UNIVERSITY OF AMSTERDAM

UvA-DARE (Digital Academic Repository)

Joint searches by FACT, H.E.S.S., MAGIC and VERITAS for VHE gamma-ray emission associated with neutrinos detected by IceCube

Schüssler, F.; Ashkar, H.; Bernardini, E.; Berti, A.; Bradascio, F.; Buson, S.; Dorner, D.; Jin, W.; Kukec Mezek, G.; Santander, M.; Satalecka, K.; Schleicher, B.; Senniappan, M.; Viale, I.; FACT Collaboration; H.E.S.S. Collaboration; IceCube Collaboration; MAGIC Collaboration; VERITAS Collaboration

DOI
10.22323/1.444.1501

Publication date
2024

Document Version
Final published version

Published in
Proceedings of Science

License
CC BY-NC-ND

Link to publication

Citation for published version (APA):
Schüssler, F., Ashkar, H., Bernardini, E., Berti, A., Bradascio, F., Buson, S., Dorner, D., Jin, W., Kukec Mezek, G., Santander, M., Satalecka, K., Schleicher, B., Senniappan, M., Viale, I., FACT Collaboration, H.E.S.S. Collaboration, IceCube Collaboration, MAGIC Collaboration, & VERITAS Collaboration (2024). Joint searches by FACT, H.E.S.S., MAGIC and VERITAS for VHE gamma-ray emission associated with neutrinos detected by IceCube. *Proceedings of Science*, *444*, Article 1501. https://doi.org/10.22323/1.444.1501

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, P.O. Box 19185, 1000 GD Amsterdam, The Netherlands. You will be contacted as soon as possible.

UvA-DARE is a service provided by the library of the University of Amsterdam (https://dare.uva.nl)

Download date:13 Oct 2026

PROCEEDINGS OF SCIENCE

Joint searches by FACT, H.E.S.S., MAGIC and VERITAS for VHE gamma-ray emission associated with neutrinos detected by IceCube

Fabian Schüssler,[a,*] **H. Ashkar,**[b] **E. Bernardini,**[c] **A. Berti,**[d] **F. Bradascio,**[a] **S. Buson,**[e] **D. Dorner,**[e,f] **W. Jin,**[g] **G. Kukec Mezek,**[h] **M. Santander,**[g] **K. Satalecka,**[i] **B. Schleicher,**[e,f] **M. Senniappan**[h] **and I. Viale**[c] **on behalf of the FACT, Fermi-LAT, H.E.S.S., IceCube, MAGIC and VERITAS collaborations**

[a] *IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*

[b] *Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS, Institut Polytechnique de Paris, Palaiseau, France*

[c] *Dipartimento di Fisica e Astronomia dell'Università and Sezione INFN, Padova, Italy, Padova, Italy*

[d] *Max-Planck-Institut für Physik, München, München, Germany*

[e] *Julius-Maximilians-Universität Würzburg, Fakultät für Physik und Astronomie, Institut für Theoretische Physik und Astrophysik, Lehrstuhl für Astronomie, Emil-Fischer-Str. 31, D-97074 Würzburg, Germany*

[f] *ETH Zurich, Institute for Particle Physics and Astrophysics, Otto-Stern-Weg 5, 8093 Zürich, Switzerland*

[g] *Department of Physics and Astronomy, University of Alabama, Tuscaloosa, Alabama, USA*

[h] *Department of Physics and Electrical Engineering, Linnaeus University, Växjö, Sweden*

[i] *Deutsches Elektronen-Synchrotron (DESY), Zeuthen, Germany*

E-mail: fabian.schussler@cea.fr

*Speaker

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

PoS(ICRC2023)1501

The sources of the astrophysical flux of high-energy neutrinos detected by IceCube are still largely unknown, but searches for temporal and spatial correlation between neutrinos and electromagnetic radiation are a promising approach in this endeavor. All major imaging atmospheric Cherenkov telescopes (IACTs) - FACT, H.E.S.S., MAGIC, and VERITAS - operate an active follow-up program of target-of-opportunity observations of neutrino alerts issued by IceCube. These programs use several complementary neutrino alert streams. A publicly distributed alert stream is formed by individual high-energy neutrino candidate events of potentially astrophysical origin, such as IceCube-170922A (which could be linked to the flaring blazar TXS 0506+056). A privately distributed alert stream is formed by clusters of neutrino events in time and space around either pre-selected gamma-ray sources or anywhere in the sky. Here, we present joint searches for multi-wavelength emission associated with a set of IceCube alerts, both private and public, received through mid-January 2021. We will give an overview of the programs of the participating IACTs. We will showcase the various follow-up and data analysis strategies employed in response to the different alert types and various possible counterpart scenarios. Finally, we will present results from a combined analysis of the VHE gamma-ray observations obtained across all involved instruments, as well as relevant multi-wavelength data.

PoS(ICRC2023)1501

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan

1. Introduction

All currently operating imaging atmospheric Cherenkov telescopes (IACTs): FACT [1], H.E.S.S. [2], MAGIC [3] and VERITAS [4] operate observational programs in cooperation with IceCube. These target-of-opportunity (ToO) follow-up observations aim at identifying potential gamma-ray emission associated to the detected neutrino events. The programs can be broadly divided into two categories, depending on the type of IceCube neutrino alert that triggered the ToO observations. The first involves following up on individual high-energy (>60 TeV) neutrino events that are likely of astrophysical origin, referred to as "singlets." These singlets are openly broadcasted by IceCube through AMON [5] via the NASA's General Coordinates Network (GCN)[1] on two streams, "GOLD" and "BRONZE", with an average astrophysical probability per event of 50% and 30%, respectively. IceCube has recently released a catalog of singlets of likely astrophysical origin up to December 2020 [6]. The second type involves conducting follow-up observations of known gamma-ray sources for which IceCube has detected a cluster of candidate neutrino events, typically with energies around $\sim$ 1 TeV, over a specific time period, known as "multiplets." These alerts are privately distributed by IceCube to individual IACTs under mutual agreements in the framework of the Gamma-ray Follow-Up (GFU) program [7].

Single-event alerts have a typical localization uncertainty of approximately 1°. This aligns well with the standard field of view (FOV) of imaging atmospheric Cherenkov telescopes (IACTs), which ranges from 3.5 to 5°. Often, potential neutrino source candidates can be found within the region of interest (ROI) defined by the uncertainty of the neutrino localization. These candidates may include previously identified objects such as active galactic nuclei (AGN) like TXS 0506+056 from the *Fermi*-LAT and IACT catalogs, or transient sources detected by other electromagnetic (EM) observatories. In such cases, observations are typically focused on these objects. However, in the absence of pre-identified promising candidates, the searches generally aim to cover the entire ROI indicated by the neutrino localization uncertainty.

On the other hand, the primary objective of the GFU multiplet alerts is to notify the IACTs of neutrino flares from the direction of known gamma-ray emitters. The duration of these flares is not predetermined and can span from seconds to 180 days. Since the associated source of the alert is already known and identified as a GeV and/or TeV emitter, the IACT observations aim to determine possible changes to the state of the source (e.g., quiescence vs. flaring or spectral changes). In its current configuration, a GFU multiplet alert is sent to the participating IACT if the statistical significance of the identified neutrino excess is greater than a predefined threshold, typically 3σ before accounting for statistical trials.

The directions of the alerts sent by IceCube as neutrino event "singlets" and GFU neutrino *flares* between October 2017 and January 2021 are illustrated on a skymap in Figure 1. In the covered time period, the IACTs observed 11 of the 62 single-event alerts sent by IceCube. In the framework of the GFU program, IceCube sent 27 neutrino *flare* alerts from 17 sources, of which seven, including one "all-sky alert", were observed. Here, we do not attempt to report a comprehensive summary of these alerts and follow-up observations, but rather will present a few examples and highlights to illustrate the various programs.

[1] https://gcn.nasa.gov/

PoS(ICRC2023)1501

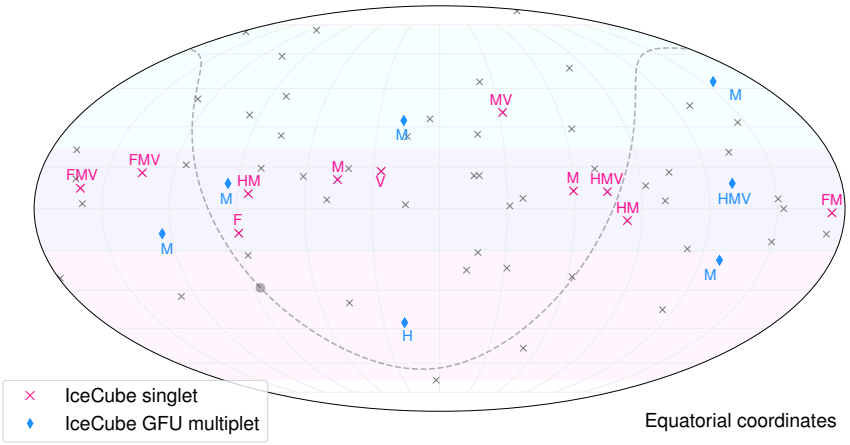

Figure 1: Sky map in equatorial coordinates showing IceCube alert positions observed by IACTs between October 2017 and January 2021 (in color, according to the alert type), and those not followed-up during the same period shown in gray. Letters indicate which IACTs participated in the observations (F - FACT, H - H.E.S.S., M - MAGIC, V - VERITAS). Light cyan and magenta bands indicate regions of the sky potentially observable at a zenith distance below 45° from the Northern (FACT, MAGIC, VERITAS) and Southern (H.E.S.S.) IACTs, respectively. The visibility windows for instruments in both hemispheres overlap around the celestial equator, where the IceCube sensitivity to neutrinos in the $\sim$ 100 TeV-energy-range is maximal.

2. Follow-up of neutrino multiplets: 1ES 1312-423

The blazar known as 1ES 1312-423, located approximately 2 degrees away from the Centaurus A (CenA) radio galaxy, has a redshift of z = 0.105 ± 0.001 [8]. Between April 2004 and July 2010, it has been observed by H.E.S.S. as part of the deep observation of Cen A, collecting a total exposure time of 150.6 h centered on CenA. This archival dataset revealed a power-law fit to the differential energy spectrum $\phi(E) = \mathrm{d}N/\mathrm{d}E$ of the VHE gamma-ray emission above 280 GeV. The best-fitting parameters obtained were $\Gamma = 2.85 \pm 0.47(\mathrm{stat}) \pm 0.20(\mathrm{sys})$ for the spectral index and a differential flux at 1 TeV of $\phi(1\ \mathrm{TeV}) = (1.89 \pm 0.58(\mathrm{stat}) \pm 0.39(\mathrm{sys})) \times 10^{-13}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{TeV}^{-1}$ [9].

Due to its Southern location 1ES 1312-423 is only part of the H.E.S.S. GFU program. On March 12, 2019, IceCube reported the detection of a short neutrino flare lasting 6.24 h from this source. H.E.S.S. conducted observations of the source for a total of 2.6 h over two nights on March 12 and 13, 2019. 1ES 1312-423 was detected above 140 GeV with a significance of 4σ. This is the only detection of VHE gamma rays in any of the ToO campaigns conducted by the IACTs in the time period covered here. Again applying a power-law fit, the best-fit parameters $\Gamma = 2.73 \pm 0.27(\mathrm{stat}) \pm 0.20(\mathrm{sys})$ for the spectral index and $\phi(1\ \mathrm{TeV}) = (5.83 \pm 3.2(\mathrm{stat}) \pm 0.4(\mathrm{sys})) \times 10^{-12}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{TeV}^{-1}$ for the differential flux at 1 TeV were obtained. A comparison of the spectral energy distribution (SED) with the archival dataset is shown in Figure 2, along with the results obtained from dedicated observations by *Swift* (UV + X-rays) and ATOM (optical). Although some variations are observed in the X-ray and UV domains, no clear change in the state of 1ES 1312-423 could be identified in this neutrino-triggered ToO.

PoS(ICRC2023)1501

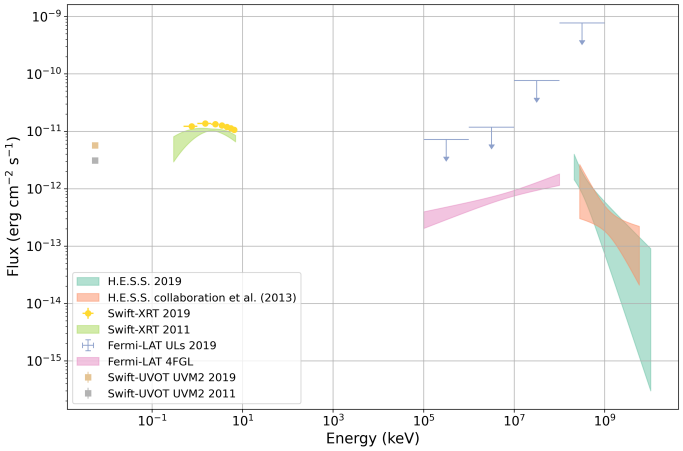

Figure 2: 1ES 1312-423 MWL SED showing archival data and observations obtained during the period following the GFU neutrino alert and contemporaneous to H.E.S.S. ToO observations.

3. Follow-up of neutrino singlets: IceCube-201114A + IceCube-171106A

IceCube reported the detection of a track-like neutrino event classified as a GOLD alert on November 14th, 2020. The event had an energy of 214 TeV and a probability to be of astrophysical origin of 0.56. Its false alert rate was determined to be 0.92 per year. The refined direction of the alert was determined to be RA: 105.25° (+1.28°, −1.12°, 90% PSF containment) and Dec: 6.05° (+0.95° −0.95°, 90% PSF containment). The position of the neutrino event is compatible with the blazar NVSS J065844+063711, also known as the Fermi source 4FGL J0658.6+0636 (RA: 104.64°, Dec: 6.60°). A map of the region is shown in Figure 5.

The event was observed by H.E.S.S., MAGIC, and VERITAS. H.E.S.S. collected 14.3 hours of data during an observation campaign conducted from November 18th to November 25th, 2020, and from December 10th, 2020, to December 11th, 2020. No significant emission was detected in the ROI, and integral upper limits on the VHE gamma-ray flux were derived at the position of NVSS J065844+063711 as 5.37×10^{-13} cm^{-2} s^{-1} above 326 GeV. The MAGIC telescopes observed the direction of NVSS J065844+063711 on November 16th, 17th, and from November 19th to 25th, 2020. The 6 h of data did not result in a detection. The integral flux upper limit was calculated above an energy threshold of 120 GeV to be 8.39×10^{-10} cm^{-2} s^{-1}. VERITAS conducted observations from November 15th to November 19th, 2020, collecting approximately 7 hours of quality-selected observation data. No detection was made at the location indicated by the IceCube neutrino event or elsewhere in the VERITAS field of view. The integral flux upper limit above an energy threshold of 200 GeV at the position of the blazar NVSS J065844+063711 was determined to be 1.37×10^{-12} cm^{-2} s^{-1}.

The profile maximum likelihood approach described in [10] is employed to generate combined flux upper limits across all IACTs. For this purpose, all collaborations utilized the same energy binning, dividing the VHE range between 71 GeV and 71 TeV into four bins per decade. We used the Rolke method [11] with a confidence level set to 95%, and including a 30% global systematic uncertainty in the efficiency of the applied cuts. Upper limits were calculated considering an

PoS(ICRC2023)1501

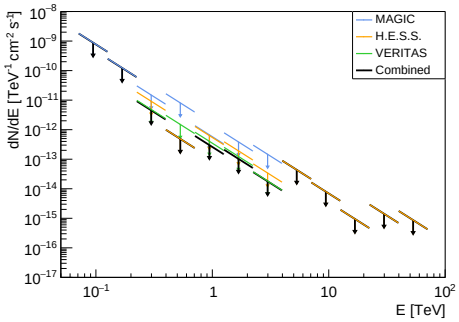

Figure 3: Combined differential flux upper limits on the VHE gamma-ray flux (black arrows) obtained from observations of IceCube-201114A by multiple IACTs (colored arrows).

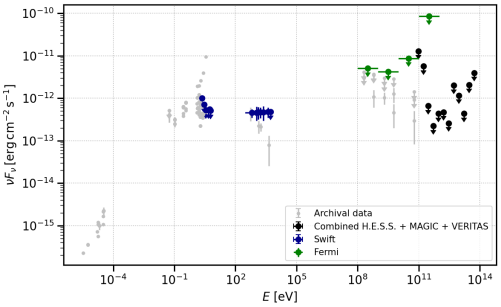

Figure 4: Multi-wavelength spectal energy distribution for NVSS J065844+063711 (4FGL J0658.6+0636) within the localisation uncertainty of IceCube-201114A.

observed spectrum modeled by a power law $\mathrm{d}N/\mathrm{d}E = KE^{-\Gamma}$ with index $\Gamma = 2.5$. The individual as well the combined upper limits at the position of of the blazar NVSS J065844+063711 are shown in Figure 3.

Complementing the VHE gamma-ray observations, *Swift*-XRT observations were triggered on November 15th, 2020. They revealed a slight increase in the X-ray flux around the time of the neutrino emission compared to previous observations in May 2012. The X-ray flux level remained relatively consistent until December 11th, 2020. A full MWL SED is shown in Figure 4.

Single-event public IceCube alerts are characterized by relatively large localization errors (~ 0.5 degree to a few degrees at 50% confidence level). As a consequence, the exact localization of the neutrino origin can not be pin-pointed to any point-source with high accuracy. Therefore, we derive sky maps containing the integral gamma-ray flux upper limits and covering the neutrino arrival localization uncertainty. Dedicated searches for a variety of possible source candidates in this region are thus possible. Examples for these upper limit maps are given in Figure 5 and Figure 6. The latter has been derived above an energy threshold of 350 GeV from about 2.5 hours of quality-selected observation data taken by VERITAS between November 13 to November 20, 2017. This ToO, that was also followed by MAGIC and FACT, was triggered following the detection of IceCube-171106A on November 6th, 2017, an event with an energy of 230 TeV and a signalness indicating the probability of the event to be of astrophysical origin of 75%.

4. Conclusions

Figure 7 shows the delay and exposure of the IACT observations of single-event alerts and GFU neutrino flares between October 2017 and January 2021. The delay is derived from the detection time of the neutrino event (for single events) or the threshold crossing time of the flare (for multiplets) up to the start of IACT observation.

From this overview, several general trends in the follow-up strategies can be inferred. Approximately 50% of the cases achieve a reaction within one day, while observations conducted more than one week after the trigger are rare. The total time allocated to the follow-up of public IceCube alerts is comparable across all collaborations, amounting to approximately 20 hours for the covered

PoS(ICRC2023)1501

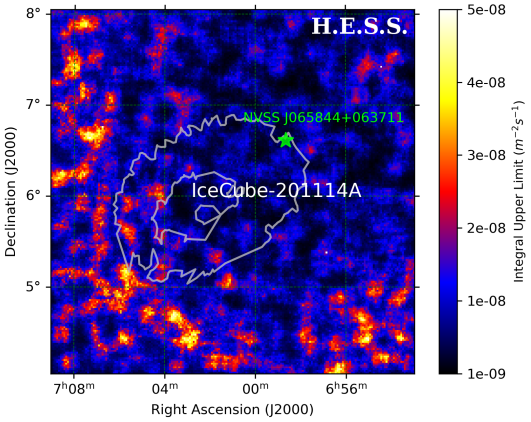

Figure 5: Integral upper limits on the VHE gamma-ray flux above 307 GeV derived from the H.E.S.S. observations of IceCube-201114A. The observations were centered around the location of NVSS J065844+063711, indicated by the green star. The grey lines denote the 50% (90%) contours of the localization of the event by IceCube.

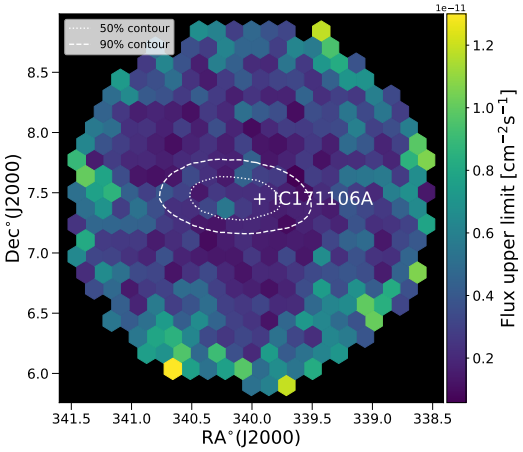

Figure 6: Map of integral upper limits of the VHE gamma-ray flux derived from the VERITAS observations of IceCube-171106A above an energy threshold of 350 GeV. The dashed lines denote the 50% (90%) contours of the localization of the event by IceCube.

period. However, there are differences in the approaches taken. H.E.S.S., and VERITAS primarily focus on longer exposures for a few selected alerts, whereas MAGIC conducts a larger number of follow-ups with shorter average exposure. Similar trends are observed for GFU neutrino alerts.

The geographic distribution of the IACTs in terms of latitude has facilitated complete coverage of the entire sky, encompassing both the Northern and Southern hemispheres. Moreover, the observatories' locations in longitude have expanded the field of regard of the combined network of IACTs, thereby increasing the likelihood of promptly conducting follow-up observations. This is particularly crucial in cases where observability from a single observatory site is restricted due to factors such as adverse weather conditions, the presence of the sun or moon, or technical issues. This aspect holds significant importance, as it enables the observation of VHE gamma rays associated with rare transient neutrino candidate events. It also allows for the exploration of other time-domain or multi-messenger triggers, as exemplified by follow-up observations of gravitational wave events (e.g., GW170817A) or gamma-ray bursts (e.g., VHE-detected GRBs and GRB 221009A). These examples underscore the value of conducting joint analyses, as presented here, to fully leverage the capabilities and strengths of the collective observatory network.

References

[1] A. Biland et al. (FACT Collaboration). Calibration and performance of the photon sensor response of FACT – The First G-APD Cherenkov telescope. *JINST*, 9(10):P10012, 2014.

[2] F. Aharonian et al. (H.E.S.S. Collaboration). Observations of the Crab nebula with HESS. *Astronomy & Astrophysics*, 457(3):899–915, October 2006.

PoS(ICRC2023)1501

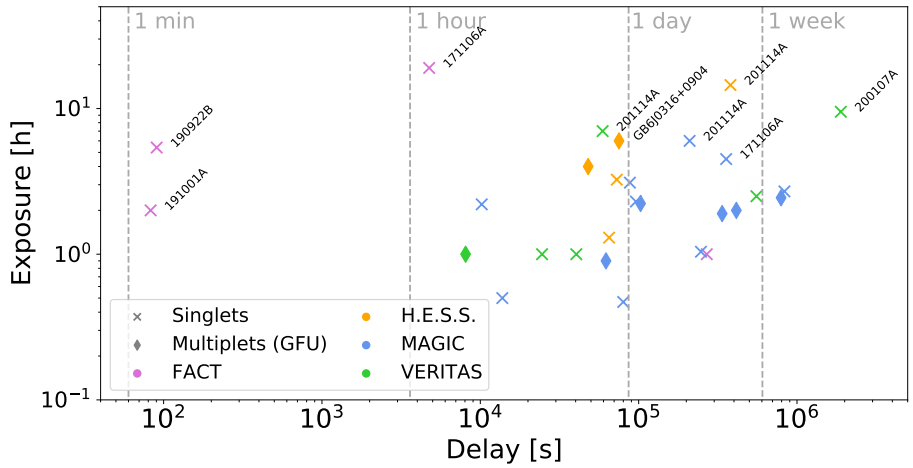

Figure 7: Delay vs exposure times for IACT follow-up of neutrino alerts from October 2017 until December 2020. The delay is calculated from the neutrino event arrival time (single events) or flare threshold crossing time (multiplets) up to the start of the IACT observation. Highlighted are observations performed with a start delay less than 100 s or with a total exposure longer than 4 h. Marker color represents the IACT observing while the marker type represents the alert type.

[3] J. Aleksić et al. (MAGIC Collaboration). Performance of the MAGIC stereo system obtained with Crab Nebula data. *Astroparticle Physics*, 35(7):435–448, February 2012.

[4] J. Holder et al. (VERITAS Collaboration). The first VERITAS telescope. *Astropart. Phys.*, 25:391–401, 2006.

[5] Hugo Alberto Ayala Solares. AMON Multimessenger Alerts: Past and Future. *Galaxies*, 7(1):19, 2019.

[6] R. Abbasi et al. (IceCube Collaboration). IceCat-1: the IceCube Event Catalog of Alert Tracks. 4 2023.

[7] M. G. Aartsen et al. (IceCube Collaboration). Very high-energy gamma-ray follow-up program using neutrino triggers from IceCube. *J. Instrum.*, 11(11):P11009, November 2016.

[8] L. S. Mao. 2MASS observation of BL Lac objects II. , 16(8):503–529, December 2011.

[9] A. Abramowski et al. (HESS Collaboration). HESS and Fermi-LAT discovery of gamma-rays from the blazar 1ES 1312-423. , 434(3):1889–1901, September 2013.

[10] H. Abe et al. Gamma-ray observations of MAXI J1820+070 during the 2018 outburst. *Mon. Not. Roy. Astron. Soc.*, 517(4):4736–4751, 2022.

[11] J. Lundberg, J. Conrad, W. Rolke, and A. Lopez. Limits, discovery and cut optimization for a poisson process with uncertainty in background and signal efficiency: Trolke 2.0. *Computer Physics Communications*, 181(3):683–686, Mar 2010.

PoS(ICRC2023)1501

Full Author List: FACT Collaboration

J. Abhir [1], D. Baack[2], M. Balbo [3], A. Biland [1], K. Brand [4], T. Bretz [1] [a], J. Buss [2], D. Dorner [1,4], L. Eisenberger [4], D. Elsaesser [2], P. Günther [4], D. Hildebrand [1], K. Mannheim [4], M. Noethe [2], A. Paravac [4], W. Rhode [2], B. Schleicher [1,4], V. Sliusar [3], S. Hasan [1], R. Walter [3]

[1] ETH Zurich, Institute for Particle Physics and Astrophysics, Otto-Stern-Weg 5, 8093 Zürich, Switzerland
[2] TU Dortmund, Experimental Physics 5, Otto-Hahn-Str. 4a, 44227 Dortmund, Germany
[3] University of Geneva, Department of Astronomy, Chemin d'Ecogia 16, 1290 Versoix, Switzerland
[4] Julius-Maximilians-Universität Würzburg, Fakultät für Physik und Astronomie, Institut für Theoretische Physik und Astrophysik, Lehrstuhl für Astronomie, Emil-Fischer-Str. 31, D-97074 Würzburg, Germany
[a] also at RWTH Aachen University

Acknowledgements

The important contributions from ETH Zurich grants ETH-10.08-2 and ETH-27.12-1 as well as the funding by the Swiss SNF and the German BMBF (Verbundforschung Astro- und Astroteilchenphysik) and HAP (Helmoltz Alliance for Astroparticle Physics) are gratefully acknowledged. Part of this work is supported by Deutsche Forschungsgemeinschaft (DFG) within the Collaborative Research Center SFB 876 "Providing Information by Resource-Constrained Analysis", project C3. We are thankful for the very valuable contributions from E. Lorenz, D. Renker and G. Viertel during the early phase of the project. We thank the Instituto de Astrofísica de Canarias for allowing us to operate the telescope at the Observatorio del Roque de los Muchachos in La Palma, the Max-Planck-Institut für Physik for providing us with the mount of the former HEGRA CT3 telescope, and the MAGIC collaboration for their support.

PoS(ICRC2023)1501

Full Author List: H.E.S.S. Collaboration

F. Aharonian[1,2,3], F. Ait Benkhali[4], A. Alkan[5], J. Aschersleben[6], H. Ashkar[7], M. Backes[8,9], A. Baktash[10], V. Barbosa Martins[11], A. Barnacka[12], J. Barnard[13], R. Batzofin[14], Y. Becherini[15,16], G. Beck[17], D. Berge[11,18], K. Bernlöhr[2], B. Bi[19], M. Böttcher[9], C. Boisson[20], J. Bolmont[21], M. de Bony de Lavergne[5], J. Borowska[18], M. Bouyahiaoui[2], F. Bradascio[5], M. Breuhaus[2], R. Brose[1], A. Brown[22], F. Brun[5], B. Bruno[23], T. Bulik[24], C. Burger-Scheidlin[1], T. Bylund[5], F. Cangemi[21], S. Caroff[25], S. Casanova[26], R. Cecil[10], J. Celic[23], M. Cerruti[15], P. Chambery[27], T. Chand[9], S. Chandra[9], A. Chen[17], J. Chibueze[9], O. Chibueze[9], T. Collins[28], G. Cotter[22], P. Cristofari[20], J. Damascene Mbarubucyeye[11], I.D. Davids[8], J. Davies[22], L. de Jonge[9], J. Devin[29], A. Djannati-Ataï[15], A. Dmytriiev[9], V. Doroshenko[19], L. Dreyer[9], L. Du Plessis[9], K. Egberts[14], S. Einecke[28], J.-P. Ernenwein[30], S. Fegan[7], K. Feijen[15], G. Fichet de Clairfontaine[20], G. Fontaine[7], F. Lott[8], M. Füßling[11], S. Funk[23], S. Gabici[15], Y.A. Gallant[29], S. Ghafourizadeh[4], G. Giavitto[11], L. Giunti[15,5], D. Glawion[23], J.F. Glicenstein[5], J. Glombitza[23], P. Goswami[15], G. Grolleron[21], M.-H. Grondin[27], L. Haerer[2], S. Hattingh[9], M. Haupt[11], G. Hermann[2], J.A. Hinton[2], W. Hofmann[2], T. L. Holch[11], M. Holler[31], D. Horns[10], Zhiqiu Huang[2], A. Jaitly[11], M. Jamrozy[12], F. Jankowsky[4], A. Jardin-Blicq[27], V. Joshi[23], I. Jung-Richardt[23], E. Kasai[8], K. Katarzyński[32], H. Katjaita[8], D. Khangulyan[33], R. Khatoon[9], B. Khélifi[15], S. Klepser[11], W. Kluźniak[34], Nu. Komin[17], R. Konno[11], K. Kosack[5], D. Kostunin[11], A. Kundu[9], G. Lamanna[25], R.G. Lang[23], S. Le Stum[30], V. Lefranc[5], F. Leitl[23], A. Lemière[15], M. Lemoine-Goumard[27], J.-P. Lenain[21], F. Leuschner[19], A. Luashvili[20], I. Lypova[4], J. Mackey[1], D. Malyshev[19], D. Malyshev[23], V. Marandon[5], A. Marcowith[29], P. Marinos[28], G. Martí-Devesa[31], R. Marx[4], G. Maurin[25], A. Mehta[11], P.J. Meintjes[13], M. Meyer[10], A. Mitchell[23], R. Moderski[34], L. Mohrmann[2], A. Montanari[4], C. Moore[35], E. Moulin[5], T. Murach[11], K. Nakashima[23], M. de Naurois[7], H. Ndiyavala[8,9], J. Niemiec[26], A. Priyana Noel[12], P. O'Brien[35], S. Ohm[11], L. Olivera-Nieto[2], E. de Ona Wilhelmi[11], M. Ostrowski[12], E. Oukacha[15], S. Panny[31], M. Panter[2], R.D. Parsons[18], U. Pensec[21], G. Peron[15], S. Pita[15], V. Poireau[25], D.A. Prokhorov[36], H. Prokoph[11], G. Pühlhofer[19], M. Punch[15], A. Quirrenbach[4], M. Regeard[15], P. Reichherzer[5], A. Reimer[31], O. Reimer[31], I. Reis[5], Q. Remy[2], H. Ren[2], M. Renaud[29], B. Reville[2], F. Rieger[2], G. Roellinghoff[23], E. Rol[36], G. Rowell[28], B. Rudak[34], H. Rueda Ricarte[5], E. Ruiz-Velasco[2], K. Sabri[29], V. Sahakian[3], S. Sailer[2], H. Salzmann[19], D.A. Sanchez[25], A. Santangelo[19], M. Sasaki[23], J. Schäfer[23], F. Schüssler[5], H.M. Schutte[9], M. Senniappan[16], J.N.S. Shapopi[8], S. Shilunga[8], K. Shiningayamwe[8], H. Sol[20], H. Spackman[22], A. Specovius[23], S. Spencer[23], Ł. Stawarz[12], R. Steenkamp[8], C. Stegmann[14,11], S. Steinmassl[2], C. Steppa[14], K. Streil[23], I. Sushch[9], H. Suzuki[37], T. Takahashi[38], T. Tanaka[37], T. Tavernier[5], A.M. Taylor[11], R. Terrier[15], A. Thakur[28], J. H.E. Thiersen[9], C. Thorpe-Morgan[19], M. Tluczykont[10], M. Tsirou[11], N. Tsuji[39], R. Tuffs[2], Y. Uchiyama[33], M. Ullmo[5], T. Unbehaun[23], P. van der Merwe[9], C. van Eldik[23], B. van Soelen[13], G. Vasileiadis[29], M. Vecchi[6], J. Veh[23], C. Venter[9], J. Vink[36], H.J. Völk[2], N. Vogel[23], T. Wach[23], S.J. Wagner[4], F. Werner[2], R. White[2], A. Wierzcholska[26], Yu Wun Wong[23], H. Yassin[9], M. Zacharias[4,9], D. Zargaryan[1], A.A. Zdziarski[34], A. Zech[20], S.J. Zhu[11], A. Zmija[23], S. Zouari[15] and N. Żywucka[9].

[1]Dublin Institute for Advanced Studies, 31 Fitzwilliam Place, Dublin 2, Ireland
[2]Max-Planck-Institut für Kernphysik, P.O. Box 103980, D 69029 Heidelberg, Germany
[3]Yerevan State University, 1 Alek Manukyan St, Yerevan 0025, Armenia
[4]Landessternwarte, Universität Heidelberg, Königstuhl, D 69117 Heidelberg, Germany
[5]IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
[6]Kapteyn Astronomical Institute, University of Groningen, Landleven 12, 9747 AD Groningen, The Netherlands
[7]Laboratoire Leprince-Ringuet, École Polytechnique, CNRS, Institut Polytechnique de Paris, F-91128 Palaiseau, France
[8]University of Namibia, Department of Physics, Private Bag 13301, Windhoek 10005, Namibia
[9]Centre for Space Research, North-West University, Potchefstroom 2520, South Africa
[10]Universität Hamburg, Institut für Experimentalphysik, Luruper Chaussee 149, D 22761 Hamburg, Germany
[11]DESY, D-15738 Zeuthen, Germany
[12]Obserwatorium Astronomiczne, Uniwersytet Jagielloński, ul. Orla 171, 30-244 Kraków, Poland
[13]Department of Physics, University of the Free State, PO Box 339, Bloemfontein 9300, South Africa
[14]Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Strasse 24/25, D 14476 Potsdam, Germany
[15]Université de Paris, CNRS, Astroparticule et Cosmologie, F-75013 Paris, France
[16]Department of Physics and Electrical Engineering, Linnaeus University, 351 95 Växjö, Sweden
[17]School of Physics, University of the Witwatersrand, 1 Jan Smuts Avenue, Braamfontein, Johannesburg, 2050 South Africa
[18]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, D 12489 Berlin, Germany
[19]Institut für Astronomie und Astrophysik, Universität Tübingen, Sand 1, D 72076 Tübingen, Germany
[20]Laboratoire Univers et Théories, Observatoire de Paris, Université PSL, CNRS, Université de Paris, 92190 Meudon, France
[21]Sorbonne Université, Université Paris Diderot, Sorbonne Paris Cité, CNRS/IN2P3, Laboratoire de Physique Nucléaire et de Hautes Energies, LPNHE, 4 Place Jussieu, F-75252 Paris, France
[22]University of Oxford, Department of Physics, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, UK
[23]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen Centre for Astroparticle Physics, Nikolaus-Fiebiger-Str. 2, D 91058 Erlangen, Germany
[24]Astronomical Observatory, The University of Warsaw, Al. Ujazdowskie 4, 00-478 Warsaw, Poland
[25]Université Savoie Mont Blanc, CNRS, Laboratoire d'Annecy de Physique des Particules - IN2P3, 74000 Annecy, France
[26]Instytut Fizyki Jądrowej PAN, ul. Radzikowskiego 152, 31-342 Kraków, Poland
[27]Université Bordeaux, CNRS, LP2I Bordeaux, UMR 5797, F-33170 Gradignan, France
[28]School of Physical Sciences, University of Adelaide, Adelaide 5005, Australia
[29]Laboratoire Univers et Particules de Montpellier, Université Montpellier, CNRS/IN2P3, CC 72, Place Eugène Bataillon, F-34095

PoS(ICRC2023)1501

Montpellier Cedex 5, France
[30]Aix Marseille Université, CNRS/IN2P3, CPPM, Marseille, France
[31]Leopold-Franzens-Universität Innsbruck, Institut für Astro- und Teilchenphysik, A-6020 Innsbruck, Austria
[32]Institute of Astronomy, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Grudziadzka 5, 87-100 Torun, Poland
[33]Department of Physics, Rikkyo University, 3-34-1 Nishi-Ikebukuro, Toshima-ku, Tokyo 171-8501, Japan
[34]Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, ul. Bartycka 18, 00-716 Warsaw, Poland
[35]Department of Physics and Astronomy, The University of Leicester, University Road, Leicester, LE1 7RH, United Kingdom
[36]GRAPPA, Anton Pannekoek Institute for Astronomy, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands
[37]Department of Physics, Konan University, 8-9-1 Okamoto, Higashinada, Kobe, Hyogo 658-8501, Japan
[38]Kavli Institute for the Physics and Mathematics of the Universe (WPI), The University of Tokyo Institutes for Advanced Study (UTIAS), The University of Tokyo, 5-1-5 Kashiwa-no-Ha, Kashiwa, Chiba, 277-8583, Japan
[39]RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan

Acknowledgements

The support of the Namibian authorities and of the University of Namibia in facilitating the construction and operation of H.E.S.S. is gratefully acknowledged, as is the support by the German Ministry for Education and Research (BMBF), the Max Planck Society, the Helmholtz Association, the French Ministry of Higher Education, Research and Innovation, the Centre National de la Recherche Scientifique (CNRS/IN2P3 and CNRS/INSU), the Commissariat à l'énergie atomique et aux énergies alternatives (CEA), the U.K. Science and Technology Facilities Council (STFC), the Irish Research Council (IRC) and the Science Foundation Ireland (SFI), the Polish Ministry of Education and Science, agreement no. 2021/WK/06, the South African Department of Science and Innovation and National Research Foundation, the University of Namibia, the National Commission on Research, Science & Technology of Namibia (NCRST), the Austrian Federal Ministry of Education, Science and Research and the Austrian Science Fund (FWF), the Australian Research Council (ARC), the Japan Society for the Promotion of Science, the University of Amsterdam and the Science Committee of Armenia grant 21AG-1C085. We appreciate the excellent work of the technical support staff in Berlin, Zeuthen, Heidelberg, Palaiseau, Paris, Saclay, Tübingen and in Namibia in the construction and operation of the equipment. This work benefited from services provided by the H.E.S.S. Virtual Organisation, supported by the national resource providers of the EGI Federation.

PoS(ICRC2023)1501

Full Author List: IceCube Collaboration

R. Abbasi[17], M. Ackermann[63], J. Adams[18], S. K. Agarwalla[40, 64], J. A. Aguilar[12], M. Ahlers[22], J.M. Alameddine[23], N. M. Amin[44], K. Andeen[42], G. Anton[26], C. Argüelles[14], Y. Ashida[53], S. Athanasiadou[63], S. N. Axani[44], X. Bai[50], A. Balagopal V.[40], M. Baricevic[40], S. W. Barwick[30], V. Basu[40], R. Bay[8], J. J. Beatty[20, 21], J. Becker Tjus[11, 65], J. Beise[61], C. Bellenghi[27], C. Benning[1], S. BenZvi[52], D. Berley[19], E. Bernardini[48], D. Z. Besson[36], E. Blaufuss[19], S. Blot[63], F. Bontempo[31], J. Y. Book[14], C. Boscolo Meneguolo[48], S. Böser[41], O. Botner[61], J. Böttcher[1], E. Bourbeau[22], J. Braun[40], B. Brinson[6], J. Brostean-Kaiser[63], R. T. Burley[2], R. S. Busse[43], D. Butterfield[40], M. A. Campana[49], K. Carloni[14], E. G. Carnie-Bronca[2], S. Chattopadhyay[40, 64], N. Chau[12], C. Chen[6], Z. Chen[55], D. Chirkin[40], S. Choi[56], B. A. Clark[19], L. Classen[43], A. Coleman[61], G. H. Collin[15], A. Connolly[20, 21], J. M. Conrad[15], P. Coppin[13], P. Correa[13], D. F. Cowen[59, 60], P. Dave[6], C. De Clercq[13], J. J. DeLaunay[58], D. Delgado[14], S. Deng[1], K. Deoskar[54], A. Desai[40], P. Desiati[40], K. D. de Vries[13], G. de Wasseige[37], T. DeYoung[24], A. Diaz[15], J. C. Díaz-Vélez[40], M. Dittmer[43], A. Domi[26], H. Dujmovic[40], M. A. DuVernois[40], T. Ehrhardt[41], P. Eller[27], E. Ellinger[62], S. El Mentawi[1], D. Elsässer[23], R. Engel[31, 32], H. Erpenbeck[40], J. Evans[19], P. A. Evenson[44], K. L. Fan[19], K. Fang[40], K. Farrag[16], A. R. Fazely[7], A. Fedynitch[57], N. Feigl[10], S. Fiedlschuster[26], C. Finley[54], L. Fischer[63], D. Fox[59], A. Franckowiak[11], A. Fritz[41], P. Fürst[1], J. Gallagher[39], E. Ganster[1], A. Garcia[14], L. Gerhardt[9], A. Ghadimi[58], C. Glaser[61], T. Glauch[27], T. Glüsenkamp[26, 61], N. Goehlke[32], J. G. Gonzalez[44], S. Goswami[58], D. Grant[24], S. J. Gray[19], O. Gries[1], S. Griffin[40], S. Griswold[52], K. M. Groth[22], C. Günther[1], P. Gutjahr[23], C. Haack[26], A. Hallgren[61], R. Halliday[24], L. Halve[1], F. Halzen[40], H. Hamdaoui[55], M. Ha Minh[27], K. Hanson[40], J. Hardin[15], A. A. Harnisch[24], P. Hatch[33], A. Haungs[31], K. Helbing[62], J. Hellrung[11], F. Henningsen[27], L. Heuermann[1], N. Heyer[61], S. Hickford[62], A. Hidvegi[54], C. Hill[16], G. C. Hill[2], K. D. Hoffman[19], S. Hori[40], K. Hoshina[40, 66], W. Hou[31], T. Huber[31], K. Hultqvist[54], M. Hünnefeld[23], R. Hussain[40], K. Hymon[23], S. In[56], A. Ishihara[16], M. Jacquart[40], O. Janik[1], M. Jansson[54], G. S. Japaridze[5], M. Jeong[56], M. Jin[14], B. J. P. Jones[4], D. Kang[31], W. Kang[56], X. Kang[49], A. Kappes[43], D. Kappesser[41], L. Kardum[23], T. Karg[63], M. Karl[27], A. Karle[40], U. Katz[26], M. Kauer[40], J. L. Kelley[40], A. Khatee Zathul[40], A. Kheirandish[34, 35], J. Kiryluk[55], S. R. Klein[8, 9], A. Kochocki[24], R. Koirala[44], H. Kolanoski[10], T. Kontrimas[27], L. Köpke[41], C. Kopper[26], D. J. Koskinen[22], P. Koundal[31], M. Kovacevich[49], M. Kowalski[10, 63], T. Kozynets[22], J. Krishnamoorthi[40, 64], K. Kruiswijk[37], E. Krupczak[24], A. Kumar[63], E. Kun[11], N. Kurahashi[49], N. Lad[63], C. Lagunas Gualda[63], M. Lamoureux[37], M. J. Larson[19], S. Latseva[1], F. Lauber[62], J. P. Lazar[14, 40], J. W. Lee[56], K. Leonard DeHolton[60], A. Leszczyńska[44], M. Lincetto[11], Q. R. Liu[40], M. Liubarska[25], E. Lohfink[41], C. Love[49], C. J. Lozano Mariscal[43], L. Lu[40], F. Lucarelli[28], W. Luszczak[20, 21], Y. Lyu[8, 9], J. Madsen[40], K. B. M. Mahn[24], Y. Makino[40], E. Manao[27], S. Mancina[40, 48], W. Marie Sainte[40], I. C. Mariş[12], S. Marka[46], Z. Marka[46], M. Marsee[58], I. Martinez-Soler[14], R. Maruyama[45], F. Mayhew[24], T. McElroy[25], F. McNally[38], J. V. Mead[22], K. Meagher[40], S. Mechbal[63], A. Medina[21], M. Meier[16], Y. Merckx[13], L. Merten[11], J. Micallef[24], J. Mitchell[7], T. Montaruli[28], R. W. Moore[25], Y. Morii[16], R. Morse[40], M. Moulai[40], T. Mukherjee[31], R. Naab[63], R. Nagai[16], M. Nakos[40], U. Naumann[62], J. Necker[63], A. Negi[4], M. Neumann[43], H. Niederhausen[24], M. U. Nisa[24], A. Noell[1], A. Novikov[44], S. C. Nowicki[24], A. Obertacke Pollmann[16], V. O'Dell[40], M. Oehler[31], B. Oeyen[29], A. Olivas[19], R. Ørsøe[27], J. Osborn[40], E. O'Sullivan[61], H. Pandya[44], N. Park[33], G. K. Parker[4], E. N. Paudel[44], L. Paul[42, 50], C. Pérez de los Heros[61], J. Peterson[40], S. Philippen[1], A. Pizzuto[40], M. Plum[50], A. Pontén[61], Y. Popovych[41], M. Prado Rodriguez[40], B. Pries[24], R. Procter-Murphy[19], G. T. Przybylski[9], C. Raab[37], J. Rack-Helleis[41], K. Rawlins[3], Z. Rechav[40], A. Rehman[44], P. Reichherzer[11], G. Renzi[12], E. Resconi[27], S. Reusch[63], W. Rhode[23], B. Riedel[40], A. Rifaie[1], E. J. Roberts[2], S. Robertson[8, 9], S. Rodan[56], G. Roellinghoff[56], M. Rongen[26], C. Rott[53, 56], T. Ruhe[23], L. Ruohan[27], D. Ryckbosch[29], I. Safa[14, 40], J. Saffer[32], D. Salazar-Gallegos[24], P. Sampathkumar[31], S. E. Sanchez Herrera[24], A. Sandrock[62], M. Santander[58], S. Sarkar[25], S. Sarkar[47], J. Savelberg[1], P. Savina[40], M. Schaufel[1], H. Schieler[31], S. Schindler[26], L. Schlickmann[1], B. Schlüter[43], F. Schlüter[12], N. Schmeisser[62], T. Schmidt[19], J. Schneider[26], F. G. Schröder[31, 44], L. Schumacher[26], G. Schwefer[1], S. Sclafani[19], D. Seckel[44], M. Seikh[36], S. Seunarine[51], R. Shah[49], A. Sharma[61], S. Shefali[32], N. Shimizu[16], M. Silva[40], B. Skrzypek[14], B. Smithers[4], R. Snihur[40], J. Soedingrekso[23], A. Søgaard[22], D. Soldin[32], P. Soldin[1], G. Sommani[11], C. Spannfellner[27], G. M. Spiczak[51], C. Spiering[63], M. Stamatikos[21], T. Stanev[44], T. Stezelberger[9], T. Stürwald[62], T. Stuttard[22], G. W. Sullivan[19], I. Taboada[6], S. Ter-Antonyan[7], M. Thiesmeyer[1], W. G. Thompson[14], J. Thwaites[40], S. Tilav[44], K. Tollefson[24], C. Tönnis[56], S. Toscano[12], D. Tosi[40], A. Trettin[63], C. F. Tung[6], R. Turcotte[31], J. P. Twagirayezu[24], B. Ty[40], M. A. Unland Elorrieta[43], A. K. Upadhyay[40, 64], K. Upshaw[7], N. Valtonen-Mattila[61], J. Vandenbroucke[40], N. van Eijndhoven[13], D. Vannerom[15], J. van Santen[63], J. Vara[43], J. Veitch-Michaelis[40], M. Venugopal[31], M. Vereecken[37], S. Verpoest[44], D. Veske[46], A. Vijai[19], C. Walck[54], C. Weaver[24], P. Weigel[15], A. Weindl[31], J. Weldert[60], C. Wendt[40], J. Werthebach[23], M. Weyrauch[31], N. Whitehorn[24], C. H. Wiebusch[1], N. Willey[24], D. R. Williams[58], L. Witthaus[23], A. Wolf[1], M. Wolf[27], G. Wrede[26], X. W. Xu[7], J. P. Yanez[25], E. Yildizci[40], S. Yoshida[16], R. Young[36], F. Yu[14], S. Yu[24], T. Yuan[40], Z. Zhang[55], P. Zhelnin[14], M. Zimmerman[40]

[1] III. Physikalisches Institut, RWTH Aachen University, D-52056 Aachen, Germany
[2] Department of Physics, University of Adelaide, Adelaide, 5005, Australia
[3] Dept. of Physics and Astronomy, University of Alaska Anchorage, 3211 Providence Dr., Anchorage, AK 99508, USA
[4] Dept. of Physics, University of Texas at Arlington, 502 Yates St., Science Hall Rm 108, Box 19059, Arlington, TX 76019, USA
[5] CTSPS, Clark-Atlanta University, Atlanta, GA 30314, USA
[6] School of Physics and Center for Relativistic Astrophysics, Georgia Institute of Technology, Atlanta, GA 30332, USA
[7] Dept. of Physics, Southern University, Baton Rouge, LA 70813, USA
[8] Dept. of Physics, University of California, Berkeley, CA 94720, USA
[9] Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
[10] Institut für Physik, Humboldt-Universität zu Berlin, D-12489 Berlin, Germany
[11] Fakultät für Physik & Astronomie, Ruhr-Universität Bochum, D-44780 Bochum, Germany
[12] Université Libre de Bruxelles, Science Faculty CP230, B-1050 Brussels, Belgium

PoS(ICRC2023)1501

[13] Vrije Universiteit Brussel (VUB), Dienst ELEM, B-1050 Brussels, Belgium
[14] Department of Physics and Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA 02138, USA
[15] Dept. of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[16] Dept. of Physics and The International Center for Hadron Astrophysics, Chiba University, Chiba 263-8522, Japan
[17] Department of Physics, Loyola University Chicago, Chicago, IL 60660, USA
[18] Dept. of Physics and Astronomy, University of Canterbury, Private Bag 4800, Christchurch, New Zealand
[19] Dept. of Physics, University of Maryland, College Park, MD 20742, USA
[20] Dept. of Astronomy, Ohio State University, Columbus, OH 43210, USA
[21] Dept. of Physics and Center for Cosmology and Astro-Particle Physics, Ohio State University, Columbus, OH 43210, USA
[22] Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark
[23] Dept. of Physics, TU Dortmund University, D-44221 Dortmund, Germany
[24] Dept. of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA
[25] Dept. of Physics, University of Alberta, Edmonton, Alberta, Canada T6G 2E1
[26] Erlangen Centre for Astroparticle Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany
[27] Technical University of Munich, TUM School of Natural Sciences, Department of Physics, D-85748 Garching bei München, Germany
[28] Département de physique nucléaire et corpusculaire, Université de Genève, CH-1211 Genève, Switzerland
[29] Dept. of Physics and Astronomy, University of Gent, B-9000 Gent, Belgium
[30] Dept. of Physics and Astronomy, University of California, Irvine, CA 92697, USA
[31] Karlsruhe Institute of Technology, Institute for Astroparticle Physics, D-76021 Karlsruhe, Germany
[32] Karlsruhe Institute of Technology, Institute of Experimental Particle Physics, D-76021 Karlsruhe, Germany
[33] Dept. of Physics, Engineering Physics, and Astronomy, Queen's University, Kingston, ON K7L 3N6, Canada
[34] Department of Physics & Astronomy, University of Nevada, Las Vegas, NV, 89154, USA
[35] Nevada Center for Astrophysics, University of Nevada, Las Vegas, NV 89154, USA
[36] Dept. of Physics and Astronomy, University of Kansas, Lawrence, KS 66045, USA
[37] Centre for Cosmology, Particle Physics and Phenomenology - CP3, Université catholique de Louvain, Louvain-la-Neuve, Belgium
[38] Department of Physics, Mercer University, Macon, GA 31207-0001, USA
[39] Dept. of Astronomy, University of Wisconsin–Madison, Madison, WI 53706, USA
[40] Dept. of Physics and Wisconsin IceCube Particle Astrophysics Center, University of Wisconsin–Madison, Madison, WI 53706, USA
[41] Institute of Physics, University of Mainz, Staudinger Weg 7, D-55099 Mainz, Germany
[42] Department of Physics, Marquette University, Milwaukee, WI, 53201, USA
[43] Institut für Kernphysik, Westfälische Wilhelms-Universität Münster, D-48149 Münster, Germany
[44] Bartol Research Institute and Dept. of Physics and Astronomy, University of Delaware, Newark, DE 19716, USA
[45] Dept. of Physics, Yale University, New Haven, CT 06520, USA
[46] Columbia Astrophysics and Nevis Laboratories, Columbia University, New York, NY 10027, USA
[47] Dept. of Physics, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom
[48] Dipartimento di Fisica e Astronomia Galileo Galilei, Università Degli Studi di Padova, 35122 Padova PD, Italy
[49] Dept. of Physics, Drexel University, 3141 Chestnut Street, Philadelphia, PA 19104, USA
[50] Physics Department, South Dakota School of Mines and Technology, Rapid City, SD 57701, USA
[51] Dept. of Physics, University of Wisconsin, River Falls, WI 54022, USA
[52] Dept. of Physics and Astronomy, University of Rochester, Rochester, NY 14627, USA
[53] Department of Physics and Astronomy, University of Utah, Salt Lake City, UT 84112, USA
[54] Oskar Klein Centre and Dept. of Physics, Stockholm University, SE-10691 Stockholm, Sweden
[55] Dept. of Physics and Astronomy, Stony Brook University, Stony Brook, NY 11794-3800, USA
[56] Dept. of Physics, Sungkyunkwan University, Suwon 16419, Korea
[57] Institute of Physics, Academia Sinica, Taipei, 11529, Taiwan
[58] Dept. of Physics and Astronomy, University of Alabama, Tuscaloosa, AL 35487, USA
[59] Dept. of Astronomy and Astrophysics, Pennsylvania State University, University Park, PA 16802, USA
[60] Dept. of Physics, Pennsylvania State University, University Park, PA 16802, USA
[61] Dept. of Physics and Astronomy, Uppsala University, Box 516, S-75120 Uppsala, Sweden
[62] Dept. of Physics, University of Wuppertal, D-42119 Wuppertal, Germany
[63] Deutsches Elektronen-Synchrotron DESY, Platanenallee 6, 15738 Zeuthen, Germany
[64] Institute of Physics, Sachivalaya Marg, Sainik School Post, Bhubaneswar 751005, India
[65] Department of Space, Earth and Environment, Chalmers University of Technology, 412 96 Gothenburg, Sweden
[66] Earthquake Research Institute, University of Tokyo, Bunkyo, Tokyo 113-0032, Japan

Acknowledgements

The authors gratefully acknowledge the support from the following agencies and institutions: USA – U.S. National Science Foundation-Office of Polar Programs, U.S. National Science Foundation-Physics Division, U.S. National Science Foundation-EPSCoR, Wisconsin Alumni Research Foundation, Center for High Throughput Computing (CHTC) at the University of Wisconsin–Madison, Open Science

PoS(ICRC2023)1501

Grid (OSG), Advanced Cyberinfrastructure Coordination Ecosystem: Services & Support (ACCESS), Frontera computing project at the Texas Advanced Computing Center, U.S. Department of Energy-National Energy Research Scientific Computing Center, Particle astrophysics research computing center at the University of Maryland, Institute for Cyber-Enabled Research at Michigan State University, and Astroparticle physics computational facility at Marquette University; Belgium – Funds for Scientific Research (FRS-FNRS and FWO), FWO Odysseus and Big Science programmes, and Belgian Federal Science Policy Office (Belspo); Germany – Bundesministerium für Bildung und Forschung (BMBF), Deutsche Forschungsgemeinschaft (DFG), Helmholtz Alliance for Astroparticle Physics (HAP), Initiative and Networking Fund of the Helmholtz Association, Deutsches Elektronen Synchrotron (DESY), and High Performance Computing cluster of the RWTH Aachen; Sweden – Swedish Research Council, Swedish Polar Research Secretariat, Swedish National Infrastructure for Computing (SNIC), and Knut and Alice Wallenberg Foundation; European Union – EGI Advanced Computing for research; Australia – Australian Research Council; Canada – Natural Sciences and Engineering Research Council of Canada, Calcul Québec, Compute Ontario, Canada Foundation for Innovation, WestGrid, and Compute Canada; Denmark – Villum Fonden, Carlsberg Foundation, and European Commission; New Zealand – Marsden Fund; Japan – Japan Society for Promotion of Science (JSPS) and Institute for Global Prominent Research (IGPR) of Chiba University; Korea – National Research Foundation of Korea (NRF); Switzerland – Swiss National Science Foundation (SNSF); United Kingdom – Department of Physics, University of Oxford.

PoS(ICRC2023)1501

Full Authors List: MAGIC Collaboration

H. Abe[1], S. Abe[1], J. Abhir[2], V. A. Acciari[3], I. Agudo[4], T. Aniello[5], S. Ansoldi[6,46], L. A. Antonelli[5], A. Arbet Engels[7], C. Arcaro[8], M. Artero[9], K. Asano[1], D. Baack[10], A. Babić[11], A. Baquero[12], U. Barres de Almeida[13], J. A. Barrio[12], I. Batković[8], J. Baxter[1], J. Becerra González[3], W. Bednarek[14], E. Bernardini[8], M. Bernardos[4], J. Bernete[15], A. Berti[7], J. Besenrieder[7], C. Bigongiari[5], A. Biland[2], O. Blanch[9], G. Bonnoli[5], Ž. Bošnjak[11], I. Burelli[6], G. Busetto[8], A. Campoy-Ordaz[16], A. Carosi[5], R. Carosi[17], M. Carretero-Castrillo[18], A. J. Castro-Tirado[4], G. Ceribella[7], Y. Chai[7], A. Chilingarian[19], A. Cifuentes[15], S. Cikota[11], E. Colombo[3], J. L. Contreras[12], J. Cortina[15], S. Covino[5], G. D'Amico[20], V. D'Elia[5], P. Da Vela[17,47], F. Dazzi[5], A. De Angelis[8], B. De Lotto[6], A. Del Popolo[21], M. Delfino[9,48], J. Delgado[9,48], C. Delgado Mendez[15], D. Depaoli[22], F. Di Pierro[22], L. Di Venere[23], D. Dominis Prester[24], A. Donini[5], D. Dorner[25], M. Doro[8], D. Elsaesser[10], G. Emery[26], J. Escudero[4], L. Fariña[9], A. Fattorini[10], L. Foffano[5], L. Font[16], S. Fröse[10], S. Fukami[2], Y. Fukazawa[27], R. J. García López[3], M. Garczarczyk[28], S. Gasparyan[29], M. Gaug[16], J. G. Giesbrecht Paiva[13], N. Giglietto[23], F. Giordano[23], P. Gliwny[14], N. Godinović[30], R. Grau[9], D. Green[7], J. G. Green[7], D. Hadasch[1], A. Hahn[7], T. Hassan[15], L. Heckmann[7,49], J. Herrera[3], D. Hrupec[31], M. Hütten[1], R. Imazawa[27], T. Inada[1], R. Iotov[25], K. Ishio[14], I. Jiménez Martínez[15], J. Jormanainen[32], D. Kerszberg[9], G. W. Kluge[20,50], Y. Kobayashi[1], P. M. Kouch[32], H. Kubo[1], J. Kushida[33], M. Láinez Lezáun[12], A. Lamastra[5], D. Lelas[30], F. Leone[5], E. Lindfors[32], L. Linhoff[10], S. Lombardi[5], F. Longo[6,51], R. López-Coto[4], M. López-Moya[12], A. López-Oramas[3], S. Loporchio[23], A. Lorini[34], E. Lyard[26], B. Machado de Oliveira Fraga[13], P. Majumdar[35], M. Makariev[36], G. Maneva[36], N. Mang[10], M. Manganaro[24], S. Mangano[15], K. Mannheim[25], M. Mariotti[8], M. Martínez[9], M. Martínez-Chicharro[15], A. Mas-Aguilar[12], D. Mazin[1,52], S. Menchiari[34], S. Mender[10], S. Mićanović[24], D. Miceli[8], T. Mienert[12], J. M. Miranda[34], R. Mirzoyan[7], M. Molero González[3], E. Molina[3], H. A. Mondal[35], A. Moralejo[9], D. Morcuende[12], T. Nakamori[37], C. Nanci[5], L. Nava[5], V. Neustroev[38], L. Nickel[10], M. Nievas Rosillo[3], C. Nigro[9], L. Nikolić[34], K. Nilsson[32], K. Nishijima[33], T. Njoh Ekoume[3], K. Noda[39], S. Nozaki[7], Y. Ohtani[1], T. Oka[40], A. Okumura[41], J. Otero-Santos[3], S. Paiano[5], M. Palatiello[6], D. Paneque[7], R. Paoletti[34], J. M. Paredes[18], L. Pavletić[24], D. Pavlović[24], M. Persic[6,53], M. Pihet[8], G. Pirola[7], F. Podobnik[34], P. G. Prada Moroni[17], E. Prandini[8], G. Principe[6], C. Priyadarshi[9], W. Rhode[10], M. Ribó[18], J. Rico[9], C. Righi[5], N. Sahakyan[29], T. Saito[1], S. Sakurai[1], K. Satalecka[32], F. G. Saturni[5], B. Schleicher[25], K. Schmidt[10], F. Schmuckermaier[7], J. L. Schubert[10], T. Schweizer[7], A. Sciaccaluga[5], J. Sitarek[14], V. Sliusar[26], D. Sobczynska[14], A. Spolon[8], A. Stamerra[5], J. Strišković[31], D. Strom[7], M. Strzys[1], Y. Suda[27], T. Surić[42], S. Suutarinen[32], H. Tajima[41], M. Takahashi[41], R. Takeishi[1], F. Tavecchio[5], P. Temnikov[36], K. Terauchi[40], T. Terzić[24], M. Teshima[7,54], L. Tosti[43], S. Truzzi[34], A. Tutone[5], S. Ubach[16], J. van Scherpenberg[7], M. Vazquez Acosta[3], S. Ventura[34], V. Verguilov[36], I. Viale[8], C. F. Vigorito[22], V. Vitale[44], I. Vovk[1], R. Walter[26], M. Will[7], C. Wunderlich[34], T. Yamamoto[45], [1] Japanese MAGIC Group: Institute for Cosmic Ray Research (ICRR), The University of Tokyo, Kashiwa, 277-8582 Chiba, Japan
[2] ETH Zürich, CH-8093 Zürich, Switzerland
[3] Instituto de Astrofísica de Canarias and Dpto. de Astrofísica, Universidad de La Laguna, E-38200, La Laguna, Tenerife, Spain
[4] Instituto de Astrofísica de Andalucía-CSIC, Glorieta de la Astronomía s/n, 18008, Granada, Spain
[5] National Institute for Astrophysics (INAF), I-00136 Rome, Italy
[6] Università di Udine and INFN Trieste, I-33100 Udine, Italy
[7] Max-Planck-Institut für Physik, D-80805 München, Germany
[8] Università di Padova and INFN, I-35131 Padova, Italy
[9] Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology (BIST), E-08193 Bellaterra (Barcelona), Spain
[10] Technische Universität Dortmund, D-44221 Dortmund, Germany
[11] Croatian MAGIC Group: University of Zagreb, Faculty of Electrical Engineering and Computing (FER), 10000 Zagreb, Croatia
[12] IPARCOS Institute and EMFTEL Department, Universidad Complutense de Madrid, E-28040 Madrid, Spain
[13] Centro Brasileiro de Pesquisas Físicas (CBPF), 22290-180 URCA, Rio de Janeiro (RJ), Brazil
[14] University of Lodz, Faculty of Physics and Applied Informatics, Department of Astrophysics, 90-236 Lodz, Poland
[15] Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, E-28040 Madrid, Spain
[16] Departament de Física, and CERES-IEEC, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain
[17] Università di Pisa and INFN Pisa, I-56126 Pisa, Italy
[18] Universitat de Barcelona, ICCUB, IEEC-UB, E-08028 Barcelona, Spain
[19] Armenian MAGIC Group: A. Alikhanyan National Science Laboratory, 0036 Yerevan, Armenia
[20] Department for Physics and Technology, University of Bergen, Norway
[21] INFN MAGIC Group: INFN Sezione di Catania and Dipartimento di Fisica e Astronomia, University of Catania, I-95123 Catania, Italy
[22] INFN MAGIC Group: INFN Sezione di Torino and Università degli Studi di Torino, I-10125 Torino, Italy
[23] INFN MAGIC Group: INFN Sezione di Bari and Dipartimento Interateneo di Fisica dell'Università e del Politecnico di Bari, I-70125 Bari, Italy
[24] Croatian MAGIC Group: University of Rijeka, Faculty of Physics, 51000 Rijeka, Croatia
[25] Universität Würzburg, D-97074 Würzburg, Germany
[26] University of Geneva, Chemin d'Ecogia 16, CH-1290 Versoix, Switzerland
[27] Japanese MAGIC Group: Physics Program, Graduate School of Advanced Science and Engineering, Hiroshima University, 739-8526 Hiroshima, Japan
[28] Deutsches Elektronen-Synchrotron (DESY), D-15738 Zeuthen, Germany
[29] Armenian MAGIC Group: ICRANet-Armenia, 0019 Yerevan, Armenia

PoS(ICRC2023)1501

[30] Croatian MAGIC Group: University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture (FESB), 21000 Split, Croatia
[31] Croatian MAGIC Group: Josip Juraj Strossmayer University of Osijek, Department of Physics, 31000 Osijek, Croatia
[32] Finnish MAGIC Group: Finnish Centre for Astronomy with ESO, University of Turku, FI-20014 Turku, Finland
[33] Japanese MAGIC Group: Department of Physics, Tokai University, Hiratsuka, 259-1292 Kanagawa, Japan
[34] Università di Siena and INFN Pisa, I-53100 Siena, Italy
[35] Saha Institute of Nuclear Physics, A CI of Homi Bhabha National Institute, Kolkata 700064, West Bengal, India
[36] Inst. for Nucl. Research and Nucl. Energy, Bulgarian Academy of Sciences, BG-1784 Sofia, Bulgaria
[37] Japanese MAGIC Group: Department of Physics, Yamagata University, Yamagata 990-8560, Japan
[38] Finnish MAGIC Group: Space Physics and Astronomy Research Unit, University of Oulu, FI-90014 Oulu, Finland
[39] Japanese MAGIC Group: Chiba University, ICEHAP, 263-8522 Chiba, Japan
[40] Japanese MAGIC Group: Department of Physics, Kyoto University, 606-8502 Kyoto, Japan
[41] Japanese MAGIC Group: Institute for Space-Earth Environmental Research and Kobayashi-Maskawa Institute for the Origin of Particles and the Universe, Nagoya University, 464-6801 Nagoya, Japan
[42] Croatian MAGIC Group: Ruđer Bošković Institute, 10000 Zagreb, Croatia
[43] INFN MAGIC Group: INFN Sezione di Perugia, I-06123 Perugia, Italy
[44] INFN MAGIC Group: INFN Roma Tor Vergata, I-00133 Roma, Italy
[45] Japanese MAGIC Group: Department of Physics, Konan University, Kobe, Hyogo 658-8501, Japan
[46] also at International Center for Relativistic Astrophysics (ICRA), Rome, Italy
[47] now at Institute for Astro- and Particle Physics, University of Innsbruck, A-6020 Innsbruck, Austria
[48] also at Port d'Informació Científica (PIC), E-08193 Bellaterra (Barcelona), Spain
[49] also at Institute for Astro- and Particle Physics, University of Innsbruck, A-6020 Innsbruck, Austria
[50] also at Department of Physics, University of Oslo, Norway
[51] also at Dipartimento di Fisica, Università di Trieste, I-34127 Trieste, Italy
[52] Max-Planck-Institut für Physik, D-80805 München, Germany
[53] also at INAF Padova
[54] Japanese MAGIC Group: Institute for Cosmic Ray Research (ICRR), The University of Tokyo, Kashiwa, 277-8582 Chiba, Japan

PoS(ICRC2023)1501

Full Author List: VERITAS Collaboration

A. Acharyya[1], C. B. Adams[2], A. Archer[3], P. Bangale[4], J. T. Bartkoske[5], P. Batista[6], W. Benbow[7], J. L. Christiansen[8], A. J. Chromey[7], A. Duerr[5], M. Errando[9], Q. Feng[7], G. M. Foote[4], L. Fortson[10], A. Furniss[11,12], W. Hanlon[7], O. Hervet[12], C. E. Hinrichs[7,13], J. Hoang[12], J. Holder[4], Z. Hughes[9], T. B. Humensky[14,15], W. Jin[1], M. N. Johnson[12], M. Kertzman[3], M. Kherlakian[6], D. Kieda[5], T. K. Kleiner[6], N. Korzoun[4], S. Kumar[14], M. J. Lang[16], M. Lundy[17], G. Maier[6], C. E McGrath[18], M. J. Millard[19], C. L. Mooney[4], P. Moriarty[16], R. Mukherjee[20], S. O'Brien[17,21], R. A. Ong[22], N. Park[23], C. Poggemann[8], M. Pohl[24,6], E. Pueschel[6], J. Quinn[18], P. L. Rabinowitz[9], K. Ragan[17], P. T. Reynolds[25], D. Ribeiro[10], E. Roache[7], J. L. Ryan[22], I. Sadeh[6], L. Saha[7], M. Santander[1], G. H. Sembroski[26], R. Shang[20], M. Splettstoesser[12], A. K. Talluri[10], J. V. Tucci[27], V. V. Vassiliev[22], A. Weinstein[28], D. A. Williams[12], S. L. Wong[17], and J. Woo[29]

[1]Department of Physics and Astronomy, University of Alabama, Tuscaloosa, AL 35487, USA
[2]Physics Department, Columbia University, New York, NY 10027, USA
[3]Department of Physics and Astronomy, DePauw University, Greencastle, IN 46135-0037, USA
[4]Department of Physics and Astronomy and the Bartol Research Institute, University of Delaware, Newark, DE 19716, USA
[5]Department of Physics and Astronomy, University of Utah, Salt Lake City, UT 84112, USA
[6]DESY, Platanenallee 6, 15738 Zeuthen, Germany
[7]Center for Astrophysics | Harvard & Smithsonian, Cambridge, MA 02138, USA
[8]Physics Department, California Polytechnic State University, San Luis Obispo, CA 94307, USA
[9]Department of Physics, Washington University, St. Louis, MO 63130, USA
[10]School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455, USA
[11]Department of Physics, California State University - East Bay, Hayward, CA 94542, USA
[12]Santa Cruz Institute for Particle Physics and Department of Physics, University of California, Santa Cruz, CA 95064, USA
[13]Department of Physics and Astronomy, Dartmouth College, 6127 Wilder Laboratory, Hanover, NH 03755 USA
[14]Department of Physics, University of Maryland, College Park, MD, USA
[15]NASA GSFC, Greenbelt, MD 20771, USA
[16]School of Natural Sciences, University of Galway, University Road, Galway, H91 TK33, Ireland
[17]Physics Department, McGill University, Montreal, QC H3A 2T8, Canada
[18]School of Physics, University College Dublin, Belfield, Dublin 4, Ireland
[19]Department of Physics and Astronomy, University of Iowa, Van Allen Hall, Iowa City, IA 52242, USA
[20]Department of Physics and Astronomy, Barnard College, Columbia University, NY 10027, USA
[21] Arthur B. McDonald Canadian Astroparticle Physics Research Institute, 64 Bader Lane, Queen's University, Kingston, ON Canada, K7L 3N6
[22]Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA
[23]Department of Physics, Engineering Physics and Astronomy, Queen's University, Kingston, ON K7L 3N6, Canada
[24]Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam-Golm, Germany
[25]Department of Physical Sciences, Munster Technological University, Bishopstown, Cork, T12 P928, Ireland
[26]Department of Physics and Astronomy, Purdue University, West Lafayette, IN 47907, USA
[27]Department of Physics, Indiana University-Purdue University Indianapolis, Indianapolis, IN 46202, USA
[28]Department of Physics and Astronomy, Iowa State University, Ames, IA 50011, USA
[29]Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027, USA

PoS(ICRC2023)1501