



Publication Year	2021
Acceptance in OA	2023-09-22T14:52:12Z
Title	Detection methods for the Cherenkov Telescope Array at very-short exposure times
Authors	DI PIANO, AMBRA, BULGARELLI, ANDREA, FIORETTI, Valentina, BARONCELLI, LEONARDO, PARMIGGIANI, Nicolo', Longo, Francesco, STAMERRA, Antonio, López-Oramas, Alicia, STRATTA, Maria Giuliana, DE CESARE, GIOVANNI
Publisher's version (DOI)	10.22323/1.395.0694
Handle	http://hdl.handle.net/20.500.12386/34402
Journal	POS PROCEEDINGS OF SCIENCE

Detection methods for the Cherenkov Telescope Array at very-short exposure times

Ambra Di Piano,^{a,*} Andrea Bulgarelli,^a Valentina Fioretti,^a Leonardo Baroncelli,^a Nicolò Parmiggiani,^a Francesco Longo,^{b,c} Antonio Stamerra,^d Alicia López-Oramas,^{e,f} Giulia Stratta^{a,g} and Giovanni De Cesare^a for the CTA Consortium

^aINAF - Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, Italy

^bUniversità degli Studi di Trieste, Italy

^cINFN Sezione di Trieste, Italy

^dINAF - Osservatorio Astronomico di Roma, Italy

^eInstituto de Astrofisica de Canarias, La Laguna, Spain

^fDepartamento de Astrofisica, Universidad de La Laguna, Spain

^gINFN, Sezione di Firenze, Italy

E-mail: ambra.dipiano@inaf.it

The Cherenkov Telescope Array (CTA) will be the next generation ground-based observatory for very-high-energy (VHE) gamma-ray astronomy, with the deployment of tens of highly sensitive and fast-reacting Cherenkov telescopes. It will cover a wide energy range (20 GeV - 300 TeV) with unprecedented sensitivity. To maximize the scientific return, the observatory will be provided with an online software system that will perform the first analysis of scientific data in real-time. This study investigates the precision and accuracy of available science tools and analysis techniques for the short-term detection of gamma-ray sources, in terms of sky localization, detection significance and, if significant detection is achieved, a first estimation of the integral photon flux. The scope is to evaluate the feasibility of the algorithms' implementation in the real-time analysis of CTA. In this contribution we present a general overview of the methods and some of the results for the test case of the short-term detection of a gamma-ray burst afterglow, as the VHE counterpart of a gravitational wave event.

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

*Presenter

1. Introduction

The Cherenkov Telescope Array (CTA) will be the next generation of Imaging Atmospheric Cherenkov Telescopes (IACTs) and the largest ground-based gamma-ray detection observatory of the next decade. IACTs operate by observing the Cherenkov radiation induced by the Extensive Air Showers (EAS) produced during the interaction of very-high energy photons with the atmosphere. Data from an array of such telescopes is usually stereoscopically combined to improve the energy and direction reconstruction of the incident gamma-rays. With dozens of telescopes deployed among two observation sites (in the northern and southern hemispheres), CTA will observe the gamma-ray sky with high energy resolution and unprecedented sensitivity over a broad energy range (20 GeV - 300 TeV). High angular resolution ($\lesssim 0.05^\circ$ at $E \geq 1$ TeV) will enable detailed imaging and precise morphology, and a large field of view (up to $\sim 8.8^\circ$ in diameter) will provide exceptional survey capabilities [1]. The arrays will couple large effective area with fast slewing capability and unprecedented sensitivity, making CTA a crucial instrument for the future of ground-based gamma-ray astronomy. To maximize the scientific return, the observatory will be provided with an online automated Science Alert Generation (SAG) system [2] as part of the Array Control and Data Acquisition System [3]. The SAG will send and receive alerts on transients and variable phenomena (like gamma-ray bursts, active galactic nuclei, gamma-ray binaries, and any serendipitous source) in real-time. The SAG will also provide low-level Cherenkov data reconstruction, data quality monitoring and science monitoring during observations. The system is required to search for transient phenomena on multiple timescales (from 10 seconds to 30 minutes) in the field of view, and to issue candidate science alerts with a latency lower than 20 seconds after data acquisition. The sensitivity of the scientific analysis in real-time is nonetheless required to be not worse than half of the sensitivity of the final processing pipelines. Although challenging, these requirements will make the SAG a key system in multi-messenger (MM) and multi-wavelength (MWL) astronomy. Two science tools are available to the community for the analysis of CTA data, *ctools* [4, 5] and *gammapy* [6, 7]. Additionally, an aperture photometry tool [8] is being developed for the real-time analysis of CTA. To characterize the precision and accuracy of the tools for the detection of candidate sources at the very short exposure (up to 100 s), we inject a simulated observation (comprising gamma-ray photons as well as a diffuse background component due to cosmic ray residuals) and perform a search in the field of view to localize the source. If a candidate is found, we evaluate the significance of the detection and estimate the integrated flux.

1.1 Aperture photometry

The standard on/off analysis for Cherenkov observation includes different approaches to aperture photometry, of which we implement the reflection method.¹ The on/off technique is based on the extraction of fundamental photometric qualities from a photon list, as the number of photons from a defined region. Conventionally, the aperture (on region) is the region centered on the source itself and is used to count the on-source photons (N_{on}). To estimate the background with the reflection method, one or more off regions with the same characteristic of the aperture (radius and offset from the center of the field of view) are defined and used to count the off-source photons

¹We use *ctools* version 1.7.3, *gammapy* version 0.18.2 and a photometry tool (version 0.1.0) in development for the SAG.

(N_{off}). The photon excess is computed as $N_S = N_{\text{on}} - \alpha N_{\text{off}}$, where α is the background scaling factor:

$$\alpha = \frac{A_{\text{on}} \cdot t_{\text{on}} \cdot k_{\text{on}}}{A_{\text{off}} \cdot t_{\text{off}} \cdot k_{\text{off}}}, \quad (1)$$

where A is the effective area, t the exposure, and k the size of the region. The reflection method allows to define on and off regions in the same observation, reducing eq (1) to $\alpha = 1/N_{\text{reg}}$, with N_{reg} the number of off regions (an example is shown in figure 1). The significance is then computed via the analytic Li and Ma [9] formula:

$$S = \sqrt{2} \left\{ N_{\text{on}} \ln \left[\frac{1 + \alpha}{\alpha} \left(\frac{N_{\text{on}}}{N_{\text{on}} + N_{\text{off}}} \right) \right] + N_{\text{off}} \ln \left[(1 + \alpha) \left(\frac{N_{\text{off}}}{N_{\text{on}} + N_{\text{off}}} \right) \right] \right\}^{1/2}. \quad (2)$$

1.2 Full field-of-view maximum likelihood

Alternatively to the standard on/off analysis, we implement an unbinned full field-of-view analysis² for the significance evaluation of the detected candidate. The analysis performs a maximum likelihood fit using the Poisson formula for maximum likelihood estimation (MLE) given the reconstructed direction \vec{p}' , the measured energy E' and the trigger time t' .

$$-\ln L(M) = e(M) - \sum_k \ln P(\mathbf{p}'_k, E'_k, t'_k | M), \quad (3)$$

where the maximum likelihood function $L(M)$ describes the probability of the collected data during the observation to be drawn from a particular model M , P is the probability density conditioned to a given model M at each event k , and e represent the total number of predicted events expected to occur given the model M . The source model comprises of two components: a simple power law spectral model and a point-like source spatial model with extension determined by the Point Spread Function (PSF) of the detector. The background rate is provided by the Instrument Response Functions (IRF) as function of off-axis angle and energy. By convolution with the IRF, the maximum likelihood fit adjusts a subset of parameters in order to find the values that best represent the measured data. The detection significance of the source model is described by a Test Statistic (TS) value:

$$TS = 2(\ln L(M_s + M_b) - \ln L(M_b)), \quad (4)$$

where $\ln L(M_s + M_b)$ is the log-likelihood value obtained when fitting the source and the background together to the data, and $\ln L(M_b)$ is the log-likelihood value obtained when fitting only the background model to the data. The number n of degrees of freedom (dof) of the analysis is the number of free parameters in the source model. In this study, the pipeline is run at $n = 1$, with the coordinates and spectral index of the candidate's model fixed, and the power law normalization free. For $n = 1$ dof, we verified that the relation $\sigma \approx \sqrt{TS}$ holds also for very-short exposure times (down to 1 s).

²We use ctools version 1.7.3; a binned 3d analysis is being developed with the use of gammapy.

2. Application to a BNS merger

In this contribution, we focus on the SAG short-term reaction to an external alert. Specifically, the application of a short gamma-ray burst afterglow search as counterpart of a gravitational wave event [10]. The goal is to verify the agreement between analyses performed with the same techniques implemented by different science tools, and to constrain the accuracy and precision that can be expected at very-short exposure times for an online automated analysis. We exploited the GW COSMoS catalogue [11, 12], a public database of simulated BNS mergers providing the GW signals as detected by the network formed with Advanced LIGO and Advanced Virgo [13]. Each GW detection comes with a sky localization probability map, for given distance and inclination of the orbital plane of the BNS. To simulate the electromagnetic counterpart of a BNS merger, we use the associated afterglow template that provides the high energy emission [14, 15] given the GRB energy, redshift and viewing angle. The intrinsic spectral model is a simple power law, with normalization varying throughout the temporal evolution. We select a BNS merger with localization uncertainty comparable to the CTA field of view, located at a redshift of 0.097. The electromagnetic counterpart is at 1.638° off-axis angle from the peak of the sky localization probability map (R.A. = 31.582 and DEC. = -53.211 degrees) that we set as pointing coordinates. The isotropic energy of the counterpart is $E_{iso} = 1.48 \cdot 10^{51}$ erg, with intrinsic spectral shape of a simple power law of photon index -2.1 and normalization varying from $2.45 \cdot 10^{-7}$ to $3.1 \cdot 10^{-15}$ ($\text{ph cm}^{-2} \text{s}^{-1} \text{GeV}^{-1}$) in its temporal evolution. We add an exponential cut off to the intrinsic source spectral model, to account for the Extra-galactic Background Light absorption as $F^{ebl}(E) = F(E) \cdot e^{-\tau(E)}$, where $\tau(E)$ is the optical depth value from Ref. [16].

3. Source localization

The analysis takes a simulated photon list as input, with given configuration for the energy range, time interval, region of interest, and Instrument Response Function³ for the analysis. The sky localization of the candidate source is performed in the field of view of the observation. We assume an extra-galactic scenario, therefore the background is mostly due to cosmic ray induced events that survive the gamma-ray selection criteria during the Cherenkov reconstruction. We perform a peak search to localize the coordinates of hot-spots with significance above a given acceptance threshold, selecting the most significant as the candidate source. The algorithm accepts exclusion regions to

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

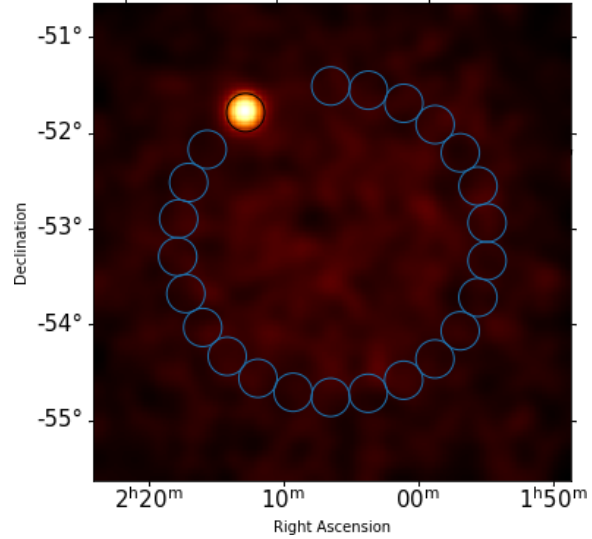


Figure 1: Example of on source and off source regions defined on a count map with the reflection method, using 0.2° region radius and 1.638° offset. The areas adjacent to the on regions can be skipped to avoid contamination for the estimation of the background.

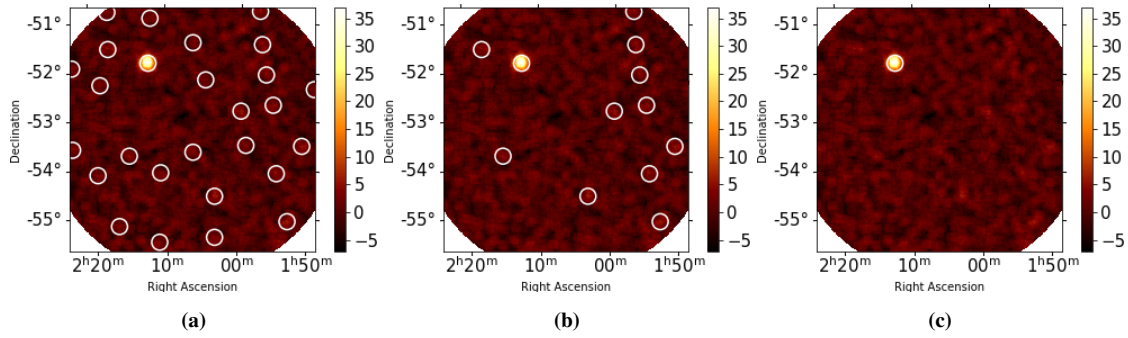


Figure 2: Source localization of a simulated gamma-ray burst afterglow ($E_{iso} = 1.48 \cdot 10^{51}$ erg at $z = 0.097$) using gammapy, in the energy range 40 GeV - 150 TeV using the 30 minutes CTA South IRF at 40° of zenith angle. The panels show a TS map with the number and position of hot-spots localized by the peak-search algorithm in a 10 s time window, requiring a significance threshold of (a) 3σ , (b) 5σ , and (c) 8σ .

mask known sources in the field of view. Figure 2 is an example of source localization in a 10 s time window, with different significance acceptance thresholds. At the very short exposure time, the background fluctuation becomes relevant due to the low counting rate and several hot spots are therefore detected. We evaluate the localization accuracy as the peak value of a Rayleigh distribution describing the on-sky distance between the detected and true coordinates of the source, whilst the precision is given by the R_{68} containment radius of 10^3 Monte Carlo realizations of the same source event. While the sigma acceptance threshold has no impact on either accuracy and precision of the localization, parameters such as the pixel size of the sky map required to run the peak-search do.

In figure 3 we present an example of the on-sky distance distribution at increasing exposure time (from 10 to 100 s) using a pixel size of 0.02° and 0.05° with respect to the difference in computational time required to complete the task. A finer spatial binning results in better accuracy and precision by a factor of 2, with little to no impact on the computational time required to complete the task (~ 0.001 s).

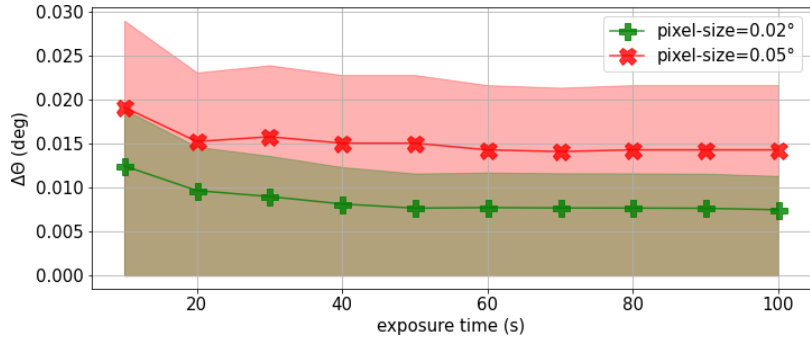


Figure 3: Comparison between the accuracy and precision of the source localization with pixel size of 0.02° (green plus markers) and 0.05° (red cross symbols) using ctools, in the energy range 40 GeV - 150 TeV using the 30 minutes CTA South IRF at 40° of zenith angle. The panel shows the peak on-sky distance ($\Delta\Theta$) between the true and detected coordinates of the source, with relative R_{68} containment radius (shaded areas).

4. Significance and flux estimation

In figure 4 we present lightcurves and detection significance with 10 s time windows, computed with a maximum likelihood analysis implemented with ctools, and the on/off reflection analysis

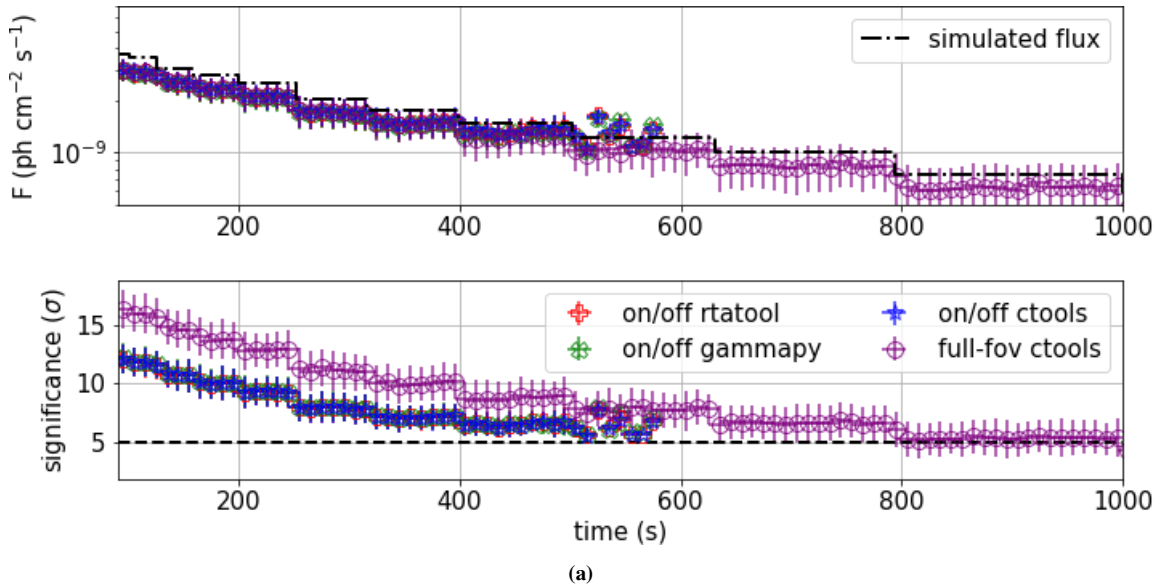


Figure 4: Lightcurves of a gamma-ray burst afterglow with 10 s of time window, computed with a full field-of-view maximum likelihood analysis (purple circles) and standard on/off analysis (red crosses, green exes and blue stars) implemented by different science tools, in the energy range 40 GeV - 150 TeV using the 30 minutes CTA South IRF at 40° of zenith angle. The top panel shows the temporal evolution of the flux (the simulated flux is represented by the dashed line), and the bottom panel provides the significance of each detection. The lightcurves last for as long the significance is above 5σ .

implemented with ctools, gammapy and the real-time photometry tool [8].

The choice of the photon index introduces the largest uncertainty in the flux estimation, due to the EBL absorption becoming increasingly relevant at higher energies. For the flux computation a simple power law with photon index -2.4 has been assumed as spectral model for the source, while the simulated model is a cutoff power law with spectral index -2.1. Due to the wide energy range and the EBL absorption not taken into account, the model assumed for reconstruction of the flux introduces a bias. Figure 5

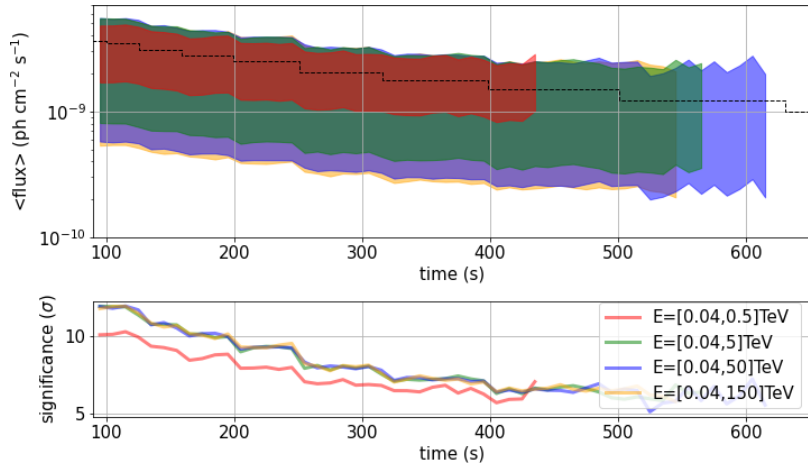


Figure 5: Impact of the choice of the photon index in the flux estimation with the SAG photometry tool, for given analysis configuration. The lightcurves have 10 s time windows. In the top panel the flux interval (shaded area) is computed with photon indexes between -1.5 and -3 for different energy ranges, compared to the simulated lightcurve (lines) using the 30 minutes CTA South IRF at 40° of zenith angle. In the bottom panel the significance is provided. The lightcurves last as long as the significance is above 5σ .

shows the integrated flux intervals computed with photon index between -1.5 and -3 for several energy ranges. The smallest energy range (0.04-0.5 TeV) improves the accuracy of the flux estimate but causes a loss in detection significance due to the reduced counting rate.

5. Summary

We have developed an automated pipeline that handles the analysis of CTA data with different techniques and science tools, to investigate their implementation in an online real-time analysis context. We used `ctools` and `gammapy` software packages as well as a photometry tool developed for the real-time analysis. Since with CTA we will be able to produce significant observation at very short exposure time, we focus on the characterization of the short-term reaction of the SAG up to 100 s where statistics is limiting. We verify that the same methods implemented in different science tools agrees under the same assumptions. Given a test case, we find that a finer binning (0.02 deg in pixel size) of the sky map produces a factor 2 more accurate and precise localization of the source with respect to a larger binning (0.05 deg) with negligible loss in terms of computational speed (~ 0.001 s). We compare the source detection significance of different techniques (a full field-of-view maximum likelihood and on/off reflection) and the estimation of the integrated photon flux. The full field-of-view analysis technique is more sensitive than the standard on/off analysis, although the two methods have proven to converge when assuming equal assumptions for the background estimation [17]. The standard on/off analysis, though, is computationally faster and provides the significance of a detection independently from model assumptions (i.e. the photon index) and fitting procedure. Due to the assumption of a simple power law spectral model, the impact of an arbitrary fixed photon index causes large uncertainties in the flux estimation mostly due to the EBL absorption that becomes increasingly relevant at higher energies. Future studies will investigate either an optimized choice of photon index (i.e., based on the energy range of the observation, knowledge of the source spectral shape and redshift), improvements on model assumptions or higher degrees of freedom analysis.

Acknowledgements

This work was conducted in the context of the CTA Consortium, and it made use of the CTA instrument response functions provided by the CTA Consortium and Observatory.⁴ We gratefully acknowledge financial support from the agencies and organizations listed here: http://www.cta-observatory.org/consortium_acknowledgments/. This research made use of `ctools`, a community-developed analysis package for Imaging Air Cherenkov Telescope data based on `GammaLib`, a community-developed toolbox for the scientific analysis of astronomical gamma-ray data; and `gammapy`,⁵ a community-developed core Python package for TeV gamma-ray astronomy.

References

- [1] CTA Consortium. *Science with the Cherenkov Telescope Array*. 2019.
- [2] A. Bulgarelli et al. The Science Alert Generation system of the Cherenkov Telescope Array Observatory. In *37th International Cosmic Ray Conference (ICRC2021)*, International Cosmic Ray Conference, 2021.

⁴<http://www.cta-observatory.org/science/cta-performance/>

⁵<https://www.gammapy.org>

- [3] I. Oya et al. The Array Control and Data Acquisition System of the Cherenkov Telescope Array. In *17th International Conference on Accelerator and Large Experimental Physics Control Systems*, page WEMPR005, New York, United States, October 2019.
- [4] J. Knödlseeder et al. ctools: Cherenkov Telescope Science Analysis Software, January 2016.
- [5] J. Knödlseeder et al. GammaLib and ctools. A software framework for the analysis of astronomical gamma-ray data. *Astronomy and Astrophysics*, 593:A1, August 2016.
- [6] C. Deil et al. Gammapy - A prototype for the CTA science tools. In *35th International Cosmic Ray Conference (ICRC2017)*, volume 301 of *International Cosmic Ray Conference*, page 766, January 2017.
- [7] C. Nigro et al. Towards open and reproducible multi-instrument analysis in gamma-ray astronomy. *Astronomy and Astrophysics*, 625:A10, May 2019.
- [8] Simone Tampieri. Real time aperture photometry with cherenkov telescope array. *Master Thesis*, March 2020.
- [9] T. P. Li and Y. Q. Ma. Analysis methods for results in gamma-ray astronomy. *The Astrophysical Journal*, 272:317–324, September 1983.
- [10] B. Patricelli et al. Searching for very-high-energy electromagnetic counterparts to gravitational-wave events with the Cherenkov Telescope Array. In *37th International Cosmic Ray Conference (ICRC2021)*, International Cosmic Ray Conference, 2021.
- [11] B. Patricelli et al. Searching for gamma-ray counterparts to gravitational waves from merging binary neutron stars with the Cherenkov Telescope Array. *Journal of Cosmology and Astroparticle Physics*, 2018(5):056, May 2018.
- [12] Barbara Patricelli et al. GW COSMoS: Gravitational Wave COmpact binary System Simulations., 2018.
- [13] B. P. Abbott et al. Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO, Advanced Virgo and KAGRA. *Living Rev. Rel.*, 21(1):3, 2018.
- [14] L. Nava et al. Clustering of LAT light curves: a clue to the origin of high-energy emission in gamma-ray bursts. *Monthly Notices of the RAS*, 443(4):3578–3585, October 2014.
- [15] Lara Nava. High-energy emission from gamma-ray bursts. *International Journal of Modern Physics D*, 27(13):1842003, January 2018.
- [16] Rudy C. Gilmore et al. Semi-analytic modelling of the extragalactic background light and consequences for extragalactic gamma-ray spectra. *Monthly Notices of the RAS*, 422(4):3189–3207, June 2012.
- [17] V. Fioretti et al. The Cherenkov Telescope Array sensitivity to the transient sky. In *36th International Cosmic Ray Conference (ICRC2019)*, volume 36 of *International Cosmic Ray Conference*, page 673, July 2019.

The Cherenkov Telescope Array Consortium July 2021 Authors

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 González³², 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 Arbeletche⁸⁰, G. Bonnoli¹², P. Bordas⁸¹, 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-Nogué⁸⁷, S. Breen⁷⁸, J. Bregeon³⁹, M. Breuhaus⁵³, A. Brill⁹, W. Briskén⁸⁸, E. Brocato²⁸, A.M. Brown⁵, K. Brüggé⁴⁶, P. Brun⁸⁹, P. Brun³⁹, F. Brun⁸⁹, L. Brunetti⁴⁵, G. Brunetti⁹⁰, P. Bruno²⁹, A. Bruno⁹¹, A. Bruzese⁶, N. Bucciantini²², J. Buckley⁸², R. Bühler⁵², A. Bulgarelli²¹, T. Bulik⁹², M. Bünning⁵², M. Bunsé⁴⁶, 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. Cornat⁸, 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'Al⁹¹, G. D'Amico¹¹⁶, F. D'Ammando⁹⁰, P. D'Avanzo⁹⁵, P. Da Vela⁷⁴, M. Dadina²¹, S. Dai¹¹⁷, M. Dalchenko¹⁷, M. Dall'Or⁸⁴, 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. Dima⁵⁵, A. Djannati-Ataï⁸⁵, J. Djuvsland¹¹⁶, A. Dmytriiev²⁰, K. Docher⁹, A. Domínguez¹¹, D. Dominis Prester¹²¹, A. Donath⁵³, A. Donini⁴¹, D. Dorner¹²², M. Doró⁵⁵, 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. Fiasson⁴⁵, 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. Garcia López³², M. Garczarczyk⁵², 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. Gourgouliatos⁵, T. Grabarczyk¹⁵², R. Graciani⁸¹, 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. Guarino²⁶, 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. Hermel⁴⁵, 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. Insolia^{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. Jamrozny¹⁶⁹, P. Janecek³³, F. Jankowsky¹⁷⁰, A. Jardin-Blicq³¹, C. Jarnot⁸⁷, P. Jean⁸⁷, I. Jiménez Martínez¹¹³, W. Jin¹⁷¹, L. Jocou¹²⁵, N. Jordana¹⁷², M. Josselin⁷³, L. Jouvin⁴¹, 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. Knödlseeder⁸⁷, 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. Landriu⁴, R.G. Lang⁸⁰, J. Lapington¹²⁴, P. Laporte²⁰, P. Lason¹⁵², J. Lasuik³⁷, J. Lazendic-Galloway⁷, T. Le Flour⁴⁵, P. Le Sidaner²⁰, S. Leach¹²⁴, A. Leckngam³¹, S.-H. Lee¹⁸⁰, W.H. Lee¹⁶, S. Lee¹¹⁸, M.A. Leigui de Oliveira¹⁸⁴, A. Lemièrre⁸⁵, 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. Linhoff⁴⁶, 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. Marti⁵⁶, J.-M. Martin²⁰, P. Martin⁸⁷, O. Martinez³⁰, 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. Mbarubucyeye⁵², L. Mc Comb⁵, I. McHardy¹¹⁵, S. McKeague¹⁰⁷, S. McMuldroy⁶³, 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. Minev¹⁸⁹, J.M. Miranda³⁰, R. 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. Musumarra¹²⁰, 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. Ndiyavala¹, 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. Petrerá¹⁸, 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. Przybiski¹⁰¹, 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. Rizi¹⁸, E. Roache⁶³, B. Röben¹⁵⁹, 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. Ruíz del Mazo¹², W. Rujopakarn³¹, C. Rulten⁵, C. Russell³, 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. Salzmänn⁶⁹, 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. Schovanek³³, F. Schussler⁸⁹, B. Schwab¹⁴², U. Schwanke¹⁸⁶, J. Schwarz⁹⁵, T. Schweizer¹⁰⁵, E. Sciacca²⁹, S. Scuderi⁶¹, M. Seglar Arroyo⁴⁵, A. Segreto⁹¹, I. Seitzzahl⁴³, 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. Stanić⁶⁸, R. Starling¹²⁴, Ł. Stawarz¹⁶⁹, R. Steenkamp⁴⁸, S. Stefanik¹⁹⁷, C. Stegmann¹²⁸, A. Steiner⁵², S. Steinmassl⁵³, C. Stella¹⁰³, C. Steppa¹²⁸, R. Sternberger⁵², M. Sterzel¹⁵², C. Stevens¹³⁵, B. Stevenson⁷¹, T. Stolarczyk⁴, G. Stratta²¹, U. Straumann²⁰⁸, J. Strišković¹⁶⁶, M. Strzys², R. Stuik¹⁷⁴, M. Suchenek²¹¹, Y. Suda¹⁴⁰, Y. Sunada¹⁷⁹, T. Suomijarvi⁷³, T. Suric²¹², P. Sutcliffe¹⁵³, H. Suzuki²¹³, P. Świerk¹⁰¹, T. Szepieniec¹⁵², 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. Thocquenne⁷⁵, W. Tian², L. Tibaldo⁸⁷, A. Tiengo²¹⁵, D. Tiziani¹⁴²,

M. Tluczykont⁵⁰, C.J. Todero Peixoto¹⁰², F. Tokanai¹⁵⁴, K. Toma¹⁶⁰, L. Tomankova¹⁴², J. Tomastik¹⁰⁴, D. Tonev¹⁸⁹, M. Tornikoski²¹⁶, D.F. Torres¹³, E. Torresi²¹, G. Tosti⁹⁵, L. Tosti²³, T. Totani⁵¹, N. Tothill¹¹⁷, F. Toussene⁷⁹, G. Tovmassian¹⁶, P. Travnicek³³, C. Trichard⁸, M. Trifoglio²¹, A. Trois⁹⁵, S. Truzzi⁶², A. Tsiaghina⁸⁷, T. Tsuru¹⁸⁰, B. Turk⁴⁵, A. Tutone⁹¹, Y. Uchiyama¹⁶¹, G. Umana²⁹, P. Utayarat³¹, L. Vaclavek¹⁰⁴, 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. Verguilov¹⁸⁹, G. Verna²⁷, S. Veretto^{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. Wetteskind¹⁰⁵, 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. Yusafzai⁵⁹, M. Zacharias²⁰, G. Zaharijas⁶⁸, B. Zaldivar¹⁴, L. Zampieri⁷⁶, R. Zanmar Sanchez²⁹, D. Zanic¹⁵⁰, M. Zavrtnik⁶⁸, D. Zavrtnik⁶⁸, 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, 56217 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 Moiarriello 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, Liberdade 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/n°, 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, Museclass 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 Matejcic 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, Sagamihara, 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. Bartycza 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, Sagamihara, 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 Cote d'Azur, Boulevard de l'Observatoire CS34229, 06304 Nice Cedex 4, France