



UvA-DARE (Digital Academic Repository)

Reconstruction of stereoscopic CTA events using deep learning with CTLearn

Miener, T.; Nieto, D.; Brill, A.; Spencer, S.; Contreras, J.L.; CTA Consortium

DOI

[10.22323/1.395.0730](https://doi.org/10.22323/1.395.0730)

Publication date

2022

Document Version

Final published version

Published in

Proceedings of Science

License

CC BY-NC-ND

[Link to publication](#)

Citation for published version (APA):

Miener, T., Nieto, D., Brill, A., Spencer, S., Contreras, J. L., & CTA Consortium (2022). Reconstruction of stereoscopic CTA events using deep learning with CTLearn. *Proceedings of Science*, 395, [730]. <https://doi.org/10.22323/1.395.0730>

General rights

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

Reconstruction of stereoscopic CTA events using deep learning with CTLearn

T. Miener,^{a,*} D. Nieto,^a A. Brill,^b S. Spencer^c and J. L. Contreras^a for the CTA Consortium

(a complete list of authors can be found at the end of the proceedings)

^a*EMFTEL department and IPARCOS, Universidad Complutense de Madrid, Madrid, Spain*

^b*Columbia University, Physics Department,
New York, USA*

^c*University of Oxford, Department of Physics,
Oxford, United Kingdom*

E-mail: tmiener@ucm.es

The Cherenkov Telescope Array (CTA), conceived as an array of tens of imaging atmospheric Cherenkov telescopes (IACTs), is an international project for a next-generation ground-based gamma-ray observatory, aiming to improve on the sensitivity of current-generation instruments a factor of five to ten and provide energy coverage from 20 GeV to more than 300 TeV. Arrays of IACTs probe the very-high-energy gamma-ray sky. Their working principle consists of the simultaneous observation of air showers initiated by the interaction of very-high-energy gamma rays and cosmic rays with the atmosphere. Cherenkov photons induced by a given shower are focused onto the camera plane of the telescopes in the array, producing a multi-stereoscopic record of the event. This image contains the longitudinal development of the air shower, together with its spatial, temporal, and calorimetric information. The properties of the originating very-high-energy particle (type, energy, and incoming direction) can be inferred from those images by reconstructing the full event using machine learning techniques. In this contribution, we present a purely deep-learning driven, full-event reconstruction of simulated, stereoscopic IACT events using CTLearn. CTLearn is a package that includes modules for loading and manipulating IACT data and for running deep learning models, using pixel-wise camera data as input.

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

*Presenter

1. Introduction

The Cherenkov Telescope Array (CTA) [1] is the next-generation ground-based gamma-ray observatory, aiming to improve on the sensitivity of current-generation instruments by a factor of five to ten and provide an energy coverage from 20 GeV to more than 300 TeV. CTA will consist of two arrays of tens of imaging atmospheric Cherenkov telescopes (IACTs) to be built in the Northern Hemisphere (La Palma, Canary Island, Spain) and in the Southern Hemisphere (near Cerro Paranal, Chile). Arrays of IACTs observe simultaneously the Cherenkov light induced by the showers of particles produced when very-high-energy (VHE; above 20 GeV) gamma rays or charged cosmic rays enter the atmosphere. Those Cherenkov photons are collected by the optical systems and focused onto cameras, producing a stereoscopic record of the event. The IACT images contain the longitudinal development of the air shower, together with its spatial, temporal, and calorimetric information.

The gamma-ray and cosmic-ray initiated showers can be distinguished from their morphological differences, translated into their IACT stereoscopic images. This distinction, dubbed particle or event classification, is crucial for IACTs since cosmic-ray events are their main background. The original approach to classify IACT events from their images was to extract handcrafted features, like the commonly used Hillas parameters [2], and perform parameter-wise selection over the multidimensional space of those parameters. As a result of the improvement in available computational resources and algorithms over the past few decades, this original approach evolved into more sophisticated strategies where supervised learning algorithms like Random Forests [3] or Boosted Decision Trees [4–6] are trained on those handcrafted features, substantially improving the performance of the particle classification and, consequently, the sensitivity of the instruments. In addition, IACT data analysis methods also need to infer further properties of the gamma-ray events, namely, the energy and the incoming direction of the originating particles. This so-called full-event reconstruction could also be performed with deep convolutional neural networks (DCNs), a particular class of deep learning algorithms, which are currently the most successful machine learning methods for computer vision, excelling at image classification and regression among other tasks [7]. Rather than crafting the features by hand, these types of algorithms are capable of learning the feature extraction by themselves (representation learning). Therefore, DCNs can access all the information contained in the images, not only those condensed in handcrafted features extracted from those images.

Previous works have demonstrated the potential application of these algorithms for IACT event reconstruction [8–13]. DCN-based monoscopic telescope performance and the application of DCNs on observational data from the first Large-Sized Telescope (LST-1 prototype) of CTA North is discussed in these proceedings elsewhere [14, 15]. As a natural continuation of this line of work, this contribution focuses on full-event reconstruction of MC-simulated stereoscopic events.

2. CTA analysis workflow with deep learning

The CTA analysis workflow consists of several software blocks. The MC simulations and later the observational data are reduced with the `stage1-tool` of `ctapipe`¹ [16, 17], a prototype

¹<https://github.com/cta-observatory/ctapipe>

low-level data processing pipeline for CTA, and the resulting calibrated images, as well as their image parameters, are stored in the official CTA Data Level 1 (DL1) format. Data loading and pre-processing, specially designed for deep learning purposes, are managed using an associated external package, DL1-Data-Handler² [18]. It supports event-wise data reading using generators to handle big datasets. The training of the deep learning models and their inference, the actual full-event reconstruction, are performed with CTLearn³ [19, 20]. The high-level products like instrument response functions (IRFs) and sensitivity curves are obtained using pyirf⁴ [16, 21], a prototype for the generation of IRFs and sensitivities for CTA. The CTA analysis workflow with conventional methods can be found in these proceedings in Ref. [16].

Full-event reconstruction with CTLearn The high-level, open-source CTLearn package provides a framework for training deep learning models for IACT full-event reconstruction using TensorFlow. This work focuses on the thin ResNet (*TRN*) model [22] (see Fig. 1, left model), a deep DCN-based architecture for monoscopic full-event reconstruction with residual connections (meaning that the original input is added to the output at each stage, demonstrated to improve performance) [23]. A dual (squeeze-and-excitation) attention mechanism [24] is deployed in each of the residual blocks. Either particle classification or regression (energy or arrival direction reconstruction) is performed with a selectable fully-connected head (FCH), a traditional multi-layer perceptron neural network (MLP), after the deep backbone, consisting of several stacked residual blocks.

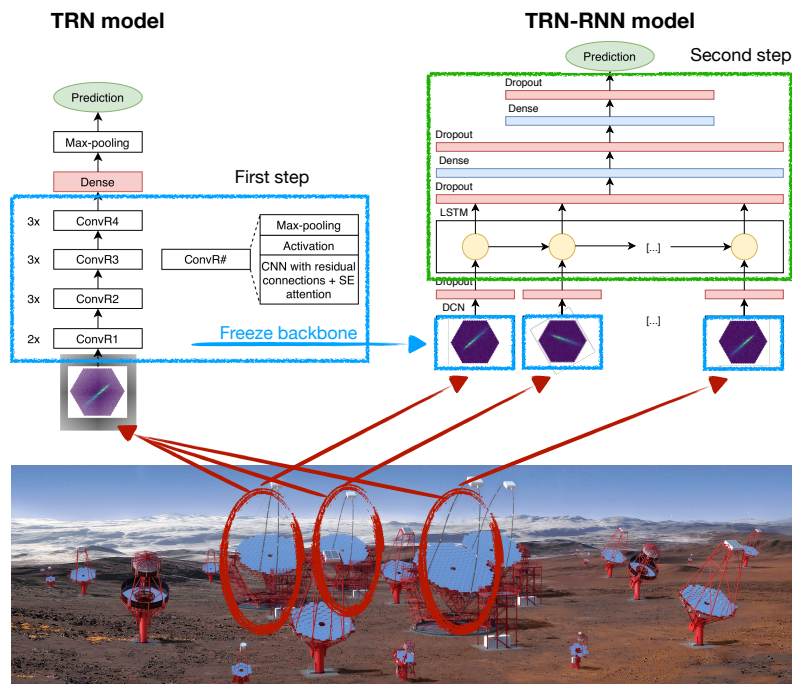


Figure 1: Diagram depicting the main layers of the *TRN* (left) and the *TRN-RNN* model (right).

²<https://github.com/cta-observatory/dl1-data-handler>

³<https://github.com/ctlearn-project/ctlearn>

⁴<https://github.com/cta-observatory/pyirf>

The stereoscopic full-event reconstruction is performed with the *TRN-RNN* model (see Fig. 1, right model), which consists of multiple thin ResNet blocks connected via a recurrent neural network (RNN) [7]. In particular, the RNN - implemented in CTLearn - is a dynamic long short-term memory network (LSTM) [7], which adjusts its size according to the number of triggered telescopes for each event. The images of triggered telescopes are sorted a priori by the total amount of integrated charge in the camera. To train this large architecture, and to overcome computing limitations, transfer learning [7] is utilized: the DCN backbone of the *TRN* model is trained beforehand, its parameters are set to be untrainable weights and transferred into the *TRN-RNN* model.

3. Dataset

The analysis is carried out with the CTA South (zenith angle of 20° , North pointing) reference dataset, processed with `ctapipe`.⁵ A detailed description of the simulation production, together with the telescope layout and performance study of CTA can be found elsewhere in Ref. [26]. For the deep learning training process of the particle classification, diffuse gamma-ray and proton-initiated events, simulated within a cone of 10° radius (covering the whole field of view of the instrument) are considered, in a balanced way so both populations contribute equally to the statistics of the datasets. 80% of the data are used for training (from which 5% are reserved for validation of the learning process) and 20% for testing. The regression models (energy or arrival direction reconstruction) are trained with the whole training set of diffuse gamma rays. The performance of the deep learning models is evaluated on simulated protons ($\sim 7e^9$), electrons ($\sim 2e^9$) and point-source gamma rays ($\sim 2e^9$) with 0.4° offset with respect to the telescope pointing.

Array layout The array layout M5C5, consists of 13 medium-size telescopes (MSTs) and 40 small-size telescopes (SSTs), and four additional large-size telescopes (LSTs) are considered in this work. The M6C5 array layout with 14 MSTs, 40 SSTs and no LSTs is depicted in lower left panel of Fig. 1 in Ref. [26]. For the monoscopic full-event reconstruction, all images from the corresponding telescope type, regardless of the particular telescope, are included at training stage. However, the single telescope performances are evaluated with one particular telescope per telescope type.

Data selection (quality cuts) In order to compare to the conventional IACT analysis methods, two different data selection cuts are performed.⁶ The *TRN* model are trained and tested with a modest cut, adapted from Ref. [14], where faint images (Hillas intensity less than 50 photoelectrons) and images close to the camera edge (leakage2 parameter more than 0.2) are discarded. For the stereoscopic reconstruction, faint and truncated images are kept, but a multiplicity cut of four or more triggered telescopes is applied.

4. Results

The *TRN* and *TRN-RNN* models successfully learn to perform monoscopic and stereoscopic full-event reconstruction, respectively, for all sizes of CTA telescopes. The standard IACT IRFs and

⁵The first stage of the analysis was performed on the EGI (www.egi.eu).

⁶Please note that DCNs are fed with all the information contained in the event images and therefore no default quality cuts have to be applied.

sensitivities are depicted in Fig. 2 and 3. The angular resolution is defined as the angle containing 68% of the reconstructed gamma-ray events relative to the simulated point source gamma-ray direction. This is calculated in each logarithmic energy bin. The energy resolution in each energy bin is calculated with 68% of containment of $(E_{\text{reco}} - E_{\text{true}})/E_{\text{true}}$. The effective collection area, which is proportional to the gamma-ray efficiency of detection, is computed as a function of the simulated energy. Only events entering the calculation of the sensitivity curve are considered for the effective collection area and the resolution curves. The differential sensitivity calculation requires a minimal significance of more than 5σ , at least ten detected gamma rays and a minimal excess over background ratio of 0.05 for an observation of 50 hours. For IACTs, the receiver operating characteristic (ROC) curve visualizes the diagnostic ability of the gamma/hadron separation as its gammaness threshold is varied. The area under the ROC curve (AUC) is a measurement of the quality of the background rejection.

4.1 Single-telescope event reconstruction (TRN model)

The *TRN* model is trained on $\sim 200\text{k}$ batches of 64 images for each telescope type, validating periodically. As expected (see Fig. 2), the LST is the most sensitive telescope type at the lowest energies; the sensitivity of an MST is best where this telescope type will be responsible for the full-array sensitivity; the SST is providing competitive sensitivity at multi-TeV energies. In the mono telescope analysis, SSTs are competitive with MSTs only at the highest energies. The LST, MST, and SST provide excellent energy resolutions of $\sim 13\%$, 9% , and 10% at their best, angular resolutions of $\sim 0.12^\circ$, 0.13° and 0.1° at their best, and an AUC of 0.89, 0.944, and 0.959, in their entire energy ranges, respectively.

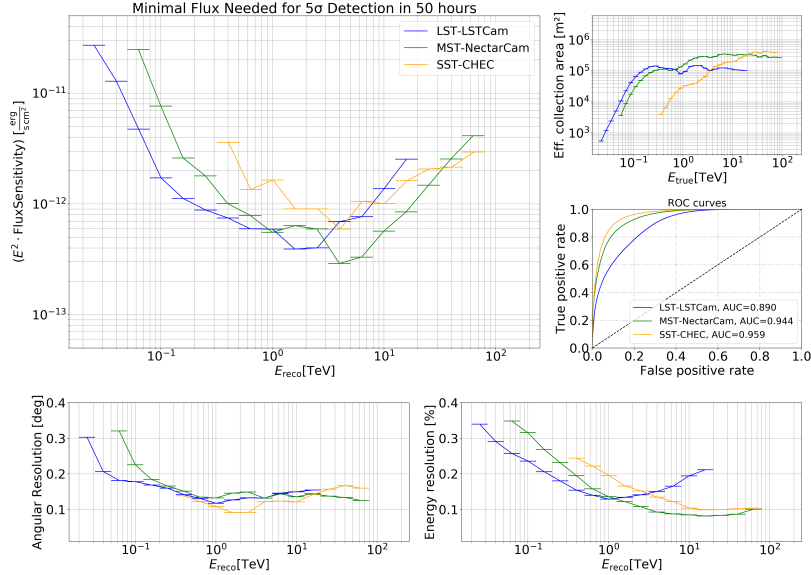


Figure 2: The single telescope IRFs and sensitivities, as defined in Sec. 4, obtained with the *TRN* model for the LST (blue), MST (green), and SST (orange).

4.2 Reconstruction of stereoscopic events (*TRN-RNN* model)

As discussed in Sec. 2, the backbone of the *TRN* model is transferred into the *TRN-RNN* model. Therefore, only $\sim 100k$ batches of 16 images for each telescope type are needed to train the RNN and the FCH blocks of the model. The learning is also validated periodically. The particle classification, performed by the *TRN-RNN* model (see Fig. 3), works well, with an AUC score of 0.98, 0.994, and 0.996 for the subarrays of 4 LSTs-LSTCam, 13 MSTs-NectarCam, and 40 SSTs-CHEC, respectively. The three subarrays reach promising top values for the the energy resolution of $\sim 10\%$, 7% , and 6% for LSTs, MSTs and SSTs, respectively. The IRFs produced with our models are cut off above 80 TeV, likely because they fail the requirement of 10 gamma rays in each energy bin. This should be solved once all telescope types would be combined in the reconstruction.

The *TRN-RNN* model performs poorly on the reconstruction of the arrival direction. The angular resolution for the highest energies differs from the conventional analysis significantly, which translates to the sensitivity curves, causing a deficit of performance especially at energies above 10 TeV. Achieving just a small improvement for the angular resolution by adding more telescopes concludes that this version of the *TRN-RNN* model needs further adjustments to be fully capable of learning stereoscopic features relevant for the arrival direction reconstruction. Including further information like the telescope position may help the network to better reconstruct the arrival direction. Future studies are planned to improve the angular resolution with DCN-based models especially in stereo mode. A fair comparison to the conventional analysis with the Eventdisplay software package (see black curves in Fig. 3) is not feasible at this stage of the development, because no LSTs are considered in the conventional analysis, and it is not limited to a per-telescope-type analysis [27].

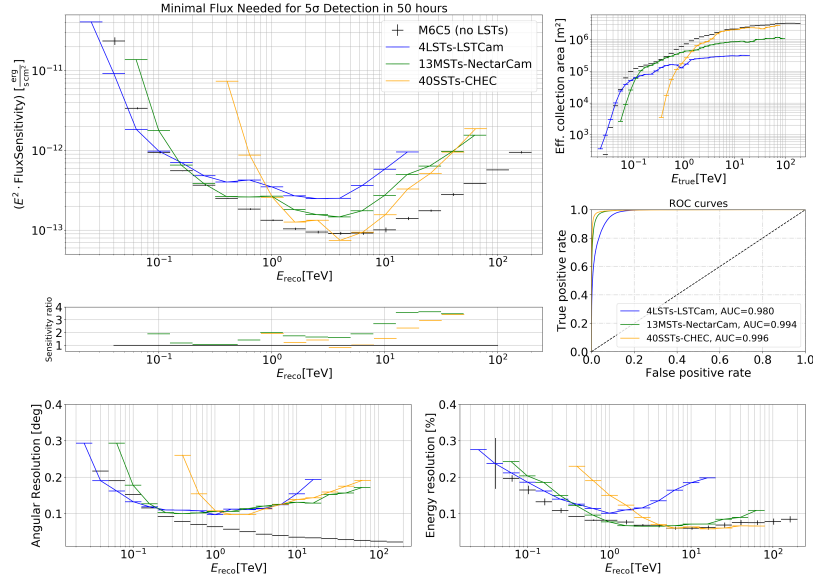


Figure 3: The multi telescopes IRFs and sensitivities, as defined in Sec. 4, obtained with the *TRN-RNN* model for 4 LSTs (blue), 13 MSTs (green), and 40 SSTs (orange). The black curves depict the IRFs and sensitivities obtained with the conventional analysis of the array layout M6C5 with 14 MSTs, 40 SSTs, and no LSTs taken from Ref. [26].

5. Conclusion and Outlook

This contribution shows for the first time that DCN-based full-event reconstruction works for all sizes of CTA telescopes, in both single-telescope and stereo modes. The performance of the *TRN* and the *TRN-RNN* models for the particle classification and the energy estimation is promising. Tackling the arrival direction reconstruction task via DCNs requires additional modifications and improvements to the existing stereoscopic deep learning models to suit the requirements of CTA.

Future developments of CTLearn will include the combination of different telescope types to evaluate the full-array performance of CTA North and South with deep learning models. The results of each telescope type are obtained with the same set of non-optimized hyperparameters. Hyperparameter optimization will be explored in future. Multitask learning experiments (see Ref. [15]), where one single model performs the IACT specific tasks (particle classification, energy and arrival direction estimation), as well as the application of DCNs model on observational data, are also planned. Further validation of DCN-based full-event reconstruction under various circumstances (i.e. off-axis performance, divergent pointing, different zenith angles and night sky backgrounds, etc.) is very important and will be considered in future works.

6. Acknowledgments

This work was conducted in the context of the CTA Analysis and Simulations Working Group. We gratefully acknowledge financial support from the agencies and organizations listed in this [link](#). TM acknowledges support from PID2019-104114RB-C32. DN and JLC acknowledges partial support from The European Science Cluster of Astronomy & Particle Physics ESFRI Research Infrastructures funded by the European Union's Horizon 2020 research and innovation program under Grant Agreement no. 824064. This work was performed using resources provided by the Cambridge Service for Data Driven Discovery (CSD3) operated by the University of Cambridge Research Computing Service (www.csd3.cam.ac.uk), provided by Dell EMC and Intel using Tier-2 funding from the Engineering and Physical Sciences Research Council (capital grant EP/P020259/1), and DiRAC funding from the Science and Technology Facilities Council (STFC, www.dirac.ac.uk). This work used IRIS computing resources funded by the STFC. SS acknowledges an STFC PhD studentship. We acknowledge the support of NVIDIA Corporation with the donation of a Titan X Pascal GPU used for part of this research.

This paper has gone through internal review by the CTA Consortium.

References

- [1] Acharyya, A. *et al.*, *Monte Carlo studies for the optimisation of the Cherenkov Telescope Array layout*, *Astropart. Phys.* **111**, 35 (2019), [doi:10.1016/j.astropartphys.2019.04.001](https://doi.org/10.1016/j.astropartphys.2019.04.001)
- [2] Hillas, A. M., *Cherenkov light images of EAS produced by primary gamma*, *International Cosmic Ray Conference* **3** (1985)
- [3] Albert, J., *et al.*, *Implementation of the Random Forest method for the Imaging Atmospheric Cherenkov Telescope MAGIC*, *Nuclear Instruments and Methods in Physics Research A* **588** 424–432 (2008), [[arXiv:0709.3719](https://arxiv.org/abs/0709.3719)]
- [4] Ohm, S., van Eldik, C., Egberts, K., *γ /hadron separation in very-high-energy γ -ray astronomy using a multivariate analysis method*, *Astroparticle Physics* **31**, 383 (2009)
- [5] Becherini, Y., Djannati-Ataï, A., Marandon, V., Punch, M., and Pita, S., *A new analysis strategy for detection of faint γ -ray sources with Imaging Atmospheric Cherenkov Telescopes*, *Astroparticle Physics* **34** 858–870 (2011), [[arXiv:1104.5359](https://arxiv.org/abs/1104.5359)]

- [6] Krause, M., Poeschel, E., and Maier, G., *Improved γ /hadron separation for the detection of faint γ -ray sources using boosted decision trees*, *Astroparticle Physics* **89** 1–9 (2017)
- [7] Goodfellow, I., Bengio, Y. and Courville, A., *Deep Learning*, MIT Press (2016), www.deeplearningbook.org
- [8] Nieto, D., Brill, A., Kim, B., Humensky, T. B., et al., *Exploring deep learning as an event classification method for the Cherenkov Telescope Array*, 35th International Cosmic Ray Conference (2017), doi:10.22323/1.301.0809
- [9] Feng Q, and Lin, T. T. Y., *The analysis of VERITAS muon images using convolutional neural networks*, *ArXiv e-prints* (2016) [[arXiv:1611.09832](https://arxiv.org/abs/1611.09832)]
- [10] Mangano, S., et al., *Extracting gamma-ray information from images with convolutional neural network methods on simulated Cherenkov Telescope Array data*, ANNPR 2018, LNAI 11081 243-254 (2018), doi:10.1007/978-3-319-99978-4
- [11] Shilon, I., et al., *Application of deep learning methods to analysis of imaging atmospheric Cherenkov telescopes data*, *Astroparticle Physics* **105**, 44 (2019)
- [12] Nieto, D., et al., *Studying deep convolutional neural networks with hexagonal lattices for imaging atmospheric Cherenkov telescope event reconstruction*, 36th International Cosmic Ray Conference (2019)
- [13] Spencer, S., et al., *Deep learning with photosensor timing information as a background rejection method for the Cherenkov Telescope Array*, *Astroparticle Physics ArXiv e-prints* (2017) [[arXiv:2103.06054](https://arxiv.org/abs/2103.06054)]
- [14] Grespan, P., et al., *Deep-learning-driven event reconstruction applied to simulated data from a single Large-Sized Telescope of CTA*, 37th International Cosmic Ray Conference (2021)
- [15] Vuillaume, T., et al., *Analysis of the Cherenkov Telescope Array first Large Size Telescope real data using convolutional neural networks*, 37th International Cosmic Ray Conference (2021)
- [16] Noethe, M., et al., *Prototype Open Event Reconstruction Pipeline for CTA*, 37th International Cosmic Ray Conference (2021)
- [17] *cta-observatory/ctapipe: v0.10.5*, Zenodo (2021) 10.5281/zenodo.4581045, <https://github.com/cta-observatory/ctapipe>.
- [18] *DLI Data Handler: HDF5 format IACT data writer, reader and processor*, Zenodo (2019) doi:10.5281/zenodo.3336560, <https://github.com/cta-observatory/dli-data-handler>.
- [19] *CTLearn: Deep Learning for IACT Event Reconstruction*, Zenodo (2019), doi:10.5281/zenodo.3342952, github.com/ctlearn-project/ctlearn
- [20] Nieto, D., et al., *CTLearn: Deep Learning for Gamma-ray Astronomy*, 36th International Cosmic Ray Conference (2019)
- [21] *cta-observatory/pyirf: v0.5.0*, Zenodo (2021) doi:10.5281/zenodo.4748994, <https://github.com/cta-observatory/pyirf>.
- [22] Xie, W., et al., *Utterance-level Aggregation For Speaker Recognition In The Wild*, Electrical Engineering and Systems Science - Audio and Speech Processing, Computer Science - Machine Learning, Computer Science - Multimedia, Computer Science - Sound *ArXiv e-prints* (2017) [[arXiv:1902.10107](https://arxiv.org/abs/1902.10107)]
- [23] He, K., et al., *Deep Residual Learning for Image Recognition*, Computer Science - Computer Vision and Pattern Recognition *ArXiv e-prints* (2017) [[arXiv:1512.03385](https://arxiv.org/abs/1512.03385)]
- [24] Hu, J., et al., *Squeeze-and-Excitation Networks*, Computer Science - Computer Vision and Pattern Recognition *ArXiv e-prints* (2017) [[arXiv:1709.01507](https://arxiv.org/abs/1709.01507)]
- [25] Nieto, D., et al., *Reconstruction of IACT events using deep learning techniques with CTLearn*, 30th Astronomical Data Analysis Software and Systems (ADASS) conference (2020)
- [26] Gueta, O., et al., *The Cherenkov Telescope Array: layout, design and performance*, 37th International Cosmic Ray Conference (2021)
- [27] Maier, G., et al., *Eventdisplay: An Analysis and ReconstructionPackage for Ground-based Gamma-ray Astronomy*, 35th International Cosmic Ray Conference (2017)

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. Ambrogi¹⁸, 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. Beckerini⁵⁷, 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. Bouyouf⁷⁵, V. Bozhilov⁸⁶, E. Bozzo³⁸, L. Brahimi³⁹, C. Braiding⁴³, S. Brau-Nogue⁸⁷, S. Breen⁷⁸, J. Bregeon³⁹, M. Breuhaus⁵³, A. Brill⁹, W. Bricken⁸⁸, 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. 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'Ài⁹¹, G. D'Amico¹¹⁶, F. D'Ammando⁹⁰, P. D'Avanzo⁹⁵, P. Da Vela⁷⁴, M. Dadaña²¹, 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 Sant⁹¹, 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-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. Etorri²¹, A. Eungwanichayapant³¹, P. Evans¹²⁴, C. Evoli¹⁸, M. Fairbairn¹³¹, D. Falcata-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. Garczarzyk⁵², F. Gargano¹²⁰, C. Gargano⁹¹, S. Garozzo²⁹, D. Gascon⁸¹, T. Gaspardo¹⁴⁵, 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. Gourgouliaos⁹, 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. Hiratsatsu¹⁵⁷, 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. Inome², 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. Jamroz¹⁶⁹, P. Janeczek³³, 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. Knölseder⁸⁷, 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. Leckngam³¹, S.-H. Lee¹⁸⁰, W.H. Lee¹¹⁸, S. Lee¹¹⁸, M.A. Leigui de Oliveira¹⁸⁴, A. Lemière⁸⁵, 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. Maieti⁵², 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. Manico⁹⁴, 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. Massimo²⁹, 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. 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. Mohrman¹⁴², 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. Moshammer⁵², 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. Ndiyavala⁴, 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. Nikoľajuk¹⁹⁰, 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. Pavletić¹²¹, 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. Pettrera¹⁸, 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. Prasad³¹, 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. Rippepi⁸⁴, M. Riquelme¹⁹², D. Riquelme³⁵, S. Rivoire³⁹, V. Rizi¹⁸, E. Roache⁶³, B. Røben¹⁵⁹, 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. 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. 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, L. 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. Stuijk¹⁷⁴, 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. Terzić¹²¹, M. Teshima^{105,2}, V. Testa²⁸, D. Thibaut⁸⁵, F. Thocquenue⁷⁵, W. Tian², L. Tibaldo⁸⁷, A. Tiengo²¹⁵, D. Tiziani¹⁴², M. Tluczykont⁵⁰, C.J. Toledor 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. Tousseneil⁷⁹, G. Tovmassian¹⁶, P. Travnicek³³, C. Trichard⁸, M. Trifoglio²¹, A. Trois⁹⁵, S. Truzzi⁶², A. Tsiahina⁸⁷, T. Tsuru¹⁸⁰, B. Turk⁴⁵, A. Tutone⁹¹, Y. Uchiyama¹⁶¹, G. Umama²⁹, 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. Vegh⁹⁸, 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. Vrstil³³, 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. Wettskind¹⁰⁵, M. White¹¹⁸, R. White⁵³, A. Wierzcholska¹⁰¹, S. Wiesand⁵², R. Wijers¹⁷⁴, M. Wilkinson¹²⁴, M. Will¹⁰⁵, D.A. Williams¹⁴³, J. Williams¹²⁴, T. Williamson¹⁶², A. Wolte⁹⁵, 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. Zavrtnik⁶⁸, D. Zavrtnik⁶⁸, A.A. Zdziarski⁴⁹, A. Zech²⁰, H. Zechlin⁶⁴, A. Zenin¹³⁹, A. Zerwekh³⁵, V.I. Zhdanov¹³⁶, K. Zięta¹⁶⁹, A. Zink¹⁴², J. Ziółkowski⁴⁹, 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, 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. Orła 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. 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, 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