely on electromagnetic shower-shape observables and on observables combining tracker and calorimetry information. The selection criteria depend on p_T^e and $|\eta^e|$, and on a categorization according to observables sensitive to the amount of bremsstrahlung emitted along the trajectory in the inner tracker. Muons are reconstructed [44] within $|\eta^\mu| < 2.4$ and $p_T^\mu > 5$ GeV, using information from both the inner tracker and the muon spectrometer. The inner track is required to be composed of more than 10 tracker-layer hits to ensure a precise measurement of the momentum. The efficiencies are measured in data, using a tag-and-probe technique [45] based on an inclusive sample of Z events. The measurements are performed in several ranges in p_T^ℓ and $|\eta|$. The product of reconstruction and identification efficiencies for electrons in the ECAL barrel (endcaps) vary from about 68% (62%) for $7 < p_T^e < 10$ GeV to 82% (74%) at $p_T^e \simeq 10$ GeV, and reach 90% (89%) for $p_T^e \simeq 20$ GeV. It drops to about 85% in the transition region, $1.44 < |\eta| < 1.57$, between the ECAL barrel and endcaps. The muons are reconstructed and identified with efficiencies above $\sim$98%. Lepton candidates are defined with a loose constraint on their isolation, by requiring the sum of the transverse momenta of tracks i within a cone around the lepton ℓ of $\Delta R = \sqrt{(\eta^\ell - \eta^i)^2 + (\phi^\ell - \phi^i)^2} < 0.3$, where ϕ is the azimuthal angle, to have $\sum_i p_{T,\text{track}}^i / p_T^\ell < 0.7$. The lepton isolation efficiency for identified leptons with this very loose definition of isolation is found to be greater than 99%.

We first require a Z candidate formed with a pair of lepton candidates satisfying $50 < m_{1,2} < 120$ GeV, $p_T^{\ell_1} > 20$ GeV, and $p_T^{\ell_2} > 10$ GeV. The p_T thresholds ensure that the leptons are on the high-efficiency plateau for the trigger. The lepton pair is required to be well isolated using a combination of the tracker, ECAL and HCAL information. The sum of the combined relative isolation R_{iso} for the two leptons is required to satisfy $R_{\text{iso}}^{\ell_1} + R_{\text{iso}}^{\ell_2} < 0.35$, where for each lepton, $R_{\text{iso}} = (1/p_T^\ell) \times \left(\sum_i p_{T,\text{track}}^i + \sum_j E_{T,\text{ECAL}}^j + \sum_k E_{T,\text{HCAL}}^k \right)$, with sums running over the charged tracks i, and the E_T from energy deposits in cells j and k of the ECAL and HCAL within a cone of radius $\Delta R < 0.3$, respectively. The footprint of the lepton is removed from the isolation sum. The combined isolation efficiencies measured with data using the tag-and-probe technique are found to be $> 99\%$ for muons and between 94% to 99% for electrons. The isolation is made largely insensitive to the number of overlapping pp interactions by correcting for the average energy flow [46] per unit area measured as a function of the number of primary vertices. The ratio of the efficiencies measured with data and with simulated $Z \to \ell\ell$ events is found to be consistent with unity. The significance of the signed impact parameter of each lepton relative to the event vertex, $\text{SIP}_{3D} = \frac{\text{IP}}{\sigma_{\text{IP}}}$, where IP is the impact parameter in three dimensions and σ_{IP} the associated uncertainty, is required to satisfy $|\text{SIP}_{3D}| < 4$. The $\ell^+\ell^-$ pair with reconstructed mass closest to the nominal Z boson mass is retained and denoted Z_1. The Z_1+X dataset thus

defined contains the samples used to estimate reducible and instrumental backgrounds, as well as the ZZ rates. In the next step, a subset of events is identified with at least a third lepton candidate. The $Z_1 + \ell$ events are used to measure misidentified lepton rates. A subset of events with at least a fourth lepton candidate of any flavour or charge is then identified. Together, the $Z_1 + \ell$ and $Z_1 + \ell\ell'$ samples provide ways to estimate the remaining reducible (Z$b\bar{b}$, $t\bar{t}$) and instrumental (Z + light jets) backgrounds. For the signal, we select a second lepton pair, denoted Z_2, from the remaining same flavour $\ell^+\ell^-$ combinations, by requiring $m_{Z_2} > 12\,\text{GeV}$, with the restriction $m_{4\ell} > 100\,\text{GeV}$. For the 4e and 4$\mu$ final states, at least three of the four combinations of opposite-sign pairs must satisfy $m_{\ell\ell} > 12\,\text{GeV}$. If more than one Z_2 candidate satisfies all criteria, the ambiguity is resolved by choosing the leptons of highest p_T. The isolation and impact parameter are used to further suppress the remaining backgrounds. We require for any combination of two leptons i and j, irrespective of flavour or charge, that $R_{\text{iso},i} + R_{\text{iso},j} < 0.35$ and also impose $|\text{SIP}_\text{3D}| < 4$ for each of the four leptons.

Finally, to select the four-lepton signal candidates, we require that the Z_1 and Z_2 masses satisfy $m_{Z_1}^\text{min} < m_{Z_1} < 120\,\text{GeV}$ and $m_{Z_2}^\text{min} < m_{Z_2} < 120\,\text{GeV}$, with $(m_{Z_1}^\text{min}, m_{Z_2}^\text{min}) = (50, 12)\,\text{GeV}$ defining the baseline selection and $(m_{Z_1}^\text{min}, m_{Z_2}^\text{min}) = (60, 60)\,\text{GeV}$ defining the high-mass selection. The baseline selection is used to search for the Higgs boson, and the high-mass selection is used to measure the ZZ cross section.

The event yields are found to be in good agreement with the MC background expectation at each step of event selection. The ZZ and Z+X backgrounds dominate after the full event selection. The overall signal detection efficiency for the 4e (4μ, 2e2μ) channel is evaluated by MC and increases from $\approx$21% (59%, 35%) at $m_\text{H} = 120\,\text{GeV}$ to $\approx$35% (71%, 50%) at $m_\text{H} = 140\,\text{GeV}$, reaching a plateau at $\approx$51% (81%, 63%) at $m_\text{H} = 200\,\text{GeV}$, and then slowly rising to $\approx$60% (83%, 72%) at $m_\text{H} = 350\,\text{GeV}$. The relative mass resolution estimated from MC signal samples is about 2.1% (1.1%, 1.6%) for 4e (4μ, 2e2μ).

The small number of observed events precludes a precise direct evaluation of background by extrapolating from mass sidebands. Instead, we rely on MC to evaluate the number of events expected from the ZZ background. The cross section for ZZ production at NLO, through the dominant process of $q\bar{q}$ annihilation and through gg fusion, is calculated with MCFM [47–49]. The theoretical uncertainties are computed as a function of $m_{4\ell}$, varying both the QCD renormalization and factorization scales and the parton distribution functions (PDF) set following the PDF4LHC recommendations [50–54]. The uncertainties for the QCD and PDF scales for each final state are on average 8%. The number of predicted ZZ $\rightarrow 4\ell$ events and their uncertainties after the baseline selection are given in Table 1. As a consistency check, an evaluation is made based on a normalization to the measured inclusive single-Z production, a procedure discussed in Refs. [55, 56]. The measured rate of single Z bosons defined in this analysis is used to predict the total ZZ rate; making use of the ratio of the theoretical cross sections for ZZ and Z production, and the ratio of the reconstruction and selection efficiencies for the four-lepton and two-lepton final states. The results are in agreement with the ZZ rates reported in Table 1 within uncertainties.

To estimate the reducible (Z$b\bar{b}$, $t\bar{t}$) and instrumental (Z + light jets) backgrounds, a region well separated from the signal region is defined by relaxing and inverting some selection criteria and verifying that the event rates change according to MC expectation. The event rates measured in the background control region are then extrapolated to the signal region. The control region for Z+X, where X stands for $b\bar{b}$, $c\bar{c}$, gluon or light quark jets, is obtained by relaxing the isolation and identification criteria for two additional reconstructed lepton objects (a measured track for muons, or a combination of a track and a cluster of ECAL energy deposits for electrons) indi-

cated as $\ell_{\mathrm{reco}}\ell_{\mathrm{reco}}$. The additional pair of leptons must have like sign charge (to avoid signal contamination) and same flavour ($e^{\pm}e^{\pm}$, $\mu^{\pm}\mu^{\pm}$), a reconstructed invariant mass m_{Z_2} either satisfying the baseline selection or the high-mass selection, and $m_{4\ell} > 100\,\mathrm{GeV}$. A sample $Z_1 + \ell_{\mathrm{reco}}$, with at least one reconstructed lepton object, is also defined for the measurement of the lepton misidentification probability, the probability for a reconstructed object to pass the isolation and identification requirements. The contamination from WZ in this set of events is suppressed by requiring that the imbalance of the measured energy deposition in the transverse plane is below 25 GeV. From the $Z + \ell_{\mathrm{reco}}\ell_{\mathrm{reco}}$ sample the expected number of Z+X background events in the signal region is obtained by taking into account the lepton misidentification probability for each of the two additional leptons. The number of background events expected in the signal region, normalized to the integrated luminosity, and the associated systematic uncertainties, are given in Table 1 for the baseline selection in the range $100 < m_{4\ell} < 600\,\mathrm{GeV}$. The reducible and instrumental background is found to be dominated by $Z + \mathrm{light\ jets}$. A small residual contamination of $Z b\bar{b}$ remains at low mass while for the high-mass selection these reducible backgrounds are an order of magnitude smaller and therefore can be neglected. This was verified by performing a measurement of $Z b\bar{b}$ and $t\bar{t}$ rates in a dedicated four-lepton background control region, defined by requiring a Z_1 and two additional leptons satisfying an inverted $\mathrm{SIP}_{3\mathrm{D}}$ requirement, namely $|\mathrm{SIP}_{3\mathrm{D}}| > 5$, and with relaxed isolation, charge, and flavour requirements. This ensures a negligible $Z + \mathrm{light\ jets}$ contribution in the four-lepton background control region, while the signal and the ZZ background are absent. To extract background rates, the reconstructed Z_1 mass for the sum of the $Z_1 + 2e$, $Z_1 + 2\mu$, and $Z_1 + e\mu$ final states is fit with a Breit-Wigner function convoluted with a Crystal Ball function [57] for the Z_1 peak from $Z b\bar{b}$ and Chebychev polynomials for the description of the $t\bar{t}$ continuum. The extrapolation to the signal region relies on knowledge of, and the distinct features of, the $\mathrm{SIP}_{3\mathrm{D}}$ distributions for the Z_2 leptons of the $t\bar{t}$ and $Z b\bar{b}$ backgrounds. The result is found to be compatible with the MC expectation in the signal region within the systematic uncertainty of 20%.

Systematic uncertainties are evaluated from data for trigger efficiency (1.5%), lepton reconstruction and identification (2–3%), and isolation efficiencies (2%). Systematic uncertainties on energy-momentum calibration (0.5%), and energy resolution are accounted for by their effect on the reconstructed mass distributions. The effect of the energy resolution uncertainties is taken into account by introducing a 30% uncertainty on the width of the signal mass peak. Additional systematic uncertainties arise from limited statistics in the reducible background control regions. All reducible and instrumental background sources are derived from control regions, and the comparison of data with the background expectation in the signal region is independent of the uncertainty on the LHC integrated luminosity of the data sample. This uncertainty (4.5%) [58] enters the evaluation of the ZZ background and in the calculation of the cross section limit through the normalization of the signal. Systematic uncertainties on the Higgs boson cross section (17–20%) and branching fraction (2%) are taken from Ref. [22].

Recent studies [22, 59, 60] show that current Monte Carlo simulations do not describe the expected Higgs boson mass line shape above $\approx$300 GeV. These effects are estimated to amount to an additional uncertainty on the theoretical cross section, and hence on the limits, of about 4% at $m_{\mathrm{H}} = 300\,\mathrm{GeV}$ and 10–30% for m_{H} of 400–600 GeV.

The number of candidates observed, as well as the estimated background in the signal region, are reported in Table 1 for the baseline selection. The reconstructed four-lepton invariant mass distribution for the combined $4e$, 4μ, and $2e2\mu$ channels with the baseline selection is shown in Fig. 1a and compared to expectations from the backgrounds. The shape of the mass distribution below $m_{\mathrm{H}} = 180\,\mathrm{GeV}$ reflects the shape of the dominant $q\bar{q}$ annihilation process [61]. The low mass range is shown in Fig. 1b together with the mass of each candidate and its uncertainty.
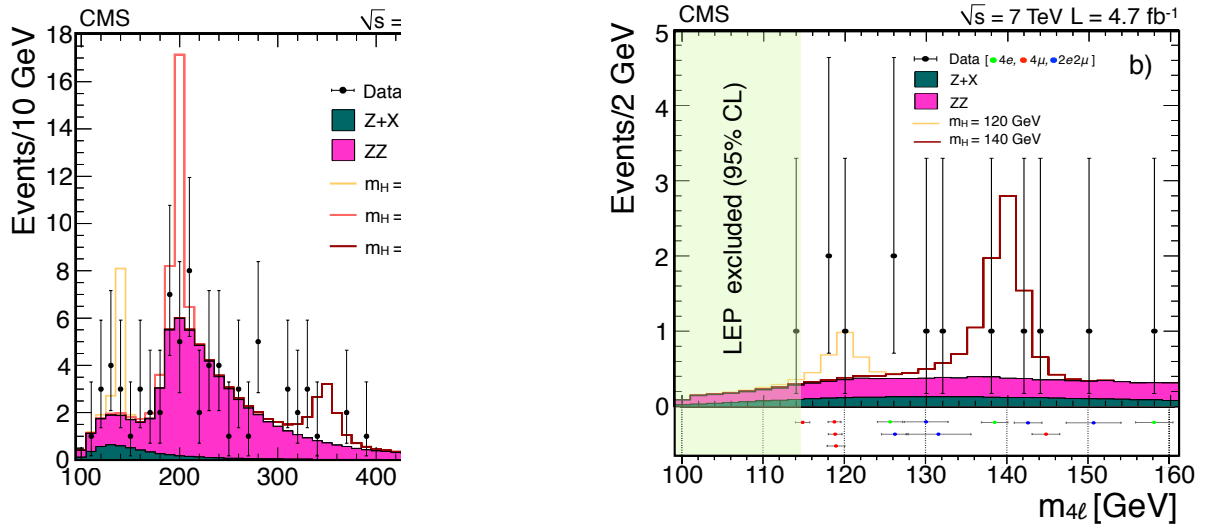
Figure 1: a) Distribution of the four-lepton reconstructed mass for the sum of the 4e, 4μ, and 2e2μ channels. b) Expansion of the low mass range with existing exclusion limits at 95% CL; also shown are the central values and individual candidate mass measurement uncertainties. Points represent the data, shaded histograms represent the background and unshaded histogram the signal expectations.

The reducible and instrumental background rates are small. These rates have been obtained from data and the corresponding $m_{4\ell}$ distributions are obtained from MC samples.

The measured distribution is compatible with the expectation from SM direct production of ZZ pairs. We observe 72 candidates, 12 in 4e, 23 in 4μ, and 37 in 2e2μ, while 67.1 ± 6.0 events are expected from standard model background processes. No hard photon ($p_T^\gamma > 5$ GeV) was found, outside the isolation veto cone that surrounds each lepton, that could be unambiguously identified as FSR. Thirteen candidates are observed within $100 < m_{4\ell} < 160$ GeV while 9.5 ± 1.3 background events are expected. We observe 53 candidates for the high-mass selection compared to an expectation of 51.3 ± 4.6 events from background. This high-mass event selection is used to provide a measurement of the total cross section $\sigma(\text{pp} \to \text{ZZ} + X) \times \mathcal{B}(\text{ZZ} \to 4\ell) = 28.1^{+4.6}_{-4.0}(\text{stat.}) \pm 1.2(\text{syst.}) \pm 1.3(\text{lumi.})$ fb. The measurement agrees with the SM prediction at NLO [47] of 27.9 ± 1.9 fb. The local p-values, representing the significance of local excesses relative to the standard model expectation, are shown as a function of m_H in Fig. 2a, obtained either taking into account or not the individual candidate mass measurement uncertainties,

Table 1: The number of candidates observed, compared to background and signal rates for each final state for $100 < m_{4\ell} < 600$ GeV for the baseline selection. For the Z+X background, the estimations are based on data

Channel	4e	4μ	2e2μ
ZZ background	12.27 ± 1.16	19.11 ± 1.75	30.25 ± 2.78
Z+X	1.67 ± 0.55	1.13 ± 0.55	2.71 ± 0.96
All background	13.94 ± 1.28	20.24 ± 1.83	32.96 ± 2.94
$m_H = 120$ GeV	0.25	0.62	0.68
$m_H = 140$ GeV	1.32	2.48	3.37
$m_H = 350$ GeV	1.95	2.61	4.64
Observed	12	23	37

for the combination of the three channels. Excesses are observed for masses near 119 GeV and 320 GeV. The small $\approx 2\sigma$ excess near 320 GeV includes three events with $p_T^{4\ell} > 50$ GeV. The most significant excess near 119 GeV corresponds to about 2.5σ significance. The significance is less than 1.0σ (about 1.6σ) when the look-elsewhere effect [62] is accounted for over the full mass range (for the low-mass range $100 < m_{4\ell} < 160$ GeV). The local significances change only slightly when including candidate mass uncertainties, instead of using the average mass resolution, e.g. rising to 2.7σ around 119 GeV and reaching 1.5σ around 126 GeV.
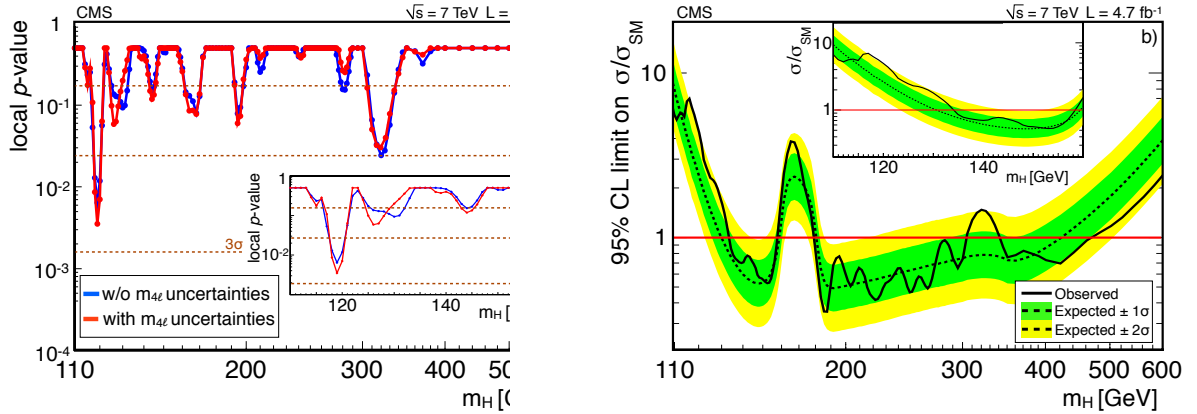

Figure 2: a) The significance of the local excesses with respect to the standard model expectation as a function of the Higgs boson mass, without (blue) or with (red) individual candidate mass measurement uncertainties. b) The observed and the median expected upper limits at 95% CL on $\sigma(pp \to H + X) \times \mathcal{B}(ZZ \to 4\ell)$, normalized to the standard model cross section values σ_{SM}, for a Higgs boson in the mass range 110–600 GeV, using the CL_s approach. The insets expand the low mass range.

In absence of a significant clustering of candidates at any given mass, we derive exclusion limits. The exclusion limits for a SM-like Higgs boson are computed for a large number of mass points in the mass range 110–600 GeV, using the predicted signal and background mass distribution shapes. The choice of the step size in the scan between Higgs mass hypotheses is driven by either detector resolution, or the natural width of the Higgs boson. The signal mass distributions shapes are determined using simulated samples for 27 values of m_H covering the full mass range. The shapes are fit using a function obtained from a convolution of a Breit-Wigner probability density function to describe the theoretical resonance line shape and a Crystal Ball function to account for the detector effects. The parameters of the Crystal Ball function are interpolated for the m_H points where there is no simulated sample available. The shapes of the background mass distributions are determined by fits to the simulated sample of events, while the normalization is taken from estimates of overall event yields as described above. For each mass hypothesis, we perform an unbinned likelihood fit using the statistical approach discussed in Ref. [63]. We account for systematic uncertainties in the form of nuisance parameters with a log-normal probability density function. The observed and median expected upper limits on $\sigma(pp \to H + X) \times \mathcal{B}(H \to ZZ) \times \mathcal{B}(ZZ \to 4\ell)$ at 95% CL are shown in Fig. 2b. The limits are calculated relative to the expected SM Higgs boson cross section values σ_{SM}, using the modified frequentist method CL_s [64, 65]. The bands represent the 1σ and 2σ probability intervals around the expected limit. These upper limits exclude the standard model Higgs boson at 95% CL in the m_H ranges 134–158 GeV, 180–305 GeV and 340–465 GeV. The limits reflect the dependence of the branching ratio $\mathcal{B}(H \to ZZ)$ on m_H. The worsening of the limits at high mass arises from the decreasing cross section for the $H \to 4\ell$ signal. By virtue of the

excellent mass resolution and low background, the structure in the measured limits follows the fluctuations of the number of observed events.

In summary, a search for the standard model Higgs boson has been presented in the four-lepton decay modes. Upper limits at 95% confidence level exclude the Higgs boson mass ranges 134–158 GeV, 180–305 GeV, and 340–465 GeV. A major fraction of the explored mass range is thus excluded at 95% CL and the exclusion limits extend beyond the sensitivity of previous collider experiments. Excesses of events are observed at the low end of the explored mass range, around masses of 119 and 126 GeV, and at high mass around 320 GeV. These excesses, although not statistically significant, make the observed limits weaker than expected in the absence of a signal. At low mass, only the region $114.4 < m_{\mathrm{H}} < 134$ GeV remains consistent with the expectation for the standard model Higgs boson production.

References

[1] S. L. Glashow, "Partial Symmetries of Weak Interactions", *Nucl. Phys.* **22** (1961) 579. `doi:10.1016/0029-5582(61)90469-2`.

[2] S. Weinberg, "A Model of Leptons", *Phys. Rev. Lett.* **19** (1967) 1264. `doi:10.1103/PhysRevLett.19.1264`.

[3] A. Salam, "Weak and electromagnetic interactions", in *Elementary particle physics: relativistic groups and analyticity*, N. Svartholm, ed., p. 367. Almquvist & Wiskell, 1968. Proceedings of the eighth Nobel symposium.

[4] F. Englert and R. Brout, "Broken Symmetry and the Mass of Gauge Vector Mesons", *Phys. Rev. Lett.* **13** (1964) 321. `doi:10.1103/PhysRevLett.13.321`.

[5] P. W. Higgs, "Broken symmetries, massless particles and gauge fields", *Phys. Lett.* **12** (1964) 132. `doi:10.1016/0031-9163(64)91136-9`.

[6] P. W. Higgs, "Broken Symmetries and the Masses of Gauge Bosons", *Phys. Rev. Lett.* **13** (1964) 508. `doi:10.1103/PhysRevLett.13.508`.

[7] G. S. Guralnik, C. R. Hagen, and T. W. B. Kibble, "Global Conservation Laws and Massless Particles", *Phys. Rev. Lett.* **13** (1964) 585. `doi:10.1103/PhysRevLett.13.585`.

[8] P. W. Higgs, "Spontaneous Symmetry Breakdown without Massless Bosons", *Phys. Rev.* **145** (1966) 1156. `doi:10.1103/PhysRev.145.1156`.

[9] T. W. B. Kibble, "Symmetry breaking in non-Abelian gauge theories", *Phys. Rev.* **155** (1967) 1554. `doi:10.1103/PhysRev.155.1554`.

[10] ALEPH, DELPHI, L3, OPAL Collaborations, and the LEP Working Group for Higgs boson searches, "Search for the standard model Higgs boson at LEP", *Phys. Lett. B* **565** (2003) 61, `arXiv:hep-ex/0306033`. `doi:10.1016/S0370-2693(03)00614-2`.

[11] CDF and D0 Collaborations, "Combination of Tevatron Searches for the Standard Model Higgs Boson in the W^+W^- Decay Mode", *Phys. Rev. Lett.* **104** (2010) 061802. A more recent, unpublished, limit is given in preprint arXiv:1103.3233. `doi:10.1103/PhysRevLett.104.061802`.

[12] ALEPH, CDF, D0, DELPHI, L3, OPAL, SLD Collaborations, the LEP Electroweak Working Group, the Tevatron Electroweak Working Group, and the SLD Electroweak and Heavy Flavour Groups, "Precision Electroweak Measurements and Constraints on the Standard Model", technical report, (2010).

[13] ATLAS Collaboration, "Search for the Standard Model Higgs boson in the decay channel $H \to ZZ^{(*)} \to 4\ell$ with the ATLAS detector", *Phys. Lett. B* **705** (2011) 435. `doi:10.1016/j.physletb.2011.10.034`.

[14] ATLAS Collaboration, "Search for a Standard Model Higgs Boson in the $H \to ZZ \to \ell^+\ell^-\nu\bar{\nu}$ decay channel with the ATLAS detector", *Phys. Rev. Lett.* **107** (2011) 221802. `doi:10.1103/PhysRevLett.107.221802`.

[15] ATLAS Collaboration, "Search for the Higgs boson in the $H \to WW(*) \to \ell^+\nu\ell^-\bar{\nu}$ decay channel in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector", (2011). `arXiv:1112.2577`. Submitted to *Phys. Rev. Lett.*

[16] CMS Collaboration, "The CMS experiment at the CERN LHC", *JINST* **3** (2008) S08004. `doi:10.1088/1748-0221/3/08/S08004`.

[17] S. Frixione, P. Nason, and C. Oleari, "Matching NLO QCD computations with Parton Shower simulations: the POWHEG method", *JHEP* **11** (2007) 070, `arXiv:0709.2092`. `doi:10.1088/1126-6708/2007/11/070`.

[18] Y. Gao et al., "Spin determination of single-produced resonances at hadron colliders", *Phys. Rev. D* **81** (2010) 075022, `arXiv:1001.3396`. `doi:10.1103/PhysRevD.81.075022`.

[19] T. Sjöstrand, S. Mrenna, and P. Z. Skands, "PYTHIA 6.4 Physics and Manual", *JHEP* **05** (2006) 026, `arXiv:hep-ph/0603175`. `doi:10.1088/1126-6708/2006/05/026`.

[20] C. Anastasiou, R. Boughezal, and F. Petriello, "Mixed QCD-electroweak corrections to Higgs boson production in gluon fusion", *JHEP* **04** (2009) 003, `arXiv:0811.3458`. `doi:10.1088/1126-6708/2009/04/003`.

[21] D. de Florian and M. Grazzini, "Higgs production through gluon fusion: updated cross sections at the Tevatron and the LHC", *Phys. Lett. B* **674** (2009) 291, `arXiv:0901.2427`. `doi:10.1016/j.physletb.2009.03.033`.

[22] LHC Higgs Cross Section Working Group, "Handbook of LHC Higgs Cross Sections: 1. Inclusive Observables", CERN Report CERN-2011-002, (2011).

[23] S. Dawson, "Radiative corrections to Higgs boson production", *Nucl. Phys. B* **359** (1991) 283. `doi:10.1016/0550-3213(91)90061-2`.

[24] M. Spira et al., "Higgs boson production at the LHC", *Nucl. Phys. B* **453** (1995) 17, `arXiv:hep-ph/9504378`. `doi:10.1016/0550-3213(95)00379-7`.

[25] R. V. Harlander and W. B. Kilgore, "Next-to-next-to-leading order Higgs production at hadron colliders", *Phys. Rev. Lett.* **88** (2002) 201801, `arXiv:hep-ph/0201206`. `doi:10.1103/PhysRevLett.88.201801`.

[26] C. Anastasiou and K. Melnikov, "Higgs boson production at hadron colliders in NNLO QCD", *Nucl. Phys. B* **646** (2002) 220, `arXiv:hep-ph/0207004`. `doi:10.1016/S0550-3213(02)00837-4`.

[27] V. Ravindran, J. Smith, and W. L. van Neerven, "NNLO corrections to the total cross section for Higgs boson production in hadron-hadron collisions", *Nucl. Phys. B* **665** (2003) 325, `arXiv:hep-ph/0302135`. `doi:10.1016/S0550-3213(03)00457-7`.

[28] S. Catani et al., "Soft-gluon resummation for Higgs boson production at hadron colliders", *JHEP* **07** (2003) 028, `arXiv:hep-ph/0306211`. `doi:10.1088/1126-6708/2003/07/028`.

[29] S. Actis et al., "NLO Electroweak Corrections to Higgs Boson Production at Hadron Colliders", *Phys. Lett. B* **670** (2008) 12, `arXiv:0809.1301`. `doi:10.1016/j.physletb.2008.10.018`.

[30] M. Ciccolini, A. Denner, and S. Dittmaier, "Strong and electroweak corrections to the production of Higgs + 2-jets via weak interactions at the LHC", *Phys. Rev. Lett.* **99** (2007) 161803, `arXiv:0707.0381`. `doi:10.1103/PhysRevLett.99.161803`.

[31] M. Ciccolini, A. Denner, and S. Dittmaier, "Electroweak and QCD corrections to Higgs production via vector-boson fusion at the LHC", *Phys. Rev. D* **77** (2008) 013002, `arXiv:0710.4749`. `doi:10.1103/PhysRevD.77.013002`.

[32] T. Figy, C. Oleari, and D. Zeppenfeld, "Next-to-leading order jet distributions for Higgs boson production via weak-boson fusion", *Phys. Rev. D* **68** (2003) 073005, `arXiv:hep-ph/0306109`. `doi:10.1103/PhysRevD.68.073005`.

[33] K. Arnold et al., "VBFNLO: A parton level Monte Carlo for processes with electroweak bosons", *Comput. Phys. Commun.* **180** (2009) 1661, `arXiv:0811.4559`. `doi:10.1016/j.cpc.2009.03.006`.

[34] P. Bolzoni et al., "Higgs production via vector-boson fusion at NNLO in QCD", *Phys. Rev. Lett.* **105** (2010) 011801, `arXiv:1003.4451`. `doi:10.1103/PhysRevLett.105.011801`.

[35] A. Bredenstein et al., "Precise predictions for the Higgs-boson decay $H \rightarrow WW/ZZ \rightarrow 4$ leptons", *Phys. Rev. D* **74** (2006) 013004, `arXiv:hep-ph/0604011`. `doi:10.1103/PhysRevD.74.013004`.

[36] A. Bredenstein et al., "Radiative corrections to the semileptonic and hadronic Higgs-boson decays H →W W / Z Z→ 4 fermions", *JHEP* **02** (2007) 080, `arXiv:hep-ph/0611234`. `doi:10.1088/1126-6708/2007/02/080`.

[37] A. Djouadi et al., "An update of the program HDECAY", in *The Les Houches 2009 workshop on TeV colliders: The tools and Monte Carlo working group summary report.* 2010. `arXiv:1003.1643`.

[38] S. Actis et al., "NNLO Computational Techniques: the Cases $H \to \gamma\gamma$ and $H \to gg$", *Nucl. Phys. B* **811** (2009) 182, `arXiv:0809.3667`. `doi:10.1016/j.nuclphysb.2008.11.024`.

[39] T. Binoth, N. Kauer, and P. Mertsch, "Gluon-induced QCD corrections to $pp \to ZZ \to \ell\bar{\ell}\ell'\bar{\ell}'$", in *Proceedings of the XVI Int. Workshop on Deep-Inelastic Scattering and Related Topics (DIS'07).* 2008. `arXiv:0807.0024`.

[40] J. Alwall et al., "MadGraph/MadEvent v4: The New Web Generation", *JHEP* **09** (2007) 028, `arXiv:0706.2334`. `doi:10.1088/1126-6708/2007/09/028`.

[41] J. Allison et al., "Geant4 developments and applications", *IEEE Trans. Nucl. Sci.* **53** (2006) 270. `doi:10.1109/TNS.2006.869826`.

[42] S. Baffioni et al., "Electron reconstruction in CMS", *Eur. Phys. J. C* **49** (2007) 1099. `doi:10.1140/epjc/s10052-006-0175-5`.

[43] CMS Collaboration, "Electron reconstruction and identification at $\sqrt{s} = 7$ TeV", CMS Physics Analysis Summary CMS-PAS-EGM-10-004, (2010).

[44] CMS Collaboration, "Performance of muon identification in pp collisions at $\sqrt{s} = 7$ TeV", CMS Physics Analysis Summary CMS-PAS-MUO-10-002, (2010).

[45] CMS Collaboration, "Measurement of the Inclusive W and Z Production Cross Sections in pp Collisions at sqrt(s) = 7 TeV", *JHEP* **10** (2011) 132. `doi:10.1007/JHEP10(2011)132`.

[46] M. Cacciari, G. P. Salam, and G. Soyez, "The Catchment Area of Jets", *JHEP* **04** (2008) 005, `arXiv:0802.1188`. `doi:10.1088/1126-6708/2008/04/005`.

[47] J. M. Campbell and R. K. Ellis, "MCFM for the Tevatron and the LHC", *Nucl. Phys. Proc. Suppl.* **205-206** (2010) 10, `arXiv:1007.3492`. `doi:10.1016/j.nuclphysbps.2010.08.011`.

[48] J. M. Campbell and R. K. Ellis, "An update on vector boson pair production at hadron colliders", *Phys. Rev. D* **60** (1999) 113006, `arXiv:hep-ph/9905386`. `doi:10.1103/PhysRevD.60.113006`.

[49] J. M. Campbell, R. Ellis, and C. Williams, "Vector boson pair production at the LHC", *JHEP* **07** (2011) 018, `arXiv:1105.0020`. `doi:10.1007/JHEP07(2011)018`.

[50] M. Botje et al., "The PDF4LHC Working Group Interim Recommendations", (2011). `arXiv:1101.0538`.

[51] S. Alekhin et al., "The PDF4LHC Working Group Interim Report", (2011). `arXiv:1101.0536`.

[52] H.-L. Lai et al., "New parton distributions for collider physics", *Phys. Rev. D* **82** (2010) 074024, `arXiv:1007.2241`. `doi:10.1103/PhysRevD.82.074024`.

[53] A. Martin et al., "Parton distributions for the LHC", *Eur. Phys. J. C* **63** (2009) 189, `arXiv:0901.0002`. `doi:10.1140/epjc/s10052-009-1072-5`.

[54] R. D. Ball et al., "Impact of Heavy Quark Masses on Parton Distributions and LHC Phenomenology", *Nucl. Phys. B* **849** (2011) 296, `arXiv:1101.1300`. `doi:10.1016/j.nuclphysb.2011.03.021`.

[55] S. Baffioni et al., "Discovery potential for the SM Higgs boson in the H $\rightarrow$ Z Z(*)$\rightarrow$ $e^+e^-e^+e^-$ decay channel", *J. Phys. G* **34** (2007) N23. `doi:10.1088/0954-3899/34/2/N01`.

[56] S. Abdullin et al., "Search Strategy for the Standard Model Higgs Boson in the H $\rightarrow$ ZZ $\rightarrow 4\mu$ decay channel", *Acta Phys. Polon. B* **38** (2007) 731.

[57] M. J. Oreglia, "A study of the reactions $\psi' \rightarrow \gamma\gamma\psi$". PhD thesis, Stanford University, 1980. SLAC Report SLAC-R-236, see Appendix D.

[58] CMS Collaboration, "Absolute Calibration of the CMS Luminosity Measurement: Summer 2011 Update", CMS Physics Analysis Summary CMS-PAS-EWK-11-001, (2011).

[59] G. Passarino, C. Sturm, and S. Uccirati, "Higgs Pseudo-Observables, Second Riemann Sheet and All That", *Nucl. Phys. B* **834** (2010) 77, `arXiv:1001.3360`. `doi:10.1016/j.nuclphysb.2010.03.013`.

[60] C. Anastasiou et al., "Total cross-section for Higgs boson hadroproduction with anomalous Standard Model interactions", *JHEP* **12** (2011) 058, `arXiv:1107.0683`. `doi:10.1007/JHEP12(2011)058`.

[61] LHC Higgs Cross Section Working Group, "Handbook of LHC Higgs Cross Sections: 2. Differential Distributions", CERN Report CERN-2012-002, (2012).

[62] E. Gross and O. Vitells, "Trial factors or the look elsewhere effect in high energy physics", *Eur. Phys. J. C* **70** (2010) 525, `arXiv:1005.1891`. `doi:10.1140/epjc/s10052-010-1470-8`.

[63] ATLAS and CMS Collaborations, "Procedure for the LHC Higgs boson search combination in Summer 2011", ATL-PHYS-PUB-2011-011, CMS NOTE-2011/005, (2011).

[64] T. Junk, "Confidence level computation for combining searches with small statistics", *Nucl. Instrum. Meth. A* **434** (1999) 435, `arXiv:hep-ex/9902006`. `doi:10.1016/S0168-9002(99)00498-2`.

[65] A. L. Read, "Modified frequentist analysis of search results (the CL_s method)", CERN Report CERN-OPEN-2000-005, (2000).

A   The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia
S. Chatrchyan, V. Khachatryan, A.M. Sirunyan, A. Tumasyan

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

National Centre for Particle and High Energy Physics, Minsk, Belarus
V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

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

Vrije Universiteit Brussel, Brussel, Belgium
F. Blekman, S. Blyweert, J. D'Hondt, R. Gonzalez Suarez, A. Kalogeropoulos, M. Maes, A. Olbrechts, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

Université Libre de Bruxelles, Bruxelles, Belgium
O. Charaf, B. Clerbaux, G. De Lentdecker, V. Dero, A.P.R. Gay, G.H. Hammad, T. Hreus, A. Léonard, P.E. Marage, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wickens

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

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

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

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

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

Instituto de Fisica Teorica, Universidade Estadual Paulista, Sao Paulo, Brazil
T.S. Anjos[3], C.A. Bernardes[3], F.A. Dias[4], T.R. Fernandez Perez Tomei, E. M. Gregores[3], C. Lagana, F. Marinho, P.G. Mercadante[3], S.F. Novaes, Sandra S. Padula

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
V. Genchev[1], P. Iaydjiev[1], S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, M. Vutova

University of Sofia, Sofia, Bulgaria
A. Dimitrov, R. Hadjiiska, A. Karadzhinova, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China
J.G. Bian, G.M. Chen, H.S. Chen, C.H. Jiang, D. Liang, S. Liang, X. Meng, J. Tao, J. Wang, J. Wang, X. Wang, Z. Wang, H. Xiao, M. Xu, J. Zang, Z. Zhang

State Key Lab. of Nucl. Phys. and Tech., Peking University, Beijing, China
C. Asawatangtrakuldee, Y. Ban, S. Guo, Y. Guo, W. Li, S. Liu, Y. Mao, S.J. Qian, H. Teng, S. Wang, B. Zhu, W. Zou

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

Technical University of Split, Split, Croatia
N. Godinovic, D. Lelas, R. Plestina[5], D. Polic, I. Puljak[1]

University of Split, Split, Croatia
Z. Antunovic, M. Dzelalija, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia
V. Brigljevic, S. Duric, K. Kadija, J. Luetic, S. Morovic

University of Cyprus, Nicosia, Cyprus
A. Attikis, M. Galanti, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis

Charles University, Prague, Czech Republic
M. Finger, M. Finger Jr.

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
Y. Assran[6], A. Ellithi Kamel[7], S. Khalil[8], M.A. Mahmoud[9], A. Radi[10]

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
A. Hektor, M. Kadastik, M. Müntel, M. Raidal, L. Rebane, A. Tiko

Department of Physics, University of Helsinki, Helsinki, Finland
V. Azzolini, P. Eerola, G. Fedi, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland
S. Czellar, J. Härkönen, A. Heikkinen, V. Karimäki, R. Kinnunen, M.J. Kortelainen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, D. Ungaro, L. Wendland

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

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

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

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

S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj[11], C. Broutin, P. Busson, C. Charlot, N. Daci, T. Dahms, L. Dobrzynski, S. Elgammal, R. Granier de Cassagnac, M. Haguenauer, P. Miné, C. Mironov, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Thiebaux, C. Veelken, A. Zabi

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

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

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

F. Fassi, D. Mercier

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

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

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

D. Lomidze

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

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

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

M. Ata, J. Caudron, E. Dietz-Laursonn, M. Erdmann, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, T. Klimkovich, D. Klingebiel, P. Kreuzer, D. Lanske[†], J. Lingemann, C. Magass, M. Merschmeyer, A. Meyer, M. Olschewski, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier, M. Weber

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

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

Deutsches Elektronen-Synchrotron, Hamburg, Germany

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

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

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

Institute of Nuclear Physics "Demokritos", Aghia Paraskevi, Greece
G. Daskalakis, T. Geralis, S. Kesisoglou, A. Kyriakis, D. Loukas, I. Manolakos, A. Markou, C. Markou, C. Mavrommatis, E. Ntomari

University of Athens, Athens, Greece
L. Gouskos, T.J. Mertzimekis, A. Panagiotou, N. Saoulidou, E. Stiliaris

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

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
A. Aranyi, G. Bencze, L. Boldizsar, C. Hajdu[1], P. Hidas, D. Horvath[15], A. Kapusi, K. Krajczar[16], F. Sikler[1], V. Veszpremi, G. Vesztergombi[16]

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

University of Debrecen, Debrecen, Hungary
J. Karancsi, P. Raics, Z.L. Trocsanyi, B. Ujvari

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

University of Delhi, Delhi, India
S. Ahuja, B.C. Choudhary, A. Kumar, A. Kumar, S. Malhotra, M. Naimuddin, K. Ranjan, V. Sharma, R.K. Shivpuri

Saha Institute of Nuclear Physics, Kolkata, India
S. Banerjee, S. Bhattacharya, S. Dutta, B. Gomber, S. Jain, S. Jain, R. Khurana, S. Sarkar

Bhabha Atomic Research Centre, Mumbai, India
R.K. Choudhury, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty[1], L.M. Pant, P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India
T. Aziz, S. Ganguly, M. Guchait[17], A. Gurtu[18], M. Maity[19], G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, A. Saha, K. Sudhakar, N. Wickramage

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

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

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

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

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

INFN Sezione di Firenze [a]**, Università di Firenze** [b]**, Firenze, Italy**
G. Barbagli[a], V. Ciulli[a,b], C. Civinini[a], R. D'Alessandro[a,b], E. Focardi[a,b], S. Frosali[a,b], E. Gallo[a], S. Gonzi[a,b], M. Meschini[a], S. Paoletti[a], G. Sguazzoni[a], A. Tropiano[a,1]

INFN Laboratori Nazionali di Frascati, Frascati, Italy
L. Benussi, S. Bianco, S. Colafranceschi[24], F. Fabbri, D. Piccolo

INFN Sezione di Genova, Genova, Italy
P. Fabbricatore, R. Musenich

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

INFN Sezione di Napoli [a]**, Università di Napoli "Federico II"** [b]**, Napoli, Italy**
S. Buontempo[a], C.A. Carrillo Montoya[a,1], N. Cavallo[a,25], A. De Cosa[a,b], O. Dogangun[a,b], F. Fabozzi[a,25], A.O.M. Iorio[a,1], L. Lista[a], M. Merola[a,b], P. Paolucci[a]

INFN Sezione di Padova [a]**, Università di Padova** [b]**, Università di Trento (Trento)** [c]**, Padova, Italy**
P. Azzi[a], N. Bacchetta[a,1], P. Bellan[a,b], D. Bisello[a,b], A. Branca[a], R. Carlin[a,b], P. Checchia[a], T. Dorigo[a], U. Dosselli[a], F. Fanzago[a], F. Gasparini[a,b], U. Gasparini[a,b], A. Gozzelino[a], K. Kanishchev, S. Lacaprara[a,26], I. Lazzizzera[a,c], M. Loreti[a], M. Margoni[a,b], M. Mazzucato[a], A.T. Meneguzzo[a,b], M. Nespolo[a,1], L. Perrozzi[a], N. Pozzobon[a,b], P. Ronchese[a,b], F. Simonetto[a,b], E. Torassa[a], M. Tosi[a,b,1], S. Vanini[a,b], P. Zotto[a,b], G. Zumerle[a,b]

INFN Sezione di Pavia [a]**, Università di Pavia** [b]**, Pavia, Italy**
U. Berzano[a], M. Gabusi[a,b], S.P. Ratti[a,b], C. Riccardi[a,b], P. Torre[a,b], P. Vitulo[a,b]

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

INFN Sezione di Pisa ^{a}, Università di Pisa ^{b}, Scuola Normale Superiore di Pisa ^{c}, Pisa, Italy
P. Azzurri^{a,c}, G. Bagliesi^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, R.T. D'Agnolo^{a,c}, R. Dell'Orso^a, F. Fiori^{a,b}, L. Foà^{a,c}, A. Giassi^a, A. Kraan^a, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,27}, A. Messineo^{a,b}, F. Palla^a, F. Palmonari^a, A. Rizzi, A.T. Serban^a, P. Spagnolo^a, R. Tenchini^a, G. Tonelli^{a,b,1}, A. Venturi^{a,1}, P.G. Verdini^a

INFN Sezione di Roma ^{a}, Università di Roma "La Sapienza" ^{b}, Roma, Italy
L. Barone^{a,b}, F. Cavallari^a, D. Del Re^{a,b,1}, M. Diemoz^a, C. Fanelli, M. Grassi^{a,1}, E. Longo^{a,b}, P. Meridiani^a, F. Micheli, S. Nourbakhsh^a, G. Organtini^{a,b}, F. Pandolfi^{a,b}, R. Paramatti^a, S. Rahatlou^{a,b}, M. Sigamani^a, L. Soffi

INFN Sezione di Torino ^{a}, Università di Torino ^{b}, Università del Piemonte Orientale (Novara) ^{c}, Torino, Italy
N. Amapane^{a,b}, R. Arcidiacono^{a,c}, S. Argiro^{a,b}, M. Arneodo^{a,c}, C. Biino^a, C. Botta^{a,b}, N. Cartiglia^a, R. Castello^{a,b}, M. Costa^{a,b}, N. Demaria^a, A. Graziano^{a,b}, C. Mariotti^{a,1}, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b}, M. Musich^a, M.M. Obertino^{a,c}, N. Pastrone^a, M. Pelliccioni^a, A. Potenza^{a,b}, A. Romero^{a,b}, M. Ruspa^{a,c}, R. Sacchi^{a,b}, V. Sola^{a,b}, A. Solano^{a,b}, A. Staiano^a, A. Vilela Pereira^a

INFN Sezione di Trieste ^{a}, Università di Trieste ^{b}, Trieste, Italy
S. Belforte^a, F. Cossutti^a, G. Della Ricca^{a,b}, B. Gobbo^a, M. Marone^{a,b}, D. Montanino^{a,b,1}, A. Penzo^a

Kangwon National University, Chunchon, Korea
S.G. Heo, S.K. Nam

Kyungpook National University, Daegu, Korea
S. Chang, J. Chung, D.H. Kim, G.N. Kim, J.E. Kim, D.J. Kong, H. Park, S.R. Ro, D.C. Son

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
J.Y. Kim, Zero J. Kim, S. Song

Konkuk University, Seoul, Korea
H.Y. Jo

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

University of Seoul, Seoul, Korea
M. Choi, S. Kang, H. Kim, J.H. Kim, C. Park, I.C. Park, S. Park, G. Ryu

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

Vilnius University, Vilnius, Lithuania
M.J. Bilinskas, I. Grigelionis, M. Janulis

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz, R. Lopez-Fernandez, R. Magaña Villalba, J. Martínez-Ortega, A. Sánchez-Hernández, L.M. Villasenor-Cendejas

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

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
H.A. Salazar Ibarguen

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

University of Auckland, Auckland, New Zealand
D. Krofcheck

University of Canterbury, Christchurch, New Zealand
A.J. Bell, P.H. Butler, R. Doesburg, S. Reucroft, H. Silverwood

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
M. Ahmad, M.I. Asghar, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi, M.A. Shah, M. Shoaib

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
G. Brona, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski

Soltan Institute for Nuclear Studies, Warsaw, Poland
H. Bialkowska, B. Boimska, T. Frueboes, R. Gokieli, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
N. Almeida, P. Bargassa, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, P. Musella, A. Nayak, J. Pela[1], P.Q. Ribeiro, J. Seixas, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia
I. Belotelov, I. Golutvin, N. Gorbounov, I. Gramenitski, A. Kamenev, V. Karjavin, V. Konoplyanikov, V. Korenkov, G. Kozlov, A. Lanev, P. Moisenz, V. Palichik, V. Perelygin, M. Savina, S. Shmatov, S. Vasil'ev, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St Petersburg), Russia
S. Evstyukhin, V. Golovtsov, Y. Ivanov, V. Kim, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev, An. Vorobyev

Institute for Nuclear Research, Moscow, Russia
Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, M. Kirsanov, N. Krasnikov, V. Matveev, A. Pashenkov, A. Toropin, S. Troitsky

Institute for Theoretical and Experimental Physics, Moscow, Russia
V. Epshteyn, M. Erofeeva, V. Gavrilov, M. Kossov[1], A. Krokhotin, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

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

P.N. Lebedev Physical Institute, Moscow, Russia
V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Leonidov, G. Mesyats, S.V. Rusakov, A. Vinogradov

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia
I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin[1], V. Kachanov, D. Konstantinov, A. Korablev,

V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
P. Adzic[28], M. Djordjevic, M. Ekmedzic, D. Krpic[28], J. Milosevic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
M. Aguilar-Benitez, J. Alcaraz Maestre, P. Arce, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, C. Diez Pardos, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, J. Puerta Pelayo, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain
C. Albajar, G. Codispoti, J.F. de Trocóniz

Universidad de Oviedo, Oviedo, Spain
J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez[29], J.M. Vizan Garcia

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Felcini[30], M. Fernandez, G. Gomez, J. Gonzalez Sanchez, C. Jorda, P. Lobelle Pardo, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, M. Sobron Sanudo, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland
D. Abbaneo, E. Auffray, G. Auzinger, P. Baillon, A.H. Ball, D. Barney, C. Bernet[5], W. Bialas, G. Bianchi, P. Bloch, A. Bocci, H. Breuker, K. Bunkowski, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, B. Curé, D. D'Enterria, A. De Roeck, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, B. Frisch, W. Funk, A. Gaddi, G. Georgiou, H. Gerwig, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, L. Guiducci, M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, H.F. Hoffmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, P. Lecoq, P. Lenzi, C. Lourenço, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, G. Mavromanolakis, F. Meijers, S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, E. Nesvold, M. Nguyen, T. Orimoto, L. Orsini, E. Palencia Cortezon, E. Perez, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, L. Quertenmont, A. Racz, W. Reece, J. Rodrigues Antunes, G. Rolandi[31], T. Rommerskirchen, C. Rovelli[32], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[33], D. Spiga, M. Spiropulu[4], M. Stoye, A. Tsirou, G.I. Veres[16], P. Vichoudis, H.K. Wöhri, S.D. Worm[34], W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland
W. Bertl, K. Deiters, W. Erdmann, K. Gabathuler, R. Horisberger, Q. Ingram, H.C. Kaestli, S. König, D. Kotlinski, U. Langenegger, F. Meier, D. Renker, T. Rohe, J. Sibille[35]

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland
L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, Z. Chen, A. Deisher, G. Dissertori, M. Dittmar, M. Dünser, J. Eugster, K. Freudenreich, C. Grab, P. Lecomte, W. Lustermann,

P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli[36], P. Nef, F. Nessi-Tedaldi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, M.-C. Sawley, A. Starodumov[37], B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli, J. Weng

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

National Central University, Chung-Li, Taiwan
Y.H. Chang, K.H. Chen, C.M. Kuo, S.W. Li, W. Lin, Z.K. Liu, Y.J. Lu, D. Mekterovic, R. Volpe, S.S. Yu

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

Cukurova University, Adana, Turkey
A. Adiguzel, M.N. Bakirci[38], S. Cerci[39], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, I. Hos, E.E. Kangal, G. Karapinar, A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk[40], A. Polatoz, K. Sogut[41], D. Sunar Cerci[39], B. Tali[39], H. Topakli[38], D. Uzun, L.N. Vergili, M. Vergili

Middle East Technical University, Physics Department, Ankara, Turkey
I.V. Akin, T. Aliev, B. Bilin, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, M. Yalvac, E. Yildirim, M. Zeyrek

Bogazici University, Istanbul, Turkey
M. Deliomeroglu, E. Gülmez, B. Isildak, M. Kaya[42], O. Kaya[42], S. Ozkorucuklu[43], N. Sonmez[44]

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

University of Bristol, Bristol, United Kingdom
F. Bostock, J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold[34], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom
L. Basso[45], K.W. Bell, A. Belyaev[45], C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley

Imperial College, London, United Kingdom
R. Bainbridge, G. Ball, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko[37], A. Papageorgiou, M. Pesaresi, K. Petridis, M. Pioppi[46], D.M. Raymond, S. Rogerson, N. Rompotis, A. Rose, M.J. Ryan, C. Seez, A. Sparrow, A. Tapper, S. Tourneur, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, D. Wardrope, T. Whyntie

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

Baylor University, Waco, USA
K. Hatakeyama, H. Liu, T. Scarborough

The University of Alabama, Tuscaloosa, USA
C. Henderson

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

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

University of California, Davis, Davis, USA
R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, M. Caulfield, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, J. Dolen, R. Erbacher, M. Gardner, R. Houtz, W. Ko, A. Kopecky, R. Lander, O. Mall, T. Miceli, R. Nelson, D. Pellett, J. Robles, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra

University of California, Los Angeles, Los Angeles, USA
V. Andreev, K. Arisaka, D. Cline, R. Cousins, J. Duris, S. Erhan, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, C. Jarvis, C. Plager, G. Rakness, P. Schlein[†], J. Tucker, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA
J. Babb, R. Clare, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng, H. Liu, O.R. Long, A. Luthra, H. Nguyen, S. Paramesvaran, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

University of California, San Diego, La Jolla, USA
W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, D. Evans, F. Golf, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, S. Padhi, C. Palmer, G. Petrucciani, H. Pi, M. Pieri, R. Ranieri, M. Sani, I. Sfiligoi, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech[47], F. Würthwein, A. Yagil, J. Yoo

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

California Institute of Technology, Pasadena, USA
A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, E. Di Marco, J. Duarte, M. Gataullin, Y. Ma, A. Mott, H.B. Newman, C. Rogan, V. Timciuc, P. Traczyk, J. Veverka, R. Wilkinson, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA
B. Akgun, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, S.Y. Jun, Y.F. Liu, M. Paulini, J. Russ, H. Vogel, I. Vorobiev

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

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

Fairfield University, Fairfield, USA
A. Biselli, D. Winn

Fermi National Accelerator Laboratory, Batavia, USA
S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, M. Atac, J.A. Bakken, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, I. Bloch, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, S. Cihangir, W. Cooper, D.P. Eartly, V.D. Elvira, S. Esen, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, D. Green, O. Gutsche, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, H. Jensen, S. Jindariani, M. Johnson, U. Joshi, B. Klima, S. Kunori, S. Kwan, C. Leonidopoulos, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, T. Miao, K. Mishra, S. Mrenna, Y. Musienko[48], C. Newman-Holmes, V. O'Dell, J. Pivarski, R. Pordes, O. Prokofyev, T. Schwarz, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, P. Tan, L. Taylor, S. Tkaczyk, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, F. Yumiceva, J.C. Yun

University of Florida, Gainesville, USA
D. Acosta, P. Avery, D. Bourilkov, M. Chen, S. Das, M. De Gruttola, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, S. Goldberg, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic[49], G. Mitselmakher, L. Muniz, R. Remington, A. Rinkevicius, M. Schmitt, B. Scurlock, P. Sellers, N. Skhirtladze, M. Snowball, D. Wang, J. Yelton, M. Zakaria

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

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

Florida Institute of Technology, Melbourne, USA
M.M. Baarmand, B. Dorney, M. Hohlmann, H. Kalakhety, I. Vodopiyanov

University of Illinois at Chicago (UIC), Chicago, USA
M.R. Adams, I.M. Anghel, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, J. Callner, R. Cavanaugh, C. Dragoiu, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, G.J. Kunde[50], F. Lacroix, M. Malek, C. O'Brien, C. Silkworth, C. Silvestre, D. Strom, N. Varelas

The University of Iowa, Iowa City, USA
U. Akgun, E.A. Albayrak, B. Bilki[51], W. Clarida, F. Duru, S. Griffiths, C.K. Lae, E. McCliment, J.-P. Merlo, H. Mermerkaya[52], A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, J. Olson, Y. Onel, F. Ozok, S. Sen, E. Tiras, J. Wetzel, T. Yetkin, K. Yi

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

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

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

Lawrence Livermore National Laboratory, Livermore, USA
J. Gronberg, D. Lange, D. Wright

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

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

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

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

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

State University of New York at Buffalo, Buffalo, USA
U. Baur, A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S.P. Shipkowski, K. Smith, Z. Wan

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

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

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

The Ohio State University, Columbus, USA
B. Bylsma, L.S. Durkin, C. Hill, P. Killewald, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, C. Vuosalo, G. Williams

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

University of Puerto Rico, Mayaguez, USA
J.G. Acosta, X.T. Huang, A. Lopez, H. Mendez, S. Oliveros, J.E. Ramirez Vargas, A. Zatserklyaniy

Purdue University, West Lafayette, USA
E. Alagoz, V.E. Barnes, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, L. Gutay, Z. Hu, M. Jones, O. Koybasi, M. Kress, A.T. Laasanen, N. Leonardo, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, M. Vidal Marono, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA
S. Guragain, N. Parashar

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

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

The Rockefeller University, New York, USA
A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, S. Malik, C. Mesropian

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

University of Tennessee, Knoxville, USA
G. Cerizza, M. Hollingsworth, S. Spanier, Z.C. Yang, A. York

Texas A&M University, College Station, USA
R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[53], V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback

Texas Tech University, Lubbock, USA
N. Akchurin, C. Bardak, J. Damgov, P.R. Dudero, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, P. Mane, Y. Roh, A. Sill, I. Volobouev, R. Wigmans

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

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

Wayne State University, Detroit, USA
S. Gollapinni, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, M. Mattson, C. Milstène, A. Sakharov

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

†: Deceased
1: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
2: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
3: Also at Universidade Federal do ABC, Santo Andre, Brazil
4: Also at California Institute of Technology, Pasadena, USA
5: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
6: Also at Suez Canal University, Suez, Egypt
7: Also at Cairo University, Cairo, Egypt
8: Also at British University, Cairo, Egypt
9: Also at Fayoum University, El-Fayoum, Egypt
10: Also at Ain Shams University, Cairo, Egypt
11: Also at Soltan Institute for Nuclear Studies, Warsaw, Poland
12: Also at Université de Haute-Alsace, Mulhouse, France
13: Also at Moscow State University, Moscow, Russia
14: Also at Brandenburg University of Technology, Cottbus, Germany
15: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
16: Also at Eötvös Loránd University, Budapest, Hungary
17: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
18: Now at King Abdulaziz University, Jeddah, Saudi Arabia
19: Also at University of Visva-Bharati, Santiniketan, India
20: Also at Sharif University of Technology, Tehran, Iran
21: Also at Isfahan University of Technology, Isfahan, Iran
22: Also at Shiraz University, Shiraz, Iran
23: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Teheran, Iran
24: Also at Facoltà Ingegneria Università di Roma, Roma, Italy
25: Also at Università della Basilicata, Potenza, Italy
26: Also at Laboratori Nazionali di Legnaro dell' INFN, Legnaro, Italy
27: Also at Università degli studi di Siena, Siena, Italy
28: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
29: Also at University of Florida, Gainesville, USA
30: Also at University of California, Los Angeles, Los Angeles, USA
31: Also at Scuola Normale e Sezione dell' INFN, Pisa, Italy
32: Also at INFN Sezione di Roma; Università di Roma "La Sapienza", Roma, Italy
33: Also at University of Athens, Athens, Greece
34: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
35: Also at The University of Kansas, Lawrence, USA
36: Also at Paul Scherrer Institut, Villigen, Switzerland
37: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
38: Also at Gaziosmanpasa University, Tokat, Turkey

39: Also at Adiyaman University, Adiyaman, Turkey
40: Also at The University of Iowa, Iowa City, USA
41: Also at Mersin University, Mersin, Turkey
42: Also at Kafkas University, Kars, Turkey
43: Also at Suleyman Demirel University, Isparta, Turkey
44: Also at Ege University, Izmir, Turkey
45: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
46: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
47: Also at Utah Valley University, Orem, USA
48: Also at Institute for Nuclear Research, Moscow, Russia
49: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
50: Also at Los Alamos National Laboratory, Los Alamos, USA
51: Also at Argonne National Laboratory, Argonne, USA
52: Also at Erzincan University, Erzincan, Turkey
53: Also at Kyungpook National University, Daegu, Korea