

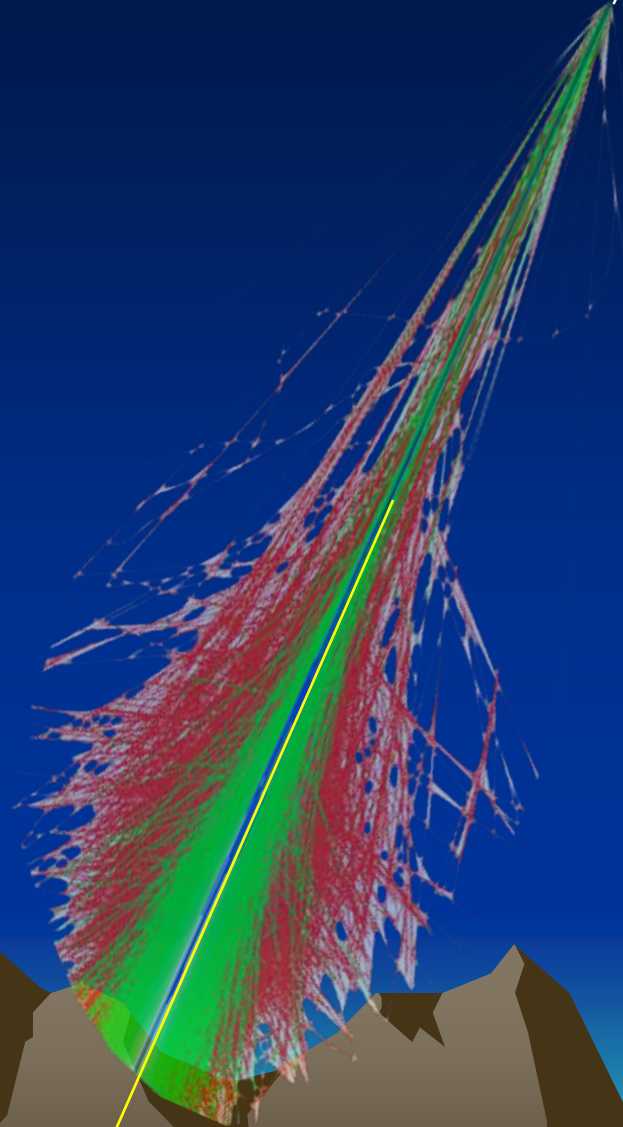


PennState

# Cosmic rays from deep underground to space

Stéphane Coutu  
Institute for Gravitation and the Cosmos  
The Pennsylvania State University

MACRO Experiment Legacy  
L'Aquila + Gran Sasso  
27 June 2025



with Giuseppe, Vincenzo, Massimo,  
Gianni, Piero, Francesco

# A personal perspective



Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

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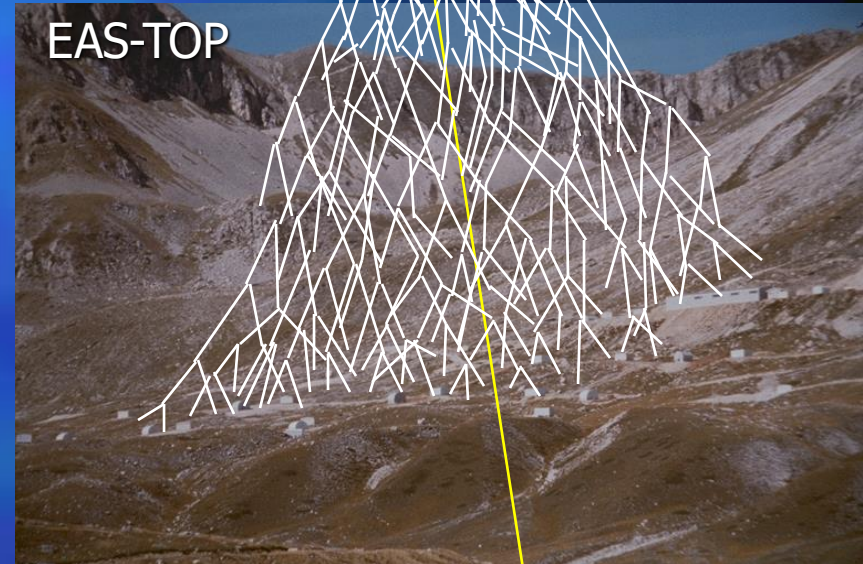
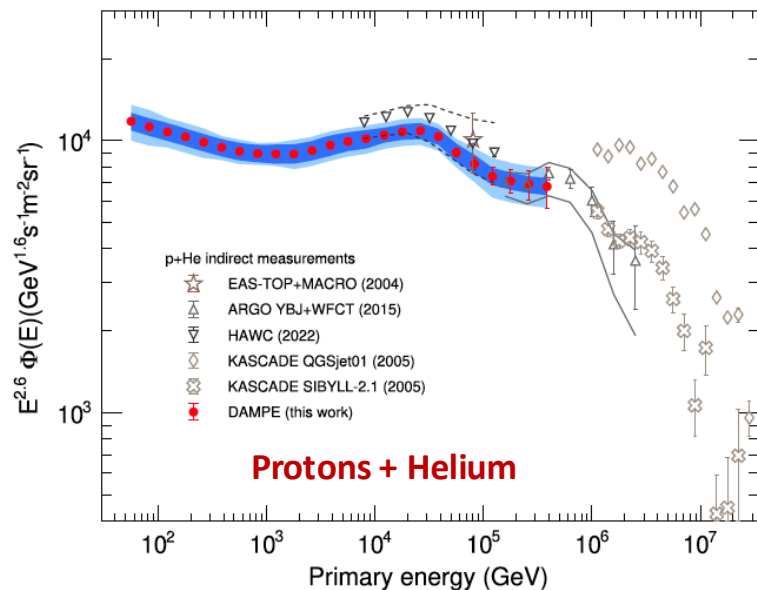
Astroparticle Physics 20 (2004) 641–652

[www.elsevier.com/locate/astropart](http://www.elsevier.com/locate/astropart)

Astroparticle  
Physics

The cosmic ray primary composition between  
 $10^{15}$  and  $10^{16}$  eV from Extensive Air Showers  
electromagnetic and TeV muon data

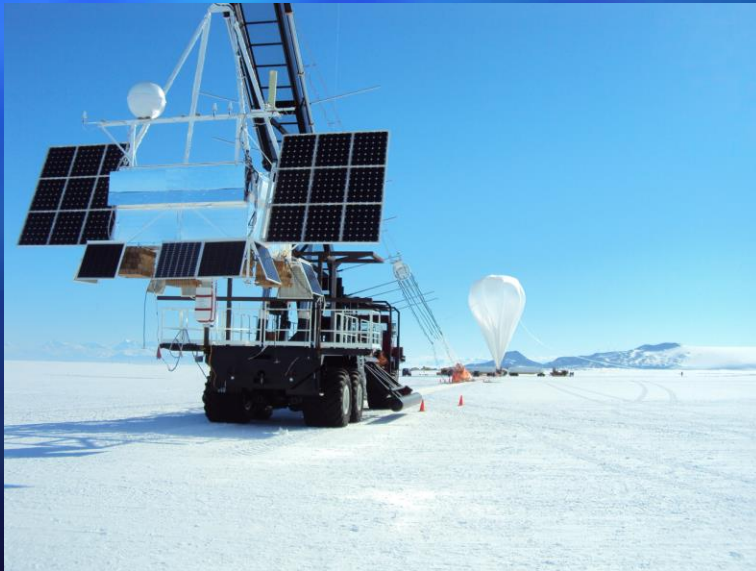
F. Alemanno et al. (DAMPE) PRD 109, L121101 (2024)



p? Fe?  
> 200 TeV



# Where the CRs live



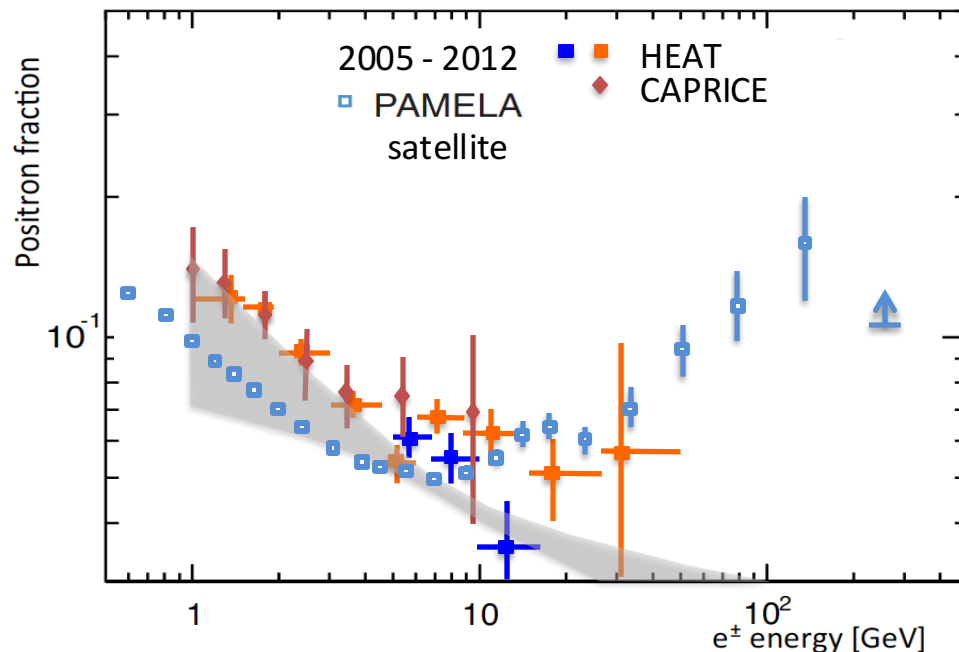
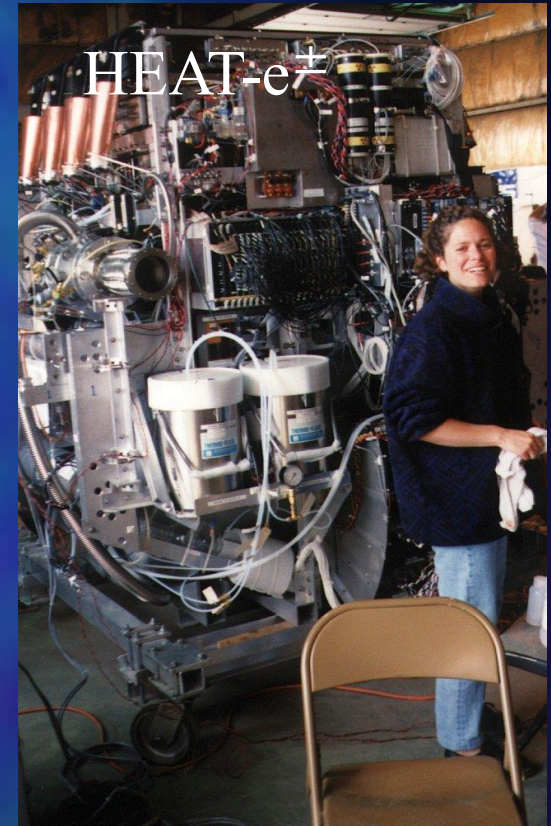


# HEAT- $e^\pm$ (High Energy Antimatter Telescope)

Superconducting magnet spectrometer with drift tube hodoscope, electromagnetic calorimeter, transition radiation detector, time-of-flight system;

May 1994, Ft. Sumner, NM (29.5 hour flight)

Aug. 1995, from Lynn Lake, Manitoba (26 hour flight)



with Greg, Jim, Chuck, Scott

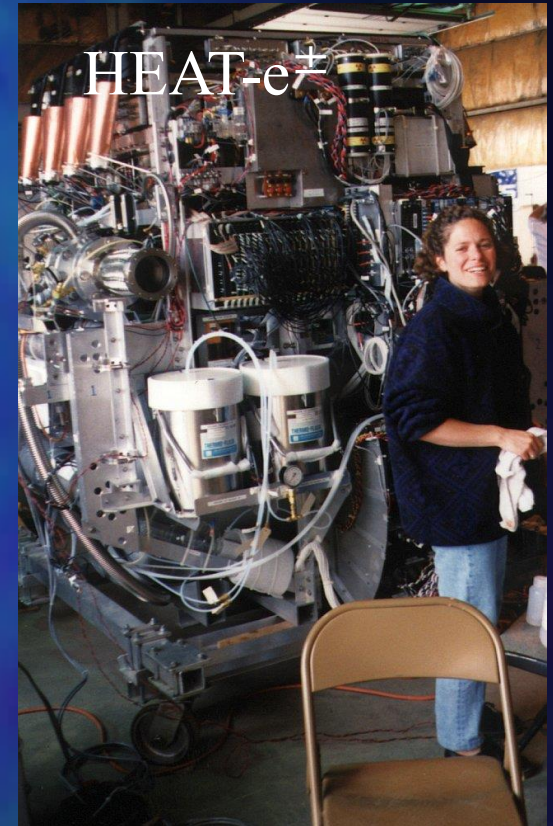
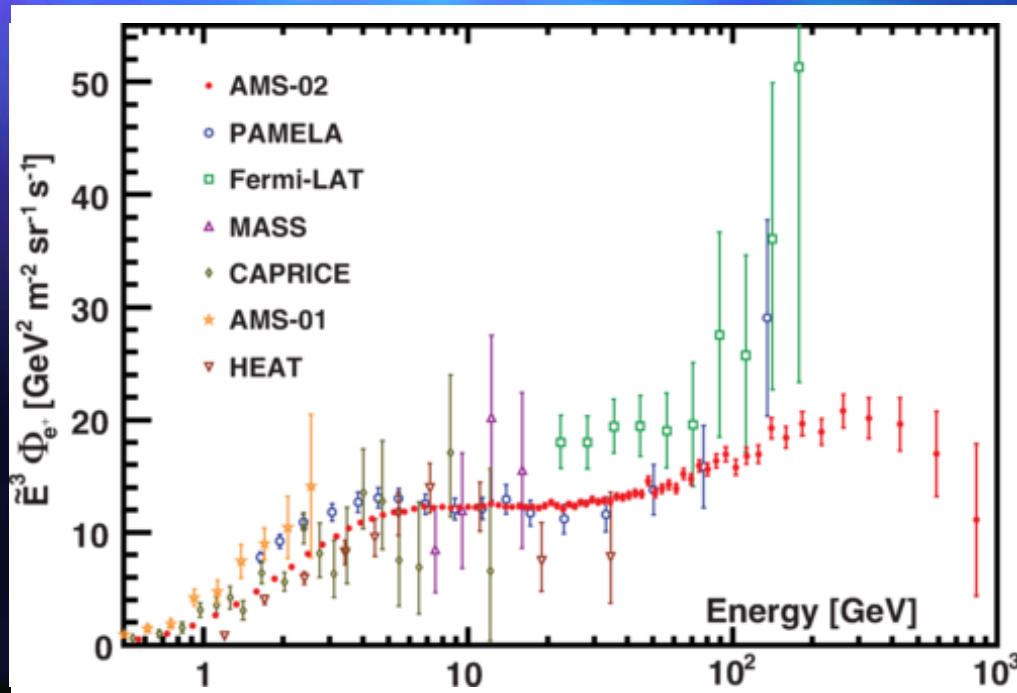


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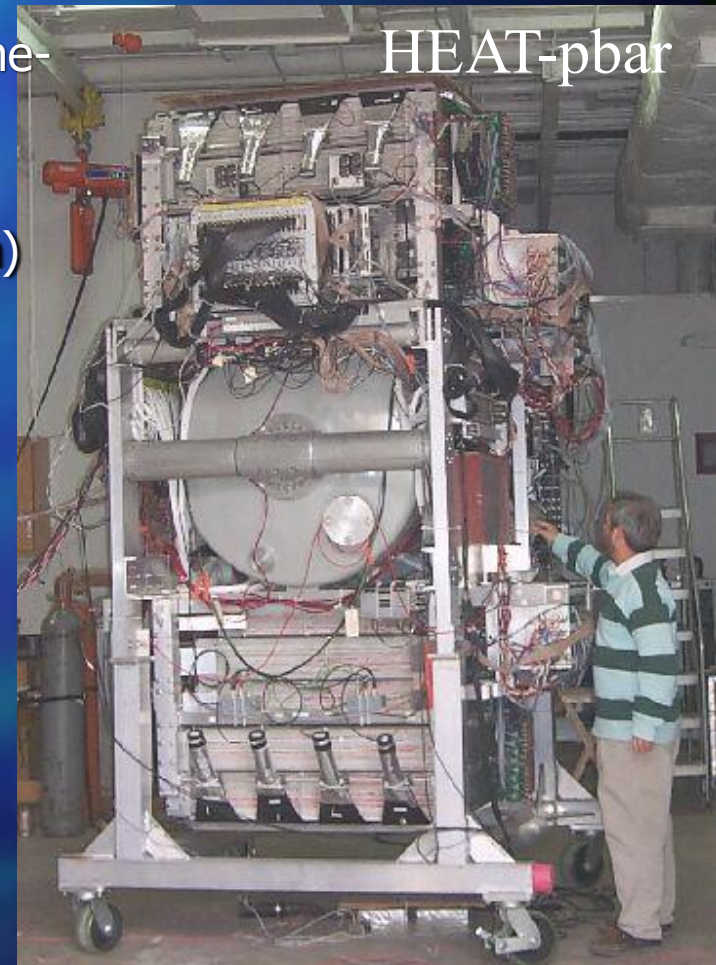
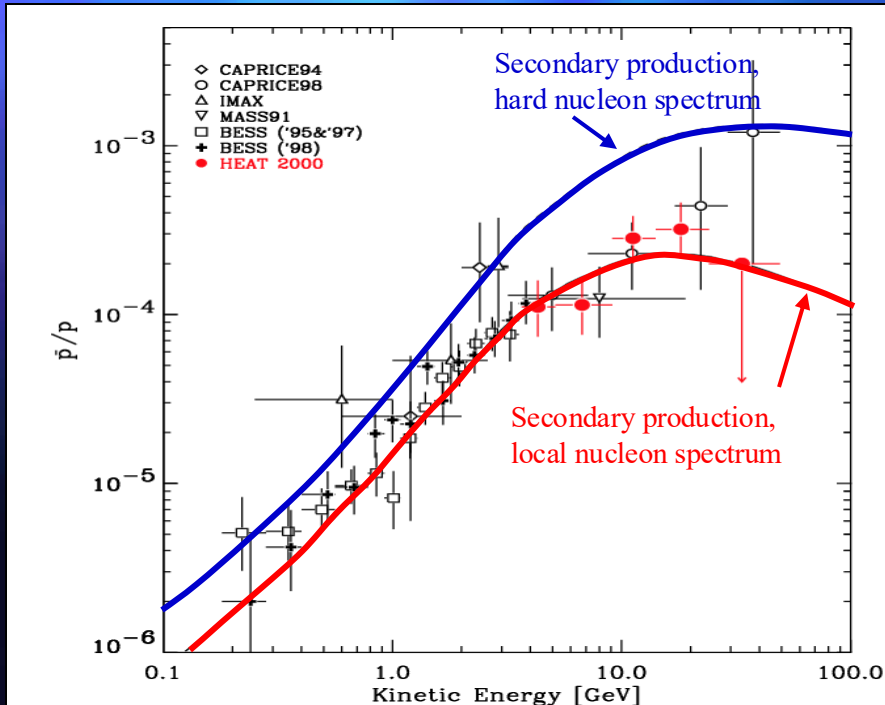
with Greg, Jim, Chuck, Scott

# HEAT-pbar (High Energy Antimatter Telescope)

Superconducting magnet spectrometer with drift tube hodoscope, multiple ionization (dE/dx) detector and time-of-flight system.

Jun. 2000, Ft. Sumner, NM (22 hour flight)

May 2002, Ft. Sumner, NM (6 hour flight; failed balloon)



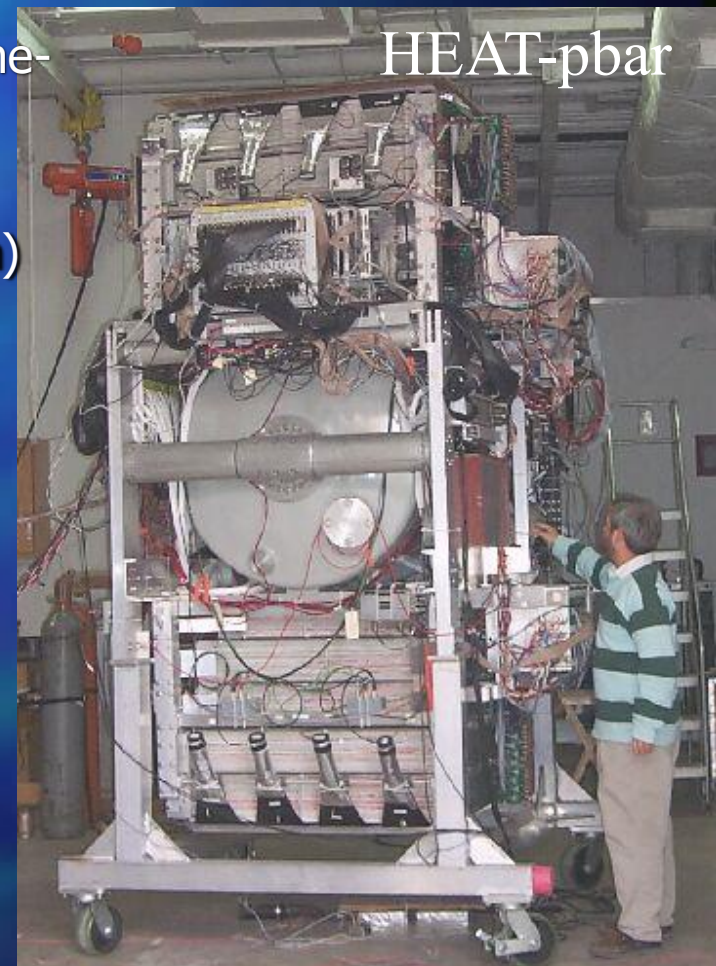
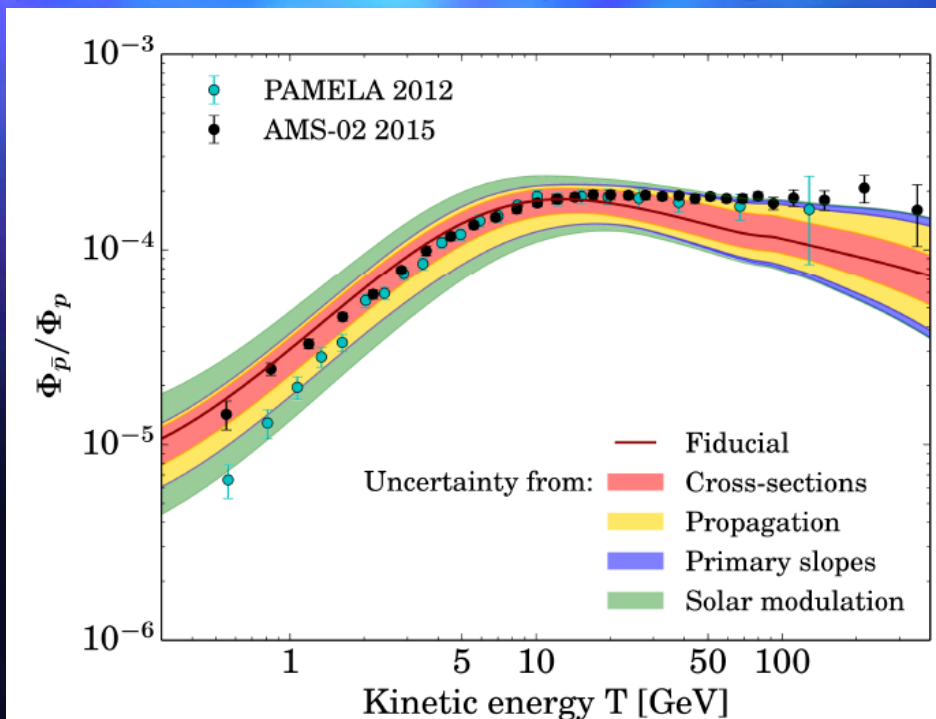


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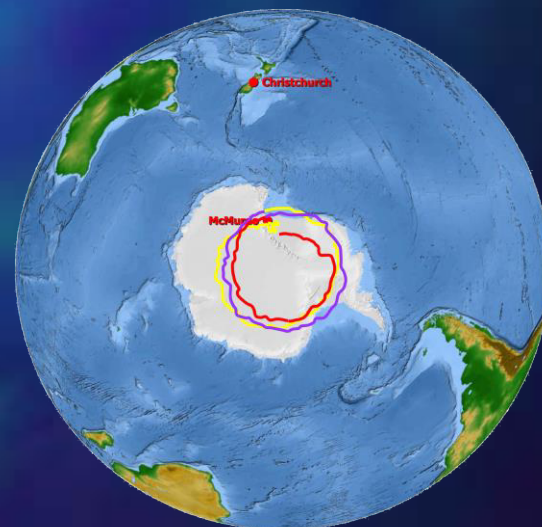
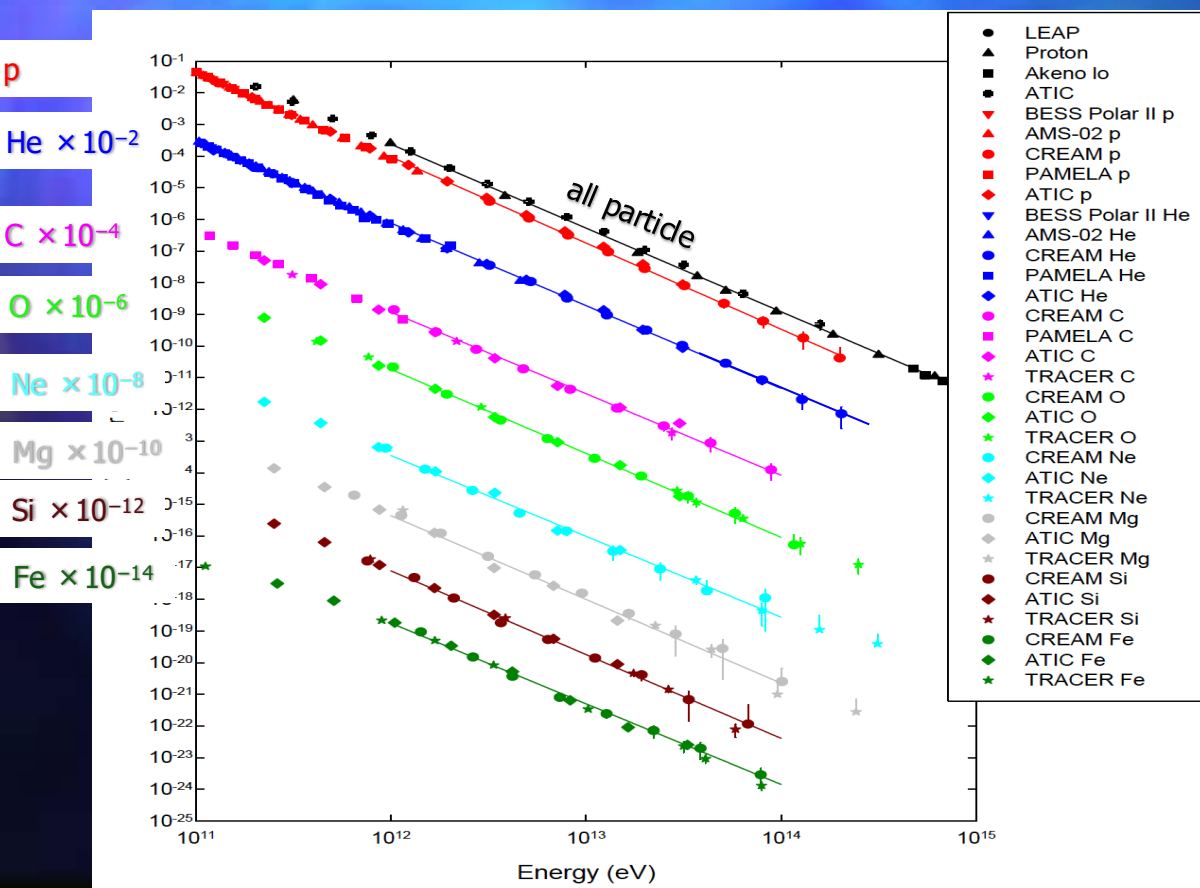




# CREAM

## (Cosmic Ray Energetics And Mass)

Timing charge detector, TRD / SCD, hodoscope /  
aerogel CK camera, C targets, thin calorimeter;  
2004-2017, 7 Antarctic flights, 187 days of exposure.







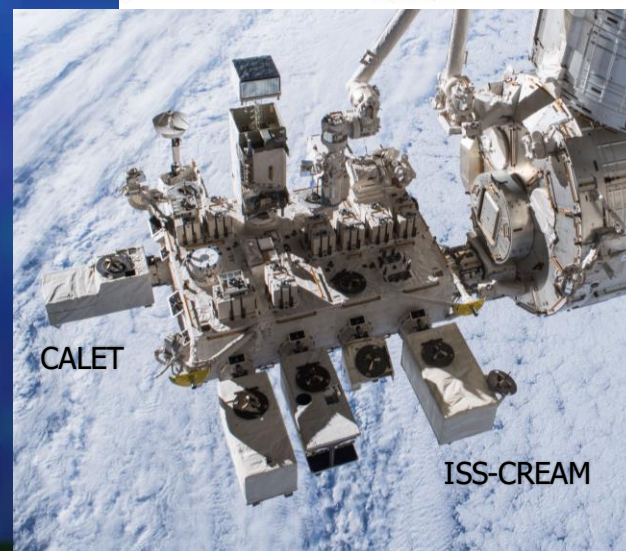
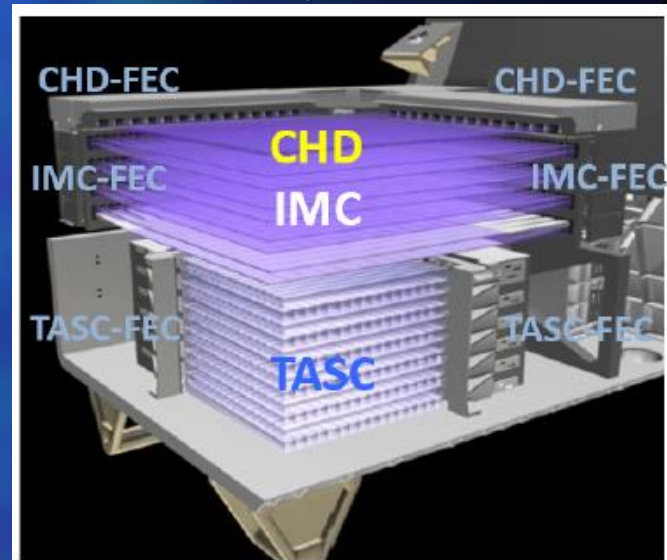
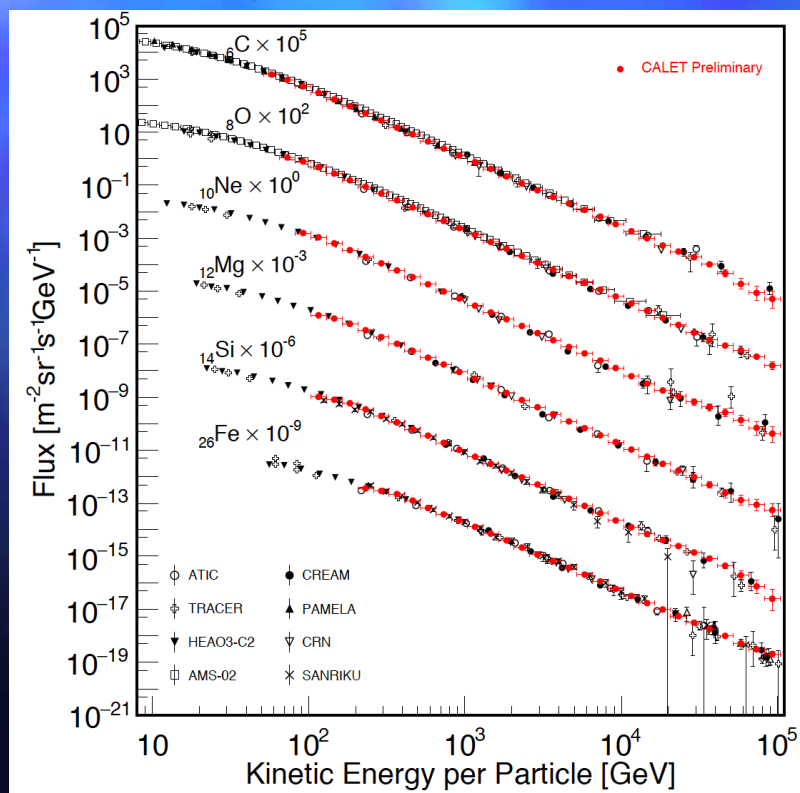
# CALET

## (CALorimetric Electron Telescope)

CALET, 2015

Scint., imaging CAL (W/SciFi), total absorption CAL (PWO crystals)  
ISS since 2015

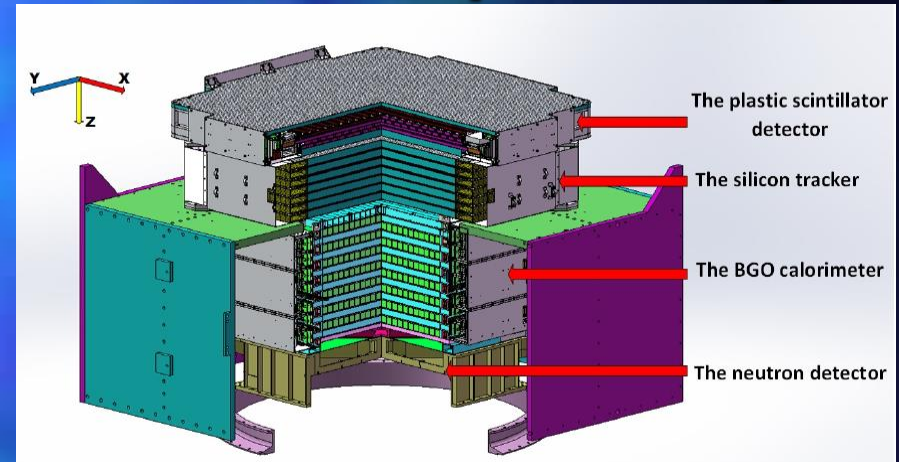
Y. Akaike et al. (CALET) 2019  
J. Phys.: Conf. Ser. 1181, 012042



# DAMPE

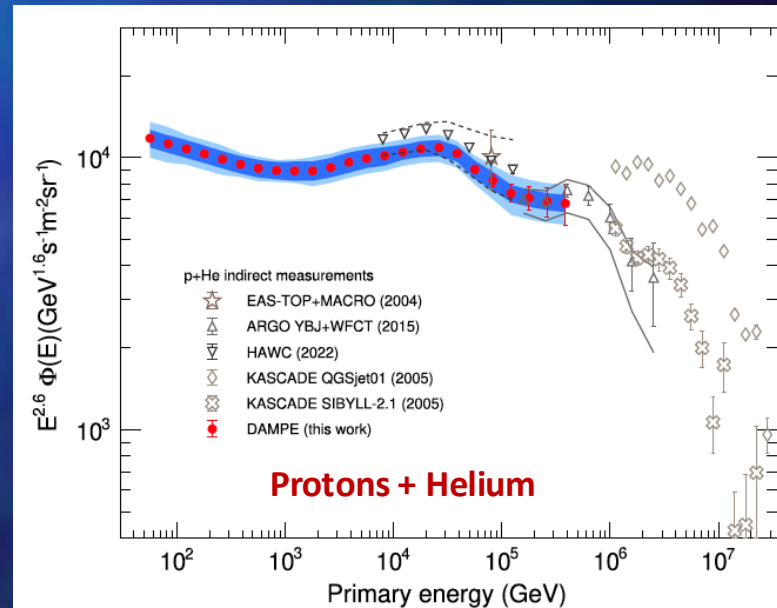
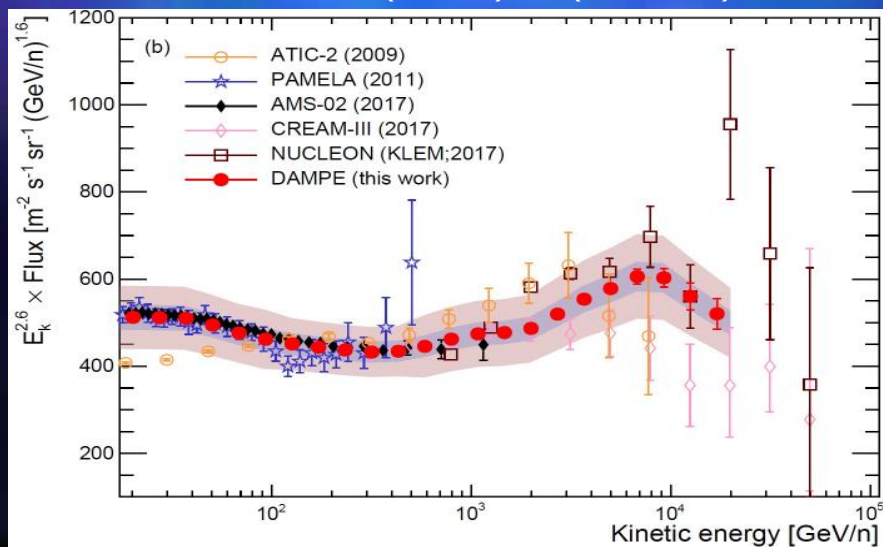
## (Dark Matter Particle Explorer)

Scint, Si tracker, BGO cal, neutron tail catcher  
free-flying satellite since 2015



F. Alemanno et al. (DAMPE) PRD 109, L121101 (2024)

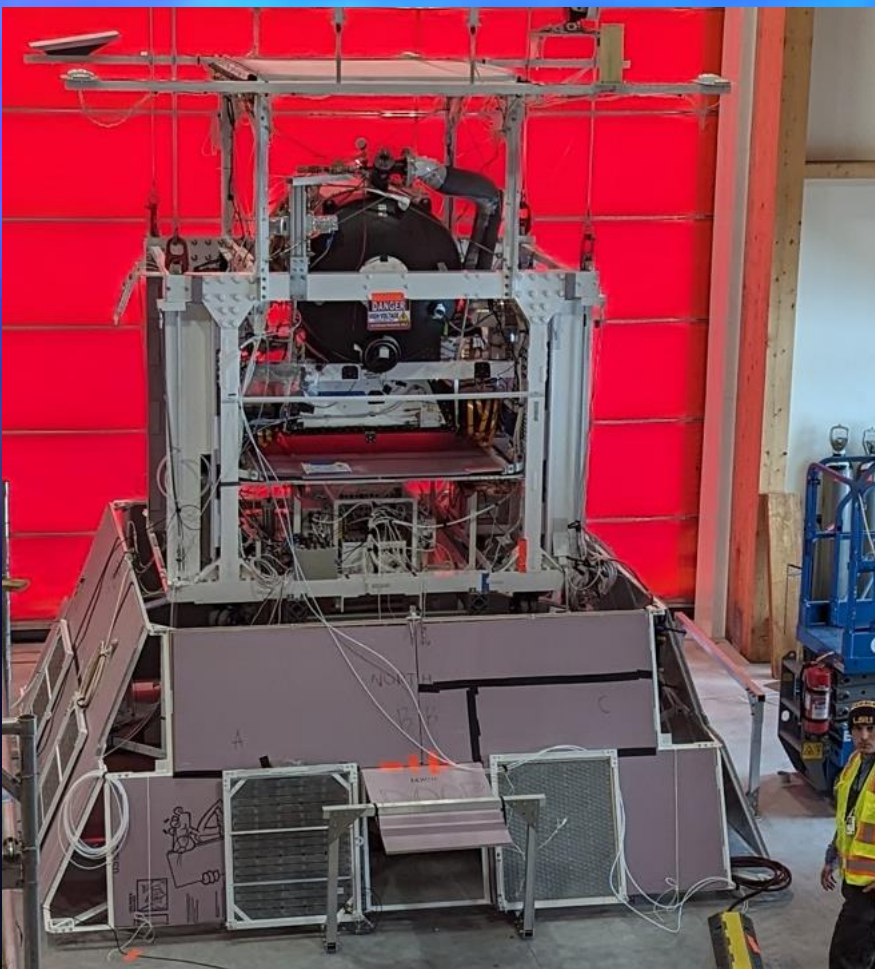
M. Di Santo et al. (DAMPE) PoS(ICRC2021)114



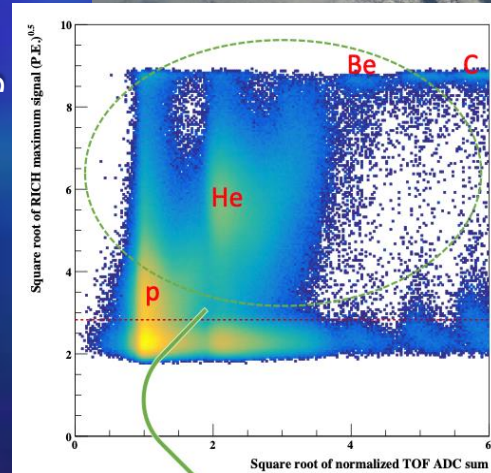


# HELIX (High-Energy Light Isotope experiment

ToF, HEAT magnet, DCT, RICH, hodoscope; May 2024, Sweden to Canada (6d8h flight)



RICH signal



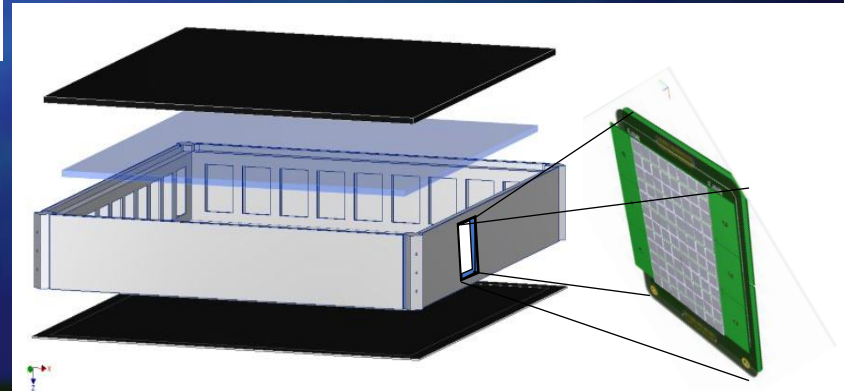
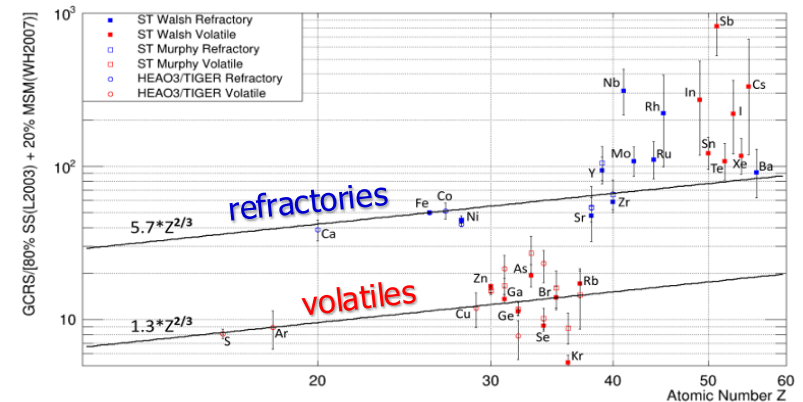
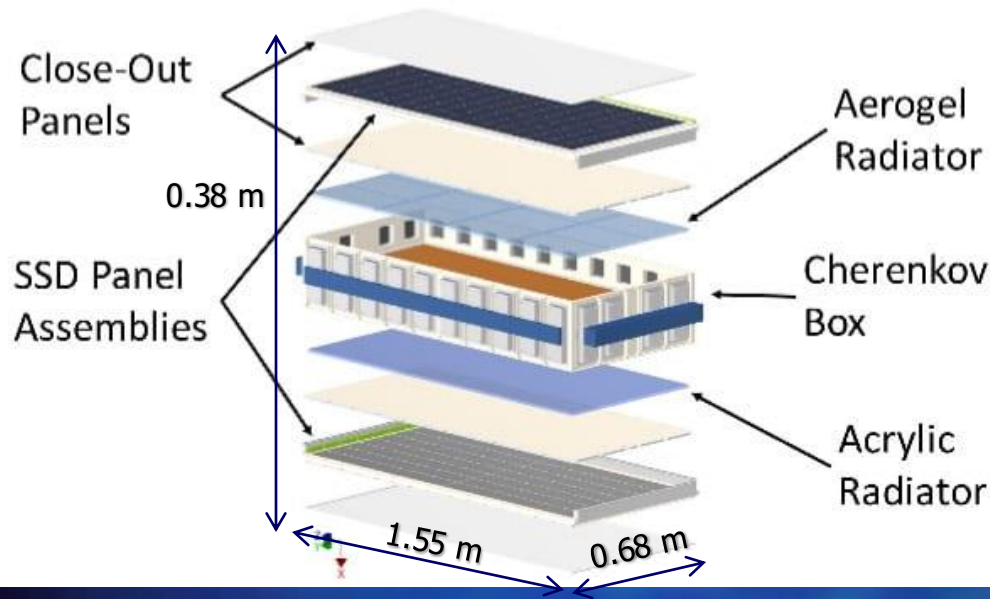
ToF signal

$^{10}\text{Be}/^9\text{Be}$   
of interest

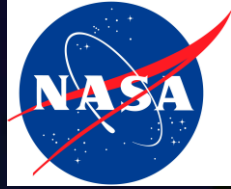
# TIGERISS (Trans-Iron Galactic Element Recorder on the ISS)



SSD, aerogel+acrylic CK detectors; 2027 deployment to ISS;  
ultraheavy CRs up to Pb







# A legacy of MACRO

Direct studies of cosmic rays now yield high precision and energy reach overlapping ground-based (or underground!) instruments.

Going where the CRs live allows:

- composition measurements (primary, secondary, ultraheavy nuclei, also isotopes);
- electron measurements;
- antimatter studies (positrons, antiprotons, antideuterons).

Long exposures possible with balloons, satellites, ISS.

Fascinating studies of the high-energy universe, and maybe some exotic physics.

Next-gen instruments are expanding and refining these measurements, which anchor composition models for studies at higher energies with ground-based detectors. New and proposed instruments push to ever higher energies.

Fun adventures, lifelong friends.