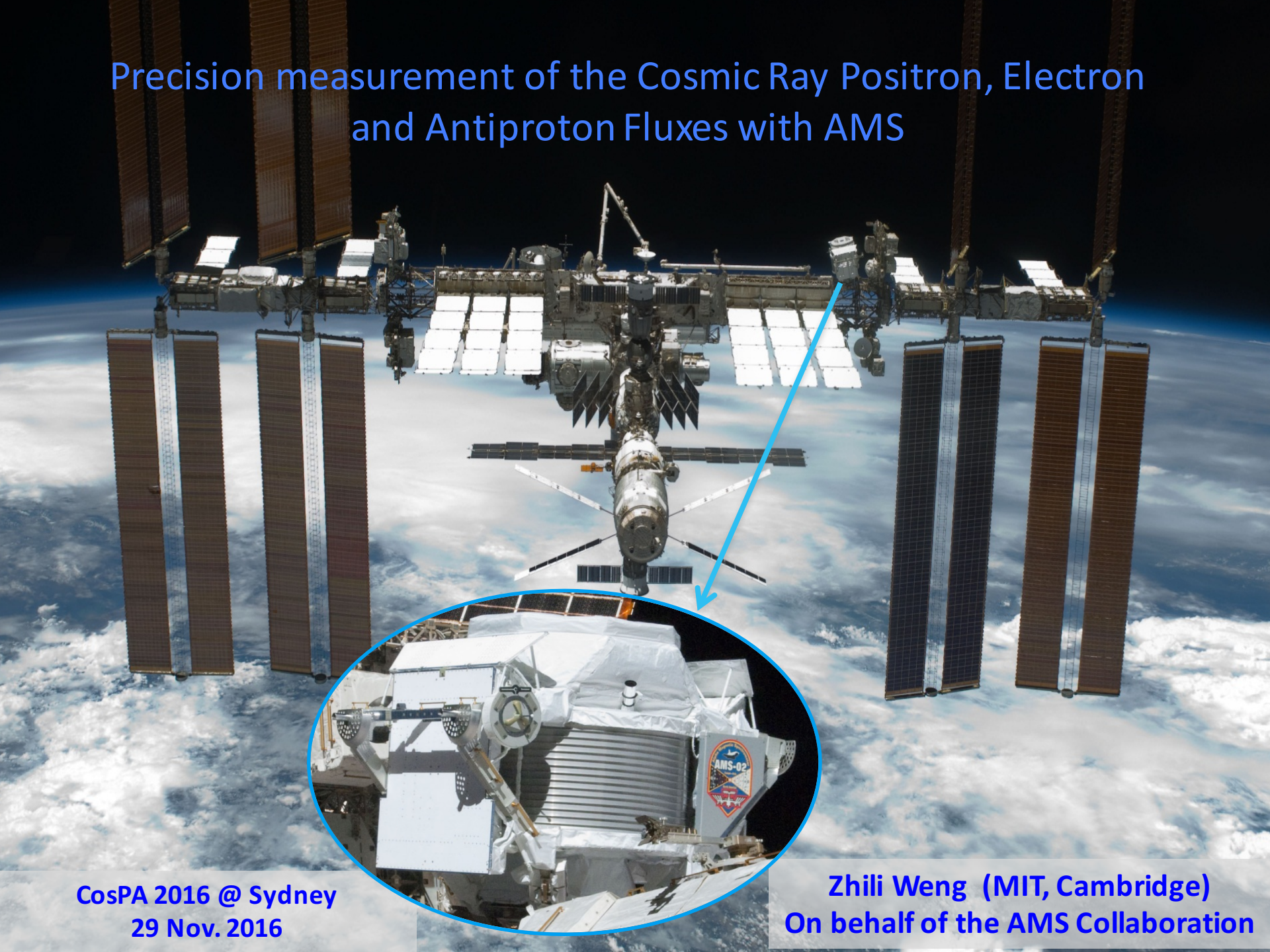
Precision measurement of the Cosmic Ray Positron, Electron and Antiproton Fluxes with AMS



Zhili Weng (MIT, Cambridge)
On behalf of the AMS Collaboration

CosPA 2016 @ Sydney
29 Nov. 2016

Origines of CR Positron and Electron and Antiprotons

e^- are produced and accelerated from SNR

Collision of "ordinary" Cosmic Rays produce secondary e^+, e^-, antiprotons

Among many possible mechanisms:

Collisions of Dark Matter will produce additional e^+, e^-, antiprotons

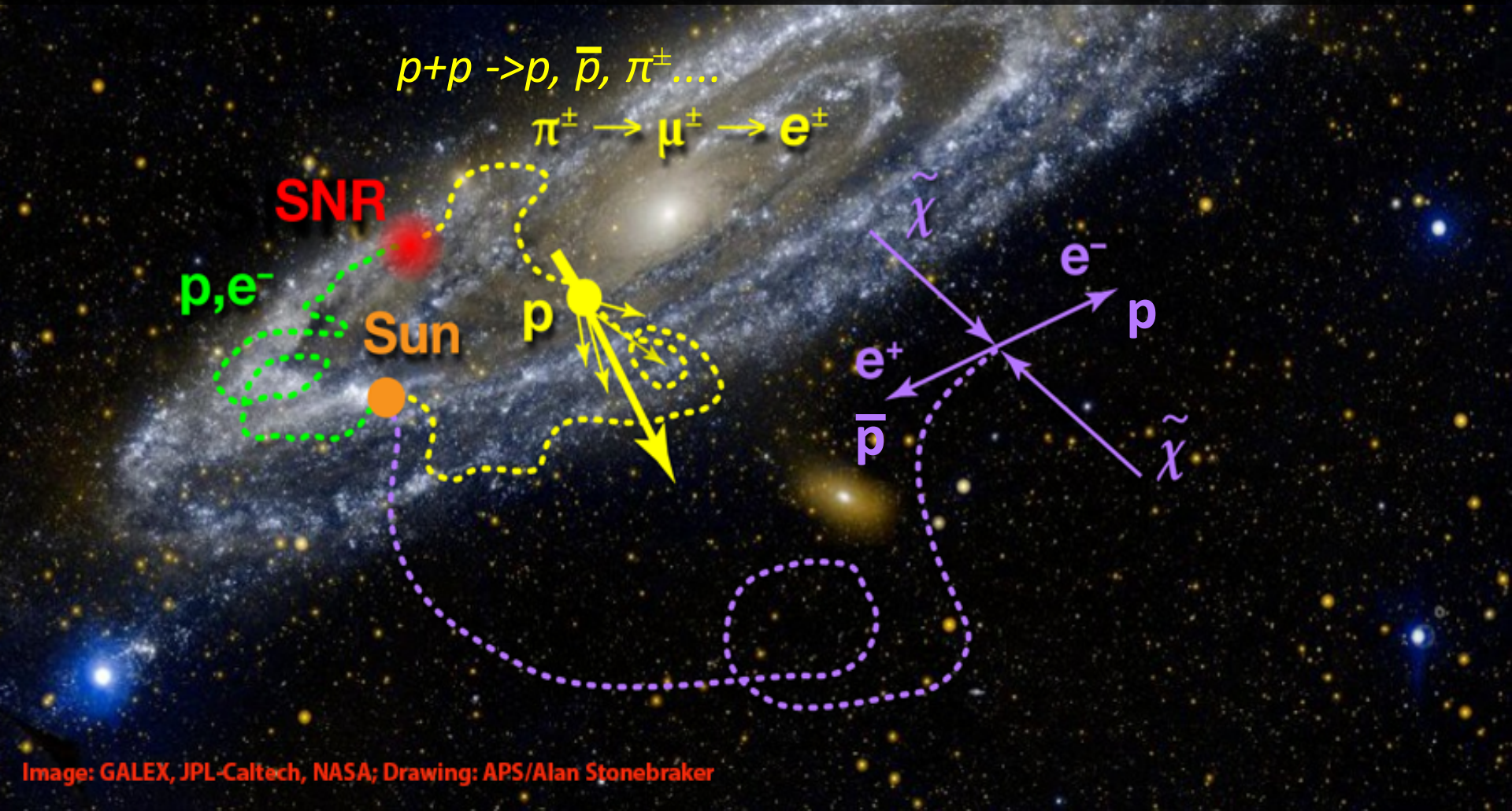


Image: GALEX, JPL-Caltech, NASA; Drawing: APS/Alan Stonebraker

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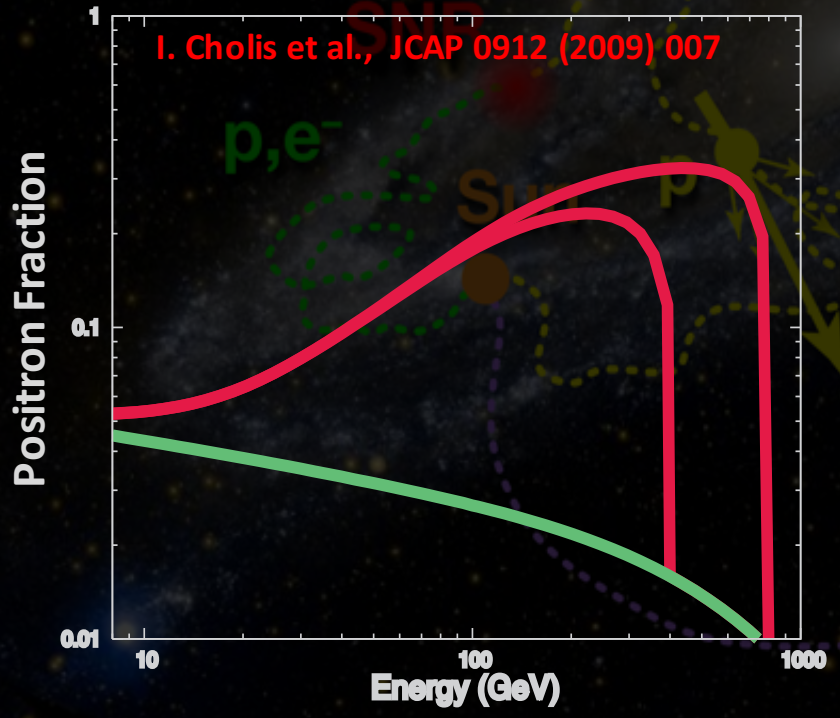
Among many possible mechanisms:

Collisions of Dark Matter will produce additional e^+, e^-, antiprotons

$p+p \rightarrow p, \bar{p}, \pi^{\pm} \ldots$

$\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$



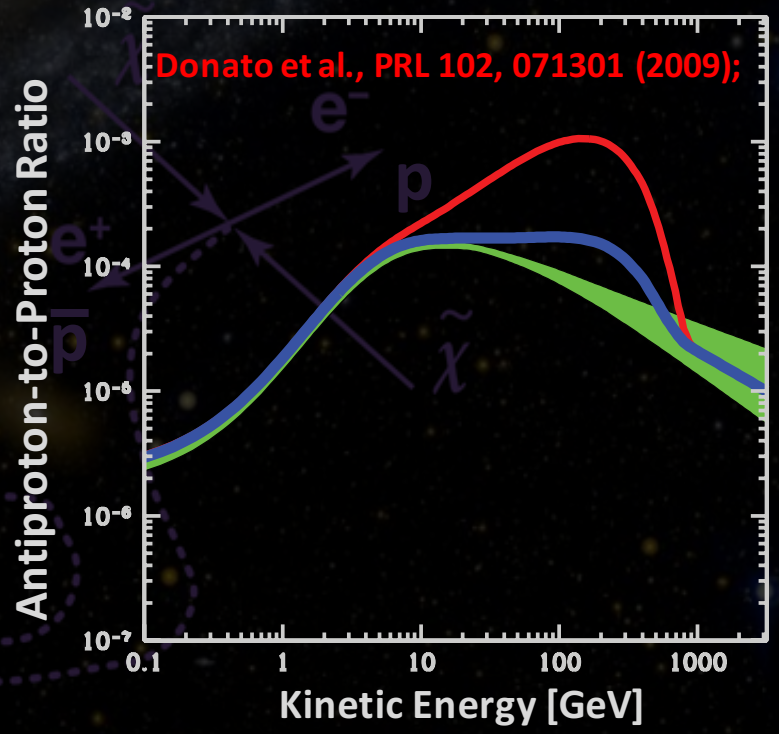
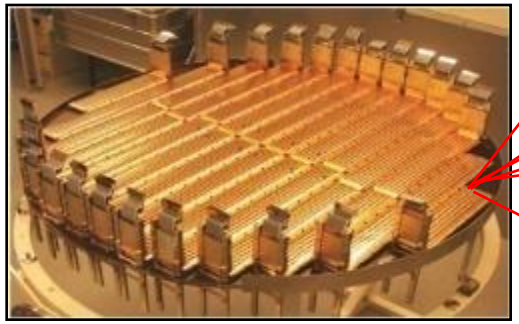


Image: GALEX, JPL-Caltech, NASA; Drawing: APS/Alan Stonebraker

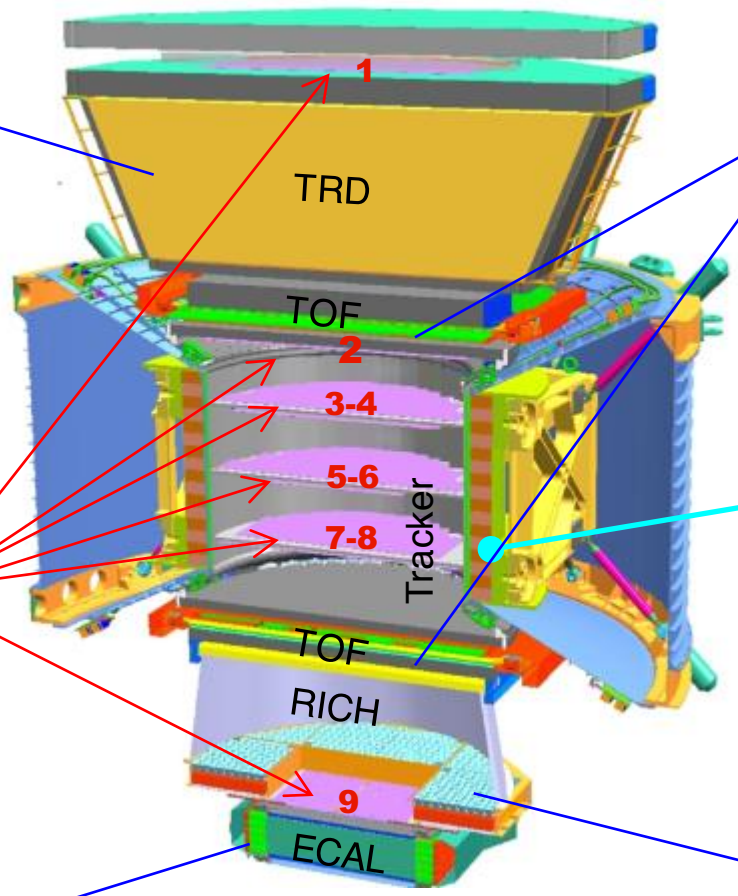
Alpha Magnetic Spectrometer

Transition Radiation Detector
Electron/proton, Z

Silicon Tracker
Z, P

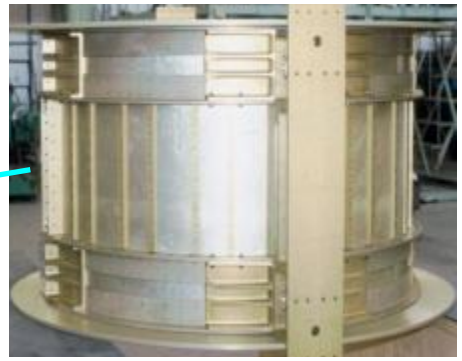


Electromagnetic Calorimeter
E of electrons



Time of Flight
Z, E

Magnet
±Z

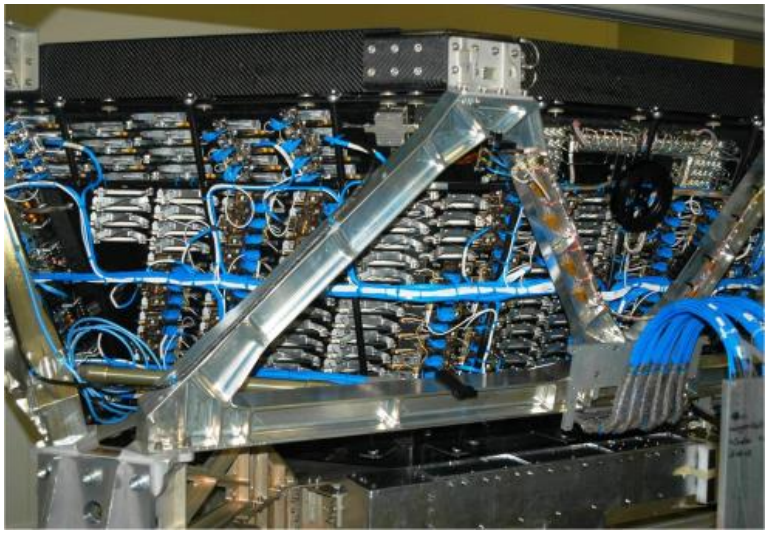


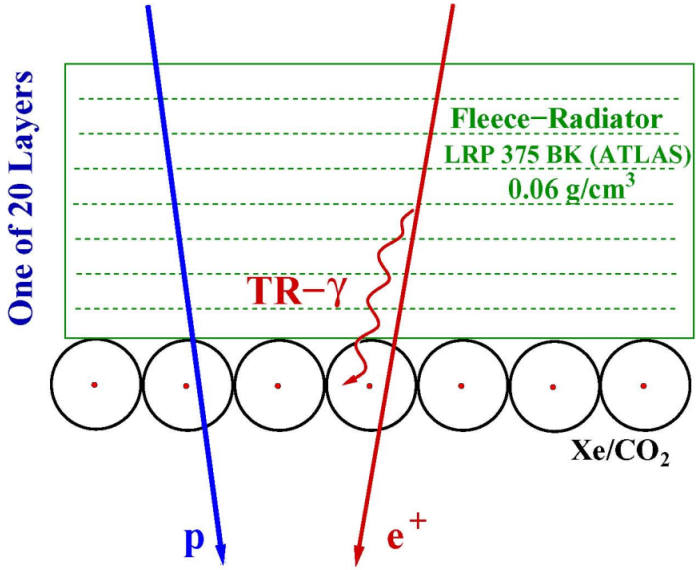
Ring Imaging Cherenkov
Z, E

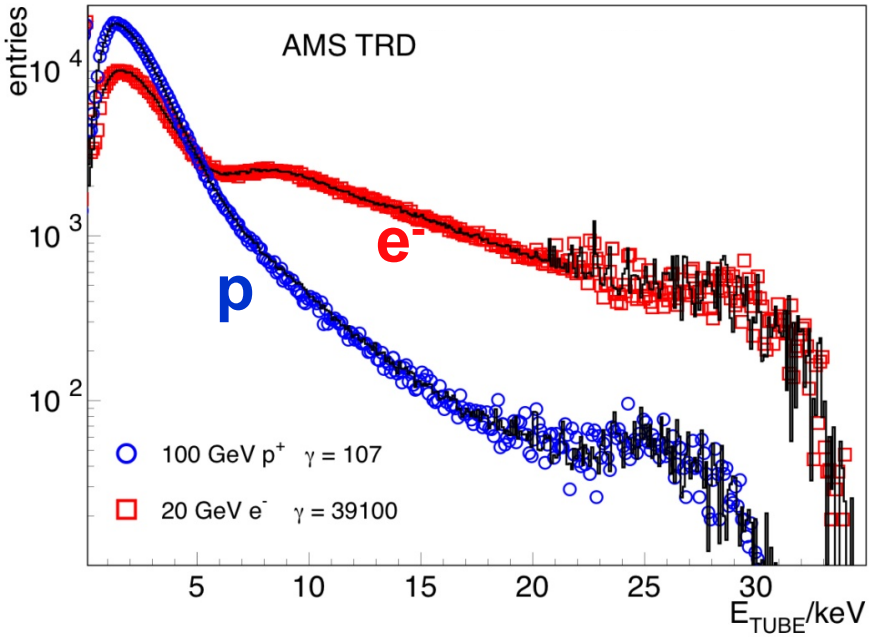
The Charge and Energy are measured independently by several detectors

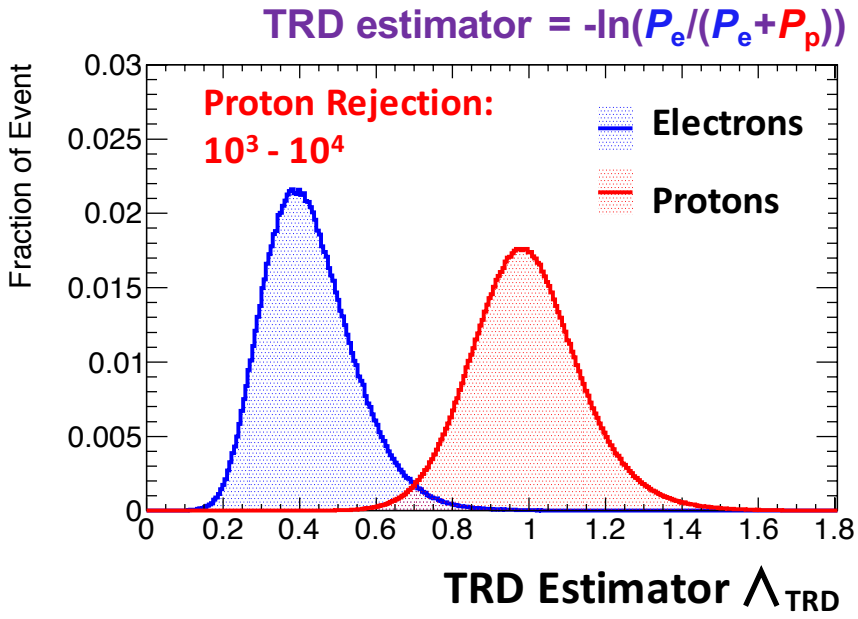
Precise identification of particle species

Transition Radiation Detector (TRD)



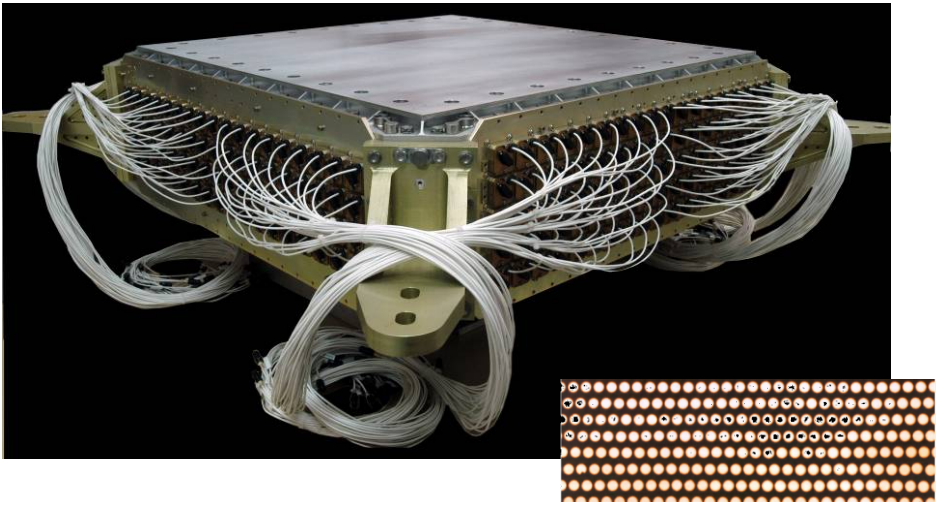






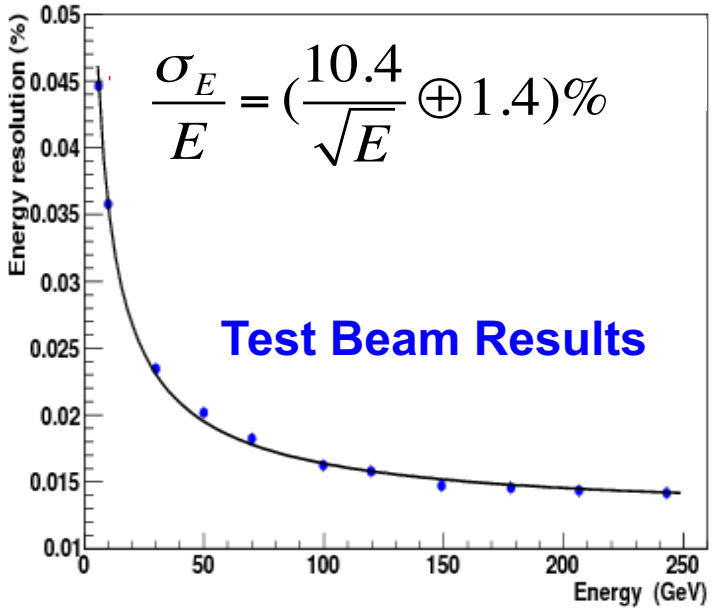
Electromagnetic Calorimeter

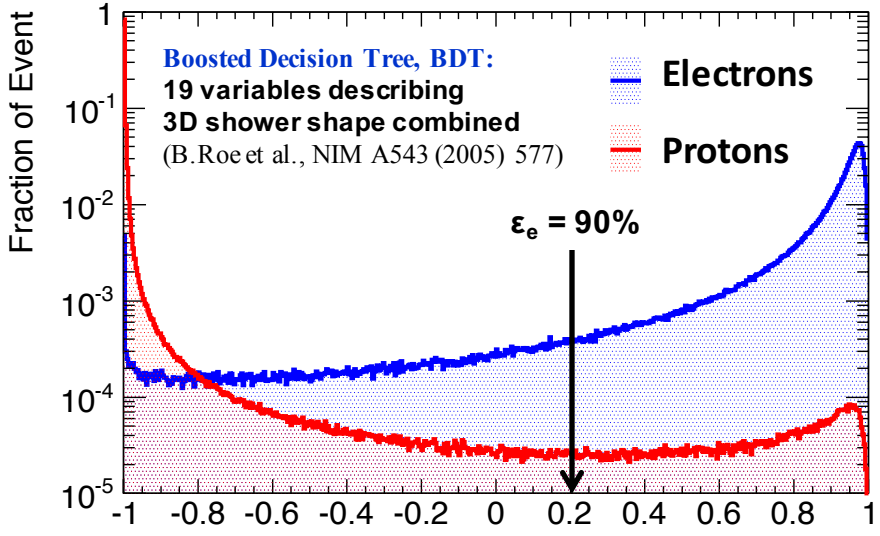
A precision, 17 X_0, TeV, 3D measurement of the directions and energies of light rays and electrons



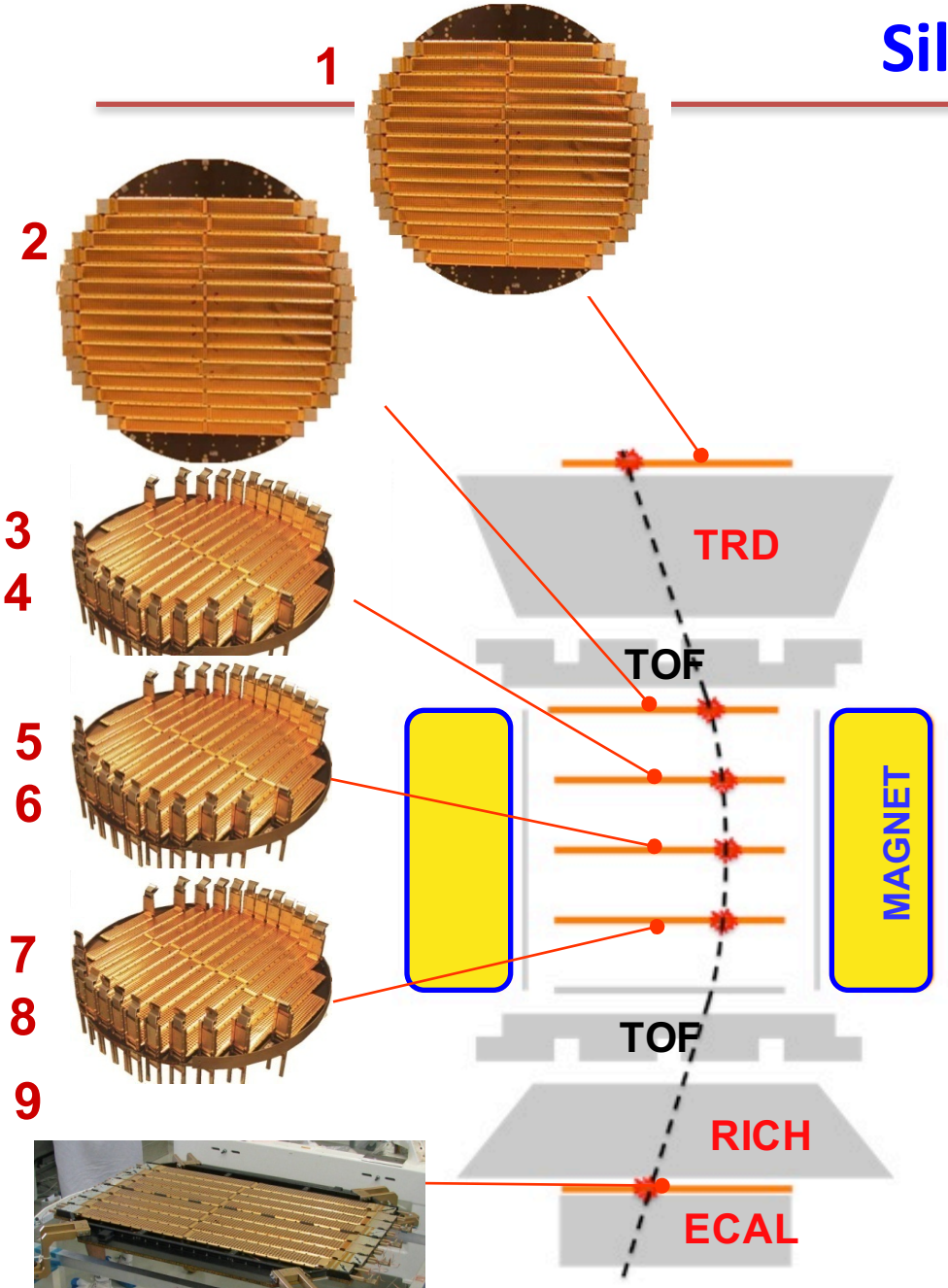
50 000 fibers, $\phi = 1$ mm distributed uniformly inside 600 kg of lead

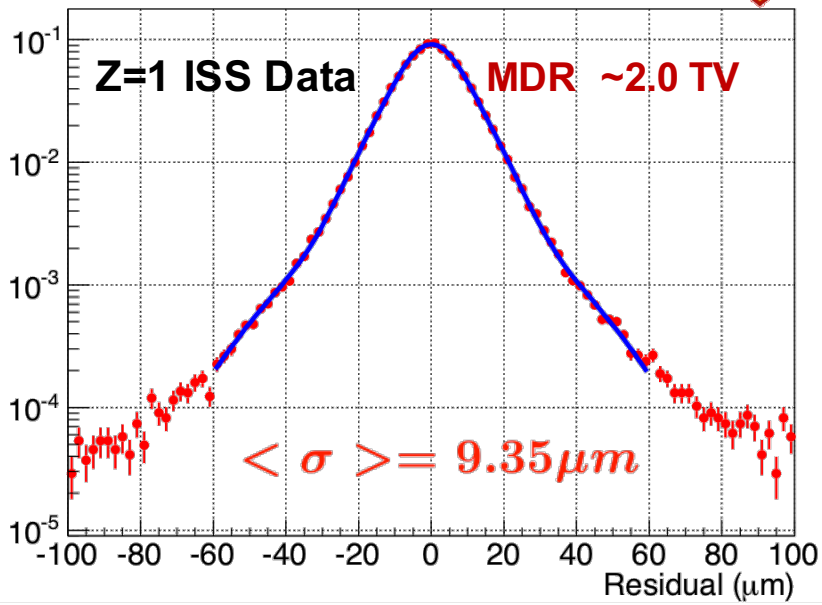
Energy scale and energy resolution measured using Test Beam

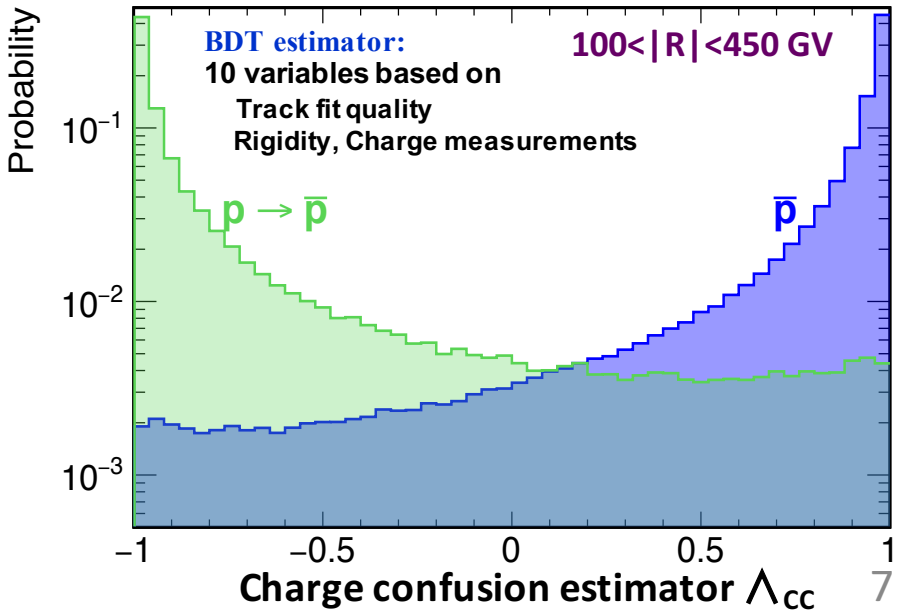




Silicon Tracker and Magnet

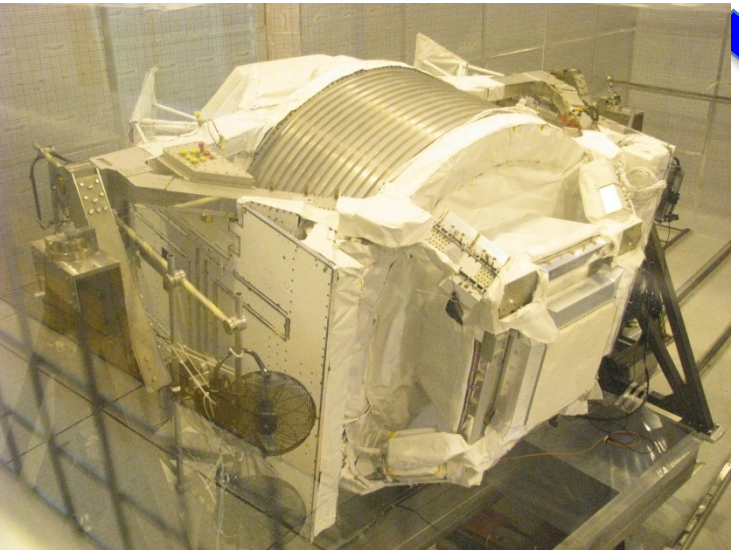






Detector Calibration and Monte Carlo simulation

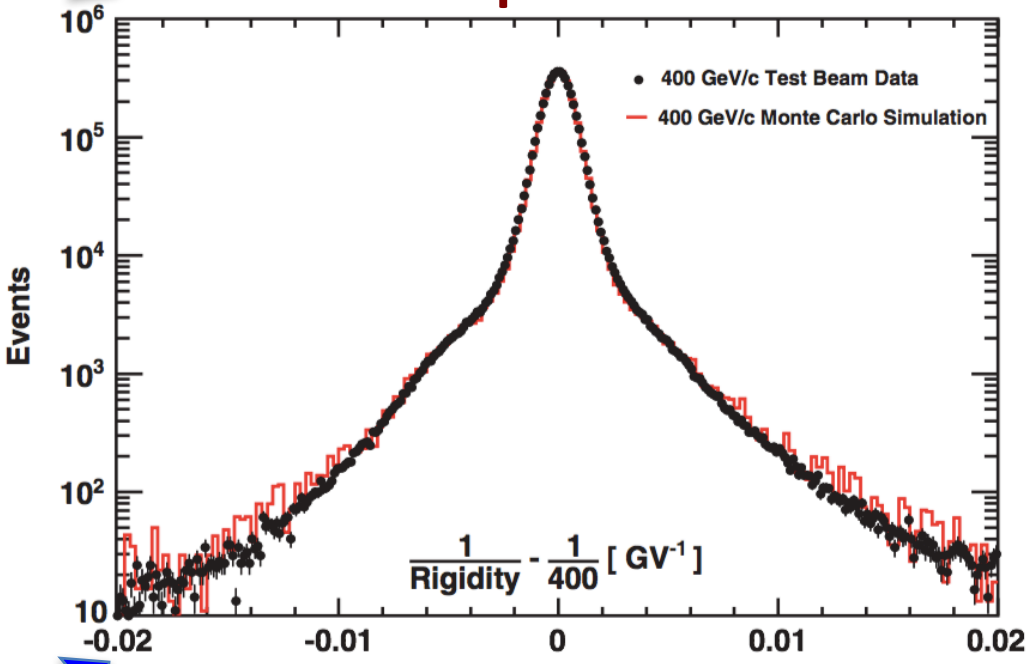
Detector calibration



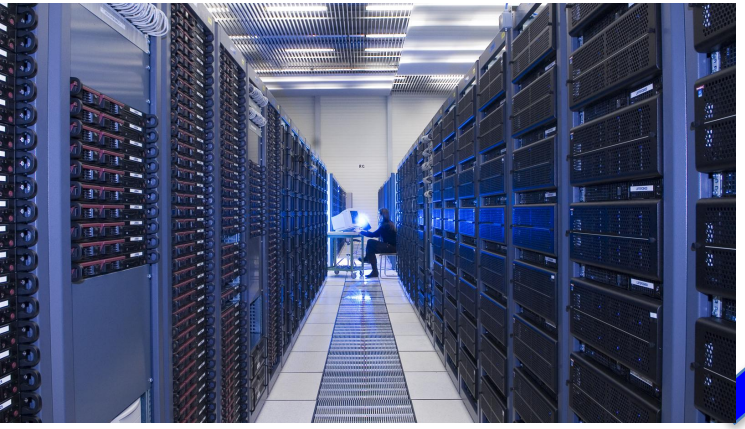
Detector response:

1. Particle type (p, $e^{\pm}$, $\pi^{\pm}$)
2. Energy (10–400 GeV)
3. Position (1600)

Comparison



Monte Carlo simulation



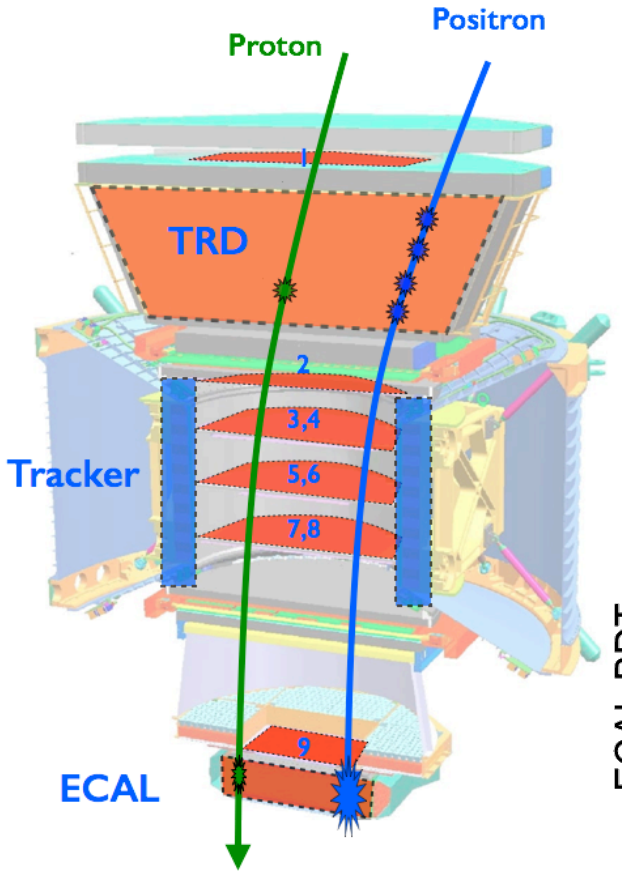
6,000 CPU cores at CERN
+ regional centers

Computer simulation program:

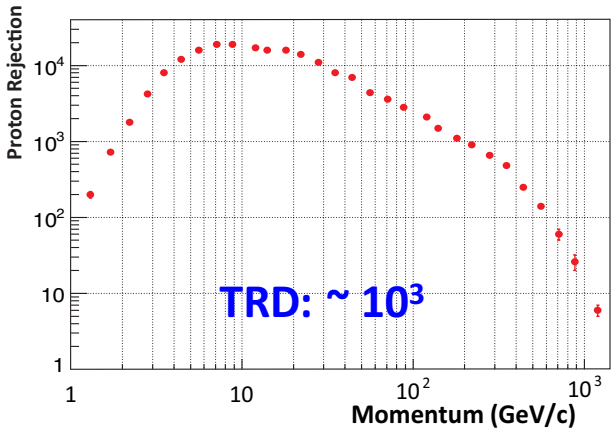
1. Interactions (physics and materials)
2. Digitization (electronics)

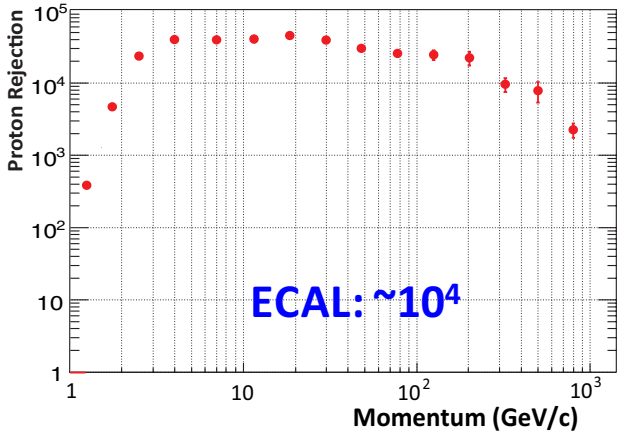
Results in data-like events

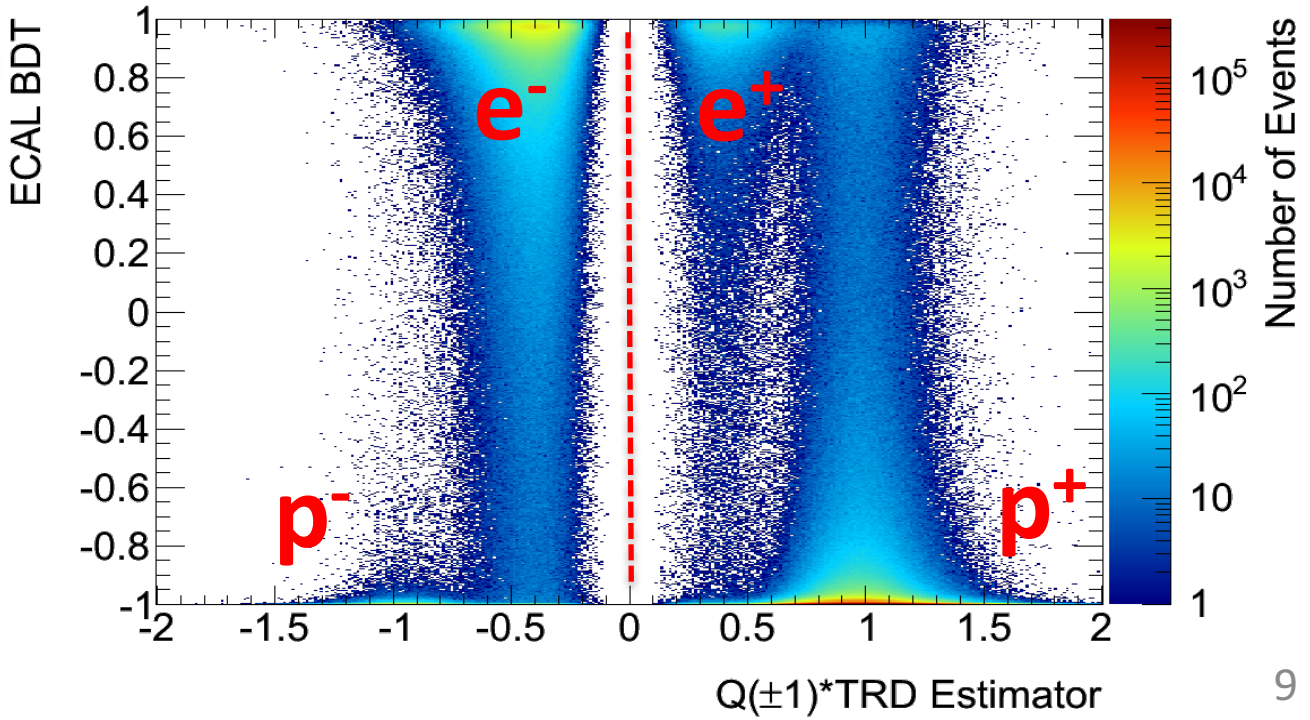
Particle Identification of AMS



Separation power @ 90% efficiency



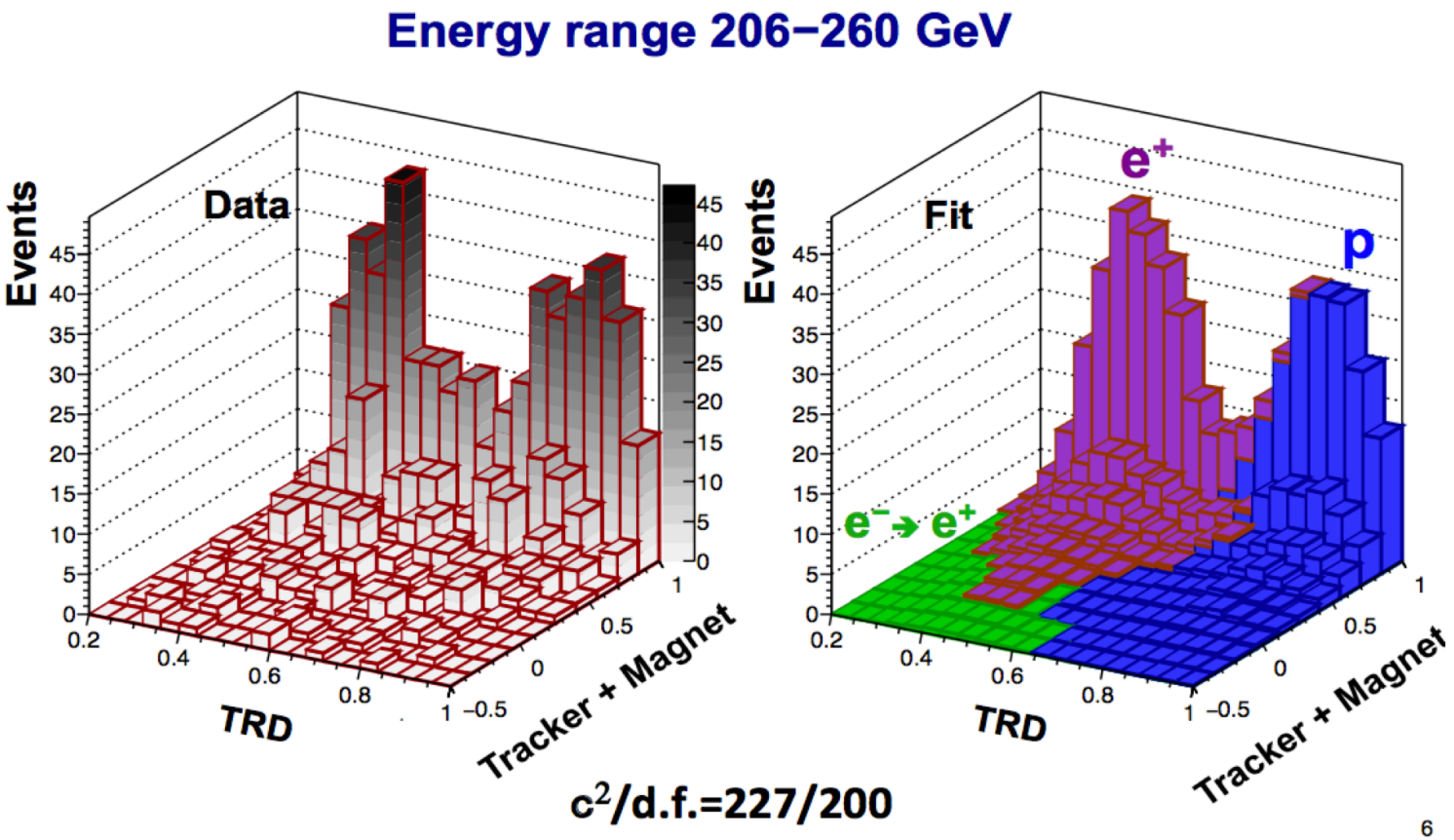




Positron Fraction

Positron Fraction: $$f_{e^+} = \frac{\Phi_{e^+}}{\Phi_{e^+} + \Phi_{e^-}} \approx \frac{N_{e^+}}{N_{e^+} + N_{e^-}}$$

The number of positrons and electrons are determined from a template fit:



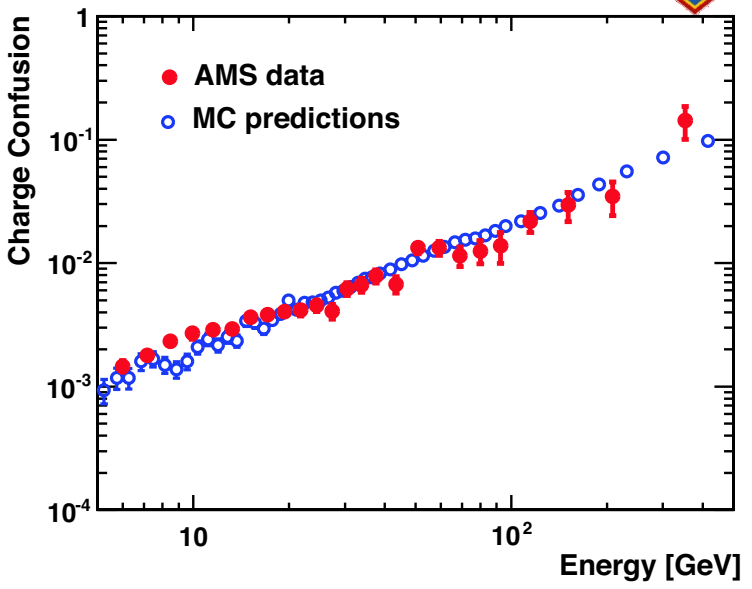
Positron Fraction

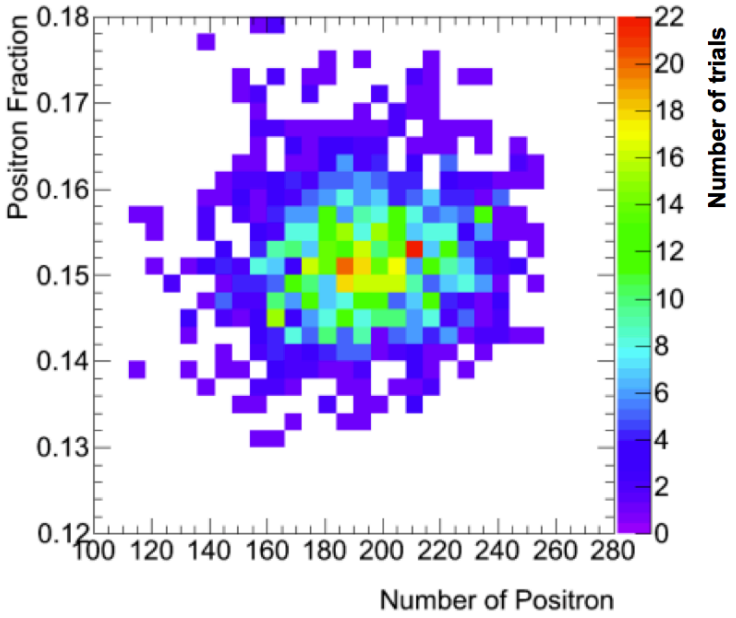
Major Systematic Errors:

- **Charge confusion**
  - Large angle scattering, Production of secondaries.
  - Well reproduced by the Monte Carlo. Measured directly from data. The small difference is taken as a systematic error.

- **Selection, Template definition;**
  - For each energy bin, over 1,000 sets of cuts (trials) were analyzed. The measurement is stable over wide ranges of the selections.

Systematic error are smaller than statistical ones



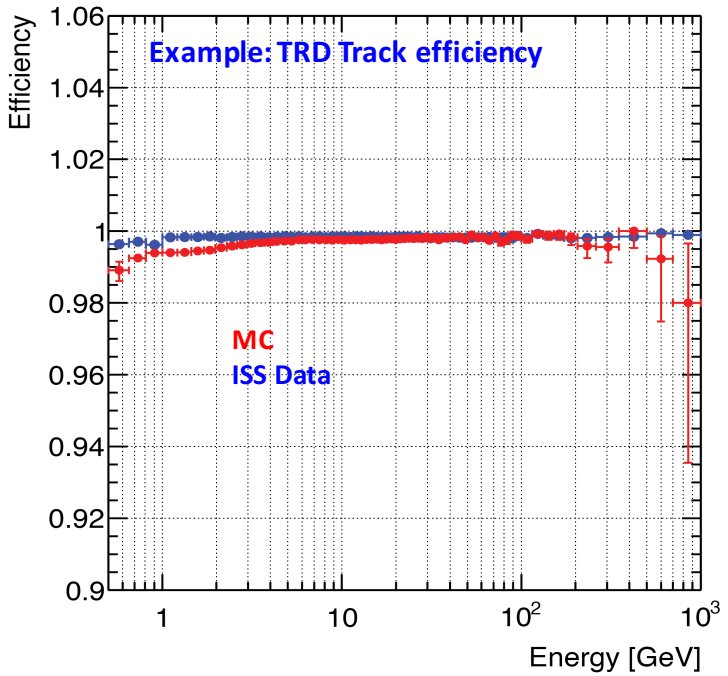


Electron/Positron Flux Measurement

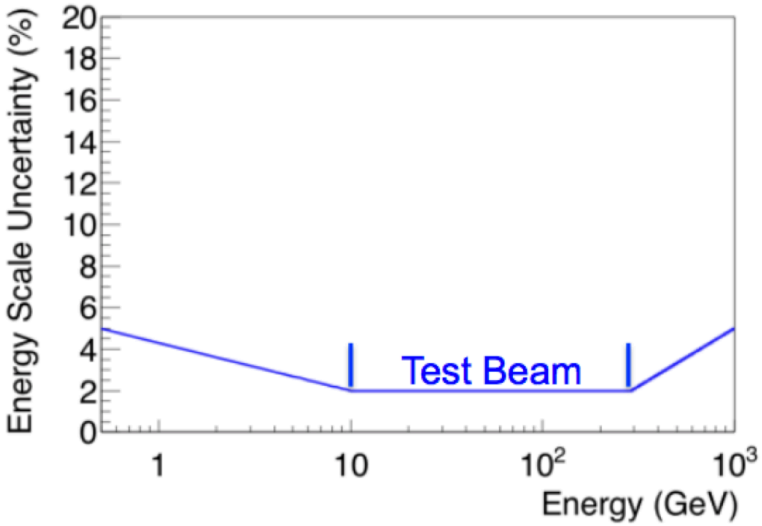
Isotropic flux:

$$\Phi_{e^\pm}(E) = \frac{N_{e^\pm}(E)}{A_{eff}(E) \cdot \varepsilon_{trig}(E) \cdot T(E) \cdot \Delta E}$$

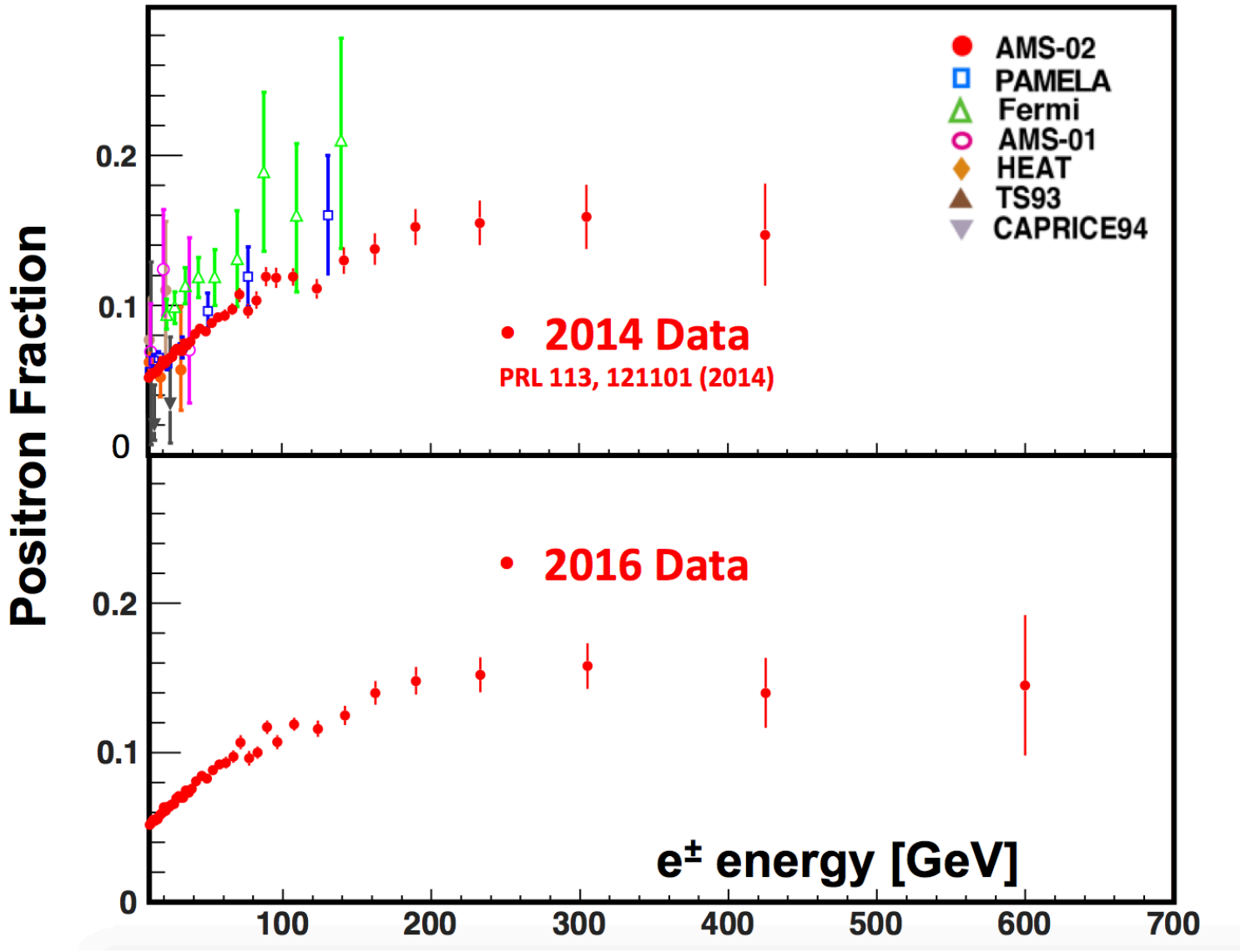
- **Effective Acceptance:** $A_{eff} = A_{geom} \cdot \varepsilon_{sel} \cdot \varepsilon_{id} \cdot (1+\delta)$
  - Estimated from MC
  - Small correction applied based on efficiency measured from Data
  - Systematic uncertainties: 2% ~ 3%



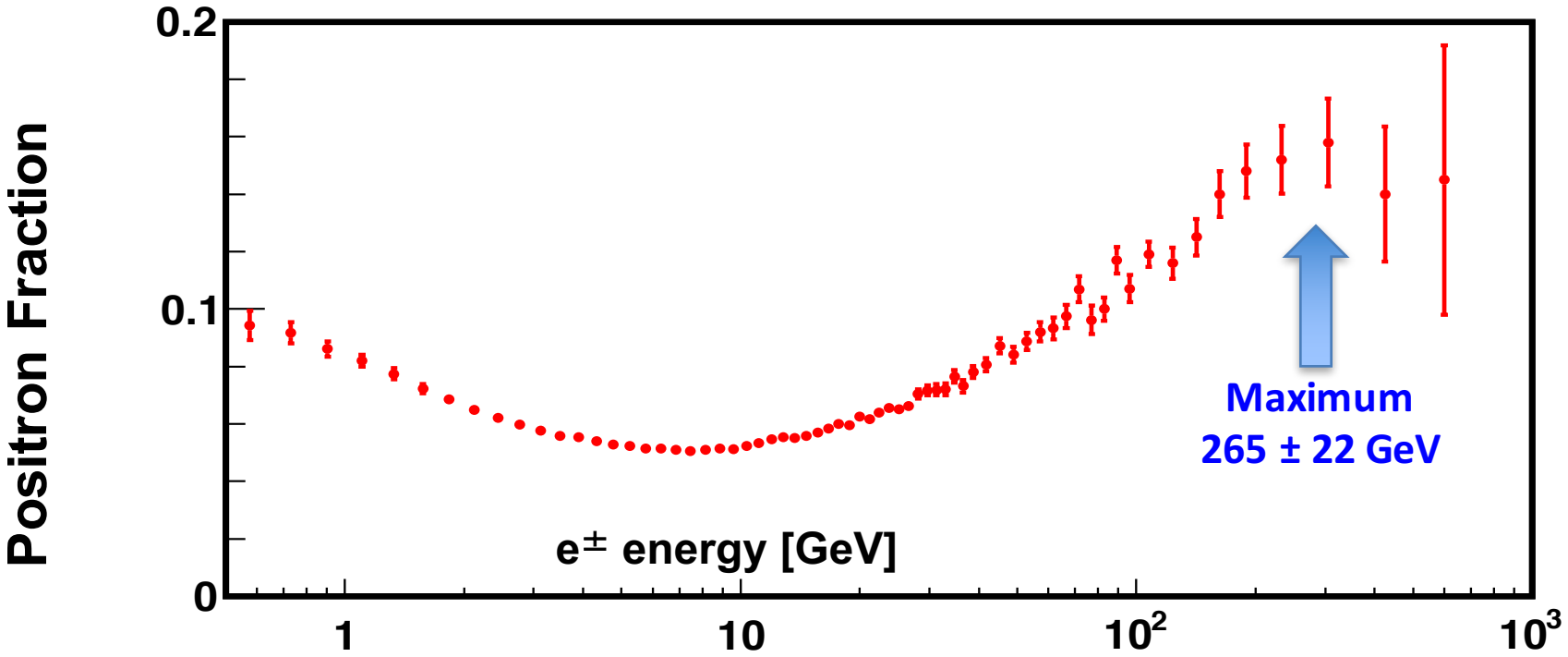
- **Energy Measurement**
  - **Minimum effect from resolution**
  - **Uncertainty in the absolute energy scale:**
    ~2% at [20, 300] GeV
    ~5% at 1TeV

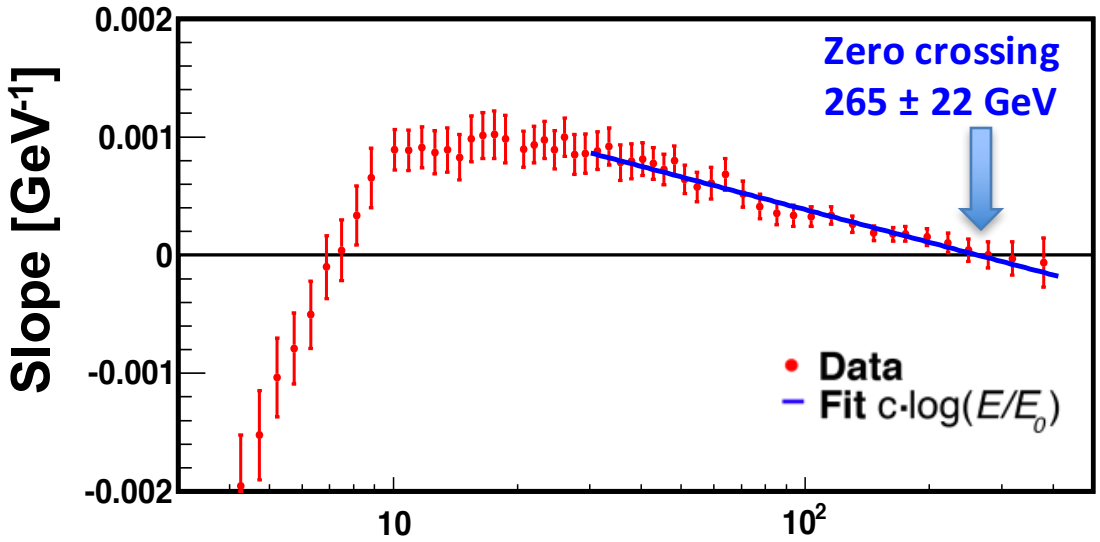


Positron Fraction: 5 years data

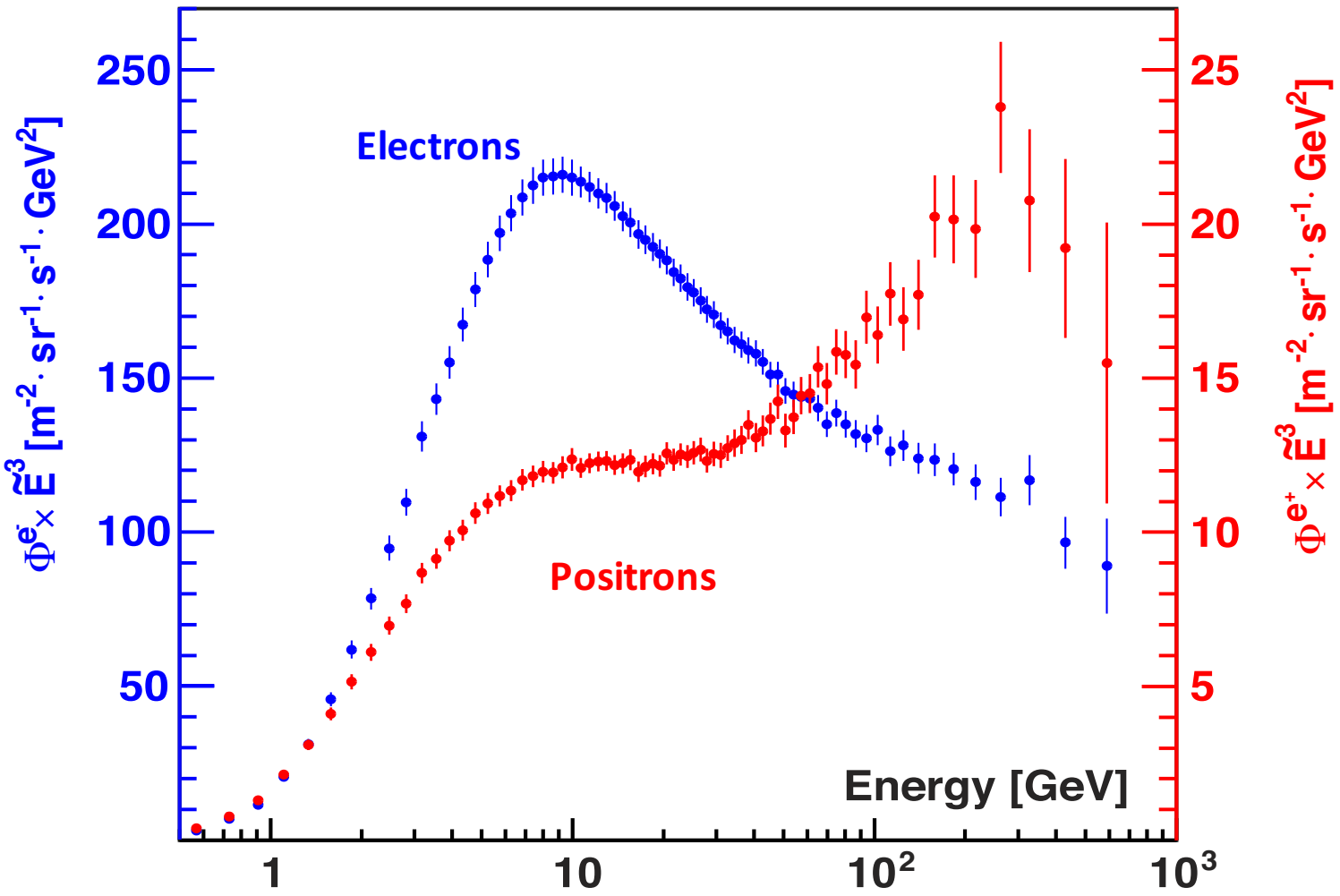


Positron Fraction: 5 years data



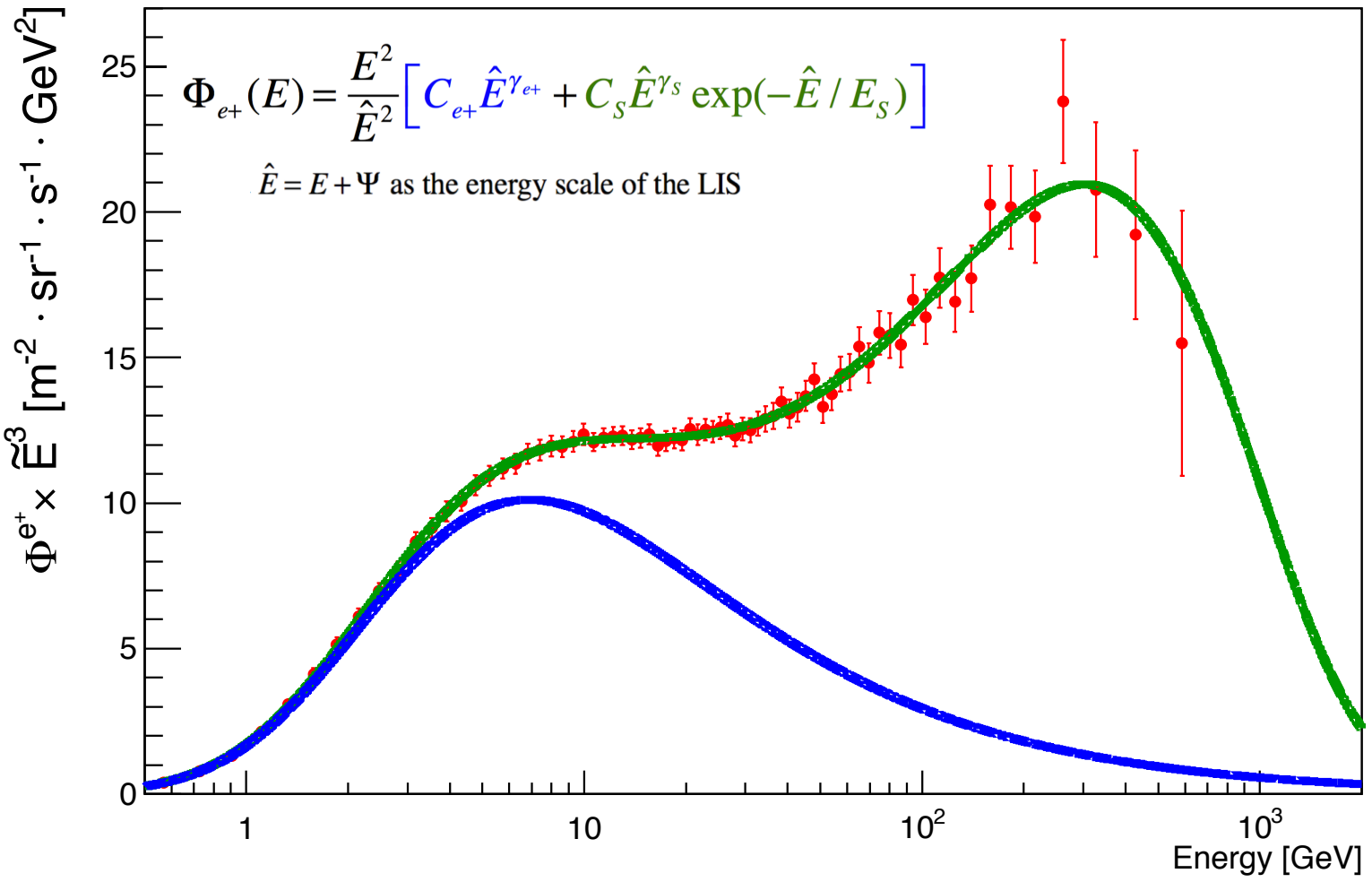


Latest result based on 20 million e^+, e^- events



- The electron flux and positron flux are different in amplitude and energy behavior.
- Both spectra show change of behavior at ~30GeV
- Rise of positron fraction from 20GeV is due to excess of positron

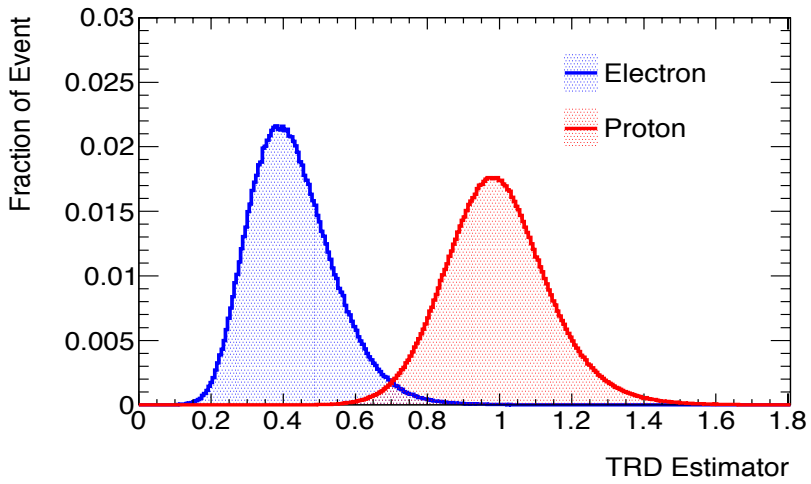
Primary source of cosmic ray positron

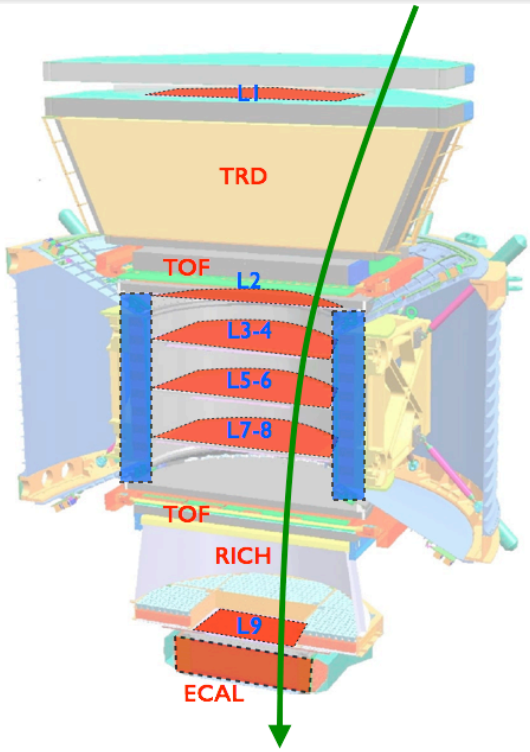


- Primary source of cosmic ray positron
- With more statistics, AMS will measure the characteristic of this excess
- Require detail and comprehensive modelling of cosmic rays to understand its origin

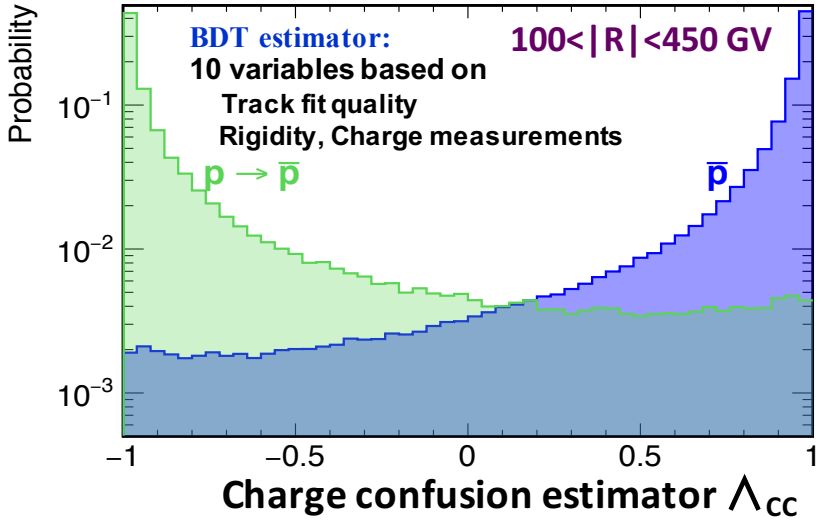
Antiproton Measurement

- TRD : Separate $e^{\pm}$ from $p^{\pm}$

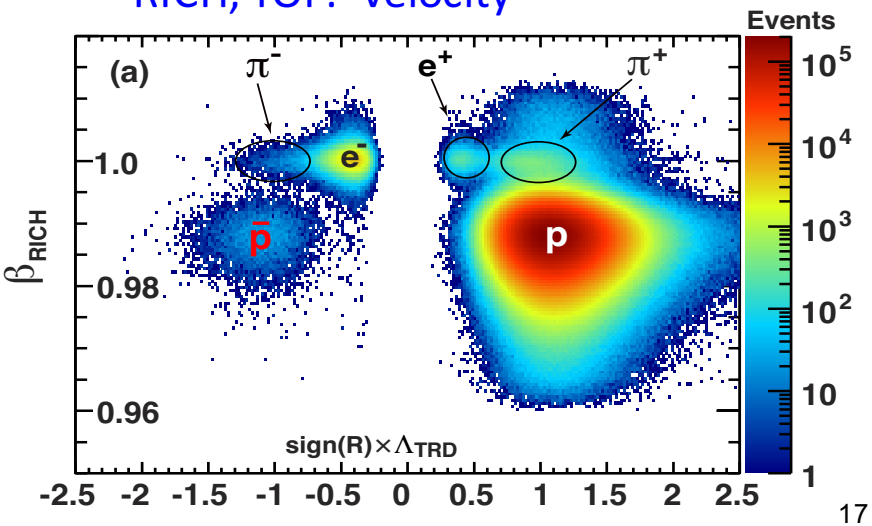




- Tracker: Rigidity , Separate + from –



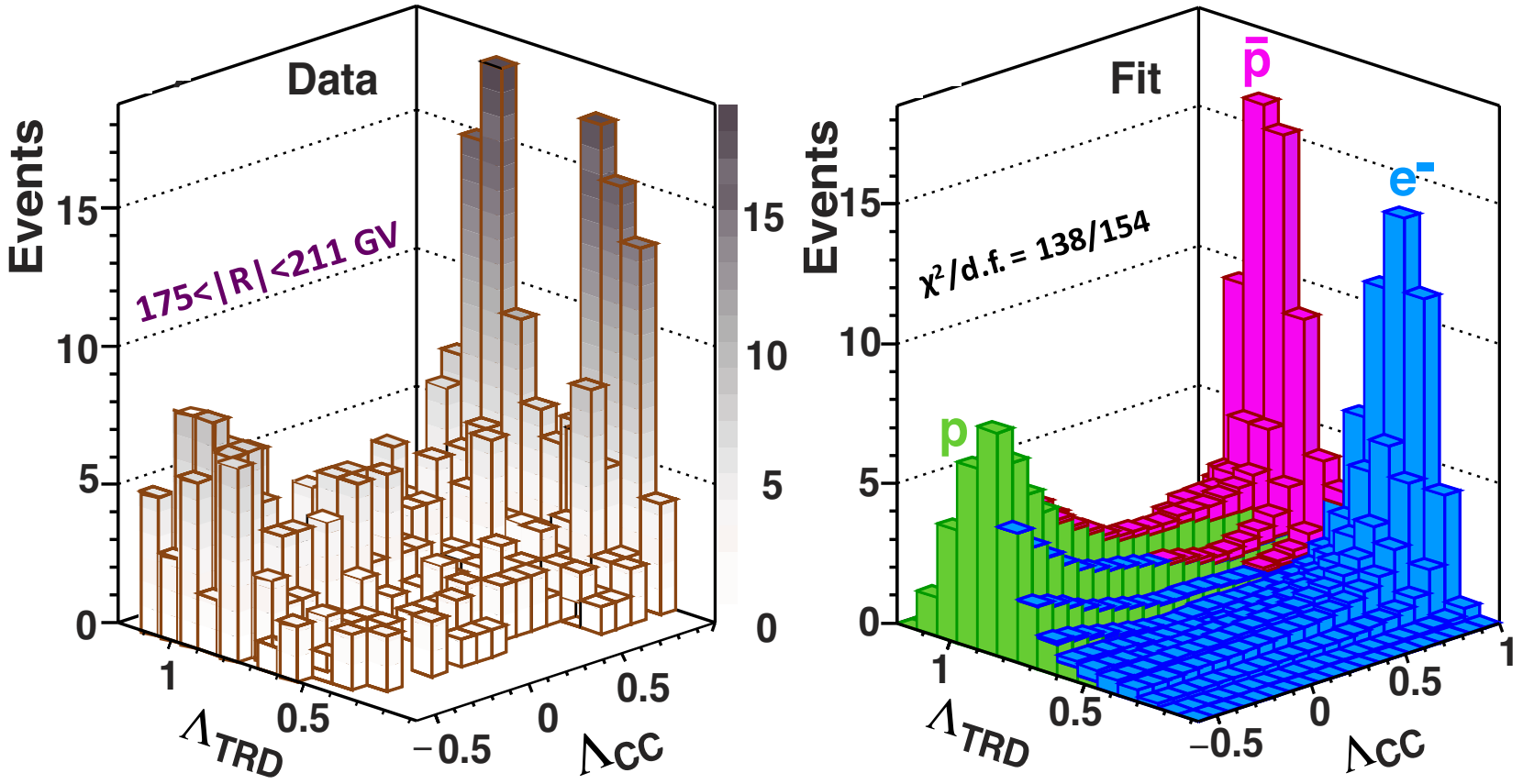
- RICH, TOF: Velocity



Antiproton Measurement

The number of antiprotons is determined from template fit.

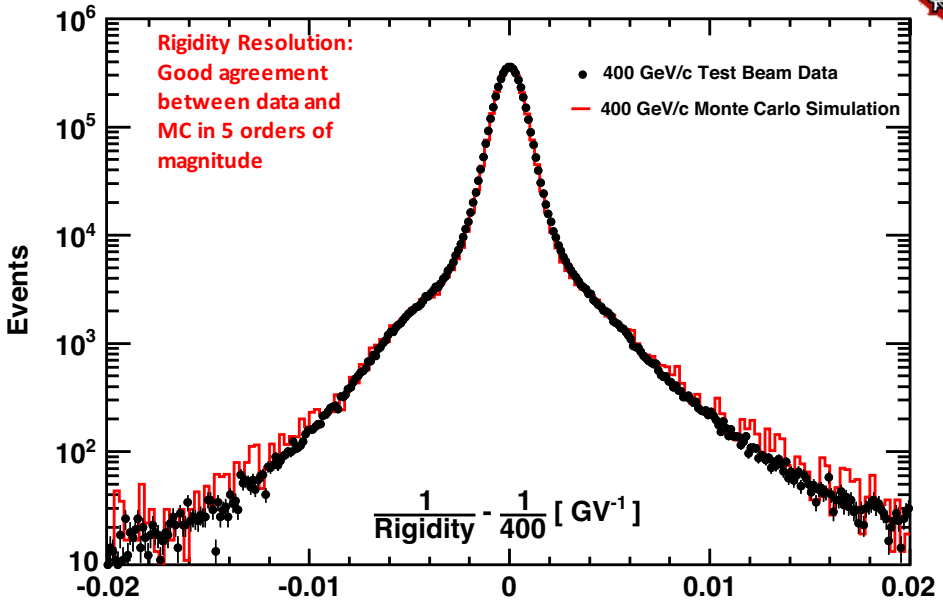
High rigidity (16.6-450) GV: TRD - Charge confusion estimator 2D template

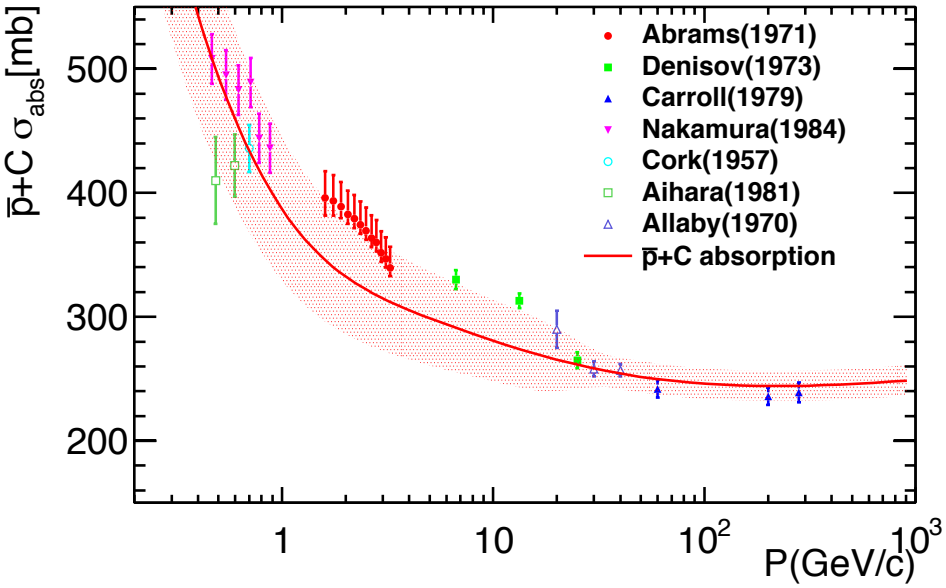


In total: 1 – 450 GV 3.49 x 10^5 antiprotons, 2.42 x 10^9 protons

Systematic Error on Antiproton Measurements

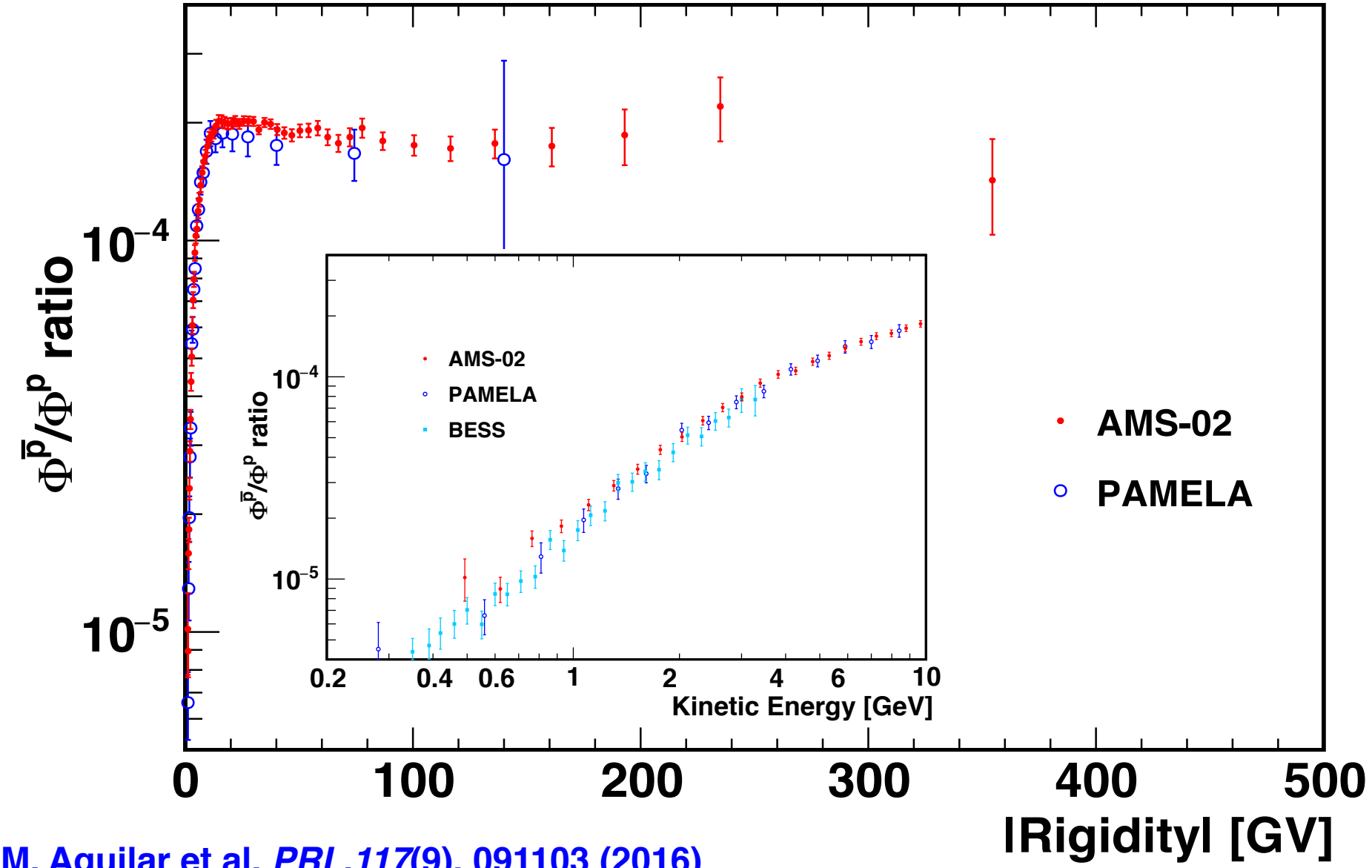
- **Antiproton counting σ_N**
  - Cutoff
  - Selection
  - **Shape of template, charge confusion**
  - ~1% @ 10GV, ~12% @ 450GV
- **Acceptance, σ_A**
  - **Cross sections**
  - Migration matrix
  - Small correction in normalization
  - ~4% @ 10GV, ~2% @450
  - Partly canceled in the flux ratio
- **Rigidity scale, σ_R**
  - <1% @10GV, ~2% @450GV
- **From ~100GeV, systematic errors are much smaller than statistic ones**





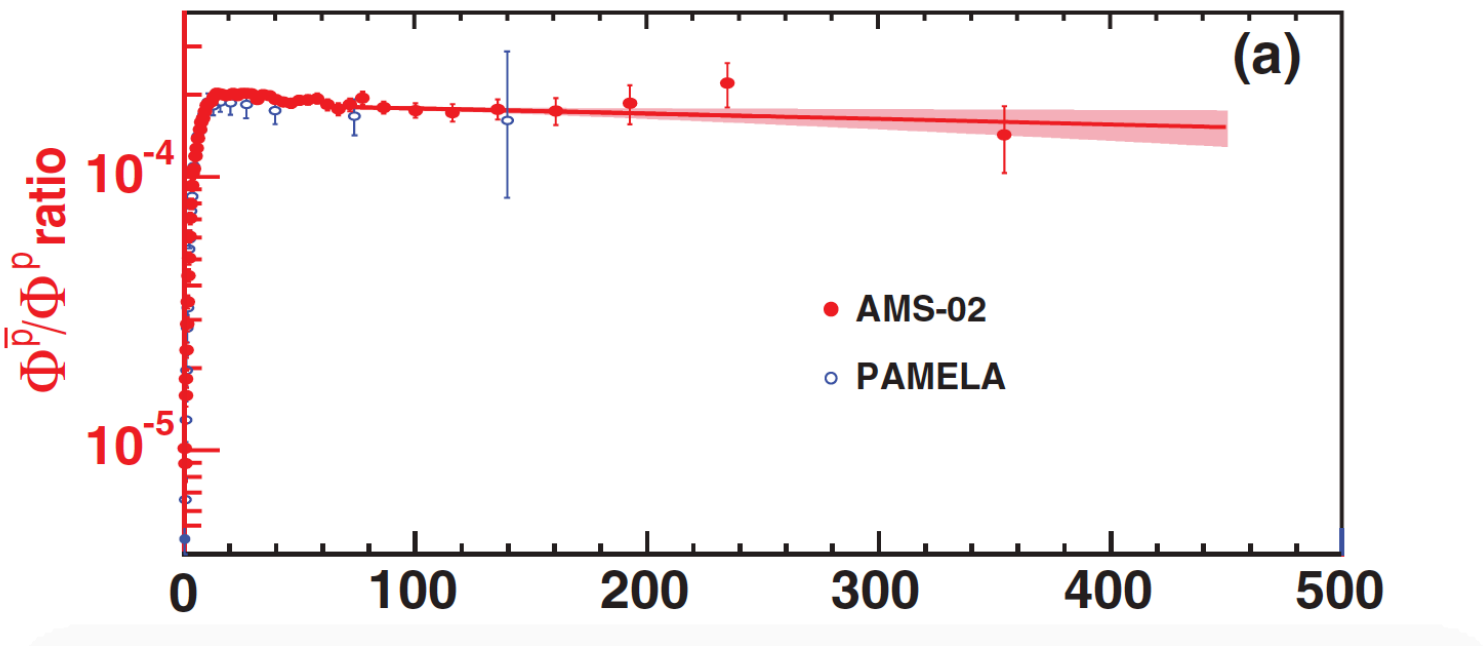
Antiproton-to-Proton Flux Ratio

3.49 x 10^5 antiprotons, 2.42 x 10^9 protons



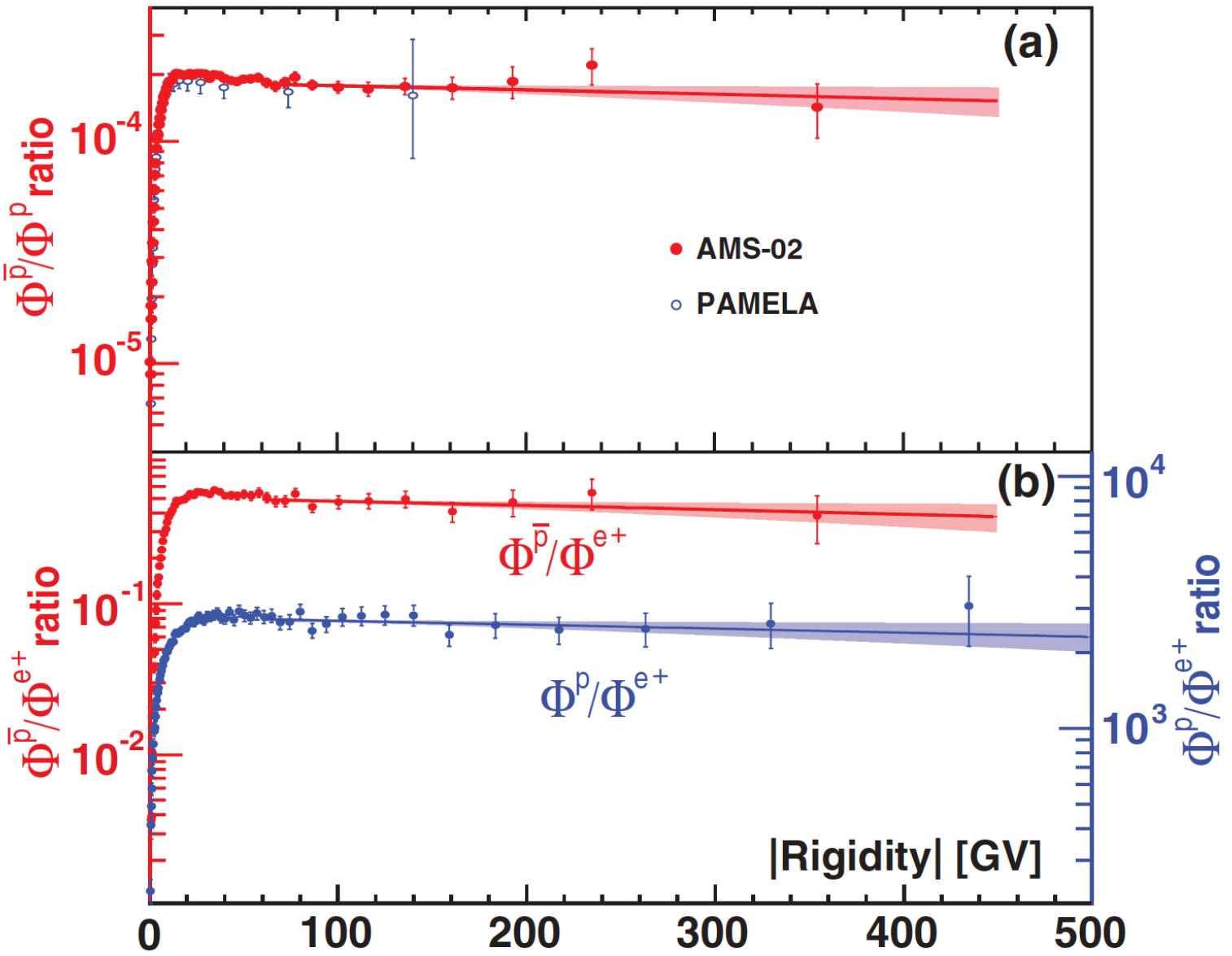
M. Aguilar et al. *PRL,117*(9), 091103 (2016)

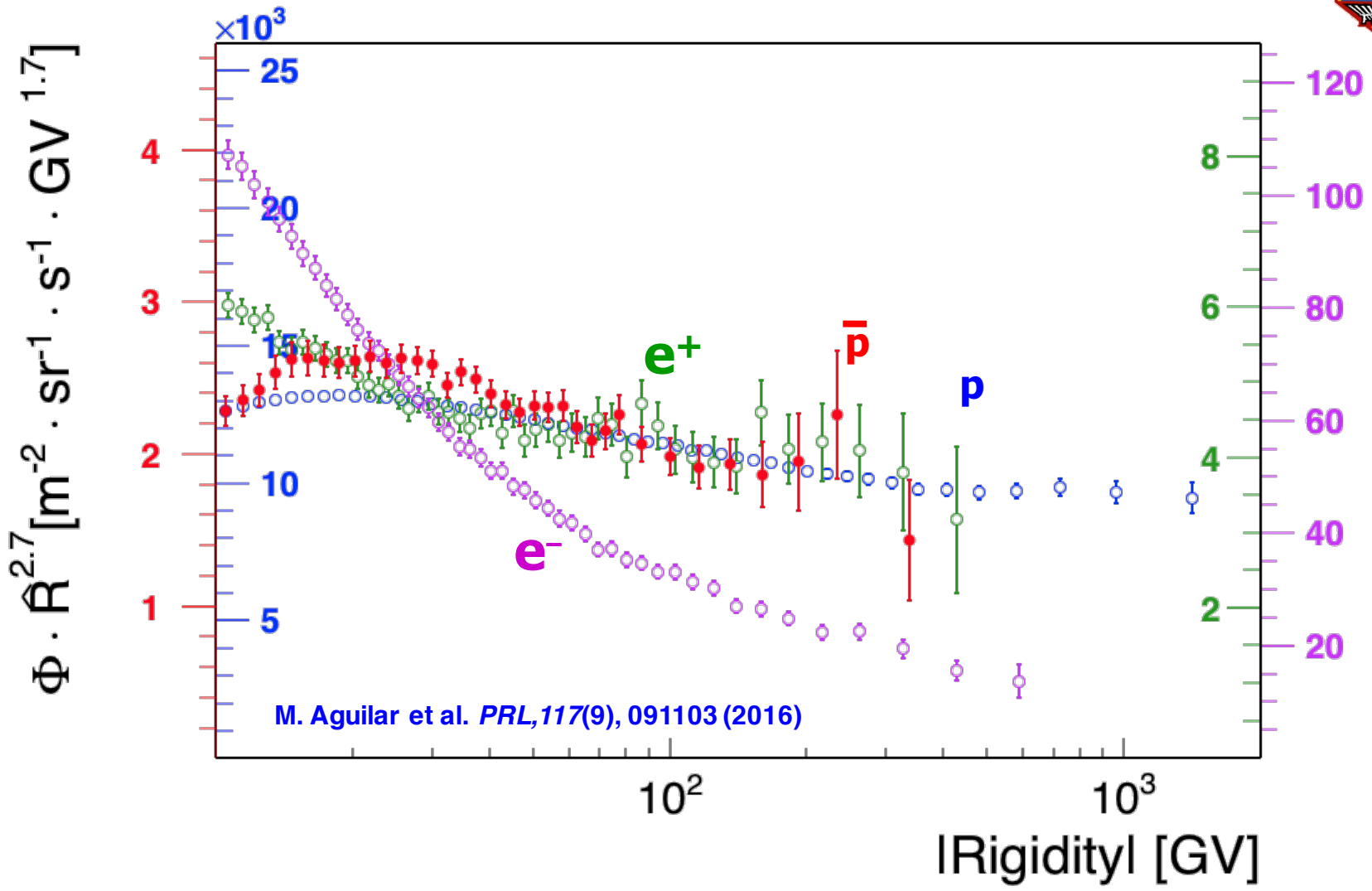
Antiproton-to-Proton Flux Ratio



Flux ratio of $\bar{p}/p$ is energy independent in the energy range ~60 to ~500 GeV

Flux ratio of $\bar{p}/e+$ and $p/e+$ are also energy independent in the energy range ~60 to ~500 GeV

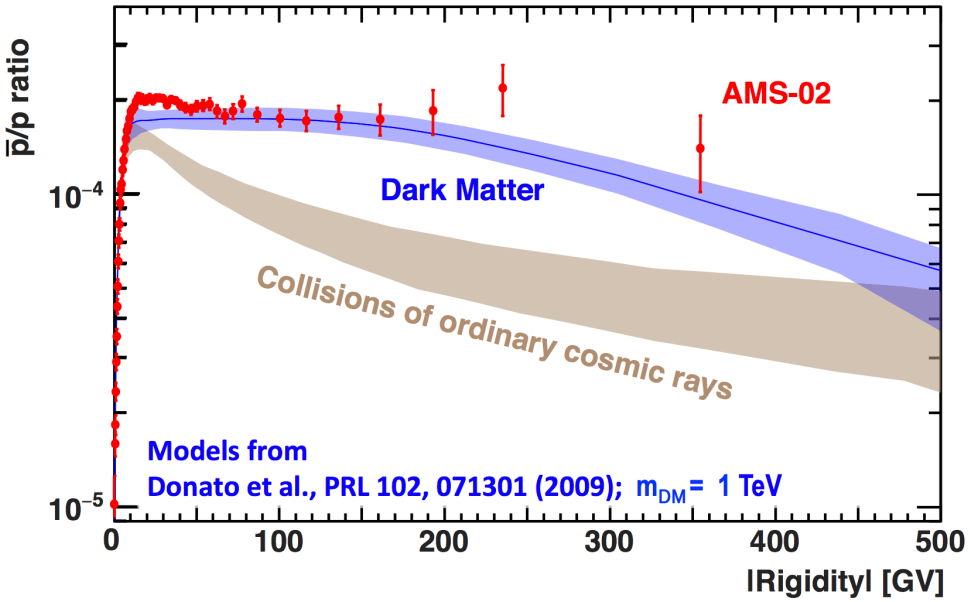


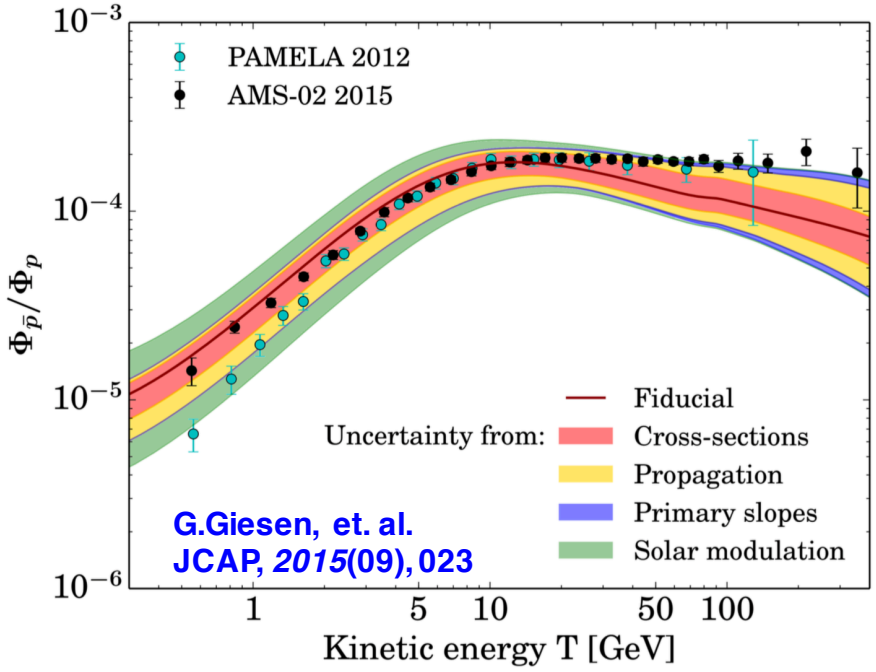


The spectra of e^+, $\bar{p}$, p have identical energy dependence from ~60 to ~500GeV

AMS results and modeling

- AMS is providing precise measurement of the cosmic ray fluxes
- To explore new physics， we need to understand the background: Precision and comprehensive modeling of CR production, propagation across different species





- AMS Measurement of different CR nuclei will significantly improve or impose constrain on different propagation/production models

Conclusion on the latest AMS measurements

1. Positron and Electron Fluxes requires an additional source of high energy e^+ and e^-
2. Antiproton-to-proton flux ratio in cosmic rays is rigidity independent above 60 GV
3. Identical flux behavior for p, $\bar{p}$ and e^+ from 60-450 GV

The accuracy of the data from many different types of cosmic rays, require a comprehensive model to ascertain if their origin is from dark matter, astrophysical sources, acceleration mechanisms or a combination.