Latest results from the AMS-02 experiment

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On behalf of the AMS-02 collaboration

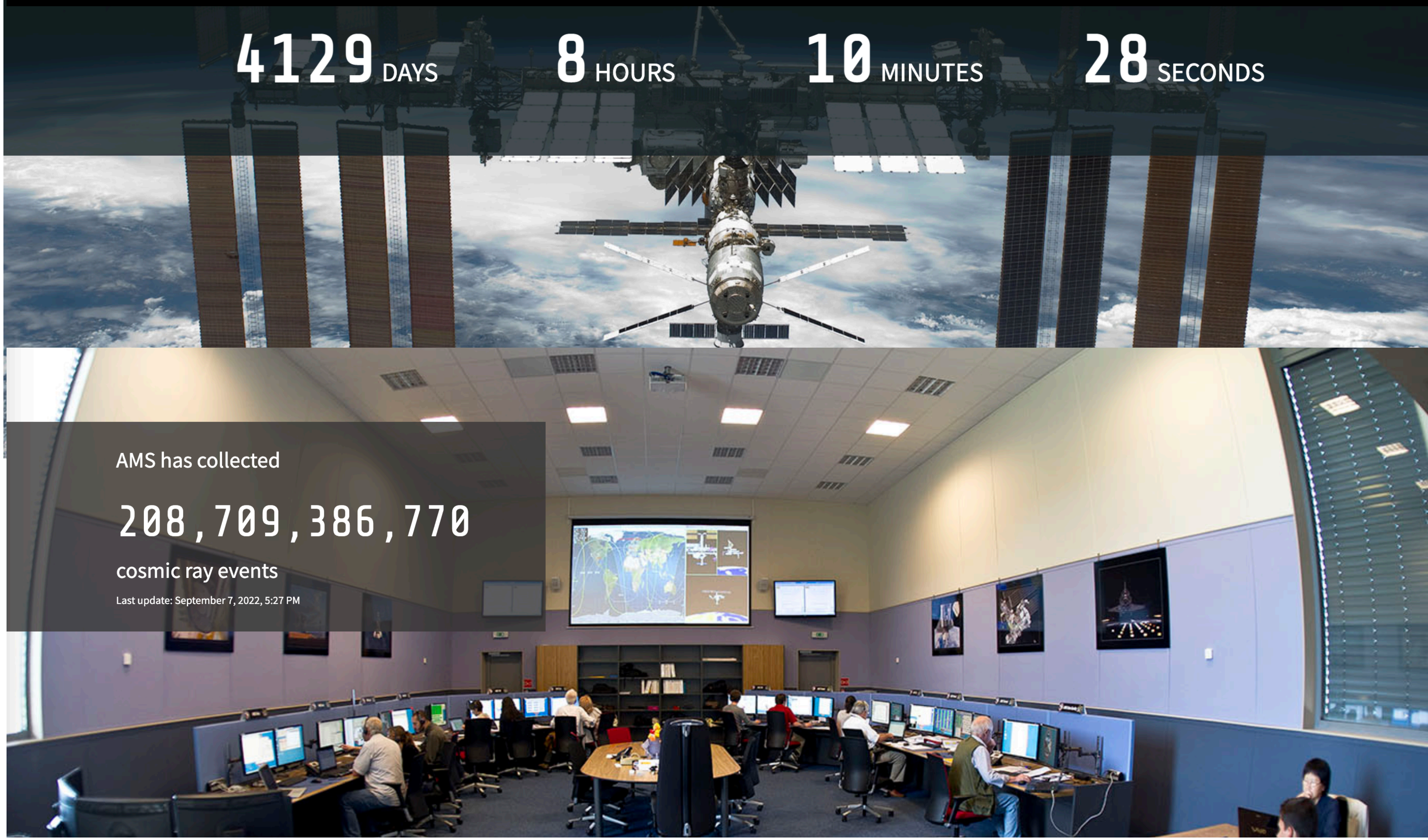
Outline

- The AMS-02 instrument
- Overview of (selected) AMS-02 results
- Measurement of the deuteron flux with AMS-02
- Conclusions

Additional AMS-02 contributions at RICAP22

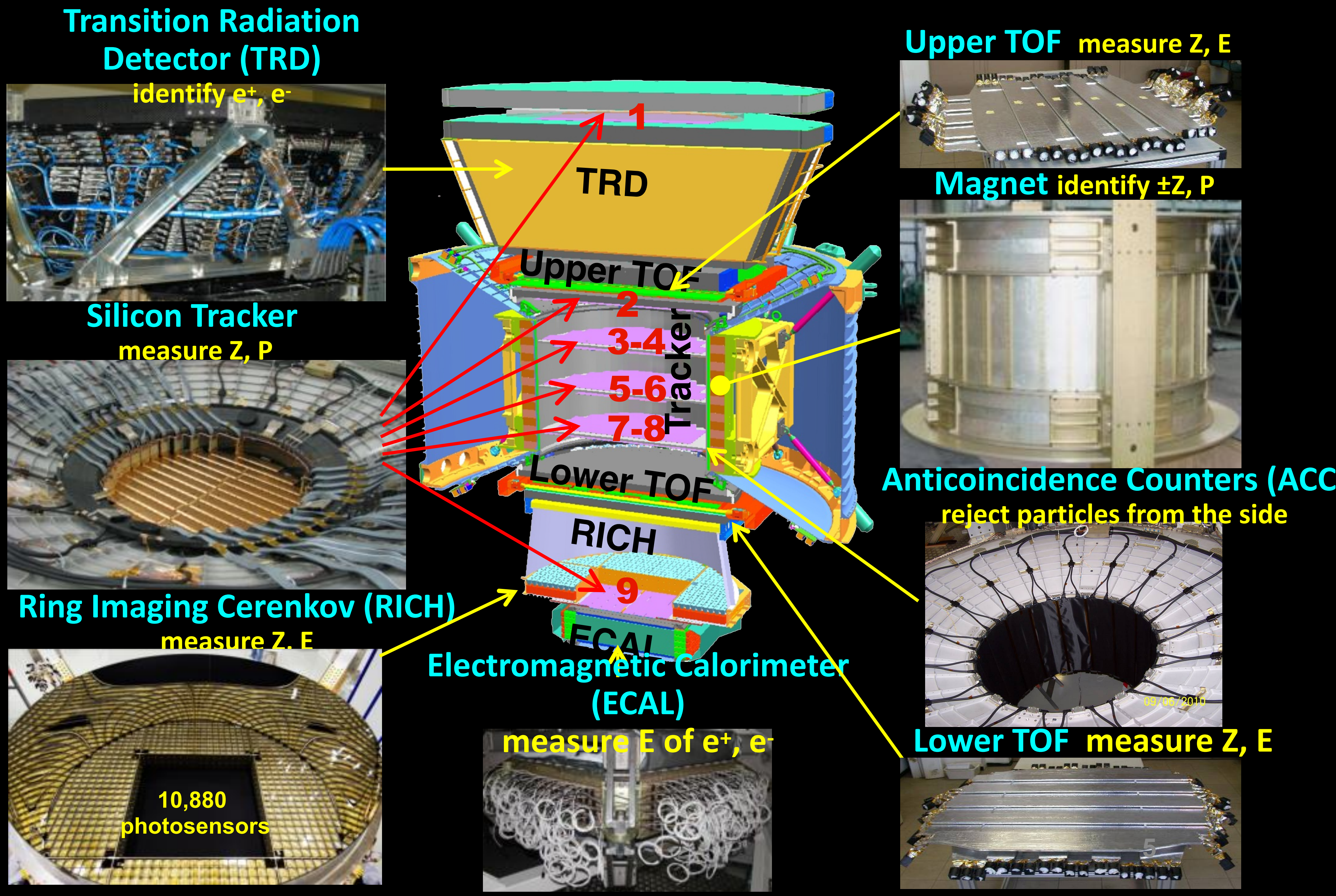
- Monthly flux of He, C, O (Alejandro Reina Conde, 7/9)
- Electrons and positrons (Matteo Duranti, 7/9)

AMS has been in space since May 2011, and it detected more than 208 billion cosmic rays

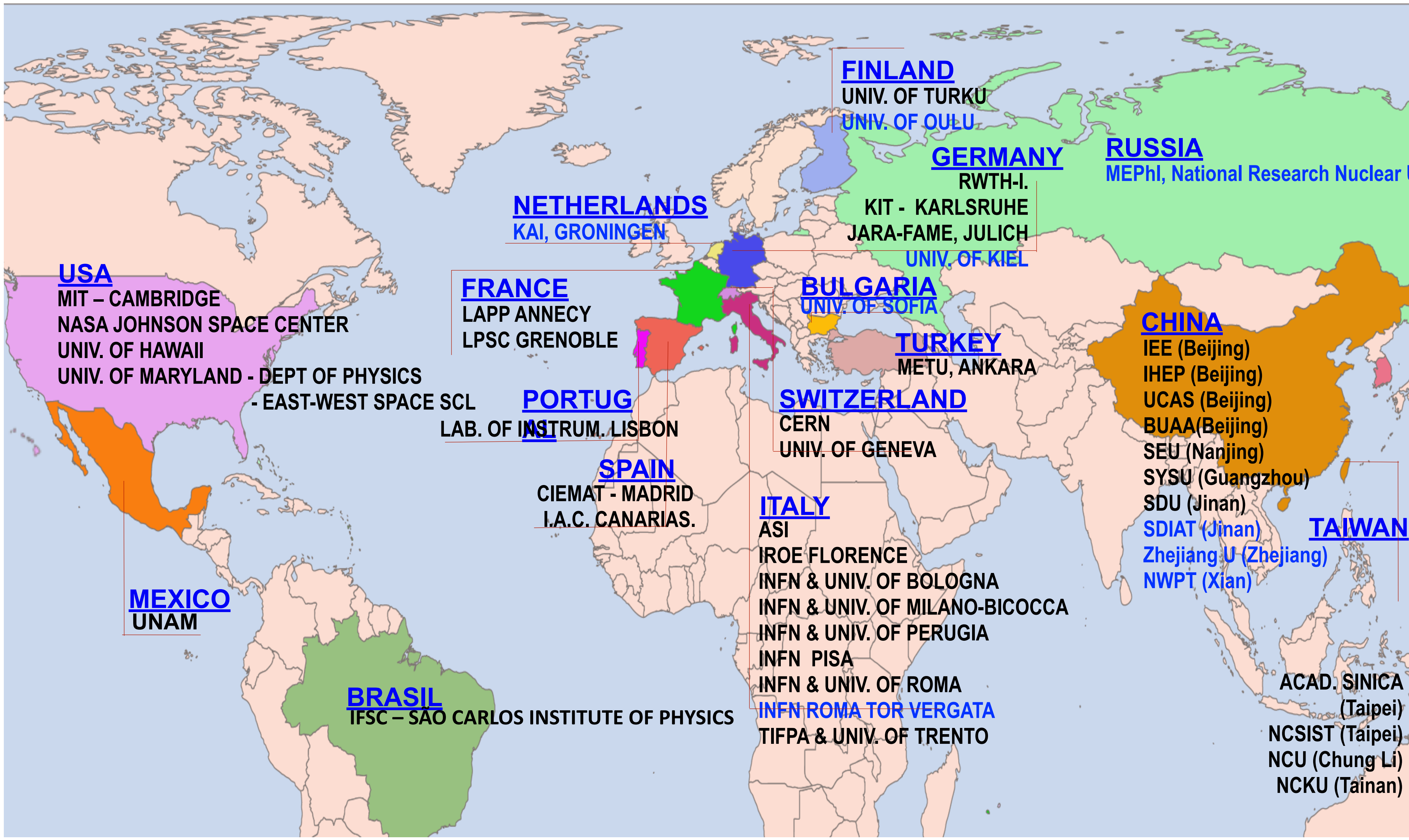


https://amso2.space

AMS is a space version of a precision detector used in accelerators



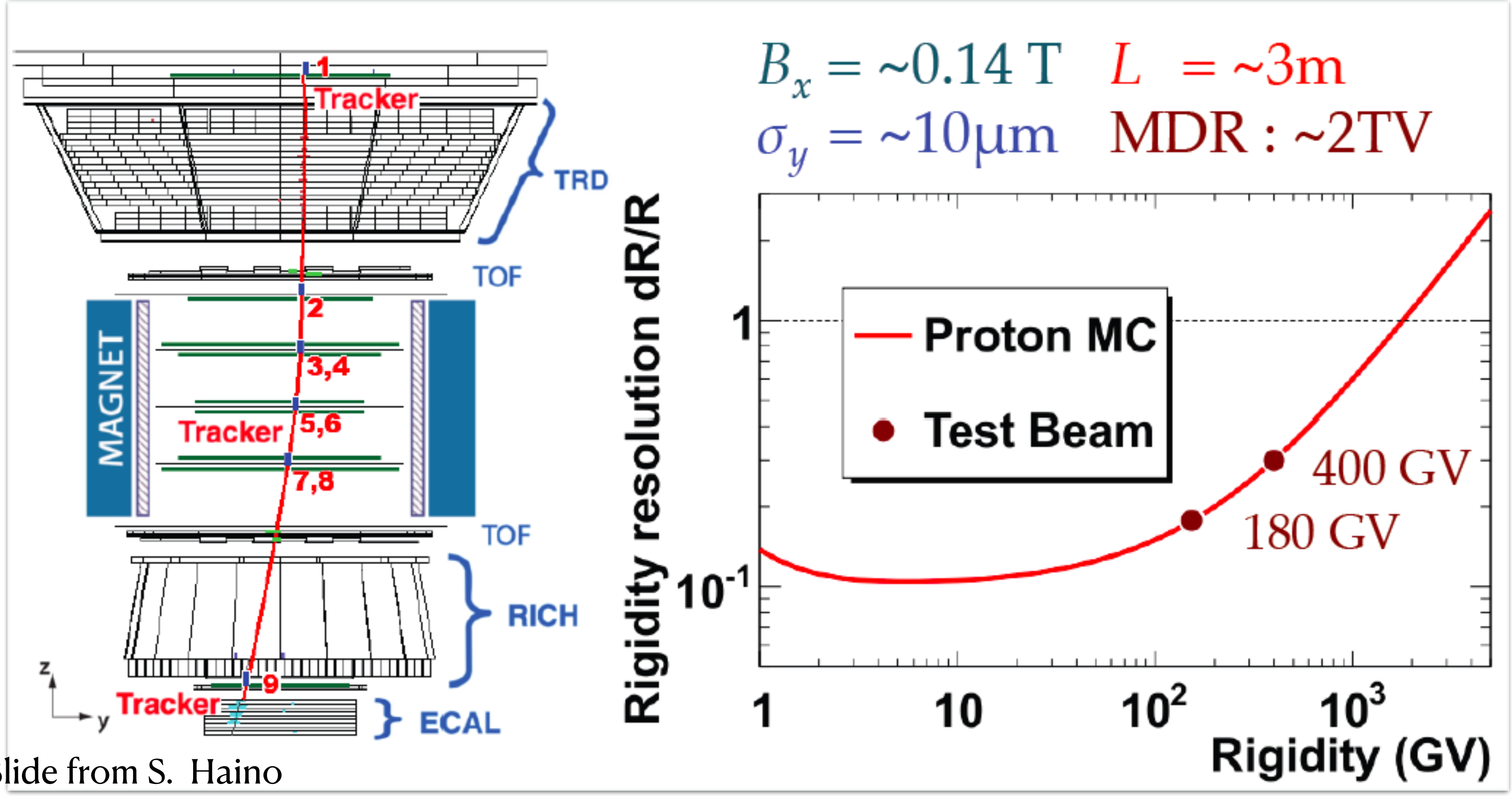
The AMS Collaboration



Rigidity measurement

CR nuclei fluxes are measured by AMS-02 a a function of the rigidity (R=pc/Ze)

AMS-02 can measure CR nuclei in the GV to the TV energy range



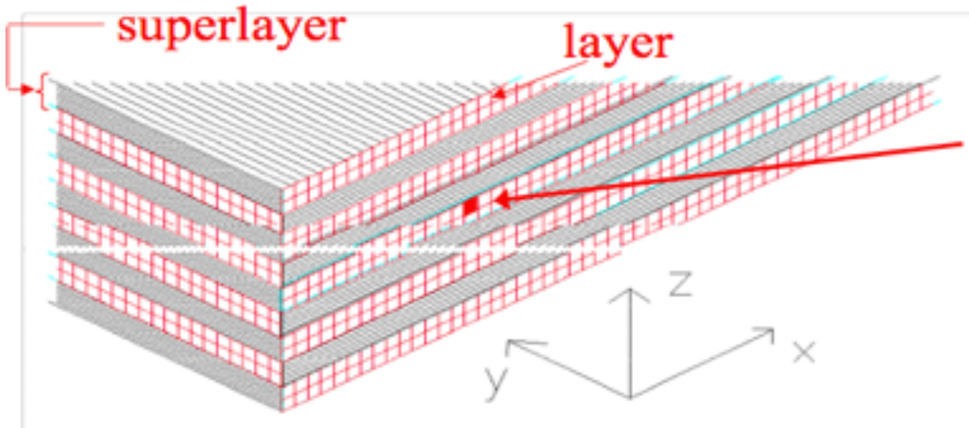
Slide from S. Haino

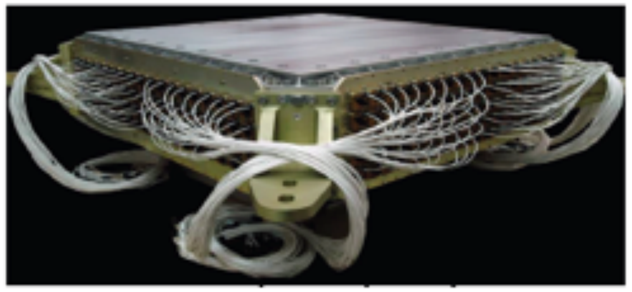
M. Aguilar *et al,* Phys. Rept. 894 (2021) 1-116

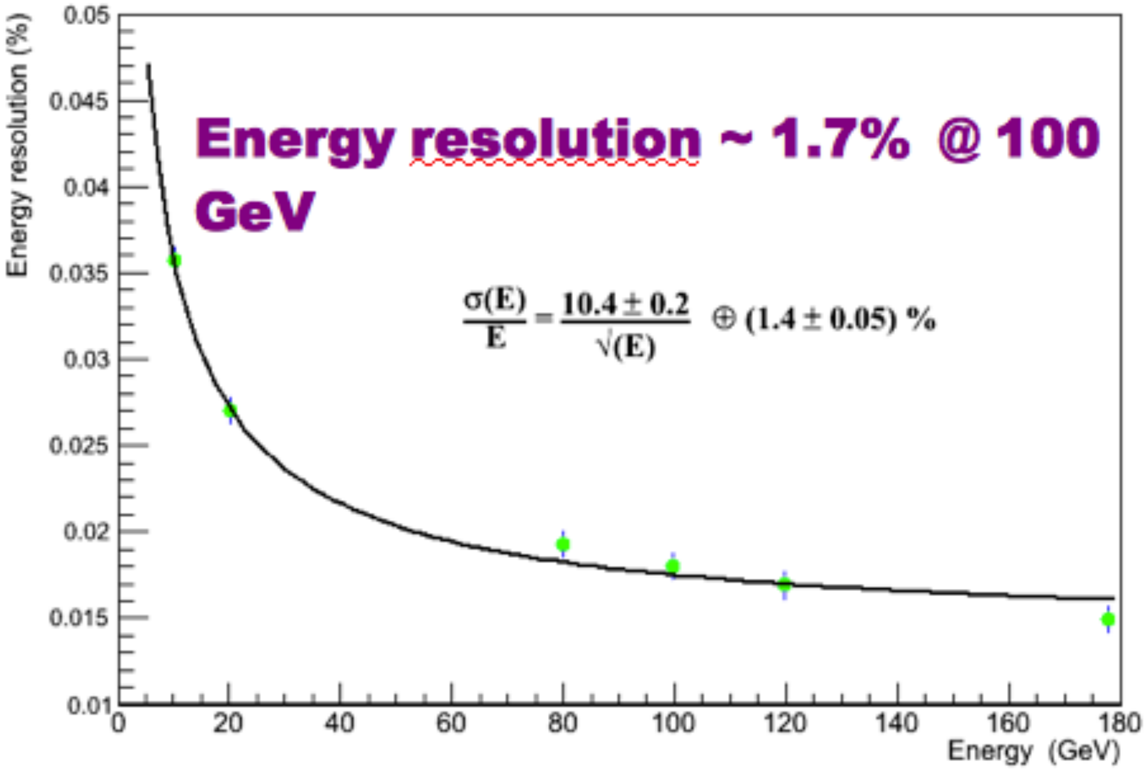
Energy measurement

The AMS-02 electromagnetic calorimeter:
a 3-D sampling calorimeter made out of lead and scintillating fibers

High granularity: ~ 0.9 x 0.9 cm^2
18 Longitudinal samplings
72 Lateral samplings
17 X_0, $\lambda_I / X_0 \sim 22$







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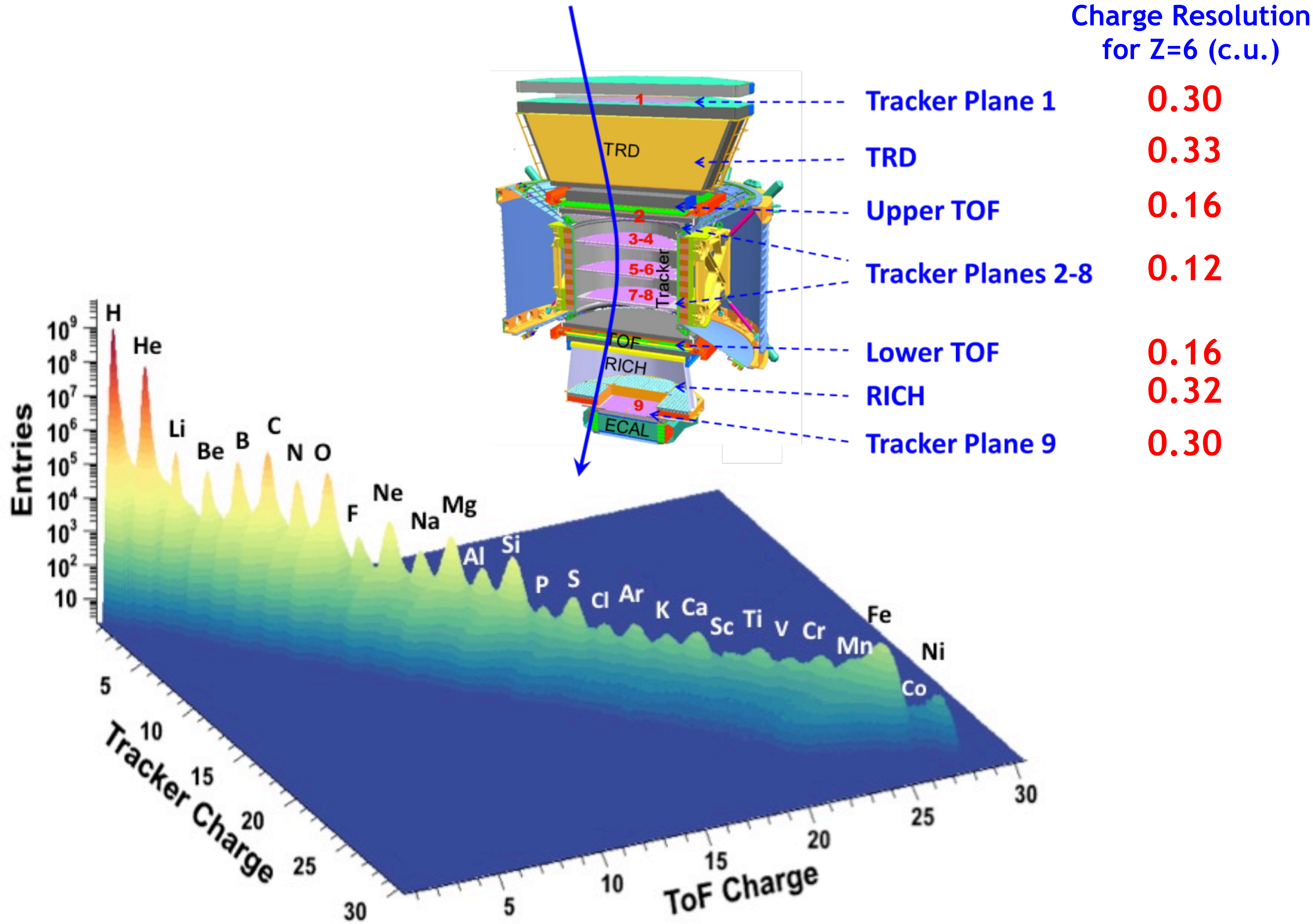
Charge measurements



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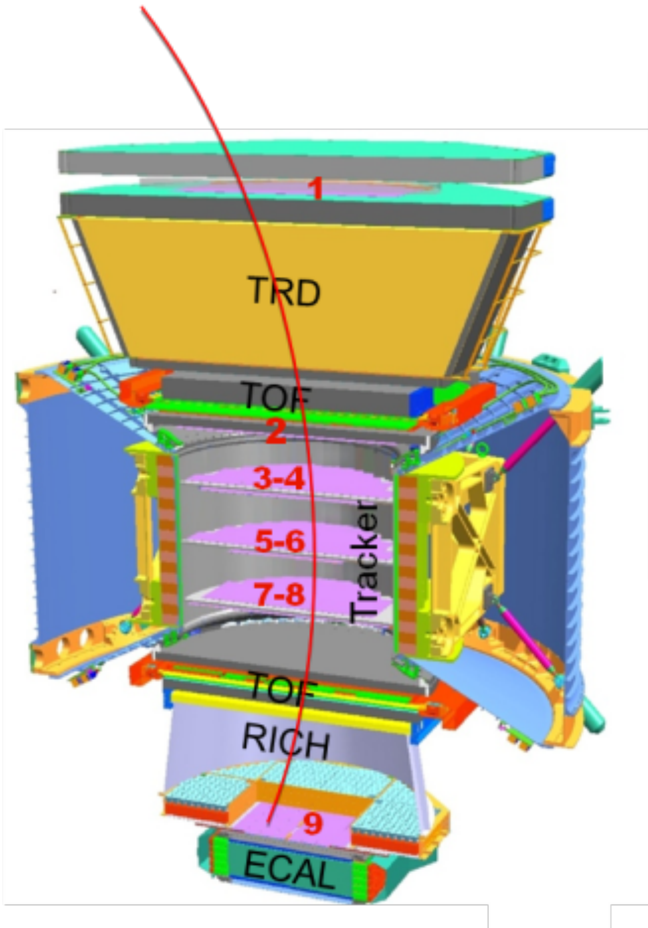
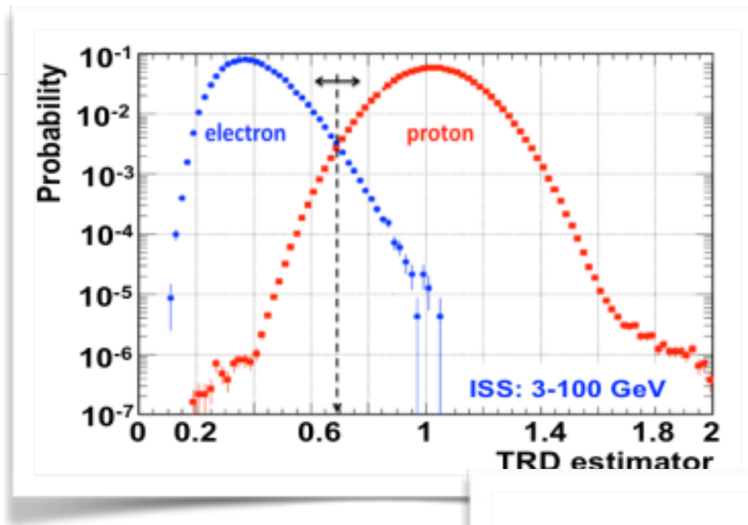
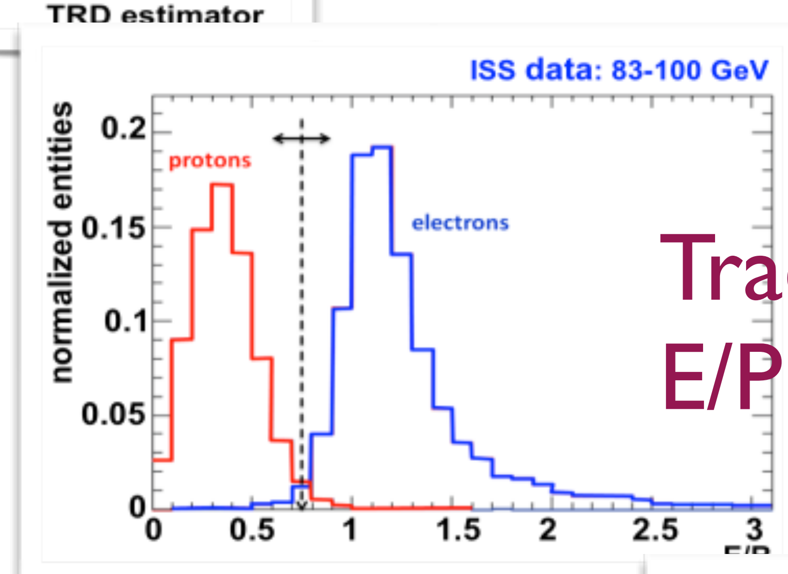
Electrons (positrons) identification

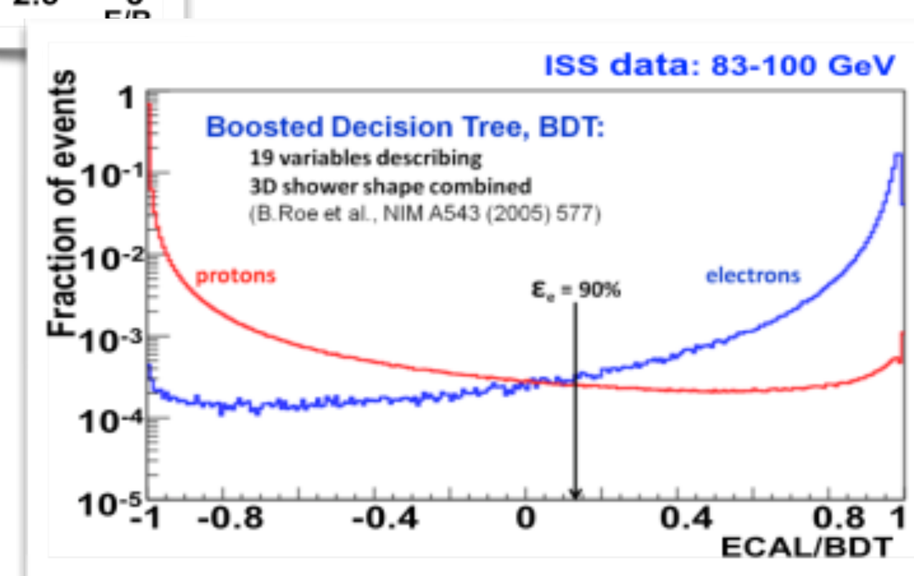




Transition Radiation Detector



Tracker:
E/P ~ 1 for e^+ and e^-

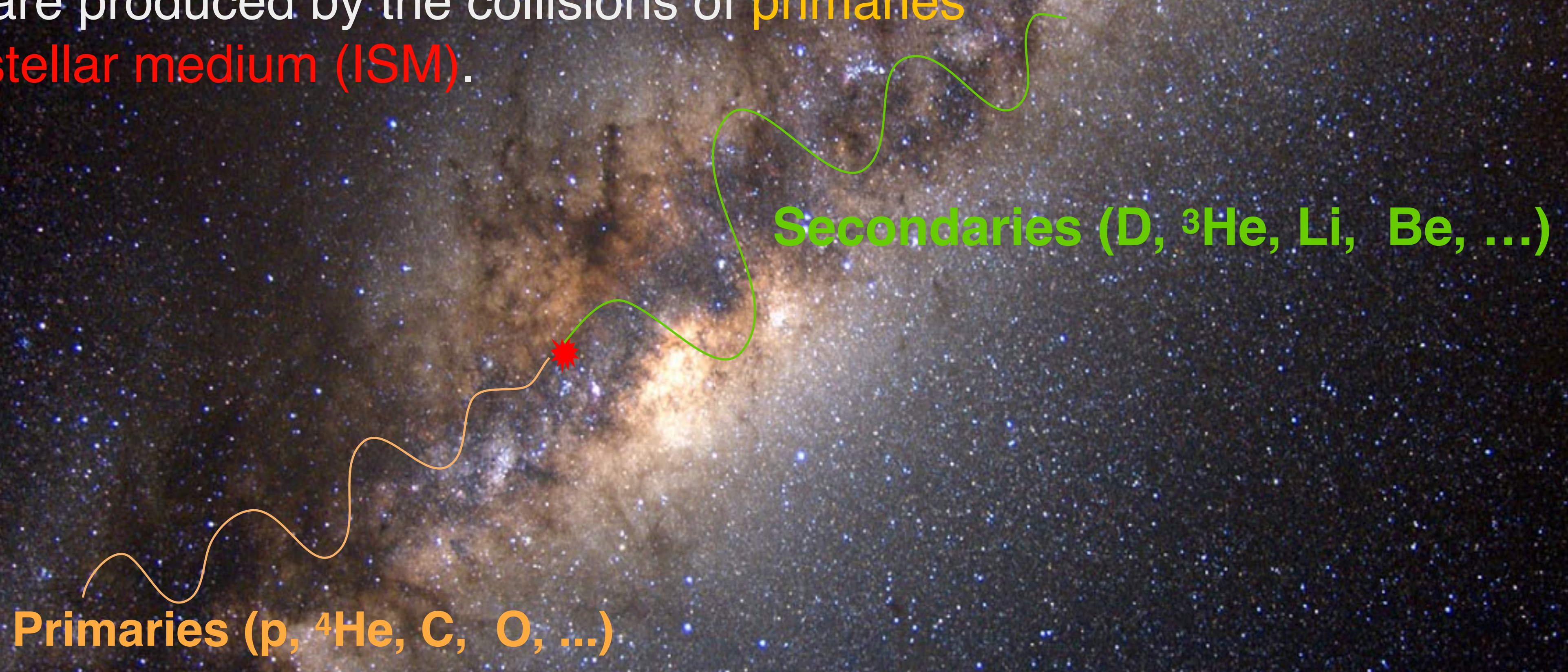


Acc(p) ~ 0.5 m^2sr
Acc(e) ~ 0.04 m^2sr

ECAL estimator: based on shower shape

Cosmic rays

Primaries are produced and accelerated at the sources.
Secondaries are produced by the collisions of primaries with the interstellar medium (ISM).



Primary CR species

- The flux of CRs is shaped by the physical phenomena occurring at the **source** and during their **propagation**.
- Primary CRs include He, O, Si and Fe …
- In the simplest scenario, the source and the diffusion provide universal spectral indices for primary species:

$$\Phi_P \propto \frac{q}{K} \propto R^{-\alpha-\delta}$$

  - q(R) is the source term (a power-law in rigidity)
  - K(R) is the diffusion coefficient (a power-law in rigidity)

AMS-02 results

Flux measurement

Isotropic Differential Flux
(m² sr s GV)⁻¹

Number of events
(corrected for bin-to-bin rigidity migrations)

$$\Phi_j = \frac{N_j}{A_j \, \epsilon_j \, T_j \, \Delta R_j}$$

Bin width

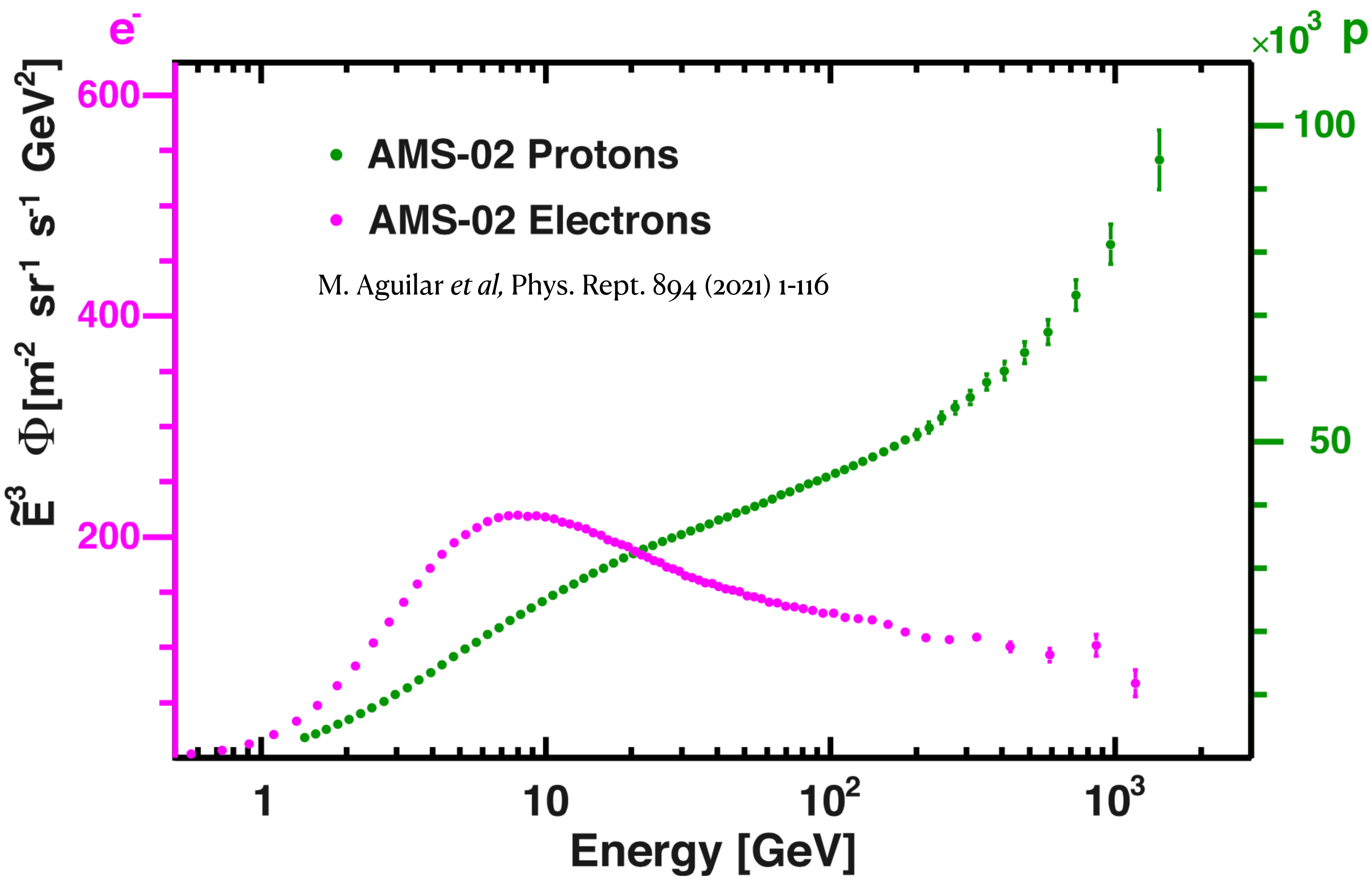
Effective geometric factor (acceptance)
estimated with MC and checked with data

Trigger efficiency
estimated from data

Exposure time
Duty cicle + Geomegnetic cutoff

Proton and electron fluxes

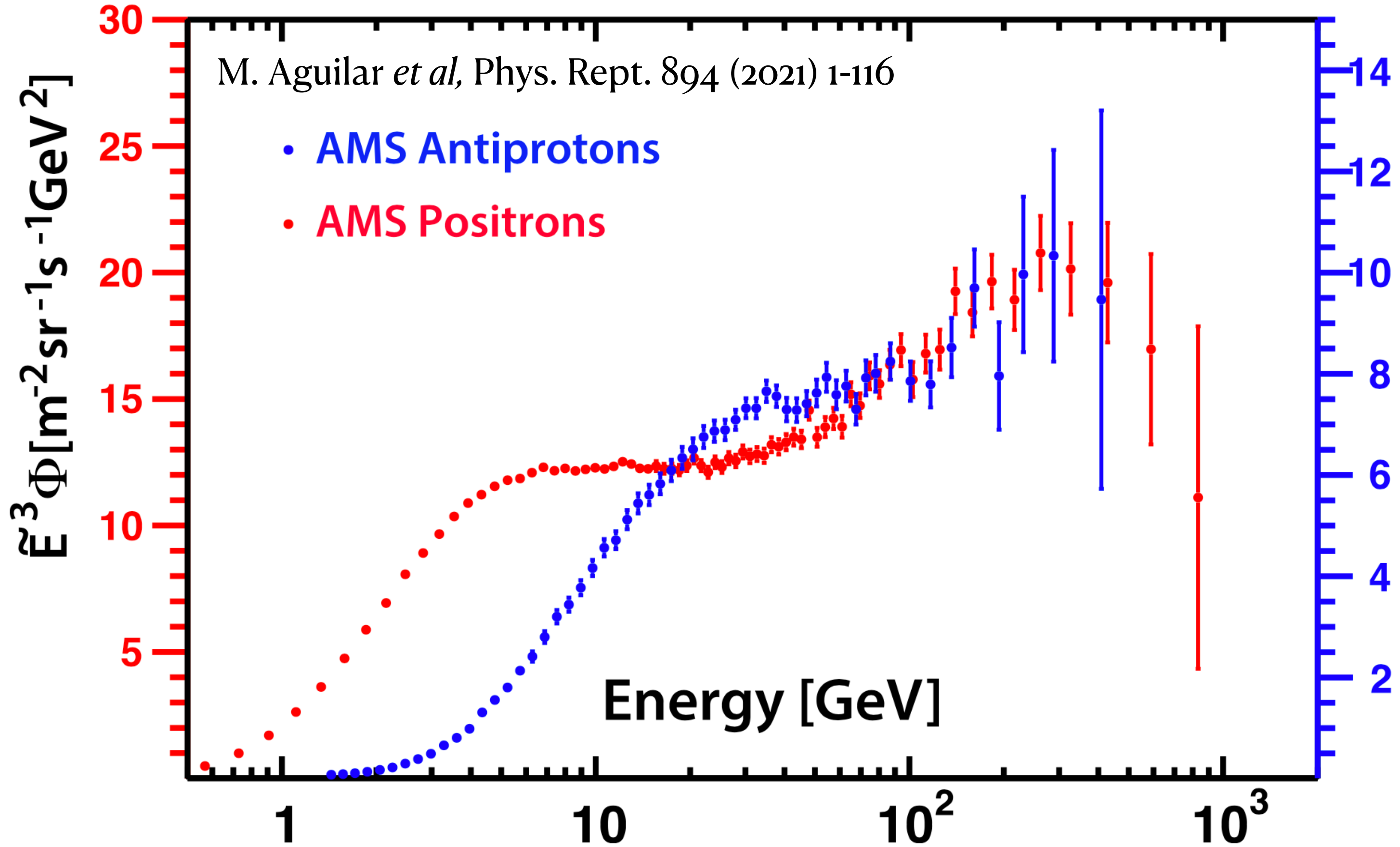
Proton and electrons are both primary species, but they do show distinct energy dependence. Above 10 GeV the electrons flux is softer than the proton one, most likely due to energy losses.

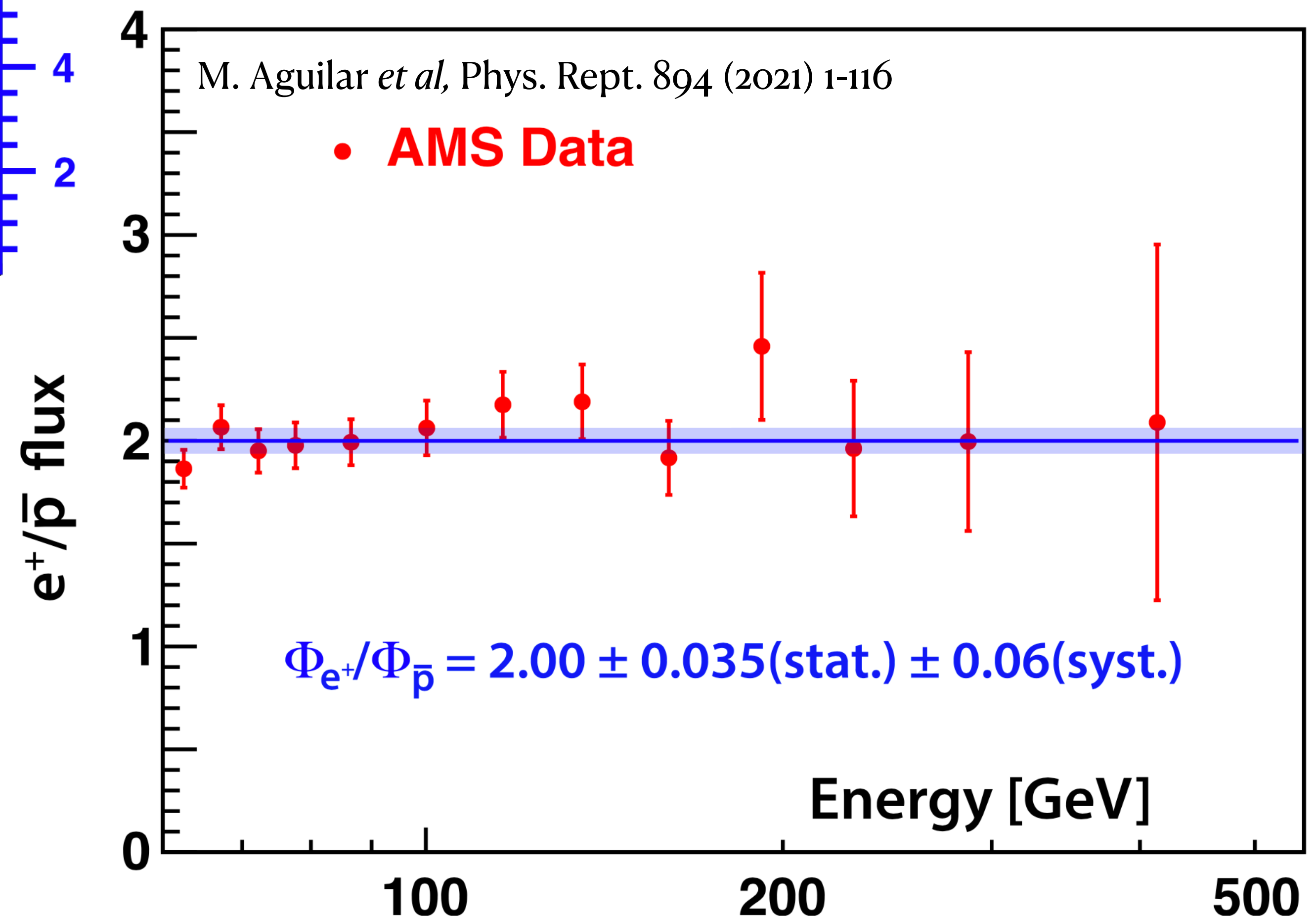


See Matteo Duranti's talk

Antimatter particles

Above 60 GeV, positrons and antiprotons have the same energy dependence.

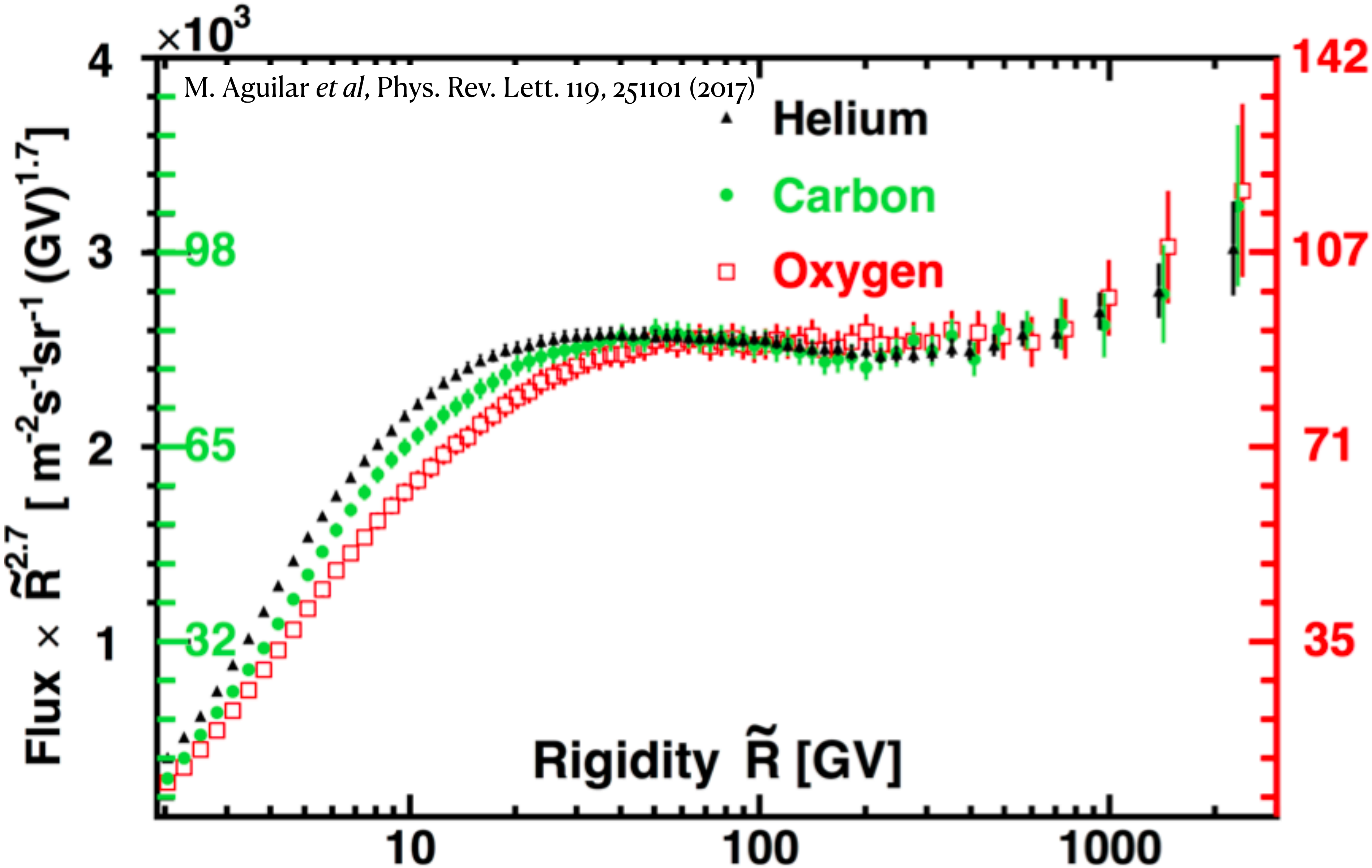




See Matteo Duranti's talk

Rigidity dependence of primary CR fluxes

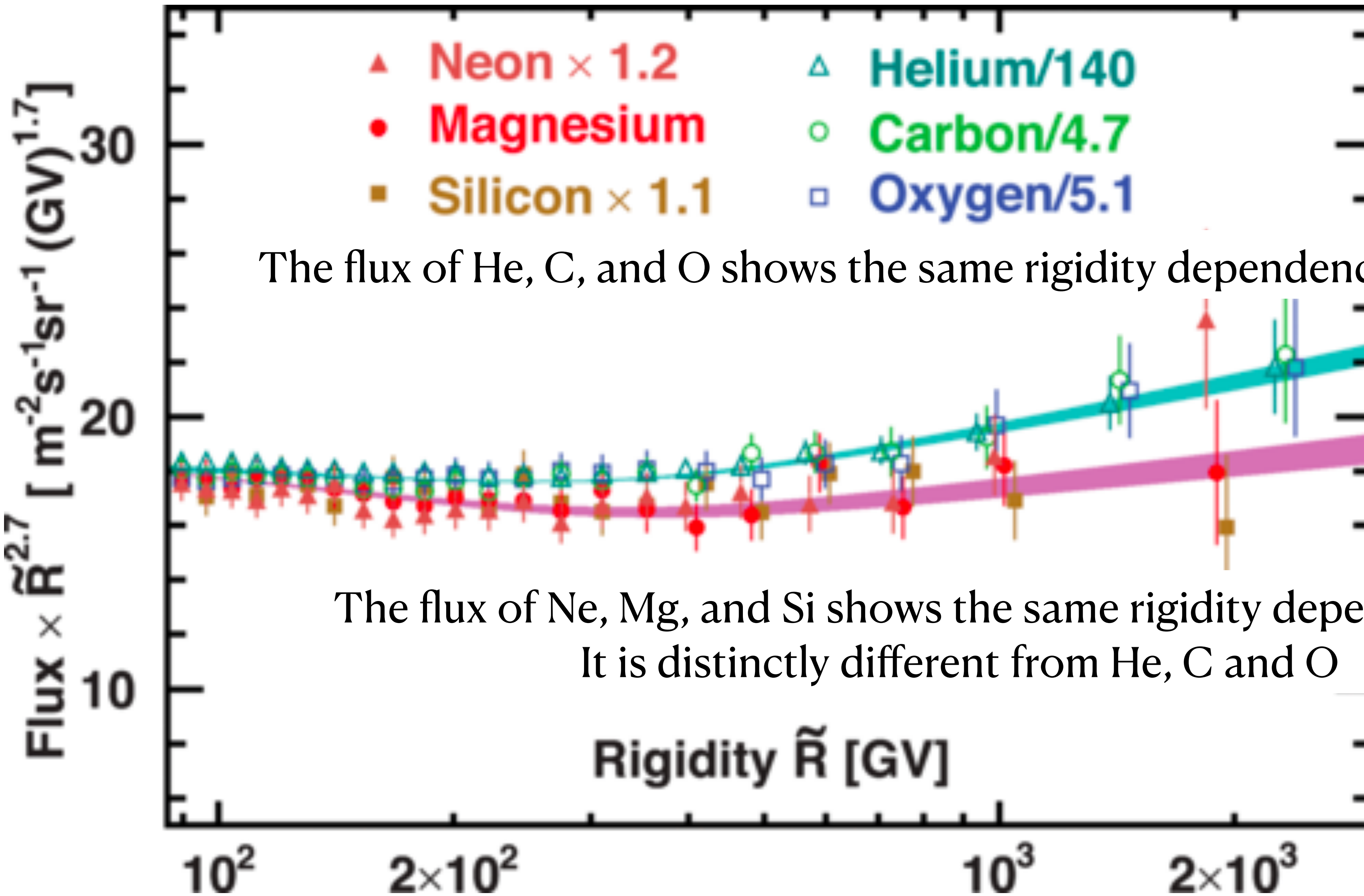
The fluxes of He, C, and O deviate from a single power-law above 200 GV and harden in an identical way.



Similar behaviour observed in all species ...

Rigidity dependence of primary CR fluxes

M. Aguilar *et al.* Phys. Rev. Lett. **124**, 211102 2020



$$\Phi_P \propto \frac{q}{K} \propto R^{-\alpha-\delta}$$

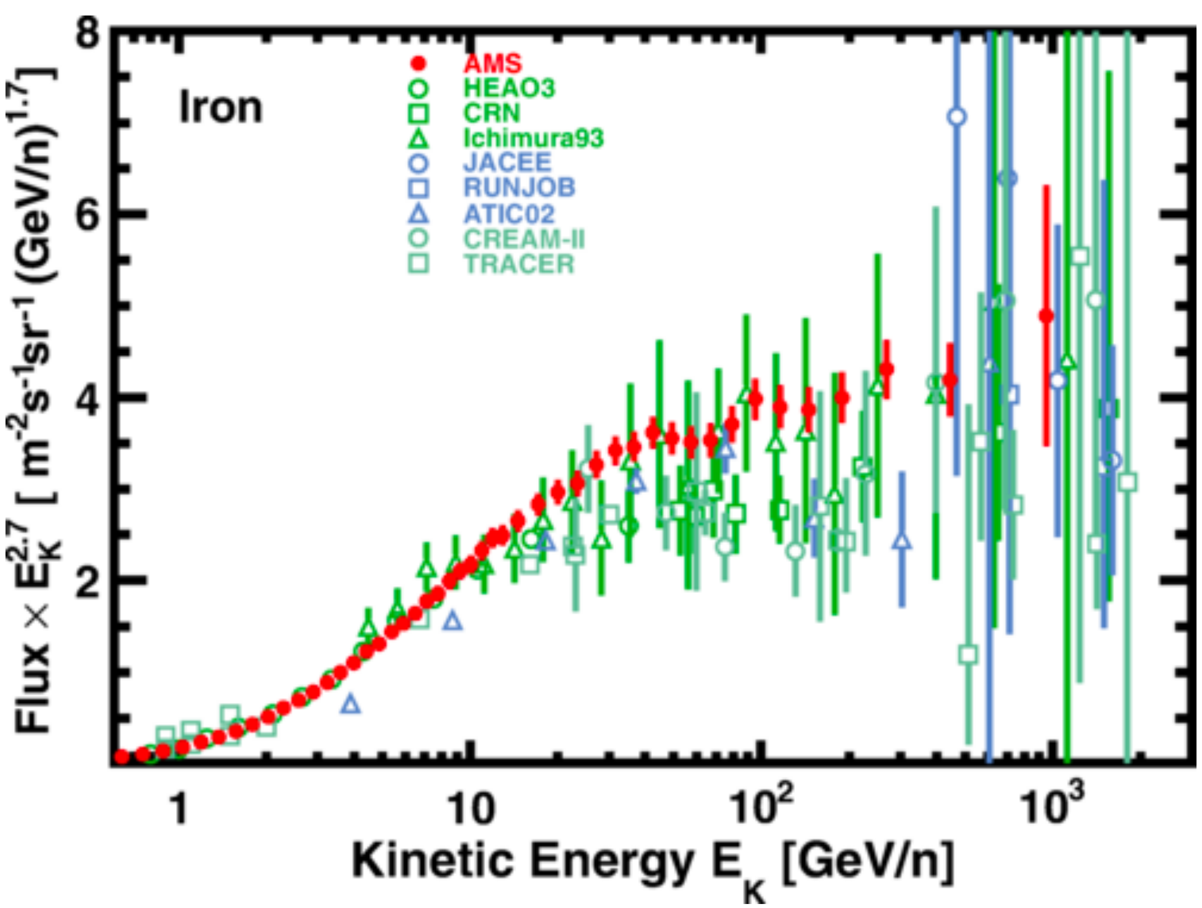
The flux of He, C, and O shows the same rigidity dependence

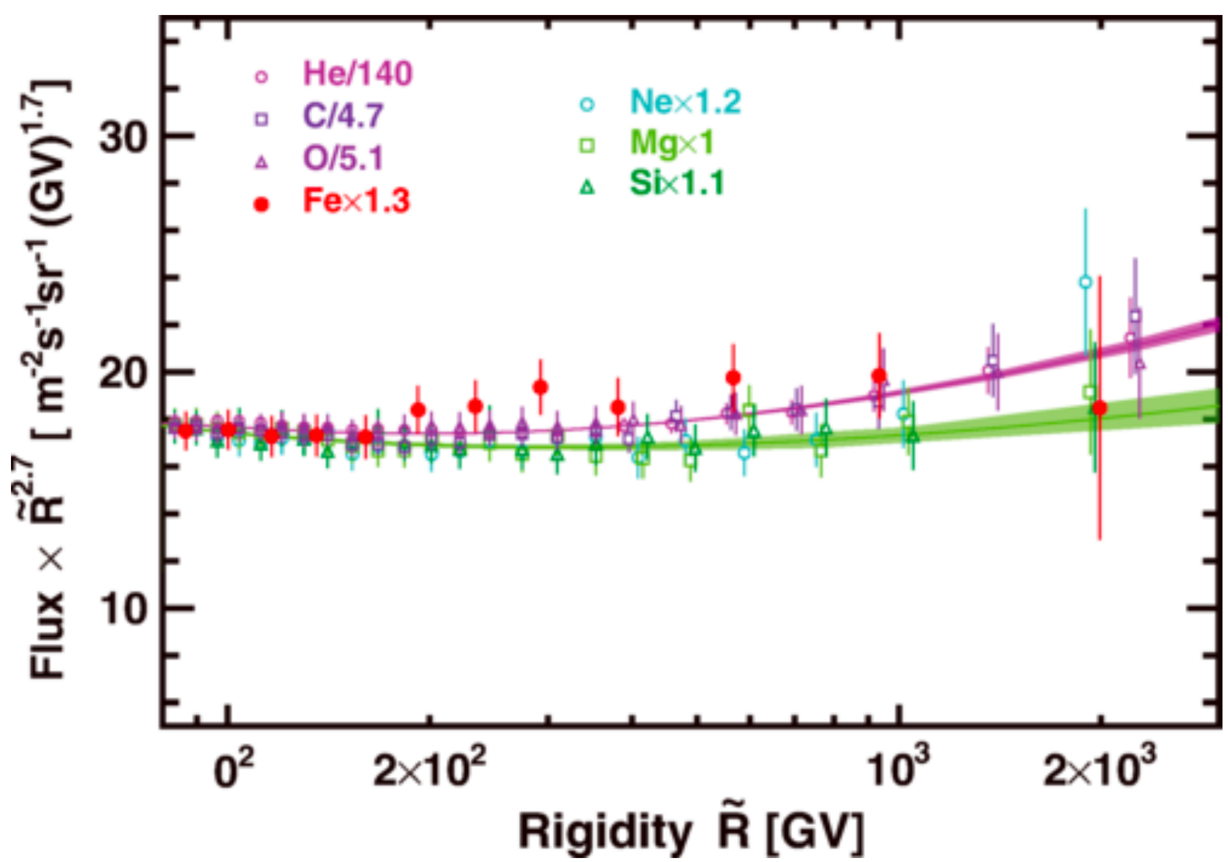
The flux of Ne, Mg, and Si shows the same rigidity dependence, but It is distinctly different from He, C and O

Measurement of the iron flux

Result obtained from 0.62 million iron events detected by AMS during the first 8.5 years of operation onboard the ISS

M. Aguilar *et al*, Phys.Rev.Lett. 126 (2021) 4, 041104





Iron follows the same rigidity behaviour of He, C and O.

Secondary CR species

- The flux of secondary particles is shaped by the physical phenomena occurring during the propagation of the parent nuclei.

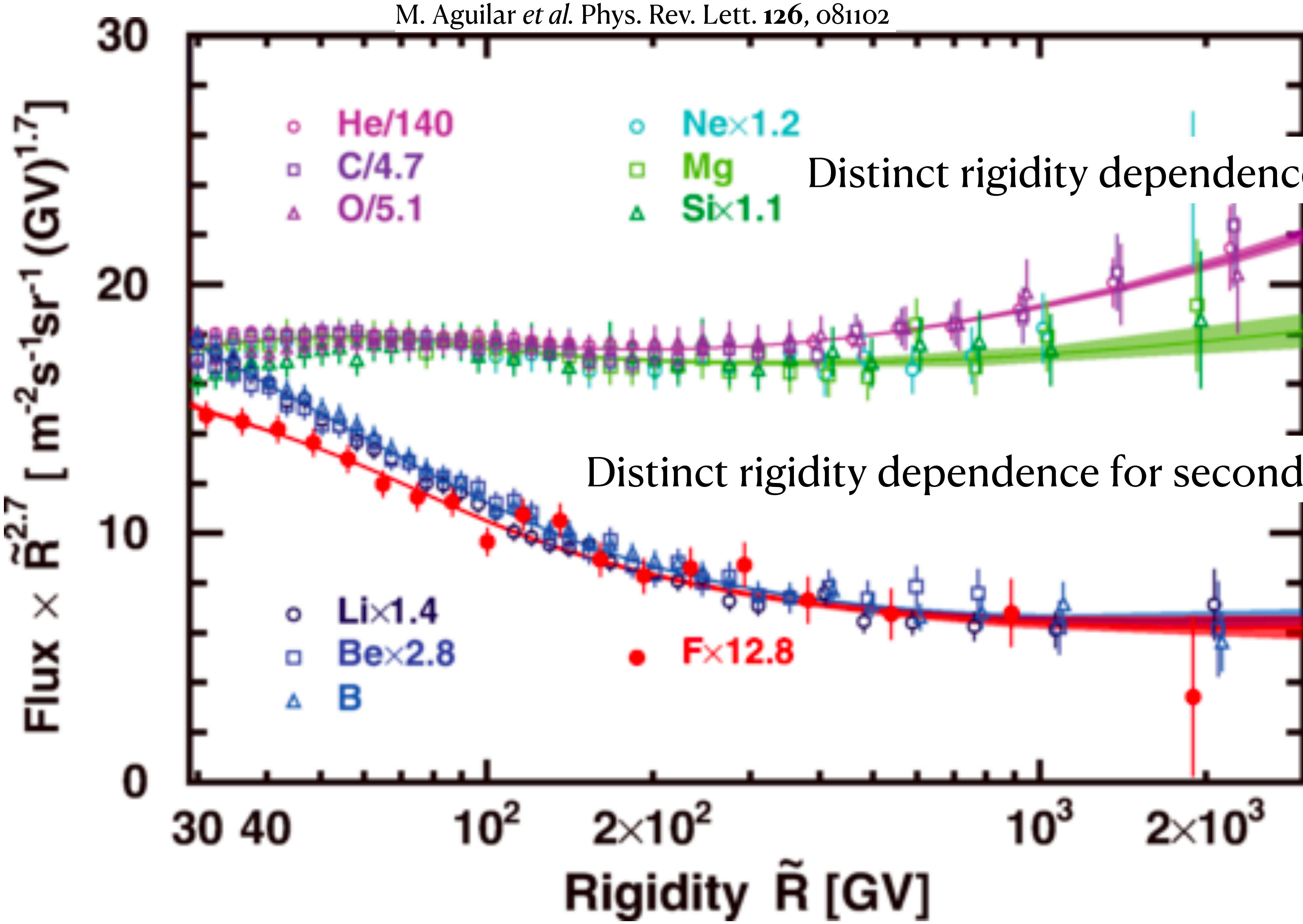
$$\Phi_S \propto \frac{\Phi_P}{K} \propto R^{-\alpha-2\delta}$$

- Secondary species include Li, Be, B and F.
- The secondary-to-primary flux ratios are extremely sensitive to propagation parameters and they are almost insensitive to the injected primary spectrum.

$$\frac{\Phi_S}{\Phi_P} \propto R^{-\delta}$$

Rigidity dependence of primary and secondary CR fluxes

M. Aguilar *et al.* Phys. Rev. Lett. **126**, 081102



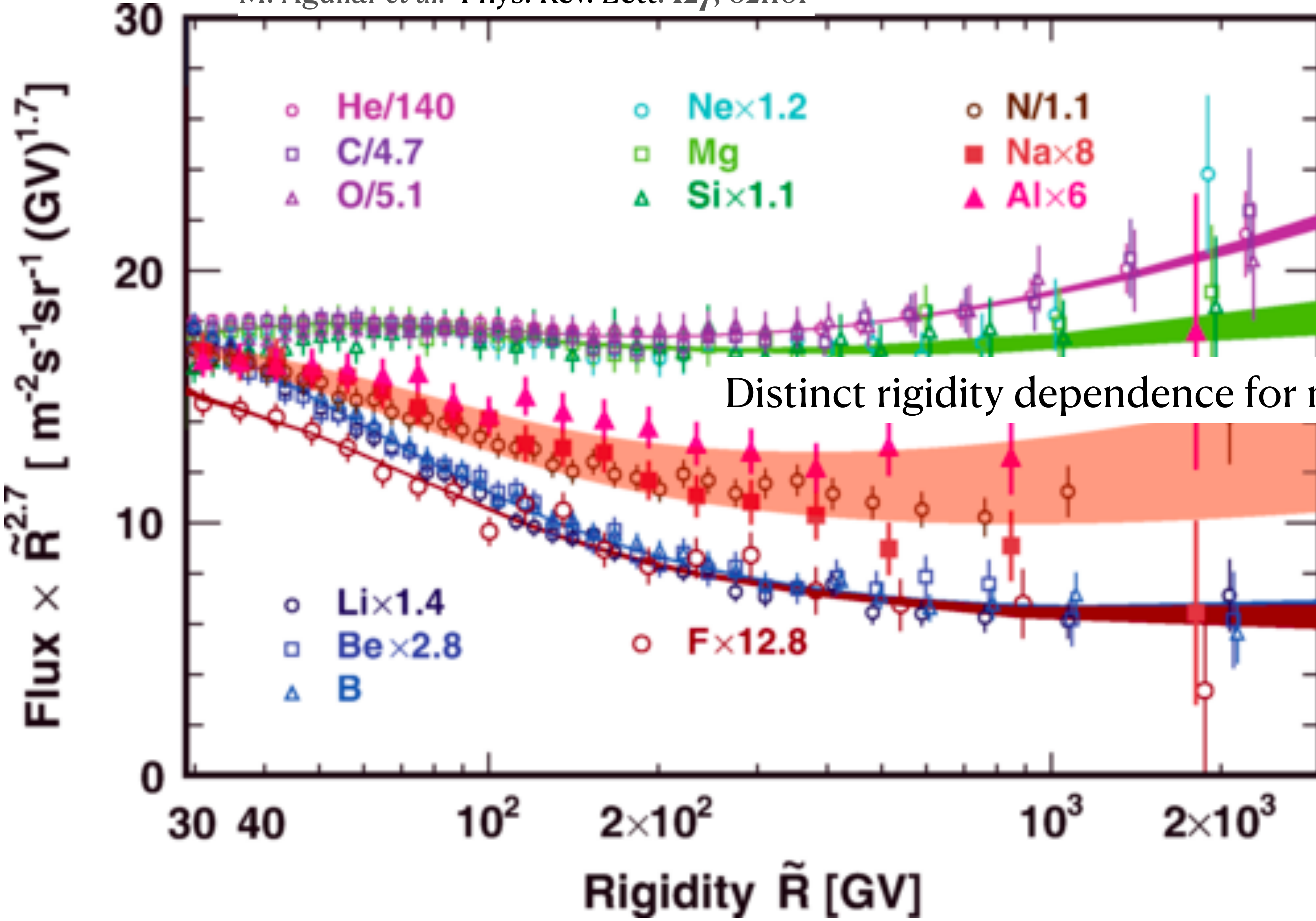
Distinct rigidity dependence for primary species

Distinct rigidity dependence for secondary species

$$\Phi_S \propto \frac{\Phi_P}{\tau_{esc}(E)} \propto R^{-\alpha-2\delta}$$

Rigidity dependence of CR fluxes

M. Aguilar *et al.* Phys. Rev. Lett. **127**, 021101



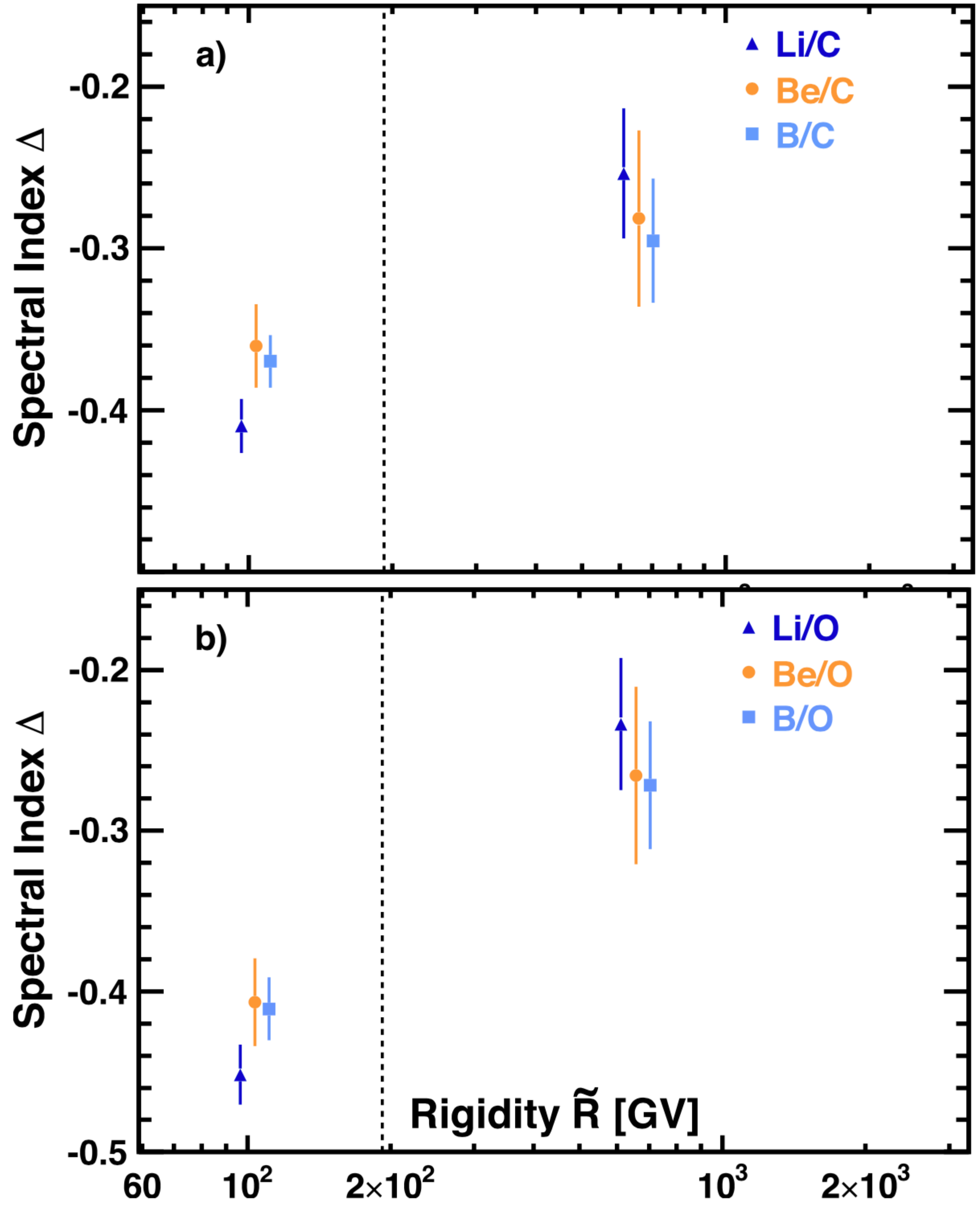
Distinct rigidity dependence for mixed species

Secondary-to-primary flux ratios

$$\frac{\Phi_B}{\Phi_C} \propto R^{\Delta}$$

- AMS provides evidence for a break in the B/C (and similar flux ratios).
- The first evidence of a diffusive origin of this spectral feature was provided by Génolini et al PRL 2019

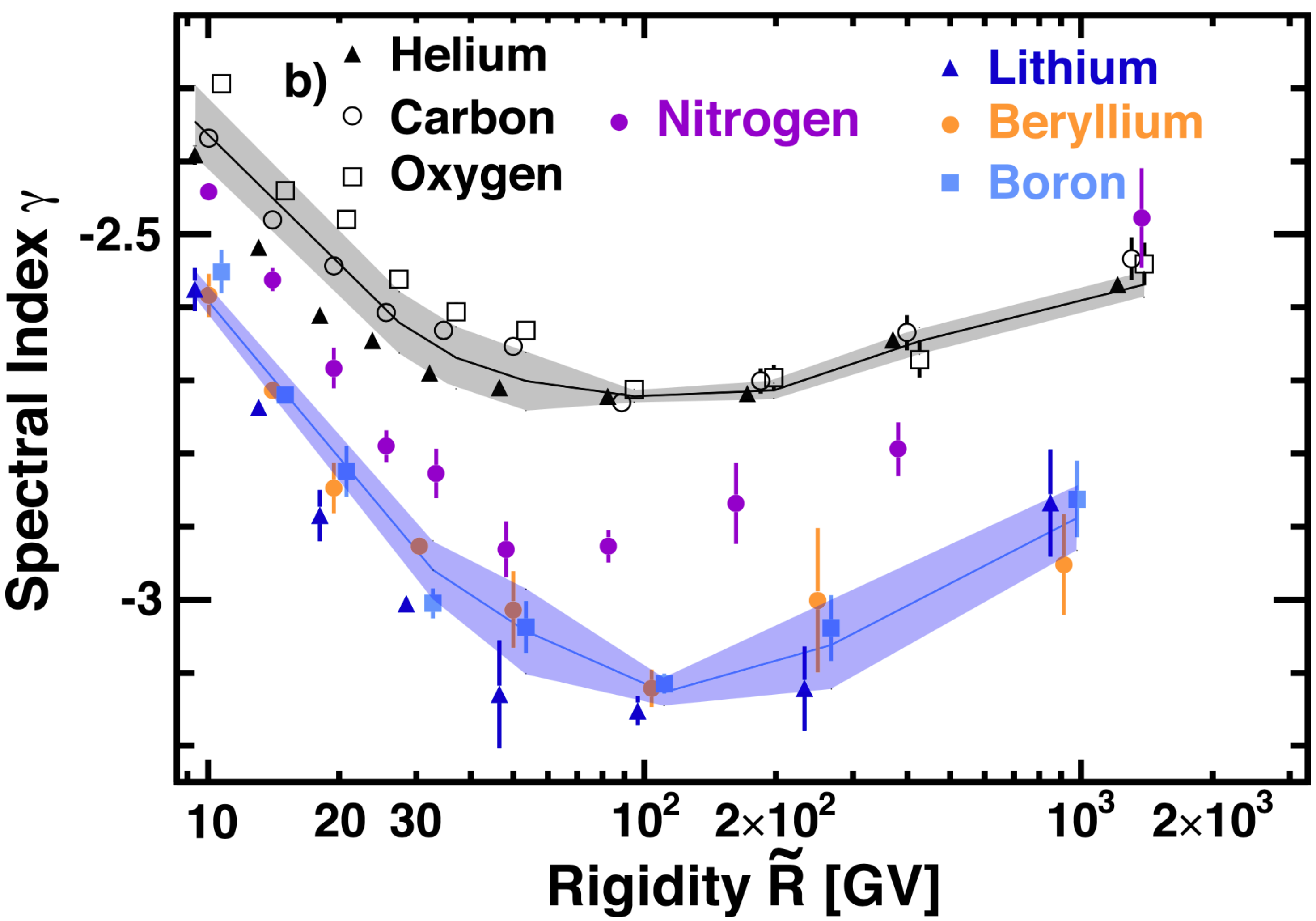
M. Aguilar *et al*, Phys. Rev. Lett. 120, 021101 (2018)

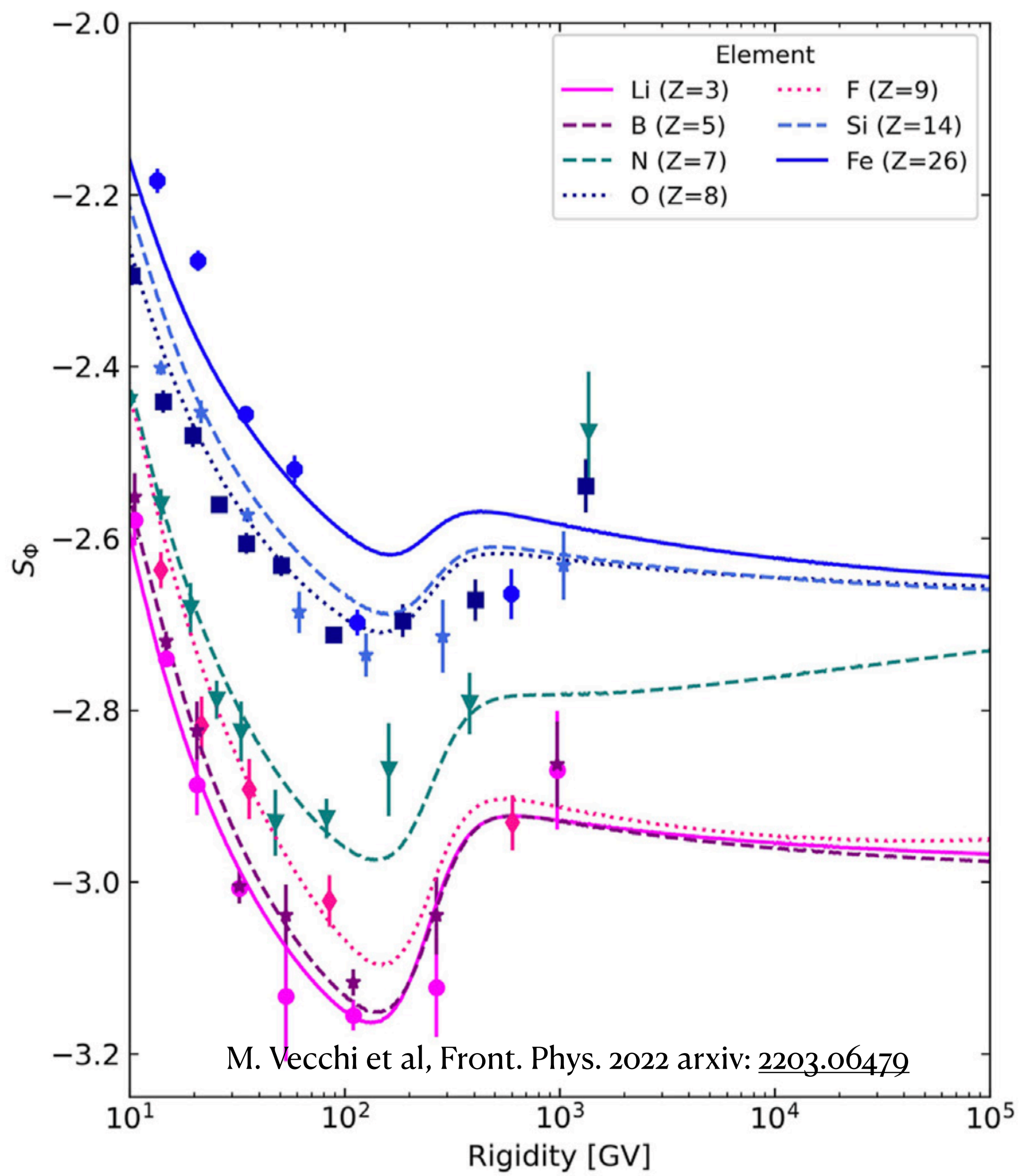


The flux slope

$$\gamma = \mathrm{d}\left[\log \phi\right] / \mathrm{d}\left[\log R\right]$$

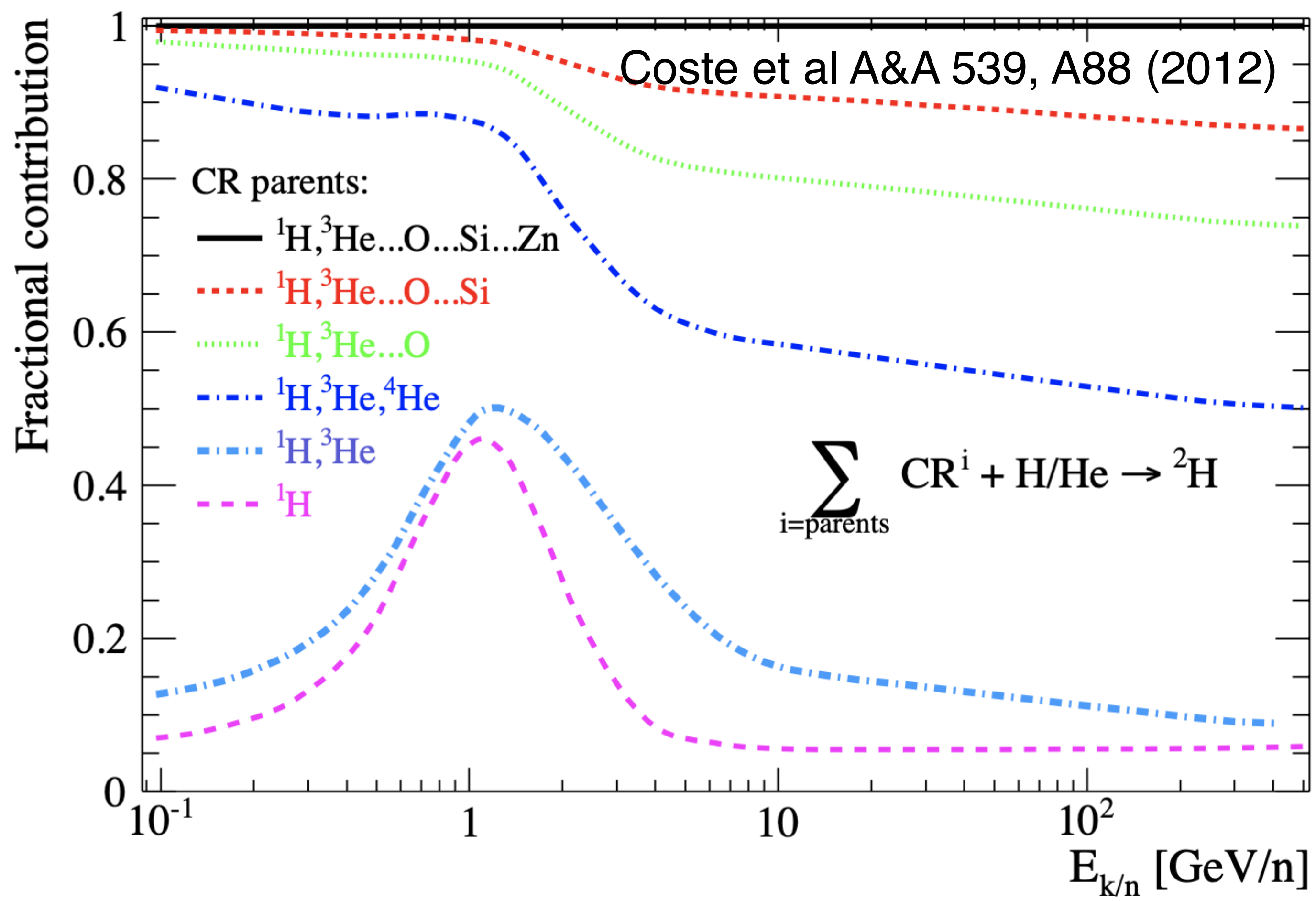
M. Aguilar *et al,* Phys. Rept. 894 (2021) 1-116



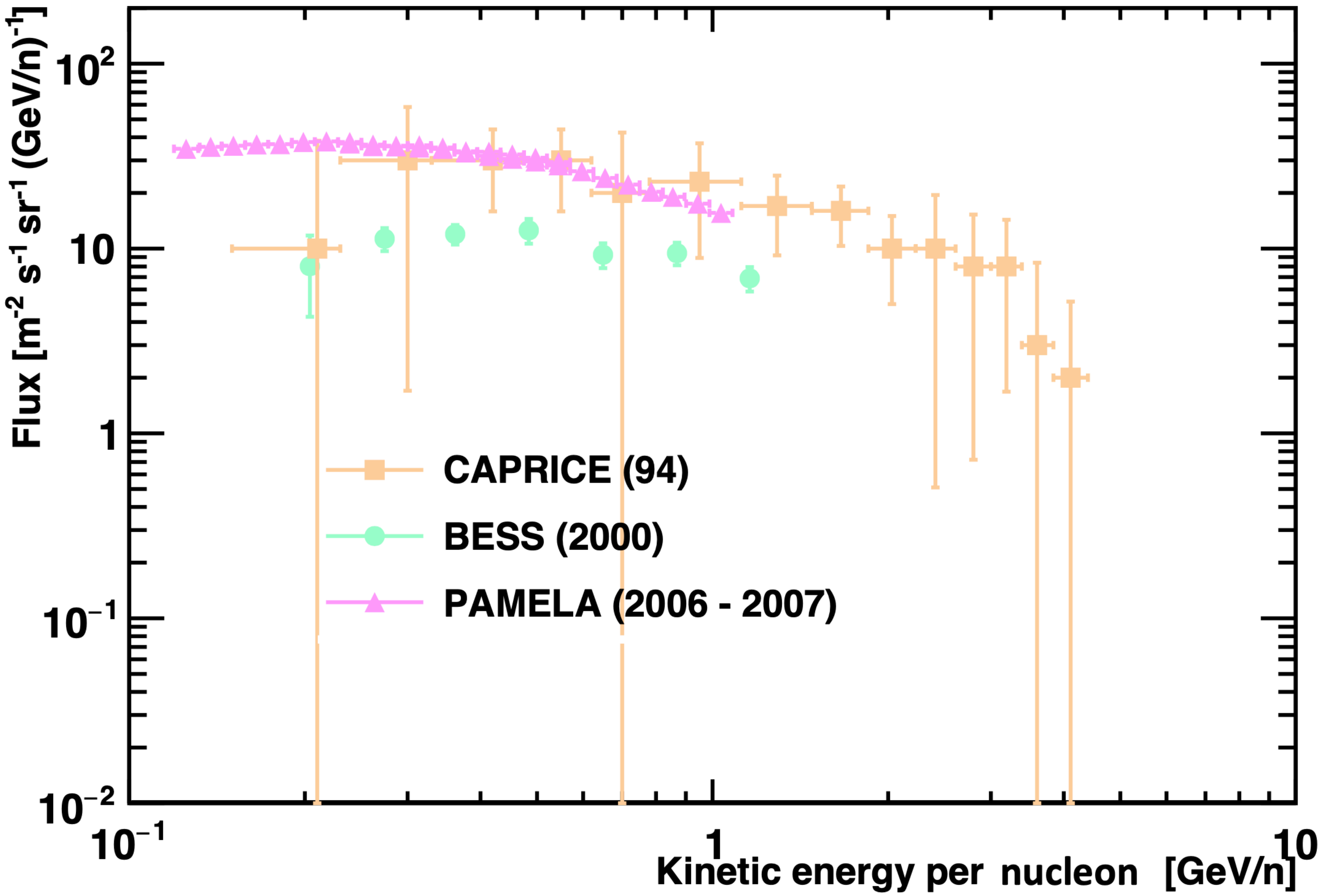


Deuterons in cosmic rays

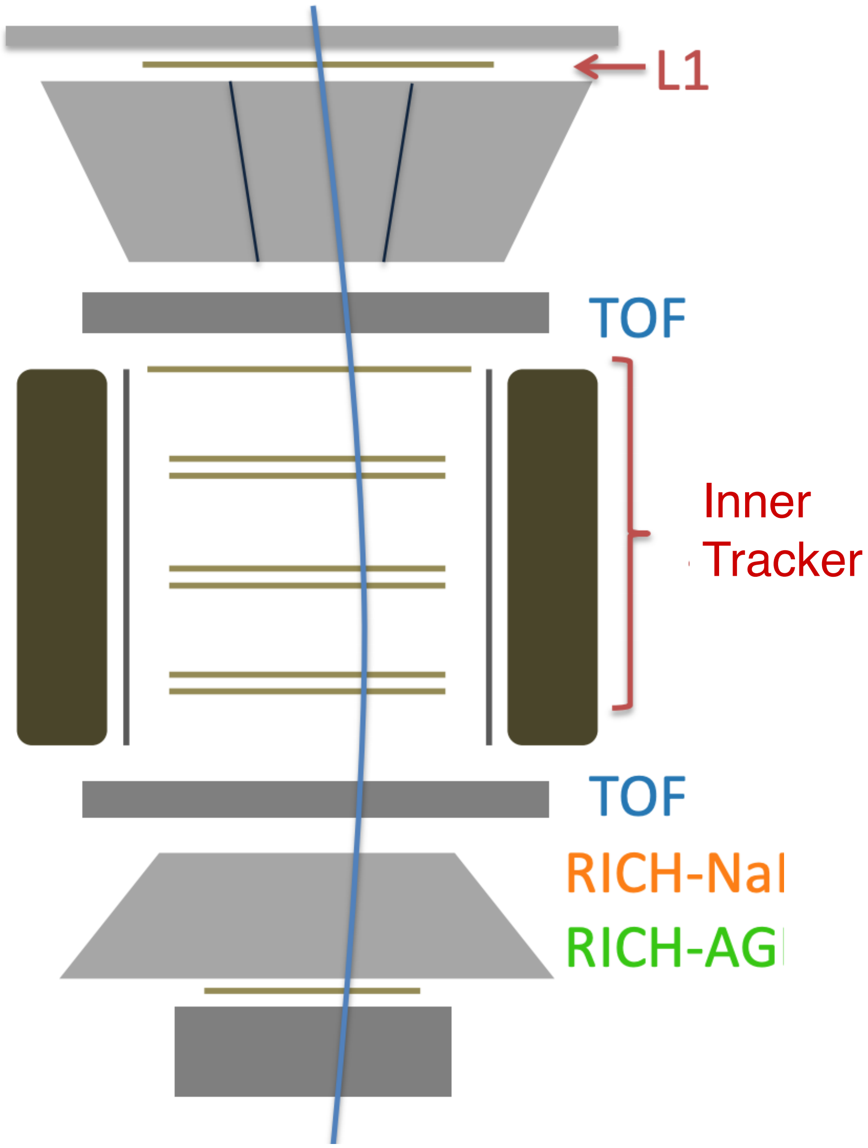
- Deuterons constitute the most abundant secondary species in galactic cosmic rays.
- The main contribution to their production comes from cosmic-ray H, ^{3}He, and ^{4}He interacting with the Interstellar Medium.
- Current deuteron measurements are affected by large uncertainties above 1 GeV/n.



Deuteron flux before AMS-02

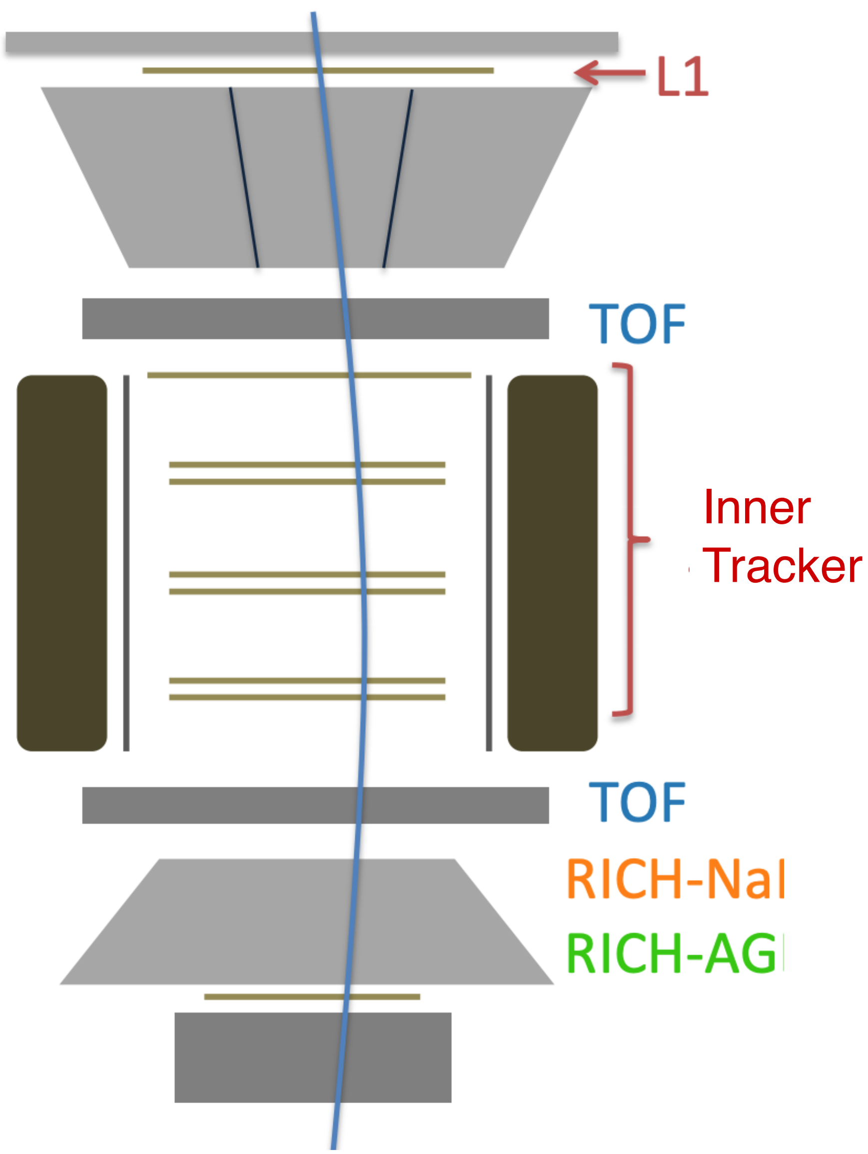


Isotope identification



$$M = \frac{RZ\sqrt{1-\beta^2}}{\beta}$$

Isotope identification

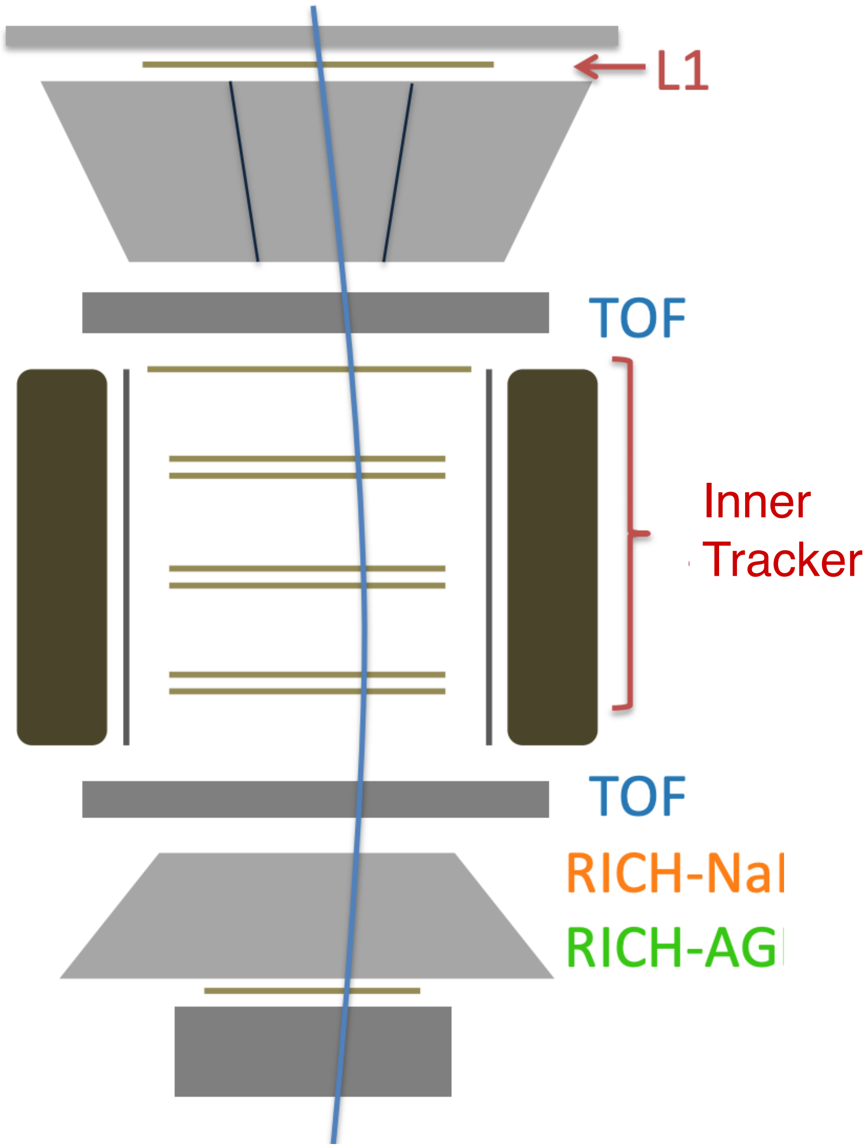


$$M = \frac{RZ\sqrt{1-\beta^2}}{\beta}$$

In this analysis:

- Charge (Z=1) **L1, TOF, Inner tracker**

Isotope identification

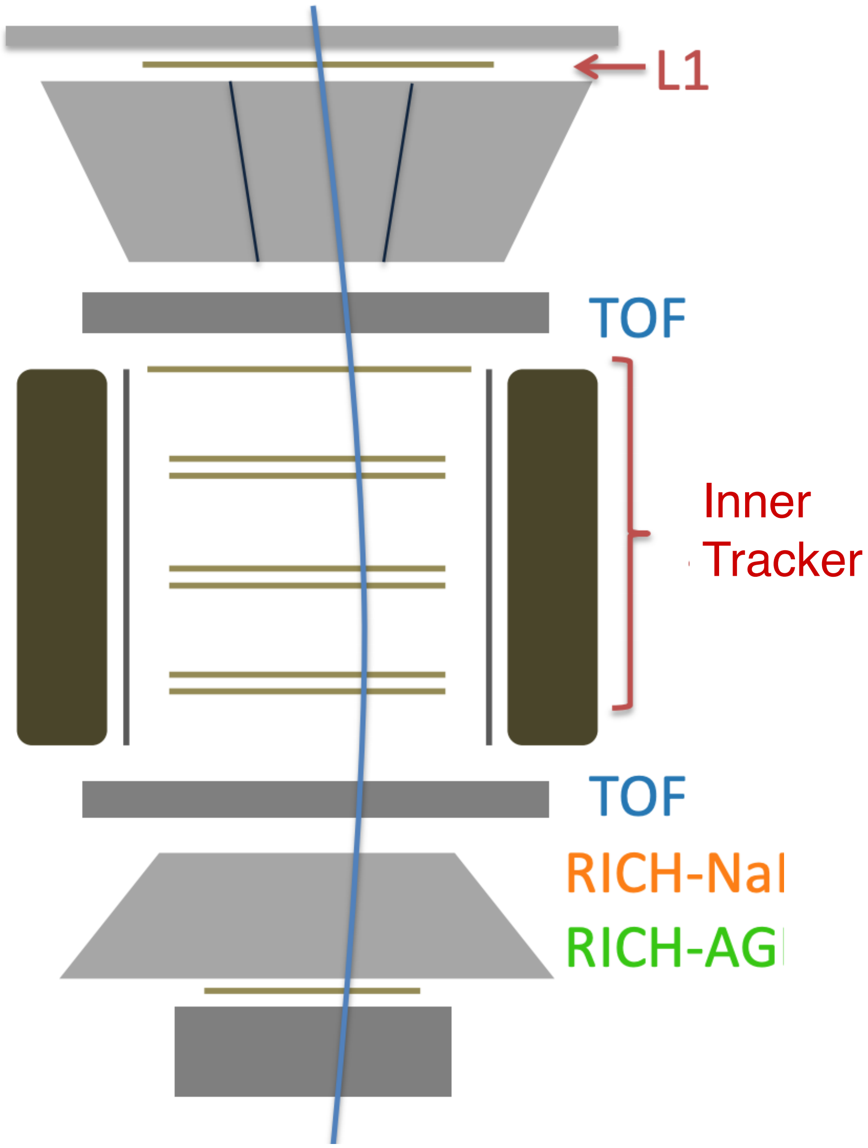


$$M = \frac{RZ\sqrt{1-\beta^2}}{\beta}$$

In this analysis:

- Charge (Z=1) **L1, TOF, Inner tracker**
- Rigidity from the inner tracker

Isotope identification

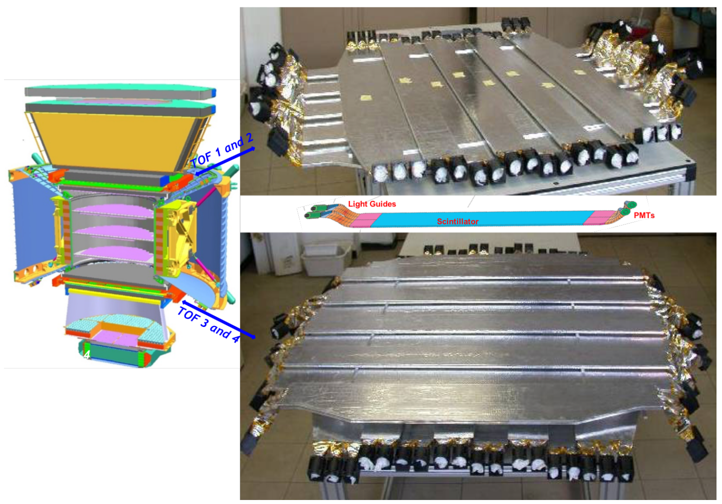


$$M = \frac{RZ\sqrt{1-\beta^2}}{\beta}$$

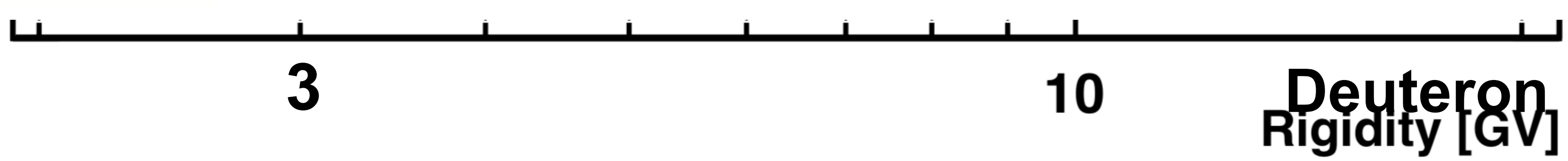
In this analysis:

- Charge (Z=1) **L1, TOF, Inner tracker**
- Rigidity from the inner tracker
- 3 complementary measurements of velocity (**TOF**, **RICH-NaF**, **RICH-Ag**)

Three velocity ranges for isotope identification

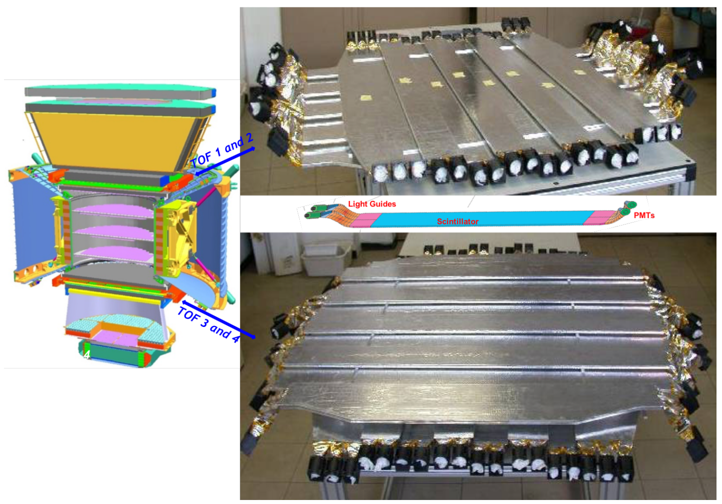


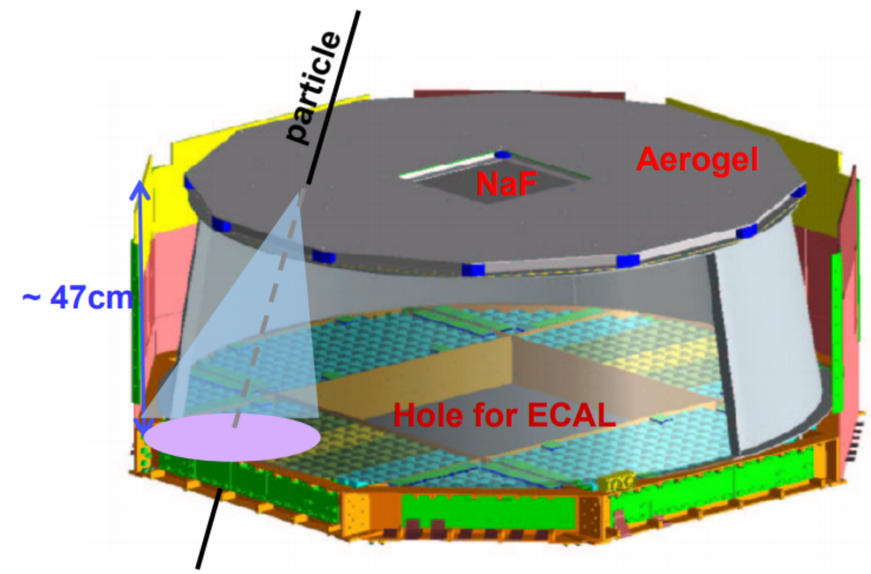
TOF
$\beta > 0.5$

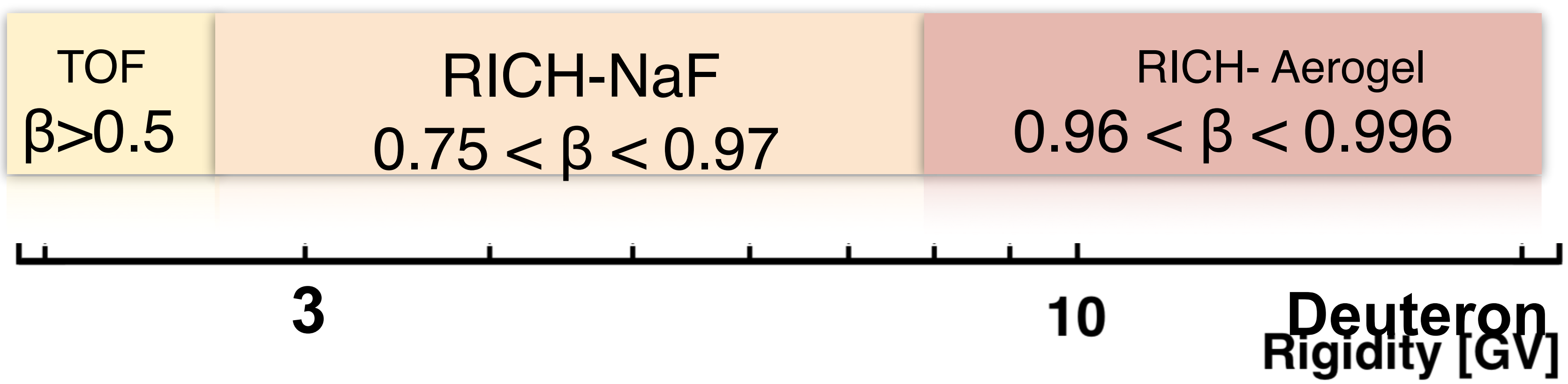


TOF $\Delta\beta/\beta^2\ (\beta=1, Z=1) \cong 4\%$

Three velocity ranges for isotope identification



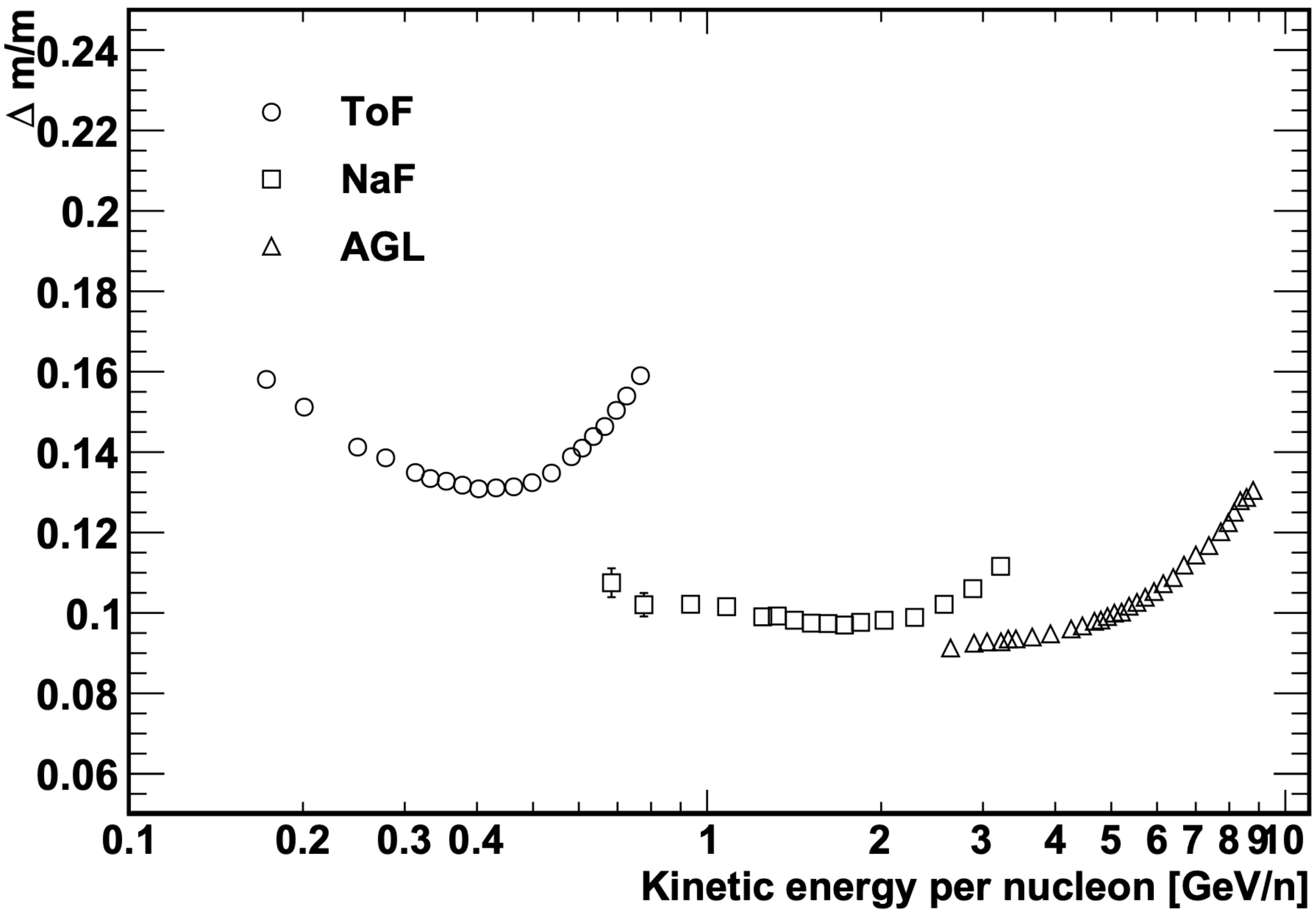




TOF	$\Delta\beta/\beta^2$ (β=1,Z=1) ≅ 4%
RICH NaF	$\Delta\beta$ (β=1,Z=1) ≅ 0.35%
RICH Agl	$\Delta\beta$ (β=1,Z=1) ≅ 0.12%

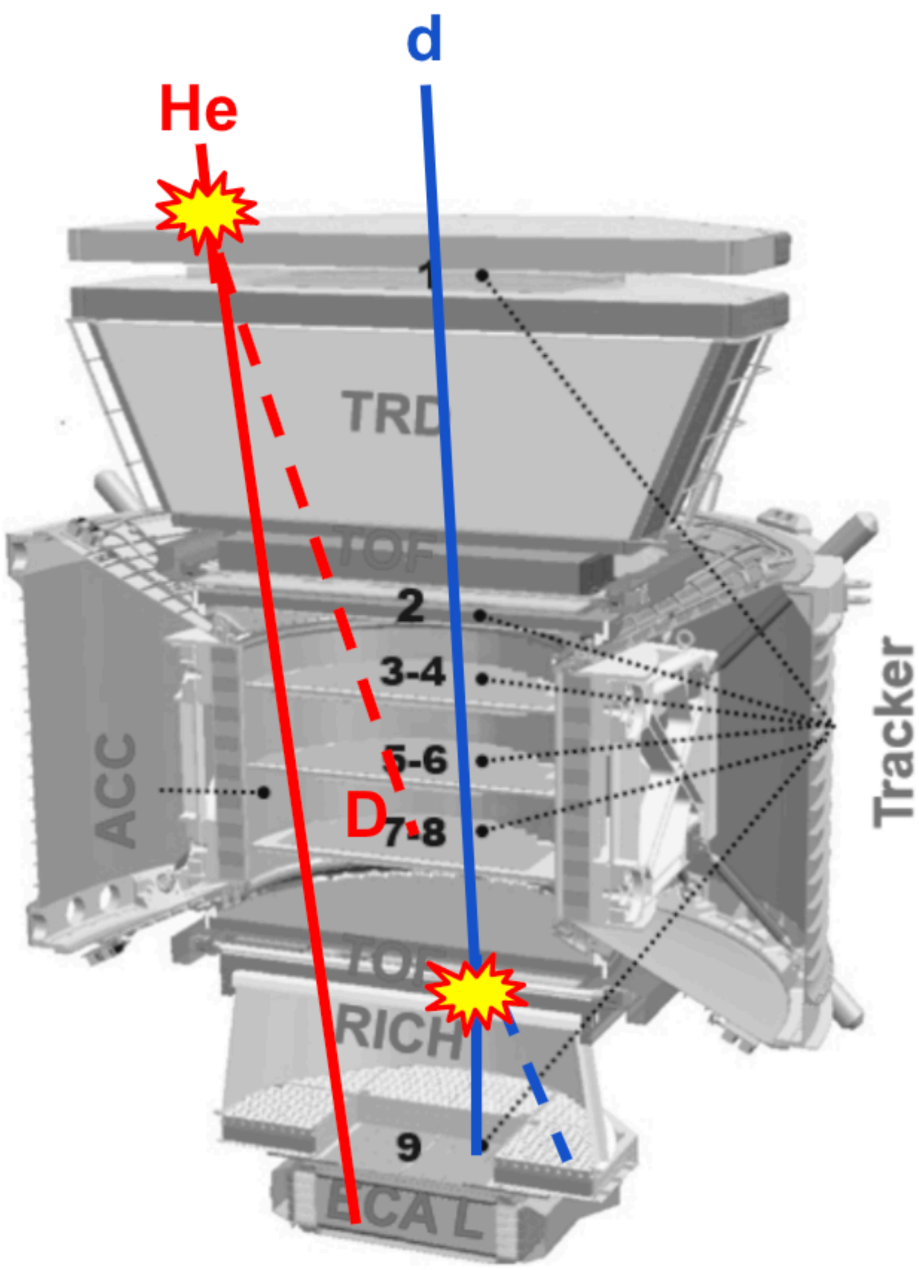
Mass resolution (Z=1 particles)

$$\left(\frac{\Delta M}{M}\right)^2 = \left(\frac{\Delta R}{R}\right)^2 + \gamma^4 \left(\frac{\Delta\beta}{\beta}\right)^2$$



E. Bueno, F. Barão, and M.Vecchi NIM A 2022 (arXiv:2203.04025)

Which events (CR nuclei) for Z=1 ?



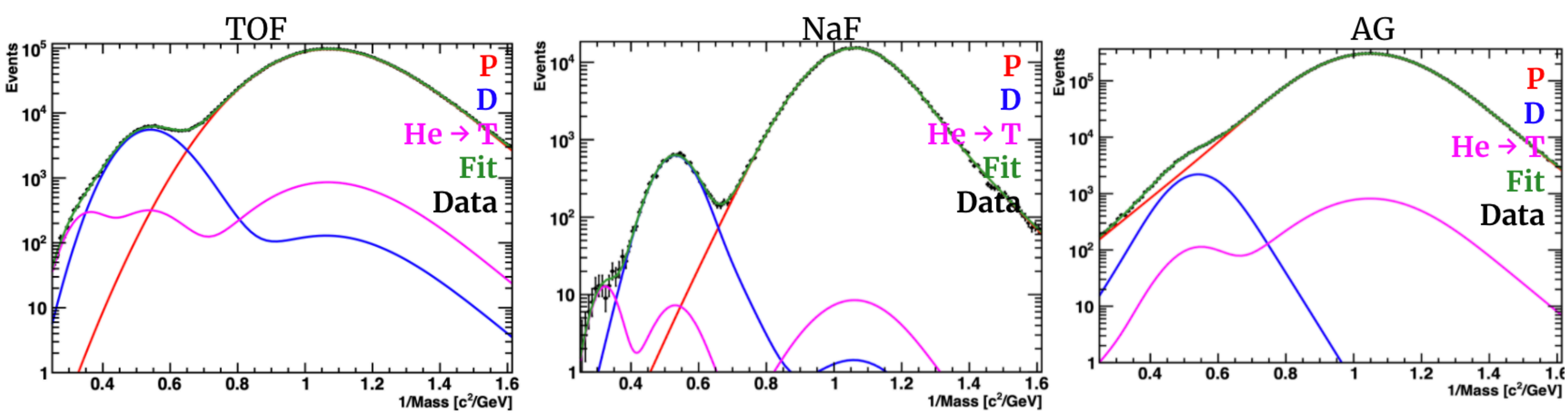
- Well reconstructed primary protons
- Well reconstructed primary deuterons

- Protons from deuteron fragmentation inside AMS

- Protons from helium fragmentation inside AMS
- Deuterons from helium fragmentation inside AMS
- Tritium from helium fragmentation inside AMS

Mass template

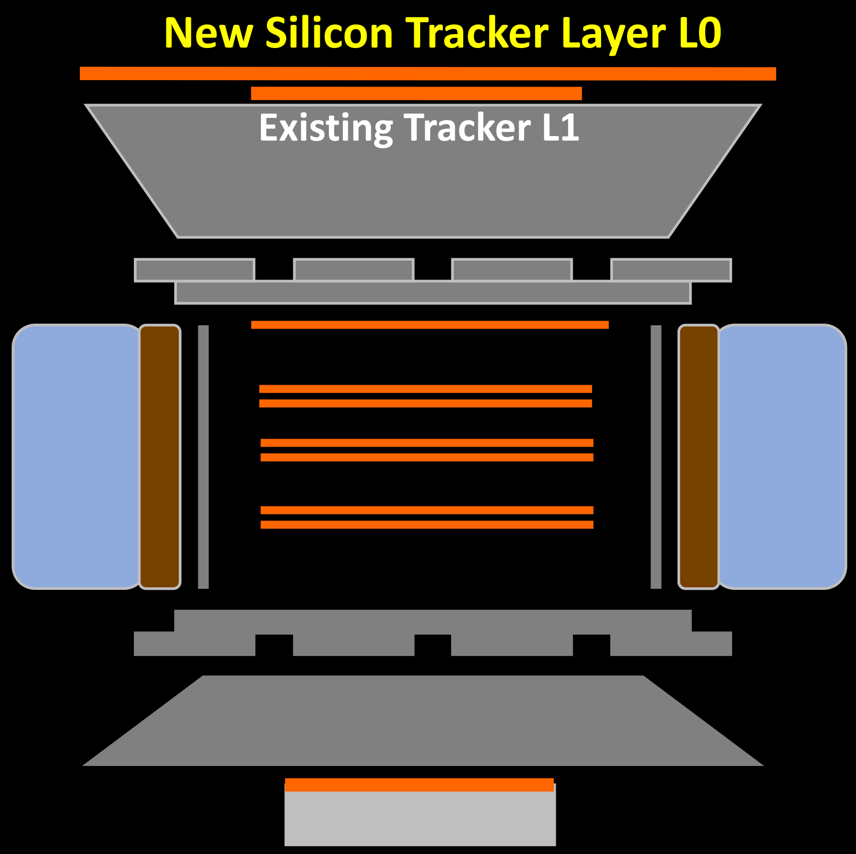
- The number of deuteron events and its statistical error is extracted by fitting the inverse mass distribution for each bin, between 2 and 20 GV.
- Data are compared to the parametric model for the 3 velocity ranges.



E. Bueno, F. Barão, and M.Vecchi, NIM A 2022 (arXiv:2203.04025)

The cosmic-ray deuteron flux

The White House announced the lifetime of the Space Station will be extended through 2030. To benefit from this extension, AMS is building an Upgrade consisting of a new Silicon Tracker layer to increase the acceptance by 300%.



The results from AMS are unexpected.
AMS will continue to collect data over the life of the Station.
This will change our understanding of the universe.

The most important goal of AMS is to explore the unknown, to search for phenomena in nature that we have never imagined nor had the tools to discover.

Thank you !