Properties of Cosmic Phosphorus Nuclei Measured by the Alpha Magnetic Spectrometer

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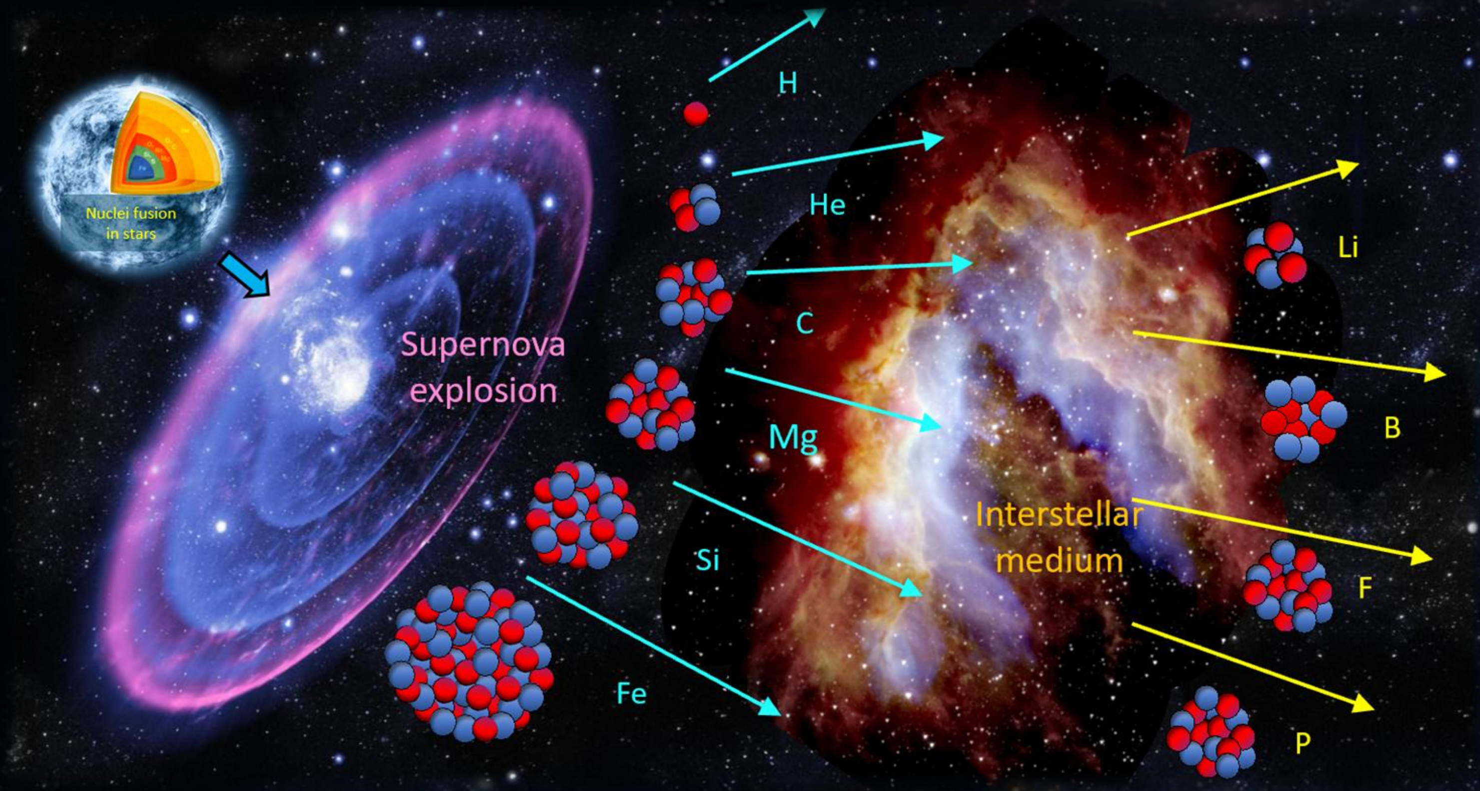
On behalf of the AMS Collaboration

TeVPA 2025

Cosmic-ray nuclei



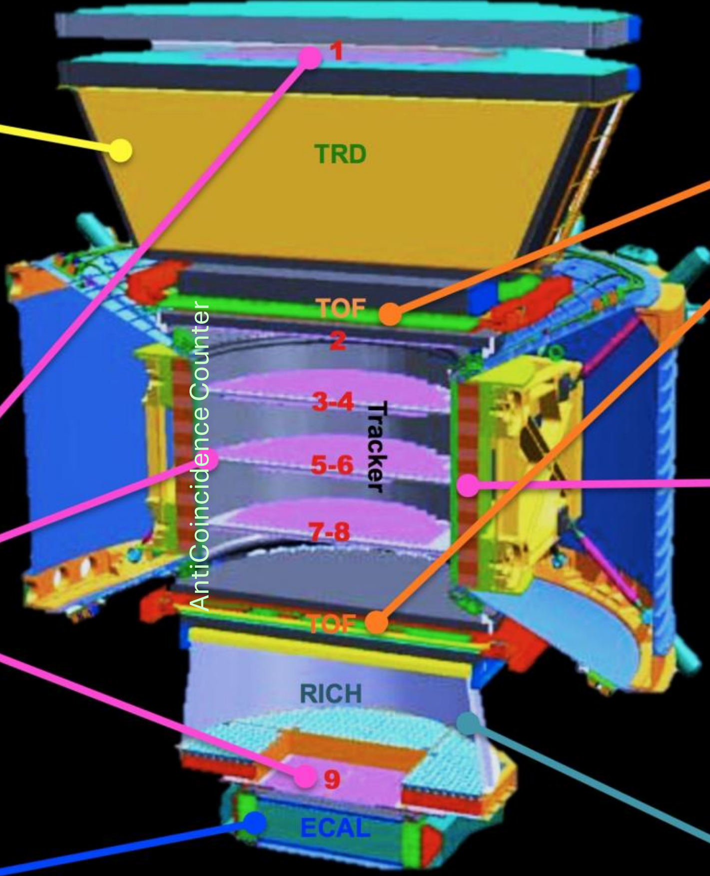
Primary Cosmic Rays: (H, He, C, O, Ne, Mg, Si, S, Fe, ...) mostly produced and accelerated by astrophysical sources.

Secondary Cosmic Rays: (Li, Be, B, F, P, ...) mostly produced via spallation of primaries on the Interstellar Medium.

Primaries can further interact and become secondary cosmic rays: N, Na, Al, ...) have both primary and secondary components.

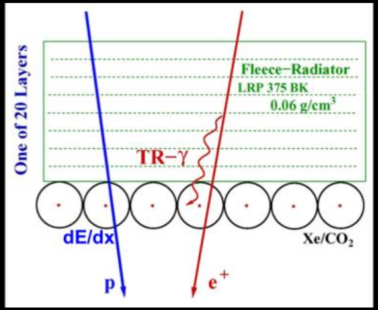
AMS-02: a TeV precision magnetic spectrometer

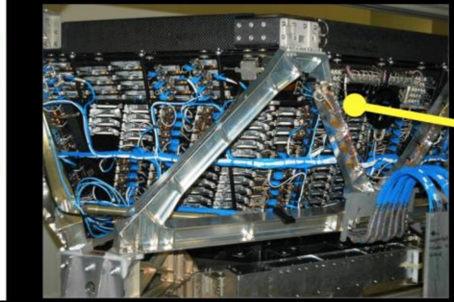
Particles and nuclei are defined by their charge Z and energy (E ≈ p ≈ β)



Transition Radiation Detector

Identify e^+, e^-

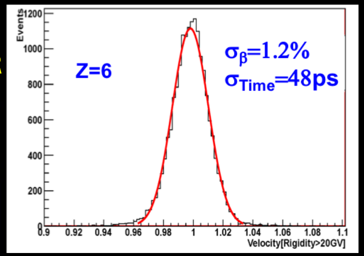




Time Of Flight

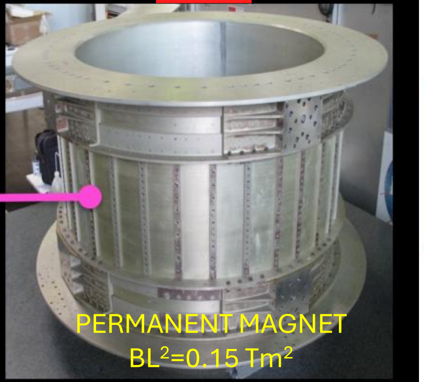
Z, β

MAIN TRIGGER



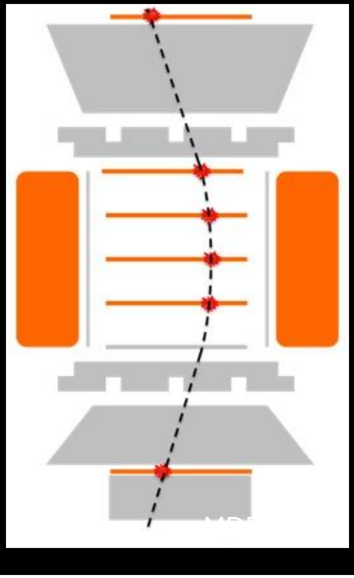
Magnet

±Z



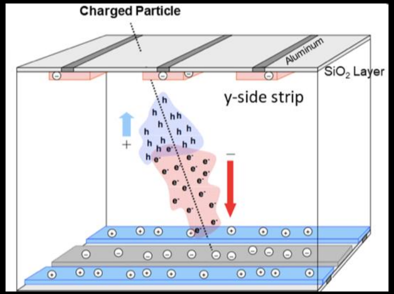
PERMANENT MAGNET

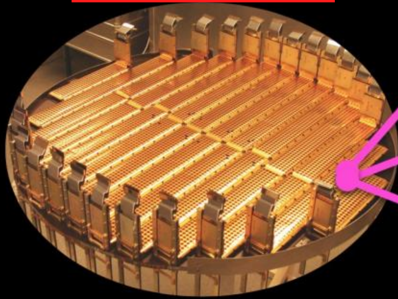
$BL^2=0.15\ Tm^2$



Silicon Tracker

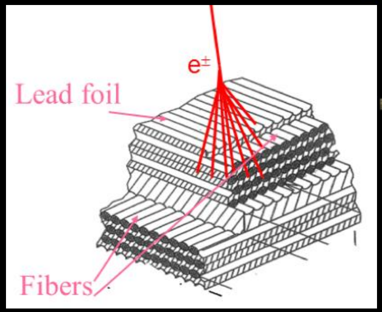
Z, Rigidity=p/Ze





Electromagnetic Calorimeter

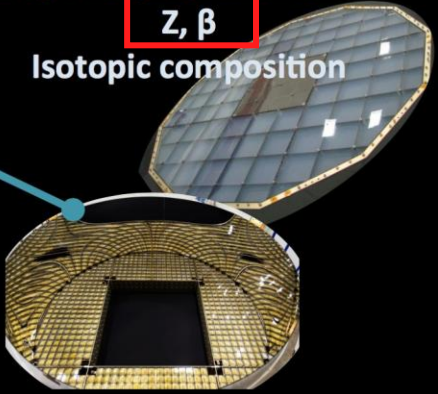
E of e^+, e^-

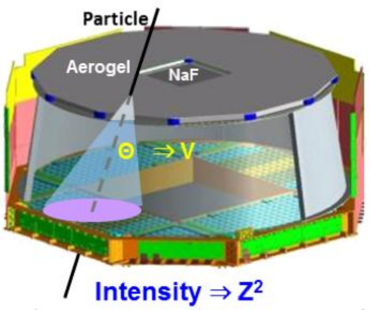


Ring Imaging Cherenkov

Z, β

Isotopic composition

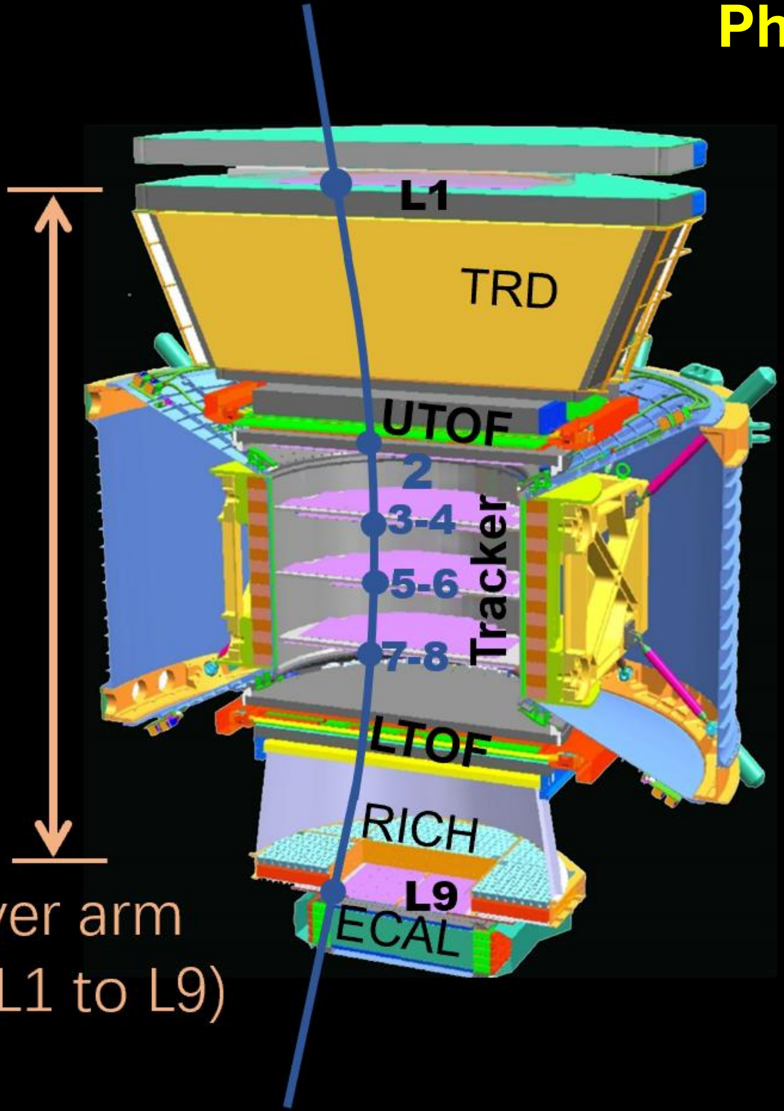




Charge Z and energy E are measured independently from Tracker, TOF, RICH, ECAL

Rigidity determination and charge resolution

Phosphorus (P) Z=15



3m lever arm
(from L1 to L9)

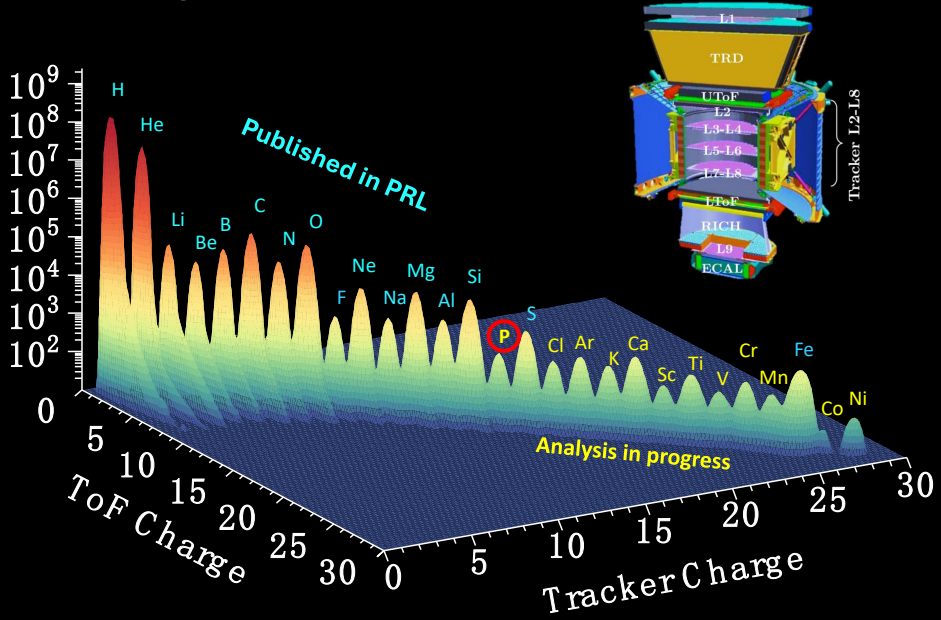
Rigidity (P/Ze) measured by Tracker (9 layers of silicon tracking detectors + Permanent Magnet)

Particle Charge	Coordinate Resolution	MDR
Z=1	$10\mu m$	2 TV
2≤Z≤8	5-$7\mu m$	3.2-3.7 TV
9≤Z≤16	6-$8\mu m$	3-3.5 TV

L1, UTOF, Inner Tracker (L2-L8), LTOF and L9 Consistent Charge Along Particle Trajectory

Particle Charge	Inner Tracker Charge Resolution (c.u.)
1≤Z≤8	0.05-0.12
9≤Z≤16	0.13-0.17

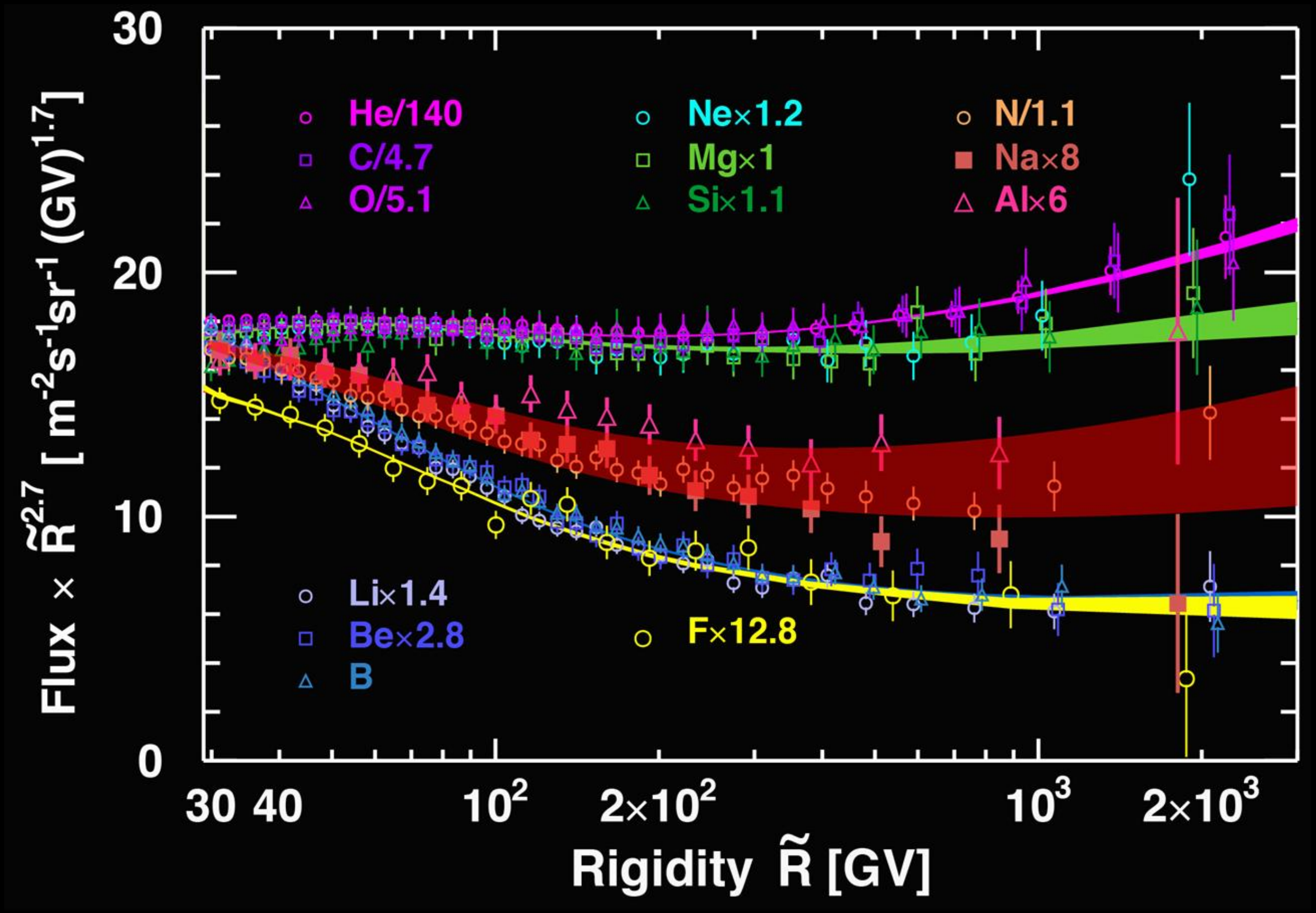
AMS cosmic-ray nuclei measurements



Published in PRL

Analysis in progress

Primary and secondary nuclei measured by AMS



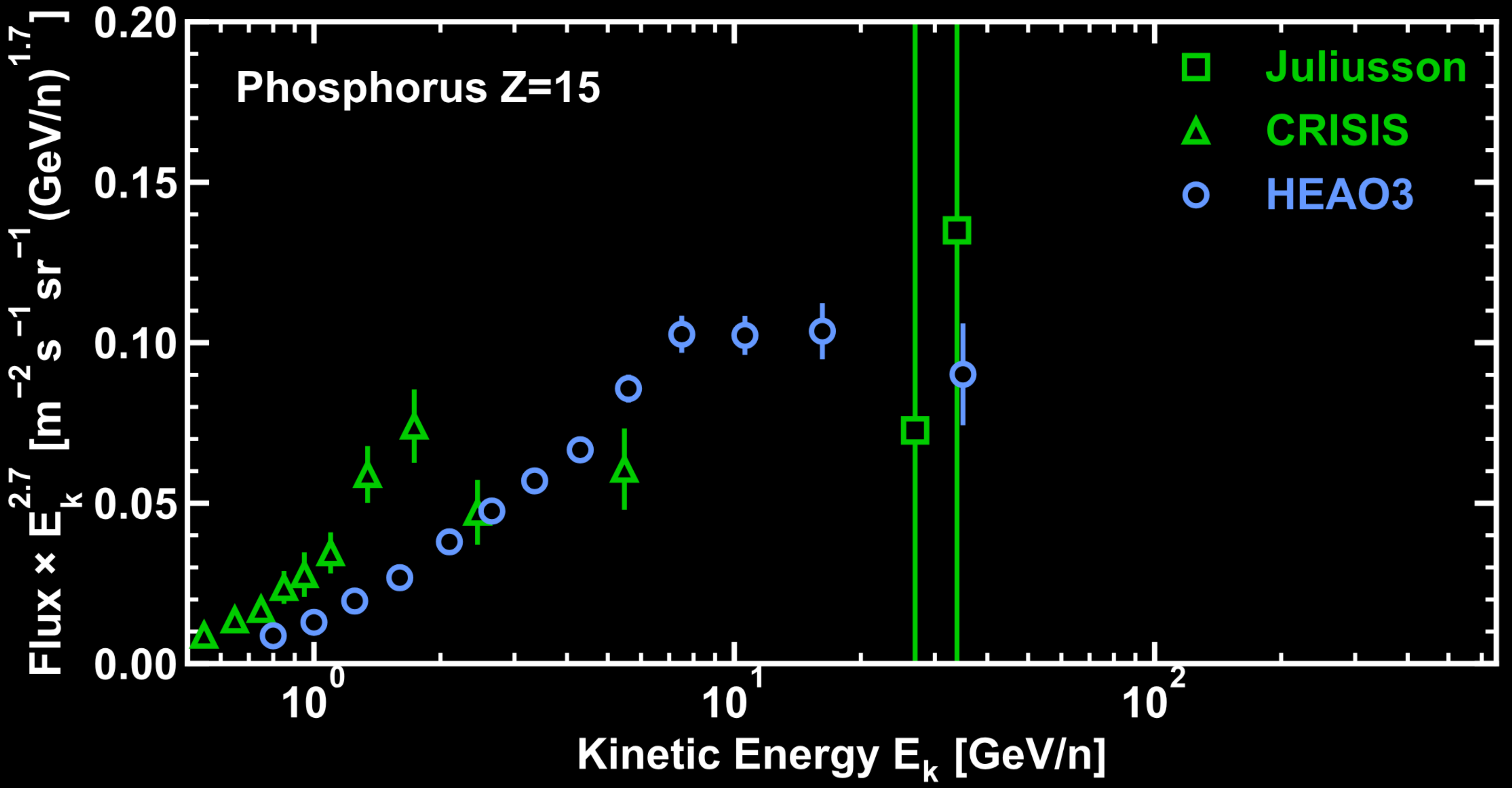
He-C-O-Fe
Ne-Mg-Si-S
} Primaries

N-Na-Al

Li-Be-B
F
} Secondaries

P is thought to be produced both in astrophysical sources and by the collisions of heavier nuclei with the interstellar medium.

P from previous measurements



- The measurement errors exceed 50% at ~50 GeV/n (~100GV in rigidity).
- There are no measurements of these fluxes in rigidity.

AMS cosmic-ray P flux

The isotropic flux Φ_i in the i_{th} rigidity bin $(\Delta R_i, R_i + \Delta R_i)$ is given by:

$$\Phi_i = \frac{N_i}{A_i \epsilon_i T_i \Delta R_i}$$

Number of events
(170k events subtracted by background and corrected for bin-to-bin migration)

Effective acceptance

- geometric acceptance,
- event reconstruction and selection efficiencies,
- inelastic interactions of nuclei in the AMS materials.

Bin width
(46 bins from 2.15 GV to 1.2 TV)

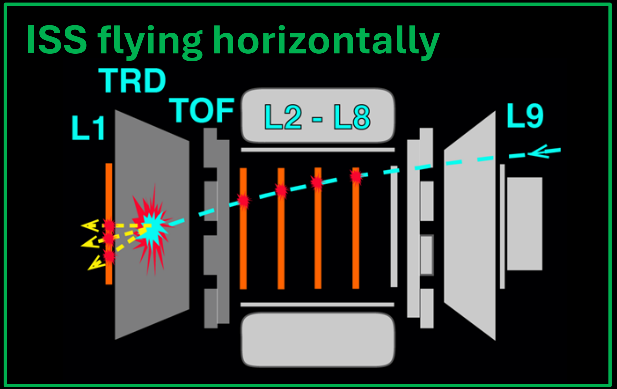
Data collection time
(during the first 13.5 years of operation aboard the International Space Station from May 19, 2011 to November 16, 2024)

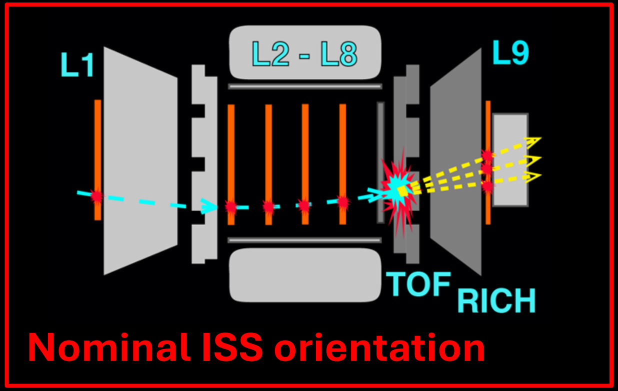
Trigger efficiency

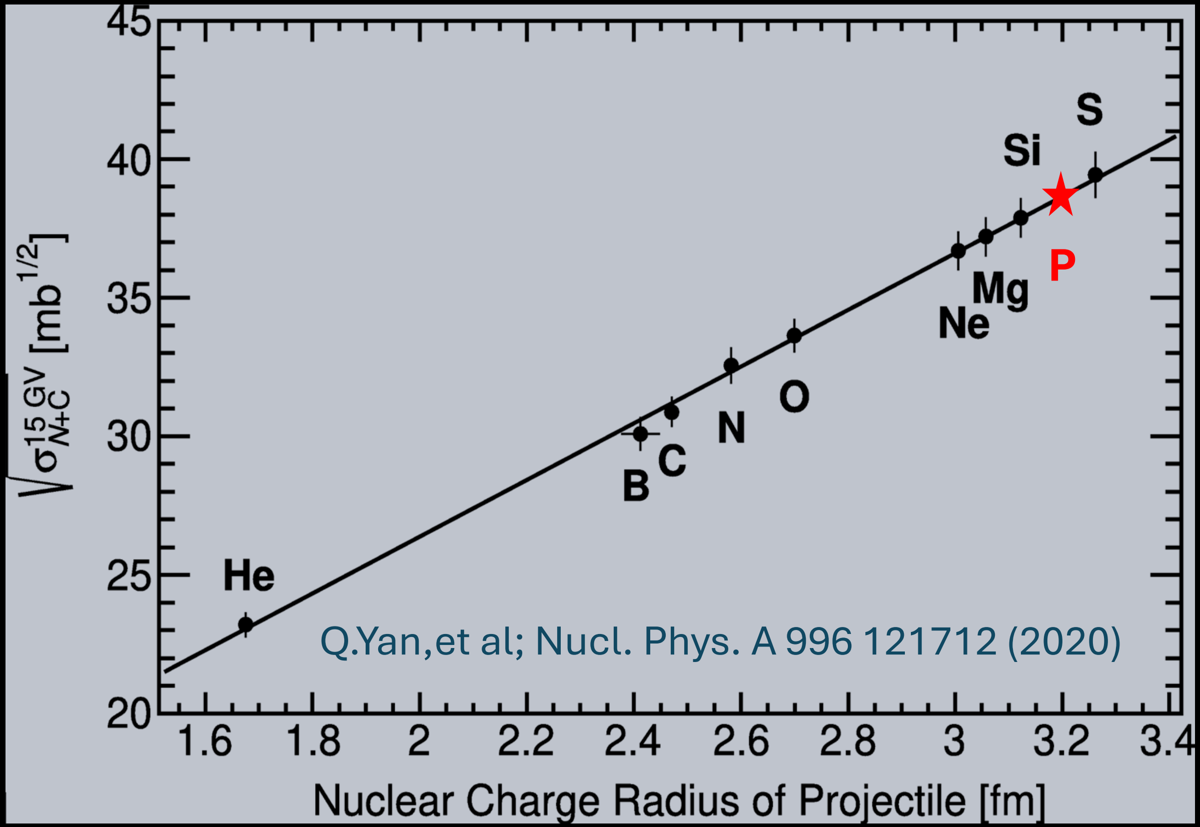
Nuclei inelastic interaction measurement with AMS-02

Accurate cosmic ray flux measurements require precise knowledge of the nuclei survival probability due to inelastic interaction with the AMS material (mainly C, Al).
Previously, inelastic cross sections data available only for few targets and projectiles, no measurement available beyond 10 GV.

AMS measured the Survival Probabilities during “Horizontal "runs in which cosmic rays can enter AMS both **right to the left** and **left to the right**

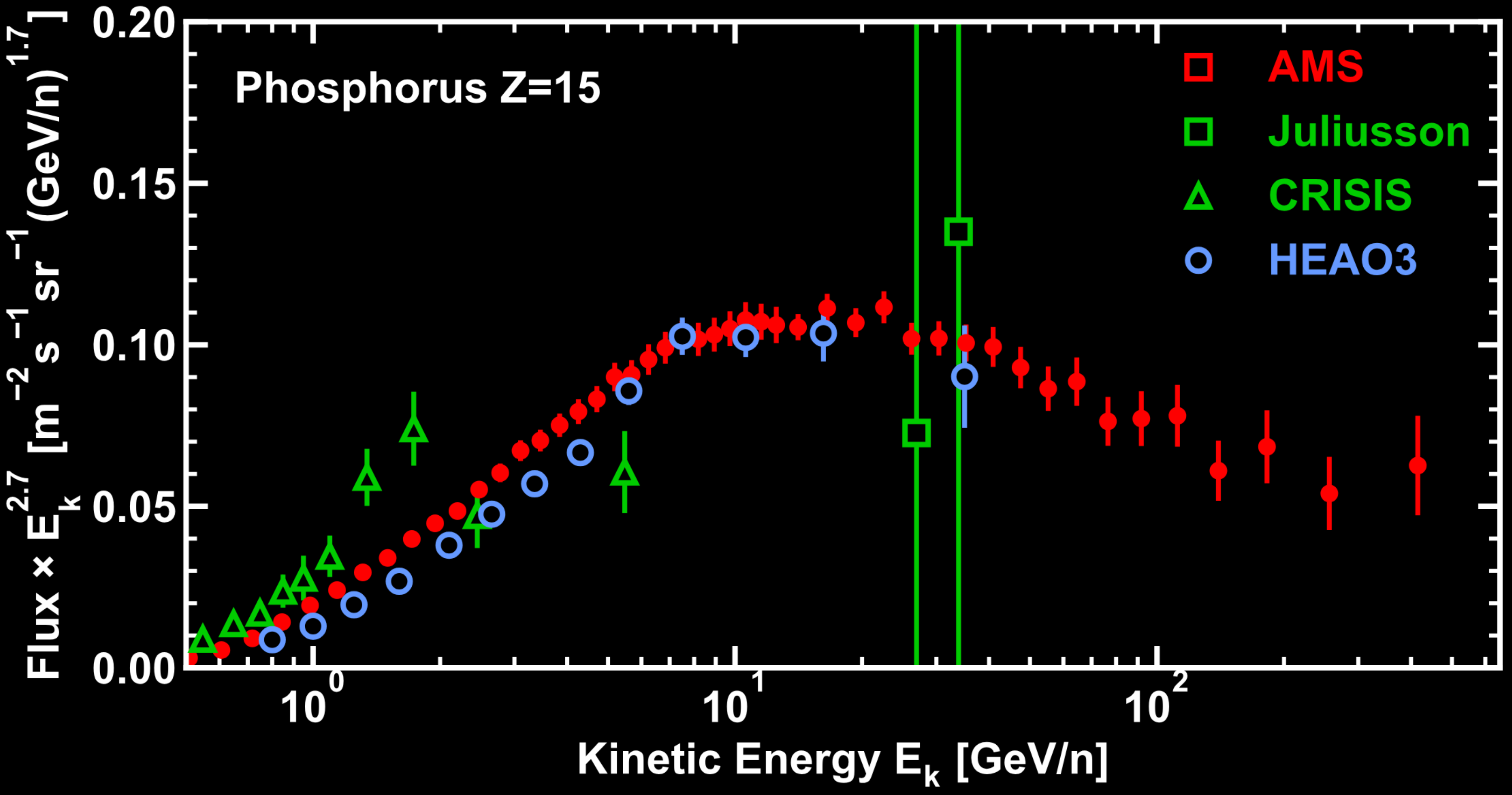

ISS flying horizontally


Nominal ISS orientation



Q.Yan,et al; Nucl. Phys. A 996 121712 (2020)

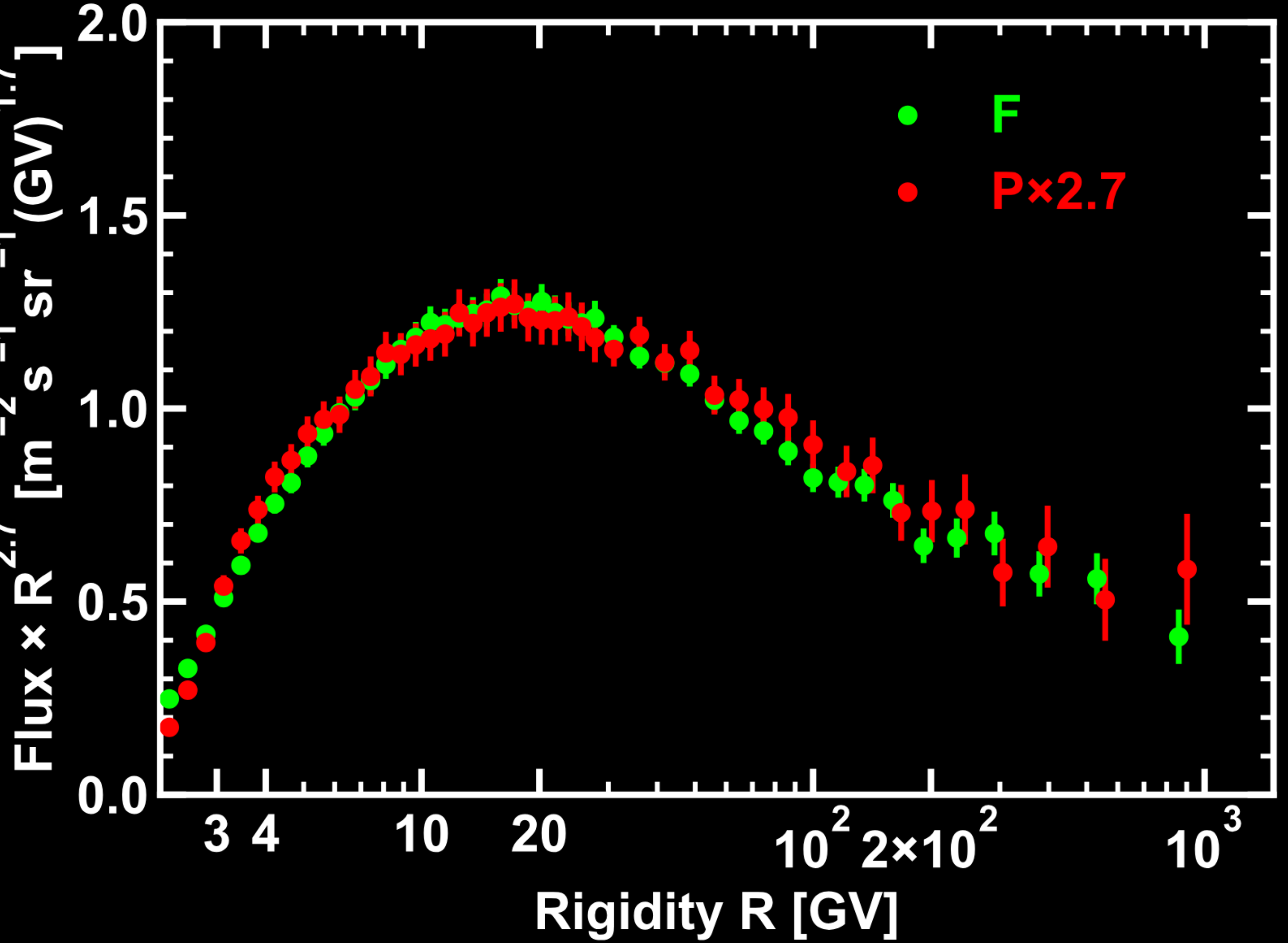
AMS P flux together with previous measurements



Refer to forthcoming publication.

- AMS extends P measurement to few hundred GeV/n;
- The total flux errors at 50GeV are ~5%;
- AMS is the first and only measurement in rigidity.

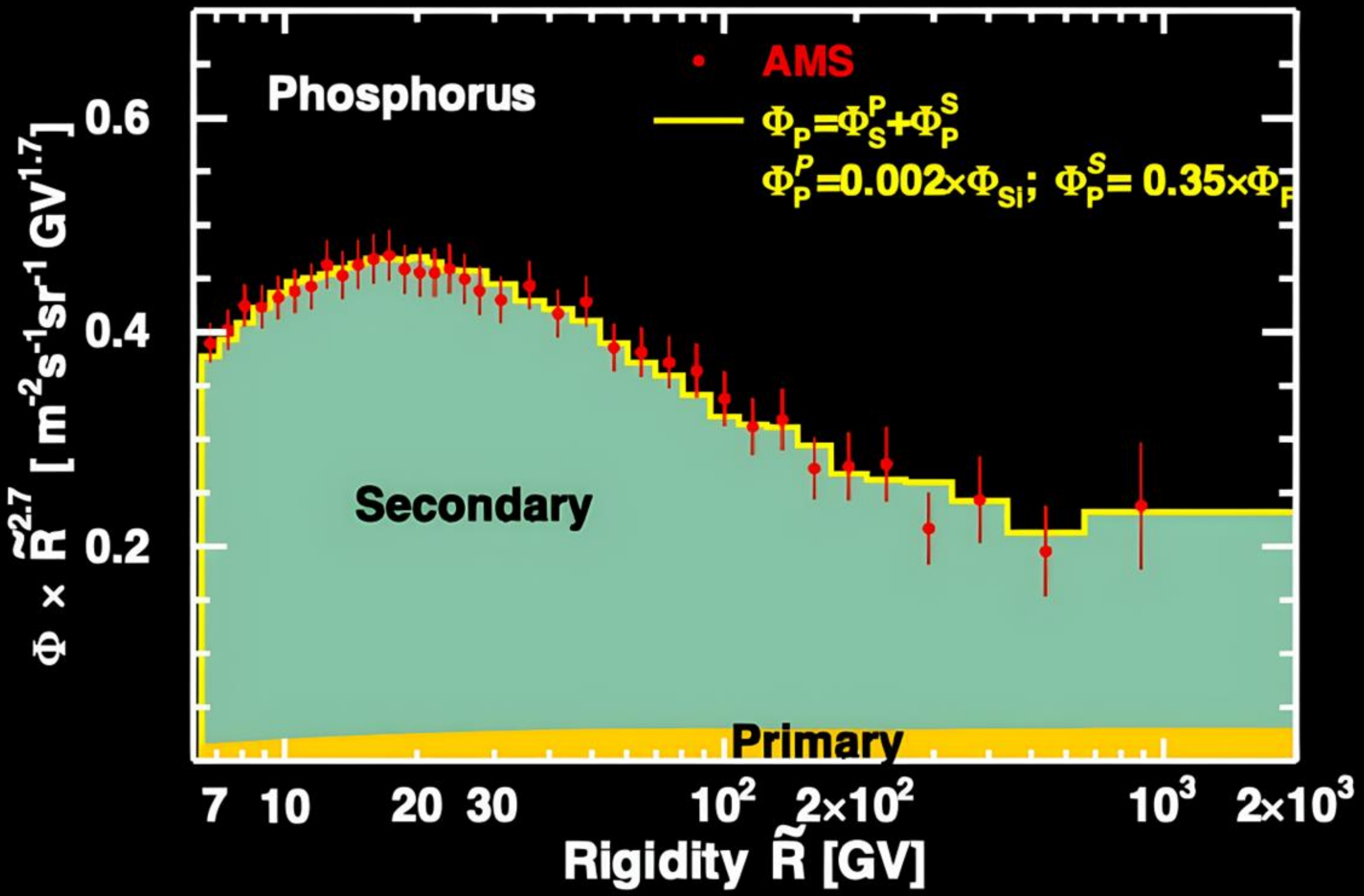
AMS P flux compared to the rigidity dependence of the AMS Fluorine (F) flux



- The rigidity dependences of P and F fluxes are similar;
- But still, a small differences can be observed in the P and F flux rigidity dependence at high rigidities.

Refer to forthcoming publication.

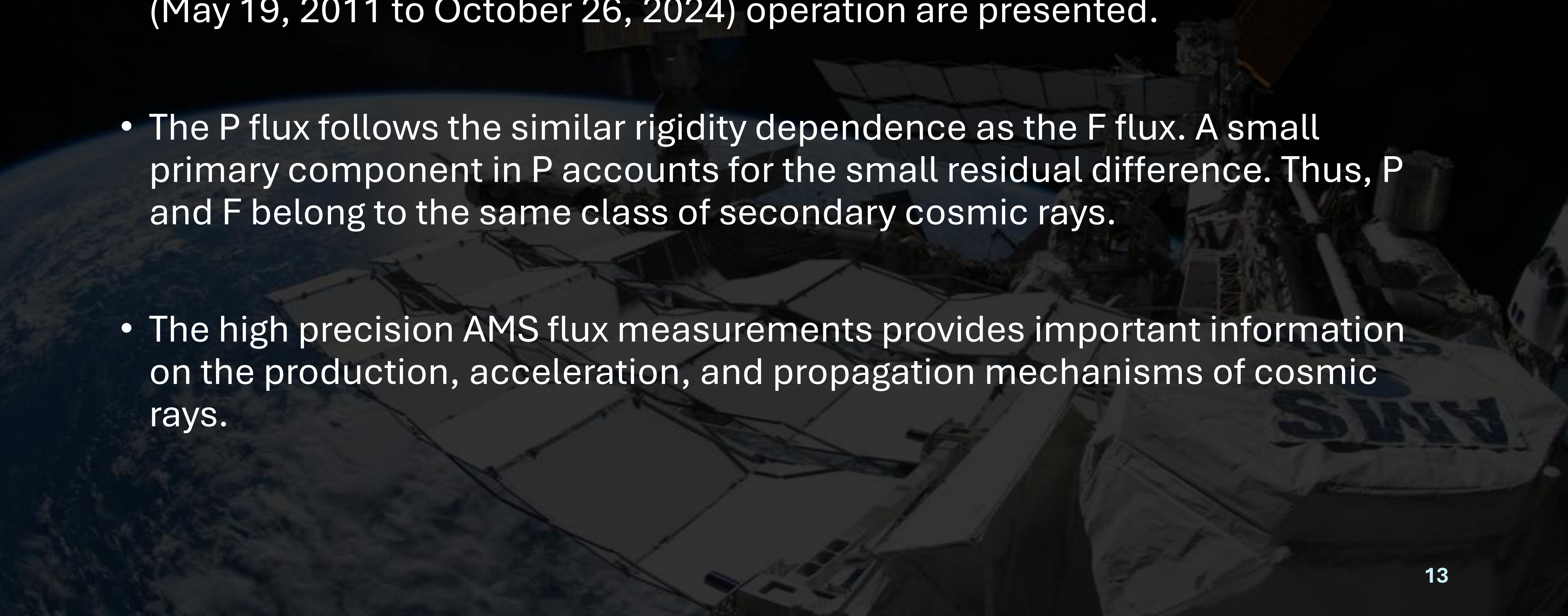
P flux: expressed as the sum of primary (Si) and secondary (F) fluxes



- Presence of the primary component (~0.2% of the Si flux) can explain the small differences in the P and F flux rigidity dependence at high rigidities;
- Consequently, P and F fluxes belong to the same class of secondary cosmic rays.

Refer to forthcoming publication.

Summary



- The precision measurements of Phosphorus (P) flux in the rigidity range from 2.15 GV to 1.2 TV based on data collected by AMS during its first 13.5 years (May 19, 2011 to October 26, 2024) operation are presented.
- The P flux follows the similar rigidity dependence as the F flux. A small primary component in P accounts for the small residual difference. Thus, P and F belong to the same class of secondary cosmic rays.
- The high precision AMS flux measurements provides important information on the production, acceleration, and propagation mechanisms of cosmic rays.