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

2025 European Physical Society Conference on High Energy Physics

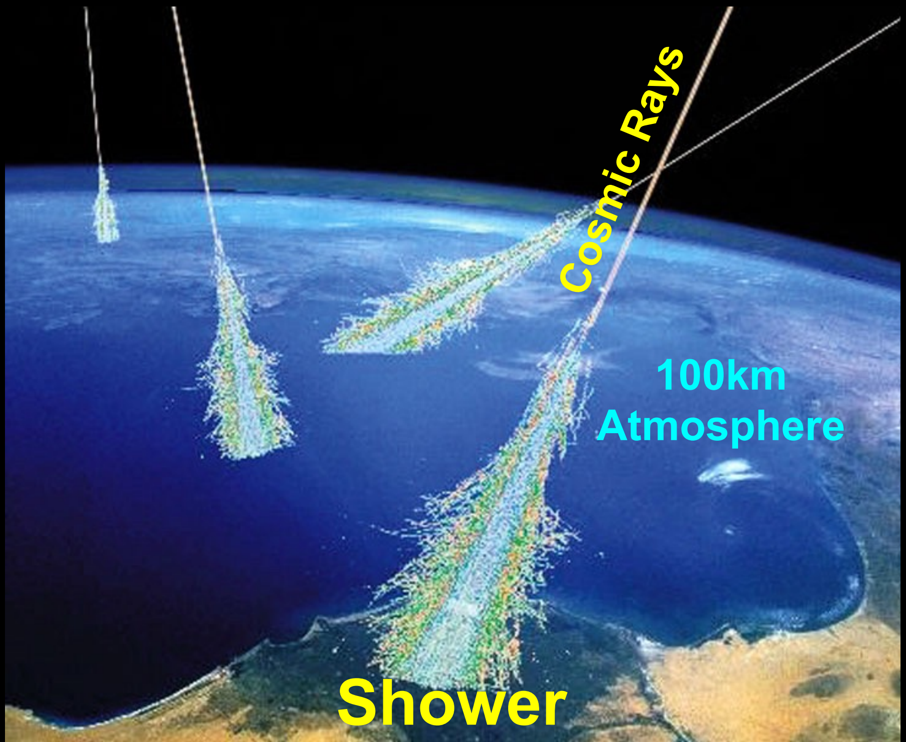
Hannah Anderson

AMS on the Space Station:

Provides precision, long-duration measurements of charged cosmic rays to study the Origin of the Cosmos, the physics of Dark Matter and Antimatter

Charged cosmic rays have mass.
They are absorbed by the
100 km of Earth's atmosphere
The properties ($\pm Z$, P) of charged cosmic rays cannot be studied on the ground.

To measure cosmic ray charge and momentum requires a magnetic spectrometer in space



Background

AMS Launch May 2011
Space Shuttle Endeavour
Mission STS-134

AMS installed on the ISS
Near Earth Orbit:
altitude 400 Km
inclination 52°
period 92 min

To-date >250 billion cosmic rays have been measured by AMS: e^+, e^-, p, $\bar{p}$, nuclei, γ,…

400 billion events expected to 2030

Background

AMS is a NASA-DOE sponsored international collaboration

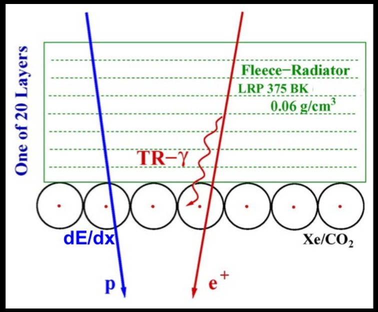
It was constructed in Europe and Asia,
assembled and tested at CERN and ESA with NASA support

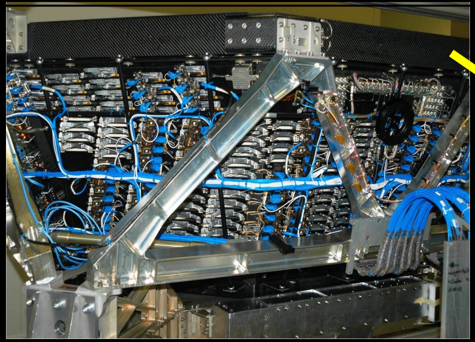
5m x 4m x 3m
7.5 tons
300,000 signals

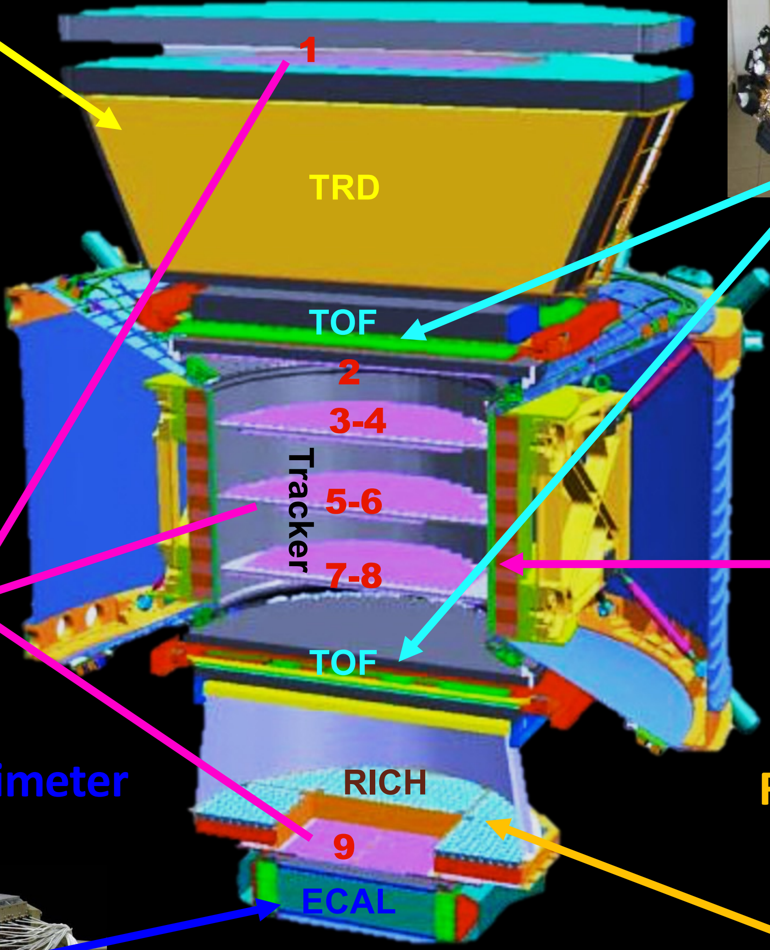
Endeavour approaching the Space Station, May 18, 2011

AMS-02: A TeV precision magnetic spectrometer in space

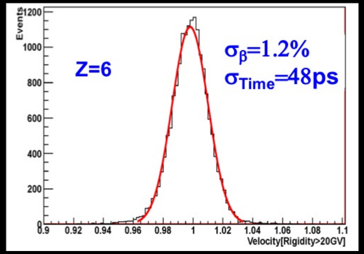
Transition Radiation Detector
Identifies e^+, e^-



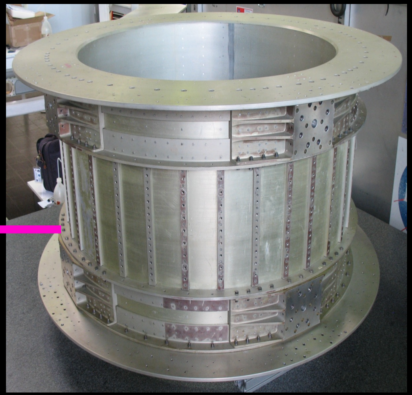


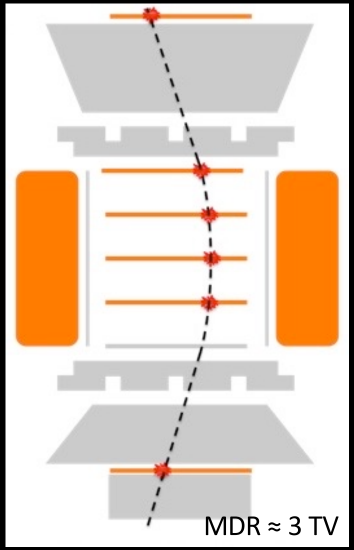


Time Of Flight
Z, β

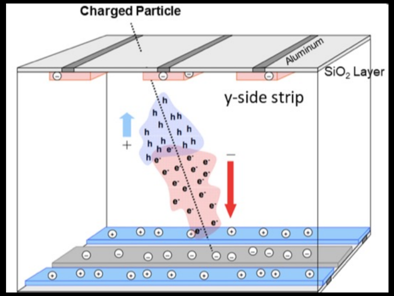


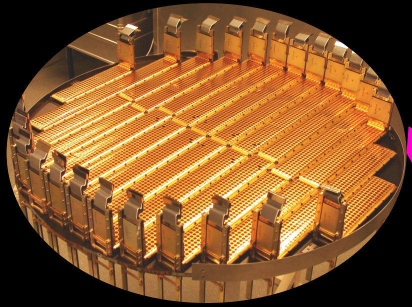
Magnet
±Z



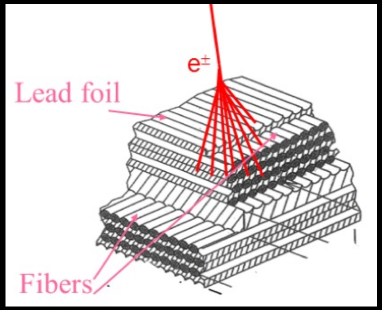


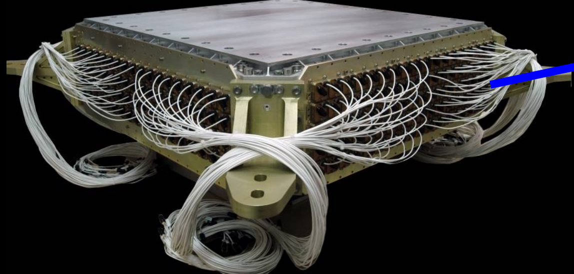
Silicon Tracker
Z, Rigidity=p/Ze





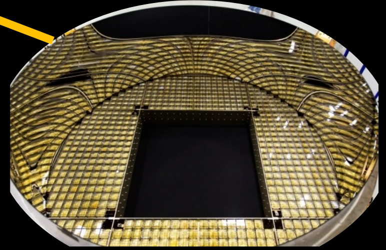
Electromagnetic Calorimeter
Energy of e^+, e^-

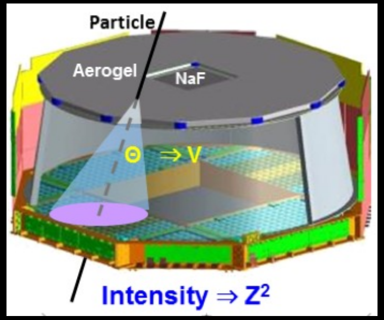




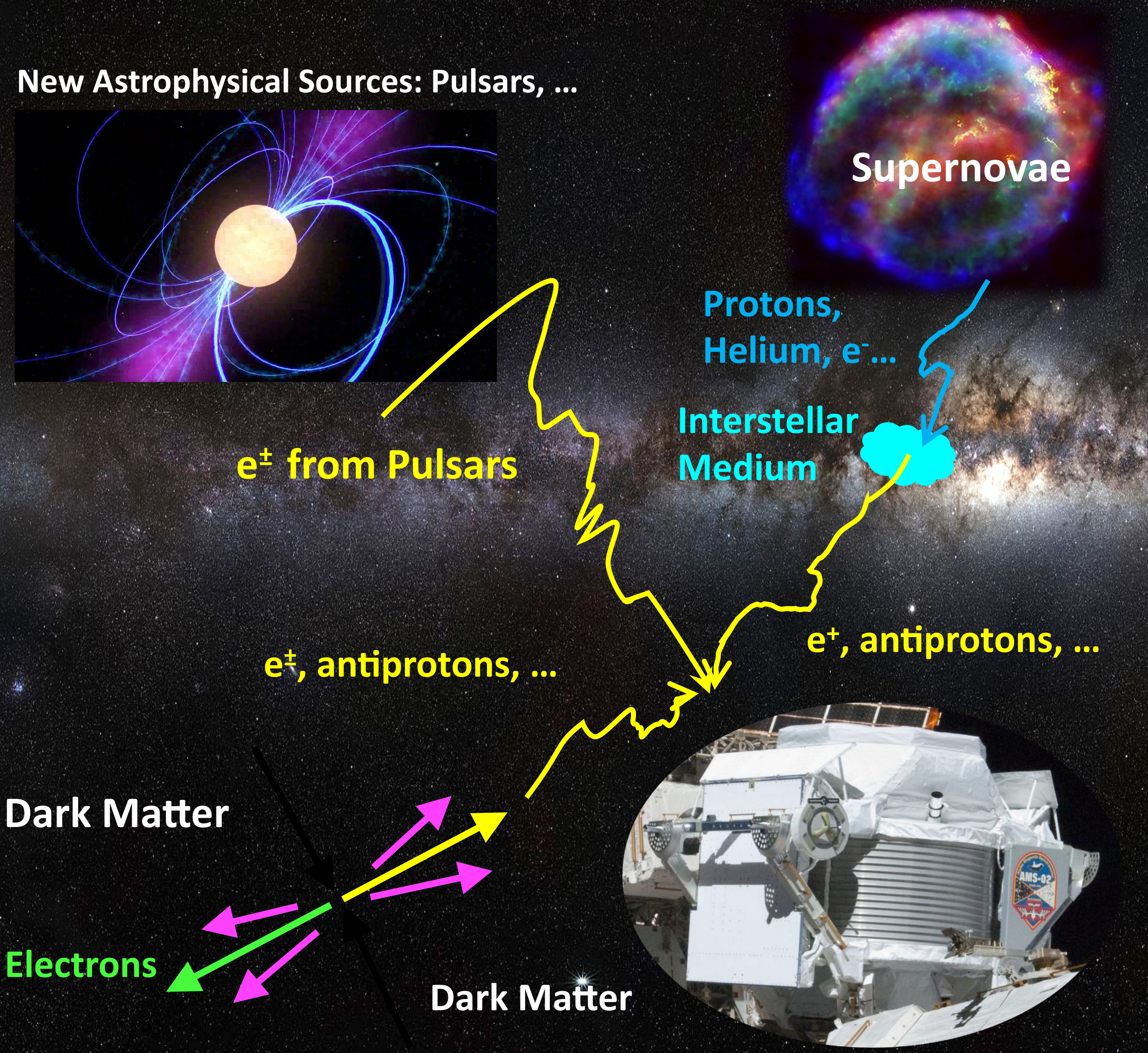
Ring Imaging Cherenkov
Z, β

Isotopic composition





Elementary Particles in Cosmic Rays



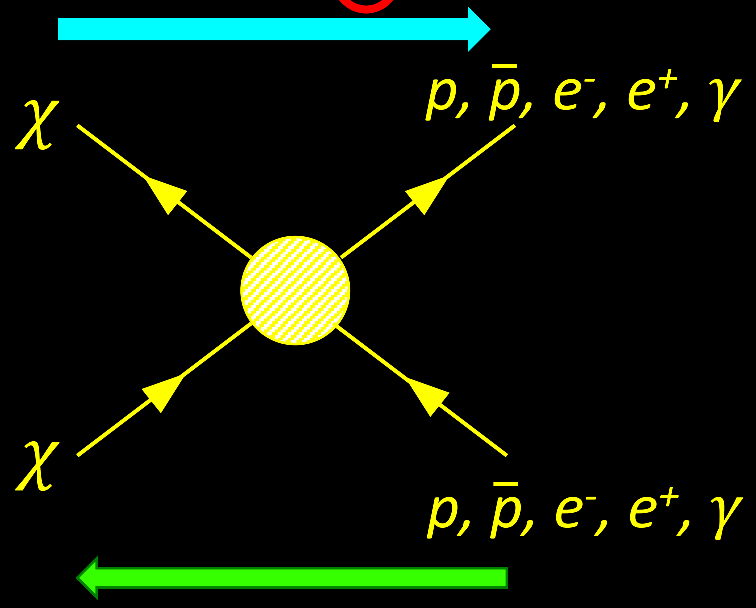
For positron and electron results, see D. Krasnopevtsev's talk

Search for Dark Matter χ through Cosmic Rays

AMS

Annihilation in space

$\chi + \chi \rightarrow e^+, \bar{p}, \bar{D}, \gamma, \ldots$



XENON
DARKSIDE
DAMA/LIBRA
LUX
CDMS II
PandaX
…

Scattering underground

$\chi + N \rightarrow \chi + N$

$\ldots + \chi + \chi \leftarrow p + p$

Production in accelerators

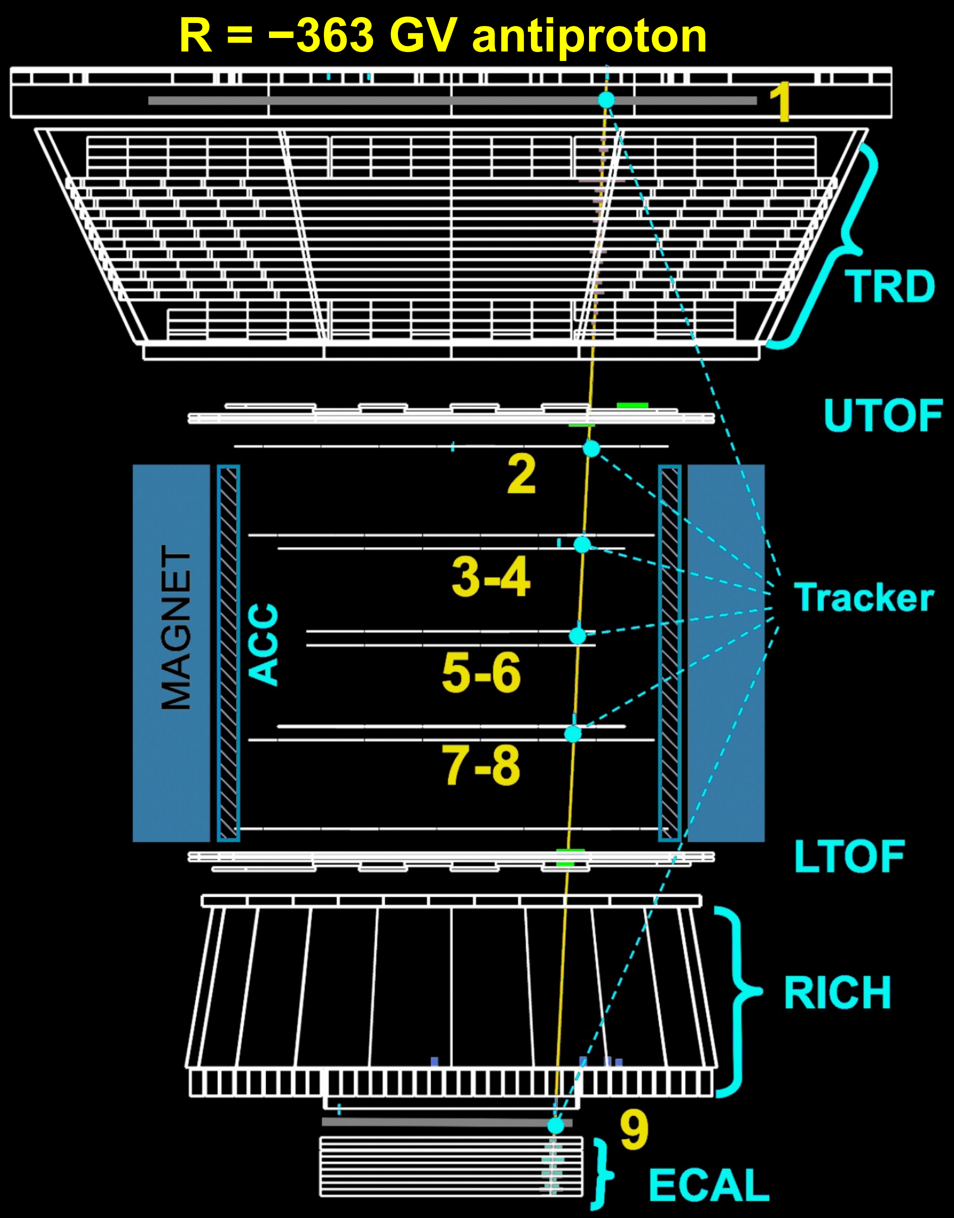
LHC CERN

Antiproton Measurements with AMS

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

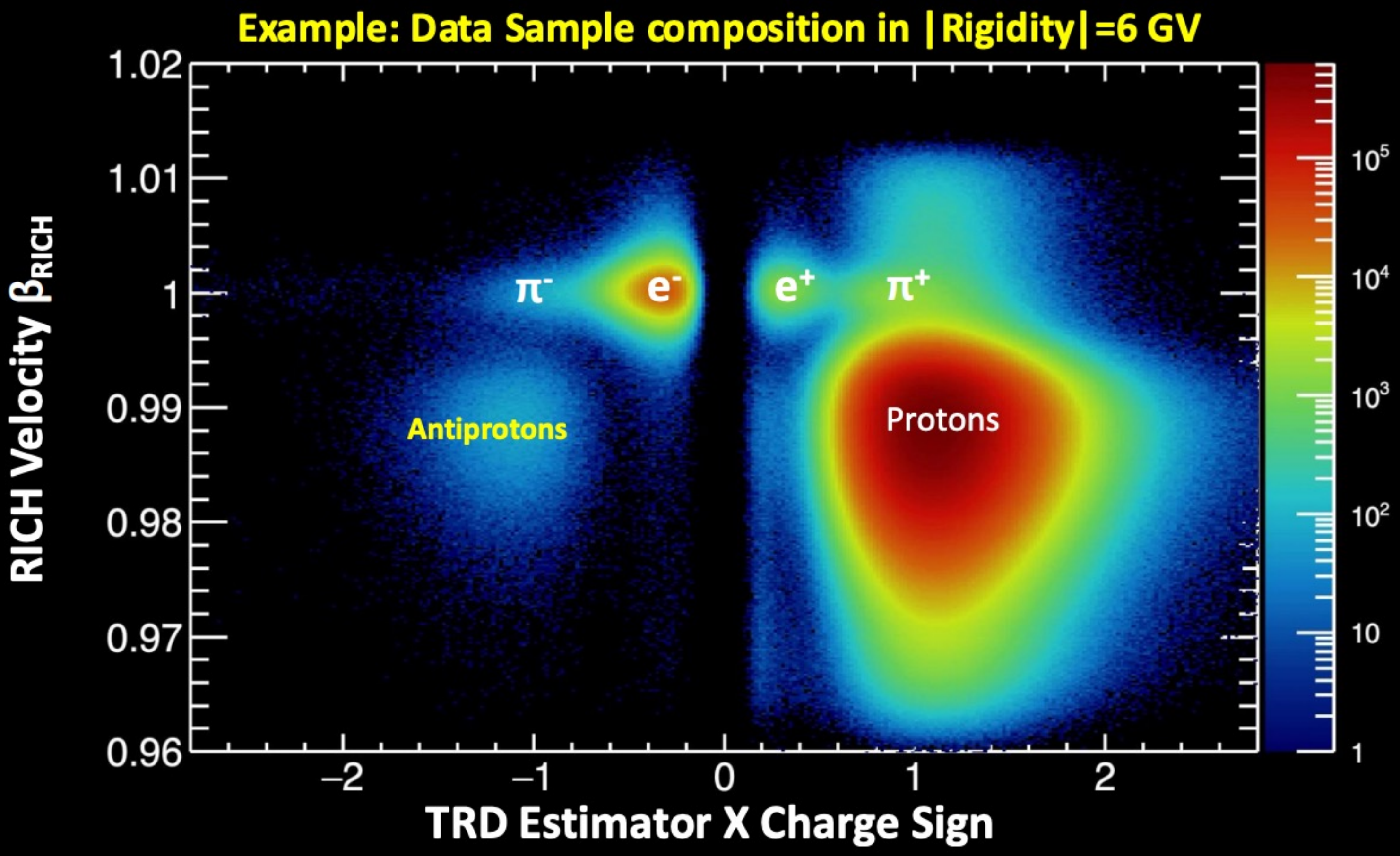
A percent precision experiment requires background rejection close to 1 in a million

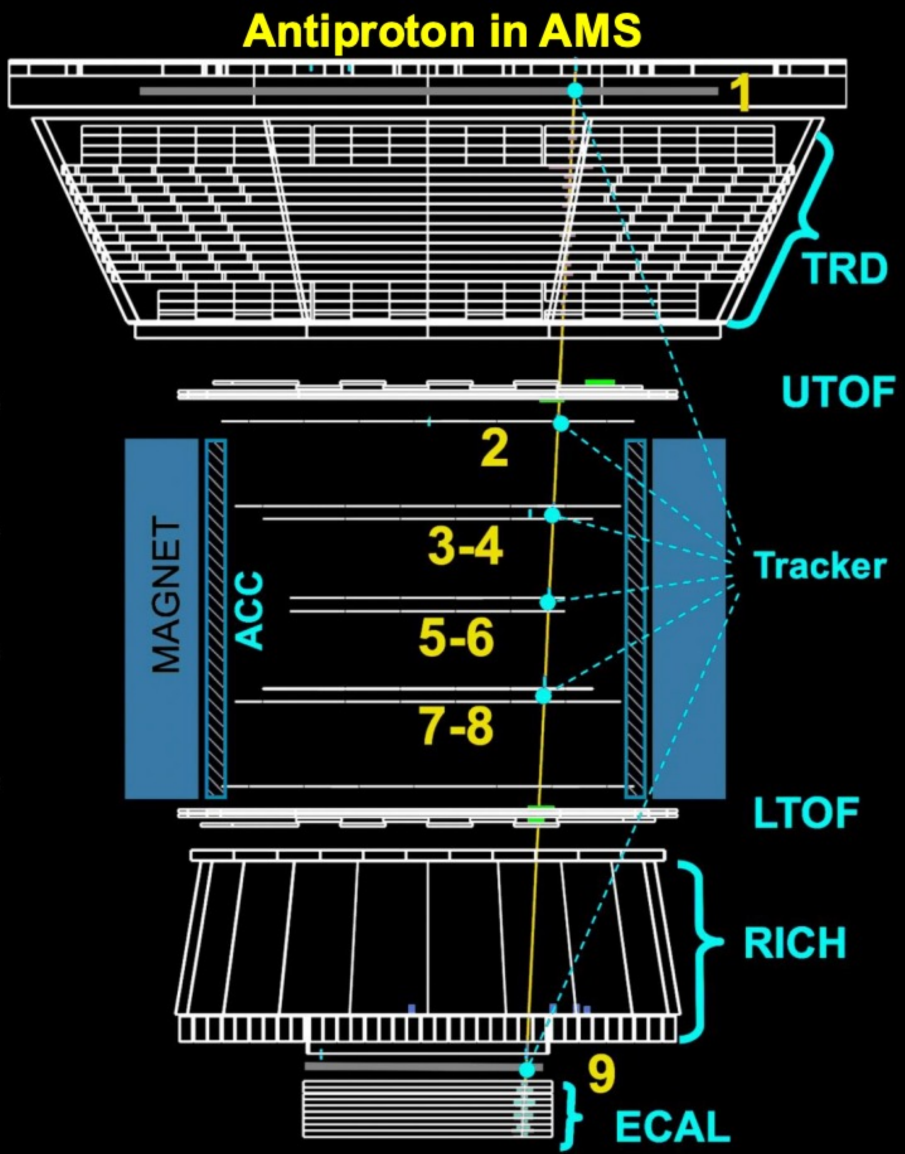
- Tracker & Magnet: measure rigidity, separate antiprotons from protons
- TRD & ECAL: reject electron background
- TOF & RICH: select down going particle and measure velocity



Example of Antiproton Analysis

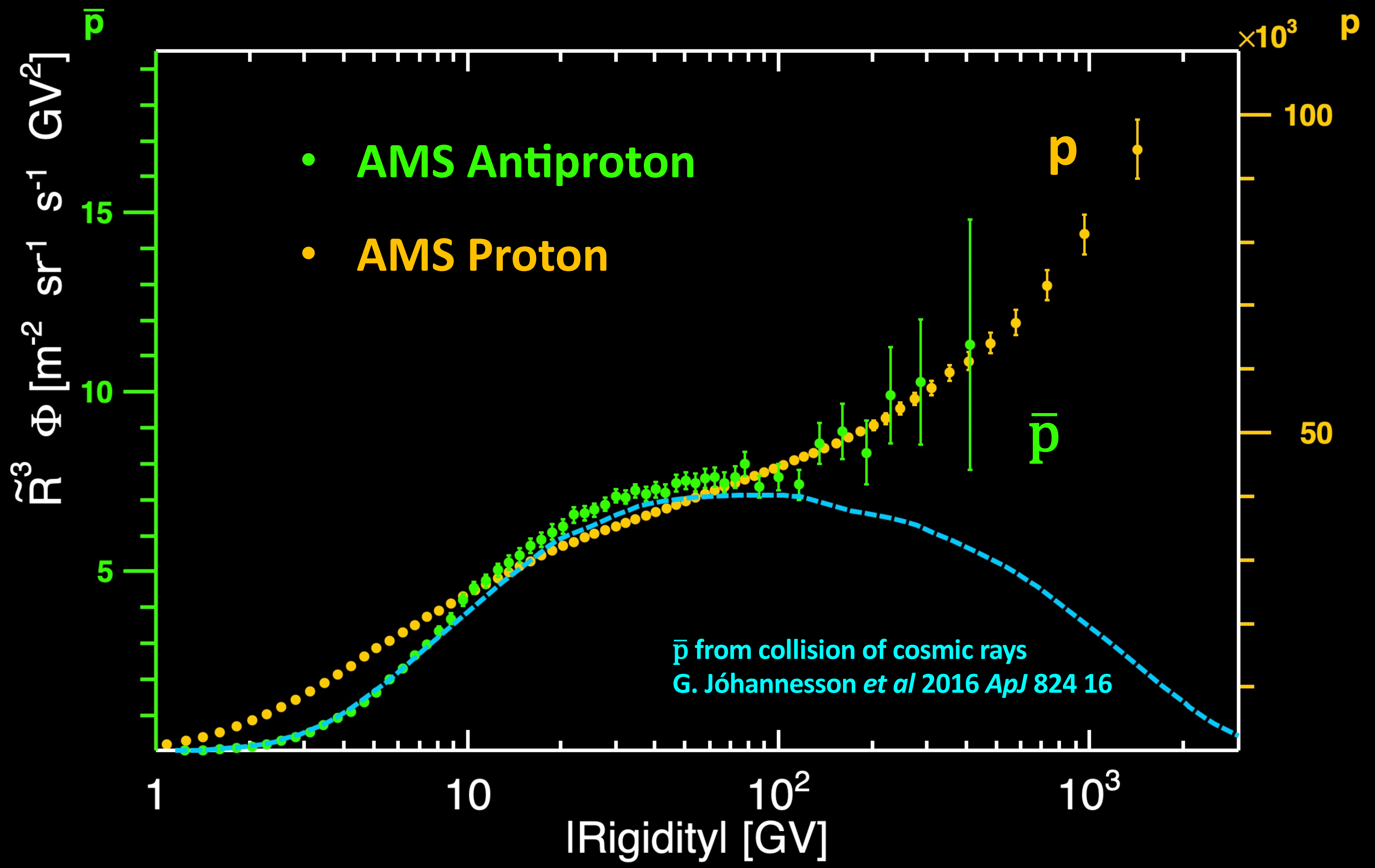
- Use Tracker, TOF, RICH, and TRD to identify antiprotons



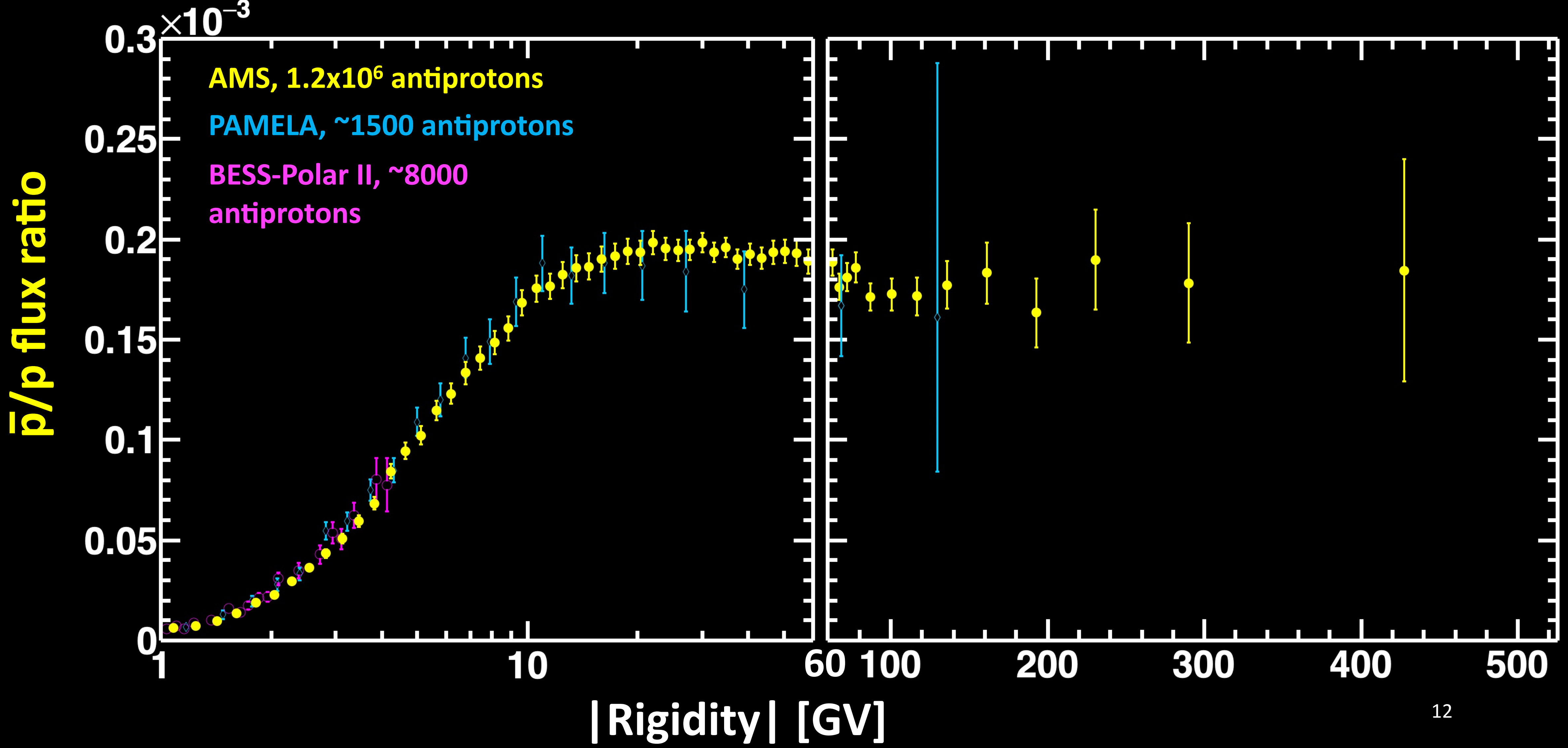


New Results on Cosmic Antiprotons

Does not agree with traditional cosmic ray model with only secondary $\bar{p}$ produced from collision of cosmic rays



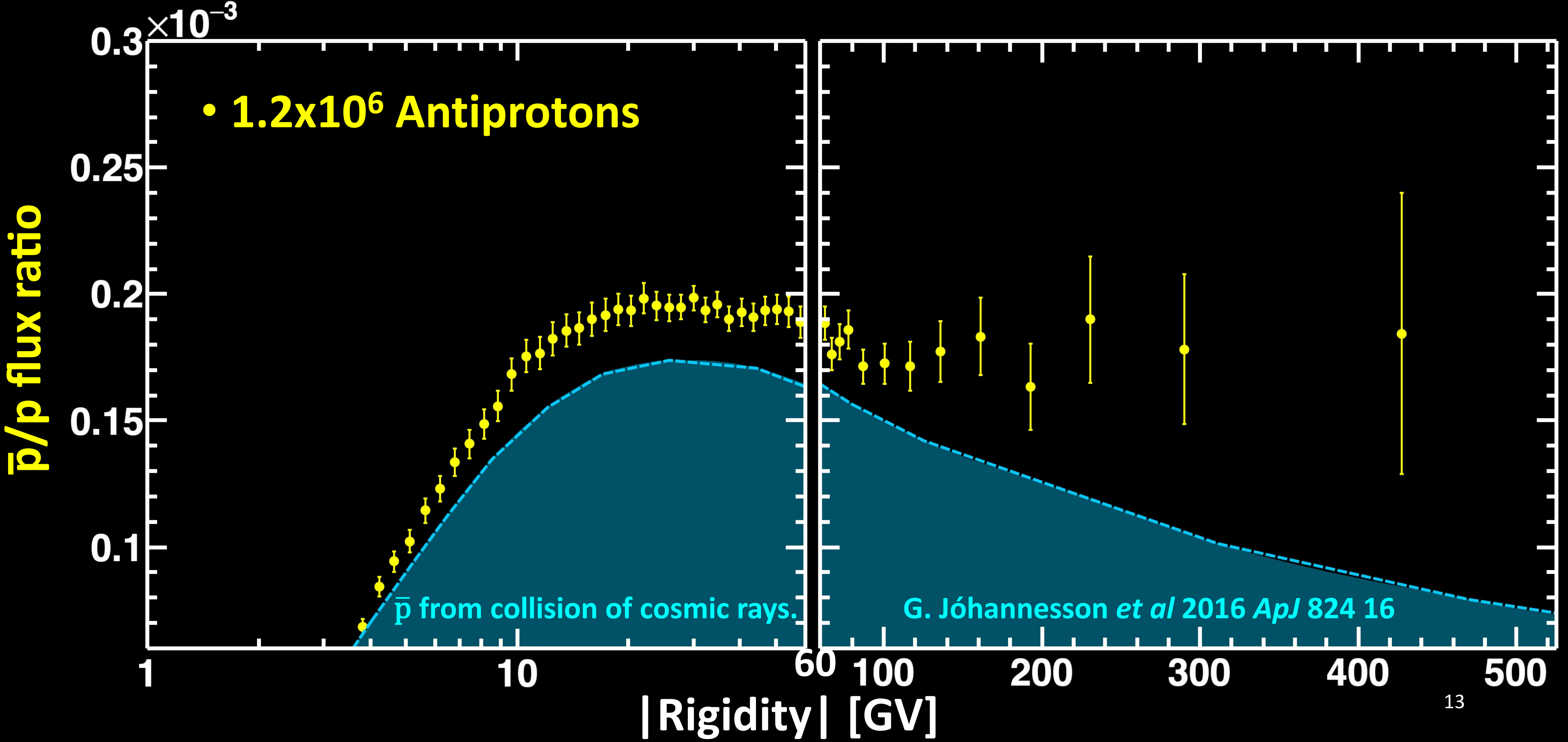
Precision study of the Properties of Cosmic Antiproton Flux



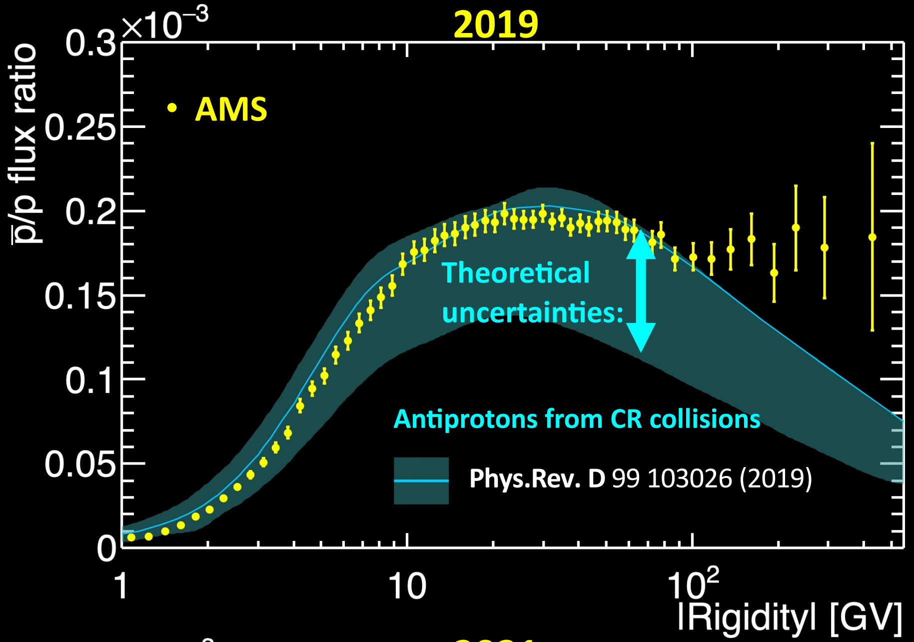
Model Example: Antiprotons from Cosmic Ray Collisions

The antiproton-to-proton flux ratio shows that above 60 GV the ratio is energy independent.

Not consistent with only secondary production of antiprotons



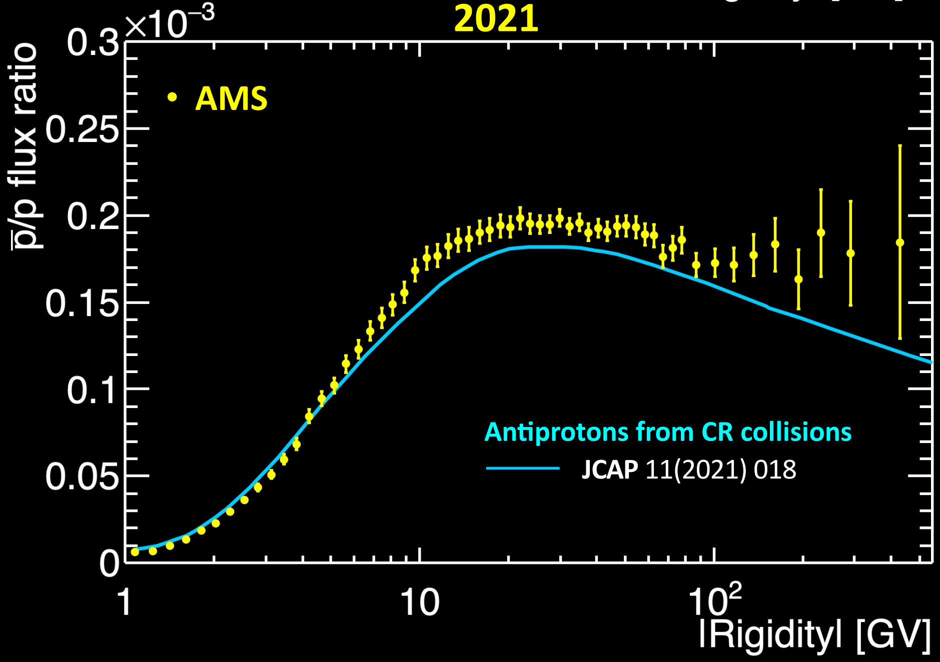
Model Examples: Antiprotons from Cosmic-Ray Collisions

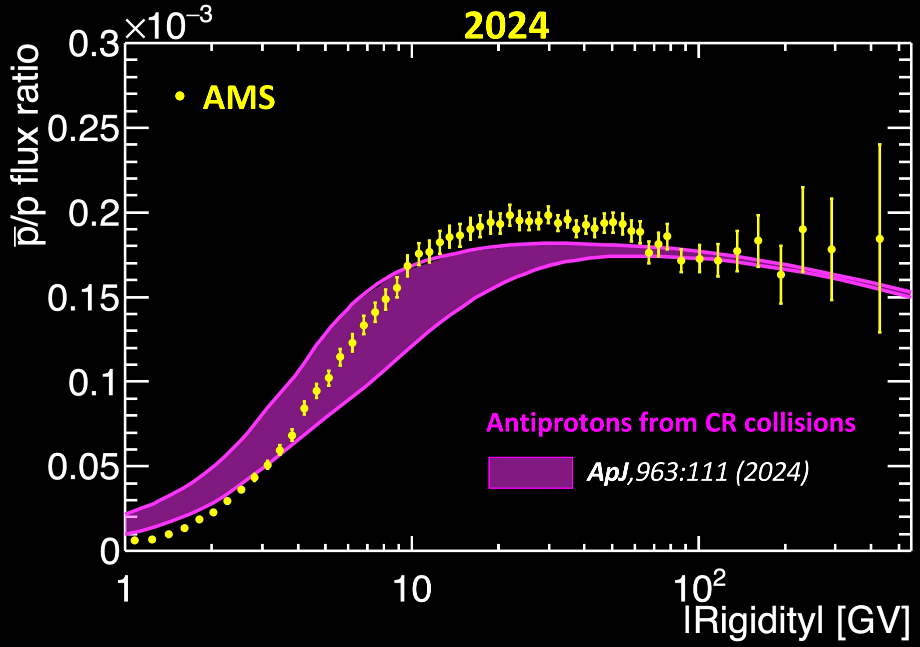


Theoretical uncertainties in Cosmic-Ray Collision Models:

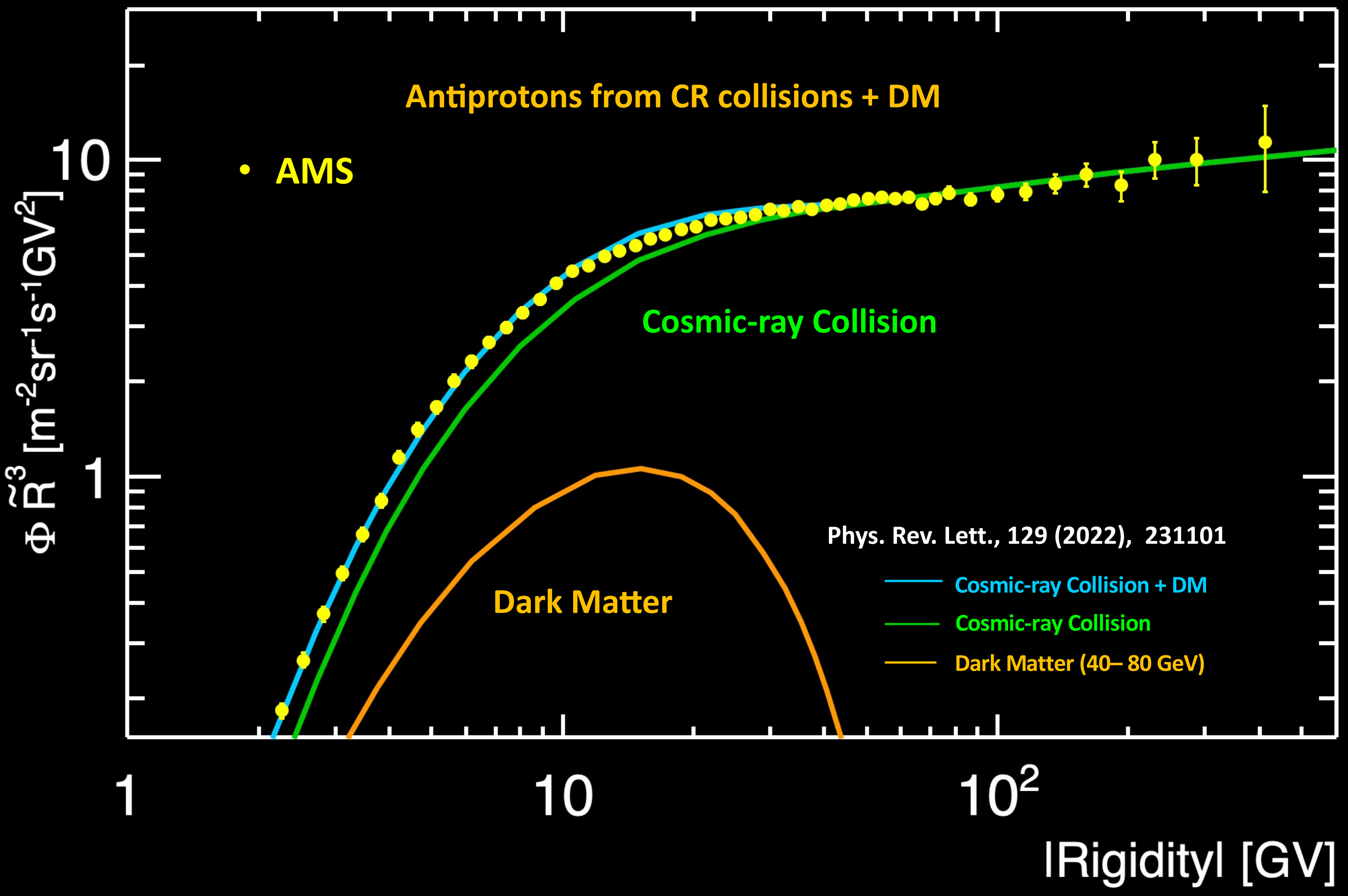
- Cosmic ray acceleration and propagation
- Particle transportation in the heliosphere
- Antiproton production cross-section

No models agree with AMS data





Model Example: Antiprotons from Cosmic-Ray Collisions and Dark Matter

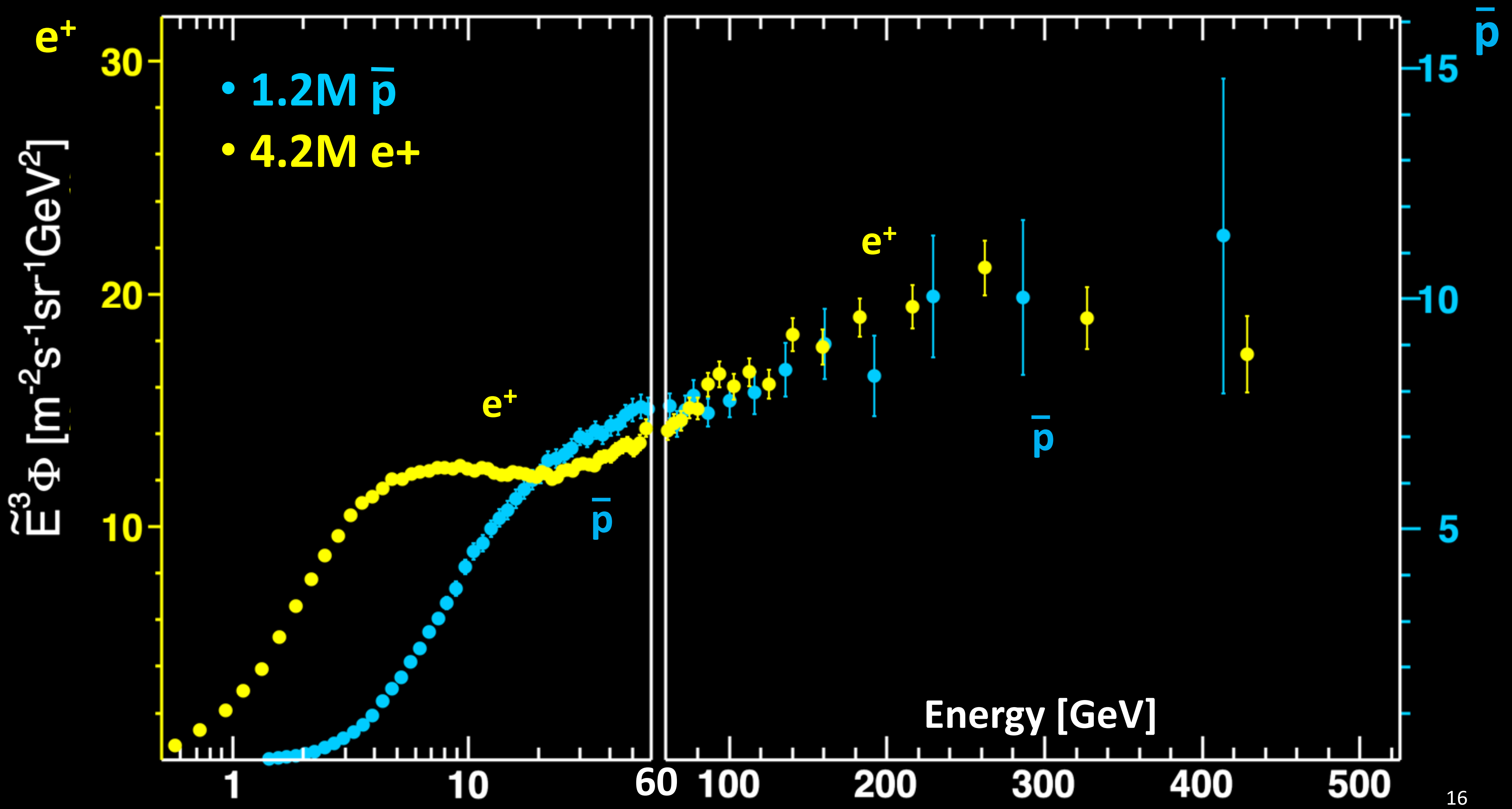


The accuracy of the models need to be improved with AMS Data

Antiprotons and Positrons

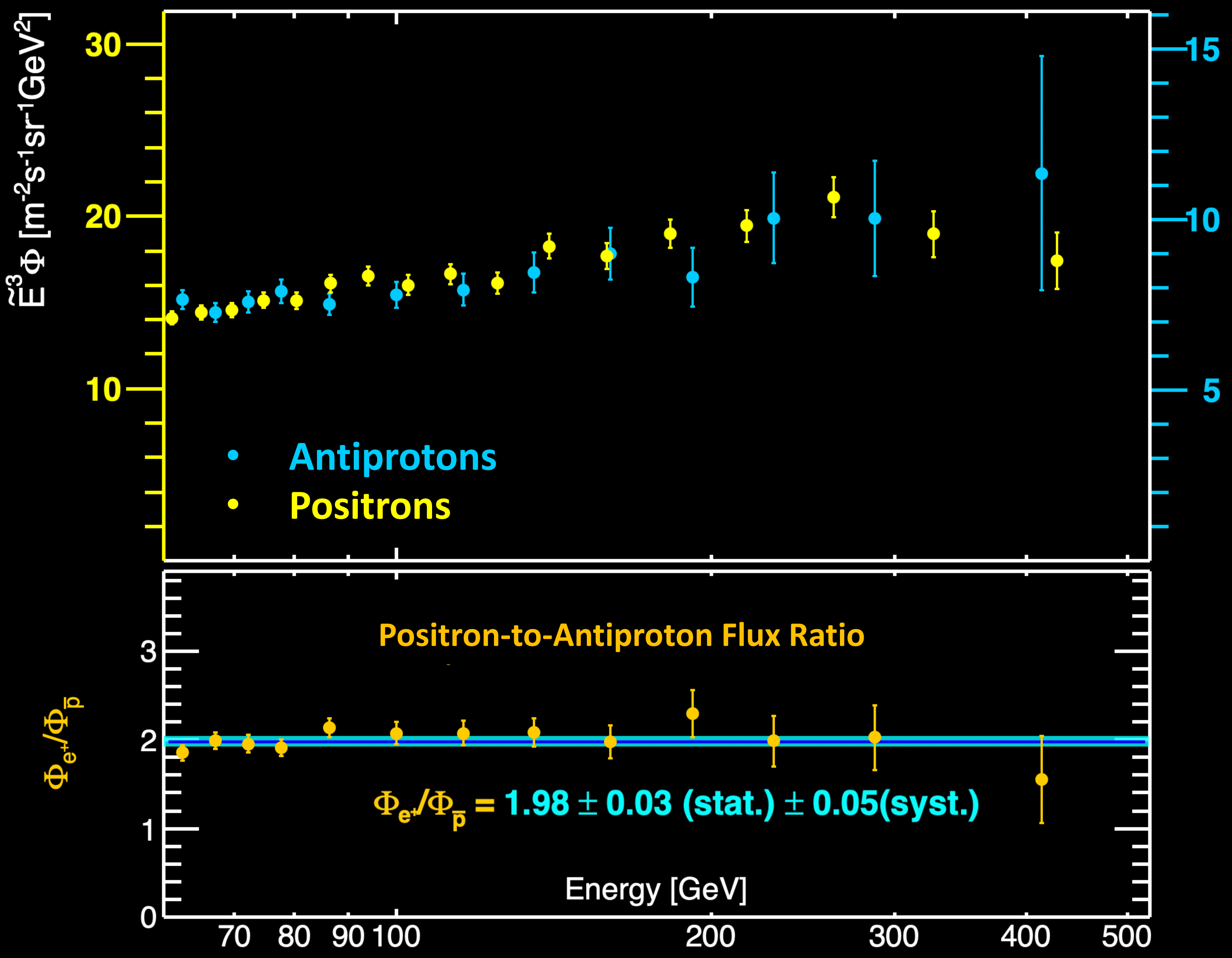
The $\bar{p}$ and e^+ fluxes have identical rigidity dependence.

See D. Krasnopevtsev for updated positron data



Unique Observation from AMS:

The antiproton and positron fluxes have identical rigidity dependence

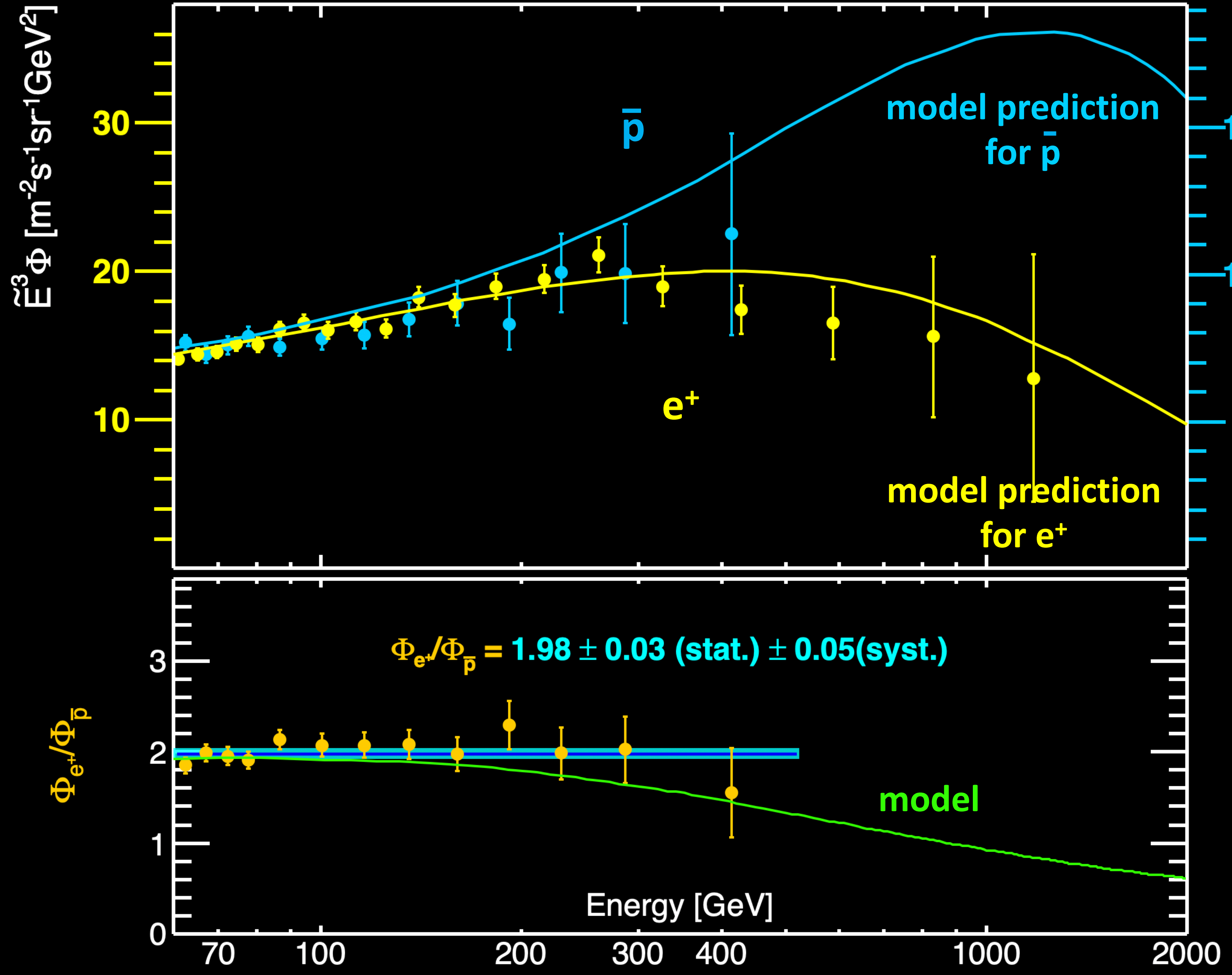


The identical behavior of positrons and antiprotons points toward a common source which disfavours the pulsar origin of positrons

Model Example: Positron and Antiproton spectra from Supernova Remnants

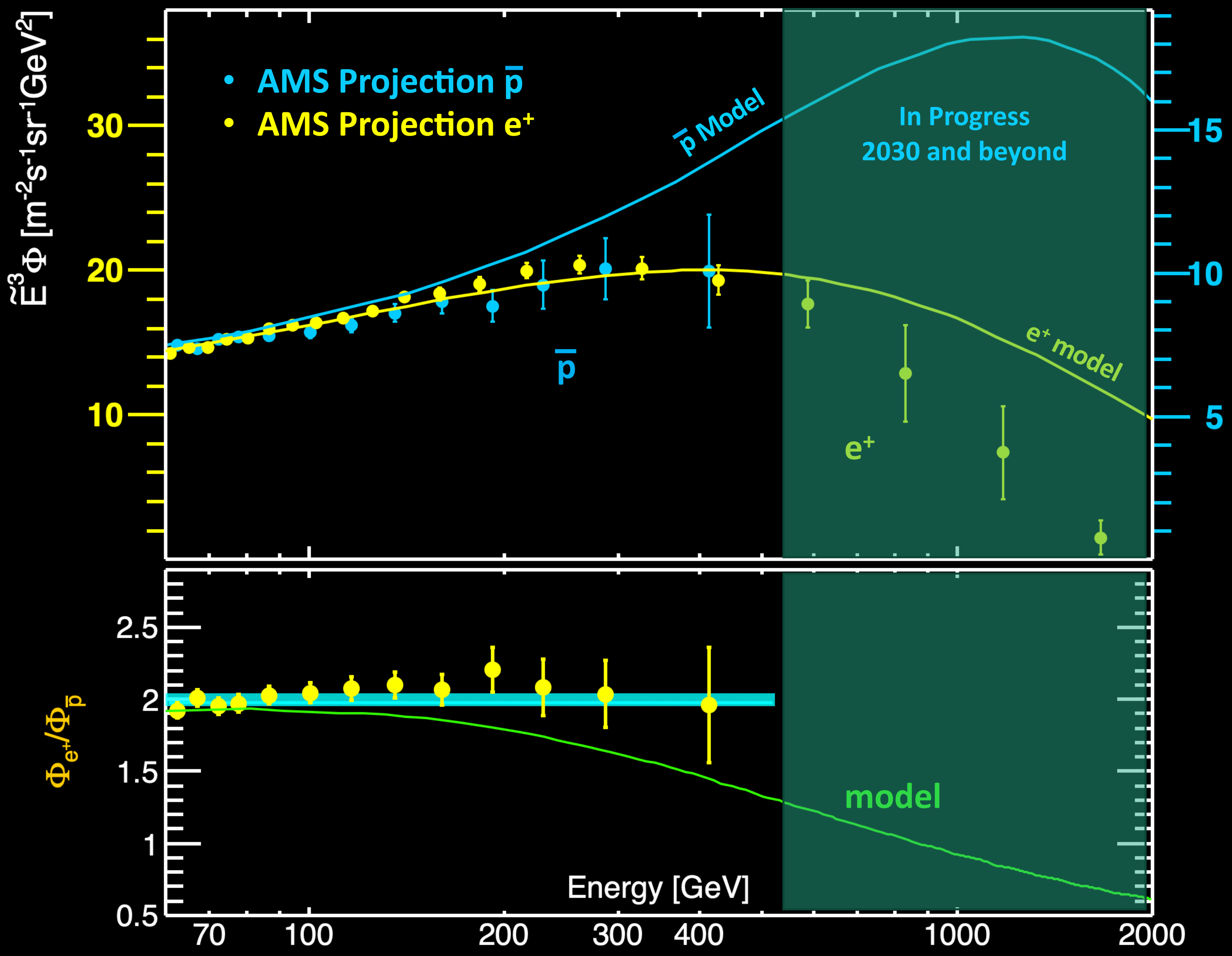
Model Example: P. Mertsch, A. Vittino, S. Sarkar, PRD 104 (2021) 103029

"Explaining cosmic ray antimatter with secondaries from old supernova remnants"



Model describes both positron and antiproton production from supernova remnants

Future Measurement of Antiprotons and Positrons

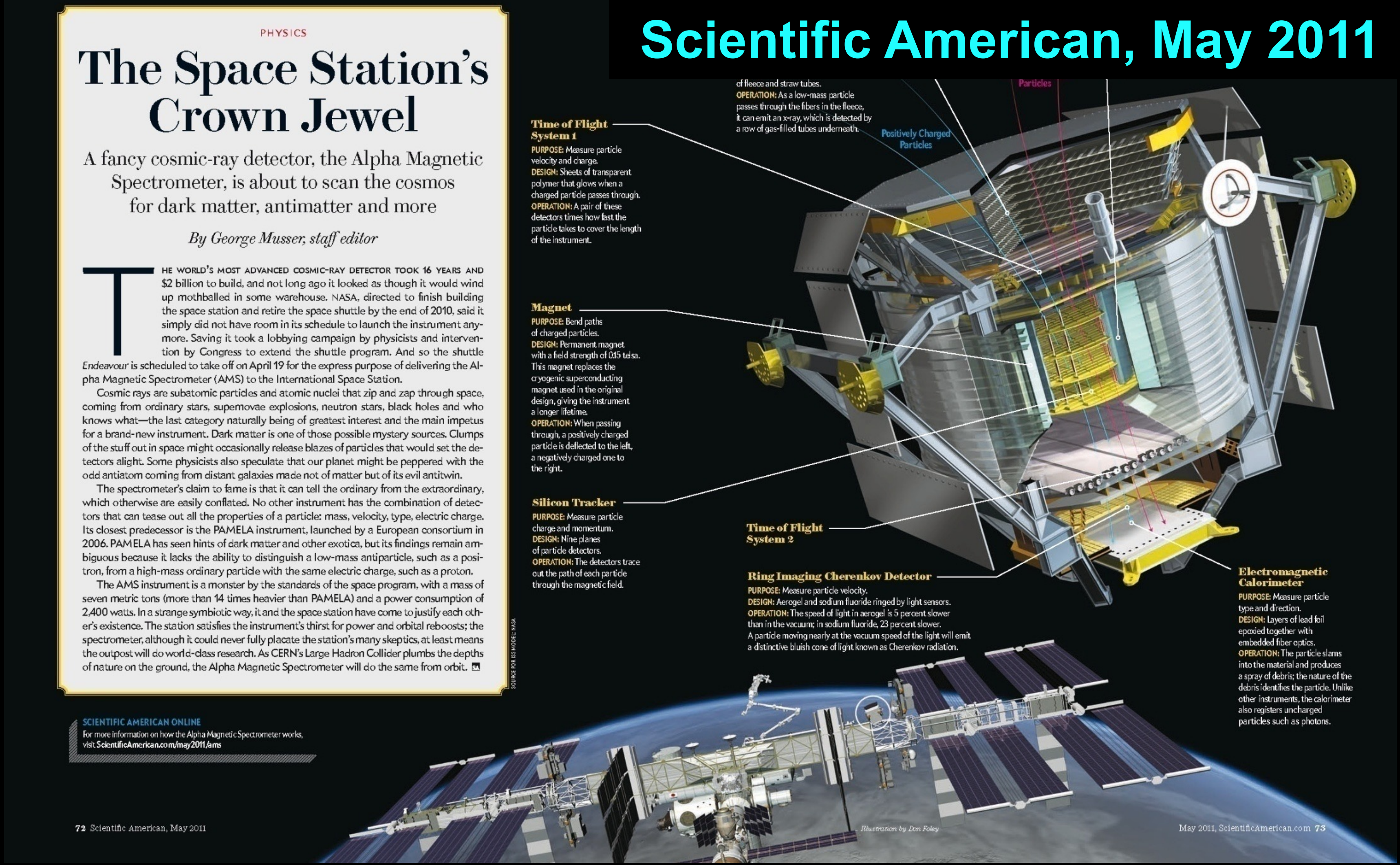


Model Example: P. Mertsch, A. Vittino, S. Sarkar, PRD 104 (2021) 103029
"Explaining cosmic ray antimatter with secondaries from old supernova remnants"

By simultaneous measurement of cosmic protons, electrons, positrons, and antiprotons through the lifetime of the space station,

AMS provides the definitive dataset to resolve the mystery of the origin of antimatter in cosmic rays.

Scientific American, May 2011



PHYSICS

The Space Station's Crown Jewel

A fancy cosmic-ray detector, the Alpha Magnetic Spectrometer, is about to scan the cosmos for dark matter, antimatter and more

By George Musser, staff editor

THE WORLD'S MOST ADVANCED COSMIC-RAY DETECTOR TOOK 16 YEARS AND $2 billion to build, and not long ago it looked as though it would wind up mothballed in some warehouse. NASA, directed to finish building the space station and retire the space shuttle by the end of 2010, said it simply did not have room in its schedule to launch the instrument anymore. Saving it took a lobbying campaign by physicists and intervention by Congress to extend the shuttle program. And so the shuttle *Endeavour* is scheduled to take off on April 19 for the express purpose of delivering the Alpha Magnetic Spectrometer (AMS) to the International Space Station.

Cosmic rays are subatomic particles and atomic nuclei that zip and zap through space, coming from ordinary stars, supernovae explosions, neutron stars, black holes and who knows what—the last category naturally being of greatest interest and the main impetus for a brand-new instrument. Dark matter is one of those possible mystery sources. Clumps of the stuff out in space might occasionally release blazes of particles that would set the detectors alight. Some physicists also speculate that our planet might be peppered with the odd antiatom coming from distant galaxies made not of matter but of its evil antitwin.

The spectrometer's claim to fame is that it can tell the ordinary from the extraordinary, which otherwise are easily conflated. No other instrument has the combination of detectors that can tease out all the properties of a particle: mass, velocity, type, electric charge. Its closest predecessor is the PAMELA instrument, launched by a European consortium in 2006. PAMELA has seen hints of dark matter and other exotica, but its findings remain ambiguous because it lacks the ability to distinguish a low-mass antiparticle, such as a positron, from a high-mass ordinary particle with the same electric charge, such as a proton.

The AMS instrument is a monster by the standards of the space program, with a mass of seven metric tons (more than 14 times heavier than PAMELA) and a power consumption of 2,400 watts. In a strange symbiotic way, it and the space station have come to justify each other's existence. The station satisfies the instrument's thirst for power and orbital reboosts; the spectrometer, although it could never fully placate the station's many skeptics, at least means the outpost will do world-class research. As CERN's Large Hadron Collider plumbs the depths of nature on the ground, the Alpha Magnetic Spectrometer will do the same from orbit.

SOURCE FOR ISS MODEL: NASA

SCIENTIFIC AMERICAN ONLINE
For more information on how the Alpha Magnetic Spectrometer works, visit ScientificAmerican.com/may2011/ams

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May 2011, ScientificAmerican.com 73

In the past hundred years, measurements of charged cosmic rays by balloons and satellites have typically had ~(30-50)% accuracy.

AMS is providing cosmic ray information with ~1% accuracy.
The improvement in accuracy and energy range is providing new insights.

AMS results contradict current cosmic ray theories and require the development of a new understanding of the universe.

Questions?