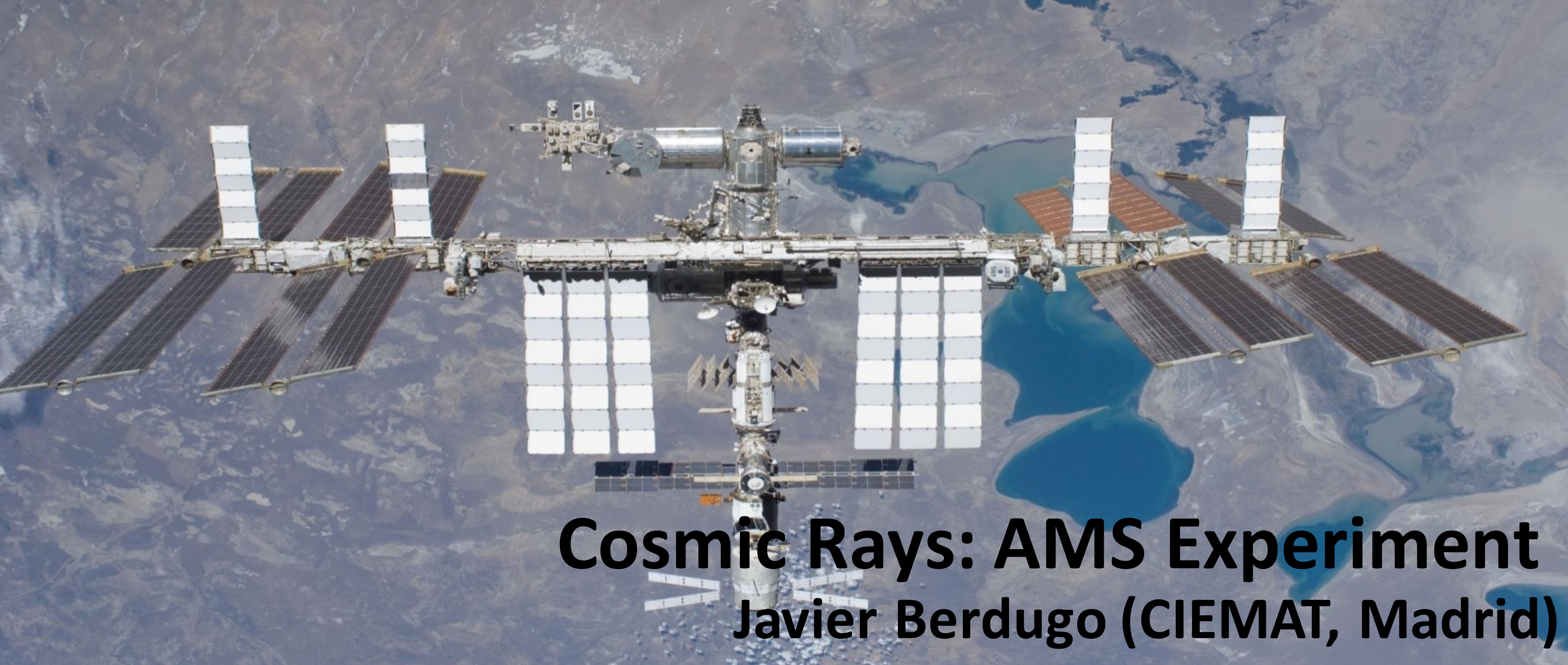


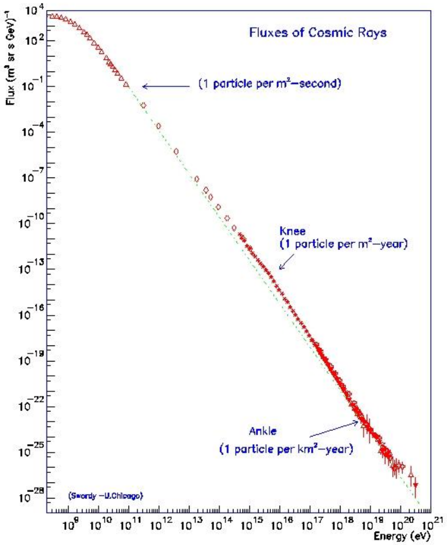
Cosmic Rays: AMS Experiment

Javier Berdugo (CIEMAT, Madrid)

Frontiers of Astroparticle Physics. La Palma October 11th 2018

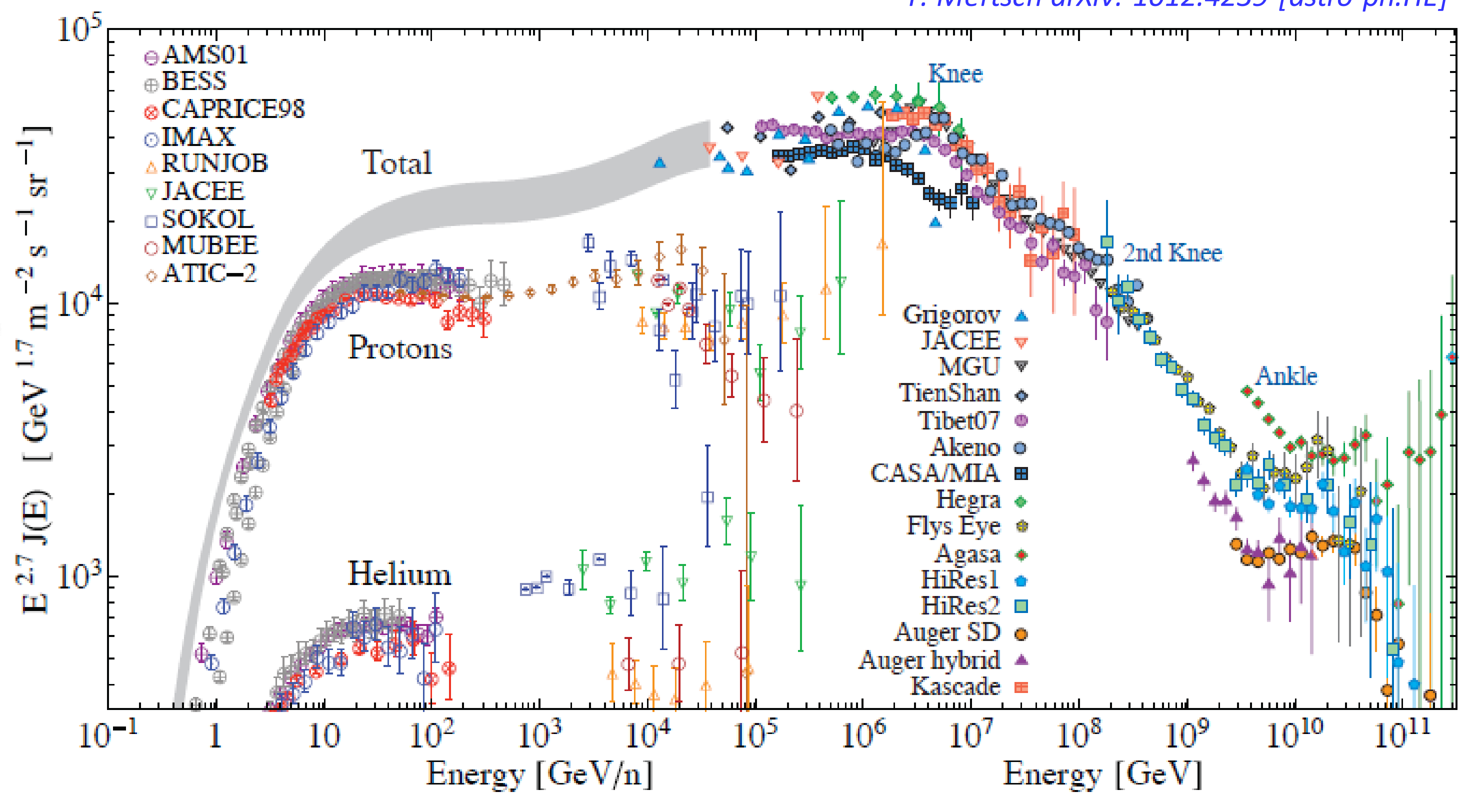
Cosmic rays

Cosmic rays are a sample of solar, galactic and extragalactic matter which includes all known nuclei and their isotopes, as well as electrons, positrons and antiprotons



Sci. Amer. 276 (1997) 44

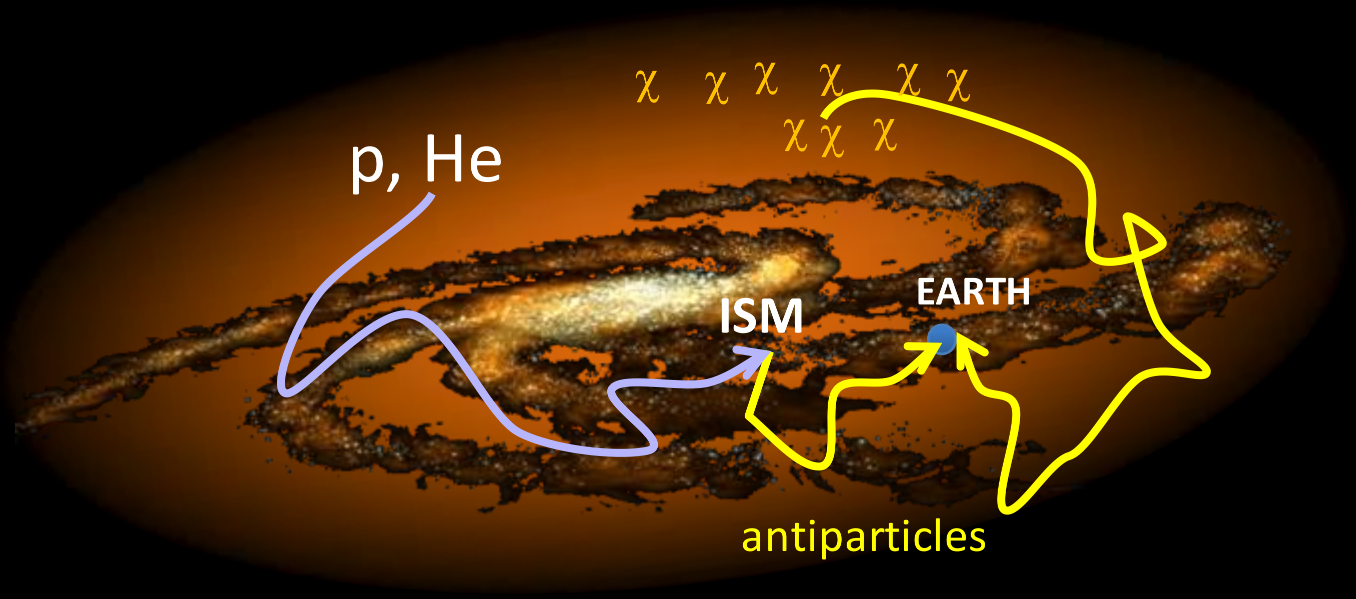
P. Mertsch arXiv: 1012.4239 [astro-ph.HE]



Antiparticles in Cosmic Rays and Dark Matter

The collision of cosmic rays with interstellar medium (ISM) produces antiparticles (e^+, $\bar{p}$, $\bar{D}$, …)

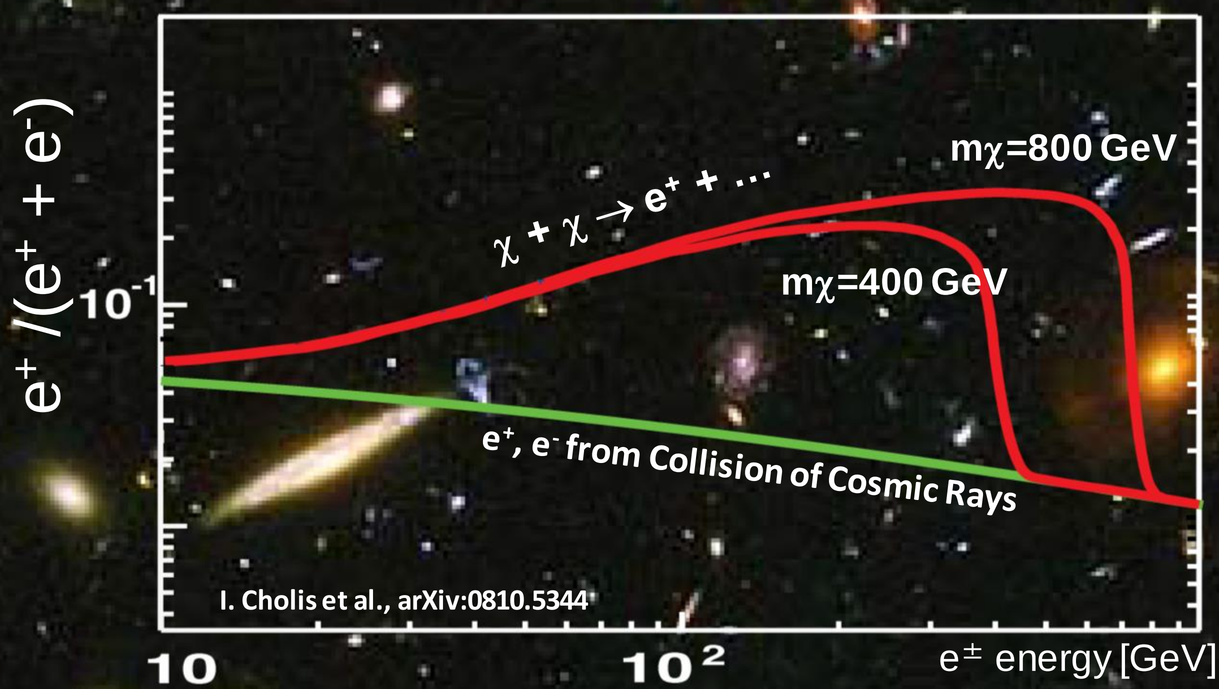
p, He + ISM → antiparticles + …



The collision of dark matter particles will produce additional antiparticles

$\chi + \chi \rightarrow$ antiparticles + …

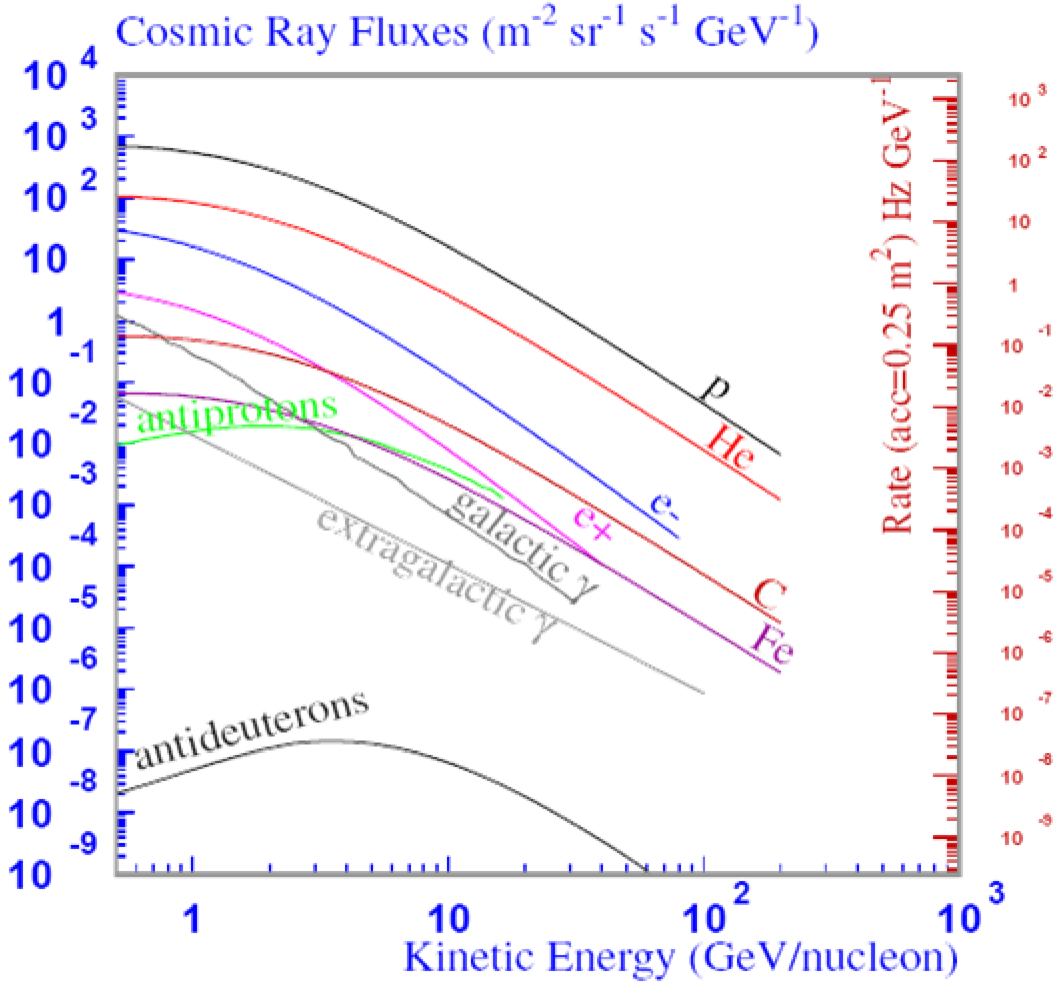
Positrons in Cosmic Rays



M. S. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001;
J. Ellis, 26th ICRC Salt Lake City (1999) astro-ph/9911440;
H. Cheng, J. Feng and K. Matchev, Phys. Rev. Lett. 89 (2002) 211301;
S. Profumo and P. Ullio, J. Cosmology Astroparticle Phys. JCAP07 (2004) 006;
D. Hooper and J. Silk, Phys. Rev. D 71 (2005) 083503;
E. Ponton and L. Randall, JHEP 0904 (2009) 080;
G. Kane, R. Lu and S. Watson, Phys. Lett. B681 (2009) 151;
D. Hooper, P. Blasi and P. D. Serpico, JCAP 0901 025 (2009) 0810.1527; B2
Y–Z. Fan et al., Int. J. Mod. Phys. D19 (2010) 2011;
M. Pato, M. Lattanzi and G. Bertone, JCAP 1012 (2010) 020.

Flux of antiparticles in cosmic rays

Precision measurements of antiparticles requires long exposure time with detectors with large acceptance and percent level precision.



Experiments operating outside the atmosphere and capable to measure simultaneously the spectra of the different cosmic ray components.

Space based cosmic ray experiments

PAMELA: Launched on June 15th 2006

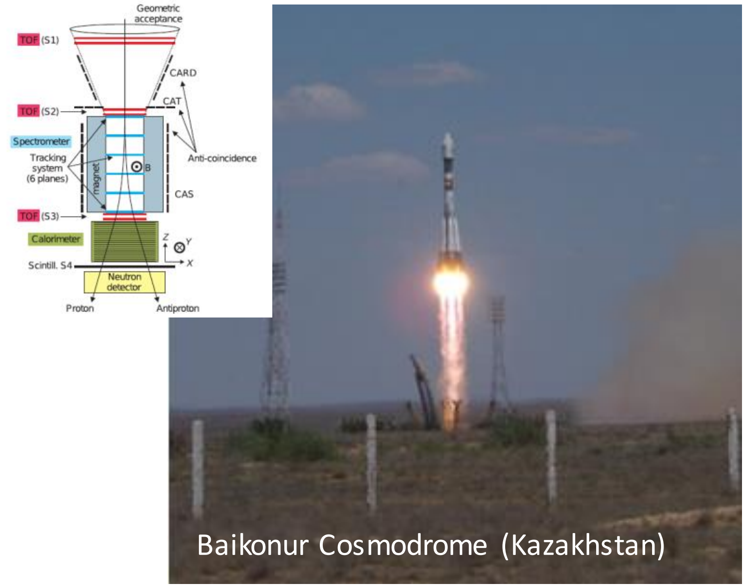


Image: http://wizard.roma2.infn.it/pamela/html/resurs.html

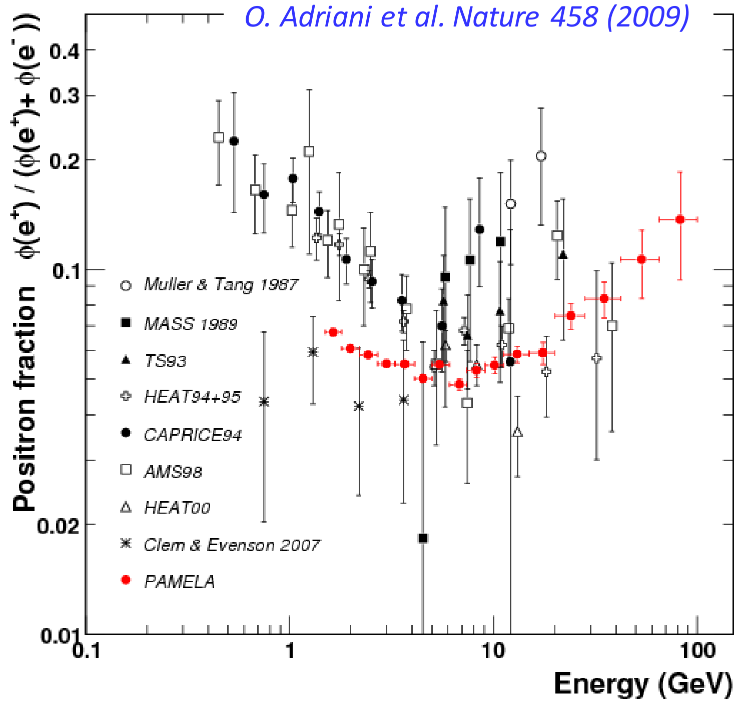
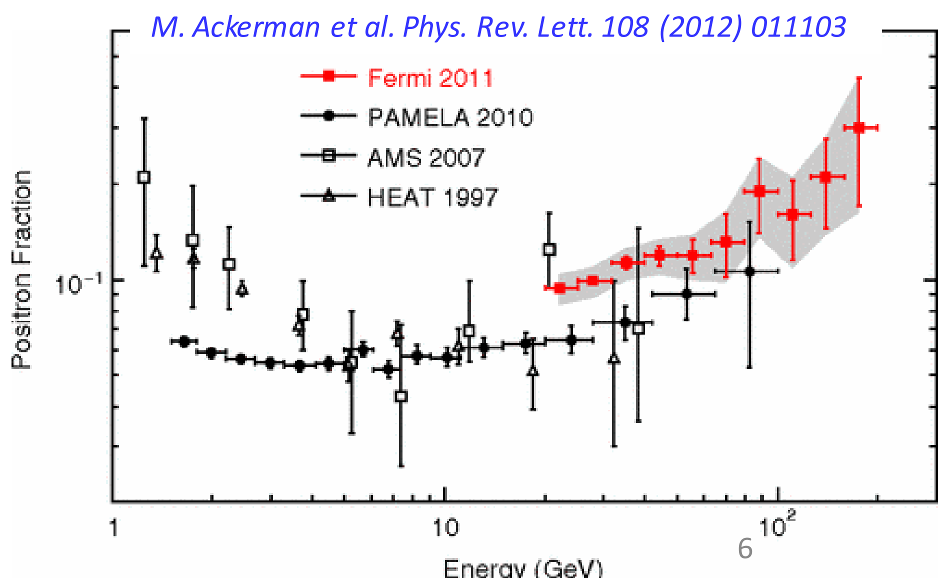
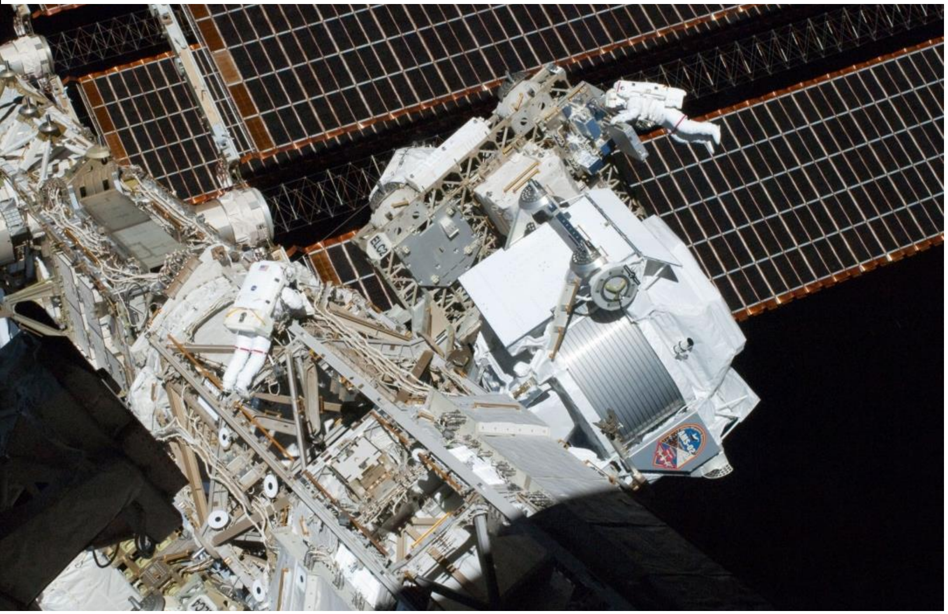


Image credit: NASA/Jerry Cannon, Robert Murray



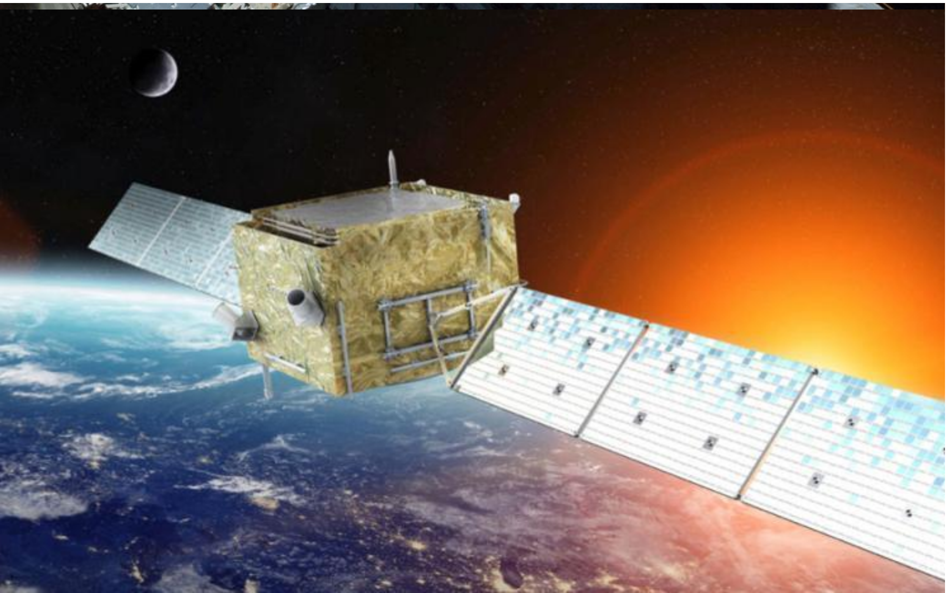
Space-born Cosmic Ray Experiments in operation

AMS, started May 2011

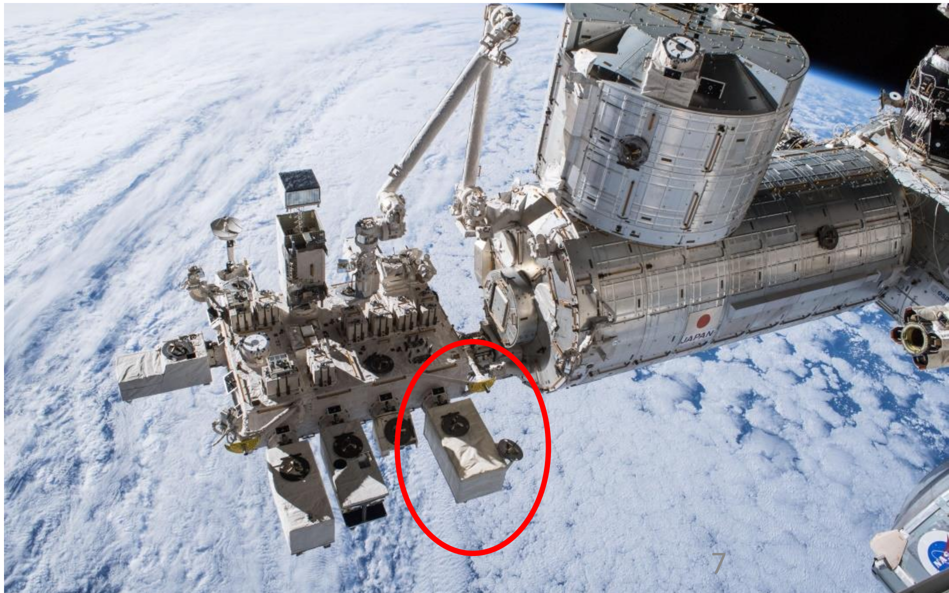


CALET, started August 2015

DAMPE, started December 2015

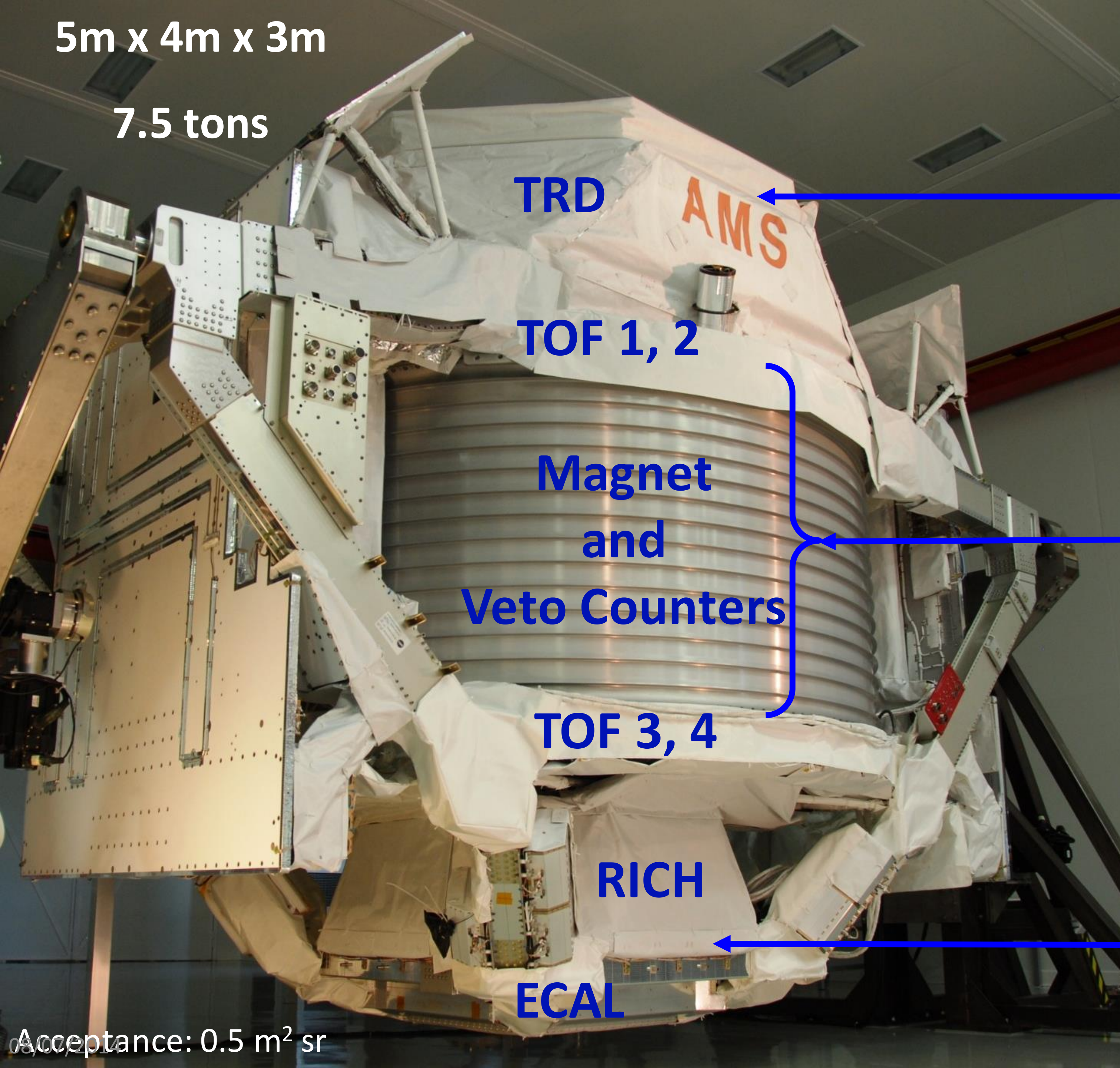


ISS CREAM, started August 2017



5m x 4m x 3m

7.5 tons



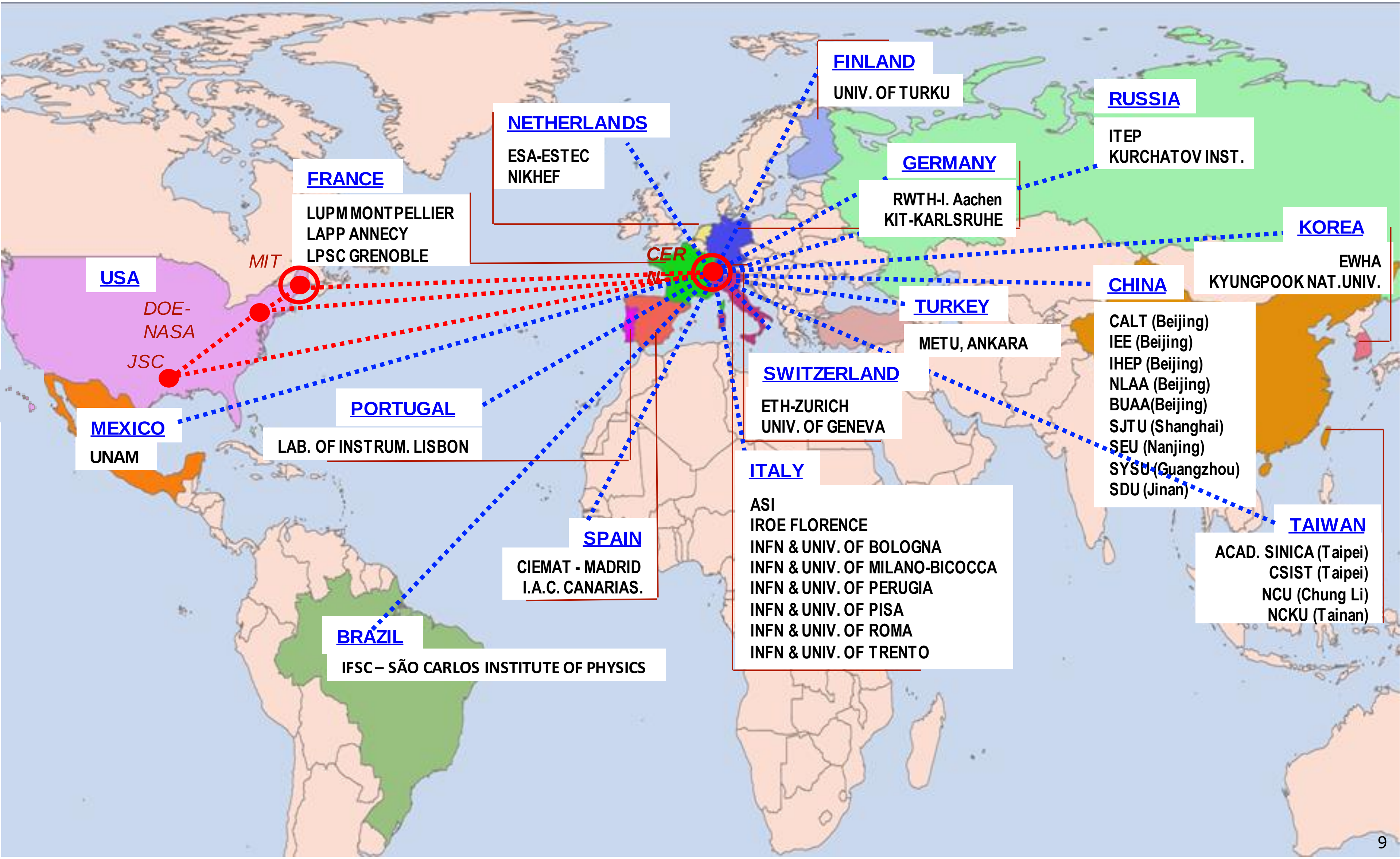
Silicon layer 1

Silicon layers 2 - 8

Silicon layer 9

Acceptance: 0.5 m^2 sr

AMS is an international collaboration based at CERN

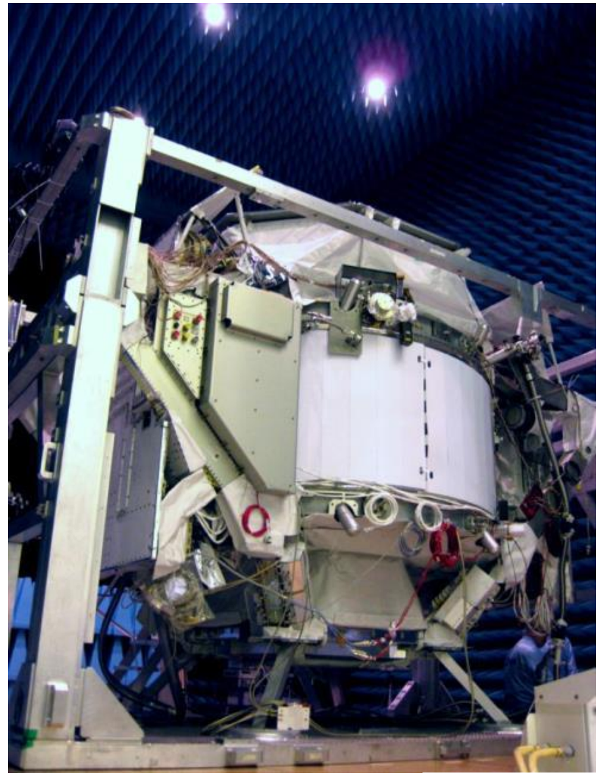


It took 650 physicists and engineers 17 years to construct AMS

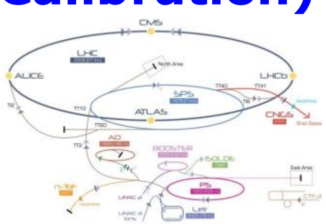
Ground Tests and Calibrations

Space Qualification (EMI and TV at ESTEC)

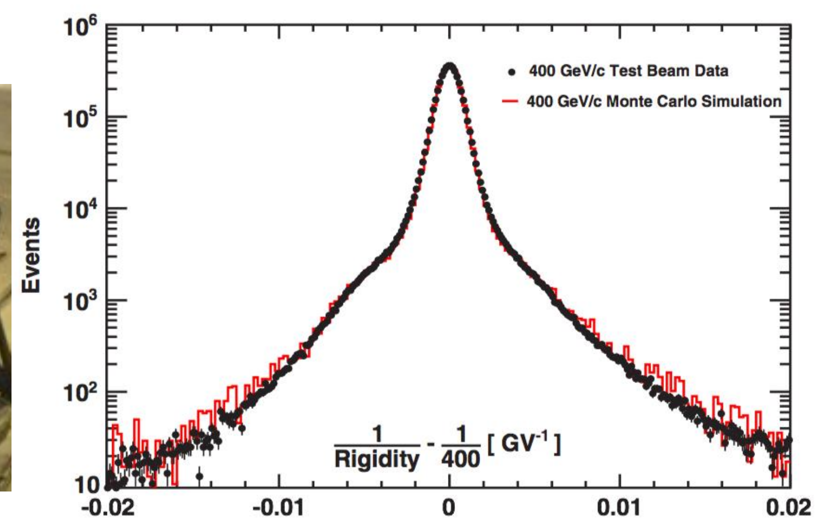
TVT Chamber: P < 10^{-9} bar
Ambient temperature:
-90°C to 40°C



Test Beam at CERN (Calibration)



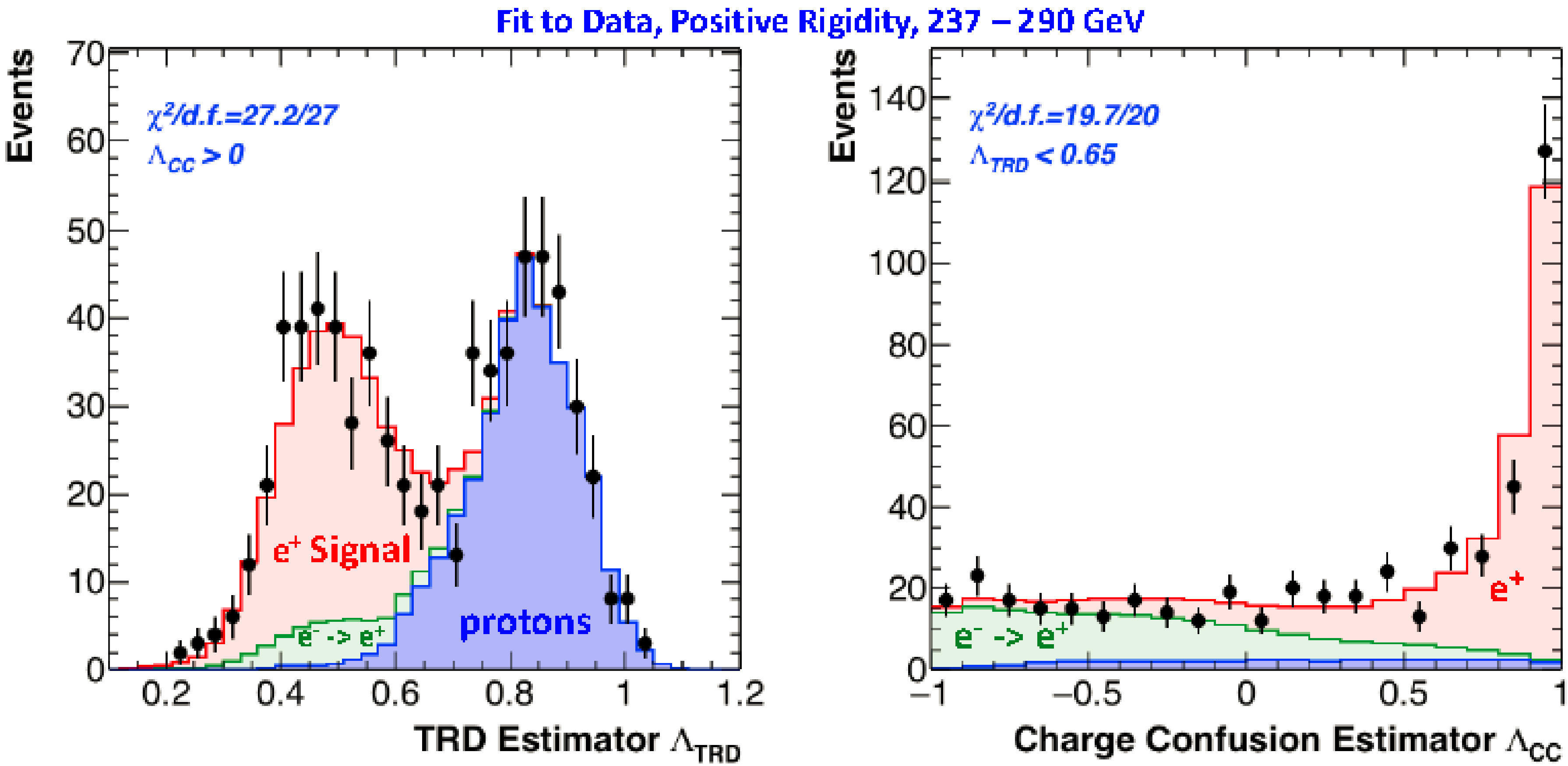
1,762 positions and angles
with p, e^+, e^-, pion beams
from 10 to 400 GeV/c



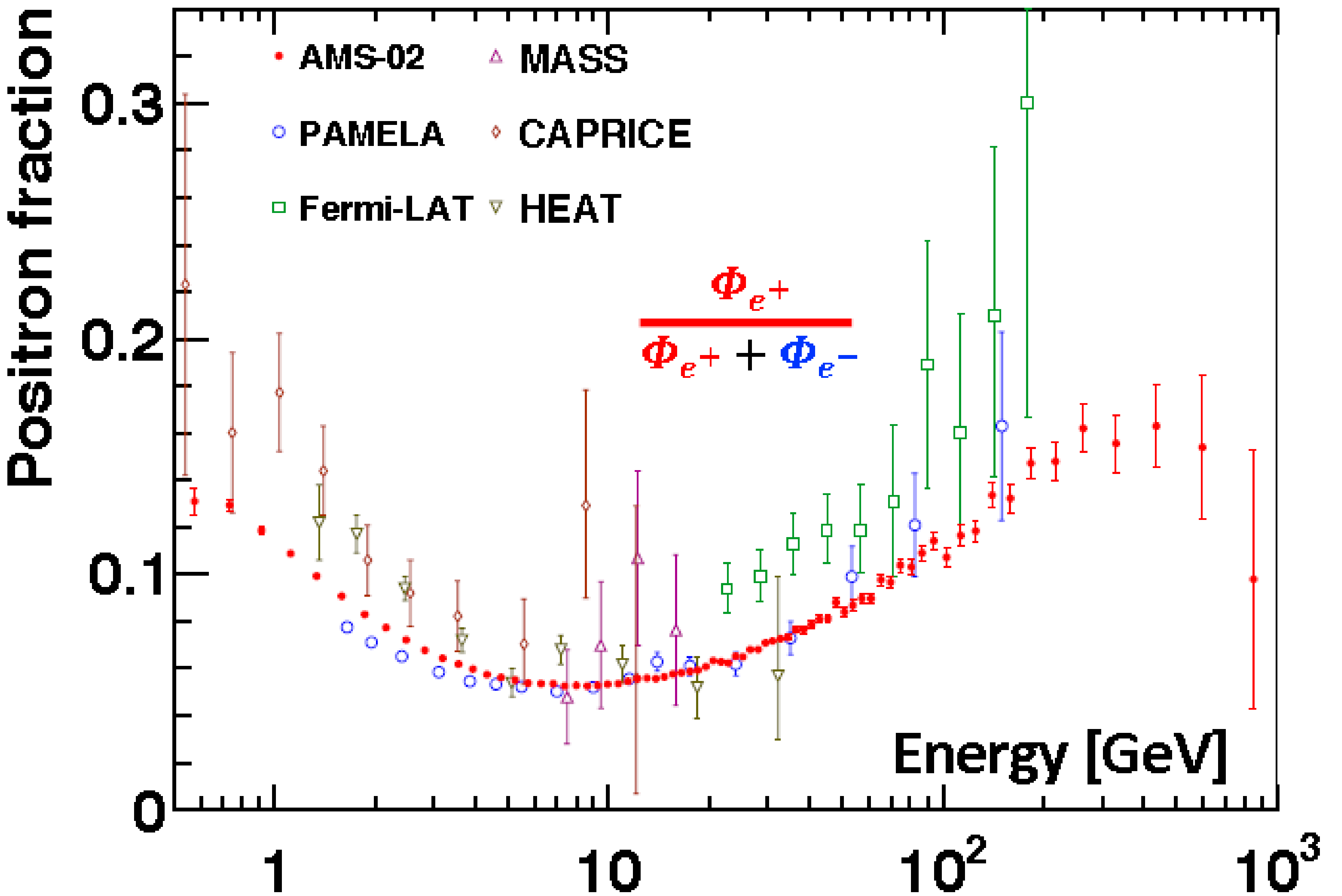
Positron measurement with AMS

Signal identification from 2D template fit in (Λ_{TRD} - Λ_{CC}) plane

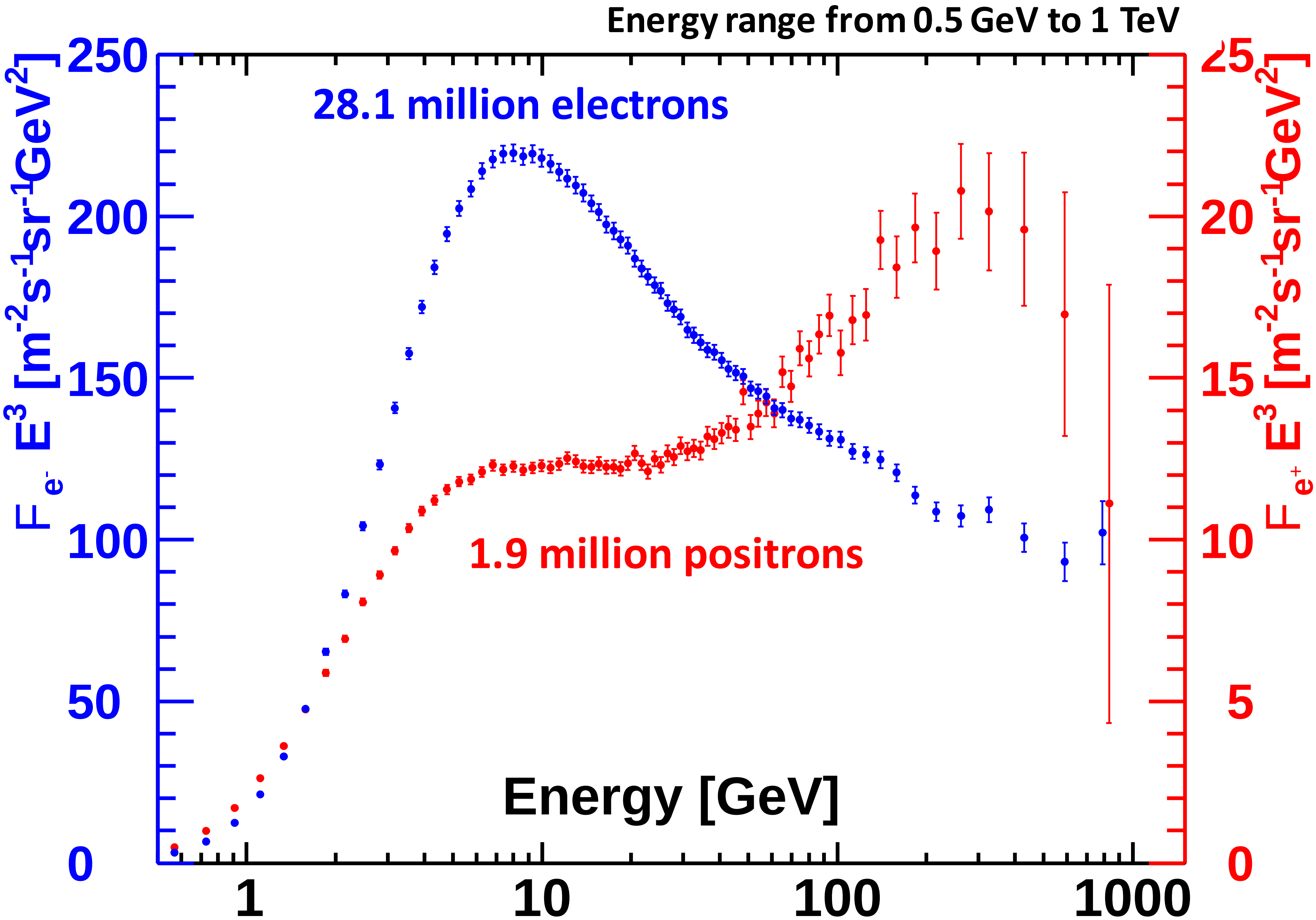
237<|R|<290 GV



Positron fraction in cosmic rays with AMS



Latest AMS results on positron and electron fluxes

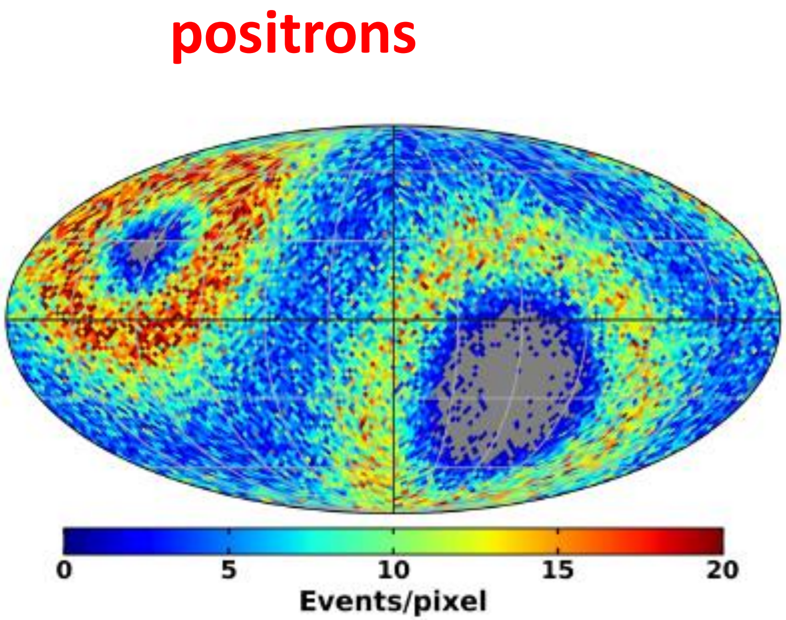


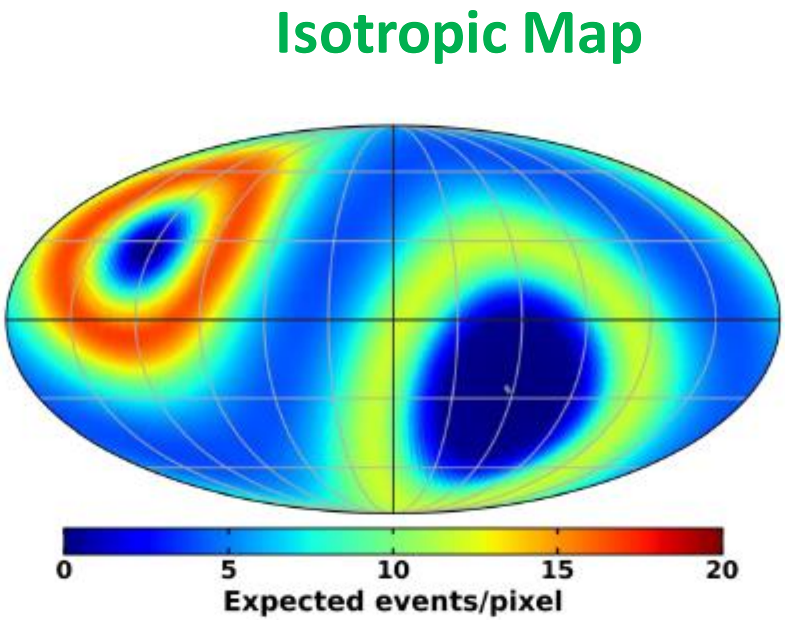
AMS Positron cosmic ray anisotropy

Astrophysical point sources like pulsars will imprint a higher anisotropy on the arrival directions of energetic positrons than a smooth dark matter halo.

The anisotropy in galactic coordinates

$$\delta = 3\sqrt{C_1/4\pi}$$ C_1 is the dipole moment





Amplitude of the dipole anisotropy on positrons
for 16 < E < 350 GeV
$\delta < 0.019$ (95% C.I.)

Positron flux modeling

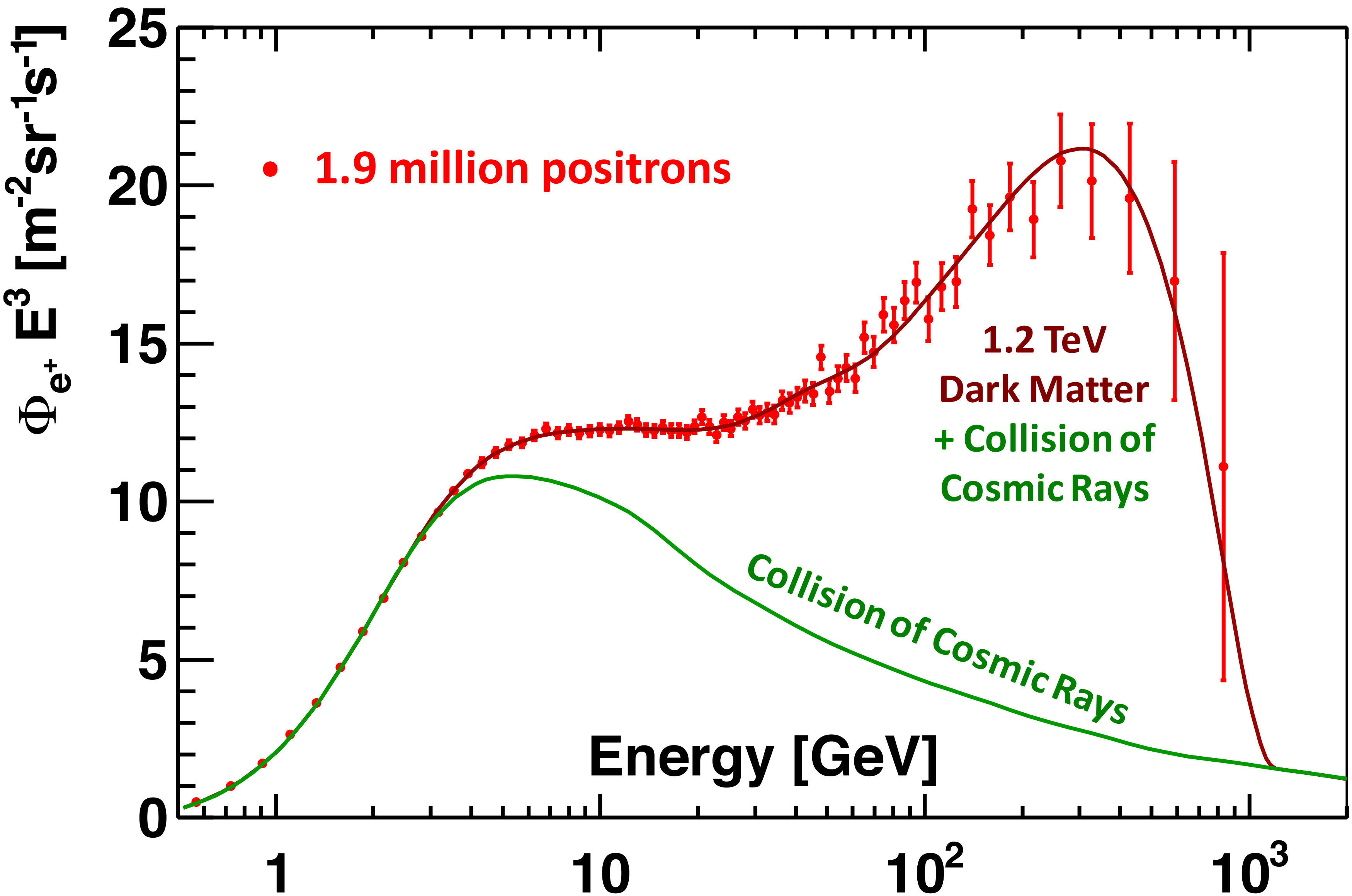
Many models proposed to explain the physics origin of the observed behavior

1) Particle origin: Dark Matter
2) Astrophysics origin: Pulsars, SNRs
3) Propagation of cosmic rays

Models based on very different assumptions describe observed trends of a single measurement.

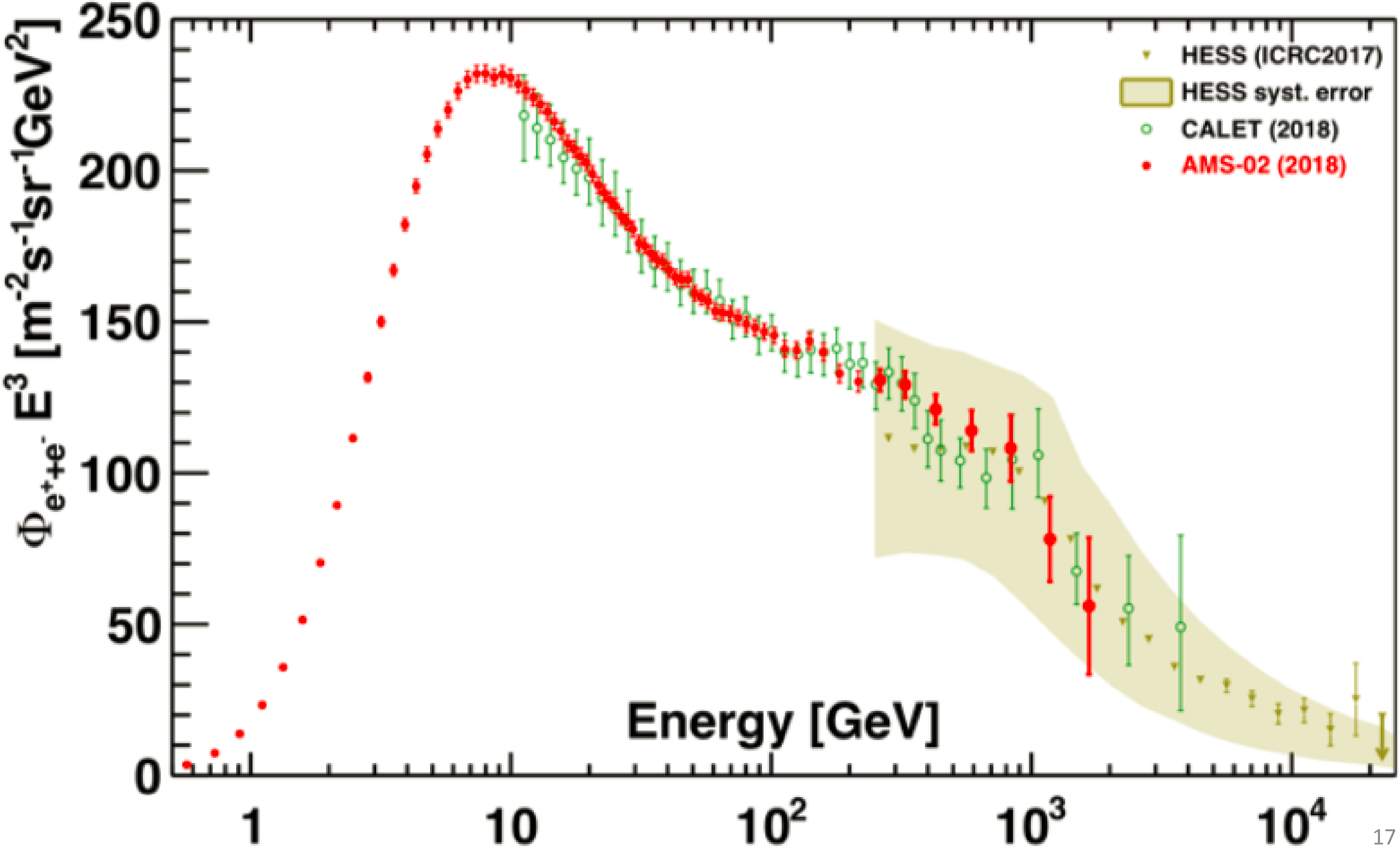
Simultaneous description of several precision measurements is difficult in the framework of a single model

The positron flux appears to be in agreement with predictions from a 1.2 TeV Dark Matter model (*J. Kopp, Phys. Rev. D 88, 076013 (2013)*)

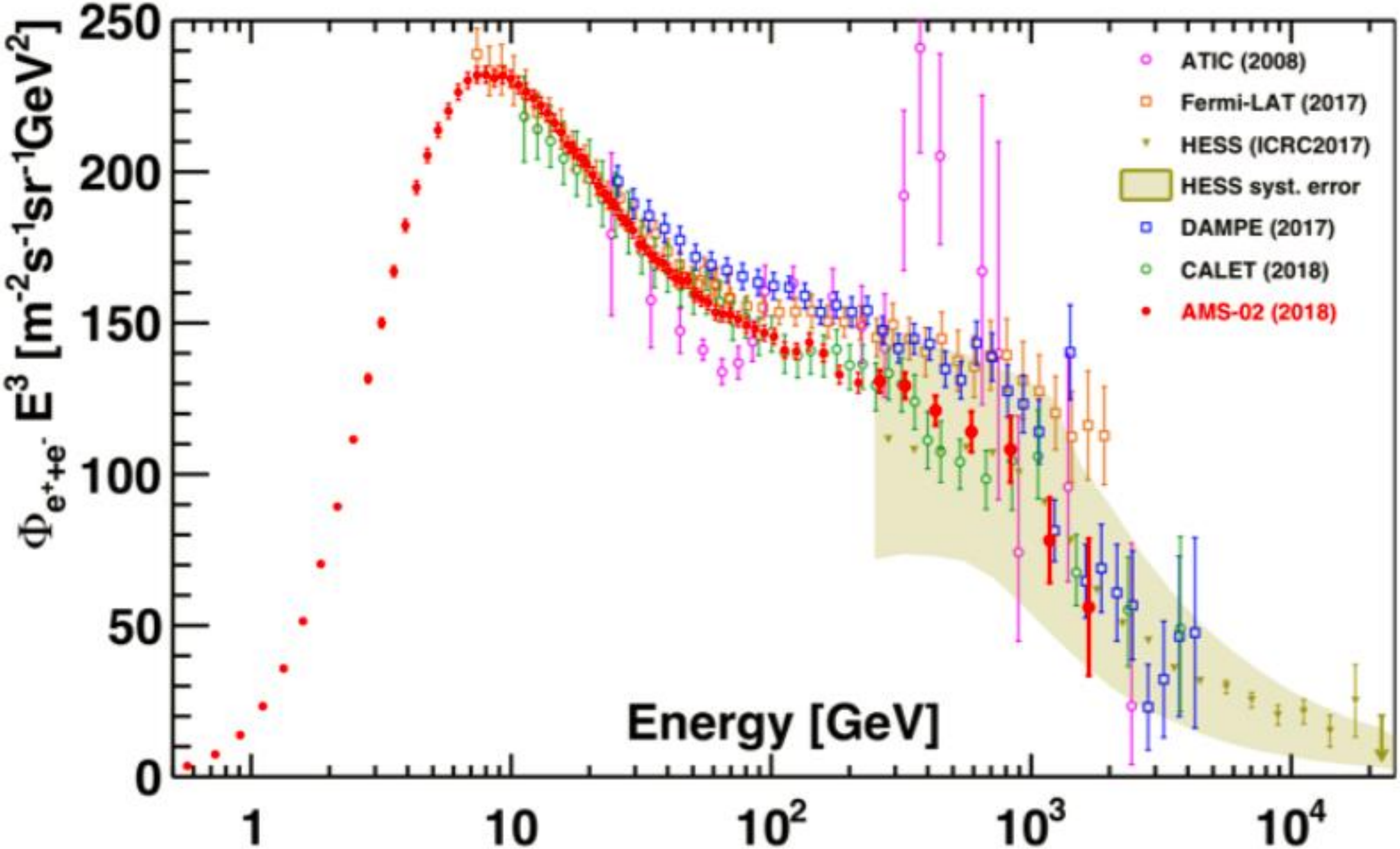


$(e^+ + e^-)$ AMS data: comparison with other detectors

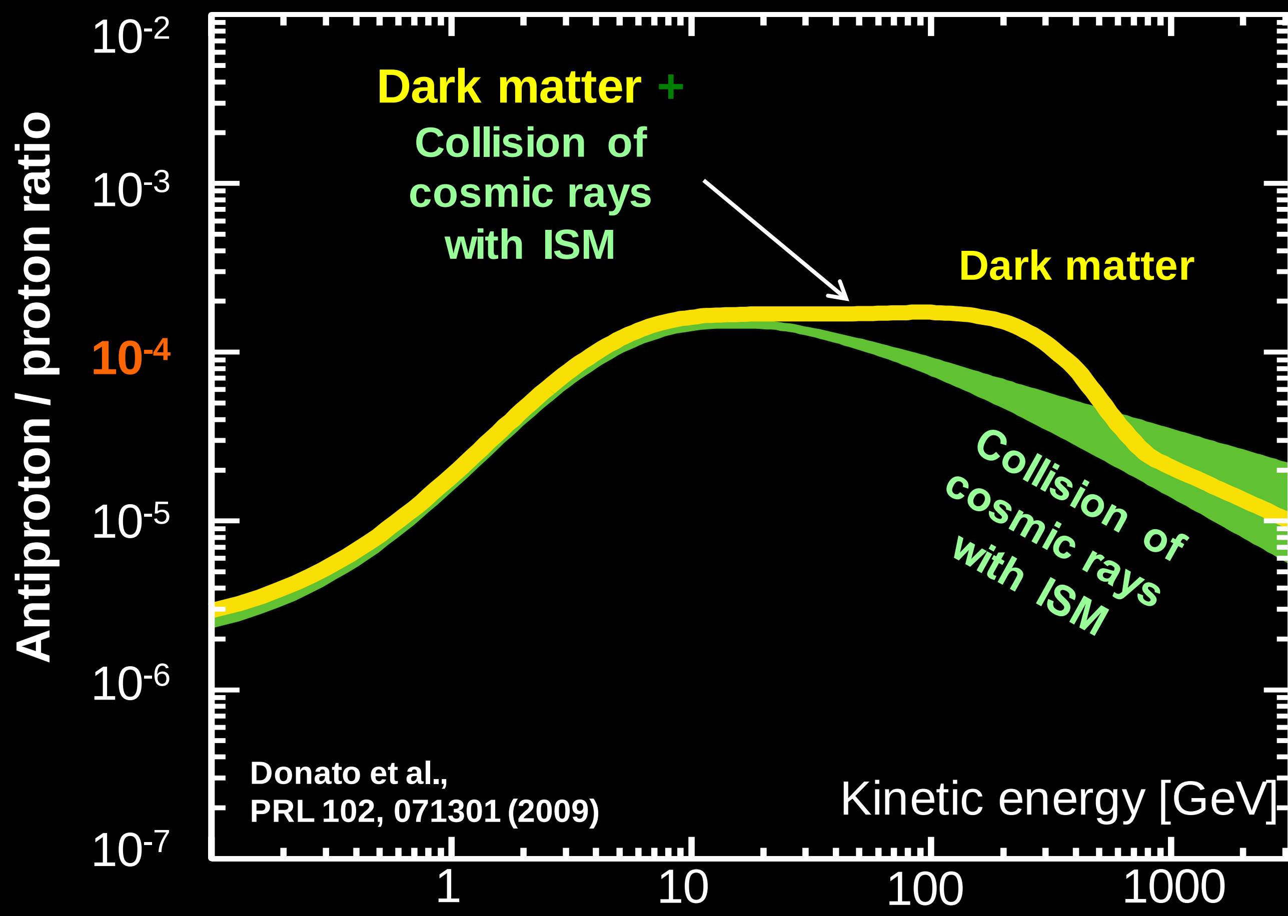
Measuring $(e^+ + e^-)$ is much less sensitive to detect the source term due to the large e^- background



$(e^+ + e^-)$ AMS data: comparison with other detectors



Antiprotons in Cosmic rays

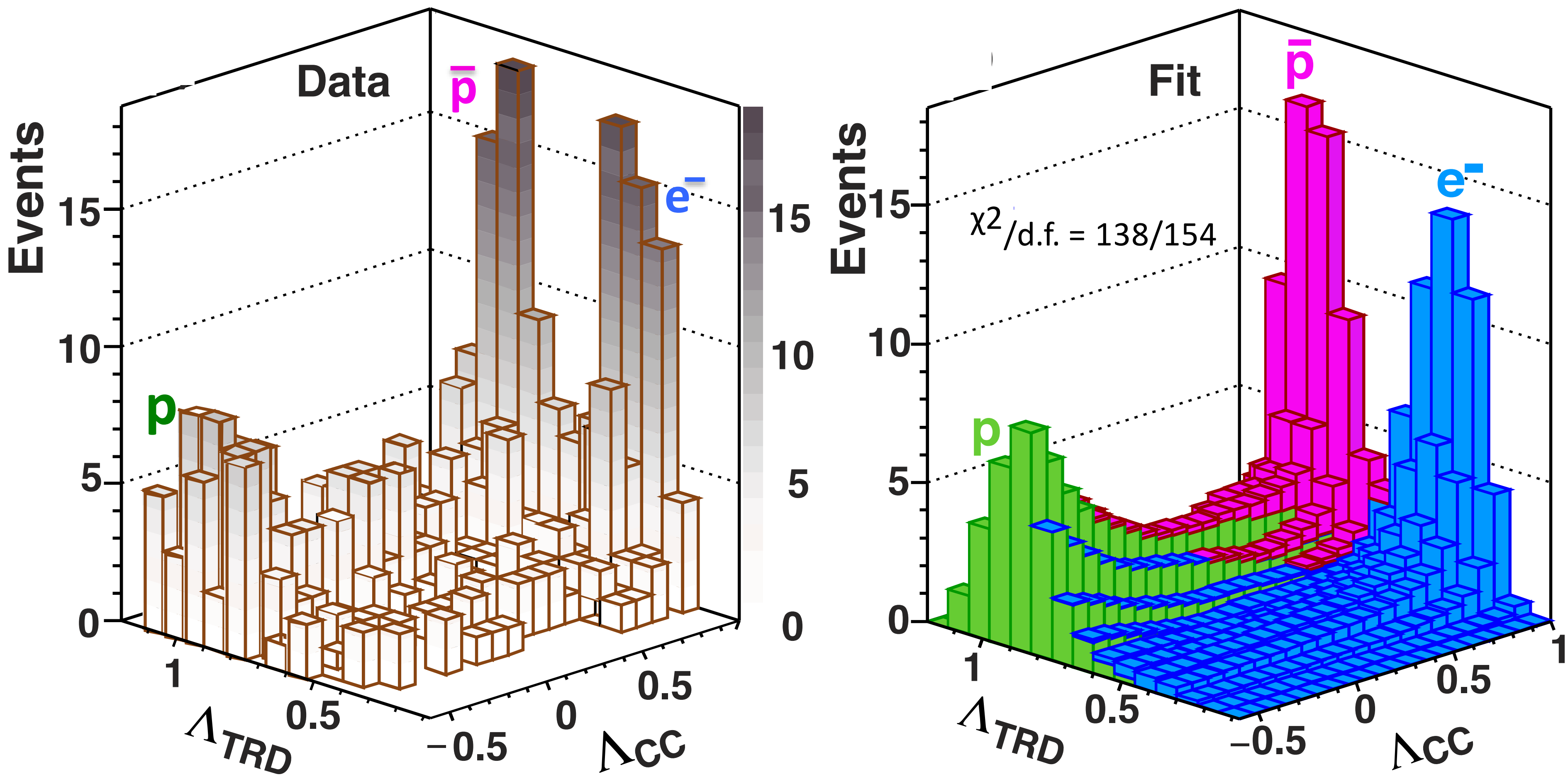


The Antiproton Flux is ~10^{-4} of the Proton Flux.
A percentage precision experiment requires background rejection close to 1 in a million

Antiproton measurement with AMS

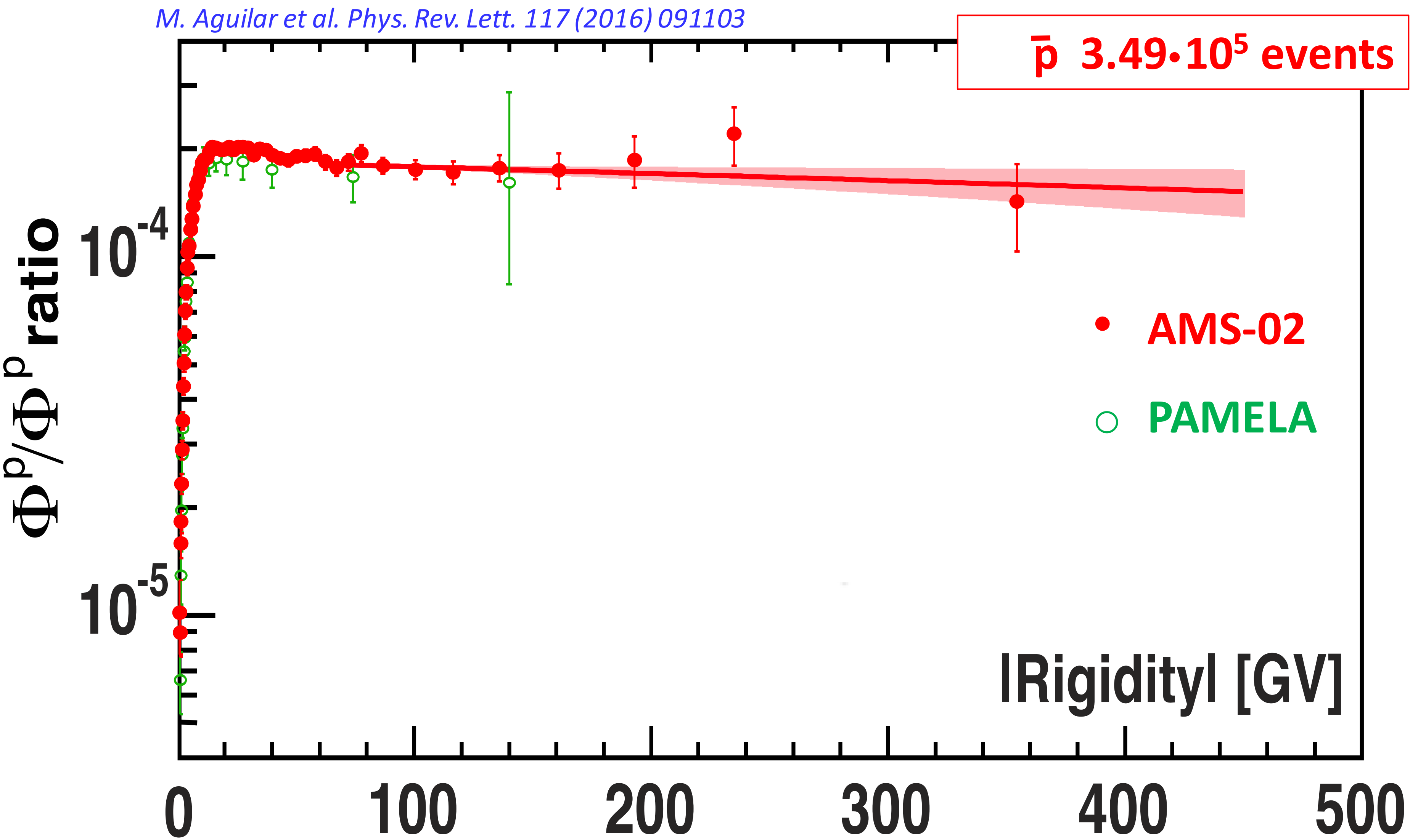
Signal identification from 2D template fit in (Λ_{TRD} - Λ_{CC}) plane

175<|R|<211 GV

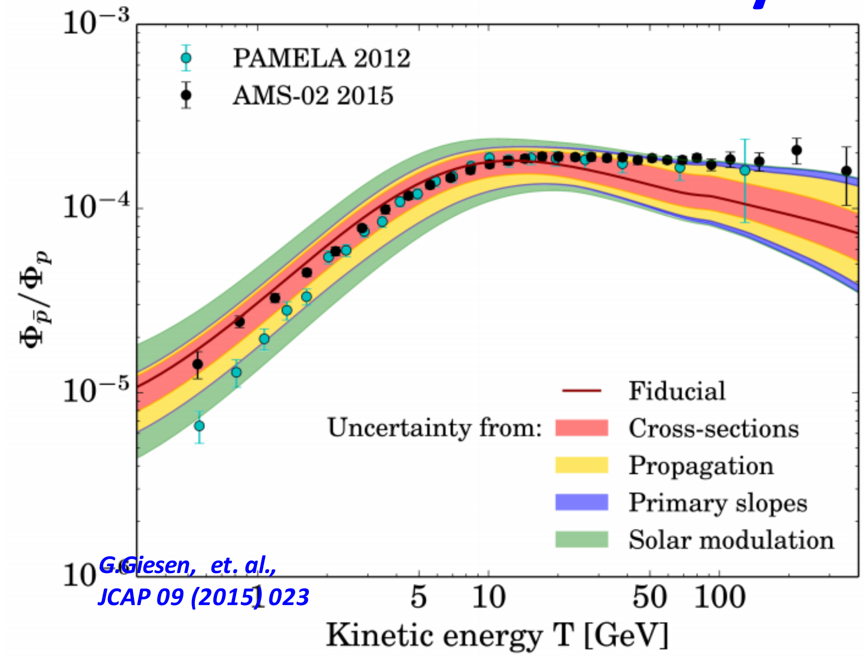


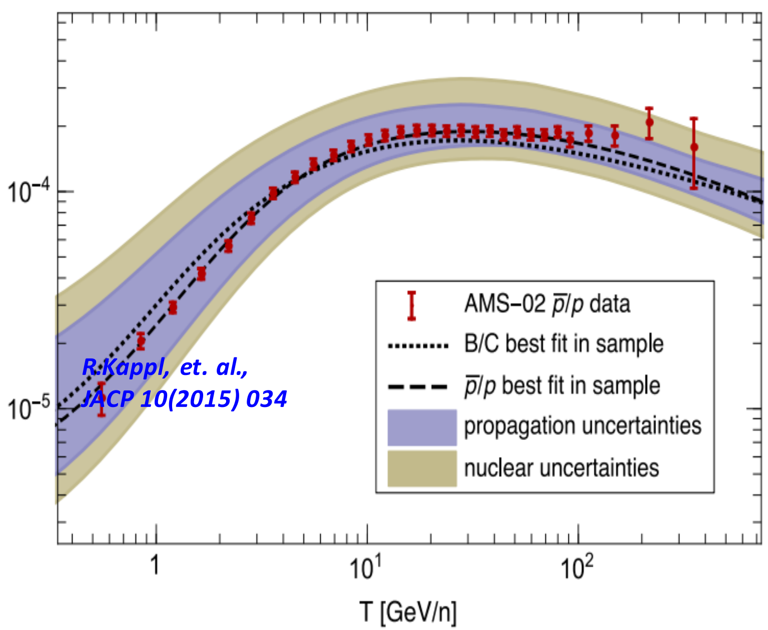
Antiproton-to-Proton Flux Ratio

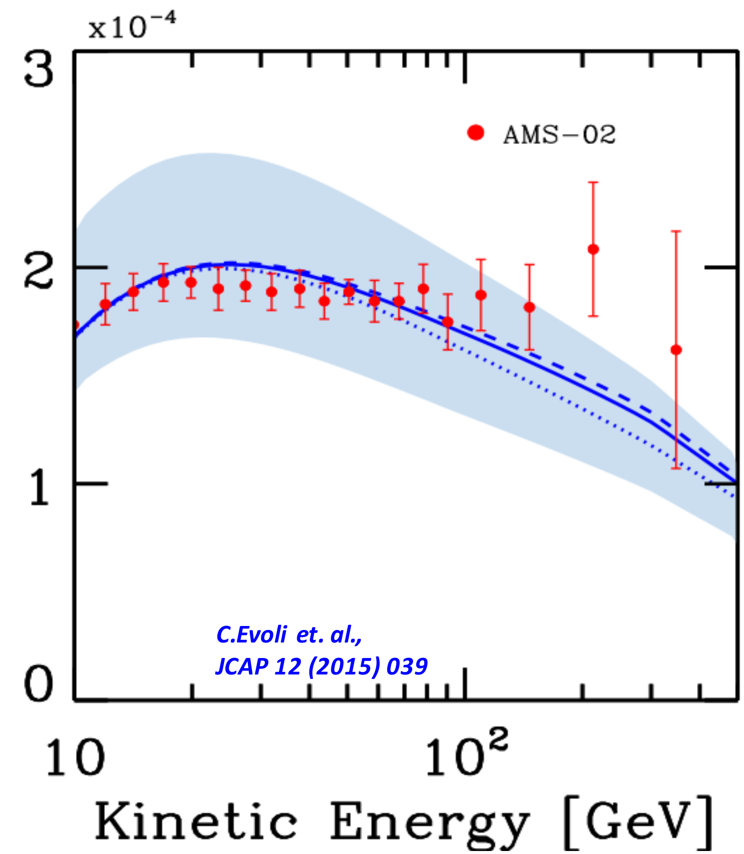
Show no rigidity dependence above 60 GV



Collision of cosmic rays with interstellar medium:



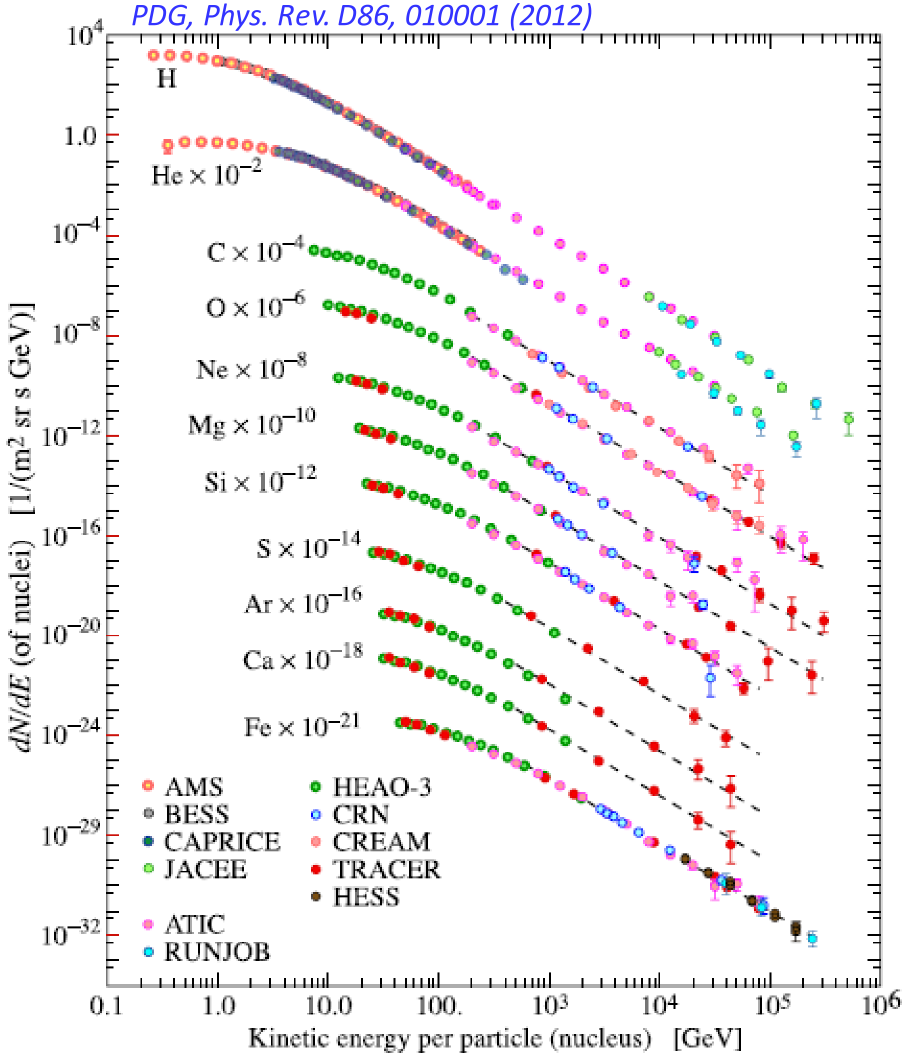




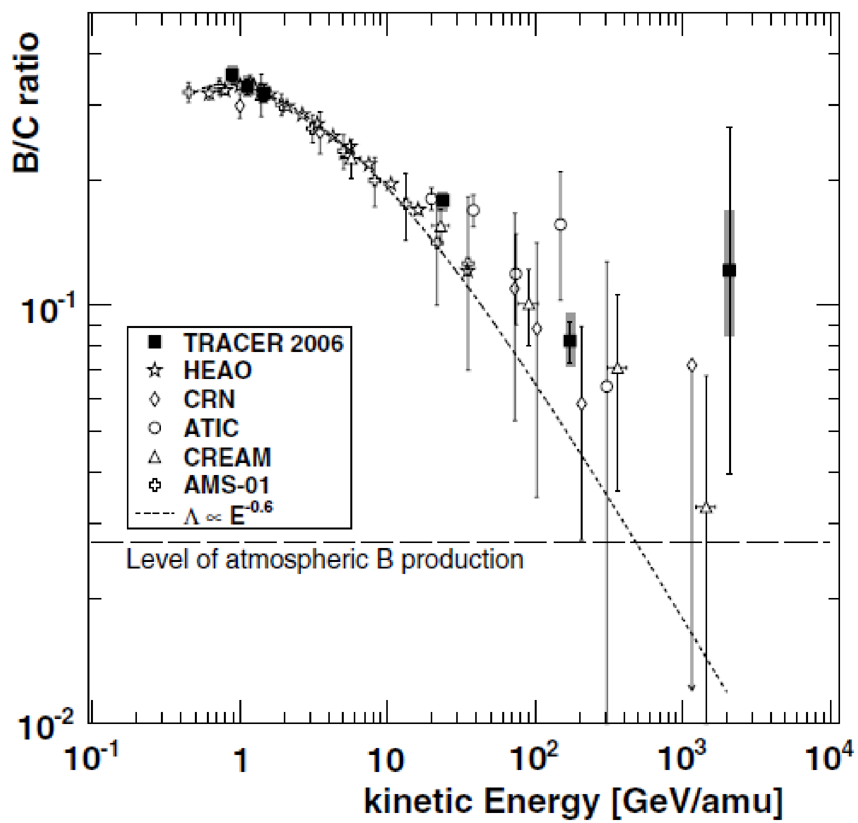
Primary and secondary cosmic ray

Understanding the origin, acceleration and propagation of CR require the knowledge of the chemical composition over a wide energy range

PDG, Phys. Rev. D86, 010001 (2012)



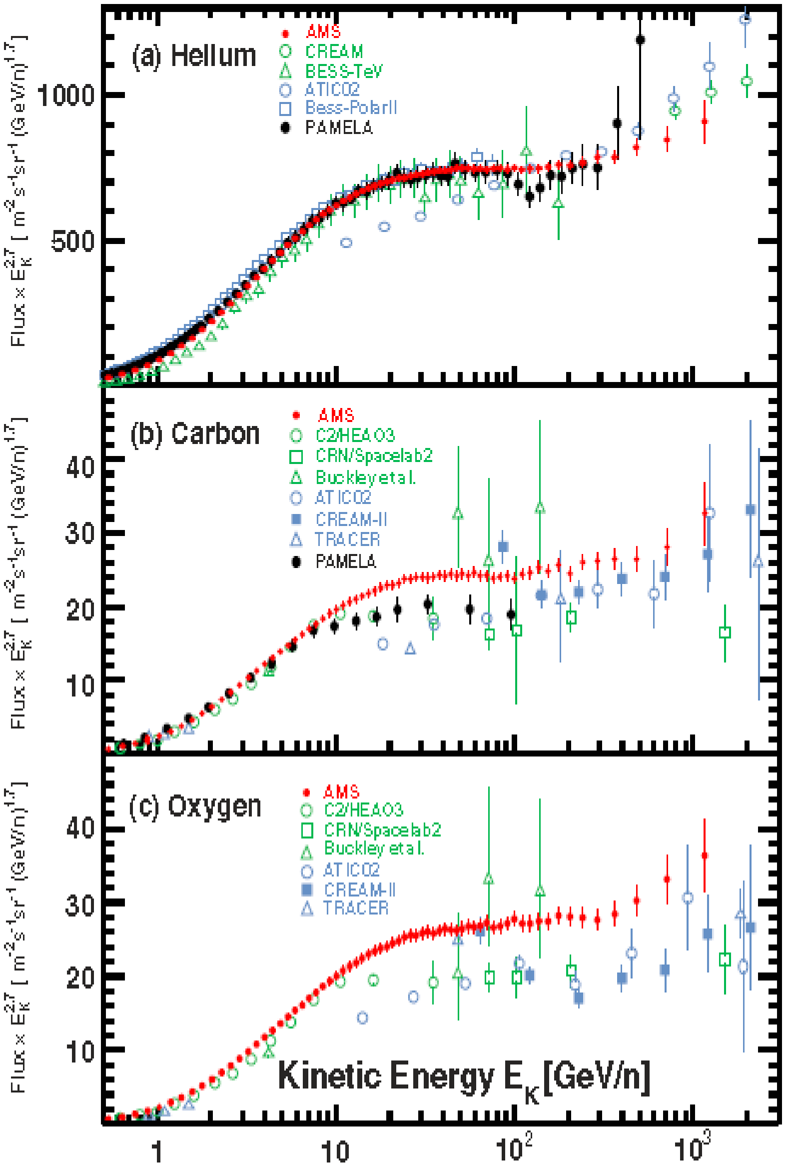
A. Obermeier et al. Astrophys. J. 742 (2011) 14



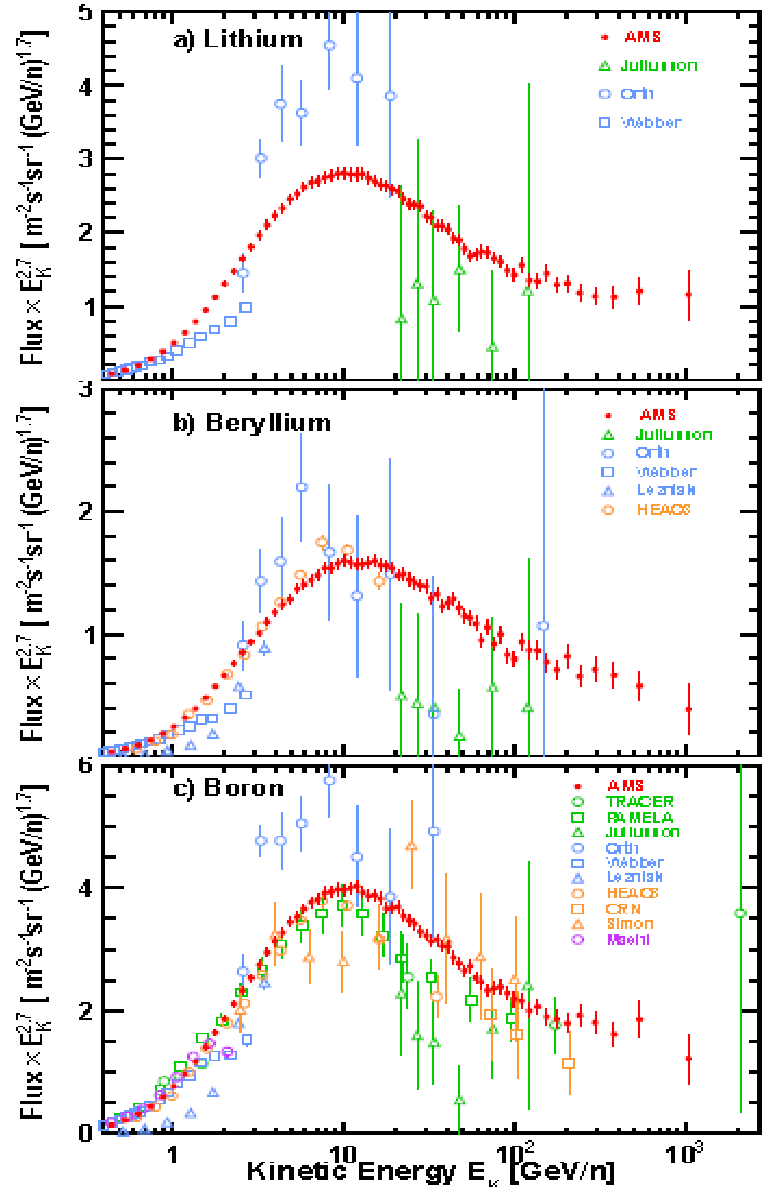
Primary and secondary Cosmic Rays

Comparison with earlier measurements

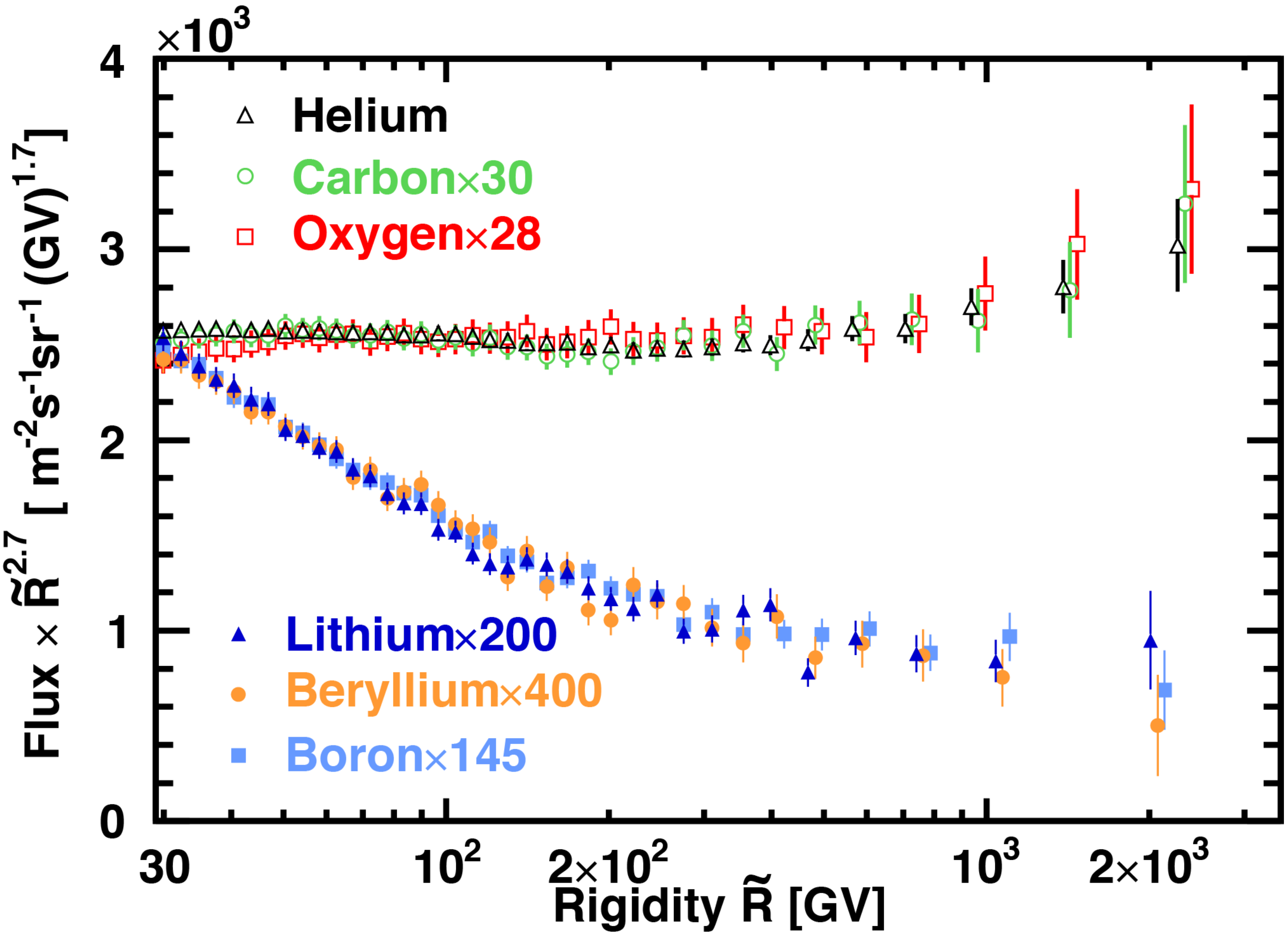
M. Aguilar et al. Phys. Rev. Lett. 119 (2017) 251101



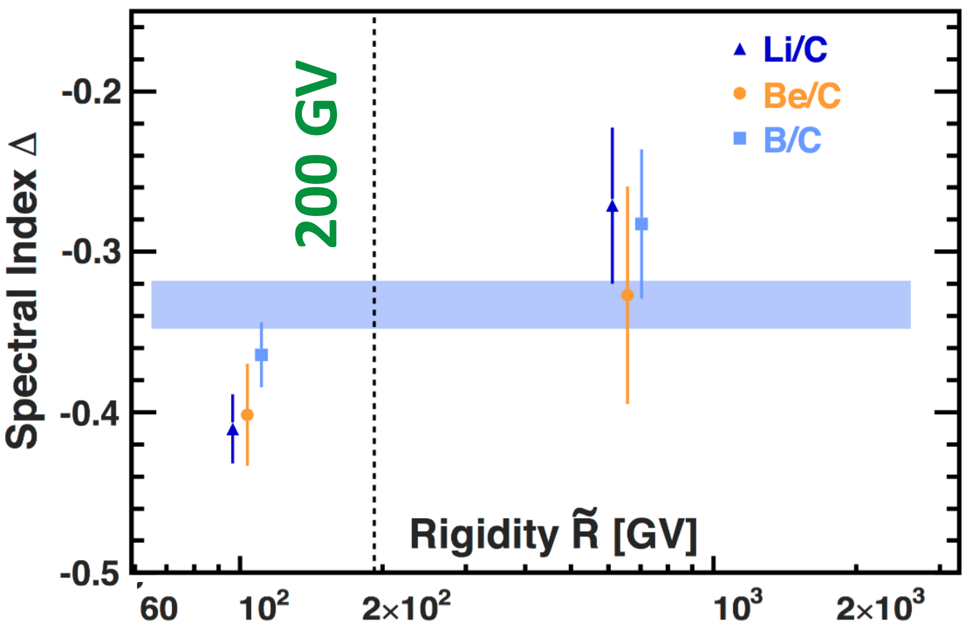
M. Aguilar et al. Phys. Rev. Lett. 120 (2018) 021101

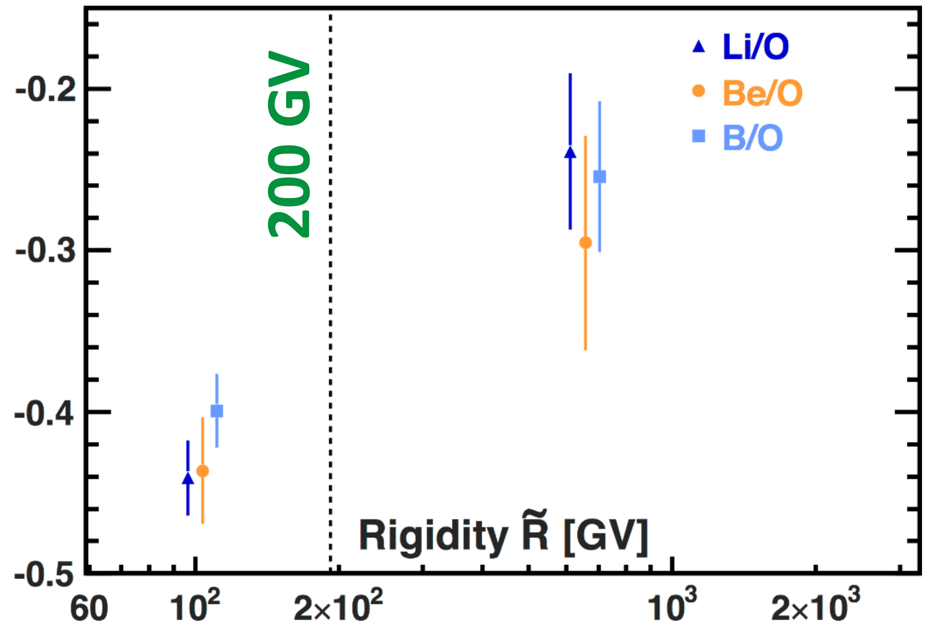


Primary and secondary Cosmic Rays with AMS



Secondary/Primary Flux Ratios = KR^{Δ}





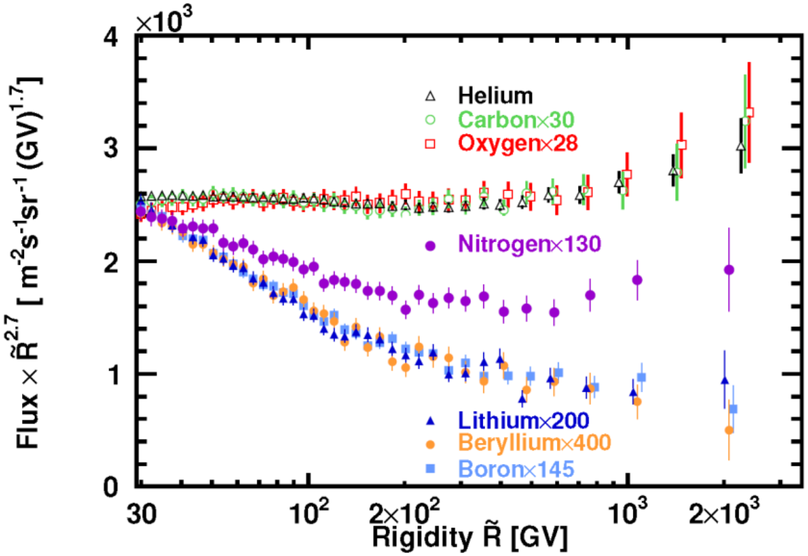
Combining the six ratios,

the secondary over primary flux ratio (B/C, …),

deviates from single power law above 200 GV by 0.13±0.03

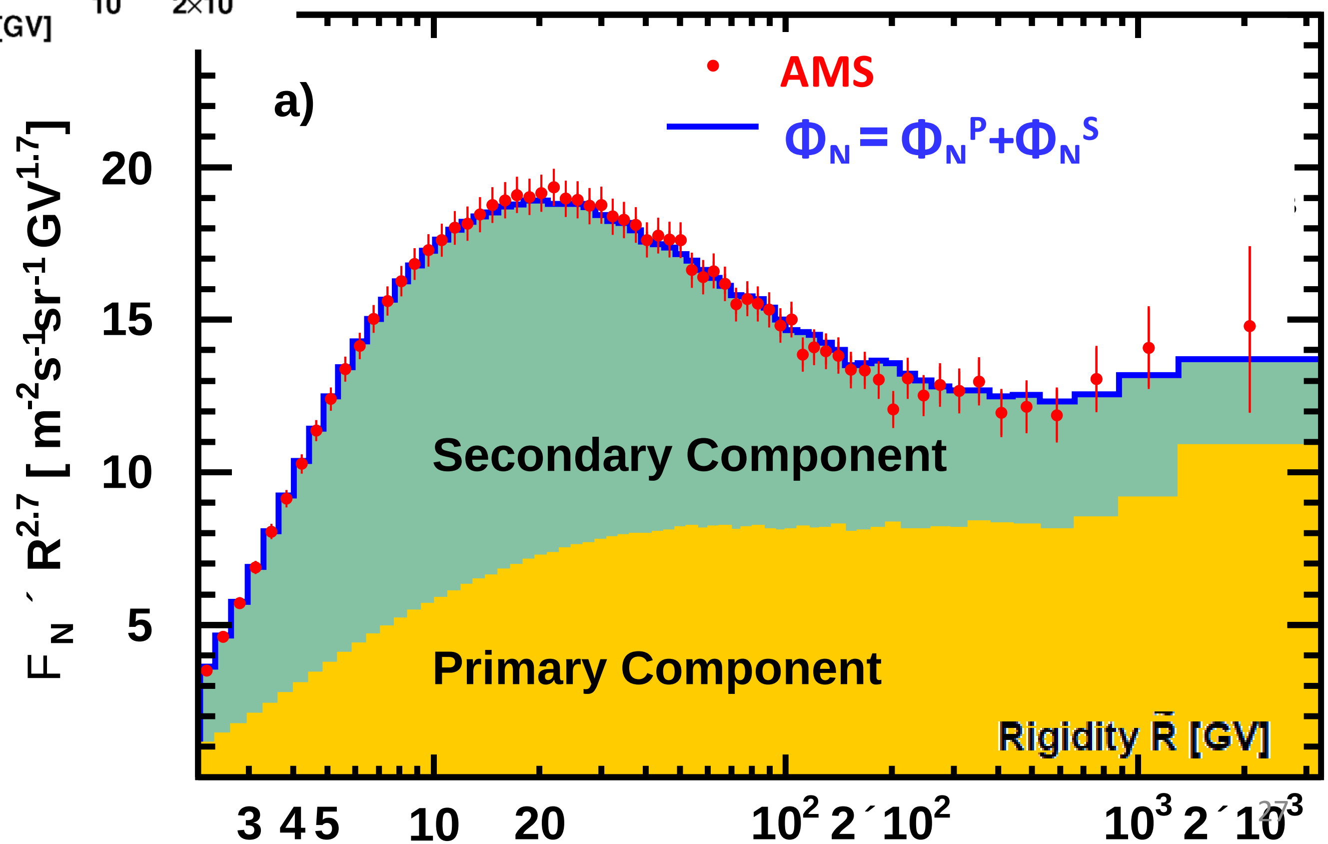
$$\Delta[200\text{-}3300\text{GV}] - \Delta[60\text{-}200\text{GV}] = 0.13 \pm 0.03$$

Nitrogen Cosmic Rays

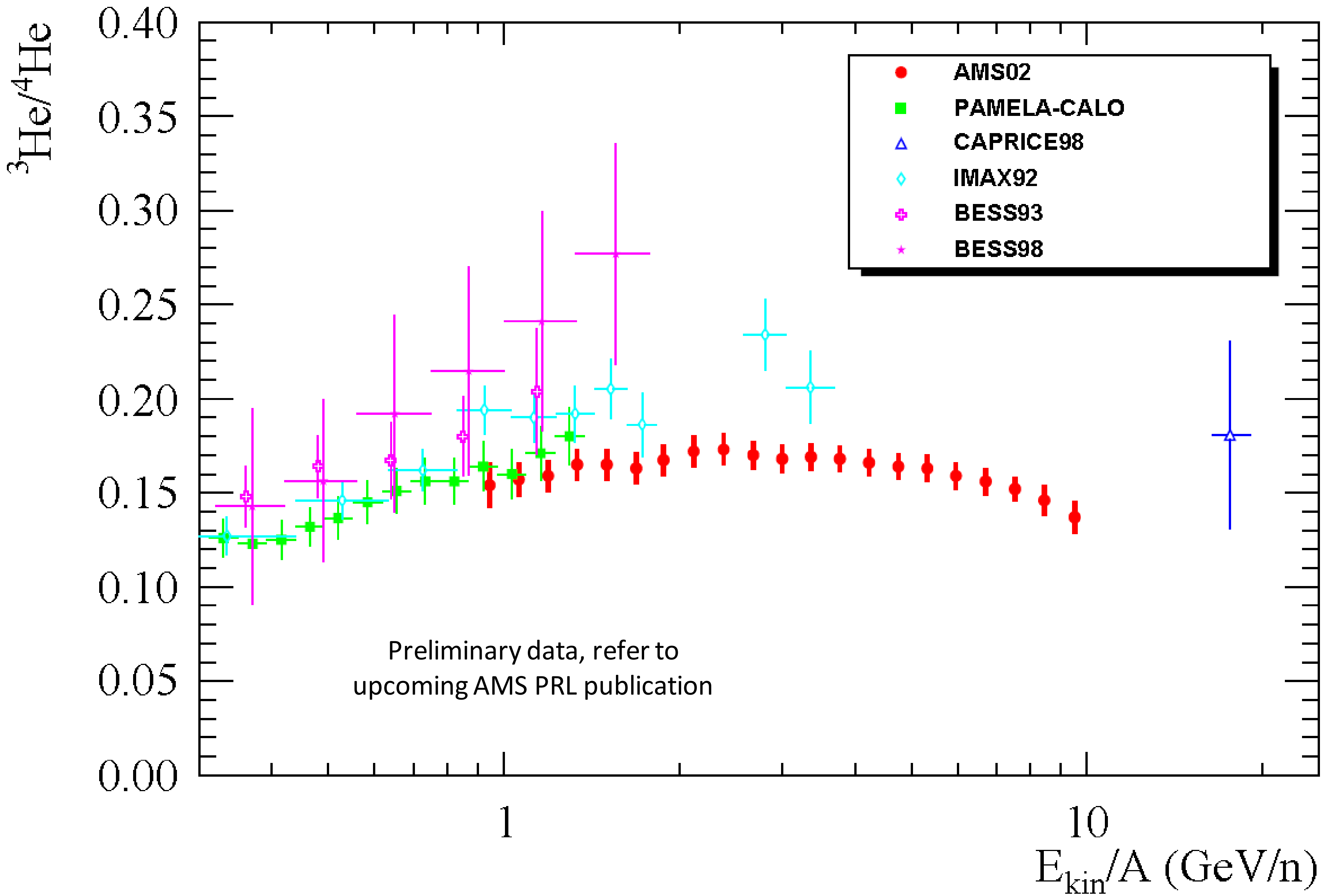


M. Aguilar et al. Phys. Rev. Lett. 121 (2018) 051103

$$\Phi_N = \Phi_N^P + \Phi_N^S = (0.090\pm0.002)\times\Phi_O + (0.62\pm0.02)\times\Phi_B$$

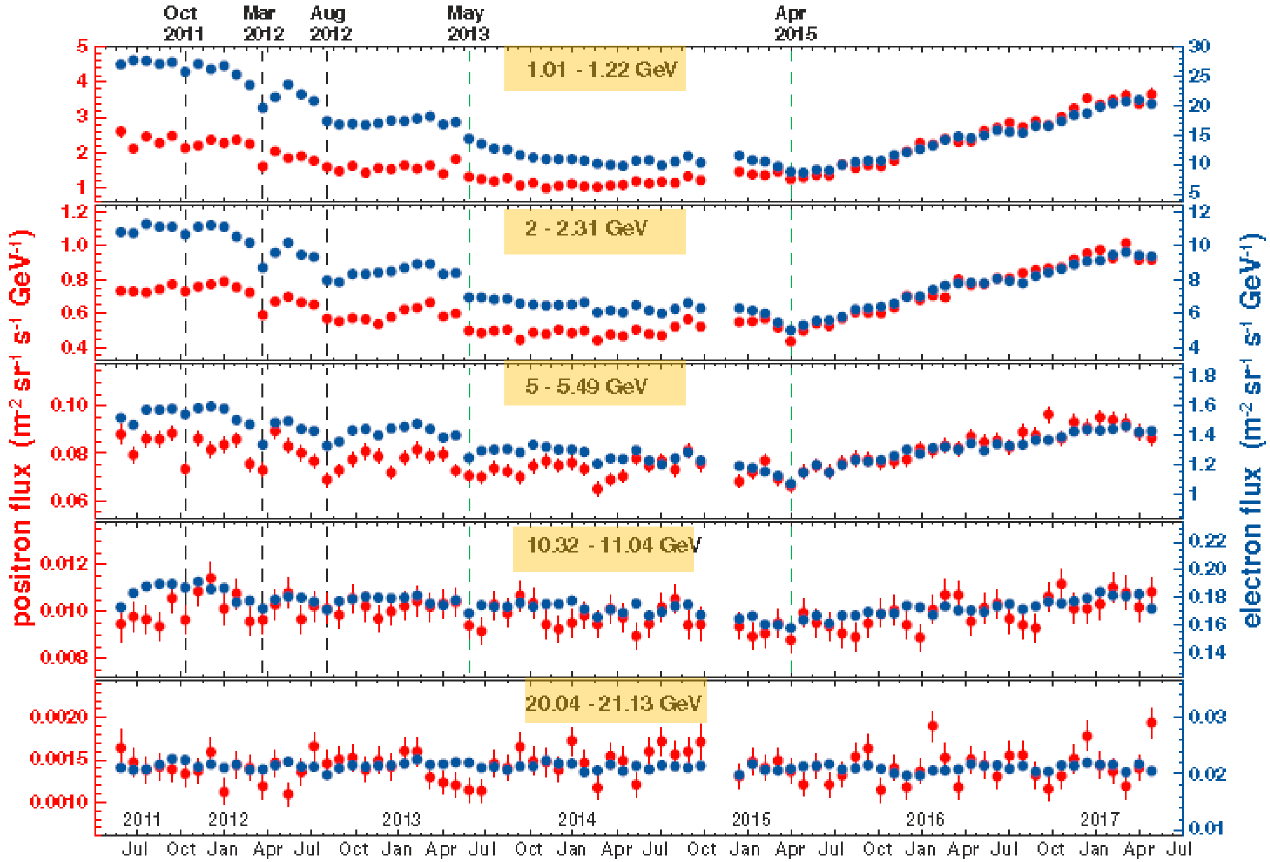


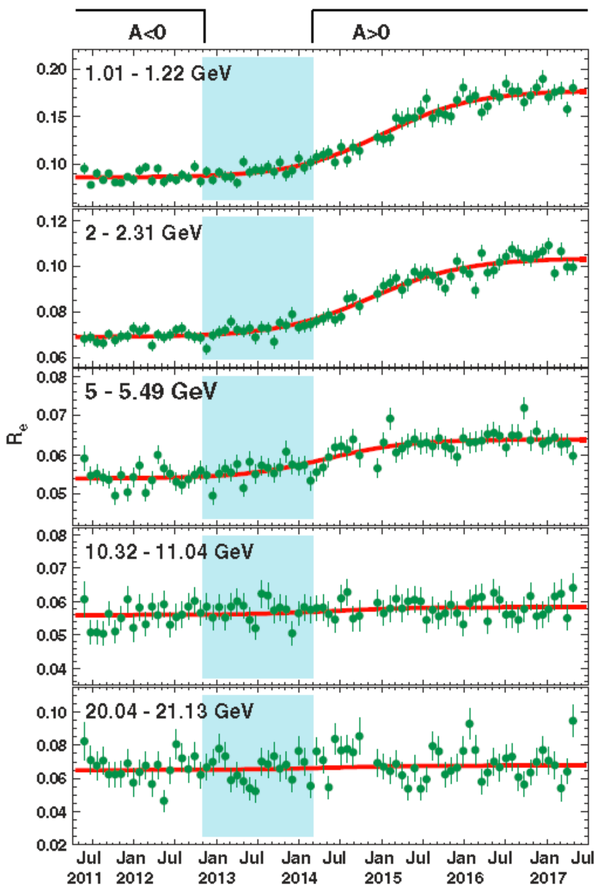
$^3He/^4He$ abundancies



AMS continous measurement of the e^+ and e^- flux in the energy range 1 -50 GeV over 6 years with a time resolution of 27 days.

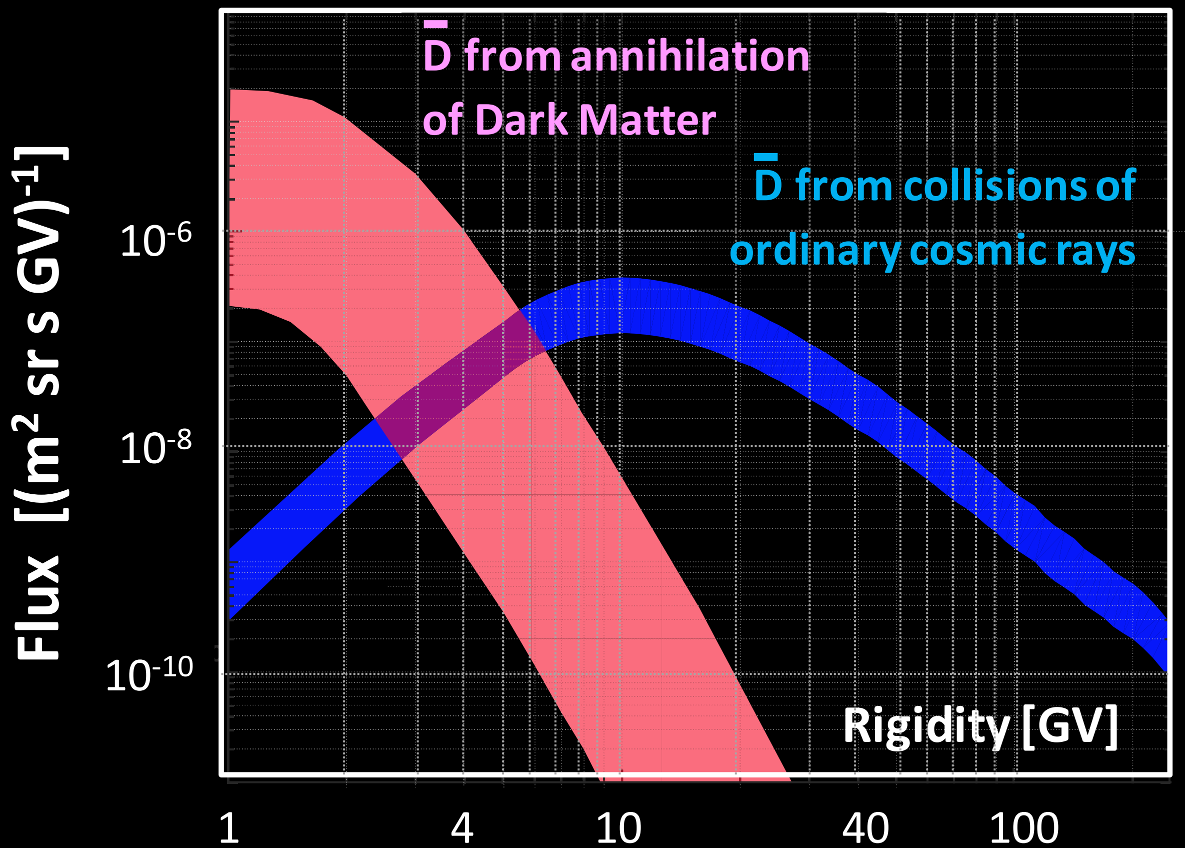
M. Aguilar et al. Phys. Rev. Lett. 121 (2018) 051102





Anti Deuterons in Cosmic rays

Anti Deuterons have been proposed as an almost background free channel for Dark Matter indirect detection



■ Dark Matter model:
F. Donato et al., Phys. Rev. D, 62 (2000) 043003

■ Collisions of CR model
K. Blum et al., Phys. Rev. D 96 (2017) 103021

The Anti Deuterons Flux is $< 10^{-4}$ of the Antiproton Flux.

Additional background rejection

Anti-deuterons have never been observed in space

PRL 95, 081101 (2005) PHYSICAL REVIEW LETTERS week ending 19 AUGUST 2005

Search for Cosmic-Ray Antideuterons

We performed a search for cosmic-ray antideuterons using data collected during four BESS balloon flights from 1997 to 2000. No candidate was found. We derived, for the first time, an upper limit of 1.9×10^{-4} $(\mathrm{m^2 s\, sr\, GeV/nucleon})^{-1}$ for the differential flux of cosmic-ray antideuterons, at the 95% confidence level, between 0.17 and 1.15 GeV/nucleon at the top of the atmosphere.

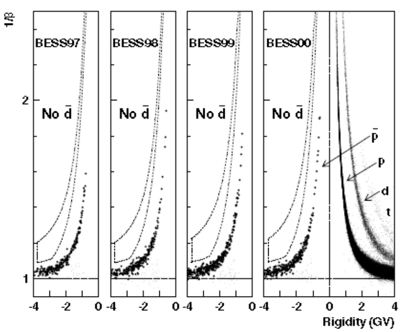
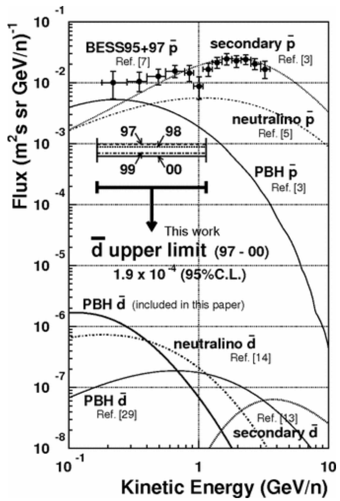
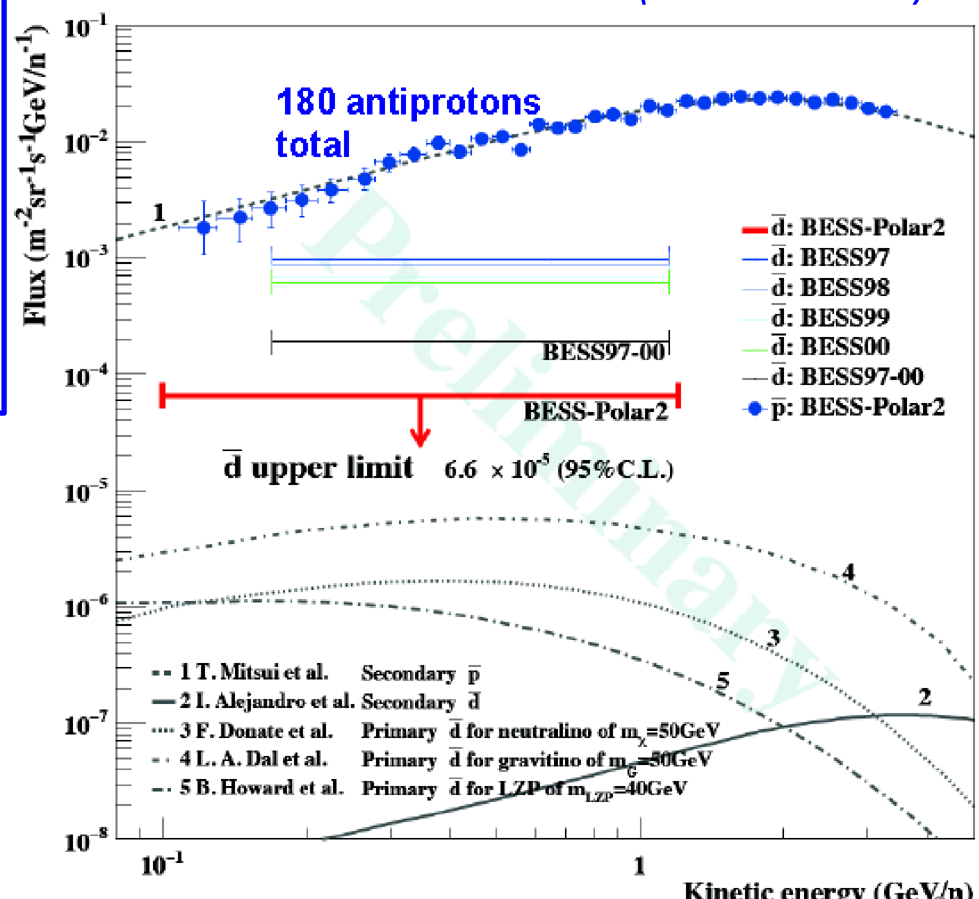


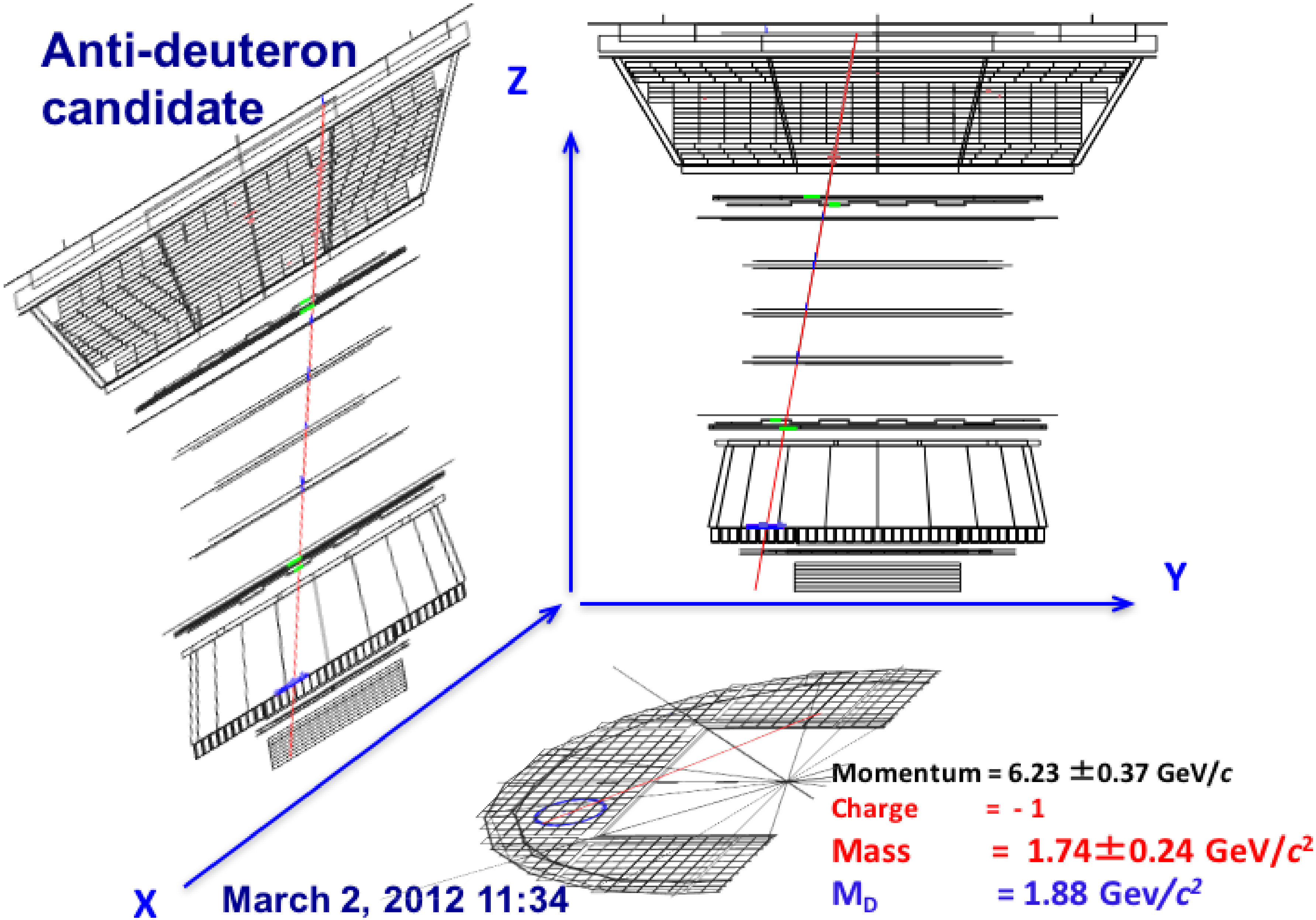
FIG. 1. The surviving single-charge events in the data of each flight. The dotted curves define the $\bar{d}$ mass bands. The dotted vertical lines at ~ -3.7 GV correspond to E_2 shown in Fig. 2.



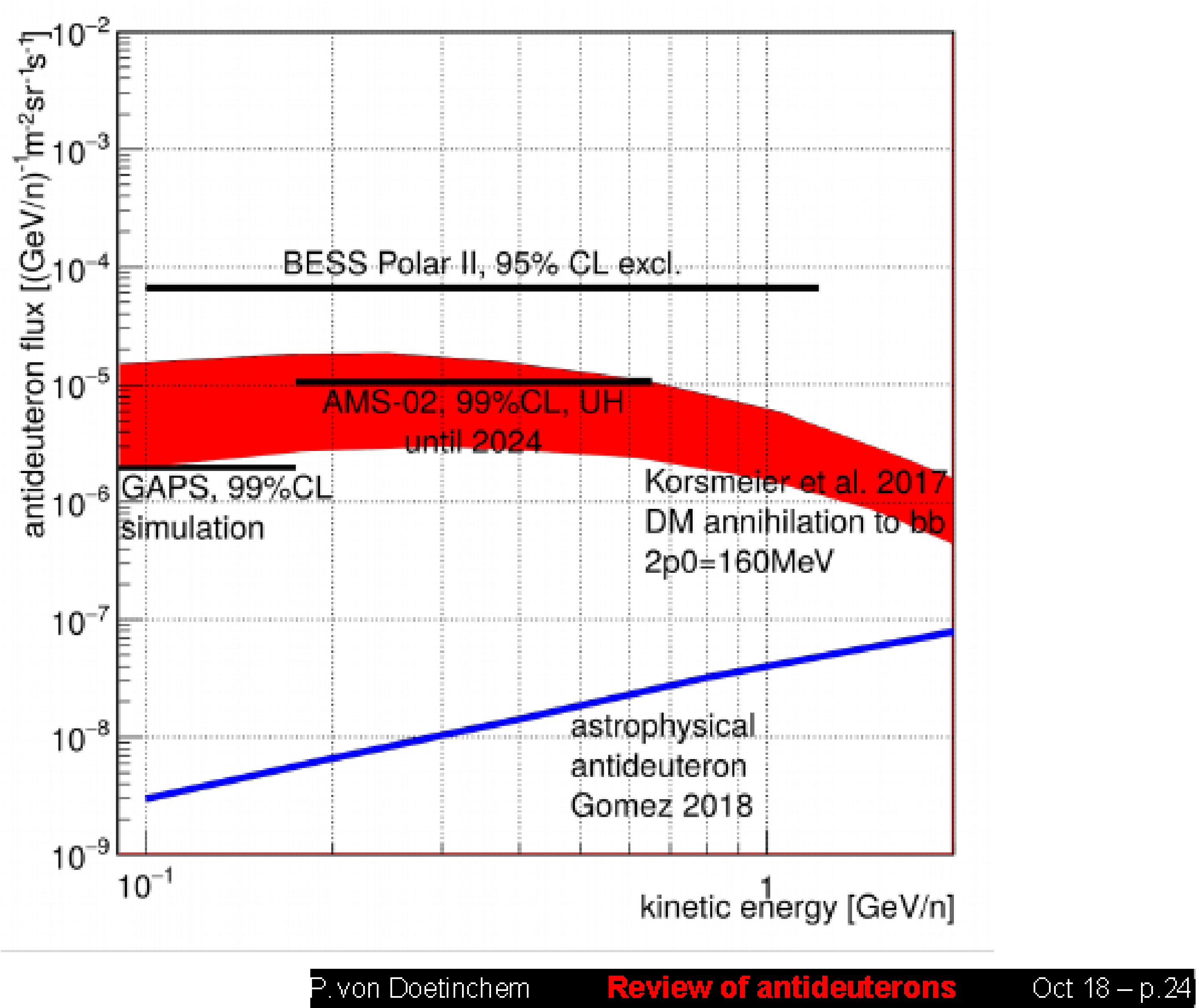
BESS results (COSPAR 2018)



Anti-Deuteron Search with AMS

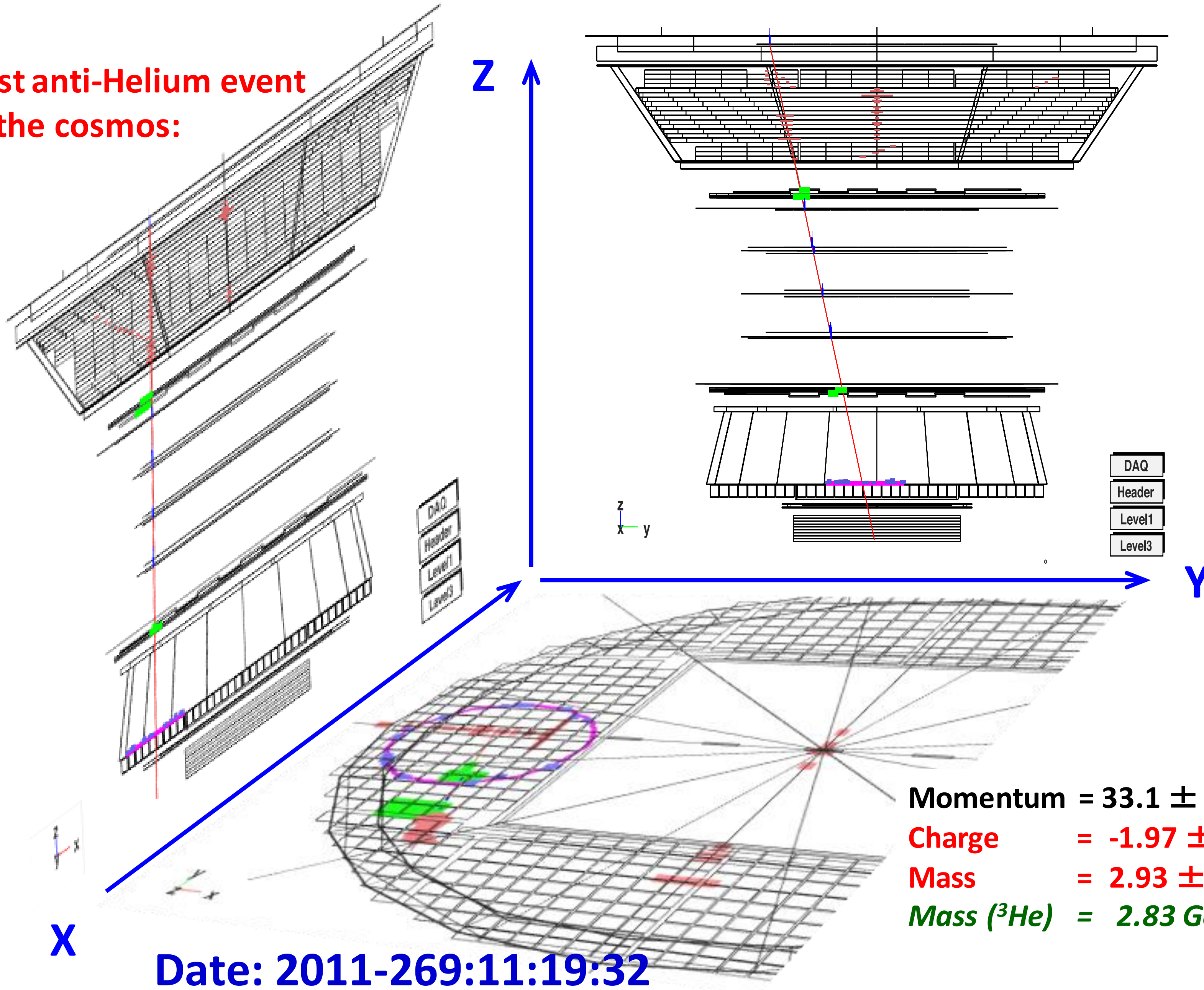


Anti-Deuteron Search prospects



Anti-Helium Search with AMS

First anti-Helium event in the cosmos:



Momentum = 33.1 ± 1.6 GeV/*c*

Charge = -1.97 ± 0.05

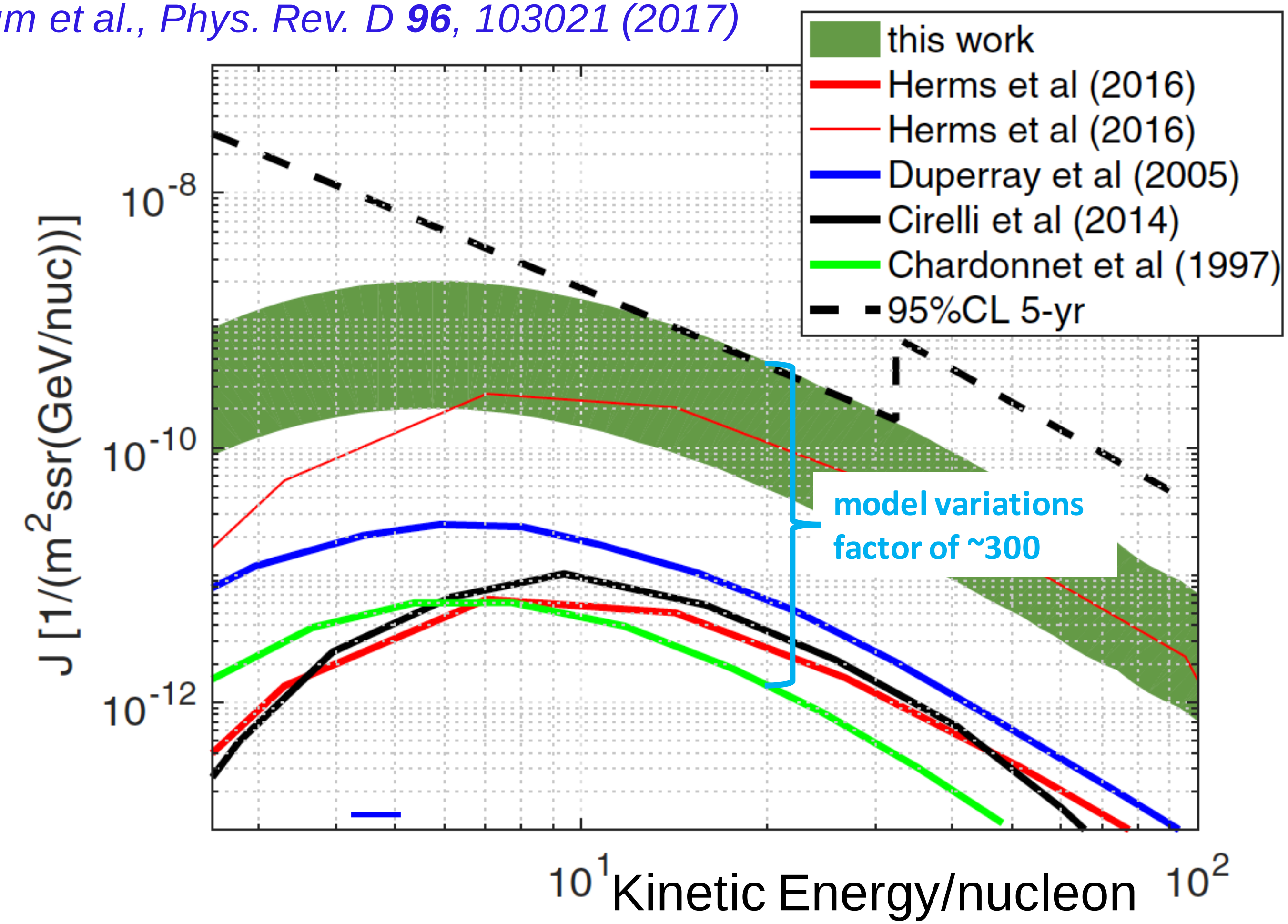
Mass = 2.93 ± 0.36 GeV/*c*²

Mass (³He) = 2.83 GeV/c ²

Date: 2011-269:11:19:32

$^{3}\overline{\text{He}}$ flux models from collisions of cosmic rays

*K. Blum et al., Phys. Rev. D **96**, 103021 (2017)*



There are large uncertainties in models to ascertain the origin of $^{3}\overline{\text{He}}$
The rate of anti-helium is ~1 in 100 million helium.
We have also observed two $^{4}\overline{\text{He}}$ candidates.
More events are necessary to ensure that there are no backgrounds.

High precision measurements of cosmic rays open new windows to observe unexpected phenomena

There are several large scale detectors in space to study high energy charged cosmic rays: AMS, CALET, DAMPE, ISS-CREAM exploring a new and exciting frontier in physics research