AMS Results and Prospects

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Physics 290E Seminar
21 October 2015

Outline

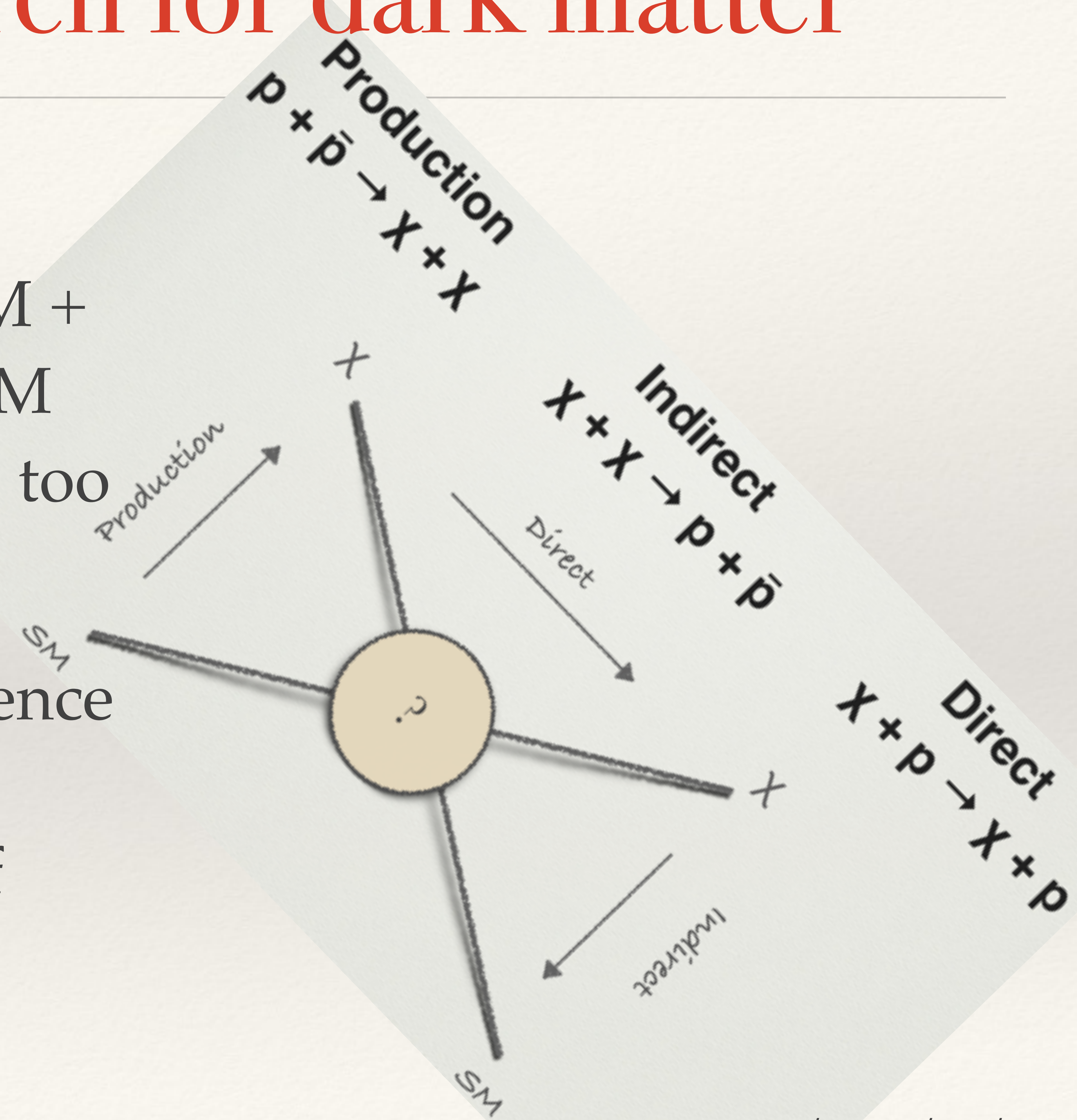
- Dark matter
- AMS Instrument
- Results
- Prospects

Dark Matter: Where is it?

- Many convincing observations of some kind of dark matter via gravitational effects
- Zero convincing observations of dark matter via any other kind of interaction

How to search for dark matter

- Maybe looking for DM + SM → stuff or SM + SM → DM is not worth it, too hard, etc.
- Instead, look for evidence of dark matter by observing products of DM annihilation



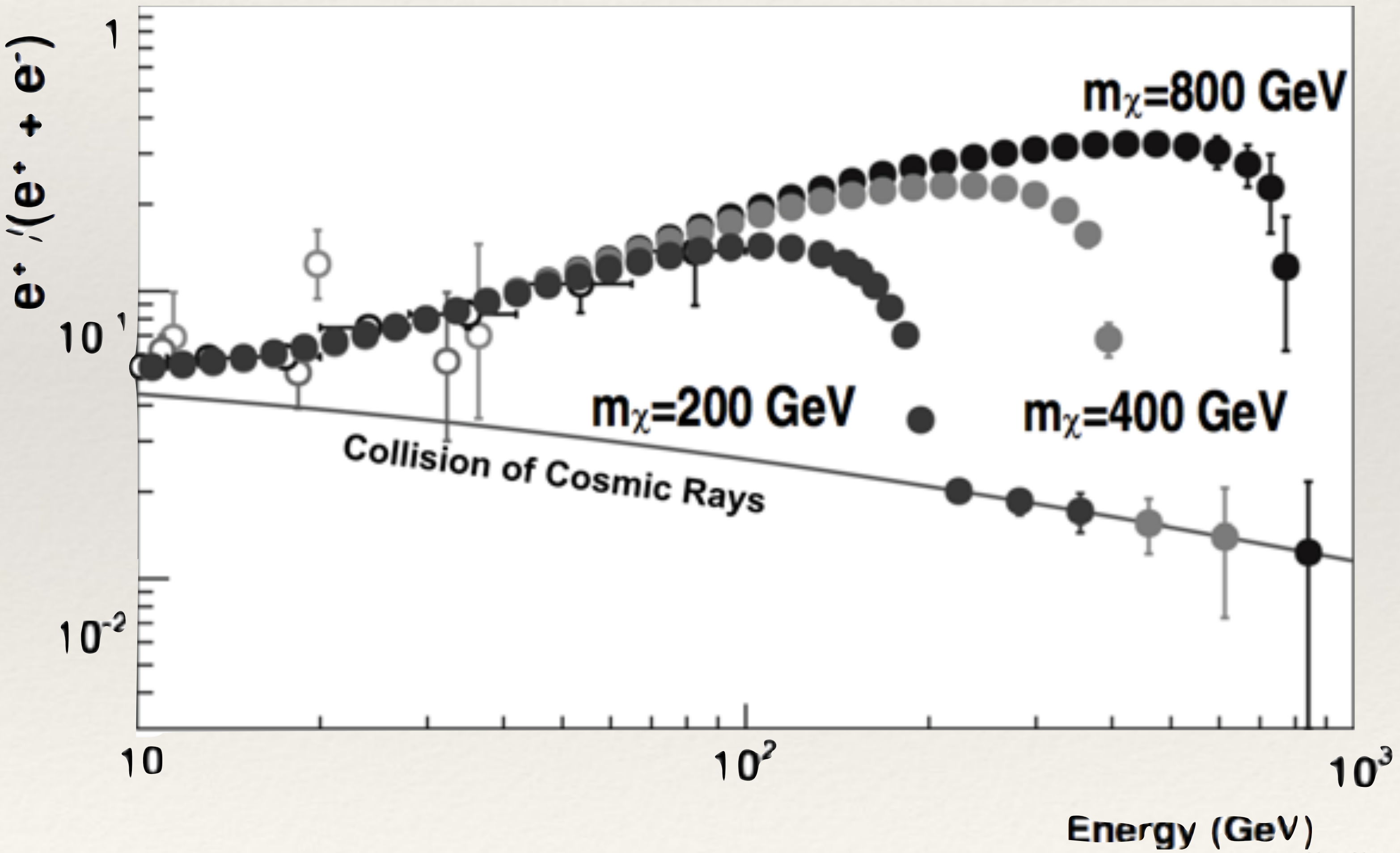
quantumdiaries.org/2014/10/22

Signal of dark matter annihilation

- Could annihilate into e^+/e^- pairs
- Experimental signal is extra e^+'s and e^-'s
- How to distinguish from other sources?
  - Additional positrons stand out much more than additional electrons since our galaxy (universe?) is made of matter, not antimatter
  - Still have poor understanding of production of positrons

Quantity to measure

- Solution: take ratio $N_+ / (N_+ + N_-)$
- a.k.a. the "positron fraction"



Expected signal for various masses of dark matter [1]


Alpha Magnetic Spectrometer
AMS-02
Europe • Asia
North America

Basic Concept: Measure everything

- “General Purpose” particle detector
- Components:
  - transition radiation detector
  - time of flight system
  - silicon trackers
  - magnet
  - anti-coincidence counter
  - ring imaging cherenkov
  - electromagnetic calorimeter

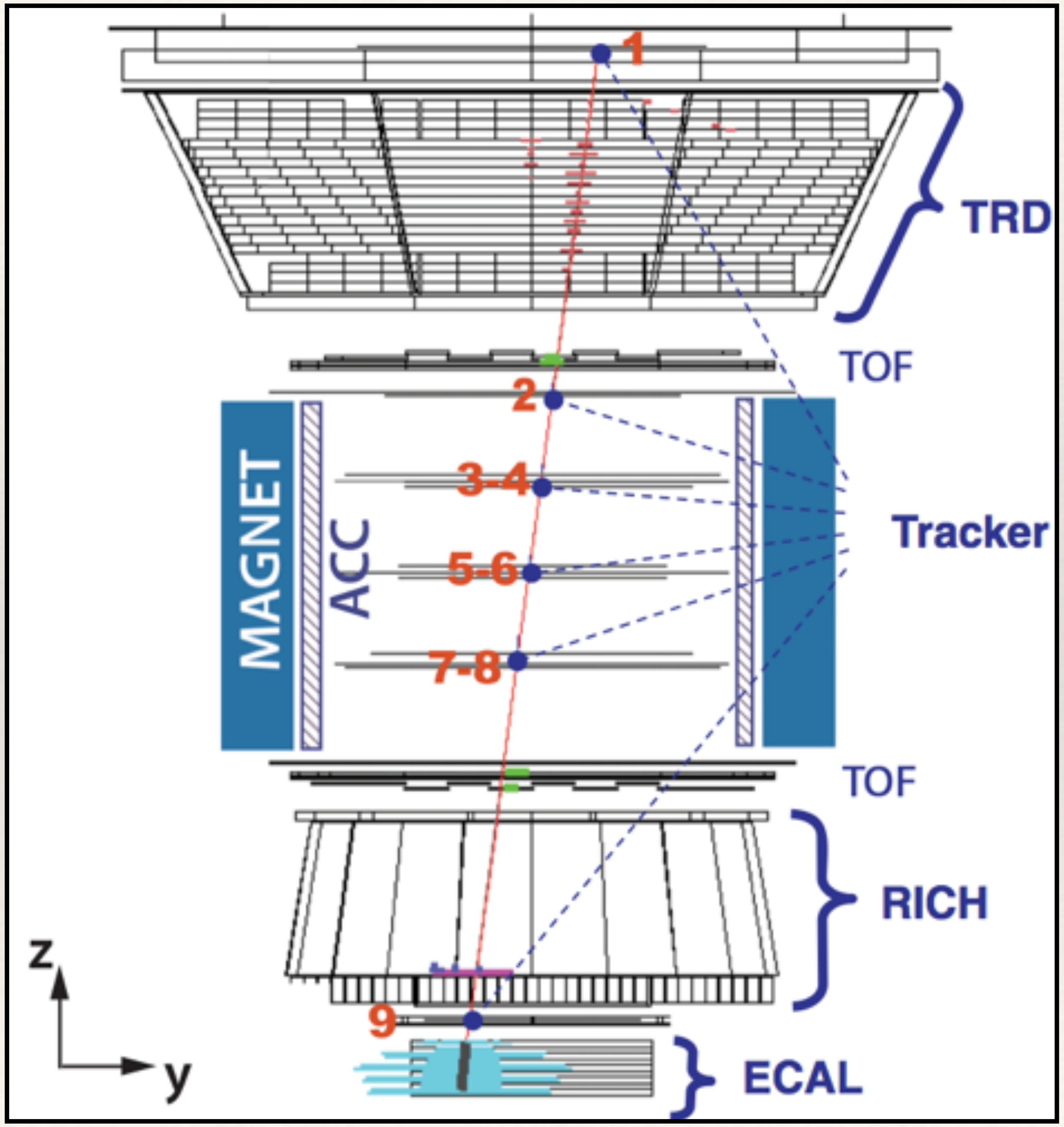
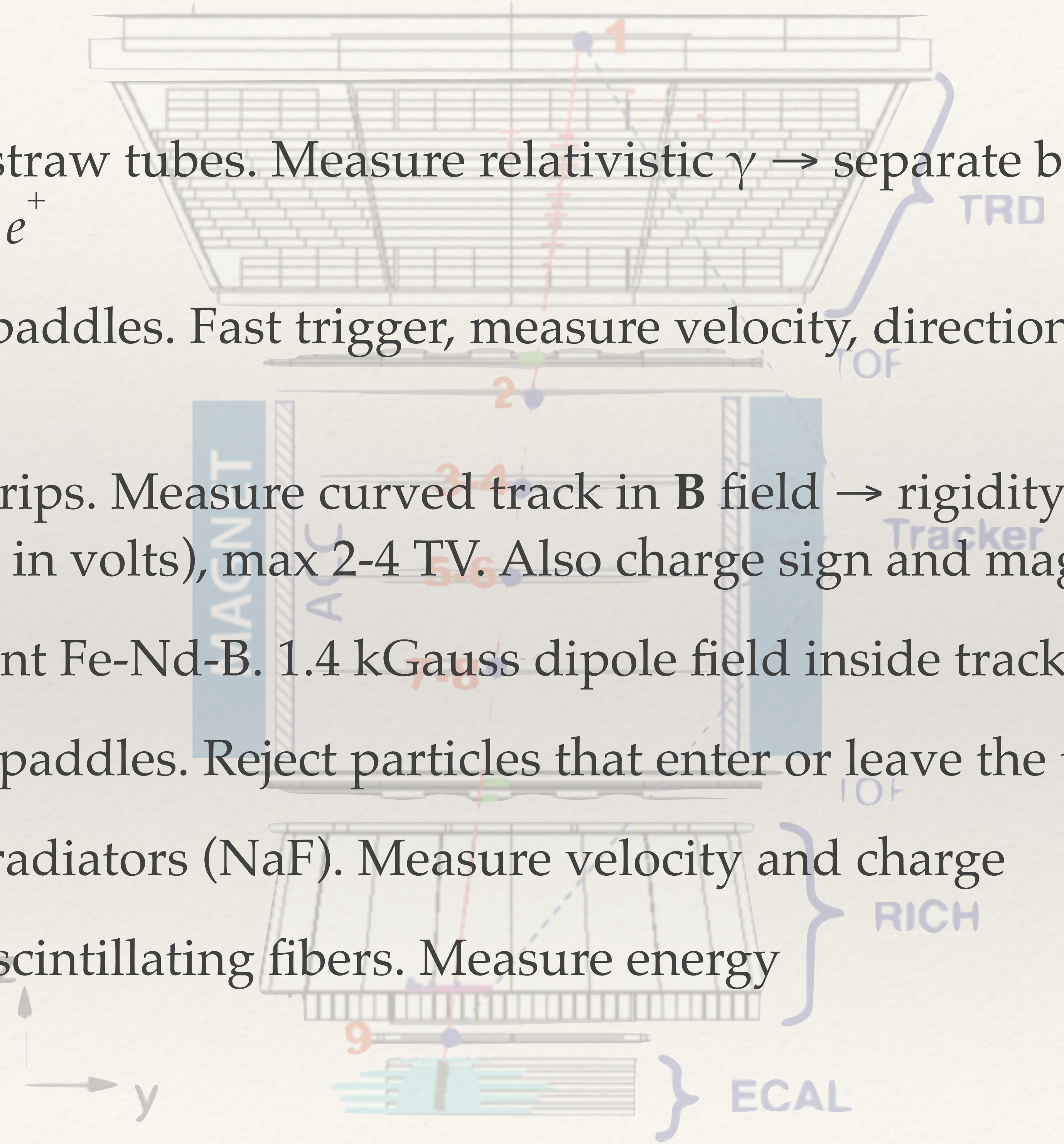


Diagram of AMS [2]

Instrumentation details



- TRD: Radiator + straw tubes. Measure relativistic γ → separate by mass → distinguish p and e^+
- TOF: Scintillator paddles. Fast trigger, measure velocity, direction (up vs. down), and charge
- Tracker: Silicon strips. Measure curved track in **B** field → rigidity (= momentum / charge, measured in volts), max 2-4 TV. Also charge sign and magnitude
- Magnet: Permanent Fe-Nd-B. 1.4 kGauss dipole field inside tracking volume.
- ACC: Scintillator paddles. Reject particles that enter or leave the tracking volume
- RICH: Dielectric radiators (NaF). Measure velocity and charge
- ECAL: Lead and scintillating fibers. Measure energy

Instrumentation details

Many redundancies

- TRD: Radiator + straw tubes. Measure relativistic $\gamma \rightarrow$ separate by mass $\rightarrow$ distinguish p and e^{+}
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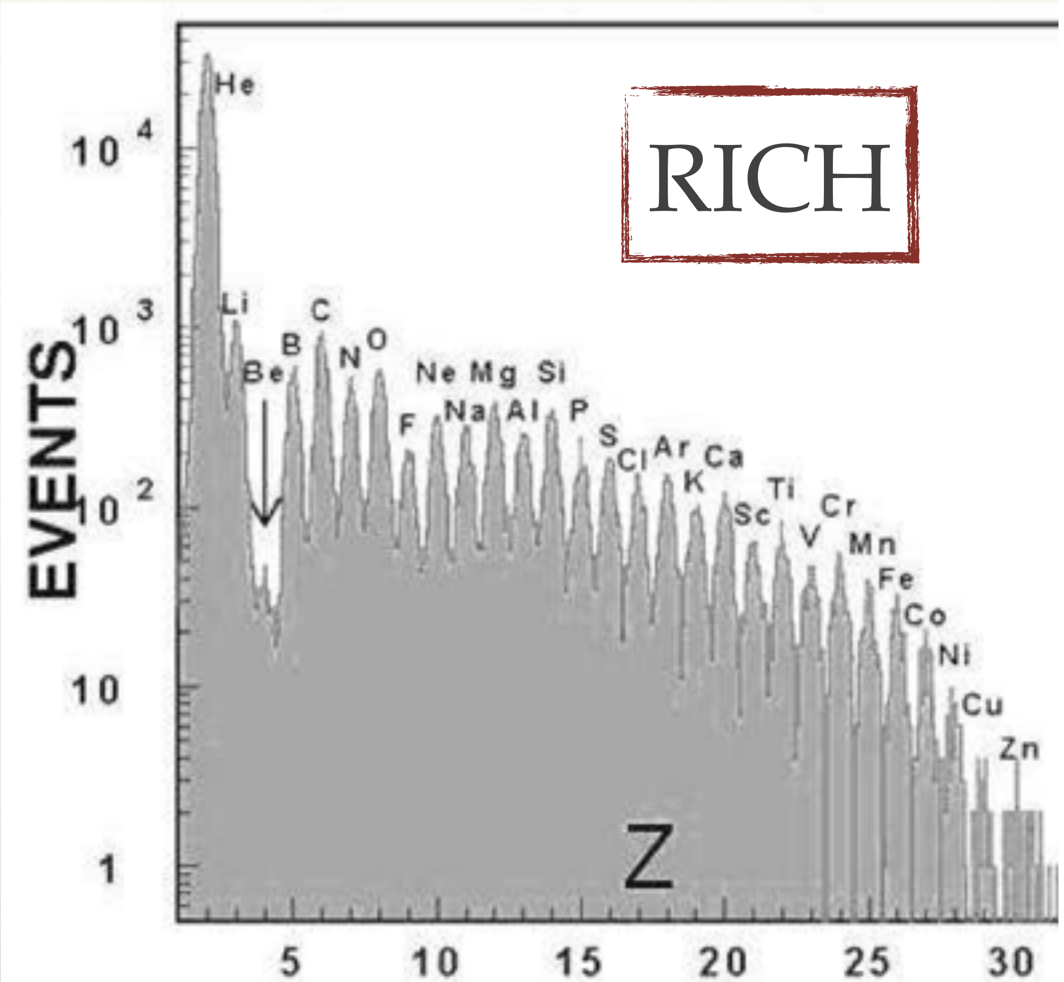
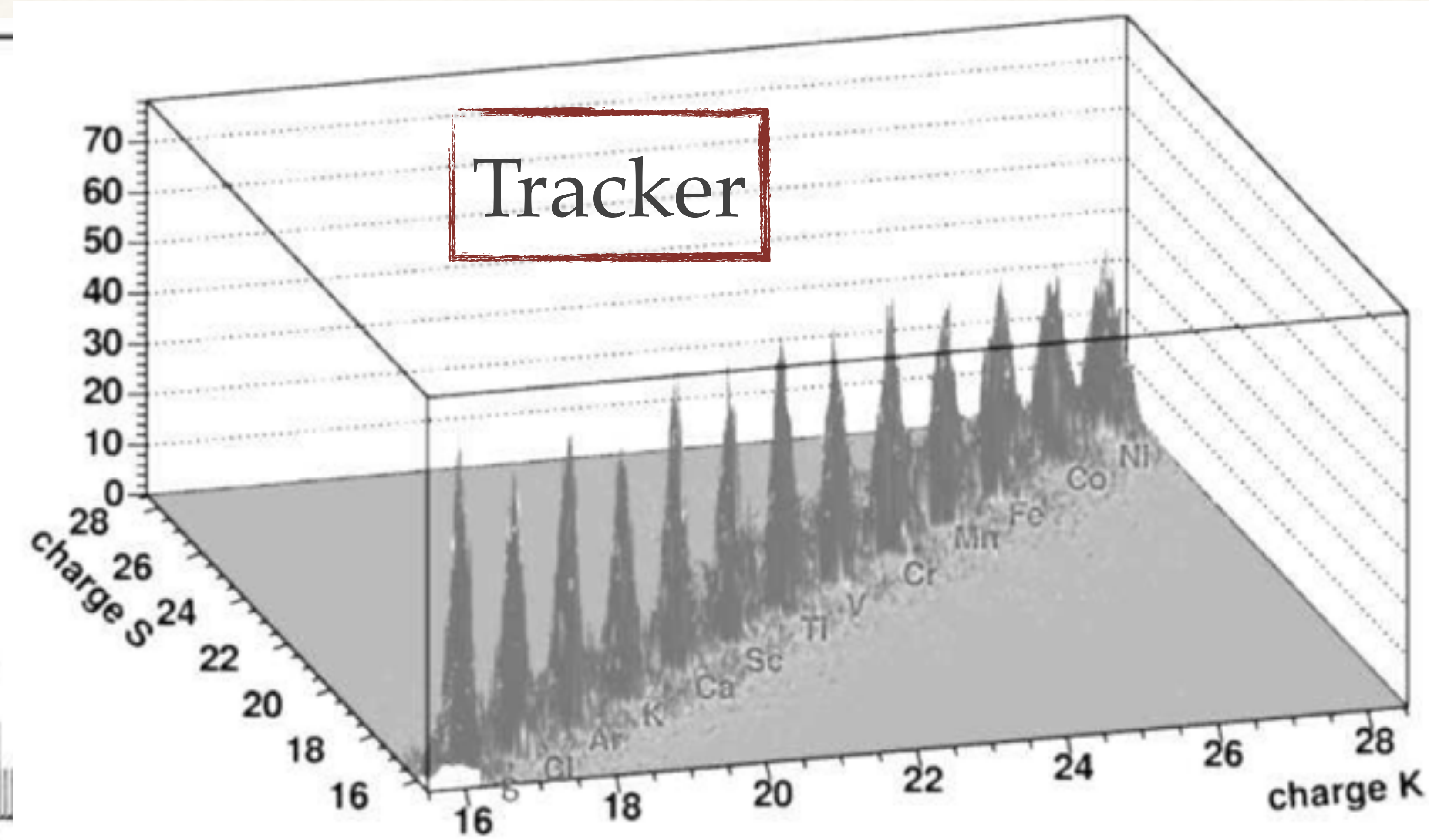
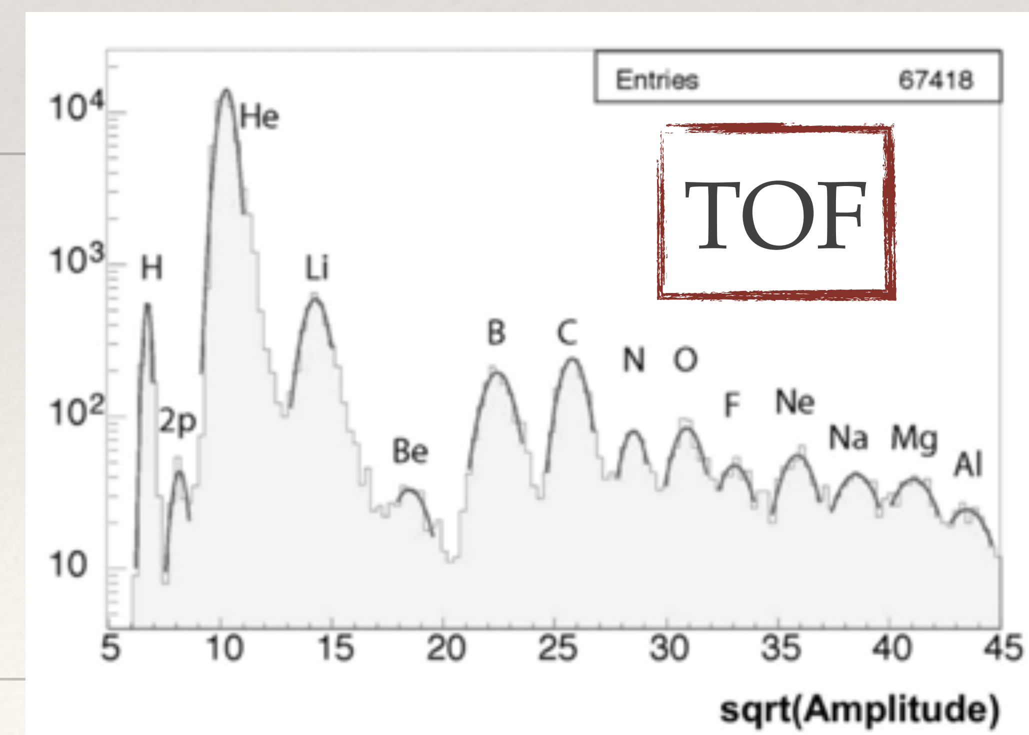
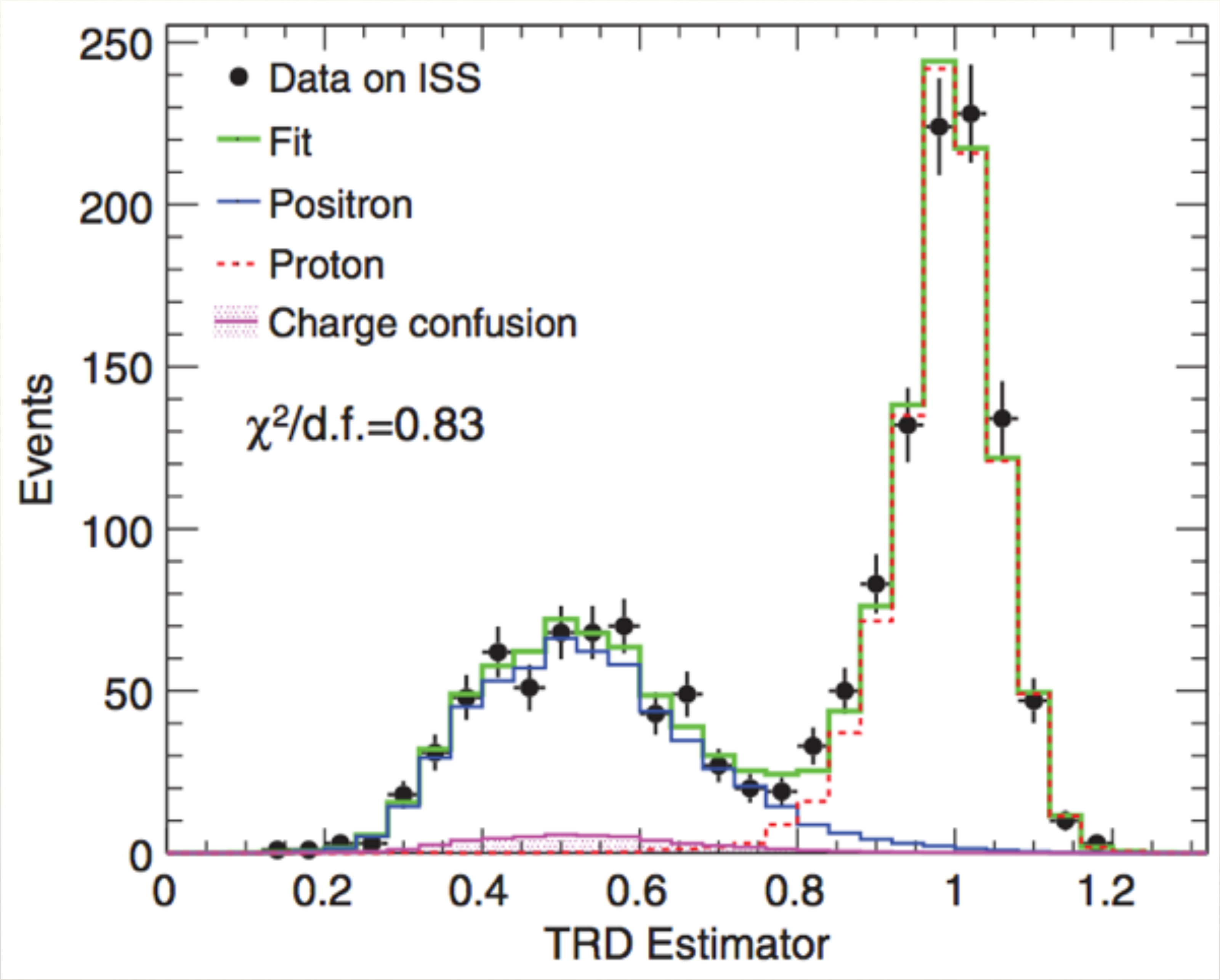






Detector performance in a test beam [1]

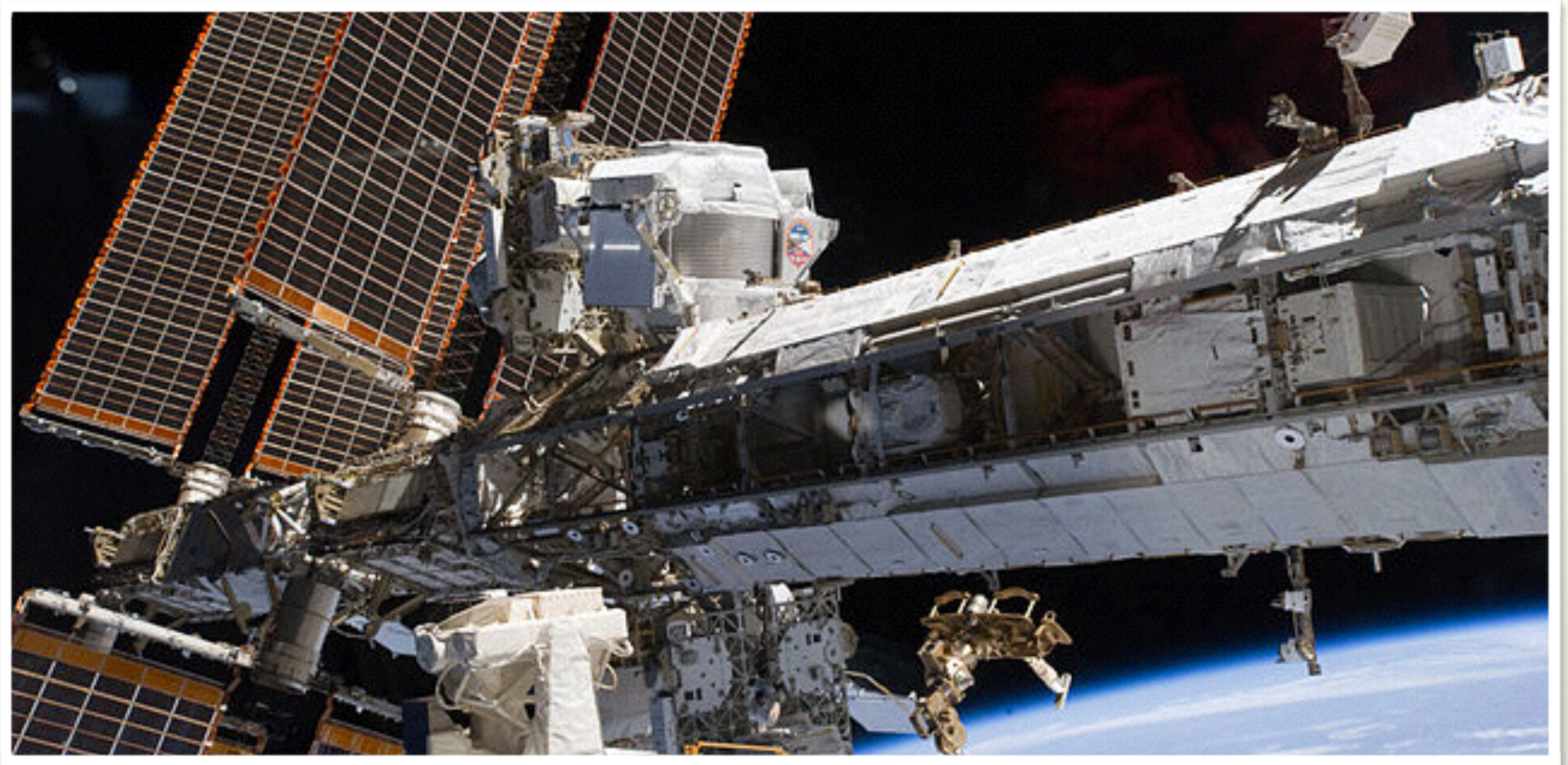
Example of instrument resolution



Separation power of the transition radiation detector's log-likelihood estimator [2]

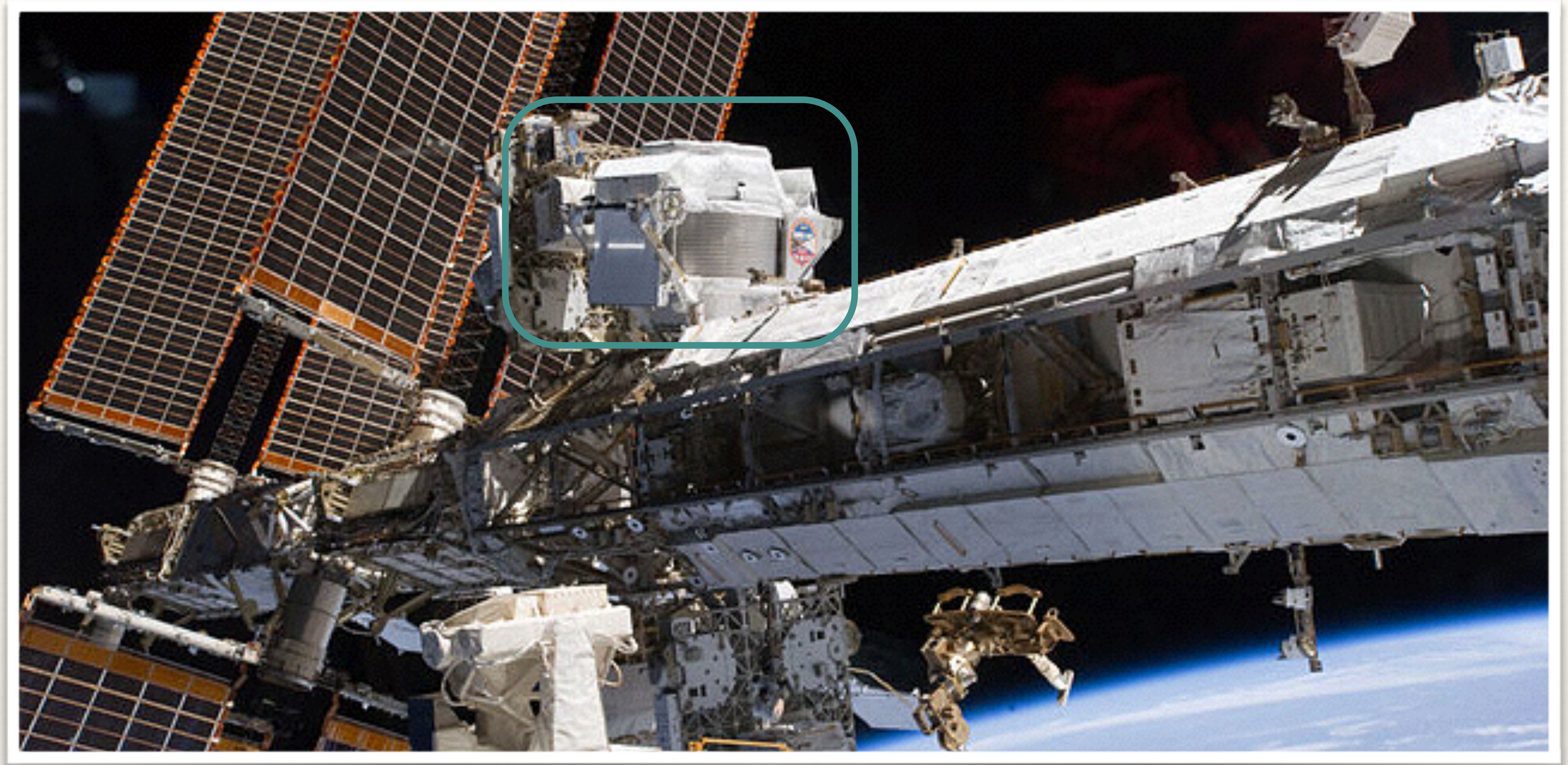
Positron-Proton Separation

Each energy bin is fit to positron and proton reference spectra to determine the number of protons and positrons



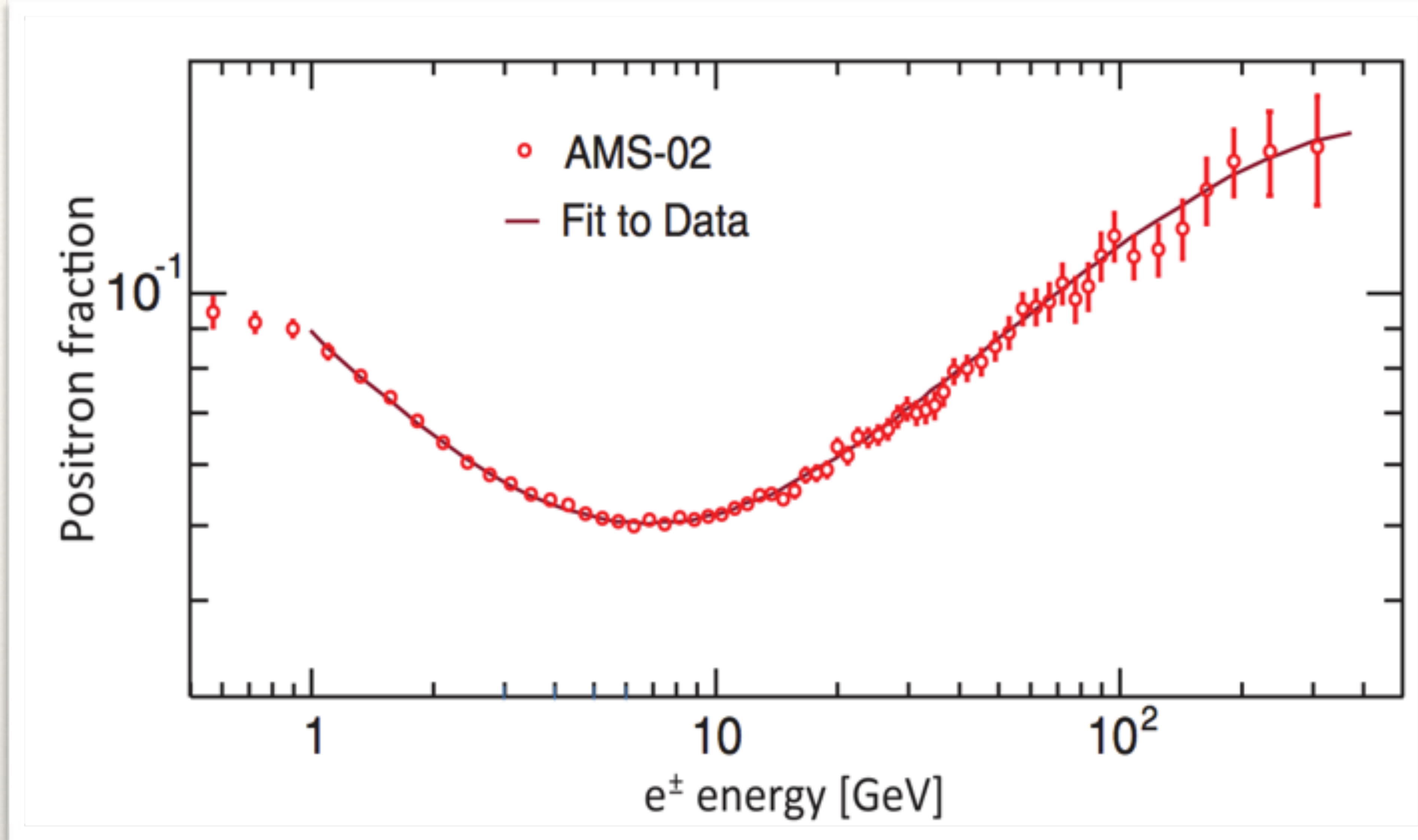
In situ

http://spaceflight.nasa.gov/gallery/images/shuttle/sts-134/html/s134e007532.html via https://commons.wikimedia.org/wiki/File:STS-134_the_starboard_truss_of_the_ISS_with_the_newly-installed_AMS-02.jpg



In situ

http://spaceflight.nasa.gov/gallery/images/shuttle/sts-134/html/s134e007532.html via https://commons.wikimedia.org/wiki/File:STS-134_the_starboard_truss_of_the_ISS_with_the_newly-installed_AMS-02.jpg



Fit includes a common cutoff at 760 GeV

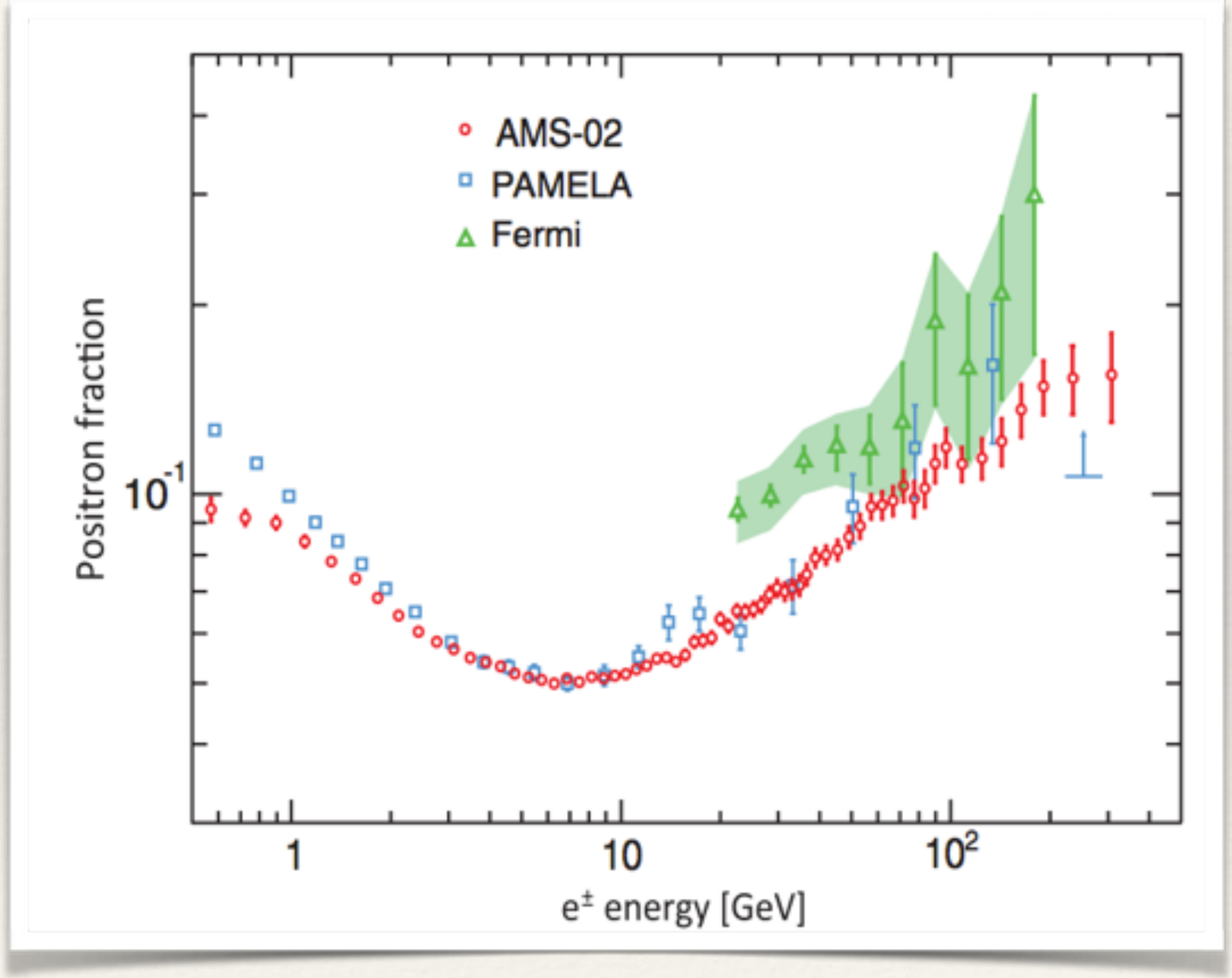
Results

Published data taken from 19 May 2011 to 10 December 2012 with 6.8×10^6 $e^{\pm}$ events between 0.5 and 350 GeV

AMS first results [2]

Interpretation

- Most astrophysical particle fluxes follow a power-law (decreasing) spectrum
- The positron fraction appears to do that from 1-10 GeV
- Something strange happens at 10 GeV: a turning point



Comparison to previous experiments [2]

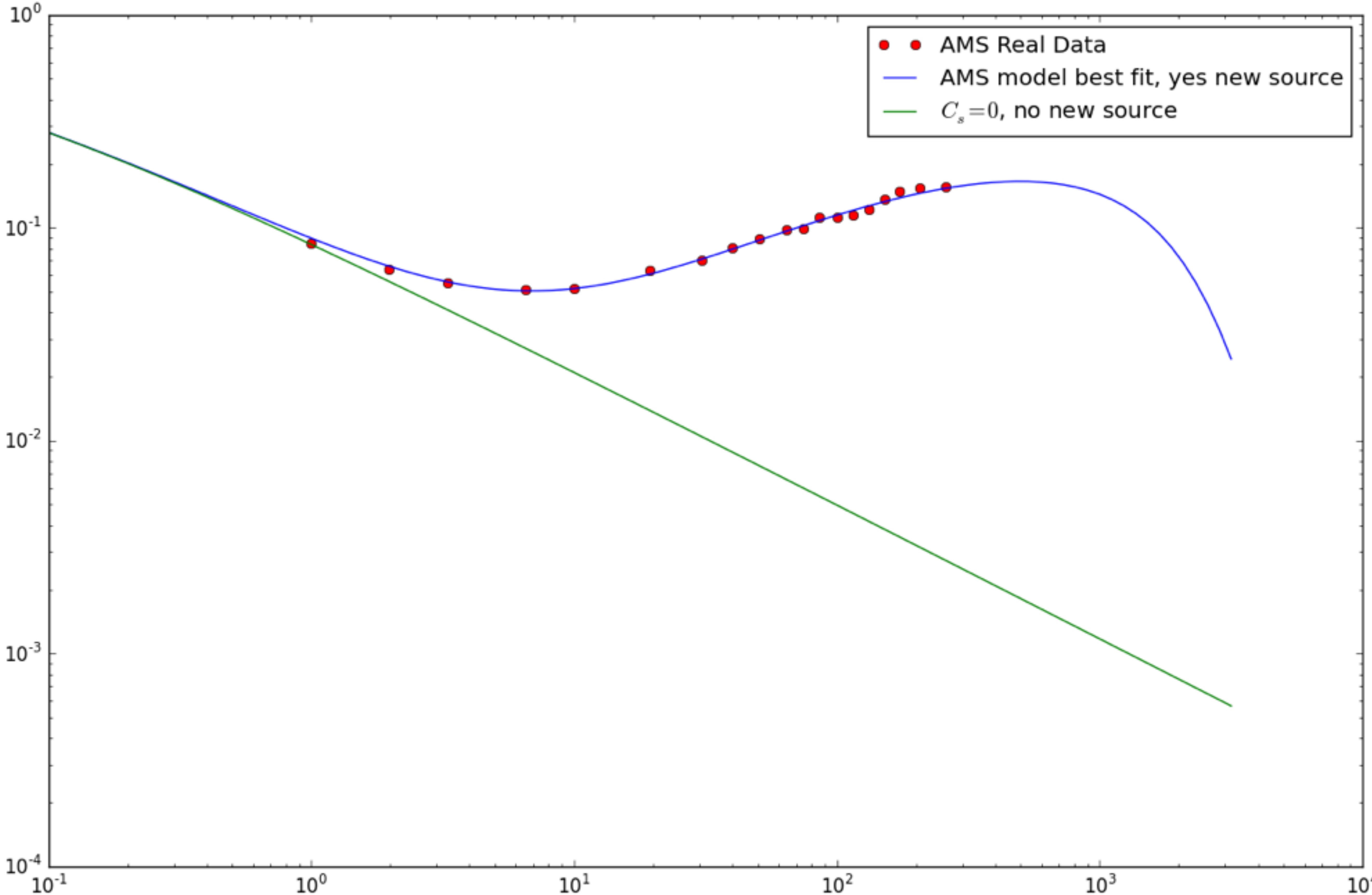
Minimal Model

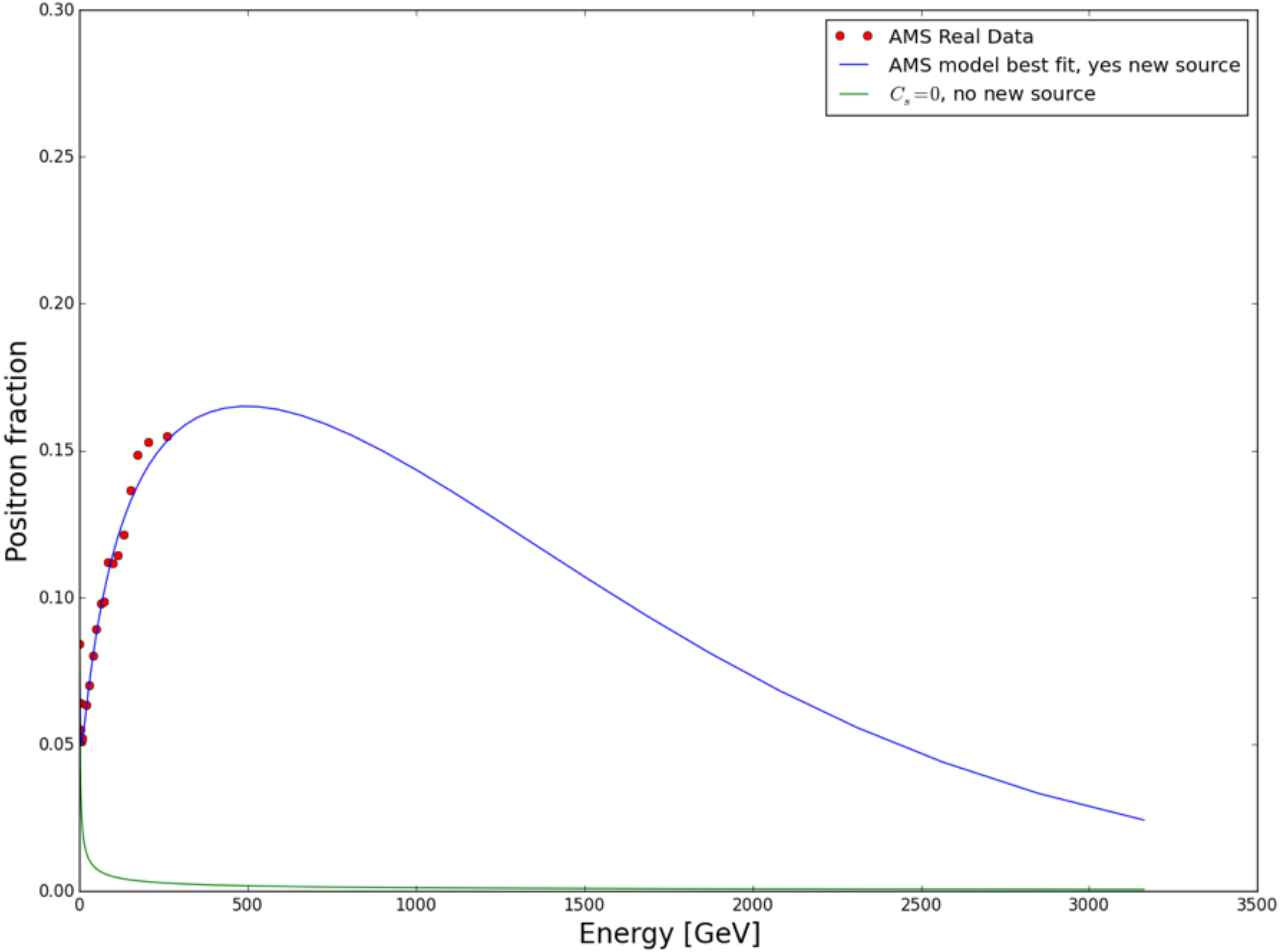
- Electron and positron fluxes are composed of independent power-law sources and a common source with a characteristic energy

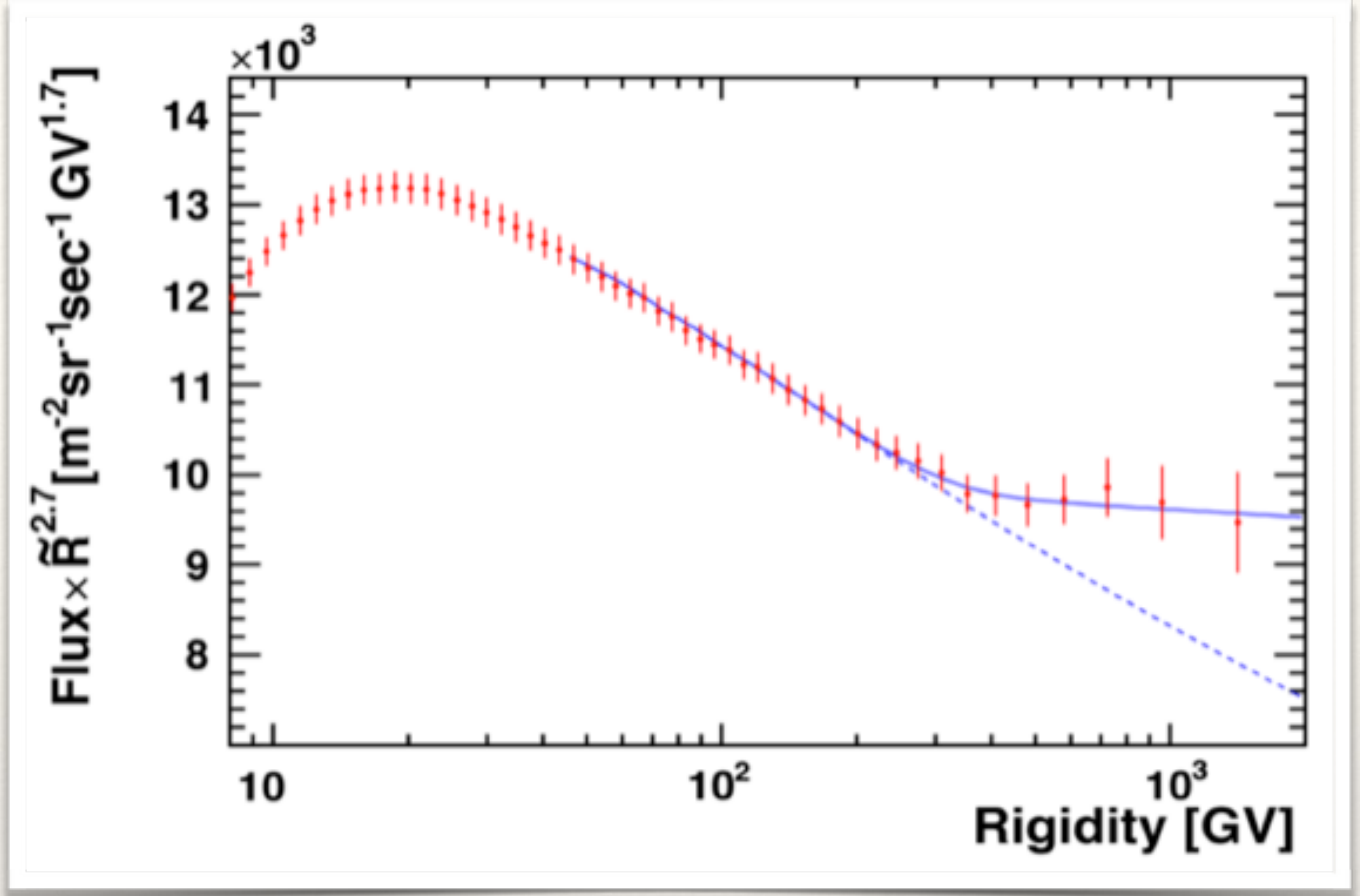
$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

- The first terms are independent and the second are shared


AMS Real Data
AMS model best fit, yes new source
$C_s=0$, no new source
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-1}
10^0
10^1
10^2
10^3
10^4

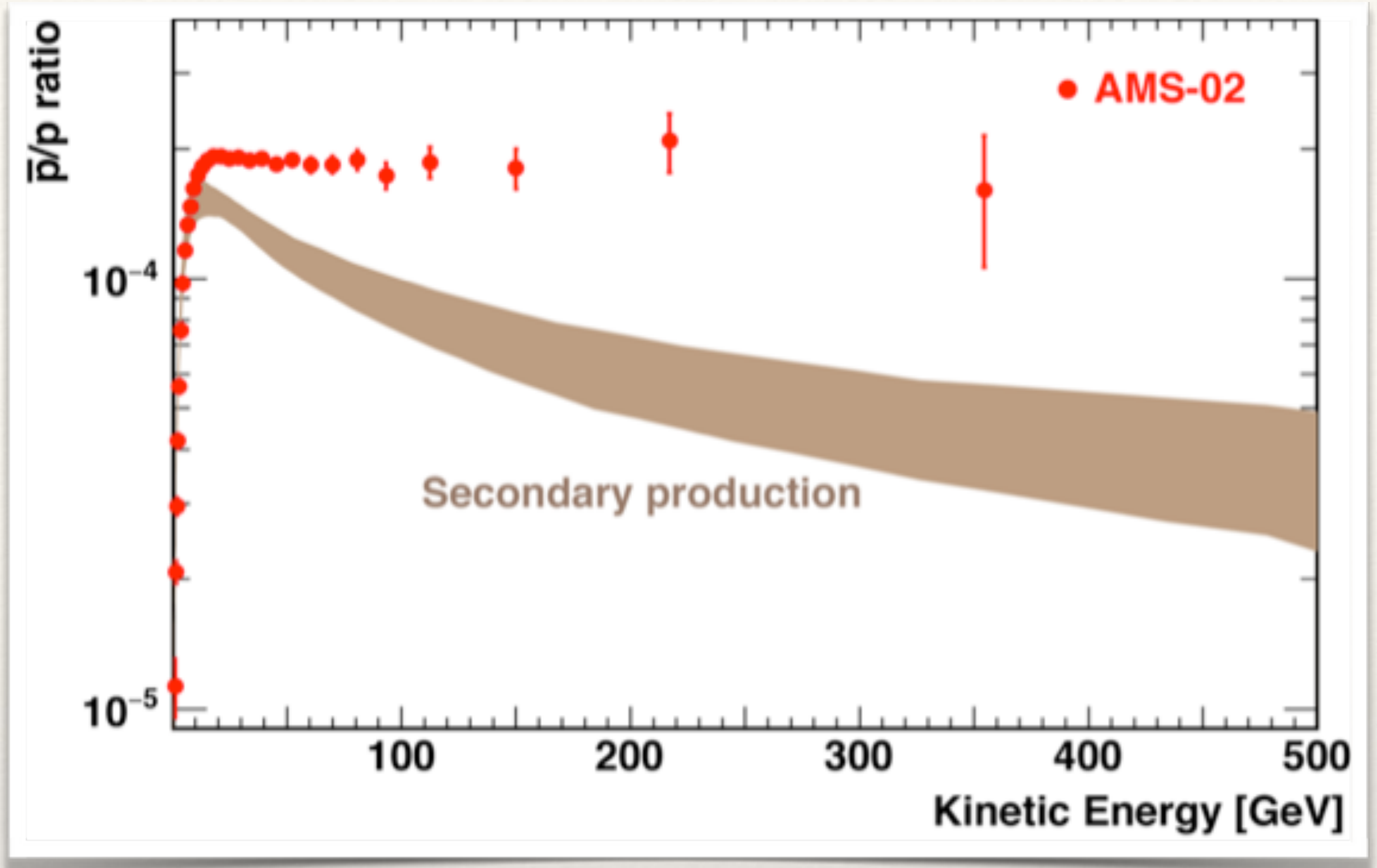

AMS Real Data
AMS model best fit, yes new source
C_s=0, no new source
Positron fraction
Energy [GeV]
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
500
1000
1500
2000
2500
3000
3500



The measured proton spectrum [3]

Other measurements

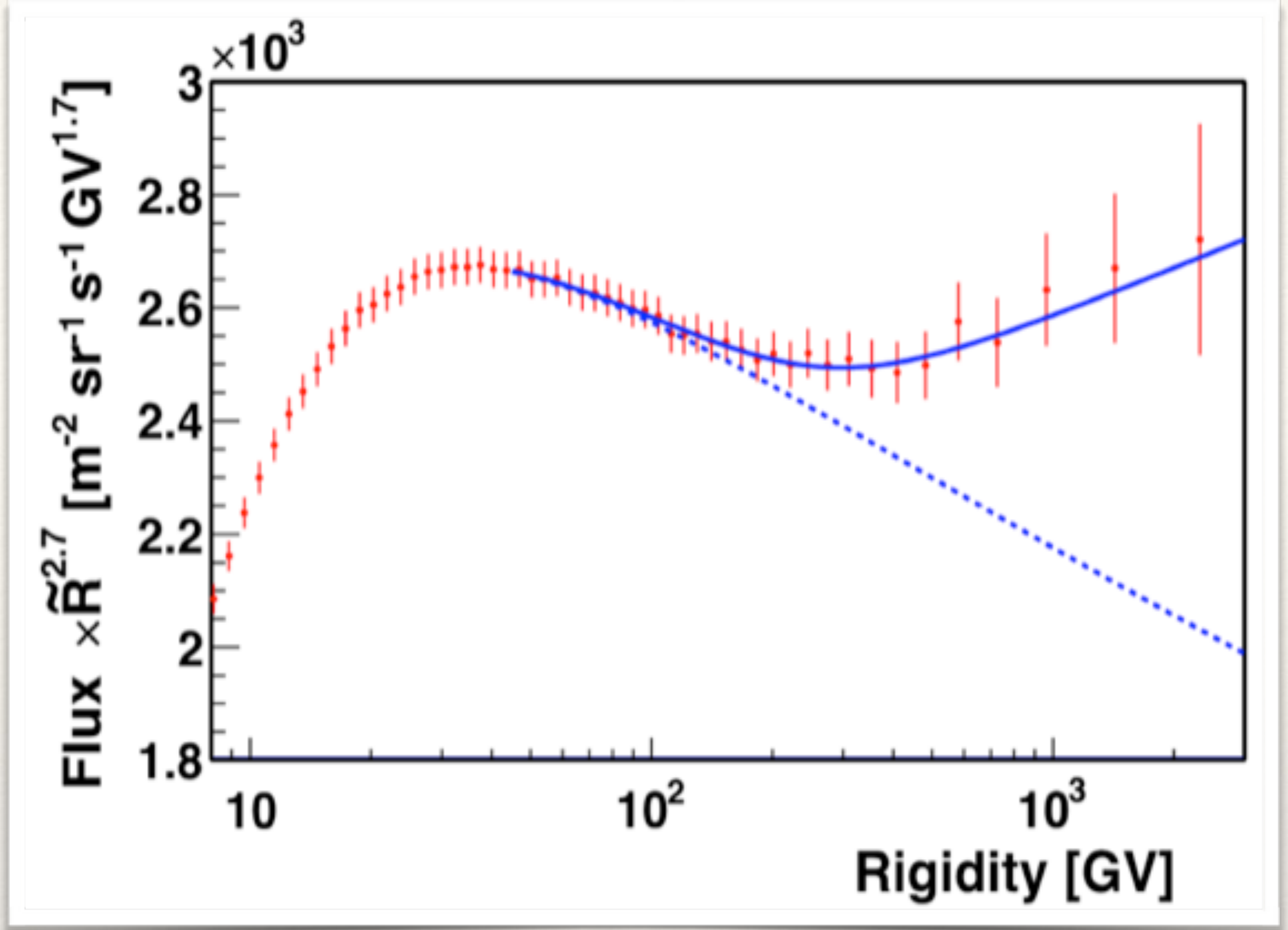
The proton spectrum also diverges from the expected behavior, this time around 300 GV rigidity (~300 GeV)



The measured antiproton fraction [3]

Other measurements

The antiproton fraction is not explained by cosmic ray collisions or pulsars



The measured helium spectrum [3]

Other measurements

The helium spectrum diverges from expectations at the same energy as the proton spectrum

No antihelium nuclei have been detected

Conclusions

- The positron fraction alone suggests a new astrophysical or particle-physics phenomenon
- Some disagree that existing sources cannot account for this behavior (e.g [4])
    - Sources include supernova remnants, pulsar wind nebulae, and cosmic rays
- Measurements of other particles support the hypothesis that something fishy is going on
- AMS expects to run until the ISS shuts down, for a total of 20-30 years
- We hope to see what happens above 250 GeV!

References

- [1] A. Kounine. Int. J. Mod. Phys. E21 (2012) 123005
- [2] M. Aguilar *et al.* Phys. Rev. Lett. **110**, 141102 (2013)
- [3] AMS-02 Website. http://www.ams02.org/2015/04/ams-days-at-cern-and-latest-results-from-the-ams-experiment-on-the-international-space-station/
- [4] M. Di Mauro and A. Vittino. "AMS-02 electrons and positrons: astrophysical interpretation and Dark Matter constraints." Proceedings of the 34th International Cosmic Ray Conference (ICRC 2015).

Thank You