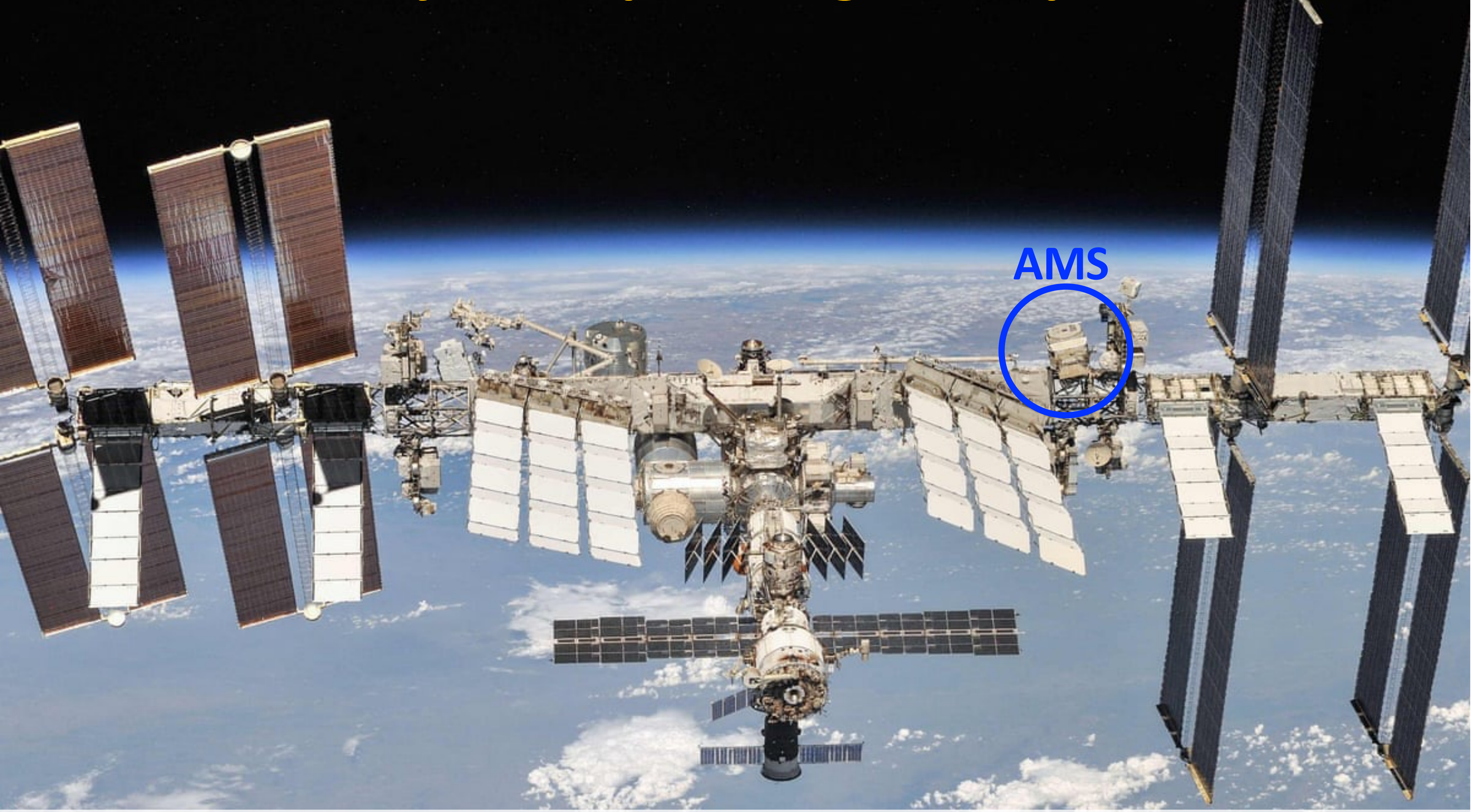
Properties of Cosmic-Ray Phosphorus Nuclei Measured by the Alpha Magnetic Spectrometer



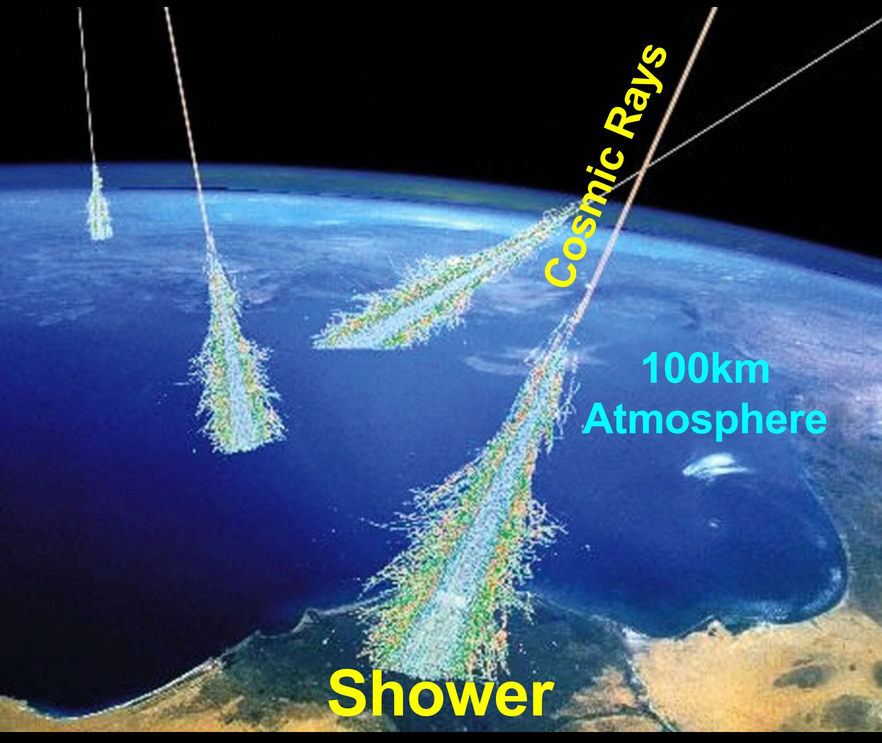
Shoudong Luo

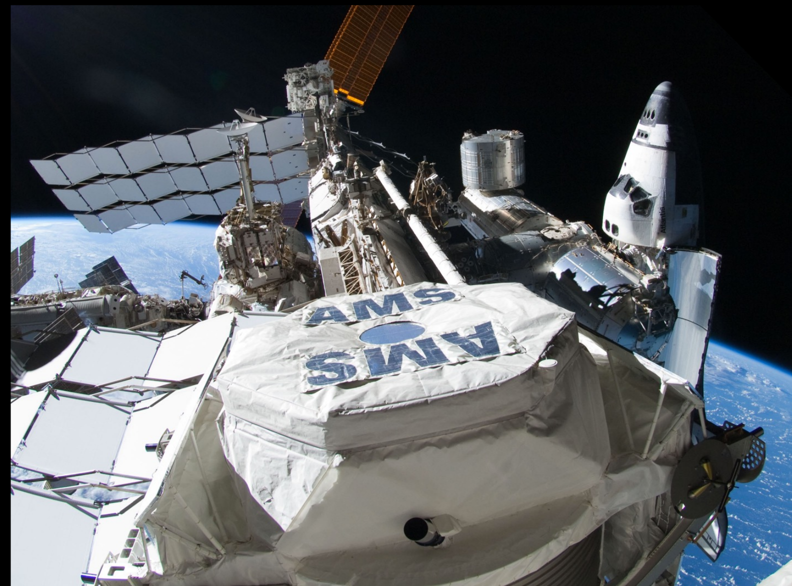
2025/01/10, Annual ZIMP Meeting, ZJU

AMS on the International Space Station

Physics of Dark Matter, Antimatter, the Origin of Cosmic rays, and new phenomena through the precision, long-duration measurement of charged cosmic rays

Charged cosmic rays have mass.
They are absorbed by the
100 km of Earth's atmosphere
(~ 10m of water).





Therefore, properties of cosmic rays cannot be studied on the ground.

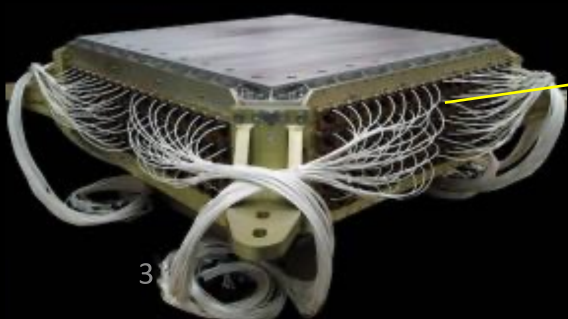
To measure their charge and momentum requires a magnetic spectrometer in space.

AMS: a unique TeV precision spectrometer in space

TRD: Identify e^+, e^-, Z

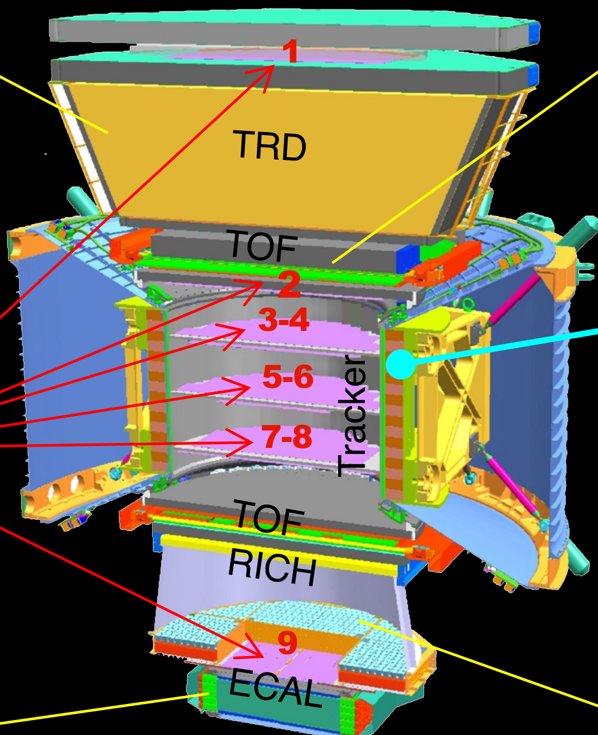
Silicon Tracker: Z, P

ECAL: E of e^+, e^-



AMS Measures:

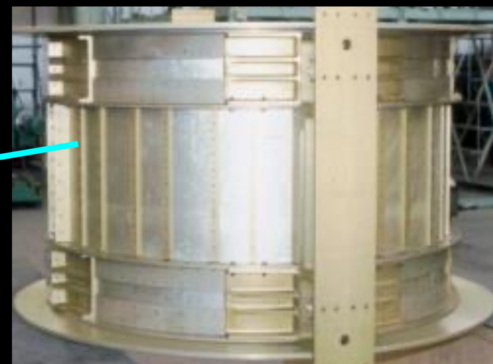
- Charge (Z)
- Energy (E, GeV/A)
- Rigidity R = P/Z (GV)
- Flux (signals/(s sr m^2 GV)



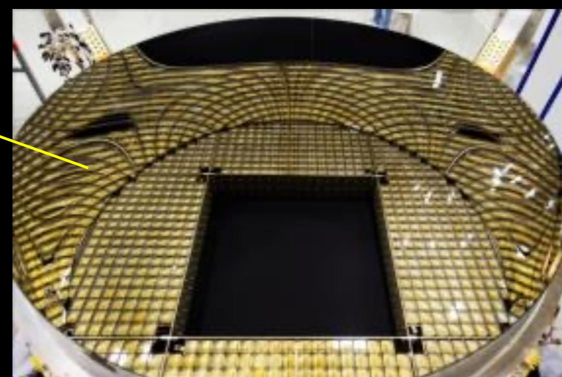
Nuclei are measured independently by Tracker, RICH, TOF, and ECAL

TOF: Z, E

Magnet: ±Z



RICH: Z, E



Phosphorus in Cosmic Rays

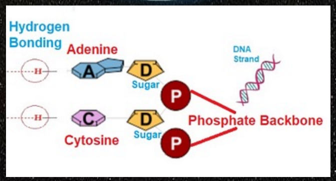
The presence of *Phosphorus* is important in the solar system due to its cosmic abundance, relevance to planetary formation and evolution, necessity for supporting life, and astrobiological significance.

1. Phosphorus can be primarily produced in Stellar Nucleosynthesis and accelerated in supernovae shocks.

Interstellar Medium

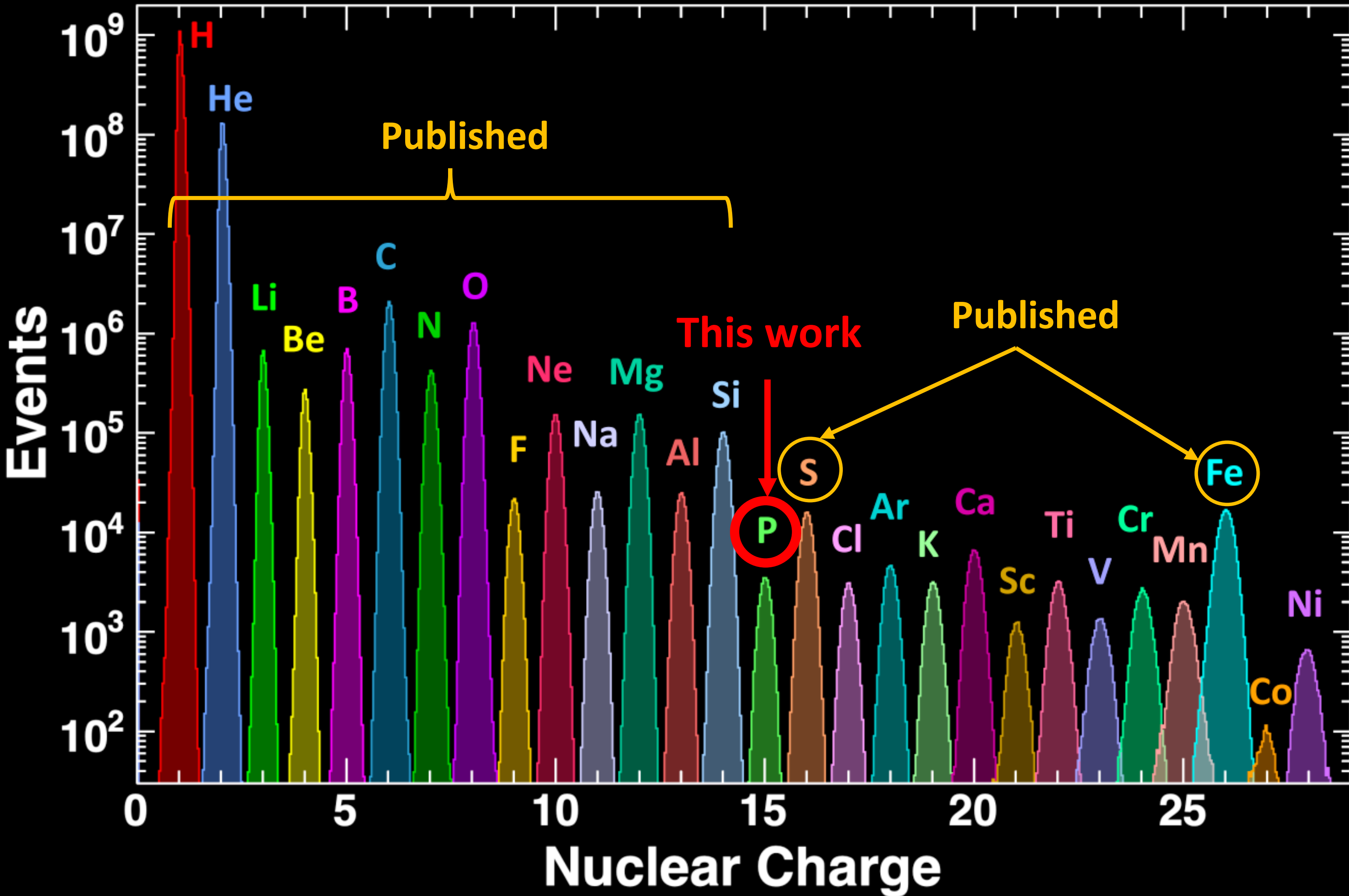
2. The enhancement of phosphorus abundance in cosmic rays is through spallation of the heavy cosmic rays with the interstellar medium.

Precise measurements of cosmic phosphorus contribute to our understanding of cosmic rays sources, acceleration, and propagation in the heavy side of the periodic table, and of our solar system and life on earth.

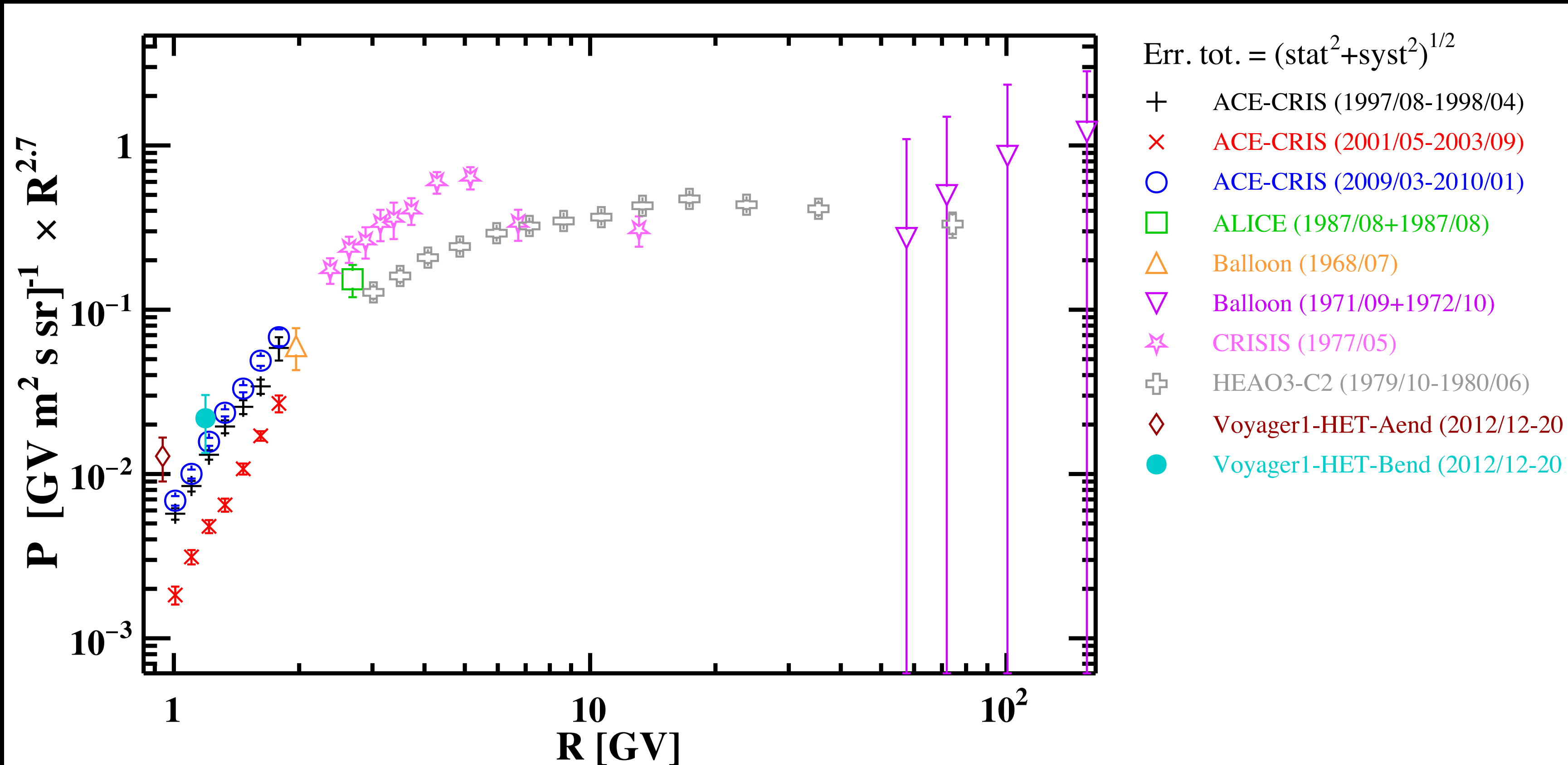


Phosphorus in Cosmic Rays

- Precise Measurement of phosphorus flux is very challenging due to its low abundance relative to nearby nuclei, such as silicon(Z=14) and sulfur(Z=16);
- The fragmentation contamination from iron(Z=26) is also non-negligible;
- The excellent charge resolution of AMS Tracker make this measurement possible.



Previous Measurements on Phosphorus



Several previous CR experiments have published phosphorus fluxes, but limited to:

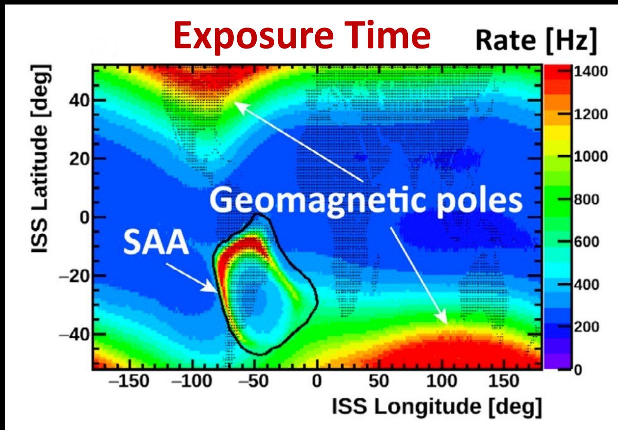
- Rigidity up to about 100GV;
- Large systematic errors.

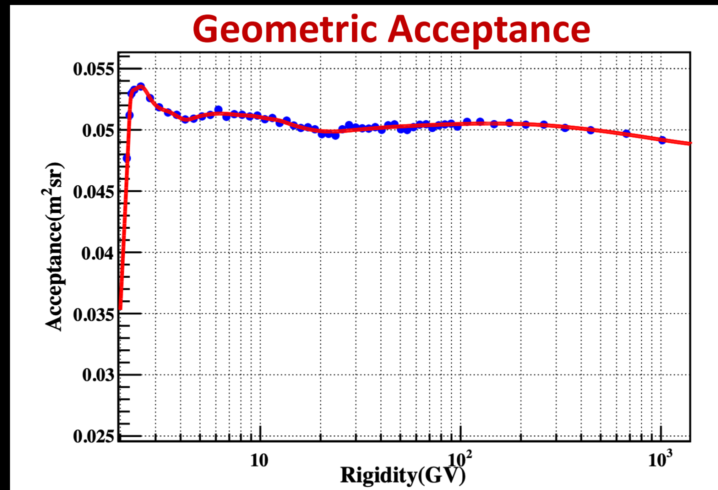
Extension of energy range and improvement on precision is the major goal in this work.

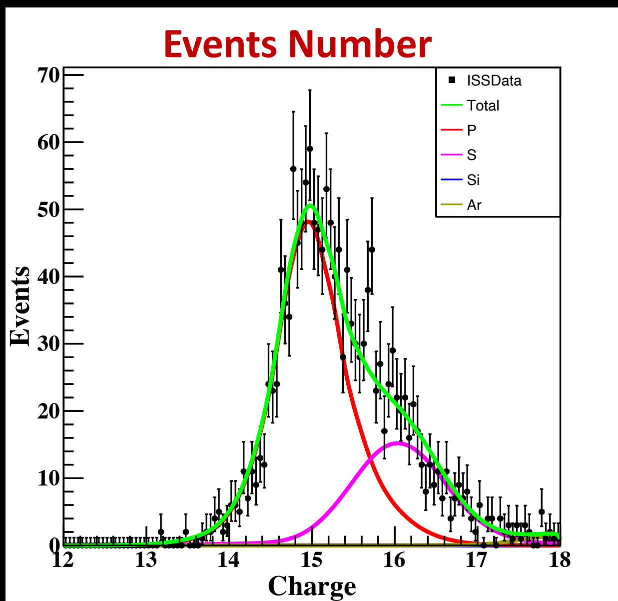
Flux Measurements of Phosphorus

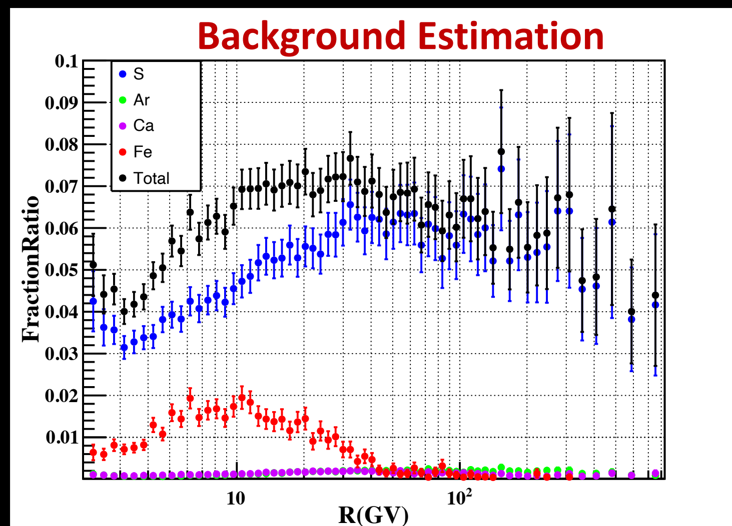
Flux Definition: $$\phi_i = \frac{N_i}{A_i T_i \epsilon_i \Delta R_i}$$

AMS collected about 0.14 million events from rigidity range 2.15 GV-3000 GV.



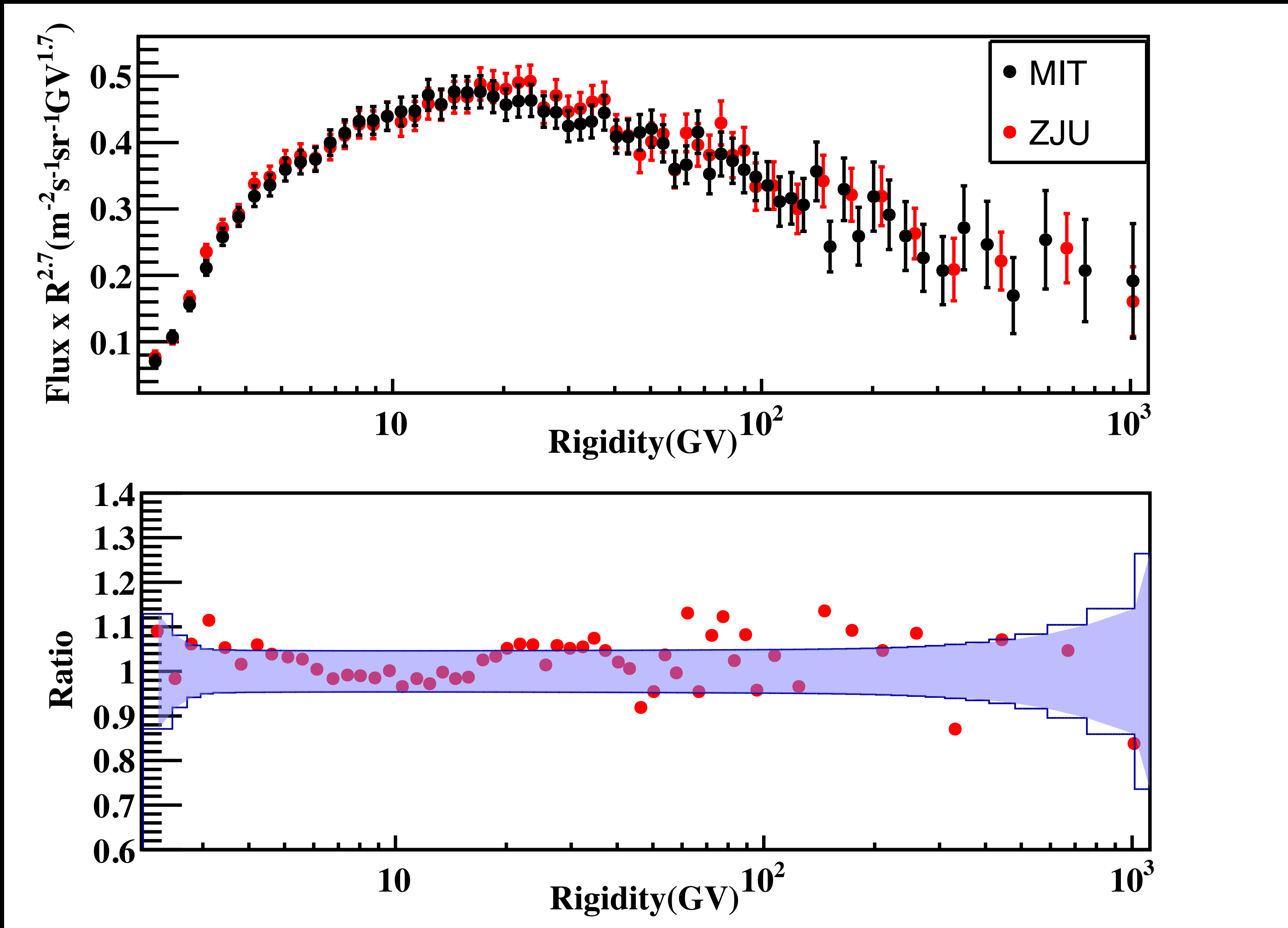






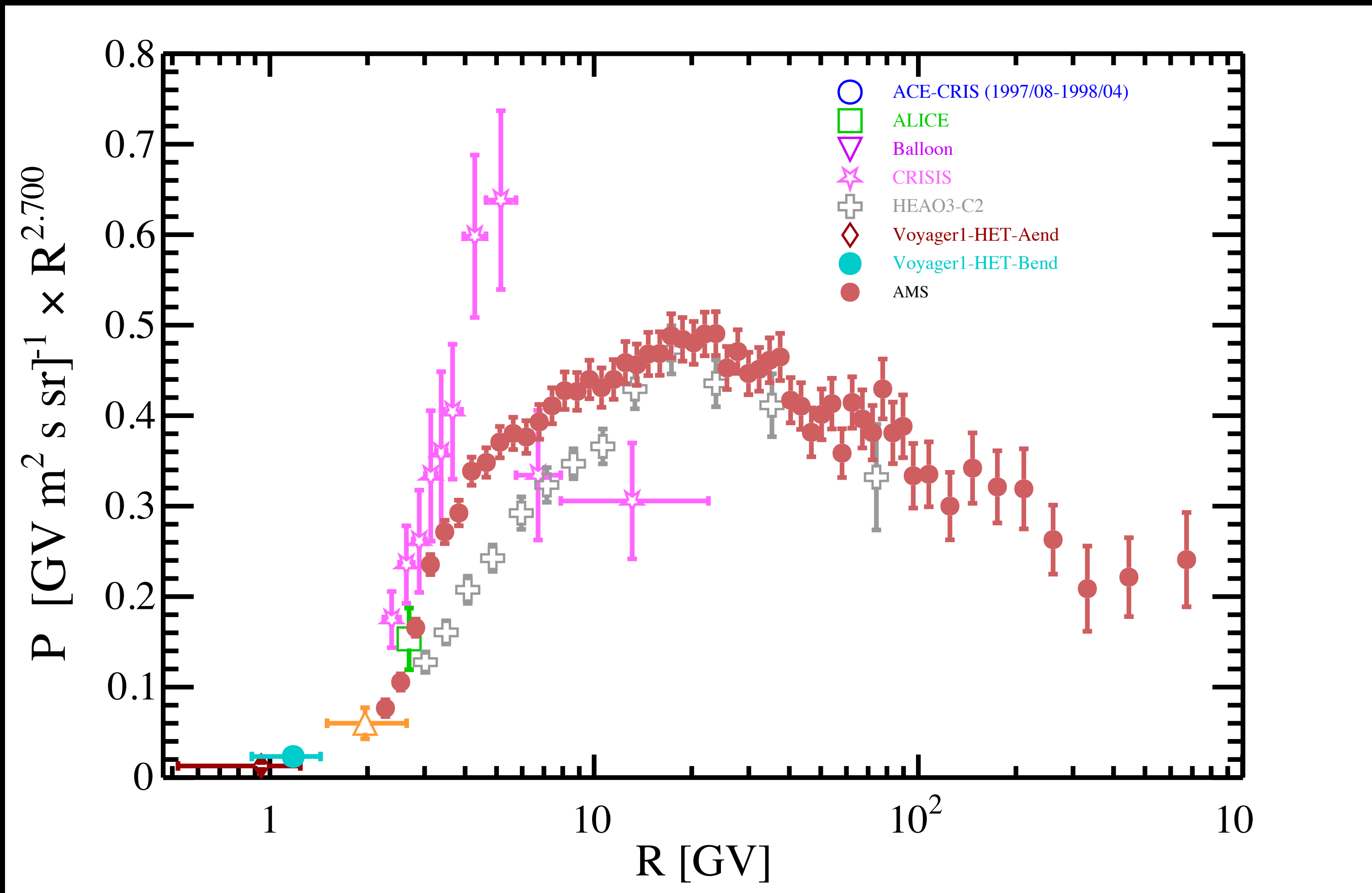
Phosphorus Flux by AMS

- We have obtained the phosphorus flux by four independent analysis groups.
- Our result is consistent with other groups, in almost all the rigidity range.



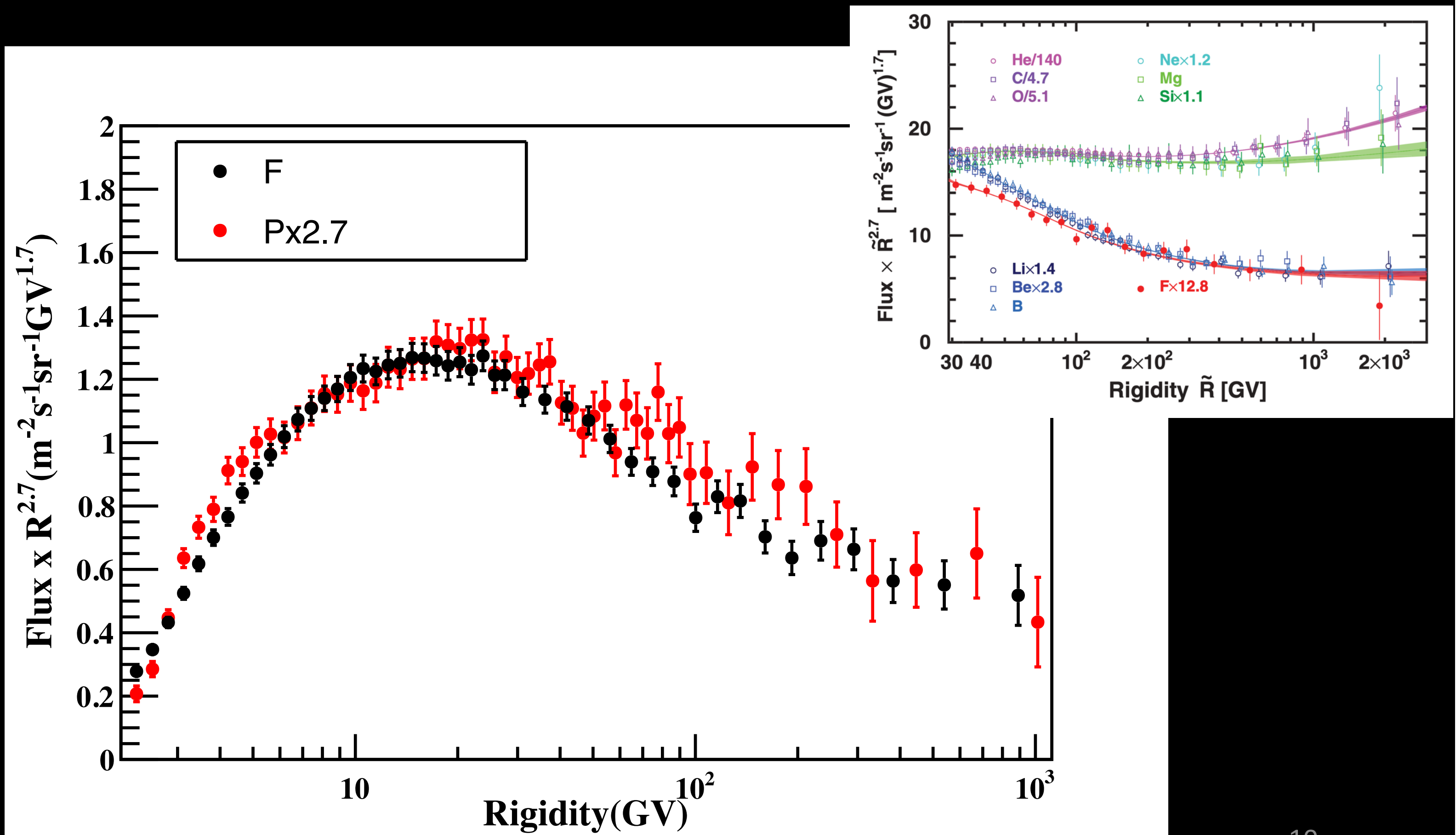
Phosphorus Flux Comparesion

- **Our result extend energy to 1TV and have much more precision on flux .**



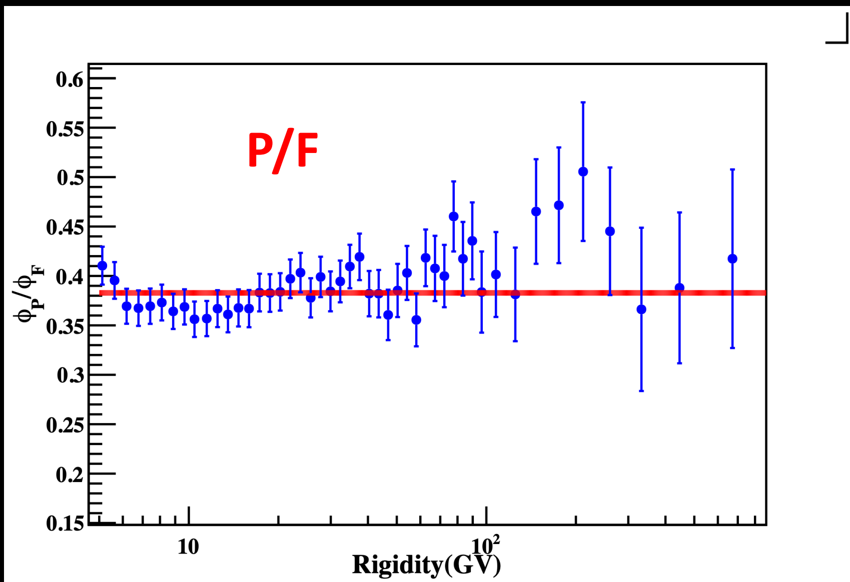
Phosphorus vs Fluorine

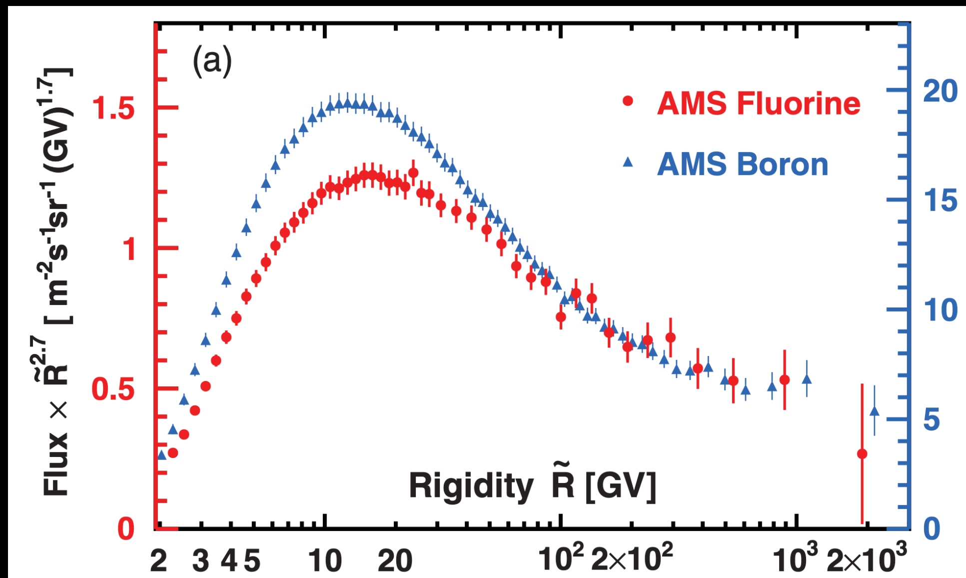
- Phosphorus is expected to be nearly pure secondary cosmic rays.
- With comparison to the latest secondary fluorine flux , the rigidity dependence of phosphorus ϕ_P and fluorine ϕ_F is very similar.



Phosphorus vs Fluorine

- A fit of the ϕ_P/ϕ_F with a power law CR^{δ} was performed above 3 GV. The fit yields $\delta = 0.002 \pm 0.009$ with χ^2/d.o.f. = 26/29, confirming that P and F rigidity dependence is similar.
- As shown in the Fluorine analysis, fluorine is different secondary species from Li/Be/B. **Phosphorus belongs to the fluorine family.**





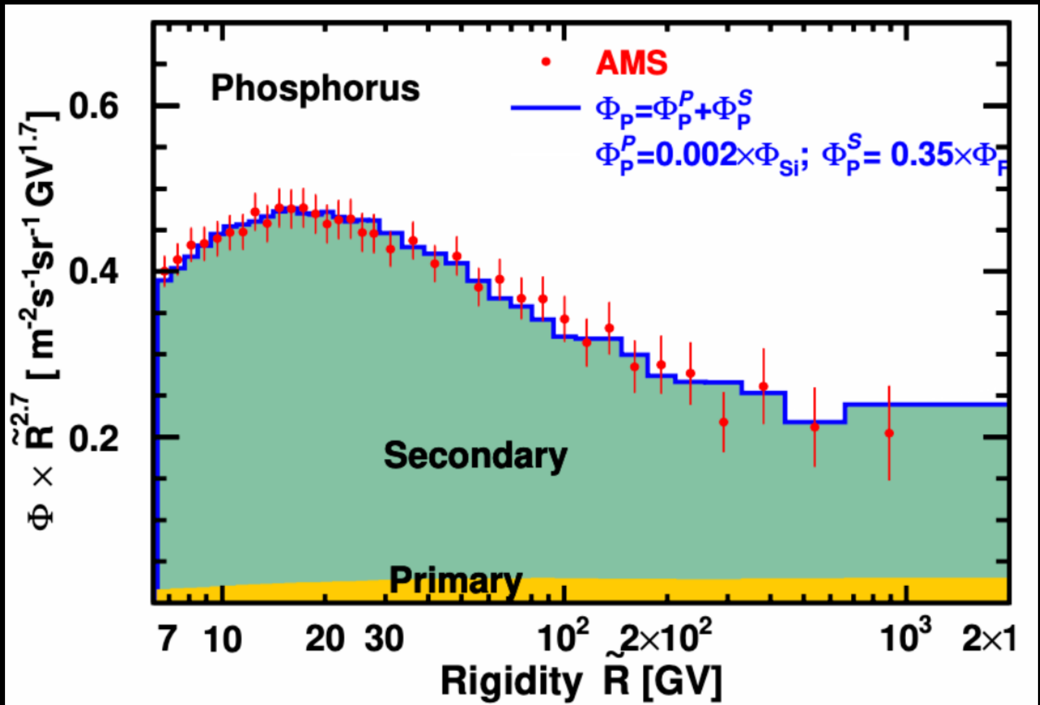
Primary and Secondary Phosphorus

To describe the primary and secondary components, we use model independent:

- Silicon flux ϕ_{Si} as the primary flux template
- Fluorine flux ϕ_F as the secondary flux template

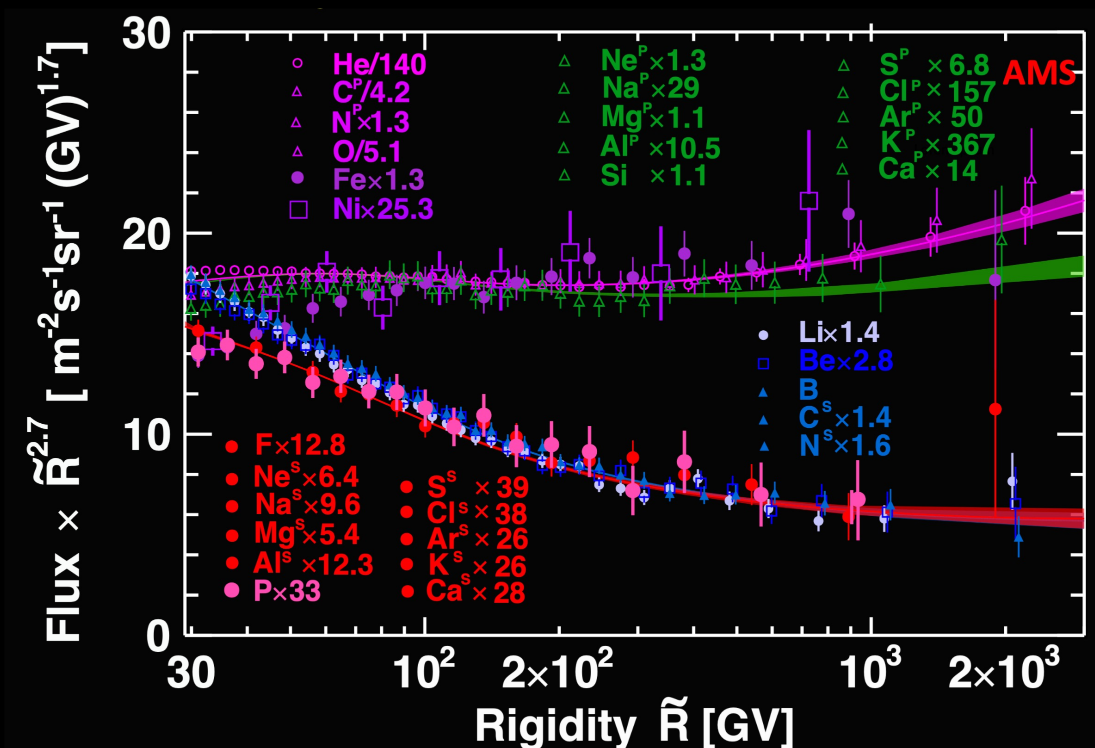
to linearly fit the phosphorus flux. Above 10 GV the fit yields:

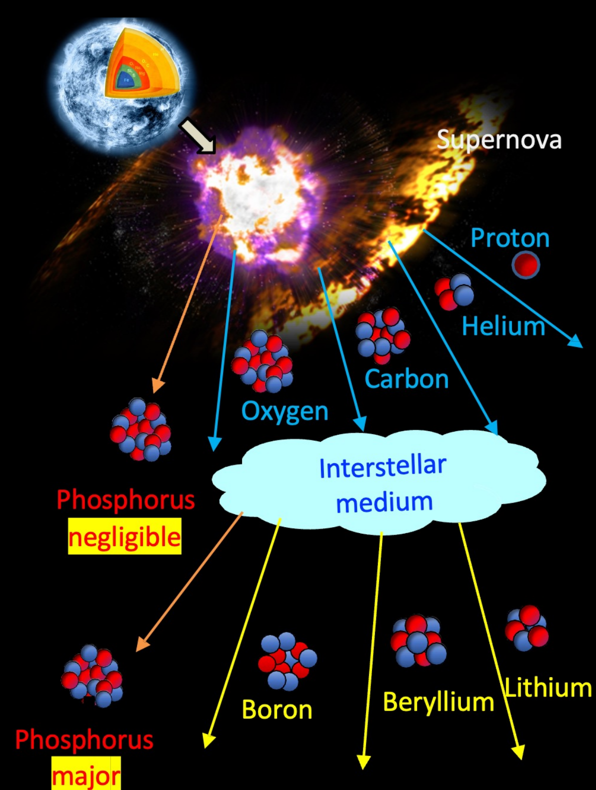
- ϕ_P^P = 0.0024+0.012 × ϕ_{Si}
- ϕ_P^S = (0.35 ± 0.02) × ϕ_F



Phosphorus in the Cosmic Table

- With a similar procedure using Silicon flux ϕ_{Si} and Fluorine flux ϕ_F, all the mixed heavy nuclei in the periodic table can be categorized as combination of primary and secondary components.
- We can conclude that there are three classes of cosmic rays: primary cosmic rays(He/O/Si…), secondary cosmic ray(Li/F/P…) and third mixed group(Na/Mg/Al….).





Summary and Prospect

To summarize, we have measured the phosphorus flux(Z=15) from 2 GV to 3 TV with unprecedented precision, revealing new and unexpected properties:

- Phosphorus flux has the same rigidity dependance with fluorine flux , which is different from Li-Be-B group.
- Phosphorus flux is nearly pure secondary cosmic rays, but still have small primary components.
- Most of the intermediate heavy nuclei are mixed group of primary and secondary cosmic rays.

Up to now, we have measured nuclei flux up to sulfur, next we will proceed to the flux of argon(Z=18) and calcium(Z=20) to complete the cosmic periodic table.