
# Antiproton Flux and Antiproton-to-Proton Flux Ratio Measured with the Alpha Magnetic Spectrometer on the ISS

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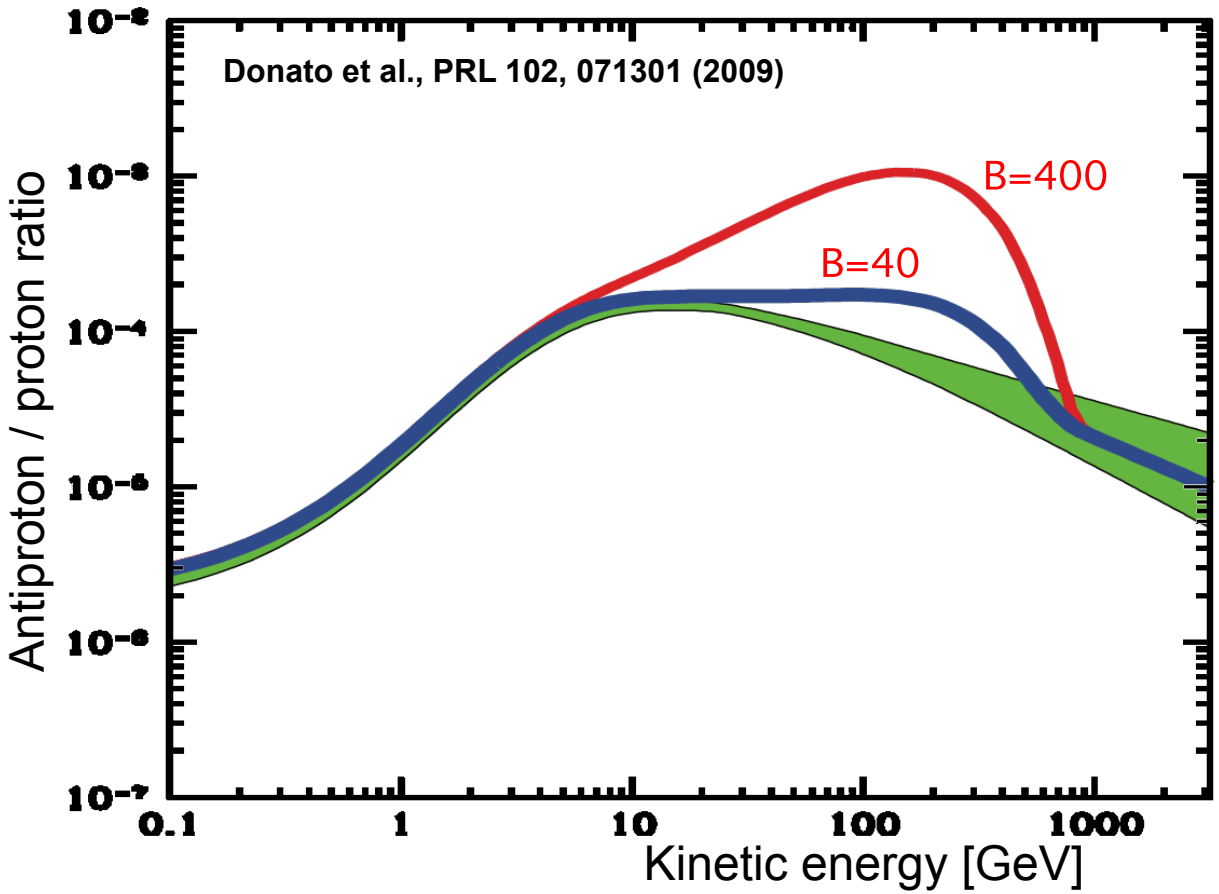
# Dark Matter and Cosmic Ray Antiprotons

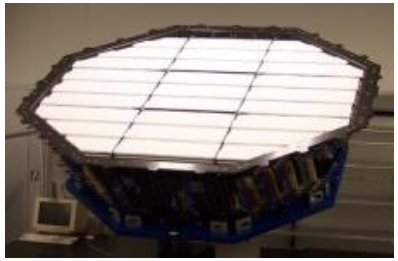
- ~85% of matter in the Universe is not visible and is called dark matter
- Collision of "ordinary" cosmic rays produce $\bar{p}$
- Annihilation of Dark Matter (neutralinos, $\chi$) will produce additional $\bar{p}$



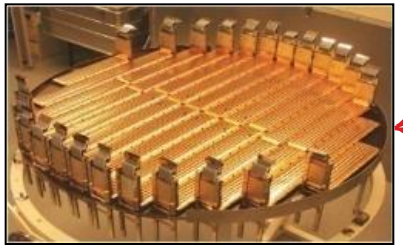
# AMS: A TeV precision, multipurpose spectrometer

Particles and nuclei are defined by their charge (Z) and energy (E)

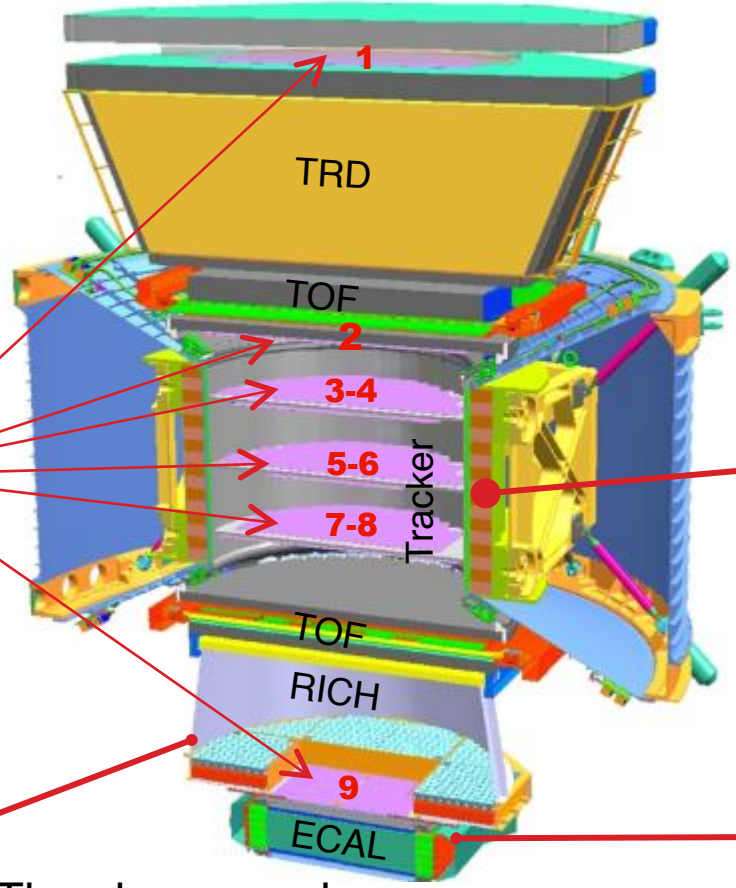
**Transition Radiation Detector**
**Identify $\bar{p}$**



**Silicon Tracker**
**Z, P**

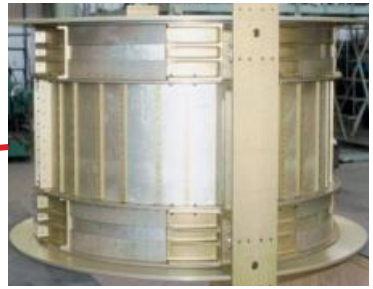


**Ring Imaging Cherenkov**
**Z, E**




**Time of Flight**
**Z, E**

**Magnet**
**± Z**

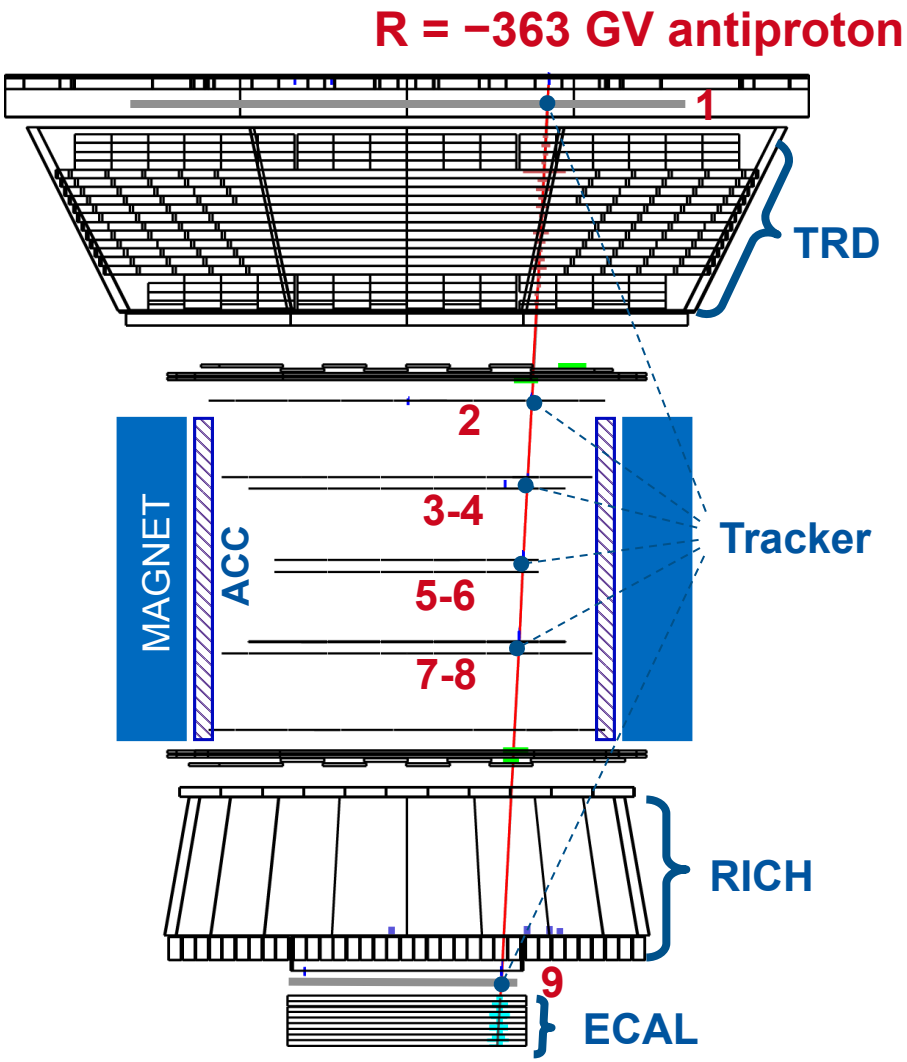


**Electromagnetic Calorimeter**
**Identify $\bar{p}$**

The charge and energy are measured independently by many detectors

# Event selection for the $\bar{p}/p$ analysis

- Primary cosmic ray particle:
  - |R| > 1.2·max cutoff
- TOF:
  - Down-going particle
  - β>0.3
- TRD:
  - at least 12 hits
- TRACKER:
  - Track quality
  - 0.8 < |Q| < 1.2
- ECAL:
  - Hadron shower shape



# Antiproton identification

**ISS data from May 19, 2011 to May 26, 2015**

- The number of antiprotons is determined from template fits.
- To maximize the measurement accuracy, different templates are used in three rigidity regions:

1. Low rigidity region: Electron, pion background
   1.00 - 4.02 GV The mass calculated from TOF and Tracker

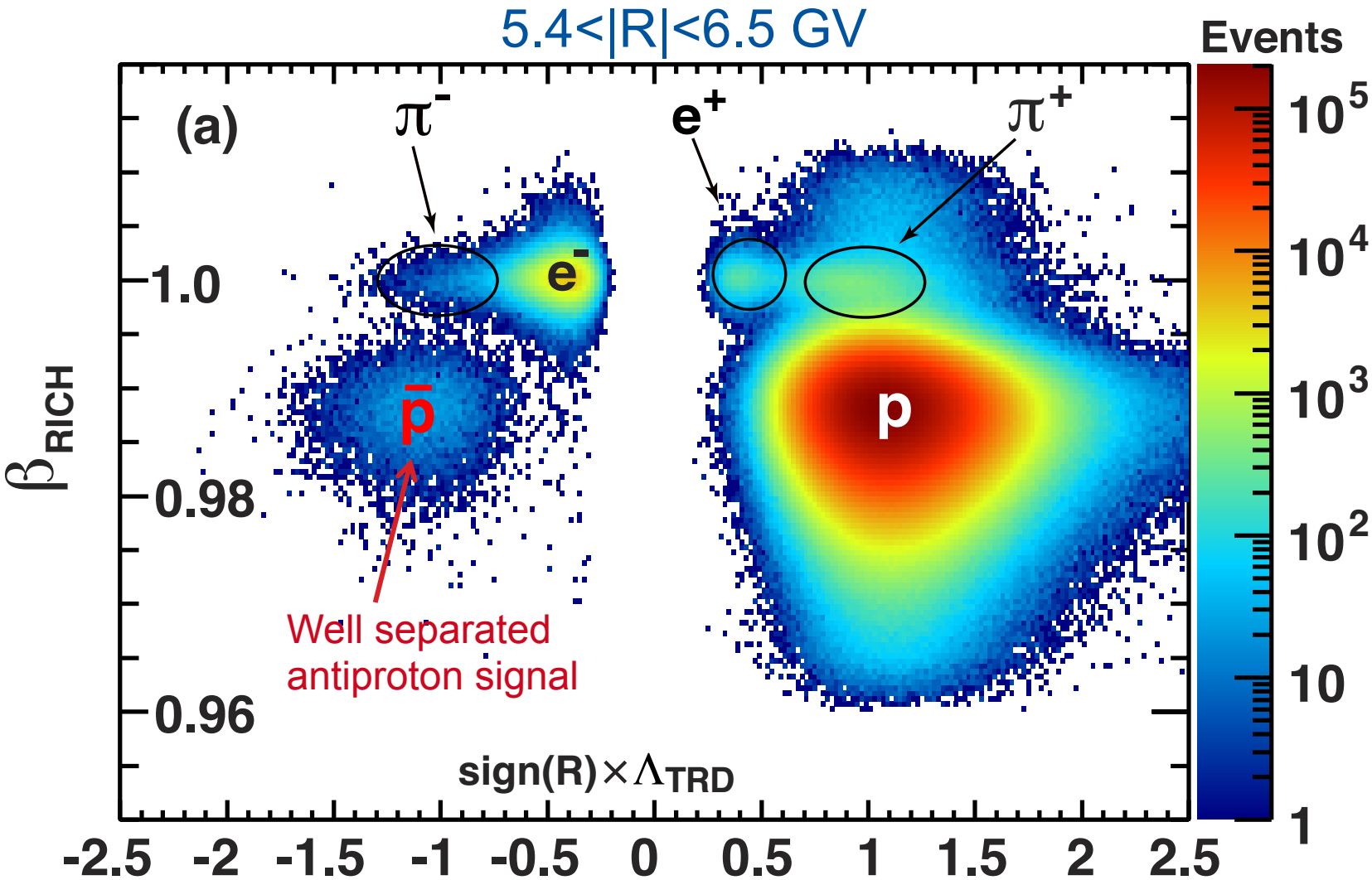
2. Intermediate region: Electron and small amount of pion background
   3.67 - 18.0 GV RICH and TRD estimator

3. High rigidity region: Electron and charge confusion proton background
   16.6 - 450 GV 2D template in ($\Lambda_{TRD}$ - $\Lambda_{CC}$ ) plane

- The regions overlap, the analysis with the smallest error is taken

**$3.49 \times 10^5$ antiprotons and $2.42 \times 10^9$ protons are selected in the rigidity range $1<|R|<450$ GV**

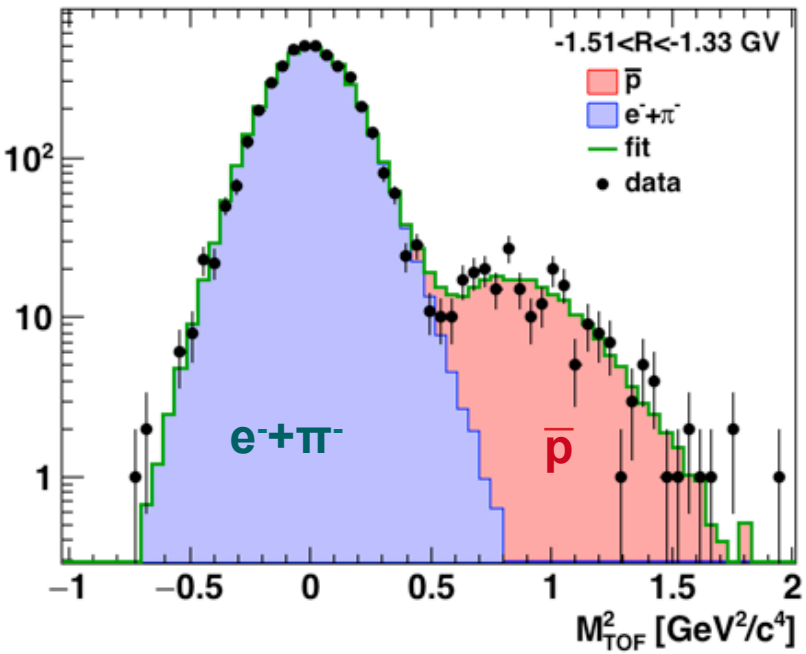
# Antiproton identification at intermediate rigidities



# Antiproton identification at low and intermediate rigidities

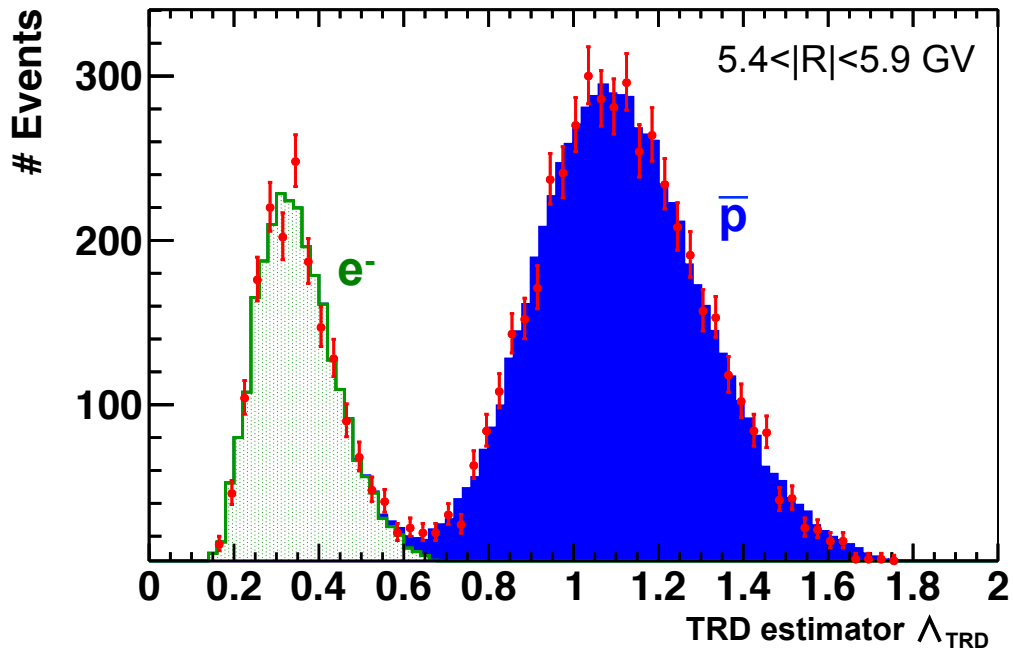
## Mass template fit

Template events selected via the RICH



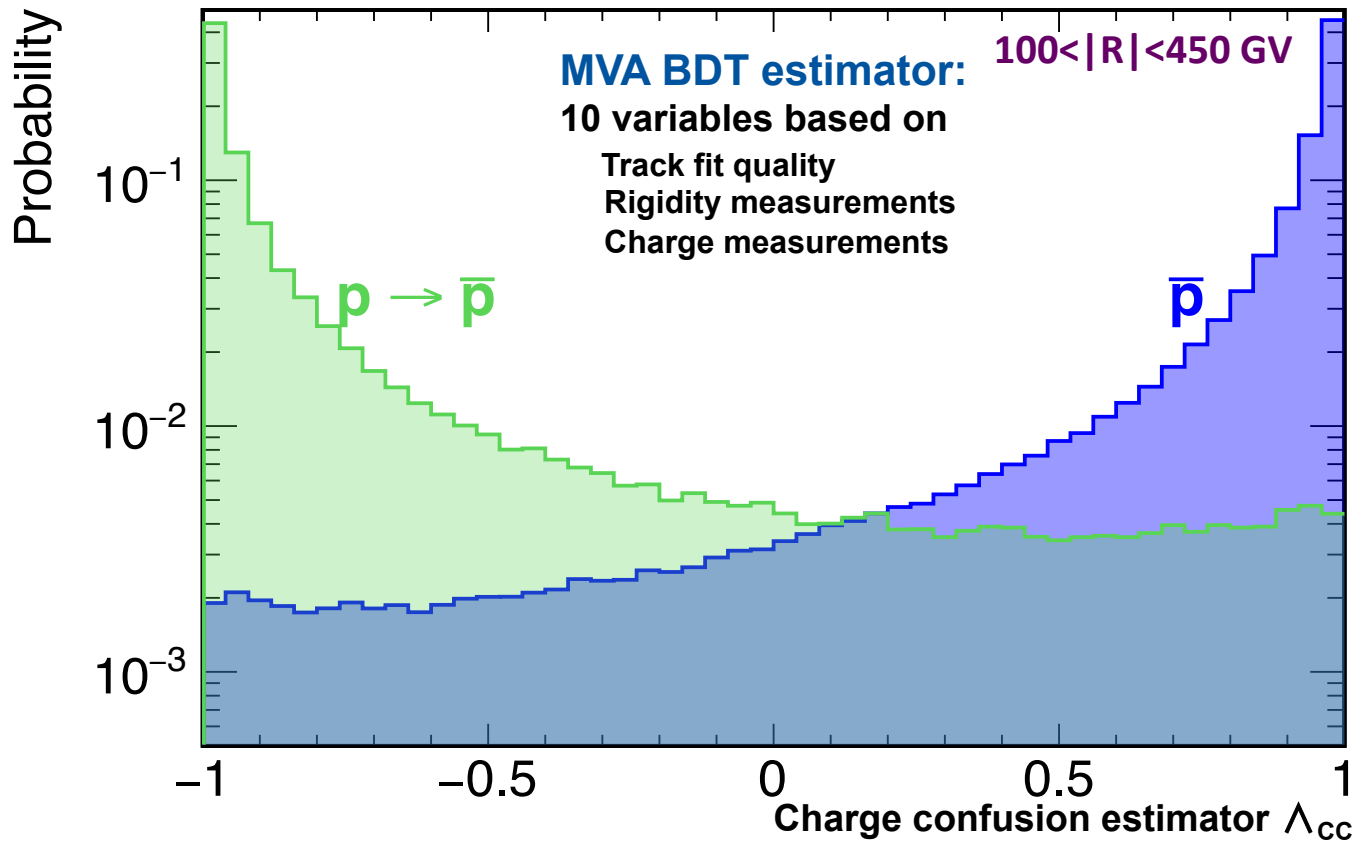

## TRD estimator template fit

Cut on RICH beta to remove Pions
Template events selected via the ECAL

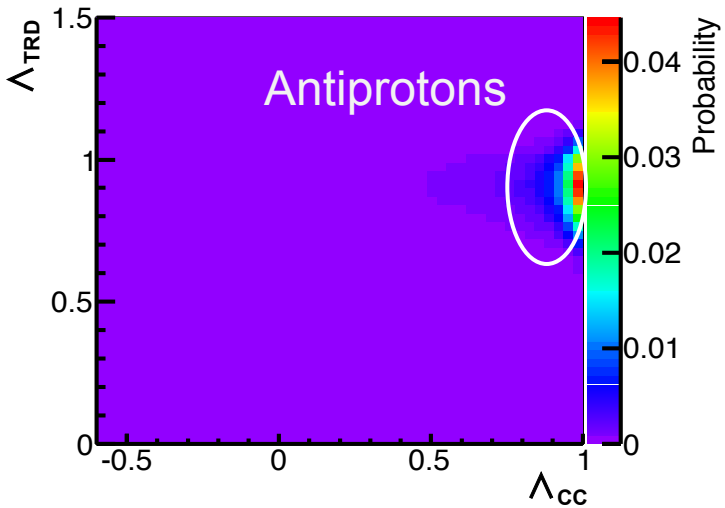


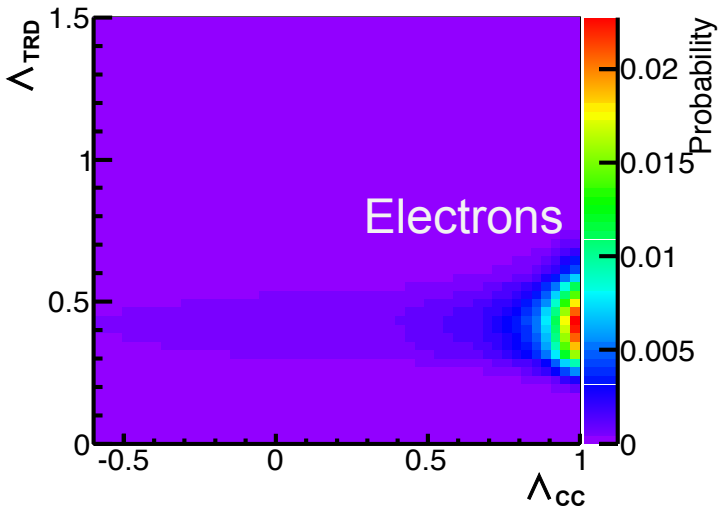
# Charge confusion estimator

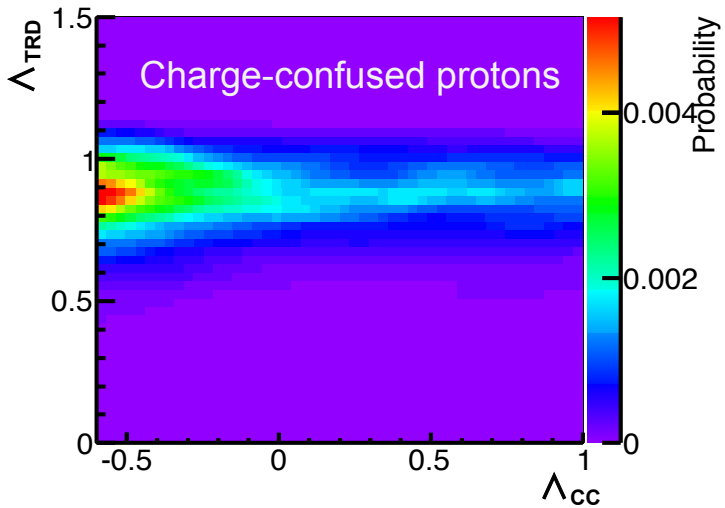
- Protons may be reconstructed with wrong charge sign, due to:
  - Finite tracker resolution
  - Particle interactions with detector material



# Antiproton identification at high rigidities



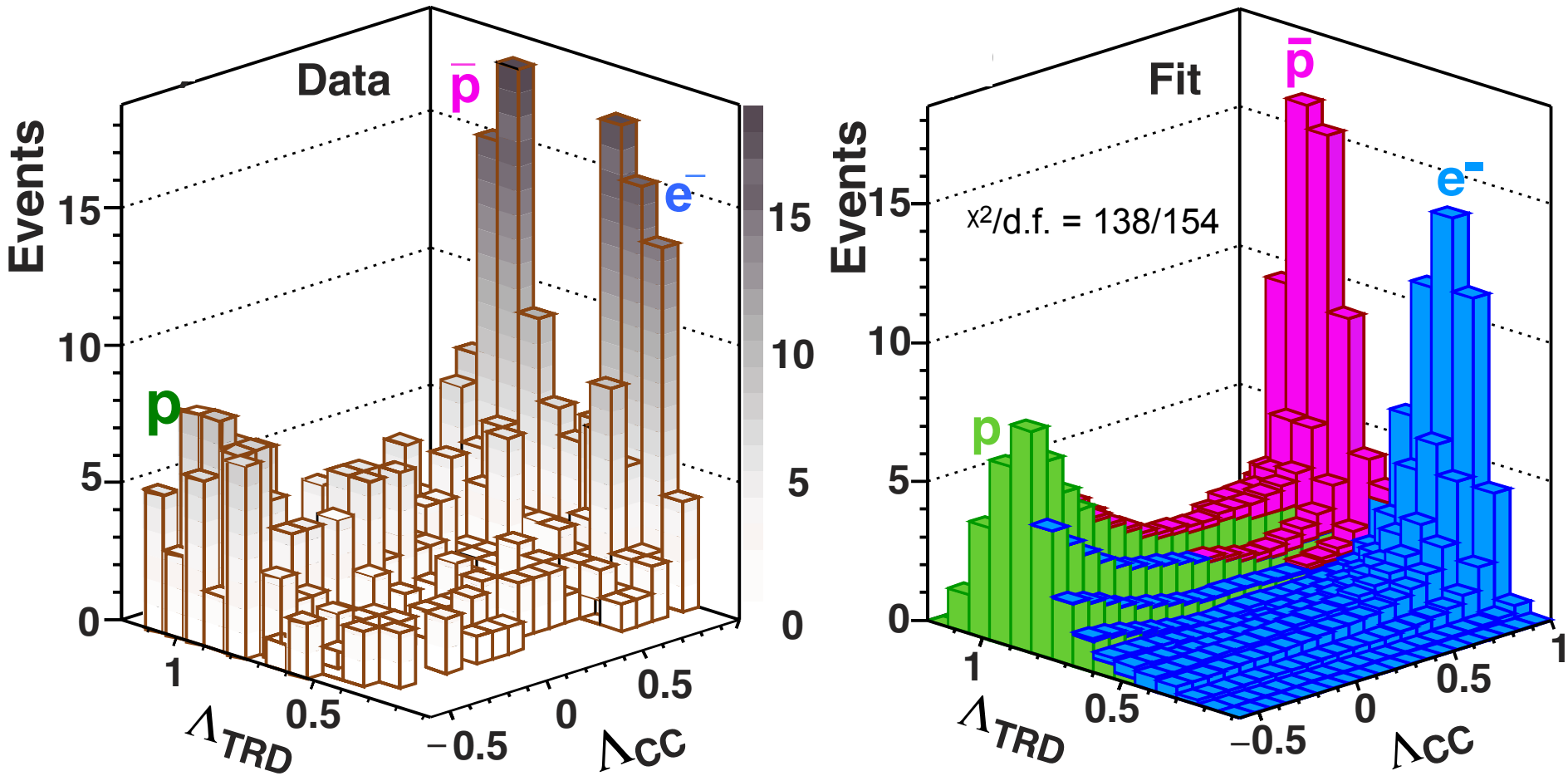




- 2D template in ( $\Lambda_{TRD}$ - $\Lambda_{CC}$ ) plane
- Antiproton template built from proton data
- Electron template from electron MC
- Charge-confused protons from proton MC
- Using Kernel Estimation to construct smooth templates

# Antiproton identification at high rigidities

## Example template fit at 175<|R|<211 GV



# Acceptance correction

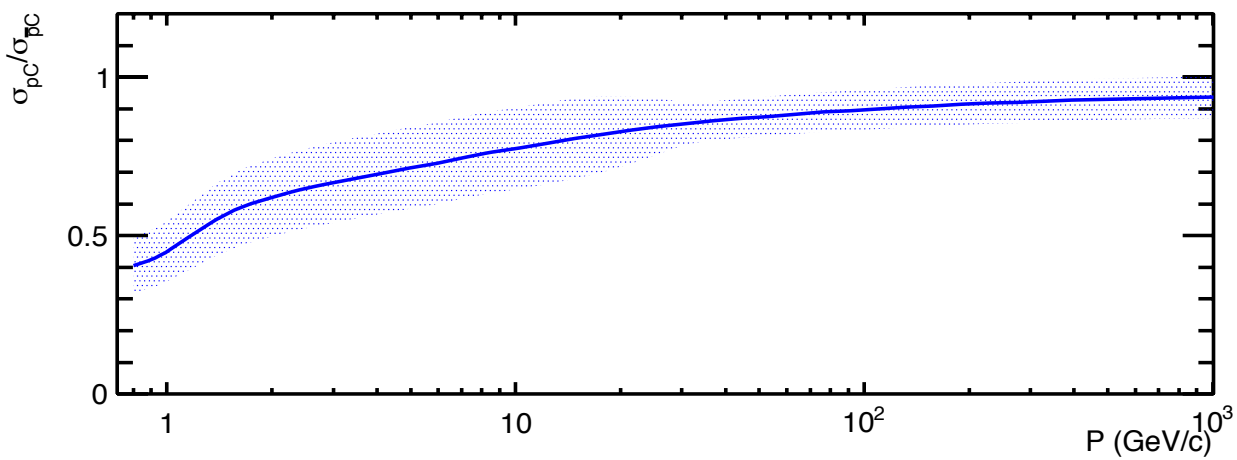
The antiproton-to-proton flux ratio is defined as

$$\left(\frac{\bar{p}}{p}\right)_i \equiv \frac{\Phi_i^{\bar{p}}}{\Phi_i^{p}} = \frac{\tilde{N}_i^{\bar{p}}}{\tilde{N}_i^{p}} \cdot \frac{\tilde{A}_i^{p}}{\tilde{A}_i^{\bar{p}}}$$

**Number of observed antiprotons and protons**

**Acceptance ratio of protons to antiprotons**

- The antiproton acceptance is different from the proton one, due to:
  1. Softer spectrum at low rigidities (unfolding)
  2. Larger inelastic cross section



# Systematic error sources

- Affect the antiproton counting $\sigma_N$
  - Cutoff
  - Selection
  - <u>Charge confusion templates</u>

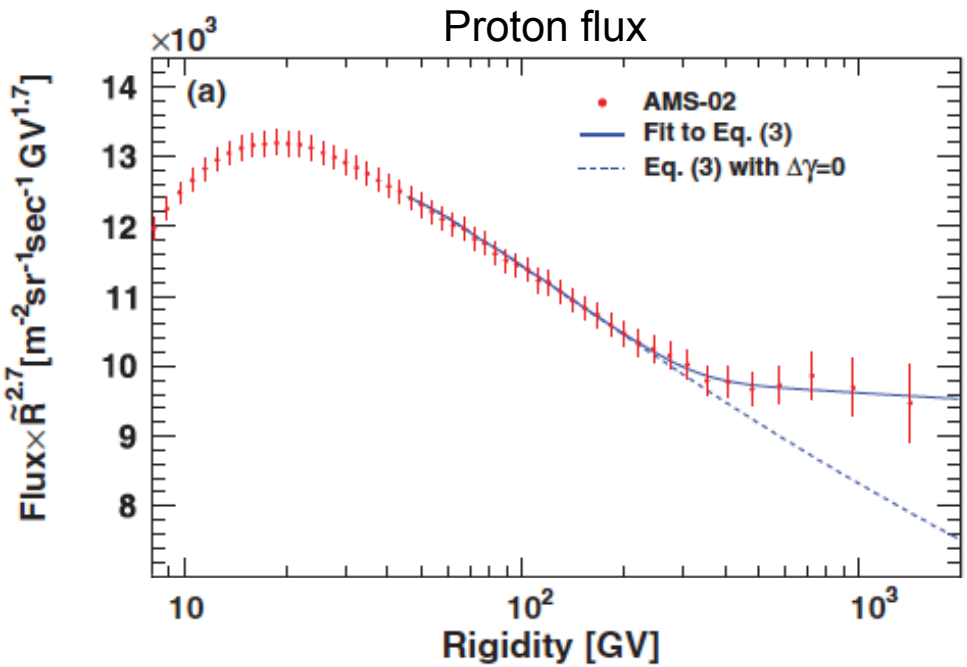
- Affect the acceptance, $\sigma_A$
  - <u>Cross sections</u>
  - MC statistic fluctuations
  - Migration matrix

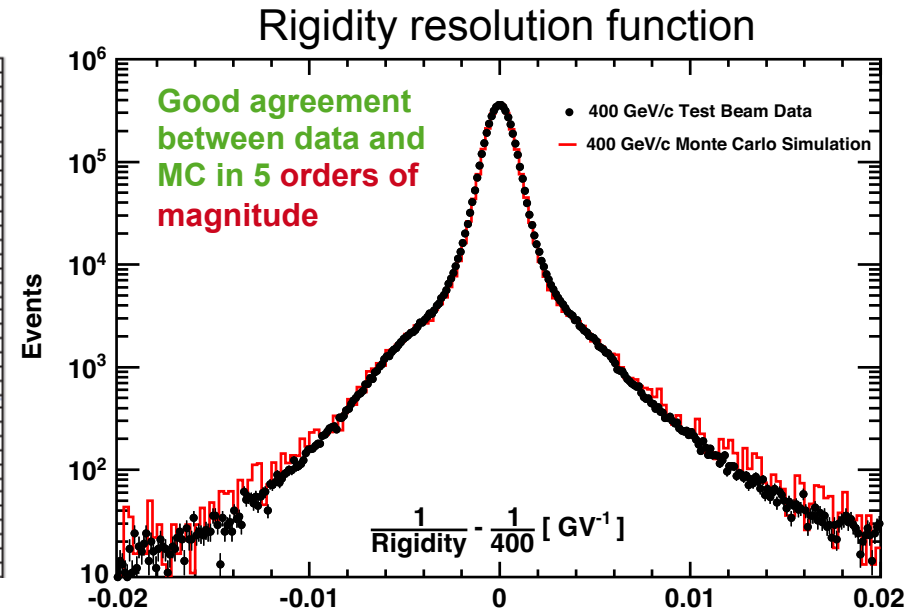
- <u>Rigidity scale, $\sigma_R$</u>

# Systematic error from charge confusion templates

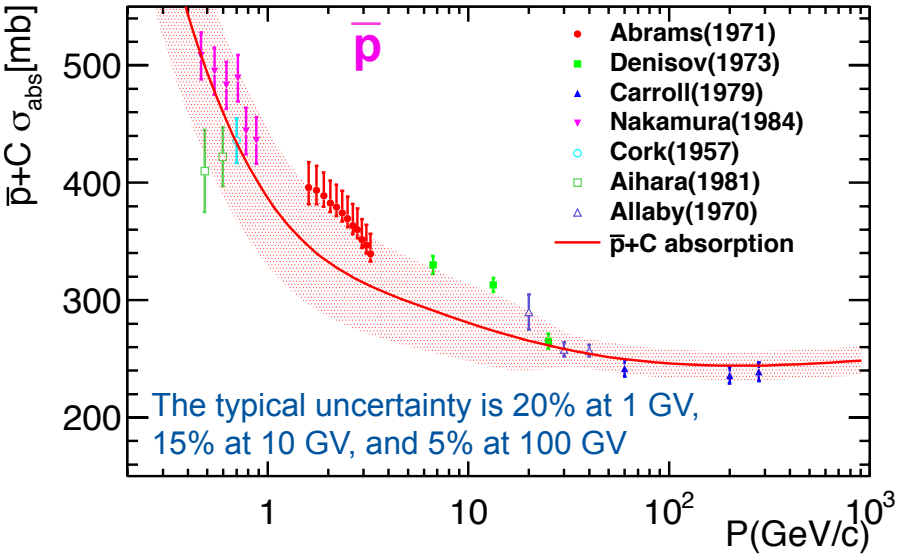
- The uncertainty of the proton flux in the TV region
  - Varying the spectral index of the proton flux within the accuracy of our proton measurement

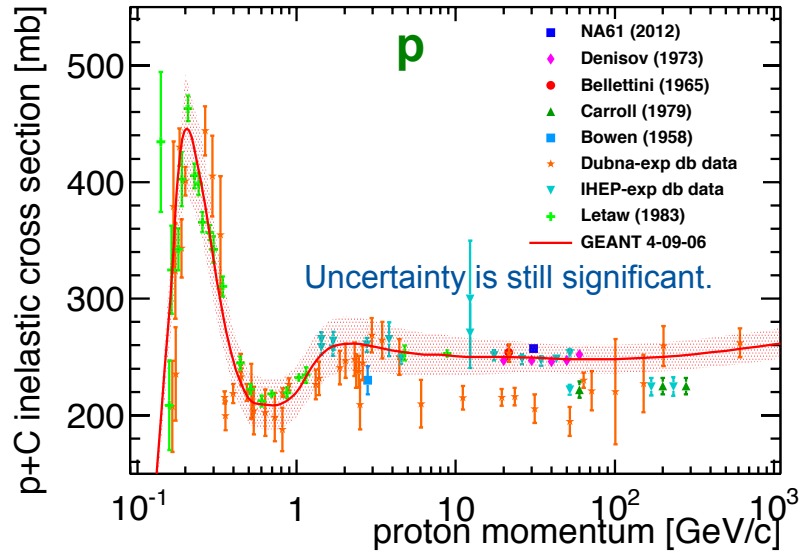
- The uncertainty of the proton rigidity resolution function
  - Comparing the charge confusion amount predicted by the Monte Carlo simulation with the one obtained from the fit

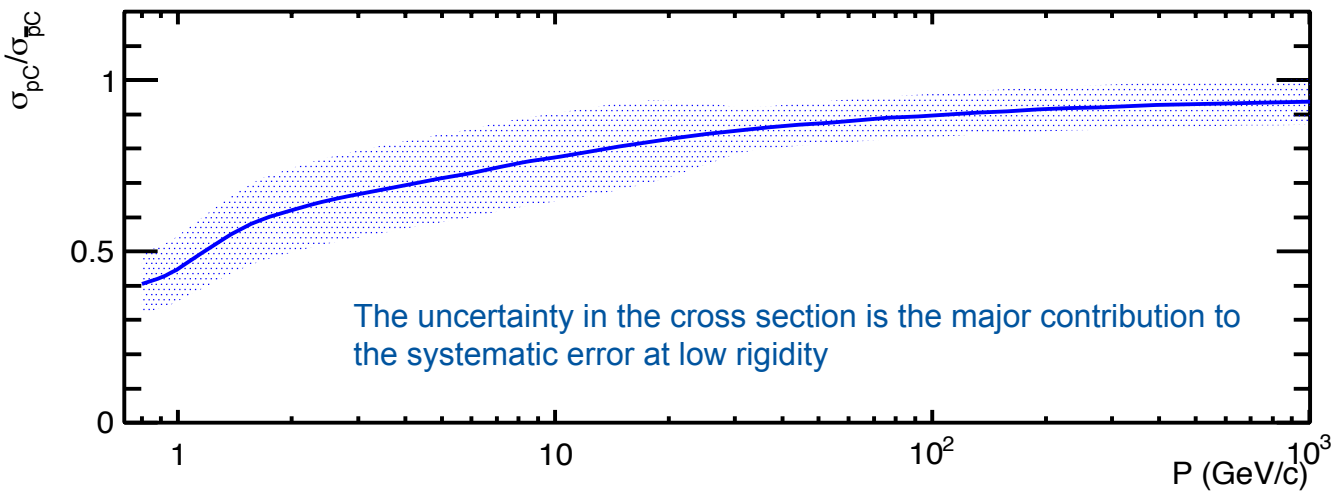


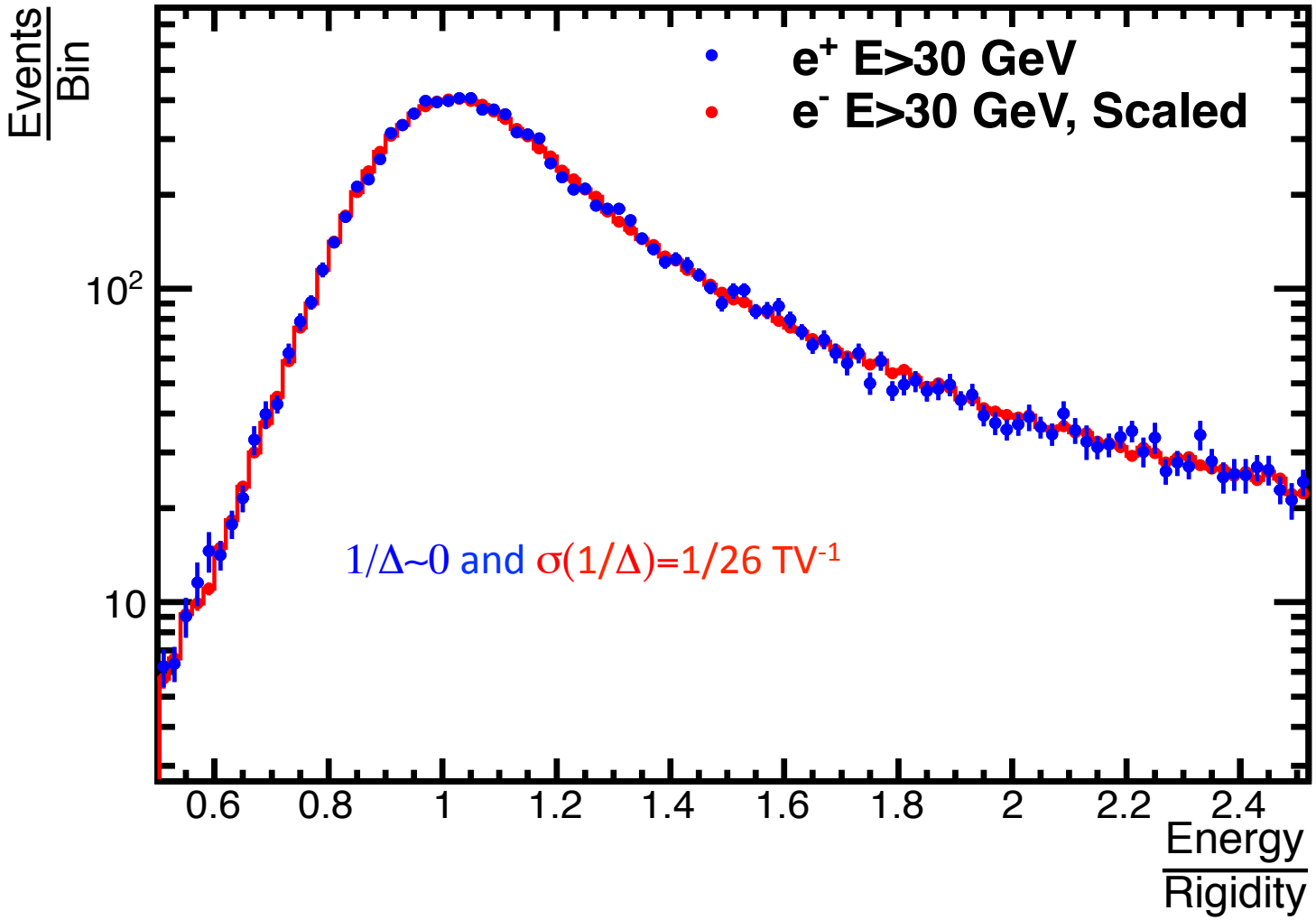
# Systematic error from acceptance correction



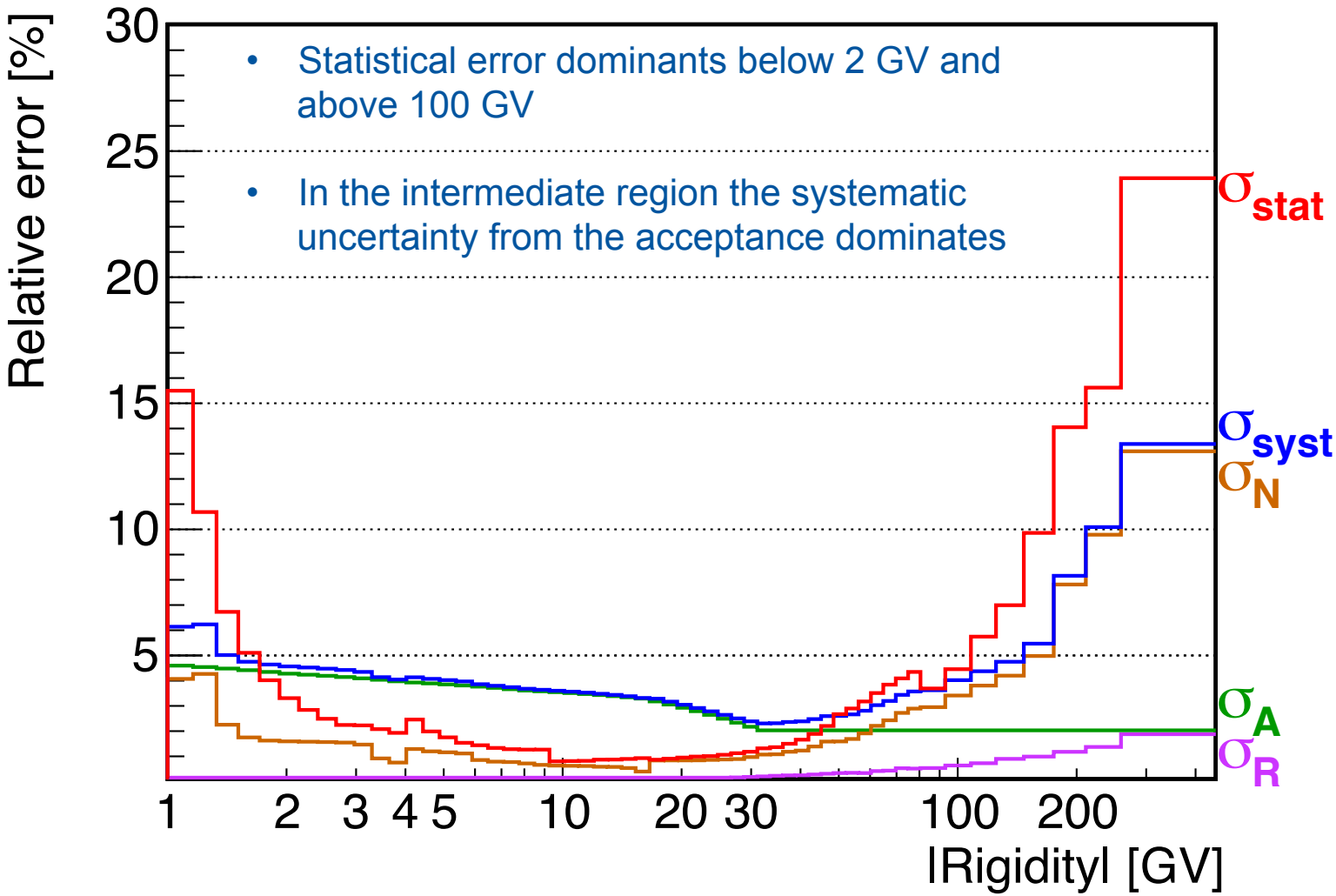



# Systematic error from the rigidity scale uncertainty



# Error breakdown

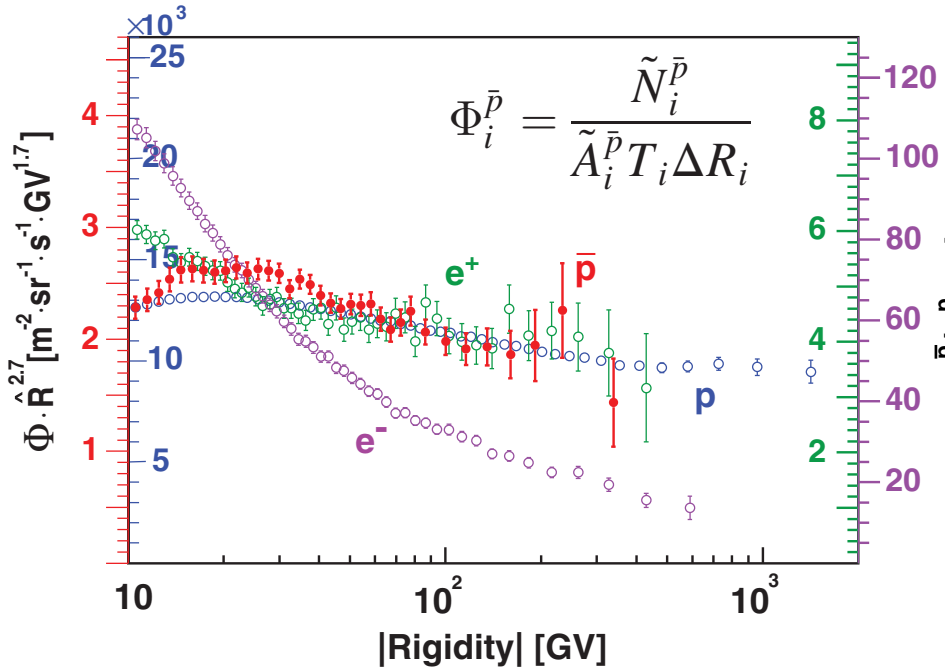



- Statistical error dominants below 2 GV and above 100 GV
- In the intermediate region the systematic uncertainty from the acceptance dominates

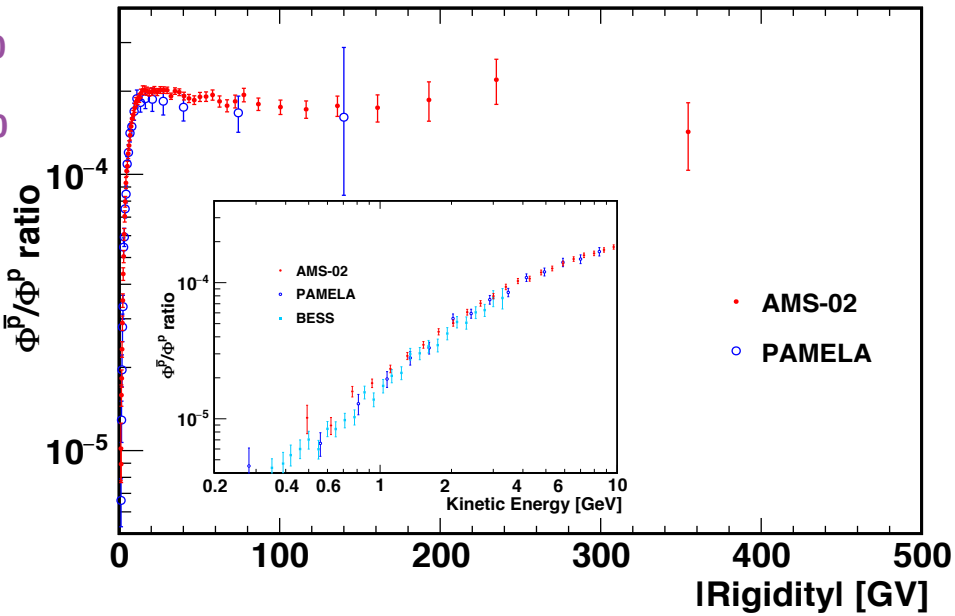
# Antiproton Flux in comparison to other species and Antiproton-to-Proton Flux Ratio

**3.49 x $10^5$ antiprotons / 2.42 x $10^9$ protons**

Fluxes




Antiproton to proton flux ratio



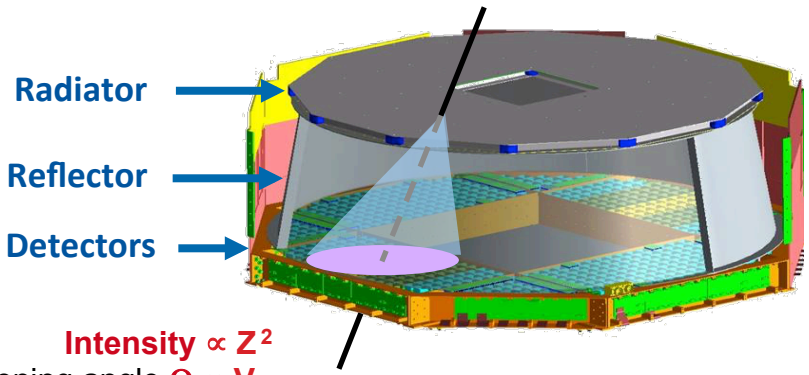

- The antiproton-to-proton flux ratio reaches its maximum at 20 GV
- The antiproton-to-proton flux ratio shows no rigidity dependence above 60 GV

## Summary

- Antiproton-to-proton flux ratio to 450 GV measured by AMS-02 based on $3.49 \times 10^5$ antiprotons and $2.42 \times 10^9$ protons
- The antiproton-to-proton flux ratio reaches its maximum at 20 GV
- The antiproton-to-proton flux ratio shows no rigidity dependence above 60 GV
- We will collect more data to further explore the high rigidity region

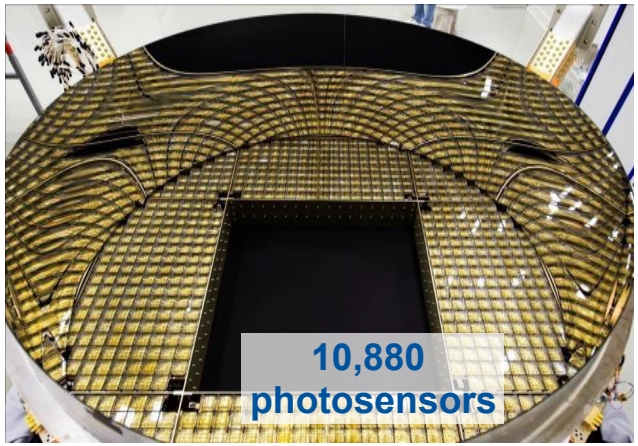
# Backup

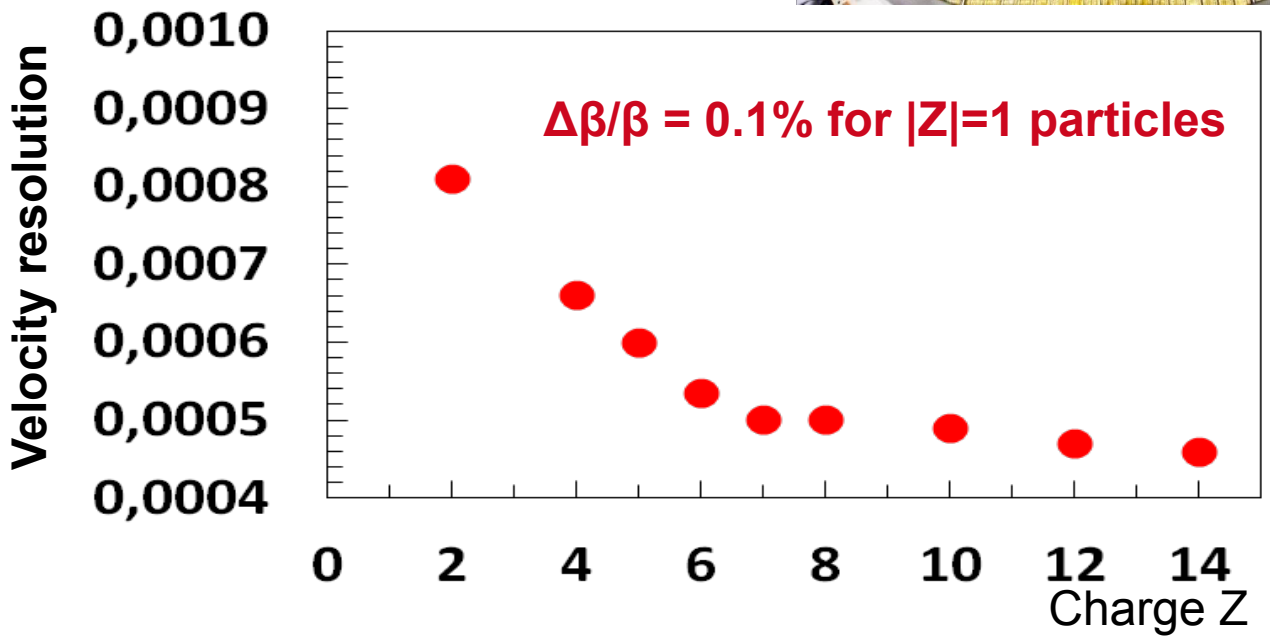
# Ring Imaging Cherenkov detector RICH




Intensity $\propto Z^2$

The opening angle $\Theta \propto V$



# Unfolding

The antiproton flux is given by

$$\Phi_i^{\bar{p}} = \frac{N_i^{\bar{p}}}{A_i^{\bar{p}}\, T_i\, \Delta R_i}$$

Number of events

Effective acceptance

After the completion of the unfolding procedure, the flux is expressed as

$$\Phi_i^{\bar{p}} = \frac{\tilde{N}_i^{\bar{p}}}{\tilde{A}_i^{\bar{p}}\, T_i\, \Delta R_i}$$

Number of observed events

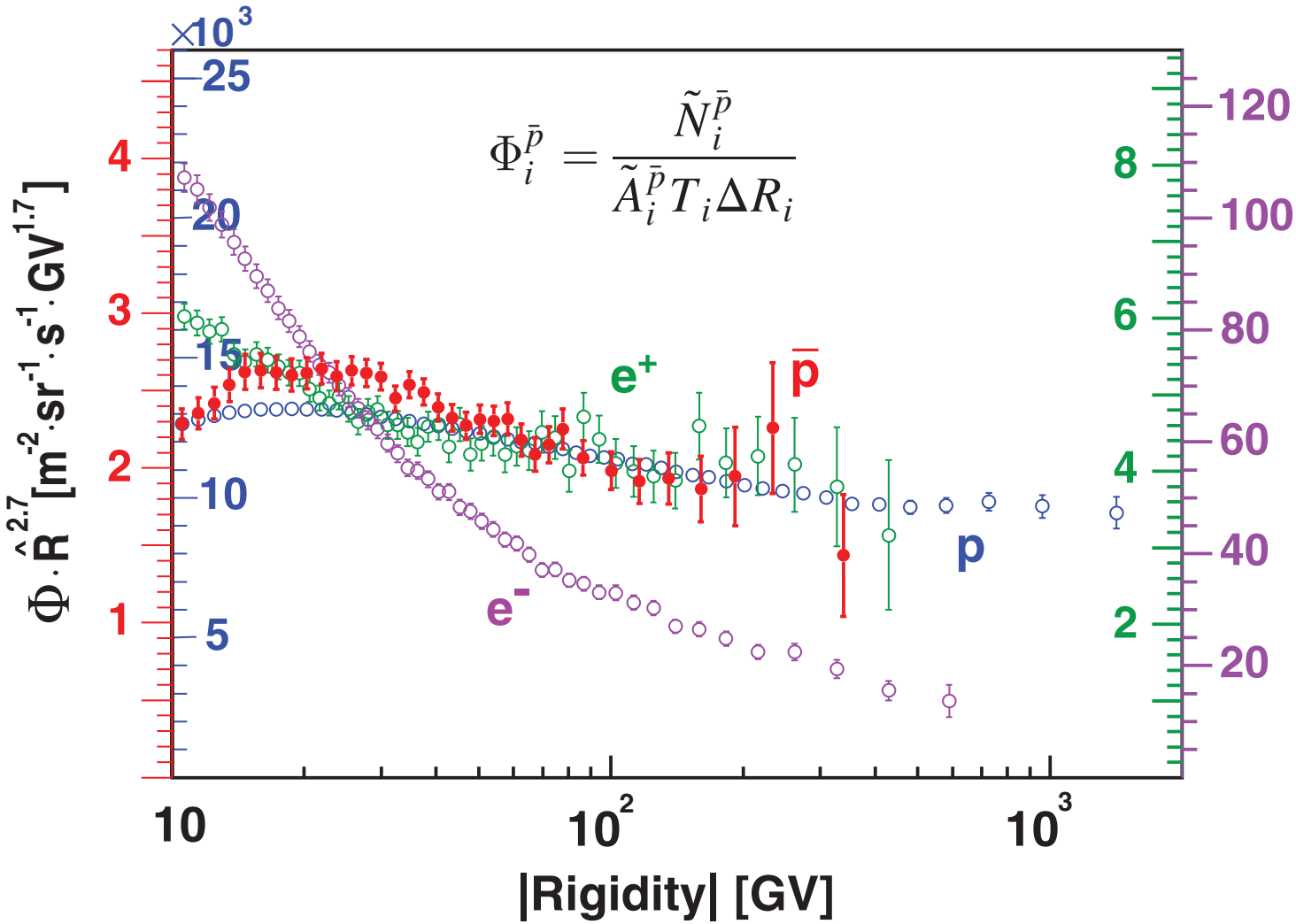
Folded acceptance

The antiproton-to-proton flux ratio is defined as

$$\left(\frac{\bar{p}}{p}\right)_i \equiv \frac{\Phi_i^{\bar{p}}}{\Phi_i^{p}} = \frac{\tilde{N}_i^{\bar{p}}}{\tilde{N}_i^{p}} \cdot \frac{\tilde{A}_i^{p}}{\tilde{A}_i^{\bar{p}}}$$

**Counting** **Acceptance correction**

# Antiproton Flux in comparison to other species



# Antiproton-to-Proton Flux Ratio

**3.49 x $10^5$ antiprotons / 2.42 x $10^9$ protons**