



Measurement of the $\Upsilon(1S)$ production cross-section in pp collisions at $\sqrt{s} = 7$ TeV in ATLAS [☆]

ATLAS Collaboration ^{*}

ARTICLE INFO

Article history:

Received 27 June 2011

Received in revised form 19 September 2011

Accepted 26 September 2011

Available online 1 October 2011

Editor: H. Weerts

ABSTRACT

A measurement of the cross-section for $\Upsilon(1S) \rightarrow \mu^+\mu^-$ production in proton–proton collisions at centre of mass energy of 7 TeV is presented. The cross-section is measured as a function of the $\Upsilon(1S)$ transverse momentum in two bins of rapidity, $|y^{\Upsilon(1S)}| < 1.2$ and $1.2 < |y^{\Upsilon(1S)}| < 2.4$. The measurement requires that both muons have transverse momentum $p_T^\mu > 4$ GeV and pseudorapidity $|\eta^\mu| < 2.5$ in order to reduce theoretical uncertainties on the acceptance, which depend on the poorly known polarisation. The results are based on an integrated luminosity of 1.13 pb^{-1} , collected with the ATLAS detector at the Large Hadron Collider. The cross-section measurement is compared to theoretical predictions: it agrees to within a factor of two with a prediction based on the NRQCD model including colour-singlet and colour-octet matrix elements as implemented in PYTHIA while it disagrees by up to a factor of ten with the next-to-leading order prediction based on the colour-singlet model.

© 2011 CERN. Published by Elsevier B.V. Open access under CC BY-NC-ND license.

1. Introduction

The production of J/ψ and Υ mesons has been studied since their discovery in the 1970s [1,2], and even today there is no conclusive coherent theoretical picture of J/ψ and Υ hadroproduction. There are major questions associated with the consistency of measurements made at the Tevatron, HERA and fixed target experiments [3]. In particular it is difficult to reconcile the cross-section measurements with those of the spin alignment [3], and there are significant disagreements between the two Tevatron experiments on the measurement of the spin alignment in the case of Υ production [4,5]. It is thus important for the LHC experiments to measure the production of these mesons in order to shed further light on the puzzle.

The CMS Collaboration has recently presented a measurement of Υ production [6], correcting for the detector acceptance of the two daughter muons in both angular and momentum range. This approach was also adopted in the ATLAS J/ψ cross-section publication [7]. Correction of the data in this way introduces uncertainties due to the poorly known spin alignment of the Υ (or J/ψ). Note that CMS quotes the measurement for a wide variety of assumptions on the spin alignment, and the ATLAS J/ψ measurement takes the differences between the corrections obtained with different spin alignments as an additional systematic uncertainty.

With that in mind, a somewhat different approach to the measurement of the $\Upsilon(1S)$ production cross-section is adopted in this

analysis. The result is presented as a function of transverse momentum, p_T , and rapidity, y , of the $\Upsilon(1S)$, corrected for detector response and efficiencies but defined within a restricted range of muon kinematics where both muons have p_T^μ greater than 4 GeV and absolute pseudorapidity,¹ $|\eta^\mu|$, less than 2.5. The relative fraction of $\Upsilon(1S)$ mesons where both muons fulfil the kinematic requirements compared to all $\Upsilon(1S)$ mesons depends strongly on the spin alignment of the $\Upsilon(1S)$. For instance, assuming full transverse or longitudinal spin alignment versus unpolarised production changes this fraction by typically 30%. By quoting the measurement in a restricted region of phase space where muons are detected, uncertainties due to the Υ spin alignment on the measurement are almost eliminated so that the quoted cross-section is free of any assumptions about this property.

A single muon trigger with a threshold of $p_T^\mu > 4$ GeV is used. This limits the dataset used for this measurement to the low luminosity periods of 2010 corresponding to an integrated luminosity of $1.13 \pm 0.04 \text{ pb}^{-1}$.

In the following sections, a brief description of the ATLAS detector is given with emphasis on the aspects most relevant to this analysis. Next the measurement strategy is outlined, followed by a description of the Monte Carlo simulation used. The event selection and the determination of the number of $\Upsilon(1S)$ events are

¹ ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$.

[☆] © CERN for the benefit of the ATLAS Collaboration.

^{*} E-mail address: atlas.publications@cern.ch.

then described before the results are presented, and a conclusion is given.

2. The ATLAS detector

The ATLAS detector [8] consists of an inner tracker, a calorimeter and a muon system. The inner detector (ID) directly surrounds the interaction point; it includes a silicon pixel detector (Pixel), a silicon strip detector (SCT) and a transition radiation tracker (TRT), and is embedded in a solenoidal 2 T magnetic field. The ID covers the range $|\eta| < 2.5$ and is enclosed by a calorimeter system containing electromagnetic and hadronic sections. The calorimeter is surrounded by a large muon spectrometer (MS) inside an air-core toroid magnet system which contains a combination of monitored drift tubes (MDT) and cathode strip chambers (CSC), designed to provide precise position measurements in the bending plane and covering the range $|\eta| < 2.0$ and $2.0 < |\eta| < 2.7$, respectively. In addition, resistive plate chambers (RPC) and thin gap chambers (TGC) with a coarse position resolution but a fast response time are used primarily to trigger muons in the rapidity ranges $|\eta| < 1.05$ and $1.05 < |\eta| < 2.4$, respectively. Momentum measurements in the MS are based on track segments formed separately in at least two of the three station layers of the MDT and the CSC. The RPC and TGC are used to improve the pattern recognition and track reconstruction in the non-bending plane. They do not improve the position measurement in the bending plane.

The first level muon trigger looks for hit coincidences within different RPC or TGC detector layers inside programmed geometrical windows that define the muon p_T and provide a rough estimate of their positions [9]. The lowest available p_T threshold is used for this analysis. In addition, muons are required to pass a high-level trigger selection similar to that of the offline reconstruction and a transverse momentum threshold of $p_T^\mu > 4$ GeV.

3. Outline of the measurement

The differential $\Upsilon(1S)$ cross-section is given as

$$\frac{d^2\sigma}{dp_T dy} \times \text{BR}(\Upsilon(1S) \rightarrow \mu^+ \mu^-) = \frac{N_{\Upsilon(1S)}}{\int \mathcal{L} dt \times \Delta p_T \times \Delta y}, \quad (1)$$

where $\int \mathcal{L} dt$ is the integrated luminosity, and Δp_T and Δy are the bin sizes in $p_T^{\Upsilon(1S)}$ and $y^{\Upsilon(1S)}$, respectively. $N_{\Upsilon(1S)}$ is the corrected number of $\Upsilon(1S)$ mesons. It is determined with an unbinned maximum likelihood fit to the dimuon mass distribution after applying a weight to each candidate that is the inverse of its selection efficiency as described in Section 5. The cross-section is defined within the fiducial cuts $p_T^\mu > 4$ GeV and $|\eta^\mu| < 2.5$ on both muons, where the μ kinematics are those before any final state QED radiation.

The key aspects of this measurement are the efficiency determination and the fit to extract $N_{\Upsilon(1S)}$. These are described in detail in Sections 5 and 6, respectively.

The effect of bin migrations due to finite detector resolution and final state photon radiation has been studied. Given the good muon momentum resolution of $\sigma(p_T)/p_T < 0.5\%$ in the momentum range relevant for this analysis [10] and the relatively coarse binning used for this measurement, the bin migrations due to detector resolution and final state radiation are smaller than 2% in all bins. This 2% also accounts for the migrations across the p_T^μ and η^μ cuts. This small effect is not corrected for and therefore considered as part of the systematic uncertainty, which is discussed in

Section 7. Any residual impacts of the assumption on the Υ polarisation have also been assessed and are within this 2% uncertainty.

4. Monte Carlo simulation

In this analysis, all efficiency factors are determined directly from the data. The differential cross-section expressed in Eq. (1) does not need any large acceptance corrections which would require a detailed modelling of the kinematic properties of the events. Monte Carlo (MC) simulation is only used to construct templates for the likelihood fits to the dimuon mass distribution, and to assess the corrections due to migrations between $p_T^{\Upsilon(1S)}$ and $y^{\Upsilon(1S)}$ bins.

MC events are generated using PYTHIA6 [11] with the ATLAS MC09 tune [12] and MRST LO* [13] parton distribution functions. They are simulated with the ATLAS simulation framework [14] using GEANT4 [15] and fully reconstructed with the same software that is used to process the data from the detector.

For the Υ MC samples, PYTHIA6's implementation of Υ production subprocesses using the non-relativistic QCD (NRQCD) [16] framework and the parameters recommended in Ref. [17] are used. In this model, quarkonium is produced in both a colour-singlet and a colour-octet state, and evolves non-perturbatively into physical quarkonium. Each $\Upsilon(nS)$ state is generated separately and includes direct production from the hard interaction, as well as production through radiative feed-down from $\chi_b(nP) \rightarrow \Upsilon(nS)\gamma$ decays. The samples are generated without polar or azimuthal anisotropy in the decay of the Υ (the default in PYTHIA).

Background contributions come mainly from open production of charm and bottom quarks with subsequent decay of the c - or b -hadron to a muon. A further, much smaller contribution comes from Drell-Yan production. These continuum backgrounds are described using the minimum-bias processes in PYTHIA. In order to avoid double-counting, any generated minimum bias events containing Υ -mesons are explicitly removed from the sample. This background sample is only used to estimate a systematic uncertainty on the background modelling.

In all samples final state QED radiation is considered using PHOTOS [18] interfaced to PYTHIA.

5. Event selection and efficiency determination

Selected events are first requested to satisfy a single muon trigger with a threshold of $p_T^\mu > 4$ GeV. Then two offline muons are required with $p_T^\mu > 4$ GeV and $|\eta^\mu| < 2.5$.

Reconstructed muons that combine a track reconstructed in the MS with a track reconstructed in the ID are referred to as *combined muons* [8]. In order to recover efficiency for muons with low momenta, *tagged muons* extrapolate an ID track to the muon system and attach MS track segments that are not associated to any MS track. For both categories of muons in this analysis, the kinematic properties of the muons are solely determined from the parameters of the ID tracks associated with the muons. At least one of the two offline muons must be a combined muon, and at least one of them must match geometrically to a trigger muon. At low dimuon p_T about 60% of the events have two combined muons, and at high p_T this fraction increases to about 90%. Since the measurement is restricted to $|y^{\Upsilon(1S)}| < 2.4$ and $p_T^\mu > 4$ GeV at least one of the two decay muons is within the trigger pseudorapidity acceptance.

Both muon tracks are required to have at least one pixel hit and six SCT hits. Since the Υ is produced promptly, background from heavy flavour decays is suppressed by requiring the muons to originate from the primary vertex. Cuts requiring $|d_0| < 150 \mu\text{m}$ and $|z_0| \sin\theta < 1.5 \text{ mm}$ are applied where d_0 (z_0) is the impact

parameter with respect to the event vertex in the transverse (longitudinal) direction. The event vertex is required to have at least three associated tracks to reject background due to cosmic ray muons. The two selected muons are further required to have opposite electric charge.

The muon trigger and reconstruction efficiencies are determined using the high statistics J/ψ data sample [19] as a function of p_T^μ and η^μ . For a single muon, the trigger efficiency varies between 40% and 90% over the relevant p_T^μ and η^μ range [19,9]. Using the single muon trigger, this results in an average trigger efficiency for the selected dimuon events between 80% and 95% in any measurement bin. Within the kinematic range considered in this measurement, the offline muon reconstruction efficiency varies with p_T^μ and η^μ between 80% and 100%. The small gaps in the muon acceptance at certain η regions (mostly at $|\eta| \approx 0$ and $|\eta| \approx 1.3$) are corrected for as part of the efficiency correction assuming the nearly flat η dependence predicted by the simulation, and represent a small fraction of the total angular range. The efficiency of the pixel and SCT hit requirements has been measured using J/ψ mesons as $99.5 \pm 0.5\%$ per track, and the efficiency of the primary vertex requirement is $> 99.9\%$. The $z_0 \sin \theta$ cut efficiency is nearly 100% in both data and MC.

The efficiencies of the transverse impact parameter cut are determined using two independent methods. The impact parameter resolution is sensitive to the alignment of the ID and to the multiple scattering in the ID volume. The former dominates the resolution at high p_T^μ while the latter dominates at low p_T^μ . The primary method to determine the resolution uses muons from J/ψ decays and fits the impact parameter distribution using templates constructed from prompt and non-prompt J/ψ MC. In order to allow for small deviations of the observed resolution with respect to the MC, an additional d_0 resolution smearing parameter is introduced. This smearing parameter is of order $10 \mu\text{m}$ due to imperfections in the material description and tracker alignment. The efficiency determined with this method agrees well with the simulation and is about 99.5% in the central region, decreasing to 96.5% at the highest η^μ and lowest p_T^μ . The second method uses Z -bosons to determine the impact parameter resolution at high p_T^μ , and translates it to the low p_T^μ region using the known dependence of the resolution on p_T^μ also taking into account the uncertainty on the material distribution within the ID [20]. The efficiencies measured using the $J/\psi \rightarrow \mu^+ \mu^-$ decays are used for the central value, and the difference between the two methods is considered as a systematic uncertainty on the muon impact parameter cut efficiency. It is less than 1% for $|\eta^\mu| < 2$, and 1.5–2.5% for $|\eta^\mu| > 2$ depending on p_T^μ .

The efficiencies are accounted for in the cross-section measurement by applying a weight to each candidate. The weight is given by the inverse of the event selection efficiency, $w = 1/\varepsilon_{\mu\mu}$, which is evaluated from the single-muon trigger and reconstruction efficiencies as

$$\varepsilon_{\mu\mu} = \varepsilon_{\text{trig}} \varepsilon_{\text{reco}} \quad (2)$$

where the individual terms are given by

$$\varepsilon_{\text{trig}} = 1 - (1 - \varepsilon_{\text{trig}}^+)(1 - \varepsilon_{\text{trig}}^-), \quad (3)$$

$$\varepsilon_{\text{reco}} = \varepsilon_{\text{cb||tag}}^+ \varepsilon_{\text{cb||tag}}^- - \varepsilon_{\text{tag}}^- \varepsilon_{\text{tag}}^+. \quad (4)$$

Here $\varepsilon_{\text{trig}}^+$ and $\varepsilon_{\text{trig}}^-$ are the trigger efficiencies for a positively and negatively charged muon, respectively. $\varepsilon_{\text{cb||tag}}^+$ ($\varepsilon_{\text{cb||tag}}^-$) and $\varepsilon_{\text{tag}}^+$ ($\varepsilon_{\text{tag}}^-$) give the single muon reconstruction efficiencies for a combined or tagged or just a tagged muon, respectively, for positively

(negatively) charged muons. For each muon the efficiency is determined as a function of p_T , η and the electric charge. The final weights span the range from about 1.4 at low p_T to 1.1 at high p_T .

6. Determination of the number of $\Upsilon(1S)$ events

The number of $\Upsilon(1S)$ events is determined from an unbinned maximum likelihood fit to the dimuon mass distributions in each bin in $p_T^{\mu\mu}$ and $y^{\mu\mu}$ where $p_T^{\mu\mu}$ ($y^{\mu\mu}$) is the p_T (y) of the dimuon system. The distributions and corresponding fit results are shown for four representative kinematic bins in Fig. 1.

The shape of these distributions is rather complex. The background varies substantially over the considered mass range and its shape changes significantly depending on the kinematic bin. At low $p_T^{\mu\mu}$, the background increases sharply with $m^{\mu\mu}$ and is significant in the $\Upsilon(1S)$ mass range. At high $p_T^{\mu\mu}$, the background is nearly independent of the dimuon mass and also relatively low compared to the signal. Additionally, the $\Upsilon(1S)$ signal is not well separated from the $\Upsilon(2S)$ and $\Upsilon(3S)$, particularly in the forward region ($1.2 < |y^{\mu\mu}| < 2.4$), due to the limited track momentum resolution [21]. Resolving the $\Upsilon(2S)$ and $\Upsilon(3S)$ is even more difficult, and thus measurements of $\Upsilon(2S)$ and $\Upsilon(3S)$ production are not presented in this Letter.

A template based likelihood fit method is employed where four parameters are fitted independently in each kinematic bin: the numbers of $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ mesons, and a background normalisation parameter. The three Υ signal templates are taken from the corresponding Υ MC samples. The background templates are constructed from data by pairing a muon with a track reconstructed in the ID of opposite electric charge (OS) that passes the ID track selection requirements described in Section 5 and the kinematic requirements of $p_T > 4 \text{ GeV}$ and $|\eta| < 2.5$. This template (denoted as “OS μ + track”) gives an adequate description of the background since its shape is primarily determined by the kinematic selection requirements. The Υ signal contamination in this sample is expected to be negligible.

The fit results for $N_{\Upsilon(1S)}$ are given in Fig. 1 for four kinematic bins. The goodness of fit is assessed by a χ^2 test comparing the data to the template distributions using the normalisations determined by the likelihood fit to the data. In all bins the χ^2 probability is $> 5\%$.

Alternative templates for the shape of the background are constructed using dimuon events in $b\bar{b}$ and $c\bar{c}$ MC or μ + track events with the same electric charge (SS μ + track). A comparison of these alternative background templates shapes is shown in Fig. 2 for two representative bins. The shapes of the alternative templates are similar to the default template at both low and high p_T , and any differences are considered as part of the systematic uncertainty, as discussed in Section 7.

The momentum resolution is determined from cosmic rays, J/ψ and Z mass distributions [21] and the central mass value for the $\Upsilon(1S)$ is fixed to the expected value [22]. The validity of fixing the mass resolution and the overall mass scale is considered as part of the systematic uncertainty, as described in Section 7.

7. Systematic uncertainties

The following systematic uncertainties are considered:

The luminosity calibration has been determined using the van der Meer scan technique [23] with a precision of 3.4% [24, 25]. It directly translates into a cross-section uncertainty of 3.4%.

The uncertainties on the single muon reconstruction efficiency, trigger efficiency [19] and impact parameter resolution (described in Section 5) result in 1%, $< 1\%$ and 1–3.5% uncertainties on the cross-section measurement, respectively.

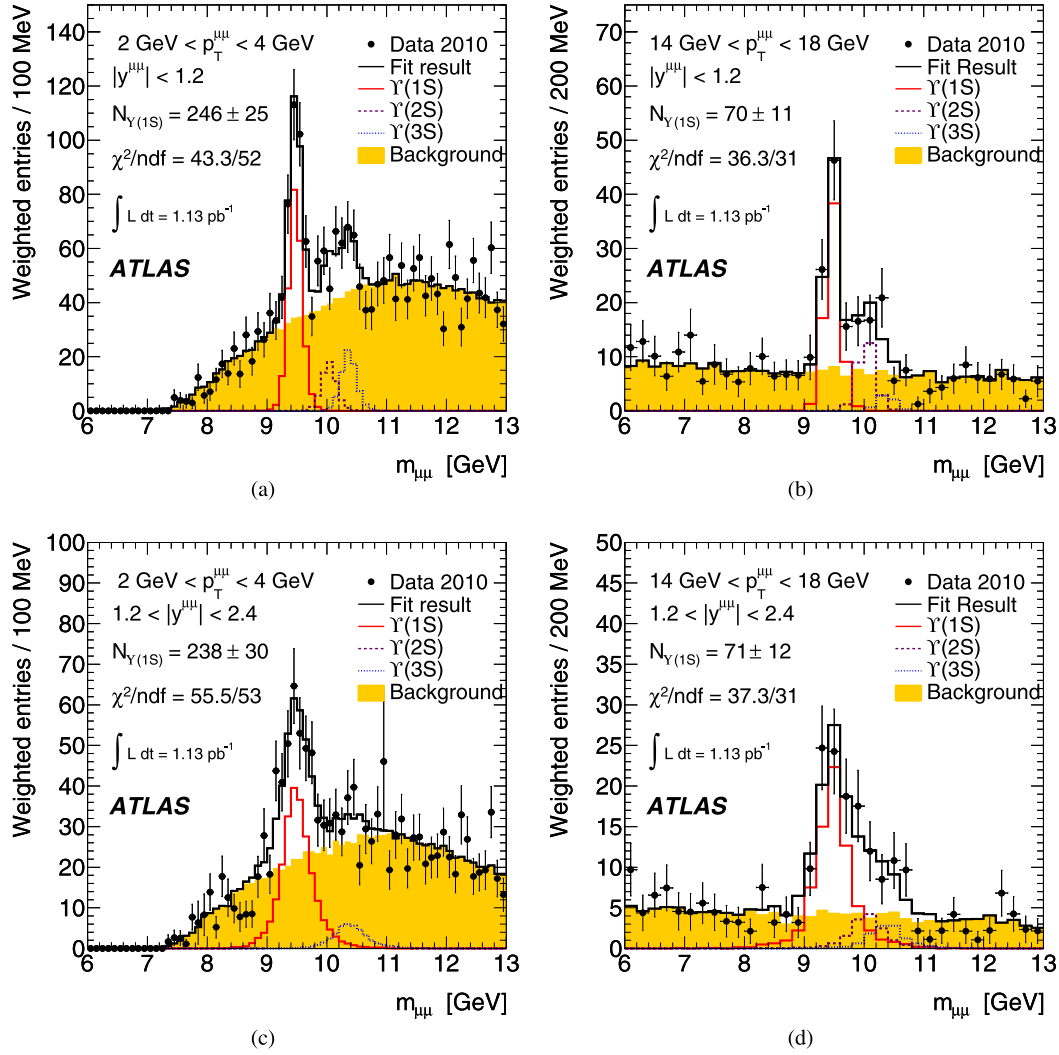


Fig. 1. Dimuon mass distributions for four representative bins in $y^{\mu\mu}$ and $p_T^{\mu\mu}$. The data (filled circles) are shown together with the result of the unbinned maximum likelihood fit (histogram) as explained in the text. The shaded histogram shows the background contribution, and the three other histograms show the contributions from the three γ states. All histograms are normalised by the factor determined in the fit. In the individual plots, the fitted $N_{\gamma(1S)}$ yield with its statistical uncertainty, the χ^2 and the number of degrees of freedom are also given. It should be noted that this is simply a binned graphical representation of the fit; the actual fit is unbinned and interpolates the template histograms to obtain the input probability density function.

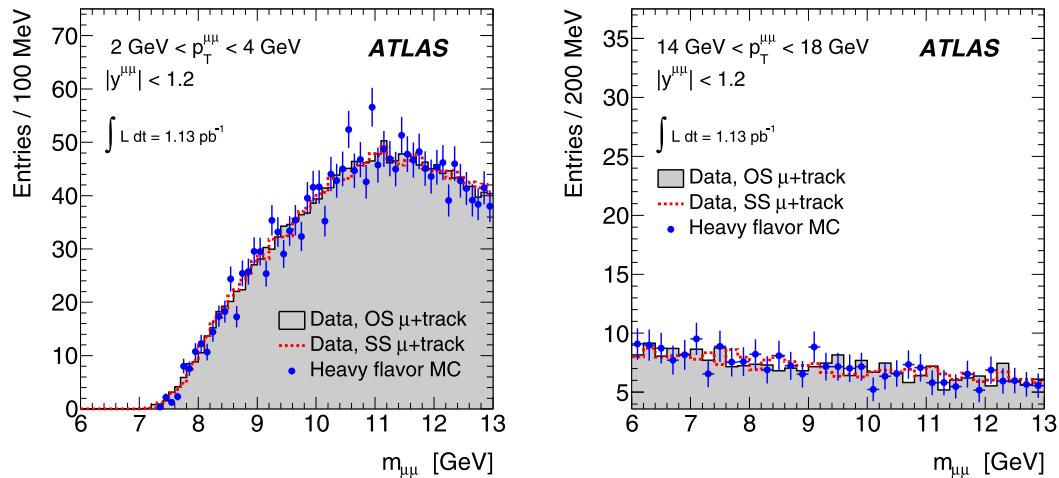


Fig. 2. Two examples of the templates used for the description of the dimuon mass dependence of the background are shown. The solid histogram shows the opposite-sign (OS) $\mu + \text{track}$, the dashed histogram shows the same-sign (SS) $\mu + \text{track}$ and the filled circles show the histogram derived from dimuon events in open $b\bar{b}$ and $c\bar{c}$ MC (heavy flavour MC). The error bars reflect the statistical uncertainty on the MC-based template. All histograms are normalised to the same absolute amount of background as determined in the fit for each kinematic bin (see also Fig. 1 and Section 6).

The impact of bin migrations is studied using MC, considering different shapes of the $p_T^{\Upsilon(1S)}$ distribution. A systematic uncertainty of 2% is associated with this.

The uncertainties on the fit model are evaluated using *pseudo-experiments*: 1000 sets of pseudo-data are created assuming a Poisson distribution corresponding to the prediction of the default template used for the data fits, and these are then fit with an alternative model as described below. The difference between the mean value of the 1000 pseudo-experiments and the value from the default template is used to assess the systematic effect. This method is used in order to avoid the propagation of statistical uncertainties in the data as part of the systematic uncertainty. However, fitting the data directly with any of the alternative choices gives consistent results. The systematic uncertainties related to the fit arise from the following contributions.

- The uncertainty on the template for the background model is assessed by constructing alternative templates based on the $SS \mu + \text{track}$ templates and on dimuon events in open $b\bar{b}$ and $c\bar{c}$ MC, as described in Section 6. The larger of the two differences, as determined using the pseudo-experiment technique described above, is taken as the uncertainty. The resulting uncertainty on the cross-section is typically about 4% but in some bins can be as high as 8%. Same-sign dimuon templates were also considered but are statistically too limited.
- The uncertainty on the signal model is assessed by changing from the signal templates to Crystal-Ball functions [26]. Here the three Υ states are considered and the differences between their mass values is fixed to the PDG value [22]. Their relative normalisations are allowed to float as in the default fit. In addition a common scale parameter and the parameters that describe the low-mass tail of the Crystal-Ball function float freely in the fit. The width is constrained to the value predicted by smeared MC to match resolutions measured in data. In the central region ($|y^{\Upsilon(1S)}| < 1.2$) the resulting difference is typically 1% while in the forward region ($1.2 < |y^{\Upsilon(1S)}| < 2.4$) it is about 5–10%, and these values are included in the systematic uncertainty. The data were also directly fitted with this alternative model and the result was found to be consistent with respect to the default fit.
- Both the overall mass scale and the separation between the three Υ states are fixed in the fit. The position of the reconstructed $\Upsilon(1S)$ mass peak is influenced by the overall momentum scale and the energy loss. The momentum scale has been determined using J/ψ mesons and Z bosons to better than 0.2% [21]. The energy loss has been evaluated from the variations of the J/ψ and K_s^0 masses [20] in different regions of the detector. Evaluated at the world average $\Upsilon(1S)$ mass, both effects together allow for a mass position uncertainty of 25 MeV. To assess the corresponding systematic uncertainty, pseudo-experiments are used to evaluate the impact of a possible shift in the mass scale by 25 MeV on $N_{\Upsilon(1S)}$. The difference to the default fit is found to be less than 1% in most bins but up to 5% in the highest- p_T forward bin. The mass separation is only influenced by the momentum scale: considering an uncertainty of 0.2% on the mass scale results in an uncertainty on the cross-section of at most 2% in any bin.
- The mass resolution is fixed to the value determined from detailed studies based on J/ψ s, Z s and cosmic rays [10]. A systematic uncertainty is assessed by changing the momentum resolution by 1σ . The resulting systematic uncertainty on the cross-section measurement is below 3% in all bins.

All these systematic uncertainties are uncorrelated and added in quadrature to give the total systematic uncertainty. It is typi-

Table 1

Measured differential cross-sections for $\Upsilon(1S)$ production in the fiducial acceptance ($p_T^\mu > 4$ GeV, $|\eta^\mu| < 2.5$ on both muons). Also listed are the corrected yields of $\Upsilon(1S)$ mesons, $N_{\Upsilon(1S)}$, and the fractional statistical (δ_{stat}), systematic (δ_{syst}) and total (δ_{tot}) uncertainties.

$p_T^{\Upsilon(1S)}$ (GeV)	$N_{\Upsilon(1S)}$	$d^2\sigma/dp_T dy$ (pb/GeV)	δ_{stat} (%)	δ_{syst} (%)	δ_{tot} (%)
$ y^{\Upsilon(1S)} < 1.2$					
0–2	213	39.3	12	6	13
2–4	246	45.4	10	5	11
4–6	190	35.0	12	5	13
6–8	175	32.2	12	6	13
8–11	203	24.9	10	4	11
11–14	110	13.6	13	7	15
14–18	70	6.5	15	7	17
18–26	17	0.8	33	9	34
$1.2 < y^{\Upsilon(1S)} < 2.4$					
0–2	163	30.0	17	13	22
2–4	238	43.8	13	13	18
4–6	124	22.9	18	9	20
6–8	129	23.7	15	9	17
8–11	132	16.2	14	7	16
11–14	75	9.3	18	9	20
14–18	71	6.5	17	10	20
18–26	28	1.3	29	15	33

cally 5% in the central and 10% in the forward region. This can be compared to the statistical uncertainty of about 10% (15%) at low $p_T^{\Upsilon(1S)}$ for the central (forward) region and 30% at the highest $p_T^{\Upsilon(1S)}$.

The number of $\Upsilon(1S)$ events and the statistical and systematic uncertainties for each bin are listed in Table 1.

8. Differential $\Upsilon(1S)$ cross-section measurement and comparison to theoretical predictions

Fig. 3 shows the differential $\Upsilon(1S)$ cross-section measurement for the central and forward regions in 8 bins in $p_T^{\Upsilon(1S)}$ covering 0–26 GeV for $p_T^\mu > 4$ GeV and $|\eta^\mu| < 2.5$ on both muons. The results are also listed in Table 1. The cross-section falls by about a factor of 50 over this p_T -range in both the central and the forward region.

Two theoretical predictions for quarkonium production are compared to the experimental data in Fig. 3. The first is the result of predictions from PYTHIA 8.135 [27] using the NRQCD [16] framework.² This prediction uses the NRQCD matrix elements as recommended in Ref. [17] and determined from Tevatron data, and a p_T and Q^2 dependent reweighting of the differential cross-section as described in Ref. [28] to prevent a divergence of the cross-section at low p_T . The CTEQ5L parton distribution functions are used [29]. The second prediction is a next-to-leading order QCD calculation of the $\Upsilon(1S)$ production cross-section in a colour-singlet state [30] as implemented in MCFM [31] which corresponds to the leading contribution in the NRQCD expansion (CSM NLO). This prediction is not available for $p_T^{\Upsilon(1S)} < 4$ GeV ($p_T^{\Upsilon(1S)} < 6$ GeV) in the central (forward) region since the perturbative expansion is not under proper control and this fixed order calculation fails to provide a reliable estimate [30]. Note that this prediction does not reproduce the differential cross-section measurements at the Tevatron unless additional higher order terms of

² The following five parameters have been changed from the default PYTHIA8.135 implementation as recommended by the PYTHIA authors: PhaseSpace:pThatMin=1 GeV, PhaseSpace:pThatMinDiverge=0.5, SuppressSmallPT(1., 3, false); Bottomonium:OUpsilon3P08=0.02, Bottomonium:Ochib03P01=0.085.

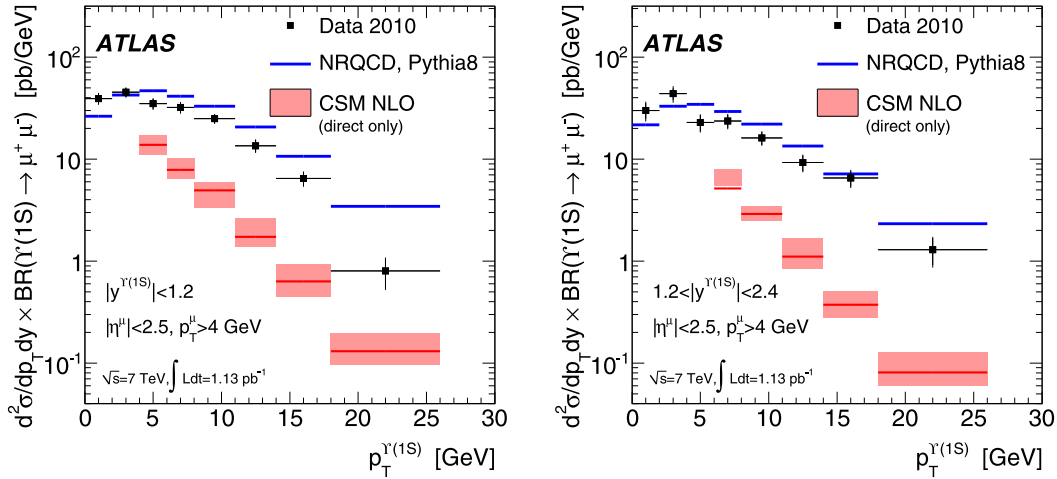


Fig. 3. The differential $\Upsilon(1S)$ cross-section for the $|y^{\Upsilon(1S)}| < 1.2$ (left) and $1.2 < |y^{\Upsilon(1S)}| < 2.4$ (right) as function of $p_T^{\Upsilon(1S)}$ for $p_T^\mu > 4$ GeV and $|\eta^\mu| < 2.5$ on both muons. Also shown is the colour-singlet NLO (CSM) prediction using m_T for the renormalisation and factorisation scales. The shaded area shows the change in the theoretical prediction when varying the renormalisation and factorisation scales by a factor of two. The CSM NLO calculation accounts only for direct production of $\Upsilon(1S)$ mesons and not for any feed-down from excited states. The NRQCD prediction as implemented in PYTHIA8 is also shown for a particular choice of parameters as discussed in the text.

$\mathcal{O}(\alpha_s^5)$ are considered and the data are corrected for feed-down from $\chi_b \rightarrow \Upsilon\gamma$ production [32] and other excited Υ states. The renormalisation and factorisation scales for this prediction are set to $m_T = \sqrt{4m_b^2 + p_T^2}$ where $m_b = 4.75$ GeV and p_T is the transverse momentum of the $\Upsilon(1S)$. These scales are varied by a factor of two to assess the sensitivity of the calculation to these parameters. The CTEQ6M parton distribution functions are used for this prediction [33].

The measured differential cross-section has a different p_T dependence, but its normalisation is in reasonable overall agreement with the NRQCD prediction. In particular, at high (low) $p_T^{\Upsilon(1S)}$ the prediction is systematically higher (lower) than the data. The cross-section from data is higher than the NLO colour-singlet prediction over the entire p_T range. Part of the discrepancy can likely be accounted for by the fact that this prediction does not include any feed-down from higher mass states which was estimated to contribute about a factor of 2 at the Tevatron [34]. In Ref. [32], it was shown that additional higher order corrections increase with increasing p_T (they contribute about a factor of 10 at high p_T), and are required to describe the Tevatron data. This is qualitatively consistent with the discrepancies observed between the data presented here and the NLO prediction. Whether or not these data can be consistently understood together with the data from previous collider experiments within a consistent theoretical framework remains to be seen.

The data are not compared directly to previous measurements [4–6] since in the present analysis no correction is made for the p_T^μ and η^μ cuts in order to avoid the need for any assumption on the spin alignment of the $\Upsilon(1S)$.

9. Conclusions

A measurement of the differential production cross-section of $\Upsilon(1S)$ mesons decaying into two muons measured in the fiducial region with $p_T^\mu > 4$ GeV and $|\eta^\mu| < 2.5$ has been presented as function of $p_T^{\Upsilon(1S)}$ and $y^{\Upsilon(1S)}$. The typical uncertainty of the measurement is about 10–15% at low $p_T^{\Upsilon(1S)}$ and 35% at high $p_T^{\Upsilon(1S)}$ and is dominated by the statistical precision of the data. Due to the restriction to $p_T^\mu > 4$ GeV and $|\eta^\mu| < 2.5$, the measurement is almost independent of any assumption on the spin alignment of the $\Upsilon(1S)$.

The data significantly exceed the NLO prediction but this may well be explained due to contributions from higher mass bound states and by the need for additional higher order corrections to $\Upsilon(1S)$ production. In contrast, the data are in reasonable agreement with the NRQCD prediction as implemented in PYTHIA8 but differences in the shape of the p_T spectrum of about a factor of two are observed. The data presented here will be useful to further understand the complex mechanisms that govern quarkonium production.

Acknowledgements

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently. We also wish to thank Pierre Artoisenet, John Campbell and Torbjörn Sjöstrand for their help with the theoretical predictions.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; ARTEMIS, European Union; IN2P3–CNRS, CEA-DSM/IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTP, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA) and in the Tier-2 facilities worldwide.

Open access

This article is published Open Access at [sciencedirect.com](http://www.sciencedirect.com). It is distributed under the terms of the Creative Commons Attribution License 3.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original authors and source are credited.

References

- [1] J.J. Aubert, et al., Phys. Rev. Lett. 33 (1974) 1404; J.-E. Augustin, et al., Phys. Rev. Lett. 33 (1974) 1406.
- [2] D.C. Hom, et al., Phys. Rev. Lett. 39 (1977) 252.
- [3] N. Brambilla, et al., Eur. Phys. J. C 71 (2011) 1.
- [4] D.E. Acosta, et al., CDF Collaboration, Phys. Rev. Lett. 88 (2002) 161802, CDF Public Note 9966.
- [5] V.M. Abazov, et al., D0 Collaboration, Phys. Rev. Lett. 94 (2005) 232001; V.M. Abazov, et al., D0 Collaboration, Phys. Rev. Lett. 101 (2008) 182004.
- [6] CMS Collaboration, Phys. Rev. D 83 (2011) 112004, arXiv:1012.5545 [hep-ex].
- [7] ATLAS Collaboration, Nucl. Phys. B 850 (2011) 387, arXiv:1104.3038 [hep-ex].
- [8] ATLAS Collaboration, JINST 3 (2008) S08003.
- [9] ATLAS Collaboration, Eur. Phys. J. C, submitted for publication, CERN-PH-EP-2011-078.
- [10] ATLAS Collaboration, ATLAS-CONF-2010-064, <http://cdsweb.cern.ch/record/1281339>.
- [11] T. Sjostrand, S. Mrenna, P. Skands, JHEP 0605 (2006) 026.
- [12] ATLAS Collaboration, ATL-PHYS-PUB-2010-002.
- [13] A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, Eur. Phys. J. C 63 (2009) 189.
- [14] ATLAS Collaboration, Eur. Phys. J. C 70 (2010) 823.
- [15] S. Agostinelli, et al., GEANT4 Collaboration, Nucl. Instrum. Methods A 506 (2003) 250.
- [16] G.T. Bodwin, E. Braaten, G.P. Lepage, Phys. Rev. D 51 (1995) 1125.
- [17] P. Nason, et al., arXiv:hep-ph/0003142.
- [18] P. Golonka, Z. Was, Eur. Phys. J. C 45 (2006) 97.
- [19] ATLAS Collaboration, ATLAS-CONF-2011-021, <http://cdsweb.cern.ch/record/1336750>.
- [20] ATLAS Collaboration, New J. Phys. 13 (2011) 053033.
- [21] ATLAS Collaboration, ATLAS-CONF-2010-078, <http://cdsweb.cern.ch/record/1281369>.
- [22] K. Nakamura, et al., Particle Data Group, J. Phys. G 37 (2010) 075021.
- [23] S. van der Meer, CERN-ISR-PO-68-31, 1968.
- [24] ATLAS Collaboration, ATLAS-CONF-2011-011, <http://cdsweb.cern.ch/record/1334563>.
- [25] ATLAS Collaboration, Eur. Phys. J. C 71 (2011) 1630.
- [26] M.J. Oreglia, PhD thesis, SLAC-R-236, 1980; J.E. Gaiser, PhD thesis, SLAC-R-255, 1982; T. Skwarnicki, PhD thesis, DESY F31-86-02, 1986.
- [27] PYTHIA version 8.135, T. Sjostrand, S. Mrenna, P. Skands, Comput. Phys. Comm. 178 (2008) 852.
- [28] A.C. Kraan, arXiv:0807.3123 [hep-ex].
- [29] H.L. Lai, et al., CTEQ Collaboration, Eur. Phys. J. C 12 (2000) 375.
- [30] J. Campbell, F. Maltoni, F. Tramontano, Phys. Rev. Lett. 98 (2007) 252002.
- [31] J.M. Campbell, R.K. Ellis, Nucl. Phys. (Proc. Suppl.) 205–206 (2010) 10; MCFM home page, <http://mcfm.fnal.gov>.
- [32] P. Artoisenet, et al., Phys. Rev. Lett. 101 (2008) 152001.
- [33] J. Pumplin, D.R. Stump, J. Huston, H.L. Lai, P.M. Nadolsky, W.K. Tung, JHEP 0207 (2002) 012.
- [34] A. Affolder, et al., CDF Collaboration, Phys. Rev. Lett. 84 (2000) 2094.

ATLAS Collaboration

G. Aad⁴⁸, B. Abbott¹¹¹, J. Abdallah¹¹, A.A. Abdelalim⁴⁹, A. Abdesselam¹¹⁸, O. Abdinov¹⁰, B. Abi¹¹², M. Abolins⁸⁸, H. Abramowicz¹⁵³, H. Abreu¹¹⁵, E. Acerbi^{89a,89b}, B.S. Acharya^{164a,164b}, D.L. Adams²⁴, T.N. Addy⁵⁶, J. Adelman¹⁷⁵, M. Aderholz⁹⁹, S. Adomeit⁹⁸, P. Adragna⁷⁵, T. Adye¹²⁹, S. Aefsky²², J.A. Aguilar-Saavedra^{124b,a}, M. Aharrouche⁸¹, S.P. Ahlen²¹, F. Ahles⁴⁸, A. Ahmad¹⁴⁸, M. Ahsan⁴⁰, G. Aielli^{133a,133b}, T. Akdogan^{18a}, T.P.A. Åkesson⁷⁹, G. Akimoto¹⁵⁵, A.V. Akimov⁹⁴, A. Akiyama⁶⁷, M.S. Alam¹, M.A. Alam⁷⁶, S. Albrand⁵⁵, M. Aleksa²⁹, I.N. Aleksandrov⁶⁵, F. Alessandria^{89a}, C. Alexa^{25a}, G. Alexander¹⁵³, G. Alexandre⁴⁹, T. Alexopoulos⁹, M. Alhroob²⁰, M. Aliev¹⁵, G. Alimonti^{89a}, J. Alison¹²⁰, M. Aliyev¹⁰, P.P. Allport⁷³, S.E. Allwood-Spiers⁵³, J. Almond⁸², A. Aloisio^{102a,102b}, R. Alon¹⁷¹, A. Alonso⁷⁹, M.G. Alviggi^{102a,102b}, K. Amako⁶⁶, P. Amaral²⁹, C. Amelung²², V.V. Ammosov¹²⁸, A. Amorim^{124a,b}, G. Amorós¹⁶⁷, N. Amram¹⁵³, C. Anastopoulos²⁹, N. Andari¹¹⁵, T. Andeen³⁴, C.F. Anders²⁰, K.J. Anderson³⁰, A. Andreazza^{89a,89b}, V. Andrei^{58a}, M.-L. Andrieux⁵⁵, X.S. Anduaga⁷⁰, A. Angerami³⁴, F. Anghinolfi²⁹, N. Anjos^{124a}, A. Annovi⁴⁷, A. Antonaki⁸, M. Antonelli⁴⁷, A. Antonov⁹⁶, J. Antos^{144b}, F. Anulli^{132a}, S. Aoun⁸³, L. Aperio Bella⁴, R. Apolle^{118,c}, G. Arabidze⁸⁸, I. Aracena¹⁴³, Y. Arai⁶⁶, A.T.H. Arce⁴⁴, J.P. Archambault²⁸, S. Arfaoui^{29,d}, J.-F. Arguin¹⁴, E. Arik^{18a,*}, M. Arik^{18a}, A.J. Armbruster⁸⁷, O. Arnaez⁸¹, C. Arnault¹¹⁵, A. Artamonov⁹⁵, G. Artoni^{132a,132b}, D. Arutinov²⁰, S. Asai¹⁵⁵, R. Asfandiyarov¹⁷², S. Ask²⁷, B. Åsman^{146a,146b}, L. Asquith⁵, K. Assamagan²⁴, A. Astbury¹⁶⁹, A. Astvatsatourov⁵², G. Atoian¹⁷⁵, B. Aubert⁴, B. Auerbach¹⁷⁵, E. Auge¹¹⁵, K. Augsten¹²⁷, M. Aurousseau^{145a}, N. Austin⁷³, R. Avramidou⁹, D. Axen¹⁶⁸, C. Ay⁵⁴, G. Azuelos^{93,e}, Y. Azuma¹⁵⁵, M.A. Baak²⁹, G. Baccaglioni^{89a}, C. Bacci^{134a,134b}, A.M. Bach¹⁴, H. Bachacou¹³⁶, K. Bachas²⁹, G. Bachy²⁹, M. Backes⁴⁹, M. Backhaus²⁰, E. Badescu^{25a}, P. Bagnaia^{132a,132b}, S. Bahinipati², Y. Bai^{32a}, D.C. Bailey¹⁵⁸, T. Bain¹⁵⁸, J.T. Baines¹²⁹, O.K. Baker¹⁷⁵, M.D. Baker²⁴, S. Baker⁷⁷, F. Baltasar Dos Santos Pedrosa²⁹, E. Banas³⁸, P. Banerjee⁹³, Sw. Banerjee¹⁷², D. Banfi²⁹, A. Bangert¹³⁷, V. Bansal¹⁶⁹, H.S. Bansil¹⁷, L. Barak¹⁷¹, S.P. Baranov⁹⁴, A. Barashkou⁶⁵, A. Barbaro Galtieri¹⁴, T. Barber²⁷, E.L. Barberio⁸⁶, D. Barberis^{50a,50b}, M. Barbero²⁰, D.Y. Bardin⁶⁵, T. Barillari⁹⁹, M. Barisonzi¹⁷⁴, T. Barklow¹⁴³, N. Barlow²⁷, B.M. Barnett¹²⁹, R.M. Barnett¹⁴, A. Baroncelli^{134a}, G. Barone⁴⁹, A.J. Barr¹¹⁸, F. Barreiro⁸⁰, J. Barreiro Guimarães da Costa⁵⁷, P. Barrillon¹¹⁵, R. Bartoldus¹⁴³, A.E. Barton⁷¹, D. Bartsch²⁰, V. Bartsch¹⁴⁹, R.L. Bates⁵³, L. Batkova^{144a}, J.R. Batley²⁷, A. Battaglia¹⁶, M. Battistin²⁹, G. Battistoni^{89a}, F. Bauer¹³⁶, H.S. Bawa^{143,f}, B. Beare¹⁵⁸, T. Beau⁷⁸, P.H. Beauchemin¹¹⁸, R. Beccherle^{50a}, P. Bechtel⁴¹, H.P. Beck¹⁶, M. Beckingham⁴⁸, K.H. Becks¹⁷⁴, A.J. Beddall^{18c}, A. Beddall^{18c}, S. Bedikian¹⁷⁵, V.A. Bednyakov⁶⁵, C.P. Bee⁸³, M. Begel²⁴, S. Behar Harpaz¹⁵², P.K. Behera⁶³, M. Beimforde⁹⁹,

C. Belanger-Champagne⁸⁵, P.J. Bell⁴⁹, W.H. Bell⁴⁹, G. Bella¹⁵³, L. Bellagamba^{19a}, F. Bellina²⁹,
 M. Bellomo^{119a}, A. Belloni⁵⁷, O. Beloborodova¹⁰⁷, K. Belotskiy⁹⁶, O. Beltramello²⁹, S. Ben Ami¹⁵²,
 O. Benary¹⁵³, D. Benchekroun^{135a}, C. Benchouk⁸³, M. Bendel⁸¹, B.H. Benedict¹⁶³, N. Benekos¹⁶⁵,
 Y. Benhammou¹⁵³, D.P. Benjamin⁴⁴, M. Benoit¹¹⁵, J.R. Bensinger²², K. Benslama¹³⁰, S. Bentvelsen¹⁰⁵,
 D. Berge²⁹, E. Bergeaas Kuutmann⁴¹, N. Berger⁴, F. Berghaus¹⁶⁹, E. Berglund⁴⁹, J. Beringer¹⁴,
 K. Bernardet⁸³, P. Bernat⁷⁷, R. Bernhard⁴⁸, C. Bernius²⁴, T. Berry⁷⁶, A. Bertin^{19a,19b}, F. Bertinelli²⁹,
 F. Bertolucci^{122a,122b}, M.I. Besana^{89a,89b}, N. Besson¹³⁶, S. Bethke⁹⁹, W. Bhimji⁴⁵, R.M. Bianchi²⁹,
 M. Bianco^{72a,72b}, O. Biebel⁹⁸, S.P. Bieniek⁷⁷, J. Biesiada¹⁴, M. Biglietti^{134a,134b}, H. Bilokon⁴⁷,
 M. Bindi^{19a,19b}, S. Binet¹¹⁵, A. Bingul^{18c}, C. Bini^{132a,132b}, C. Biscarat¹⁷⁷, U. Bitenc⁴⁸, K.M. Black²¹,
 R.E. Blair⁵, J.-B. Blanchard¹¹⁵, G. Blanchot²⁹, T. Blazek^{144a}, C. Blocker²², J. Blocki³⁸, A. Blondel⁴⁹,
 W. Blum⁸¹, U. Blumenschein⁵⁴, G.J. Bobbink¹⁰⁵, V.B. Bobrovnikov¹⁰⁷, S.S. Bocchetta⁷⁹, A. Bocci⁴⁴,
 C.R. Boddy¹¹⁸, M. Boehler⁴¹, J. Boek¹⁷⁴, N. Boelaert³⁵, S. Böser⁷⁷, J.A. Bogaerts²⁹, A. Bogdanchikov¹⁰⁷,
 A. Bogouch^{90,*}, C. Bohm^{146a}, V. Boisvert⁷⁶, T. Bold^{163,g}, V. Boldea^{25a}, N.M. Bolnet¹³⁶, M. Bona⁷⁵,
 V.G. Bondarenko⁹⁶, M. Boonekamp¹³⁶, G. Boorman⁷⁶, C.N. Booth¹³⁹, S. Bordini⁷⁸, C. Borer¹⁶,
 A. Borisov¹²⁸, G. Borissov⁷¹, I. Borjanovic^{12a}, S. Borroni^{132a,132b}, K. Bos¹⁰⁵, D. Boscherini^{19a},
 M. Bosman¹¹, H. Boterenbrood¹⁰⁵, D. Botterill¹²⁹, J. Bouchami⁹³, J. Boudreau¹²³,
 E.V. Bouhova-Thacker⁷¹, C. Boulahouache¹²³, C. Bourdarios¹¹⁵, N. Bousson⁸³, A. Boveia³⁰, J. Boyd²⁹,
 I.R. Boyko⁶⁵, N.I. Bozhko¹²⁸, I. Bozovic-Jelisavcic^{12b}, J. Bracinik¹⁷, A. Braem²⁹, P. Branchini^{134a},
 G.W. Brandenburg⁵⁷, A. Brandt⁷, G. Brandt¹⁵, O. Brandt⁵⁴, U. Bratzler¹⁵⁶, B. Brau⁸⁴, J.E. Brau¹¹⁴,
 H.M. Braun¹⁷⁴, B. Brelrier¹⁵⁸, J. Bremer²⁹, R. Brenner¹⁶⁶, S. Bressler¹⁵², D. Breton¹¹⁵, D. Britton⁵³,
 F.M. Brochu²⁷, I. Brock²⁰, R. Brock⁸⁸, T.J. Brodbeck⁷¹, E. Brodet¹⁵³, F. Broggi^{89a}, C. Bromberg⁸⁸,
 G. Brooijmans³⁴, W.K. Brooks^{31b}, G. Brown⁸², H. Brown⁷, P.A. Bruckman de Renstrom³⁸,
 D. Bruncko^{144b}, R. Bruneliere⁴⁸, S. Brunet⁶¹, A. Bruni^{19a}, G. Bruni^{19a}, M. Bruschi^{19a}, T. Buanes¹³,
 F. Bucci⁴⁹, J. Buchanan¹¹⁸, N.J. Buchanan², P. Buchholz¹⁴¹, R.M. Buckingham¹¹⁸, A.G. Buckley⁴⁵,
 S.I. Buda^{25a}, I.A. Budagov⁶⁵, B. Budick¹⁰⁸, V. Büscher⁸¹, L. Bugge¹¹⁷, D. Buirra-Clark¹¹⁸, O. Bulekov⁹⁶,
 M. Bunse⁴², T. Buran¹¹⁷, H. Burckhart²⁹, S. Burdin⁷³, T. Burgess¹³, S. Burke¹²⁹, E. Busato³³, P. Bussey⁵³,
 C.P. Buszello¹⁶⁶, F. Butin²⁹, B. Butler¹⁴³, J.M. Butler²¹, C.M. Buttar⁵³, J.M. Butterworth⁷⁷,
 W. Buttinger²⁷, T. Byatt⁷⁷, S. Cabrera Urbán¹⁶⁷, D. Caforio^{19a,19b}, O. Cakir^{3a}, P. Calafiura¹⁴,
 G. Calderini⁷⁸, P. Calfayan⁹⁸, R. Calkins¹⁰⁶, L.P. Caloba^{23a}, R. Caloi^{132a,132b}, D. Calvet³³, S. Calvet³³,
 R. Camacho Toro³³, P. Camarri^{133a,133b}, M. Cambiaghi^{119a,119b}, D. Cameron¹¹⁷, S. Campana²⁹,
 M. Campanelli⁷⁷, V. Canale^{102a,102b}, F. Canelli³⁰, A. Canepa^{159a}, J. Cantero⁸⁰, L. Capasso^{102a,102b},
 M.D.M. Capeans Garrido²⁹, I. Caprini^{25a}, M. Caprini^{25a}, D. Capriotti⁹⁹, M. Capua^{36a,36b}, R. Caputo¹⁴⁸,
 C. Caramarcu^{25a}, R. Cardarelli^{133a}, T. Carli²⁹, G. Carlino^{102a}, L. Carminati^{89a,89b}, B. Caron^{159a},
 S. Caron⁴⁸, G.D. Carrillo Montoya¹⁷², A.A. Carter⁷⁵, J.R. Carter²⁷, J. Carvalho^{124a,h}, D. Casadei¹⁰⁸,
 M.P. Casado¹¹, M. Cascella^{122a,122b}, C. Caso^{50a,50b,*}, A.M. Castaneda Hernandez¹⁷²,
 E. Castaneda-Miranda¹⁷², V. Castillo Gimenez¹⁶⁷, N.F. Castro^{124a}, G. Cataldi^{72a}, F. Cataneo²⁹,
 A. Catinaccio²⁹, J.R. Catmore⁷¹, A. Cattai²⁹, G. Cattani^{133a,133b}, S. Caughron⁸⁸, D. Cauz^{164a,164c},
 P. Cavalleri⁷⁸, D. Cavalli^{89a}, M. Cavalli-Sforza¹¹, V. Cavasinni^{122a,122b}, F. Ceradini^{134a,134b},
 A.S. Cerqueira^{23a}, A. Cerri²⁹, L. Cerrito⁷⁵, F. Cerutti⁴⁷, S.A. Cetin^{18b}, F. Cevenini^{102a,102b}, A. Chafaq^{135a},
 D. Chakraborty¹⁰⁶, K. Chan², B. Chapleau⁸⁵, J.D. Chapman²⁷, J.W. Chapman⁸⁷, E. Chareyre⁷⁸,
 D.G. Charlton¹⁷, V. Chavda⁸², C.A. Chavez Barajas²⁹, S. Cheatham⁸⁵, S. Chekanov⁵, S.V. Chekulaev^{159a},
 G.A. Chelkov⁶⁵, M.A. Chelstowska¹⁰⁴, C. Chen⁶⁴, H. Chen²⁴, S. Chen^{32c}, T. Chen^{32c}, X. Chen¹⁷²,
 S. Cheng^{32a}, A. Cheplakov⁶⁵, V.F. Chepurinov⁶⁵, R. Cherkaoui El Moursli^{135e}, V. Chernyatin²⁴, E. Cheu⁶,
 S.L. Cheung¹⁵⁸, L. Chevalier¹³⁶, G. Chiefari^{102a,102b}, L. Chikovani⁵¹, J.T. Childers^{58a}, A. Chilingarov⁷¹,
 G. Chiodini^{72a}, M.V. Chizhov⁶⁵, G. Choudalakis³⁰, S. Chouridou¹³⁷, I.A. Christidi⁷⁷, A. Christov⁴⁸,
 D. Chromek-Burckhart²⁹, M.L. Chu¹⁵¹, J. Chudoba¹²⁵, G. Ciapetti^{132a,132b}, K. Ciba³⁷, A.K. Ciftci^{3a},
 R. Ciftci^{3a}, D. Cinca³³, V. Cindro⁷⁴, M.D. Ciobotaru¹⁶³, C. Ciocca^{19a,19b}, A. Ciocio¹⁴, M. Cirilli⁸⁷,
 M. Ciubancan^{25a}, A. Clark⁴⁹, P.J. Clark⁴⁵, W. Cleland¹²³, J.C. Clemens⁸³, B. Clement⁵⁵,
 C. Clement^{146a,146b}, R.W. Clift¹²⁹, Y. Coadou⁸³, M. Cobal^{164a,164c}, A. Coccaro^{50a,50b}, J. Cochran⁶⁴,
 P. Coe¹¹⁸, J.G. Cogan¹⁴³, J. Coggeshall¹⁶⁵, E. Cogneras¹⁷⁷, C.D. Cojocaru²⁸, J. Colas⁴, A.P. Colijn¹⁰⁵,
 C. Collard¹¹⁵, N.J. Collins¹⁷, C. Collins-Tooth⁵³, J. Collot⁵⁵, G. Colon⁸⁴, P. Conde Muiño^{124a},
 E. Coniavitis¹¹⁸, M.C. Conidi¹¹, M. Consonni¹⁰⁴, V. Consorti⁴⁸, S. Constantinescu^{25a}, C. Conta^{119a,119b},

F. Conventi^{102a,i}, J. Cook²⁹, M. Cooke¹⁴, B.D. Cooper⁷⁷, A.M. Cooper-Sarkar¹¹⁸, N.J. Cooper-Smith⁷⁶,
 K. Copic³⁴, T. Cornelissen^{50a,50b}, M. Corradi^{19a}, F. Corriveau^{85,j}, A. Cortes-Gonzalez¹⁶⁵, G. Cortiana⁹⁹,
 G. Costa^{89a}, M.J. Costa¹⁶⁷, D. Costanzo¹³⁹, T. Costin³⁰, D. Côté²⁹, R. Coura Torres^{23a}, L. Courneyea¹⁶⁹,
 G. Cowan⁷⁶, C. Cowden²⁷, B.E. Cox⁸², K. Cranmer¹⁰⁸, F. Crescioli^{122a,122b}, M. Cristinziani²⁰,
 G. Crosetti^{36a,36b}, R. Crupi^{72a,72b}, S. Crépe-Renaudin⁵⁵, C.-M. Cuciuc^{25a}, C. Cuenca Almenar¹⁷⁵,
 T. Cuhadar Donszelmann¹³⁹, S. Cuneo^{50a,50b}, M. Curatolo⁴⁷, C.J. Curtis¹⁷, P. Cwetanski⁶¹, H. Czirr¹⁴¹,
 Z. Czyzula¹¹⁷, S. D'Auria⁵³, M. D'Onofrio⁷³, A. D'Orazio^{132a,132b}, P.V.M. Da Silva^{23a}, C. Da Via⁸²,
 W. Dabrowski³⁷, T. Dai⁸⁷, C. Dallapiccola⁸⁴, M. Dam³⁵, M. Dameri^{50a,50b}, D.S. Damiani¹³⁷,
 H.O. Danielsson²⁹, D. Dannheim⁹⁹, V. Dao⁴⁹, G. Darbo^{50a}, G.L. Darlea^{25b}, C. Daum¹⁰⁵, J.P. Dauvergne²⁹,
 W. Davey⁸⁶, T. Davidek¹²⁶, N. Davidson⁸⁶, R. Davidson⁷¹, E. Davies^{118,c}, M. Davies⁹³, A.R. Davison⁷⁷,
 Y. Davygora^{58a}, E. Dawe¹⁴², I. Dawson¹³⁹, J.W. Dawson^{5,*}, R.K. Daya³⁹, K. De⁷, R. de Asmundis^{102a},
 S. De Castro^{19a,19b}, P.E. De Castro Faria Salgado²⁴, S. De Cecco⁷⁸, J. de Graat⁹⁸, N. De Groot¹⁰⁴,
 P. de Jong¹⁰⁵, C. De La Taille¹¹⁵, H. De la Torre⁸⁰, B. De Lotto^{164a,164c}, L. De Mora⁷¹, L. De Nooij¹⁰⁵,
 M. De Oliveira Branco²⁹, D. De Pedis^{132a}, P. de Saintignon⁵⁵, A. De Salvo^{132a}, U. De Sanctis^{164a,164c},
 A. De Santo¹⁴⁹, J.B. De Vivie De Regie¹¹⁵, S. Dean⁷⁷, D.V. Dedovich⁶⁵, J. Degenhardt¹²⁰, M. Dehchar¹¹⁸,
 M. Deile⁹⁸, C. Del Papa^{164a,164c}, J. Del Peso⁸⁰, T. Del Prete^{122a,122b}, M. Deliyergiyev⁷⁴, A. Dell'Acqua²⁹,
 L. Dell'Asta^{89a,89b}, M. Della Pietra^{102a,i}, D. della Volpe^{102a,102b}, M. Delmastro²⁹, P. Delpierre⁸³,
 N. Delruelle²⁹, P.A. Delsart⁵⁵, C. Deluca¹⁴⁸, S. Demers¹⁷⁵, M. Demichev⁶⁵, B. Demirkoz^{11,k}, J. Deng¹⁶³,
 S.P. Denisov¹²⁸, D. Derendarz³⁸, J.E. Derkaoui^{135d}, F. Derue⁷⁸, P. Dervan⁷³, K. Desch²⁰, E. Devetak¹⁴⁸,
 P.O. Deviveiros¹⁵⁸, A. Dewhurst¹²⁹, B. DeWilde¹⁴⁸, S. Dhaliwal¹⁵⁸, R. Dhullipudi^{24,l},
 A. Di Ciaccio^{133a,133b}, L. Di Ciaccio⁴, A. Di Girolamo²⁹, B. Di Girolamo²⁹, S. Di Luise^{134a,134b},
 A. Di Mattia⁸⁸, B. Di Micco²⁹, R. Di Nardo^{133a,133b}, A. Di Simone^{133a,133b}, R. Di Sipio^{19a,19b},
 M.A. Diaz^{31a}, F. Diblen^{18c}, E.B. Diehl⁸⁷, J. Dietrich⁴¹, T.A. Dietzsch^{58a}, S. Diglio¹¹⁵, K. Dindar Yagci³⁹,
 J. Dingfelder²⁰, C. Dionisi^{132a,132b}, P. Dita^{25a}, S. Dita^{25a}, F. Dittus²⁹, F. Djama⁸³, T. Djobava⁵¹,
 M.A.B. do Vale^{23a}, A. Do Valle Wemans^{124a}, T.K.O. Doan⁴, M. Dobbs⁸⁵, R. Dobinson^{29,*}, D. Dobos⁴²,
 E. Dobson²⁹, M. Dobson¹⁶³, J. Dodd³⁴, C. Doglioni¹¹⁸, T. Doherty⁵³, Y. Doi^{66,*}, J. Dolejsi¹²⁶, I. Dolenc⁷⁴,
 Z. Dolezal¹²⁶, B.A. Dolgoshein^{96,*}, T. Dohmae¹⁵⁵, M. Donadelli^{23b}, M. Donega¹²⁰, J. Donini⁵⁵,
 J. Dopke²⁹, A. Doria^{102a}, A. Dos Anjos¹⁷², M. Dosil¹¹, A. Dotti^{122a,122b}, M.T. Dova⁷⁰, J.D. Dowell¹⁷,
 A.D. Doxiadis¹⁰⁵, A.T. Doyle⁵³, Z. Drasal¹²⁶, J. Drees¹⁷⁴, N. Dressnandt¹²⁰, H. Drevermann²⁹,
 C. Driouichi³⁵, M. Dris⁹, J. Dubbert⁹⁹, T. Dubbs¹³⁷, S. Dube¹⁴, E. Duchovni¹⁷¹, G. Duckeck⁹⁸,
 A. Dudarev²⁹, F. Dudziak⁶⁴, M. Dührssen²⁹, I.P. Duerdoth⁸², L. Dufлот¹¹⁵, M.-A. Dufour⁸⁵, M. Dunford²⁹,
 H. Duran Yildiz^{3b}, R. Duxfield¹³⁹, M. Dwuznik³⁷, F. Dydak²⁹, D. Dzahini⁵⁵, M. Düren⁵²,
 W.L. Ebenstein⁴⁴, J. Ebke⁹⁸, S. Eckert⁴⁸, S. Eckweiler⁸¹, K. Edmonds⁸¹, C.A. Edwards⁷⁶, N.C. Edwards⁵³,
 W. Ehrenfeld⁴¹, T. Ehrich⁹⁹, T. Eifert²⁹, G. Eigen¹³, K. Einsweiler¹⁴, E. Eisenhandler⁷⁵, T. Ekelof¹⁶⁶,
 M. El Kacimi^{135c}, M. Ellert¹⁶⁶, S. Elles⁴, F. Ellinghaus⁸¹, K. Ellis⁷⁵, N. Ellis²⁹, J. Elmsheuser⁹⁸,
 M. Elsing²⁹, R. Ely¹⁴, D. Emeliyanov¹²⁹, R. Engelmann¹⁴⁸, A. Engl⁹⁸, B. Epp⁶², A. Eppig⁸⁷,
 J. Erdmann⁵⁴, A. Ereditato¹⁶, D. Eriksson^{146a}, J. Ernst¹, M. Ernst²⁴, J. Ernwein¹³⁶, D. Errede¹⁶⁵,
 S. Errede¹⁶⁵, E. Ertel⁸¹, M. Escalier¹¹⁵, C. Escobar¹⁶⁷, X. Espinal Curull¹¹, B. Esposito⁴⁷, F. Etienne⁸³,
 A.I. Etievre¹³⁶, E. Etzion¹⁵³, D. Evangelakou⁵⁴, H. Evans⁶¹, L. Fabbri^{19a,19b}, C. Fabre²⁹,
 R.M. Fakhruddinov¹²⁸, S. Falciano^{132a}, Y. Fang¹⁷², M. Fanti^{89a,89b}, A. Farbin⁷, A. Farilla^{134a}, J. Farley¹⁴⁸,
 T. Farooque¹⁵⁸, S.M. Farrington¹¹⁸, P. Farthouat²⁹, P. Fassnacht²⁹, D. Fassouliotis⁸, B. Fatholahzadeh¹⁵⁸,
 A. Favareto^{89a,89b}, L. Fayard¹¹⁵, S. Fazio^{36a,36b}, R. Febbraro³³, P. Federic^{144a}, O.L. Fedin¹²¹,
 W. Fedorko⁸⁸, M. Fehling-Kaschek⁴⁸, L. Feligioni⁸³, D. Fellmann⁵, C.U. Felzmann⁸⁶, C. Feng^{32d},
 E.J. Feng³⁰, A.B. Fenyuk¹²⁸, J. Ferencei^{144b}, J. Ferland⁹³, W. Fernando¹⁰⁹, S. Ferrag⁵³, J. Ferrando⁵³,
 V. Ferrara⁴¹, A. Ferrari¹⁶⁶, P. Ferrari¹⁰⁵, R. Ferrari^{119a}, A. Ferrer¹⁶⁷, M.L. Ferrer⁴⁷, D. Ferrere⁴⁹,
 C. Ferretti⁸⁷, A. Ferretto Parodi^{50a,50b}, M. Fiascaris³⁰, F. Fiedler⁸¹, A. Filipčič⁷⁴, A. Filippas⁹,
 F. Filthaut¹⁰⁴, M. Fincke-Keeler¹⁶⁹, M.C.N. Fiolhais^{124a,h}, L. Fiorini¹⁶⁷, A. Firan³⁹, G. Fischer⁴¹,
 P. Fischer²⁰, M.J. Fisher¹⁰⁹, S.M. Fisher¹²⁹, M. Flechl⁴⁸, I. Fleck¹⁴¹, J. Fleckner⁸¹, P. Fleischmann¹⁷³,
 S. Fleischmann¹⁷⁴, T. Flick¹⁷⁴, L.R. Flores Castillo¹⁷², M.J. Flowerdew⁹⁹, F. Föhlich^{58a}, M. Fokitis⁹,
 T. Fonseca Martin¹⁶, D.A. Forbush¹³⁸, A. Formica¹³⁶, A. Forti⁸², D. Fortin^{159a}, J.M. Foster⁸²,
 D. Fournier¹¹⁵, A. Foussat²⁹, A.J. Fowler⁴⁴, K. Fowler¹³⁷, H. Fox⁷¹, P. Francavilla^{122a,122b},
 S. Franchino^{119a,119b}, D. Francis²⁹, T. Frank¹⁷¹, M. Franklin⁵⁷, S. Franz²⁹, M. Fraternali^{119a,119b},

S. Fratina¹²⁰, S.T. French²⁷, R. Froeschl²⁹, D. Froidevaux²⁹, J.A. Frost²⁷, C. Fukunaga¹⁵⁶,
 E. Fullana Torregrosa²⁹, J. Fuster¹⁶⁷, C. Gabaldon²⁹, O. Gabizon¹⁷¹, T. Gadfort²⁴, S. Gadomski⁴⁹,
 G. Gagliardi^{50a,50b}, P. Gagnon⁶¹, C. Galea⁹⁸, E.J. Gallas¹¹⁸, M.V. Gallas²⁹, V. Gallo¹⁶, B.J. Gallop¹²⁹,
 P. Gallus¹²⁵, E. Galyaev⁴⁰, K.K. Gan¹⁰⁹, Y.S. Gao^{143,f}, V.A. Gapienko¹²⁸, A. Gaponenko¹⁴,
 F. Garberon¹⁷⁵, M. Garcia-Sciveres¹⁴, C. García¹⁶⁷, J.E. García Navarro⁴⁹, R.W. Gardner³⁰, N. Garelli²⁹,
 H. Garitaonandia¹⁰⁵, V. Garonne²⁹, J. Garvey¹⁷, C. Gatti⁴⁷, G. Gaudio^{119a}, O. Gaumer⁴⁹, B. Gaur¹⁴¹,
 L. Gauthier¹³⁶, I.L. Gavrilenko⁹⁴, C. Gay¹⁶⁸, G. Gaycken²⁰, J.-C. Gayde²⁹, E.N. Gazis⁹, P. Ge^{32d},
 C.N.P. Gee¹²⁹, D.A.A. Geerts¹⁰⁵, Ch. Geich-Gimbel²⁰, K. Gellerstedt^{146a,146b}, C. Gemme^{50a},
 A. Gemmell⁵³, M.H. Genest⁹⁸, S. Gentile^{132a,132b}, M. George⁵⁴, S. George⁷⁶, P. Gerlach¹⁷⁴,
 A. Gershon¹⁵³, C. Geweniger^{58a}, H. Ghazlane^{135b}, P. Ghez⁴, N. Ghodbane³³, B. Giacobbe^{19a},
 S. Giagu^{132a,132b}, V. Giakoumopoulou⁸, V.angiobbe^{122a,122b}, F. Gianotti²⁹, B. Gibbard²⁴, A. Gibson¹⁵⁸,
 S.M. Gibson²⁹, L.M. Gilbert¹¹⁸, M. Gilchriese¹⁴, V. Gilewsky⁹¹, D. Gillberg²⁸, A.R. Gillman¹²⁹,
 D.M. Gingrich^{2,e}, J. Ginzburg¹⁵³, N. Giokaris⁸, R. Giordano^{102a,102b}, F.M. Giorgi¹⁵, P. Giovannini⁹⁹,
 P.F. Giraud¹³⁶, D. Giugni^{89a}, M. Giunta^{132a,132b}, P. Giusti^{19a}, B.K. Gjelsten¹¹⁷, L.K. Gladilin⁹⁷,
 C. Glasman⁸⁰, J. Glatzer⁴⁸, A. Glazov⁴¹, K.W. Glitza¹⁷⁴, G.L. Glonti⁶⁵, J. Godfrey¹⁴², J. Godlewski²⁹,
 M. Goebel⁴¹, T. Göpfert⁴³, C. Goeringer⁸¹, C. Gössling⁴², T. Göttfert⁹⁹, S. Goldfarb⁸⁷, D. Goldin³⁹,
 T. Golling¹⁷⁵, S.N. Golovnia¹²⁸, A. Gomes^{124a,b}, L.S. Gomez Fajardo⁴¹, R. Gonçalo⁷⁶,
 J. Goncalves Pinto Firmino Da Costa⁴¹, L. Gonella²⁰, A. Gonidec²⁹, S. Gonzalez¹⁷²,
 S. González de la Hoz¹⁶⁷, M.L. Gonzalez Silva²⁶, S. Gonzalez-Sevilla⁴⁹, J.J. Goodson¹⁴⁸, L. Goossens²⁹,
 P.A. Gorbounov⁹⁵, H.A. Gordon²⁴, I. Gorelov¹⁰³, G. Gorfine¹⁷⁴, B. Gorini²⁹, E. Gorini^{72a,72b},
 A. Gorišek⁷⁴, E. Gornicki³⁸, S.A. Gorokhov¹²⁸, V.N. Goryachev¹²⁸, B. Gosdzik⁴¹, M. Gosselink¹⁰⁵,
 M.I. Gostkin⁶⁵, M. Gouanère⁴, I. Gough Eschrich¹⁶³, M. Gouighri^{135a}, D. Goujdami^{135c}, M.P. Goulette⁴⁹,
 A.G. Goussiou¹³⁸, C. Goy⁴, I. Grabowska-Bold^{163,g}, V. Grabski¹⁷⁶, P. Grafström²⁹, C. Grah¹⁷⁴,
 K.-J. Grah⁴¹, F. Grancagnolo^{72a}, S. Grancagnolo¹⁵, V. Grassi¹⁴⁸, V. Gratchev¹²¹, N. Grau³⁴, H.M. Gray²⁹,
 J.A. Gray¹⁴⁸, E. Graziani^{134a}, O.G. Grebenyuk¹²¹, D. Greenfield¹²⁹, T. Greenshaw⁷³, Z.D. Greenwood^{24,i},
 I.M. Gregor⁴¹, P. Grenier¹⁴³, J. Griffiths¹³⁸, N. Grigalashvili⁶⁵, A.A. Grillo¹³⁷, S. Grinstein¹¹,
 Y.V. Grishkevich⁹⁷, J.-F. Grivaz¹¹⁵, J. Grognuz²⁹, M. Groh⁹⁹, E. Gross¹⁷¹, J. Grosse-Knetter⁵⁴,
 J. Groth-Jensen¹⁷¹, K. Grybel¹⁴¹, V.J. Guarino⁵, D. Guest¹⁷⁵, C. Guicheney³³, A. Guida^{72a,72b},
 T. Guillemin⁴, S. Guindon⁵⁴, H. Guler^{85,m}, J. Gunther¹²⁵, B. Guo¹⁵⁸, J. Guo³⁴, A. Gupta³⁰, Y. Gusakov⁶⁵,
 V.N. Gushchin¹²⁸, A. Gutierrez⁹³, P. Gutierrez¹¹¹, N. Guttman¹⁵³, O. Gutzwiller¹⁷², C. Guyot¹³⁶,
 C. Gwenlan¹¹⁸, C.B. Gwilliam⁷³, A. Haas¹⁴³, S. Haas²⁹, C. Haber¹⁴, R. Hackenberg²⁴, H.K. Hadavand³⁹,
 D.R. Hadley¹⁷, P. Haefner⁹⁹, F. Hahn²⁹, S. Haider²⁹, Z. Hajduk³⁸, H. Hakobyan¹⁷⁶, J. Haller⁵⁴,
 K. Hamacher¹⁷⁴, P. Hamal¹¹³, A. Hamilton⁴⁹, S. Hamilton¹⁶¹, H. Han^{32a}, L. Han^{32b}, K. Hanagaki¹¹⁶,
 M. Hance¹²⁰, C. Handel⁸¹, P. Hanke^{58a}, J.R. Hansen³⁵, J.B. Hansen³⁵, J.D. Hansen³⁵, P.H. Hansen³⁵,
 P. Hansson¹⁴³, K. Hara¹⁶⁰, G.A. Hare¹³⁷, T. Harenberg¹⁷⁴, S. Harkusha⁹⁰, D. Harper⁸⁷,
 R.D. Harrington²¹, O.M. Harris¹³⁸, K. Harrison¹⁷, J. Hartert⁴⁸, F. Hartjes¹⁰⁵, T. Haruyama⁶⁶, A. Harvey⁵⁶,
 S. Hasegawa¹⁰¹, Y. Hasegawa¹⁴⁰, S. Hassani¹³⁶, M. Hatch²⁹, D. Hauff⁹⁹, S. Haug¹⁶, M. Hauschild²⁹,
 R. Hauser⁸⁸, M. Havranek²⁰, B.M. Hawes¹¹⁸, C.M. Hawkes¹⁷, R.J. Hawkings²⁹, D. Hawkins¹⁶³,
 T. Hayakawa⁶⁷, D. Hayden⁷⁶, H.S. Hayward⁷³, S.J. Haywood¹²⁹, E. Hazen²¹, M. He^{32d}, S.J. Head¹⁷,
 V. Hedberg⁷⁹, L. Heelan⁷, S. Heim⁸⁸, B. Heinemann¹⁴, S. Heisterkamp³⁵, L. Helary⁴, M. Heller¹¹⁵,
 S. Hellman^{146a,146b}, C. Hensens¹¹, R.C.W. Henderson⁷¹, M. Henke^{58a}, A. Henrichs⁵⁴,
 A.M. Henriques Correia²⁹, S. Henrot-Versille¹¹⁵, F. Henry-Couannier⁸³, C. Hensel⁵⁴, T. Henß¹⁷⁴,
 C.M. Hernandez⁷, Y. Hernández Jiménez¹⁶⁷, R. Herrberg¹⁵, A.D. Hershenhorn¹⁵², G. Herten⁴⁸,
 R. Hertenberger⁹⁸, L. Hervas²⁹, N.P. Hessey¹⁰⁵, A. Hidvegi^{146a}, E. Higón-Rodríguez¹⁶⁷, D. Hill^{5,*},
 J.C. Hill²⁷, N. Hill⁵, K.H. Hiller⁴¹, S. Hillert²⁰, S.J. Hillier¹⁷, I. Hinchliffe¹⁴, E. Hines¹²⁰, M. Hirose¹¹⁶,
 F. Hirsch⁴², D. Hirschbuehl¹⁷⁴, J. Hobbs¹⁴⁸, N. Hod¹⁵³, M.C. Hodgkinson¹³⁹, P. Hodgson¹³⁹,
 A. Hoecker²⁹, M.R. Hoferkamp¹⁰³, J. Hoffman³⁹, D. Hoffmann⁸³, M. Hohlfeld⁸¹, M. Holder¹⁴¹,
 A. Holmes¹¹⁸, S.O. Holmgren^{146a}, T. Holy¹²⁷, J.L. Holzbauer⁸⁸, Y. Homma⁶⁷, T.M. Hong¹²⁰,
 L. Hooft van Huysduynen¹⁰⁸, T. Horazdovsky¹²⁷, C. Horn¹⁴³, S. Horner⁴⁸, K. Horton¹¹⁸, J.-Y. Hostachy⁵⁵,
 S. Hou¹⁵¹, M.A. Houlden⁷³, A. Hoummada^{135a}, J. Howarth⁸², D.F. Howell¹¹⁸, I. Hristova⁴¹, J. Hrivnac¹¹⁵,
 I. Hruska¹²⁵, T. Hryn'ova⁴, P.J. Hsu¹⁷⁵, S.-C. Hsu¹⁴, G.S. Huang¹¹¹, Z. Hubacek¹²⁷, F. Hubaut⁸³,
 F. Huegging²⁰, T.B. Huffman¹¹⁸, E.W. Hughes³⁴, G. Hughes⁷¹, R.E. Hughes-Jones⁸², M. Huhtinen²⁹,

P. Hurst⁵⁷, M. Hurwitz¹⁴, U. Husemann⁴¹, N. Huseynov^{65,n}, J. Huston⁸⁸, J. Huth⁵⁷, G. Iacobucci⁴⁹,
 G. Iakovidis⁹, M. Ibbotson⁸², I. Ibragimov¹⁴¹, R. Ichimiya⁶⁷, L. Iconomidou-Fayard¹¹⁵, J. Idarraga¹¹⁵,
 M. Idzik³⁷, P. Iengo^{102a,102b}, O. Igonkina¹⁰⁵, Y. Ikegami⁶⁶, M. Ikeno⁶⁶, Y. Ilchenko³⁹, D. Iliadis¹⁵⁴,
 D. Imbault⁷⁸, M. Imhaeuser¹⁷⁴, M. Imori¹⁵⁵, T. Ince²⁰, J. Inigo-Golfín²⁹, P. Ioannou⁸, M. Iodice^{134a},
 G. Ionescu⁴, A. Irlles Quiles¹⁶⁷, K. Ishii⁶⁶, A. Ishikawa⁶⁷, M. Ishino⁶⁶, R. Ishmukhametov³⁹, C. Issever¹¹⁸,
 S. Istin^{18a}, Y. Itoh¹⁰¹, A.V. Ivashin¹²⁸, W. Iwanski³⁸, H. Iwasaki⁶⁶, J.M. Izen⁴⁰, V. Izzo^{102a}, B. Jackson¹²⁰,
 J.N. Jackson⁷³, P. Jackson¹⁴³, M.R. Jaekel²⁹, V. Jain⁶¹, K. Jakobs⁴⁸, S. Jakobsen³⁵, J. Jakubek¹²⁷,
 D.K. Jana¹¹¹, E. Jankowski¹⁵⁸, E. Jansen⁷⁷, A. Jantsch⁹⁹, M. Janus²⁰, G. Jarlskog⁷⁹, L. Jeanty⁵⁷,
 K. Jelen³⁷, I. Jen-La Plante³⁰, P. Jenni²⁹, A. Jeremie⁴, P. Jež³⁵, S. Jézéquel⁴, M.K. Jha^{19a}, H. Ji¹⁷², W. Ji⁸¹,
 J. Jia¹⁴⁸, Y. Jiang^{32b}, M. Jimenez Belenguer⁴¹, G. Jin^{32b}, S. Jin^{32a}, O. Jinnouchi¹⁵⁷, M.D. Joergensen³⁵,
 D. Joffe³⁹, L.G. Johansen¹³, M. Johansen^{146a,146b}, K.E. Johansson^{146a}, P. Johansson¹³⁹, S. Johnert⁴¹,
 K.A. Johns⁶, K. Jon-And^{146a,146b}, G. Jones⁸², R.W.L. Jones⁷¹, T.W. Jones⁷⁷, T.J. Jones⁷³, O. Jonsson²⁹,
 C. Joram²⁹, P.M. Jorge^{124a,b}, J. Joseph¹⁴, T. Jovin^{12b}, X. Ju¹³⁰, V. Juranek¹²⁵, P. Jussel⁶²,
 V.V. Kabachenko¹²⁸, S. Kabana¹⁶, M. Kaci¹⁶⁷, A. Kaczmarek³⁸, P. Kadlecik³⁵, M. Kado¹¹⁵, H. Kagan¹⁰⁹,
 M. Kagan⁵⁷, S. Kaiser⁹⁹, E. Kajomovitz¹⁵², S. Kalinin¹⁷⁴, L.V. Kalinovskaya⁶⁵, S. Kama³⁹, N. Kanaya¹⁵⁵,
 M. Kaneda²⁹, T. Kanno¹⁵⁷, V.A. Kantserov⁹⁶, J. Kanzaki⁶⁶, B. Kaplan¹⁷⁵, A. Kapliy³⁰, J. Kaplon²⁹,
 D. Kar⁴³, M. Karagoz¹¹⁸, M. Karnevskiy⁴¹, K. Karr⁵, V. Kartvelishvili⁷¹, A.N. Karyukhin¹²⁸, L. Kashif¹⁷²,
 A. Kasmi³⁹, R.D. Kass¹⁰⁹, A. Kastanas¹³, M. Kataoka⁴, Y. Kataoka¹⁵⁵, E. Katsoufis⁹, J. Katzy⁴¹,
 V. Kaushik⁶, K. Kawagoe⁶⁷, T. Kawamoto¹⁵⁵, G. Kawamura⁸¹, M.S. Kayl¹⁰⁵, V.A. Kazanin¹⁰⁷,
 M.Y. Kazarinov⁶⁵, J.R. Keates⁸², R. Keeler¹⁶⁹, R. Kehoe³⁹, M. Keil⁵⁴, G.D. Kekelidze⁶⁵, M. Kelly⁸²,
 J. Kennedy⁹⁸, C.J. Kenney¹⁴³, M. Kenyon⁵³, O. Kepka¹²⁵, N. Kerschen²⁹, B.P. Kerševan⁷⁴, S. Kersten¹⁷⁴,
 K. Kessoku¹⁵⁵, C. Ketterer⁴⁸, J. Keung¹⁵⁸, M. Khakzad²⁸, F. Khalil-zada¹⁰, H. Khandanyan¹⁶⁵,
 A. Khanov¹¹², D. Kharchenko⁶⁵, A. Khodinov⁹⁶, A.G. Kholodenko¹²⁸, A. Khomich^{58a}, T.J. Khoo²⁷,
 G. Khoraiuli²⁰, A. Khoroshilov¹⁷⁴, N. Khovanskiy⁶⁵, V. Khovanskiy⁹⁵, E. Khramov⁶⁵, J. Khubua⁵¹,
 H. Kim⁷, M.S. Kim², P.C. Kim¹⁴³, S.H. Kim¹⁶⁰, N. Kimura¹⁷⁰, O. Kind¹⁵, B.T. King⁷³, M. King⁶⁷,
 R.S.B. King¹¹⁸, J. Kirk¹²⁹, G.P. Kirsch¹¹⁸, L.E. Kirsch²², A.E. Kiryunin⁹⁹, D. Kisielowska³⁷,
 T. Kittelmann¹²³, A.M. Kiver¹²⁸, H. Kiyamura⁶⁷, E. Kladiva^{144b}, J. Klaiber-Lodewigs⁴², M. Klein⁷³,
 U. Klein⁷³, K. Kleinknecht⁸¹, M. Klemetti⁸⁵, A. Klier¹⁷¹, A. Klimentov²⁴, R. Klingenberg⁴²,
 E.B. Klinkby³⁵, T. Klioutchnikova²⁹, P.F. Klok¹⁰⁴, S. Klous¹⁰⁵, E.-E. Kluge^{58a}, T. Kluge⁷³, P. Kluit¹⁰⁵,
 S. Kluth⁹⁹, E. Kneringer⁶², J. Knobloch²⁹, E.B.F.G. Knoops⁸³, A. Knue⁵⁴, B.R. Ko⁴⁴, T. Kobayashi¹⁵⁵,
 M. Kobel⁴³, M. Kocian¹⁴³, A. Kocnar¹¹³, P. Kodys¹²⁶, K. Köneke²⁹, A.C. König¹⁰⁴, S. Koenig⁸¹,
 L. Köpke⁸¹, F. Koetsveld¹⁰⁴, P. Koevesarki²⁰, T. Koffas²⁹, E. Koffeman¹⁰⁵, F. Kohn⁵⁴, Z. Kohout¹²⁷,
 T. Kohriki⁶⁶, T. Koi¹⁴³, T. Kokott²⁰, G.M. Kolachev¹⁰⁷, H. Kolanoski¹⁵, V. Kolesnikov⁶⁵, I. Koletsou^{89a},
 J. Koll⁸⁸, D. Kollar²⁹, M. Kollefrath⁴⁸, S.D. Kolya⁸², A.A. Komar⁹⁴, J.R. Komaragiri¹⁴², Y. Komori¹⁵⁵,
 T. Kondo⁶⁶, T. Kono^{41,o}, A.I. Kononov⁴⁸, R. Konoplich^{108,p}, N. Konstantinidis⁷⁷, A. Kootz¹⁷⁴,
 S. Koperny³⁷, S.V. Kopikov¹²⁸, K. Korcyl³⁸, K. Kordas¹⁵⁴, V. Koreshev¹²⁸, A. Korn¹⁴, A. Korol¹⁰⁷,
 I. Korolkov¹¹, E.V. Korolkova¹³⁹, V.A. Korotkov¹²⁸, O. Kortner⁹⁹, S. Kortner⁹⁹, V.V. Kostyukhin²⁰,
 M.J. Kotamäki²⁹, S. Kotov⁹⁹, V.M. Kotov⁶⁵, A. Kotwal⁴⁴, C. Kourkoumelis⁸, V. Kouskoura¹⁵⁴,
 A. Koutsman¹⁰⁵, R. Kowalewski¹⁶⁹, T.Z. Kowalski³⁷, W. Kozanecki¹³⁶, A.S. Kozhin¹²⁸, V. Kral¹²⁷,
 V.A. Kramarenko⁹⁷, G. Kramberger⁷⁴, O. Krasel⁴², M.W. Krasny⁷⁸, A. Krasznahorkay¹⁰⁸, J. Kraus⁸⁸,
 A. Kreisel¹⁵³, F. Krejci¹²⁷, J. Kretzschmar⁷³, N. Krieger⁵⁴, P. Krieger¹⁵⁸, K. Kroeninger⁵⁴, H. Kroha⁹⁹,
 J. Kroll¹²⁰, J. Kroseberg²⁰, J. Krstic^{12a}, U. Kruchonak⁶⁵, H. Krüger²⁰, T. Kruker¹⁶, Z.V. Krumshteyn⁶⁵,
 A. Kruth²⁰, T. Kubota⁸⁶, S. Kuehn⁴⁸, A. Kugel^{58c}, T. Kuhl¹⁷⁴, D. Kuhn⁶², V. Kukhtin⁶⁵, Y. Kulchitsky⁹⁰,
 S. Kuleshov^{31b}, C. Kummer⁹⁸, M. Kuna⁷⁸, N. Kundu¹¹⁸, J. Kunkle¹²⁰, A. Kupco¹²⁵, H. Kurashige⁶⁷,
 M. Kurata¹⁶⁰, Y.A. Kurochkin⁹⁰, V. Kus¹²⁵, W. Kuykendall¹³⁸, M. Kuze¹⁵⁷, P. Kuzhir⁹¹, O. Kvasnicka¹²⁵,
 J. Kvita²⁹, R. Kwee¹⁵, A. La Rosa¹⁷², L. La Rotonda^{36a,36b}, L. Labarga⁸⁰, J. Labbe⁴, S. Lablak^{135a},
 C. Lacasta¹⁶⁷, F. Lacava^{132a,132b}, H. Lacker¹⁵, D. Lacour⁷⁸, V.R. Lacuesta¹⁶⁷, E. Ladygin⁶⁵, R. Lafaye⁴,
 B. Laforge⁷⁸, T. Lagouri⁸⁰, S. Lai⁴⁸, E. Laisne⁵⁵, M. Lamanna²⁹, C.L. Lampen⁶, W. Lampl⁶, E. Lancon¹³⁶,
 U. Landgraf⁴⁸, M.P.J. Landon⁷⁵, H. Landsman¹⁵², J.L. Lane⁸², C. Lange⁴¹, A.J. Lankford¹⁶³, F. Lanni²⁴,
 K. Lantsch²⁹, S. Laplace⁷⁸, C. Lapoire²⁰, J.F. Laporte¹³⁶, T. Lari^{89a}, A.V. Larionov¹²⁸, A. Larner¹¹⁸,
 C. Lasseur²⁹, M. Lassnig²⁹, W. Lau¹¹⁸, P. Laurelli⁴⁷, A. Lavorato¹¹⁸, W. Lavrijsen¹⁴, P. Laycock⁷³,
 A.B. Lazarev⁶⁵, A. Lazzaro^{89a,89b}, O. Le Dortz⁷⁸, E. Le Guirriec⁸³, C. Le Maner¹⁵⁸, E. Le Menedeu¹³⁶,

C. Lebel⁹³, T. LeCompte⁵, F. Ledroit-Guillon⁵⁵, H. Lee¹⁰⁵, J.S.H. Lee¹⁵⁰, S.C. Lee¹⁵¹, L. Lee¹⁷⁵,
 M. Lefebvre¹⁶⁹, M. Legendre¹³⁶, A. Leger⁴⁹, B.C. LeGeyt¹²⁰, F. Legger⁹⁸, C. Leggett¹⁴, M. Lehmacher²⁰,
 G. Lehmann Miotto²⁹, X. Lei⁶, M.A.L. Leite^{23b}, R. Leitner¹²⁶, D. Lellouch¹⁷¹, J. Lellouch⁷⁸,
 M. Leltchouk³⁴, V. Lendermann^{58a}, K.J.C. Leney^{145b}, T. Lenz¹⁷⁴, G. Lenzen¹⁷⁴, B. Lenzi²⁹,
 K. Leonhardt⁴³, S. Leontsinis⁹, C. Leroy⁹³, J.-R. Lessard¹⁶⁹, J. Lesser^{146a}, C.G. Lester²⁷,
 A. Leung Fook Cheong¹⁷², J. Levêque⁴, D. Levin⁸⁷, L.J. Levinson¹⁷¹, M.S. Levitski¹²⁸, M. Lewandowska²¹,
 A. Lewis¹¹⁸, G.H. Lewis¹⁰⁸, A.M. Leyko²⁰, M. Leyton¹⁵, B. Li⁸³, H. Li¹⁷², S. Li^{32b,d}, X. Li⁸⁷, Z. Liang³⁹,
 Z. Liang^{118,q}, B. Liberti^{133a}, P. Lichard²⁹, M. Lichtnecker⁹⁸, K. Lie¹⁶⁵, W. Liebig¹³, R. Lifshitz¹⁵²,
 J.N. Lilley¹⁷, C. Limbach²⁰, A. Limosani⁸⁶, M. Limper⁶³, S.C. Lin^{151,r}, F. Linde¹⁰⁵, J.T. Linnemann⁸⁸,
 E. Lipeles¹²⁰, L. Lipinsky¹²⁵, A. Lipniacka¹³, T.M. Liss¹⁶⁵, D. Lissauer²⁴, A. Lister⁴⁹, A.M. Litke¹³⁷,
 C. Liu²⁸, D. Liu^{151,s}, H. Liu⁸⁷, J.B. Liu⁸⁷, M. Liu^{32b}, S. Liu², Y. Liu^{32b}, M. Livan^{119a,119b},
 S.S.A. Livermore¹¹⁸, A. Lleres⁵⁵, J. Llorente Merino⁸⁰, S.L. Lloyd⁷⁵, E. Lobodzinska⁴¹, P. Loch⁶,
 W.S. Lockman¹³⁷, S. Lockwitz¹⁷⁵, T. Loddenkoetter²⁰, F.K. Loebinger⁸², A. Loginov¹⁷⁵, C.W. Loh¹⁶⁸,
 T. Lohse¹⁵, K. Lohwasser⁴⁸, M. Lokajicek¹²⁵, J. Loken¹¹⁸, V.P. Lombardo⁴, R.E. Long⁷¹, L. Lopes^{124a,b},
 D. Lopez Mateos^{34,t}, M. Losada¹⁶², P. Loscutoff¹⁴, F. Lo Sterzo^{132a,132b}, M.J. Losty^{159a}, X. Lou⁴⁰,
 A. Lounis¹¹⁵, K.F. Loureiro¹⁶², J. Love²¹, P.A. Love⁷¹, A.J. Lowe^{143,f}, F. Lu^{32a}, H.J. Lubatti¹³⁸,
 C. Luci^{132a,132b}, A. Lucotte⁵⁵, A. Ludwig⁴³, D. Ludwig⁴¹, I. Ludwig⁴⁸, J. Ludwig⁴⁸, F. Luehring⁶¹,
 G. Luijckx¹⁰⁵, D. Lumb⁴⁸, L. Luminari^{132a}, E. Lund¹¹⁷, B. Lund-Jensen¹⁴⁷, B. Lundberg⁷⁹,
 J. Lundberg^{146a,146b}, J. Lundquist³⁵, M. Lungwitz⁸¹, A. Lupi^{122a,122b}, G. Lutz⁹⁹, D. Lynn²⁴, J. Lys¹⁴,
 E. Lytken⁷⁹, H. Ma²⁴, L.L. Ma¹⁷², J.A. Macana Goia⁹³, G. Maccarrone⁴⁷, A. Macchiolo⁹⁹, B. Maček⁷⁴,
 J. Machado Miguens^{124a}, D. Macina⁴⁹, R. Mackeprang³⁵, R.J. Madaras¹⁴, W.F. Mader⁴³, R. Maenner^{58c},
 T. Maeno²⁴, P. Mättig¹⁷⁴, S. Mättig⁴¹, P.J. Magalhaes Martins^{124a,h}, L. Magnoni²⁹, E. Magradze⁵⁴,
 Y. Mahalalel¹⁵³, K. Mahboubi⁴⁸, G. Mahout¹⁷, C. Maiani^{132a,132b}, C. Maidantchik^{23a}, A. Maio^{124a,b},
 S. Majewski²⁴, Y. Makida⁶⁶, N. Makovec¹¹⁵, P. Mal⁶, Pa. Malecki³⁸, P. Malecki³⁸, V.P. Maleev¹²¹,
 F. Malek⁵⁵, U. Mallik⁶³, D. Malon⁵, S. Maltezos⁹, V. Malyshev¹⁰⁷, S. Malyukov²⁹, R. Mameghani⁹⁸,
 J. Mamuzic^{12b}, A. Manabe⁶⁶, L. Mandelli^{89a}, I. Mandić⁷⁴, R. Mandrysch¹⁵, J. Maneira^{124a},
 P.S. Mangeard⁸⁸, I.D. Manjavidze⁶⁵, A. Mann⁵⁴, P.M. Manning¹³⁷, A. Manousakis-Katsikakis⁸,
 B. Mansoulie¹³⁶, A. Manz⁹⁹, A. Mapelli²⁹, L. Mapelli²⁹, L. March⁸⁰, J.F. Marchand²⁹,
 F. Marchese^{133a,133b}, G. Marchiori⁷⁸, M. Marcisovsky¹²⁵, A. Marin^{21,*}, C.P. Marino⁶¹, F. Marroquim^{23a},
 R. Marshall⁸², Z. Marshall²⁹, F.K. Martens¹⁵⁸, S. Marti-Garcia¹⁶⁷, A.J. Martin¹⁷⁵, B. Martin²⁹,
 B. Martin⁸⁸, F.F. Martin¹²⁰, J.P. Martin⁹³, Ph. Martin⁵⁵, T.A. Martin¹⁷, B. Martin dit Latour⁴⁹,
 M. Martinez¹¹, V. Martinez Outschoorn⁵⁷, A.C. Martyniuk⁸², M. Marx⁸², F. Marzano^{132a}, A. Marzin¹¹¹,
 L. Masetti⁸¹, T. Mashimo¹⁵⁵, R. Mashinistov⁹⁴, J. Masik⁸², A.L. Maslennikov¹⁰⁷, M. Maß⁴²,
 I. Massa^{19a,19b}, G. Massaro¹⁰⁵, N. Massol⁴, P. Mastrandrea^{132a,132b}, A. Mastroberardino^{36a,36b},
 T. Masubuchi¹⁵⁵, M. Mathes²⁰, P. Matricon¹¹⁵, H. Matsumoto¹⁵⁵, H. Matsunaga¹⁵⁵, T. Matsushita⁶⁷,
 C. Mattraversi^{118,c}, J.M. Maugain²⁹, S.J. Maxfield⁷³, D.A. Maximov¹⁰⁷, E.N. May⁵, A. Mayne¹³⁹,
 R. Mazini¹⁵¹, M. Mazur²⁰, M. Mazzanti^{89a}, E. Mazzoni^{122a,122b}, S.P. Mc Kee⁸⁷, A. McCarn¹⁶⁵,
 R.L. McCarthy¹⁴⁸, T.G. McCarthy²⁸, N.A. McCubbin¹²⁹, K.W. McFarlane⁵⁶, J.A. McFayden¹³⁹,
 H. McGlone⁵³, G. Mchedlidze⁵¹, R.A. McLaren²⁹, T. Mclaughlan¹⁷, S.J. McMahon¹²⁹,
 R.A. McPherson^{169,j}, A. Meade⁸⁴, J. Mechnich¹⁰⁵, M. Mechtel¹⁷⁴, M. Medinnis⁴¹, R. Meera-Lebbai¹¹¹,
 T. Meguro¹¹⁶, R. Mehdiyev⁹³, S. Mehlhase³⁵, A. Mehta⁷³, K. Meier^{58a}, J. Meinhardt⁴⁸, B. Meirose⁷⁹,
 C. Melachrinou³⁰, B.R. Mellado Garcia¹⁷², L. Mendoza Navas¹⁶², Z. Meng^{151,s}, A. Mengarelli^{19a,19b},
 S. Menke⁹⁹, C. Menot²⁹, E. Meoni¹¹, K.M. Mercurio⁵⁷, P. Mermoud¹¹⁸, L. Merola^{102a,102b}, C. Meroni^{89a},
 F.S. Merritt³⁰, A. Messina²⁹, J. Metcalfe¹⁰³, A.S. Mete⁶⁴, S. Meuser²⁰, C. Meyer⁸¹, J.-P. Meyer¹³⁶,
 J. Meyer¹⁷³, J. Meyer⁵⁴, T.C. Meyer²⁹, W.T. Meyer⁶⁴, J. Miao^{32d}, S. Michal²⁹, L. Micu^{25a},
 R.P. Middleton¹²⁹, P. Miele²⁹, S. Migas⁷³, L. Mijović⁴¹, G. Mikenberg¹⁷¹, M. Mikestikova¹²⁵,
 M. Mikuž⁷⁴, D.W. Miller¹⁴³, R.J. Miller⁸⁸, W.J. Mills¹⁶⁸, C. Mills⁵⁷, A. Milov¹⁷¹, D.A. Milstead^{146a,146b},
 D. Milstein¹⁷¹, A.A. Minaenko¹²⁸, M. Miñano¹⁶⁷, I.A. Minashvili⁶⁵, A.I. Mincer¹⁰⁸, B. Mindur³⁷,
 M. Mineev⁶⁵, Y. Ming¹³⁰, L.M. Mir¹¹, G. Mirabelli^{132a}, L. Miralles Verge¹¹, A. Misiejuk⁷⁶,
 J. Mitrevski¹³⁷, G.Y. Mitrofanov¹²⁸, V.A. Mitsou¹⁶⁷, S. Mitsui⁶⁶, P.S. Miyagawa⁸², K. Miyazaki⁶⁷,
 J.U. Mjörnmark⁷⁹, T. Moa^{146a,146b}, P. Mockett¹³⁸, S. Moed⁵⁷, V. Moeller²⁷, K. Mönig⁴¹, N. Möser²⁰,
 S. Mohapatra¹⁴⁸, B. Mohn¹³, W. Mohr⁴⁸, S. Mohrdieck-Möck⁹⁹, A.M. Moiseev^{128,*}, R. Moles-Valls¹⁶⁷,

J. Molina-Perez²⁹, J. Monk⁷⁷, E. Monnier⁸³, S. Montesano^{89a,89b}, F. Monticelli⁷⁰, S. Monzani^{19a,19b},
 R.W. Moore², G.F. Moorhead⁸⁶, C. Mora Herrera⁴⁹, A. Moraes⁵³, A. Morais^{124a,b}, N. Morange¹³⁶,
 J. Morel⁵⁴, G. Morello^{36a,36b}, D. Moreno⁸¹, M. Moreno Llácer¹⁶⁷, P. Morettini^{50a}, M. Morii⁵⁷, J. Morin⁷⁵,
 Y. Morita⁶⁶, A.K. Morley²⁹, G. Mornacchi²⁹, M.-C. Morone⁴⁹, S.V. Morozov⁹⁶, J.D. Morris⁷⁵,
 L. Morvaj¹⁰¹, H.G. Moser⁹⁹, M. Mosidze⁵¹, J. Moss¹⁰⁹, R. Mount¹⁴³, E. Mountricha¹³⁶, S.V. Mouraviev⁹⁴,
 E.J.W. Moyse⁸⁴, M. Mudrinic^{12b}, F. Mueller^{58a}, J. Mueller¹²³, K. Mueller²⁰, T.A. Müller⁹⁸,
 D. Muenstermann²⁹, A. Muijs¹⁰⁵, A. Muir¹⁶⁸, Y. Munwes¹⁵³, K. Murakami⁶⁶, W.J. Murray¹²⁹,
 I. Mussche¹⁰⁵, E. Musto^{102a,102b}, A.G. Myagkov¹²⁸, M. Myska¹²⁵, J. Nadal¹¹, K. Nagai¹⁶⁰, K. Nagano⁶⁶,
 Y. Nagasaka⁶⁰, A.M. Nairz²⁹, Y. Nakahama²⁹, K. Nakamura¹⁵⁵, I. Nakano¹¹⁰, G. Nanava²⁰, A. Napier¹⁶¹,
 M. Nash^{77,c}, N.R. Nation²¹, T. Nattermann²⁰, T. Naumann⁴¹, G. Navarro¹⁶², H.A. Neal⁸⁷, E. Nebot⁸⁰,
 P.Yu. Nechaeva⁹⁴, A. Negri^{119a,119b}, G. Negri²⁹, S. Nektarijevic⁴⁹, A. Nelson⁶⁴, S. Nelson¹⁴³,
 T.K. Nelson¹⁴³, S. Nemecek¹²⁵, P. Nemethy¹⁰⁸, A.A. Nepomuceno^{23a}, M. Nessi^{29,u}, S.Y. Nesterov¹²¹,
 M.S. Neubauer¹⁶⁵, A. Neusiedl⁸¹, R.M. Neves¹⁰⁸, P. Nevski²⁴, P.R. Newman¹⁷, R.B. Nickerson¹¹⁸,
 R. Nicolaidou¹³⁶, L. Nicolas¹³⁹, B. Nicquevert²⁹, F. Niedercorn¹¹⁵, J. Nielsen¹³⁷, T. Niinikoski²⁹,
 A. Nikiforov¹⁵, V. Nikolaenko¹²⁸, K. Nikolaev⁶⁵, I. Nikolic-Audit⁷⁸, K. Nikolics⁴⁹, K. Nikolopoulos²⁴,
 H. Nilsen⁴⁸, P. Nilsson⁷, Y. Ninomiya¹⁵⁵, A. Nisati^{132a}, T. Nishiyama⁶⁷, R. Nisius⁹⁹, L. Nodulman⁵,
 M. Nomachi¹¹⁶, I. Nomidis¹⁵⁴, M. Nordberg²⁹, B. Nordkvist^{146a,146b}, P.R. Norton¹²⁹, J. Novakova¹²⁶,
 M. Nozaki⁶⁶, M. Nožička⁴¹, L. Nozka¹¹³, I.M. Nugent^{159a}, A.-E. Nuncio-Quiroz²⁰, G. Nunes Hanninger⁸⁶,
 T. Nunnemann⁹⁸, E. Nurse⁷⁷, T. Nyman²⁹, B.J. O'Brien⁴⁵, S.W. O'Neale^{17,*}, D.C. O'Neil¹⁴², V. O'Shea⁵³,
 F.G. Oakham^{28,e}, H. Oberlack⁹⁹, J. Ocariz⁷⁸, A. Ochi⁶⁷, S. Oda¹⁵⁵, S. Odaka⁶⁶, J. Odier⁸³, H. Ogren⁶¹,
 A. Oh⁸², S.H. Oh⁴⁴, C.C. Ohm^{146a,146b}, T. Ohshima¹⁰¹, H. Ohshita¹⁴⁰, T.K. Ohska⁶⁶, T. Ohsugi⁵⁹,
 S. Okada⁶⁷, H. Okawa¹⁶³, Y. Okumura¹⁰¹, T. Okuyama¹⁵⁵, M. Olcese^{50a}, A.G. Olchevski⁶⁵,
 M. Oliveira^{124a,h}, D. Oliveira Damazio²⁴, E. Oliver Garcia¹⁶⁷, D. Olivito¹²⁰, A. Olszewski³⁸,
 J. Olszowska³⁸, C. Omachi⁶⁷, A. Onofre^{124a,v}, P.U.E. Onyisi³⁰, C.J. Oram^{159a}, M.J. Oreglia³⁰, Y. Oren¹⁵³,
 D. Orestano^{134a,134b}, I. Orlov¹⁰⁷, C. Oropeza Barrera⁵³, R.S. Orr¹⁵⁸, B. Osculati^{50a,50b}, R. Ospanov¹²⁰,
 C. Osuna¹¹, G. Otero y Garzon²⁶, J. P. Ottersbach¹⁰⁵, M. Ouchrif^{135d}, F. Ould-Saada¹¹⁷, A. Ouraou¹³⁶,
 Q. Ouyang^{32a}, M. Owen⁸², S. Owen¹³⁹, O.K. Øye¹³, V.E. Ozcan^{18a}, N. Ozturk⁷, A. Pacheco Pages¹¹,
 C. Padilla Aranda¹¹, S. Pagan Griso¹⁴, E. Paganis¹³⁹, F. Paige²⁴, K. Pajchel¹¹⁷, S. Palestini²⁹, D. Pallin³³,
 A. Palma^{124a,b}, J.D. Palmer¹⁷, Y.B. Pan¹⁷², E. Panagiotopoulou⁹, B. Panes^{31a}, N. Panikashvili⁸⁷,
 S. Panitkin²⁴, D. Pantea^{25a}, M. Panuskova¹²⁵, V. Paolone¹²³, A. Papadelis^{146a}, Th.D. Papadopoulou⁹,
 A. Paramonov⁵, W. Park^{24,w}, M.A. Parker²⁷, F. Parodi^{50a,50b}, J.A. Parsons³⁴, U. Parzefall⁴⁸,
 E. Pasqualucci^{132a}, A. Passeri^{134a}, F. Pastore^{134a,134b}, Fr. Pastore²⁹, G. Pásztor^{49,x}, S. Pataria¹⁷²,
 N. Patel¹⁵⁰, J.R. Pater⁸², S. Patricelli^{102a,102b}, T. Pauly²⁹, M. Pecsý^{144a}, M.I. Pedraza Morales¹⁷²,
 S.V. Peleganchuk¹⁰⁷, H. Peng¹⁷², R. Pengo²⁹, A. Penson³⁴, J. Penwell⁶¹, M. Perantoni^{23a}, K. Perez^{34,t},
 T. Perez Cavalcanti⁴¹, E. Perez Codina¹¹, M.T. Pérez García-Estañ¹⁶⁷, V. Perez Reale³⁴, L. Perini^{89a,89b},
 H. Pernegger²⁹, R. Perrino^{72a}, P. Perrodo⁴, S. Persema^{3a}, V.D. Peshekhonov⁶⁵, O. Peters¹⁰⁵,
 B.A. Petersen²⁹, J. Petersen²⁹, T.C. Petersen³⁵, E. Petit⁸³, A. Petridis¹⁵⁴, C. Petridou¹⁵⁴, E. Petrolu^{132a},
 F. Petrucci^{134a,134b}, D. Petschull⁴¹, M. Petteni¹⁴², R. Pezoa^{31b}, A. Phan⁸⁶, A.W. Phillips²⁷,
 P.W. Phillips¹²⁹, G. Piacquadio²⁹, E. Piccaro⁷⁵, M. Piccinini^{19a,19b}, A. Pickford⁵³, S.M. Piec⁴¹,
 R. Piegaia²⁶, J.E. Pilcher³⁰, A.D. Pilkington⁸², J. Pina^{124a,b}, M. Pinamonti^{164a,164c}, A. Pinder¹¹⁸,
 J.L. Pinfold², J. Ping^{32c}, B. Pinto^{124a,b}, O. Pirotte²⁹, C. Pizio^{89a,89b}, R. Placakyte⁴¹, M. Plamondon¹⁶⁹,
 W.G. Plano⁸², M.-A. Pleier²⁴, A.V. Pleskach¹²⁸, A. Poblaguev²⁴, S. Poddar^{58a}, F. Podlyski³³,
 L. Poggioli¹¹⁵, T. Poghosyan²⁰, M. Pohl⁴⁹, F. Polci⁵⁵, G. Polesello^{119a}, A. Policicchio¹³⁸, A. Polini^{19a},
 J. Poll⁷⁵, V. Polychronakos²⁴, D.M. Pomarede¹³⁶, D. Pomeroy²², K. Pommès²⁹, L. Pontecorvo^{132a},
 B.G. Pope⁸⁸, G.A. Popeneciu^{25a}, D.S. Popovic^{12a}, A. Poppleton²⁹, X. Portell Bueso⁴⁸, R. Porter¹⁶³,
 C. Posch²¹, G.E. Pospelov⁹⁹, S. Pospisil¹²⁷, I.N. Potrap⁹⁹, C.J. Potter¹⁴⁹, C.T. Potter¹¹⁴, G. Poulard²⁹,
 J. Poveda¹⁷², R. Prabhu⁷⁷, P. Pralavorio⁸³, S. Prasad⁵⁷, R. Pravahan⁷, S. Prell⁶⁴, K. Pretzl¹⁶, L. Pribyl²⁹,
 D. Price⁶¹, L.E. Price⁵, M.J. Price²⁹, P.M. Prichard⁷³, D. Prieur¹²³, M. Primavera^{72a}, K. Prokofiev¹⁰⁸,
 F. Prokoshin^{31b}, S. Protopopescu²⁴, J. Proudfoot⁵, X. Prudent⁴³, H. Przysiezniak⁴, S. Psoroulas²⁰,
 E. Ptacek¹¹⁴, J. Purdham⁸⁷, M. Purohit^{24,w}, P. Puzo¹¹⁵, Y. Pylypchenko¹¹⁷, J. Qian⁸⁷, Z. Qian⁸³, Z. Qin⁴¹,
 A. Quadt⁵⁴, D.R. Quarrie¹⁴, W.B. Quayle¹⁷², F. Quinonez^{31a}, M. Raas¹⁰⁴, V. Radescu^{58b}, B. Radics²⁰,
 T. Rador^{18a}, F. Ragusa^{89a,89b}, G. Rahal¹⁷⁷, A.M. Rahimi¹⁰⁹, D. Rahm²⁴, S. Rajagopalan²⁴,

M. Rammensee⁴⁸, M. Rammes¹⁴¹, M. Ramstedt^{146a,146b}, K. Randrianarivony²⁸, P.N. Ratoff⁷¹,
 F. Rauscher⁹⁸, E. Rauter⁹⁹, M. Raymond²⁹, A.L. Read¹¹⁷, D.M. Rebuffi^{119a,119b}, A. Redelbach¹⁷³,
 G. Redlinger²⁴, R. Reece¹²⁰, K. Reeves⁴⁰, A. Reichold¹⁰⁵, E. Reinherz-Aronis¹⁵³, A. Reinsch¹¹⁴,
 I. Reisinger⁴², D. Reljic^{12a}, C. Rembser²⁹, Z.L. Ren¹⁵¹, A. Renaud¹¹⁵, P. Renkel³⁹, M. Rescigno^{132a},
 S. Resconi^{89a}, B. Resende¹³⁶, P. Reznicek⁹⁸, R. Rezvani¹⁵⁸, A. Richards⁷⁷, R. Richter⁹⁹,
 E. Richter-Was^{38,y}, M. Ridel⁷⁸, S. Rieke⁸¹, M. Rijpstra¹⁰⁵, M. Rijssenbeek¹⁴⁸, A. Rimoldi^{119a,119b},
 L. Rinaldi^{19a}, R.R. Rios³⁹, I. Riu¹¹, G. Rivoltella^{89a,89b}, F. Rizatdinova¹¹², E. Rizvi⁷⁵, S.H. Robertson^{85,j},
 A. Robichaud-Veronneau⁴⁹, D. Robinson²⁷, J.E.M. Robinson⁷⁷, M. Robinson¹¹⁴, A. Robson⁵³,
 J.G. Rocha de Lima¹⁰⁶, C. Roda^{122a,122b}, D. Roda Dos Santos²⁹, S. Rodier⁸⁰, D. Rodriguez¹⁶²,
 Y. Rodriguez Garcia¹⁵, A. Roe⁵⁴, S. Roe²⁹, O. Røhne¹¹⁷, V. Rojo¹, S. Rolli¹⁶¹, A. Romaniouk⁹⁶,
 V.M. Romanov⁶⁵, G. Romeo²⁶, D. Romero Maltrana^{31a}, L. Roos⁷⁸, E. Ros¹⁶⁷, S. Rosati^{132a,132b},
 K. Rosbach⁴⁹, M. Rose⁷⁶, G.A. Rosenbaum¹⁵⁸, E.I. Rosenberg⁶⁴, P.L. Rosendahl¹³, L. Rosselet⁴⁹,
 V. Rossetti¹¹, E. Rossi^{102a,102b}, L.P. Rossi^{50a}, L. Rossi^{89a,89b}, M. Rotaru^{25a}, I. Roth¹⁷¹, J. Rothberg¹³⁸,
 D. Rousseau¹¹⁵, C.R. Royon¹³⁶, A. Rozanov⁸³, Y. Rozen¹⁵², X. Ruan¹¹⁵, I. Rubinskiy⁴¹, B. Ruckert⁹⁸,
 N. Ruckstuhl¹⁰⁵, V.I. Rud⁹⁷, C. Rudolph⁴³, G. Rudolph⁶², F. Rühr⁶, F. Ruggieri^{134a,134b},
 A. Ruiz-Martinez⁶⁴, E. Rulikowska-Zarebska³⁷, V. Rumiantsev^{91,*}, L. Romyantsev⁶⁵, K. Runge⁴⁸,
 O. Runolfsson²⁰, Z. Rurikova⁴⁸, N.A. Rusakovich⁶⁵, D.R. Rust⁶¹, J.P. Rutherford⁶, C. Ruwiedel¹⁴,
 P. Ruzicka¹²⁵, Y.F. Ryabov¹²¹, V. Ryadovikov¹²⁸, P. Ryan⁸⁸, M. Rybar¹²⁶, G. Rybkin¹¹⁵, N.C. Ryder¹¹⁸,
 S. Rzaeva¹⁰, A.F. Saavedra¹⁵⁰, I. Sadeh¹⁵³, H.F.-W. Sadrozinski¹³⁷, R. Sadykov⁶⁵, F. Safai Tehrani^{132a,132b},
 H. Sakamoto¹⁵⁵, G. Salamanna⁷⁵, A. Salamon^{133a}, M. Saleem¹¹¹, D. Salihagic⁹⁹, A. Salnikov¹⁴³,
 J. Salt¹⁶⁷, B.M. Salvachua Ferrando⁵, D. Salvatore^{36a,36b}, F. Salvatore¹⁴⁹, A. Salvucci¹⁰⁴, A. Salzburger²⁹,
 D. Sampsonidis¹⁵⁴, B.H. Samset¹¹⁷, A. Sanchez^{102a,102b}, H. Sandaker¹³, H.G. Sander⁸¹, M.P. Sanders⁹⁸,
 M. Sandhoff¹⁷⁴, T. Sandoval²⁷, R. Sandstroem⁹⁹, S. Sandvoss¹⁷⁴, D.P.C. Sankey¹²⁹, A. Sansoni⁴⁷,
 C. Santamarina Rios⁸⁵, C. Santoni³³, R. Santonico^{133a,133b}, H. Santos^{124a}, J.G. Saraiva^{124a,b}, T. Sarangi¹⁷²,
 E. Sarkisyan-Grinbaum⁷, F. Sarri^{122a,122b}, G. Sartisohn¹⁷⁴, O. Sasaki⁶⁶, T. Sasaki⁶⁶, N. Sasao⁶⁸,
 I. Satsounkevitch⁹⁰, G. Sauvage⁴, E. Sauvan⁴, J.B. Sauvan¹¹⁵, P. Savard^{158,e}, V. Savinov¹²³, D.O. Savu²⁹,
 P. Savva⁹, L. Sawyer^{24,l}, D.H. Saxon⁵³, L.P. Says³³, C. Sbarra^{19a,19b}, A. Sbrizzi^{19a,19b}, O. Scallon⁹³,
 D.A. Scannicchio¹⁶³, J. Schaarschmidt¹¹⁵, P. Schacht⁹⁹, U. Schäfer⁸¹, S. Schaepe²⁰, S. Schaezel^{58b},
 A.C. Schaffer¹¹⁵, D. Schaile⁹⁸, R.D. Schamberger¹⁴⁸, A.G. Schamov¹⁰⁷, V. Scharf^{58a}, V.A. Schegelsky¹²¹,
 D. Scheirich⁸⁷, M.I. Scherzer¹⁴, C. Schiavi^{50a,50b}, J. Schieck⁹⁸, M. Schioppa^{36a,36b}, S. Schlenker²⁹,
 J.L. Schlereth⁵, E. Schmidt⁴⁸, K. Schmieden²⁰, C. Schmitt⁸¹, S. Schmitt^{58b}, M. Schmitz²⁰,
 A. Schöning^{58b}, M. Schott²⁹, D. Schouten¹⁴², J. Schovancova¹²⁵, M. Schram⁸⁵, C. Schroeder⁸¹,
 N. Schroer^{58c}, S. Schuh²⁹, G. Schuler²⁹, J. Schultes¹⁷⁴, H.-C. Schultz-Coulon^{58a}, H. Schulz¹⁵,
 J.W. Schumacher²⁰, M. Schumacher⁴⁸, B.A. Schumm¹³⁷, Ph. Schune¹³⁶, C. Schwanenberger⁸²,
 A. Schwartzman¹⁴³, Ph. Schwemling⁷⁸, R. Schwienhorst⁸⁸, R. Schwierz⁴³, J. Schwindling¹³⁶,
 W.G. Scott¹²⁹, J. Searcy¹¹⁴, E. Sedykh¹²¹, E. Segura¹¹, S.C. Seidel¹⁰³, A. Seiden¹³⁷, F. Seifert⁴³,
 J.M. Seixas^{23a}, G. Sekhniaidze^{102a}, D.M. Seliverstov¹²¹, B. Sellden^{146a}, G. Sellers⁷³, M. Seman^{144b},
 N. Semprini-Cesari^{19a,19b}, C. Serfon⁹⁸, L. Serin¹¹⁵, R. Seuster⁹⁹, H. Severini¹¹¹, M.E. Sevir⁸⁶,
 A. Sfyrla²⁹, E. Shabalina⁵⁴, M. Shamim¹¹⁴, L.Y. Shan^{32a}, J.T. Shank²¹, Q.T. Shao⁸⁶, M. Shapiro¹⁴,
 P.B. Shatalov⁹⁵, L. Shaver⁶, C. Shaw⁵³, K. Shaw^{164a,164c}, D. Sherman¹⁷⁵, P. Sherwood⁷⁷, A. Shibata¹⁰⁸,
 H. Shichi¹⁰¹, S. Shimizu²⁹, M. Shimojima¹⁰⁰, T. Shin⁵⁶, A. Shmeleva⁹⁴, M.J. Shochet³⁰, D. Short¹¹⁸,
 M.A. Shupe⁶, P. Sicho¹²⁵, A. Sidoti^{132a,132b}, A. Siebel¹⁷⁴, F. Siegert⁴⁸, J. Siegrist¹⁴, Dj. Sijacki^{12a},
 O. Silbert¹⁷¹, J. Silva^{124a,b}, Y. Silver¹⁵³, D. Silverstein¹⁴³, S.B. Silverstein^{146a}, V. Simak¹²⁷, O. Simard¹³⁶,
 Lj. Simic^{12a}, S. Simion¹¹⁵, B. Simmons⁷⁷, M. Simonyan³⁵, P. Sinervo¹⁵⁸, N.B. Sinev¹¹⁴, V. Sipica¹⁴¹,
 G. Siragusa¹⁷³, A.N. Sisakyan⁶⁵, S.Yu. Sivoklov⁹⁷, J. Sjölín^{146a,146b}, T.B. Sjursen¹³, L.A. Skinnari¹⁴,
 K. Skovpen¹⁰⁷, P. Skubic¹¹¹, N. Skvorodnev²², M. Slater¹⁷, T. Slavicek¹²⁷, K. Sliwa¹⁶¹, T.J. Sloan⁷¹,
 J. Sloper²⁹, V. Smakhtin¹⁷¹, S.Yu. Smirnov⁹⁶, L.N. Smirnova⁹⁷, O. Smirnova⁷⁹, B.C. Smith⁵⁷, D. Smith¹⁴³,
 K.M. Smith⁵³, M. Smizanska⁷¹, K. Smolek¹²⁷, A.A. Snesarev⁹⁴, S.W. Snow⁸², J. Snow¹¹¹, J. Snuverink¹⁰⁵,
 S. Snyder²⁴, M. Soares^{124a}, R. Sobie^{169,j}, J. Sodomka¹²⁷, A. Soffer¹⁵³, C.A. Solans¹⁶⁷, M. Solar¹²⁷,
 J. Solc¹²⁷, E. Soldatov⁹⁶, U. Soldevila¹⁶⁷, E. Solfaroli Camillocci^{132a,132b}, A.A. Solodkov¹²⁸,
 O.V. Solovyanov¹²⁸, J. Sondericker²⁴, N. Soni², V. Sopko¹²⁷, B. Sopko¹²⁷, M. Sorbi^{89a,89b}, M. Sosebee⁷,
 A. Soukharev¹⁰⁷, S. Spagnolo^{72a,72b}, F. Spanò³⁴, R. Spighi^{19a}, G. Spigo²⁹, F. Spila^{132a,132b}, E. Spiriti^{134a},

R. Spiwoks²⁹, M. Spousta¹²⁶, T. Spreitzer¹⁵⁸, B. Spurlock⁷, R.D.St. Denis⁵³, T. Stahl¹⁴¹, J. Stahlman¹²⁰,
 R. Stamen^{58a}, E. Stanecka²⁹, R.W. Stanek⁵, C. Stanescu^{134a}, S. Stapnes¹¹⁷, E.A. Starchenko¹²⁸, J. Stark⁵⁵,
 P. Staroba¹²⁵, P. Starovoitov⁹¹, A. Staude⁹⁸, P. Stavina^{144a}, G. Stavropoulos¹⁴, G. Steele⁵³, P. Steinbach⁴³,
 P. Steinberg²⁴, I. Stekl¹²⁷, B. Stelzer¹⁴², H.J. Stelzer⁴¹, O. Stelzer-Chilton^{159a}, H. Stenzel⁵²,
 K. Stevenson⁷⁵, G.A. Stewart²⁹, J.A. Stillings²⁰, T. Stockmanns²⁰, M.C. Stockton²⁹, K. Stoerig⁴⁸,
 G. Stoicea^{25a}, S. Stonjek⁹⁹, P. Strachota¹²⁶, A.R. Stradling⁷, A. Straessner⁴³, J. Strandberg¹⁴⁷,
 S. Strandberg^{146a,146b}, A. Strandlie¹¹⁷, M. Strang¹⁰⁹, E. Strauss¹⁴³, M. Strauss¹¹¹, P. Strizenec^{144b},
 R. Ströhmer¹⁷³, D.M. Strom¹¹⁴, J.A. Strong^{76,*}, R. Stroynowski³⁹, J. Strube¹²⁹, B. Stugu¹³, I. Stumer^{24,*},
 J. Stupak¹⁴⁸, P. Sturm¹⁷⁴, D.A. Soh^{151,q}, D. Su¹⁴³, H.S. Subramania², A. Succurro¹¹, Y. Sugaya¹¹⁶,
 T. Sugimoto¹⁰¹, C. Suhr¹⁰⁶, K. Suita⁶⁷, M. Suk¹²⁶, V.V. Sulin⁹⁴, S. Sultansoy^{3d}, T. Sumida²⁹, X. Sun⁵⁵,
 J.E. Sundermann⁴⁸, K. Suruliz¹³⁹, S. Sushkov¹¹, G. Susinno^{36a,36b}, M.R. Sutton¹⁴⁹, Y. Suzuki⁶⁶,
 M. Svatos¹²⁵, Yu.M. Sviridov¹²⁸, S. Swedish¹⁶⁸, I. Sykora^{144a}, T. Sykora¹²⁶, B. Szeless²⁹, J. Sánchez¹⁶⁷,
 D. Ta¹⁰⁵, K. Tackmann⁴¹, A. Taffard¹⁶³, R. Tafirout^{159a}, A. Taga¹¹⁷, N. Taiblum¹⁵³, Y. Takahashi¹⁰¹,
 H. Takai²⁴, R. Takashima⁶⁹, H. Takeda⁶⁷, T. Takeshita¹⁴⁰, M. Talby⁸³, A. Talyshev¹⁰⁷, M.C. Tamsett²⁴,
 J. Tanaka¹⁵⁵, R. Tanaka¹¹⁵, S. Tanaka¹³¹, S. Tanaka⁶⁶, Y. Tanaka¹⁰⁰, K. Tani⁶⁷, N. Tannoury⁸³,
 G.P. Tappern²⁹, S. Tapprogge⁸¹, D. Tardif¹⁵⁸, S. Tarem¹⁵², F. Tarrade²⁴, G.F. Tartarelli^{89a}, P. Tas¹²⁶,
 M. Tasevsky¹²⁵, E. Tassi^{36a,36b}, M. Tatarkhanov¹⁴, C. Taylor⁷⁷, F.E. Taylor⁹², G.N. Taylor⁸⁶, W. Taylor^{159b},
 M. Teixeira Dias Castanheira⁷⁵, P. Teixeira-Dias⁷⁶, K.K. Temming⁴⁸, H. Ten Kate²⁹, P.K. Teng¹⁵¹,
 S. Terada⁶⁶, K. Terashi¹⁵⁵, J. Terron⁸⁰, M. Terwort^{41,o}, M. Testa⁴⁷, R.J. Teuscher^{158,j}, J. Thadome¹⁷⁴,
 J. Therhaag²⁰, T. Theveneaux-Pelzer⁷⁸, M. Thioye¹⁷⁵, S. Thoma⁴⁸, J.P. Thomas¹⁷, E.N. Thompson⁸⁴,
 P.D. Thompson¹⁷, P.D. Thompson¹⁵⁸, A.S. Thompson⁵³, E. Thomson¹²⁰, M. Thomson²⁷, R.P. Thun⁸⁷,
 T. Tic¹²⁵, V.O. Tikhomirov⁹⁴, Y.A. Tikhonov¹⁰⁷, C.J.W.P. Timmermans¹⁰⁴, P. Tipton¹⁷⁵,
 F.J. Tique Aires Viegas²⁹, S. Tisserant⁸³, J. Tobias⁴⁸, B. Toczec³⁷, T. Todorov⁴, S. Todorova-Nova¹⁶¹,
 B. Toggerson¹⁶³, J. Tojo⁶⁶, S. Tokár^{144a}, K. Tokunaga⁶⁷, K. Tokushuku⁶⁶, K. Tollefson⁸⁸, M. Tomoto¹⁰¹,
 L. Tompkins¹⁴, K. Toms¹⁰³, G. Tong^{32a}, A. Tonoyan¹³, C. Topfel¹⁶, N.D. Topilin⁶⁵, I. Torchiani²⁹,
 E. Torrence¹¹⁴, H. Torres⁷⁸, E. Torró Pastor¹⁶⁷, J. Toth^{83,x}, F. Touchard⁸³, D.R. Tovey¹³⁹, D. Traynor⁷⁵,
 T. Trefzger¹⁷³, L. Tremblet²⁹, A. Tricoli²⁹, I.M. Trigger^{159a}, S. Trincaz-Duvoid⁷⁸, T.N. Trinh⁷⁸,
 M.F. Tripiana⁷⁰, W. Trischuk¹⁵⁸, A. Trivedi^{24,w}, B. Trocmé⁵⁵, C. Troncon^{89a}, M. Trotter-McDonald¹⁴²,
 A. Trzupek³⁸, C. Tsarouchas²⁹, J.C.-L. Tseng¹¹⁸, M. Tsiakiris¹⁰⁵, P.V. Tsiarehka⁹⁰, D. Tsiou⁴,
 G. Tsipolitis⁹, V. Tsiskaridze⁴⁸, E.G. Tskhadadze⁵¹, I.I. Tsukerman⁹⁵, V. Tsulaia¹⁴, J.-W. Tsung²⁰,
 S. Tsuno⁶⁶, D. Tsybychev¹⁴⁸, A. Tua¹³⁹, J.M. Tuggle³⁰, M. Turala³⁸, D. Turecek¹²⁷, I. Turk Cakir^{3e},
 E. Turlay¹⁰⁵, R. Turra^{89a,89b}, P.M. Tuts³⁴, A. Tykhonov⁷⁴, M. Tylmad^{146a,146b}, M. Tyndel¹²⁹,
 H. Tyrvaainen²⁹, G. Tzanakos⁸, K. Uchida²⁰, I. Ueda¹⁵⁵, R. Ueno²⁸, M. Ugland¹³, M. Uhlenbrock²⁰,
 M. Uhrmacher⁵⁴, F. Ukegawa¹⁶⁰, G. Unal²⁹, D.G. Underwood⁵, A. Undrus²⁴, G. Unel¹⁶³, Y. Unno⁶⁶,
 D. Urbaniec³⁴, E. Urkovsky¹⁵³, P. Urrejola^{31a}, G. Usai⁷, M. Uslenghi^{119a,119b}, L. Vacavant⁸³, V. Vacek¹²⁷,
 B. Vachon⁸⁵, S. Vahsen¹⁴, J. Valenta¹²⁵, P. Valente^{132a}, S. Valentinetti^{19a,19b}, S. Valkar¹²⁶,
 E. Valladolid Gallego¹⁶⁷, S. Vallecorsa¹⁵², J.A. Valls Ferrer¹⁶⁷, H. van der Graaf¹⁰⁵, E. van der Kraaij¹⁰⁵,
 R. Van Der Leeuw¹⁰⁵, E. van der Poel¹⁰⁵, D. van der Ster²⁹, B. Van Eijk¹⁰⁵, N. van Eldik⁸⁴,
 P. van Gemmeren⁵, Z. van Kesteren¹⁰⁵, I. van Vulpen¹⁰⁵, W. Vandelli²⁹, G. Vandoni²⁹, A. Vaniachine⁵,
 P. Vankov⁴¹, F. Vannucci⁷⁸, F. Varela Rodriguez²⁹, R. Vari^{132a}, E.W. Varnes⁶, D. Varouchas¹⁴,
 A. Vartapetian⁷, K.E. Varvell¹⁵⁰, V.I. Vassilakopoulos⁵⁶, F. Vazeille³³, G. Vegni^{89a,89b}, J.J. Veillet¹¹⁵,
 C. Vellidis⁸, F. Veloso^{124a}, R. Veness²⁹, S. Veneziano^{132a}, A. Ventura^{72a,72b}, D. Ventura¹³⁸, M. Venturi⁴⁸,
 N. Venturi¹⁶, V. Vercesi^{119a}, M. Verducci¹³⁸, W. Verkerke¹⁰⁵, J.C. Vermeulen¹⁰⁵, A. Vest⁴³,
 M.C. Vetterli^{142,e}, I. Vichou¹⁶⁵, T. Vickey^{145b,z}, G.H.A. Viehhauser¹¹⁸, S. Viel¹⁶⁸, M. Villa^{19a,19b},
 M. Villaplana Perez¹⁶⁷, E. Vilucchi⁴⁷, M.G. Vincker²⁸, E. Vinek²⁹, V.B. Vinogradov⁶⁵, M. Virchaux^{136,*},
 J. Virzi¹⁴, O. Vitells¹⁷¹, M. Viti⁴¹, I. Vivarelli⁴⁸, F. Vives Vaque¹¹, S. Vlachos⁹, M. Vlasak¹²⁷, N. Vlasov²⁰,
 A. Vogel²⁰, P. Vokac¹²⁷, G. Volpi⁴⁷, M. Volpi¹¹, G. Volpini^{89a}, H. von der Schmitt⁹⁹, J. von Loeben⁹⁹,
 H. von Radziewski⁴⁸, E. von Toerne²⁰, V. Vorobel¹²⁶, A.P. Vorobiev¹²⁸, V. Vorwerk¹¹, M. Vos¹⁶⁷,
 R. Voss²⁹, T.T. Voss¹⁷⁴, J.H. Vosseveld⁷³, N. Vranjes^{12a}, M. Vranjes Milosavljevic^{12a}, V. Vrba¹²⁵,
 M. Vreeswijk¹⁰⁵, T. Vu Anh⁸¹, R. Vuillermet²⁹, I. Vukotic¹¹⁵, W. Wagner¹⁷⁴, P. Wagner¹²⁰,
 H. Wahlen¹⁷⁴, J. Wakabayashi¹⁰¹, J. Walbersloh⁴², S. Walch⁸⁷, J. Walder⁷¹, R. Walker⁹⁸,
 W. Walkowiak¹⁴¹, R. Wall¹⁷⁵, P. Waller⁷³, C. Wang⁴⁴, H. Wang¹⁷², H. Wang^{32b,aa}, J. Wang¹⁵¹,

J. Wang^{32d}, J.C. Wang¹³⁸, R. Wang¹⁰³, S.M. Wang¹⁵¹, A. Warburton⁸⁵, C.P. Ward²⁷, M. Warsinsky⁴⁸, P.M. Watkins¹⁷, A.T. Watson¹⁷, M.F. Watson¹⁷, G. Watts¹³⁸, S. Watts⁸², A.T. Waugh¹⁵⁰, B.M. Waugh⁷⁷, J. Weber⁴², M. Weber¹²⁹, M.S. Weber¹⁶, P. Weber⁵⁴, A.R. Weidberg¹¹⁸, P. Weigell⁹⁹, J. Weingarten⁵⁴, C. Weiser⁴⁸, H. Wellenstein²², P.S. Wells²⁹, M. Wen⁴⁷, T. Wenaus²⁴, S. Wendler¹²³, Z. Weng^{151,q}, T. Wengler²⁹, S. Wenig²⁹, N. Wermes²⁰, M. Werner⁴⁸, P. Werner²⁹, M. Werth¹⁶³, M. Wessels^{58a}, C. Weydert⁵⁵, K. Whalen²⁸, S.J. Wheeler-Ellis¹⁶³, S.P. Whitaker²¹, A. White⁷, M.J. White⁸⁶, S. White²⁴, S.R. Whitehead¹¹⁸, D. Whiteson¹⁶³, D. Whittington⁶¹, F. Wicek¹¹⁵, D. Wicke¹⁷⁴, F.J. Wickens¹²⁹, W. Wiedenmann¹⁷², M. Wielers¹²⁹, P. Wienemann²⁰, C. Wiglesworth⁷⁵, L.A.M. Wiik⁴⁸, P.A. Wijeratne⁷⁷, A. Wildauer¹⁶⁷, M.A. Wildt^{41,o}, I. Wilhelm¹²⁶, H.G. Wilkens²⁹, J.Z. Will⁹⁸, E. Williams³⁴, H.H. Williams¹²⁰, W. Willis³⁴, S. Willocq⁸⁴, J.A. Wilson¹⁷, M.G. Wilson¹⁴³, A. Wilson⁸⁷, I. Wingerter-Seez⁴, S. Winkelmann⁴⁸, F. Winklmeier²⁹, M. Wittgen¹⁴³, M.W. Wolter³⁸, H. Wolters^{124a,h}, G. Wooden¹¹⁸, B.K. Wosiek³⁸, J. Wotschack²⁹, M.J. Woudstra⁸⁴, K. Wraight⁵³, C. Wright⁵³, B. Wrona⁷³, S.L. Wu¹⁷², X. Wu⁴⁹, Y. Wu^{32b,ab}, E. Wulf³⁴, R. Wunstorf⁴², B.M. Wynne⁴⁵, L. Xaplanteris⁹, S. Xella³⁵, S. Xie⁴⁸, Y. Xie^{32a}, C. Xu^{32b,ac}, D. Xu¹³⁹, G. Xu^{32a}, B. Yabsley¹⁵⁰, M. Yamada⁶⁶, A. Yamamoto⁶⁶, K. Yamamoto⁶⁴, S. Yamamoto¹⁵⁵, T. Yamamura¹⁵⁵, J. Yamaoka⁴⁴, T. Yamazaki¹⁵⁵, Y. Yamazaki⁶⁷, Z. Yan²¹, H. Yang⁸⁷, U.K. Yang⁸², Y. Yang⁶¹, Y. Yang^{32a}, Z. Yang^{146a,146b}, S. Yanush⁹¹, W.-M. Yao¹⁴, Y. Yao¹⁴, Y. Yasu⁶⁶, G.V. Ybeles Smit¹³⁰, J. Ye³⁹, S. Ye²⁴, M. Yilmaz^{3c}, R. Yoosofmiya¹²³, K. Yorita¹⁷⁰, R. Yoshida⁵, C. Young¹⁴³, S. Youssef²¹, D. Yu²⁴, J. Yu⁷, J. Yu^{32c,ac}, L. Yuan^{32a,ad}, A. Yurkewicz¹⁴⁸, V.G. Zaets¹²⁸, R. Zaidan⁶³, A.M. Zaitsev¹²⁸, Z. Zajacova²⁹, Yo.K. Zalite¹²¹, L. Zanello^{132a,132b}, P. Zarzhitsky³⁹, A. Zaytsev¹⁰⁷, C. Zeitnitz¹⁷⁴, M. Zeller¹⁷⁵, A. Zemla³⁸, C. Zender²⁰, A.V. Zenin¹²⁸, O. Zenin¹²⁸, T. Ženiš^{144a}, Z. Zenonos^{122a,122b}, S. Zenz¹⁴, D. Zerwas¹¹⁵, G. Zevi della Porta⁵⁷, Z. Zhan^{32d}, D. Zhang^{32b,aa}, H. Zhang⁸⁸, J. Zhang⁵, X. Zhang^{32d}, Z. Zhang¹¹⁵, L. Zhao¹⁰⁸, T. Zhao¹³⁸, Z. Zhao^{32b}, A. Zhemchugov⁶⁵, S. Zheng^{32a}, J. Zhong^{151,ae}, B. Zhou⁸⁷, N. Zhou¹⁶³, Y. Zhou¹⁵¹, C.G. Zhu^{32d}, H. Zhu⁴¹, J. Zhu⁸⁷, Y. Zhu¹⁷², X. Zhuang⁹⁸, V. Zhuravlov⁹⁹, D. Zieminska⁶¹, R. Zimmermann²⁰, S. Zimmermann²⁰, S. Zimmermann⁴⁸, M. Ziolkowski¹⁴¹, R. Zitoun⁴, L. Živković³⁴, V.V. Zmouchko^{128,*}, G. Zobernig¹⁷², A. Zoccoli^{19a,19b}, Y. Zolnierowski⁴, A. Zsenei²⁹, M. zur Nedden¹⁵, V. Zutshi¹⁰⁶, L. Zwalinski²⁹

¹ University at Albany, Albany, NY, United States

² Department of Physics, University of Alberta, Edmonton, AB, Canada

³ ^(a) Department of Physics, Ankara University, Ankara; ^(b) Department of Physics, Dumlupinar University, Kutahya; ^(c) Department of Physics, Gazi University, Ankara;

^(d) Division of Physics, TOBB University of Economics and Technology, Ankara; ^(e) Turkish Atomic Energy Authority, Ankara, Turkey

⁴ LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France

⁵ High Energy Physics Division, Argonne National Laboratory, Argonne, IL, United States

⁶ Department of Physics, University of Arizona, Tucson, AZ, United States

⁷ Department of Physics, The University of Texas at Arlington, Arlington, TX, United States

⁸ Physics Department, University of Athens, Athens, Greece

⁹ Physics Department, National Technical University of Athens, Zografou, Greece

¹⁰ Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

¹¹ Institut de Física d'Altes Energies and Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain

¹² ^(a) Institute of Physics, University of Belgrade, Belgrade; ^(b) Vinca Institute of Nuclear Sciences, Belgrade, Serbia

¹³ Department for Physics and Technology, University of Bergen, Bergen, Norway

¹⁴ Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, CA, United States

¹⁵ Department of Physics, Humboldt University, Berlin, Germany

¹⁶ Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland

¹⁷ School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom

¹⁸ ^(a) Department of Physics, Bogazici University, Istanbul; ^(b) Division of Physics, Dogus University, Istanbul; ^(c) Department of Physics Engineering, Gaziantep University, Gaziantep;

^(d) Department of Physics, Istanbul Technical University, Istanbul, Turkey

¹⁹ ^(a) INFN Sezione di Bologna; ^(b) Dipartimento di Fisica, Università di Bologna, Bologna, Italy

²⁰ Physikalisches Institut, University of Bonn, Bonn, Germany

²¹ Department of Physics, Boston University, Boston, MA, United States

²² Department of Physics, Brandeis University, Waltham, MA, United States

²³ ^(a) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; ^(b) Instituto de Física, Universidade de Sao Paulo, Sao Paulo, Brazil

²⁴ Physics Department, Brookhaven National Laboratory, Upton, NY, United States

²⁵ ^(a) National Institute of Physics and Nuclear Engineering, Bucharest; ^(b) University Politehnica Bucharest, Bucharest; ^(c) West University in Timisoara, Timisoara, Romania

²⁶ Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina

²⁷ Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom

²⁸ Department of Physics, Carleton University, Ottawa, ON, Canada

²⁹ CERN, Geneva, Switzerland

³⁰ Enrico Fermi Institute, University of Chicago, Chicago, IL, United States

³¹ ^(a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; ^(b) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile

³² ^(a) Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; ^(b) Department of Modern Physics, University of Science and Technology of China, Anhui;

^(c) Department of Physics, Nanjing University, Jiangsu; ^(d) High Energy Physics Group, Shandong University, Shandong, China

³³ Laboratoire de Physique Corpusculaire, Clermont Université and CNRS/IN2P3, Aubiere Cedex, France

³⁴ Nevis Laboratory, Columbia University, Irvington, NY, United States

³⁵ Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark

³⁶ ^(a) INFN Gruppo Collegato di Cosenza; ^(b) Dipartimento di Fisica, Università della Calabria, Arcavata di Rende, Italy

- 37 Faculty of Physics and Applied Computer Science, AGH – University of Science and Technology, Krakow, Poland
- 38 The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
- 39 Physics Department, Southern Methodist University, Dallas, TX, United States
- 40 Physics Department, University of Texas at Dallas, Richardson, TX, United States
- 41 DESY, Hamburg and Zeuthen, Germany
- 42 Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
- 43 Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany
- 44 Department of Physics, Duke University, Durham, NC, United States
- 45 SUPA – School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
- 46 Fachhochschule Wiener Neustadt, Johannes Gutenbergstrasse 3, 2700 Wiener Neustadt, Austria
- 47 INFN Laboratori Nazionali di Frascati, Frascati, Italy
- 48 Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg i.Br., Germany
- 49 Section de Physique, Université de Genève, Geneva, Switzerland
- 50 ^(a) INFN Sezione di Genova; ^(b) Dipartimento di Fisica, Università di Genova, Genova, Italy
- 51 Institute of Physics and HEP Institute, Georgian Academy of Sciences and Tbilisi State University, Tbilisi, Georgia
- 52 II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
- 53 SUPA – School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
- 54 II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
- 55 Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier and CNRS/IN2P3 and Institut National Polytechnique de Grenoble, Grenoble, France
- 56 Department of Physics, Hampton University, Hampton, VA, United States
- 57 Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA, United States
- 58 ^(a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg;
- ^(c) ZITI Institut für Technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
- 59 Faculty of Science, Hiroshima University, Hiroshima, Japan
- 60 Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
- 61 Department of Physics, Indiana University, Bloomington, IN, United States
- 62 Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
- 63 University of Iowa, Iowa City, IA, United States
- 64 Department of Physics and Astronomy, Iowa State University, Ames, IA, United States
- 65 Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
- 66 KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
- 67 Graduate School of Science, Kobe University, Kobe, Japan
- 68 Faculty of Science, Kyoto University, Kyoto, Japan
- 69 Kyoto University of Education, Kyoto, Japan
- 70 Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
- 71 Physics Department, Lancaster University, Lancaster, United Kingdom
- 72 ^(a) INFN Sezione di Lecce; ^(b) Dipartimento di Fisica, Università del Salento, Lecce, Italy
- 73 Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
- 74 Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
- 75 Department of Physics, Queen Mary University of London, London, United Kingdom
- 76 Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
- 77 Department of Physics and Astronomy, University College London, London, United Kingdom
- 78 Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- 79 Fysiska Institutionen, Lunds Universitet, Lund, Sweden
- 80 Departamento de Física Teórica, C-15, Universidad Autónoma de Madrid, Madrid, Spain
- 81 Institut für Physik, Universität Mainz, Mainz, Germany
- 82 School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
- 83 CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- 84 Department of Physics, University of Massachusetts, Amherst, MA, United States
- 85 Department of Physics, McGill University, Montreal, QC, Canada
- 86 School of Physics, University of Melbourne, Victoria, Australia
- 87 Department of Physics, The University of Michigan, Ann Arbor, MI, United States
- 88 Department of Physics and Astronomy, Michigan State University, East Lansing, MI, United States
- 89 ^(a) INFN Sezione di Milano; ^(b) Dipartimento di Fisica, Università di Milano, Milano, Italy
- 90 B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus
- 91 National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Belarus
- 92 Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, United States
- 93 Group of Particle Physics, University of Montreal, Montreal, QC, Canada
- 94 P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
- 95 Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
- 96 Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
- 97 Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
- 98 Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
- 99 Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
- 100 Nagasaki Institute of Applied Science, Nagasaki, Japan
- 101 Graduate School of Science, Nagoya University, Nagoya, Japan
- 102 ^(a) INFN Sezione di Napoli; ^(b) Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
- 103 Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States
- 104 Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
- 105 Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
- 106 Department of Physics, Northern Illinois University, DeKalb, IL, United States
- 107 Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia
- 108 Department of Physics, New York University, New York, NY, United States
- 109 Ohio State University, Columbus, OH, United States
- 110 Faculty of Science, Okayama University, Okayama, Japan
- 111 Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, United States
- 112 Department of Physics, Oklahoma State University, Stillwater, OK, United States
- 113 Palacký University, RCPTM, Olomouc, Czech Republic
- 114 Center for High Energy Physics, University of Oregon, Eugene, OR, United States

- 115 LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
- 116 Graduate School of Science, Osaka University, Osaka, Japan
- 117 Department of Physics, University of Oslo, Oslo, Norway
- 118 Department of Physics, Oxford University, Oxford, United Kingdom
- 119 ^(a) INFN Sezione di Pavia; ^(b) Dipartimento di Fisica Nucleare e Teorica, Università di Pavia, Pavia, Italy
- 120 Department of Physics, University of Pennsylvania, Philadelphia, PA, United States
- 121 Petersburg Nuclear Physics Institute, Gatchina, Russia
- 122 ^(a) INFN Sezione di Pisa; ^(b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
- 123 Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA, United States
- 124 ^(a) Laboratório de Instrumentação e Física Experimental de Partículas – LIP, Lisboa, Portugal; ^(b) Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
- 125 Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
- 126 Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
- 127 Czech Technical University in Prague, Praha, Czech Republic
- 128 State Research Center Institute for High Energy Physics, Protvino, Russia
- 129 Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
- 130 Physics Department, University of Regina, Regina, SK, Canada
- 131 Ritsumeikan University, Kusatsu, Shiga, Japan
- 132 ^(a) INFN Sezione di Roma I; ^(b) Dipartimento di Fisica, Università La Sapienza, Roma, Italy
- 133 ^(a) INFN Sezione di Roma Tor Vergata; ^(b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
- 134 ^(a) INFN Sezione di Roma Tre; ^(b) Dipartimento di Fisica, Università Roma Tre, Roma, Italy
- 135 ^(a) Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies – Université Hassan II, Casablanca; ^(b) Centre National de l’Energie des Sciences Techniques Nucleaires, Rabat; ^(c) Université Cadi Ayyad, Faculté des Sciences Semlalia, Département de Physique, B.P. 2390, Marrakech 40000; ^(d) Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; ^(e) Faculté des Sciences, Université Mohammed V, Rabat, Morocco
- 136 DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l’Univers), CEA Saclay (Commissariat à l’Energie Atomique), Gif-sur-Yvette, France
- 137 Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, CA, United States
- 138 Department of Physics, University of Washington, Seattle, WA, United States
- 139 Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
- 140 Department of Physics, Shinshu University, Nagano, Japan
- 141 Fachbereich Physik, Universität Siegen, Siegen, Germany
- 142 Department of Physics, Simon Fraser University, Burnaby, BC, Canada
- 143 SLAC National Accelerator Laboratory, Stanford, CA, United States
- 144 ^(a) Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava; ^(b) Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
- 145 ^(a) Department of Physics, University of Johannesburg, Johannesburg; ^(b) School of Physics, University of the Witwatersrand, Johannesburg, South Africa
- 146 ^(a) Department of Physics, Stockholm University; ^(b) The Oskar Klein Centre, Stockholm, Sweden
- 147 Physics Department, Royal Institute of Technology, Stockholm, Sweden
- 148 Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY, United States
- 149 Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
- 150 School of Physics, University of Sydney, Sydney, Australia
- 151 Institute of Physics, Academia Sinica, Taipei, Taiwan
- 152 Department of Physics, Technion – Israel Inst. of Technology, Haifa, Israel
- 153 Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
- 154 Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
- 155 International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
- 156 Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
- 157 Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
- 158 Department of Physics, University of Toronto, Toronto, ON, Canada
- 159 ^(a) TRIUMF, Vancouver, BC; ^(b) Department of Physics and Astronomy, York University, Toronto, ON, Canada
- 160 Institute of Pure and Applied Sciences, University of Tsukuba, Ibaraki, Japan
- 161 Science and Technology Center, Tufts University, Medford, MA, United States
- 162 Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
- 163 Department of Physics and Astronomy, University of California Irvine, Irvine, CA, United States
- 164 ^(a) INFN Gruppo Collegato di Udine; ^(b) ICTP, Trieste; ^(c) Dipartimento di Fisica, Università di Udine, Udine, Italy
- 165 Department of Physics, University of Illinois, Urbana, IL, United States
- 166 Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
- 167 Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
- 168 Department of Physics, University of British Columbia, Vancouver, BC, Canada
- 169 Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada
- 170 Waseda University, Tokyo, Japan
- 171 Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
- 172 Department of Physics, University of Wisconsin, Madison, WI, United States
- 173 Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
- 174 Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
- 175 Department of Physics, Yale University, New Haven, CT, United States
- 176 Yerevan Physics Institute, Yerevan, Armenia
- 177 Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France

^a Also at Laboratório de Instrumentação e Física Experimental de Partículas – LIP, Lisboa, Portugal.

^b Also at Faculdade de Ciências and CFNUL, Universidade de Lisboa, Lisboa, Portugal.

^c Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom.

^d Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.

^e Also at TRIUMF, Vancouver, BC, Canada.

^f Also at Department of Physics, California State University, Fresno, CA, United States.

^g Also at Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland.

^h Also at Department of Physics, University of Coimbra, Coimbra, Portugal.

- ⁱ Also at Università di Napoli Parthenope, Napoli, Italy.
- ^j Also at Institute of Particle Physics (IPP), Canada.
- ^k Also at Department of Physics, Middle East Technical University, Ankara, Turkey.
- ^l Also at Louisiana Tech University, Ruston, LA, United States.
- ^m Also at Group of Particle Physics, University of Montreal, Montreal, QC, Canada.
- ⁿ Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
- ^o Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
- ^p Also at Manhattan College, New York, NY, United States.
- ^q Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China.
- ^r Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.
- ^s Also at High Energy Physics Group, Shandong University, Shandong, China.
- ^t Also at California Institute of Technology, Pasadena, CA, United States.
- ^u Also at Section de Physique, Université de Genève, Geneva, Switzerland.
- ^v Also at Departamento de Física, Universidade de Minho, Braga, Portugal.
- ^w Also at Department of Physics and Astronomy, University of South Carolina, Columbia, SC, United States.
- ^x Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary.
- ^y Also at Institute of Physics, Jagiellonian University, Krakow, Poland.
- ^z Also at Department of Physics, Oxford University, Oxford, United Kingdom.
- ^{aa} Also at Institute of Physics, Academia Sinica, Taipei, Taiwan.
- ^{ab} Also at Department of Physics, The University of Michigan, Ann Arbor, MI, United States.
- ^{ac} Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique), Gif-sur-Yvette, France.
- ^{ad} Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France.
- ^{ae} Also at Department of Physics, Nanjing University, Jiangsu, China.
- * Deceased.