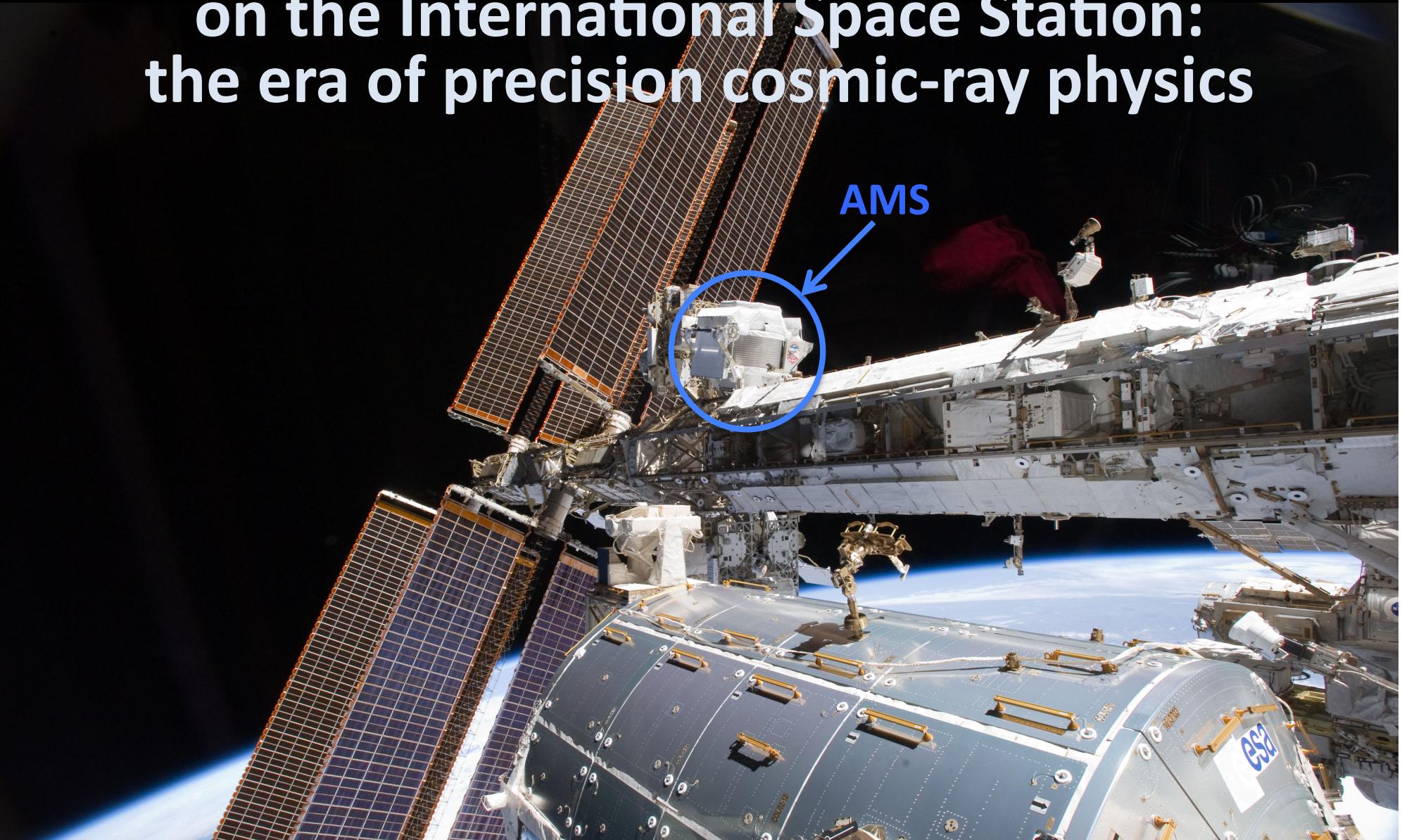


The Alpha Magnetic Spectrometer on the International Space Station: the era of precision cosmic-ray physics



CosPA 2016

28th November to 2nd December
The University of Sydney, Australia

Mercedes Paniccia, University of Geneva
on behalf of the AMS Collaboration

The AMS Experiment

Magnetic Spectrometer:

Rigidities from GV to TV

Charged particles from Z=1 to 28

Installed on ISS since May 2011

Near Earth Orbit:

altitude 400 Km

inclination 52°

period 92 min

Cosmic Ray data taking rate:

18 billion events per year

Mission duration:

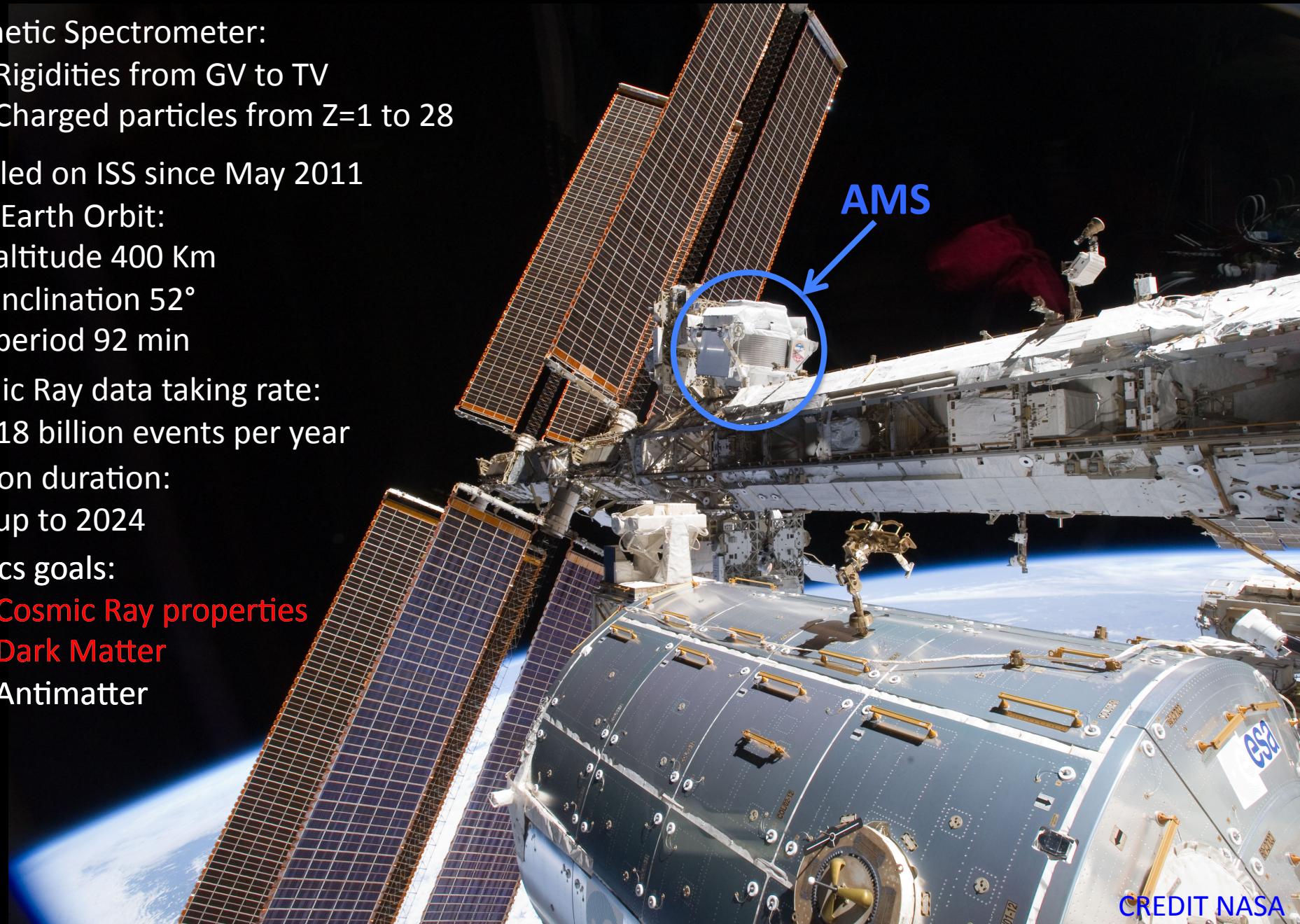
up to 2024

Physics goals:

Cosmic Ray properties

Dark Matter

Antimatter



CREDIT NASA

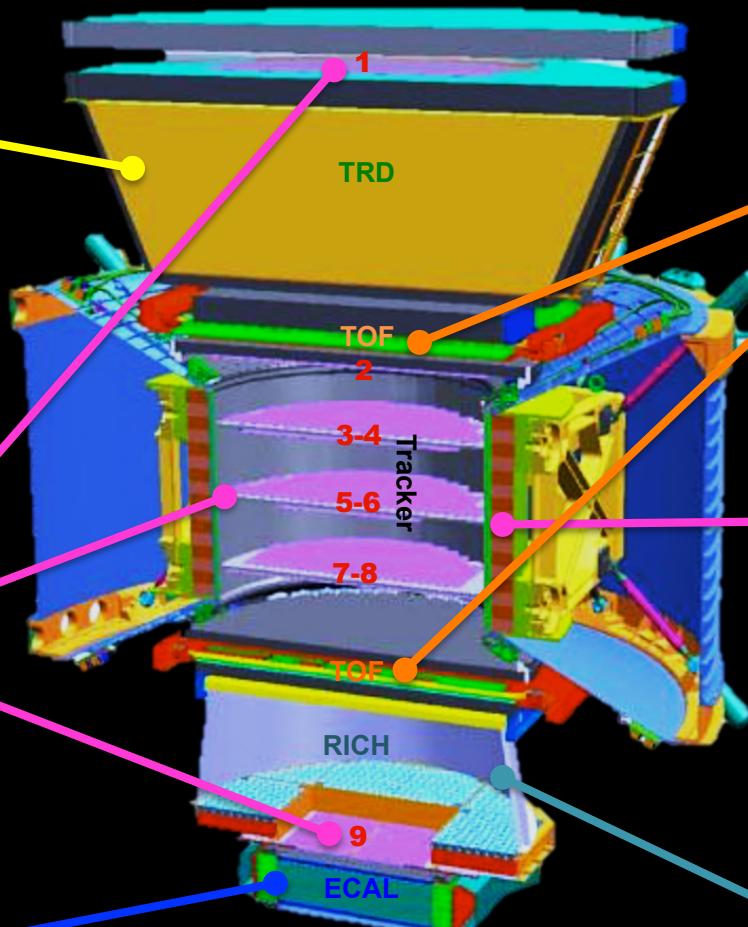
AMS: A TeV precision, multipurpose spectrometer

Transition Radiation Detector

Identify e^+ , e^-



Particles and nuclei are defined by their charge Z and energy ($E \approx p \approx \beta$)



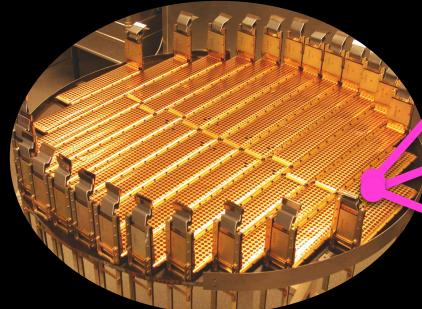
Time Of Flight

Z, β



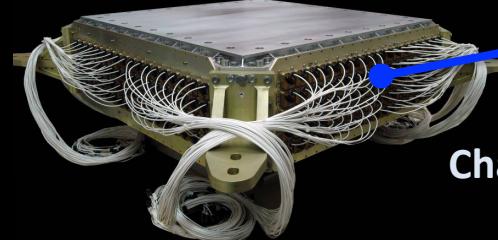
Silicon Tracker

$Z, \text{Rigidity} = p/Ze$



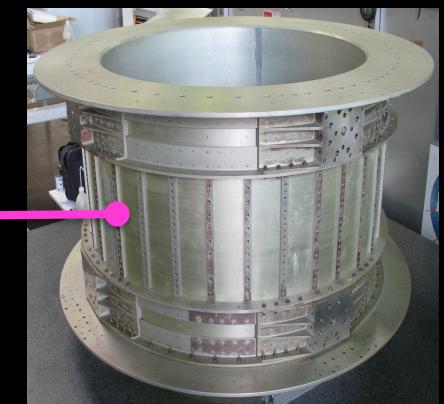
Electromagnetic Calorimeter

E of e^+, e^-



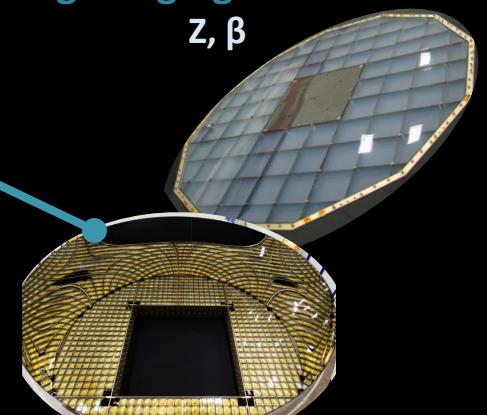
Magnet

$\pm Z$



Ring Imaging Cherenkov

Z, β



Charge Z and energy E are measured independently from Tracker, TOF, RICH, ECAL

AMS Results (so far)

1. Positron fraction from 0.5 to 500 GeV
2. Anisotropy of e^+/e^-
3. Electron and positron fluxes
4. $(e^+ + e^-)$ flux from 0.5 GeV to 1 TeV
5. Proton flux from 1 GV to 1.8 TV
6. Helium flux from 1.9 GV to 3 TV
7. Antiproton flux and antiproton to proton flux ratio from 1 to 450 GV and properties of elementary particle fluxes in CR
8. Boron-to-Carbon flux ratio
9. Lithium flux
10. Boron flux
11. Carbon flux

For more details on:

e^+ , e^- , and antiproton analysis see talk by Z. Weng
nuclei analysis see talk by V. Formato
this afternoon in the Particle astrophysics session

PRL 113, 121101 (2014), PRL 110, 141102 (2013)

PRL 113, 121102 (2014)

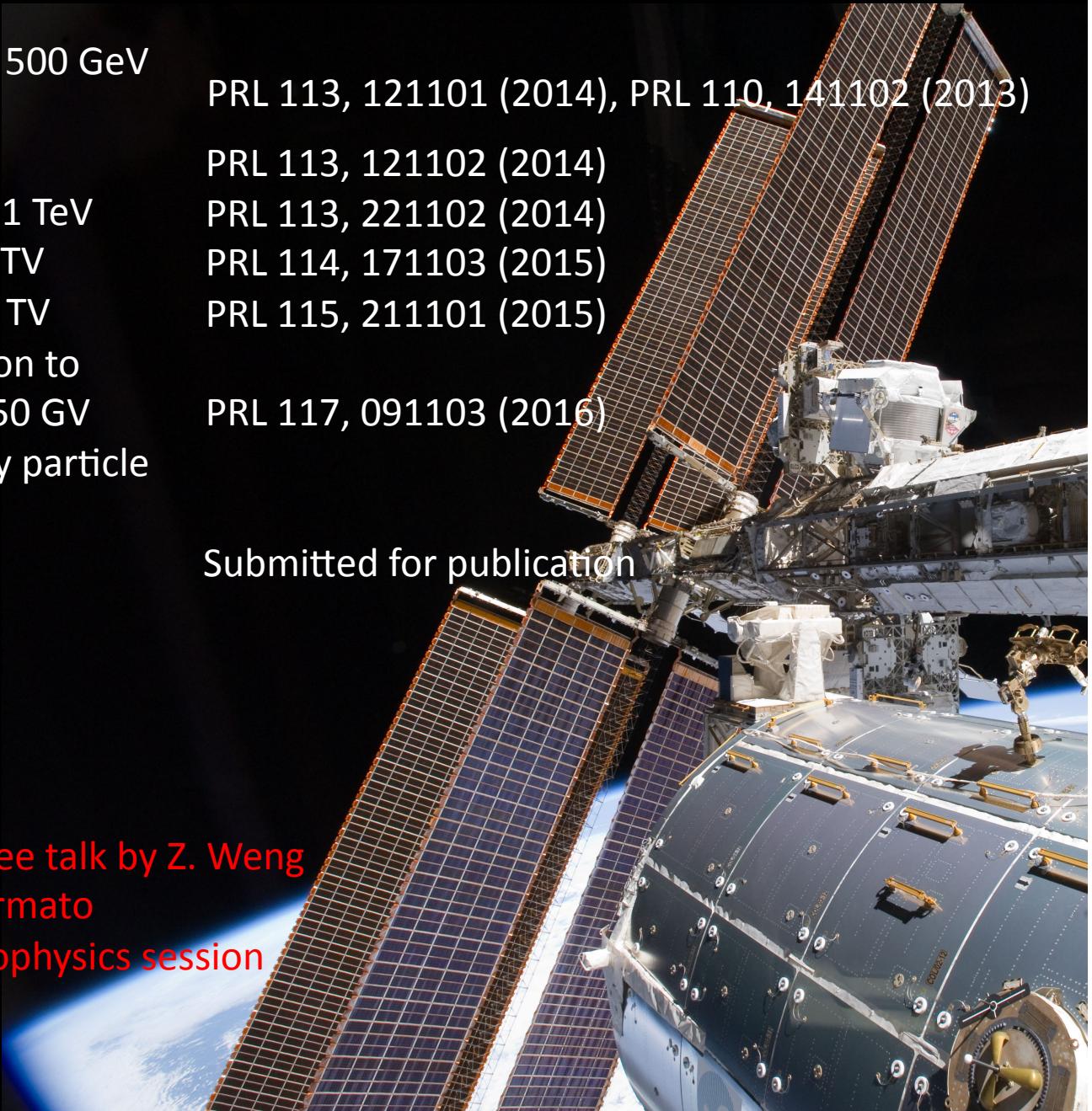
PRL 113, 221102 (2014)

PRL 114, 171103 (2015)

PRL 115, 211101 (2015)

PRL 117, 091103 (2016)

Submitted for publication

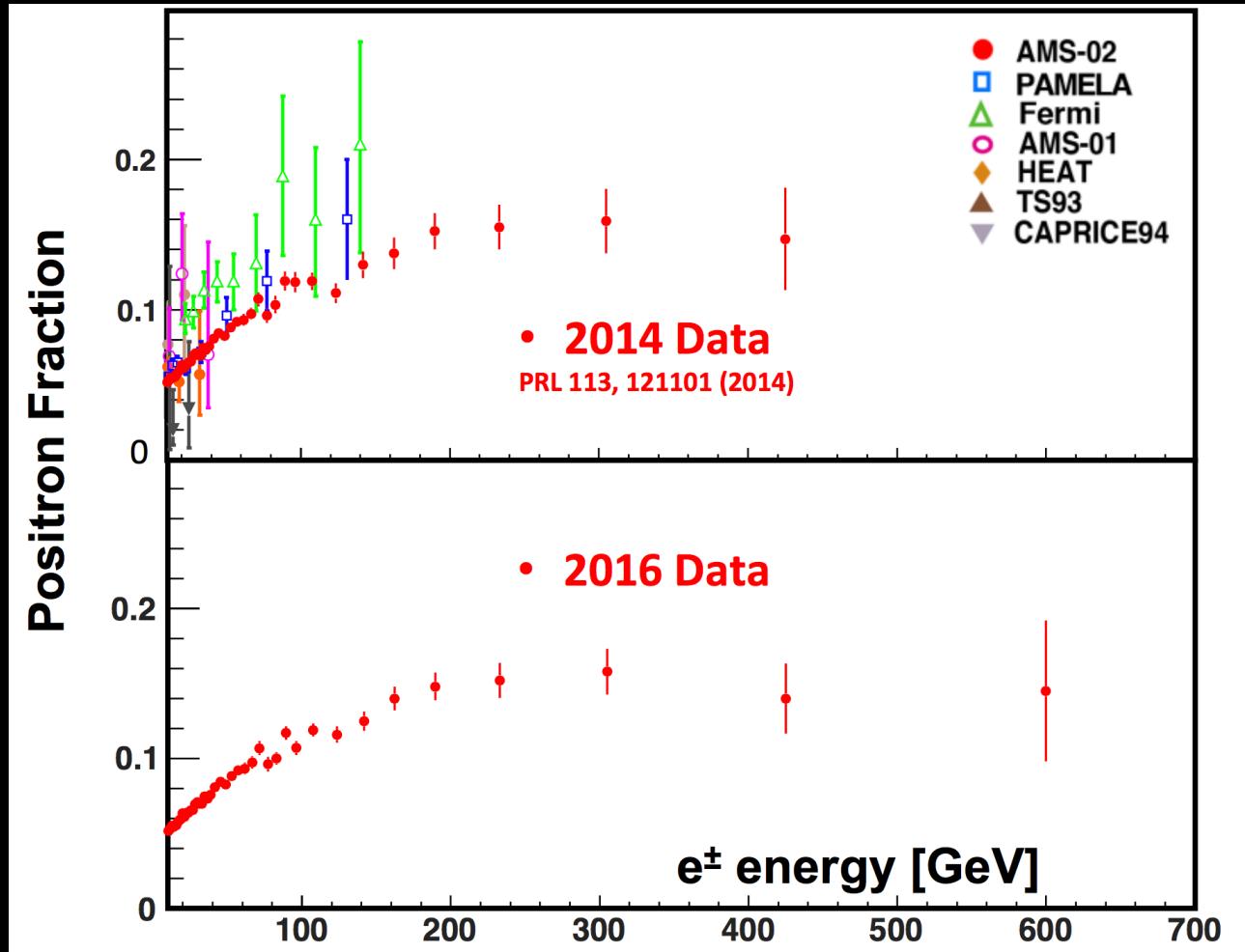


Updated Positron fraction measurement:

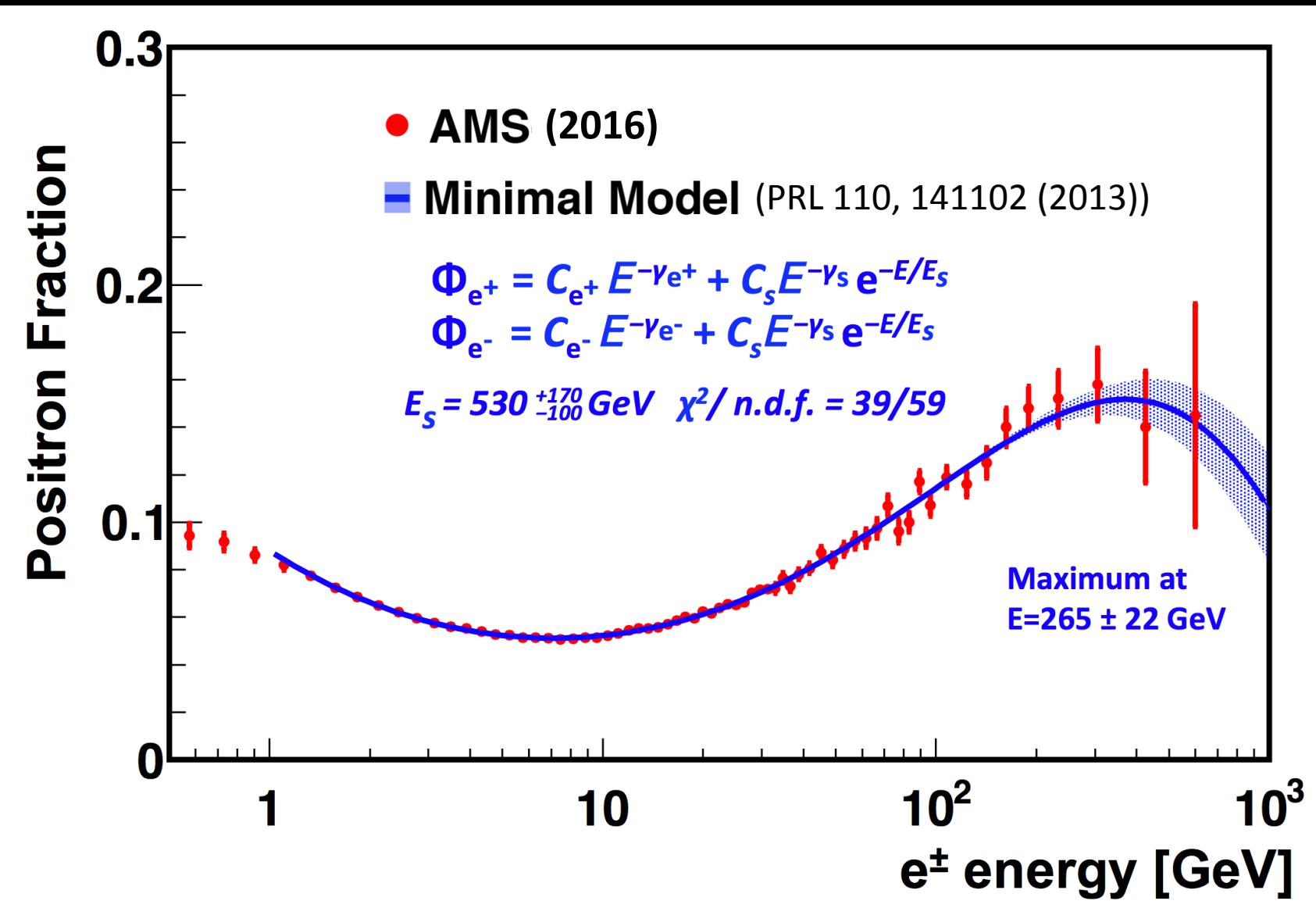
PRL 110, 141102 (2013) : energy range 0.5 to 350 GeV , 6.8 million e^\pm events

PRL 113, 121101 (2014) : energy range increased to 500 GeV , 11 million e^\pm events

Latest result (2016): energy range increased to 700 GeV, 20 million e^\pm events

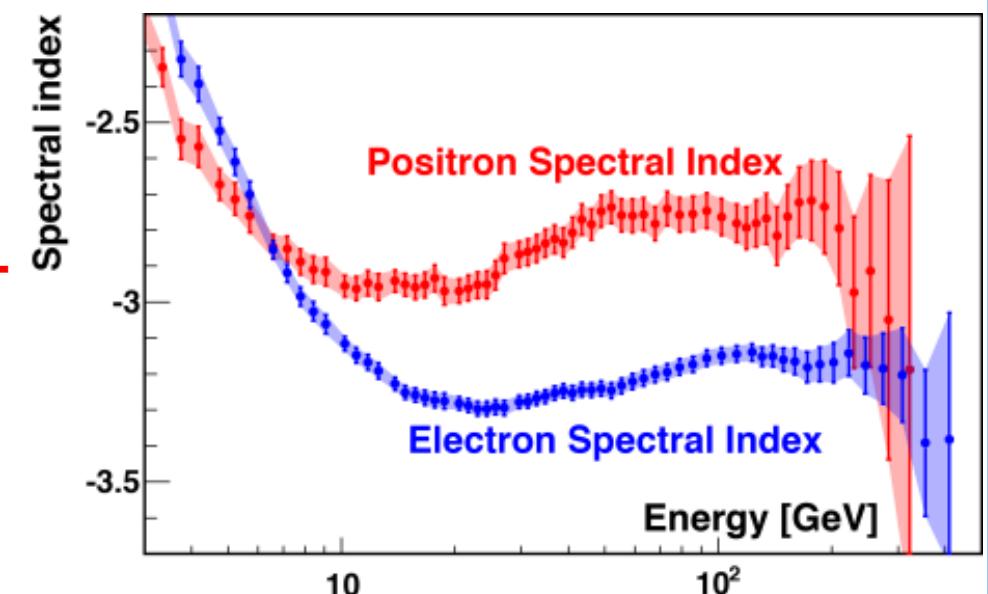
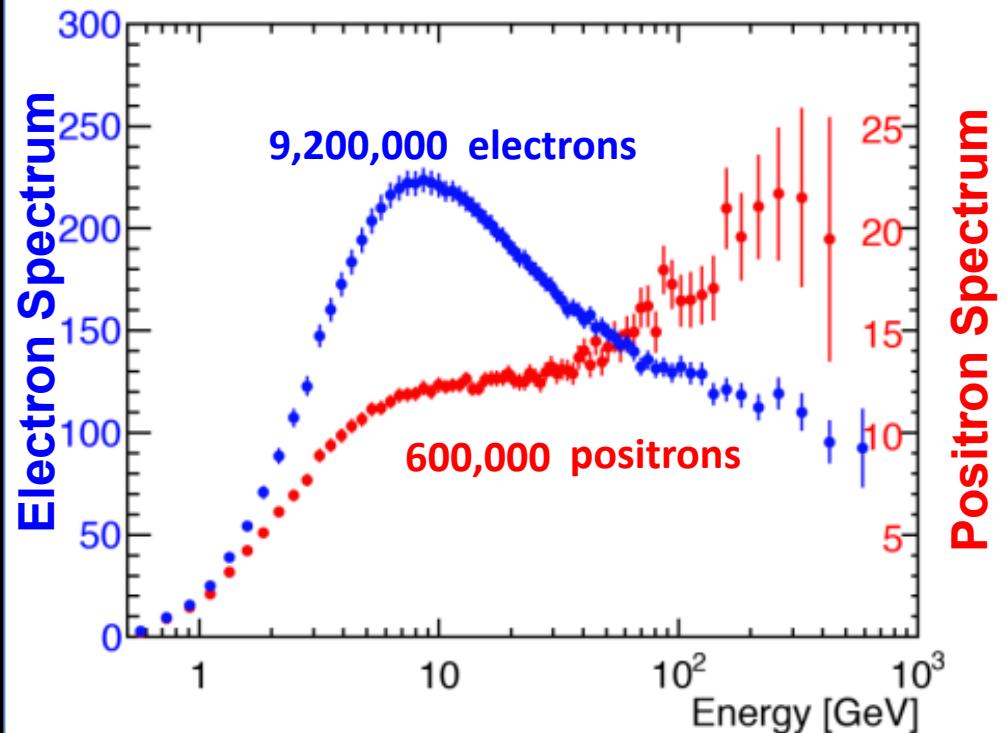


Evidence of additional source: positron fraction fit to a phenomenological model



Evidence of additional source: individual positron and electron fluxes

AMS Measurement of Electron and Positron fluxes (PRL 113, 121102 (2014))



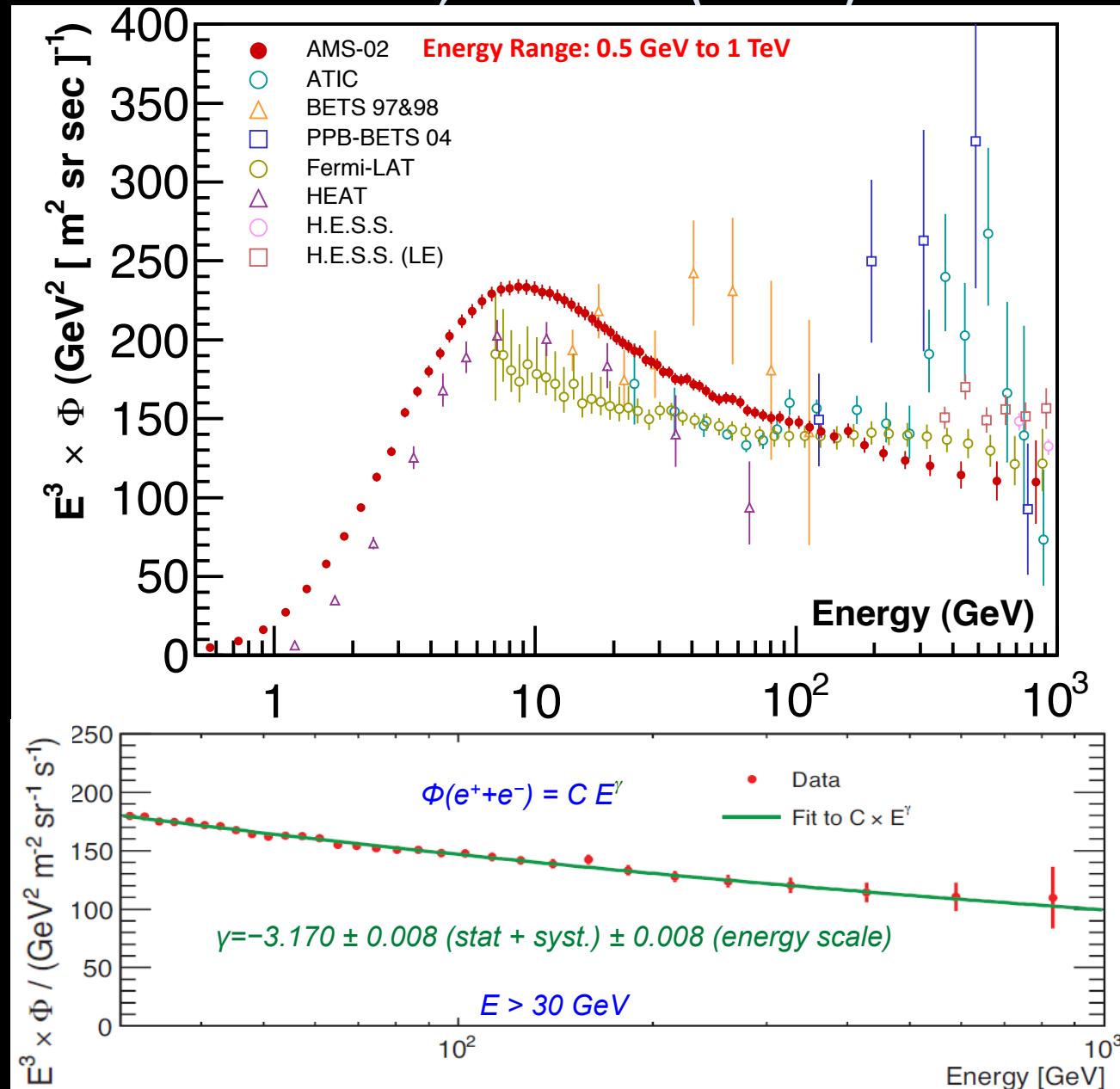
See talk by Zhili Weng for 2016 result

Both spectra harden above 30 GeV , so cannot be described by single power law

Different behavior of the spectral indices indicate high-energy e^+ have a different origins from e^-

The precision AMS measurement of the ($e^+ + e^-$) flux

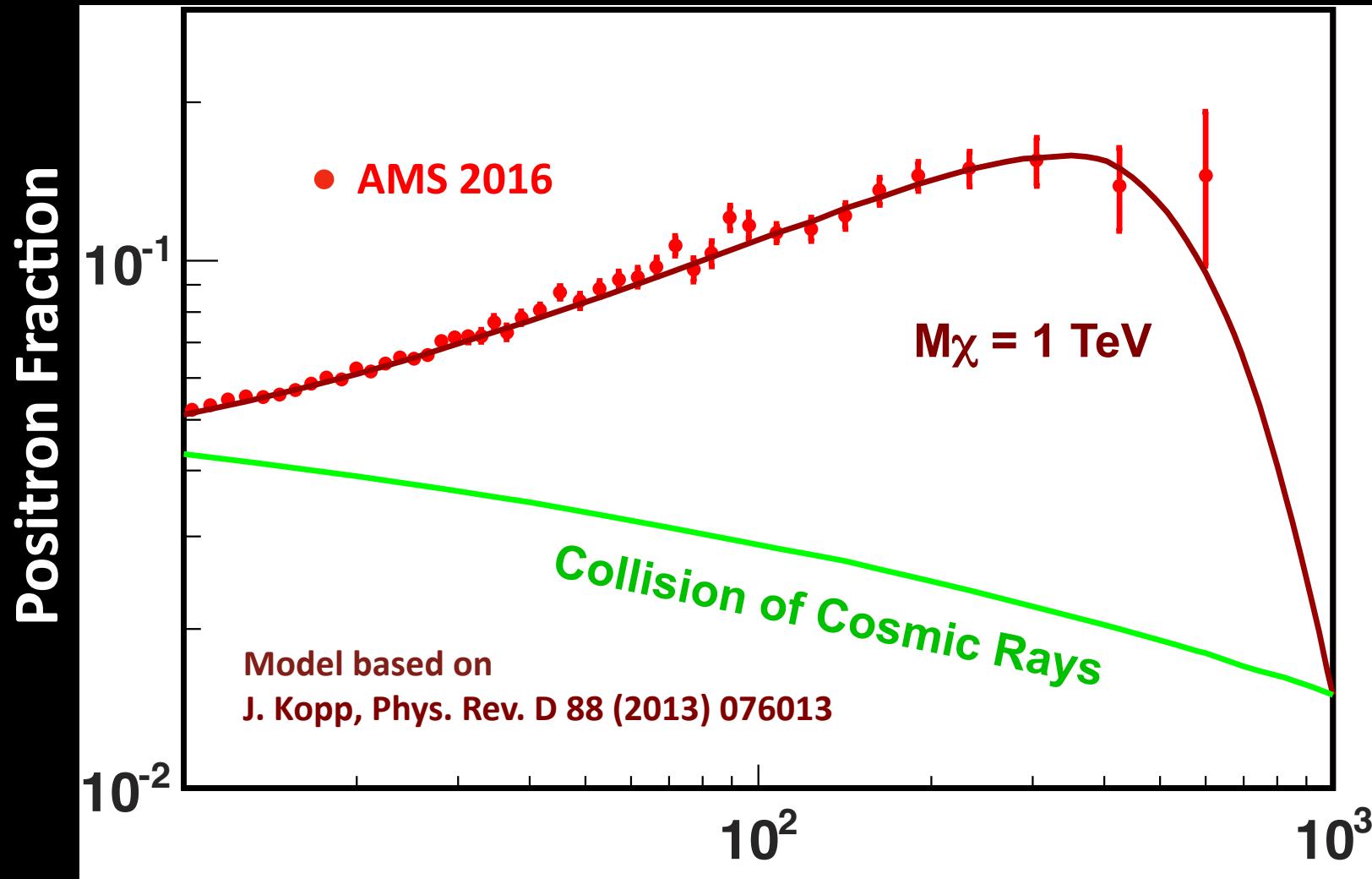
PRL 113, 221102 (2014)



Indirect search for Dark Matter

Possible enhancement of rare secondary CR spectra from $\chi + \chi \rightarrow e^+, \text{anti-p}, \text{anti-d}, \dots$

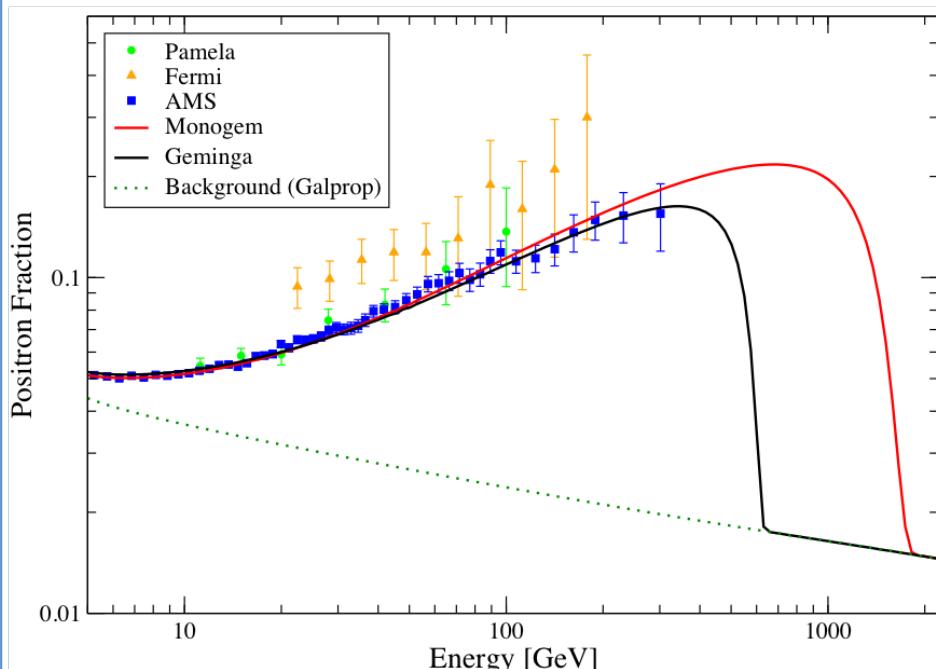
The excess of positrons is measured by the positron fraction: $e^+/(e^+ + e^-)$



However DM is not the only possible interpretation of the observed positron excess

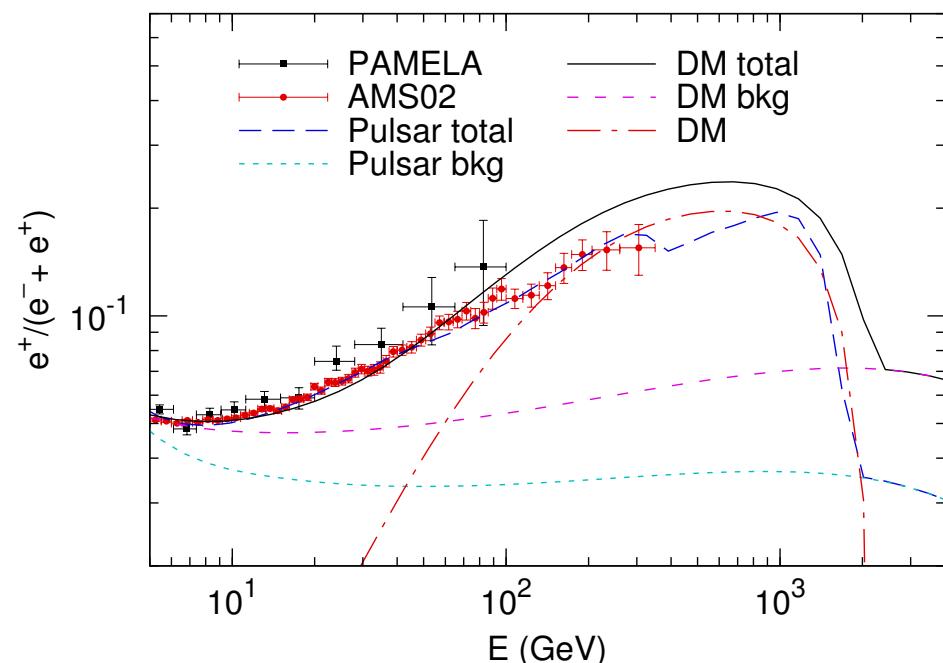
Possible interpretation of the observed positron fraction excess: astrophysical sources vs DM

Pulsar:



Tim Linden and Stefano Profumo
arXiv:1304.1791v1 [astro-ph.HE] 5 Apr 2013

Multiple Pulsars + Dark Matter:

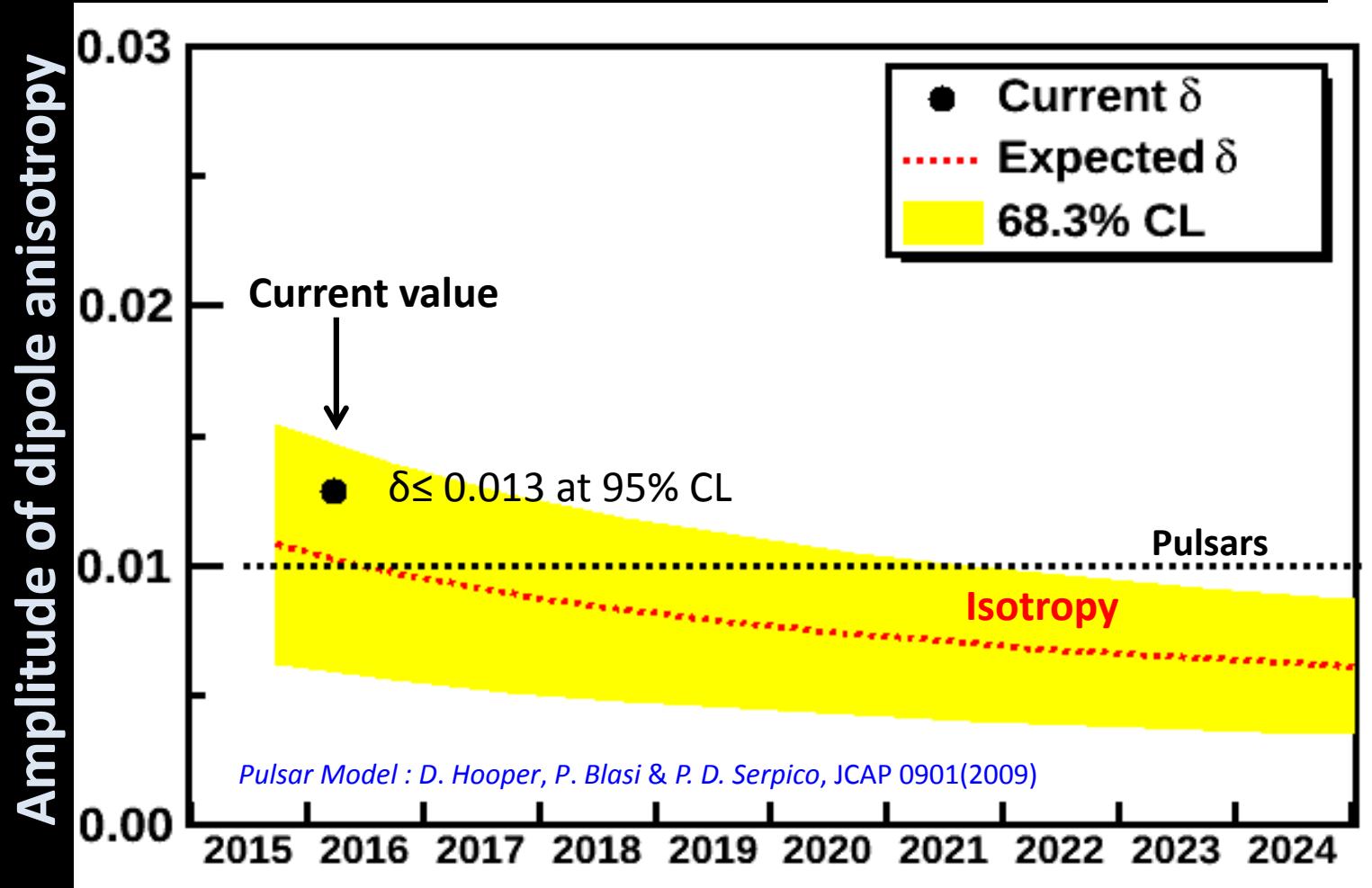
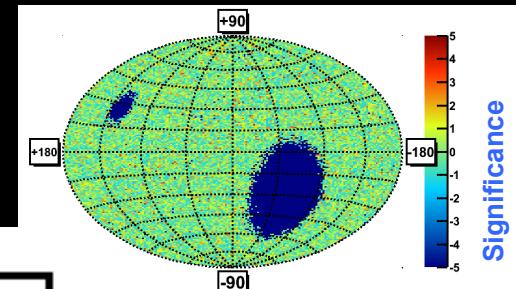


Peng-Fei Yin, Zhao-Huan Yu, Qiang Yuan and Xiao-Jun Bi
arXiv:1304.4128v1 [astro-ph.HE] 15 Apr 2013

Higher level of anisotropy in the arrival direction of e^+ and e^- is expected from Pulsars wrt DM

Anisotropy of e^+/e^-

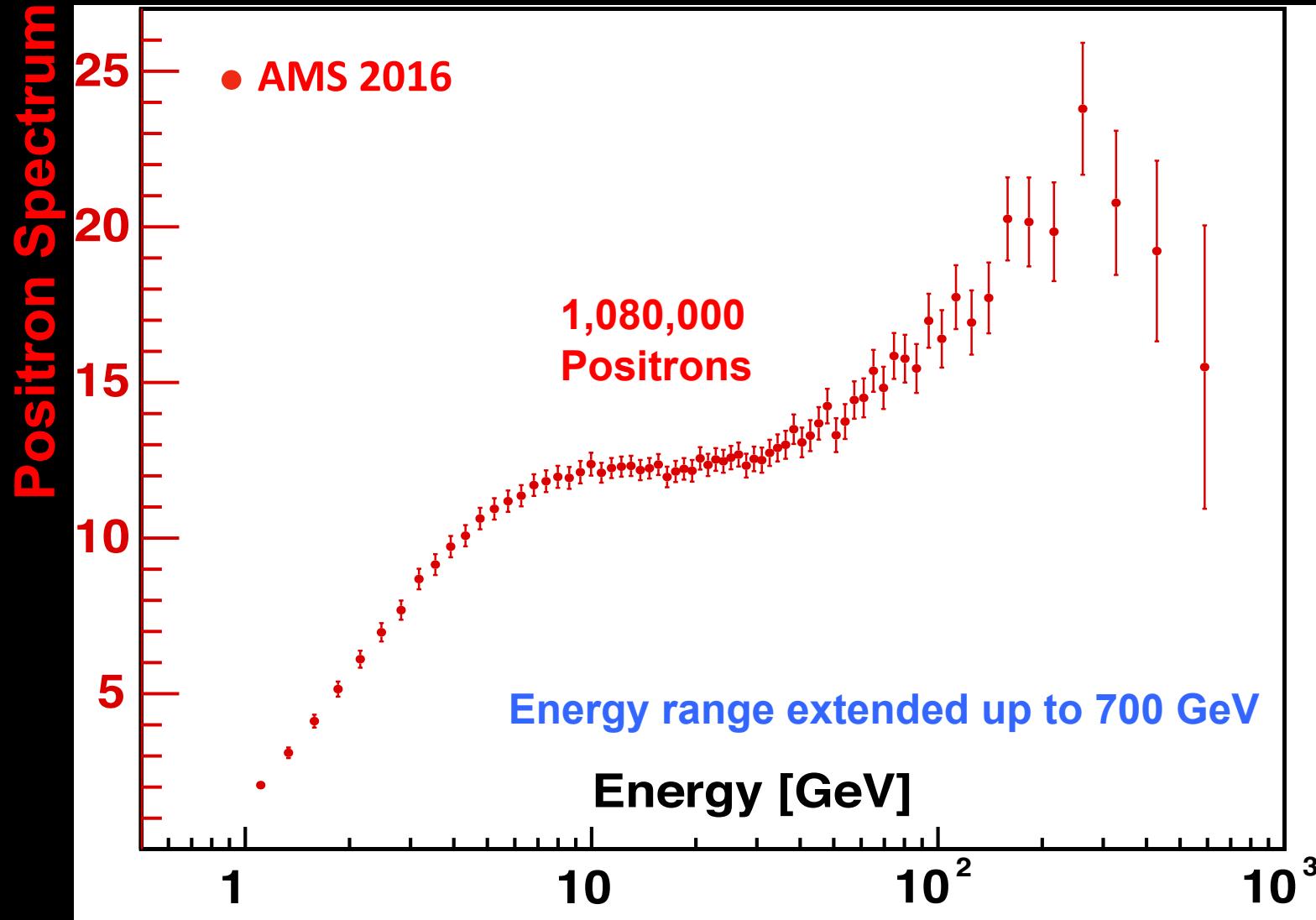
With the current data fluctuations of the positron ratio e^+/e^- are isotropic.



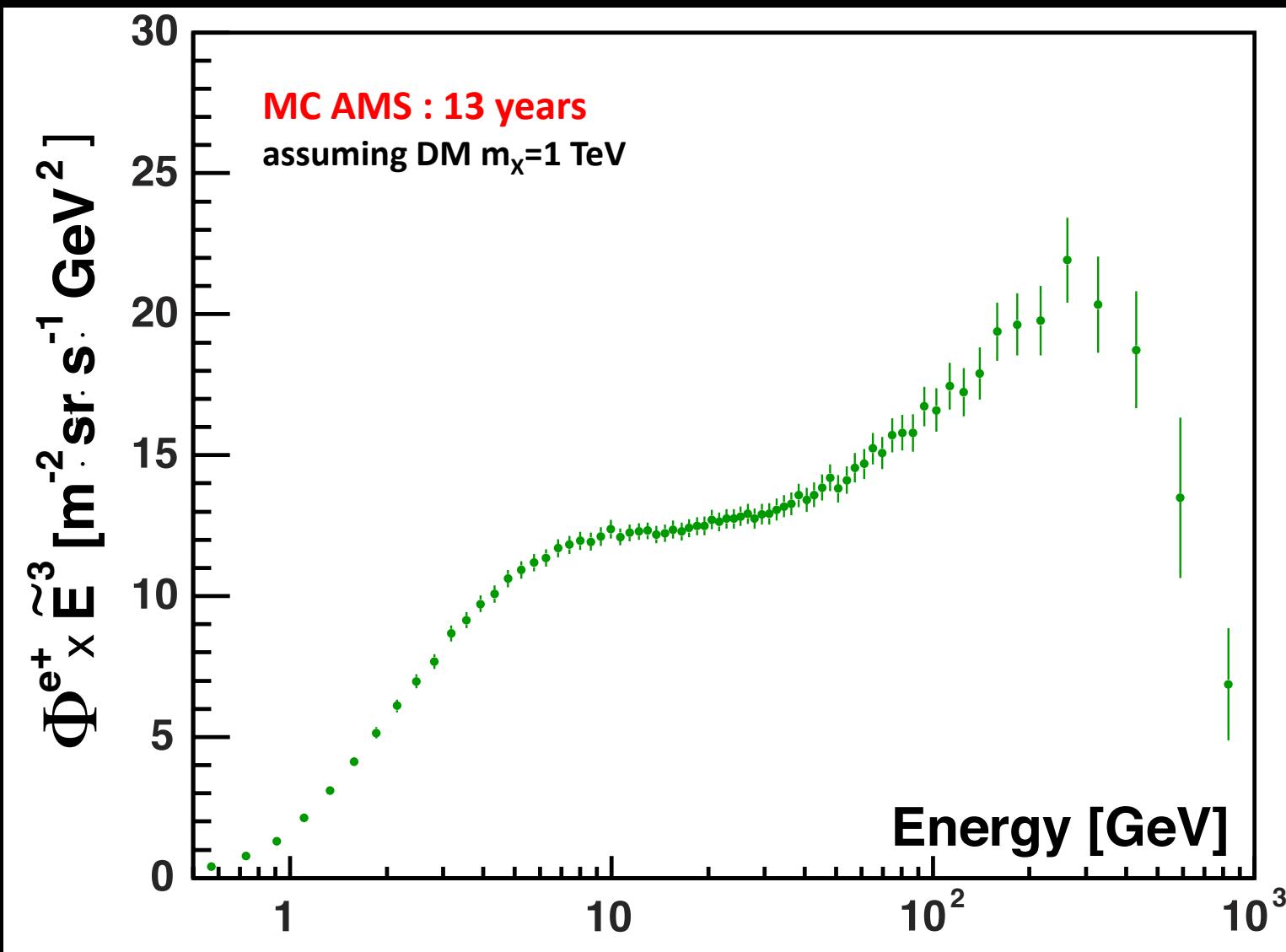
Data taking to 2024, will allow to explore anisotropies of 1%

Positron flux

Latest results based on 1.08 million e⁺ events



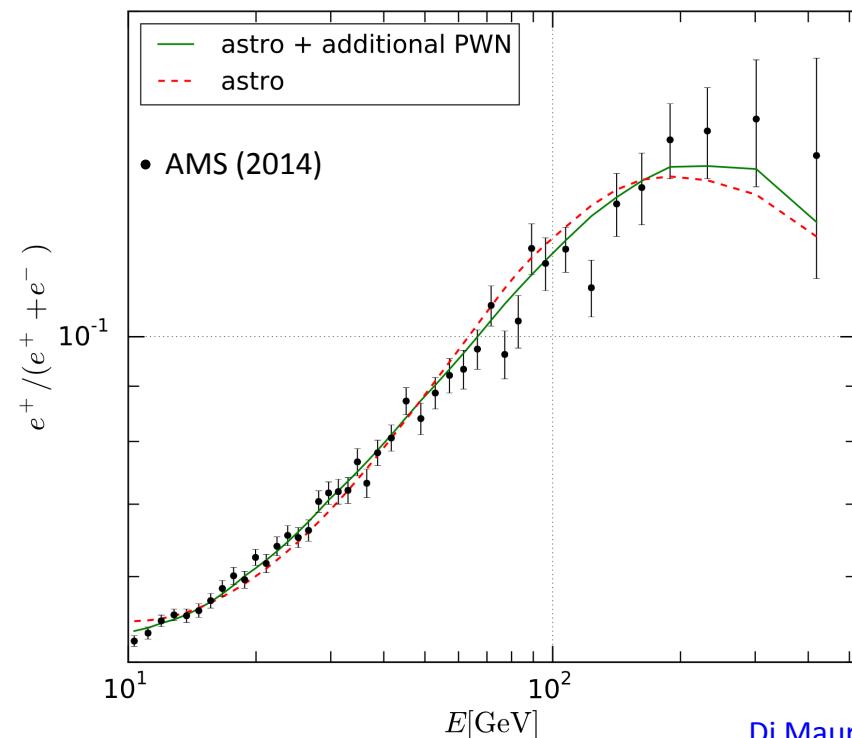
Positron flux 2024 prospect



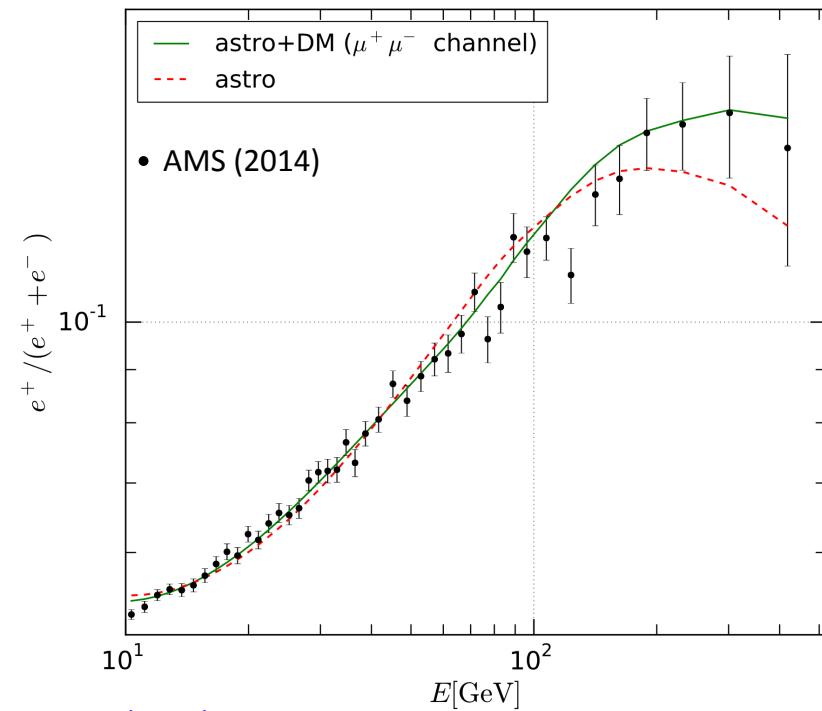
Possible interpretations of the positron excess

The measurement of positron flux, electron flux, ($e^+ + e^-$) flux and positron fraction make possible accurate comparisons with various DM models and astrophysical models

Pulsars:



Pulsars + Dark Matter:

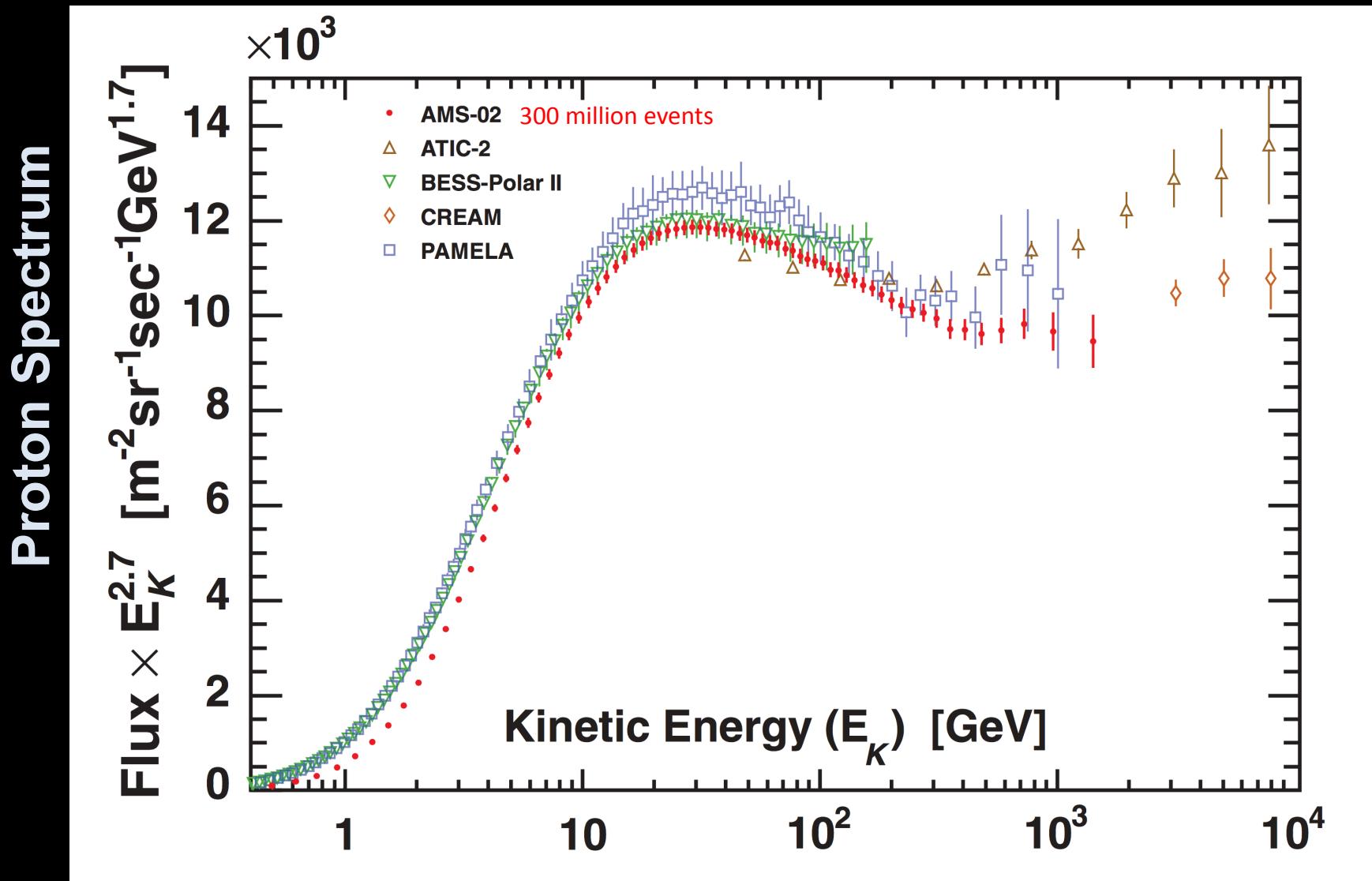


Di Mauro et al, JCAP05 (2016) 031

AMS p and He fluxes are used to estimate secondary positrons from collision of cosmic rays
Global fit of the model to the AMS e^+ , e^- , $(e^+ + e^-)$ fluxes and positron fraction.

AMS Precision Measurement of the proton flux

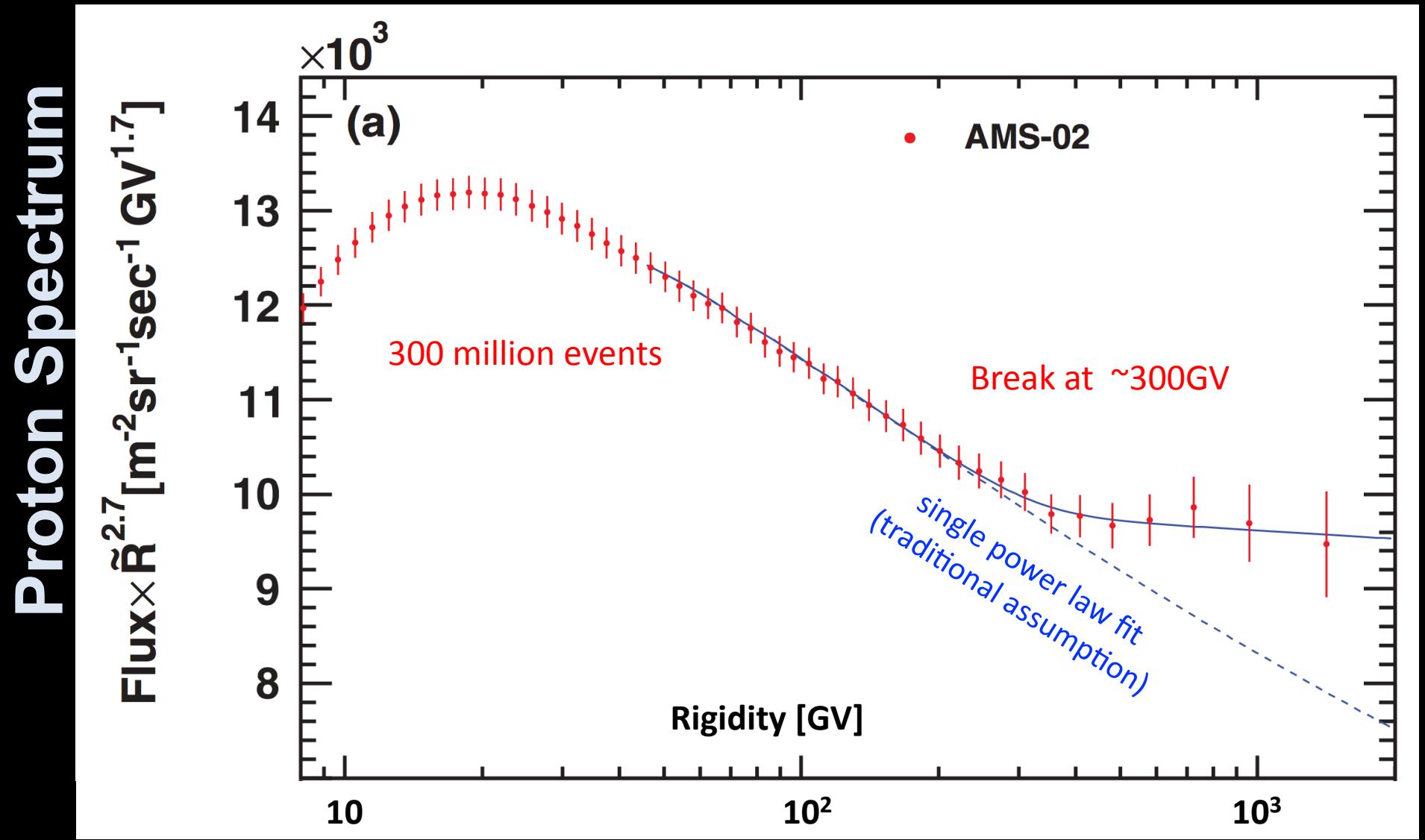
PRL 114, 171103 (2015)



AMS Precision Measurement of the proton flux

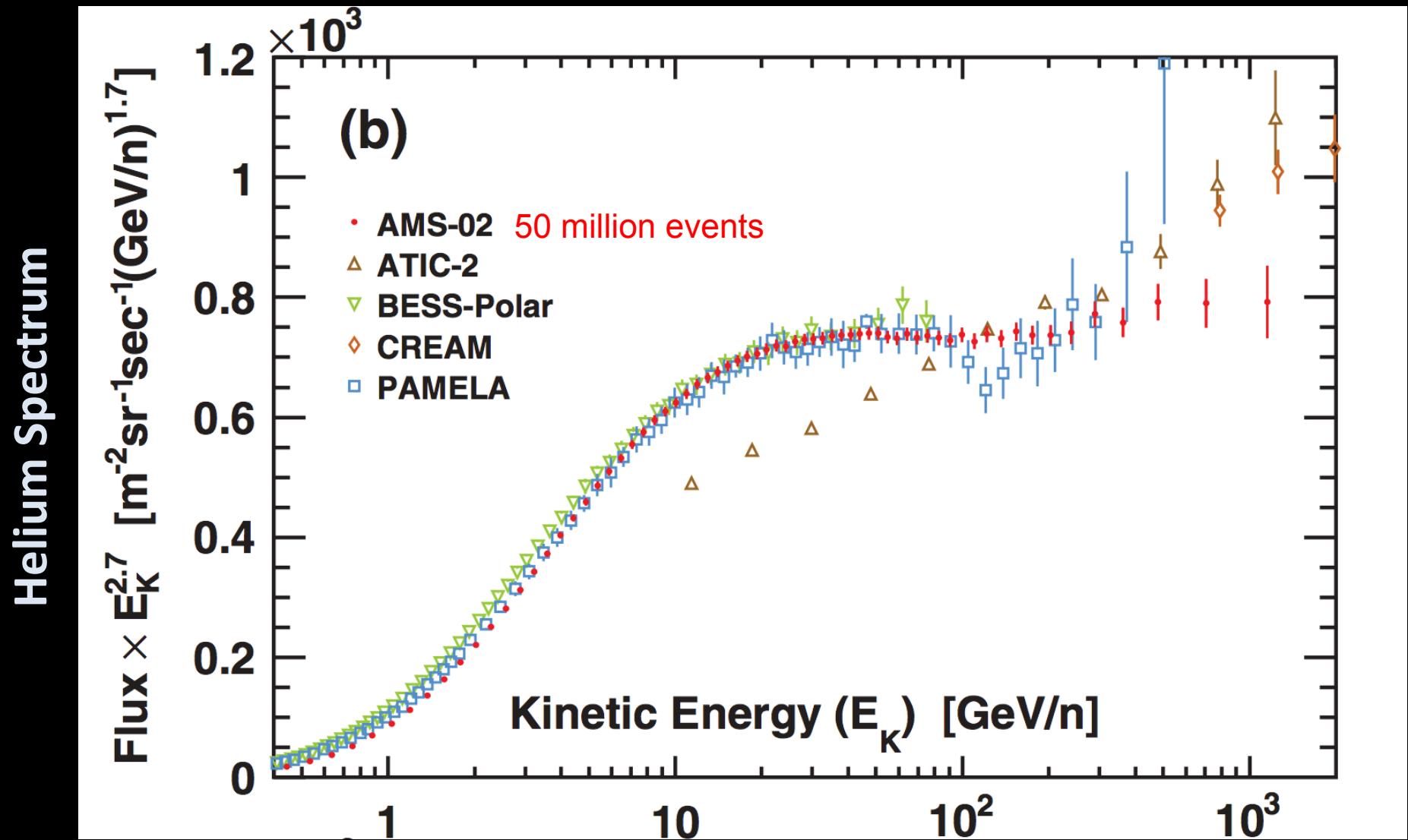
PRL 114, 171103 (2015)

The spectrum cannot be described by a single power law



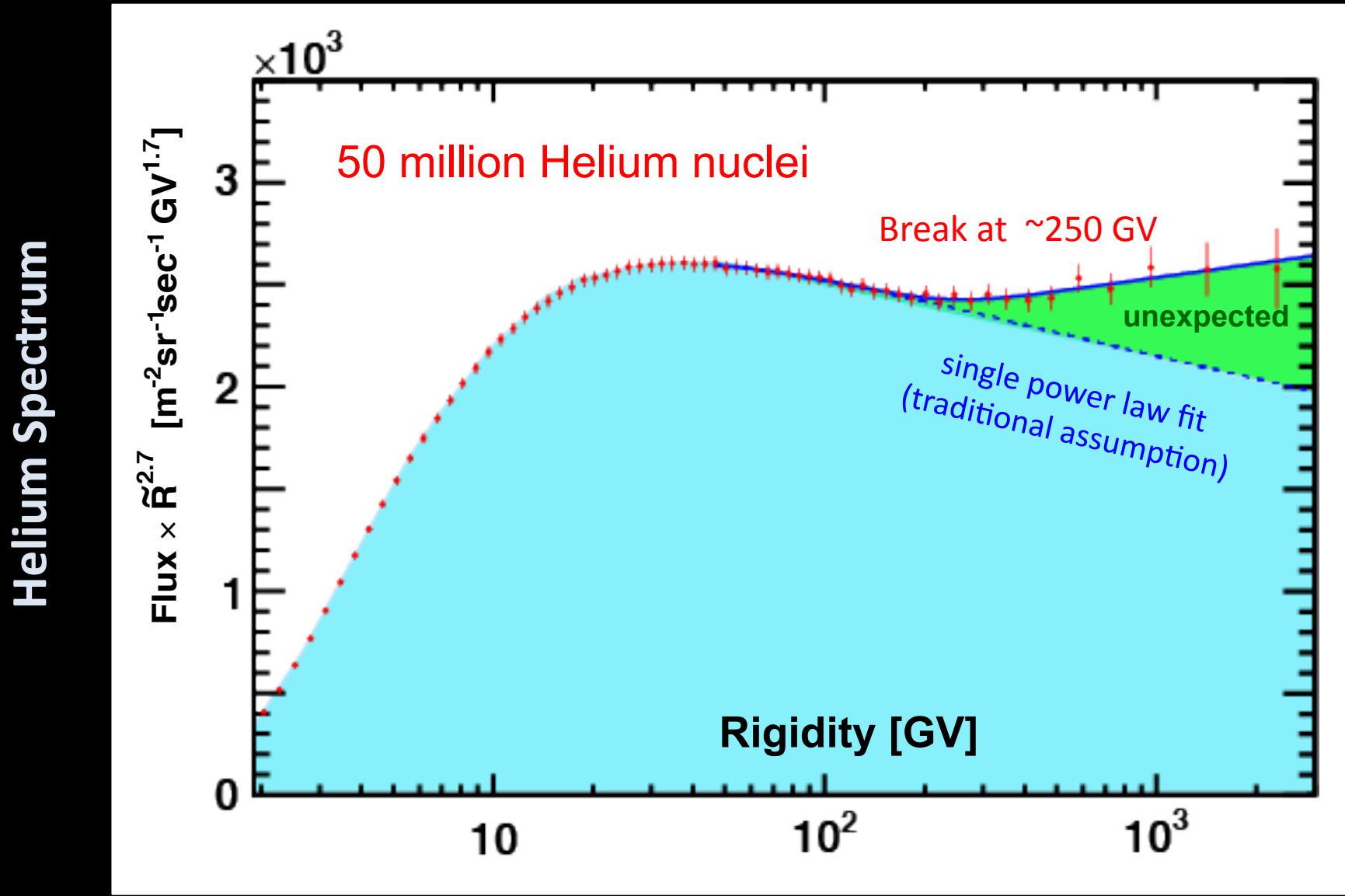
AMS Precision measurement of the Helium flux

PRL 115, 211101 (2015)



AMS Precision measurement of the Helium flux

PRL 115, 211101 (2015)

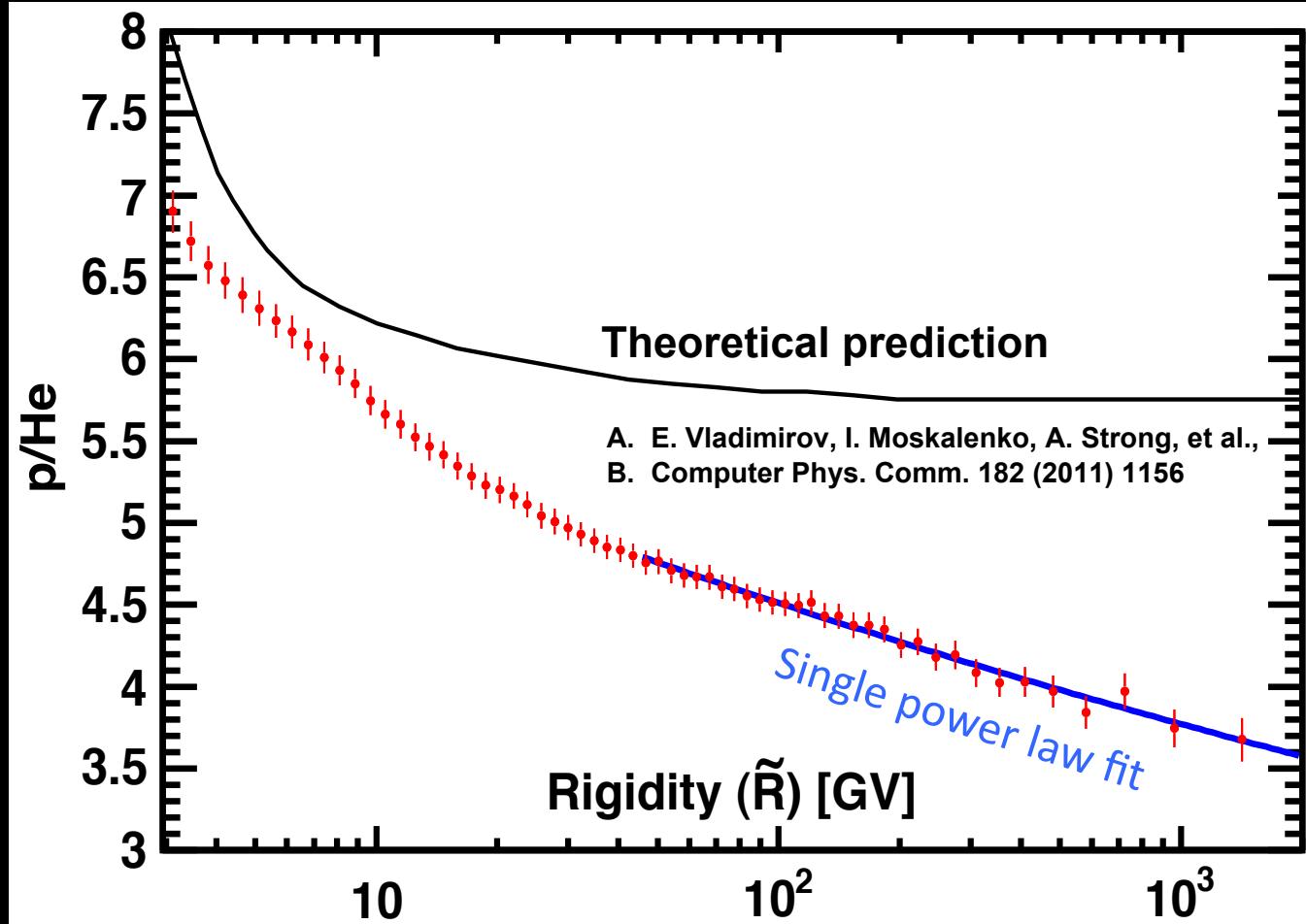


AMS Proton to Helium flux ratio

PRL 115, 211101 (2015)

Protons and helium are both “primary” cosmic rays.

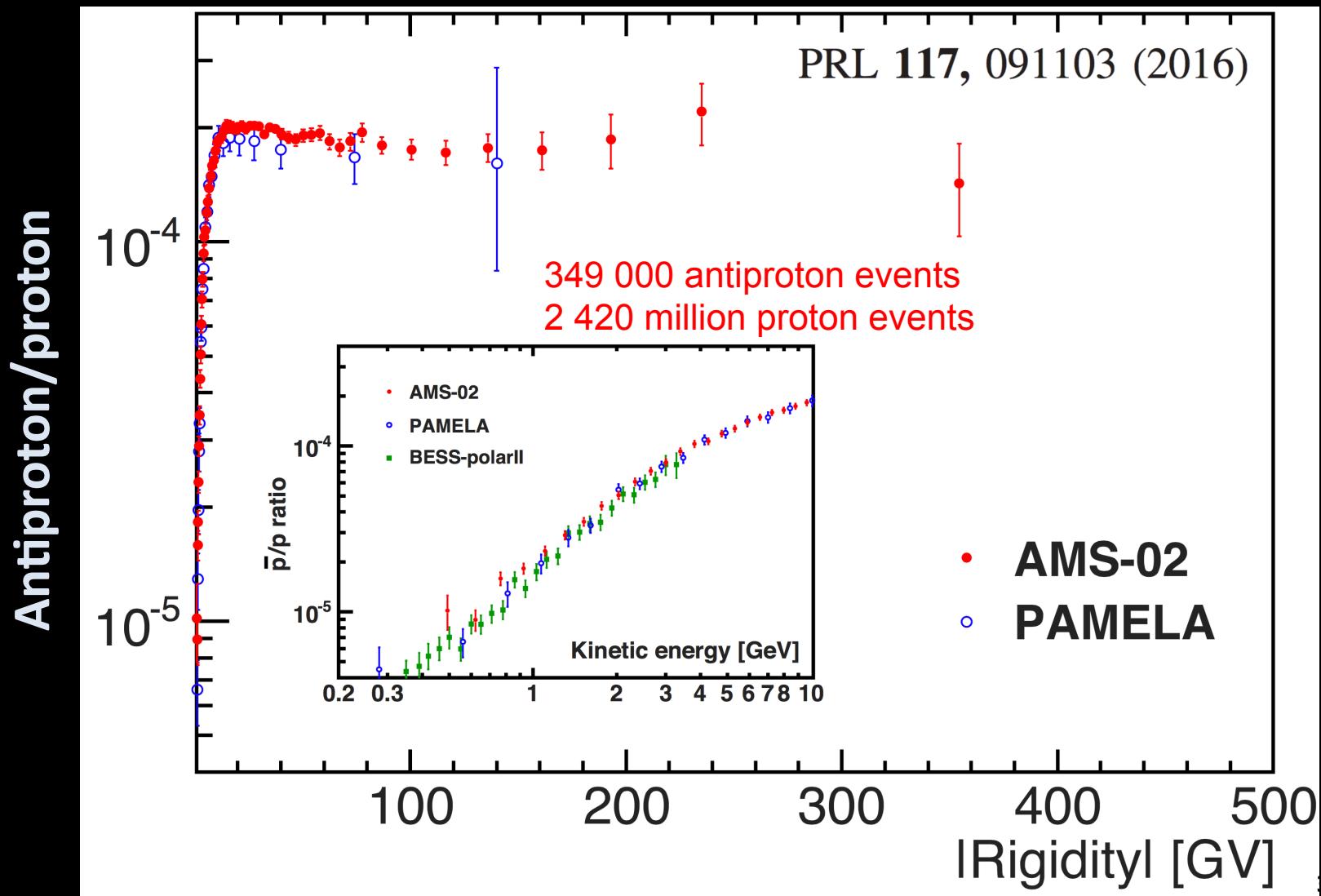
Their rigidity ratio has traditionally been assumed to be flat.



AMS p/He ratio is not flat: He spectra harder than p.

Measurement of antiproton-to-proton ratio

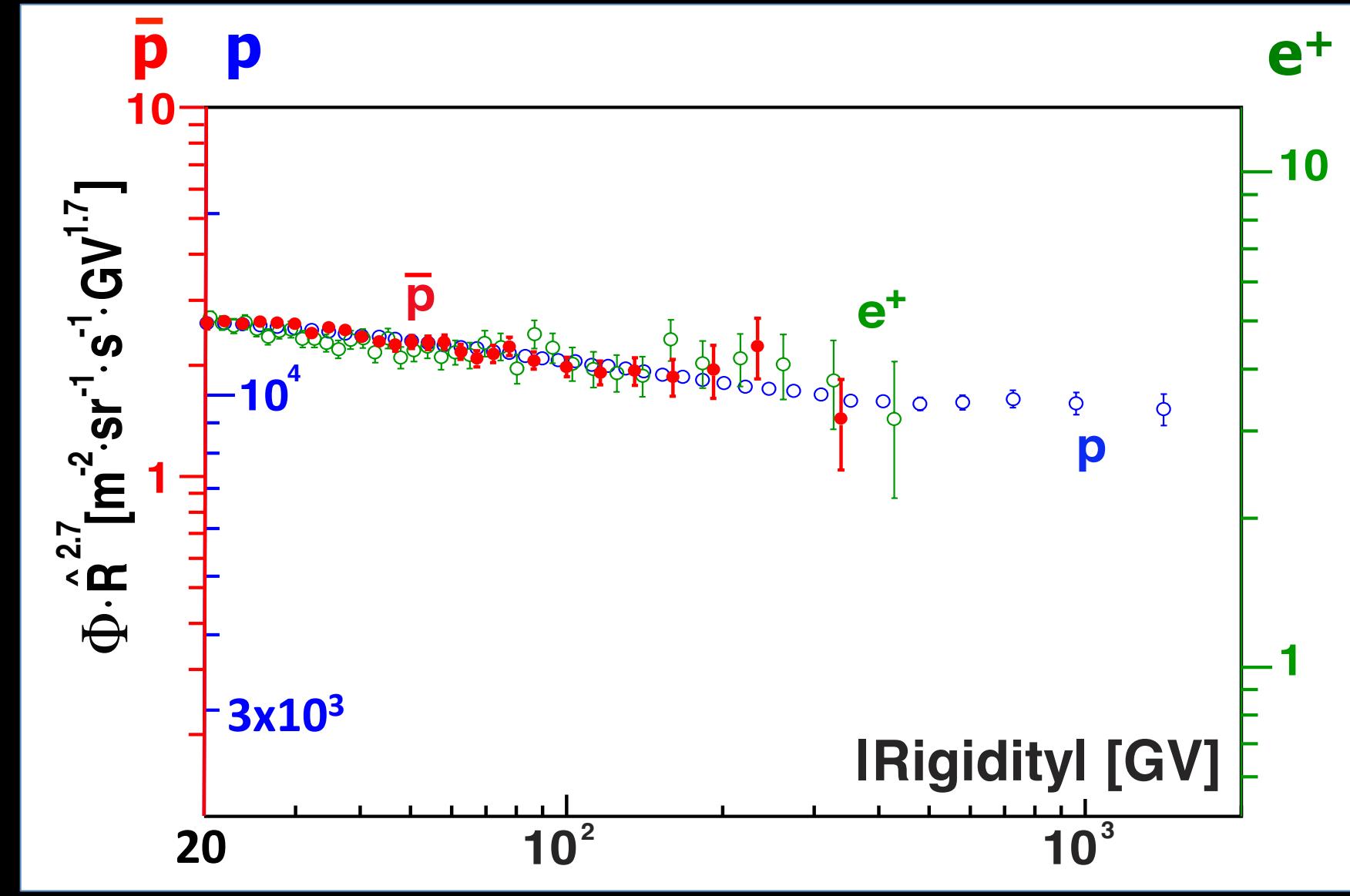
PRL 117, 091103 (2016)



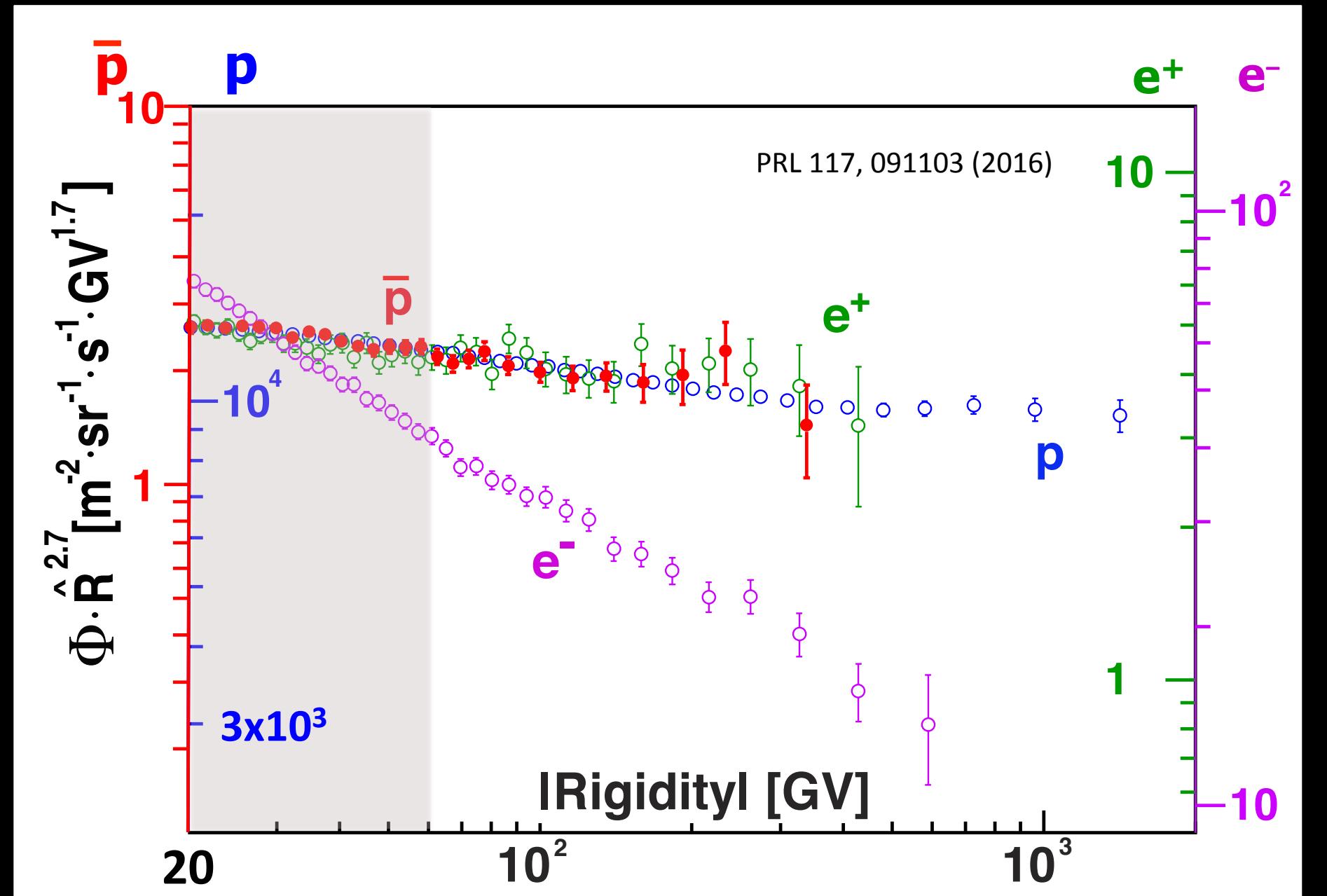
Antiproton to proton ratio is energy independent above 60 GV

The antiproton flux and properties of elementary particle fluxes

PRL 117, 091103 (2016)

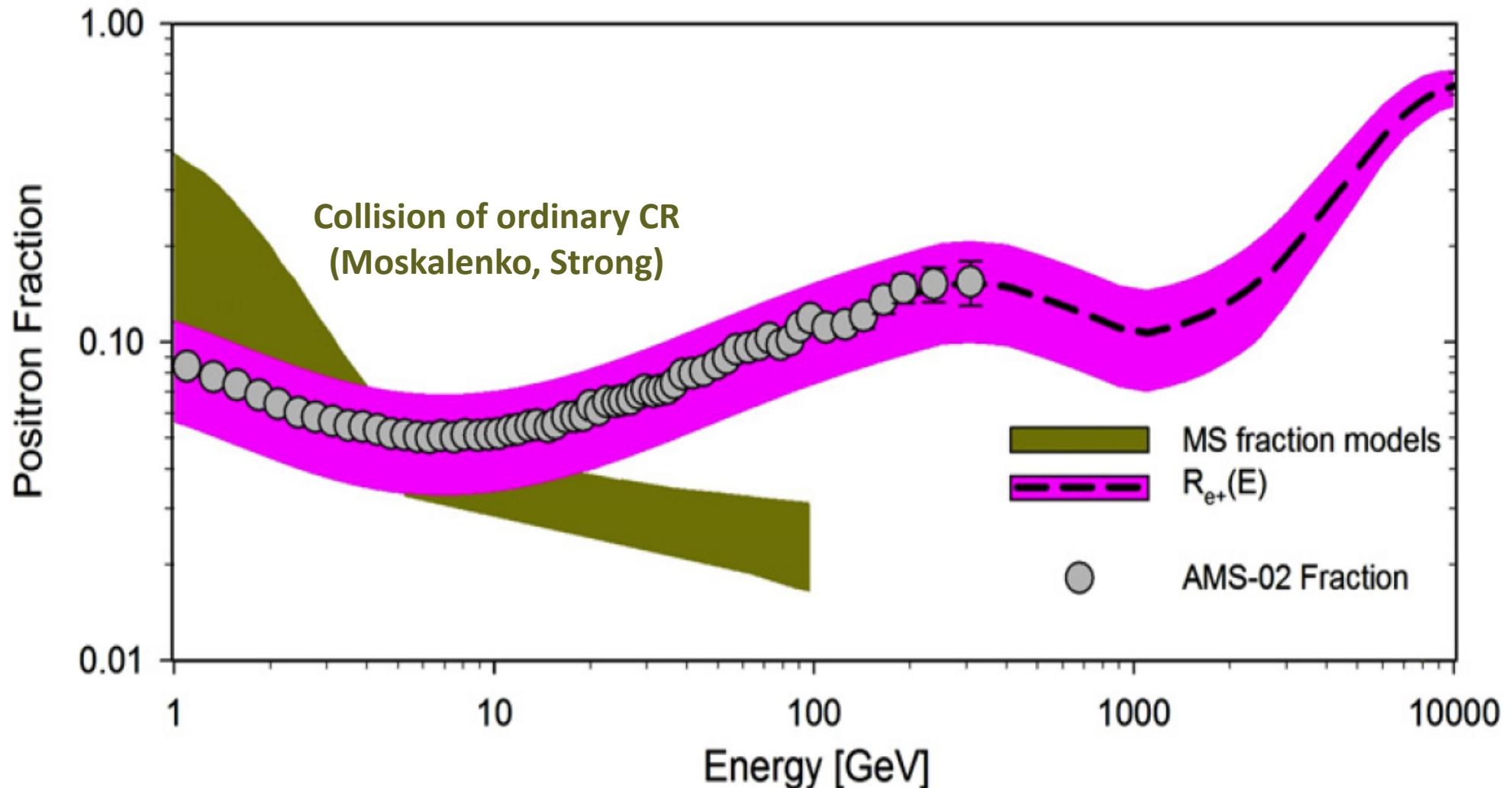


Unexpected Result: The Spectra of e^+ , \bar{p} , p
have identical energy dependence above 60 GeV e^- does not



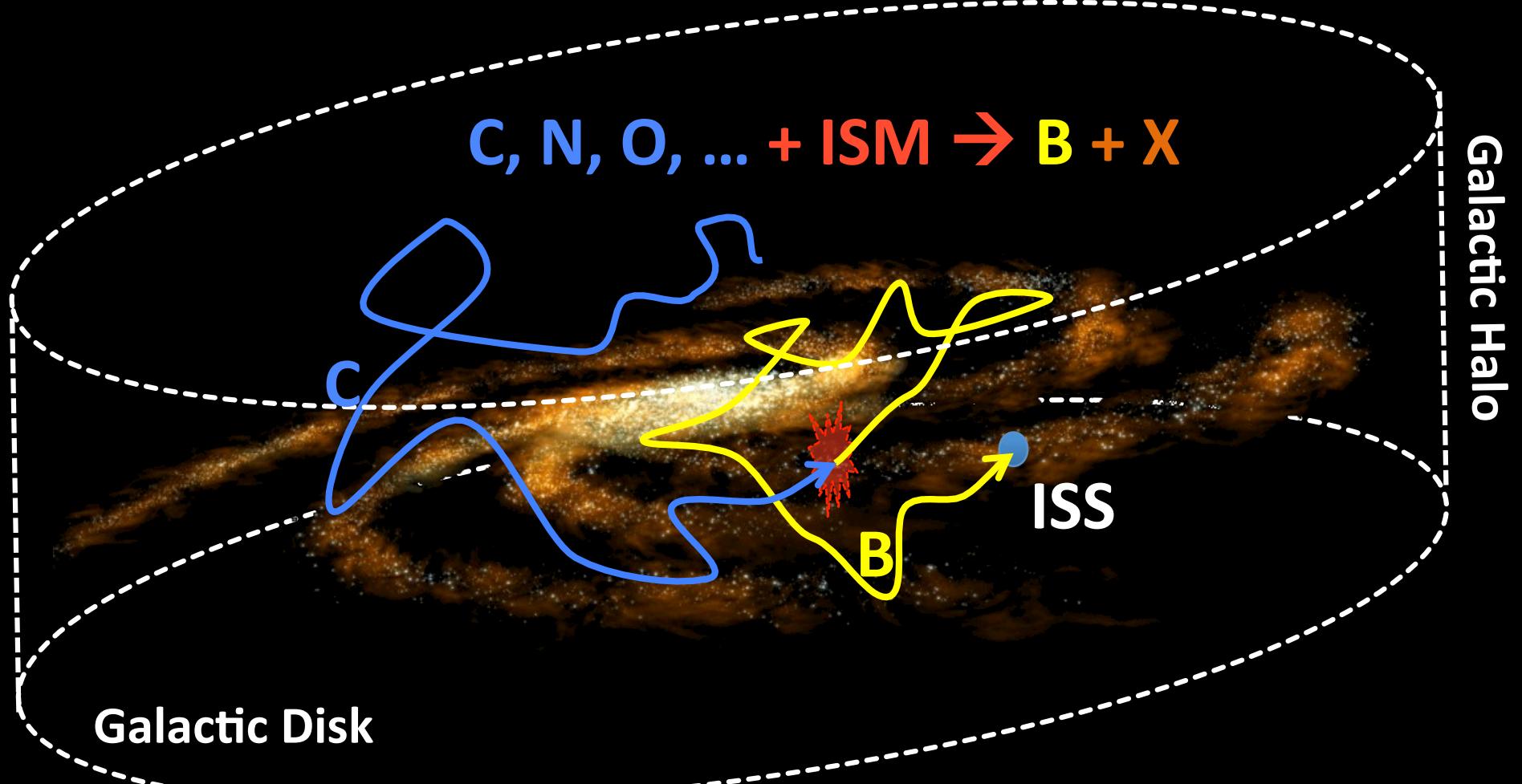
Possible explanation for the positron excess: propagation of secondaries (example of a model)

R. Cowsik, B. Burch, and T. Madziwa-Nussinov, Ap. J. 786 (2014) 124



Cowsik's model predicts flattening of B/C at high rigidities ($R>200$ GV).
Simultaneous fit to all relevant CR species is the key to success

Flux Ratios: Boron/Carbon and propagation



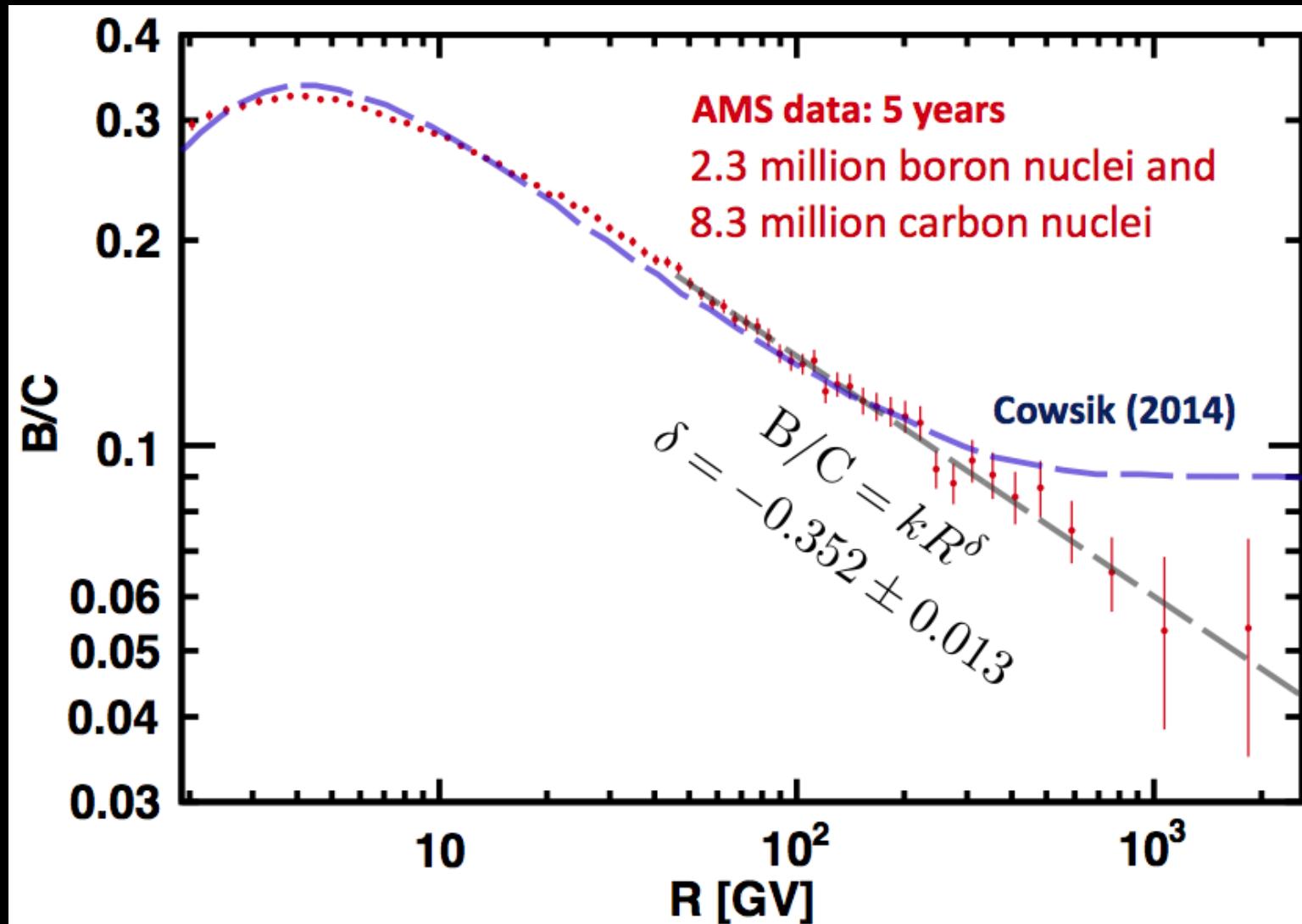
Cosmic Rays are commonly modeled as a relativistic gas diffusing through a magnetized plasma.

Models of the magnetized plasma predict different behavior for $B/C = k R^\delta$.

With the Kolmogorov turbulence model $\delta = -1/3$ is expected,
while the Kraichnan theory leads to $\delta = -1/2$.

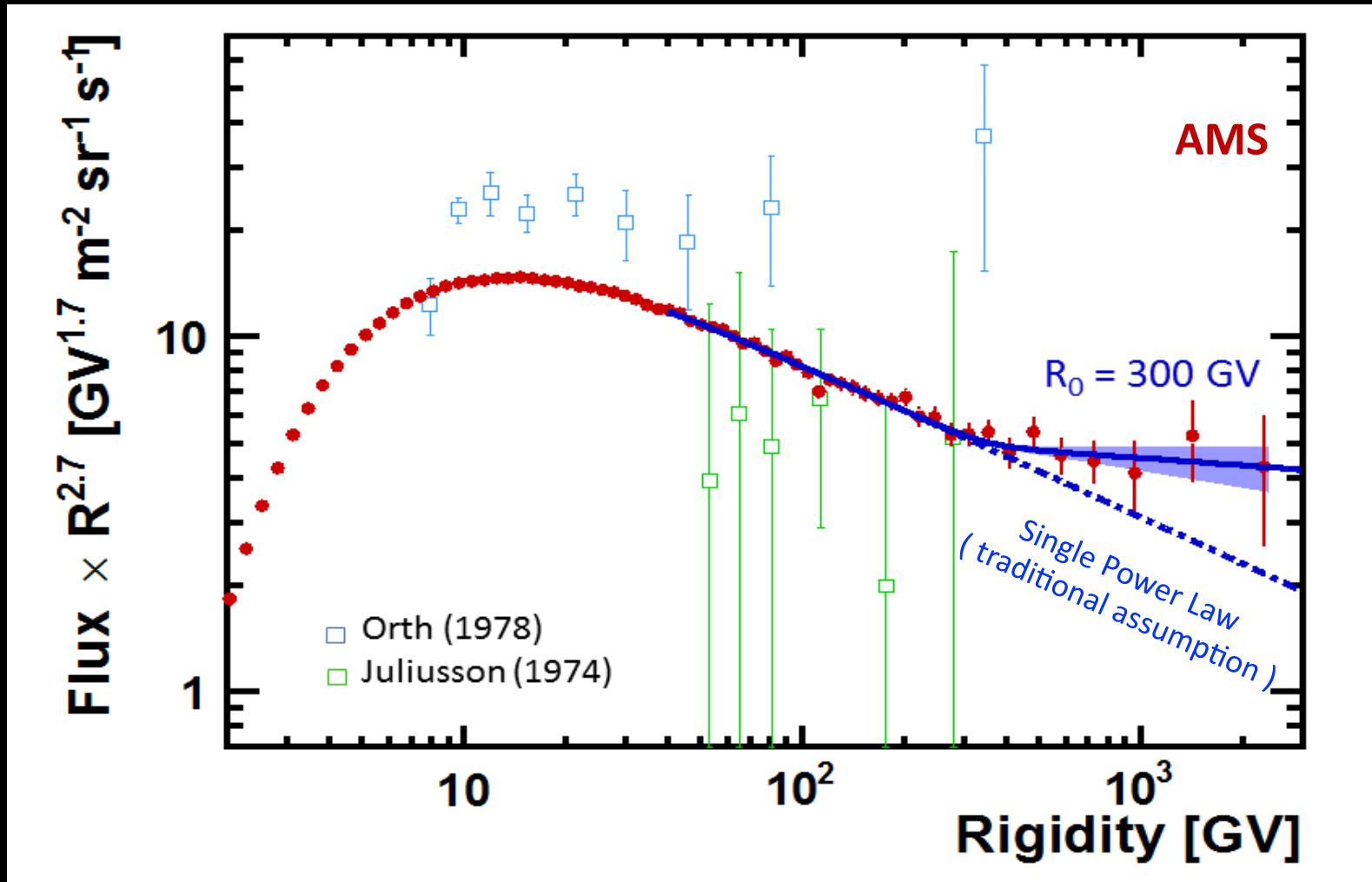
Measurement of Boron to Carbon flux ratio

Paper submitted for publication



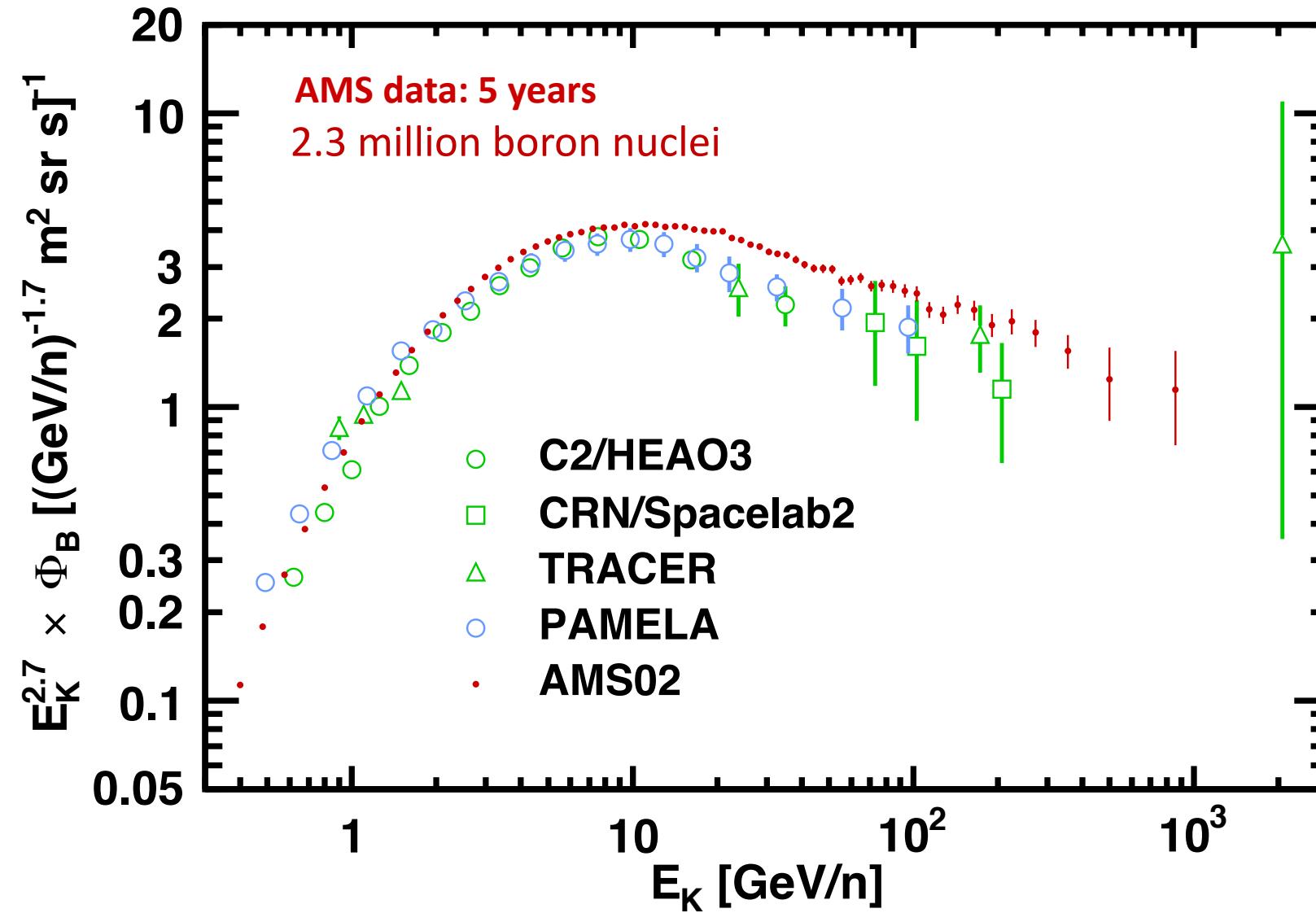
AMS measurement of Lithium flux

Up to now it was assumed that cosmic lithium is purely secondary in origin.

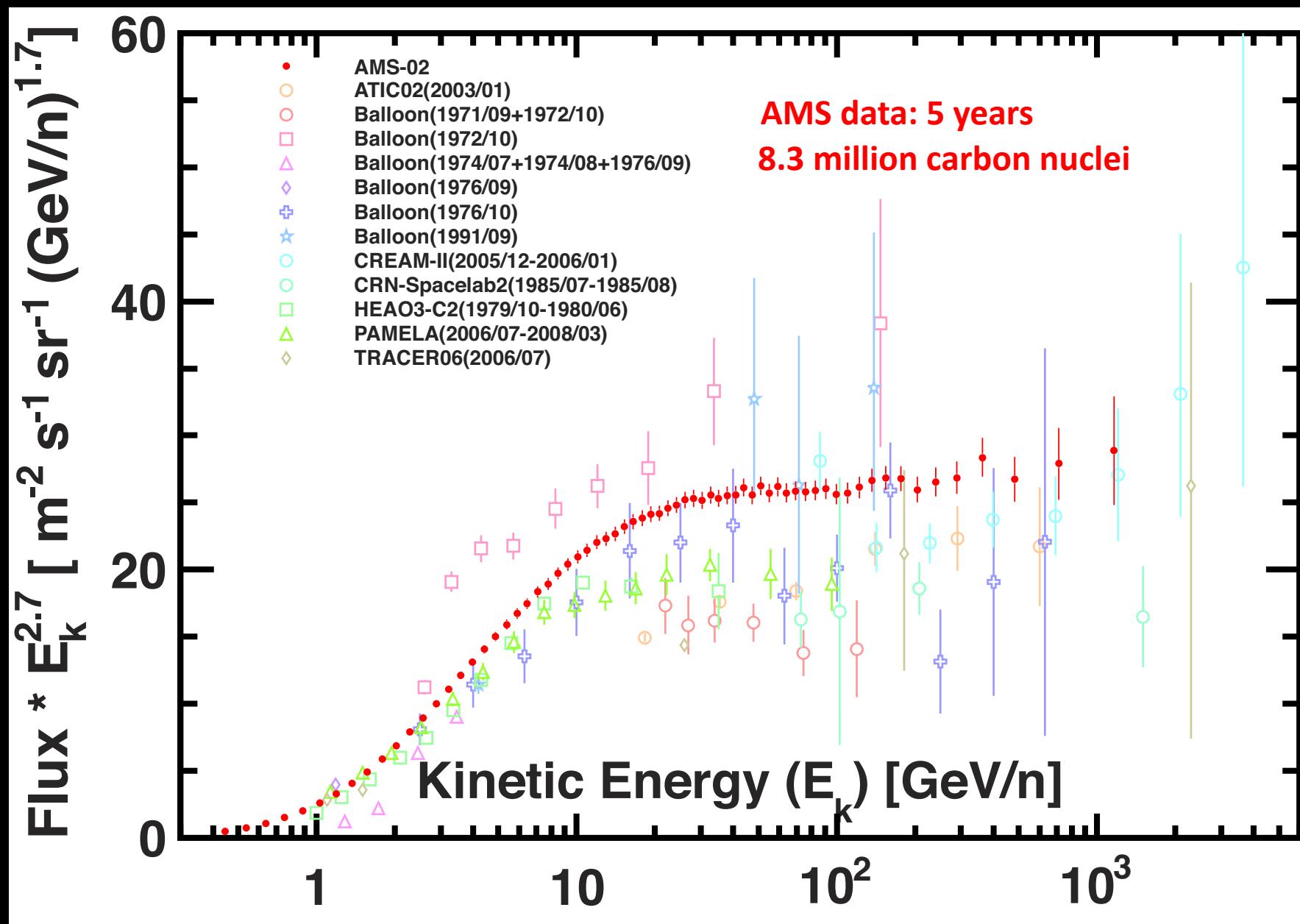


AMS data show that either cosmic lithium has also a primary origin or the diffusion coefficient describing propagation of cosmic rays is rigidity dependent.

AMS measurement of Boron flux



AMS measurement of Carbon flux



Conclusions

In the past hundred years, balloons and satellites have measured charged cosmic rays with ~30% accuracy.

AMS is providing cosmic ray information with ~1% accuracy.

This accuracy provides new understanding of the nature of the universe.

