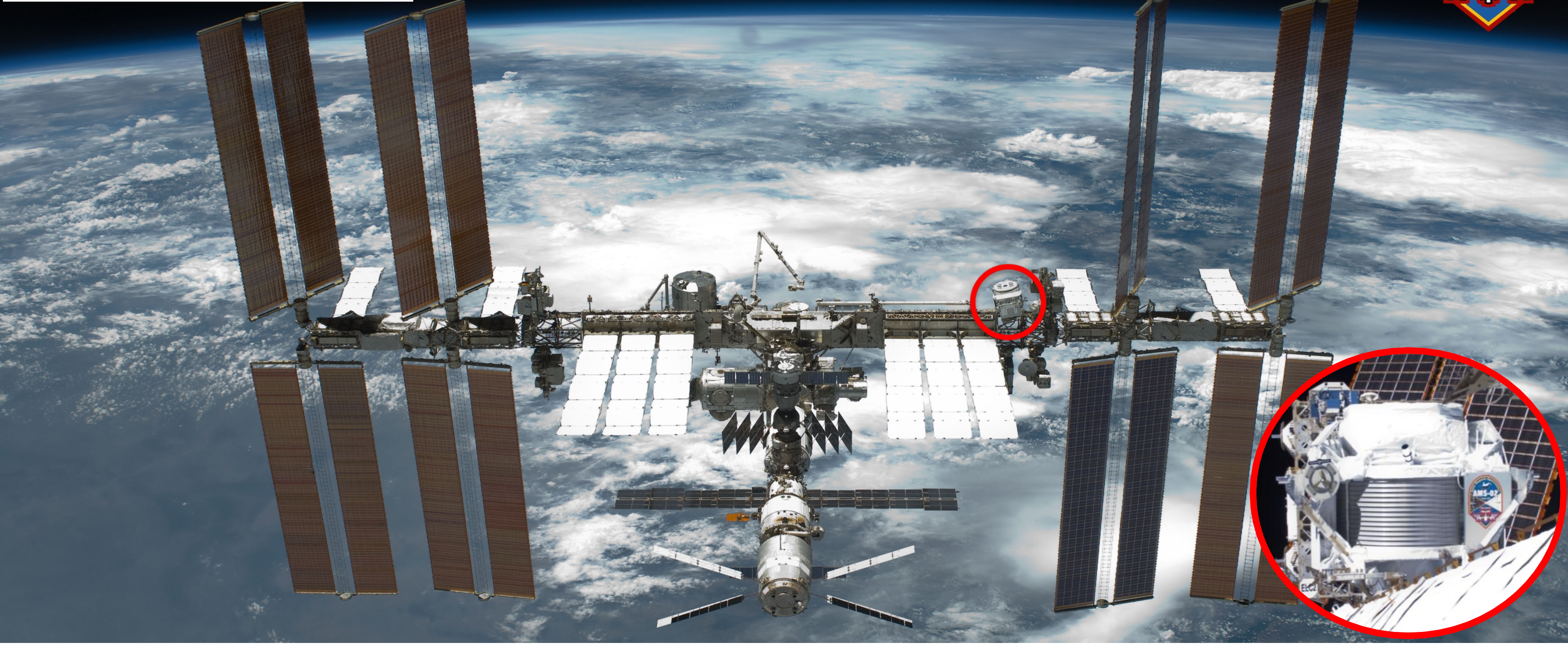
XV International Conference on Interconnections between Particle Physics and Cosmology

June 6-10, 2022

Hosted by Washington University in St. Louis

AMS Physics Results



Matteo Duranti

INFN Sez. Perugia

on behalf of the AMS Collaboration

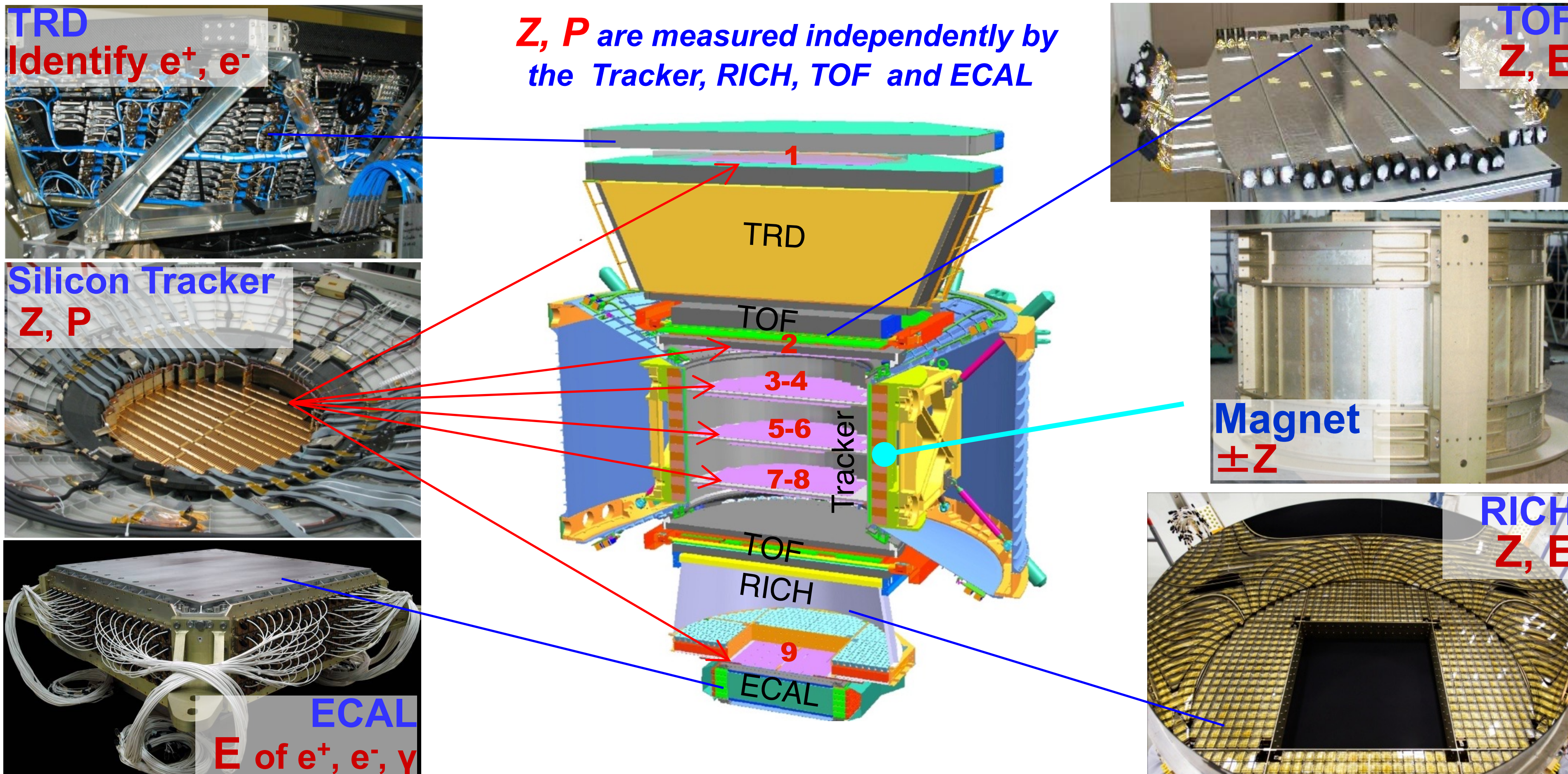
Outline

- the instrument
- physics results
- the future…

The instrument

A precision, multipurpose, TeV spectrometer

***Z, P** are measured independently by the Tracker, RICH, TOF and ECAL*



2010: AMS-02 assembled

AMS facts:

- 5 m x 4 m x 3m
- 7.5 tons
- 300k read-out channels
- more than 600 microprocessors reduce the *rate* from 7 Gb/s to 10 Mb/s
- total power < 2.5 kW

2011: AMS launch - @ JSC, Texas

2011: AMS launch - @ KSC, Florida

- Total weight: 2008 t
- AMS weight: 7.5 t

Cape Canaveral, KSC - 16 May, 2011, 08:56 AM

AMS mission

AMS has collected

203,924,102,396

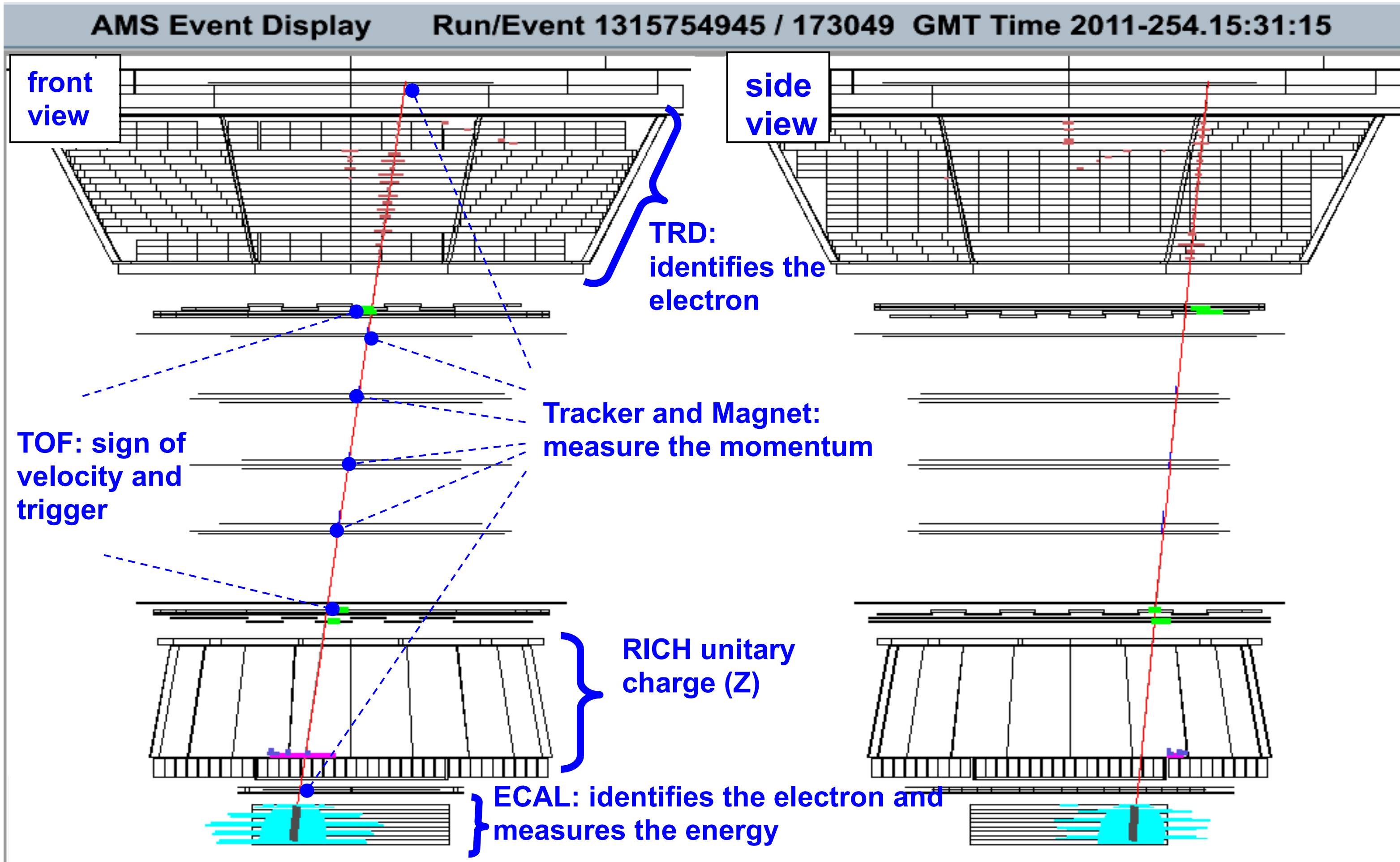
cosmic ray events

Last update: June 2, 2022, 6:12 PM

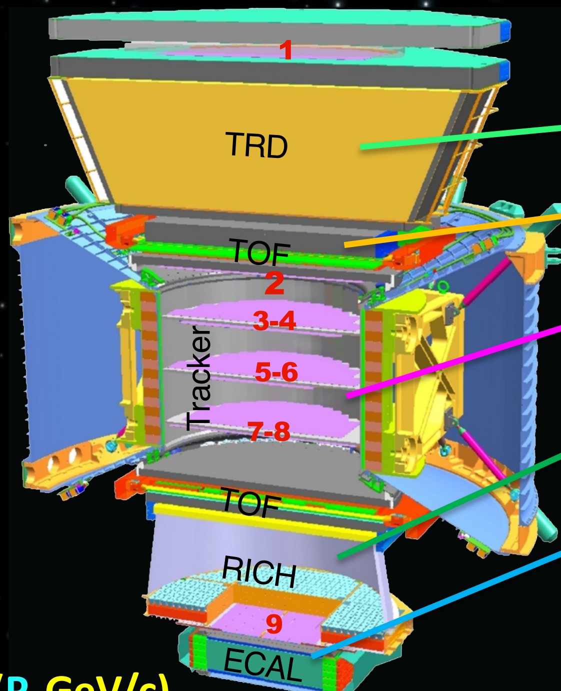
AMS-02 time on ISS since May 19th, 5:46 a.m. EDT:

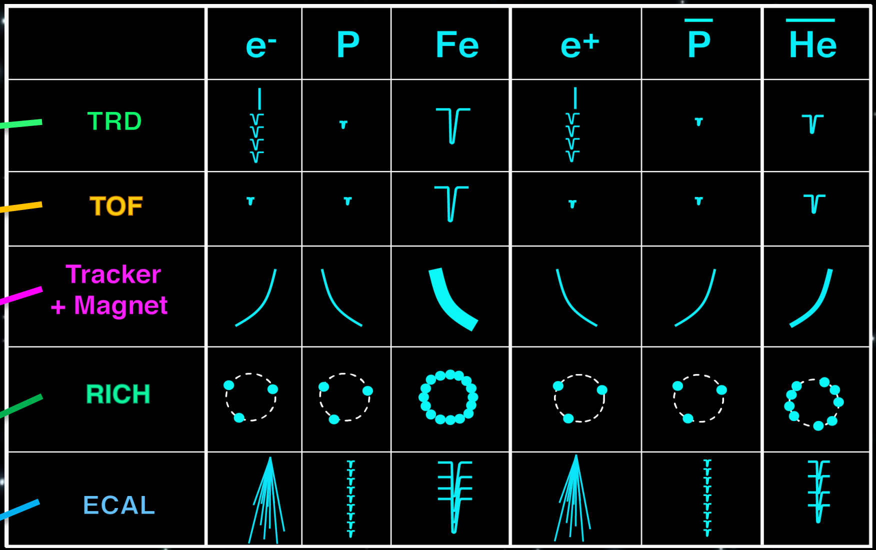
4032 DAYS **8** HOURS **59** MINUTES **38** SECONDS

ISS Data – 1.03 TeV Electron



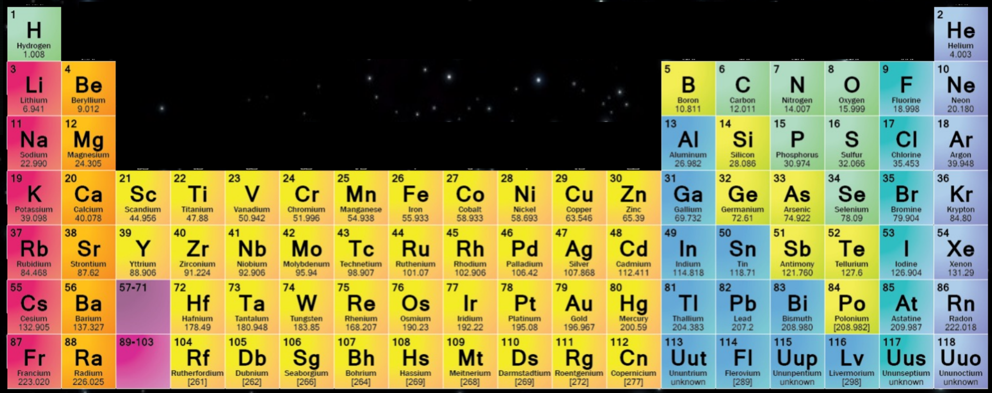
Particle identification





AMS measures :

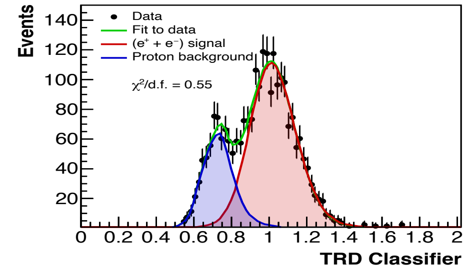
- Momentum (P, GeV/c)
- Charge (Z)
- Rigidity (R=P/Z, GV)
- Energy (E, GeV/A)
- Flux (signals/(s sr m^2 GeV))



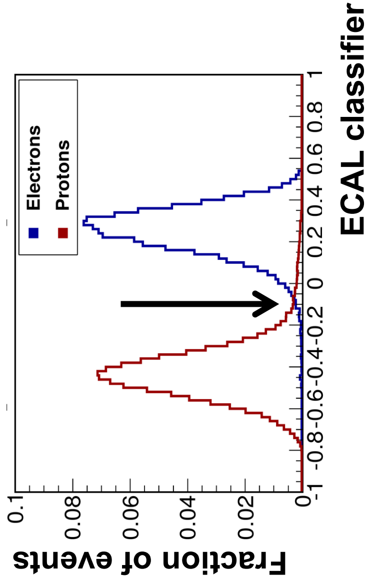
e/p discrimination

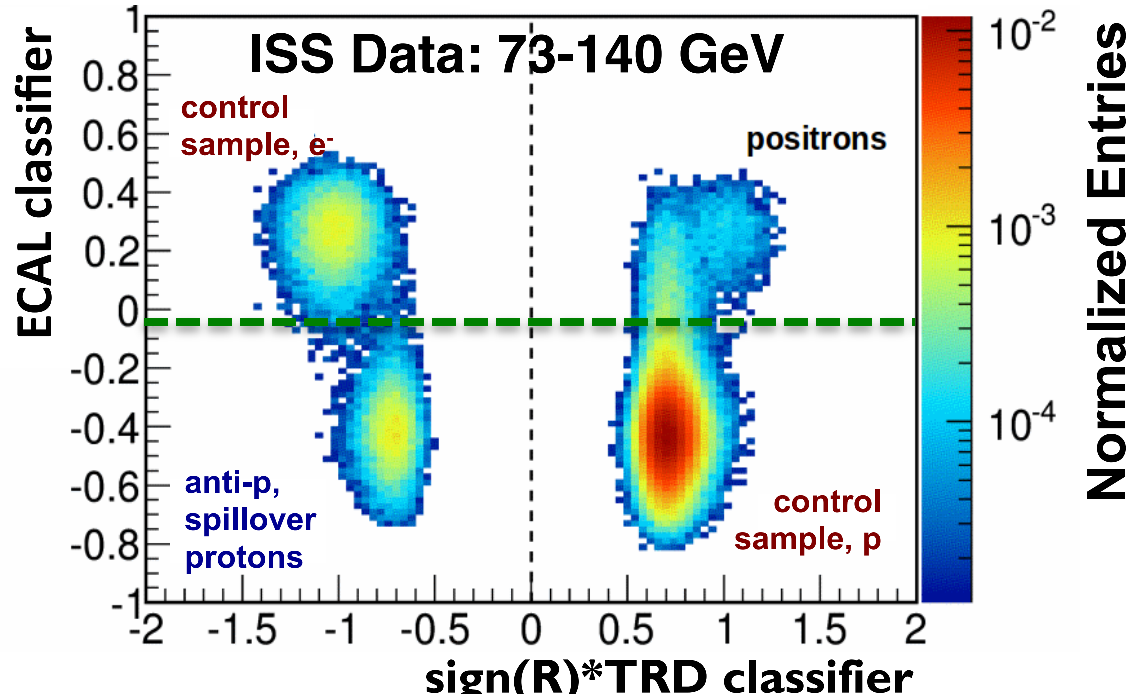
One important lesson from the AMS experiment is the importance of the redundancy: use one detector to create control sample for another one.

Study of the difference (i.e. likelihood) between dE/dx and TR in 20 layers of fleece radiator + straw tubes

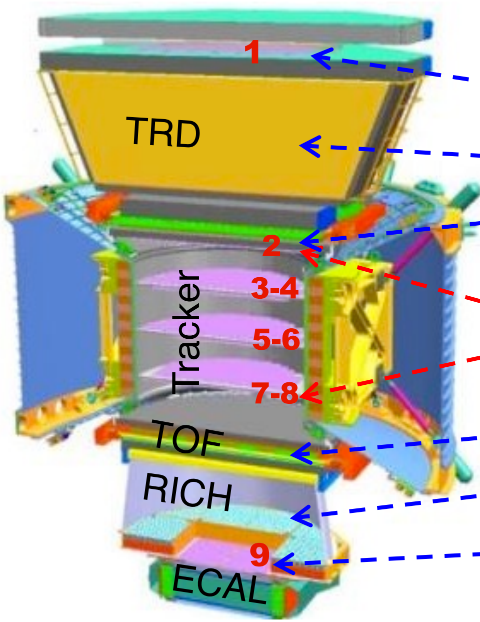


Study of the difference (i.e. Boosted Decision Tree, BDT) between hadrons and EM particles in 19 variables describing 3D shower shape



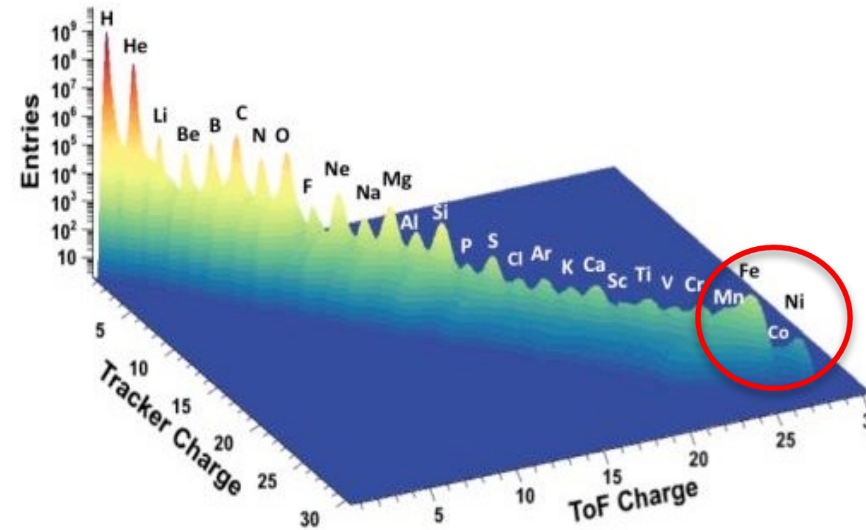


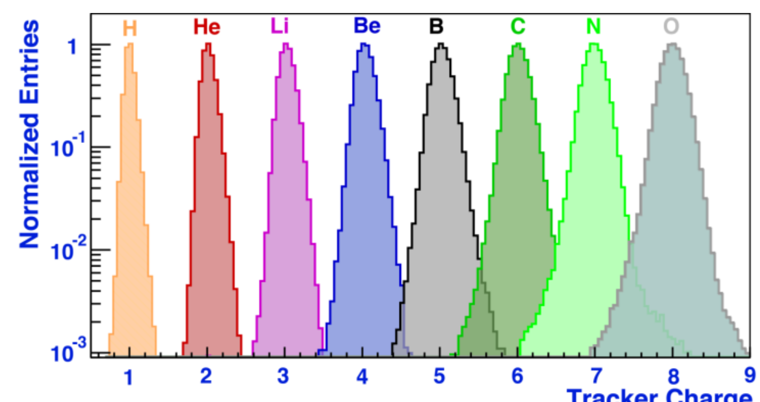
Charge measurement



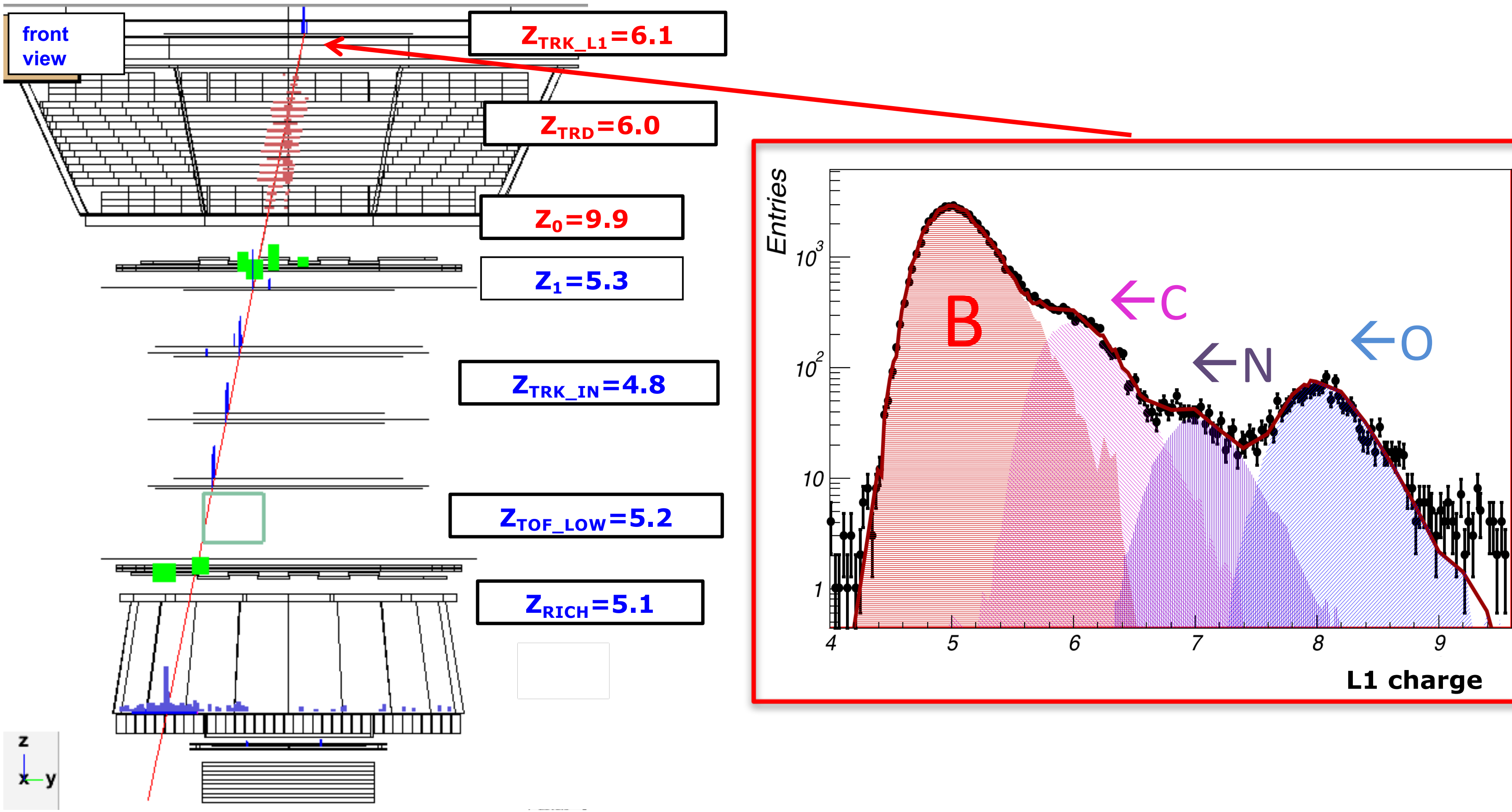
Charge Resolution (Z=6)

Tracker Plane 1	0.30
TRD	0.33
Upper TOF	0.16
Inner Tracker 2-8	0.12
Lower TOF	0.16
RICH	0.32
Tracker Plane 9	0.30

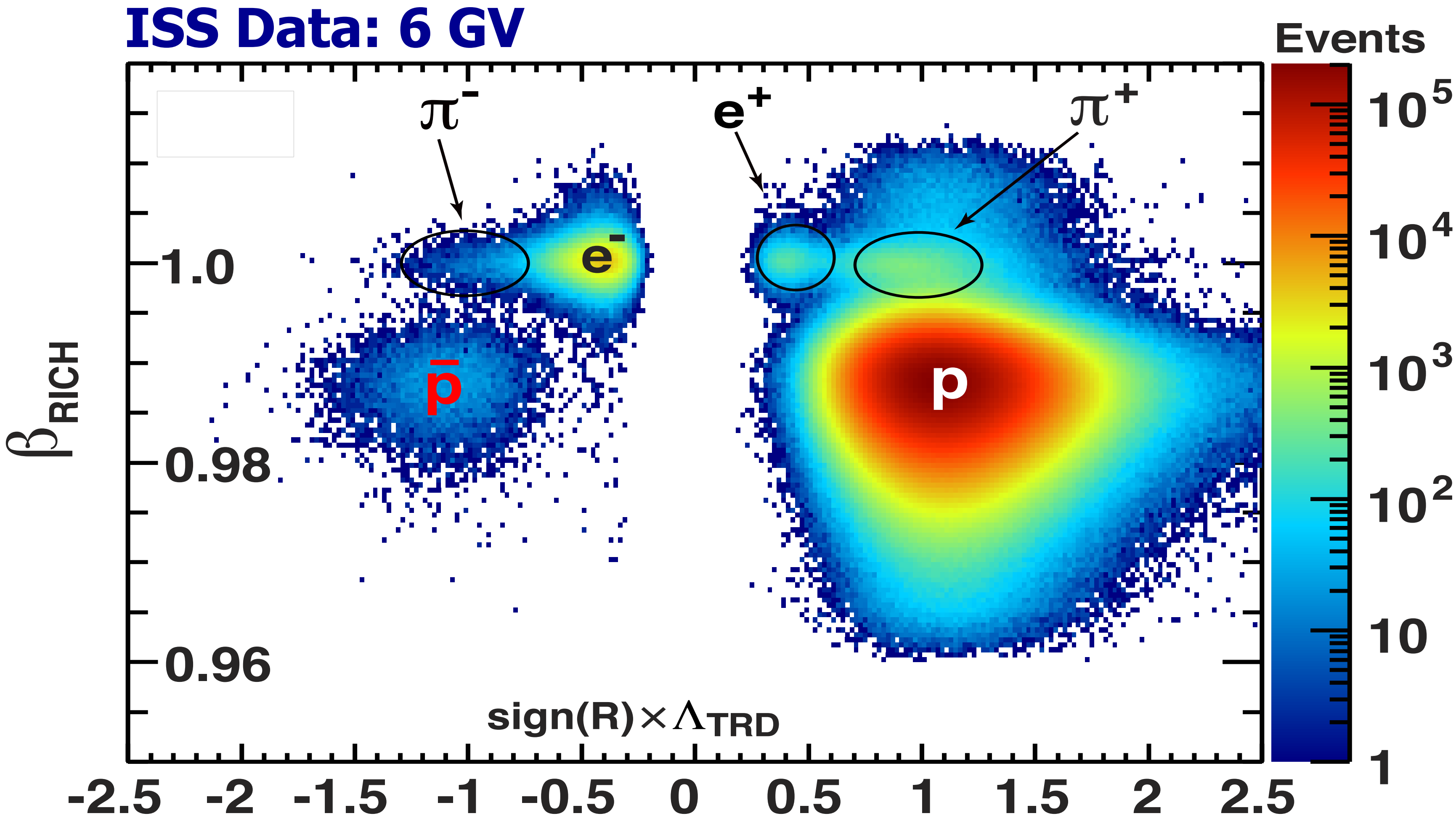




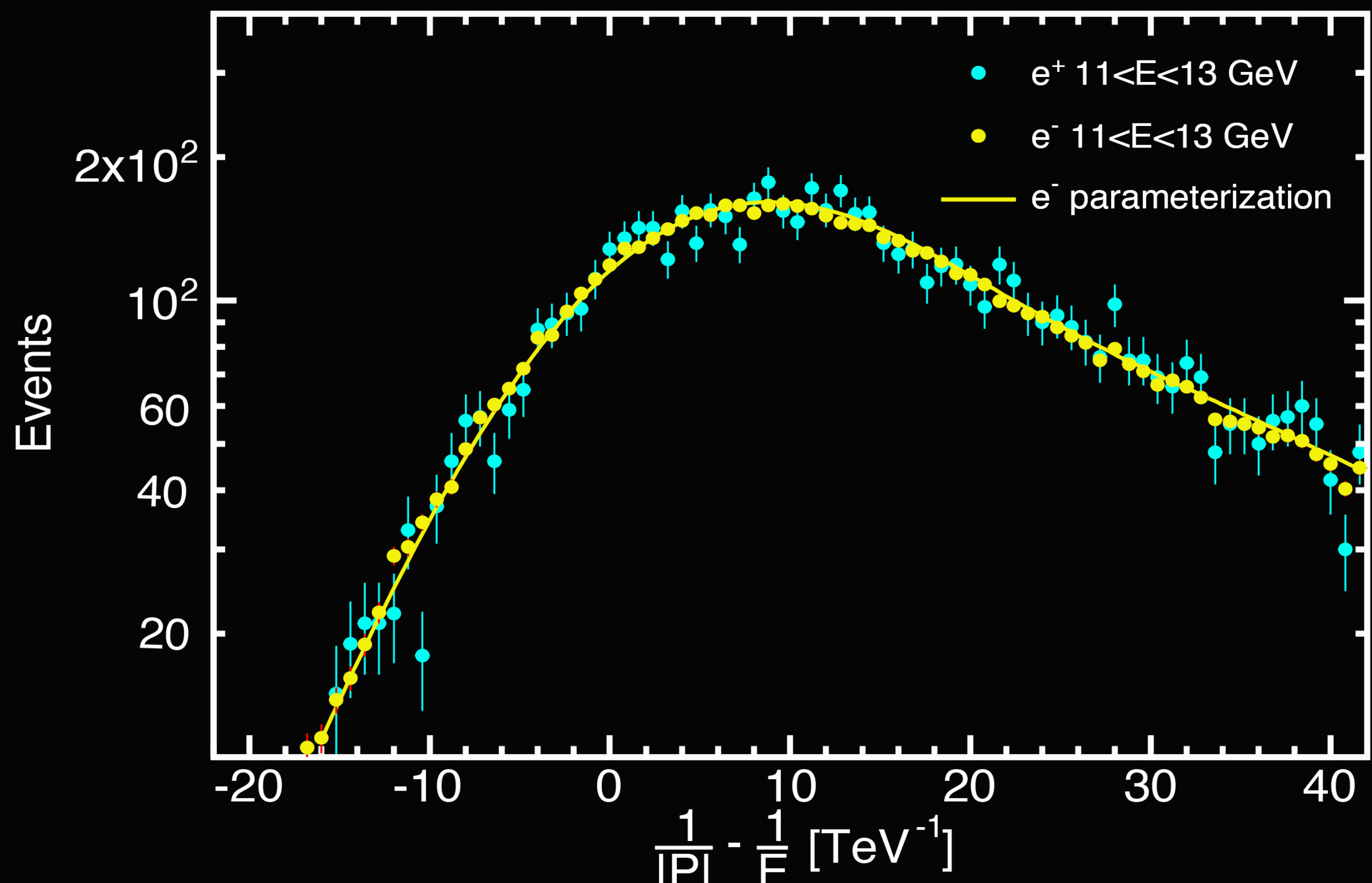
Control of fragmentation inside the detector



Mass separation (i.e. isotopical measurement)



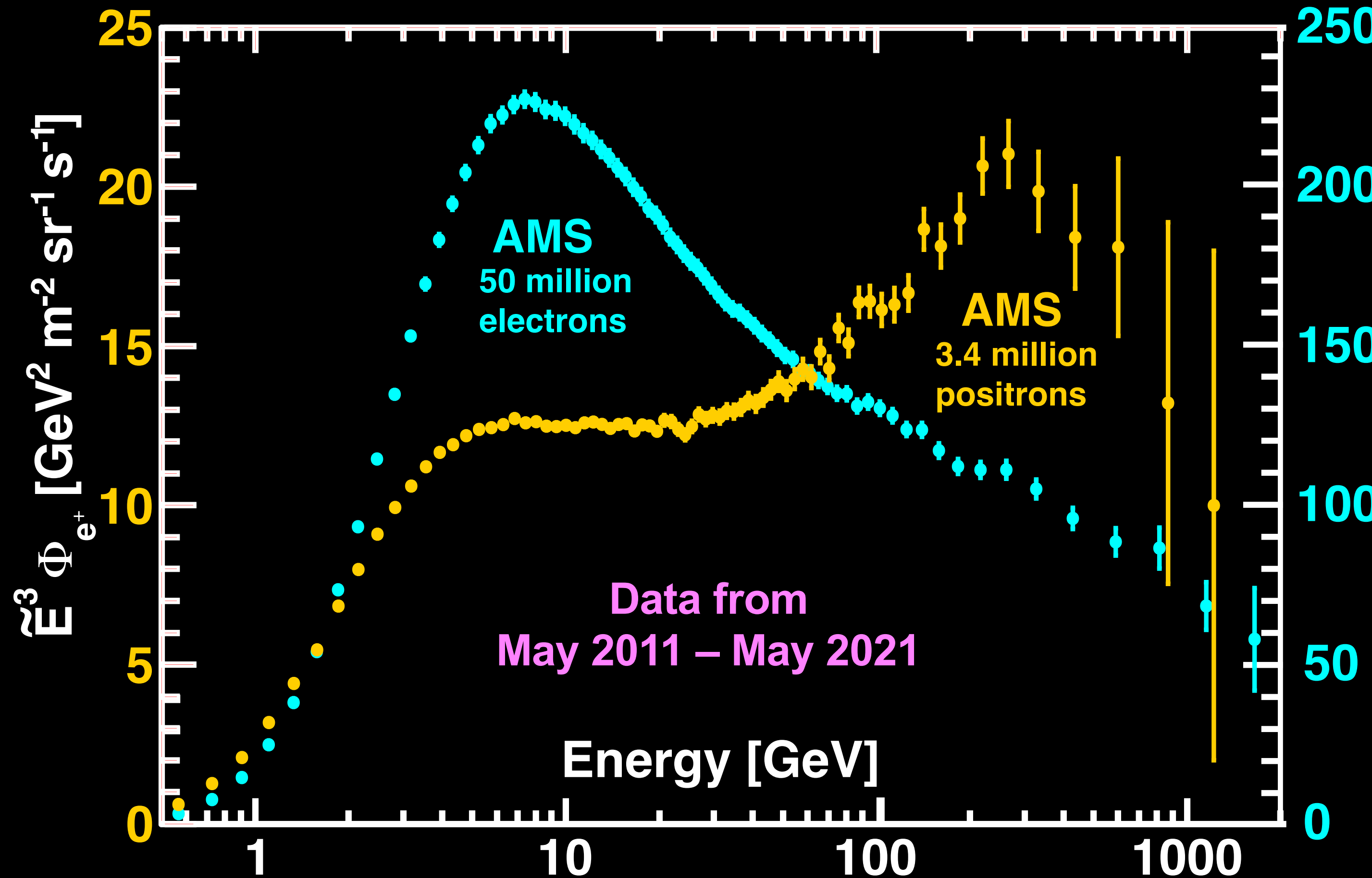
Momentum Scale Verification



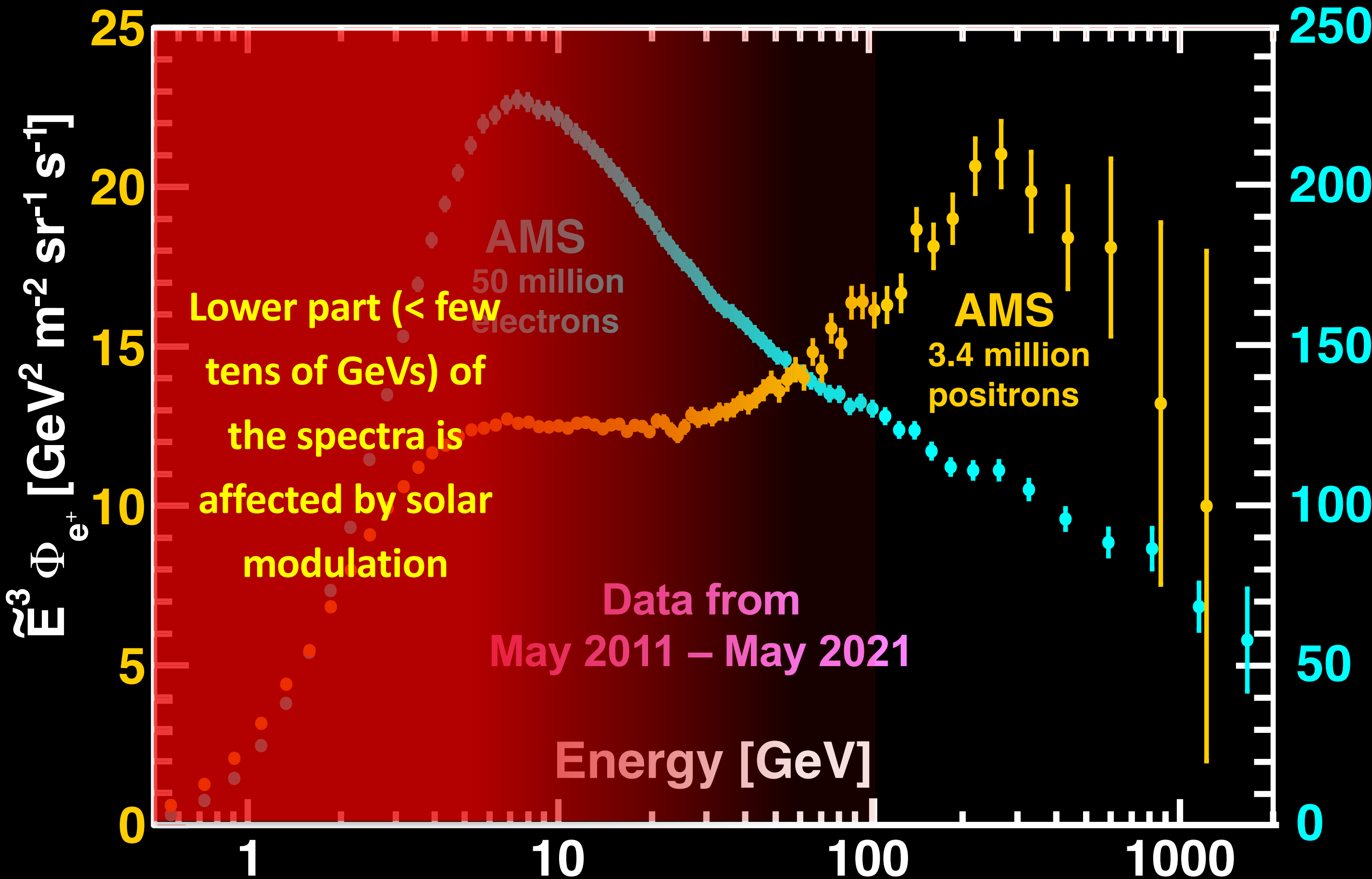
The accuracy of the momentum is determined to be 1/(30,000 GeV) i.e. at 1 TeV the uncertainty is 3%

Physics Results

Study of Positrons & Electrons



Study of Positrons & Electrons

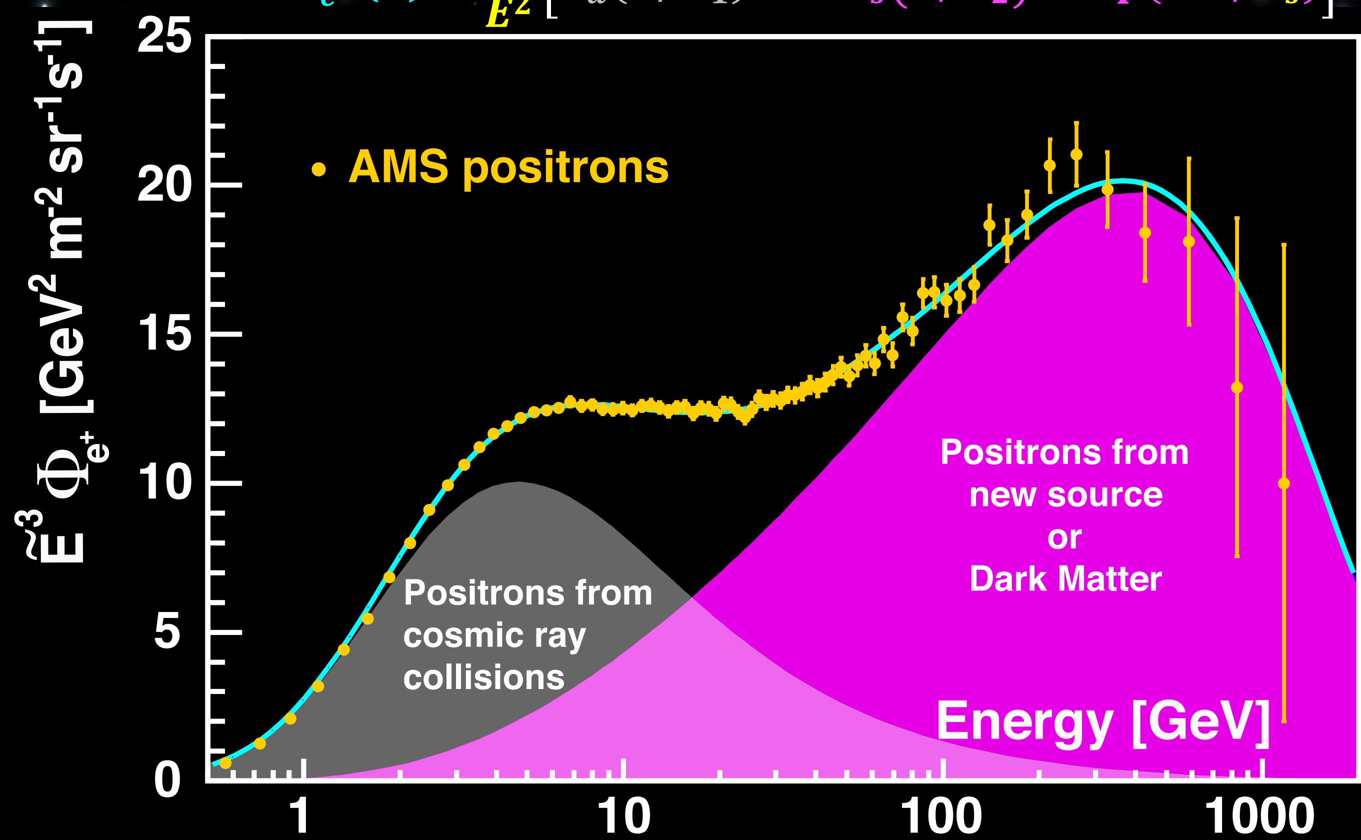


Study of Positrons

Collisions | New Source or Dark Matter

$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right]$$

The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from a new source or dark matter both with a cutoff energy E_S.

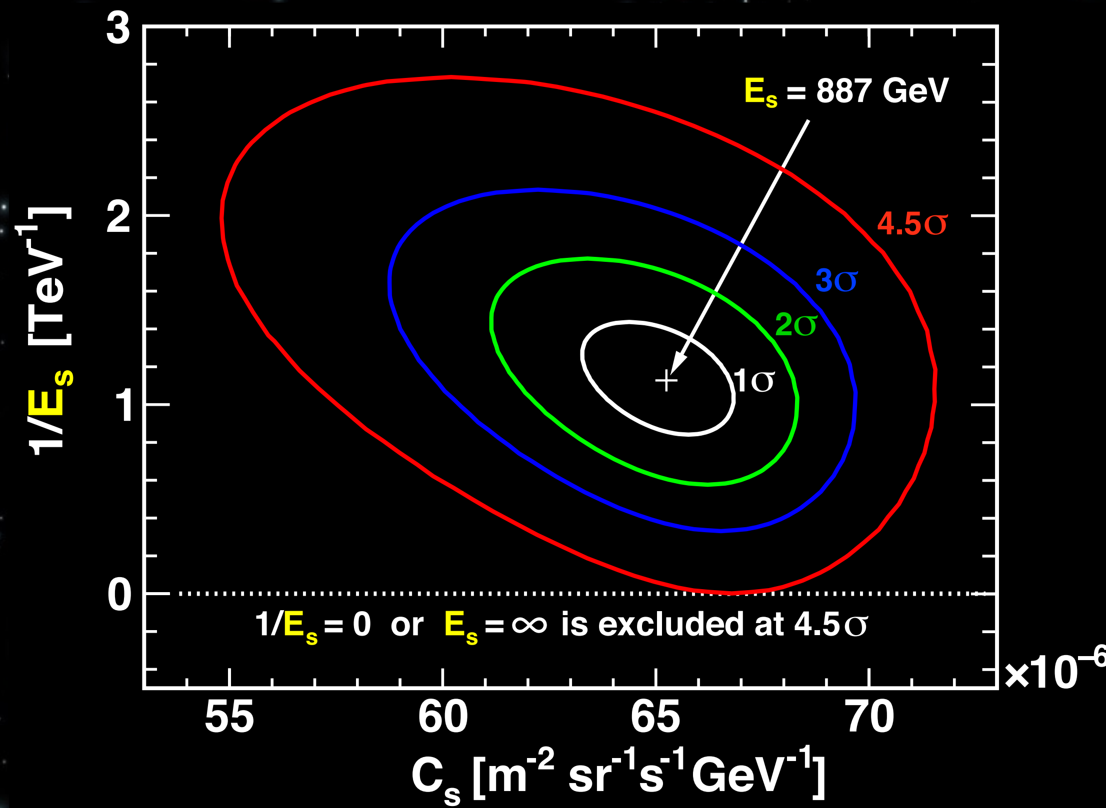


Study of Positrons & Electrons

Collisions — New Source or Dark Matter

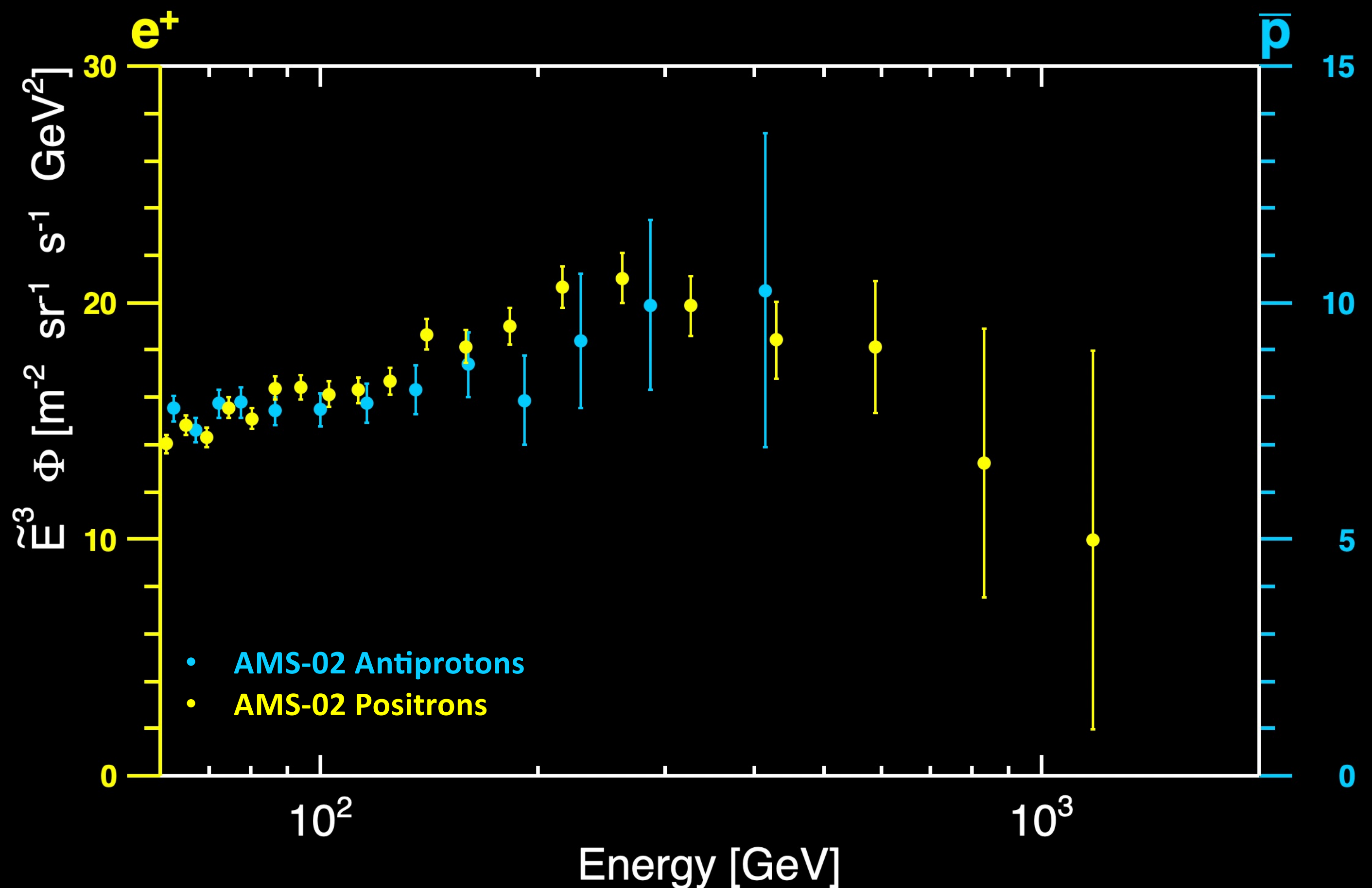
$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right]$$

The finite cutoff energy E_S is established at 4.5 σ



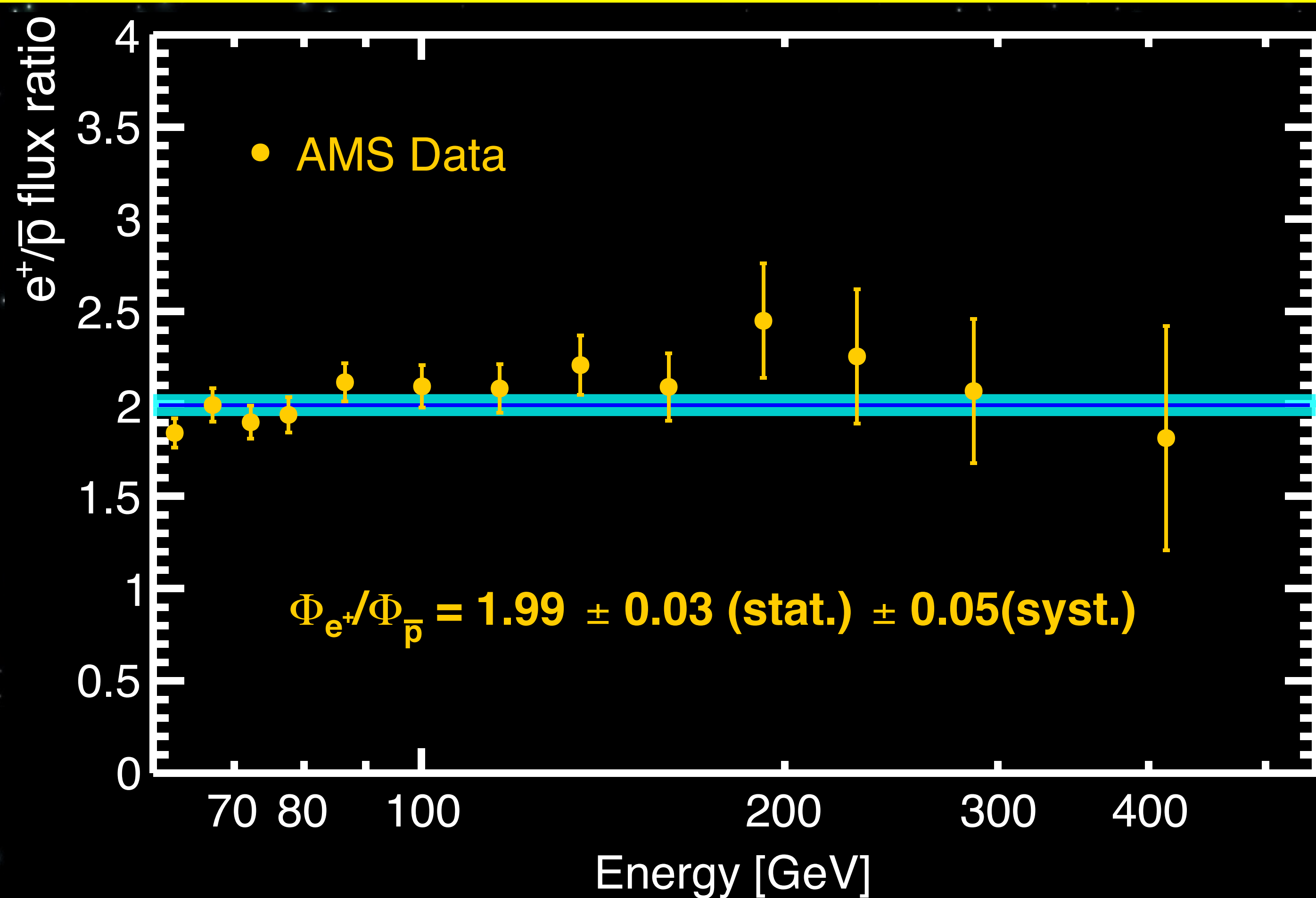
Antiprotons vs positrons

Antiproton data show a similar trend as positrons.



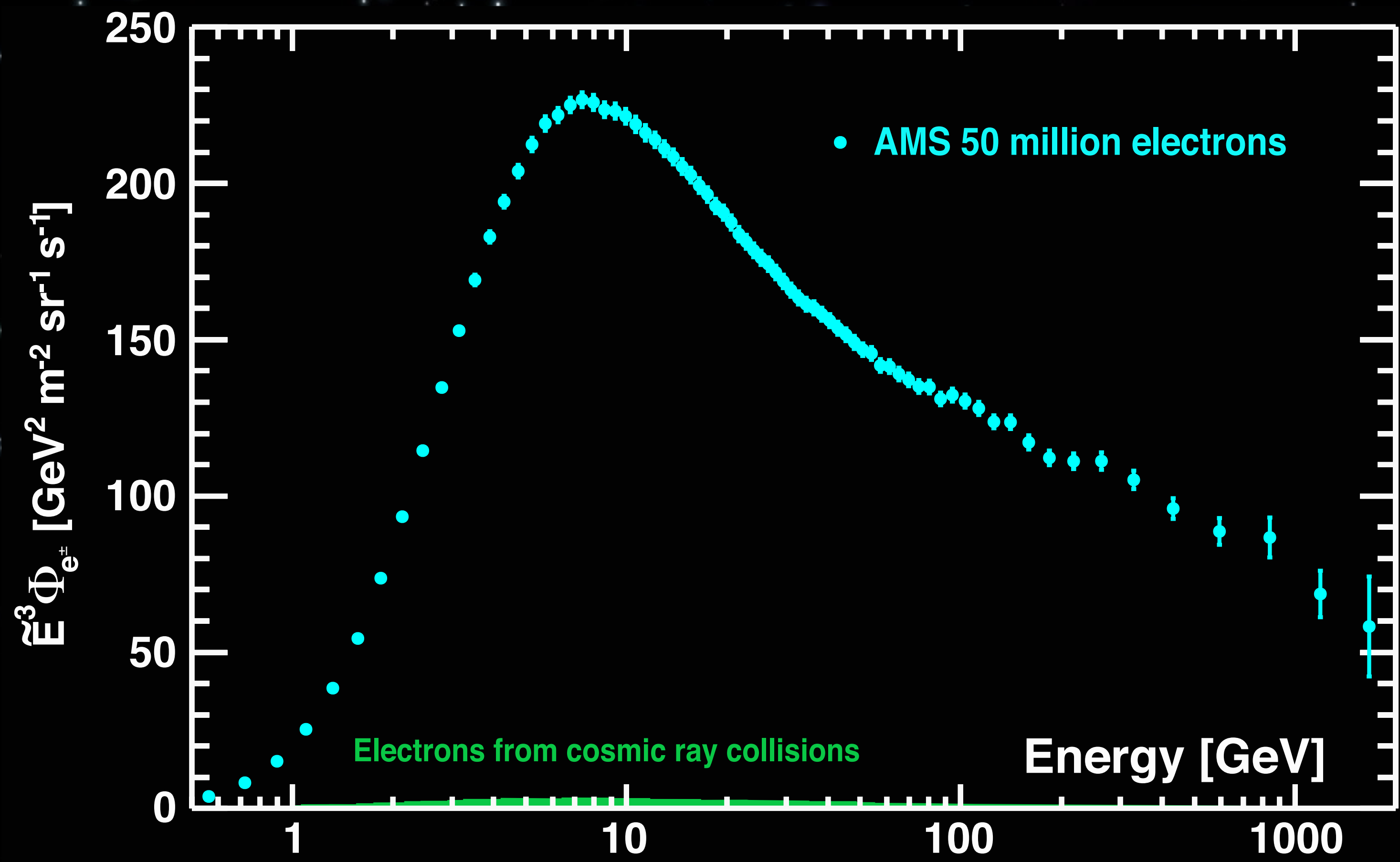
Antiprotons vs positrons

The positron-to-antiproton flux ratio is **constant independently of energy.** Antiprotons cannot come from pulsars.



Electrons

The contribution from cosmic ray collisions is negligible

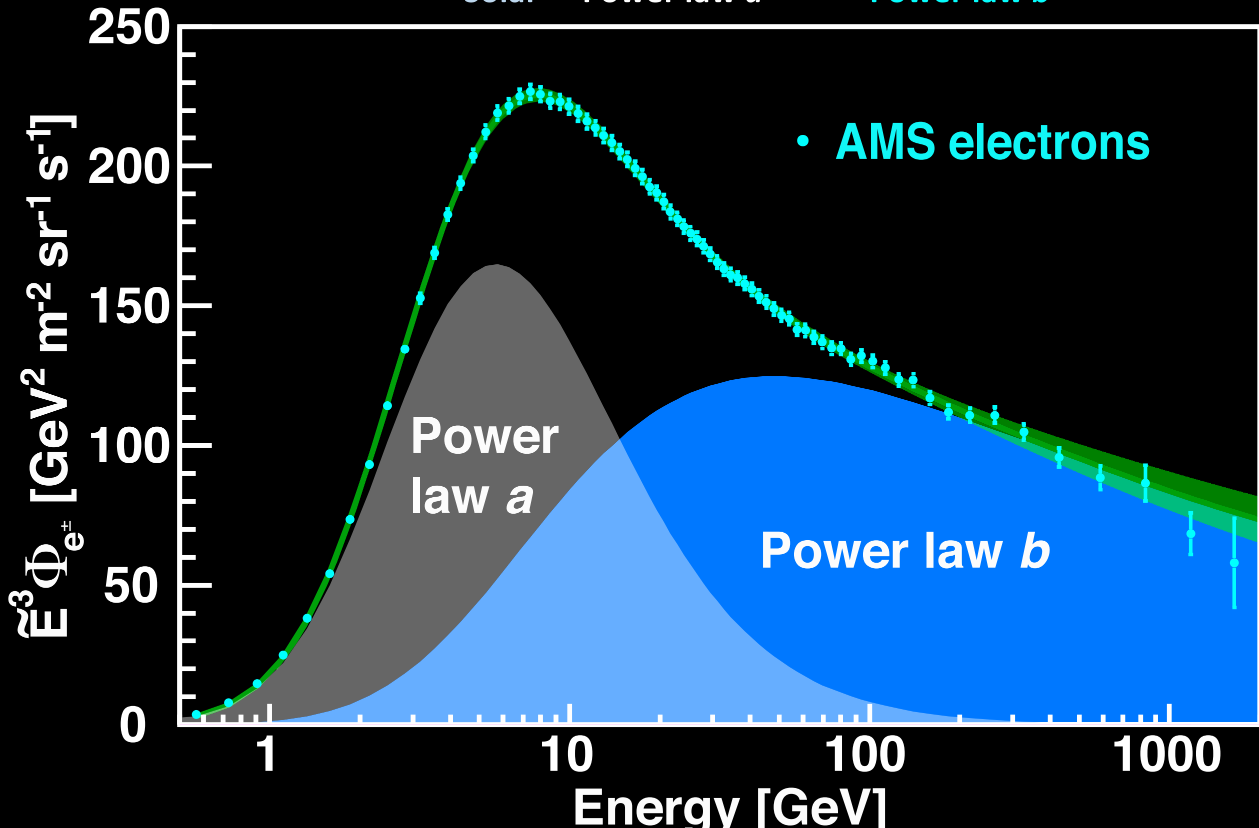


Electrons

$$\Phi_{e^-}(E) = S(E)\left[C_a(\hat{E}/E_a)^{\gamma_a} + C_b(\hat{E}/E_b)^{\gamma_b}\right]$$

Solar Power law *a* Power law *b*

Electron spectrum without source term disfavored

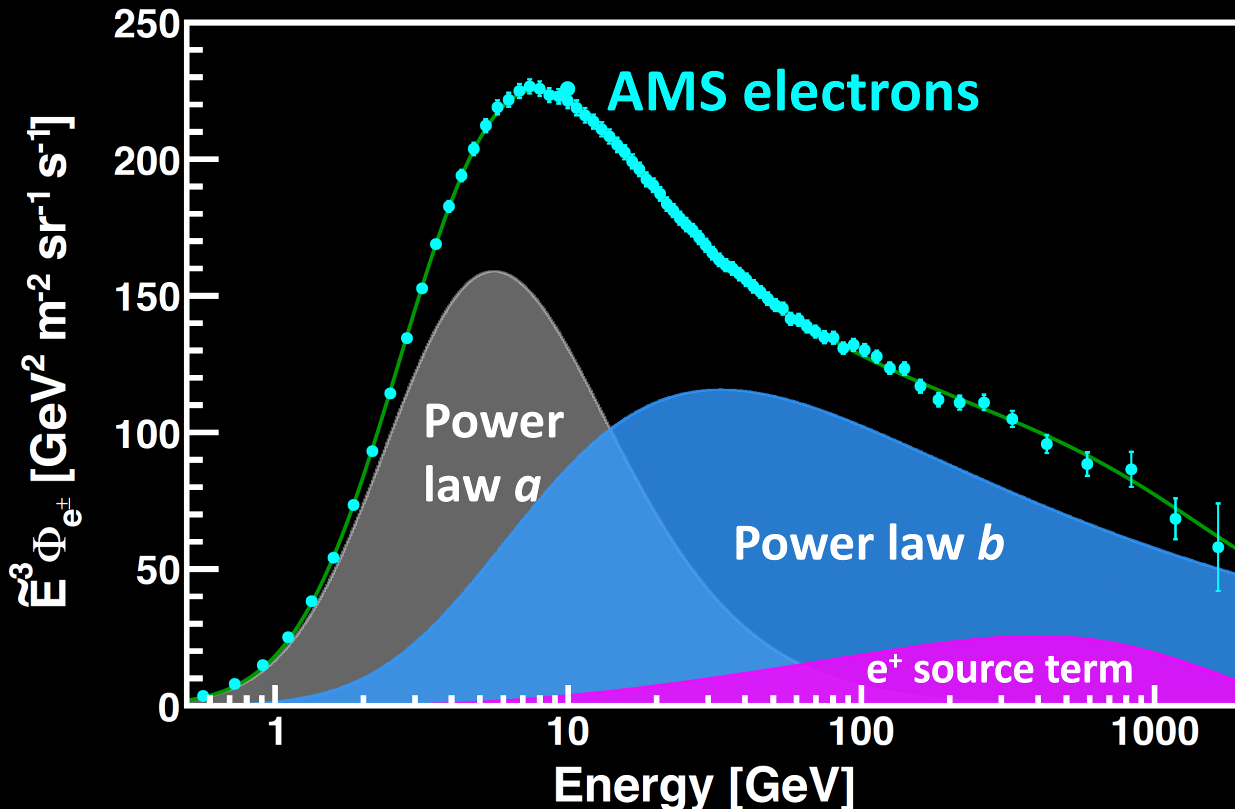


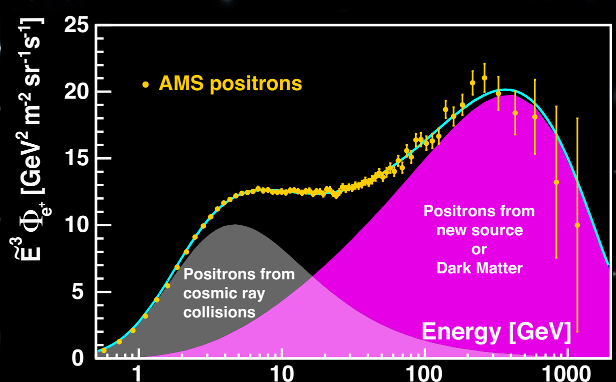
Electrons

$$\Phi_{e^-}(E) = S(E)\left[C_a(\hat{E}/E_a)^{\gamma_a} + C_b(\hat{E}/E_b)^{\gamma_b} + f_s C_s^{e^+}(\hat{E}/E_2)^{\gamma_s^{e^+}}\exp(-E/E_s^{e^+})\right]$$

Solar | Power law *a* | Power law *b* | Positron source term

Electron spectrum favors the contribution of the positron-like source term at 2σ level

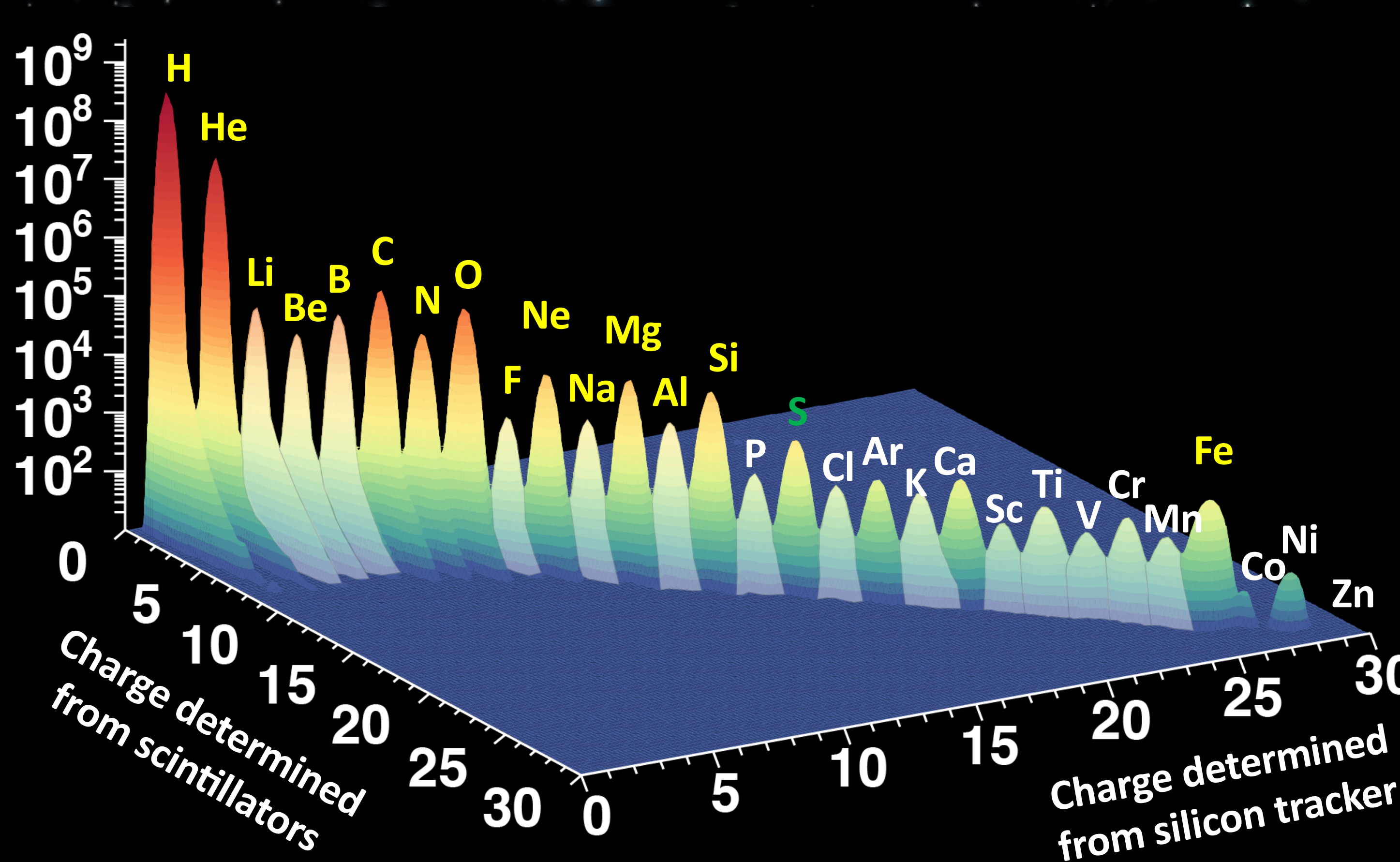




Nuclear matter

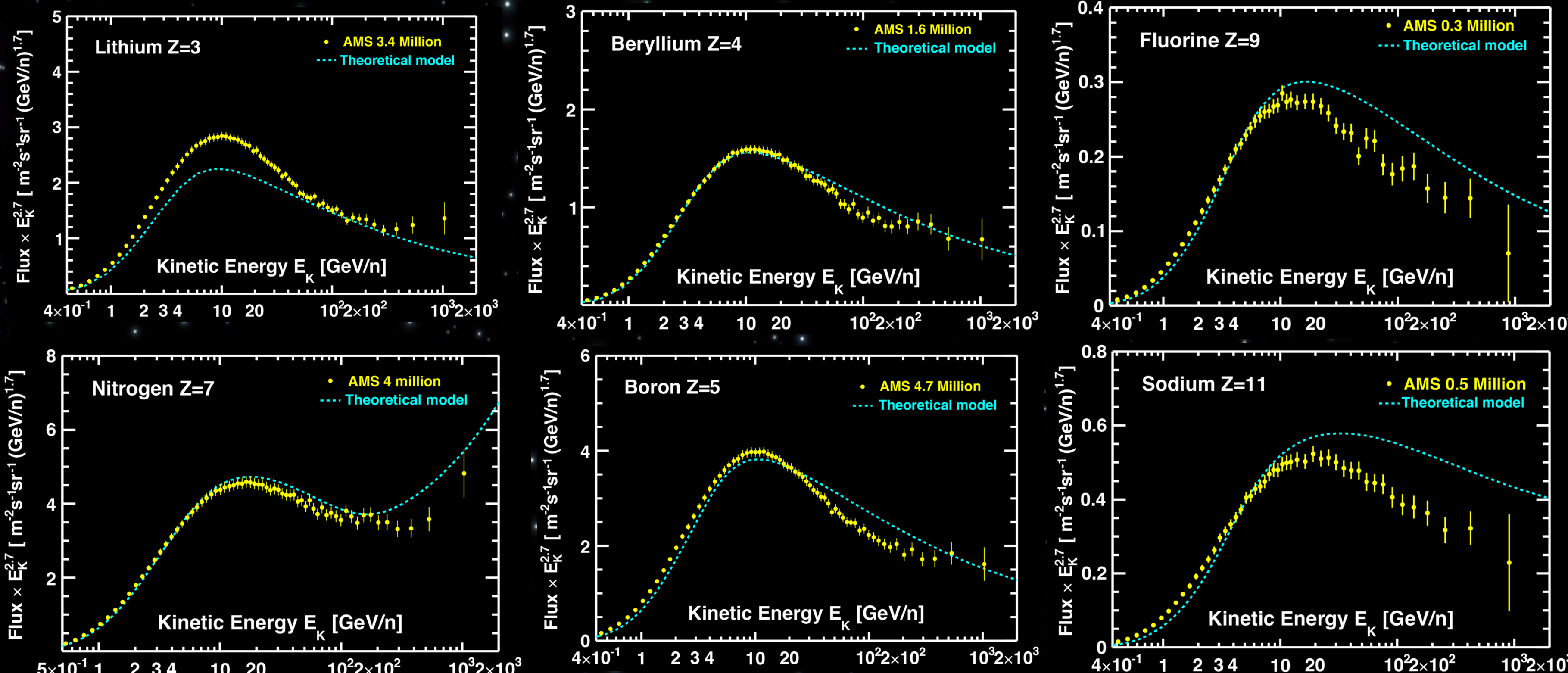
In ten years we have studied 15 (16) elements.
In the next ten years we will study the other 14 elements.

This will provide the foundation for a comprehensive theory of the cosmos

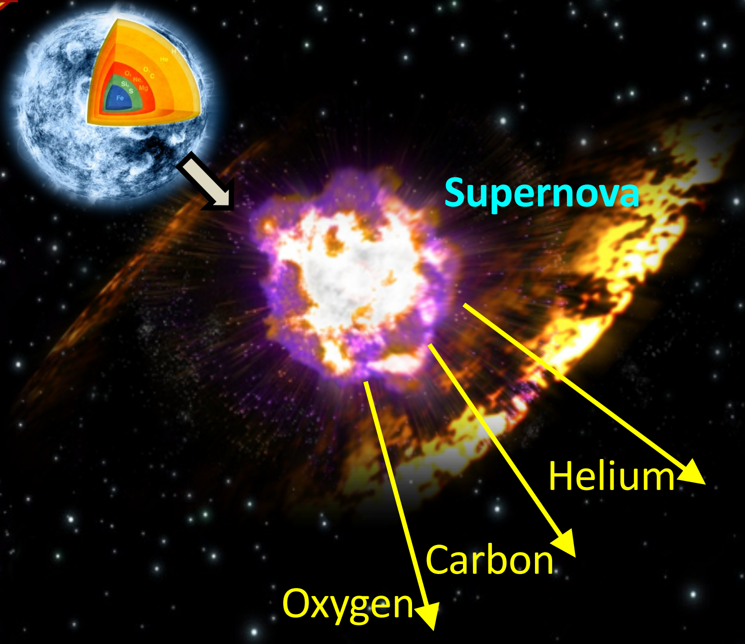


Nuclear matter

The full set of AMS results is challenging all the theoretical models

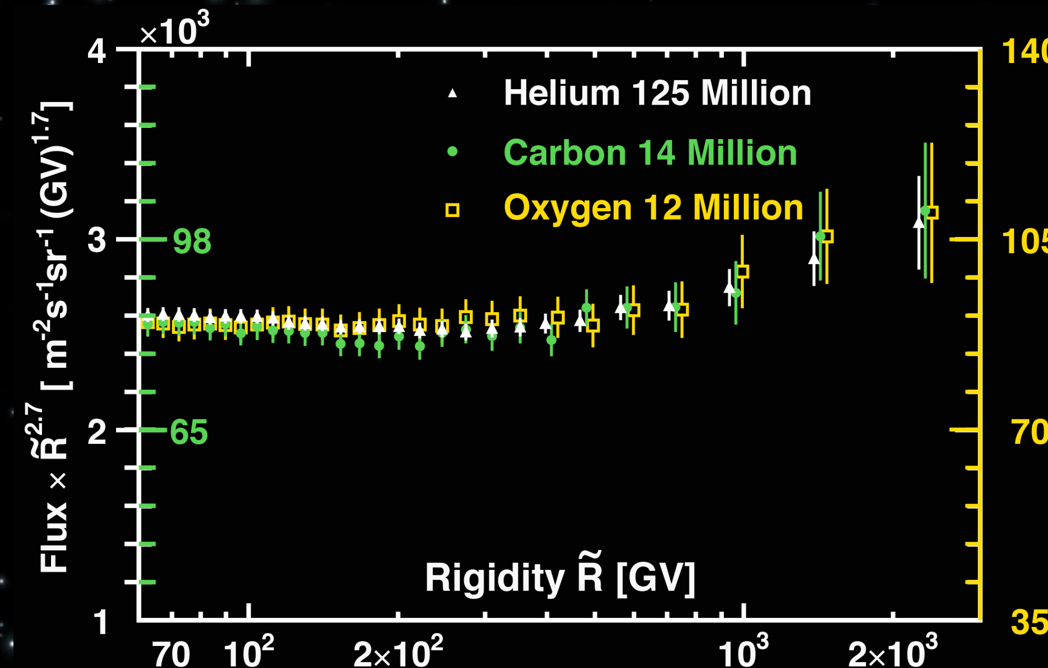


Primary Cosmic Rays



Primary elements (H, He, C, ..., Fe) are produced during the lifetime of stars.

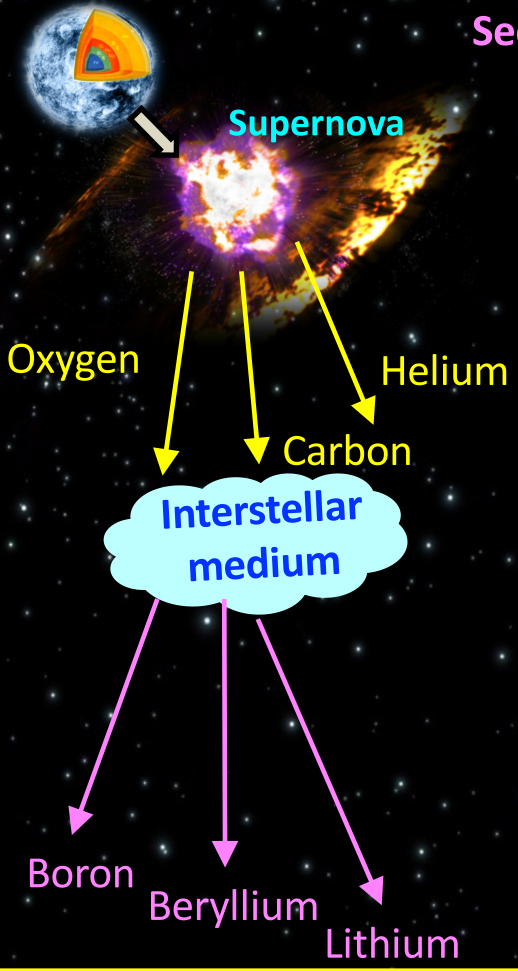
They are accelerated by the explosion of stars (supernovae).

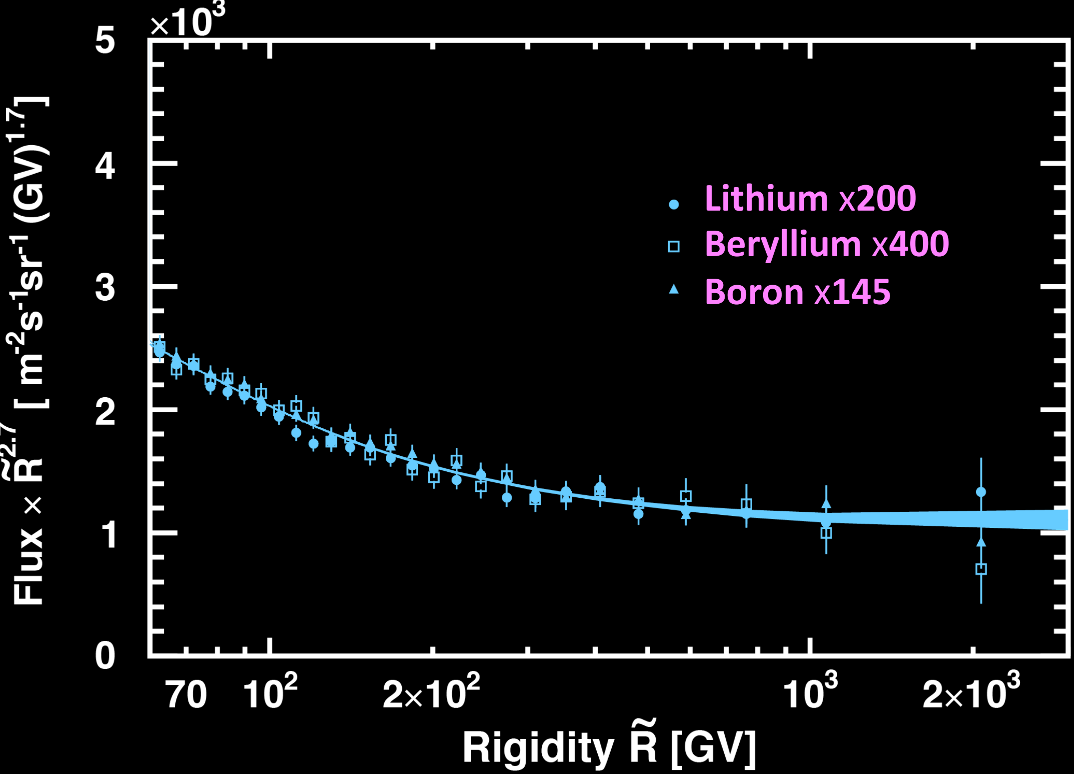


Surprisingly,
the primary cosmic rays
He, C, and O
have identical rigidity (P/Z)
dependence

Secondary Cosmic Rays

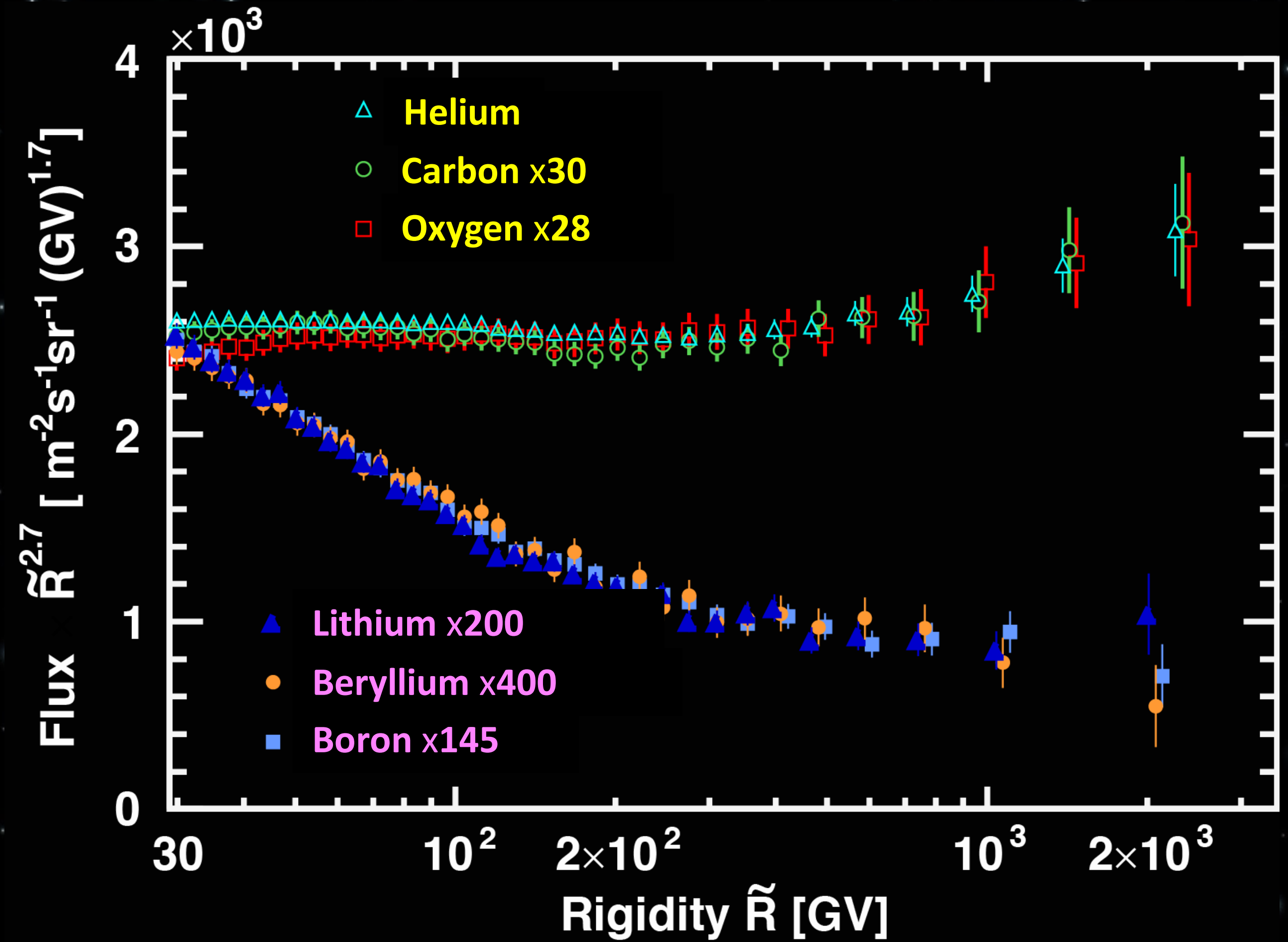
Secondary cosmic nuclei (Li, Be, B, …) are produced by the collision of primary cosmic rays and the interstellar medium.
Secondary cosmic rays also have identical rigidity dependence





Primaries vs Secondaries

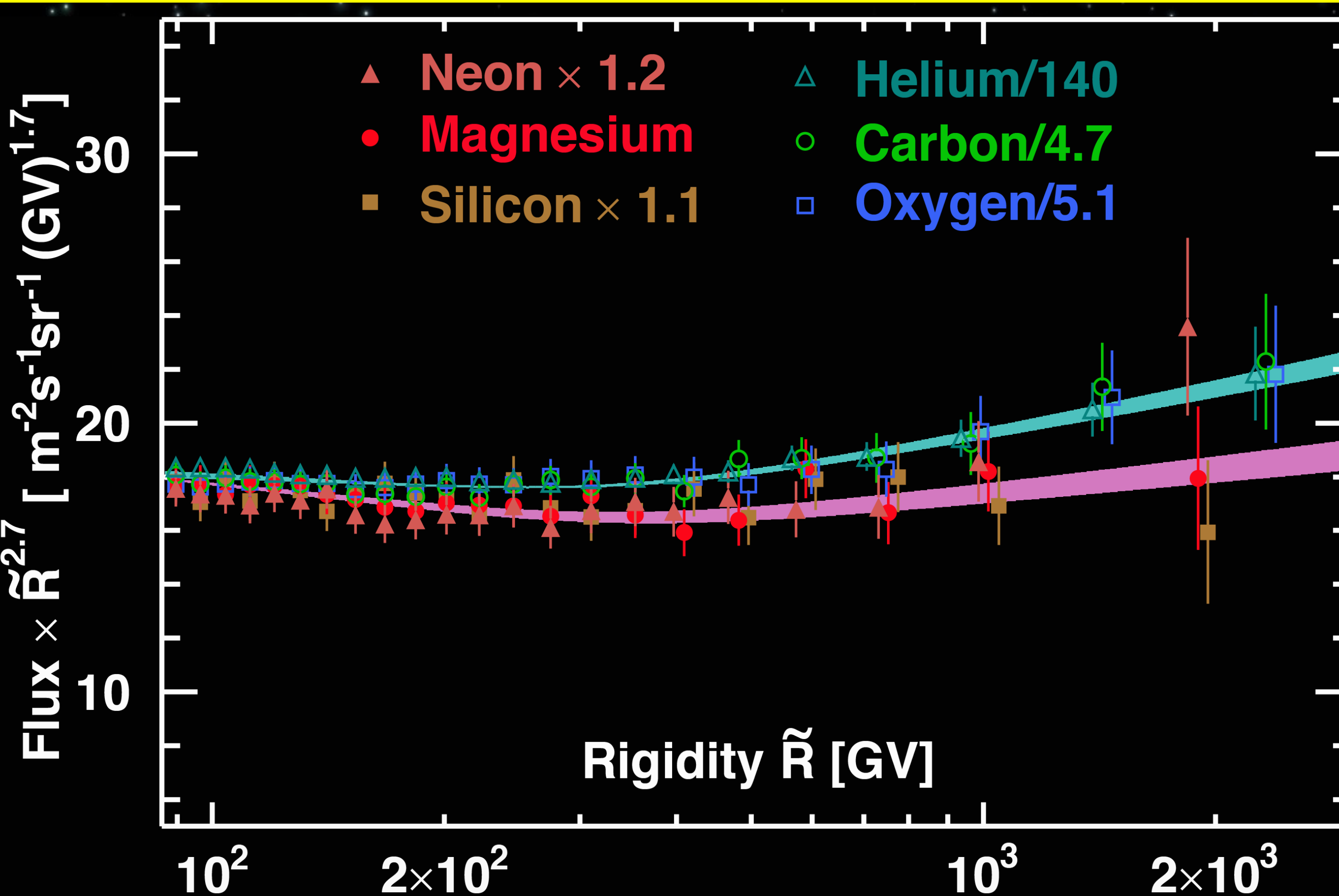
Each has their own rigidity dependence but distinctly different from each other.



Heavier primary cosmic rays

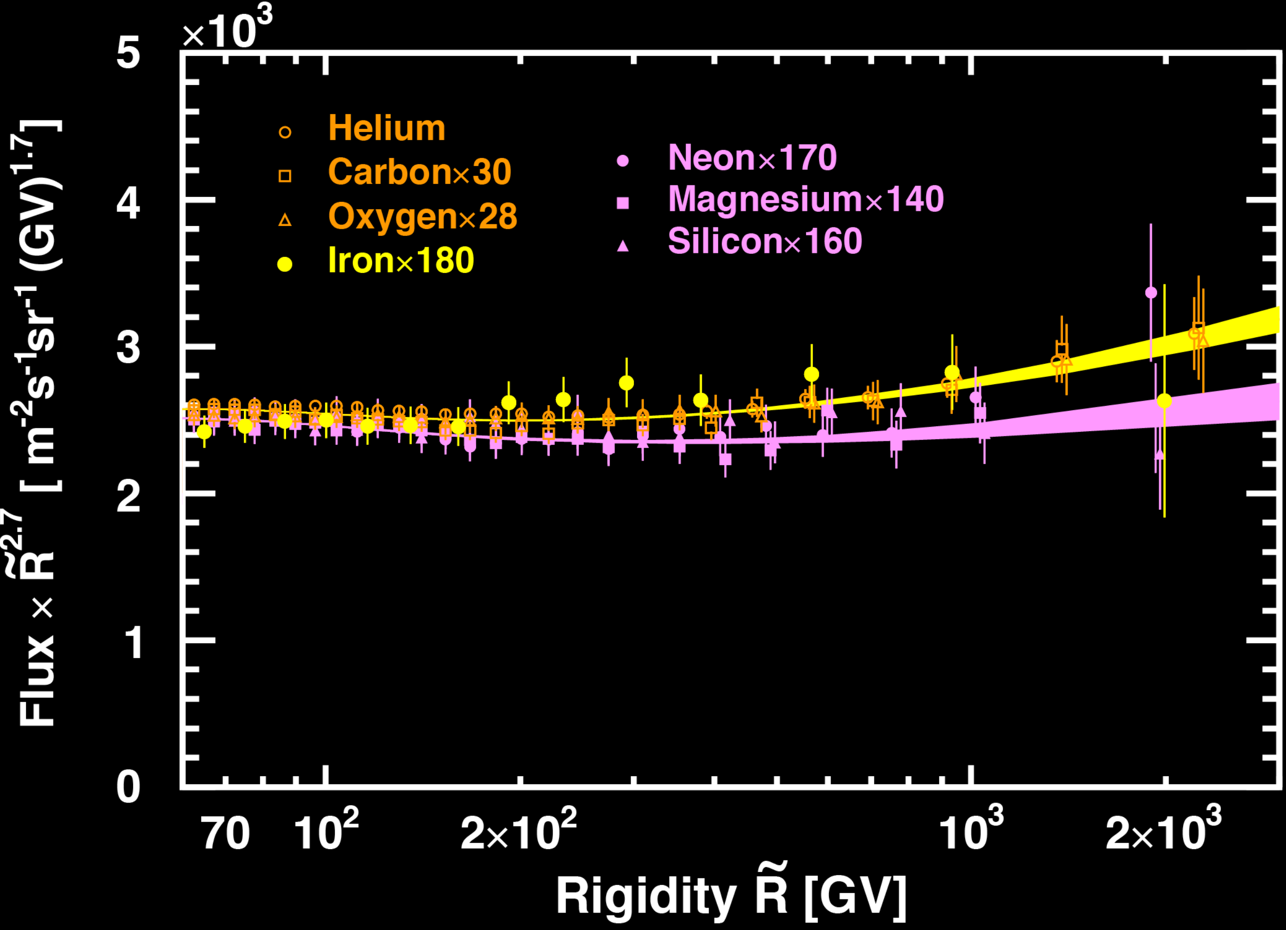
Heavier primary cosmic rays Ne, Mg, Si: have their own identical rigidity behavior but different from He, C, O.

Unexpectedly, primary cosmic rays have at least two classes.



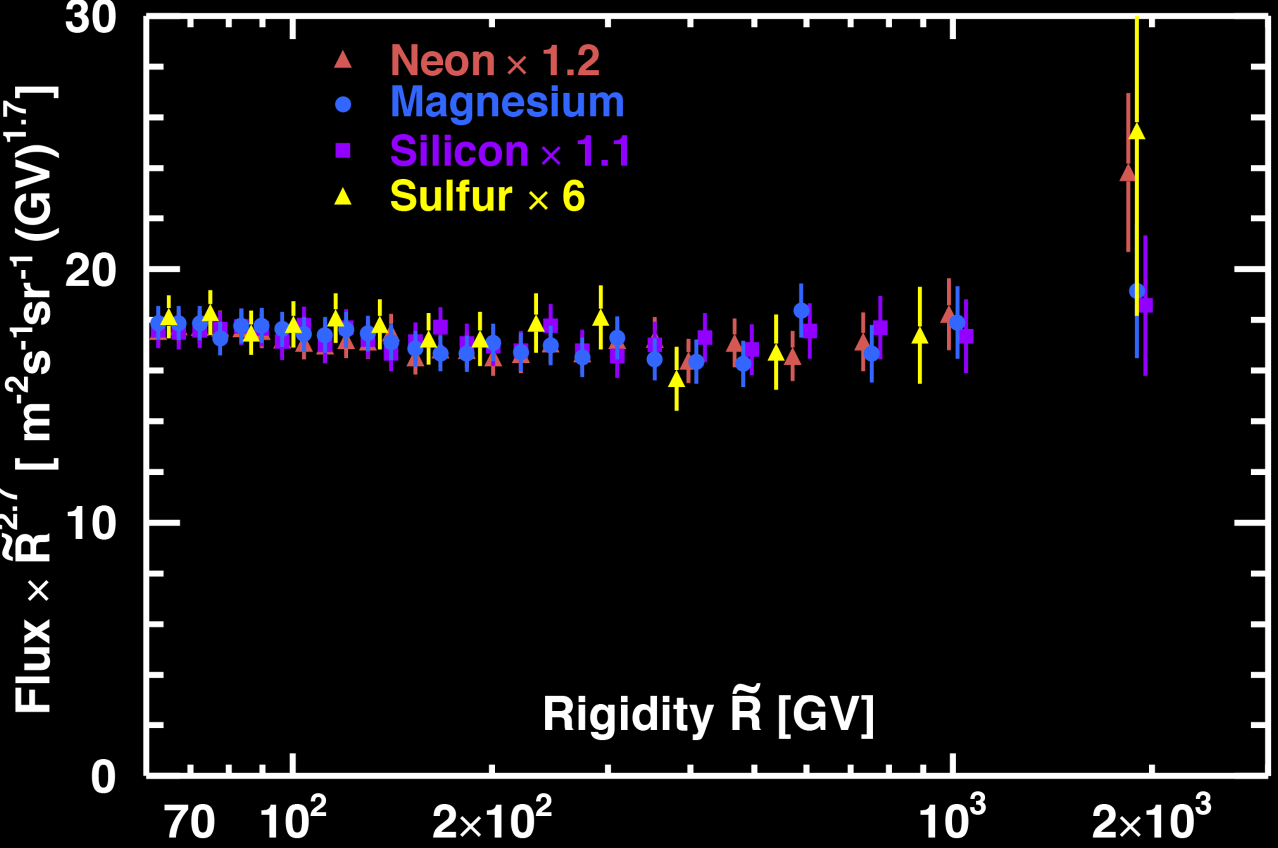
Iron

Unexpected Result:
Iron is in the He, C, O primary cosmic ray group instead of the expected Ne, Mg, Si group.



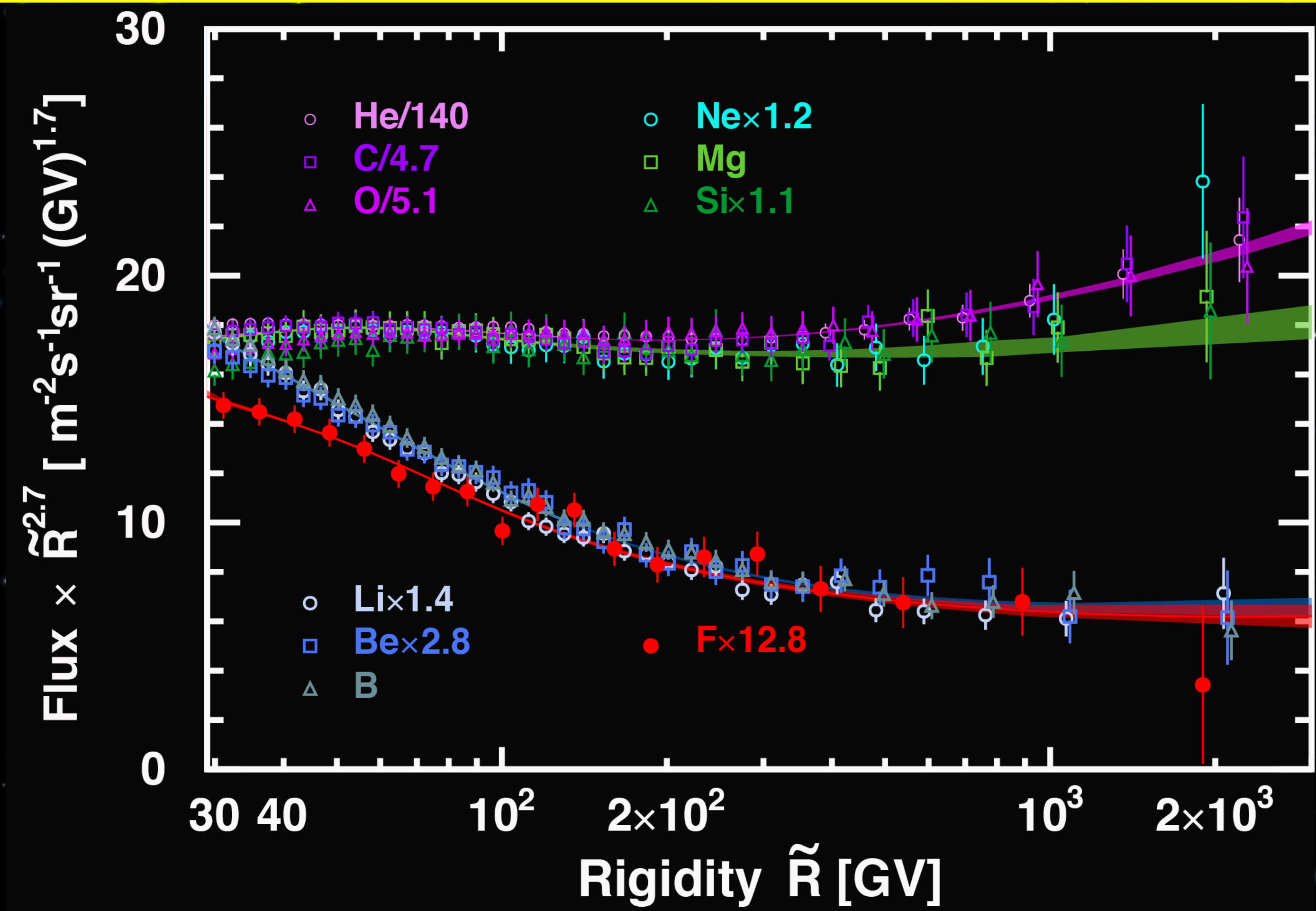
Sulfur

S belongs to the same class as Ne, Mg, and Si



Fluorine

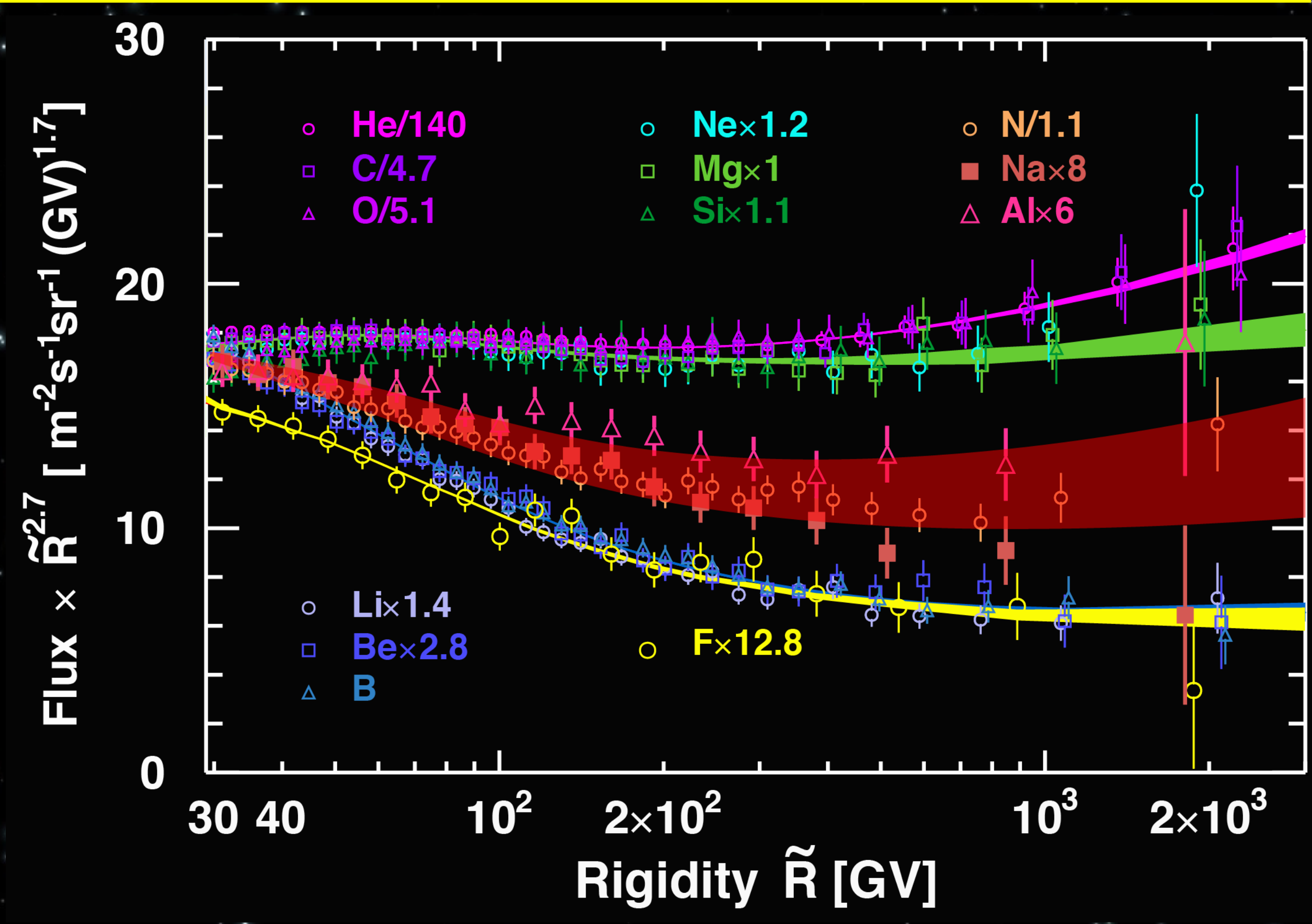
Unexpectedly, secondary cosmic rays also have two classes



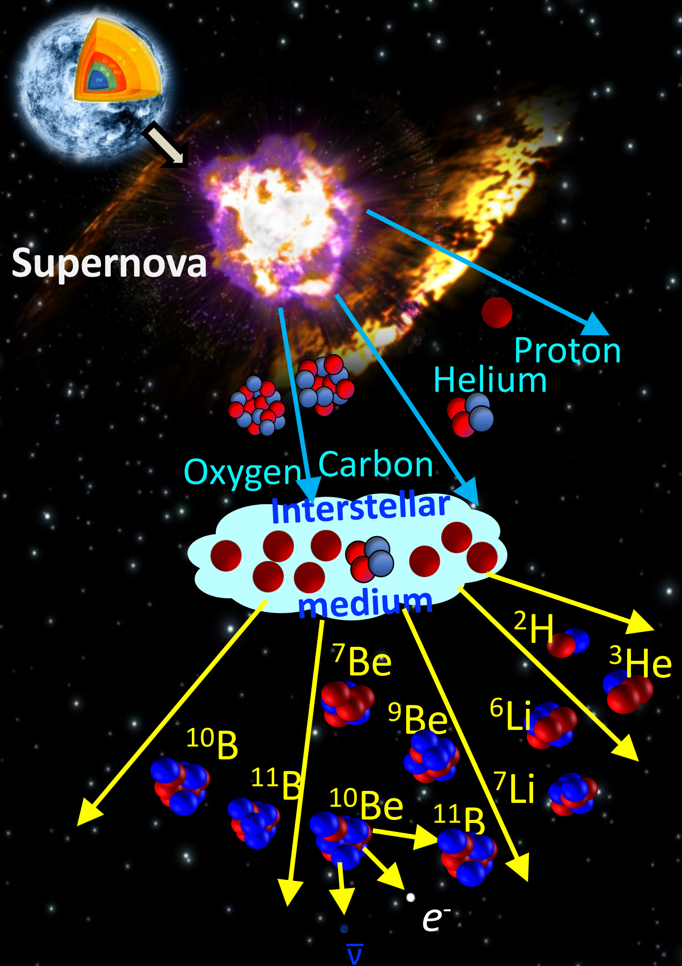
Third group

The Third Group of Cosmic Rays:
N, Na, Al

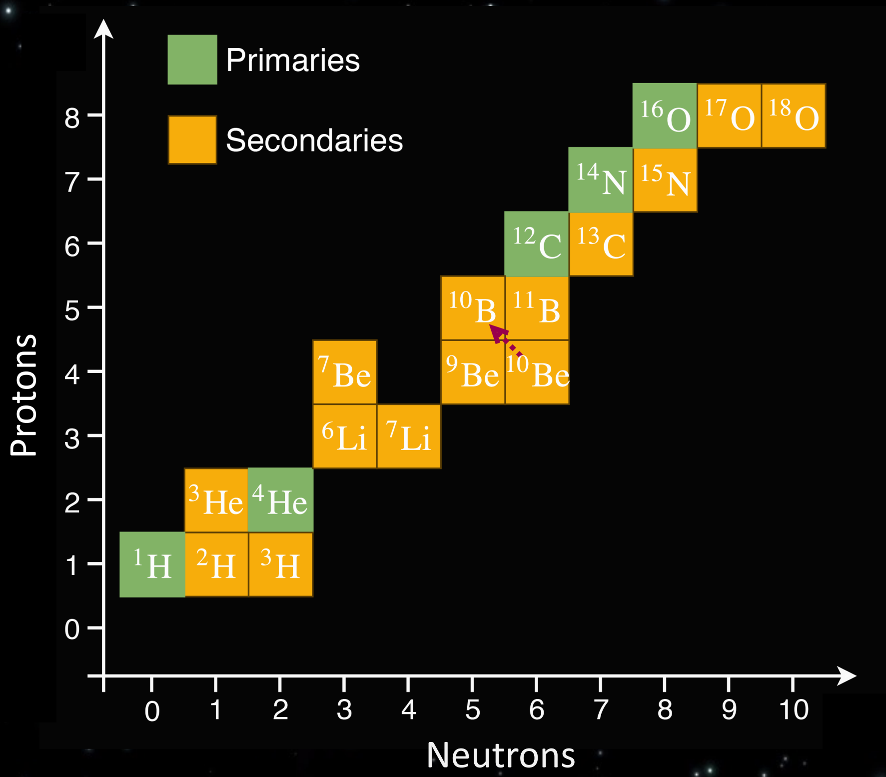
The fluxes are well described as a sum of a primary component + a secondary component



Isotopes



Provides unique information on production and propagation of secondary cosmic rays ($^{6,7}Li$, $^{9,7}B$) and age of cosmic rays ($^{9,10}Be$).

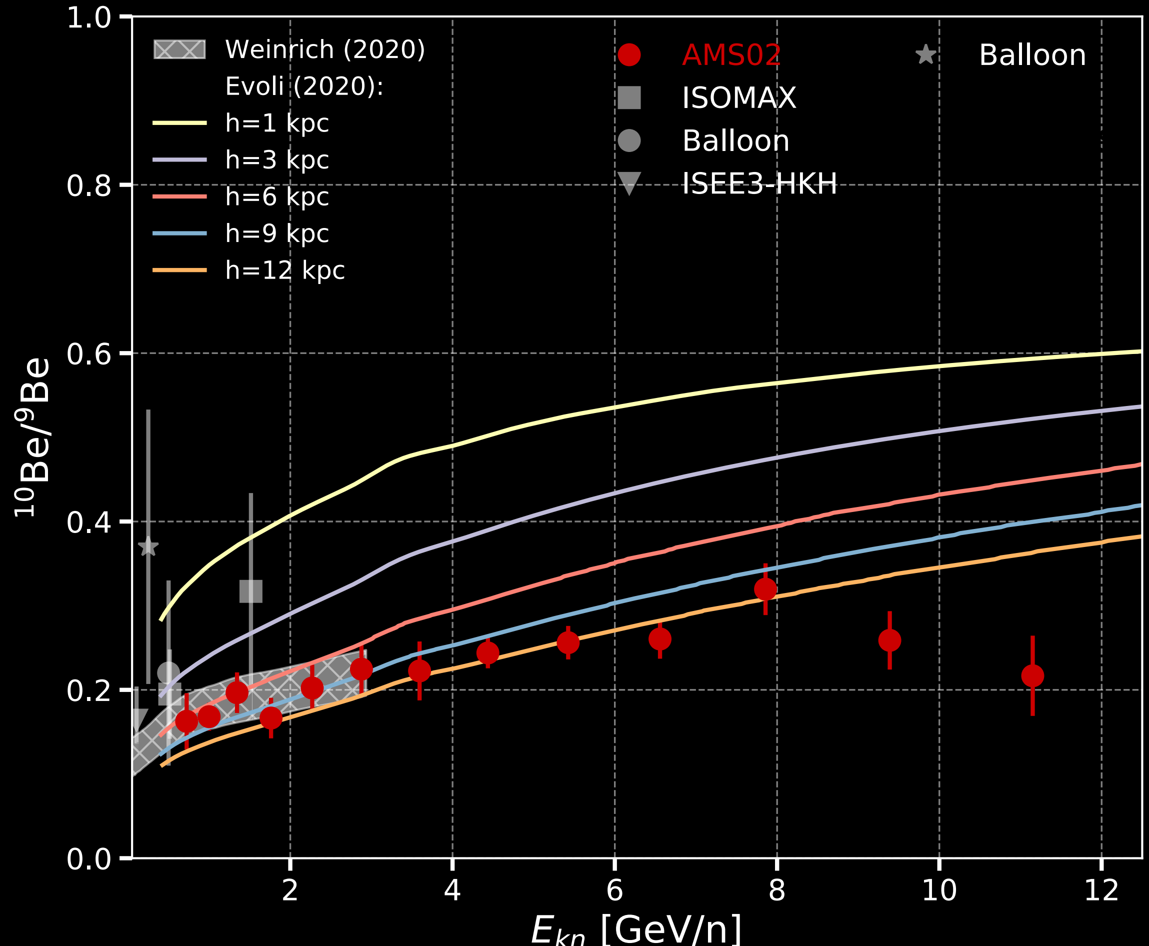


$^{10}Be/^{9}Be$

^{9}Be stable

$^{10}Be \sim 1.4\ 10^{6}$ y

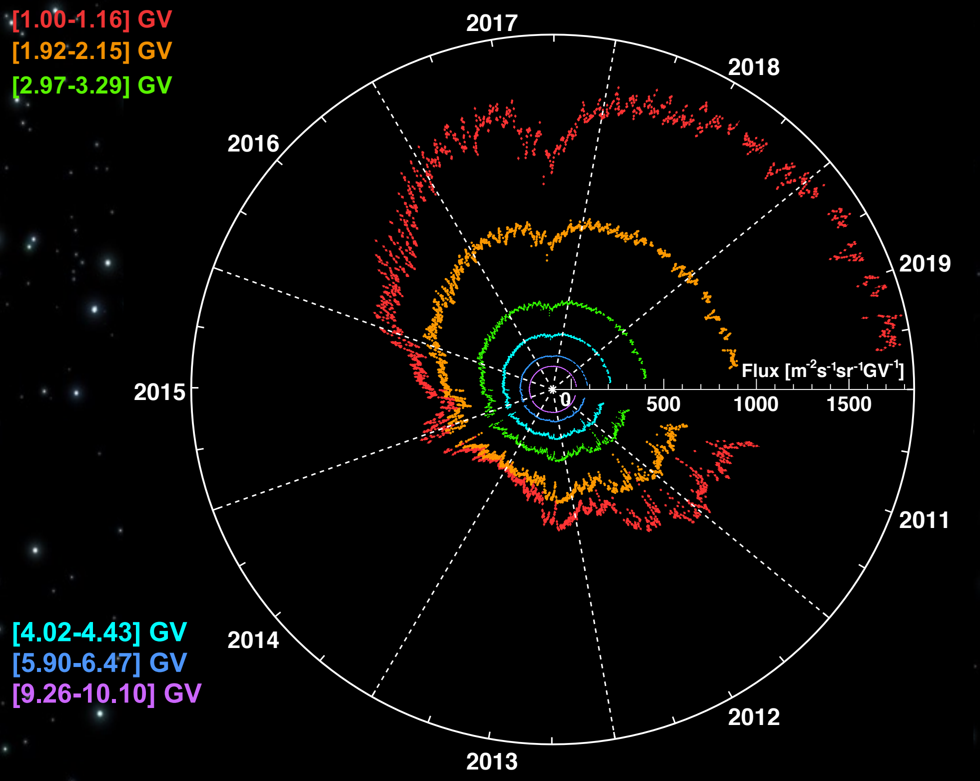
AMS data constrains the halo size h



Time variations: protons

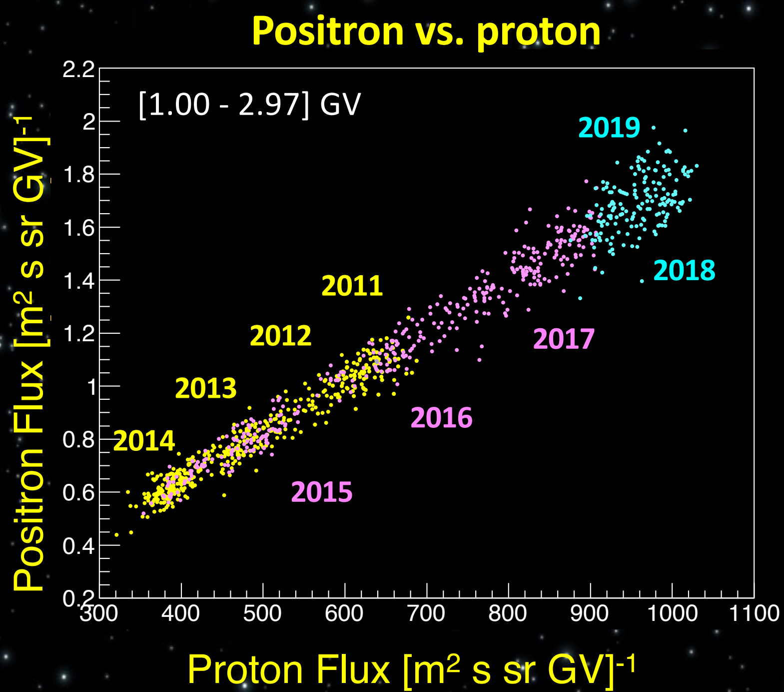
Yearly, Monthly, Daily Proton Flux from 5.5 billion events

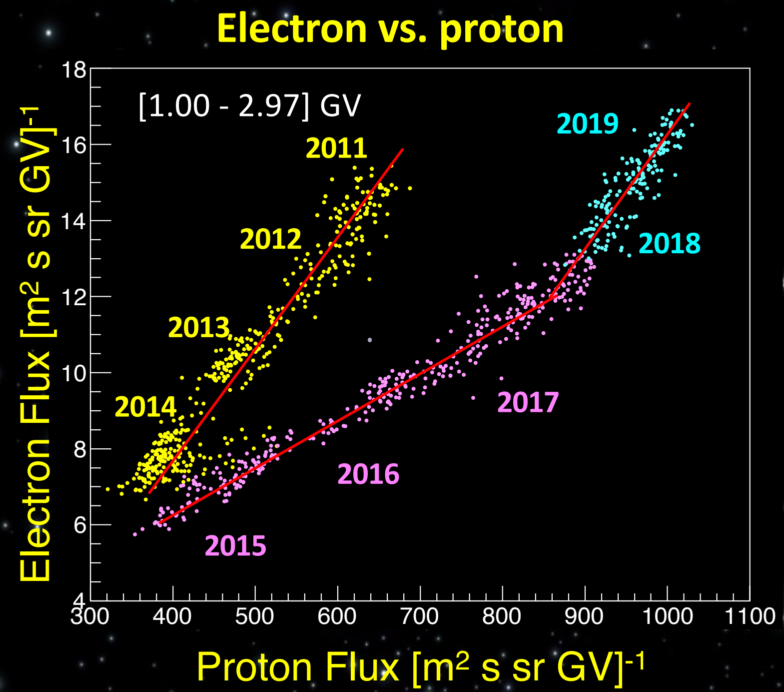
Unexpected observation of periodic structures which are momentum dependent



These are new and unique probes of fundamental properties of solar system and provide safety information for interplanetary travel.

Protons vs electrons and positrons





Positrons and protons fluxes have a linear relation

The relation between the electron and proton fluxes is a surprise

Conclusion

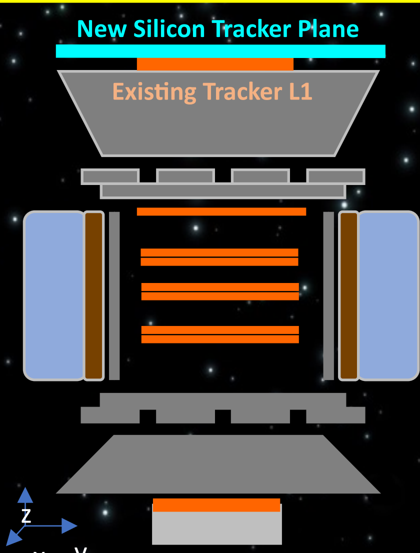
- in the first 10 years AMS-02 produced a wide set of high statistics, high accuracy, unprecedented, cosmic ray measurements

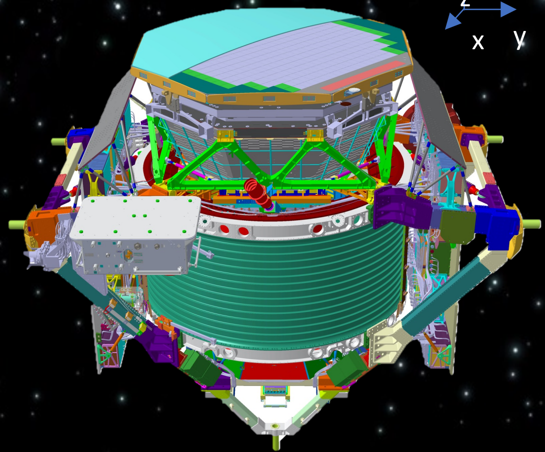
- this set of measurements is challenging the theoretical community for a fully comprehensive model able to explain all the observed features

- AMS will be operated for the full life-time of the ISS (2032?). In case of upgrade, some channels will have a significant boost in statistics/accuracy

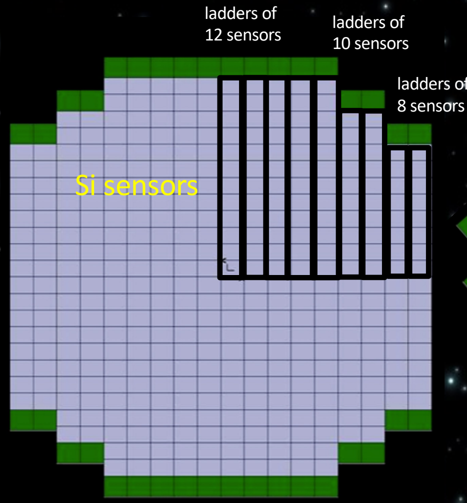
AMS-02 upgrade "L0"

New Silicon Tracker Layer: one plane, two layers, each ~ 4m^2

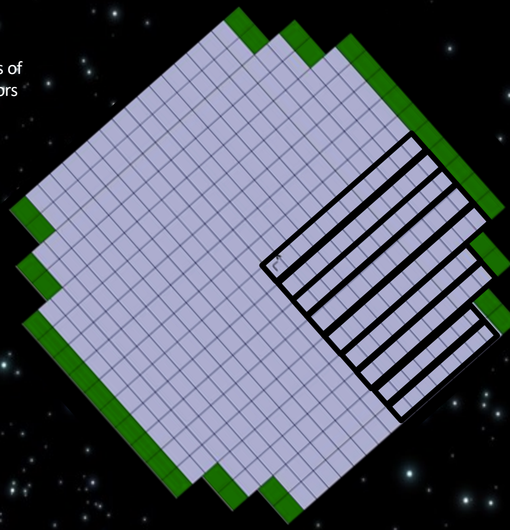




L0-Y
bending direction
7 micron



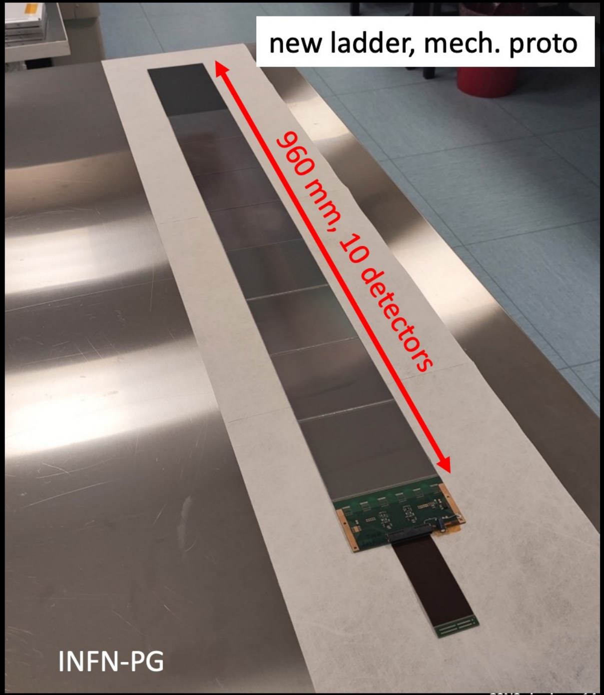
L0-U
rotated 45°
10 micron bending
10 micron non-bending

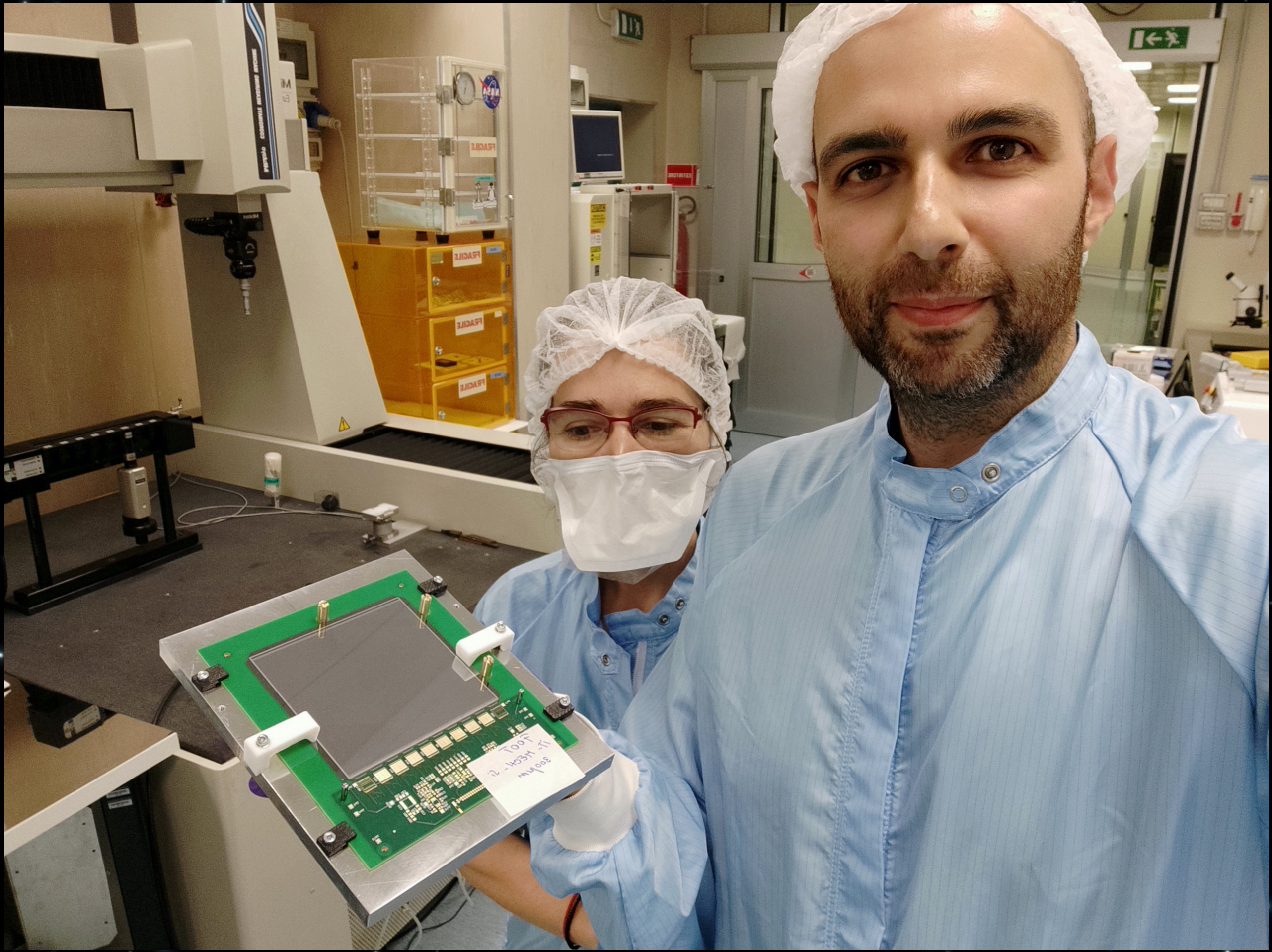


Acceptance increased to 300% (10 years data becomes 30 years data)

AMS-02 upgrade "L0"

10x10 cm² sensors (INFN-Perugia, Italy)





Stay tuned...