New Properties of Primary and Secondary Cosmic Rays measured by AMS

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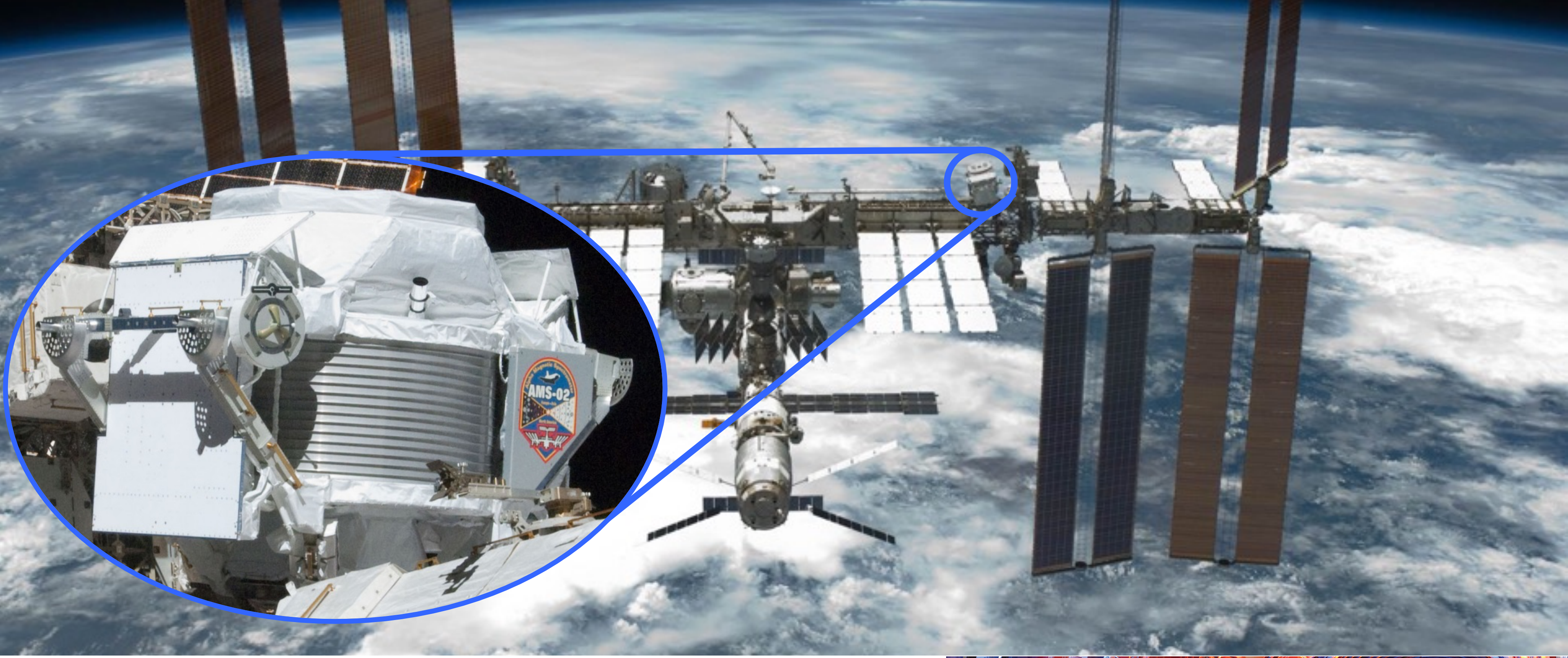
(DPNC - University of Geneva, Switzerland)

on behalf of the AMS Collaboration



UNIVERSITÉ DE GENÈVE

FACULTÉ DES SCIENCES

Département de physique nucléaire et corpusculaire

ICHEP 2020 | PRAGUE

40th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

VIRTUAL CONFERENCE

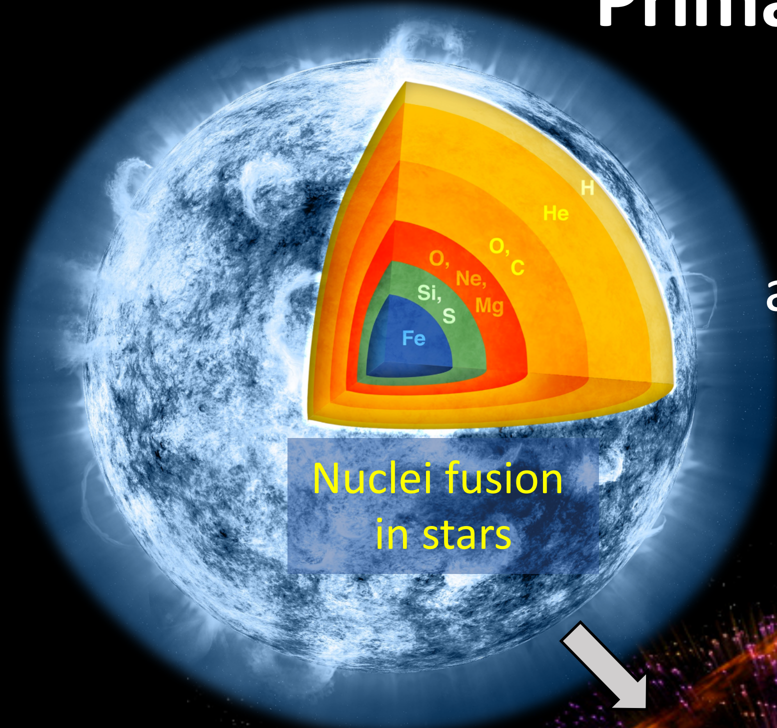
28 JULY - 6 AUGUST 2020

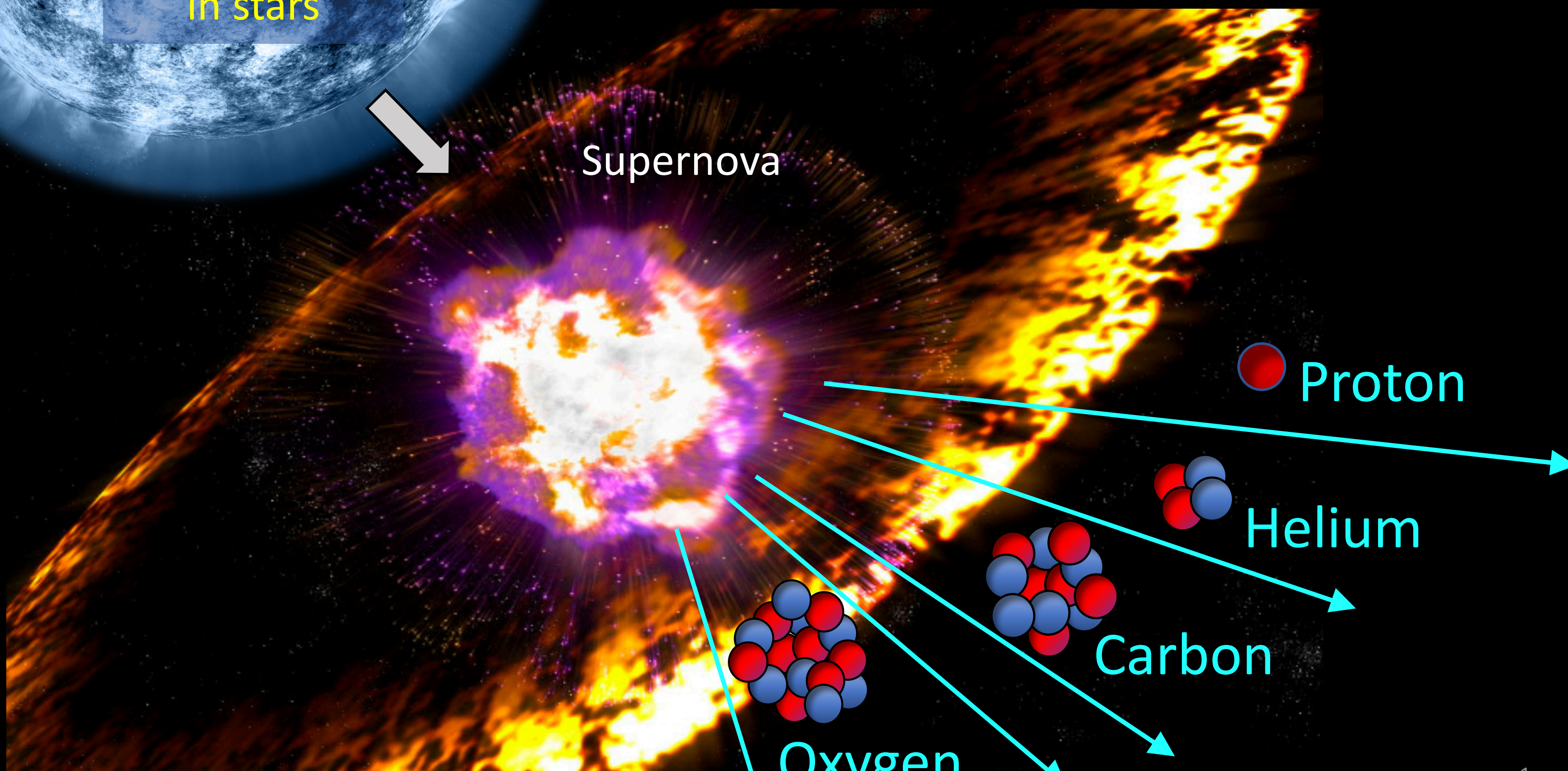
PRAGUE, CZECH REPUBLIC

July 28th 2020

Primary Cosmic Rays

Primary elements
(H, He, C, O, Ne, Mg, Si..., Fe)
are produced during the lifetime of stars.
They are accelerated in
supernovae explosions.





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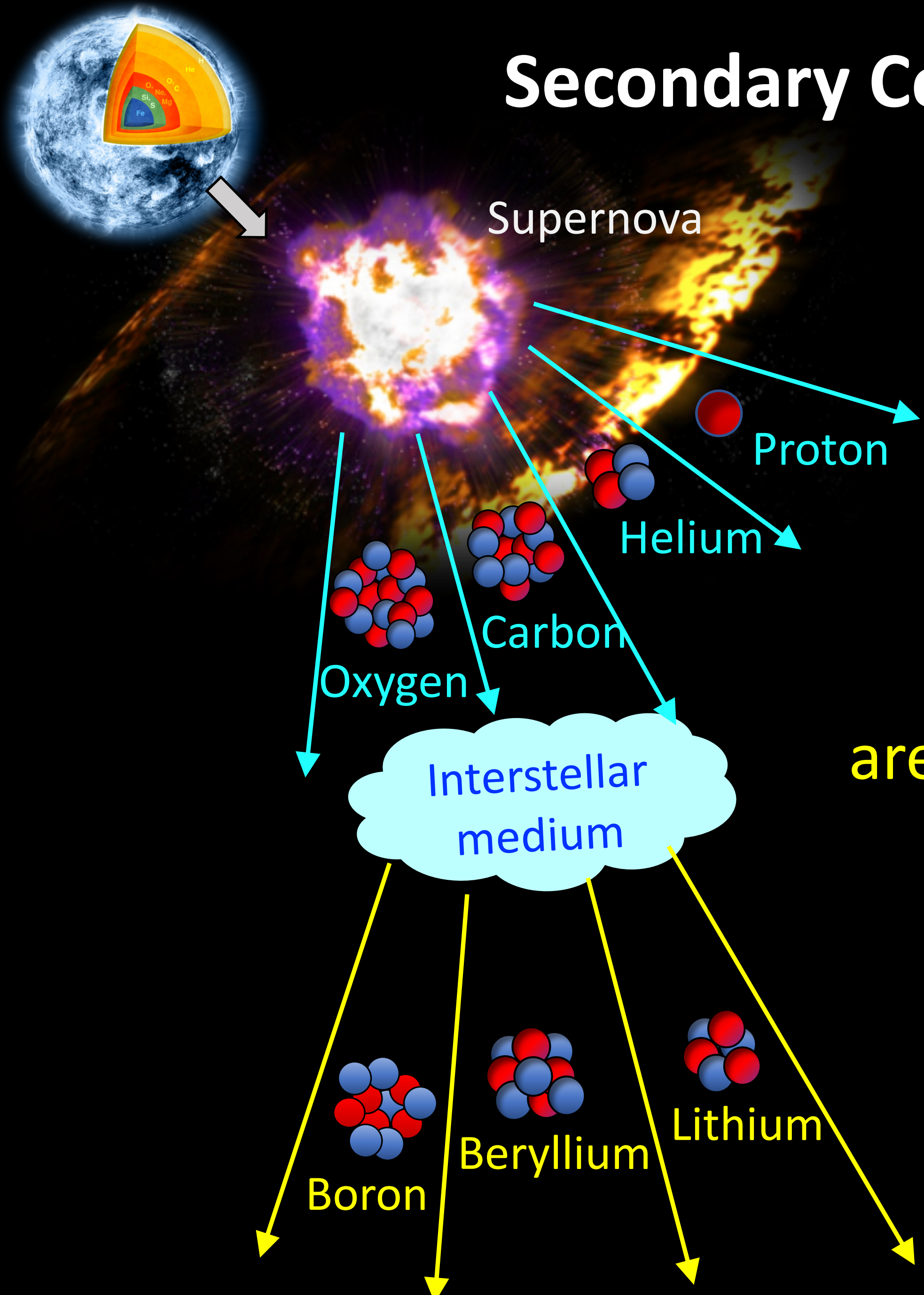
Secondary Cosmic Rays

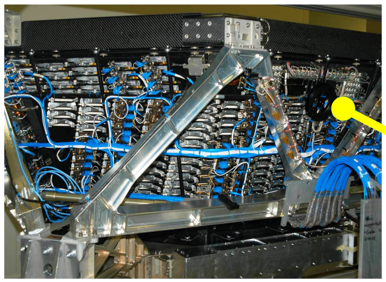


Secondary cosmic nuclei
(Li, Be, B, ...)
are produced by the collision of
primary cosmic rays and
interstellar medium

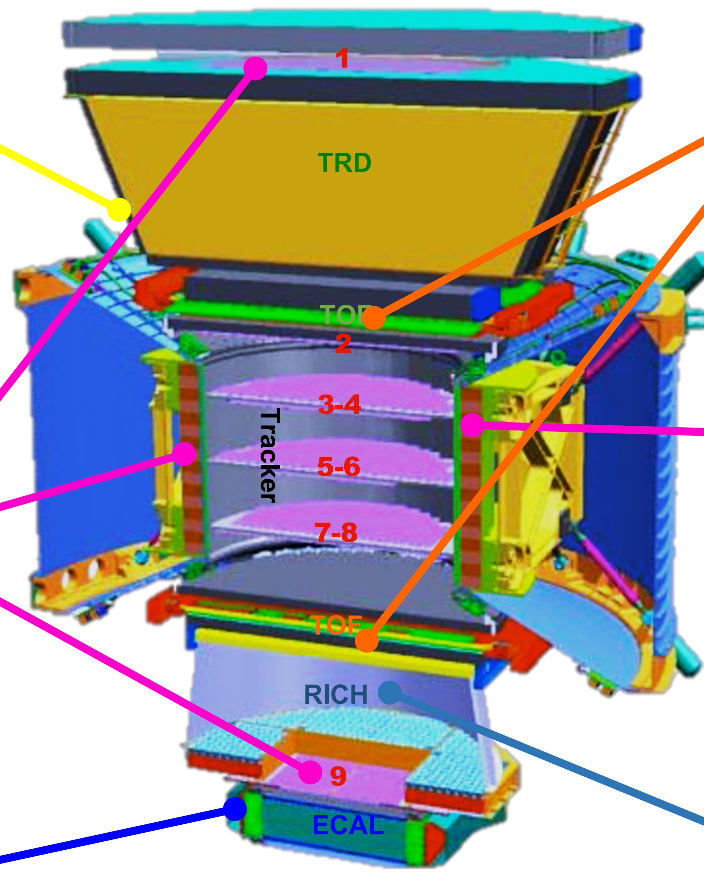
AMS-02: A TeV precision magnetic spectrometer

Particles and nuclei are defined by their charge Z and energy ($E \approx p \approx \beta$)

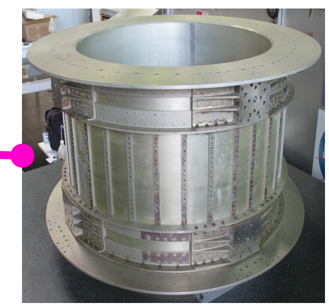
Transition Radiation Detector
Identifies e^+, e^-



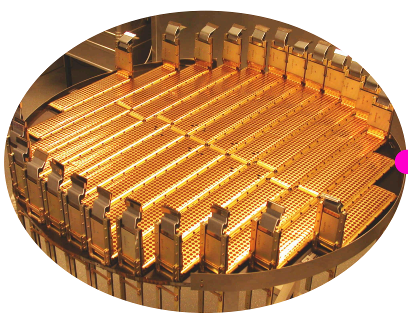
Time Of Flight
Z, β



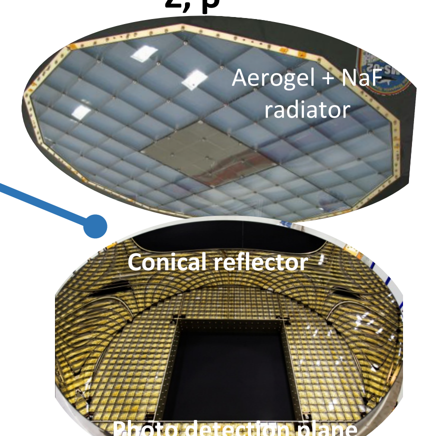
Magnet
$\pm$Z



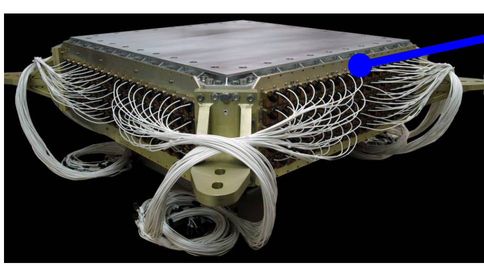
Silicon Tracker
Z, Rigidity=p/Ze



Ring Imaging Cherenkov
Z, β



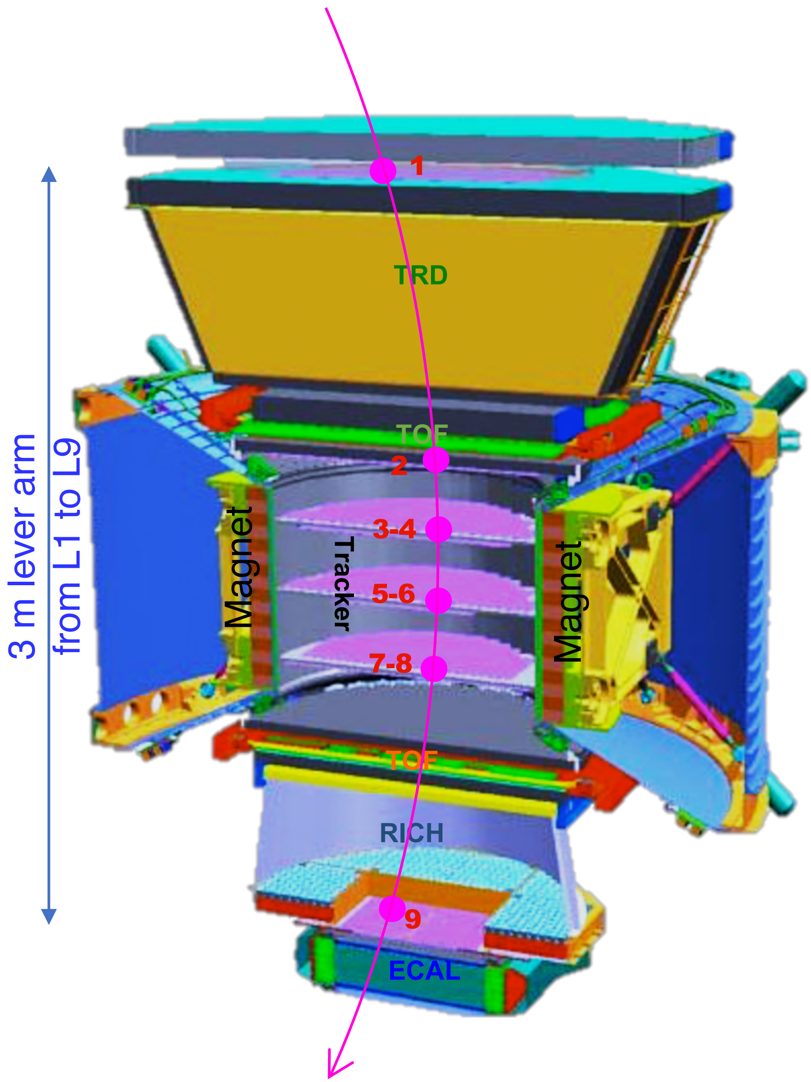
Electromagnetic Calorimeter
Energy of e^+, e^-



Charge Z and energy ($E \approx p \approx \beta$) are measured independently by Tracker, TOF, RICH, ECAL

Rigidity determination

Tracker: 9 layers of silicon tracking detectors
+ Permanent Magnet



$$Rigidity = \frac{p}{Z\,e}$$

Spatial resolution in the bending coordinate:

Particle Charge	Spatial resolution	Maximum Detectable Rigidity
$Z = 1$	$10\ \mu m$	$2\ TV$
$2 \leq Z \leq 8$	$5 \div 7\ \mu m$	$3.2 \div 3.7\ TV$
$9 \leq Z \leq 14$	$6 \div 8\ \mu m$	$3 \div 3.5\ TV$

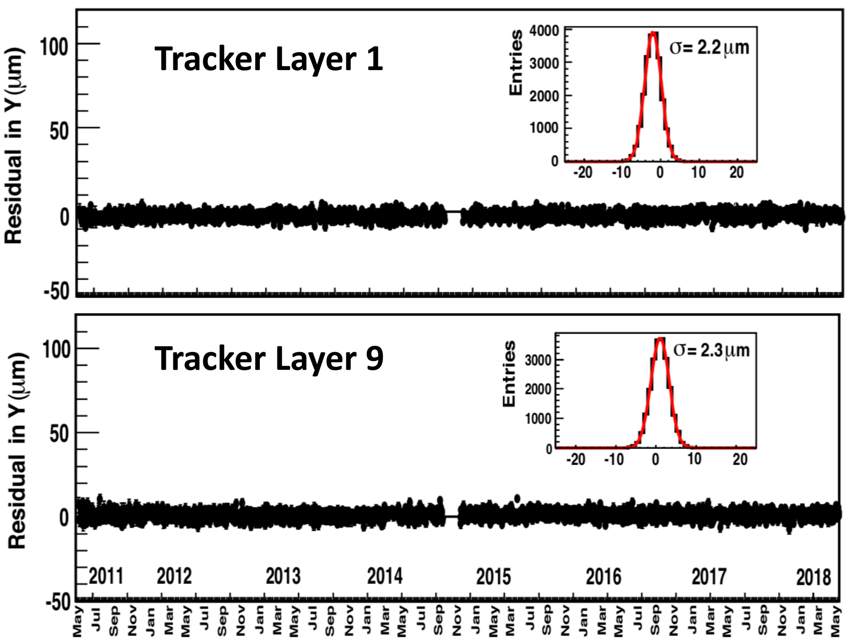
G.Ambrosi et al. NIM Phys. Res. Sect. A. 869, 29 (2017)

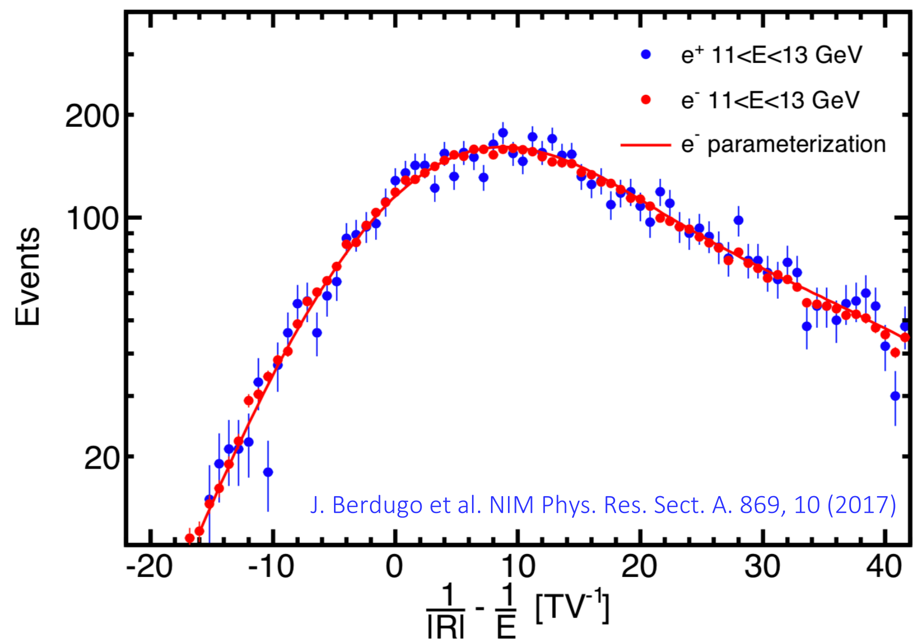
Absolute Rigidity scale determination

The determination of the absolute rigidity scale is crucial for the accuracy of the flux measurement at the highest energies.

The positions of the external tracker layer, L1 and L9, are aligned in flight using cosmic ray protons every 2 minutes. They are stable to 2÷3 μm.

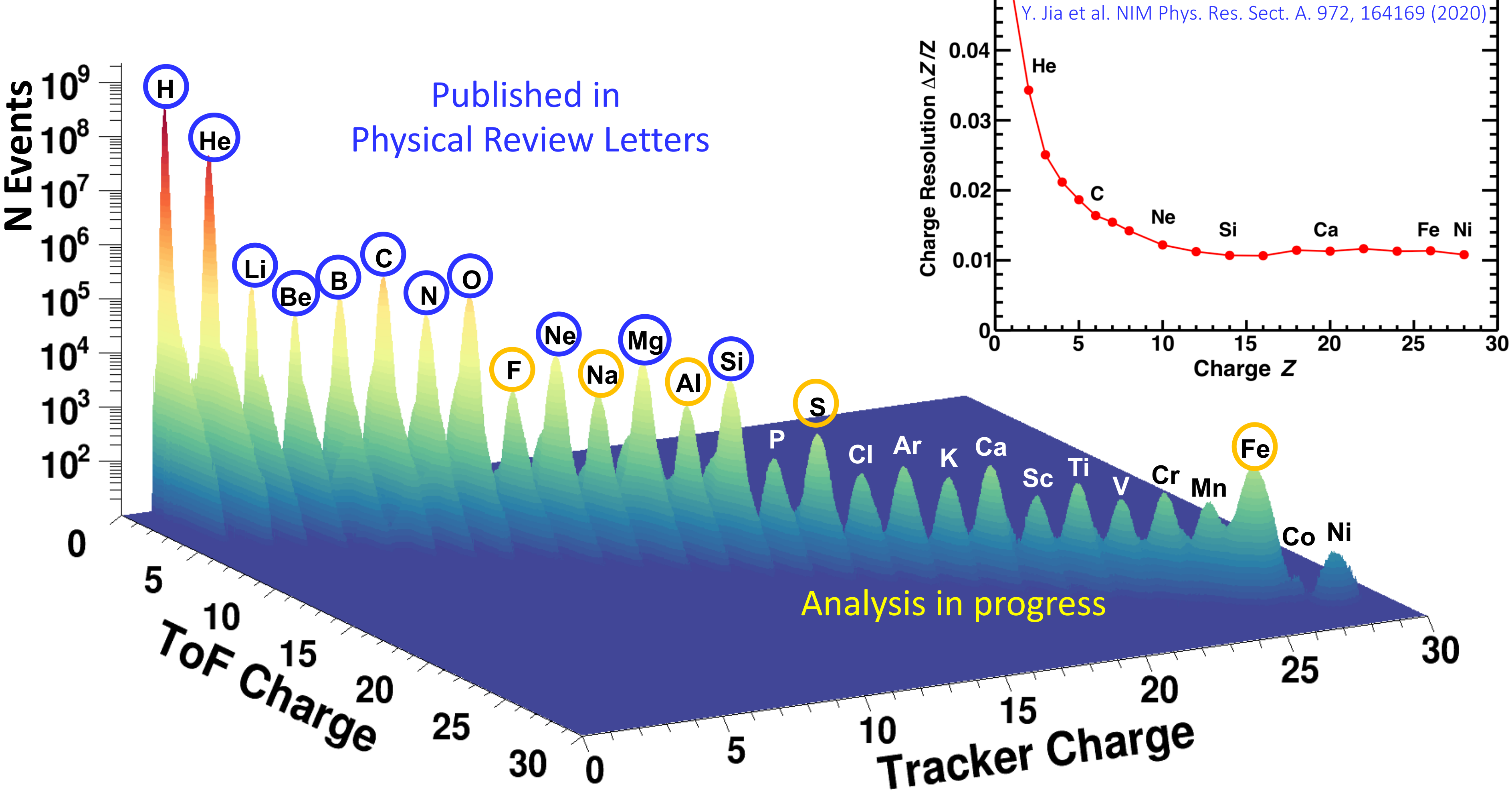
The in-flight rigidity scale shift and its uncertainty are obtained comparing the inverse rigidity 1/|R| to the energy measured by ECAL 1/E for electrons and positrons. The rigidity scale shift is determined with an accuracy of 3% at 1 TV.





Nuclei identification with AMS

Charge from dE/dx in the Tracker and TOF layers



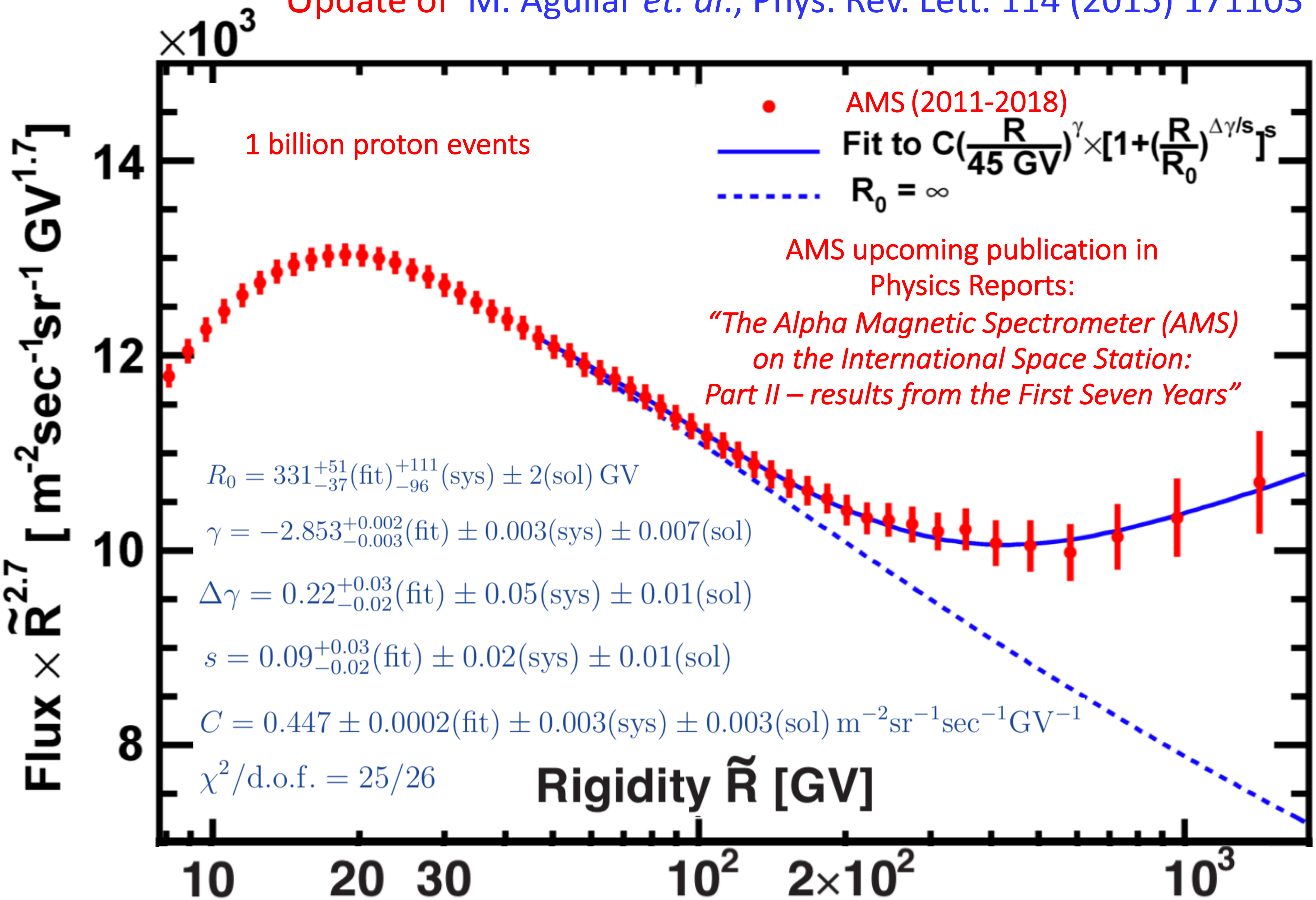
AMS has collected > 160 billion cosmic rays as of today. We have updated the nuclei fluxes measurements with the 7-years dataset, publication submitted to Physics Reports.

This talk: H to Oxygen

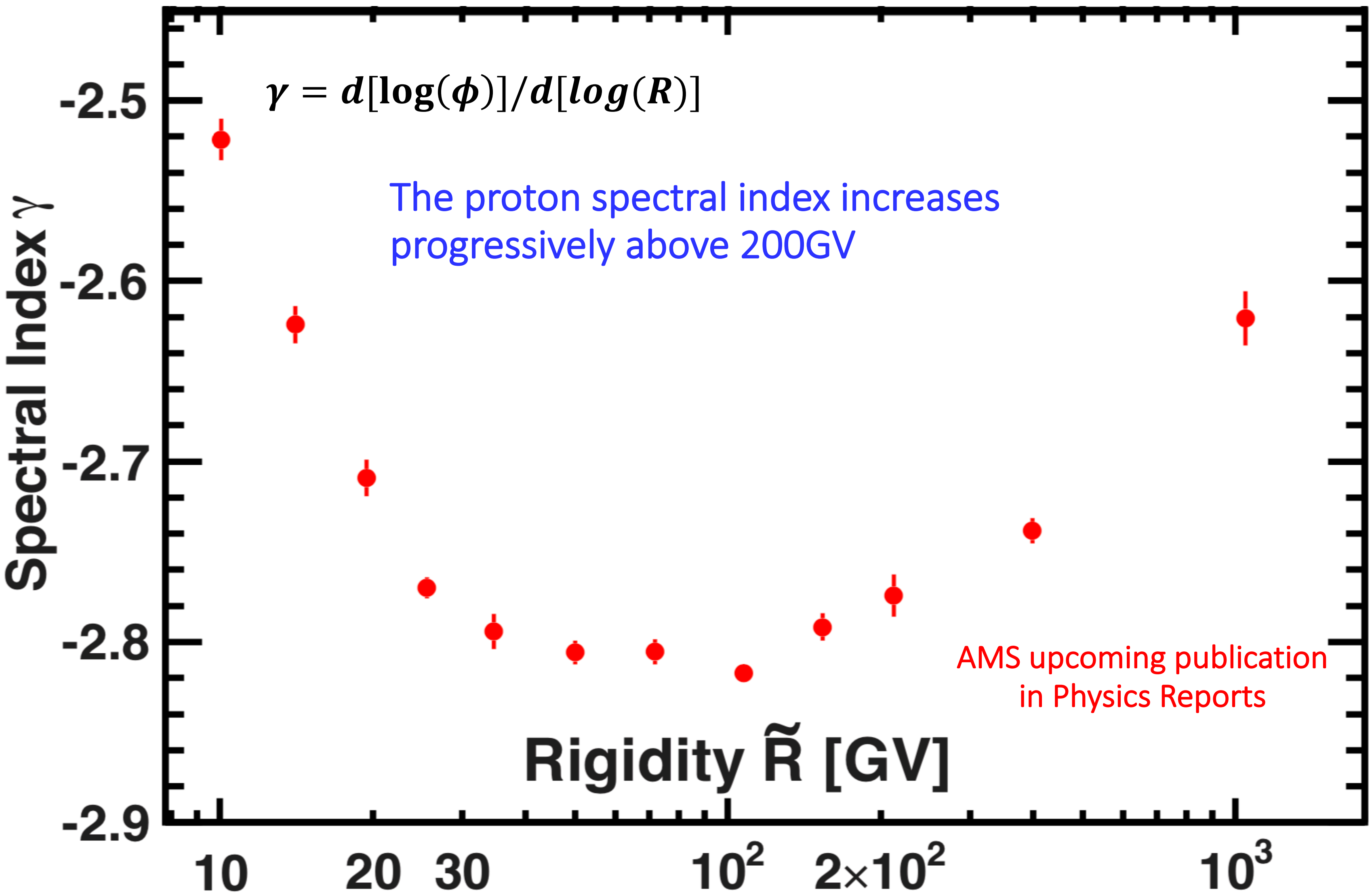
Ne, Mg, Si: Qi Yan's talk

AMS-02 Proton spectrum – first 7 years (2011-2018)

Update of M. Aguilar *et. al.*, Phys. Rev. Lett. 114 (2015) 171103



AMS-02 Proton spectrum – first 7 years (2011-2018)



Nuclear cross section measurement with AMS

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

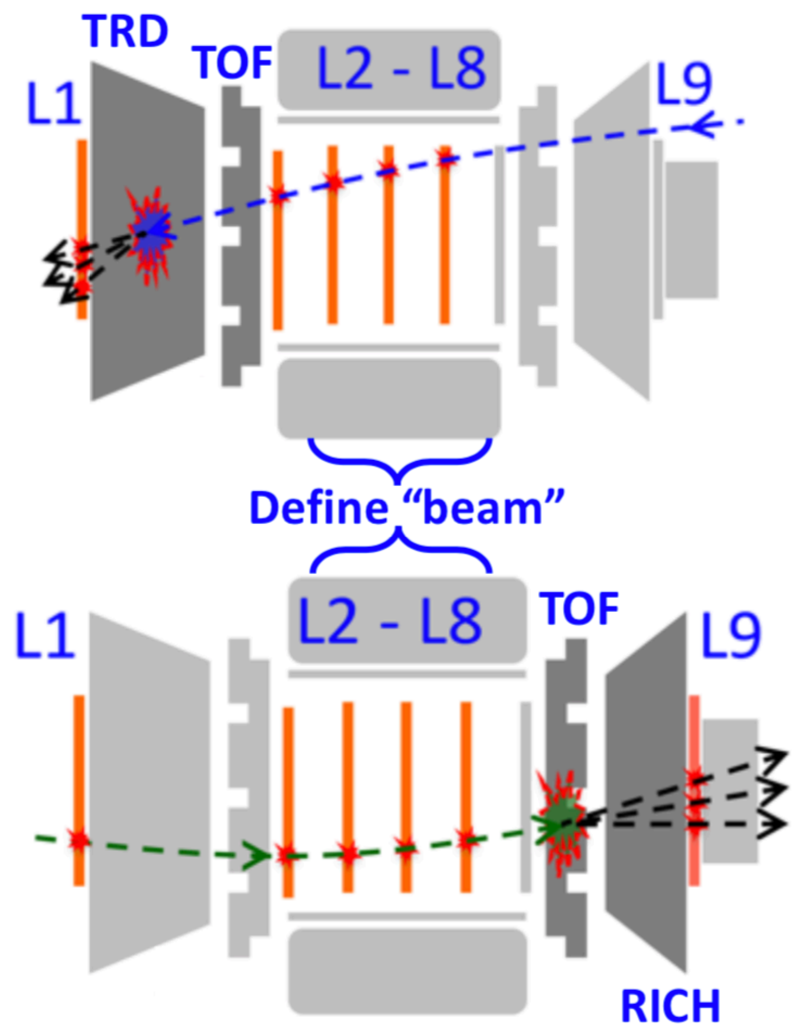
Knowledge of nuclei interaction cross sections in the AMS material (mostly carbon and aluminum) crucial to accurately measure nuclei fluxes.

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.

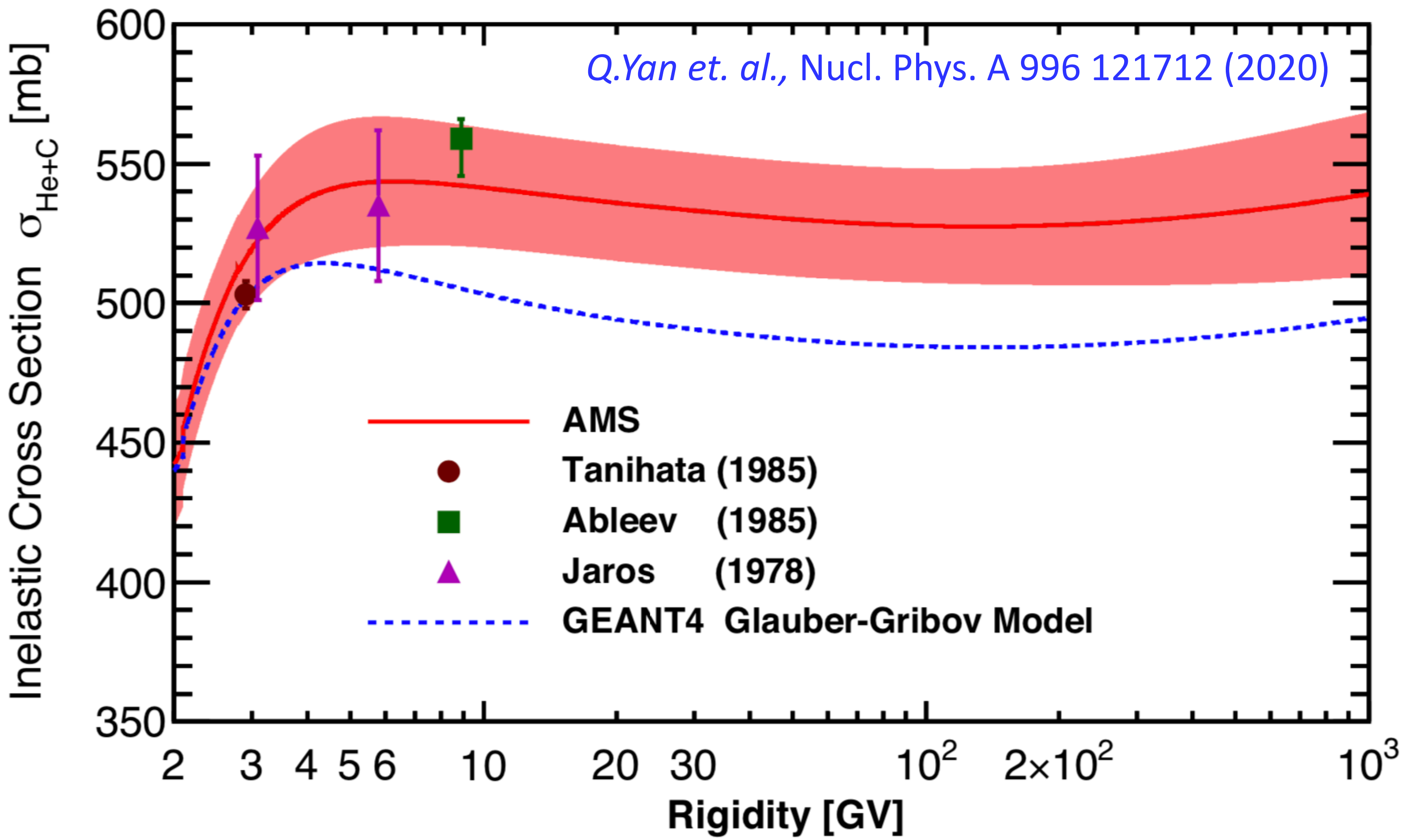
Survival probabilities in the upper AMS material (upper TOF + TRD) , from L2 to L1, are measured for the most abundant nuclei (light) when the ISS was flying horizontally, when CRs can enter from L9, righ-to-left (0.13% of total exposure time).

Survival probabilities in the lower AMS material (lower TOF + RICH), from L8 to L9, are also measured in normal operation conditions.



Nuclear cross section measurement with AMS

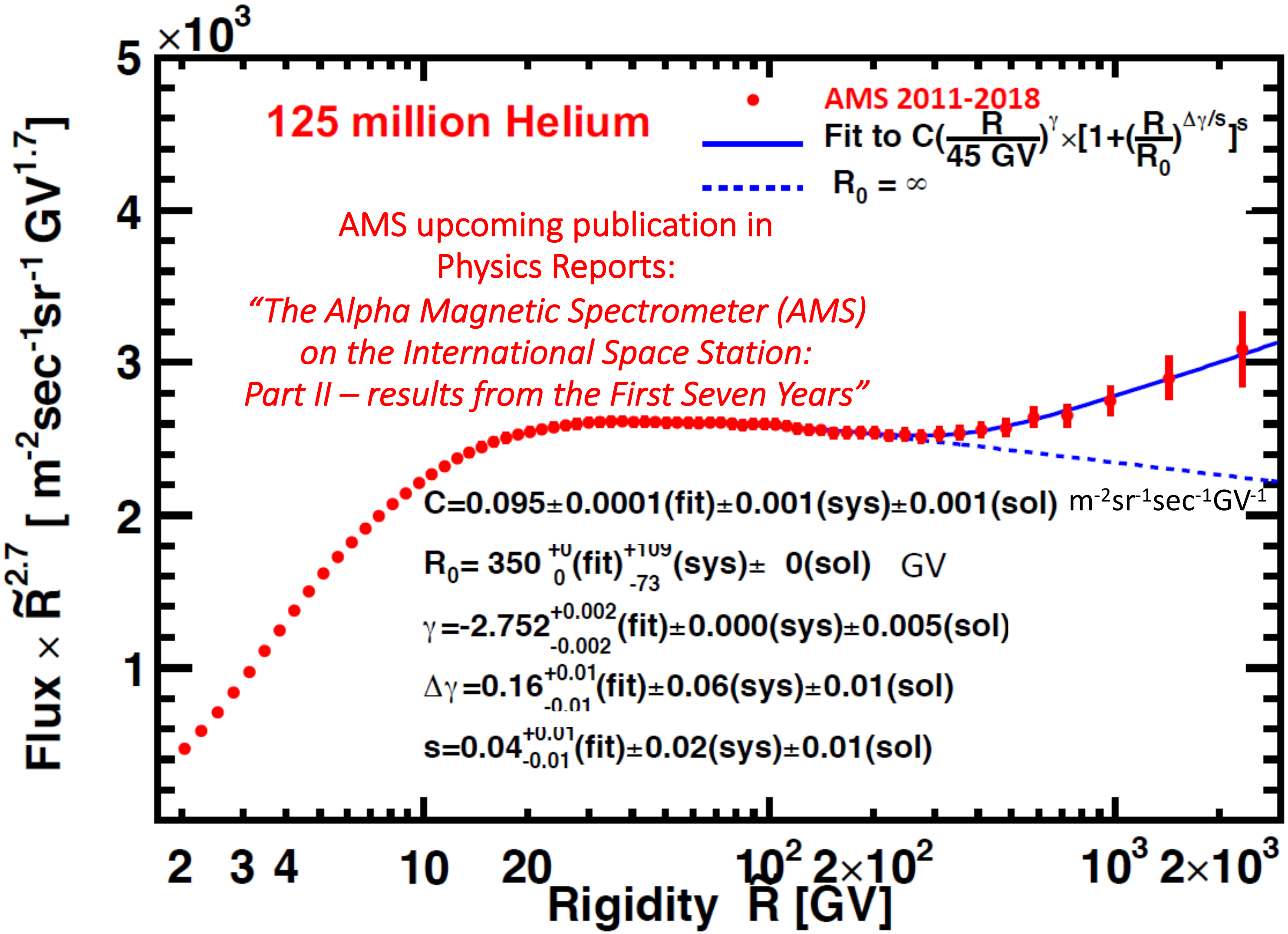
Dedicated Monte Carlo samples were simulated with the Glauber-Gribov model varying inelastic cross sections by $\pm$ 10%. The one which best agreed to our measurement was selected.



See Qi Yan's talk for heavier nuclei cross section measurements and modelisation.

AMS-02 Helium spectrum - first 7 years (2011-2018)

Update of M. Aguilar *et. al.*, Phys. Rev. Lett. 115 (2015) 211101



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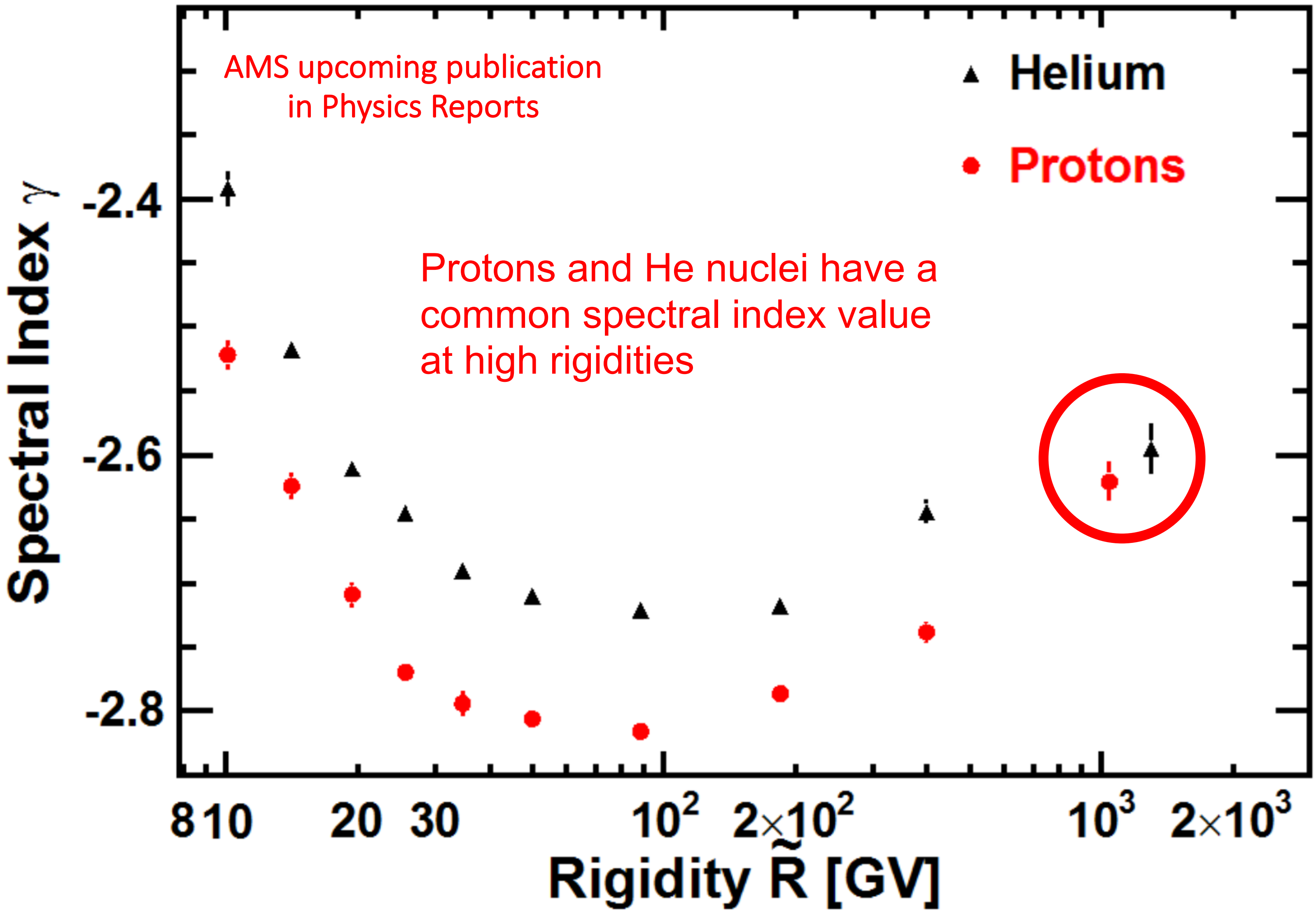
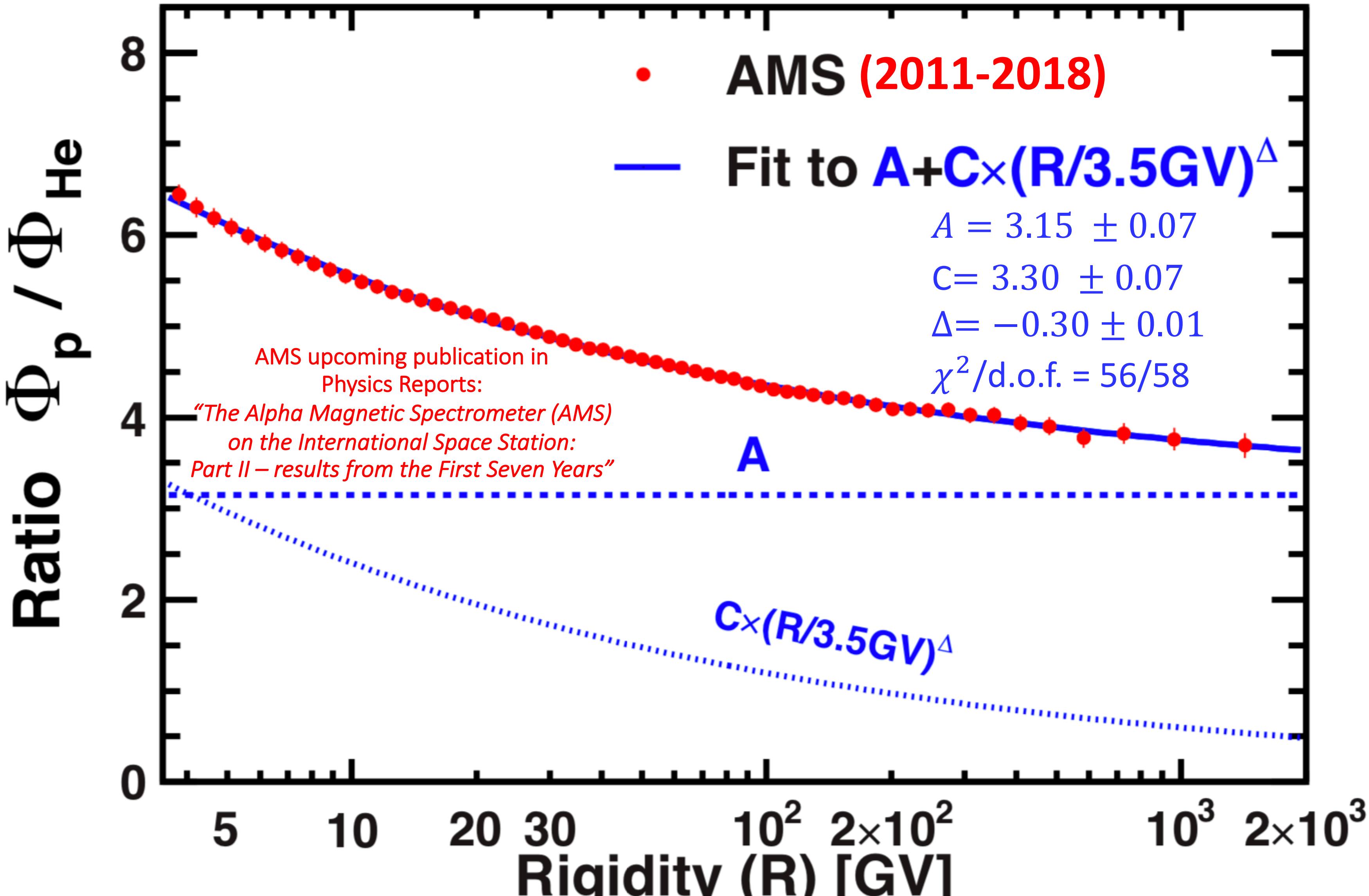
AMS-02 Helium spectrum - first 7 years (2011-2018)



AMS-02 proton to Helium ratio - first 7 years (2011-2018)

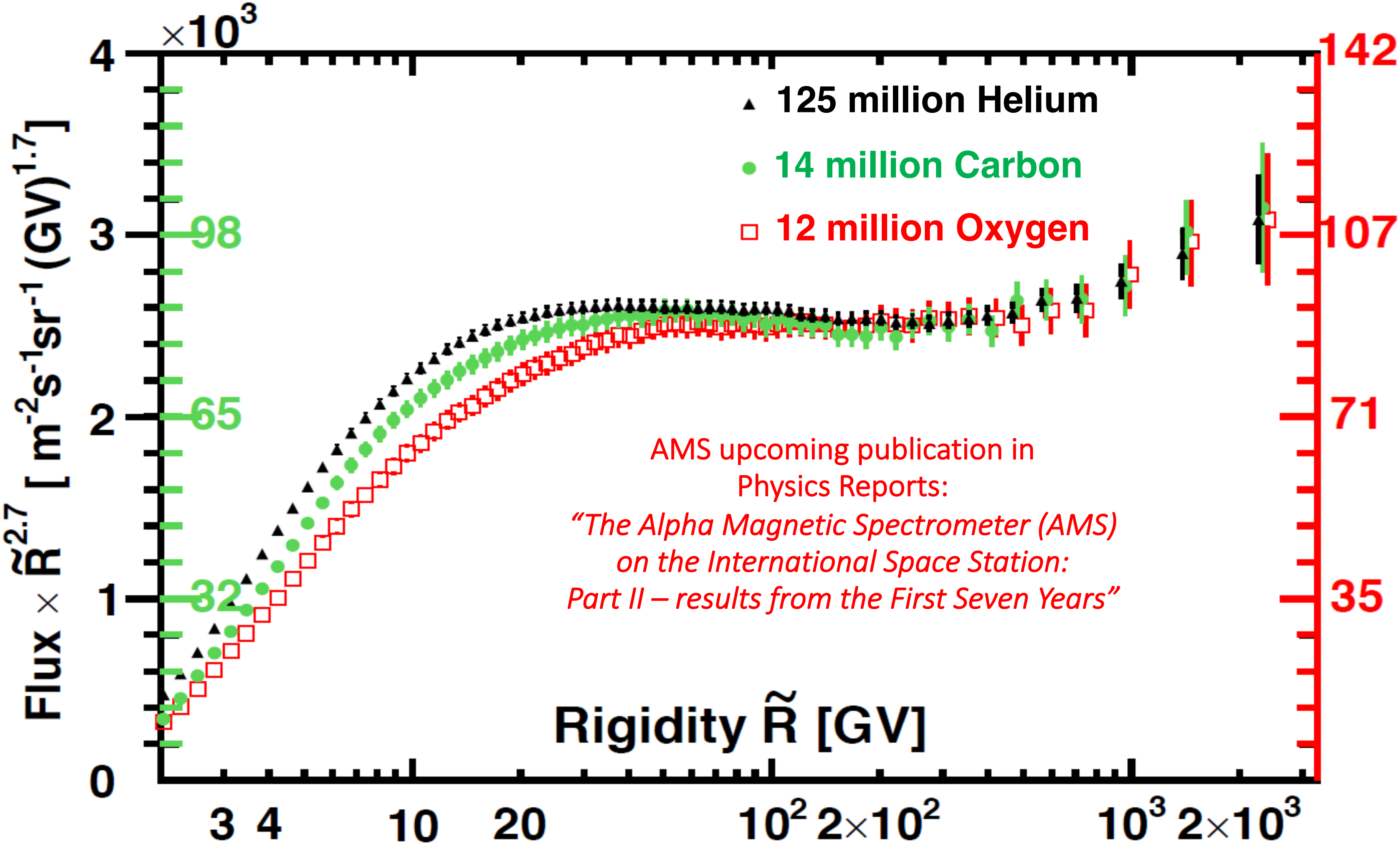
The proton-to-helium ratio decreases in the rigidity range from 1.9 GV to 1.8 TV.

The rate of decrease vanishes at high rigidity



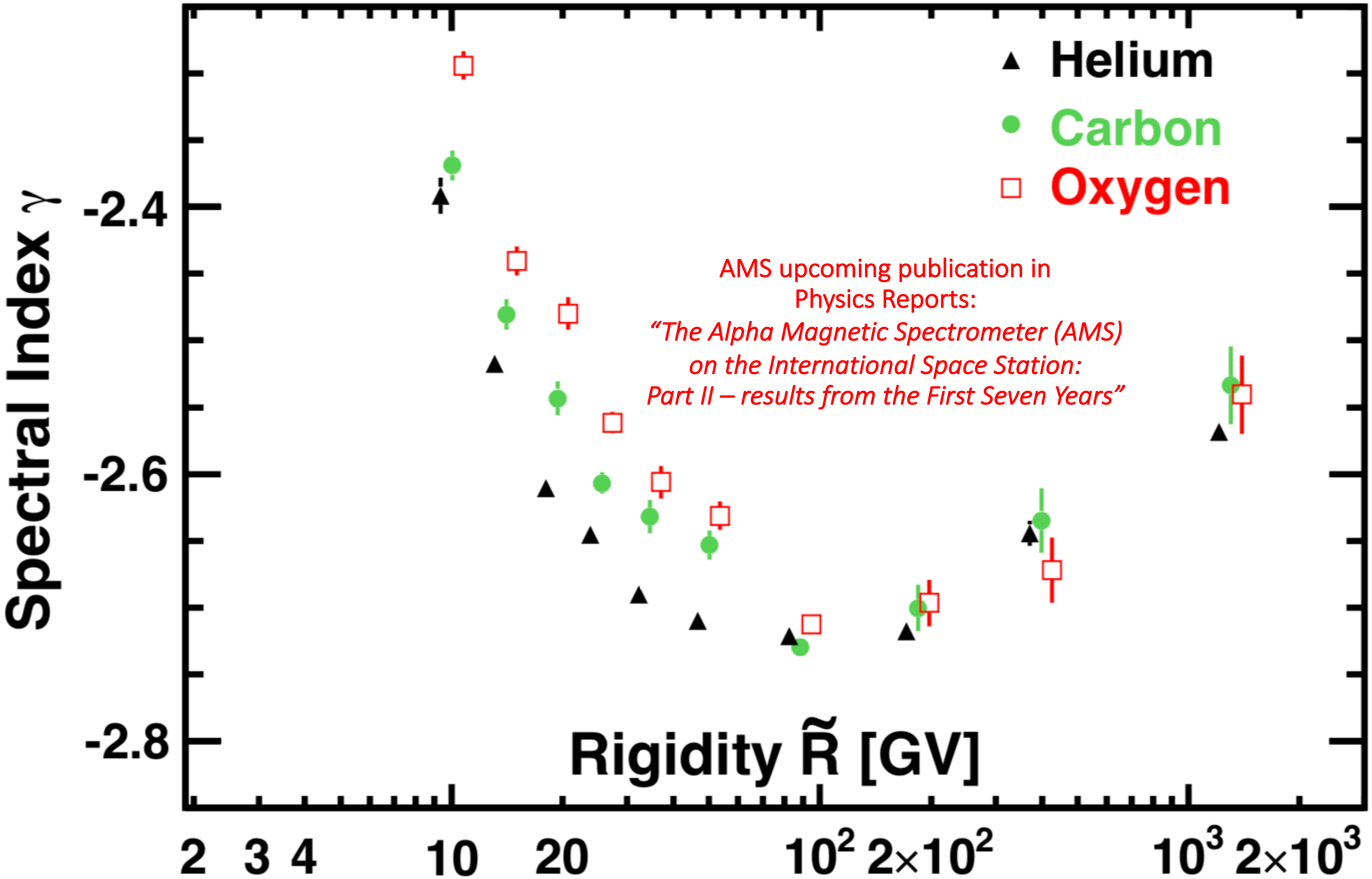
AMS-02 He, Carbon, and Oxygen spectra – first 7 years

Update of M. Aguilar *et. al*., Phys. Rev. Lett. 119 (2017) 251101



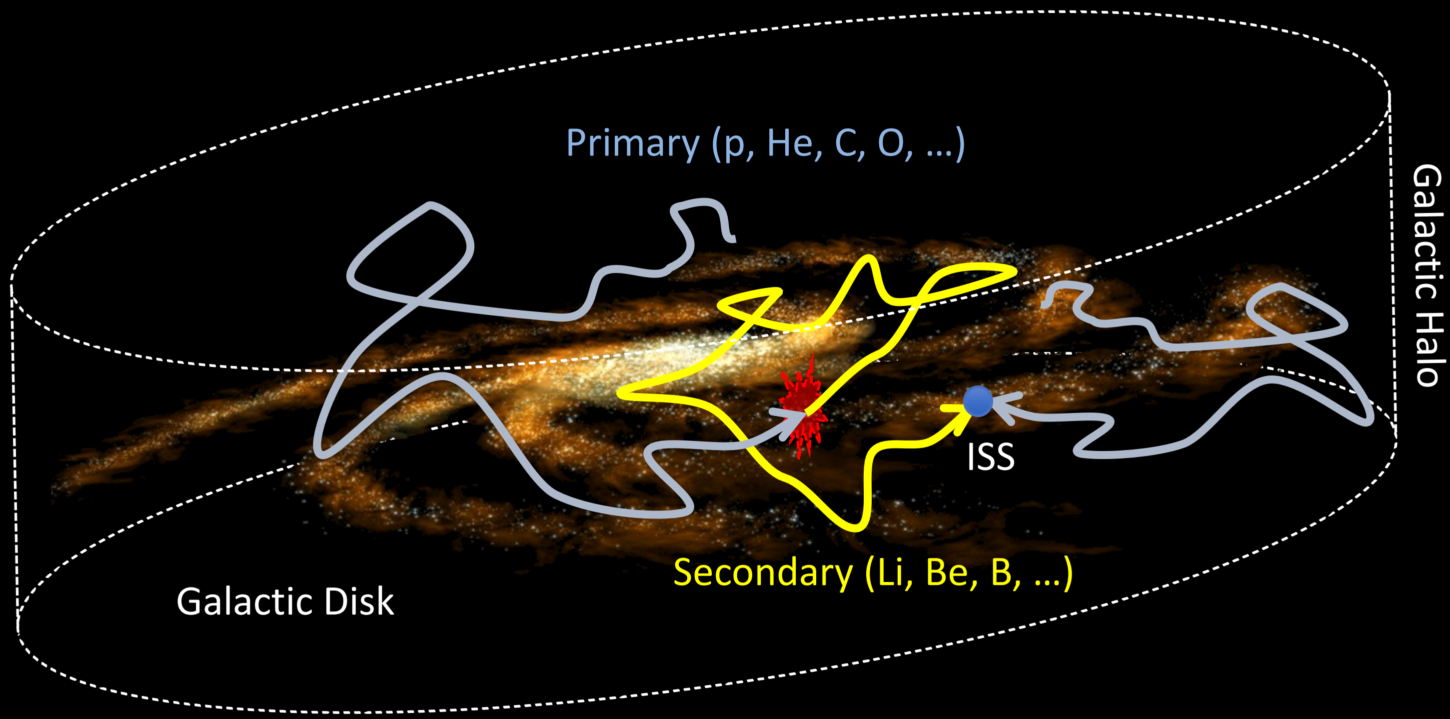
AMS-02 He, Carbon, and Oxygen spectral indices

He, C, and O spectral indices are identical above 60GV,
all harden with rigidity above 200GV



Secondary Cosmic Rays

Lithium, Beryllium and Boron are mostly produced from collision of primary cosmic rays, such as Carbon and Oxygen, with the interstellar medium (ISM).

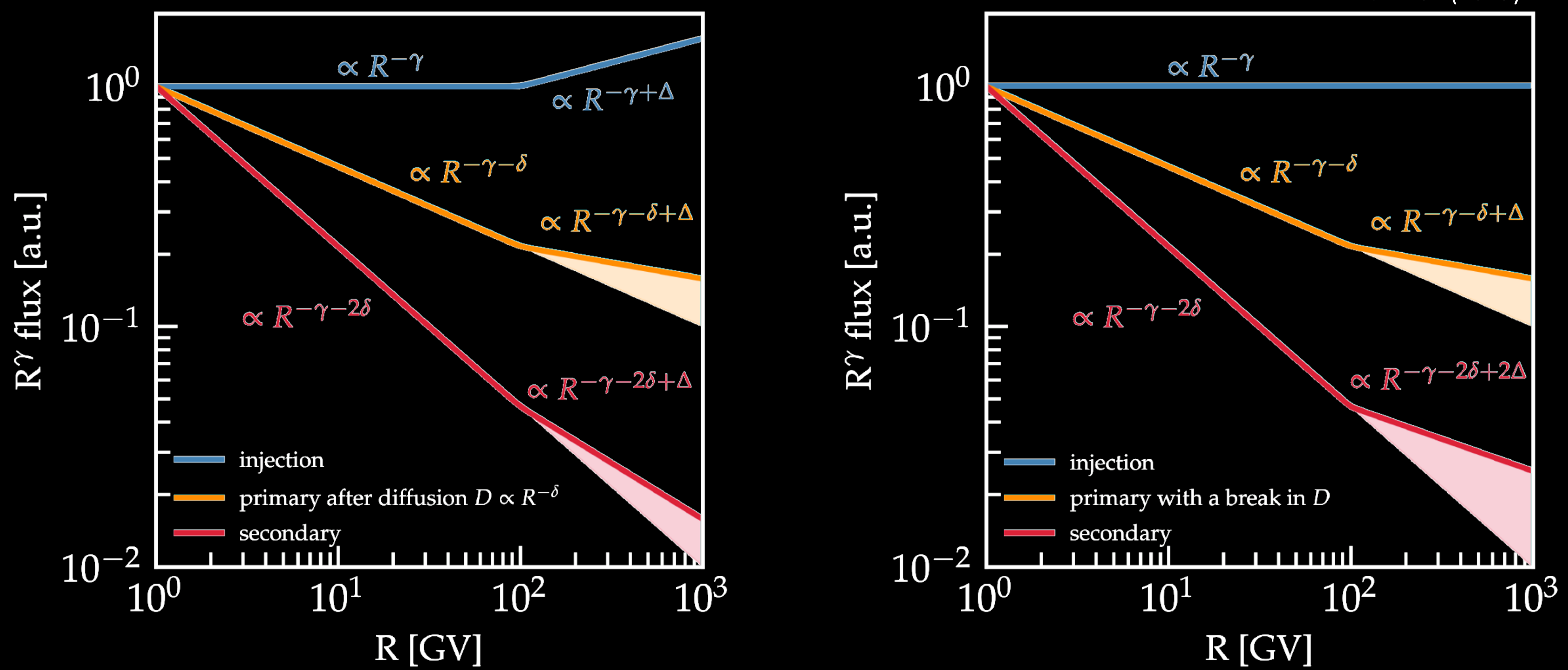


Cosmic rays are commonly modeled as a relativistic gas diffusing into a magnetized plasma. Diffusion models based on different assumptions predict a Secondary/Primary ratio asymptotically proportional to $\mathbf{R}^{\delta}$.

With Kolmogorov turbulence model a $\boldsymbol{\delta = -1/3}$ is expected, while Kraichnan theory leads to $\boldsymbol{\delta = -1/2}$.

Secondary Cosmic Rays and origin of spectral breaks

C. Evoli (2019)



If the hardening in CRs is related to the **injected spectra** at their source, then **similar hardening** is expected both for secondaries and primary cosmic rays.

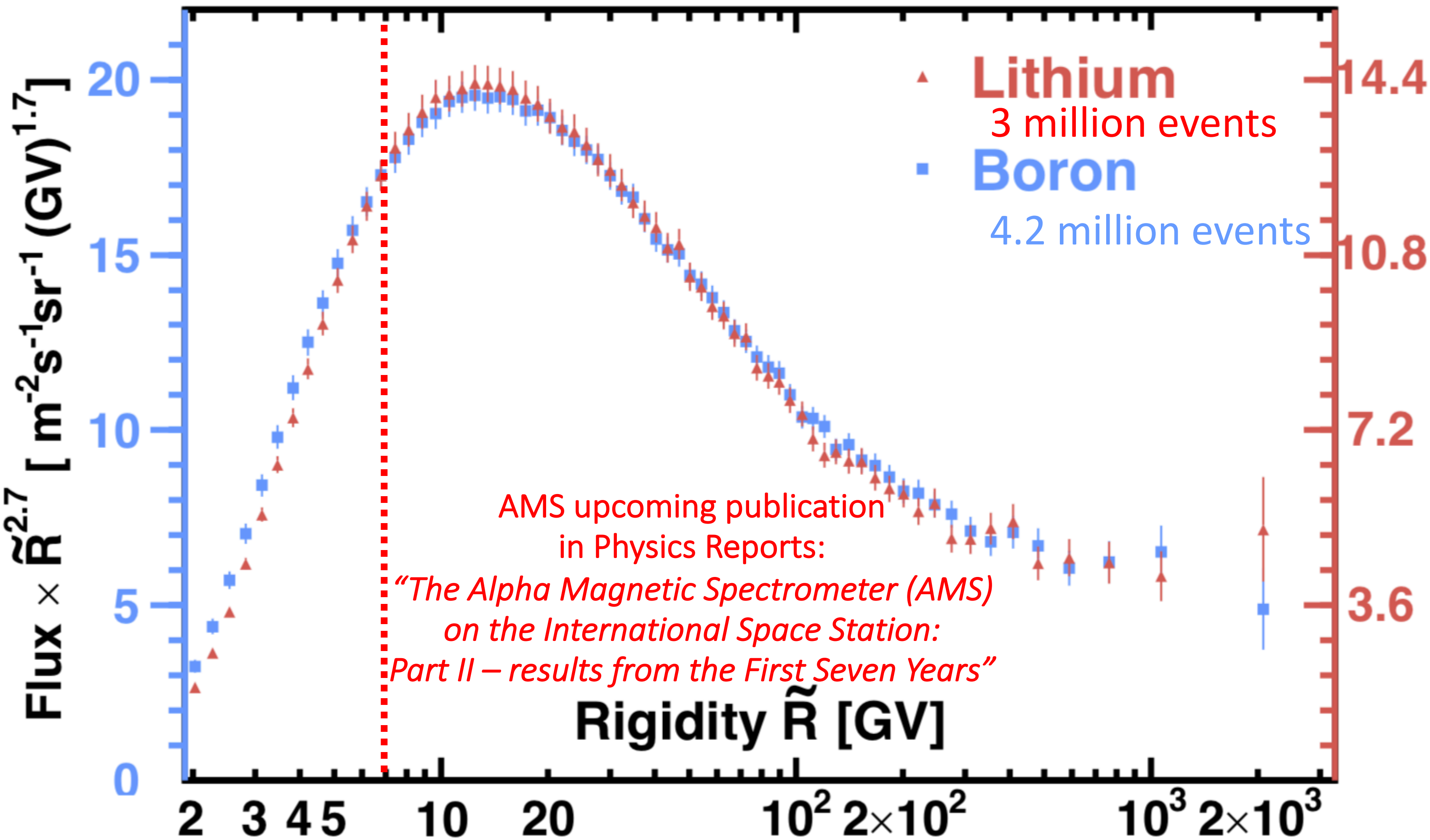
If the hardening is related to **propagation properties** in the Galaxy then a **stronger hardening** is expected for the secondary with respect to the primary cosmic rays.

See also Serpico *J. Astrophys. Astr.* (2018) 39-41

AMS-02 Lithium and Boron spectra – 7 years (2011-2018)

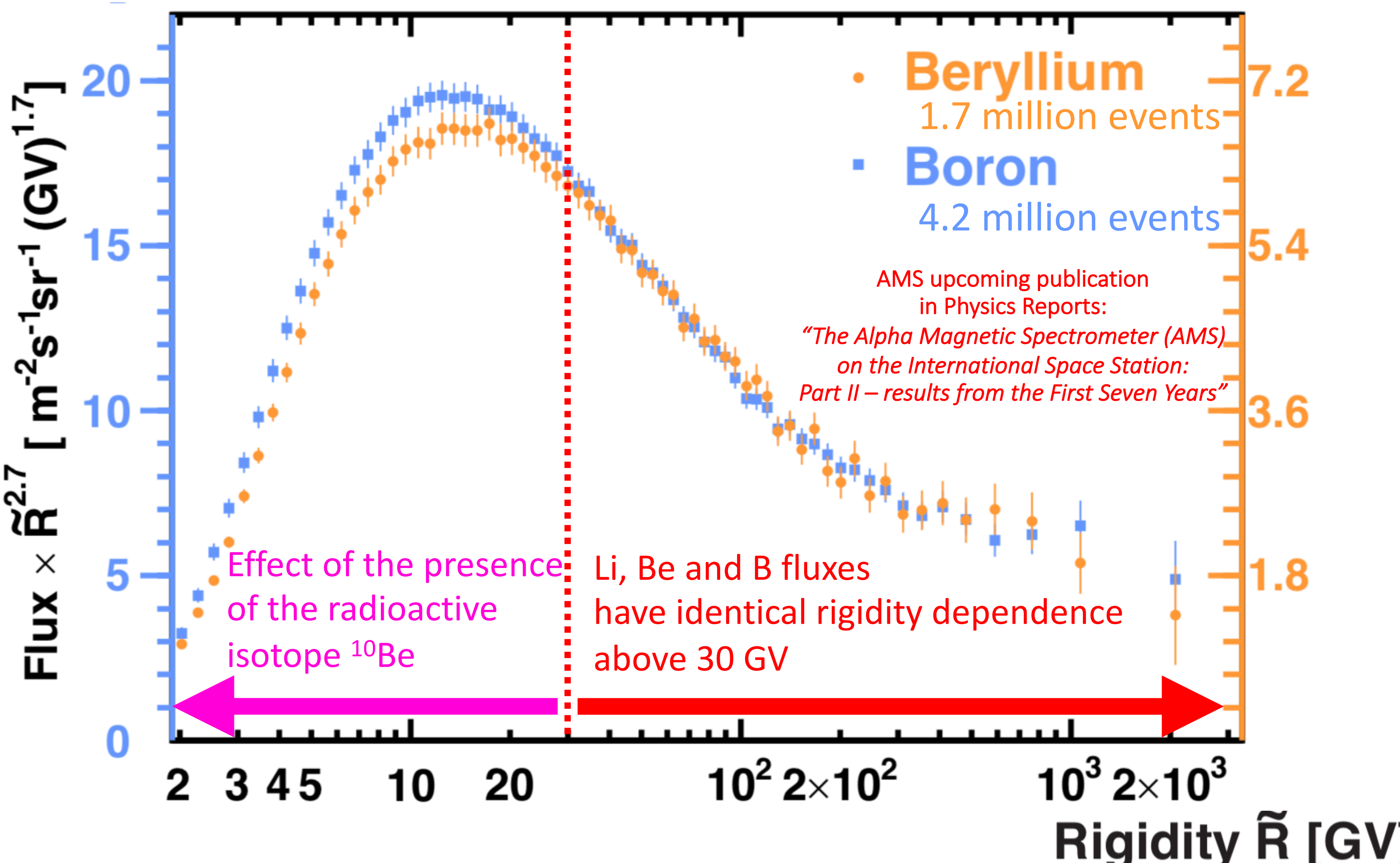
Update of M. Aguilar *et. al.*, Phys. Rev. Lett. 120 (2018) 021101

Lithium and Boron fluxes have identical rigidity dependence above 7 GV



AMS-02 Beryllium and Boron spectra – 7 years (2011-2018)

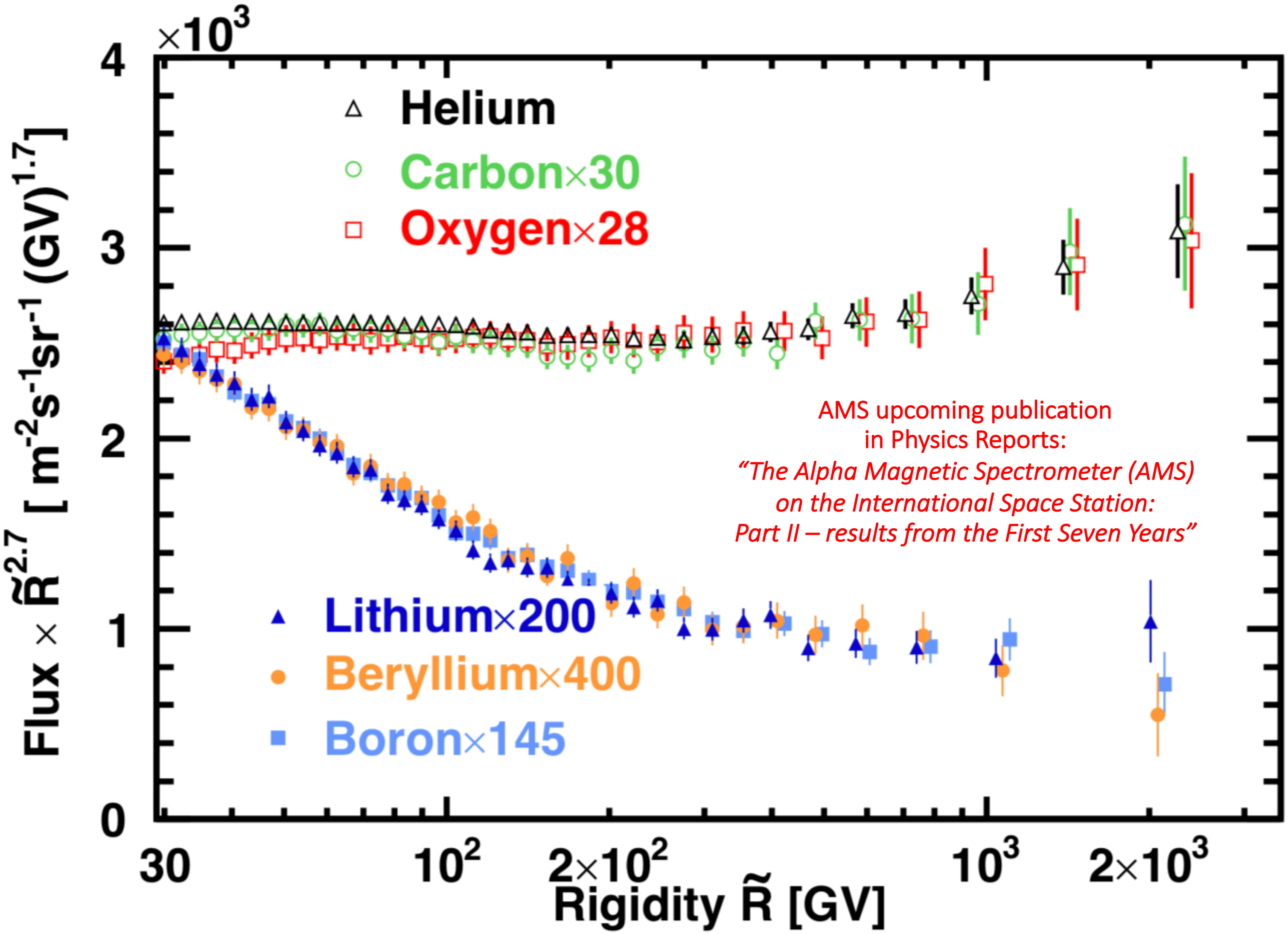
Update of M. Aguilar *et. al.*, Phys. Rev. Lett. 120 (2018) 021101



Li and Be isotopic composition: see Jiahui Wei's talk on July 30th

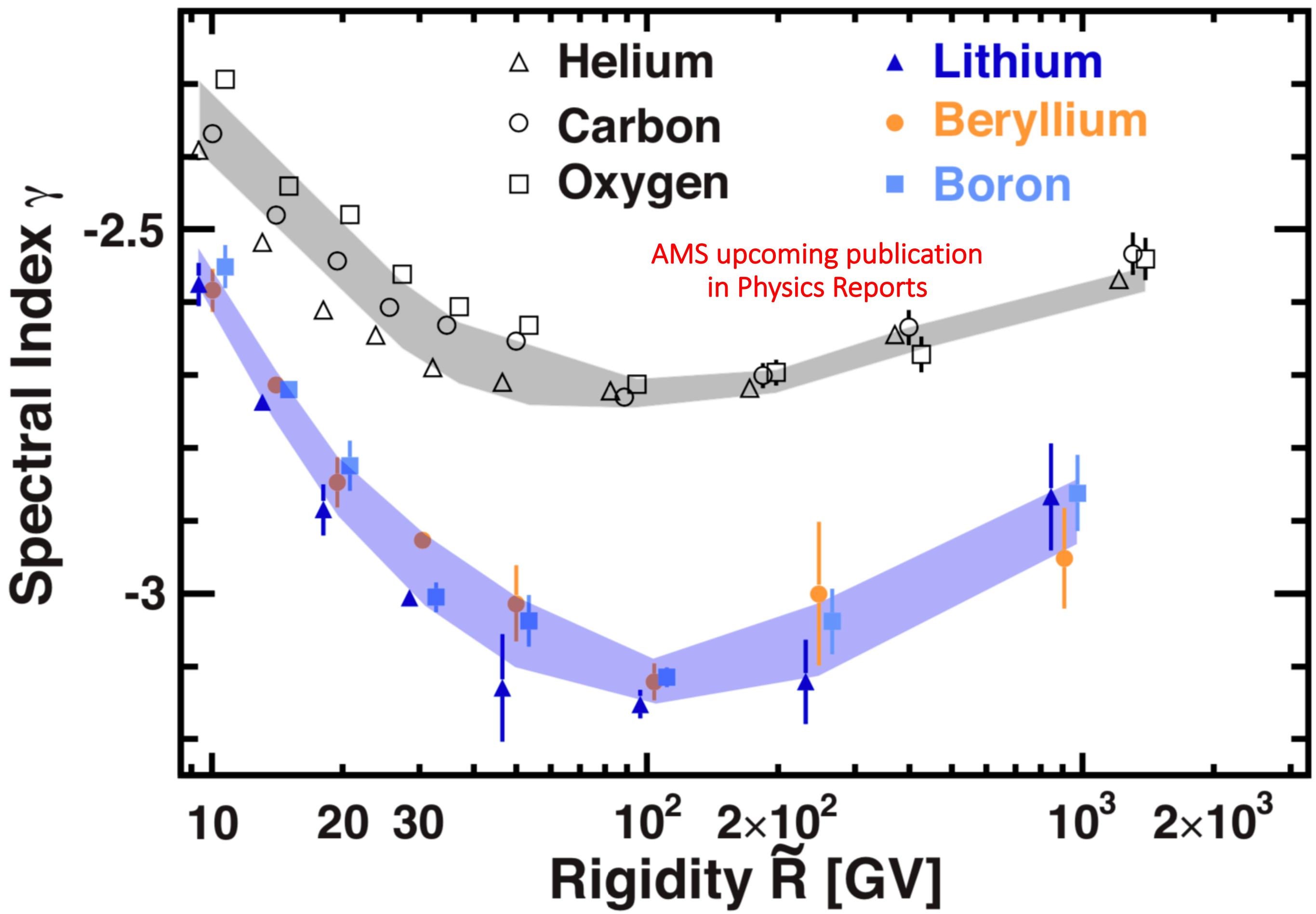
AMS-02 Primary (He,C,O) vs Secondary (Li, Be, B) spectra

Secondaries and primaries have distinctly different spectral shapes



AMS-02 Primary (He,C,O) vs Secondary (Li, Be, B) spectral indices

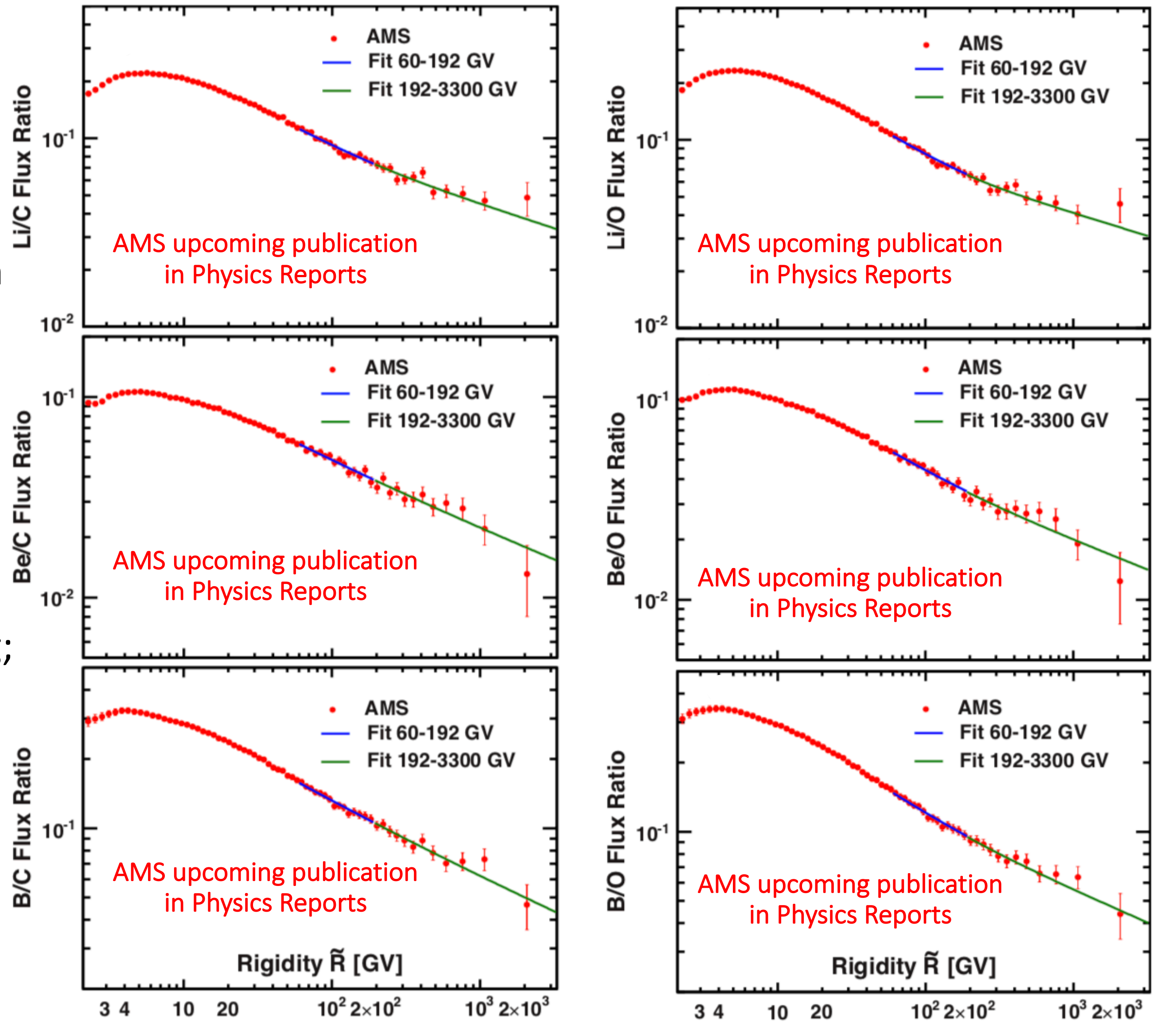
Both primaries and secondaries deviate from a single power law above 200 GV. Secondaries harden more than primaries.



AMS-02 Secondary/Primary Flux ratios

Flux ratios have been fit with a power law in rigidity intervals [60.3 GV; 192 GV] and [192 GV;3300 GV]

All ratios exhibit a hardening; Secondaries hardens more than primaries.

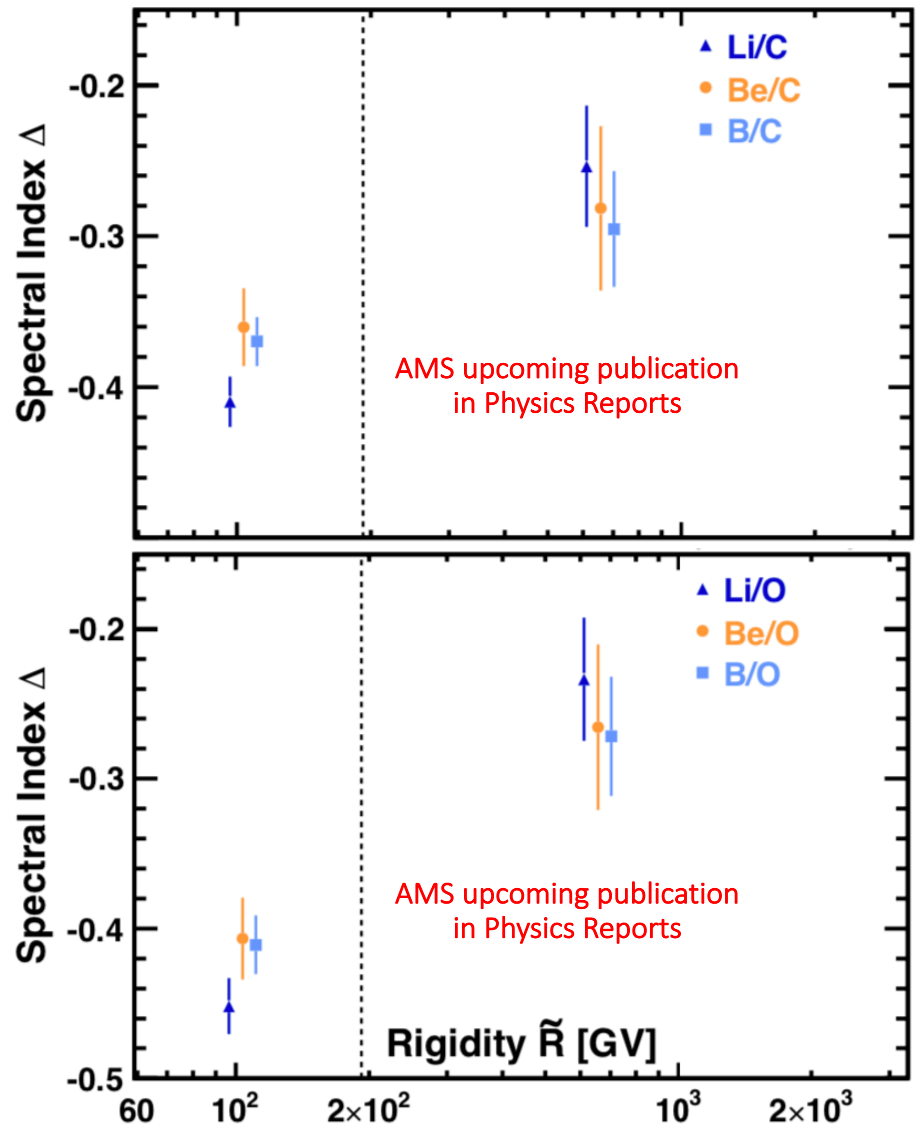


AMS-02 Secondary/Primary Flux ratios spectral indices

Combining the six **secondary-to-primary flux ratios** an average **hardening** at 192 GV of 0.140 ± 0.025 is observed.

The significance of this hardening is found to exceed 5σ.

This new observation favours the hypothesis that **the flux hardening** is a **universal propagation effect**.

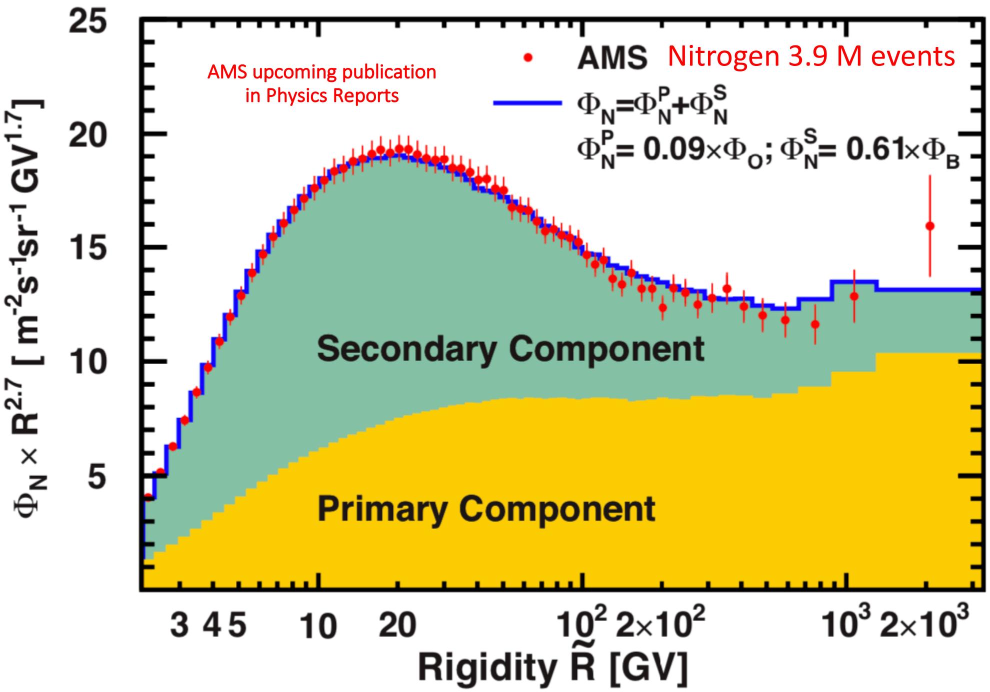


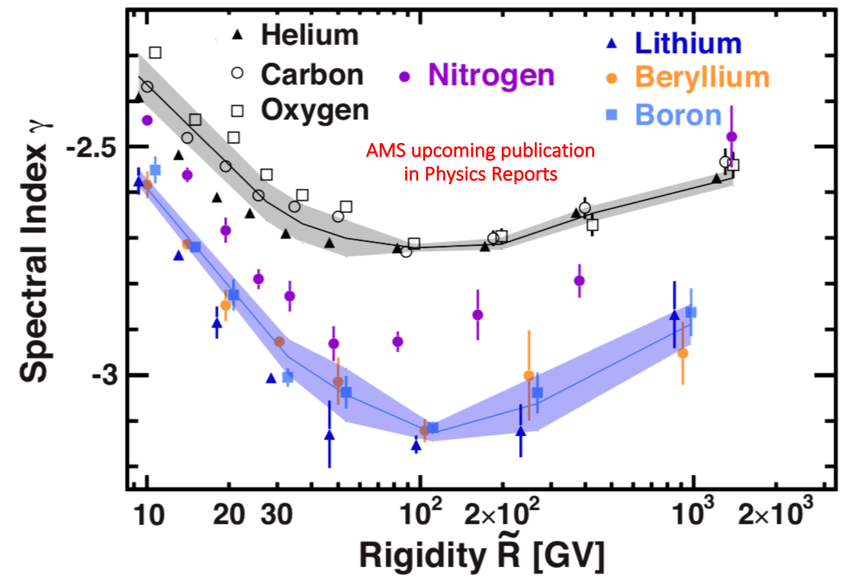
AMS-02 Nitrogen flux – 7 years (2011-2018)

Update of M. Aguilar *et. al.*, Phys. Rev. Lett. 121 (2018) 051103 with the 7-year dataset containing 3.9 million Nitrogen nuclei events

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.

Conclusions

Using the first seven years of AMS-02 data, primary (protons, He, C, and O) and secondary (Li, Be and B) cosmic ray fluxes have been measured from the GV to few TV with percent accuracy at 100 GV.

The presented primary CRs fluxes are based on 1 billion proton, 125M Helium, 14M Carbon and 12M Oxygen nuclei events. All primary spectra deviate from a single power law above 200GV. The proton-to-He flux ratio is well described by a constant term + a single power law term that vanishes at high rigidities. Helium Carbon and Oxygen exhibit identical spectral shape above 60 GV.

Lithium, Beryllium and Boron fluxes measurements are based on 3M, 1.7M and 4.2M nuclei respectively. All three secondary spectra deviate from a single power law above 200 GV in an identical way. This hardening is larger than the one observed for primary species (He, C, O).

The secondary/primary flux ratios Li/C, Be/C, B/C, Li/O, Be/O, and B/O were measured taking into account correlations on systematic errors. The secondary/primary flux ratios show an average hardening of 0.140 ± 0.025. These observations favor the hypothesis that the flux hardening is an universal propagation effect.

The Nitrogen spectrum has been measured from 2.2 GV to 3.3 TV, with 3.9M events.
The flux is described by the sum of a primary (Oxygen) and a secondary (Boron) component.
The model independent N/O ratio at source of 0.09 ± 0.02 is derived.

Heavier nuclei secondary fluxes will be measured, probing origin and propagation of cosmic rays at high mass and charge.