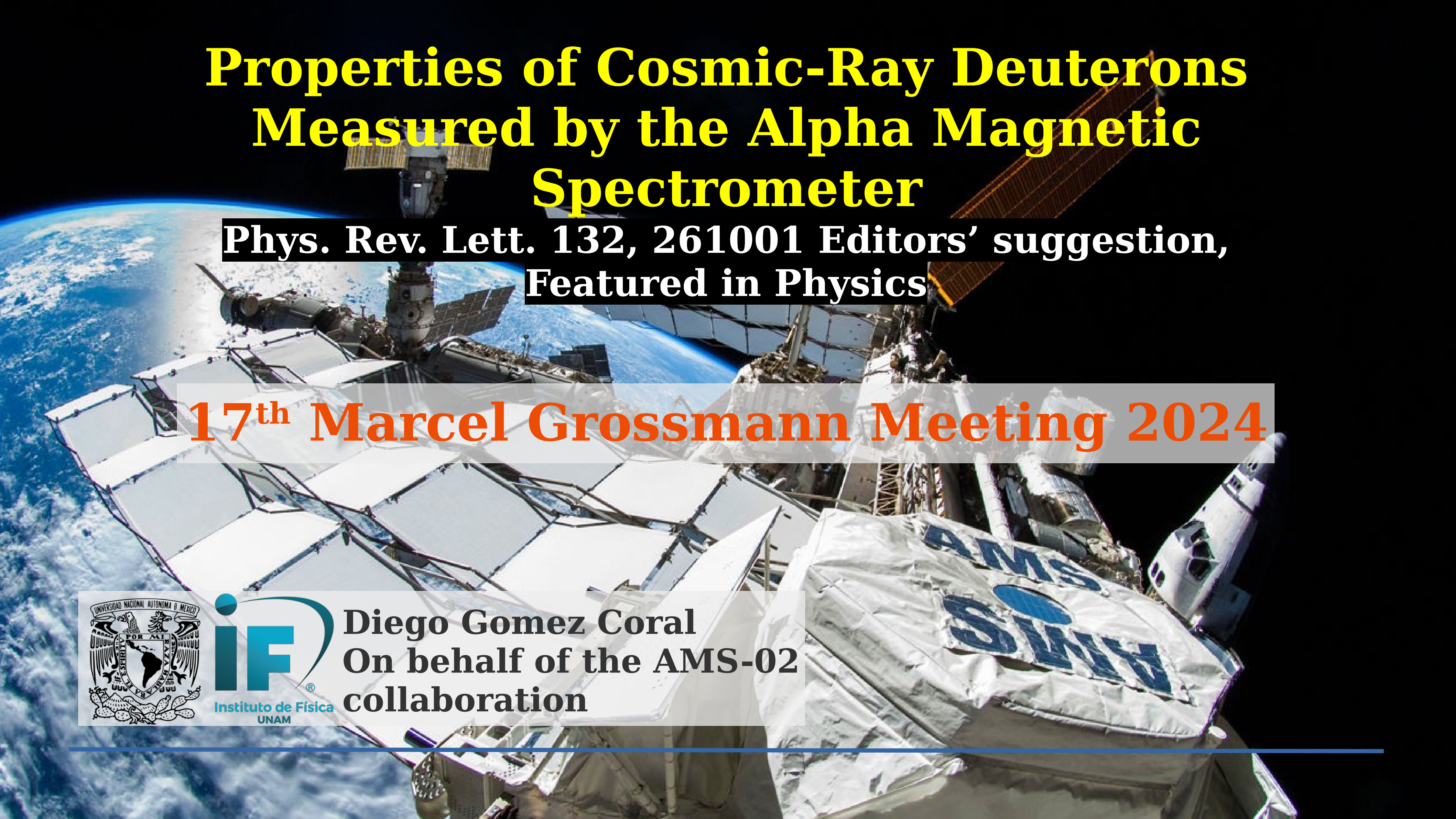


Properties of Cosmic-Ray Deuterons Measured by the Alpha Magnetic Spectrometer

Phys. Rev. Lett. 132, 261001 Editors’ suggestion, Featured in Physics

17th Marcel Grossmann Meeting 2024

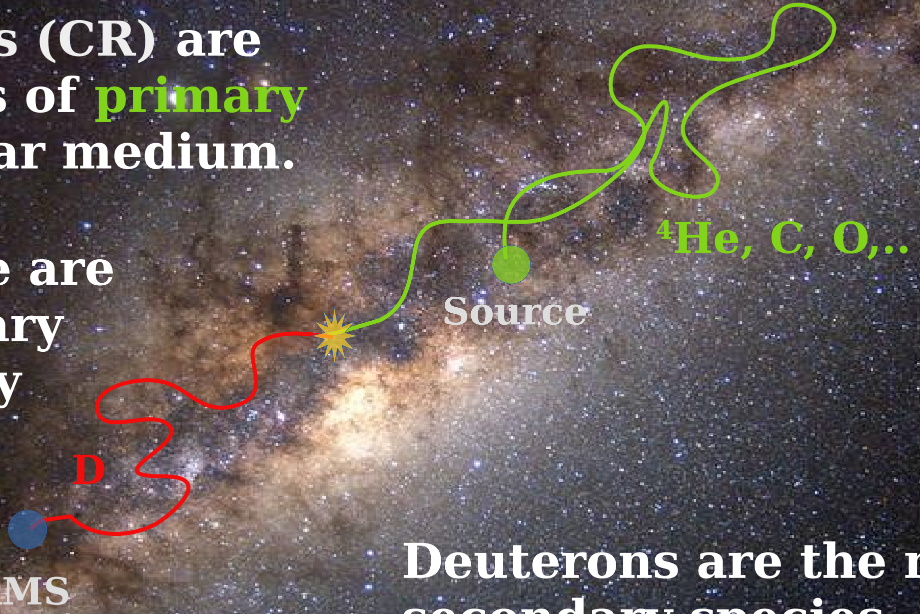
Instituto de Física UNAM

Diego Gomez Coral
On behalf of the AMS-02 collaboration

Cosmic-ray Deuterons

Secondary cosmic-rays (CR) are produced by collisions of **primary** CR with the Interstellar medium.

Deuterons (D) and ^{3}He are believed to be secondary CR produced mostly by fragmentation of ^{4}He nuclei



Deuterons are the most abundant secondary species

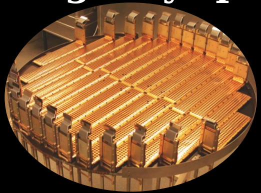
D/^{4}He and ^{3}He/^{4}He carry important information about CR propagation in the Galaxy

AMS detector

Transition Radiation Detector (e^+, e^-)

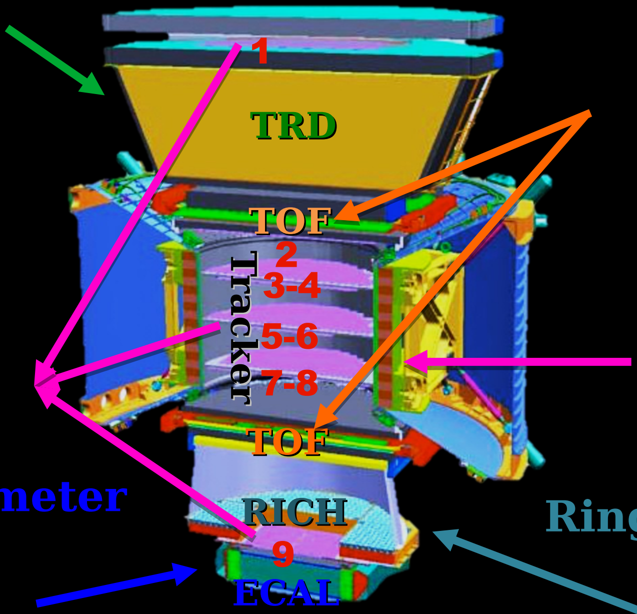
Silicon Tracker

Z, Rigidity=p/Ze



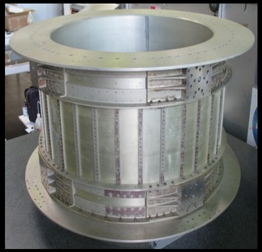
Electromagnetic Calorimeter

Energy of e^+, e^-



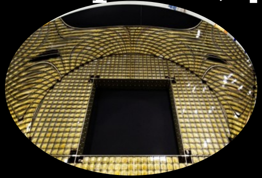
Time Of Flight (Z, β)

Magnet (±Z)



Ring Imaging Cherenkov

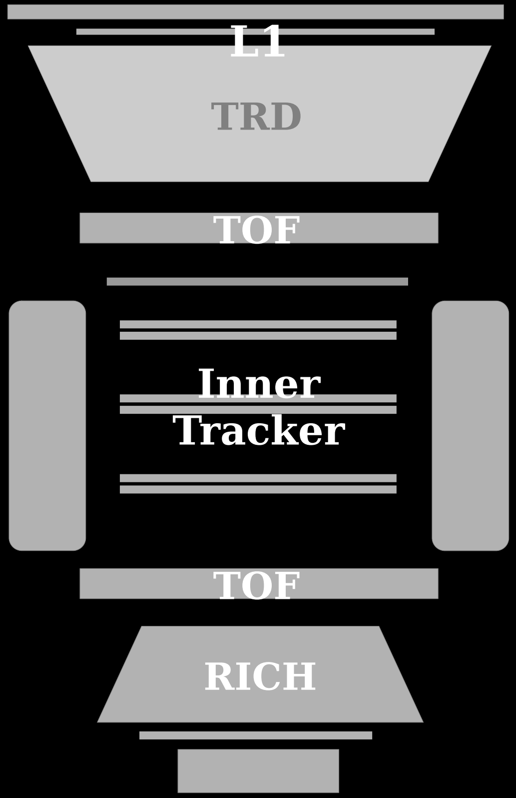
(Isotopes Z, β)



Deuteron identification

- **Isotopes are identified by their mass:**

$$M = \frac{ZR}{\beta\gamma} \quad \text{where} \quad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$



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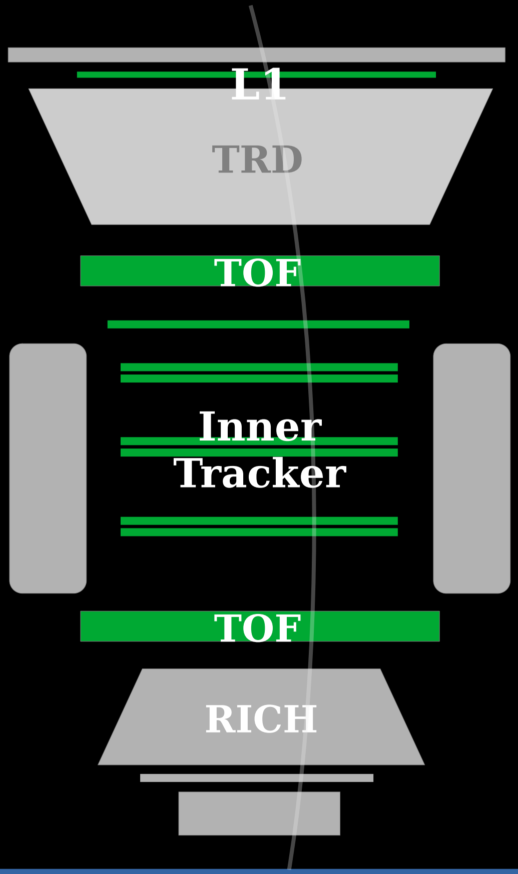
- **Charge (Z) is obtained from**
  - **TOF, L1, and Inner Tracker (Z=1)**



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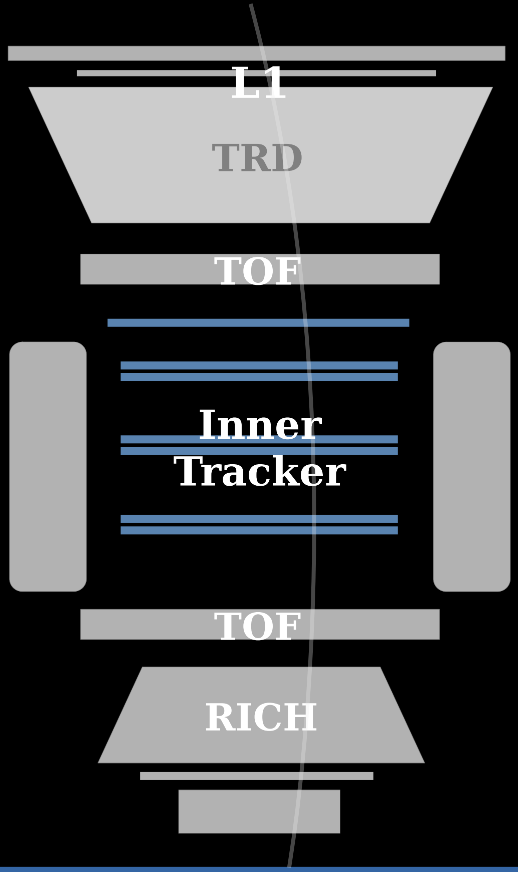

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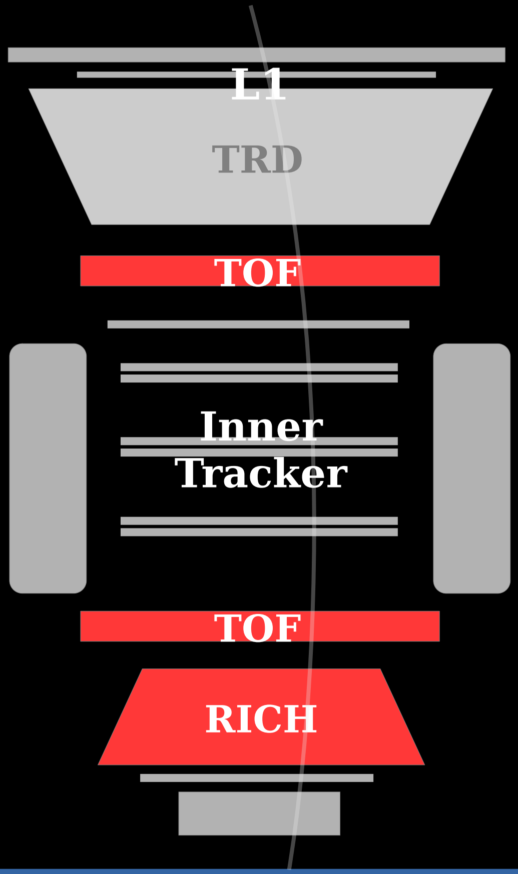
$$M = \frac{ZR}{\beta\gamma} \quad \text{where} \quad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

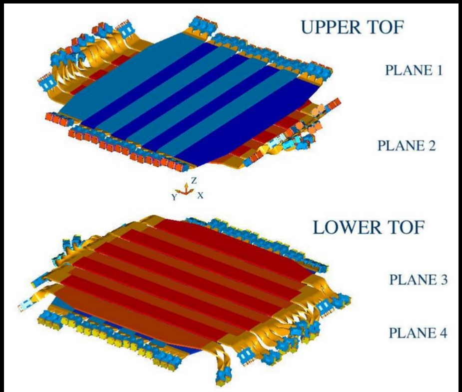
- **Charge (Z)** is obtained from
  - TOF, L1, and Inner Tracker (Z=1)
- **Rigidity (R)** is measured with
  - Inner Tracker
- **Velocity (β)**
  - TOF or RICH



Velocity measurement

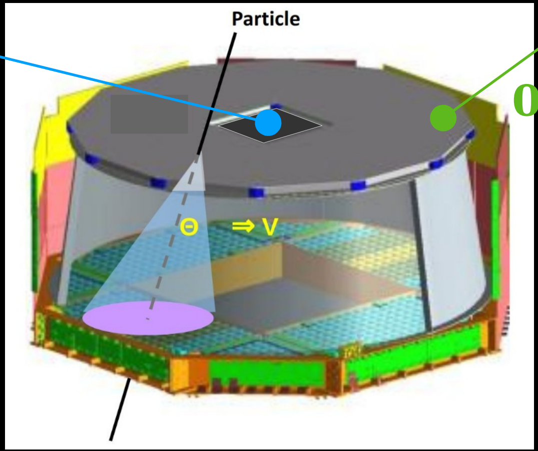
- **Velocity is obtained in three complementary regions.**

TOF $0.5 < \beta < 0.8$



RICH

NaF
n = 1.33
$0.75 < \beta < 0.96$



Aerogel
n = 1.05
$0.95 < \beta < 0.99$

β_{TOF} is calculated from time difference between upper and lower planes.

β_{RICH} is calculated from Cherenkov angle in light cone. Two types of radiators.

Isotope separation

Isotope power separation depends on rigidity and velocity resolutions

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

Tracker rigidity resolution:

ΔR/R ~ 9% for R<20GV

Velocity resolutions:

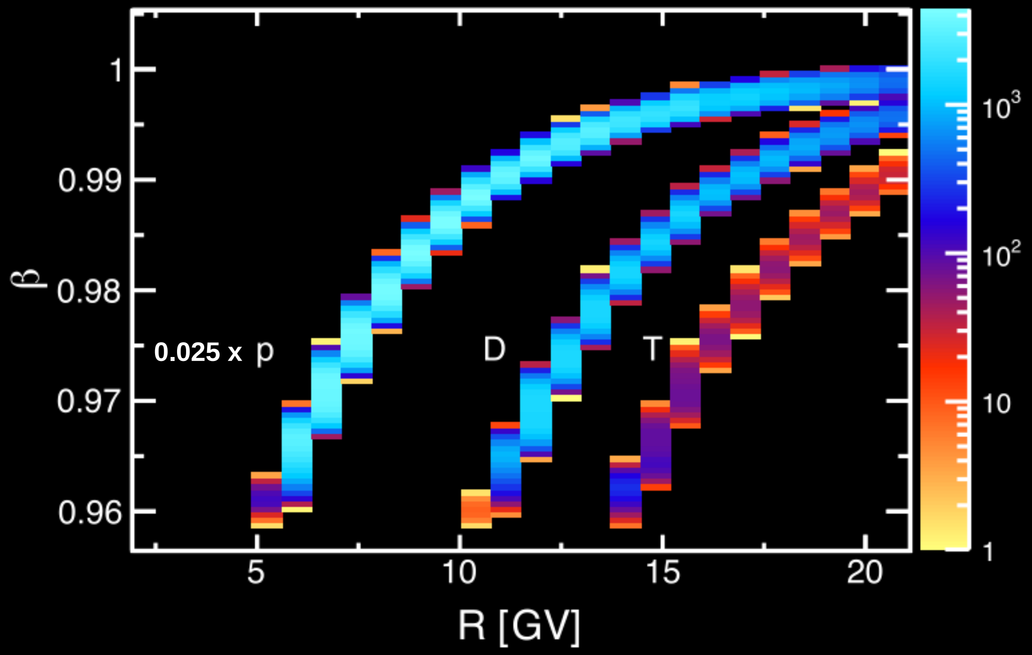
TOF Δβ ≈ 4% (Z=1)

RICH-NaF Δβ ≈ 0.35% (Z=1),

RICH-Aerogel Δβ ≈ 0.12% (Z=1)

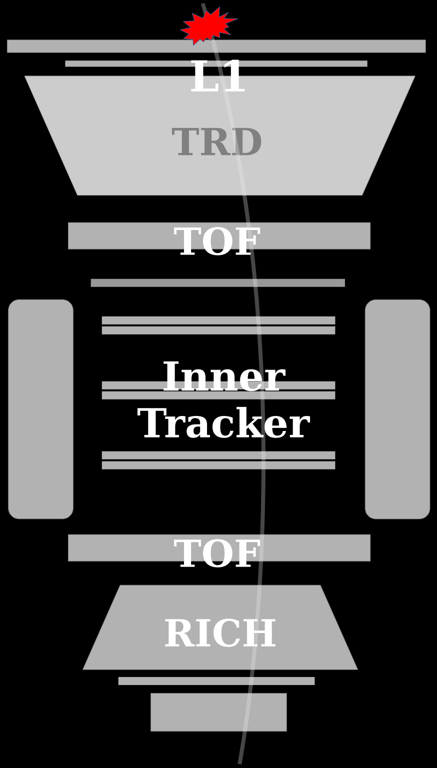
Deuteron measurement

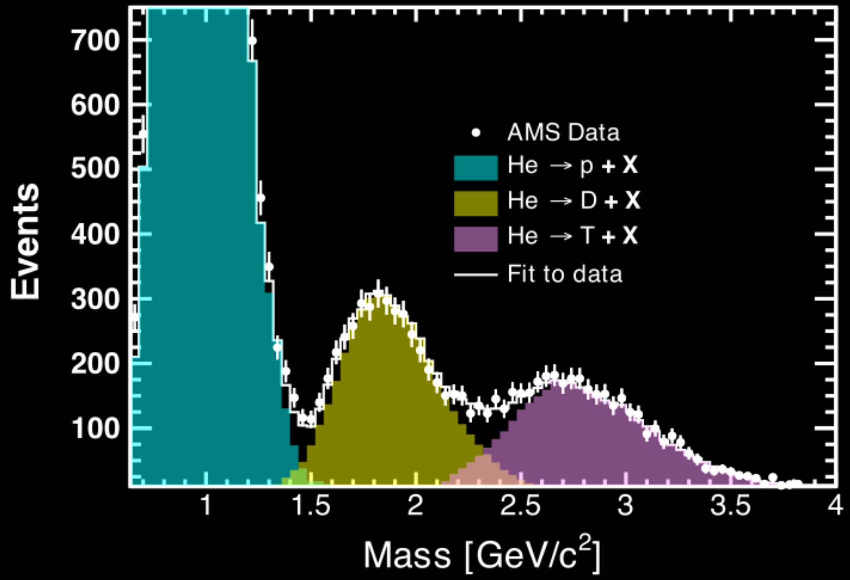
- **Deuterons are obtained by an unfolding method of the two-dimensional event distributions in rigidity and β.**



Background extraction

- Main source of background is He fragmentation above L1

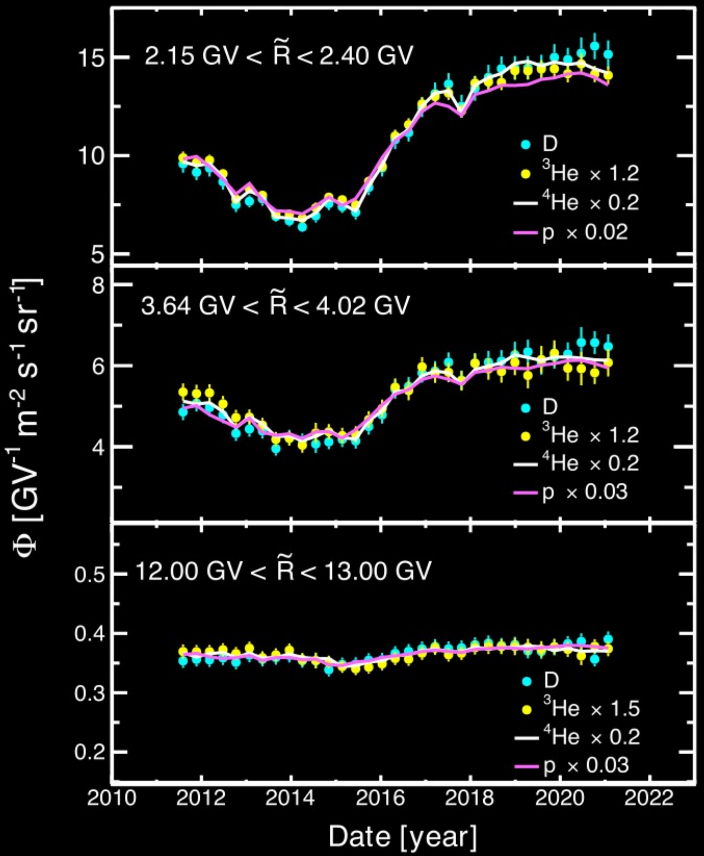




Background is estimated from data, and is ≤ 4% in the entire rigidity range

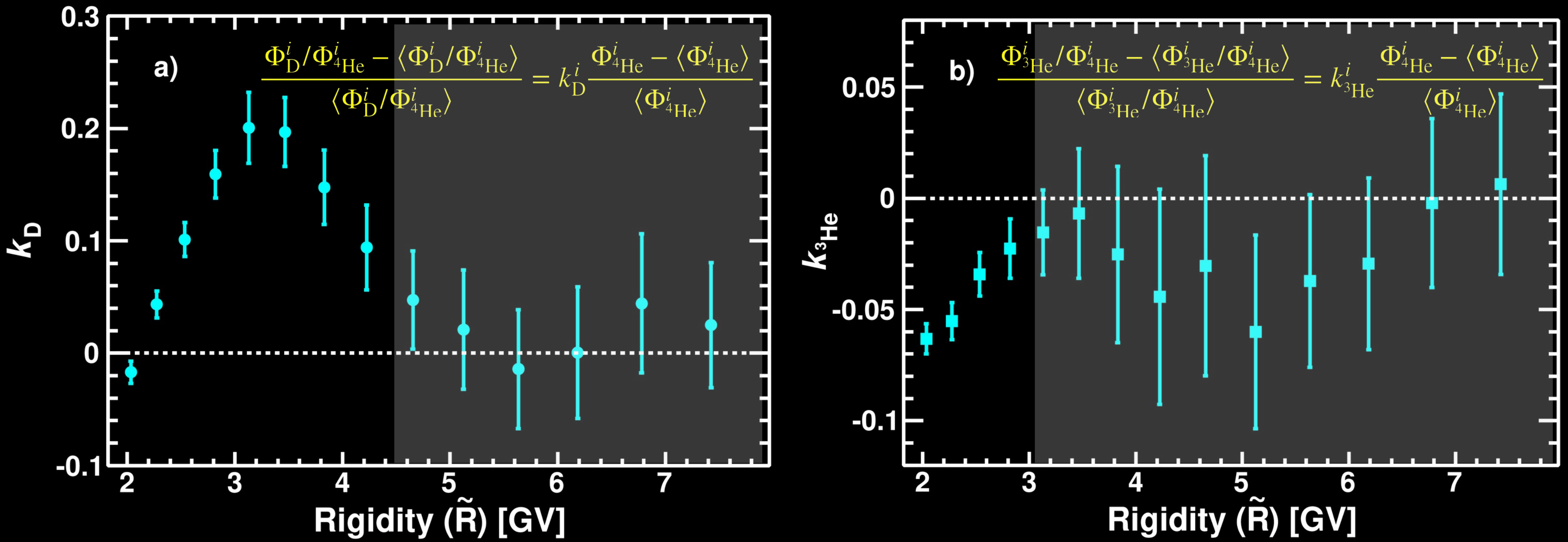
Time dependence

- **D were measured from May 2011 to April 2021 in 33 periods of four Bartels' rotations.**
- **p, D, ^{3}He and ^{4}He exhibit nearly identical variations with time.**
- **Time variations decrease as rigidity increase.**
- **Above 4.5 GV D/^{4}He is time independent**

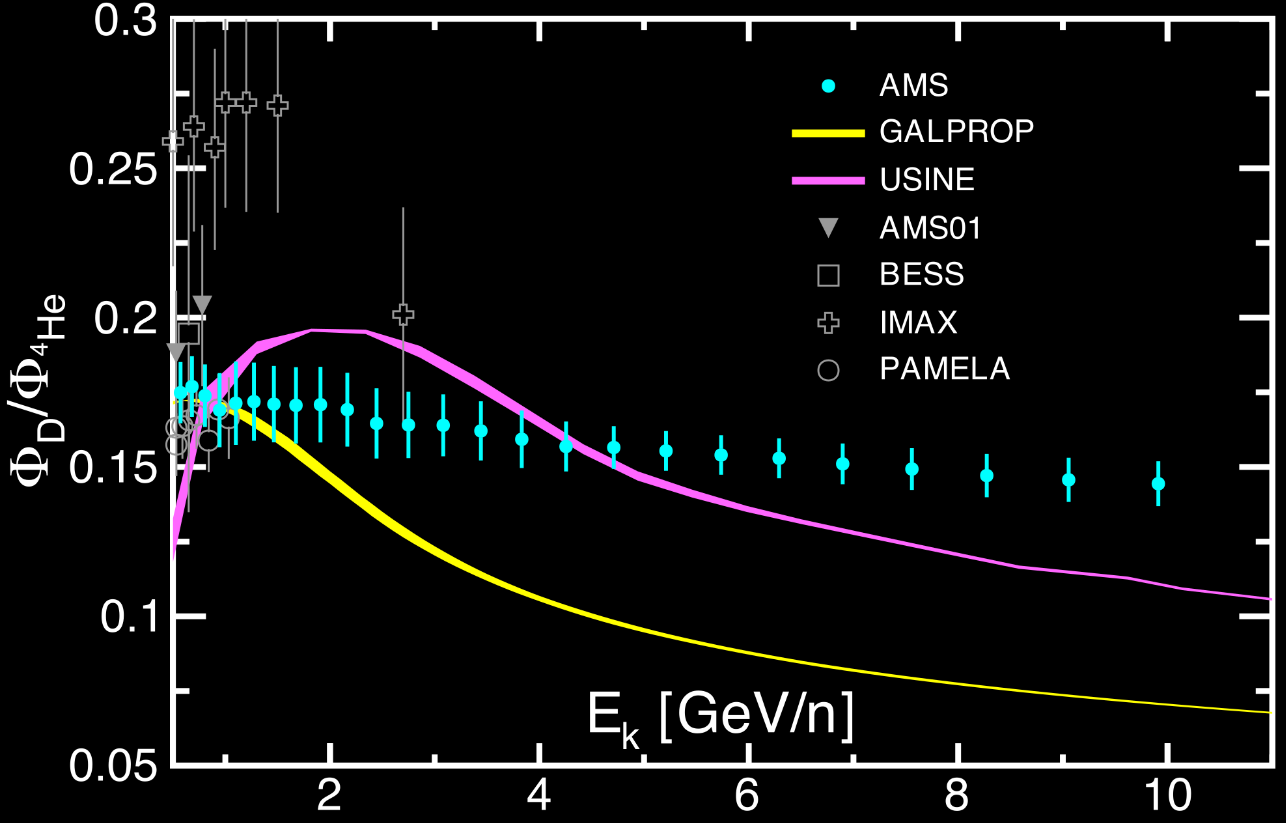


Flux ratios time dependence

To study the differences in time variation for the D, ^{3}He, and ^{4}He fluxes in detail, we fit a linear relation between the relative variations of Φ_D/Φ_{4He} and Φ_{3He}/Φ_{4He} and of Φ_{4He} for the ith rigidity bin, $(R_i, R_i + \Delta R_i)$:



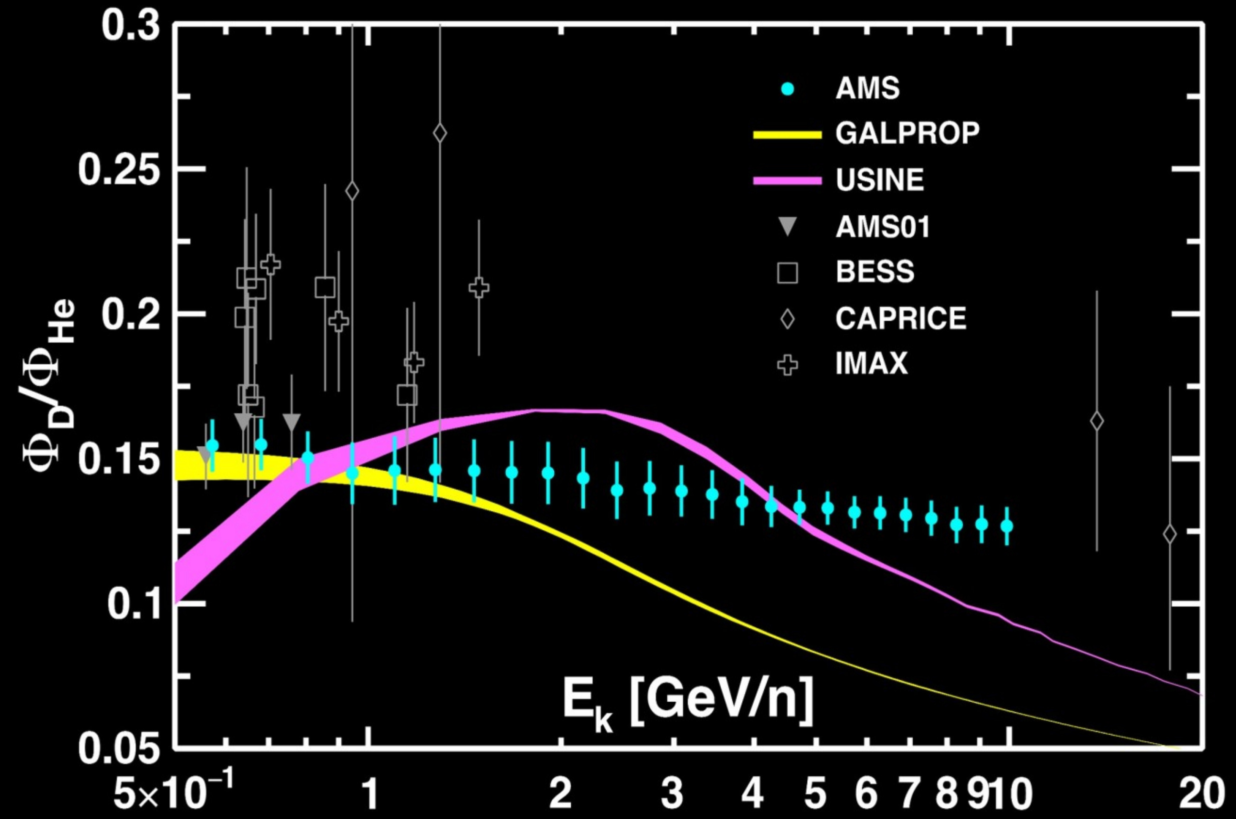
Deuteron to ^{4}He ratio in Kinetic Energy compared to models



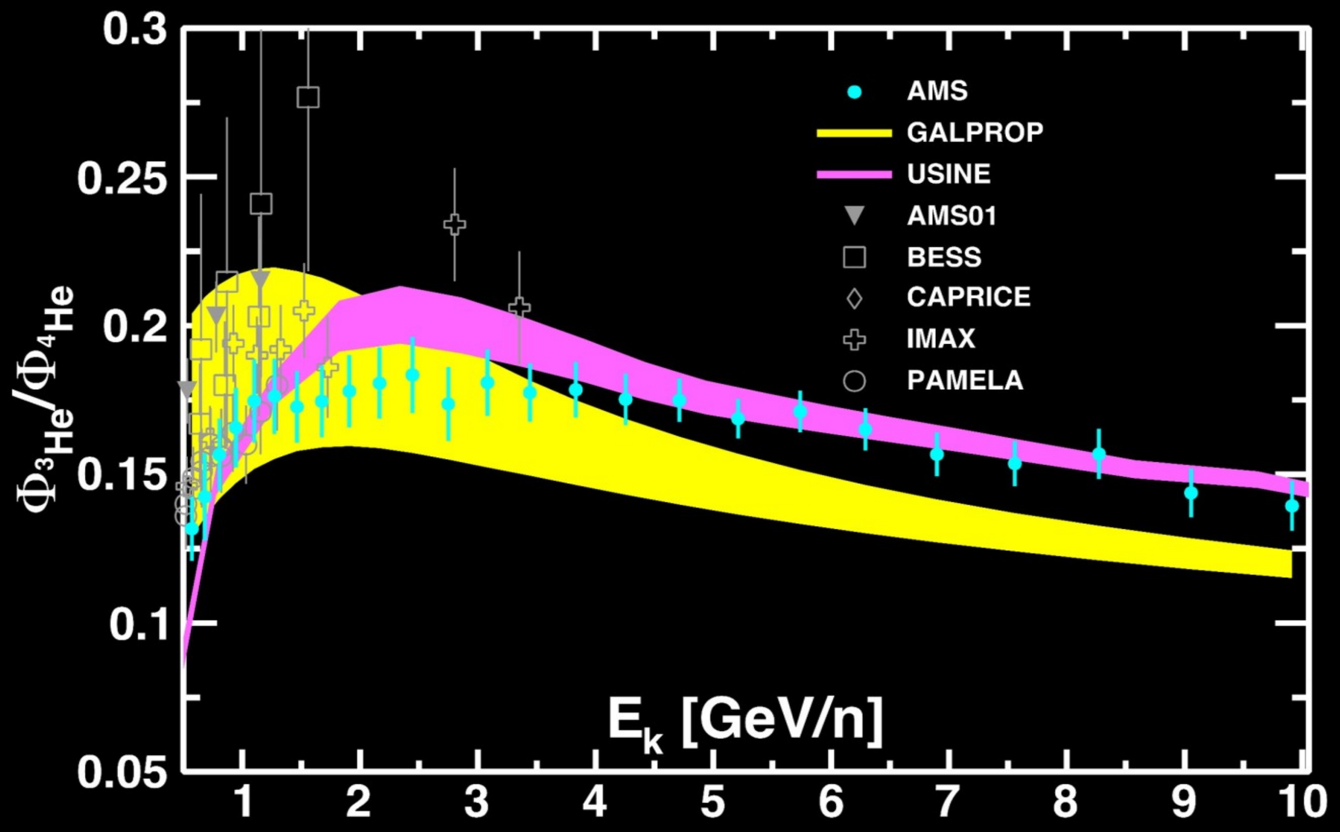
A&A 639, A131 (2020)

PRD107, 123008 (2023)

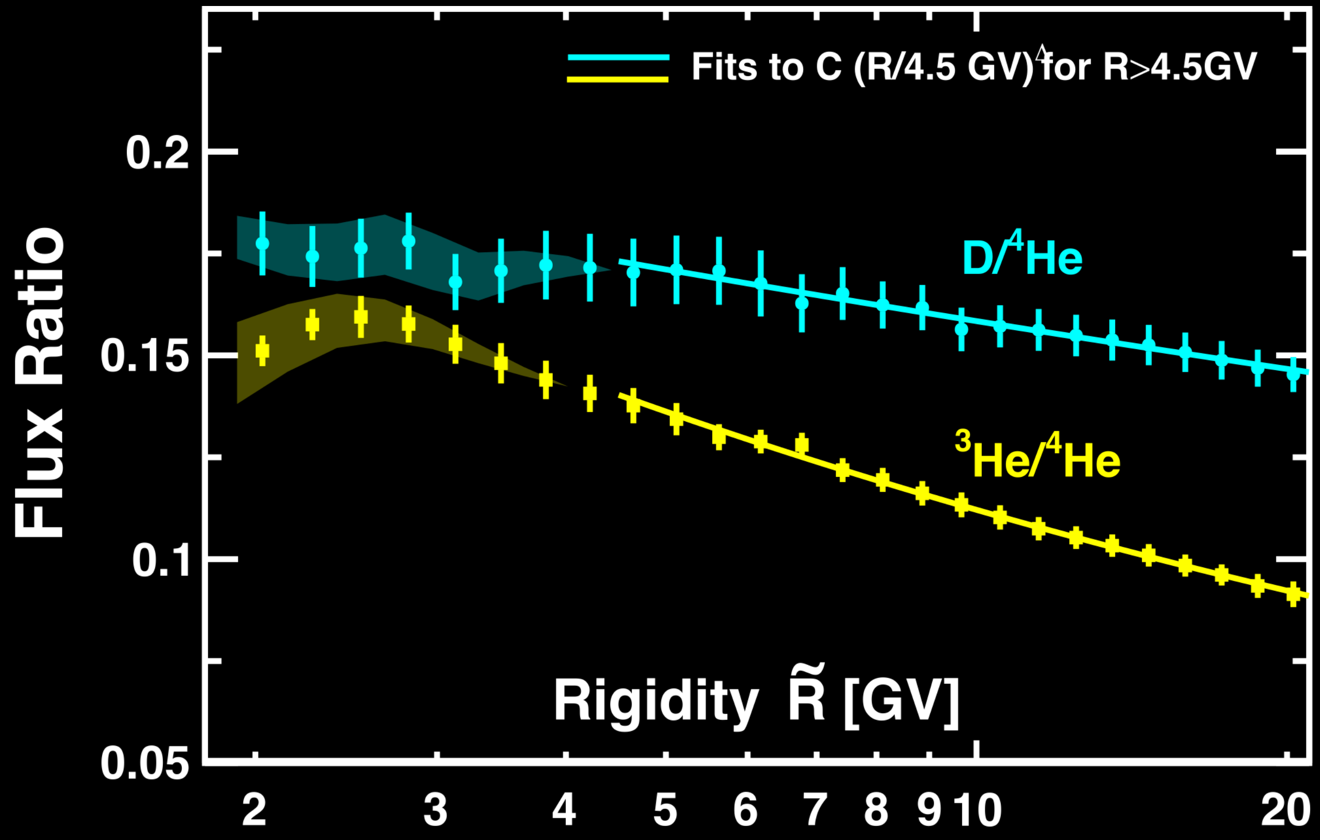
Deuteron to He ratio in Kinetic Energy compared to models



^{3}He to ^{4}He flux ratio in Kinetic Energy



Deuteron to Helium-4 ratio in Rigidity



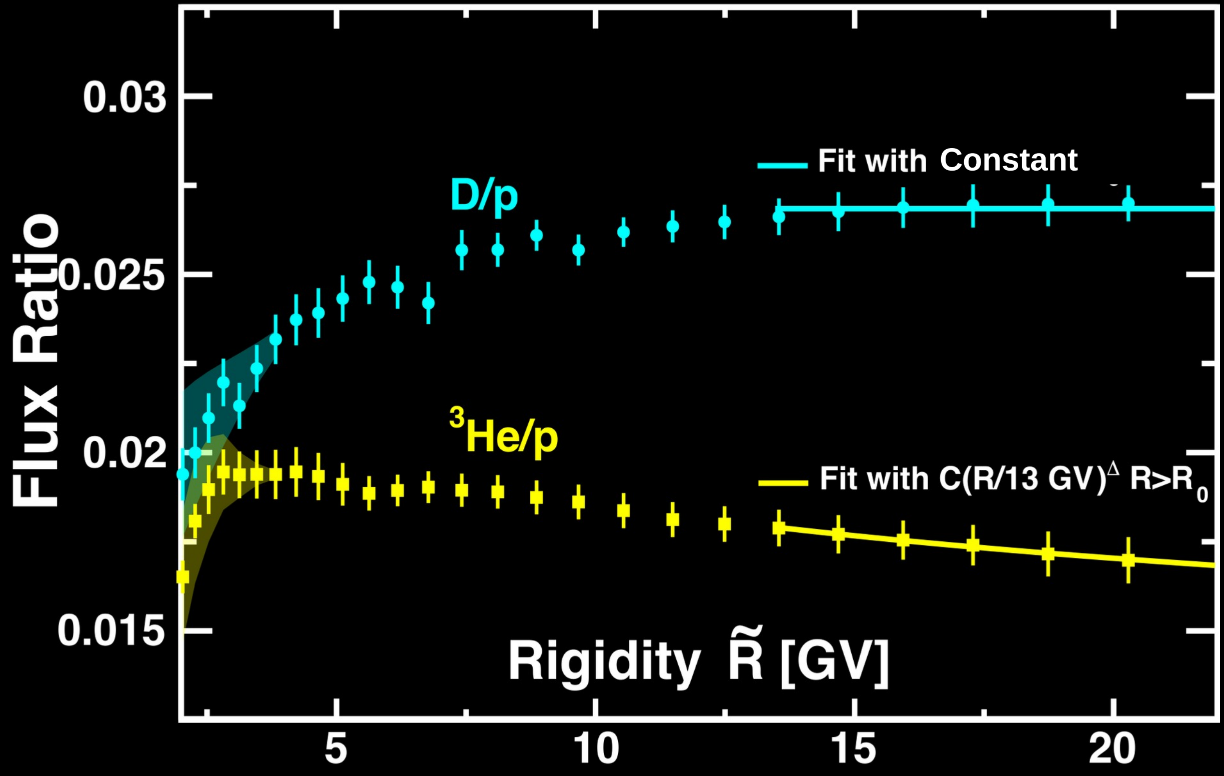
$C(R/4.5)^{\Delta}$

$\Delta_{D/4He}$ = -0.108±0.005

$C(R/4.5)^{\Delta}$

$\Delta_{3He/4He}$ = -0.289±0.003

Deuteron to proton ratio in Rigidity

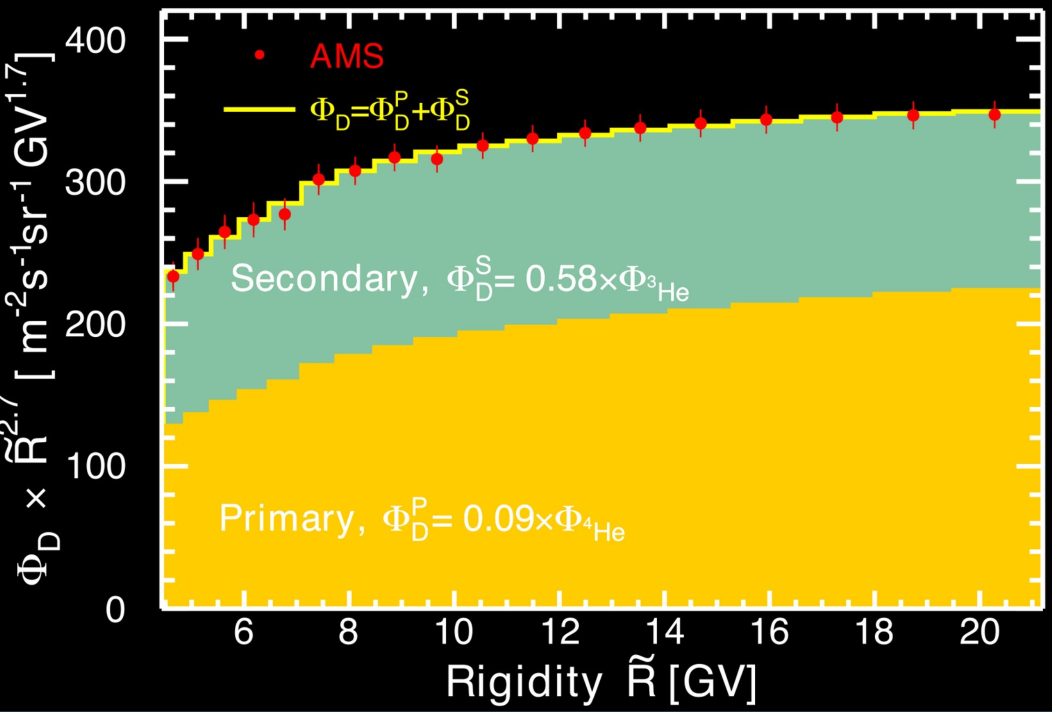


Constant =
0.027±0.001

C(R/13)$^{\Delta}$
Δ = -0.13±0.03

Primary-like and secondary components for deuteron

- Deuteron primary-like (Φ^P_D) and secondary (Φ^S_D) components are estimated fitting D flux to the weighted sum of ^4He and ^3He fluxes above 4.5GV.



Conclusions

- **The precision measurement of Deuteron cosmic-ray flux using 21 million events collected by AMS-02 from May 2011 to April 2021, as function of rigidity (1.9-21 GV) and kinetic energy per nucleon (0.6-10 GeV/n) was presented.**

- **It was observed D flux exhibits nearly identical time variation with p, ^{3}He, and ^{4}He. Above 4.5 GV D/^{4}He is time independent.**

- **Results show D/^{4}He ratio is described by a single power law (above 4.5GV) R^Δ with $\Delta_{D/4He}$ = -0.108±0.005. On the other hand, ^{3}He/^{4}He ratio is described by a single power law R^Δ with $\Delta_{3He/4He}$ = -0.289±0.003. The significance of $\Delta_{D/4He} > \Delta_{3He/4He}$ exceeds 10σ.**

Conclusions

- **Deuteron to proton ratio reaches a constant value of 0.027±0.001 above 13 GV, showing a nearly identical dependence in rigidity.**

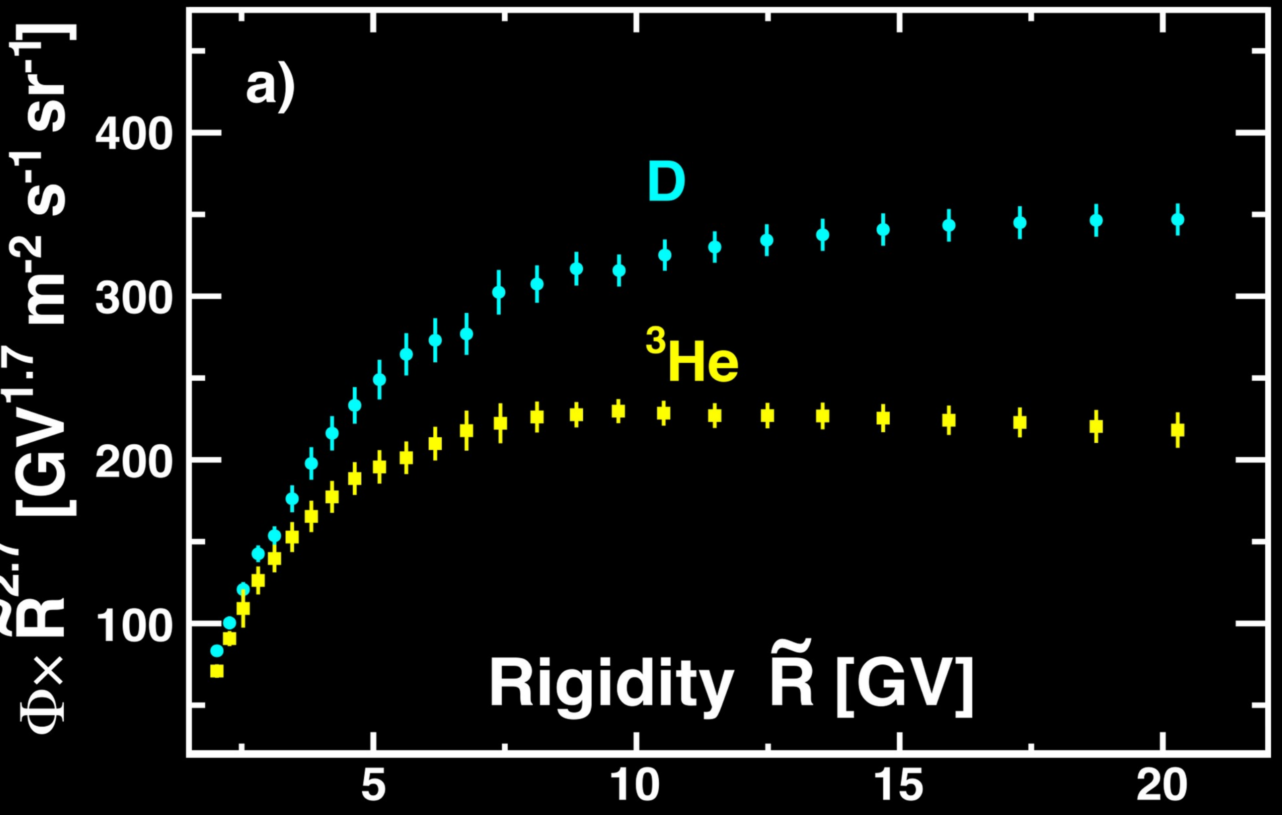
- **These unexpected observations show that contrary to expectations, cosmic deuterons have a sizeable primary-like component.**

- **With a method independent of cosmic ray propagation, we obtain the primary component of the D flux equal to 9.4 ± 0.5% of the ^{4}He flux and the secondary component of the D flux equal to 58±5% of the ^{3}He flux.**

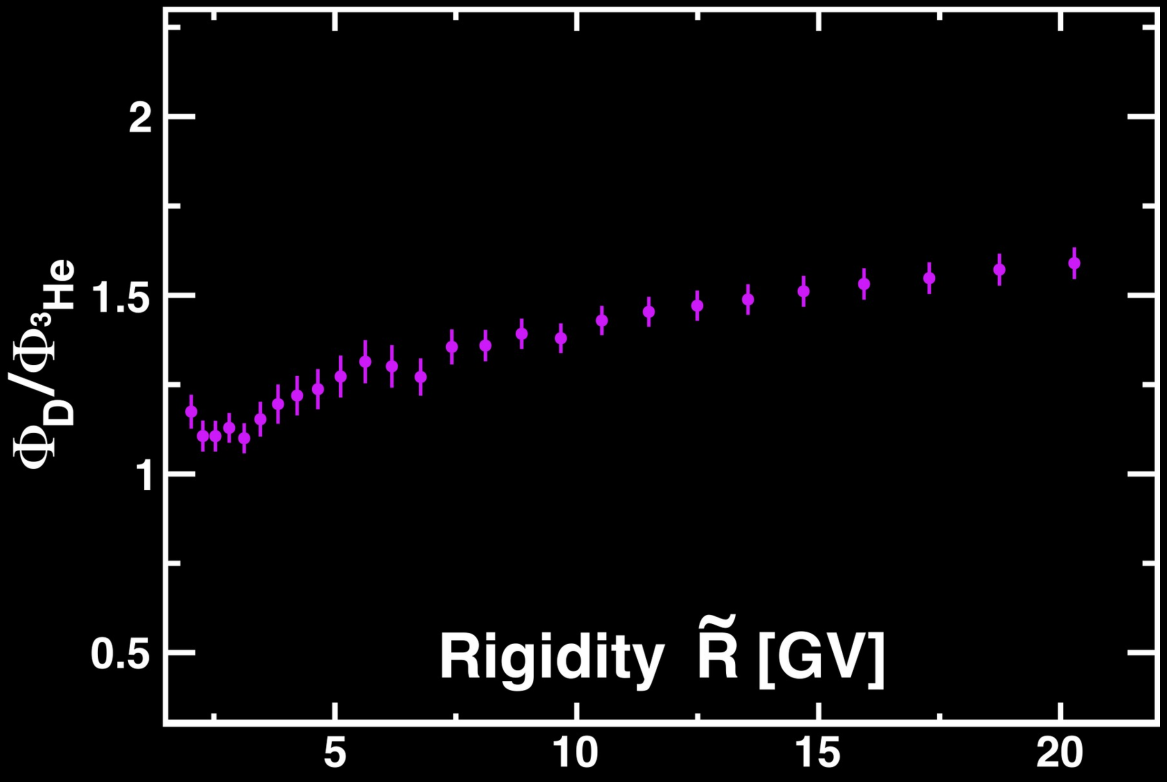
Questions?

For more info email dgomezco@fisica.unam.mx

Deuteron and ^{3}He Fluxes in Rigidity



Deuteron over ^{3}He ratio in Rigidity



1/β Resolution

- **Inverse velocity resolution functions at β=1 for TOF and RICH.**