Simulation of the Instrument Performance of the Antarctic Demonstrator for the Advanced Particle-astrophysics Telescope in the Presence of the MeV Background

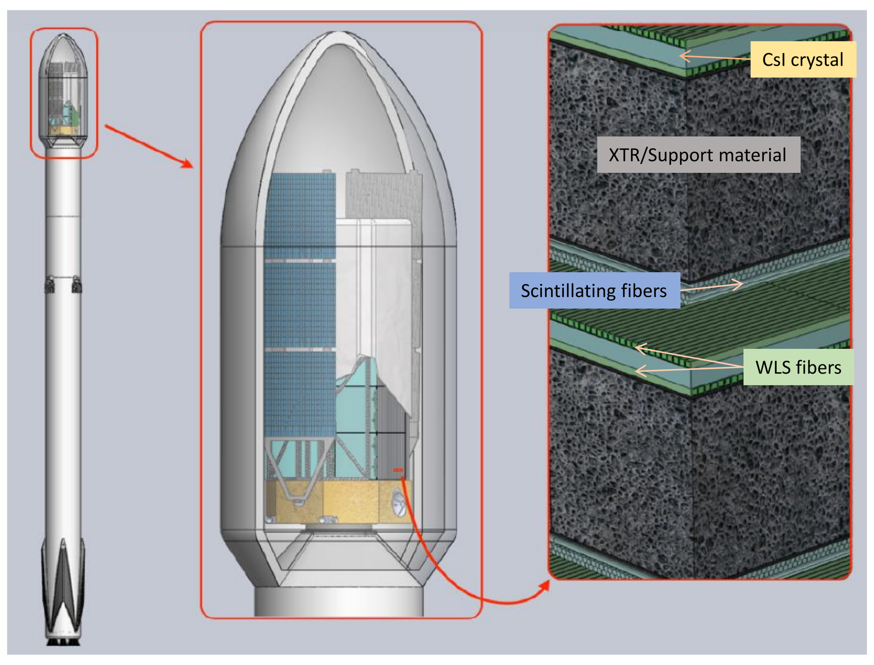
Wenlei Chen[1*] and James Buckley[2], for the APT Collaboration†

[1]University of Minnesota, Minneapolis, MN 55455, USA; [2]Washington University in St. Louis, St. Louis, MO 63130, USA (* Presenter)

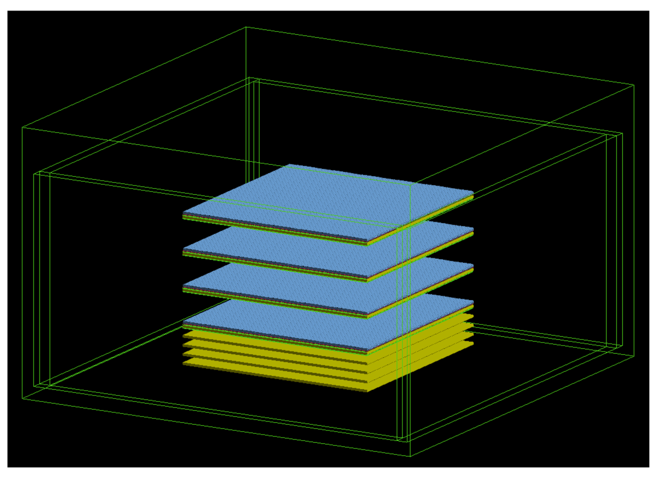
The Advanced Particle-astrophysics Telescope (APT) and the Antarctic Demonstrator for the APT (ADAPT)

• Advanced Particle-astrophysics Telescope

- The APT is a mission concept of a gamma-ray and cosmic-ray observatory in an orbit around the second sun-Earth Lagrange point (L2). With a multiple-layer tracker and an imaging calorimeter, APT is designed to observe gamma-rays at energies from hundreds of keV up to a few TeV.
- The instrument design is aimed at maximizing effective area and field of view for MeV-TeV gamma-ray and cosmic-ray measurements. The current detector design is based on 3-meter scintillating fibers read out by Silicon photomultipliers (SiPMs). The APT detector includes a multiple-layer tracker composed of scintillating fibers and an imaging calorimeter composed of thin layers of sodium-doped CsI (CsI:Na) scintillators and wavelength-shifting (WLS) fibers. The CsI:Na crystals are coupled to crossed planes of wavelength shifting fibers to localize energy deposition to ~mm accuracy.



• Antarctic Demonstrator for the APT



Geometry of the ADAPT payload and sensitive detector for our Geant4 simulation.

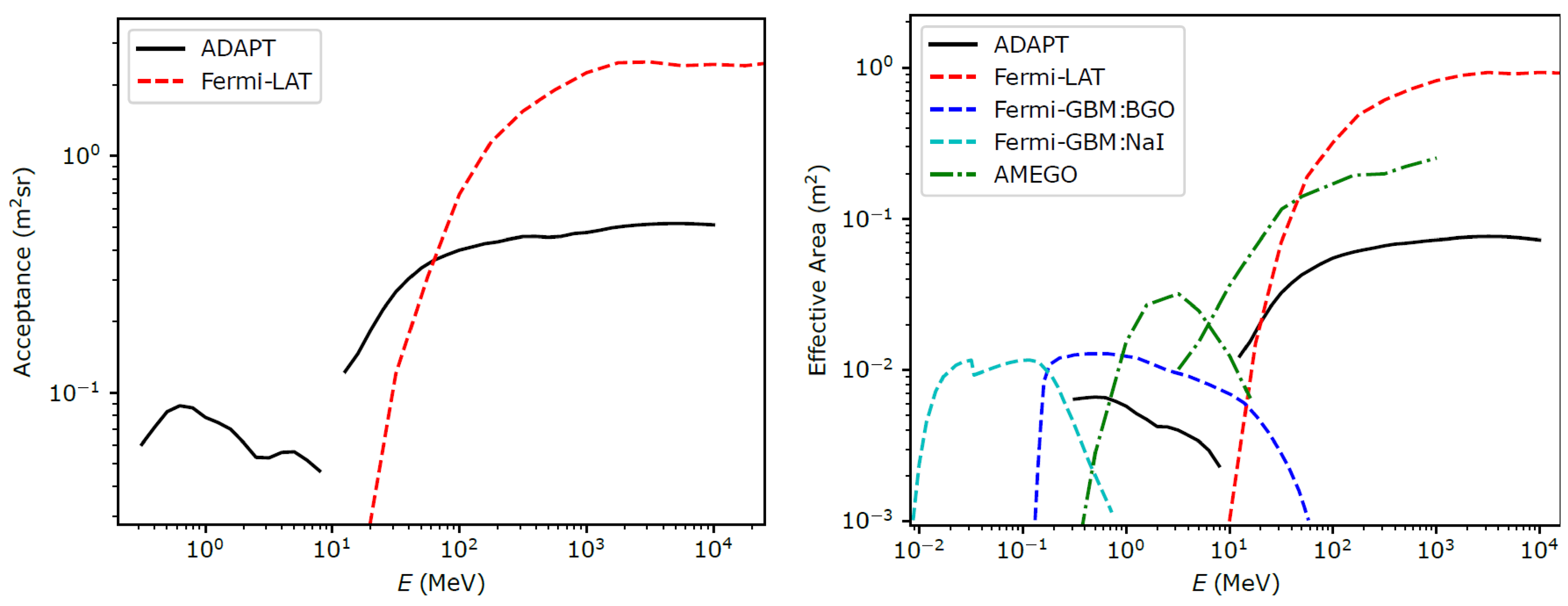
- ADAPT is a high-altitude balloon experiment scheduled to fly during the 2025–2026 summer window in the Antarctic. **The ADAPT detector uses only ~ 1% of the total amount of sensitive materials used in the full APT detector.**
- The ADAPT experiment is aimed to demonstrate the potential of the APT instrument and test our gamma-ray and cosmic-ray reconstruction algorithms. The mission will provide real-time alerts and localization of gamma-ray bursts (GRBs) and other gamma-ray transients that occur during the long-duration Antarctic flight.
- The sensitive detector of ADAPT consists of 4 fully instrumented tracker/imaging-CsI-calorimeter (ICC) layers and 4 additional CsI-calorimeter layers on bottom to increase the radiation length of the instrument. Each CsI-calorimeter layer includes 3 × 3 tiles of 15cm × 15cm × 5mm CsI:Na crystals. The design will achieve a ~ 1/2-meter square aperture for gamma-ray and cosmic-ray observations.

ADAPT Performance for Gamma-Ray Detection

• Gamma-Ray Detection Using ADAPT

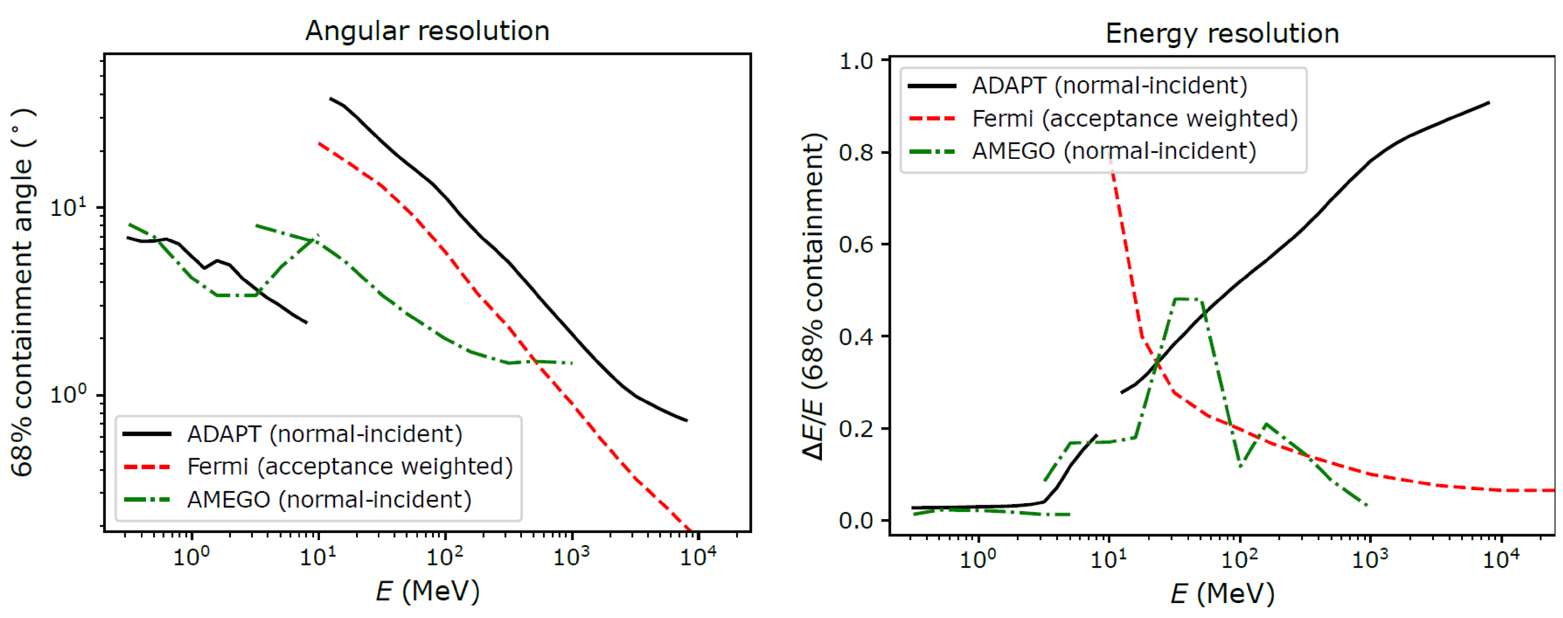
- At energies above 30 MeV, pair production is the dominant photon interaction in most materials, by which an electron-positron pair is created as the cosmic gamma-ray interacts in the electric fields of atoms in the detector. At lower energies (< 10 MeV), incident gamma-rays experience multiple Compton scatterings. The ADAPT instrument will function both as a pair telescope for 30 MeV to 10 GeV gamma-rays and as a Compton telescope with excellent sensitivity down to ~ 0.3 MeV.

• Geometric Factor and Effective Area



- Acceptance/geometry factor (left) and normal-incident effective area (right) versus energy. The lower energy solid black curves denote ADAPT Compton reconstruction and the higher denote ADAPT pair reconstruction. Dashed red and dash-dotted green curves are for Fermi P8R2_SOURCE_V6 events and AMEGO, respectively. Dashed blue and cyan curves show the Fermi-GBM effective area for the BGO and NaI detectors, respectively.

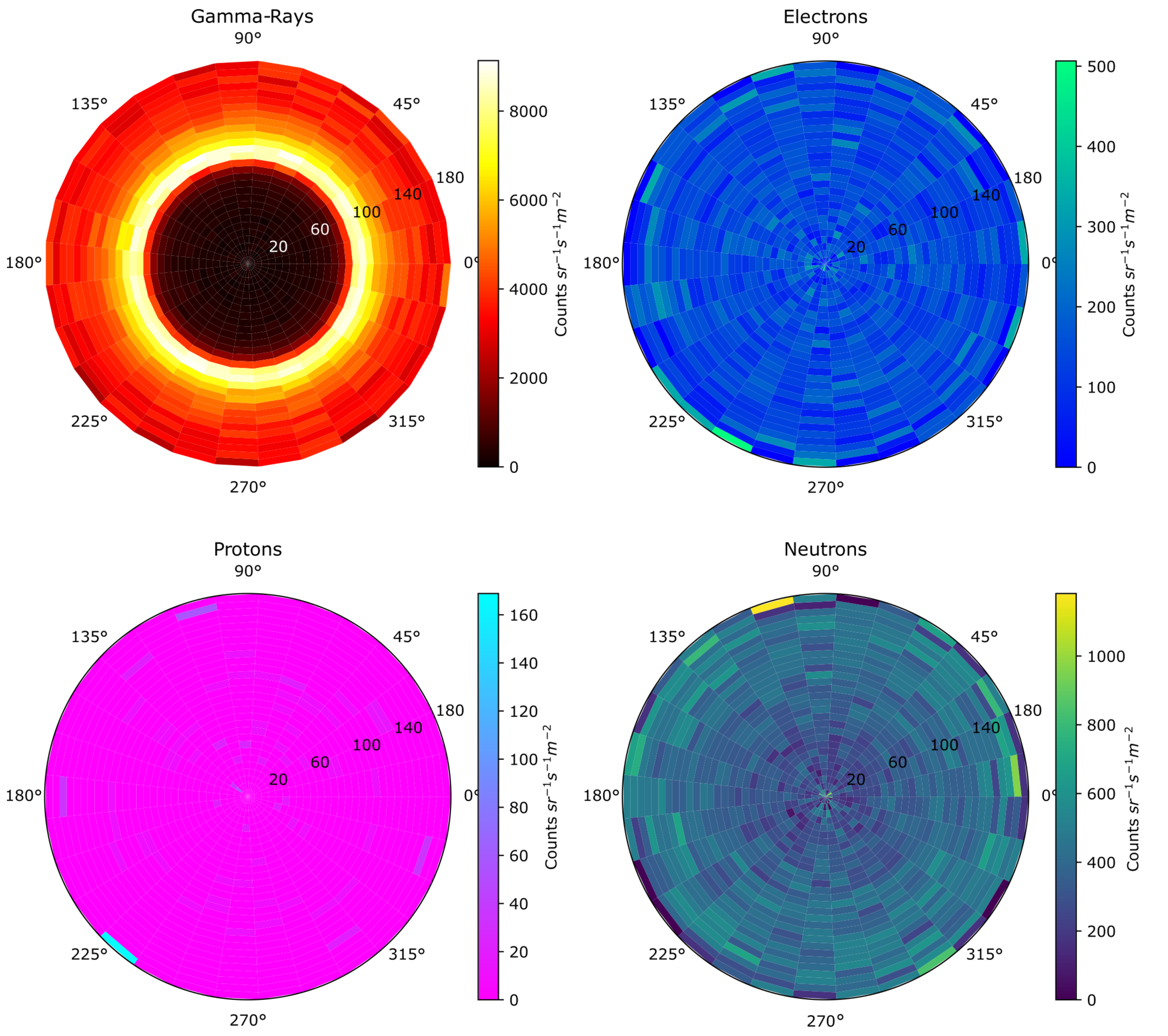
• Angular and Energy Resolution



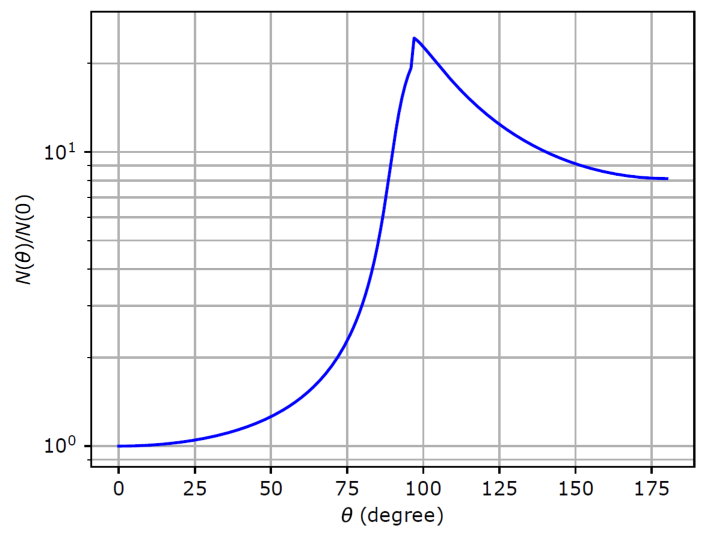
- Angular resolution (left) and energy resolution (right) as shown by the 68% containment versus energy. Solid black curves are for ADAPT normal-incident events. Dashed red and dash-dotted green curves are for Fermi P8R2_SOURCE_V6 events and AMEGO, respectively.

The Gamma-Ray and Cosmic-Ray Background for ADAPT

- We construct a semi-analytical model of the gamma-ray and cosmic-ray background for ADAPT based on observations from previous high-altitude balloon experiments and simulations of the upper atmosphere.



Simulated background for a 5s exposure of ADAPT. Sky maps are azimuthal projected centered at the zenith.



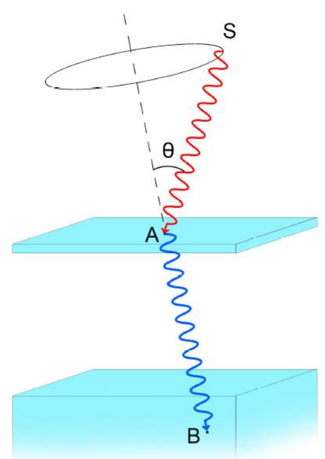
Background gamma-ray distribution as a function of the inclination angle (θ). θ = 0 is the zenith.

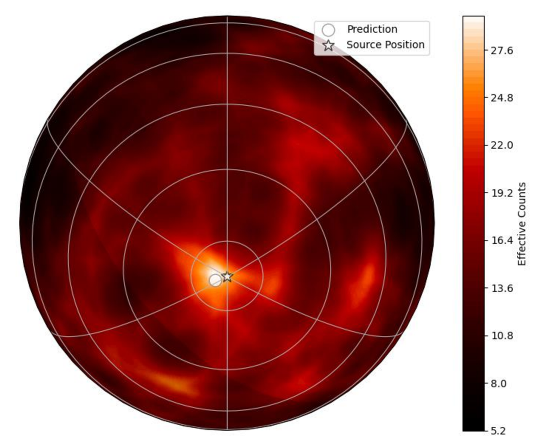
- As a high-altitude balloon mission, ADAPT will experience a strong background of gamma-ray and cosmic-ray radiation produced near the Earth. The background is dominated by atmospheric gamma-ray radiation and terrestrial cosmic-ray emission.
- The gamma-ray radiation peaks at $\theta \sim 90^\circ$ from the so-called "Earth's limb". The gamma-ray background is dominated by the gamma-ray albedo from the atmosphere, where the flux at $\theta > 90^\circ$ is an order of magnitude larger than the zenith flux.

GRB Localization in the Presence of the MeV Background

• GRB Localization Using ADAPT

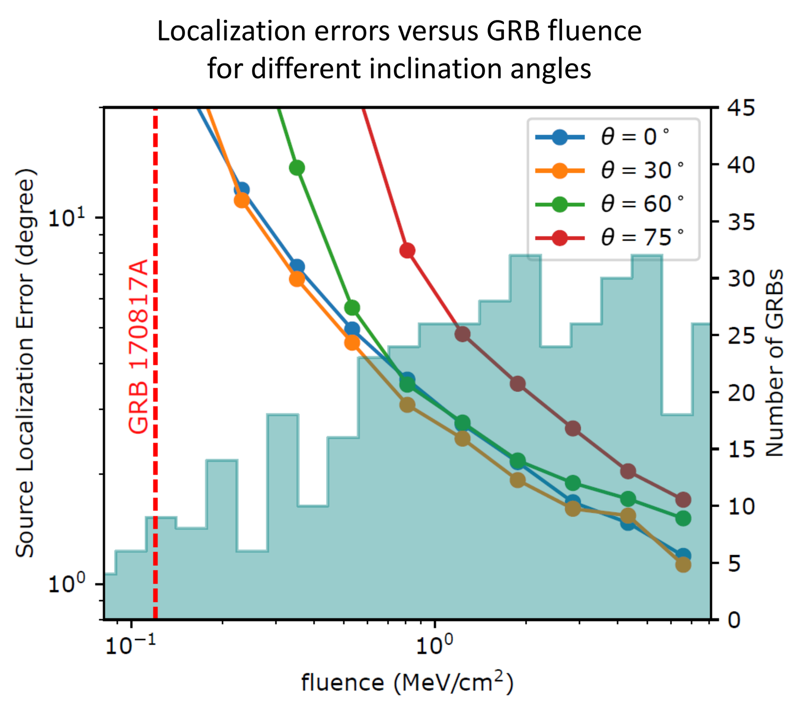
- A single MeV gamma-ray will be detected as a Compton ring by a Compton telescope. A sky map of gamma-rays observed by a Compton telescope is a stack of many Compton rings.
- For a gamma-ray transient such as a GRB, we localize the event by finding the centroid of the brightest region resulting from the pileup of Compton rings in the sky map.





An example of a gamma-ray transient detected by a Compton telescope

• GRB-Localization Performance in the Presence of the MeV Background



- For each fluence value and inclination angle, we calculate the offset of the reconstructed position from the true source direction. The 68% containment of the offset angle is plotted as a function of fluence, as shown on the left, where the estimated fluence of GRB170817A (an electromagnetic counterpart of the gravitational-wave event GW170817) in the ADAPT energy range is shown as the red dashed line and the shaded region shows the number of GRBs from the first Fermi-GBM catalog as a function of the fluence in the energy range from 10 keV to 1 MeV.
- For zenith angle $\theta < 75^\circ$, ADAPT has degree-level accuracy of localizing bright GRBs with fluence > 1 MeV/cm^{-2} in the presence of the MeV gamma-ray and cosmic-ray background. ADAPT would be able to detect a few GRBs during the planned Antarctic balloon flight.

† Corrado Altomare[12], Matthew Andrew[5], Blake Bal[7], Richard G. Bose[7], Dana Braun[7], James H. Buckley[7], Jeremy Buhler[2], Eric Burns[4], Roger D. Chamberlain[2], Wenlei Chen[6], Michael L. Cherry[4], Leonardo Di Venere[12], Jeffrey Dumonthier[13], Manel Errando[7], Stefan Funk[10], Priya Ghosh[8], Francesco Giordano[9], Jonah Hoffman[7], Ye Htet[2], Zachary Hughes[7], Aera Jung[5], Patrick L. Kelly[6], John F. Krizmanic[13], Makiko Kuwahara[3], Francesco Licciulli[12], Gang Liu[16], Leonarda Lorusso[9], Mario Nicola Mazziotta[12], John Grant Mitchell[11], John W. Mitchell[1], Georgia A. de Nolfo[11], Giuliana Panzarini[15], Richard Peschke[5], Riccardo Paoletti[17], Roberta Pillera[15], Brian Rauch[7], Davide Serini[12], Garry Simburger[7], Marion Sudvarg[2], George Suarez[13], Teresa Tatoli[11], Gary S. Varner[5], Eric A. Wulf[14], Adrian Zink[10], and Wolfgang V. Zober[7]

1. Astroparticle Physics Laboratory, NASA/GSFC, Greenbelt, MD 20771, USA. 2. Department of Computer Science & Engineering, Washington University, St. Louis, MO 63130-4899, USA. 3. Department of Engineering, University of Hawai'i at M¯anoa, Honolulu, HI 96822, USA. 4. Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803, USA. 5. Department of Physics and Astronomy, University of Hawai'i at M¯anoa, Honolulu, HI 96822, USA. 6. Department of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455, USA. 7. Department of Physics and McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130, USA. 8. Department of Physics, Catholic University of America, Washington DC, 20064. 9. Dipartimento di Fisica "M. Merlin" dell'Università e del Politecnico di Bari, I-70126 Bari, Italy. 10. Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen Centre for Astroparticle Physics, D-91058 Erlangen, Germany. 11. Heliospheric Physics Laboratory, NASA/GSFC, Greenbelt, MD 20771, USA. 12. Istituto Nazionale di Fisica Nucleare, Sezione di Bari, I-70126 Bari, Italy. 13. NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA. 14. Naval Research Laboratory, Washington, DC 20375, USA. 15. Politecnico di Bari, Department of Mechanics, Mathematics and Management, via Orabona, 4, I-70125 Bari, Italy. 16. SLAC National Accelerator Laboratory, 2575 Sand Hill Rd, Mailstop 0094, Menlo Park, CA 94025, USA. 17. Università di Siena and INFN Pisa, I-53100 Siena, Italy.