PROCEEDINGS OF SCIENCE

Event reconstruction using pattern spectra and convolutional neural networks for the Cherenkov Telescope Array

---

J. Aschersleben,[a,b,*] **M. Vecchi,**[a] **M. H. F. Wilkinson**[b] **and R. F. Peletier**[a] **on behalf of the CTA Consortium**
(a complete list of authors can be found at the end of the proceedings)

[a] *Kapteyn Astronomical Institute*
University of Groningen, PO Box 800, 9700 AV Groningen, The Netherlands
[b] *Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence*
University of Groningen, PO Box 407, NL-9700 AK Groningen, The Netherlands
E-mail: `j.j.m.aschersleben@rug.nl`, `r.f.peletier@rug.nl`, `m.vecchi@rug.nl`, `m.h.f.wilkinson@rug.nl`

The Cherenkov Telescope Array (CTA) is the future observatory for ground-based imaging atmospheric Cherenkov telescopes. Each telescope will provide a snapshot of gamma-ray induced particle showers by capturing the induced Cherenkov emission at ground level. The simulation of such events provides camera images that can be used as training data for convolutional neural networks (CNNs) to differentiate signals from background events and to determine the energy of the initial gamma-ray events. Pattern spectra are commonly used tools for image classification and provide the distributions of the sizes and shapes of features comprising an image. The application of pattern spectra on a CNN allows the selection of relevant combinations of features within an image.

In this work, we generate pattern spectra from simulated gamma-ray images to train a CNN for signal-background separation and energy reconstruction for CTA. We compare our results to a CNN trained with CTA images and find that the pattern spectra-based analysis is computationally less expensive but not competitive with the purely CTA images-based analysis. Thus, we conclude that the CNN must rely on additional features in the CTA images not captured by the pattern spectra.

7th Heidelberg International Symposium on High-Energy Gamma-Ray Astronomy (Gamma2022)
4-8 July 2022
Barcelona, Spain

---

[*] Speaker

PoS(Gamma2022)211

1. Introduction

Gamma rays induce air showers when interacting with the Earth's atmosphere, which results in the creation of secondary particles. These secondary particles can travel with a velocity larger than the speed of light in air, which induces a flash of Cherenkov light [1]. The Cherenkov light contains information about the initial particle, such as its type, energy and direction, and can be captured by imaging atmospheric Cherenkov telescopes (IACTs) from the ground [2]. The Cherenkov Telescope Array (CTA)[1] [3] is the future observatory for ground-based imaging atmospheric Cherenkov telescopes and will be located in the northern hemisphere at the Roque de los Muchachos Observatory in La Palma (CTA North) and in the southern hemisphere in the Atacama Desert in Chile (CTA South). It will consist of three different telescope types: Small-Sized Telescopes (SSTs), Medium-Sized Telescopes (MSTs) and Large-Sized Telescope (LSTs). The different telescope types will allow CTA to cover a wide energy range between 20 GeV and 300 TeV with an energy resolution of 5 % around 1 TeV and an angular resolution of $\sim 1\,'$ on individual photons for the upper end of the CTA energy range [4].

Gamma-ray events can be reconstructed by applying Hillas parameters [5] on machine learning algorithms, such as Random Forest [6] or Boosted Decision Trees [7, 8]. Other reconstruction methods are based on semi-analytical or Gaussian photosphere shower models, such as model analysis [9] and 3D model analysis [10]. Lately, convolutional neural networks (CNNs) have been applied to IACT data [11–15] motivated by their success in other image classification and regression tasks [16]. However, one of the main drawbacks of this method is that the training of CNNs is computationally very expensive [17].

In this work, we extract pattern spectra from CTA data aiming to reduce the computational resources needed to train a CNN for signal-background separation and gamma-ray energy reconstruction. Pattern spectra are commonly used tools for image classification [18, 19] and provide a 2-dimensional histogram of the sizes and shapes of features within an image. Our pattern spectra algorithm is based on the work presented in Urbach et al. (2007) [18] and makes use of connected operators, which merge regions within an image with the same grey scale value. Compared to other pattern spectra algorithms, our method provides the following main advantages: (i) the computing time for creating the pattern spectra is independent of its dimensions and (ii) it is significantly less sensitive to noise [18].

2. Dataset

Two different datasets have been used for the signal-background separation and the energy reconstruction, respectively. The signal-background dataset consists of $\sim 6 \cdot 10^5$ gamma-rays and $\sim 6 \cdot 10^5$ protons generated in a view cone of 10 °. The energy reconstruction dataset consists of $\sim 2.5 \cdot 10^6$ gamma-ray events generated with a 0.4 ° offset from the telescope pointing position. All events have been simulated for the southern CTA array with a telescope zenith angle of 20 ° (North pointing) and an energy range between 500 GeV and 100 TeV. Since the current pattern spectra algorithm is limited in processing images with rectangular pixels, only data from the SSTs are considered in this analysis. The SST images containing the charge information, i.e. the integrated photodetector

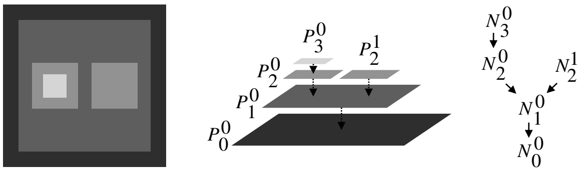
---

[1] www.cta-observatory.org

pulse, will be referred to as *CTA images* in the following.
Some events can initiate several CTA images if the event is captured by several telescopes. The number of triggered telescopes per events, however, is not constant but varies depending on the properties of the initial particle, e.g. its type, energy and point of impact. Moreover, the construction of a CNN that can process a varying number of input images is rather challenging. As a first step towards the implementation of pattern spectra to the analysis of CTA data, we constructed a single CTA image for each event by adding up the individual pixel values of each CTA image of each event. This certainly reduces the performance of the analysis but we adopt this strategy to simplify our proof of concept work.

3. Analysis

The pattern spectra algorithm detects features within the CTA image and classifies these features based on their size and shape attribute. The basic working principle of the algorithm is shown in Figure 1. Figure 1 (a) shows an example of a 2D greyscale image f, (b) the corresponding *peak components* $P_h^k(f)$, which are defined as the kth grain of the threshold set $T_h(f)$ with grey level h, and (c) its *Max-tree* composed of *nodes* $N_h^k(f)$ describing the subset of the peak components $P_h^k(f)$. The size and shape attribute for each node $N_h^k(f)$ of the Max-tree is determined by computing $A(P_h^k(f))$ and $I(P_h^k(f))/A(P_h^k(f))^2$ respectively. $A(P_h^k(f))$ corresponds to the *area* of the peak component and $I(P_h^k(f))$ to the *moment of inertia* describing the sum of squared differences to the centre of gravity of the feature. Large (small) $A(P_h^k(f))$ values correspond to features with a large (small) size and large (small) values of $I(P_h^k(f))/A(P_h^k(f))^2$ correspond to features with a elliptical-like (circular-like) shape. For further details about the pattern spectra algorithm, we refer to Urbach et al. (2007) [18].



(a) 2D image (b) Peak components (c) Max-tree

Figure 1: Basic principle of the pattern spectra algorithm (adapted from [18, 20])

Figure 2 shows an example of a 1.9 TeV gamma-ray event captured by eight SSTs (top row) and its corresponding pattern spectrum (bottom row). Each pattern spectrum pixel corresponds to a set of detected features with corresponding shape and size. Two examples of a set of detected features are shown in the second and third column of Figure 2. The detected features in the CTA image are displayed in red/orange and the corresponding pattern spectrum pixel is marked in red. Whereas the detected features in the second column mostly consist of noise, the features in the third column consist of the Cherenkov emission initiated by the particle shower. The latter contains information about the energy and type of the initial particle which is of particular interest for this analysis.
The architecture of our CNN is motivated by the work of Miener et al. (2021) [14], W. Xie et al. (2019) [21] and K. He et al. (2016) [22]. Two almost identical but independent CNNs are

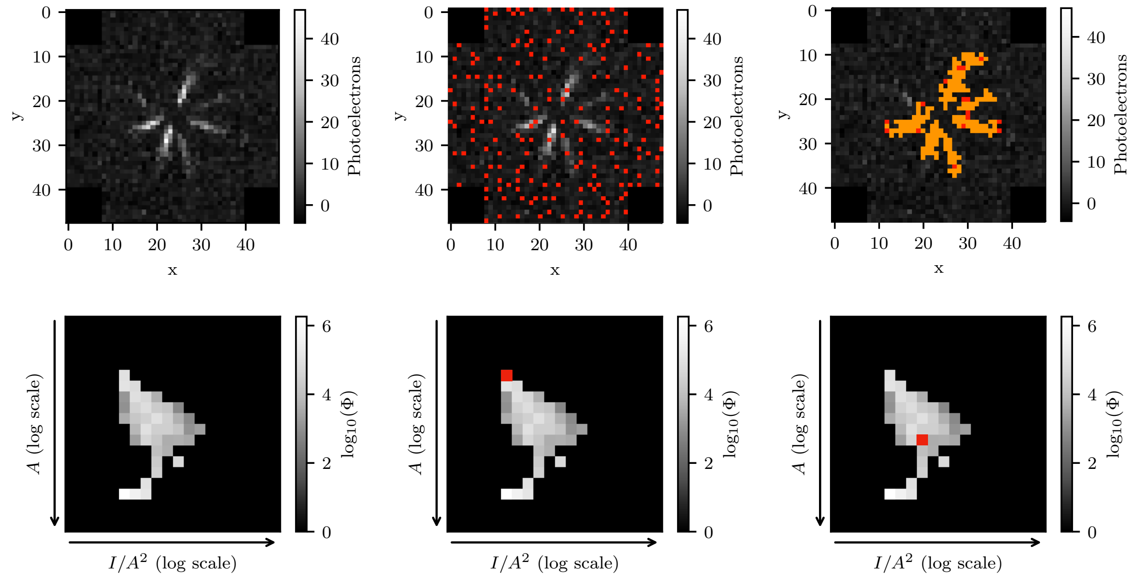


Figure 2: Top-row: CTA image example of a 1.9 TeV gamma-ray event captured by eight SSTs with detected features highlighted in red/orange. Bottom-row: pattern spectrum extracted from the CTA image with pixel corresponding to the detected features marked in red (adapted from [12]).

constructed for the signal-background separation and energy reconstruction task taking either the CTA images or the pattern spectra as input. We refer to our CNN as *thin residual neural network* (TRN) in the following based on its rather shallow architecture compared to the residual neural network presented in K. He et al. (2016) [22]. The detailed architecture of the TRN is shown in Figure 3. It consists of 13 convolutional layers, a global average pooling layer and two fully connected (dense) layers. The *ReLU* activation function [23] has been applied for all convolutional and fully connected layers. One neuron is used as the output layer for the energy reconstruction task and two neurons with *softmax* [24] activation function for the signal-background separation. The TRN is constructed using Tensorflow 2.3.1 [25] and Keras 2.4.3 [26] and has a total number of about 150000 trainable parameters. The data is split into 90 % training data, of which 10 % is used for validation, and 10 % test data. For the TRN training process, the *adaptive moment* (ADAM) optimizer [27] with a constant learning rate of 1×10^{-3}, a batch size of 32 and 30 epochs are used. The *categorical cross entropy* has been applied as the loss function for the signal-background separation and the *mean squared error* [28] for the energy reconstruction. After the completion of the training, the performance of the TRN is evaluated on the test data.

4. Results

4.1 Signal-background separation

The TRN predicts the *gammaness* of the initial particle, which corresponds to a pseudo-probability of the particle being a gamma ray (photon). For a given *gammaness* threshold α_g, the *true positive rate* (correctly classified photons, i.e. photons with $gammaness > \alpha_g$) and *false positive rate*

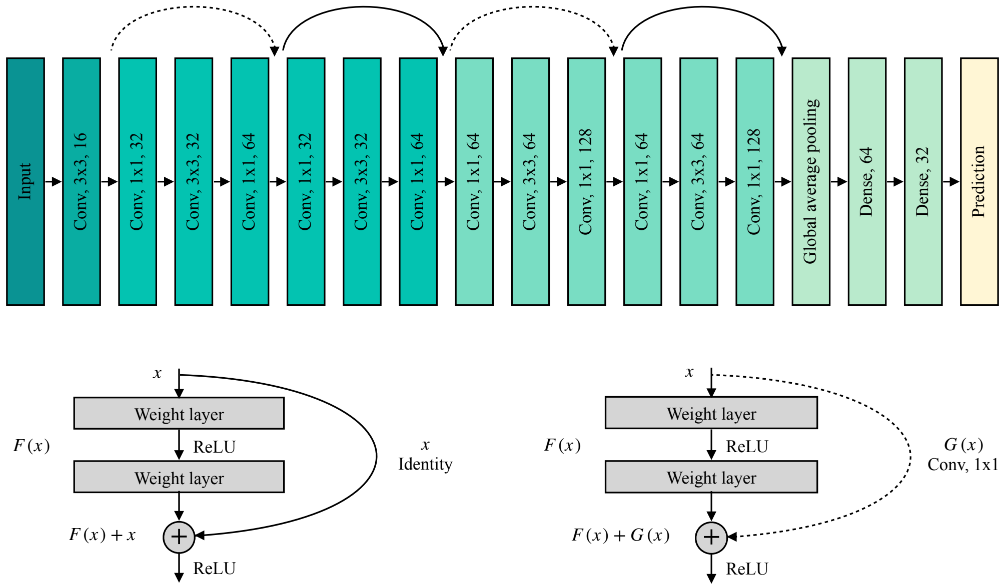


Figure 3: Top: thin residual neural network (TRN) architecture used in this work. The kernel size and number of filters for each convolutional layer and the number of neurons in each dense layer is specified in each box. The dashed and solid arrows correspond to linear (bottom left) and non-linear shortcut connections (bottom right) (adapted from [22]).

(misclassified protons, i.e. protons with $gammaness > \alpha_g$) are determined. The *receiver operating characteristic* (ROC) curves [29], describing the *true positive rate* versus the *false positive rate* are shown in Figure 4 (left). The area under the ROC curve (AUC) is a measure for the separation capabilities of an algorithm and calculated for both the CTA images and pattern spectra-based analyses. The TRN trained on CTA images achieves an AUC value of 0.961 which is about a factor of 1.15 higher compared to the AUC value of 0.836 achieved with the pattern spectra.

4.2 Energy reconstruction

The performance of the TRN for the energy reconstruction is evaluated by calculating the *relative energy error* $\Delta E/E_{\mathrm{true}} = (E_{\mathrm{rec}} - E_{\mathrm{true}})/E_{\mathrm{true}}$ from the reconstructed energy E_{rec} obtained from the TRN and the true energy E_{true}. The whole $0.5 - 100\,\mathrm{TeV}$ energy range is split logarithmically into nine bins and each event is allocated to its corresponding bin based on its true energy E_{true}. The distribution of the relative energy error $\Delta E/E_{\mathrm{true}}$ is determined for each energy bin and its energy biases, i.e. the median of the relative energy error distribution, is calculated. Then, the distributions are bias-corrected by subtracting the energy bias via $(\Delta E/E_{\mathrm{true}})_{\mathrm{corr}} = \Delta E/E_{\mathrm{true}} - \mathrm{median}(\Delta E/E_{\mathrm{true}})$. We define the energy resolution $(\Delta E/E_{\mathrm{true}})_{68}$ as the 68th percentile of the distribution $|(\Delta E/E_{\mathrm{true}})_{\mathrm{corr}}|$. The training of the TRN for the energy reconstruction is performed ten times for both the CTA images and the pattern spectra in order to calculate a mean energy resolution and its standard deviation for each energy bin. The results are shown in Figure 4 (right). The CTA images-based analysis outperforms the pattern spectra in each energy bin with a maximum factor

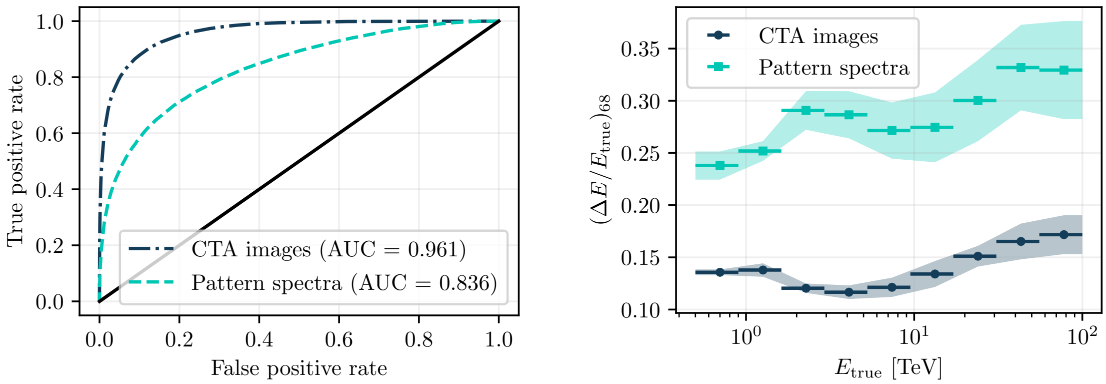


Figure 4: ROC curves and corresponding AUC values (left) and energy resolutions (right) obtained from the CTA images and pattern spectra-based analyses.

of 2.5 between the two curves.

5. Conclusions

In this work, we have extracted pattern spectra from CTA images and applied them on a TRN to perform signal-background separation and reconstruction of the energy of gamma rays. As shown in Table 1, the training of the TRN with the pattern spectra requires about a factor of 3 less memory and is about a factor of 2.5 faster than the TRN training with CTA images. However, the CTA images-based analysis outperforms the pattern spectra in both signal-background separation and energy reconstruction capabilities. The AUC values obtained from the CTA images is about a factor of 1.15 higher than the pattern spectra value and the energy resolution obtained from the CTA images and pattern spectra differ by a maximum factor of 2.5. We therefore conclude that the pattern spectra algorithm is not able to detect all relevant features within the CTA images and/or that the size and shape attributes of the pattern spectra are not sufficient to fully describe the detected features. The pattern spectra algorithm applied on a different dataset consisting of larger images may result in a better performance. The work presented here is preliminary and results in a lower performance compared to other existing works applying CTA images on a CNN, e.g. in [14]. The final results, including the performance on the Alpha Configuration of CTA, are discussed in [30].

Table 1: Time and RAM required to train the TRN for signal-background separation and energy reconstruction. Since the TRN training was performed ten times for the energy reconstruction task, the mean time μ_{time} and mean RAM μ_{RAM} have been calculated. The training was performed on a *Nvidia V100 GPU*.

	γ/p-separation		energy reconstruction	
	Time	RAM	μ_{time}	μ_{RAM}
CTA images	12.9 ks	41.0 GB	29.1 ks	100.0 GB
pattern spectra	5.2 ks	13.3 GB	11.0 ks	31.9 GB
ratio	2.5	3.1	2.6	3.1

Acknowledgments

This work was conducted in the context of the CTA Consortium and CTA Observatory. We gratefully acknowledge financial support from the agencies and organizations listed at http://www.cta-observatory.org/consortium_acknowledgments. We would like to thank the Centre for Information Technology of the University of Groningen for their support and for providing access to the Peregrine high performance computing cluster.

References

[1] P. A. Cherenkov, “Visible emission of clean liquids by action of gamma radiation,” *Doklady Akad. Nauk SSSR*, vol. 8, no. 451, 1934.

[2] M. de Naurois and D. Mazin, “Ground-based detectors in very-high-energy gamma-ray astronomy,” *Comptes Rendus Physique*, vol. 16, no. 6-7, pp. 610–627, 2015.

[3] CTA Consortium, *Science with the Cherenkov Telescope Array*. WORLD SCIENTIFIC, 2019.

[4] O. Gueta, “The Cherenkov Telescope Array: layout, design and performance,” *PoS*, vol. ICRC2021, p. 885, 2021.

[5] A. M. Hillas, “Cerenkov light images of EAS produced by primary gamma,” *International Cosmic Ray Conference*, vol. 3, 1985.

[6] J. Albert *et al.*, “Implementation of the random forest method for the imaging atmospheric cherenkov telescope MAGIC,” *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 588, no. 3, pp. 424–432, 2008.

[7] S. Ohm, C. van Eldik, and K. Egberts, “gamma/hadron separation in very-high-energy gamma-ray astronomy using a multivariate analysis method,” *Astroparticle Physics*, vol. 31, no. 5, pp. 383–391, 2009.

[8] Y. Becherini, A. Djannati-Ataï, V. Marandon, M. Punch, and S. Pita, “A new analysis strategy for detection of faint gamma-ray sources with imaging atmospheric cherenkov telescopes,” *Astroparticle Physics*, vol. 34, no. 12, pp. 858–870, 2011.

[9] M. de Naurois, J. Guy, A. Djannati-Atai, and J. P. Tavernet, “Application of an analysis method based on a semi-analytical shower model to the first H.E.S.S. telescope,” *International Cosmic Ray Conference 28 ICRC*, pp. 2907–2910, 2003.

[10] M. Lemoine-Goumard, B. Degrange, and M. Tluczykont, “Selection and 3D-reconstruction of gamma-ray-induced air showers with a stereoscopic system of atmospheric cherenkov telescopes,” *Astroparticle Physics*, vol. 25, no. 3, pp. 195–211, 2006.

[11] M. Jacquemont, T. Vuillaume, A. Benoit, G. Maurin, and P. Lambert, “Multi-Task Architecture with Attention for Imaging Atmospheric Cherenkov Telescope Data Analysis,” in *Proceedings of VISAPP 2021*, 2021, p. none.

[12] J. Aschersleben, R. Peletier, M. Vecchi, and M. Wilkinson, “Application of Pattern Spectra and Convolutional Neural Networks to the Analysis of Simulated Cherenkov Telescope Array Data,” in *Proceedings of 37th International Cosmic Ray Conference — PoS(ICRC2021)*, vol. 395, 2021, p. 697.

[13] D. Nieto, A. Brill, Q. Feng, T. Humensky, B. Kim *et al.*, “CTLearn: Deep learning for gamma-ray astronomy,” *arXiv preprint, arXiv:1912.09877*, 2019.

[14] T. Miener, D. Nieto, A. Brill, S. T. Spencer, and J. L. Contreras, “Reconstruction of stereoscopic CTA events using deep learning with CTLearn,” in *Proceedings of 37th International Cosmic Ray Conference — PoS(ICRC2021)*, vol. 395, 2021, p. 730.

[15] S. Spencer, T. Armstrong, J. Watson, S. Mangano, Y. Renier *et al.*, “Deep learning with photosensor timing information as a background rejection method for the Cherenkov Telescope Array,” *Astroparticle Physics*, vol. 129, p. 102579, 2021.

[16] L. Alzubaidi, J. Zhang, A. J. Humaidi, A. Al-Dujaili, Y. Duan *et al.*, “Review of deep learning: Concepts, cnn architectures, challenges, applications, future directions,” *Journal of big Data*, vol. 8, no. 1, pp. 1–74, 2021.

[17] E. Strubell, A. Ganesh, and A. McCallum, “Energy and policy considerations for deep learning in nlp,” *arXiv preprint arXiv:1906.02243*, 2019.

[18] E. Urbach, J. Roerdink, and M. Wilkinson, “Connected shape-size pattern spectra for rotation and scale-invariant classification of gray-scale images,” *IEEE transactions on pattern analysis and machine intelligence*, 2007, doi:10.1109/TPAMI.2007.28.

[19] S. Batman and E. R. Dougherty, “Size distributions for multivariate morphological granulometries: texture classification and statistical properties,” *Optical Engineering*, vol. 36, no. 5, pp. 1518–1529, 1997.

[20] P. Teeninga, U. Moschini, S. C. Trager, and M. H. Wilkinson, “Statistical attribute filtering to detect faint extended astronomical sources,” *Mathematical Morphology - Theory and Applications*, vol. 1, no. 1, 2016.

[21] W. Xie, A. Nagrani, J. S. Chung, and A. Zisserman, “Utterance-level aggregation for speaker recognition in the wild,” in *Proceedings of ICASSP 2019-2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. IEEE, 2019, pp. 5791–5795.

[22] K. He, X. Zhang, S. Ren, and J. Sun, “Deep residual learning for image recognition,” in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2016, pp. 770–778.

[23] V. Nair and G. E. Hinton, “Rectified linear units improve restricted boltzmann machines,” in *Proceedings of the 27th International Conference on International Conference on Machine Learning*, ser. ICML’10. Madison, WI, USA: Omnipress, 2010, pp. 807–814.

[24] J. S. Bridle, “Training stochastic model recognition algorithms as networks can lead to maximum mutual information estimation of parameters,” in *Proceedings of the 2nd International Conference on Neural Information Processing Systems*, ser. NIPS’89. Cambridge, MA, USA: MIT Press, 1989, pp. 211–217.

[25] M. Abadi *et al.*, “Tensorflow: Large-scale machine learning on heterogeneous systems,” tensorflow.org, 2015.

[26] F. Chollet *et al.*, “Keras,” https://github.com/fchollet/keras, 2015.

[27] D. P. Kingma and J. Ba, “Adam: A Method for Stochastic Optimization,” in *International Conference on Learning Representations*, 2017, arXiv:1412.6980.

[28] K. Janocha and W. M. Czarnecki, "On loss functions for deep neural networks in classification," *arXiv preprint, arXiv:1702.05659*, 2017.

[29] A. P. Bradley, "The use of the area under the ROC curve in the evaluation of machine learning algorithms," *Pattern Recognition*, vol. 30, no. 7, pp. 1145–1159, 1997.

[30] J. Aschersleben, T. T. H. Arnesen, R. Peletier, M. Vecchi, C. Vlasakidis *et al.*, "Signal-background separation and energy reconstruction of gamma rays using pattern spectra and convolutional neural networks for the Small-Sized Telescopes of the Cherenkov Telescope Array," 2022, manuscript in preparation.

Full Authors List: The Cherenkov Telescope Array Consortium

H. Abdalla[1], H. Abe[2], S. Abe[2], A. Abusleme[3], F. Acero[4], A. Acharyya[5], V. Acín Portella[6], K. Ackley[7], R. Adam[8], C. Adams[9], S.S. Adhikari[10], I. Aguado-Ruesga[11], I. Agudo[12], R. Aguilera[13], A. Aguirre-Santaella[14], F. Aharonian[15], A. Alberdi[12], R. Alfaro[16], J. Alfaro[3], C. Alispach[17], R. Aloisio[18], R. Alves Batista[19], J.-P. Amans[20], L. Amati[21], E. Amato[22], L. Ambrogi[18], G. Ambrosi[23], M. Ambrosio[24], R. Ammendola[25], J. Anderson[26], M. Anduze[8], E.O. Angüner[27], L.A. Antonelli[28], V. Antonuccio[29], P. Antoranz[30], R. Anutarawiramkul[31], J. Aragunde Gutierrez[32], C. Aramo[24], A. Araudo[33,34], M. Araya[35], A. Arbet-Engels[36], C. Arcaro[1], V. Arendt[37], C. Armand[38], T. Armstrong[27], F. Arqueros[11], L. Arrabito[39], B. Arsioli[40], M. Artero[41], K. Asano[2], Y. Ascasíbar[14], J. Aschersleben[42], M. Ashley[43], P. Attinà[44], P. Aubert[45], C. B. Singh[19], D. Baack[46], A. Babic[47], M. Backes[48], V. Baena[13], S. Bajtlik[49], A. Baktash[50], C. Balazs[7], M. Balbo[38], O. Ballester[41], J. Ballet[4], B. Balmaverde[44], A. Bamba[51], R. Bandiera[22], A. Baquero Larriva[11], P. Barai[19], C. Barbier[45], V. Barbosa Martins[52], M. Barcelo[53], M. Barkov[54], M. Barnard[1], L. Baroncelli[21], U. Barres de Almeida[40], J.A. Barrio[11], D. Bastieri[55], P.I. Batista[52], I. Batkovic[55], C. Bauer[53], R. Bautista-González[56], J. Baxter[2], U. Becciani[29], J. Becerra González[32], Y. Becherini[57], G. Beck[58], J. Becker Tjus[59], W. Bednarek[60], A. Belfiore[61], L. Bellizzi[62], R. Belmont[4], W. Benbow[63], D. Berge[52], E. Bernardini[52], M.I. Bernardos[55], K. Bernlöhr[53], A. Berti[64], M. Berton[65], B. Bertucci[23], V. Beshley[66], N. Bhatt[67], S. Bhattacharyya[67], W. Bhattacharyya[52], S. Bhattacharyya[68], B. Bi[69], G. Bicknell[70], N. Biederbeck[46], C. Bigongiari[28], A. Biland[36], R. Bird[71], E. Bissaldi[72], J. Biteau[73], M. Bitossi[74], O. Blanch[41], M. Blank[50], J. Blazek[33], J. Bobin[75], C. Boccato[76], F. Bocchino[77], C. Boehm[78], M. Bohacova[33], C. Boisson[20], J. Boix[41], J.-P. Bolle[52], J. Bolmont[79], G. Bonanno[29], C. Bonavolontà[24], L. Bonneau Arbeletche[80], G. Bonnoli[12], P. Bordas[81], J. Borkowski[49], S. Bórquez[35], R. Bose[82], D. Bose[83], Z. Bosnjak[47], E. Bottacini[55], M. Böttcher[1], M.T. Botticella[84], C. Boutonnet[85], F. Bouyjou[75], V. Bozhilov[86], E. Bozzo[38], L. Brahimi[39], C. Braiding[43], S. Brau-Nogué[87], S. Breen[78], J. Bregeon[39], M. Breuhaus[53], A. Brill[9], W. Brisken[88], E. Brocato[28], A.M. Brown[5], K. Brügge[46], P. Brun[89], P. Brun[39], F. Brun[89], L. Brunetti[45], G. Brunetti[90], P. Bruno[29], A. Bruno[91], A. Bruzzese[6], N. Bucciantini[22], J. Buckley[82], R. Bühler[52], A. Bulgarelli[21], T. Bulik[92], M. Bünning[52], M. Bunse[46], M. Burton[93], A. Burtovoi[76], M. Buscemi[94], S. Buschjäger[46], G. Busetto[55], J. Buss[46], K. Byrum[26], A. Caccianiga[95], F. Cadoux[17], A. Calanducci[29], C. Calderón[3], J. Calvo Tovar[32], R. Cameron[96], P. Campaña[35], R. Canestrari[91], F. Cangemi[79], B. Cantlay[31], M. Capalbi[91], M. Capasso[9], M. Cappi[21], A. Caproni[97], R. Capuzzo-Dolcetta[28], P. Caraveo[61], V. Cárdenas[98], L. Cardiel[41], M. Cardillo[99], C. Carlile[100], S. Caroff[45], R. Carosi[74], A. Carosi[17], E. Carquín[35], M. Carrère[39], J.-M. Casandjian[4], S. Casanova[101,53], E. Cascone[84], F. Cassol[27], A.J. Castro-Tirado[12], F. Catalani[102], O. Catalano[91], D. Cauz[103], A. Ceccanti[64], C. Celestino Silva[80], S. Celli[18], K. Cerny[104], M. Cerruti[85], E. Chabanne[45], P. Chadwick[5], Y. Chai[105], P. Chambery[106], C. Champion[85], S. Chandra[1], S. Chaty[4], A. Chen[58], K. Cheng[2], M. Chernyakova[107], G. Chiaro[61], A. Chiavassa[64,108], M. Chikawa[2], V.R. Chitnis[109], J. Chudoba[33], L. Chytka[104], S. Cikota[47], A. Circiello[24,110], P. Clark[5], M. Çolak[41], E. Colombo[32], J. Colome[13], S. Colonges[85], A. Comastri[21], A. Compagnino[91], V. Conforti[21], E. Congiu[95], R. Coniglione[94], J. Conrad[111], F. Conte[53], J.L. Contreras[11], P. Coppi[112], R. Cornat[8], J. Coronado-Blazquez[14], J. Cortina[113], A. Costa[29], H. Costantini[27], G. Cotter[114], B. Courty[85], S. Covino[95], S. Crestan[61], P. Cristofari[20], R. Crocker[70], J. Croston[115], K. Cubuk[93], O. Cuevas[98], X. Cui[2], G. Cusumano[91], S. Cutini[23], A. D'Aì[91], G. D'Amico[116], F. D'Ammando[90], P. D'Avanzo[95], P. Da Vela[74], M. Dadina[21], S. Dai[117], M. Dalchenko[17], M. Dall' Ora[84], M.K. Daniel[63], J. Dauguet[85], I. Davids[48], J. Davies[114], B. Dawson[118], A. De Angelis[55], A.E. de Araújo Carvalho[40], M. de Bony de Lavergne[45], V. De Caprio[84], G. De Cesare[21], F. De Frondat[20], E.M. de Gouveia Dal Pino[19], I. de la Calle[11], B. De Lotto[103], A. De Luca[61], D. De Martino[84], R.M. de Menezes[19], M. de Naurois[8], E. de Oña Wilhelmi[13], F. De Palma[64], F. De Persio[119], N. de Simone[52], V. de Souza[80], M. Del Santo[91], M.V. del Valle[19], E. Delagnes[75], G. Deleglise[45], M. Delfino Reznicek[6], C. Delgado[113], A.G. Delgado Giler[80], J. Delgado Mengual[6], R. Della Ceca[95], M. Della Valle[84], D. della Volpe[17], D. Depaoli[64,108], D. Depouez[27], J. Devin[85], T. Di Girolamo[24,110], C. Di Giulio[25], A. Di Piano[21], F. Di Pierro[64], L. Di Venere[120], C. Díaz[113], C. Díaz-Bahamondes[3], C. Dib[35], S. Diebold[69], S. Digel[96], R. Dima[55], A. Djannati-Ataï[85], J. Djuvsland[116], A. Dmytriiev[20], K. Docher[9], A. Domínguez[11], D. Dominis Prester[121], A. Donath[53], A. Donini[41], D. Dorner[122], M. Doro[55], R.d.C. dos Anjos[123], J.-L. Dournaux[20], T. Downes[107], G. Drake[26], H. Drass[3], D. Dravins[100], C. Duangchan[31], A. Duara[124], G. Dubus[125], L. Ducci[69], C. Duffy[124], D. Dumora[106], K. Dundas Morå[111], A. Durkalec[126], V.V. Dwarkadas[127], J. Ebr[33], C. Eckner[45], J. Eder[105], A. Ederoclite[19], E. Edy[8], K. Egberts[128], S. Einecke[118], J. Eisch[129], C. Eleftheriadis[130], D. Elsässer[46], G. Emery[17], D. Emmanoulopoulos[115], J.-P. Ernenwein[27], M. Errando[82], P. Escarate[35], J. Escudero[12], C. Espinoza[3], S. Ettori[21], A. Eungwanichayapant[31], P. Evans[124], C. Evoli[18], M. Fairbairn[131], D. Falceta-Goncalves[132], A. Falcone[133], V. Fallah Ramazani[65], R. Falomo[76], K. Farakos[134], G. Fasola[20], A. Fattorini[46], Y. Favre[17], R. Fedora[135], E. Fedorova[136], S. Fegan[8], K. Feijen[118], Q. Feng[9], G. Ferrand[54], G. Ferrara[94], O. Ferreira[8], M. Fesquet[75], E. Fiandrini[23], A. Fiasson[45], M. Filipovic[117], D. Fink[105], J.P. Finley[137],

V. Fioretti[21], D.F.G. Fiorillo[24,110], M. Fiorini[61], S. Flis[52], H. Flores[20], L. Foffano[17], C. Föhr[53], M.V. Fonseca[11], L. Font[138], G. Fontaine[8], O. Fornieri[52], P. Fortin[63], L. Fortson[88], N. Fouque[45], A. Fournier[106], B. Fraga[40], A. Franceschini[76], F.J. Franco[30], A. Franco Ordovas[32], L. Freixas Coromina[113], L. Fresnillo[30], C. Fruck[105], D. Fugazza[95], Y. Fujikawa[139], Y. Fujita[2], S. Fukami[2], Y. Fukazawa[140], Y. Fukui[141], D. Fulla[52], S. Funk[142], A. Furniss[143], O. Gabella[39], S. Gabici[85], D. Gaggero[14], G. Galanti[61], G. Galaz[3], P. Galdemard[144], Y. Gallant[39], D. Galloway[7], S. Gallozzi[28], V. Gammaldi[14], R. Garcia[41], E. Garcia[45], E. García[13], R. Garcia López[32], M. Garczarczyk[52], F. Gargano[120], C. Gargano[91], S. Garozzo[29], D. Gascon[81], T. Gasparetto[145], D. Gasparrini[25], H. Gasparyan[52], M. Gaug[138], N. Geffroy[45], A. Gent[146], S. Germani[76], L. Gesa[13], A. Ghalumyan[147], A. Ghedina[148], G. Ghirlanda[95], F. Gianotti[21], S. Giarrusso[91], M. Giarrusso[94], G. Giavitto[52], B. Giebels[8], N. Giglietto[72], V. Gika[134], F. Gillardo[45], R. Gimenes[19], F. Giordano[149], G. Giovannini[90], E. Giro[76], M. Giroletti[90], A. Giuliani[61], L. Giunti[85], M. Gjaja[9], J.-F. Glicenstein[89], P. Gliwny[60], N. Godinovic[150], H. Göksu[53], P. Goldoni[85], J.L. Gómez[12], G. Gómez-Vargas[3], M.M. González[16], J.M. González[151], K.S. Gothe[109], D. Götz[4], J. Goulart Coelho[123], K. Gourgouliatos[5], T. Grabarczyk[152], R. Graciani[81], P. Grandi[21], G. Grasseau[8], D. Grasso[74], A.J. Green[78], D. Green[105], J. Green[28], T. Greenshaw[153], I. Grenier[4], P. Grespan[55], A. Grillo[29], M.-H. Grondin[106], J. Grube[131], V. Guarino[26], B. Guest[37], O. Gueta[52], M. Gündüz[59], S. Gunji[154], A. Gusdorf[20], G. Gyuk[155], J. Hackfeld[59], D. Hadasch[2], J. Haga[139], L. Hagge[52], A. Hahn[105], J.E. Hajlaoui[85], H. Hakobyan[35], A. Halim[89], P. Hamal[33], W. Hanlon[63], S. Hara[156], Y. Harada[157], M.J. Hardcastle[158], M. Harvey[5], K. Hashiyama[2], T. Hassan Collado[113], T. Haubold[105], A. Haupt[52], U.A. Hautmann[159], M. Havelka[33], K. Hayashi[141], K. Hayashi[160], M. Hayashida[161], H. He[54], L. Heckmann[105], M. Heller[17], J.C. Helo[35], F. Henault[125], G. Henri[125], G. Hermann[53], R. Hermel[45], S. Hernández Cadena[16], J. Herrera Llorente[32], A. Herrero[32], O. Hervet[143], J. Hinton[53], A. Hiramatsu[157], N. Hiroshima[54], K. Hirotani[2], B. Hnatyk[136], R. Hnatyk[136], J.K. Hoang[11], D. Hoffmann[27], W. Hofmann[53], C. Hoischen[128], J. Holder[162], M. Holler[163], B. Hona[164], D. Horan[8], J. Hörandel[165], D. Horns[50], P. Horvath[104], J. Houles[27], T. Hovatta[65], M. Hrabovsky[104], D. Hrupec[166], Y. Huang[135], J.-M. Huet[20], G. Hughes[159], D. Hui[2], G. Hull[73], T.B. Humensky[9], M. Hütten[105], R. Iaria[77], M. Iarlori[18], J.M. Illa[41], R. Imazawa[140], D. Impiombato[91], T. Inada[2], F. Incardona[29], A. Ingallinera[29], Y. Inome[2], S. Inoue[54], T. Inoue[141], Y. Inoue[167], A. Insolia[120,94], F. Iocco[24,110], K. Ioka[168], M. Ionica[23], M. Iori[119], S. Iovenitti[95], A. Iriarte[16], K. Ishio[105], W. Ishizaki[168], Y. Iwamura[2], C. Jablonski[105], J. Jacquemier[45], M. Jacquemont[45], M. Jamrozy[169], P. Janecek[33], F. Jankowsky[170], A. Jardin-Blicq[31], C. Jarnot[87], P. Jean[87], I. Jiménez Martínez[113], W. Jin[171], L. Jocou[125], N. Jordana[172], M. Josselin[73], L. Jouvin[41], I. Jung-Richardt[142], F.J.P.A. Junqueira[19], C. Juramy-Gilles[79], J. Jurysek[38], P. Kaaret[173], L.H.S. Kadowaki[19], M. Kagaya[2], O. Kalekin[142], R. Kankanyan[53], D. Kantzas[174], V. Karas[34], A. Karastergiou[114], S. Karkar[79], E. Kasai[48], J. Kasperek[175], H. Katagiri[176], J. Kataoka[177], K. Katarzyński[178], S. Katsuda[179], U. Katz[142], N. Kawanaka[180], D. Kazanas[130], D. Kerszberg[41], B. Khélifi[85], M.C. Kherlakian[52], T.P. Kian[181], D.B. Kieda[164], T. Kihm[53], S. Kim[3], S. Kimeswenger[163], S. Kisaka[140], R. Kissmann[163], R. Kleijwegt[135], T. Kleiner[52], G. Kluge[10], W. Kluźniak[49], J. Knapp[52], J. Knödlseder[87], A. Kobakhidze[78], Y. Kobayashi[2], B. Koch[3], J. Kocot[152], K. Kohri[182], K. Kokkotas[69], N. Komin[58], A. Kong[2], K. Kosack[4], G. Kowal[132], F. Krack[52], M. Krause[52], F. Krennrich[129], M. Krumholz[70], H. Kubo[180], V. Kudryavtsev[183], S. Kunwar[53], Y. Kuroda[139], J. Kushida[157], P. Kushwaha[19], A. La Barbera[91], N. La Palombara[61], V. La Parola[91], G. La Rosa[91], R. Lahmann[142], G. Lamanna[45], A. Lamastra[28], M. Landoni[95], D. Landriu[4], R.G. Lang[80], J. Lapington[124], P. Laporte[20], P. Lason[152], J. Lasuik[37], J. Lazendic-Galloway[7], T. Le Flour[45], P. Le Sidaner[20], S. Leach[124], A. Leckngam[31], S.-H. Lee[180], W.H. Lee[16], S. Lee[118], M.A. Leigui de Oliveira[184], A. Lemière[85], M. Lemoine-Goumard[106], J.-P. Lenain[79], F. Leone[94,185], V. Leray[8], G. Leto[29], F. Leuschner[69], C. Levy[79,20], R. Lindemann[52], E. Lindfors[65], L. Linhoff[46], I. Liodakis[65], A. Lipniacka[116], S. Lloyd[5], M. Lobo[113], T. Lohse[186], S. Lombardi[28], F. Longo[145], A. Lopez[32], M. López[11], R. López-Coto[55], S. Loporchio[149], F. Louis[75], M. Louys[20], F. Lucarelli[28], D. Lucchesi[55], H. Ludwig Boudi[39], P.L. Luque-Escamilla[56], E. Lyard[38], M.C. Maccarone[91], T. Maccarone[187], E. Mach[101], A.J. Maciejewski[188], J. Mackey[15], G.M. Madejski[96], P. Maeght[39], C. Maggio[138], G. Maier[52], A. Majczyna[126], P. Majumdar[83,2], M. Makariev[189], M. Mallamaci[55], R. Malta Nunes de Almeida[184], S. Maltezos[134], D. Malyshev[142], D. Malyshev[69], D. Mandat[33], G. Maneva[189], M. Manganaro[121], G. Manicò[94], P. Manigot[8], K. Mannheim[122], N. Maragos[134], D. Marano[29], M. Marconi[84], A. Marcowith[39], M. Marculewicz[190], B. Marčun[68], J. Marín[98], N. Marinello[55], P. Marinos[118], M. Mariotti[55], S. Markoff[174], P. Marquez[41], G. Marsella[94], J. Martí[56], J.-M. Martin[20], P. Martin[87], O. Martinez[30], M. Martínez[41], G. Martínez[113], O. Martínez[41], H. Martínez-Huerta[80], C. Marty[87], R. Marx[53], N. Masetti[21,151], P. Massimino[29], A. Mastichiadis[191], H. Matsumoto[167], N. Matthews[164], G. Maurin[45], W. Max-Moerbeck[192], N. Maxted[43], D. Mazin[2,105], M.N. Mazziotta[120], S.M. Mazzola[77], J.D. Mbarubucyeye[52], L. Mc Comb[5], I. McHardy[115], S. McKeague[107], S. McMuldroch[63], E. Medina[64], D. Medina Miranda[17], A. Melandri[95], C. Melioli[19], D. Melkumyan[52], S. Menchiari[62], S. Mender[46], S. Mereghetti[61], G. Merino Arévalo[6], E. Mestre[13], J.-L. Meunier[79], T. Meures[135], M. Meyer[142], S. Micanovic[121], M. Miceli[77], M. Michailidis[69], J. Michałowski[101], T. Miener[11], I. Mievre[45], J. Miller[35], I.A. Minaya[153], T. Mineo[91], M. Minev[189], J.M. Miranda[30], R. Mirzoyan[105], A. Mitchell[36], T. Mizuno[193], B. Mode[135], R. Moderski[49], L. Mohrmann[142], E. Molina[81], E. Molinari[148], T. Montaruli[17], I. Monteiro[45], C. Moore[124], A. Moralejo[41], D. Morcuende-Parrilla[11], E. Moretti[41], L. Morganti[64], K. Mori[194], P. Moriarty[15], K. Morik[46], G. Morlino[22], P. Morris[114], A. Morselli[25], K. Mosshammer[52], P. Moya[192], R. Mukherjee[9], J. Muller[8], C. Mundell[172], J. Mundet[41], T. Murach[52], A. Muraczewski[49], H. Muraishi[195], K. Murase[2], I. Musella[84], A. Musumarra[120], A. Nagai[17], N. Nagar[196], S. Nagataki[54], T. Naito[156], T. Nakamori[154], K. Nakashima[142], K. Nakayama[51], N. Nakhjiri[13], G. Naletto[55], D. Naumann[52], L. Nava[95], R. Navarro[174], M.A. Nawaz[132], H. Ndiyavala[1], D. Neise[36], L. Nellen[16], R. Nemmen[19], M. Newbold[164], N. Neyroud[45], K. Ngernphat[31], T. Nguyen Trung[73], L. Nicastro[21], L. Nickel[46], J. Niemiec[101], D. Nieto[11], M. Nievas[32], C. Nigro[41], M. Nikołajuk[190], D. Ninci[41], K. Nishijima[157], K. Noda[2], Y. Nogami[176], S. Nolan[5], R. Nomura[2], R. Norris[117], D. Nosek[197], M. Nöthe[46], B. Novosyadlyj[198], V. Novotny[197], S. Nozaki[180], F. Nunio[144], P. O'Brien[124], K. Obara[176], R. Oger[85], Y. Ohira[51], M. Ohishi[2], S. Ohm[52], Y. Ohtani[2], T. Oka[180], N. Okazaki[2], A. Okumura[139,199], J.-F. Olive[87], C. Oliver[30], G. Olivera[52], B. Olmi[22], R.A. Ong[71], M. Orienti[90], R. Orito[200], M. Orlandini[21], S. Orlando[77], E. Orlando[145], J.P. Osborne[124], M. Ostrowski[169], N. Otte[146], E. Ovcharov[86], E. Owen[2], I. Oya[159], A. Ozieblo[152], M. Padovani[22], I. Pagano[29], A. Pagliaro[91], A. Paizis[61], M. Palatiello[145], M. Palatka[33], E. Palazzi[21], J.-L. Panazol[45], D. Paneque[105], B. Panes[3], S. Panny[163], F.R. Pantaleo[72], M. Panter[53], R. Paoletti[62], M. Paolillo[24,110], A. Papitto[28], A. Paravac[122], J.M. Paredes[81], G. Pareschi[95], N. Park[127], N. Parmiggiani[21], R.D. Parsons[186], P. Paśko[201], S. Patel[52],

B. Patricelli[28], G. Pauletta[103], L. Pavletić[121], S. Pavy[8], A. Pe’er[105], M. Pech[33], M. Pecimotika[121], M.G. Pellegriti[120], P. Peñil Del Campo[11], M. Penno[52], A. Pepato[55], S. Perard[106], C. Perennes[55], G. Peres[77], M. Peresano[4], A. Pérez-Aguilera[11], J. Pérez-Romero[14], M.A. Pérez-Torres[12], M. Perri[28], M. Persic[103], S. Petrera[18], P.-O. Petrucci[125], O. Petruk[66], B. Peyaud[89], K. Pfrang[52], E. Pian[21], G. Piano[99], P. Piatteli[94], E. Pietropaolo[18], R. Pillera[149], B. Pilszyk[101], D. Pimentel[202], F. Pintore[91], C. Pio García[41], G. Pirola[64], F. Piron[39], A. Pisarski[190], S. Pita[85], M. Pohl[128], V. Poireau[45], P. Poledrelli[159], A. Pollo[126], M. Polo[113], C. Pongkitivanichkul[31], J. Porthault[144], J. Powell[171], D. Pozo[98], R.R. Prado[52], E. Prandini[55], P. Prasit[31], J. Prast[45], K. Pressard[73], G. Principe[90], C. Priyadarshi[41], N. Produit[38], D. Prokhorov[174], H. Prokoph[52], M. Prouza[33], H. Przybilski[101], E. Pueschel[52], G. Pühlhofer[69], I. Puljak[150], M.L. Pumo[94], M. Punch[85,57], F. Queiroz[203], J. Quinn[204], A. Quirrenbach[170], S. Rainò[149], P.J. Rajda[175], R. Rando[55], S. Razzaque[205], E. Rebert[20], S. Recchia[85], P. Reichherzer[59], O. Reimer[163], A. Reimer[163], A. Reisenegger[3,206], Q. Remy[53], M. Renaud[39], T. Reposeur[106], B. Reville[53], J.-M. Reymond[75], J. Reynolds[15], W. Rhode[46], D. Ribeiro[9], M. Ribó[81], G. Richards[162], T. Richtler[196], J. Rico[41], F. Rieger[53], L. Riitano[135], V. Ripepi[84], M. Riquelme[192], D. Riquelme[35], S. Rivoire[39], V. Rizi[18], E. Roache[63], B. Röben[159], M. Roche[106], J. Rodriguez[4], G. Rodriguez Fernandez[25], J.C. Rodriguez Ramirez[19], J.J. Rodríguez Vázquez[113], F. Roepke[170], G. Rojas[207], L. Romanato[55], P. Romano[95], G. Romeo[29], F. Romero Lobato[11], C. Romoli[53], M. Roncadelli[103], S. Ronda[30], J. Rosado[11], A. Rosales de Leon[5], G. Rowell[118], B. Rudak[49], A. Rugliancich[74], J.E. Ruíz del Mazo[12], W. Rujopakarn[31], C. Rulten[5], C. Russell[3], F. Russo[21], I. Sadeh[52], E. Sæther Hatlen[10], S. Safi-Harb[37], L. Saha[11], P. Saha[208], V. Sahakian[147], S. Sailer[53], T. Saito[2], N. Sakaki[54], S. Sakurai[2], F. Salesa Greus[101], G. Salina[25], H. Salzmann[69], D. Sanchez[45], M. Sánchez-Conde[14], H. Sandaker[10], A. Sandoval[16], P. Sangiorgi[91], M. Sanguillon[39], H. Sano[2], M. Santander[171], A. Santangelo[69], E.M. Santos[202], R. Santos-Lima[19], A. Sanuy[81], L. Sapozhnikov[96], T. Saric[150], S. Sarkar[114], H. Sasaki[157], N. Sasaki[179], K. Satalecka[52], Y. Sato[209], F.G. Saturni[28], M. Sawada[54], U. Sawangwit[31], J. Schaefer[142], A. Scherer[3], J. Scherpenberg[105], P. Schipani[84], B. Schleicher[122], J. Schmoll[5], M. Schneider[143], H. Schoorlemmer[53], P. Schovanek[33], F. Schussler[89], B. Schwab[142], U. Schwanke[186], J. Schwarz[95], T. Schweizer[105], E. Sciacca[29], S. Scuderi[61], M. Seglar Arroyo[45], A. Segreto[91], I. Seitenzahl[43], D. Semikoz[85], O. Sergijenko[136], J.E. Serna Franco[16], M. Servillat[20], K. Seweryn[201], V. Sguera[21], A. Shalchi[37], R.Y. Shang[71], P. Sharma[73], R.C. Shellard[40], L. Sidoli[61], J. Sieiro[81], H. Siejkowski[152], J. Silk[114], A. Sillanpää[65], B.B. Singh[109], K.K. Singh[210], A. Sinha[39], C. Siqueira[80], G. Sironi[95], J. Sitarek[60], P. Sizun[75], V. Sliusar[38], A. Slowikowska[178], D. Sobczyńska[60], R.W. Sobrinho[184], H. Sol[20], G. Sottile[91], H. Spackman[114], A. Specovius[142], S. Spencer[114], G. Spengler[186], D. Spiga[95], A. Spolon[55], W. Springer[164], A. Stamerra[28], S. Stanič[68], R. Starling[124], Ł. Stawarz[169], R. Steenkamp[48], S. Stefanik[197], C. Stegmann[128], A. Steiner[52], S. Steinmassl[53], C. Stella[103], C. Steppa[128], R. Sternberger[52], M. Sterzel[152], C. Stevens[135], B. Stevenson[71], T. Stolarczyk[4], G. Stratta[21], U. Straumann[208], J. Strišković[166], M. Strzys[2], R. Stuik[174], M. Suchenek[211], Y. Suda[140], Y. Sunada[179], T. Suomijarvi[73], T. Suric[212], P. Sutcliffe[153], H. Suzuki[213], P. Świerk[101], T. Szepieniec[152], A. Tacchini[21], K. Tachihara[141], G. Tagliaferri[95], H. Tajima[139], N. Tajima[2], D. Tak[52], K. Takahashi[214], H. Takahashi[140], M. Takahashi[2], M. Takahashi[2], J. Takata[2], R. Takeishi[2], T. Tam[2], M. Tanaka[182], T. Tanaka[213], S. Tanaka[209], D. Tateishi[179], M. Tavani[99], F. Tavecchio[95], T. Tavernier[89], L. Taylor[135], A. Taylor[52], L.A. Tejedor[11], P. Temnikov[189], Y. Terada[179], K. Terauchi[180], J.C. Terrazas[192], R. Terrier[85], T. Terzic[121], M. Teshima[105,2], V. Testa[28], D. Thibaut[85], F. Thocquenne[75], W. Tian[2], L. Tibaldo[87], A. Tiengo[215], D. Tiziani[142], M. Tluczykont[50], C.J. Todero Peixoto[102], F. Tokanai[154], K. Toma[160], L. Tomankova[142], J. Tomastik[104], D. Tonev[189], M. Tornikoski[216], D.F. Torres[13], E. Torresi[21], G. Tosti[95], L. Tosti[23], T. Totani[51], N. Tothill[117], F. Toussenel[79], G. Tovmassian[16], P. Travnicek[33], C. Trichard[8], M. Trifoglio[21], A. Trois[95], S. Truzzi[62], A. Tsiahina[87], T. Tsuru[180], B. Turk[45], A. Tutone[91], Y. Uchiyama[161], G. Umana[29], P. Utayarat[31], L. Vaclavek[104], M. Vacula[104], V. Vagelli[23,217], F. Vagnetti[25], F. Vakili[218], J.A. Valdivia[192], M. Valentino[24], A. Valio[19], B. Vallage[89], P. Vallania[44,64], J.V. Valverde Quispe[8], A.M. Van den Berg[42], W. van Driel[20], C. van Eldik[142], C. van Rensburg[1], B. van Soelen[210], J. Vandenbroucke[135], J. Vanderwalt[1], G. Vasileiadis[39], V. Vassiliev[71], M. Vázquez Acosta[32], M. Vecchi[42], A. Vega[98], J. Veh[142], P. Veitch[118], P. Venault[75], C. Venter[1], S. Ventura[62], S. Vercellone[95], S. Vergani[20], V. Verguilov[189], G. Verna[27], S. Vernetto[44,64], V. Verzi[25], G.P. Vettolani[90], C. Veyssiere[144], I. Viale[55], A. Viana[80], N. Viaux[35], J. Vicha[33], J. Vignatti[35], C.F. Vigorito[64,108], J. Villanueva[98], J. Vink[174], V. Vitale[23], V. Vittorini[99], V. Vodeb[68], H. Voelk[53], N. Vogel[142], V. Voisin[79], S. Vorobiov[68], I. Vovk[2], M. Vrastil[33], T. Vuillaume[45], S.J. Wagner[170], R. Wagner[105], P. Wagner[52], K. Wakazono[139], S.P. Wakely[127], R. Walter[38], M. Ward[5], D. Warren[54], J. Watson[52], N. Webb[87], M. Wechakama[31], P. Wegner[52], A. Weinstein[129], C. Weniger[174], F. Werner[53], H. Wetteskind[105], M. White[118], R. White[53], A. Wierzcholska[101], S. Wiesand[52], R. Wijers[174], M. Wilkinson[124], M. Will[105], D.A. Williams[143], J. Williams[124], T. Williamson[162], A. Wolter[95], Y.W. Wong[142], M. Wood[96], C. Wunderlich[62], T. Yamamoto[213], H. Yamamoto[141], Y. Yamane[141], R. Yamazaki[209], S. Yanagita[176], L. Yang[205], S. Yoo[180], T. Yoshida[176], T. Yoshikoshi[2], P. Yu[71], P. Yu[85], A. Yusafzai[59], M. Zacharias[20], G. Zaharijas[68], B. Zaldivar[14], L. Zampieri[76], R. Zanmar Sanchez[29], D. Zaric[150], M. Zavrtanik[68], D. Zavrtanik[68], A.A. Zdziarski[49], A. Zech[20], H. Zechlin[64], A. Zenin[139], A. Zerwekh[35], V.I. Zhdanov[136], K. Ziętara[169], A. Zink[142], J. Ziółkowski[49], V. Zitelli[21], M. Živec[68], A. Zmija[142]

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 Bellaterrra (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 Vallés, 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 Fisica d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Campus UAB, 08193 Bellaterra (Barcelona), Spain
42 : Kapteyn Astronomical Institute, University of Groningen, P.O. Box 800, 9700 AV 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 Lódź, ul. Pomorska 149-153, 90-236 Lódź, 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 Moiariello 16, 80131 Napoli, Italy
85 : Université de Paris, CNRS, Astroparticule et Cosmologie, 10, rue Alice Domon et Léonie Duquet, 75013 Paris Cedex 13, France
86 : Astronomy Department of Faculty of Physics, Sofia University, 5 James Bourchier Str., 1164 Sofia, Bulgaria
87 : Institut de Recherche en Astrophysique et Planétologie, CNRS-INSU, Université Paul Sabatier, 9 avenue Colonel Roche, BP 44346, 31028 Toulouse Cedex 4, France
88 : School of Physics and Astronomy, University of Minnesota, 116 Church Street S.E. Minneapolis, Minnesota 55455-0112, USA
89 : IRFU, CEA, Université Paris-Saclay, Bât 141, 91191 Gif-sur-Yvette, France
90 : INAF - Istituto di Radioastronomia, Via Gobetti 101, 40129 Bologna, Italy
91 : INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica di Palermo, Via U. La Malfa 153, 90146 Palermo, Italy
92 : Astronomical Observatory, Department of Physics, University of Warsaw, Aleje Ujazdowskie 4, 00478 Warsaw, Poland
93 : Armagh Observatory and Planetarium, College Hill, Armagh BT61 9DG, United Kingdom
94 : INFN Sezione di Catania, Via S. Sofia 64, 95123 Catania, Italy
95 : INAF - Osservatorio Astronomico di Brera, Via Brera 28, 20121 Milano, Italy
96 : Kavli Institute for Particle Astrophysics and Cosmology, Department of Physics and SLAC National Accelerator Laboratory, Stanford University, 2575 Sand Hill Road, Menlo Park, CA 94025, USA
97 : Universidade Cruzeiro do Sul, Núcleo de Astrofísica Teórica (NAT/UCS), Rua Galvão Bueno 8687, Bloco B, sala 16, Libertade 01506-000 - São Paulo, Brazil
98 : Universidad de Valparaíso, Blanco 951, Valparaiso, 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 - Universitá 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 : Universitá 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 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 Sołtana7, 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. Boskovica 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, Universitá 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