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Updates on the Lake Design for SWGO

Hazal Goksu[a,*] **for the SWGO collaboration**

[a] *Max Planck Institut fur Kernphysik (MPIK), Saupfercheckweg 1, Heidelberg, Germany*

E-mail: hgoksu@mpi-hd.mpg.de

The lake concept is one of the detector design options considered for the Southern Wide-field Gamma-ray Observatory (SWGO), a next-generation high altitude gamma-ray observatory in the southern hemisphere consisting of an array of water Cherenkov detectors. With its wide energy range, wide field of view, large duty cycle and location it will complement the other existing and planned gamma-ray observatories. In the lake concept, instead of having tanks filled with water, bladders filled with clean water are deployed near the surface of a natural or artificial lake. Each bladder is a light-tight stand-alone unit containing one or more photosensors. The prototyping efforts for the lake concept are in an advanced stage with multiple options and factors, such as the impact of chosen materials on water quality, being considered. In this contribution, we will give an update on the planning and prototyping studies for this detector design option.

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*Speaker

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1. Introduction

The Southern Wide-field Gamma-ray Observatory (SWGO) is a next generation ground particle array that will be built in the Southern hemisphere. Similar to other similar ground particle gamma-ray observatories such as High-Altitude Water Cherenkov Observatory (HAWC) [1] and Large High Altitude Air Shower Observatory (LHAASO) [2], it will be an array of water Cherenkov detectors.

The individual water Cherenkov detector units of SWGO may consist of rotomolded or steel tanks or bladders floating in a body of water [5]. The lake concept is a possible unit detector design that is considered by SWGO, where light-tight stand-alone units containing one or more photosensors, namely bladders, filled with clean water are deployed near the surface of a natural or artificial lake. As outlined in a previous proceedings contribution [6], the lake design presents the advantage of an anticipated lower cost and higher flexibility in design, however, it also brings about a restriction of choice in sites and more requirements on bladders.

2. Detector Unit Design

The unit detectors in the lake design are separate stand-alone bladders that are kept in position with floaters. The bladders do not need support from any tank structure as they would be inside a large body of water.

The unit detector bladder is a circular structure with a photomultiplier tube (PMT) with a PVC support hanging from a hatch at the top side of the bladder. It is held in position with floaters, circular pipes filled with air that are connected to the bladder.

The bladder materials are required to have mechanical strength and durability, withstand increased UV radiation at high altitudes, be light tight and are needed to not contaminate the purified water they are filled with. If the bladders are to be placed in a natural lake, depending on the size of the lake the tensile strength requirements to withstand water motion becomes even more crucial. If instead an artificial lake is built to insert bladders, wave motion can be minimized. HDPE materials are seen to be ideal for this purpose, in light of our water contamination and light tightness tests. In order to fulfill these requirements, custom-made films with several layers would be used to manufacture bladders, this is similar to the approach of HAWC, LHAASO and the Pierre Auger Observatory [11] bladders.

The bladders are also expected to be double-chamber units, where the upper volume is for electromagnetic detection and the lower volume is for helping with muon identification. In the double-chamber designs, a single PMT support structure houses a PMT facing upward for the electromagnetic chamber, and a second PMT facing downward for the muon chamber. Optimization studies regarding the aspect ratio of these optically separate volumes [7] show that a ratio of 2.5 to 0.5 would optimize the cost and signal. The optimal height of these volumes also depends on their diameter. This study and other simulations show that having the lower layer coated with a reflective material would maximize its signal efficiency while worsening the timing. This trade-off is optimized with an upper chamber that has a partially reflective coating, and a lower chamber that is completely reflective.

There are different design options being considered for the reflective-material-coated lower chamber, shown in Figure 1. The first option is to have a bladder with a membrane in the middle,

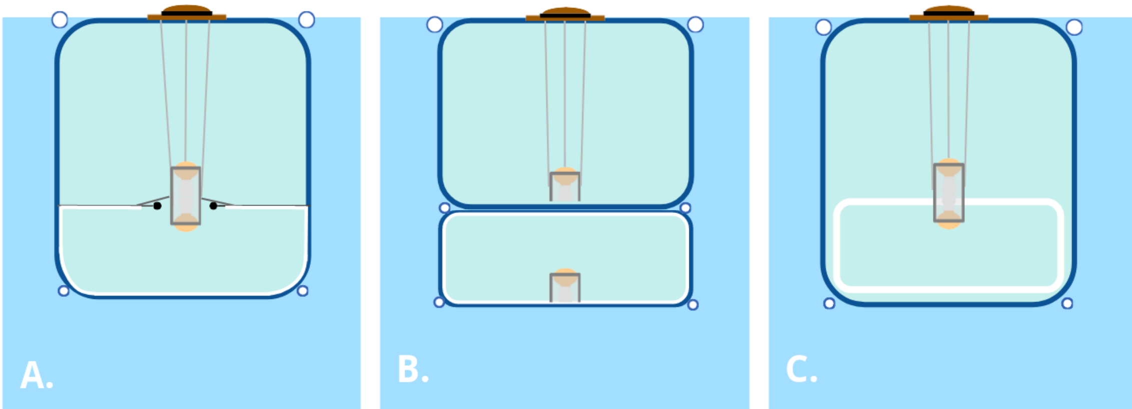

Figure 1: The options for the lower chamber. *A.* Double-layered bladder with a membrane. *B.* Two separate bladders are connected in the middle. *C.* A Tyvek-only bladder immersed in a bigger bladder.

the second option is to have two different bladders that are connected, and the third option is to have a bladder within the bladder approach. For the first two options, the reflective material needs to be connected directly to the outer bladder material. Although options such as spot gluing were tried out, the best option for large-scale production would be to laminate reflective material to the bladder material directly and produce the bladder afterward. The last option, bladder within bladder, or 'muon matryoshka', eliminates the need to connect the reflective liner to the outer bladder altogether. In this option, a bladder is made only using the reflective liner and is inserted along with the double-PMT setup inside the bladder.

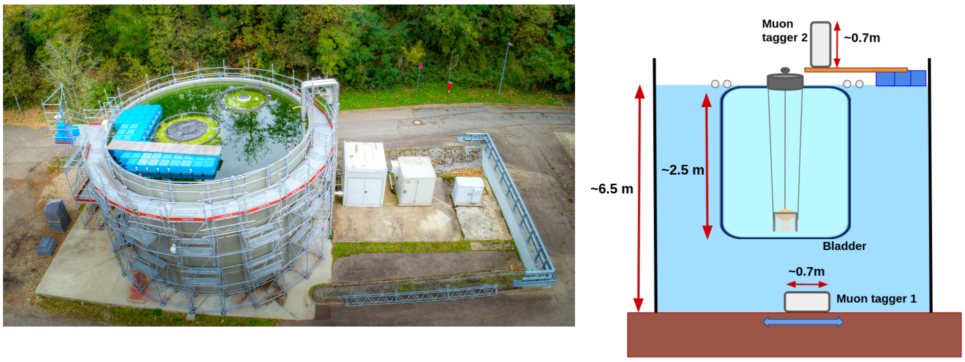

Figure 2: Lake Simulation Tank *Left:* The Lake simulation tank at MPIK has a 10-meter diameter and is 7 meters in height. It contains two prototype bladders *Right:* Sketch of the one-chamber PVC bladder inside lake simulation tank, along with two muon taggers. This setup was used to perform three-fold coincidence measurements.

3. Single Chamber Tests

Prior to double-layer tests, prototyping tests with bladders consisting of a single chamber were carried out. As was explained in the previous proceedings contribution [6], there is a lake simulation tank in our institute, seen in Figure 2. In order to make initial tests, we used two muon taggers to tag muons that passed through the entire water simulation tank, by inserting one at the bottom of our tank, one at the top, and putting our bladder of interest in the middle of these taggers. Each of the muon taggers consists of an 8-inch Hamamatsu R5912 PMT inside a commercial black barrel of 41 cm diameter and 75 cm length, lined with reflective material (Tyvek 1082D) and filled with clean water. We use two muon taggers to have well-defined particle trajectories, enabling us to make three-fold coincidence measurements.

Our first realistic-scale bladder was made up of PVC material, with one chamber and a single PMT inserted inside. The bladder has a hatch at the top, with the single PMT hanging via three ropes from the hatch as shown in the sketch in Figure 2.

Detector signals from the bladders and taggers inside the lake simulation tank are routed to a cabin next to the tank that is equipped with the *FlashCam* Data Acquisition(DAQ) system [8], which, throughout our studies, had a readout window of 128 samples and takes one sample every 4 nanoseconds, giving a total of 512 ns readout.

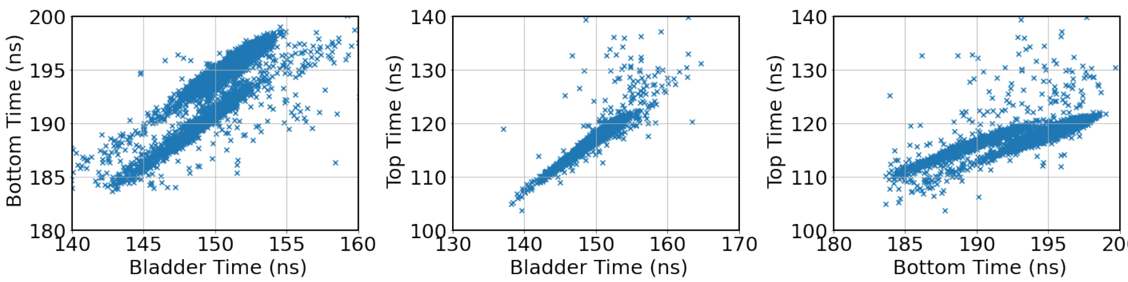

Figure 3: The time signal of the three-fold coincidence runs taken with the one-chamber PVC bladder. "Bottom" and "top" denote the bottom and top muon taggers. The 4 ns time difference between the two lines is within the precision of the ADC. The offset in the axis is due to the differences in cable length.

the plots in Figure 3 show our first three-fold coincidence measurements, using the two muon taggers and the bladder. For these measurements, a threshold of 20 LSB and a trigger condition of 100 ns between the top and bottom taggers was used. The correlation between the bladder and top & bottom muon taggers is seen in these plots, where the time difference is due to cable length differences. The measured coincidence rate is ≈ 0.017, which is consistent with simulations done using HAWCSim, a package based on GEANT4 [9] with water absorption lengths less than 1 m. Rates ranging from 0.010 to 0.05 were seen in these simulations.

These measurements were done with the PVC bladder, which was shown to degrade water quality significantly through our water absorption studies. Furthermore, the PVC bladder has a single chamber. Our next step would be to perform four-fold coincidence measurements using the two muon taggers and a bladder made from a more realistic material that has two chambers.

4. First Double Chamber Concept

Different double chamber concepts are being considered as shown in Figure 1. Options A and B most likely require the lamination of reflective materials (Tyvek) onto the outer bladder material, which should be done before the bladders are manufactured. On the other hand, option C is an approach we are able to use without waiting to produce our custom Tyvek-laminated bladder materials. Since we do not have such materials available to us at the moment, in order to be able to carry out double-chamber prototyping tests with our lake simulation tank, we are working on building an option C prototype in our facility in Heidelberg. We have already built the first 'matryoshka' prototype at the time of writing.

The first prototype for the lower chamber is made in the shape of an octagon that is held via a spider/umbrella structure made up of eight PVC pipes. The chamber is entirely made up of Tyvek 1082D and is spot-attached with a custom impulse heat sealer.

The umbrella mechanism is designed such that in its closed position the muon matryoshka is able to go through the hatch of a one-chamber bladder, and then once it is through the hatch, the umbrella structure can be opened via ropes.

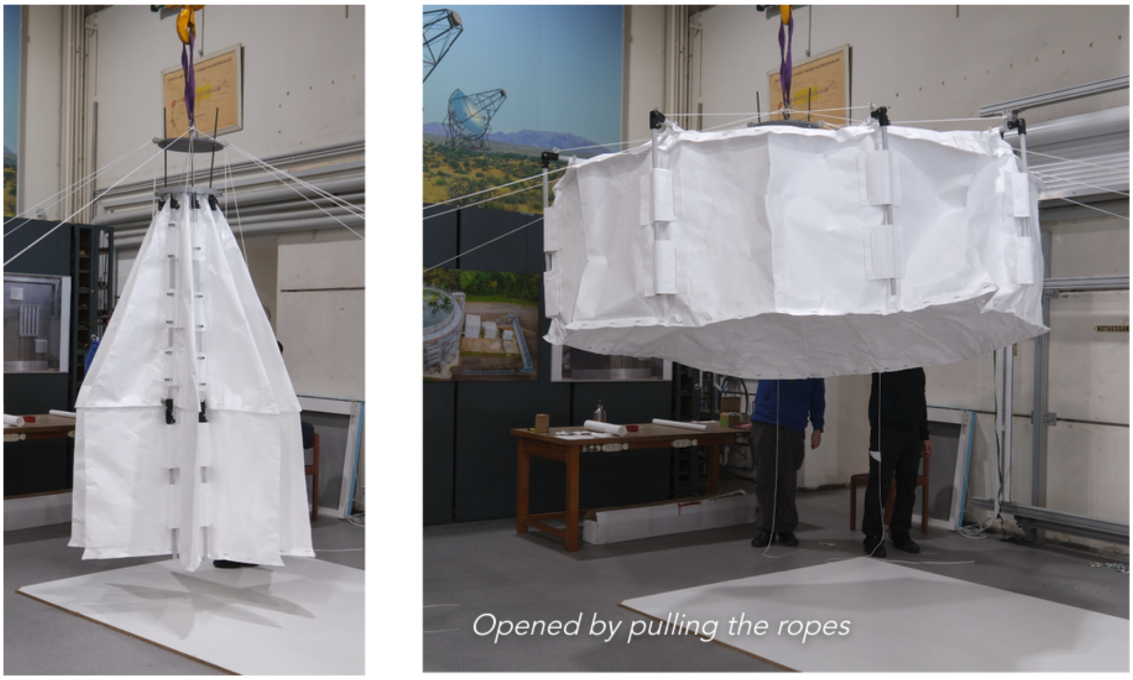

Figure 4: The prototyping of a muon matryoshka. *Left:* Muon matryoshka in closed position. *Right:* Muon matryoshka in open position, how it would sit inside the larger bladder.

Currently, we are carrying out mechanical tests to see the feasibility of this approach, as shown in Figure 4. After testing a 70 cm long diagonal prototype with four umbrella arms inside and outside water, we have built our very first full-scale prototype, with a 3/m long diagonal. We are in the process of testing this mechanism inside water. The 'muon matryoshka' could provide us with a quick way to make four-fold coincidence tests in our lake simulation tank and could also be a plausible option for the final array (including tank options).

5. Outlook

SWGO will be the first ground-particle gamma-ray observatory in the Southern Hemisphere and is expected to complement the existing ones in the North. The lake design is a promising unit detector design idea that is expected to be cost-effective.

The prototyping work done for the lake design is in close contact with any other alternative unit detector design that requires bladders that are in contact with purified water. Any bladder designed for the lake concept could also be used inside tanks. Moreover, the lake design is flexible in that it can be used inside suitable natural lakes as well as artificial ponds.

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Full Authors List: SWGO Collaboration

[0,2],P. Abreu [3],A. Albert [4],R. Alfaro [5],A. Alfonso [6],C. Álvarez [7],Q. An [8],E. O. Angüner [9],C. Arcaro [6],R. Arceo [10],S. Arias [11],H. Arnaldi [1,2],P. Assis [12],H. A. Ayala Solares [13],A. Bakalova [14,15],U. Barres de Almeida [9,16],I. Batkovic [17],J. Bazo [18,19],J. Bellido [4],E. Belmont [20],S. Y. BenZvi [21],A. Bernal [22],W. Bian [23],C. Bigongiari [9,16],E. Bottacini [1,2],P. Brogueira [24],T. Bulik [9,16],G. Busetto [6],K. S. Caballero-Mora [25,26],P. Camarri [27],S. Campos [7],W. Cao [7],Z. Cao [28],Z. Cao [21],T. Capistrán [23],M. Cardillo [29],E. Carquin [30],A. Carramiñana [31],C. Castromonte [28],J. Chang [32],O. Chaparro [22],S. Chen [33,34],M. Chianese [35,36],A. Chiavassa [13],L. Chytka [33,34],R. Colallillo [1,2],R. Conceição [37,38],G. Consolati [39],R. Cordero [1,2],P. J. Costa [40],J. Cotzomi [41],S. Dasso [9,16],A. De Angelis [42],P. Desiati [36],F. Di Pierro [25],G. Di Sciascio [42],J. C. Díaz Vélez [29],C. Dib [3],B. Dingus [43],J. Djuvsland [44],C. Dobrigkeit [1,45],L. M. Domingues Mendes [9],T. Dorigo [9,16],M. Doro [14],A. C. dos Reis [42],M. Du Vernois [5],M. Echiburú [46],D. Elsaesser [2,46],K. Engel [48],T. Ergin [5],F. Espinoza [42],K. Fang [49],F. Farfán Carreras [38,50],A. Fazzi [51],C. Feng [23],M. Feroci [21],N. Fraija [21],S. Fraija [16],A. Franceschini [14],G. F. Franco

[52],S. Funk [10],S. Garcia [53],J. A. García-González [21],F. Garfias [22],G. Giacinti [1,2],L. Gibilisco [52],J. Glombitza [43],H. Goksu [54],G. Gong [1,2],B. S. González [21],M. M. Gonzalez [47],J. Goodman [28],M. Gu [33,34],F. Guarino [55],S. Gupta [43],F. Haist [29],H. Hakobyan [56],G. Han [57],P. Hansen [3],J. P. Harding [5],J. Helo [58],I. Herzog [6],H. d. Hidalgo [43],J. Hinton [51],K. Hu [47],D. Huang [59],P. Huentemeyer [6],F. Hueyotl-Zahuantitla [21],A. Iriarte [60],J. Isaković [61],A. Isolia [52],V. Joshi [13],J. Juryšek [22],S. Kaci [62],D. Kieda [23],F. La Monaca [1],G. La Mura [52],R. G. Lang [27],R. Laspiur [34],L. Lavitola [63],J. Lee [52],F. Leitl [23],L. Lessio [28],C. Li [7],J. Li [28],K. Li [22],T. Li [25,26],B. Liberti [64],S. Lin [51],D. Liu [28],J. Liu [65],R. Liu [66,67],F. Longo [22],Y. Luo [68],J. Lv [38,50],E. Macerata [3],K. Malone [13],D. Mandat [60],M. Manganaro [38,50],M. Mariani [57],A. Mariazzi [9,16],M. Mariotti [43],T. Marrodan [32],J. Martinez [69],H. Martínez-Huerta [5],S. Medina [70],D. Melo [2],L. F. Mendes [72],E. Meza [9],D. Miceli [25],S. Miozzi [52],A. Mitchell [36,71],A. Molinario [6],O. G. Morales-Olivares [40],E. Moreno [25,26],A. Morselli [38,50],E. Mossini [12],M. Mostafá [23],F. Muleri [9,16],F. Nardi [35,36],A. Negro [73],L. Nellen [13],V. Novotny [66,67],E. Orlando [21],M. Osorio [72],L. Otiniano [35,36],M. Peresano [23],G. Piano [41],A. Pichel [9,16],M. Pihet [1,2],M. Pimenta [9,16],E. Prandini [7],J. Qin [72,74],E. Quispe [75],S. Rainò [21],E. Rangel [55],A. Reisenegger [43],H. Ren [60],F. Reščić [43],B. Reville [76],C. D. Rho [77],M. Riquelme [25],G. Rodriguez Fernandez [63],Y. Roh [49],G. E. Romero [34],B. Rossi [41],A. C. Rovero [43],E. Ruiz-Velasco [27],G. Salazar [72],J. Samanes [70],F. Sanchez [4],A. Sandoval [78],M. Santander [25,26],R. Santonico [14],G. L. P. Santos [33,34],N. Saviano [47],M. Schneider [52],M. Schneider [79],H. Schoorlemmer [4],J. Serna-Franco [27],V. Serrano [47],A. Smith [63],Y. Son [80],O. Soto [62],R. W. Springer [81],L. A. Stuani [51],H. Sun [22],R. Tang [7],Z. Tang [29],S. Tapia [23],M. Tavani [60],T. Terzić [58],K. Tollefson [1,2],B. Tomé [30],I. Torres [22],R. Torres-Escobedo [36,71],G. C. Trinchero [59],R. Turner [80],P. Ulloa [33,34],L. Valore [52],C. van Eldik [57],I. Vergara [82],A. Viana [13],J. Vícha [35,36],C. F. Vigorito [23],V. Vittorini [51],B. Wang [43],J. Wang [28],L. Wang [59],X. Wang [65],X. Wang [83],X. Wang [22],Z. Wang [33,34],M. Waqas [63],I. J. Watson [43],F. Werner [43],R. White [84],C. Wiebusch [47],E. J. Willox [43],F. Wohlleben [28],S. Wu [28],S. Xi [28],G. Xiao [64],L. Yang [7],R. Yang [18],R. Yanyachi [28],Z. Yao [85],D. Zavrtanik [22],H. Zhang [65],H. Zhang [86],S. Zhang [28],X. Zhang [68],Y. Zhang [28],J. Zhao [7],L. Zhao [22],H. Zhou [51],C. Zhu [87],P. Zhu [28],X. Zuo

[1]Laboratório de Instrumentação de Física Experimental de Partículas - LIP, Av. Prof. Gama Pinto, 2, 1649-003 Lisboa, Portugal [2]Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal [3]Physics Division, Los Alamos National Laboratory, Los Alamos, NM, USA [4]Instituto de Física, Universidad Nacional Autónoma de México, Circuito de la Investigación Científica, C.U., A. Postal 70-364, 04510 Cd. de México, México [5]Universidad de La Serena, Chile [6]Facultad de Ciencias en Física y Matemáticas, Universidad Autónoma de Chiapas, C. P. 29050, Tuxtla Gutiérrez, Chiapas, México [7]School of physical science, University of Science and Technology of China, 96 Jinzhai Road, Hefei, Anhui 230026, China [8]TÜBİTAK Research Institute for Fundamental Sciences, 41470 Gebze, Turkey [9]INFN - Sezione di Padova, I-35131, Padova, Italy [10]Universidad Nacional de San Antonio Abad del Cusco, Av. de la Cultura, Nro. 733, Cusco - Perú [11]Centro Atómico Bariloche (CNEA-CONICET-IB/UNCuyo), Av. E. Bustillo 9500, (8400) San Carlos de Bariloche, Rio Negro, Argentina [12]Department of Physics, Pennsylvania State University, University Park, PA, USA [13]Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic [14]Centro Brasileiro de Pesquisas Físicas (CBPF), Rua Dr. Xavier Sigaud 150, 22290-180 Rio de Janeiro, Brasil [15]Universidade de São Paulo, Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Departamento de Astronomia, Rua do Matão 1226, 05508-090 São Paulo, Brasil [16]Università di Padova, I-35131, Padova, Italy [17]Pontificia Universidad Católica del Perú, Av. Universitaria 1801, San Miguel, 15088, Lima, Perú [18]Universidad Nacional de San Agustin de Arequipa, Santa Catalina Nro. 117. Arequipa [19]University of Adelaide, Adelaide, S.A., Australia [20]Department of Physics and Astronomy, University of Rochester, Rochester, NY, USA [21]Instituto de Astronomía, Universidad Nacional Autónoma de México, Circuito Exterior, C.U., A. Postal 70-264, 04510 Cd. de México, México [22]Tsung-Dao Lee Institute & School of Physics and Astronomy, Shanghai Jiao Tong University, 520 Shengrong Road, Shanghai 201210, China [23]Istituto Nazionale Di Astrofisica (INAF), Roma, Italy [24]Astronomical Observatory Warsaw University, 00-478 Warsaw, Poland [25]INFN, Roma Tor Vergata, Italy [26]Department of Physics, University of Roma Tor Vergata, Viale della Ricerca Scientifica 1, I-00133 Roma, Italy [27]Facultad de Ciencias Exactas, Universidad Nacional de Salta, Avda. Bolivia 5150, A4408FVY, Salta, Argentina [28]Institute of High Energy Physics, Chinese Academy of Science, 19B Yuquan Road, Shijingshan District, Beijing 100049, China [29]CCTVal, Universidad Tecnica Federico Santa Maria, Chile [30]Instituto Nacional de Astrofísica, Óptica y Electrónica, Puebla, Mexico [31]Universidad Nacional de Ingeniería, Av. Túpac Amaru 210 - Rímac. Apartado 1301, Lima Perú [32]Centro de Investigación en Computación, Instituto Politécnico Nacional, Ciudad de México, Mexico [33]Università di Napoli "Federico II", Dipartimento di Fisica "Ettore Pancini", Napoli, Italy [34]INFN, Sezione di Napoli, Napoli, Italy [35]Università degli Studi di Torino, I-10125 Torino, Italy [36]INFN, Sezione di Torino, Torino, Italy [37]Politecnico di Milano, Dipartimento di Scienze e Tecnologie Aerospaziali, Milano, Italy [38]INFN, sezione di Milano, Milano, Italy [39]Departamento de Física, Universidad de Santiago de Chile, Chile [40]Facultad de Ciencias Físico Matemáticas, Benemérita Universidad Autónoma de Puebla, Av. San Claudio y 18 Sur, Ciudad Universitaria 72570, Puebla, Mexico. [41]Instituto de Astronomía y Física del Espacio (IAFE (CONICET-UBA)), Ciudad Universitaria, CABA, Argentina [42]Department of Physics, University of Wisconsin-Madison, Madison, WI, USA [43]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany [44]Departamento de Raios Cósmicos e Cronologia, Instituto de Física "Gleb Wataghin", Universidade Estadual de Campinas, C.P. 6165, 13083-970 Campinas, Brasil [45]Centro Federal de Educação Tecnológica Celso Suckow da Fonseca (CEFET), Rio de Janeiro, Brasil [46]Technische Universität Dortmund, D-44221 Dortmund, Germany [47]Department of Physics, University of Maryland, College Park, MD, USA [48]Middle East Technical University, Northern Cyprus Campus, 99738 Kalkanli via Mersin 10, Turkey [49]Instituto Argentino de Radioastronomía (CONICET, CIC, UNLP), Camino Gral. Belgrano Km 40, Berazategui, Argentina [50]Politecnico di Milano, Dipartimento di Energia, Milano, Italy [51]Key Laboratory of Particle Physics and Particle Irradiation (MOE), Institute of Frontier and Interdisciplinary Science, Shandong University, Qingdao, Shandong 266237, China [52]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen Centre for Astroparticle Physics, Nikolaus-Fiebiger-Str. 2, D 91058 Erlangen, Germany [53]Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Ave. Eugenio Garza Sada 2501, Monterrey, N.L., Mexico, 64849 [54]Dept. of Engineering Physics, Tsinghua University, 1

Tsinghua Yuan, Haidian District, Beijing 100084, China [55]Universidad Metropolitana de Ciencias de la Educación (UMCE), Chile [56]School of Mechanical Engineering and Electronic Information, China University of Geosciences, Wuhan, Hubei 430074, China [57]IFLP, Universidad Nacional de La Plata and CONICET, La Plata, Argentina [58]Department of Physics and Astronomy, Michigan State University, East Lansing, MI, USA [59]Michigan Technological University, Houghton, Michigan, 49931, USA [60]University of Rijeka, Faculty of Physics, 51000 Rijeka, Croatia [61]Università di Catania, Catania, Italy [62]Department of Physics and Astronomy, University of Utah, Salt Lake City, UT, USA [63]University of Seoul, Seoul, Rep. of Korea [64]School of Physics and Astronomy, Sun Yat-sen University, Zhuhai, Guangdong 519082, China [65]School of Astronomy and Space Science, Nanjing University, Xianlin Avenue 163, Qixia District, Nanjing, Jiangsu 210023, China [66]Dipartimento di Fisica, Università degli Studi di Trieste, Trieste, Italy [67]INFN - Sezione di Trieste, via Valerio 2, I - 34149 ,Trieste, Italy [68]Aerospace Information Research Institute, Chinese Academy of Science, 9 Dengzhuang South Road, Haidian District, Beijing 100094, China [69]Departamento de Física y Matemáticas, Universidad de Monterrey, Av. Morones Prieto 4500, 66238, San Pedro Garza García NL, México [70]Instituto de Tecnologías en Detección y Astropartículas (CNEA, CONICET, UNSAM), Buenos Aires, Argentina [71]Instituto Nazionale Di Astrofisica (INAF), Torino, Italy [72]Comisión Nacional de Investigación y Desarrollo Aeroespacial, Perú [73]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Circuito Exterior, C.U., A. Postal 70-543, 04510 Cd. de México, México [74]Universidad Nacional de Moquegua [75]Università degli Studi di Bari Aldo Moro, Italy [76]Department of Physis, Sungkyunkwan University, Suwon, South Korea [77]Universidad de Chile, Chile [78]Department of Physics and Astronomy, University of Alabama, Tuscaloosa, Alabama, 35487, USA [79]IMAPP, Radboud University Nijmegen, Nijmegen, The Netherlands [80]Unidade Acadêmica de Física, Universidade Federal de Campina Grande, Av. Aprígio Veloso 882, CY2, 58.429-900 Campina Grande, Brasil [81]Instituto de Física de São Carlos, Universidade de São Paulo, Av. Trabalhador São-carlense 400, São Carlos, Brasil [82]School of Integrated Circuit, Ludong University, 186 Hongqi Middle Road, Zhifu District, Yantai, Shandong, China [83]III. Physics Institute A, RWTH Aachen University, Templergraben 56, D-52062 Aachen, Germany [84]Center for Astrophysics and Cosmology (CAC), University of Nova Gorica, Nova Gorica, Slovenia [85]College of Engineering, Hebei Normal University, 20 South Second Ring East Road, Shijiazhuang, Hebei, China [86]School of mechanical engineering, University of Science and Technology Beijing, 30 Xueyuan Road, Haidian District, Beijing 100083, China

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