Deuteron and Helium-3 production cross sections and propagation in the Galaxy

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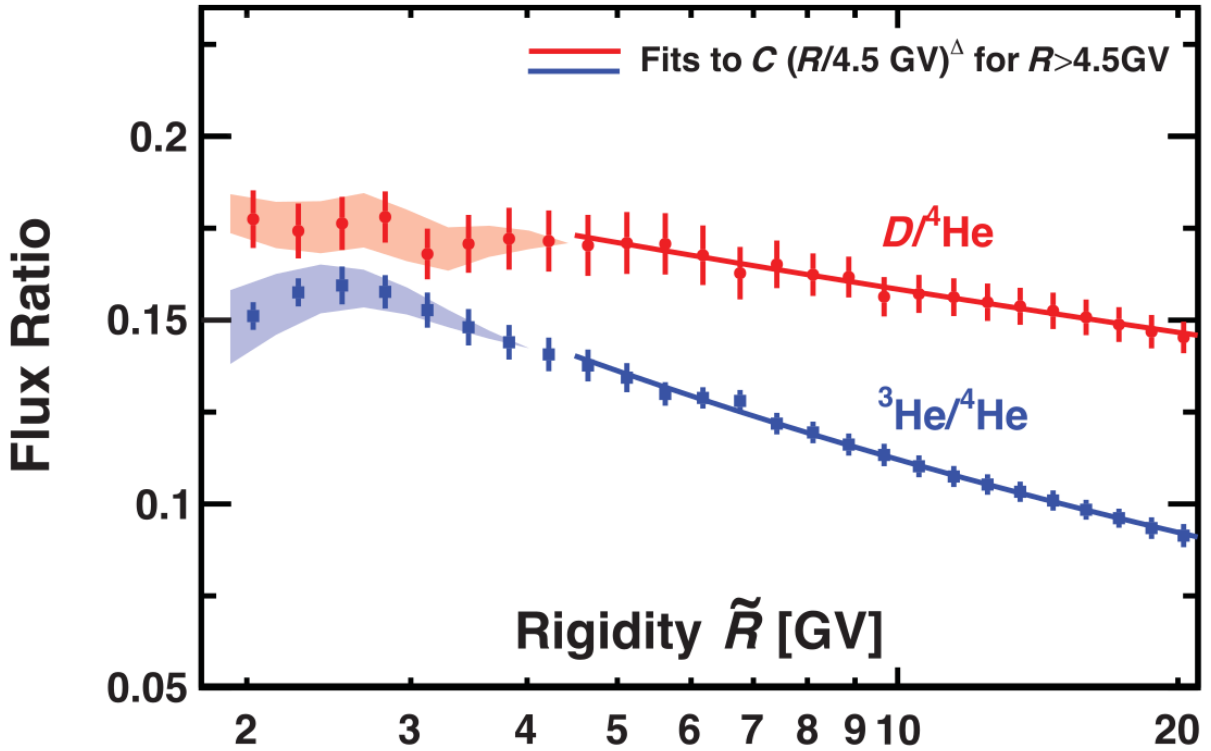
Latest results from AMS-02 on D and ^{3}He



$C(R/4.5)^{\Delta}$
$\Delta_{D/4He} = -0.108 \pm 0.005$

$C(R/4.5)^{\Delta}$
$\Delta_{3He/4He} = -0.289 \pm 0.003$

$\Delta_{D/4He} > \Delta_{3He/4He}$

Contrary to expectations, D seems to have a primary-like component.

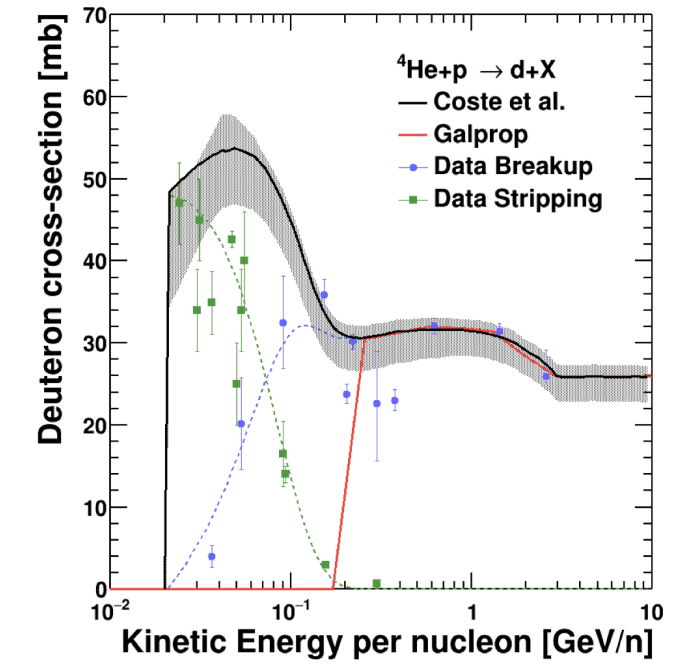
M. Aguilar et al. (AMS Collaboration) Phys. Rev. Lett. ***132****, 261001 2024*

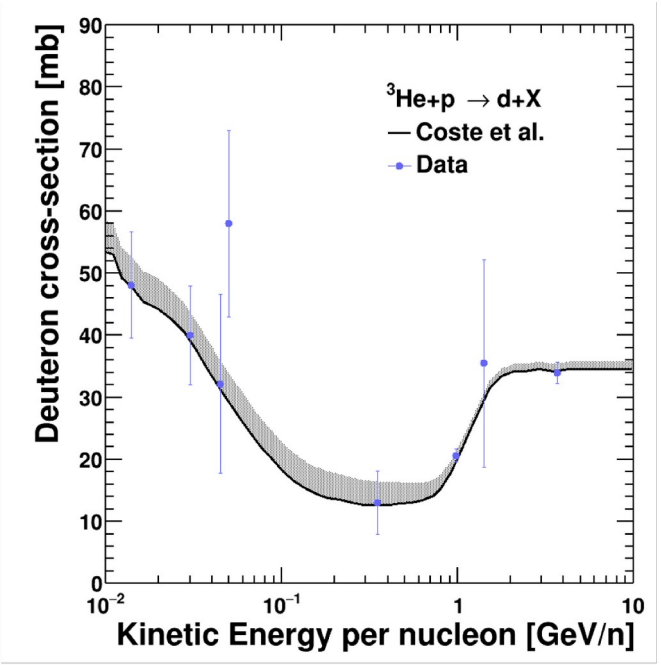
Deuteron and ^{3}He production cross sections

- Interpretation of this new data through propagation models requires well known production cross sections for D and ^{3}He.
- Most cited work on D and ^{3}He production in cosmic-ray interactions is: "*Constraining Galactic cosmic-ray parameters with Z≤2 nuclei. B. Coste, L. Derome, D. Maurin, and A. Putze. A&A 539, A88 (2012)".*
  - Review of D and ^{3}He production cross section with data up to early 2000 and their parametrizations.
  - Major contribution expected from ^{4}He, ^{3}He and CNO projectiles.
- We implemented Coste et al. parametrizations in GALPROP56 independently *Phys. Rev. D 107, 123008 (2023).*
- Others have also included them: *N. Weinrich, et al Astron. Astrophys. 639, A131 (2020)*, *N. Tomassetti,Astrophys. Space Sci. 342, 131 (2012)*,...
- GALPROP included Coste et al. parametrizations in new version 57

Deuterons from ^{4}He and ^{3}He projectiles

- Two main processes are involved in deuteron production: Stripping and Breakup.

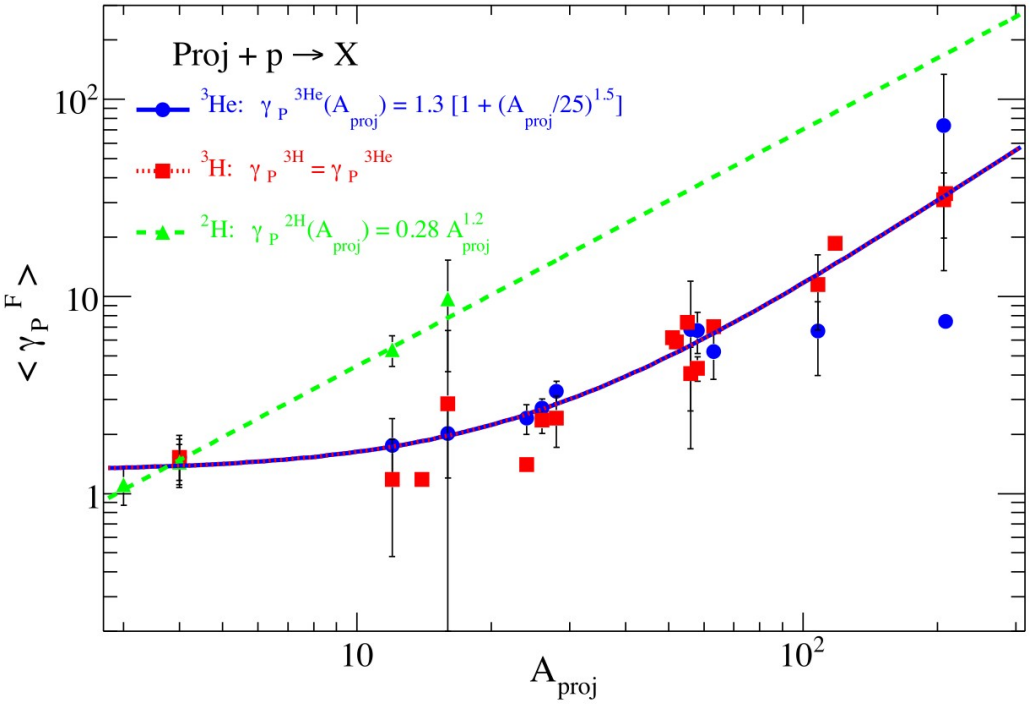




Cross sections for projectiles A>4

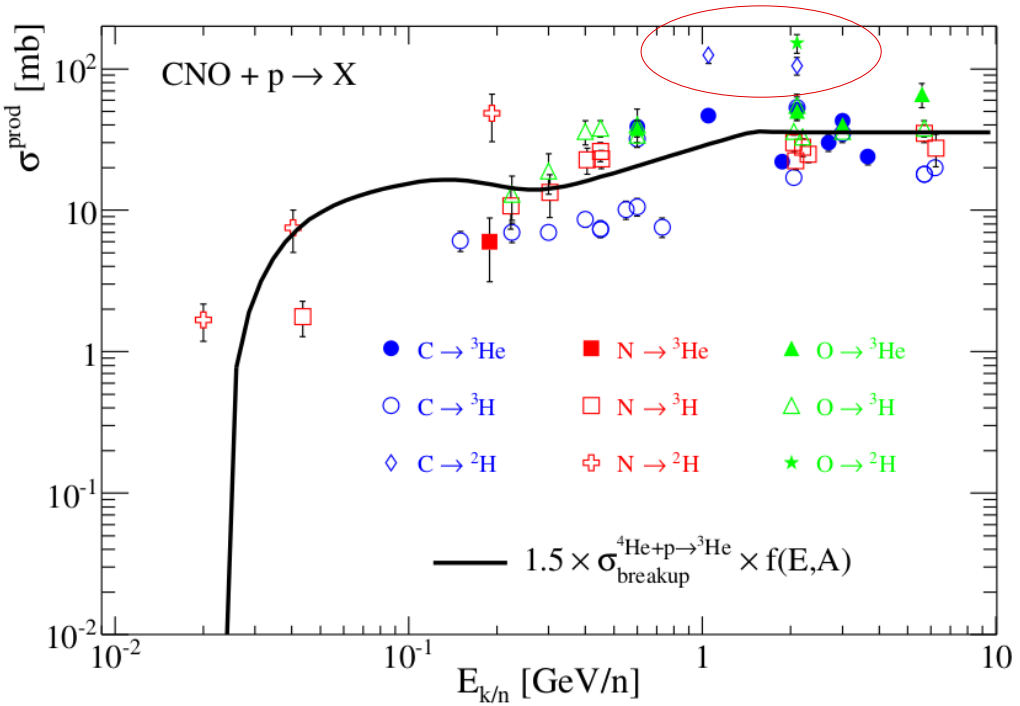
Coste et al. follows the next parametrization based on data.

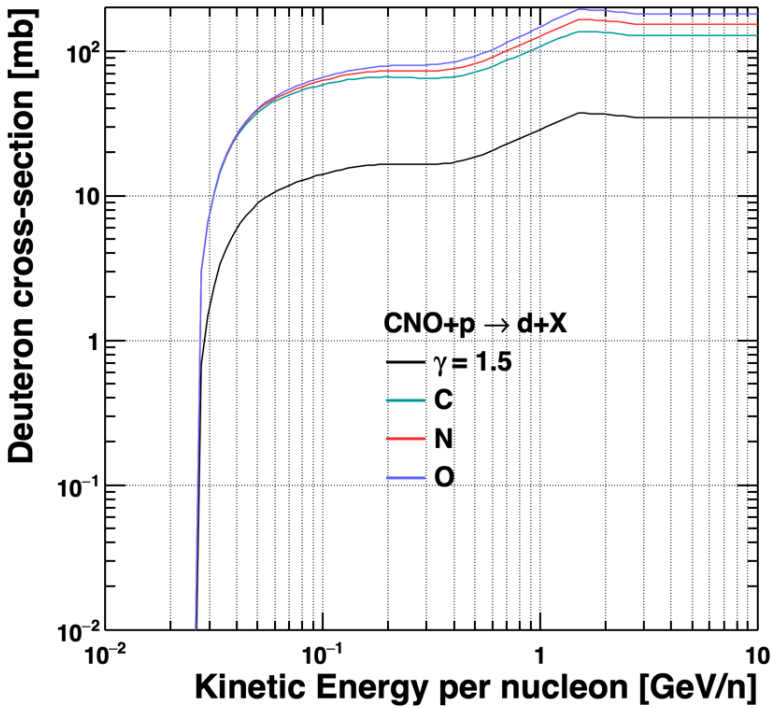
- $\sigma^{\mathrm{Pp}\to\mathrm{F}}(E_{k/n}, A_{\mathrm{P}}) = \gamma_{\mathrm{P}}^{\mathrm{F}} \cdot f(E_{k/n}, A_{\mathrm{P}}) \cdot \sigma_{\mathrm{breakup}}^{^4\mathrm{Hep}\to{}^3\mathrm{He}}(E_{k/n})$
- $\gamma_{\mathrm{P}}^{^3\mathrm{He}} = \gamma_{\mathrm{P}}^{^3\mathrm{H}} = 1.3 \left[1 + \left(\frac{A_{\mathrm{P}}}{25}\right)^{1.5}\right],$
- $\gamma_{\mathrm{P}}^{^2\mathrm{H}} = 0.28\, A_{\mathrm{P}}^{1.2}.$
- γ_P^F factor depends strongly on A (projectile).



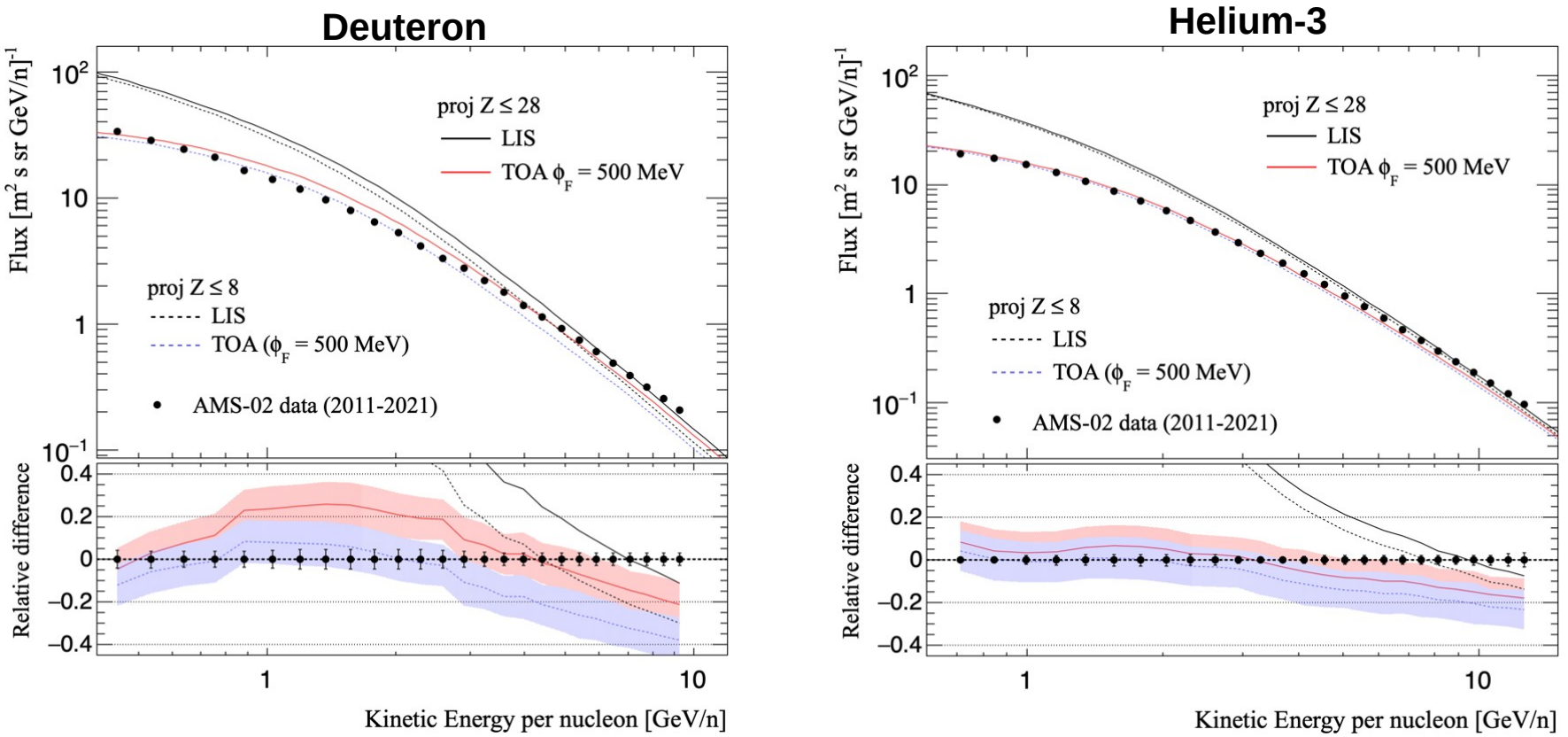
D production from CNO projectiles

- Coste et al. uses a value of γ = 1.5 that fits all data (D, ^{3}H, ^{3}He).
- Parametrization predicts a higher cross section for deuterons.





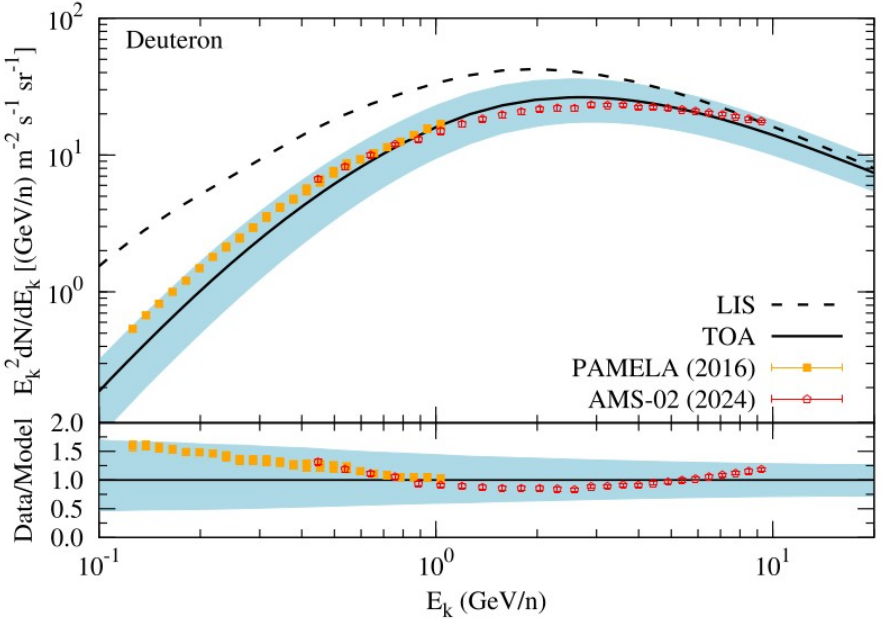
Deuteron and Helium-3 fluxes

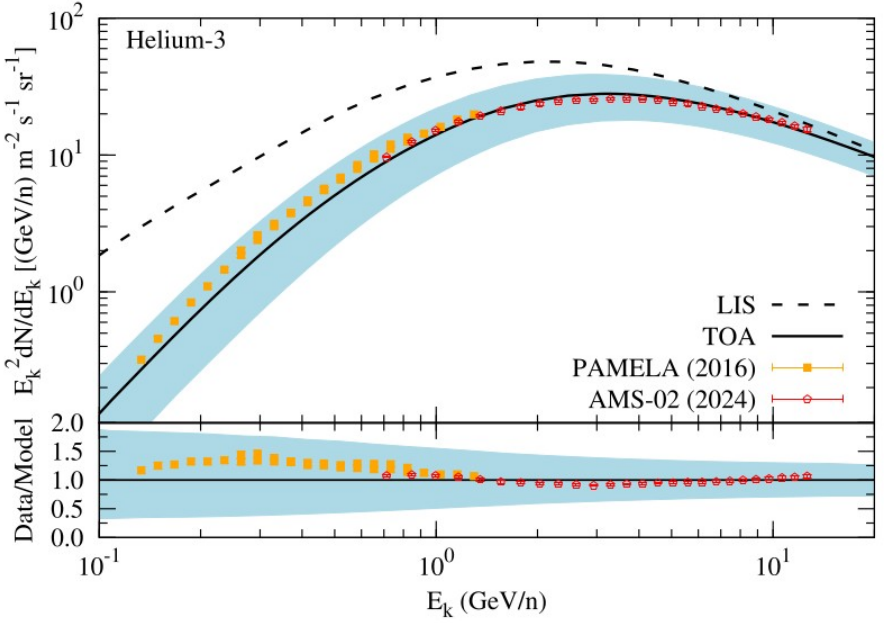


- Band shows an uncertainty of 10% in cross sections.

D and ^{3}He fluxes by Yuan & Fan

- Coste et al. parametrizations plugged in GALPROP56.
- Secondary production explain AMS observations.



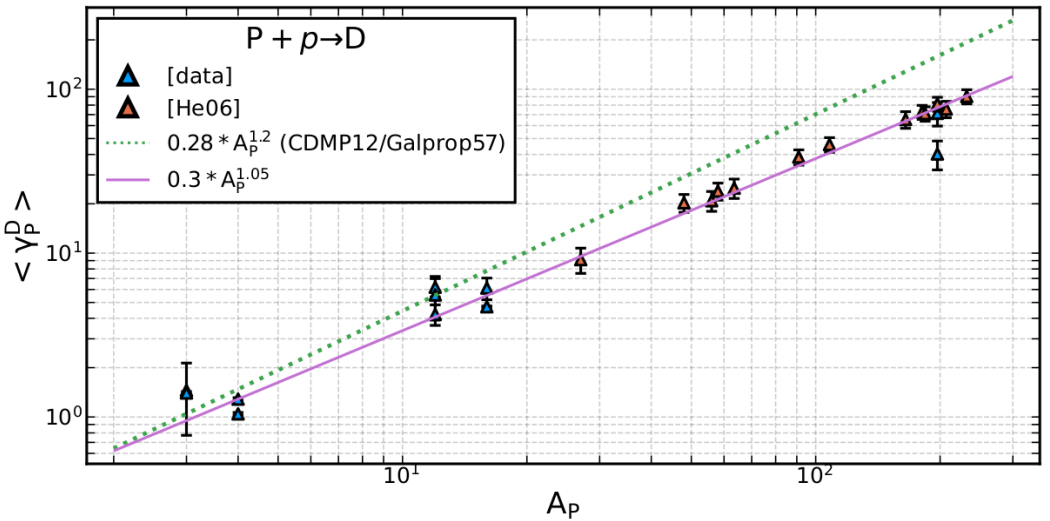


- Band shows an uncertainty of 10-15% in cross sections.

*Qiang Yuan and Yi-Zhong Fan 2024 ApJL **974** L14*

Revised parametrization for D

- Xing-Jian Lv et al (*arXiv:2409.07139v1*) propose a new parametrization for the γ factor, considering additional data on deuteron production by fragmentation of heavier nuclei.
- This is expected to reduced the deuteron flux.



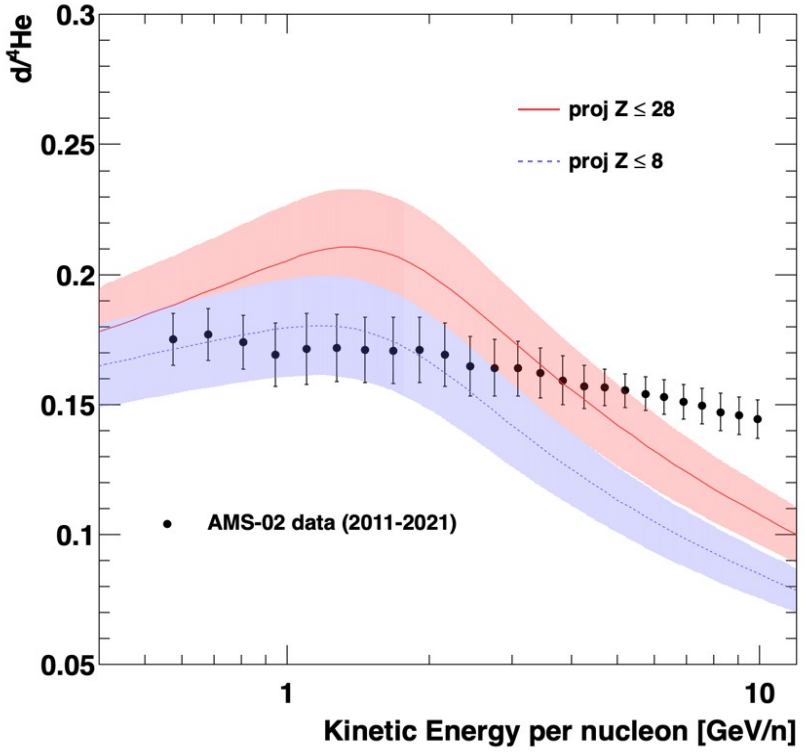
Conclusions

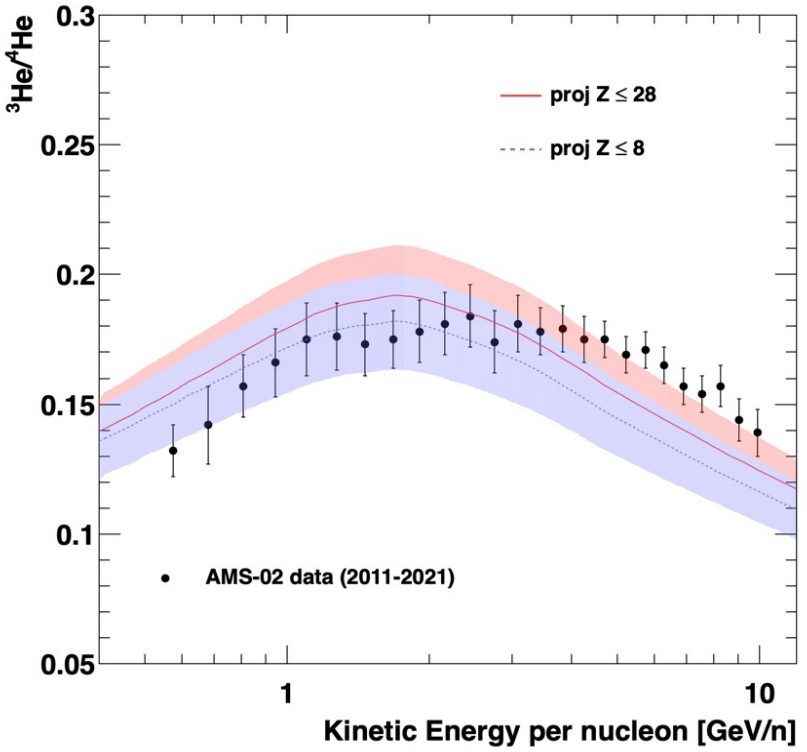
- New precision measurements from AMS experiment on D and ^{3}He cosmic ray challenges the standard propagation model predictions and opens questions about D production in the Galaxy.
- Contribution to D and ^{3}He from fragmentation of nuclei with Z>8 is important and should be study further. This also has been the conclusion of a recent study by Yuan and Fan (*Qiang Yuan and Yi-Zhong Fan 2024 ApJL* ***974*** *L14*).
- Yuan and Fan claim secondary production explain AMS observations.
- However, a recent study by Xing-Jian Lv et al (*arXiv:2409.07139v1*), points to a reduced deuteron production cross sections when data not taken into account in Coste et al. is considered.

Outline

- New data on D and ^{3}He production cross section from light and heavy nuclei projectiles is necessary to reduce uncertainties.
- Which cross sections? A ranking would be helpful.
- A deeper investigation of data and parametrizations on D and ^{3}He production cross sections and their uncertainties from light and heavier nuclei is necessary to have a better interpretation of the possible primary component in D.

Deuteron and ^{3}He to ^{4}He flux ratios

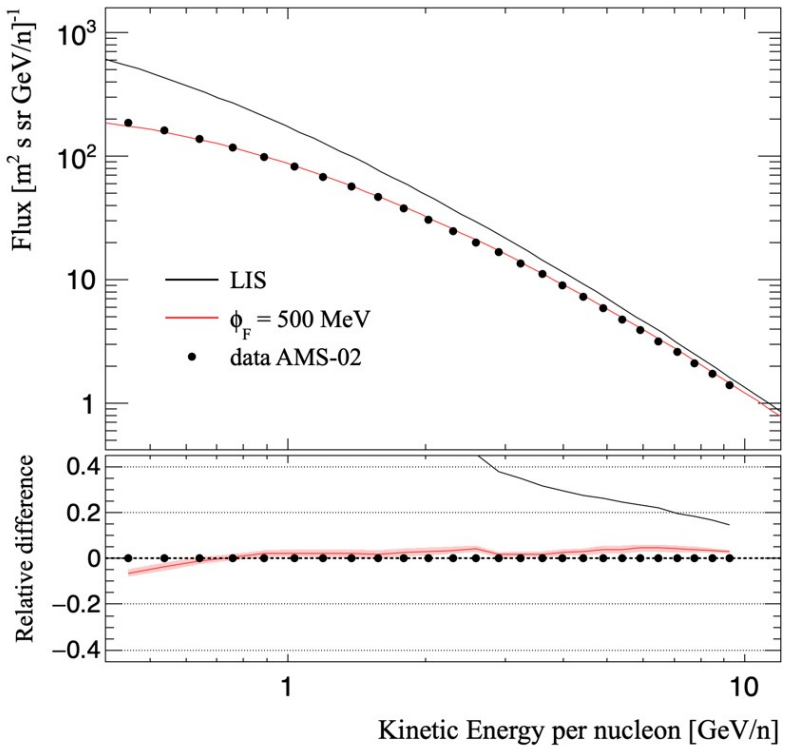




- Band shows an uncertainty of 10% in cross sections.

^{4}He flux

- The value of the parameter in force field is set to fit AMS data.



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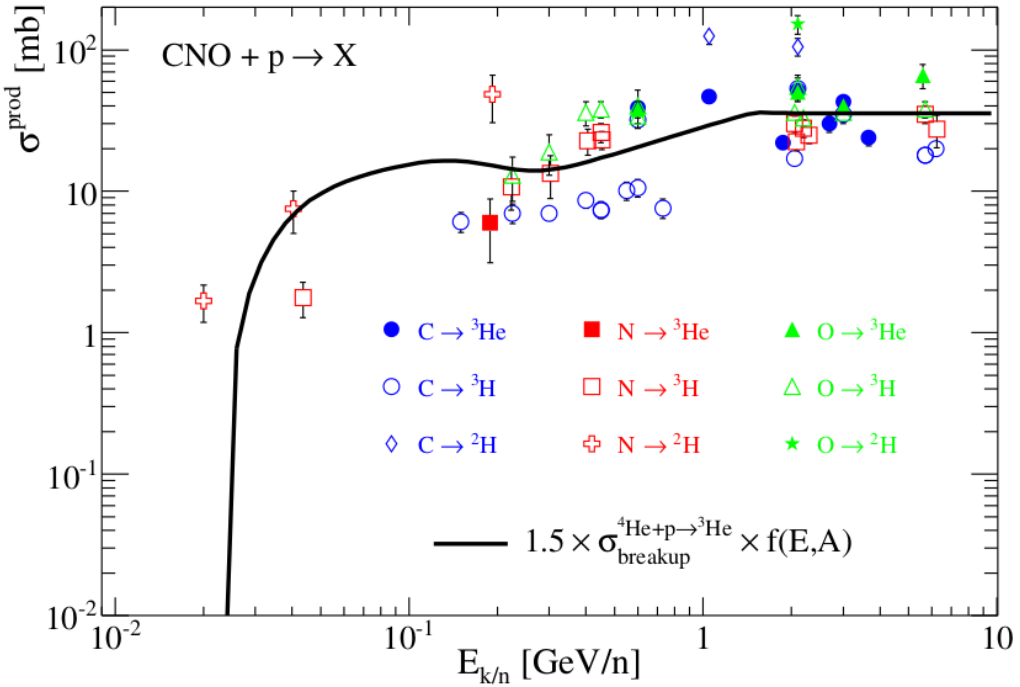
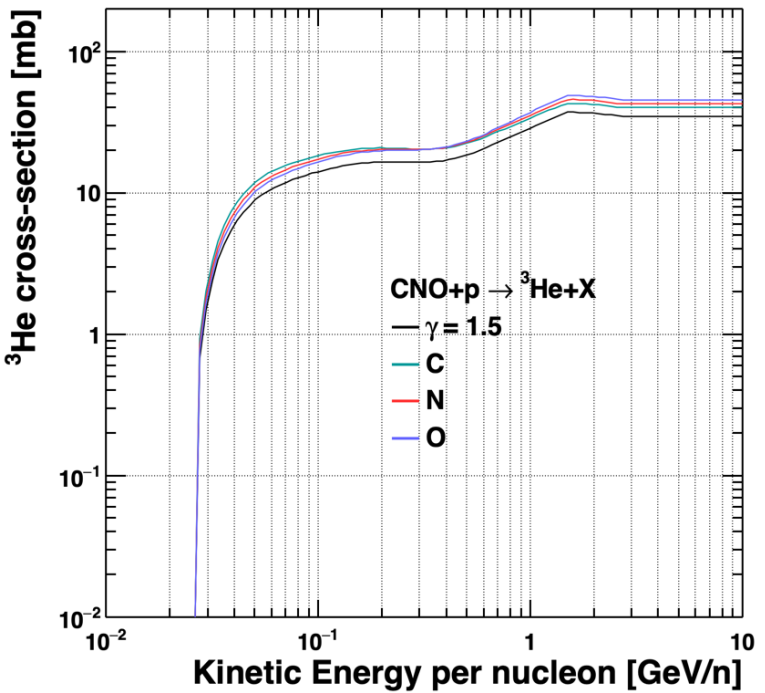
- Parametrization predicts a slightly higher cross section for ^{3}He.





Deuteron and ^{3}He production cross sections

- Important reactions are:

Deuterons:

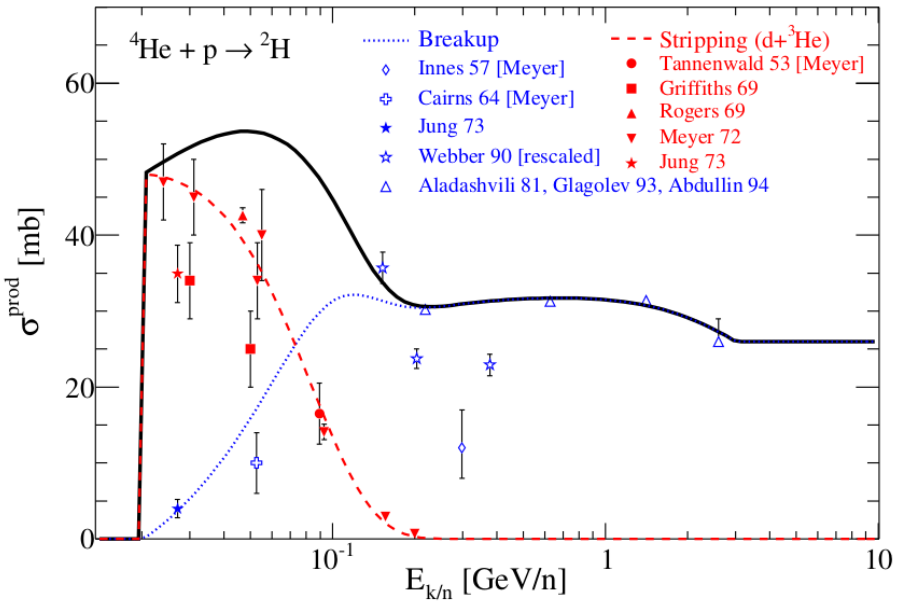
- He4+p → D+X
- He3+p → D+X
- CNO+p → D+X
- Proj(Z>8)+p → D+X

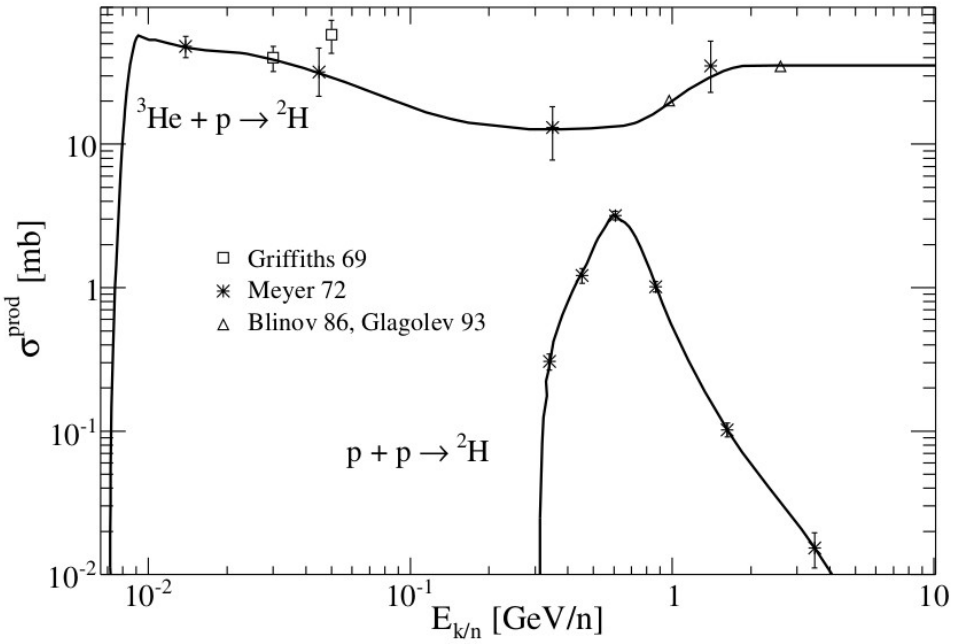
Helium-3:

- 4He+p → 3He+X
- 4He+p → 3H+X → 3He+X
- CNO+p → 3He+X
- CNO+p → 3H+X → ^{3}He+X
- Proj(Z>8)+p → ^{3}He+X
- Proj(Z>8)+p → ^{3}H+X → ^{3}He+X

Deuterons from He4 and He3 projectiles

- Two main processes are involved: Stripping and Breakup.
- p+p → d+pi+ only relevant for Ekn < 1 GeV/n
- Cross section ~ 25-30 mb @ [1-10 GeV] for He4 projectile.





^{3}He from ^{4}He projectile

- Two main processes are involved: Stripping and Breakup.
- H3 decays in He3.
- Cross section ~ 25-30 mb @ [1-10 GeV] for He4 projectile.