Secondary nuclei with the DAMPE space mission

Andrea Parenti on behalf of the DAMPE collaboration

(Gran Sasso Science Institute and INFN - LNGS,
now at Université Libre de Bruxelles)

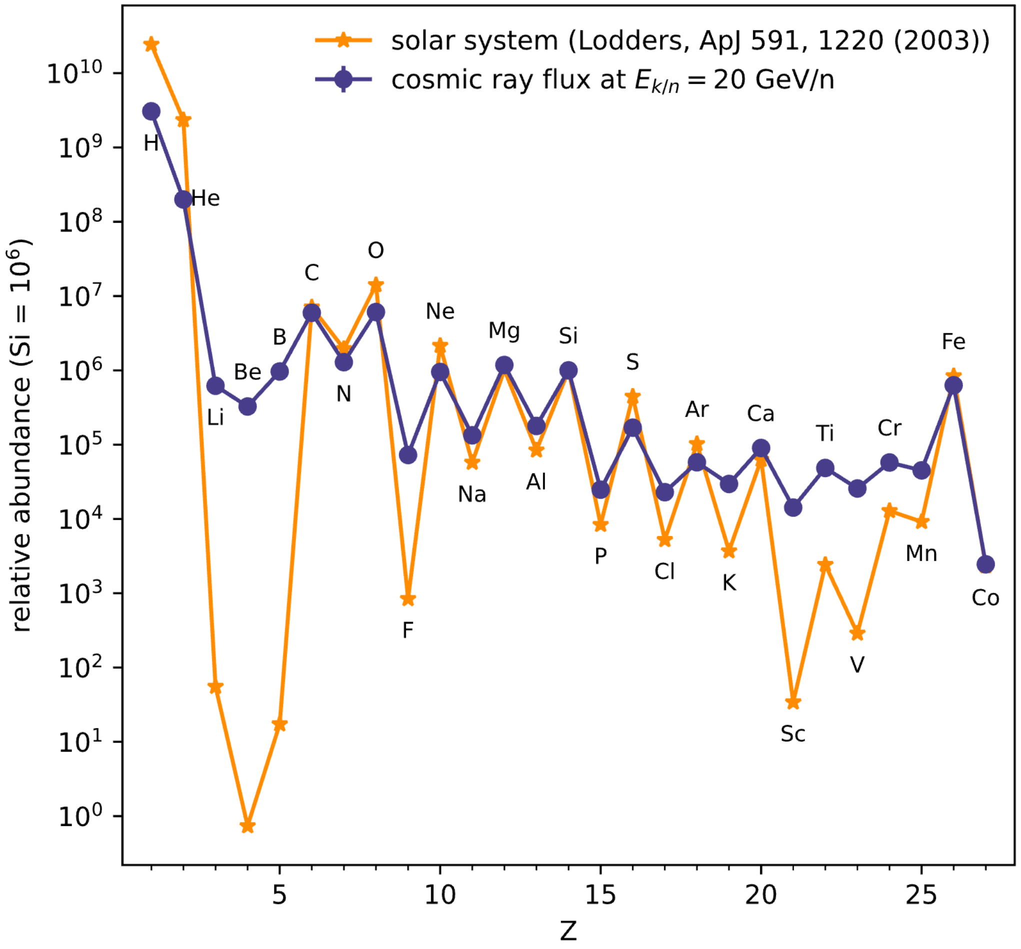
e-mail: andrea.parenti@ulb.be

GRAN SASSO SCIENCE INSTITUTE
CENTER FOR ADVANCED STUDIES INFN

UNIVERSITÉ LIBRE DE BRUXELLES

DARK MATTER PARTICLE EXPLORER

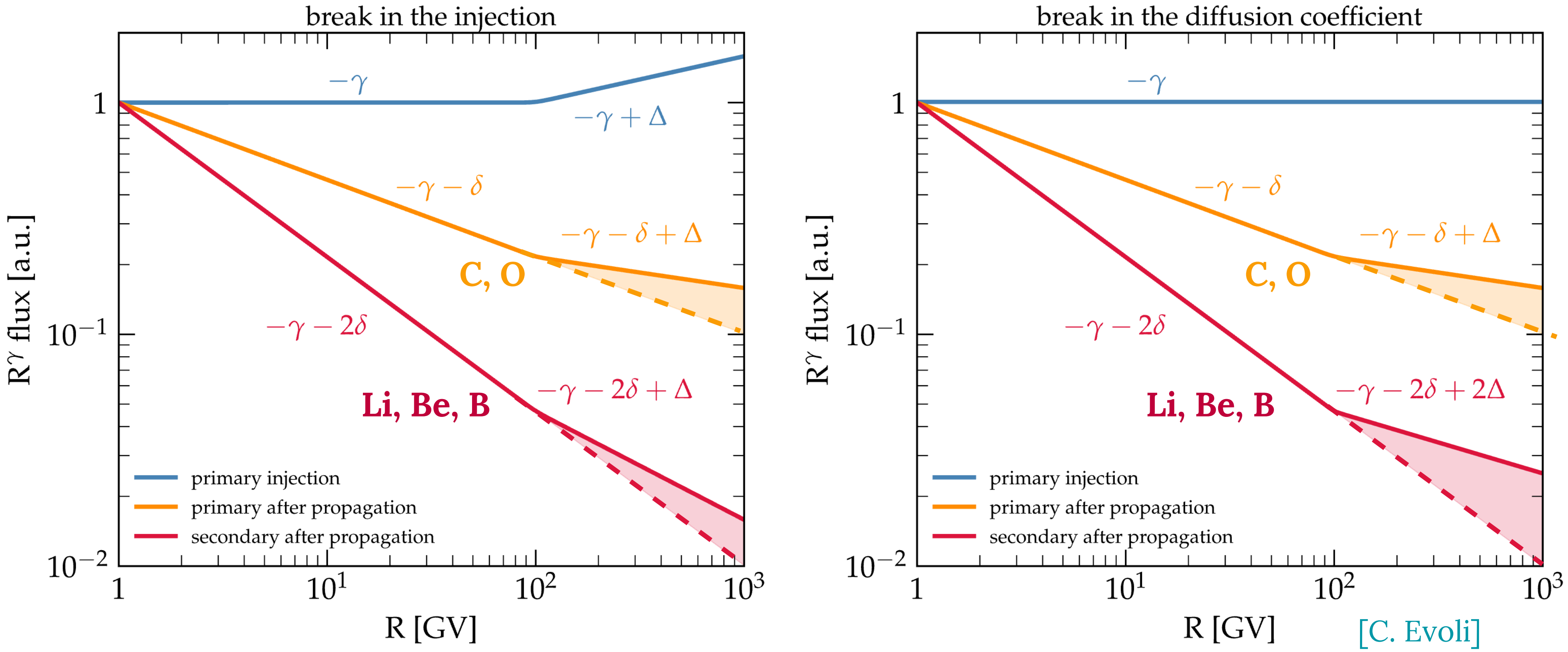
Secondary Cosmic Rays



[D. Maurin et al. A *cosmic-ray database update*: CRDB v4.1]

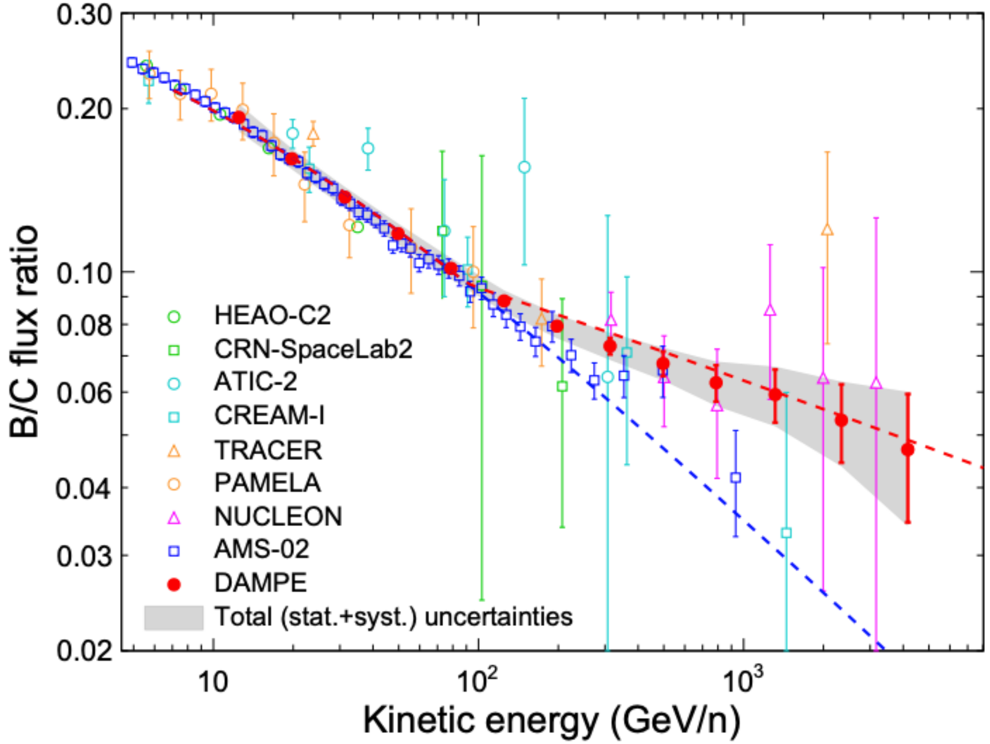
- Production: **cosmic ray (CR) spallation** with the Interstellar Medium
- Mainly from primary Carbon, Oxygen
- Abundances of secondaries are much higher in CRs than in the solar system
- Measuring the flux of secondaries can offer insight into mechanisms of CR propagation

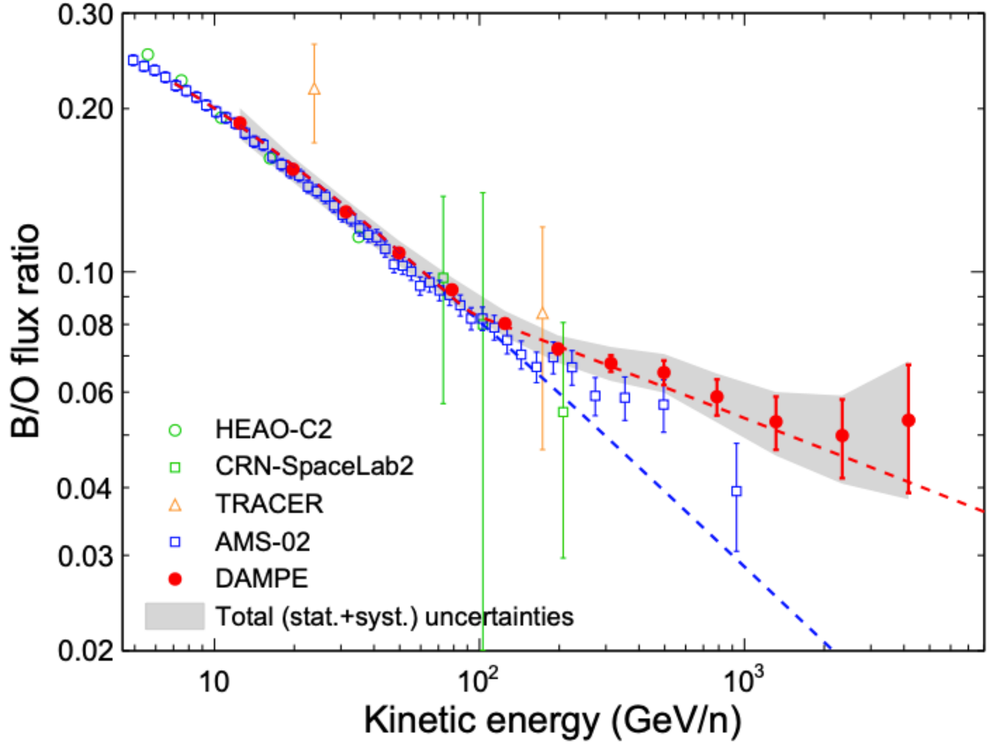
Origin of the CR hardening



- Spectral **hardening** at a hundred GV observed for virtually all measured CR nuclei
- **Is it a source or a propagation effect?** Precisely measuring the hardening in the secondaries can provide an answer

B/C and B/O ratios





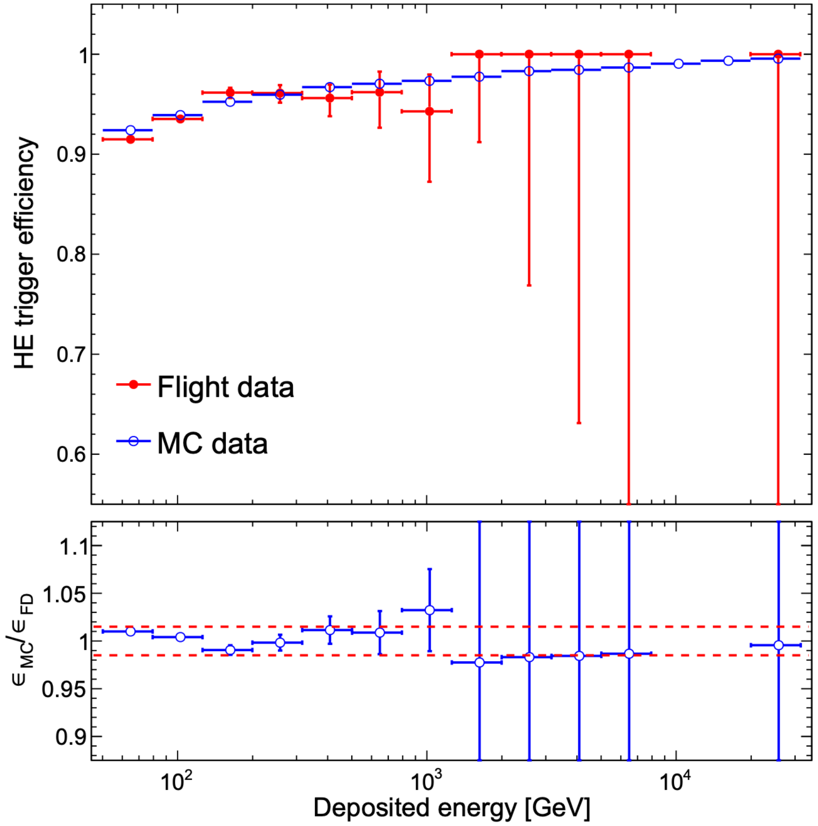
[DAMPE collab., Science Bulletin 67 (2022) 2162]

- B/C and B/O flux ratio measured from 10 GeV/n to 5.6 TeV/n
- Detected hardening with 5.6σ and 6.9σ significance
- Strong evidence of propagation-related mechanism

Event selection

Orbital data:

- **8 years** of data from Jan 2016 to Dec 2023
- Total exposure **~74%** operation time



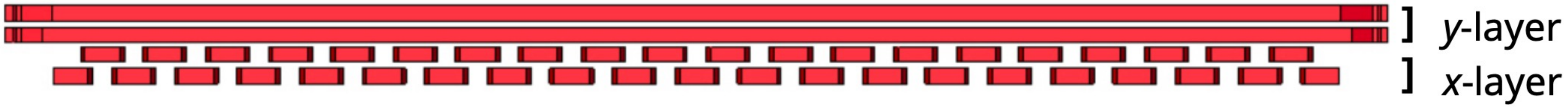
MC simulation:

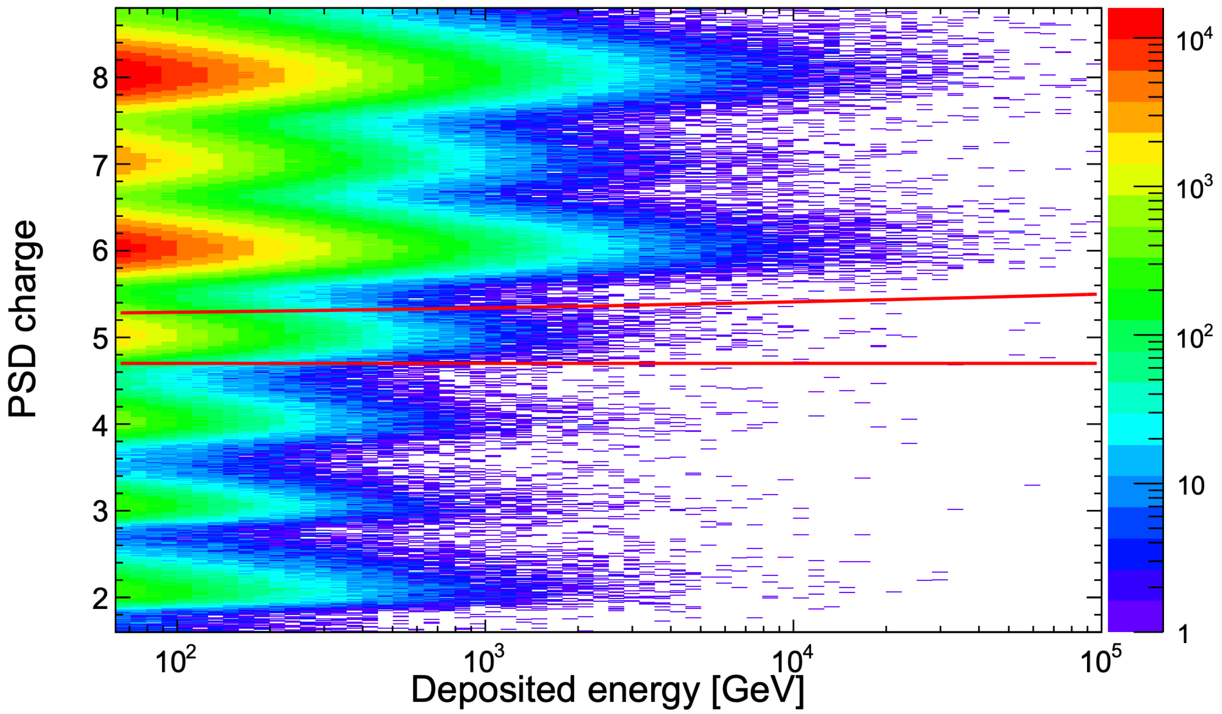
- **Li6-7, Be7-9-10, B10-B11**
- **10 GeV – 500 TeV**
- `GEANT4` with `FTFP_BERT` and `EPOS-LHC`
- FLUKA simulation for systematics evaluation

Pre-selection:

- HET trigger
- E_{BGO} > 40 GeV
- Each BGO layer deposit < 35% total deposit
- Track selection: both Kalman filter and machine learning approach

B: Charge selection





Charge estimator defined to reject events with fragmentation inside the PSD:

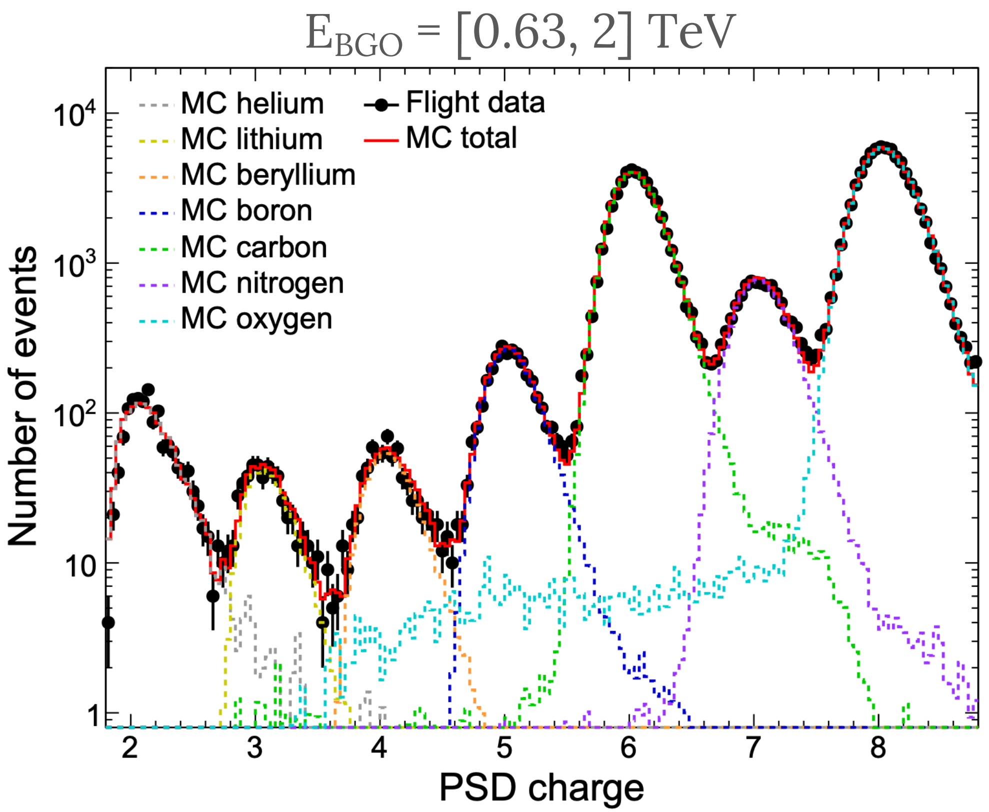
$$Q_{\mathrm{PSD}} = \frac{\sum_i Q_{\mathrm{PSD},i}}{N_{\mathrm{PSD}}}$$

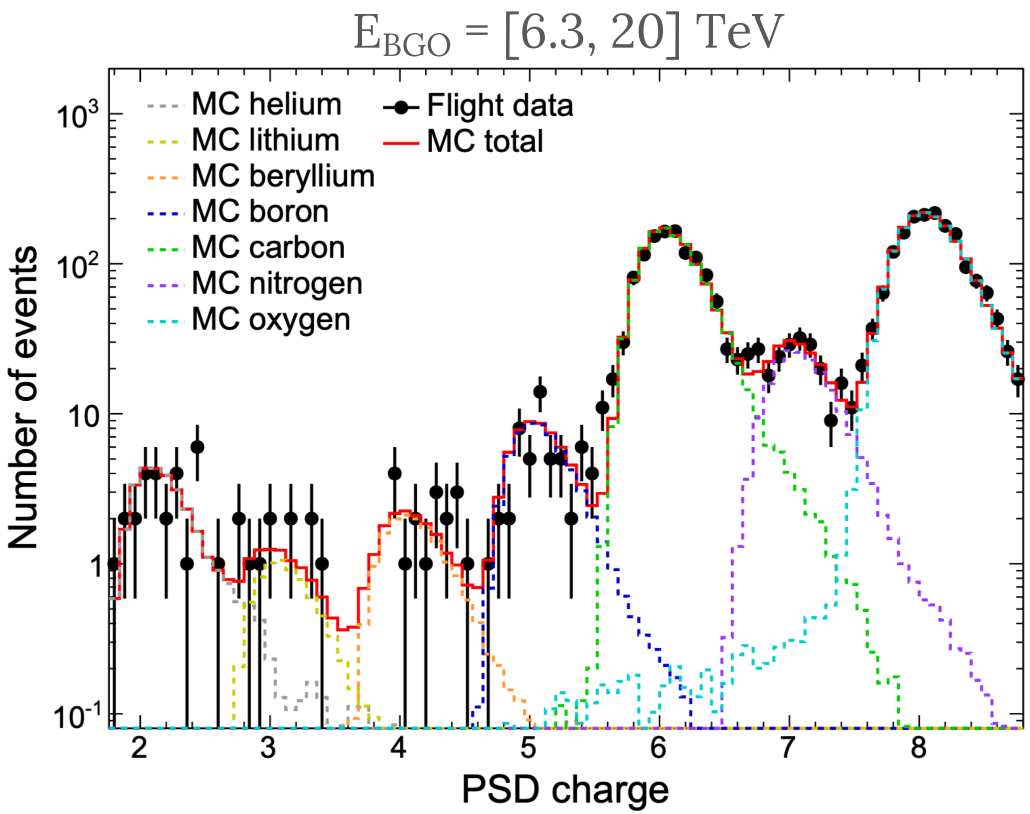
$$|Q_{\mathrm{PSD},i} - Q_{\mathrm{PSD},i+1}| < 1$$

STK charge used to reject background from p, He:

$$Q_{STK} > 3$$

B: Background estimation

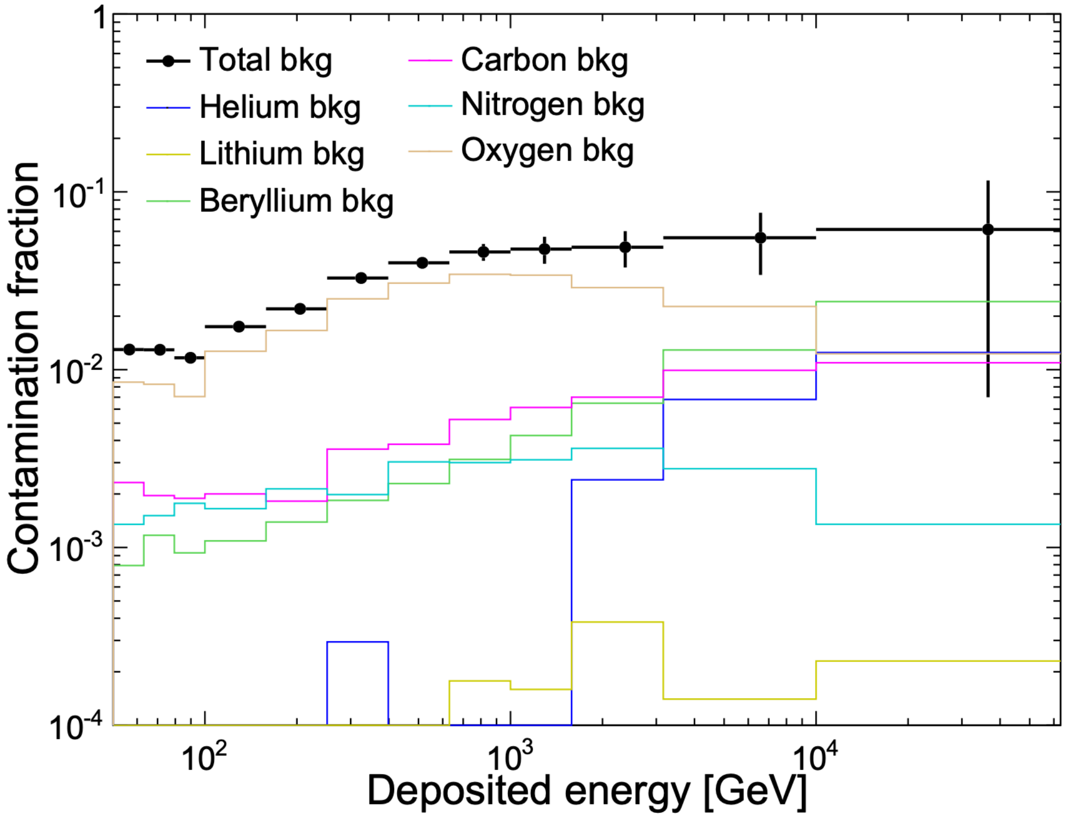




MC templates for nuclei from He to O, generated with GEANT4

Remarkable agreement between data and MC, allowing accurate estimation of the background

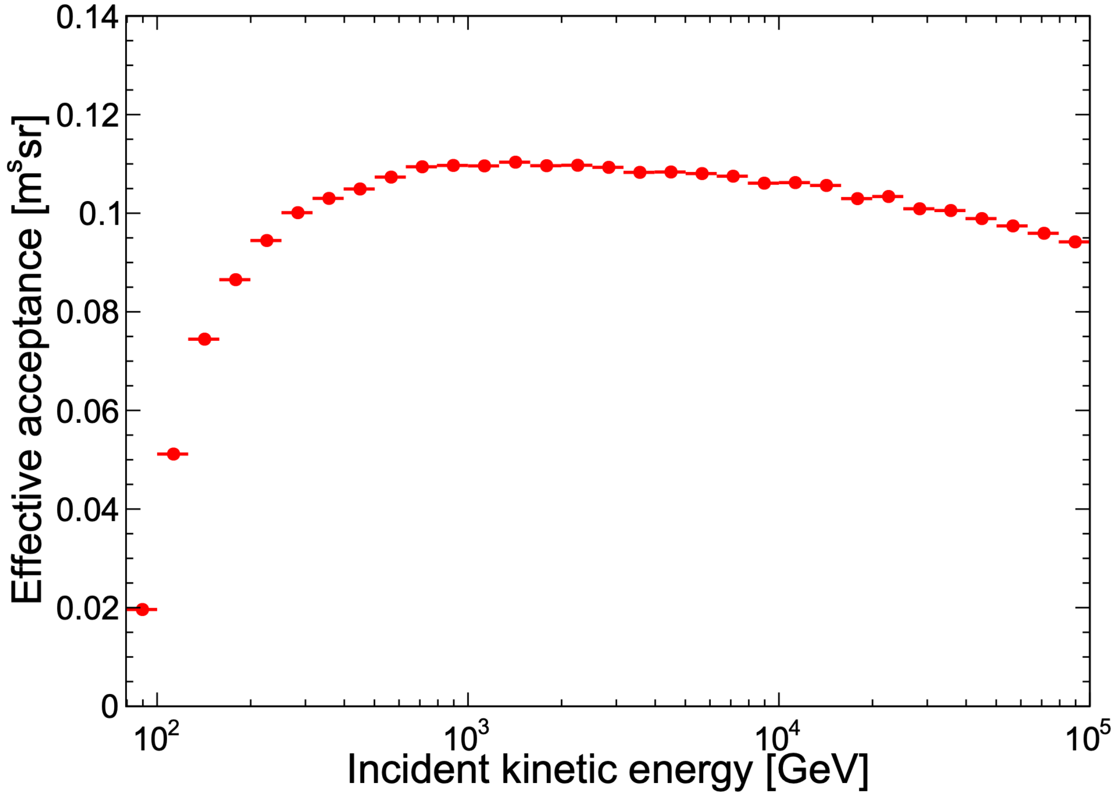
B: Background estimation



Main contributions from C and O at low energies, at high energies He and Be become dominant

Small background fraction ~6% at the highest energies

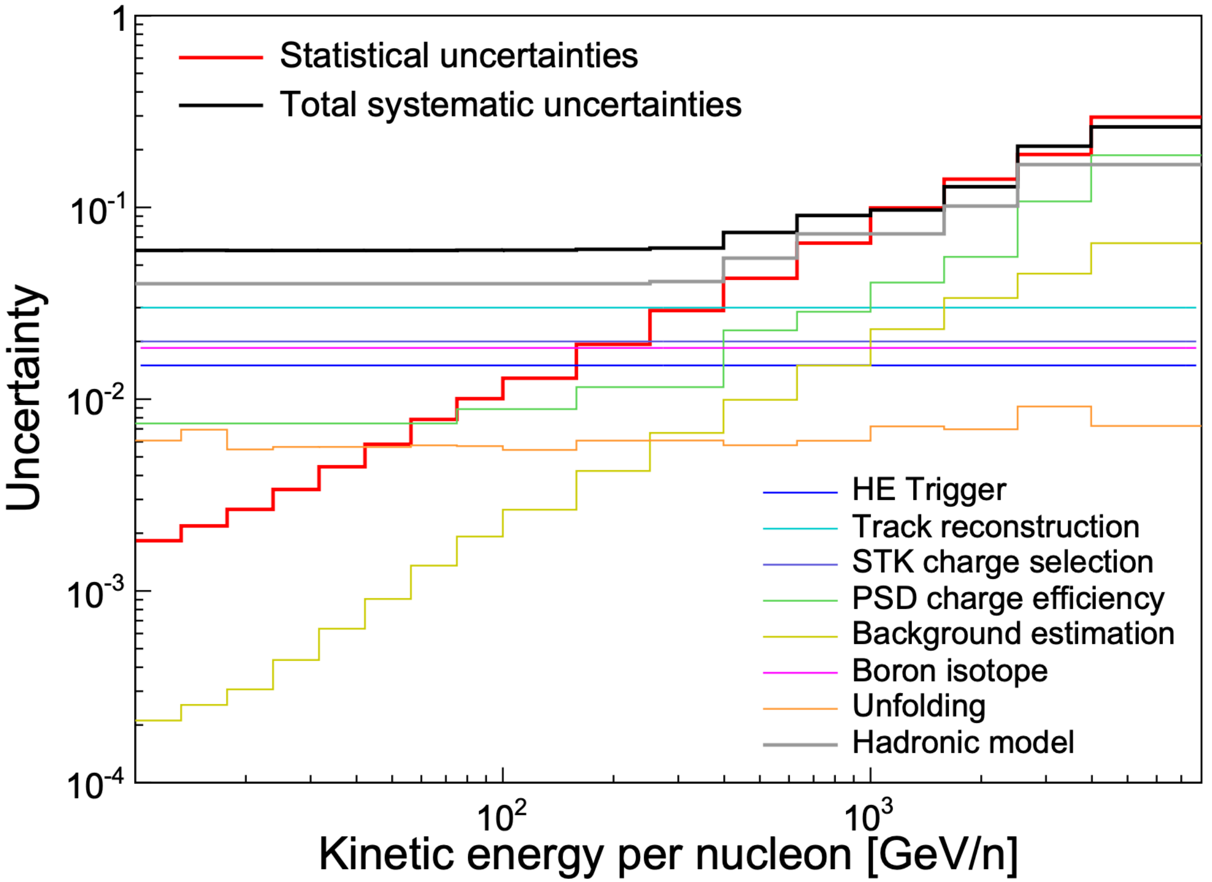
B: Unfolding



$$N(E^i_{\mathrm{dep}})(1-\beta_i) = \sum_{j=1}^{n} P(E^i_{\mathrm{dep}}|E^j_{\mathrm{inc}})N(E^j_{\mathrm{inc}})$$

- β_i = background fraction in i-th Edep bin
- $P(E^i_{dep}|E^j_{inc})$ = energy response matrix from MC simulation. Corrected for BGO saturation and quenching effects
- $N(E^j_{inc})$ unfolded with iterative Bayesian procedure

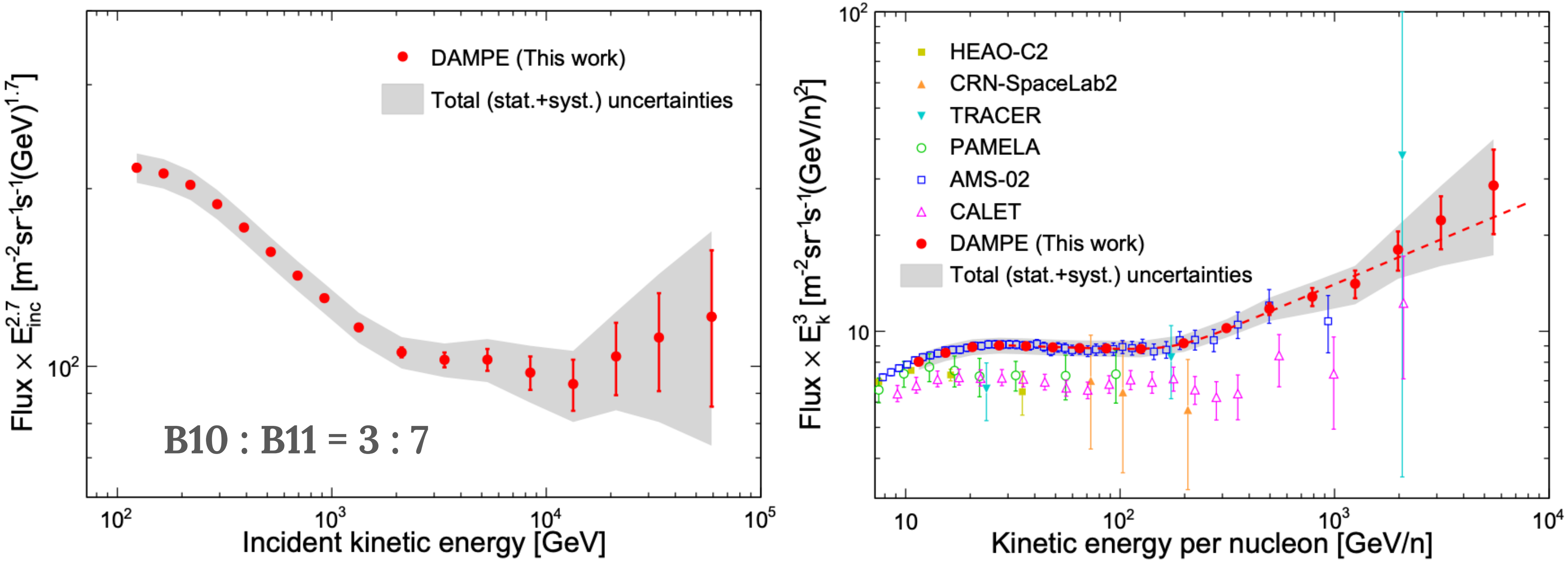
B: Systematic uncertainty



Hadronic model uncertainty: comparison with flux obtained using FLUKA simulations

Statistical and hadronic model contributions dominate the total uncertainty

Boron flux



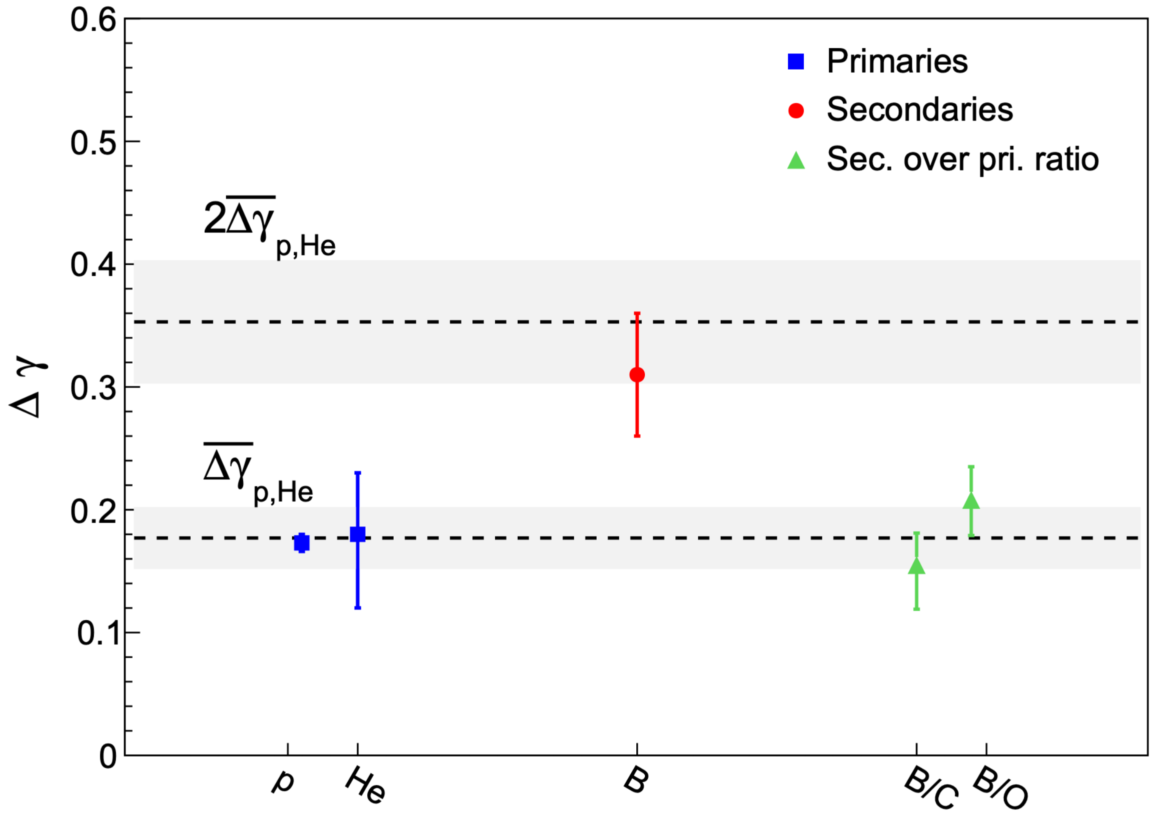
$$\Phi_i = \Phi(E^i_{\rm inc}, E^i_{\rm inc} + \Delta E_i) = \frac{N(E^i_{\rm inc})}{\Delta T \cdot A_i \cdot \Delta E_i}$$

Boron flux measured from 10 GeV/n to 8 TeV/n, highest energies ever measured. Published in PRL in 2025.

Agreement with AMS-02 in the overlapping energy range

[DAMPE collab., Phys. Rev. Lett. 134, 191001 (2025)]

Boron spectral fit

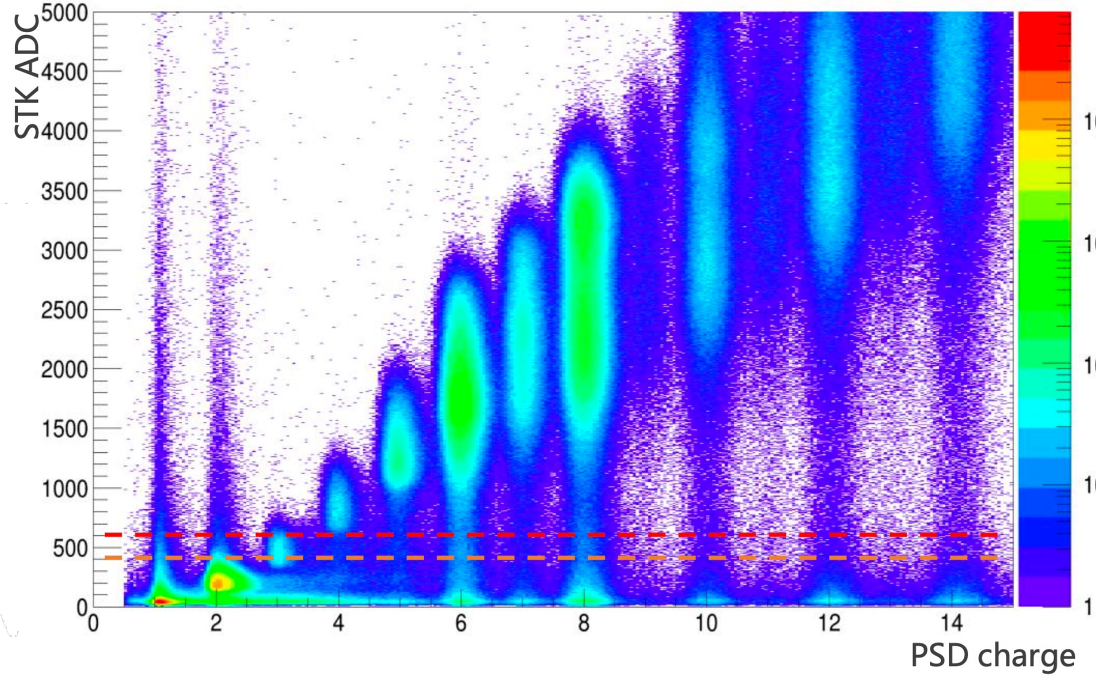


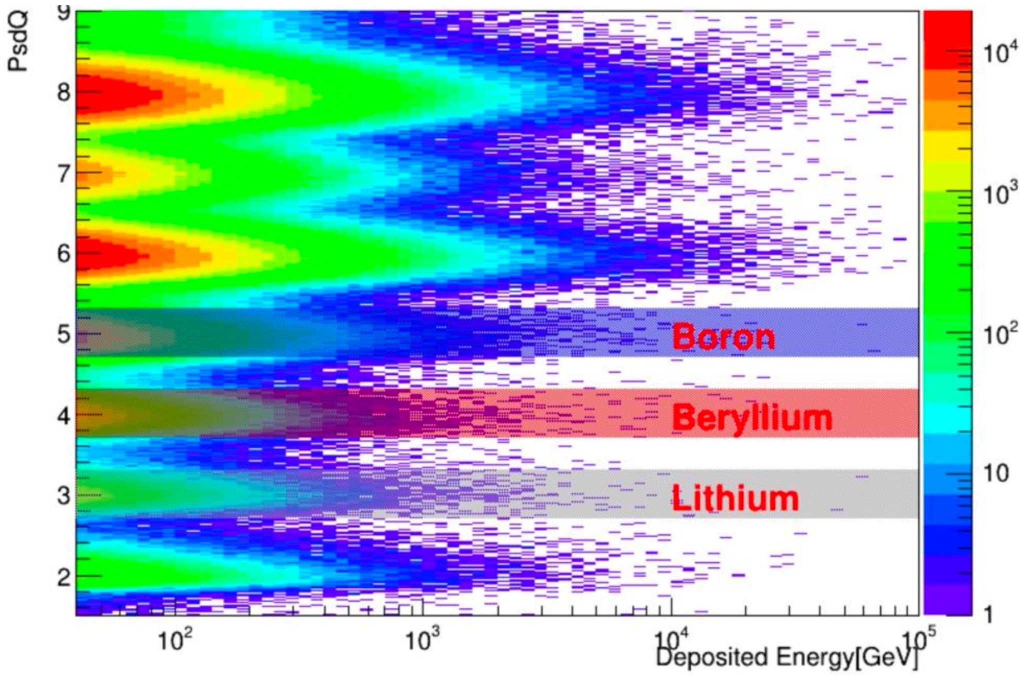
Boron hardening at 182 GeV/n, single power law disfavored at 8σ

Δγ is double of p, He, B/C, B/O

Measurements strongly points to a propagation-related effect

Li, Be : Charge selection



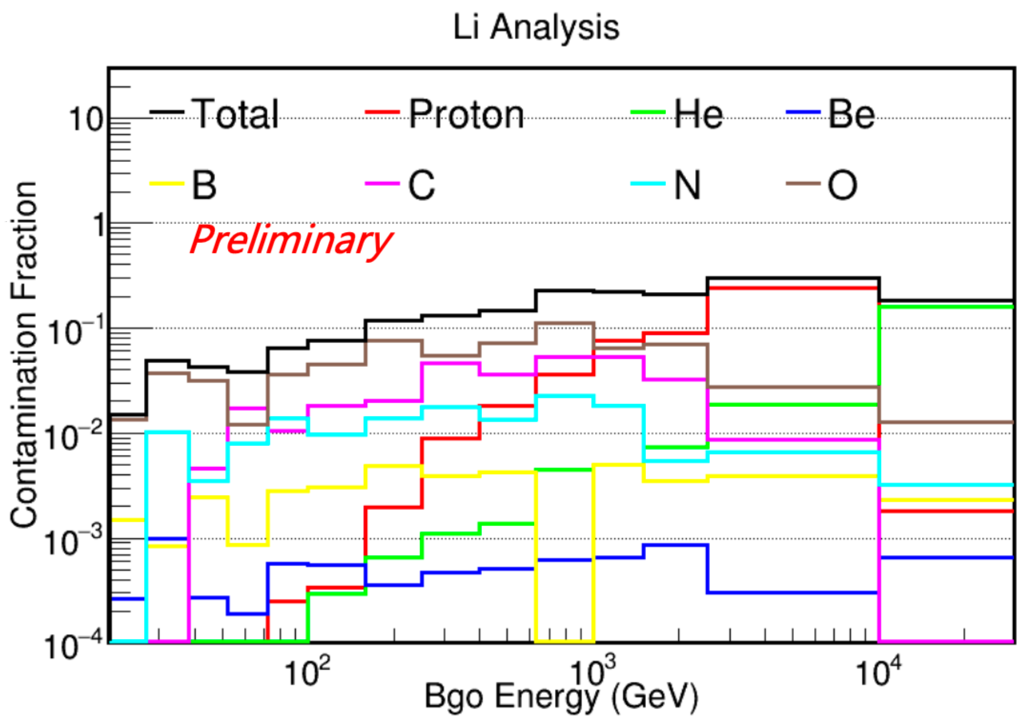


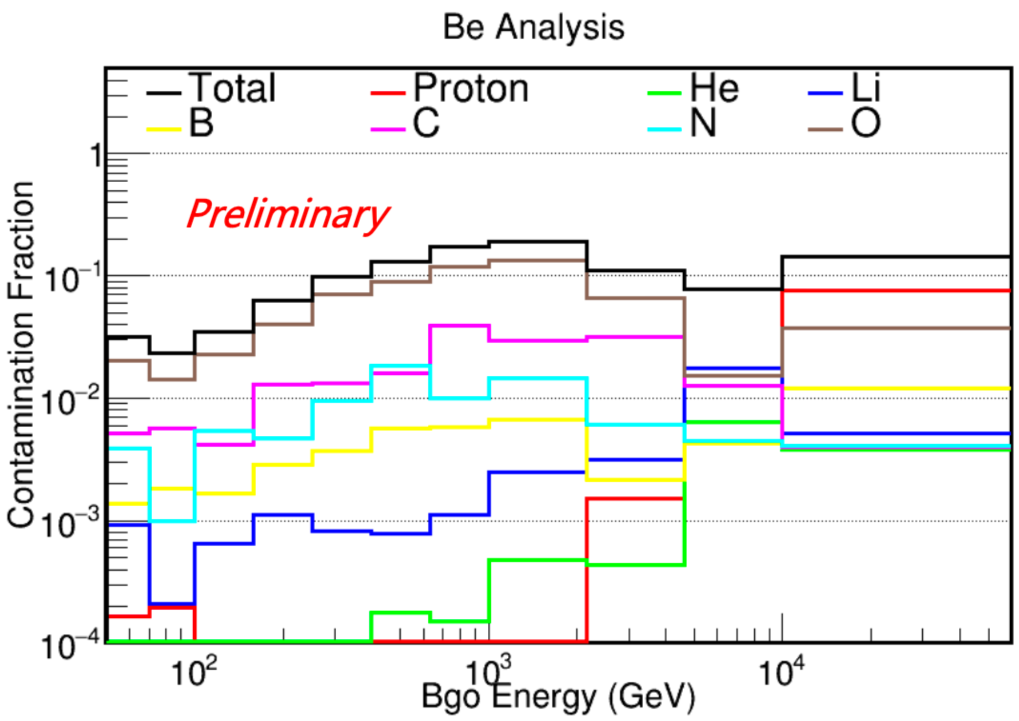
STK charge used to reject background from p, He.

- Q_{STK} > 400 ADC for Li analysis
- Q_{STK} > 600 ADC for Be analysis

Q_{PSD} signal windows specific to each nucleus

Li, Be : Background estimation

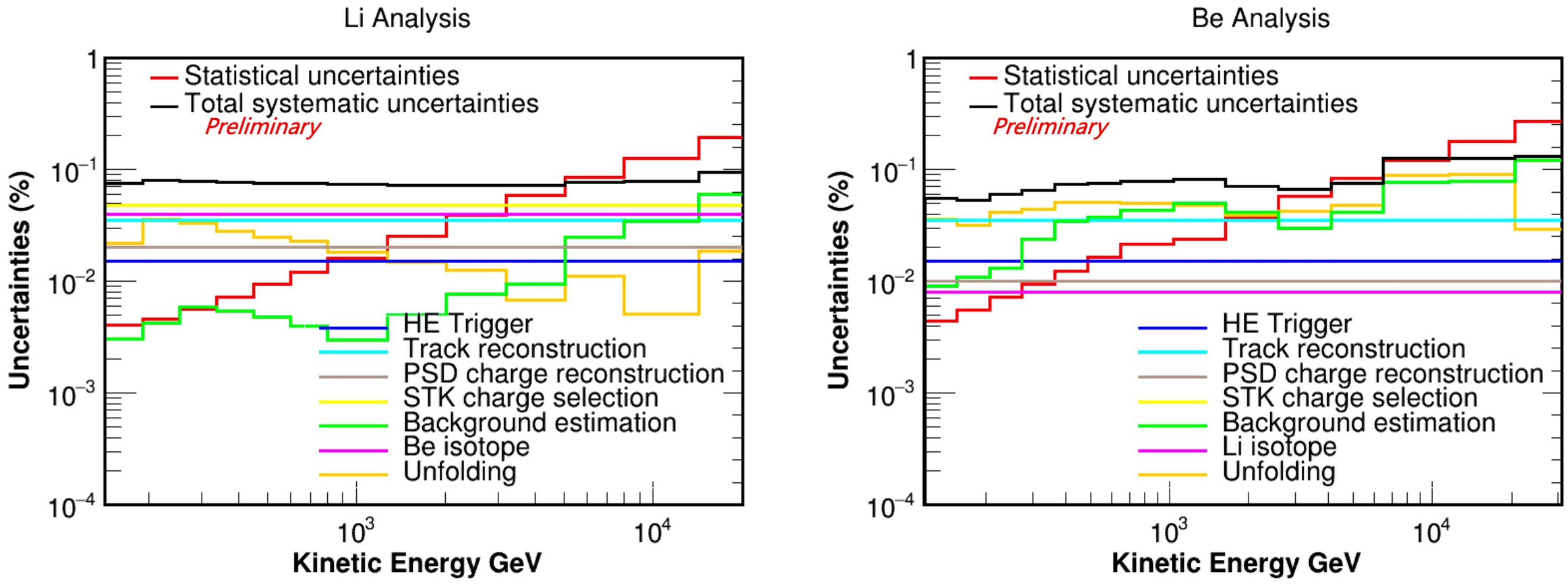




Background estimated with MC template fit

Contamination between 10–20% at the highest energies

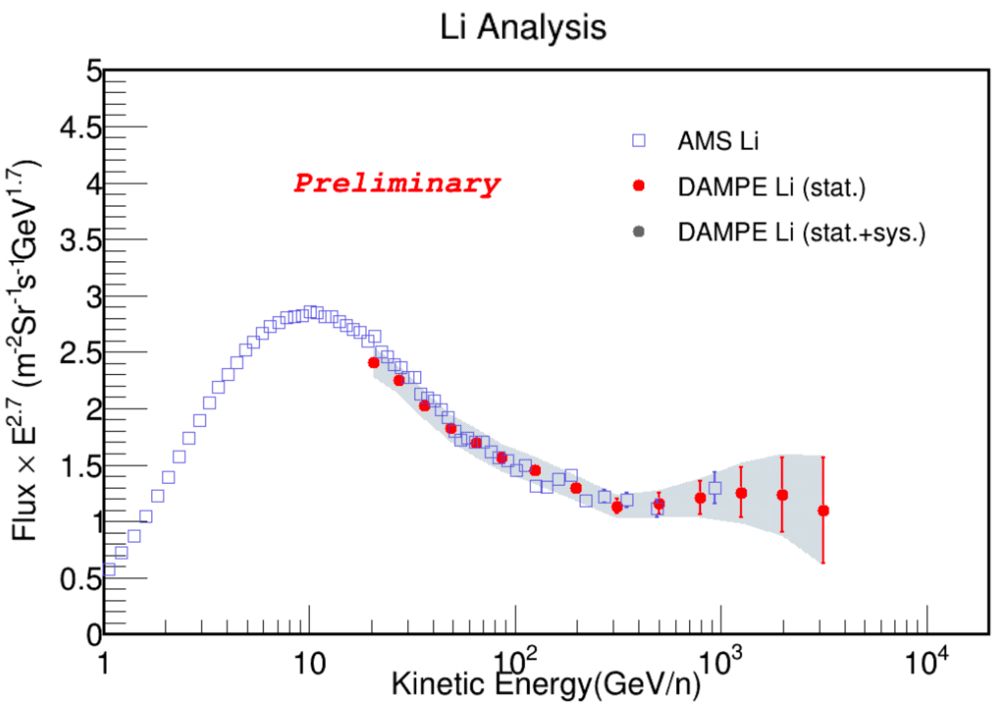
Li, Be : Uncertainties

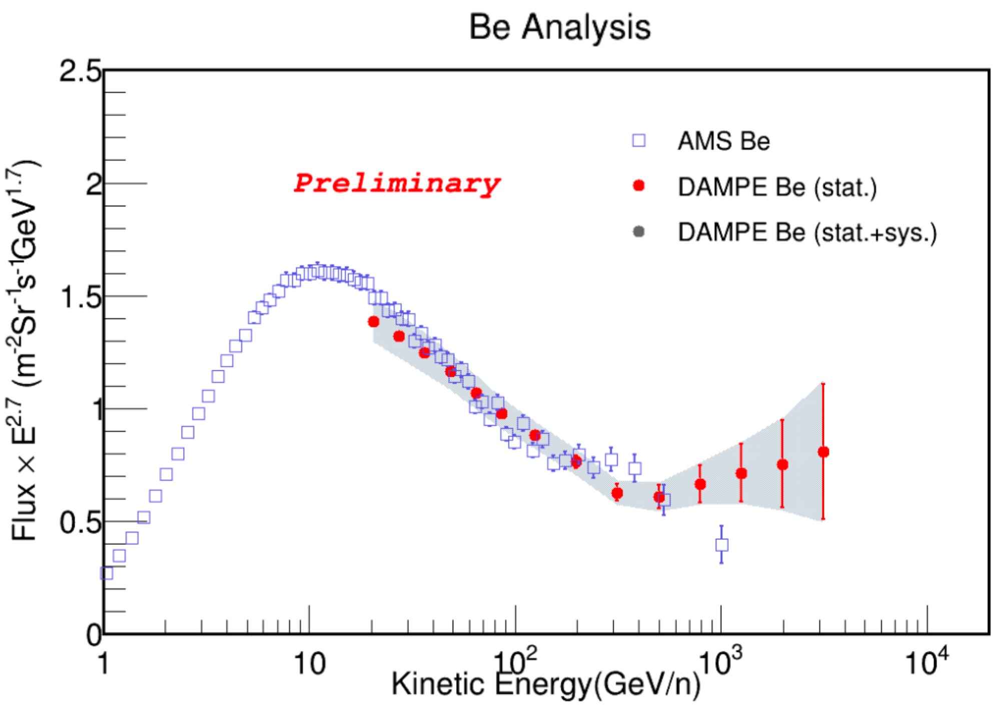


Statistical uncertainty dominates at higher energies

Preliminary results, hadronic model contribution still under evaluation

Li, Be fluxes





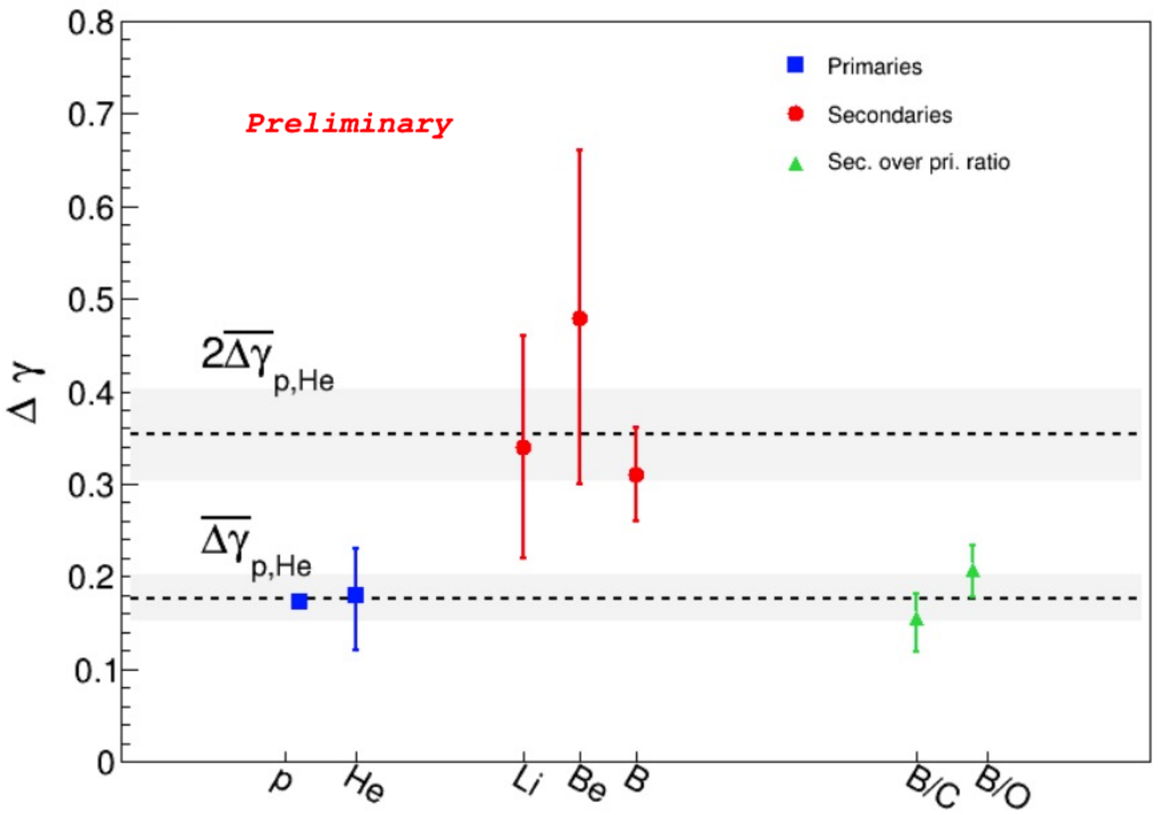
Preliminary measurement of lithium and beryllium flux

Energy range: 16 GeV/n to 4.1 TeV/n

Agreement with AMS-02 in overlapping energy range, DAMPE extends to higher energies

Clear evidence of a hardening

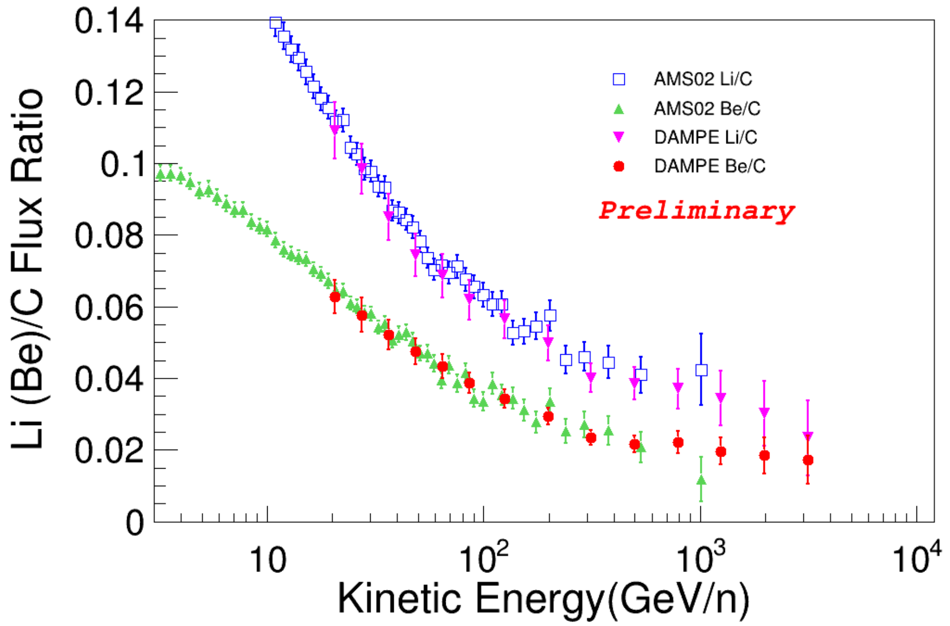
Li, Be: spectral fit

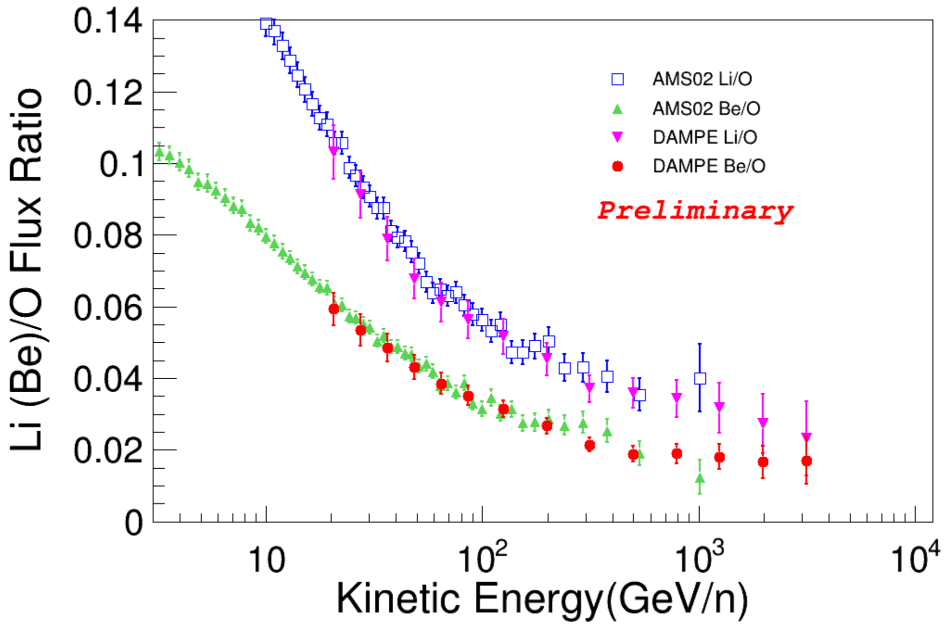


Hardening Δγ is consistent with previous DAMPE results

Consistent picture indicating that the spectral feature is propagation-related

Flux ratios





Preliminary measurement of Li/C, Li/o, Be/C, Be/O flux ratios.

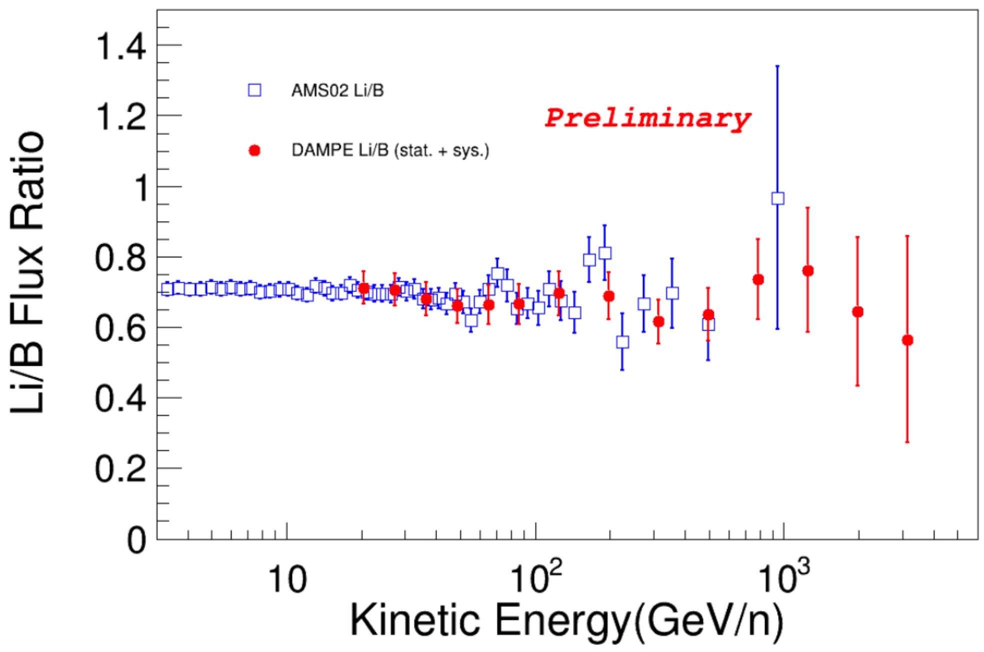
Energy range: 16 GeV/n to 4.1 TeV/n

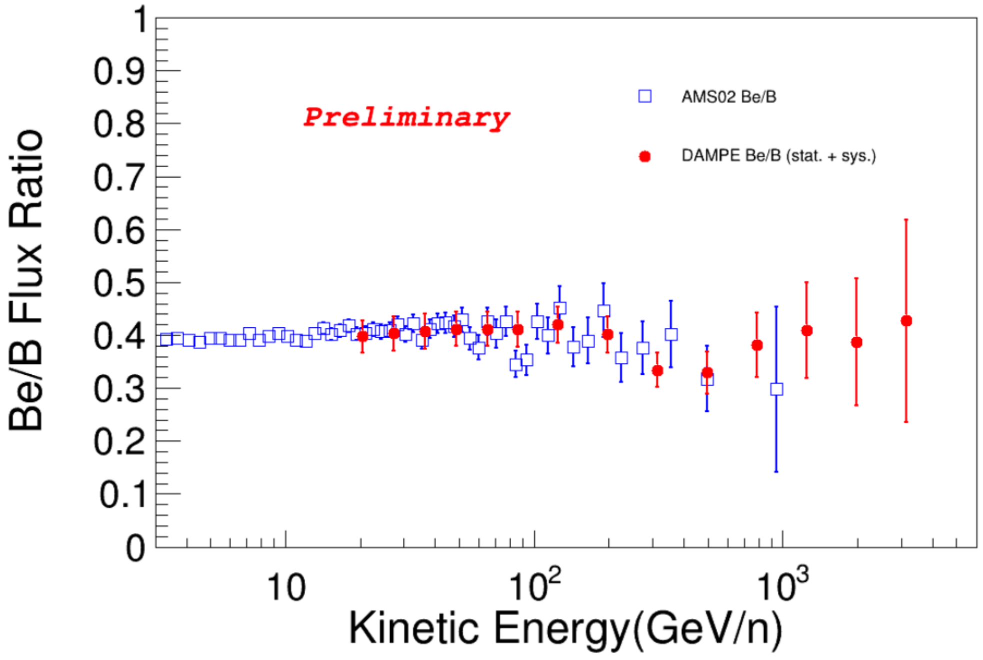
Systematic uncertainties are preliminary

Push to higher energies to test grammage at sources, re-acceleration, …

[C. Evoli et al, Phys. Rev. D 99, 103023 (2019)]

Flux ratios





Preliminary measurement of Li/B, Be/B

Energy range: 16 GeV/n to 4.1 TeV/n

Systematic uncertainties are preliminary

Conclusions

- DAMPE has published important results regarding secondary cosmic rays in the latest years
- **B/C and B/O ratios** published in **2022** on Science Bulletin
- **B flux** published in **2025** on PRL
- All fluxes point to a hardening that is propagation-driven
- **Preliminary Li, Be fluxes** do confirm overall picture
- Important to push measurements to highest energies possible to test different theories (re-acceleration, grammage at sources, …)