18 Cosmic Ray Secondary nuclei: observations and impact on theories | CRD

Convener: Laurent Derome | Igor Moskalenko | Nahee Park

The session will be organized as 1 min per summary (3 min for AMS-02) followed by max. ~3 min (18 min for AMS-02) of discussions
Physicists Coffee Bar is open for further discussions after this meeting: https://desy.zoom.us/j/96770164890 (BreakOut: Bruno Rossi)

AMS-02	Henning Gast, Qi Yan, Eduardo Ferronato Bueno, Laurent Derome, Francesca Giovacchini
CALET	Yosui Akaike, Wolfgang Zober
DAMPE	Chuan Yue
ISS-CREAM	Eun-Suk Seo
BESS (Cosmic-ray beryllium isotope ratio measured by BESS Polar-II)	Takuya Wada
Super-Tiger	Nathan Walsh
NA61/SHINE	Neeraj Amin

How well do we understand the properties of the Galactic cosmic ray accelerators and of cosmic ray propagation in the Galaxy ? A critical view.	Paolo Lipari
Explaining cosmic ray antimatter with secondaries from old supernova remnants	Philipp Mertsch
Combined analysis of AMS-02 secondary-to-primary ratios: universality of cosmic ray propagation and consistency of nuclear cross sections	Manuela Vecchi
Implications of Li to O data of AMS-02 on our understanding cosmic-ray propagation	Michael Korsmeier
Cosmic-ray propagation analyses and implications of current spallation cross sections parametrisations with the DRAGON2 code	Pedro De la Torre Luque
A unified picture for three different cosmic-ray observables.	Daniele Gaggero
GALPROP Framework for Galactic Cosmic Ray Propagation and Associated Photon Emissions	Igor Moskalenko
Study Of Cosmic Ray Spectral Hardening Using GALPROP	Hongyi Wu
Interpretation of the spectral inhomogeneity in the 10TV region in terms of a close source	Vladimir Yurovsky

Summary of AMS Results for Session #18

Cosmic Ray Secondary nuclei: observations and impact on theories

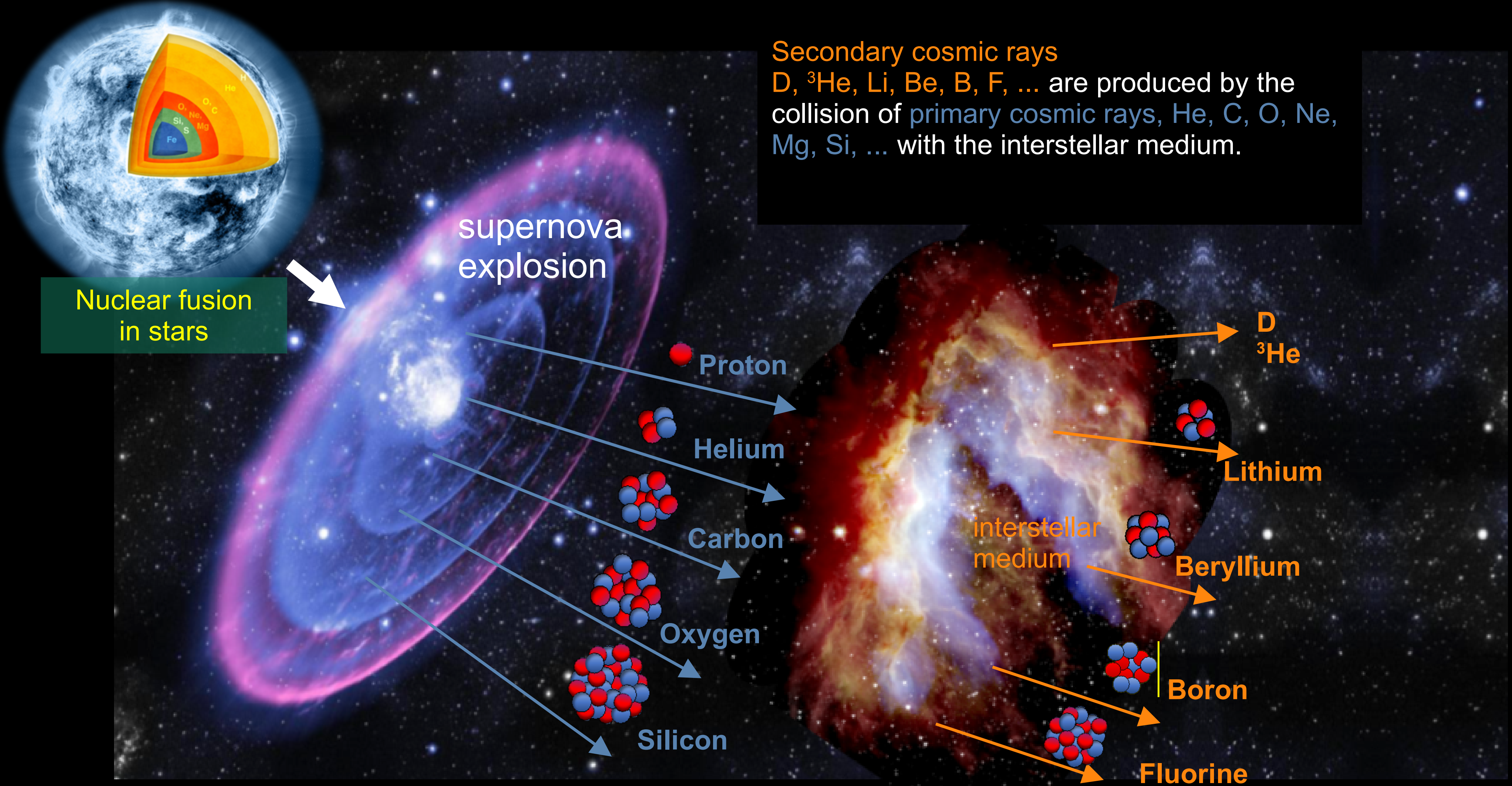
Henning Gast

for the AMS Collaboration

ICRC 2021

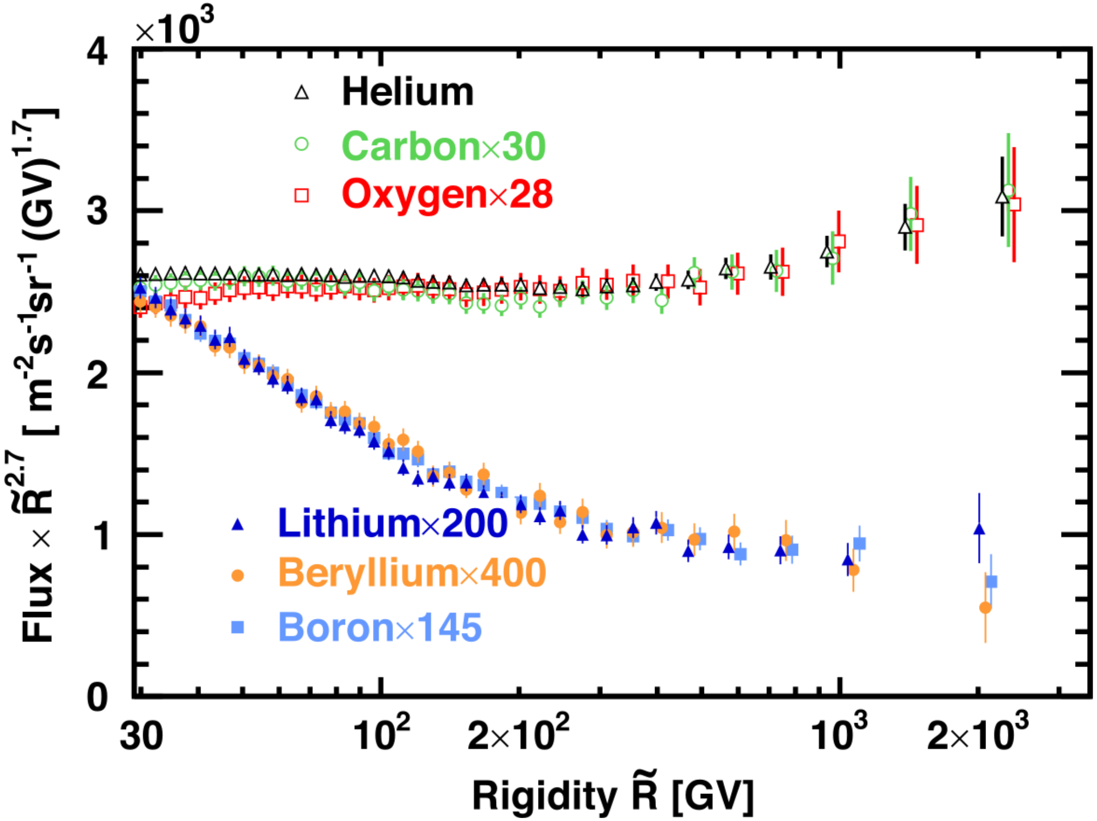
Secondary cosmic rays

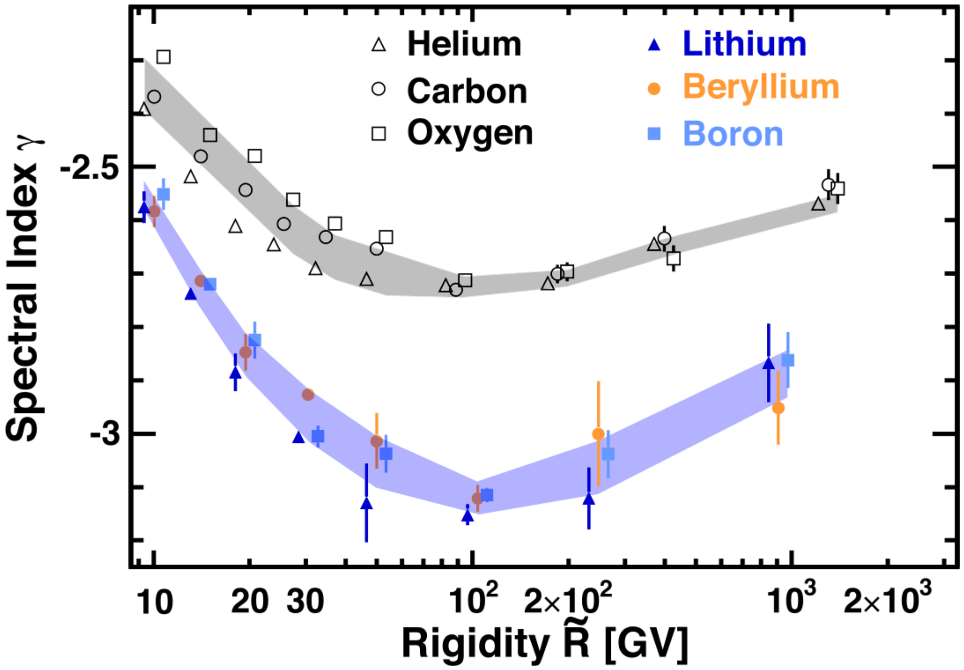
Secondary cosmic rays
D, ^{3}He, Li, Be, B, F, ... are produced by the collision of primary cosmic rays, He, C, O, Ne, Mg, Si, ... with the interstellar medium.



Light nuclei: Lithium, Beryllium, Boron vs He, C, O

Henning Gast
for AMS





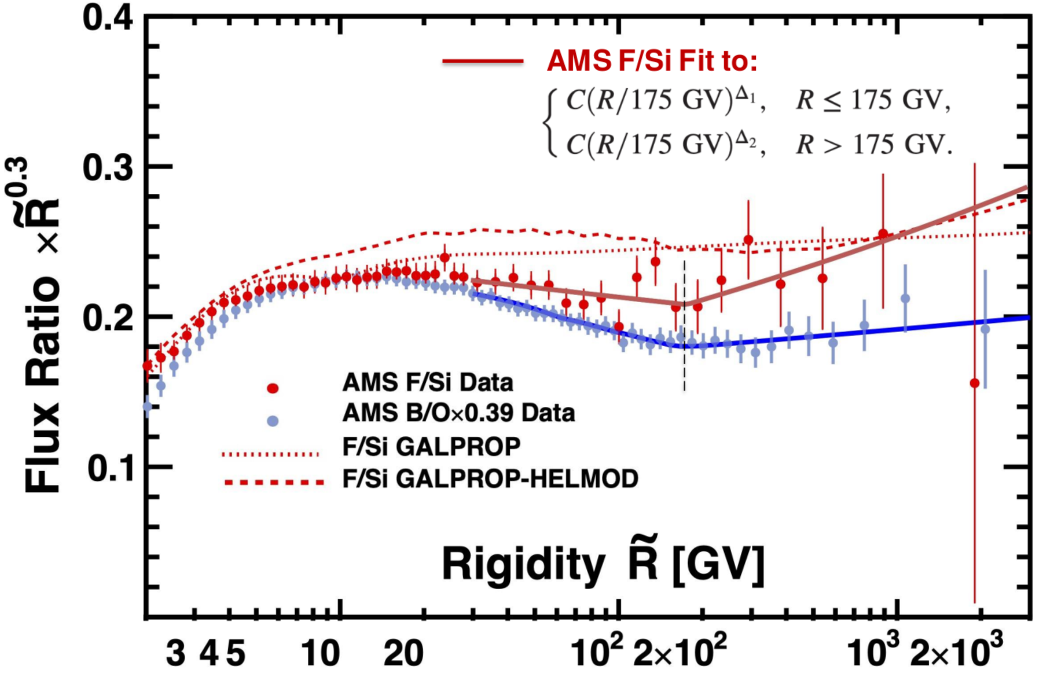
Above ~200 GV, the light secondaries Li, Be, B harden more than the primaries He, C, O.

Average hardening of secondary/primary ratios: $\Delta_{[192-3300]\,\mathrm{GV}} - \Delta_{[60.3-192]\,\mathrm{GV}} = 0.140 \pm 0.025$

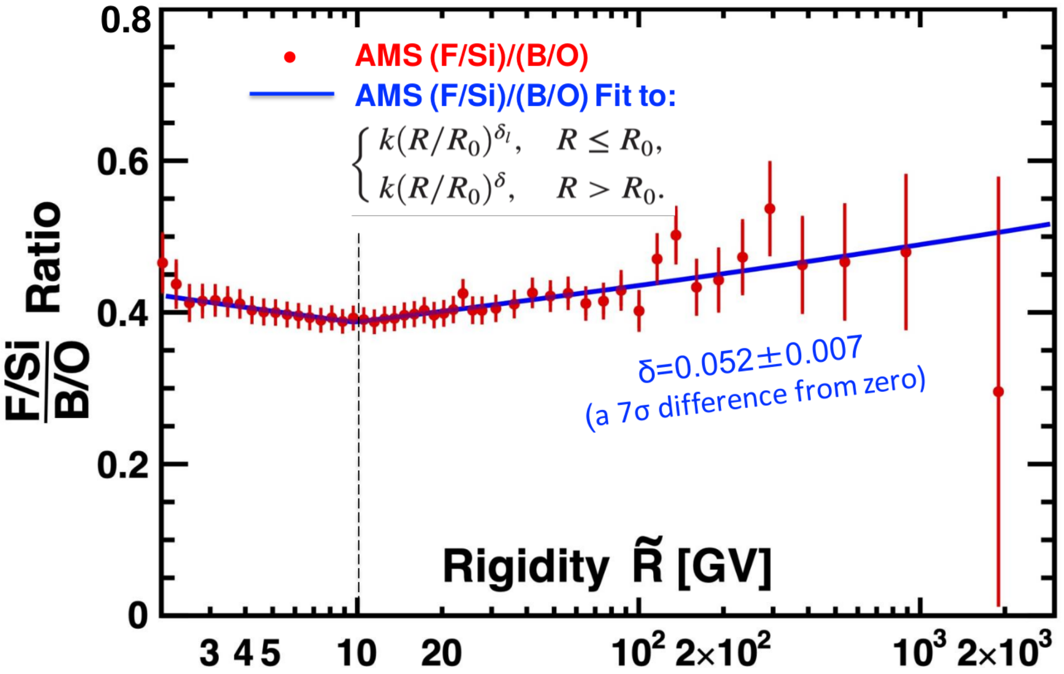
This is consistent with expectations when the hardening is due to propagation in the Galaxy.

Heavy secondary: Flourine

Qi Yan
for AMS



Above 175 GV, the F/Si ratio exhibits a hardening ($\Delta_2^{F/Si} - \Delta_1^{F/Si}$) = 0.15±0.07, compatible with the AMS result on the hardening of the lighter secondary/primary flux ratios.

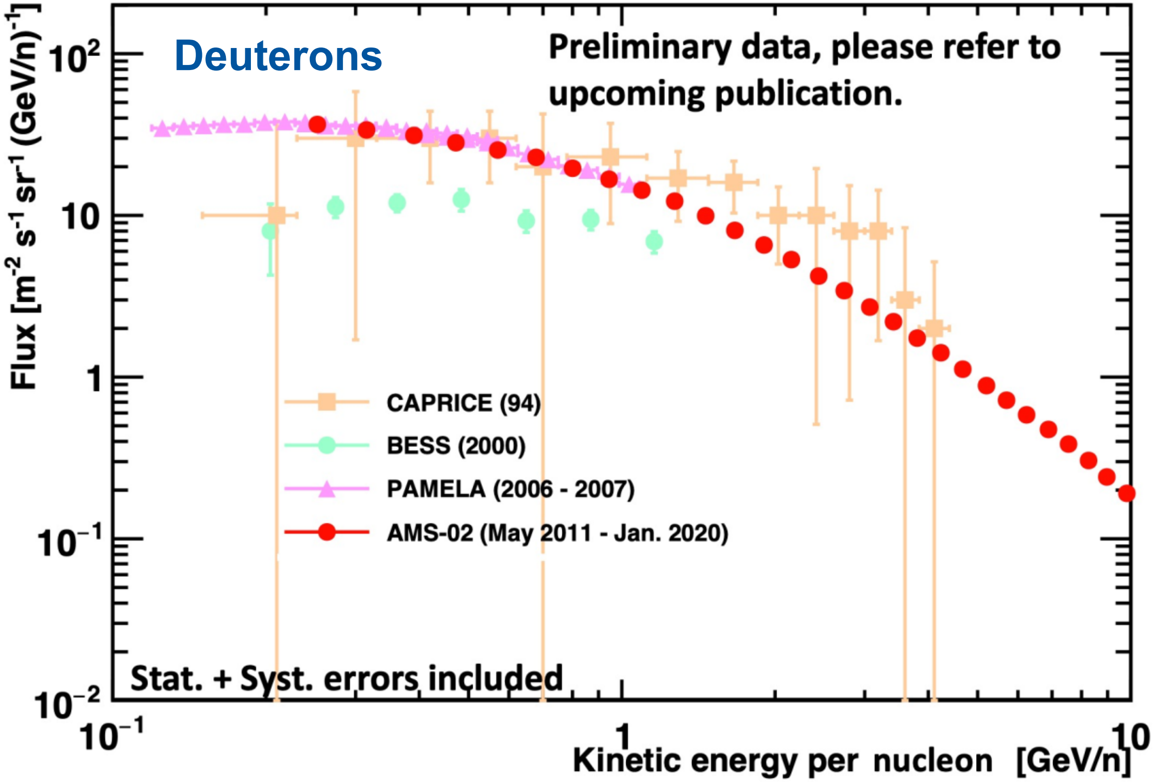


Above 10 GeV, the (F/Si) / (B/O) ratio can be described by a single power law with δ=0.052±0.007, revealing that the propagation properties of heavy cosmic rays, from F to Si, are different from those of light cosmic rays, from He to O.

Deuteron flux

Eduardo Ferronato Bueno for AMS

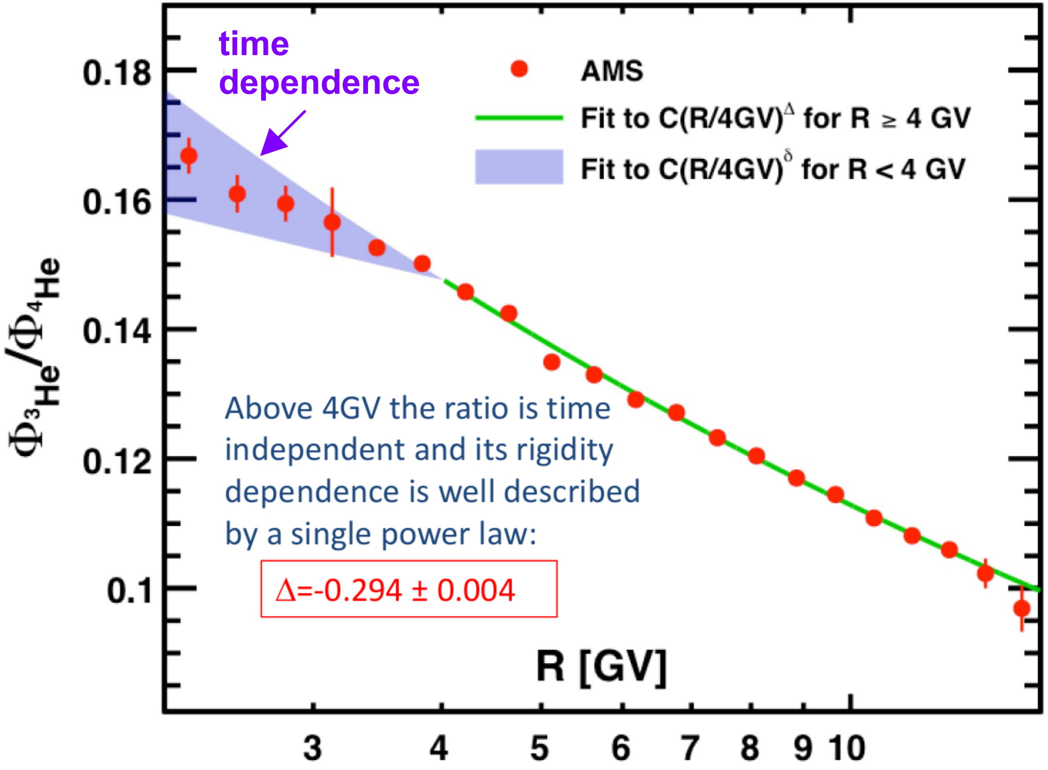
Analysis performed with mass template fits. Results based on 15 million deuteron events detected in 8.5 years.

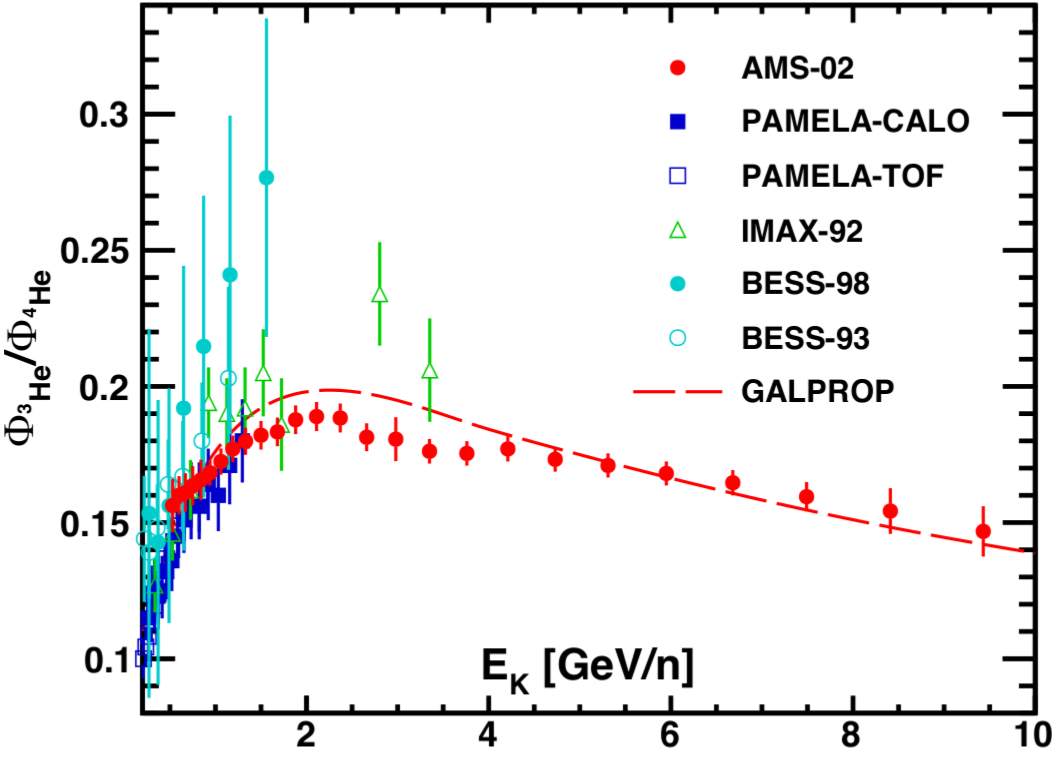


Helium Isotopes

Francesca Giovacchini for AMS

Precision measurements of the ^3He and ^4He fluxes, based on 18 million ^3He and 100 million ^4He events.

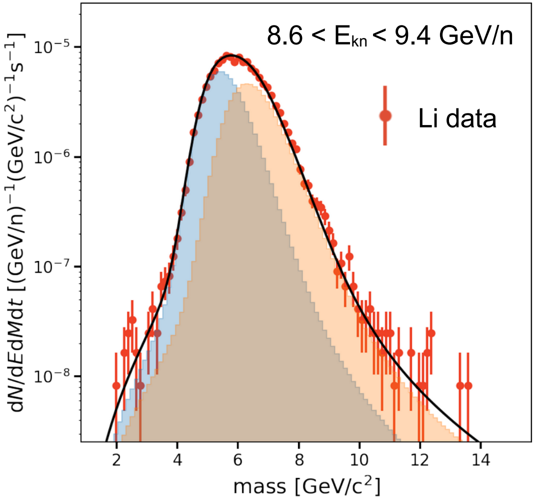


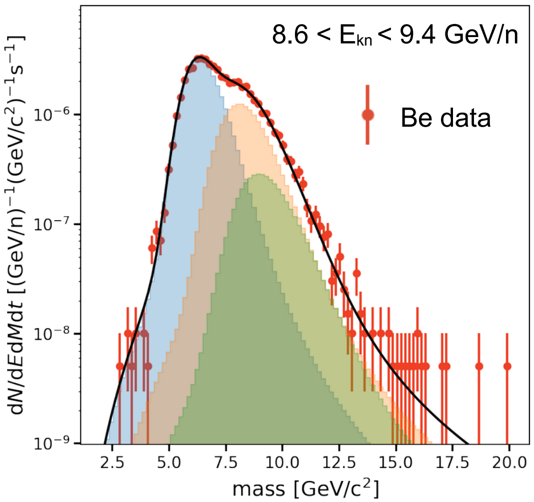


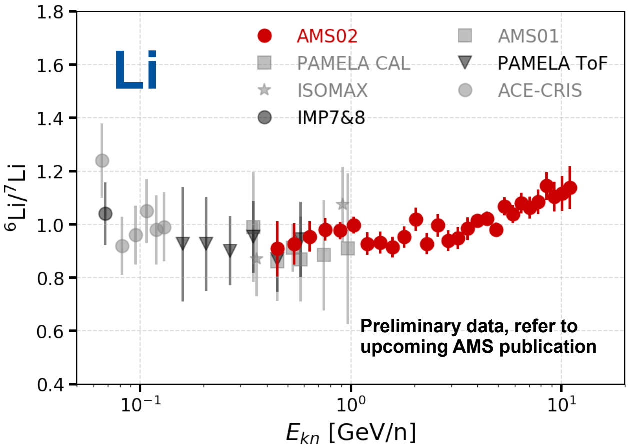
Lithium and Beryllium isotopes

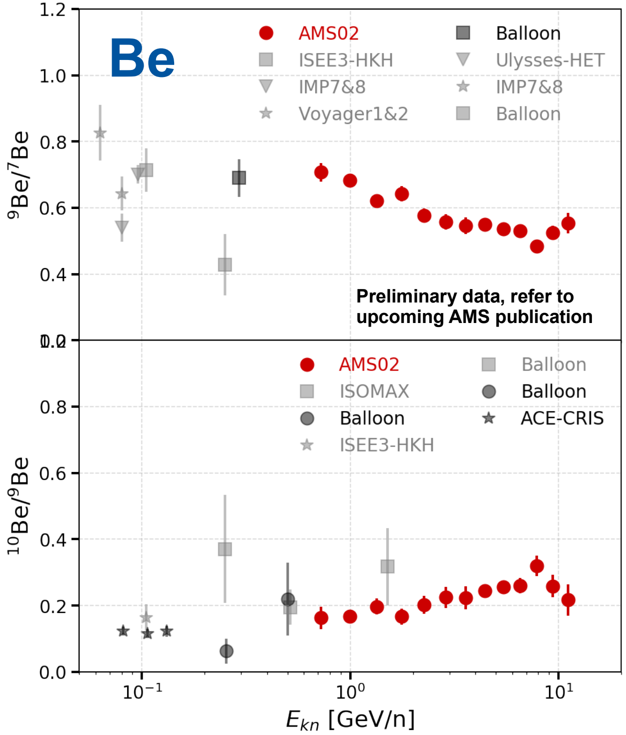
Laurent Derome for AMS

- Measurement of Lithium and Beryllium isotopic fluxes and ratios between 0.4 GeV/n and 11 GeV/n.
- Dedicated method based on template used to fit the event rates vs. mass to measure the isotopic fluxes.
- Results presented based on 0.8 million Lithium events and 0.4 million Beryllium events.
- Systematic errors breakdown and associated covariance matrices presented.









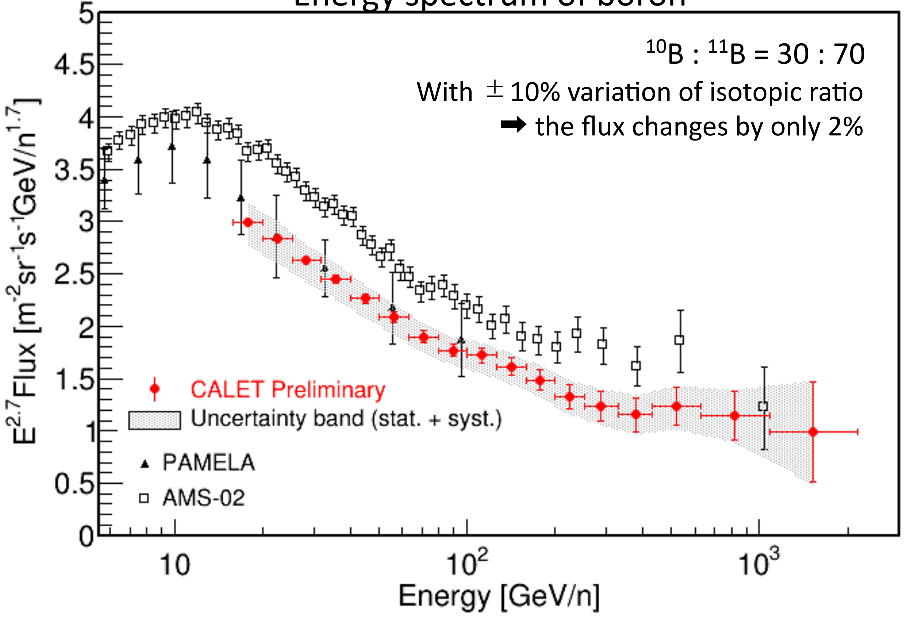
CRD-842

Measurement of Cosmic-ray secondary-to-primary ratios with CALET on the International Space Station

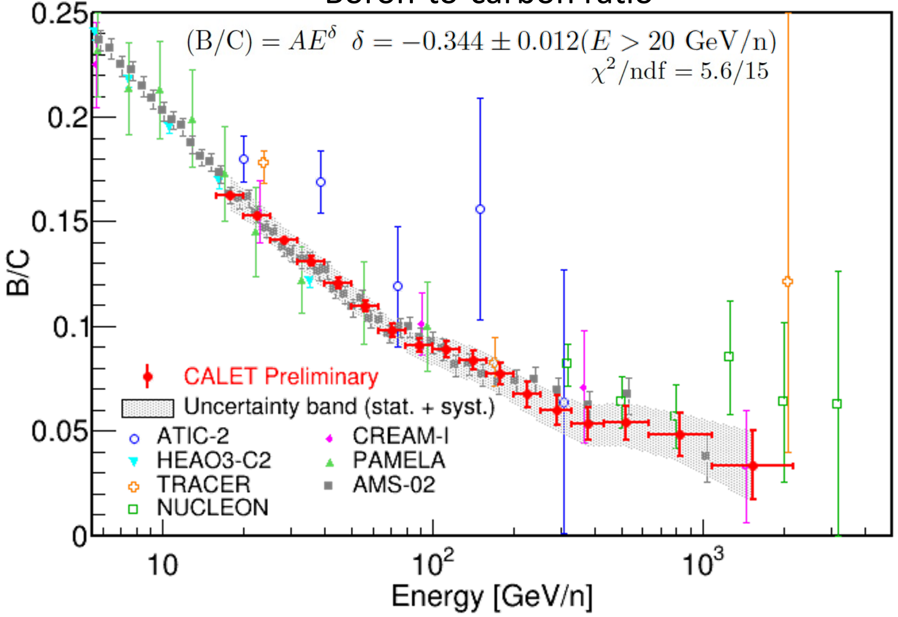
Yosui Akaike (Waseda University),
Paolo Maestro (Siena Univ./INFN-Pisa)
on behalf of CALET collaboration

- Using data for 5 years of operation from October 2015 to September 2020, preliminary results of boron spectrum and B/C ratio from 16GeV/n to 2.2TeV/n are obtained
  - Background for boron is less than 4%
  - Systematics uncertainties: trigger, charge ID, energy scale (beam test), MC model, etc.
- Boron spectrum is consistent with PAMELA, but lower than AMS-02
- B/C ratio is well consistent with previous observations

Energy spectrum of boron



Boron-to-carbon ratio

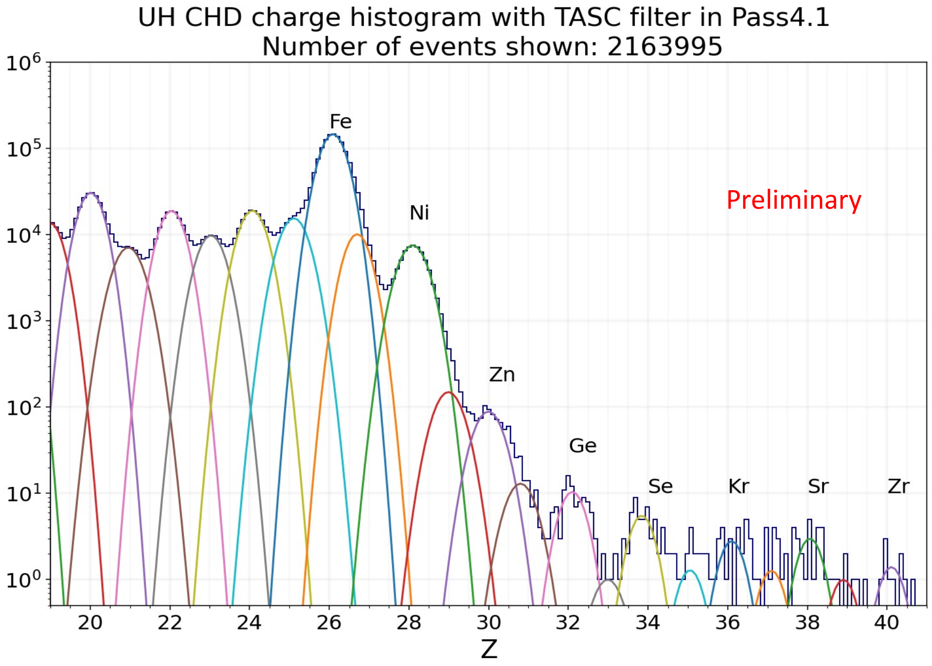


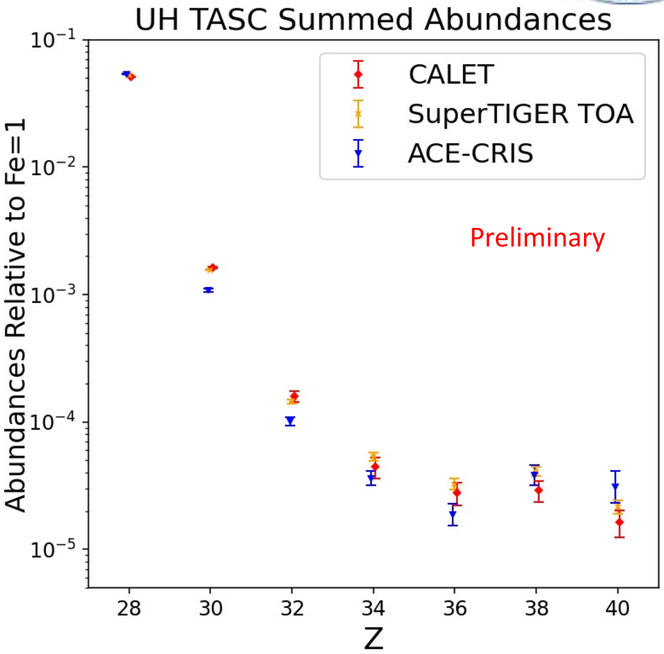
CRD 1044

Progress on Ultra-Heavy Cosmic-Ray Analysis with CALET on the International Space Station

Wolfgang Zober, Brian Rauch (WUSTL), Anthony Ficklin (LSU), Nicholas Cannady (NASA GSFC/CRESST) on behalf of CALET collaboration

- Using data for 5 years of operation from October 2015 to September 2020, we show preliminary results of the relative abundances of elements above Fe through $_{40}$Zr.
- The relative abundances of the summed odd-even peaks are consistent with previous measurements made by both ACE-CRIS and SuperTIGER
  - Error bars are statistical only

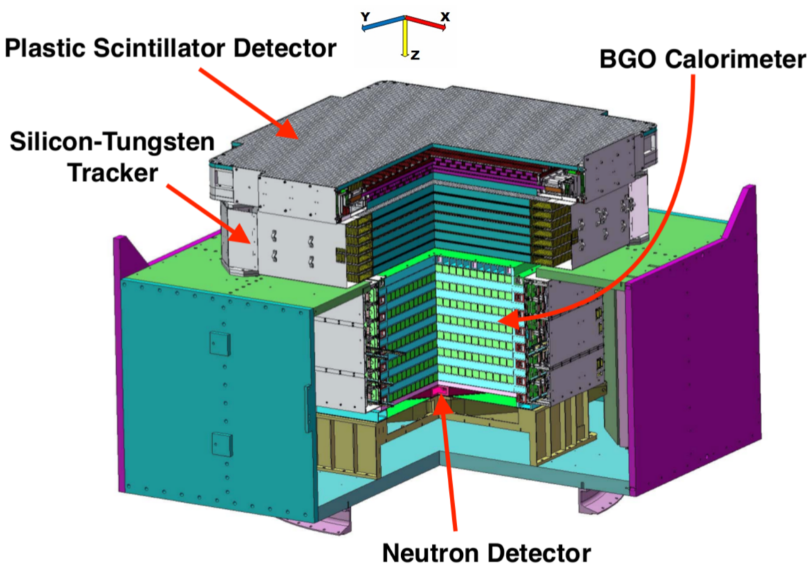


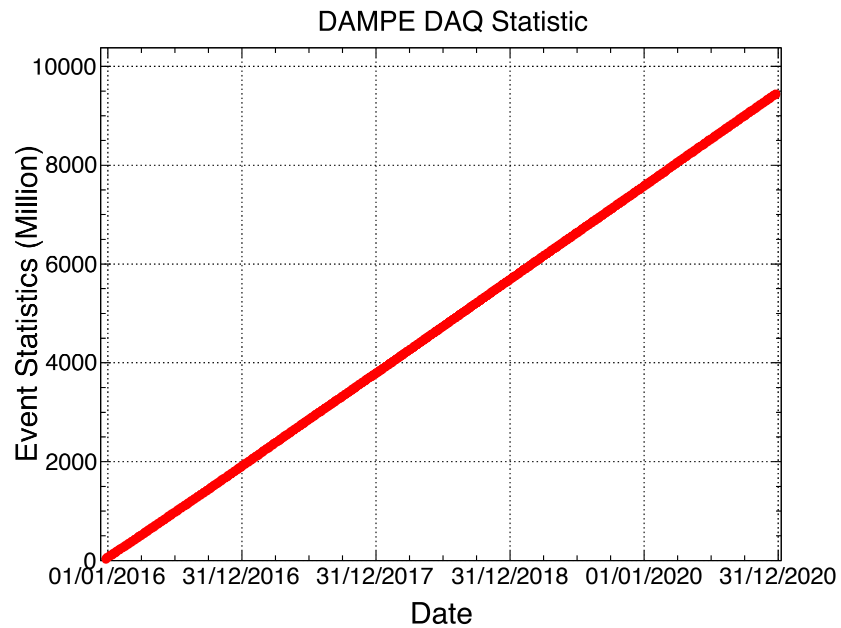


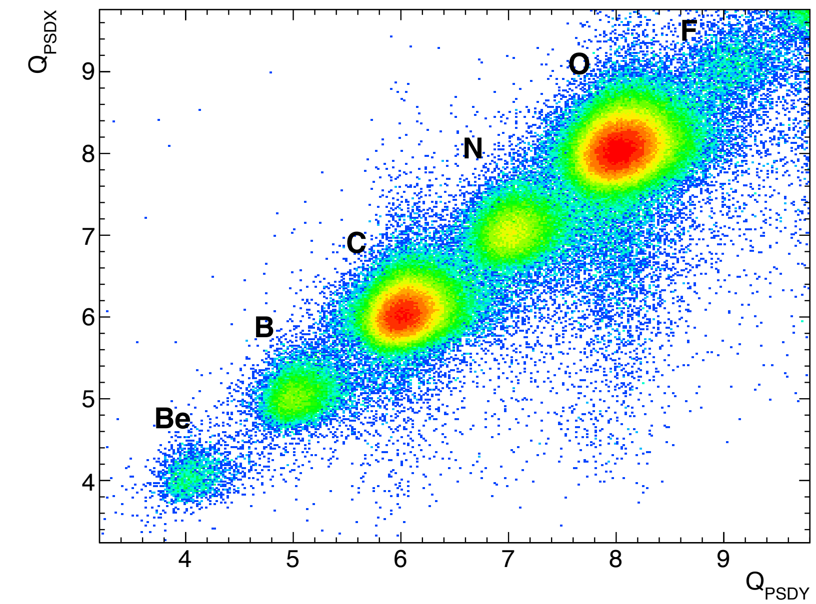
Measurement of the Boron to Carbon Flux Ratio in Cosmic Rays with the DAMPE Experiment

Chuan Yue*, Zhan-Fang Chen, Ming-Yang Cui, Dimitrios Kyratzis, Li-Bo Wu
(on behalf of the DAMPE Collaboration)

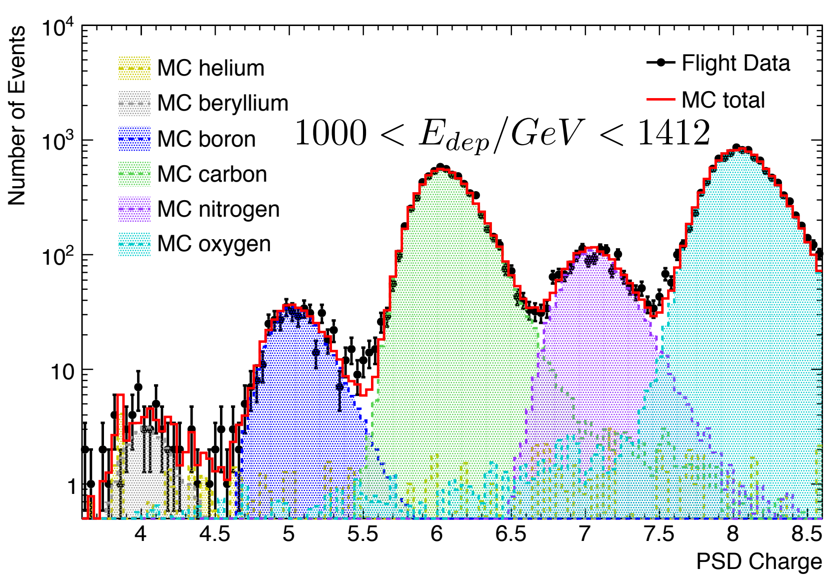
DAMPE

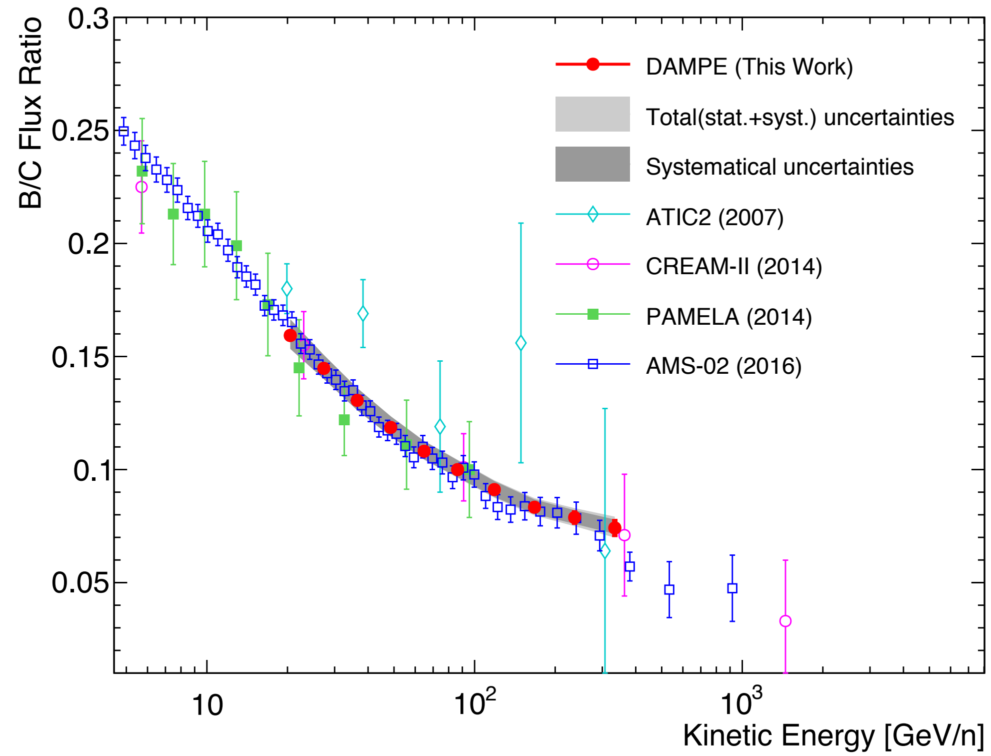




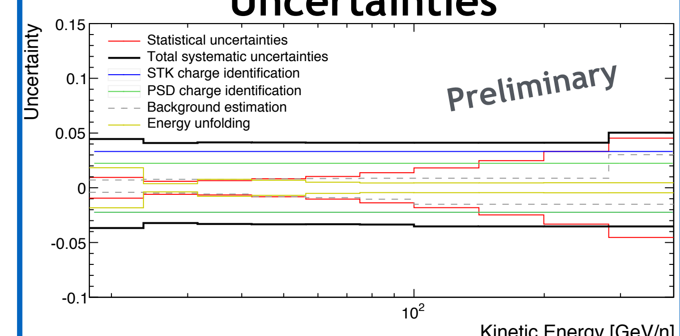


- Since Launched at Dec. 17, 2015, DAMPE ("Wukong") has been operated for more than five and a half years
- Five years of on-orbit data with live time of 1.1977446×10^8 seconds are analysed for the boron to carbon flux ratio





Uncertainties

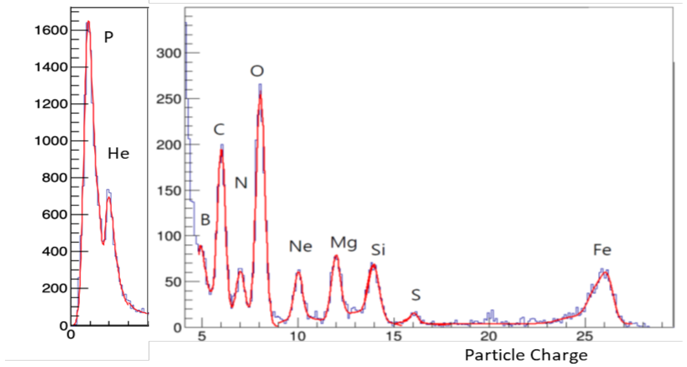


- Preliminary result of B/C flux ratio from 20GeV/n to 400GeV/n has been obtained.
- DAMPE measurement is well consistent with PAMELA and AMS-02 within uncertainties

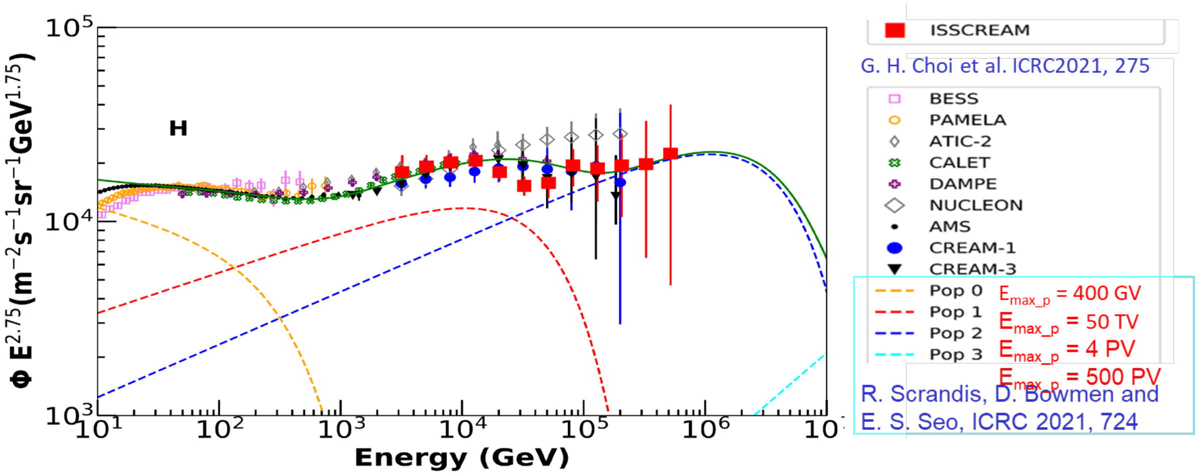
The B/C flux ratio measurement of DAMPE will be extended up to few TeV/n in the near future.

Results from the Cosmic Ray Energetics And Mass for the International Space Station (ISS-CREAM) experiment

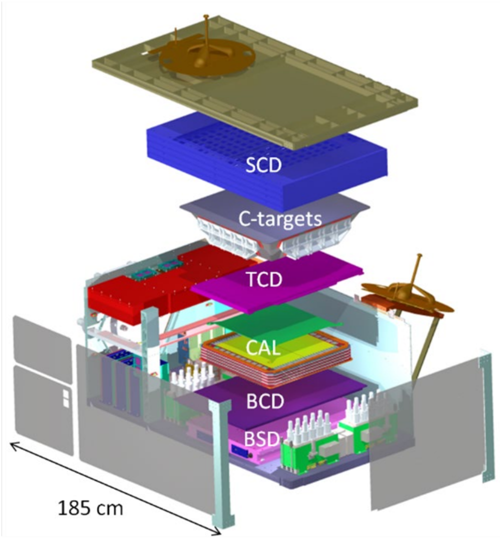
Eun-Suk Seo for the ISS-CREAM Collaboration, PoS(ICRC2021)095

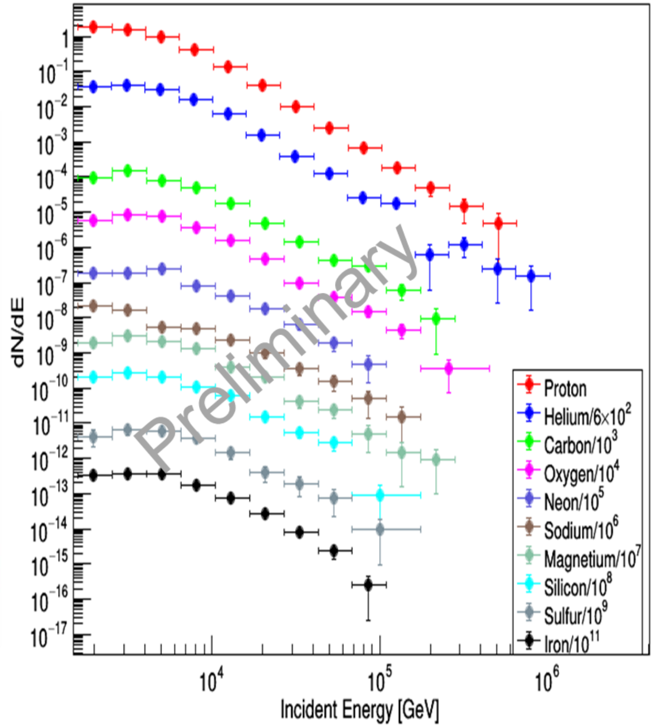


The ISS-CREAM instrument successfully took high-energy cosmic-ray data for 539 days from 8/14/17 to 2/12/19.



- A proton spectrum is measured in the energy range 2.5 - 655 TeV.
  - A broken power law fit to 2.5 – 100 TeV data: $\gamma = 2.65 \pm 0.06$ and a break at ~9.94 ± 4.6 TeV with $\Delta\gamma = 0.26 \pm 0.1$.
  - At higher energies, the softening does not continue but the spectrum becomes harder again.
  - The deviation from a single power law near 10 TeV is consistent with the softening reported by CREAM-I &III, DAMPE, and NUCLEON, but ISS-CREAM extends measurements to higher energies than those prior measurements.
  - The spectral hardening at ~ 200 GV and softening ~ 10 TeV could indicate a transition from one type of source to another.
- Other nuclei analysis is in progress.



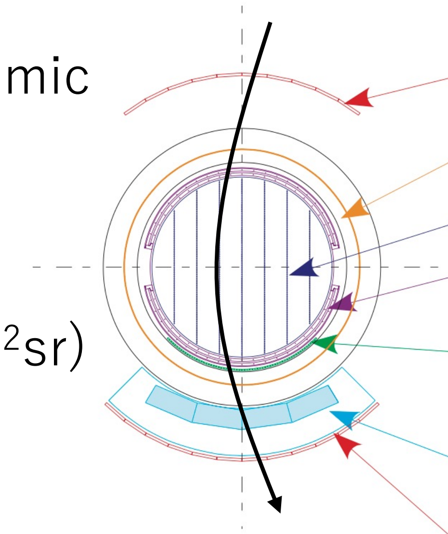


Cosmic-ray Be isotope ratio measured by BESS-Polar II

Takuya Wada (ISAS/JAXA) for the BESS Collaboration

The BESS-Polar II

- Launched in December 2007, observed cosmic rays for 24.5 days
- Tracker on a concentric axis in a solenoid
  - ✓ Larger geometrical acceptance (0.23 m^2sr)
  - ✓ Better rigidity resolution (0.4% at 1 GV)



BESS Data Analysis

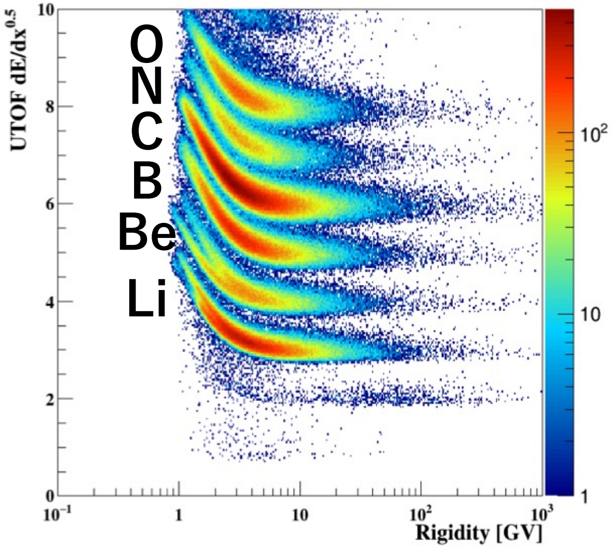
- Published: proton, helium, anti-proton, anti-helium
- Ongoing: anti-deuteron(PoS(ICRC2021)123), ultra-low-energy antiproton, **beryllium isotope**
- This is the first beryllium isotope analysis in the history of BESS

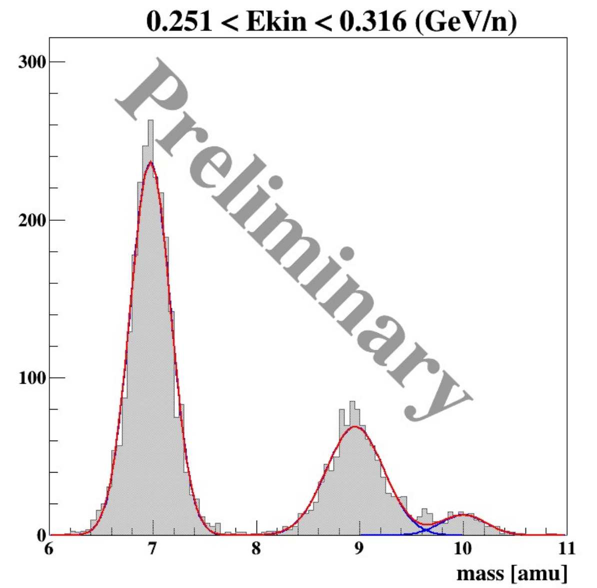
Cosmic-ray Be isotope ratio measured by BESS-Polar II

Takuya Wada (ISAS/JAXA) for the BESS Collaboration

- The BESS-Polar II has sufficient instrument performance to identify Z ≧ 3 events
- Identify the Be events and calculate $^{10}Be/^{9}Be$ ratio
- The detailed study is ongoing following the established analysis method

$$M^2 = (ZeR)^2 \left(\frac{1}{{\beta_{UL}}^2} - 1 \right)$$

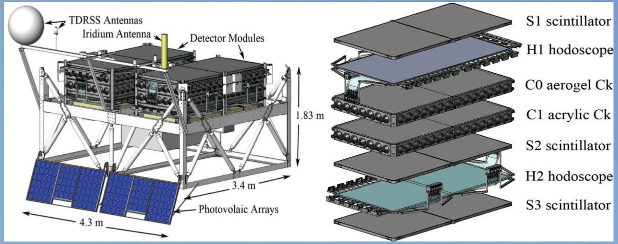




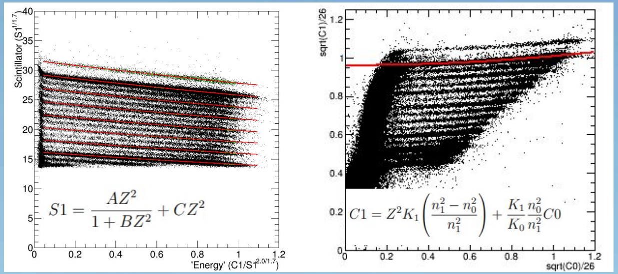
SUPER TIGER
WUSTL · NASA GSFC · CALTECH

SuperTIGER Abundances of Galactic Cosmic Rays for the Charge Interval Z=41-56

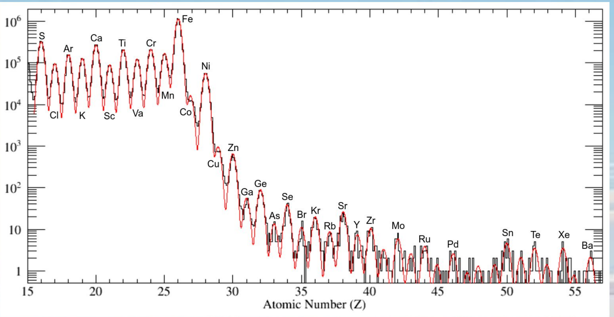
Nathan Walsh for the SuperTIGER Collaboration | ICRC 2021



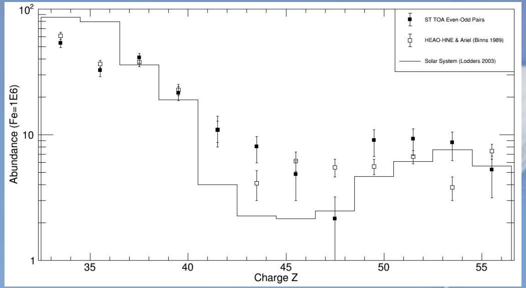
➔ SuperTIGER (Super Trans-Iron Galactic Element Recorder) is designed to measure ultra-heavy galactic cosmic rays (GCR) and probe their source and acceleration mechanism.



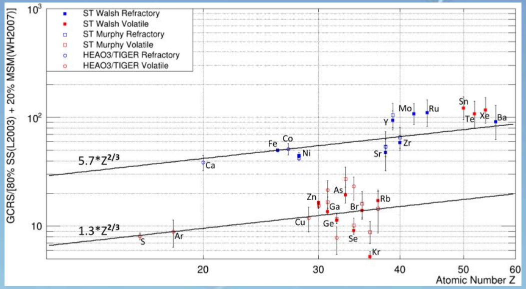
➔ A low-energy (left) and a high-energy (right) charge assignment method is used to extrapolate the *Z* dependence of detector signals to higher signal space, where high-*Z* events appear but charge bands are not visible.



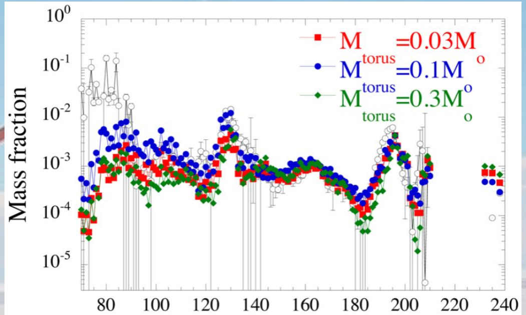
➔ Elements with *Z*>40 shows well defined peaks at even-*Z* elements but very low statistics and lack of clear element resolution at odd-*Z* elements.



➔ There is good consistency between the newly measured charge range and satellites HEAO-3 & Ariel that did not have individual element resolution and thus measured odd-even charge pairs.



➔ The GCRS abundances suggest that the preferential acceleration of refractory elements by OB SNe, seen for GCR with *Z*≤40, does not hold for *Z*>40. Instead, the volatiles are bumped up to the refractory line.



Just et al. 2015

➔ Binary neutron star mergers (BNSM), are known to produce vast amounts of r-process nuclei in a single event. Interestingly, the BNSM r-process production falls off for *Z*<40 (*A*<~90), which is the point where the GCR source model appears to change.

Measurement of Nuclear Fragmentation Cross Sections with NA61/SHINE

Neeraj Amin for the NA61/SHINE Collaboration, Karlsruhe Institute of Technology, Germany

Cosmic Ray Propagation:

$^{12}C + p_{ISM} \rightarrow$ light secondary nuclei (Li, Be, B, ^{11}**C**)

Ghosts in Space:

- Short lived secondary nuclei, $^{11}C \rightarrow {}^{11}B + \beta^{+}$ ($\tau \approx 20$ min)
- Important for total B production

secondary-to-primary flux ratio

precise measurements from AMS, CALET

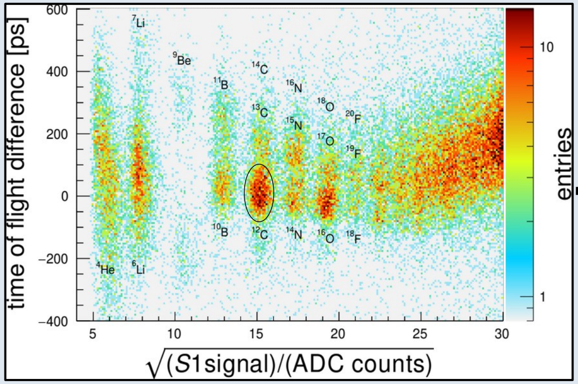
Galactic Cosmic Ray Propagation Models

nuclear fragmentation cross sections

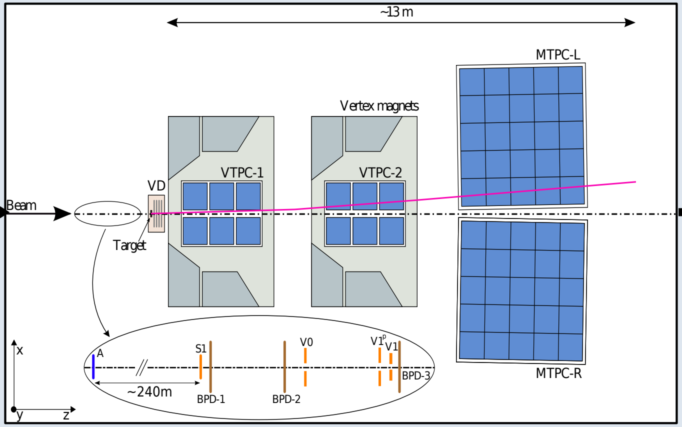
current values induce ~20% uncertainty

Need for precision laboratory measurements of nuclear fragmentation cross sections!

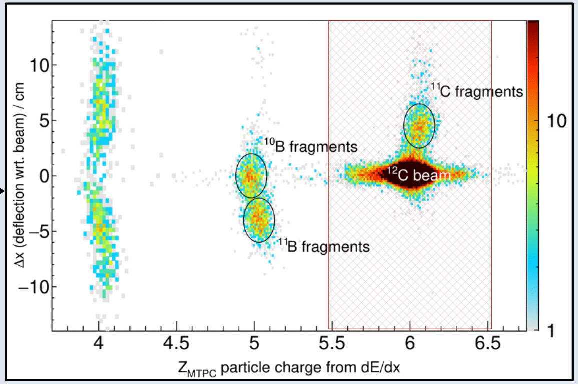
Pilot Run data from NA61/SHINE:



Secondary ion beam composition at NA61/SHINE emerging from H2 beam line



Experimental setup during the 2018 pilot run



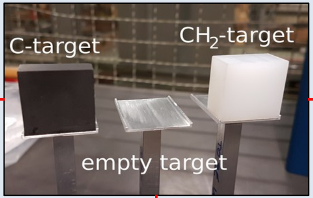
Resultant fragments separated by dE/dx in the main detector

Measurement of Nuclear Fragmentation Cross Sections with NA61/SHINE

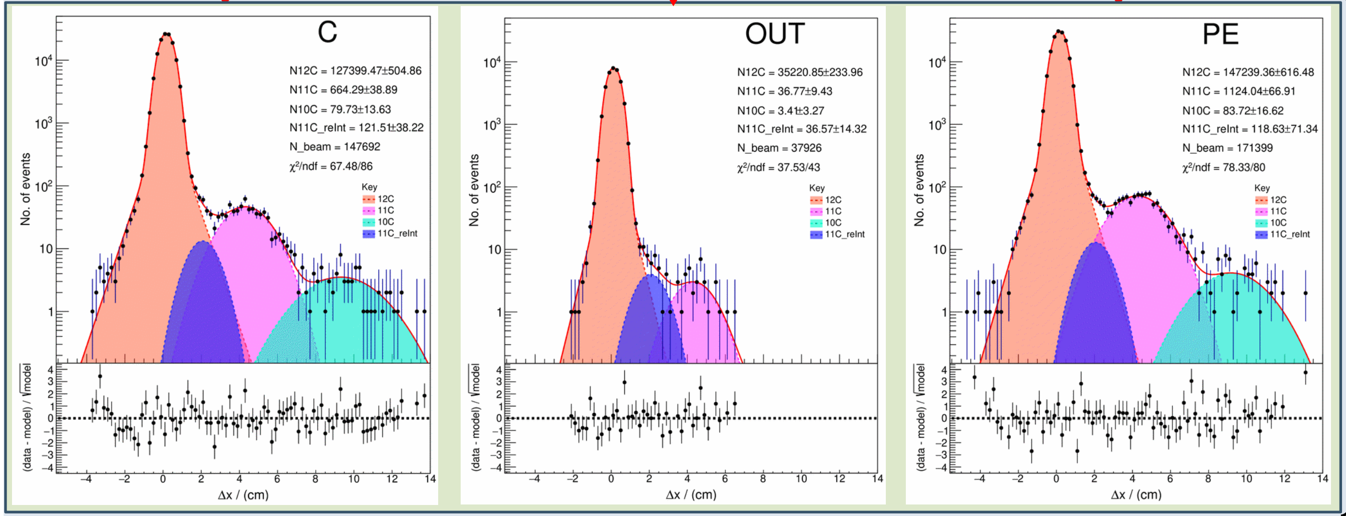
Neeraj Amin for the NA61/SHINE Collaboration, Karlsruhe Institute of Technology, Germany

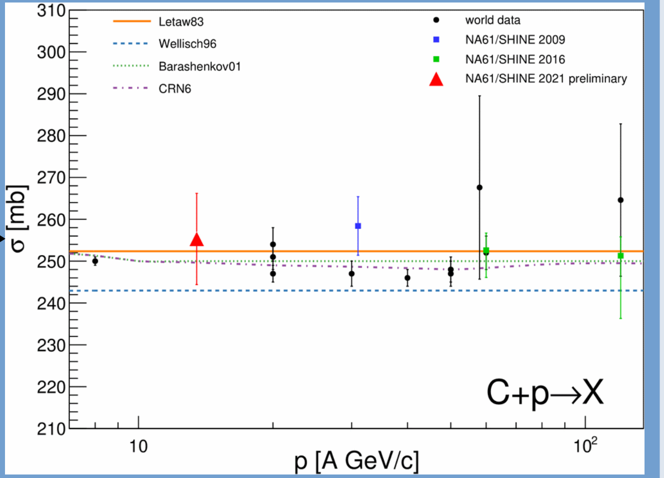
Preliminary results from Pilot Run:

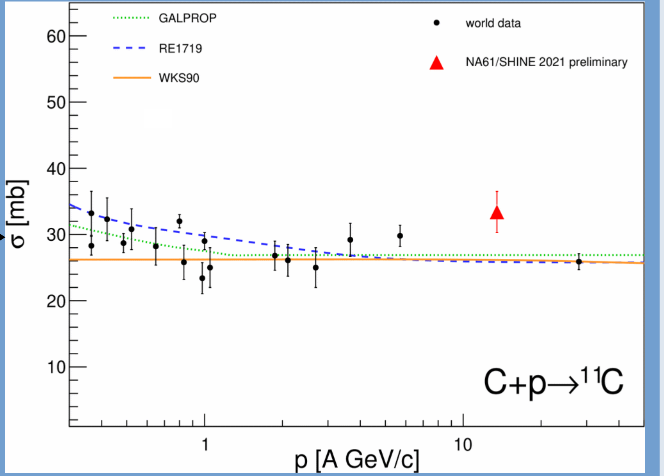
Target settings: C, OUT and PE



Fit Carbon distributions:



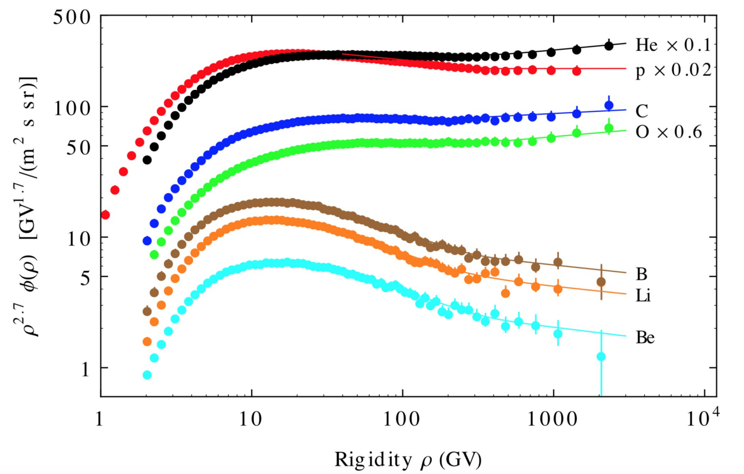


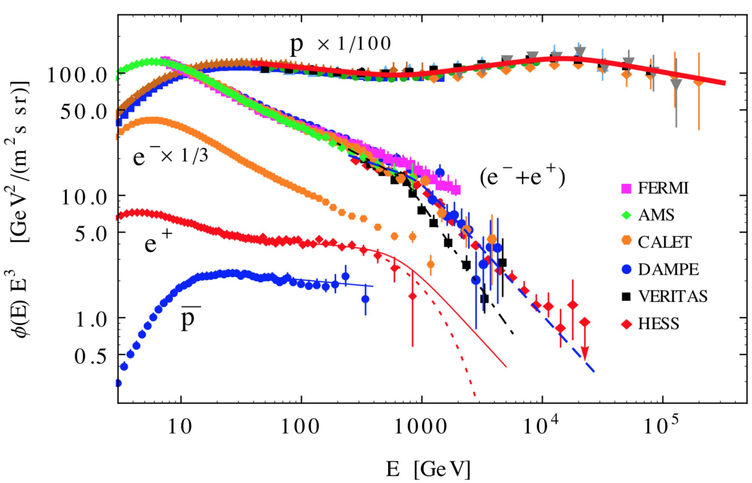


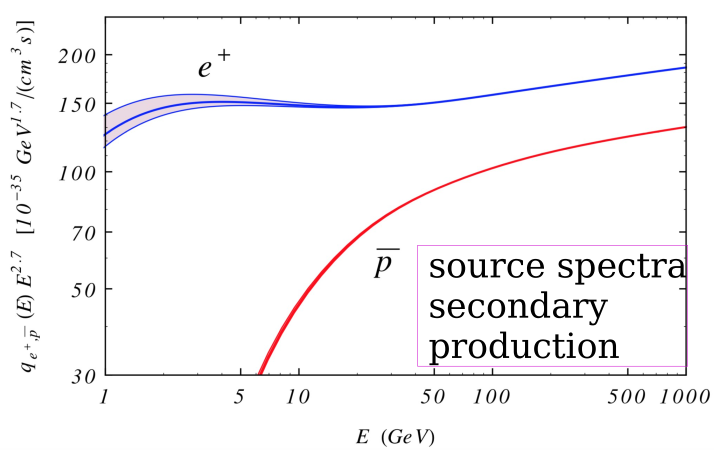
Summary & Outlook:

- Our preliminary results prove the feasibility of measuring nuclear fragmentation cross sections at SPS energies.
- High statistics data taking for light nuclei fragmentation(C,N,O) planned in 2022.

Paolo Lipari 395/169, “How well...”







”Standard Model for Galactic Propagation”

has as fundamental basis the interpretation of secondary nuclei (Li/Be/B)

The study of sec. nuclei really measures **grammage** and then ***assumes*** that it is accumulated in interstellar space (and not inside or near CR sources).

Crucial to VERIFY with independent observations

Implications are broad and profound:

Estimate of CR lifetime and of its rigidity dependence $T_{\rm esc}(R) \propto R^{-\delta}$

Source spectra of Cosmic Rays $\alpha_0 \approx \alpha - \delta$

Electron, positron spectra $T^{e^\pm}_{\rm loss}(E)$ vs $T_{\rm esc}(E)$

Potential Problems: (Need experimental verifications)

1. Requires an extra positron source [verification needed!]
2. Predicts a too soft anti-proton flux
3. Possible conflict with Be-10 measurements
4. Difficulty in identifying E-loss signatures in e± spectra
5. Multi-TeV electron accelerators should be detected.
6. Requires model for the TeV break in (e^++e^-) spectrum

Intriguing “Coincidence”:

$$(e^+/\overline{p})_{\rm flux} \approx (e^+/\overline{p})_{\rm sec.prod.}$$

Suggests alternative Propagation scenario *(faster escape, E-losses important only at higher E)*

a. Energy loss break of similar structure at E≈1 TeV for e+-
b. Need model for sec. nuclei grammage in the sources
c. Need model for electron/proton acceleration

Acceleration of cosmic ray secondaries inside old supernova remnants

Philipp Mertsch

with Subir Sarkar (Oxford) and Andrea Vittino (Aachen)

TTK Institute for Theoretical Particle Physics and Cosmology | RWTH AACHEN UNIVERSITY

What is this contribution about?

Secondary cosmic rays are produced and accelerated in the shocks of supernova remnants.

Why is it relevant / interesting?

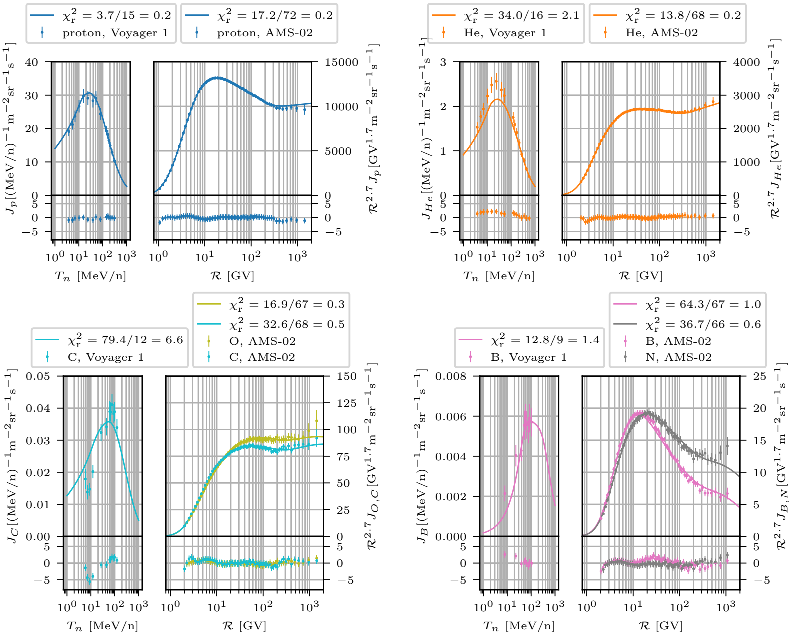
This can explain the positron excess and accommodate the measured antiproton flux.

What have we done?

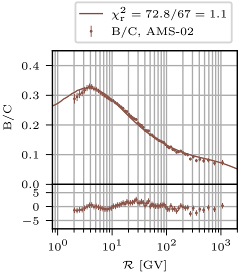
We have computed the shock-accelerated secondaries and studied the parameter space.

What is the result?

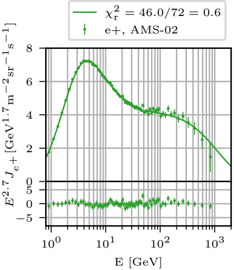
Good fit of proton, helium, carbon, oxygen, boron, nitrogen, positrons and antiprotons!



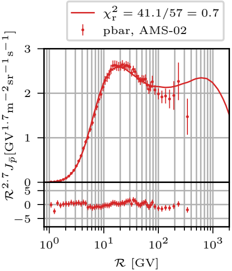
$\chi^2_r = 3.7/15 = 0.2$
proton, Voyager 1
$\chi^2_r = 17.2/72 = 0.2$
proton, AMS-02
$\chi^2_r = 34.0/16 = 2.1$
He, Voyager 1
$\chi^2_r = 13.8/68 = 0.2$
He, AMS-02
$J_p [(\mathrm{MeV/n})^{-1} \mathrm{m}^{-2} \mathrm{sr}^{-1} \mathrm{s}^{-1}]$
$\mathcal{R}^{2.7} J_p [\mathrm{GV}^{1.7} \mathrm{m}^{-2} \mathrm{sr}^{-1} \mathrm{s}^{-1}]$
$J_{He} [(\mathrm{MeV/n})^{-1} \mathrm{m}^{-2} \mathrm{sr}^{-1} \mathrm{s}^{-1}]$
$\mathcal{R}^{2.7} J_{He} [\mathrm{GV}^{1.7} \mathrm{m}^{-2} \mathrm{sr}^{-1} \mathrm{s}^{-1}]$
T_n [MeV/n]
$\mathcal{R}$ [GV]
$\chi^2_r = 79.4/12 = 6.6$
C, Voyager 1
$\chi^2_r = 16.9/67 = 0.3$
$\chi^2_r = 32.6/68 = 0.5$
O, AMS-02
C, AMS-02
$\chi^2_r = 12.8/9 = 1.4$
B, Voyager 1
$\chi^2_r = 64.3/67 = 1.0$
$\chi^2_r = 36.7/66 = 0.6$
B, AMS-02
N, AMS-02
$J_C [(\mathrm{MeV/n})^{-1} \mathrm{m}^{-2} \mathrm{sr}^{-1} \mathrm{s}^{-1}]$
$\mathcal{R}^{2.7} J_{O,C} [\mathrm{GV}^{1.7} \mathrm{m}^{-2} \mathrm{sr}^{-1} \mathrm{s}^{-1}]$
$J_B [(\mathrm{MeV/n})^{-1} \mathrm{m}^{-2} \mathrm{sr}^{-1} \mathrm{s}^{-1}]$
$\mathcal{R}^{2.7} J_{B,N} [\mathrm{GV}^{1.7} \mathrm{m}^{-2} \mathrm{sr}^{-1} \mathrm{s}^{-1}]$



$\chi^2_r = 72.8/67 = 1.1$
B/C, AMS-02
B/C
$\mathcal{R}$ [GV]



$\chi^2_r = 46.0/72 = 0.6$
e+, AMS-02
$E^{2.7} J_{e+}$ [GeV$^{1.7}$m^{-2}sr^{-1}s^{-1}]
E [GeV]

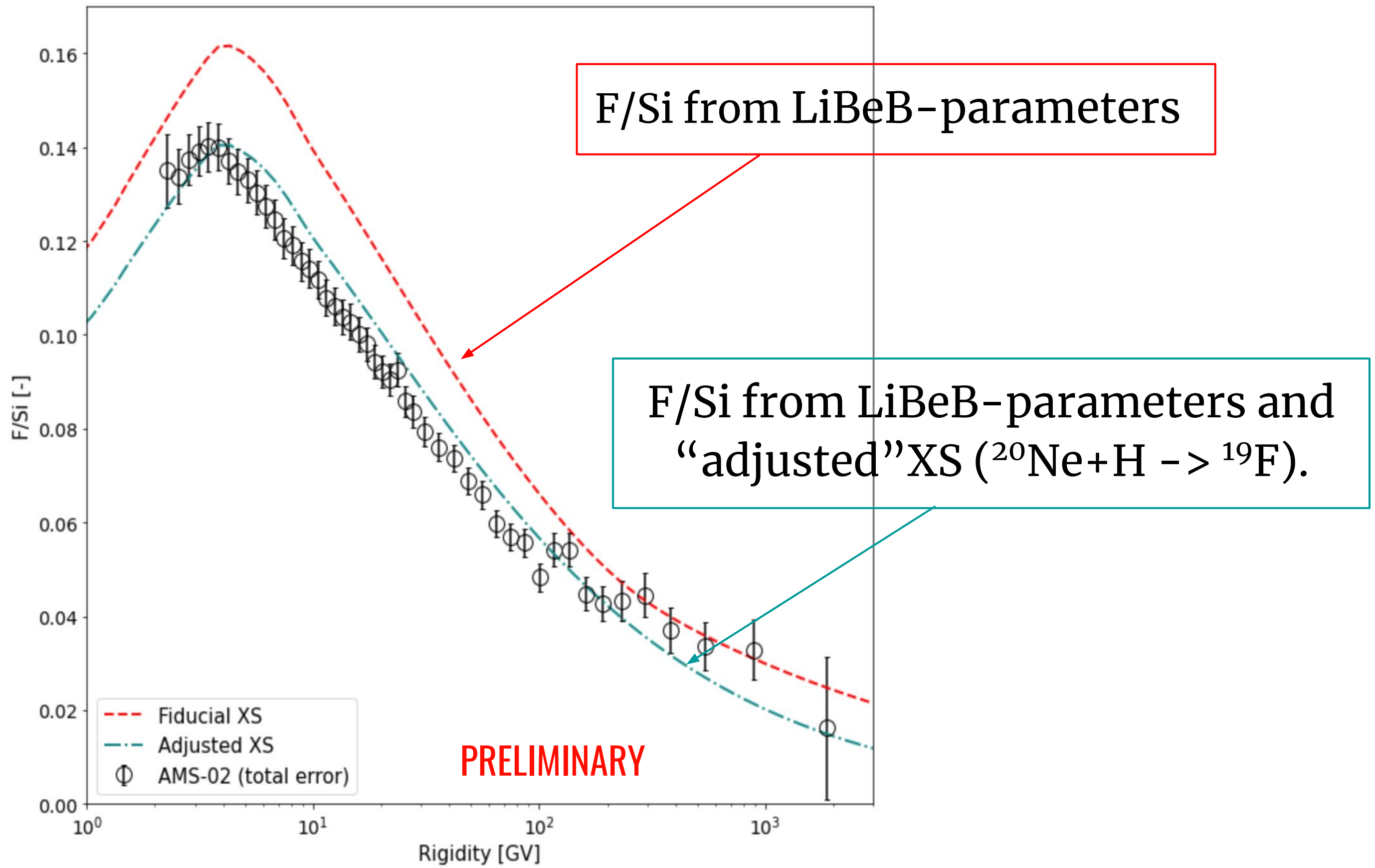


$\chi^2_r = 41.1/57 = 0.7$
pbar, AMS-02
$\mathcal{R}^{2.7} J_{\bar{p}}$[GV$^{1.7}$m^{-2}sr^{-1}s^{-1}]
$\mathcal{R}$ [GV]

Universality of propagation and consistency of cross-sections

https://dmaurin.gitlab.io/USINE/

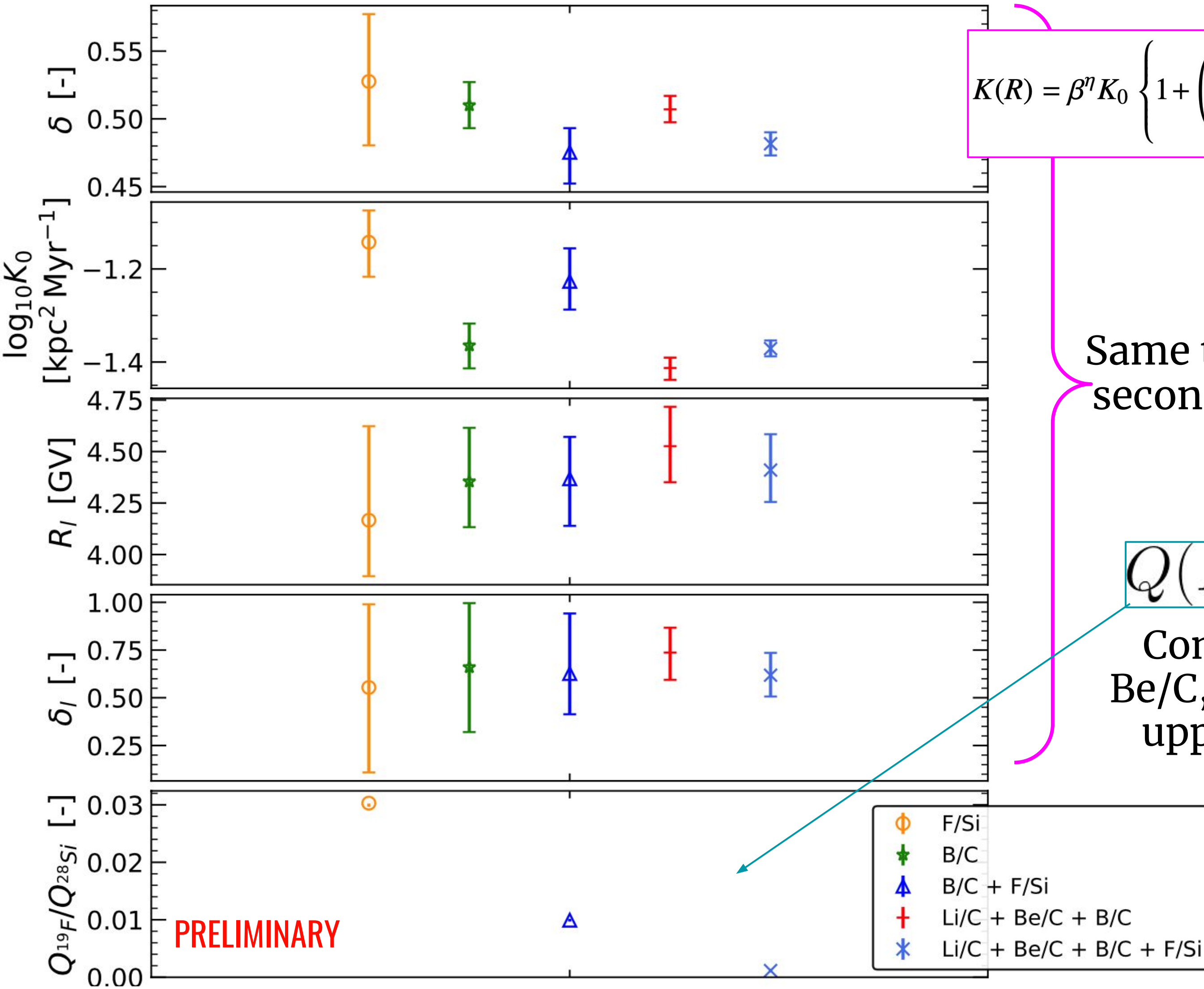
M. Vecchi, E. F. Bueno, L. Derome, Y. Génolini, and D. Maurin



Using the propagation parameters which give a best fit of lighter secondary-to-primary ratios, our model overestimates the data by 10% - 15%. However, this difference can be explained by the F production cross-sections uncertainties

Universality of propagation and consistency of cross-sections

M. Vecchi, E. F. Bueno, L. Derome, Y. Génolini, and D. Maurin



$$K(R) = \beta^\eta K_0 \left\{1+\left(\frac{R}{R_l}\right)^{\frac{\delta_l-\delta}{s_l}}\right\}^{s_l} \left\{\frac{R}{R_0=1\,\mathrm{GV}}\right\}^{\delta} \left\{1+\left(\frac{R}{R_h}\right)^{\frac{\delta-\delta_h}{s_h}}\right\}^{-s_h}.$$

Same transport parameters for secondary species from Li to F

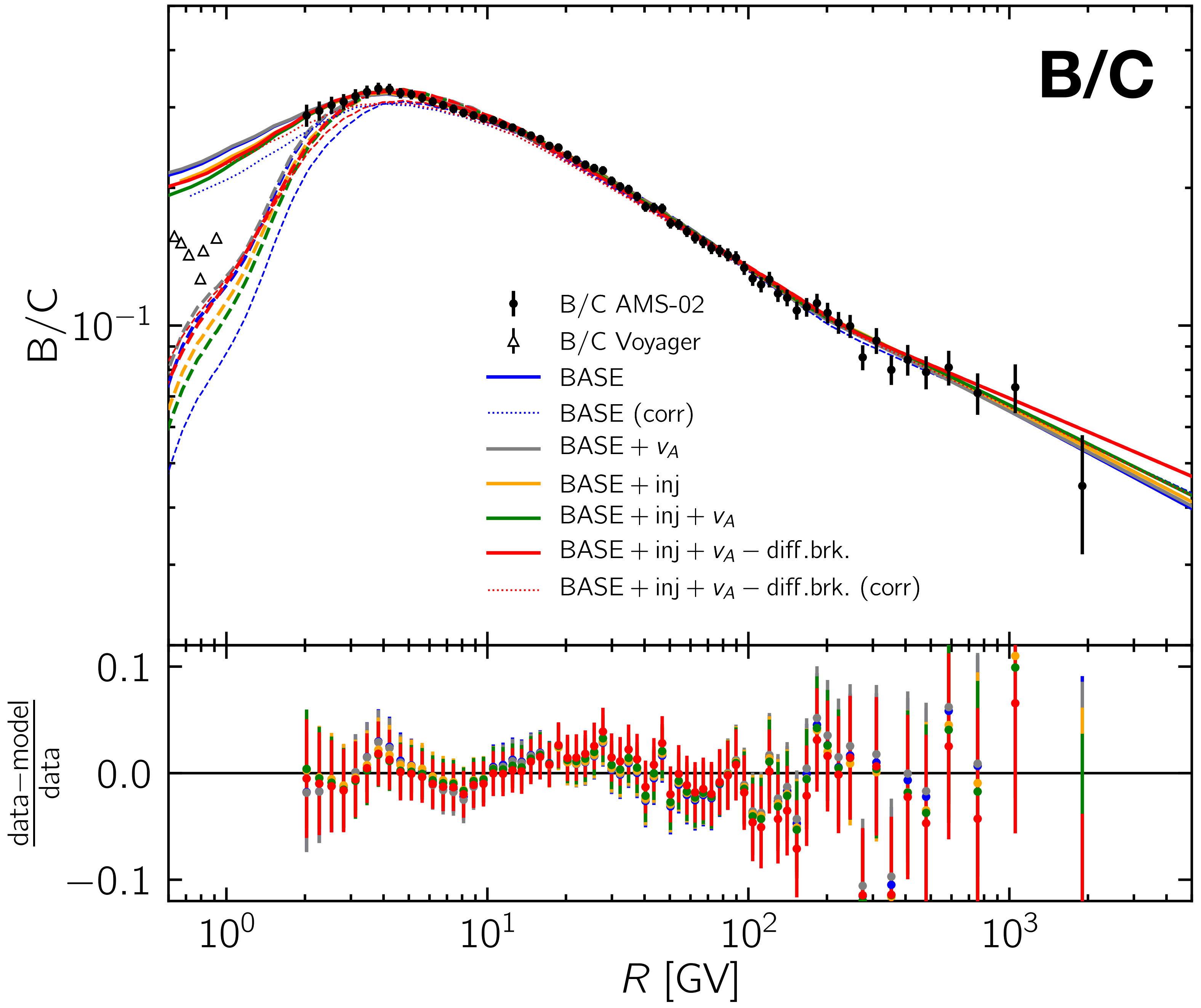
$$Q(R) = Q_{19F}\beta^{\eta_S} R^{-\alpha}$$

Combined analysis of Li/C, Be/C, B/C and F/Si provides an upper limit on the F source abundance

Constraining CR diffusion with AMS-02 data from Li to O

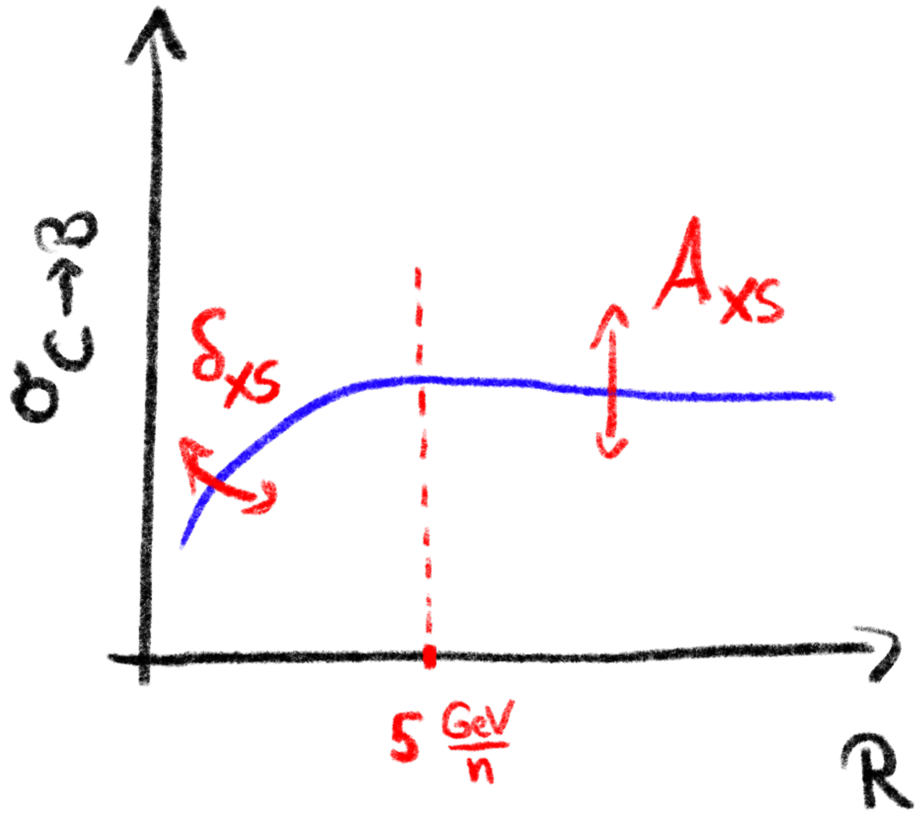
We use GALPROP to perform global fits of CR propagation and profile over nuisance parameters for fragmentation cross sections.

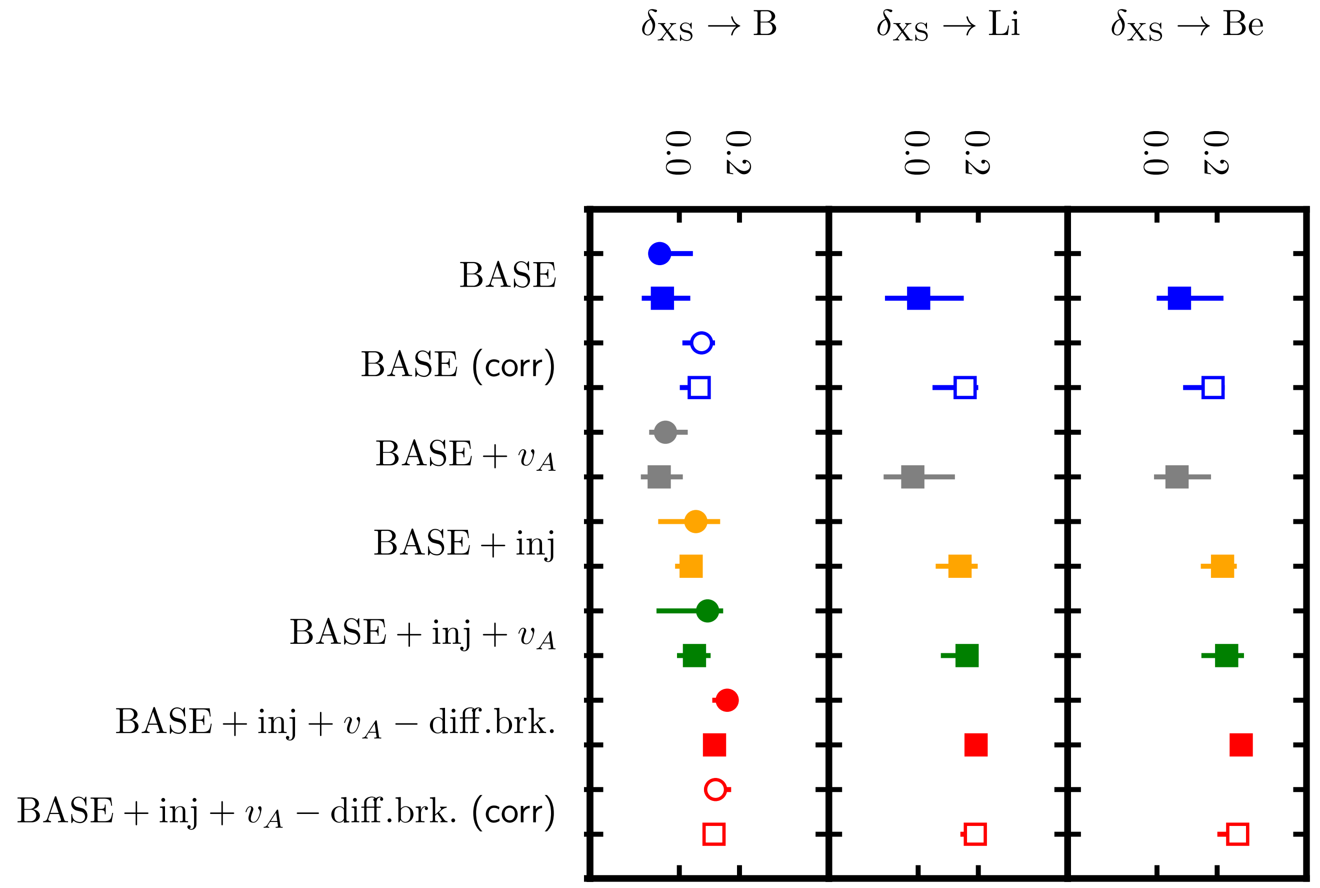
We test 5 different propagation scenarios!



Conclusions

- **AMS-02 data of CR Li to O is fitted well by the traditional diffusion models**
- **Cross section uncertainties prevent better understanding of CR propagation**
- **Small half-heights of the halo $z_h < 3$ kpc are excluded**
- **Diffusion coefficient is well constrained above 10 GV**

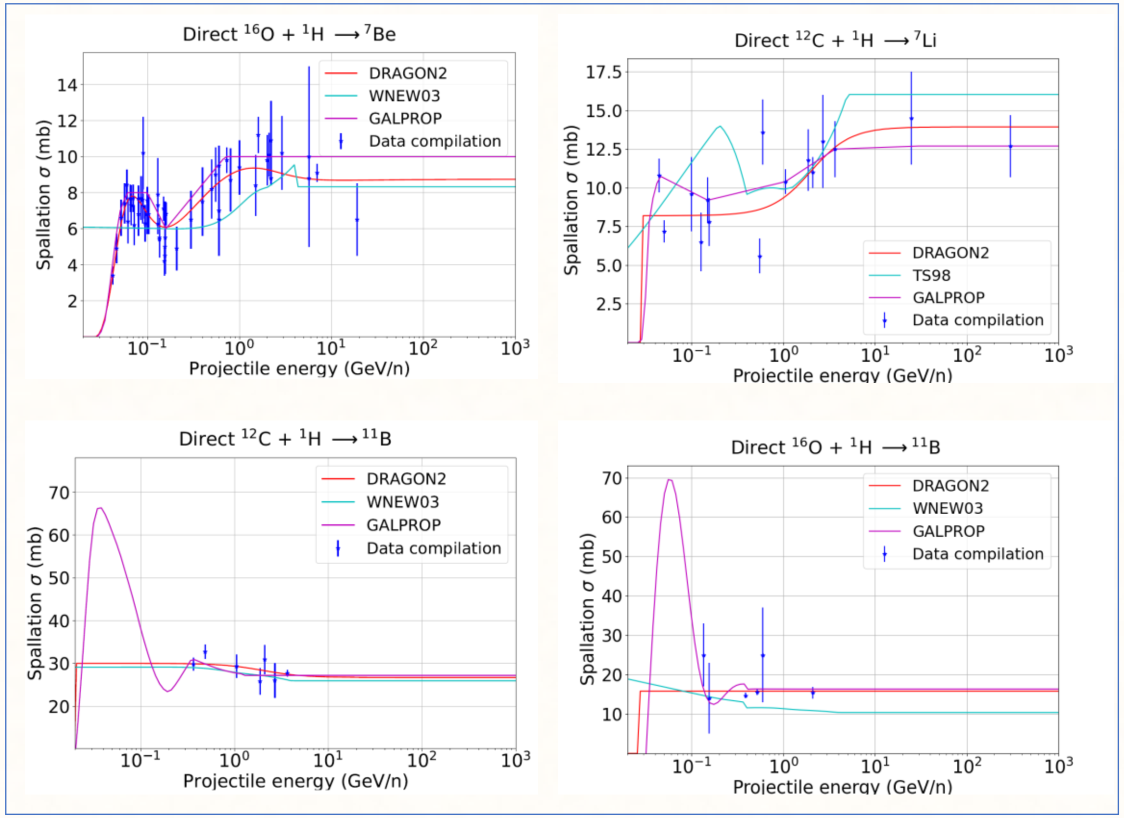


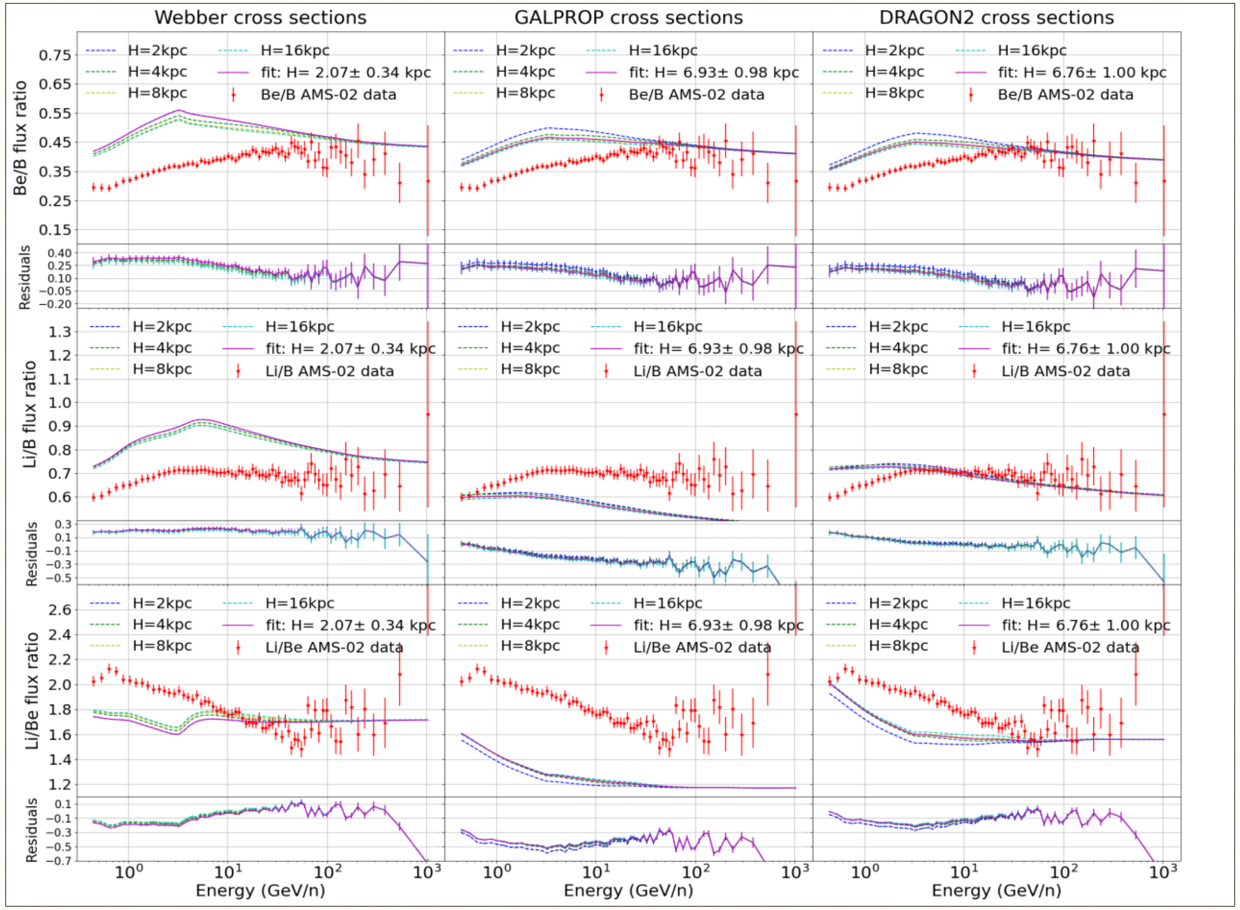


Impact of cross sections uncertainties on GCR propagation studies

P. De la Torre Luque[1], M. N. Mazziotta[2], F. Gargano[2], F. Loparco[2,3], D. Serini[2,3]

1. Stockholm University. 2. INFN, sezione di Bari. 3. Bari University





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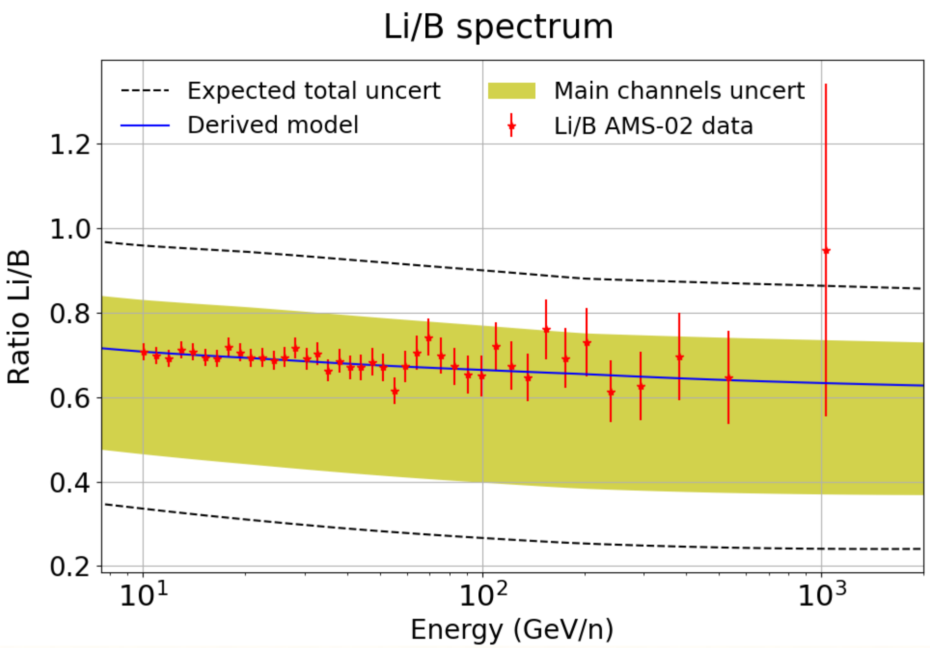

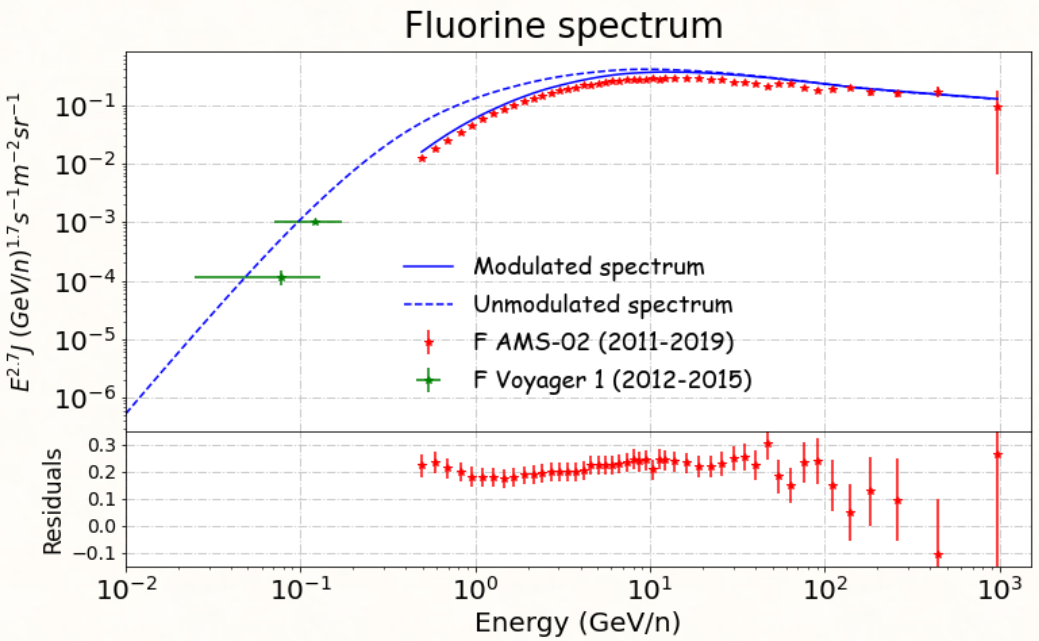

Taking into account cross sections uncertainties, we could reproduce B, Be, Li and F with the same propagation parameters

Impact of cross sections uncertainties on GCR propagation studies

P. De la Torre Luque[1], M. N. Mazziotta[2], F. Gargano[2], F. Loparco[2,3], D. Serini[2,3]

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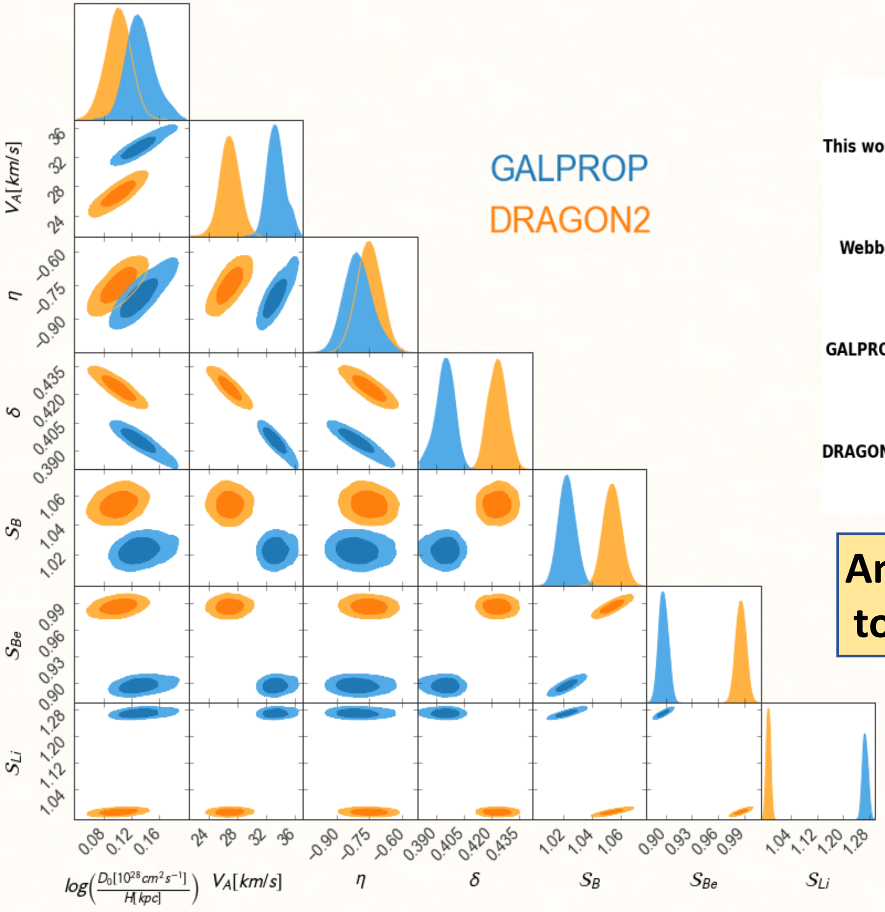
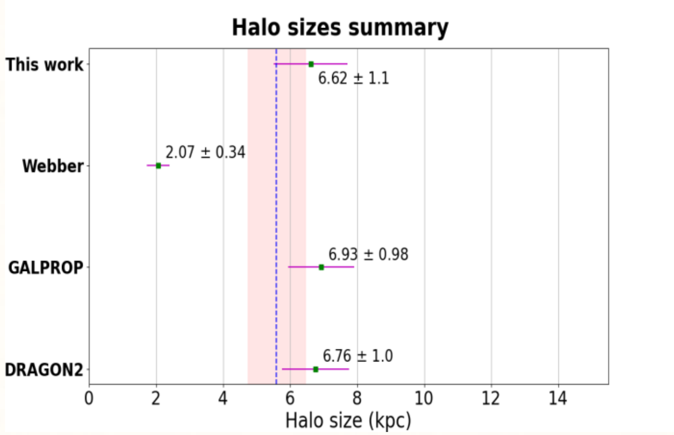
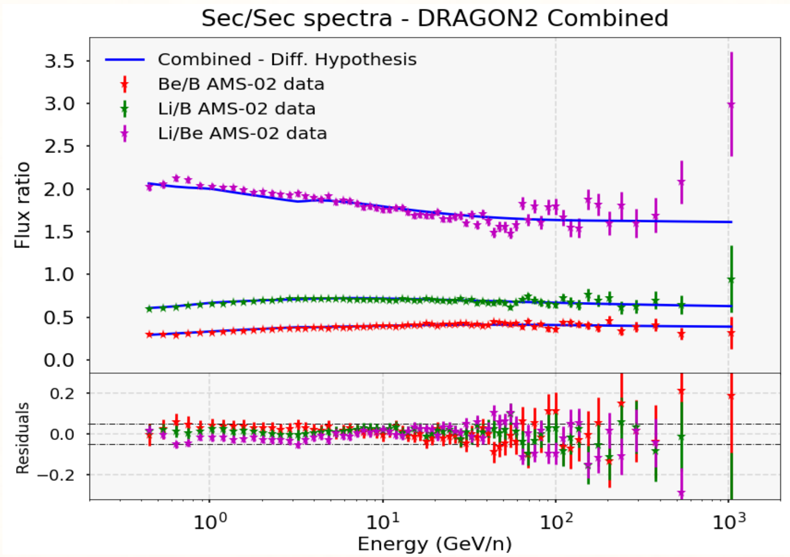




Analyses of different XSecs lead to similar diffusion parameters

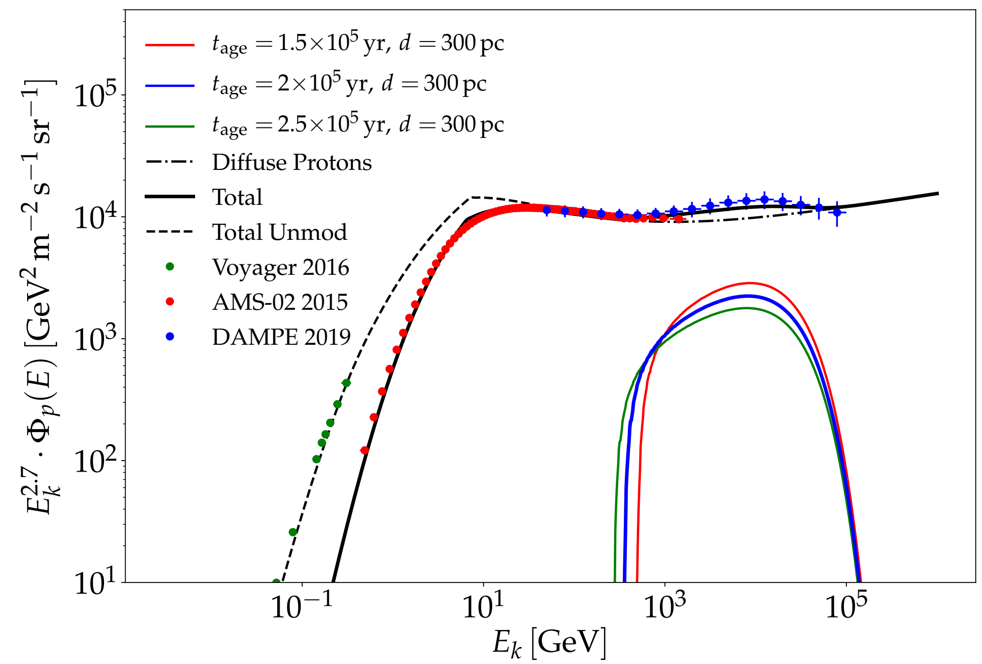
Possible to simultaneously reproduce AMS-02 data in the full energy range for all the secondary CRs



A unified picture for three different CR observables

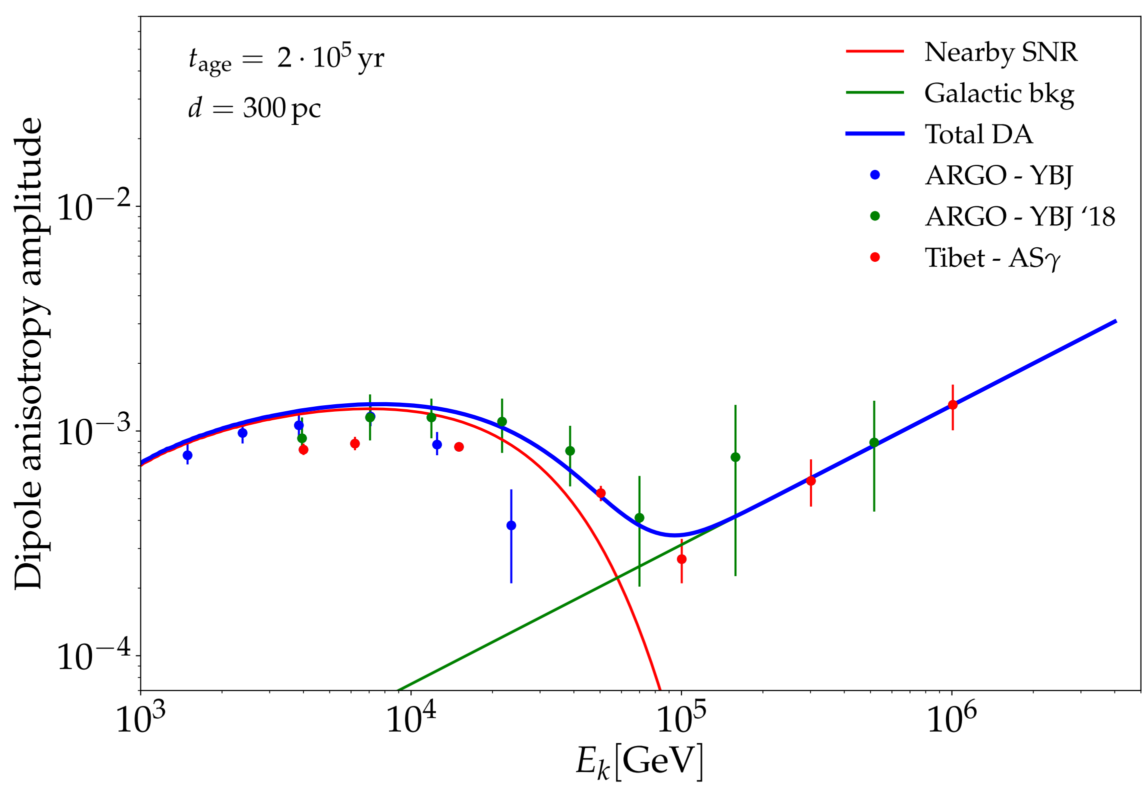
Ottavio Fornieri, Daniele Gaggero, Daniel Guberman, Lohann Brahimi, Pedro De La Torre Luque, Alexandre Marcowith

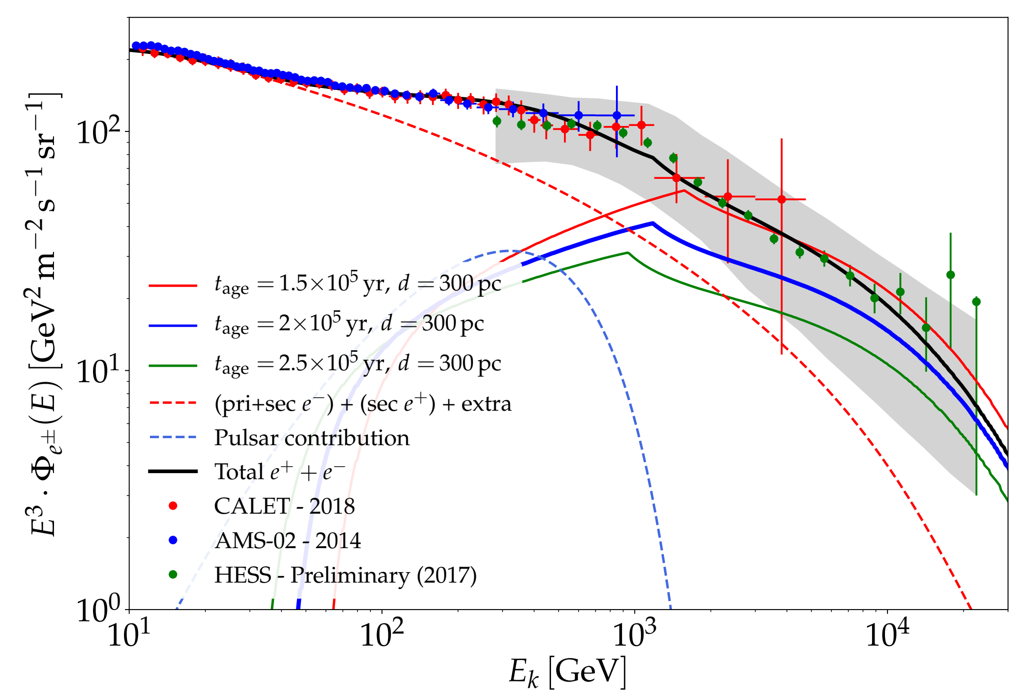
- We have reproduced simultaneously **three different channels** with the **same nearby accelerator: proton spectrum, electron spectrum, dipole anisotropy**

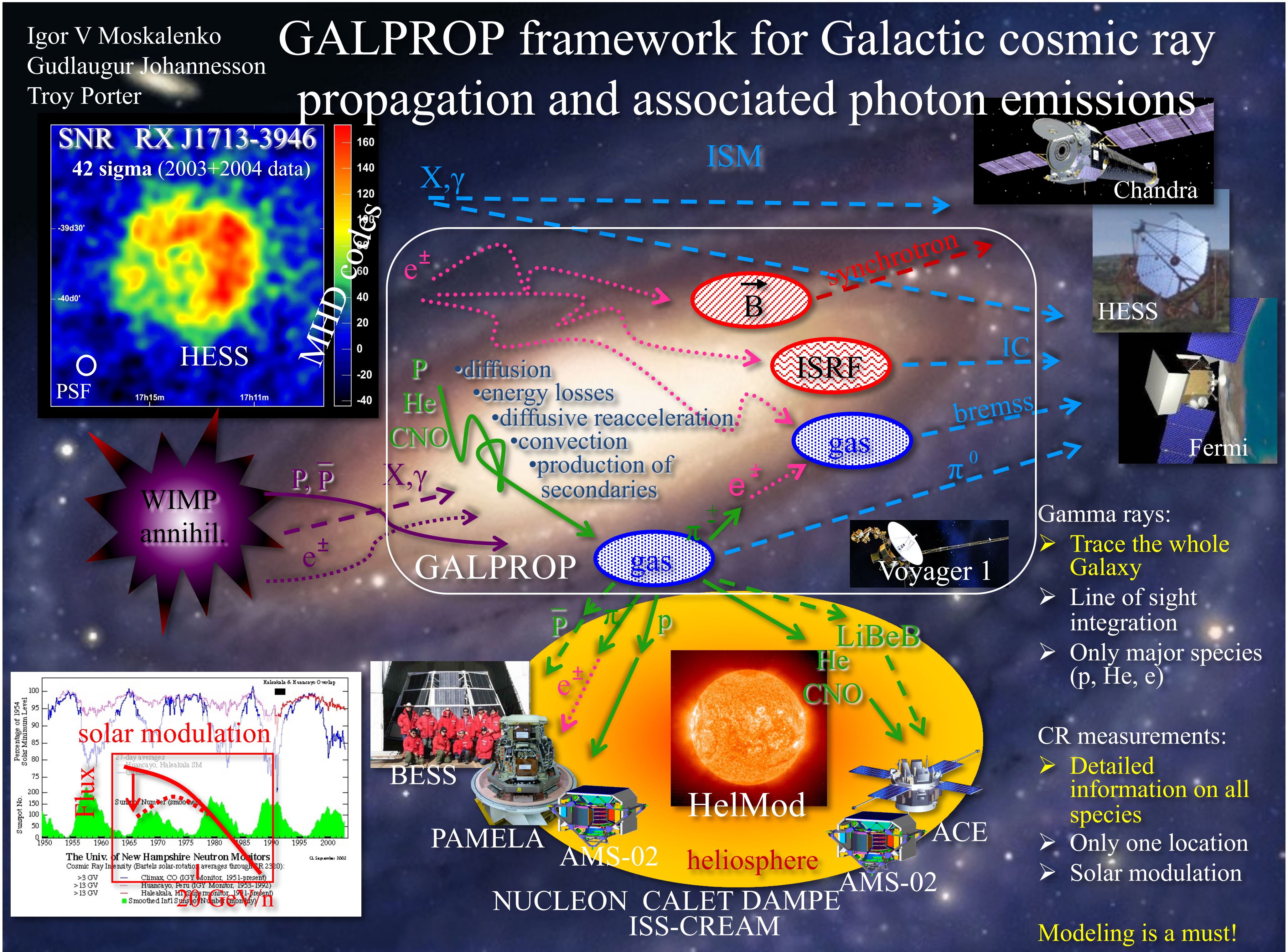


- The **key feature** is a transport setup that changes its properties with rigidity, suggested by AMS data

Smoothly broken-power-law $D(E) \propto E^{\delta(E)}$



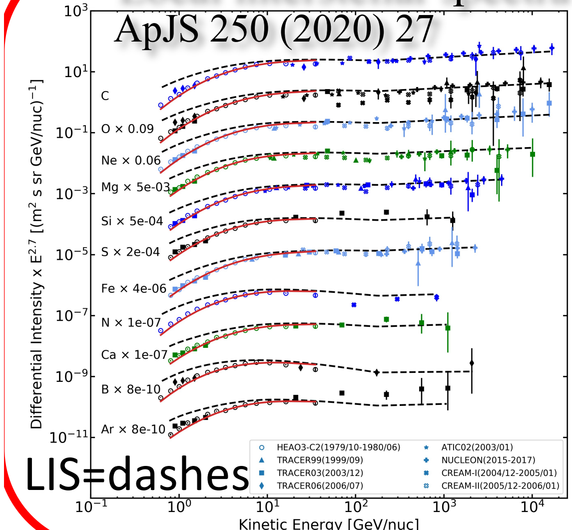


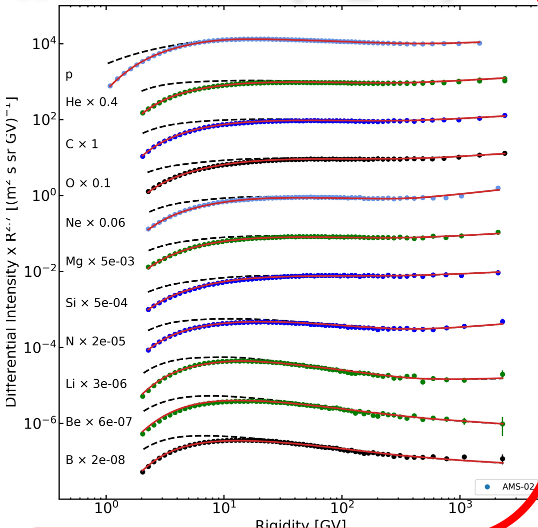


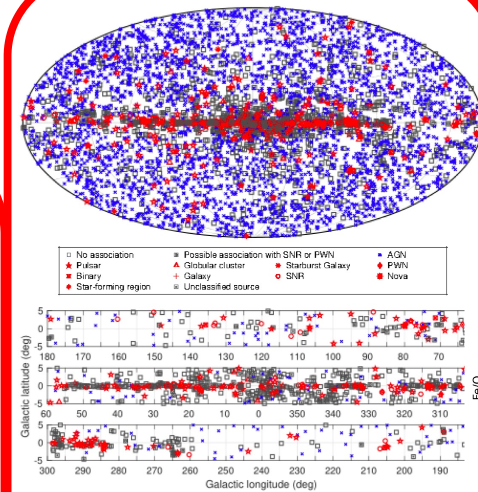
Igor V Moskalenko
Gudlaugur Johannesson
Troy Porter
GALPROP framework for Galactic cosmic ray propagation and associated photon emissions
SNR RX J1713-3946
42 sigma (2003+2004 data)
-39d30'
-40d0'
HESS
PSF
17h15m
17h11m
160
140
120
100
80
60
40
20
0
-20
-40
MHD codes
ISM
X,γ
Chandra
HESS
Fermi
e±
B
synchrotron
ISRF
IC
gas
bremss
π0
P
He
CNO
•diffusion
•energy losses
•diffusive reacceleration
•convection
•production of secondaries
e±
π±
WIMP annihil.
P, P̄
X,γ
e±
GALPROP
gas
Voyager 1
Gamma rays:
Trace the whole Galaxy
Line of sight integration
Only major species (p, He, e)
P̄
π
p
e±
LiBeB
He
CNO
BESS
PAMELA
AMS-02
HelMod
heliosphere
ACE
AMS-02
NUCLEON CALET DAMPE
ISS-CREAM
CR measurements:
Detailed information on all species
Only one location
Solar modulation
Modeling is a must!
solar modulation
Flux
20 GeV/n
The Univ. of New Hampshire Neutron Monitors
Cosmic Ray Intensity (Bartels solar-rotation averages through BR 2320):
Climax, CO (IGY Monitor, 1951-present)
Huancayo, Peru (IGY Monitor, 1953-1992)
Haleakala, HI (Super monitor, 1991-present)
Smoothed Int'l Sunspot Number (monthly)
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000

Recent GalProp applications

Local interstellar spectra of H-Ni nuclei ($Z \leq 28$)
ApJS 250 (2020) 27

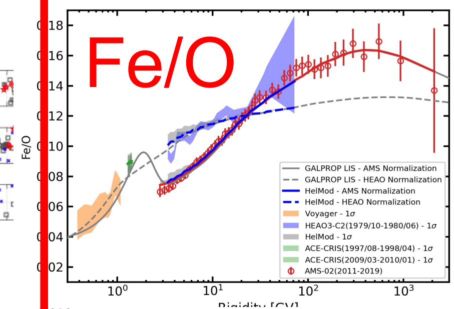


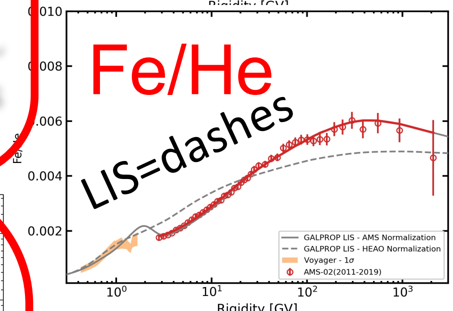


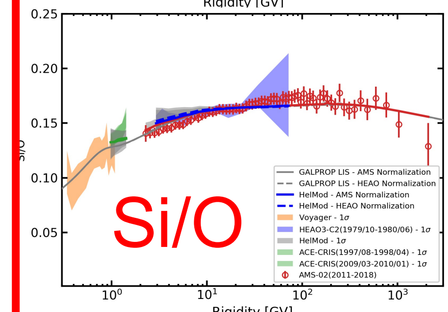


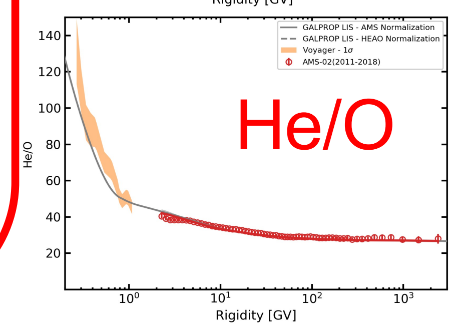
Background model for Fermi-LAT 4FGL catalog: 5500 sources
ApJ 247 (2020) 33

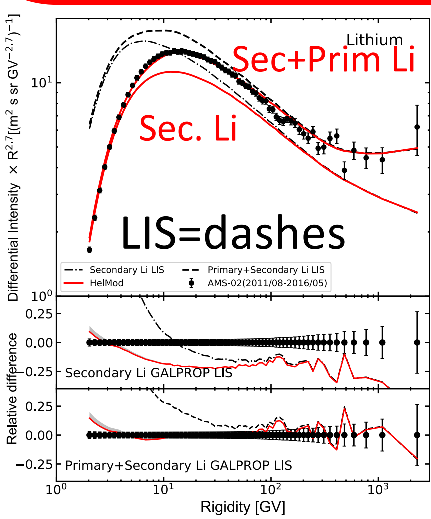
Discovery of a low-energy excess in CR Iron (<2 GV)
ApJ 913 (2021) 5



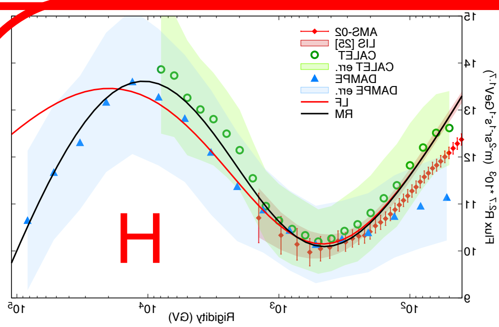


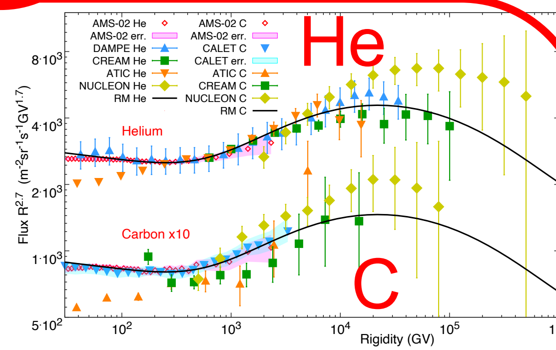


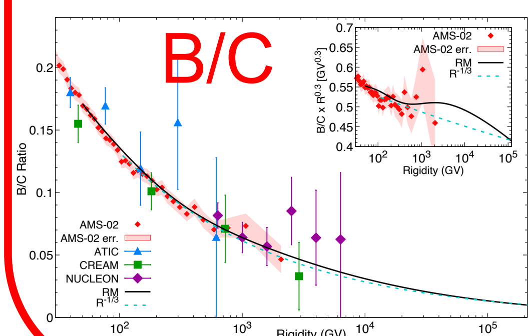




An evidence of primary Li in CRs
ApJ 889 (2020) 167B







On the origin of observed cosmic ray spectrum below 100 TV

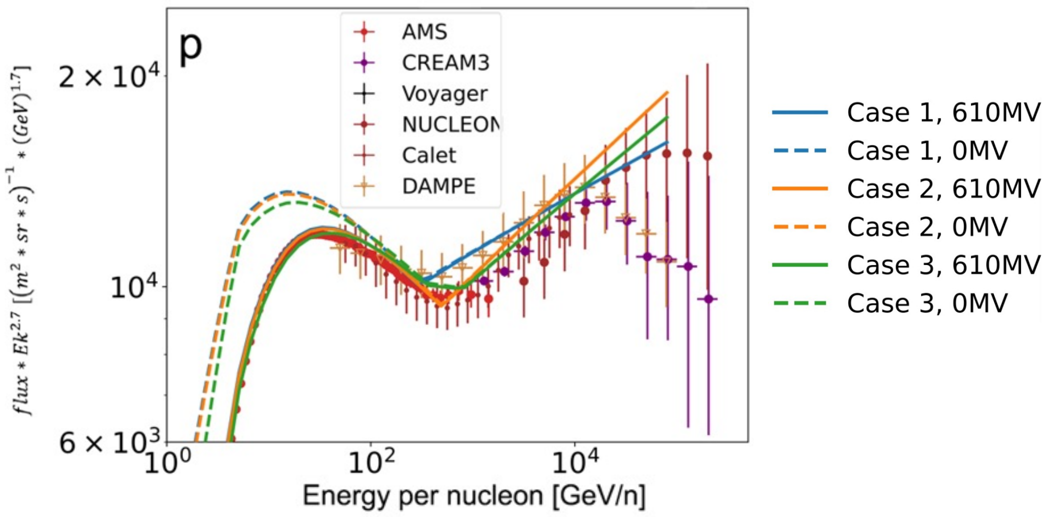
Malkov & IVM
arXiv:2105.04630
ApJ 911 (2021) 151

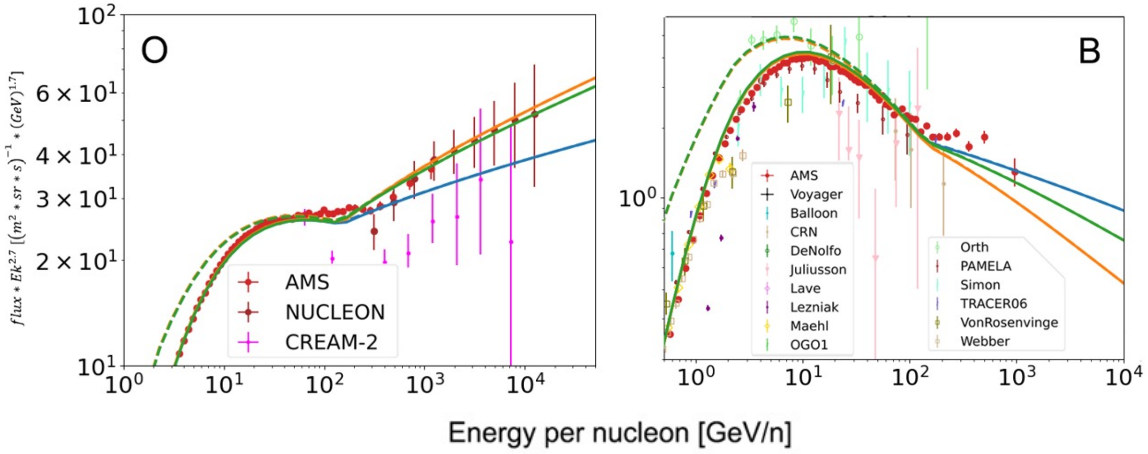
Study of cosmic ray propagation using GALPROP

Hongyi Wu[1], Eun-Suk Seo[1], Vladimir Ptuskin[1,2]
[1]Univ of Maryland-College Park, MD, USA, [2]IZMIRAN, Moscow, Russia

- Recent high-accuracy measurements of cosmic ray energy spectra have revealed spectral deviation from a single power law. We studied three cases introducing a diffusion coefficient break, source injection breaks, and a combination of both using Galprop v56.

- Case 1: By adding a diffusion coefficient break at 300 GV where the index changes from 0.514 to 0.27, GALPROP produces acceptable B/C ratio.
    - But it results in a break lower than the observed break in the p spectrum and higher than that in the p- spectrum. The resulting spectral hardening agrees with the p and He data but is not sufficient to fit the C and O data.
- Case 2: By changing the injection index from 2.350 to 2.035 at 500 GV for p, from 2.274 to 2.039 at 300 GV for He, and from 2.364 to 2.06 at 300 GV for heavy nuclei (Z > 2), GALPROP produces spectral hardening in agreement with all the primary cosmic ray data including C and O.
    - But the resulting spectral hardening is not sufficient to fit the B and Be data.
- Case 3: By having both diffusion coefficient and source injection breaks, GALPROP produces the spectral hardening in agreement with data simultaneously.





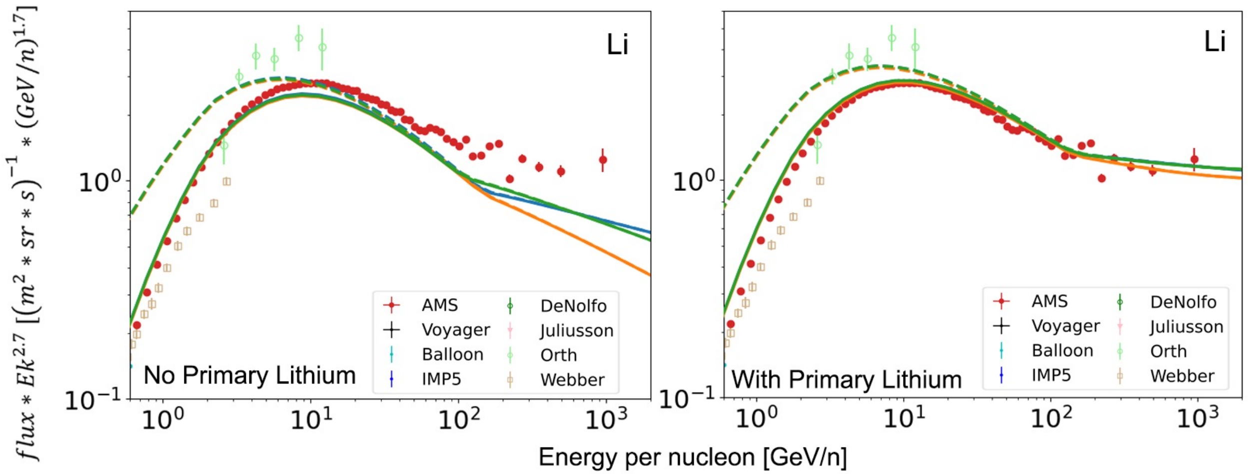
Study of cosmic ray propagation using GALPROP

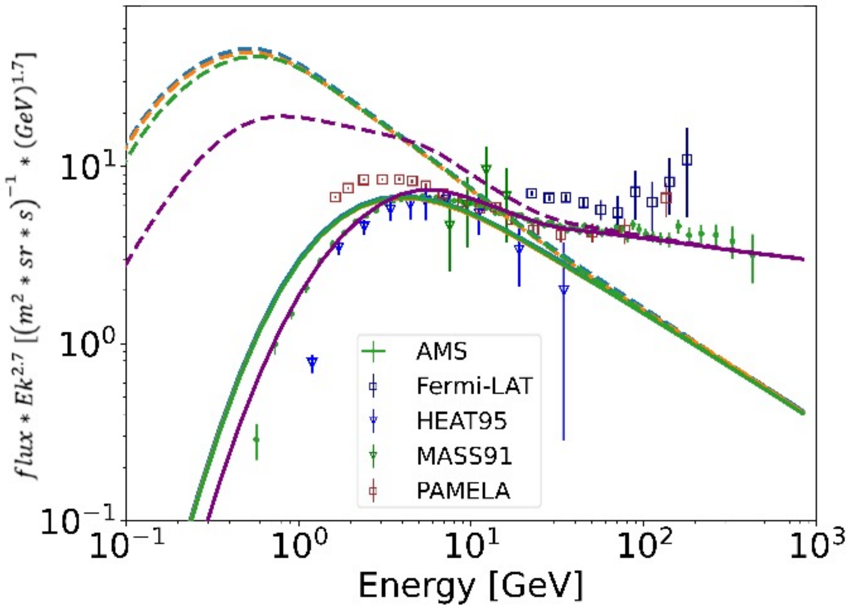
Hongyi Wu[1], Eun-Suk Seo[1], Vladimir Ptuskin[1,2]
[1]Univ of Maryland-College Park, MD, USA, [2]IZMIRAN, Moscow, Russia

- Case 3: By having both diffusion coefficient and source injection breaks, GALPROP produces the spectral hardening in agreement with data simultaneously. The diffusion coefficient index changes from 0.514 to 0.40 at 200 GV, and the injection index changes from 2.330 to 2.18 at 800 GV for p, from 2.274 to 2.099 at 400 GV for He, and from 2.364 to 2.18 at 250 GV for heavy nuclei (Z > 2).

- We also examined if the spectral hardening supports the existence of a primary Li source and calculated the relative abundance. The Li source with the same source injection as the heavy nuclei (Z > 2) and an abundance of 65 (relative to the p source abundance 1.06*106) greatly improves the consistency of GALPROP results with data.

- The hardening in the e+ spectrum cannot be explained with all three cases we studied but can be fitted by adding a primary e+ source. This e+ source has a rigidity break at 30 GV at which the injection index changes from 2.5 to 2.05.





Case 4 610MV
Case 4 0MV

Case 4 e+ source injection is given by: $\boldsymbol{\Phi} \propto \boldsymbol{R}^{-\gamma}$

$$\begin{cases} \gamma = 1.83, for\ R \le 5.78\ GV \\ \gamma = 2.5, for\ 5.78\ GV \le R < 30\ GV \\ \gamma = 2.05, for\ R > 30\ GV \end{cases}$$

Interpretation of the spectral inhomogeneity in the 10TV region in terms of a close source

Vladimir Yurovsky

In this paper, we consider the possibility of interpreting the experimental spectral inhomogeneity as the contribution of a single point instantaneous source in the isotropic diffusion approximation.

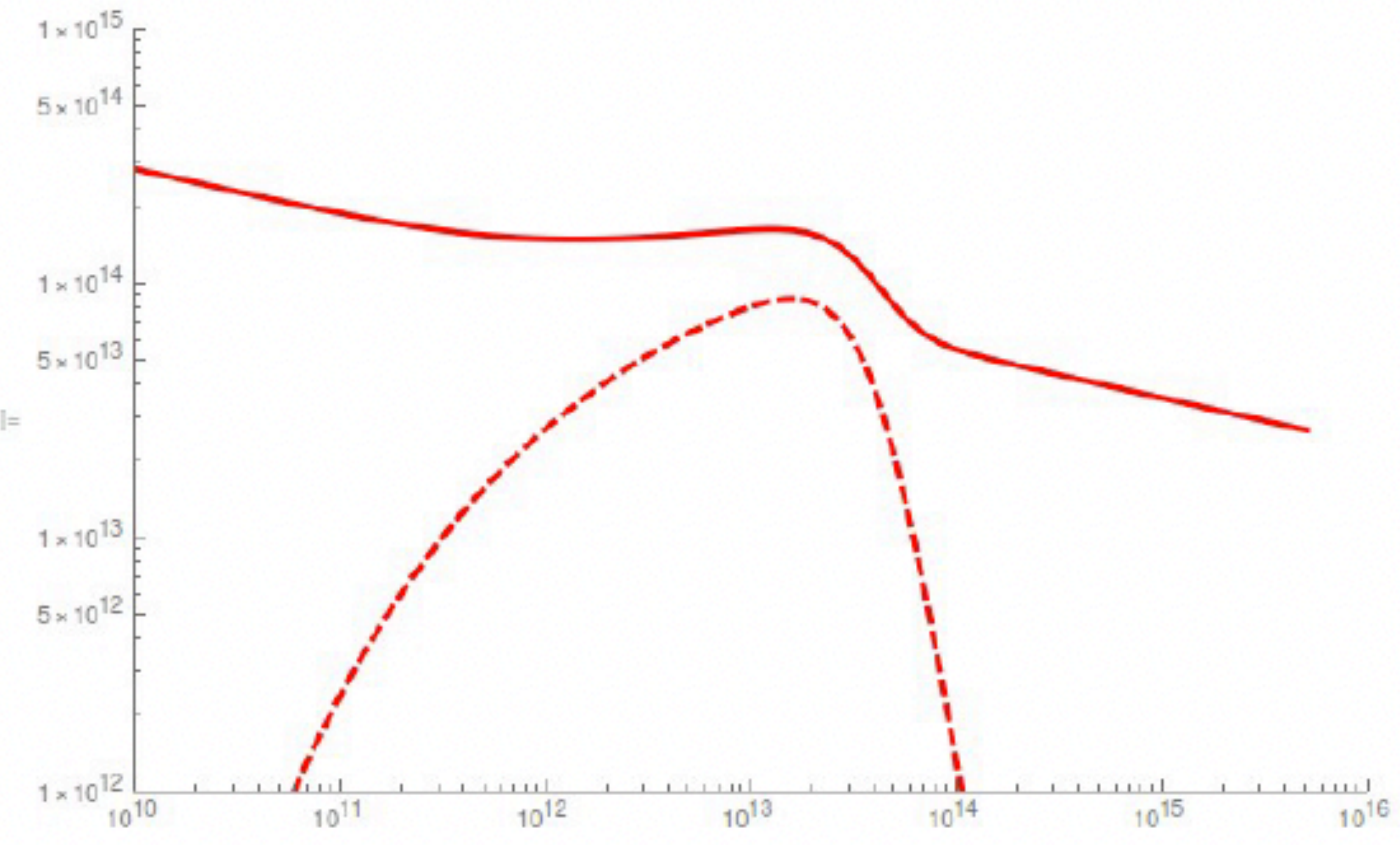
The emission spectrum of the source is represented by the function:

$$Q(R,t,r)=R^{-\gamma_0}\left(1+\left(R/R_{ref}\right)^{\omega_0}\right)^{-\delta\gamma/\omega_0}\delta(t-t_0)\,\delta(r-r_0)$$

Equation describing the evolution of the CL concentration in the diffusion approximation:

$$\frac{\partial N}{\partial t}-\nabla\,(D\nabla\,N)=Q(R,t,r)$$

Where D [R] = $D_0\,(R/R_0)\delta$, D_0 =4,3*10^{28} cm^2/s, δ=0,395, R_0=4,5 GV
The model signal represents the sum of the background flux and the flux from the source, obtained as a solution to the diffusion equation $F_{summ} = F_{bgr}(R) + F_{star}(R)$



A feature of this work is the simultaneous consideration of a set of existing direct experiments that measure elemental spectra and reveal the elemental structure of inhomogeneity and the spectrum of all particles measured by HAWC. The penalty method was applied with a two-dimensional correlation function μ = aR + b to account for different properties of measurement uncertainties.

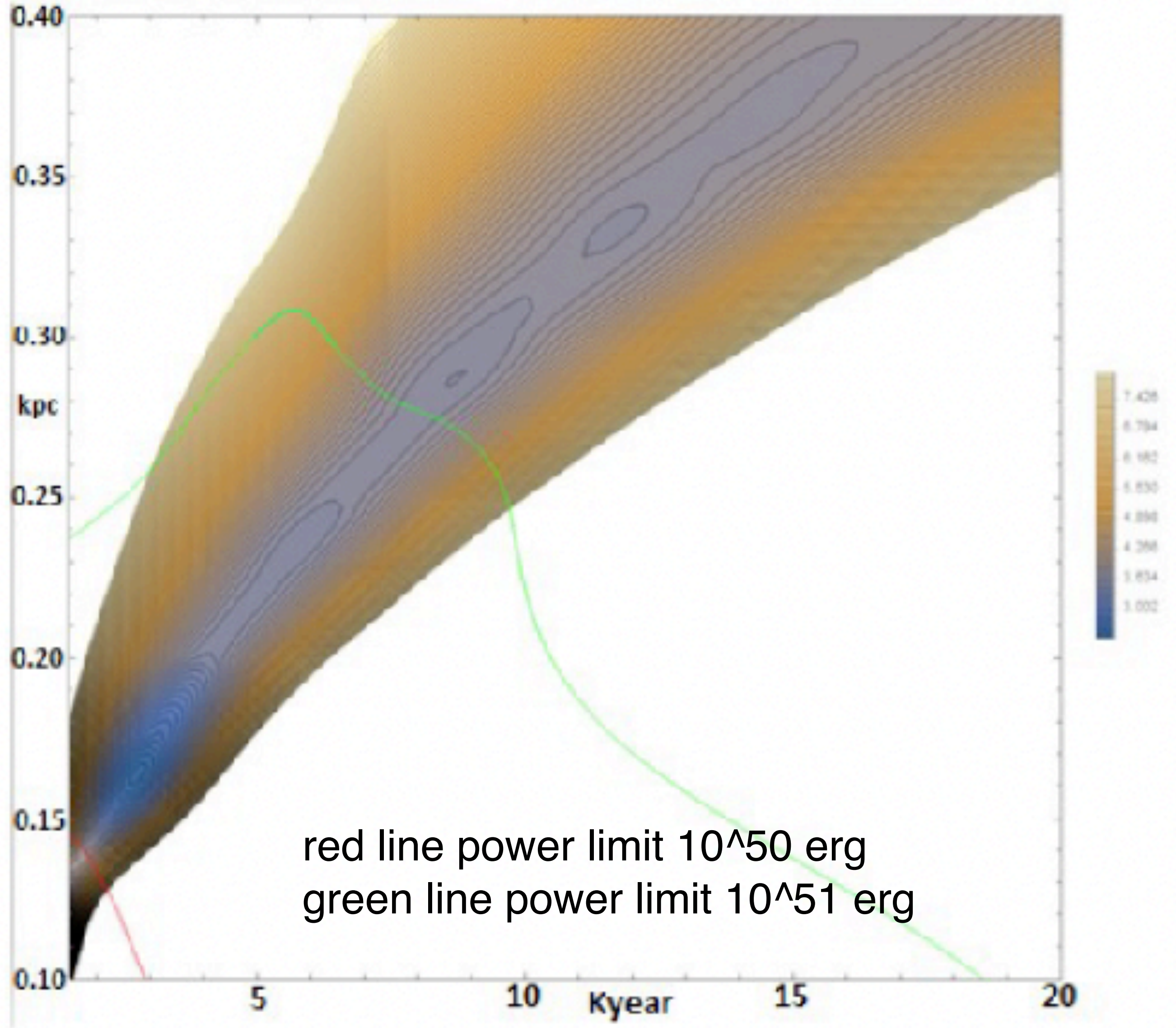
$$\chi^2(\xi,\alpha)=\Sigma_i\frac{\left(F_i\left(1+\Sigma_j\frac{\partial\mu_i}{\partial\alpha_j}\Lambda\alpha_j\right)-P_i(\xi)\right)^2}{\delta_i^2\left(1+\Sigma_j\frac{\partial\mu_i}{\partial\alpha_j}\Delta\alpha_j\right)}+\Sigma_i\Sigma_j\Delta\alpha_i\Delta\alpha_j(A_s)^{-1}_{ij}$$

$$A_s=\begin{bmatrix}\sigma 1^2 & \rho\sigma 1\sigma 2\\ \rho\sigma 1\sigma 2 & \sigma 2^2\end{bmatrix}\quad \sigma_1=\frac{B}{(AB-C^2)}\quad \sigma_2=\frac{A}{(AB-C^2)}\quad \rho=\frac{-C}{AB}$$

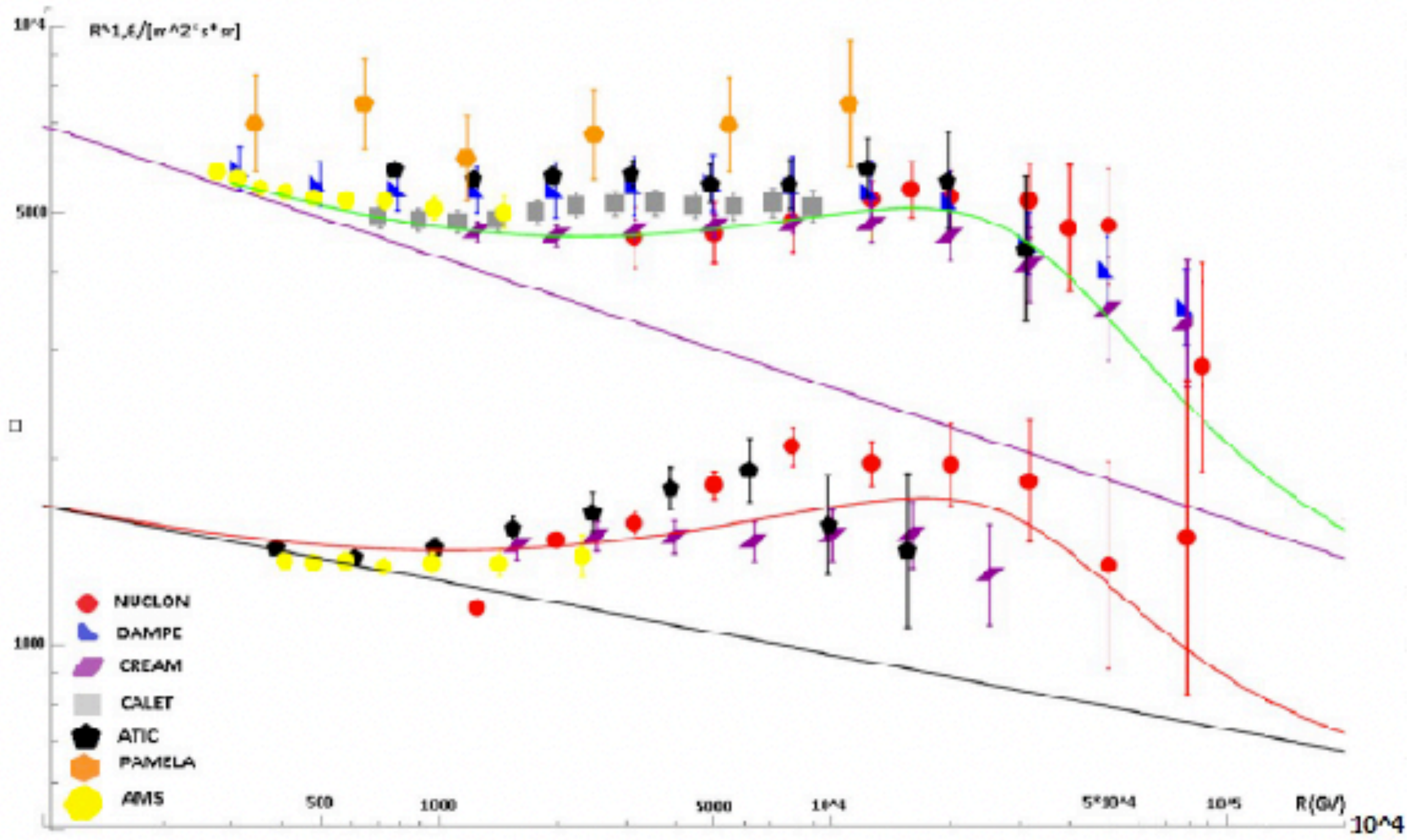
where δ-relative systematic error

$$A=\sum_i^n\frac{E_i^2}{\sigma_i^2}\quad B=\sum_i^n\frac{1}{\sigma_i^2}\quad C=\sum_i^n\frac{E_i}{\sigma_i^2}$$

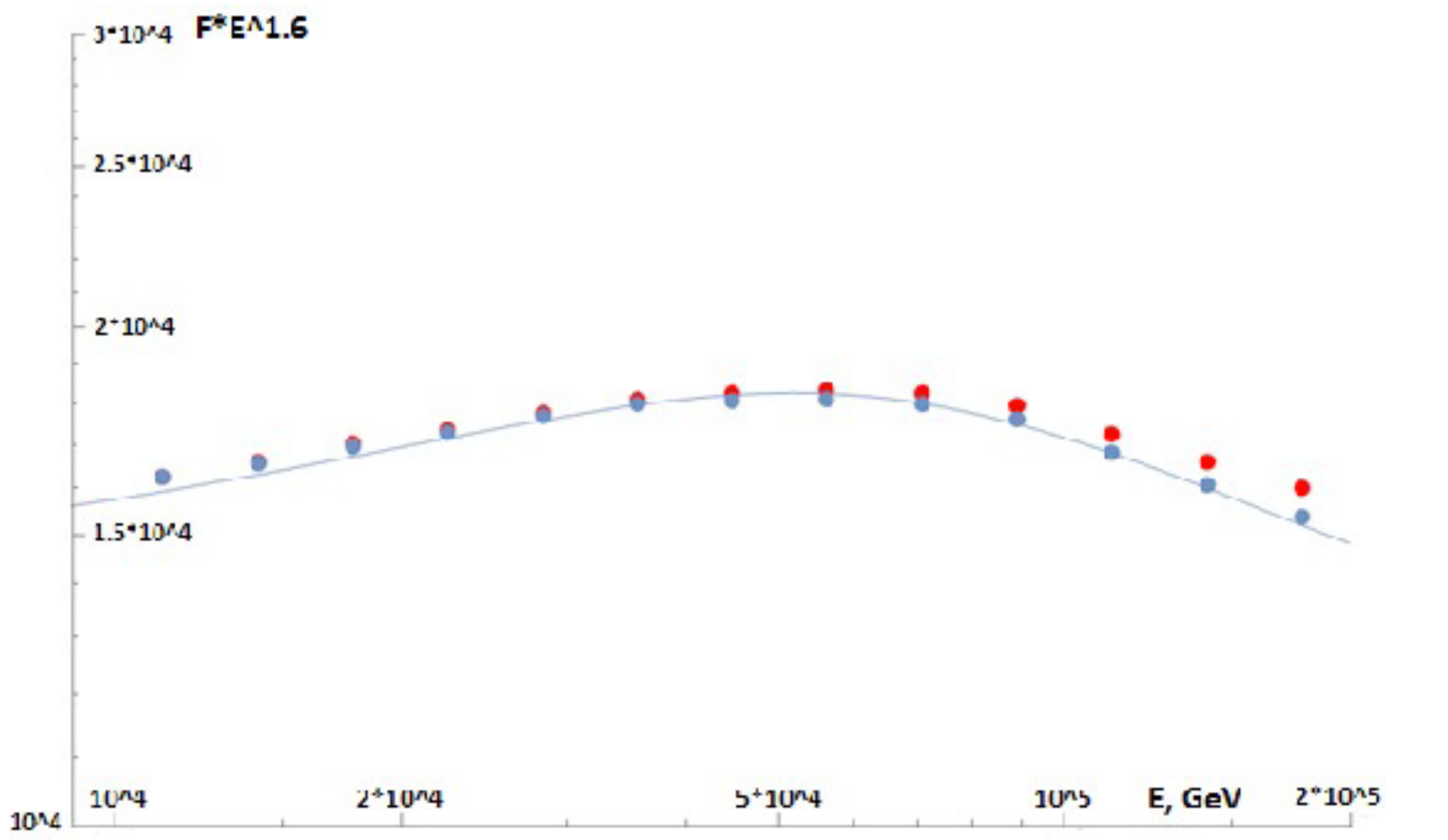
Localization of a hypothetical source in distance-age coordinates, color denoted xi2



Best fit experimental data



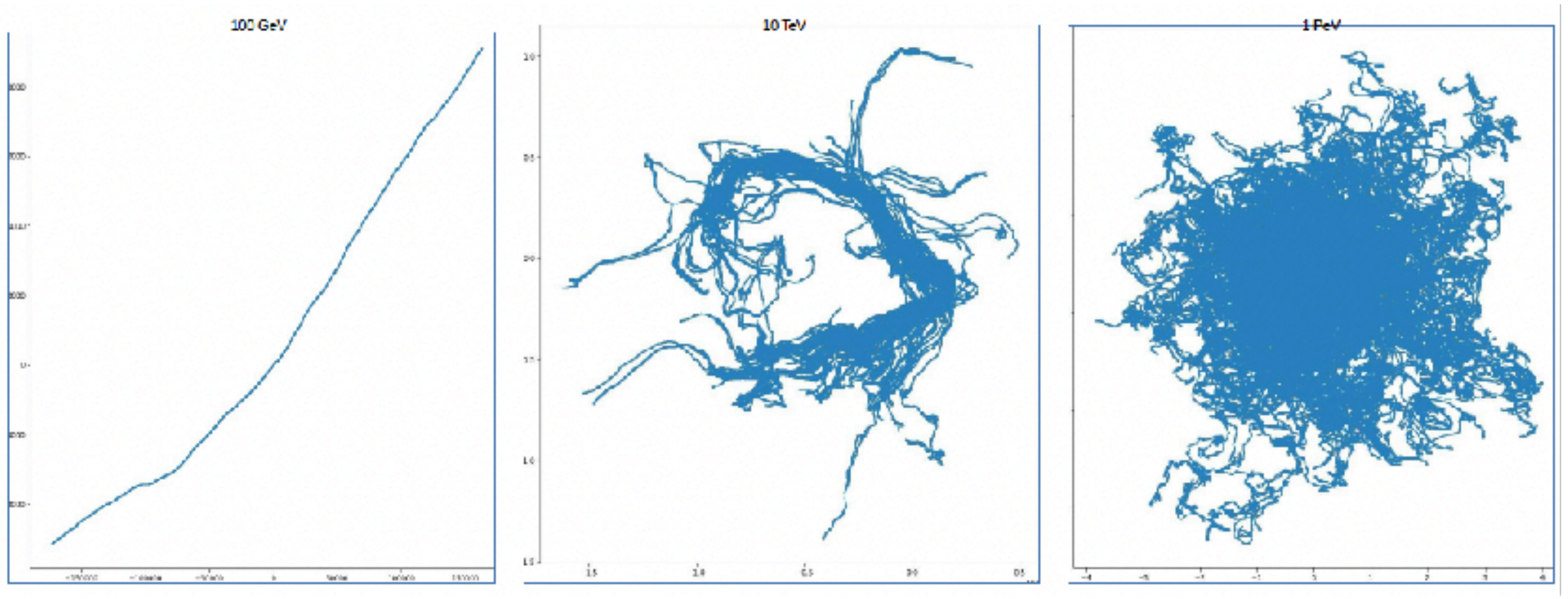
Predictive model of spectra P & He for a source with minimum Xi2~3 at a distance of 170 parsecs and an age of 4000 years and experimental data



Predictive model of all particle spectra for a source with minimum Xi2 ~ 3 at a distance of 170 parsecs and an age of 4000 years and experimental data. Red point -HAWC data Blue point- HAWC data multiplied by the correlation function

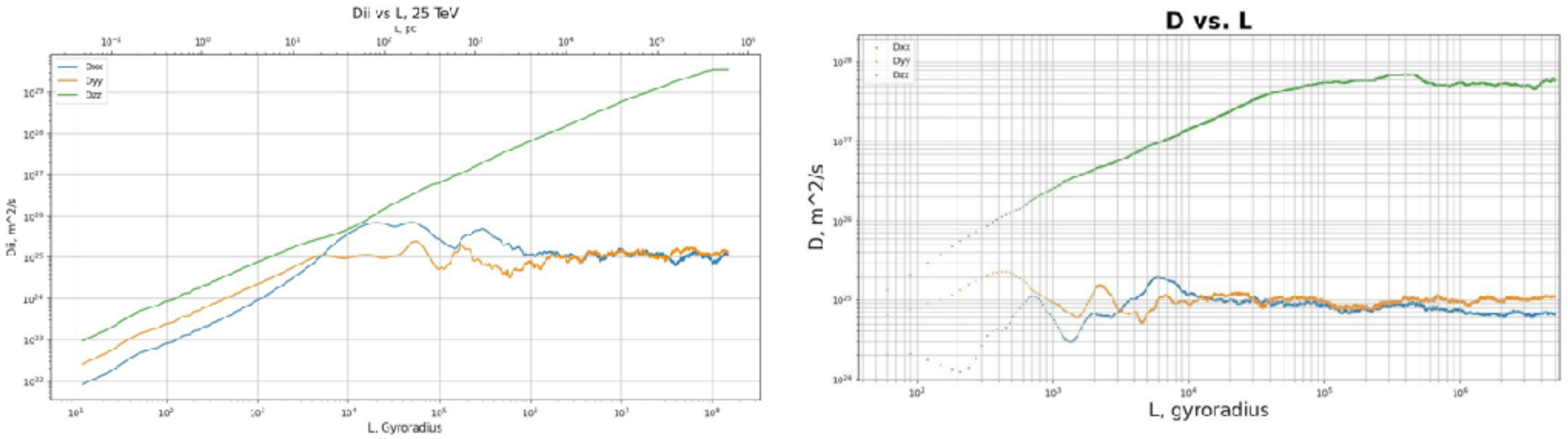
Interpretation of the spectral inhomogeneity in the 10TV region in terms of a close source (2)

Calculation of particle trajectories in the generated magnetic field



Trajectories of particles with energies of 100 GeV (not to scale), 10 TeV and 1 PeV in turbulent magnetic field Brandom at Bmean =0. From these trajectories it can be seen that for energies below 10 TeV the anisotropy is determined by the local field

Calculation of transport coefficients to refine the position of the source and take into account the anisotropy



Diffusion coefficients for protons 25 TeV (left) and 1 PeV(right) as a function of the path L (in gyroradii), calculated in the configuration Brms = 6muG and Bmean = 6muG (directed along the Z axis).
Significant anisotropy of transport coefficients is visible, this will be taken into account in the next work.
It is also worth paying attention to the fact that the transport coefficient along the regular field behaves in a superdiffusion manner at small ranges, when the transverse transport already demonstrates diffusion behavior.
This feature will be taken into account in future work.

Conclusion

A model of the contribution of a single point source-flash to the background spectrum of CR in the approximation of diffusion without energy losses and fragmentation is proposed to explain the nature of the observed spectral inhomogeneity of CR.
For the first time, the model takes into account the combination of direct experiments that measure the spectra of elements separately and the HAWC experiment that measures the spectrum of all particles. To take into account the data of the ground-based experiment, the penalty method was applied with a twodimensional correlation function
The model demonstrates reasonable agreement with experimental data at the source energy up to 1051 erg, localizes the position of a hypothetical source in the distance-time space in a narrow region of phase space, and also predicts the most likely area of existence of such a hypothetical source at 0.1 – 0.2 kpc and an age of 1 to 5 thousand years.
Transport coefficients were calculated for a wide energy range (25 TeV-10PeV) in a realistic magnetic field with configuration regular field 6 μG + 6 μG random field distributed over the Kolmogorov spectrum in the range from 100 astronomical units to 100 parsecs. Significant anisotropy of diffusion coefficients is shown.
It should be noted that the optimal source is obtained quite young, so the approximation of the source-flash for its description is not very accurate, and given that the isotropic diffusion for these energies is a very rough approximation, the presented results should be considered preliminary, and in the subsequent work we assume to take into account the anisotropy of the diffusion tensor and the evolution of the supernova remnant at the Sedov-Taylor stage. Thus, it is demonstrated that the explanation of the observed spectral inhomogeneity of the CR near 10 TV in terms of magnetic rigidity by the contribution of a single remnant of a close supernova to the observed cosmic ray fluxes is possible.