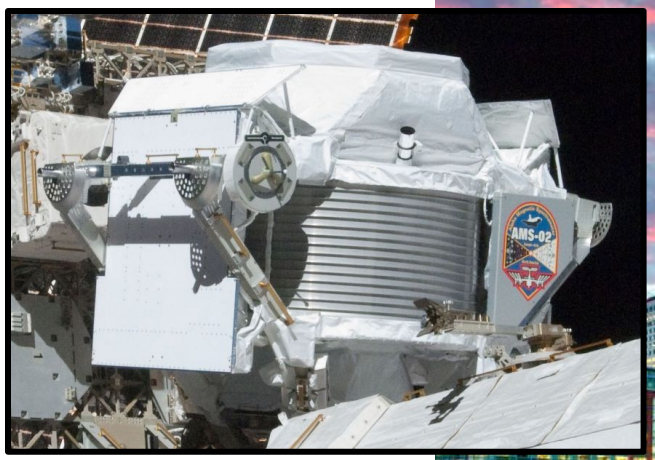
# Cosmic ray isotopes measured by AMS-02



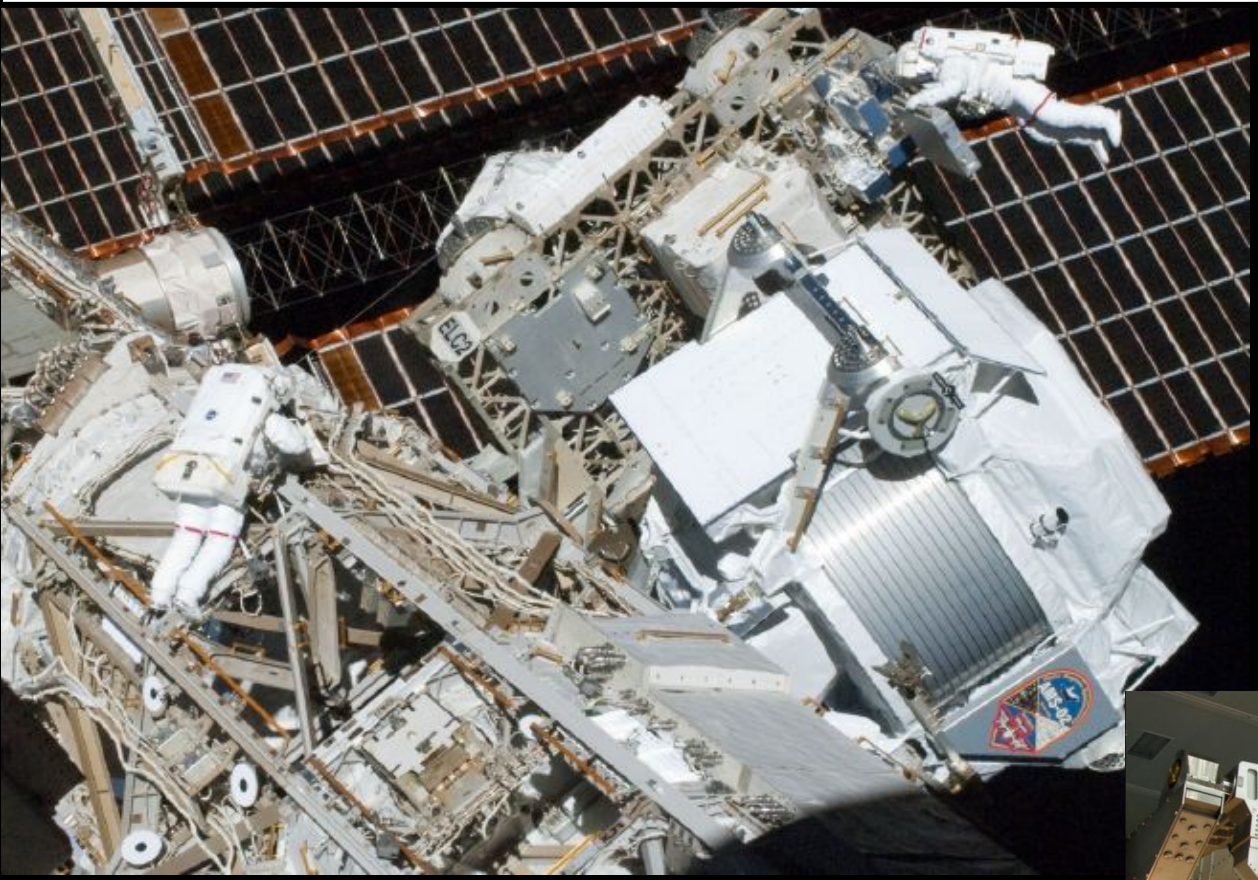

**2019 Meeting of the division of Particles & Fields of the APS**

July 29 - Aug 2, 2019
Boston, USA

**Francesco Dimiccoli**
**on behalf of the AMS-02 collaboration**

TIFPA - Trento Institute for Fundamental Physics and Applications

# AMS: a unique TeV precision, accelerator-type spectrometer in space

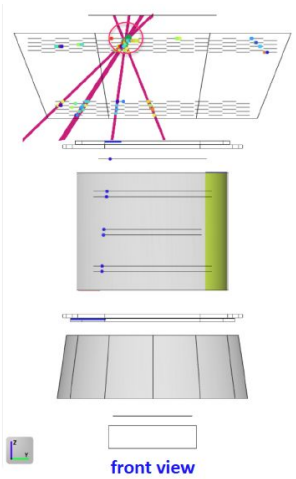


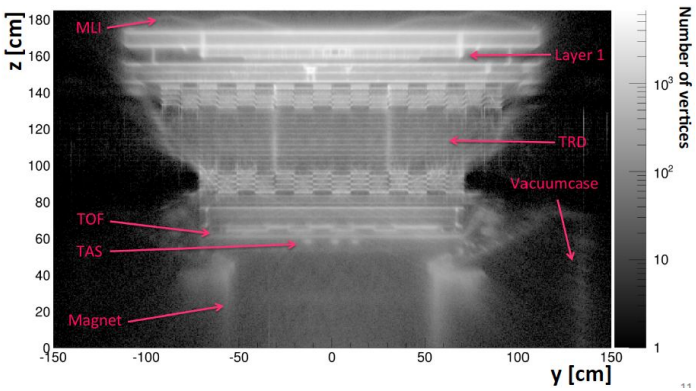
AMS was installed on ISS
in May 2011
it will continue
through the lifetime of ISS

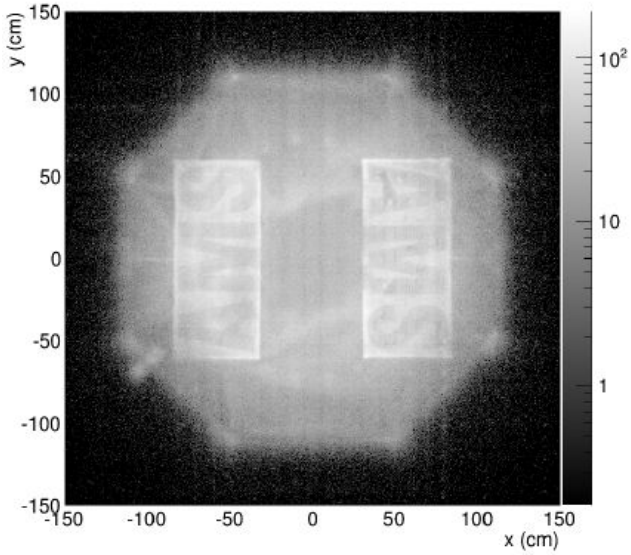

**To date, it collected more than 140 billions of charged particles: $e^+$, $e^-$, p, pbar, nuclei...**

# AMS Physics Goals

- **Searches for primordial antimatter:**
  - Anti-nuclei: AntiHe, ...
- **Dark Matter searches:**
  - e+ , AntiD , …
- **Measuring CR spectra – refining propagation models;**
  - Nuclei spectra from p, He -> Fe
- **Study effects of solar modulation on CR spectra over 11 year solar cycle**
- **...**

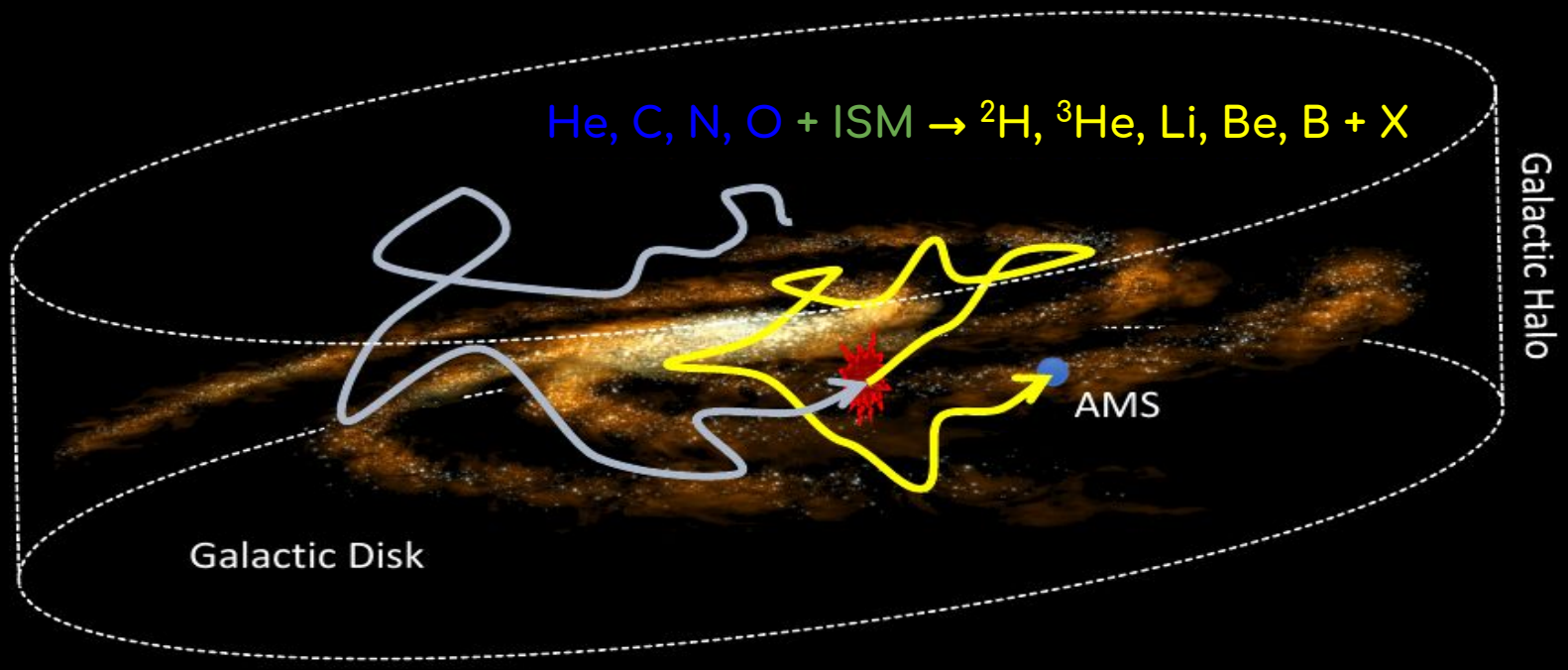


# Secondary nuclei in Cosmic Rays (CR)

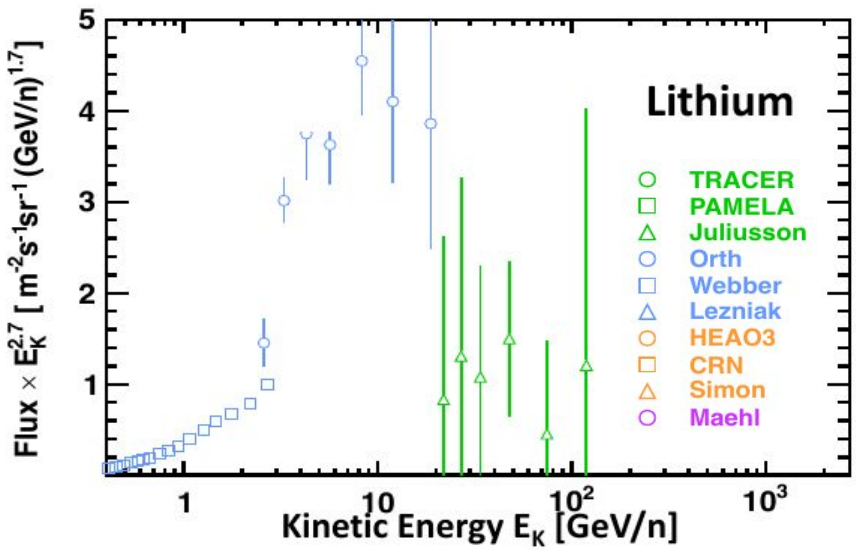
**Secondary CR** are produced from collisions of **primary CR** with the **interstellar medium (ISM)**

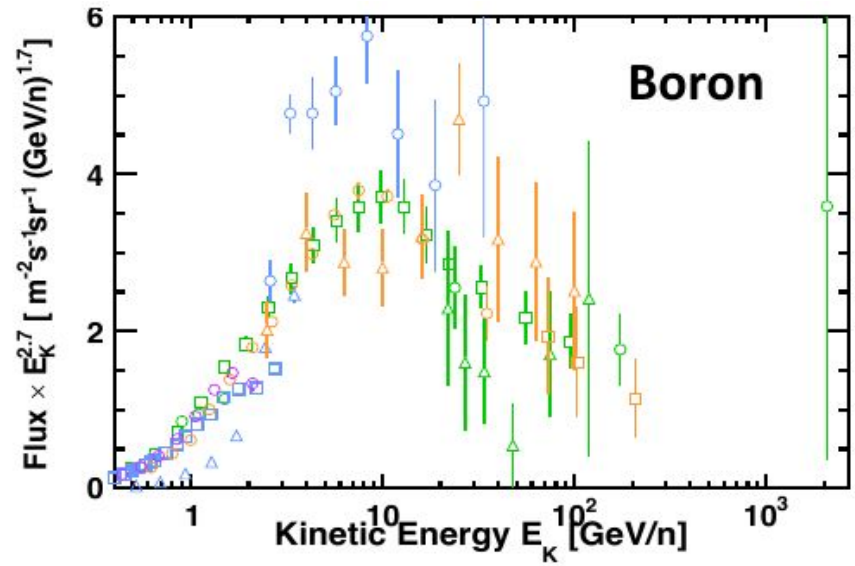


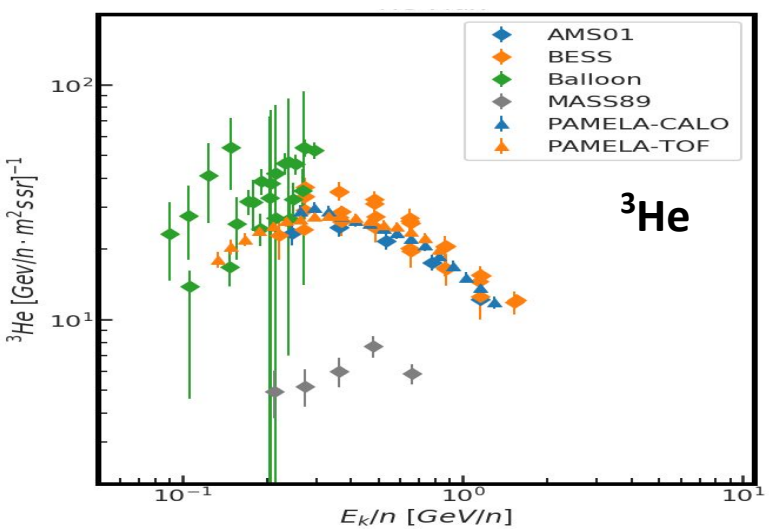

**The fluxes of the secondary species are very important for the understanding of the origin and propagation of cosmic rays**

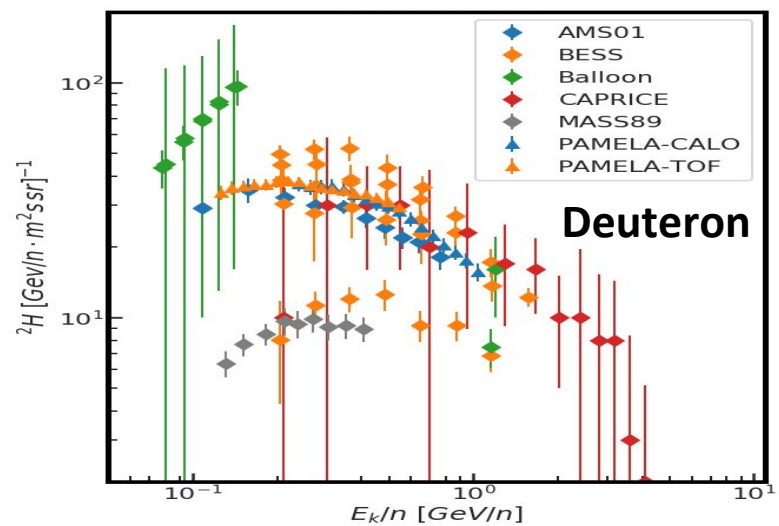
- They carry information on the history of the travel and **properties of ISM**
- Most abundant species: **Li, Be, B and light isotopes ($^{3}$He, $^{6}$Li and D)**

# Secondary CR Flux before AMS



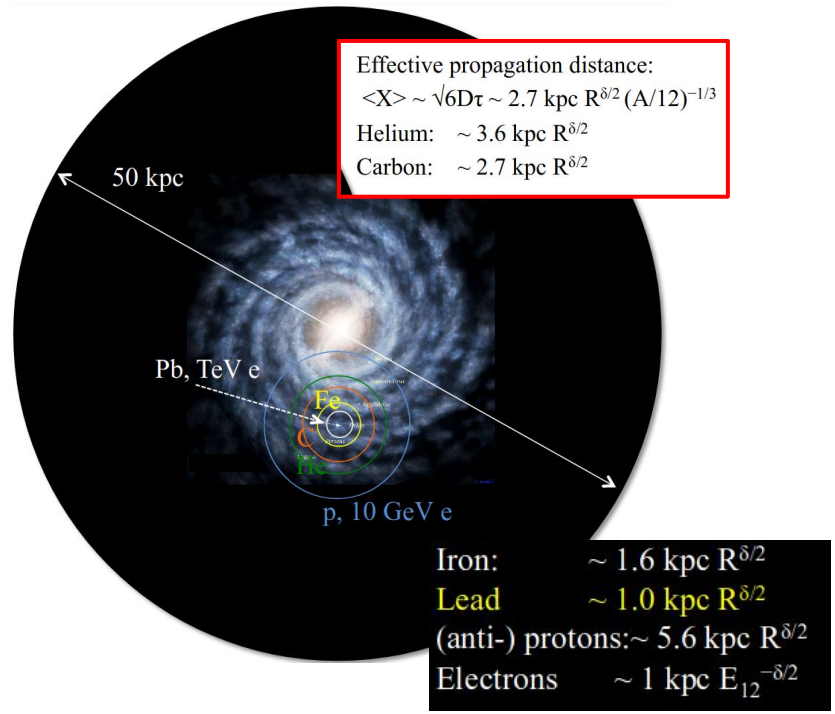



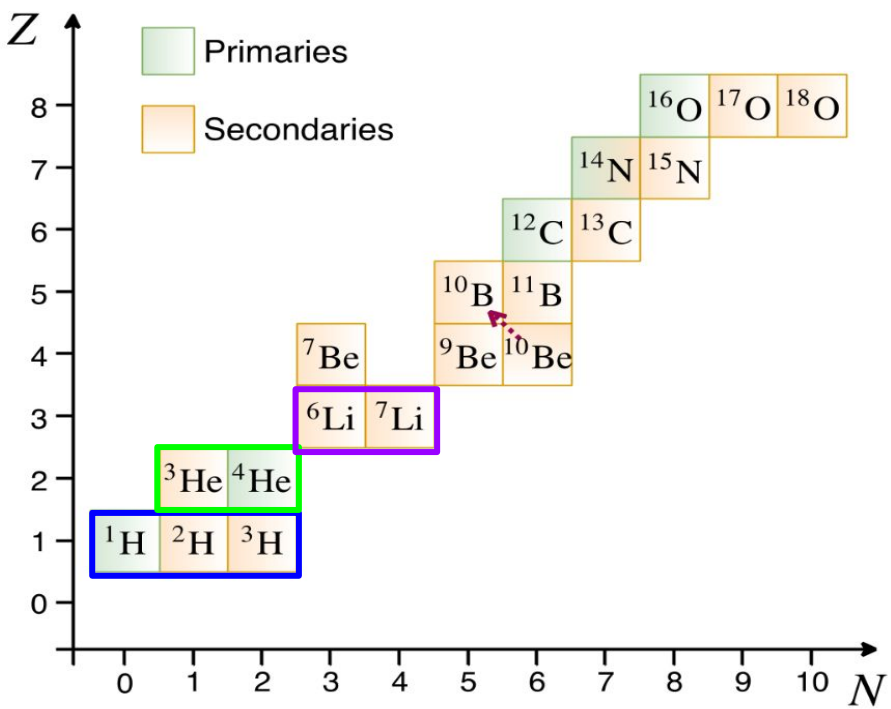



# Light isotopes in cosmic rays

- B/C probes mostly “local” propagation
- p,D and p-bar come from much further
- light secondary like D, 3He and Li constrain better the p-bar secondary prod.



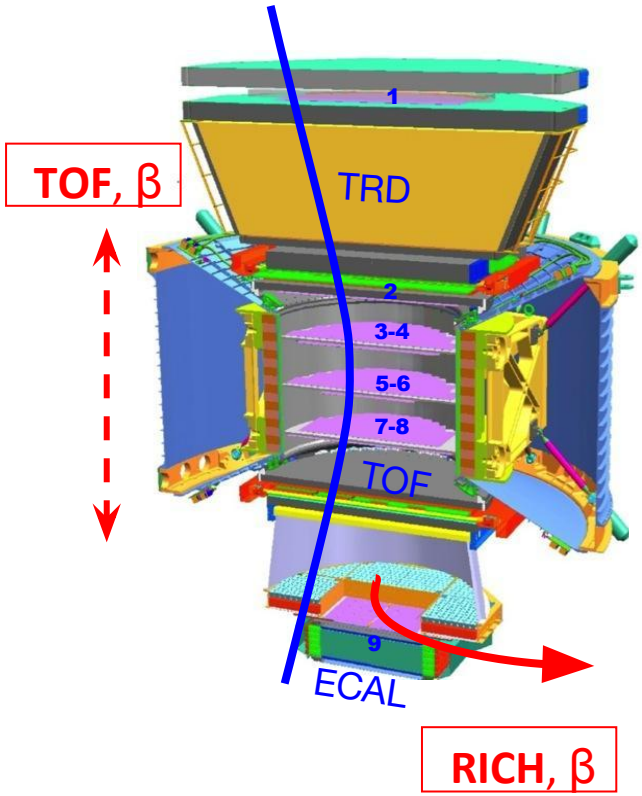




- $^6$Li/$^7$Li: Both from C,N,O fragmentation
- $^3$He/$^4$He: sec/primary
- D/p: sec/primary, D-bar searches

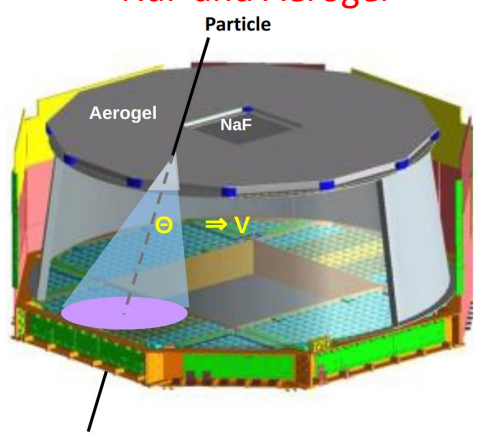
# AMS: Identification of isotopes

**Isotopes:** Identified from the concurrent measurement of **Rigidity (p/Z)** and **Velocity**

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



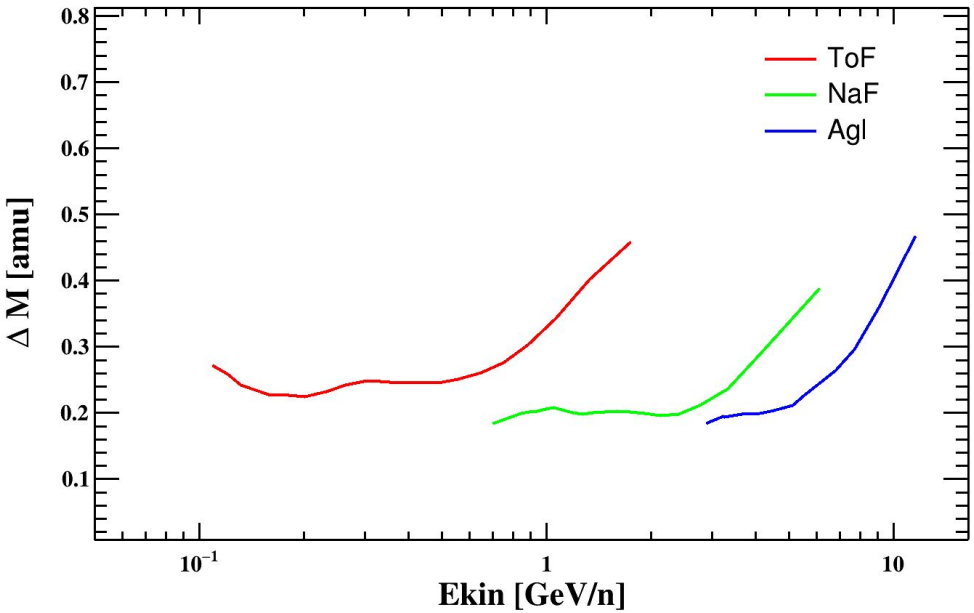

**RICH radiators:**
NaF and Aerogel



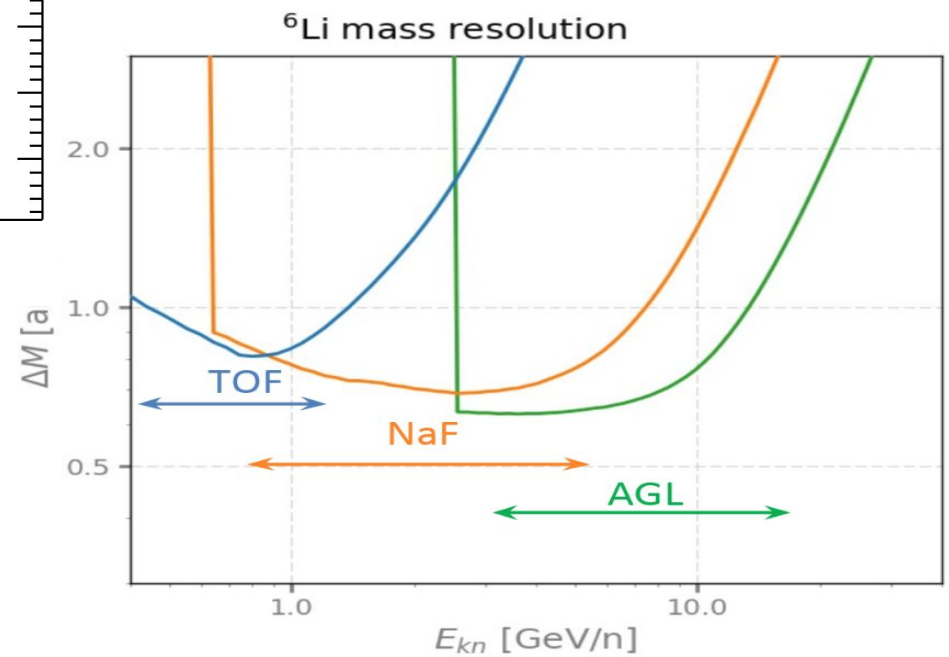

- **Z measurement:**
  L1->UTof->(L1-L8)Tracker->LTof:
  negligible charge confusion
- **R measurement:**
  (L1-L8) Tracker
- **Velocity measurement:**
  - ToF: 4 Layers, Δβ/β~1-2%
  - RICH NaF: Δβ/β~0.3%, β>0.75
  - RICH AgI: Δβ/β~0.1%, β>0.95

# AMS: Identification of isotopes

D mass resolution




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

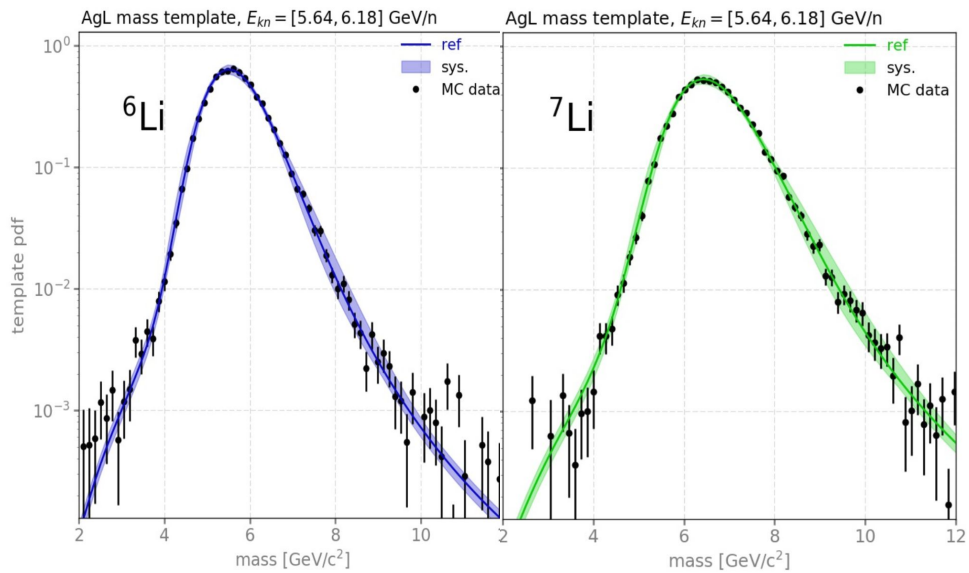



**-> Template fit of mass distributions**

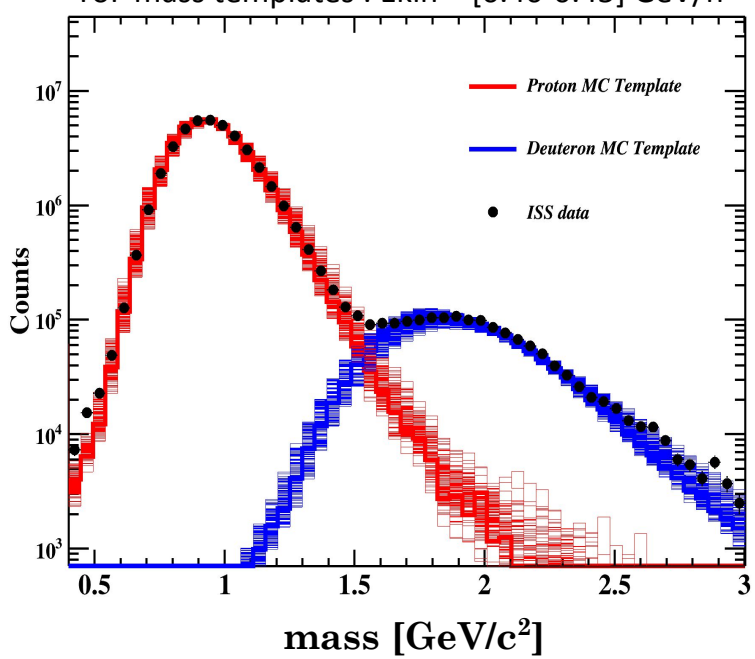
# Templates for the mass distributions

**$^6$Li/$^7$Li and $^3$He/$^4$He:**

- Template reconstructed from β and R resolution models obtined from MC
- Systematic in the mass template shapes: varying the *β* resolution and *R* resolution models (shift, width and tails)




ToF mass templates : Ekin = [0.40-0.45] GeV/n



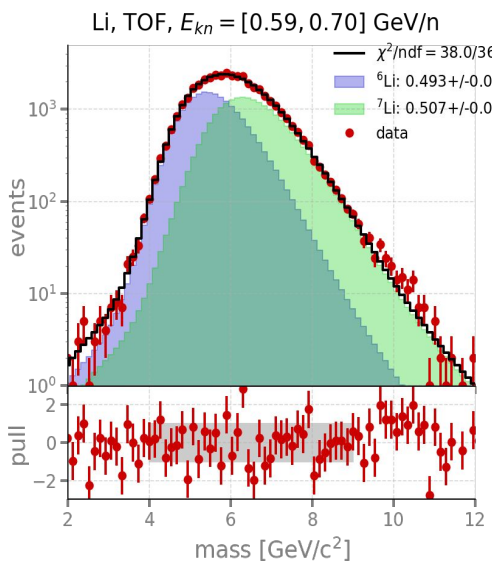

**D/p:**

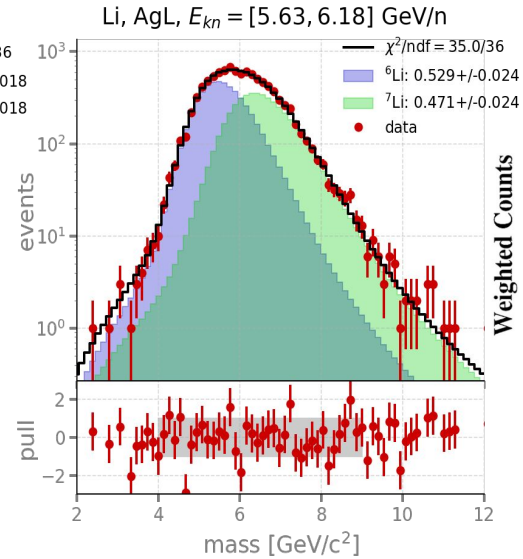
- Collection of mass templates from MC of D and p: Fine tuning of MC β resolution
- Best fitting template is chosen
- Systematic in the mass template fit from spread of results

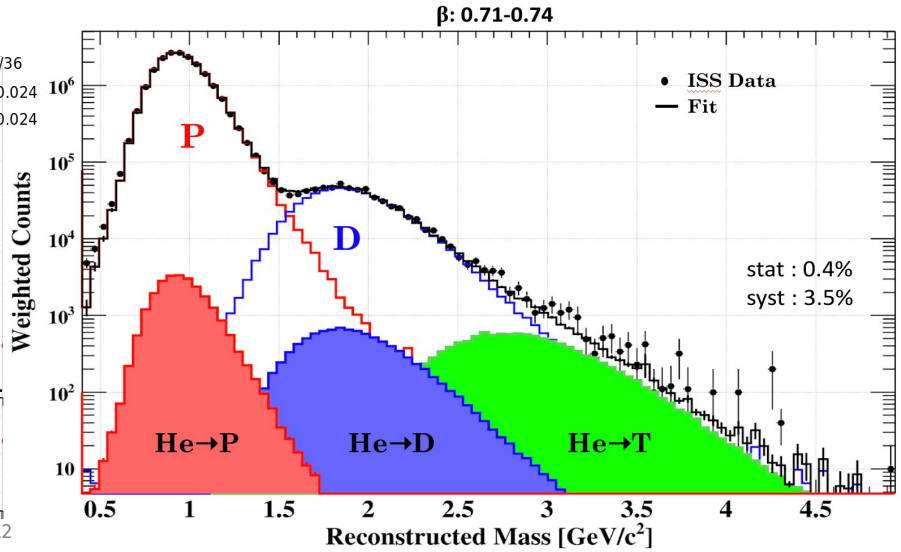
**1 template for each isotope, each energy bin, each analysis.**

# Measurement of the Isotope abundances

- Isotope abundances fitted on the mass distributions on data by weighting isotope mass templates:



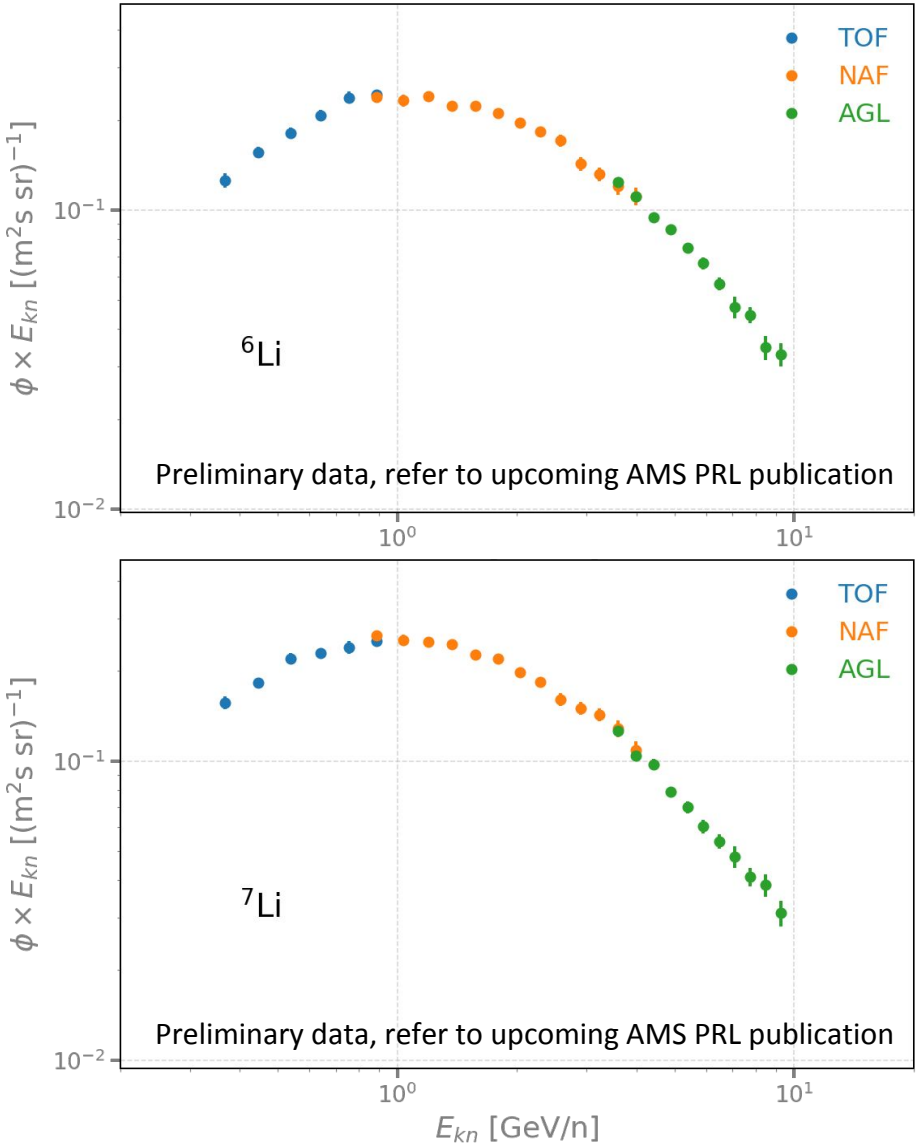




- Errors on abundances include statistical error and systematic error from the mass template shapes.

# Reconstruction of fluxes

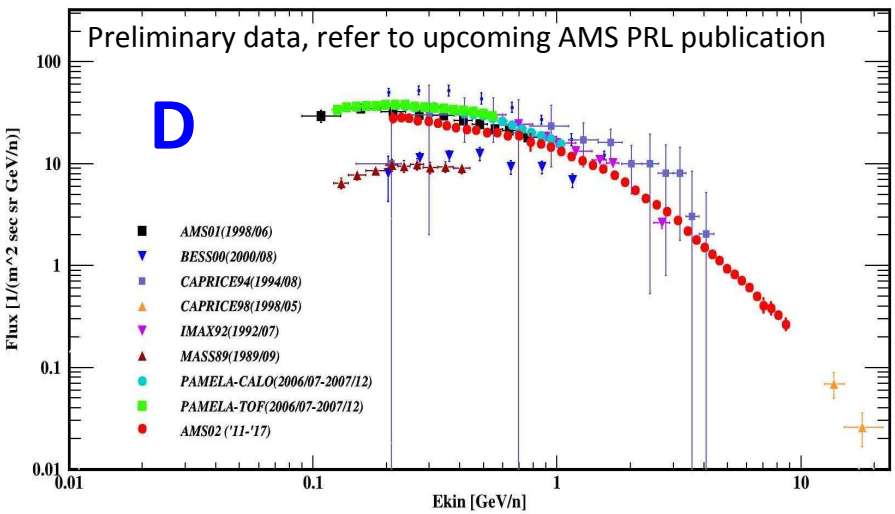
## Isotopic fluxes :

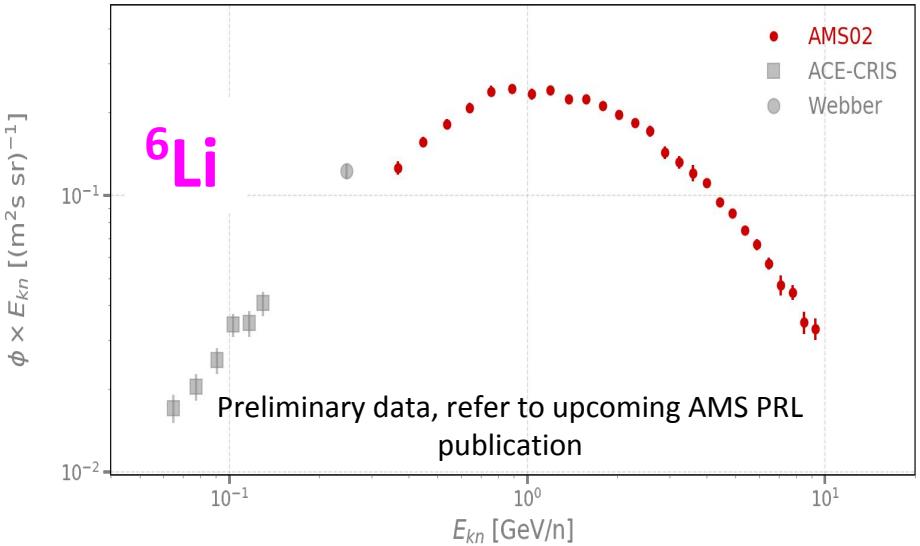
- Computed from abundances, effective acceptances and exposure time.
- Corrected for contamination from fragmentation of heavier nuclei.
- Unfolded to correct energy migration due to finite β resolution.

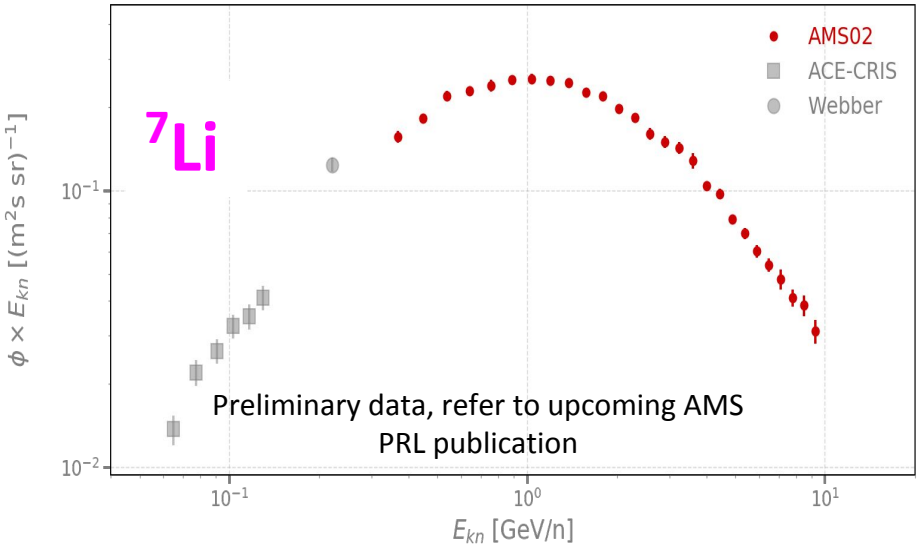


# Isotope fluxes vs kinetic energy per nucleon

- **Ekin per n:** Comparison with previous experiments
- First measurement of $^{6}$Li and $^{7}$Li fluxes above 0.3 GeV/n.
- First precision measurement of D above 1 GeV/n

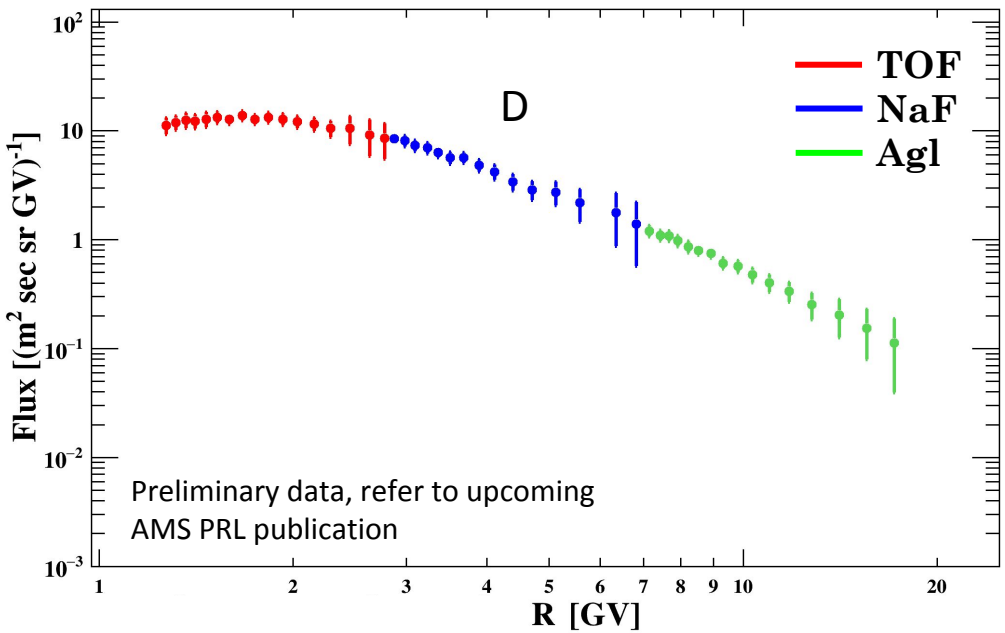


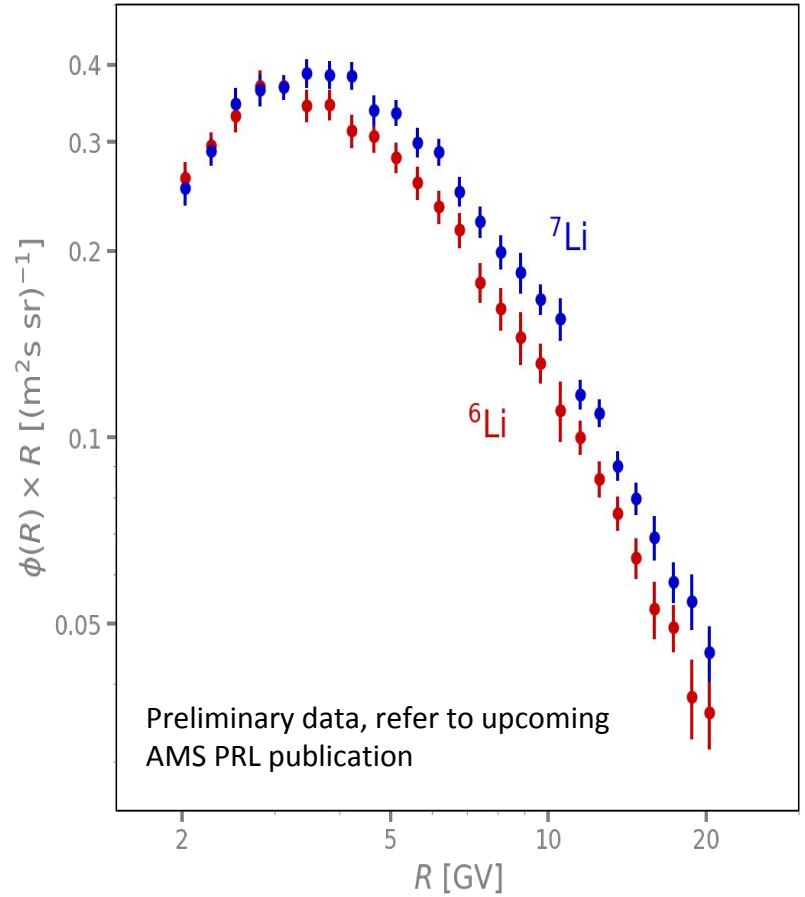



# Isotope fluxes vs Rigidity

- Use of different binning vs $E_{k/n}$ to get the same rigidity bins (accounting for En. loss)
- Full isotopic analysis done for the two binning
- $E_{k/n}$->R conversion for each Isotope.

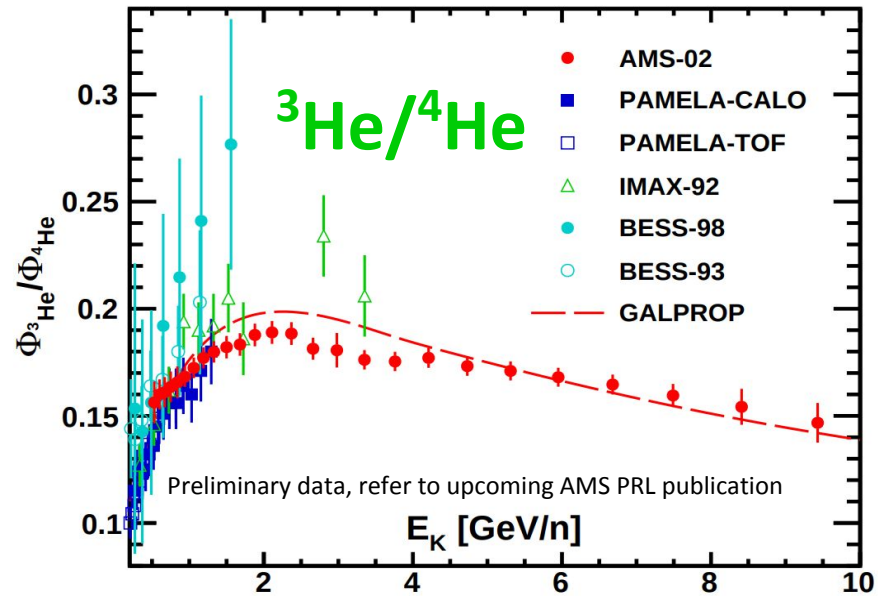


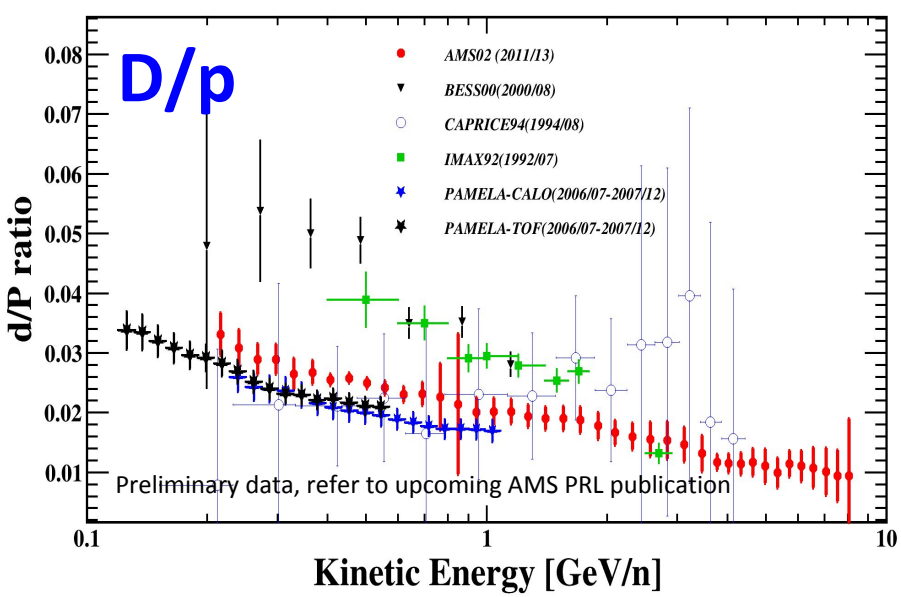



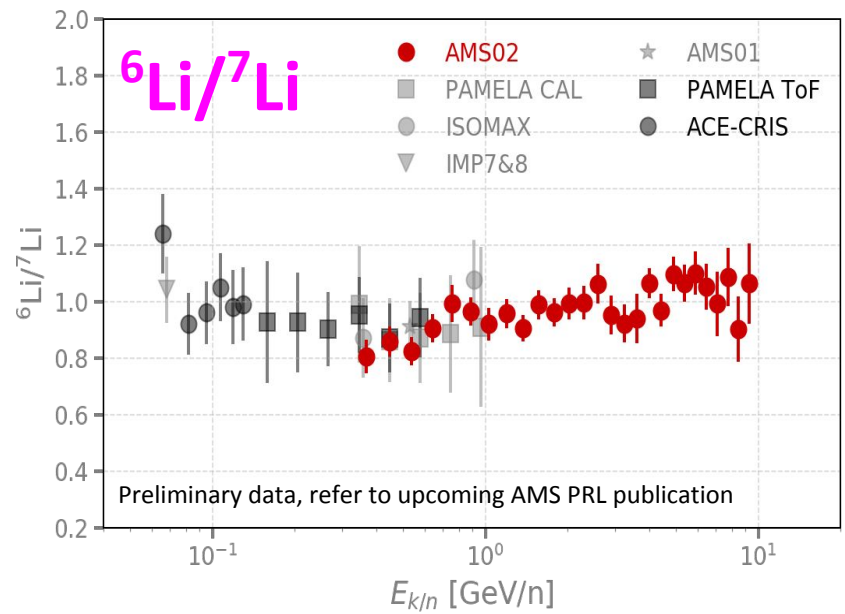

First isotopic measurements in the 1-20 GV rigidity range

# Isotope flux ratios vs Ekin/n

- **Ekin per n:** Comparison with previous experiments
- First measurement of $^4He/^4He$ above 3 GeV/n
- First measurement of $^6Li/^7Li$ above 1 GeV/n
- First precision measurement of D above 1 GeV/n

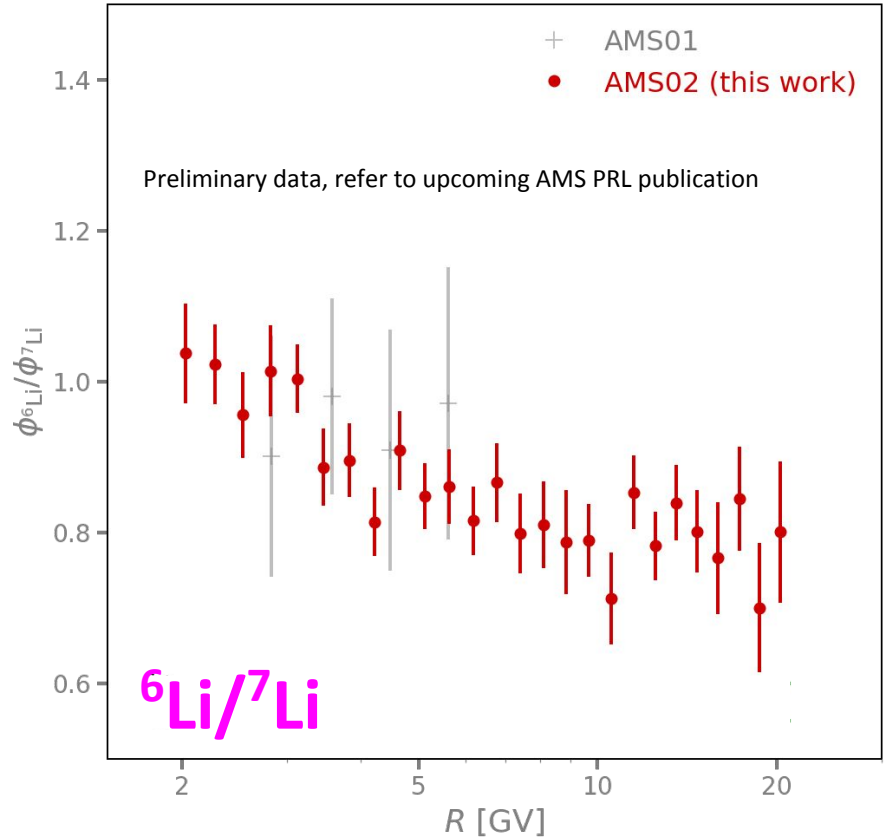


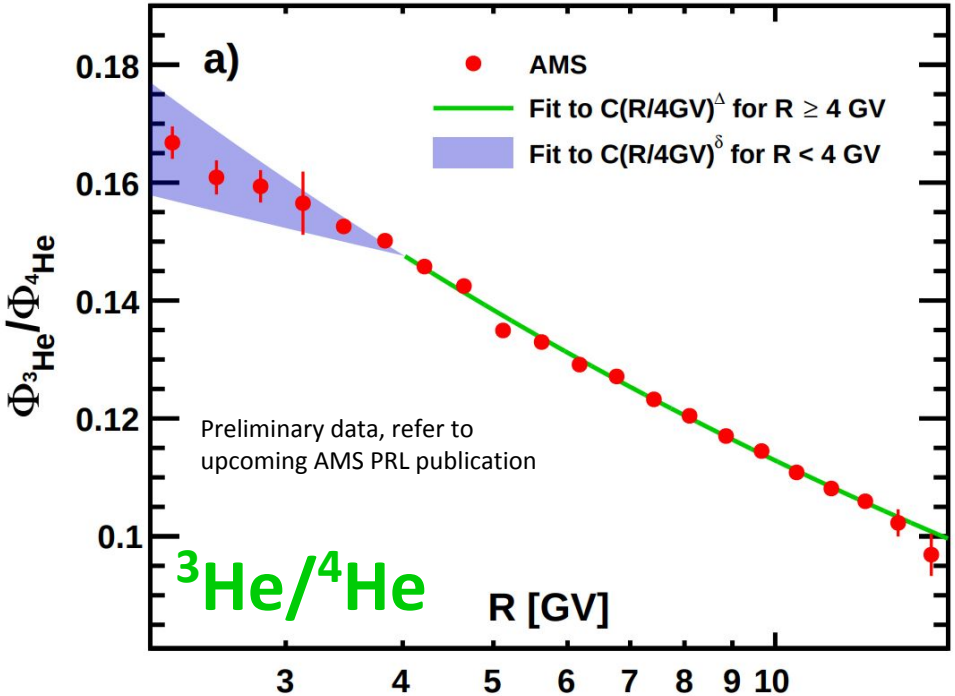



# Isotope flux ratios vs R

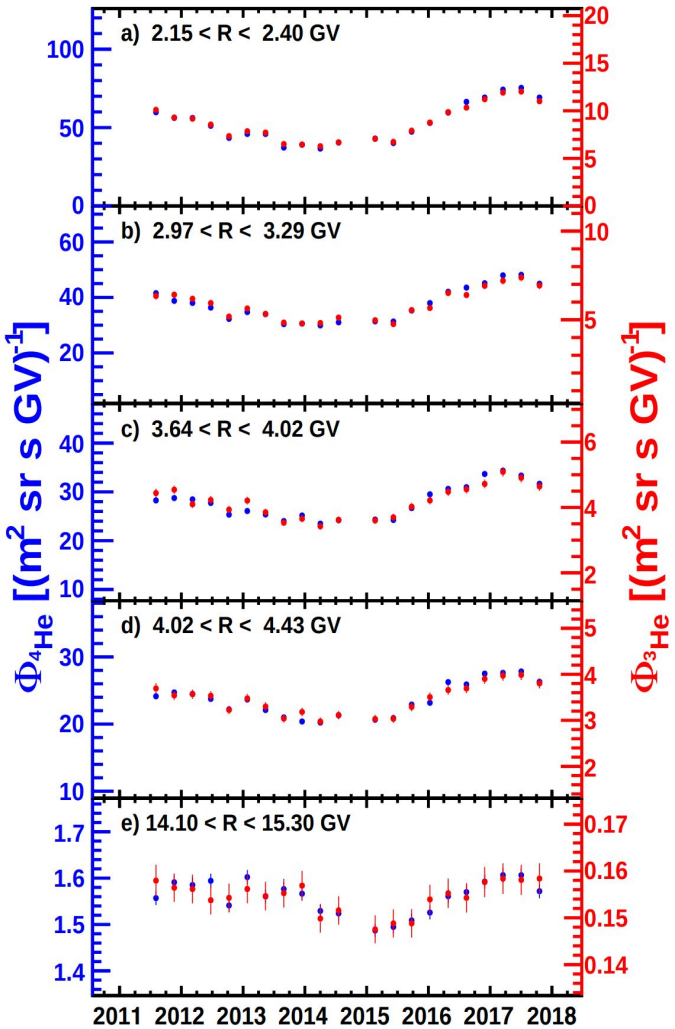
- **R: ~ time independent** (Interaction with variable solar wind is R-dependent)
- First measurement of $^6Li/^7Li$ against rigidity above 6 GV

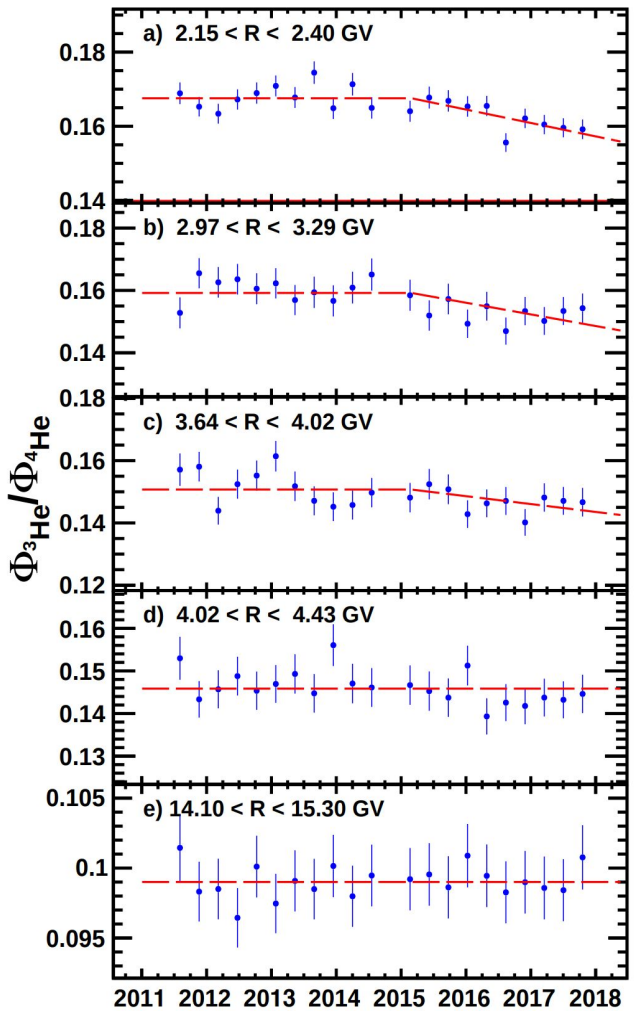


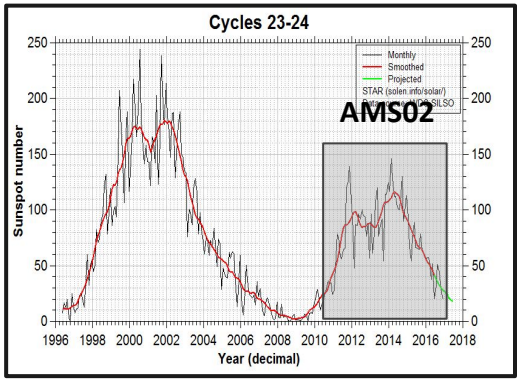




- **Above 4 GV:** compatible with single power law
- **Below 4 GV:** AMS02 discovered a low energy **time dependence** of the $^3He/^4He$ ratio

# $^3He/^4He$ flux ratio time dependence




- In general, CR flux is **anticorrelated** with solar activity
- AMS-02 scanned the complete 24th cycle
- Time dep. of $^3He/^4He$ ratio modeled with:

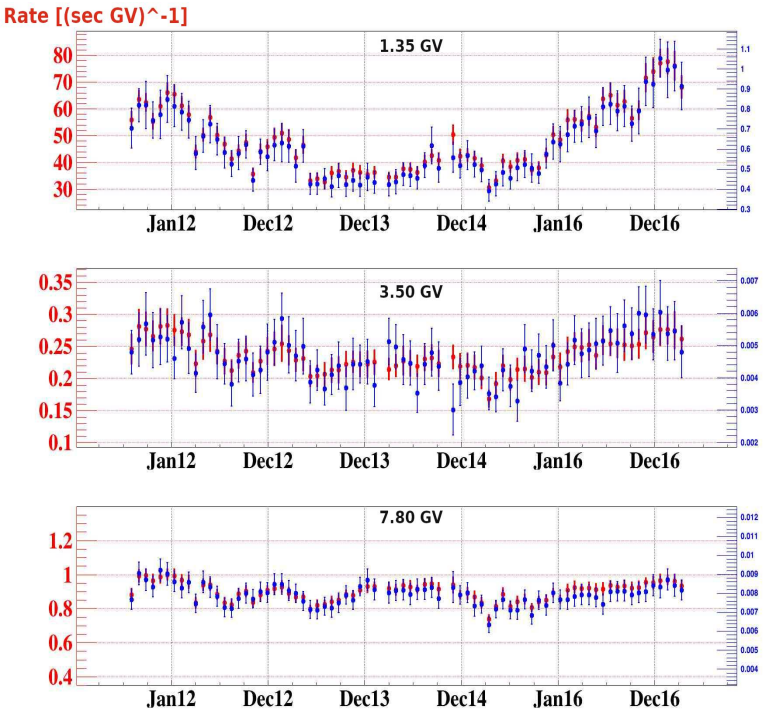
$$r_i(t) = \begin{cases} a_i & t < t_i \\ a_i + b_i(t - t_i) & t \geq t_i, \end{cases}$$

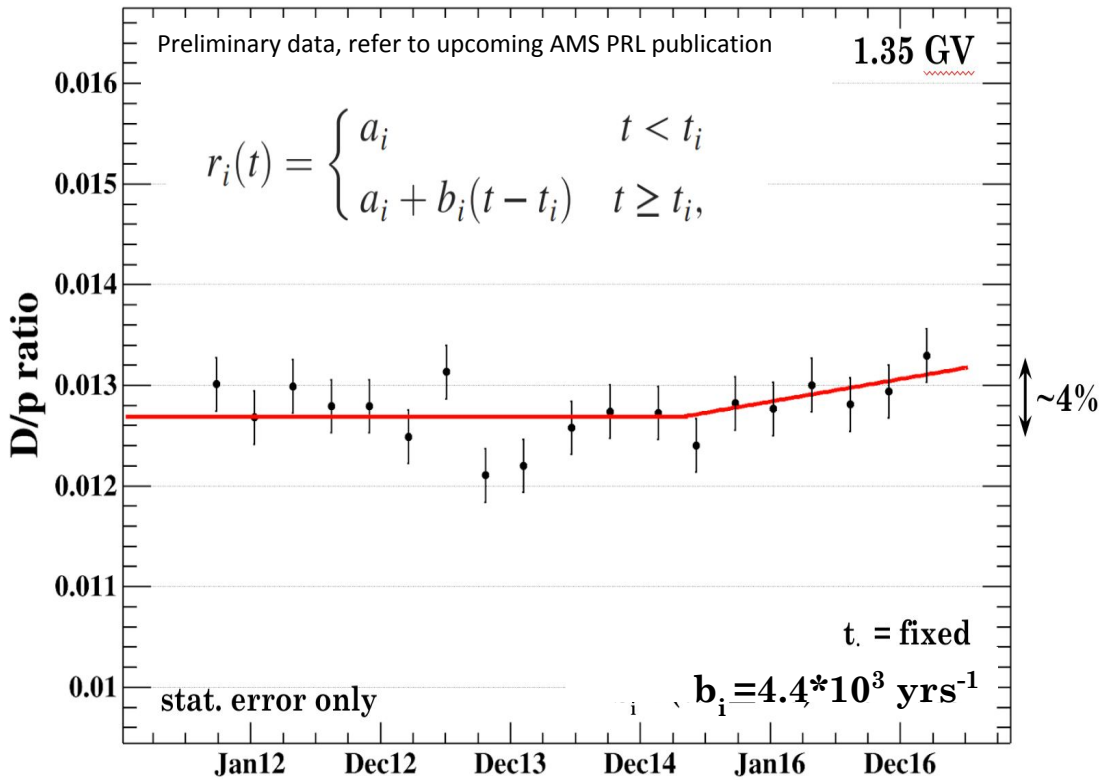
**$t_i$ = February 25th, 2015**

Preliminary data, refer to upcoming AMS PRL publication

# D/p flux ratio time dependence

- ΔT = 1 Bartel rot. (27 days):
  D show same time structures as p




- ΔT = 4 Bartel rot.: First hints of low energy D flux time dependence
- Same break at 2015, 25th February, correlated with polarity flip of solar mag field

# Conclusions

- Isotopic composition of light nuclei in cosmic rays is a key measurement to understand cosmic rays origin and propagation.
- First measurement of $^{6}$Li and $^{7}$Li fluxes above 0.3 GeV/n.
- First precision measurement of D flux above 1 GeV/n
- First measurement of $^{3}$He/$^{4}$He ratio above 2 GeV/n.
- Measurements in rigidity from 1 to 20 GV.
- AMS02 discovered a time dependence in the low energy (R < 4GV) $^{3}$He/$^{4}$He ratio.
- Similar time dependence from the measurement of D/p ratio.


Thanks for your attention
AMS
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