The Cherenkov Telescope Array: layout, design and performance

Orel Gueta\textsuperscript{a,}\textsuperscript{*} on behalf of the CTA Consortium and the CTA Observatory
(a complete list of authors can be found at the end of the proceedings)

\textsuperscript{a}Deutsches Elektronen-Synchrotron (DESY),
Platanenallee 6, Zeuthen, Germany
E-mail: orel.gueta@desy.de

The Cherenkov Telescope Array (CTA) will be the next generation very-high-energy gamma-ray observatory. CTA is expected to provide substantial improvement in accuracy and sensitivity with respect to existing instruments thanks to a tenfold increase in the number of telescopes and their state-of-the-art design. Detailed Monte Carlo simulations are used to further optimise the number of telescopes and the array layout, and to estimate the observatory performance using updated models of the selected telescope designs. These studies are presented in this contribution for the two CTA stations located on the island of La Palma (Spain) and near Paranal (Chile) and for different operation and observation conditions.
1. Introduction

The Cherenkov Telescope Array (CTA) [1] will be the next generation very-high-energy (VHE; 10 GeV \( \lesssim E \lesssim 100 \) TeV) gamma-ray observatory. CTA will be composed of more than 50 imaging atmospheric Cherenkov telescopes (IACTs) and will be built at two sites located on the island of La Palma (Spain; 17.89W, 28.76N; 2158 m altitude) and near Paranal (Chile; 70.32W, 24.68S; 2147 m altitude). IACTs detect gamma rays by recording the Cherenkov light induced by extensive air shower particles produced in the interaction of the gamma ray with particles in the atmosphere [2]. CTA will be sensitive to gamma rays in a wide energy range, from 20 GeV to beyond 300 TeV, thanks to the use of three types of telescopes of varying sizes; namely the Large-Sized Telescopes (LSTs), Medium-Sized Telescopes (MSTs) and Small-Sized Telescopes (SSTs). Its sensitivity is expected to be about a factor of five to ten better than current IACTs across the entire energy range, providing the capability to e.g., perform deep surveys of various sky regions. The short-term sensitivity of CTA will be a few orders of magnitude better than that of Fermi-LAT. This would enable the measurement of very-fast variability in active galactic nuclei flares and increase the likelihood of detecting short-timescale transient phenomena like gamma-ray bursts or black-hole mergers. CTA is expected to provide a substantial improvement in angular and energy resolution. The angular resolution of CTA is expected to reach around one arc minute at high energies. This, together with the large field of view (4.5° – 8.5°), will enable detailed imaging of extended gamma-ray sources. The improved energy resolution, reaching around 5% at 1 TeV, will make it easier to measure spectral cutoffs and detect spectral features such as those expected from dark matter.

The telescope simulation models used in previous CTA performance studies [3] were updated and new estimates were derived. These estimates, together with the telescope layout optimisation process, are presented in this contribution. The number of telescopes considered here is not the final one and is subject to change.

2. Simulation and analysis

To optimise the CTA telescope layout and derive its performance, detailed Monte Carlo simulations were generated. The process starts with simulations of extensive air showers and the Cherenkov light they induce using the CORSIKA program (version 7.7100) [4]. The Cherenkov photons from the air shower are propagated through the telescopes using the sim_telarray simulation package (version 2020-06-28) [5]. Detailed simulation models of the CTA telescopes, are included in sim_telarray. These models were updated for the purpose of this study. The update process included:

- obtaining an updated atmospheric model for La Palma and geomagnetic field values for both sites;
- performing detailed ray-tracing simulations of optical elements to e.g., update the reference model used in sim_telarray to model the shadowing on the camera as a function of off-axis angle due to various telescope components;
- collecting lab and on-site prototype measurements of various telescope components simulated in sim_telarray;
• tuning simulation parameters to fit the measurements where necessary;
• deriving appropriate trigger threshold levels;
• estimating the expected night-sky background light level in each pixel.

A summary of the samples simulated for each site, including the number of events per particle type per site and the energy ranges, is given in Table 1. Three zenith angles (20°, 40° and 60°) and both north and south pointings were simulated, with all telescopes pointing parallel to each other.

<table>
<thead>
<tr>
<th>Particle type</th>
<th>Energy range [TeV]</th>
<th>Number of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point source gamma</td>
<td>0.003 – 330</td>
<td>1e9</td>
</tr>
<tr>
<td>Diffuse gamma</td>
<td>0.003 – 330</td>
<td>5e9</td>
</tr>
<tr>
<td>Electron/Positron</td>
<td>0.003 – 330</td>
<td>1e9</td>
</tr>
<tr>
<td>Proton</td>
<td>0.006 – 600</td>
<td>20e9</td>
</tr>
</tbody>
</table>

Table 1: Number of events simulated per particle type and the corresponding energy ranges. The same number of events was simulated for both the northern and southern sites.

The telescope layouts for a larger number of telescopes on both sites were extensively optimised in a previous study [6]. In order to further optimise the layout with fewer telescopes as considered here, a total of 180 telescope positions were simulated in the southern site and 84 positions in the northern site. Out of those simulated positions, many telescope configurations were considered. Figure 1 shows one configuration for the northern site, the Alpha configuration to be built in the construction phase, and three configurations for the southern site. The three telescope layouts in the southern site shown in Figure 1 are the leading candidates to be selected for construction. A final decision on the layout is dependent on the number of telescopes to be built. Also shown are the positions of four LSTs not included in the simulations. Those will potentially be added to the array in the future.

The reconstruction and analysis of the simulation output were performed using the Eventdisplay [7] analysis software (version prod5_d20200702). The main steps of the analysis consist of waveform integration, image cleaning, stereoscopic reconstruction and cut optimisation. A detailed description of the reconstruction can be found elsewhere (see e.g., Ref. [8]).

All of the performance evaluations shown in Figures 2 – 4 are for point-like gamma-ray sources observed at a zenith angle of 20 deg, located either at the centre of the field of view (on-axis) or 3° – 4° off axis as indicated in the figures. Results were averaged between the two north and south pointings. Further zenith angles, off-axis angles and night-sky background levels were taken into account in the layout optimisation, but are not shown here for reasons of brevity.

3. Layout optimisation and performance

The main criteria typically used to evaluate the performance of IACTs are effective collection area, angular resolution, energy resolution, residual background rate and differential sensitivity. All

\footnote{Dedicated CTA reconstruction software is currently under development and is expected to provide improved performance compared to the one presented here.}
Figure 1: Telescope layouts for the CTA northern La Palma site (top left) and the southern Paranal site (top right, bottom). Telescope types are indicated in the legend. The Alpha layout shown for the northern site will be built during the construction phase. Three possible layouts are shown for the southern site, where the difference is in the layout of the SSTs. The LSTs shown in the southern layouts were not included in the simulations. They will potentially be added to the array in the future. Note that the area covered by the southern layout is approximately 19 times that of the northern layout.

were considered in the layout optimisation, but only the effective collection area, angular resolution and differential sensitivity are discussed here.

The differential sensitivity, defined as the minimal flux required to detect a point-like source ($\sigma > 5$), is the primary metric used to decide between telescope layouts. To calculate the sensitivity, apart from the detection requirement, at least ten detected gamma rays and a minimal signal to background ratio of 1/20 in each energy bin were required. The analysis cuts in each energy bin were optimised for best flux sensitivity in the northern site. In the southern site both flux sensitivity and angular resolution were taken into account in the optimisation process, with a higher weight
given to the angular resolution. Figure 2 shows the on-axis sensitivity achieved with the various telescope layouts on both sites for an assumed 50 hour observation time (the optimal analysis cuts depend on the observation time). For the northern site, also the off-axis sensitivity is shown, where such off-axis observations at $3^\circ – 4^\circ$ from the camera centre will be possible for the first time thanks to the large field of view of CTA cameras. The differential sensitivities of other instruments [9–16] are shown for comparison. These should provide only a rough comparison of the sensitivity of the different instruments, as the method of calculation and the criteria applied are not identical. The MAGIC and VERITAS sensitivities were combined by taking the more sensitive value of the two arrays in each bin and are represented by the IACT North curve.

A comparison between the effective collection areas of the three candidate layouts of the southern site are shown in the inset in Figure 2. The effective collection area is defined as the differential gamma-ray detection rate divided by the differential flux of incident gamma rays. The effective collection area was calculated assuming 30 minutes observation time and optimising the cuts for best sensitivity.

![Figure 2](image.png)

**Figure 2:** The CTA differential point-source sensitivity as a function of reconstructed energy in the northern array site (left) and for the various telescope layouts in the southern array site (right), assuming 50 hour observation time, pointing to 20 degrees zenith and averaged between pointing north and south. Filled markers represent observations assuming a gamma-ray source located at the centre of the field of view, while empty markers are for a source located $3^\circ – 4^\circ$ off axis (northern site only). The differential sensitivities of other instruments [9–16] are shown for comparison. The IACT North curve represents the best-of sensitivity of MAGIC and VERITAS. The curves for Fermi-LAT and HAWC are scaled by a factor 1.2 relative those provided in the references, to account for the different energy binning. A comparison between the effective collection areas of the different telescope layouts in the south, calculated assuming 30 minutes observation time, is shown in the inset in the figure.

CTA will outperform current generation IACTs by about a factor five across the entire energy range. The energy coverage will expand as well, in particular at high energies, reaching hundreds of TeV, compared to $\sim 10$ TeV with current IACTs. Above $10 – 20$ TeV, HAWC, LHAASO and SWGO are more sensitive than CTA, albeit with a worse angular resolution (at 100 TeV, the angular resolution of HAWC and SWGO is about $0.1^\circ$ and the LHAASO one is around $0.2^\circ$ [14, 16, 17]).

In the southern site, a difference of about $10 – 20\%$ in sensitivity is seen between the layouts. In particular, the M6D1a layout, where the SSTs are spread further apart (see the bottom right of Figure 1), is less sensitive around 5 TeV and more sensitive above 10 TeV. This can be explained by the differences seen between the layouts in the effective collection area.
The angular resolution as a function of the reconstructed energy obtained with the various telescope layouts on both sites is shown in Figure 3. The angular resolution in each energy bin is defined as the angle containing 68% of the reconstructed gamma-ray events relative to the simulated gamma-ray direction. A small improvement of less than 0.01° in angular resolution is observed around 10 TeV between the layouts in the southern site, where the angular resolution of the M6D1a layout is worse than of the other layouts. The angular resolution of other instruments [9, 11–14, 16, 17] is shown in Figure 3 for comparison. CTA will provide a significant improvement in angular resolution compared to other instruments, ranging between 0.02° to 0.2°. It should be noted that the analysis performed here was only partially optimised for best angular resolution. Better angular resolution is obtainable with appropriately optimised cuts in case of e.g., morphology studies of bright sources.

![Figure 3](image-url)

**Figure 3:** Angular resolution as a function of reconstructed energy for the northern (left) and southern site (right) of CTA. The angular resolution curves of the various layouts are indicated in the legend, where filled markers represent observations assuming a gamma-ray source located at the centre of the field of view, while empty markers are for a source located 3° – 4° off axis (northern site only). The angular resolution of other instruments is shown for comparison [9, 11–14, 16, 17].

The short-transient phenomena discovery potential of the northern site of CTA is demonstrated in Figure 4, where the integral sensitivity in each energy bin for selected energies is shown as a function of observation time. The short-term sensitivity of Fermi-LAT is shown for comparison. CTA is a few orders of magnitude more sensitive than Fermi-LAT for such short observation times. The discovery potential of CTA for e.g., gamma-ray bursts, is therefore significantly higher than that of Fermi-LAT. However, that is true only for sources which are in the field of view. The Fermi-LAT field of view is substantially larger at 2.4 sr, making such occurrences much more likely. To enhance the efficiency of CTA in discovering short-term phenomena, CTA telescopes were designed with fast repointing capabilities. The LSTs will be able to repoint within 20 seconds of receiving an alert of a potential transient source.
**Figure 4:** Differential flux sensitivity of the northern site of CTA at selected energies as function of observing time for 20 degrees zenith observation and averaged between pointing north and south, in comparison with Fermi-LAT (Pass 8 analysis, extragalactic background, standard survey observing mode).

### 4. Conclusions

The performance of various CTA telescope layouts was estimated and compared. The northern site of CTA is expected to be about five times more sensitive than MAGIC and VERITAS, while the southern site is expected to be an order of magnitude more sensitive than HESS. At energies above 10 – 30 TeV, CTA is less sensitive than water Cherenkov detector arrays, but provides significantly better angular and energy resolution. The differences between the sensitivities of the layouts in the southern site are of the order of 20% at energies above 1 TeV. The short-term sensitivity of CTA is expected to be a few orders of magnitude better than Fermi-LAT, making it a great instrument for short-term phenomena detections, in particular for serendipitous discoveries of sources in the field of view.

### 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 here: [http://www.cta-observatory.org/consortium_acknowledgments](http://www.cta-observatory.org/consortium_acknowledgments). We also would like to thank the computing centres that provided resources for the generation of the instrument response functions, see Ref. [18] for a full list of contributing institutions.

### References


[10] Holler et al. (The H.E.S.S. collaboration), 2015 Proceedings of the 34th ICRC (adapted)


19: Instituto de Astronomía, 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 Electromagnetica, 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: CECTar, 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: University of Groningen, KVI - Center for Advanced Radiation Technology, Zernikelaan 25, 9747 AG 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, Unsa 3, 10000 Zagreb, Croatia
48: University of Namibia, Department of Physics, 340 Mandume Ndemuyo 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 Vaxjö, Sweden
58: University of the Witwatersrand, 1 Jan Smuts Avenue, Braamfontein, 2000 Johannesburg, South Africa
59: Institut für Theoretische Physik, Lehrstuhl IV. Plasma-Astroteilchenphysik, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany
60: Faculty of Physics and Applied Computer Science, University of Łódź, ul. Pomorska 149-153, 90-236 Łódź, Poland
61: INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica di Milano, Via A. Corti 12, 20133 Milano, Italy
62: INFN and Università degli Studi di Siena, Dipartimento di Scienze Fisiche, della Terra e dell’Ambiente (DSFTA), Sezione di Fisica, Via Roma 56, 53100 Siena, Italy
63: Center for Astrophysics | Harvard & Smithsonian, 60 Garden St, Cambridge, MA 02138, 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 Orahova 4, 70124 Bari, Italy
73: Laboratoire de Physique des 2 inifs, Irene Joliot-Curie-IN2P3/CNRS, Université Paris-Saclay, Université de Paris, 15 rue Georges Clemenceau, 91406 Orsay, Cedex, France
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. Andrzejja Sołtana 7, 05-400 Orwock, 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 Kiev, 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 1, 34127 Trieste, Italy
146 : School of Physics & Center for Relativistic Astrophysics, Georgia Institute of Technology, 837 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 7ZL, United Kingdom
154 : Department of Physics, Yamagata University, Yamagata, Yamagata 990-8606, 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, Toku University, 4-1-1, Kita-Kamame, 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, Aoba, 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-Universitat, 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, PO. Box 9010, 6500 GL Nijmegen, The Netherlands
166 : Josip Juraj Strossmayer University of Osijek, Trg Ljudevita Gaja 6, 31000 Osijek, Croatia
167 : Department of Earth and Space Science, Graduate School of Science, Osaka University, Toyonaka 560-0043, Japan
168 : Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan
169 : Astronomical Observatory, Jagiellonian University, ul. Orła 171, 30-244 Cracow, Poland
170 : Landessternwarte, Zentrum für Astronomie der Universität Heidelberg, Königstuhl 12, 69117 Heidelberg, Germany
171 : University of Alabama, Tuscaloosa, Department of Physics and Astronomy, Gallowee 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
PoS(ICRC2021)885

Orel Gueta

176: Faculty of Science, Ibaraki University, Mito, Ibaraki, 310-8512, Japan
177: Faculty of Science and Engineering, Waseda University, Shinjuku, Tokyo 169-8555, Japan
178: Institute of Astronomy, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University in Toruń, ul. Grudziądzka 5, 87-100 Toruń, Poland
179: Graduate School of Science and Engineering, Saitama University, 255 Simo-Ohkubo, Sakura-ku, Saitama city, Saitama 338-8570, Japan
180: Division of Physics and Astronomy, Graduate School of Science, Kyoto University, Sakyo-ku, Kyoto, 606-8502, Japan
181: Centre for Quantum Technologies, National University Singapore, Block S15, 3 Science Drive 2, Singapore 117543, Singapore
182: Institute of Particle and Nuclear Studies, KEK (High Energy Accelerator Research Organization), 1-1 Oho, Tsukuba, 305-0801, Japan
183: Department of Physics and Astronomy, University of Sheffield, Hounsfield Road, Sheffield S3 7RH, United Kingdom
184: Centro de Ciências Naturais e Humanas, Universidade Federal do ABC, Av. dos Estados, 5001, CEP: 09.210-580, Santo André - SP, Brazil
185: Dipartimento di Fisica e Astronomia, Sezione Astrofisica, Università di Catania, Via S. Sofia 78, I-95123 Catania, Italy
186: Department of Physics, Humboldt University Berlin, Newtonstr. 15, 12489 Berlin, Germany
187: Texas Tech University, 2500 Broadway, Lubbock, Texas 79409-1035, USA
188: University of Zielona Góra, ul. Licealna 9, 65-417 Zielona Góra, Poland
189: Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, 72 boul. Tsarigradsko chaussee, 1784 Sofia, Bulgaria
190: University of Białystok, Faculty of Physics, ul. K. Ciołkowskiego 1L, 15-254 Białystok, Poland
191: Faculty of Physics, National and Kapodestrian University of Athens, Panepistimiopolis, 15771 Ilissia, Athens, Greece
192: Universidad de Chile, Av. Libertador Bernardo O’Higgins 1058, Santiago, Chile
193: Hiroshima Astrophysical Science Center, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-8526, Japan
194: Department of Applied Physics, University of Miyazaki, 1-1 Gakuen Kibana-dai Nishi, Miyazaki, 889-2192, Japan
195: School of Allied Health Sciences, Kitasato University, Sagamihara, Kanagawa 228-8555, Japan
196: Departamento de Astronomia, 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 Fisica - Universidade de São Paulo, Rua do Matão Travessa R N.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
219: CTAO gGmbH, Via Piero Gobetti 93/3, 40129 Bologna, Italy