



# Determination of the top-quark pole mass and strong coupling constant from the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s} = 7$ TeV<sup>☆</sup>



CMS Collaboration<sup>\*</sup>

CERN, Switzerland

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## ABSTRACT

The inclusive cross section for top-quark pair production measured by the CMS experiment in proton–proton collisions at a center-of-mass energy of 7 TeV is compared to the QCD prediction at next-to-next-to-leading order with various parton distribution functions to determine the top-quark pole mass,  $m_t^{\text{pole}}$ , or the strong coupling constant,  $\alpha_S$ . With the parton distribution function set NNPDF2.3, a pole mass of  $176.7_{-3.4}^{+3.8}$  GeV is obtained when constraining  $\alpha_S$  at the scale of the Z boson mass,  $m_Z$ , to the current world average. Alternatively, by constraining  $m_t^{\text{pole}}$  to the latest average from direct mass measurements, a value of  $\alpha_S(m_Z) = 0.1151_{-0.0032}^{+0.0033}$  is extracted. This is the first determination of  $\alpha_S$  using events from top-quark production.

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## 1. Introduction

The Large Hadron Collider (LHC) has provided a wealth of proton–proton collisions, which has enabled the Compact Muon Solenoid (CMS) experiment [1] to measure cross sections for the production of top-quark pairs ( $t\bar{t}$ ) with high precision employing a variety of approaches [2–10]. Comparing the presently available results, obtained at a center-of-mass energy,  $\sqrt{s}$ , of 7 TeV, to theoretical predictions allows for stringent tests of the underlying models and for constraints on fundamental parameters. Top-quark pair production can be described in the framework of quantum chromodynamics (QCD) and calculations for the inclusive  $t\bar{t}$  cross section,  $\sigma_{t\bar{t}}$ , have recently become available to complete next-to-next-to-leading order (NNLO) in perturbation theory [11]. Crucial inputs to these calculations are: the top-quark mass,  $m_t$ ; the strong coupling constant,  $\alpha_S$ ; and the gluon distribution in the proton,

since  $t\bar{t}$  production at LHC energies is expected to occur predominantly via gluon–gluon fusion.

The top-quark mass is one of the fundamental parameters of the standard model (SM) of particle physics. Its value significantly affects predictions for many observables either directly or via radiative corrections. As a consequence, the measured  $m_t$  is one of the key inputs to electroweak precision fits, which enable comparisons between experimental results and predictions within and beyond the SM. Furthermore, together with the Higgs-boson mass and  $\alpha_S$ ,  $m_t$  has direct implications on the stability of the electroweak vacuum [12,13]. The most precise result for  $m_t$ , obtained by combining direct measurements performed at the Tevatron, is  $173.18 \pm 0.94$  GeV [14]. Similar measurements performed by the CMS Collaboration [2,15–17] are in agreement with the Tevatron result and of comparable precision. However, except for a few cases [17], these direct measurements rely on the relation between  $m_t$  and the respective experimental observable, e.g., a reconstructed invariant mass, as expected from simulated events. In QCD beyond leading order,  $m_t$  depends on the renormalization scheme [18,19]. The available Monte Carlo generators contain matrix elements at leading order or next-to-leading order (NLO), while

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<sup>\*</sup> E-mail address: cms-publication-committee-chair@cern.ch.

higher orders are simulated by applying parton showering. Studies suggest that  $m_t$  as implemented in Monte Carlo generators corresponds approximately to the pole (“on-shell”) mass,  $m_t^{\text{pole}}$ , but that the value of the true pole mass could be of the order of 1 GeV higher compared to  $m_t$  in the current event generators [20]. In addition to direct  $m_t$  measurements, the mass dependence of the QCD prediction for  $\sigma_{t\bar{t}}$  can be used to determine  $m_t$  by comparing the measured to the predicted cross section [13,19,21–24]. Although the sensitivity of  $\sigma_{t\bar{t}}$  to  $m_t$  might not be strong enough to make this approach competitive in precision, it yields results affected by different sources of systematic uncertainties compared to the direct  $m_t$  measurements and allows for extractions of  $m_t$  in theoretically well-defined mass schemes. It has been advocated to directly extract the  $\overline{\text{MS}}$  mass of the top quark using the  $\sigma_{t\bar{t}}$  prediction in that scheme [21]. The relation between pole and  $\overline{\text{MS}}$  mass is known to three-loop level in QCD but might receive large electroweak corrections [25]. In principle, the difference between the results obtained when extracting  $m_t$  in the pole and converting it to the  $\overline{\text{MS}}$  scheme or extracting the  $\overline{\text{MS}}$  mass directly should be small in view of the precision that the extraction of  $m_t$  from the inclusive  $\sigma_{t\bar{t}}$  at a hadron collider provides. Therefore, only the pole mass scheme is employed in this Letter.

With the exception of the quark masses,  $\alpha_S$  is the only free parameter of the QCD Lagrangian. While the renormalization group equation predicts the energy dependence of the strong coupling, i.e., gives a functional form for  $\alpha_S(Q)$ , where  $Q$  is the energy scale of the process, actual values of  $\alpha_S$  can only be obtained based on experimental data. By convention and to facilitate comparisons,  $\alpha_S$  values measured at different energy scales are typically evolved to  $Q = m_Z$ , the mass of the Z boson. The current world average for  $\alpha_S(m_Z)$  is  $0.1184 \pm 0.0007$  [26]. In spite of this relatively precise result, the uncertainty on  $\alpha_S$  still contributes significantly to many QCD predictions, including expected cross sections for top-quark pairs or Higgs bosons. Furthermore, thus far very few measurements allow  $\alpha_S$  to be tested at high  $Q$  and the precision on the average for  $\alpha_S(m_Z)$  is driven by low- $Q$  measurements. Energies up to 209 GeV were probed with hadronic final states in electron-positron collisions at LEP using NNLO predictions [27–30]. Jet measurements at the Tevatron and the LHC have recently extended the range up to 400 GeV [31], 600 GeV [32], and 1.4 TeV [33]. However, most predictions for jet production in hadron collisions are only available up to NLO QCD. Even when these predictions are available at approximate NNLO, as used in [34], they suffer from significant uncertainties related to the choice and variation of the renormalization and factorization scales,  $\mu_R$  and  $\mu_F$ , as well as from uncertainties related to non-perturbative corrections.

In cross section calculations,  $\alpha_S$  appears not only in the expression for the parton-parton interaction but also in the QCD evolution of the parton distribution functions (PDFs). Varying the value of  $\alpha_S(m_Z)$  in the  $\sigma_{t\bar{t}}$  calculation therefore requires a consistent modification of the PDFs. Moreover, a strong correlation between  $\alpha_S$  and the gluon PDF at large partonic momentum fractions is expected to significantly enhance the sensitivity of  $\sigma_{t\bar{t}}$  to  $\alpha_S$  [35].

In this Letter, the predicted  $\sigma_{t\bar{t}}$  is compared to the most precise single measurement to date [6], and values of  $m_t^{\text{pole}}$  and  $\alpha_S(m_Z)$  are determined. This extraction is performed under the assumption that the measured  $\sigma_{t\bar{t}}$  is not affected by non-SM physics. The interplay of the values of  $m_t^{\text{pole}}$ ,  $\alpha_S$  and the proton PDFs in the prediction of  $\sigma_{t\bar{t}}$  is studied. Five different PDF sets, available at NNLO, are employed and for each a series of different choices of  $\alpha_S(m_Z)$  are considered. A simultaneous extraction of top-quark mass and

strong coupling constant from the total  $t\bar{t}$  cross section alone is not possible since both parameters alter the predicted  $\sigma_{t\bar{t}}$  in such a way that any variation of one parameter can be compensated by a variation of the other. Values of  $m_t^{\text{pole}}$  and  $\alpha_S(m_Z)$  are therefore determined at fixed values of  $\alpha_S(m_Z)$  and  $m_t^{\text{pole}}$ , respectively. For the  $m_t^{\text{pole}}$  extraction,  $\alpha_S(m_Z)$  is constrained to the latest world average value with its corresponding uncertainty ( $0.1184 \pm 0.0007$ ) [26]. Furthermore, it is assumed that the  $m_t$  parameter of the Monte Carlo generator that is employed in the  $\sigma_{t\bar{t}}$  measurement is equal to  $m_t^{\text{pole}}$  within  $\pm 1.00$  GeV [20]. For the  $\alpha_S$  extraction,  $m_t^{\text{pole}}$  is set to the Tevatron average of  $173.18 \pm 0.94$  GeV [14]. To account for the possible difference between the pole mass and the Monte Carlo generator mass [20], an additional uncertainty, assumed to be 1.00 GeV, is added in quadrature to the experimental uncertainty, resulting in a total uncertainty on the top-quark mass constraint,  $\delta m_t^{\text{pole}}$ , of 1.4 GeV. Although the potential  $\alpha_S$  dependence of the direct  $m_t$  measurements has not been explicitly evaluated, it is assumed to be covered by the quoted mass uncertainty.

## 2. Predicted cross section

The expected  $\sigma_{t\bar{t}}$  has been calculated to NNLO for all production channels, namely the all-fermionic scattering modes ( $q\bar{q}$ ,  $q\bar{q}'$ ,  $q\bar{q}'$ ,  $q\bar{q} \rightarrow t\bar{t} + X$ ) [36,37], the reaction  $qg \rightarrow t\bar{t} + X$  [38], and the dominant process  $gg \rightarrow t\bar{t} + X$  [11]. In the present analysis, these calculations are used as implemented in the program Top++ 2.0 [39]. Soft-gluon resummation is performed at next-to-next-leading-log (NNLL) accuracy [40,41]. The scales  $\mu_R$  and  $\mu_F$  are set to  $m_t^{\text{pole}}$ . In order to evaluate the theoretical uncertainty of the fixed-order calculation, the missing contributions from higher orders are estimated by varying  $\mu_R$  and  $\mu_F$  up and down by a factor of 2 independently, while using the restriction  $0.5 \leq \mu_F/\mu_R \leq 2$ . These choices for the central scale and the variation procedure were suggested by the authors of the NNLO calculations and used for earlier  $\sigma_{t\bar{t}}$  predictions as well [42].

Five different NNLO PDF sets are employed: ABM11 [43], CT10 [44], HERAPDF1.5 [45], MSTW2008 [46,47], and NNPDF2.3 [48]. The corresponding uncertainties are calculated at the 68% confidence level for all PDF sets. This is done by recalculating the  $\sigma_{t\bar{t}}$  at NNLO + NNLL for each of the provided eigenvectors or replicas of the respective PDF set and then performing error propagation according to the prescription of that PDF group. In the specific case of the CT10 PDF set, the uncertainties are provided for the 90% confidence level only. For this Letter, following the recommendation of the CTEQ group, these uncertainties are adjusted using the general relation between confidence intervals based on Gaussian distributions [26], i.e., scaled down by a factor of  $\sqrt{2} \text{erf}^{-1}(0.90) = 1.64$ , where erf denotes the error function.

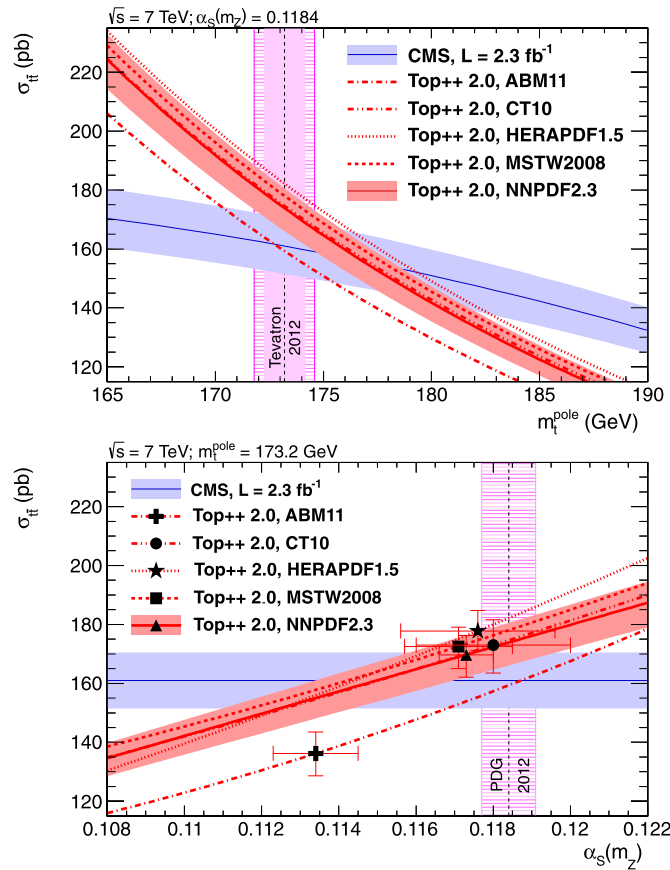
The dependence of the predicted  $\sigma_{t\bar{t}}$  on the choice of  $m_t^{\text{pole}}$  is studied by varying  $m_t^{\text{pole}}$  in the range from 130 to 220 GeV in steps of 1 GeV and found to be well described by a third-order polynomial in  $m_t^{\text{pole}}$  divided by  $(m_t^{\text{pole}})^4$ . The  $\alpha_S$  dependence of  $\sigma_{t\bar{t}}$  is studied by varying the value of  $\alpha_S(m_Z)$  over the entire valid range for a particular PDF set, as listed in Table 1. The relative change of  $\sigma_{t\bar{t}}$  as a function of  $\alpha_S(m_Z)$  can be parametrized using a second-order polynomial in  $\alpha_S(m_Z)$ , where the three coefficients of that polynomial depend linearly on  $m_t^{\text{pole}}$ .

The resulting  $\sigma_{t\bar{t}}$  predictions are compared in Fig. 1, both as a function of  $m_t^{\text{pole}}$  and of  $\alpha_S(m_Z)$ . For a given value of  $\alpha_S(m_Z)$ , the predictions based on NNPDF2.3 and CT10 are very similar. The cross sections obtained with MSTW2008 and HERAPDF1.5 are

**Table 1**

Default  $\alpha_S(m_Z)$  values and  $\alpha_S(m_Z)$  variation ranges of the NNLO PDF sets used in this analysis. Because the NNPDF2.3 PDF set does not have a default value of  $\alpha_S(m_Z)$ , preferring to provide the full uncertainties and systematic variations for various  $\alpha_S(m_Z)$  points, the  $\alpha_S(m_Z)$  value obtained by the NNPDF Collaboration with NNPDF2.1 [49] is used. The step size for the  $\alpha_S(m_Z)$  scans is 0.0010 in all cases. The uncertainties on the default values are shown for illustration purposes only.

	Default $\alpha_S(m_Z)$	Uncertainty	Provided $\alpha_S(m_Z)$ scan	
			Range	# of points
ABM11	0.1134	$\pm 0.0011$	0.1040–0.1200	17
CT10	0.1180	$\pm 0.0020$	0.1100–0.1300	21
HERAPDF1.5	0.1176	$\pm 0.0020$	0.1140–0.1220	9
MSTW2008	0.1171	$\pm 0.0014$	0.1070–0.1270	21
NNPDF2.3	0.1174	$\pm 0.0007$	0.1140–0.1240	11



**Fig. 1.** Predicted  $t\bar{t}$  cross section at NNLO+NNLL, as a function of the top-quark pole mass (top) and of the strong coupling constant (bottom), using five different NNLO PDF sets, compared to the cross section measured by CMS assuming  $m_t = m_t^{\text{pole}}$ . The uncertainties on the measured  $\sigma_{t\bar{t}}$  as well as the renormalization and factorization scale and PDF uncertainties on the prediction with NNPDF2.3 are illustrated with filled bands. The uncertainties on the  $\sigma_{t\bar{t}}$  predictions using the other PDF sets are indicated only in the bottom panel at the corresponding default  $\alpha_S(m_Z)$  values. The  $m_t^{\text{pole}}$  and  $\alpha_S(m_Z)$  regions favored by the direct measurements at the Tevatron and by the latest world average, respectively, are shown as hatched areas. In the top panel, the inner (solid) area of the vertical band corresponds to the original uncertainty of the direct  $m_t$  average, while the outer (hatched) area additionally accounts for the possible difference between this mass and  $m_t^{\text{pole}}$ .

slightly higher while the predictions obtained with ABM11 are significantly lower due to a smaller gluon density in the relevant kinematic range [43]. In addition to the absolute normalization, differences in the slope of  $\sigma_{t\bar{t}}$  as a function of  $\alpha_S(m_Z)$  are observed between some of the PDF sets.

### 3. Measured cross section

In this Letter, the most precise single measurement for  $\sigma_{t\bar{t}}$  [6] is used. It was derived at  $\sqrt{s} = 7$  TeV by the CMS Collaboration from data collected in 2011 in the dileptonic decay channel and corresponding to an integrated luminosity of  $2.3 \text{ fb}^{-1}$ . Assuming  $m_t = 172.5$  GeV and  $\alpha_S(m_Z) = 0.1180$ , the observed cross section is  $161.9 \pm 6.7$  pb. Systematic effects on this measurement from the choice and uncertainties of the PDFs were studied and found to be negligible.

The measured  $\sigma_{t\bar{t}}$  shows a dependence on the value of  $m_t$  that is used in the Monte Carlo simulations since the change in the event kinematics affects the expected selection efficiency and thus the acceptance corrections that are employed to infer  $\sigma_{t\bar{t}}$  from the observed event yield. A parametrization for this dependence, which is illustrated in Fig. 1, was already given in Section 8 of Ref. [6]. At  $m_t = 173.2$  GeV, for example, the observed cross section is 161.0 pb. The relative uncertainty of 4.1% on the measured  $\sigma_{t\bar{t}}$  is independent of  $m_t$  to very good approximation.

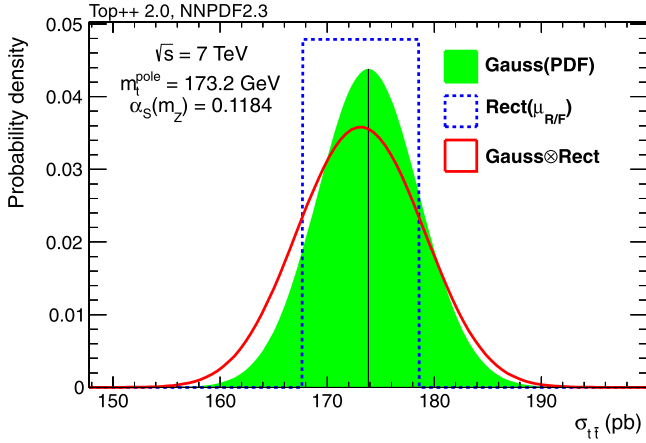
Changes of the assumed value of  $\alpha_S(m_Z)$  in the simulation used to derive the acceptance corrections can alter the measured  $\sigma_{t\bar{t}}$  as well, which is discussed in this Letter for the first time. QCD radiation effects increase at higher  $\alpha_S(m_Z)$ , both at the matrix-element level and at the hadronization level. The  $\alpha_S(m_Z)$ -dependence of the acceptance corrections is studied using the NLO CTEQ6AB PDF sets [50], and the POWHEG Box 1.4 [51,52] NLO generator for  $t\bar{t}$  production interfaced with PYTHIA 6.4.24 [53] for the parton showering. Additionally, the impact of  $\alpha_S(m_Z)$  variations on the acceptance is studied with standalone PYTHIA as a plain leading-order generator with parton showering and cross-checked with MCFM 6.2 [54] as an NLO prediction without parton showering. In all cases, a relative change of the acceptance by less than 1% is observed when varying  $\alpha_S(m_Z)$  by  $\pm 0.0100$  with respect to the CTEQ reference value of 0.1180. This is accounted for by applying an  $\alpha_S(m_Z)$ -dependent uncertainty to the measured  $\sigma_{t\bar{t}}$ . This additional uncertainty is also included in the uncertainty band shown in Fig. 1. Over the relevant  $\alpha_S(m_Z)$  range, there is almost no increase in the total uncertainty of 4.1% on the measured  $\sigma_{t\bar{t}}$ .

In the  $m_t$  and  $\alpha_S(m_Z)$  regions favored by the direct measurements at the Tevatron and by the latest world average, respectively, the measured and the predicted cross section are compatible within their uncertainties for all considered PDF sets. When using ABM11 with its default  $\alpha_S(m_Z)$ , the discrepancy between measured and predicted cross section is larger than one standard deviation.

### 4. Probabilistic approach

In the following, the theory prediction for  $\sigma_{t\bar{t}}$  is employed to construct a Bayesian prior to the cross section measurement, from which a joint posterior in  $\sigma_{t\bar{t}}$ ,  $m_t^{\text{pole}}$  and  $\alpha_S(m_Z)$  is derived. Finally, this posterior is marginalized by integration over  $\sigma_{t\bar{t}}$  and a Bayesian confidence interval for  $m_t^{\text{pole}}$  or  $\alpha_S(m_Z)$  is computed based on the external constraint for  $\alpha_S(m_Z)$  or  $m_t^{\text{pole}}$ , respectively.

The probability function for the predicted cross section,  $f_{\text{th}}(\sigma_{t\bar{t}})$ , is obtained through an analytic convolution of two probability distributions, one accounting for the PDF uncertainty and the other for scale uncertainties. A Gaussian distribution of width  $\delta_{\text{PDF}}$  is used to describe the PDF uncertainty. Given that no particular probability distribution is known that should be adequate for the confidence interval obtained from the variation of  $\mu_R$  and  $\mu_F$  [42], the corresponding uncertainty on the  $\sigma_{t\bar{t}}$  prediction is approximated using a flat prior, i.e., a rectangular function that provides equal probability over the whole range covered by the scale



**Fig. 2.** Probability distributions for the predicted  $t\bar{t}$  cross section at NNLO + NNLL with  $m_t^{\text{pole}} = 173.2$  GeV,  $\alpha_s(m_Z) = 0.1184$  and the NNLO parton distributions from NNPDF2.3. The resulting probability,  $f_{\text{th}}(\sigma_{t\bar{t}})$ , represented by a solid line, is obtained by convolving a Gaussian distribution (filled area) that accounts for the PDF uncertainty with a rectangular function (dashed line) that covers the scale variation uncertainty.

variation and vanishes elsewhere. The resulting probability function is given by:

$$f_{\text{th}}(\sigma_{t\bar{t}}) = \frac{1}{2(\sigma_{t\bar{t}}^{(h)} - \sigma_{t\bar{t}}^{(l)})} \left( \text{erf} \left[ \frac{\sigma_{t\bar{t}}^{(h)} - \sigma_{t\bar{t}}}{\sqrt{2}\delta_{\text{PDF}}} \right] - \text{erf} \left[ \frac{\sigma_{t\bar{t}}^{(l)} - \sigma_{t\bar{t}}}{\sqrt{2}\delta_{\text{PDF}}} \right] \right).$$

Here,  $\sigma_{t\bar{t}}^{(l)}$  and  $\sigma_{t\bar{t}}^{(h)}$  denote the lowest and the highest cross section values, respectively, that are obtained when varying  $\mu_R$  and  $\mu_F$  as described in Section 2. An example for the resulting probability distributions is shown in Fig. 2.

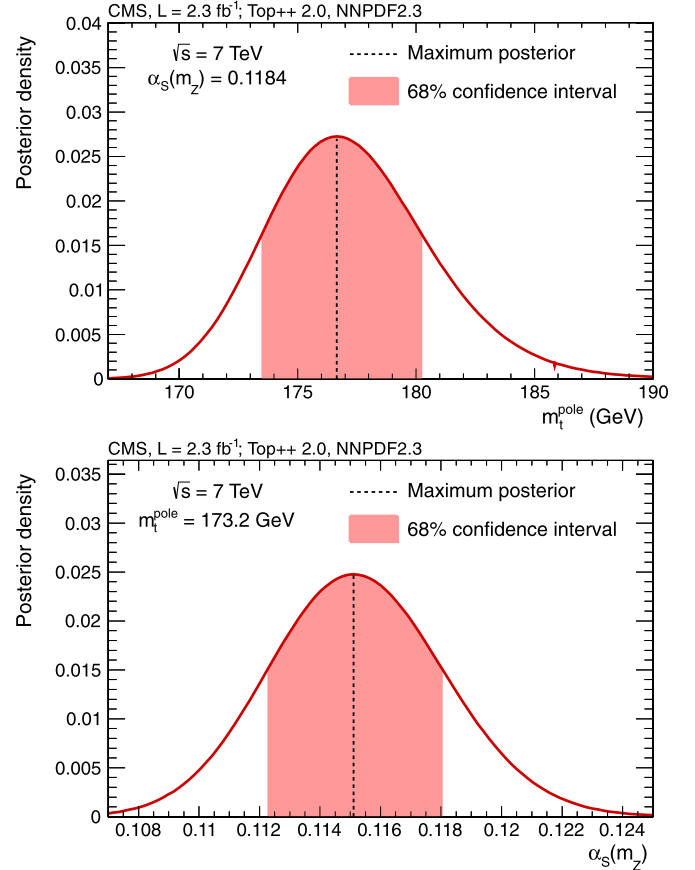
The probability distribution  $f_{\text{th}}(\sigma_{t\bar{t}})$  is multiplied by another Gaussian probability,  $f_{\text{exp}}(\sigma_{t\bar{t}})$ , which represents the measured cross section and its uncertainty, to obtain the most probable  $m_t^{\text{pole}}$  or  $\alpha_s(m_Z)$  value for a given  $\alpha_s(m_Z)$  or  $m_t^{\text{pole}}$ , respectively, from the maximum of the marginalized posterior:

$$P(x) = \int f_{\text{exp}}(\sigma_{t\bar{t}}|x) f_{\text{th}}(\sigma_{t\bar{t}}|x) d\sigma_{t\bar{t}}, \quad x = m_t^{\text{pole}}, \alpha_s(m_Z).$$

Examples of  $P(m_t^{\text{pole}})$  and  $P(\alpha_s)$  are shown in Fig. 3. Confidence intervals are determined from the 68% area around the maximum of the posterior and requiring equal function values at the left and right edges.

The approximate contributions of the uncertainties on the measured and the predicted cross sections to the width of this Bayesian confidence interval can be estimated by repeatedly rescaling the size of the corresponding uncertainty component. The widths of the obtained confidence intervals are then used to extrapolate to the case in which a given component vanishes.

To assess the impact of the uncertainties on the  $\alpha_s(m_Z)$  and  $m_t^{\text{pole}}$  values that are used as constraints in the present analysis,  $P(m_t^{\text{pole}})$  is re-evaluated at  $\alpha_s(m_Z) = 0.1177$  and  $0.1191$ , reflecting the  $\pm 0.0007$  uncertainty on the  $\alpha_s(m_Z)$  world average, and  $P(\alpha_s)$  is re-evaluated at  $m_t^{\text{pole}} = 171.8$  and  $174.6$  GeV, reflecting the  $\delta m_t^{\text{pole}} = 1.4$  GeV as explained in Section 1. The resulting shifts in the most likely values of  $m_t^{\text{pole}}$  and  $\alpha_s(m_Z)$  are added in quadrature to those obtained from the 68% areas of the posteriors calculated with the central values of the constraints.



**Fig. 3.** Marginal posteriors  $P(m_t^{\text{pole}})$  (top) and  $P(\alpha_s)$  (bottom) based on the cross section prediction at NNLO + NNLL with the NNLO parton distributions from NNPDF2.3. The posteriors are constructed as described in the text. Here,  $P(m_t^{\text{pole}})$  is shown for  $\alpha_s(m_Z) = 0.1184$  and  $P(\alpha_s)$  for  $m_t^{\text{pole}} = 173.2$  GeV.

## 5. Results and conclusions

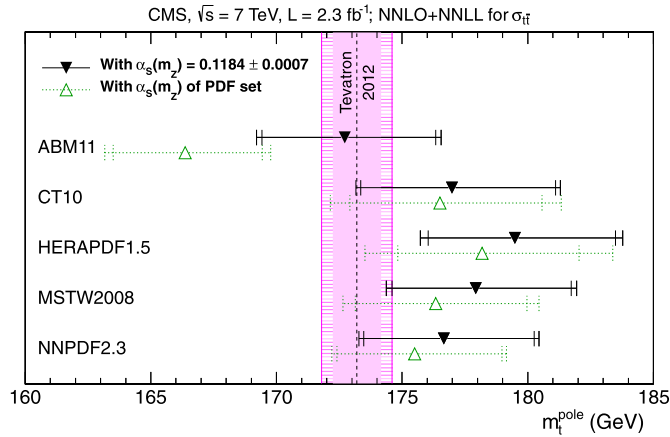
Values of the top-quark pole mass determined using the  $t\bar{t}$  cross section measured by CMS together with the cross section prediction from NNLO + NNLL QCD and five different NNLO PDF sets are listed in Table 2. These values are extracted under the assumption that the  $m_t$  parameter in the Monte Carlo generator that was employed to obtain the mass-dependent acceptance correction of the measured cross section, shown in Fig. 1, is equal to the pole mass. A difference of 1.0 GeV between the two mass definitions [20] would result in changes of 0.3–0.6 GeV in the extracted pole masses, which is included as a systematic uncertainty. As illustrated in Fig. 4, the results based on NNPDF2.3, CT10, MSTW2008, and HERAPDF1.5 are higher than the latest average of direct  $m_t$  measurements but generally compatible within the uncertainties. They are also consistent with the indirect determination of the top-quark pole mass obtained in the electroweak fits [55,56] when employing the mass of the new boson discovered at the LHC [57, 58] under the assumption that this is the SM Higgs boson. The central  $m_t^{\text{pole}}$  value obtained with the ABM11 PDF set, which has a significantly smaller gluon density than the other PDF sets, is also compatible with the average from direct  $m_t$  measurements. Note, however, that all these results in Table 2 are obtained employing the  $\alpha_s(m_Z)$  world average of  $0.1184 \pm 0.0007$ , while ABM11 with its default  $\alpha_s(m_Z)$  of  $0.1134 \pm 0.0011$  would yield an  $m_t^{\text{pole}}$  value of  $166.3_{-3.1}^{+3.3}$  GeV.

**Table 2**  
Results obtained for  $m_t^{\text{pole}}$  by comparing the measured  $t\bar{t}$  cross section to the NNLO + NNLL prediction with different NNLO PDF sets. The total uncertainties account for the full uncertainty on the measured cross section ( $\sigma_{t\bar{t}}^{\text{meas}}$ ), the PDF and scale ( $\mu_{R,F}$ ) uncertainties on the predicted cross section, the uncertainties of the  $\alpha_S(m_Z)$  world average and of the LHC beam energy ( $E_{\text{LHC}}$ ), and the ambiguity in translating the dependence of the measured cross section on the top-quark mass value used in the Monte Carlo generator ( $m_t^{\text{MC}}$ ) into the pole-mass scheme.

	$m_t^{\text{pole}}$ (GeV)	Uncertainty on $m_t^{\text{pole}}$ (GeV)						$m_t^{\text{MC}}$
		Total	$\sigma_{t\bar{t}}^{\text{meas}}$	PDF	$\mu_{R,F}$	$\alpha_S$	$E_{\text{LHC}}$	
ABM11	172.7	+3.9 -3.5	+2.8 -2.5	+2.2 -2.0	+0.7 -0.7	+1.0 -1.0	+0.8 -0.8	+0.4 -0.3
CT10	177.0	+4.3 -3.8	+3.2 -2.8	+2.4 -2.0	+0.9 -0.9	+0.8 -0.8	+0.9 -0.9	+0.5 -0.4
HERAPDF1.5	179.5	+4.3 -3.8	+3.5 -3.0	+1.7 -1.5	+0.9 -0.8	+1.2 -1.1	+1.0 -1.0	+0.6 -0.5
MSTW2008	177.9	+4.1 -3.6	+3.4 -2.9	+1.6 -1.4	+0.9 -0.9	+0.9 -0.9	+1.6 -0.9	+0.5 -0.5
NNPDF2.3	176.7	+3.8 -3.4	+3.1 -2.8	+1.5 -1.3	+0.9 -0.9	+0.7 -0.7	+0.9 -0.9	+0.5 -0.4

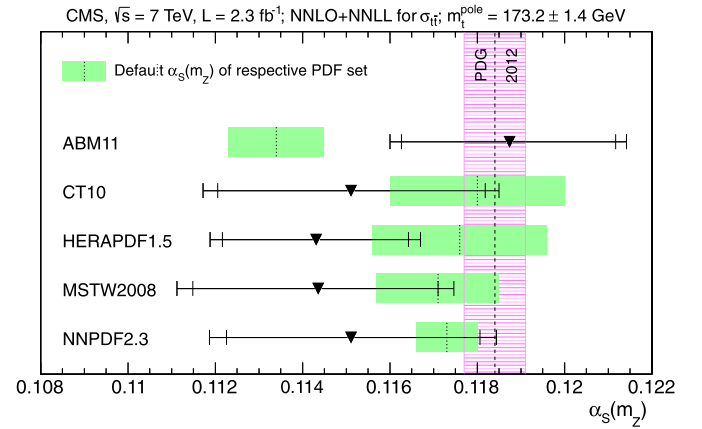
**Table 3**  
Results obtained for  $\alpha_S(m_Z)$  by comparing the measured  $t\bar{t}$  cross section to the NNLO + NNLL prediction with different NNLO PDF sets. The total uncertainties account for the full uncertainty on the measured cross section ( $\sigma_{t\bar{t}}^{\text{meas}}$ ), the PDF and scale ( $\mu_{R,F}$ ) uncertainties on the predicted cross section, the uncertainty assigned to the knowledge of  $m_t^{\text{pole}}$ , and the uncertainty of the LHC beam energy ( $E_{\text{LHC}}$ ).

	$\alpha_S(m_Z)$	Uncertainty on $\alpha_S(m_Z)$					
		Total	$\sigma_{t\bar{t}}^{\text{meas}}$	PDF	$\mu_{R,F}$	$m_t^{\text{pole}}$	$E_{\text{LHC}}$
ABM11	0.1187	+0.0027 -0.0027	+0.0018 -0.0019	+0.0015 -0.0014	+0.0006 -0.0005	+0.0010 -0.0010	+0.0006 -0.0006
CT10	0.1151	+0.0034 -0.0034	+0.0024 -0.0025	+0.0018 -0.0016	+0.0008 -0.0007	+0.0012 -0.0013	+0.0007 -0.0007
HERAPDF1.5	0.1143	+0.0024 -0.0024	+0.0018 -0.0019	+0.0010 -0.0009	+0.0005 -0.0004	+0.0010 -0.0010	+0.0006 -0.0006
MSTW2008	0.1144	+0.0031 -0.0032	+0.0024 -0.0025	+0.0012 -0.0011	+0.0008 -0.0007	+0.0012 -0.0013	+0.0007 -0.0008
NNPDF2.3	0.1151	+0.0033 -0.0032	+0.0025 -0.0025	+0.0013 -0.0011	+0.0009 -0.0008	+0.0013 -0.0013	+0.0008 -0.0008



**Fig. 4.** Results obtained for  $m_t^{\text{pole}}$  from the measured  $t\bar{t}$  cross section together with the prediction at NNLO + NNLL using different NNLO PDF sets. The filled symbols represent the results obtained when using the  $\alpha_S(m_Z)$  world average, while the open symbols indicate the results obtained with the default  $\alpha_S(m_Z)$  value of the respective PDF set. The inner error bars include the uncertainties on the measured cross section and on the LHC beam energy as well as the PDF and scale uncertainties on the predicted cross section. The outer error bars additionally account for the uncertainty on the  $\alpha_S(m_Z)$  value used for a specific prediction. For comparison, the latest average of direct  $m_t$  measurements is shown as vertical band, where the inner (solid) area corresponds to the original uncertainty of the direct  $m_t$  average, while the outer (hatched) area additionally accounts for the possible difference between this mass and  $m_t^{\text{pole}}$ .

The  $\alpha_S(m_Z)$  values obtained when fixing the value of  $m_t^{\text{pole}}$  to  $173.2 \pm 1.4$  GeV, i.e., inverting the logic of the extraction, are listed in Table 3. As illustrated in Fig. 5, the results obtained using NNPDF2.3, CT10, MSTW2008, and HERAPDF1.5 are lower than the  $\alpha_S(m_Z)$  world average but in most cases still compatible with it within the uncertainties. While the  $\alpha_S(m_Z)$  value obtained with ABM11 is compatible with the world average, it is significantly different from the default  $\alpha_S(m_Z)$  of this PDF set.



**Fig. 5.** Results obtained for  $\alpha_S(m_Z)$  from the measured  $t\bar{t}$  cross section together with the prediction at NNLO + NNLL using different NNLO PDF sets. The inner error bars include the uncertainties on the measured cross section and on the LHC beam energy as well as the PDF and scale uncertainties on the predicted cross section. The outer error bars additionally account for the uncertainty on  $m_t^{\text{pole}}$ . For comparison, the latest  $\alpha_S(m_Z)$  world average with its uncertainty is shown as a hatched band. For each PDF set, the default  $\alpha_S(m_Z)$  value and its uncertainty are indicated using a dotted line and a shaded band.

Modeling the uncertainty related to the choice and variation of the renormalization and factorization scales with a Gaussian instead of the flat prior results in only minor changes of the  $m_t^{\text{pole}}$  and  $\alpha_S(m_Z)$  values and uncertainties. With the precise NNLO + NNLL calculation, these scale uncertainties are found to be of the size of 0.7–0.9 GeV on  $m_t^{\text{pole}}$  and 0.0004–0.0009 on  $\alpha_S(m_Z)$ , i.e., of the order of 0.3–0.8%.

The energy of the LHC beams is known to an accuracy of 0.65% [59] and thus the center-of-mass energy of 7 TeV with an uncertainty of  $\pm 46$  GeV. Based on the expected dependence of  $\sigma_{t\bar{t}}$  on  $\sqrt{s}$ , this can be translated into an additional uncertainty of  $\pm 1.8\%$  on the comparison of the measured to the predicted  $t\bar{t}$  cross

section, which yields an additional uncertainty of  $\pm(0.5\text{--}0.7)\%$  on the obtained  $m_t^{\text{pole}}$  and  $\alpha_S(m_Z)$  values.

For the main results of this Letter, the  $m_t^{\text{pole}}$  and  $\alpha_S(m_Z)$  values determined with the parton densities of NNPDF2.3 are used. The primary motivation is that parton distributions derived using the NNPDF methodology can be explicitly shown to be parametrization independent, in the sense that results are unchanged even when the number of input parameters is substantially increased [60].

In summary, a top-quark pole mass of  $176.7^{+3.8}_{-3.4}$  GeV is obtained by comparing the measured cross section for inclusive  $t\bar{t}$  production in proton–proton collisions at  $\sqrt{s} = 7$  TeV to QCD calculations at NNLO + NNLL. Due to the small uncertainty on the measured cross section and the state-of-the-art NNLO calculations, the precision of this result is higher compared to earlier determinations of  $m_t^{\text{pole}}$  following the same approach. This extraction provides an important test of the mass scheme applied in Monte Carlo simulations and gives complementary information, with different sensitivity to theoretical and experimental uncertainties, than direct measurements of  $m_t$ . Alternatively,  $\alpha_S(m_Z) = 0.1151^{+0.0033}_{-0.0032}$  is obtained from the  $t\bar{t}$  cross section when constraining  $m_t^{\text{pole}}$  to  $173.2 \pm 1.4$  GeV. This is the first determination of the strong coupling constant from top-quark production and the first  $\alpha_S(m_Z)$  result at full NNLO QCD obtained at a hadron collider.

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## CMS Collaboration

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

*Yerevan Physics Institute, Yerevan, Armenia*

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan<sup>1</sup>, M. Friedl, R. Frühwirth<sup>1</sup>, V.M. Ghete, N. Hörmann, J. Hrubec, M. Jeitler<sup>1</sup>, W. Kiesenhofer, V. Knünz, M. Krammer<sup>1</sup>, I. Krätschmer, D. Liko, I. Mikulec, D. Rabady<sup>2</sup>, B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Treberer-Treberspur, W. Waltenberger, C.-E. Wulz<sup>1</sup>

*Institut für Hochenergiephysik der OeAW, Wien, Austria*

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

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

S. Alderweireldt, M. Bansal, S. Bansal, T. Cornelis, E.A. De Wolf, X. Janssen, A. Knutsson, S. Luyckx, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, Z. Staykova, H. Van Haeveermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

*Universiteit Antwerpen, Antwerpen, Belgium*

F. Blekman, S. Blyweert, J. D'Hondt, A. Kalogeropoulos, J. Keaveney, M. Maes, A. Olbrechts, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

*Vrije Universiteit Brussel, Brussel, Belgium*

B. Clerboux, G. De Lentdecker, L. Favart, A.P.R. Gay, T. Hreus, A. Léonard, P.E. Marage, A. Mohammadi, L. Perniè, T. Reis, T. Seva, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wang

*Université Libre de Bruxelles, Bruxelles, Belgium*

V. Adler, K. Beernaert, L. Benucci, A. Cimmino, S. Costantini, S. Dildick, G. Garcia, B. Klein, J. Lellouch, A. Marinov, J. McCartin, A.A. Ocampo Rios, D. Ryckbosch, M. Sigamani, N. Strobbe, F. Thyssen, M. Tytgat, S. Walsh, E. Yazgan, N. Zaganidis

*Ghent University, Ghent, Belgium*

S. Basegmez, C. Beluffi<sup>3</sup>, G. Bruno, R. Castello, A. Caudron, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco<sup>4</sup>, J. Hollar, P. Jez, V. Lemaître, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrkowski, A. Popov<sup>5</sup>, M. Selvaggi, J.M. Vizán Garcia

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

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

*Université de Mons, Mons, Belgium*

G.A. Alves, M. Correa Martins Junior, T. Martins, M.E. Pol, M.H.G. Souza

*Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*

W.L. Aldá Júnior, W. Carvalho, J. Chinellato<sup>6</sup>, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, M. Malek, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, A. Santoro, A. Sznajder, E.J. Tonelli Manganote<sup>6</sup>, A. Vilela Pereira

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

C.A. Bernardes<sup>b</sup>, F.A. Dias<sup>a,7</sup>, T.R. Fernandez Perez Tomei<sup>a</sup>, E.M. Gregores<sup>b</sup>, C. Lagana<sup>a</sup>, P.G. Mercadante<sup>b</sup>, S.F. Novaes<sup>a</sup>, Sandra S. Padula<sup>a</sup>

<sup>a</sup> *Universidade Estadual Paulista, São Paulo, Brazil*

<sup>b</sup> *Universidade Federal do ABC, São Paulo, Brazil*

V. Genchev<sup>2</sup>, P. Iaydjiev<sup>2</sup>, S. Piperov, M. Rodozov, G. Sultanov, M. Vutova

*Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria*

A. Dimitrov, R. Hadjiiska, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

*University of Sofia, Sofia, Bulgaria*

J.G. Bian, G.M. Chen, H.S. Chen, C.H. Jiang, D. Liang, S. Liang, X. Meng, J. Tao, J. Wang, X. Wang, Z. Wang, H. Xiao, M. Xu

*Institute of High Energy Physics, Beijing, China*

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

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



C. Avila, C.A. Carrillo Montoya, L.F. Chaparro Sierra, J.P. Gomez, B. Gomez Moreno, J.C. Sanabria

*Universidad de Los Andes, Bogota, Colombia*

N. Godinovic, D. Lelas, R. Plestina<sup>8</sup>, D. Polic, I. Puljak

*Technical University of Split, Split, Croatia*

Z. Antunovic, M. Kovac

*University of Split, Split, Croatia*

V. Brigljevic, S. Duric, K. Kadija, J. Luetic, D. Mekterovic, S. Morovic, L. Tikvica

*Institute Rudjer Boskovic, Zagreb, Croatia*

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

*University of Cyprus, Nicosia, Cyprus*

M. Finger, M. Finger Jr.

*Charles University, Prague, Czech Republic*

A.A. Abdelalim<sup>9</sup>, Y. Assran<sup>10</sup>, S. Elgammal<sup>9</sup>, A. Ellithi Kamel<sup>11</sup>, M.A. Mahmoud<sup>12</sup>, A. Radi<sup>13,14</sup>

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

M. Kadastik, M. Müntel, M. Murumaa, M. Raidal, L. Rebane, A. Tiko

*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*

P. Eerola, G. Fedi, M. Voutilainen

*Department of Physics, University of Helsinki, Helsinki, Finland*

J. Härkönen, 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, L. Wendland

*Helsinki Institute of Physics, Helsinki, Finland*

T. Tuuva

*Lappeenranta University of Technology, Lappeenranta, Finland*

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

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

S. Baffioni, F. Beaudette, L. Benhabib, M. Bluj<sup>15</sup>, P. Busson, C. Charlot, N. Daci, T. Dahms, M. Dalchenko, L. Dobrzynski, A. Florent, R. Granier de Cassagnac, M. Haguenaue, P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Veelken, A. Zabi

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

J.-L. Agram<sup>16</sup>, J. Andrea, D. Bloch, J.-M. Brom, E.C. Chabert, C. Collard, E. Conte<sup>16</sup>, F. Drouhin<sup>16</sup>, J.-C. Fontaine<sup>16</sup>, D. Gelé, U. Goerlach, C. Goetzmann, P. Juillot, A.-C. Le Bihan, P. Van Hove

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

S. Gadrat

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

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

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

Z. Tsamalaidze<sup>17</sup>

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

C. Autermann, S. Beranek, B. Calpas, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, K. Klein, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov<sup>5</sup>

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

M. Ata, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, P. Kreuzer, M. Merschmeyer, A. Meyer, M. Olschewski, K. Padeken, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teysier, S. Thüer, M. Weber

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

V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, J. Lingemann<sup>2</sup>, A. Nowack, I.M. Nugent, L. Perchalla, O. Pooth, A. Stahl

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

M. Aldaya Martin, I. Asin, N. Bartosik, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz<sup>18</sup>, A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, S. Choudhury, F. Costanza, C. Diez Pardos, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, G. Flucke, A. Geiser, I. Glushkov, P. Gunnellini, S. Habib, J. Hauk, G. Hellwig, D. Horton, H. Jung, M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, J. Leonard, K. Lipka, W. Lohmann<sup>18</sup>, B. Lutz, R. Mankel, I. Marfin, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, O. Novgorodova, F. Nowak, J. Olzem, H. Perrey, A. Petrukhin, D. Pitzl, R. Placakyte, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M.Ö. Sahin, J. Salfeld-Nebgen, R. Schmidt<sup>18</sup>, T. Schoerner-Sadenius, N. Sen, M. Stein, R. Walsh, C. Wissing

*Deutsches Elektronen-Synchrotron, Hamburg, Germany*

V. Blobel, H. Enderle, J. Erfle, E. Garutti, U. Gebbert, M. Görner, M. Gosselink, J. Haller, K. Heine, R.S. Höing, G. Kaussen, H. Kirschenmann, R. Klanner, R. Kogler, J. Lange, I. Marchesini, T. Peiffer, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Schröder, T. Schum, M. Seidel, J. Sibille<sup>19</sup>, V. Sola, H. Stadie, G. Steinbrück, J. Thomsen, D. Troendle, E. Usai, L. Vanelderren

*University of Hamburg, Hamburg, Germany*

C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff<sup>2</sup>, F. Hartmann<sup>2</sup>, T. Hauth<sup>2</sup>, H. Held, K.H. Hoffmann, U. Husemann, I. Katkov<sup>5</sup>, J.R. Komaragiri, A. Kornmayer<sup>2</sup>, P. Lobelle Pardo, D. Martschei, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, J. Ott, G. Quast, K. Rabbertz, F. Ratnikov, S. Röcker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, M. Zeise

*Institut für Experimentelle Kernphysik, Karlsruhe, Germany*

G. Anagnostou, G. Daskalakis, T. Geralis, S. Kesisoglou, A. Kyriakis, D. Loukas, A. Markou, C. Markou, E. Ntomari

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

L. Gouskos, A. Panagiotou, N. Saoulidou, E. Stiliaris

*University of Athens, Athens, Greece*

X. Aslanoglou, I. Evangelou, G. Flouris, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos, E. Paradas

*University of Ioánnina, Ioánnina, Greece*

G. Bencze, C. Hajdu, P. Hidas, D. Horvath<sup>20</sup>, F. Sikler, V. Veszpremi, G. Vesztergombi<sup>21</sup>, A.J. Zsigmond

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

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

*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*

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

*University of Debrecen, Debrecen, Hungary*

S.K. Swain<sup>22</sup>

*National Institute of Science Education and Research, Bhubaneswar, India*

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

*Panjab University, Chandigarh, India*

Ashok Kumar, Arun Kumar, S. Ahuja, A. Bhardwaj, B.C. Choudhary, S. Malhotra, M. Naimuddin, K. Ranjan, P. Saxena, V. Sharma, R.K. Shivpuri

*University of Delhi, Delhi, India*

S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, A. Modak, S. Mukherjee, D. Roy, S. Sarkar, M. Sharan

*Saha Institute of Nuclear Physics, Kolkata, India*

A. Abdulsalam, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty<sup>2</sup>, L.M. Pant, P. Shukla, A. Topkar

*Bhabha Atomic Research Centre, Mumbai, India*

T. Aziz, R.M. Chatterjee, S. Ganguly, S. Ghosh, M. Guchait<sup>23</sup>, A. Gurtu<sup>24</sup>, G. Kole, S. Kumar, M. Maity<sup>25</sup>, G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage<sup>26</sup>

*Tata Institute of Fundamental Research – EHEP, Mumbai, India*

S. Banerjee, S. Dugad

*Tata Institute of Fundamental Research – HECR, Mumbai, India*

H. Arfaei, H. Bakhshiansohi, S.M. Etesami<sup>27</sup>, A. Fahim<sup>28</sup>, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh<sup>29</sup>, M. Zeinali

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

M. Grunewald

*University College Dublin, Dublin, Ireland*

M. Abbrescia<sup>a,b</sup>, L. Barbone<sup>a,b</sup>, C. Calabria<sup>a,b</sup>, S.S. Chhibra<sup>a,b</sup>, A. Colaleo<sup>a</sup>, D. Creanza<sup>a,c</sup>, N. De Filippis<sup>a,c</sup>, M. De Palma<sup>a,b</sup>, L. Fiore<sup>a</sup>, G. Iaselli<sup>a,c</sup>, G. Maggi<sup>a,c</sup>, M. Maggi<sup>a</sup>, B. Marangelli<sup>a,b</sup>, S. My<sup>a,c</sup>, S. Nuzzo<sup>a,b</sup>, N. Pacifico<sup>a</sup>, A. Pompili<sup>a,b</sup>, G. Pugliese<sup>a,c</sup>, G. Selvaggi<sup>a,b</sup>, L. Silvestris<sup>a</sup>, G. Singh<sup>a,b</sup>,

R. Venditti <sup>a,b</sup>, P. Verwilligen <sup>a</sup>, G. Zito <sup>a</sup>

<sup>a</sup> INFN Sezione di Bari, Bari, Italy

<sup>b</sup> Università di Bari, Bari, Italy

<sup>c</sup> Politecnico di Bari, Bari, Italy

G. Abbiendi <sup>a</sup>, A.C. Benvenuti <sup>a</sup>, D. Bonacorsi <sup>a,b</sup>, S. Braibant-Giacomelli <sup>a,b</sup>, L. Brigliadori <sup>a,b</sup>,  
R. Campanini <sup>a,b</sup>, P. Capiluppi <sup>a,b</sup>, A. Castro <sup>a,b</sup>, F.R. Cavallo <sup>a</sup>, G. Codispoti <sup>a,b</sup>, M. Cuffiani <sup>a,b</sup>,  
G.M. Dallavalle <sup>a</sup>, F. Fabbri <sup>a</sup>, A. Fanfani <sup>a,b</sup>, D. Fasanella <sup>a,b</sup>, P. Giacomelli <sup>a</sup>, C. Grandi <sup>a</sup>, L. Guiducci <sup>a,b</sup>,  
S. Marcellini <sup>a</sup>, G. Masetti <sup>a</sup>, M. Meneghelli <sup>a,b</sup>, A. Montanari <sup>a</sup>, F.L. Navarria <sup>a,b</sup>, F. Odorici <sup>a</sup>, A. Perrotta <sup>a</sup>,  
F. Primavera <sup>a,b</sup>, A.M. Rossi <sup>a,b</sup>, T. Rovelli <sup>a,b</sup>, G.P. Siroli <sup>a,b</sup>, N. Tosi <sup>a,b</sup>, R. Travaglini <sup>a,b</sup>

<sup>a</sup> INFN Sezione di Bologna, Bologna, Italy

<sup>b</sup> Università di Bologna, Bologna, Italy

S. Albergo <sup>a,b</sup>, M. Chiorboli <sup>a,b</sup>, S. Costa <sup>a,b</sup>, F. Giordano <sup>a,2</sup>, R. Potenza <sup>a,b</sup>, A. Tricomi <sup>a,b</sup>, C. Tuve <sup>a,b</sup>

<sup>a</sup> INFN Sezione di Catania, Catania, Italy

<sup>b</sup> Università di Catania, Catania, Italy

G. Barbagli <sup>a</sup>, V. Ciulli <sup>a,b</sup>, C. Civinini <sup>a</sup>, R. D'Alessandro <sup>a,b</sup>, E. Focardi <sup>a,b</sup>, S. Frosali <sup>a,b</sup>, E. Gallo <sup>a</sup>,  
S. Gonzi <sup>a,b</sup>, V. Gori <sup>a,b</sup>, P. Lenzi <sup>a,b</sup>, M. Meschini <sup>a</sup>, S. Paoletti <sup>a</sup>, G. Sguazzoni <sup>a</sup>, A. Tropiano <sup>a,b</sup>

<sup>a</sup> INFN Sezione di Firenze, Firenze, Italy

<sup>b</sup> Università di Firenze, Firenze, Italy

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

INFN Laboratori Nazionali di Frascati, Frascati, Italy

P. Fabbriatore <sup>a</sup>, R. Musenich <sup>a</sup>, S. Tosi <sup>a,b</sup>

<sup>a</sup> INFN Sezione di Genova, Genova, Italy

<sup>b</sup> Università di Genova, Genova, Italy

A. Benaglia <sup>a</sup>, F. De Guio <sup>a,b</sup>, M.E. Dinardo, S. Fiorendi <sup>a,b</sup>, S. Gennai <sup>a</sup>, A. Ghezzi <sup>a,b</sup>, P. Govoni,  
M.T. Lucchini <sup>2</sup>, S. Malvezzi <sup>a</sup>, R.A. Manzoni <sup>a,b,2</sup>, A. Martelli <sup>a,b,2</sup>, D. Menasce <sup>a</sup>, L. Moroni <sup>a</sup>,  
M. Paganoni <sup>a,b</sup>, D. Pedrini <sup>a</sup>, S. Ragazzi <sup>a,b</sup>, N. Redaelli <sup>a</sup>, T. Tabarelli de Fatis <sup>a,b</sup>

<sup>a</sup> INFN Sezione di Milano-Bicocca, Milano, Italy

<sup>b</sup> Università di Milano-Bicocca, Milano, Italy

S. Buontempo <sup>a</sup>, N. Cavallo <sup>a,c</sup>, A. De Cosa <sup>a,b</sup>, F. Fabozzi <sup>a,c</sup>, A.O.M. Iorio <sup>a,b</sup>, L. Lista <sup>a</sup>, S. Meola <sup>a,d,2</sup>,  
M. Merola <sup>a</sup>, P. Paolucci <sup>a,2</sup>

<sup>a</sup> INFN Sezione di Napoli, Napoli, Italy

<sup>b</sup> Università di Napoli 'Federico II', Napoli, Italy

<sup>c</sup> Università della Basilicata (Potenza), Napoli, Italy

<sup>d</sup> Università G. Marconi (Roma), Napoli, Italy

P. Azzi <sup>a</sup>, N. Bacchetta <sup>a</sup>, M. Bellato <sup>a</sup>, M. Biasotto <sup>a,30</sup>, D. Bisello <sup>a,b</sup>, A. Branca <sup>a,b</sup>, R. Carlin <sup>a,b</sup>, P. Checchia <sup>a</sup>,  
T. Dorigo <sup>a</sup>, F. Fanzago <sup>a</sup>, M. Galanti <sup>a,b,2</sup>, F. Gasparini <sup>a,b</sup>, U. Gasparini <sup>a,b</sup>, P. Giubilato <sup>a,b</sup>, A. Gozzelino <sup>a</sup>,  
K. Kanishchev <sup>a,c</sup>, S. Lacaprara <sup>a</sup>, I. Lazzizzera <sup>a,c</sup>, M. Margoni <sup>a,b</sup>, A.T. Meneguzzo <sup>a,b</sup>, J. Pazzini <sup>a,b</sup>,  
N. Pozzobon <sup>a,b</sup>, P. Ronchese <sup>a,b</sup>, F. Simonetto <sup>a,b</sup>, E. Torassa <sup>a</sup>, M. Tosi <sup>a,b</sup>, A. Triossi <sup>a</sup>, S. Ventura <sup>a</sup>,  
P. Zotto <sup>a,b</sup>, A. Zucchetta <sup>a,b</sup>, G. Zumerle <sup>a,b</sup>

<sup>a</sup> INFN Sezione di Padova, Padova, Italy

<sup>b</sup> Università di Padova, Padova, Italy

<sup>c</sup> Università di Trento (Trento), Padova, Italy

M. Gabusi <sup>a,b</sup>, S.P. Ratti <sup>a,b</sup>, C. Riccardi <sup>a,b</sup>, P. Vitulo <sup>a,b</sup>

<sup>a</sup> INFN Sezione di Pavia, Pavia, Italy

<sup>b</sup> Università di Pavia, Pavia, Italy

M. Biasini <sup>a,b</sup>, G.M. Bilei <sup>a</sup>, L. Fanò <sup>a,b</sup>, P. Lariccia <sup>a,b</sup>, G. Mantovani <sup>a,b</sup>, M. Menichelli <sup>a</sup>, A. Nappi <sup>a,b,†</sup>,  
F. Romeo <sup>a,b</sup>, A. Saha <sup>a</sup>, A. Santocchia <sup>a,b</sup>, A. Spiezia <sup>a,b</sup>

<sup>a</sup> INFN Sezione di Perugia, Perugia, Italy

<sup>b</sup> Università di Perugia, Perugia, Italy

K. Androsova <sup>a,31</sup>, P. Azzurri <sup>a</sup>, G. Bagliesi <sup>a</sup>, J. Bernardini <sup>a</sup>, T. Boccali <sup>a</sup>, G. Broccolo <sup>a,c</sup>, R. Castaldi <sup>a</sup>,  
M.A. Ciocci <sup>a</sup>, R.T. D'Agnolo <sup>a,c,2</sup>, R. Dell'Orso <sup>a</sup>, F. Fiori <sup>a,c</sup>, L. Foà <sup>a,c</sup>, A. Giassi <sup>a</sup>, M.T. Grippo <sup>a,31</sup>, A. Kraan <sup>a</sup>,  
F. Ligabue <sup>a,c</sup>, T. Lomtadze <sup>a</sup>, L. Martini <sup>a,31</sup>, A. Messineo <sup>a,b</sup>, F. Palla <sup>a</sup>, A. Rizzi <sup>a,b</sup>, A. Savoy-Navarro <sup>a,32</sup>,  
A.T. Serban <sup>a</sup>, P. Spagnolo <sup>a</sup>, P. Squillacioti <sup>a</sup>, R. Tenchini <sup>a</sup>, G. Tonelli <sup>a,b</sup>, A. Venturi <sup>a</sup>, P.G. Verdini <sup>a</sup>,  
C. Vernieri <sup>a,c</sup>

<sup>a</sup> INFN Sezione di Pisa, Pisa, Italy

<sup>b</sup> Università di Pisa, Pisa, Italy

<sup>c</sup> Scuola Normale Superiore di Pisa, Pisa, Italy

L. Barone <sup>a,b</sup>, F. Cavallari <sup>a</sup>, D. Del Re <sup>a,b</sup>, M. Diemoz <sup>a</sup>, M. Grassi <sup>a,b</sup>, E. Longo <sup>a,b</sup>, F. Margaroli <sup>a,b</sup>,  
P. Meridiani <sup>a</sup>, F. Micheli <sup>a,b</sup>, S. Nourbakhsh <sup>a,b</sup>, G. Organtini <sup>a,b</sup>, R. Paramatti <sup>a</sup>, S. Rahatlou <sup>a,b</sup>, C. Rovelli <sup>a</sup>,  
L. Soffi <sup>a,b</sup>

<sup>a</sup> INFN Sezione di Roma, Roma, Italy

<sup>b</sup> Università di Roma, Roma, Italy

N. Amapane <sup>a,b</sup>, R. Arcidiacono <sup>a,c</sup>, S. Argiro <sup>a,b</sup>, M. Arneodo <sup>a,c</sup>, C. Biino <sup>a</sup>, N. Cartiglia <sup>a</sup>, S. Casasso <sup>a,b</sup>,  
M. Costa <sup>a,b</sup>, N. Demaria <sup>a</sup>, C. Mariotti <sup>a</sup>, S. Maselli <sup>a</sup>, E. Migliore <sup>a,b</sup>, V. Monaco <sup>a,b</sup>, M. Musich <sup>a</sup>,  
M.M. Obertino <sup>a,c</sup>, G. Ortona <sup>a,b</sup>, N. Pastrone <sup>a</sup>, M. Pelliccioni <sup>a,2</sup>, A. Potenza <sup>a,b</sup>, A. Romero <sup>a,b</sup>, M. Ruspa <sup>a,c</sup>,  
R. Sacchi <sup>a,b</sup>, A. Solano <sup>a,b</sup>, A. Staiano <sup>a</sup>, U. Tamponi <sup>a</sup>

<sup>a</sup> INFN Sezione di Torino, Torino, Italy

<sup>b</sup> Università di Torino, Torino, Italy

<sup>c</sup> Università del Piemonte Orientale (Novara), Torino, Italy

S. Belforte <sup>a</sup>, V. Candelise <sup>a,b</sup>, M. Casarsa <sup>a</sup>, F. Cossutti <sup>a,2</sup>, G. Della Ricca <sup>a,b</sup>, B. Gobbo <sup>a</sup>, C. La Licata <sup>a,b</sup>,  
M. Marone <sup>a,b</sup>, D. Montanino <sup>a,b</sup>, A. Penzo <sup>a</sup>, A. Schizzi <sup>a,b</sup>, A. Zanetti <sup>a</sup>

<sup>a</sup> INFN Sezione di Trieste, Trieste, Italy

<sup>b</sup> Università di Trieste, Trieste, Italy

S. Chang, T.Y. Kim, S.K. Nam

Kangwon National University, Chunchon, Republic of Korea

D.H. Kim, G.N. Kim, J.E. Kim, D.J. Kong, Y.D. Oh, H. Park, D.C. Son

Kyungpook National University, Daegu, Republic of Korea

J.Y. Kim, Zero J. Kim, S. Song

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

S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, T.J. Kim, K.S. Lee, S.K. Park, Y. Roh

Korea University, Seoul, Republic of Korea

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

University of Seoul, Seoul, Republic of Korea

Y. Choi, Y.K. Choi, J. Goh, M.S. Kim, E. Kwon, B. Lee, J. Lee, S. Lee, H. Seo, I. Yu

Sungkyunkwan University, Suwon, Republic of Korea

I. Grigelionis, A. Juodagalvis

Vilnius University, Vilnius, Lithuania

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz<sup>33</sup>, R. Lopez-Fernandez, J. Martínez-Ortega, A. Sanchez-Hernandez, L.M. Villasenor-Cendejas

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

S. Carrillo Moreno, F. Vazquez Valencia

*Universidad Iberoamericana, Mexico City, Mexico*

H.A. Salazar Ibarguen

*Benemerita Universidad Autonoma de Puebla, Puebla, Mexico*

E. Casimiro Linares, A. Morelos Pineda, M.A. Reyes-Santos

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

D. Krofcheck

*University of Auckland, Auckland, New Zealand*

A.J. Bell, P.H. Butler, R. Doesburg, S. Reucroft, H. Silverwood

*University of Canterbury, Christchurch, New Zealand*

M. Ahmad, M.I. Asghar, J. Butt, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi, M.A. Shah, M. Shoab

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

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

*National Centre for Nuclear Research, Swierk, Poland*

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

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

N. Almeida, P. Bargassa, C. Beirão Da Cruz E Silva, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, F. Nguyen, J. Rodrigues Antunes, J. Seixas<sup>2</sup>, J. Varela, P. Vischia

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

S. Afanasiev, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, V. Konoplyanikov, A. Lanev, A. Malakhov, V. Matveev, P. Moisezenz, V. Palichik, V. Perelygin, S. Shmatov, N. Skatchkov, V. Smirnov, A. Zarubin

*Joint Institute for Nuclear Research, Dubna, 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

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

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

*Institute for Nuclear Research, Moscow, Russia*

V. Epshteyn, M. Erofeeva, V. Gavrillov, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, A. Spiridonov, V. Stolin, E. Vlasov, A. Zhokin

*Institute for Theoretical and Experimental Physics, Moscow, Russia*

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

*P.N. Lebedev Physical Institute, Moscow, Russia*

A. Belyaev, E. Boos, V. Bunichev, M. Dubinin<sup>7</sup>, L. Dudko, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, V. Savrin, N. Tsirova

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

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

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

P. Adzic<sup>34</sup>, M. Djordjevic, M. Ekmedzic, D. Krpic<sup>34</sup>, J. Milosevic

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

M. Aguilar-Benitez, J. Alcaraz Maestre, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas<sup>2</sup>, N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, E. Navarro De Martino, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares, C. Willmott

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

C. Albajar, J.F. de Trocóniz

*Universidad Autónoma de Madrid, Madrid, Spain*

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

*Universidad de Oviedo, Oviedo, Spain*

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Fernandez, G. Gomez, J. Gonzalez Sanchez, A. Graziano, C. Jorda, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

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

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, J. Bendavid, J.F. Benitez, C. Bernet<sup>8</sup>, G. Bianchi, P. Bloch, A. Bocci, A. Bonato, O. Bondu, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, S. Colafranceschi<sup>35</sup>, D. d'Enterria, A. Dabrowski, A. David, A. De Roeck, S. De Visscher, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, J. Eugster, W. Funk, G. Georgiou, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Girone, M. Giunta, F. Glege, R. Gomez-Reino Garrido, S. Gowdy, R. Guida, J. Hammer, M. Hansen, P. Harris, C. Hartl, A. Hinzmann, V. Innocente, P. Janot, E. Karavakis, K. Kousouris, K. Krajczar, P. Lecoq, Y.-J. Lee, C. Lourenço, N. Magini, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, R. Moser, M. Mulders, P. Musella, E. Nesvold, L. Orsini, E. Palencia Cortezon, E. Perez, L. Perrozzi, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, M. Plagge, L. Quertenmont, A. Racz, W. Reece, J. Rojo, G. Rolandi<sup>36</sup>, M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas<sup>37</sup>, D. Spiga, M. Stoye, A. Tsirova, G.I. Veres<sup>21</sup>, J.R. Vlimant, H.K. Wöhri, S.D. Worm<sup>38</sup>, W.D. Zeuner

*CERN, European Organization for Nuclear Research, Geneva, Switzerland*

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

*Paul Scherrer Institut, Villigen, Switzerland*

F. Bachmair, L. Bäni, L. Bianchini, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, K. Freudenreich, C. Grab, D. Hits, P. Lecomte, W. Lustermann, B. Mangano, A.C. Marini, P. Martinez Ruiz del Arbol, D. Meister, N. Mohr, F. Moortgat, C. Nägeli<sup>39</sup>, P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov<sup>40</sup>, B. Stieger, M. Takahashi, L. Tauscher<sup>†</sup>, A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber

*Institute for Particle Physics, ETH Zurich, Zurich, Switzerland*

C. Amsler<sup>41</sup>, V. Chiochia, C. Favaro, M. Ivova Rikova, B. Kilminster, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, S. Taroni, S. Tupputi, M. Verzetti

*Universität Zürich, Zurich, Switzerland*

M. Cardaci, K.H. Chen, C. Ferro, C.M. Kuo, S.W. Li, W. Lin, Y.J. Lu, R. Volpe, S.S. Yu

*National Central University, Chung-Li, 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

*National Taiwan University (NTU), Taipei, Taiwan*

B. Asavapibhop, N. Suwonjandee

*Chulalongkorn University, Bangkok, Thailand*

A. Adiguzel, M.N. Bakirci<sup>42</sup>, S. Cerci<sup>43</sup>, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, A. Kayis Topaksu, G. Onengut<sup>44</sup>, K. Ozdemir, S. Ozturk<sup>42</sup>, A. Polatoz, K. Sogut<sup>45</sup>, D. Sunar Cerci<sup>43</sup>, B. Tali<sup>43</sup>, H. Topakli<sup>42</sup>, M. Vergili

*Cukurova University, Adana, Turkey*

I.V. Akin, T. Aliev, B. Bilin, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, G. Karapinar<sup>46</sup>, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, M. Yalvac, M. Zeyrek

*Middle East Technical University, Physics Department, Ankara, Turkey*

E. Gülmez, B. Isildak<sup>47</sup>, M. Kaya<sup>48</sup>, O. Kaya<sup>48</sup>, S. Ozkorucuklu<sup>49</sup>, N. Sonmez<sup>50</sup>

*Bogazici University, Istanbul, Turkey*

H. Bahtiyar<sup>51</sup>, E. Barlas, K. Cankocak, Y.O. Günaydin<sup>52</sup>, F.I. Vardarli, M. Yücel

*Istanbul Technical University, Istanbul, Turkey*

L. Levchuk, P. Sorokin

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

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<sup>38</sup>, K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

*University of Bristol, Bristol, United Kingdom*

K.W. Bell, A. Belyaev<sup>53</sup>, C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley

*Rutherford Appleton Laboratory, Didcot, United Kingdom*

R. Bainbridge, O. Buchmuller, D. Burton, 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, M. Kenzie, R. Lane, R. Lucas<sup>38</sup>, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko<sup>40</sup>, J. Pela, M. Pesaresi, K. Petridis, M. Pioppi<sup>54</sup>, D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp<sup>†</sup>, A. Sparrow, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

*Imperial College, London, United Kingdom*

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

*Brunel University, Uxbridge, United Kingdom*

J. Dittmann, K. Hatakeyama, A. Kasmi, H. Liu, T. Scarborough

*Baylor University, Waco, USA*

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

*The University of Alabama, Tuscaloosa, USA*

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

*Boston University, Boston, USA*

J. Alimena, S. Bhattacharya, G. Christopher, D. Cutts, Z. Demiragli, A. Ferapontov, A. Garabedian, U. Heintz, S. Jabeen, G. Kukartsev, E. Laird, G. Landsberg, M. Luk, M. Narain, M. Segala, T. Sinthuprasith, T. Speer

*Brown University, Providence, USA*

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, M. Gardner, R. Houtz, W. Ko, A. Kopecky, R. Lander, T. Miceli, D. Pellett, F. Ricci-Tam, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, S. Wilbur, R. Yohay

*University of California, Davis, USA*

V. Andreev, D. Cline, R. Cousins, S. Erhan, P. Everaerts, C. Farrell, M. Felcini, J. Hauser, M. Ignatenko, C. Jarvis, G. Rakness, P. Schlein<sup>†</sup>, E. Takasugi, P. Traczyk, V. Valuev, M. Weber

*University of California, Los Angeles, USA*

J. Babb, R. Clare, J. Ellison, J.W. Gary, G. Hanson, P. Jandir, H. Liu, O.R. Long, A. Luthra, H. Nguyen, S. Paramesvaran, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

*University of California, Riverside, USA*

W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, D. Evans, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, S. Padhi, C. Palmer, G. Petrucciani, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech<sup>55</sup>, F. Würthwein, A. Yagil, J. Yoo

*University of California, San Diego, La Jolla, USA*

D. Barge, R. Bellan, C. Campagnari, M. D'Alfonso, T. Danielson, K. Flowers, P. Geffert, C. George, F. Golf, J. Incandela, C. Justus, P. Kalavase, D. Kovalskyi, V. Krutelyov, S. Lowette, R. Magaña Villalba, N. Mccoll, V. Pavlunin, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, C. West

*University of California, Santa Barbara, USA*

A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, E. Di Marco, J. Duarte, D. Kcira, Y. Ma, A. Mott, H.B. Newman, C. Rogan, M. Spiropulu, V. Timciuc, J. Veverka, R. Wilkinson, S. Xie, Y. Yang, R.Y. Zhu

*California Institute of Technology, Pasadena, USA*

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

*Carnegie Mellon University, Pittsburgh, USA*

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

*University of Colorado at Boulder, Boulder, USA*

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

*Cornell University, Ithaca, USA*

D. Winn

*Fairfield University, Fairfield, USA*

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, L. Gray, D. Green, O. Gutsche, D. Hare, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, K. Kaadze, B. Klima, S. Kunori, S. Kwan, J. Linacre, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko<sup>56</sup>, C. Newman-Holmes, V. O'Dell, O. Prokofyev, N. Ratnikova, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, J.C. Yun

*Fermi National Accelerator Laboratory, Batavia, USA*

D. Acosta, P. Avery, D. Bourilkov, M. Chen, T. Cheng, S. Das, M. De Gruttola, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic<sup>57</sup>, G. Mitselmakher, L. Muniz, R. Remington, A. Rinkevicius, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

*University of Florida, Gainesville, USA*

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

*Florida International University, Miami, USA*

T. Adams, A. Askew, J. Bochenek, J. Chen, B. Diamond, S.V. Gleyzer, J. Haas, S. Hagopian, V. Hagopian, K.F. Johnson, H. Prosper, V. Veeraraghavan, M. Weinberg

*Florida State University, Tallahassee, USA*

M.M. Baarmand, B. Dorney, M. Hohlmann, H. Kalakhety, F. Yumiceva

*Florida Institute of Technology, Melbourne, USA*

M.R. Adams, L. Apanasevich, V.E. Bazterra, R.R. Betts, I. Bucinskaite, J. Callner, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, P. Kurt, F. Lacroix, D.H. Moon, C. O'Brien, C. Silkworth, D. Strom, P. Turner, N. Varelas

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

U. Akgun, E.A. Albayrak<sup>51</sup>, B. Bilki<sup>58</sup>, W. Clarida, K. Dilsiz, F. Duru, S. Griffiths, J.-P. Merlo, H. Mermerkaya<sup>59</sup>, A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, H. Ogul, Y. Onel, F. Ozok<sup>51</sup>, S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin<sup>60</sup>, K. Yi

*The University of Iowa, Iowa City, USA*

B.A. Barnett, B. Blumenfeld, S. Bolognesi, G. Giurgiu, A.V. Gritsan, G. Hu, P. Maksimovic, C. Martin, M. Swartz, A. Whitbeck

*Johns Hopkins University, Baltimore, USA*

P. Baringer, A. Bean, G. Benelli, R.P. Kenny III, M. Murray, D. Noonan, S. Sanders, R. Stringer, J.S. Wood

*The University of Kansas, Lawrence, USA*

A.F. Barfuss, I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, S. Shrestha, I. Svintradze

*Kansas State University, Manhattan, USA*

J. Gronberg, D. Lange, F. Rebassoo, D. Wright

*Lawrence Livermore National Laboratory, Livermore, USA*

A. Baden, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, K. Pedro, A. Peterman, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar

*University of Maryland, College Park, USA*

A. Apyan, G. Bauer, W. Busza, I.A. Cali, M. Chan, L. Di Matteo, V. Dutta, G. Gomez Ceballos, M. Goncharov, D. Gulhan, Y. Kim, M. Klute, Y.S. Lai, A. Levin, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, G.S.F. Stephans, F. Stöckli, K. Sumorok, D. Velicanu, R. Wolf, B. Wyslouch, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti, V. Zhukova

*Massachusetts Institute of Technology, Cambridge, USA*

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

*University of Minnesota, Minneapolis, USA*

J.G. Acosta, L.M. Cremaldi, R. Kroeger, S. Oliveros, L. Perera, R. Rahmat, D.A. Sanders, D. Summers

*University of Mississippi, Oxford, USA*

E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, M. Eads, R. Gonzalez Suarez, J. Keller, I. Kravchenko, J. Lazo-Flores, S. Malik, F. Meier, G.R. Snow

*University of Nebraska-Lincoln, Lincoln, USA*

J. Dolen, A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S. Rappoccio, Z. Wan

*State University of New York at Buffalo, Buffalo, USA*

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, A. Massironi, D. Nash, T. Orimoto, D. Trocino, D. Wood, J. Zhang

*Northeastern University, Boston, USA*

A. Anastassov, K.A. Hahn, A. Kubik, L. Lusito, N. Mucia, N. Odell, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, K. Sung, M. Velasco, S. Won

*Northwestern University, Evanston, USA*

D. Berry, A. Brinkerhoff, K.M. Chan, M. Hildreth, C. Jessop, D.J. Karmgard, J. Kolb, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, M. Planer, R. Ruchti, J. Slaunwhite, N. Valls, M. Wayne, M. Wolf

*University of Notre Dame, Notre Dame, USA*

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

*The Ohio State University, Columbus, USA*

E. Berry, P. Elmer, V. Halyo, P. Hebda, J. Hegeman, A. Hunt, P. Jindal, S.A. Koay, 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, S.C. Zenz, A. Zuranski

*Princeton University, Princeton, USA*

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

*University of Puerto Rico, Mayaguez, USA*

E. Alagoz, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M. Jones, K. Jung, O. Koybasi, M. Kress, N. Leonardo, D. Lopes Pegna, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, M. Vidal Marono, F. Wang, W. Xie, L. Xu, H.D. Yoo, J. Zablocki, Y. Zheng

*Purdue University, West Lafayette, USA*

S. Guragain, N. Parashar

*Purdue University Calumet, Hammond, USA*

A. Adair, B. Akgun, K.M. Ecklund, F.J.M. Geurts, W. Li, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

*Rice University, Houston, USA*

B. Betchart, A. Bodek, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, D.C. Miner, G. Petrillo, D. Vishnevskiy, M. Zielinski

*University of Rochester, Rochester, USA*

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

*The Rockefeller University, New York, USA*

S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, J. Robles, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

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

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

*University of Tennessee, Knoxville, USA*

O. Bouhali<sup>61</sup>, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon<sup>62</sup>, V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, I. Suarez, A. Tatarinov, D. Toback

*Texas A&M University, College Station, USA*

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

*Texas Tech University, Lubbock, USA*

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

*Vanderbilt University, Nashville, USA*

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

*University of Virginia, Charlottesville, USA*

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

*Wayne State University, Detroit, USA*

D.A. Belknap, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, E. Friis, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, J. Klukas, A. Lanaro, R. Loveless, A. Mohapatra, M.U. Mozer, I. Ojalvo, G.A. Pierro, G. Polese, I. Ross, A. Savin, W.H. Smith, J. Swanson

*University of Wisconsin, Madison, USA*

† Deceased.

<sup>1</sup> Also at Vienna University of Technology, Vienna, Austria.

<sup>2</sup> Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.

<sup>3</sup> Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France.

<sup>4</sup> Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia.

<sup>5</sup> Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.

<sup>6</sup> Also at Universidade Estadual de Campinas, Campinas, Brazil.

<sup>7</sup> Also at California Institute of Technology, Pasadena, USA.

<sup>8</sup> Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France.

<sup>9</sup> Also at Zewail City of Science and Technology, Zewail, Egypt.

<sup>10</sup> Also at Suez Canal University, Suez, Egypt.

<sup>11</sup> Also at Cairo University, Cairo, Egypt.

<sup>12</sup> Also at Fayoum University, El-Fayoum, Egypt.

<sup>13</sup> Also at British University in Egypt, Cairo, Egypt.

<sup>14</sup> Now at Ain Shams University, Cairo, Egypt.

<sup>15</sup> Also at National Centre for Nuclear Research, Swierk, Poland.

<sup>16</sup> Also at Université de Haute Alsace, Mulhouse, France.

<sup>17</sup> Also at Joint Institute for Nuclear Research, Dubna, Russia.

<sup>18</sup> Also at Brandenburg University of Technology, Cottbus, Germany.

<sup>19</sup> Also at The University of Kansas, Lawrence, USA.

<sup>20</sup> Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.

<sup>21</sup> Also at Eötvös Loránd University, Budapest, Hungary.

<sup>22</sup> Also at Tata Institute of Fundamental Research – EHEP, Mumbai, India.

<sup>23</sup> Also at Tata Institute of Fundamental Research – HECP, Mumbai, India.

<sup>24</sup> Now at King Abdulaziz University, Jeddah, Saudi Arabia.

<sup>25</sup> Also at University of Visva-Bharati, Santiniketan, India.

<sup>26</sup> Also at University of Ruhuna, Matara, Sri Lanka.

<sup>27</sup> Also at Isfahan University of Technology, Isfahan, Iran.

<sup>28</sup> Also at Sharif University of Technology, Tehran, Iran.

<sup>29</sup> Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.

<sup>30</sup> Also at Laboratori Nazionali di Legnaro dell'INFN, Legnaro, Italy.

<sup>31</sup> Also at Università degli Studi di Siena, Siena, Italy.

<sup>32</sup> Also at Purdue University, West Lafayette, USA.

<sup>33</sup> Also at Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico.

<sup>34</sup> Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.

<sup>35</sup> Also at Facoltà Ingegneria, Università di Roma, Roma, Italy.

<sup>36</sup> Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.

<sup>37</sup> Also at University of Athens, Athens, Greece.

<sup>38</sup> Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.

<sup>39</sup> Also at Paul Scherrer Institut, Villigen, Switzerland.

<sup>40</sup> Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.

<sup>41</sup> Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland.

<sup>42</sup> Also at Gaziosmanpasa University, Tokat, Turkey.

<sup>43</sup> Also at Adiyaman University, Adiyaman, Turkey.

<sup>44</sup> Also at Cag University, Mersin, Turkey.

<sup>45</sup> Also at Mersin University, Mersin, Turkey.

<sup>46</sup> Also at Izmir Institute of Technology, Izmir, Turkey.

<sup>47</sup> Also at Ozyegin University, Istanbul, Turkey.

<sup>48</sup> Also at Kafkas University, Kars, Turkey.

<sup>49</sup> Also at Suleyman Demirel University, Isparta, Turkey.

<sup>50</sup> Also at Ege University, Izmir, Turkey.

<sup>51</sup> Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.

<sup>52</sup> Also at Kahramanmaraş Sütcü Imam University, Kahramanmaraş, Turkey.

<sup>53</sup> Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.

- <sup>54</sup> Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy.
- <sup>55</sup> Also at Utah Valley University, Orem, USA.
- <sup>56</sup> Also at Institute for Nuclear Research, Moscow, Russia.
- <sup>57</sup> Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
- <sup>58</sup> Also at Argonne National Laboratory, Argonne, USA.
- <sup>59</sup> Also at Erzincan University, Erzincan, Turkey.
- <sup>60</sup> Also at Yildiz Technical University, Istanbul, Turkey.
- <sup>61</sup> Also at Texas A&M University at Qatar, Doha, Qatar.
- <sup>62</sup> Also at Kyungpook National University, Daegu, Republic of Korea.