Is the B/C slope in AMS-02 data actually telling us something about the diffusion coefficient slope ?

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Scientific motivations and goals

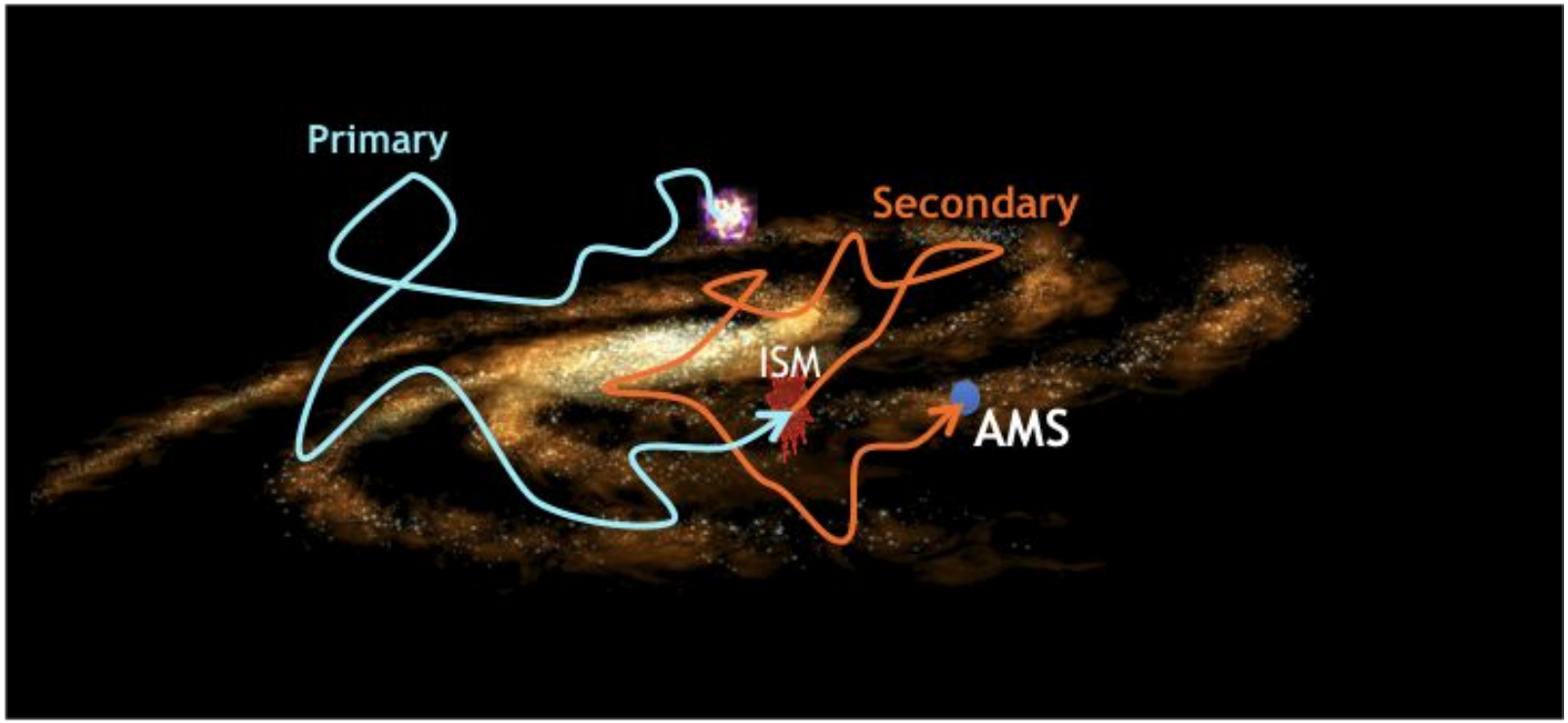
There is a common misconception about the fact that high-energy B/C data from AMS-02 directly provides the slope of the diffusion coefficient, implying that additional effects at play (convection, reacceleration, and destruction) can be neglected.

$$\boxed{\frac{\Phi_S}{\Phi_P} \propto R^{-\delta} \quad or \quad \frac{\Phi_S}{\Phi_P} = kR^{-\delta} \quad ??}$$

Using the code USINE for CR propagation and taking into account all relevant processes, we study:

- the slope of the B/C in different propagation scenarios, and compare to the B/C data from AMS-02.
- the slope for different CR species, and compare to the AMS-02 results.

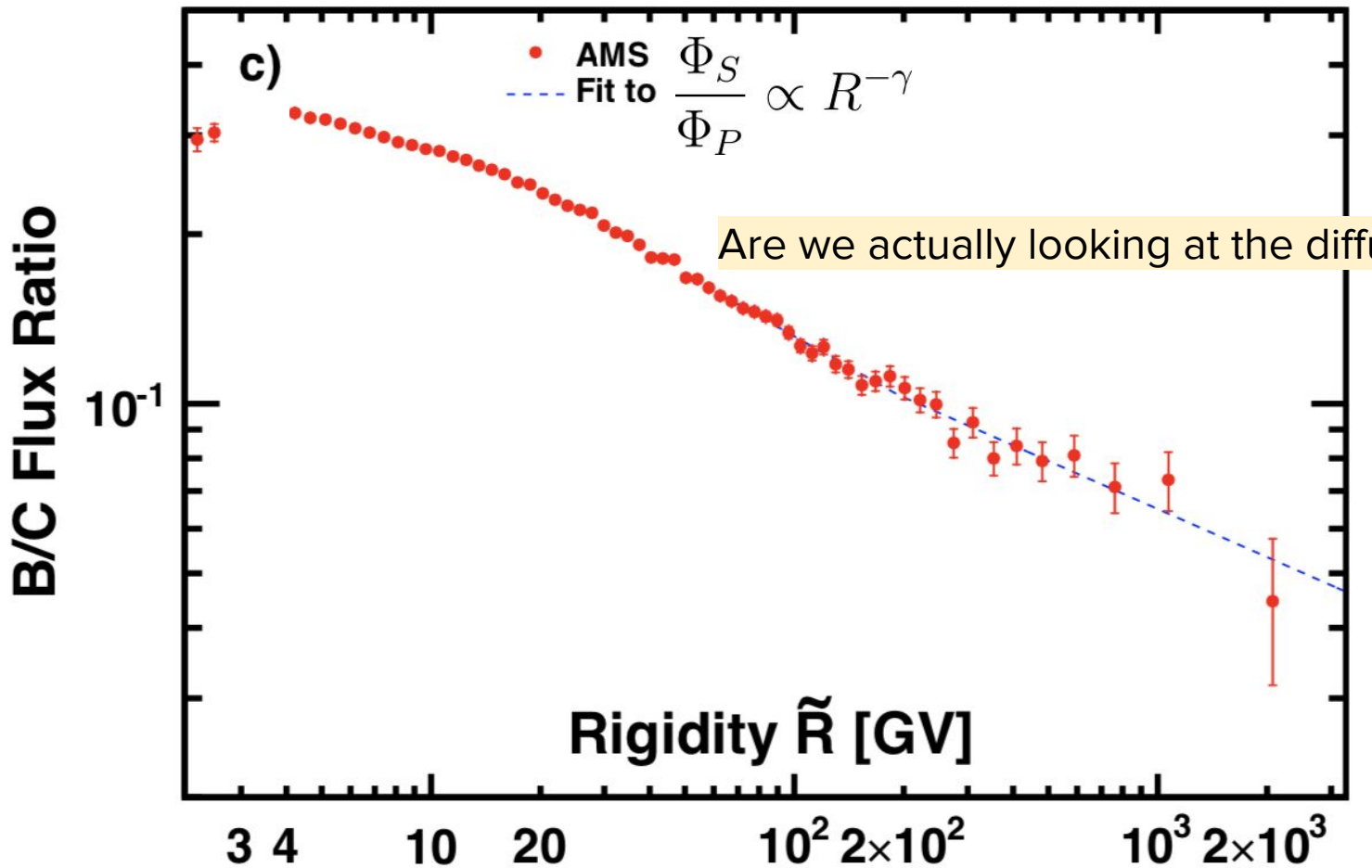
Primary and secondary cosmic ray species



$$\Phi_P \propto R^{-\alpha-\delta}, \quad \Phi_S \propto R^{-\alpha-2\delta} \rightarrow \frac{\Phi_S}{\Phi_P} \propto R^{-\delta}$$

Secondary-to-primary ratios measurements

PRL 120, 021101 (2018)



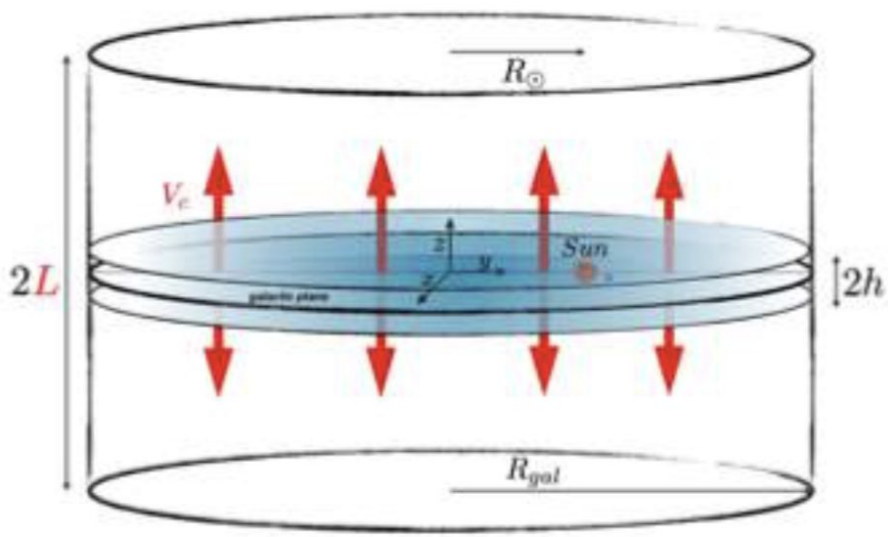
Are we actually looking at the diffusion coefficient ?

Cosmic ray transport description

Transport equation for a CR species of index α (steady-state):

$$-\vec{\nabla}_{\mathbf{x}}\left\{K(E)\,\vec{\nabla}_{\mathbf{x}}\psi_\alpha - \vec{V}_{\rm c}\psi_\alpha\right\} + \frac{\partial}{\partial E}\left\{b_{\rm tot}(E)\,\psi_\alpha - \beta^2\,K_{pp}\,\frac{\partial\psi_\alpha}{\partial E}\right\} + \sigma_\alpha\,v_\alpha\,n_{\rm ism}\,\psi_\alpha + \Gamma_\alpha\,\psi_\alpha$$
$$= q_\alpha + \sum_\beta\left\{\sigma_{\beta\to\alpha}v_\beta n_{\rm ism} + \Gamma_{\beta\to\alpha}\right\}\psi_\beta\,.$$

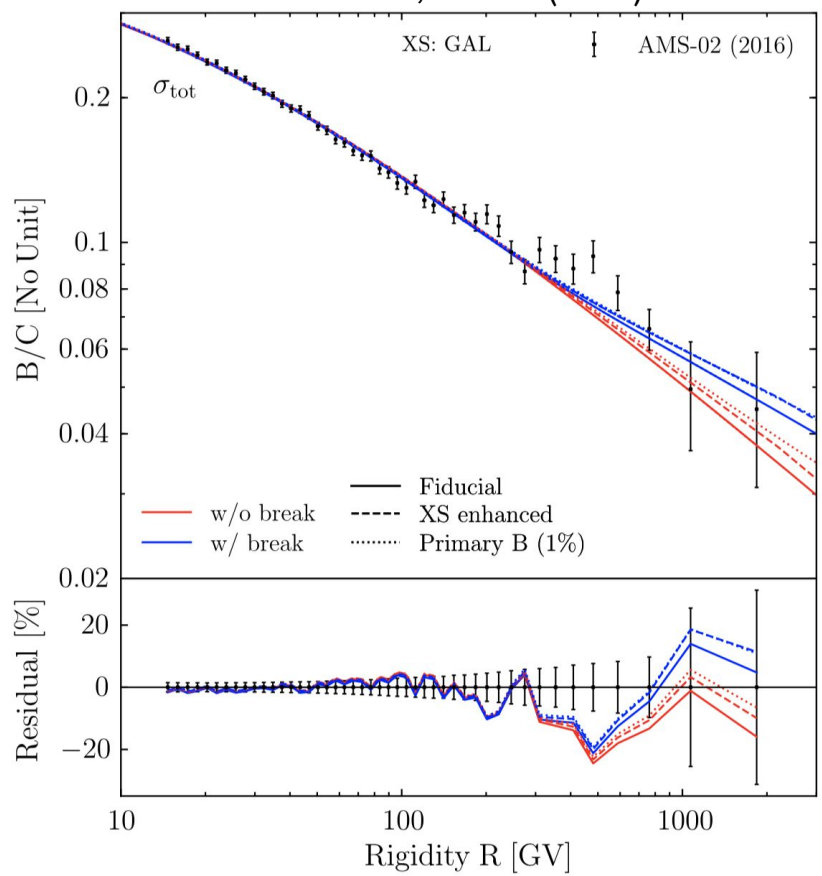
1d model and semi-analytic approach with the USINE code [arxiv: 1807.02968]



The diffusion coefficient

$$K(R) = \frac{\beta^{\eta_T} K_0 R^{\delta}}{\left[1 + \left(\frac{R}{R_b}\right)^{\Delta\delta/s}\right]^{s}}$$

PRL 119, 241101 (2017)



Transport parameters

- 8 transport parameters: L, Va, Vc, K0, delta, eta_T, Delta delta, s, Rb
- Solar modulation is not taken into account.
- In this study: L = 10 kpc, V_a=90.45 km/s, V_c=0 km/s, delta=0.5, eta_T=-0.85, Delta delta = 0.4 , s=0.08, R_b=300 GV

See talks by Y. Genolini and L. Derome

Test on diffusion-only scenario

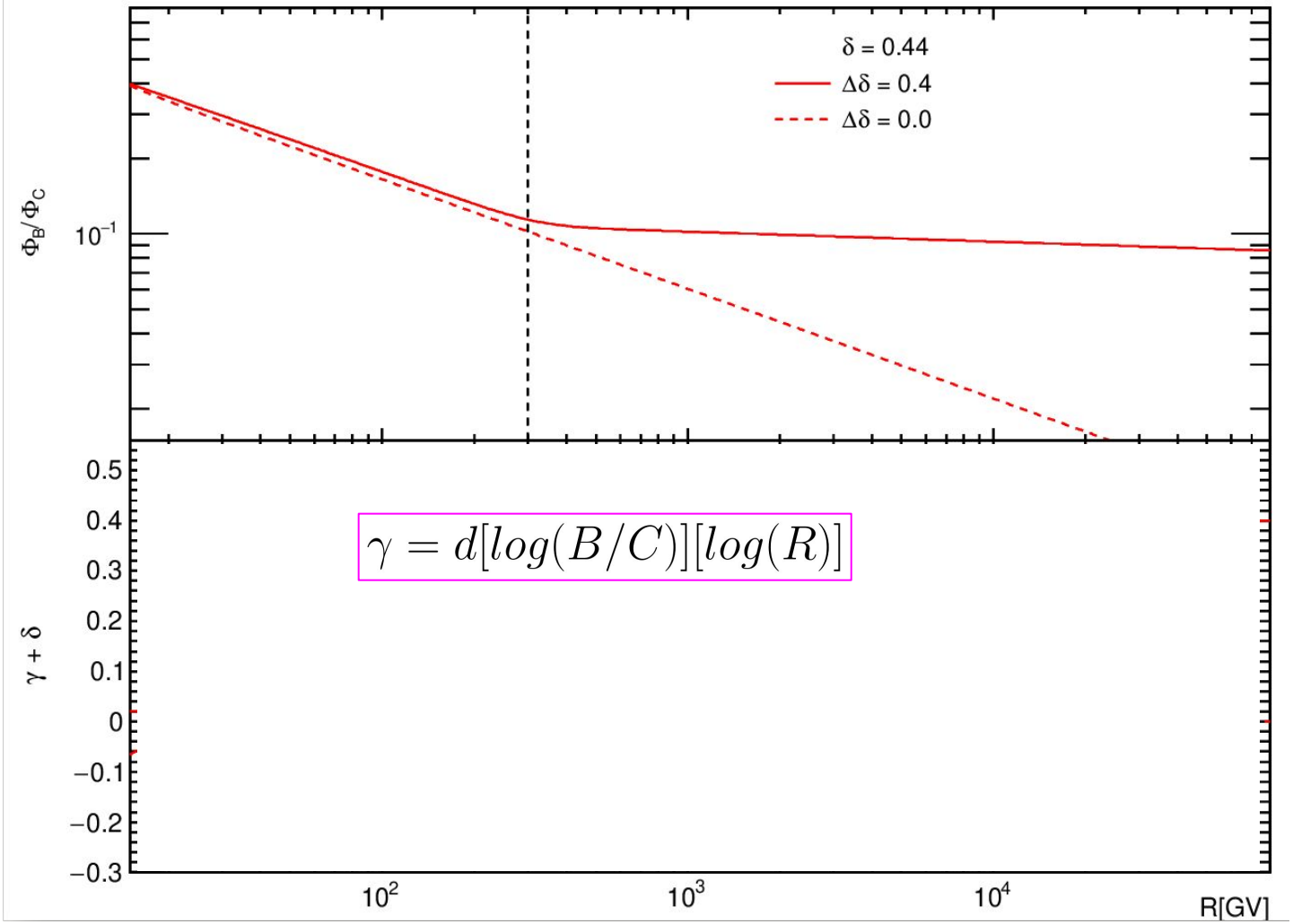
Transport equation for a CR species of index α (steady-state), neglecting all terms but diffusion, source and production by spallation.

$$- \vec{\nabla}_{\mathbf{x}} \left\{ K(E)\, \vec{\nabla}_{\mathbf{x}} \psi_\alpha - \cancel{\mathbf{V}} \right\} + \frac{\partial}{\partial E} \left\{ \cancel{\theta} \psi_\alpha - \beta^2 \cancel{K} \frac{\psi_\alpha}{E} \right\} + \sigma_\alpha \cancel{v} \psi_\alpha + \cancel{\Gamma}$$
$$= q_\alpha + \sum_\beta \left\{ \sigma_{\beta \to \alpha} v_\beta n_{\mathrm{ism}} + \Gamma_{\beta \to \alpha} \right\} \psi_\beta \, .$$

B/C on diffusion-only scenario

Goal: simulate the B/C for a given set of propagation parameters, and study its slope

(https://lpsc. in2p3.fr/usine)

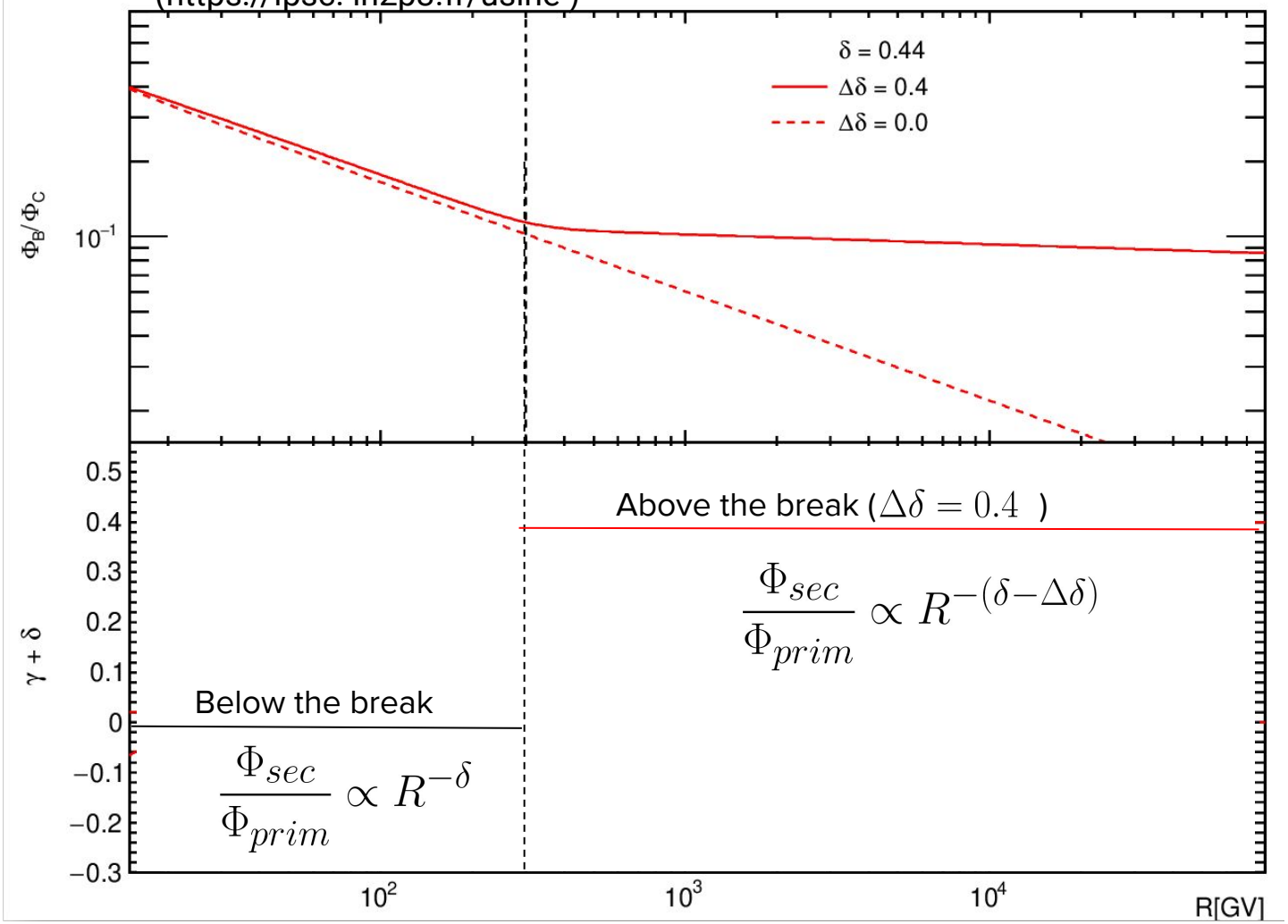


$$\gamma = d[log(B/C)][log(R)]$$

Diffusion-only scenario

Sanity check: simulate the B/C for a given set of propagation parameters, and study its slope

(https://lpsc. in2p3.fr/usine)



Diffusion-only scenario

Sanity check: simulate the B/C for a given set of propagation parameters, and study its slope

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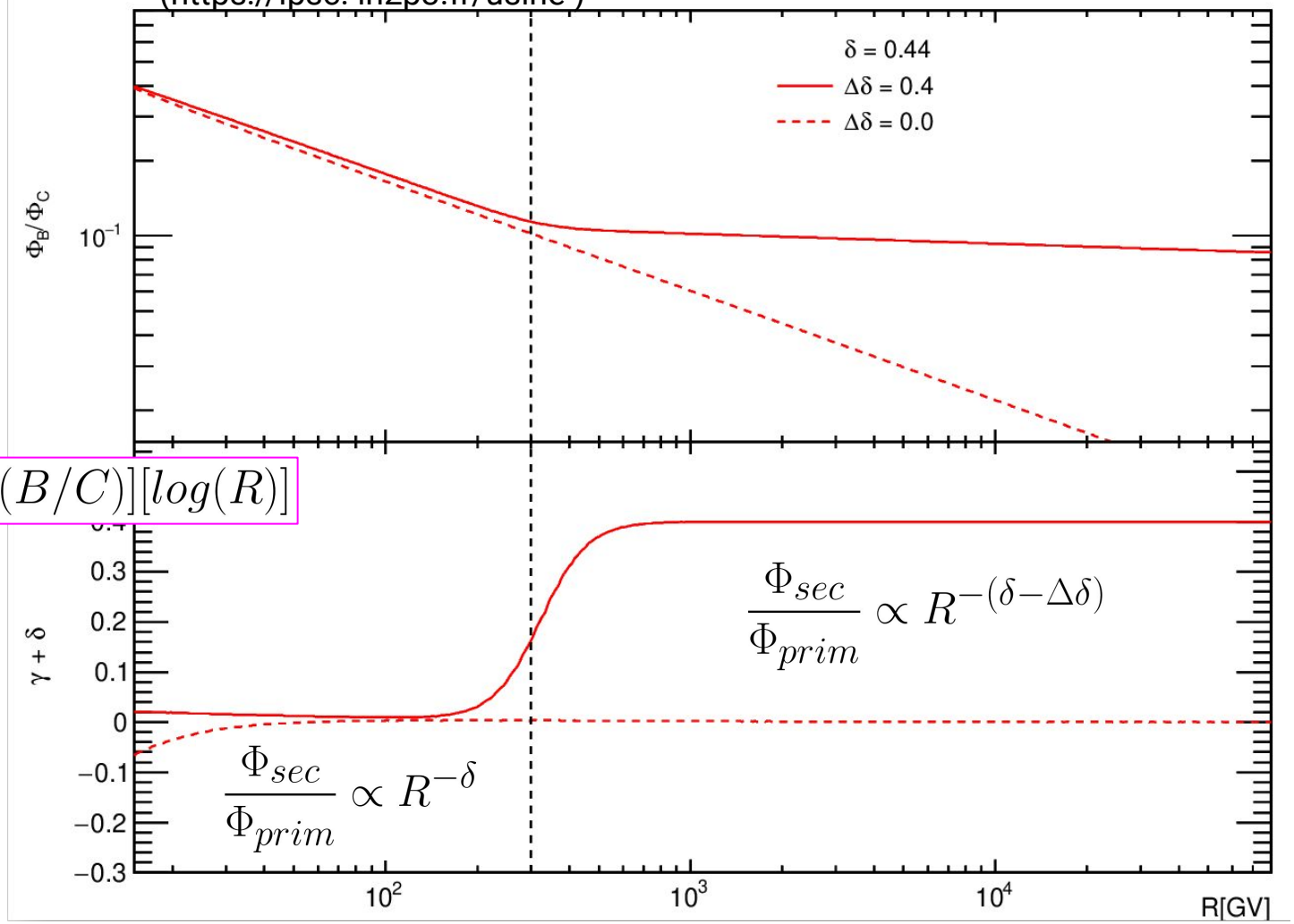


$$\gamma = d[log(B/C)][log(R)]$$

Full transport equation

Transport equation for a CR species of index α (steady-state), neglecting all terms but diffusion, source and production by spallation.

$$- \vec{\nabla}_{\mathbf{x}} \left\{ K(E) \vec{\nabla}_{\mathbf{x}} \psi_\alpha - \vec{v}_c \psi_\alpha \right\} - \frac{\partial}{\partial E} \left\{ \dot{E}(E) \psi_\alpha - \beta^2 D_{EE}(E) \frac{\partial \psi_\alpha}{\partial E} \right\} - \sigma_\alpha v \psi_\alpha + \Gamma_\alpha \psi_\alpha$$
$$= q_\alpha + \sum_\beta \left\{ \sigma_{\beta \to \alpha} v_\beta n_{\rm ism} + \Gamma_{\beta \to \alpha} \right\} \psi_\beta \ .$$

Convection

Energy losses

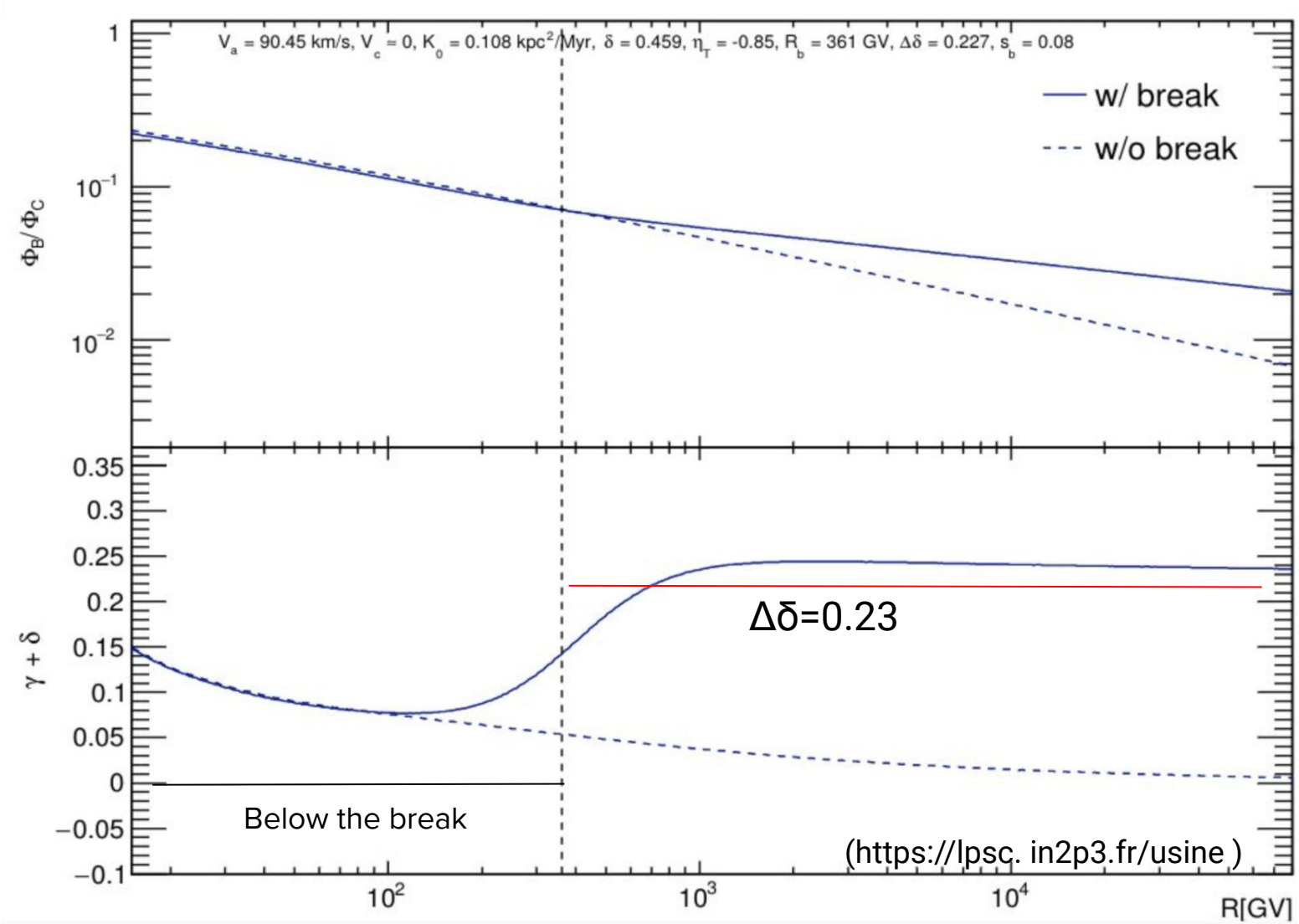
Re-acceleration

destruction

decay

Full transport equation

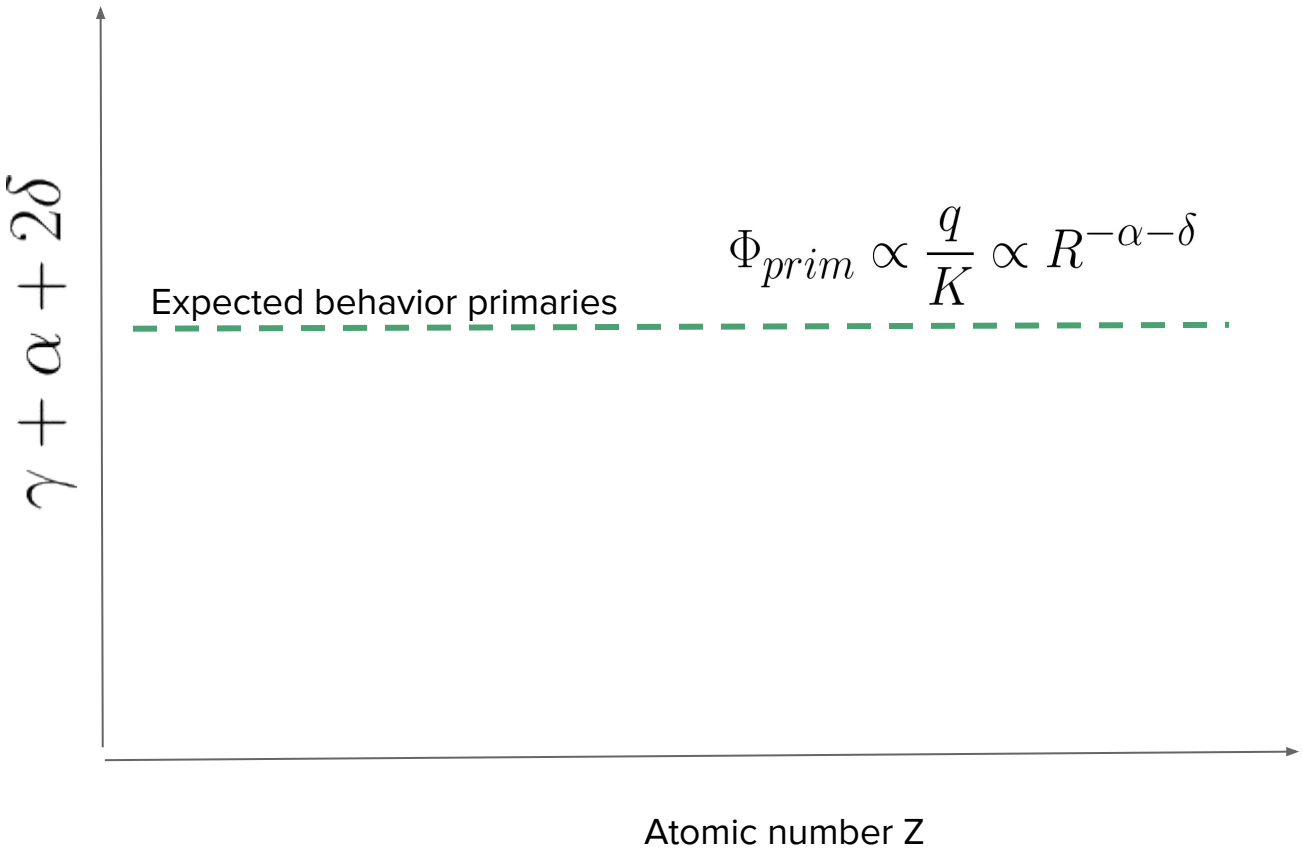
The B/C slope is not constant, its rigidity dependence is shaped in particular by inelastic interactions up to TeV energies.



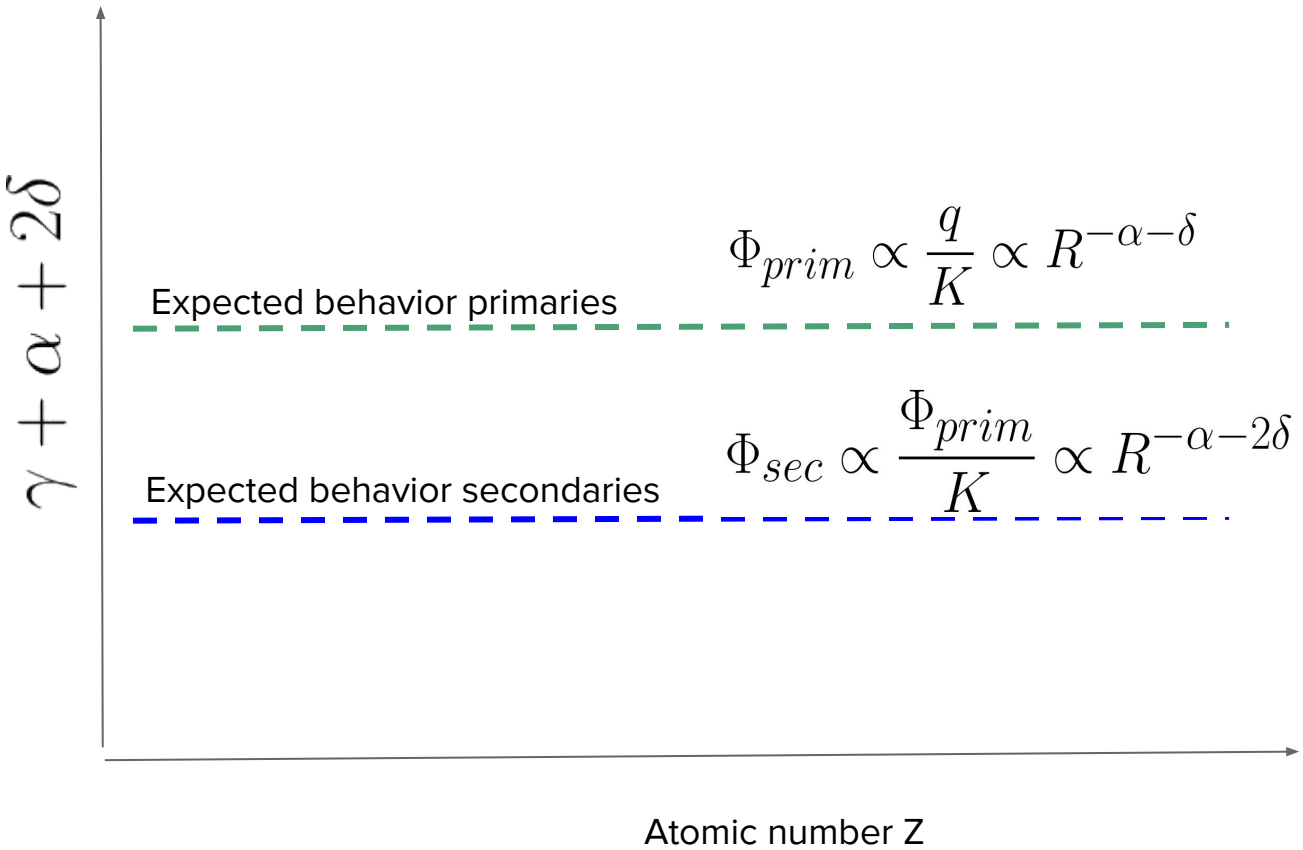
Take home message

To be completed...

Flux slope dependence on Z



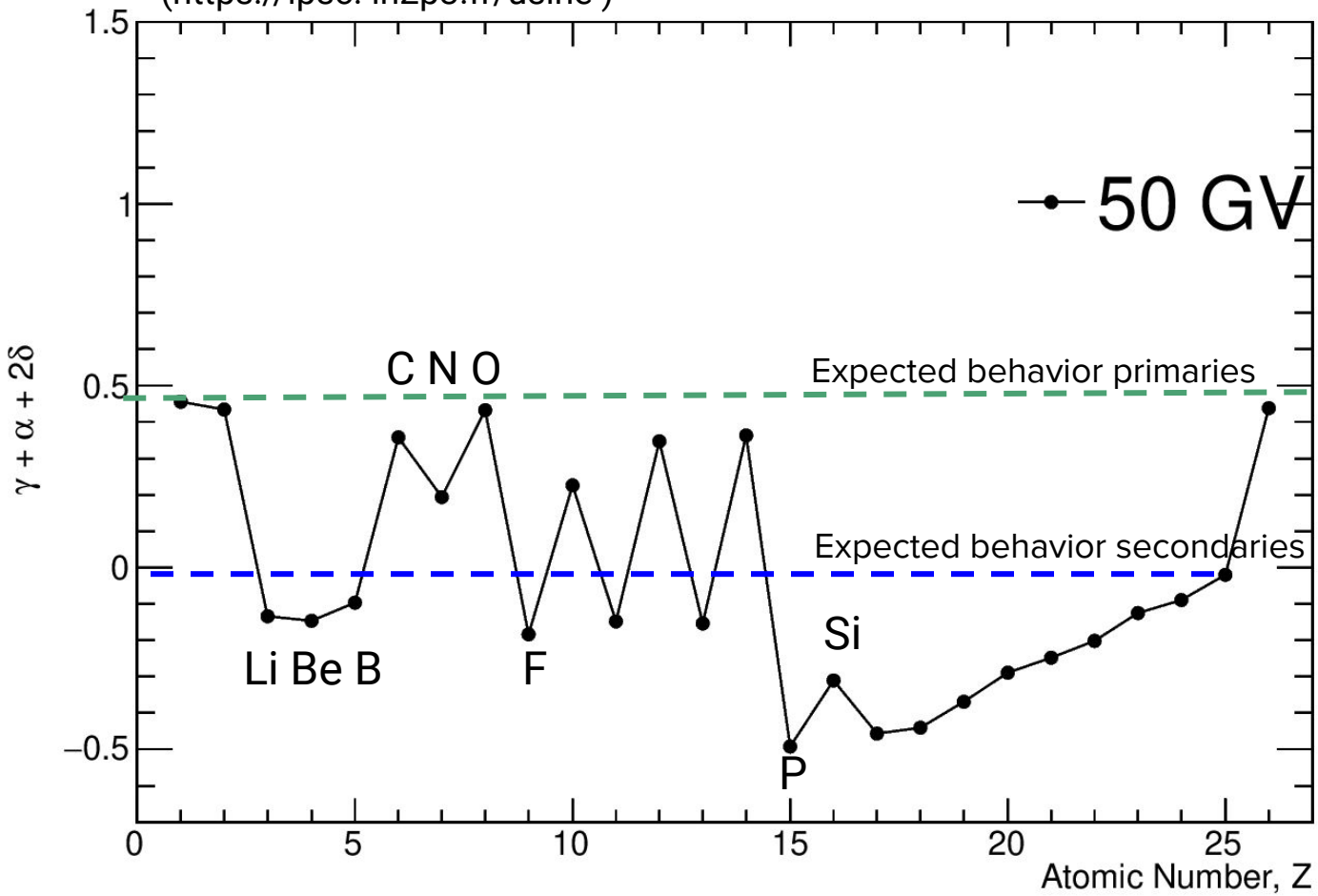
Flux slope dependence on Z



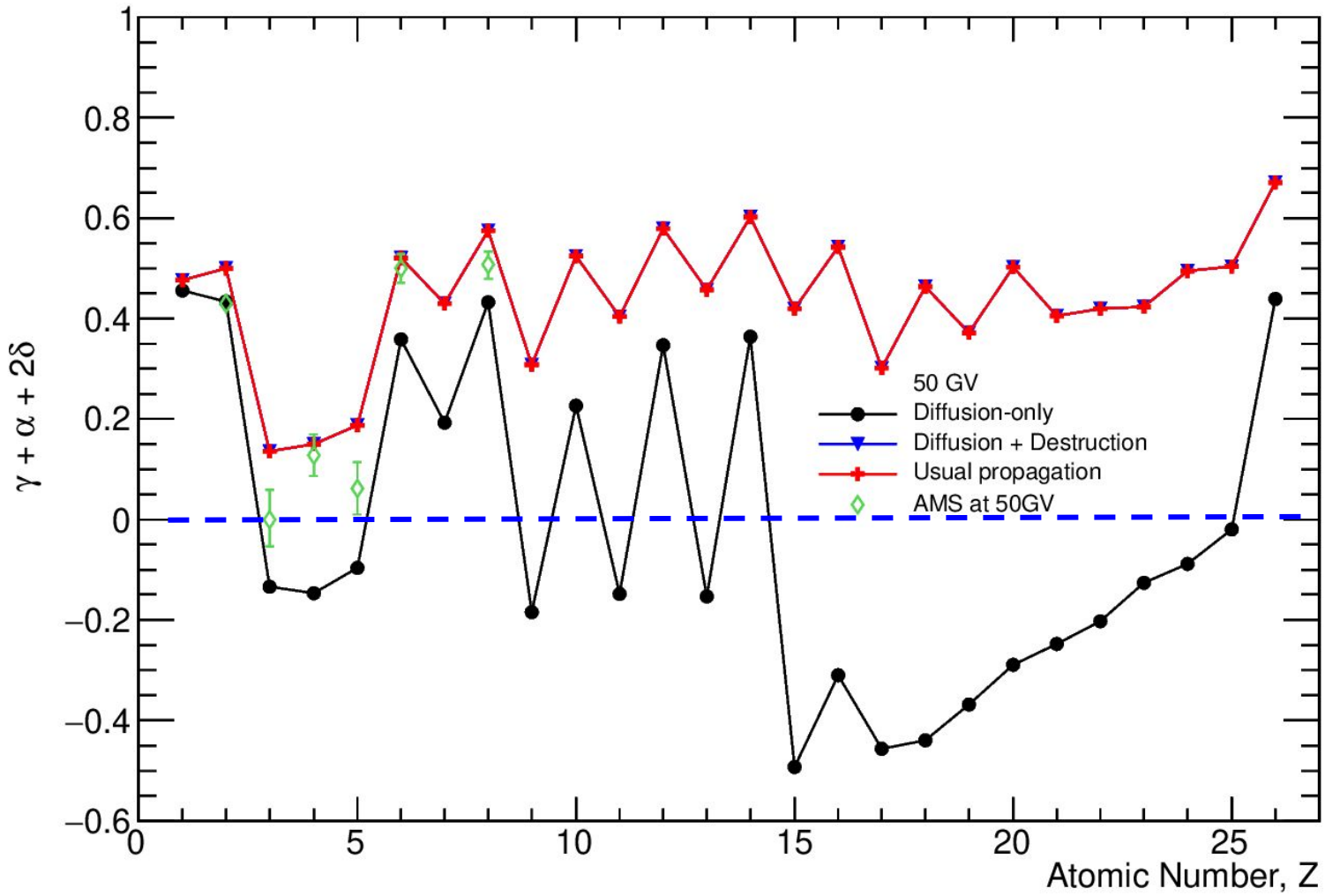
Flux slope dependence on Z: diffusion-only scenario

Propagation parameters used:
Source spectral index α = 2.23 (universal)
δ=0.46
Δδ=0.23

(https://lpsc. in2p3.fr/usine)



Flux slope dependence on Z: full transport scenario



Summary

In progress

- The measurement of the boron to carbon flux ratio provides relevant insights on the cosmic-ray transport in the Galaxy.
- The slope of the diffusion coefficient is different from the slope of the B/C data: the additional transport effects at play (convection, reacceleration, and destruction) cannot be neglected.
- The slope dependence as a function of the atomic number Z is also studied: again, diffusion cannot be considered as the only relevant mechanisms at play, especially destruction. Heavier species are more impacted than lighter ones.