The RICH Detector of the AMS-02 experiment aboard the International Space Station

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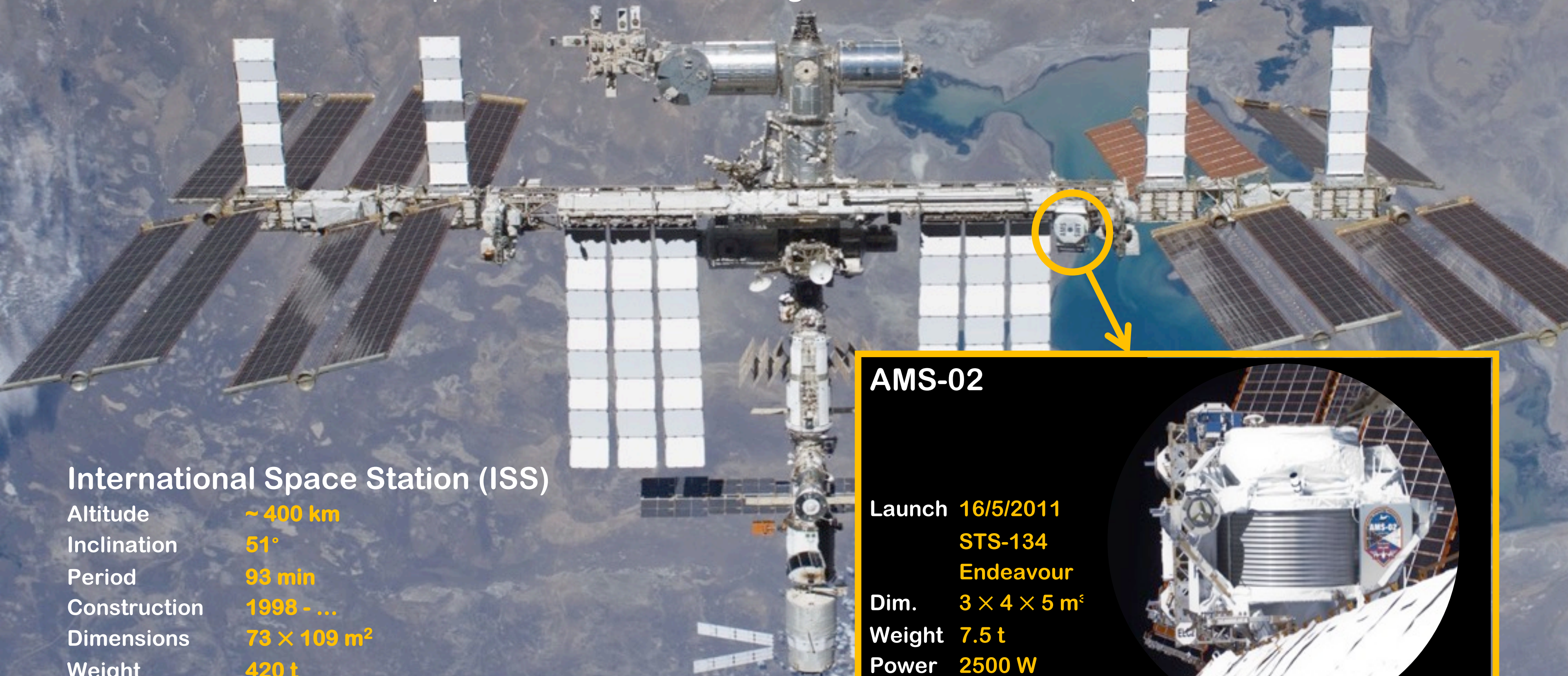
on behalf of the AMS-02 Collaboration

13/09/2022, Edinburgh

The Alpha Magnetic Spectrometer

Installed in 2011 on the ISS. Takes data continuously since then.
AMS-02 collected more than **200 billion cosmic** rays up to now.
It is expected to take data during the whole ISS lifetime (2030).



International Space Station (ISS)

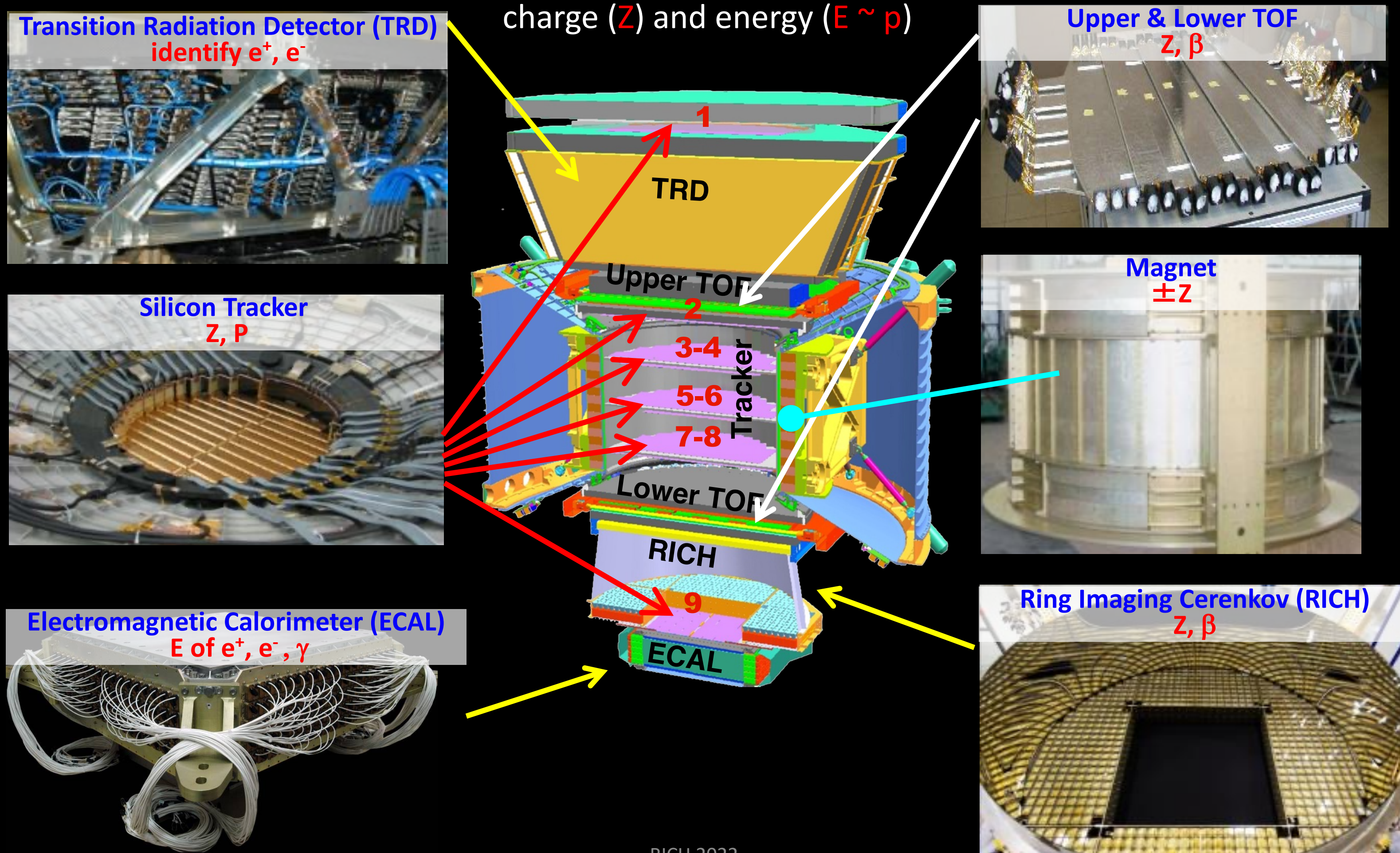
Altitude	~ 400 km
Inclination	51°
Period	93 min
Construction	1998 - …
Dimensions	73 × 109 m^2
Weight	420 t

AMS-02

Launch	16/5/2011
	STS-134
	Endeavour
Dim.	3 × 4 × 5 m^3
Weight	7.5 t
Power	2500 W

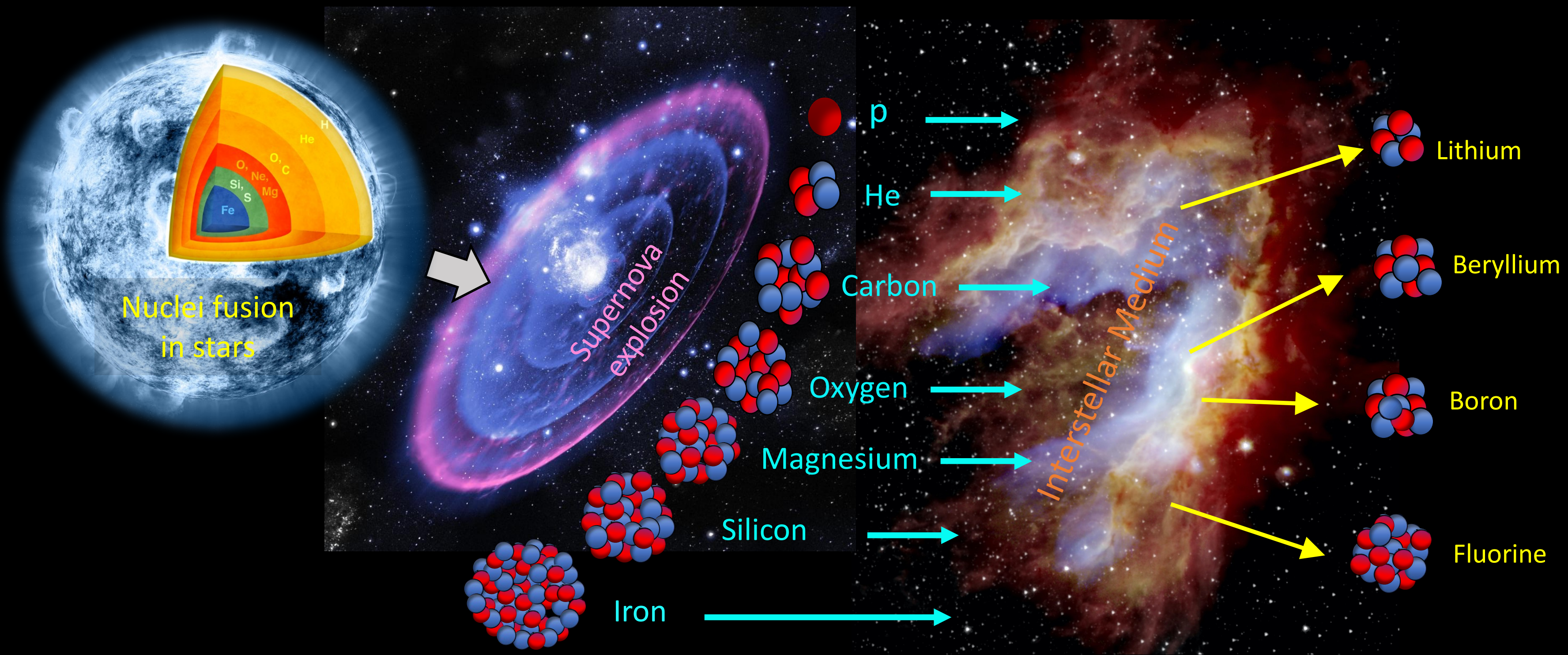
AMS: a high energy physics detector in space

Particles and nuclei are defined by their charge (Z) and energy (E ~ p)



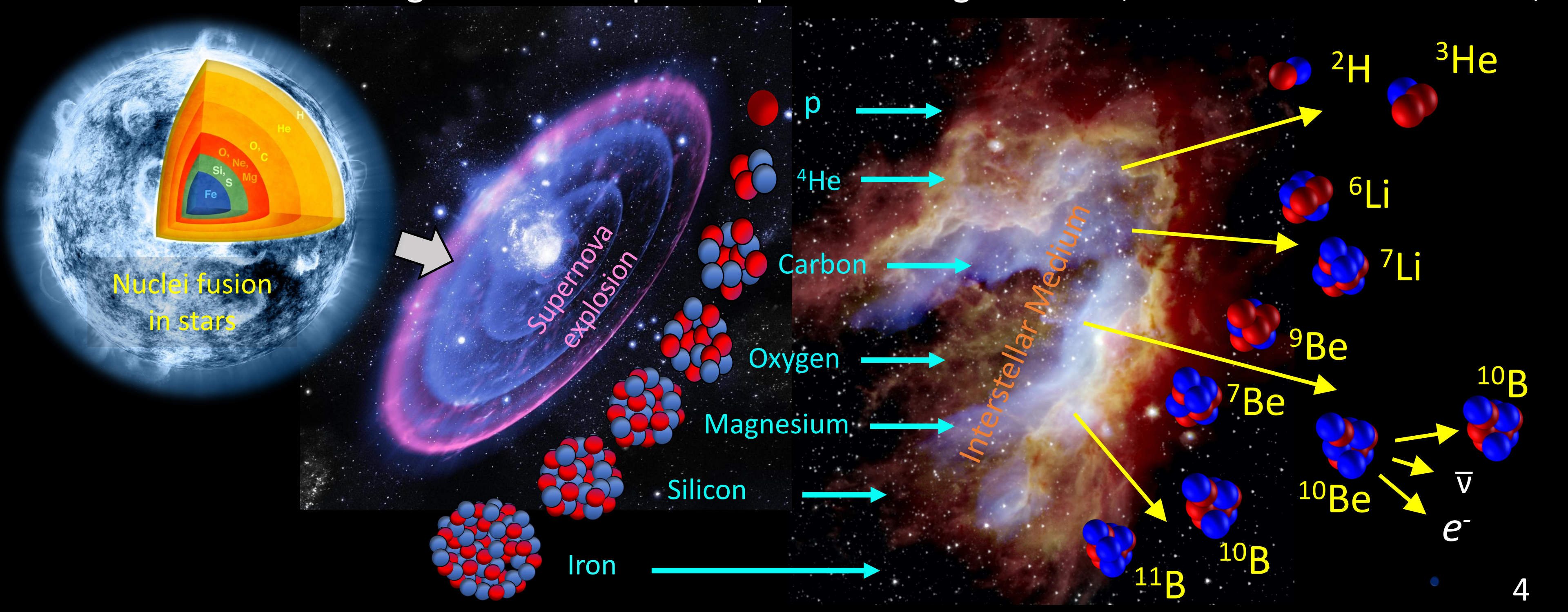
AMS: Physics goals

- Search for Anti Matter ($\overline{He}$) and Dark Matter hints in our galaxy as excess on rare CRs components (like positrons, $\overline{p}$, $\overline{d}$) above the expected astrophysical background;
- Precise measurement of primary and secondary cosmic ray spectra: fundamental to understand the origin, acceleration and propagation of Cosmic Rays in our Galaxy.

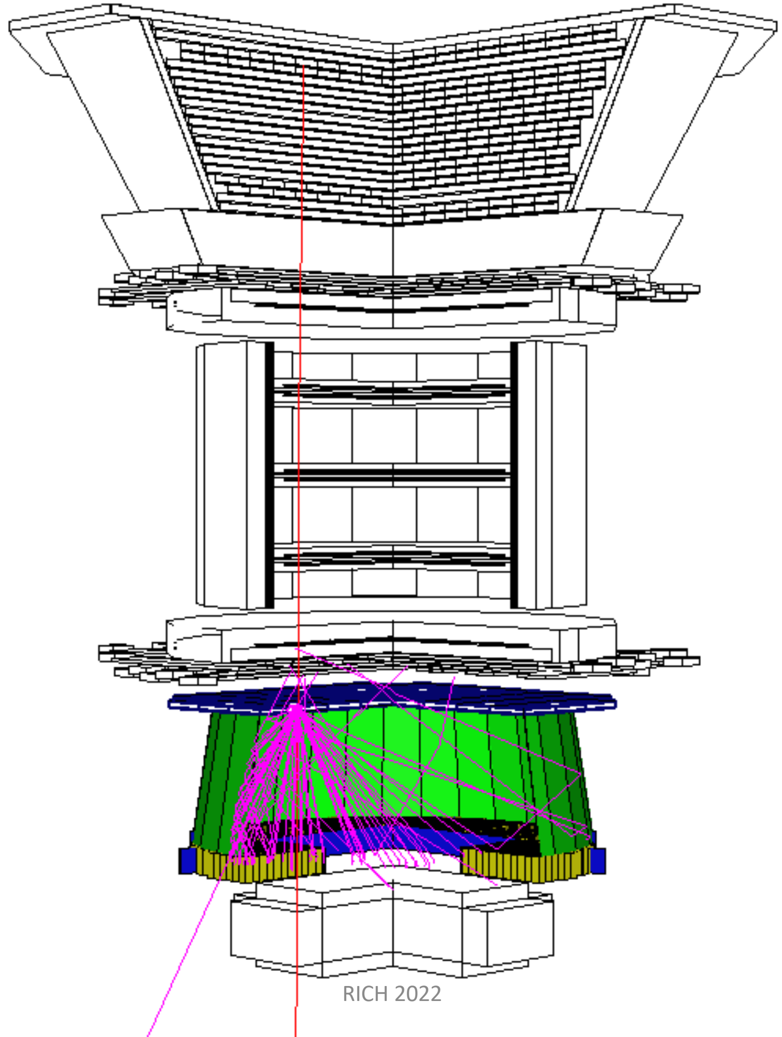


AMS: Physics goals

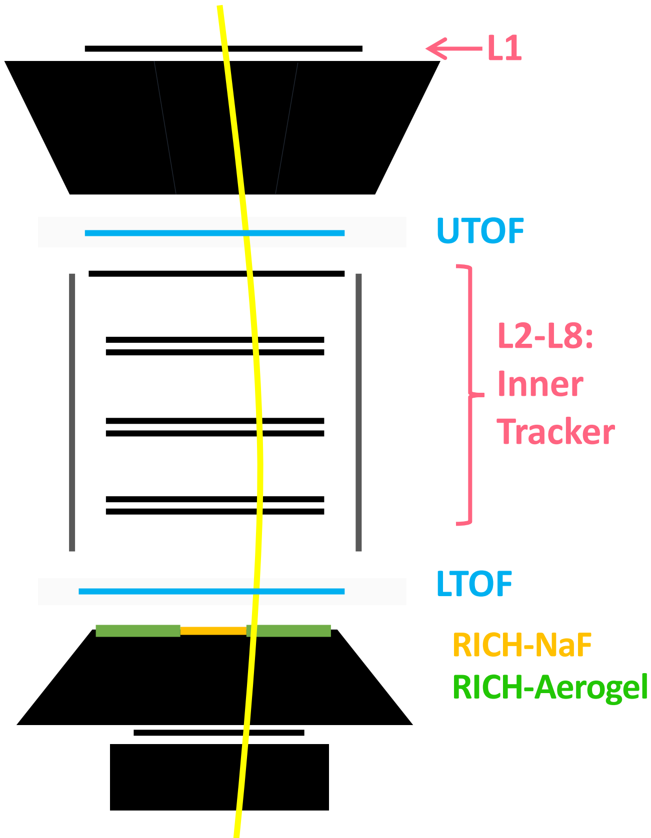
- Search for Anti Matter ($\overline{He}$) and Dark Matter hints in our galaxy as excess on rare CRs components (like positrons, $\overline{p}$, $\overline{d}$) above the expected astrophysical background;
- Precise measurement of primary and secondary cosmic ray spectra: fundamental to understand the origin, acceleration and propagation of Cosmic Rays in our Galaxy. A more detailed insight from isotopic composition of light nuclei (D, ^3He, ^4He, ^6Li, ^7Li, ^7Be, ^9Be, ^{10}Be)



The AMS Ring Imaging Cherenkov detector



Isotopes identification in AMS



$$M = \frac{RZ}{\beta\gamma}$$

$$\frac{\Delta M}{M} = \sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\gamma^2 \frac{\Delta\beta}{\beta}\right)^2}$$

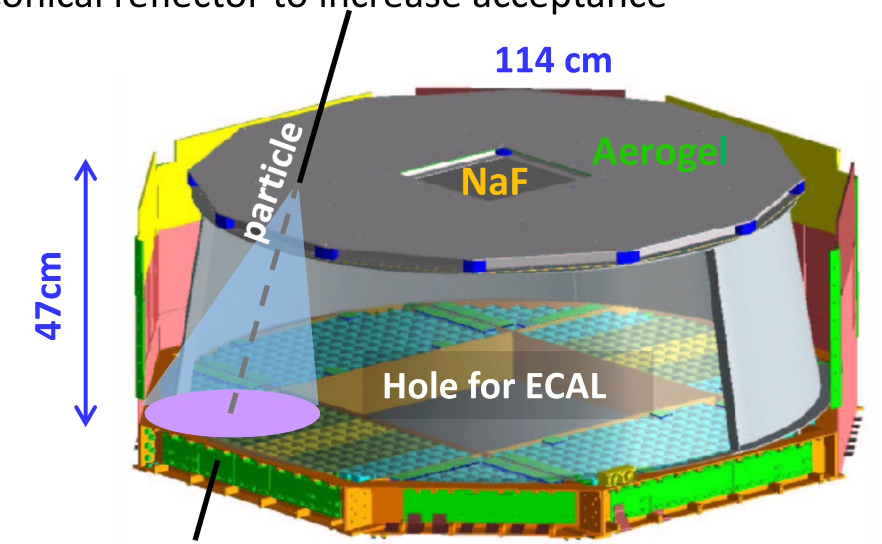
- Charge measurement:
  Tracker layers, UTOF, LTOF, RICH
- *Rigidity=p/Z* measurement :
  Tracker, $\Delta R/R \sim 10\%$ at 10 GV
- β measurements: TOF, RICH-NaF, RICH-Aerogel

	E_{kn} range (GeV/n)	$\Delta\beta/\beta$ (Z=2, β=1)	(Z=4, β=1)
TOF	(0.5, 1.2)	~2%	~1.5%
RICH-NaF (n=1.33)	(0.8, 4.0)	~0.25%	~0.15%
RICH-Agl (n=1.05)	(3.0, 12)	~0.07%	~0.05%

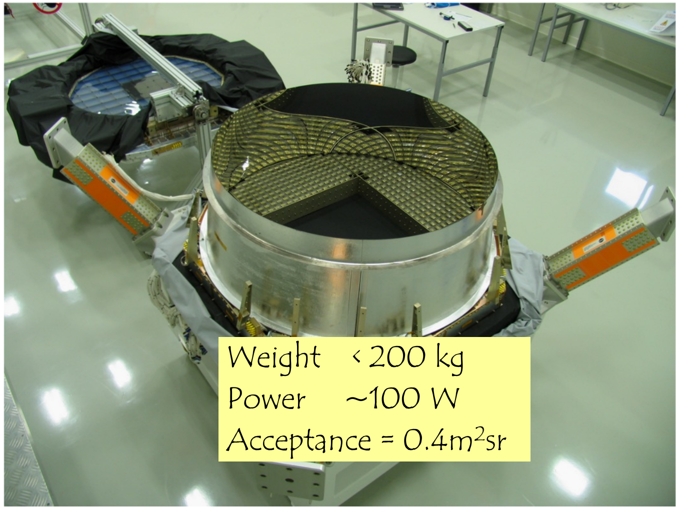
The AMS-02 RICH: Detector Layout

Proximity Focusing detector with:

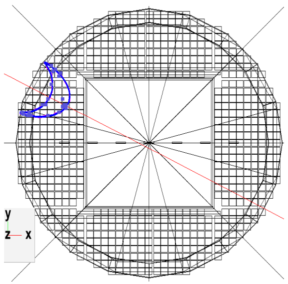
- Dual radiator configuration
- Detection matrix with central hole (match ECAL)
- Conical reflector to increase acceptance



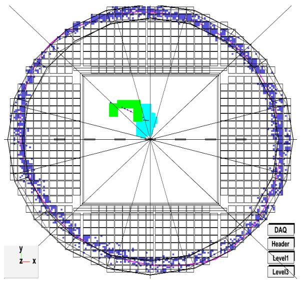
Θ -> v
Intensity -> Z^2



Z = 2 (^{3}He)
P = 19GeV/c

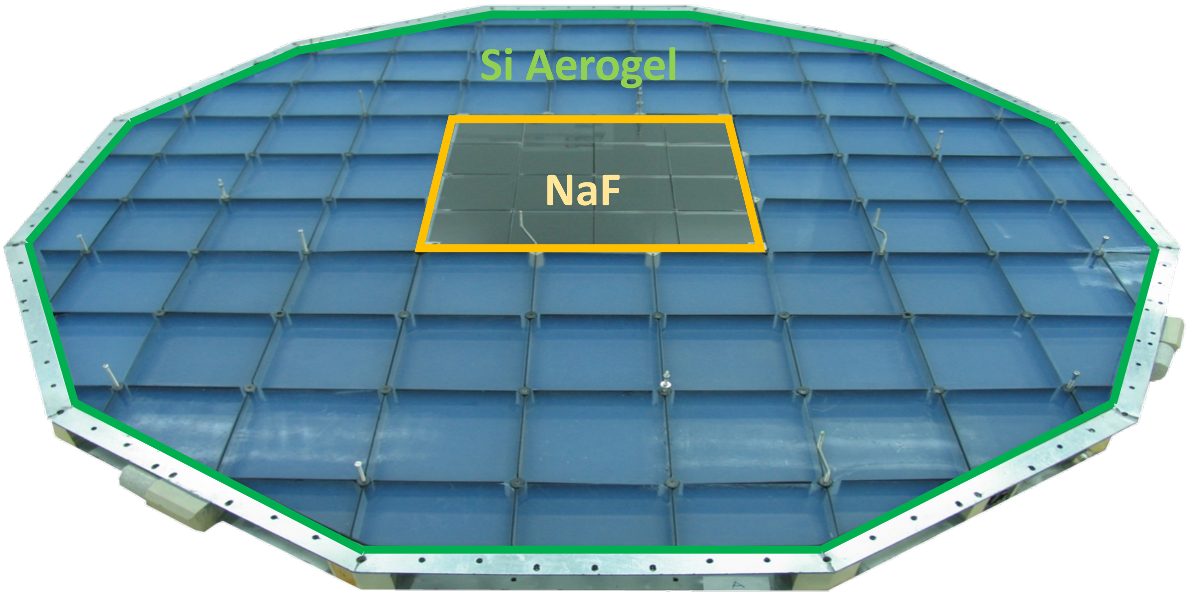


Z = 26 (Fe)
P = 167 GeV/c



- Tracker inner track provide the entry point and direction
- On average one ring per event is reconstructed

The AMS-02 RICH: Radiator



92 Agl tiles (n=1.05)

Catalysis Institute of Novosibirsk	
Refraction index	**1.05**
Δn among different tiles	≤ 0.001
Thickness (mm)	25
Size (mm^2)	113 x113
Clarity (mm^4/cm)	0.0055
Opening Angle at b→1 (deg)	17.8
Threshold velocity	0.952

16 NaF (n=1.33)

SODIUM FLUORIDE	
Refraction index	**1.33**
Thickness (mm)	5
Size (mm^2)	85 x 85
Opening Angle at $\beta \to 1$ (deg)	41.5
Threshold velocity	0.752

NaF radiator:

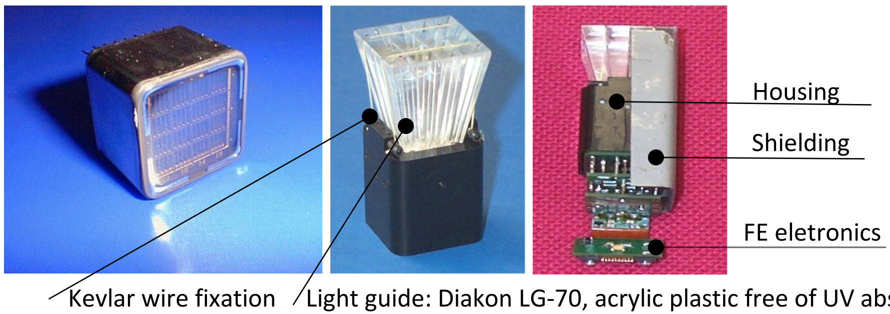
- Cover the energy range gap between TOF and agl;
- Larger Cherenkov angle (D $ring_{NAF} \approx 85$ cm-D $ring_{Agl} \approx 31$ cm for $\beta \to 1$) allows to recover detection efficiency for central particle;

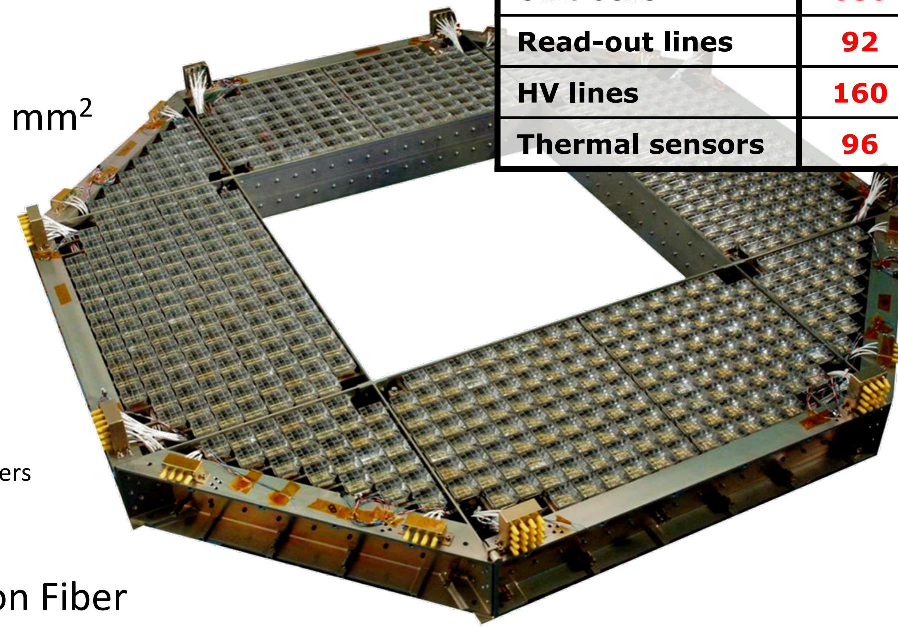
The AMS-02 RICH: Detection plane

Detection plane:

680 PMT Hamamatsu R7900-M16 (multianode 4x4)

10880 channels with detection granularity of 8.5 x 8.5 mm^2





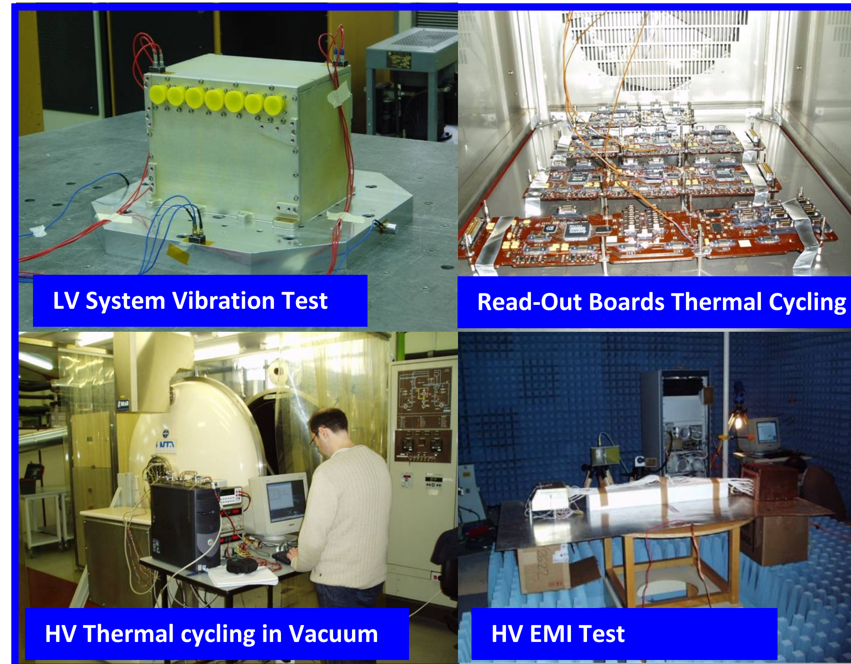
Unit Cells	**680**
Read-out lines	**92**
HV lines	**160**
Thermal sensors	**96**

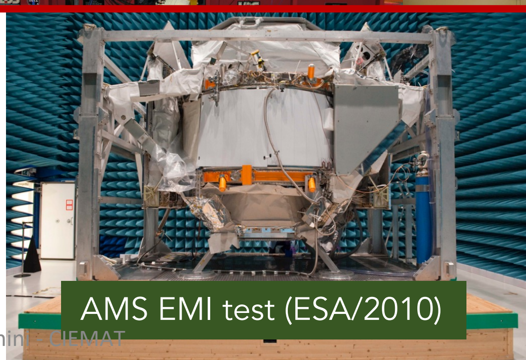
Conical Reflector

3 sectors of Multilayer Structure deposited on a Carbon Fiber Reinforced Composite (CFRC) Substrate

Structure:	Carbon Fiber with epoxy resin
Reflecting surface:	100 nm of Aluminum- Nickel Plated with 300 nm SiO_2 coating
Reflectivity:	≥ 85 % (at λ = 420 nm)
Roughness:	≤ 15 nm

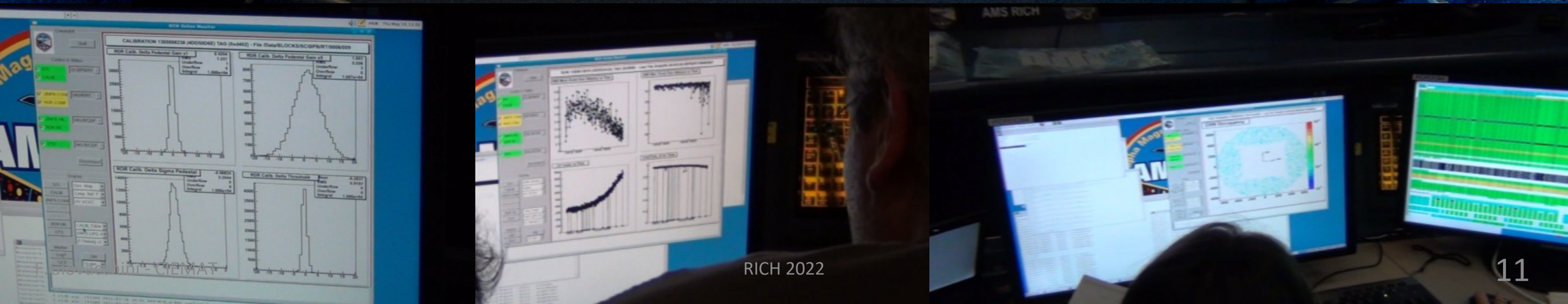
The AMS RICH detector: Space Qualification





The AMS-02 RICH: Monitoring & operations

- The detector in continously running
- RICH critical parameters are constantly monitored 24/7 at CERN AMS Payload Control Center (POCC) to ensure detector integrity and optimal performances
- In >11 years of data taking no major intervention required
- More than 95% of the channels are working properly



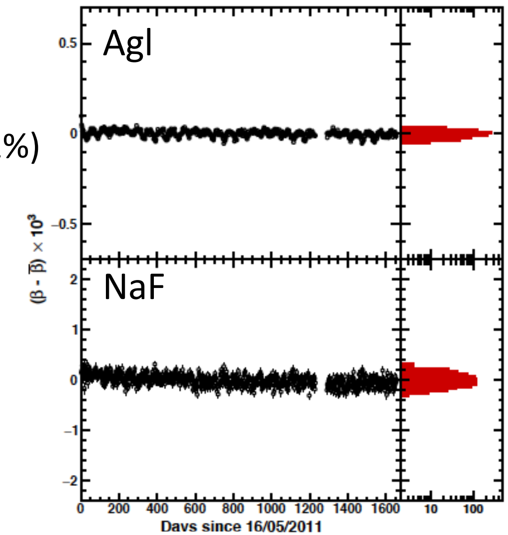
RICH Performances on ISS

Response stability

Charge: after temperature corrections the detectors response is stable

- The residual Photon Yield variation < 2 x 10^{-3} (95% CL) well within requirements (1%)

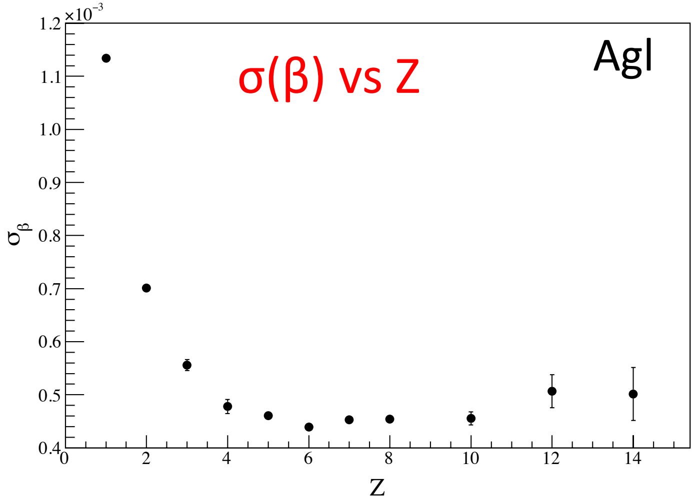
Beta: Residual effect on beta are small enought to have no impact in the resolution

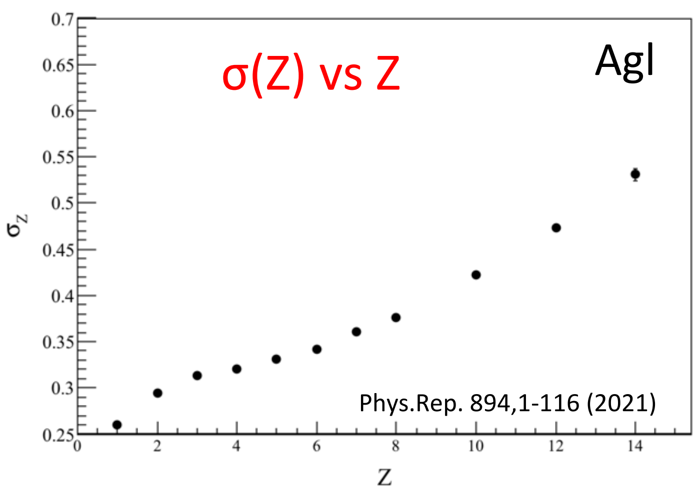


Resolution

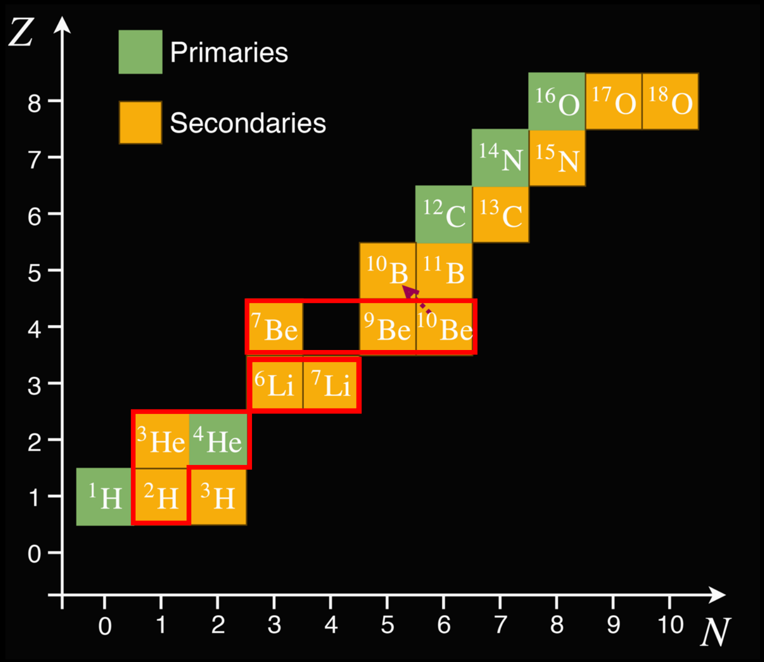
Beta: Agl(NaF) resolution ~ 0.7 (1.2) per mil per Helium and better for higher Z

Charge: Resolution ~ 0.3 for Helium



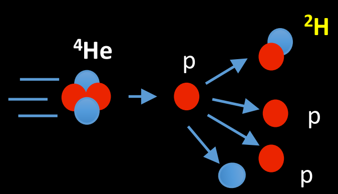


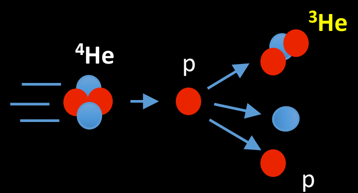
Physics Results: Light Isotopes



Deuterium and Helium Isotopes

- Helium nuclei are the second most abundant nuclei in cosmic rays.
- **^{2}H** and **^{3}He** are mostly produced by the fragmentation of **^{4}He:** simpler comparison with propagation models than with heavier secondary to primary nuclei ratios.

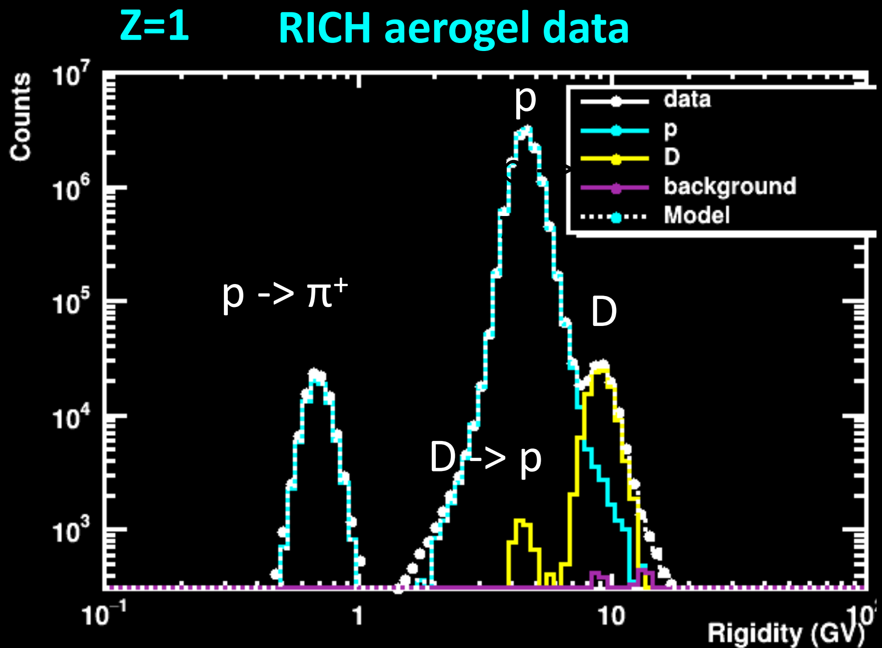


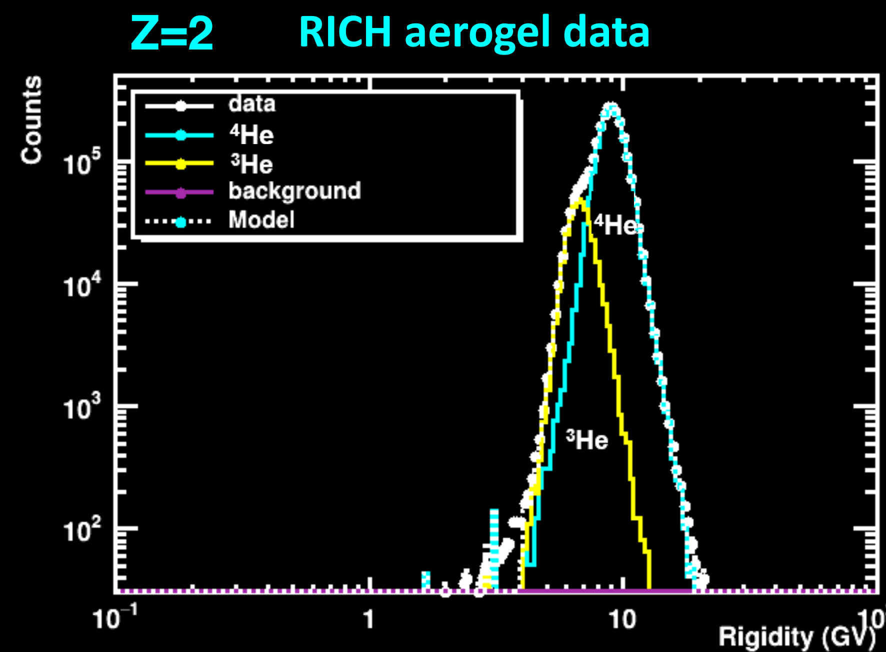


- The small cross section of He with respect to heavier nuclei, allows ^{2}H/^{4}He and ^{3}He/^{4}He to probe the properties of diffusion at larger distances than any secondary to primary ratio.
- In addition, the different A/Z ratios of ^{2}H and ^{3}He allow to disentangle kinetic energy and rigidity dependence of propagation.

He & H Isotopes identification

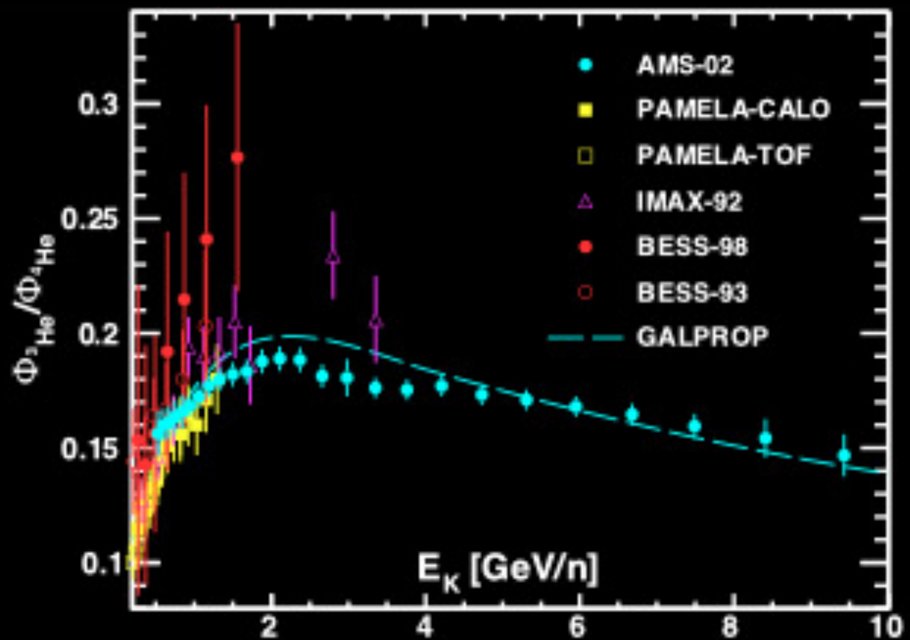
Beta ~ 0.985

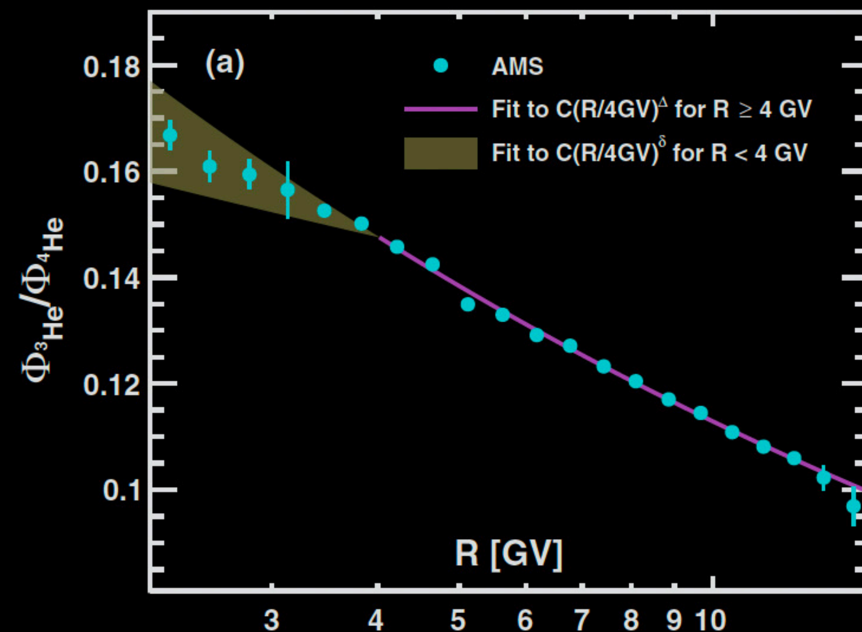




Helium Isotopes Fluxes

PRL 12,181102 (2019) - Editor's suggestion



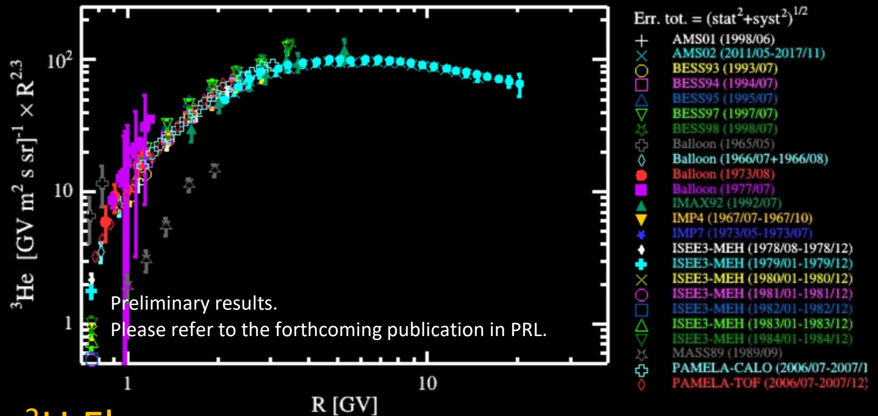


Based on 6.5 years AMS-02 data

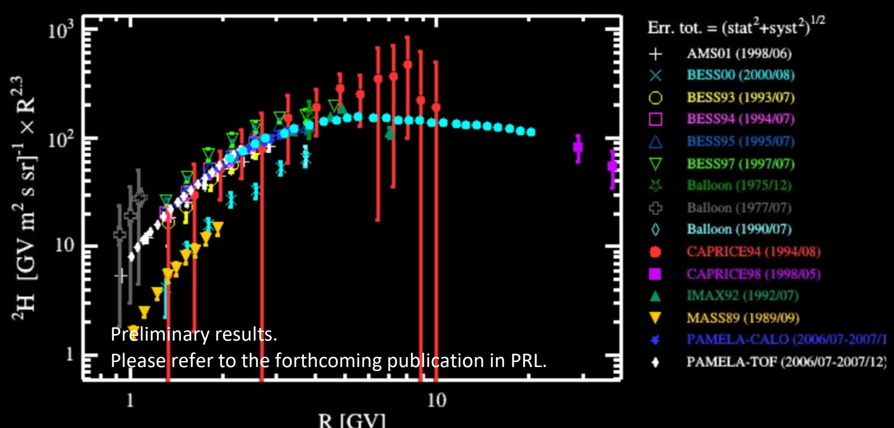
He & H Isotopes Fluxes

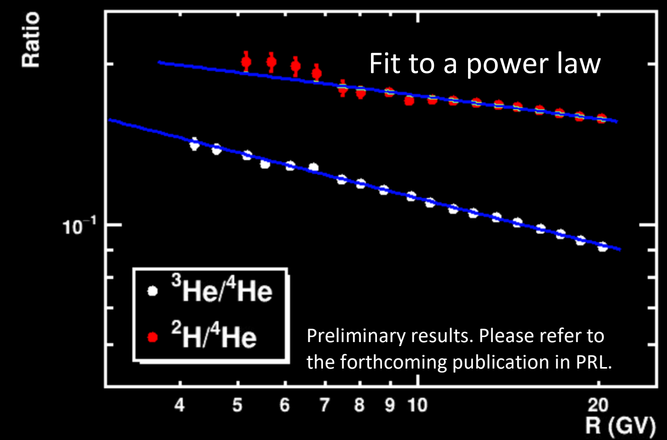
based on 10 years AMS-02 data

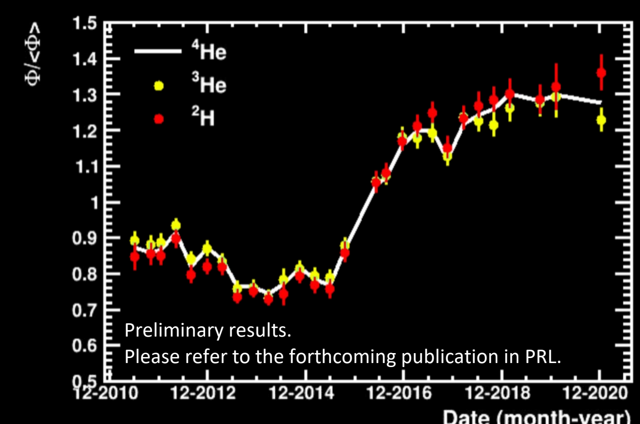
^{3}He Flux



^{2}H Flux



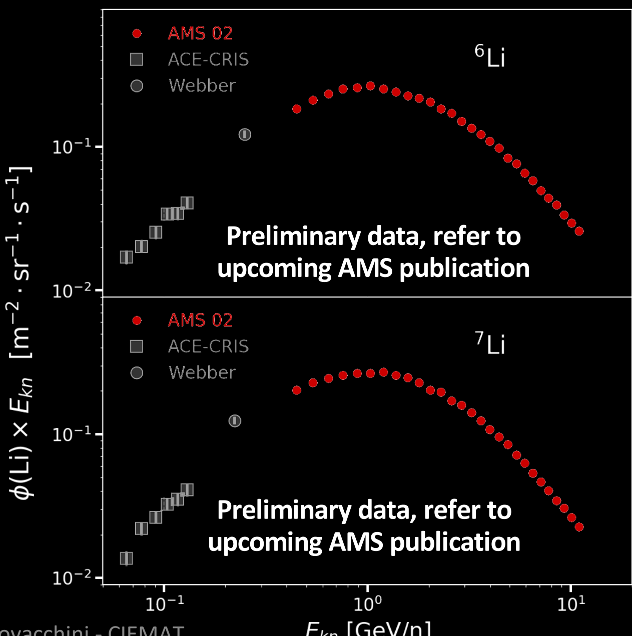




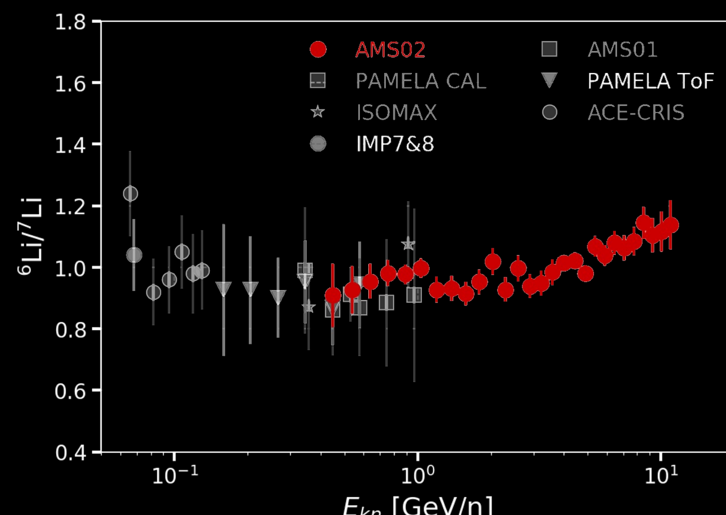
Lithium Isotopes

- Both ^{6}Li and ^{7}Li Secondary produced by the spallation of heavier primary nuclei in CRs.
- Some studies show lithium flux higher than model prediction: Uncertainty in the production cross-section? (Weinrich et al. A&A, 2020); Primary lithium? (Boschini et al. APJ, 2020)

→ First measurement of ^{6}Li and ^{7}Li fluxes above 0.5 GeV/n and up to 12 GeV/n



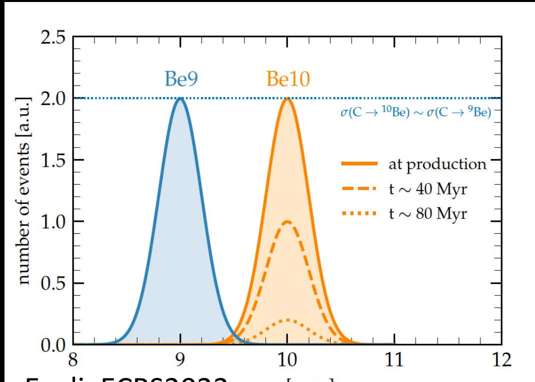
→ Extend the measurement of ^{6}Li/^{7}Li flux ratio above 1 GeV/n to 12 GeV/n



- Based on 0.8 million lithium events

Beryllium Isotopes

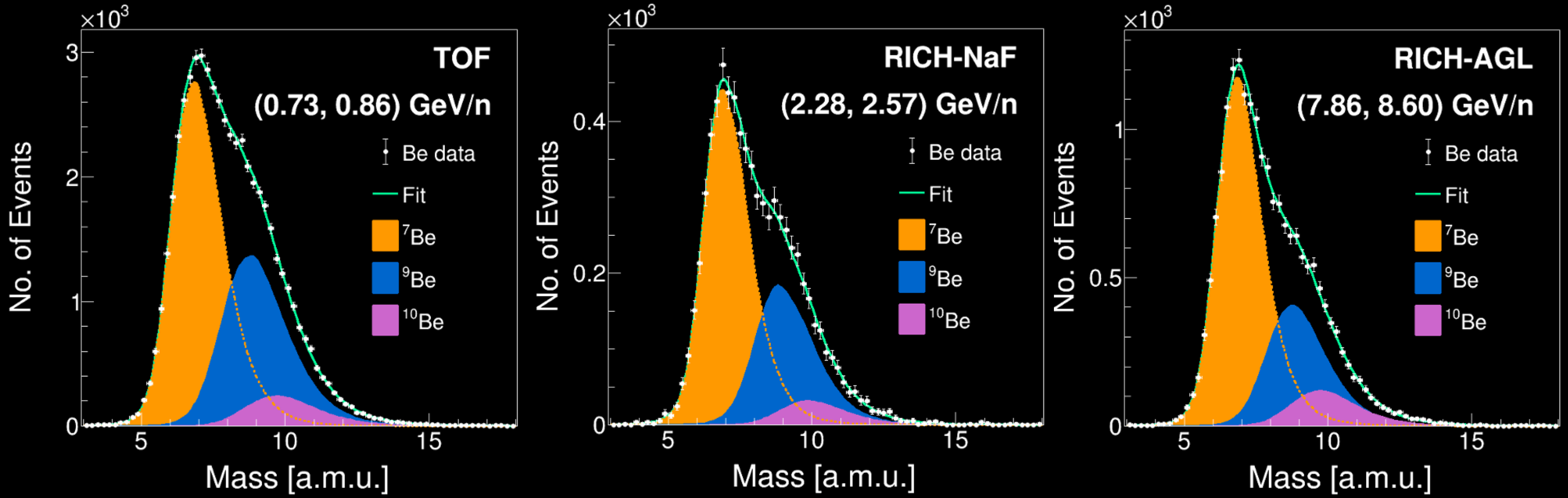
- The flux on unstable secondary CRs can be used to constrain the CRs residence time in the galaxy.
- $^{10}Be \rightarrow ^{10}B$, $t_{1/2} \approx 1.38$ My: "radioactive clock"
- Recent studies of cosmic ray propagation using Be/B flux ratio (Evoli et al. PRD, 2020,Weinrich et al. A&A, 2020)



Evoli, ECRS2022

➢ $^{10}Be/^{9}Be$ provides more sensitive measurement of the age of cosmic rays.

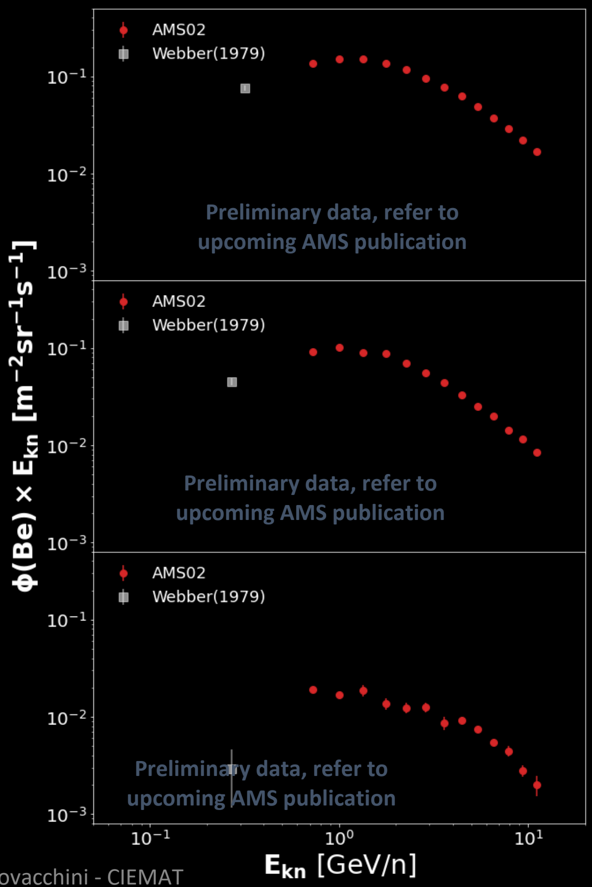
Be Isotopes identification



- Isotopic abundances obtained from mass template fit carried out in difference energy ranges.
- Mass templates are based on Monte Carlo simulation validated by data.

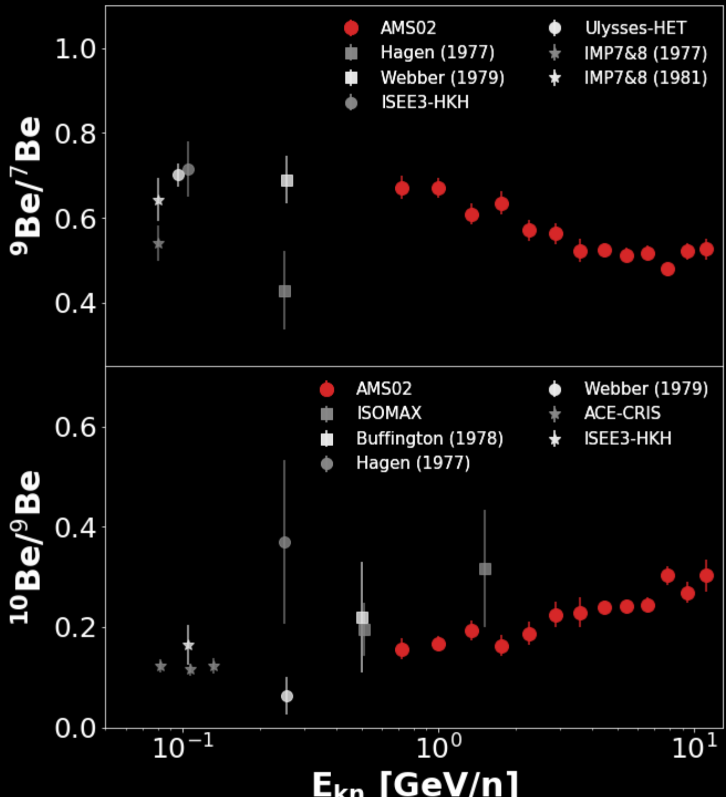
Beryllium Isotopes Fluxes and ratios

→ First measurement of ^{7}Be, ^{9}Be and ^{10}Be fluxes above 0.5 GeV/n and up to 12 GeV/n.



→ First measurement of:

- $^{9}Be/^{7}Be$ flux ratios above 0.5 GeV/n.
- $^{10}Be/^{9}Be$ flux ratios above 2 GeV/n.

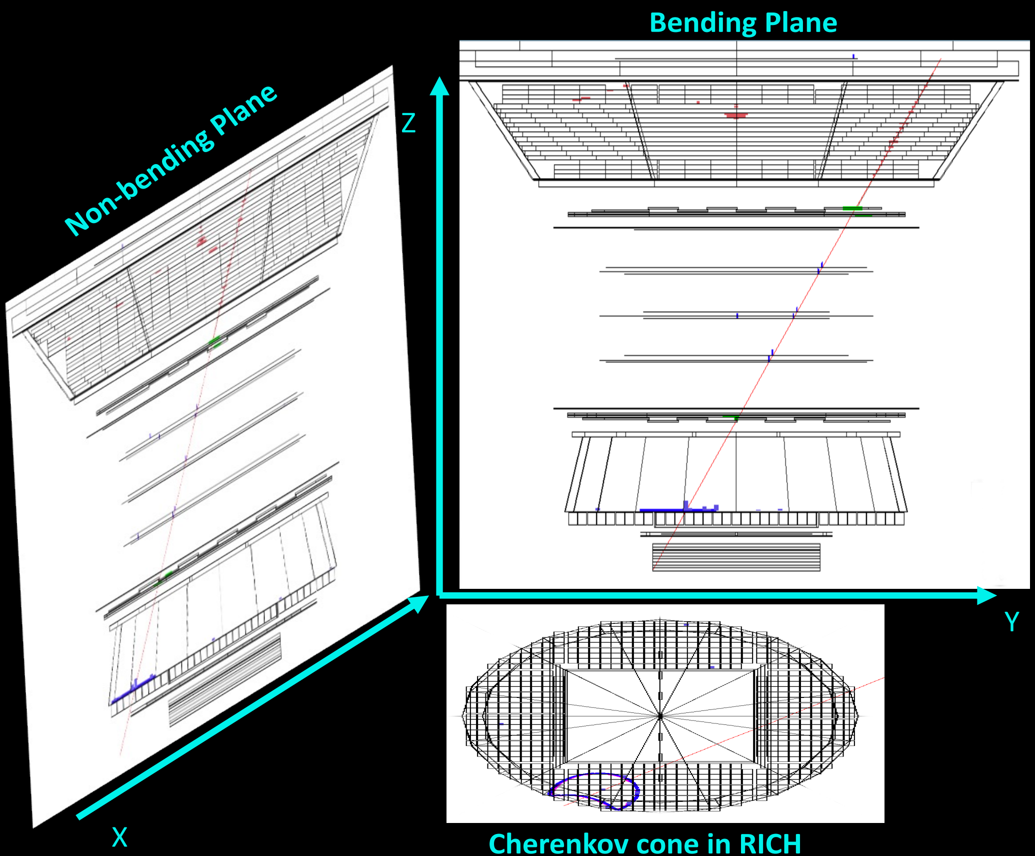


The AMS-RICH detector is successfully taking data since more than 10 years is space aboard the International Space Station proving great contribution to AMS physics!

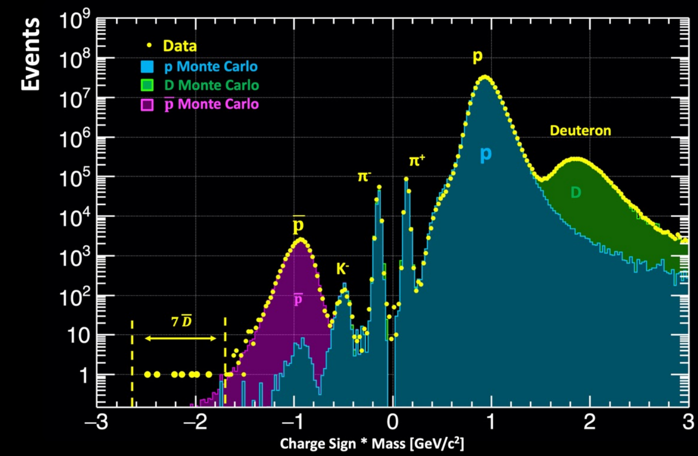
Search for Light anti-matter

BONUS TRACK

Search for Anti-D candidates



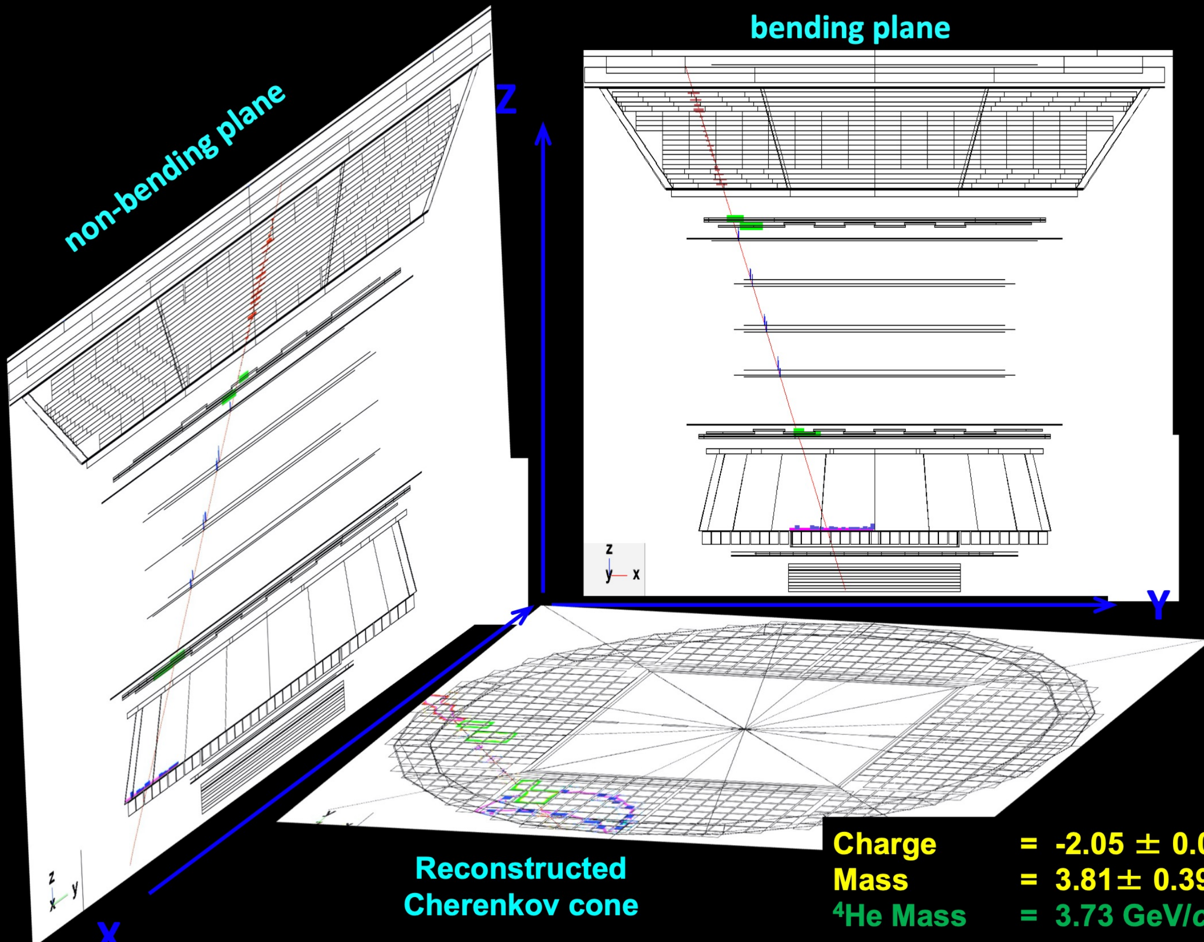
Anti-deuteron Candidate
Charge = -1.02 ± 0.05
Mass = 1.9±0.1 *GeV/c²*



A few antideuteron candidates were selected. Extensive study of the Monte Carlo simulation is on-going to understand the detector effects.

Benefit from continuous data taking through the lifetime of the Space Station

Search for Anti-He candidates



Charge = -2.05 ± 0.05
Mass = 3.81± 0.39 GeV/c^2
^{4}He Mass = 3.73 GeV/c^2

- Few anti-helium candidates were observed with R<50 GV;
- All masses are in the ^{3}He or ^{4}He mass ranges ;
- 1 anti-He in about 100 million helium;
- No bg expected by MC;
- At this level MC simulation are difficult to validate.
- ➢ Increase acceptance with L)0 upgrade (300%)

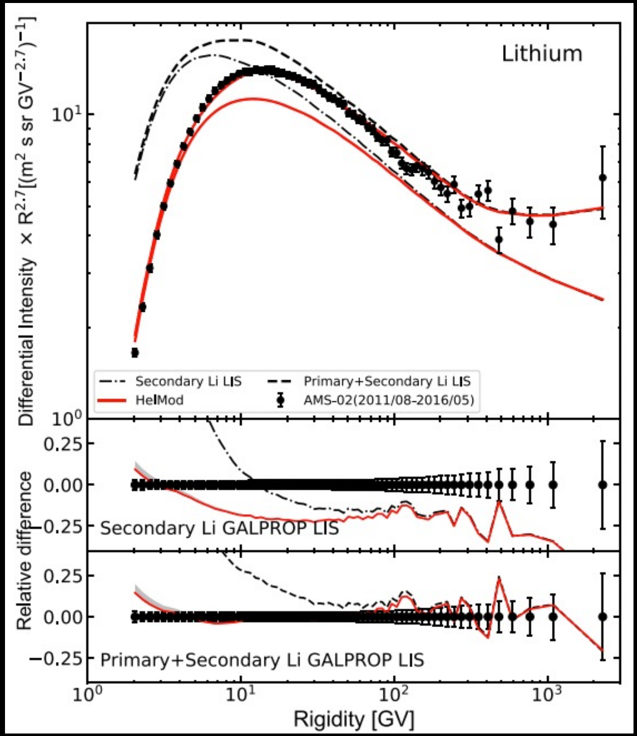
Lithium Isotopes

- Both ^{6}Li and ^{7}Li Secondary produced by the spallation of heavier primary nuclei in CRs.

- Some studies show lithium flux higher than model prediction: Uncertainty in the production cross-section? (Weinrich et al. A&A, 2020);Primary lithium? (Boschini et al. APJ, 2020)

- Studies of lithium isotopic composition may help to investigate the mechanism.

Boschini et al. APJ, 2020



Beryllium Isotopes

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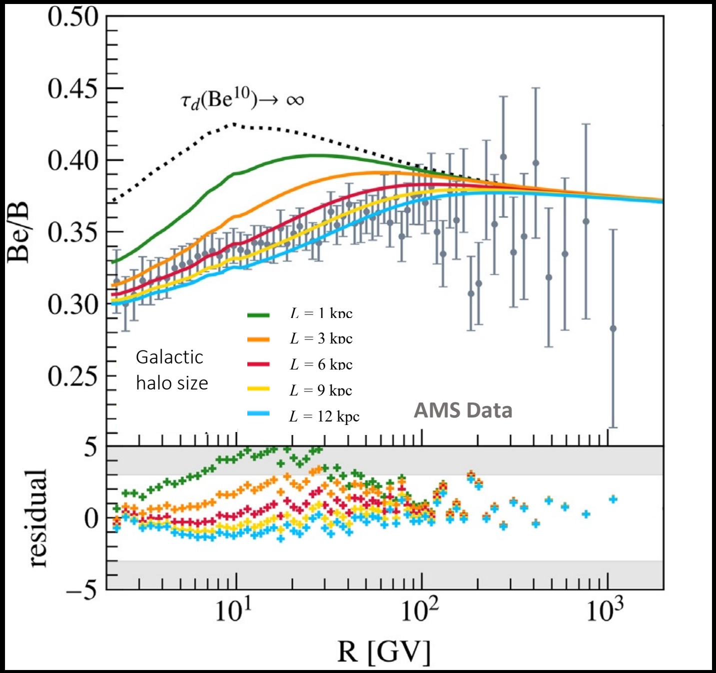
- $^{10}Be \rightarrow ^{10}B$, $t_{1/2} \approx 1.38$ My: "radioactive clock"
- Recent studies of cosmic ray propagation using Be/B flux ratio:
  - Evoli et al. PRD, 2020
  - Weinrich et al. A&A, 2020
- $^{10}Be/^{9}Be$ provides more sensitive measurement of the age of cosmic rays.

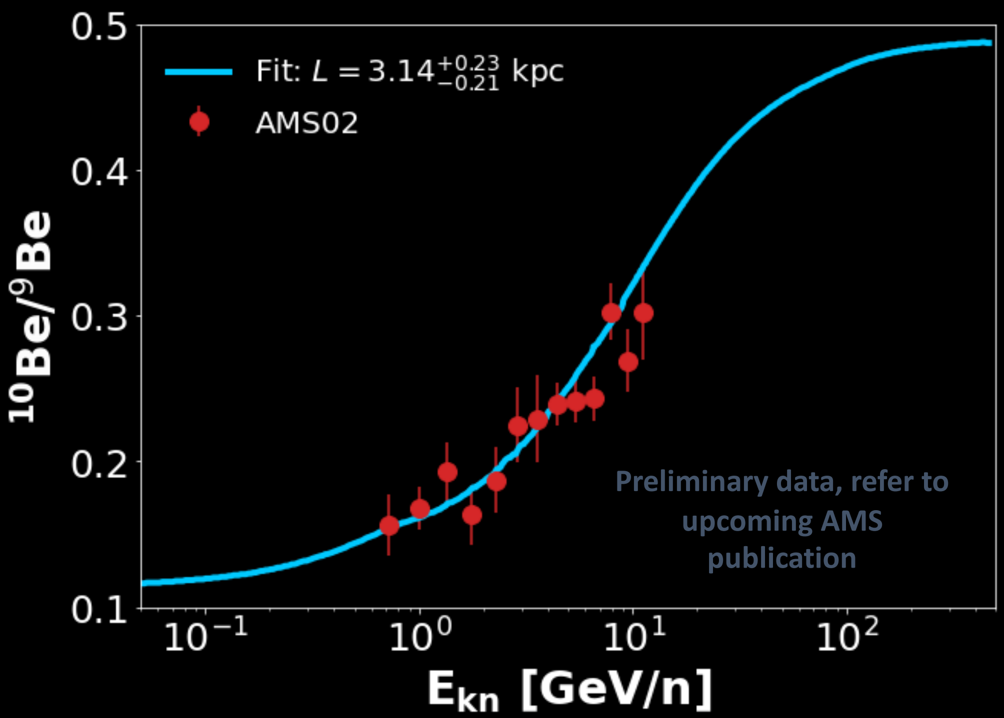
Evoli et al. PRD, 2020



Fitting the $^{10}Be/^{9}Be$ Flux Ratios

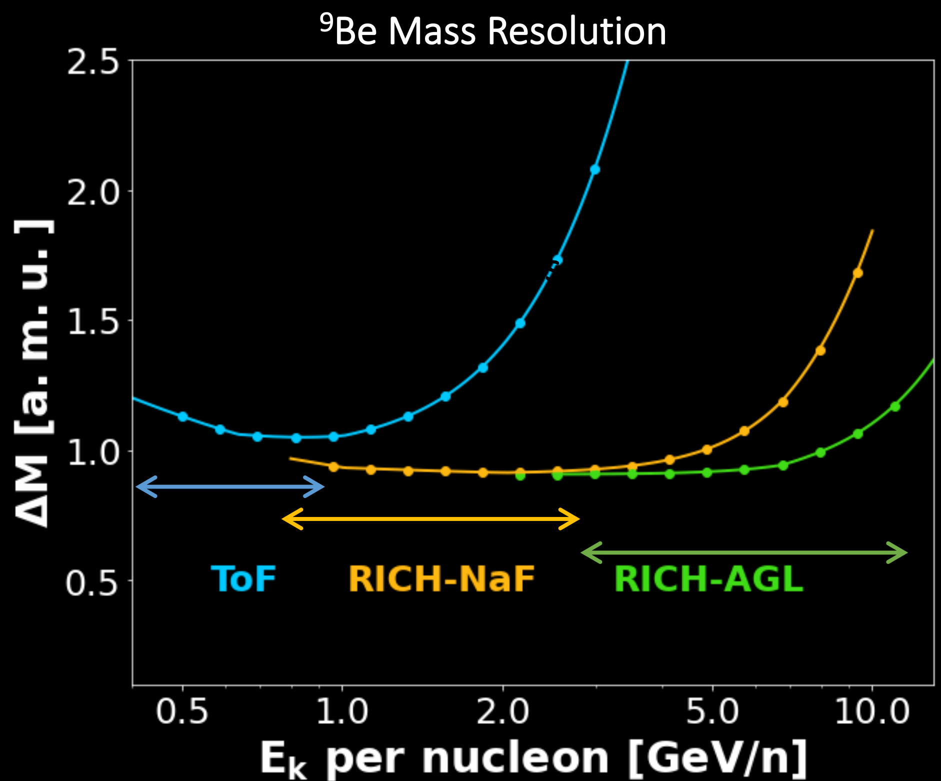
- Galactic diffusion halo size L fitted on AMS02 data with an analytical formula:
  (D. Maurin *et al.*, arXiv:2203.07265)

- **Precision on L from AMS02 data $\Delta L_{\mathbf{AMS02}} \sim \mathbf{0.2\ kpc.}$**
- Error dominated by uncertainty from production cross-section (1 kpc).



Be Isotopes identification

$$\frac{\Delta M}{M} = \sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\gamma^2 \frac{\Delta \beta}{\beta}\right)^2}$$

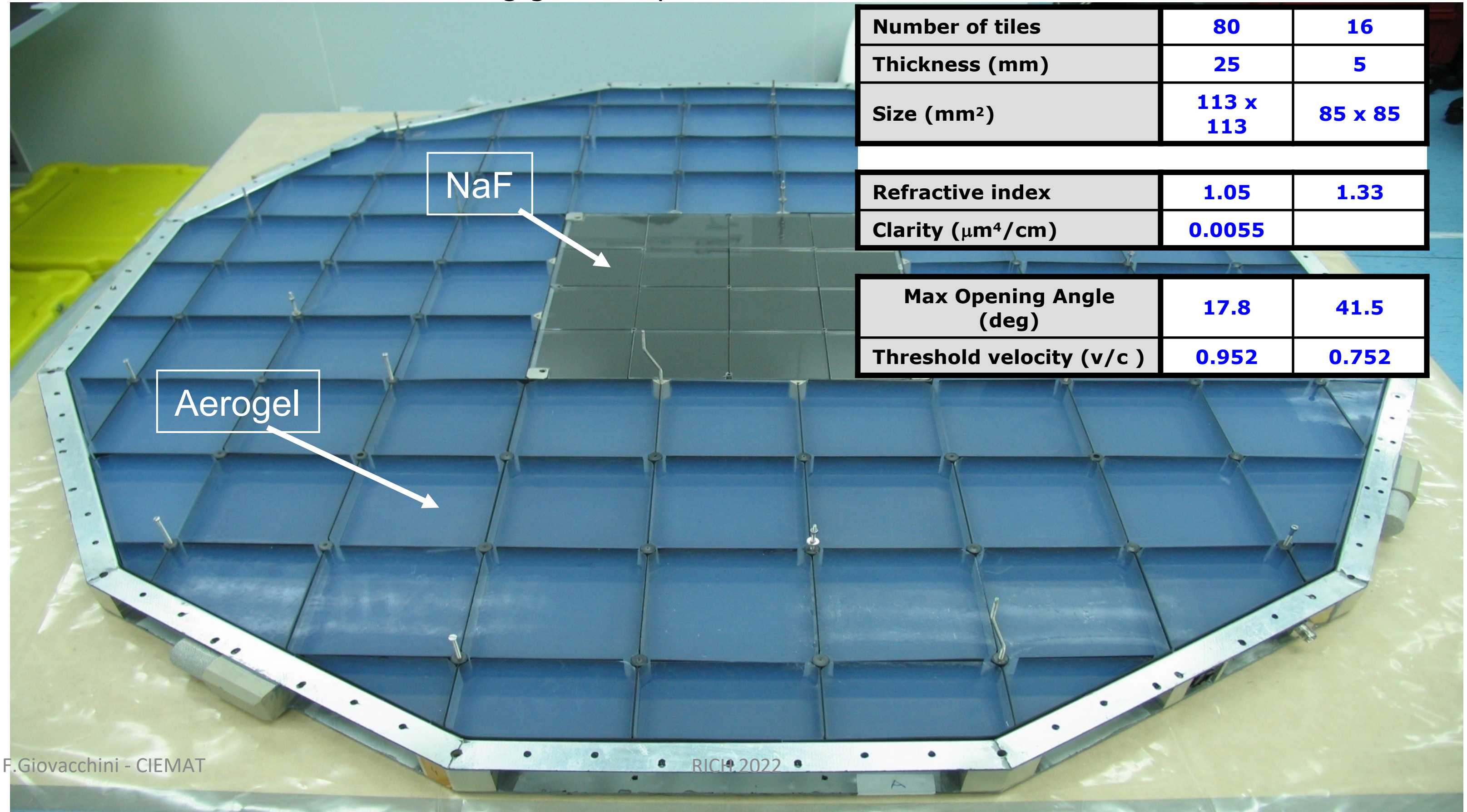


ΔM ~ 1 a.m.u.→ Unable to do event-by-event isotope identification

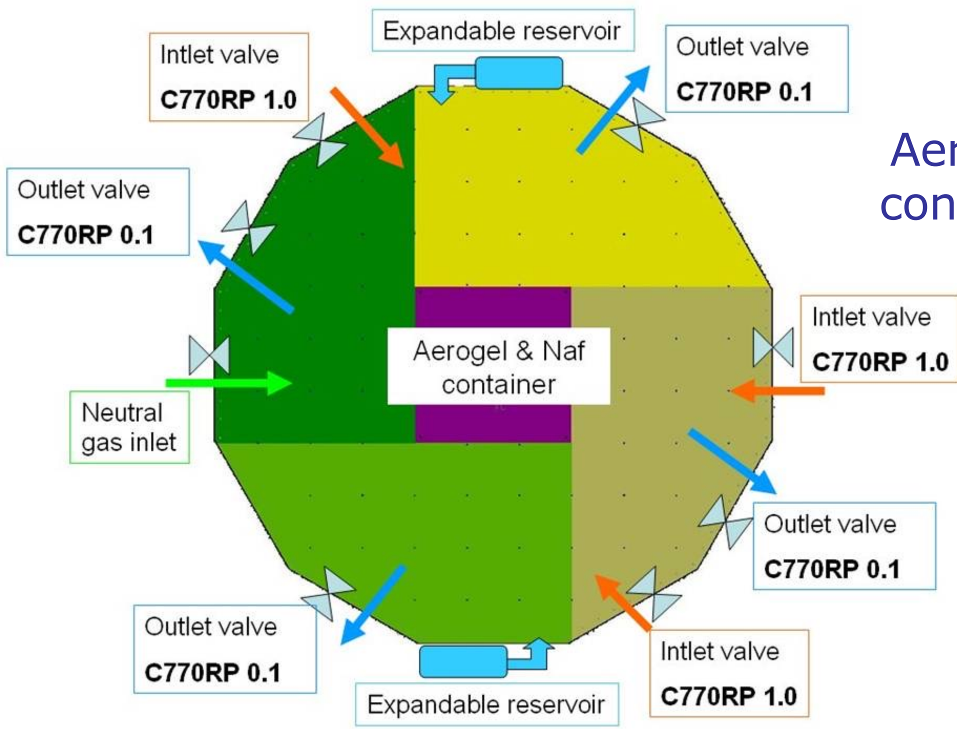
Radiator: Structure & Container

- The tiles are enclosed inside a sealed carbon fibre structure.
- A set of inlet and outlet valves equipped with filters allows the vent-out and vent-in of the container for launch and landing.
- Container is filled with N_2 during ground operations.

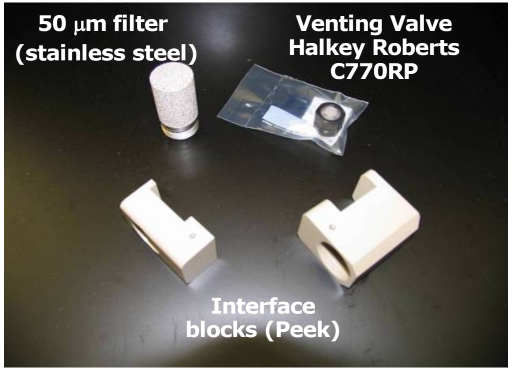
	Aerogel	NaF
Number of tiles	80	16
Thickness (mm)	25	5
Size (mm²)	113 x 113	85 x 85
Refractive index	1.05	1.33
Clarity (μm⁴/cm)	0.0055	
Max Opening Angle (deg)	17.8	41.5
Threshold velocity (v/c)	0.952	0.752



Radiator: Venting



Aerogel and NaF require a controlled dry environment



Container filled with neutral gas (Nitrogen) whenever not in dry atmosphere

- compensates atmospheric pressure variations
- Launch/landing venting capability

PRL 12,181102 (2019) - Editor's suggestion