

## Outreach activities at the Pierre Auger Observatory

---

**K.S. Caballero-Mora<sup>a,b,\*</sup> on behalf of the Pierre Auger Collaboration**

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

<sup>a</sup>*Facultad de Ciencias en Física y Matemáticas, Universidad Autónoma de Chiapas*

*Boulevard Belisario Domínguez, Km. 1081, Sin Número, Terán, Tuxtla Gutiérrez, Chiapas, Mexico*

<sup>b</sup>*Observatorio Pierre Auger, Av. San Martín Norte 304, 5613 Malargüe, Argentina*

*E-mail: [spokespersons@auger.org](mailto:spokespersons@auger.org)*

The Pierre Auger Observatory, sited in Malargüe, Argentina, is the largest observatory available for measuring ultra-high-energy cosmic rays (UHECR). The Auger Collaboration has measured and analysed an unprecedented number of UHECRs. Along with making important scientific discoveries, for example, the demonstration that cosmic rays above 8 EeV are of extragalactic origin and the observation of a new feature in the energy spectrum at around 13 EeV, outreach work has been carried out across the 18 participating countries and online. This program ranges from talks to a varied audience, to the creation of a local Visitor Center, which attracts 8000 visitors annually, to initiating masterclasses. Permanent and temporary exhibitions have been prepared both in reality and virtually. Science fairs for elementary- and high-school students have been organised, together with activities associated with interesting phenomena such as eclipses. In addition, we participate in international events such as the International Cosmic Day, Frontiers from H2020, and the International Day of Women and Girls in Science. Part of the Collaboration website is aimed at the general public. Here the most recent articles published are summarised. Thus the Collaboration informs people about work in our field, which may seem remote from everyday life. Furthermore, the Auger Observatory has been a seed for scientific and technological activities in and around Malargüe. Different outreach ventures that already have been implemented and others which are foreseen will be described.

*37<sup>th</sup> International Cosmic Ray Conference (ICRC 2021)*

*July 12th – 23rd, 2021*

*Online – Berlin, Germany*

---

\*Presenter

## 1. Introduction

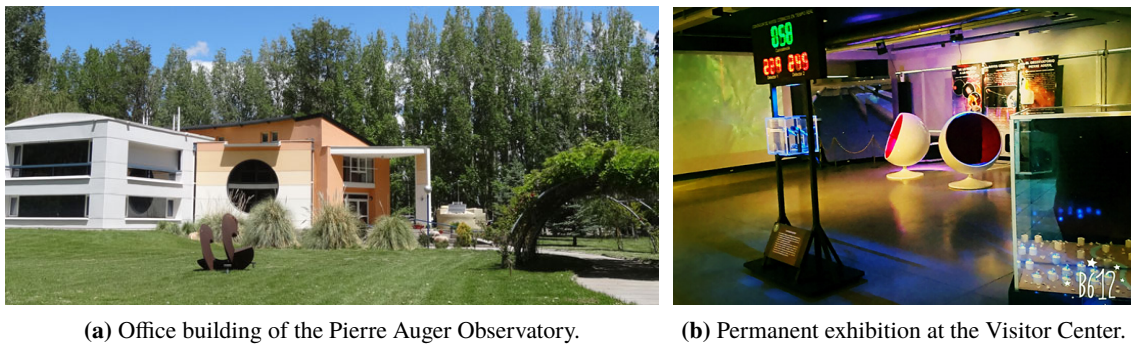
The Pierre Auger Observatory studies the most energetic astroparticles in the universe. It has been measuring UHECR for 12 years already with the complete original array. The area of the observatory is  $3000 \text{ km}^2$  and uses different kind of detectors, such as water-Cherenkov stations (WCD), Fluorescence Telescopes (FD), Scintillators and Radio antennas [1]. Some of the most important scientific discoveries made by the Auger Collaboration are the demonstration that cosmic rays above 8 EeV are of extragalactic origin [2] and the observation of a new feature in the energy spectrum at around 13 EeV [3]. The performance of the experiment relates not only to the scientific discoveries but also to the development of the technology used in the detectors. In the case of the Pierre Auger Observatory, its growth is bound to the interaction with the community of the place where it is located, Malargüe, Argentina, and with the communities of all institutions in the 18 participating countries as well. The Collaboration has the responsibility of sharing with these communities information related to the science and technology which is being produced in the observatory. Therefore Outreach activities are very important to allow people from several kind of audiences to access the information the Collaboration needs to transmit. In the following sections some of these activities are described.

## 2. Auger Observatory, Visitor Center and Web page

The Collaboration has prepared a section devoted to outreach efforts at its web site under the tab *Outreach* [4], most of the activities and resources are available in english and spanish. The Observatary itself is already a very impressive effort of technology to be appreciated by the visitors of the Pampa Amarilla in Argentina. When people travel through the roads and highways inside the Observatory, it is possible to distinguish the small water tanks following straight lines which disappear in the distance (Figure 1a). From the experience the travelers get already intrigued about what is the purpose of those tanks, and the locals are ready to explain them the presence of the huge facility of the Auger experiment. It has became part of the everyday life of the inhabitants of this part of Mendoza province. Once in Malargüe, where the office building of the Pierre Auger Observatory is located (Figure 2a), it is possible to go into the Visitor Center, which was created in 2001, with the main purpose of introducing the Observatory and the physics studied by the researchers involved, to the general public. The Visitor Center welcomes on average 8000 visitors a year (see Figure 3), which are mostly students from the local schools but also many tourists come to learn more about the Observatory. The activities performed in the Visitor Center are talks introducing the Observatory and permanent and interactive exhibitions (Figure 2b), which allows the access of visitors for almost the whole day. As part of the community of Malargüe, every year the Pierre Auger Observatory takes part of the parade celebrating the anniversary of the town (Figure 1b). Recently a virtual visitor tour has also been available in english and spanish, it can be found in the web of Auger at [6], this has became very important during the lockdown period, when the visits in person have been very limited. The staff of the Visitor Center also prepare leaflets and podcasts which can be distributed by the collaborators in the different countries where they come from.

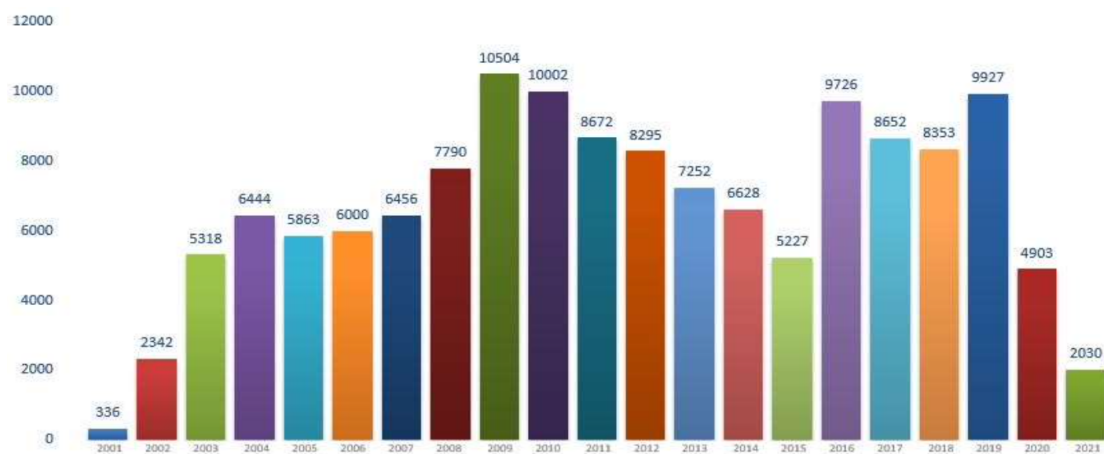


**Figure 1:** WCDs mixed in the landscape of Mendoza Province and the Collaboration in the parade.



**(a)** Office building of the Pierre Auger Observatory. **(b)** Permanent exhibition at the Visitor Center.

**Figure 2:** Visitor Center at Malargüe, Argentina.



**Figure 3:** Statistics of the number of visitors received at the Visitor Center [5]

### 3. Women in Science

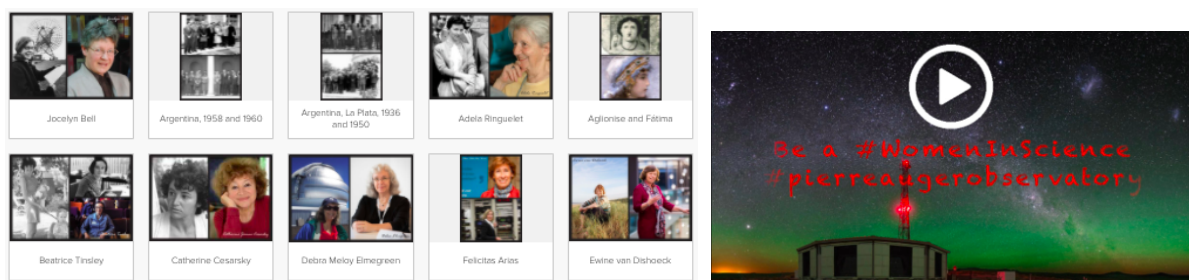
To highlight the importance of the work in science developed by women, a virtual exhibition, called "Women hold up half the sky" (Figure 4a) has been created, which can be found at [7], also available in spanish at [8]. Part of the exhibition is also shown at the Thesaurus Convention and Exhibition Center at the town of Malargüe. In every country collaborators participate in the STEM initiatives for women which take place, like the International Day of Women and Girls in Science on February 11. At last Women's day, March 8th., most of the female collaborators prepared few words on their experience being a woman in science and also a short video has been prepared [9]. The goal was to encourage women and girls to study and work in Science. (Figure 4b) The information can be found at [10].

### 4. Talks and Science fairs

Talks are the main tool for collaborators to share their results to the general public, these take place in each institution which is part of the Collaboration (Figure 5a). Every year during the Collaboration meeting in November a Science fair is organized at the site. The students from high schools from Malargüe present projects to the general public and members of the Pierre Auger Collaboration judge the projects, giving interesting comments and ideas as a feedback to the students (Figures 5b, 5c and 5d).

### 5. Data release and Software approach

The Observatory has collected a great deal of data in more than ten years of work. In 2021 the Collaboration decided to release 10% of the data used for the results reported at the International Cosmic Ray Conference 2019. The purpose of the release is to allow a wide community including professional scientists, people interested in education and outreach initiatives, and citizen scientists to re-use the data in their projects. This first sample amounts to over 20000 showers measured with the surface detector array and over 3000 hybrid events obtained from the surface and fluorescence detectors. These data are made available as pseudo-raw data in JSON format. Detailed explanations



(a) Online Exhibition *Women hold up half the sky*.

(b) Messages by female collagorators for girls and women interested in science.

**Figure 4:** Outreach actions for women in science.

of the data, and the conditions under which the data were taken, along with simple software tools for analyzing them, are provided in the Open Data portal [11], see also [12]. There are other tools for displaying the data as a Public Event Browser available at [13] with simplified data from the SD that have been widely used for outreach purposes since 2007, and a tool for performing standard analysis online at [14].

## 6. Master Classes

The Master Classes are a very powerful tool to get high school students involved in the work made in the big experiments since years. The Pierre Auger Collaboration has prepared Master Classes to reinforce outreach efforts, one of them is called "Hands on Cosmic Rays @ the Pierre Auger Observatory" (LIP, Portugal). This consists of lectures, a work guide in several languages, and files to perform examples of data analysis with an Event Visualizer (Figure 6); which is complemented with the efforts of other Master Class which developed AGATA, A Graphical Analysis Tool for Auger masterclass (INFN, Italy). More information can be found at [15].



(a) Talk during the *Science fair*.



(b) Visitors and judges.



(c) Participants.



(d) Staff, visitors, participants and judges.

**Figure 5:** Science fair in Malargüe.

## 7. International Cosmic Day and other events

The ICD is organized every year by DESY [16]. During this event students from all around the world perform measurements of atmospheric muons at the same time. In every participant institution, the local organizers can also give talks and conduct the measurement, at the end the students write a scientific report, which is published by DESY. Several institutions members of Auger take part of this experience every year (Figures 7a and 7b). In every institution there are different ideas and efforts to perform outreach according to their resources and specific interests. In this sense, some institutions have prepared puzzles, interactive games, documents, artistic expressions as painting or music (Figure 8a) [17], installation of devices like projection globes (Figure 8b), summer camps, workshops, schools, etc. Other international events devoted to outreach where the Pierre Auger Collaboration participates are Frontiers from H2020 [19], and the Outreach Cosmic Ray Activities (OCRA) [20] among others.

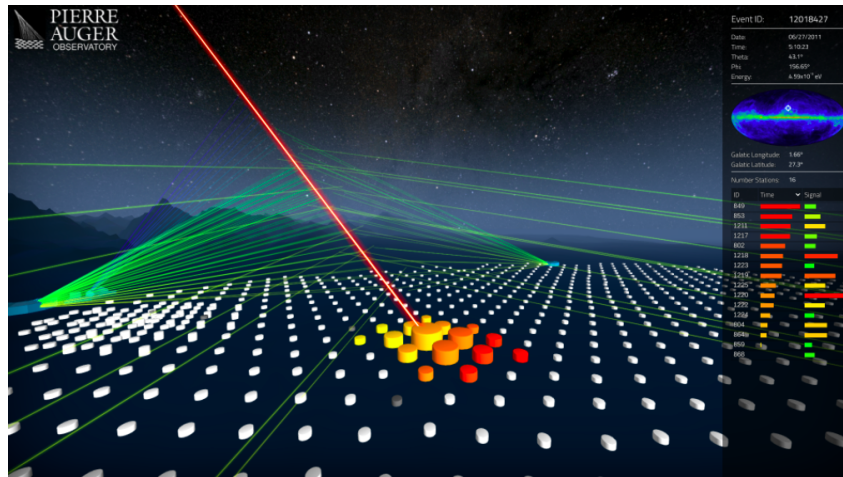


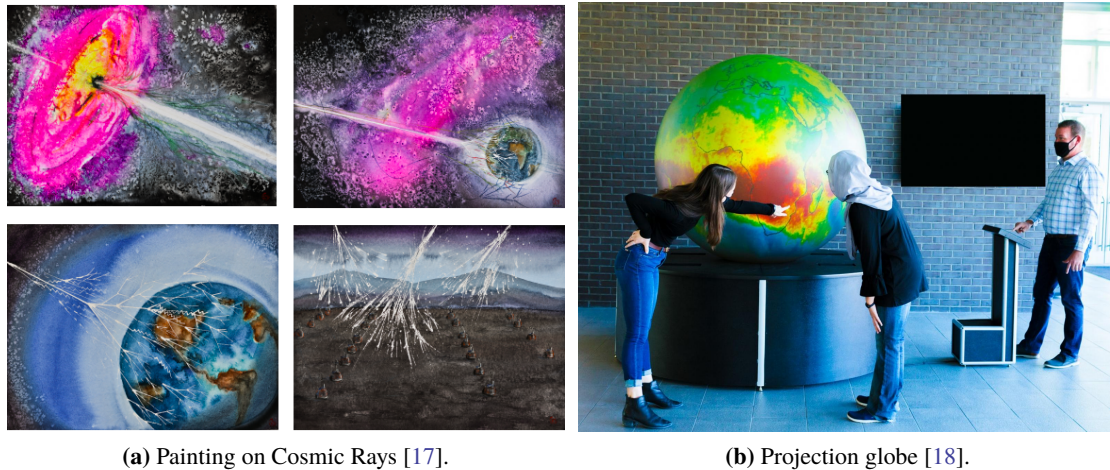
Figure 6: Event Visualizer for the Master Classes.



(a) Some ICD OCRA cities in Italy.

(b) Nijmegen, The Netherlands.

Figure 7: The ICD in two of the Countries members of The Pierre Auger Collaboration.



(a) Painting on Cosmic Rays [17].

(b) Projection globe [18].

**Figure 8:** Examples of different efforts on outreach in the frame of the Pierre Auger Collaboration.

## References

- [1] A. Castellina [for the Pierre Auger Coll.], *Epj. Web Conf.* **210** (2019) 06002.
- [2] A. Aab et al. [Pierre Auger Coll.], *ApJL* **853** (2018) L29.
- [3] A. Aab et al. [Pierre Auger Coll.], *Phys. Rev. Lett.* **125** (2020) 121106.
- [4] <https://www.auger.org/index.php>
- [5] Prepared by Analía Cáceres from the Visitor Center staff.
- [6] <https://izi.travel/en/6095-pierre-auger-observatory/en>
- [7] <https://izi.travel/en/c824-women-hold-up-half-the-sky/en>
- [8] <https://izi.travel/en/c824-las-mujeres-sostienen-la-mitad-del-cielo/es>
- [9] <https://www.youtube.com/watch?v=e69ccX5Rw0Y>
- [10] <https://www.auger.org/index.php/edu-outreach/women-in-science>
- [11] <https://opendata.auger.org/>
- [12] V. Scherini [for the Pierre Auger Coll.], these proceedings.
- [13] <https://labdpr.cab.cnea.gov.ar/ED/index.php?lang=en>
- [14] <https://vispa.physik.rwth-aachen.de/>
- [15] <https://www.lip.pt/experiments/auger/?p=public-data>
- [16] <https://icd.desy.de>
- [17] <http://www.spacescience.ro/collaborations/auger/>, tabs *Tools* and *Art*.
- [18] <https://www.minesnewsroom.com/news/mines-sphere-new-projection-globe-installed-coorstek-center-atrium>
- [19] <https://ec.europa.eu/programmes/horizon2020/en/tags/frontier-research>
- [20] <https://web.infn.it/OCRA/>

## The Pierre Auger Collaboration



PIERRE  
AUGER  
OBSERVATORY

P. Abreu<sup>72</sup>, M. Aglietta<sup>54,52</sup>, J.M. Albury<sup>13</sup>, I. Allekotte<sup>1</sup>, A. Almela<sup>8,12</sup>, J. Alvarez-Muñiz<sup>79</sup>, R. Alves Batista<sup>80</sup>, G.A. Anastasi<sup>63,52</sup>, L. Anchordoqui<sup>87</sup>, B. Andrada<sup>8</sup>, S. Andringa<sup>72</sup>, C. Aramo<sup>50</sup>, P.R. Araújo Ferreira<sup>42</sup>, J. C. Arteaga Velázquez<sup>67</sup>, H. Asorey<sup>8</sup>, P. Assis<sup>72</sup>, G. Avila<sup>11</sup>, A.M. Badescu<sup>75</sup>, A. Bakalova<sup>32</sup>, A. Balaceanu<sup>73</sup>, F. Barbato<sup>45,46</sup>, R.J. Bareaire Luz<sup>72</sup>, K.H. Becker<sup>38</sup>, J.A. Bellido<sup>13,69</sup>, C. Berat<sup>36</sup>, M.E. Bertaina<sup>63,52</sup>, X. Bertou<sup>1</sup>, P.L. Biermann<sup>b</sup>, V. Binet<sup>6</sup>, K. Bismark<sup>39,8</sup>, T. Bister<sup>42</sup>, J. Biteau<sup>37</sup>, J. Blazek<sup>32</sup>, C. Bleve<sup>36</sup>, M. Boháčová<sup>32</sup>, D. Boncioli<sup>57,46</sup>, C. Bonifazi<sup>9,26</sup>, L. Bonneau Arbeletche<sup>21</sup>, N. Borodai<sup>70</sup>, A.M. Botti<sup>8</sup>, J. Brack<sup>d</sup>, T. Bretz<sup>42</sup>, P.G. Bricchetto Orchera<sup>8</sup>, F.L. Briechele<sup>42</sup>, P. Buchholz<sup>44</sup>, A. Bueno<sup>78</sup>, S. Buitink<sup>15</sup>, M. Buscemi<sup>47</sup>, M. Büsken<sup>39,8</sup>, K.S. Caballero-Mora<sup>66</sup>, L. Caccianiga<sup>59,49</sup>, F. Canfora<sup>80,81</sup>, I. Caracas<sup>38</sup>, J.M. Carceller<sup>78</sup>, R. Caruso<sup>58,47</sup>, A. Castellina<sup>54,52</sup>, F. Catalani<sup>19</sup>, G. Cataldi<sup>48</sup>, L. Cazon<sup>72</sup>, M. Cerda<sup>10</sup>, J.A. Chinellato<sup>22</sup>, J. Chudoba<sup>32</sup>, L. Chytka<sup>33</sup>, R.W. Clay<sup>13</sup>, A.C. Cobos Cerutti<sup>7</sup>, R. Colalillo<sup>60,50</sup>, A. Coleman<sup>93</sup>, M.R. Coluccia<sup>48</sup>, R. Conceição<sup>72</sup>, A. Condorelli<sup>45,46</sup>, G. Consolati<sup>49,55</sup>, F. Contreras<sup>11</sup>, F. Convenga<sup>56,48</sup>, D. Correia dos Santos<sup>28</sup>, C.E. Covault<sup>85</sup>, S. Dasso<sup>5,3</sup>, K. Daumiller<sup>41</sup>, B.R. Dawson<sup>13</sup>, J.A. Day<sup>13</sup>, R.M. de Almeida<sup>28</sup>, J. de Jesús<sup>8,41</sup>, S.J. de Jong<sup>80,81</sup>, G. De Mauro<sup>80,81</sup>, J.R.T. de Mello Neto<sup>26,27</sup>, I. De Mitri<sup>45,46</sup>, J. de Oliveira<sup>18</sup>, D. de Oliveira Franco<sup>22</sup>, F. de Palma<sup>56,48</sup>, V. de Souza<sup>20</sup>, E. De Vito<sup>56,48</sup>, M. del Río<sup>11</sup>, O. Deligny<sup>34</sup>, L. Deval<sup>41,8</sup>, A. di Matteo<sup>52</sup>, C. Dobrigkeit<sup>22</sup>, J.C. D'Olivo<sup>68</sup>, L.M. Domingues Mendes<sup>72</sup>, R.C. dos Anjos<sup>25</sup>, D. dos Santos<sup>28</sup>, M.T. Dova<sup>4</sup>, J. Ebr<sup>32</sup>, R. Engel<sup>39,41</sup>, I. Epicoco<sup>56,48</sup>, M. Erdmann<sup>42</sup>, C.O. Escobar<sup>a</sup>, A. Etchegoyen<sup>8,12</sup>, H. Falcke<sup>80,82,81</sup>, J. Farmer<sup>92</sup>, G. Farrar<sup>90</sup>, A.C. Fauth<sup>22</sup>, N. Fazzini<sup>a</sup>, F. Feldbusch<sup>40</sup>, F. Fenu<sup>54,52</sup>, B. Fick<sup>89</sup>, J.M. Figueira<sup>8</sup>, A. Filipčić<sup>77,76</sup>, T. Fitoussi<sup>41</sup>, T. Fodran<sup>80</sup>, M.M. Freire<sup>6</sup>, T. Fujii<sup>92,e</sup>, A. Fuster<sup>8,12</sup>, C. Galea<sup>80</sup>, C. Galelli<sup>59,49</sup>, B. García<sup>7</sup>, A.L. Garcia Vegas<sup>42</sup>, H. Gemmeke<sup>40</sup>, F. Gesualdi<sup>8,41</sup>, A. Gherghel-Lascu<sup>73</sup>, P.L. Ghia<sup>34</sup>, U. Giaccari<sup>80</sup>, M. Giammarchi<sup>49</sup>, J. Glombitza<sup>42</sup>, F. Gobbi<sup>10</sup>, F. Gollan<sup>8</sup>, G. Golup<sup>1</sup>, M. Gómez Berisso<sup>1</sup>, P.F. Gómez Vitale<sup>11</sup>, J.P. Gongora<sup>11</sup>, J.M. González<sup>1</sup>, N. González<sup>14</sup>, I. Goos<sup>1,41</sup>, D. Góra<sup>70</sup>, A. Gorgi<sup>54,52</sup>, M. Gottowik<sup>38</sup>, T.D. Grubb<sup>13</sup>, F. Guarino<sup>60,50</sup>, G.P. Guedes<sup>23</sup>, E. Guido<sup>52,63</sup>, S. Hahn<sup>41,8</sup>, P. Hamal<sup>32</sup>, M.R. Hampel<sup>8</sup>, P. Hansen<sup>4</sup>, D. Harari<sup>1</sup>, V.M. Harvey<sup>13</sup>, A. Haungs<sup>41</sup>, T. Hebbeker<sup>42</sup>, D. Heck<sup>41</sup>, G.C. Hill<sup>13</sup>, C. Hojvat<sup>a</sup>, J.R. Hörandel<sup>80,81</sup>, P. Horvath<sup>33</sup>, M. Hrabovský<sup>33</sup>, T. Huege<sup>41,15</sup>, A. Insolia<sup>58,47</sup>, P.G. Isar<sup>74</sup>, P. Janecek<sup>32</sup>, J.A. Johnsen<sup>86</sup>, J. Jurysek<sup>32</sup>, A. Kääpä<sup>38</sup>, K.H. Kampert<sup>38</sup>, N. Karastathis<sup>41</sup>, B. Keilhauer<sup>41</sup>, J. Kemp<sup>42</sup>, A. Khakurdikar<sup>80</sup>, V.V. Kizakke Covilakam<sup>8,41</sup>, H.O. Klages<sup>41</sup>, M. Kleifges<sup>40</sup>, J. Kleinfeller<sup>10</sup>, M. Köpke<sup>39</sup>, N. Kunka<sup>40</sup>, B.L. Lago<sup>17</sup>, R.G. Lang<sup>20</sup>, N. Langner<sup>42</sup>, M.A. Leigui de Oliveira<sup>24</sup>, V. Lenok<sup>41</sup>, A. Letessier-Selvon<sup>35</sup>, I. Lhenry-Yvon<sup>34</sup>, D. Lo Presti<sup>58,47</sup>, L. Lopes<sup>72</sup>, R. López<sup>64</sup>, L. Lu<sup>94</sup>, Q. Luce<sup>39</sup>, J.P. Lundquist<sup>76</sup>, A. Machado Payeras<sup>22</sup>, G. Mancarella<sup>56,48</sup>, D. Mandat<sup>32</sup>, B.C. Manning<sup>13</sup>, J. Manshanden<sup>43</sup>, P. Mantsch<sup>a</sup>, S. Marafico<sup>34</sup>, A.G. Mariuzzi<sup>4</sup>, I.C. Mariş<sup>14</sup>, G. Marsella<sup>61,47</sup>, D. Martello<sup>56,48</sup>, S. Martinelli<sup>41,8</sup>, O. Martínez Bravo<sup>64</sup>, M. Mastrodicasa<sup>57,46</sup>, H.J. Mathes<sup>41</sup>, J. Matthews<sup>88</sup>, G. Matthiae<sup>62,51</sup>, E. Mayotte<sup>38</sup>, P.O. Mazur<sup>a</sup>, G. Medina-Tanco<sup>68</sup>, D. Melo<sup>8</sup>, A. Menshikov<sup>40</sup>, K.-D. Merenda<sup>86</sup>, S. Michal<sup>33</sup>, M.I. Micheletti<sup>6</sup>, L. Miramonti<sup>59,49</sup>, S. Mollerach<sup>1</sup>, F. Montanet<sup>36</sup>, C. Morello<sup>54,52</sup>, M. Mostafá<sup>91</sup>, A.L. Müller<sup>8</sup>, M.A. Muller<sup>22</sup>, K. Mulrey<sup>15</sup>, R. Mussa<sup>52</sup>, M. Muzio<sup>90</sup>, W.M. Namasaka<sup>38</sup>, A. Nasr-Esfahani<sup>38</sup>, L. Nellen<sup>68</sup>, M. Niculescu-Oglinazu<sup>73</sup>, M. Niechciol<sup>44</sup>, D. Nitz<sup>89</sup>, D. Nosek<sup>31</sup>, V. Novotny<sup>31</sup>, L. Nožka<sup>33</sup>, A. Nucita<sup>56,48</sup>, L.A. Núñez<sup>30</sup>, M. Palatka<sup>32</sup>, J. Pallotta<sup>2</sup>, P. Papenbreer<sup>38</sup>, G. Parente<sup>79</sup>, A. Parra<sup>64</sup>, J. Pawlowsky<sup>38</sup>, M. Pech<sup>32</sup>, F. Pedreira<sup>79</sup>, J. Pękala<sup>70</sup>, R. Pelayo<sup>65</sup>, J. Peña-Rodríguez<sup>30</sup>, E.E. Pereira Martins<sup>39,8</sup>, J. Perez Armand<sup>21</sup>, C. Pérez Bertoli<sup>8,41</sup>, M. Perlin<sup>8,41</sup>, L. Perrone<sup>56,48</sup>, S. Petretera<sup>45,46</sup>, T. Pierog<sup>41</sup>, M. Pimenta<sup>72</sup>, V. Pirronello<sup>58,47</sup>, M. Platino<sup>8</sup>, B. Pont<sup>80</sup>, M. Pothast<sup>81,80</sup>, P. Privitera<sup>92</sup>, M. Prouza<sup>32</sup>, A. Puyleart<sup>89</sup>, S. Querchfeld<sup>38</sup>, J. Rautenberg<sup>38</sup>, D. Ravnani<sup>8</sup>, M. Reininghaus<sup>41,8</sup>, J. Ridky<sup>32</sup>, F. Riehn<sup>72</sup>, M. Risse<sup>44</sup>, V. Rizi<sup>57,46</sup>, W. Rodrigues de Carvalho<sup>21</sup>, J. Rodriguez Rojo<sup>11</sup>, M.J. Roncoroni<sup>8</sup>, S. Rossoni<sup>43</sup>, M. Roth<sup>41</sup>, E. Roulet<sup>1</sup>, A.C. Rovero<sup>5</sup>, P. Ruehl<sup>44</sup>, A. Saftoiu<sup>73</sup>, F. Salamida<sup>57,46</sup>, H. Salazar<sup>64</sup>, G. Salina<sup>51</sup>, J.D. Sanabria Gomez<sup>30</sup>, F. Sánchez<sup>8</sup>, E.M. Santos<sup>21</sup>, E. Santos<sup>32</sup>, F. Sarazin<sup>86</sup>, R. Sarmento<sup>72</sup>, C. Sarmiento-Cano<sup>8</sup>, R. Sato<sup>11</sup>,



P. Savina<sup>56,48,34,94</sup>, C.M. Schäfer<sup>41</sup>, V. Scherini<sup>56,48</sup>, H. Schieler<sup>41</sup>, M. Schimassek<sup>39,8</sup>, M. Schimp<sup>38</sup>, F. Schlüter<sup>41,8</sup>, D. Schmidt<sup>39</sup>, O. Scholten<sup>84,15</sup>, P. Schovánek<sup>32</sup>, F.G. Schröder<sup>93,41</sup>, S. Schröder<sup>38</sup>, J. Schulte<sup>42</sup>, S.J. Sciutto<sup>4</sup>, M. Scornavacche<sup>8,41</sup>, A. Segreto<sup>53,47</sup>, S. Sehgal<sup>38</sup>, R.C. Shellard<sup>16</sup>, G. Sigl<sup>43</sup>, G. Silli<sup>8,41</sup>, O. Sima<sup>73,f</sup>, R. Šmída<sup>92</sup>, P. Sommers<sup>91</sup>, J.F. Soriano<sup>87</sup>, J. Souchard<sup>36</sup>, R. Squartini<sup>10</sup>, M. Stadelmaier<sup>41,8</sup>, D. Stanca<sup>73</sup>, S. Stanič<sup>76</sup>, J. Stasielak<sup>70</sup>, P. Stassi<sup>36</sup>, A. Streich<sup>39,8</sup>, M. Suárez-Durán<sup>14</sup>, T. Sudholz<sup>13</sup>, T. Suomijärvi<sup>37</sup>, A.D. Supanitsky<sup>8</sup>, Z. Szadkowski<sup>71</sup>, A. Tapia<sup>29</sup>, C. Taricco<sup>63,52</sup>, C. Timmermans<sup>81,80</sup>, O. Tkachenko<sup>41</sup>, P. Tobiska<sup>32</sup>, C.J. Toderó Peixoto<sup>19</sup>, B. Tomé<sup>72</sup>, Z. Torrès<sup>36</sup>, A. Travaini<sup>10</sup>, P. Travnicek<sup>32</sup>, C. Trimarelli<sup>57,46</sup>, M. Tueros<sup>4</sup>, R. Ulrich<sup>41</sup>, M. Unger<sup>41</sup>, L. Vaclavěk<sup>33</sup>, M. Vacula<sup>33</sup>, J.F. Valdés Galicia<sup>68</sup>, L. Valore<sup>60,50</sup>, E. Varela<sup>64</sup>, A. Vásquez-Ramírez<sup>30</sup>, D. Veberič<sup>41</sup>, C. Ventura<sup>27</sup>, I.D. Vergara Quispe<sup>4</sup>, V. Verzi<sup>51</sup>, J. Vicha<sup>32</sup>, J. Vink<sup>83</sup>, S. Vorobiov<sup>76</sup>, H. Wahlberg<sup>4</sup>, C. Watanabe<sup>26</sup>, A.A. Watson<sup>c</sup>, M. Weber<sup>40</sup>, A. Weindl<sup>41</sup>, L. Wiencke<sup>86</sup>, H. Wilczyński<sup>70</sup>, M. Wirtz<sup>42</sup>, D. Wittkowski<sup>38</sup>, B. Wundheiler<sup>8</sup>, A. Yushkov<sup>32</sup>, O. Zapparrata<sup>14</sup>, E. Zas<sup>79</sup>, D. Zavrtanik<sup>76,77</sup>, M. Zavrtanik<sup>77,76</sup>, L. Zehrer<sup>76</sup>

- 
- <sup>1</sup> Centro Atómico Bariloche and Instituto Balseiro (CNEA-UNCuyo-CONICET), San Carlos de Bariloche, Argentina  
<sup>2</sup> Centro de Investigaciones en Láseres y Aplicaciones, CITEDEF and CONICET, Villa Martelli, Argentina  
<sup>3</sup> Departamento de Física and Departamento de Ciencias de la Atmósfera y los Océanos, FCEyN, Universidad de Buenos Aires and CONICET, Buenos Aires, Argentina  
<sup>4</sup> IFLP, Universidad Nacional de La Plata and CONICET, La Plata, Argentina  
<sup>5</sup> Instituto de Astronomía y Física del Espacio (IAFE, CONICET-UBA), Buenos Aires, Argentina  
<sup>6</sup> Instituto de Física de Rosario (IFIR) – CONICET/U.N.R. and Facultad de Ciencias Bioquímicas y Farmacéuticas U.N.R., Rosario, Argentina  
<sup>7</sup> Instituto de Tecnologías en Detección y Astropartículas (CNEA, CONICET, UNSAM), and Universidad Tecnológica Nacional – Facultad Regional Mendoza (CONICET/CNEA), Mendoza, Argentina  
<sup>8</sup> Instituto de Tecnologías en Detección y Astropartículas (CNEA, CONICET, UNSAM), Buenos Aires, Argentina  
<sup>9</sup> International Center of Advanced Studies and Instituto de Ciencias Físicas, ECyT-UNSAM and CONICET, Campus Miguelete – San Martín, Buenos Aires, Argentina  
<sup>10</sup> Observatorio Pierre Auger, Malargüe, Argentina  
<sup>11</sup> Observatorio Pierre Auger and Comisión Nacional de Energía Atómica, Malargüe, Argentina  
<sup>12</sup> Universidad Tecnológica Nacional – Facultad Regional Buenos Aires, Buenos Aires, Argentina  
<sup>13</sup> University of Adelaide, Adelaide, S.A., Australia  
<sup>14</sup> Université Libre de Bruxelles (ULB), Brussels, Belgium  
<sup>15</sup> Vrije Universiteit Brussels, Brussels, Belgium  
<sup>16</sup> Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, RJ, Brazil  
<sup>17</sup> Centro Federal de Educação Tecnológica Celso Suckow da Fonseca, Nova Friburgo, Brazil  
<sup>18</sup> Instituto Federal de Educação, Ciência e Tecnologia do Rio de Janeiro (IFRJ), Brazil  
<sup>19</sup> Universidade de São Paulo, Escola de Engenharia de Lorena, Lorena, SP, Brazil  
<sup>20</sup> Universidade de São Paulo, Instituto de Física de São Carlos, São Carlos, SP, Brazil  
<sup>21</sup> Universidade de São Paulo, Instituto de Física, São Paulo, SP, Brazil  
<sup>22</sup> Universidade Estadual de Campinas, IFGW, Campinas, SP, Brazil  
<sup>23</sup> Universidade Estadual de Feira de Santana, Feira de Santana, Brazil  
<sup>24</sup> Universidade Federal do ABC, Santo André, SP, Brazil  
<sup>25</sup> Universidade Federal do Paraná, Setor Palotina, Palotina, Brazil  
<sup>26</sup> Universidade Federal do Rio de Janeiro, Instituto de Física, Rio de Janeiro, RJ, Brazil  
<sup>27</sup> Universidade Federal do Rio de Janeiro (UFRJ), Observatório do Valongo, Rio de Janeiro, RJ, Brazil  
<sup>28</sup> Universidade Federal Fluminense, EEIMVR, Volta Redonda, RJ, Brazil  
<sup>29</sup> Universidad de Medellín, Medellín, Colombia  
<sup>30</sup> Universidad Industrial de Santander, Bucaramanga, Colombia  
<sup>31</sup> Charles University, Faculty of Mathematics and Physics, Institute of Particle and Nuclear Physics, Prague, Czech Republic  
<sup>32</sup> Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic

- <sup>33</sup> Palacky University, RCPTM, Olomouc, Czech Republic
- <sup>34</sup> CNRS/IN2P3, IJCLab, Université Paris-Saclay, Orsay, France
- <sup>35</sup> Laboratoire de Physique Nucléaire et de Hautes Energies (LPNHE), Sorbonne Université, Université de Paris, CNRS-IN2P3, Paris, France
- <sup>36</sup> Univ. Grenoble Alpes, CNRS, Grenoble Institute of Engineering Univ. Grenoble Alpes, LPSC-IN2P3, 38000 Grenoble, France
- <sup>37</sup> Université Paris-Saclay, CNRS/IN2P3, IJCLab, Orsay, France
- <sup>38</sup> Bergische Universität Wuppertal, Department of Physics, Wuppertal, Germany
- <sup>39</sup> Karlsruhe Institute of Technology (KIT), Institute for Experimental Particle Physics, Karlsruhe, Germany
- <sup>40</sup> Karlsruhe Institute of Technology (KIT), Institut für Prozessdatenverarbeitung und Elektronik, Karlsruhe, Germany
- <sup>41</sup> Karlsruhe Institute of Technology (KIT), Institute for Astroparticle Physics, Karlsruhe, Germany
- <sup>42</sup> RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
- <sup>43</sup> Universität Hamburg, II. Institut für Theoretische Physik, Hamburg, Germany
- <sup>44</sup> Universität Siegen, Department Physik – Experimentelle Teilchenphysik, Siegen, Germany
- <sup>45</sup> Gran Sasso Science Institute, L'Aquila, Italy
- <sup>46</sup> INFN Laboratori Nazionali del Gran Sasso, Assergi (L'Aquila), Italy
- <sup>47</sup> INFN, Sezione di Catania, Catania, Italy
- <sup>48</sup> INFN, Sezione di Lecce, Lecce, Italy
- <sup>49</sup> INFN, Sezione di Milano, Milano, Italy
- <sup>50</sup> INFN, Sezione di Napoli, Napoli, Italy
- <sup>51</sup> INFN, Sezione di Roma “Tor Vergata”, Roma, Italy
- <sup>52</sup> INFN, Sezione di Torino, Torino, Italy
- <sup>53</sup> Istituto di Astrofisica Spaziale e Fisica Cosmica di Palermo (INAF), Palermo, Italy
- <sup>54</sup> Osservatorio Astrofisico di Torino (INAF), Torino, Italy
- <sup>55</sup> Politecnico di Milano, Dipartimento di Scienze e Tecnologie Aerospaziali, Milano, Italy
- <sup>56</sup> Università del Salento, Dipartimento di Matematica e Fisica “E. De Giorgi”, Lecce, Italy
- <sup>57</sup> Università dell’Aquila, Dipartimento di Scienze Fisiche e Chimiche, L’Aquila, Italy
- <sup>58</sup> Università di Catania, Dipartimento di Fisica e Astronomia, Catania, Italy
- <sup>59</sup> Università di Milano, Dipartimento di Fisica, Milano, Italy
- <sup>60</sup> Università di Napoli “Federico II”, Dipartimento di Fisica “Ettore Pancini”, Napoli, Italy
- <sup>61</sup> Università di Palermo, Dipartimento di Fisica e Chimica “E. Segrè”, Palermo, Italy
- <sup>62</sup> Università di Roma “Tor Vergata”, Dipartimento di Fisica, Roma, Italy
- <sup>63</sup> Università Torino, Dipartimento di Fisica, Torino, Italy
- <sup>64</sup> Benemérita Universidad Autónoma de Puebla, Puebla, México
- <sup>65</sup> Unidad Profesional Interdisciplinaria en Ingeniería y Tecnologías Avanzadas del Instituto Politécnico Nacional (UPIITA-IPN), México, D.F., México
- <sup>66</sup> Universidad Autónoma de Chiapas, Tuxtla Gutiérrez, Chiapas, México
- <sup>67</sup> Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán, México
- <sup>68</sup> Universidad Nacional Autónoma de México, México, D.F., México
- <sup>69</sup> Universidad Nacional de San Agustín de Arequipa, Facultad de Ciencias Naturales y Formales, Arequipa, Peru
- <sup>70</sup> Institute of Nuclear Physics PAN, Krakow, Poland
- <sup>71</sup> University of Łódź, Faculty of High-Energy Astrophysics, Łódź, Poland
- <sup>72</sup> Laboratório de Instrumentação e Física Experimental de Partículas – LIP and Instituto Superior Técnico – IST, Universidade de Lisboa – UL, Lisboa, Portugal
- <sup>73</sup> “Horia Hulubei” National Institute for Physics and Nuclear Engineering, Bucharest-Magurele, Romania
- <sup>74</sup> Institute of Space Science, Bucharest-Magurele, Romania
- <sup>75</sup> University Politehnica of Bucharest, Bucharest, Romania
- <sup>76</sup> Center for Astrophysics and Cosmology (CAC), University of Nova Gorica, Nova Gorica, Slovenia
- <sup>77</sup> Experimental Particle Physics Department, J. Stefan Institute, Ljubljana, Slovenia
- <sup>78</sup> Universidad de Granada and C.A.F.P.E., Granada, Spain
- <sup>79</sup> Instituto Galego de Física de Altas Enerxías (IGFAE), Universidade de Santiago de Compostela, Santiago de Compostela, Spain

- <sup>80</sup> IMAPP, Radboud University Nijmegen, Nijmegen, The Netherlands  
<sup>81</sup> Nationaal Instituut voor Kernfysica en Hoge Energie Fysica (NIKHEF), Science Park, Amsterdam, The Netherlands  
<sup>82</sup> Stichting Astronomisch Onderzoek in Nederland (ASTRON), Dwingeloo, The Netherlands  
<sup>83</sup> Universiteit van Amsterdam, Faculty of Science, Amsterdam, The Netherlands  
<sup>84</sup> University of Groningen, Kapteyn Astronomical Institute, Groningen, The Netherlands  
<sup>85</sup> Case Western Reserve University, Cleveland, OH, USA  
<sup>86</sup> Colorado School of Mines, Golden, CO, USA  
<sup>87</sup> Department of Physics and Astronomy, Lehman College, City University of New York, Bronx, NY, USA  
<sup>88</sup> Louisiana State University, Baton Rouge, LA, USA  
<sup>89</sup> Michigan Technological University, Houghton, MI, USA  
<sup>90</sup> New York University, New York, NY, USA  
<sup>91</sup> Pennsylvania State University, University Park, PA, USA  
<sup>92</sup> University of Chicago, Enrico Fermi Institute, Chicago, IL, USA  
<sup>93</sup> University of Delaware, Department of Physics and Astronomy, Bartol Research Institute, Newark, DE, USA  
<sup>94</sup> University of Wisconsin-Madison, Department of Physics and WIPAC, Madison, WI, USA
- 
- <sup>a</sup> Fermi National Accelerator Laboratory, Fermilab, Batavia, IL, USA  
<sup>b</sup> Max-Planck-Institut für Radioastronomie, Bonn, Germany  
<sup>c</sup> School of Physics and Astronomy, University of Leeds, Leeds, United Kingdom  
<sup>d</sup> Colorado State University, Fort Collins, CO, USA  
<sup>e</sup> now at Hakubi Center for Advanced Research and Graduate School of Science, Kyoto University, Kyoto, Japan  
<sup>f</sup> also at University of Bucharest, Physics Department, Bucharest, Romania