ICHEP 2020 | PRAGUE

40th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

VIRTUAL CONFERENCE

Measurements of Light Nuclear Isotopic Composition in Cosmic Rays with AMS-02

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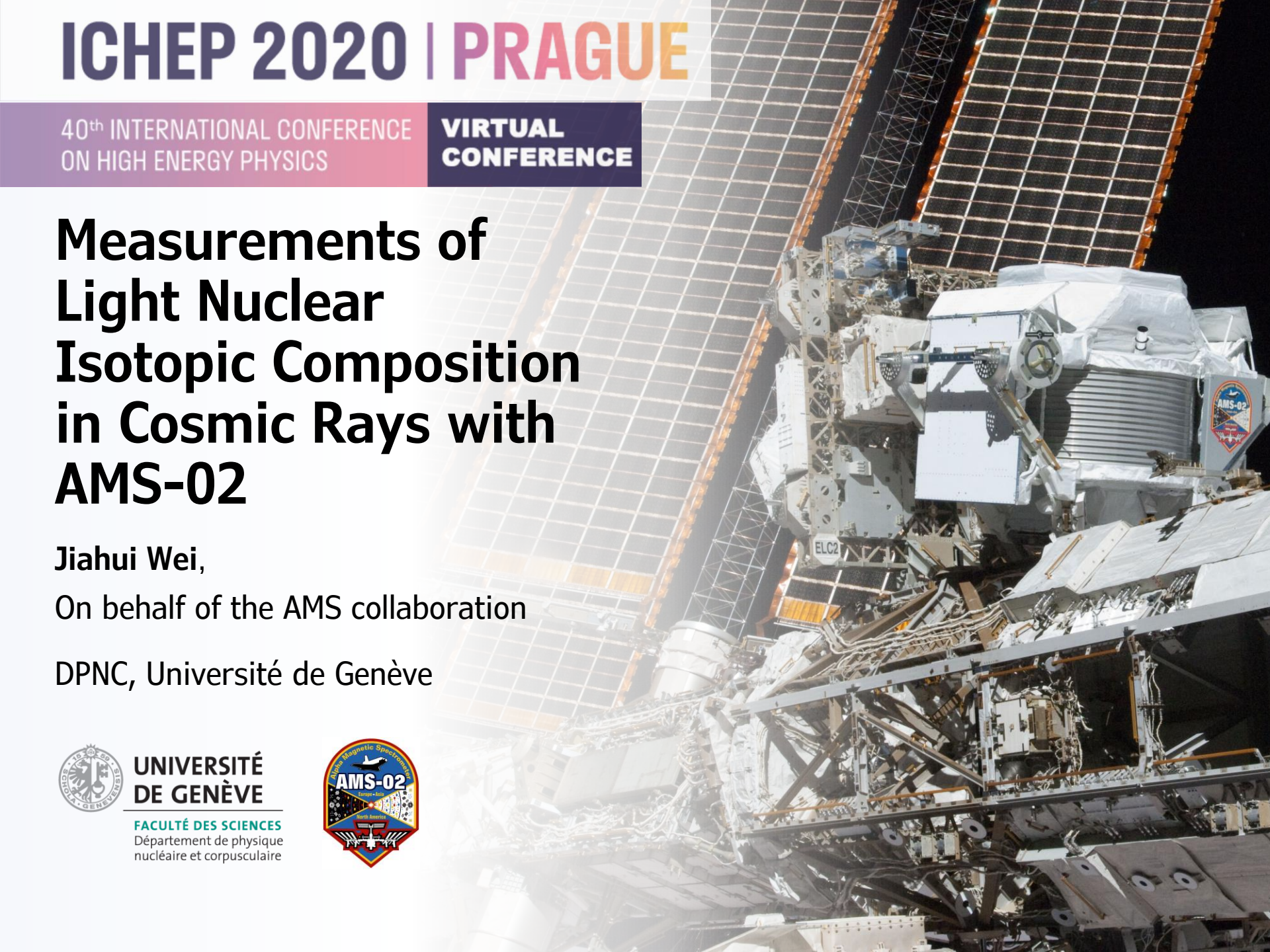


Light isotopes in cosmic rays

- Precision measurements of primary and secondary nuclei fluxes by AMS

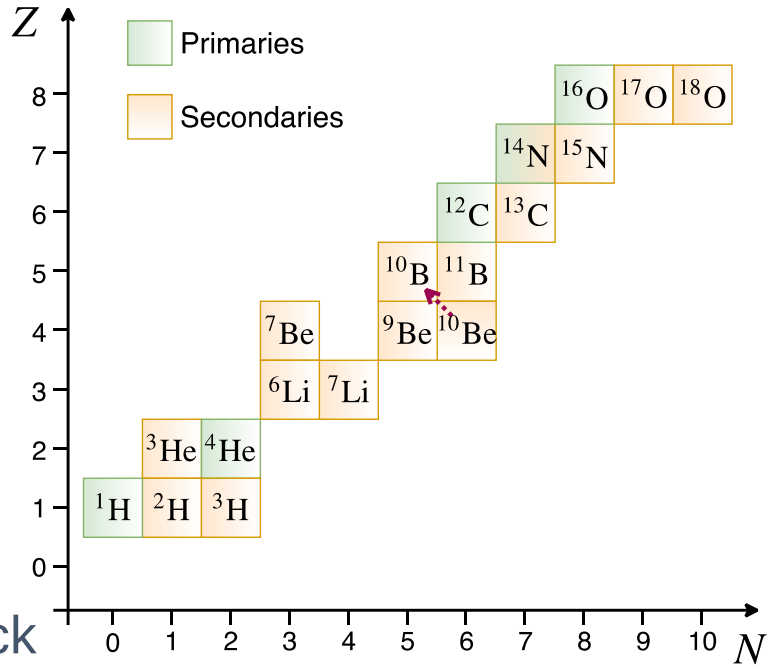
See M. Paniccia Talk (28/07)

→ Important information to understand the origin and the propagation of Cosmic Rays

- Additional information from Isotopic composition:
  - Different origins (secondary/primary):
    - ^{3}He/^{4}He, D/*p*

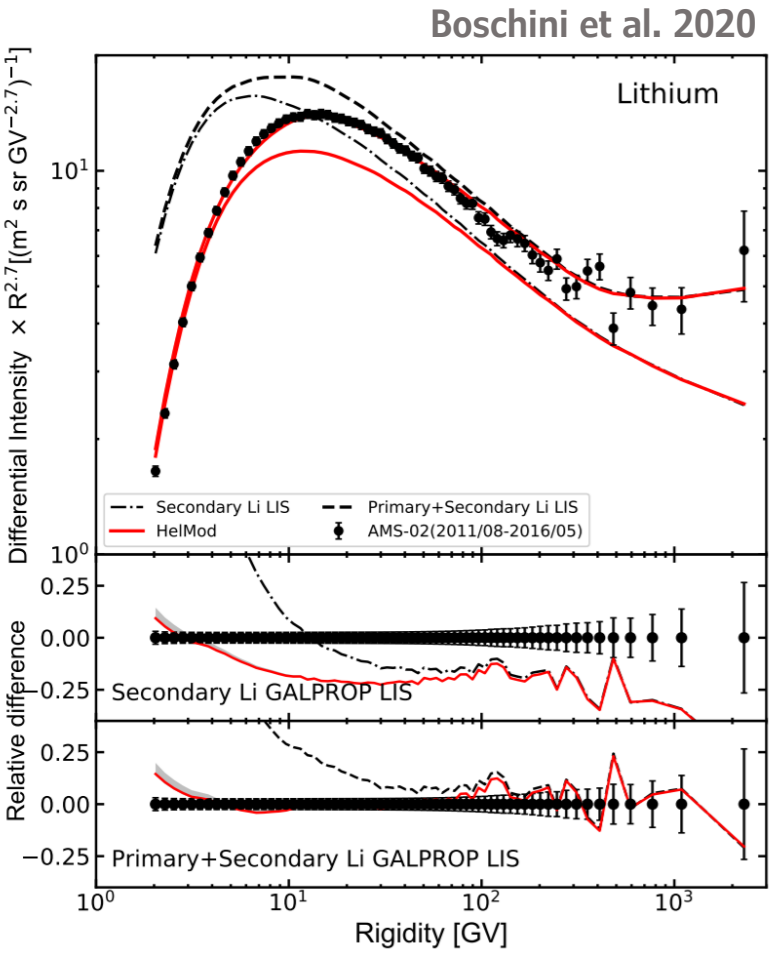
      See F. Giovacchini and F. Dimiccoli Talks (30/07)
  - Different propagation history
    - ^{10}Be: $t_{1/2}$ = 1.4 My: radioactive clock
  - ^{6}Li/^{7}Li mainly determined by the secondary production cross sections from C, O fragmentation, but may also be used to test the presence of primary lithium in Cosmic Rays.
- This presentation focuses on Lithium and Beryllium isotopes
  - Develop isotopic composition measurements with AMS.

Isotopes in light cosmic rays:



Light isotopes in cosmic rays: Lithium

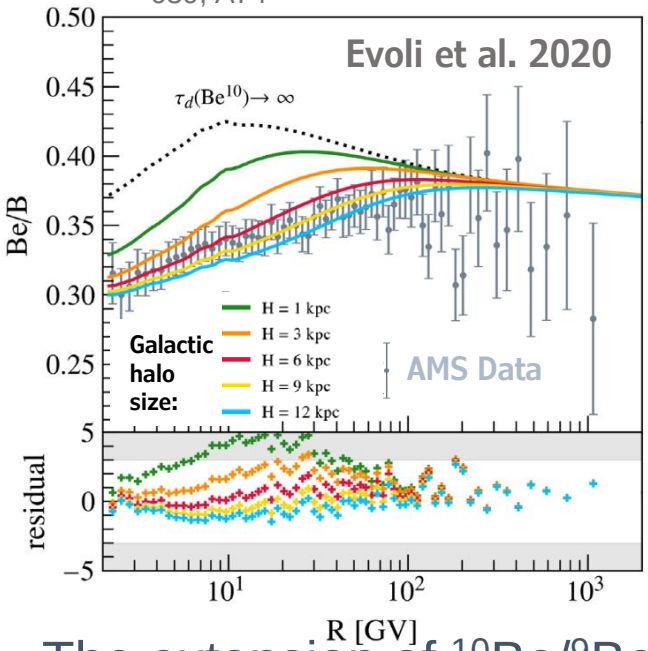
- Two recent CR propagation studies which attempt to perform a global fit of LiBeB AMS data:
  1. N. Weinrich, Y. Génolini, M. Boudaud, L. Derome, D. Maurin, 2020, A&A accepted
  2. M. J. Boschini, S. D. Torre, M. Gervasi, et al. 2020, ApJ, 889, 167
- Both studies found some tension with lithium flux larger in data than expected from the model.
- In **Weinrich et al.:** interpreted as an uncertainty in the Lithium production cross-section (+~15%).
- In **Boschini et al.:** interpreted as a contribution from primary lithium produced in low-mass stars and super-novae via the decay of ^{7}Be produced by alpha capture reaction ^{3}He(α, γ)^{7}Be.

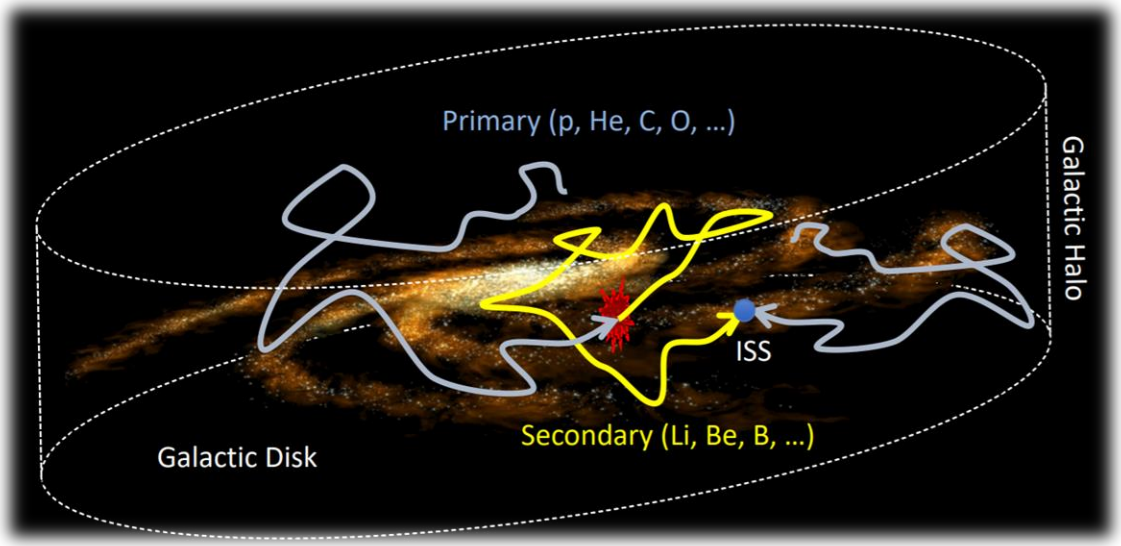


→ Lithium isotopic composition may help to investigate this tension as primary lithium is expected to be ^{7}Li

Light isotopes in cosmic rays: Beryllium

- The approach to study CR propagation using $^{10}Be \rightarrow ^{10}B$ is illustrated in the recent studies of
  - Evoli, C., Morlino, G., Blasi, P., & Aloisio, R. , 2020, PRD, 101(2), 023013.
  - N. Weinrich, M. Boudaud, L. Derome, Y. Génolini, J. Lavalle, D. Maurin, P. Salati, P. Serpico, G. Weymann-Despres, 2020, A&A 639, A74

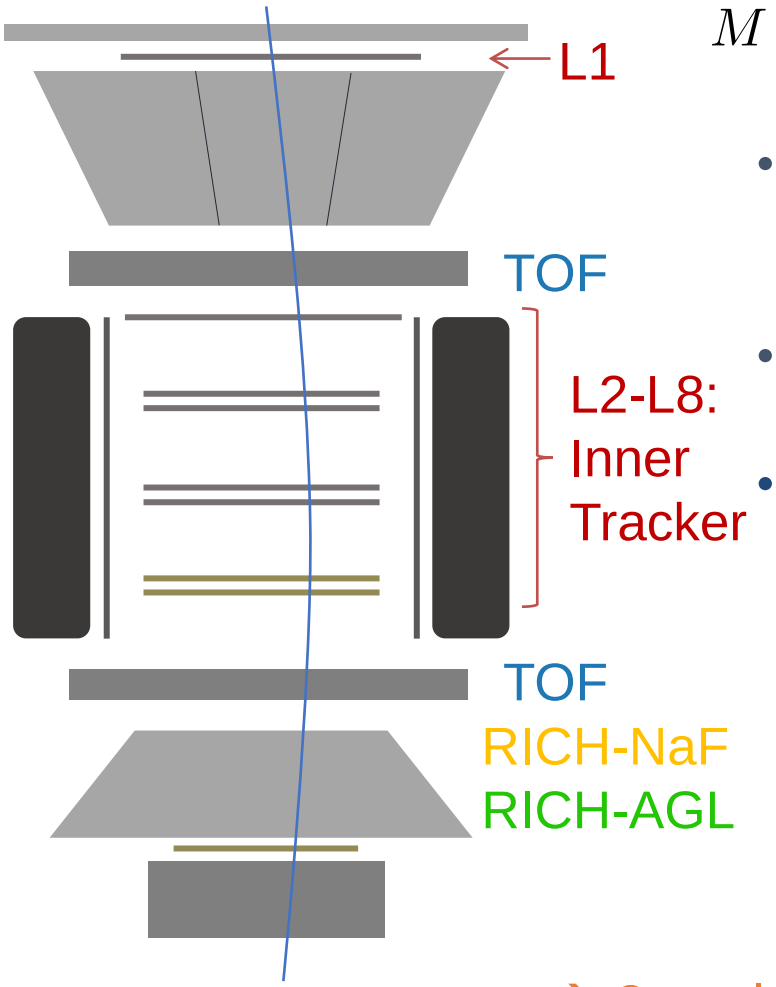




The extension of $^{10}Be/^{9}Be$ ratio measurement to higher energy with improved accuracy, will help to discriminate between propagation models and further constrain parameters in the models with better understanding of the lifetime of CRs (residence time) in the Galaxy.

→ AMS is able to extend the measurement of $^{10}Be/^{9}Be$ to 20 GV.

Measurement of isotopic composition with AMS-02



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

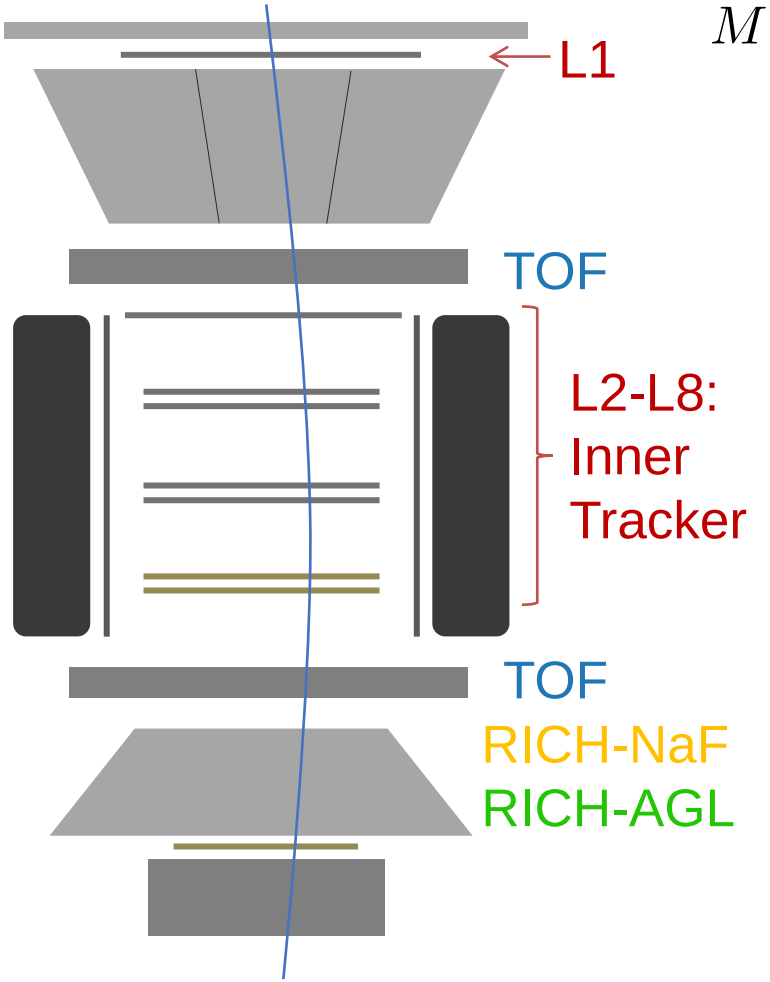
- *Z* measurement :
  - L1 - UTOF - Inner Tracker - LTOF

  → Negligible charge confusion
- *R* measurement :
  - Tracker (Inner)
- β measurements:

	β range	$\Delta\beta/\beta$ (Z=3, 4)
TOF (4 layers)	(0.65, 0.9)	~ 2%
RICH-NaF (n=1.33)	(0.85, 0.98)	~ 0.15%
RICH-AGL (n=1.05)	(0.97, 0.997)	~ 0.05%

→ 3 analyses which cover different energy ranges

Measurement of isotopic composition with AMS-02



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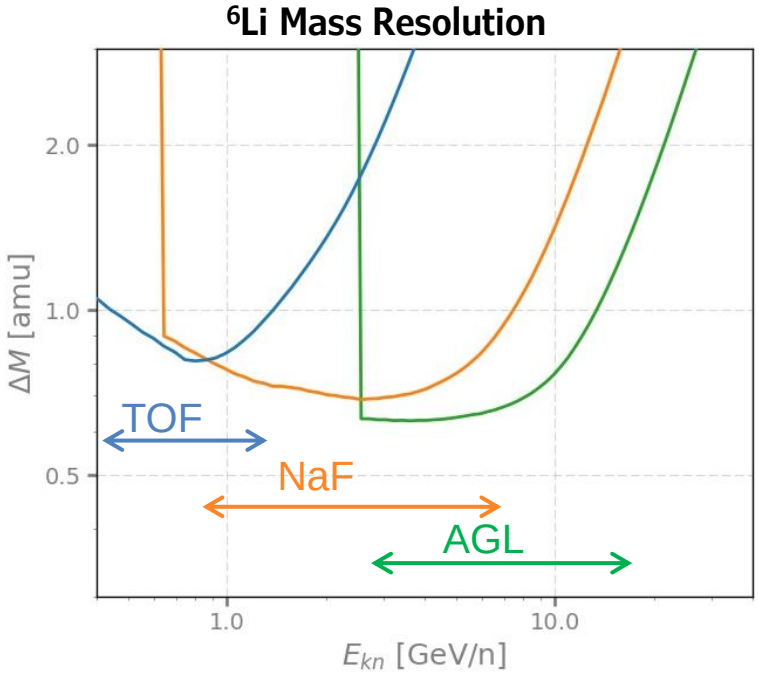
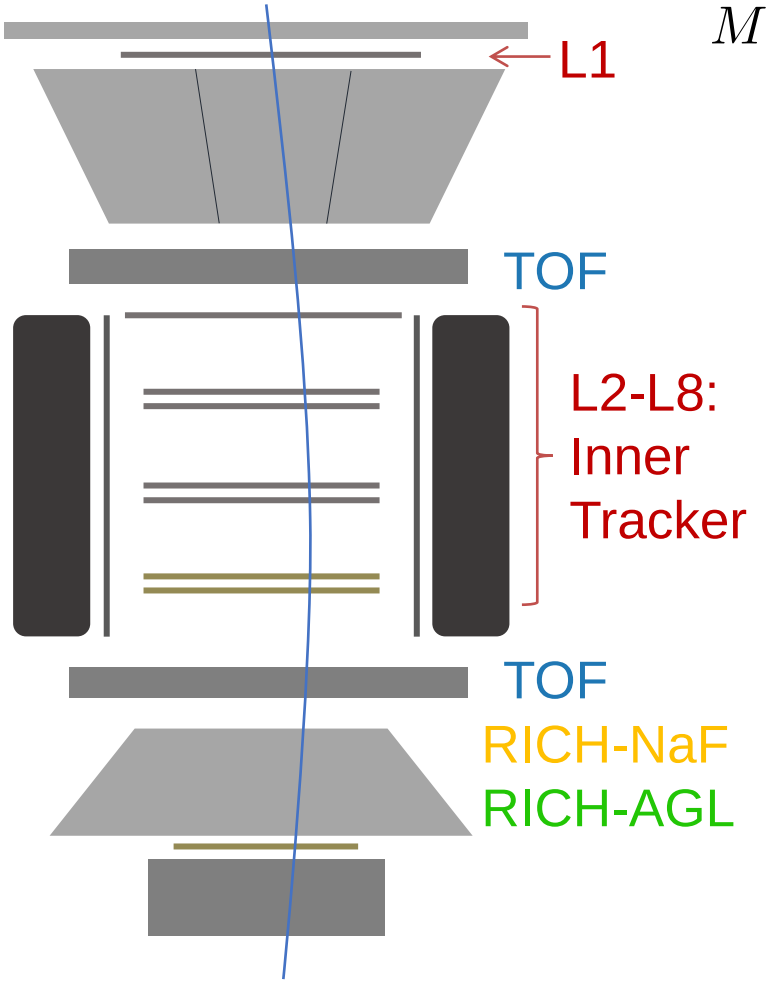


$\Delta M \sim 1$ amu→ Event by Event isotopic identification not reachable.

→ Isotopic abundances from the shape of the mass distribution.

Measurement of isotopic composition with AMS-02



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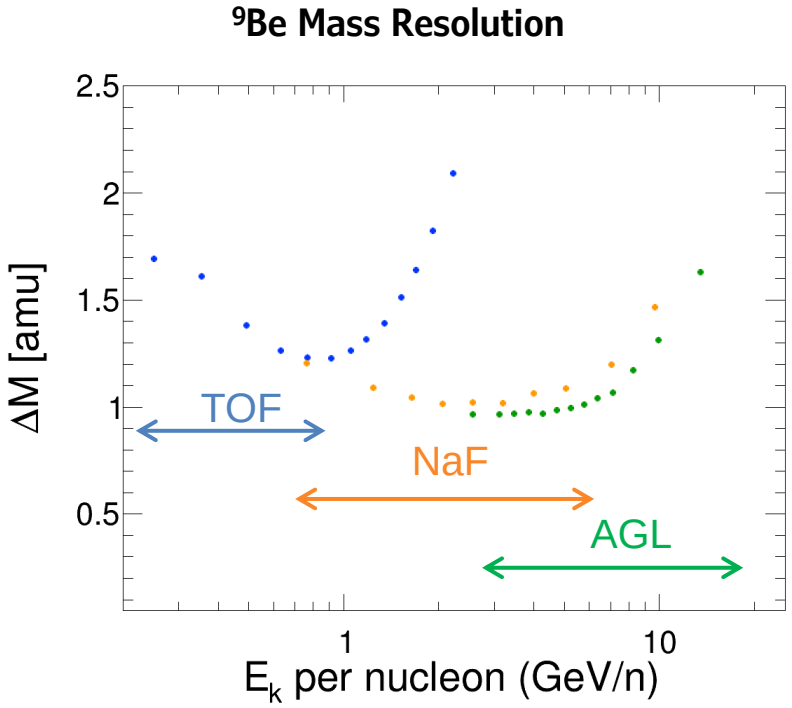
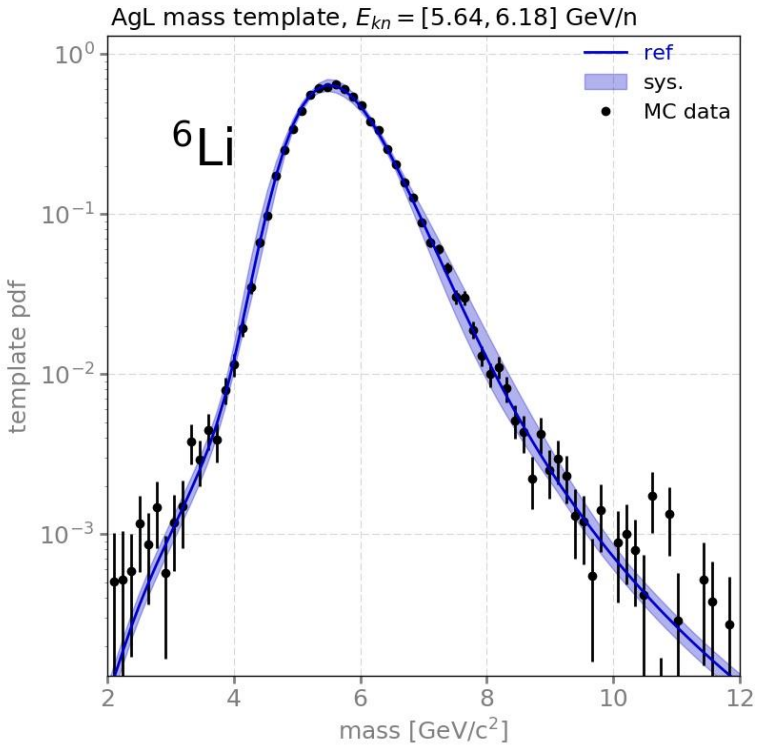
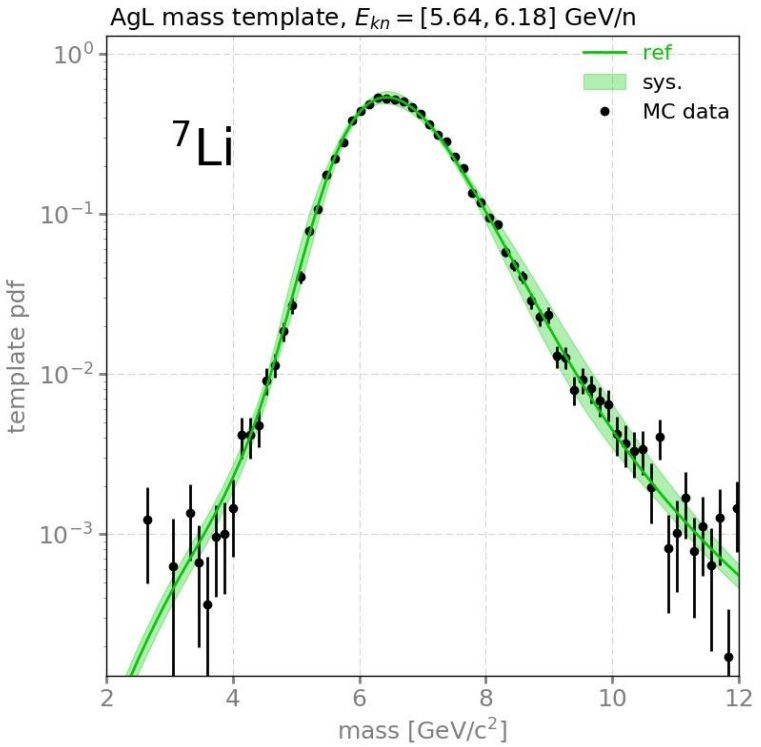


Mass templates



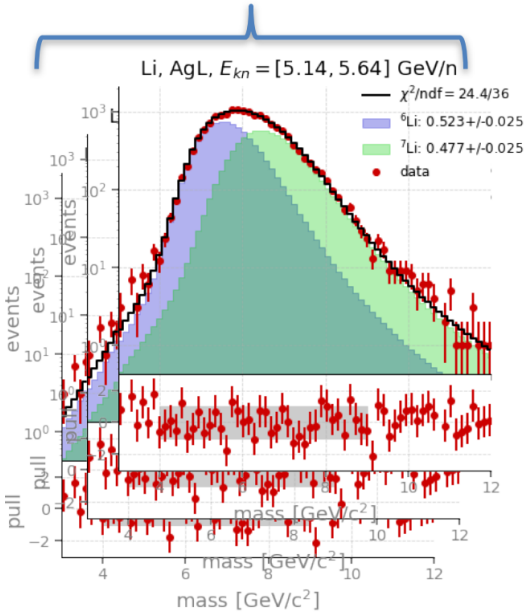


- Mass templates reconstructed from the β resolution and R resolution models obtained from MC simulation.
- Systematic in the mass template shapes are implemented by varying the β resolution and R resolution models with nuisance parameters (shift, width and tails).
- 1 template for each isotope, each energy bin, each analysis.

Isotopic abundances: global fit

- One global χ^2 minimization with bin-to-bin correlation introduced for nuisance parameters:

$$\chi^2 = \sum_{E_{kn}\text{bins } i}^{n} \sum_{\text{mass bin } k} \frac{(\text{data}^i(k) - \sum_{A=6,7} C_A^i \times \text{template}_A^i(k; \nu_1^i, \cdots, \nu_m^i))^2}{\text{data}^i(k)} + \sum_{\text{nui. par. } l} (\hat{\nu}_l)^T \text{Cov}_l^{-1} \hat{\nu}_l$$

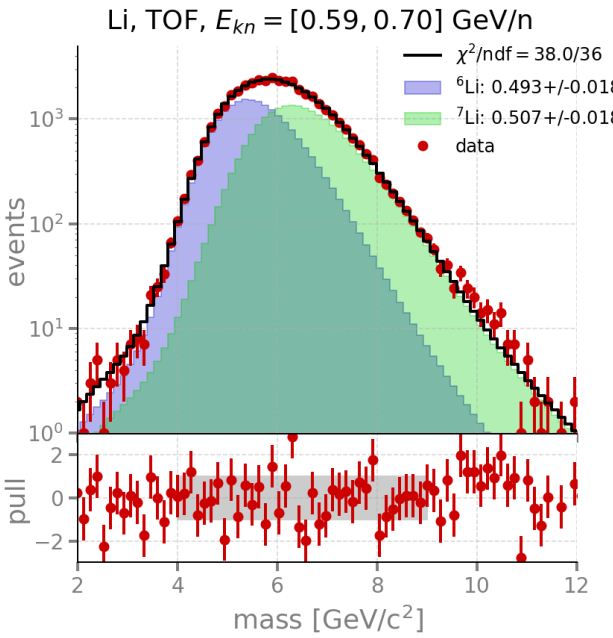


- C_A^i : Abundance of isotope A for E_{kn} bin i
- ν_l^i: Nuisance parameter l for E_{kn} bin i (centered and scaled such that values ± 1 corresponds to the nominal uncertainty). Nuisance parameters describe the uncertainty on the shape of β and R resolution functions. The covariance matrix is chosen to take correlation between bins into account .

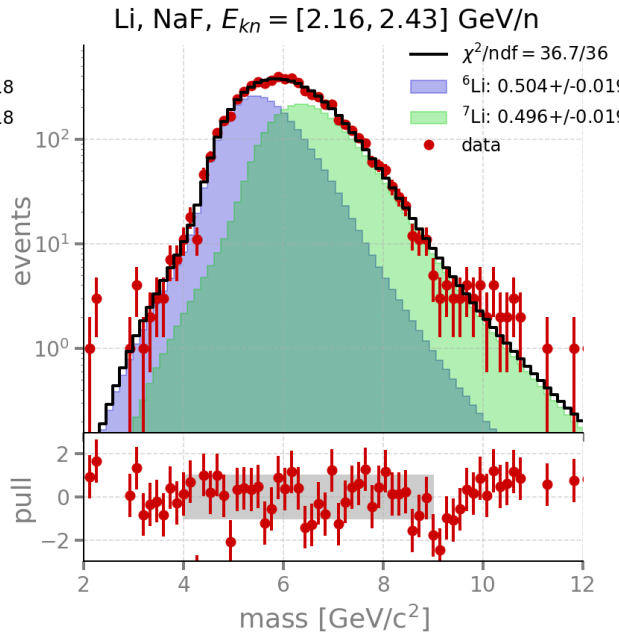
^{6}Li/^{7}Li abundances

^{6}Li and ^{7}Li abundances fitted on the mass distribution for Z=3 data:

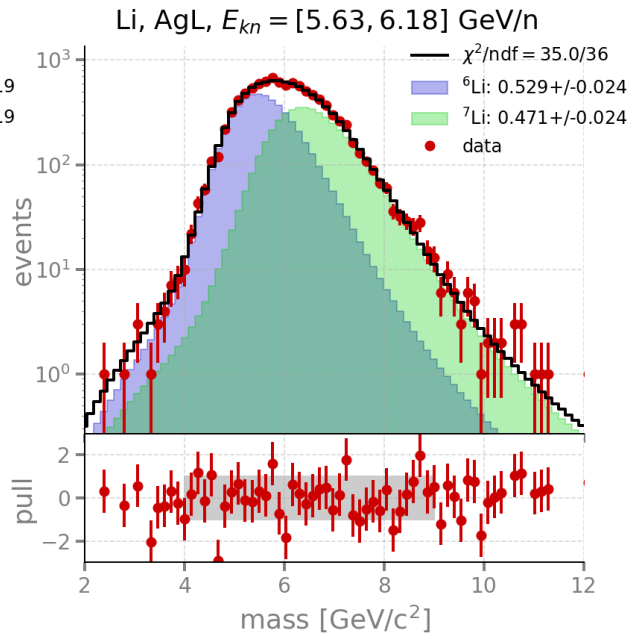
TOF



NaF



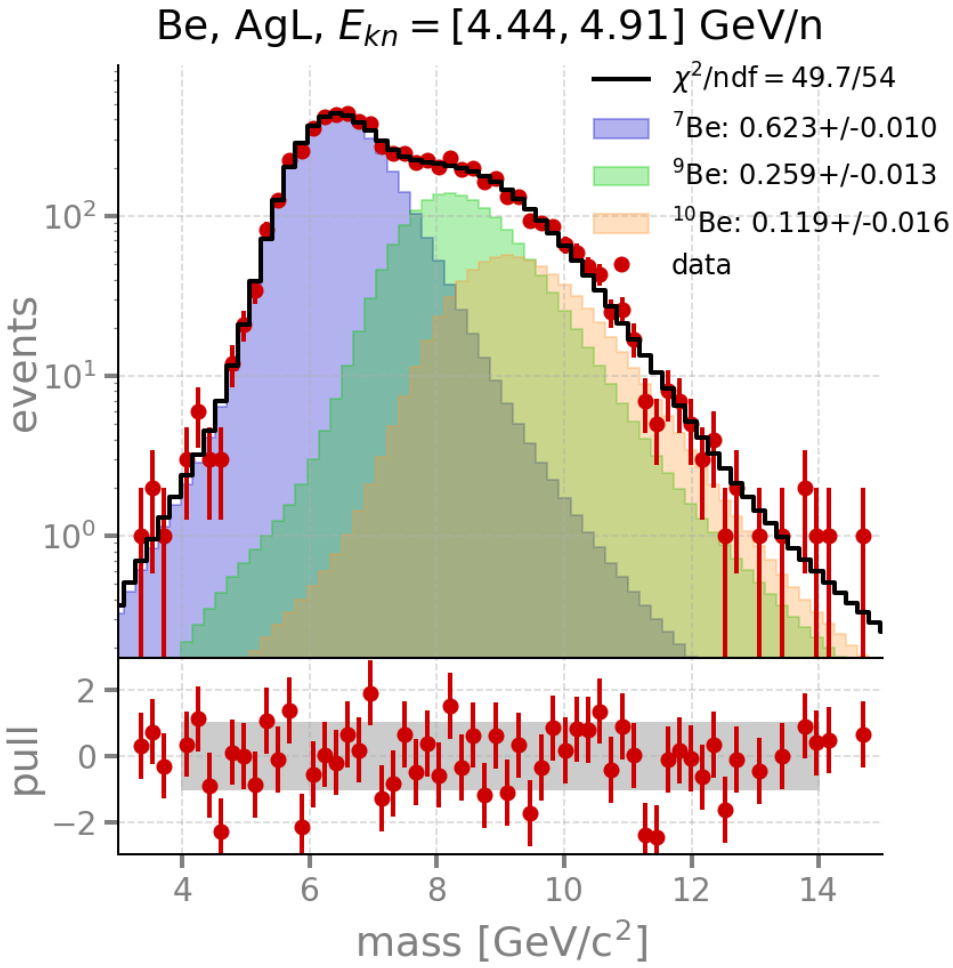
AGL



Errors on abundances include statistical error and systematic error from the mass template shapes.

Beryllium abundances

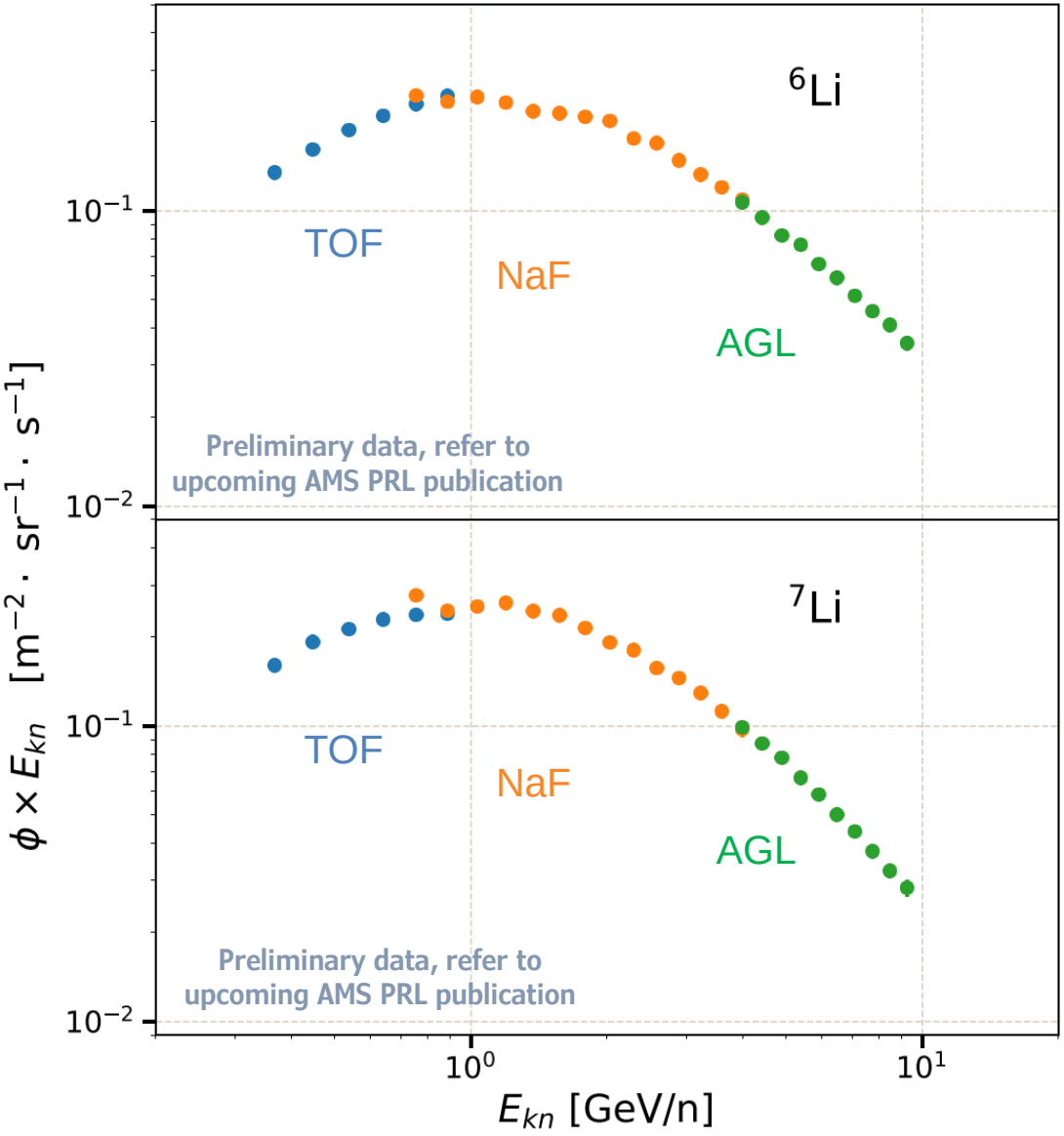
- Same method is developed to study Beryllium isotopic composition.
- Fit of ^{7}Be, ^{9}Be, ^{10}Be abundances:



Flux reconstruction

Isotopic fluxes:

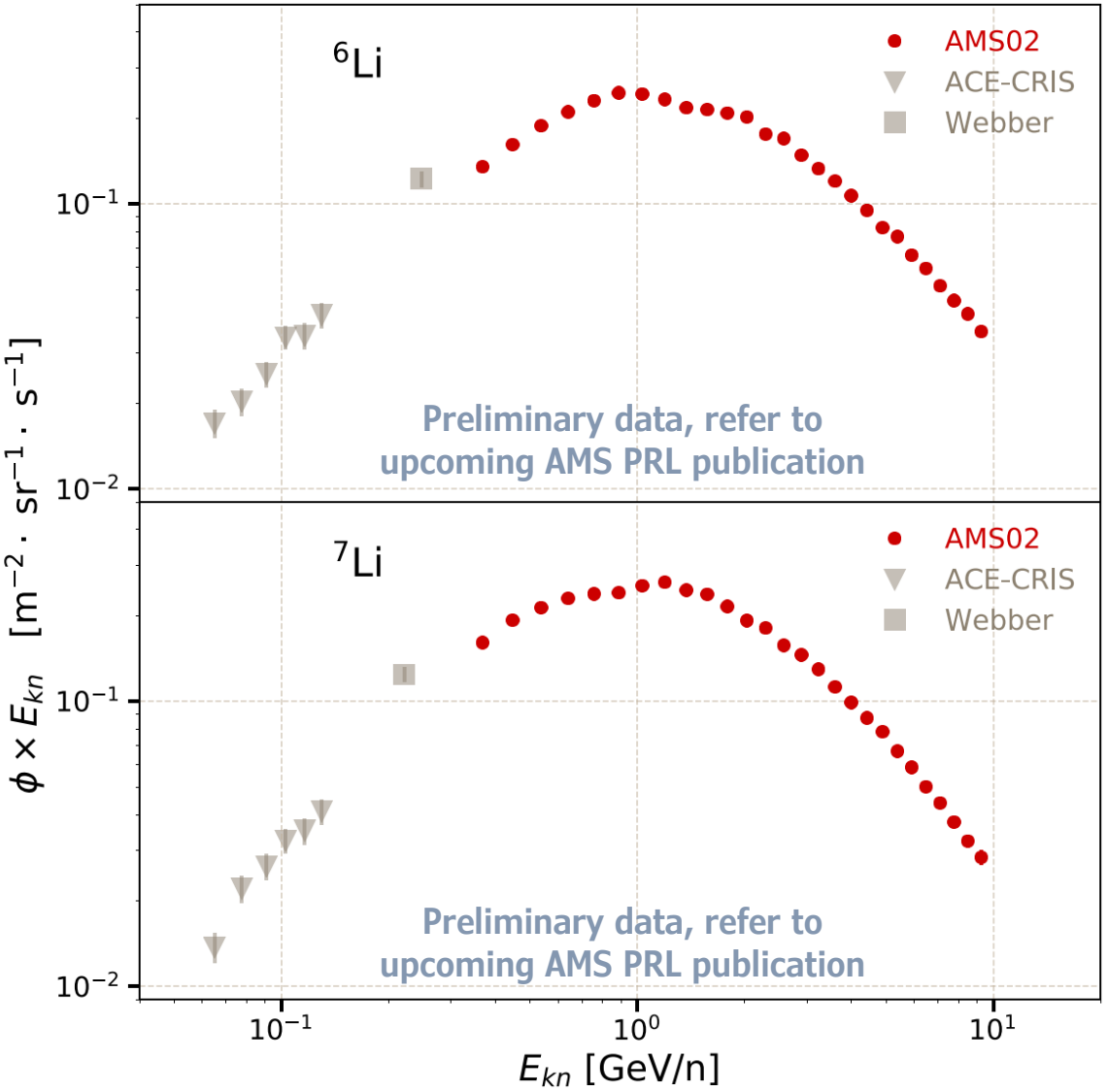
- computed from abundances, effective acceptances and exposure time.
- Corrected for contamination from fragmentation of heavier nuclei.
- Unfolded to correct energy migration due to finite β resolution.



^{6}Li and ^{7}Li fluxes vs kinetic energy per nucleon

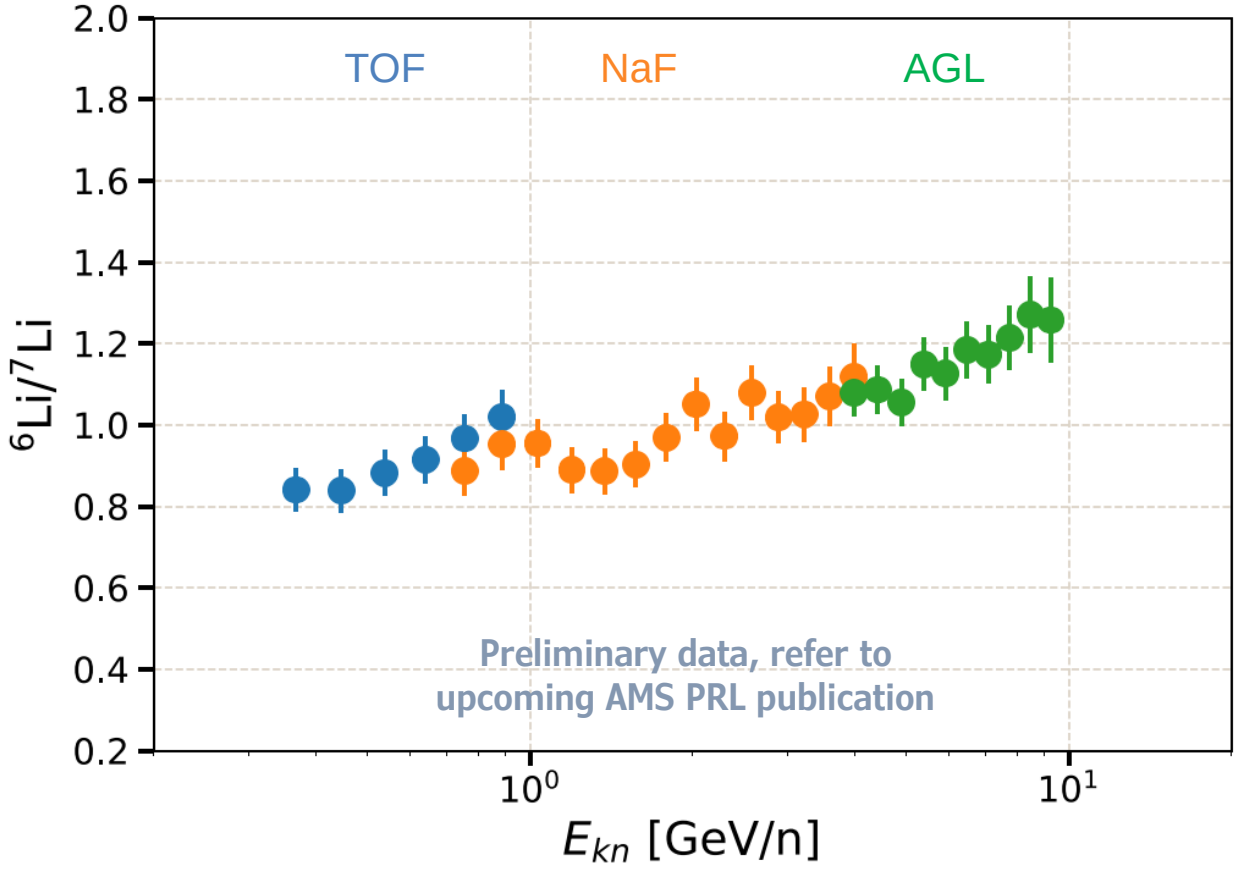
Comparison with previous experiments:

→ First measurement of ^{6}Li and ^{7}Li fluxes above 0.3 GeV/n.



$^6Li/^7Li$ ratio vs kinetic energy per nucleon

- Isotopic ratio computed from the fit (obtained from the fluxes):



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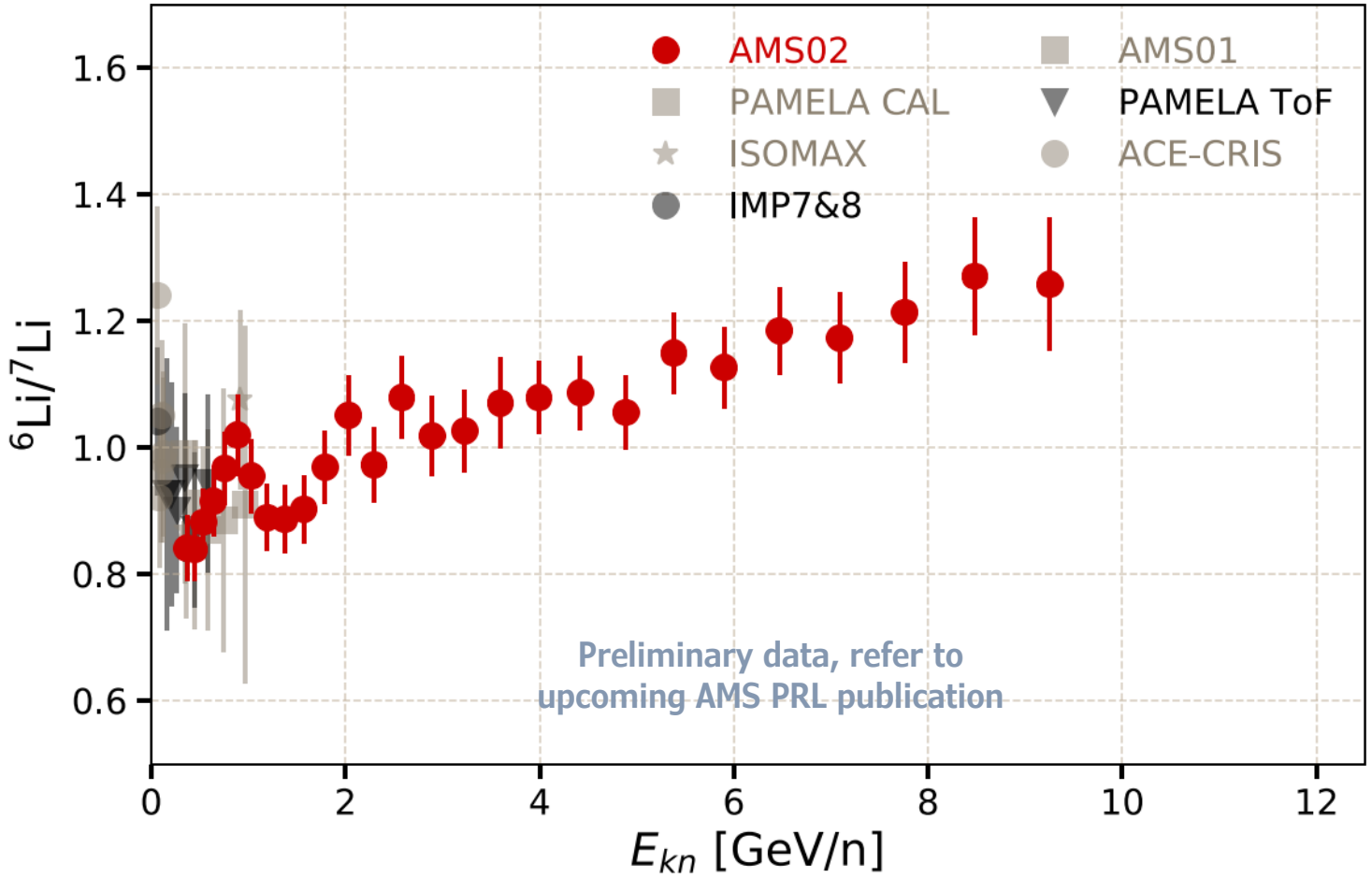
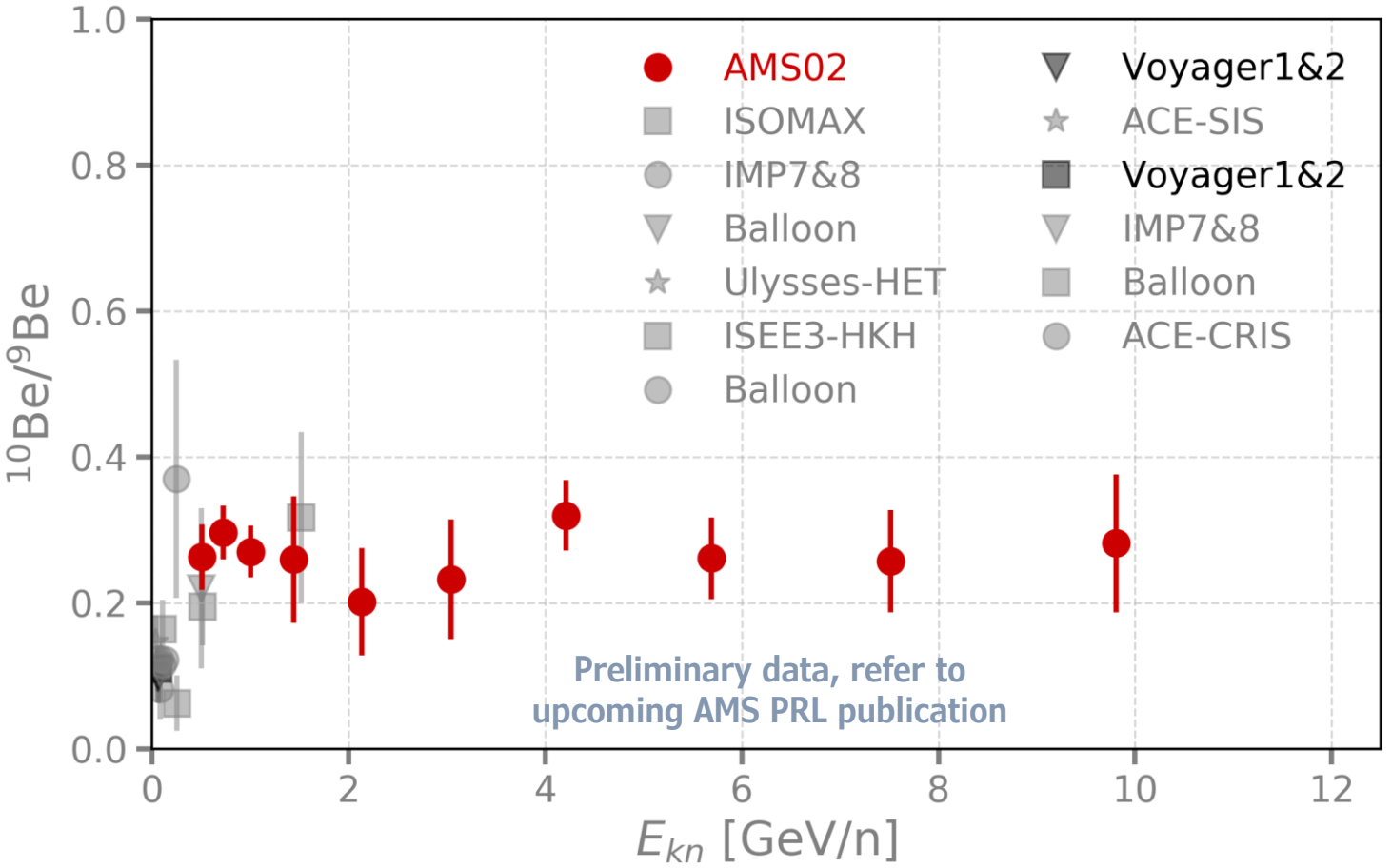


→ Extends $^6Li/^7Li$ ratio measurement above 1 GeV/n up to 10 GeV/n

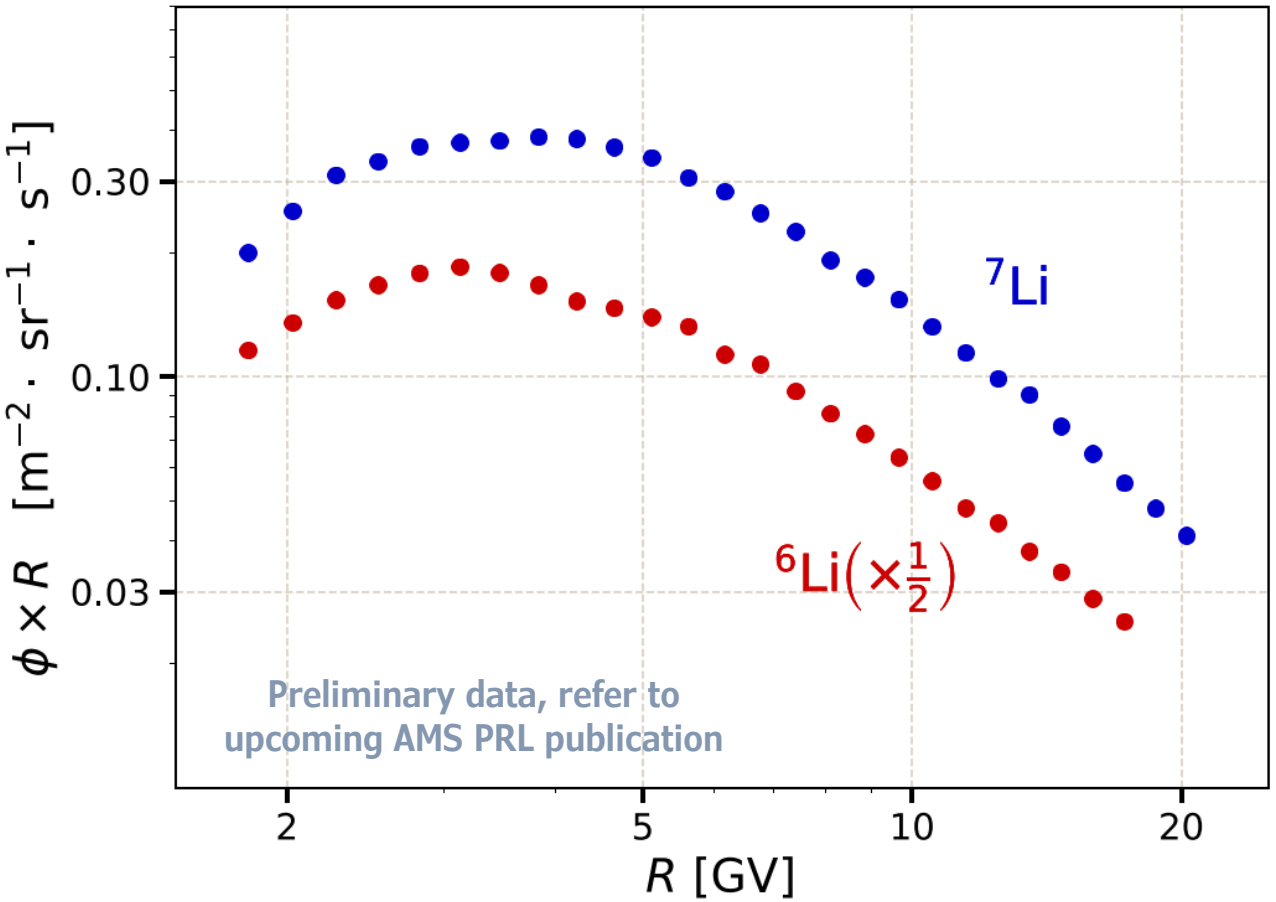
$^{10}Be/^{9}Be$ ratio vs kinetic energy per nucleon

Comparison with previous experiments:



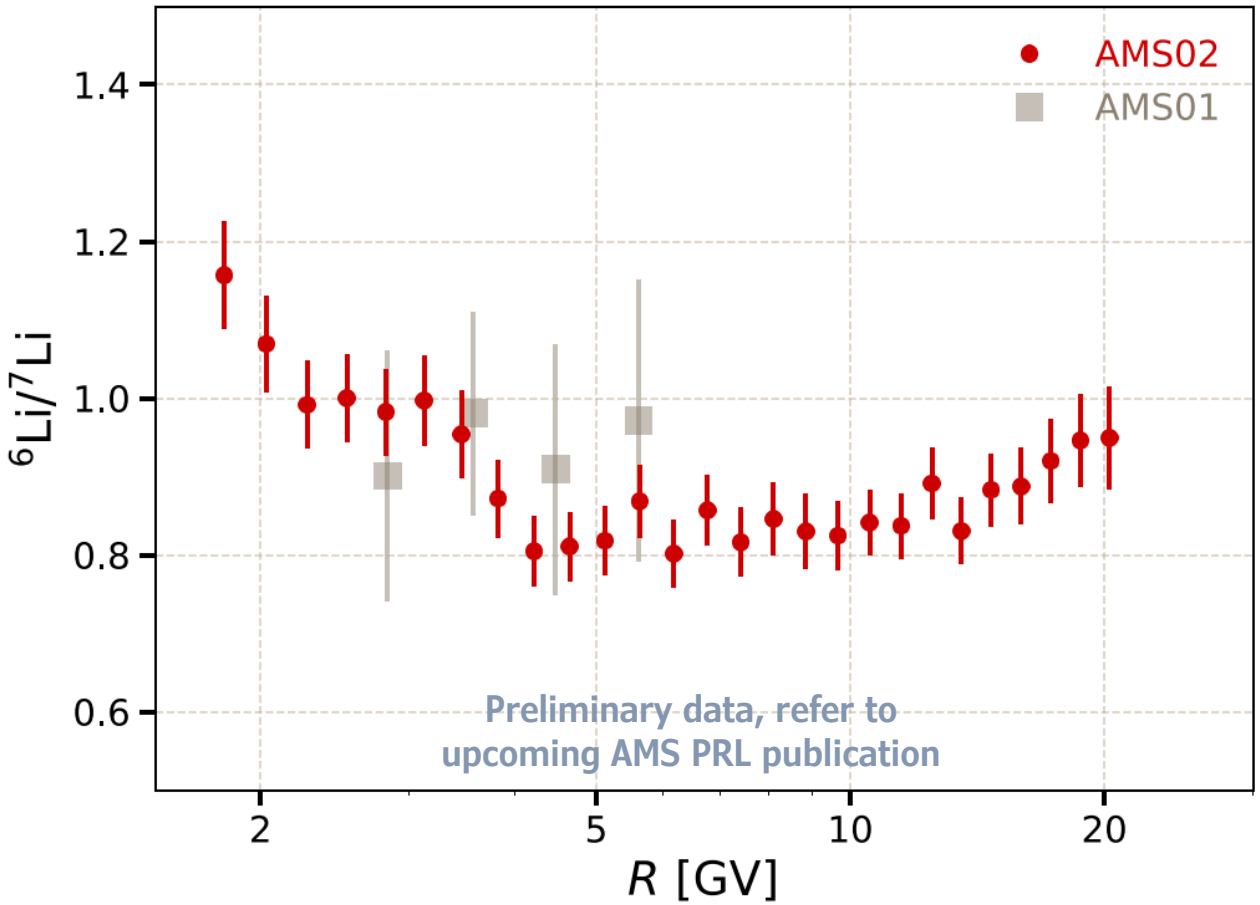
→ Extends $^{10}Be/^{9}Be$ ratio measurement above 1 GeV/n up to 10 GeV/n

^{6}Li and ^{7}Li fluxes vs rigidity



- Use of different binning vs $E_{k/n}$ for ^{6}Li and ^{7}Li to get the same rigidity bins
- Full isotopic analysis done for the two binning
- $E_{k/n}$ → R conversion for each Isotope.

^{6}Li/^{7}Li flux ratio vs rigidity



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- Full isotopic analysis done for the two binning
- $E_{k/n}$ → R conversion for each Isotope.

Conclusion

- Isotopic composition of light nuclei in cosmic rays is a key measurement to understand cosmic-ray origin and propagation.
- Dedicated method based on template fit of the mass distributions have been presented.
- The following preliminary AMS results have been presented:
  - First measurement of ^{6}Li and ^{7}Li fluxes vs E_{kn} above 0.3 GeV/n and vs rigidity from 2 to 20 GV.
  - First measurement of ^{6}Li/^{7}Li and ^{10}Be/^{9}Be ratio above 1 GeV/n.
- The analysis will be extended to measure the B isotopic composition.