Properties of Cosmic H, He, Li and Be Isotopes Measured by the Alpha Magnetic Spectrometer

Jiahui Wei

Shandong Institute of Advanced Technology (SDIAT)

On behalf of the AMS collaboration

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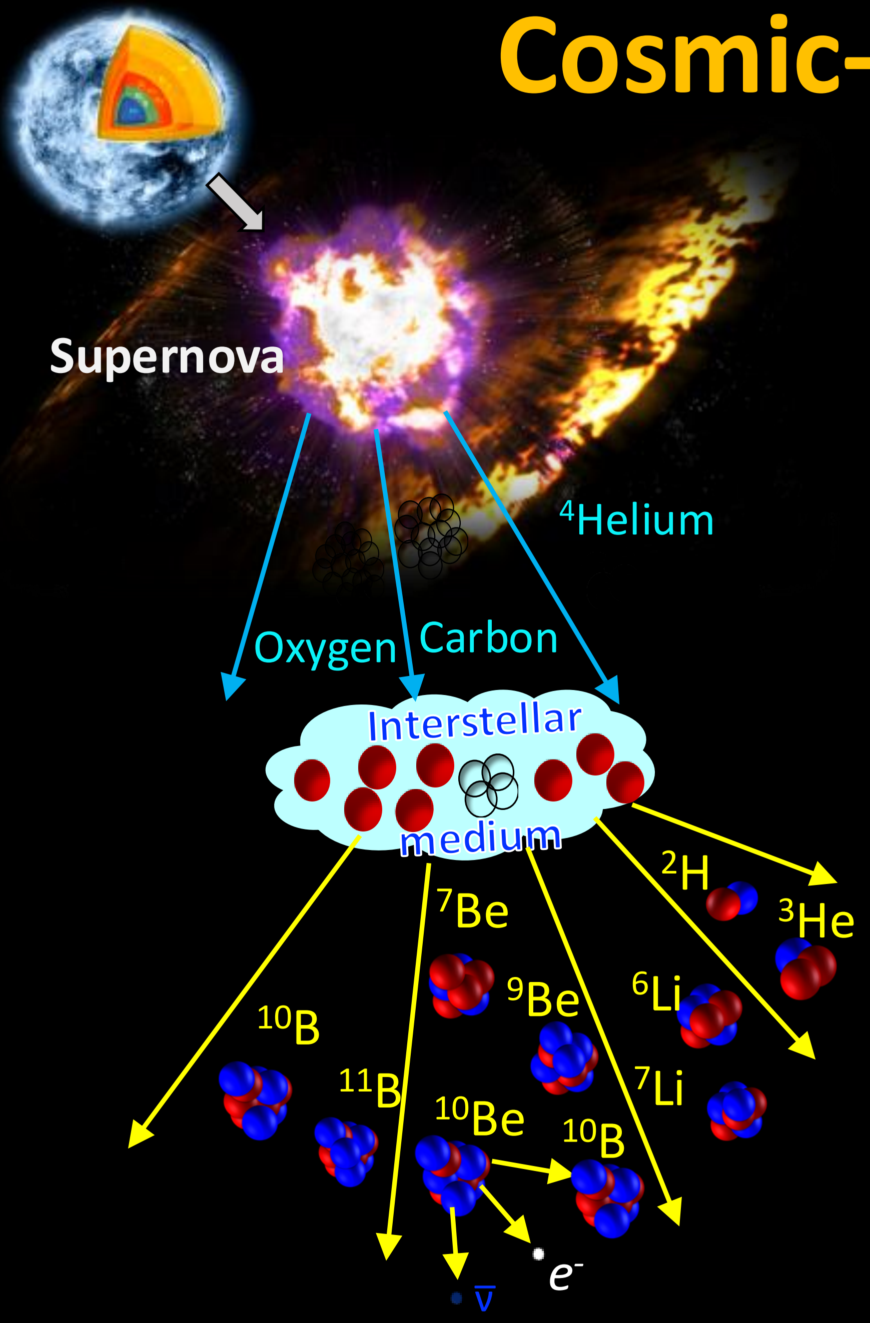
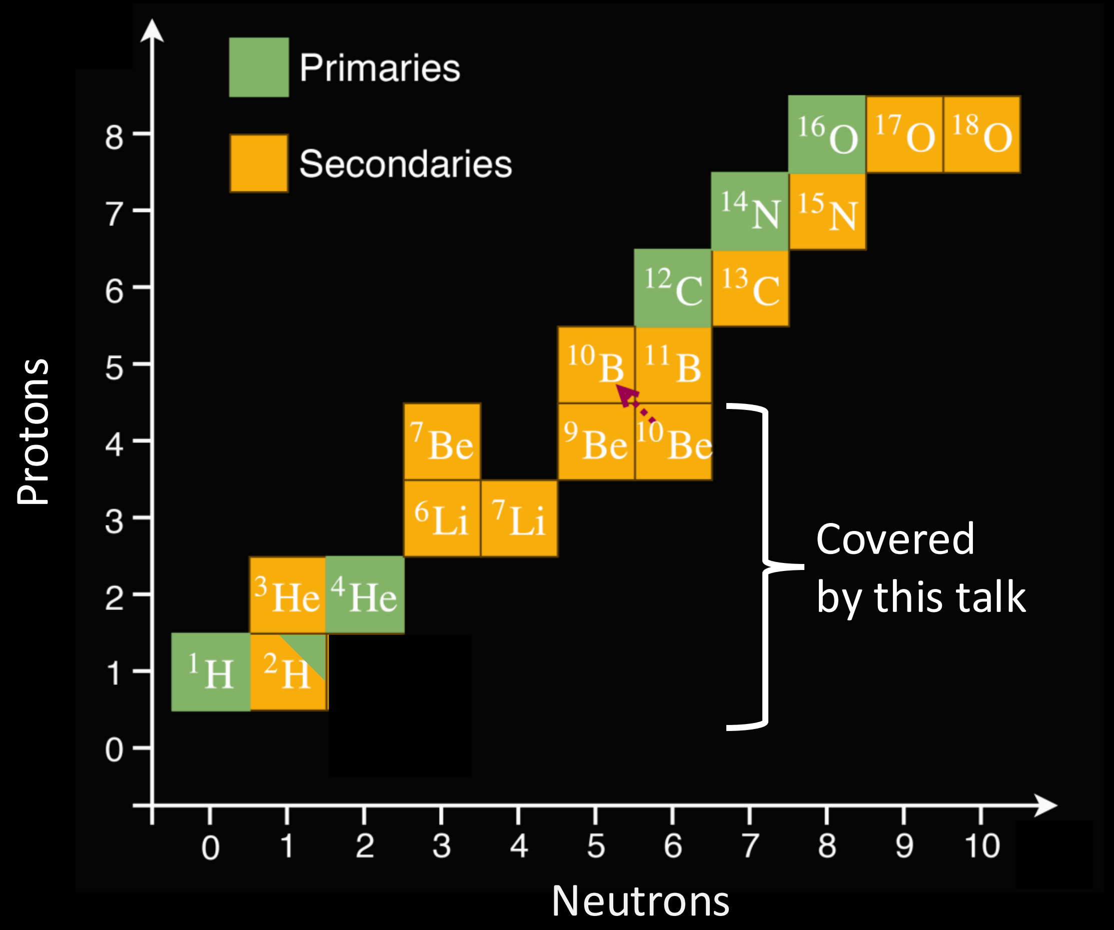
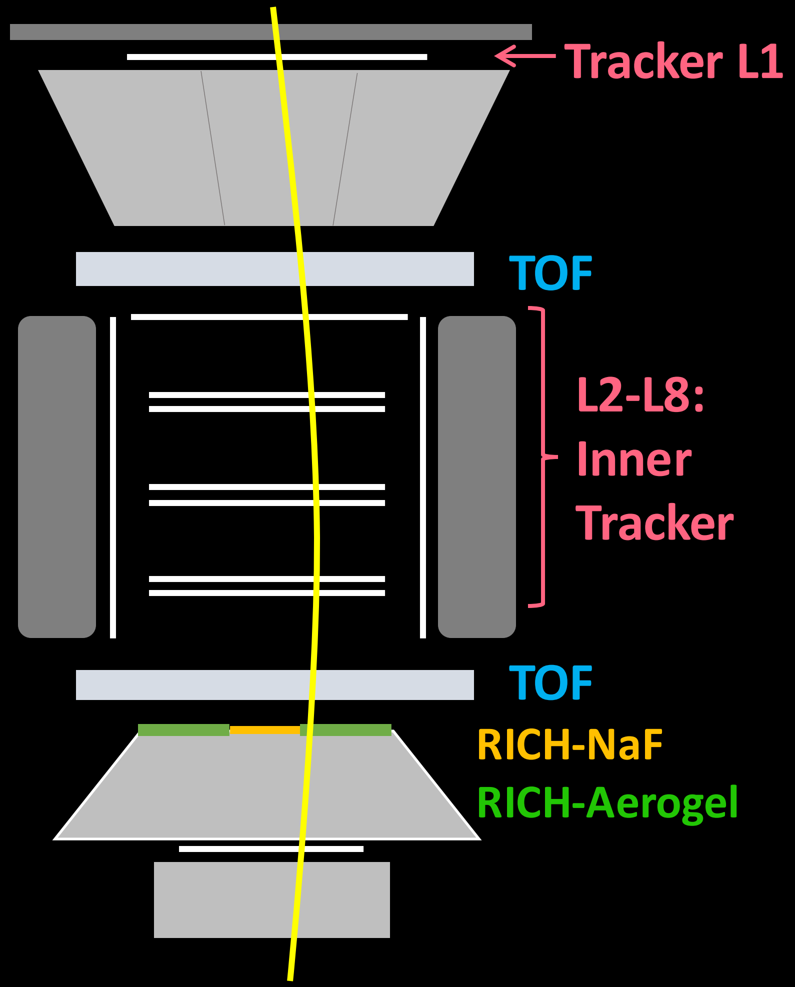
Cosmic-ray Light Isotopes





Measurement of Isotopes with AMS-02



- AMS mass resolution depends on rigidity ($R = P/Z$) and velocity (β) resolutions:

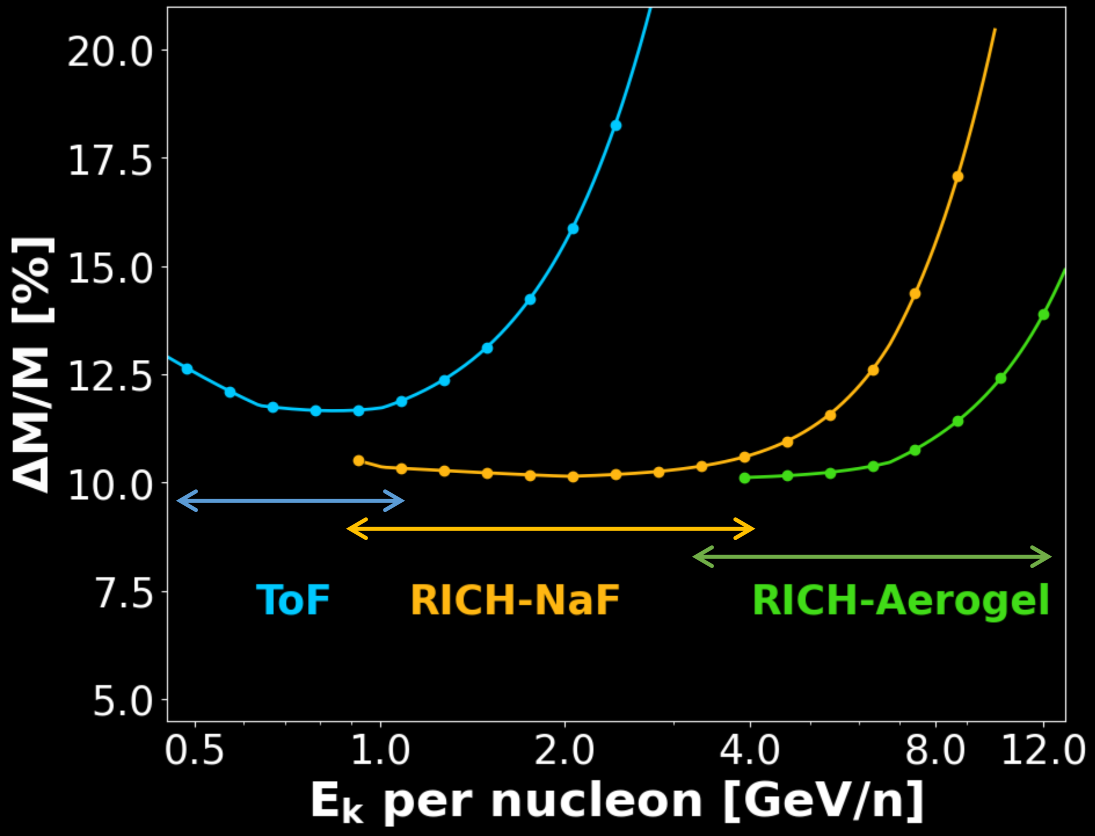
$$\frac{\Delta M}{M} = \sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\frac{1}{1-\beta^2} \cdot \frac{\Delta \beta}{\beta}\right)^2}$$

- R measurement :
  - Tracker, $\frac{\Delta R}{R} \sim 9\%(Z=1), 10\%(Z=4)$ below 20 GV
- β measurements:

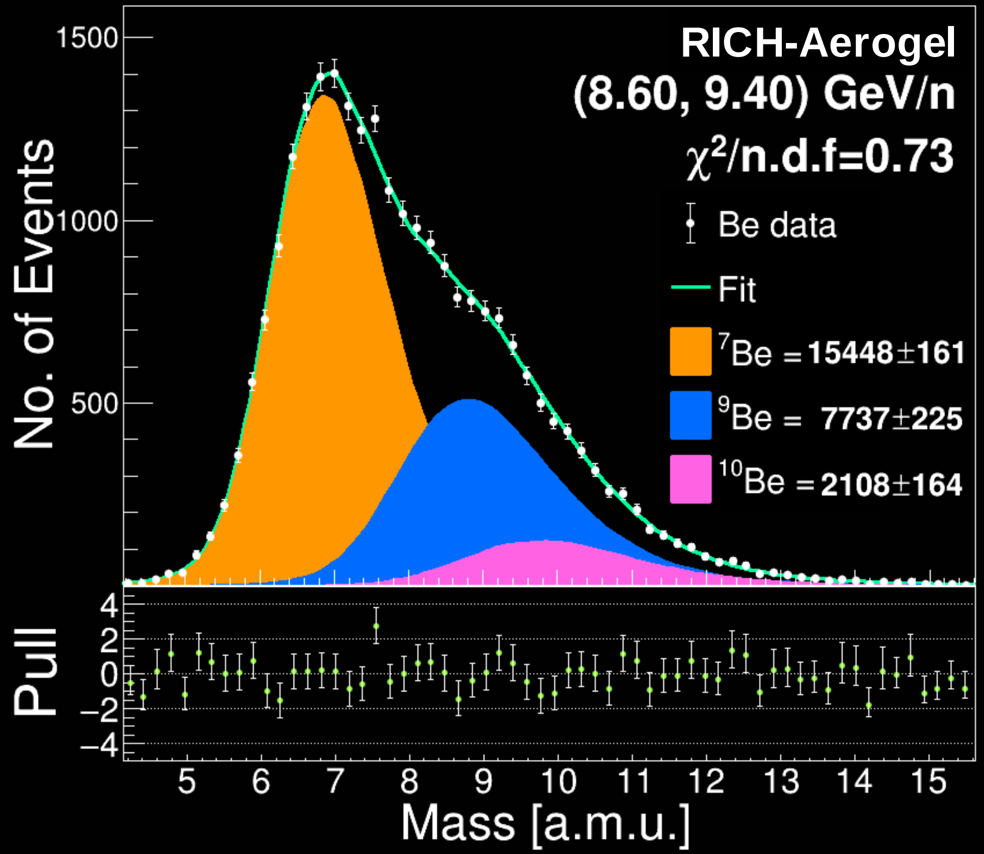
	E$_k$/n range (GeV/n)	$\Delta\beta/\beta$ $(Z=1)$	$\Delta\beta/\beta$ $(Z=4)$
TOF	(0.4, 1.2)	$\sim 4\%$	$\sim 1.5\%$
RICH-NaF	(0.8, 4.0)	$\sim 0.35\%$	$\sim 0.15\%$
RICH-Aerogel	(3.0, 12)	$\sim 0.12\%$	$\sim 0.05\%$

Measurement of Isotopes with AMS-02

Mass Resolution for Z=4



Example of Mass Template Fit

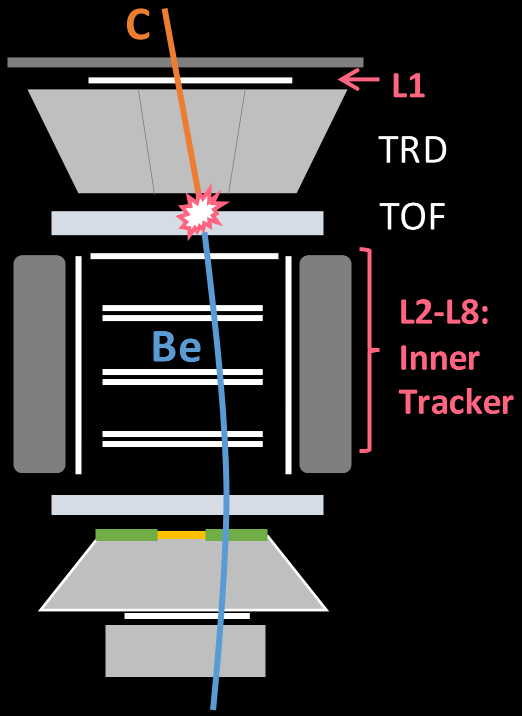


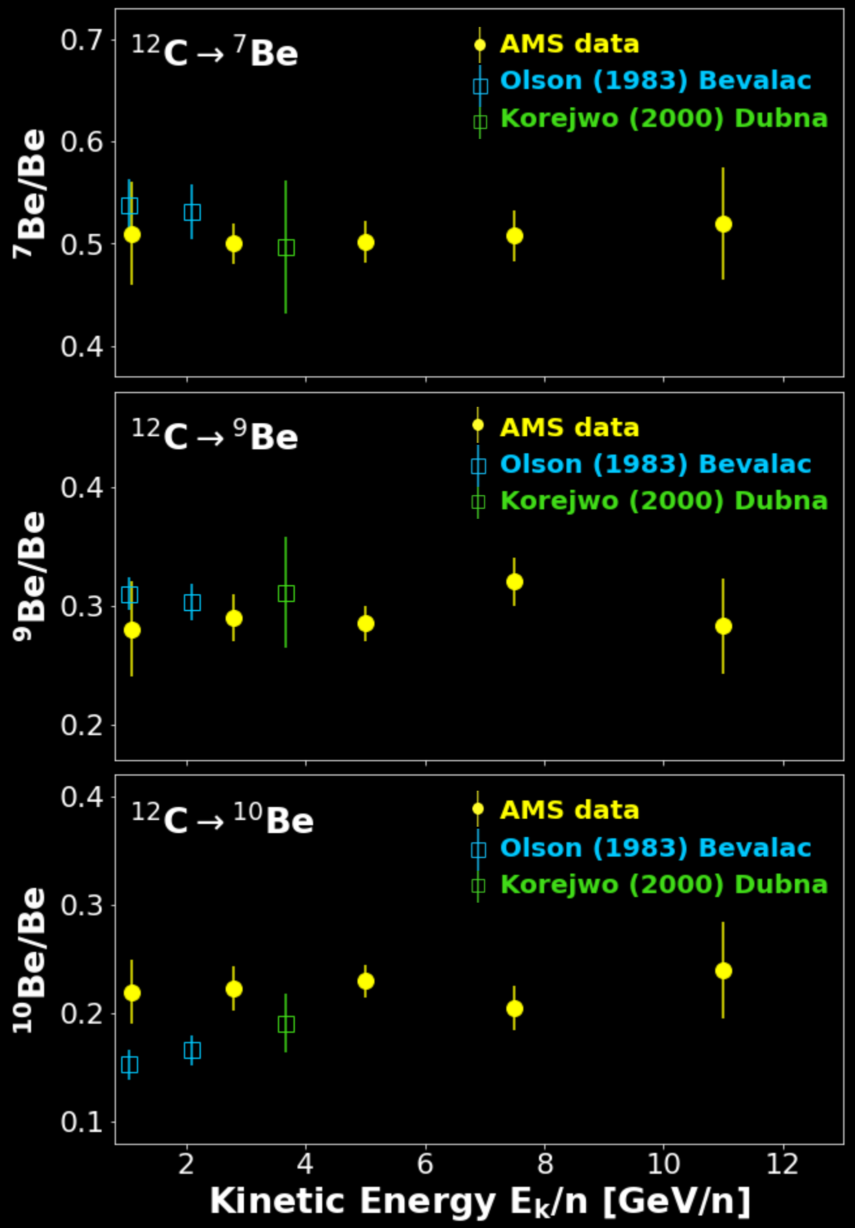
The isotopic composition is extracted from mass template fits of mass distributions

Validation of Fragmentation Cross Sections

- The fragmentation background is not negligible.
- Measurements of nuclei interaction cross sections are limited to few projectiles and low energy.
- We used AMS data to validate the fragmentation cross sections (Q. Yan et al. Nucl. Phy. A 2020) and isotopic cross sections in our MC simulation.

Example of Carbon nuclei fragmenting to beryllium isotopes in TRD+TOF:

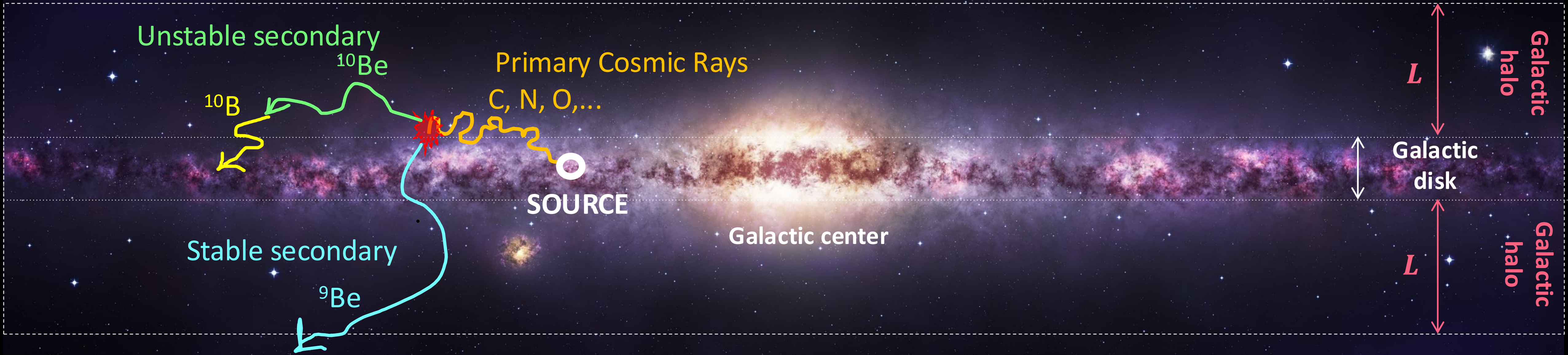




Cosmic-ray Beryllium isotopes

Beryllium nuclei are secondary cosmic rays.
They include three isotopes, two stable, ^{7}Be and ^{9}Be, and one unstable, ^{10}Be.

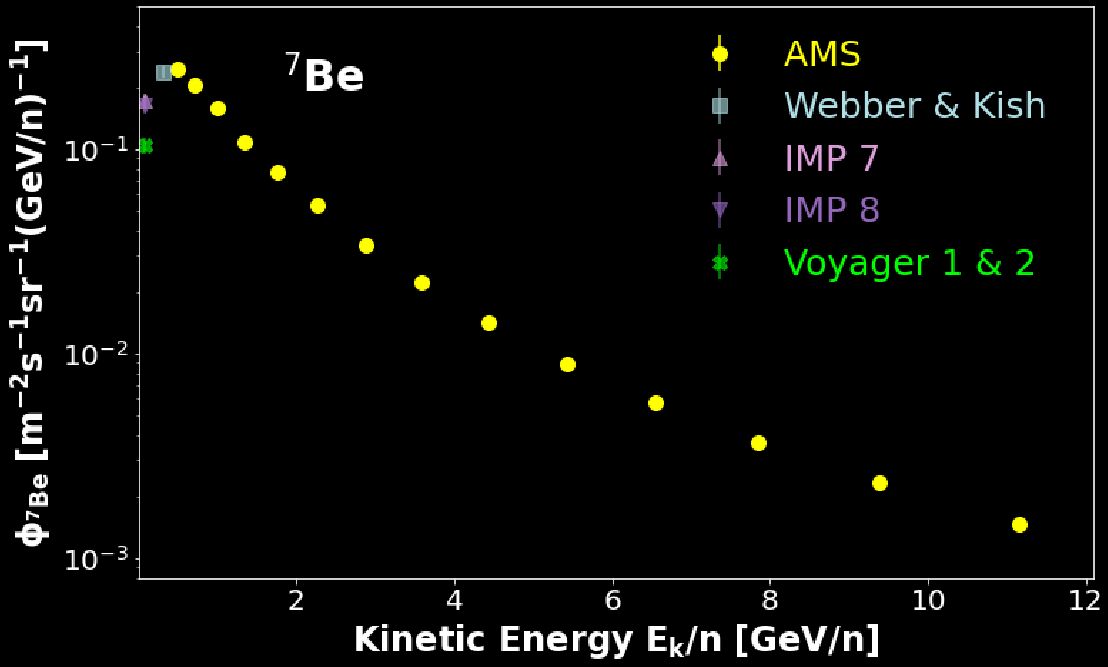
Stable secondaries as ^{9}Be propagate in the entire galactic halo
while ^{10}Be decay to ^{10}B before reaching the boundary of the Galaxy,

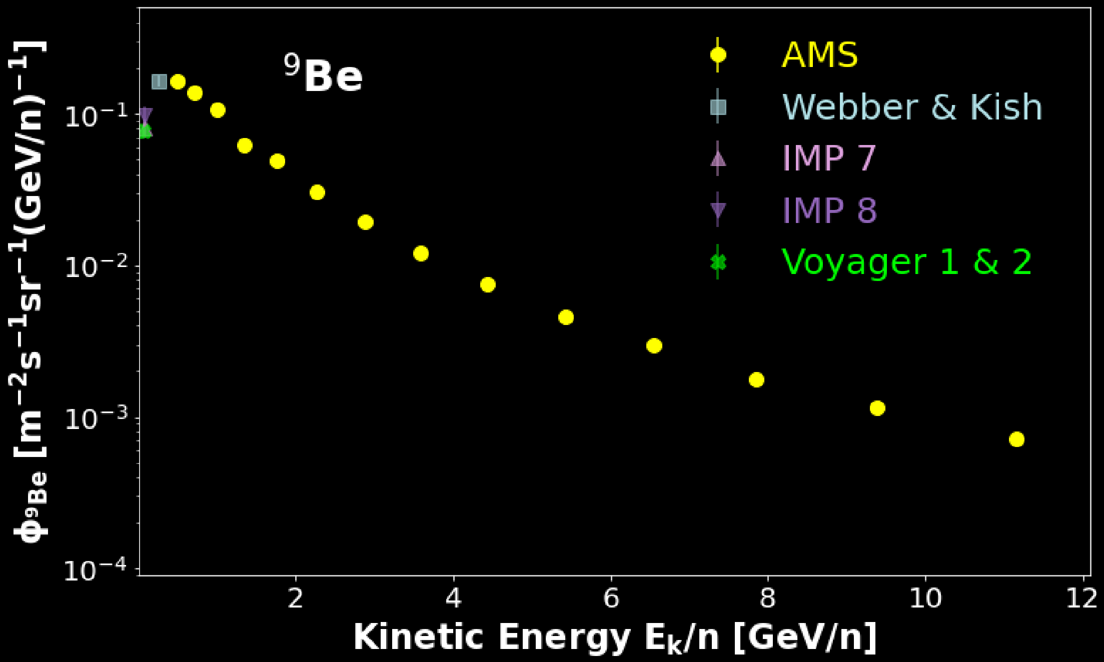


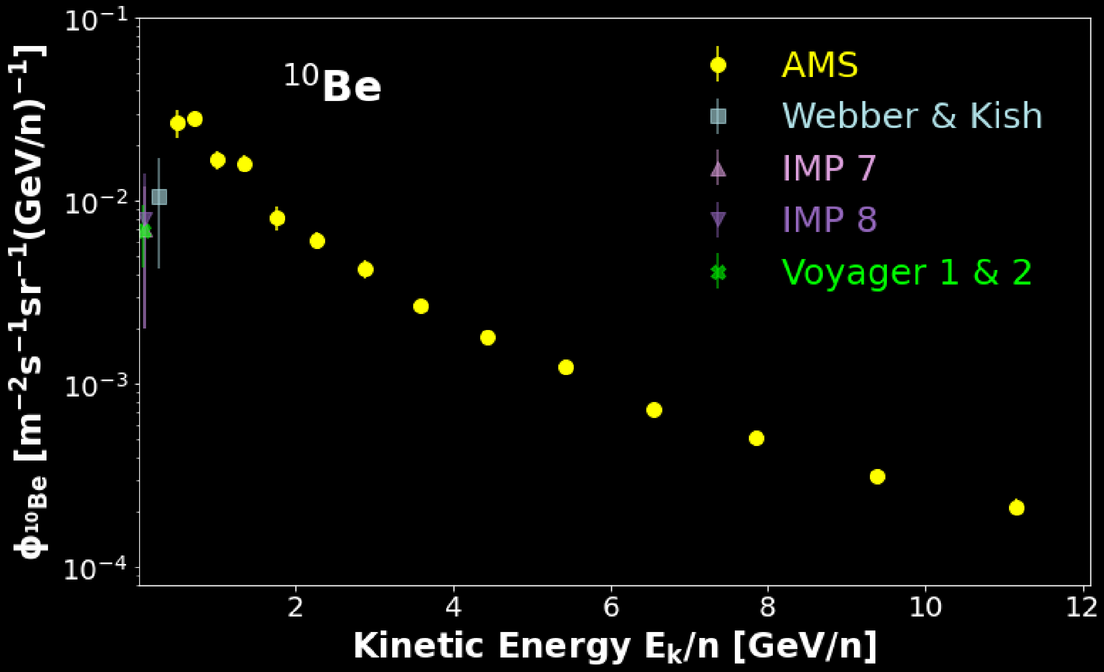
The ratio of unstable-to-stable secondary cosmic rays ^{10}Be/^{9}Be measures the Galactic halo size L.
L determines the galactic cosmic ray propagation volume .

Beryllium Isotope Fluxes

- Based on 0.9 million beryllium events.

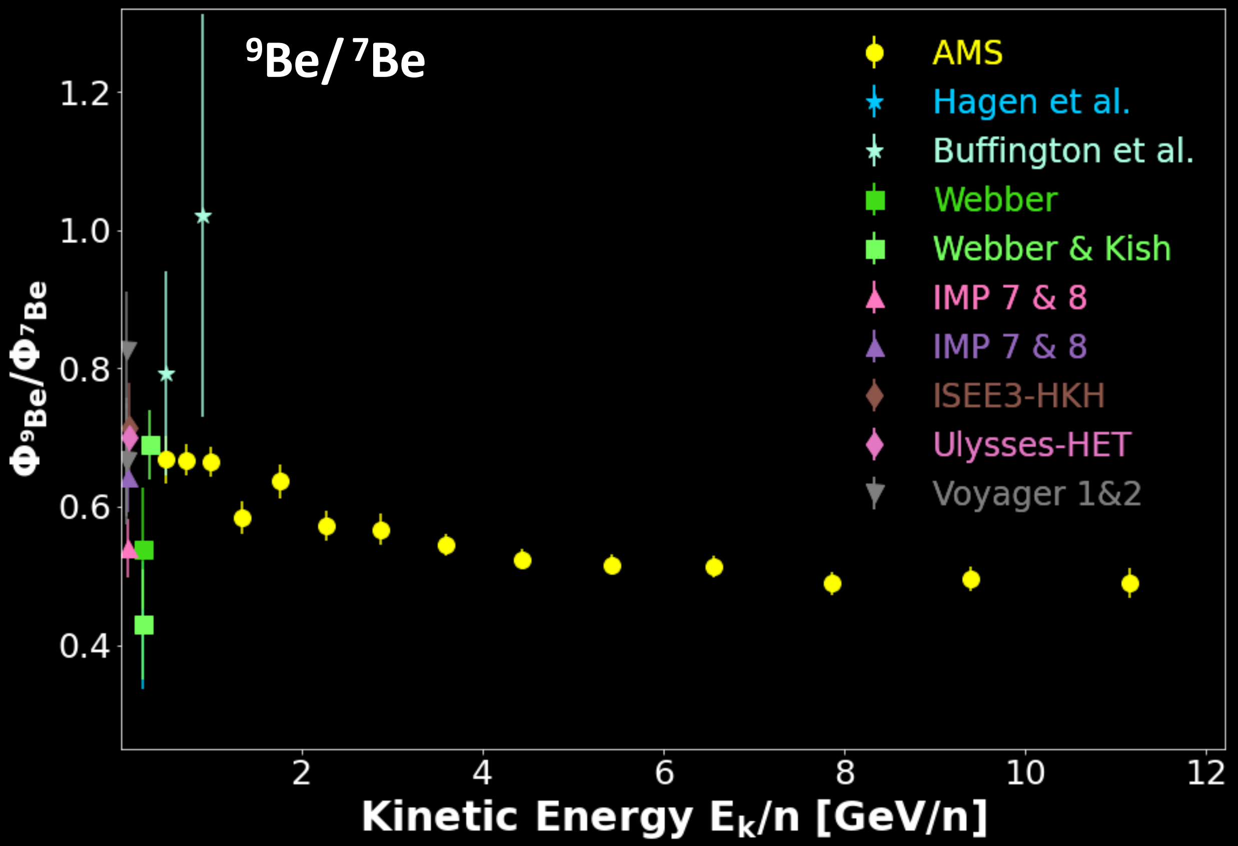


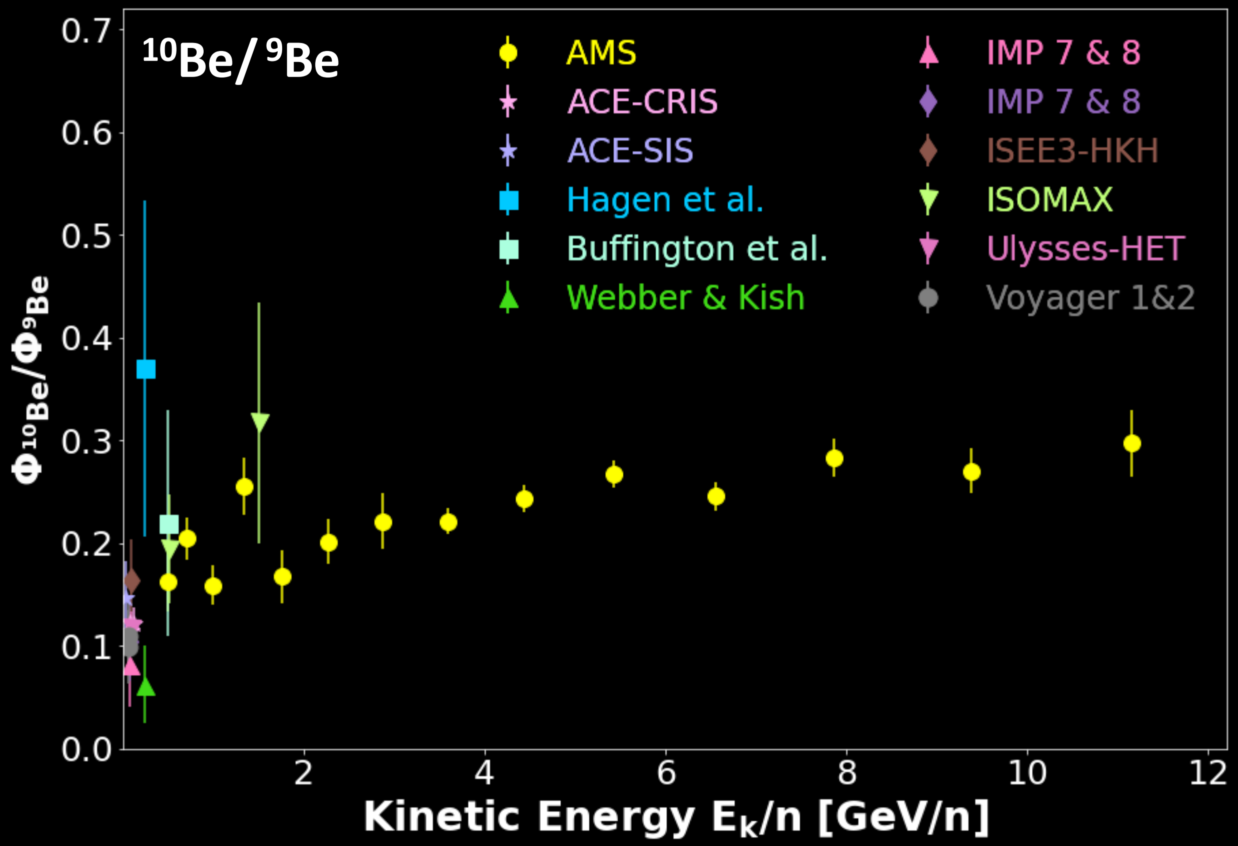




(Preliminary data, refer to upcoming AMS publication)

Beryllium Isotope Flux Ratios

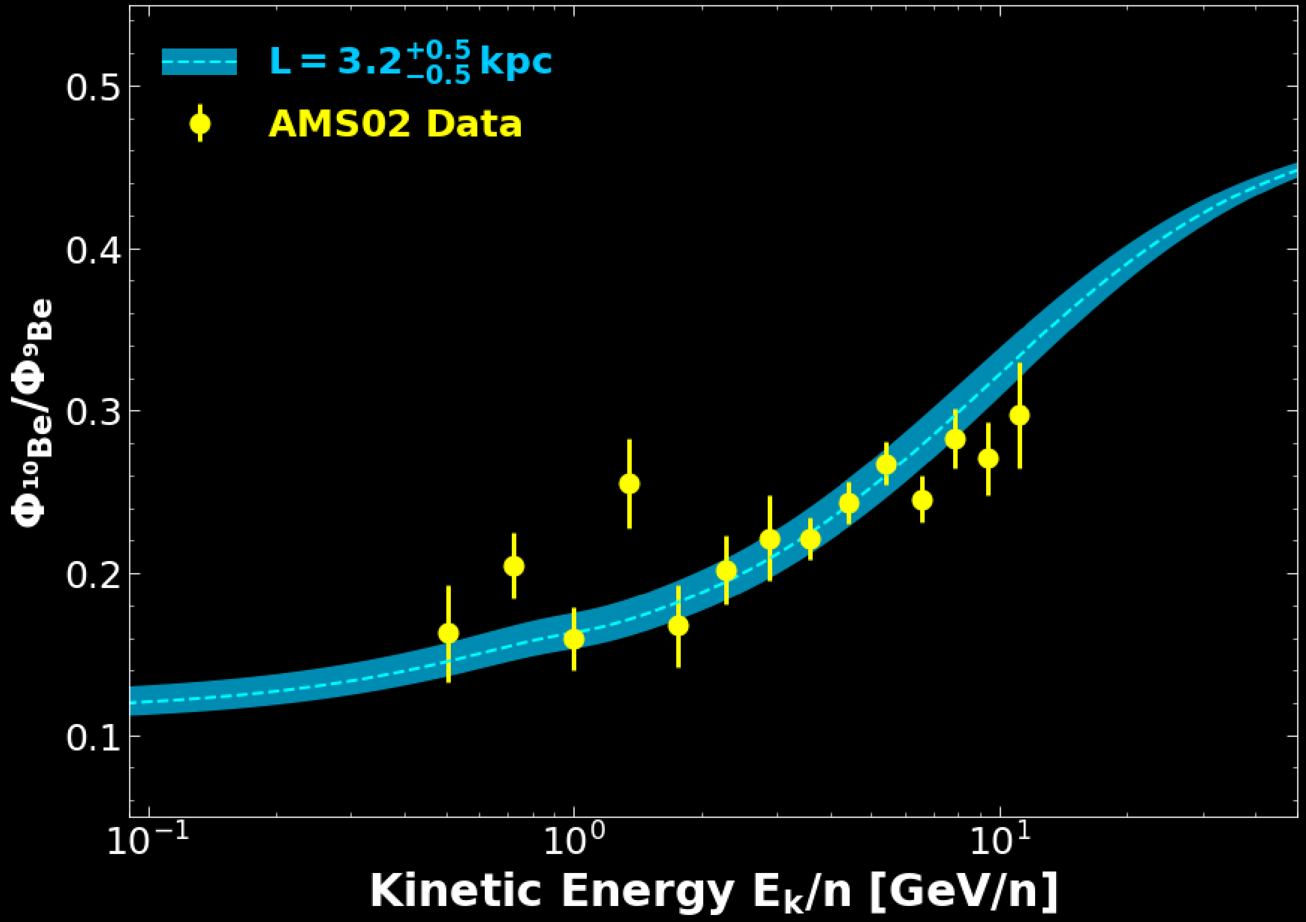




(Preliminary data, refer to upcoming AMS publication)

Galactic halo size *L* with AMS ^{10}Be/^{9}Be Flux Ratio

Fitted Galactic halo size *L* with an analytical model (Maurin et al.2022)



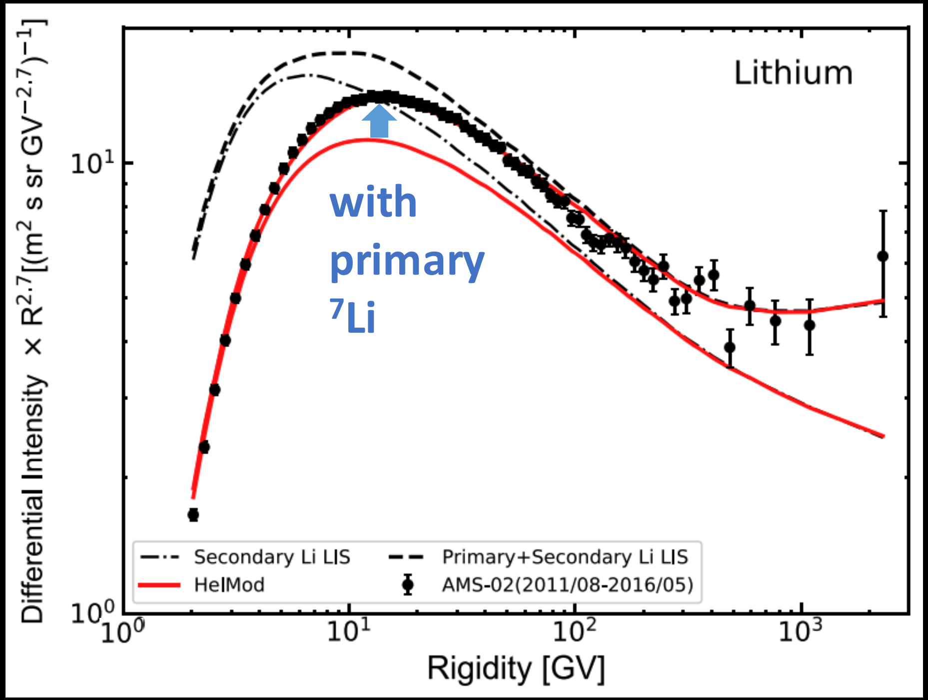
(Preliminary data, refer to upcoming AMS publication)

The precision on the Galactic halo size *L* from the AMS data is about $\sim \pm 0.5\ kpc$ (15%)
Error on *L* is dominated by the uncertainty on spallation cross-sections $\sim \pm 1\ kpc$

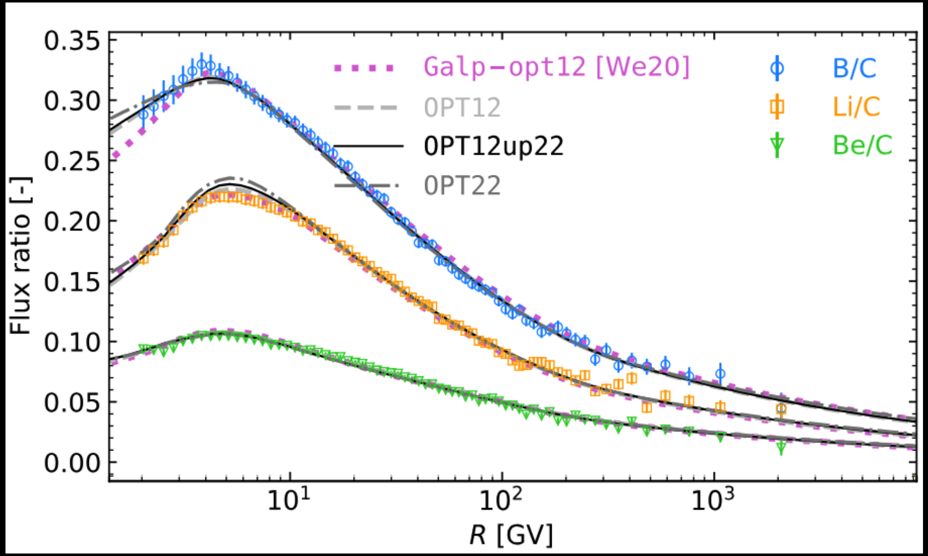
Origin of Cosmic-ray Lithium

- Cosmic lithium is assumed to be secondary.
- Some studies show lithium flux higher than model prediction:
  - Primary lithium (^{7}Li)? (Boschini et al. APJ, 2020)
  - Uncertainty in the production cross-section? (Maurin et al. A&A, 2022)
- Measurements of lithium isotope fluxes will shed light on the origin of cosmic lithium.

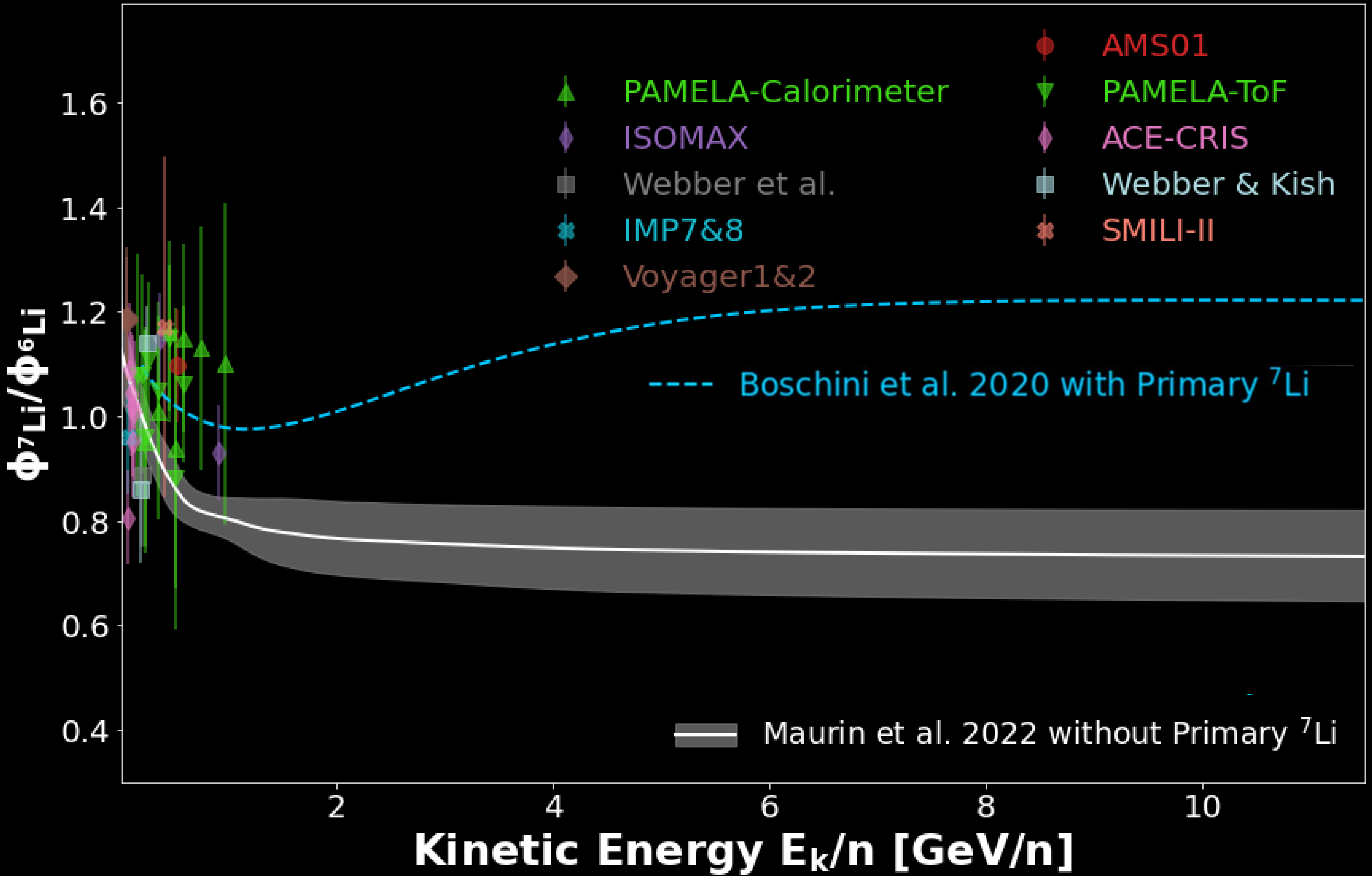
Boschini et al. APJ, 2020



Maurin et al. A&A, 2022



Testing the Origin of Lithium Isotopes

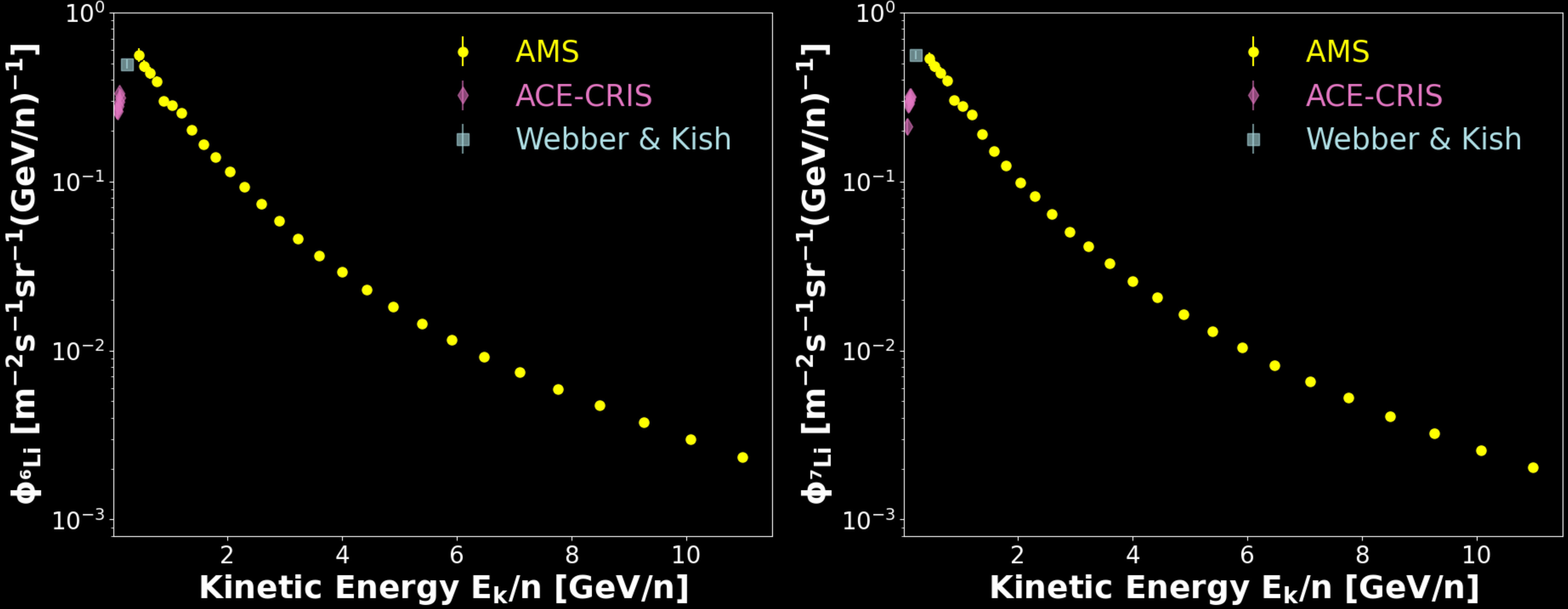


Secondary + Primary ^{7}Li

Secondary ^{7}Li

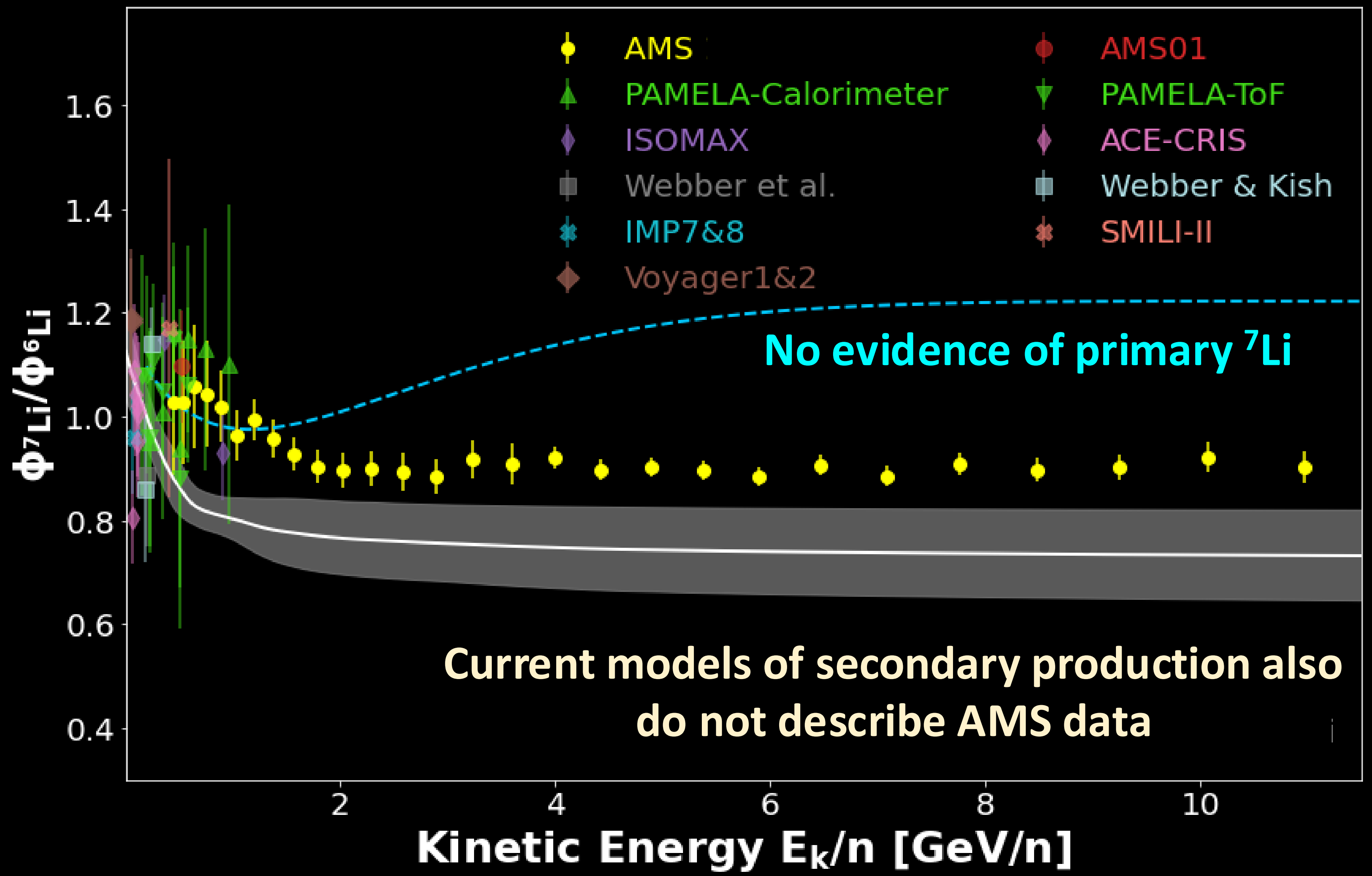
Lithium Isotope Fluxes

Based on 1.4 million lithium events.



(Preliminary data, refer to upcoming AMS publication)

Lithium Isotope Flux Ratios



No evidence of primary ^{7}Li

Current models of secondary production also do not describe AMS data

Secondary
+
Primary
^{7}Li

Secondary
^{7}Li

(Preliminary data, refer to upcoming AMS publication)

Origin of Cosmic Deuterons D

(He, C, O, …) + Interstellar Media → (D, ^{3}He) + X

D and ^{3}He are both considered to be secondary cosmic rays

A. W. Strong, I. V. Moskalenko, and V. S. Ptuskin, Annu. Rev. Nucl. Part. Sci. **57**, 285 (2007)

E. G. Adelberger et al., Rev. Mod. Phys. **83**, 195 (2011)

N. Tomassetti, Astroph. Space Sci. **342**, 131 (2012)

B. Coste, L. Derome, D. Maurin, and A. Putze, A&A **539**, A88 (2012)

P. Blasi, Astron. Astrophys. Rev. **21**, 70 (2013)

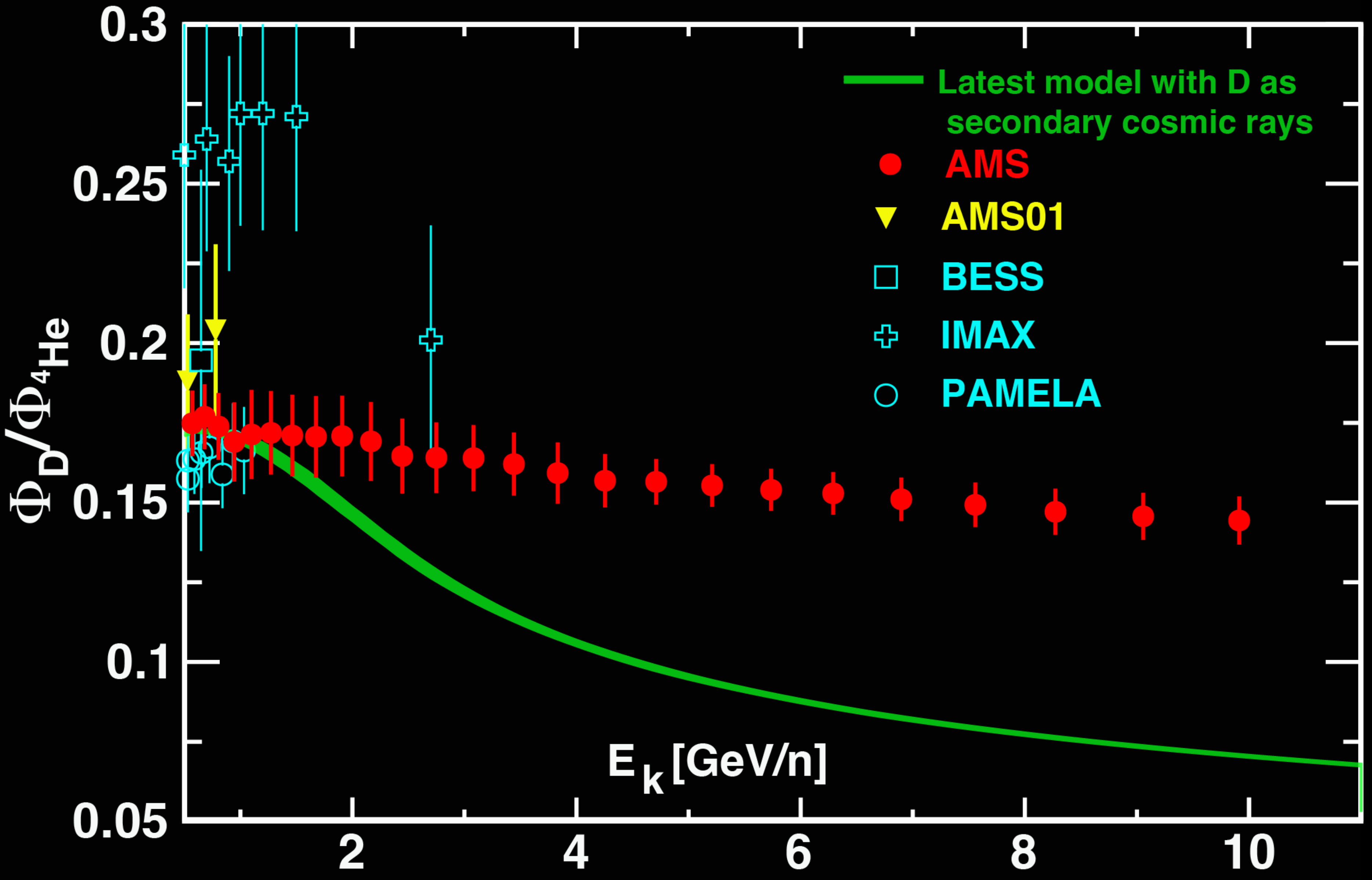
I. A. Grenier, J. H. Black and A. W. Strong, Annu. Rev. Astron. Astrophys. **53**, 199 (2015)

G. Johannesson et al., Astroph. J. **824**, 16 (2016)

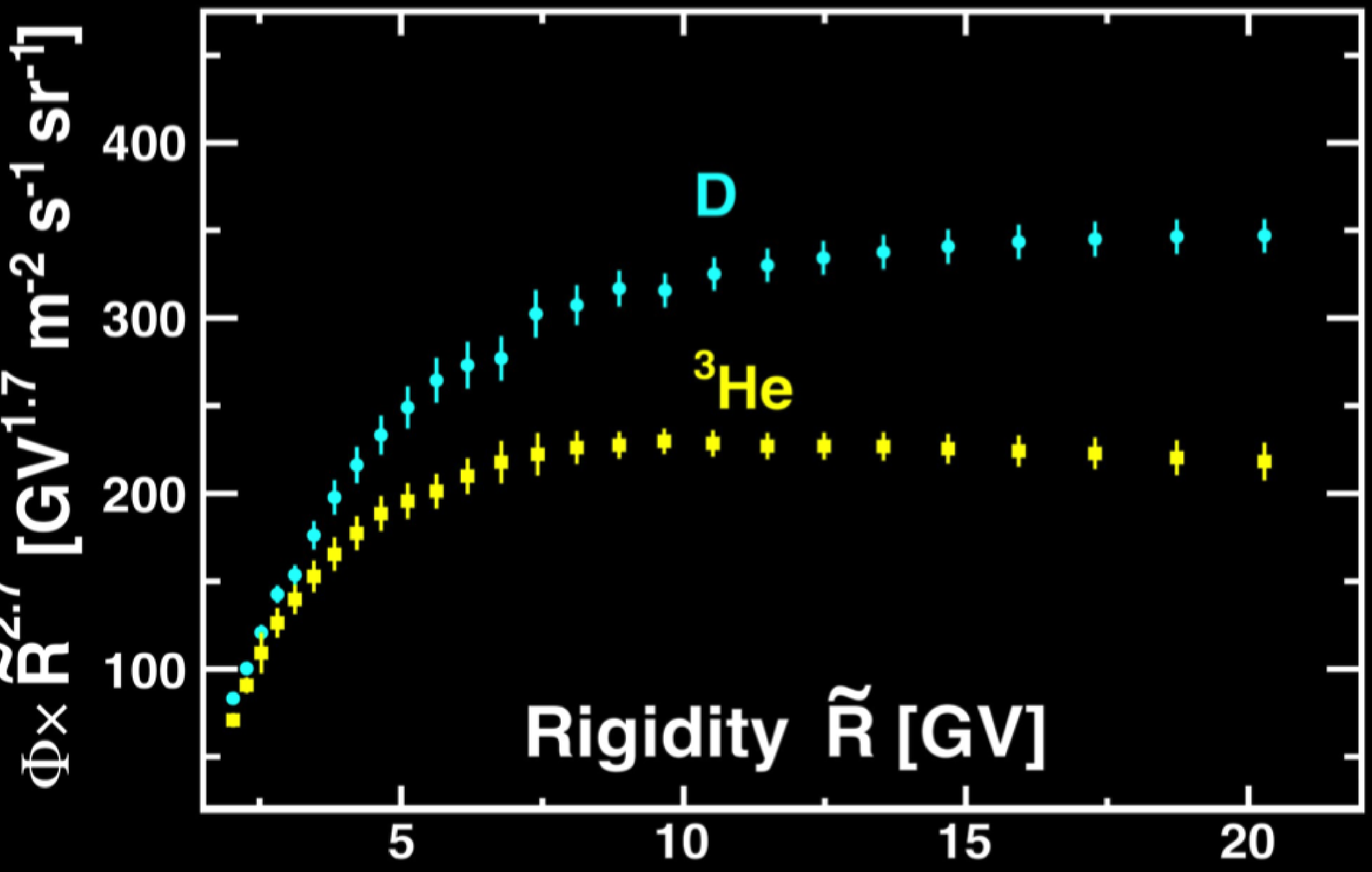
This is challenged by the recent AMS publication

M. Aguilar et al., Phys. Rev. Lett. **132**, 261001 (2024)

AMS result on Deuterons



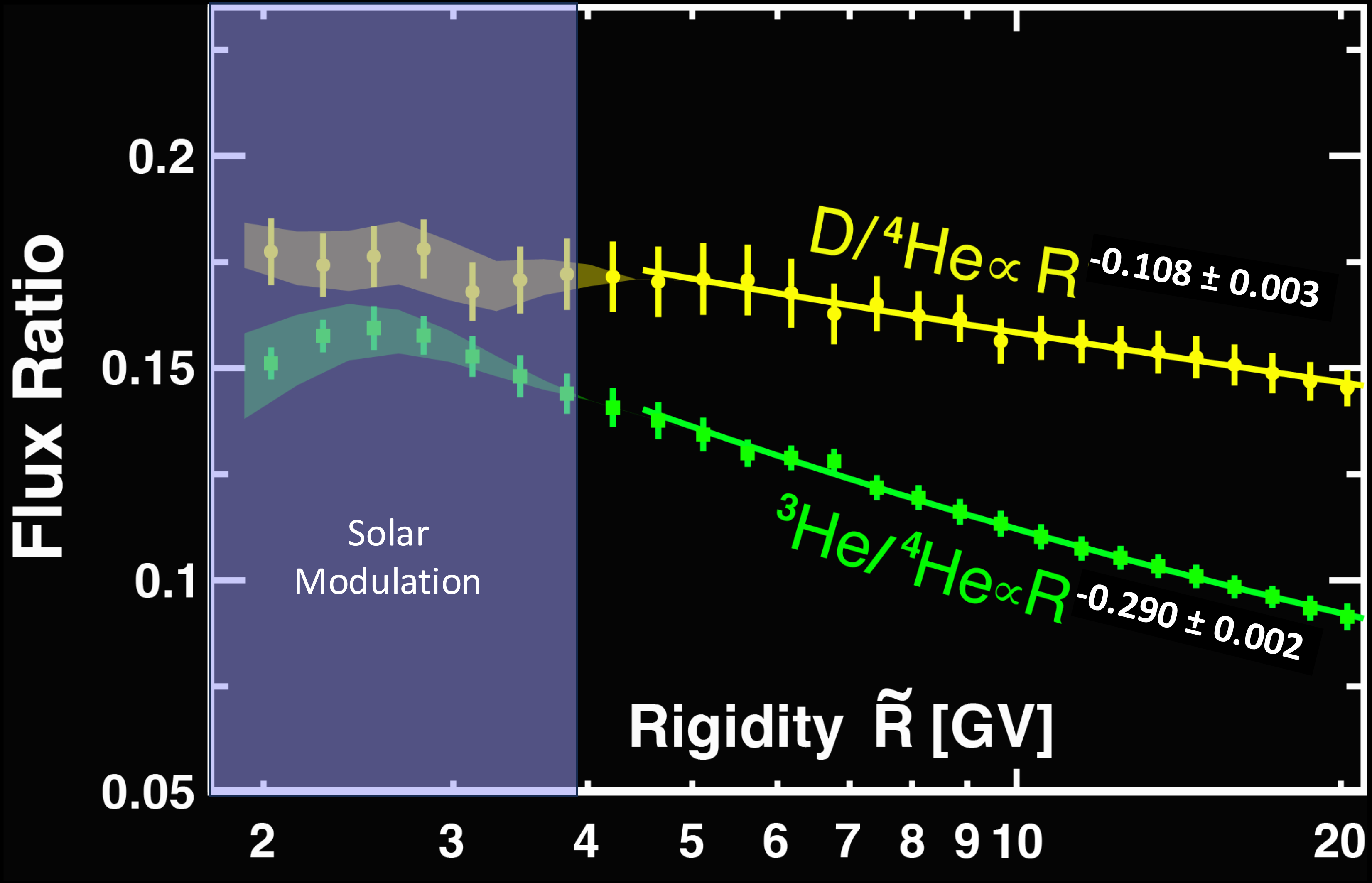
Deuteron and ^{3}He Fluxes



The Flux Ratios of D/^{4}He and ^{3}He/^{4}He

have completely different rigidity dependence:

^{3}He is only secondary, D must have an additional new source

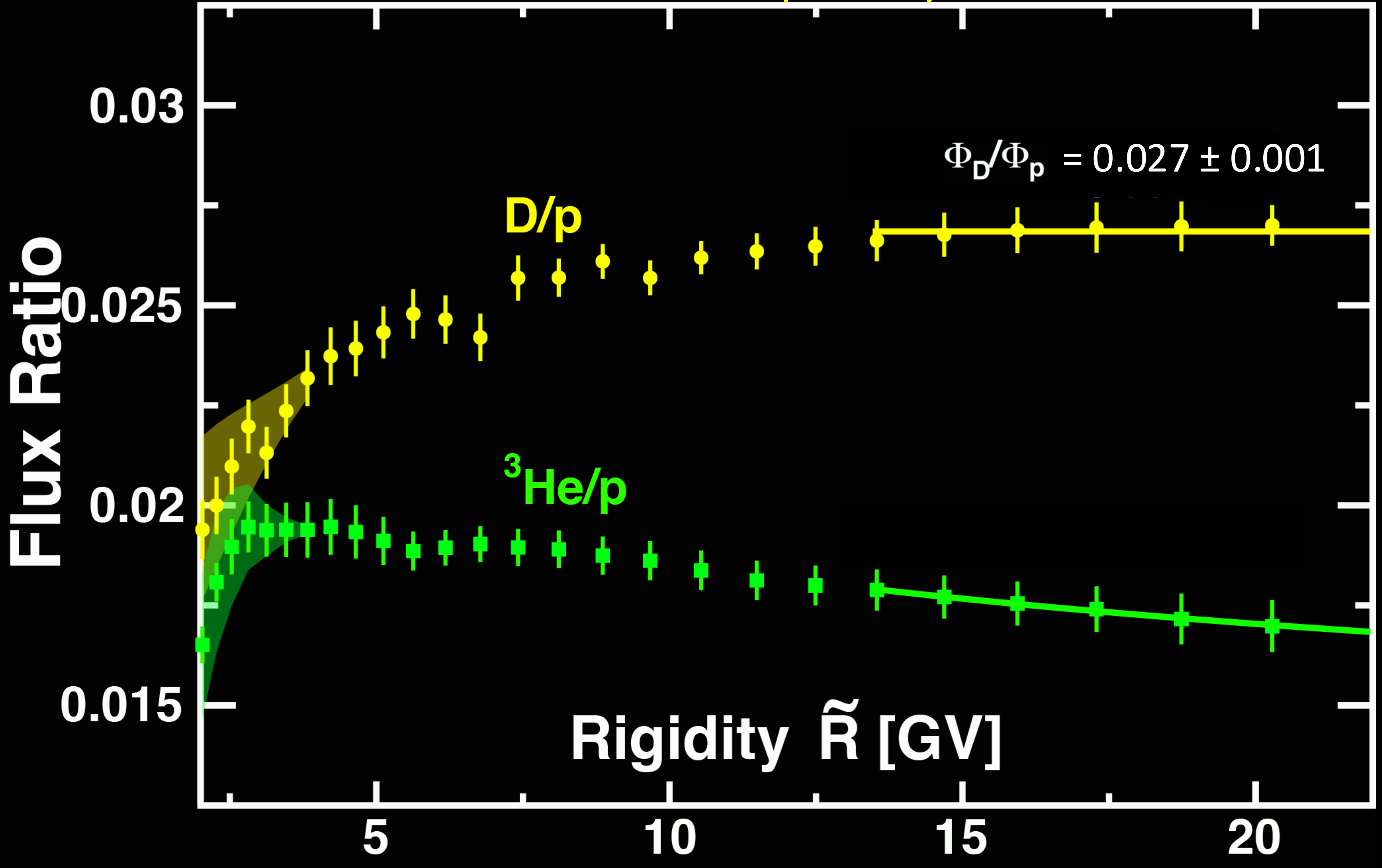


The D/*p* Flux Ratio increases with rigidity and is constant above 13 GV

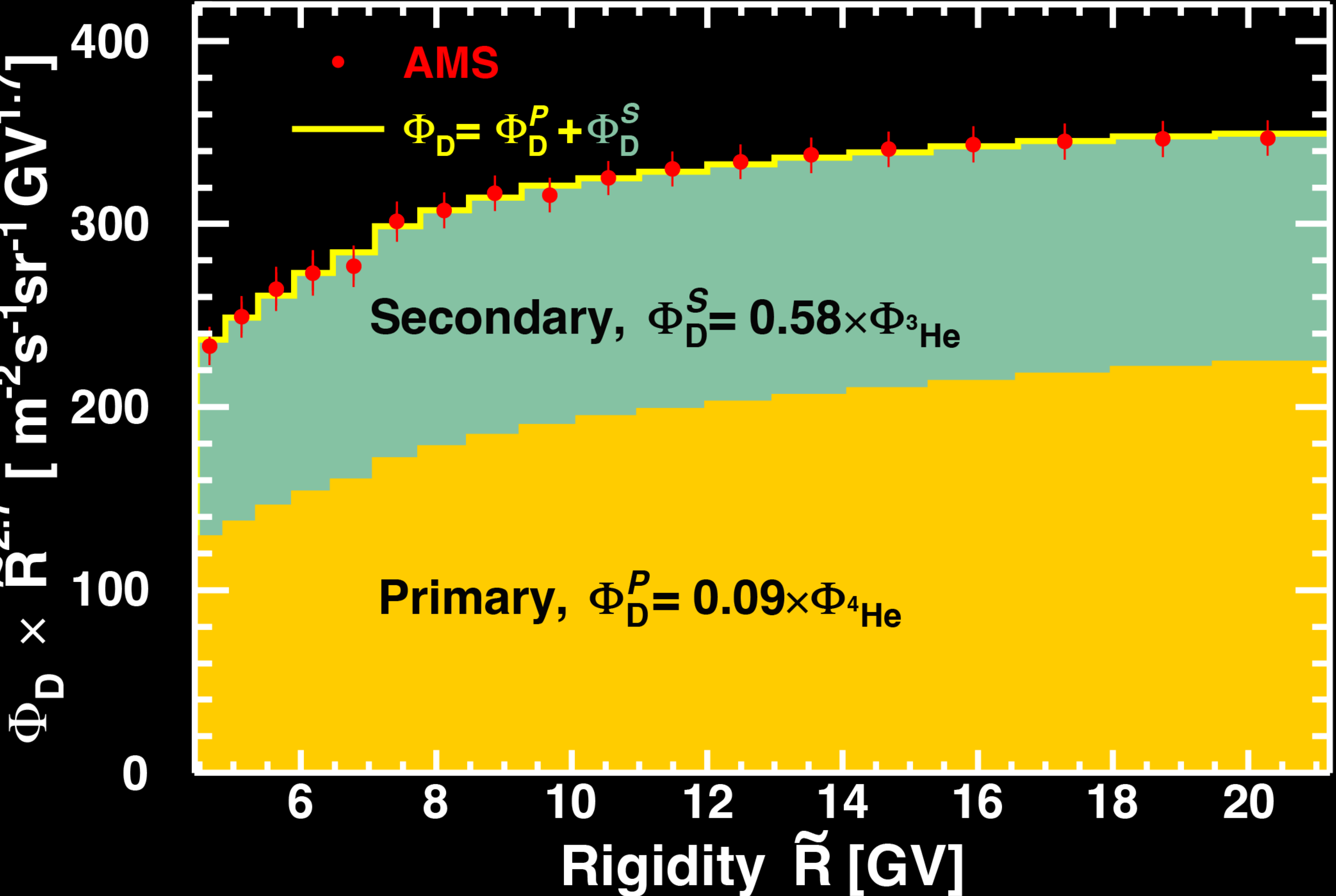
Both D and *p* have Z=1, *p* are primary particles.

If D is pure secondary, Φ_D/Φ_p must decrease with rigidity above ~4GV

D must have an additional primary-like source



Unexpected Results: Deuterons have a significant primary component



Conclusions

- The AMS results on H, He, Li and Be isotope fluxes and their ratios have been presented, extending over the rigidity range from 1.9 GV to 21 GV for H and He isotopes, and over the energy range from 0.4 GeV/n to 12 GeV/n for Li and Be isotopes, covering the range above 2 GeV/n uncharted by previous experiments.

- The AMS ^{10}Be/^{9}Be flux ratio allows the determination of the galactic halo size *L* with the unprecedented accuracy of 15%.

- The AMS ^{7}Li/^{6}Li flux ratio does not agree with the hypothesis of a primary component in ^{7}Li, and current models of secondary production also do not describe AMS data.

- The AMS D and He measurements show unexpected observation that cosmic D have a sizable primary like component.