Current problems in cosmic ray physics

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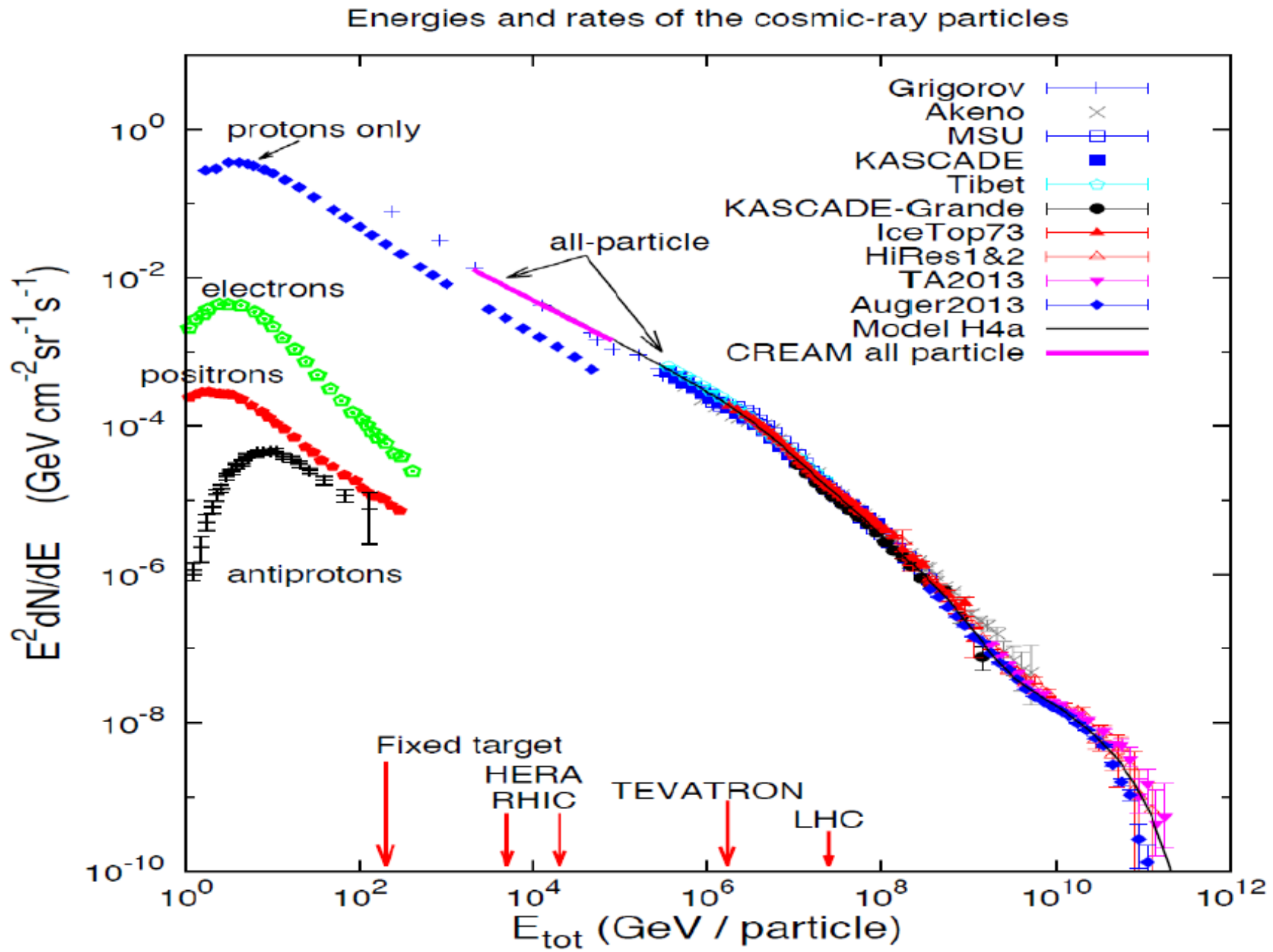
Contents

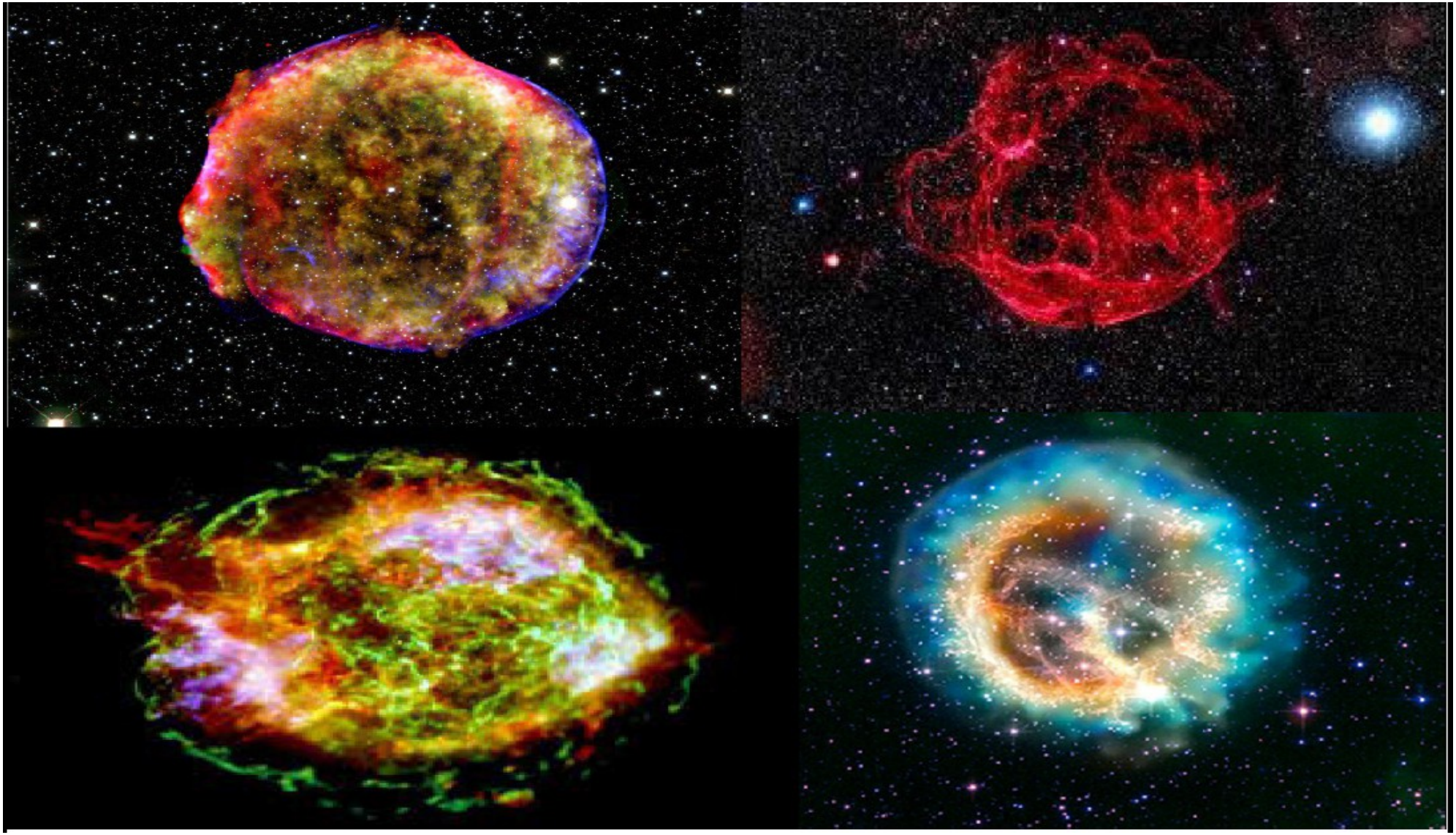
- Cosmic rays "standard model"
- What the current data shows

Cosmic rays

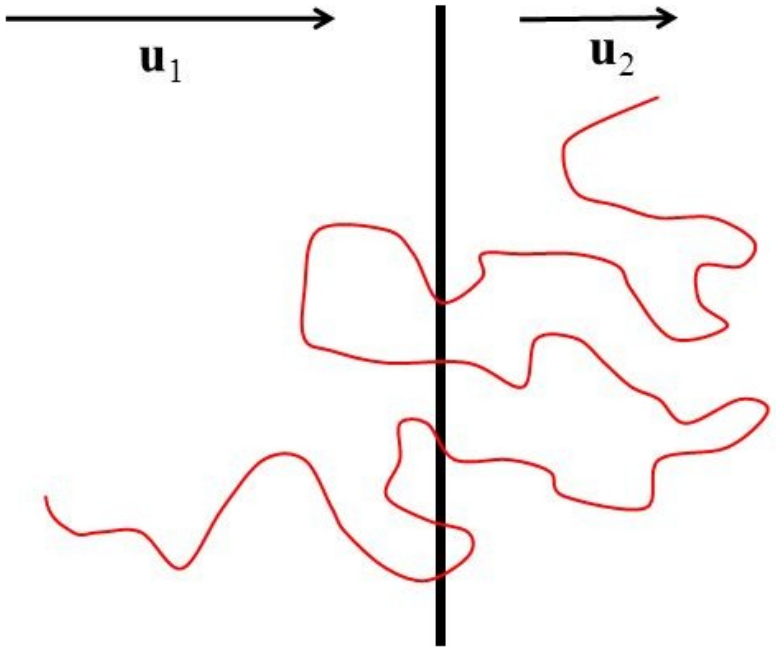
- Cosmic rays are high energy charged particles, arriving to Earth from interstellar space
- Their energy spans from a few hundred MeV up to 300EeV ($3x10^{20}$ eV).
- Main component is nuclei, almost 99%
  - Of nuclei about 89% are protons
  - About 10% helium nuclei
  - 1% heavier nuclei
- 1% of rest is mainly electrons


Energies and rates of the cosmic-ray particles
protons only
all-particle
electrons
positrons
antiprotons
Grigorov
Akeno
MSU
KASCADE
Tibet
KASCADE-Grande
IceTop73
HiRes1&2
TA2013
Auger2013
Model H4a
CREAM all particle
Fixed target
HERA
RHIC
TEVATRON
LHC
E²dN/dE (GeV cm⁻² sr⁻¹ s⁻¹)
E_tot (GeV / particle)

Production



Diffusive shock acceleration: $r_g >> d$



in the shock rest frame

shock compression

$R \approx u_1/u_2$

I order acceleration

$$\Delta p \sim p \frac{u}{v}$$

where u = u1-u2

Compressive discontinuity of the plasma flow leads to acceleration of particles reflecting at both sides of the discontinuity: diffusive shock acceleration (I-st order Fermi)

the differential energy spectrum is:

compression ratio $r = u_1/u_2$

$$n\mathrm{d}p \propto p^{-(r+2)/(r-1)}\mathrm{d}p.$$

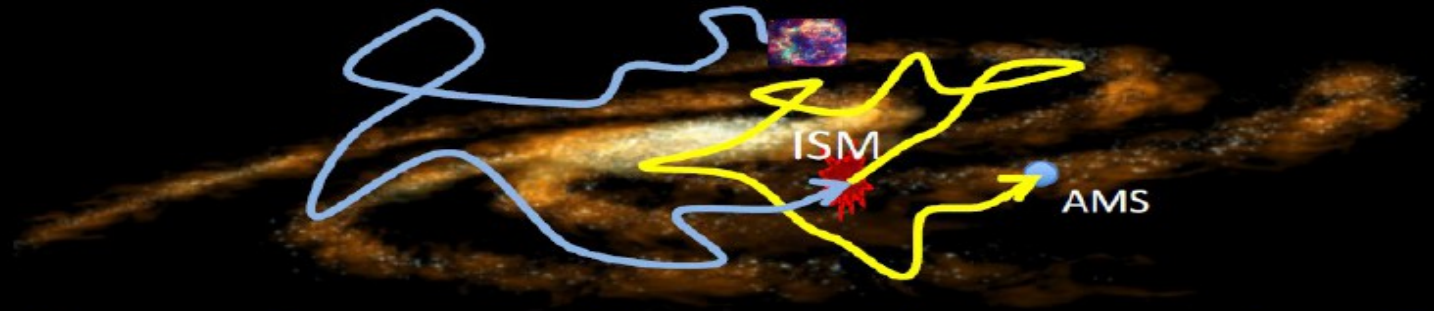
Propagation

Primary Cosmic Rays (p, He, C, O, …)

Primary cosmic rays carry information about their original spectra and propagation.

Secondary Cosmic Rays (Li, Be, B, …)

C, O, …, Fe + ISM → Li, Be, B + X



Secondary cosmic rays carry information about propagation of primaries, secondaries and the ISM.

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Propagation

Galactic magnetic field´s turbulence spectrum

- Kolmgorovs – delta 1/3
- Kraichnan – delta 1/2

- Secondaries – grammage of material traversed, function of CR residence time in the galaxy

Precision CR physics

- Pamela (2008) – discovery of the positron excess
- AMS-02 (2011) – measurment of CR fluxes up to 1%

5 years of AMS

SPEAKER: Prof. TING, S. (Massachusetts Inst. of Technology (US))

TITLE: **The First Five Years of the Alpha Magnetic Spectrometer on the International Space Station**

DATE: Thu 08/12/2016 17:00

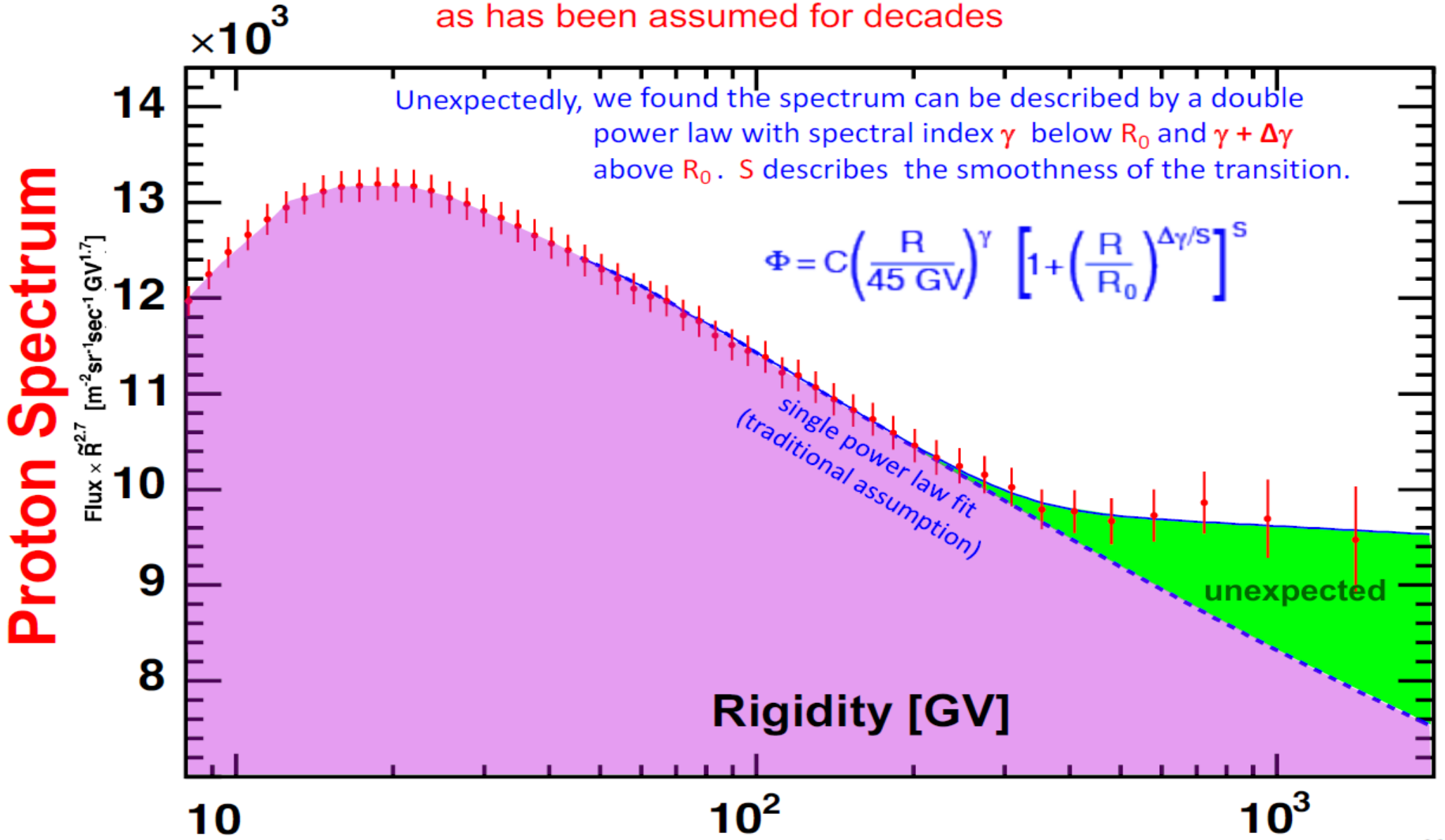
Unexpected Excesses in everything

CR standard model predicts

- Power law sources
- Power law preserving transport
- Power law fluxes at Earth

AMS proton flux

New information: The proton flux cannot be described by a single power law = CR^{γ}, as has been assumed for decades



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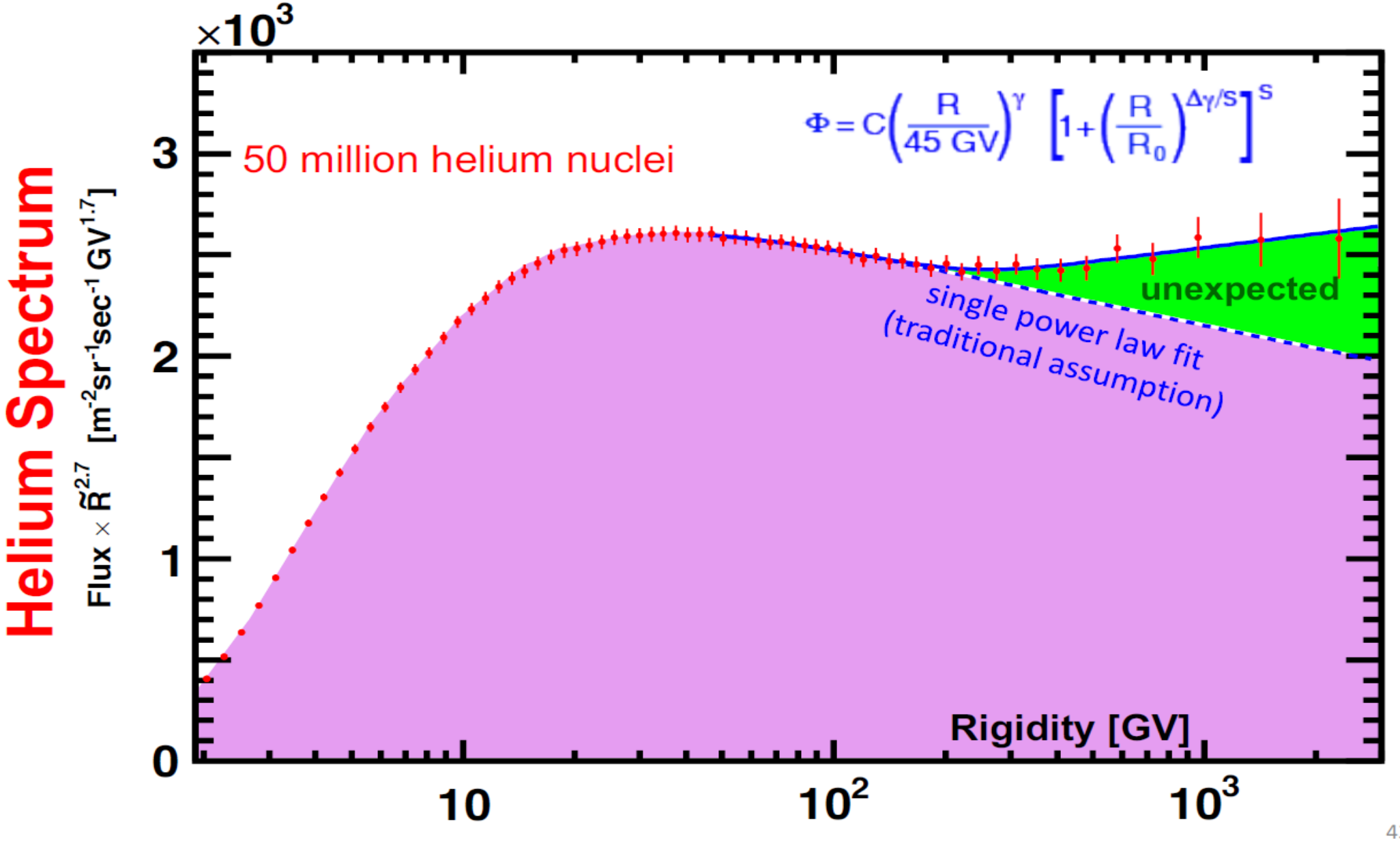
AMS Helium Flux

New information: The Helium flux cannot be described by a single power law.



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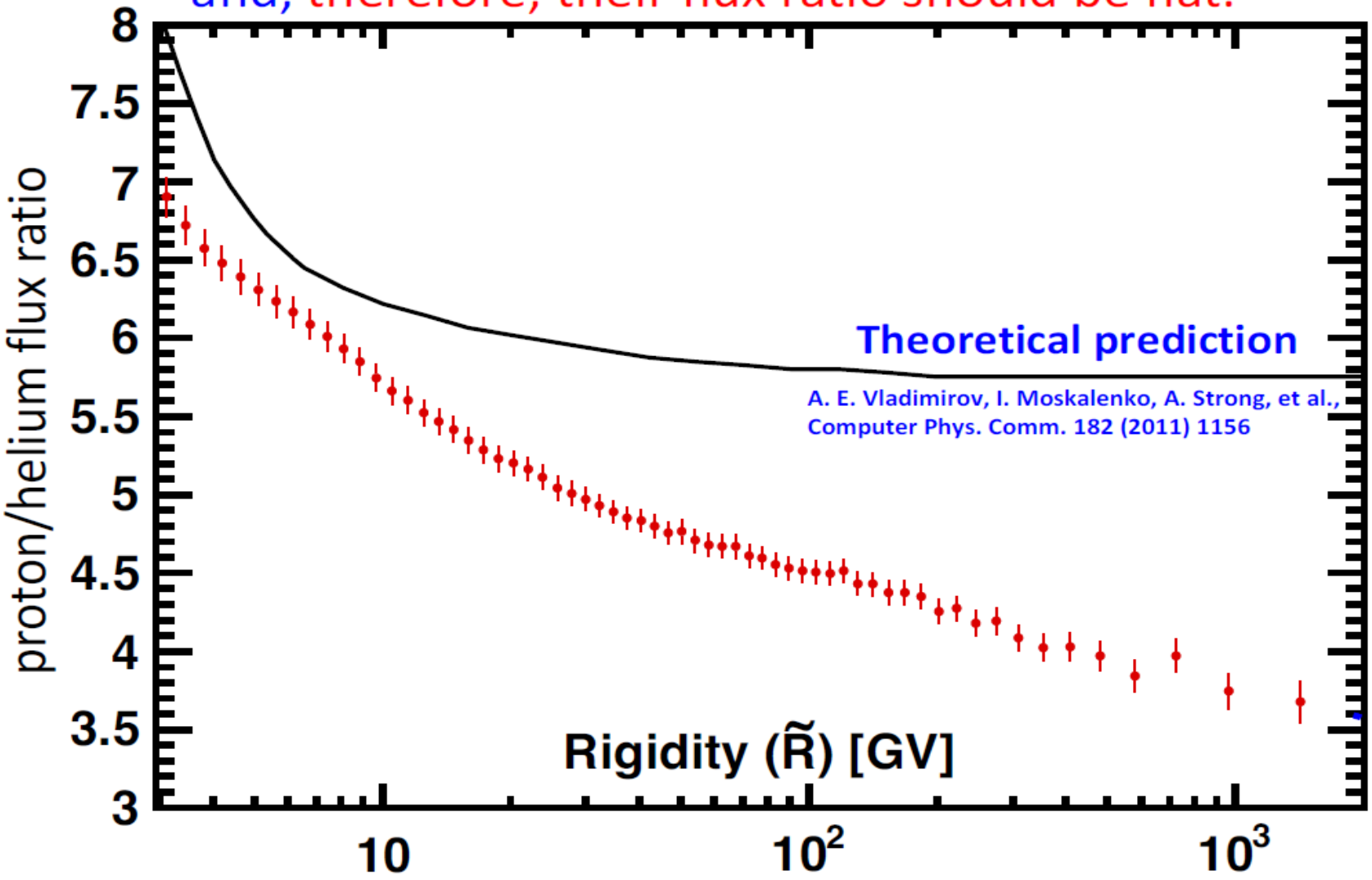
Physics Result 9: The AMS proton/helium flux ratio

Protons and helium are both "primary" cosmic rays.
Traditionally, they are assumed to be produced in the same sources and, therefore, their flux ratio should be flat.



AMS result: this ratio is not flat.

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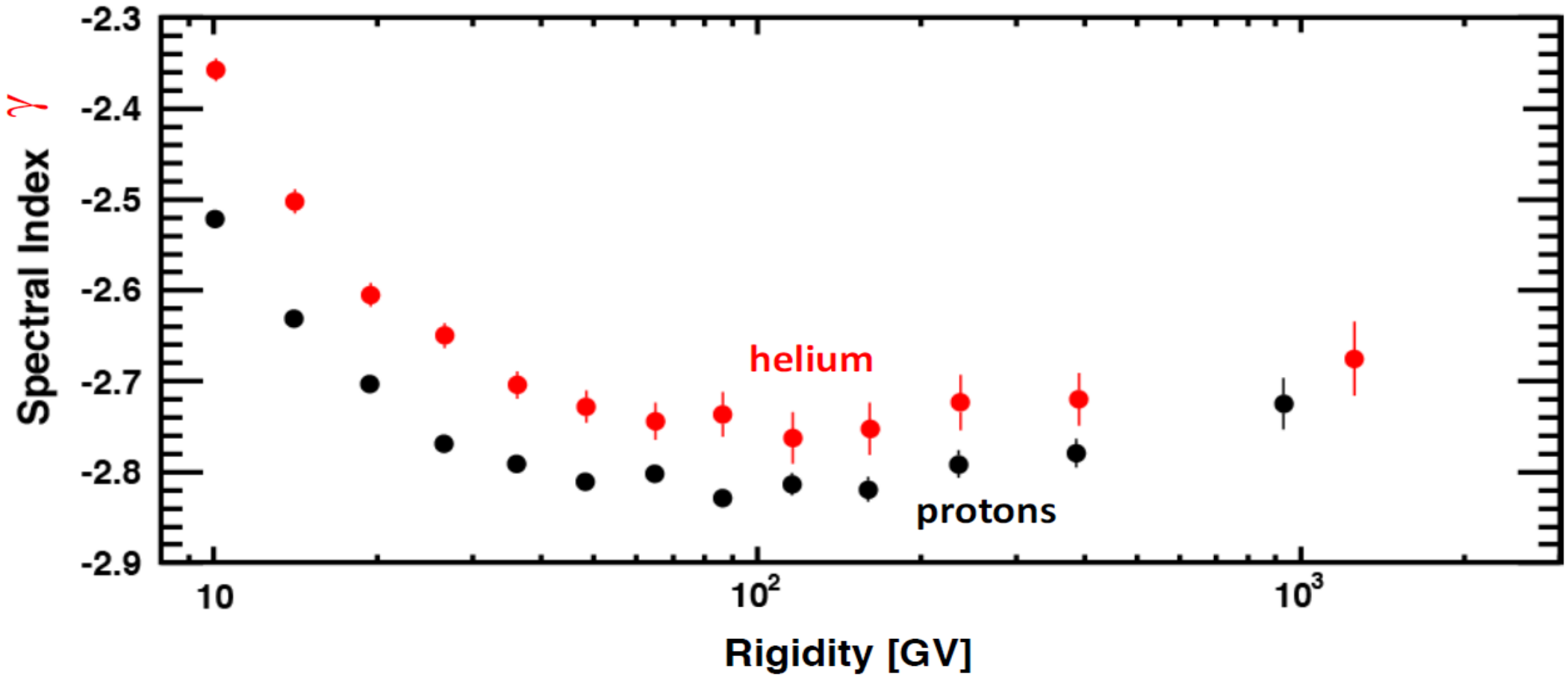
New information: The helium spectral index changes with rigidity in a similar way to that of the proton spectral index but the values are different



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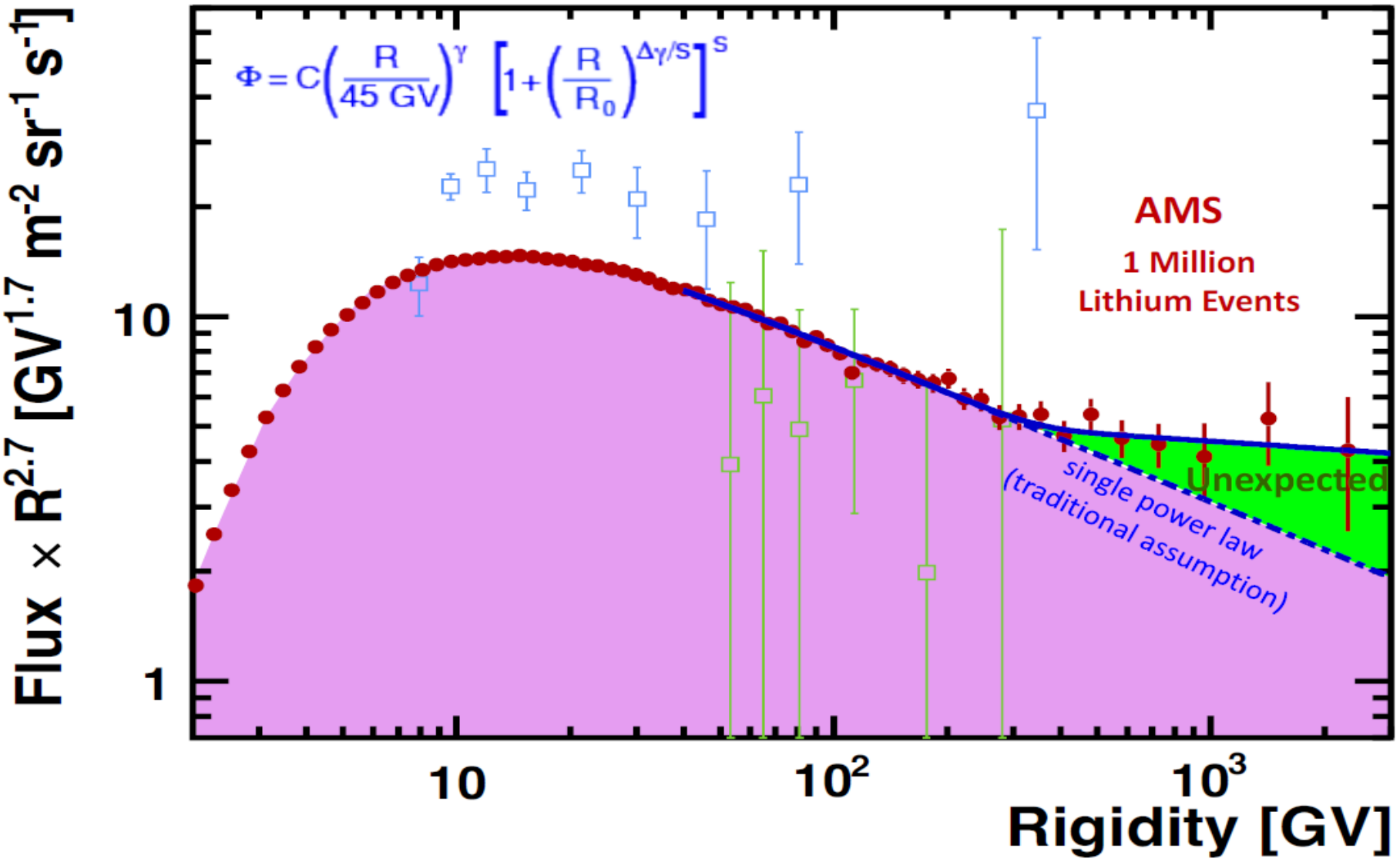
Physics Result 10: The Lithium flux

New AMS results on Secondary Cosmic Rays (Lithium)

New information: The Lithium spectrum behaves similar to protons and Helium and the Lithium flux cannot be described by a single power law.



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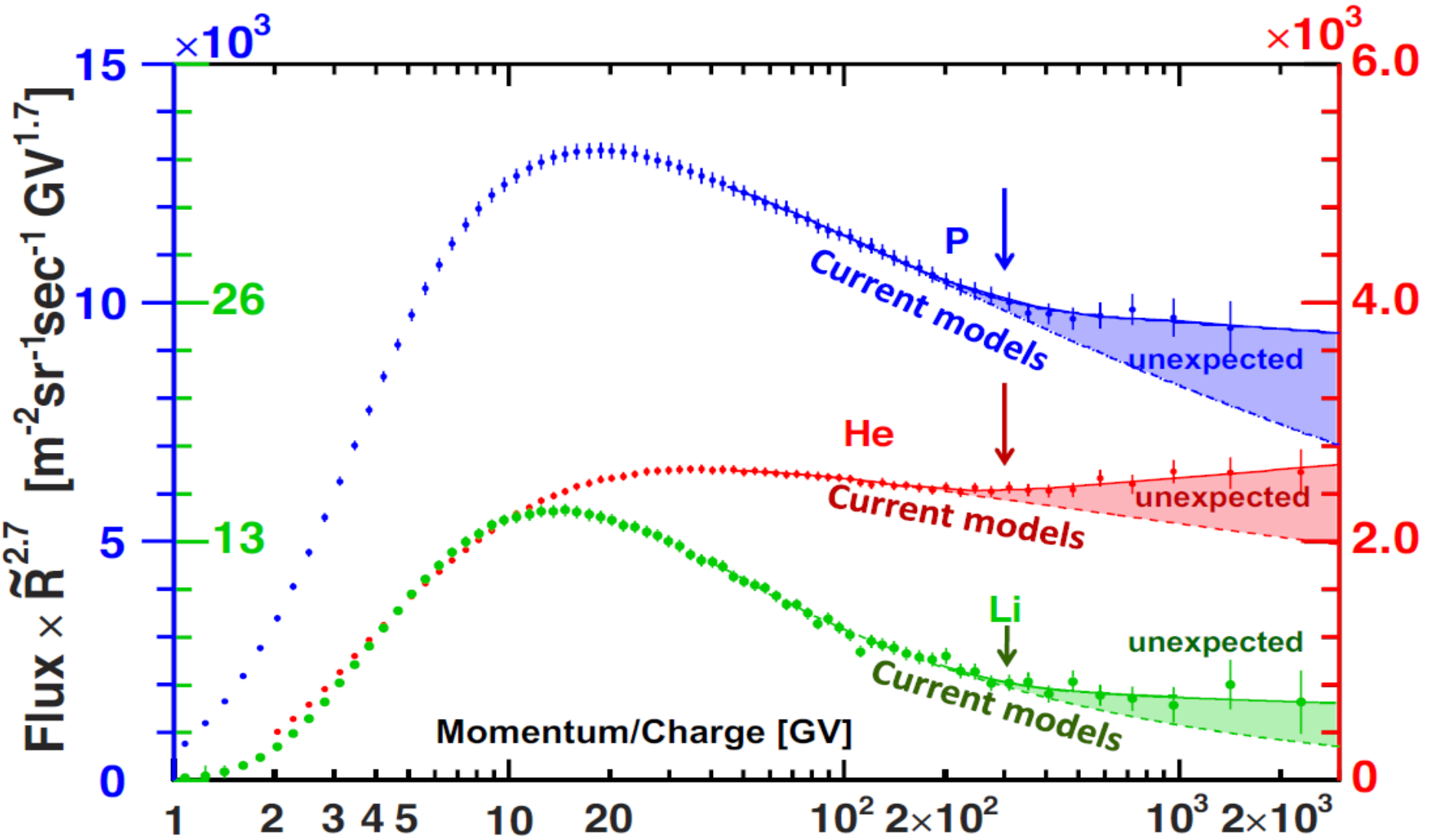
Summary (on nuclei)

The spectra of protons, helium and lithium do not follow the traditional single power law. They all change their behavior at the same energy.



- CR nuclei have a break at rigidity ~450GV
- Proton and helium fluxes have different indexes

  Propagation?

Low energy break

- CR nuclei seem to have a break

  at rigidity ~10-20GV
- With low energy spectral index being ~2.3-2.4
- That being consistent with diffusive gamma-ray background from inner galaxy

  "Cosmic ray spectrum in the local Galaxy"

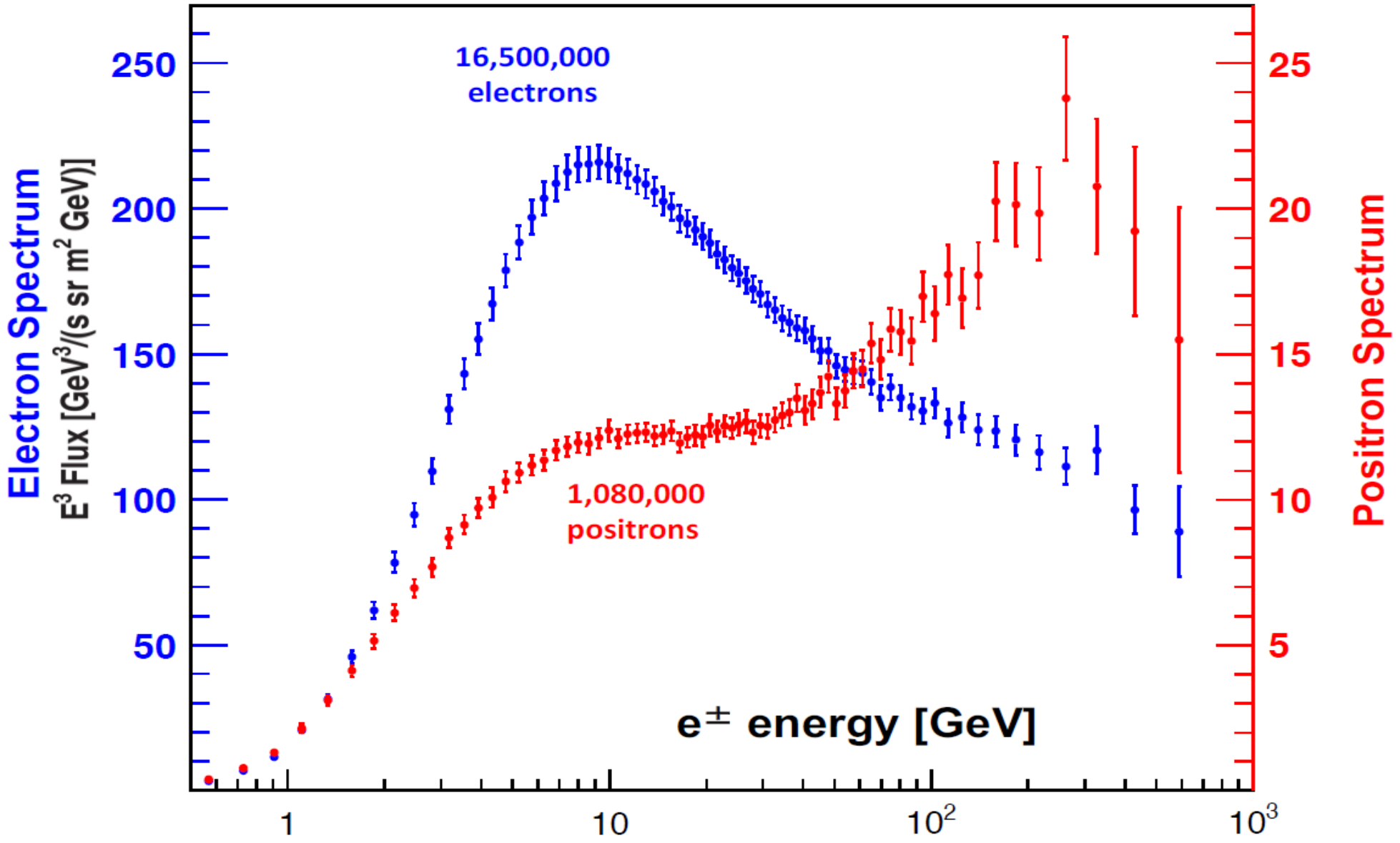
  Andrii Neronov, Denys Malyshev, Dmitri V. Semikoz

  https://arxiv.org/abs/1705.02200

Antimater excesses

Summary (on elementary particles)

The electron flux and the positron flux are different in their magnitude and energy dependence.



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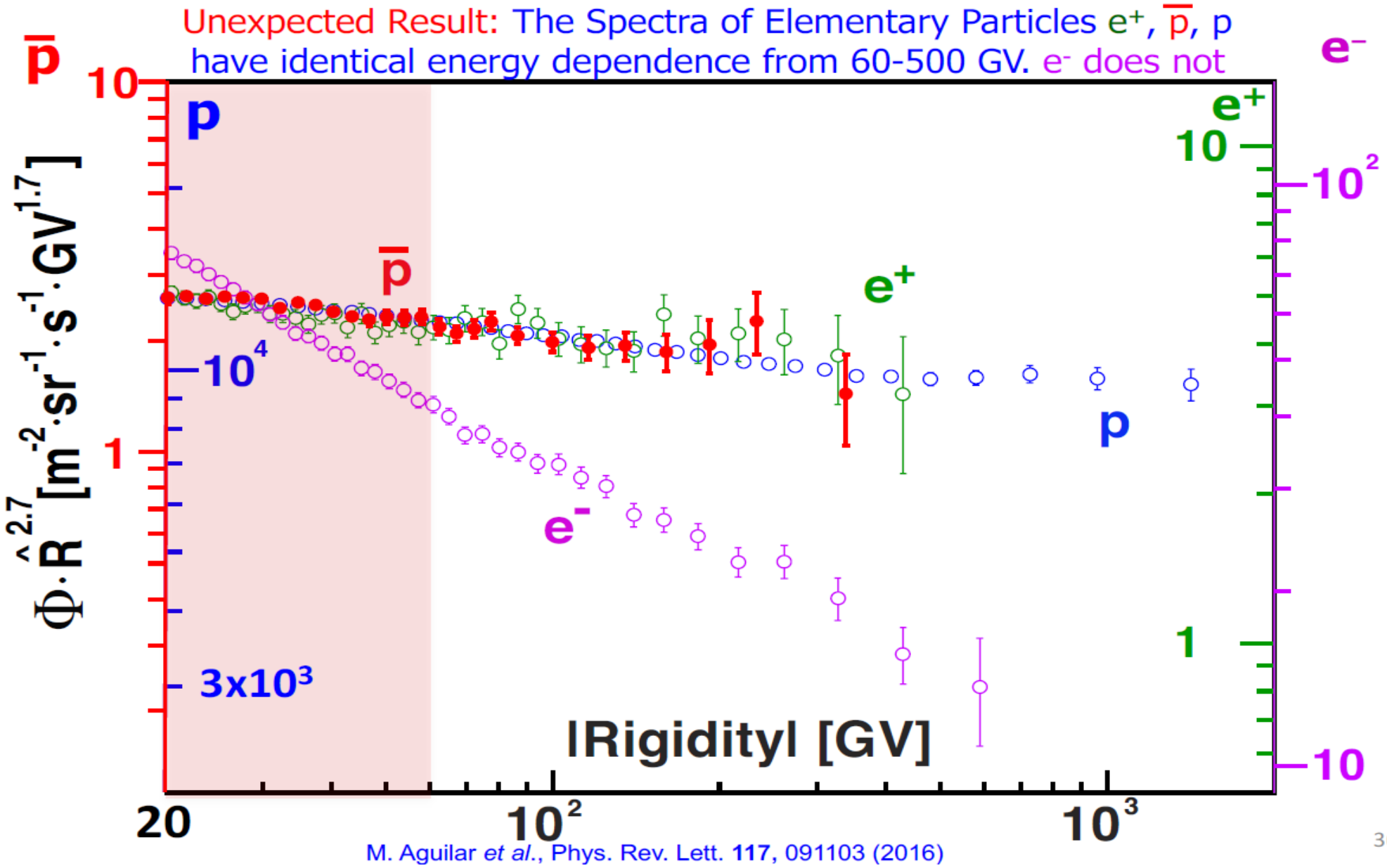
Physics Result 7: The antiproton flux and properties of elementary particle fluxes



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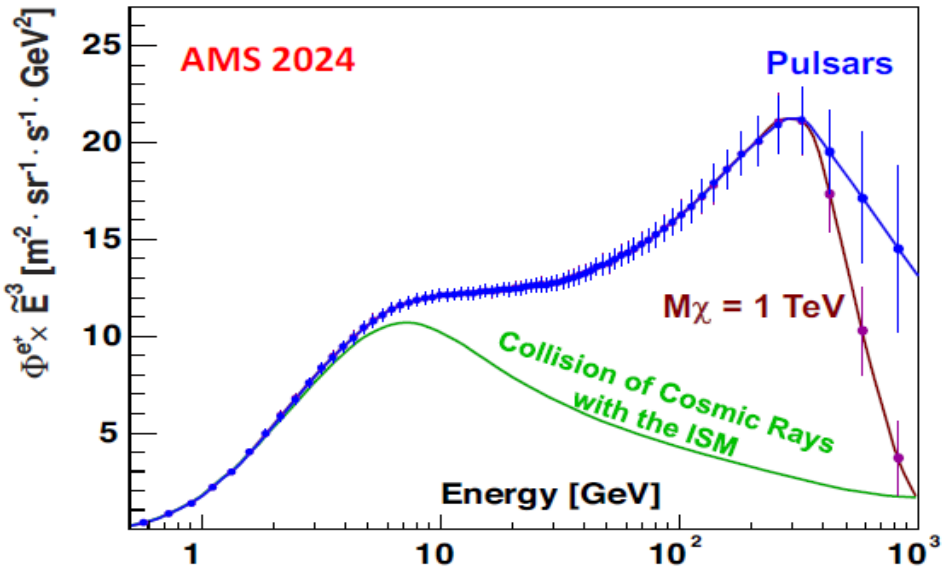
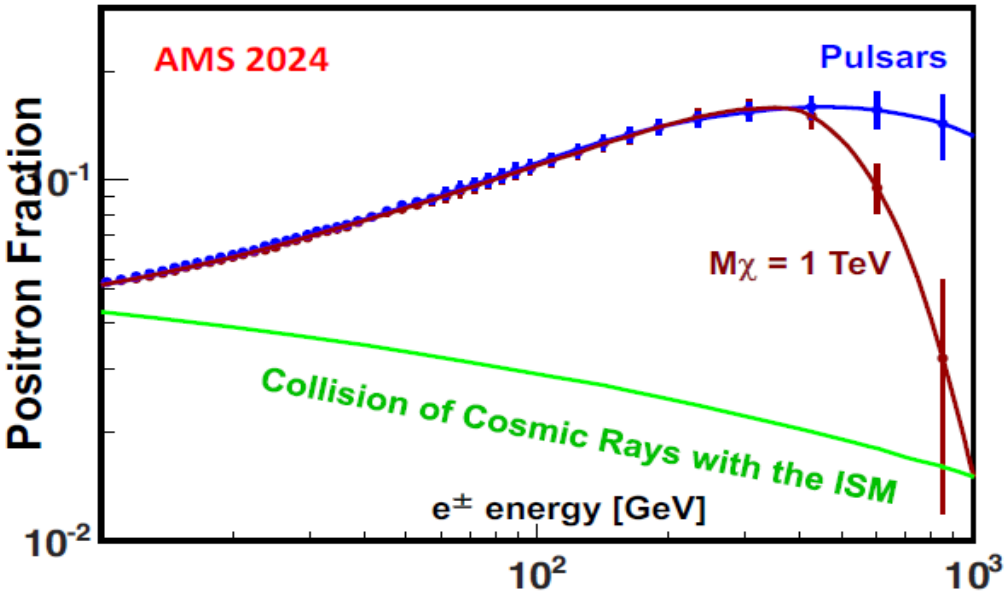
Summary (on elementary particles)

Positron Spectrum | **Positron Fraction**

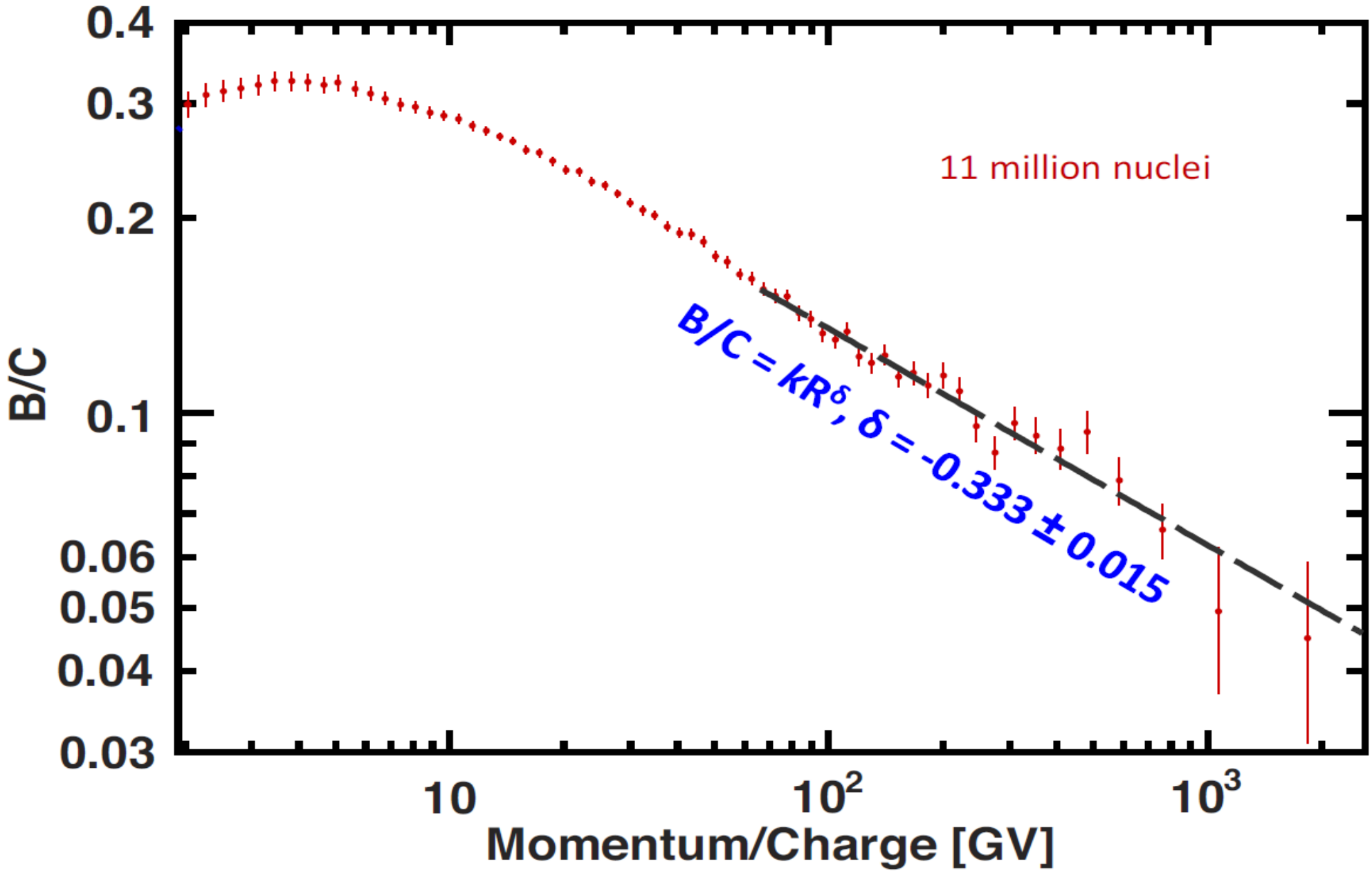
By 2024 we will should be able understand the origin of this unexpected data.





Some clarity with propagation

Physics Result 14: The Boron-to-Carbon (B/C) flux ratio



M. Aguilar *et al.*, Phys. Rev. Lett. **117**, 231101 (2016)

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AMS B/C results

The B/C ratio does not show any significant structures in contrast to many cosmic ray models that require such structures at high rigidities.

Remarkably, above 65 GV, the B/C ratio is well described by a single power law
$B/C = k\,R^{\delta}$ with $\delta = -0.333 \pm 0.015$.

This is in agreement with
the Kolmogorov turbulence model
of magnetized plasma of
$\delta = -1/3$ asymptotically.

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Summary

Possible explenations

- Dark matter
- Flawed models of producton and propagation
- Local effects

Thank you for your attention!