

Active Galactic Nuclei population studies with the Cherenkov Telescope Array

Anthony M. Brown,^{a,b,*} Atreya Acharyya,^a Alberto Dominguez,^c Tarek Hassan,^d Jean-Philippe Lenain^e and Santiago Pita^f on behalf of the CTA Consortium
(a complete list of authors can be found at the end of the proceedings)

^aCentre for Advanced Instrumentation, Durham University, South Road, Durham, DH1 3LE, UK

^bCentre for Extragalactic Astronomy, Durham University, South Road, Durham, DH1 3LE, UK

^cIPARCOS and Department of EMFTEL, Universidad Complutense de Madrid, E-28040 Madrid, Spain

^dCIEMAT: Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, 40 Ave. Complutense, 28040 Madrid, Spain

^eSorbonne Université, Université Paris Diderot, Sorbonne Paris Cité, CNRS/IN2P3, Laboratoire de Physique Nucléaire et de Hautes Energies, LPNHE, 4 Place Jussieu, F-75252 Paris, France

^fUniversité de Paris, CNRS, Astroparticule et Cosmologie, F-75013 Paris, France

E-mail: anthony.brown@durham.ac.uk

The Cherenkov Telescope Array (CTA) observatory is the next generation of ground-based imaging atmospheric Cherenkov telescopes (IACTs). Building on the strengths of current IACTs, CTA is designed to achieve an order of magnitude improvement in sensitivity, with unprecedented angular and energy resolution. CTA will also increase the energy reach of IACTs, observing photons in the energy range from 20 GeV to beyond 100 TeV. These advances in performance will see CTA heralding in a new era for high-energy astrophysics, with the emphasis shifting from source discovery, to population studies and precision measurements. In this talk we discuss CTA's ability to conduct source population studies of γ -ray bright active galactic nuclei and how this ability will enhance our understanding on the redshift evolution of this dominant γ -ray source class.

37th International Cosmic Ray Conference (ICRC 2021)
July 12th – 23rd, 2021
Online – Berlin, Germany

*Presenter

1. Introduction

Over the last 15 years, the current generation of space and ground-based γ -ray telescopes has revolutionised our view of the high-energy non-thermal Universe. To build upon this success, the international community is now working towards the next generation of ground-based Imaging Atmospheric Cherenkov Telescope (IACT) instruments, the Cherenkov Telescope Array (CTA; [1]). CTA is designed to achieve an order of magnitude improvement in sensitivity with respect to the current generation of IACTs, with unprecedented angular and energy resolution over nearly 4 decades in energy, from 20 GeV to beyond 100 TeV.

The envisaged step-change in performance afforded by CTA will in part be due to CTA's sheer size, and the fact that it will be comprised of three telescope size classes, the Small-Sized-Telescopes (SST), Medium-Sized-Telescopes (MST) and Large-Sized-Telescopes (LST), with each size class optimised to observe a different γ -ray energy range. The SST component of CTA is primarily responsible for extending the high-energy reach of CTA, predominantly observing γ -rays with energies from a few TeV up to 100 TeV and beyond. At these extreme photon energies, the limiting factor is not the amount of Cherenkov radiation produced by air showers, but simply the number of γ -ray induced air showers to observe. As such, the SSTs will be modest in physical size, only 4 m diameter primary mirrors, but there will be a large number of SSTs spread over $\sim 4\text{km}^2$ [2]¹. More than two thirds of CTA's southern array telescopes are foreseen to be SSTs. The MSTs will have a diameter of ~ 12 m and will dominate the improvement in flux sensitivity in the core $0.2 \leq E_\gamma \leq 10$ TeV energy range. With a diameter of ~ 23 m, the LSTs are designed to observe the low Cherenkov photon intensity associated with $20 \leq E_\gamma \leq 200$ GeV photon-induced air showers; however, unlike the SSTs, due to the expected γ -ray flux in this energy range, there will only be 4 LSTs at the centre of CTA. To allow all-sky coverage, the CTA observatory will consist of two different arrays, one in each hemisphere. The northern array is intended to contain ~ 20 telescopes (LSTs and MSTs) spread over about 1km^2 , while the southern array is intended to contain ~ 100 telescopes (LSTs, MSTs and SSTs) spread over an area of approximately four square kilometres. These improvements in telescope performance will see CTA heralding in a new era for ground-based γ -ray astronomy, with the emphasis shifting from source discovery, to population studies and precision measurements. During the initial phase of constructing CTA, first arrays of telescopes will enable early scientific observations, with 4 LSTs and 9 MSTs on the Northern site, and 14 MSTs and 37 SSTs on the Southern site, whilst a later construction phase will follow to complete the array. In the following study, this is referred as "alpha configuration", while the full-scope CTA arrays will be referred as "omega configuration".

These proceedings are dedicated to characterising CTA's ability to observe the population of γ -ray bright Active Galactic Nuclei (AGN). Considering sources in the fourth *Fermi*-LAT AGN (4LAC; [3]) catalogue with known redshifts, we use the `GAMMAPY` software suite [4, 5] with a variety of spectral extrapolation models to higher energies and exposure times, to estimate the number of AGN possibly detectable by both the Northern array and Southern array arrays when accounting for the extragalactic background light (EBL). Importantly, to highlight the impact that the full CTA arrays will have in the context of AGN population studies, we quantify the number

¹Also see Gueta et al. from these proceedings.

of AGN observed with the full CTA arrays, as well as the smaller total expected with CTA's initial alpha configuration.

2. The 4LAC catalogue

Since 2008 August 4, the vast majority of data taken by the Large Area Telescope (LAT) on board the *Fermi* satellite has been performed in all-sky-survey mode, whereby the *Fermi*-LAT detector points away from the Earth and rocks north and south of its orbital plane, on subsequent orbits. This rocking motion, coupled with *Fermi*-LAT's large effective area, allows the LAT instrument to scan the entire γ -ray sky in about a few hours. This observational characteristic, coupled with *Fermi*-LAT's long mission lifetime, allows us to construct a deep exposure of the γ -ray sky in the 0.1 – 100 GeV photon energy range.

The 4LAC catalogue lists all γ -ray bright AGN detected by the LAT during the first 8 years of the *Fermi* mission. In particular, the 4LAC reports the position and best-fit spectral parameters for 2863 γ -ray bright AGN derived from integrating over the entire 8-year data set. The vast majority of the 4LAC AGN are of the blazar class ($\sim 98\%$). Of this 4LAC blazar population, 38% are BL Lac-type objects (BL Lacs), 24% are Flat Spectrum Radio Quasars (FSRQs) and 38% blazar candidates of unknown types (BCUs). Importantly, all AGN currently detected by IACTs are present in 4LAC. As such, the 4LAC catalogue represents a natural starting point from which to quantify the potential of CTA to observe the γ -ray bright AGN population. For this study, we use a subset of the 4LAC catalog revised to only contain sources with a well-known redshift [6]. This target AGN list is then extrapolated to the TeV regime, and prospects of CTA detectability are calculated by using GAMMAPY. A total of 1551 AGN were considered over the whole sky.

3. Extrapolation and computing sensitivity of CTA to the AGN population

3.1 Extrapolating from the 4LAC

Starting with the 4LAC, to quantify CTA's potential to observe the γ -ray bright AGN population we must extrapolate the 4LAC spectra up across the entire observable energy range expected for CTA. During this extrapolation process, there are several key aspects that need to be considered:

- **Extrapolation scheme:** the functional form of the extrapolation from *Fermi*-LAT to CTA energies influences the total number of AGN detected. Given our lack of a-priori knowledge of the most appropriate functional form for extrapolation, we use a bracketing approach by assuming both (i) power-law (optimistic) extrapolation (PL) (ii) log-parabola (pessimistic) extrapolation (LP). We note however the LP fits should be taken with caution as existing TeV observations disfavour such an extrapolation of LAT spectra.
- **Extragalactic Background Light:** during propagation from source to Earth, the γ -rays emitted by AGN can interact with the diffuse flux of the Extragalactic Background Light (EBL) creating a positron-electron pair. This interaction will result in an attenuation of the observed γ -ray flux, with the probability of this attenuation being redshift and γ -ray energy dependent. Throughout this study, we describe this probability with the Dominguez 2011

EBL model [7]. Furthermore, due to the redshift dependence of the EBL-attenuation, this study only considered 4LAC AGN with a well-known redshift².

As such, taking these two aspects into consideration, for each AGN, we apply two different extrapolation schemes: (i) Power-law + EBL and (ii) log-parabola + EBL. Given the MeV-GeV energy range over which the 4LAC detects AGN and the fact that the EBL has a minimal impact on γ -rays in the 4LAC energy range, these two extrapolation schemes were applied to the observed 4LAC spectra rather than their EBL-corrected counterparts.

3.2 GAMMAPY simulations

For this study, GAMMAPY v0.17 was used with a standard ON-OFF (or aperture photometry) approach. The instrument response functions (IRFs) utilised by GAMMAPY were the final omega array configuration and the proposed initial alpha array configuration, for both Northern sites and Southern sites, from the so-called prod3b-v2 production version³ [9]. As each of these IRF configurations were simulated for three different sets of zenith distances, depending on each source culmination altitude at each site, the correct IRF was used: 20°, 40° and 60° in zenith IRFs were used for sources culminating below 25°, between 25° to 45° and between 45° to 65° from zenith respectively. Those sources culminating above 65° from zenith on a site were considered un-observable. For each of these array configurations, a 5 hour and 20 hour exposure per source was considered along with five different energy thresholds: 30 GeV, 50 GeV, 100 GeV, 300 GeV, 500 GeV and 1 TeV.

Throughout the analysis, we employ detectability conditions as follows: (i) detection significance: $S > 5\sigma$ (eq. 17 from [10]); (ii) excess required to be larger than 5% the background rate (five times the systematic uncertainty on the background rate) and (iii) excess required to be larger than 10 events. For each AGN, once the two different extrapolations were applied, for each array configuration, exposure time and energy threshold configurations, 100 separate GAMMAPY simulations were performed. Any AGN for which the average of these 100 simulations satisfied the detection criteria, were considered to be detectable by CTA.

4. Results

The results of these simulations for the Northern site alpha and omega configurations can be seen in Table 1, whilst the Southern site alpha and omega configuration results can be seen in Table 2. For both arrays, there are significant differences in the number of AGN detected by the predicted sensitivity of the two different array configurations. As expected, the omega configuration performs better than the initial smaller alpha array, showing that we will be able to expand science reach as more telescopes are installed. In some cases, the final omega array detects over double the number of AGN compared to the initial alpha array. This is most notable in the lower energy threshold analysis of the Southern array arrays where the lack of LSTs in the Southern array alpha array has a

²CTA has a dedicated ‘redshift working group’ that validates 4LAC redshifts where necessary, as well as organizes observational campaigns to determine the redshifts for CTA AGN candidates that currently do not have a known redshift [e.g. 8]; for example, see also Kasai et al. from these proceedings.

³See <https://www.cta-observatory.org/science/cta-performance/>.

Northern omega array	30 GeV	50 GeV	100 GeV	300 GeV	500 GeV	1 TeV
5 hour - PL	51	84	114	98	83	65
20 hour - PL	93	171	209	164	135	103
5 hour - LP	30	50	73	62	54	41
20 hour - LP	51	101	131	107	87	64
Northern alpha array	30 GeV	50 GeV	100 GeV	300 GeV	500 GeV	1 TeV
5 hour - PL	30	53	76	73	63	49
20 hour - PL	60	117	154	131	105	84
5 hour - LP	19	35	45	45	40	27
20 hour - LP	33	64	96	86	68	56

Table 1: Number of AGN detected for Northern array alpha and omega configurations for the different extrapolation schemes, exposures and energy thresholds considered in this study.

Southern omega array	100 GeV	300 GeV	500 GeV	1 TeV
5 hour - PL	117	112	90	71
20 hour - PL	209	173	147	116
5 hour - LP	68	66	52	45
20 hour - LP	122	108	92	73
Southern alpha array	100 GeV	300 GeV	500 GeV	1 TeV
5 hour - PL	50	72	72	53
20 hour - PL	100	124	125	96
5 hour - LP	30	45	46	39
20 hour - LP	57	78	74	56

Table 2: Number of AGN detected for Southern array alpha and omega configurations for the different extrapolation schemes, exposures and energy thresholds considered in this study.

significant impact in the number of AGN detected. It should be highlighted that in both Table 1 & 2, the number of AGN detected doesn't simply decrease as the energy threshold increases; rather, the number of AGN detected by CTA varies due to the fact that, at the lowest energies there is a large background, whilst at the highest energy, the signal from the AGN becomes statistics limited.

To achieve some of its key science goals [11], CTA needs to expand the cosmic distances at which blazars are studied. Figure 1 shows the redshift distributions of the simulated and detected AGN for both the alpha and omega configurations of the Northern array and Southern array, for 20 h exposures considering a power-law extrapolation scheme. In both cases, the omega array detects significantly more AGN at large redshifts compared to the alpha configuration. It should be stressed that in this study, we only consider the average 4LAC spectra for extrapolation, integrated over 8 years of the *Fermi*-LAT data. AGN undergoing γ -ray flares often exhibit 'harder-when-brighter' spectral characteristics (see e.g. [12, 13]), which can facilitate CTA detecting AGN at higher redshifts than those reported here.

The difference in performance of the alpha and omega configurations will also result in differences in the spectral characteristics that CTA will be able to detect from this AGN population.

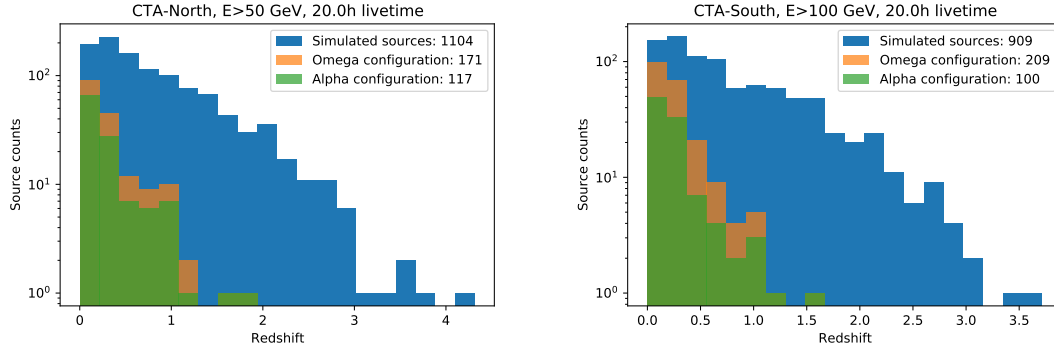


Figure 1: Redshift distributions of AGN detected by CTA-North (left) and Southern array (right) with 20 h exposures considering a power-law extrapolation scheme. In both cases, the increased sensitivity of the omega array significantly increases the number of AGN detected at larger redshift of the further detected AGN, compared to the alpha configuration. It should be noted that the Southern array comparison considers an energy threshold of 100 GeV, thus negating the major difference between the two array configurations due to the LSTs. As such, this comparison is a conservative one, and we would expect a greater difference.

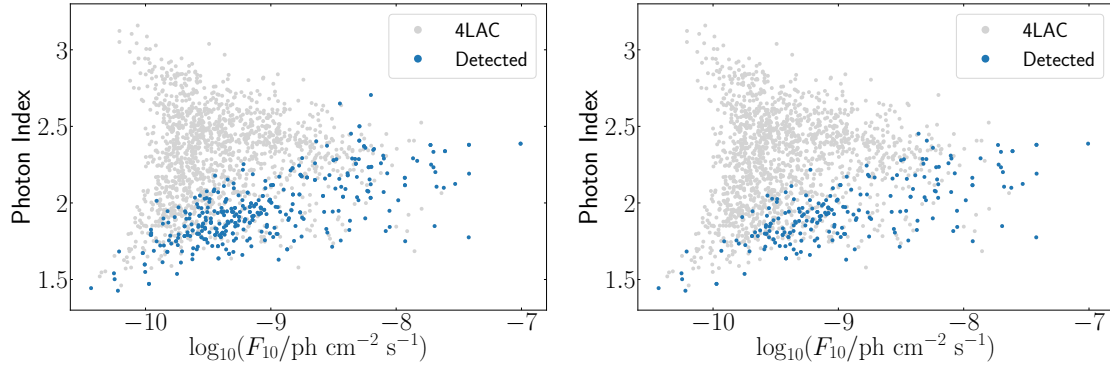


Figure 2: Flux vs index parameter space for the AGN considered in this study. The grey symbols indicate all AGN simulated, whilst the blue symbols represent the AGN detected by CTA (by either the Northern or Southern array). From left to right, the panels depict the results for the omega and alpha configurations, respectively.

This is best seen in Figure 2, which shows the photon index versus integrated flux of all AGN considered in this study. Figure 2 clearly indicates that the omega configuration will increase CTA's reach across the 'photon index versus integrated flux' parameter space compared to the alpha configuration, with CTA being able to detect fainter and/or softer AGN than is possible in its smaller initial alpha configuration.

The results highlight that the CTA will not only multiply the number of sources detected, but also expand the horizons to which we can observe the gamma-ray sky. As described in [14], the detection of high-redshift blazars will enable scientists to explore a range of topics in astronomy, cosmology and fundamental physics. These include the measurement of the gamma-ray absorption by the EBL, investigations of intergalactic magnetic fields, searches for evidence of axion-like particles and multiple tests for Lorentz invariance violation. The increased number of sources will

also provide a basis for a robust reliable estimate of the luminosity function of blazars and help investigate the evolution of the different source populations in this energy regime.

5. Conclusions

With its improved sensitivity, we find that in all analysis configurations considered in this study, the omega configuration performs better than the initial alpha configuration, which shows that we will be able to expand science reach of CTA as more telescopes are installed. In some cases, specifically the Southern array low threshold energy analysis, the difference in the number of AGN detected between the Southern array omega and alpha configurations is greater than 100%. Furthermore, CTA's omega configuration will detect more AGN at higher redshifts compared to current IACTs, as well as detecting a larger number of fainter and softer AGN compared to the alpha configuration. In addition, multiple propagation studies will already be possible due to the alpha configuration being able to detect sources up to a redshift of $\simeq 1.8$.

This study shows that even during the construction phase, CTA will already be able to double the number of extragalactic sources detected in the VHE regime, even taking into account that these predictions are most likely conservative, given *Fermi*-LAT 8-year-averaged spectra are dominated by AGN in low-activity states.

Unfortunately, other γ -ray cosmology studies which require the detection of numerous AGN across a large redshift range, such as attempting to measure the evolution of the EBL across different cosmological epochs or Lorentz invariance violation [14], would greatly profit from the LST component of the omega configuration for the Southern array. This benefit relating to the lower energy threshold is afforded to us by the LSTs, which allow for additional AGN to be detected at large redshifts.

Acknowledgments

We gratefully acknowledge financial support from the agencies and organizations listed here: http://www.cta-observatory.org/consortium_acknowledgments.

References

- [1] B.S. Acharya, M. Actis, T. Aghajani, G. Agnetta, J. Aguilar, F. Aharonian et al.,
Introducing the CTA concept, *Astroparticle Physics* **43** (2013) 3.
- [2] A. Acharyya, I. Agudo, E.O. Angüner, R. Alfaro, J. Alfaro, C. Alispach et al.,
Monte Carlo studies for the optimisation of the Cherenkov Telescope Array layout,
Astroparticle Physics **111** (2019) 35 [1904.01426].
- [3] M. Ajello, R. Angioni, M. Axelsson, J. Ballet, G. Barbiellini, D. Bastieri et al.,
The Fourth Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope,
ApJ **892** (2020) 105 [1905.10771].

- [4] C. Deil, R. Zanin, J. Lefaucheur, C. Boisson, B. Khelifi, R. Terrier et al., Gammapy - A prototype for the CTA science tools, in 35th International Cosmic Ray Conference (ICRC2017), vol. 301 of International Cosmic Ray Conference, p. 766, Jan., 2017 [[1709.01751](#)].
- [5] C. Nigro, C. Deil, R. Zanin, T. Hassan, J. King, J.E. Ruiz et al., Towards open and reproducible multi-instrument analysis in gamma-ray astronomy, A&A **625** (2019) A10 [[1903.06621](#)].
- [6] P. Goldoni, Review of redshift values of bright AGNs with hard spectra in 4LAC catalog, Apr., 2021. [10.5281/zenodo.4721386](#).
- [7] A. Domínguez, J.R. Primack, D.J. Rosario, F. Prada, R.C. Gilmore, S.M. Faber et al., Extragalactic background light inferred from AEGIS galaxy-SED-type fractions, MNRAS **410** (2011) 2556 [[1007.1459](#)].
- [8] P. Goldoni, S. Pita, C. Boisson, W. Max-Moerbeck, E. Kasai, D.A. Williams et al., Optical spectroscopy of blazars for the Cherenkov Telescope Array, A&A **650** (2021) A106 [[2012.05176](#)].
- [9] T. Hassan, L. Arrabito, K. Bernlöhr, J. Bregeon, J. Cortina, P. Cumani et al., Monte Carlo performance studies for the site selection of the Cherenkov Telescope Array, Astroparticle Physics **93** (2017) 76 [[1705.01790](#)].
- [10] T.P. Li and Y.Q. Ma, Analysis methods for results in gamma-ray astronomy, ApJ **272** (1983) 317.
- [11] Cherenkov Telescope Array Consortium, B.S. Acharya, I. Agudo, I. Al Samarai, R. Alfaro, J. Alfaro et al., Science with the Cherenkov Telescope Array (2019), [10.1142/10986](#).
- [12] A.M. Brown and J. Adams, High-energy γ -ray properties of the Fanaroff-Riley type I radio galaxy NGC 1275, MNRAS **413** (2011) 2785 [[1101.2687](#)].
- [13] V.A. Acciari, S. Ansoldi, L.A. Antonelli, K. Asano, A. Babić, B. Banerjee et al., Multiwavelength variability and correlation studies of Mrk 421 during historically low X-ray and γ -ray activity MNRAS **504** (2021) 1427 [[2012.01348](#)].
- [14] H. Abdalla, H. Abe, F. Acero, A. Acharyya, R. Adam, I. Agudo et al., Sensitivity of the Cherenkov Telescope Array for probing cosmology and fundamental physics with gamma-ray J. Cosmology Astropart. Phys. **2021** (2021) 048 [[2010.01349](#)].

Full Authors List: CTA Consortium

H. Abdalla¹, H. Abe², S. Abe², A. Abusleme³, F. Acero⁴, A. Acharyya⁵, V. Acín Portella⁶, K. Ackley⁷, R. Adam⁸, C. Adams⁹, S.S. Adhikari¹⁰, I. Aguado-Ruesga¹¹, I. Agudo¹², R. Aguilera¹³, A. Aguirre-Santaella¹⁴, F. Aharonian¹⁵, A. Alberdi¹², R. Alfaro¹⁶, J. Alfaro³, C. Alispach¹⁷, R. Aloisio¹⁸, R. Alves Batista¹⁹, J.-P. Amans²⁰, L. Amati²¹, E. Amato²², L. Ambrogio¹⁸, G. Ambrosi²³, M. Ambrosio²⁴, R. Ammendola²⁵, J. Anderson²⁶, M. Anduze⁸, E.O. Angüner²⁷, L.A. Antonelli²⁸, V. Antonuccio²⁹, P. Antoranz³⁰, R. Anutarawiramkul³¹, J. Aragunde Gutierrez³², C. Aramo²⁴, A. Araudo^{33,34}, M. Araya³⁵, A. Arbet-Engels³⁶, C. Arcaro¹, V. Arendt³⁷, C. Armand³⁸, T. Armstrong²⁷, F. Arqueros¹¹, L. Arrabito³⁹, B. Arsoli⁴⁰, M. Artero⁴¹, K. Asano², Y. Ascasíbar¹⁴, J. Aschersleben⁴², M. Ashley⁴³, P. Attinà⁴⁴, P. Aubert⁴⁵, C. B. Singh¹⁹, D. Baack⁴⁶, A. Babic⁴⁷, M. Backes⁴⁸, V. Baena¹³, S. Bajtlik⁴⁹, A. Baktash⁵⁰, C. Balazs⁷, M. Balbo³⁸, O. Ballester⁴¹, J. Ballet⁴, B. Balmaverde⁴⁴, A. Bamba⁵¹, R. Bandiera²², A. Baquero Larriva¹¹, P. Barai¹⁹, C. Barbier⁴⁵, V. Barbosa Martins⁵², M. Barcelo⁵³, M. Barkov⁵⁴, M. Barnard¹, L. Baroncelli²¹, U. Barres de Almeida⁴⁰, J.A. Barrio¹¹, D. Bastieri⁵⁵, P.I. Batista⁵², I. Batkovic⁵⁵, C. Bauer⁵³, R. Bautista-González⁵⁶, J. Baxter², U. Becciani²⁹, J. Becerra González³⁹, Y. Becherini⁵⁷, G. Beck⁵⁸, J. Becker Tjus⁵⁹, W. Bednarek⁶⁰, A. Belfiore⁶¹, L. Bellizzi⁶², R. Belmont⁴, W. Benbow⁶³, D. Berge⁵², E. Bernardini⁵², M.I. Bernardos⁵⁵, K. Bernlöhr⁵³, A. Berti⁶⁴, M. Berton⁶⁵, B. Bertucci²³, V. Beshley⁶⁶, N. Bhatt⁶⁷, S. Bhattacharyya⁶⁷, W. Bhattacharyya⁵², S. Bhattacharyya⁶⁸, B. Bi⁶⁹, G. Bicknell⁷⁰, N. Biederbeck⁴⁶, C. Bigongiari²⁸, A. Biland³⁶, R. Bird⁷¹, E. Bissaldi⁷², J. Biteau⁷³, M. Bitossi⁷⁴, O. Blanch⁴¹, M. Blank⁵⁰, J. Blazek³³, J. Bobin⁷⁵, C. Boccato⁷⁶, F. Bocchino⁷⁷, C. Boehm⁷⁸, M. Bohacova³³, C. Boisson²⁰, J. Boix⁴¹, J.-P. Bolle⁵², J. Bolmont⁷⁹, G. Bonanno²⁹, C. Bonavolontà²⁴, L. Bonneau Arbeleche⁸⁰, G. Bonnoli¹², P. Bordes⁸¹, J. Borkowski⁴⁹, S. Bórquez³⁵, R. Bose⁸², D. Bose⁸³, Z. Bosnjak⁴⁷, E. Bottacini⁵⁵, M. Böttcher¹, M.T. Botticella⁸⁴, C. Boutonnet⁸⁵, F. Bouyjou⁷⁵, V. Bozhilov⁸⁶, E. Bozzo³⁸, L. Brahimi³⁹, C. Braiding⁴³, S. Brau-Nogue⁸⁷, S. Breen⁷⁸, J. Bregeon³⁹, M. Breuhaus⁵³, A. Brill⁹, W. Briskén⁸⁸, E. Brocato²⁸, A.M. Brown⁵, K. Brügge⁴⁶, P. Brun⁸⁹, P. Brun⁸⁹, F. Brun⁸⁹, L. Brunetti⁴⁵, G. Brunetti⁹⁰, P. Bruno²⁹, A. Bruno⁹¹, A. Bruzzese⁶, N. Bucciantini²², J. Buckley⁸², R. Bühler⁵², A. Bulgarelli²¹, T. Bulik⁹², M. Bünning⁵², M. Bunse⁴⁶, M. Burton⁹³, A. Burtovoi⁷⁶, M. Buscemi⁹⁴, S. Buschjäger⁴⁶, G. Busetto⁵⁵, J. Buss⁴⁶, K. Byrum²⁶, A. Caccianiga⁹⁵, F. Cadoux¹⁷, A. Calanducci²⁹, C. Calderón³, J. Calvo Tovar³², R. Cameron⁹⁶, P. Campaña³⁵, R. Canestrari⁹¹, F. Cangemi⁷⁹, B. Cantlay³¹, M. Capalbi⁹¹, M. Capasso⁹, M. Cappi²¹, A. Caproni⁹⁷, R. Capuzzo-Dolcetta²⁸, P. Caraveo⁶¹, V. Cárdenas⁹⁸, L. Cardiel⁴¹, M. Cardillo⁹⁹, C. Carlile¹⁰⁰, S. Caroff⁴⁵, R. Carosi⁷⁴, A. Carosi¹⁷, E. Carquín³⁵, M. Carrère³⁹, J.-M. Casandjian⁴, S. Casanova^{101,53}, E. Cascone⁸⁴, F. Cassol²⁷, A.J. Castro-Tirado¹², F. Catalani¹⁰², O. Catalano⁹¹, D. Cauz¹⁰³, A. Ceccanti⁶⁴, C. Celestino Silva⁸⁰, S. Celli¹⁸, K. Cerny¹⁰⁴, M. Cerruti⁸⁵, E. Chabanne⁴⁵, P. Chadwick⁵, Y. Chai¹⁰⁵, P. Chambery¹⁰⁶, C. Champion⁸⁵, S. Chandra¹, S. Chaty⁴, A. Chen⁵⁸, K. Cheng², M. Chernyakova¹⁰⁷, G. Chiaro⁶¹, A. Chiavassa^{64,108}, M. Chikawa², V.R. Chitnis¹⁰⁹, J. Chudoba³³, L. Chytka¹⁰⁴, S. Cikota⁴⁷, A. Circiello^{24,110}, P. Clark⁵, M. Çolak⁴¹, E. Colombo³², J. Colome¹³, S. Colonges⁸⁵, A. Comastri²¹, A. Compagnino⁹¹, V. Conforti²¹, E. Congiu⁹⁵, R. Coniglione⁹⁴, J. Conrad¹¹¹, F. Conte⁵³, J.L. Contreras¹¹, P. Coppi¹¹², R. Cornal⁸, J. Coronado-Blazquez¹⁴, J. Cortina¹¹³, A. Costa²⁹, H. Costantini²⁷, G. Cotter¹¹⁴, B. Courty⁸⁵, S. Covino⁹⁵, S. Crestan⁶¹, P. Cristofari²⁰, R. Crocker⁷⁰, J. Croston¹¹⁵, K. Cubuk⁹³, O. Cuevas⁹⁸, X. Cui², G. Cusumano⁹¹, S. Cutini²³, A. D'Ai⁹¹, G. D'Amico¹¹⁶, F. D'Ammando⁹⁰, P. D'Avanzo⁹⁵, P. Da Vela⁷⁴, M. Dadina²¹, S. Dai¹¹⁷, M. Dalchenko¹⁷, M. Dall'Orta⁸⁴, M.K. Daniel⁶³, J. Dauguet⁸⁵, I. Davids⁴⁸, J. Davies¹¹⁴, B. Dawson¹¹⁸, A. De Angelis⁵⁵, A.E. de Araújo Carvalho⁴⁰, M. de Bony de Lavergne⁴⁵, V. De Caprio⁸⁴, G. De Cesare²¹, F. De Frondat²⁰, E.M. de Gouveia Dal Pino¹⁹, I. de la Calle¹¹, B. De Lotto¹⁰³, A. De Luca⁶¹, D. De Martino⁸⁴, R.M. de Menezes¹⁹, M. de Naurois⁸, E. de Oña Wilhelmi¹³, F. De Palma⁶⁴, F. De Persio¹¹⁹, N. de Simone⁵², V. de Souza⁸⁰, M. Del Santo⁹¹, M.V. del Valle¹⁹, E. Delagnes⁷⁵, G. Deleglise⁴⁵, M. Delfino Reznicek⁶, C. Delgado¹¹³, A.G. Delgado Giler⁸⁰, J. Delgado Mengual⁶, R. Della Ceca⁹⁵, M. Della Valle⁸⁴, D. della Volpe¹⁷, D. Depaoli^{64,108}, D. Depouez²⁷, J. Devin⁸⁵, T. Di Girolamo^{24,110}, C. Di Giulio²⁵, A. Di Piano²¹, F. Di Piero⁶⁴, L. Di Venere¹²⁰, C. Díaz¹¹³, C. Díaz-Bahamondes³, C. Dib³⁵, S. Diebold⁶⁹, S. Digel⁹⁶, R. Dimas⁵⁵, A. Djannati-Atai⁸⁵, J. Djvuksland¹¹⁶, A. Dmytriiev²⁰, K. Docher⁹, A. Domínguez¹¹, D. Dominis Prester¹²¹, A. Donath⁵³, A. Donini⁴¹, D. Dorner¹²², M. Doro⁵⁵, R.d.C. dos Anjos¹²³, J.-L. Dournaux²⁰, T. Downes¹⁰⁷, G. Drake²⁶, H. Drass³, D. Dravins¹⁰⁰, C. Duangchan³¹, A. Duara¹²⁴, G. Dubus¹²⁵, L. Ducci⁶⁹, C. Duffy¹²⁴, D. Dumora¹⁰⁶, K. Dundas Morá¹¹¹, A. Durkalec¹²⁶, V.V. Dwarkadas¹²⁷, J. Ebr³³, C. Eckner⁴⁵, J. Eder¹⁰⁵, A. Ederoclite¹⁹, E. Edy⁸, K. Egberts¹²⁸, S. Einecke¹¹⁸, J. Eisch¹²⁹, C. Eleftheriadis¹³⁰, D. Elsässer⁴⁶, G. Emery¹⁷, D. Emmanoulopoulos¹¹⁵, J.-P. Ernenwein²⁷, M. Errando⁸², P. Escarate³⁵, J. Escudero¹², C. Espinoza³, S. Etori²¹, A. Eungwanichayapant³¹, P. Evans¹²⁴, C. Evoli¹⁸, M. Fairbairn¹³¹, D. Falceta-Goncalves¹³², A. Falcone¹³³, V. Fallah Ramazani⁶⁵, R. Falomo⁷⁶, K. Farakos¹³⁴, G. Fasola²⁰, A. Fattorini⁴⁶, Y. Favre¹⁷, R. Fedora¹³⁵, E. Fedorova¹³⁶, S. Fegan⁸, K. Feijen¹¹⁸, Q. Feng⁹, G. Ferrand⁵⁴, G. Ferrara⁹⁴, O. Ferreira⁸, M. Fesquet⁷⁵, E. Fiandrini²³, A. Fiascon⁴⁵, M. Filipovic¹¹⁷, D. Fink¹⁰⁵, J.P. Finley¹³⁷, V. Fioretti²¹, D.F.G. Fiorillo^{24,110}, M. Fiorini⁶¹, S. Flis⁵², H. Flores²⁰, L. Foffano¹⁷, C. Föhr⁵³, M.V. Fonseca¹¹, L. Font¹³⁸, G. Fontaine⁸, O. Fornieri⁵², P. Fortin⁶³, L. Fortson⁸⁸, N. Fouque⁴⁵, A. Fournier¹⁰⁶, B. Fraga⁴⁰, A. Franceschini⁷⁶, F.J. Franco³⁰, A. Franco Ordovas³², L. Freixas Coromina¹¹³, L. Fresnillo³⁰, C. Fruck¹⁰⁵, D. Fugazza⁹⁵, Y. Fujikawa¹³⁹, Y. Fujita², S. Fukami², Y. Fukazawa¹⁴⁰, Y. Fukui¹⁴¹, D. Fulla⁵², S. Funk¹⁴², A. Furniss¹⁴³, O. Gabella³⁹, S. Gabici⁸⁵, D. Gaggero¹⁴, G. Galanti⁶¹, G. Galaz³, P. Galdemard¹⁴⁴, Y. Gallant³⁹, D. Galloway⁷, S. Gallozzi²⁸, V. Gammaldi¹⁴, R. Garcia⁴¹, E. Garcia⁴⁵, E. García¹³, R. García López³², M. Garczarzyk⁵², F. Gargano¹²⁰, C. Gargano⁹¹, S. Garozzo²⁹, D. Gascon⁸¹, T. Gasparetto¹⁴⁵, D. Gasparrini²⁵, H. Gasparyan⁵², M. Gaug¹³⁸, N. Geffroy⁴⁵, A. Gent¹⁴⁶, S. Germani⁷⁶, L. Gesa¹³, A. Ghalumyan¹⁴⁷, A. Ghedina¹⁴⁸, G. Ghirlanda⁹⁵, F. Gianotti²¹, S. Giarrusso⁹¹, M. Giarrusso⁹⁴, G. Giavitto⁵², B. Giebels⁸, N. Giglietto⁷², V. Gika¹³⁴, F. Gillardo⁴⁵, R. Gimenes¹⁹, F. Giordano¹⁴⁹, G. Giovannini⁹⁰, E. Giro⁷⁶, M. Giroletti⁹⁰, A. Giuliani⁶¹, L. Giunti⁸⁵, M. Gjaja⁹, J.-F. Glicenstein⁸⁹, P. Gliwny⁶⁰, N. Godinovic¹⁵⁰, H. Göksu⁵³, P. Goldoni⁸⁵, J.L. Gómez¹², G. Gómez-Vargas³, M.M. González¹⁶, J.M. González¹⁵¹, K.S. Gothe¹⁰⁹, D. Götz⁴, J. Goulart Coelho¹²³, K. Gourgoullos⁹, T. Grabarczyk¹⁵², R. Gracián⁸¹, P. Grandi²¹, G. Grasseau⁸, D. Grasso⁷⁴, A.J. Green⁷⁸, D. Green¹⁰⁵, J. Green²⁸, T. Greenshaw¹⁵³, I. Grenier⁴, P. Grespan⁵⁵, A. Grillo²⁹, M.-H. Grondin¹⁰⁶, J. Grube¹³¹, V. Guarino²⁰, B. Guest³⁷, O. Gueta⁵², M. Gündüz⁵⁹, S. Gunji¹⁵⁴, A. Gusdorf²⁰, G. Gyuk¹⁵⁵, J. Hackfeld⁵⁹, D. Hadasch², J. Haga¹³⁹, L. Hagge⁵², A. Hahn¹⁰⁵, J.E. Hajlaoui⁸⁵, H. Hakobyan³⁵, A. Halim⁸⁹, P. Hamal³³, W. Hanlon⁶³, S. Hara¹⁵⁶, Y. Harada¹⁵⁷, M.J. Hardcastle¹⁵⁸, M. Harvey⁵,

K. Hashiyama², T. Hassan Collado¹¹³, T. Haubold¹⁰⁵, A. Haupt⁵², U.A. Hautmann¹⁵⁹, M. Havelka³³, K. Hayashi¹⁴¹, K. Hayashi¹⁶⁰, M. Hayashida¹⁶¹, H. He⁵⁴, L. Heckmann¹⁰⁵, M. Heller¹⁷, J.C. Helo³⁵, F. Henault¹²⁵, G. Henri¹²⁵, G. Hermann⁵³, R. Herndl⁴⁵, S. Hernández Cadena¹⁶, J. Herrera Llorente³², A. Herrero³², O. Hervet¹⁴³, J. Hinton⁵³, A. Hiramatsu¹⁵⁷, N. Hiroshima⁵⁴, K. Hirotani², B. Hnatyk¹³⁶, R. Hnatyk¹³⁶, J.K. Hoang¹¹, D. Hoffmann²⁷, W. Hofmann⁵³, C. Hoischen¹²⁸, J. Holder¹⁶², M. Holler¹⁶³, B. Hona¹⁶⁴, D. Horan⁸, J. Hörandel¹⁶⁵, D. Horns⁵⁰, P. Horvath¹⁰⁴, J. Houles²⁷, T. Hovatta⁶⁵, M. Hrabovsky¹⁰⁴, D. Hrupec¹⁶⁶, Y. Huang¹³⁵, J.-M. Huet²⁰, G. Hughes¹⁵⁹, D. Hui², G. Hull⁷³, T.B. Humensky⁹, M. Hütten¹⁰⁵, R. Iaria⁷⁷, M. Iarlori¹⁸, J.M. Illa⁴¹, R. Imazawa¹⁴⁰, D. Impiombato⁹¹, T. Inada², F. Incardona²⁹, A. Ingallinera²⁹, Y. Inoue², S. Inoue⁵⁴, T. Inoue¹⁴¹, Y. Inoue¹⁶⁷, A. Insolita^{120,94}, F. Iocco^{24,110}, K. Ioka¹⁶⁸, M. Ionica²³, M. Iori¹¹⁹, S. Iovenitti⁹⁵, A. Iriarte¹⁶, K. Ishio¹⁰⁵, W. Ishizaki¹⁶⁸, Y. Iwamura², C. Jablonski¹⁰⁵, J. Jacquemier⁴⁵, M. Jacquemont⁴⁵, M. Jamroz¹⁶⁹, P. Janeczek³³, F. Jankowsky¹⁷⁰, A. Jardin-Blicq³¹, C. Jarnot⁸⁷, P. Jean⁸⁷, I. Jiménez Martínez¹¹³, W. Jin¹⁷¹, L. Jocou¹²⁵, N. Jordana¹⁷², M. Josselin⁷³, L. Jouvain⁴¹, I. Jung-Richardt¹⁴², F.J.P.A. Junqueira¹⁹, C. Juramy-Gilles⁷⁹, J. Jurysek³⁸, P. Kaaret¹⁷³, L.H.S. Kadowaki¹⁹, M. Kagaya², O. Kalekin¹⁴², R. Kankanyan⁵³, D. Kantzas¹⁷⁴, V. Karas³⁴, A. Karastergiou¹¹⁴, S. Karkar⁷⁹, E. Kasai⁴⁸, J. Kasperek¹⁷⁵, H. Katagiri¹⁷⁶, J. Kataoka¹⁷⁷, K. Katarzyński¹⁷⁸, S. Katsuda¹⁷⁹, U. Katz¹⁴², N. Kawanaka¹⁸⁰, D. Kazanas¹³⁰, D. Kerszberg⁴¹, B. Khélifi⁸⁵, M.C. Kherlakian⁵², T.P. Kian¹⁸¹, D.B. Kieda¹⁶⁴, T. Kihm⁵³, S. Kim³, S. Kimeswenger¹⁶³, S. Kisaka¹⁴⁰, R. Kissmann¹⁶³, R. Kleijwegt¹³⁵, T. Kleiner⁵², G. Kluge¹⁰, W. Kluźniak⁴⁹, J. Knapp⁵², J. Knödseder⁸⁷, A. Kobakhidze⁷⁸, Y. Kobayashi², B. Koch³, J. Kocot¹⁵², K. Kohri¹⁸², K. Kokkotas⁶⁹, N. Komin⁵⁸, A. Kong², K. Kosack⁴, G. Kowal¹³², F. Krack⁵², M. Krause⁵², F. Krennrich¹²⁹, M. Krumholz⁷⁰, H. Kubo¹⁸⁰, V. Kudryavtsev¹⁸³, S. Kunwar⁵³, Y. Kuroda¹³⁹, J. Kushida¹⁵⁷, P. Kushwaha¹⁹, A. La Barbera⁹¹, N. La Palombara⁶¹, V. La Parola⁹¹, G. La Rosa⁹¹, R. Lahmann¹⁴², G. Lamanna⁴⁵, A. Lamastra²⁸, M. Landoni⁹⁵, D. Landriau⁴, R.G. Lang⁸⁰, J. Lapington¹²⁴, P. Laporte²⁰, P. Lason¹⁵², J. Lasui³⁷, J. Lazendic-Galloway⁷, T. Le Flour⁴⁵, P. Le Sidaner²⁰, S. Leach¹²⁴, A. Lecknam³¹, S.-H. Lee¹⁸⁰, W.H. Lee¹⁶, S. Lee¹¹⁸, M.A. Leigui de Oliveira¹⁸⁴, A. Lemièrès⁸⁵, M. Lemoine-Goumard¹⁰⁶, J.-P. Lenain⁷⁹, F. Leone^{94,185}, V. Leray⁸, G. Leto²⁹, F. Leuschner⁶⁹, C. Levy^{79,20}, R. Lindemann⁵², E. Lindfors⁶⁵, L. Linhof⁴⁶, I. Liodakis⁶⁵, A. Lipniacka¹¹⁶, S. Lloyd⁵, M. Lobo¹¹³, T. Lohse¹⁸⁶, S. Lombardi²⁸, F. Longo¹⁴⁵, A. Lopez³², M. López¹¹, R. López-Coto⁵⁵, S. Loporchio¹⁴⁹, F. Louis⁷⁵, M. Louys²⁰, F. Lucarelli²⁸, D. Lucchesi⁵⁵, H. Ludwig Boudi³⁹, P.L. Luque-Escamilla⁵⁶, E. Lyard³⁸, M.C. Maccarone⁹¹, T. Maccarone¹⁸⁷, E. Mach¹⁰¹, A.J. Maciejewski¹⁸⁸, J. Mackey¹⁵, G.M. Madejski⁹⁶, P. Maeght³⁹, C. Maggio¹³⁸, G. Maier⁵², A. Majczyna¹²⁶, P. Majumdar^{83,2}, M. Makariev¹⁸⁹, M. Mallamaci⁵⁵, R. Malta Nunes de Almeida¹⁸⁴, S. Maltezos¹³⁴, D. Malyshev¹⁴², D. Malyshev⁶⁹, D. Mandat³³, G. Maneva¹⁸⁹, M. Manganaro¹²¹, G. Manicò⁹⁴, P. Manigot⁸, K. Mannheim¹²², N. Maragos¹³⁴, D. Marano²⁹, M. Marconi⁸⁴, A. Marcowith³⁹, M. Marculewicz¹⁹⁰, B. Marčun⁶⁸, J. Marin⁹⁸, N. Marinello⁵⁵, P. Marinos¹¹⁸, M. Mariotti⁵⁵, S. Markoff¹⁷⁴, P. Marquez⁴¹, G. Marsella⁹⁴, J. Martí⁵⁶, J.-M. Martin²⁰, P. Martin⁸⁷, O. Martínez³⁰, M. Martínez⁴¹, G. Martínez¹¹³, O. Martínez⁴¹, H. Martínez-Huerta⁸⁰, C. Marty⁸⁷, R. Marx⁵³, N. Masetti^{21,151}, P. Massimino²⁹, A. Mastichiadis¹⁹¹, H. Matsumoto¹⁶⁷, N. Matthews¹⁶⁴, G. Maurin⁴⁵, W. Max-Moerbeck¹⁹², N. Maxted⁴³, D. Mazin^{2,105}, M.N. Mazziotta¹²⁰, S.M. Mazzola⁷⁷, J.D. Mbarubucye⁵², L. Mc Comb⁵, I. McHardy¹¹⁵, S. McKeague¹⁰⁷, S. McMuldrough⁶³, E. Medina⁶⁴, D. Medina Miranda¹⁷, A. Melandri⁹⁵, C. Melioli¹⁹, D. Melkumyan⁵², S. Menchiari⁶², S. Mender⁴⁶, S. Mereghetti⁶¹, G. Merino Arévalo⁶, E. Mestre¹³, J.-L. Meunier⁷⁹, T. Meures¹³⁵, M. Meyer¹⁴², S. Micanovic¹²¹, M. Miceli⁷⁷, M. Michailidis⁶⁹, J. Michałowski¹⁰¹, T. Miener¹¹, I. Mievre⁴⁵, J. Miller³⁵, I.A. Minaya¹⁵³, T. Mineo⁹¹, M. Mineev¹⁸⁹, J.M. Miranda³⁰, P. Mirzoyan¹⁰⁵, A. Mitchell³⁶, T. Mizuno¹⁹³, B. Mode¹³⁵, R. Moderski⁴⁹, L. Mohrmann¹⁴², E. Molina⁸¹, E. Molinari¹⁴⁸, T. Montaruli¹⁷, I. Monteiro⁴⁵, C. Moore¹²⁴, A. Moralejo⁴¹, D. Morcuende-Parrilla¹¹, E. Moretti⁴¹, L. Morganti⁶⁴, K. Mori¹⁹⁴, P. Moriarty¹⁵, K. Morik⁴⁶, G. Morlino²², P. Morris¹¹⁴, A. Morselli²⁵, K. Mosshammer⁵², P. Moya¹⁹², R. Mukherjee⁹, J. Muller⁸, C. Mundell¹⁷², J. Mundet⁴¹, T. Murach⁵², A. Muraczewski⁴⁹, H. Muraishi¹⁹⁵, K. Murase², I. Musella⁸⁴, A. Musummarra¹²⁰, A. Nagai¹⁷, N. Nagar¹⁹⁶, S. Nagataki⁵⁴, T. Naito¹⁵⁶, T. Nakamori¹⁵⁴, K. Nakashima¹⁴², K. Nakayama⁵¹, N. Nakhjiri¹³, G. Naletto⁵⁵, D. Naumann⁵², L. Nava⁹⁵, R. Navarro¹⁷⁴, M.A. Nawaz¹³², H. Ndiayvala⁴, D. Neise³⁶, L. Nellen¹⁶, R. Nemmen¹⁹, M. Newbold¹⁶⁴, N. Neyroud⁴⁵, K. Ngernphat³¹, T. Nguyen Trung⁷³, L. Nicastro²¹, L. Nickel⁴⁶, J. Niemiec¹⁰¹, D. Nieto¹¹, M. Nievas³², C. Nigro⁴¹, M. Nikolajuk¹⁹⁰, D. Ninci⁴¹, K. Nishijima¹⁵⁷, K. Noda², Y. Nogami¹⁷⁶, S. Nolan⁵, R. Nomura², R. Norris¹¹⁷, D. Nosek¹⁹⁷, M. Nöthe⁴⁶, B. Novosyadlyj¹⁹⁸, V. Novotny¹⁹⁷, S. Nozaki¹⁸⁰, F. Nunio¹⁴⁴, P. O'Brien¹²⁴, K. Obara¹⁷⁶, R. Oger⁸⁵, Y. Ohira⁵¹, M. Ohishi², S. Ohm⁵², Y. Ohtani², T. Oka¹⁸⁰, N. Okazaki², A. Okumura^{139,199}, J.-F. Olive⁸⁷, C. Oliver³⁰, G. Olivera⁵², B. Olmi²², R.A. Ong⁷¹, M. Orienti⁹⁰, R. Orito²⁰⁰, M. Orlandini²¹, S. Orlando⁷⁷, E. Orlando¹⁴⁵, J.P. Osborne¹²⁴, M. Ostrowski¹⁶⁹, N. Otte¹⁴⁶, E. Ovcharov⁸⁶, E. Owen², I. Oya¹⁵⁹, A. Ozieblo¹⁵², M. Padovani²², I. Pagano²⁹, A. Pagliaro⁹¹, A. Paizis⁶¹, M. Palatiello¹⁴⁵, M. Palatka³³, E. Palazzi²¹, J.-L. Panazol⁴⁵, D. Paneque¹⁰⁵, B. Panes³, S. Panny¹⁶³, F.R. Pantaleo⁷², M. Panter⁵³, R. Paoletti⁶², M. Paolillo^{24,110}, A. Papitto²⁸, A. Paravac¹²², J.M. Paredes⁸¹, G. Pareschi⁹⁵, N. Park¹²⁷, N. Parmiggiani²¹, R.D. Parsons¹⁸⁶, P. Paško²⁰¹, S. Patel⁵², B. Patricelli²⁸, G. Pauletta¹⁰³, L. Pavletic¹²¹, S. Pavy⁸, A. Pe'er¹⁰⁵, M. Pech³³, M. Pecimotika¹²¹, M.G. Pellegriti¹²⁰, P. Peñil Del Campo¹¹, M. Penno⁵², A. Pepato⁵⁵, S. Perard¹⁰⁶, C. Perennes⁵⁵, G. Peres⁷⁷, M. Peresano⁴, A. Pérez-Aguilera¹¹, J. Pérez-Romero¹⁴, M.A. Pérez-Torres¹², M. Perri²⁸, M. Persic¹⁰³, S. Petrer¹⁸, P.-O. Petrucci¹²⁵, O. Petruk⁶⁶, B. Peyaud⁸⁹, K. Pfrang⁵², E. Pian²¹, G. Piano⁹⁹, P. Piattelli⁹⁴, E. Pietropaolo¹⁸, R. Pillera¹⁴⁹, B. Pilszyk¹⁰¹, D. Pimentel²⁰², F. Pintore⁹¹, C. Pio García⁴¹, G. Pirola⁶⁴, F. Piron³⁹, A. Pisarski¹⁹⁰, S. Pita⁸⁵, M. Pohl¹²⁸, V. Poireau⁴⁵, P. Poledrelli¹⁵⁹, A. Pollo¹²⁶, M. Polo¹¹³, C. Pongkitivanichkul³¹, J. Porthault¹⁴⁴, J. Powell¹⁷¹, D. Pozo⁹⁸, R.R. Prado⁵², E. Prandini⁵⁵, P. Prasit³¹, J. Prast⁴⁵, K. Pressard⁷³, G. Principe⁹⁰, C. Priyadarshi⁴¹, N. Produit³⁸, D. Prokhorov¹⁷⁴, H. Prokoph⁵², M. Prouza³³, H. Przybilski¹⁰¹, E. Pueschel⁵², G. Pühlhofer⁶⁹, I. Puljak¹⁵⁰, M.L. Pumo⁹⁴, M. Punch^{85,57}, F. Queiroz²⁰³, J. Quinn²⁰⁴, A. Quirrenbach¹⁷⁰, S. Rainò¹⁴⁹, P.J. Rajda¹⁷⁵, R. Rando⁵⁵, S. Razaque²⁰⁵, E. Rebert²⁰, S. Recchia⁸⁵, P. Reichherzer⁵⁹, O. Reimer¹⁶³, A. Reimer¹⁶³, A. Reisenegger^{3,206}, Q. Remy⁵³, M. Renaud³⁹, T. Reposeur¹⁰⁶, B. Reville⁵³, J.-M. Reymond⁷⁵, J. Reynolds¹⁵, W. Rhode⁴⁶, D. Ribeiro⁹, M. Ribó⁸¹, G. Richards¹⁶², T. Richtler¹⁹⁶, J. Rico⁴¹, F. Rieger⁵³, L. Riitano¹³⁵, V. Ripepi⁸⁴, M. Riquelme¹⁹², D. Riquelme³⁵, S. Rivoire³⁹, V. Rizzi¹⁸, E. Roache⁶³, B. Rösen¹⁵⁹, M. Roche¹⁰⁶, J. Rodriguez⁴, G. Rodriguez Fernandez²⁵, J.C. Rodriguez Ramirez¹⁹, J.J. Rodríguez Vázquez¹¹³, F. Roepke¹⁷⁰, G. Rojas²⁰⁷, L. Romanato⁵⁵, P. Romano⁹⁵, G. Romeo²⁹, F. Romero Lobato¹¹, C. Romoli⁵³, M. Roncadelli¹⁰³, S. Ronda³⁰, J. Rosado¹¹, A. Rosales de Leon⁵, G. Rowell¹¹⁸, B. Rudak⁴⁹, A. Rugliancich⁷⁴, J.E. Ruiz del Mazo¹², W. Rujopakarn³¹, C. Rulten⁵, C. Russell³³

F. Russo²¹, I. Sadeh⁵², E. Sæther Hatlen¹⁰, S. Safi-Harb³⁷, L. Saha¹¹, P. Saha²⁰⁸, V. Sahakian¹⁴⁷, S. Sailer⁵³, T. Saito², N. Sakaki⁵⁴, S. Sakurai², F. Salesa Greus¹⁰¹, G. Salina²⁵, H. Salzmann⁶⁹, D. Sanchez⁴⁵, M. Sánchez-Conde¹⁴, H. Sandaker¹⁰, A. Sandoval¹⁶, P. Sangiorgi⁹¹, M. Sanguillon³⁹, H. Sano², M. Santander¹⁷¹, A. Santangelo⁶⁹, E.M. Santos²⁰², R. Santos-Lima¹⁹, A. Sanuy⁸¹, L. Sapozhnikov⁹⁶, T. Saric¹⁵⁰, S. Sarkar¹¹⁴, H. Sasaki¹⁵⁷, N. Sasaki¹⁷⁹, K. Satalecka⁵², Y. Sato²⁰⁹, F.G. Saturni²⁸, M. Sawada⁵⁴, U. Sawangwit³¹, J. Schaefer¹⁴², A. Scherer³, J. Scherpenberg¹⁰⁵, P. Schipani⁸⁴, B. Schleicher¹²², J. Schmoll⁵, M. Schneider¹⁴³, H. Schoorlemmer⁵³, P. Schovaneck³³, F. Schussler⁸⁹, B. Schwab¹⁴², U. Schwanke¹⁸⁶, J. Schwarz⁹⁵, T. Schweizer¹⁰⁵, E. Sciacca²⁹, S. Scuderi⁶¹, M. Seglar Arroyo⁴⁵, A. Segreto⁹¹, I. Seitenzahl⁴³, D. Semikoz⁸⁵, O. Sergijenko¹³⁶, J.E. Serna Franco¹⁶, M. Servillat²⁰, K. Seweryn²⁰¹, V. Sguera²¹, A. Shalchi³⁷, R.Y. Shang⁷¹, P. Sharma⁷³, R.C. Shellard⁴⁰, L. Sidoli⁶¹, J. Sieiro⁸¹, H. Siejkowski¹⁵², J. Silk¹¹⁴, A. Sillanpää⁶⁵, B.B. Singh¹⁰⁹, K.K. Singh²¹⁰, A. Sinha³⁹, C. Siqueira⁸⁰, G. Sironi⁹⁵, J. Sitarek⁶⁰, P. Sizun⁷⁵, V. Sliusar³⁸, A. Slowikowska¹⁷⁸, D. Sobczyńska⁶⁰, R.W. Sobrinho¹⁸⁴, H. Sol²⁰, G. Sottile⁹¹, H. Spackman¹¹⁴, A. Specovius¹⁴², S. Spencer¹¹⁴, G. Spengler¹⁸⁶, D. Spiga⁹⁵, A. Spolon⁵⁵, W. Springer¹⁶⁴, A. Stamerra²⁸, S. Stanic⁶⁸, R. Starling¹²⁴, L. Stawarz¹⁶⁹, R. Steenkamp⁴⁸, S. Stefanik¹⁹⁷, C. Stegmann¹²⁸, A. Steiner⁵², S. Steinmassi⁵³, C. Stella¹⁰³, C. Steppa¹²⁸, R. Sternberger⁵², M. Sterzel¹⁵², C. Stevens¹³⁵, H. Stevenson⁷¹, T. Stolarczyk⁴, G. Stratta²¹, U. Straumann²⁰⁸, J. Strišković¹⁶⁶, M. Strzys², R. Stuk¹⁷⁴, M. Suchenek²¹¹, Y. Suda¹⁴⁰, Y. Sunada¹⁷⁹, T. Suomijarvi⁷³, T. Suric²¹², P. Sutcliffe¹⁵³, H. Suzuki²¹³, P. Świerk¹⁰¹, T. Szeplieniec¹⁵², A. Tacchini²¹, K. Tachihara¹⁴¹, G. Tagliaferri⁹⁵, H. Tajima¹³⁹, N. Tajima², D. Tak⁵², K. Takahashi²¹⁴, H. Takahashi¹⁴⁰, M. Takahashi², M. Takahashi², J. Takata², R. Takeishi², T. Tam², M. Tanaka¹⁸², T. Tanaka²¹³, S. Tanaka²⁰⁹, D. Tateishi¹⁷⁹, M. Tavani⁹⁹, F. Tavecchio⁹⁵, T. Tavernier⁸⁹, L. Taylor¹³⁵, A. Taylor⁵², L.A. Tejedor¹¹, P. Temnikov¹⁸⁹, Y. Terada¹⁷⁹, K. Terauchi¹⁸⁰, J.C. Terrazas¹⁹², R. Terrier⁸⁵, T. Terzic¹²¹, M. Teshima^{105,2}, V. Testa²⁸, D. Thibaut⁸⁵, F. Thocquenue⁷⁵, W. Tian², L. Tibaldo⁸⁷, A. Tiengo²¹⁵, D. Tiziani¹⁴², M. Tluczykont⁵⁰, C.J. Toderó Peixoto¹⁰², F. Tokana¹⁵⁴, K. Toma¹⁶⁰, L. Tomankova¹⁴², J. Tomastik¹⁰⁴, D. Tonev¹⁸⁹, M. Tornikoski²¹⁶, D.F. Torres¹³, E. Torres²¹, G. Tosti⁹⁵, L. Tosti²³, T. Totani⁵¹, N. Tothill¹¹⁷, F. Tousseneil⁷⁹, G. Tovmassian¹⁶, P. Travnicek³³, C. Trichard⁸, M. Trifoglio²¹, A. Trois⁹⁵, S. Truzzi⁶², A. Tsiachina⁸⁷, T. Tsuru¹⁸⁰, B. Turk⁴⁵, A. Tutone⁹¹, Y. Uchiyama¹⁶¹, G. Umana²⁹, P. Utayarat³¹, L. Vaclavik¹⁰⁴, M. Vacula¹⁰⁴, V. Vagelli^{23,217}, F. Vagnetti²⁵, F. Vakili²¹⁸, J.A. Valdivia¹⁹², M. Valentino²⁴, A. Valio¹⁹, B. Vallage⁸⁹, P. Vallania^{44,64}, J.V. Valverde Quispe⁸, A.M. Van den Berg⁴², W. van Driel²⁰, C. van Eldik¹⁴², C. van Rensburg¹, B. van Soelen²¹⁰, J. Vandenbroucke¹³⁵, J. Vanderwalt¹, G. Vasileiadis³⁹, V. Vassiliev⁷¹, M. Vázquez Acosta³², M. Vecchi⁴², A. Vega⁹⁸, J. Veh¹⁴², P. Veitch¹¹⁸, P. Venault⁷⁵, C. Venter¹, S. Ventura⁶², S. Vercellone⁹⁵, S. Vergani²⁰, V. Verguillov¹⁸⁹, G. Verna²⁷, S. Vernetto^{44,64}, V. Verzi²⁵, G.P. Vettolani⁹⁰, C. Veyssiere¹⁴⁴, I. Viale⁵⁵, A. Viana⁸⁰, N. Viaux³⁵, J. Vicha³³, J. Vignatti³⁵, C.F. Vigorito^{64,108}, J. Villanueva⁹⁸, J. Vink¹⁷⁴, V. Vitale²³, V. Vittorini⁹⁹, V. Vodeb⁶⁸, H. Voelk⁵³, N. Vogel¹⁴², V. Voisin⁷⁹, S. Vorobiov⁶⁸, I. Vovk², M. Vrastil³³, T. Vuillaume⁴⁵, S.J. Wagner¹⁷⁰, R. Wagner¹⁰⁵, P. Wagner⁵², K. Wakazono¹³⁹, S.P. Wakely¹²⁷, R. Walter³⁸, M. Ward⁵, D. Warren⁵⁴, J. Watson⁵², N. Webb⁸⁷, M. Wechakama³¹, P. Wegner⁵², A. Weinstein¹²⁹, C. Weniger¹⁷⁴, F. Werner⁵³, H. Wetterskind¹⁰⁵, M. White¹¹⁸, R. White⁵³, A. Wierzcholska¹⁰¹, S. Wiesand⁵², R. Wijers¹⁷⁴, M. Wilkinson¹²⁴, M. Will¹⁰⁵, D.A. Williams¹⁴³, J. Williams¹²⁴, T. Williamson¹⁶², A. Wolter⁹⁵, Y.W. Wong¹⁴², M. Wood⁹⁶, C. Wunderlich⁶², T. Yamamoto²¹³, H. Yamamoto¹⁴¹, Y. Yamane¹⁴¹, R. Yamazaki²⁰⁹, S. Yanagita¹⁷⁶, L. Yang²⁰⁵, S. Yoo¹⁸⁰, T. Yoshida¹⁷⁶, T. Yoshikoshi², P. Yu⁷¹, P. Yu⁸⁵, A. Yusufzai⁵⁹, M. Zacharias²⁰, G. Zaharijas⁶⁸, B. Zaldivar¹⁴, L. Zampieri⁷⁶, R. Zanmar Sanchez²⁹, D. Zaric¹⁵⁰, M. Zavrtanik⁶⁸, D. Zavrtanik⁶⁸, A.A. Zdziarski⁴⁹, A. Zech²⁰, H. Zechlin⁶⁴, A. Zenin¹³⁹, A. Zerwekh³⁵, V.I. Zhdanov¹³⁶, K. Zięta¹⁶⁹, A. Zink¹⁴², J. Ziolkowski⁴⁹, V. Zitelli²¹, M. Živec⁶⁸, A. Zmija¹⁴²

1 : Centre for Space Research, North-West University, Potchefstroom, 2520, South Africa

2 : Institute for Cosmic Ray Research, University of Tokyo, 5-1-5, Kashiwa-no-ha, Kashiwa, Chiba 277-8582, Japan

3 : Pontificia Universidad Católica de Chile, Av. Libertador Bernardo O'Higgins 340, Santiago, Chile

4 : AIM, CEA, CNRS, Université Paris-Saclay, Université Paris Diderot, Sorbonne Paris Cité, CEA Paris-Saclay, IRFU/DAP, Bat 709, Orme des Merisiers, 91191 Gif-sur-Yvette, France

5 : Centre for Advanced Instrumentation, Dept. of Physics, Durham University, South Road, Durham DH1 3LE, United Kingdom

6 : Port d'Informació Científica, Edifici D, Carrer de l'Albareda, 08193 Bellaterra (Cerdanyola del Vallès), Spain

7 : School of Physics and Astronomy, Monash University, Melbourne, Victoria 3800, Australia

8 : Laboratoire Leprince-Ringuet, École Polytechnique (UMR 7638, CNRS/IN2P3, Institut Polytechnique de Paris), 91128 Palaiseau, France

9 : Department of Physics, Columbia University, 538 West 120th Street, New York, NY 10027, USA

10 : University of Oslo, Department of Physics, Sem Saelandsvei 24 - PO Box 1048 Blindern, N-0316 Oslo, Norway

11 : EMFTEL department and IPARCOS, Universidad Complutense de Madrid, 28040 Madrid, Spain

12 : Instituto de Astrofísica de Andalucía-CSIC, Glorieta de la Astronomía s/n, 18008, Granada, Spain

13 : Institute of Space Sciences (ICE-CSIC), and Institut d'Estudis Espacials de Catalunya (IEEC), and Institució Catalana de Recerca i Estudis Avançats (ICREA), Campus UAB, Carrer de Can Magrans, s/n 08193 Cerdanyola del Vallès, Spain

14 : Instituto de Física Teórica UAM/CSIC and Departamento de Física Teórica, Universidad Autónoma de Madrid, c/ Nicolás Cabrera 13-15, Campus de Cantoblanco UAM, 28049 Madrid, Spain

15 : Dublin Institute for Advanced Studies, 31 Fitzwilliam Place, Dublin 2, Ireland

16 : Universidad Nacional Autónoma de México, Delegación Coyoacán, 04510 Ciudad de México, Mexico

17 : University of Geneva - Département de physique nucléaire et corpusculaire, 24 rue du Général-Dufour, 1211 Genève 4, Switzerland

18 : INFN Dipartimento di Scienze Fisiche e Chimiche - Università degli Studi dell'Aquila and Gran Sasso Science Institute, Via Vetoio 1, Viale Crispi 7, 67100 L'Aquila, Italy

19 : Instituto de Astronomia, Geofísico, e Ciências Atmosféricas - Universidade de São Paulo, Cidade Universitária, R. do Matão, 1226, CEP 05508-090, São Paulo, SP, Brazil

20 : LUTH, GEPI and LERMA, Observatoire de Paris, CNRS, PSL University, 5 place Jules Janssen, 92190, Meudon, France

- 21 : INAF - Osservatorio di Astrofisica e Scienza dello spazio di Bologna, Via Piero Gobetti 93/3, 40129 Bologna, Italy
- 22 : INAF - Osservatorio Astrofisico di Arcetri, Largo E. Fermi, 5 - 50125 Firenze, Italy
- 23 : INFN Sezione di Perugia and Università degli Studi di Perugia, Via A. Pascoli, 06123 Perugia, Italy
- 24 : INFN Sezione di Napoli, Via Cintia, ed. G, 80126 Napoli, Italy
- 25 : INFN Sezione di Roma Tor Vergata, Via della Ricerca Scientifica 1, 00133 Rome, Italy
- 26 : Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439, USA
- 27 : Aix-Marseille Université, CNRS/IN2P3, CPPM, 163 Avenue de Luminy, 13288 Marseille cedex 09, France
- 28 : INAF - Osservatorio Astronomico di Roma, Via di Frascati 33, 00040, Monteporzio Catone, Italy
- 29 : INAF - Osservatorio Astrofisico di Catania, Via S. Sofia, 78, 95123 Catania, Italy
- 30 : Grupo de Electronica, Universidad Complutense de Madrid, Av. Complutense s/n, 28040 Madrid, Spain
- 31 : National Astronomical Research Institute of Thailand, 191 Huay Kaew Rd., Suthep, Muang, Chiang Mai, 50200, Thailand
- 32 : Instituto de Astrofísica de Canarias and Departamento de Astrofísica, Universidad de La Laguna, La Laguna, Tenerife, Spain
- 33 : FZU - Institute of Physics of the Czech Academy of Sciences, Na Slovance 1999/2, 182 21 Praha 8, Czech Republic
- 34 : Astronomical Institute of the Czech Academy of Sciences, Bocni II 1401 - 14100 Prague, Czech Republic
- 35 : CCTVal, Universidad Técnica Federico Santa María, Avenida España 1680, Valparaíso, Chile
- 36 : ETH Zurich, Institute for Particle Physics, Schafmattstr. 20, CH-8093 Zurich, Switzerland
- 37 : The University of Manitoba, Dept of Physics and Astronomy, Winnipeg, Manitoba R3T 2N2, Canada
- 38 : Department of Astronomy, University of Geneva, Chemin d'Ecogia 16, CH-1290 Versoix, Switzerland
- 39 : Laboratoire Univers et Particules de Montpellier, Université de Montpellier, CNRS/IN2P3, CC 72, Place Eugène Bataillon, F-34095 Montpellier Cedex 5, France
- 40 : Centro Brasileiro de Pesquisas Físicas, Rua Xavier Sigaud 150, RJ 22290-180, Rio de Janeiro, Brazil
- 41 : Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Campus UAB, 08193 Bellaterra (Barcelona), Spain
- 42 : University of Groningen, KVI - Center for Advanced Radiation Technology, Zernikelaan 25, 9747 AA Groningen, The Netherlands
- 43 : School of Physics, University of New South Wales, Sydney NSW 2052, Australia
- 44 : INAF - Osservatorio Astrofisico di Torino, Strada Osservatorio 20, 10025 Pino Torinese (TO), Italy
- 45 : Univ. Savoie Mont Blanc, CNRS, Laboratoire d'Annecy de Physique des Particules - IN2P3, 74000 Annecy, France
- 46 : Department of Physics, TU Dortmund University, Otto-Hahn-Str. 4, 44221 Dortmund, Germany
- 47 : University of Zagreb, Faculty of electrical engineering and computing, Unska 3, 10000 Zagreb, Croatia
- 48 : University of Namibia, Department of Physics, 340 Mandume Ndemufayo Ave., Pioneerspark, Windhoek, Namibia
- 49 : Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, ul. Bartycka 18, 00-716 Warsaw, Poland
- 50 : Universität Hamburg, Institut für Experimentalphysik, Luruper Chaussee 149, 22761 Hamburg, Germany
- 51 : Graduate School of Science, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
- 52 : Deutsches Elektronen-Synchrotron, Platanenallee 6, 15738 Zeuthen, Germany
- 53 : Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany
- 54 : RIKEN, Institute of Physical and Chemical Research, 2-1 Hirosawa, Wako, Saitama, 351-0198, Japan
- 55 : INFN Sezione di Padova and Università degli Studi di Padova, Via Marzolo 8, 35131 Padova, Italy
- 56 : Escuela Politécnica Superior de Jaén, Universidad de Jaén, Campus Las Lagunillas s/n, Edif. A3, 23071 Jaén, Spain
- 57 : Department of Physics and Electrical Engineering, Linnaeus University, 351 95 Växjö, Sweden
- 58 : University of the Witwatersrand, 1 Jan Smuts Avenue, Braamfontein, 2000 Johannesburg, South Africa
- 59 : Institut für Theoretische Physik, Lehrstuhl IV: Plasma-Astroteilchenphysik, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany
- 60 : Faculty of Physics and Applied Computer Science, University of Łódź, ul. Pomorska 149-153, 90-236 Łódź, Poland
- 61 : INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica di Milano, Via A. Corti 12, 20133 Milano, Italy
- 62 : INFN and Università degli Studi di Siena, Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente (DSFTA), Sezione di Fisica, Via Roma 56, 53100 Siena, Italy
- 63 : Center for Astrophysics | Harvard & Smithsonian, 60 Garden St, Cambridge, MA 02180, USA
- 64 : INFN Sezione di Torino, Via P. Giuria 1, 10125 Torino, Italy
- 65 : Finnish Centre for Astronomy with ESO, University of Turku, Finland, FI-20014 University of Turku, Finland
- 66 : Pidstryhach Institute for Applied Problems in Mechanics and Mathematics NASU, 3B Naukova Street, Lviv, 79060, Ukraine
- 67 : Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India
- 68 : Center for Astrophysics and Cosmology, University of Nova Gorica, Vipavska 11c, 5270 Ajdovščina, Slovenia
- 69 : Institut für Astronomie und Astrophysik, Universität Tübingen, Sand 1, 72076 Tübingen, Germany
- 70 : Research School of Astronomy and Astrophysics, Australian National University, Canberra ACT 0200, Australia
- 71 : Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA
- 72 : INFN Sezione di Bari and Politecnico di Bari, via Orabona 4, 70124 Bari, Italy
- 73 : Laboratoire de Physique des 2 infinis, Irene Joliot-Curie, IN2P3/CNRS, Université Paris-Saclay, Université de Paris, 15 rue Georges Clemenceau, 91406 Orsay, Cedex, France
- 74 : INFN Sezione di Pisa, Largo Pontecorvo 3, 56127 Pisa, Italy
- 75 : IRFU/DEDIP, CEA, Université Paris-Saclay, Bat 141, 91191 Gif-sur-Yvette, France
- 76 : INAF - Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, 35122 Padova, Italy

- 77 : INAF - Osservatorio Astronomico di Palermo "G.S. Vaiana", Piazza del Parlamento 1, 90134 Palermo, Italy
- 78 : School of Physics, University of Sydney, Sydney NSW 2006, Australia
- 79 : Sorbonne Université, Université Paris Diderot, Sorbonne Paris Cité, CNRS/IN2P3, Laboratoire de Physique Nucléaire et de Hautes Energies, LPNHE, 4 Place Jussieu, F-75005 Paris, France
- 80 : Instituto de Física de São Carlos, Universidade de São Paulo, Av. Trabalhador São-carlense, 400 - CEP 13566-590, São Carlos, SP, Brazil
- 81 : Departament de Física Quàntica i Astrofísica, Institut de Ciències del Cosmos, Universitat de Barcelona, IEEC-UB, Martí i Franquès, 1, 08028, Barcelona, Spain
- 82 : Department of Physics, Washington University, St. Louis, MO 63130, USA
- 83 : Saha Institute of Nuclear Physics, Bidhannagar, Kolkata-700 064, India
- 84 : INAF - Osservatorio Astronomico di Capodimonte, Via Salita Moiariello 16, 80131 Napoli, Italy
- 85 : Université de Paris, CNRS, Astroparticule et Cosmologie, 10, rue Alice Domon et Léonie Duquet, 75013 Paris Cedex 13, France
- 86 : Astronomy Department of Faculty of Physics, Sofia University, 5 James Bourchier Str., 1164 Sofia, Bulgaria
- 87 : Institut de Recherche en Astrophysique et Planétologie, CNRS-INSU, Université Paul Sabatier, 9 avenue Colonel Roche, BP 44346, 31028 Toulouse Cedex 4, France
- 88 : School of Physics and Astronomy, University of Minnesota, 116 Church Street S.E. Minneapolis, Minnesota 55455-0112, USA
- 89 : IRFU, CEA, Université Paris-Saclay, Bât 141, 91191 Gif-sur-Yvette, France
- 90 : INAF - Istituto di Radioastronomia, Via Gobetti 101, 40129 Bologna, Italy
- 91 : INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica di Palermo, Via U. La Malfa 153, 90146 Palermo, Italy
- 92 : Astronomical Observatory, Department of Physics, University of Warsaw, Aleje Ujazdowskie 4, 00478 Warsaw, Poland
- 93 : Armagh Observatory and Planetarium, College Hill, Armagh BT61 9DG, United Kingdom
- 94 : INFN Sezione di Catania, Via S. Sofia 64, 95123 Catania, Italy
- 95 : INAF - Osservatorio Astronomico di Brera, Via Brera 28, 20121 Milano, Italy
- 96 : Kavli Institute for Particle Astrophysics and Cosmology, Department of Physics and SLAC National Accelerator Laboratory, Stanford University, 2575 Sand Hill Road, Menlo Park, CA 94025, USA
- 97 : Universidade Cruzeiro do Sul, Núcleo de Astrofísica Teórica (NAT/UCS), Rua Galvão Bueno 8687, Bloco B, sala 16, Libertade 01506-000 - São Paulo, Brazil
- 98 : Universidad de Valparaíso, Blanco 951, Valparaíso, Chile
- 99 : INAF - Istituto di Astrofisica e Planetologia Spaziali (IAPS), Via del Fosso del Cavaliere 100, 00133 Roma, Italy
- 100 : Lund Observatory, Lund University, Box 43, SE-22100 Lund, Sweden
- 101 : The Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, ul. Radzikowskiego 152, 31-342 Cracow, Poland
- 102 : Escola de Engenharia de Lorena, Universidade de São Paulo, Área I - Estrada Municipal do Campinho, s/nº, CEP 12602-810, Pte. Nova, Lorena, Brazil
- 103 : INFN Sezione di Trieste and Università degli Studi di Udine, Via delle Scienze 208, 33100 Udine, Italy
- 104 : Palacky University Olomouc, Faculty of Science, RCPTM, 17. listopadu 1192/12, 771 46 Olomouc, Czech Republic
- 105 : Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany
- 106 : CENBG, Univ. Bordeaux, CNRS-IN2P3, UMR 5797, 19 Chemin du Solarium, CS 10120, F-33175 Gradignan Cedex, France
- 107 : Dublin City University, Glasnevin, Dublin 9, Ireland
- 108 : Dipartimento di Fisica - Università degli Studi di Torino, Via Pietro Giuria 1 - 10125 Torino, Italy
- 109 : Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Mumbai 400005, India
- 110 : Università degli Studi di Napoli "Federico II" - Dipartimento di Fisica "E. Pancini", Complesso universitario di Monte Sant'Angelo, Via Cintia - 80126 Napoli, Italy
- 111 : Oskar Klein Centre, Department of Physics, University of Stockholm, Albanova, SE-10691, Sweden
- 112 : Yale University, Department of Physics and Astronomy, 260 Whitney Avenue, New Haven, CT 06520-8101, USA
- 113 : CIEMAT, Avda. Complutense 40, 28040 Madrid, Spain
- 114 : University of Oxford, Department of Physics, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, United Kingdom
- 115 : School of Physics & Astronomy, University of Southampton, University Road, Southampton SO17 1BJ, United Kingdom
- 116 : Department of Physics and Technology, University of Bergen, Museplass 1, 5007 Bergen, Norway
- 117 : Western Sydney University, Locked Bag 1797, Penrith, NSW 2751, Australia
- 118 : School of Physical Sciences, University of Adelaide, Adelaide SA 5005, Australia
- 119 : INFN Sezione di Roma La Sapienza, P.le Aldo Moro, 2 - 00185 Roma, Italy
- 120 : INFN Sezione di Bari, via Orabona 4, 70126 Bari, Italy
- 121 : University of Rijeka, Department of Physics, Radmile Matejčić 2, 51000 Rijeka, Croatia
- 122 : Institute for Theoretical Physics and Astrophysics, Universität Würzburg, Campus Hubland Nord, Emil-Fischer-Str. 31, 97074 Würzburg, Germany
- 123 : Universidade Federal Do Paraná - Setor Palotina, Departamento de Engenharias e Exatas, Rua Pioneiro, 2153, Jardim Dallas, CEP: 85950-000 Palotina, Paraná, Brazil
- 124 : Dept. of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH, United Kingdom
- 125 : Univ. Grenoble Alpes, CNRS, IPAG, 414 rue de la Piscine, Domaine Universitaire, 38041 Grenoble Cedex 9, France

- 126 : National Centre for nuclear research (Narodowe Centrum Badań Jądrowych), Ul. Andrzeja Sołtana 7, 05-400 Otwock, Świerk, Poland
- 127 : Enrico Fermi Institute, University of Chicago, 5640 South Ellis Avenue, Chicago, IL 60637, USA
- 128 : Institut für Physik & Astronomie, Universität Potsdam, Karl-Liebknecht-Strasse 24/25, 14476 Potsdam, Germany
- 129 : Department of Physics and Astronomy, Iowa State University, Zaffarano Hall, Ames, IA 50011-3160, USA
- 130 : School of Physics, Aristotle University, Thessaloniki, 54124 Thessaloniki, Greece
- 131 : King's College London, Strand, London, WC2R 2LS, United Kingdom
- 132 : Escola de Artes, Ciências e Humanidades, Universidade de São Paulo, Rua Arlindo Bettio, CEP 03828-000, 1000 São Paulo, Brazil
- 133 : Dept. of Astronomy & Astrophysics, Pennsylvania State University, University Park, PA 16802, USA
- 134 : National Technical University of Athens, Department of Physics, Zografos 9, 15780 Athens, Greece
- 135 : University of Wisconsin, Madison, 500 Lincoln Drive, Madison, WI, 53706, USA
- 136 : Astronomical Observatory of Taras Shevchenko National University of Kyiv, 3 Observatorna Street, Kyiv, 04053, Ukraine
- 137 : Department of Physics, Purdue University, West Lafayette, IN 47907, USA
- 138 : Unitat de Física de les Radiacions, Departament de Física, and CERES-IEEC, Universitat Autònoma de Barcelona, Edifici C3, Campus UAB, 08193 Bellaterra, Spain
- 139 : Institute for Space-Earth Environmental Research, Nagoya University, Chikusa-ku, Nagoya 464-8601, Japan
- 140 : Department of Physical Science, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-8526, Japan
- 141 : Department of Physics, Nagoya University, Chikusa-ku, Nagoya, 464-8602, Japan
- 142 : Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen Centre for Astroparticle Physics (ECAP), Erwin-Rommel-Str. 1, 91058 Erlangen, Germany
- 143 : Santa Cruz Institute for Particle Physics and Department of Physics, University of California, Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, USA
- 144 : IRFU / DIS, CEA, Université de Paris-Saclay, Bat 123, 91191 Gif-sur-Yvette, France
- 145 : INFN Sezione di Trieste and Università degli Studi di Trieste, Via Valerio 2 I, 34127 Trieste, Italy
- 146 : School of Physics & Center for Relativistic Astrophysics, Georgia Institute of Technology, 837 State Street, Atlanta, Georgia, 30332-0430, USA
- 147 : Alikhanyan National Science Laboratory, Yerevan Physics Institute, 2 Alikhanyan Brothers St., 0036, Yerevan, Armenia
- 148 : INAF - Telescopio Nazionale Galileo, Roche de los Muchachos Astronomical Observatory, 38787 Garafia, TF, Italy
- 149 : INFN Sezione di Bari and Università degli Studi di Bari, via Orabona 4, 70124 Bari, Italy
- 150 : University of Split - FESB, R. Boskovicica 32, 21 000 Split, Croatia
- 151 : Universidad Andres Bello, República 252, Santiago, Chile
- 152 : Academic Computer Centre CYFRONET AGH, ul. Nawojki 11, 30-950 Cracow, Poland
- 153 : University of Liverpool, Oliver Lodge Laboratory, Liverpool L69 7ZE, United Kingdom
- 154 : Department of Physics, Yamagata University, Yamagata, Yamagata 990-8560, Japan
- 155 : Astronomy Department, Adler Planetarium and Astronomy Museum, Chicago, IL 60605, USA
- 156 : Faculty of Management Information, Yamanashi-Gakuin University, Kofu, Yamanashi 400-8575, Japan
- 157 : Department of Physics, Tokai University, 4-1-1, Kita-Kaname, Hiratsuka, Kanagawa 259-1292, Japan
- 158 : Centre for Astrophysics Research, Science & Technology Research Institute, University of Hertfordshire, College Lane, Hertfordshire AL10 9AB, United Kingdom
- 159 : Cherenkov Telescope Array Observatory, Saupfercheckweg 1, 69117 Heidelberg, Germany
- 160 : Tohoku University, Astronomical Institute, Aobaku, Sendai 980-8578, Japan
- 161 : Department of Physics, Rikkyo University, 3-34-1 Nishi-Ikebukuro, Toshima-ku, Tokyo, Japan
- 162 : Department of Physics and Astronomy and the Bartol Research Institute, University of Delaware, Newark, DE 19716, USA
- 163 : Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Technikerstr. 25/8, 6020 Innsbruck, Austria
- 164 : Department of Physics and Astronomy, University of Utah, Salt Lake City, UT 84112-0830, USA
- 165 : IMAPP, Radboud University Nijmegen, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands
- 166 : Josip Juraj Strossmayer University of Osijek, Trg Ljudevita Gaja 6, 31000 Osijek, Croatia
- 167 : Department of Earth and Space Science, Graduate School of Science, Osaka University, Toyonaka 560-0043, Japan
- 168 : Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan
- 169 : Astronomical Observatory, Jagiellonian University, ul. Orla 171, 30-244 Cracow, Poland
- 170 : Landessternwarte, Zentrum für Astronomie der Universität Heidelberg, Königstuhl 12, 69117 Heidelberg, Germany
- 171 : University of Alabama, Tuscaloosa, Department of Physics and Astronomy, Gallalee Hall, Box 870324 Tuscaloosa, AL 35487-0324, USA
- 172 : Department of Physics, University of Bath, Claverton Down, Bath BA2 7AY, United Kingdom
- 173 : University of Iowa, Department of Physics and Astronomy, Van Allen Hall, Iowa City, IA 52242, USA
- 174 : Anton Pannekoek Institute/GRAPPA, University of Amsterdam, Science Park 904 1098 XH Amsterdam, The Netherlands
- 175 : Faculty of Computer Science, Electronics and Telecommunications, AGH University of Science and Technology, Kraków, al. Mickiewicza 30, 30-059 Cracow, Poland
- 176 : Faculty of Science, Ibaraki University, Mito, Ibaraki, 310-8512, Japan
- 177 : Faculty of Science and Engineering, Waseda University, Shinjuku, Tokyo 169-8555, Japan

- 178 : Institute of Astronomy, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University in Toruń, ul. Grudziądzka 5, 87-100 Toruń, Poland
- 179 : Graduate School of Science and Engineering, Saitama University, 255 Simo-Ohkubo, Sakura-ku, Saitama city, Saitama 338-8570, Japan
- 180 : Division of Physics and Astronomy, Graduate School of Science, Kyoto University, Sakyo-ku, Kyoto, 606-8502, Japan
- 181 : Centre for Quantum Technologies, National University Singapore, Block S15, 3 Science Drive 2, Singapore 117543, Singapore
- 182 : Institute of Particle and Nuclear Studies, KEK (High Energy Accelerator Research Organization), 1-1 Oho, Tsukuba, 305-0801, Japan
- 183 : Department of Physics and Astronomy, University of Sheffield, Hounsfield Road, Sheffield S3 7RH, United Kingdom
- 184 : Centro de Ciências Naturais e Humanas, Universidade Federal do ABC, Av. dos Estados, 5001, CEP: 09.210-580, Santo André - SP, Brazil
- 185 : Dipartimento di Fisica e Astronomia, Sezione Astrofisica, Università di Catania, Via S. Sofia 78, I-95123 Catania, Italy
- 186 : Department of Physics, Humboldt University Berlin, Newtonstr. 15, 12489 Berlin, Germany
- 187 : Texas Tech University, 2500 Broadway, Lubbock, Texas 79409-1035, USA
- 188 : University of Zielona Góra, ul. Licealna 9, 65-417 Zielona Góra, Poland
- 189 : Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, 72 boul. Tsarigradsko chaussee, 1784 Sofia, Bulgaria
- 190 : University of Białystok, Faculty of Physics, ul. K. Ciołkowskiego 1L, 15-254 Białystok, Poland
- 191 : Faculty of Physics, National and Kapodestrian University of Athens, Panepistimiopolis, 15771 Ilissia, Athens, Greece
- 192 : Universidad de Chile, Av. Libertador Bernardo O'Higgins 1058, Santiago, Chile
- 193 : Hiroshima Astrophysical Science Center, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-8526, Japan
- 194 : Department of Applied Physics, University of Miyazaki, 1-1 Gakuen Kibana-dai Nishi, Miyazaki, 889-2192, Japan
- 195 : School of Allied Health Sciences, Kitasato University, Sagami-hara, Kanagawa 228-8555, Japan
- 196 : Departamento de Astronomía, Universidad de Concepción, Barrio Universitario S/N, Concepción, Chile
- 197 : Charles University, Institute of Particle & Nuclear Physics, V Holešovičkách 2, 180 00 Prague 8, Czech Republic
- 198 : Astronomical Observatory of Ivan Franko National University of Lviv, 8 Kyryla i Mephodia Street, Lviv, 79005, Ukraine
- 199 : Kobayashi-Maskawa Institute (KMI) for the Origin of Particles and the Universe, Nagoya University, Chikusa-ku, Nagoya 464-8602, Japan
- 200 : Graduate School of Technology, Industrial and Social Sciences, Tokushima University, Tokushima 770-8506, Japan
- 201 : Space Research Centre, Polish Academy of Sciences, ul. Bartycka 18A, 00-716 Warsaw, Poland
- 202 : Instituto de Física - Universidade de São Paulo, Rua do Matão Travessa R Nr.187 CEP 05508-090 Cidade Universitária, São Paulo, Brazil
- 203 : International Institute of Physics at the Federal University of Rio Grande do Norte, Campus Universitário, Lagoa Nova CEP 59078-970 Rio Grande do Norte, Brazil
- 204 : University College Dublin, Belfield, Dublin 4, Ireland
- 205 : Centre for Astro-Particle Physics (CAPP) and Department of Physics, University of Johannesburg, PO Box 524, Auckland Park 2006, South Africa
- 206 : Departamento de Física, Facultad de Ciencias Básicas, Universidad Metropolitana de Ciencias de la Educación, Santiago, Chile
- 207 : Núcleo de Formação de Professores - Universidade Federal de São Carlos, Rodovia Washington Luís, km 235 CEP 13565-905 - SP-310 São Carlos - São Paulo, Brazil
- 208 : Physik-Institut, Universität Zürich, Winterthurerstrasse 190, 8057 Zürich, Switzerland
- 209 : Department of Physical Sciences, Aoyama Gakuin University, Fuchinobe, Sagami-hara, Kanagawa, 252-5258, Japan
- 210 : University of the Free State, Nelson Mandela Avenue, Bloemfontein, 9300, South Africa
- 211 : Faculty of Electronics and Information, Warsaw University of Technology, ul. Nowowiejska 15/19, 00-665 Warsaw, Poland
- 212 : Rudjer Boskovic Institute, Bijenicka 54, 10 000 Zagreb, Croatia
- 213 : Department of Physics, Konan University, Kobe, Hyogo, 658-8501, Japan
- 214 : Kumamoto University, 2-39-1 Kurokami, Kumamoto, 860-8555, Japan
- 215 : University School for Advanced Studies IUSS Pavia, Palazzo del Broletto, Piazza della Vittoria 15, 27100 Pavia, Italy
- 216 : Aalto University, Otakaari 1, 00076 Aalto, Finland
- 217 : Agenzia Spaziale Italiana (ASI), 00133 Roma, Italy
- 218 : Observatoire de la Côte d'Azur, Boulevard de l'Observatoire CS34229, 06304 Nice Cedex 4, France