Cosmic Ray Nuclei: Results from AMS-02

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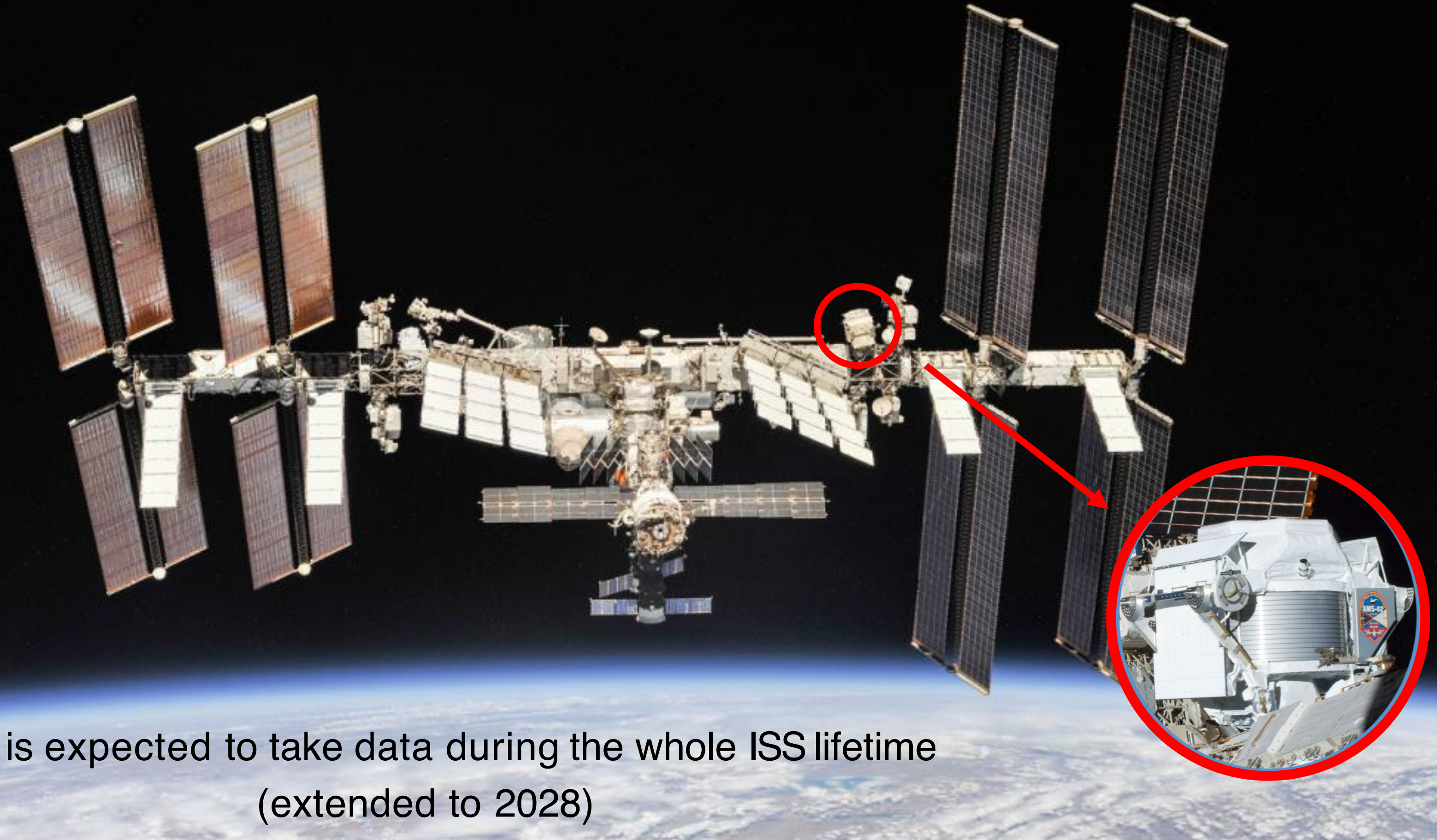
on behalf of the AMS Collaboration

ISCRA-2021, 8–10 June 2021

AMS-02 is operating onboard the International Space Station (ISS) since 2011 May 19th and recorded more than 170 billion CR triggers in 10 years of operation

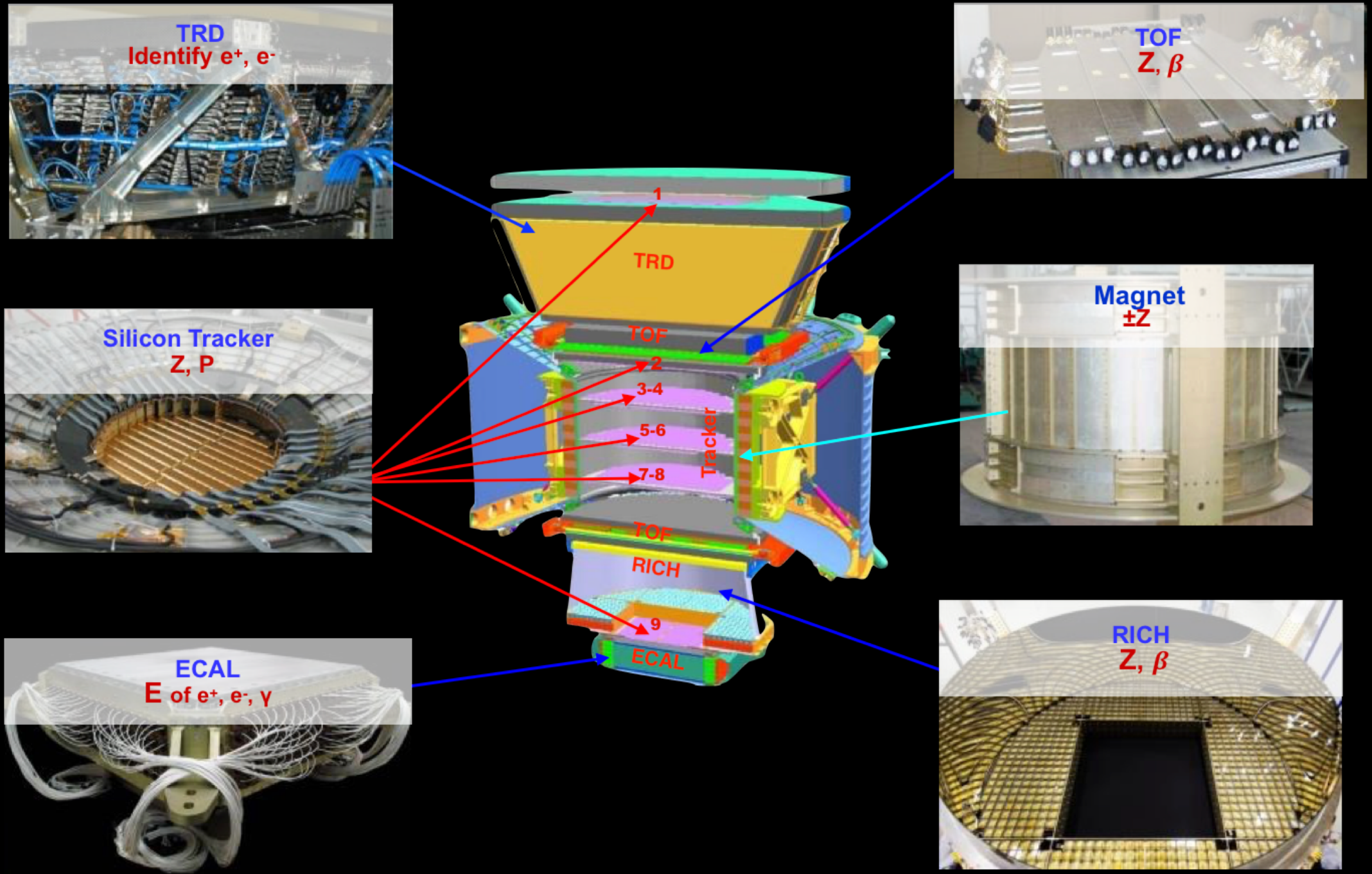


AMS is expected to take data during the whole ISS lifetime (extended to 2028)

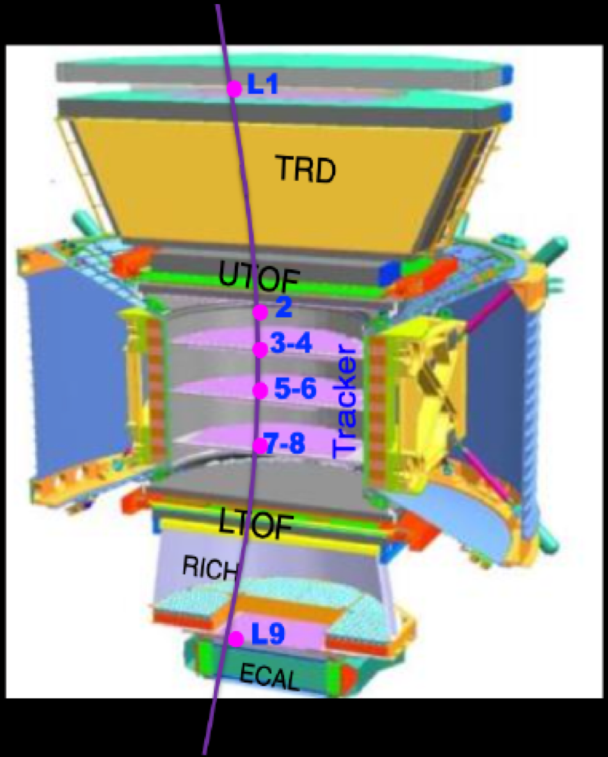
AMS-02 detector

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

Both quantities are measured redundantly and independently by the *Tracker, TOF, RICH* and/or *ECAL*



AMS Nuclei Flux Measurement



- L1, UTOF, Inner Tracker (L2-L8), LTOF* and L9*
  Consistent Charge along Particle Trajector

	Charge Resolution (c.u)
$1 \leqq Z \leqq 8$	$\Delta Z/Z \sim 0.05 - 0.12$
$9 \leqq Z \leqq 16$	$\Delta Z/Z \sim 0.13 - 0.19$
$Z = 26$	$\Delta Z/Z \sim 0.33$

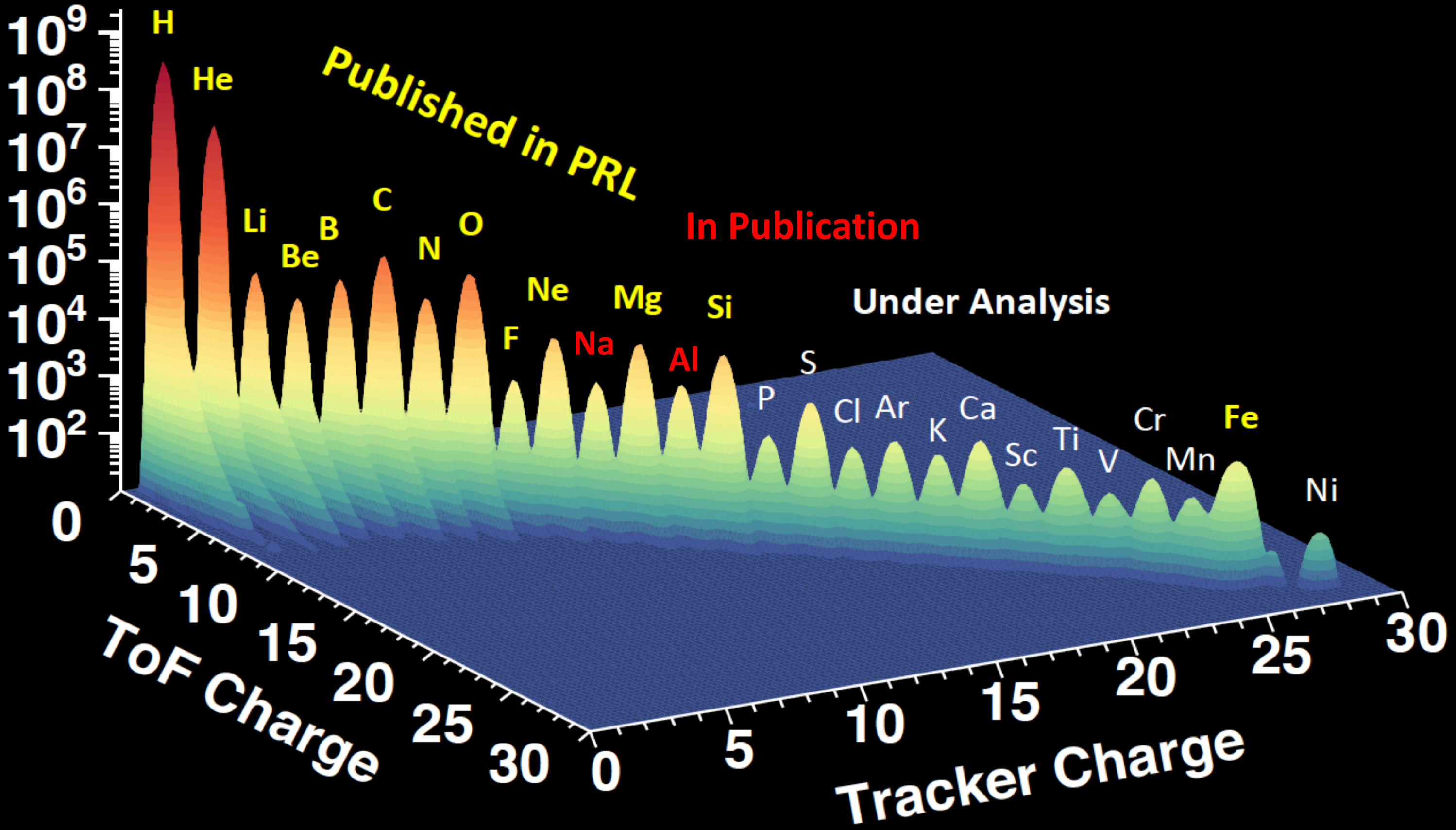
- TOF (4 Layers): Velocity and Direction

$Z = 1$	$\Delta\beta/\beta^2 \sim 4\%$
$Z \geqq 2$	$\Delta\beta/\beta^2 \sim 1 - 2\%$

- Tracker (9 layers) + Magnet: Rigidity (Momentum/Charge)

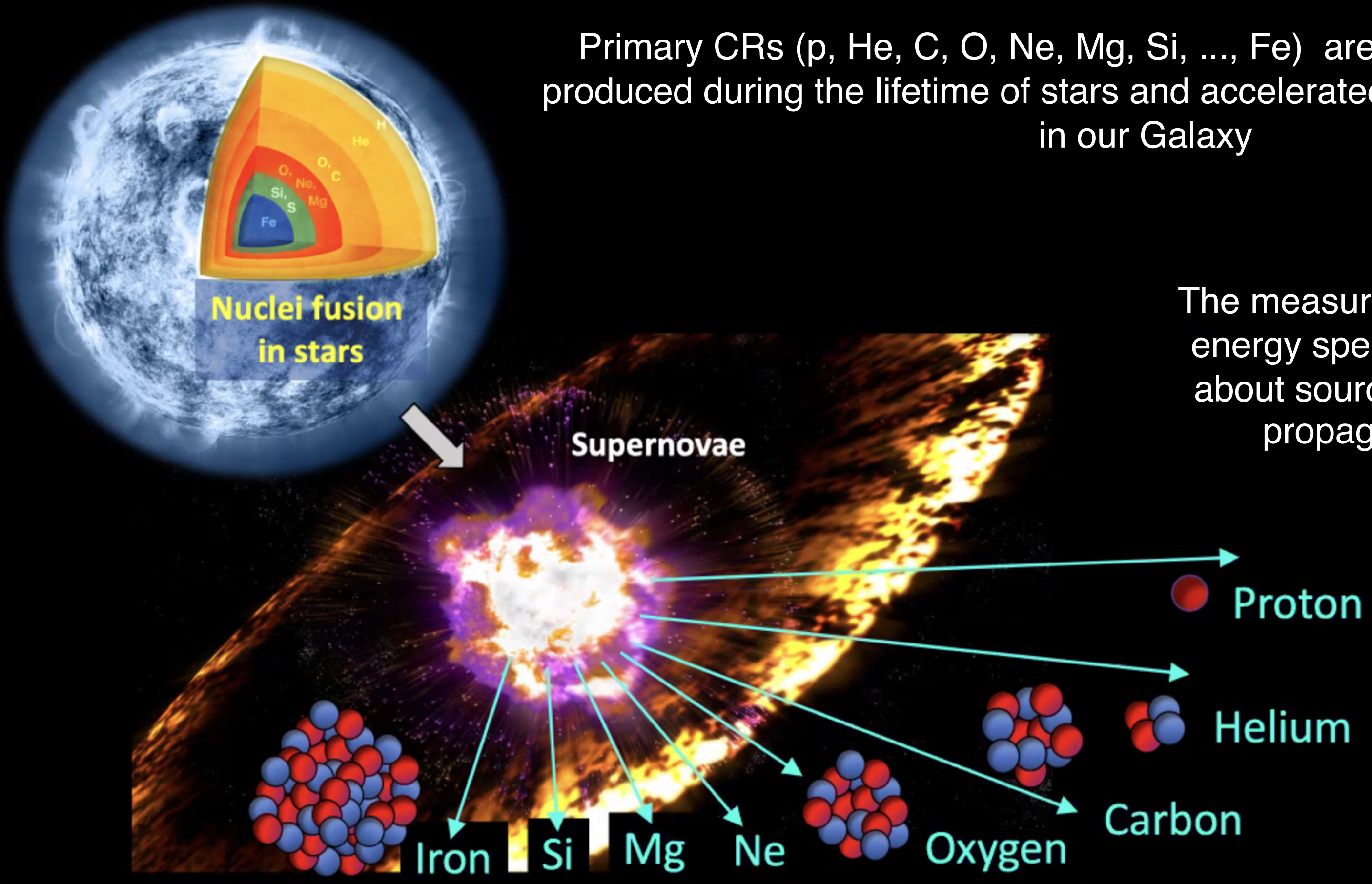
	Coordinates Resolution	MDR
$Z = 1$	10 μm	2 TV
$2 \leqq Z \leqq 8$	5 - 7 μm	3.2 - 3.7 TV
$9 \leqq Z \leqq 16$	6 - 8 μm	3.0 - 3.5 TV
$Z = 26$	5.8 μm	3.5 TV

AMS-02 Periodic Table



Primary Cosmic Rays

Primary CRs (p, He, C, O, Ne, Mg, Si, ..., Fe) are thought to be mostly produced during the lifetime of stars and accelerated in supernovae shocks in our Galaxy

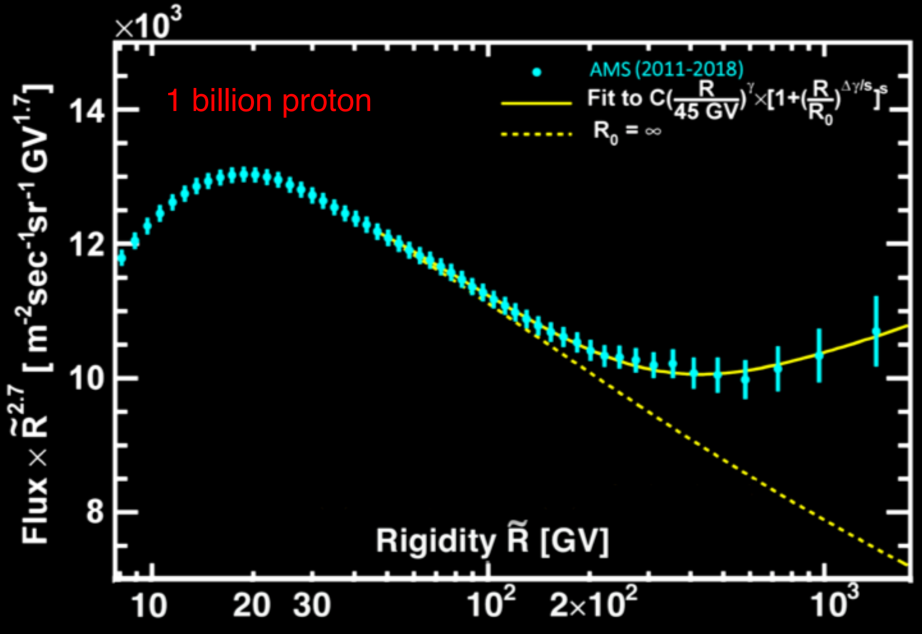


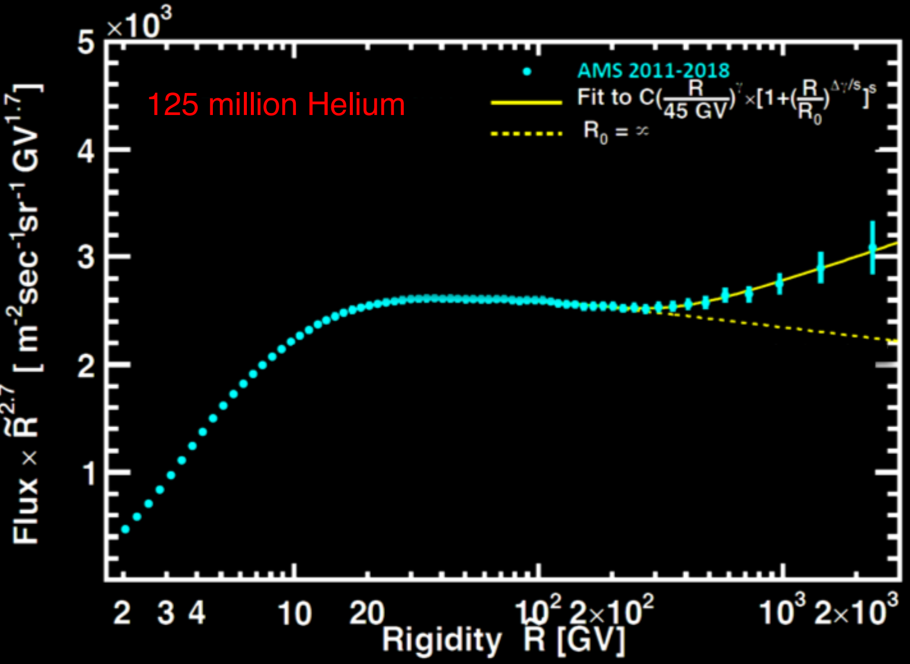
The measurement of CRs primary energy spectra carry information about sources, acceleration and propagation processes.

Primary CR: protons and Helium

AMS-02 Proton and Helium spectra – first 7 years (2011-2018) [Phys. Rep. 894, 1 (2021)]

➢ They deviate from a single power law at about 200 GV

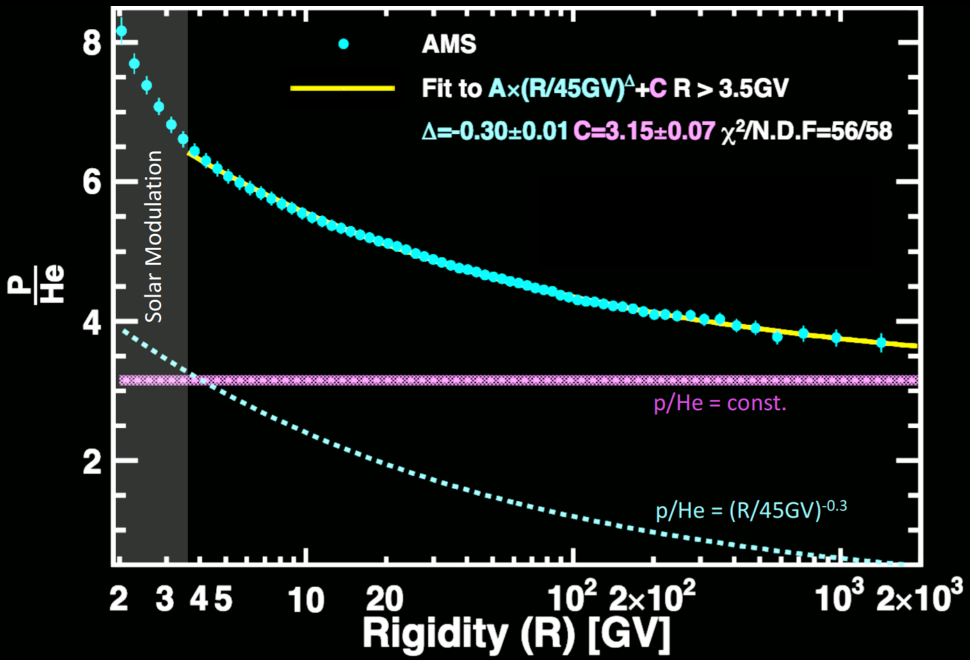


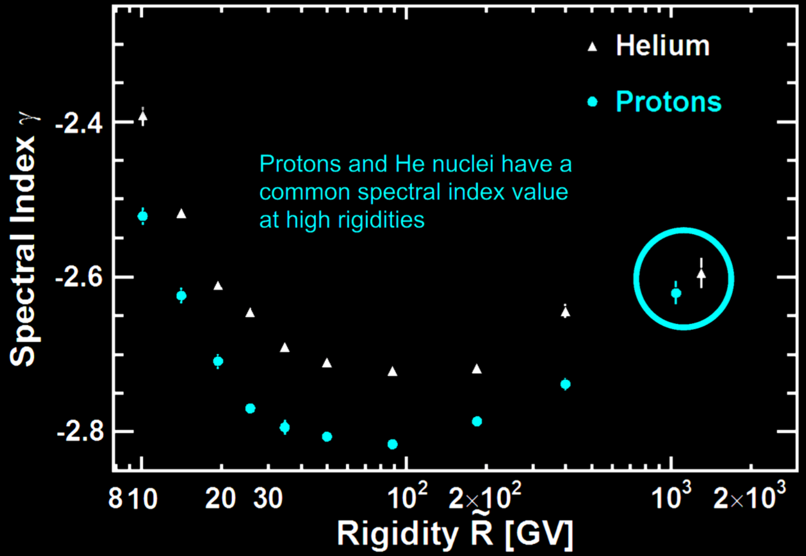


Primary CR: protons and Helium

AMS-02 Proton and Helium spectra – first 7 years (2011-2018) [Phys. Rep. 894, 1 (2021)]

➢ The ratio is not constant, it decreases in the rigidity range from 1.9 GV up to 1.8 TV, but the rate of decrease vanishes at high rigidities.

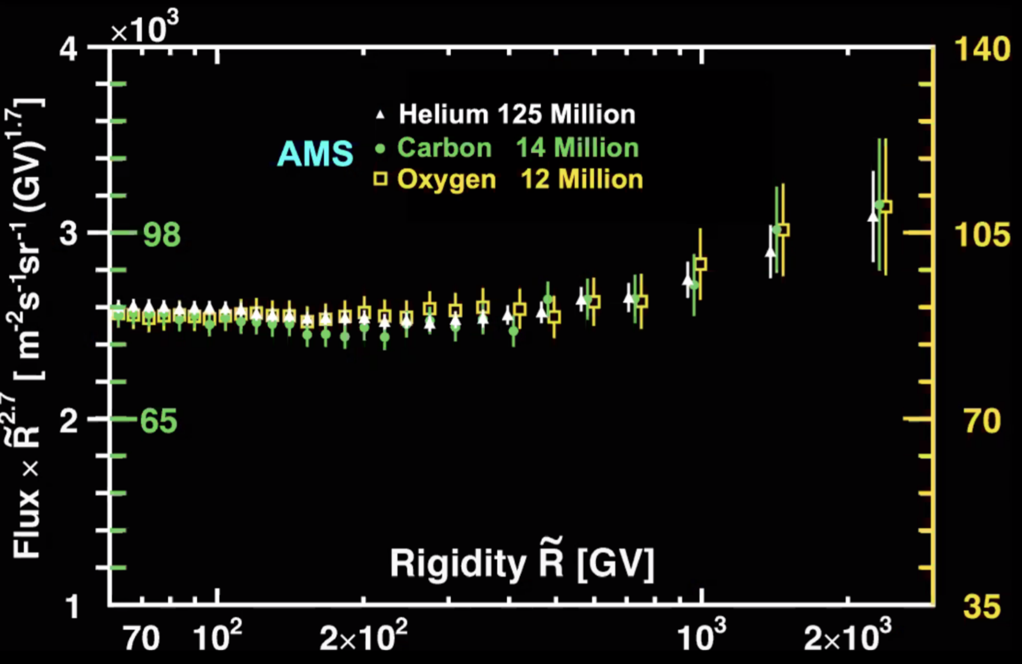


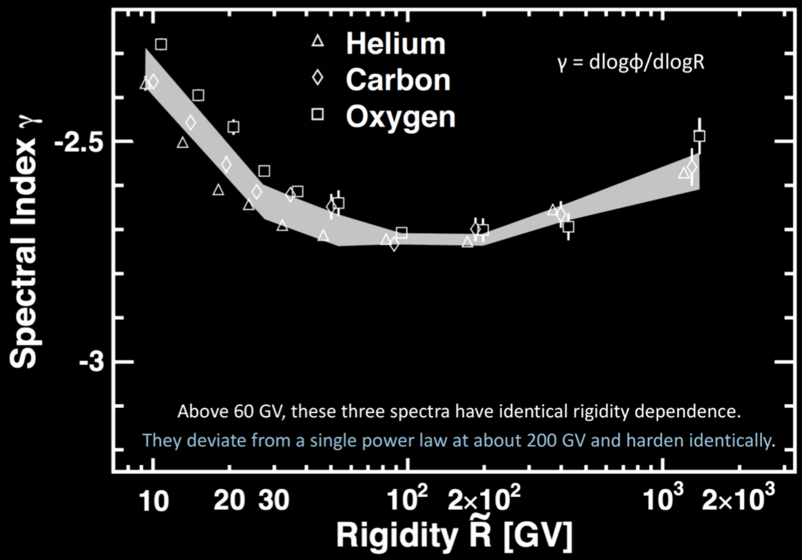


Primary CR: Helium Carbon and Oxygen

AMS-02 Helium, Carbon, and Oxygen spectra – first 7 years [Phys. Rep. 894, 1 (2021)]

- Above 60 GV, the primary cosmic rays Helium, Carbon and Oxygen have Identical rigidity dependence.
- They deviate from a single power law at about 200 GV and harden identically

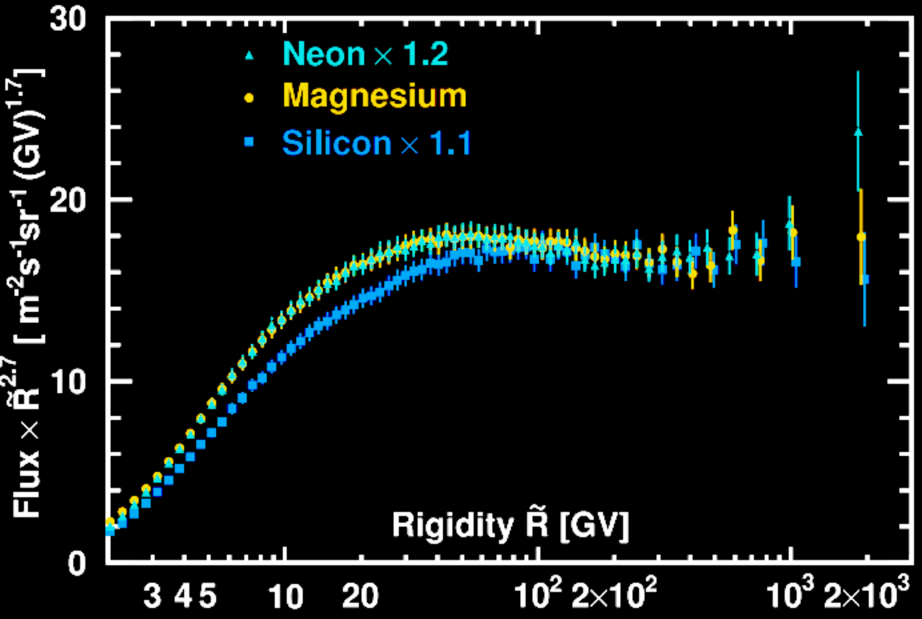


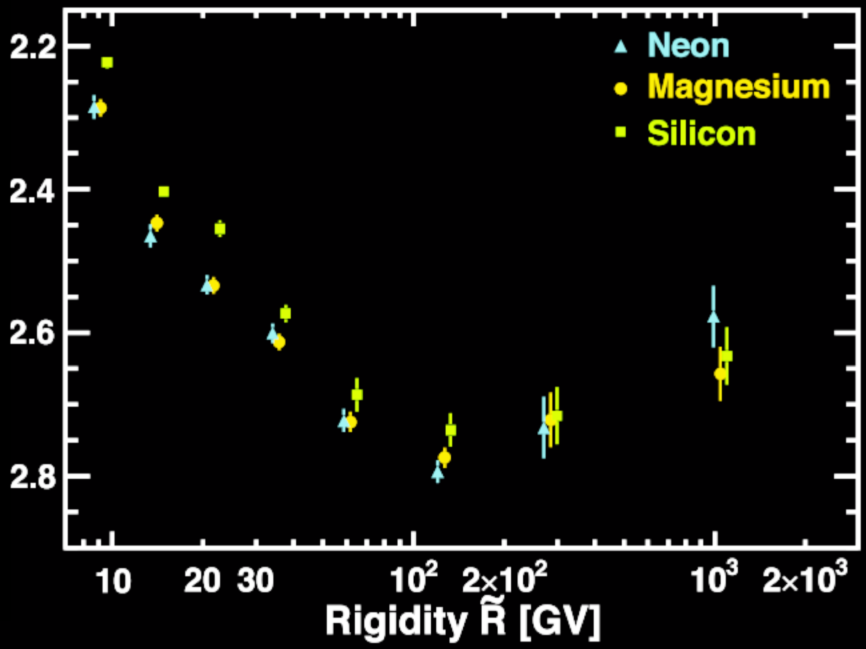


Primary CR: Neon, Magnesium and Silicon

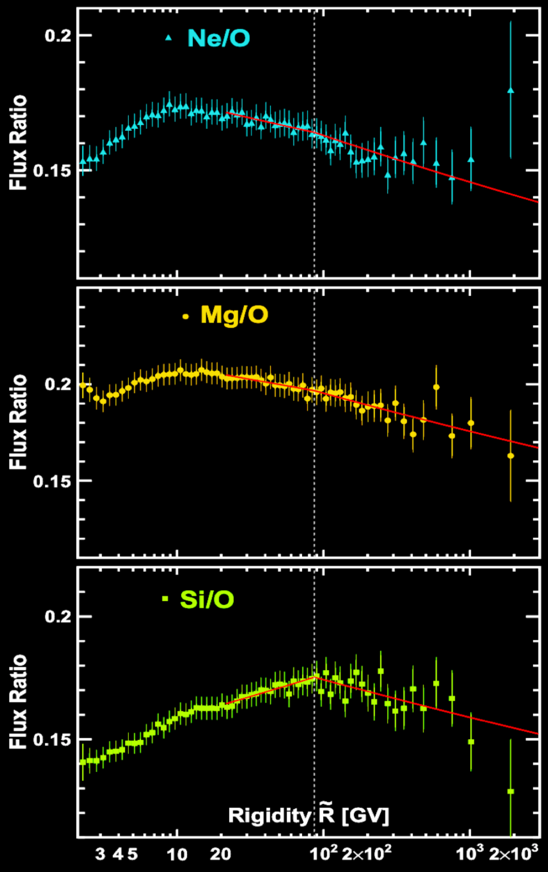
AMS-02 Neon, Magnesium and Silicon spectra – first 7 years Phys. Rev. Lett. 124 (2020) 211102

- Neon, Magnesium fluxes have an identical rigidity dependence above 4 GV.
- All three fluxes have an identical rigidity dependence above 86.5 GV.

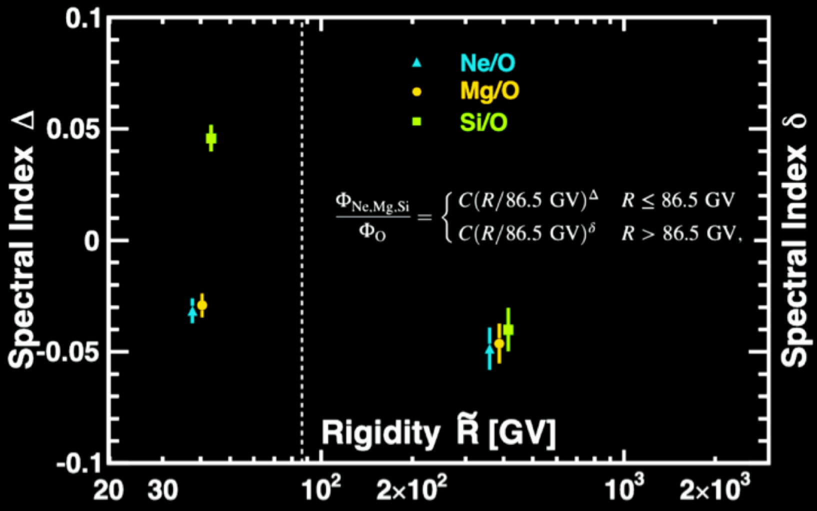




Primary CR: Neon, Magnesium and Silicon



The AMS-02 Ne/O, Mg/O, and Si/O indices obtained with fits of broken power law as a function of rigidity. Above 86.5 GV all spectral indeces are identical with average value <δ = -0.045 ± 0.008>.



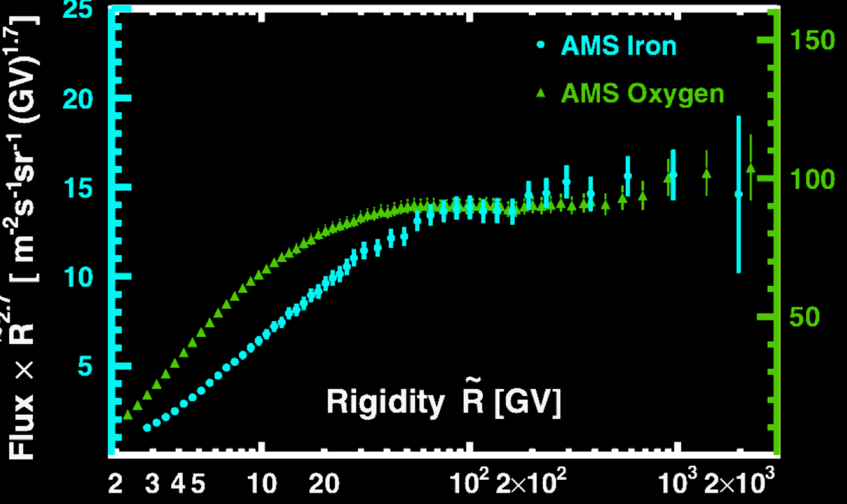
- Neon, Magnesium and Silicon belong to different Helium, Carbon and Oxygen class of primary cosmic rays

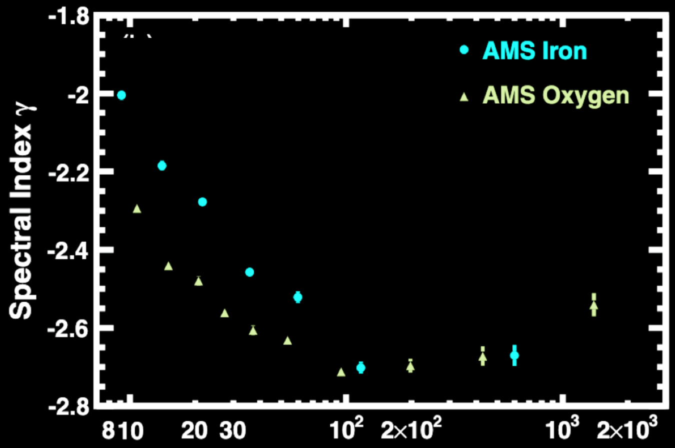
Primary CR: Iron

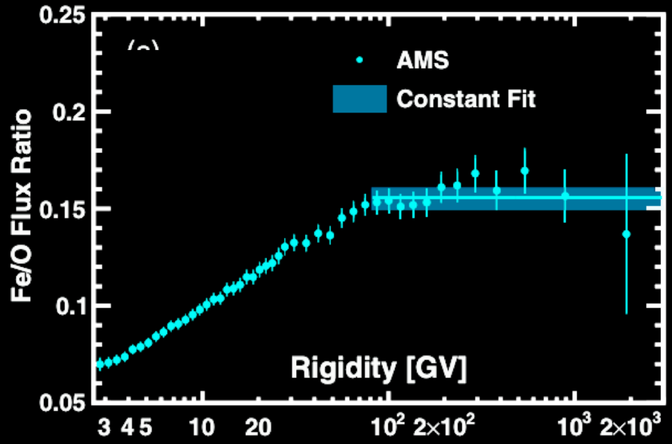
AMS-02 Iron spectrum – first 8.5 years

➢ Above 80.5 GV the rigidity dependence of the cosmic ray Fe flux is identical to the rigidity dependence of the primary cosmic ray He, C, and O class.

Phys. Rev. Lett. 126 (2021) 041104



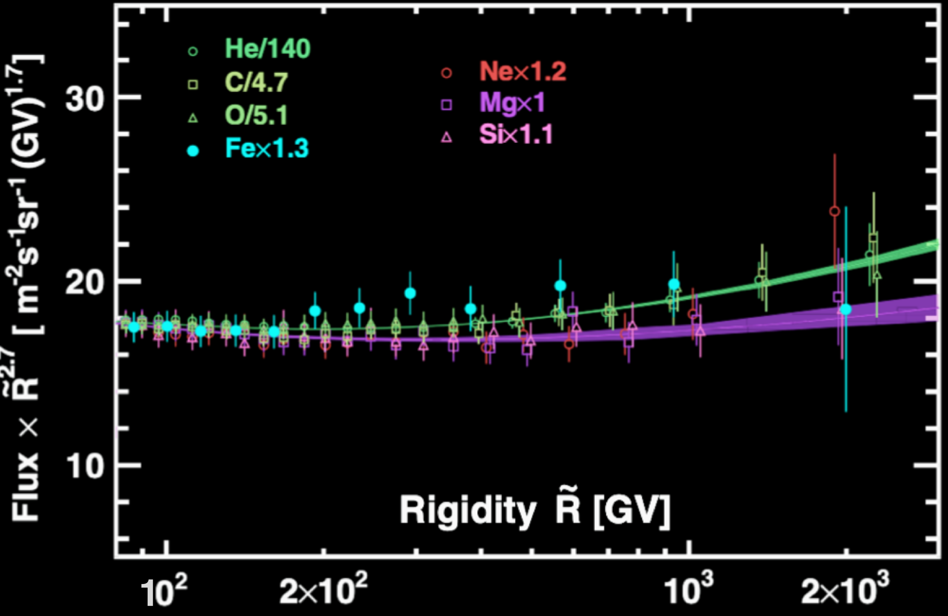




➢ Primary cosmic ray Fe belong to the same class of light primary cosmic rays He, C, and O.

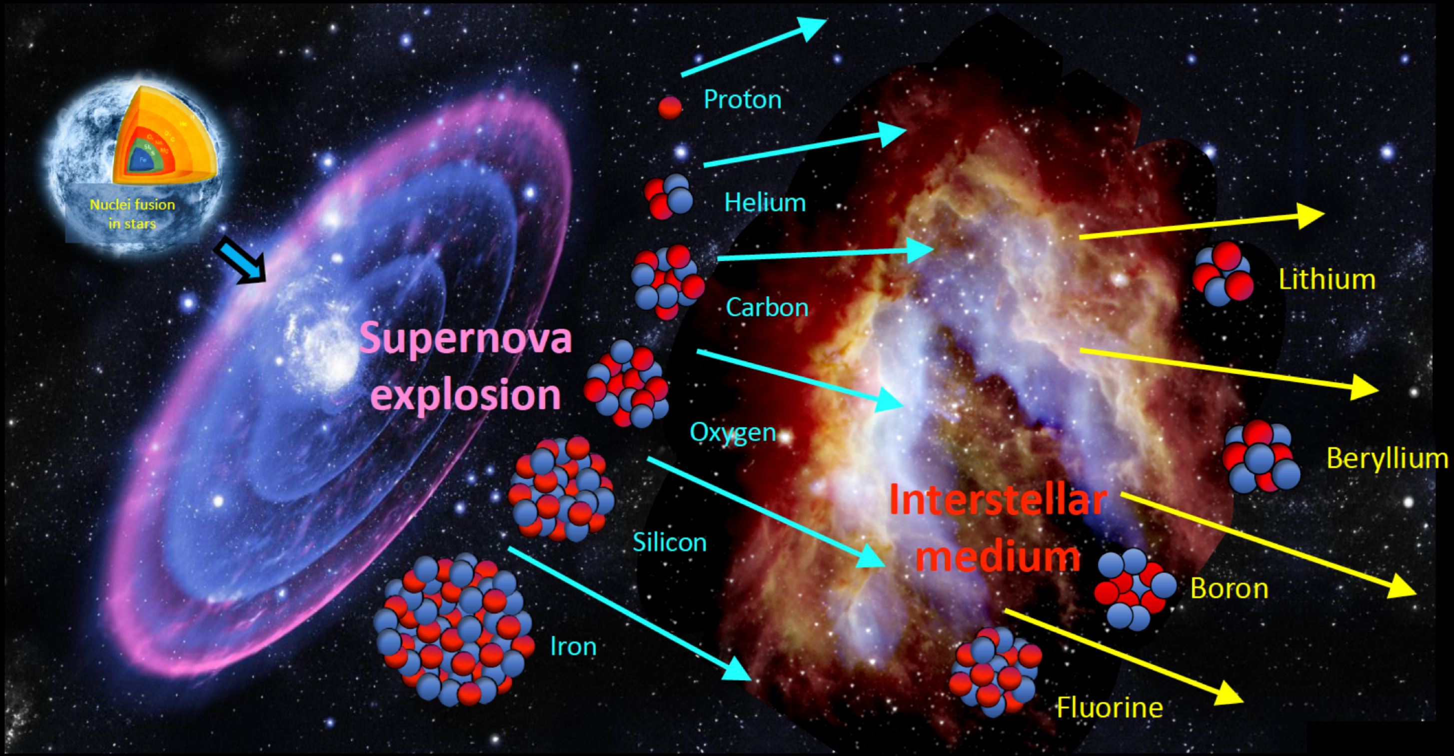
Primary CR

- Light primary cosmic rays He, C, and O have identical rigidity dependence above 60 GV and deviate from a single power law above 200 GV.
- Heavy primary cosmic rays Ne, Mg and Si have identical rigidity dependence above 86 GV, but it is distinctly different from light primary cosmic rays.This show that primary cosmic rays have at least two distinct classess of rigidity dependence
- Primary cosmic ray Fe belong to the same class of light primary cosmic rays He, C, and O.



Secondary Cosmic Rays

Secondary Li, Be, B, and F nuclei in cosmic rays are produced by the collision of primary cosmic rays, C, O, Ne, Mg, Si, …, Fe, with the interstellar medium.

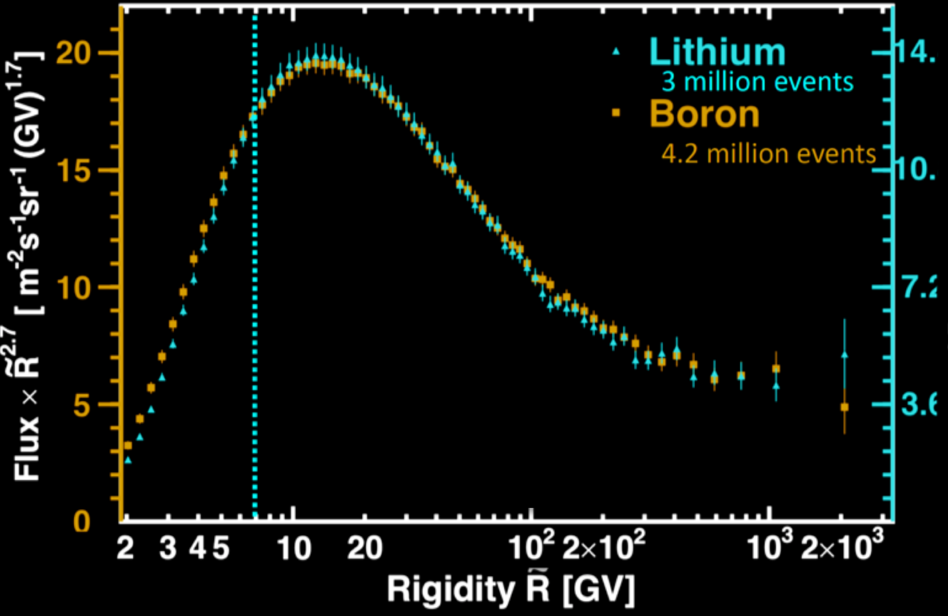


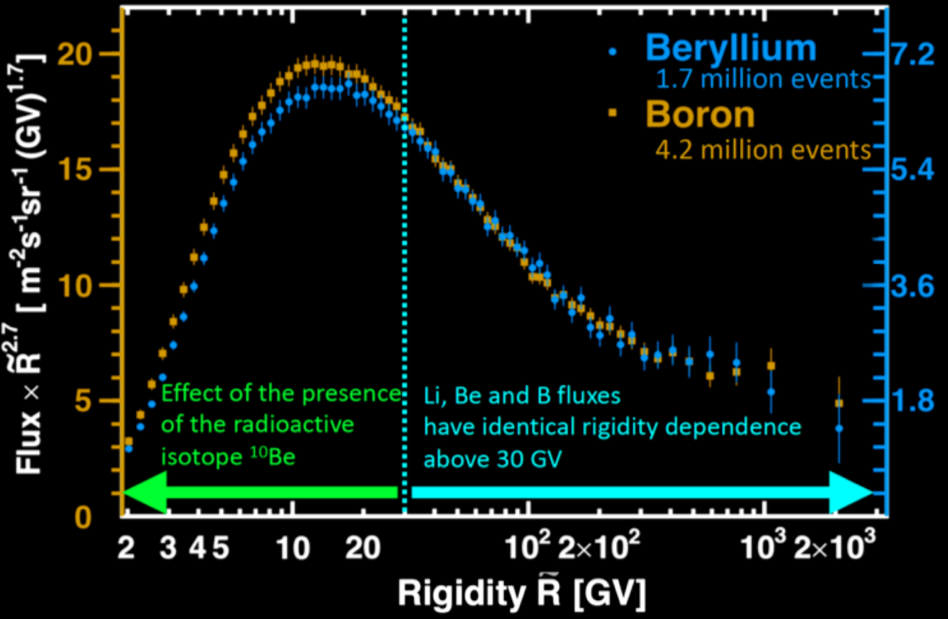
Measurements of the secondary cosmic ray nuclei fluxes and the secondary to primary flux ratios are important in understanding the propagation of cosmic rays in the Galaxy.

Secondary CR: Lithium, Beryllium and Boron

AMS-02 Lithium, Beryllium, and Boron spectra – first 7 years [Phys. Rep. 894, 1 (2021)]

- Lithium and Boron fluxes have identical rigidity dependence above 7 GV.
- All three fluxes have identical rigidity dependence above 30 GV.
- They deviate from a single power law at about 200 GV and harden identically
- Li/Be flux ratio is 2.0 ± 0.1above 30 GV.

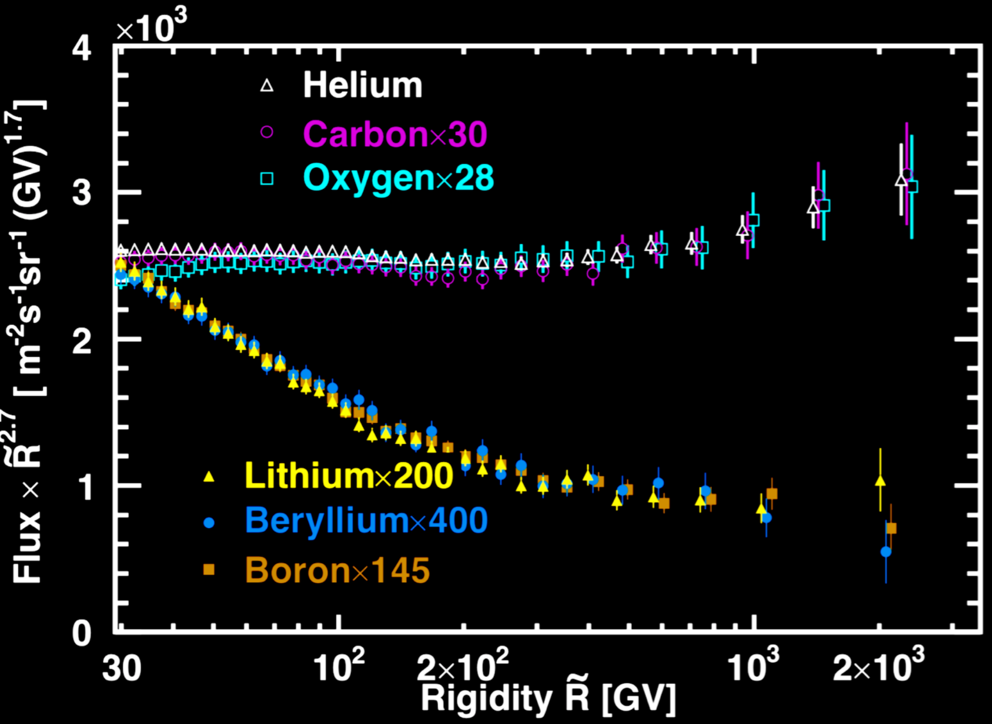


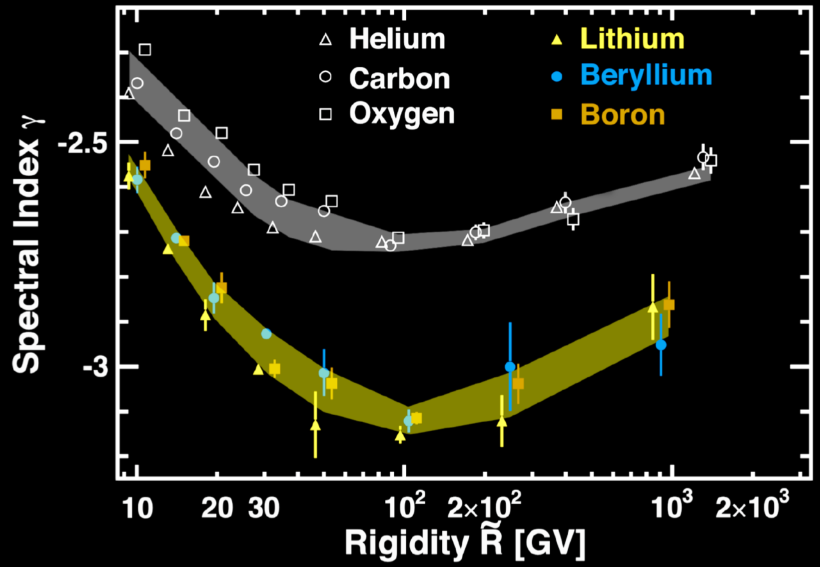


Secondary CR: Lithium, Beryllium and Boron

AMS-02 Light Primary (He,C,O) vs Light Secondary (Li, Be, B) spectra

➢ Secondaries and primaries have distinctly different spectral shapes



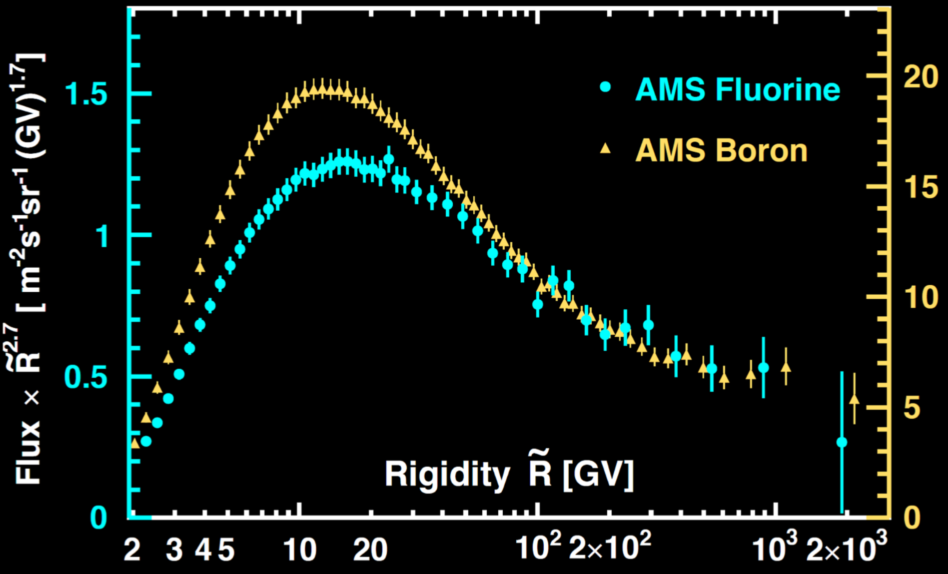


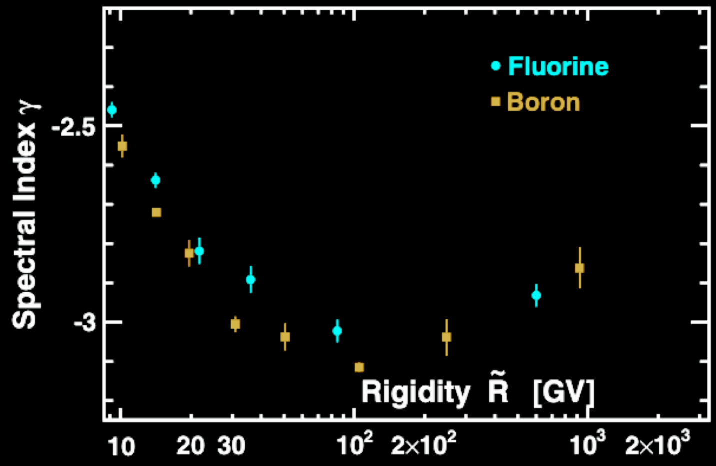
Secondary CR: Fluorine

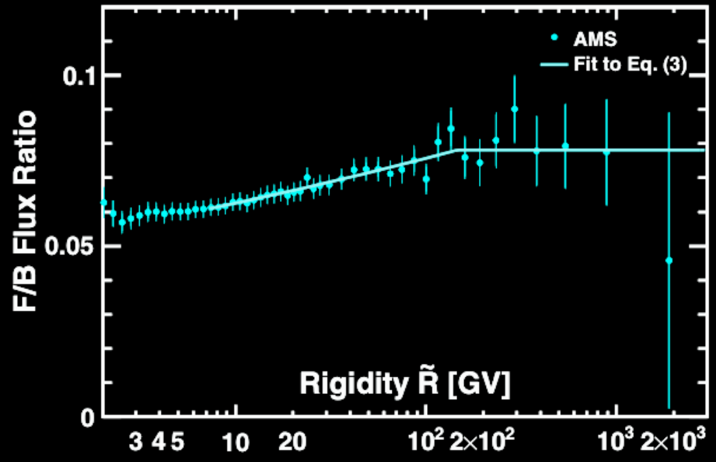
AMS-02 Fluorine spectrum – first 8.5 years

- Above 150 GV, the rigidity dependences of the F and B fluxes are identical, and at lower rigidities they are different.

M. Aguilar et. al., Phys. Rev. Lett. 126 (2021) 081102



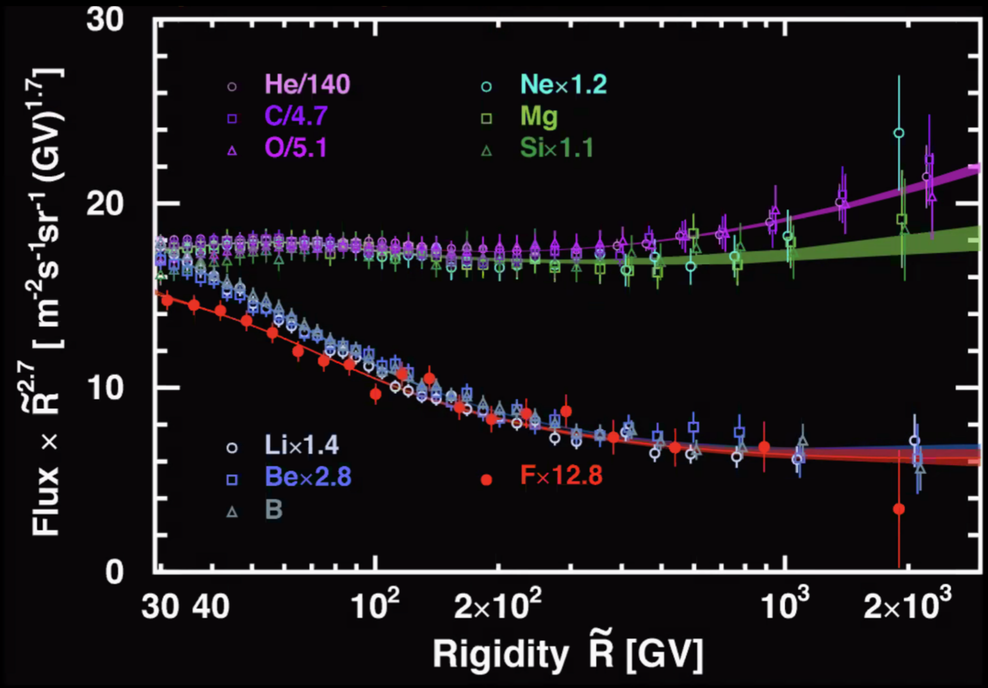




Primary and Secondary CR

AMS-02 Primary vs Secondary spectra

- ➢ Secondaries and primaries have distinctly different spectral shapes

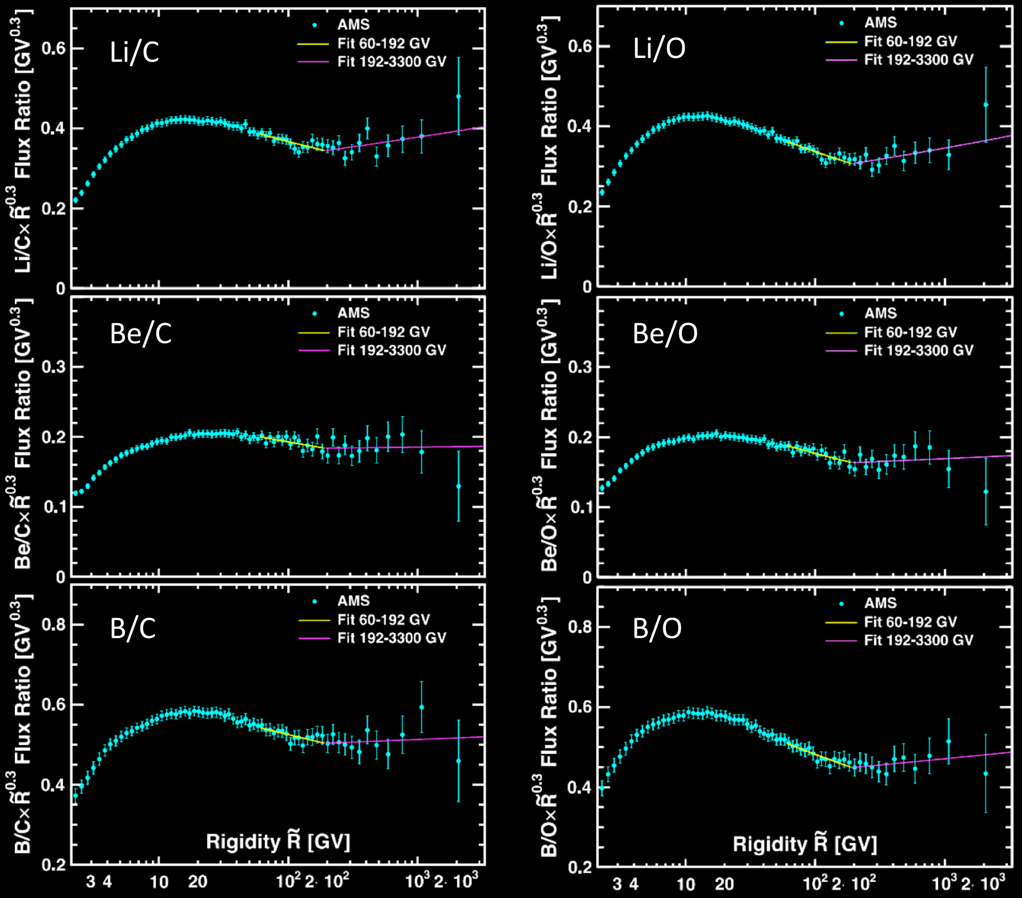


Light Secondary/Primary Flux Ratios

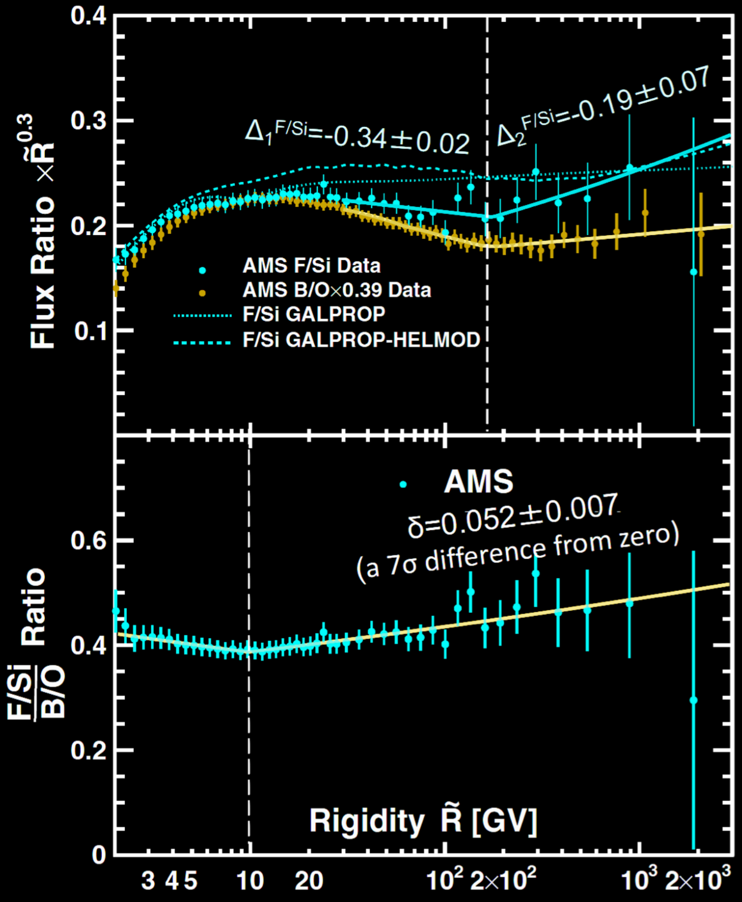
AMS-02 Light Secondary/Primary ratio – first 7 years [Phys. Rep. 894, 1 (2021)]

- All ratios exhibit a hardening. An average value of 0.140 ± 0.025 at 192 GV is observed

- Secondaries hardens more than primaries, and this observation favorite the hypothesis that the flux hardening is an universal propagation effect



Heavy Secondary/Primary Flux Ratios



AMS-02 Heavier F/Si Flux Ratio compared with lighter B/O Flux Ratio – first 7 years

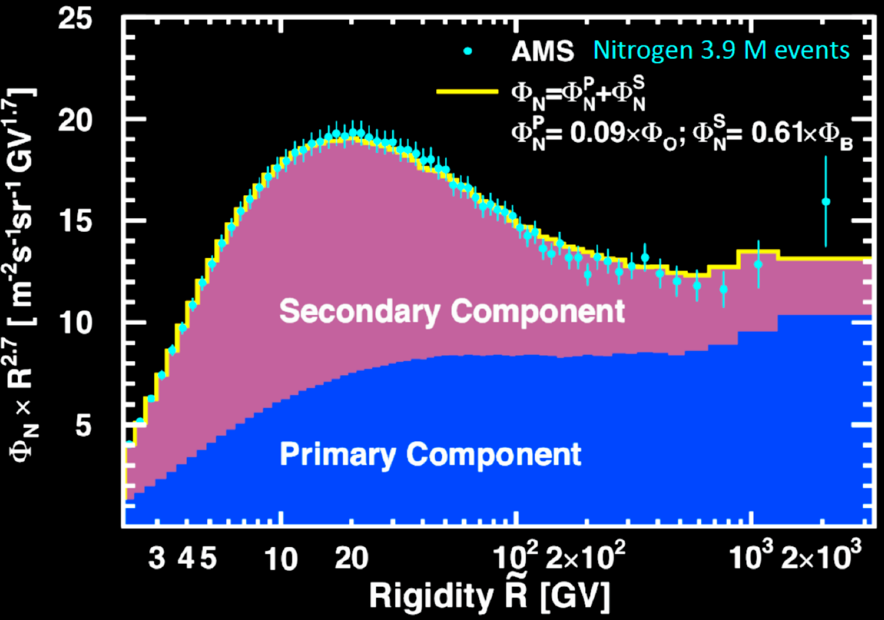
Above 175 GV, the F/Si ratio exhibit an hardening compatible with the results obtained for the light Secondary/Primary flux ratios

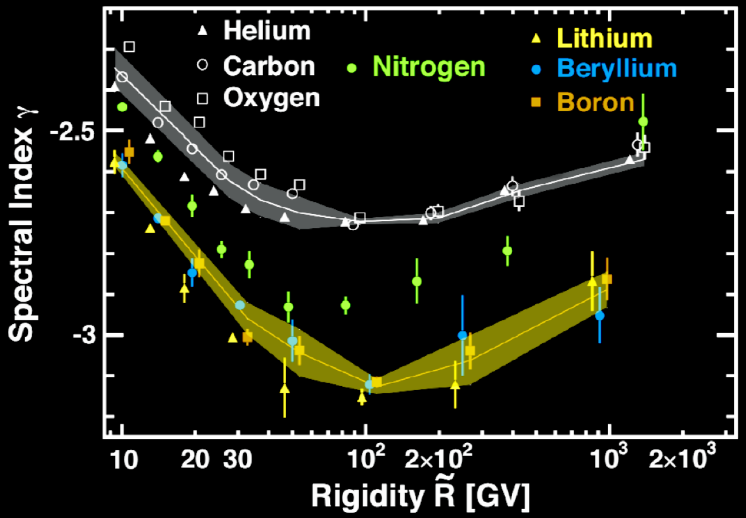
Above 10 GV, the (F/Si)/(B/O) reveals that the propagation properties of heavy cosmic rays, from F to Si, are different from those of light cosmic rays, from He to O

New Class of CR: Nitrogen

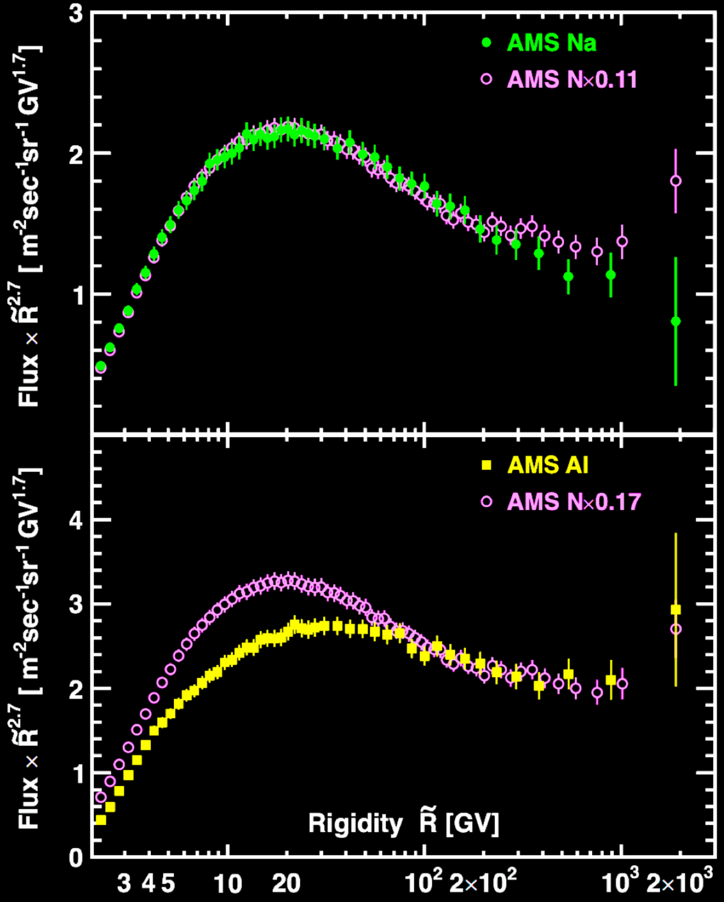
AMS-02 Nitrogen spectrum – 7 years Phys. Rep. 894, 1 (2021)

- Cosmic-ray Nitrogen nuclei are partly primaries and partly secondaries. The Nitrogen flux is well described by primary + secondary components
- The Nitrogen spectral index is situated between the primary and the secondary spectral indices. It hardens rapidly with rigidity above 100 GV and becomes identical to the spectral indices of primaries above 700 GV.

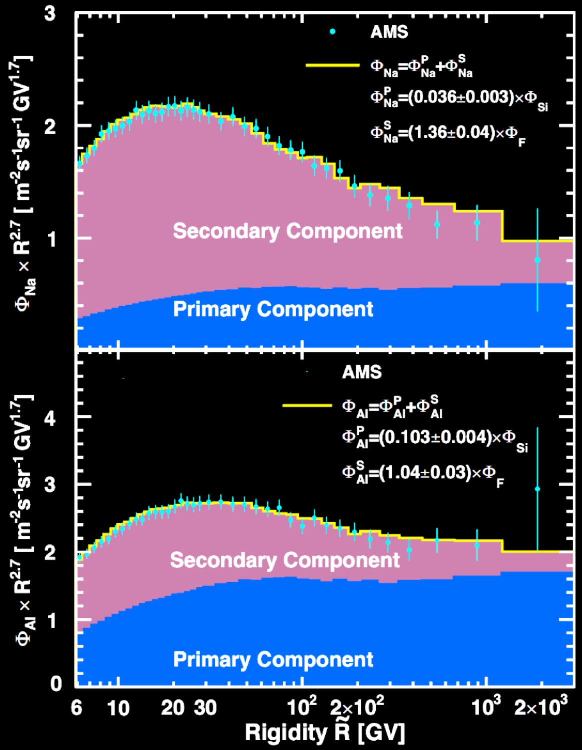




New Class of CR: Sodium, Aluminum



AMS-02 Sodium and Aluminum spectra – 8.5 years

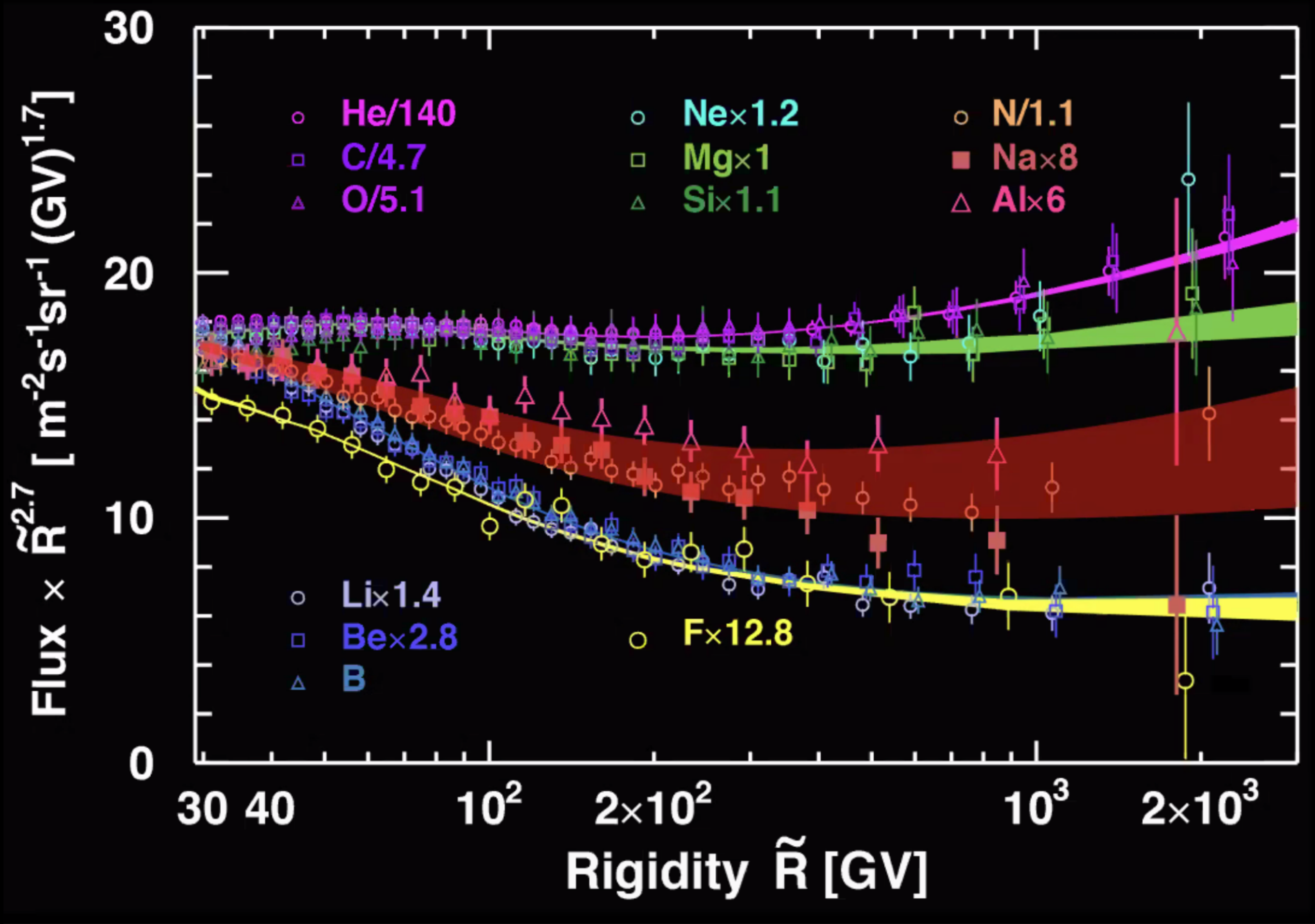


At Rigidities below ~100 GV the Na flux and the N flux have similar rigidity dependence and, at Rigidities above ~100 GV the Al flux and the N flux have similar rigidity dependence.

All these elements, are well described by primary + secondary components

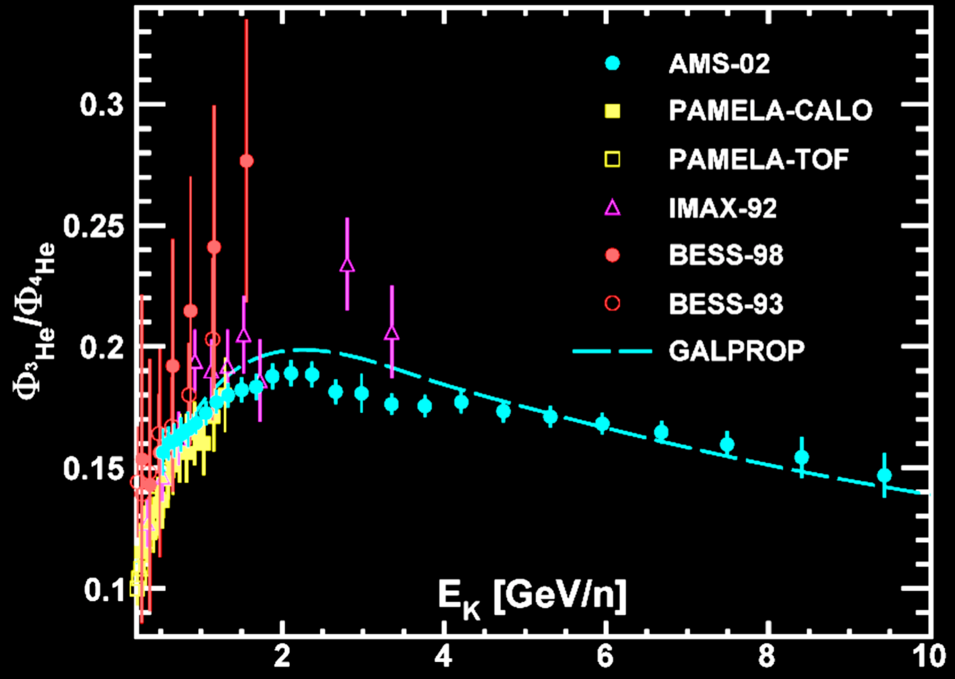
Preliminary Data.
Please refer to the
AMS forthcoming publication in PRL

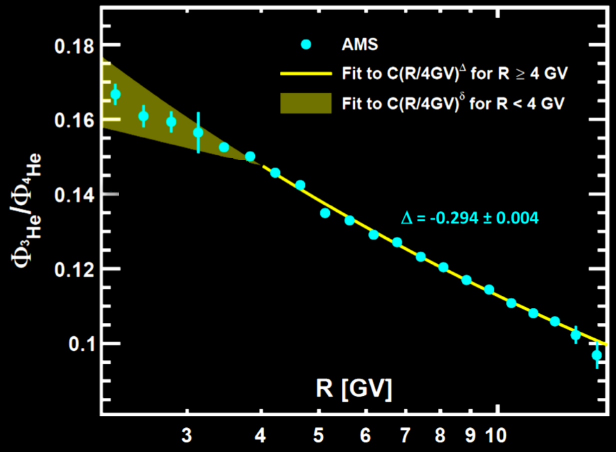
Summary of CR classes

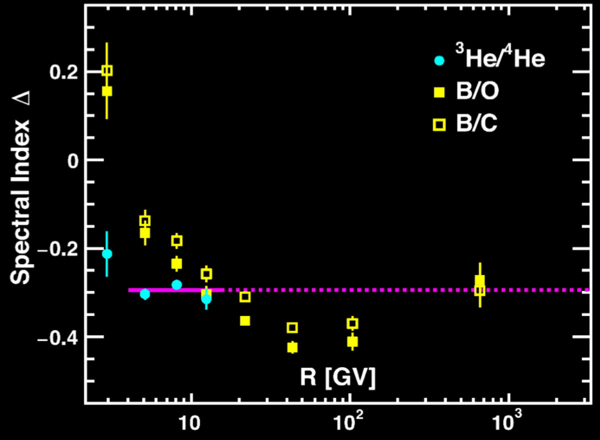


He Isotopes in Cosmic Rays

AMS-02 $^3He/^4He$ ratio – first 7 years [Phys. Rep. 894, 1 (2021)]
The $^3He/^4He$ extrapolated to the highest energies is in good agreement with the B/O and B/C spectral indices







Conclusions

- AMS is able to measure cosmic ray nuclei in the rigidity range from GV to TV.
  In 10 years of operation onboard the ISS it collected more than 170 billion of cosmic ray triggers.

- All spectra deviate from a single power law above 200GV.

- Light primary cosmic rays (He, C, and O) exhibit identical spectral shape above 60 GV.
  Heavy primary cosmic rays Ne, Mg and Si have identical rigidity dependence above 86 GV, but it is distinctly different from light primary cosmic rays.
  Iron spectra instead belong to the same class of light primary cosmic rays.

- Light secondary cosmic rays (Li, Be, and B) exhibit identical spectral shape above 30 GV.
  Fuorine have identical rigidity dependence with respect light secondary cosmic rays above 150 GV.

- The secondary/primary flux ratios flux ratios show that secondary harden more than primary. These observations favor the hypothesis that the flux hardening is an universal propagation effect.

- AMS-2, taking data for the entire duration of the ISS lifetime, will be able to improve the accuracy of the cosmic ray nuclei fluxes, and to measure heavier nuclei fluxes, probing origin and propagation of cosmic rays at high mass and charge.