PRECISE MEASUREMENTS OF THE COSMIC RAY FLUXES WITH AMS-02 AND IMPLICATIONS FOR DARK MATTER SEARCH

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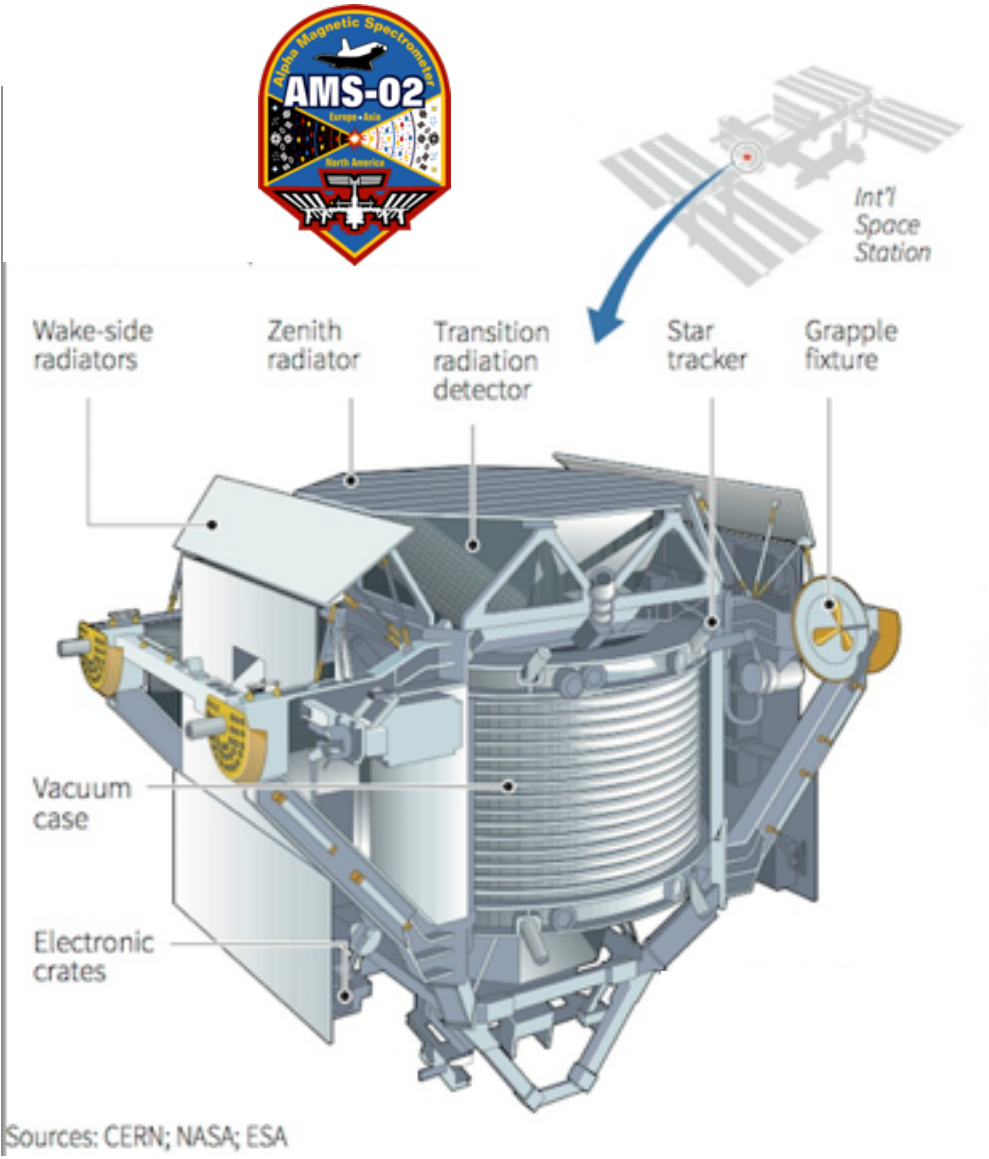
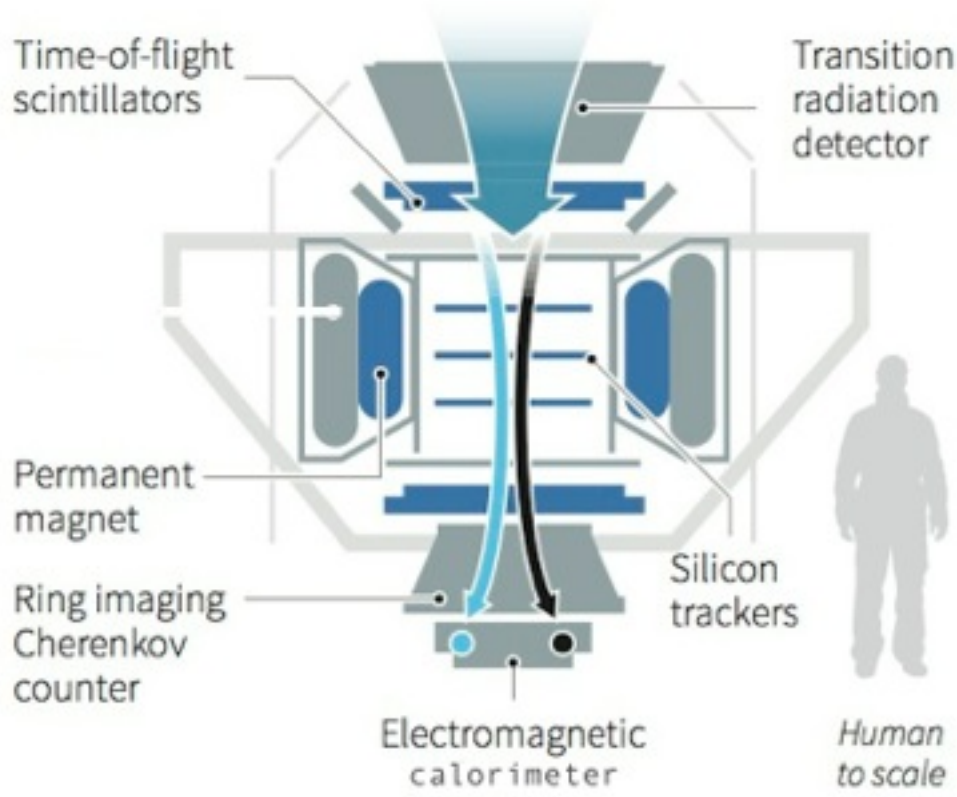
THE ALPHA MAGNETIC SPECTROMETER

A particle physics detector operating on the International Space Station



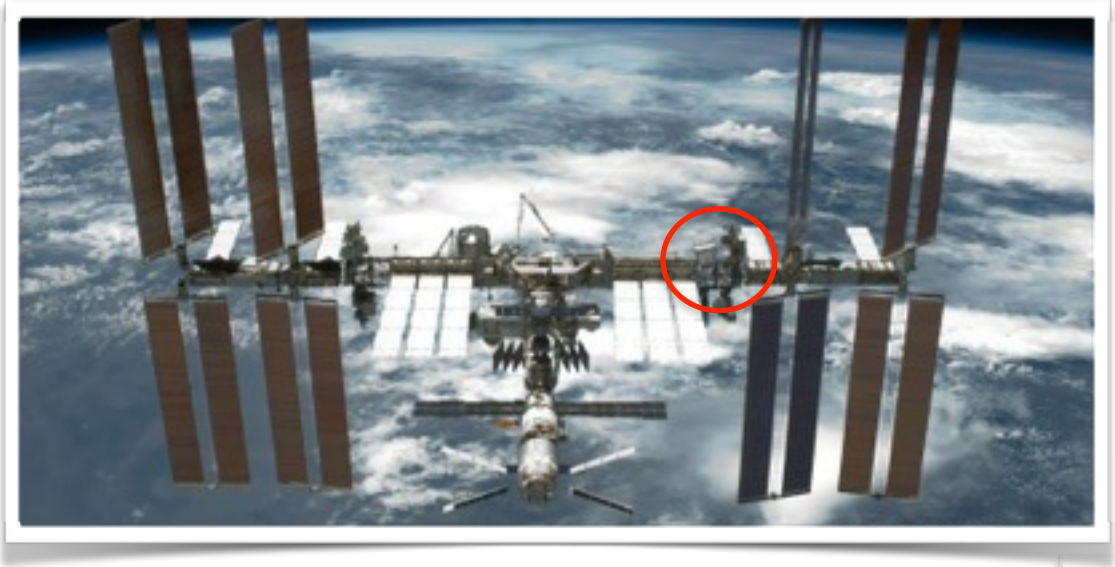


- Size: 5m X 4m X 3m
- Weight: 7.5 Tons
- Power consumption: less than 2.5 kW

THE LAUNCH OF AMS-02

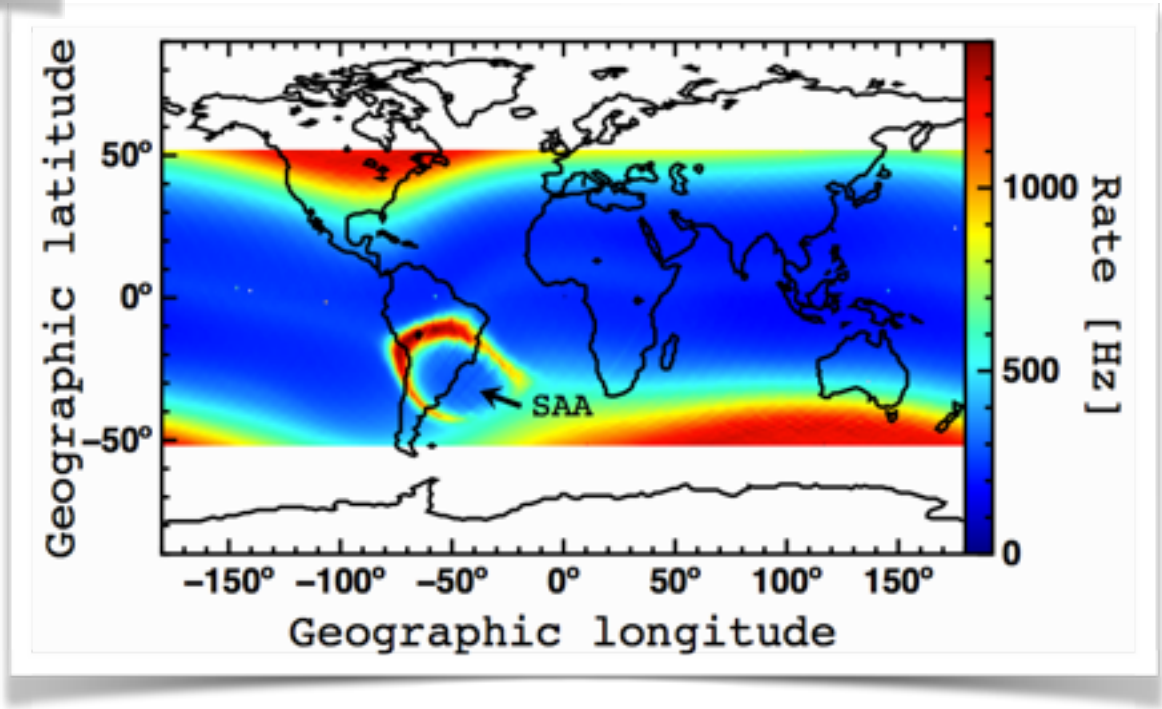
Cape Canaveral: May 16th 2011

AMS-02: THE EXPERIMENTAL CHALLENGES



- AMS-02 detects 54 million particles/day
- Data taking is running continuously since 4 years:
  - 35 TB/year
  - More than 68 Billion events detected

Average rate ~ 700 Hz

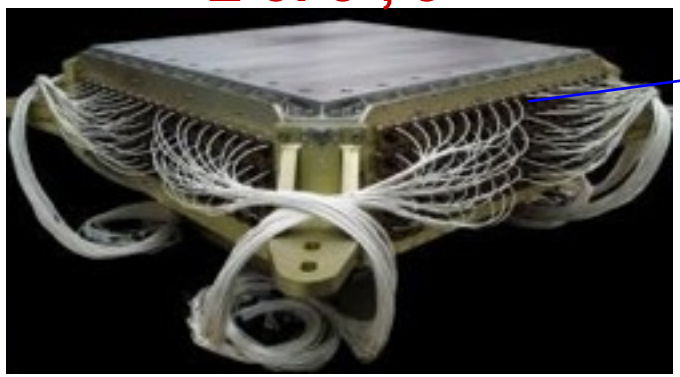


AMS: A TeV precision, multipurpose spectrometer

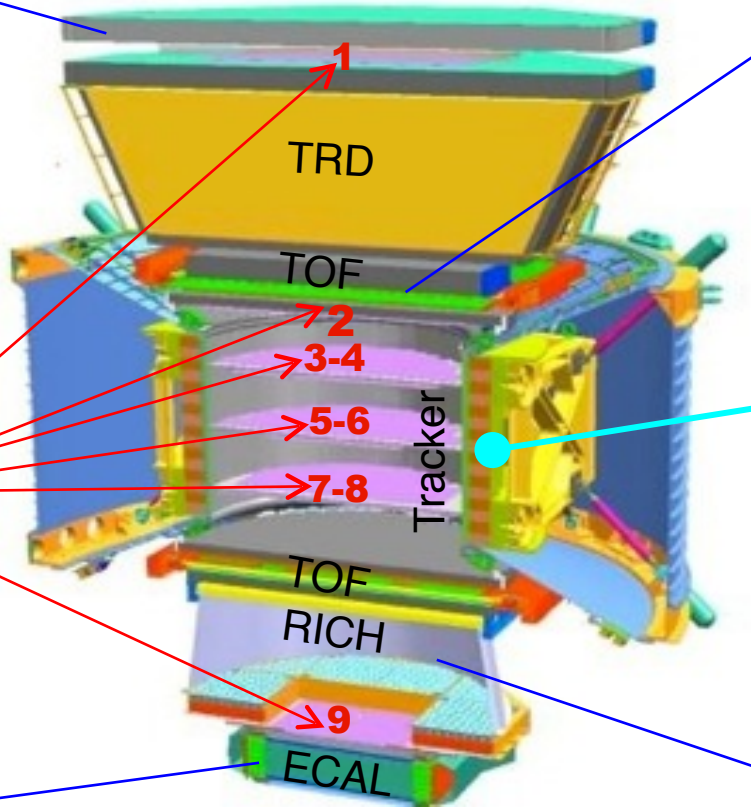
TRD
Identify e^+, e^-

Silicon Tracker
Z, P

ECAL
E of e^+, e^-



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



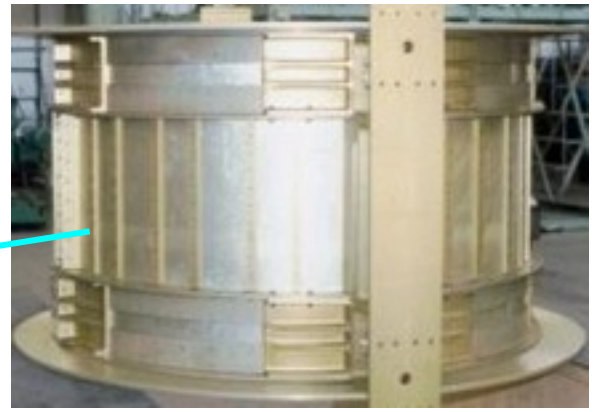
Z and P ~ E

are measured independently by the

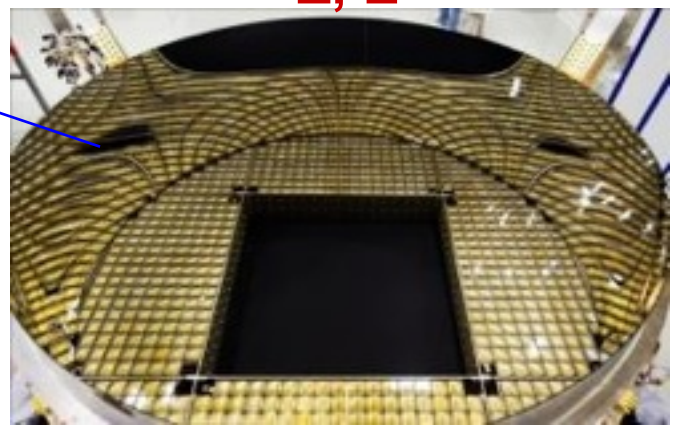
Tracker, RICH, TOF and ECAL

TOF
Z, E

Magnet
±Z



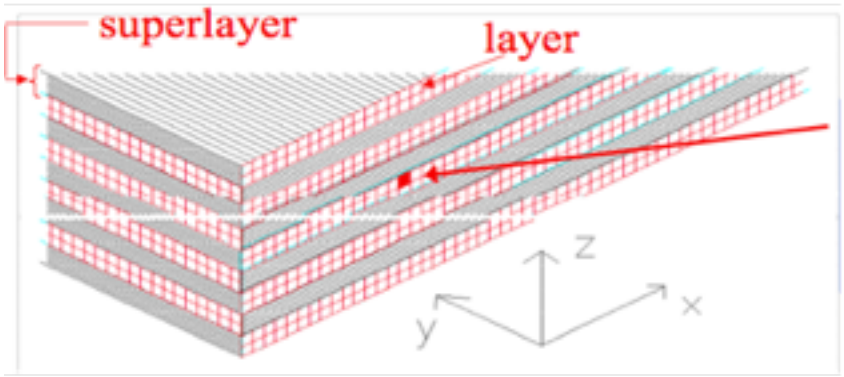
RICH
Z, E



ENERGY MEASUREMENT

The AMS-02 electromagnetic calorimeter:

a 3-D sampling calorimeter made out of lead and scintillating fibers

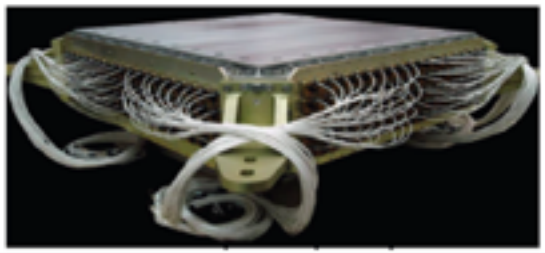


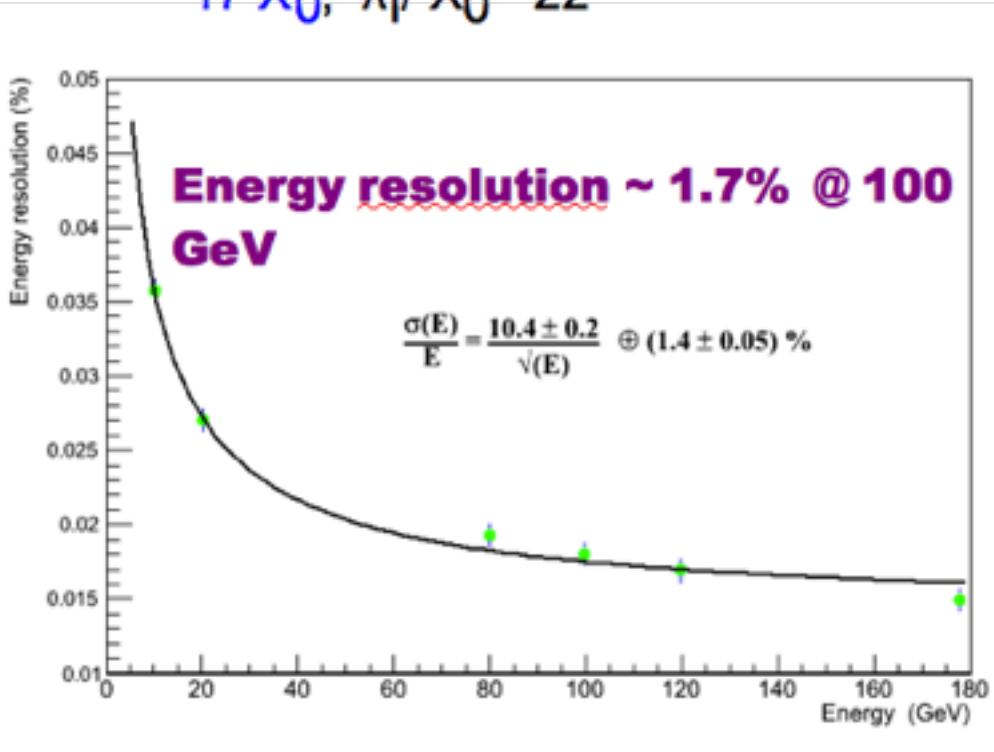
High granularity: ~ 0.9 x 0.9 cm^2

18 Longitudinal samplings

72 Lateral samplings

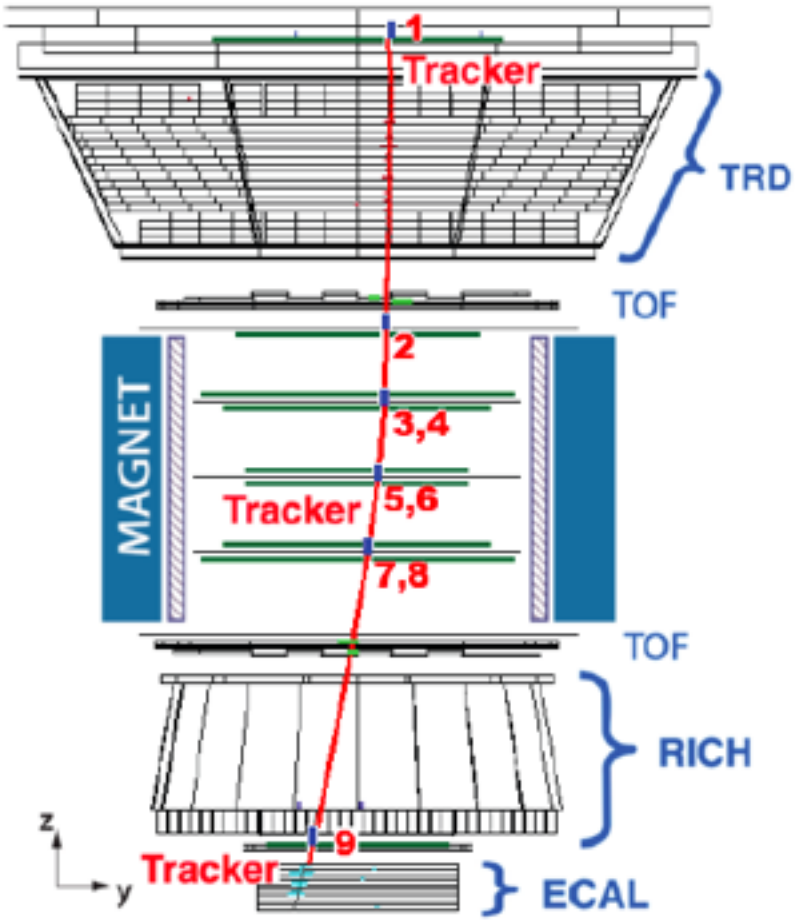
17 X_0, $\lambda_I / X_0 \sim 22$

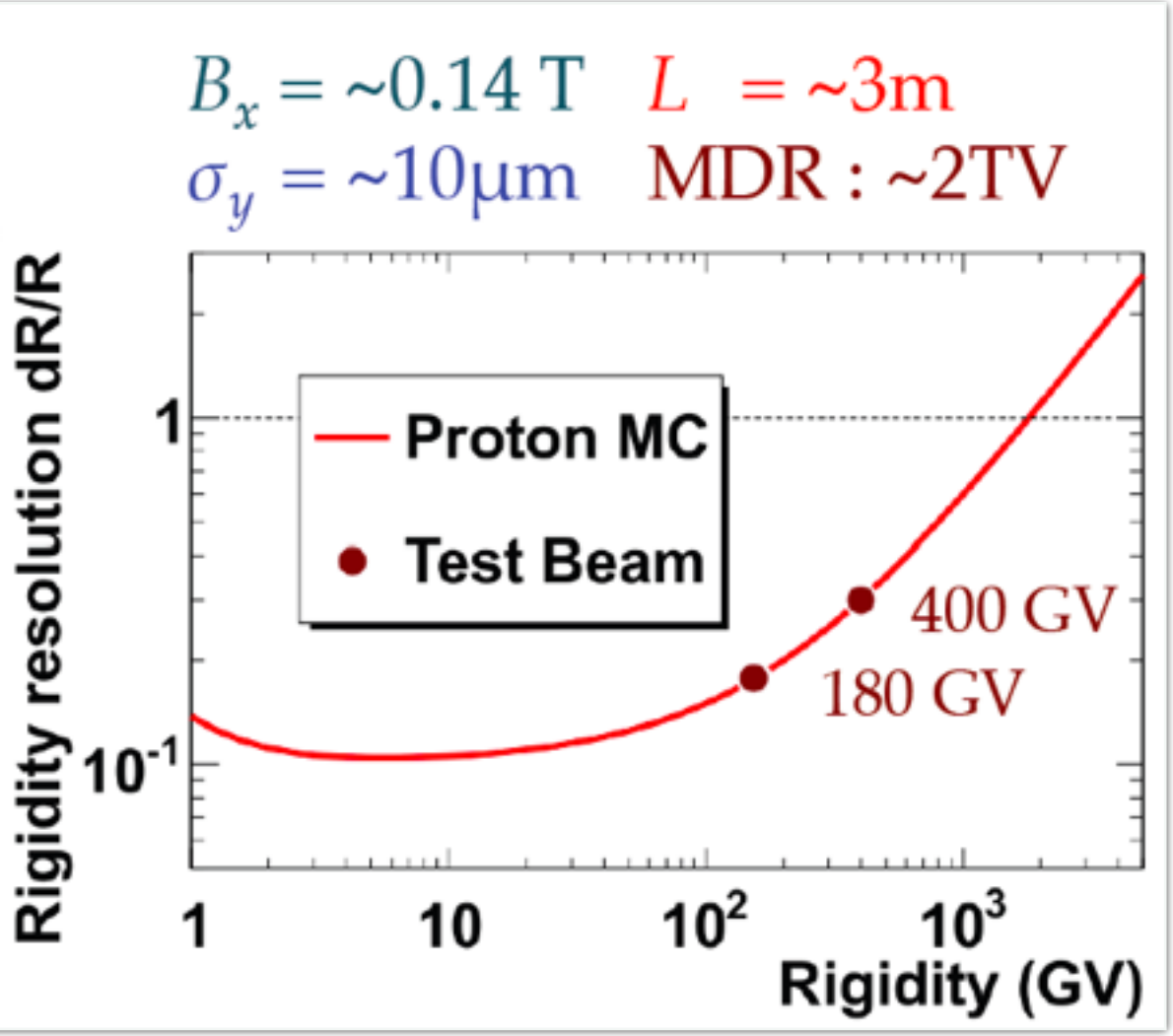


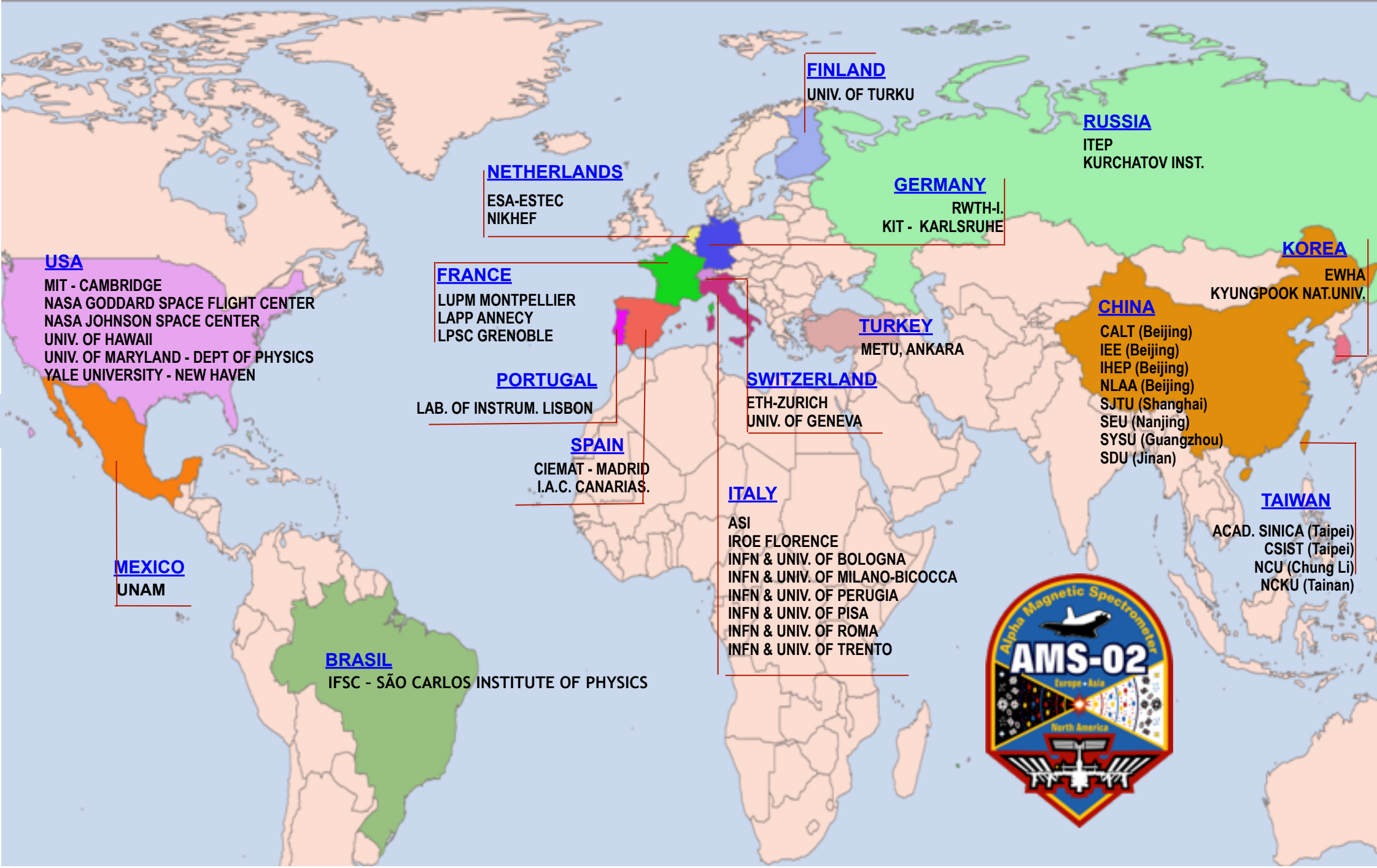


MOMENTUM MEASUREMENT

Rigidity=pc/(Z|e|)







The AMS-02 Collaboration

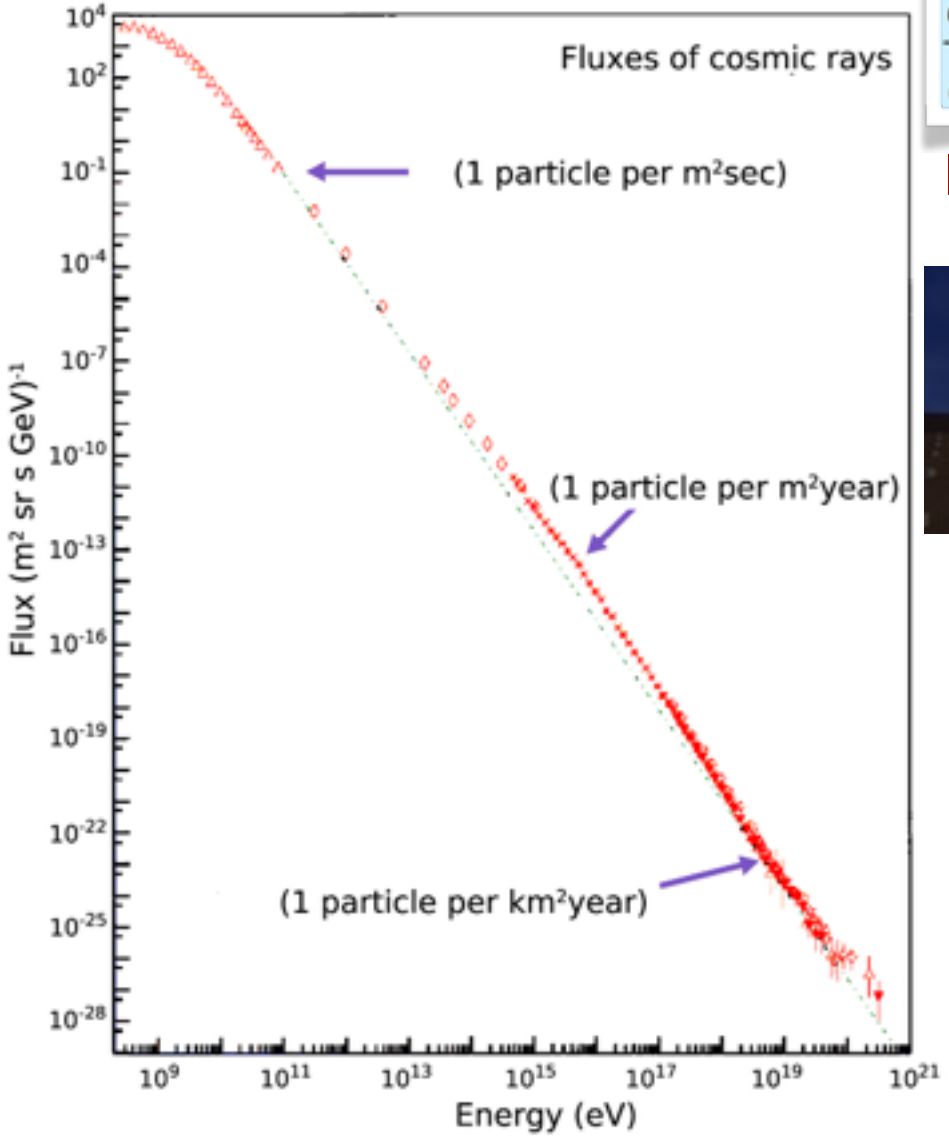
AMS-02: SCIENTIFIC GOALS

- Precise measurements of cosmic rays in the GeV to TeV region
- Study cosmic ray sources and propagation
- Search for primordial antimatter
- Indirect search for dark matter

COSMIC RAYS

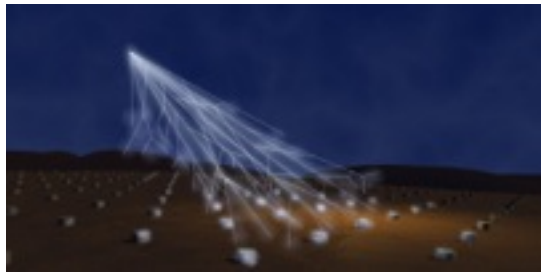
Cosmic rays are high energy particles produced outside the solar system

Direct measurements



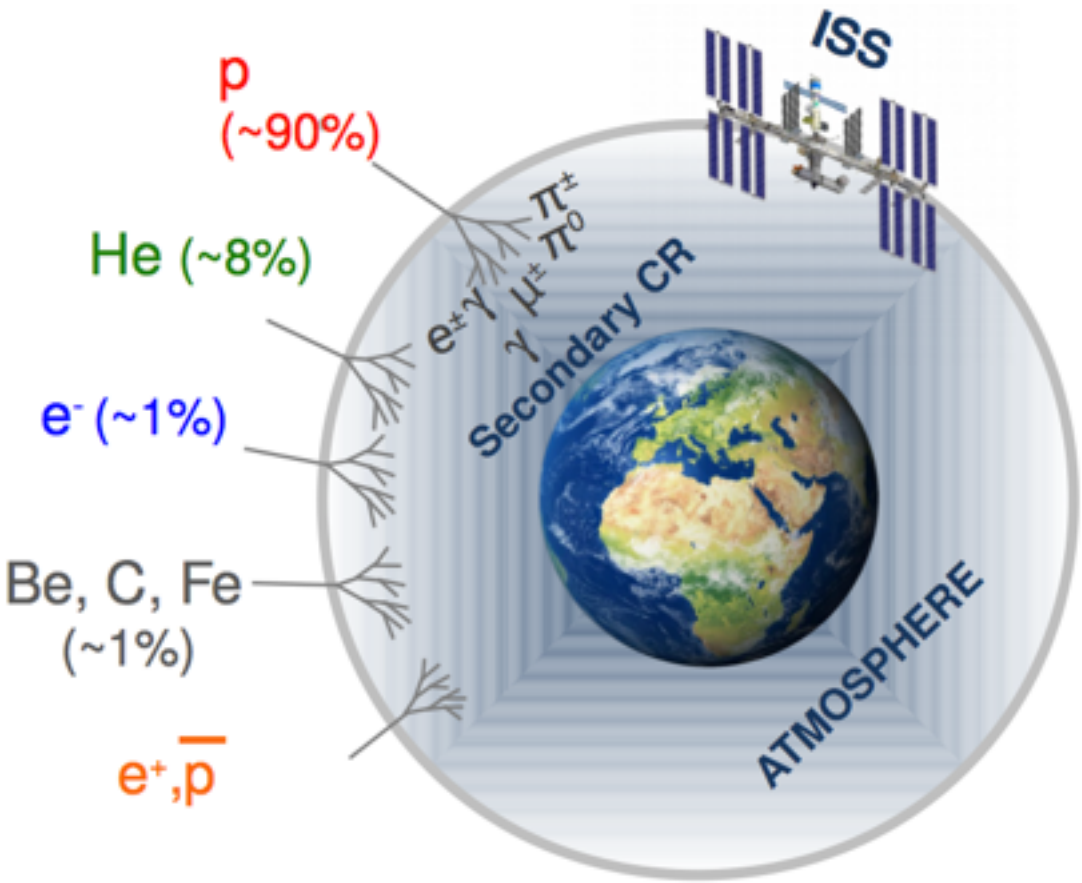
$$\frac{dN}{dE} = [m^{-2} sr^{-1} s^{-1} GeV^{-1}]$$

Indirect measurements

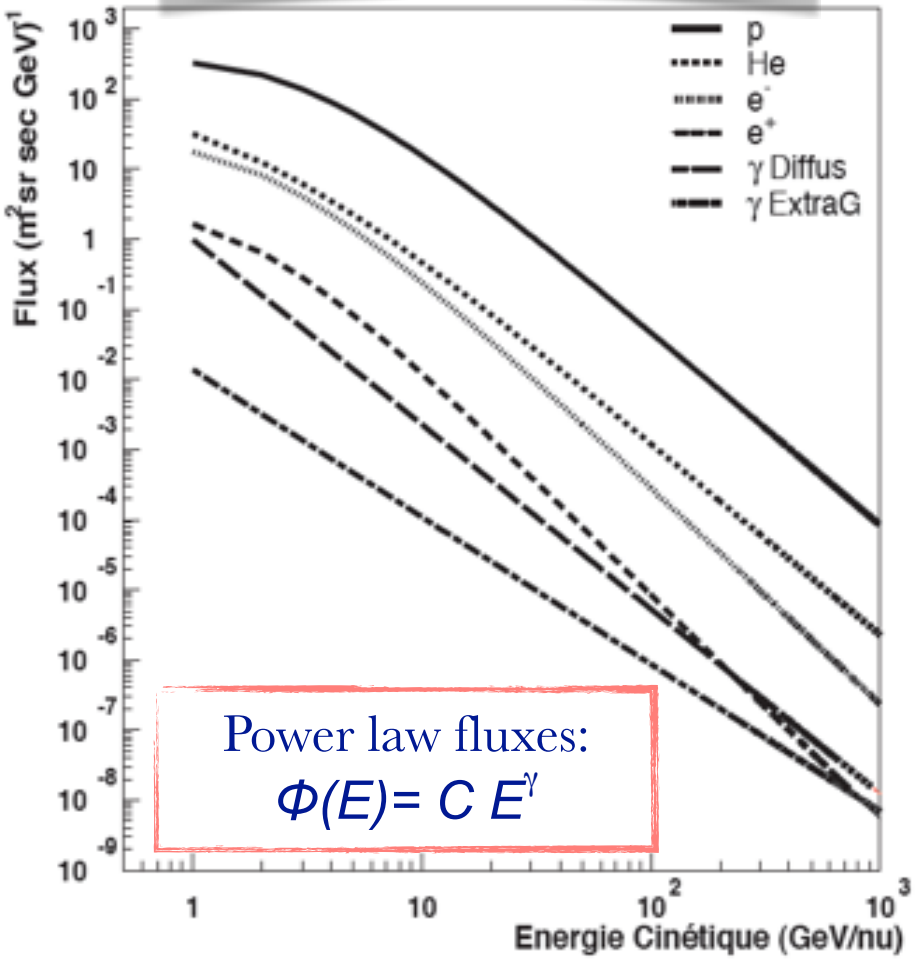


COSMIC RAYS FLUXES

[in the GeV to TeV energy range]



$$\frac{dN}{dE} = [m^{-2} sr^{-1} s^{-1} GeV^{-1}]$$



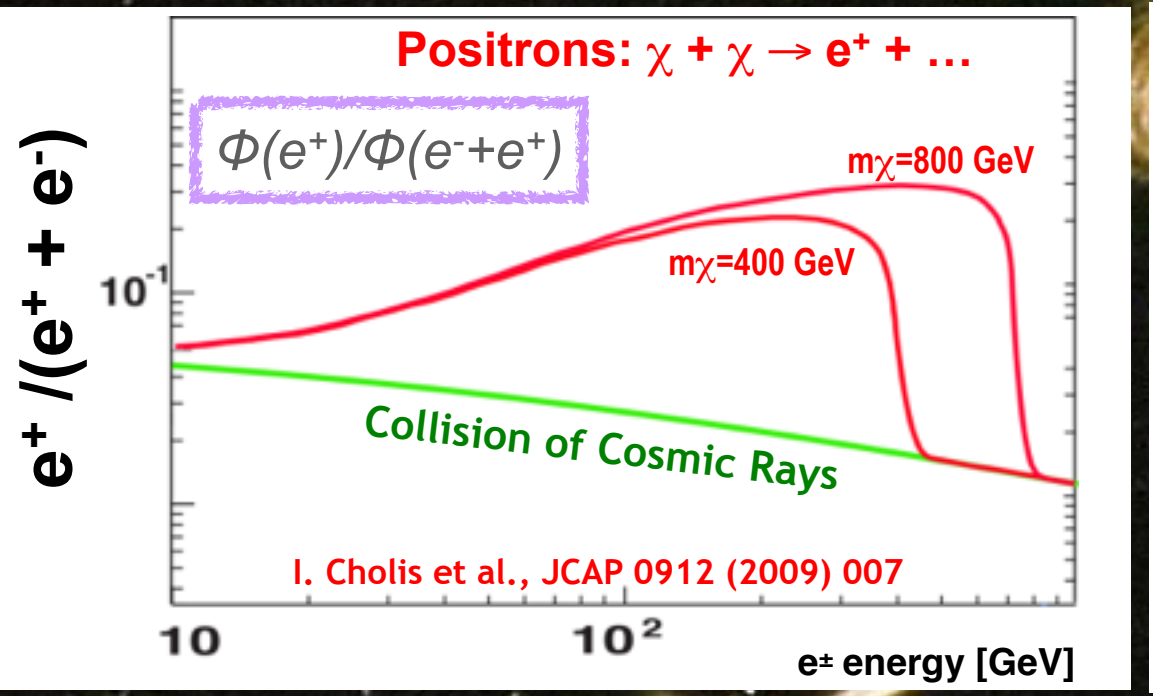
Power law fluxes:

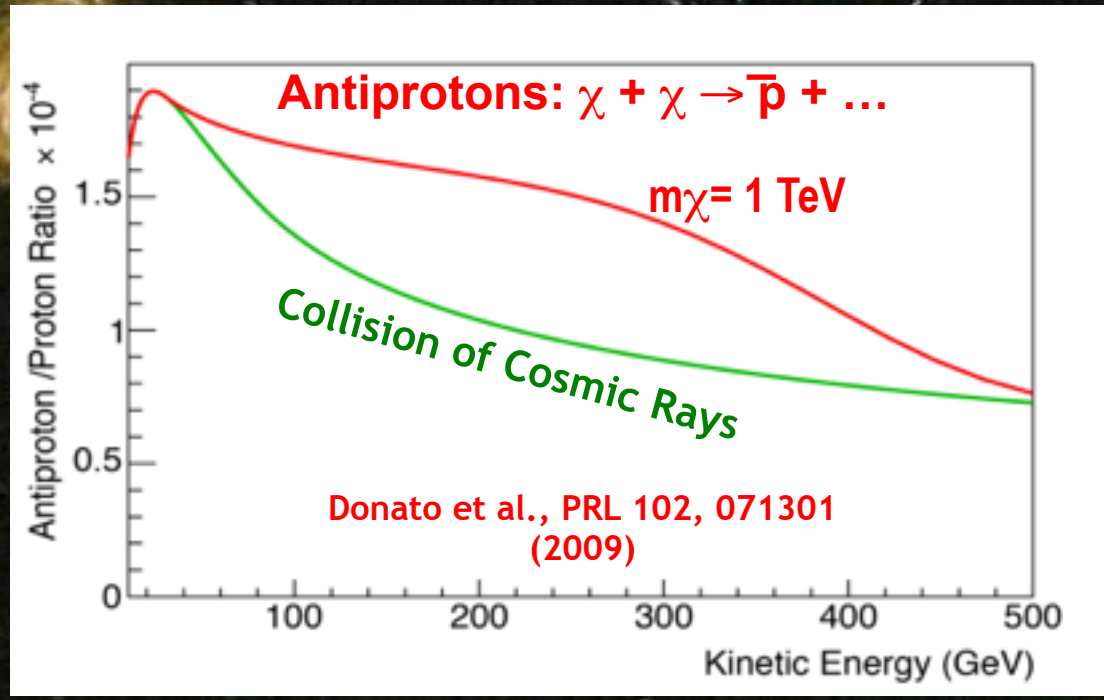
$\Phi(E) = C\, E^{\gamma}$

The Search for the Origin of Dark Matter

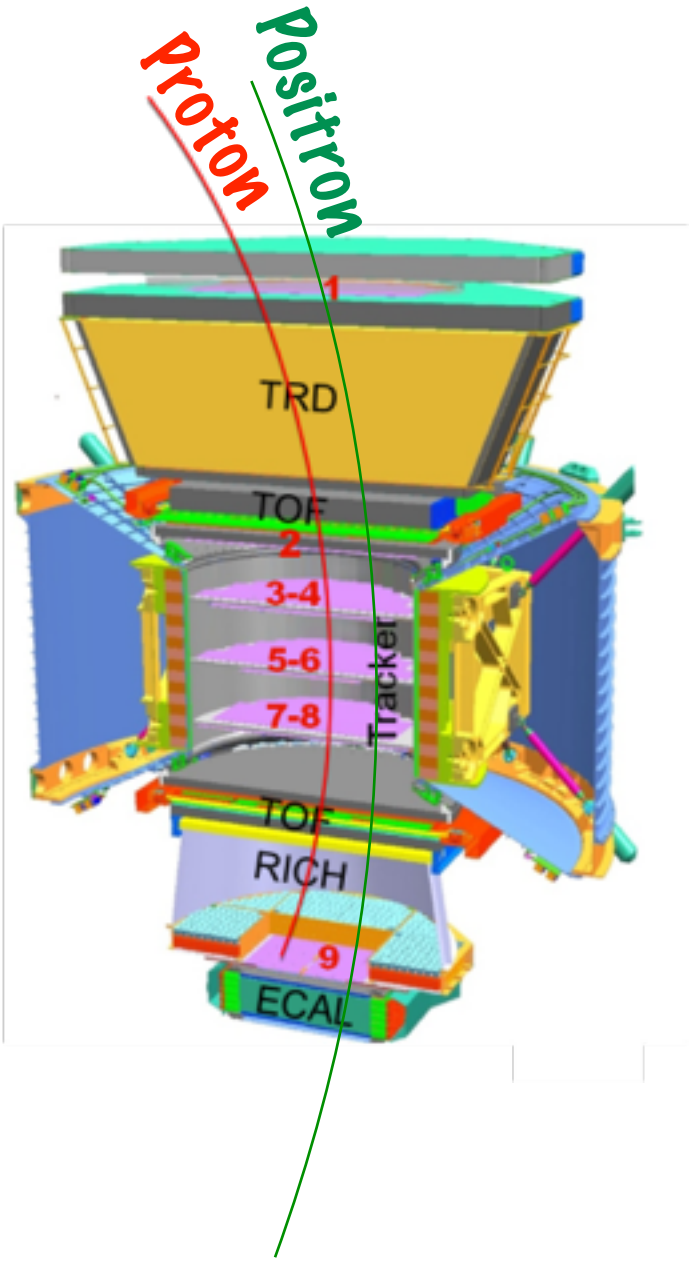
Collisions of Dark Matter (neutralinos, χ) will produce a signal of e+, $\bar{p}$, …

above the background from the collisions of "ordinary" cosmic rays



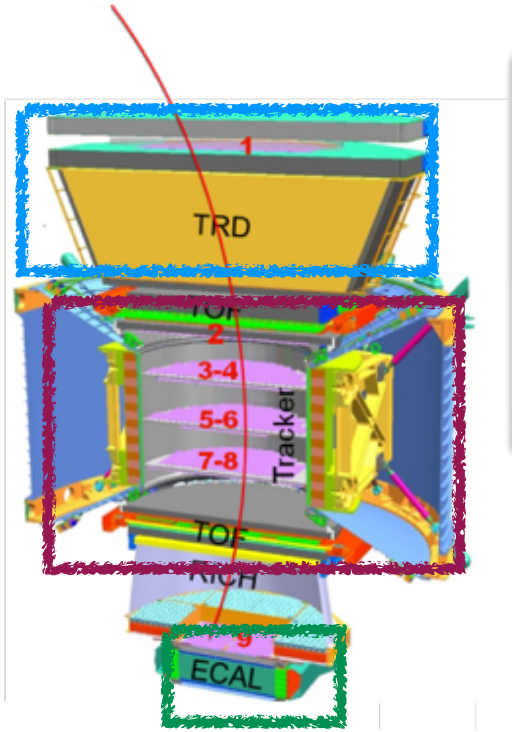


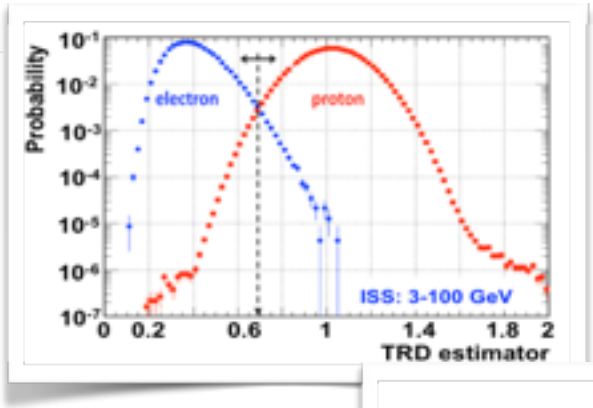
SEARCH FOR PRIMARY ANTIMATTER: POSITRONS



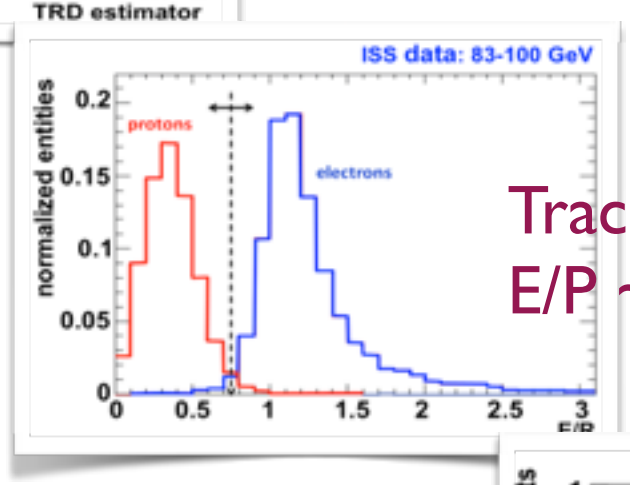
Main background: protons ($S/B \sim 10^{-4}$)
Background is reduced combining complementary detection techniques

LEPTON-HADRON SEPARATION



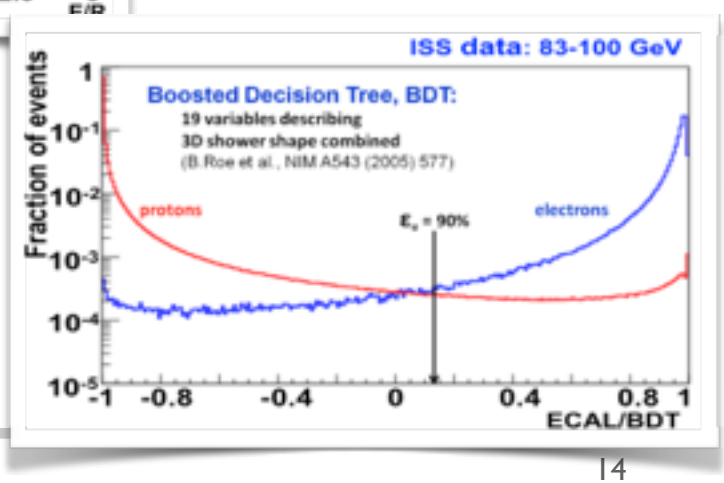


Transition Radiation Detector



Tracker:
E/P ~ 1 for e^+ and e^-

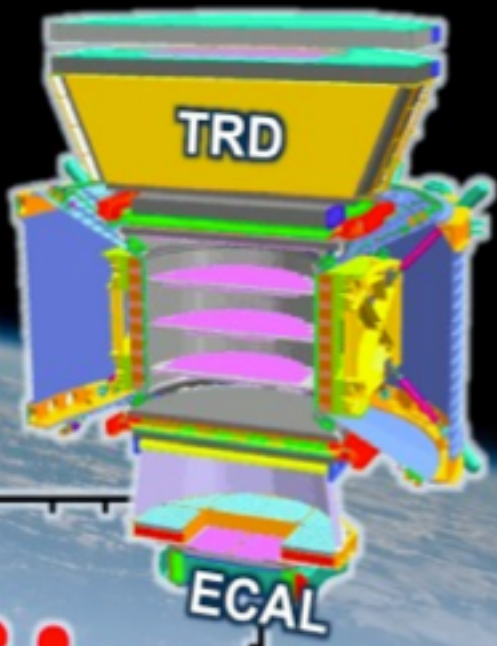
Acc(p) ~ 0.5 m^2sr
Acc(e) ~ 0.04 m^2sr

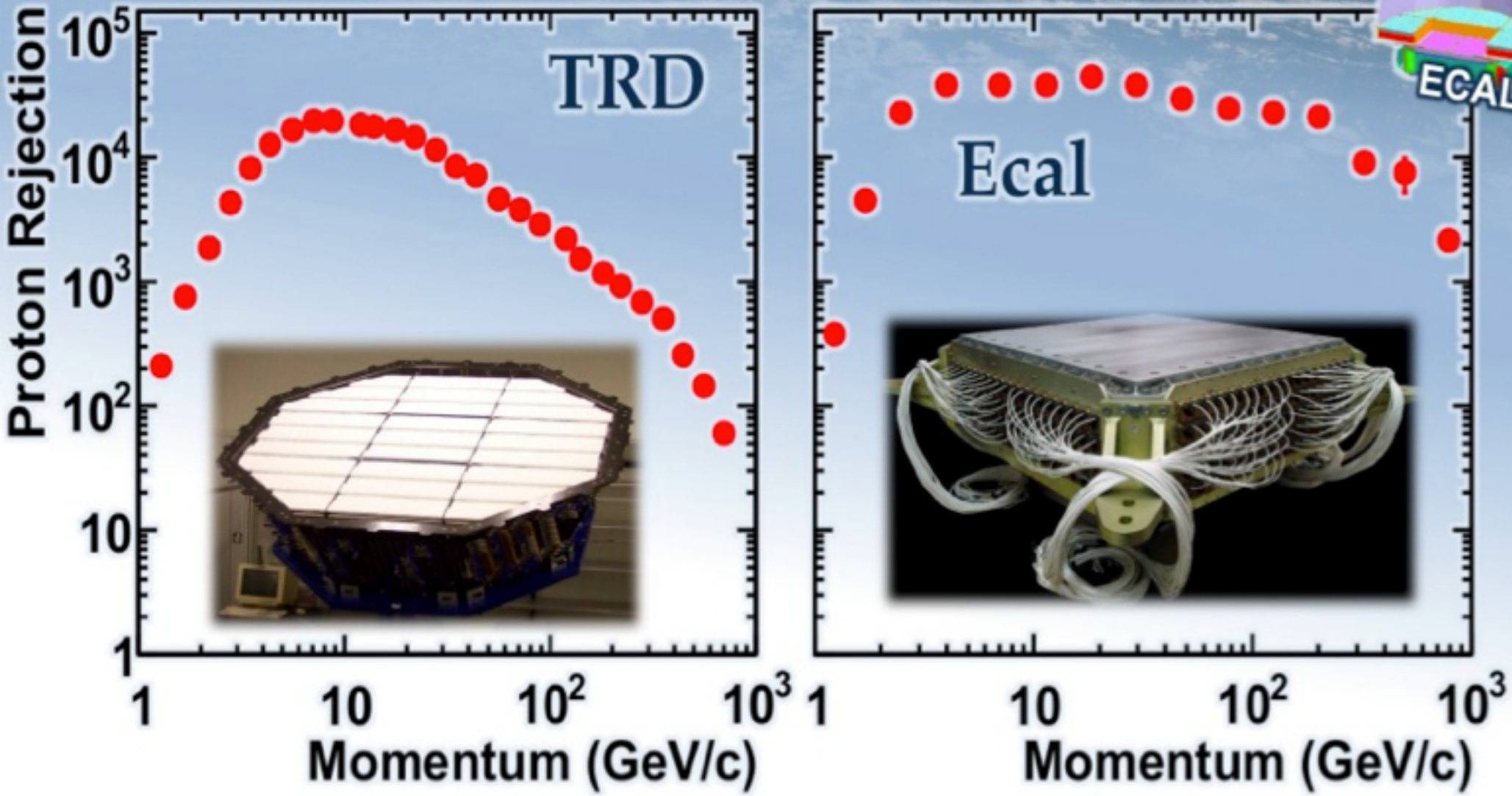


ECAL estimator: based on shower shape

Proton rejection

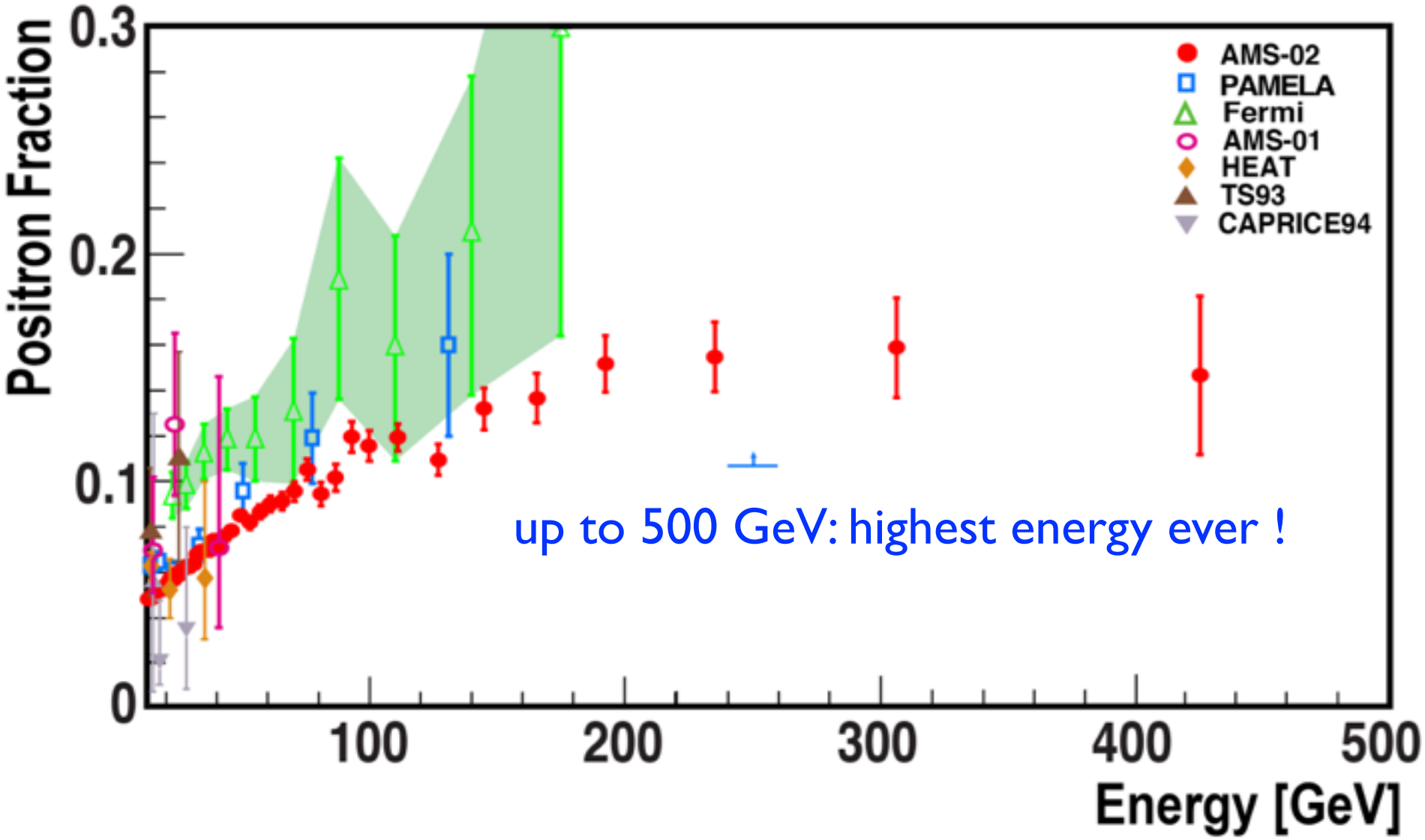
With 90 % e^+ efficiency





High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station

10.9 million e+ and e- events



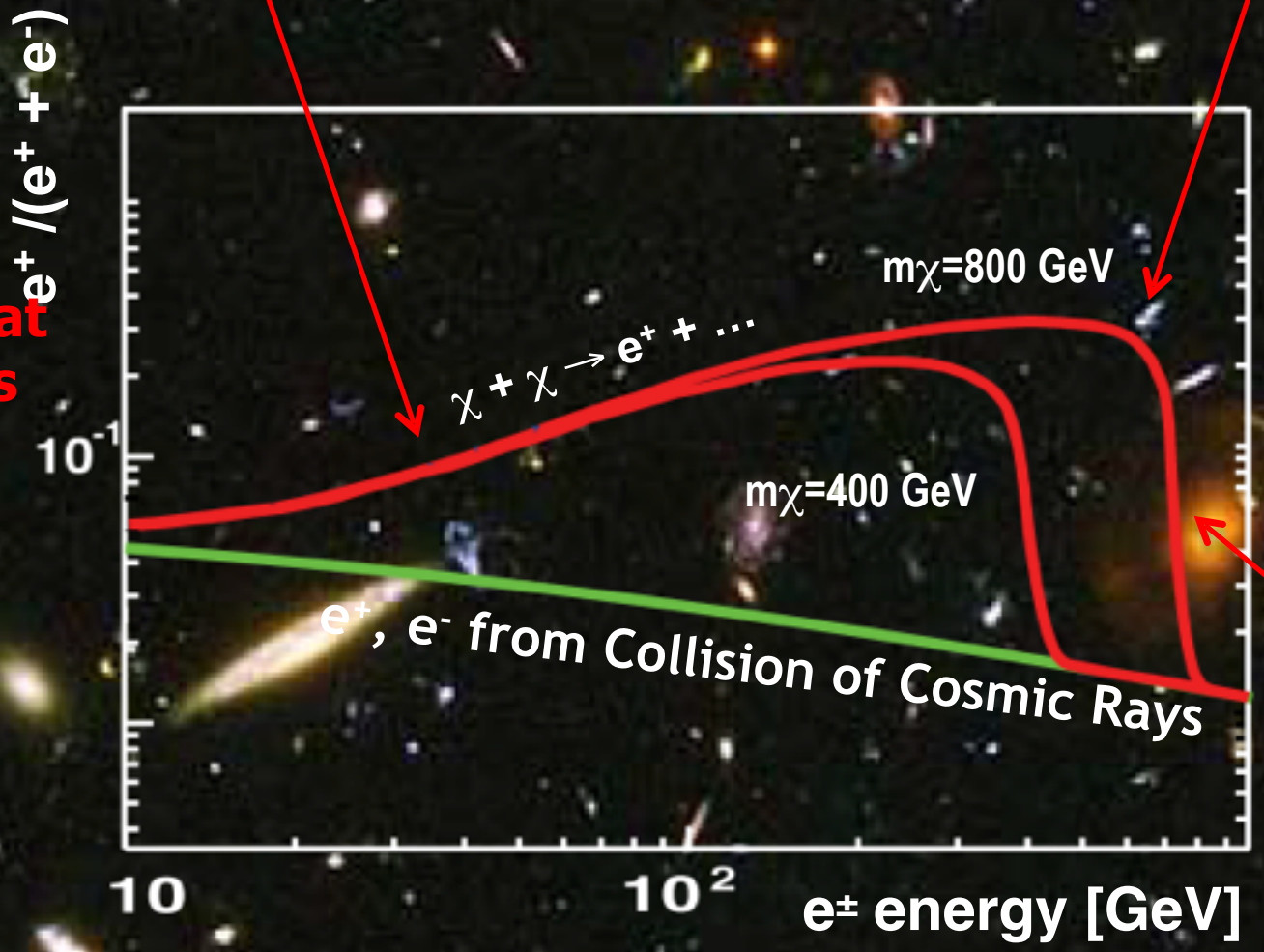
2. The rate of increase with energy

3. The existence of sharp structures.

4. The energy beyond which it ceases to increase.

5. Isotropy.

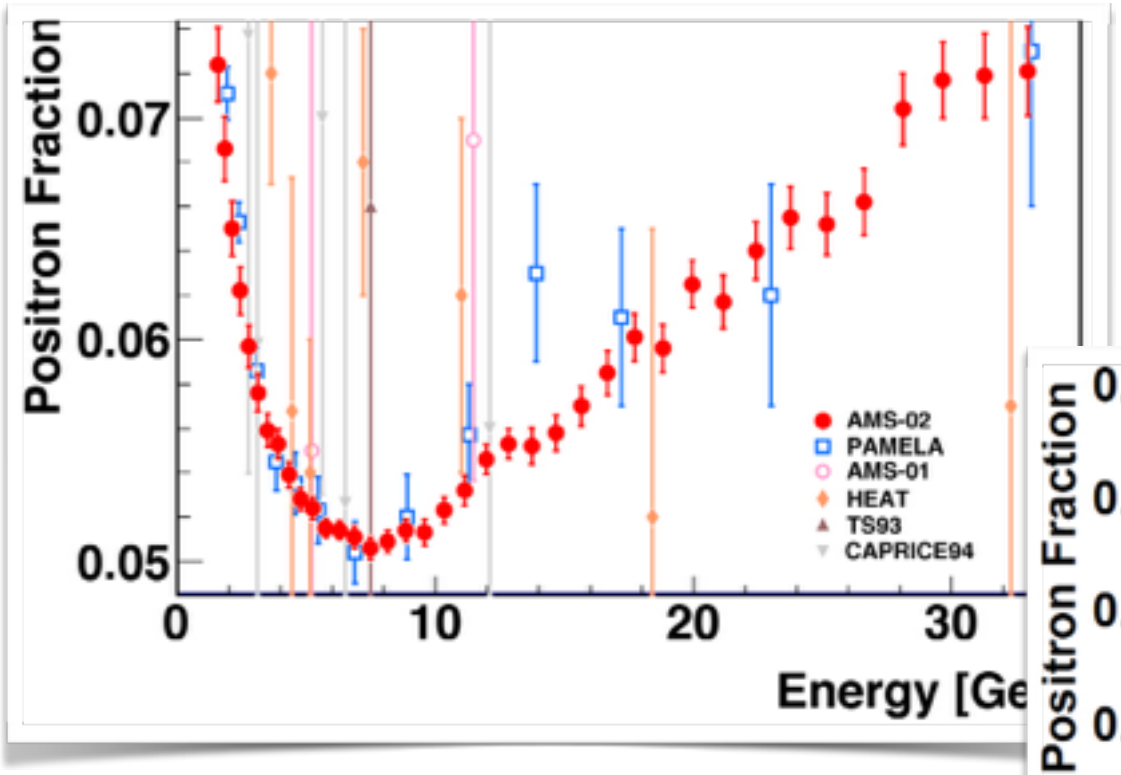
1. The energy at which it begins to increase.

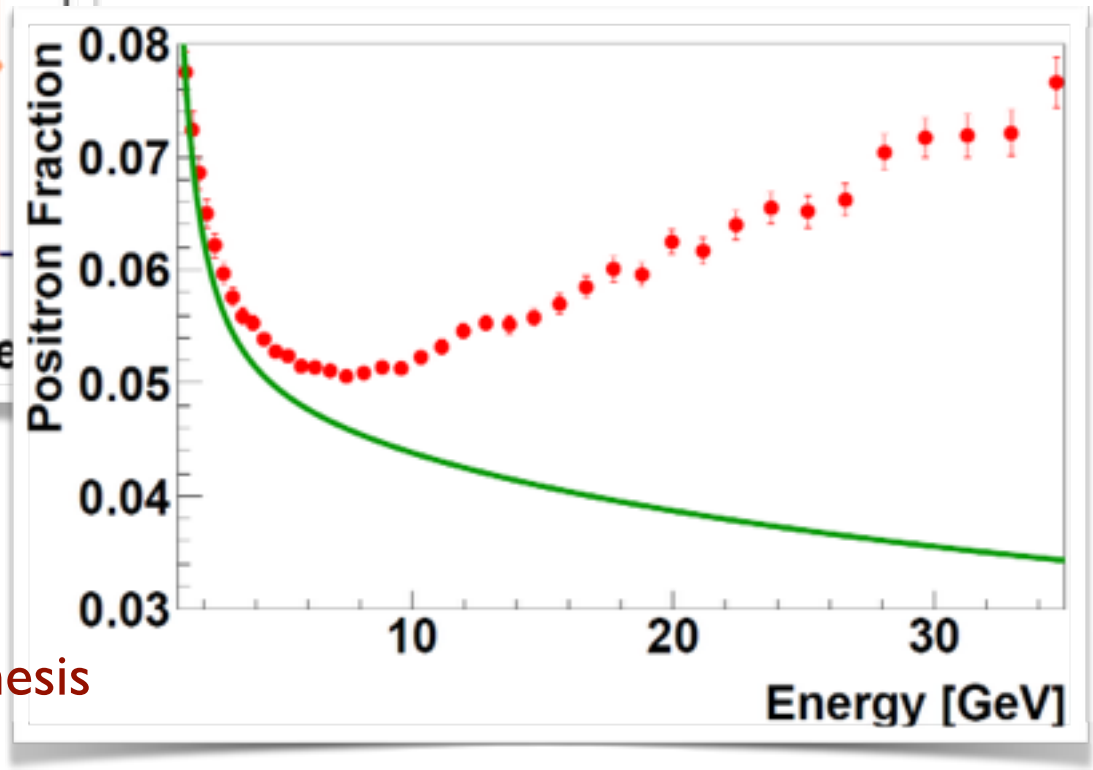


6. The rate at which it falls beyond the turning point.

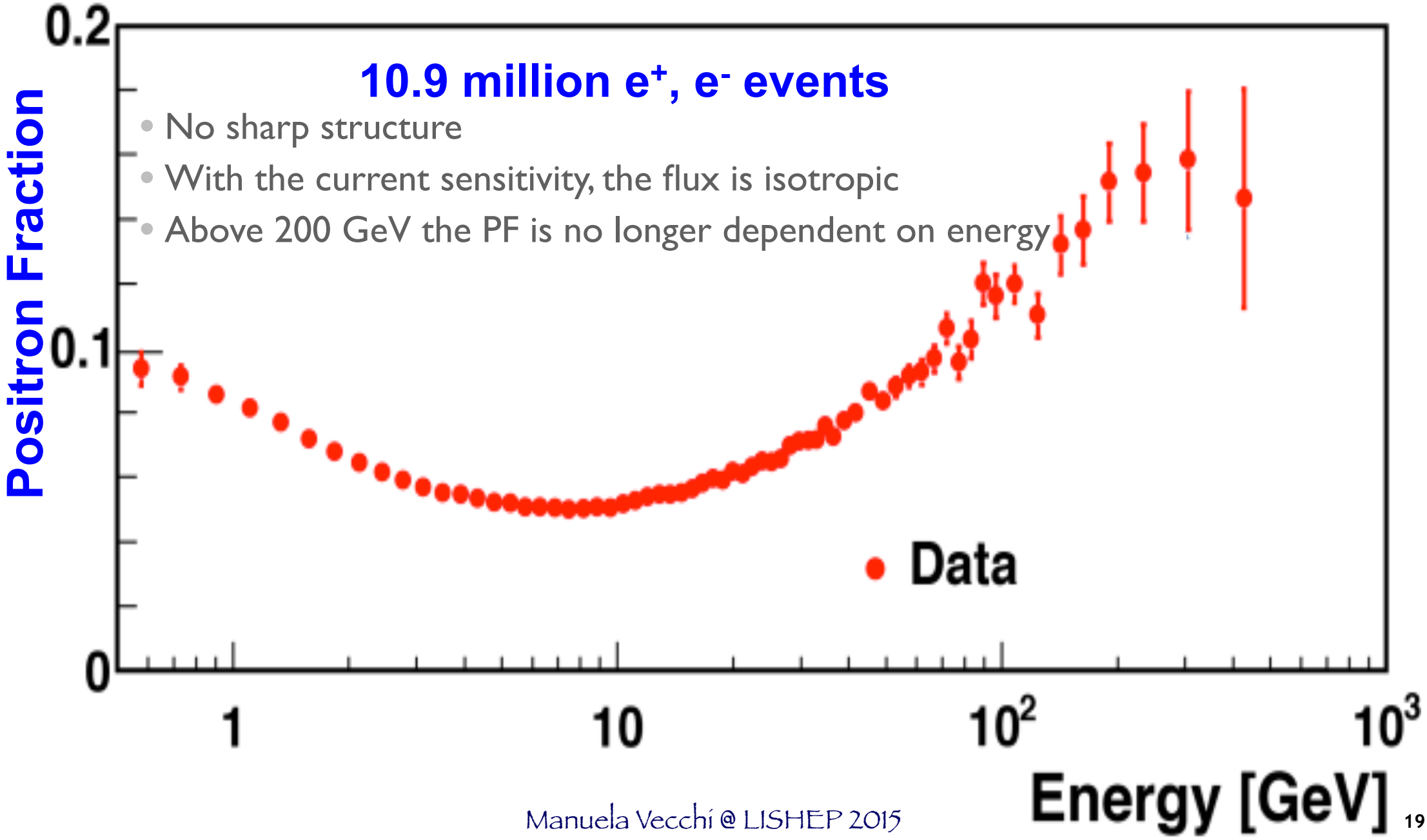
LOW ENERGY POSITRON FRACTION

Fraction begins to increase above 10 GeV

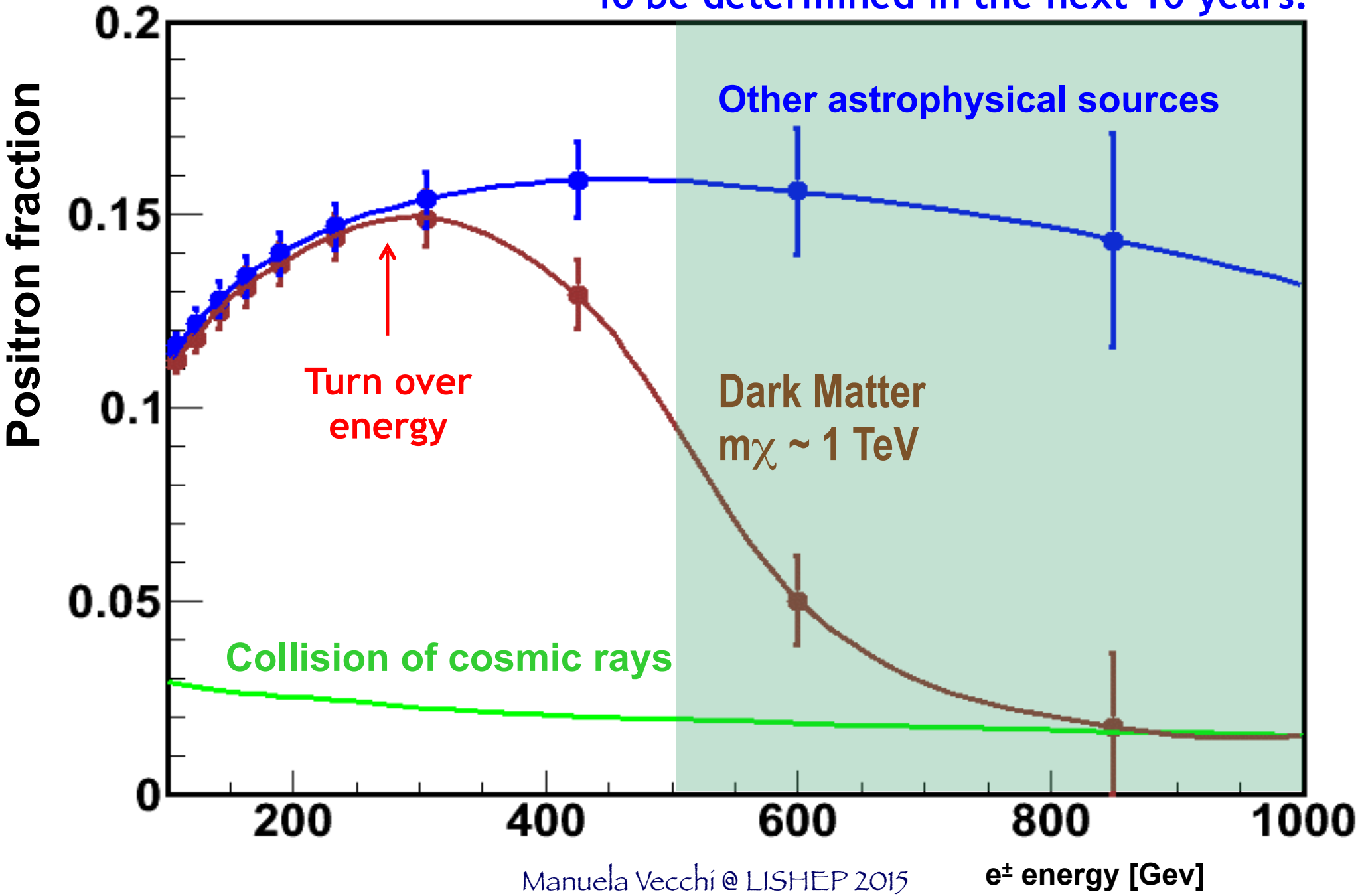




Incompatible with pure secondary hypothesis


10.9 million e+, e- events
No sharp structure
With the current sensitivity, the flux is isotropic
Above 200 GeV the PF is no longer dependent on energy
Positron Fraction
0.2
0.1
0
Data
1
10
10^2
10^3
Energy [GeV]

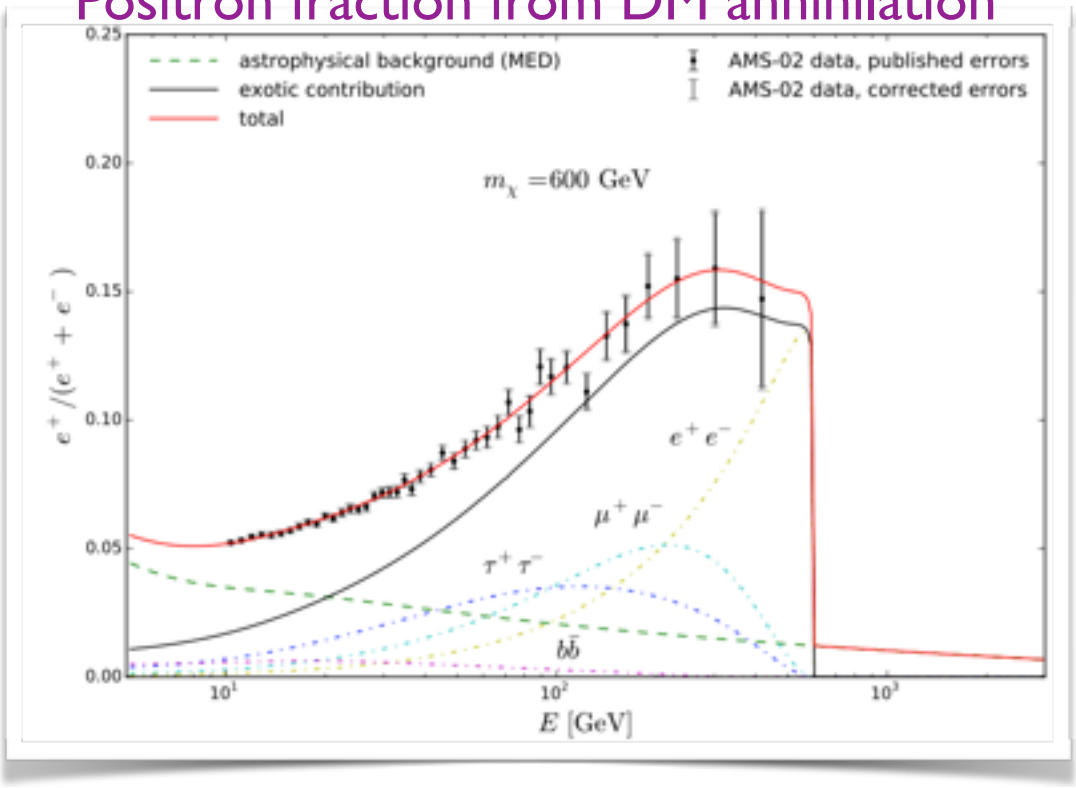
To be determined in the next 10 years:



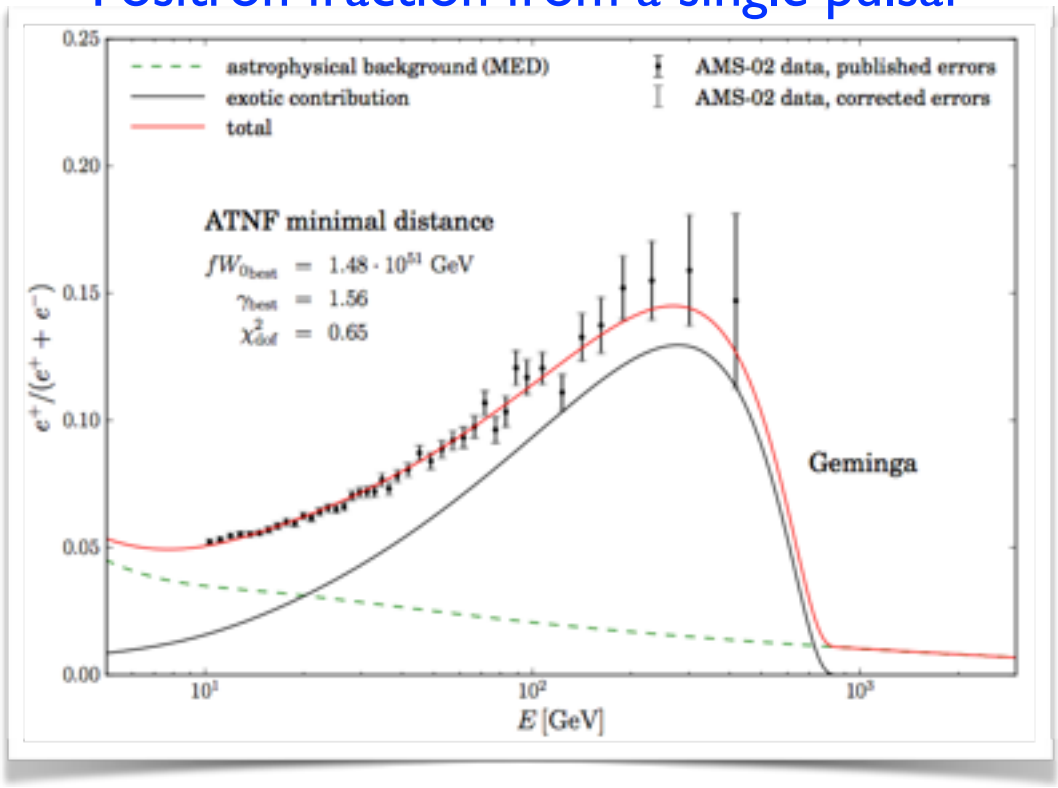
INTERPRETATION OF THE AMS-02 POSITRON DATA

M. Boudaud et al, A&A 575, A67 [arXiv:1410.3799]

Positron fraction from DM annihilation



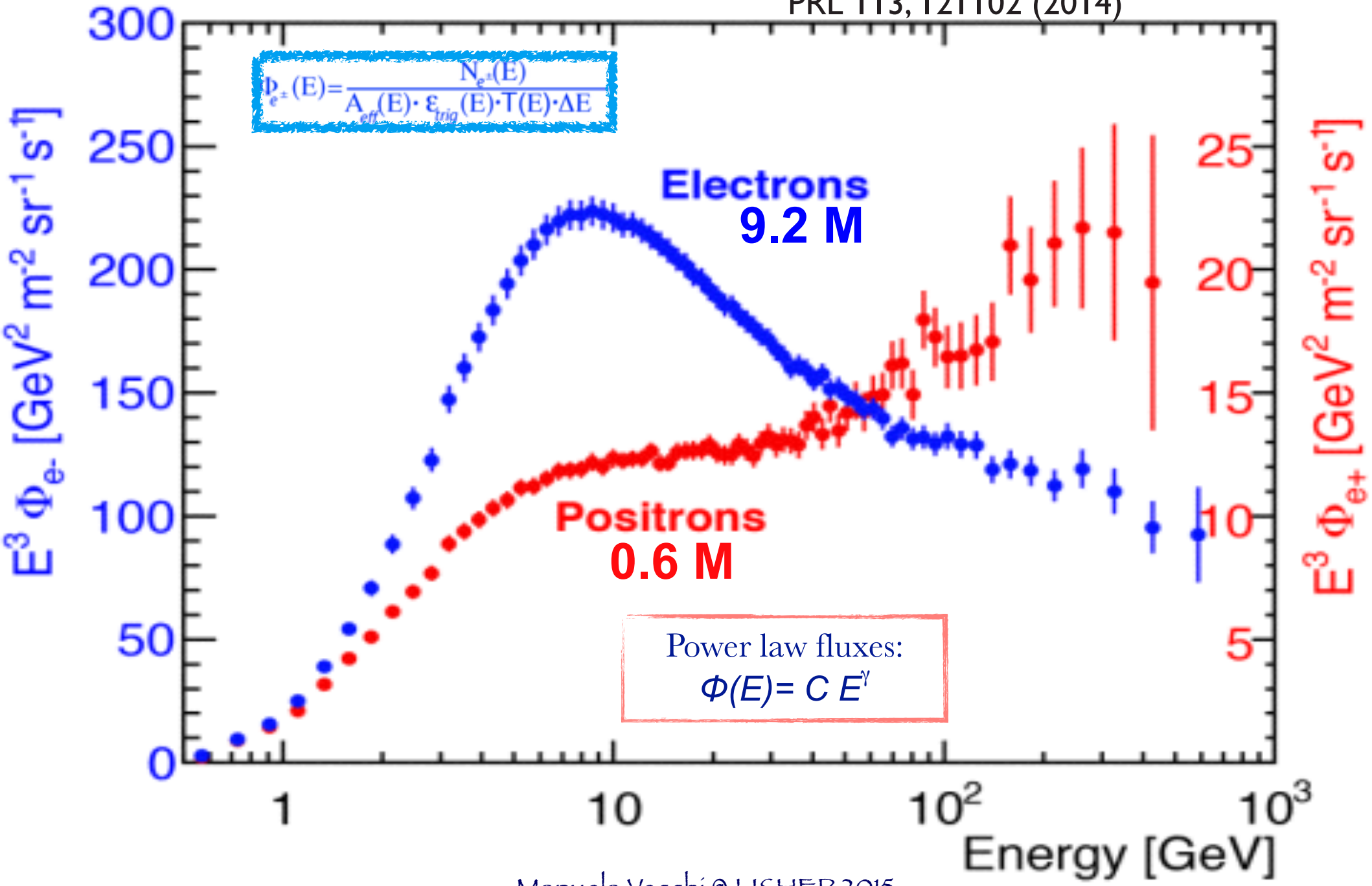
Positron fraction from a single pulsar



- AMS-02 data are consistent with Dark Matter interpretation, given:
  - A large enhancement of the annihilation cross section
- Young nearby pulsars or SNR can also fit the positron fraction

AMS, Electron Flux and the Positron Flux

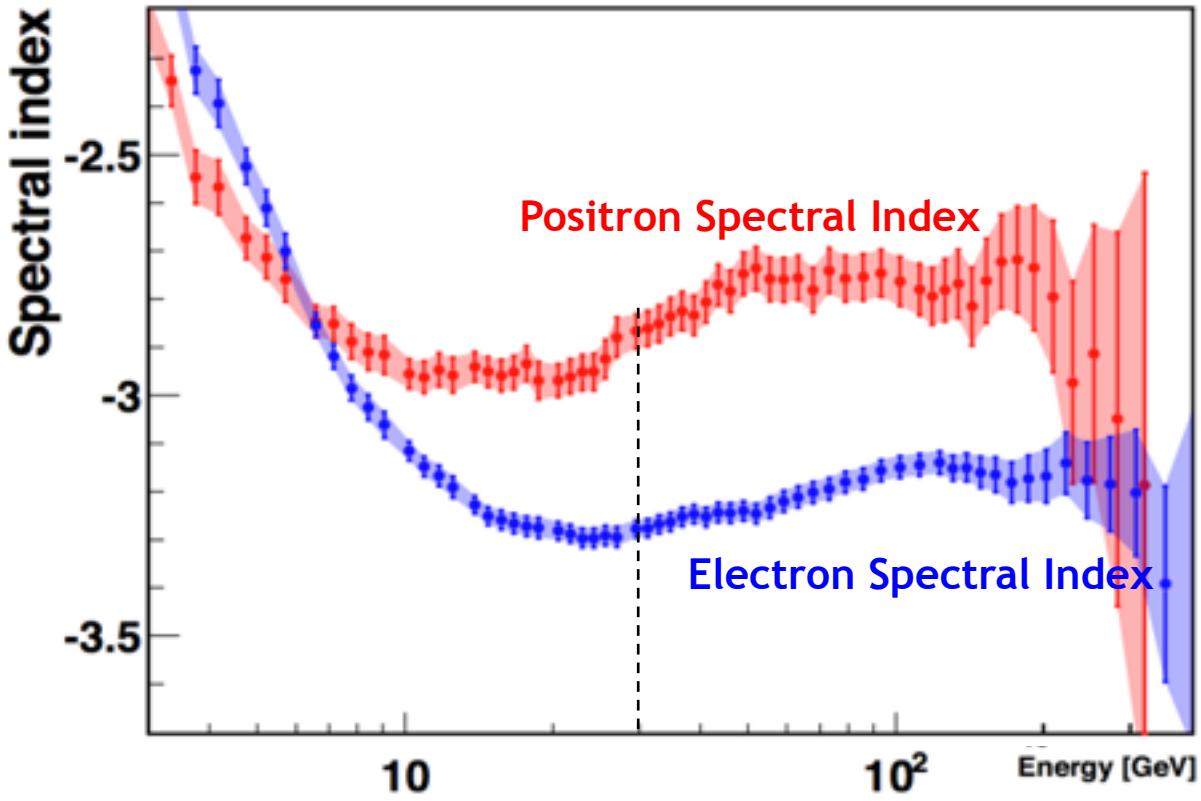
PRL 113, 121102 (2014)



SPECTRAL INDEX

Positron flux: $\Phi(E) = C\, E^{\gamma+}$

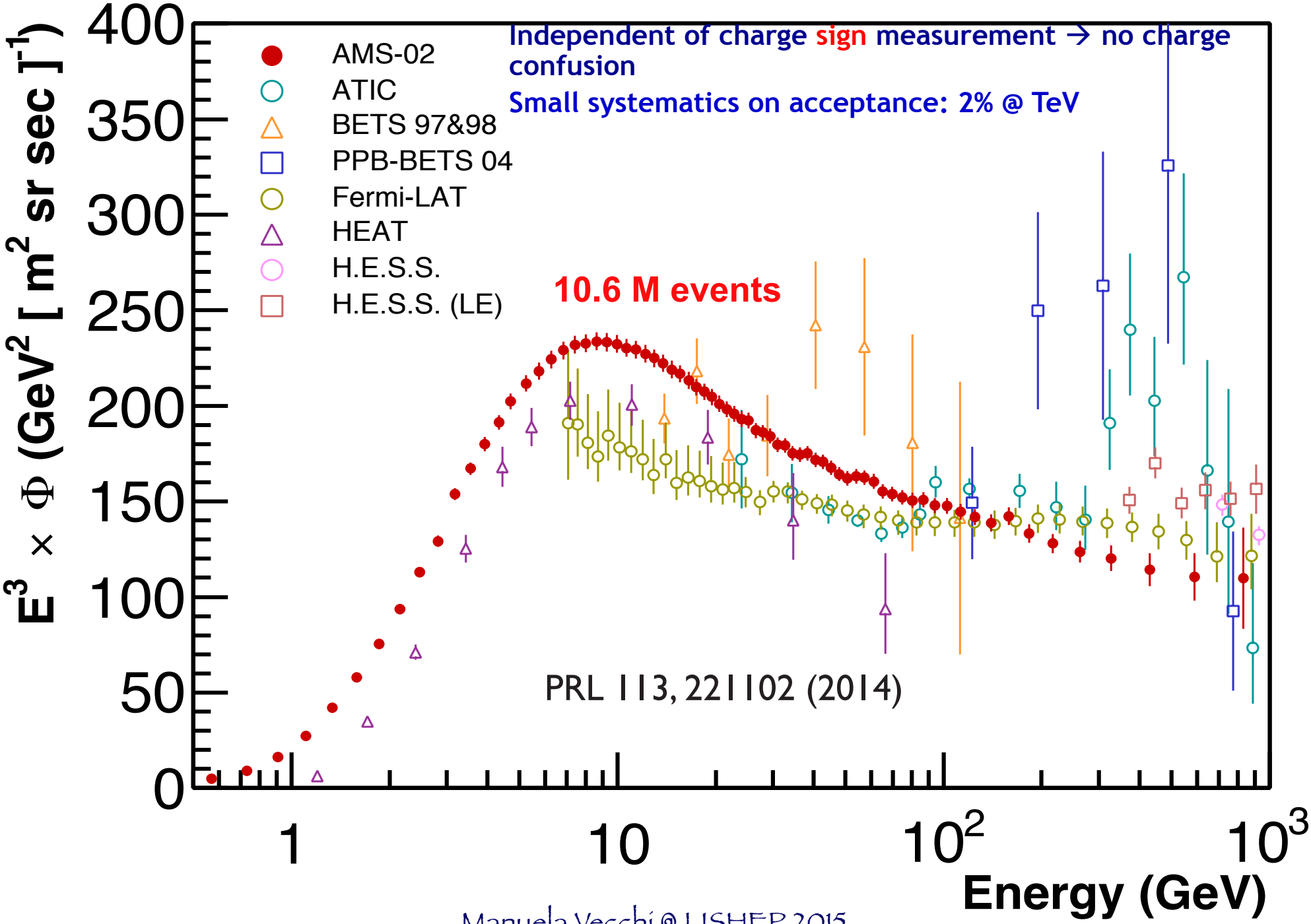
Electron flux: $\Phi(E) = C\, E^{\gamma-}$



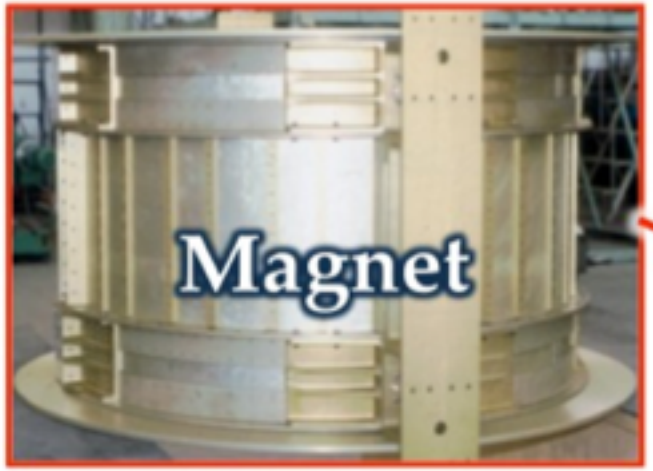
- The spectral indices of electrons and positrons are different
- Both spectra cannot be described by single power laws
- Change of behaviour at ~30GeV

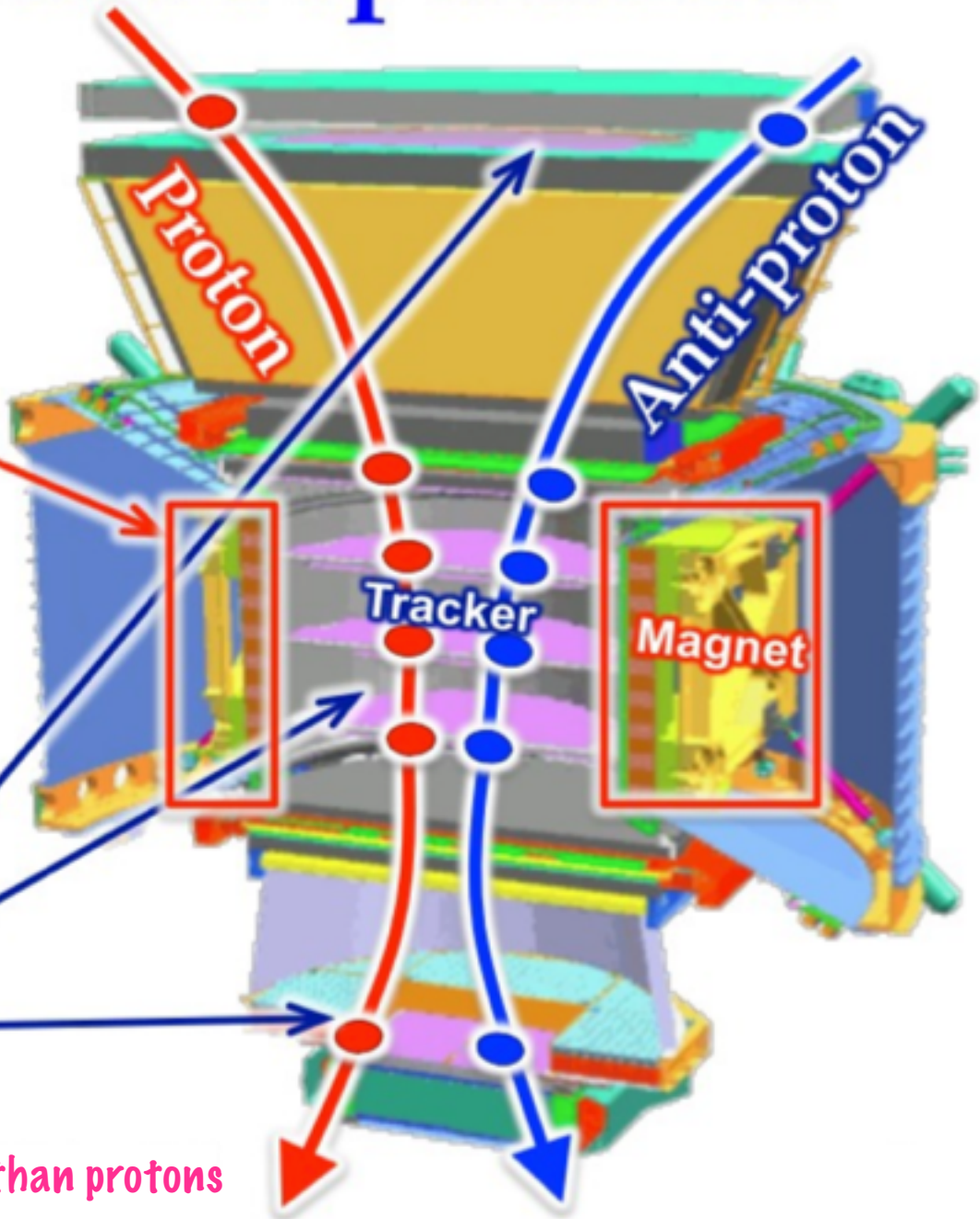
The rise in the positron fraction is actually due to an excess of positrons, not the loss of electrons (the positron flux is harder).

AMS Results: ($e^+ + e^-$) flux



Antiproton/proton separation

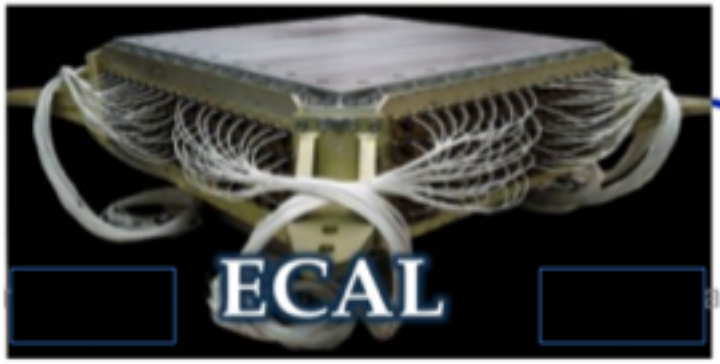


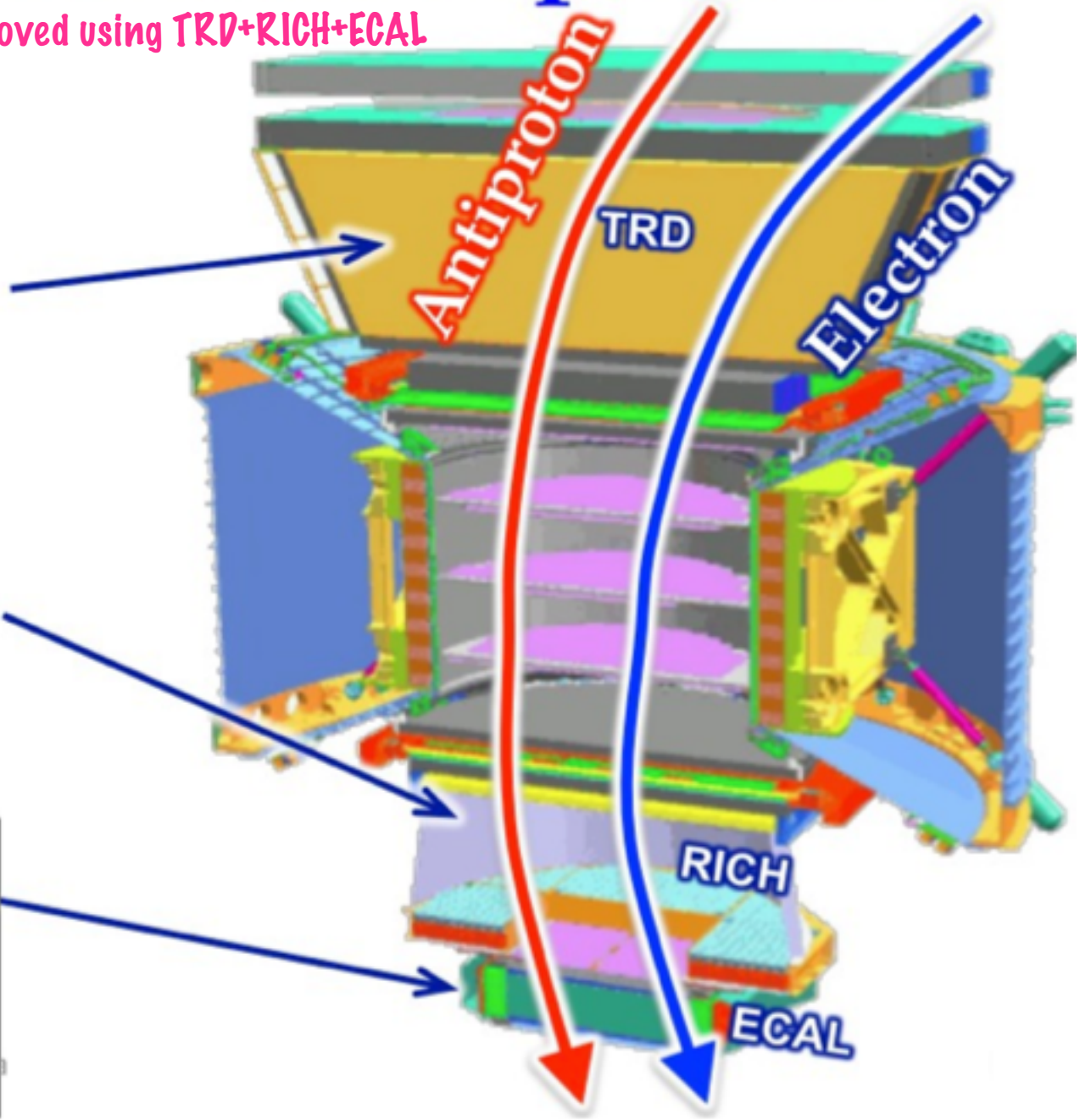


Antiprotons are 10^4 times less abundant than protons

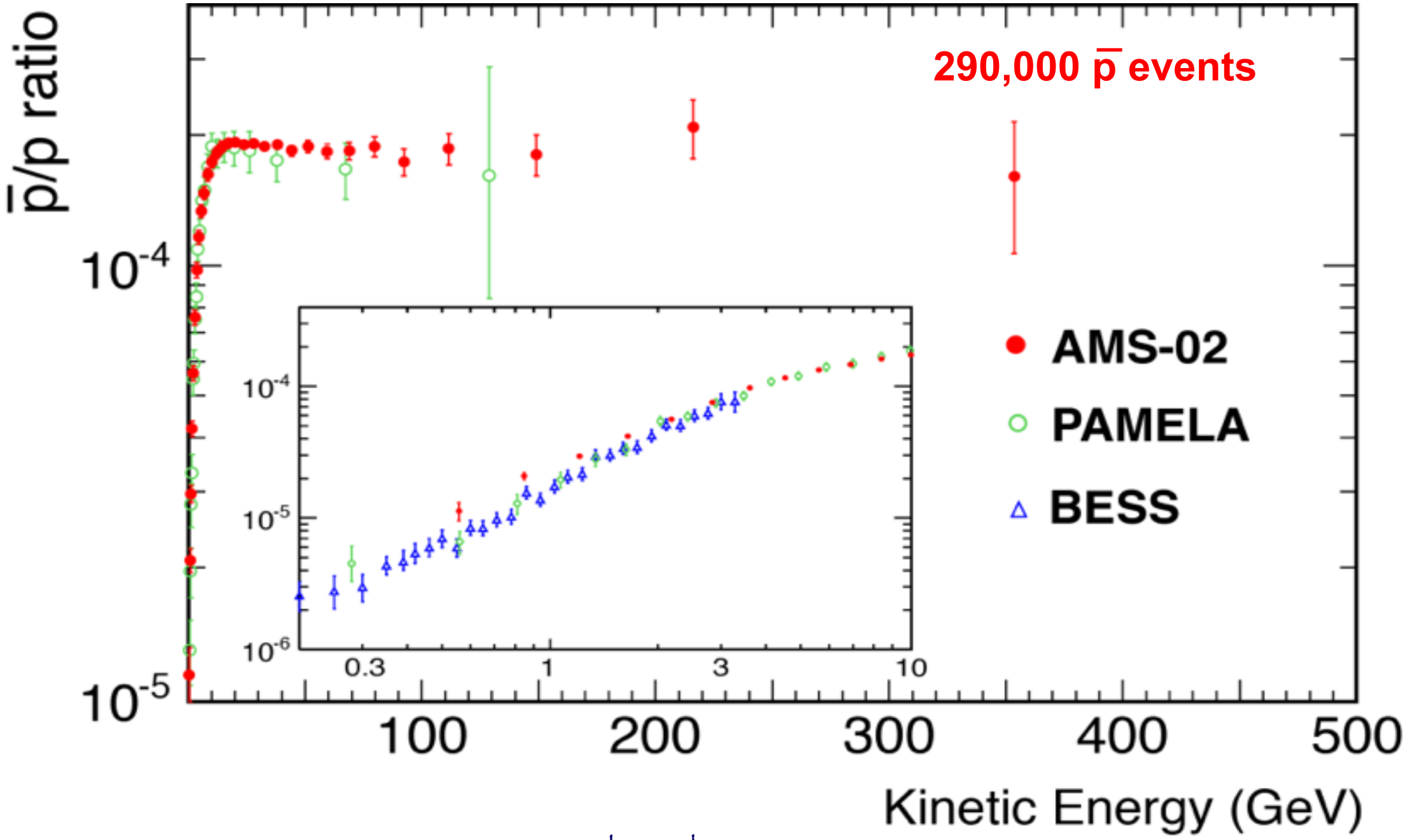
Antiproton/electron separation

Electrons/kaons/pions can be removed using TRD+RICH+ECAL

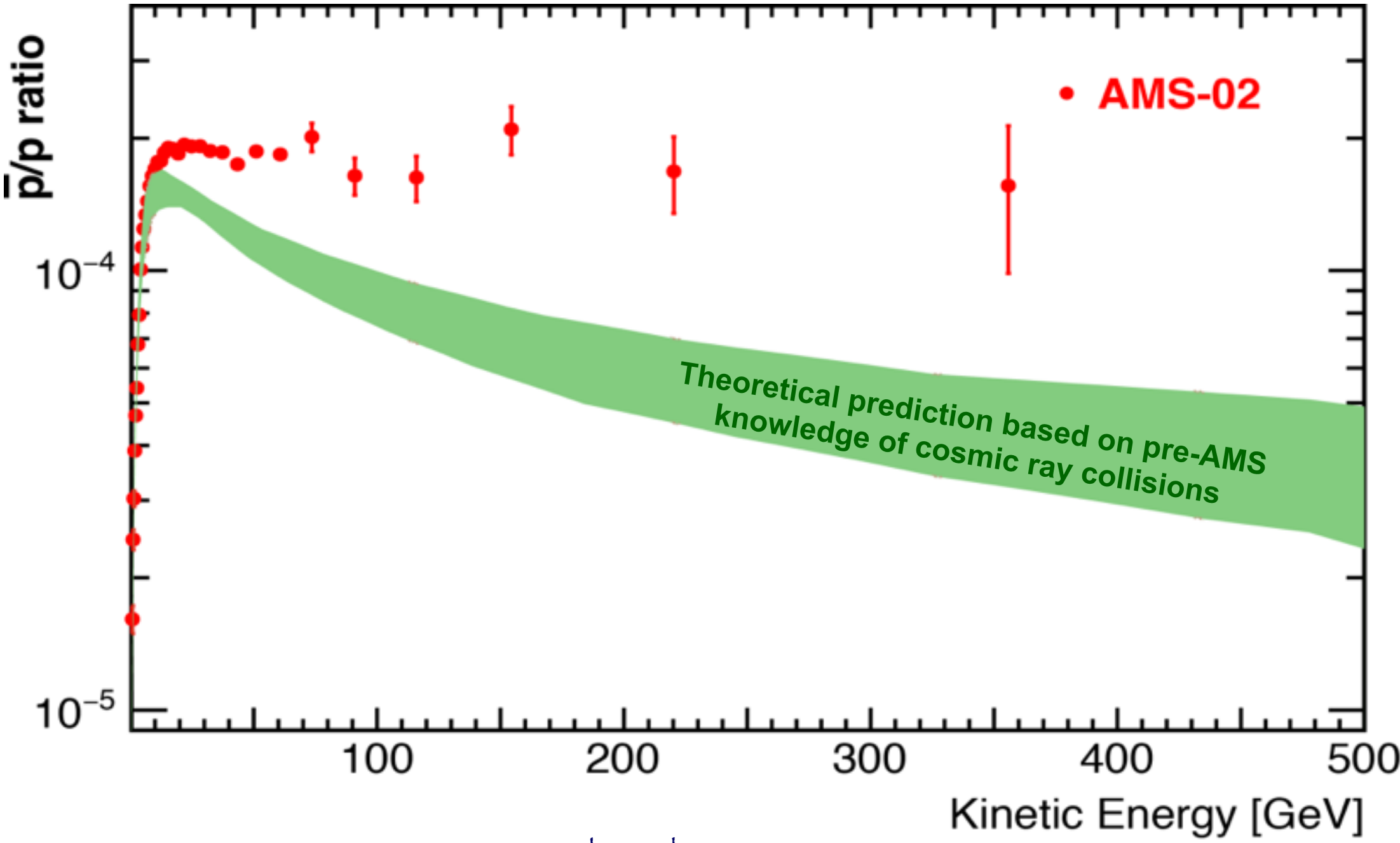




AMS $\bar{p}/p$ results



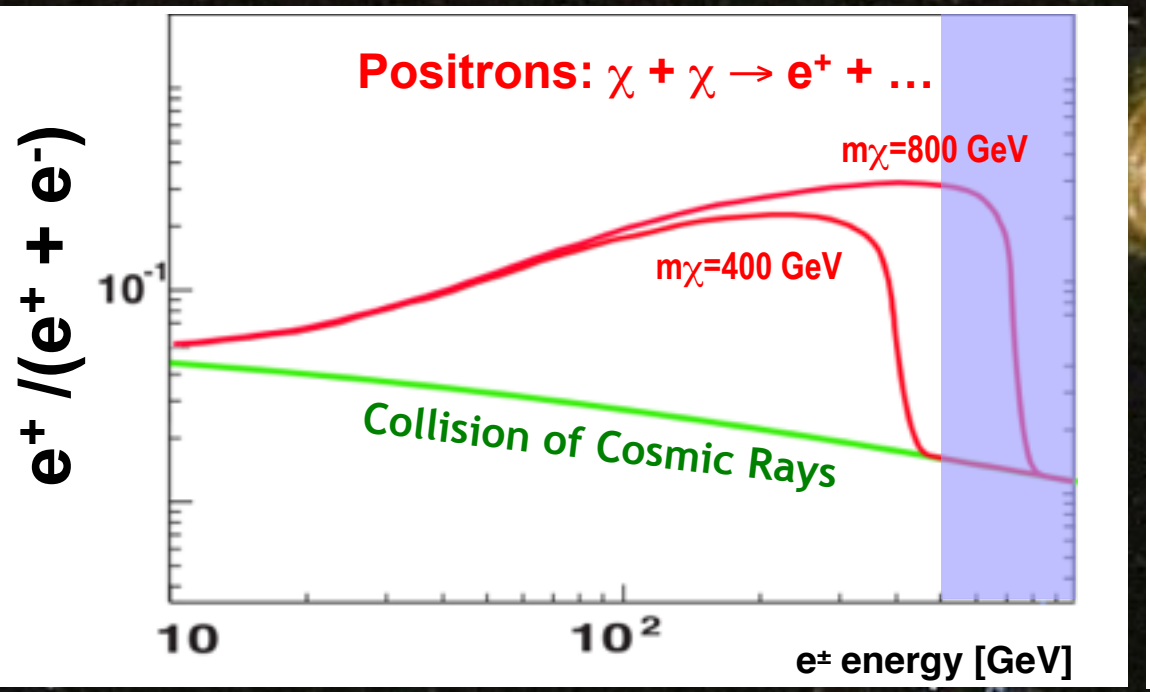
AMS $\bar{p}/p$ results

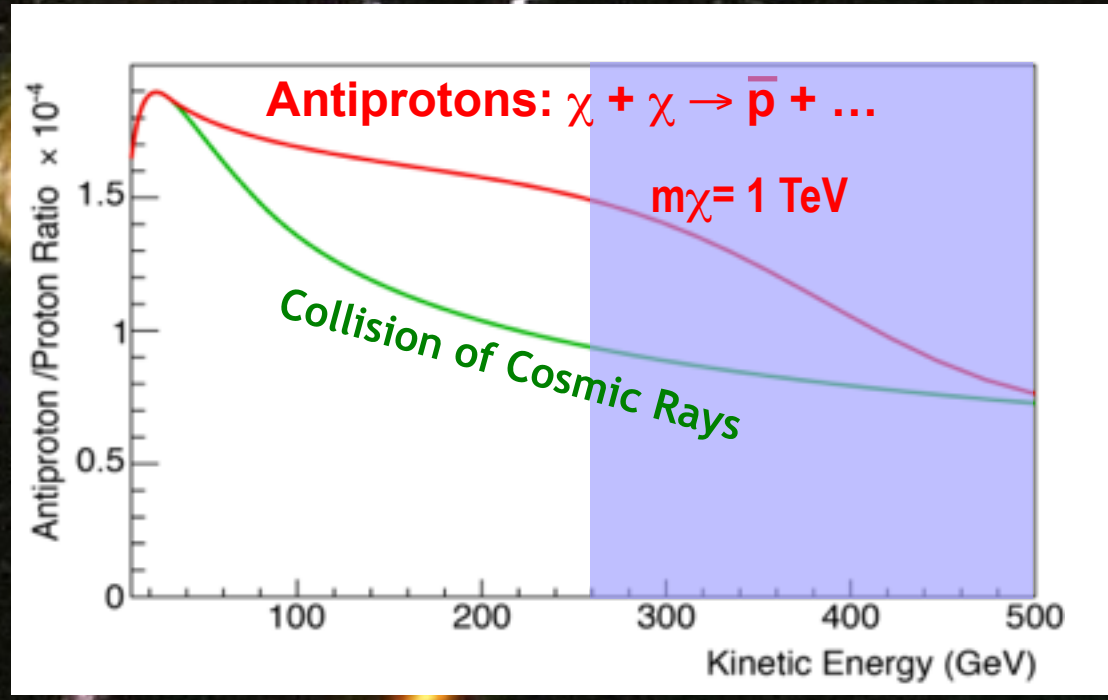


The Search for the Origin of Dark Matter

To identify the Dark Matter signal we need

to measure the e^+, e^- and $\bar{p}$ signal accurately until 2024.

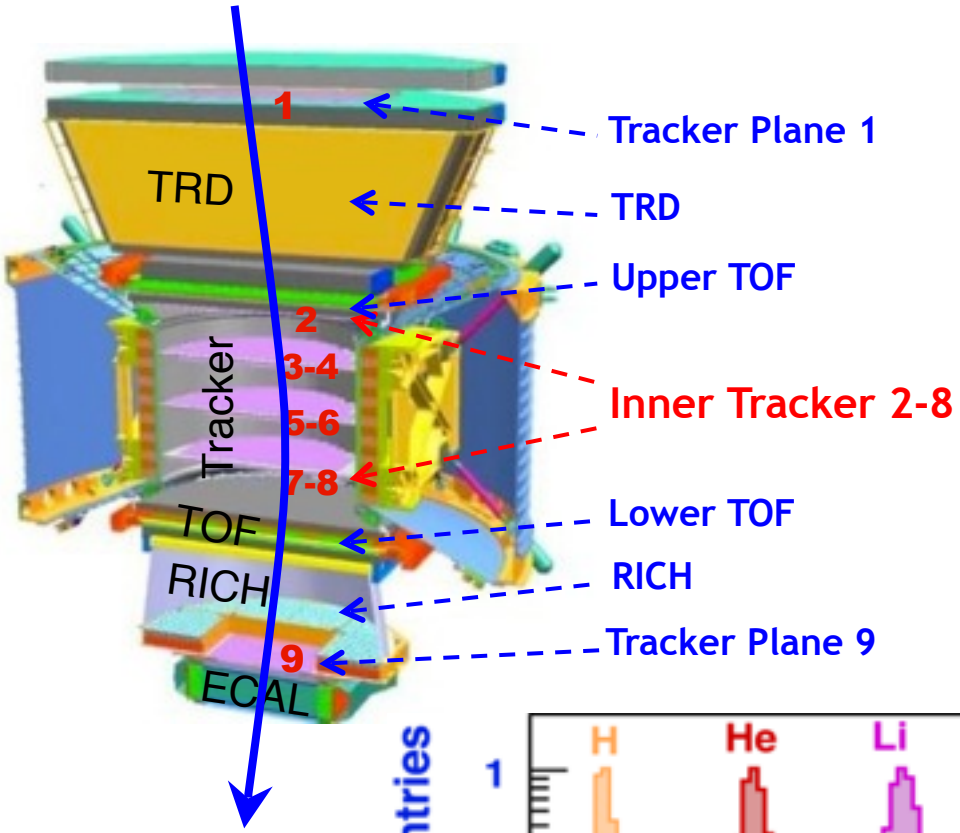


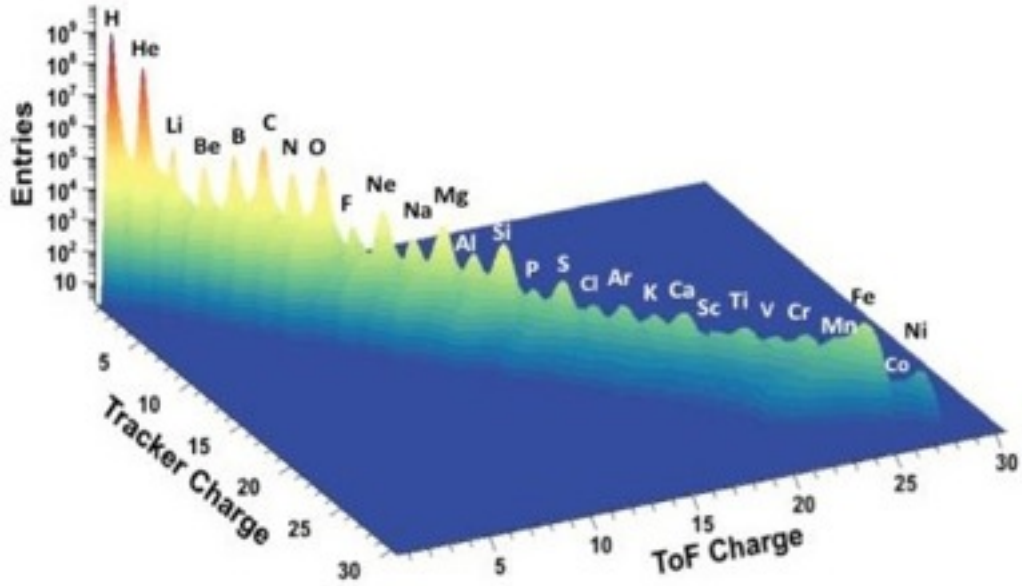


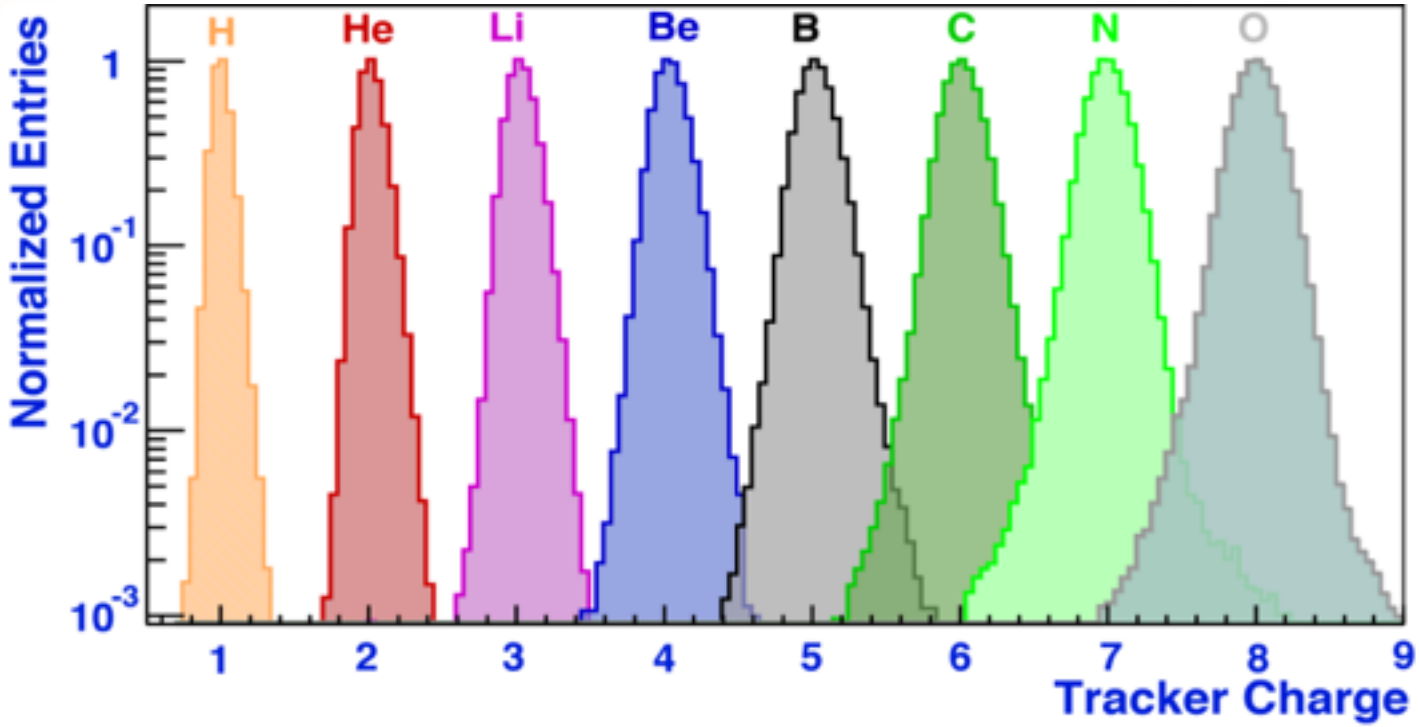
To understand background, we need precise knowledge of:

1. The cosmic ray fluxes (p, He, C, …)
2. Propagation and Acceleration (Li, B/C, …)

AMS: Multiple Measurements of Nuclear Charge

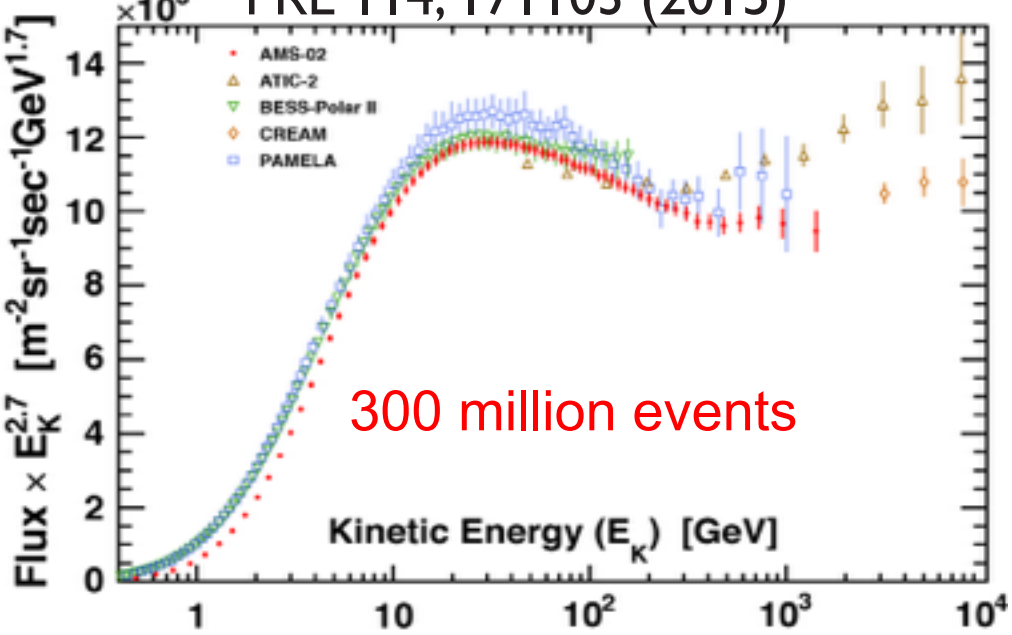




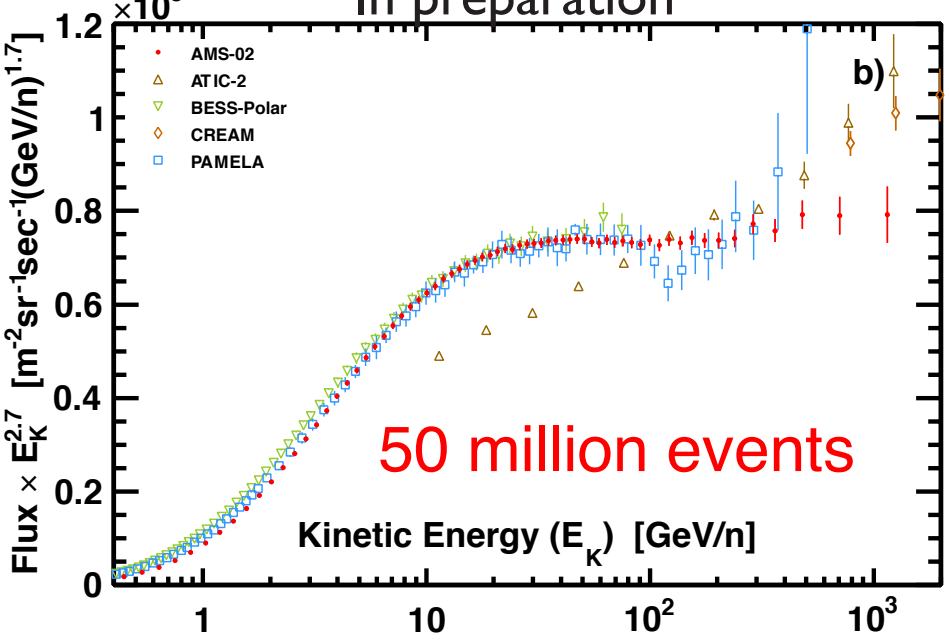


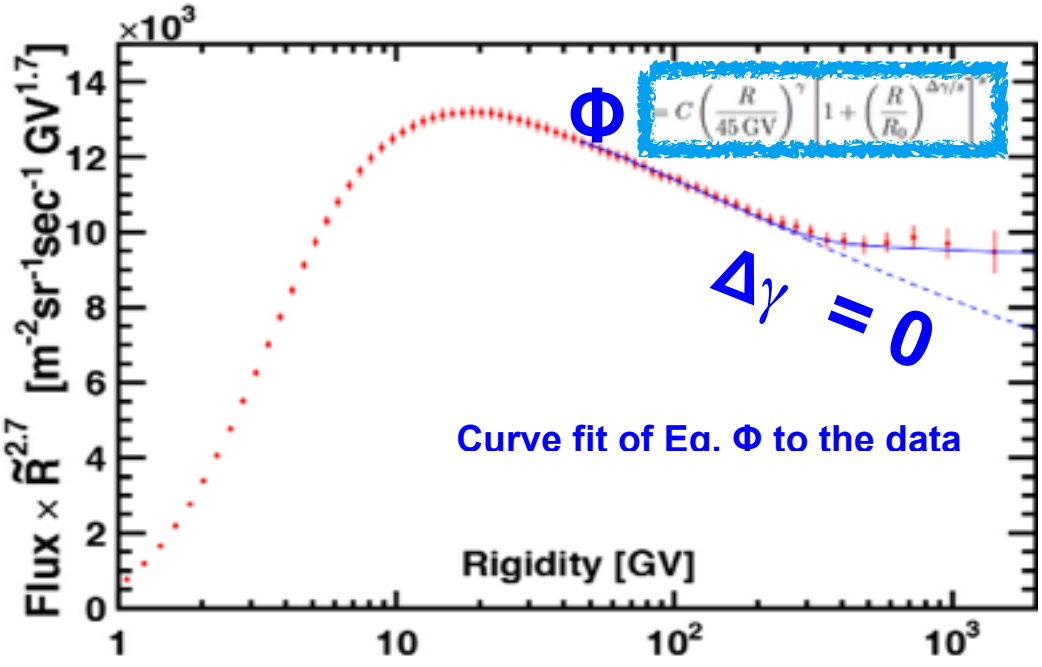
PROTON AND HELIUM FLUXES

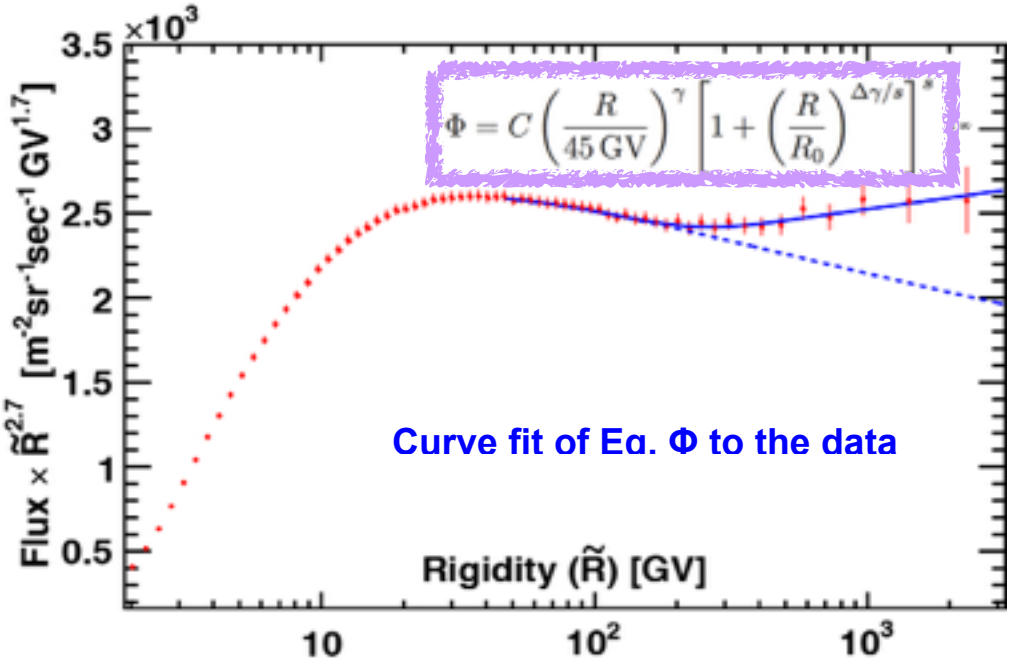
PRL 114, 171103 (2015)



In preparation

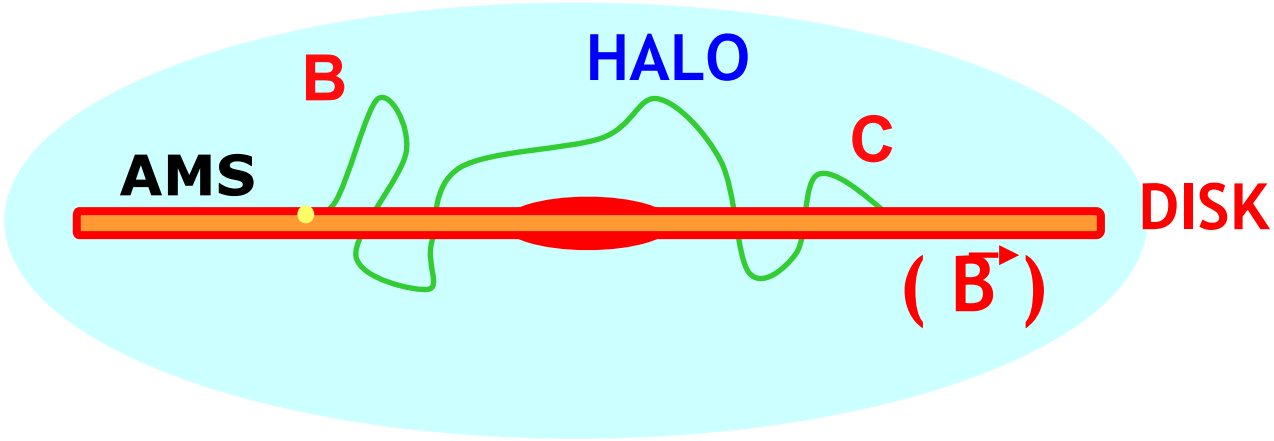






STATUS REPORT ON CR NUCLEI

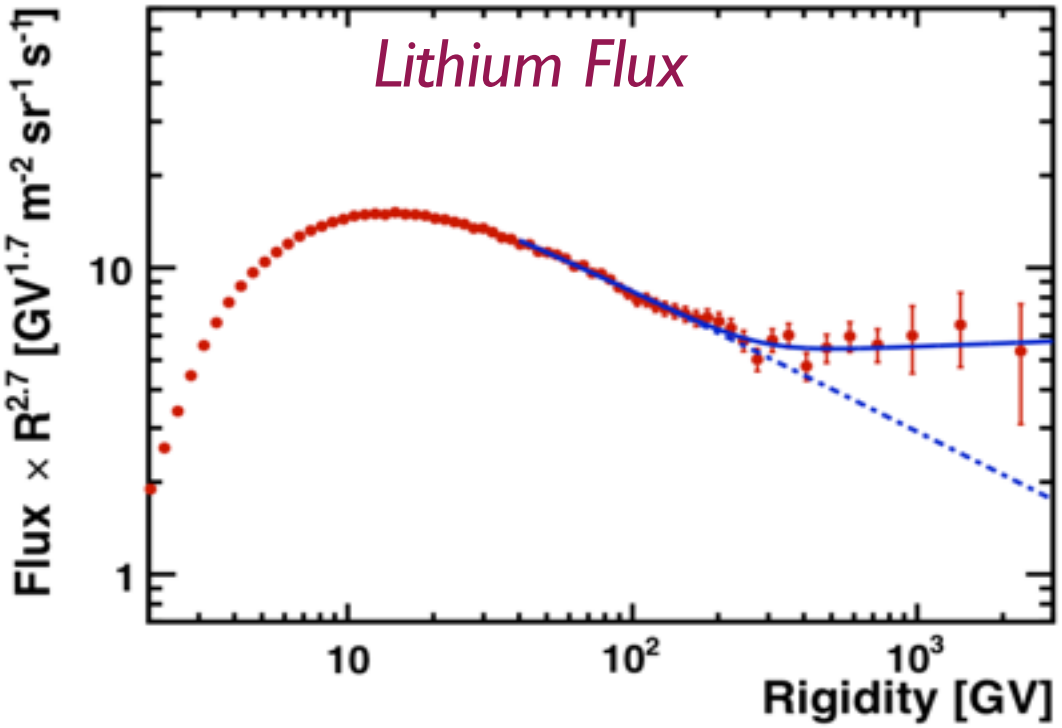
Sensitive to cosmic ray propagation history

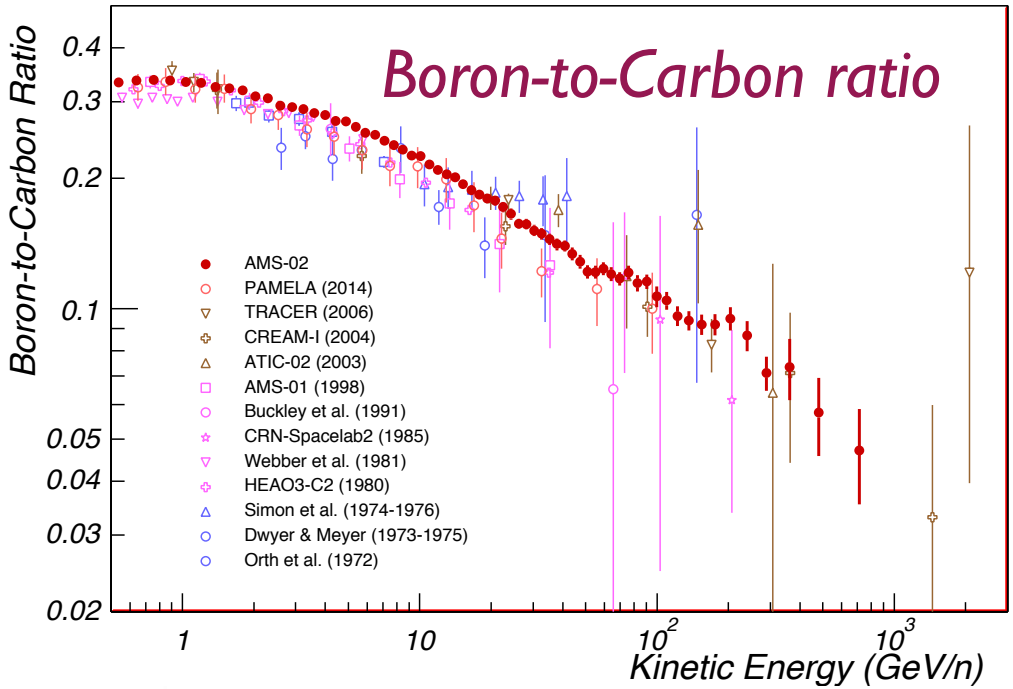


Lithium Flux

Boron-to-Carbon ratio

STATUS REPORT ON CR NUCLEI



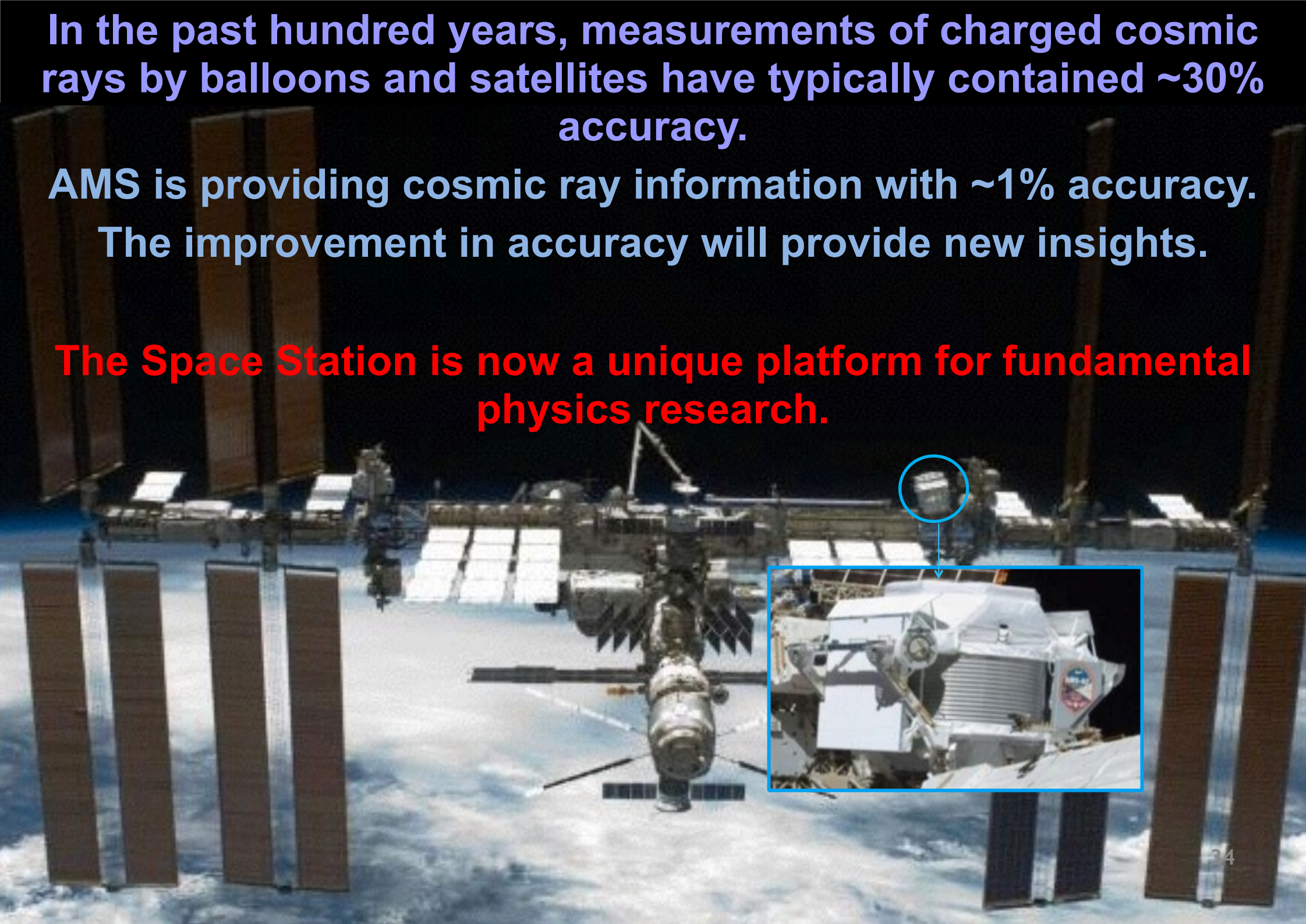


In the past hundred years, measurements of charged cosmic rays by balloons and satellites have typically contained ~30% accuracy.

AMS is providing cosmic ray information with ~1% accuracy.

The improvement in accuracy will provide new insights.

The Space Station is now a unique platform for fundamental physics research.



THANK YOU FOR YOUR ATTENTION !