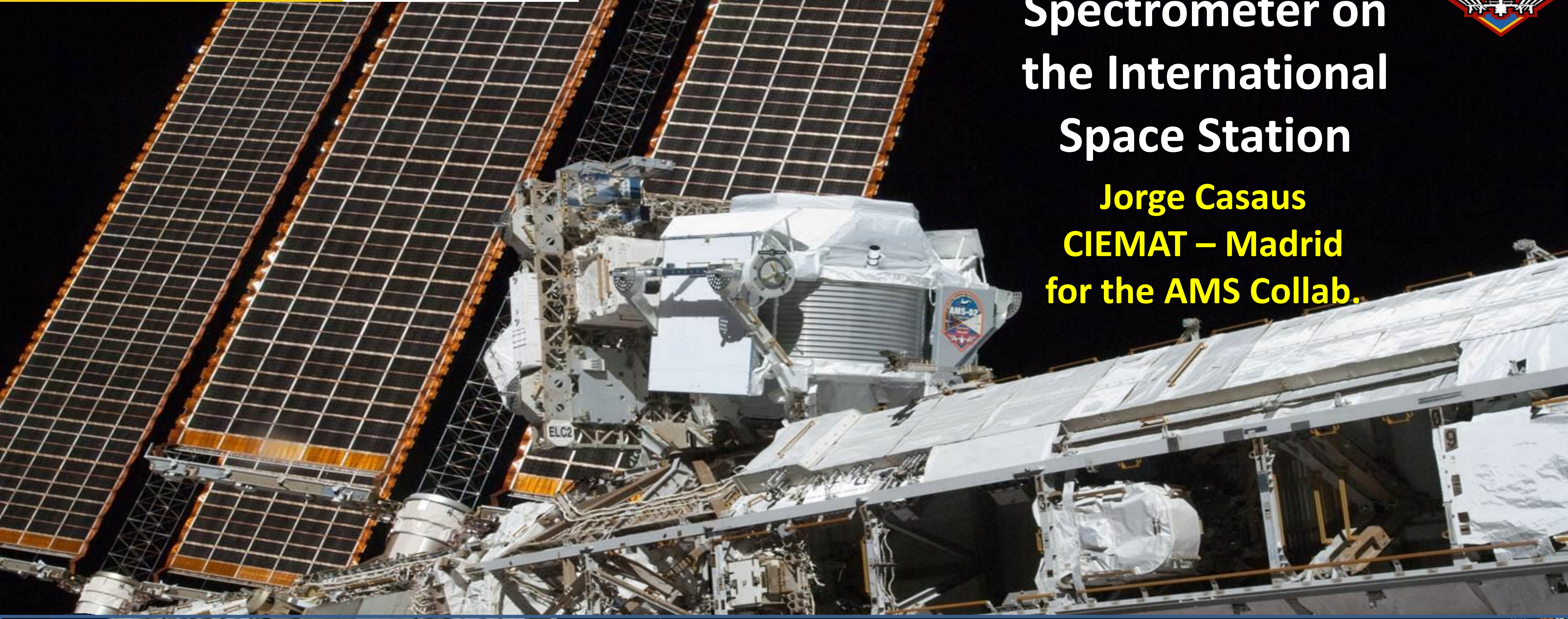
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

The Alpha Magnetic Spectrometer on the International Space Station

Jorge Casaus
CIEMAT – Madrid
for the AMS Collab.



19–23 Jun 2023
Perugia (IT)

ASAPP 2023 - Advances in Space AstroParticle Physics: frontier technologies for particle measurements in space

AMS Launch May 2011
Space Shuttle Endeavour
Mission STS-134

To-date >220 billion cosmic. rays have been measured by AMS: e^+, e^-, p, $\bar{p}$, nuclei, γ,…

400 billion events expected to 2030

AMS installed on the ISS
Near Earth Orbit:
altitude 400 Km
inclination 52°
period 92 min

AMS Launch May 2011

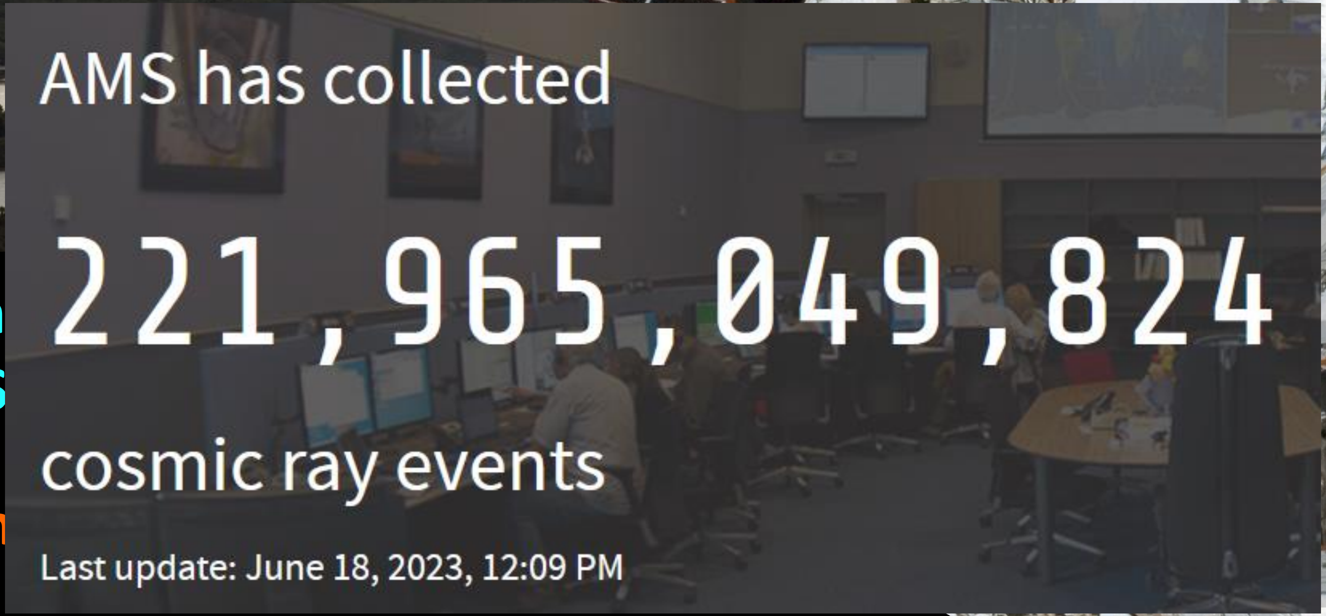
S

M

To-date >220 billion

measured by AMS

400 billion even



installed on the ISS

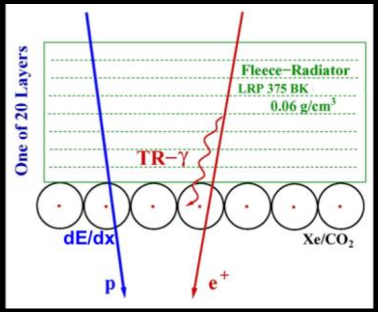
Earth Orbit:

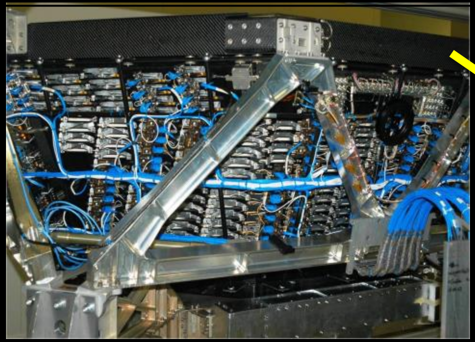
- altitude 400 Km
- inclination 52°
- period 92 min

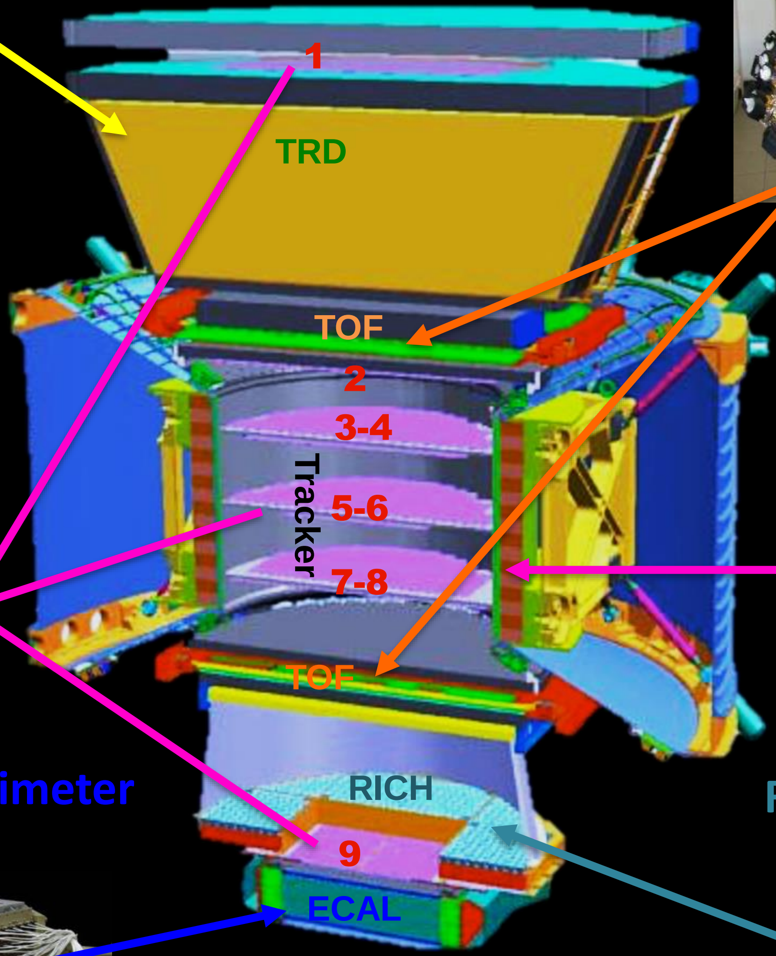
AMS-02: A TeV precision magnetic spectrometer in space

Transition Radiation Detector

Identifies e^+, e^-

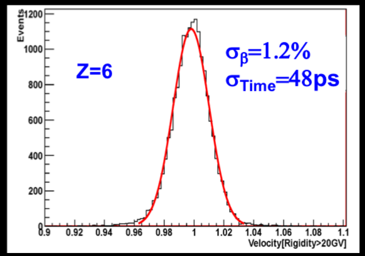






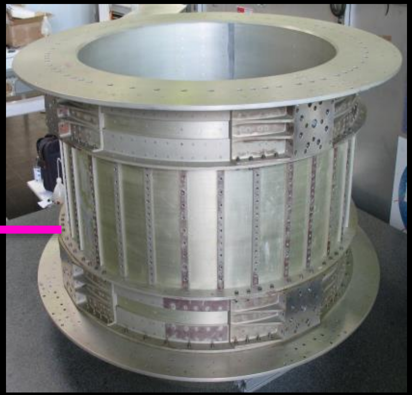
Time Of Flight

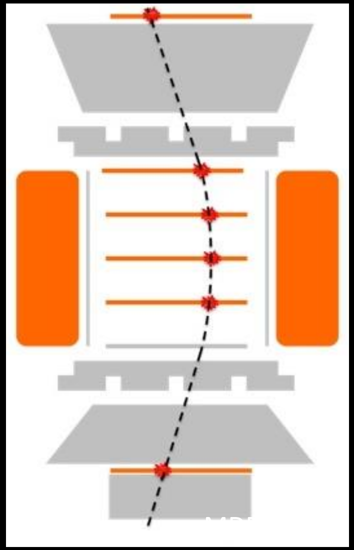
Z, β



Magnet

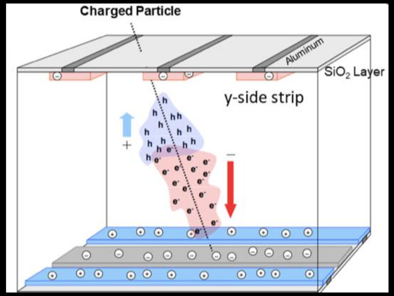
±Z

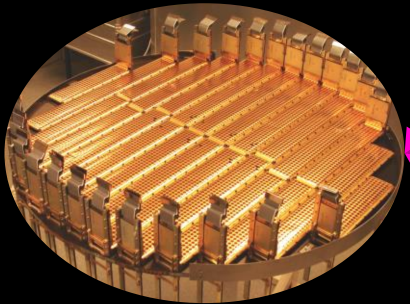




Silicon Tracker

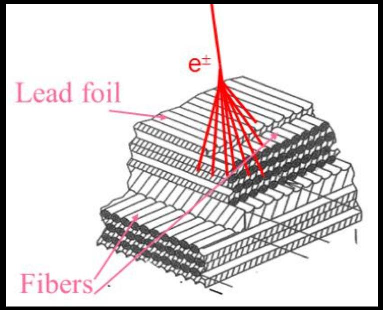
Z, Rigidity=p/Ze





Electromagnetic Calorimeter

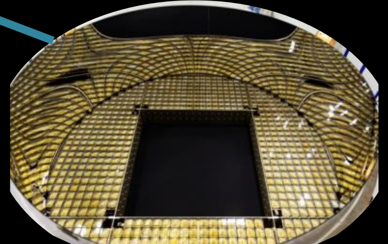
Energy of e^+, e^-

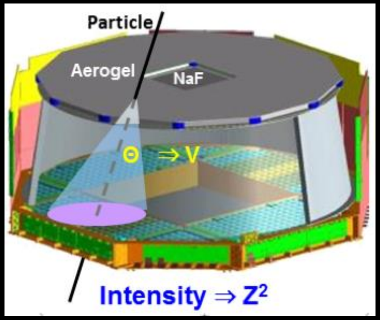


Ring Imaging Cherenkov

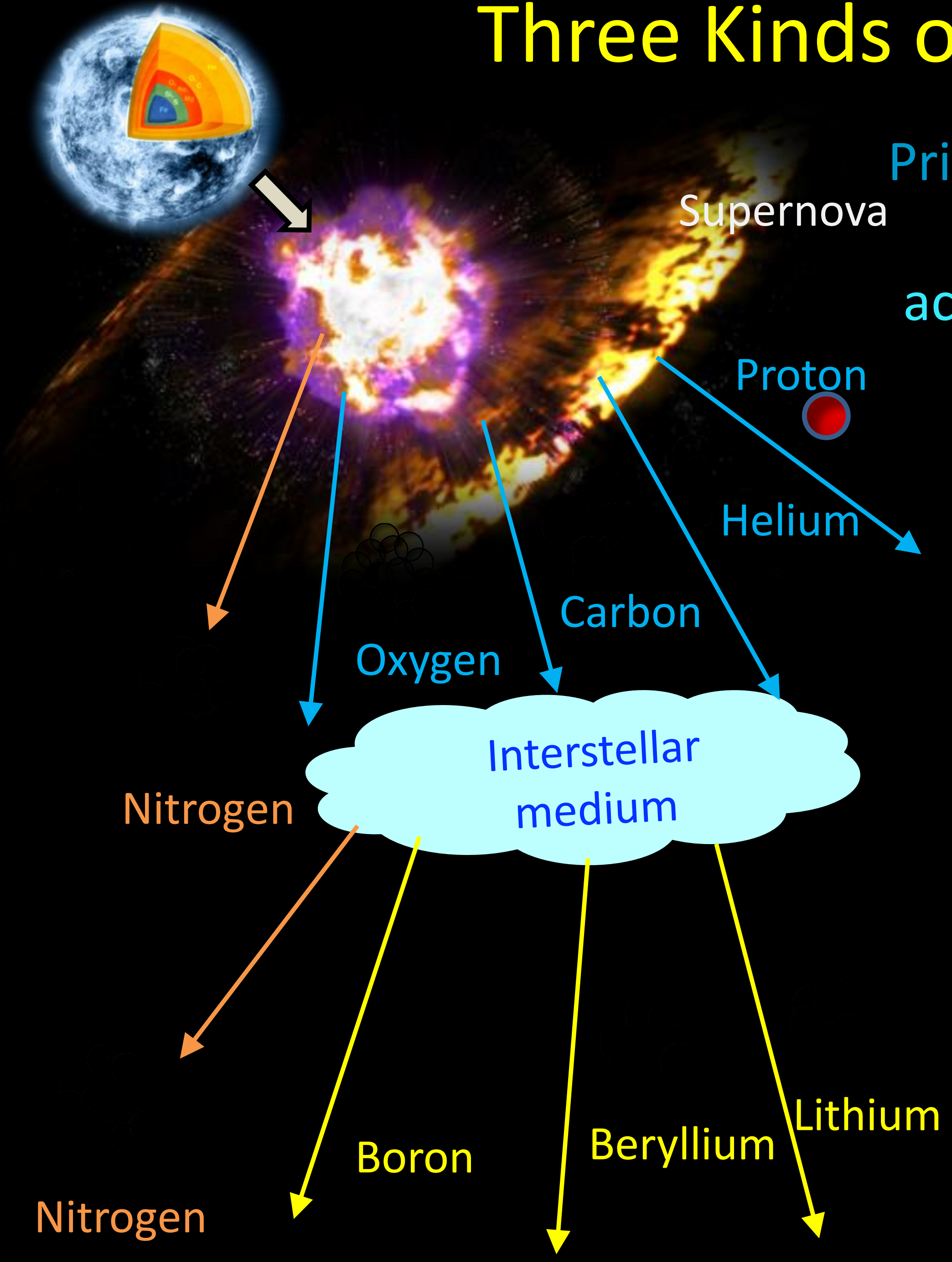
Z, β

Isotopic composition





Three Kinds of Charged Cosmic Rays

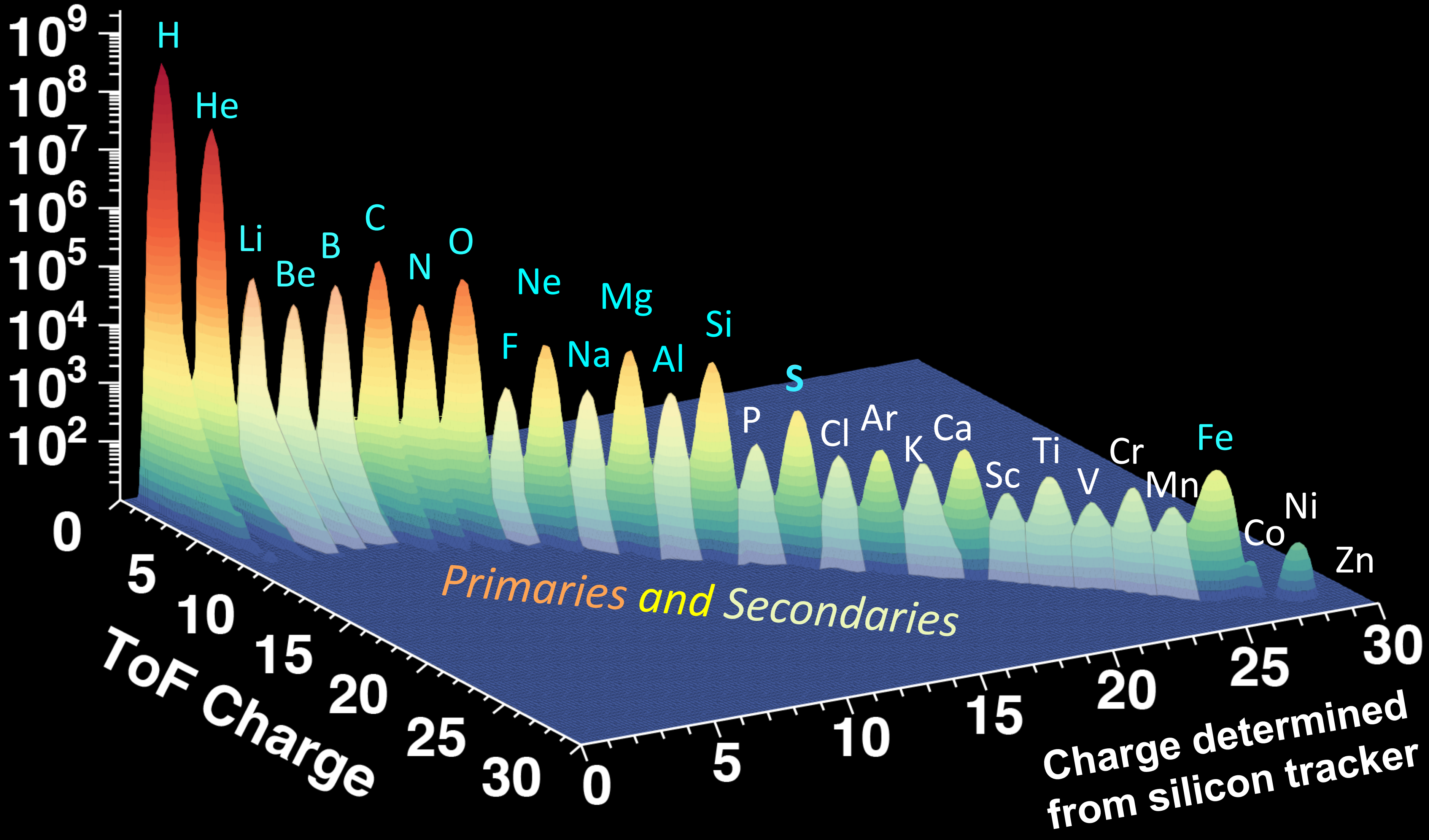


Primary cosmic rays (p, He, C, O, Ne, Mg, S ,Ar, ..., Fe) are mostly produced during the lifetime of stars and are accelerated in supernovae shocks, whose explosion rate is about 2-3 per century in our Galaxy.

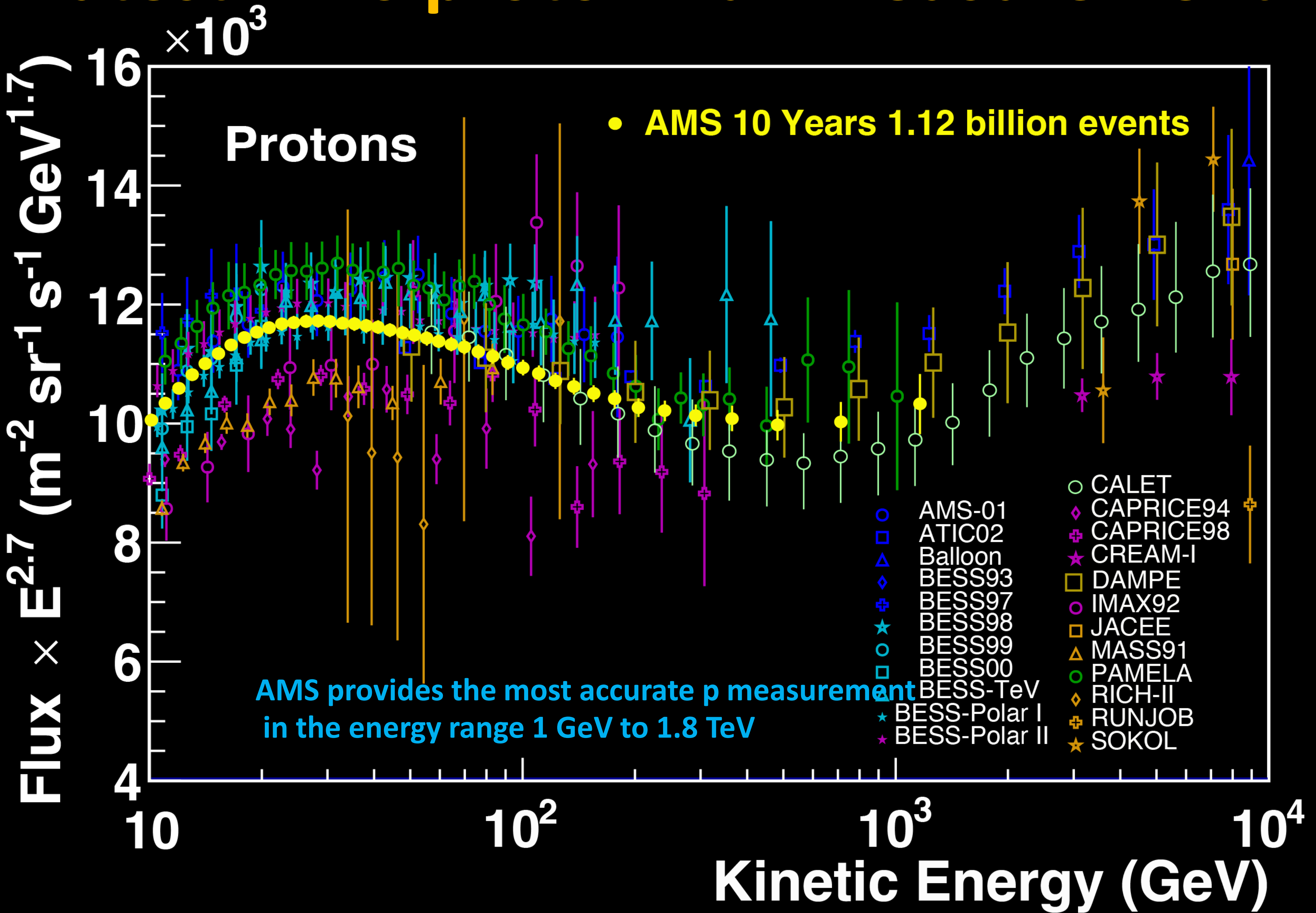
Secondary cosmic nuclei (Li, Be, B, F, ...) are produced by the collisions of primary cosmic rays and interstellar medium.

Cosmic nuclei with both Primary and Secondary Components (N, Na, Al, Cl,...) . Many primary cosmic rays C, Ne, Mg, S are also expected to have sizeable secondary component.

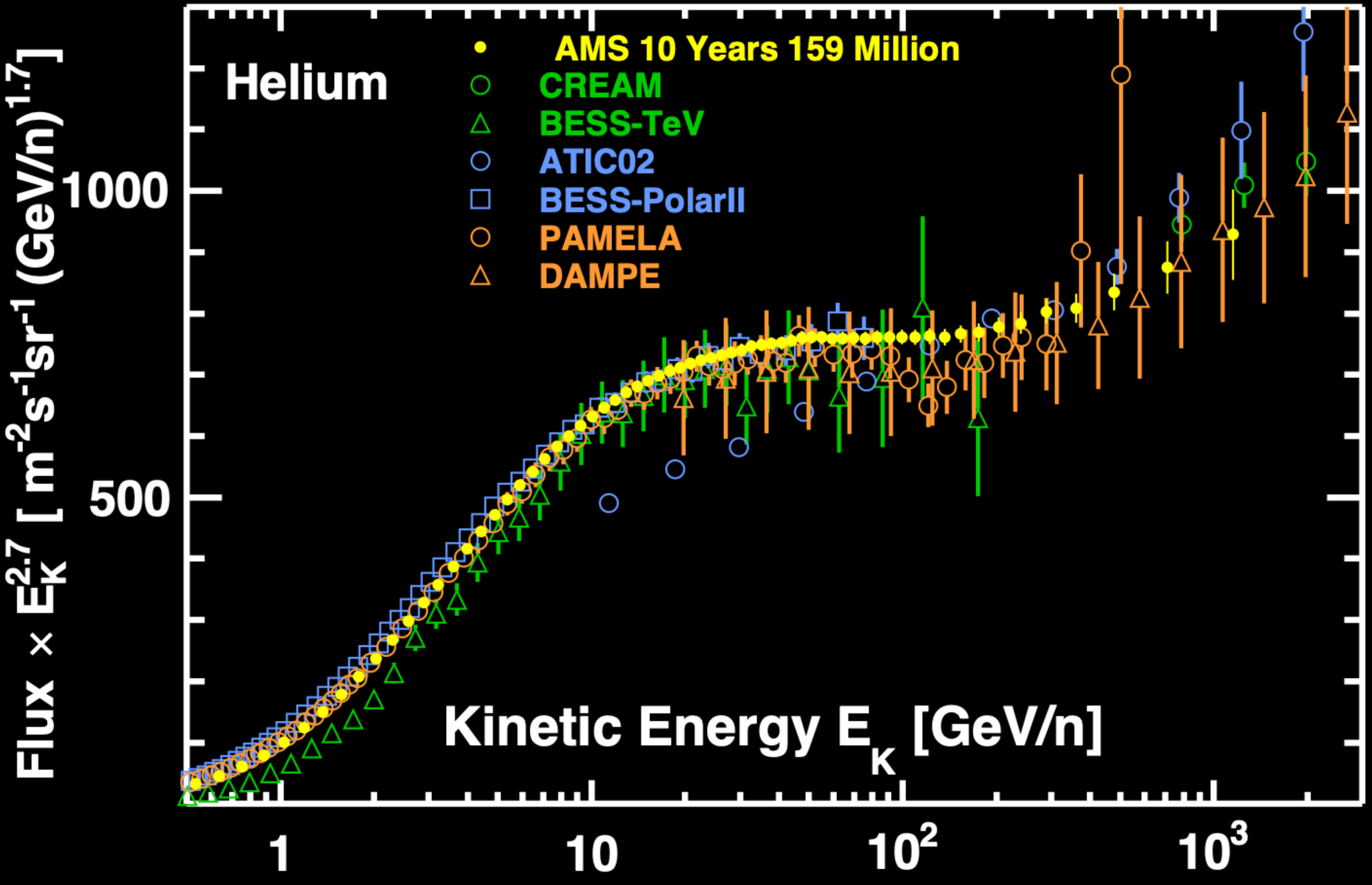
AMS Study of Cosmic Nuclei



Latest AMS proton flux measurement

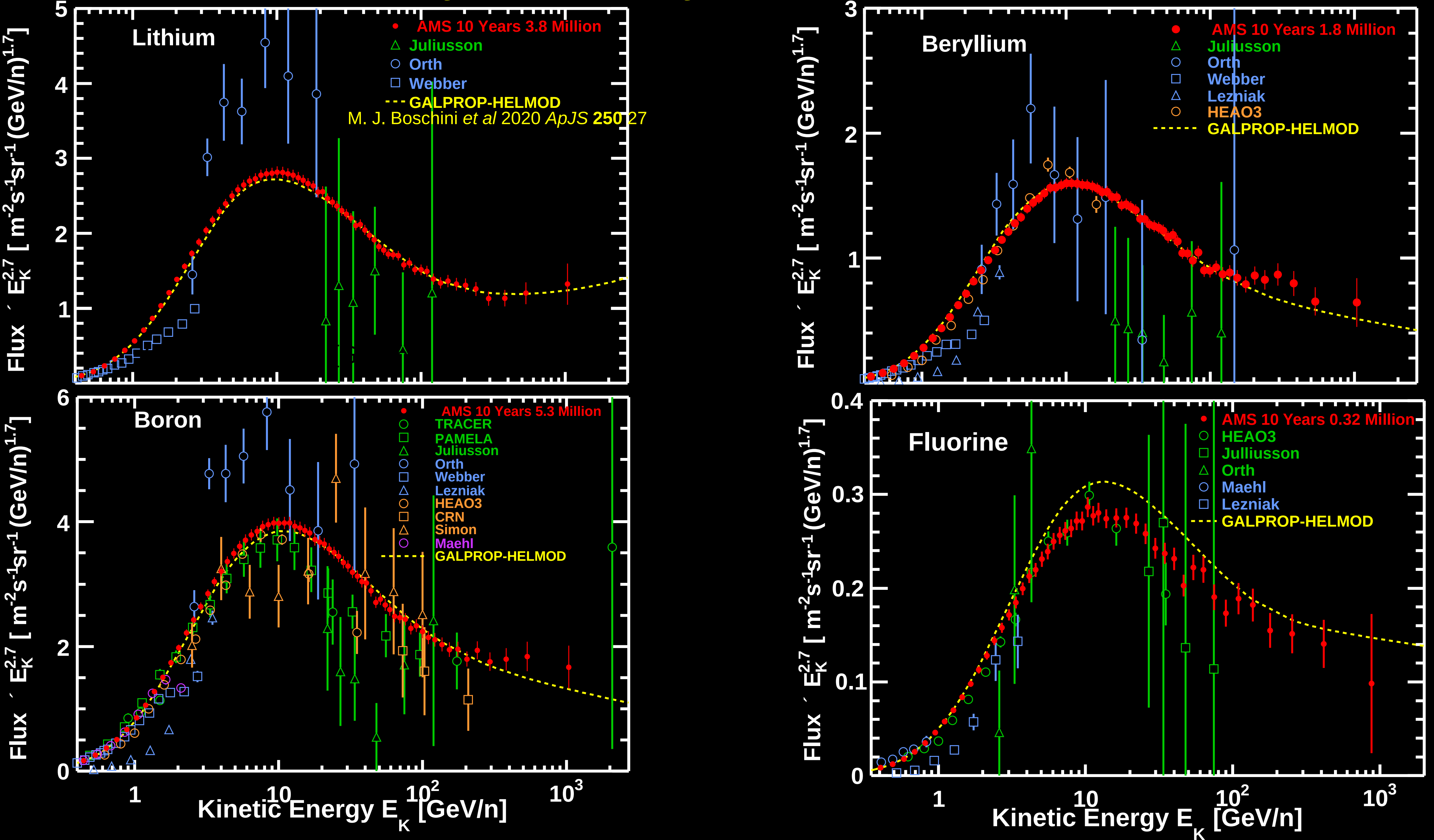


Latest AMS Helium flux measurement

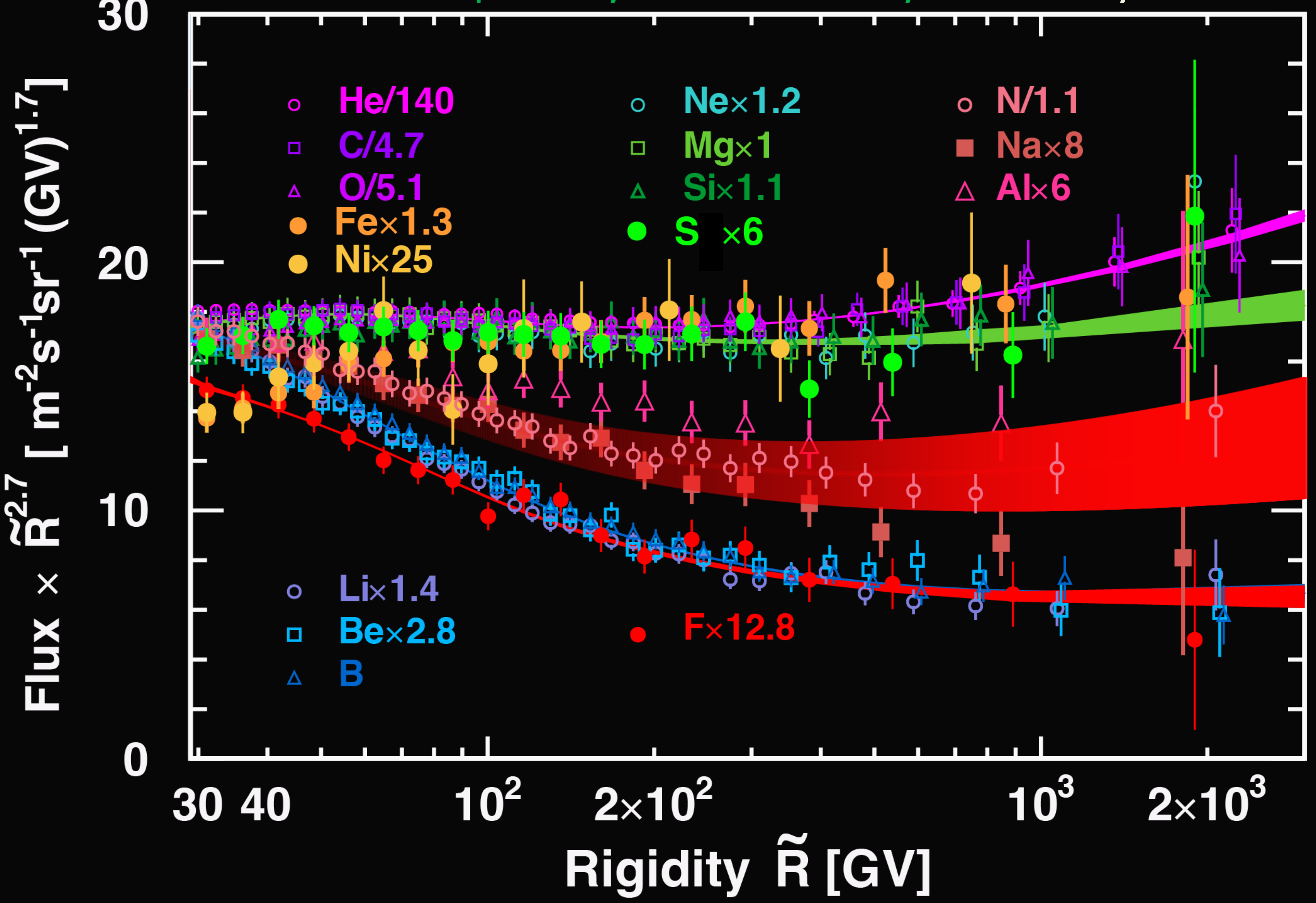


AMS provides the most accurate He measurement in the energy range 1 GeV to 6 TeV

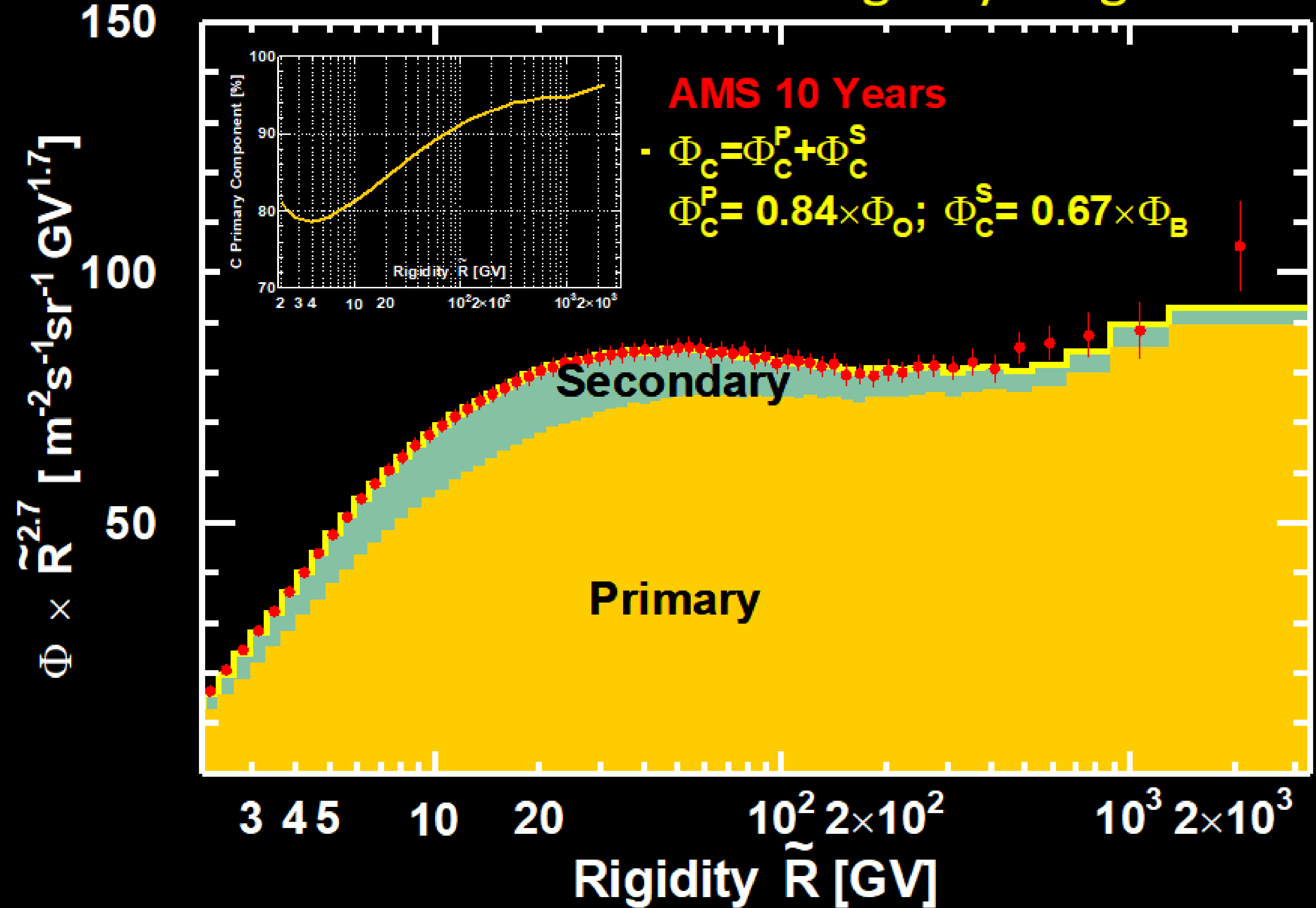
Secondary Cosmic Rays Li, Be, B, and F fluxes



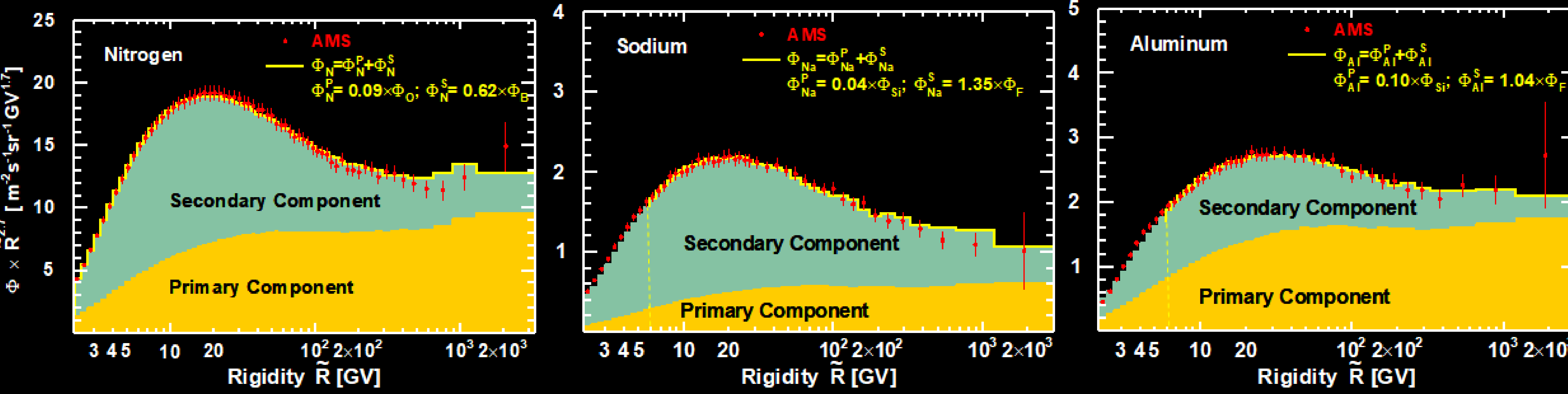
There are two classes of primary cosmic rays, He-C-O-Fe-Ni and Ne-Mg-Si-S, and two classes of secondary cosmic rays, Li-Be-B and F. N, Na, and Al, belong to a distinct group and are the combinations of primary and secondary cosmic rays.



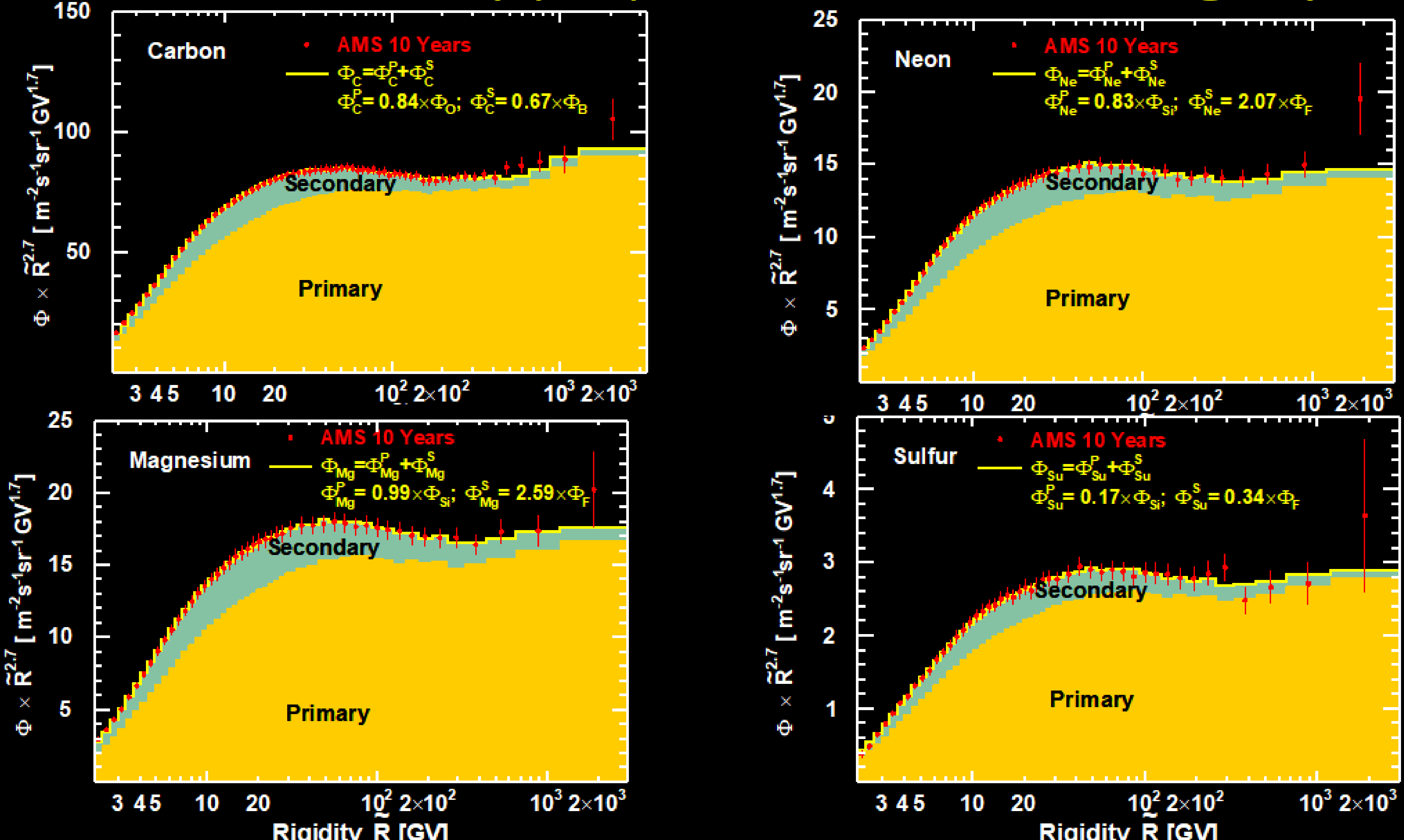
C flux can also be expressed as a sum of primary (O) and secondary (B) fluxes over the entire rigidity range



N, Na and Al fluxes can be expressed as a sum of primary (O,Si) and secondary (B,F) fluxes



C, Ne, Mg, and S fluxes can also be expressed as a sum of primary (O,Si) and secondary (B,F) fluxes over the entire rigidity range



Summary C to S Primary and Secondary Components

Nuclei Flux	Primary	Secondary	Secondary Fraction,% 6 GV	Secondary Fraction,% 2 TV
Φ_C	$(0.84 \pm 0.02) \times \Phi_O$	$(0.67 \pm 0.02) \times \Phi_B$	21±1	4±0.5
Φ_N	$(0.090 \pm 0.002) \times \Phi_O$	$(0.62 \pm 0.02) \times \Phi_B$	69±1	23±2
Φ_{Ne}	$(0.83 \pm 0.02) \times \Phi_{Si}$	$(2.07 \pm 0.1) \times \Phi_F$	24±1	4±0.5
Φ_{Na}	$(0.036 \pm 0.003) \times \Phi_{Si}$	$(1.35 \pm 0.04) \times \Phi_F$	81±2	32±1
Φ_{Mg}	$(0.99 \pm 0.03) \times \Phi_{Si}$	$(2.59 \pm 0.09) \times \Phi_F$	25±1	4±0.5
Φ_{Al}	$(0.104 \pm 0.005) \times \Phi_{Si}$	$(1.04 \pm 0.03) \times \Phi_F$	57±2	14±1
Φ_S	$(0.165 \pm 0.005) \times \Phi_{Si}$	$(0.34 \pm 0.04) \times \Phi_F$	24±1	4±0.5

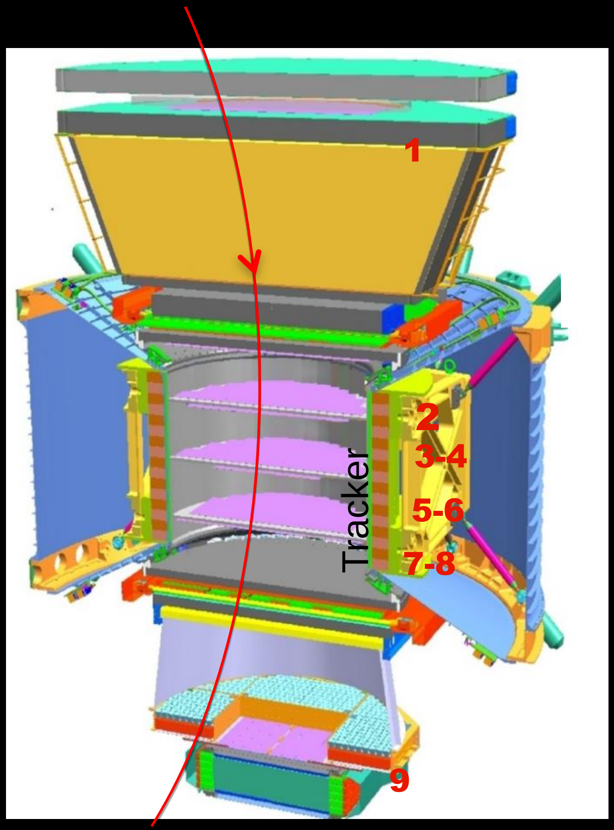
The C (Z=6) to S (Z=16) cosmic ray nuclei primary and secondary components derived as fractions of O(Si) and B(F) fluxes, respectively, and their secondary fractions at 6 GV and 2 TV.

This allows to measure relative cosmic ray abundances of C/O, N/O, Ne/Si, Na/Si, Mg/Si, Al/Si, and S/Si at the source independently of cosmic ray propagation.

Absolute Momentum Scale

In AMS, the largest systematic error in the determination of the fluxes at the highest energies is due to the uncertainty in the absolute momentum scale.

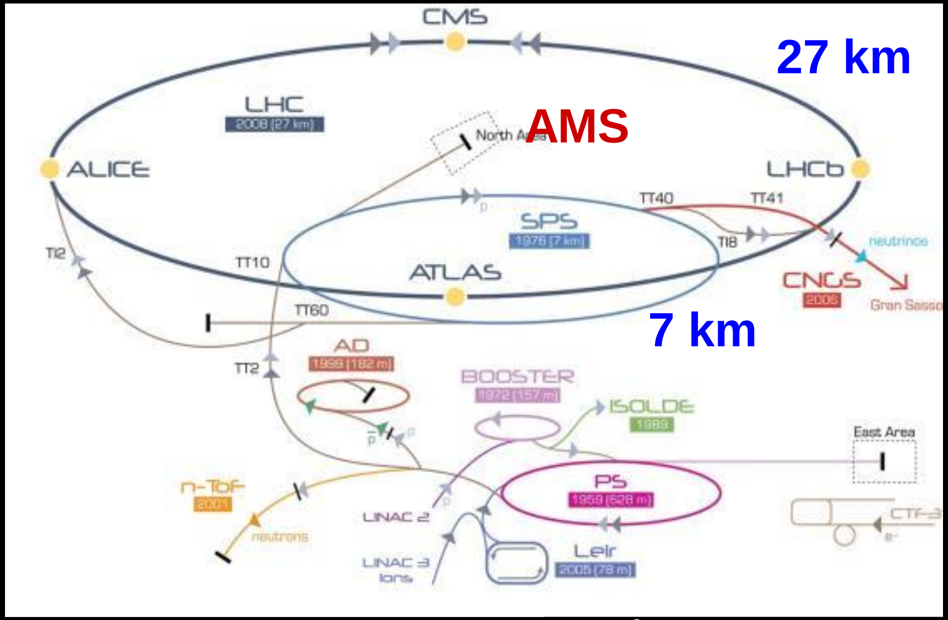
In space continuous outgassing of the carbon fiber supporting structure can affect the position of the tracker sensors at the sub-micron level.

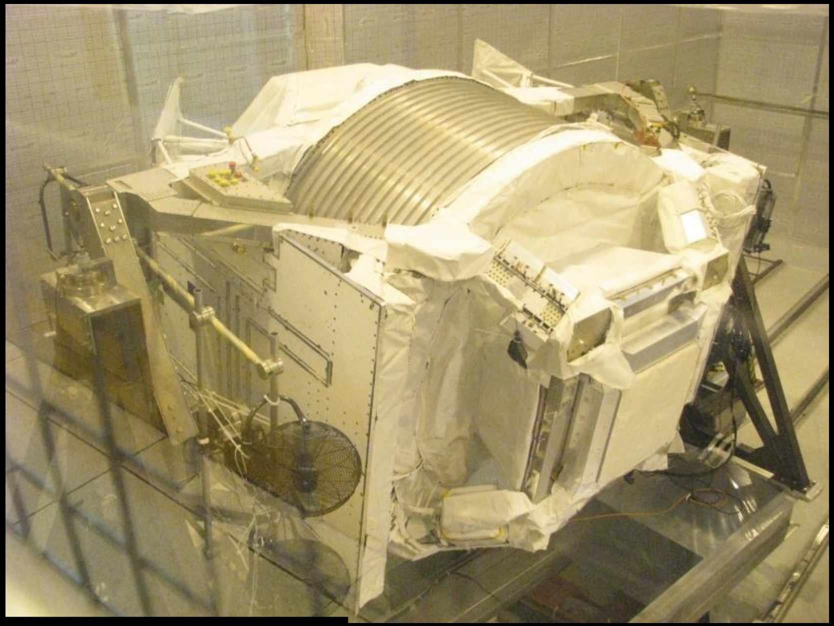


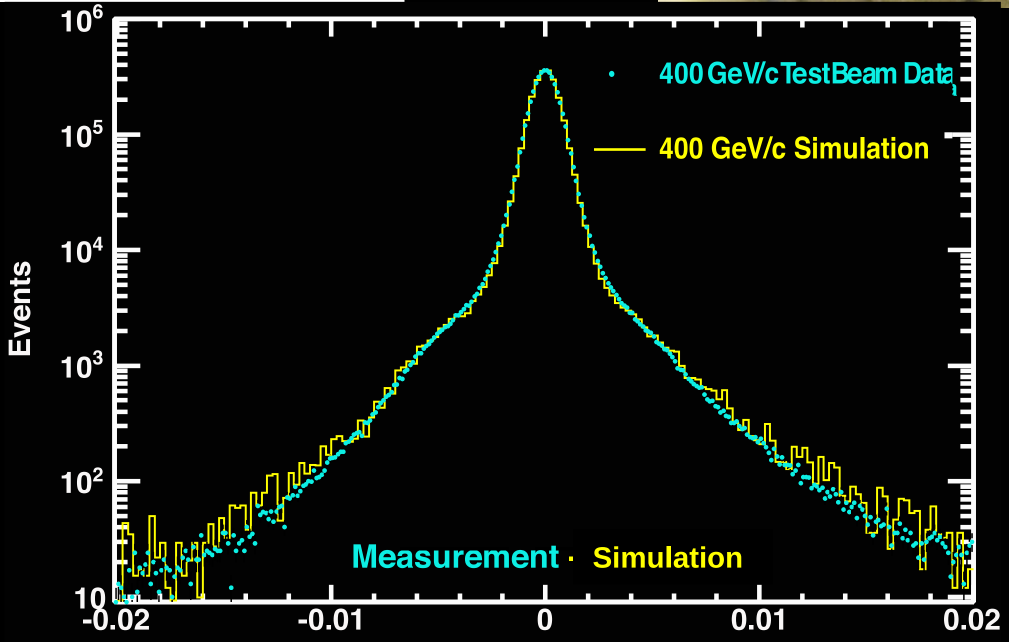
A shift in the central tracker planes of 0.2 microns is sufficient to create a momentum shift of 10% at 3 TeV and bias flux measurements both in normalization and shape.

2000 Calibration Runs at CERN

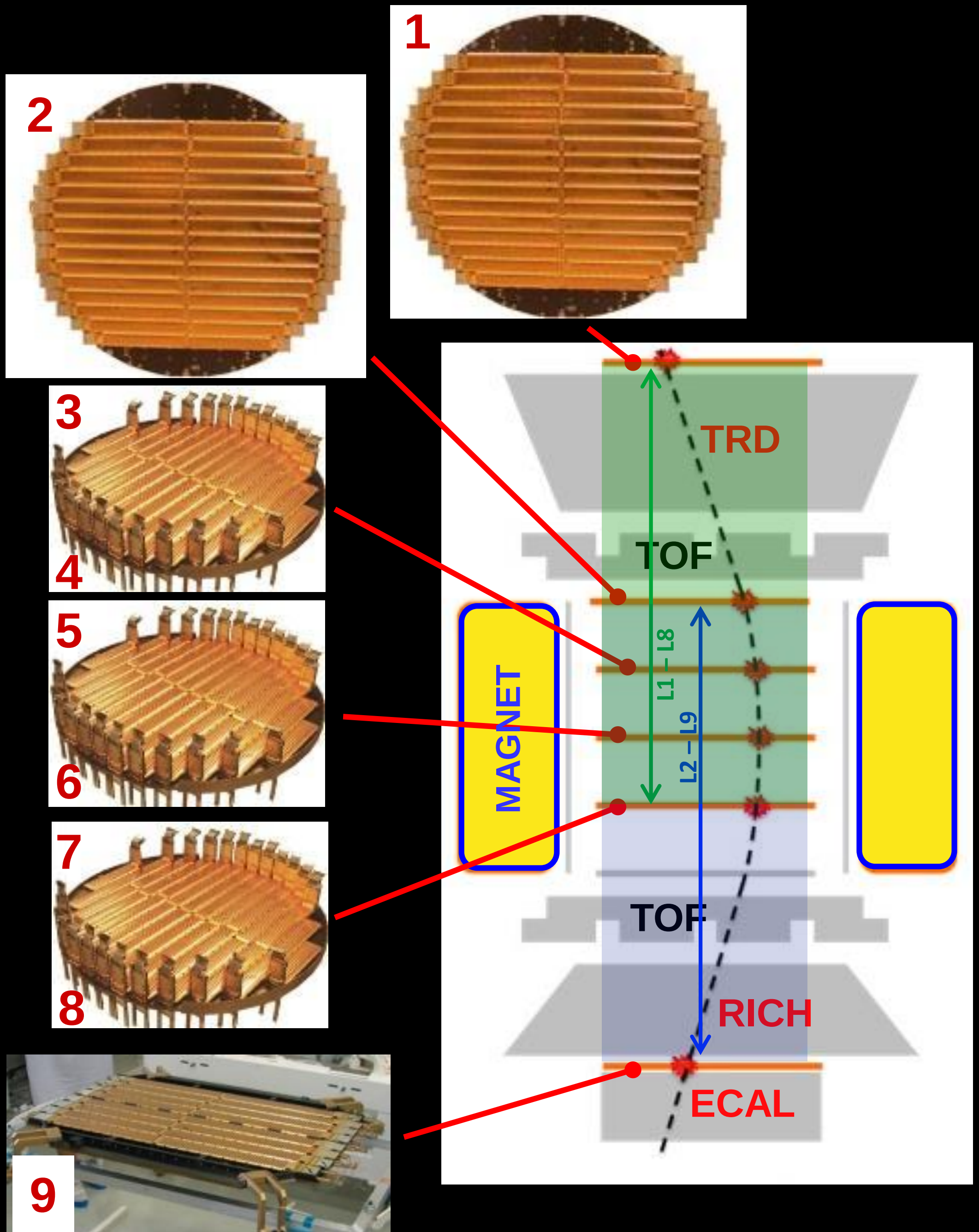
with different particles at different energies in different directions







Twelve years of operation of AMS on the ISS: Continuous Calibration

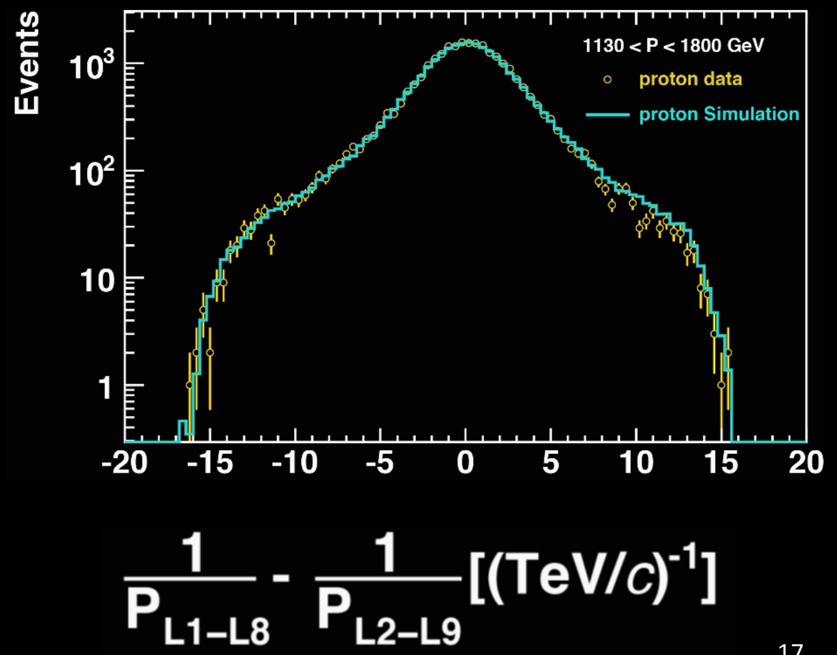


By comparing proton data and simulation from

the upper spectrometer (L1 to L8)

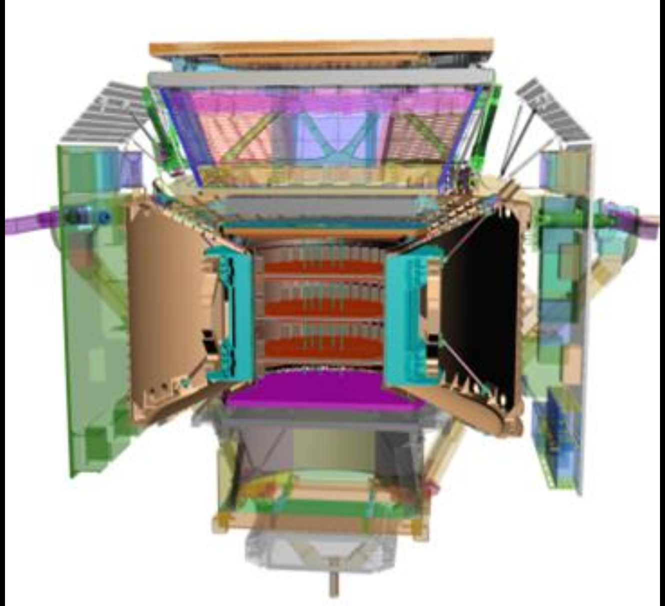
and

the lower spectrometer (L2 to L9)

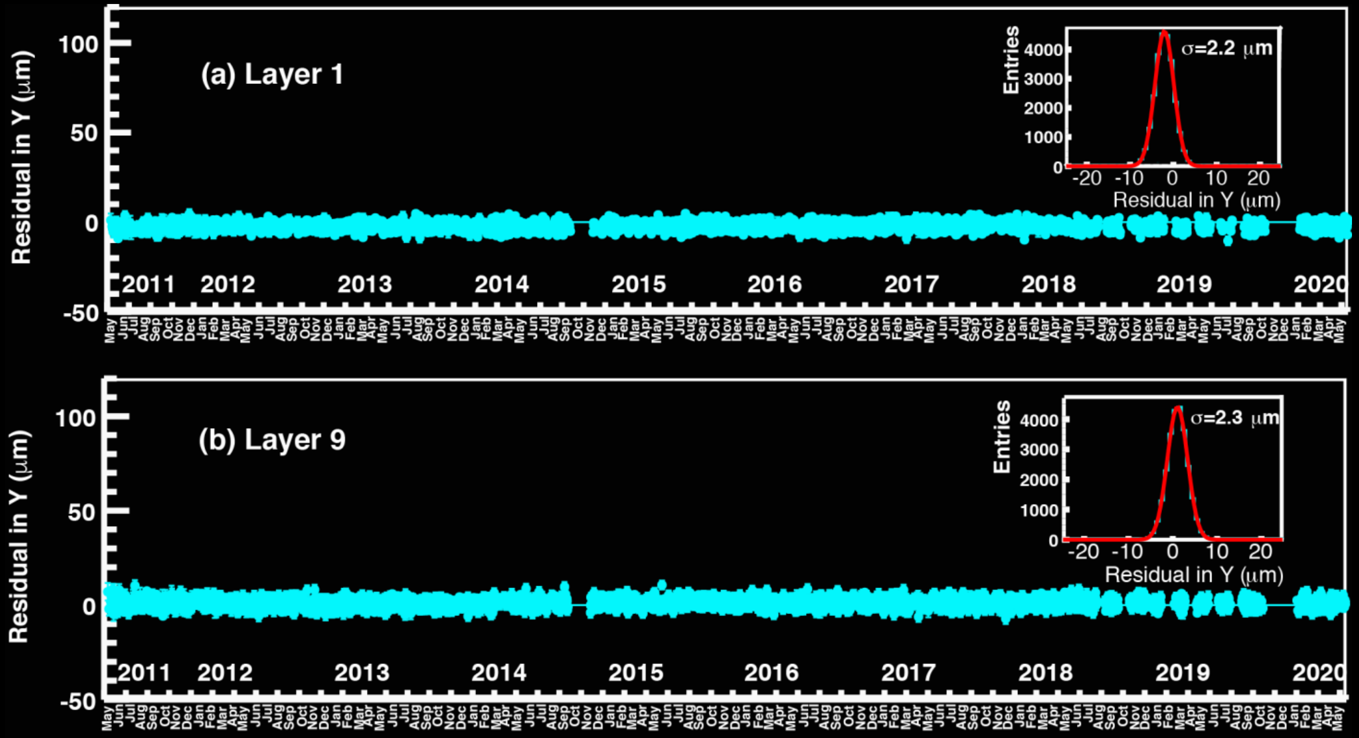


Examples of Detector Monitoring: Tracker Alignment

Monitored every 2 minutes by cosmic rays



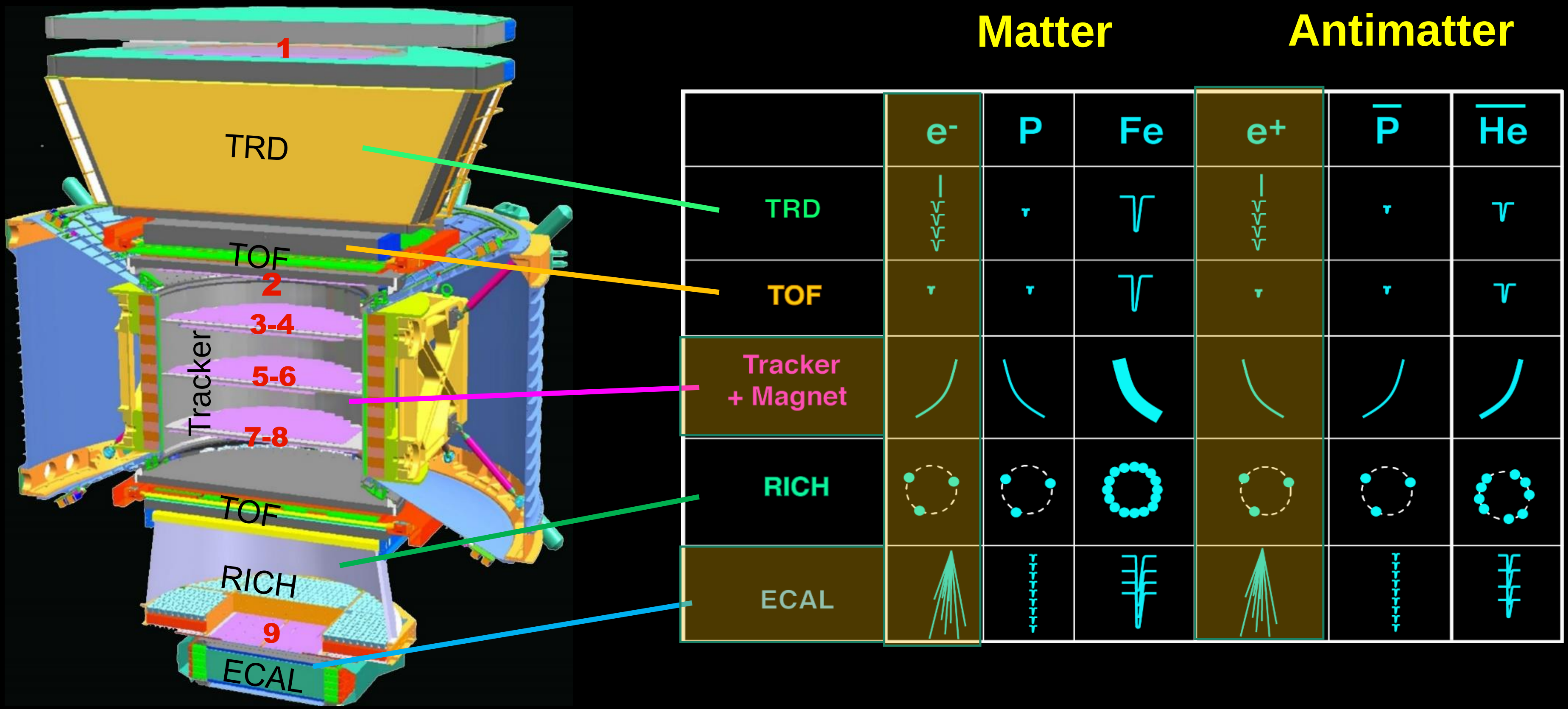
Inner tracker alignment
(< 1 micron)
monitored with IR lasers



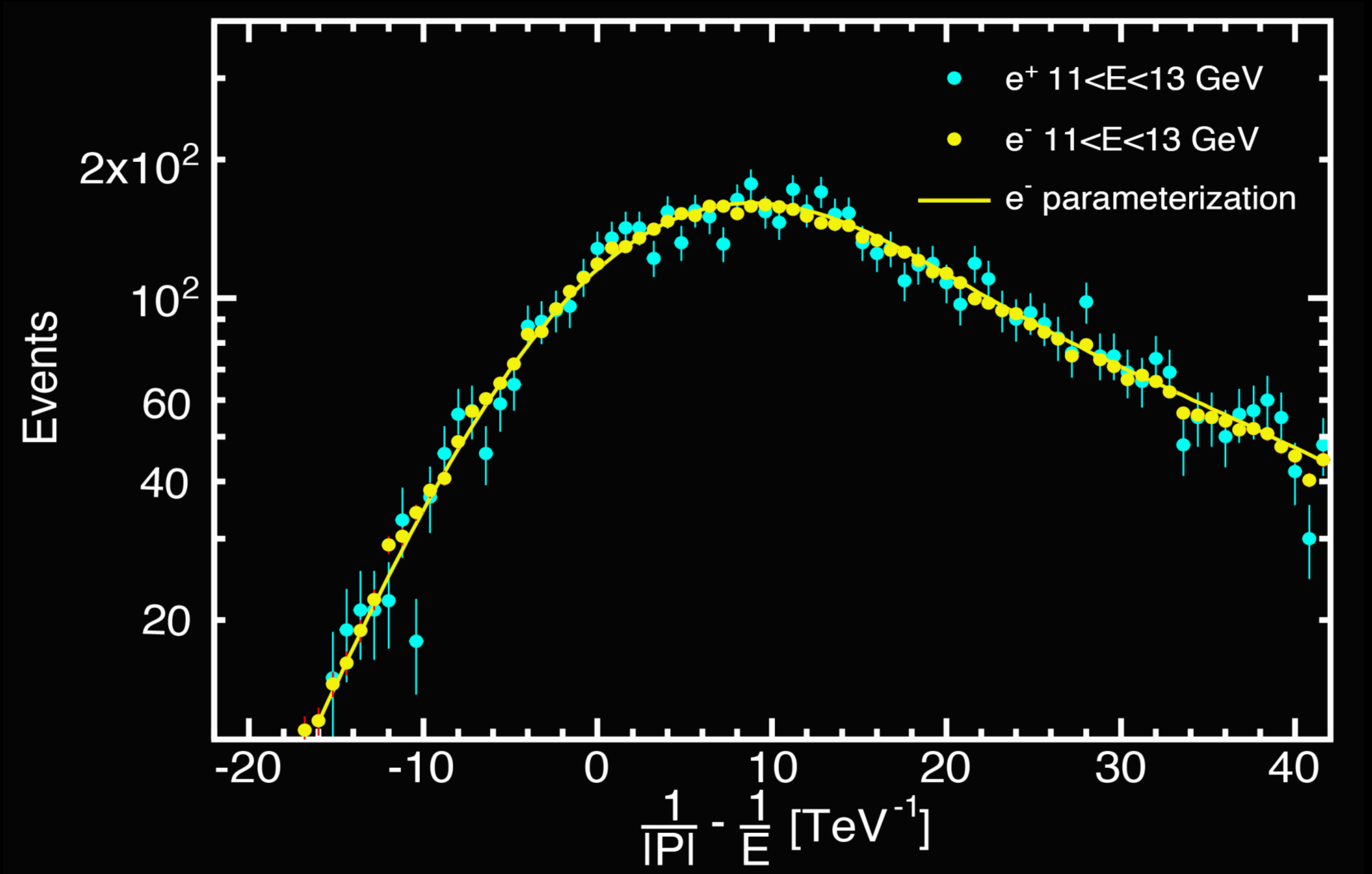
Outer tracker **(a)** Layer-1 and **(b)** Layer-9 stable to 2 micron over 9 years

Momentum Scale Verification:

By matching the momentum determined by the tracker and magnet with the energy measured in the ECAL for both e^+ and e^-



Momentum Scale Verification



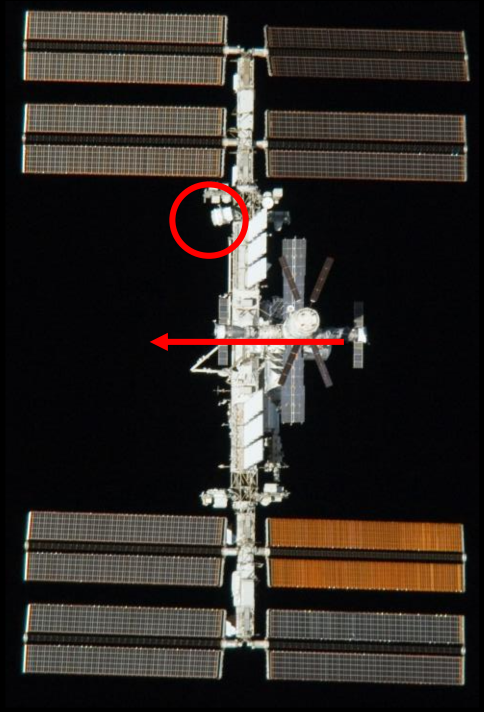
The accuracy of the momentum is determined to be 1/(33TeV);

i.e., at 1 TeV the uncertainty is 3%

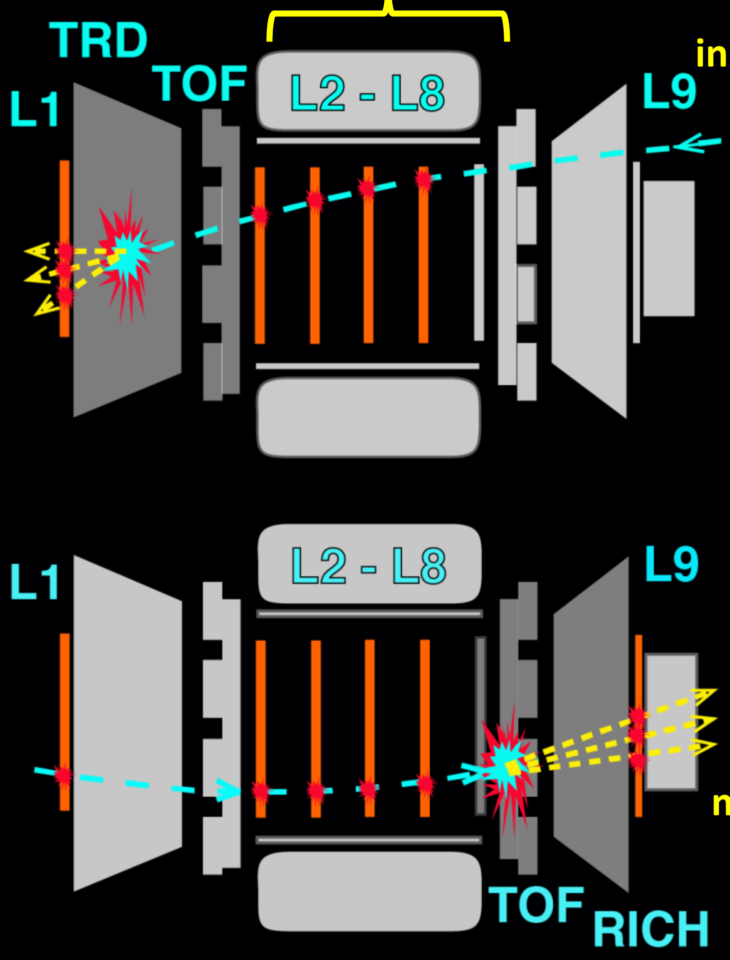
Precision measurement of cosmic-ray nuclei spectra requires an determination of nuclear interactions of each element in the detector material

Define (P, Z) of nuclei with the central spectrometer

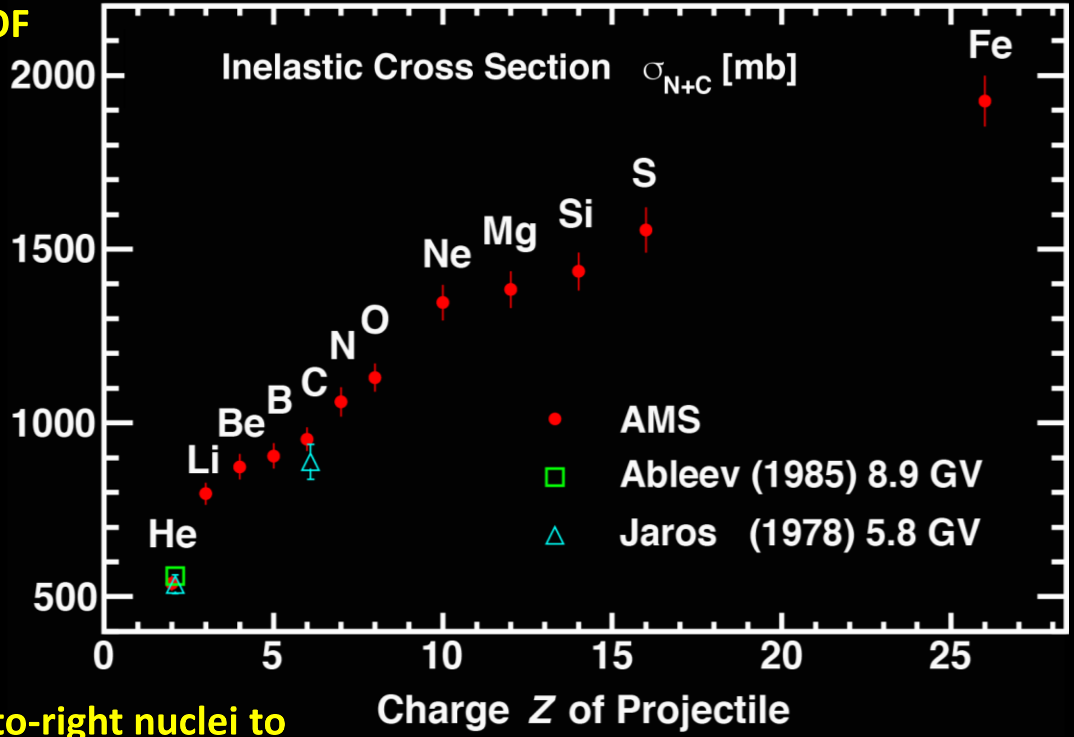
ISS horizontal



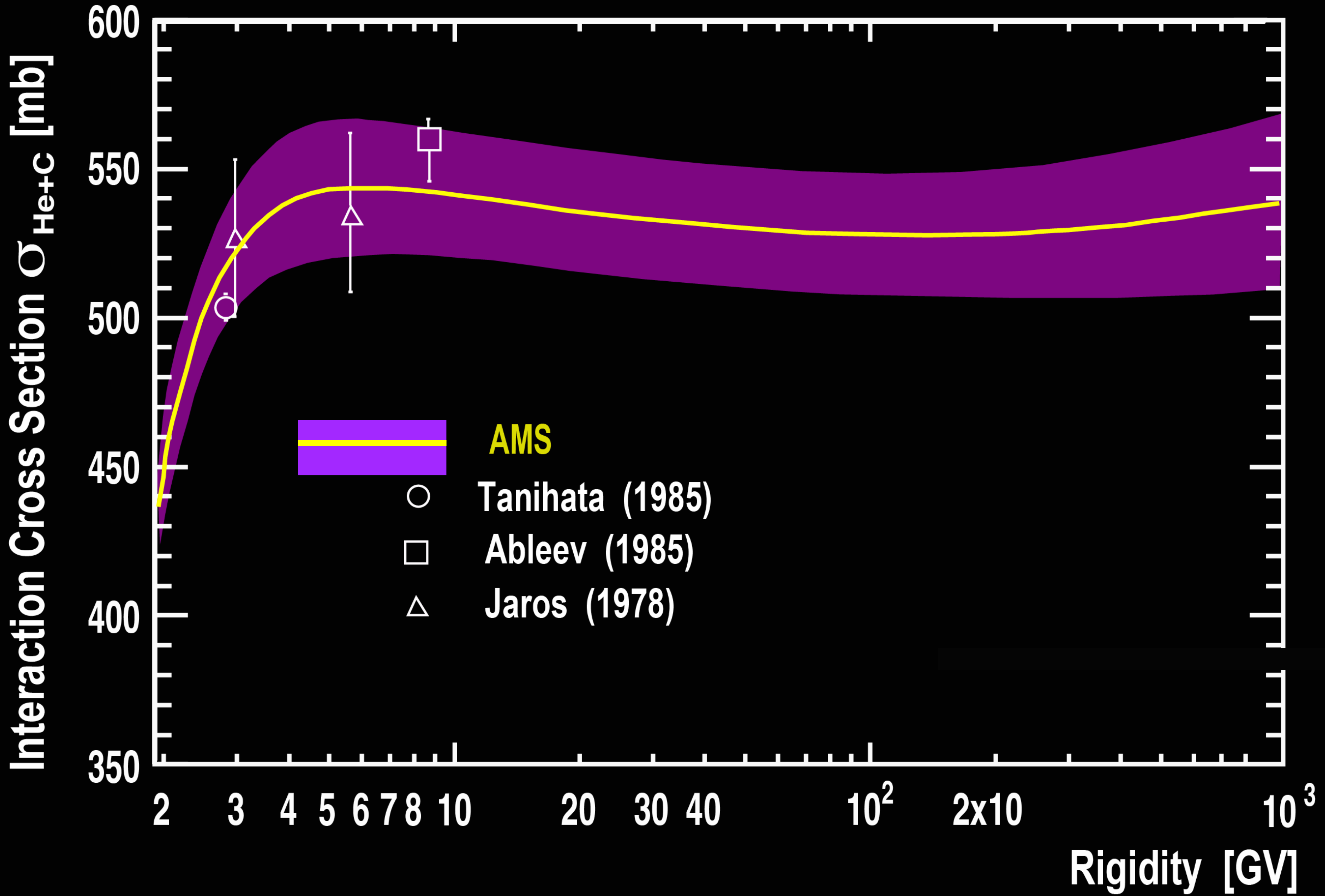
Use right-to-left nuclei to measure nuclear interactions in the TRD+TOF



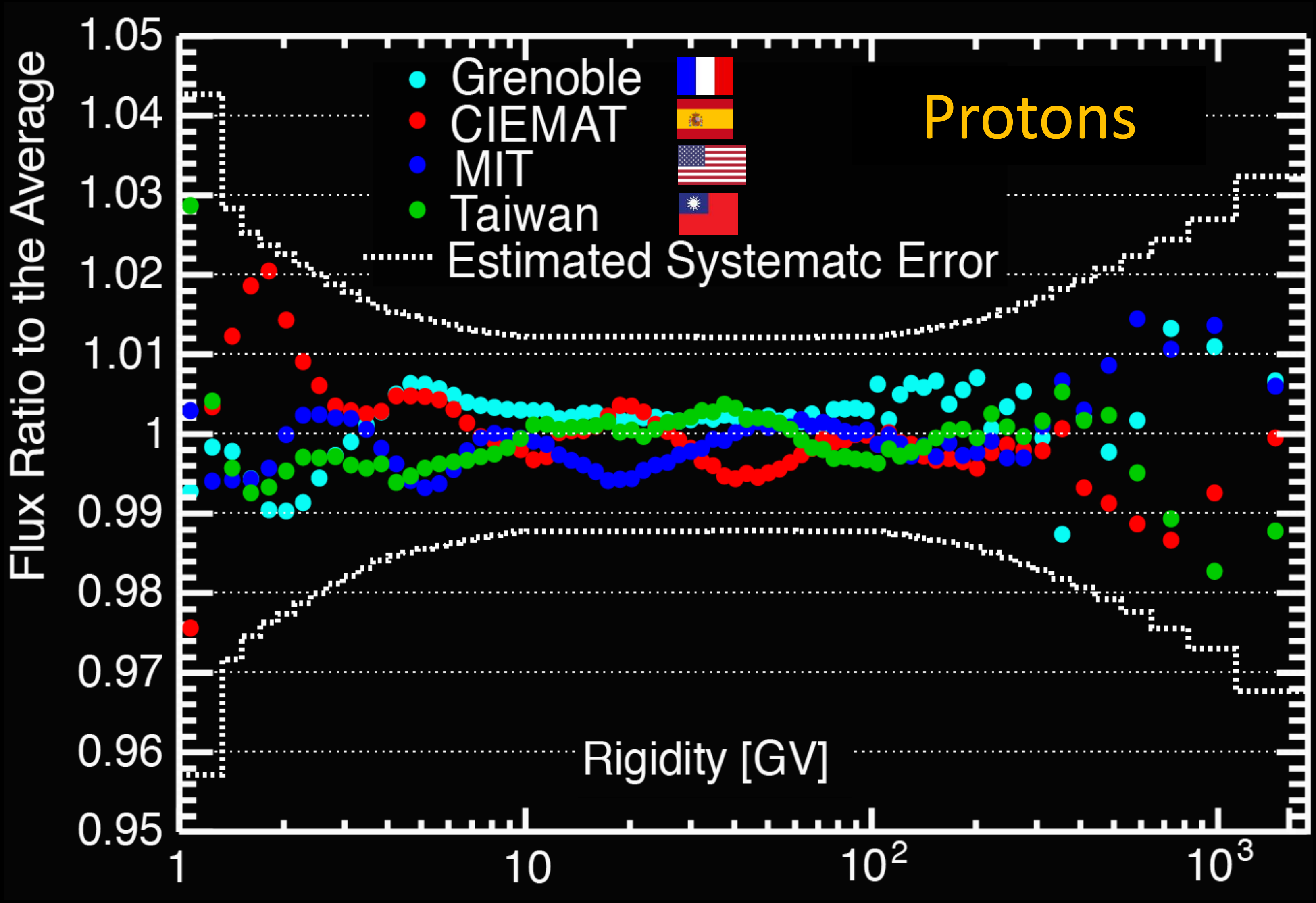
Use left-to-right nuclei to measure the nuclear interactions in the TOF+RICH



He on C Target Cross Section Measurement



The AMS results are analyzed by multiple teams and compared.



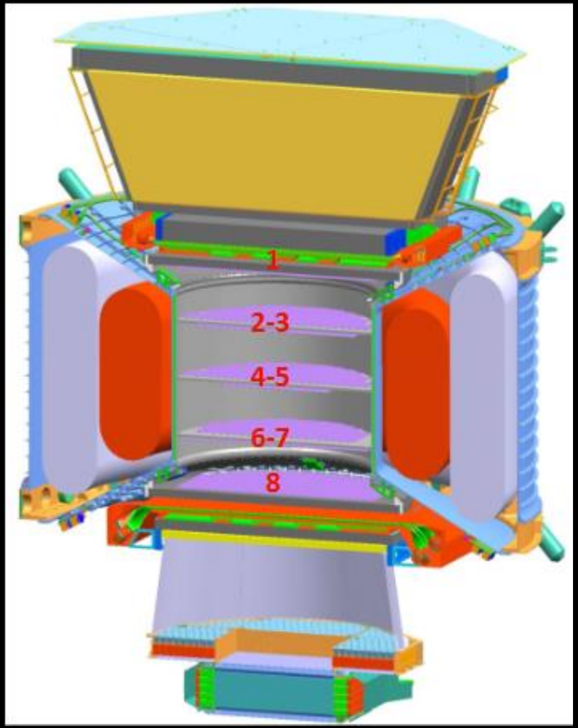
- AMS has successfully operated for 12 years on the ISS and measured the individual CR species in the GeV – TeV range with unprecedented (percent level) precision, which challenge the current GCR models
- The success of the AMS detector is based on:
  - Redundant design providing independent particle identification and measurement
  - Extensive calibration on ground and continuous monitoring in flight
  - Cross check by independent analysis groups to assess the results

ISS is scheduled to operate through 2030.

An upgrade of AMS to reach its original acceptance

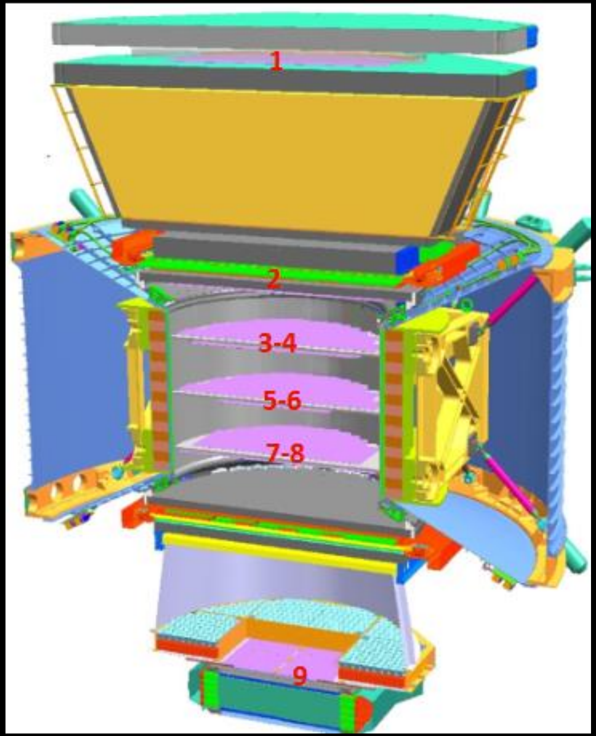
AMS as approved by the DOE Review Panel in 1995, 1999, and 2006:

Superconducting Magnet
8 layers of Silicon,
Large Acceptance



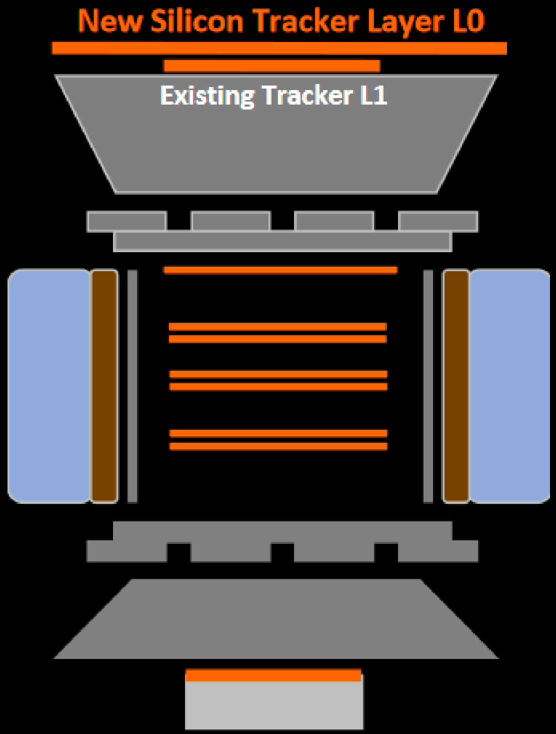
AMS on ISS due to termination of the Shuttle

Permanent Magnet,
9 layers of Silicon
(to maintain the resolution),
1/3 of the acceptance



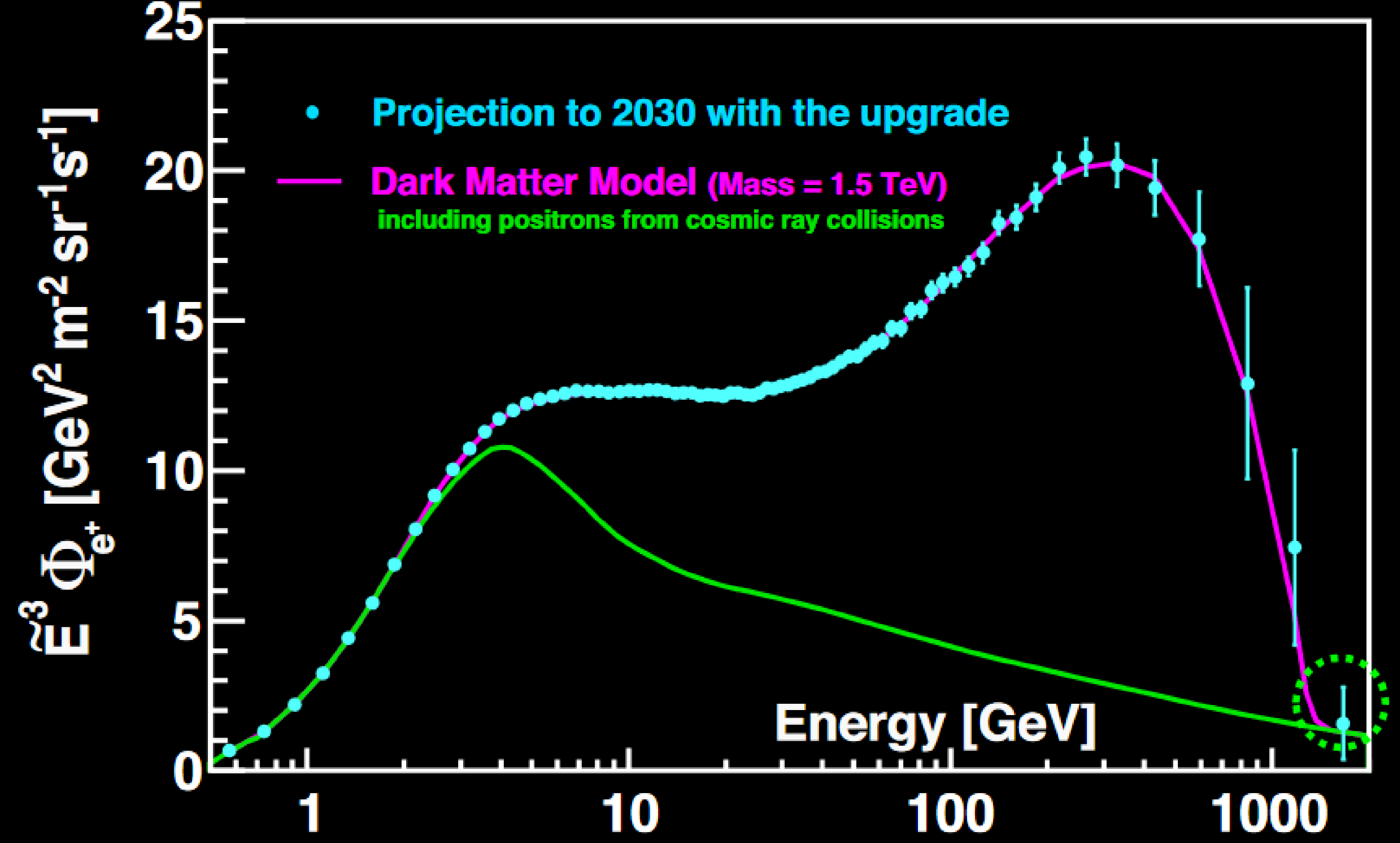
AMS on ISS to 2030

Permanent Magnet,
10 layers of Silicon
to upgrade to
full acceptance



Physics of the Upgrade

This is particularly important at high energies as it will ensure that **the measured high energy positron spectrum** indeed **drops off quickly and, in the 1-2 TeV region**, the positrons only come from cosmic ray collisions as predicted by dark matter models



The upgrade will enable us to provide a complete and accurate spectrum for all the 29 elements and provide the foundation for a comprehensive theory of cosmic rays.