CR propagation interpretation and key measurements

1) Galactic cosmic rays (GCR)

2) XS for GCR data interpretation

3) Conclusions and perspectives

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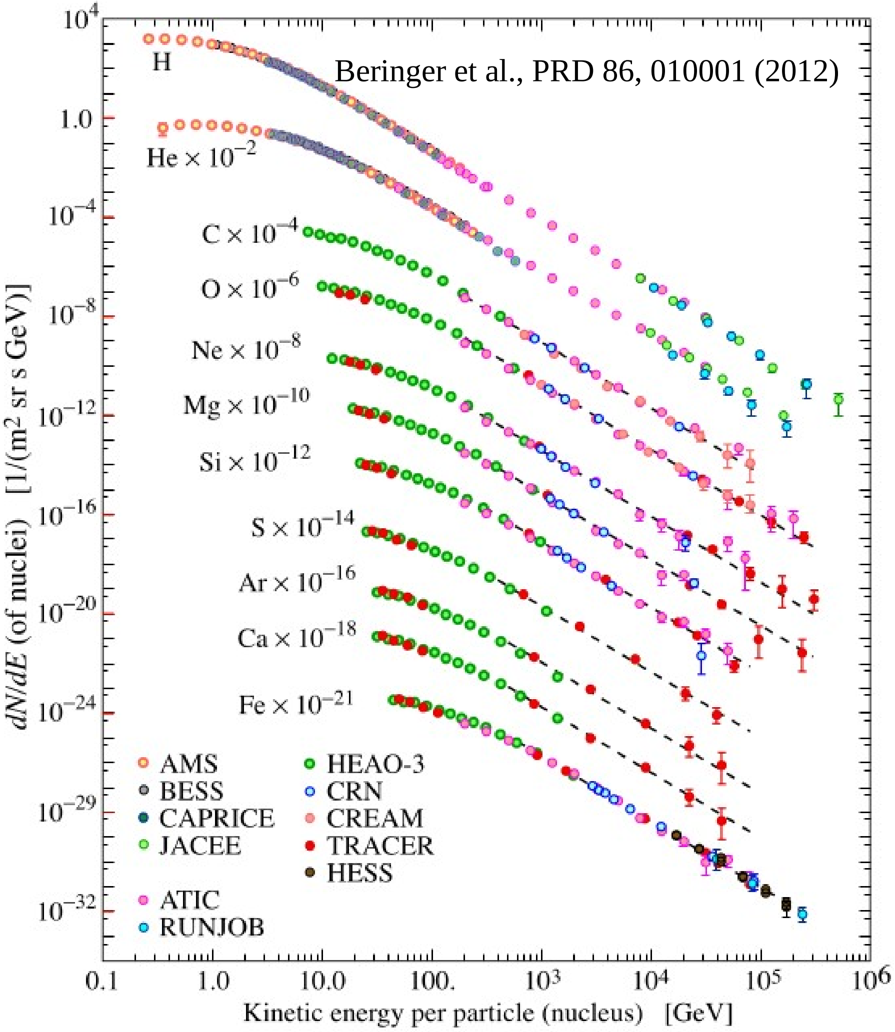
JENAA @ CERN
20 August 2024

1) Intro: Galactic CR data ($E \sim 10^{8}$-10^{15} eV)

Elemental spectra

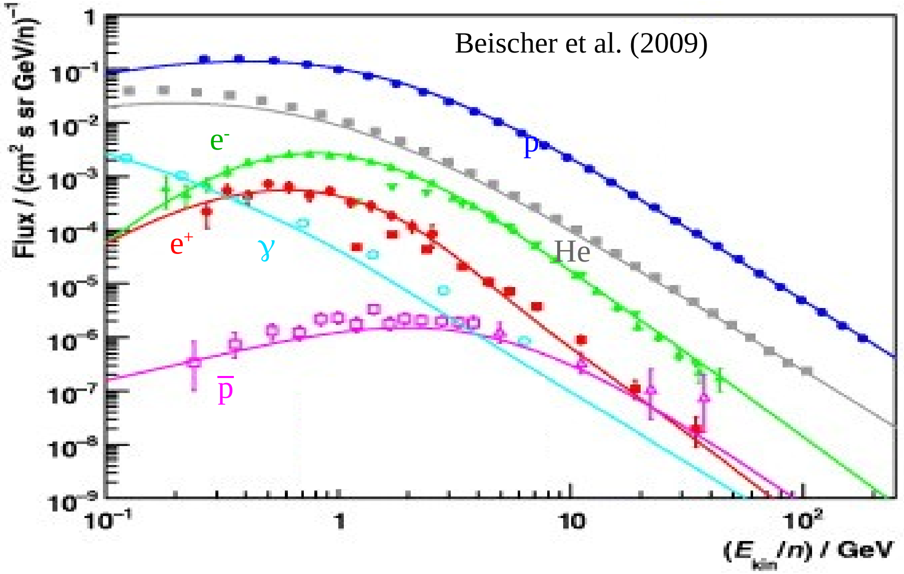


Astrophysical questions

- Sources: origin, abundances, E_{max}
- Transport: turbulence, anisotropies ($\delta < 10^{-3}$)

+ origin of quasi-universal power law ($E^{-2.8}$)

Protons and He
vs
diffuse γ-rays, pbar, and e^{+}



Dark-matter related
(in rare CRs)

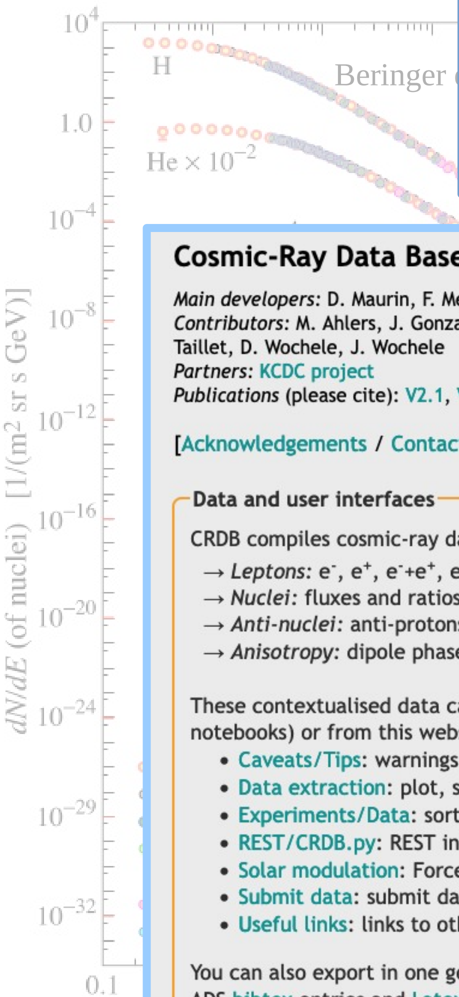
- How well do we know astro. prod.?
- Are there primary sources?

1) Intro: CR data in CRDB (https://lpsc.in2p3.fr/crdb)

CRDB (Cosmic Ray Data Base)

DM, Ahlers, Dembinski, Haungs, Mangeard, Melot, Mertsch, Wochele (2023)

All charged CR data and meta-data (references, dates, infos) + plotting tools (online or pip library/tutorial) + Solar mod. Levels + …
(https://github.com/crdb-project/tutorial)



Cosmic-Ray Data Base (CRDB)

Main developers: D. Maurin, F. Melot, and H. Dembinski (+ logo by H. Dembinski)
Contributors: M. Ahlers, J. Gonzalez, A. Haungs, P.-S. Mangeard, I. Mariş, P. Mertsch, R. Taillet, D. Wochele, J. Wochele
Partners: KCDC project
Publications (please cite): V2.1, V4.0, V4.1

[Acknowledgements / Contact us / Funding support]

DB status

Current version: v4.1 (June 2023)
Code last change: 15/01/2024
DB content: 131 exps from 504 publications (4111 sub-exps, 316126 data points)

[ChangeLog / Latest data / View traffic]

[Gallery from CRDB.py and notebook]

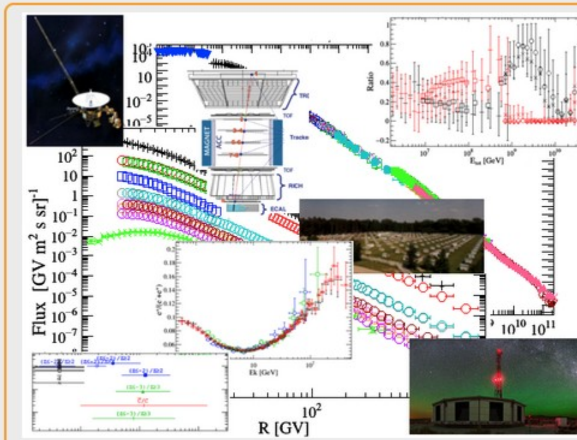
Data and user interfaces

CRDB compiles cosmic-ray data and meta-data from 10^6 eV to 10^{21} eV:

→ *Leptons*: e^-, e^+, e^-+e^+, $e^+/(e^-+e^+)$, and e^+/e^-
→ *Nuclei*: fluxes and ratios of isotopes, elements, and groups of elements
→ *Anti-nuclei*: anti-protons, limits on anti-deuterons and anti-nuclei
→ *Anisotropy*: dipole phase and amplitude

These contextualised data can be retrieved from a pip-installable python library (see also the example notebooks) or from this website:

- Caveats/Tips: warnings on some datasets and info on data transformations
- Data extraction: plot, save, and export user-selected CR quantities
- Experiments/Data: sorted lists of experiments, publications, and their data
- REST/CRDB.py: REST interface (query from script) and python library
- Solar modulation: Force-Field modulation level time series (and REST access)
- Submit data: submit data and their associated meta-data
- Useful links: links to other CR databases or resources



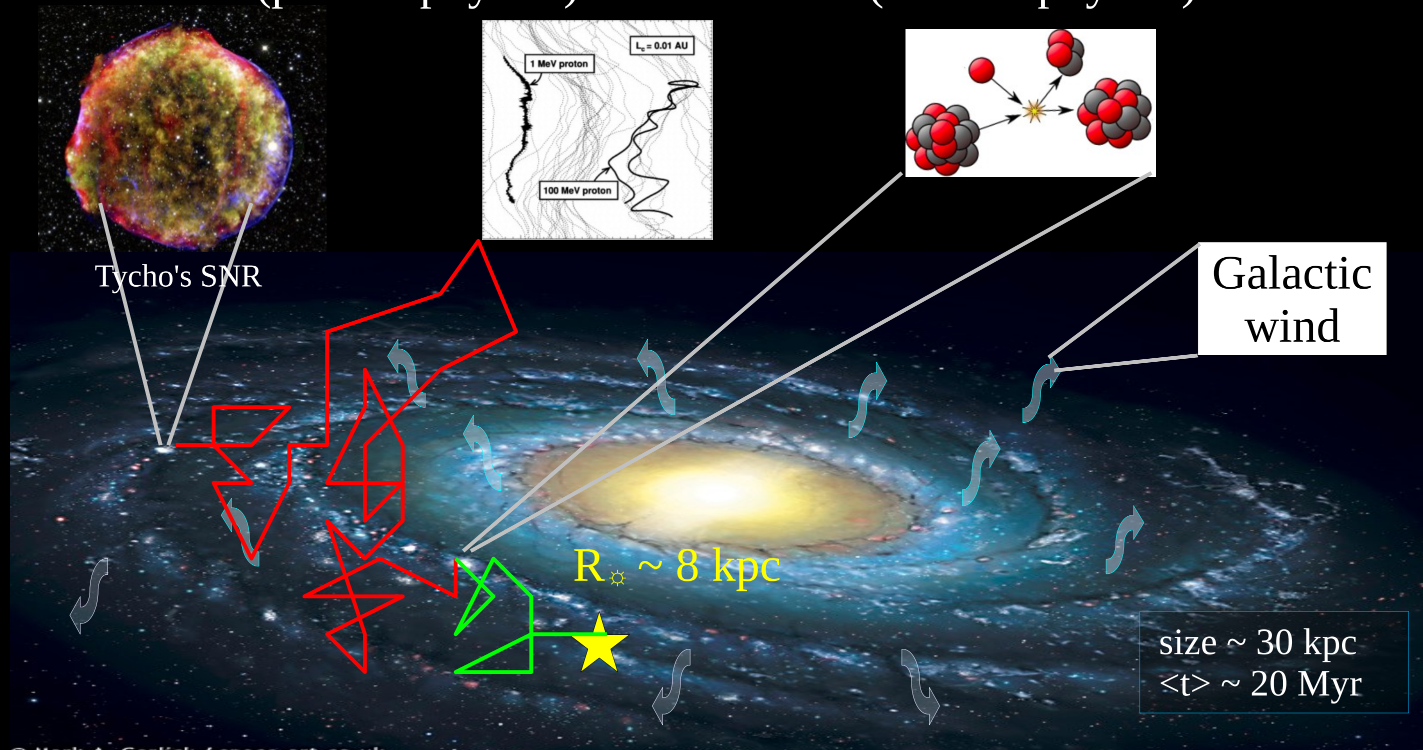
You can also export in one go the DB content (USINE, GALPROP, csv, or csv-asimport format) and the associated ADS bibtex entries and Latex cite (sorted by sub-experiment).

Behind the scene

- *Architecture:* LAMP solution (Linux OS, Apache HTTP server, MySQL database, PHP Hypertext PreProcessor) hosted at LPSC on a virtual server
- *Web pages:* PHP language, AJAX, sorting and displays with jquery (and jquery-ui, jquery.cluetip, table-sorter), and Rest interfaces enabled
- *Scripts and codes:* c++ and ROOT CERN library for plots, cron job scheduler for meta-data and modulation data updates
- *Data extraction:* extensive use of the ADS system, DataThief, and a lot of patience!

1) Intro: GCR transport

(plasma physics) (nuclear physics)



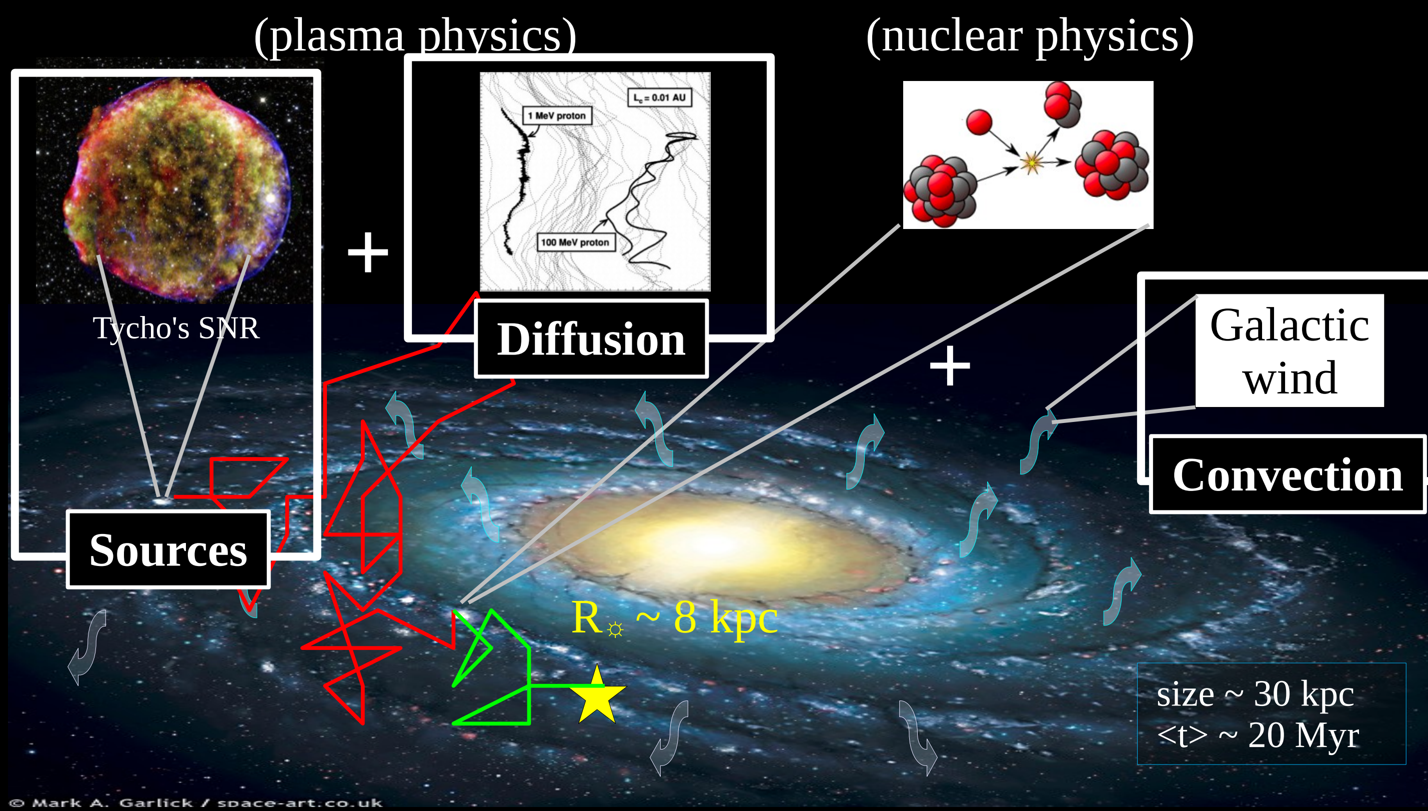
(astrophysics + particle physics)

→ Phenomenological transport models to interpret CR data
(DRAGON, GALPROP, PICARD, *USINE*)

DM, CPC (2020)
https://dmaurin.gitlab.io/USINE/

N.B: microphysics-based approaches make progress!
(e.g., moving-mesh MHD code AREPO)

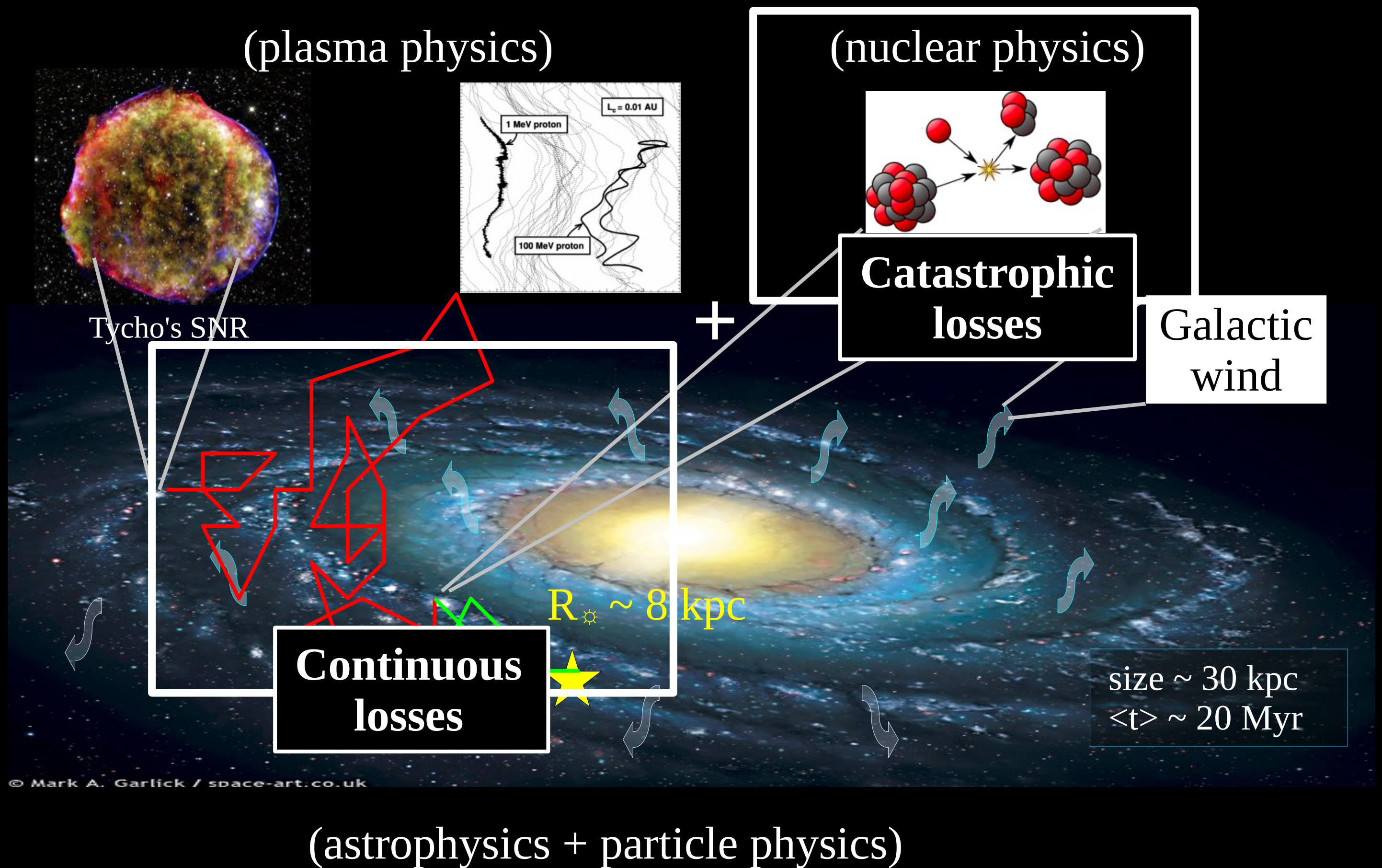
1) Intro: model parameters



(astrophysics + particle physics)

Source and transport parameters
= free parameters to determine from GCR data

1) Intro: XS as key ingredient

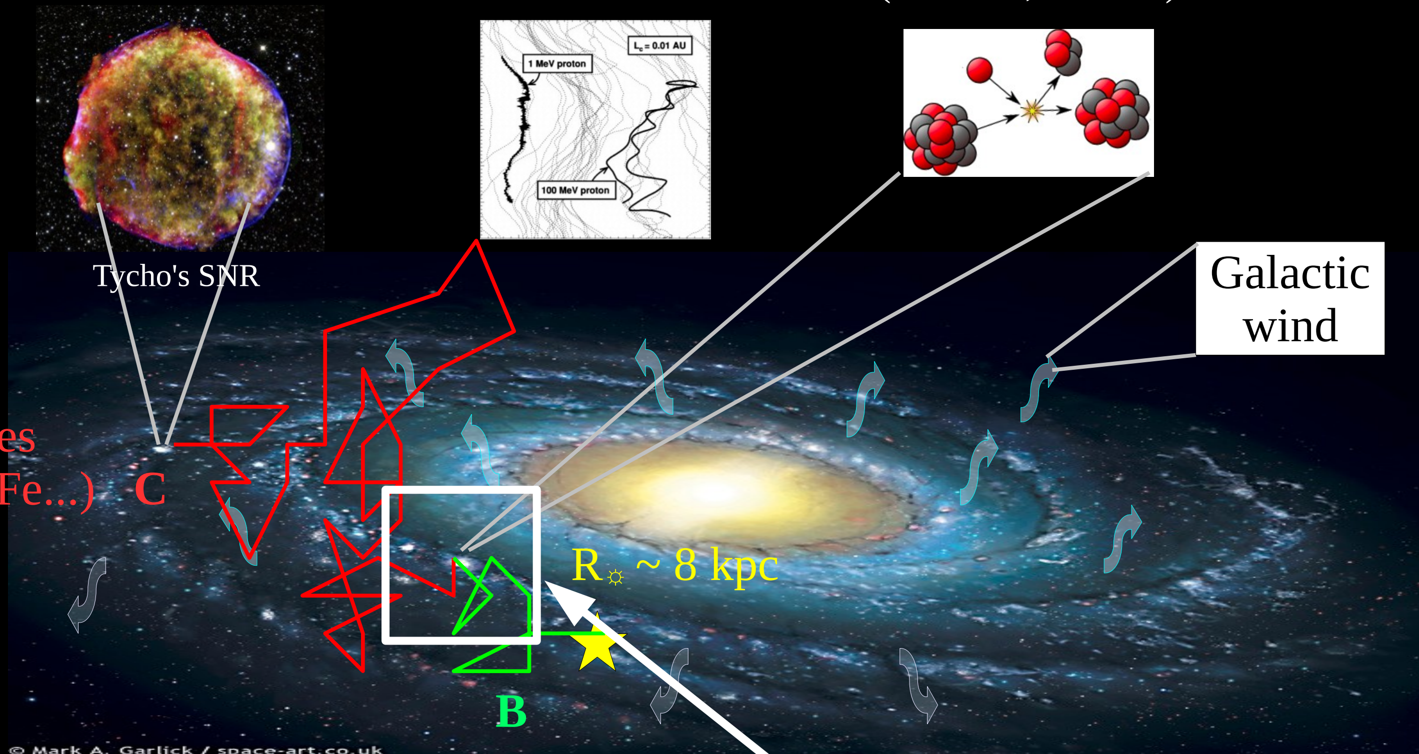


Continuous and **catastrophic losses**
= input ingredients of the GCR calculation

This talk = nuclear XS uncertainties are a limitation for data interpretation (astro and dark matter)

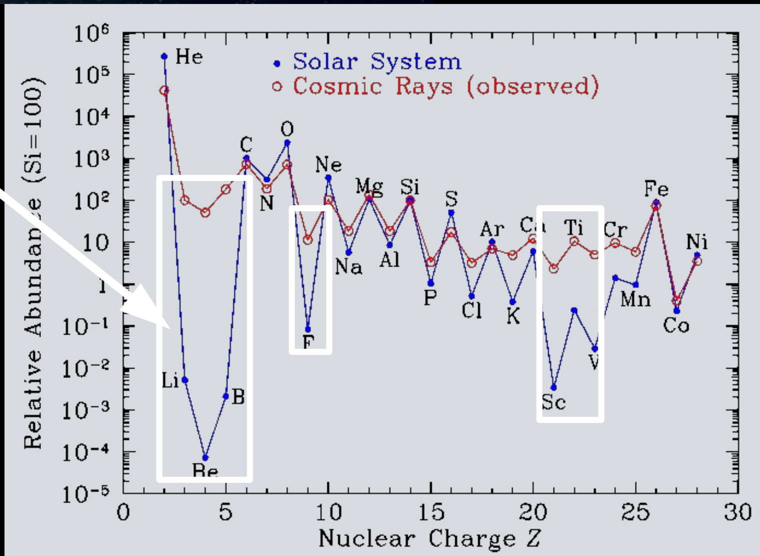
2) Nuclear XS for transport parameters

ISM = targets
(~ 90% H, 10% He)



Primary species
(p, He, C, O, Si, Fe...)

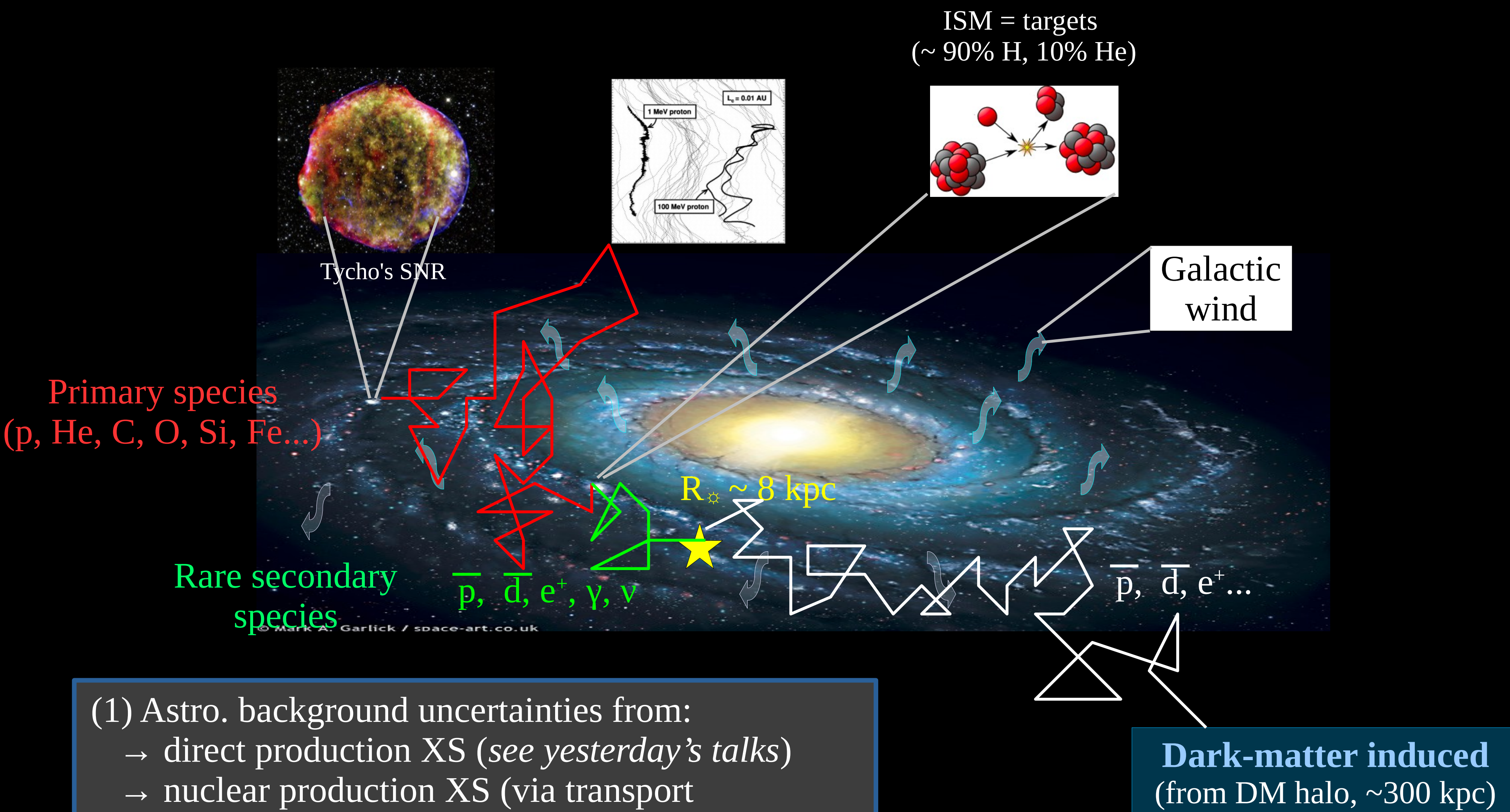
Secondary species
(^{2}H, ^{3}He, Li-Be-B, F, sub-Fe)



→ Secondary fluxes proportional to nuclear production XS
→ Sec./prim. (B/C, F/Si…) constrain transport parameters
[e.g. Weinrich et al., 2020; Ferronato Bueno et al., 2024]

Transport uncertainties depend on nuclear production XS

2) Nuclear XS for dark matter searches



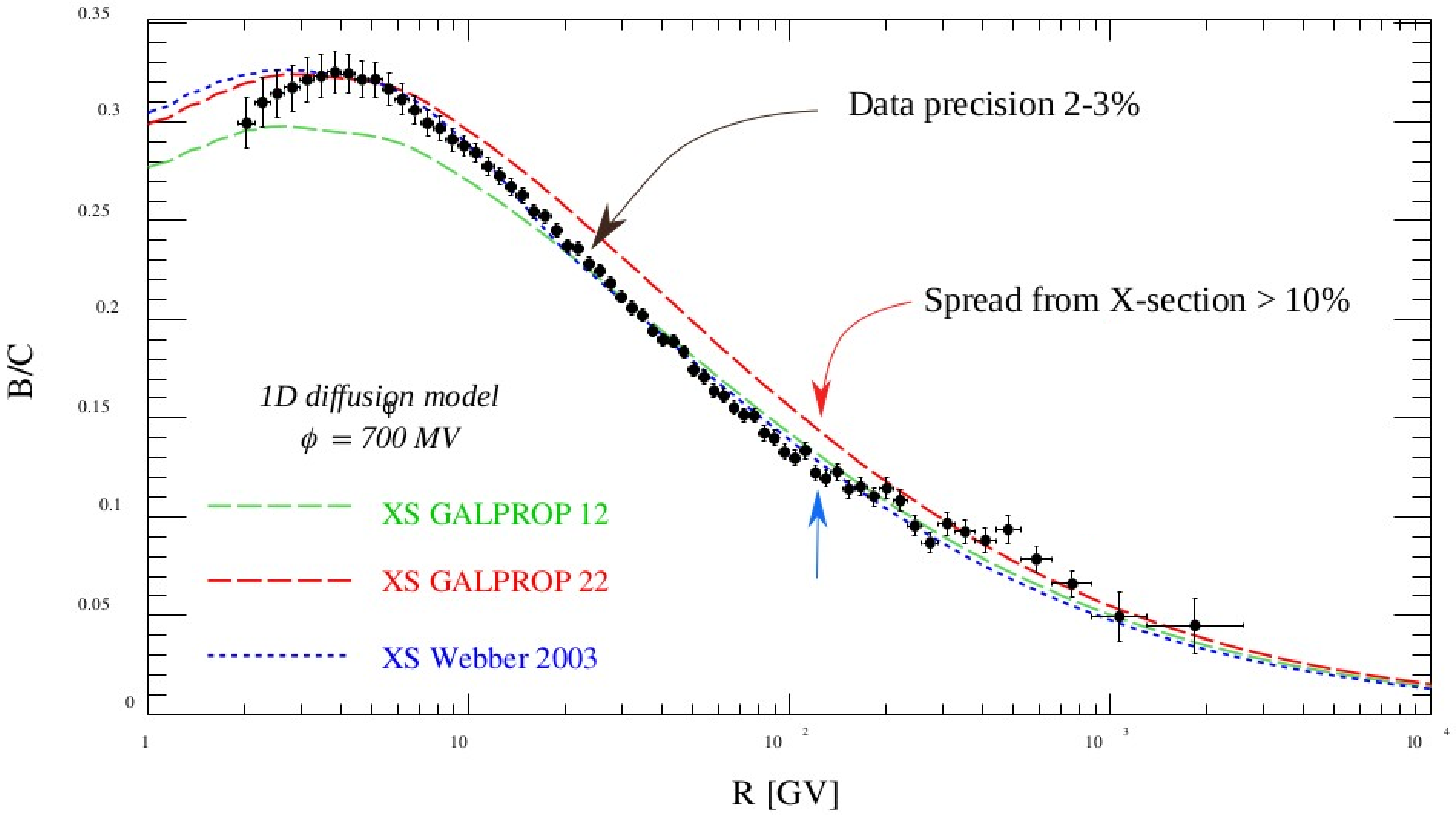
(1) Astro. background uncertainties from:
- → direct production XS (*see yesterday's talks*)
- → nuclear production XS (via transport parameters fixed from LiBeB/C)

(2) DM signal uncertainties from:
- → nuclear production XS (diffusive halo size L determined from ^{10}Be/^{9}Be data and XS)

2) XS for GCRs vs AMS-02 data

Modelling systematics (from XS) vs CR data uncertainties

[N.B.: XS parametrizations rely on same nuclear data]



→ **Interpretation of recent data (e.g. universality of transport for all species) limited by XS uncertainties**

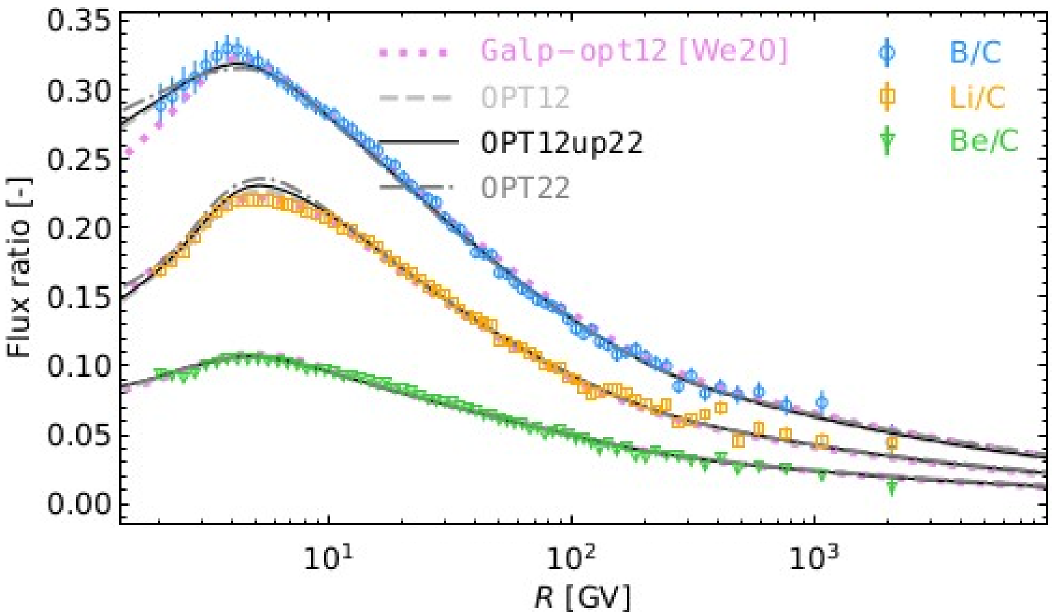
2) XS for GCRs vs AMS-02 data

Modelling systematics (from XS) vs CR data uncertainties

[N.B.: XS parametrizations rely on same nuclear data]

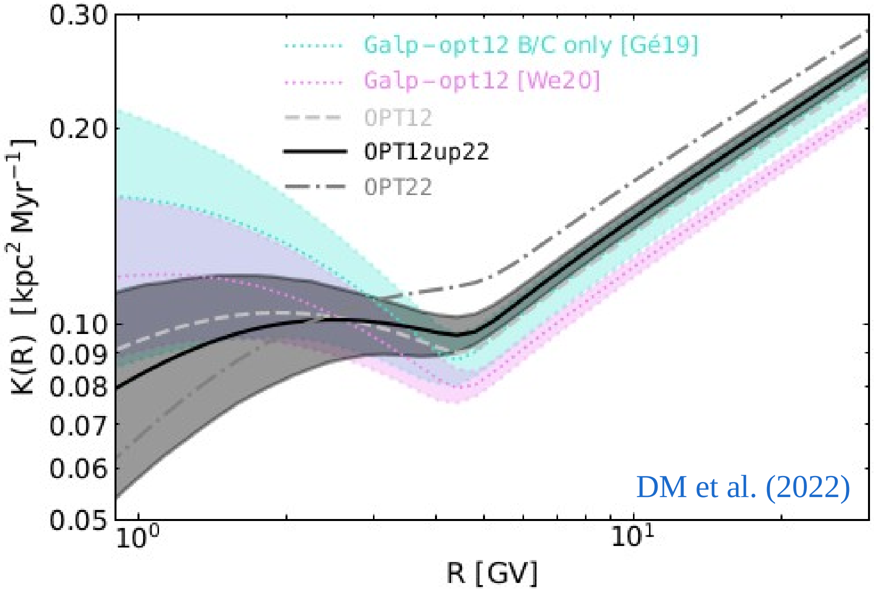
Fit to AMS-02 data

[including nuisance parameters on XS]



Uncertainty on diffusion coefficient

[including OPT12up22 XS model updated on unaccounted for 2003-2022 XS data]



Universality of transport?

→ Yes within current nuclear uncertainties

(*no need for source of primary Li*)

But to fully exploit CR data, new/better XS data are needed… but which ones?

2) XS for GCRs: ranking of desired nuclear data

→ Network of ~1000 reactions (up to ^{56}Fe) to rank!

[N.B.: CR fluxes use cumulative XS (account for short-lived nuclei)]

$$\sigma^{c}(X+H\rightarrow Y) \;=\; \sigma(X+H\rightarrow Y) \;+\; \sum_{G\,\in\,\text{ghosts}} \sigma(X+H\rightarrow G)\cdot \mathcal{B}r\,(G\rightarrow Y)$$

1) Ranking of reactions for LiBeB [Génolini, DM, Moskalenko & Unger, 2018]

2) Motivated pilot run in 2019 (PI M. Unger) [NA61/SHINE Collab., ICRC 2019+2021]

3) Ranking up to Si + all infos to calculate necessary beam time + forecast of impact of new measurements [Génolini, DM, Moskalenko & Unger, 2024]

+ *next step: ranking for light nuclei, relevant CR isotopes, and Si-Fe*

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Illustration of ranking on Li

	Flux impact f_{abc}	σ (mb)		
Reaction	**Mean**	[Min,Max]	Data	$\frac{\sigma}{\sigma^{\mathrm{cumul}}}$
$^{16}\mathrm{O}+\mathrm{H}\to{}^{6}\mathrm{Li}$	**15.2**	[13.0, 18.4]	√	1.0
$^{12}\mathrm{C}+\mathrm{H}\to{}^{6}\mathrm{Li}$	**12.5**	[14.0, 15.4]	√	0.9
$^{12}\mathrm{C}+\mathrm{H}\to{}^{7}\mathrm{Li}$	**9.93**	[11.9, 12.6]	√	1.0
$^{16}\mathrm{O}+\mathrm{H}\to{}^{7}\mathrm{Li}$	**9.74**	[10.7, 11.2]	√	1.0
$^{11}\mathrm{B}+\mathrm{H}\to{}^{7}\mathrm{Li}$	**2.92**	[21.5, 21.5]	√	1.0
$^{16}\mathrm{O}+\mathrm{He}\to{}^{6}\mathrm{Li}$	**2.86**	[20.6, 31.8]		1.0
$^{12}\mathrm{C}+\mathrm{He}\to{}^{6}\mathrm{Li}$	**2.14**	[21.6, 23.7]		0.9
$^{7}\mathrm{Li}+\mathrm{H}\to{}^{6}\mathrm{Li}$	**2.11**	[31.5, 31.5]	√	0.7
$^{13}\mathrm{C}+\mathrm{H}\to{}^{7}\mathrm{Li}$	**2.05**	22.1		1.0
$^{56}\mathrm{Fe}+\mathrm{H}\to{}^{7}\mathrm{Li}$	**2.03**	[23.0, 23.0]	√	1.0
$^{15}\mathrm{N}+\mathrm{H}\to{}^{7}\mathrm{Li}$	**1.95**	18.6	√	1.0
$^{16}\mathrm{O}+\mathrm{H}\to{}^{15}\mathrm{N}$	**1.88**	34.3	√	0.5
$^{16}\mathrm{O}+\mathrm{He}\to{}^{7}\mathrm{Li}$	**1.82**	[17.8, 18.6]		1.0
$^{56}\mathrm{Fe}+\mathrm{H}\to{}^{6}\mathrm{Li}$	**1.74**	[17.8, 22.5]	√	0.8
$^{12}\mathrm{C}+\mathrm{He}\to{}^{7}\mathrm{Li}$	**1.71**	[18.4, 19.4]		1.0

...

Ranking

- Top 10 reactions → ~80% of Li
- Next 100 → ~15% of Li
- All the rest → ~5% of Li

About the nuclear data

- No data for many reactions
- Many reactions with 1 or 2 points
- Very partial E coverage
- Inconsistent data
- ...

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[N.B.: CR fluxes use cumulative XS (account for short-lived nuclei)]

$$\sigma^{c}(X+H\to Y) \;=\; \sigma(X+H\to Y) \;+\; \sum_{G\,\in\,\text{ghosts}} \sigma(X+H\to G)\cdot \mathcal{B}r\,(G\to Y)$$

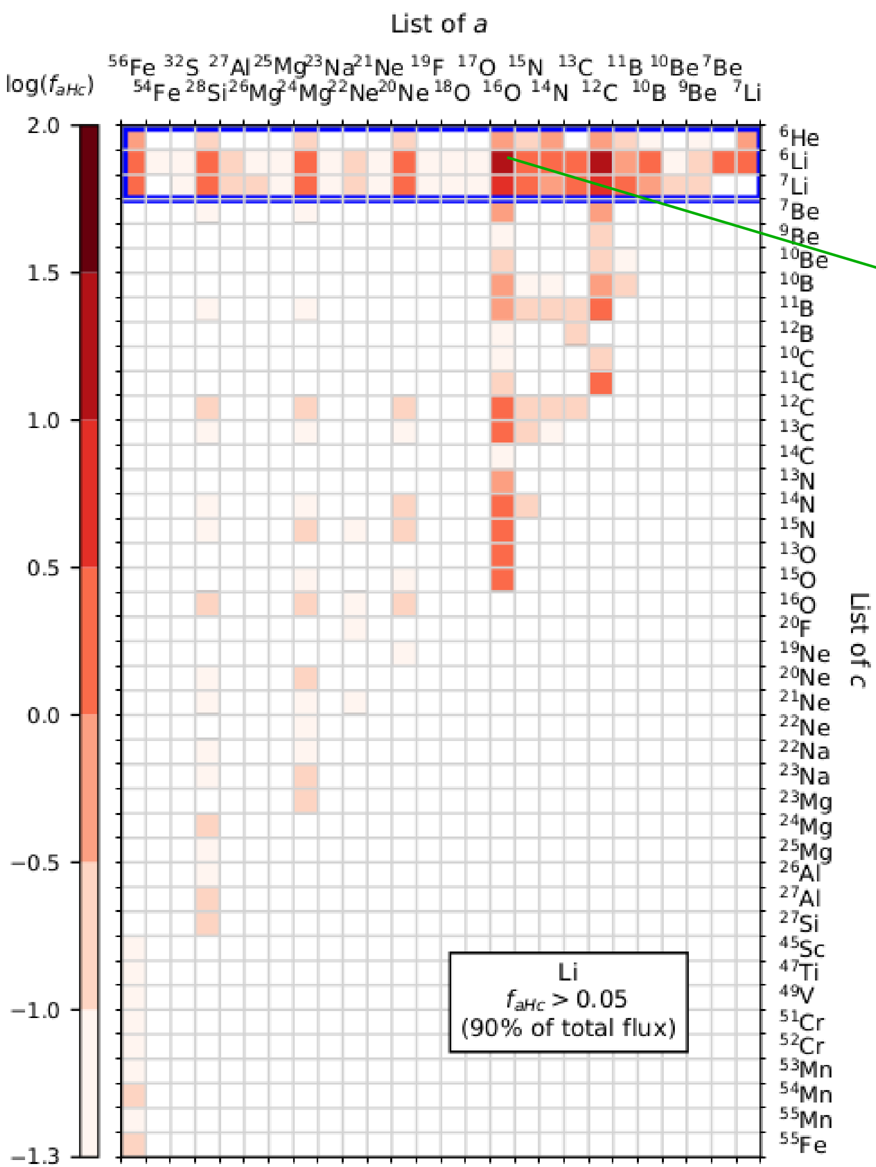
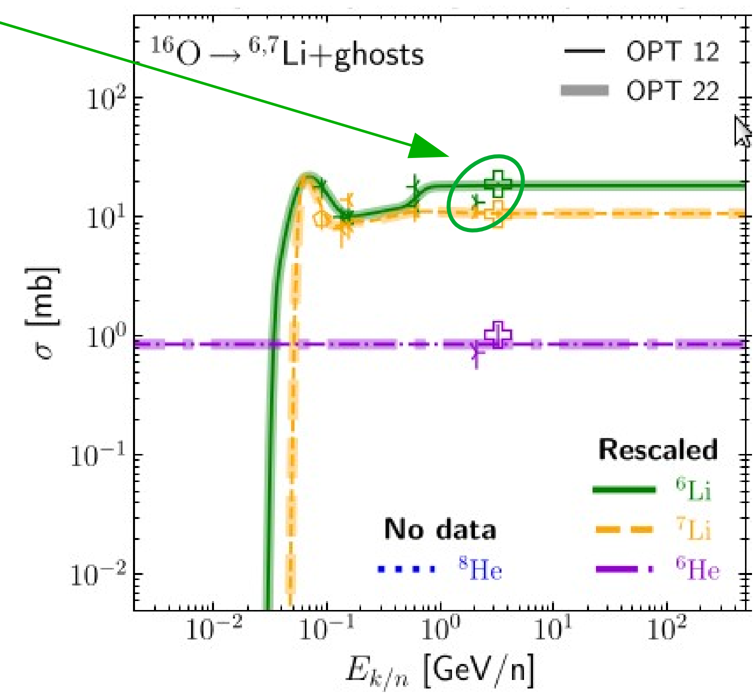


Illustration of limitation of current nuclear data and models

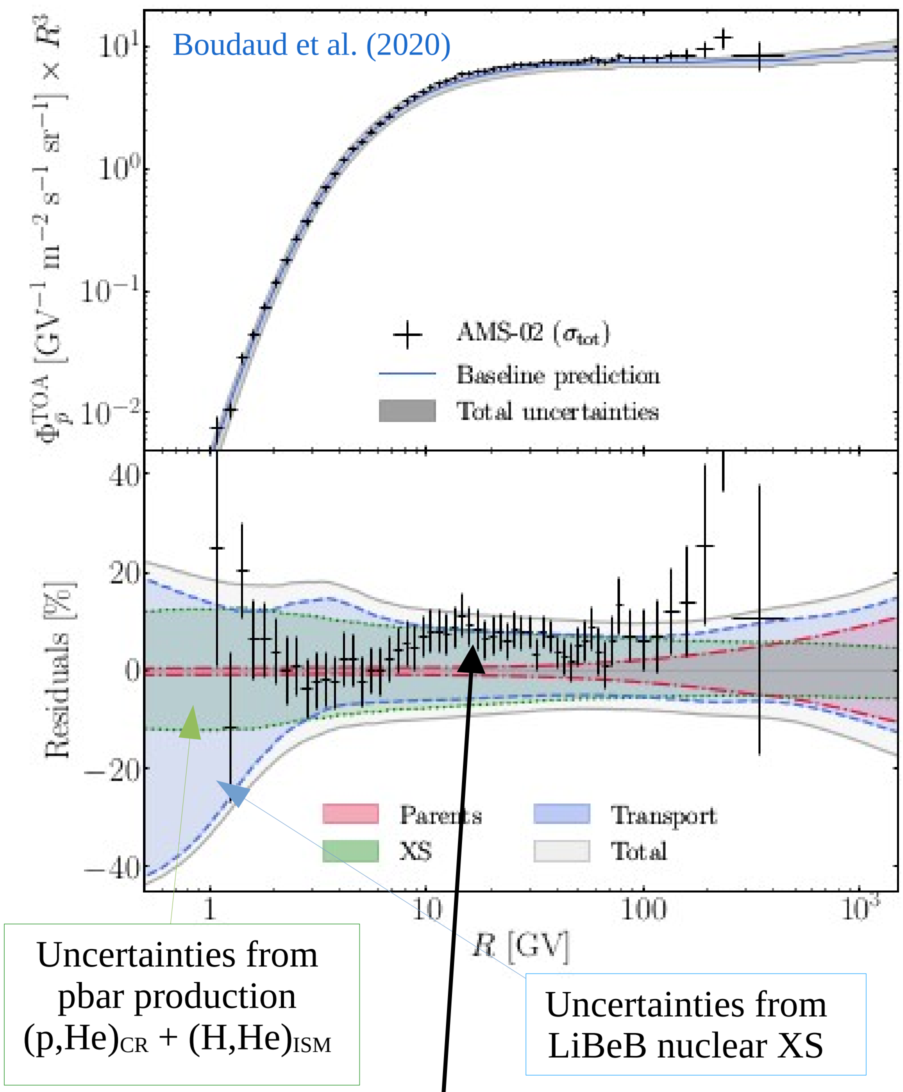


^{16}O+H → ^{6}Li (σ~20 mb) responsible for 16% of Li

→ **based on two inconsistent data points**

2) Nuclear XS for dark matter searches

Background (astro. contrib.)



Cannot take full benefit of AMS-02 high-precision data

[N.B.: any future improvement on pbar data moot if no better XS!]

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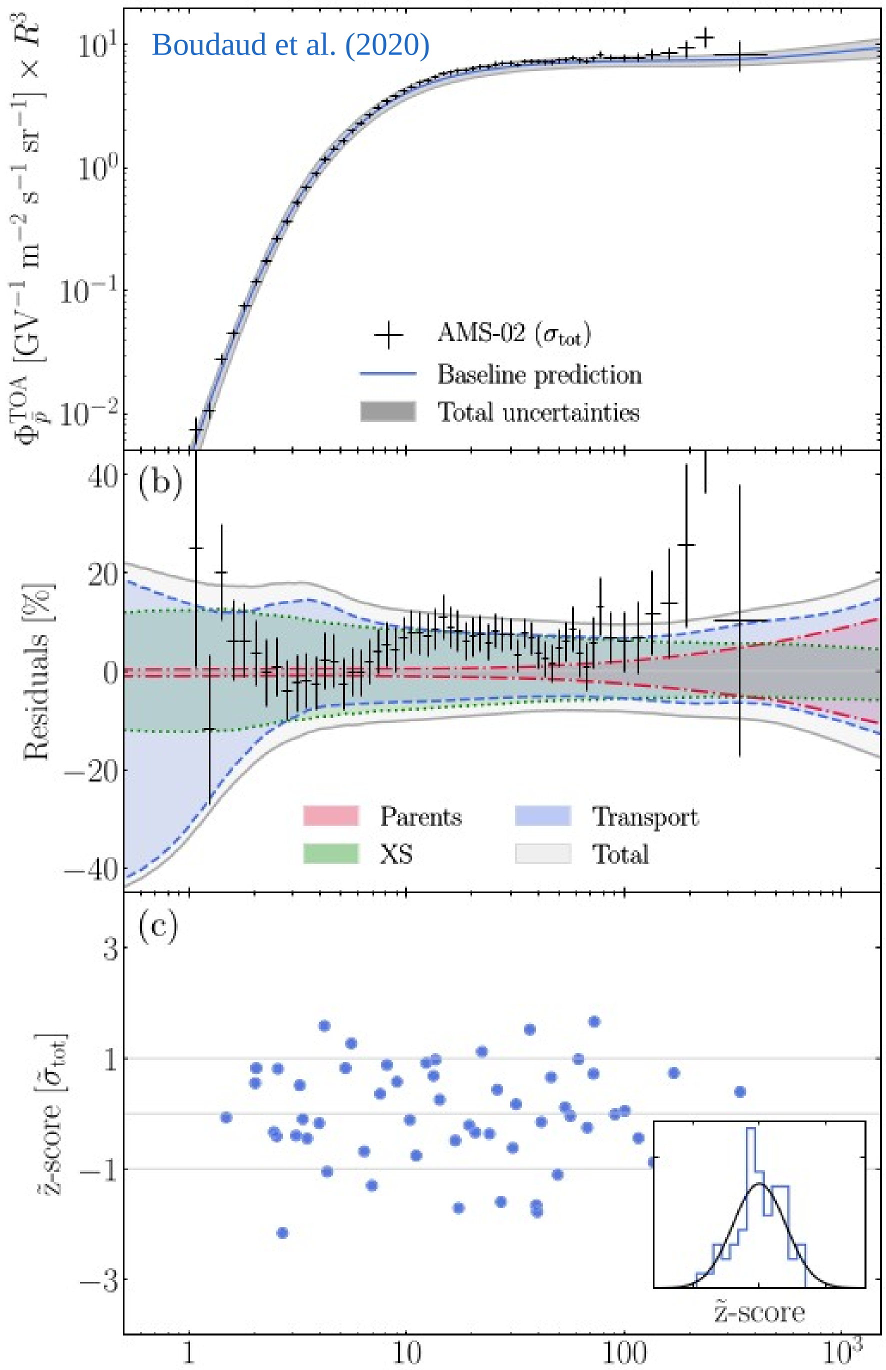

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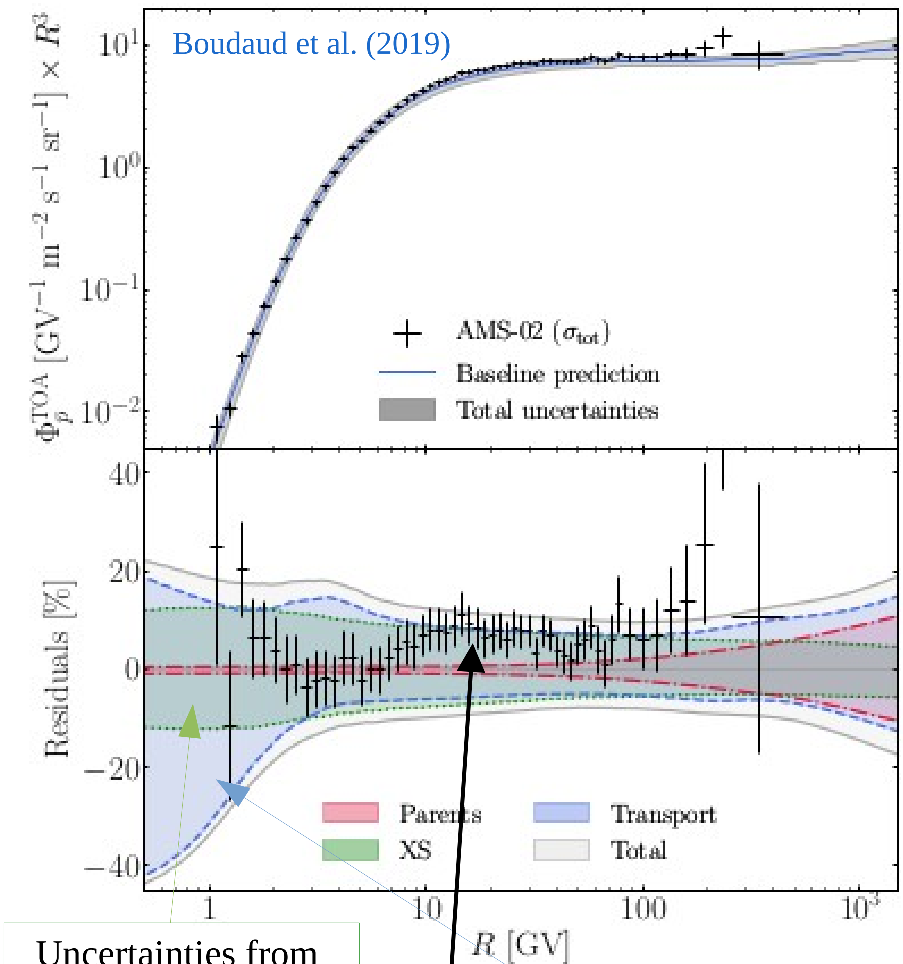

Uncertainties from pbar production $(p,He)_{CR} + (H,He)_{ISM}$

Uncertainties from LiBeB nuclear XS

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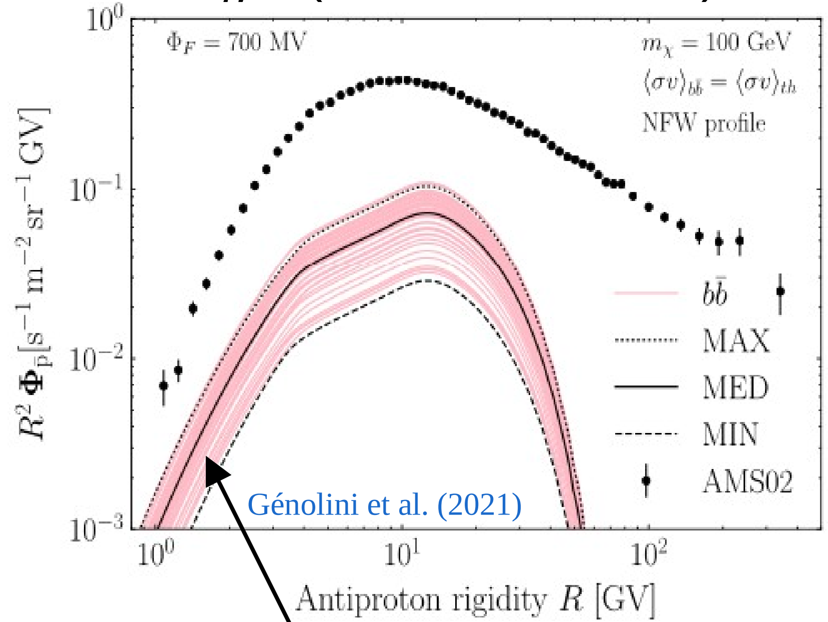
Signal (dark matter contrib.)



Signal uncertainty directly related to L (diffusive halo size)

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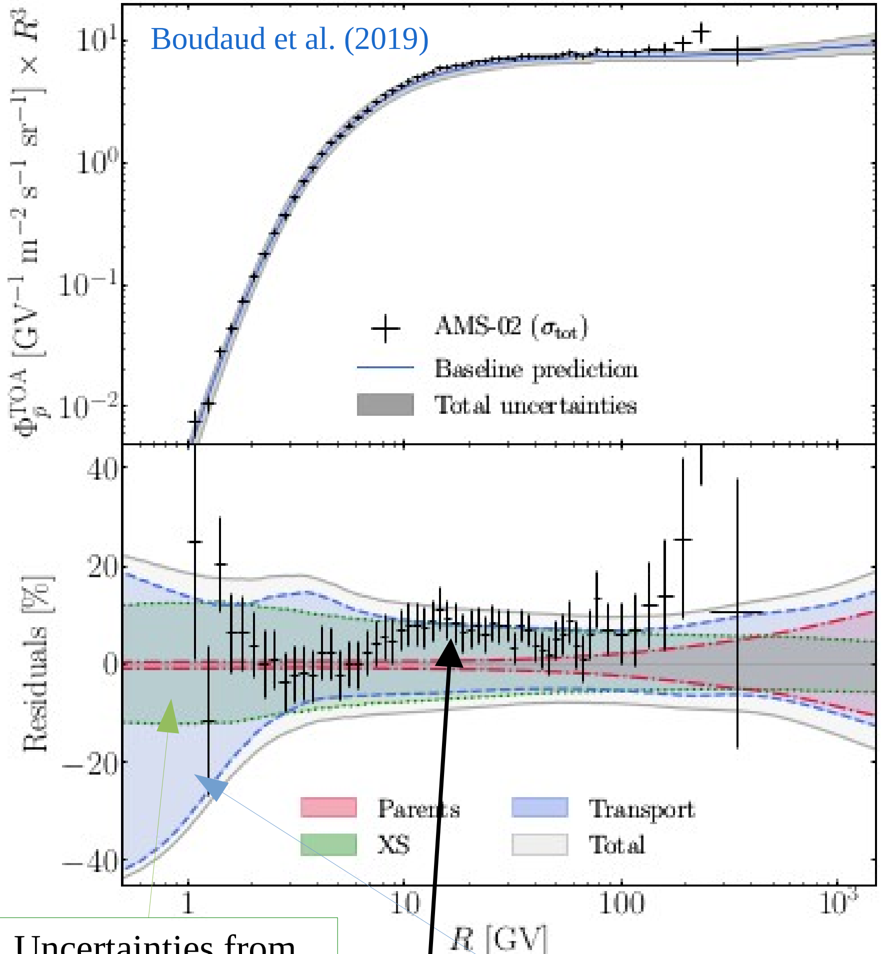

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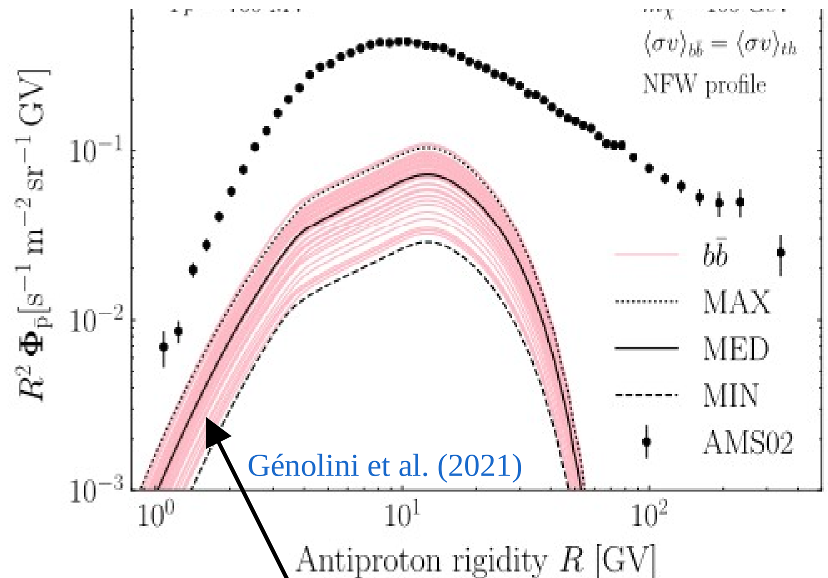

Signal uncertainty directly related to L (diffusive halo size)

Fit $^{10}Be/^{9}Be$ (analytical)		
Cross-section set	L [kpc]	χ^2_r
DM et al. (2022b)		
Galp-opt12	5.1 ± 0.6	0.46
OPT12up22	2.8 ± 0.3	0.40

Uncertainty on L large because of uncertain Be isotopic production XS

[N.B.: will plague interpretation of AMS-02 and HELIX measurement of this ratio]

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3) Conclusions and perspectives

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Improvement on XS models if no new data

Update XS parametrisations with “missed” nuclear data?
→ *Already done for main progenitors of LiBeB and F*

Use machine learning to improve/evaluate XS uncertainties?
→ *Preliminary study show potential for model improvement*

3) Conclusions and perspectives

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Use machine learning to improve/evaluate XS uncertainties?
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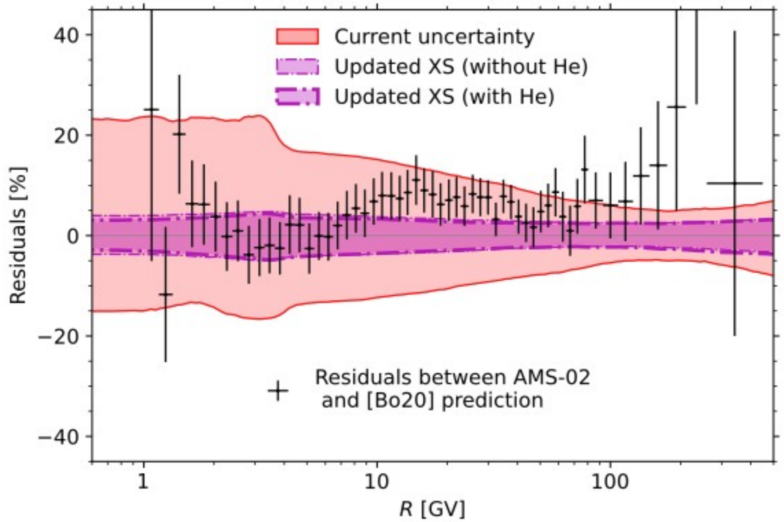
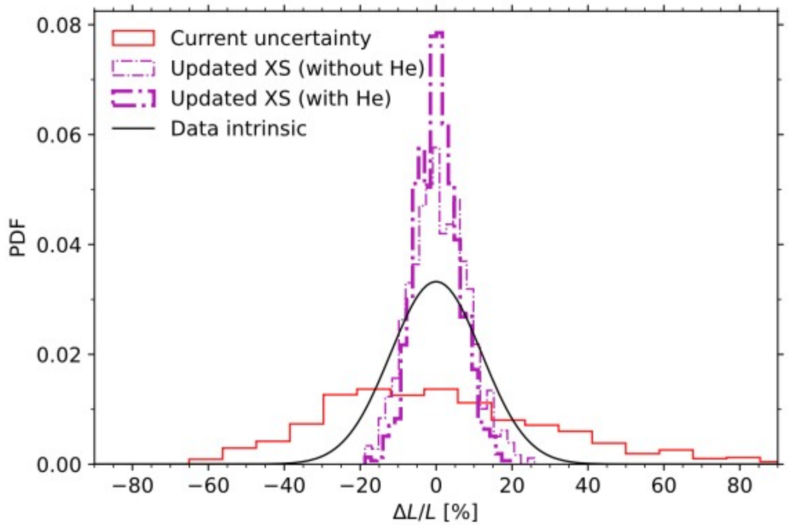
New data mandatory to fully exploit current GCR data
Configuration to reach ~3% precision on GCR fluxes
with a few 10^5 reactions @ a facility like NA61

Génolini, DM, Moskalenko & Unger (2024)





→ Stay tune for possible run at NA61 this year...

XSCRC2024: Cross sections for Cosmic Rays @ CERN

16–18 Oct 2024
CERN
Europe/Zurich timezone

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- Speaker List
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  - Directions to and inside CERN
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  - Child care

Support

THworkshops.secretaria...

Cosmic-ray (CR) physics in the GeV-TeV range has entered a precision era with recent data from space-based experiments. However, the poor knowledge of nuclear reactions (production of antimatter and secondary nuclei) limits the information that can be extracted from these data (such as source properties, transport in the Galaxy, indirect searches for dark matter).

The first edition of this workshop was held in 2017 : XSCRC17. Its goal, bringing together different communities (CR theorists, CR experimentalists, nuclear and particle physicists), was to review theoretical motivations for CR studies, new CR data, and how the modelling of CRs crucially depends on nuclear reactions. The workshop was also strongly aimed at presenting current efforts and discussing forthcoming perspectives for particle/nuclear measurement campaigns.

This second edition , XSCRC2019, review the advances made in the last two years, and highlight some results obtained thanks to collaborations started during the first edition.

The 2024 edition will further strengthen these emergent synergies, taking advantage of the complementarity and know-how in different communities: the challenges that pose the interpretation of high-precision CR data can only be undertaken with a collective and coordinated effort.

Duration: The workshop will start Wednesday, October 16th at 2pm, and will end Friday, October 18th by 4pm.

Organizing Committee: Fiorenza Donato (chair), Saverio Mariani (co-chair), David Maurin (co-chair)

Scientific Advisory Committee: Denise Boncioli (L'Aquila Univ.), Michela Chiosso (Torino Univ.), Gian Giudice (CERN), Giacomo Graziani (INFN Florence), Mercedes Paniccia (Geneva Univ.), Pasquale D. Serpico (LAPTh, CNRS), Vincent Tatischeff (IJClab, CNRS), Philip von Doetinchem (Hawaii Univ.)

Invited Speakers (list being updated): Adriani Oscar (Firenze INFN and Univ.), Eugenio Berti (INFN Firenze), Mattia Di Mauro (Torino INFN), Carmelo Evoli (Gran Sasso Science Institute), Davide Giordano (Torino INFN and Univ.), Chiara Lucarelli (INFN Firenze), Paolo Maestro (Pisa INFN, Siena Univ.), David Maurin (LPSC Grenoble), Luca Orusa (Princeton Univ.), Mercedes Paniccia (Geneva Univ.), Tanguy Pierog (KIT, Karlsruhe, IKP), Laura Serksnyte (TUM Munich), Andrii Tykhonov (Geneva Univ.), Michael Unger (KIT, Karlsruhe, IAP)

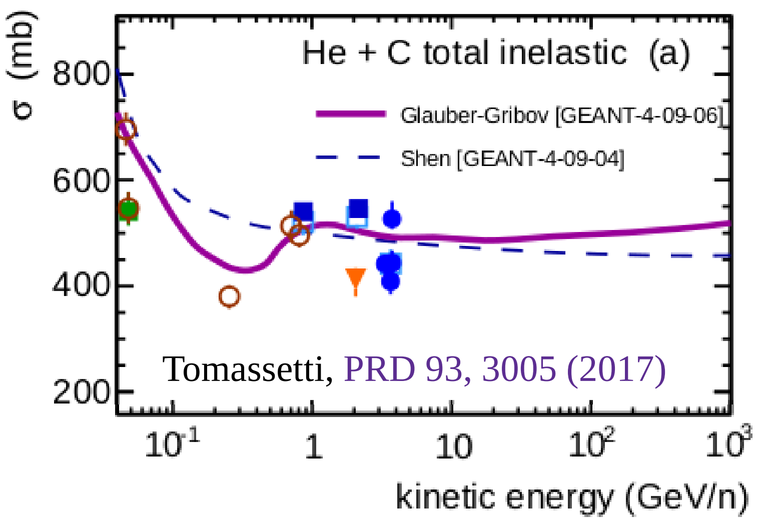
Still time to register and/or submit talks!

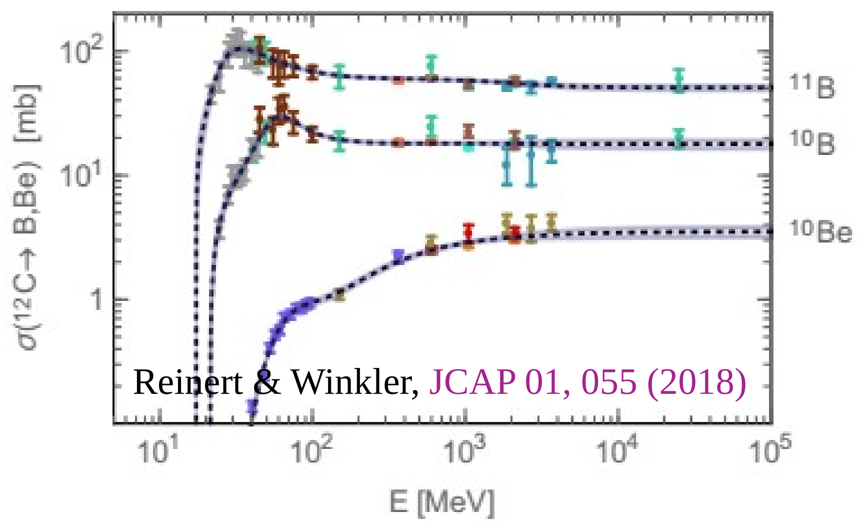
XS for GCRs and their typical uncertainties

Reaction cross sections
(CR destruction)

Production cross sections
(creation of secondary species)

on targets
(ISM = 90% H+10% He)





Uncertainties ~ 5-10% (on H)
→ **mostly OK in AMS02 era**

Uncertainties ~ 10-20% (on H)
→ **big issue in AMS02 era!**

Beam time calculation

Génolini et al. (2024)

TABLE IV. Required number of interactions to be recorded per reaction, as calculated from Eq. (18) with $\beta = 1$. The reactions are given in three groups of increasing projectile mass (up to O, Si, or Fe). The cumulative number of required interactions is quoted at the end of each group.

Reaction	$N_{\rm int}$
^{16}O + H	60k
^{12}C + H	50k
^{16}O + He	20k
^{11}B + H	10k
^{15}N + H	10k
^{14}N + H	10k
^{12}C + He	10k
^{10}B + H	5k
^{13}C + H	5k
^{7}Li + H	5k
	$N(\leqslant \mathrm{O}) = 1.9 \times 10^5$
^{28}Si + H	50k
^{24}Mg + H	50k
^{20}Ne + H	50k
^{22}Ne + H	20k
^{28}Si + He	10k
^{27}Al + H	10k
^{26}Mg + H	10k
^{24}Mg + He	10k
^{23}Na + H	10k
^{25}Mg + H	10k
^{21}Ne + H	10k
^{20}Ne + He	10k
^{32}S + H	5k
^{29}Si + H	5k
^{22}Ne + He	5k
	$N(\leqslant \mathrm{Si}) = 3.8 \times 10^5$
^{56}Fe + H	30k
^{56}Fe + He	10k
	$N(\leqslant \mathrm{Fe}) = 4.2 \times 10^5$

$$\left(\frac{\Delta\psi}{\psi}\right)^2_{a+b} = \frac{f^2_{\rm sec}}{N}\mathcal{C}^2_{ab}, \qquad \mathcal{C}^2_{ab} \equiv \sum_c f^2_{abc}\frac{\sigma_{a+b}}{\sigma_{a+b\to c}}.$$

The above uncertainty is only for one contributing reaction. The total flux uncertainty is obtained from the quadratic sum over all contributing reactions (i.e., reactions $a+b$, $d+e$, $f+g$, etc.). Labelling these n_r reactions with the index k, we can write $\{\mathcal{C}_{ab}, \mathcal{C}_{de}, \mathcal{C}_{fg}, \ldots\}$ as $\{\mathcal{C}_k\}_{k=1\ldots n_r}$, and assuming N_k interactions recorded for each reaction k, we get

$$\left(\frac{\Delta\psi}{\psi}\right)^2 = f^2_{\rm sec}\sum_{k=1}^{n_r}\frac{1}{N_k}\mathcal{C}^2_k. \tag{15}$$

We aim at the desired model uncertainty to be smaller than the uncertainty of the current and near future CR experiments. The AMS-02 experiment claims ≈3% uncertainty for most of its data. Therefore, since the contribution from cross-section uncertainties should be a subdominant of the overall uncertainty, we investigate how keep this contribution at the 1% level. If in addition an experimental systematic uncertainty of typically 0.5% can be achieved (e.g., Ref. [121]), then we arrive to the required statistical accuracy of $\xi = \sqrt{0.01^2 - 0.005^2} = 0.0087$ as in Ref. [122]. Adopting the optimal power-law exponent $\beta = 1$ derived in Sec. III C results in the required number of interactions listed in Table IV. It is worthwhile noting that a scaling with $\beta = 0$, as investigated in Paper I, would require about a factor-of-two more interactions to be recorded to obtain the same accuracy, but it involves fewer interaction channels.

Impact of new data (various XS model hypotheses)

Correlated uncertainties?

→ measurements from same experimental setup

→ parametrizations induce systematics

$$\left(\frac{\Delta\psi^{\rm tot}}{\psi^{\rm tot}}\right)^{\rm corr} \approx f^{\rm sec} \sum_{a,b,c} f_{abc} \frac{\Delta\sigma^{abc}}{\sigma^{abc}}$$

Uncorrelated uncertainties?

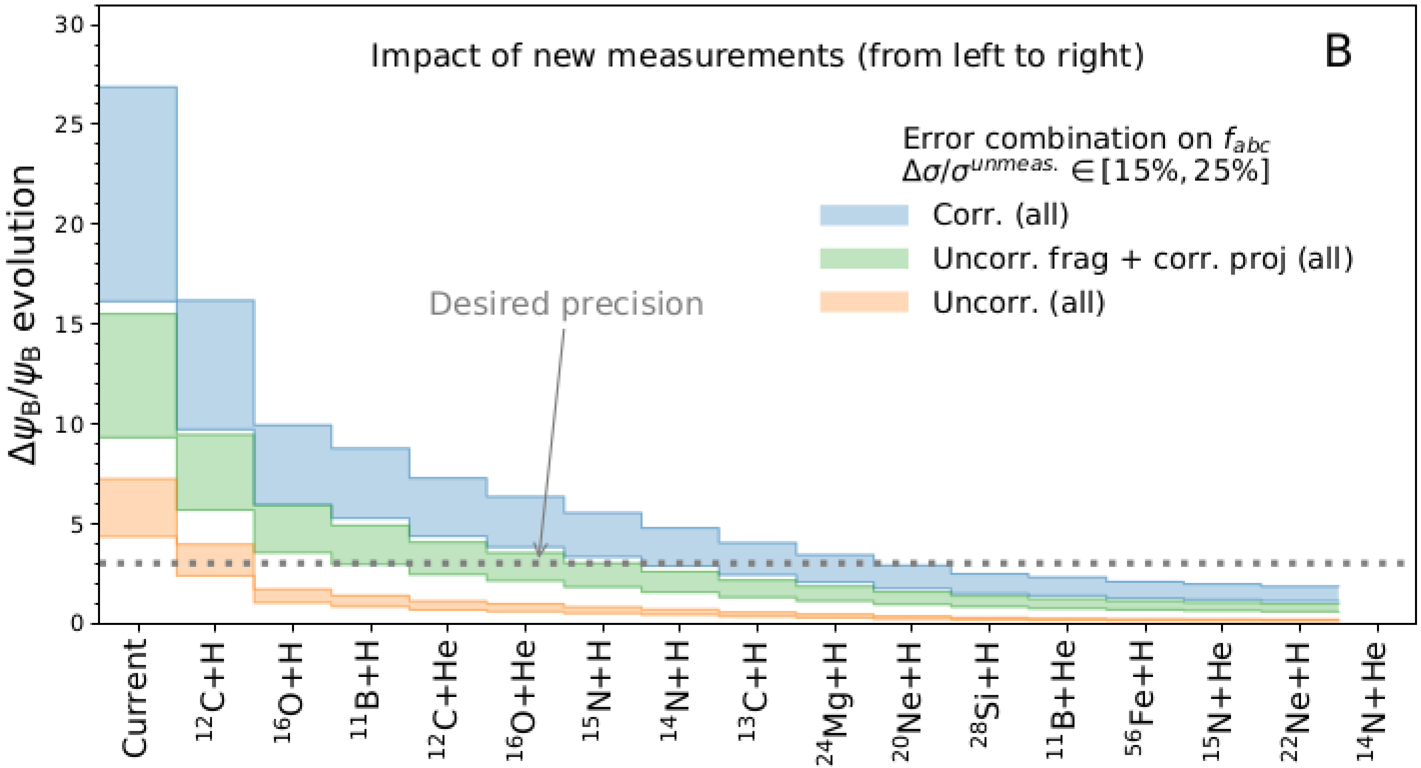
→ data from different experimental setups

$$\left(\frac{\Delta\psi^{\rm tot}}{\psi^{\rm tot}}\right)^{\rm uncorr} \approx f^{\rm sec} \sqrt{\sum_{a,b,c} \left(f_{abc} \frac{\Delta\sigma^{abc}}{\sigma^{abc}}\right)^2}$$

Looking at the data/parameterizations

- correlated for all fragments of a given projectile
- Uncorrelated between different projectile

$$\left(\frac{\Delta\psi^{\rm tot}}{\psi^{\rm tot}}\right)^{\rm mix} \approx f^{\rm sec} \sum_{a} \sqrt{\sum_{b,c} \left(f_{abc} \frac{\Delta\sigma^{abc}}{\sigma^{abc}}\right)^2},$$



XS parametrisations and EXFOR data base

XS Parametrisations

Two "historical" groups/codes

- WNEW (Webber et al., up to 2003): semi-empirical formula based on "regularities" observed in data
- YIELDX (Tsao & Silberberg, up to 2000): semi-analytical formula "driven" by theory

Model parameters = global fit on all data
YIELDX better than WNEW for XS reaction with "no data"

GALPROP implementation

Use of WNEW and YIELDX + rescaling on existing data (Moskalenko & Mashnick, 2003):

- Galp-opt12: starts from WNEW
- Galp-opt22: starts from YIELDX

XS extraction: EXFOR database

https://www.nndc.bnl.gov/exfor/exfor.htm

Type of measured reactions

- Direct: beam on H (or using CH2 − C subtraction technique)
- Indirect: target irradiated by proton beam (γ-spectrometry or mass spectrometry after chemical extraction)

Relevant publications for Fe

- Napolitani et al. (2004)
- Herbach et al. (2006)
- Villagrasa-Canton et al. (2007)
- Titarenko et al. (2008,2011)

In practice

- update all relevant XS for relevant progenitors (see Génolini et al., 2018): ^{56}Fe, ^{28}Si, ^{24}Mg, ^{20}Ne, ^{16}O, ^{14,15}N, 12C…
- Apply rescaling procedure

Most significant differences in updated XS

DM et al. (2022)

Beware: cumulative XS required in CRs
(must account for short-lived nuclei, aka ghosts)

$$\sigma^c(X+H\to Y) = \sigma(X+H\to Y) + \sum_{G\,\in\,\text{ghosts}} \sigma(X+H\to G)\cdot \mathcal{B}r(G\to Y),$$

For Fe in LiBeB, overall:

- Galp-opt12 (left factor) undershoots
- Galp-opt12 (right factor) overshoots

x = no data

	Li				Be					B					
	^{6}Li	^{7}Li	^{6}He (100%)	^{8}He (16%)	^{7}Be	^{9}Be	^{10}Be	^{11}Li (85%)	^{9}Li (49%)	^{10}B	^{11}B	^{11}C (100%)	^{10}C (100%)	^{11}Be (97%)	^{11}Li (7.8%)
^{56}Fe	∞|0.8	∞|1	∞|0.6	×	15|0.8	21|1.4	19|0.7	×	∞|0.3	20|0.8	15|1	2.0|1.7	×	×	×
^{28}Si	×	×	×	×	1	1.05	1.02	×	0.4	×	×	0.5|1.2	×	×	×
^{24}Mg	×	×	×	×	1.04	2.04	0.95	×	0.6	×	×	0.5|1.1	×	×	×
^{20}Ne	×	×	×	×	×	×	×	×	×	×	×	0.95	1	×	×
^{16}O	1.4	0.96	∞	×	0.98	1.41	1.18	×	0.7	0.96	0.4	∞	∞	∞	×
^{15}N	1	1	×	×	1	1	1	×	0.5	1.34	1.17	1	×	×	×
^{14}N	1	1	∞	×	1.18	0.94	1.02	×	0.8	0.91	0.6	∞	∞	×	×
^{12}C	1.1	0.94	∞	×	0.94	0.91	1.04	×	∞	1.08	0.92	1.04	0.7	×	×
^{11}B	1	1	×	×	1.06|1.16	1.04	0.4	×	0.97	0.93	...	∞|0.7	∞|1.16	×	×
^{10}B	×	×	×	×	0.94	×	×	...	×	...	...	...	∞|1.75	...	...
^{10}Be	×	×	×	×	×	×	...	...	×	×	...	...	×	...	...
^{9}Be	1	1	×	×	1	...	...	...	×	...	...	...	...	...	...
^{7}Be	×	×	×	...	...	...	...	...	...	...	...	...	...	...	...
^{7}Li	1	...	×	...	∞	...	...	...	...	...	...	...	...	...	...

For O in LiBeB (dominant progenitor, ~50% of total):

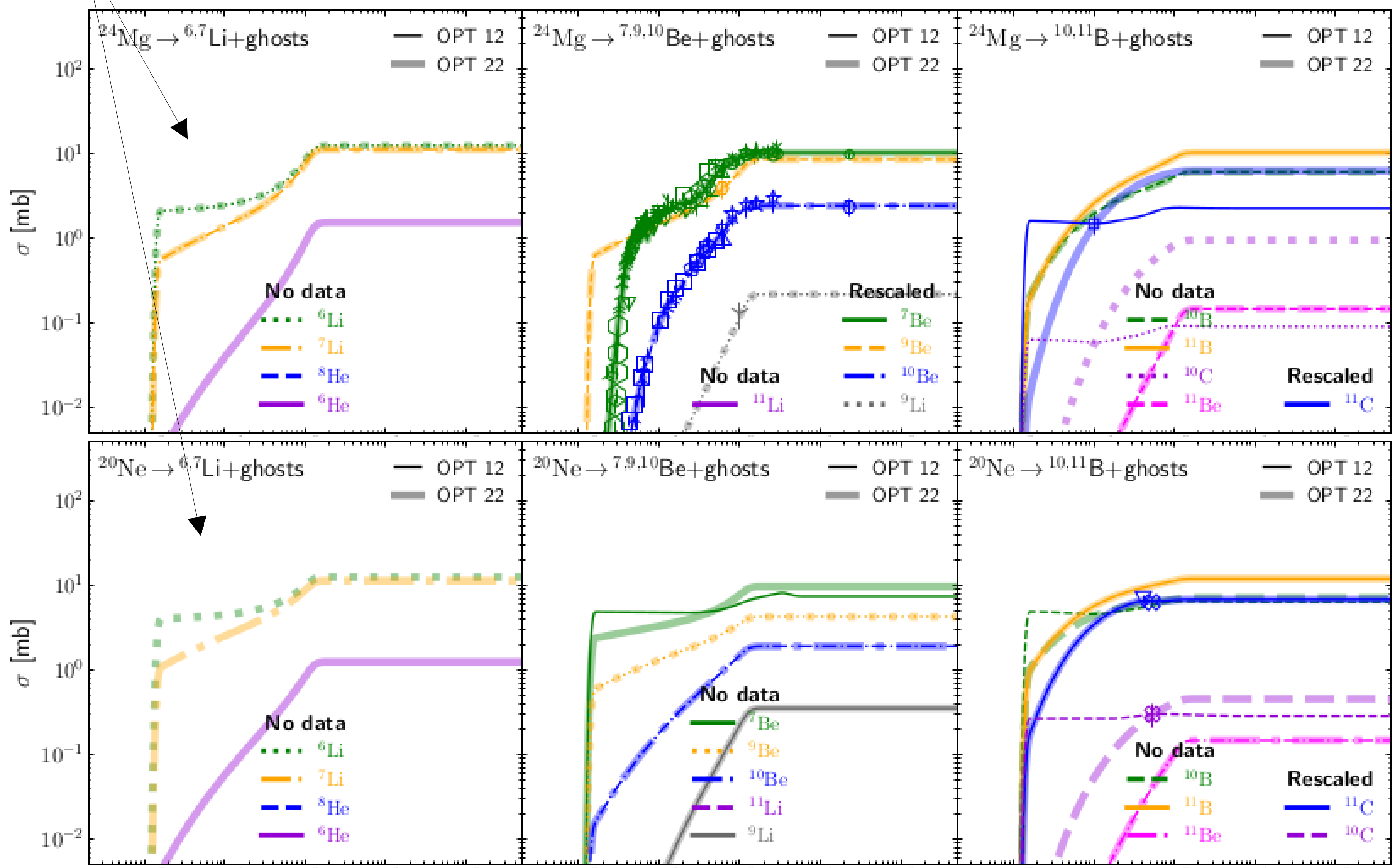
- Significant differences after update

Scare/no data for important reactions...

Beware: cumulative XS required in CRs
(must account for short-lived nuclei, aka ghosts)

$$\sigma^c(X+H\to Y) = \sigma(X+H\to Y) + \sum_{G\,\in\,\text{ghosts}} \sigma(X+H\to G)\cdot \mathcal{B}r(G\to Y)\,,$$

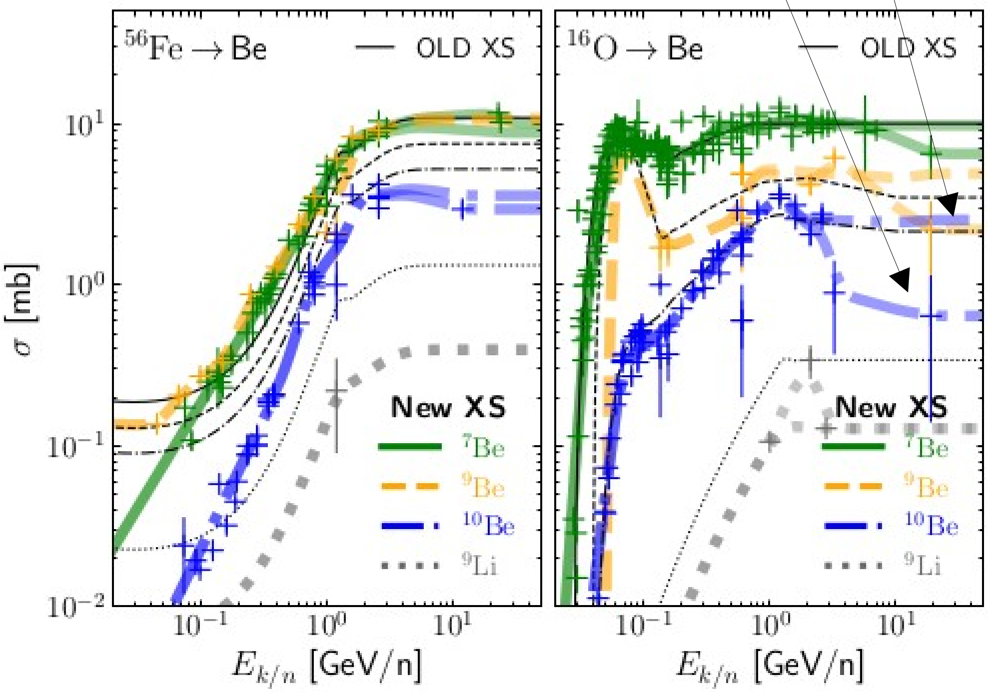
No data for many progenitors into Li!



Large discrepancies for 10Be production XS

Extra- uncertainty at high energy:

- assume constant above 1.5 GeV/n?
- try to pass through all data?



References for LiBeB production XS

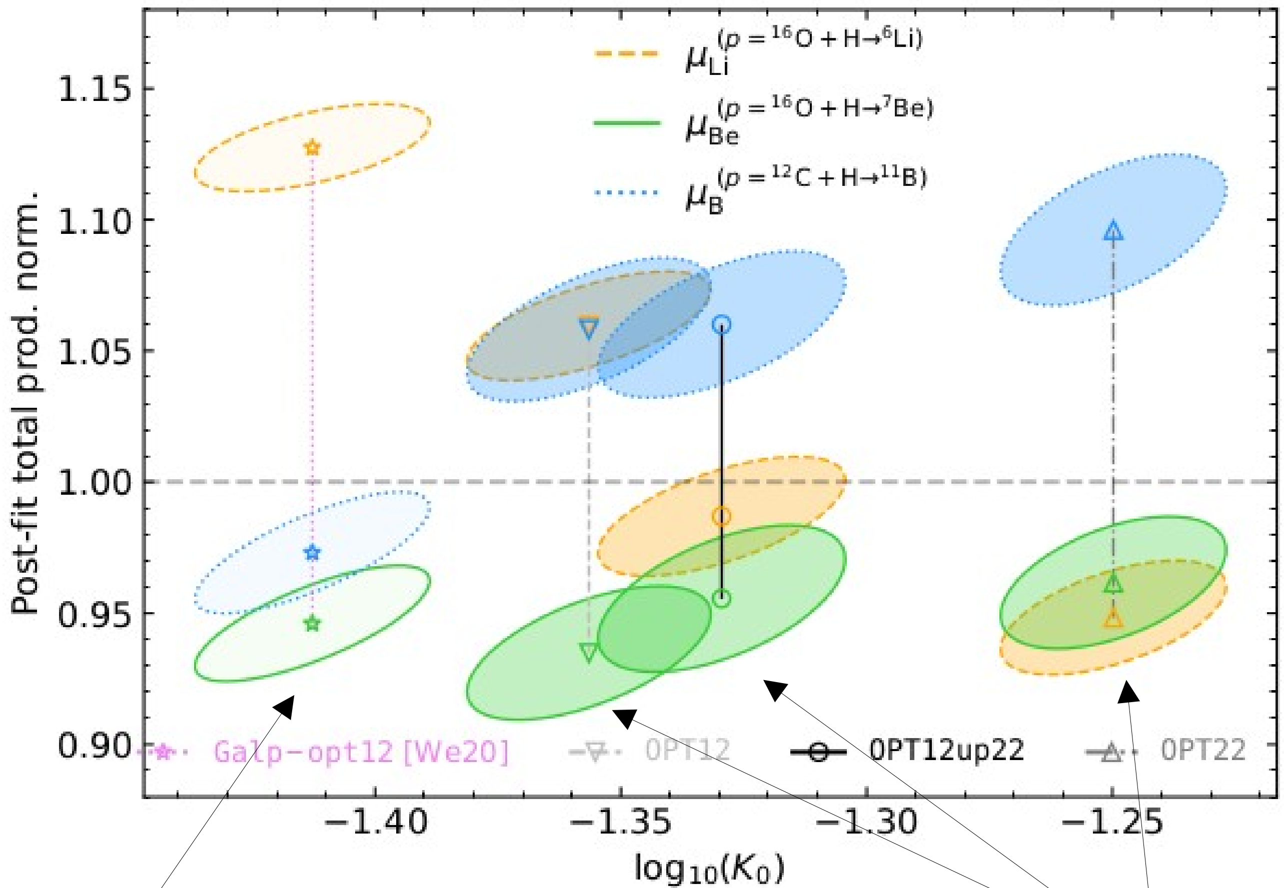
(direct and inverse kinematics, activation,
gamma-detection, subtraction CH4-C, ...)

[Ba19]	[Ba05]	[Fa98]	[Sh93]	[Mi86]	[Fo77]	[La73]	[St68]	[Re65]	[La63]	[Pa60]
[Ma18]	[Ya04]	[Si97]	[Bo93]	[RV84]	[Ka76]	[Ra72]	[Ra68]	[Do65]	[Li62]	[Ho60]
[Ge17]	[Na04]	[Mi97]	[Si92]	[Ol83]	[In76]	[Bu72]	[Do68]	[Be65]	[Ga62]	[Hi60]
[Ma16]	[Ke04]	[Le97]	[We90]	[Re81]	[Ho76]	[Am72]	[An68]	[Wa64]	[Fo62]	[Be60]
[Du13]	[Ko02]	[Fa97]	[Ko90]	[Ra79]	[He76]	[St71]	[Wi67]	[Ra64]	[Cu62b]	[Ba58]
[Ak13]	[Ki02]	[We96]	[Di90b]	[Mo79]	[Re75]	[Ra71]	[Me66]	[Po64]	[Cu62a]	[Sy57]
[Ti11]	[imos]	[Si96]	[Di90a]	[Iz78]	[Ra75b]	[Fo71]	[La66]	[Ka64]	[Br62]	[Pr57]
[Ti08]	[Ko99]	[Sc96]	[Al90]	[Go78]	[Ra75]	[Bi71]	[Ga66]	[Ho64]	[Le61]	[Bu55]
[He06]	[We98a]	[Pa96]	[Mi89]	[Sc77]	[Ra74]	[Ba71]	[Va65]	[Va63]	[Cl61]	[Di50]
[Ge05]	[NU98]	[Mi95]	[Ki89]	[Ra77]	[Ja74]	[Da70]				

Impact of updated XS: Li primary source?

DM et al. (2022)

Interpretation of post-fit nuisance XS parameters



Old XS dataset

→ Need a ~13% increase of Li production to match the data

→ Alternative (Boschini et al., 2020): need primary source of Li

New XS datasets

→ Depending on XS dataset, need to increase or decrease Li production

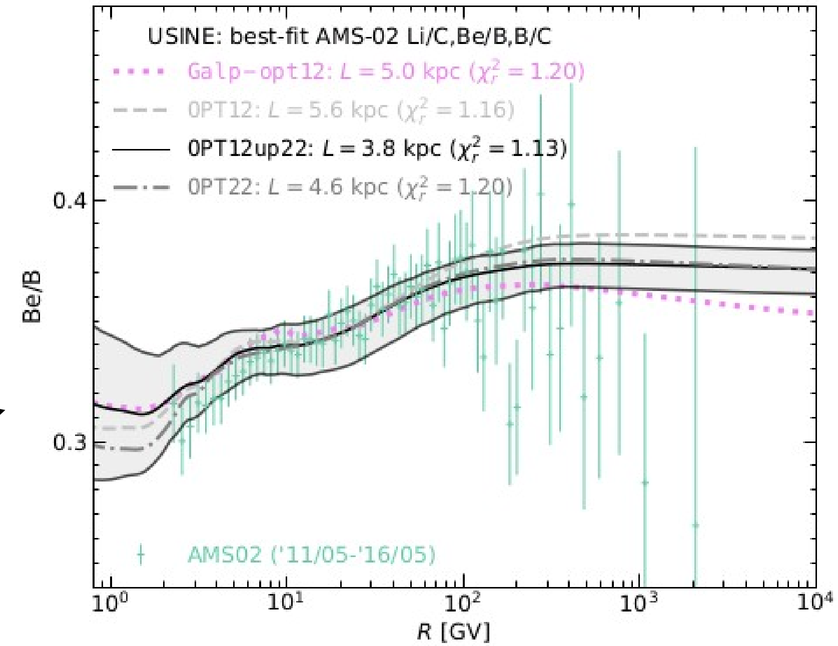
→ Need for Li primary source alleviated: any claim for primary Li, Be, or B source cannot be significant (XS too uncertain)

Impact of updated XS: halo size of the Galaxy

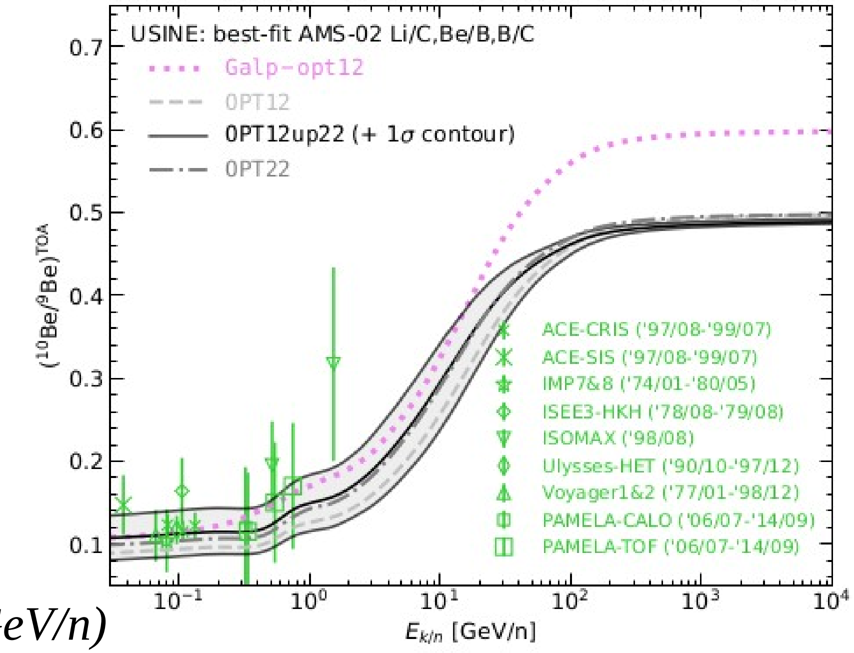
Halo size (*determined from radioactive CR ^{10}Be*)
critical parameter for dark matter searches
(e.g., Génolini et al., PRD 2021)

DM, E. Ferronato Bueno, and L. Derome
https://arxiv.org/abs/2203.07265

Fit Li/C+Be/B+B/C with USINE		
Cross-section set	L [kpc]	χ^2_r
Galp-opt12	$5.0^{+3.0}_{-1.8}$	1.20
OPT12	$5.6^{+5.6}_{-2.5}$	1.16
OPT12up22	$3.8^{+2.8}_{-1.6}$	1.13
OPT22	$4.6^{+4.0}_{-2.1}$	1.20



Fit ^{10}Be/^{9}Be (analytical)		
Cross-section set	L [kpc]	χ^2_r
Galp-opt12	5.1 ± 0.6	0.46
OPT12up22	2.8 ± 0.3	0.40



→ Also impacted by XS uncertainties

N.B.: ^{10}Be/^{9}Be data soon by AMS-02 and HELIX (up to 10 GeV/n)

Shrincking of transport parameters with new XS data

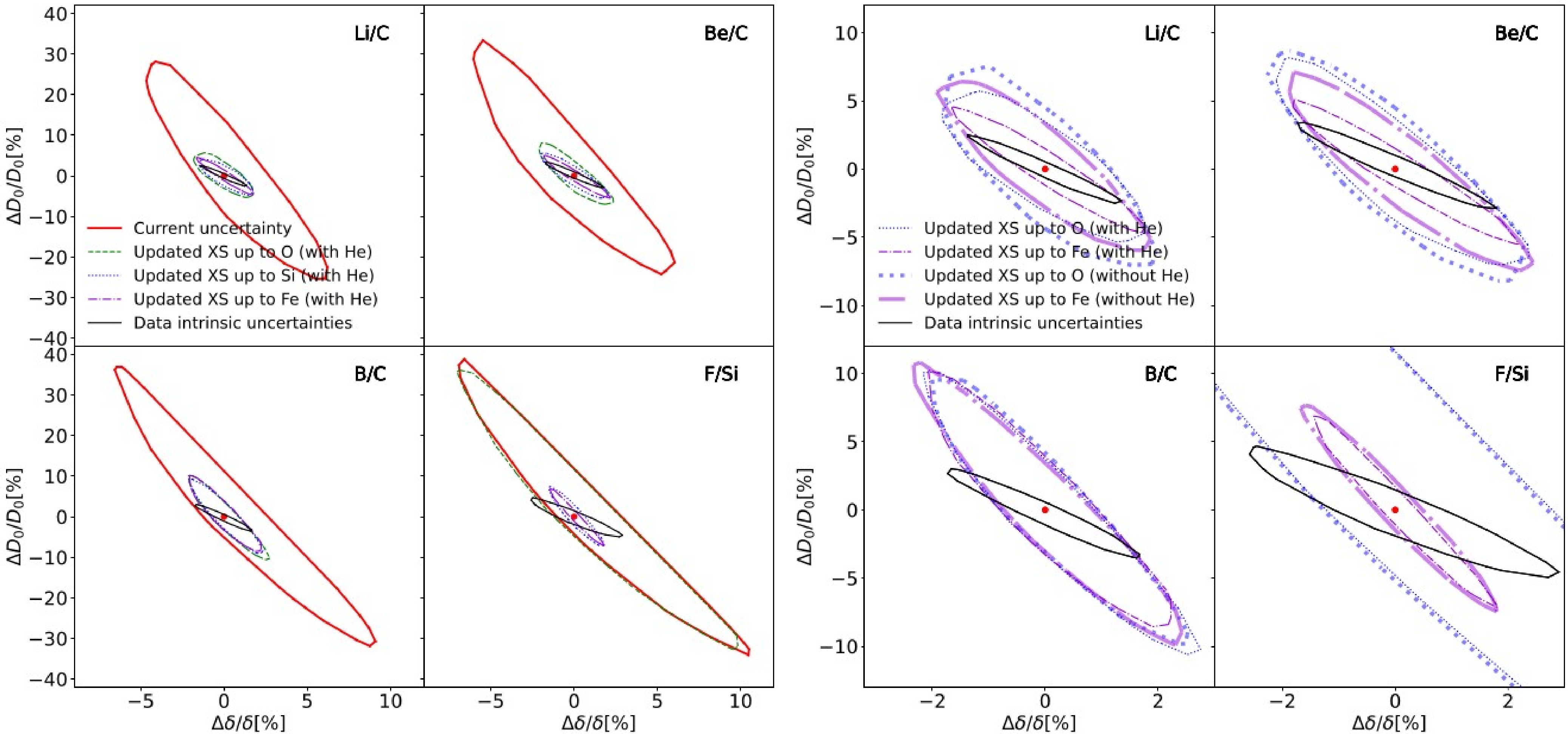
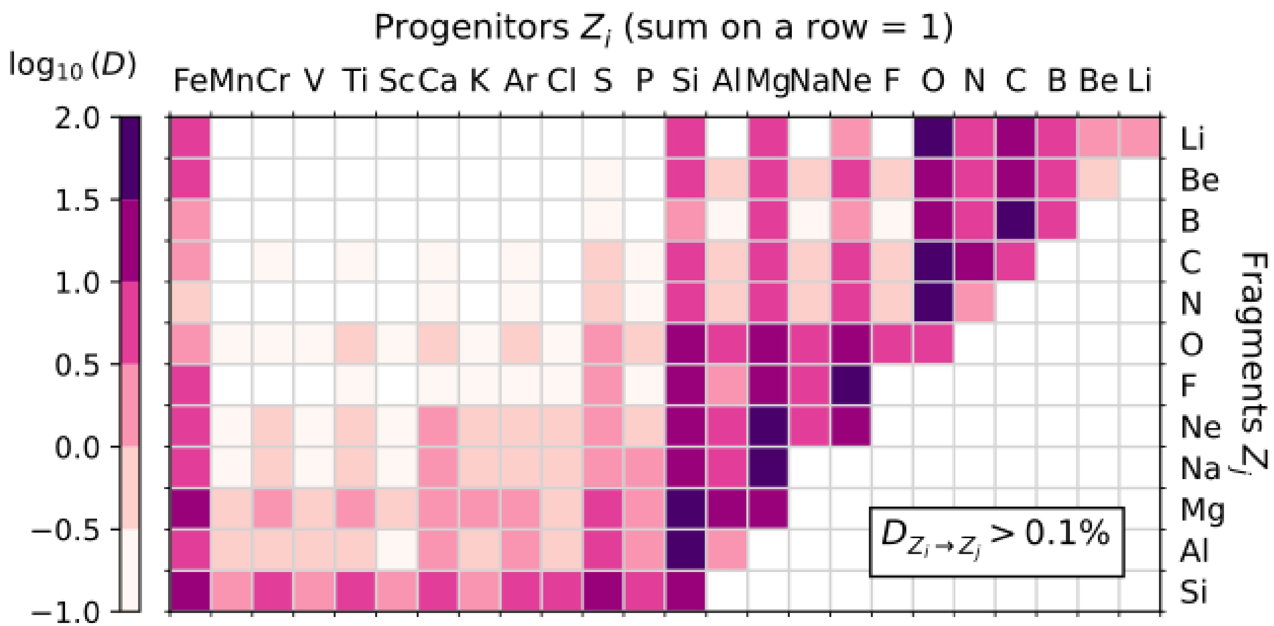
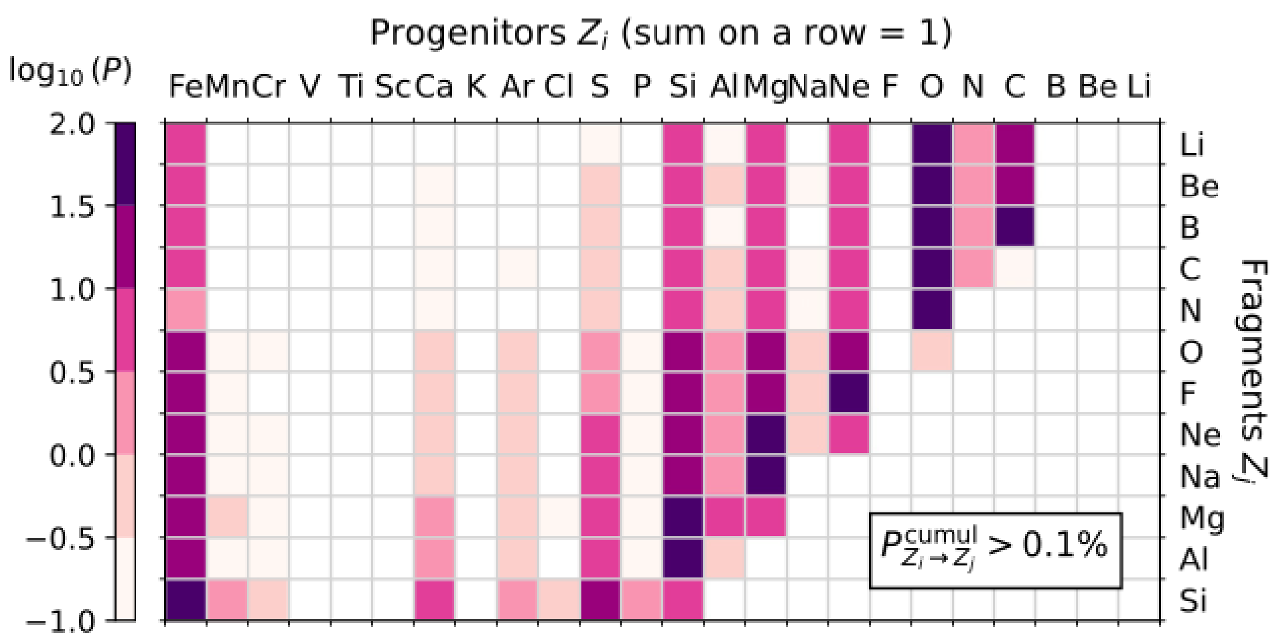
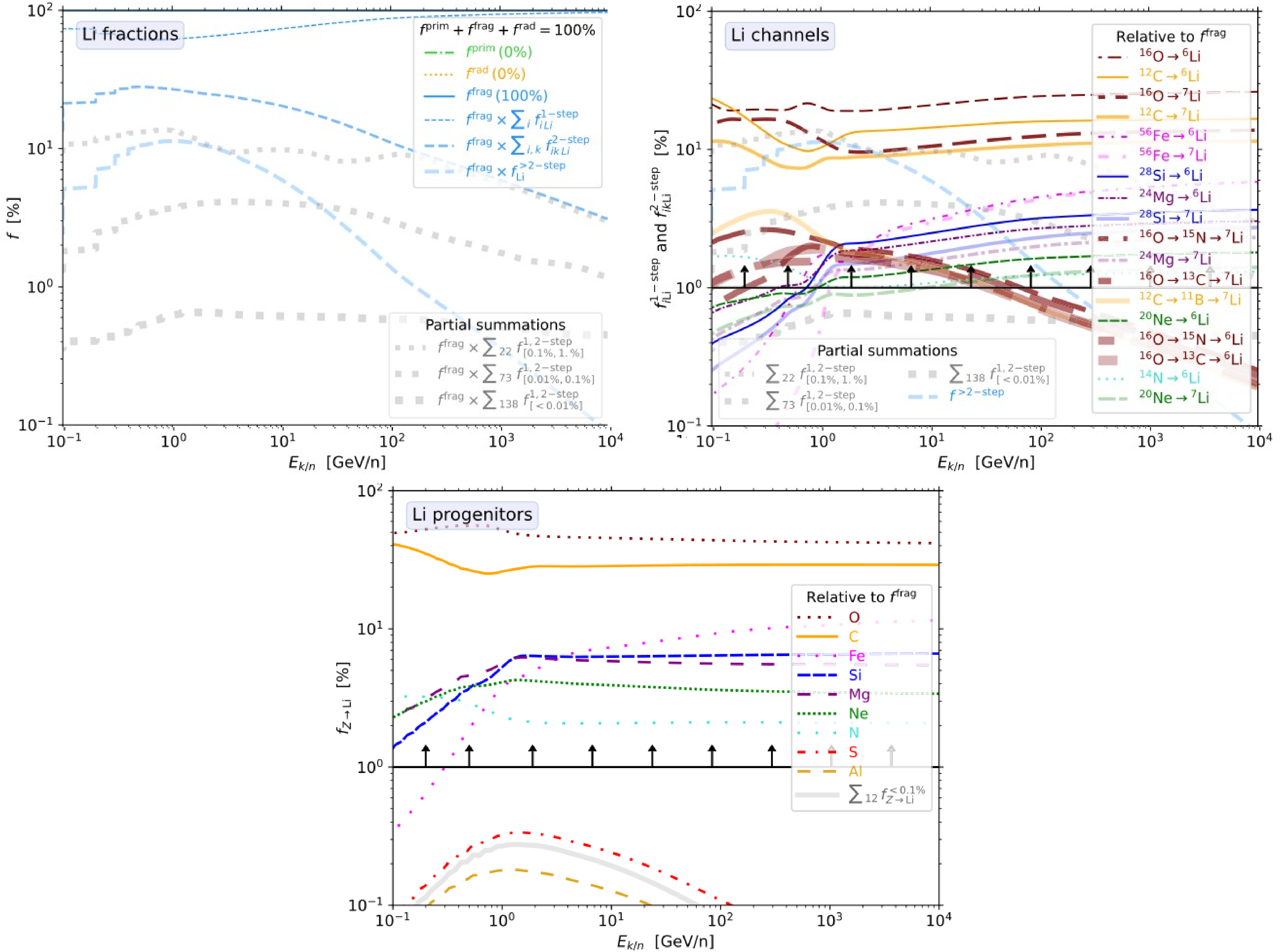


FIG. 4. Forecast of transport parameters determination from new cross-section measurement campaigns. Each figure shows 1σ contours in the (D_0, δ) relative error plane in different scenarios. The *left panel* shows the estimated current uncertainty (solid red line) and three cases were a subsets of cross sections have been updated according to our proposition Table IV, increasing the mass of the heavier progenitor from O to Fe. Finally, for comparison, we show the irreducible/intrinsic data uncertainty (solid black line). The *right panel* is a zoom of the left one and compares subcases where we would not measure the fragmentations of Table IV on a helium target. More details on how these bounds

Ranking: direct production channels vs progenitor contribs

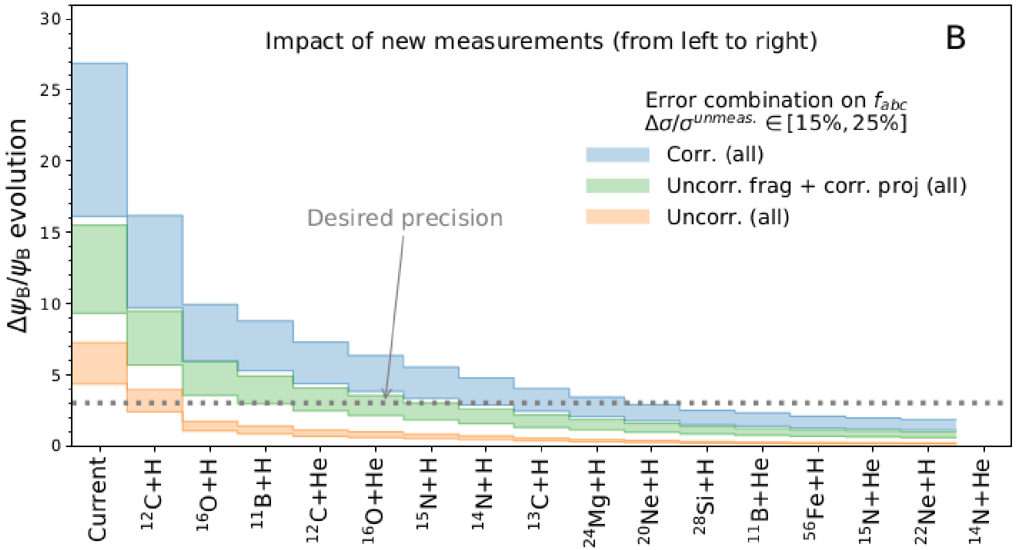






Li fractions
$f^{\rm prim} + f^{\rm frag} + f^{\rm rad} = 100\%$
$f^{\rm prim}$ (0%)
$f^{\rm rad}$ (0%)
$f^{\rm frag}$ (100%)
$f^{\rm frag} \times \sum_i f_{iLi}^{1-\rm step}$
$f^{\rm frag} \times \sum_{i,k} f_{ikLi}^{2-\rm step}$
$f^{\rm frag} \times f_{\rm Li}^{>2-\rm step}$
Partial summations
$f^{\rm frag} \times \sum_{22} f^{1,2-\rm step}_{[0.1\%, 1.\%]}$
$f^{\rm frag} \times \sum_{73} f^{1,2-\rm step}_{[0.01\%, 0.1\%]}$
$f^{\rm frag} \times \sum_{138} f^{1,2-\rm step}_{[<0.01\%]}$
f [%]
$E_{k/n}$ [GeV/n]
Li channels
Relative to $f^{\rm frag}$
^{16}O → ^{6}Li
^{12}C → ^{6}Li
^{16}O → ^{7}Li
^{12}C → ^{7}Li
^{56}Fe → ^{6}Li
^{56}Fe → ^{7}Li
^{28}Si → ^{6}Li
^{24}Mg → ^{6}Li
^{28}Si → ^{7}Li
^{16}O → ^{15}N → ^{7}Li
^{24}Mg → ^{7}Li
^{16}O → ^{13}C → ^{7}Li
^{12}C → ^{11}B → ^{7}Li
^{20}Ne → ^{6}Li
^{16}O → ^{15}N → ^{6}Li
^{16}O → ^{13}C → ^{6}Li
^{14}N → ^{6}Li
^{20}Ne → ^{7}Li
Partial summations
$\sum_{22} f^{1,2-\rm step}_{[0.1\%, 1.\%]}$
$\sum_{73} f^{1,2-\rm step}_{[0.01\%, 0.1\%]}$
$\sum_{138} f^{1,2-\rm step}_{[<0.01\%]}$
$f^{>2-\rm step}$
$f_{i\rm Li}^{1-\rm step}$ and $f_{ik\rm Li}^{2-\rm step}$ [%]
$E_{k/n}$ [GeV/n]
Li progenitors
Relative to $f^{\rm frag}$
O
C
Fe
Si
Mg
Ne
N
S
Al
$\sum_{12} f_{Z\to\rm Li}^{<0.1\%}$
$f_{Z\to\rm Li}$ [%]
$E_{k/n}$ [GeV/n]

Génolini et al., PRC 98, 034611 (2019)



Desired measurements to reach 3% precision on GCRs

September 27, 2017

Addendum to the NA61/SHINE Proposal SPSC-P-330

Measurement of Nuclear Fragmentation Cross Sections with NA61/SHINE at the CERN SPS

Unger & NA61 collaboration (arXiv:1909.07136)
Amin & NA61 collaboration (arXiv:2107.12275)