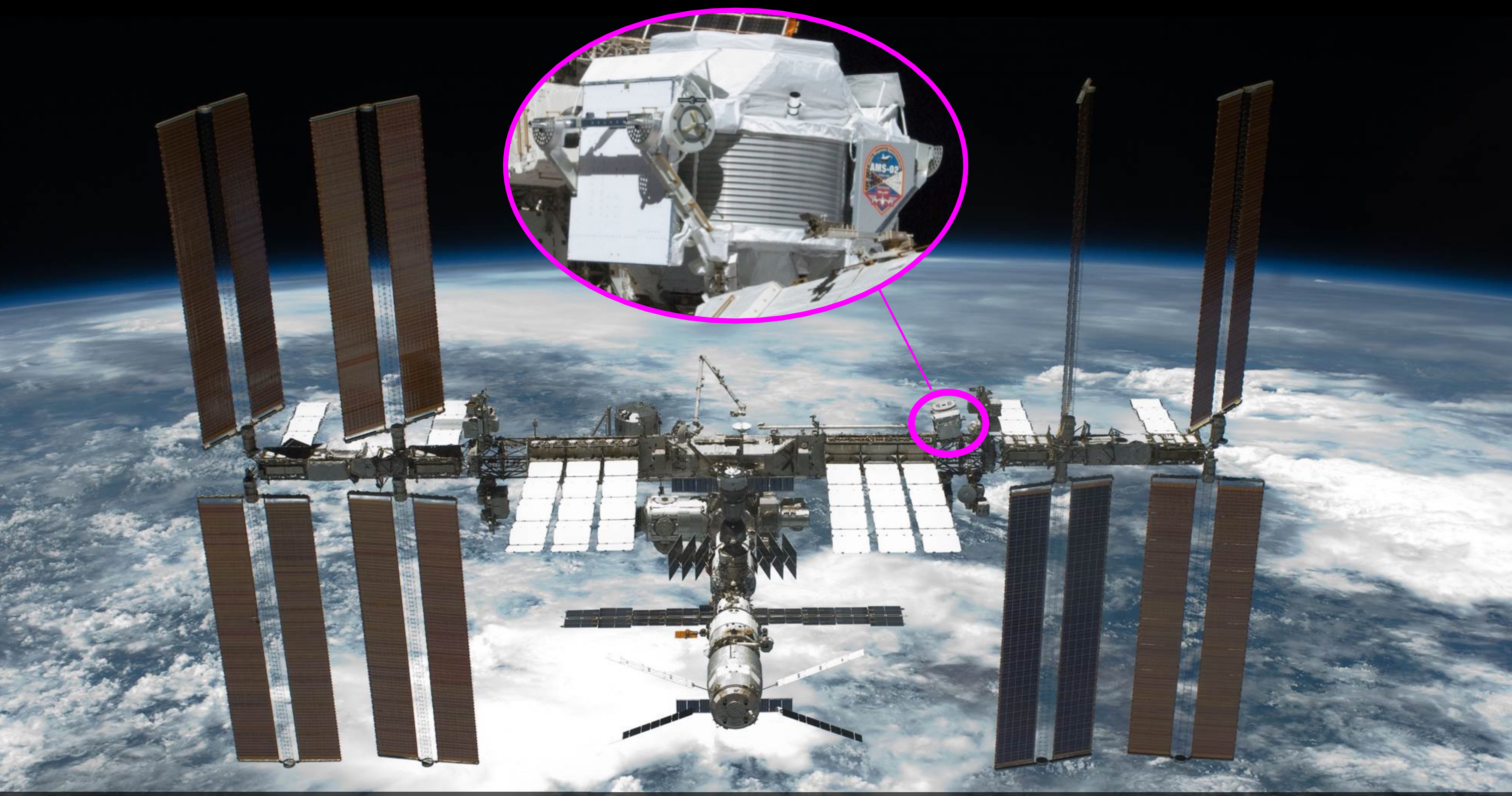
Antiproton Flux and Properties of Elementary Particle Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the ISS



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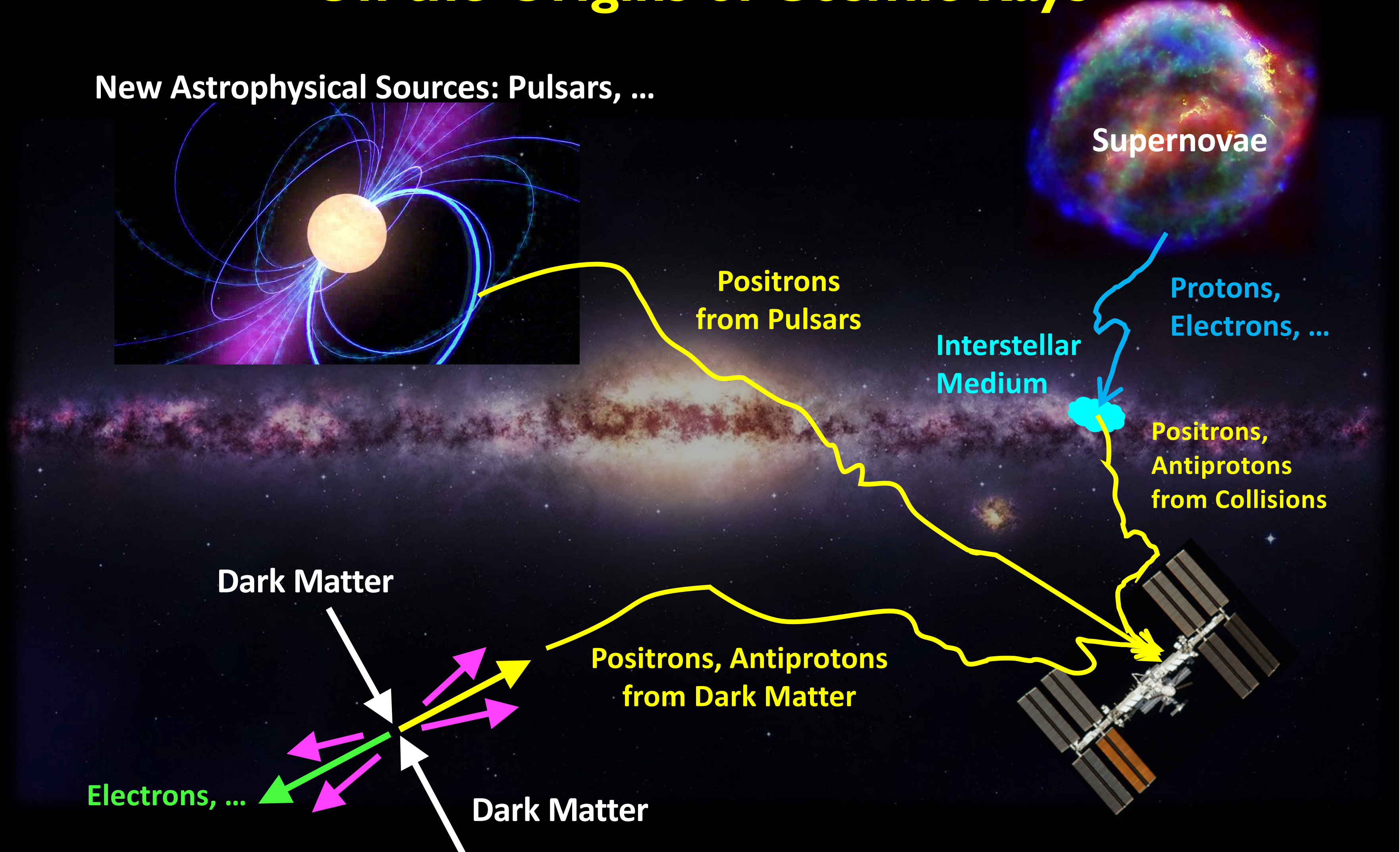
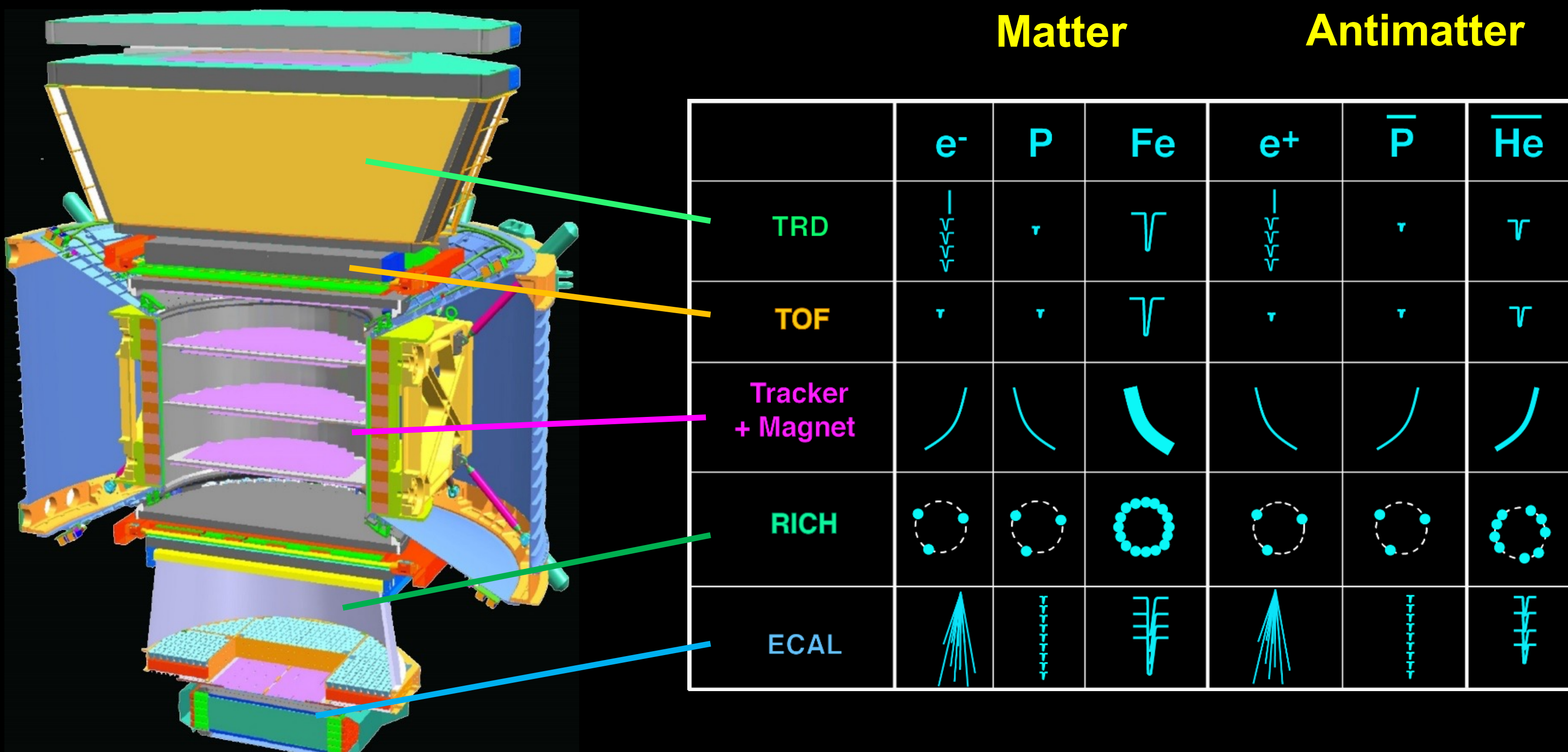
Hsin-Yi Chou / Academia Sinica, Taiwan
on behalf of the AMS Collaboration

On the Origins of Cosmic Rays



Measurement of these elementary particles ($p, \overline{p}, e^{-}, e^{+}$)
is a major tool to study new physics in space

AMS is a unique magnetic spectrometer in space



Cosmic rays are defined by:

- Energy (E in units of GeV)
- Charge (Z - location on the periodic table: H Z=1, He Z=2, …)
- Rigidity (R=P/Z in units of GV)

Antiproton Analysis

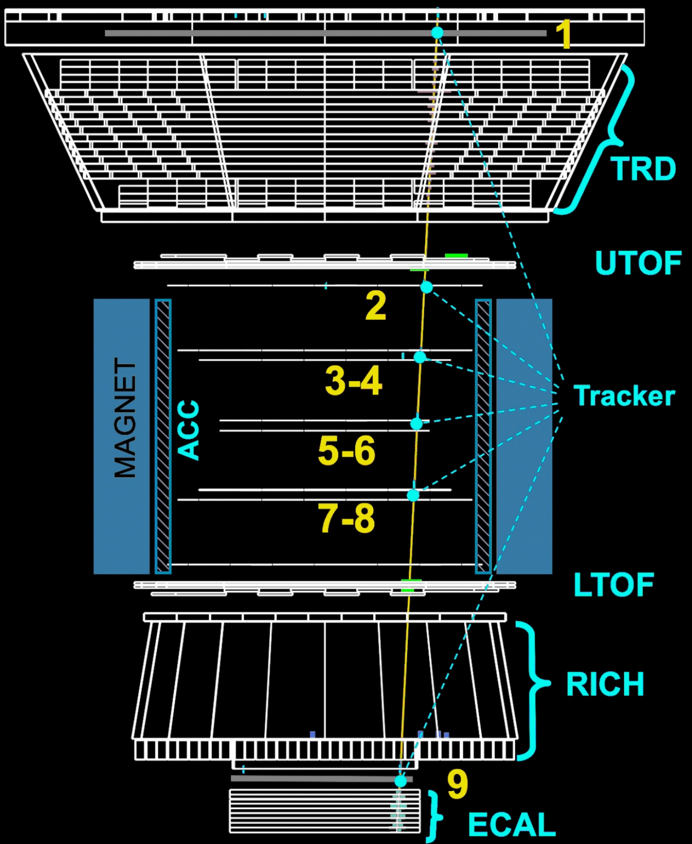
The Antiproton Flux is ~10^{-4} of the Proton Flux.

A percent precision experiment requires background rejection close to 1 in a million.

- **TOF & RICH:** select down going particles and measure velocity
- **TRD & ECAL:** reject electron background
- **Tracker:** Measure rigidity, separate antiprotons from charge confusion protons

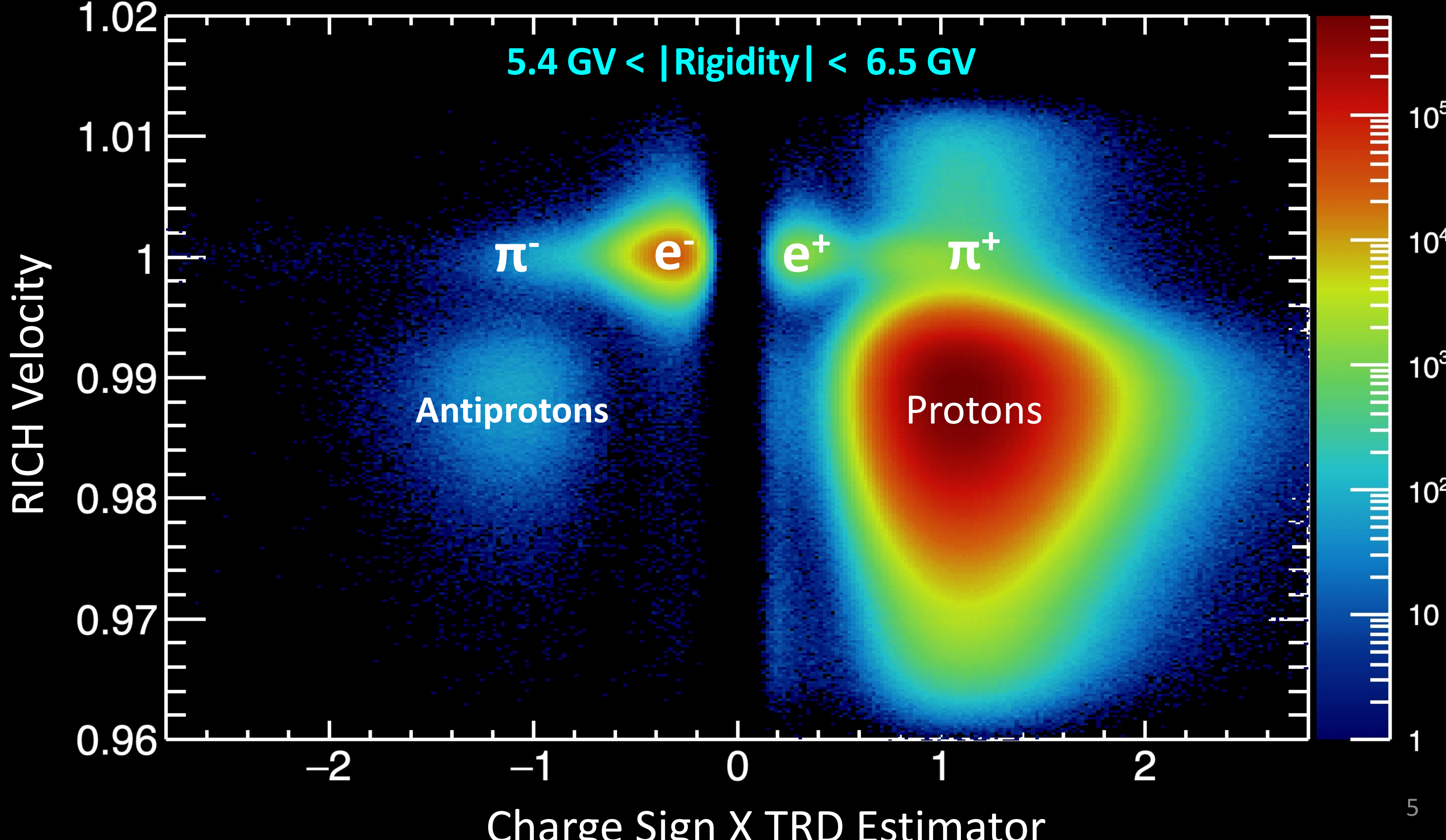
- **A charge confusion estimator was built with Tracker and TOF information to reject protons measured as negative rigidity.**

R = −363 GV antiproton



Antiproton identification at Low Rigidity

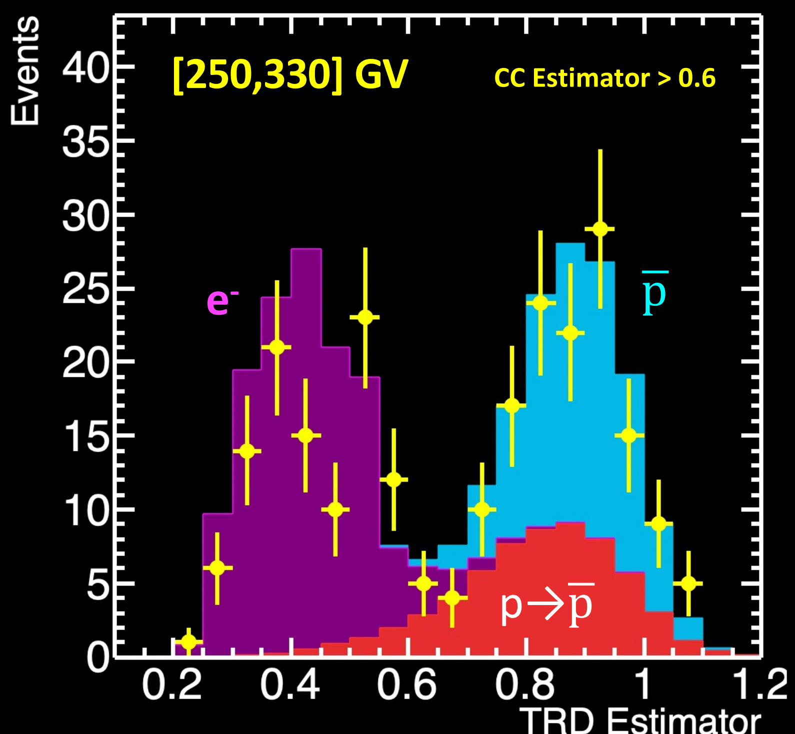
- **Use TOF, RICH, and TRD identify antiproton from backgrounds**
  - **Antiproton & Electron: separated by TRD estimator**
  - **Antiproton & Pion: separated by RICH velocity**



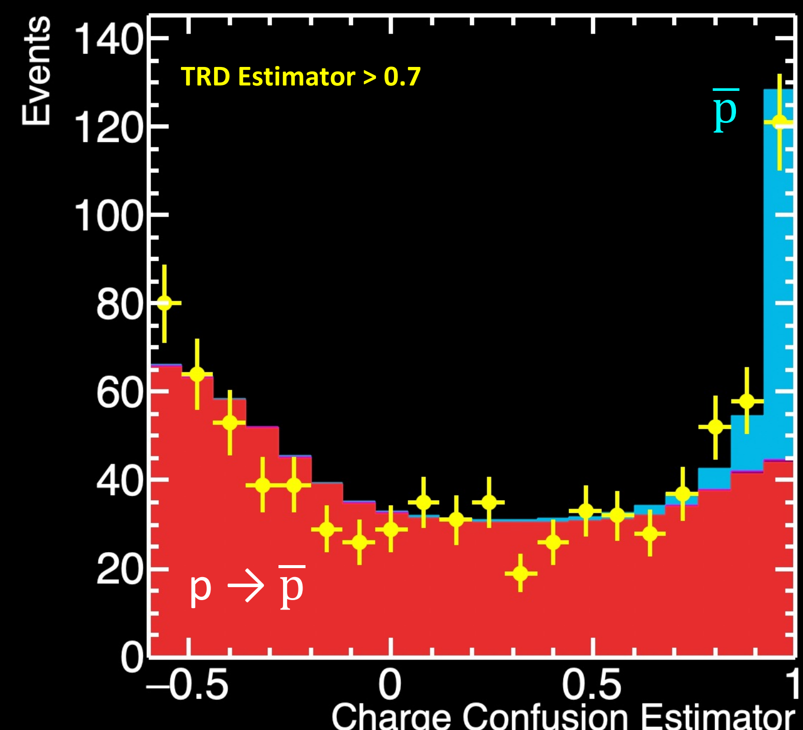
Antiproton identification at High Rigidity

- **Number of antiprotons are obtained by a fit in (TRD-Estimator – Charge Confusion Estimator) 2-D plane.**
  - **Electron: identified by TRD estimator**
  - **Charge Confusion Proton: identified by Charge Confusion estimator**

TRD Estimator Projection



Charge Confusion (CC) Estimator Projection

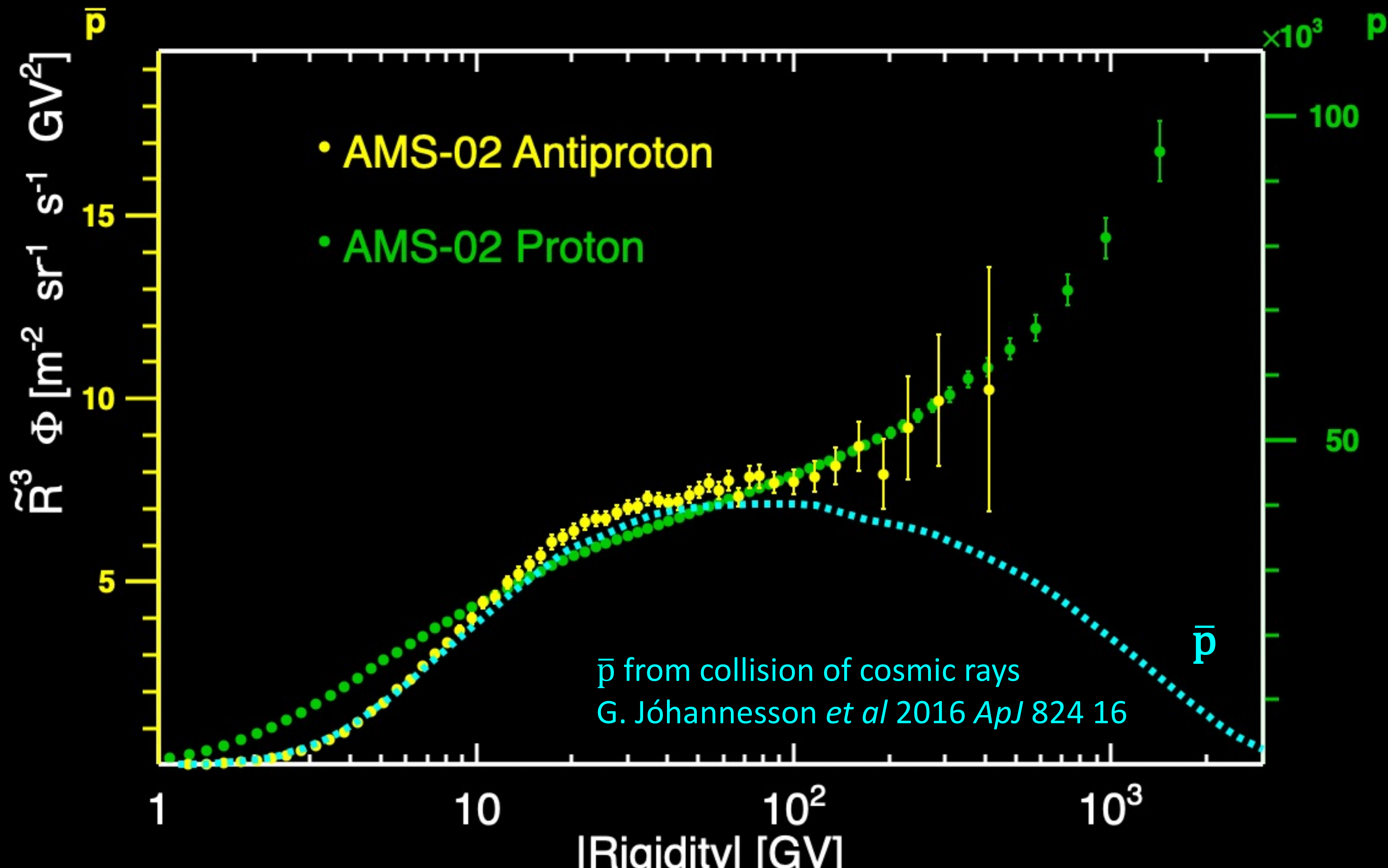


Antiproton Signal are clearly identified in the signal region.

Precision Measurement of Antiproton Flux

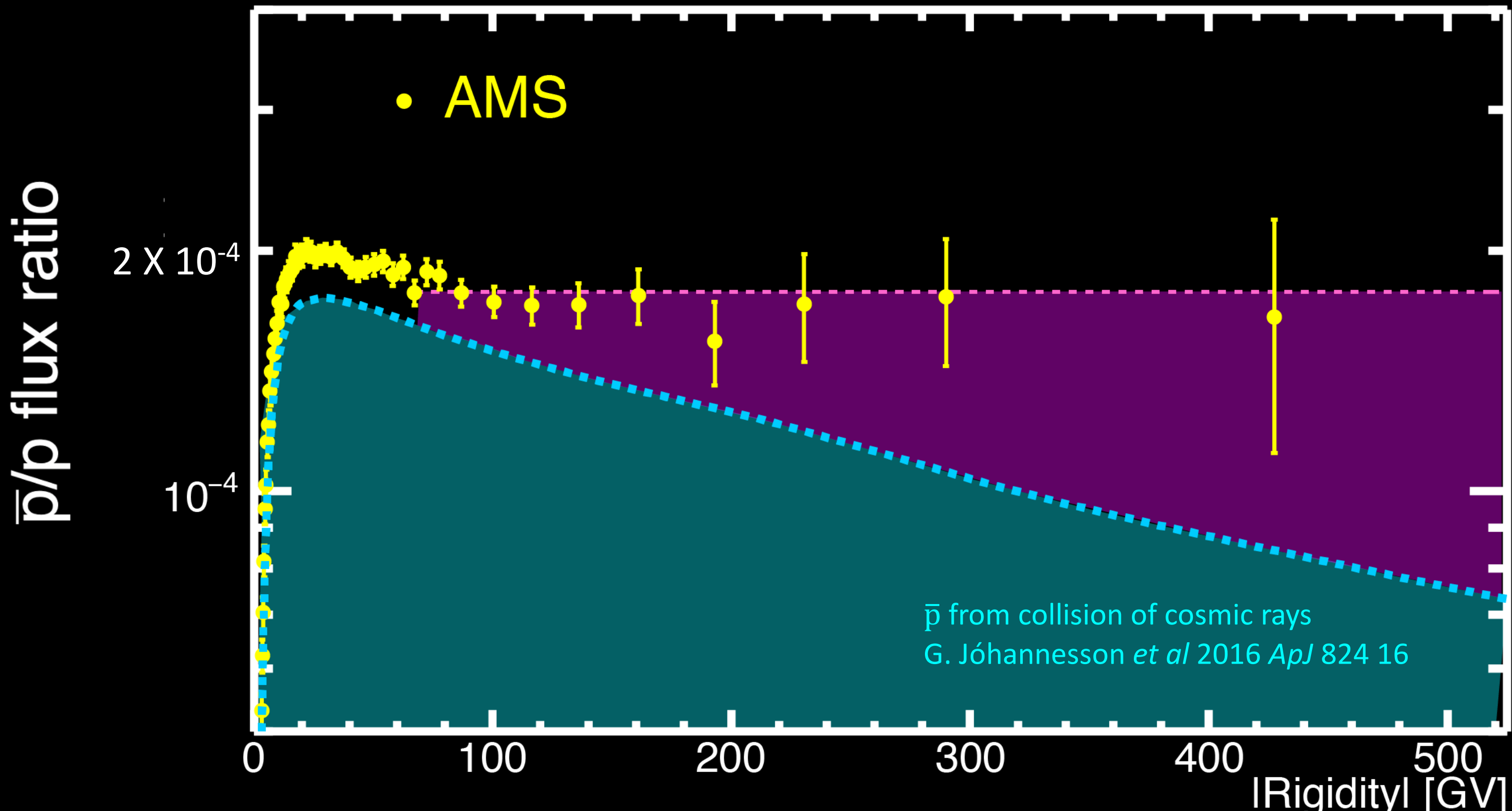
In 10 years, AMS has identified over 0.8 million Antiproton Events from 1 to 525 GV

If $\bar{p}$ are secondaries produced from collision of cosmic rays, their rigidity dependence should be different than p



Antiproton-to-Proton flux ratio

AMS measurements show that p and p̄ have identical rigidity dependence



- **Starting from 60 GV, the flux ratio is a constant up to 525 GV.**
- **This result is not expected if antiprotons are produced only in collisions of cosmic rays with the interstellar medium.**

A sample of recent papers on AMS antiproton data

Antiproton production and propagation

P. Mertsch et al., Phys. Rev. D 104 (2021), 103029

M. Boudaud et al. Phys. Rev. Research 2, 023022 (2020)

V. Bresci et al., Mon. Not. R. Astron. Soc., 488 (2019), p. 2068

M. Korsmeier et al. Phys. Rev. D 97 (2018), 103019

P. Lipari, Phys. Rev. D 95 (2017), 063009

I. Cholis et al., Phys. Rev. D 95 (2017), 123007

M. Winkler, JCAP, 2017(02), 048

……

Antiprotons from Dark Matter

J. Heisig, Modern Physics Letters A, (2021), 36, 05

Y. Genolini et al., arXiv:2103.04108 (2021)

I. Cholis et al., Phys. Rev. D, 99 (2019), 103026

A. Cuoco et al., Phys. Rev. D, 100 (2019), 103014

M. Carena et al., Phys. Rev. D, 100 (2019), 055002

A. Reinert et al., JCAP, 01 (2018), p.055

A. Cuoco et al., Phys. Rev. Lett., 118 (2017), 191102

M. Cui et al. Phys. Lett. 118 (2017). 191101

Y. Chen et al., Phys. Rev. D, 93 (2016), p. 015015

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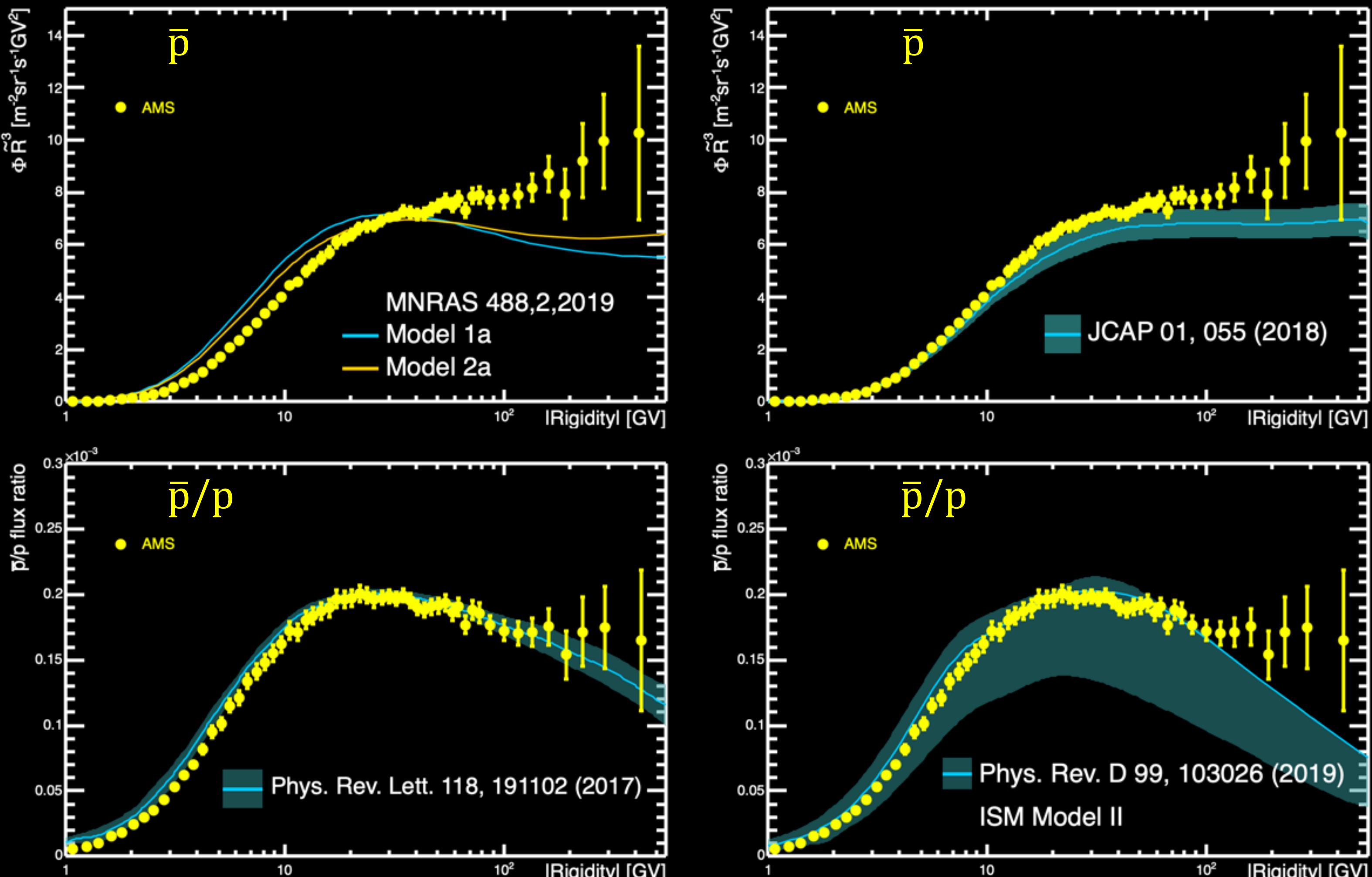
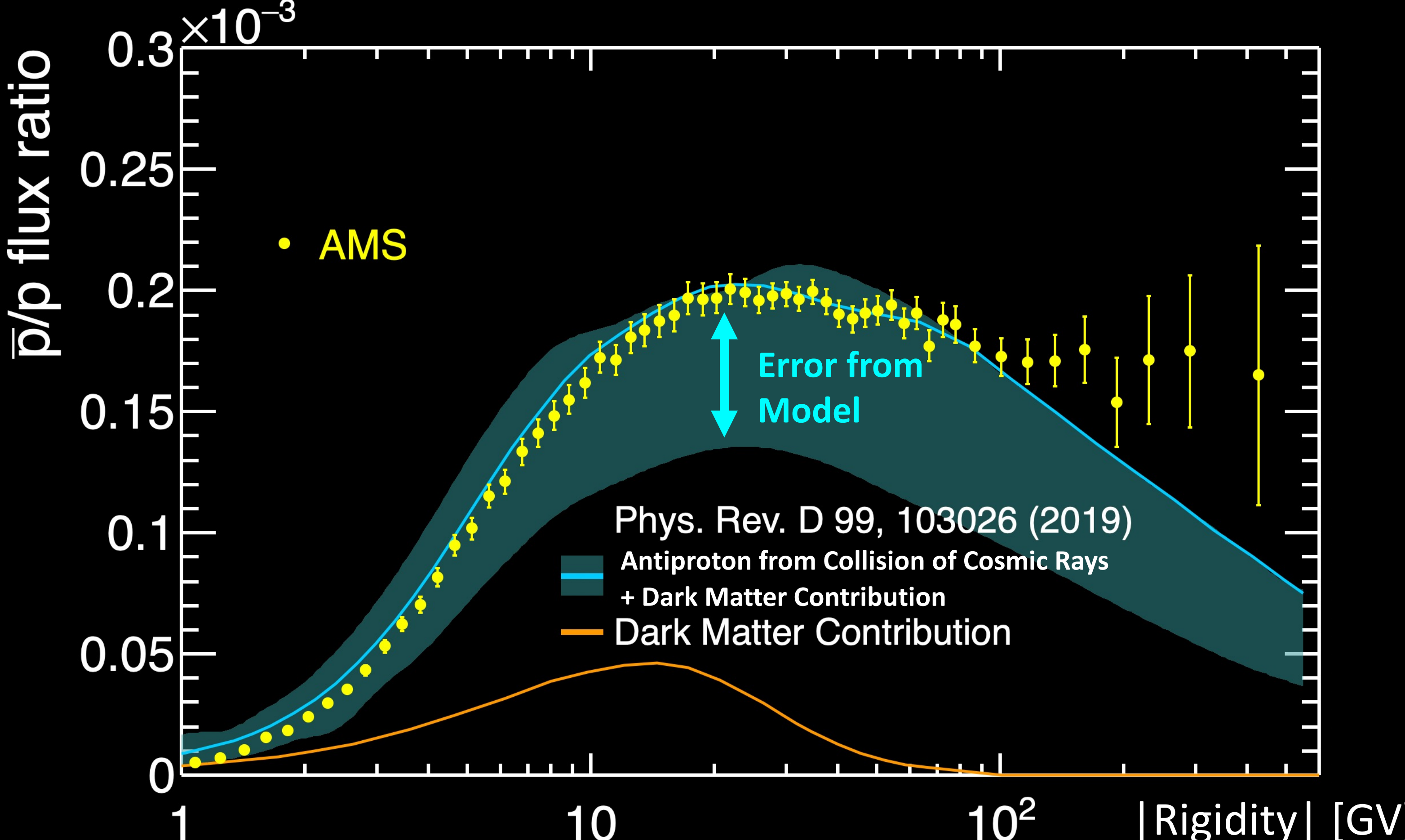
Example: AMS Antiproton Results compared with Models

Theoretical models include only collisions of cosmic rays.



Example: AMS Antiproton Results compared with Low Mass Dark Matter Model

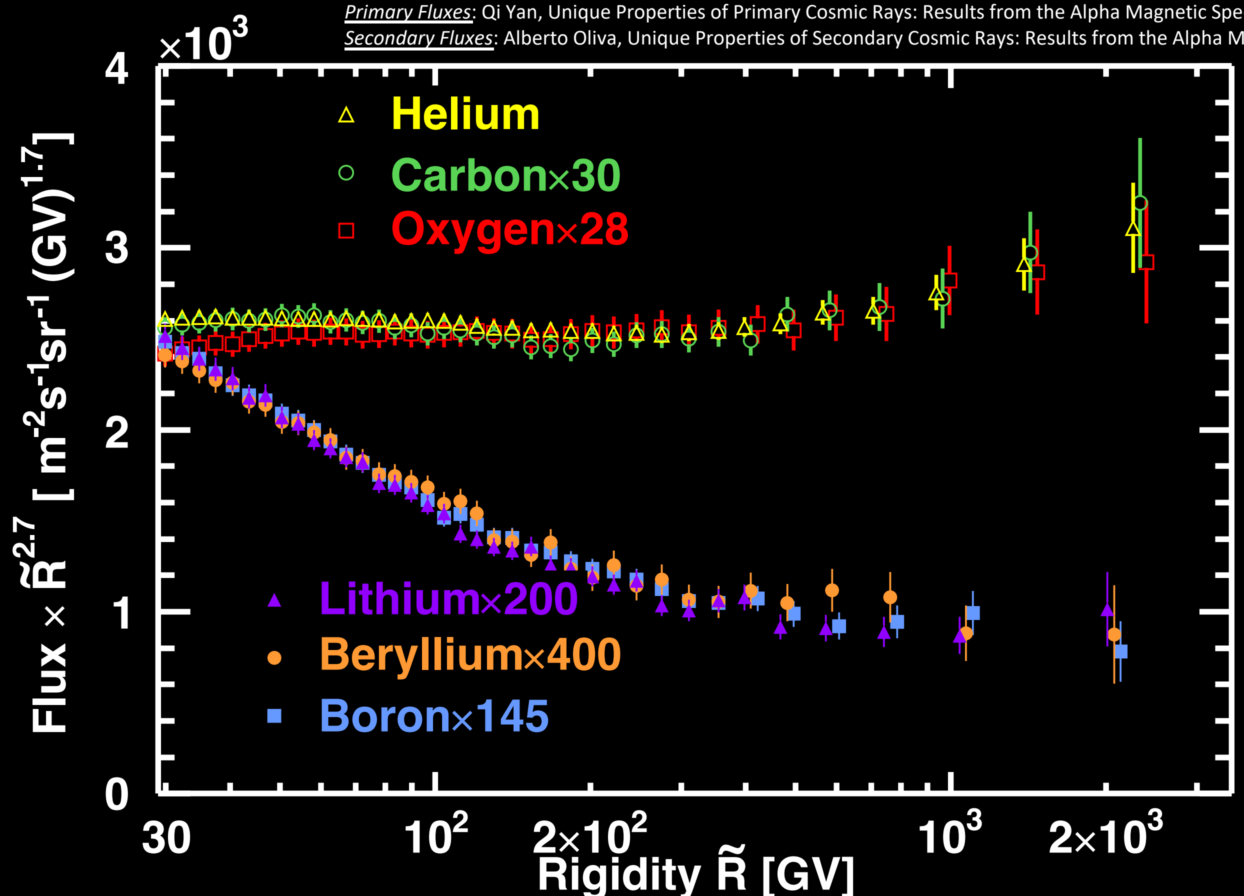


These uncertainties mainly come from understanding of solar modulation, cosmic-ray propagation, and antiproton production cross-sections.

Understanding Antiprotons with AMS Measurements

Precision AMS measurement of primary fluxes and secondary fluxes significantly improved the understanding of cosmic-ray propagation

Primary Fluxes: Qi Yan, Unique Properties of Primary Cosmic Rays: Results from the Alpha Magnetic Spectrometer
Secondary Fluxes: Alberto Oliva, Unique Properties of Secondary Cosmic Rays: Results from the Alpha Magnetic Spectrometer

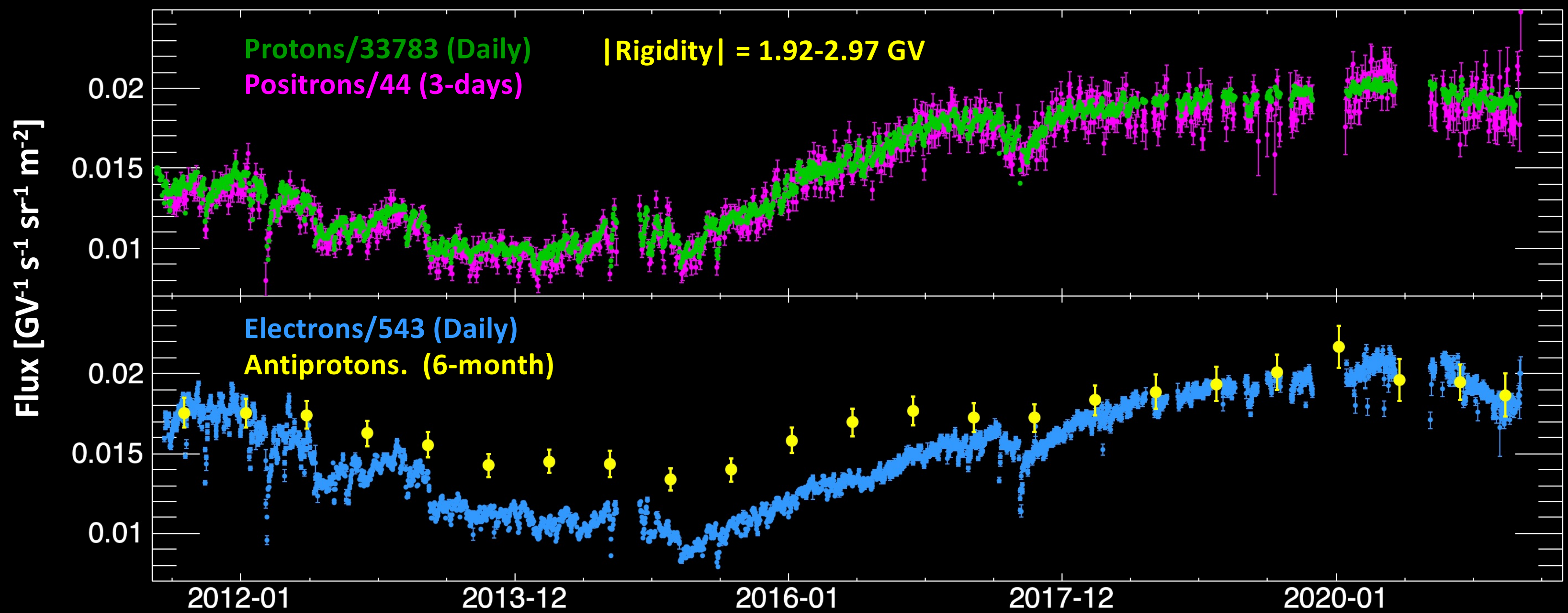


Understanding Antiprotons with AMS Measurements

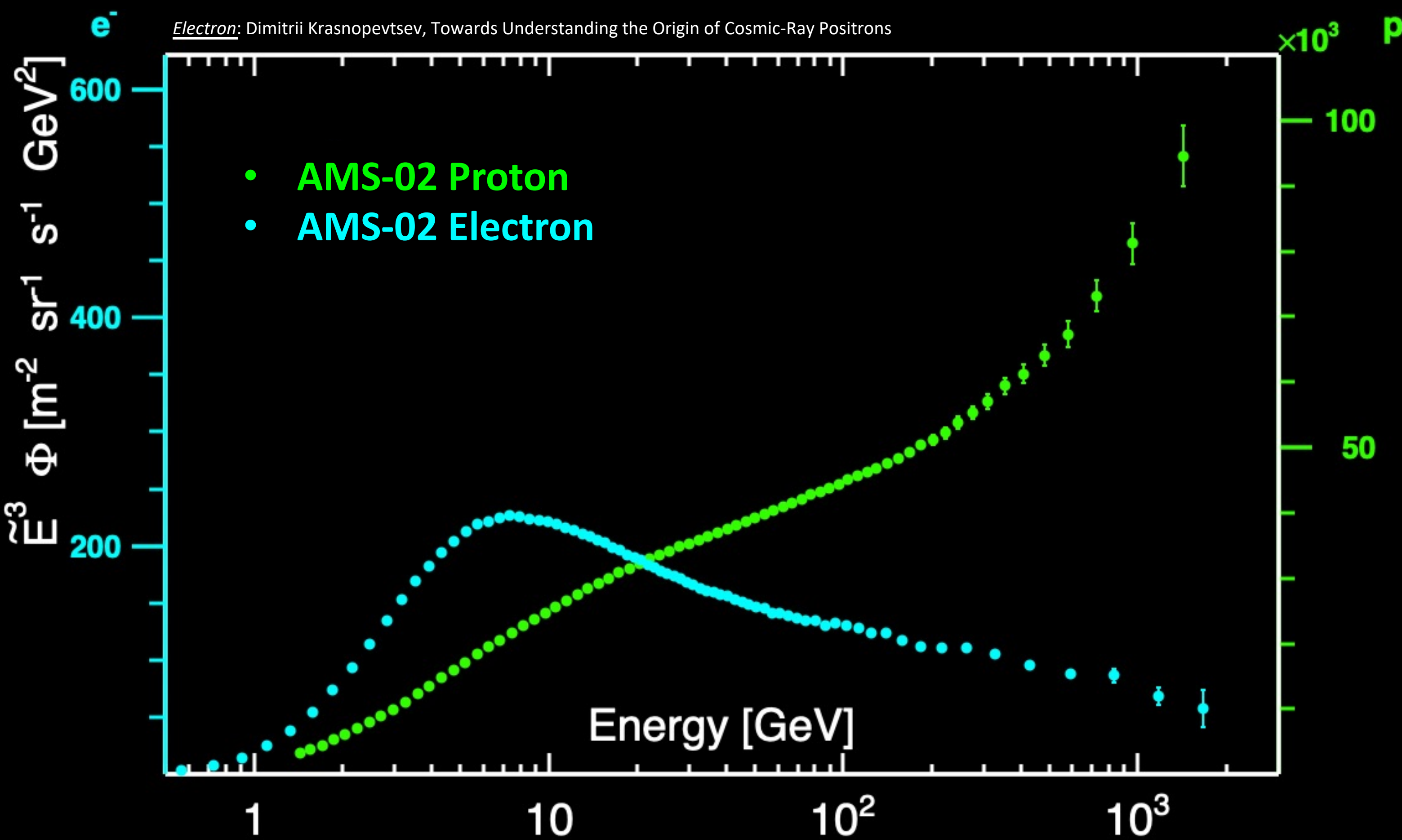
To study dark matter signal at lower rigidities, solar modulation effect needs to be understood.

AMS is the only instrument to measure antiproton and other cosmic ray flux across the entire solar cycle.

Proton: Cristina Consolandi, Unique Properties of Daily Proton Fluxes up to 100 GV
Positron&Electron: Carmen Gámez López, Precision Measurement of low energy positron fluxes by AMS



The Spectra of Electrons and Protons

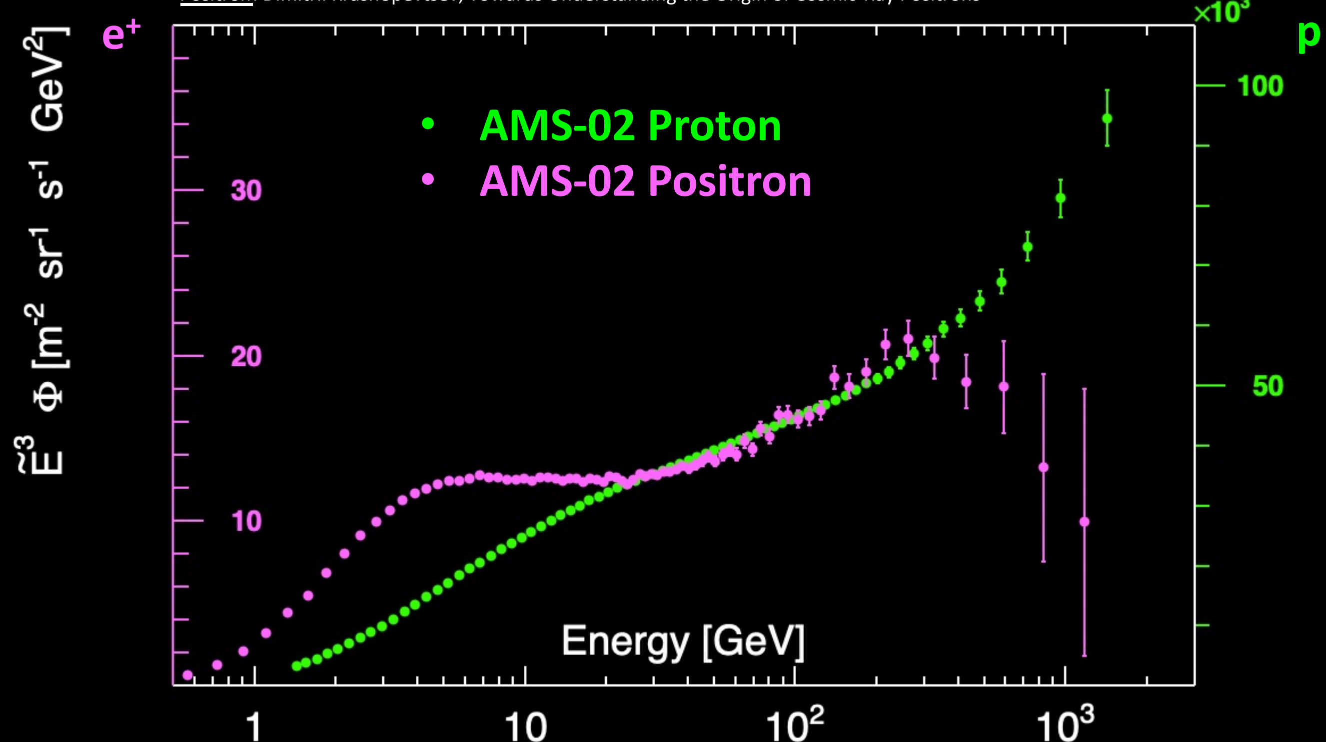


- **Starting from ~10 GeV, electrons spectrum is much softer compared to protons.**
- **Electrons lose energy much faster than proton during propagation**

The Spectra of Positrons and Protons

- **Protons and positron have a very different origin and propagation history:**
  - Secondary positrons: softer than proton due to diffusion and energy loss

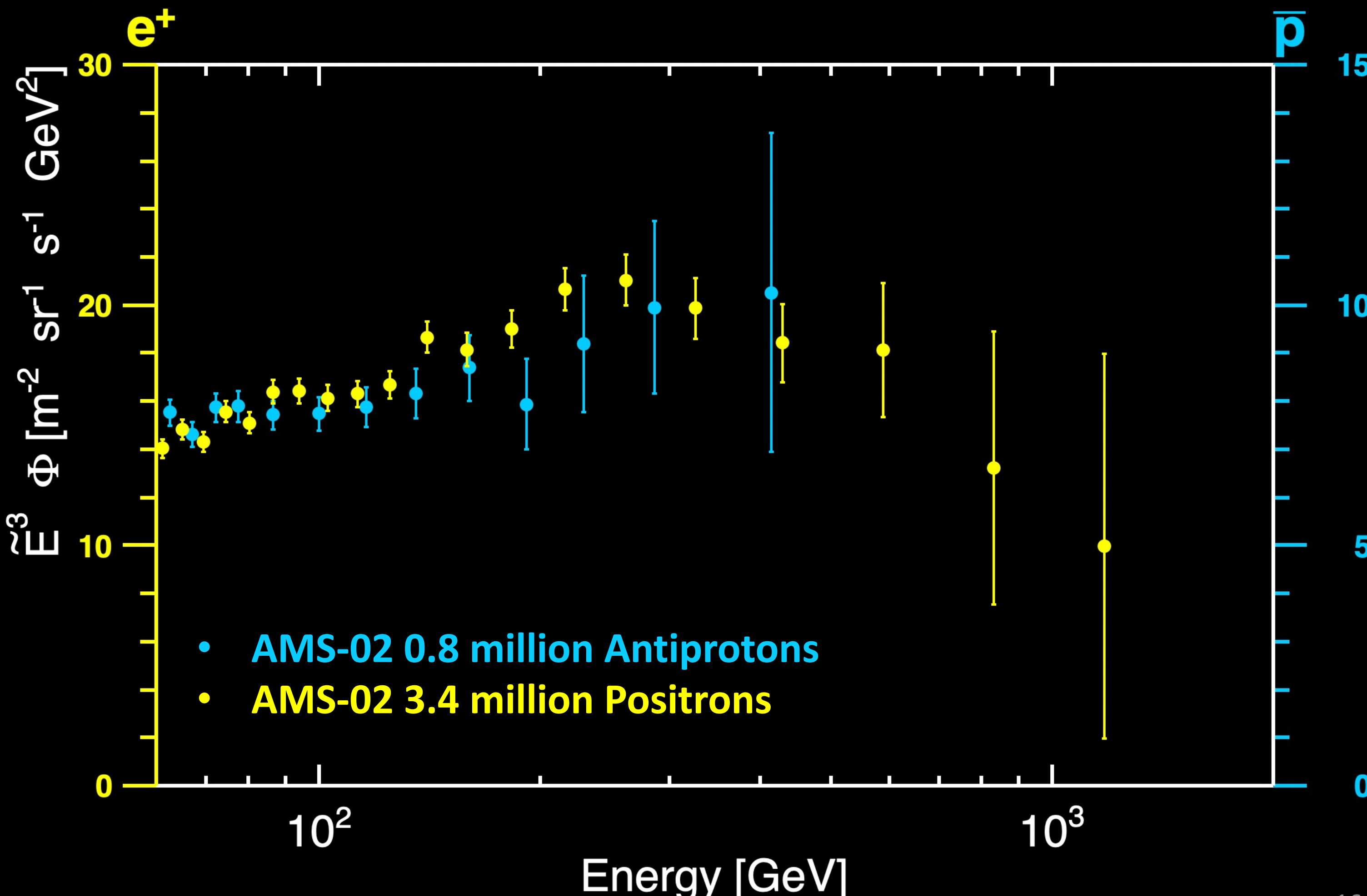
Positron: Dimitrii Krasnopevtsev, Towards Understanding the Origin of Cosmic-Ray Positrons



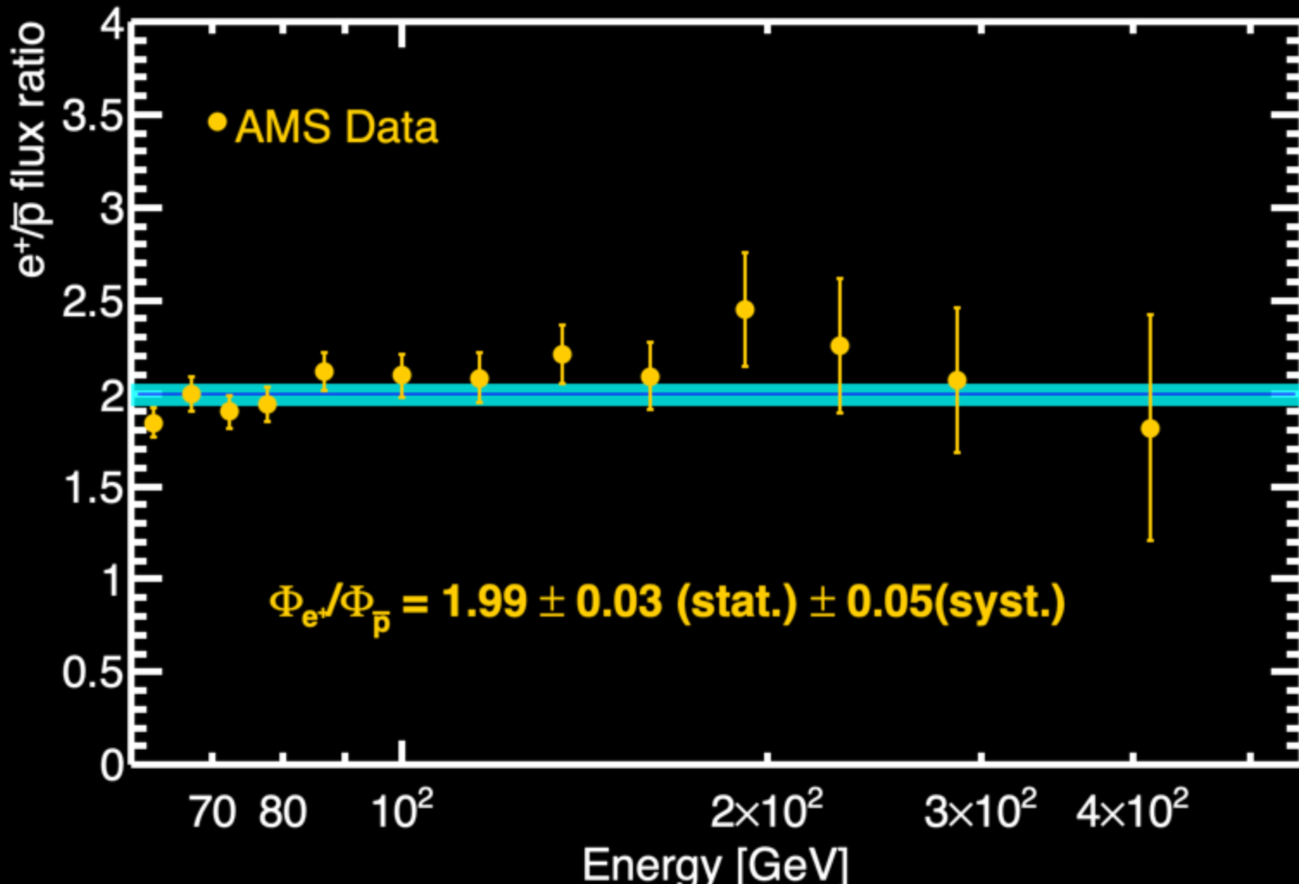
- **From ~60 GeV, Positron and Proton have very similar rigidity dependence.**
- **Starting from ~280 GeV, two flux start to show significant deviation: Positron flux shows a drop-off.**

Unique Observation from AMS:

Antiproton and positron have nearly identical energy dependence.

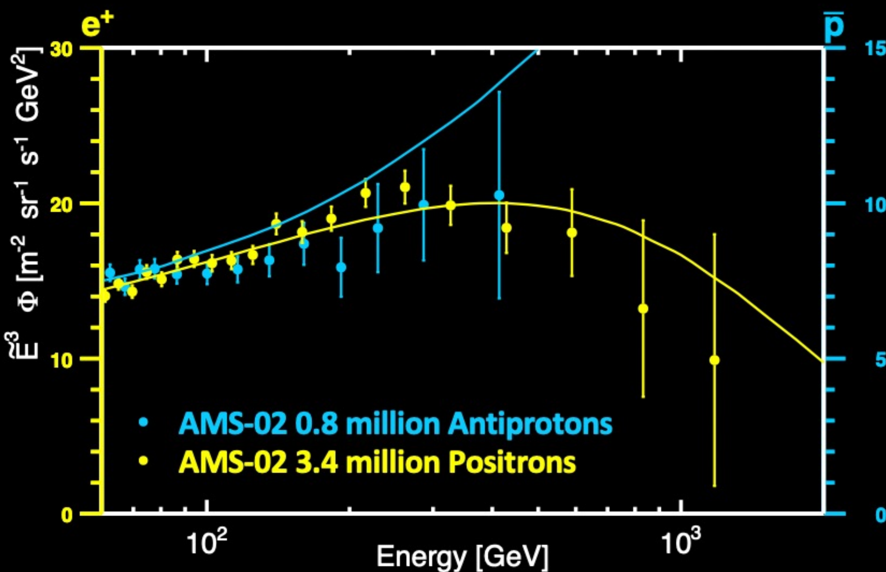


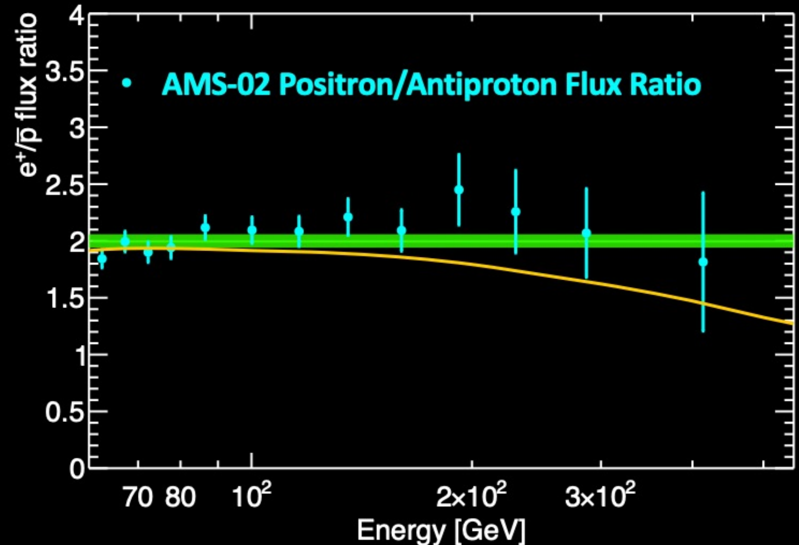
Unique Observation from AMS:
The positron-to-antiproton flux ratio is independent of energy.



High-energy antiprotons cannot come from pulsars.

Example: Positron and Antiproton spectra compared with recent models





Model Example:
P. Mertsch, A. Vittino, S. Sarkar, PRD 104 (2021) 103029
"Explaining cosmic ray antimatter with secondaries from old supernova remnants"

Conclusion

- AMS has measured the fluxes of all charged elementary particles ($p, \bar{p}, e^-, e^+$). Detail comparisons of different fluxes are performed:
    - Antiproton and proton flux have identical rigidity dependence up to 525 GV.
    - Positron/antiproton flux ratio is independence of energy above 60 GeV.
- The continuation of AMS data taking through the lifetime of ISS will provide an important confirmation of the origin of high-energy positrons and antiprotons.

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