CRISPP project:

Cosmic-Ray Initiative for Strategic cross-Section Prioritisation

1. Why Cross-sections (XS) for Galactic cosmic rays (GCRs)?
2. Recent efforts and synergies towards new XS measurements
3. The CRISSP project

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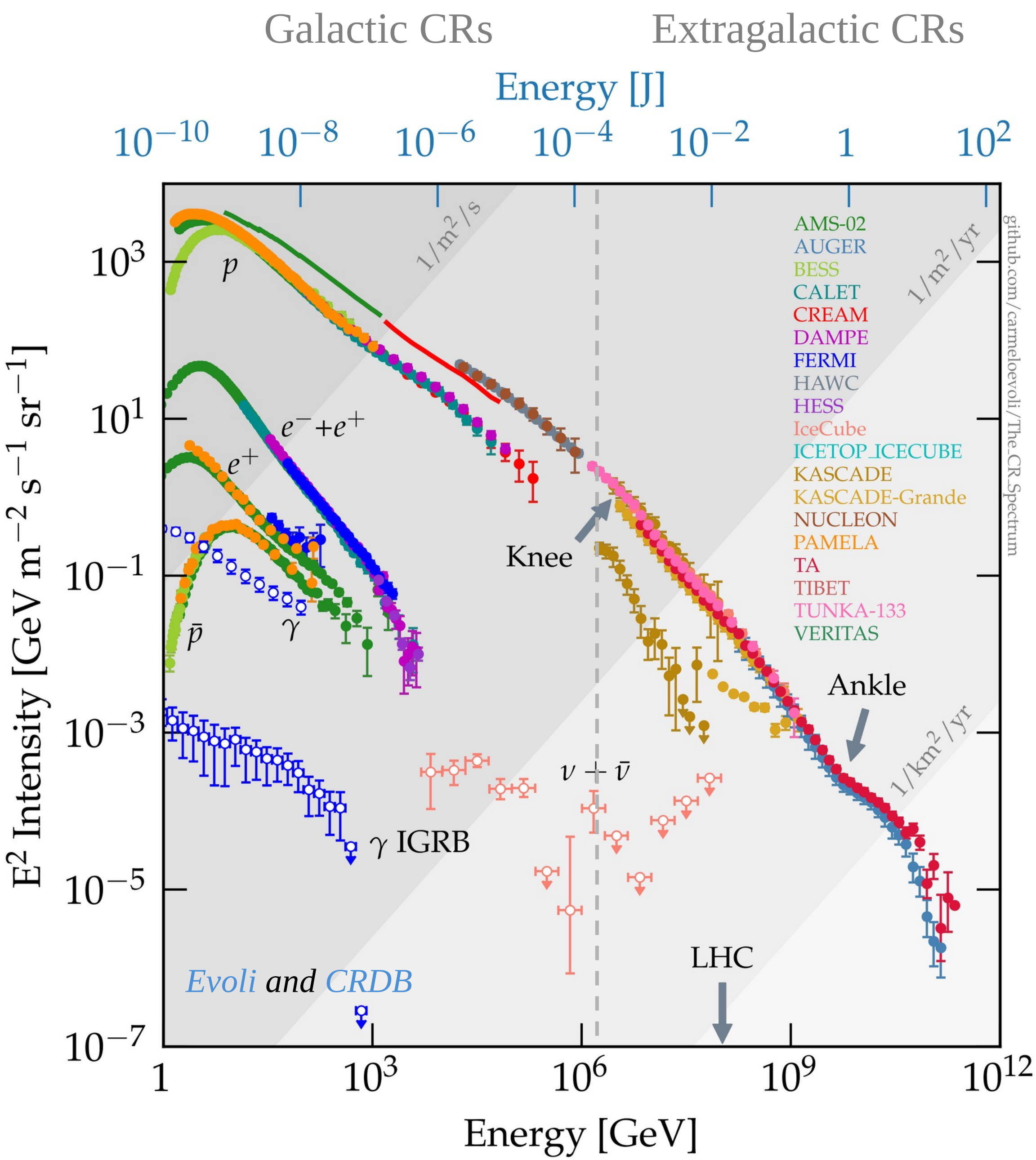
2 July 2026 (Lyon)

1. GCRs: challenges

Cosmic-Ray Data Base (update in prep.)
- Meta-data (refs, dates, infos)
- Plots (online+notebooks+pip-installable)



Astrophysical challenges
- Sources: origin, abundances, E_{max}
- Transport: turbulence, anisotropies ($\delta<10^{-3}$)
- Origin of quasi-universal power law ($E^{-2.8}$)

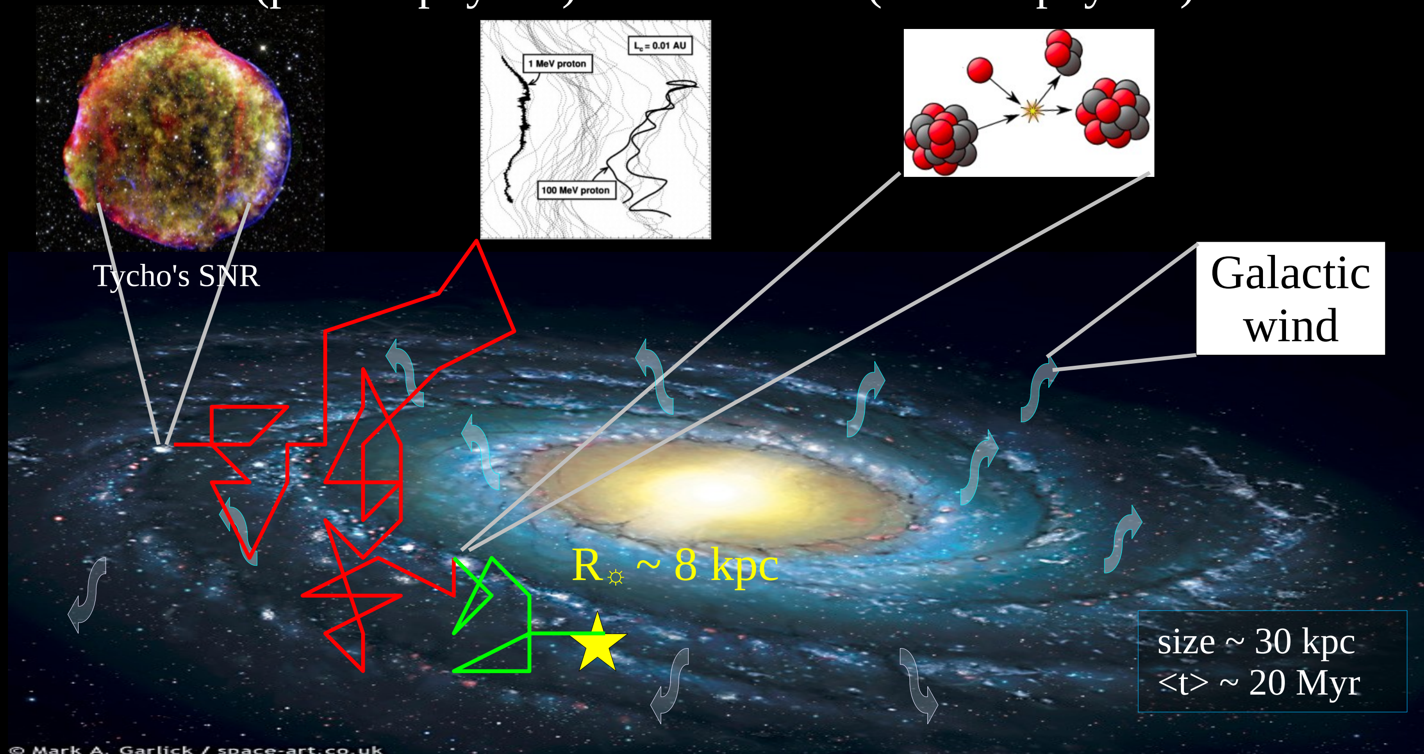
Primary Li in GCRs?
Inconsistency of modelled 2H, Li and F with data?
Residual grammage at source (gas cocoons)?

Dark-matter related challenges
(in rare CRs = e^+, pbar, diffuse γ-rays)
- How well do we know astro. prod.?
- Are there primary sources?

Excess in pbar at 10 GeV/n?
Anti-helium in AMS-02 data?

1. GCRs: from sources to fluxes (transport)

(plasma physics) (nuclear physics)



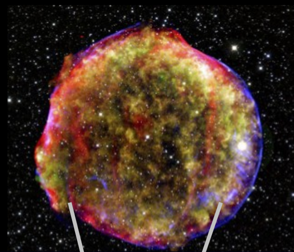
(astrophysics + particle physics)

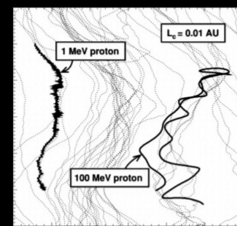
→ Phenomenological transport models to interpret GCR data (DRAGON, GALPROP, PICARD, *USINE*)

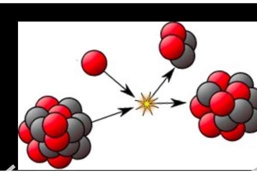
1. GCRs: transport uncertainties from XS uncertainties

$D(R) \propto R^{\delta \approx 0.5}$

$\sigma \propto A^{\sim 2/3}$
ISM targets
(~ 90% H + 10% He)





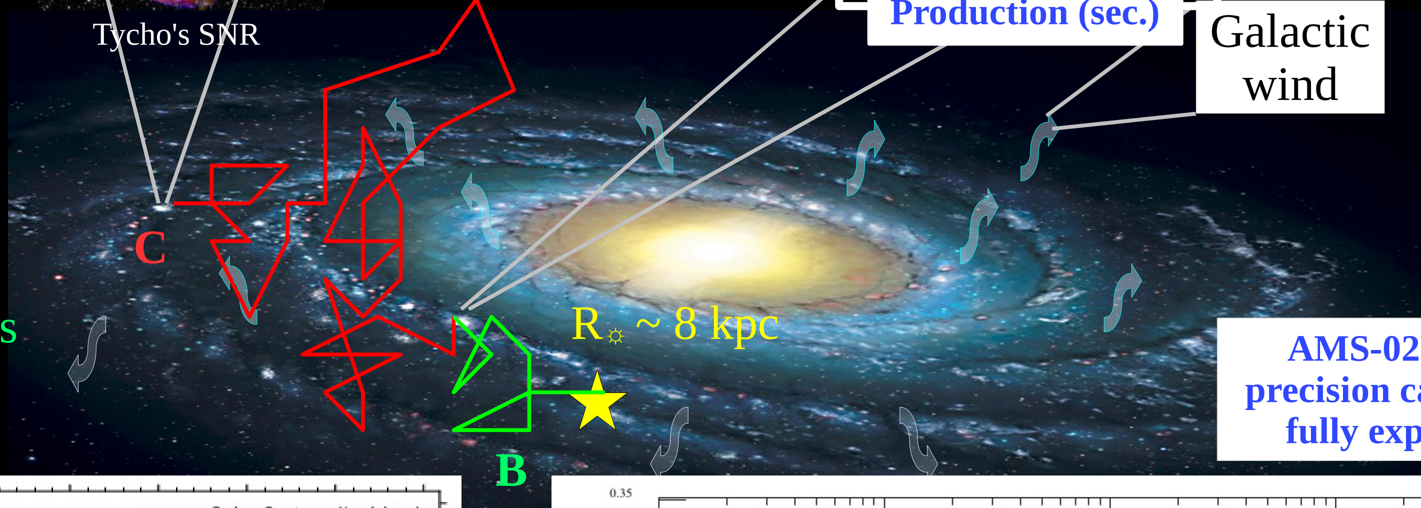


Destruction (all)
Production (sec.)

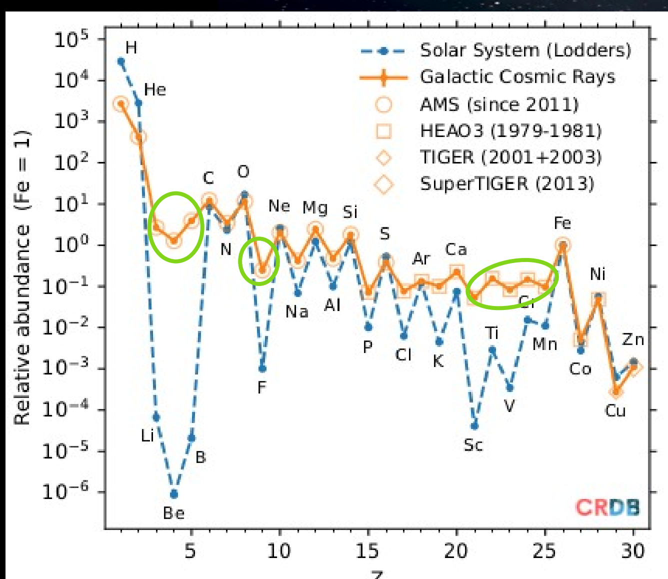
Galactic wind

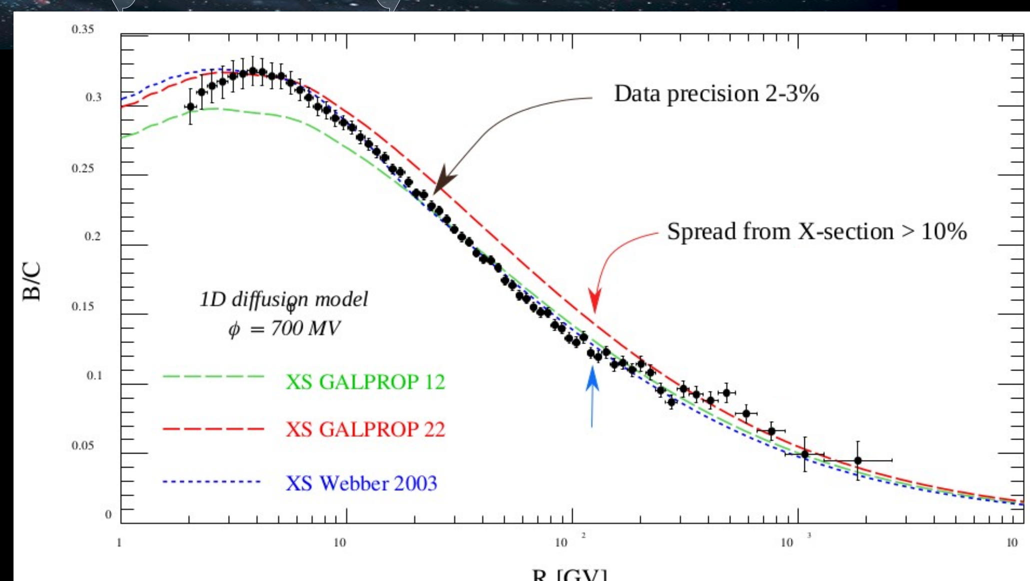
Primary species
(p, He, C,
O, Si, Fe...)

Secondary species
(^{2}H, ^{3}He, LiBeB,
F, subFe...)



AMS-02 high-precision cannot be fully exploited

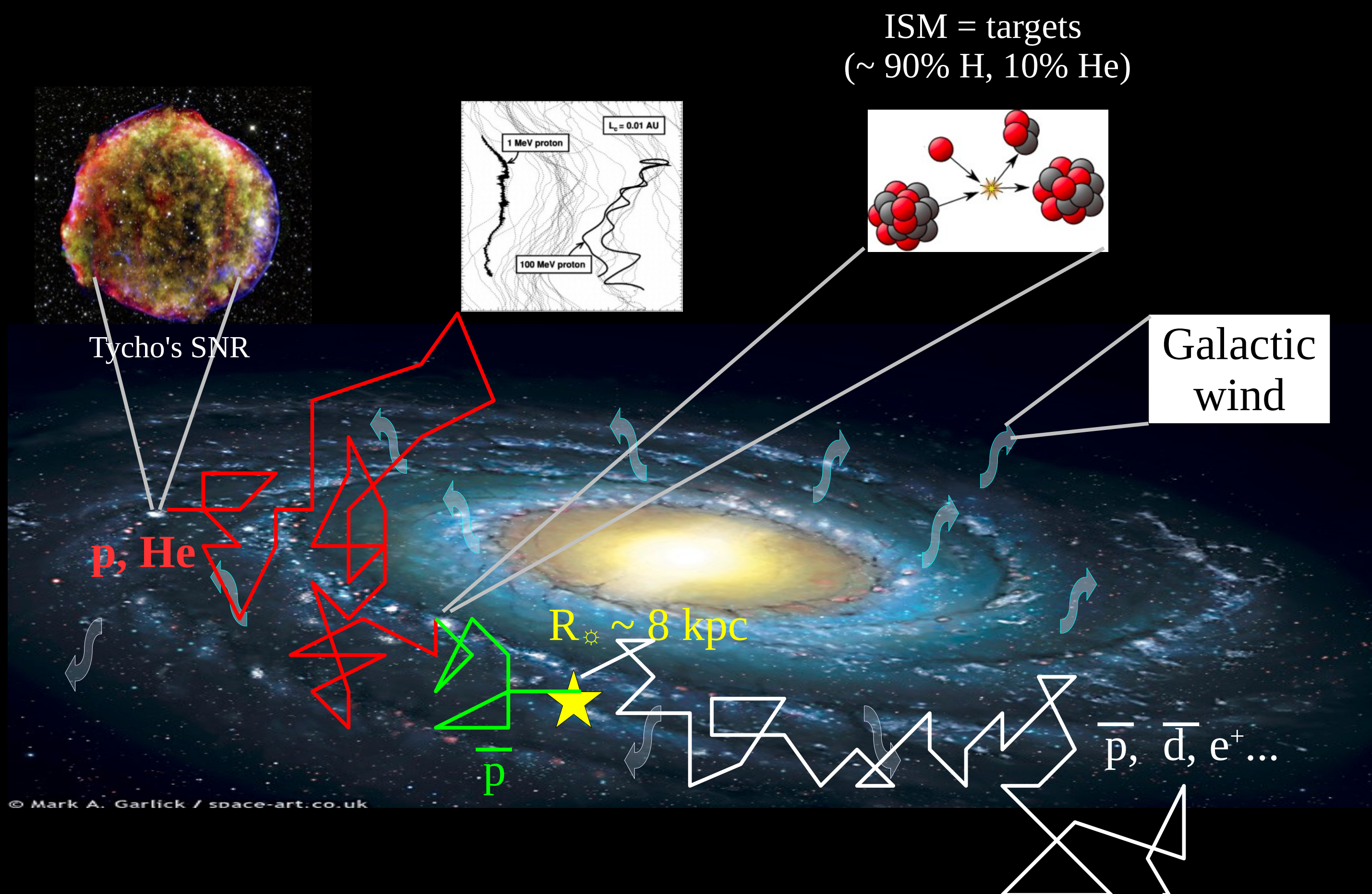




1. GCRs: DM searches limited by XS uncertainties

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

Rare secondary species
($\overline{p}$, $\overline{d}$, e^+, γ, ν...)



Dark-matter induced
(from DM halo, ~300 kpc)

Astro. Background uncertainties from:
→ direct production XS (*~20% on $\overline{p}$*)
→ transport uncertainties (*~20% on antinuclei*) from LiBeB prod.

DM signal uncertainties from:
→ halo size uncertainties (*~factor 2 on $\overline{p}$, $\overline{d}$, e^+*) from ^{9,10}Be prod. XS

⇒ **… whereas CR data precision ~ 3%**

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2. XSCRC series at CERN (2017, 2019, 2024, 2027)

Cross-Sections for Cosmic Rays at CERN (XSCRC)

2017: 1st contact between communities (CR/nuclear/particle phys...)

2019: 1st fruitful collaborations (advances and highlights)

2024: several successful synergies, roadmap for the future

2027: focus on XS data/verification/codes/benchmarks

Outcomes of the 2024 edition

→ *Precision XS for advancing CR physics and other applications: a comprehensive programme for the next decade*
DM et al., arxiv:2503.16173
Physics Report 1161 (2026) 1-81

Highlight of plots and tables in the review

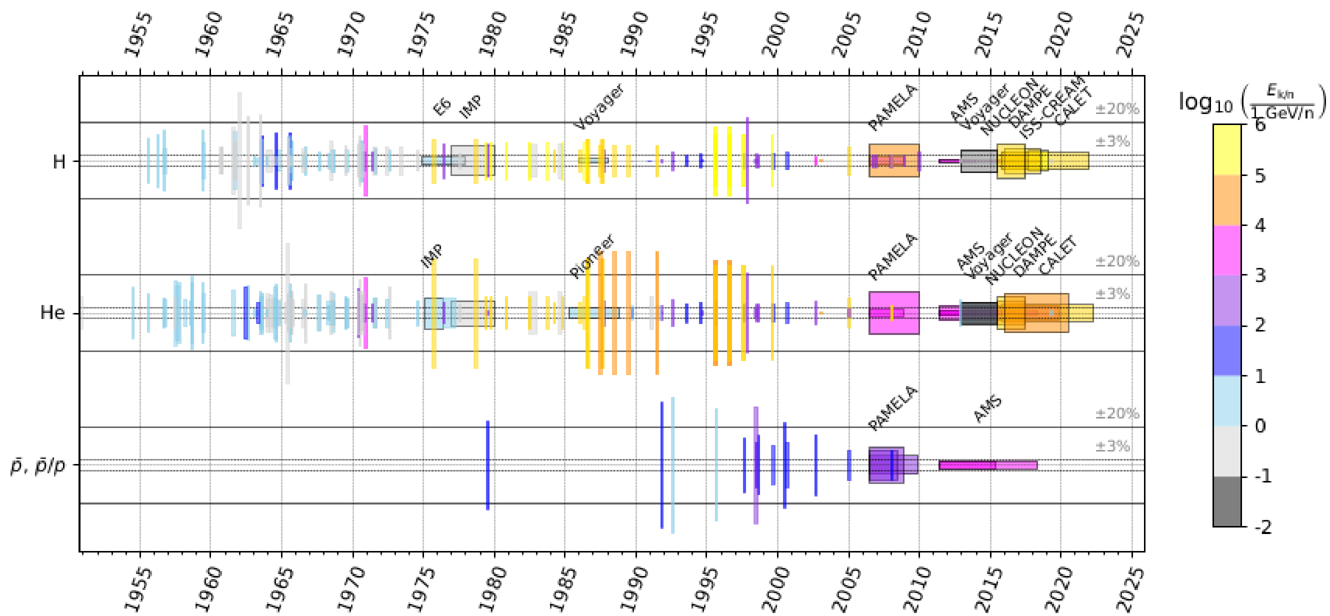
→ *Precision XS for advancing CR physics: input to the 2026 ESPPU from the XSCRC community*
Mariani et al., arxiv:2503.22783
(ESPPU = European Strategy for Particle Physics Update)

→ *Letter of intent for CERN Antiproton Decelerator*
Losekamm, Pöschl et al., CERN doc 2931063

… and hopefully more to come!

2. High-precision era (many topics)

arxiv:2503.16173



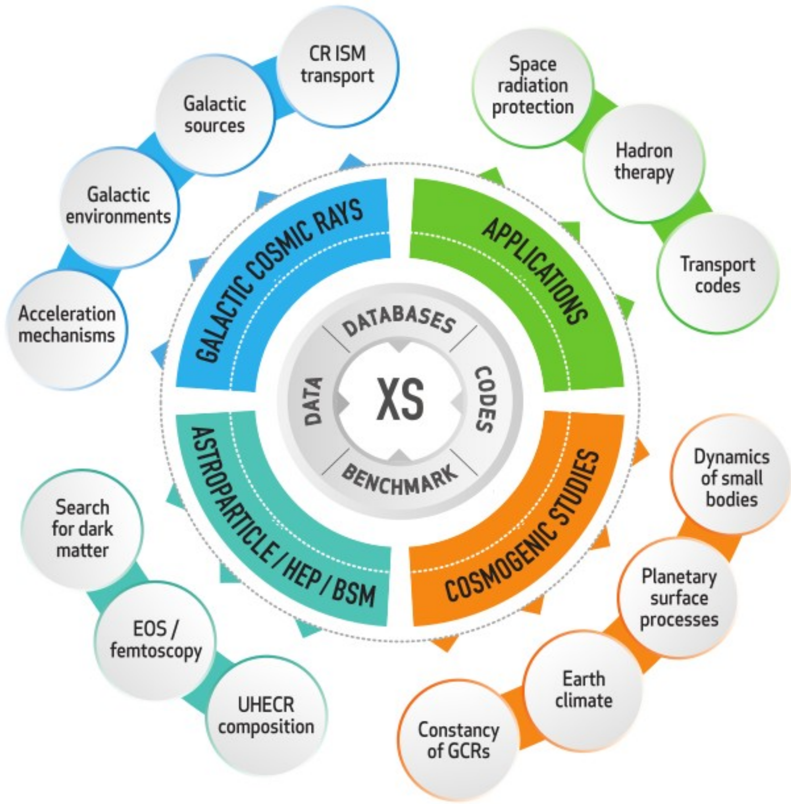
High-precision era for GCR physics (percent-level)

[+ CR data at higher energies]

Cannot advance without high-precision XS data

→ Similar situation for other physics cases
→ Some overlapping XS needs

N.B.: need for benchmarked nuclear codes

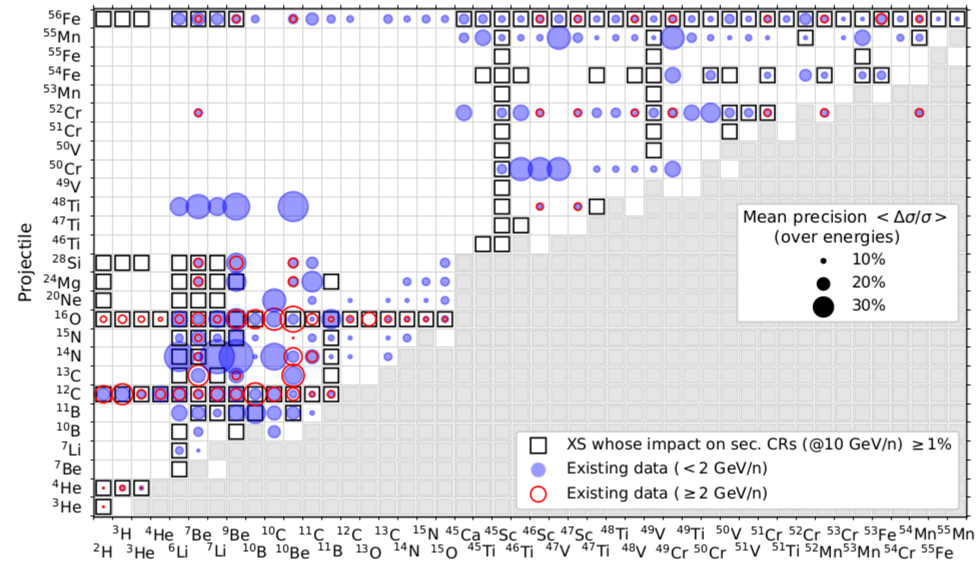


2. XS needs (reaction & precision) identified

arxiv:2503.16173

Existing nuclear data

→ Scarce (not all reactions)
→ Incomplete (not all energies)
→ Inconsistent (for some data)
→ Not accurate enough (~10-20%)

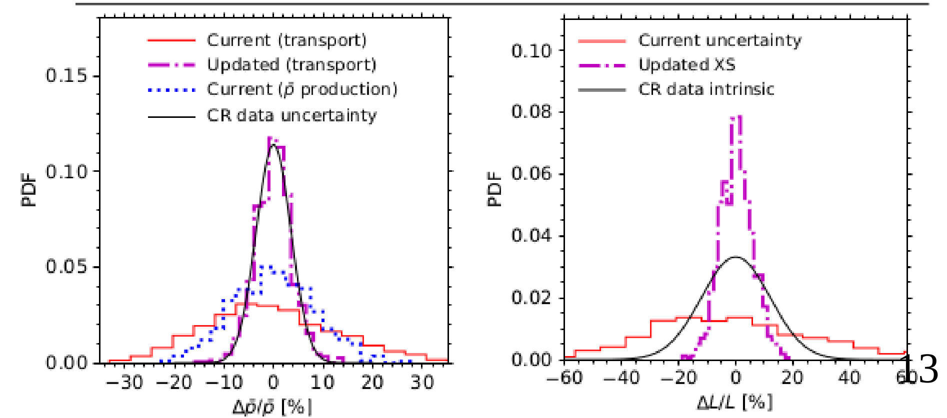


Detailed list of reactions & precision for today's needs

→ All GCR-relevant XS (prod., inel., ann., etc.)
→ All relevant proj./targ./frag. for (anti)nuclei
→ And also for cosmogenic studies, space radiation protection, hadrontherapy

Particle	Reaction	Measurement	$\sqrt{s}$	Sought precision
$\bar{p}$	$p+p \to \bar{p}+X$	σ_{inv}	5 to 100 GeV	$< 3\%$
	$p+He \to \bar{p}+X$			$< 5\%$
	$p+p \to \bar{\Lambda}+X$			$< 10\%$
	$p+He \to \bar{\Lambda}+X$			$< 10\%$
	$p+p \to \bar{n}+X$			$< 5\%$
	$p+n \to \bar{p}+X$			$< 5\%$
$\bar{d}$	$p+p \to \bar{d}+X$	σ_{inv}/n_{tot}	5 to 100 GeV	(any data)
	$p+He \to \bar{d}+X$	σ_{inv}/n_{tot}	5 to 100 GeV	(any data)
	$\bar{p}+p \to \bar{d}+X$	σ_{inv}	2 to 10 GeV	(any data)
$\overline{He}$	$p+p \to \overline{He}+X$	σ_{inv}/n_{tot}	5 to 100 GeV	(any data)
$e^{\pm}$	$p+He \to \pi^{\pm}+X$	σ_{inv}	5 to 100 GeV	$< 5\%$
	$p+He \to K^{\pm}+X$			$< 5\%$
γ	$p+p \to \pi^{0}+X$	σ_{inv}	5 to 1000 GeV	$< 5\%$
	$p+He \to \pi^{0}+X$			$< 5\%$

New nuclear data
=
guaranteed game changer
(for GCRs)



2. High-precision era (many topics)

arxiv:2503.16173

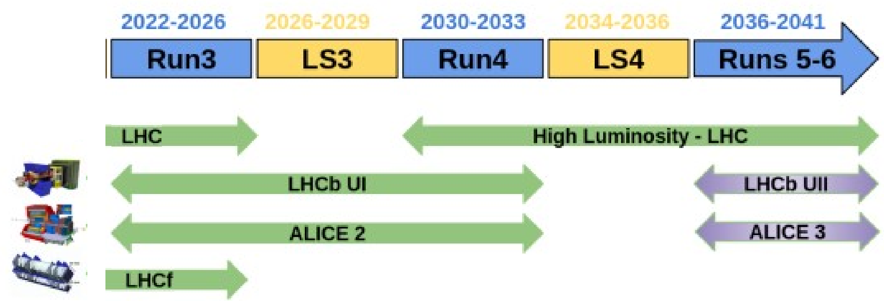
Variety of facilities able to perform needed measurements

→ Nuclear physics facilities
(100 MeV/n to up to 3 GeV/n)

→ CERN PS and SPS
(up to hundreds of GeV)

→ CERN LHC and detectors
(13.6 TeV)

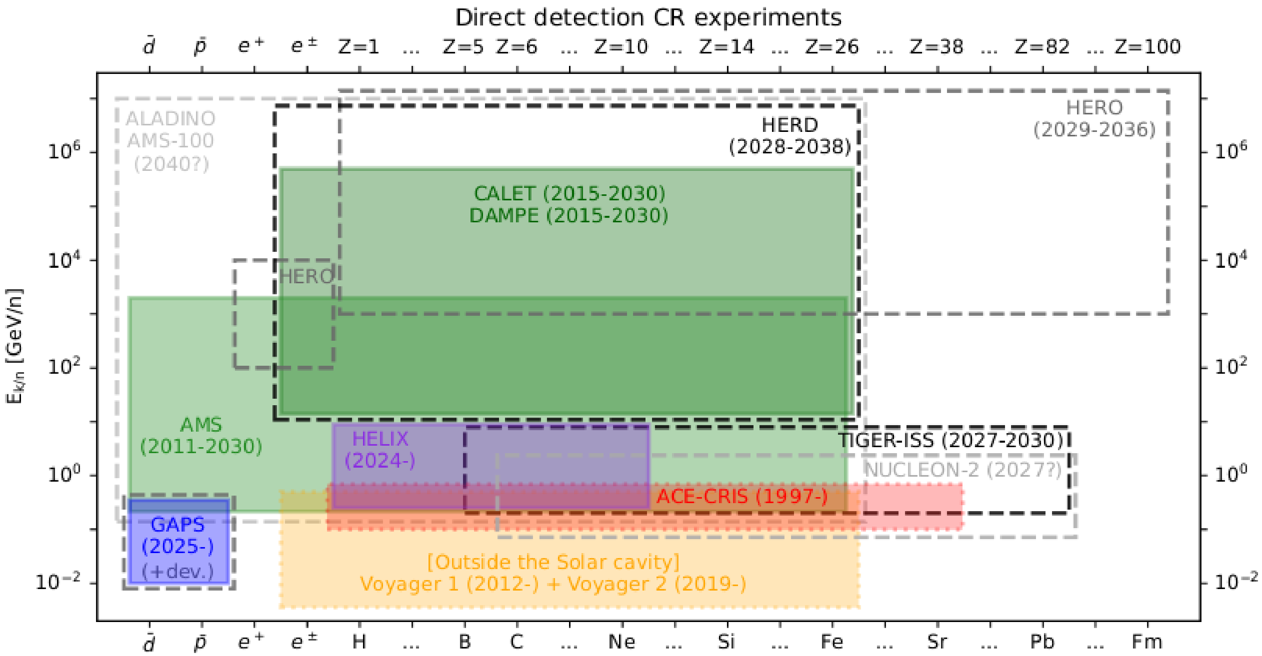
Facility	Selected beams and maximum $E_{k/n}$ (GeV/n) p	^{4}He	^{7}Li	^{12}C	^{16}O	^{20}Ne	^{28}Si	^{56}Fe	Secondary beams	Experiment type
CNAO	0.25			0.4					no	Spectrometry
NSRL	2.5	1.5		1.0	1.0	1.0	1.0	1.0	no	Activation
FAIR	4.5	2.0	1.55	2.0	2.0	2.0	2.0	1.75	yes	Spectrometry
HIAF	6.5	2.9	2.4	2.9	2.9	2.9	2.9	2.7	yes	Spectrometry
SPS	400	158	158	158	158	158	158	158	yes	Spectrometry



+ XS needs will increase!
(from vivid CR programme)

→ A, E, isotope, antinuc. frontiers
(~2030)

→ sub-percent-precision frontier
(beyond 2040)



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3. CRISSP project

Cosmic-Ray Initiative for Strategic cross-Section Prioritisation

What?

Seek to address the XS bottleneck for the interpretation of high-precision GCR data for astrophysics and dark matter searches. By fostering French-Chinese collaboration, the project aims to:

1) Ranking of the most urgently needed XS measurements – currently covering elements up to silicon (Z=14) – up to nickel (Z=28), aligning with upcoming AMS-02 data.
2) Promote, through targeted workshops (XSCRC27) and reciprocal visits, unique potential for game-changing nuclear data campaigns at China's Heavy-Ion Accelerator Facility (HIAF) facility.

Who?

- **China:** *Meng-Jie Zhao* (IMP), Shi-Tao Wang (IMP), Xiao-Jun Bi (IHEP)
- **France**: *David Maurin* (LPSC), Laurent Audoin (IJCLab), Yoann Génolini (LAPTh), Marie Vanstalle (IPHC)

In practice

Step 1. Follow up on previous “Ranking XS for GCRs” studies (*lead by DM)*

- Paper I: Li to O (PRC 2018), *Editor's Suggestion* → triggered NA61 successful pilot run (Unger et al., 2018)
- Paper II: F to Si (PRC 2024) → enabled to secure 1 week NA61 data (w/ 10x better trigger) in 2025
- Paper III (in prep.): ^{1}H, ^{2}H, ^{3}He and ^{4}He
- **Paper IV (entry point of CRISSP): Z=15-30** [ongoing update of XS models by Meng-Jie Zhao]

Step 2. Visit at IMP (from French side) + visit at LPSC back-to-back (from Chinese side) with XSCRC2027

N.B.: checkout XSCRC2027 (13-15 January 2027)

Backup slides

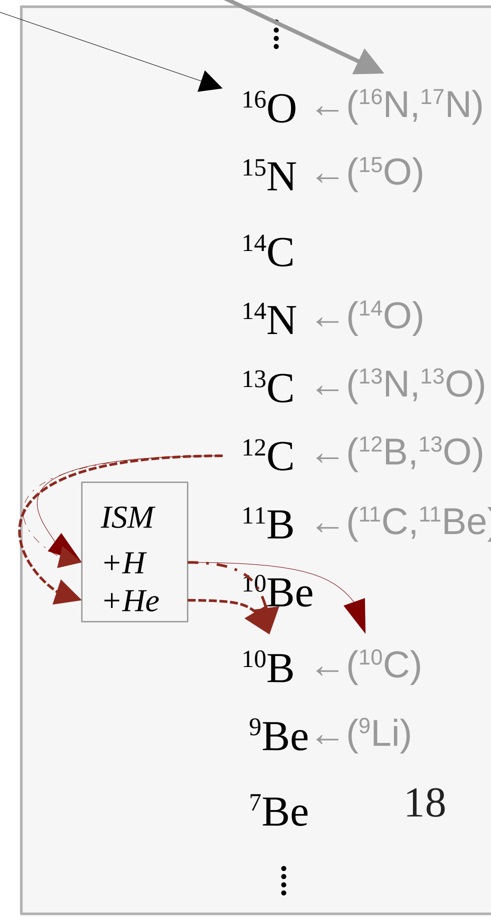
3. CRISSP project

Illustration on Be production (Paper I and II)

→ Network of ~1000 reactions (up to ^{56}Fe) to rank!
[N.B.: CR fluxes use cumulative XS (account for short-lived nuclei)]

$$\sigma^{\rm cumul}_{a+b\to c} = \sigma_{a+b\to c} + \sum_g \mathcal{B}r_g \cdot \sigma_{a+b\to g}$$

Ghosts (=short-lived) nuclei



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

…

Ranking
- Top 10 reacs ~ 80%
- Next 100 ~ 15%
- All the rest ~ 5%

About the nuclear data
- No data for many reacs
- Many with 1 or 2 pts
- Very partial E coverage
- Inconsistent data
- …

One to one correspondence between f_{abc} and $\sigma_{a+b\to c}$

$f_{12C\ H\ 10Be}$

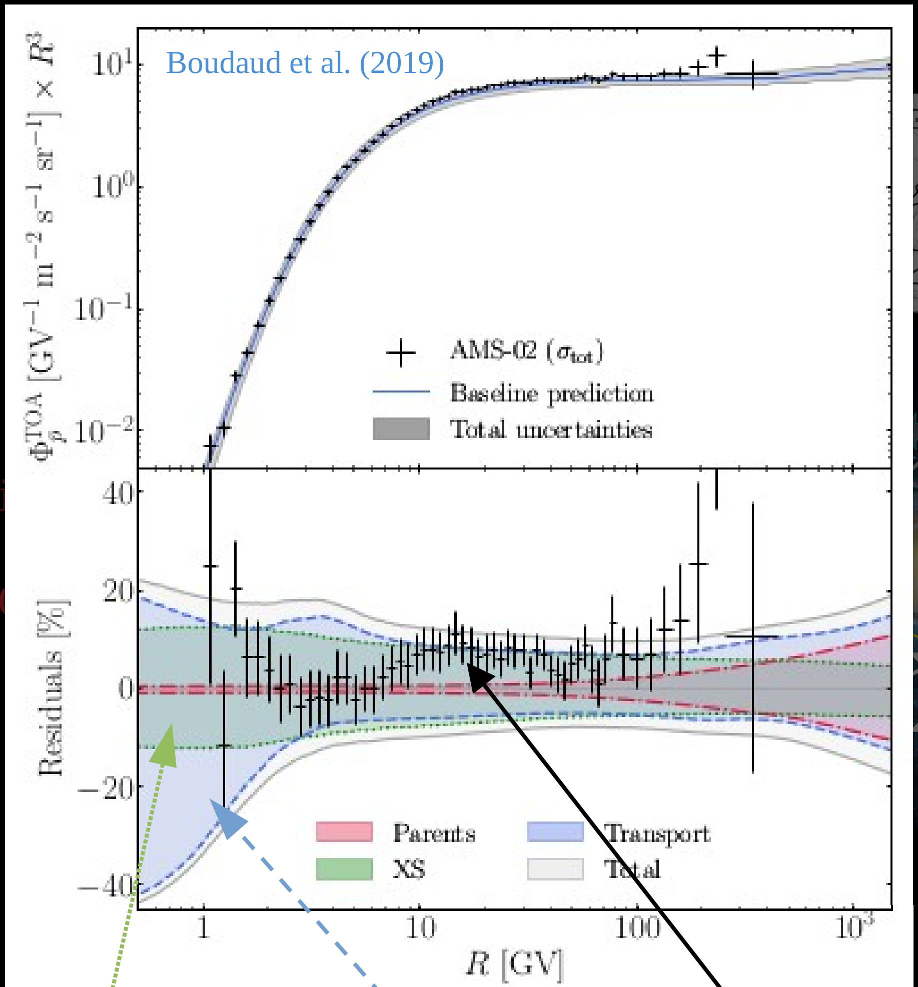
$f_{12C\ He\ 10Be}$

$f_{12C\ H\ 10C}$

We have:
→ Ranked reactions + beam time requirements (Paper I) => NA61 successful 2.5 days pilot test (2018)
→ Forecast of impact of new XS measurements (Paper II) => Secured 1 week NA61 (11/2024)

Dark matter searches: signal uncertainties

Background (astro. contribution)



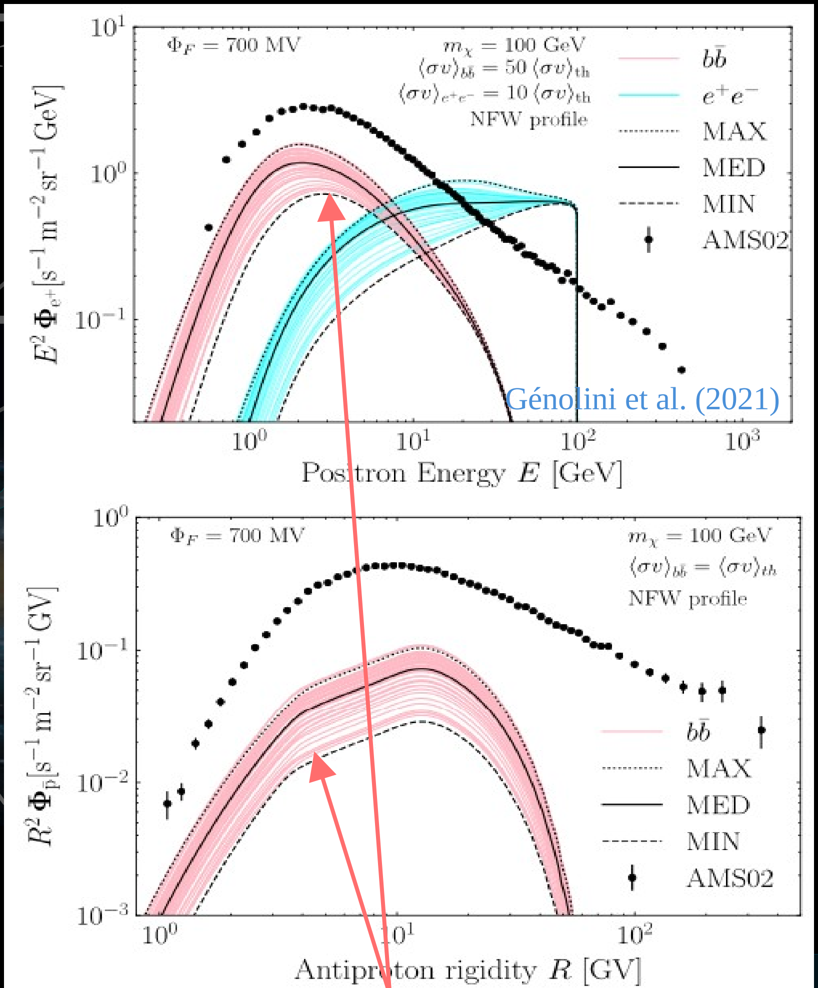
Uncertainties pbar prod.

Uncertainties LiBeB prod.

Cannot take full benefit of high-precision data

Uncertainties dominated by
→ anti-matter production XS
→ transport (via nuclear prod. XS)

Signal (DM contribution)



Uncertainty scales with L (^{10}Be vs ^{9}Be prod.)

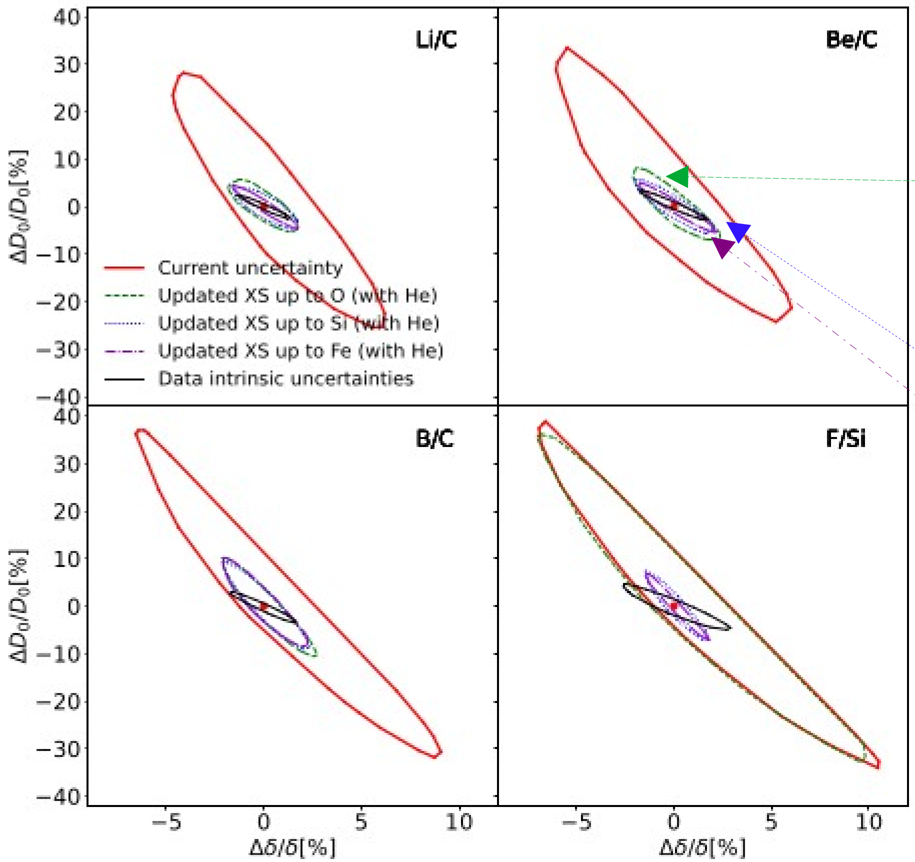
Uncertainties dominated by
→ halo size L (via nuclei prod. XS)

2) Error on flux: forecast on transport parameters

Assumption on existing or future XS uncertainties	Error propagation formula on propagated flux
Fragments multinomially distributed = all fragments of interaction measured in exp. (*precision better than* ξ *on* $(\Delta\psi_{\rm tot}/\psi_{\rm tot})$ *for minimal number of interactions* $N_{\rm tot}=\sum_{a,b} N_{ab}$ *if each* N_{ab} *ensures* $N_{ab} \geq (f_{\rm sec}^2/\xi^2)\times C_{ab}\times \sum_{a,b} C_{ab}$)	$\left(\frac{\Delta\psi_{\rm tot}}{\psi_{\rm tot}}\right)^{\rm multi} \approx f_{\rm sec}\sqrt{\sum_{a,b}\frac{1}{N_{ab}}C_{ab}^2}$ with $C_{ab}^2 \equiv \sum_c f_{abc}^2 \frac{\sigma_{a+b}^{\rm inel}}{\sigma_{a+b\to c}}$

1000 MC realisation of XS values + fit of GCR data
→ sample estimate of 1σ contours on parameters

[Following Génolini et al 2019, DM et al., 2022b]



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
	$N(\leqslant {\rm O}) = 1.9\times 10^5$
^{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
	$N(\leqslant {\rm Si}) = 3.8\times 10^5$
^{56}Fe + H	30k
^{56}Fe + He	10k
	$N(\leqslant {\rm Fe}) = 4.2\times 10^5$

2) Error on flux: forecast on pbar flux and L (halo size)

Assumption on existing or future XS uncertainties	Error propagation formula on propagated flux
Fragments multinomially distributed = all fragments of interaction measured in exp. *(precision better than ξ on $(\Delta\psi_{\rm tot}/\psi_{\rm tot})$ for minimal number of interactions $N_{\rm tot}=\sum_{a,b} N_{ab}$ if each N_{ab} ensures $N_{ab} \geq (f^2_{\rm sec}/\xi^2) \times C_{ab} \times \sum_{a,b} C_{ab}$*	$\left(\frac{\Delta\psi_{\rm tot}}{\psi_{\rm tot}}\right)^{\rm multi} \approx f_{\rm sec}\sqrt{\sum_{a,b}\frac{1}{N_{ab}}C^2_{ab}}$ with $C^2_{ab} \equiv \sum_c f^2_{abc}\frac{\sigma^{\rm inel}_{a+b}}{\sigma_{a+b\to c}}$

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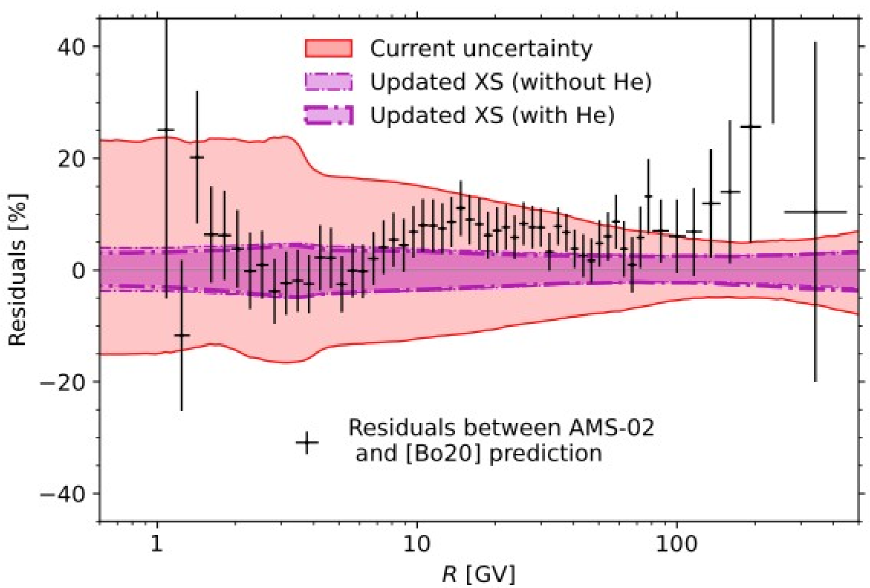
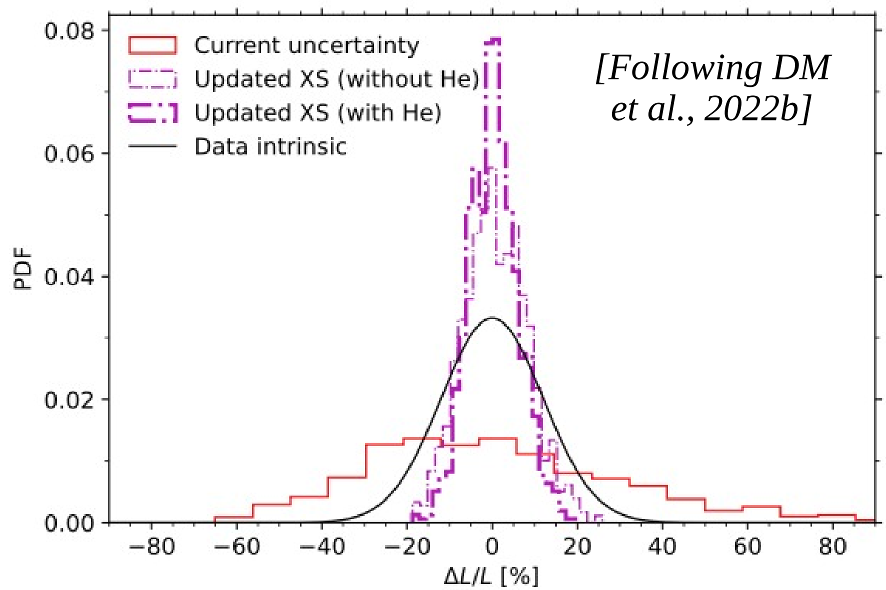
^{15}N + H	10k
^{14}N + H	10k
^{12}C + He	10k
^{10}B + H	5k
^{13}C + H	5k
^{7}Li + H	5k

$N(\leqslant \mathrm{O}) = 1.9 \times 10^5$

[Following Boudaud et al., 2020]



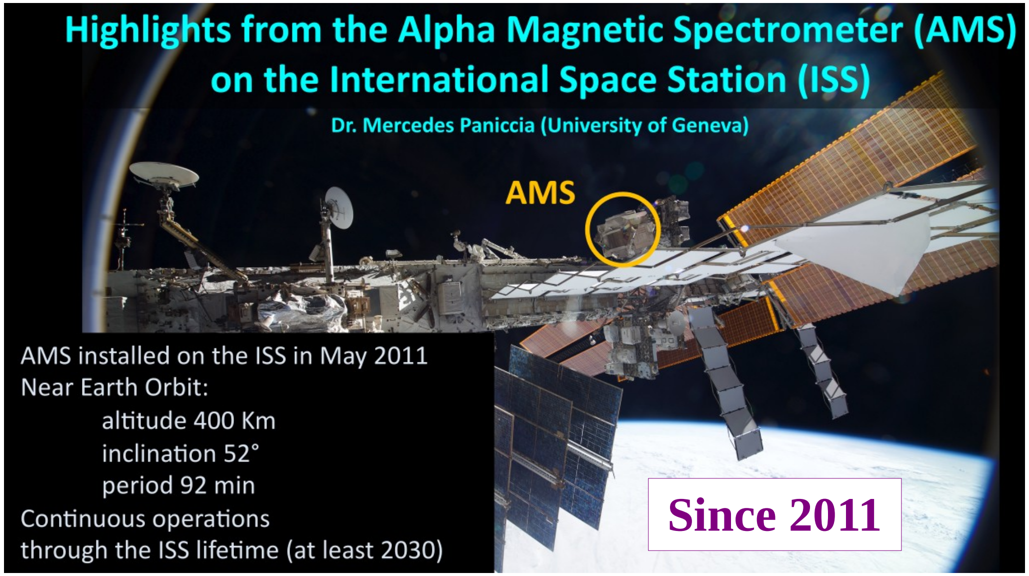


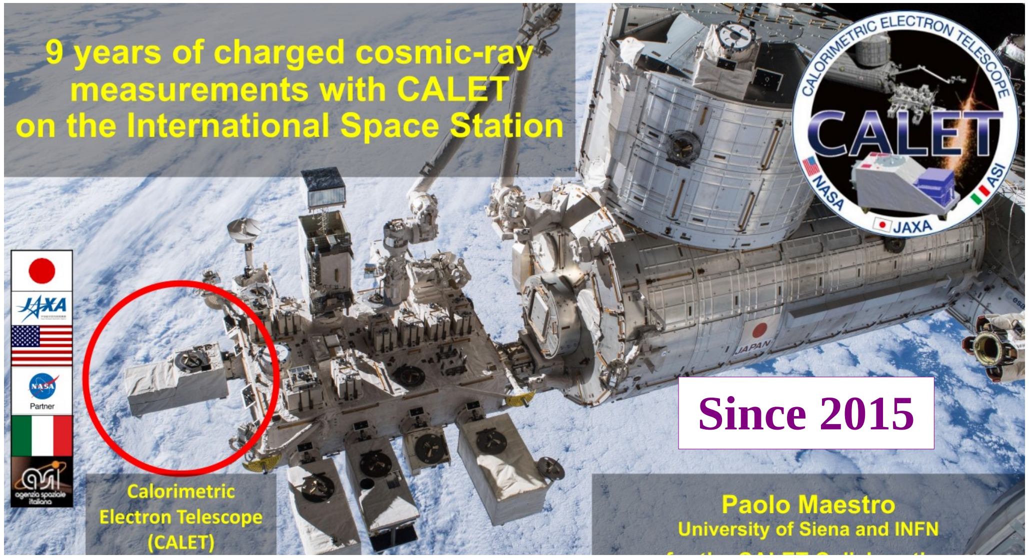
→ New nuclear XS measurements
low risk / high benefit (game changer for GCRs)
NA61: pilot test in 2018 (Unger et al.)
+ full week run in November 2025

XSCRC2024: GCR experiments

Talks by *P. Coppin*, *P. Maestro*, *M. Paniccia*, *A. Tykhonov*

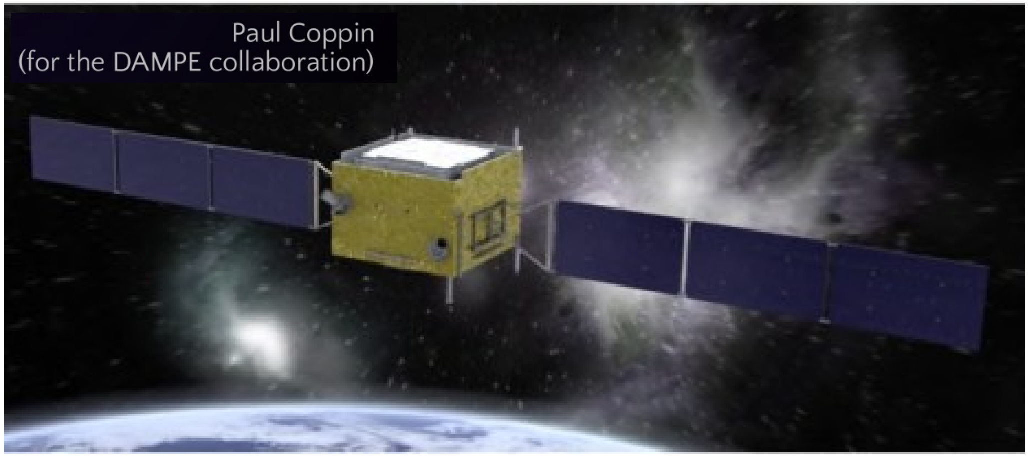
Installed on the ISS





Onboard satellites

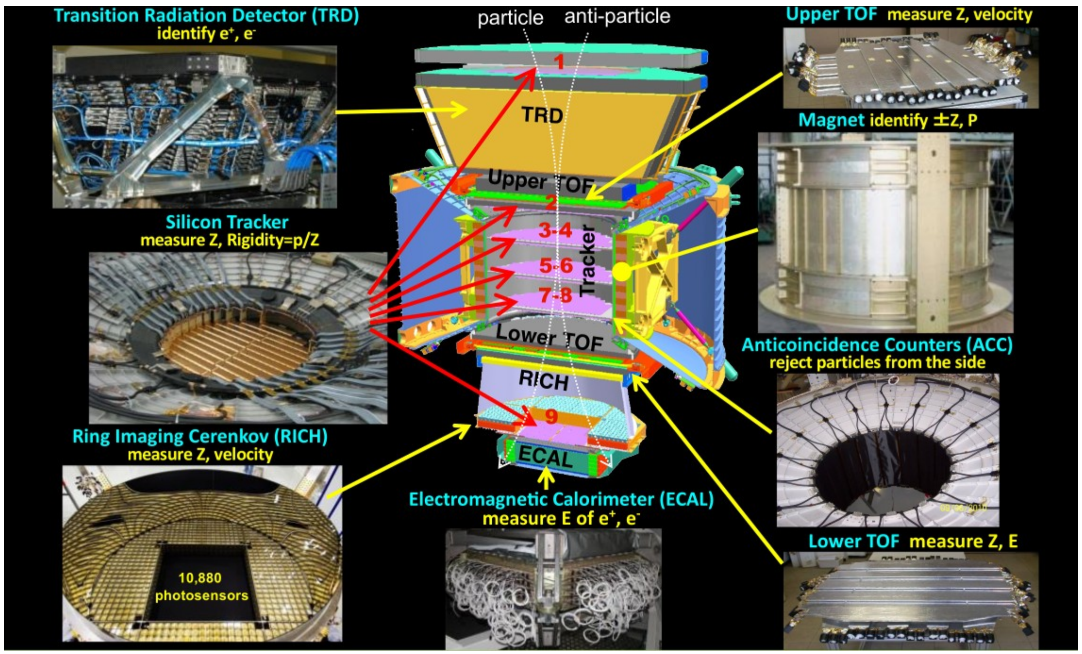
(and also balloons)



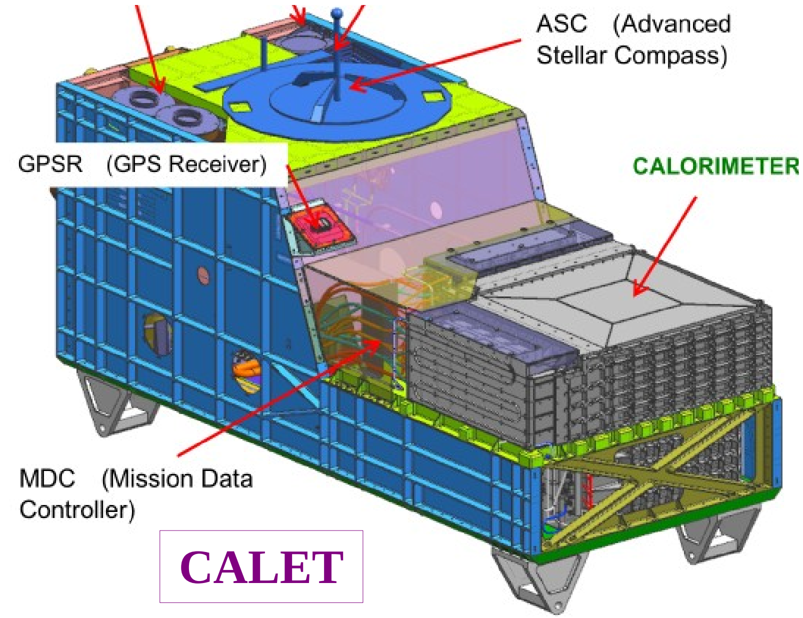
Talks by *P. Coppin*, *P. Maestro*, *M. Paniccia*, *A. Tykhonov*

Spectrometers

AMS-02

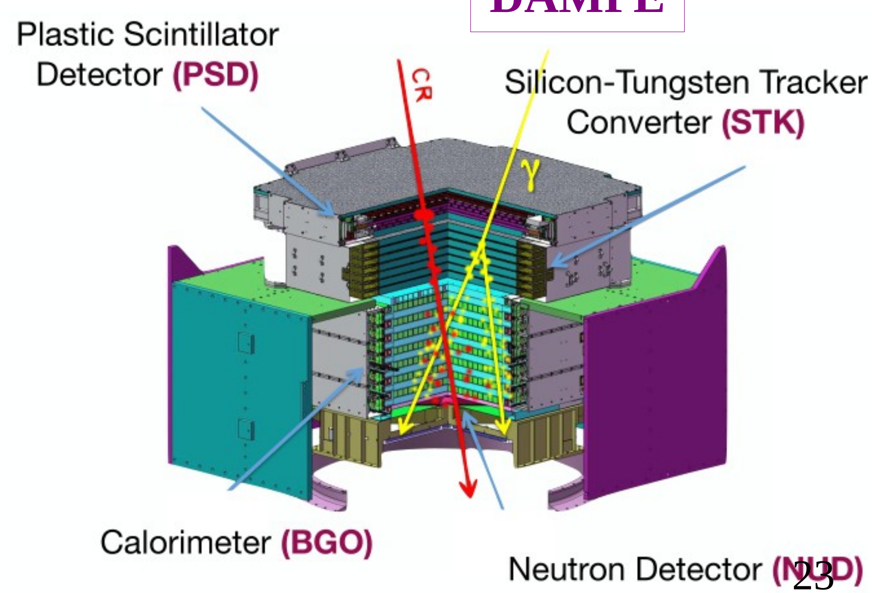


Calorimeters



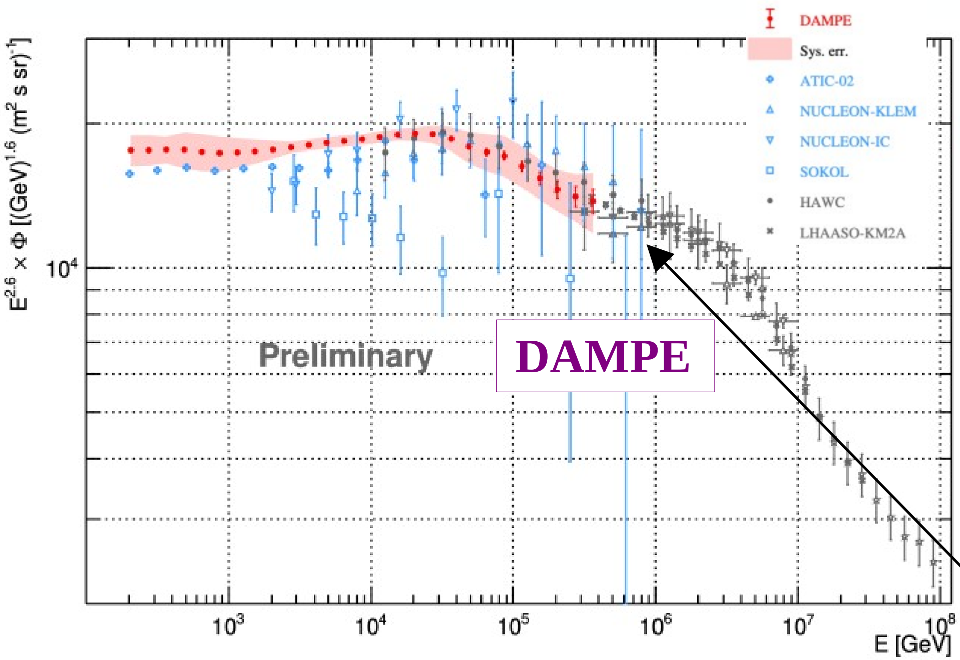
CALET

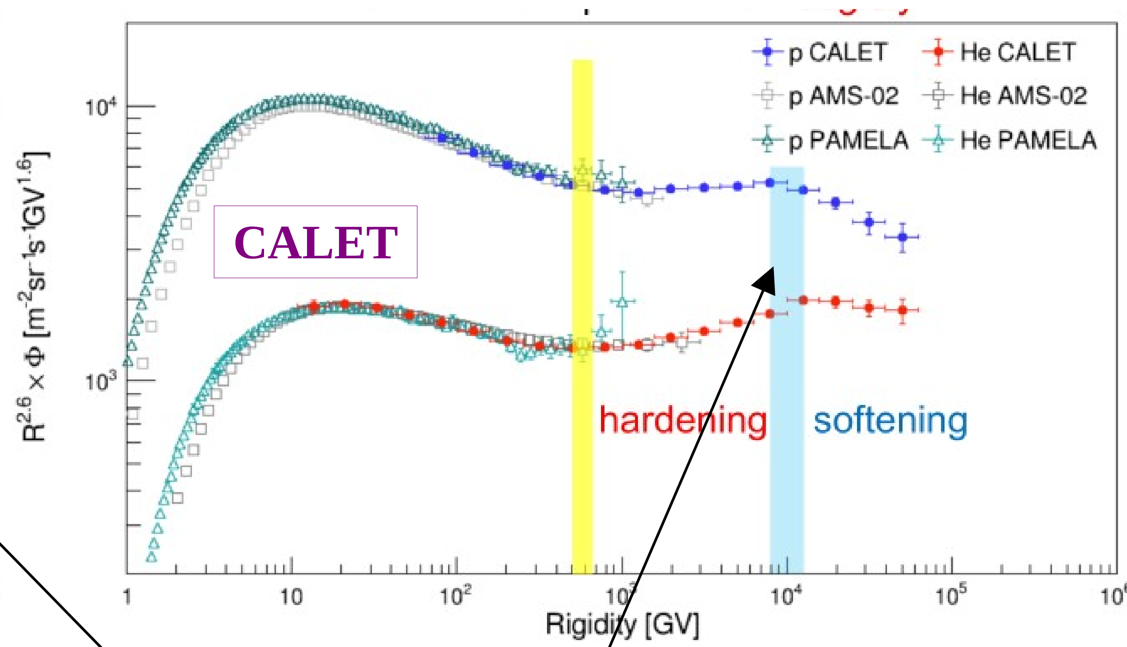
DAMPE

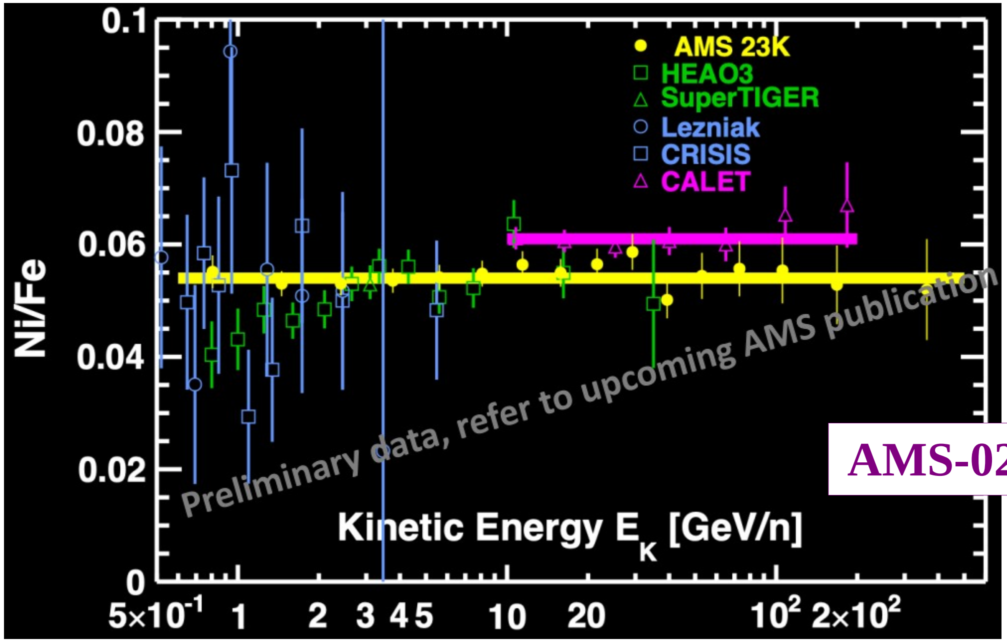


XSCRC2024: GCR experiments

Talks by *P. Coppin*, *P. Maestro*, *M. Paniccia*, *A. Tykhonov*





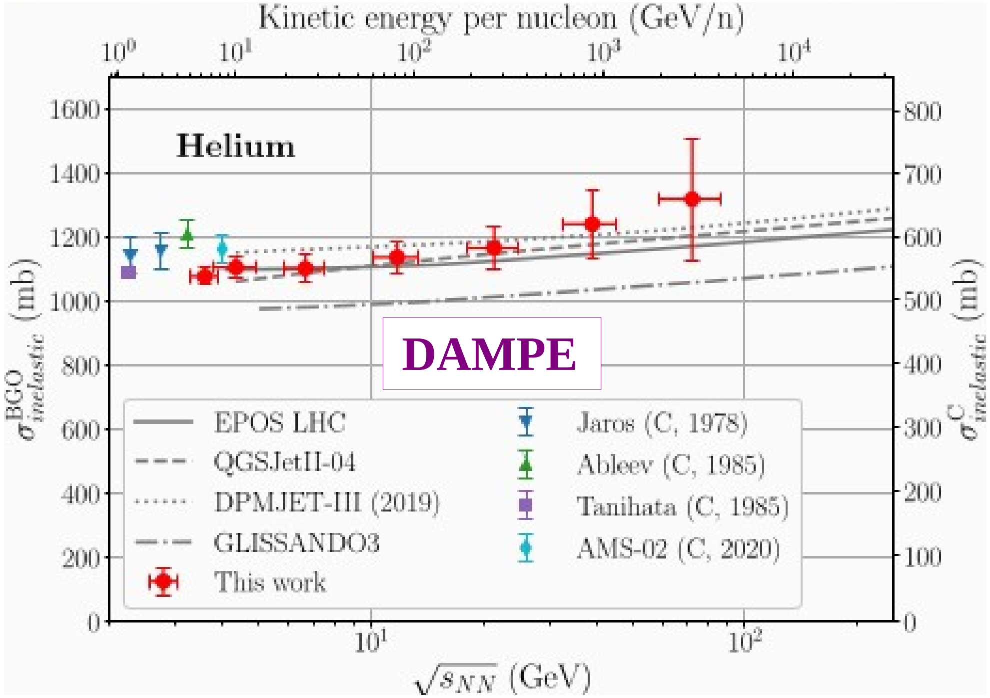


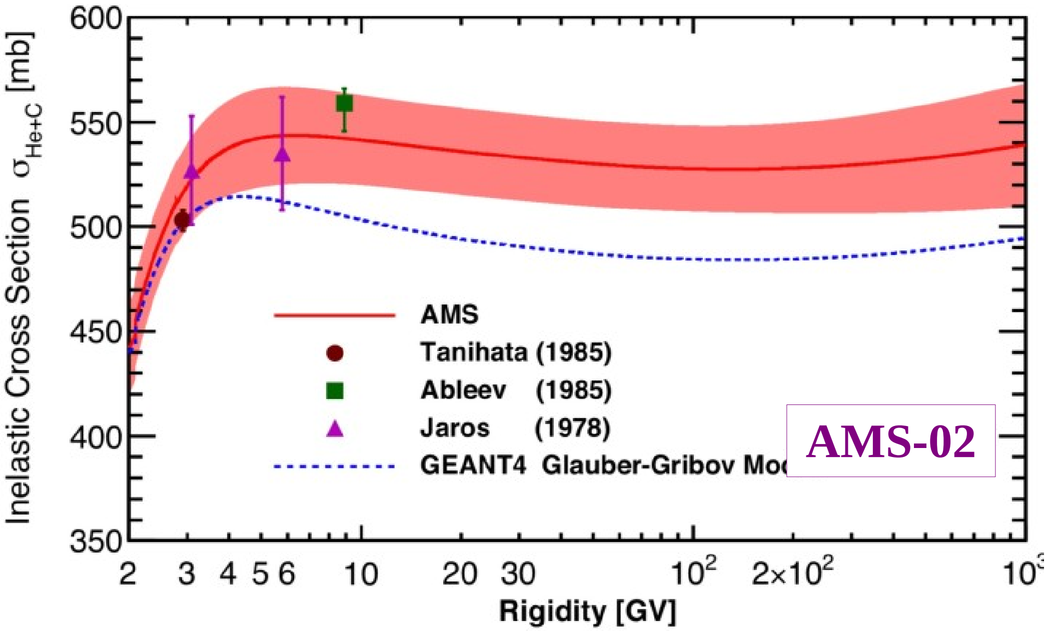
- Second rigidity break?
- Bridge between direct and indirect
- High precision heavy nuclei frontier
- …

N.B.: this is in addition to the plethora of results already published (200 GV break, e^- and e^+ spectra, pbar, daily time series, etc.)

XSCRC2024: GCR experiments

Talks by *P. Coppin*, *P. Maestro*, *M. Paniccia*, *A. Tykhonov*





Measurement of some inelastic and prod. XS, allowing comparisons/validations between

- Flight data
- Beam test data
- MC

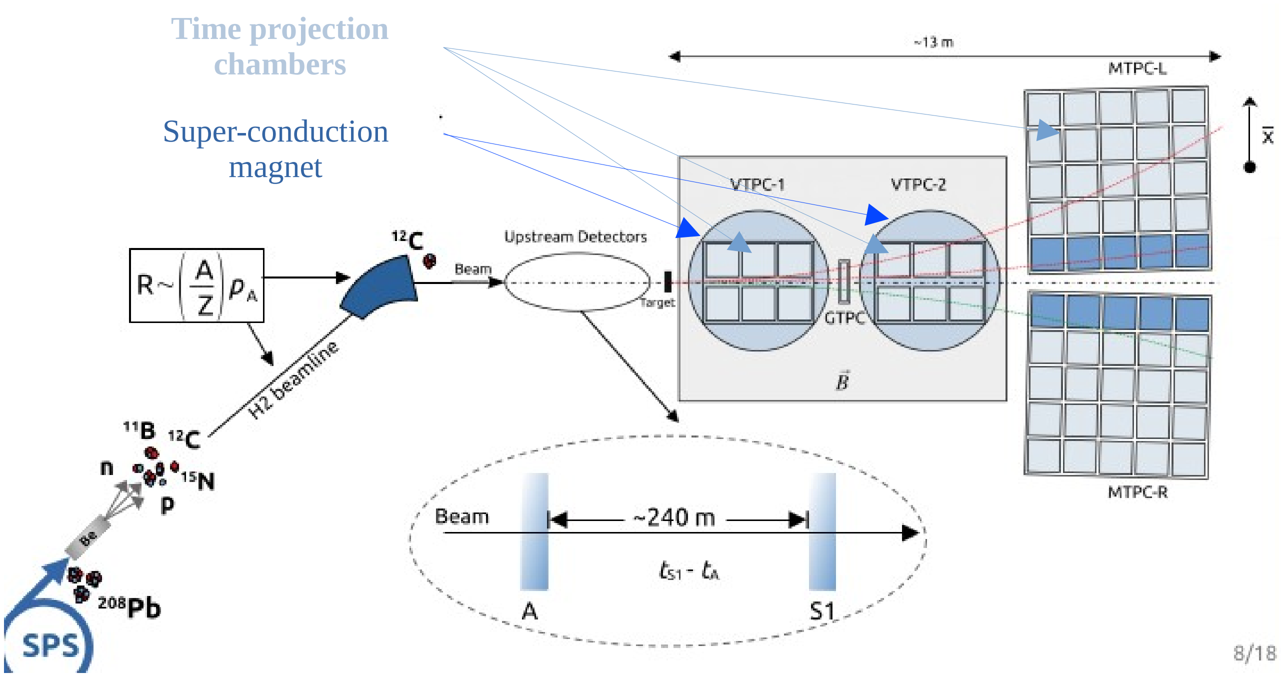
N.B.: normalisation issues on some fluxes between AMS-02, CALET and DAMPE data

Talk by *M. Unger*

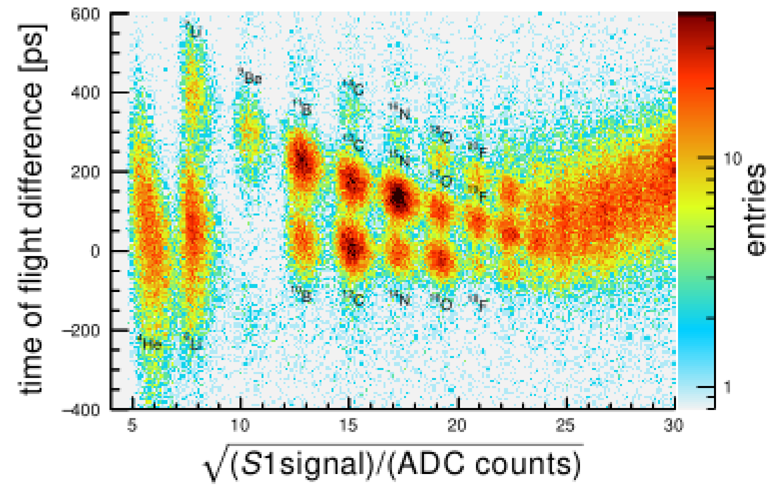
NA61/SHINE at the SPS H2 Beam Line

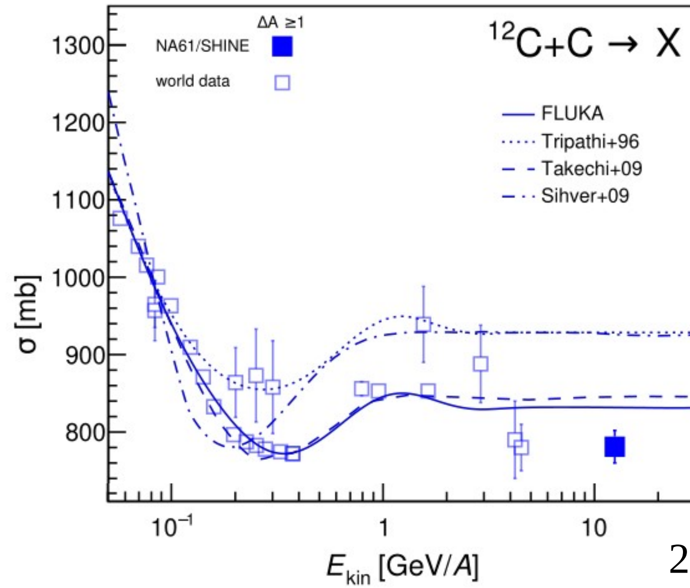
(strong interactions, ν, UHECR and *GCR physics*)

Illustration of successful collaboration (XSCRC2017)
→ *Pilot run in 2018 (2.5 days)*



- large acceptance ≈ 50% at $p_T \leq 2.5$ GeV/c
- momentum resolution: $\sigma(p)/p^2 \approx 10^{-4}(GeV/c)^{-1}$
- tracking efficiency: > 95%, pid with dE/dx and ToF





What next?

→ One week *fragmented Pb* beam (11/2024)
(10-fold increase of readout-rate wrt. pilot run)

→ 2025 primary oxygen (O+O interactions, CR frag.)?

XSCRC2024: XS for nuclei

Talks by *L. Audoin*, *P. Ghosh*, *M. Vanstalle*, *M.-J. Zhao*

Nuclear facilities

Pavia (Italy)
→ 200-700 MeV/n, ^{4}He|^{12}C|^{16}O|^{56}Fe beams
(ongoing measurements)

Brookhaven (USA)
→ below 1 GeV/n
(ongoing measurements sub-Fe)

Future nuclear facilities

Darmstadt (Germany)
→ up to 2 GeV/n (10 GeV/n in later phase)

Guangdong Province (South China)
→ quite similar to FAIR

XSCRC2024: XS for anti-protons

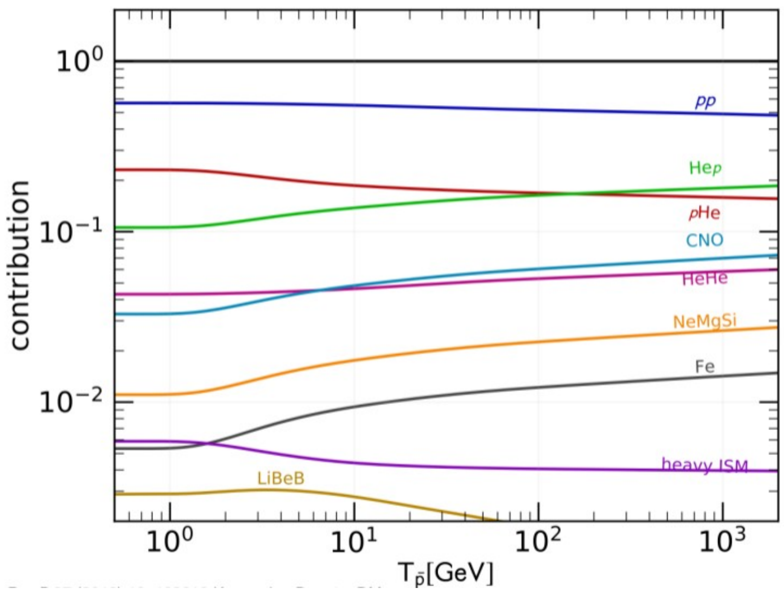
Talks by *M. Di Mauro*
L. Orusa

Source term
(~20% uncertainty)

1) Relevant reactions

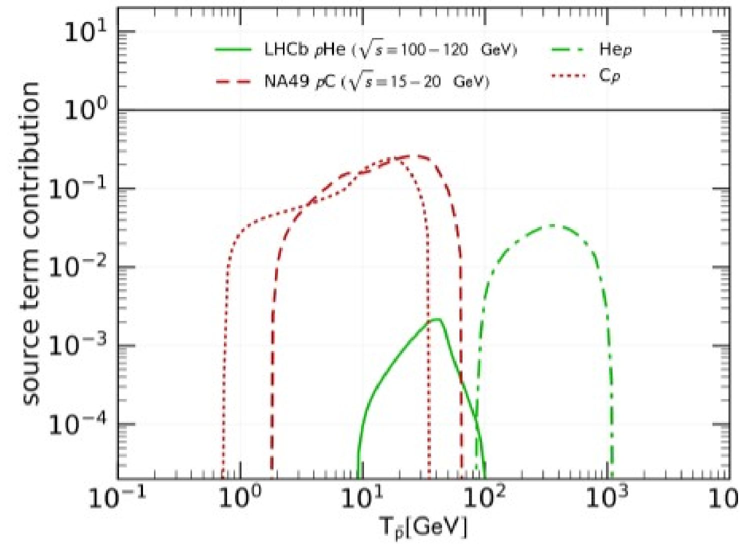
→ 90% of reactions involve p and He

→ All production XS rescaled to pp



2) Relevant kinematic regions

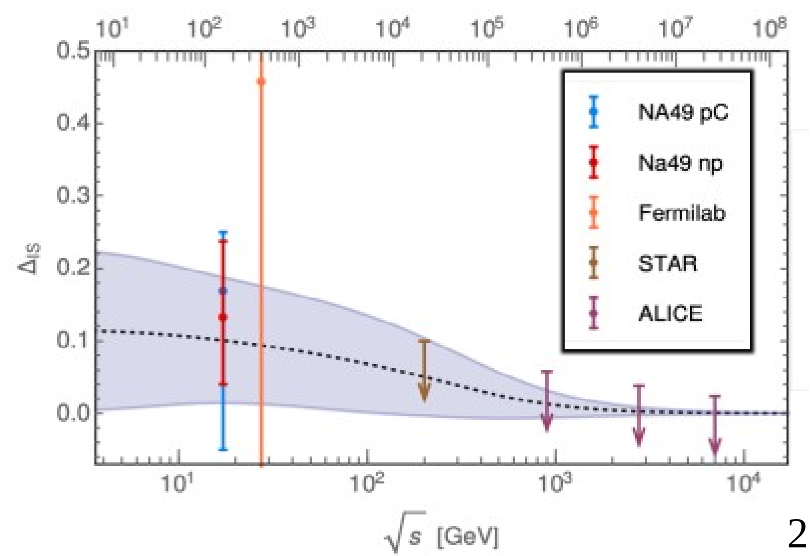
→ poorly sampled



3) Isospin asymmetry
($\overline{\mathrm{p}}$ and $\overline{\mathrm{n}}$)?

→ almost no data

$$\sigma_{\rm inv}^{\rm Galaxy} = \sigma_{\rm inv}(2 + \Delta_{\rm IS} + 2\Delta_{\Lambda})$$

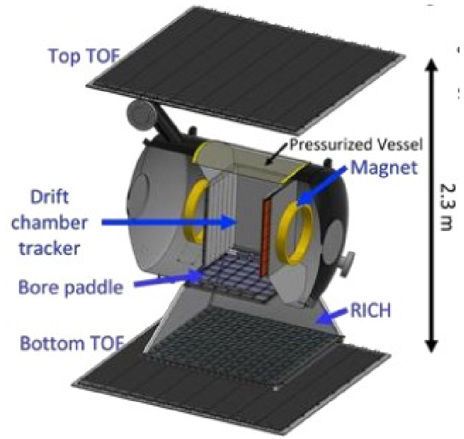


XSCRC2024: forthcoming GCR experiments

Talk by
A. Oliva

Isotope, anti-nuclei, mass, energy, and precision frontiers

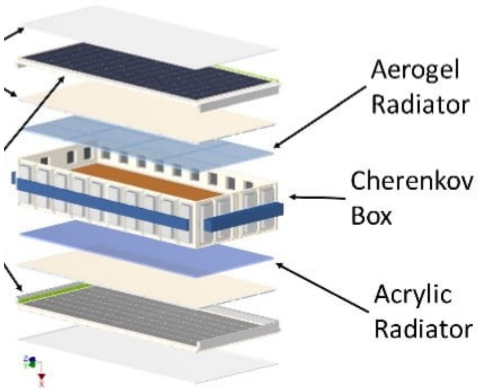
HELIX: ^{10}Be/^{9}Be (2024-...)



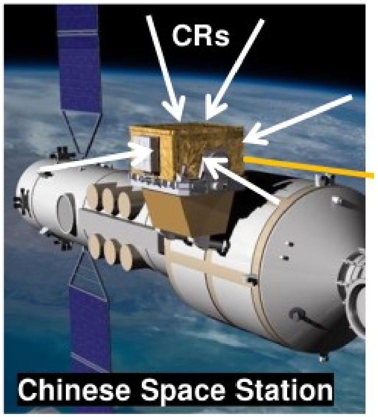
GAPS: dbar (2024-...)

AMS upgrade (2026-2030)

TIGERISS: Z>30 (2026-2030)



HERD: 55 X_0 (2026-2038)



ESA *Voyager 2050* call (ideas for next generation)