Properties of Cosmic Deuterons Measured by the Alpha Magnetic Spectrometer

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Editors’ Suggestion
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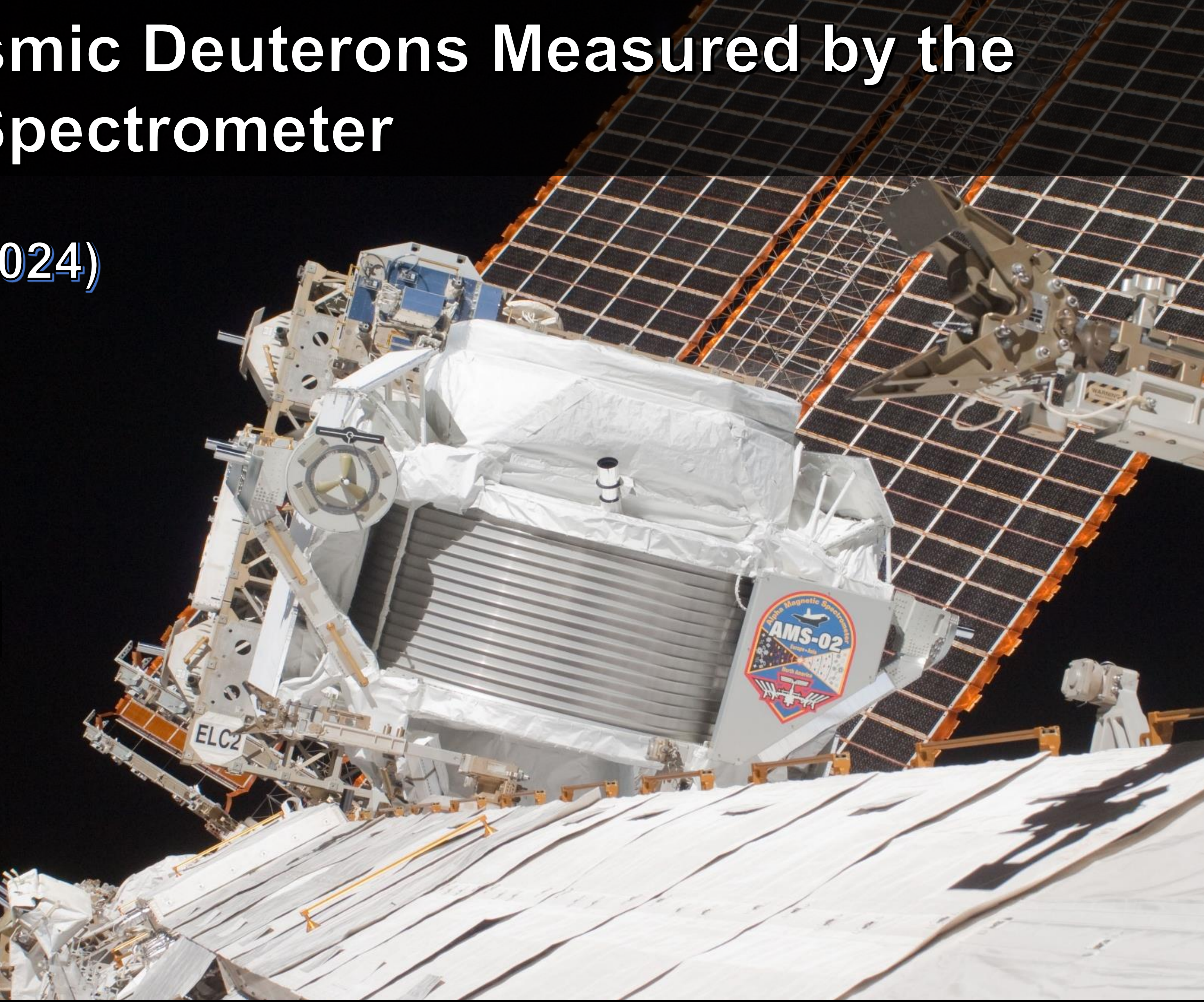
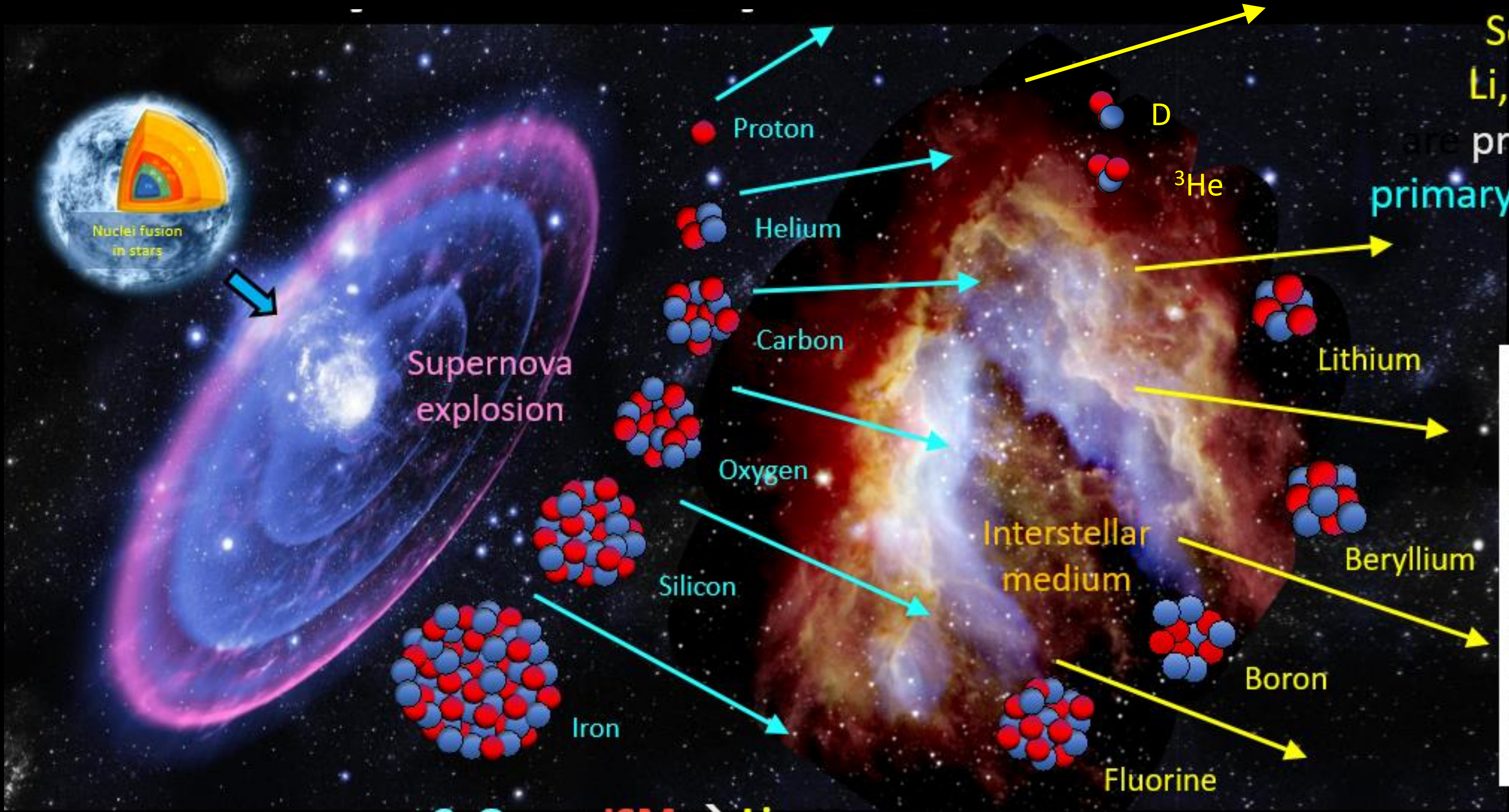
C. Delgado (CIEMAT)

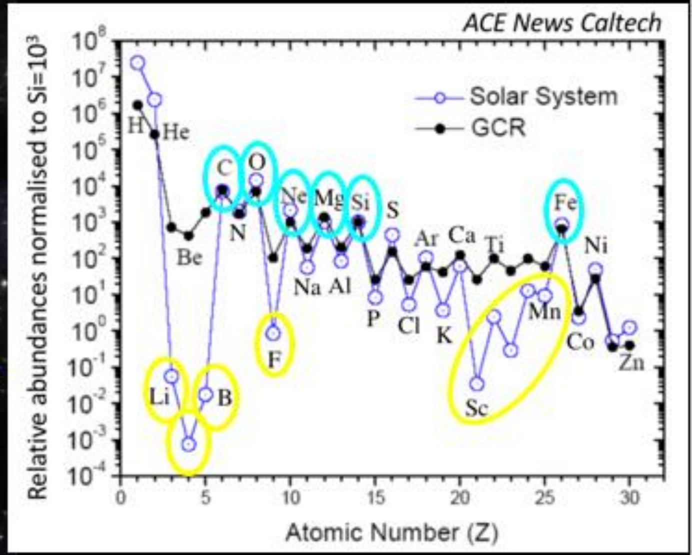


ICHEP 2024
PRAGUE

Cosmic Rays Nuclei



Secondary
Li, Be, B, F, sub-Fe nuclei
are produced by the collision of
primary cosmic rays C, O, Si, ... , Fe
with the
interstellar medium

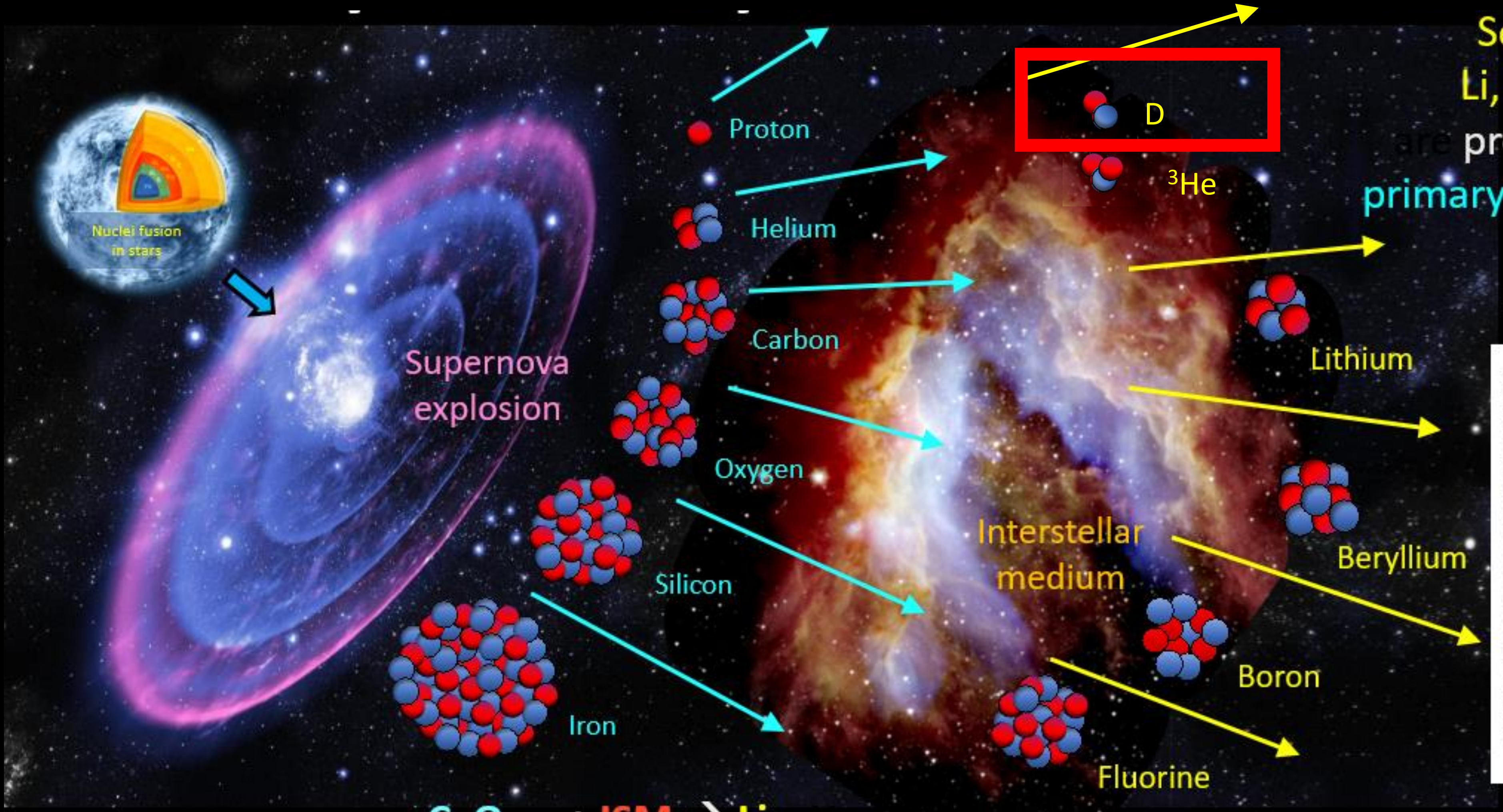


C, O, ... + ISM → Li
C, O, ... + ISM → Be
C, O, ... + ISM → B

Ne, Mg, Si, ... + ISM → F + X

Fe, ... + ISM → Sc, ... ,Mn

Cosmic Rays Nuclei



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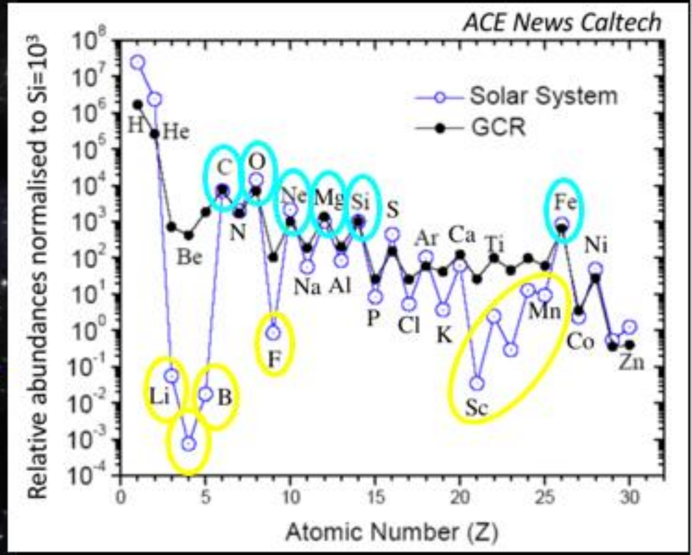

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Deuterium in Cosmic Rays

Deuterium and ^{3}He are believed to be mostly produced by the fragmentation of ^{4}He.

The smaller interaction cross section of He with respect to heavier nuclei, allows to probe the properties of diffusion and the ISM at larger distances than any other nuclei.

The different A/Z ratios of D and ^{3}He could allow to disentangle kinetic energy and rigidity dependence in propagation models.

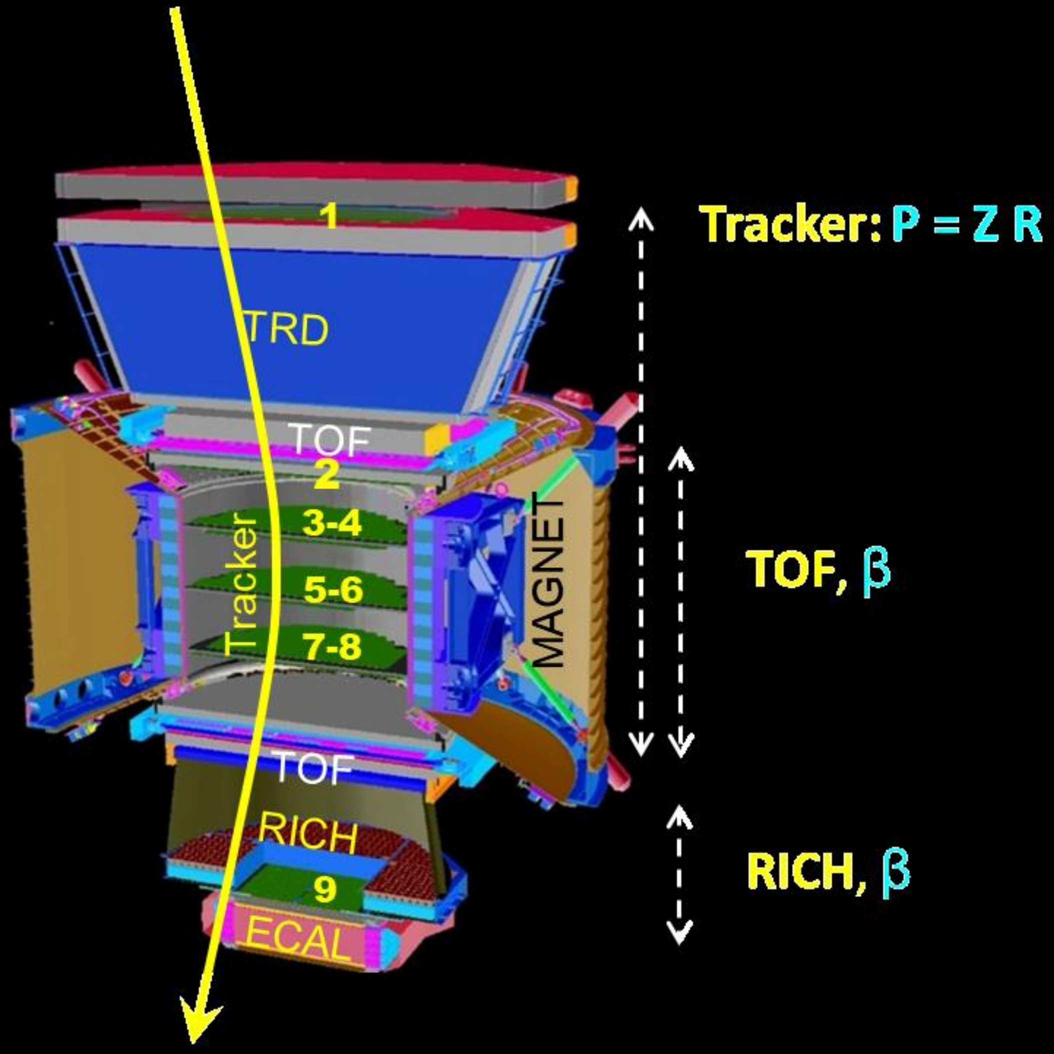
D/^{4}He ratio is specially interesting since for their Kinetic Energy per nucleon is the same for equal rigidity, so the effect of modulation is expected to be reduced compared with other nuclei ratios.

Properties of Cosmic Deuterons Measured by the Alpha Magnetic Spectrometer

Precision measurements by the Alpha Magnetic Spectrometer (AMS) on the International Space Station of the deuteron (D) flux are presented.

The measurements are based on 21 million D nuclei in the rigidity range from 1.9 to 21 GV collected from May 2011 to April 2021.

Isotope identification in AMS



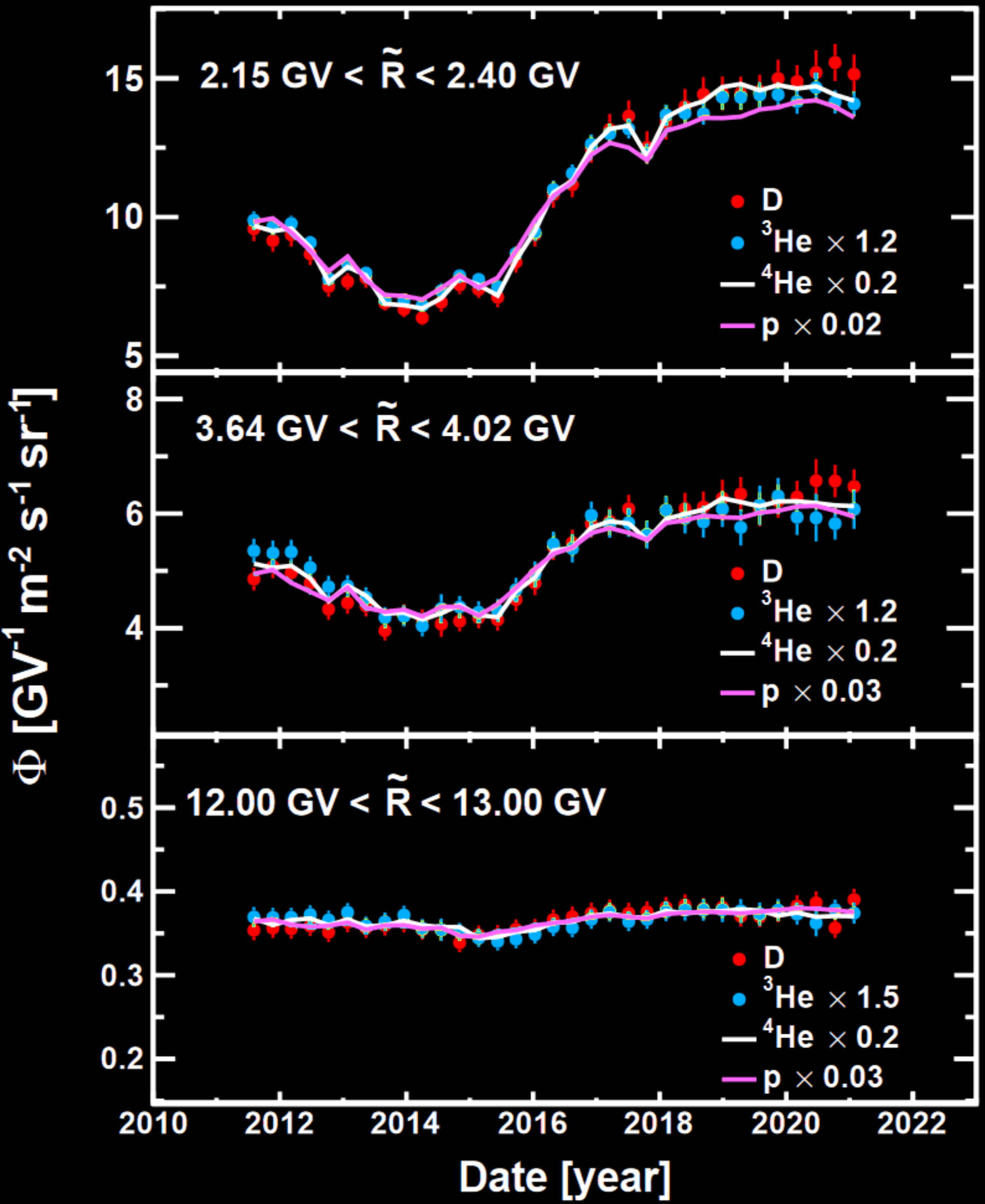
Separation requires mass reconstruction

$$m = \frac{RZ}{\beta\gamma}$$

Separation power depends on rigidity and velocity (β) resolutions

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

Fluxes Time Dependence



The AMS D, ^{3}He, ^{4}He, and p fluxes as functions of time for three characteristic rigidity bins.

Fluxes have been scaled to obtain the same time-averaged flux as D in each rigidity bin.

The errors are the quadratic sum of the statistical and time-dependent systematic errors.

In each rigidity bin the four fluxes show a similar time behavior.

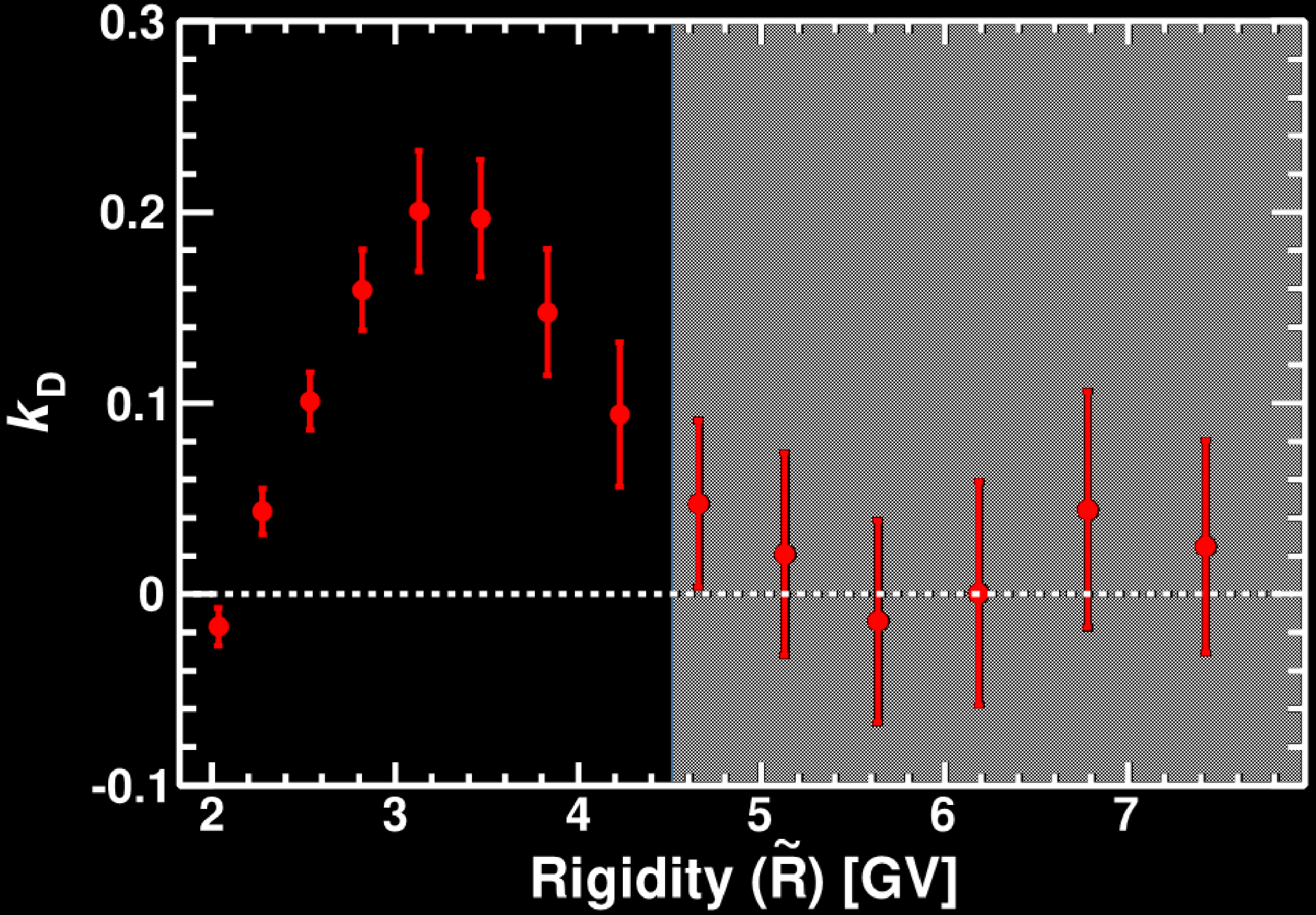
Flux Ratios Time Dependence

To study the differences in time variation for the D and ^{4}He fluxes (Φ) in detail we fit a linear relation between the relative variations of the fluxes ratio and ^{4}He flux for each rigidity bin *i*

$$\frac{\Phi^i_{\mathrm{D}}/\Phi^i_{^4\mathrm{He}} - \langle \Phi^i_{\mathrm{D}}/\Phi^i_{^4\mathrm{He}} \rangle}{\langle \Phi^i_{\mathrm{D}}/\Phi^i_{^4\mathrm{He}} \rangle} = k^i_{\mathrm{D}} \frac{\Phi^i_{^4\mathrm{He}} - \langle \Phi^i_{^4\mathrm{He}} \rangle}{\langle \Phi^i_{^4\mathrm{He}} \rangle}$$

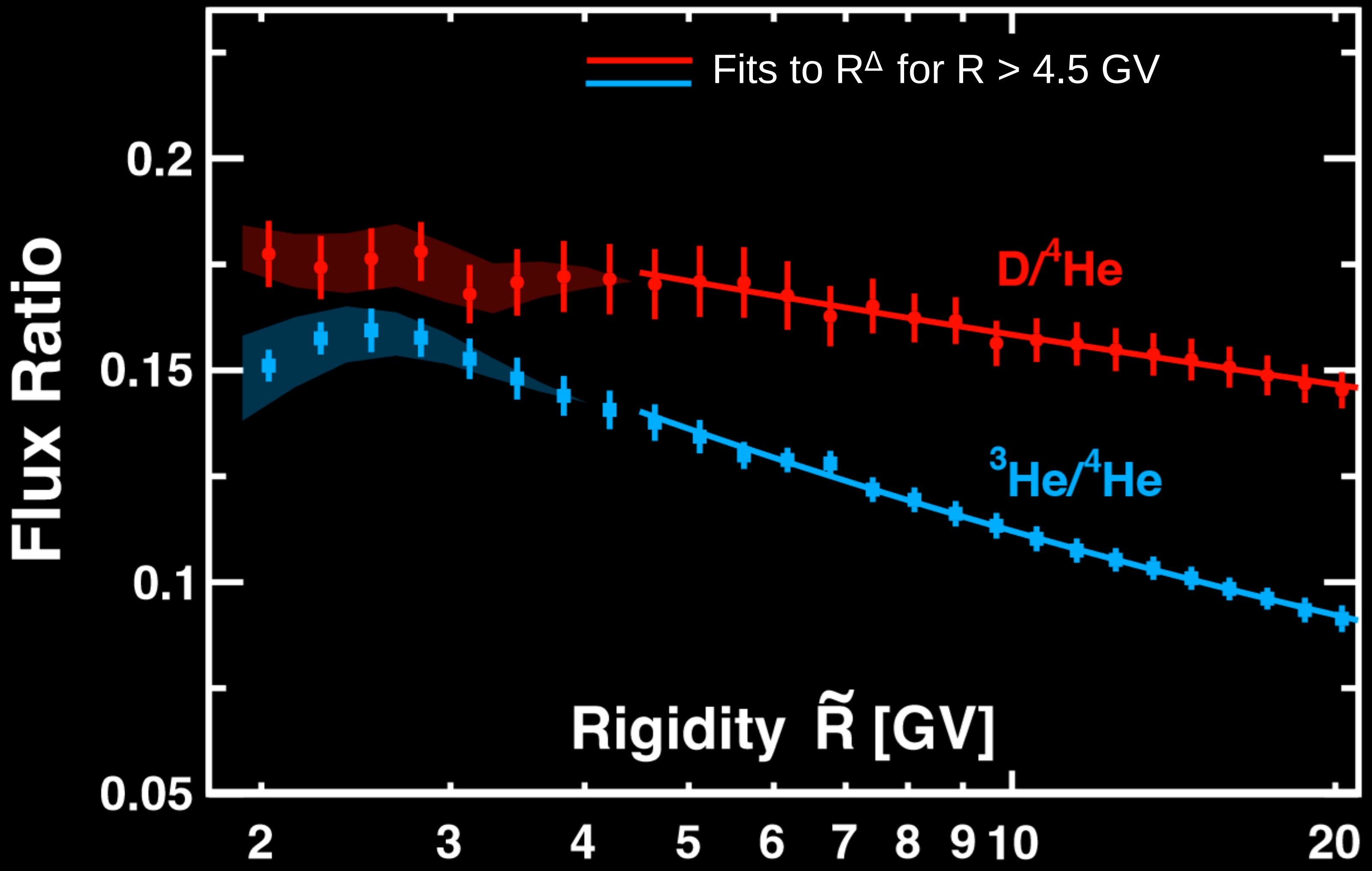
Flux Ratios Time Dependence

k_D is compatible with zero above 4.5 GV showing that D/^{4}He flux ratio is time independent above this rigidity.



3He/4He and D/4He Flux Ratios

Unexpectedly, the D/^{4}He flux ratio spectral index is different from that observed for the ^{3}He/^{4}He flux ratio.



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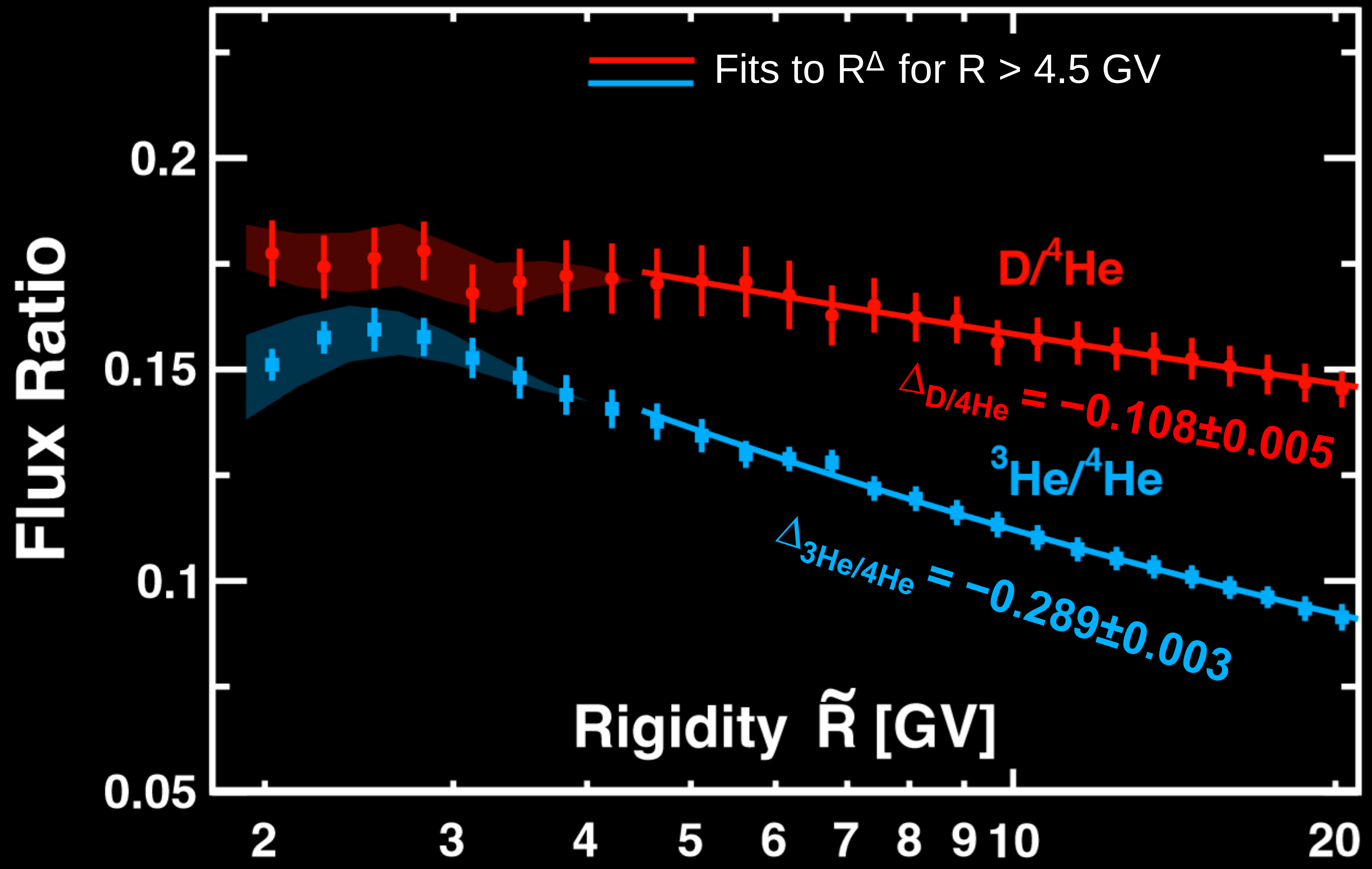
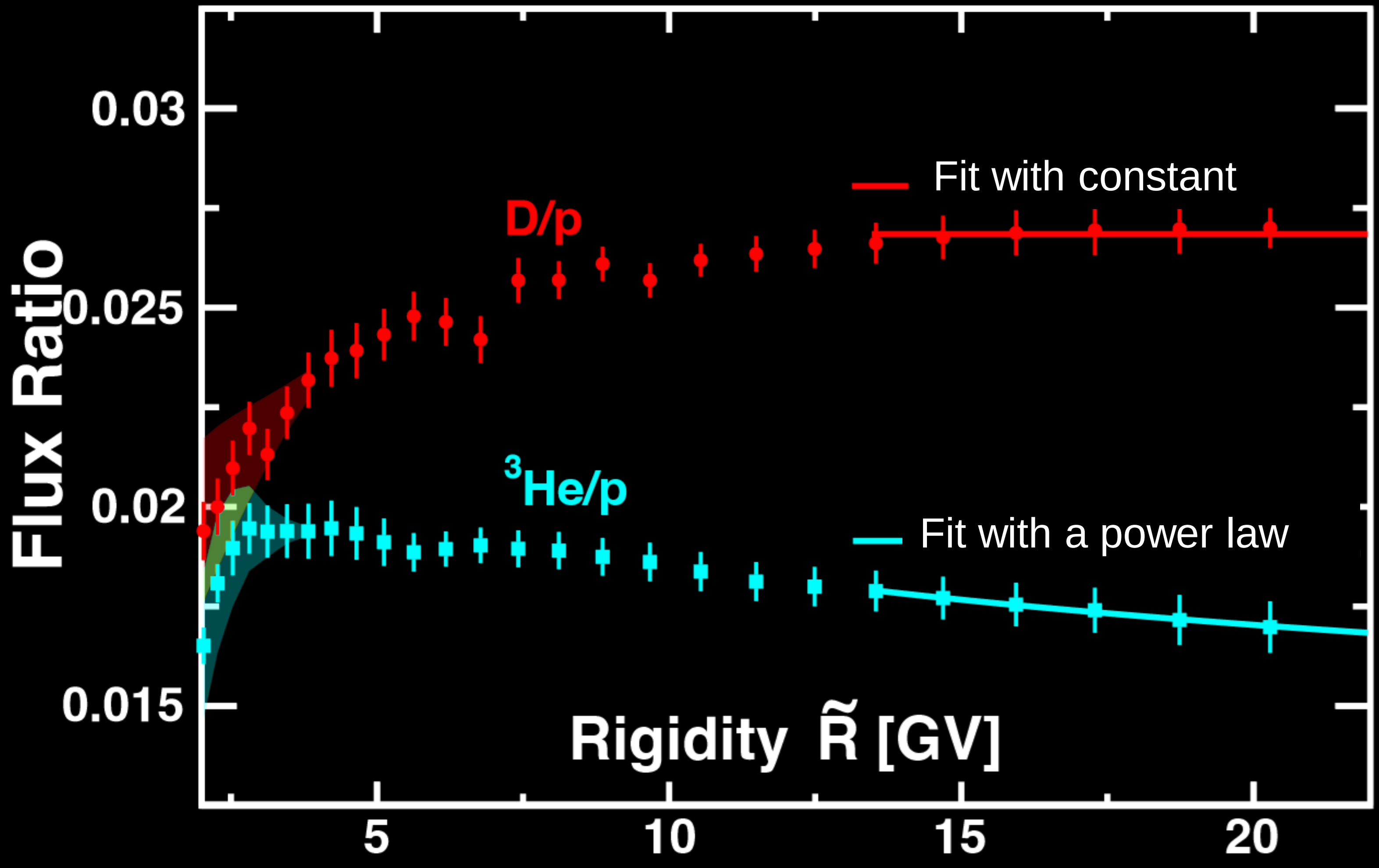


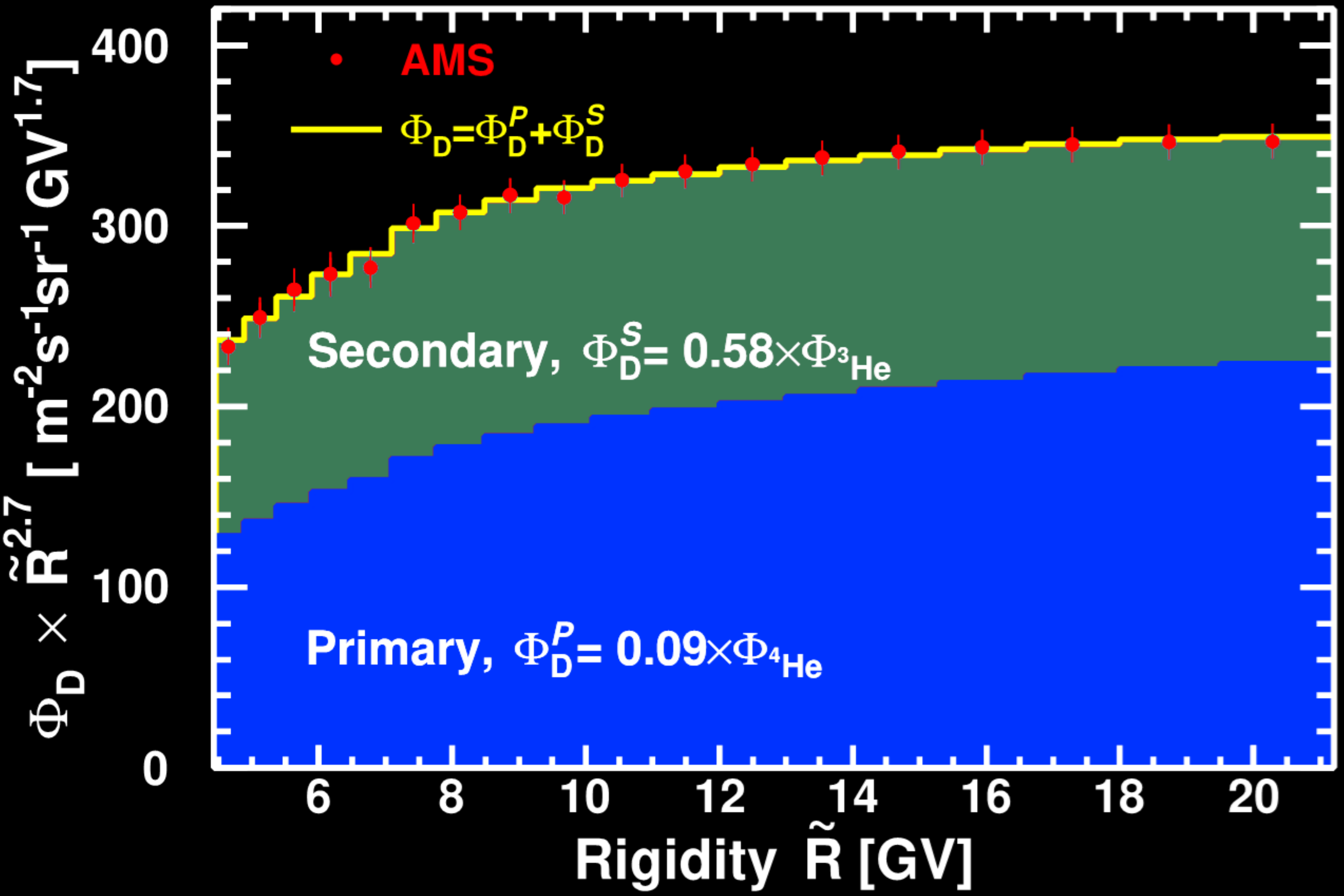
D/p Flux Ratio

D/p flux ratio is increasing with rigidity and flattens out at high rigidities.
This shows that the D and p fluxes have a nearly identical rigidity dependence between 13 and 21 GV



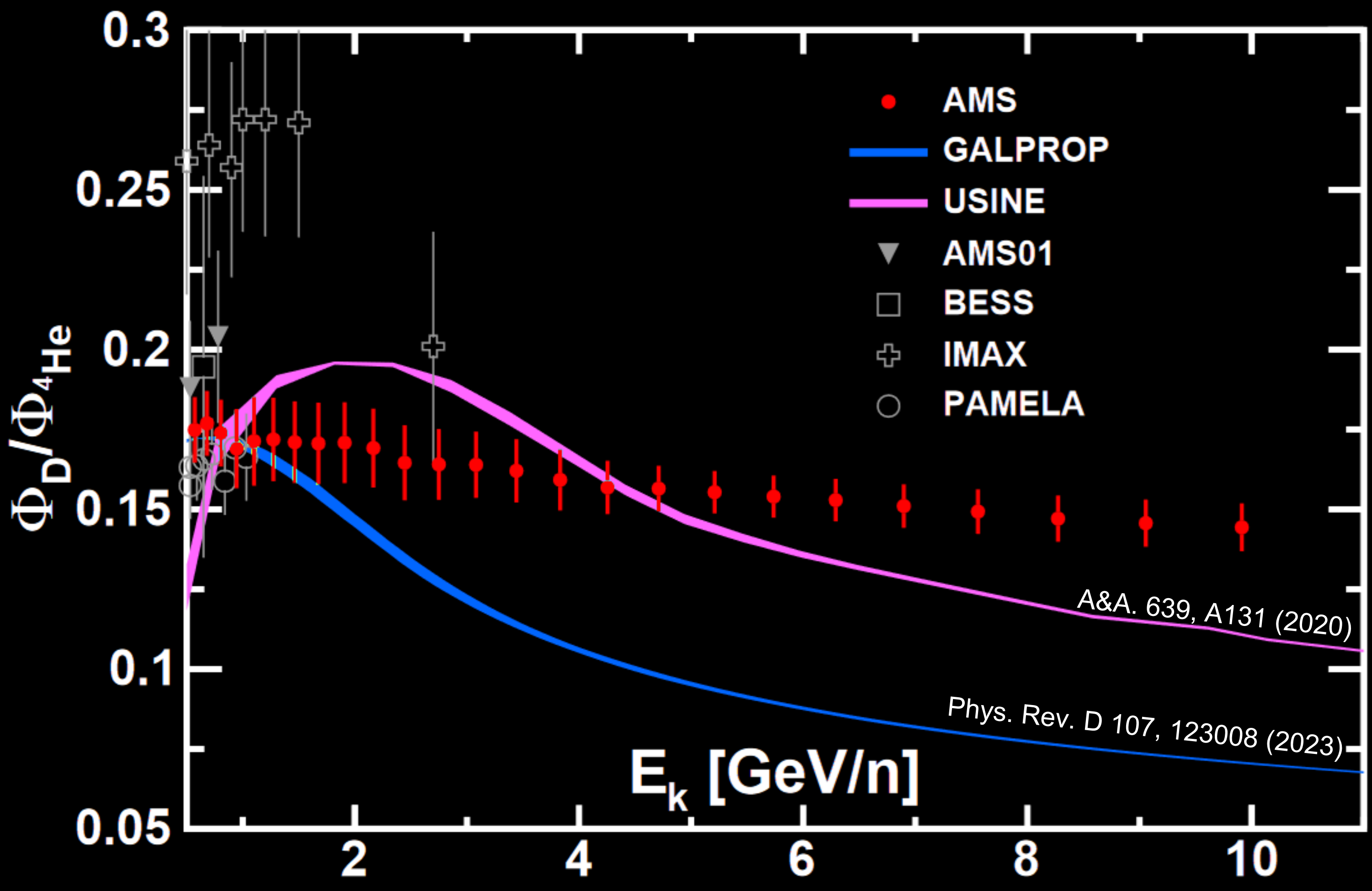
Deuteron as Primary and Secondary like components

To find the primary-like and secondary-like contributions in the D flux we have fitted the D flux as weighted linear combination of primary flux , $\Phi_{^4He}$ and secondary flux, $\Phi_{^3He}$ above 4.5 GV.



AMS results together with previous measurements and model predictions.

The shaded areas show the variations of the model predictions due to solar modulation.



Conclusions

D flux exhibits nearly identical time variations with the p, ^{3}He, and ^{4}He fluxes.

Above 4.5 GV, the D/^{4}He and ^{3}He/^{4}He flux ratios are time independent and their rigidity dependence is well described by power laws.

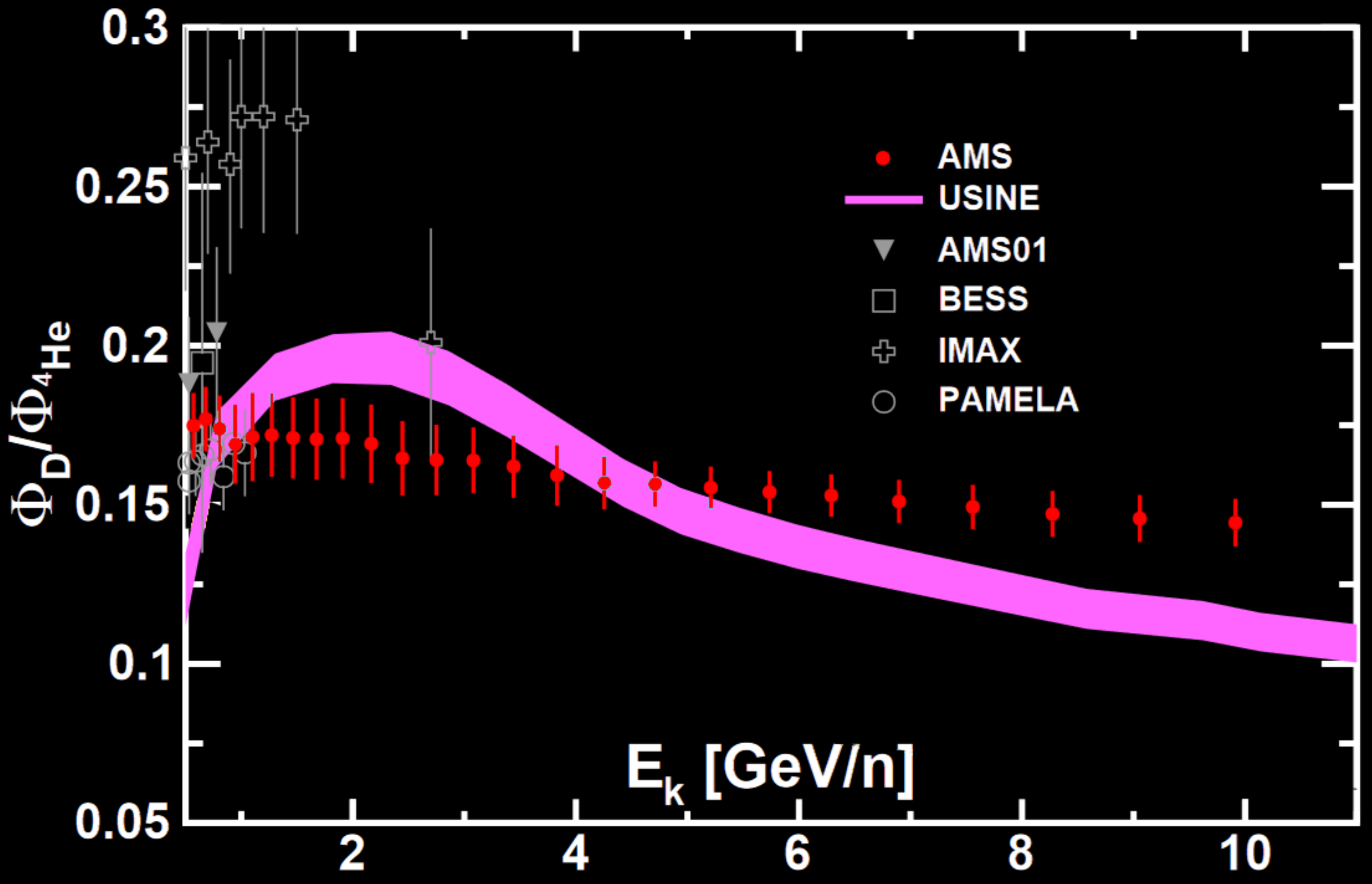
The spectral indexes of the two power laws are different at 10 σ level.

Above ~13 GV the rigidity dependence of the D and p fluxes is nearly identical with a constant D/p flux ratio of 0.027.

These unexpected observations show that contrary to traditional expectations, deuterons must have a primary-like component.

AMS results together with previous measurements and model predictions.

Shaded area shows the variations of the USINE model predictions due to uncertainties in the cross sections and propagation parameters (1σ).



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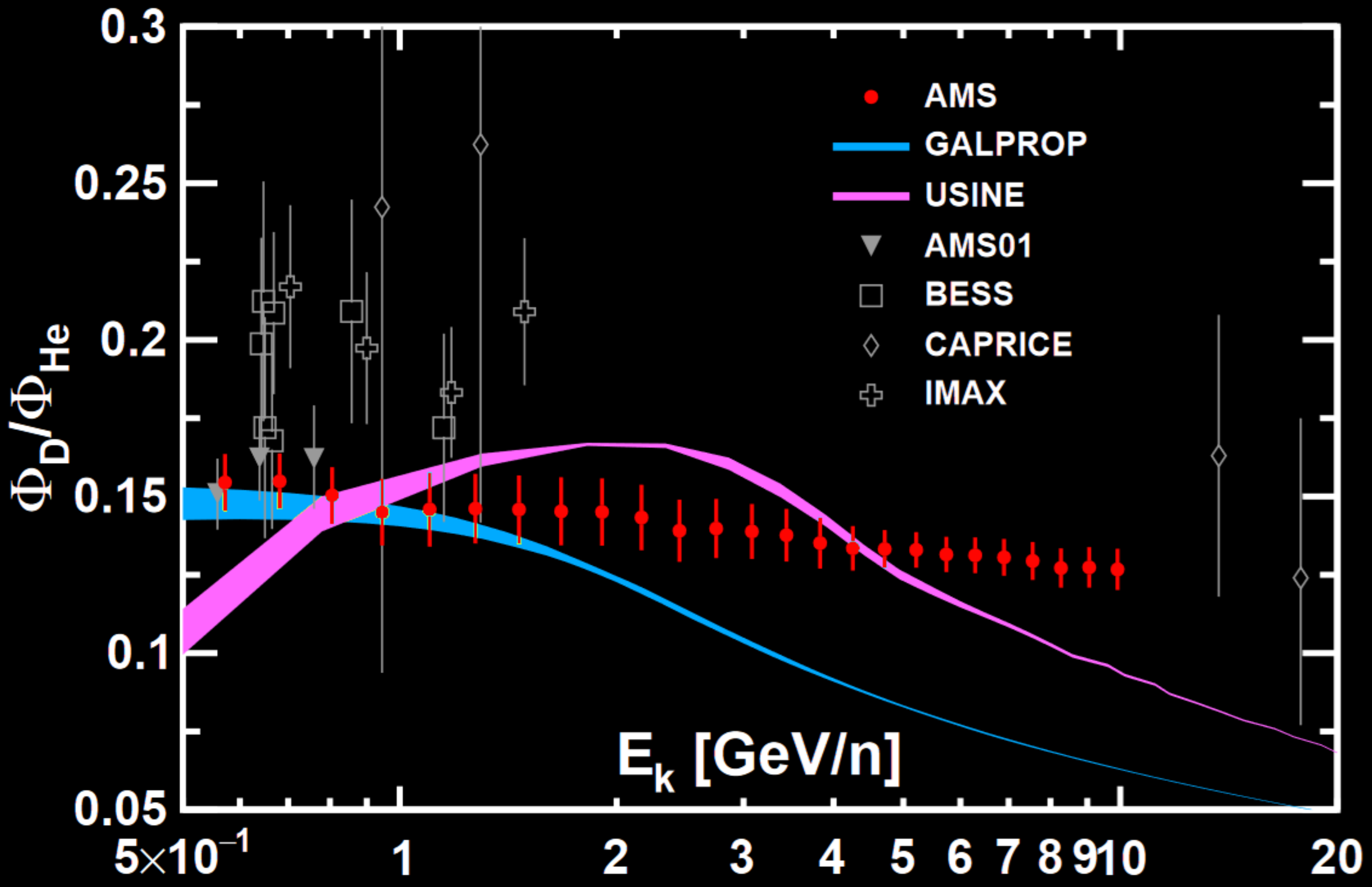

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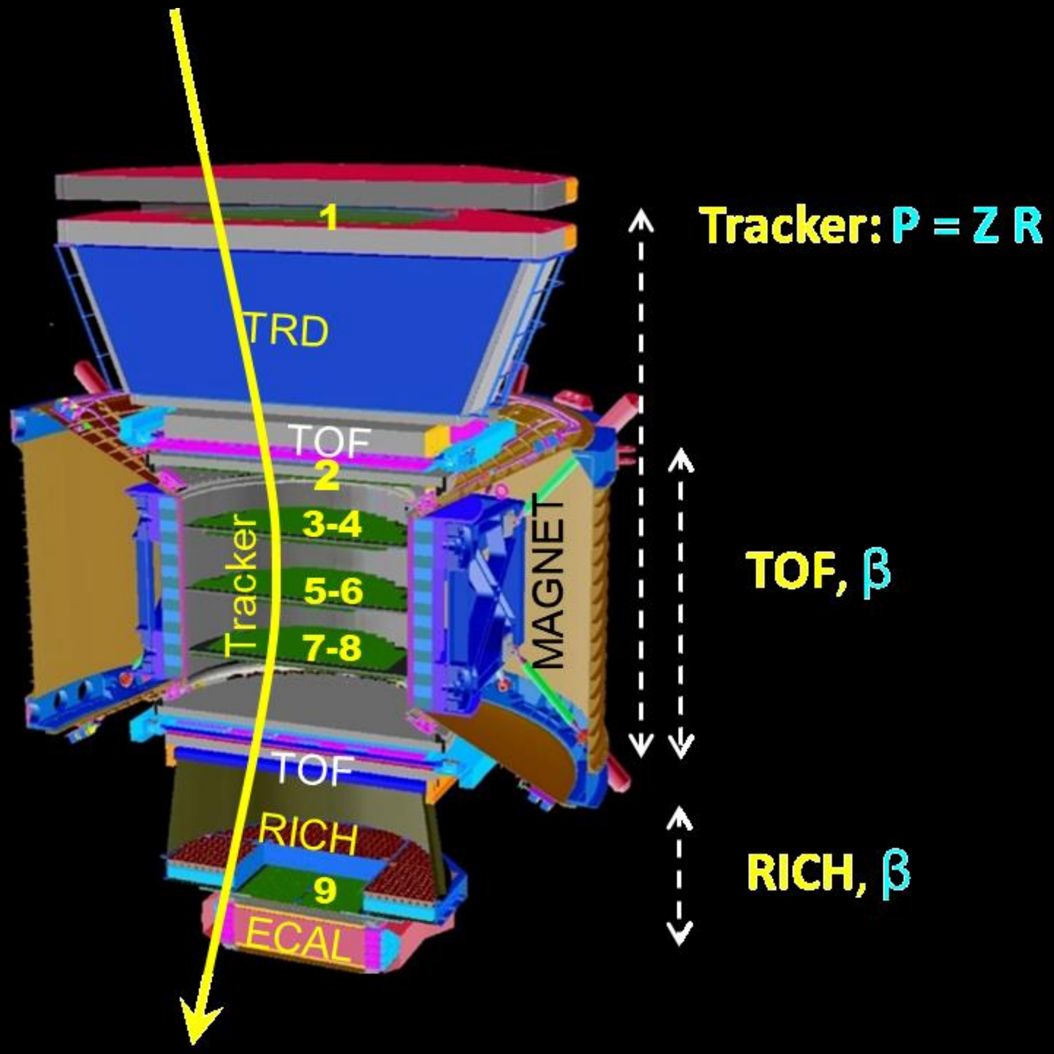


Tracker rigidity resolution

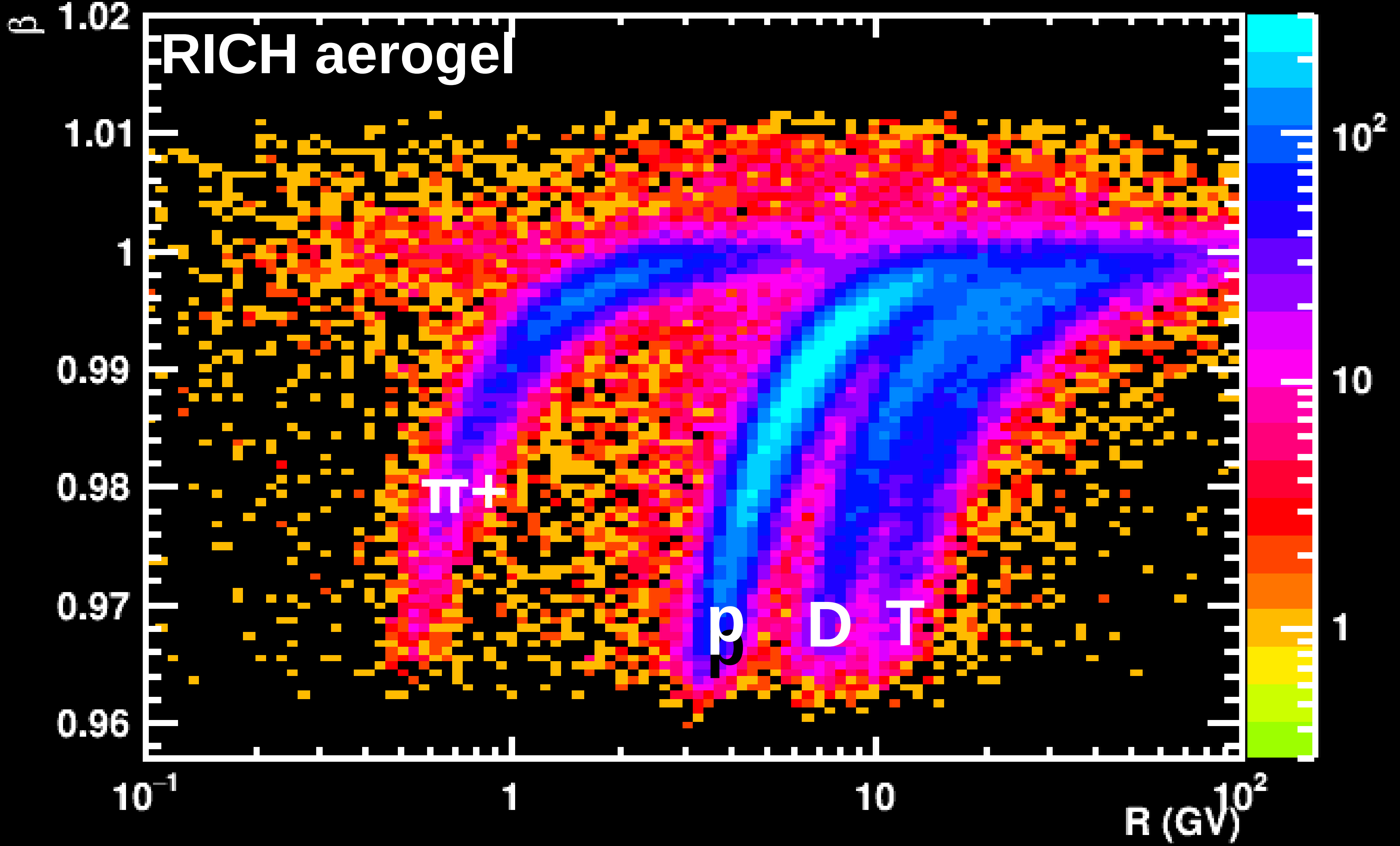
$$\frac{\Delta R}{R} \sim 9\% \text{ for } R < 20 \text{ GV}$$

Velocity (β) resolution for Z=1

TOF	$\sigma_\beta/\beta \sim 3\%$
RICH NaF	$\sigma_\beta/\beta \sim 0.3\%$
RICH AgI	$\sigma_\beta/\beta \sim 0.1\%$

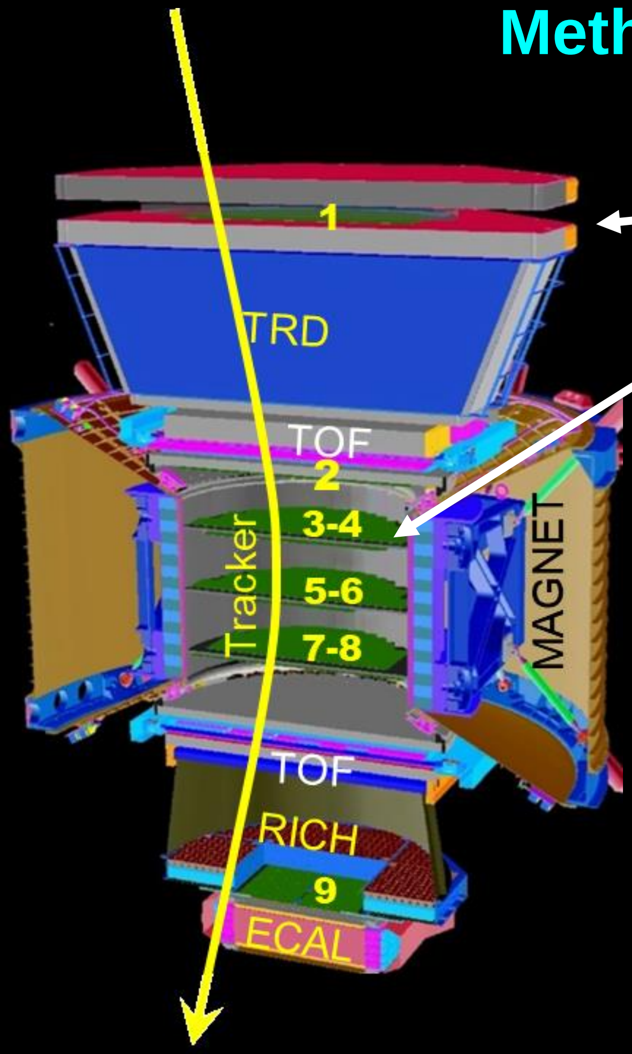
D production in AMS detector

The relative contribution of D and T (and p) is fixed by the measurement

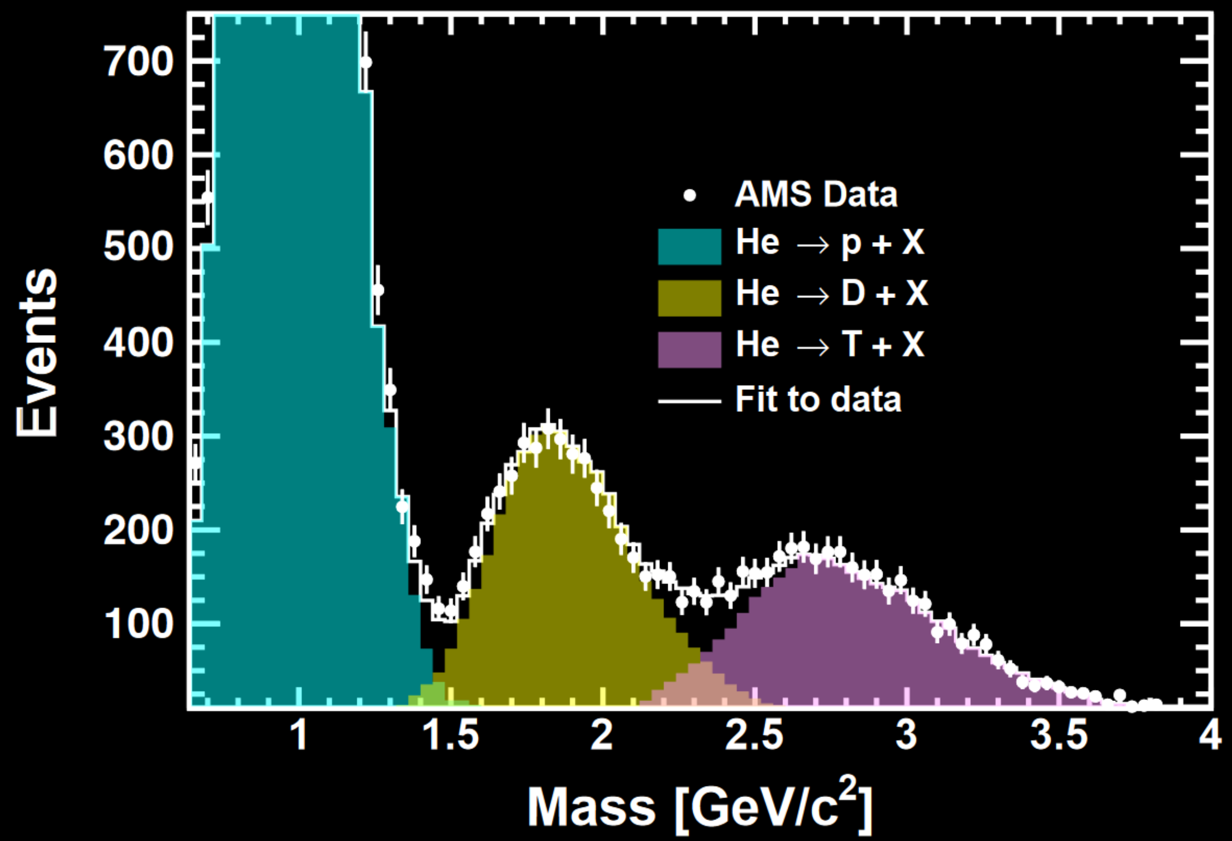


D production in AMS detector

Method developed for 2019 AMS He isotopes paper



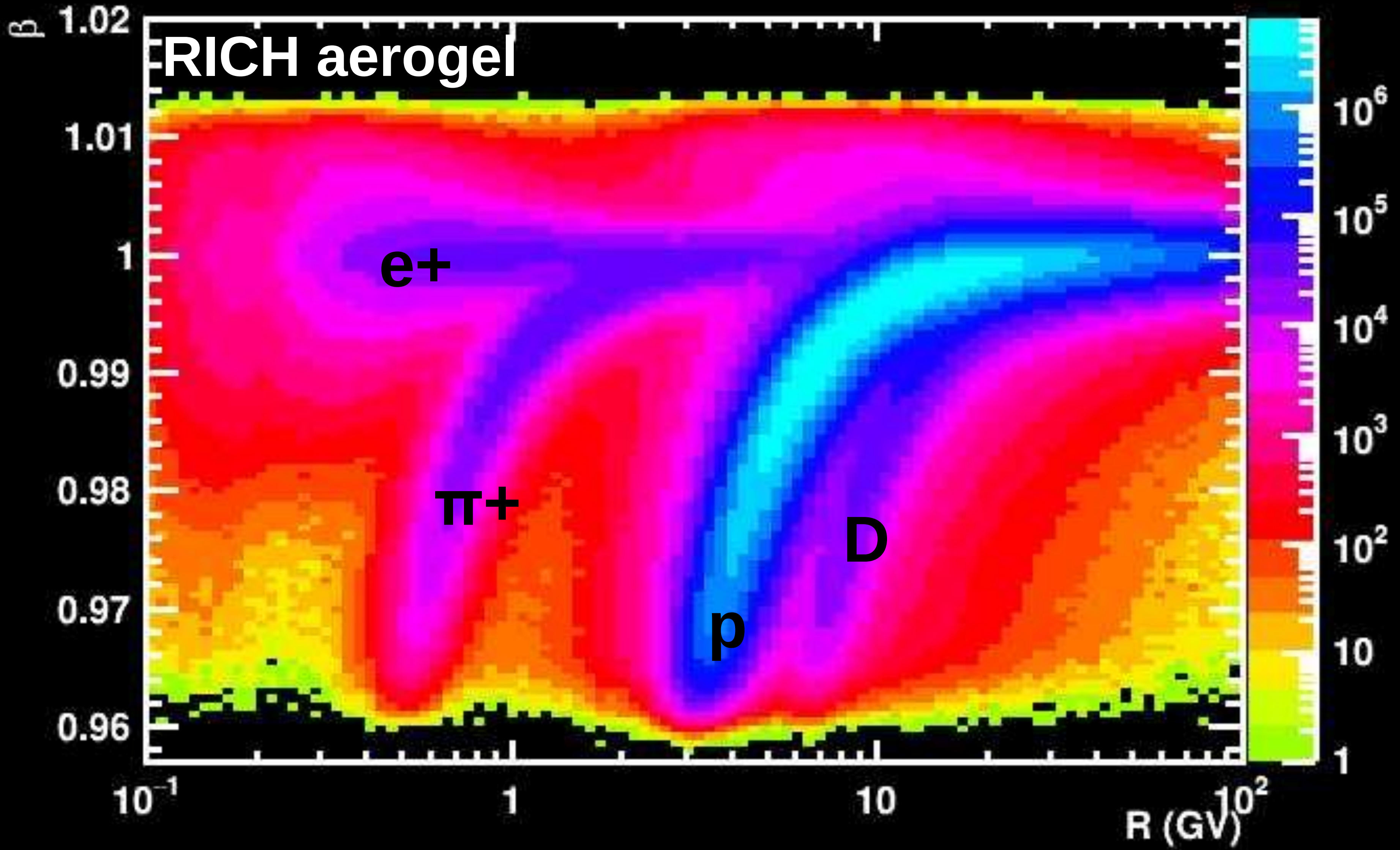
Conversion of Z=2 in L1 to Z=1 in inner tracker



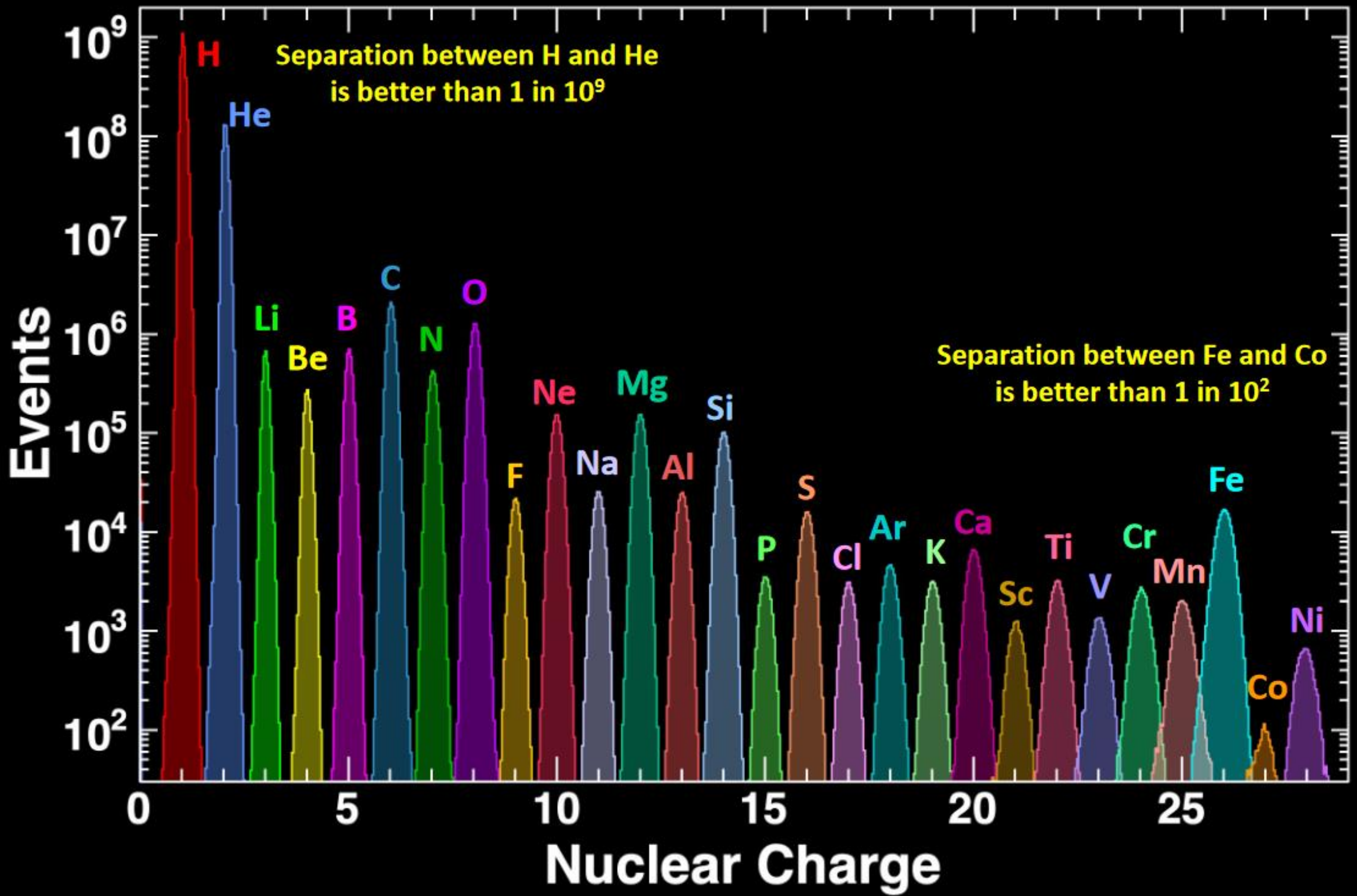
The relative contribution of D and T is determined by the measurement for any R and β

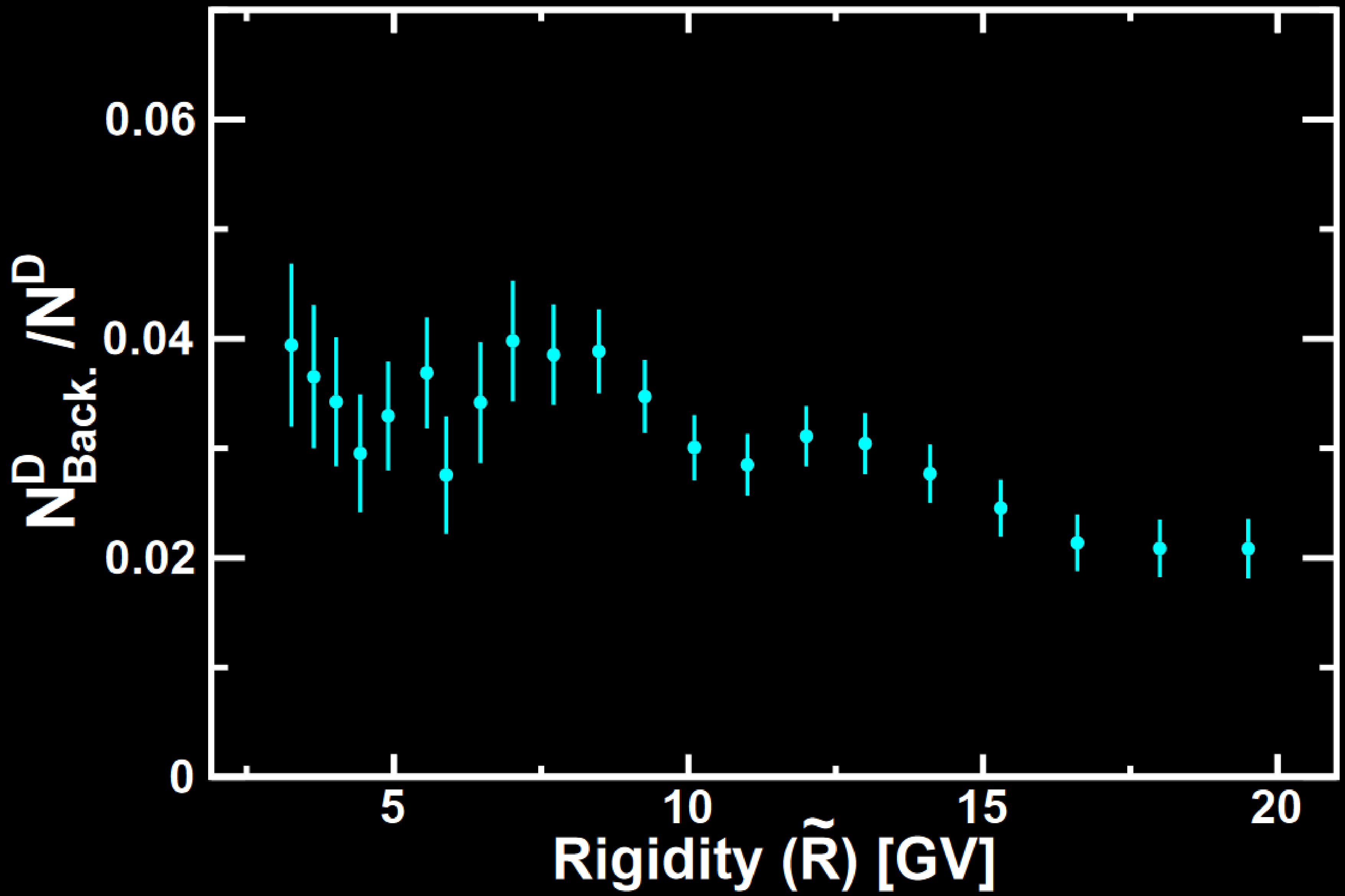
H Isotopes identification in AMS

2011-2021 data



Precision Measurements of Cosmic Nuclei by AMS




0.06
0.04
0.02
0
5
10
15
20
Rigidity ($\tilde{R}$) [GV]
$N^{D}_{Back.}/N^{D}$