PHYSICAL REVIEW LETTERS **122,** 231801 (2019)

Combination of Searches for Invisible Higgs Boson Decays with the ATLAS Experiment

M. Aaboud *et al.*[*]
(ATLAS Collaboration)

(Received 11 April 2019; published 13 June 2019)

Dark matter particles, if sufficiently light, may be produced in decays of the Higgs boson. This Letter presents a statistical combination of searches for $H \to$ invisible decays where H is produced according to the standard model via vector boson fusion, $Z(\ell\ell)H$, and $W/Z(\text{had})H$, all performed with the ATLAS detector using 36.1 fb^{-1} of pp collisions at a center-of-mass energy of $\sqrt{s} = 13$ TeV at the LHC. In combination with the results at $\sqrt{s} = 7$ and 8 TeV, an exclusion limit on the $H \to$ invisible branching ratio of $0.26(0.17^{+0.07}_{-0.05})$ at 95% confidence level is observed (expected).

DOI: 10.1103/PhysRevLett.122.231801

One of the central open questions in physics today is the nature of dark matter (DM) that is found to comprise most of the matter in the Universe [1–4]. A compelling candidate for DM is a stable electrically neutral particle χ whose nongravitational interactions with Standard Model (SM) particles are weak. Such a particle with a mass comparable to the mass scale of the electroweak sector particles could be detectable [5–7] and accommodate the observed DM relic density [8,9]. Numerous models predict detectable production rates of such DM particles at the Large Hadron Collider (LHC) [10–12]. In a wide class of those models, the 125 GeV Higgs boson H [13,14] acts as a portal between a dark sector and the SM sector, either through Yukawa-type couplings to fermionic dark matter, or other mechanisms [15–28]. If kinematically allowed, decays of the Higgs boson to DM particles represent a distinct signature in such models. Higgs boson decays to DM particles can only be indirectly inferred through missing transverse momentum [29] $E_{\text{T}}^{\text{miss}}$ due to DM particles escaping detection, and are therefore termed "invisible" (inv).

Direct searches for invisible Higgs boson decays have been carried out with the ATLAS detector [30–32] in Run 1 of the LHC, using up to 4.7 fb^{-1} of pp collision data at a center-of-mass energy of $\sqrt{s} = 7$ TeV and up to 20.3 fb^{-1} at 8 TeV. Different event topologies were considered, assuming SM production rates: vector boson fusion (VBF) [33], Higgsstrahlung from a Z boson decaying into a pair of electrons or muons ($Z(\text{lep})H$) [34], and Higgsstrahlung from a W or Z boson decaying into hadrons ($V(\text{had})H$) [35]. These searches for invisible Higgs boson decays have been statistically combined, and an upper limit at 95% confidence level (C.L.) on the invisible Higgs boson branching ratio of $\mathcal{B}_{H\to\text{inv}} < 0.25(0.27^{+0.10}_{-0.08})$ [36] was observed (expected). In combination with visible decay modes of the Higgs boson, the upper observed (expected) limit improved to 0.23 (0.24) [36]. Direct searches for invisible Higgs decays were performed using up to 36.1 fb^{-1} of pp collision data at $\sqrt{s} = 13$ TeV recorded in 2015 and 2016 in the VBF [37], $Z(\text{lep})H$ [38], and $V(\text{had})H$ [39] topologies at ATLAS. The aforementioned results at $\sqrt{s} = 13$ TeV will be referred to as "Run 2 results" in the following. Similar searches were performed by the CMS Collaboration [40–44].

This Letter presents the statistical combination of the Run 2 searches with 36.1 fb^{-1} of data for invisible decays of the Higgs boson using the ATLAS detector. Subsequently, a statistical combination with the combined Run 1 result [36] from ATLAS is performed. An overview of all results used as inputs in this combination is given in Table I. The analysis is performed under the assumption of SM Higgs boson production. Visible decay modes of the Higgs boson are not considered.

A brief overview of the Run 2 searches for $H \to$ inv is given below.

VBF topology [37].—The analysis of the VBF production mode employs an $E_{\text{T}}^{\text{miss}}$ trigger that is 98% efficient or better in the considered region of phase space. The event selection requires $E_{\text{T}}^{\text{miss}} > 180$ GeV. Jets (j) are reconstructed up to $|\eta(j)| < 4.5$ from energy clusters in the calorimeter using the anti-k_t algorithm [45] with a radius parameter $R = 0.4$. The two jets leading in p_{T} are required to be separated by $|\Delta\eta_{jj}| > 4.8$. There should be no additional jets with $p_{\text{T}} > 25$ GeV and no isolated electron or muon candidate with $p_{\text{T}} > 7$ GeV. These requirements serve to reduce the contribution from W/Z production in association with jets (V + jets). In the search signal region

---

[*] Full author list given at the end of the Letter.

TABLE I. Observed and expected upper limits on $\mathcal{B}_{H\to\mathrm{inv}}$ at 95% C.L. from direct searches for invisible decays of the 125 GeV Higgs boson and statistical combinations. Also given are the observed p values under the SM hypothesis.

Analysis	$\sqrt{s}$	Int. luminosity	Observed	Expected	p_{SM} value	Reference
Run 2 VBF	13 TeV	36.1 fb^{-1}	0.37	$0.28^{+0.11}_{-0.08}$	0.19	[37]
Run 2 $Z(\mathrm{lep})H$	13 TeV	36.1 fb^{-1}	0.67	$0.39^{+0.17}_{-0.11}$	0.06	[38]
Run 2 $V(\mathrm{had})H$	13 TeV	36.1 fb^{-1}	0.83	$0.58^{+0.23}_{-0.16}$	0.12	[39]
Run 2 Comb.	13 TeV	36.1 fb^{-1}	0.38	$0.21^{+0.08}_{-0.06}$	0.03	this Letter
Run 1 Comb.	7,8 TeV	4.7, 20.3 fb^{-1}	0.25	$0.27^{+0.10}_{-0.08}$	⋯	[36]
Run 1 + 2 Comb.	7,8,13 TeV	4.7, 20.3, 36.1 fb^{-1}	0.26	$0.17^{+0.07}_{-0.05}$	0.10	this Letter

(SR) the m_{jj} distribution of the background falls more rapidly than the signal, where m_{jj} represents the invariant mass of the two selected leading jets. Thus the SR is divided into three m_{jj} regions ($1 < m_{jj}/\mathrm{TeV} < 1.5$, $1.5 < m_{jj}/\mathrm{TeV} < 2$, and $m_{jj}/\mathrm{TeV} > 2$) to improve the search sensitivity. The dominant background sources are $Z(\nu\nu) + \mathrm{jets}$ and $W(\ell\nu) + \mathrm{jets}$ production, where the charged lepton ℓ is not detected. Control regions (CR) enriched in $Z(\ell\ell) + \mathrm{jets}$ and $W(\ell\nu) + \mathrm{jets}$ processes with $\ell = e, \mu$ are defined to determine the respective normalization factors in the SR. The main contributions to uncertainties are from the finite number of simulated Monte Carlo (MC) events, the modeling of $V + \mathrm{jets}$ production, and accuracy of the jet energy scale (JES). The final discriminant is the number of events in the three m_{jj} regions.

***Z*(lep)*H* topology** *[38].*—This search is conducted in the Higgsstrahlung channel where the Z boson decays into a pair of electrons or muons. A selected candidate event must pass at least one of the various single-lepton triggers, fulfill $E_{\mathrm{T}}^{\mathrm{miss}} > 90$ GeV and $E_{\mathrm{T}}^{\mathrm{miss}}/H_T > 0.6$, where H_T is calculated as the scalar sum of the p_{T} of the selected leptons and jets, and have exactly one pair of isolated electrons or muons with an invariant mass that is consistent with that of the Z boson. The transverse momentum requirement on the leading (subleading) charged lepton is $p_{\mathrm{T}} > 30\,(20)$ GeV. To reduce the $Z + \mathrm{jets}$ background, the dilepton system must be aligned back to back relative to the $E_{\mathrm{T}}^{\mathrm{miss}}$ vector in the transverse plane. Events with jets originating from b-quarks (b-jets) are vetoed to suppress backgrounds from top quark pair ($t\bar{t}$) production and W boson production in association with a single top quark (Wt). The irreducible $Z(\nu\nu)Z(\ell\ell)$ background is estimated from MC simulations and its production yield is normalized to the theoretical prediction of Refs. [46,47]. The $W(\ell\nu)Z(\ell\ell)$ background contribution is also predicted with MC simulations and is normalized by a scale factor that is obtained from a CR enriched in WZ events. The $Z + \mathrm{jets}$ background is estimated with a data-driven method that uses Z-enriched CRs. The final discriminant is $E_{\mathrm{T}}^{\mathrm{miss}}$.

***V*(had)*H* topology** *[39].*—This analysis considers the Higgsstrahlung channel where the associated W or Z boson decays into hadrons. The final state signature of large $E_{\mathrm{T}}^{\mathrm{miss}}$ and jets also receives contributions from Higgs boson production via gluon fusion with jets originating from initial state radiation, and production via the VBF process. Selected events must pass a $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger and must not contain an isolated electron or muon with $p_{\mathrm{T}} > 7$ GeV. As a V is boosted, the two jets from its decay become increasingly collimated and are eventually merged into one single reconstructed jet. Thus, this search is conducted in two topological channels. In the “merged” topology, the SR is defined with $E_{\mathrm{T}}^{\mathrm{miss}} > 250$ GeV and has at least one trimmed [48,49] large-R jet (J) that is reconstructed using the anti-k_t algorithm with $R = 1.0$. The signal large-R jet is the one with the highest p_{T}. For the “resolved” topology, the selected event should have $E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV and at least two small-R jets (j) with $R = 0.4$. Each event is first passed through the merged topology selection and, if it fails, it is passed through the resolved topology selection. To improve the search sensitivity, the selected events are further split into categories with zero, one, and two identified b-jets, and into two mass regions of the invariant mass of the signal large-R jet (two signal small-R jets) for the merged (resolved) topology. The low mass region ($70 \lesssim m_J,\ m_{jj}/\mathrm{GeV} \lesssim 100$) targets the hadronic W/Z boson decays of the associated production, whereas the high mass region ($100 \lesssim m_J, m_{jj}/\mathrm{GeV} < 250$) is sensitive to gluon fusion and VBF production. The main background contributions are from the $V + \mathrm{jets}$ and $t\bar{t}$ processes. The predictions from MC simulations are constrained with CRs that contained one or two leptons, and are kinematically similar to the SR. The final discriminant is $E_{\mathrm{T}}^{\mathrm{miss}}$.

The SRs and CRs of the individual input analyses are either orthogonal by construction, or were shown to have an overlap below 1%, which is neglected in the following.

The statistical combination of the analyses is performed by constructing the product of their likelihoods and maximizing the resulting likelihood ratio $\Lambda(\mathcal{B}_{H\to\mathrm{inv}};\theta)$ [50]. This is done following the implementation described in Ref. [51,52], with $\mathcal{B}_{H\to\mathrm{inv}}$ as the parameter of interest. Systematic uncertainties are modeled in the likelihood function as nuisance parameters θ constrained by Gaussian or log-normal probability density functions [36].

Expected results are obtained using the Asimov dataset technique [50].

In the combination of Run 2 results, most experimental systematic uncertainties as well as the uncertainty on the integrated luminosity and the modeling of additional pp collisions in the same and neighboring bunch crossings (pileup) are correlated across all search channels. Some experimental uncertainties related to flavor tagging and the JES are represented through different parametrizations in the input analyses and are therefore treated as uncorrelated. The impact of this assumption on the combined result is estimated using alternative correlation models where the leading sources of systematic uncertainty in the respective parametrizations are treated as correlated, and found to have an absolute effect on the $\mathcal{B}_{H\to \mathrm{inv}}$ limit of the order of 0.01. The systematic uncertainties on the total $H \to \mathrm{inv}$ signal cross section due to the choice of parton distribution functions (PDF) are considered correlated among all channels. By contrast, uncertainties due to missing higher order corrections are estimated through variations of factorization and renormalization scales and treated as correlated between the $Z(\mathrm{lep})H$ and $V(\mathrm{had})H$ processes. This is not done for VBF, which represents a distinct topology. The impact of the corresponding uncertainties on the acceptance rather than the total cross section of $V(\mathrm{had})H$ production is evaluated and found negligible. Few systematic uncertainties that are tightly constrained in a given analysis are left uncorrelated in order not to introduce any potential phase space specific biases.

The negative logarithmic profile likelihood ratios $-2\Delta\ln(\Lambda)(\mathcal{B}_{H\to \mathrm{inv}};\theta)$ as a function of $\mathcal{B}_{H\to \mathrm{inv}}$ of the individual analyses and of the combined Run 2 result are shown in Fig. 1, corresponding to a best-fit combined value of $\mathcal{B}_{H\to \mathrm{inv}} = 0.20 \pm 0.10$. The dominant uncertainty sources are finite event yields in data and MC simulations, reconstruction of jets and leptons, and modeling of diboson and $W/Z+\mathrm{jets}$ production. In absence of a significant excess, an upper limit at 95% C.L. of $\mathcal{B}_{H\to \mathrm{inv}} < 0.38(0.21^{+0.08}_{-0.06})$ is observed (expected) with the CL_s formalism [53] using the profile likelihood ratio as a test statistic. The excess in data corresponds to a p_{SM} value of 3% under the SM hypothesis of $\mathcal{B}_{H\to \mathrm{inv}} \simeq 10^{-3}$, and is a direct consequence of the excesses that are present in each of the three input analyses, see Table I. Each of the individual analyses has been scrutinized and these excesses have been found nonsignificant and independent.

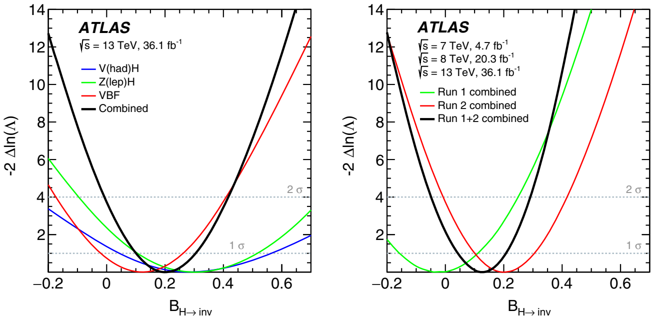

FIG. 1. The observed negative logarithmic profile likelihood ratios $-2\Delta\ln(\Lambda)$ as a function of $\mathcal{B}_{H\to \mathrm{inv}}$ of the $V(\mathrm{had})H$, $Z(\mathrm{lep})H$, and VBF topologies using Run 2 data only and their statistical combination (left). The $-2\Delta\ln(\Lambda)$ functions for the Run 2 combination together with the Run 1 combination and the total Run $1+2$ combination (right).

Subsequently, the above Run 2 result is combined with the Run 1 searches for $H \to \mathrm{inv}$ decays [36]. Because of the differences between the detector layouts and data-taking conditions, reconstruction algorithms and their calibrations, and treatment of systematic uncertainties, the correlations between the runs are not clearly identifiable. Hence, no correlations between Run 1 and 2 are assumed for most instrumental uncertainties. The uncertainties related to the modeling of the calorimeter response dependence on jet flavor and pileup are taken as either correlated or uncorrelated between the runs, and the choice which results in a weaker expected exclusion limit on $\mathcal{B}_{H\to \mathrm{inv}}$ is adopted. The uncertainty on the JES of b-quark jets was estimated using MC simulations [54,55] and is therefore considered correlated. For the signal modeling, the parton shower uncertainty in the $V(\mathrm{had})H$ channel, the uncertainty from missing higher order corrections in the $Z(\mathrm{lep})H$ analysis, and the uncertainty on the jet multiplicity in the VBF channel [56] are each taken as correlated between the runs since the estimated uncertainties stem from the same source. For the same reason, the uncertainty from missing higher order corrections on the $E_{\mathrm{T}}^{\mathrm{miss}}$ observable in the dominant background from diboson production in the $Z(\mathrm{lep})H$ search is treated as correlated. All other background modeling uncertainties are considered uncorrelated. The impact of these correlation assumptions on the combined $\mathcal{B}_{H\to \mathrm{inv}}$ limit is found to be at most 0.005. In addition, the impact on $\mathcal{B}_{H\to \mathrm{inv}}$ in scenarios ranging from full anticorrelation to full correlation is studied using the best linear unbiased estimator (BLUE) [57] for the components of the JES uncertainty, the $V+\mathrm{jets}$ background, and diboson production that are nominally not correlated due to different parametrizations in Run 1 and 2. The resulting absolute effect on the $\mathcal{B}_{H\to \mathrm{inv}}$ limit is at most 0.01.

The observed $-2\Delta\ln(\Lambda)(\mathcal{B}_{H\to \mathrm{inv}};\theta)$ ratio of the combined Run $1+2$ result is represented in Fig. 1, alongside the individual Run 1 and Run 2 combinations. A best-fit value of $\mathcal{B}_{H\to \mathrm{inv}} = 0.13 \pm 0.08$ is obtained, corresponding to an observed (expected) upper limit of $\mathcal{B}_{H\to \mathrm{inv}} < 0.26(0.17^{+0.07}_{-0.05})$ at 95% C.L. The p_{SM} value under the SM hypothesis is 10%, and the compatibility between the Run 1 and Run 2 results is 1.5 standard deviations. The final result, together with the results in the individual Run 2 analyses as well as the Run 2-only and the Run 1-only combinations, are summarized in Table I, and the upper limits on $\mathcal{B}_{H\to \mathrm{inv}}$ are graphically represented in Fig. 2.

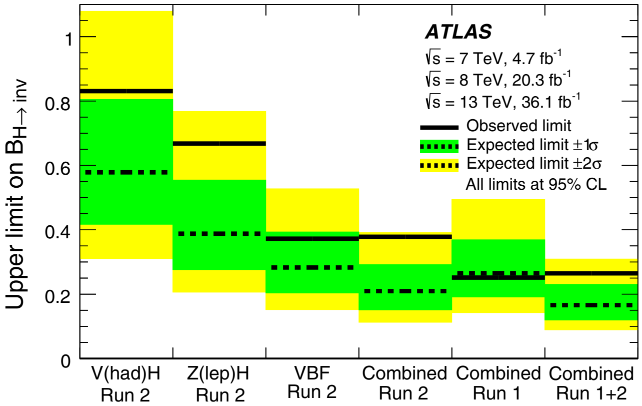

FIG. 2. The observed and expected upper limits on $\mathcal{B}_{H\to\mathrm{inv}}$ at 95% C.L. from direct searches for invisible decays of the 125 GeV Higgs boson and their statistical combinations in Run 1 and 2.

The results are consistent with a similar statistical combination in Ref. [40].

The constraint from the combined observed Run $1+2$ exclusion limit of $\mathcal{B}_{H\to\mathrm{inv}} < 0.24$ at 90% C.L. is compared to the results from representative direct DM detection experiments [58–62] in Fig. 3. This comparison is performed in the context of Higgs portal models [63]. The translation of the $H \to \mathrm{inv}$ result into a weak interacting massive particle–nucleon scattering cross section $\sigma_{\mathrm{WIMP}\text{-}N}$ relies on an effective field theory approach [33] under the assumption that invisible Higgs decays to a pair of WIMPs are kinematically possible and that the WIMP is a scalar or a fermion [23,64,65], using the nuclear form factor $f_N = 0.308 \pm 0.018$ [66]. The excluded $\sigma_{\mathrm{WIMP}\text{-}N}$ values range down to 2×10^{-45} cm^2 in the scalar WIMP scenario. In the fermion WIMP case, the effective coupling is reduced by m_H^2 [33], excluding $\sigma_{\mathrm{WIMP}\text{-}N}$ values down to 10^{-46} cm^2. While the ATLAS exclusion limits extend to $m_{\mathrm{WIMP}} < 1$ GeV, that region is subject to uncertainties in modelling of the nuclear recoil and is therefore not included in Fig. 3.

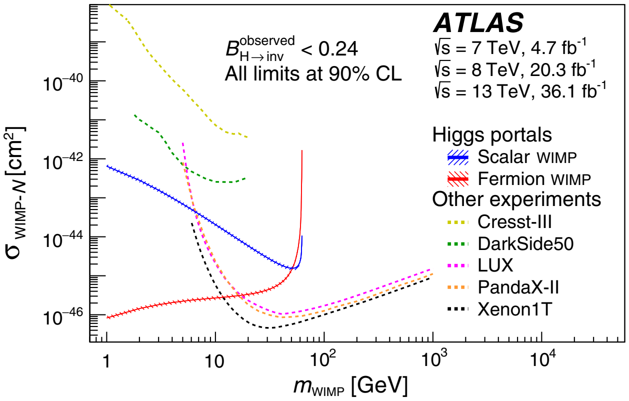

FIG. 3. Comparison of the upper limits at 90% C.L. from direct detection experiments [58–62] on the spin-independent WIMP-nucleon scattering cross section to the observed exclusion limits from this analysis, assuming Higgs portal scenarios where the 125 GeV Higgs boson decays to a pair of DM particles [33,63]. The regions above the limit contours are excluded in the range shown in the plot.

In summary, direct searches for invisible Higgs boson decays using 36.1 fb^{-1} of pp collision data at $\sqrt{s} = 13$ TeV recorded in 2015 and 2016 in the VBF, $Z(\mathrm{lep})H$, and $V(\mathrm{had})H$ topologies are statistically combined assuming SM-like Higgs boson production. An upper limit on the invisible Higgs branching ratio of $\mathcal{B}_{H\to\mathrm{inv}} < 0.38(0.21^{+0.08}_{-0.06})$ is observed (expected) at 95% C.L. A statistical combination of this result with the combination of direct $H \to \mathrm{inv}$ searches using up to 4.7 fb^{-1} of pp collision data at $\sqrt{s} = 7$ TeV and up to 20.3 fb^{-1} at 8 TeV collected in Run 1 of the LHC yields an observed (expected) upper limit of $\mathcal{B}_{H\to\mathrm{inv}} < 0.26(0.17^{+0.07}_{-0.05})$ at 95% C.L. The combined Run $1+2$ result is translated into upper limits on the WIMP-nucleon scattering cross section for Higgs portal models. The derived limits range down to 2×10^{-45} cm^2 in the scalar and 10^{-46} cm^2 in the fermion WIMP scenarios, highlighting the complementarity of DM searches at the LHC and direct detection experiments.

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 acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, 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 and DNSRC, Denmark; IN2P3-CNRS, CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF, and MPG, Germany; GSRT, Greece; RGC, Hong Kong SAR, China; ISF and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MNiSW and NCN, Poland; FCT, Portugal; MNE/IFA, Romania; MES of Russia and NRC KI, Russian Federation; JINR; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MINECO, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, CANARIE, CRC and Compute Canada, Canada; COST, ERC, ERDF, Horizon 2020, and Marie Skłodowska-Curie Actions, European Union; Investissements d' Avenir Labex and Idex, ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and GIF, Israel; CERCA Programme Generalitat de Catalunya, Spain; The Royal Society and Leverhulme Trust, United Kingdom. The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, 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), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [67].

[1] Planck Collaboration, Planck 2018 results. I. Overview and the cosmological legacy of Planck, arXiv:1807.06205.

[2] WMAP Collaboration, Nine-year Wilkinson microwave anisotropy probe (WMAP) observations: Cosmological parameter results, Astrophys. J. Suppl. Ser. **208**, 19 (2013).

[3] G. Bertone, D. Hooper, and J. Silk, Particle dark matter: Evidence, candidates and constraints, Phys. Rep. **405**, 279 (2005).

[4] V. Trimble, Existence and nature of dark matter in the universe, Annu. Rev. Astron. Astrophys. **25**, 425 (1987).

[5] H. Goldberg, Constraint on the Photino Mass from Cosmology, Phys. Rev. Lett. **50** (1983) 1419; Erratum, Phys. Rev. Lett. **103**, 099905(E) (2009).

[6] J. R. Ellis, J. S. Hagelin, D. V. Nanopoulos, K. A. Olive, and M. Srednicki, Supersymmetric relics from the big bang, Nucl. Phys. **B238**, 453 (1984).

[7] G. Jungman, M. Kamionkowski, and K. Griest, Supersymmetric dark matter, Phys. Rep. **267**, 195 (1996).

[8] G. Steigman and M. S. Turner, Cosmological constraints on the properties of weakly interacting massive particles, Nucl. Phys. **B253**, 375 (1985).

[9] R. J. Scherrer and M. S. Turner, On the relic, cosmic abundance of stable, weakly interacting massive particles, Phys. Rev. D **33** (1986) 1585; Erratum, Phys. Rev. D **34**, 3263(E) (1986).

[10] D. Abercrombie *et al.*, Dark matter benchmark models for early LHC Run-2 searches: Report of the ATLAS/CMS dark matter forum, arXiv:1507.00966.

[11] J. L. Feng, Dark matter candidates from particle physics and methods of detection, Annu. Rev. Astron. Astrophys. **48**, 495 (2010).

[12] A. Boveia and C. Doglioni, Dark matter searches at colliders, Annu. Rev. Nucl. Part. Sci. **68**, 429 (2018).

[13] ATLAS Collaboration, Observation of a new particle in the search for the standard model Higgs boson with the ATLAS detector at the LHC, Phys. Lett. B **716**, 1 (2012).

[14] CMS Collaboration, Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, Phys. Lett. B **716**, 30 (2012).

[15] I. Antoniadis, M. Tuckmantel, and F. Zwirner, Phenomenology of a leptonic goldstino and invisible Higgs boson decays, Nucl. Phys. **707**, 215 (2005).

[16] N. Arkani-Hamed, S. Dimopoulos, G. R. Dvali, and J. March-Russell, Neutrino masses from large extra dimensions, Phys. Rev. D **65**, 024032 (2001).

[17] A. Datta, K. Huitu, J. Laamanen, and B. Mukhopadhyaya, Linear collider signals of an invisible Higgs boson in theories of large extra dimensions, Phys. Rev. D **70**, 075003 (2004).

[18] S. Kanemura, S. Matsumoto, T. Nabeshima, and N. Okada, Can WIMP dark matter overcome the nightmare scenario?, Phys. Rev. D **82**, 055026 (2010).

[19] A. Djouadi, O. Lebedev, Y. Mambrini, and J. Quevillon, Implications of LHC searches for Higgs-portal dark matter, Phys. Lett. B **709**, 65 (2012).

[20] A. Djouadi, A. Falkowski, Y. Mambrini, and J. Quevillon, Direct detection of Higgs-portal dark matter at the LHC, Eur. Phys. J. C **73**, 2455 (2013).

[21] R. E. Shrock and M. Suzuki, Invisible decays of Higgs bosons, Phys. Lett. **110B**, 250 (1982).

[22] D. Choudhury and D. P. Roy, Signatures of an invisibly decaying Higgs particle at LHC, Phys. Lett. B **322**, 368 (1994).

[23] O. J. P. Eboli and D. Zeppenfeld, Observing an invisible Higgs boson, Phys. Lett. B **495**, 147 (2000).

[24] H. Davoudiasl, T. Han, and H. E. Logan, Discovering an invisibly decaying Higgs at hadron colliders, Phys. Rev. D **71**, 115007 (2005).

[25] R. M. Godbole, M. Guchait, K. Mazumdar, S. Moretti, and D. P. Roy, Search for ‘invisible’ Higgs signals at LHC via associated production with gauge bosons, Phys. Lett. B **571**, 184 (2003).

[26] D. Ghosh, R. Godbole, M. Guchait, K. Mohan, and D. Sengupta, Looking for an invisible Higgs signal at the LHC, Phys. Lett. B **725**, 344 (2013).

[27] G. Belanger, B. Dumont, U. Ellwanger, J. F. Gunion, and S. Kraml, Status of invisible Higgs decays, Phys. Lett. B **723**, 340 (2013).

[28] D. Curtin *et al.*, Exotic decays of the 125 GeV Higgs boson, Phys. Rev. D **90**, 075004 (2014).

[29] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z axis along the beam pipe. The x axis points to the center 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 z axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. The distance between two objects in η–ϕ space is $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. Transverse momentum is defined by $p_{\mathrm{T}} = p\sin\theta$.

[30] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, J. Instrum. **3**, S08003 (2008).

[31] ATLAS Collaboration, ATLAS insertable B-layer technical design report, CERN Report No. ATLAS-TDR-19, 2010, http://cds.cern.ch/record/1291633; Addendum, CERN Report No. ATLAS-TDR-19-ADD-1, 2012, http://cds.cern.ch/record/1451888.

[32] B. Abbott *et al.*, Production and integration of the ATLAS insertable B-layer, J. Instrum. **13**, T05008 (2018).

[33] ATLAS Collaboration, Search for invisible decays of a Higgs boson using vector-boson fusion in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, J. High Energy Phys. 01 (2016) 172.

[34] ATLAS Collaboration, Search for Invisible Decays of a Higgs Boson Produced in Association with a Z Boson in ATLAS, Phys. Rev. Lett. **112**, 201802 (2014).

[35] ATLAS Collaboration, Search for invisible decays of the Higgs boson produced in association with a hadronically decaying vector boson in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, Eur. Phys. J. C **75**, 337 (2015).
[36] ATLAS Collaboration, Constraints on new phenomena via Higgs boson couplings and invisible decays with the ATLAS detector, J. High Energy Phys. 11 (2015) 206.
[37] ATLAS Collaboration, Search for invisible Higgs boson decays in vector boson fusion at $\sqrt{s} = 13$ TeV with the ATLAS detector, arXiv:1809.06682.
[38] ATLAS Collaboration, Search for an invisibly decaying Higgs boson or dark matter candidates produced in association with a Z boson in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Lett. B **776**, 318 (2018).
[39] ATLAS Collaboration, Search for dark matter in events with a hadronically decaying vector boson and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, J. High Energy Phys. 10 (2018) 180.
[40] CMS Collaboration, Search for invisible decays of a Higgs boson produced through vector boson fusion in proton-proton collisions at $\sqrt{s} = 13$ TeV, Phys. Lett. B, https://doi.org/10.1016/j.physletb.2019.04.025.
[41] CMS Collaboration, Search for new physics in events with a leptonically decaying Z boson and a large transverse momentum imbalance in proton-proton collisions at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C **78**, 291 (2018).
[42] CMS Collaboration, Search for new physics in final states with an energetic jet or a hadronically decaying W or Z boson and transverse momentum imbalance at $\sqrt{s} = 13$ TeV, Phys. Rev. D **97**, 092005 (2018).
[43] CMS Collaboration, Searches for invisible decays of the Higgs boson in pp collisions at $\sqrt{s} = 7$, 8, and 13 TeV, J. High Energy Phys. 02 (**2017**) 135.
[44] CMS Collaboration, Search for invisible decays of Higgs bosons in the vector boson fusion and associated ZH production modes, Eur. Phys. J. C **74**, 2980 (2014).
[45] M. Cacciari, G. P. Salam, and G. Soyez, The anti-k_t jet clustering algorithm, J. High Energy Phys. 04 (2008) 063.
[46] M. Grazzini, S. Kallweit, and D. Rathlev, ZZ production at the LHC: Fiducial cross sections and distributions in NNLO QCD, Phys. Lett. B **750**, 407 (2015).
[47] F. Caola, K. Melnikov, R. Rontsch, and L. Tancredi, QCD corrections to ZZ production in gluon fusion at the LHC, Phys. Rev. D **92**, 094028 (2015).
[48] D. Krohn, J. Thaler, and L.-T. Wang, Jet trimming, J. High Energy Phys. 02 (2010) 084.
[49] ATLAS Collaboration, Jet mass reconstruction with the ATLAS Detector in early Run 2 data, CERN Report No. ATLAS-CONF-2016-035, 2016, https://cds.cern.ch/record/2200211.
[50] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, Eur. Phys. J. C **71**, 1554 (2011); Erratum, Eur. Phys. J. C **73**, 2501(E) (2013).
[51] W. Verkerke and D. P. Kirkby, The RooFit toolkit for data modeling, eConf **C0303241**, MOLT007 (2003).
[52] L. Moneta *et al.*, The RooStats project, Proc. Sci., ACAT2010 (**2010**) 057.
[53] A. L. Read, Presentation of search results: The CL$_s$ technique, J. Phys. G **28**, 2693 (2002).
[54] ATLAS Collaboration, Jet energy measurement and its systematic uncertainty in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, Eur. Phys. J. C **75**, 17 (2015).
[55] ATLAS Collaboration, Jet energy scale measurements and their systematic uncertainties in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Rev. D **96**, 072002 (2017).
[56] I. W. Stewart and F. J. Tackmann, Theory uncertainties for Higgs and other searches using jet bins, Phys. Rev. D **85**, 034011 (2012).
[57] L. Lyons, D. Gibaut, and P. Clifford, How to combine correlated estimates of a single physical quantity, Nucl. Instrum. Methods Phys. Res., Sect. A **270**, 110 (1988).
[58] F. Petricca *et al.*, First results on low-mass dark matter from the CRESST-III experiment, in *15th International Conference on Topics in Astroparticle and Underground Physics (TAUP 2017) Sudbury, Ontario, Canada*, arXiv:1711.07692.
[59] D. S. Akerib *et al.*, Results from a Search for Dark Matter in the Complete LUX Exposure, Phys. Rev. Lett. **118**, 021303 (2017).
[60] X. Cui *et al.*, Dark Matter Results From 54-Ton-Day Exposure of PandaX-II Experiment, Phys. Rev. Lett. **119**, 181302 (2017).
[61] E. Aprile *et al.*, Dark Matter Search Results from a One Ton-Year Exposure of XENON1T, Phys. Rev. Lett. **121**, 111302 (2018).
[62] P. Agnes *et al.*, Low-Mass Dark Matter Search with the DarkSide-50 Experiment, Phys. Rev. Lett. **121**, 081307 (2018).
[63] B. Patt and F. Wilczek, Higgs-field portal into hidden sectors, arXiv:hep-ph/0605188.
[64] P. J. Fox, R. Harnik, J. Kopp, and Y. Tsai, Missing energy signatures of dark matter at the LHC, Phys. Rev. D **85**, 056011 (2012).
[65] A. De Simone, G. F. Giudice, and A. Strumia, Benchmarks for dark matter searches at the LHC, J. High Energy Phys. 06 (2014) 081.
[66] M. Hoferichter, P. Klos, J. Menéndez, and A. Schwenk, Improved Limits for Higgs-Portal Dark Matter from LHC Searches, Phys. Rev. Lett. **119**, 181803 (2017).
[67] ATLAS Collaboration, ATLAS computing acknowledgements, CERN Report No. ATL-GEN-PUB-2016-002, https://cds.cern.ch/record/2202407.

M. Aaboud,[35d] G. Aad,[101] B. Abbott,[128] D. C. Abbott,[102] O. Abdinov,[13,a] A. Abed Abud,[70a,70b] D. K. Abhayasinghe,[93]
S. H. Abidi,[167] O. S. AbouZeid,[40] N. L. Abraham,[156] H. Abramowicz,[161] H. Abreu,[160] Y. Abulaiti,[6] B. S. Acharya,[66a,66b,b]
S. Adachi,[163] L. Adam,[99] C. Adam Bourdarios,[132] L. Adamczyk,[83a] L. Adamek,[167] J. Adelman,[121] M. Adersberger,[114]
A. Adiguzel,[12c,c] S. Adorni,[54] T. Adye,[144] A. A. Affolder,[146] Y. Afik,[160] C. Agapopoulou,[132] M. N. Agaras,[38]
A. Aggarwal,[119] C. Agheorghiesei,[27c] J. A. Aguilar-Saavedra,[140f,140a,d] F. Ahmadov,[79] G. Aielli,[73a,73b] S. Akatsuka,[85]
T. P. A. Åkesson,[96] E. Akilli,[54] A. V. Akimov,[110] K. Al Khoury,[132] G. L. Alberghi,[23b,23a] J. Albert,[176]
M. J. Alconada Verzini,[88] S. Alderweireldt,[119] M. Aleksa,[36] I. N. Aleksandrov,[79] C. Alexa,[27b] D. Alexandre,[19]
T. Alexopoulos,[10] A. Alfonsi,[120] M. Alhroob,[128] B. Ali,[142] G. Alimonti,[68a] J. Alison,[37] S. P. Alkire,[148] C. Allaire,[132]
B. M. M. Allbrooke,[156] B. W. Allen,[131] P. P. Allport,[21] A. Aloisio,[69a,69b] A. Alonso,[40] F. Alonso,[88] C. Alpigiani,[148]
A. A. Alshehri,[57] M. I. Alstaty,[101] M. Alvarez Estevez,[98] B. Alvarez Gonzalez,[36] D. Álvarez Piqueras,[174]
M. G. Alviggi,[69a,69b] Y. Amaral Coutinho,[80b] A. Ambler,[103] L. Ambroz,[135] C. Amelung,[26] D. Amidei,[105]
S. P. Amor Dos Santos,[140a,140c] S. Amoroso,[46] C. S. Amrouche,[54] F. An,[78] C. Anastopoulos,[149] N. Andari,[145] T. Andeen,[11]
C. F. Anders,[61b] J. K. Anders,[20] A. Andreazza,[68a,68b] V. Andrei,[61a] C. R. Anelli,[176] S. Angelidakis,[38] I. Angelozzi,[120]
A. Angerami,[39] A. V. Anisenkov,[122b,122a] A. Annovi,[71a] C. Antel,[61a] M. T. Anthony,[149] M. Antonelli,[51] D. J. A. Antrim,[171]
F. Anulli,[72a] M. Aoki,[81] J. A. Aparisi Pozo,[174] L. Aperio Bella,[36] G. Arabidze,[106] J. P. Araque,[140a] V. Araujo Ferraz,[80b]
R. Araujo Pereira,[80b] A. T. H. Arce,[49] F. A. Arduh,[88] J-F. Arguin,[109] S. Argyropoulos,[77] J.-H. Arling,[46] A. J. Armbruster,[36]
L. J. Armitage,[92] A. Armstrong,[171] O. Arnaez,[167] H. Arnold,[120] A. Artamonov,[111,a] G. Artoni,[135] S. Artz,[99] S. Asai,[163]
N. Asbah,[59] E. M. Asimakopoulou,[172] L. Asquith,[156] K. Assamagan,[29] R. Astalos,[28a] R. J. Atkin,[33a] M. Atkinson,[173]
N. B. Atlay,[151] H. Atmani,[132] K. Augsten,[142] G. Avolio,[36] R. Avramidou,[60a] M. K. Ayoub,[15a] A. M. Azoulay,[168b]
G. Azuelos,[109,e] A. E. Baas,[61a] M. J. Baca,[21] H. Bachacou,[145] K. Bachas,[67a,67b] M. Backes,[135] F. Backman,[45a,45b]
P. Bagnaia,[72a,72b] M. Bahmani,[84] H. Bahrasemani,[152] A. J. Bailey,[174] V. R. Bailey,[173] J. T. Baines,[144] M. Bajic,[40] C. Bakalis,[10]
O. K. Baker,[183] P. J. Bakker,[120] D. Bakshi Gupta,[8] S. Balaji,[157] E. M. Baldin,[122b,122a] P. Balek,[180] F. Balli,[145]
W. K. Balunas,[135] J. Balz,[99] E. Banas,[84] A. Bandyopadhyay,[24] Sw. Banerjee,[181,f] A. A. E. Bannoura,[182] L. Barak,[161]
W. M. Barbe,[38] E. L. Barberio,[104] D. Barberis,[55b,55a] M. Barbero,[101] T. Barillari,[115] M-S. Barisits,[36] J. Barkeloo,[131]
T. Barklow,[153] R. Barnea,[160] S. L. Barnes,[60c] B. M. Barnett,[144] R. M. Barnett,[18] Z. Barnovska-Blenessy,[60a] A. Baroncelli,[60a]
G. Barone,[29] A. J. Barr,[135] L. Barranco Navarro,[174] F. Barreiro,[98] J. Barreiro Guimarães da Costa,[15a] R. Bartoldus,[153]
G. Bartolini,[101] A. E. Barton,[89] P. Bartos,[28a] A. Basalaev,[46] A. Bassalat,[132] R. L. Bates,[57] S. J. Batista,[167] S. Batlamous,[35e]
J. R. Batley,[32] B. Batool,[151] M. Battaglia,[146] M. Bauce,[72a,72b] F. Bauer,[145] K. T. Bauer,[171] H. S. Bawa,[31,g] J. B. Beacham,[126]
T. Beau,[136] P. H. Beauchemin,[170] P. Bechtle,[24] H. C. Beck,[53] H. P. Beck,[20,h] K. Becker,[52] M. Becker,[99] C. Becot,[46]
A. Beddall,[12d] A. J. Beddall,[12a] V. A. Bednyakov,[79] M. Bedognetti,[120] C. P. Bee,[155] T. A. Beermann,[76] M. Begalli,[80b]
M. Begel,[29] A. Behera,[155] J. K. Behr,[46] F. Beisiegel,[24] A. S. Bell,[94] G. Bella,[161] L. Bellagamba,[23b] A. Bellerive,[34] P. Bellos,[9]
K. Beloborodov,[122b,122a] K. Belotskiy,[112] N. L. Belyaev,[112] O. Benary,[161,a] D. Benchekroun,[35a] N. Benekos,[10]
Y. Benhammou,[161] D. P. Benjamin,[6] M. Benoit,[54] J. R. Bensinger,[26] S. Bentvelsen,[120] L. Beresford,[135] M. Beretta,[51]
D. Berge,[46] E. Bergeaas Kuutmann,[172] N. Berger,[5] B. Bergmann,[142] L. J. Bergsten,[26] J. Beringer,[18] S. Berlendis,[7]
N. R. Bernard,[102] G. Bernardi,[136] C. Bernius,[153] F. U. Bernlochner,[24] T. Berry,[93] P. Berta,[99] C. Bertella,[15a] G. Bertoli,[45a,45b]
I. A. Bertram,[89] G. J. Besjes,[40] O. Bessidskaia Bylund,[182] N. Besson,[145] A. Bethani,[100] S. Bethke,[115] A. Betti,[24]
A. J. Bevan,[92] J. Beyer,[115] R. Bi,[139] R. M. Bianchi,[139] O. Biebel,[114] D. Biedermann,[19] R. Bielski,[36] K. Bierwagen,[99]
N. V. Biesuz,[71a,71b] M. Biglietti,[74a] T. R. V. Billoud,[109] M. Bindi,[53] A. Bingul,[12d] C. Bini,[72a,72b] S. Biondi,[23b,23a] M. Birman,[180]
T. Bisanz,[53] J. P. Biswal,[161] A. Bitadze,[100] C. Bittrich,[48] D. M. Bjergaard,[49] J. E. Black,[153] K. M. Black,[25] T. Blazek,[28a]
I. Bloch,[46] C. Blocker,[26] A. Blue,[57] U. Blumenschein,[92] G. J. Bobbink,[120] V. S. Bobrovnikov,[122b,122a] S. S. Bocchetta,[96]
A. Bocci,[49] D. Boerner,[46] D. Bogavac,[114] A. G. Bogdanchikov,[122b,122a] C. Bohm,[45a] V. Boisvert,[93] P. Bokan,[53,172] T. Bold,[83a]
A. S. Boldyrev,[113] A. E. Bolz,[61b] M. Bomben,[136] M. Bona,[92] J. S. Bonilla,[131] M. Boonekamp,[145] H. M. Borecka-Bielska,[90]
A. Borisov,[123] G. Borissov,[89] J. Bortfeldt,[36] D. Bortoletto,[135] V. Bortolotto,[73a,73b] D. Boscherini,[23b] M. Bosman,[14]
J. D. Bossio Sola,[30] K. Bouaouda,[35a] J. Boudreau,[139] E. V. Bouhova-Thacker,[89] D. Boumediene,[38] S. K. Boutle,[57]
A. Boveia,[126] J. Boyd,[36] D. Boye,[33b] I. R. Boyko,[79] A. J. Bozson,[93] J. Bracinik,[21] N. Brahimi,[101] G. Brandt,[182] O. Brandt,[61a]
F. Braren,[46] U. Bratzler,[164] B. Brau,[102] J. E. Brau,[131] W. D. Breaden Madden,[57] K. Brendlinger,[46] L. Brenner,[46]
R. Brenner,[172] S. Bressler,[180] B. Brickwedde,[99] D. L. Briglin,[21] D. Britton,[57] D. Britzger,[115] I. Brock,[24] R. Brock,[106]
G. Brooijmans,[39] T. Brooks,[93] W. K. Brooks,[147b] E. Brost,[121] J. H Broughton,[21] P. A. Bruckman de Renstrom,[84]
D. Bruncko,[28b] A. Bruni,[23b] G. Bruni,[23b] L. S. Bruni,[120] S. Bruno,[73a,73b] B. H. Brunt,[32] M. Bruschi,[23b] N. Bruscino,[139]

P. Bryant,[37] L. Bryngemark,[96] T. Buanes,[17] Q. Buat,[36] P. Buchholz,[151] A. G. Buckley,[57] I. A. Budagov,[79] M. K. Bugge,[134]
F. Bührer,[52] O. Bulekov,[112] T. J. Burch,[121] S. Burdin,[90] C. D. Burgard,[120] A. M. Burger,[129] B. Burghgrave,[8] K. Burka,[84]
J. T. P. Burr,[46] V. Büscher,[99] E. Buschmann,[53] P. J. Bussey,[57] J. M. Butler,[25] C. M. Buttar,[57] J. M. Butterworth,[94] P. Butti,[36]
W. Buttinger,[36] A. Buzatu,[158] A. R. Buzykaev,[122b,122a] G. Cabras,[23b,23a] S. Cabrera Urbán,[174] D. Caforio,[142] H. Cai,[173]
V. M. M. Cairo,[153] O. Cakir,[4a] N. Calace,[36] P. Calafiura,[18] A. Calandri,[101] G. Calderini,[136] P. Calfayan,[65] G. Callea,[57]
L. P. Caloba,[80b] S. Calvente Lopez,[98] D. Calvet,[38] S. Calvet,[38] T. P. Calvet,[155] M. Calvetti,[71a,71b] R. Camacho Toro,[136]
S. Camarda,[36] D. Camarero Munoz,[98] P. Camarri,[73a,73b] D. Cameron,[134] R. Caminal Armadans,[102] C. Camincher,[36]
S. Campana,[36] M. Campanelli,[94] A. Camplani,[40] A. Campoverde,[151] V. Canale,[69a,69b] A. Canesse,[103] M. Cano Bret,[60c]
J. Cantero,[129] T. Cao,[161] Y. Cao,[173] M. D. M. Capeans Garrido,[36] M. Capua,[41b,41a] R. Cardarelli,[73a] F. C. Cardillo,[149]
I. Carli,[143] T. Carli,[36] G. Carlino,[69a] B. T. Carlson,[139] L. Carminati,[68a,68b] R. M. D. Carney,[45a,45b] S. Caron,[119] E. Carquin,[147b]
S. Carrá,[68a,68b] J. W. S. Carter,[167] M. P. Casado,[14,i] A. F. Casha,[167] D. W. Casper,[171] R. Castelijn,[120] F. L. Castillo,[174]
V. Castillo Gimenez,[174] N. F. Castro,[140a,140e] A. Catinaccio,[36] J. R. Catmore,[134] A. Cattai,[36] J. Caudron,[24] V. Cavaliere,[29]
E. Cavallaro,[14] D. Cavalli,[68a] M. Cavalli-Sforza,[14] V. Cavasinni,[71a,71b] E. Celebi,[12b] F. Ceradini,[74a,74b] L. Cerda Alberich,[174]
A. S. Cerqueira,[80a] A. Cerri,[156] L. Cerrito,[73a,73b] F. Cerutti,[18] A. Cervelli,[23b,23a] S. A. Cetin,[12b] A. Chafaq,[35a]
D. Chakraborty,[121] S. K. Chan,[59] W. S. Chan,[120] W. Y. Chan,[90] J. D. Chapman,[32] B. Chargeishvili,[159b] D. G. Charlton,[21]
C. C. Chau,[34] C. A. Chavez Barajas,[156] S. Che,[126] A. Chegwidden,[106] S. Chekanov,[6] S. V. Chekulaev,[168a] G. A. Chelkov,[79,j]
M. A. Chelstowska,[36] B. Chen,[78] C. Chen,[60a] C. H. Chen,[78] H. Chen,[29] J. Chen,[60a] J. Chen,[39] S. Chen,[137] S. J. Chen,[15c]
X. Chen,[15b,k] Y. Chen,[82] Y-H. Chen,[46] H. C. Cheng,[63a] H. J. Cheng,[15a,15d] A. Cheplakov,[79] E. Cheremushkina,[123]
R. Cherkaoui El Moursli,[35e] E. Cheu,[7] K. Cheung,[64] T. J. A. Chevalérias,[145] L. Chevalier,[145] V. Chiarella,[51] G. Chiarelli,[71a]
G. Chiodini,[67a] A. S. Chisholm,[36,21] A. Chitan,[27b] I. Chiu,[163] Y. H. Chiu,[176] M. V. Chizhov,[79] K. Choi,[65] A. R. Chomont,[132]
S. Chouridou,[162] Y. S. Chow,[120] M. C. Chu,[63a] J. Chudoba,[141] A. J. Chuinard,[103] J. J. Chwastowski,[84] L. Chytka,[130]
D. Cinca,[47] V. Cindro,[91] I. A. Cioară,[27b] A. Ciocio,[18] F. Cirotto,[69a,69b] Z. H. Citron,[180] M. Citterio,[68a] B. M. Ciungu,[167]
A. Clark,[54] M. R. Clark,[39] P. J. Clark,[50] C. Clement,[45a,45b] Y. Coadou,[101] M. Cobal,[66a,66c] A. Coccaro,[55b] J. Cochran,[78]
H. Cohen,[161] A. E. C. Coimbra,[180] L. Colasurdo,[119] B. Cole,[39] A. P. Colijn,[120] J. Collot,[58] P. Conde Muiño,[140a,l]
E. Coniavitis,[52] S. H. Connell,[33b] I. A. Connelly,[57] S. Constantinescu,[27b] F. Conventi,[69a,m] A. M. Cooper-Sarkar,[135]
F. Cormier,[175] K. J. R. Cormier,[167] L. D. Corpe,[94] M. Corradi,[72a,72b] E. E. Corrigan,[96] F. Corriveau,[103,n]
A. Cortes-Gonzalez,[36] M. J. Costa,[174] F. Costanza,[5] D. Costanzo,[149] G. Cowan,[93] J. W. Cowley,[32] J. Crane,[100] K. Cranmer,[124]
S. J. Crawley,[57] R. A. Creager,[137] S. Crépé-Renaudin,[58] F. Crescioli,[136] M. Cristinziani,[24] V. Croft,[120] G. Crosetti,[41b,41a]
A. Cueto,[5] T. Cuhadar Donszelmann,[149] A. R. Cukierman,[153] S. Czekierda,[84] P. Czodrowski,[36]
M. J. Da Cunha Sargedas De Sousa,[60b] J. V. Da Fonseca Pinto,[80b] C. Da Via,[100] W. Dabrowski,[83a] T. Dado,[28a] S. Dahbi,[35e]
T. Dai,[105] C. Dallapiccola,[102] M. Dam,[40] G. D'amen,[23b,23a] J. Damp,[99] J. R. Dandoy,[137] M. F. Daneri,[30] N. P. Dang,[181]
N. D Dann,[100] M. Danninger,[175] V. Dao,[36] G. Darbo,[55b] O. Dartsi,[5] A. Dattagupta,[131] T. Daubney,[46] S. D'Auria,[68a,68b]
W. Davey,[24] C. David,[46] T. Davidek,[143] D. R. Davis,[49] E. Dawe,[104] I. Dawson,[149] K. De,[8] R. De Asmundis,[69a]
A. De Benedetti,[128] M. De Beurs,[120] S. De Castro,[23b,23a] S. De Cecco,[72a,72b] N. De Groot,[119] P. de Jong,[120] H. De la Torre,[106]
A. De Maria,[15c] D. De Pedis,[72a] A. De Salvo,[72a] U. De Sanctis,[73a,73b] M. De Santis,[73a,73b] A. De Santo,[156]
K. De Vasconcelos Corga,[101] J. B. De Vivie De Regie,[132] C. Debenedetti,[146] D. V. Dedovich,[79] A. M. Deiana,[42]
M. Del Gaudio,[41b,41a] J. Del Peso,[98] Y. Delabat Diaz,[46] D. Delgove,[132] F. Deliot,[145] C. M. Delitzsch,[7] M. Della Pietra,[69a,69b]
D. Della Volpe,[54] A. Dell'Acqua,[36] L. Dell'Asta,[25] M. Delmastro,[5] C. Delporte,[132] P. A. Delsart,[58] D. A. DeMarco,[167]
S. Demers,[183] M. Demichev,[79] G. Demontigny,[109] S. P. Denisov,[123] D. Denysiuk,[120] L. D'Eramo,[136] D. Derendarz,[84]
J. E. Derkaoui,[35d] F. Derue,[136] P. Dervan,[90] K. Desch,[24] C. Deterre,[46] K. Dette,[167] M. R. Devesa,[30] P. O. Deviveiros,[36]
A. Dewhurst,[144] S. Dhaliwal,[26] F. A. Di Bello,[54] A. Di Ciaccio,[73a,73b] L. Di Ciaccio,[5] W. K. Di Clemente,[137]
C. Di Donato,[69a,69b] A. Di Girolamo,[36] G. Di Gregorio,[71a,71b] B. Di Micco,[74a,74b] R. Di Nardo,[102] K. F. Di Petrillo,[59]
R. Di Sipio,[167] D. Di Valentino,[34] C. Diaconu,[101] F. A. Dias,[40] T. Dias Do Vale,[140a,140e] M. A. Diaz,[147a] J. Dickinson,[18]
E. B. Diehl,[105] J. Dietrich,[19] S. Díez Cornell,[46] A. Dimitrievska,[18] W. Ding,[15b] J. Dingfelder,[24] F. Dittus,[36] F. Djama,[101]
T. Djobava,[159b] J. I. Djuvsland,[17] M. A. B. Do Vale,[80c] M. Dobre,[27b] D. Dodsworth,[26] C. Doglioni,[96] J. Dolejsi,[143]
Z. Dolezal,[143] M. Donadelli,[80d] J. Donini,[38] A. D'onofrio,[92] M. D'Onofrio,[90] J. Dopke,[144] A. Doria,[69a] M. T. Dova,[88]
A. T. Doyle,[57] E. Drechsler,[152] E. Dreyer,[152] S. S. Dreyer,[61a] T. Dreyer,[53] Y. Du,[60b] Y. Duan,[60b] F. Dubinin,[110]
M. Dubovsky,[28a] A. Dubreuil,[54] E. Duchovni,[180] G. Duckeck,[114] A. Ducourthial,[136] O. A. Ducu,[109,o] D. Duda,[115]
A. Dudarev,[36] A. C. Dudder,[99] E. M. Duffield,[18] L. Duflot,[132] M. Dührssen,[36] C. Dülsen,[182] M. Dumancic,[180]

A. E. Dumitriu,[27b] A. K. Duncan,[57] M. Dunford,[61a] A. Duperrin,[101] H. Duran Yildiz,[4a] M. Düren,[56] A. Durglishvili,[159b] D. Duschinger,[48] B. Dutta,[46] D. Duvnjak,[1] G. I. Dyckes,[137] M. Dyndal,[46] S. Dysch,[100] B. S. Dziedzic,[84] K. M. Ecker,[115] R. C. Edgar,[105] T. Eifert,[36] G. Eigen,[17] K. Einsweiler,[18] T. Ekelof,[172] M. El Kacimi,[35c] R. El Kosseifi,[101] V. Ellajosyula,[172] M. Ellert,[172] F. Ellinghaus,[182] A. A. Elliot,[92] N. Ellis,[36] J. Elmsheuser,[29] M. Elsing,[36] D. Emeliyanov,[144] A. Emerman,[39] Y. Enari,[163] J. S. Ennis,[178] M. B. Epland,[49] J. Erdmann,[47] A. Ereditato,[20] M. Escalier,[132] C. Escobar,[174] O. Estrada Pastor,[174] A. I. Etienvre,[145] E. Etzion,[161] H. Evans,[65] A. Ezhilov,[138] M. Ezzi,[35e] F. Fabbri,[57] L. Fabbri,[23b,23a] V. Fabiani,[119] G. Facini,[94] R. M. Faisca Rodrigues Pereira,[140a] R. M. Fakhrutdinov,[123] S. Falciano,[72a] P. J. Falke,[5] S. Falke,[5] J. Faltova,[143] Y. Fang,[15a] Y. Fang,[15a] G. Fanourakis,[44] M. Fanti,[68a,68b] A. Farbin,[8] A. Farilla,[74a] E. M. Farina,[70a,70b] T. Farooque,[106] S. Farrell,[18] S. M. Farrington,[178] P. Farthouat,[36] F. Fassi,[35e] P. Fassnacht,[36] D. Fassouliotis,[9] M. Faucci Giannelli,[50] W. J. Fawcett,[32] L. Fayard,[132] O. L. Fedin,[138,p] W. Fedorko,[175] M. Feickert,[42] S. Feigl,[134] L. Feligioni,[101] A. Fell,[149] C. Feng,[60b] E. J. Feng,[36] M. Feng,[49] M. J. Fenton,[57] A. B. Fenyuk,[123] J. Ferrando,[46] A. Ferrari,[172] P. Ferrari,[120] R. Ferrari,[70a] D. E. Ferreira de Lima,[61b] A. Ferrer,[174] D. Ferrere,[54] C. Ferretti,[105] F. Fiedler,[99] A. Filipčič,[91] F. Filthaut,[119] K. D. Finelli,[25] M. C. N. Fiolhais,[140a] L. Fiorini,[174] C. Fischer,[14] F. Fischer,[114] W. C. Fisher,[106] I. Fleck,[151] P. Fleischmann,[105] R. R. M. Fletcher,[137] T. Flick,[182] B. M. Flierl,[114] L. F. Flores,[137] L. R. Flores Castillo,[63a] F. M. Follega,[75a,75b] N. Fomin,[17] G. T. Forcolin,[75a,75b] A. Formica,[145] F. A. Förster,[14] A. C. Forti,[100] A. G. Foster,[21] D. Fournier,[132] H. Fox,[89] S. Fracchia,[149] P. Francavilla,[71a,71b] M. Franchini,[23b,23a] S. Franchino,[61a] D. Francis,[36] L. Franconi,[20] M. Franklin,[59] M. Frate,[171] A. N. Fray,[92] B. Freund,[109] W. S. Freund,[80b] E. M. Freundlich,[47] D. C. Frizzell,[128] D. Froidevaux,[36] J. A. Frost,[135] C. Fukunaga,[164] E. Fullana Torregrosa,[174] E. Fumagalli,[55b,55a] T. Fusayasu,[116] J. Fuster,[174] A. Gabrielli,[23b,23a] A. Gabrielli,[18] G. P. Gach,[83a] S. Gadatsch,[54] P. Gadow,[115] G. Gagliardi,[55b,55a] L. G. Gagnon,[109] C. Galea,[27b] B. Galhardo,[140a,140c] E. J. Gallas,[135] B. J. Gallop,[144] P. Gallus,[142] G. Galster,[40] R. Gamboa Goni,[92] K. K. Gan,[126] S. Ganguly,[180] J. Gao,[60a] Y. Gao,[90] Y. S. Gao,[31,g] C. García,[174] J. E. García Navarro,[174] J. A. García Pascual,[15a] C. Garcia-Argos,[52] M. Garcia-Sciveres,[18] R. W. Gardner,[37] N. Garelli,[153] S. Gargiulo,[52] V. Garonne,[134] A. Gaudiello,[55b,55a] G. Gaudio,[70a] I. L. Gavrilenko,[110] A. Gavrilyuk,[111] C. Gay,[175] G. Gaycken,[24] E. N. Gazis,[10] C. N. P. Gee,[144] J. Geisen,[53] M. Geisen,[99] M. P. Geisler,[61a] C. Gemme,[55b] M. H. Genest,[58] C. Geng,[105] S. Gentile,[72a,72b] S. George,[93] T. Geralis,[44] D. Gerbaudo,[14] L. O. Gerlach,[53] G. Gessner,[47] S. Ghasemi,[151] M. Ghasemi Bostanabad,[176] M. Ghneimat,[24] A. Ghosh,[77] B. Giacobbe,[23b] S. Giagu,[72a,72b] N. Giangiacomi,[23b,23a] P. Giannetti,[71a] A. Giannini,[69a,69b] S. M. Gibson,[93] M. Gignac,[146] D. Gillberg,[34] G. Gilles,[182] D. M. Gingrich,[3,e] M. P. Giordani,[66a,66c] F. M. Giorgi,[23b] P. F. Giraud,[145] G. Giugliarelli,[66a,66c] D. Giugni,[68a] F. Giuli,[135] M. Giulini,[61b] S. Gkaitatzis,[162] I. Gkialas,[9,q] E. L. Gkougkousis,[14] P. Gkountoumis,[10] L. K. Gladilin,[113] C. Glasman,[98] J. Glatzer,[14] P. C. F. Glaysher,[46] A. Glazov,[46] M. Goblirsch-Kolb,[26] S. Goldfarb,[104] T. Golling,[54] D. Golubkov,[123] A. Gomes,[140a,140b] R. Goncalves Gama,[53] R. Gonçalo,[140a,140b] G. Gonella,[52] L. Gonella,[21] A. Gongadze,[79] F. Gonnella,[21] J. L. Gonski,[59] S. González de la Hoz,[174] S. Gonzalez-Sevilla,[54] G. R. Gonzalvo Rodriguez,[174] L. Goossens,[36] P. A. Gorbounov,[111] H. A. Gordon,[29] B. Gorini,[36] E. Gorini,[67a,67b] A. Gorišek,[91] A. T. Goshaw,[49] C. Gössling,[47] M. I. Gostkin,[79] C. A. Gottardo,[24] C. R. Goudet,[132] D. Goujdami,[35c] A. G. Goussiou,[148] N. Govender,[33b,r] C. Goy,[5] E. Gozani,[160] I. Grabowska-Bold,[83a] P. O. J. Gradin,[172] E. C. Graham,[90] J. Gramling,[171] E. Gramstad,[134] S. Grancagnolo,[19] M. Grandi,[156] V. Gratchev,[138] P. M. Gravila,[27f] F. G. Gravili,[67a,67b] C. Gray,[57] H. M. Gray,[18] C. Grefe,[24] K. Gregersen,[96] I. M. Gregor,[46] P. Grenier,[153] K. Grevtsov,[46] N. A. Grieser,[128] J. Griffiths,[8] A. A. Grillo,[146] K. Grimm,[31,s] S. Grinstein,[14,t] J.-F. Grivaz,[132] S. Groh,[99] E. Gross,[180] J. Grosse-Knetter,[53] Z. J. Grout,[94] C. Grud,[105] A. Grummer,[118] L. Guan,[105] W. Guan,[181] J. Guenther,[36] A. Guerguichon,[132] F. Guescini,[168a] D. Guest,[171] R. Gugel,[52] B. Gui,[126] T. Guillemin,[5] S. Guindon,[36] U. Gul,[57] J. Guo,[60c] W. Guo,[105] Y. Guo,[60a,u] Z. Guo,[101] R. Gupta,[46] S. Gurbuz,[12c] G. Gustavino,[128] P. Gutierrez,[128] C. Gutschow,[94] C. Guyot,[145] M. P. Guzik,[83a] C. Gwenlan,[135] C. B. Gwilliam,[90] A. Haas,[124] C. Haber,[18] H. K. Hadavand,[8] N. Haddad,[35e] A. Hadef,[60a] S. Hageböck,[36] M. Hagihara,[169] M. Haleem,[177] J. Haley,[129] G. Halladjian,[106] G. D. Hallewell,[101] K. Hamacher,[182] P. Hamal,[130] K. Hamano,[176] H. Hamdaoui,[35e] G. N. Hamity,[149] K. Han,[60a,v] L. Han,[60a] S. Han,[15a,15d] K. Hanagaki,[81,w] M. Hance,[146] D. M. Handl,[114] B. Haney,[137] R. Hankache,[136] P. Hanke,[61a] E. Hansen,[96] J. B. Hansen,[40] J. D. Hansen,[40] M. C. Hansen,[24] P. H. Hansen,[40] E. C. Hanson,[100] K. Hara,[169] A. S. Hard,[181] T. Harenberg,[182] S. Harkusha,[107] P. F. Harrison,[178] N. M. Hartmann,[114] Y. Hasegawa,[150] A. Hasib,[50] S. Hassani,[145] S. Haug,[20] R. Hauser,[106] L. Hauswald,[48] L. B. Havener,[39] M. Havranek,[142] C. M. Hawkes,[21] R. J. Hawkings,[36] D. Hayden,[106] C. Hayes,[155] R. L. Hayes,[175] C. P. Hays,[135] J. M. Hays,[92] H. S. Hayward,[90] S. J. Haywood,[144] F. He,[60a] M. P. Heath,[50] V. Hedberg,[96] L. Heelan,[8] S. Heer,[24] K. K. Heidegger,[52] J. Heilman,[34] S. Heim,[46] T. Heim,[18] B. Heinemann,[46,x] J. J. Heinrich,[131] L. Heinrich,[36] C. Heinz,[56] J. Hejbal,[141] L. Helary,[61b] A. Held,[175] S. Hellesund,[134] C. M. Helling,[146] S. Hellman,[45a,45b]

C. Helsens,[36] R. C. W. Henderson,[89] Y. Heng,[181] S. Henkelmann,[175] A. M. Henriques Correia,[36] G. H. Herbert,[19] H. Herde,[26]
V. Herget,[177] Y. Hernández Jiménez,[33c] H. Herr,[99] M. G. Herrmann,[114] T. Herrmann,[48] G. Herten,[52] R. Hertenberger,[114]
L. Hervas,[36] T. C. Herwig,[137] G. G. Hesketh,[94] N. P. Hessey,[168a] A. Higashida,[163] S. Higashino,[81] E. Higón-Rodriguez,[174]
K. Hildebrand,[37] E. Hill,[176] J. C. Hill,[32] K. K. Hill,[29] K. H. Hiller,[46] S. J. Hillier,[21] M. Hils,[48] I. Hinchliffe,[18]
F. Hinterkeuser,[24] M. Hirose,[133] S. Hirose,[52] D. Hirschbuehl,[182] B. Hiti,[91] O. Hladik,[141] D. R. Hlaluku,[33c] X. Hoad,[50]
J. Hobbs,[155] N. Hod,[180] M. C. Hodgkinson,[149] A. Hoecker,[36] F. Hoenig,[114] D. Hohn,[52] D. Hohov,[132] T. R. Holmes,[37]
M. Holzbock,[114] L. B. A. H Hommels,[32] S. Honda,[169] T. Honda,[81] T. M. Hong,[139] A. Hönle,[115] B. H. Hooberman,[173]
W. H. Hopkins,[6] Y. Horii,[117] P. Horn,[48] A. J. Horton,[152] L. A. Horyn,[37] J-Y. Hostachy,[58] A. Hostiuc,[148] S. Hou,[158]
A. Hoummada,[35a] J. Howarth,[100] J. Hoya,[88] M. Hrabovsky,[130] J. Hrdinka,[76] I. Hristova,[19] J. Hrivnac,[132] A. Hrynevich,[108]
T. Hryn'ova,[5] P. J. Hsu,[64] S.-C. Hsu,[148] Q. Hu,[29] S. Hu,[60c] Y. Huang,[15a] Z. Hubacek,[142] F. Hubaut,[101] M. Huebner,[24]
F. Huegging,[24] T. B. Huffman,[135] M. Huhtinen,[36] R. F. H. Hunter,[34] P. Huo,[155] A. M. Hupe,[34] N. Huseynov,[79,y] J. Huston,[106]
J. Huth,[59] R. Hyneman,[105] S. Hyrych,[28a] G. Iacobucci,[54] G. Iakovidis,[29] I. Ibragimov,[151] L. Iconomidou-Fayard,[132]
Z. Idrissi,[35e] P. I. Iengo,[36] R. Ignazzi,[40] O. Igonkina,[120,z] R. Iguchi,[163] T. Iizawa,[54] Y. Ikegami,[81] M. Ikeno,[81] D. Iliadis,[162]
N. Ilic,[119] F. Iltzsche,[48] G. Introzzi,[70a,70b] M. Iodice,[74a] K. Iordanidou,[39] V. Ippolito,[72a,72b] M. F. Isacson,[172] N. Ishijima,[133]
M. Ishino,[163] M. Ishitsuka,[165] W. Islam,[129] C. Issever,[135] S. Istin,[160] F. Ito,[169] J. M. Iturbe Ponce,[63a] R. Iuppa,[75a,75b]
A. Ivina,[180] H. Iwasaki,[81] J. M. Izen,[43] V. Izzo,[69a] P. Jacka,[141] P. Jackson,[1] R. M. Jacobs,[24] V. Jain,[2] G. Jäkel,[182]
K. B. Jakobi,[99] K. Jakobs,[52] S. Jakobsen,[76] T. Jakoubek,[141] J. Jamieson,[57] D. O. Jamin,[129] R. Jansky,[54] J. Janssen,[24]
M. Janus,[53] P. A. Janus,[83a] G. Jarlskog,[96] N. Javadov,[79,y] T. Javůrek,[36] M. Javurkova,[52] F. Jeanneau,[145] L. Jeanty,[131]
J. Jejelava,[159a,aa] A. Jelinskas,[178] P. Jenni,[52,bb] J. Jeong,[46] N. Jeong,[46] S. Jézéquel,[5] H. Ji,[181] J. Jia,[155] H. Jiang,[78] Y. Jiang,[60a]
Z. Jiang,[153,cc] S. Jiggins,[52] F. A. Jimenez Morales,[38] J. Jimenez Pena,[174] S. Jin,[15c] A. Jinaru,[27b] O. Jinnouchi,[165] H. Jivan,[33c]
P. Johansson,[149] K. A. Johns,[7] C. A. Johnson,[65] K. Jon-And,[45a,45b] R. W. L. Jones,[89] S. D. Jones,[156] S. Jones,[7] T. J. Jones,[90]
J. Jongmanns,[61a] P. M. Jorge,[140a,140b] J. Jovicevic,[168a] X. Ju,[18] J. J. Junggeburth,[115] A. Juste Rozas,[14,t] A. Kaczmarska,[84]
M. Kado,[132] H. Kagan,[126] M. Kagan,[153] T. Kaji,[179] E. Kajomovitz,[160] C. W. Kalderon,[96] A. Kaluza,[99] A. Kamenshchikov,[123]
L. Kanjir,[91] Y. Kano,[163] V. A. Kantserov,[112] J. Kanzaki,[81] L. S. Kaplan,[181] D. Kar,[33c] M. J. Kareem,[168b] E. Karentzos,[10]
S. N. Karpov,[79] Z. M. Karpova,[79] V. Kartvelishvili,[89] A. N. Karyukhin,[123] L. Kashif,[181] R. D. Kass,[126] A. Kastanas,[45a,45b]
Y. Kataoka,[163] C. Kato,[60d,60c] J. Katzy,[46] K. Kawade,[82] K. Kawagoe,[87] T. Kawaguchi,[117] T. Kawamoto,[163] G. Kawamura,[53]
E. F. Kay,[176] V. F. Kazanin,[122b,122a] R. Keeler,[176] R. Kehoe,[42] J. S. Keller,[34] E. Kellermann,[96] J. J. Kempster,[21] J. Kendrick,[21]
O. Kepka,[141] S. Kersten,[182] B. P. Kerševan,[91] S. Ketabchi Haghighat,[167] R. A. Keyes,[103] M. Khader,[173] F. Khalil-Zada,[13]
A. Khanov,[129] A. G. Kharlamov,[122b,122a] T. Kharlamova,[122b,122a] E. E. Khoda,[175] A. Khodinov,[166] T. J. Khoo,[54] E. Khramov,[79]
J. Khubua,[159b] S. Kido,[82] M. Kiehn,[54] C. R. Kilby,[93] Y. K. Kim,[37] N. Kimura,[66a,66c] O. M. Kind,[19] B. T. King,[90,a]
D. Kirchmeier,[48] J. Kirk,[144] A. E. Kiryunin,[115] T. Kishimoto,[163] V. Kitali,[46] O. Kivernyk,[5] E. Kladiva,[28b,a]
T. Klapdor-Kleingrothaus,[52] M. H. Klein,[105] M. Klein,[90] U. Klein,[90] K. Kleinknecht,[99] P. Klimek,[121] A. Klimentov,[29]
T. Klingl,[24] T. Klioutchnikova,[36] F. F. Klitzner,[114] P. Kluit,[120] S. Kluth,[115] E. Kneringer,[76] E. B. F. G. Knoops,[101] A. Knue,[52]
D. Kobayashi,[87] T. Kobayashi,[163] M. Kobel,[48] M. Kocian,[153] P. Kodys,[143] P. T. Koenig,[24] T. Koffas,[34] N. M. Köhler,[115]
T. Koi,[153] M. Kolb,[61b] I. Koletsou,[5] T. Kondo,[81] N. Kondrashova,[60c] K. Köneke,[52] A. C. König,[119] T. Kono,[125]
R. Konoplich,[124,dd] V. Konstantinides,[94] N. Konstantinidis,[94] B. Konya,[96] R. Kopeliansky,[65] S. Koperny,[83a] K. Korcyl,[84]
K. Kordas,[162] G. Koren,[161] A. Korn,[94] I. Korolkov,[14] E. V. Korolkova,[149] N. Korotkova,[113] O. Kortner,[115] S. Kortner,[115]
T. Kosek,[143] V. V. Kostyukhin,[24] A. Kotwal,[49] A. Koulouris,[10] A. Kourkoumeli-Charalampidi,[70a,70b] C. Kourkoumelis,[9]
E. Kourlitis,[149] V. Kouskoura,[29] A. B. Kowalewska,[84] R. Kowalewski,[176] C. Kozakai,[163] W. Kozanecki,[145] A. S. Kozhin,[123]
V. A. Kramarenko,[113] G. Kramberger,[91] D. Krasnopevtsev,[60a] M. W. Krasny,[136] A. Krasznahorkay,[36] D. Krauss,[115]
J. A. Kremer,[83a] J. Kretzschmar,[90] P. Krieger,[167] A. Krishnan,[61b] K. Krizka,[18] K. Kroeninger,[47] H. Kroha,[115] J. Kroll,[141]
J. Kroll,[137] J. Krstic,[16] U. Kruchonak,[79] H. Krüger,[24] N. Krumnack,[78] M. C. Kruse,[49] T. Kubota,[104] S. Kuday,[4b]
J. T. Kuechler,[46] S. Kuehn,[36] A. Kugel,[61a] T. Kuhl,[46] V. Kukhtin,[79] R. Kukla,[101] Y. Kulchitsky,[107,ee] S. Kuleshov,[147b]
Y. P. Kulinich,[173] M. Kuna,[58] T. Kunigo,[85] A. Kupco,[141] T. Kupfer,[47] O. Kuprash,[52] H. Kurashige,[82] L. L. Kurchaninov,[168a]
Y. A. Kurochkin,[107] A. Kurova,[112] M. G. Kurth,[15a,15d] E. S. Kuwertz,[36] M. Kuze,[165] A. K. Kvam,[148] J. Kvita,[130] T. Kwan,[103]
A. La Rosa,[115] J. L. La Rosa Navarro,[80d] L. La Rotonda,[41b,41a] F. La Ruffa,[41b,41a] C. Lacasta,[174] F. Lacava,[72a,72b]
D. P. J. Lack,[100] H. Lacker,[19] D. Lacour,[136] E. Ladygin,[79] R. Lafaye,[5] B. Laforge,[136] T. Lagouri,[33c] S. Lai,[53] S. Lammers,[65]
W. Lampl,[7] E. Lançon,[29] U. Landgraf,[52] M. P. J. Landon,[92] M. C. Lanfermann,[54] V. S. Lang,[46] J. C. Lange,[53]
R. J. Langenberg,[36] A. J. Lankford,[171] F. Lanni,[29] K. Lantzsch,[24] A. Lanza,[70a] A. Lapertosa,[55b,55a] S. Laplace,[136]

J. F. Laporte,[145] T. Lari,[68a] F. Lasagni Manghi,[23b,23a] M. Lassnig,[36] T. S. Lau,[63a] A. Laudrain,[132] A. Laurier,[34]
M. Lavorgna,[69a,69b] M. Lazzaroni,[68a,68b] B. Le,[104] O. Le Dortz,[136] E. Le Guirriec,[101] M. LeBlanc,[7] T. LeCompte,[6]
F. Ledroit-Guillon,[58] C. A. Lee,[29] G. R. Lee,[147a] L. Lee,[59] S. C. Lee,[158] S. J. Lee,[34] B. Lefebvre,[168a] M. Lefebvre,[176]
F. Legger,[114] C. Leggett,[18] K. Lehmann,[152] N. Lehmann,[182] G. Lehmann Miotto,[36] W. A. Leight,[46] A. Leisos,[162,ff]
M. A. L. Leite,[80d] R. Leitner,[143] D. Lellouch,[180,a] K. J. C. Leney,[42] T. Lenz,[24] B. Lenzi,[36] R. Leone,[7] S. Leone,[71a]
C. Leonidopoulos,[50] A. Leopold,[136] G. Lerner,[156] C. Leroy,[109] R. Les,[167] C. G. Lester,[32] M. Levchenko,[138] J. Levêque,[5]
D. Levin,[105] L. J. Levinson,[180] D. J. Lewis,[21] B. Li,[15b] B. Li,[105] C-Q. Li,[60a,gg] F. Li,[60c] H. Li,[60a] H. Li,[60b] J. Li,[60c] K. Li,[153]
L. Li,[60c] M. Li,[15a] Q. Li,[15a,15d] Q. Y. Li,[60a] S. Li,[60d,60c] X. Li,[46] Y. Li,[46] Z. Liang,[15a] B. Liberti,[73a] A. Liblong,[167] K. Lie,[63c]
S. Liem,[120] C. Y. Lin,[32] K. Lin,[106] T. H. Lin,[99] R. A. Linck,[65] J. H. Lindon,[21] A. L. Lionti,[54] E. Lipeles,[137] A. Lipniacka,[17]
M. Lisovyi,[61b] T. M. Liss,[173,hh] A. Lister,[175] A. M. Litke,[146] J. D. Little,[8] B. Liu,[78] B L Liu,[6] H. B. Liu,[29] H. Liu,[105]
J. B. Liu,[60a] J. K. K. Liu,[135] K. Liu,[136] M. Liu,[60a] P. Liu,[18] Y. Liu,[15a,15d] Y. L. Liu,[105] Y. W. Liu,[60a] M. Livan,[70a,70b] A. Lleres,[58]
J. Llorente Merino,[15a] S. L. Lloyd,[92] C. Y. Lo,[63b] F. Lo Sterzo,[42] E. M. Lobodzinska,[46] P. Loch,[7] S. Loffredo,[73a,73b]
T. Lohse,[19] K. Lohwasser,[149] M. Lokajicek,[141] J. D. Long,[173] R. E. Long,[89] L. Longo,[36] K. A. Looper,[126] J. A. Lopez,[147b]
I. Lopez Paz,[100] A. Lopez Solis,[149] J. Lorenz,[114] N. Lorenzo Martinez,[5] M. Losada,[22] P. J. Lösel,[114] A. Lösle,[52] X. Lou,[46]
X. Lou,[15a] A. Lounis,[132] J. Love,[6] P. A. Love,[89] J. J. Lozano Bahilo,[174] H. Lu,[63a] M. Lu,[60a] Y. J. Lu,[64] H. J. Lubatti,[148]
C. Luci,[72a,72b] A. Lucotte,[58] C. Luedtke,[52] F. Luehring,[65] I. Luise,[136] L. Luminari,[72a] B. Lund-Jensen,[154] M. S. Lutz,[102]
D. Lynn,[29] R. Lysak,[141] E. Lytken,[96] F. Lyu,[15a] V. Lyubushkin,[79] T. Lyubushkina,[79] H. Ma,[29] L. L. Ma,[60b] Y. Ma,[60b]
G. Maccarrone,[51] A. Macchiolo,[115] C. M. Macdonald,[149] J. Machado Miguens,[137,140b] D. Madaffari,[174] R. Madar,[38]
W. F. Mader,[48] N. Madysa,[48] J. Maeda,[82] K. Maekawa,[163] S. Maeland,[17] T. Maeno,[29] M. Maerker,[48] A. S. Maevskiy,[113]
V. Magerl,[52] N. Magini,[78] D. J. Mahon,[39] C. Maidantchik,[80b] T. Maier,[114] A. Maio,[140a,140b,140d] O. Majersky,[28a]
S. Majewski,[131] Y. Makida,[81] N. Makovec,[132] B. Malaescu,[136] Pa. Malecki,[84] V. P. Maleev,[138] F. Malek,[58] U. Mallik,[77]
D. Malon,[6] C. Malone,[32] S. Maltezos,[10] S. Malyukov,[36] J. Mamuzic,[174] G. Mancini,[51] I. Mandić,[91]
L. Manhaes de Andrade Filho,[80a] I. M. Maniatis,[162] J. Manjarres Ramos,[48] K. H. Mankinen,[96] A. Mann,[114] A. Manousos,[76]
B. Mansoulie,[145] I. Manthos,[162] S. Manzoni,[120] A. Marantis,[162] G. Marceca,[30] L. Marchese,[135] G. Marchiori,[136]
M. Marcisovsky,[141] C. Marcon,[96] C. A. Marin Tobon,[36] M. Marjanovic,[38] F. Marroquim,[80b] Z. Marshall,[18]
M. U. F Martensson,[172] S. Marti-Garcia,[174] C. B. Martin,[126] T. A. Martin,[178] V. J. Martin,[50] B. Martin dit Latour,[17]
M. Martinez,[14,t] V. I. Martinez Outschoorn,[102] S. Martin-Haugh,[144] V. S. Martoiu,[27b] A. C. Martyniuk,[94] A. Marzin,[36]
L. Masetti,[99] T. Mashimo,[163] R. Mashinistov,[110] J. Masik,[100] A. L. Maslennikov,[122b,122a] L. H. Mason,[104] L. Massa,[73a,73b]
P. Massarotti,[69a,69b] P. Mastrandrea,[71a,71b] A. Mastroberardino,[41b,41a] T. Masubuchi,[163] A. Matic,[114] P. Mättig,[24] J. Maurer,[27b]
B. Maček,[91] S. J. Maxfield,[90] D. A. Maximov,[122b,122a] R. Mazini,[158] I. Maznas,[162] S. M. Mazza,[146] S. P. Mc Kee,[105]
T. G. McCarthy,[115] L. I. McClymont,[94] W. P. McCormack,[18] E. F. McDonald,[104] J. A. Mcfayden,[36] G. Mchedlidze,[53]
M. A. McKay,[42] K. D. McLean,[176] S. J. McMahon,[144] P. C. McNamara,[104] C. J. McNicol,[178] R. A. McPherson,[176,n]
J. E. Mdhluli,[33c] Z. A. Meadows,[102] S. Meehan,[148] T. Megy,[52] S. Mehlhase,[114] A. Mehta,[90] T. Meideck,[58] B. Meirose,[43]
D. Melini,[174] B. R. Mellado Garcia,[33c] J. D. Mellenthin,[53] M. Melo,[28a] F. Meloni,[46] A. Melzer,[24] S. B. Menary,[100]
E. D. Mendes Gouveia,[140a,140e] L. Meng,[36] X. T. Meng,[105] S. Menke,[115] E. Meoni,[41b,41a] S. Mergelmeyer,[19]
S. A. M. Merkt,[139] C. Merlassino,[20] P. Mermod,[54] L. Merola,[69a,69b] C. Meroni,[68a] O. Meshkov,[113] J. K. R. Meshreki,[151]
A. Messina,[72a,72b] J. Metcalfe,[6] A. S. Mete,[171] C. Meyer,[65] J. Meyer,[160] J-P. Meyer,[145] H. Meyer Zu Theenhausen,[61a]
F. Miano,[156] R. P. Middleton,[144] L. Mijović,[50] G. Mikenberg,[180] M. Mikestikova,[141] M. Mikuž,[91] H. Mildner,[149]
M. Milesi,[104] A. Milic,[167] D. A. Millar,[92] D. W. Miller,[37] A. Milov,[180] D. A. Milstead,[45a,45b] R. A. Mina,[153,cc]
A. A. Minaenko,[123] M. Miñano Moya,[174] I. A. Minashvili,[159b] A. I. Mincer,[124] B. Mindur,[83a] M. Mineev,[79] Y. Minegishi,[163]
Y. Ming,[181] L. M. Mir,[14] A. Mirto,[67a,67b] K. P. Mistry,[137] T. Mitani,[179] J. Mitrevski,[114] V. A. Mitsou,[174] M. Mittal,[60c]
A. Miucci,[20] P. S. Miyagawa,[149] A. Mizukami,[81] J. U. Mjörnmark,[96] T. Mkrtchyan,[184] M. Mlynarikova,[143] T. Moa,[45a,45b]
K. Mochizuki,[109] P. Mogg,[52] S. Mohapatra,[39] R. Moles-Valls,[24] M. C. Mondragon,[106] K. Mönig,[46] J. Monk,[40] E. Monnier,[101]
A. Montalbano,[152] J. Montejo Berlingen,[36] M. Montella,[94] F. Monticelli,[88] S. Monzani,[68a] N. Morange,[132] D. Moreno,[22]
M. Moreno Llácer,[36] P. Morettini,[55b] M. Morgenstern,[120] S. Morgenstern,[48] D. Mori,[152] M. Morii,[59] M. Morinaga,[179]
V. Morisbak,[134] A. K. Morley,[36] G. Mornacchi,[36] A. P. Morris,[94] L. Morvaj,[155] P. Moschovakos,[10] B. Moser,[120]
M. Mosidze,[159b] H. J. Moss,[149] J. Moss,[31,ii] K. Motohashi,[165] E. Mountricha,[36] E. J. W. Moyse,[102] S. Muanza,[101]
F. Mueller,[115] J. Mueller,[139] R. S. P. Mueller,[114] D. Muenstermann,[89] G. A. Mullier,[96] J. L. Munoz Martinez,[14]
F. J. Munoz Sanchez,[100] P. Murin,[28b] W. J. Murray,[178,144] A. Murrone,[68a,68b] M. Muškinja,[18] C. Mwewa,[33a]

A. G. Myagkov,[123,jj] J. Myers,[131] M. Myska,[142] B. P. Nachman,[18] O. Nackenhorst,[47] A. Nag Nag,[48] K. Nagai,[135] K. Nagano,[81] Y. Nagasaka,[62] M. Nagel,[52] E. Nagy,[101] A. M. Nairz,[36] Y. Nakahama,[117] K. Nakamura,[81] T. Nakamura,[163] I. Nakano,[127] H. Nanjo,[133] F. Napolitano,[61a] R. F. Naranjo Garcia,[46] R. Narayan,[11] D. I. Narrias Villar,[61a] I. Naryshkin,[138] T. Naumann,[46] G. Navarro,[22] H. A. Neal,[105,a] P. Y. Nechaeva,[110] F. Nechansky,[46] T. J. Neep,[145] A. Negri,[70a,70b] M. Negrini,[23b] S. Nektarijevic,[119] C. Nellist,[53] M. E. Nelson,[135] S. Nemecek,[141] P. Nemethy,[124] M. Nessi,[36,kk] M. S. Neubauer,[173] M. Neumann,[182] P. R. Newman,[21] T. Y. Ng,[63c] Y. S. Ng,[19] Y. W. Y. Ng,[171] H. D. N. Nguyen,[101] T. Nguyen Manh,[109] E. Nibigira,[38] R. B. Nickerson,[135] R. Nicolaidou,[145] D. S. Nielsen,[40] J. Nielsen,[146] N. Nikiforou,[11] V. Nikolaenko,[123,jj] I. Nikolic-Audit,[136] K. Nikolopoulos,[21] P. Nilsson,[29] H. R. Nindhito,[54] Y. Ninomiya,[81] A. Nisati,[72a] N. Nishu,[60c] R. Nisius,[115] I. Nitsche,[47] T. Nitta,[179] T. Nobe,[163] Y. Noguchi,[85] M. Nomachi,[133] I. Nomidis,[136] M. A. Nomura,[29] M. Nordberg,[36] N. Norjoharuddeen,[135] T. Novak,[91] O. Novgorodova,[48] R. Novotny,[142] L. Nozka,[130] K. Ntekas,[171] E. Nurse,[94] F. Nuti,[104] F. G. Oakham,[34,e] H. Oberlack,[115] J. Ocariz,[136] A. Ochi,[82] I. Ochoa,[39] J. P. Ochoa-Ricoux,[147a] K. O'Connor,[26] S. Oda,[87] S. Odaka,[81] S. Oerdek,[53] A. Ogrodnik,[83a] A. Oh,[100] S. H. Oh,[49] C. C. Ohm,[154] H. Oide,[55b,55a] M. L. Ojeda,[167] H. Okawa,[169] Y. Okazaki,[85] Y. Okumura,[163] T. Okuyama,[81] A. Olariu,[27b] L. F. Oleiro Seabra,[140a] S. A. Olivares Pino,[147a] D. Oliveira Damazio,[29] J. L. Oliver,[1] M. J. R. Olsson,[171] A. Olszewski,[84] J. Olszowska,[84] D. C. O'Neil,[152] A. Onofre,[140a,140e] K. Onogi,[117] P. U. E. Onyisi,[11] H. Oppen,[134] M. J. Oreglia,[37] G. E. Orellana,[88] Y. Oren,[161] D. Orestano,[74a,74b] N. Orlando,[14] R. S. Orr,[167] B. Osculati,[55b,55a,a] V. O'Shea,[57] R. Ospanov,[60a] G. Otero y Garzon,[30] H. Otono,[87] M. Ouchrif,[35d] F. Ould-Saada,[134] A. Ouraou,[145] Q. Ouyang,[15a] M. Owen,[57] R. E. Owen,[21] V. E. Ozcan,[12c] N. Ozturk,[8] J. Pacalt,[130] H. A. Pacey,[32] K. Pachal,[49] A. Pacheco Pages,[14] C. Padilla Aranda,[14] S. Pagan Griso,[18] M. Paganini,[183] G. Palacino,[65] S. Palazzo,[50] S. Palestini,[36] M. Palka,[83b] D. Pallin,[38] I. Panagoulias,[10] C. E. Pandini,[36] J. G. Panduro Vazquez,[93] P. Pani,[46] G. Panizzo,[66a,66c] L. Paolozzi,[54] C. Papadatos,[109] K. Papageorgiou,[9,q] A. Paramonov,[6] D. Paredes Hernandez,[63b] S. R. Paredes Saenz,[135] B. Parida,[166] T. H. Park,[167] A. J. Parker,[89] M. A. Parker,[32] F. Parodi,[55b,55a] E. W. P. Parrish,[121] J. A. Parsons,[39] U. Parzefall,[52] L. Pascual Dominguez,[136] V. R. Pascuzzi,[167] J. M. P. Pasner,[146] E. Pasqualucci,[72a] S. Passaggio,[55b] F. Pastore,[93] P. Pasuwan,[45a,45b] S. Pataraia,[99] J. R. Pater,[100] A. Pathak,[181] T. Pauly,[36] B. Pearson,[115] M. Pedersen,[134] L. Pedraza Diaz,[119] R. Pedro,[140a,140b] S. V. Peleganchuk,[122b,122a] O. Penc,[141] C. Peng,[15a] H. Peng,[60a] B. S. Peralva,[80a] M. M. Perego,[132] A. P. Pereira Peixoto,[140a,140e] D. V. Perepelitsa,[29] F. Peri,[19] L. Perini,[68a,68b] H. Pernegger,[36] S. Perrella,[69a,69b] V. D. Peshekhonov,[79,a] K. Peters,[46] R. F. Y. Peters,[100] B. A. Petersen,[36] T. C. Petersen,[40] E. Petit,[58] A. Petridis,[1] C. Petridou,[162] P. Petroff,[132] M. Petrov,[135] F. Petrucci,[74a,74b] M. Pettee,[183] N. E. Pettersson,[102] K. Petukhova,[143] A. Peyaud,[145] R. Pezoa,[147b] T. Pham,[104] F. H. Phillips,[106] P. W. Phillips,[144] M. W. Phipps,[173] G. Piacquadio,[155] E. Pianori,[18] A. Picazio,[102] R. H. Pickles,[100] R. Piegaia,[30] D. Pietreanu,[27b] J. E. Pilcher,[37] A. D. Pilkington,[100] M. Pinamonti,[73a,73b] J. L. Pinfold,[3] M. Pitt,[180] L. Pizzimento,[73a,73b] M.-A. Pleier,[29] V. Pleskot,[143] E. Plotnikova,[79] D. Pluth,[78] P. Podberezko,[122b,122a] R. Poettgen,[96] R. Poggi,[54] L. Poggioli,[132] I. Pogrebnyak,[106] D. Pohl,[24] I. Pokharel,[53] G. Polesello,[70a] A. Poley,[18] A. Policicchio,[72a,72b] R. Polifka,[36] A. Polini,[23b] C. S. Pollard,[46] V. Polychronakos,[29] D. Ponomarenko,[112] L. Pontecorvo,[36] S. Popa,[27a] G. A. Popeneciu,[27d] D. M. Portillo Quintero,[136] S. Pospisil,[142] K. Potamianos,[46] I. N. Potrap,[79] C. J. Potter,[32] H. Potti,[11] T. Poulsen,[96] J. Poveda,[36] T. D. Powell,[149] G. Pownall,[46] M. E. Pozo Astigarraga,[36] P. Pralavorio,[101] S. Prell,[78] D. Price,[100] M. Primavera,[67a] S. Prince,[103] M. L. Proffitt,[148] N. Proklova,[112] K. Prokofiev,[63c] F. Prokoshin,[147b] S. Protopopescu,[29] J. Proudfoot,[6] M. Przybycien,[83a] A. Puri,[173] P. Puzo,[132] J. Qian,[105] Y. Qin,[100] A. Quadt,[53] M. Queitsch-Maitland,[46] A. Qureshi,[1] P. Rados,[104] F. Ragusa,[68a,68b] G. Rahal,[97] J. A. Raine,[54] S. Rajagopalan,[29] A. Ramirez Morales,[92] K. Ran,[15a,15d] T. Rashid,[132] S. Raspopov,[5] M. G. Ratti,[68a,68b] D. M. Rauch,[46] F. Rauscher,[114] S. Rave,[99] B. Ravina,[149] I. Ravinovich,[180] J. H. Rawling,[100] M. Raymond,[36] A. L. Read,[134] N. P. Readioff,[58] M. Reale,[67a,67b] D. M. Rebuzzi,[70a,70b] A. Redelbach,[177] G. Redlinger,[29] R. G. Reed,[33c] K. Reeves,[43] L. Rehnisch,[19] J. Reichert,[137] D. Reikher,[161] A. Reiss,[99] A. Rej,[151] C. Rembser,[36] H. Ren,[15a] M. Rescigno,[72a] S. Resconi,[68a] E. D. Resseguie,[137] S. Rettie,[175] E. Reynolds,[21] O. L. Rezanova,[122b,122a] P. Reznicek,[143] E. Ricci,[75a,75b] R. Richter,[115] S. Richter,[46] E. Richter-Was,[83b] O. Ricken,[24] M. Ridel,[136] P. Rieck,[115] C. J. Riegel,[182] O. Rifki,[46] M. Rijssenbeek,[155] A. Rimoldi,[70a,70b] M. Rimoldi,[20] L. Rinaldi,[23b] G. Ripellino,[154] B. Ristić,[89] E. Ritsch,[36] I. Riu,[14] J. C. Rivera Vergara,[147a] F. Rizatdinova,[129] E. Rizvi,[92] C. Rizzi,[36] R. T. Roberts,[100] S. H. Robertson,[103,n] D. Robinson,[32] J. E. M. Robinson,[46] A. Robson,[57] E. Rocco,[99] C. Roda,[71a,71b] Y. Rodina,[101] S. Rodriguez Bosca,[174] A. Rodriguez Perez,[14] D. Rodriguez Rodriguez,[174] A. M. Rodríguez Vera,[168b] S. Roe,[36] O. Røhne,[134] R. Röhrig,[115] C. P. A. Roland,[65] J. Roloff,[59] A. Romaniouk,[112] M. Romano,[23b,23a] N. Rompotis,[90] M. Ronzani,[124] L. Roos,[136] S. Rosati,[72a] K. Rosbach,[52] N-A. Rosien,[53] G. Rosin,[102] B. J. Rosser,[137] E. Rossi,[46] E. Rossi,[74a,74b] E. Rossi,[69a,69b] L. P. Rossi,[55b] L. Rossini,[68a,68b] J. H. N. Rosten,[32] R. Rosten,[14]

M. Rotaru,[27b] J. Rothberg,[148] D. Rousseau,[132] D. Roy,[33c] A. Rozanov,[101] Y. Rozen,[160] X. Ruan,[33c] F. Rubbo,[153] F. Rühr,[52] A. Ruiz-Martinez,[174] A. Rummler,[36] Z. Rurikova,[52] N. A. Rusakovich,[79] H. L. Russell,[103] L. Rustige,[38,47] J. P. Rutherfoord,[7] E. M. Rüttinger,[46,ll] Y. F. Ryabov,[138] M. Rybar,[39] G. Rybkin,[132] S. Ryu,[6] A. Ryzhov,[123] G. F. Rzehorz,[53] P. Sabatini,[53] G. Sabato,[120] S. Sacerdoti,[132] H. F-W. Sadrozinski,[146] R. Sadykov,[79] F. Safai Tehrani,[72a] P. Saha,[121] S. Saha,[103] M. Sahinsoy,[61a] A. Sahu,[182] M. Saimpert,[46] M. Saito,[163] T. Saito,[163] H. Sakamoto,[163] A. Sakharov,[124,dd] D. Salamani,[54] G. Salamanna,[74a,74b] J. E. Salazar Loyola,[147b] P. H. Sales De Bruin,[172] D. Salihagic,[115,a] A. Salnikov,[153] J. Salt,[174] D. Salvatore,[41b,41a] F. Salvatore,[156] A. Salvucci,[63a,63b,63c] A. Salzburger,[36] J. Samarati,[36] D. Sammel,[52] D. Sampsonidis,[162] D. Sampsonidou,[162] J. Sánchez,[174] A. Sanchez Pineda,[66a,66c] H. Sandaker,[134] C. O. Sander,[46] M. Sandhoff,[182] C. Sandoval,[22] D. P. C. Sankey,[144] M. Sannino,[55b,55a] Y. Sano,[117] A. Sansoni,[51] C. Santoni,[38] H. Santos,[140a,140b] S. N. Santpur,[18] A. Santra,[174] A. Sapronov,[79] J. G. Saraiva,[140a,140d] O. Sasaki,[81] K. Sato,[169] E. Sauvan,[5] P. Savard,[167,e] N. Savic,[115] R. Sawada,[163] C. Sawyer,[144] L. Sawyer,[95,mm] C. Sbarra,[23b] A. Sbrizzi,[23a] T. Scanlon,[94] J. Schaarschmidt,[148] P. Schacht,[115] B. M. Schachtner,[114] D. Schaefer,[37] L. Schaefer,[137] J. Schaeffer,[99] S. Schaepe,[36] U. Schäfer,[99] A. C. Schaffer,[132] D. Schaile,[114] R. D. Schamberger,[155] N. Scharmberg,[100] V. A. Schegelsky,[138] D. Scheirich,[143] F. Schenck,[19] M. Schernau,[171] C. Schiavi,[55b,55a] S. Schier,[146] L. K. Schildgen,[24] Z. M. Schillaci,[26] E. J. Schioppa,[36] M. Schioppa,[41b,41a] K. E. Schleicher,[52] S. Schlenker,[36] K. R. Schmidt-Sommerfeld,[115] K. Schmieden,[36] C. Schmitt,[99] S. Schmitt,[46] S. Schmitz,[99] J. C. Schmoeckel,[46] U. Schnoor,[52] L. Schoeffel,[145] A. Schoening,[61b] E. Schopf,[135] M. Schott,[99] J. F. P. Schouwenberg,[119] J. Schovancova,[36] S. Schramm,[54] A. Schulte,[99] H-C. Schultz-Coulon,[61a] M. Schumacher,[52] B. A. Schumm,[146] Ph. Schune,[145] A. Schwartzman,[153] T. A. Schwarz,[105] Ph. Schwemling,[145] R. Schwienhorst,[106] A. Sciandra,[24] G. Sciolla,[26] M. Scornajenghi,[41b,41a] F. Scuri,[71a] F. Scutti,[104] L. M. Scyboz,[115] C. D. Sebastiani,[72a,72b] P. Seema,[19] S. C. Seidel,[118] A. Seiden,[146] T. Seiss,[37] J. M. Seixas,[80b] G. Sekhniaidze,[69a] K. Sekhon,[105] S. J. Sekula,[42] N. Semprini-Cesari,[23b,23a] S. Sen,[49] S. Senkin,[38] C. Serfon,[76] L. Serin,[132] L. Serkin,[66a,66b] M. Sessa,[60a] H. Severini,[128] F. Sforza,[170] A. Sfyrla,[54] E. Shabalina,[53] J. D. Shahinian,[146] N. W. Shaikh,[45a,45b] D. Shaked Renous,[180] L. Y. Shan,[15a] R. Shang,[173] J. T. Shank,[25] M. Shapiro,[18] A. S. Sharma,[1] A. Sharma,[135] P. B. Shatalov,[111] K. Shaw,[156] S. M. Shaw,[100] A. Shcherbakova,[138] Y. Shen,[128] N. Sherafati,[34] A. D. Sherman,[25] P. Sherwood,[94] L. Shi,[158,nn] S. Shimizu,[81] C. O. Shimmin,[183] Y. Shimogama,[179] M. Shimojima,[116] I. P. J. Shipsey,[135] S. Shirabe,[87] M. Shiyakova,[79,oo] J. Shlomi,[180] A. Shmeleva,[110] M. J. Shochet,[37] S. Shojaii,[104] D. R. Shope,[128] S. Shrestha,[126] E. Shulga,[180] P. Sicho,[141] A. M. Sickles,[173] P. E. Sidebo,[154] E. Sideras Haddad,[33c] O. Sidiropoulou,[36] A. Sidoti,[23b,23a] F. Siegert,[48] Dj. Sijacki,[16] M. Silva Jr.,[181] M. V. Silva Oliveira,[80a] S. B. Silverstein,[45a] S. Simion,[132] E. Simioni,[99] M. Simon,[99] R. Simoniello,[99] P. Sinervo,[167] N. B. Sinev,[131] M. Sioli,[23b,23a] I. Siral,[105] S. Yu. Sivoklokov,[113] J. Sjölin,[45a,45b] E. Skorda,[96] P. Skubic,[128] M. Slawinska,[84] K. Sliwa,[170] R. Slovak,[143] V. Smakhtin,[180] B. H. Smart,[144] J. Smiesko,[28a] N. Smirnov,[112] S. Yu. Smirnov,[112] Y. Smirnov,[112] L. N. Smirnova,[113,pp] O. Smirnova,[96] J. W. Smith,[53] M. Smizanska,[89] K. Smolek,[142] A. Smykiewicz,[84] A. A. Snesarev,[110] I. M. Snyder,[131] S. Snyder,[29] R. Sobie,[176,n] A. M. Soffa,[171] A. Soffer,[161] A. Søgaard,[50] F. Sohns,[53] G. Sokhrannyi,[91] C. A. Solans Sanchez,[36] E. Yu. Soldatov,[112] U. Soldevila,[174] A. A. Solodkov,[123] A. Soloshenko,[79] O. V. Solovyanov,[123] V. Solovyev,[138] P. Sommer,[149] H. Son,[170] W. Song,[144] W. Y. Song,[168b] A. Sopczak,[142] F. Sopkova,[28b] C. L. Sotiropoulou,[71a,71b] S. Sottocornola,[70a,70b] R. Soualah,[66a,66c,qq] A. M. Soukharev,[122b,122a] D. South,[46] S. Spagnolo,[67a,67b] M. Spalla,[115] M. Spangenberg,[178] F. Spanò,[93] D. Sperlich,[19] T. M. Spieker,[61a] R. Spighi,[23b] G. Spigo,[36] L. A. Spiller,[104] M. Spina,[156] D. P. Spiteri,[57] M. Spousta,[143] A. Stabile,[68a,68b] B. L. Stamas,[121] R. Stamen,[61a] M. Stamenkovic,[120] S. Stamm,[19] E. Stanecka,[84] R. W. Stanek,[6] B. Stanislaus,[135] M. M. Stanitzki,[46] M. Stankaityte,[135] B. Stapf,[120] E. A. Starchenko,[123] G. H. Stark,[146] J. Stark,[58] S. H Stark,[40] P. Staroba,[141] P. Starovoitov,[61a] S. Stärz,[103] R. Staszewski,[84] G. Stavropoulos,[44] M. Stegler,[46] P. Steinberg,[29] B. Stelzer,[152] H. J. Stelzer,[36] O. Stelzer-Chilton,[168a] H. Stenzel,[56] T. J. Stevenson,[156] G. A. Stewart,[36] M. C. Stockton,[36] G. Stoicea,[27b] M. Stolarski,[140a] P. Stolte,[53] S. Stonjek,[115] A. Straessner,[48] J. Strandberg,[154] S. Strandberg,[45a,45b] M. Strauss,[128] P. Strizenec,[28b] R. Ströhmer,[177] D. M. Strom,[131] R. Stroynowski,[42] A. Strubig,[50] S. A. Stucci,[29] B. Stugu,[17] J. Stupak,[128] N. A. Styles,[46] D. Su,[153] S. Suchek,[61a] Y. Sugaya,[133] V. V. Sulin,[110] M. J. Sullivan,[90] D. M. S. Sultan,[54] S. Sultansoy,[4c] T. Sumida,[85] S. Sun,[105] X. Sun,[3] K. Suruliz,[156] C. J. E. Suster,[157] M. R. Sutton,[156] S. Suzuki,[81] M. Svatos,[141] M. Swiatlowski,[37] S. P. Swift,[2] A. Sydorenko,[99] I. Sykora,[28a] M. Sykora,[143] T. Sykora,[143] D. Ta,[99] K. Tackmann,[46,rr] J. Taenzer,[161] A. Taffard,[171] R. Tafirout,[168a] E. Tahirovic,[92] H. Takai,[29] R. Takashima,[86] K. Takeda,[82] T. Takeshita,[150] E. P. Takeva,[50] Y. Takubo,[81] M. Talby,[101] A. A. Talyshev,[122b,122a] J. Tanaka,[163] M. Tanaka,[165] R. Tanaka,[132] B. B. Tannenwald,[126] S. Tapia Araya,[173] S. Tapprogge,[99] A. Tarek Abouelfadl Mohamed,[136] S. Tarem,[160] G. Tarna,[27b,ss] G. F. Tartarelli,[68a] P. Tas,[143] M. Tasevsky,[141] T. Tashiro,[85] E. Tassi,[41b,41a] A. Tavares Delgado,[140a,140b] Y. Tayalati,[35e]

A. J. Taylor,[50] G. N. Taylor,[104] P. T. E. Taylor,[104] W. Taylor,[168b] A. S. Tee,[89] R. Teixeira De Lima,[153] P. Teixeira-Dias,[93]
H. Ten Kate,[36] J. J. Teoh,[120] S. Terada,[81] K. Terashi,[163] J. Terron,[98] S. Terzo,[14] M. Testa,[51] R. J. Teuscher,[167,n] S. J. Thais,[183]
T. Theveneaux-Pelzer,[46] F. Thiele,[40] D. W. Thomas,[93] J. O. Thomas,[42] J. P. Thomas,[21] A. S. Thompson,[57] P. D. Thompson,[21]
L. A. Thomsen,[183] E. Thomson,[137] Y. Tian,[39] R. E. Ticse Torres,[53] V. O. Tikhomirov,[110,tt] Yu. A. Tikhonov,[122b,122a]
S. Timoshenko,[112] P. Tipton,[183] S. Tisserant,[101] K. Todome,[23b,23a] S. Todorova-Nova,[5] S. Todt,[48] J. Tojo,[87] S. Tokár,[28a]
K. Tokushuku,[81] E. Tolley,[126] K. G. Tomiwa,[33c] M. Tomoto,[117] L. Tompkins,[153,cc] K. Toms,[118] B. Tong,[59] P. Tornambe,[102]
E. Torrence,[131] H. Torres,[48] E. Torró Pastor,[148] C. Tosciri,[135] J. Toth,[101,uu] D. R. Tovey,[149] C. J. Treado,[124] T. Trefzger,[177]
F. Tresoldi,[156] A. Tricoli,[29] I. M. Trigger,[168a] S. Trincaz-Duvoid,[136] W. Trischuk,[167] B. Trocmé,[58] A. Trofymov,[132]
C. Troncon,[68a] M. Trovatelli,[176] F. Trovato,[156] L. Truong,[33b] M. Trzebinski,[84] A. Trzupek,[84] F. Tsai,[46] J. C-L. Tseng,[135]
P. V. Tsiareshka,[107,ee] A. Tsirigotis,[162] N. Tsirintanis,[9] V. Tsiskaridze,[155] E. G. Tskhadadze,[159a] M. Tsopoulou,[162]
I. I. Tsukerman,[111] V. Tsulaia,[18] S. Tsuno,[81] D. Tsybychev,[155] Y. Tu,[63b] A. Tudorache,[27b] V. Tudorache,[27b] T. T. Tulbure,[27a]
A. N. Tuna,[59] S. Turchikhin,[79] D. Turgeman,[180] I. Turk Cakir,[4b,vv] R. J. Turner,[21] R. T. Turra,[68a] P. M. Tuts,[39] S. Tzamarias,[162]
E. Tzovara,[99] G. Ucchielli,[47] I. Ueda,[81] M. Ughetto,[45a,45b] F. Ukegawa,[169] G. Unal,[36] A. Undrus,[29] G. Unel,[171]
F. C. Ungaro,[104] Y. Unno,[81] K. Uno,[163] J. Urban,[28b] P. Urquijo,[104] G. Usai,[8] J. Usui,[81] L. Vacavant,[101] V. Vacek,[142]
B. Vachon,[103] K. O. H. Vadla,[134] A. Vaidya,[94] C. Valderanis,[114] E. Valdes Santurio,[45a,45b] M. Valente,[54] S. Valentinetti,[23b,23a]
A. Valero,[174] L. Valéry,[46] R. A. Vallance,[21] A. Vallier,[36] J. A. Valls Ferrer,[174] T. R. Van Daalen,[14] P. Van Gemmeren,[6]
I. Van Vulpen,[120] M. Vanadia,[73a,73b] W. Vandelli,[36] A. Vaniachine,[166] R. Vari,[72a] E. W. Varnes,[7] C. Varni,[55b,55a] T. Varol,[42]
D. Varouchas,[132] K. E. Varvell,[157] M. E. Vasile,[27b] G. A. Vasquez,[176] J. G. Vasquez,[183] F. Vazeille,[38] D. Vazquez Furelos,[14]
T. Vazquez Schroeder,[36] J. Veatch,[53] V. Vecchio,[74a,74b] L. M. Veloce,[167] F. Veloso,[140a,140c] S. Veneziano,[72a] A. Ventura,[67a,67b]
N. Venturi,[36] A. Verbytskyi,[115] V. Vercesi,[70a] M. Verducci,[74a,74b] C. M. Vergel Infante,[78] C. Vergis,[24] W. Verkerke,[120]
A. T. Vermeulen,[120] J. C. Vermeulen,[120] M. C. Vetterli,[152,e] N. Viaux Maira,[147b] M. Vicente Barreto Pinto,[54] I. Vichou,[173,a]
T. Vickey,[149] O. E. Vickey Boeriu,[149] G. H. A. Viehhauser,[135] L. Vigani,[135] M. Villa,[23b,23a] M. Villaplana Perez,[68a,68b]
E. Vilucchi,[51] M. G. Vincter,[34] V. B. Vinogradov,[79] A. Vishwakarma,[46] C. Vittori,[23b,23a] I. Vivarelli,[156] M. Vogel,[182]
P. Vokac,[142] G. Volpi,[14] S. E. von Buddenbrock,[33c] E. Von Toerne,[24] V. Vorobel,[143] K. Vorobev,[112] M. Vos,[174]
J. H. Vossebeld,[90] N. Vranjes,[16] M. Vranjes Milosavljevic,[16] V. Vrba,[142] M. Vreeswijk,[120] T. Šfiligoj,[91] R. Vuillermet,[36]
I. Vukotic,[37] T. Ženiš,[28a] L. Živković,[16] P. Wagner,[24] W. Wagner,[182] J. Wagner-Kuhr,[114] H. Wahlberg,[88] S. Wahrmund,[48]
K. Wakamiya,[82] V. M. Walbrecht,[115] J. Walder,[89] R. Walker,[114] S. D. Walker,[93] W. Walkowiak,[151] V. Wallangen,[45a,45b]
A. M. Wang,[59] C. Wang,[60b] F. Wang,[181] H. Wang,[18] H. Wang,[3] J. Wang,[157] J. Wang,[61b] P. Wang,[42] Q. Wang,[128]
R.-J. Wang,[136] R. Wang,[60a] R. Wang,[6] S. M. Wang,[158] W. T. Wang,[60a] W. Wang,[15c,ww] W. X. Wang,[60a,ww] Y. Wang,[60a,gg]
Z. Wang,[60c] C. Wanotayaroj,[46] A. Warburton,[103] C. P. Ward,[32] D. R. Wardrope,[94] A. Washbrook,[50] A. T. Watson,[21]
M. F. Watson,[21] G. Watts,[148] B. M. Waugh,[94] A. F. Webb,[11] S. Webb,[99] C. Weber,[183] M. S. Weber,[20] S. A. Weber,[34]
S. M. Weber,[61a] A. R. Weidberg,[135] J. Weingarten,[47] M. Weirich,[99] C. Weiser,[52] P. S. Wells,[36] T. Wenaus,[29] T. Wengler,[36]
S. Wenig,[36] N. Wermes,[24] M. D. Werner,[78] P. Werner,[36] M. Wessels,[61a] T. D. Weston,[20] K. Whalen,[131] N. L. Whallon,[148]
A. M. Wharton,[89] A. S. White,[105] A. White,[8] M. J. White,[1] R. White,[147b] D. Whiteson,[171] B. W. Whitmore,[89]
F. J. Wickens,[144] W. Wiedenmann,[181] M. Wielers,[144] C. Wiglesworth,[40] L. A. M. Wiik-Fuchs,[52] F. Wilk,[100] H. G. Wilkens,[36]
L. J. Wilkins,[93] H. H. Williams,[137] S. Williams,[32] C. Willis,[106] S. Willocq,[102] J. A. Wilson,[21] I. Wingerter-Seez,[5]
E. Winkels,[156] F. Winklmeier,[131] O. J. Winston,[156] B. T. Winter,[52] M. Wittgen,[153] M. Wobisch,[95] A. Wolf,[99] T. M. H. Wolf,[120]
R. Wolff,[101] R. W. Wölker,[135] J. Wollrath,[52] M. W. Wolter,[84] H. Wolters,[140a,140c] V. W. S. Wong,[175] N. L. Woods,[146]
S. D. Worm,[21] B. K. Wosiek,[84] K. W. Woźniak,[84] K. Wraight,[57] S. L. Wu,[181] X. Wu,[54] Y. Wu,[60a] T. R. Wyatt,[100]
B. M. Wynne,[50] S. Xella,[40] Z. Xi,[105] L. Xia,[178] D. Xu,[15a] H. Xu,[60a,ss] L. Xu,[29] T. Xu,[145] W. Xu,[105] Z. Xu,[60b] Z. Xu,[153]
B. Yabsley,[157] S. Yacoob,[33a] K. Yajima,[133] D. P. Yallup,[94] D. Yamaguchi,[165] Y. Yamaguchi,[165] A. Yamamoto,[81]
T. Yamanaka,[163] F. Yamane,[82] M. Yamatani,[163] T. Yamazaki,[163] Y. Yamazaki,[82] Z. Yan,[25] H. J. Yang,[60c,60d] H. T. Yang,[18]
S. Yang,[77] X. Yang,[60b,58] Y. Yang,[163] Z. Yang,[17] W-M. Yao,[18] Y. C. Yap,[46] Y. Yasu,[81] E. Yatsenko,[60c,60d] J. Ye,[42] S. Ye,[29]
I. Yeletskikh,[79] E. Yigitbasi,[25] E. Yildirim,[99] K. Yorita,[179] K. Yoshihara,[137] C. J. S. Young,[36] C. Young,[153] J. Yu,[78] X. Yue,[61a]
S. P. Y. Yuen,[24] B. Zabinski,[84] G. Zacharis,[10] E. Zaffaroni,[54] J. Zahreddine,[136] R. Zaidan,[14] A. M. Zaitsev,[123,jj]
T. Zakareishvili,[159b] N. Zakharchuk,[34] S. Zambito,[59] D. Zanzi,[36] D. R. Zaripovas,[57] S. V. Zeißner,[47] C. Zeitnitz,[182]
G. Zemaityte,[135] J. C. Zeng,[173] O. Zenin,[123] D. Zerwas,[132] M. Zgubič,[135] D. F. Zhang,[15b] F. Zhang,[181] G. Zhang,[60a]
G. Zhang,[15b] H. Zhang,[15c] J. Zhang,[6] L. Zhang,[15c] L. Zhang,[60a] M. Zhang,[173] R. Zhang,[60a] R. Zhang,[24] X. Zhang,[60b]
Y. Zhang,[15a,15d] Z. Zhang,[63a] Z. Zhang,[132] P. Zhao,[49] Y. Zhao,[60b] Z. Zhao,[60a] A. Zhemchugov,[79] Z. Zheng,[105] D. Zhong,[173]

B. Zhou,[105] C. Zhou,[181] M. S. Zhou,[15a,15d] M. Zhou,[155] N. Zhou,[60c] Y. Zhou,[7] C. G. Zhu,[60b] H. L. Zhu,[60a] H. Zhu,[15a] J. Zhu,[105] Y. Zhu,[60a] X. Zhuang,[15a] K. Zhukov,[110] V. Zhulanov,[122b,122a] D. Zieminska,[65] N. I. Zimine,[79] S. Zimmermann,[52] Z. Zinonos,[115] M. Ziolkowski,[151] G. Zobernig,[181] A. Zoccoli,[23b,23a] K. Zoch,[53] T. G. Zorbas,[149] R. Zou,[37] and L. Zwalinski[36]

(ATLAS Collaboration)

[1]*Department of Physics, University of Adelaide, Adelaide, Australia*
[2]*Physics Department, SUNY Albany, Albany, New York, USA*
[3]*Department of Physics, University of Alberta, Edmonton, Alberta, Canada*
[4a]*Department of Physics, Ankara University, Ankara, Turkey*
[4b]*Istanbul Aydin University, Istanbul, Turkey*
[4c]*Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey*
[5]*LAPP, Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy, France*
[6]*High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois, USA*
[7]*Department of Physics, University of Arizona, Tucson, Arizona, USA*
[8]*Department of Physics, University of Texas at Arlington, Arlington, Texas, USA*
[9]*Physics Department, National and Kapodistrian University of Athens, Athens, Greece*
[10]*Physics Department, National Technical University of Athens, Zografou, Greece*
[11]*Department of Physics, University of Texas at Austin, Austin, Texas, USA*
[12a]*Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*
[12b]*Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*
[12c]*Department of Physics, Bogazici University, Istanbul, Turkey*
[12d]*Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey*
[13]*Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*
[14]*Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain*
[15a]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
[15b]*Physics Department, Tsinghua University, Beijing, China*
[15c]*Department of Physics, Nanjing University, Nanjing, China*
[15d]*University of Chinese Academy of Science (UCAS), Beijing, China*
[16]*Institute of Physics, University of Belgrade, Belgrade, Serbia*
[17]*Department for Physics and Technology, University of Bergen, Bergen, Norway*
[18]*Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, California, USA*
[19]*Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany*
[20]*Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
[21]*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
[22]*Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogota, Colombia*
[23a]*INFN Bologna and Universita' di Bologna, Dipartimento di Fisica, Italy*
[23b]*INFN Sezione di Bologna, Bologna, Italy*
[24]*Physikalisches Institut, Universität Bonn, Bonn, Germany*
[25]*Department of Physics, Boston University, Boston, Massachusetts, USA*
[26]*Department of Physics, Brandeis University, Waltham, Massachusetts, USA*
[27a]*Transilvania University of Brasov, Brasov, Romania*
[27b]*Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
[27c]*Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, Romania*
[27d]*National Institute for Research and Development of Isotopic and Molecular Technologies,*
Physics Department, Cluj-Napoca, Romania
[27e]*University Politehnica Bucharest, Bucharest, Romania*
[27f]*West University in Timisoara, Timisoara, Romania*
[28a]*Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic*
[28b]*Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
[29]*Physics Department, Brookhaven National Laboratory, Upton, New York, USA*
[30]*Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina*
[31]*California State University, California, USA*
[32]*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
[33a]*Department of Physics, University of Cape Town, Cape Town, South Africa*
[33b]*Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa*
[33c]*School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
[34]*Department of Physics, Carleton University, Ottawa, Ontario, Canada*

[35a]*Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies—Université Hassan II, Casablanca, Morocco*
[35b]*Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco*
[35c]*Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco*
[35d]*Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda, Morocco*
[35e]*Faculté des sciences, Université Mohammed V, Rabat, Morocco*
[36]*CERN, Geneva, Switzerland*
[37]*Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA*
[38]*LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France*
[39]*Nevis Laboratory, Columbia University, Irvington, New York, USA*
[40]*Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
[41a]*Dipartimento di Fisica, Università della Calabria, Rende, Italy*
[41b]*INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Frascati, Italy*
[42]*Physics Department, Southern Methodist University, Dallas, Texas, USA*
[43]*Physics Department, University of Texas at Dallas, Richardson, Texas, USA*
[44]*National Centre for Scientific Research "Demokritos", Agia Paraskevi, Greece*
[45a]*Department of Physics, Stockholm University, Sweden*
[45b]*Oskar Klein Centre, Stockholm, Sweden*
[46]*Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany*
[47]*Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany*
[48]*Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*
[49]*Department of Physics, Duke University, Durham, North Carolina, USA*
[50]*SUPA—School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
[51]*INFN e Laboratori Nazionali di Frascati, Frascati, Italy*
[52]*Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany*
[53]*II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany*
[54]*Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland*
[55a]*Dipartimento di Fisica, Università di Genova, Genova, Italy*
[55b]*INFN Sezione di Genova, Genova, Italy*
[56]*II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
[57]*SUPA—School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
[58]*LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France*
[59]*Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA*
[60a]*Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China*
[60b]*Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China*
[60c]*School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai, China*
[60d]*Tsung-Dao Lee Institute, Shanghai, China*
[61a]*Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
[61b]*Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
[62]*Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan*
[63a]*Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China*
[63b]*Department of Physics, University of Hong Kong, Hong Kong, China*
[63c]*Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
[64]*Department of Physics, National Tsing Hua University, Hsinchu, Taiwan*
[65]*Department of Physics, Indiana University, Bloomington, Indiana, USA*
[66a]*INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy*
[66b]*ICTP, Trieste, Italy*
[66c]*Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy*
[67a]*INFN Sezione di Lecce, Lecce, Italy*
[67b]*Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy*
[68a]*INFN Sezione di Milano, Italy*
[68b]*Dipartimento di Fisica, Università di Milano, Milano, Italy*
[69a]*INFN Sezione di Napoli, Napoli, Italy*
[69b]*Dipartimento di Fisica, Università di Napoli, Napoli, Italy*
[70a]*INFN Sezione di Pavia, Pavia, Italy*
[70b]*Dipartimento di Fisica, Università di Pavia, Pavia, Italy*
[71a]*INFN Sezione di Pisa, Pisa, Italy*

[71b]*Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy*
[72a]*INFN Sezione di Roma, Roma, Italy*
[72b]*Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy*
[73a]*INFN Sezione di Roma Tor Vergata, Roma, Italy*
[73b]*Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*
[74a]*INFN Sezione di Roma Tre, Italy*
[74b]*Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy*
[75a]*INFN-TIFPA, Trento, Italy*
[75b]*Università degli Studi di Trento, Trento, Italy*
[76]*Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria*
[77]*University of Iowa, Iowa City, Iowa, USA*
[78]*Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA*
[79]*Joint Institute for Nuclear Research, Dubna, Russia*
[80a]*Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil*
[80b]*Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil*
[80c]*Universidade Federal de São João del Rei (UFSJ), São João del Rei, Brazil*
[80d]*Instituto de Física, Universidade de São Paulo, São Paulo, Brazil*
[81]*KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
[82]*Graduate School of Science, Kobe University, Kobe, Japan*
[83a]*AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland*
[83b]*Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
[84]*Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
[85]*Faculty of Science, Kyoto University, Kyoto, Japan*
[86]*Kyoto University of Education, Kyoto, Japan*
[87]*Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan*
[88]*Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
[89]*Physics Department, Lancaster University, Lancaster, United Kingdom*
[90]*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
[91]*Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*
[92]*School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
[93]*Department of Physics, Royal Holloway University of London, Egham, United Kingdom*
[94]*Department of Physics and Astronomy, University College London, London, United Kingdom*
[95]*Louisiana Tech University, Ruston, Louisiana, USA*
[96]*Fysiska institutionen, Lunds universitet, Lund, Sweden*
[97]*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*
[98]*Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain*
[99]*Institut für Physik, Universität Mainz, Mainz, Germany*
[100]*School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
[101]*CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*
[102]*Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA*
[103]*Department of Physics, McGill University, Montreal, Quebec, Canada*
[104]*School of Physics, University of Melbourne, Victoria, Australia*
[105]*Department of Physics, University of Michigan, Ann Arbor, Michigan, USA*
[106]*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA*
[107]*B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus*
[108]*Research Institute for Nuclear Problems of Byelorussian State University, Minsk, Belarus*
[109]*Group of Particle Physics, University of Montreal, Montreal, Quebec, Canada*
[110]*P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia*
[111]*Institute for Theoretical and Experimental Physics of the National Research Centre Kurchatov Institute, Moscow, Russia*
[112]*National Research Nuclear University MEPhI, Moscow, Russia*
[113]*D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*
[114]*Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
[115]*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
[116]*Nagasaki Institute of Applied Science, Nagasaki, Japan*
[117]*Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*
[118]*Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA*
[119]*Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*
[120]*Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*
[121]*Department of Physics, Northern Illinois University, DeKalb, Illinois, USA*

[122a]*Budker Institute of Nuclear Physics and NSU, SB RAS, Novosibirsk, Russia*
[122b]*Novosibirsk State University Novosibirsk, Russia*
[123]*Institute for High Energy Physics of the National Research Centre Kurchatov Institute, Protvino, Russia*
[124]*Department of Physics, New York University, New York, New York, USA*
[125]*Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan*
[126]*The Ohio State University, Columbus, Ohio, USA*
[127]*Faculty of Science, Okayama University, Okayama, Japan*
[128]*Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA*
[129]*Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA*
[130]*Palacký University, RCPTM, Joint Laboratory of Optics, Olomouc, Czech Republic*
[131]*Center for High Energy Physics, University of Oregon, Eugene, Oregon, USA*
[132]*LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France*
[133]*Graduate School of Science, Osaka University, Osaka, Japan*
[134]*Department of Physics, University of Oslo, Oslo, Norway*
[135]*Department of Physics, Oxford University, Oxford, United Kingdom*
[136]*LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France*
[137]*Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA*
[138]*Konstantinov Nuclear Physics Institute of National Research Centre "Kurchatov Institute", PNPI, St. Petersburg, Russia*
[139]*Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA*
[140a]*Laboratório de Instrumentação e Física Experimental de Partículas—LIP, Portugal*
[140b]*Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal*
[140c]*Departamento de Física, Universidade de Coimbra, Coimbra, Portugal*
[140d]*Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal*
[140e]*Departamento de Física, Universidade do Minho, Braga, Portugal*
[140f]*Universidad de Granada, Granada (Spain), Spain*
[140g]*Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal*
[141]*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*
[142]*Czech Technical University in Prague, Prague, Czech Republic*
[143]*Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*
[144]*Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*
[145]*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
[146]*Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA*
[147a]*Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile*
[147b]*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
[148]*Department of Physics, University of Washington, Seattle, Washington, USA*
[149]*Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*
[150]*Department of Physics, Shinshu University, Nagano, Japan*
[151]*Department Physik, Universität Siegen, Siegen, Germany*
[152]*Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada*
[153]*SLAC National Accelerator Laboratory, Stanford, California, USA*
[154]*Physics Department, Royal Institute of Technology, Stockholm, Sweden*
[155]*Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA*
[156]*Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
[157]*School of Physics, University of Sydney, Sydney, Australia*
[158]*Institute of Physics, Academia Sinica, Taipei, Taiwan*
[159a]*E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia*
[159b]*High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
[160]*Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel*
[161]*Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
[162]*Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
[163]*International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan*
[164]*Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*
[165]*Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
[166]*Tomsk State University, Tomsk, Russia*
[167]*Department of Physics, University of Toronto, Toronto, Ontario, Canada*
[168a]*TRIUMF, Vancouver, British Columbia, Canada*
[168b]*Department of Physics and Astronomy, York University, Toronto, Ontario, Canada*
[169]*Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*
[170]*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA*

[171]*Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA*
[172]*Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
[173]*Department of Physics, University of Illinois, Urbana, Illinois, USA*
[174]*Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia—CSIC, Valencia, Spain*
[175]*Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada*
[176]*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*
[177]*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*
[178]*Department of Physics, University of Warwick, Coventry, United Kingdom*
[179]*Waseda University, Tokyo, Japan*
[180]*Department of Particle Physics, Weizmann Institute of Science, Rehovot, Israel*
[181]*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*
[182]*Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
[183]*Department of Physics, Yale University, New Haven, Connecticut, USA*
[184]*Yerevan Physics Institute, Yerevan, Armenia*

[a] Deceased.
[b] Also at Department of Physics, King's College London, London, United Kingdom.
[c] Also at Istanbul University, Dept. of Physics, Istanbul, Turkey.
[d] Also at Instituto de Fisica Teorica, IFT-UAM/CSIC, Madrid, Spain.
[e] Also at TRIUMF, Vancouver, British Columbia, Canada.
[f] Also at Department of Physics and Astronomy, University of Louisville, Louisville, Kentucky, USA.
[g] Also at Department of Physics, California State University, Fresno, California, USA.
[h] Also at Department of Physics, University of Fribourg, Fribourg, Switzerland.
[i] Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona, Spain.
[j] Also at Tomsk State University, Tomsk, and Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
[k] Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China.
[l] Also at Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal.
[m] Also at Universita di Napoli Parthenope, Napoli, Italy.
[n] Also at Institute of Particle Physics (IPP), Canada.
[o] Also at Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania.
[p] Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[q] Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.
[r] Also at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town, South Africa.
[s] Also at Department of Physics, California State University, East Bay, Hayward, California, USA.
[t] Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
[u] Also at Department of Physics, University of Michigan, Ann Arbor, Michigan, USA.
[v] Also at LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France.
[w] Also at Graduate School of Science, Osaka University, Osaka, Japan.
[x] Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.
[y] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
[z] Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands.
[aa] Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.
[bb] Also at CERN, Geneva, Switzerland.
[cc] Also at Department of Physics, Stanford University, Stanford, California, USA.
[dd] Also at Manhattan College, New York, New York, USA.
[ee] Also at Joint Institute for Nuclear Research, Dubna, Russia.
[ff] Also at Hellenic Open University, Patras, Greece.
[gg] Also at LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France.
[hh] Also at The City College of New York, New York, New York, USA.
[ii] Also at Department of Physics, California State University, Sacramento, California, USA.
[jj] Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
[kk] Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.
[ll] Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom.
[mm] Also at Louisiana Tech University, Ruston, Louisiana, USA.
[nn] Also at School of Physics, Sun Yat-sen University, Guangzhou, China.
[oo] Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.
[pp] Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia.
[qq] Also at Department of Applied Physics and Astronomy, University of Sharjah, Sharjah, United Arab Emirates.
[rr] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
[ss] Also at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France.

[tt] Also at National Research Nuclear University MEPhI, Moscow, Russia.
[uu] Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
[vv] Also at Giresun University, Faculty of Engineering, Giresun, Turkey.
[ww] Also at Institute of Physics, Academia Sinica, Taipei, Taiwan.