Particles in South Atlantic Anomaly with AMS-02: Status and Perspectives

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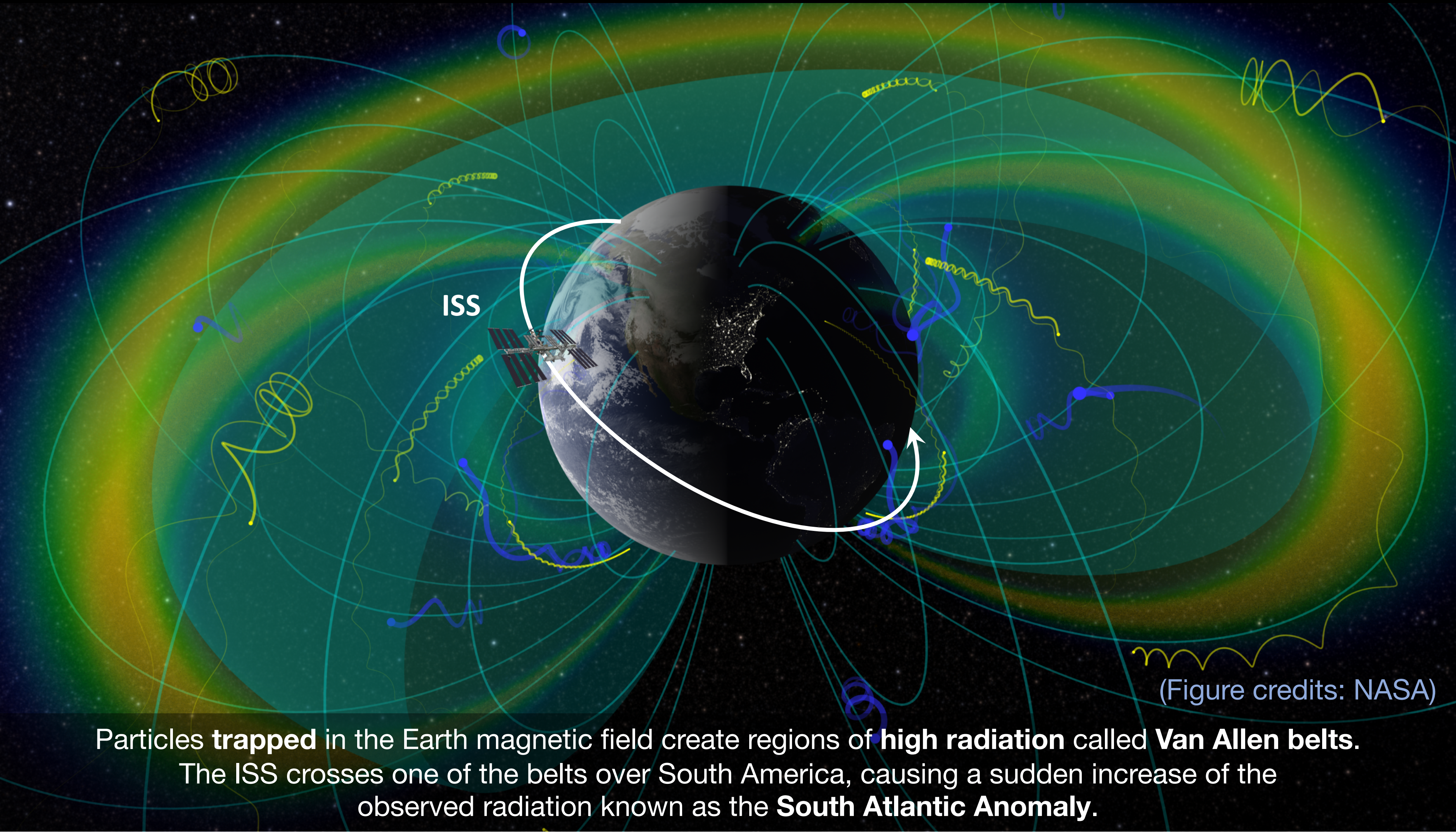
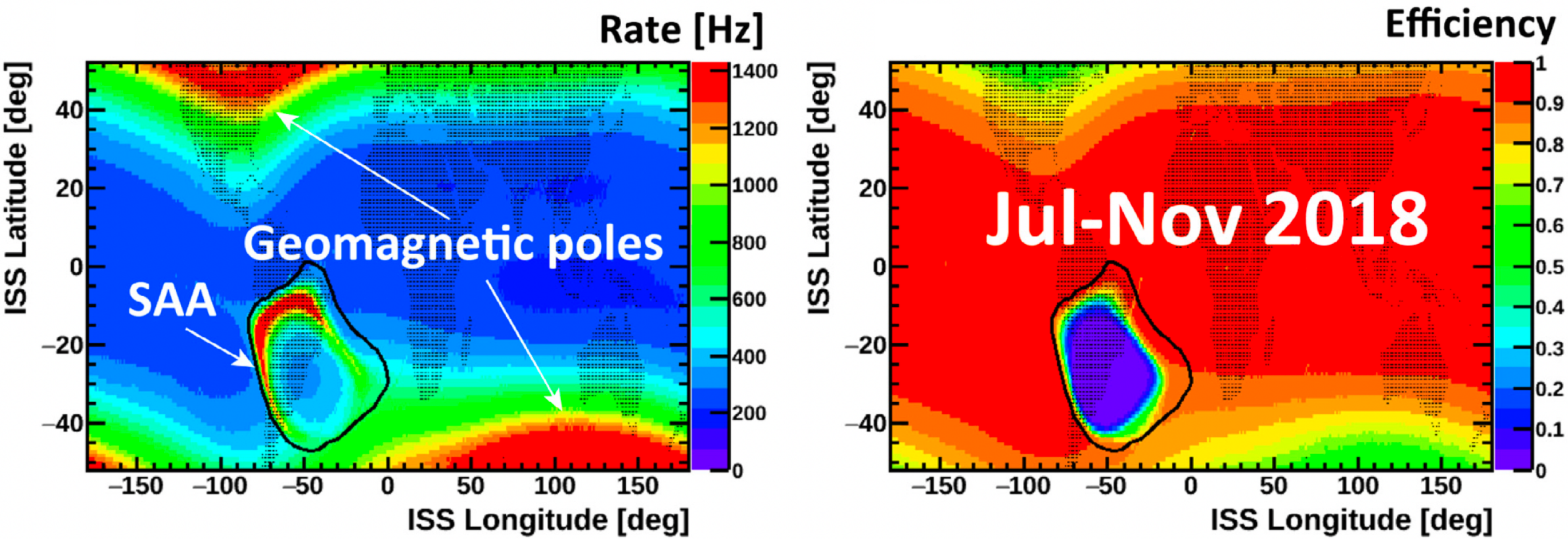
Particles Trapped in the Magnetosphere



Particles **trapped** in the Earth magnetic field create regions of **high radiation** called **Van Allen belts.** The ISS crosses one of the belts over South America, causing a sudden increase of the observed radiation known as the **South Atlantic Anomaly.**

The SAA as Seen by AMS

Incoming particle rate at the poles and in the SAA is high.
This causes low collection efficiency, mostly in the inner part of the SAA.
However, the efficiency is high on the external sides of the SAA.



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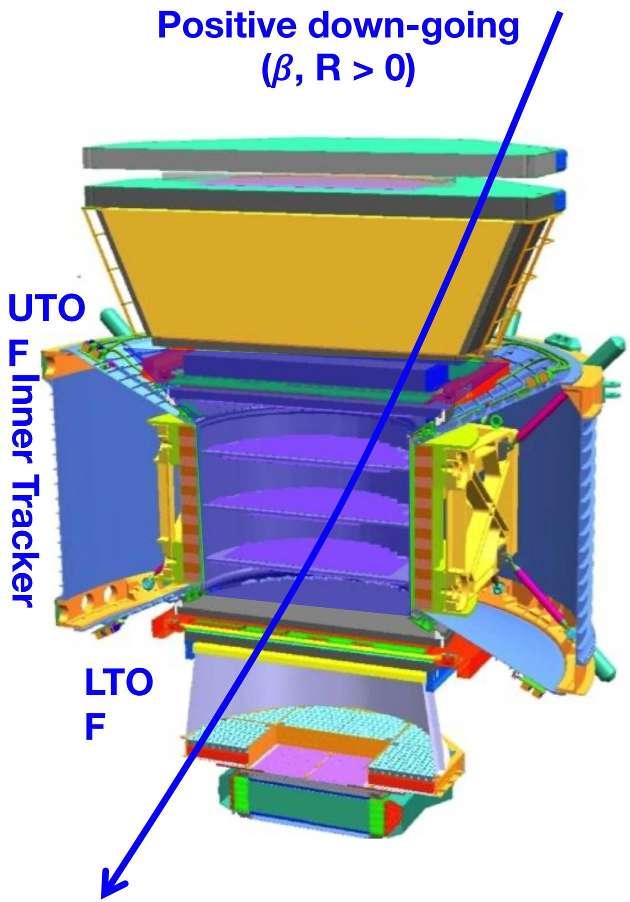
Energetic particle with charge up to 2 are known to exist in this region.
While there is no previous observation of energetic (R>1GV) Z>2 particles inside SAA.

Event Selection

Since trapped particles are expected to enter from all directions, the analysis is performed in the largest field of view (defined by inner tracker) and all available directions including both **down-going** and **up-going** events.
Only nuclei with **Z>2** considered.

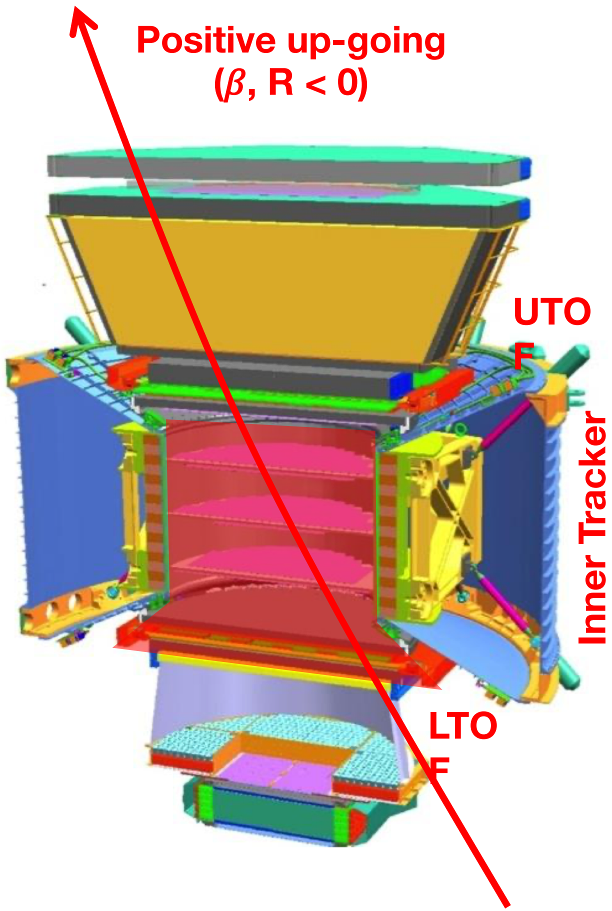


Velocity, β, and direction
measured with TOF
($\Delta\beta\approx1\%$ at $\beta=1$ and $Z=6$).

Rigidity, $R=p/Z$, and charge sign
with Inner Tracker
($\Delta R/R\approx10\%$ at $R=2$ GV).

Charge identification, Z,
with Inner Tracker ($\Delta Z/Z\approx2\%$ for $Z=6$) and **UTOF** or **LTOF**
($\Delta Z/Z\approx4\%$ for $Z=6$).

Mass identification, m,
by combination of β and R.

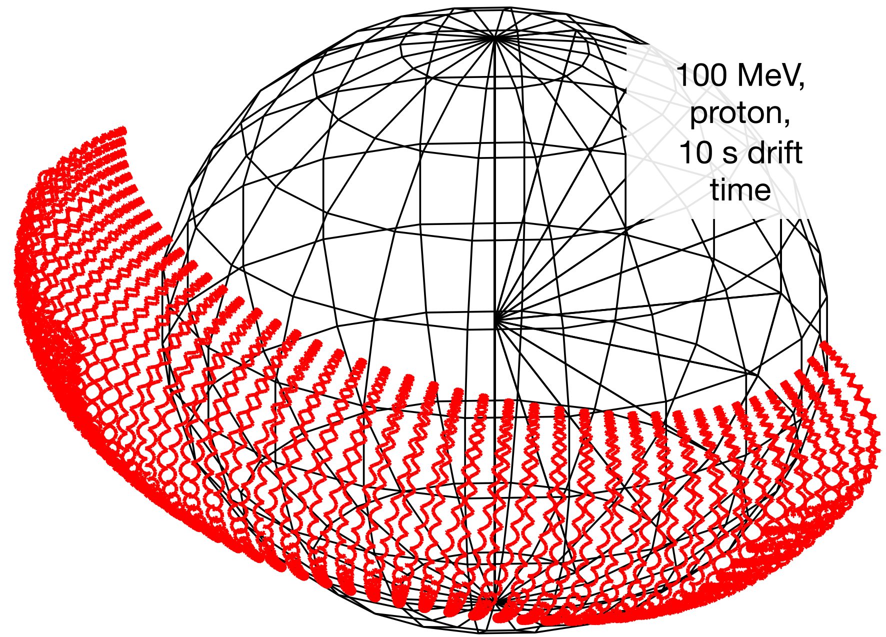


Backtracing Algorithm

Backtracing is used to understand the **origin** of the particle.
It consists in propagating the particle backwards in time in the Earth's magnetic field.

Relativistic Lorentz equation of motion

$$\begin{cases} \dfrac{\mathrm{d}\vec{x}}{\mathrm{d}t} = \dfrac{\vec{p}c}{E} \\[2ex] \dfrac{\mathrm{d}\vec{p}}{\mathrm{d}t} = \dfrac{qc^2}{E}\vec{p} \times \vec{B} \end{cases}$$



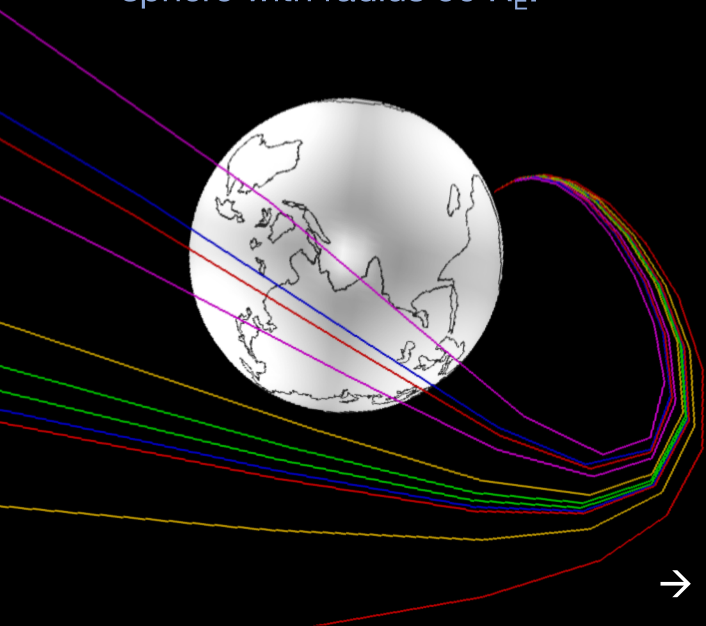
Earth's magnetic field modelized using IGRF-13.
Integration using adaptive Runge-Kutta-Fehlberg 7(8) integration ($\Delta t \ll \tau_G = 2\pi E/qB$).

Backtracing of the Selected Sample

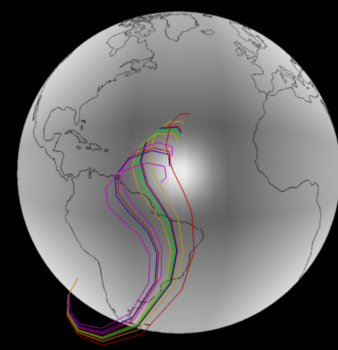
Selected particles are backtraced. To avoid tracing instabilities and measurement systematics, the procedure is repeated several times variating:

- Arrival direction with a spread of $\Delta\vartheta = 0.2°$;
- Rigidity with a resolution of $\Delta R/R = 10\%$, and for several points at lower R to detect penumbra;
- Coordinate evaluation width a time spread of $\Delta t = 50$ ms.

Primary**:** the particle intersects in finite time a sphere with radius 50 R_E.



Secondary: if intersects Earth's atmosphere set at 100 km from ground.

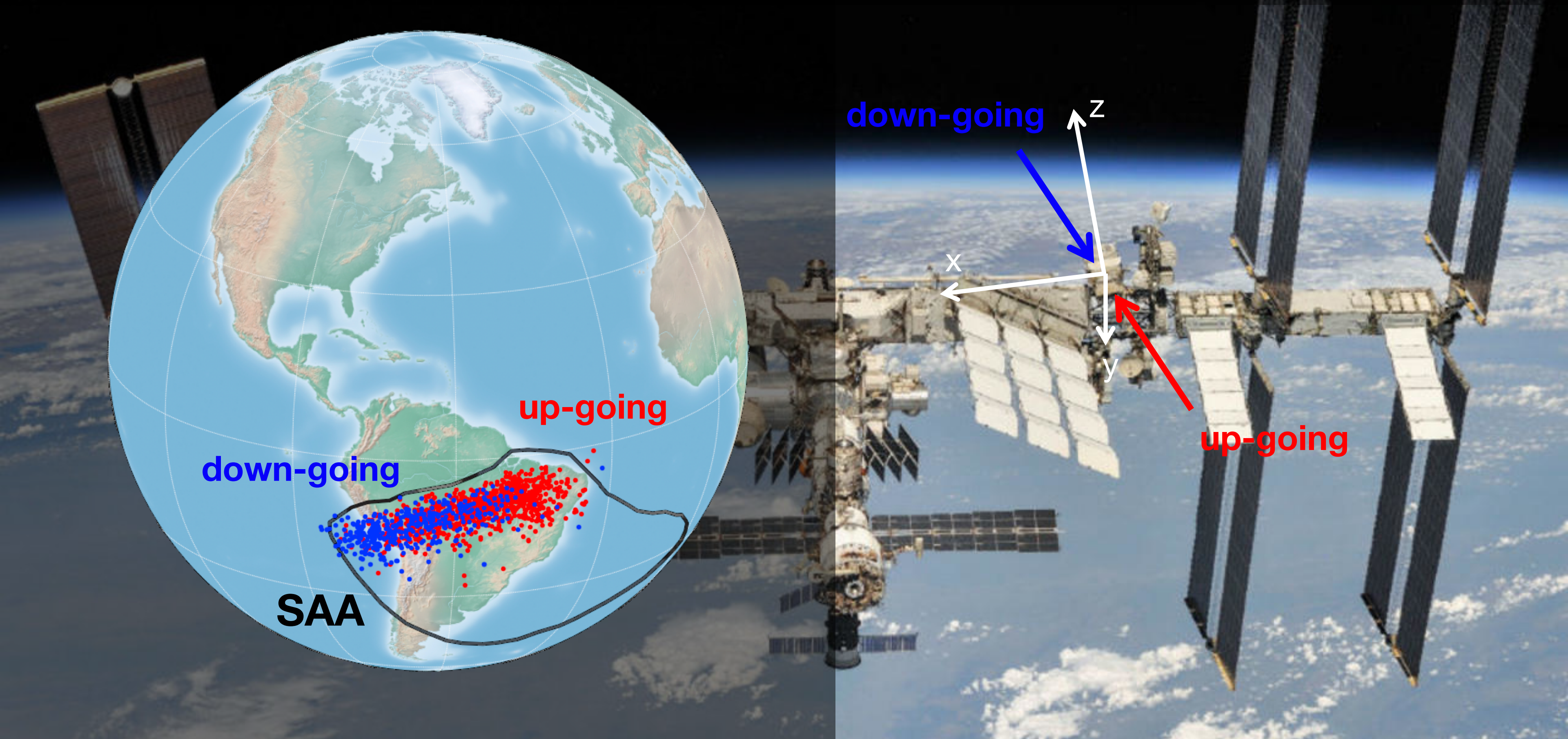


Stably-Trapped: trajectory exceeding maximum number of laps around the Earth (10).

→ Backtracing samples verified against GeoMagSphere (MiB) backtracing.

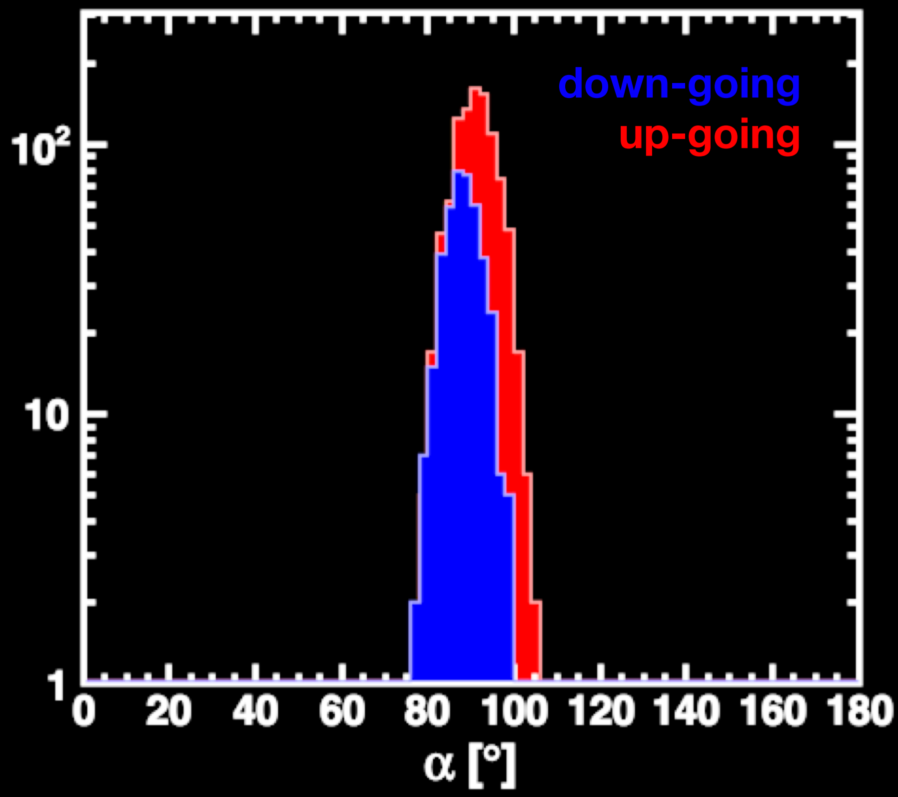
Stably Trapped Nuclei in the SAA

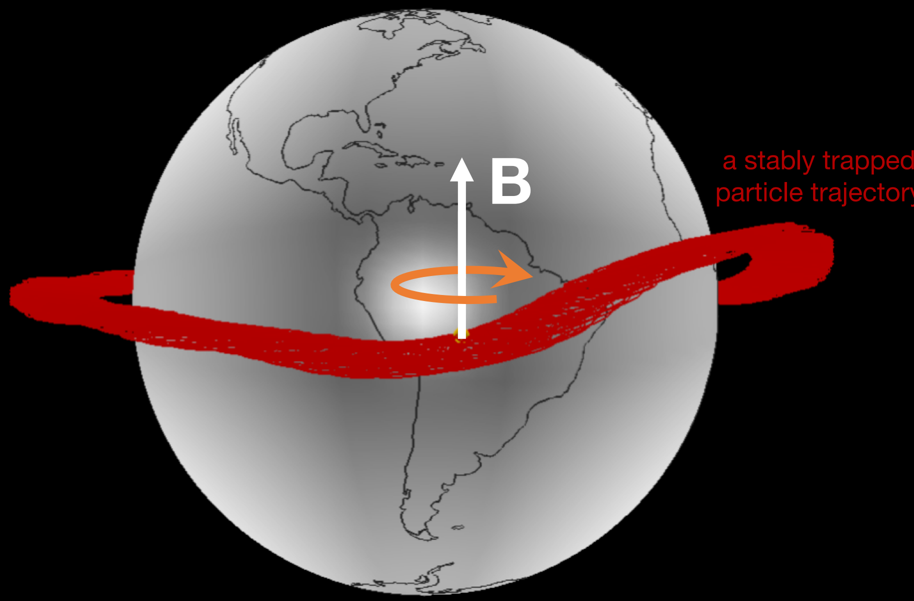
Backtracing allows to select particles stably-trapped in Earth's magnetosphere.
A clear population of stably trapped ions (Z>2) entering in AMS
both from the **top** and the **bottom** has been identified.



Stably Trapped Nuclei: Pitch Angle

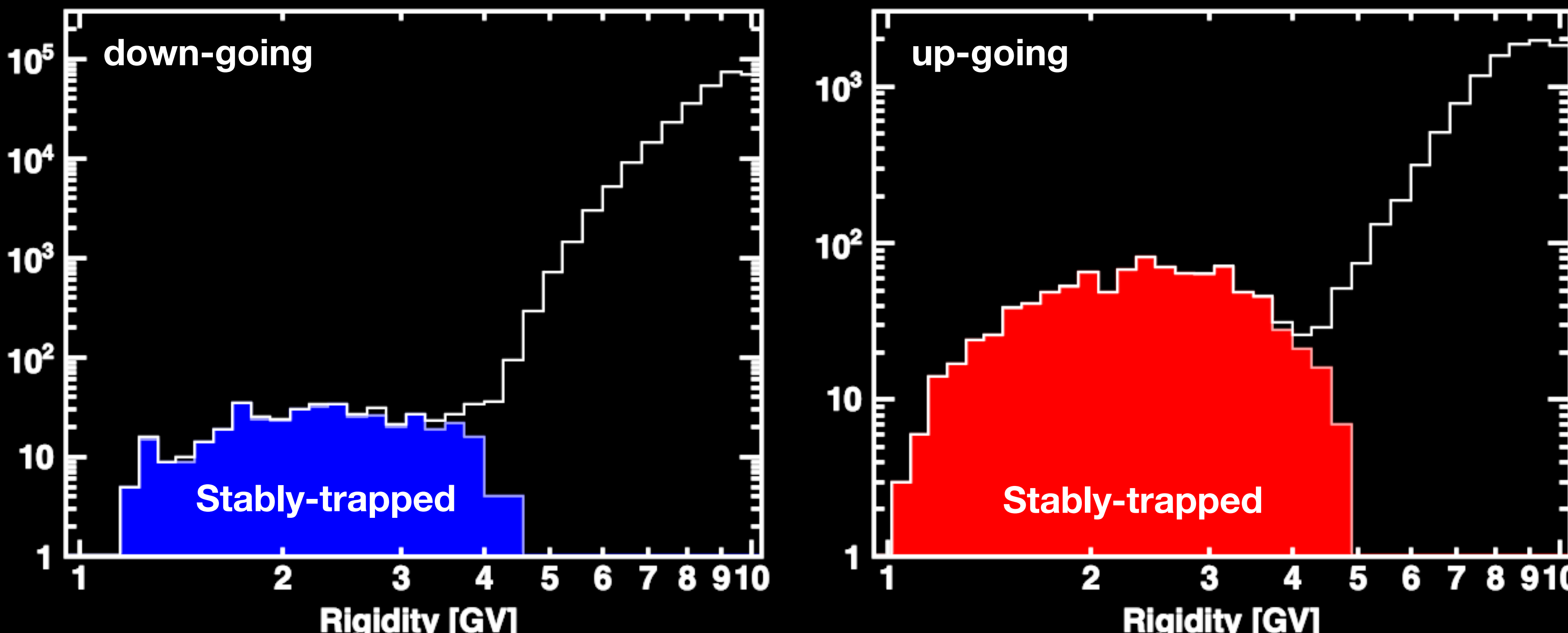
Pitch angle is the angle between particle and magnetic field.
All stably-trapped ions have a pitch angle of about 90°.





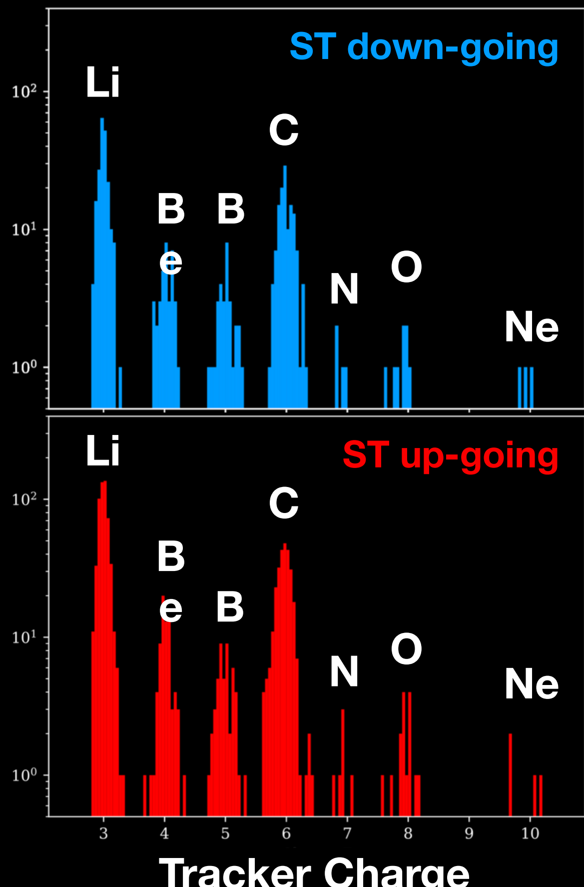
Stably Trapped Nuclei: Rigidity Distribution

Selecting North SAA ($-20<\vartheta_M<10$, $-10<\varphi_M<50$).
Rigidity spectra extends from 1 to 5 GV.
These populations are below the geomagnetic cutoff.



Stably Trapped Nuclei: Chemical Composition

The chemical composition of up-going and down-going is similar.
The charge distribution of stably trapped nuclei and GCRs is different (Li>C>O, while in GCRs O~C>Li)



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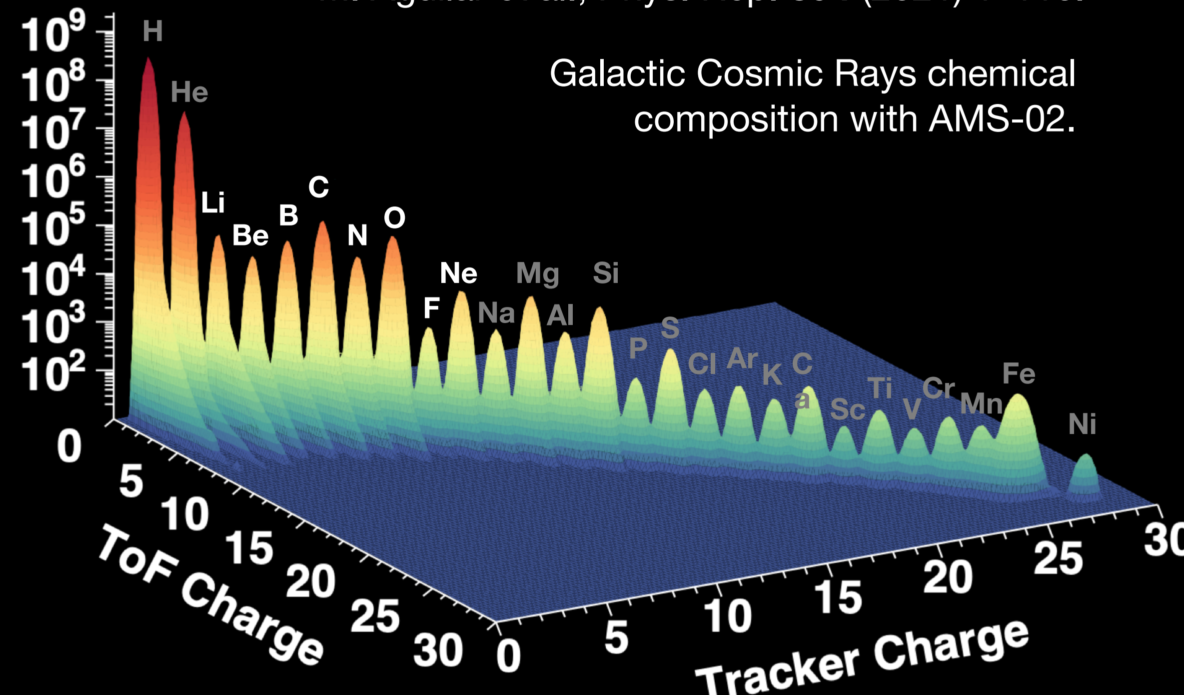
Galactic Cosmic Rays chemical composition with AMS-02.

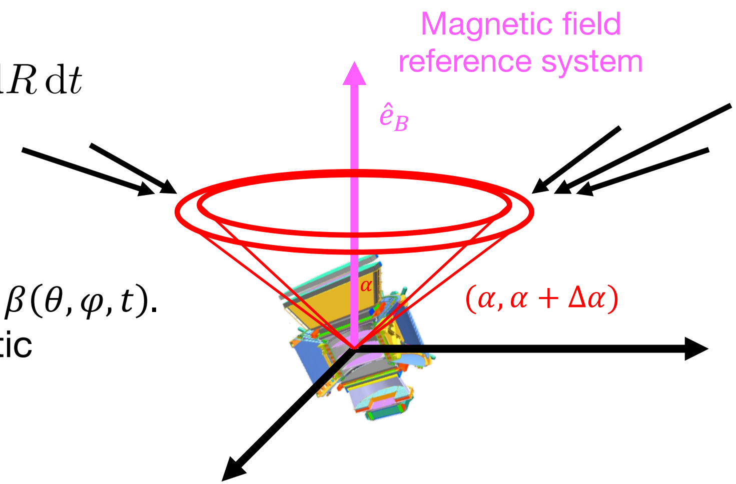


Directional Flux

Flux of particles in SAA is highly anisotropic.
We assume that trapped nuclei in SAA have similar pitch angle α (mainly from $\alpha \sim 90°$).
The flux can be provided as function of rigidity and α.

differential acceptance — solid angle

$$N(R, R+\Delta R) = \int_{t_0}^{t_0+T} \int_{R}^{R+\Delta R} \int_{\Omega} A(R,\omega)\, \Phi(R,\omega)\, \mathrm{d}\omega\, \mathrm{d}R\, \mathrm{d}t$$



For each data-taking second we can get the field orientation $\hat{e}_B$.
We can rotate to get the mag. field coord. $\alpha = \alpha(\theta, \varphi, t)$ and $\beta = \beta(\theta, \varphi, t)$.
Then we integrate the differential acceptance around the magnetic azimuthal angle β (that we are not interested on):

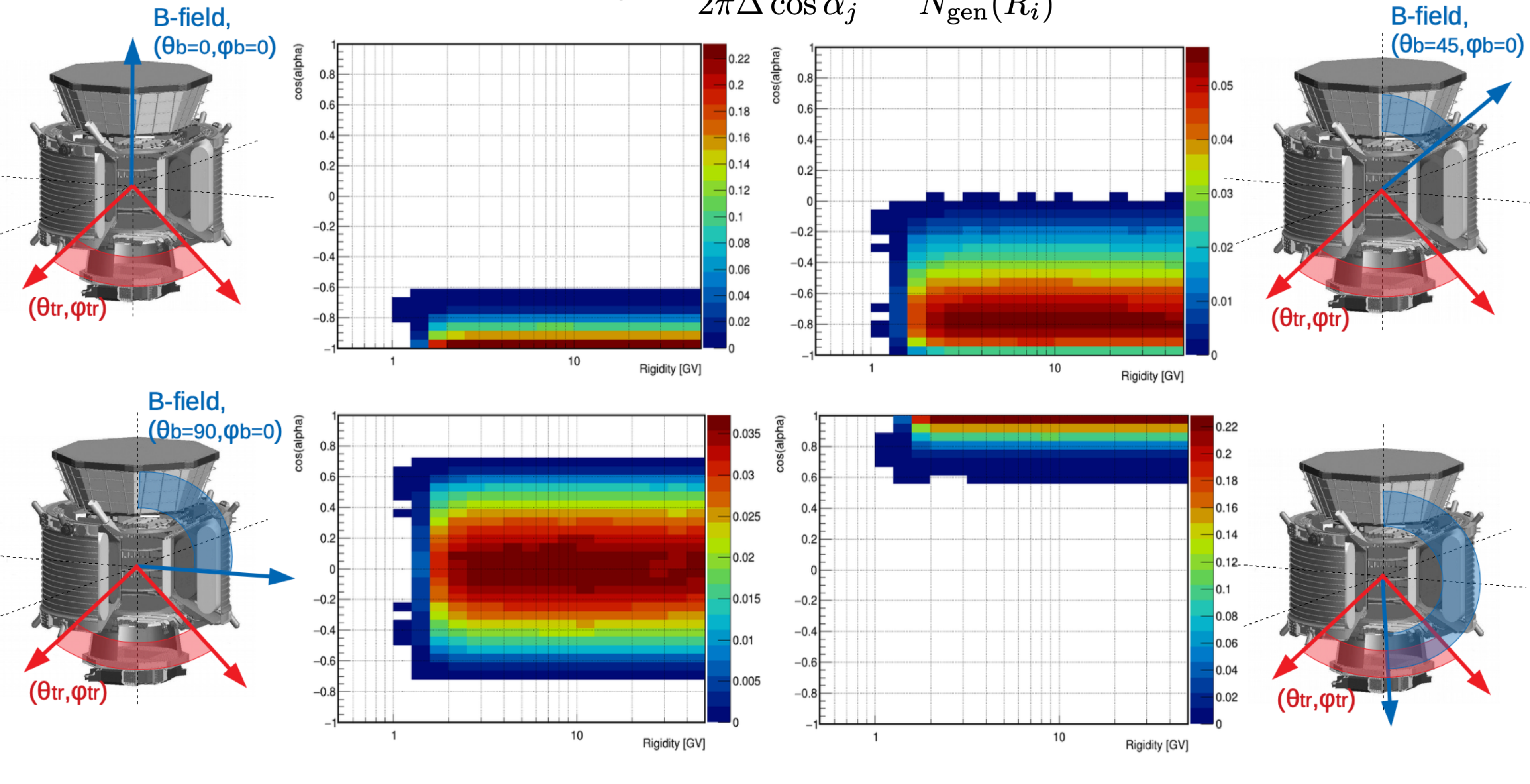
$$N(R+\Delta R, \cos\alpha + \Delta\cos\alpha) = \int_{R}^{R+\Delta R} \int_{\cos\alpha}^{\cos\alpha+\Delta\cos\alpha} \mathcal{E}(R,\cos\alpha)\, \Phi(R,\cos\alpha)\, \mathrm{d}\cos\alpha\, \mathrm{d}R$$

$$\mathcal{E}(R,\cos\alpha) = \int_{t_0}^{t_0+T} \int_{0}^{2\pi} J\left(\frac{\mathrm{d}\cos\theta, \mathrm{d}\phi}{\mathrm{d}\cos\alpha, \mathrm{d}\beta}\right) A(R,\cos\alpha,\beta)\, \mathrm{d}\beta\, \mathrm{d}t$$

Exposure [m^2 rad s]

Acceptance Calculation for Downgoing Carbon

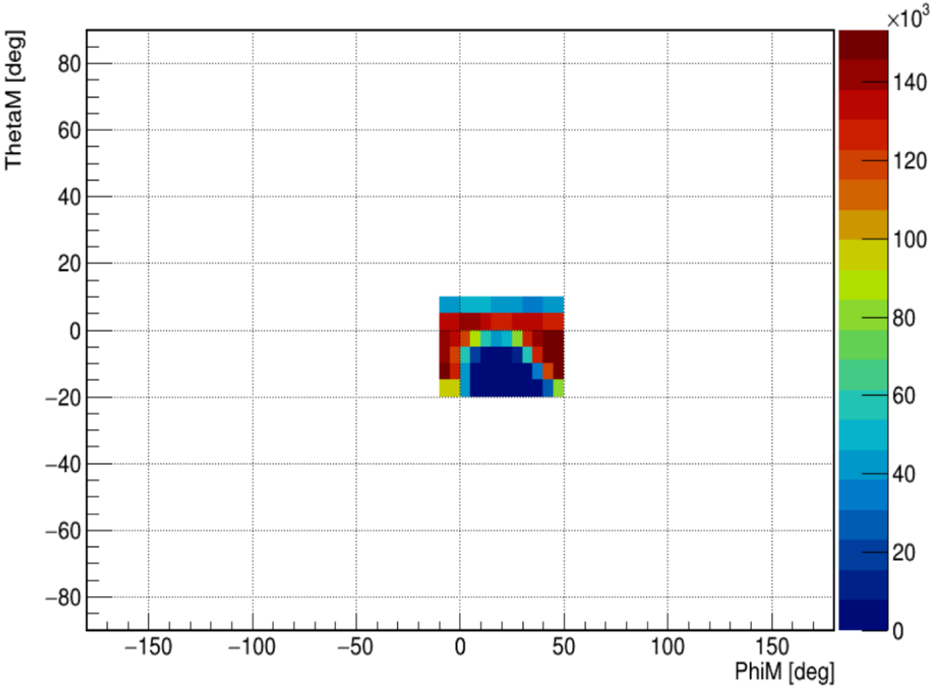
$$A(R_i, \cos\alpha_j) = \frac{A_{\text{gen}}}{2\pi\Delta\cos\alpha_j}\frac{N_{\text{acc}}(R_i, \cos\alpha_j)}{N_{\text{gen}}(R_i)}$$

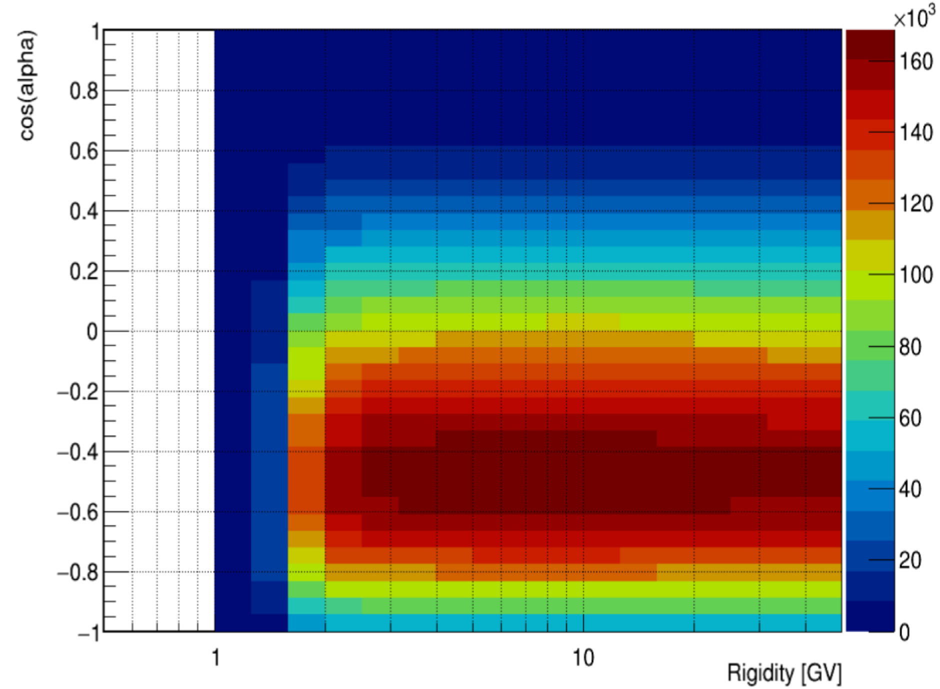


Exposure for Downgoing Carbon in SAA

Exposure time in considered cell [s]

$$\mathcal{E}(R, \cos\alpha) = \int_{t_0}^{t_0+T} \int_0^{2\pi} J\left(\frac{\mathrm{d}\cos\theta, \mathrm{d}\phi}{\mathrm{d}\cos\alpha, \mathrm{d}\beta}\right) A(R, \cos\alpha, \beta)\,\mathrm{d}\beta\,\mathrm{d}t$$

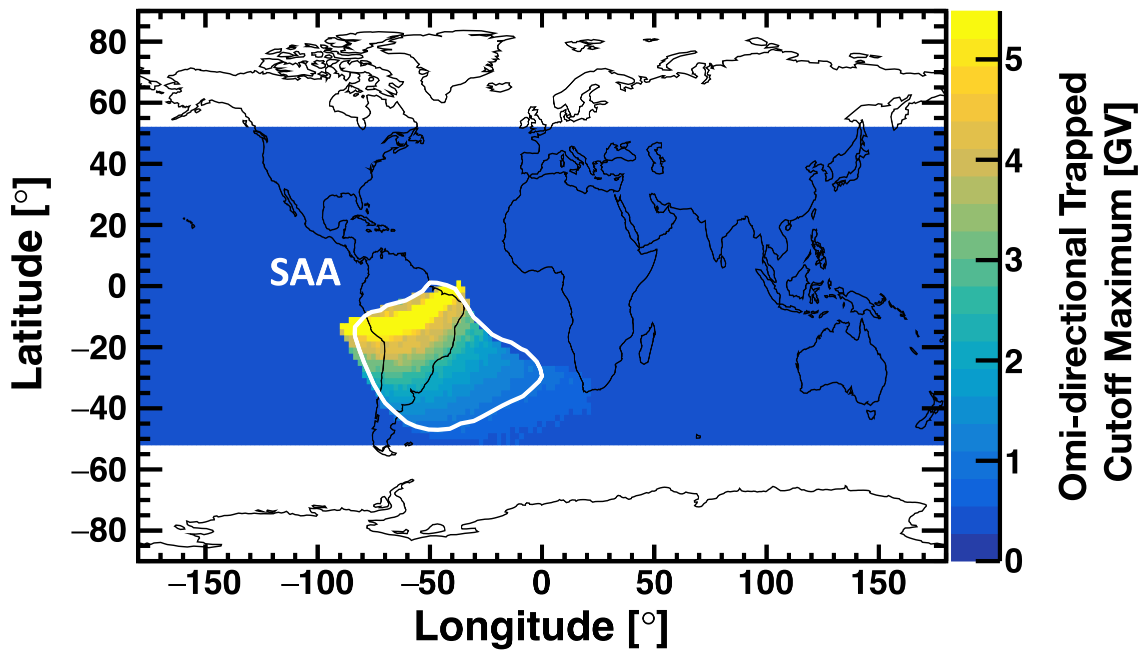


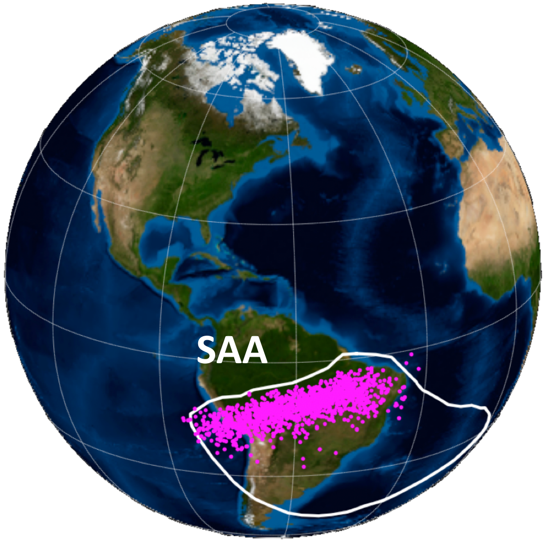


→ Flux verification using particles above cutoff, expected independent from α.

Status and Perspectives

- 10 years of AMS-02 data have been used to look for ions with Z>2 below geomagnetic cutoff.
- A **stably trapped** population has been clearly identified below 5 GV in the SAA region.
- This population has properties (rigidity, charge, arrival direction) distinctly different from GCRs.
- In the process of calculating the directional flux (however very few events …).





→ Use pass8 NAIA to produce backtrackings inside SAA (which particles?).
→ Use the guiding center approximation?
→ Use maximum trapped cutoff?