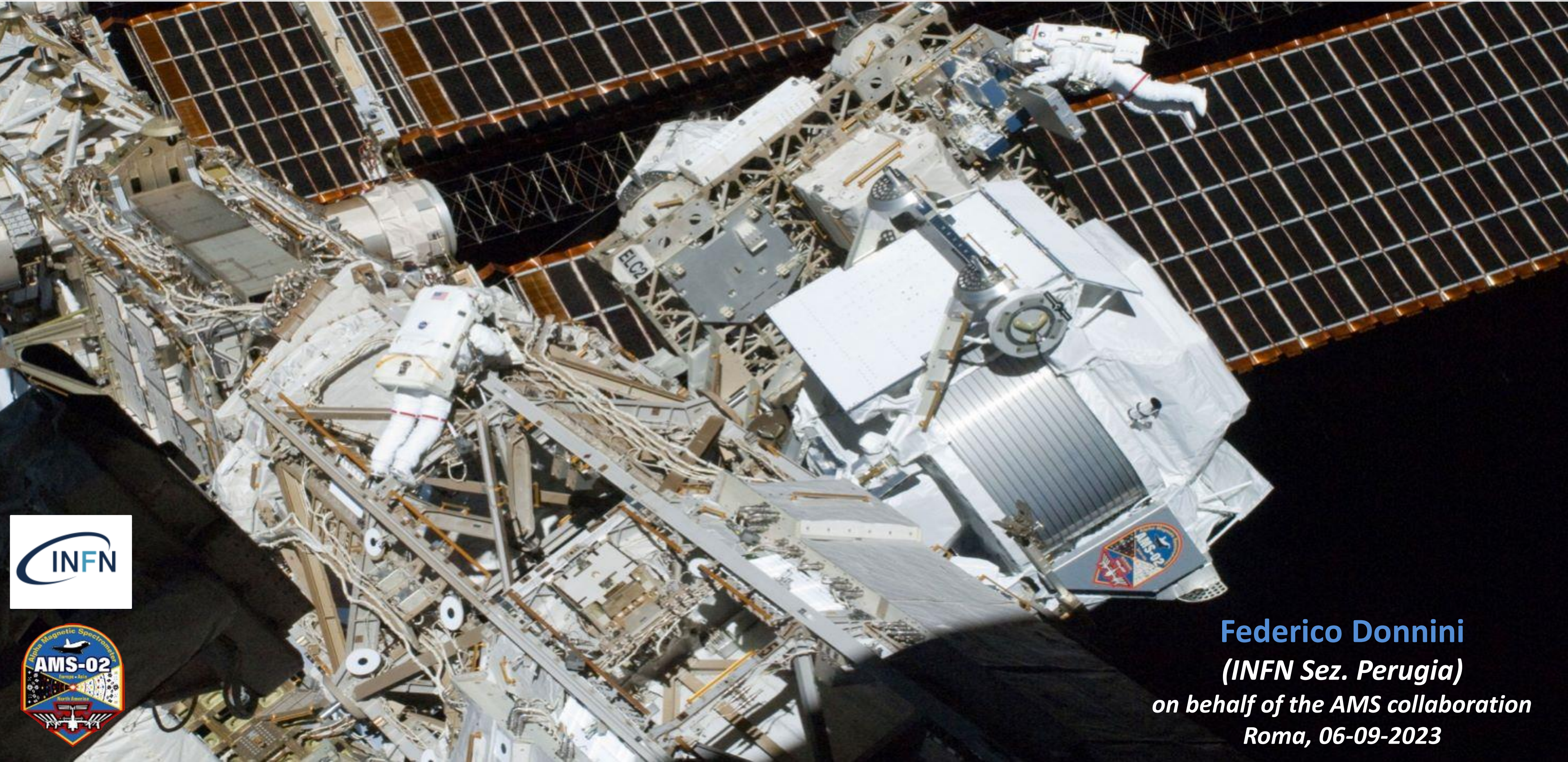
Precision measurement of the Monthly Light Ion Fluxes in Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station



Federico Donnini

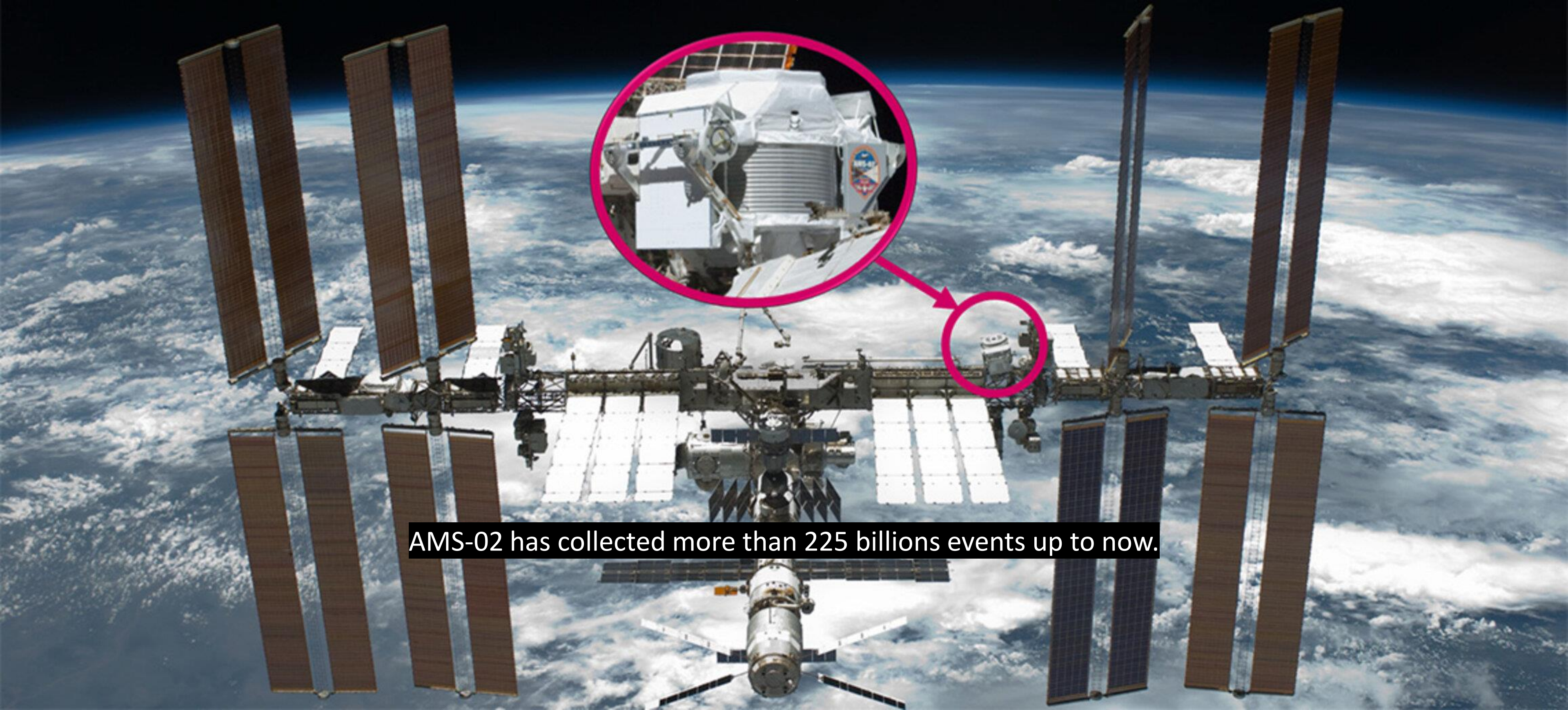
(INFN Sez. Perugia)

on behalf of the AMS collaboration

Roma, 06-09-2023

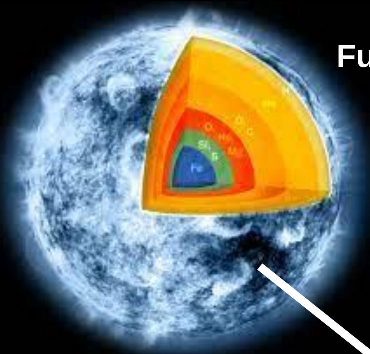
The Alpha Magnetic Spectrometer (AMS-02)

AMS-02 is a high energy particle physics experiment operating continuously on board of the International Space Station since May 2011.

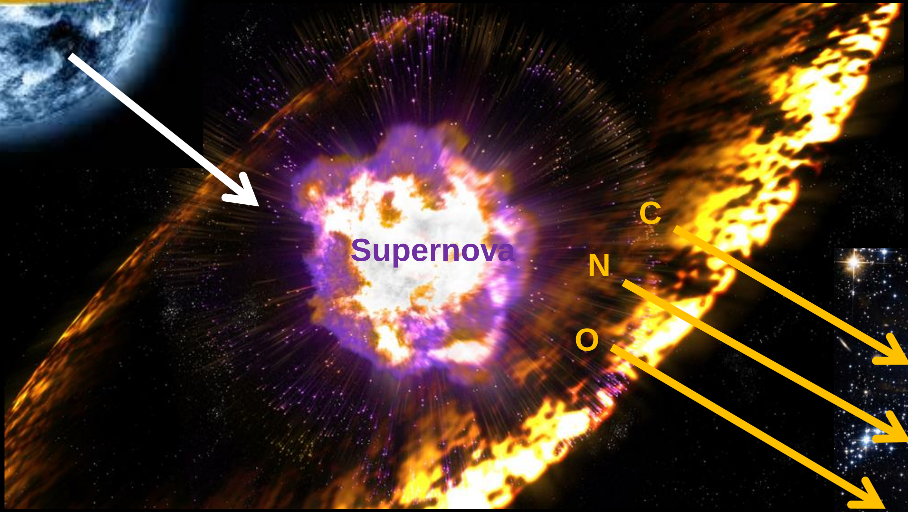


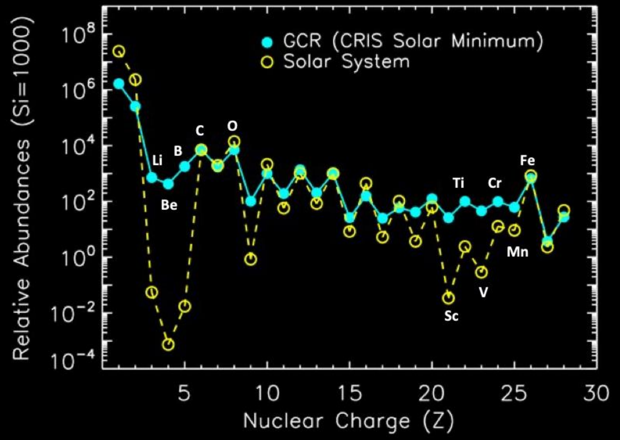
AMS-02 has collected more than 225 billions events up to now.

Galactic Cosmic Rays (GCRs) Propagation



Fusion inside stars

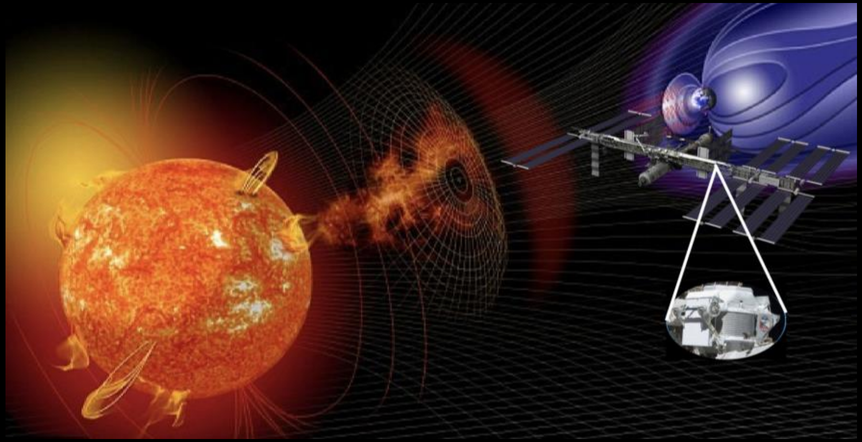


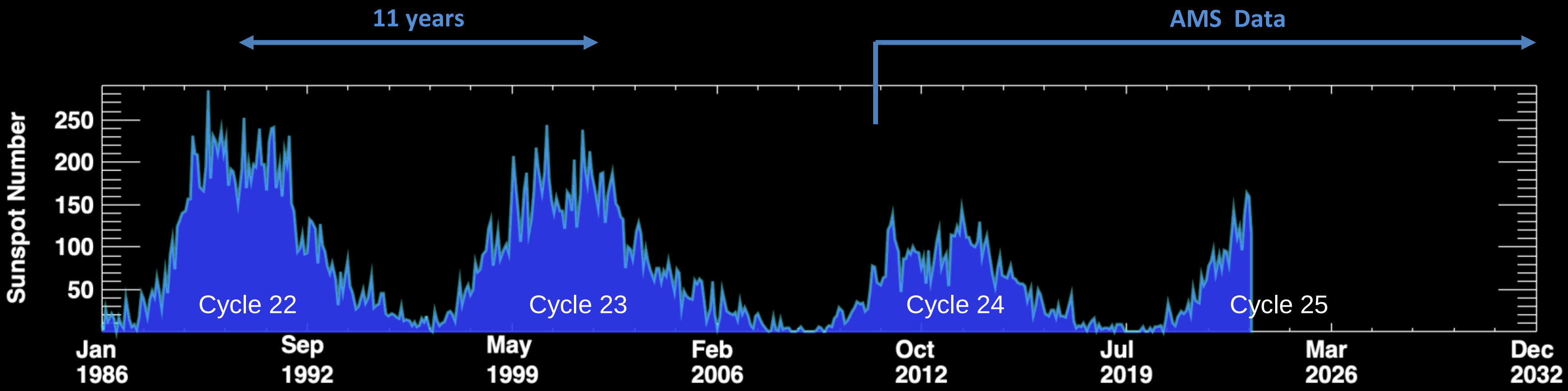


Primary GCRs are mostly created inside stars and accelerated in supernovae.
Secondary GCRs are mostly produced by the collisions of primaries with the **ISM**.

Solar physics with AMS-02

- **Large time scale effects** (~years):
  - intensity variation of CRs
  - charge sign dependence:
    - at solar maximum: diffusion
    - at solar minimum: diffusion + magnetic drift
- **Small time scale effects** (~days):
  - Forbush decrease & Solar Energetic Particles (SEP)





Solar physics with AMS-02: Nuclei

The Cosmic Rays propagation in the heliosphere is described by Parker equation:

$$\frac{\partial f}{\partial t} = -\vec{V}_{SW} \cdot \vec{\nabla} f + \vec{\nabla} \cdot (\mathrm{K} \cdot \vec{\nabla} f) + \frac{1}{3} \vec{\nabla} \cdot \vec{V}_{SW} \frac{\partial f}{\partial lnR}$$

Particle density in phase space — **Solar wind convection** — **Diffusion and Drifts** — **Adiabatic energy losses**

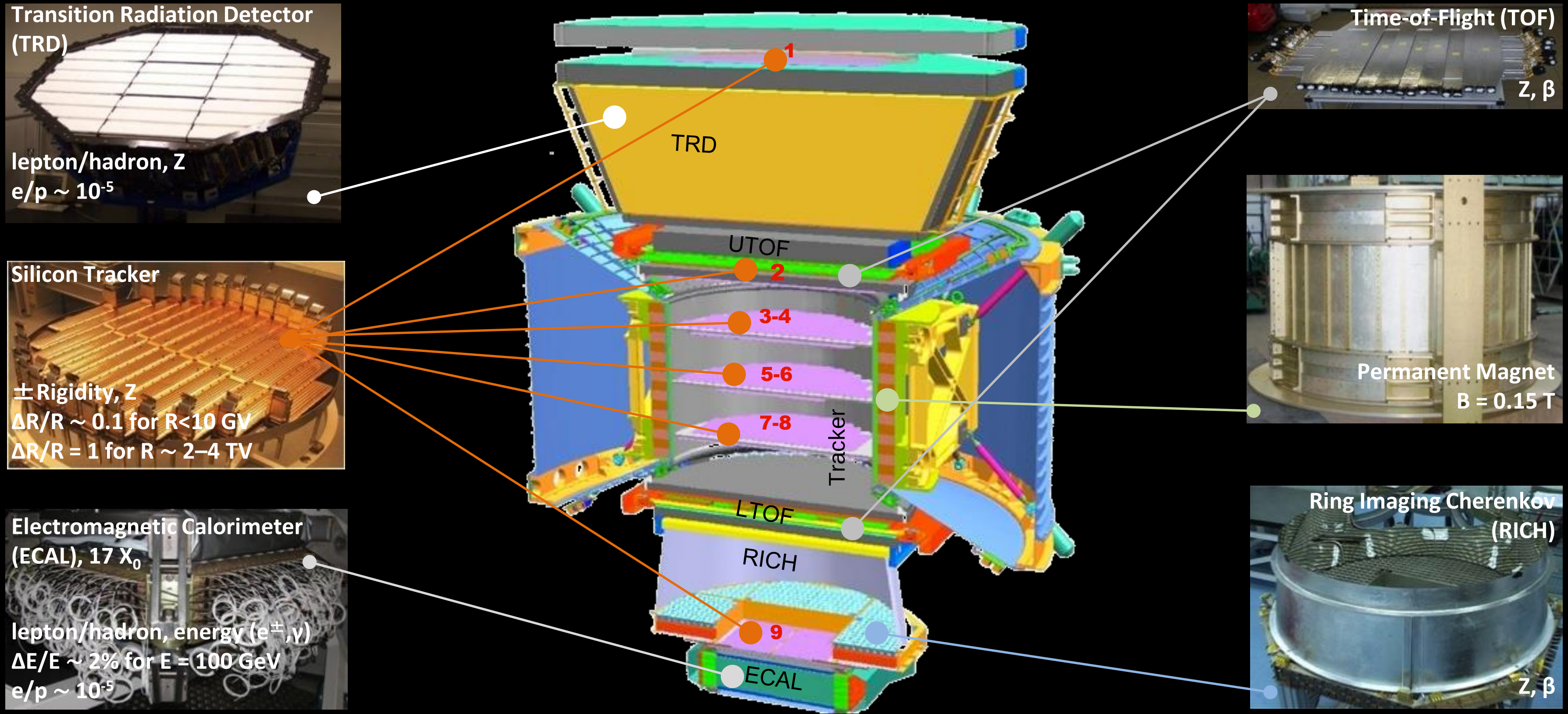
- Velocity dependence of the diffusion tensor: the velocity induces changes in this term for nuclei with different A/Z since $\beta(R) = \frac{R}{\sqrt{R^2+(A/Z)^2(mc)^2}}$

- Difference in spectral shape: the adiabatic energy losses term depends on the spectral shape. If two nuclei have different spectral shape outside the heliosphere (LIS), the last term will be different.

→ Measuring the effect of solar modulation on elements with **different spectral shape** (primary/secondary) and/or **different A/Z** (as ex. C, O = 2, Li~2.3) provides information of the propagation of CRs in the Heliosphere

AMS-02 detector

AMS-02 makes multiple and/or Independent measurements of charge (Z), energy (β, p, E) and charge sign (±).
It separates hadrons from leptons, matter from anti-matter, chemical and isotopic composition from fraction of GeV to multi-TeV.



AMS Flux Measurement

The isotropic differential flux in the i-th rigidity bin (R_i; $R_i + \Delta R_i$)

Number of events after contamination correction

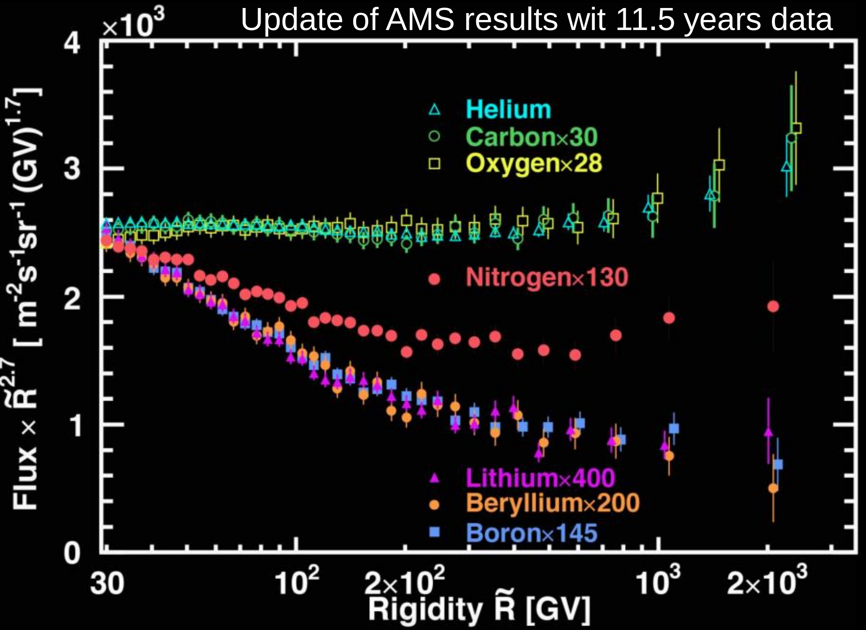
$$\Phi_i = \frac{N_i}{\aleph_i T_i A_i \Delta R_i}$$

Unfolding factor, bin-to-bin migration correction

Exposure time

Effective acceptance

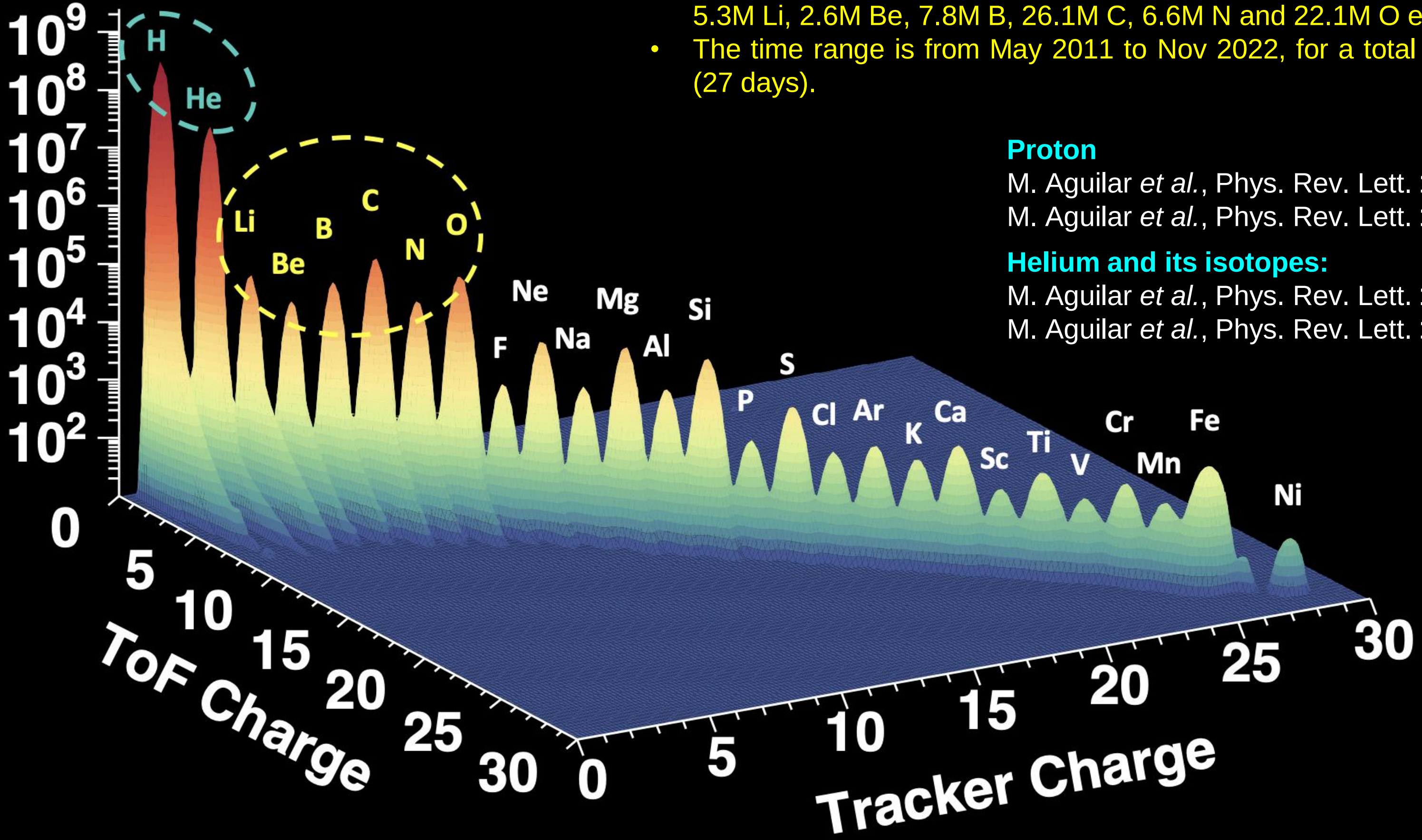
Bin width



- The Time dependent flux measurement is performed in 141 Bartels rotations (time periods of 27 days). Each flux is calculated including specific corrections for detector efficiencies, unfolding, background subtraction specific for each period.

AMS Periodic Table

- In this work is presented the time evolution of light nuclei from 2 GV to 60 GV, with 5.3M Li, 2.6M Be, 7.8M B, 26.1M C, 6.6M N and 22.1M O events.
- The time range is from May 2011 to Nov 2022, for a total of 141 Bartels rotations (27 days).



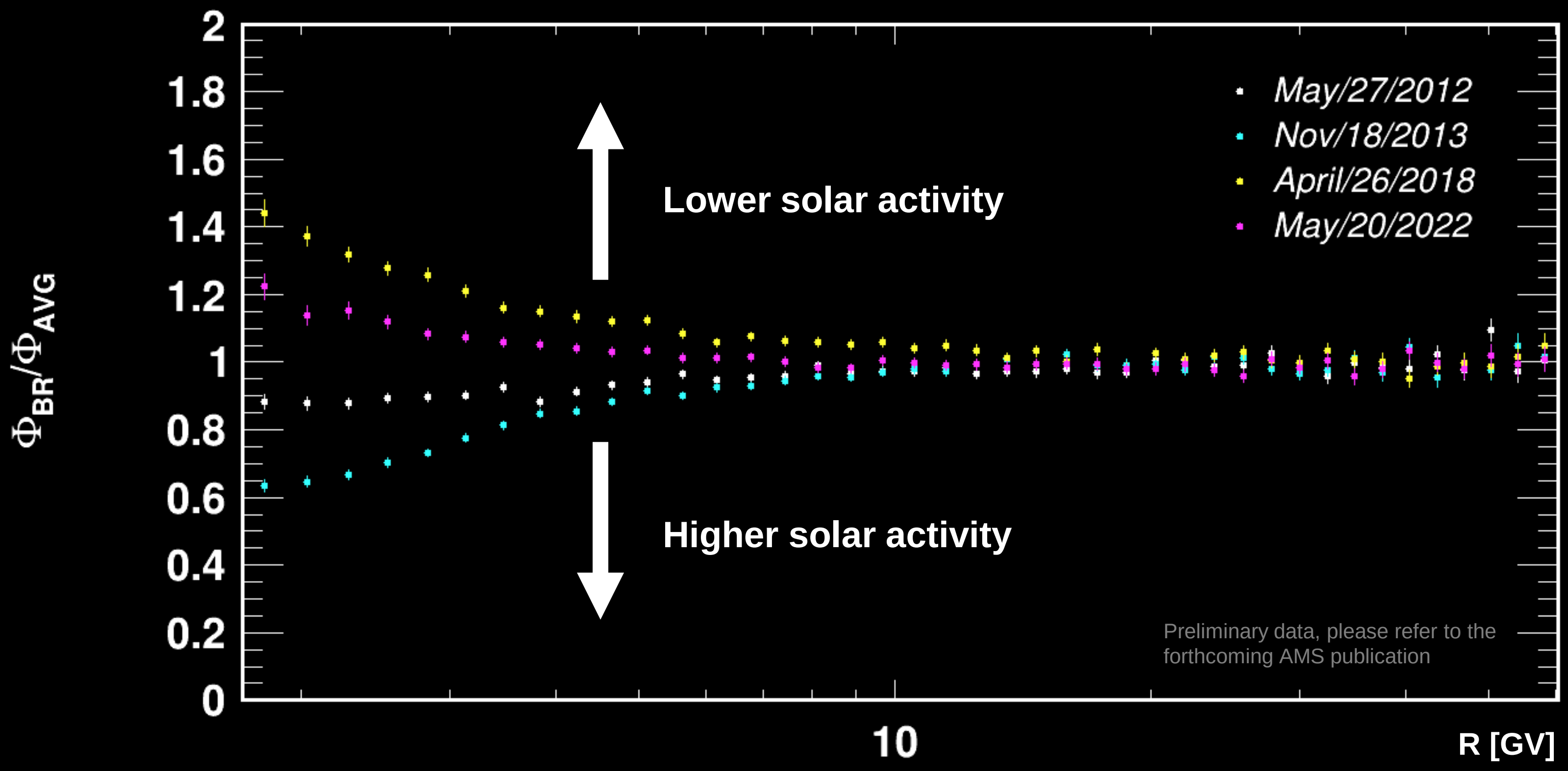
Proton

M. Aguilar *et al.*, Phys. Rev. Lett. **121**, 051101 (2018)
M. Aguilar *et al.*, Phys. Rev. Lett. **127**, 271102 (2021)

Helium and its isotopes:

M. Aguilar *et al.*, Phys. Rev. Lett. **123**, 181102 (2019)
M. Aguilar *et al.*, Phys. Rev. Lett. **128**, 231102 (2022)

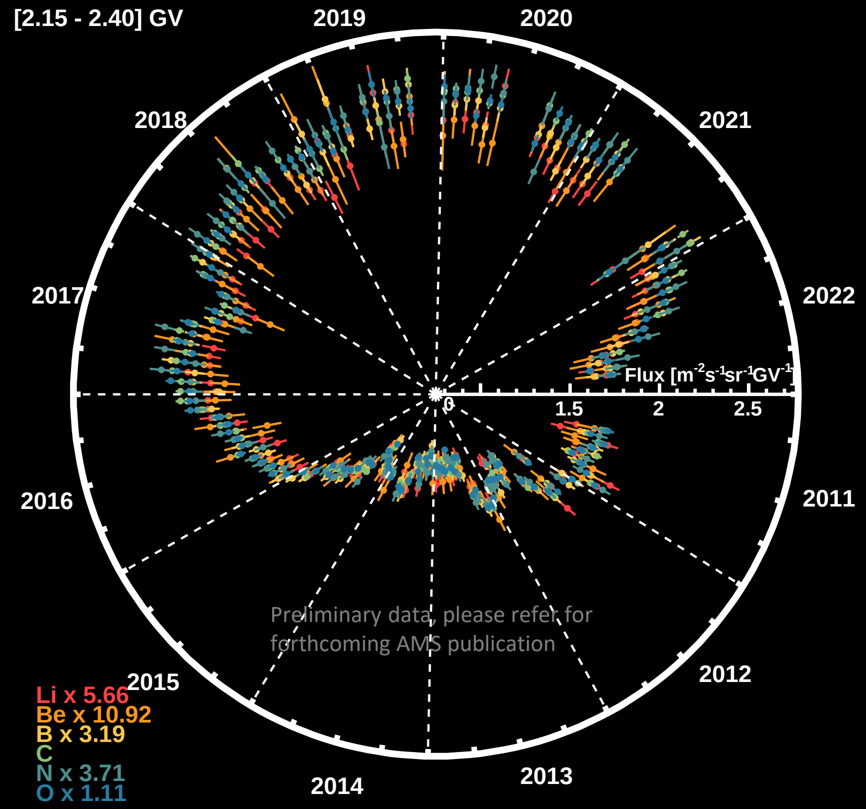
Relative Flux variation during the Solar Cycle

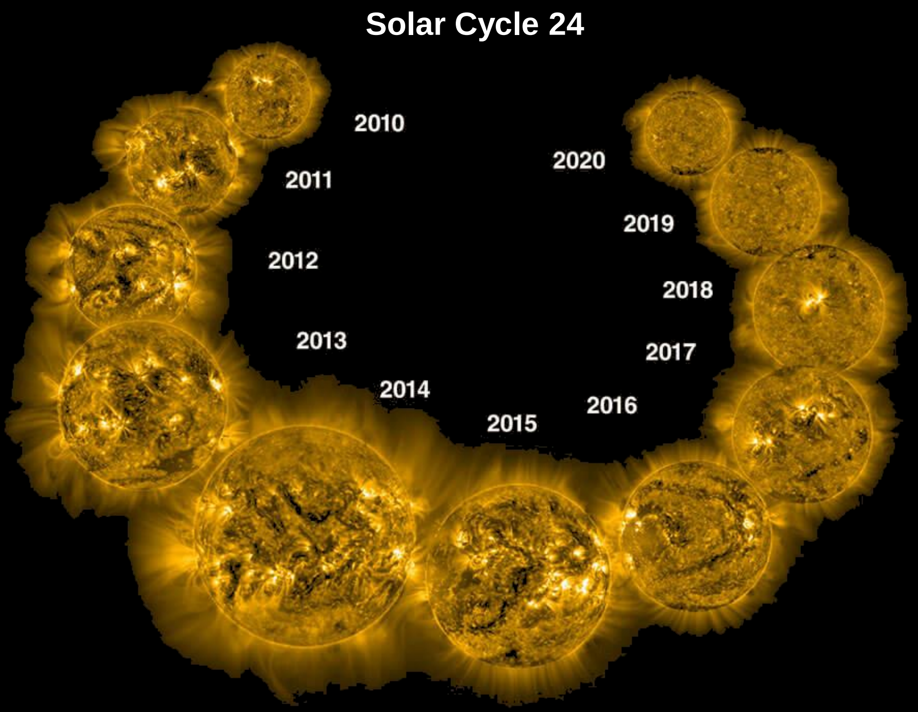


The $\Phi_{BR}/\ \Phi_{AVG}$ for four Bartels rotations, shows the anti-correlation between flux and solar activity.

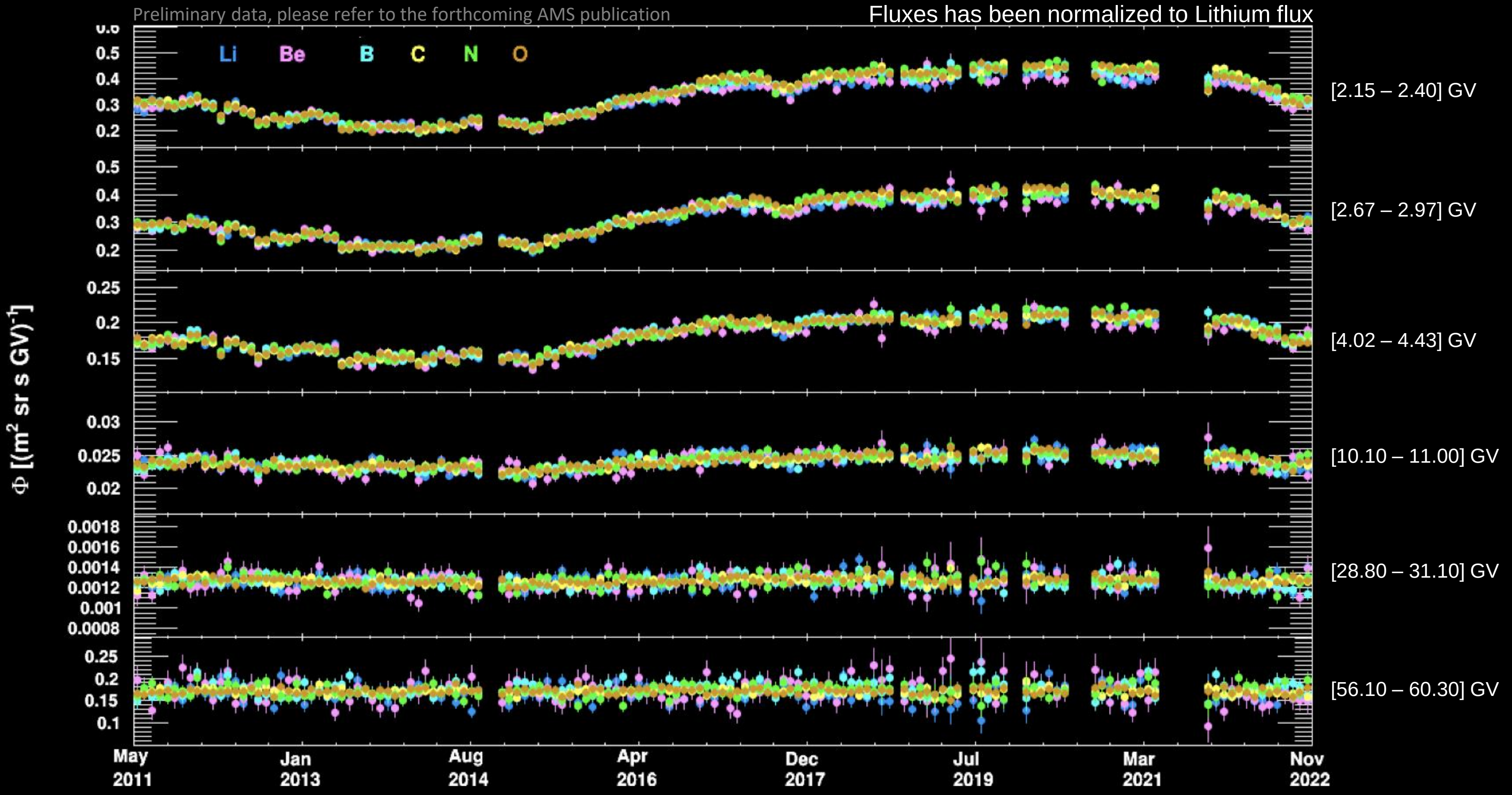
Light Nuclei Fluxes as Function of Time

Fluxes are anti-correlated with solar activity, being higher during epoch of low solar activity and lower during epoch of high solar activity. All nuclei exhibit similar long-term and short-term time dependences.

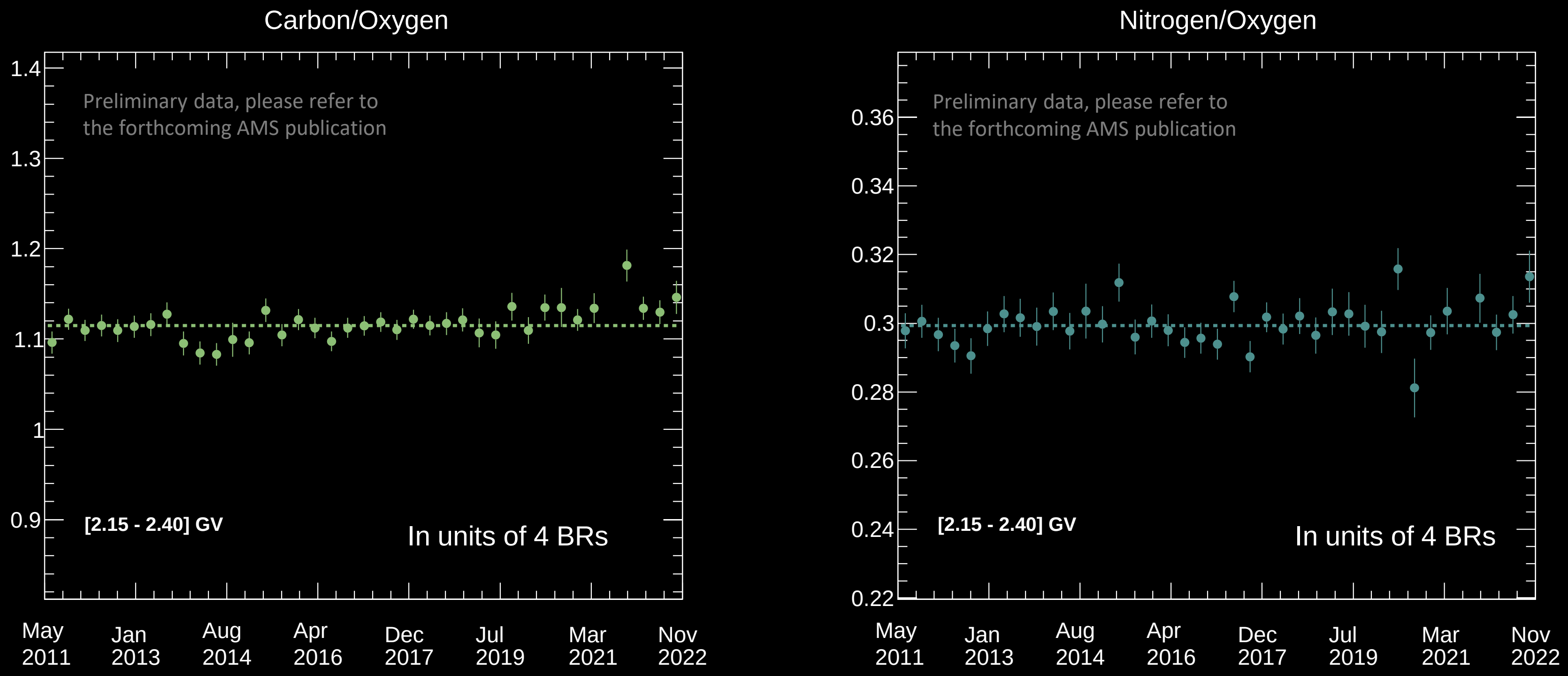




Light Nuclei Fluxes as Function of Time

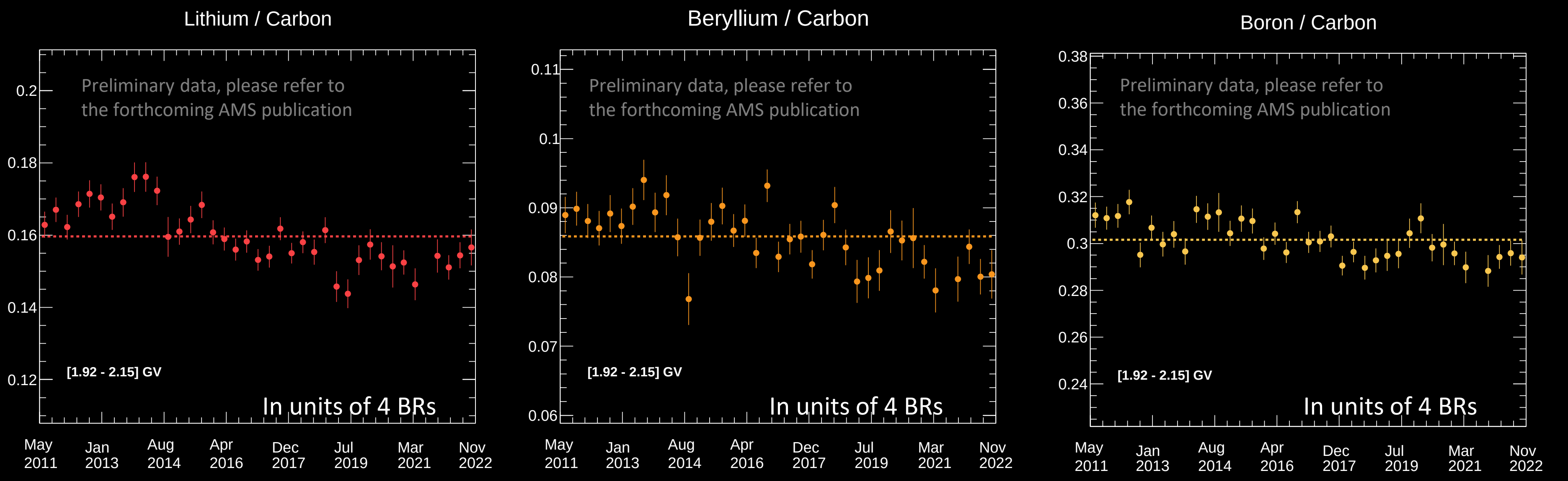


C/O and N/O as Function of Time



No significant time dependence is observed for Carbon over Oxygen (very similar spectrum and A/Z ratio) and Nitrogen over Oxygen (similar spectrum and A/Z ratio).

Li/C, Be/C and B/C as Function of Time



- Lithium, Beryllium and Boron are secondaries with similar spectra, and different from Carbon.
- The A/Z is 2.17 for Lithium, 2 for Beryllium and 2.14 for Boron.
- The time trend is more visible in Lithium/Carbon ratio.
- These ratios allow us to test some properties of the propagation inside the heliosphere.

Conclusions

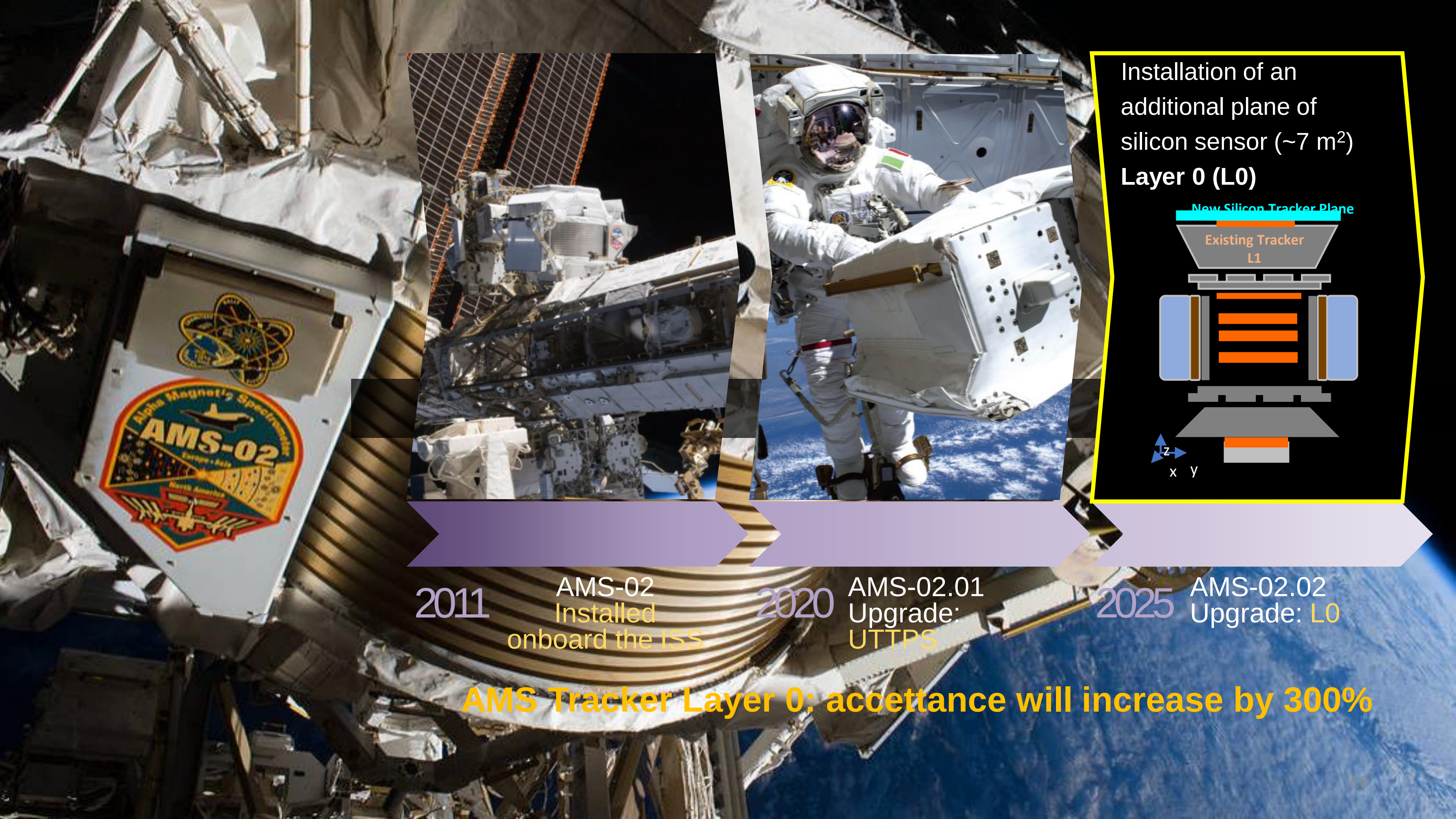
- The AMS fluxes vs time for light ions (Li to O), from May 2011 to Nov 2022, has been presented. It is the first time-dependent measurement of these fluxes between 1.92 (2.15) and 60 GV. The fluxes and their ratios have been determined for 141 Bartels rotations, i.e. on a 27-day basis.

- The fluxes are anti-correlated with solar activity, and the amplitude of the time structures decrease with rigidity. All nuclei exhibit similar long-term and short-term time variation.

- The ratios of light nuclei has been inspected as function of time. Ratios between nuclei with differences in spectral shape and A/Z (Li/C, Be/C, B/C) exhibit some non-negligible time variation, while ratios with more similar spectral shape and A/Z (C/O, N/O) do not exhibit time variation.

- AMS-02 will continue operating during the full Solar Cycle 25. Its precise data will improve our understanding in the cosmic rays propagation mechanism inside the heliosphere.

- For the final data and results of this analysis, please refers to the forthcoming publication.

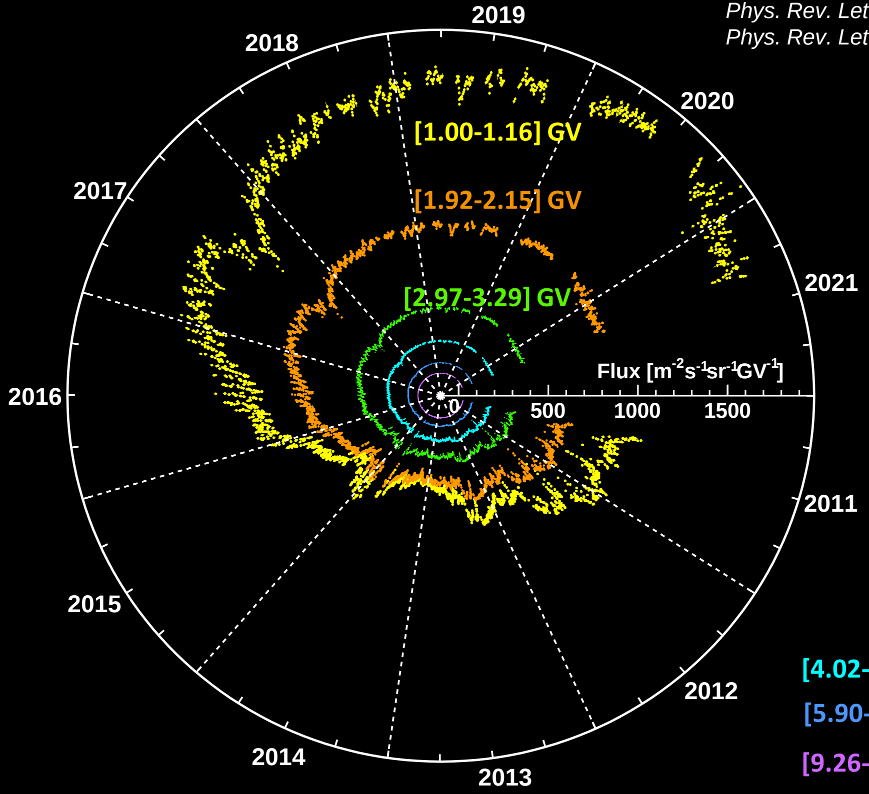

Installation of an additional plane of silicon sensor (~7 m²)
Layer 0 (L0)
New Silicon Tracker Plane
Existing Tracker L1
z
x
y
2011
AMS-02
Installed onboard the ISS
2020
AMS-02.01
Upgrade: UTTPS
2025
AMS-02.02
Upgrade: L0
AMS Tracker Layer 0: accettance will increase by 300%

Proton and Helium Daily Fluxes

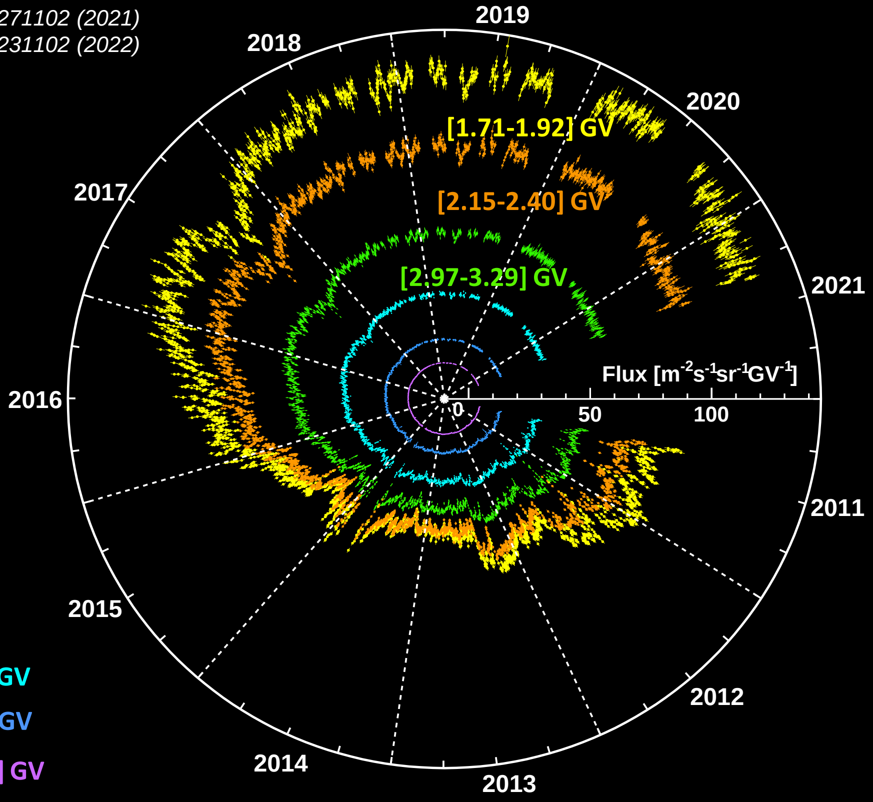
AMS collected 6 billion protons and 850 million Helium nuclei from **May 2011 up to May 2021**

AMS 10 years update. First results in:
Phys. Rev. Lett. 127, 271102 (2021)
Phys. Rev. Lett. 128, 231102 (2022)

Protons

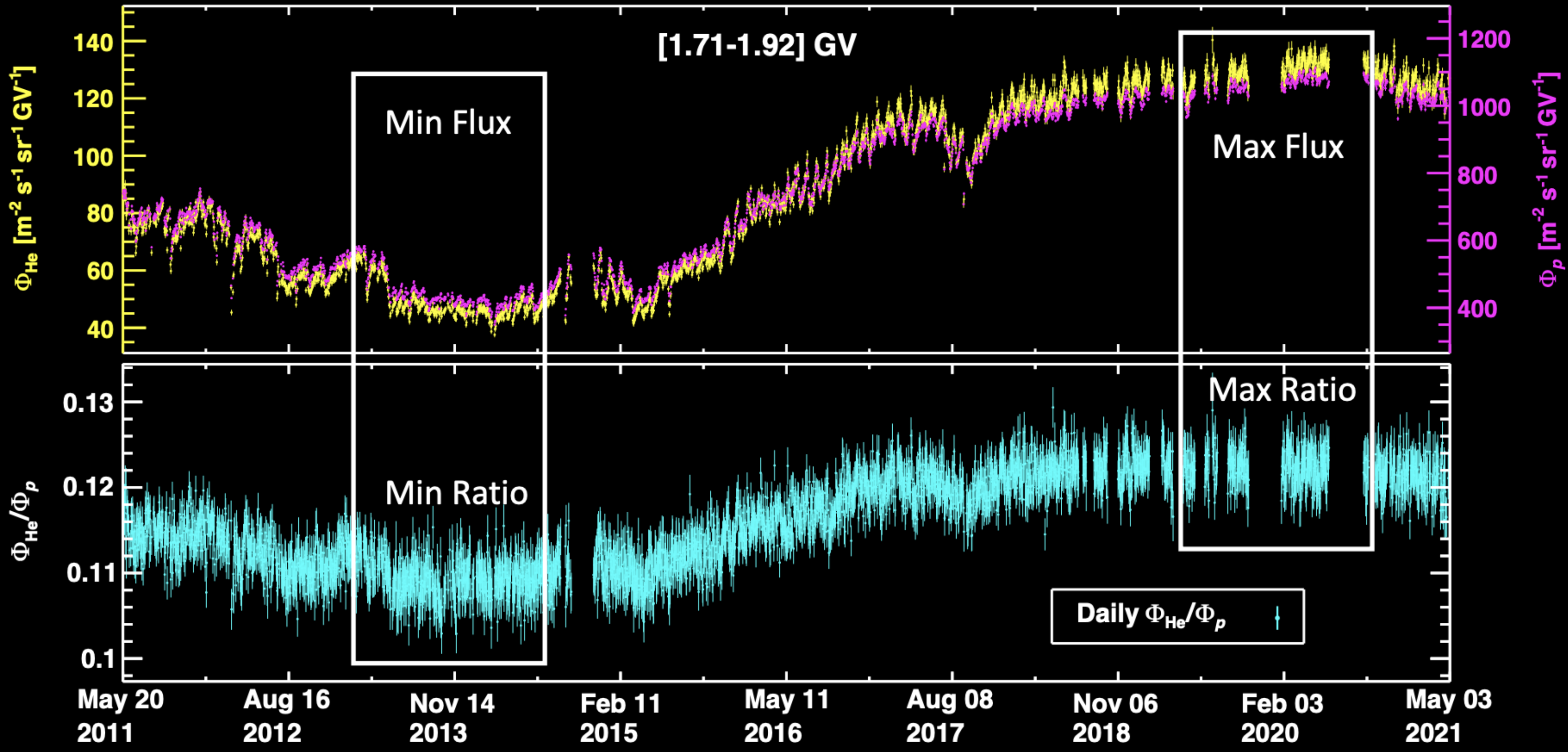


Helium

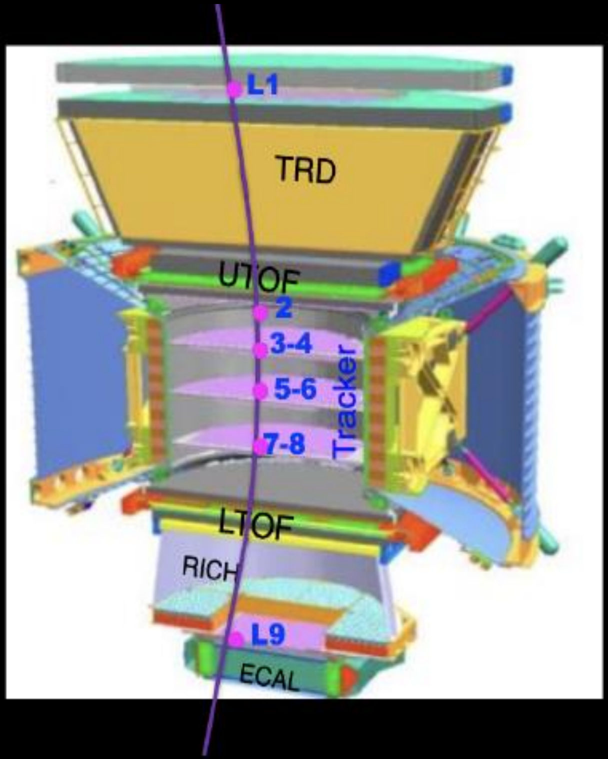


[4.02-4.43] GV
[5.90-6.47] GV
[9.26-10.10] GV

Proton and Helium Daily Fluxes



AMS Nuclei Flux Measurement



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

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

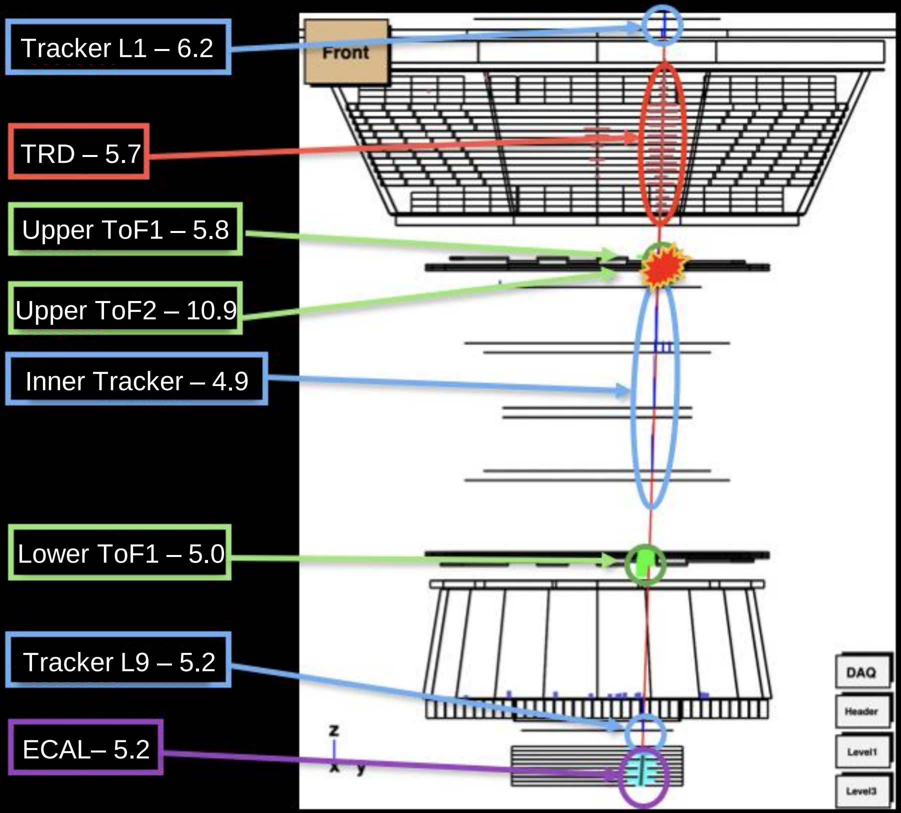
- TOF (4 Layers): Velocity and Direction

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

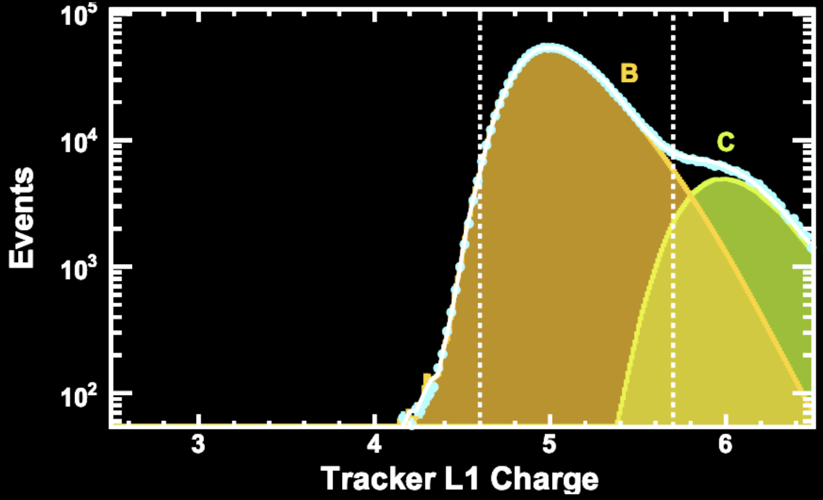
- Tracker (9 layers) + Magnet: Rigidity (Momentum/Charge)

	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

Residual Background



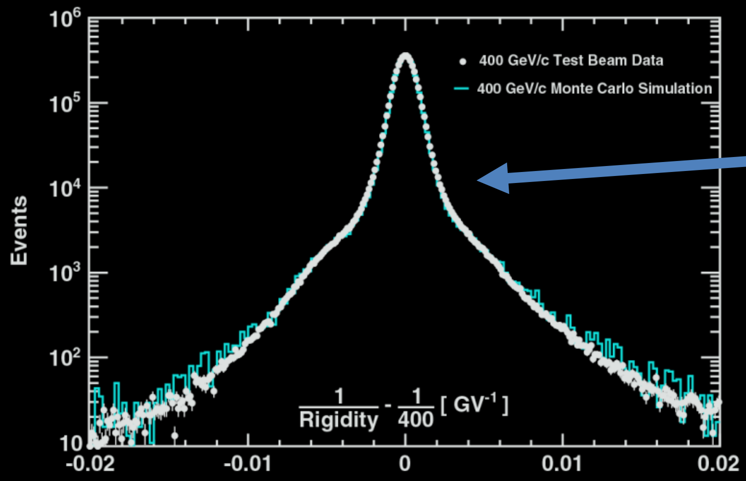
With the track defined by the inner tracker (L2-L8), examine the charge distribution on the tracker L1. The high redundancy of charge measurements allows to keep under control interactions in the upper part of the detector (between Tracker L1 and L2)



Rigidity Measurement

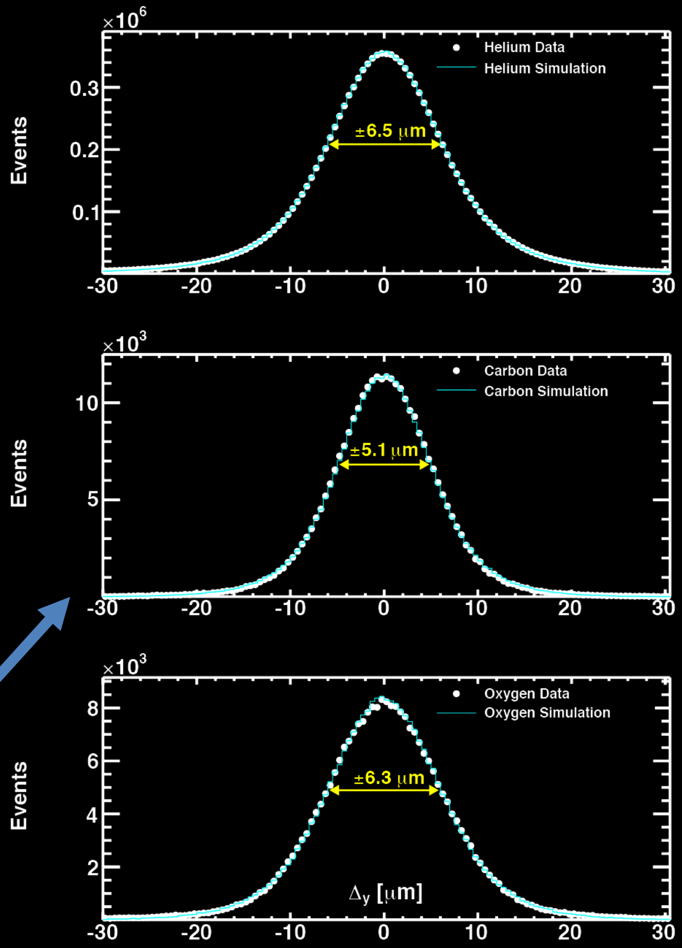
One important source of systematic uncertainties is the knowledge of the rigidity measurement.

This affects both the energy scale of the AMS spectrometer and the bin-to-bin migrations due to the spectrometer resolution.



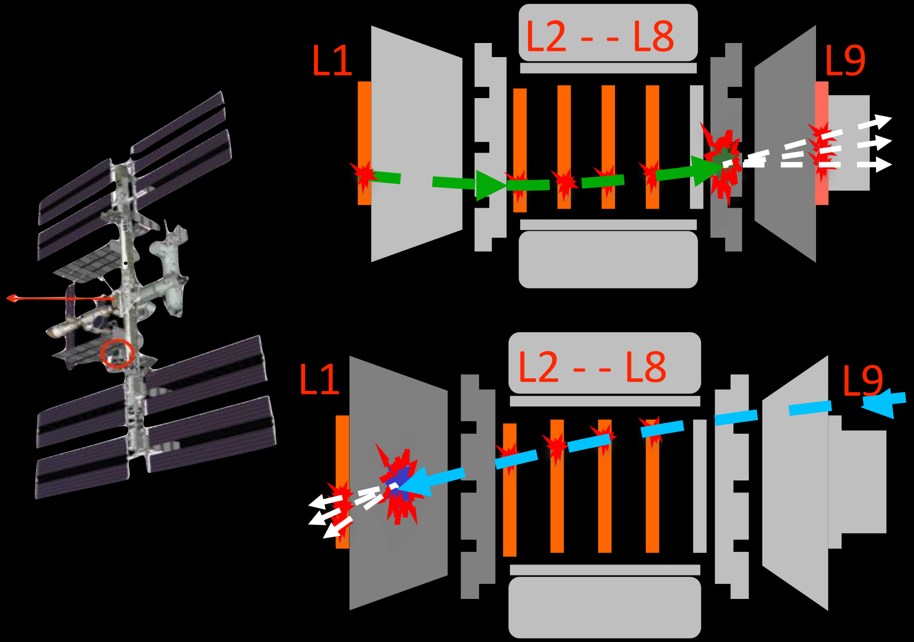
For protons the resolution function has been measured on the 400GV SPS beam.

For heavier nuclei it can be validated with the MC simulation by examining the spatial resolution of the silicon sensors.



Nuclear cross section measurement with AMS

Knowledge of nuclei interaction cross sections in the AMS material (mostly carbon and aluminum) crucial to accurately measure nuclei fluxes.
Inelastic cross sections data available only for few target and projectiles. No measurement beyond 10 GV.
We measure the survival probabilities of nuclei with in-flight AMS data. *Q.Yan et. al.*, Nucl. Phys. A 996 121712 (2020)



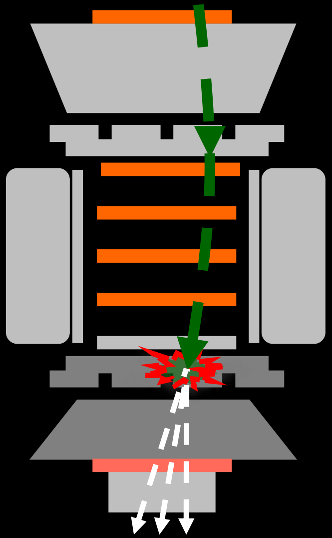
First, we use the seven inner tracker layers, L2-L8, to define beams of nuclei: He, Li, Be, B, …

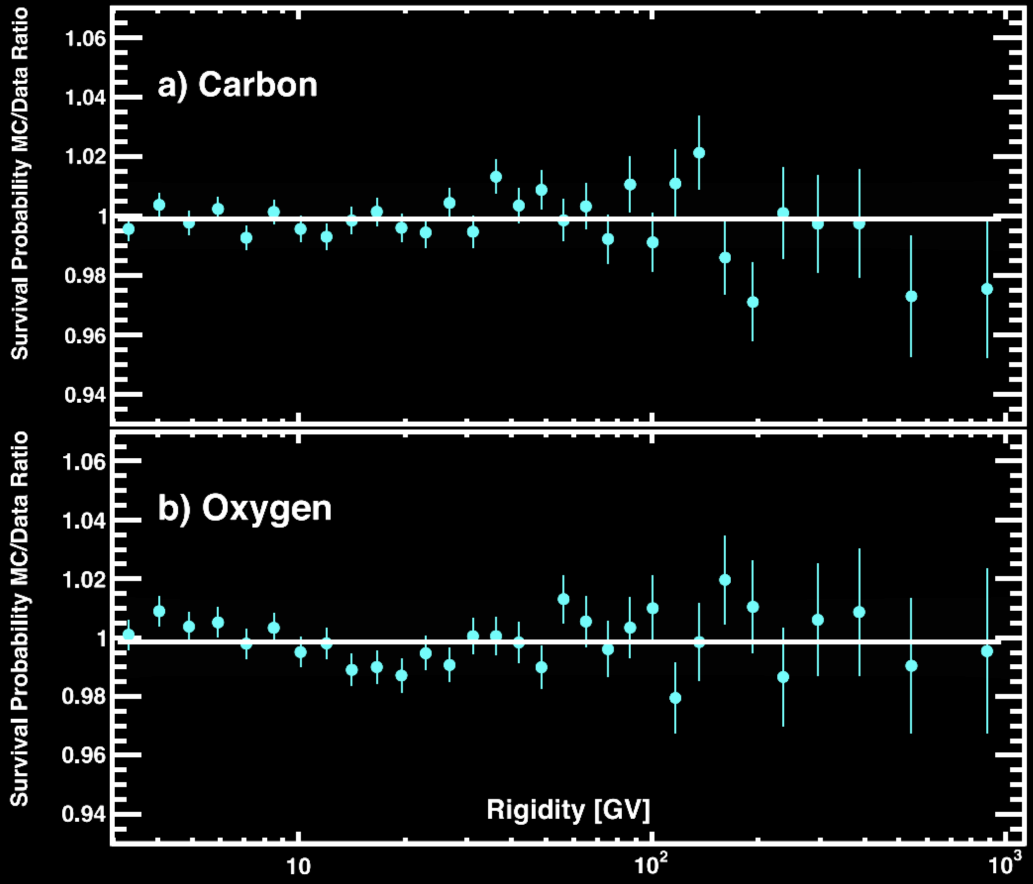
Second, we use left-to-right particles to measure the nuclear interactions in the lower part of the detector.

Third, we use right-to-left particles to measure the nuclear interactions in the upper part of detector.

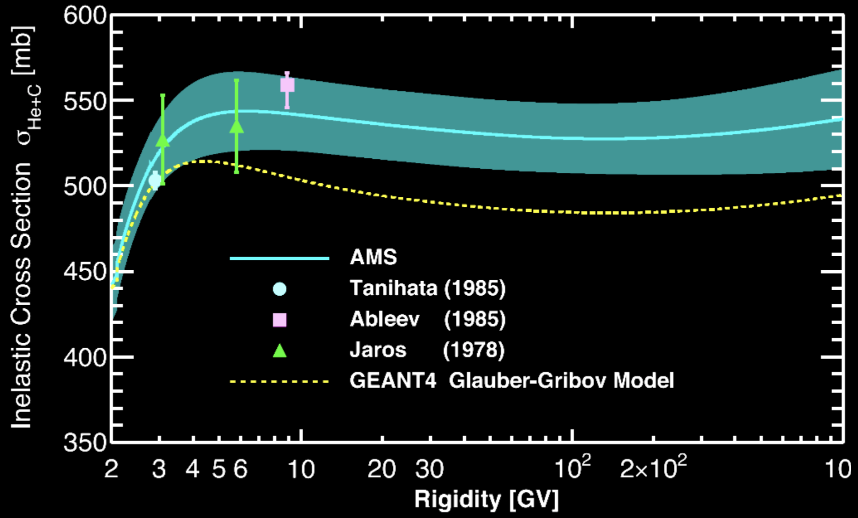
Nuclear cross section measurement with AMS

The measured “Survival probabilities” are then compared with the corresponding predictions from the MC simulation. The relevant cross-sections are then estimated from this procedure and corrected in the MC simulation.

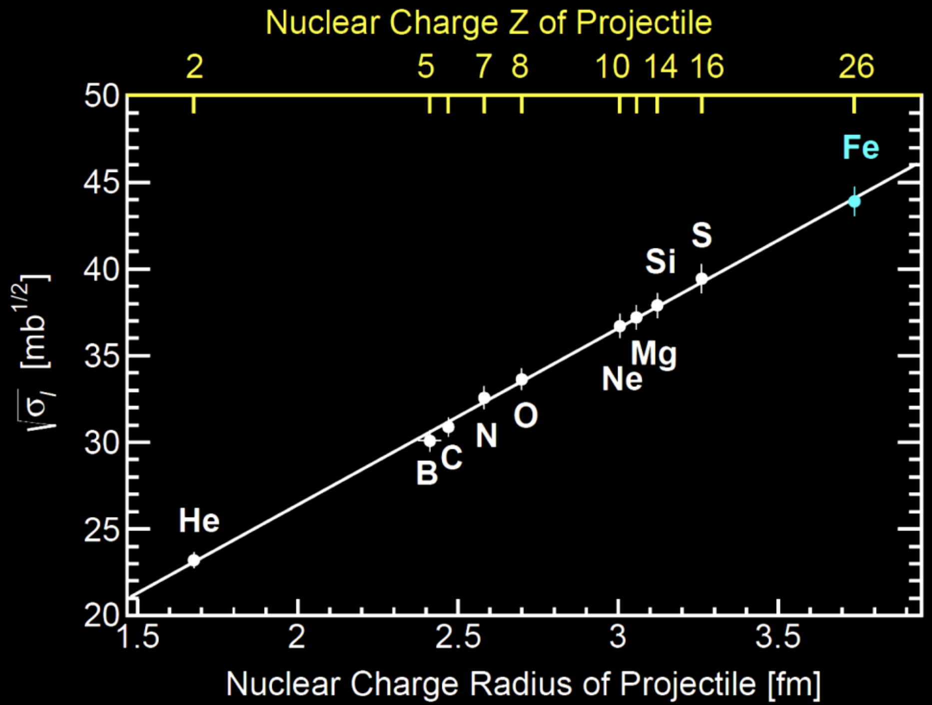




Nuclear cross section measurement with AMS



AMS result of the He+C cross section as a function of rigidity together with the original geant4 Glauber–Gribov model and measurements from ground-based accelerators.



With **L1-L2**and **L8-L9**survival probabilities, AMS can obtain the inelastic cross sections of many other nuclei on **C (Al)**.

Nuclear cross section measurement with AMS

The cross-sections are studied at the level of the single nuclear branching-factor thanks, again, to the high redundancy in the charge measurements in AMS. *Q.Yan et. al.*, Nucl. Phys. A 996 121712 (2020)