Measurement of cosmic Li, Be, B energy spectra with DAMPE and R&D activity for HERD

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End of year report
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Contents

Li-Be-B analysis with DAMPE:

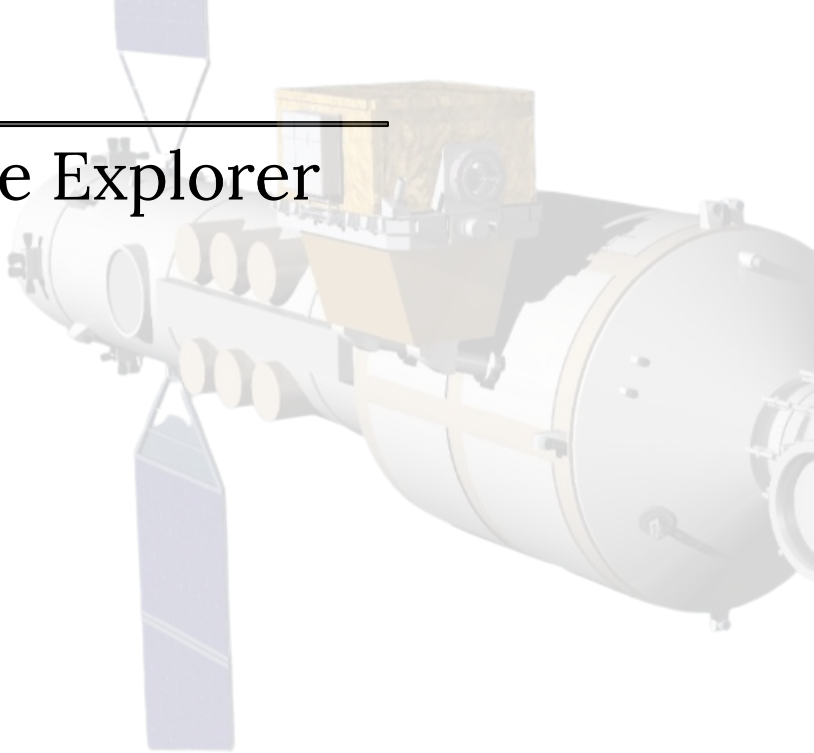
- Secondary cosmic rays
- CR direct detection in space with DAMPE
- Analysis on Lithium spectrum

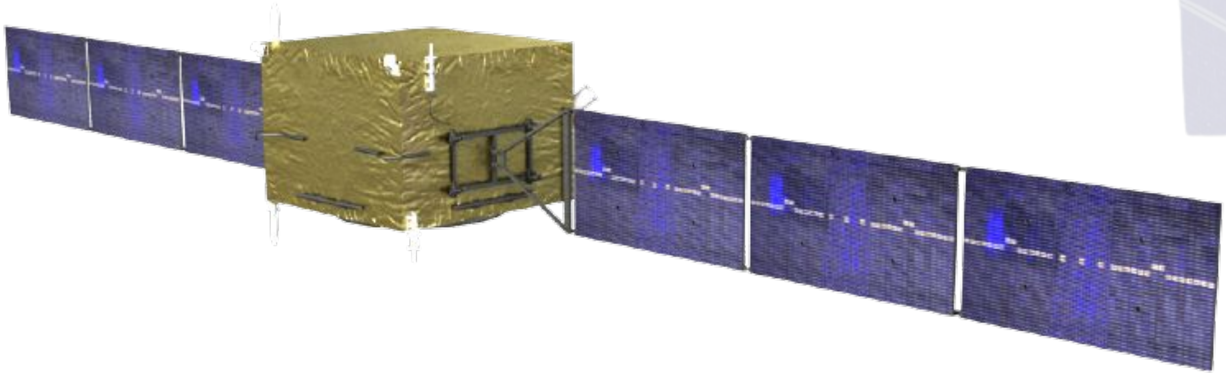
Study of light propagation in HERD PSD bars:

- The HERD mission
- GEANT4 based simulation of the Plastic Scintillator Detector
- Comparison study between rectangular and trapezoidal PSD bars

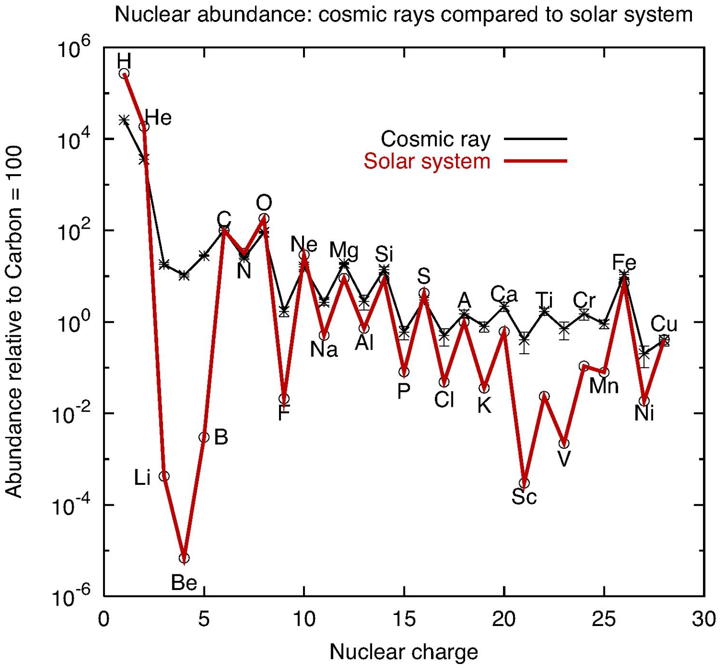
DAMPE

DArk Matter Particle Explorer





Secondary Cosmic Rays



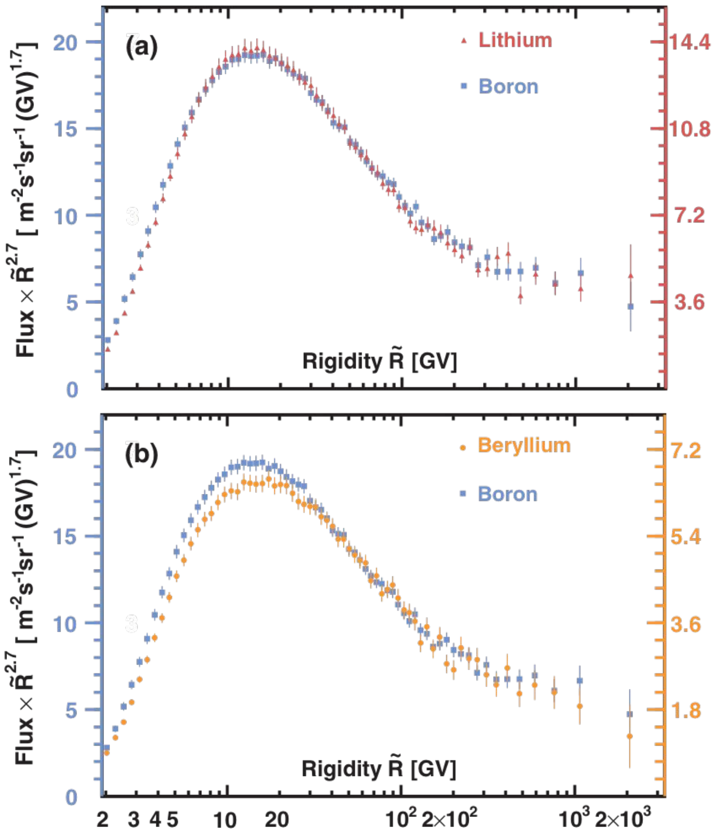
Li, Be and B:

- Lithium, Beryllium and Boron (***secondaries***) are not produced in main stellar nucleosynthesis reactions
- Abundances of Li, Be, B are much higher in Cosmic Rays (CRs) than in the solar system
- Production: **cosmic ray spallation** with the ISM Mainly from C, O (***primaries***)

CR propagation:

- Measuring the flux of secondaries can offer insight into:
  - Mechanisms of CR propagation
  - Origin of structures in the primaries spectra

Current measurements



AMS-02:

- Li, Be, B fluxes measured with first 5 years data
- Rigidity range: 1.9 GV - 3.3 TV
- Identical rigidity dependence over 30 GV
- Hardening at 200 GV observed in all three nuclei
- Rigidity dependencies of primaries and secondaries are significantly different

New highlighted CR properties.

Extend measurement to higher energies.

The DAMPE mission

Launched in December 2015

- Sun-synchronous orbit
- Altitude: 500 km
- Payload: 1400 kg

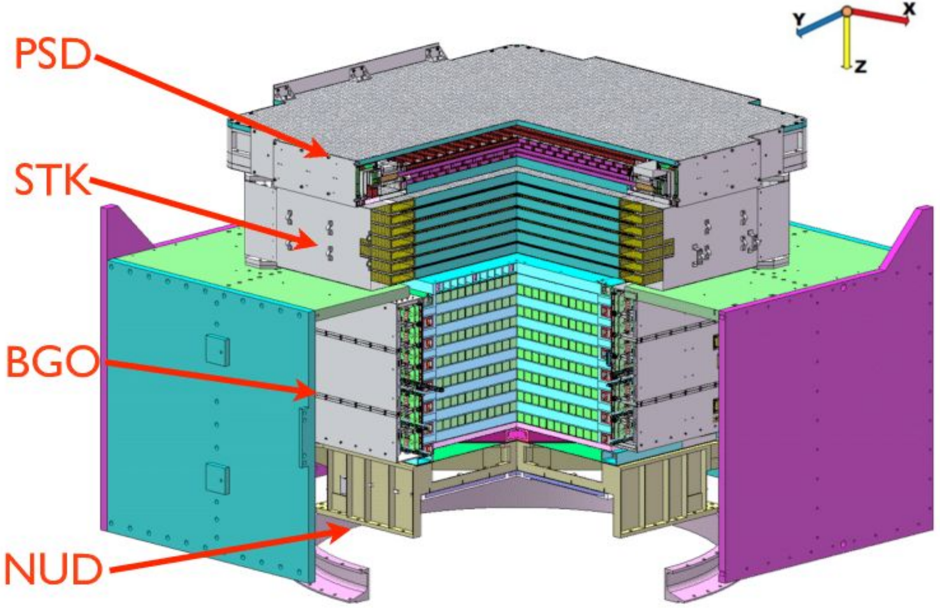
Collaboration:

- China
- Italy
- Switzerland

Science goals:

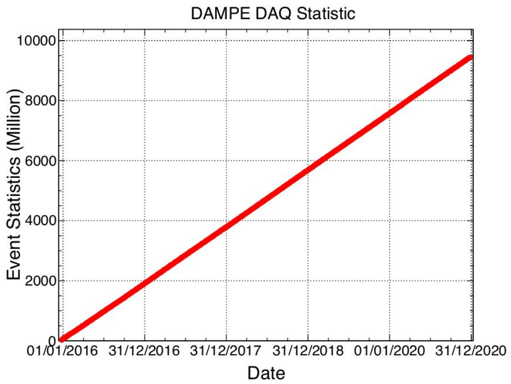
- Cosmic all-electron spectrum
- <u>**Cosmic protons and nuclei: spectrum and composition**</u>
- High energy gamma-ray astronomy
- Gamma-ray line search
- … “unexpected” such as gamma-ray transients for multi-messenger astronomy

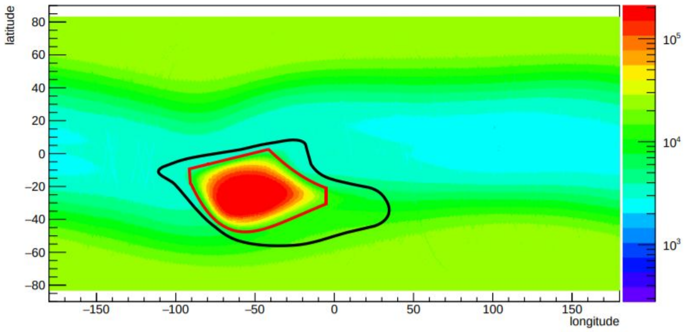
The DAMPE detector



- **Plastic Scintillator Detector (PSD):**
  - 2 X/Y planes of scintillator bars
  - Charge measurement + Gamma-ray ID
- **Silicon Tracker (STK):**
  - 6 Si planes + W converter
  - Tracking + Additional charge measurement
- **BGO calorimeter (BGO):**
  - 14 layers of BGO bars (32 X_0)
  - Energy measurement + e/p separation
- **Neutron detector (NUD):**
  - 4 tiles of boron loaded scintillator
  - Further e/p separation

Event selection





60 months of orbital flight data (2016-2020)

MC ^{7}Li sample 10 GeV-100 TeV

Preselection:

- Dead time (SAA, instrumental dead-time, calibration)
- Good event reconstruction
- Avoid geomagnetic cutoff effect

Trigger:

- High energy trigger: energy deposit > 10 MIPs in each hit bar of the first 3 BGO layers

Good quality track selection

+ **Specific selection for Lithium**

PSD charge measurement

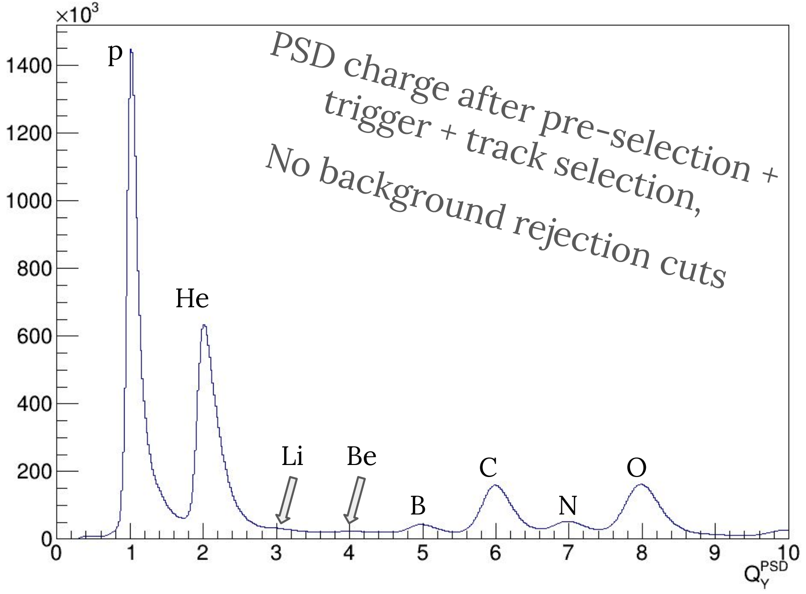
- Absolute value of the incoming CR charge can be estimated through the energy deposit in the PSD.
- Define PSD charge variables to take into account that there can be hits in 2, 3 or 4 layers.
- Request at least one signal in plane Y and in plane X.

- Define a charge for each PSD plane as:

$$Q_Y^{PSD} = \frac{isY0 \times Q_{Y0}^{PSD} + isY1 \times Q_{Y1}^{PSD}}{isY0 + isY1}$$

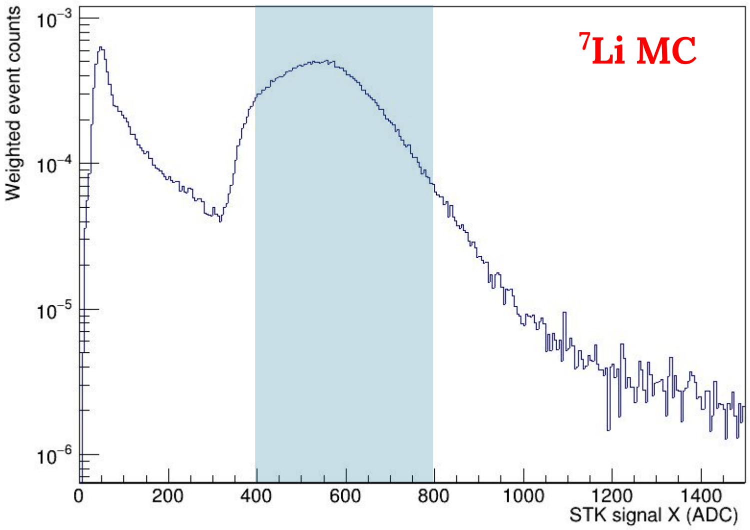
$$Q_X^{PSD} = \frac{isX0 \times Q_{X0}^{PSD} + isX1 \times Q_{X1}^{PSD}}{isX0 + isX1}$$

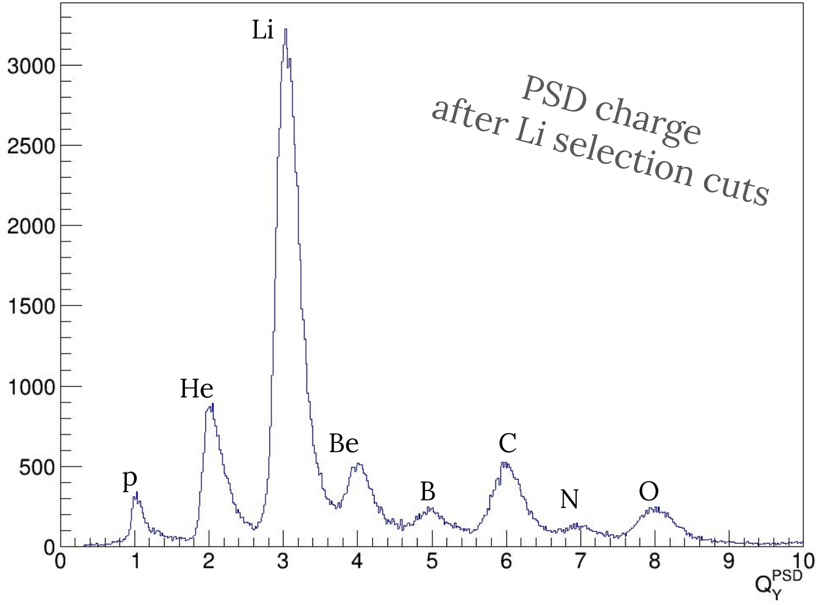
- **Lithium completely hidden under proton and Helium peaks**
- No background rejection cuts applied yet



Li selection: STK signal

- **Li selection**: use energy deposit in first STK plane (layers along X and Y) to reject p and He background.
  - 400 ADC < STK signal X and Y < 800 ADC -> **specific to Li**
  - Excellent background suppression, Li peak clearly visible



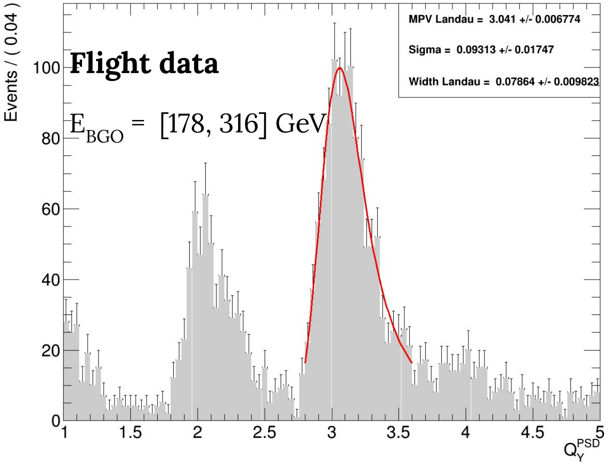


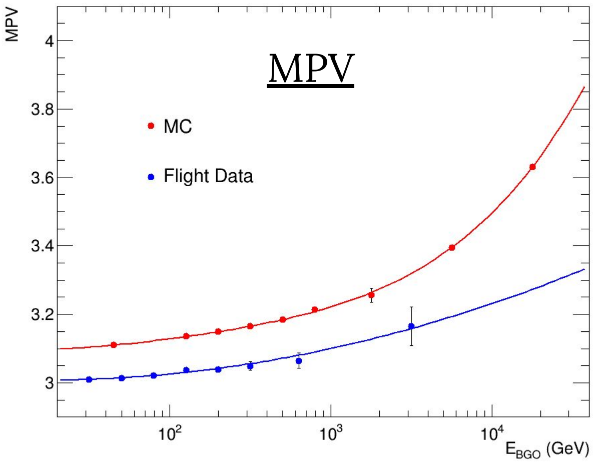
Li selection: PSD signal

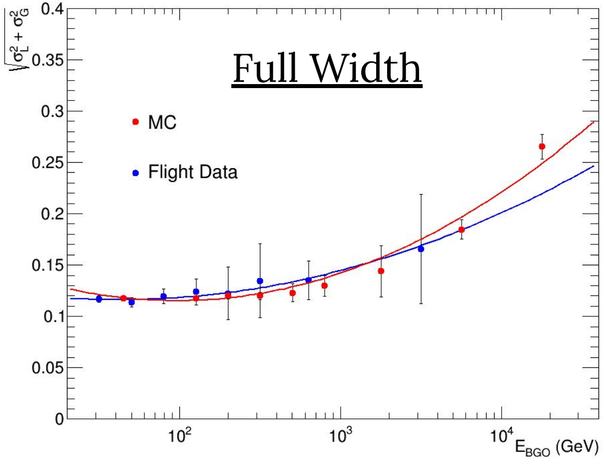
For both flight data and MC:

- Fit PSD **Li charge peak** for different E_{BGO} bins with Landau distribution convoluted with a Gaussian
- Fit MPV and Full Width = $\sqrt{(\sigma_L^2 + \sigma_G^2)}$ as a function of E_{BGO} with log-polynomial functions

PSD charge smearing is applied to reach agreement between MC and data.



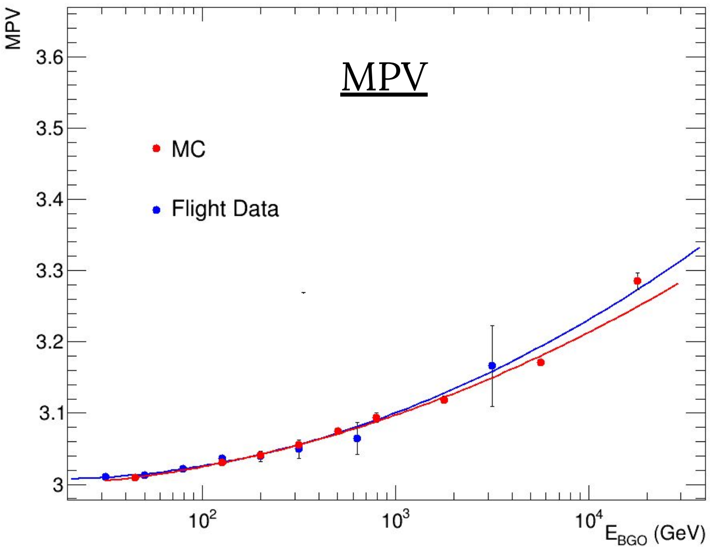


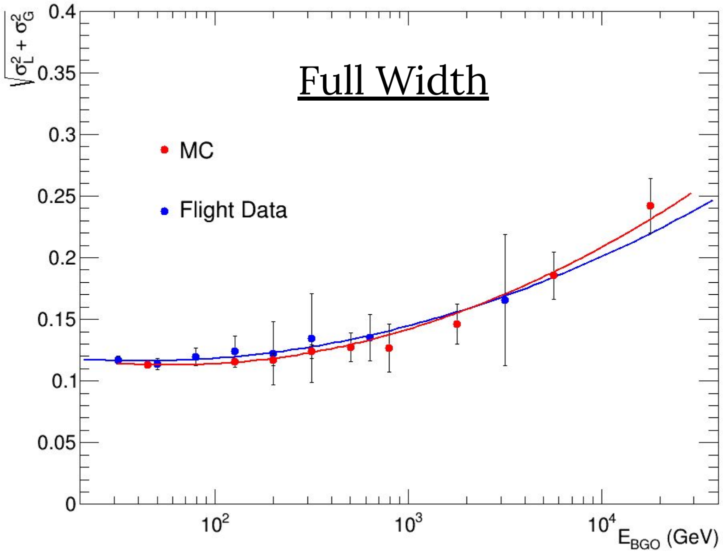


PSD charge smearing

- Correct MC PSD charge using log polynomial functions:

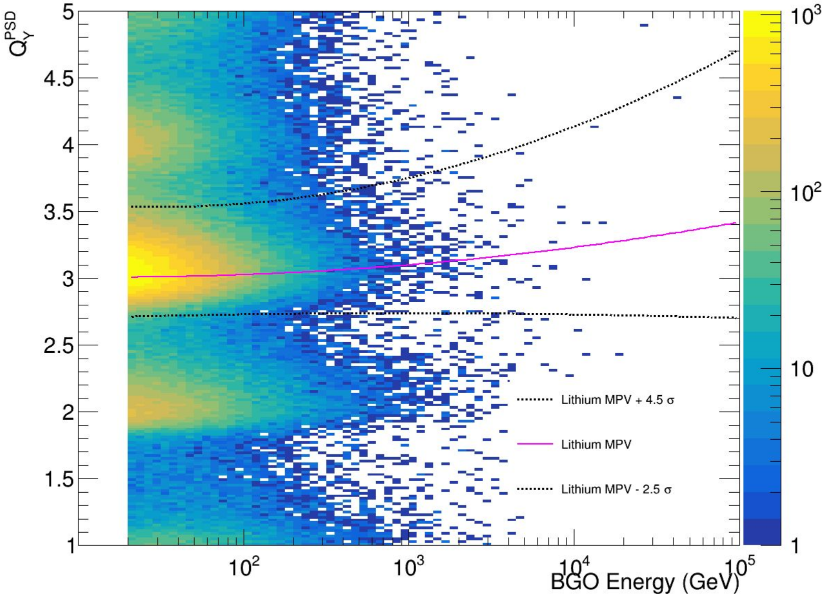
$$Q^{PSD}_{corr} = (Q^{PSD} - f^{MC}_{MPV}(E_{BGO})) \cdot \frac{f^{FD}_{FullWidth}(E_{BGO})}{f^{MC}_{FullWidth}(E_{BGO})} + f^{FD}_{MPV}(E_{BGO})$$



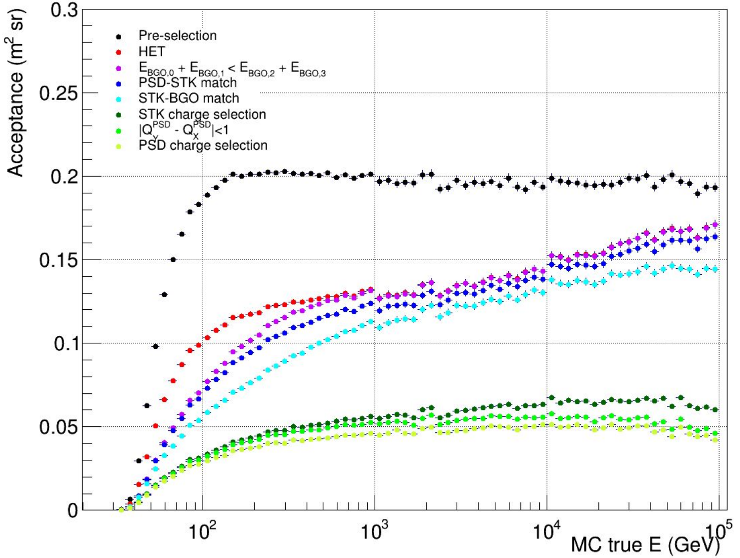


Good agreement between flight data and MC after the charge smearing correction.

Li selection: PSD signal (2)



<u>*Overall acceptance estimated from ^{7}Li MC*</u>



Define PSD charge selection for Li with functions obtained from fitting:

$$f_{MPV}(E_{BGO}) - 2.5 \times f_{FW}(E_{BGO}) < Q^{Y/X}_{PSD} < f_{MPV}(E_{BGO}) + 4.5 \times f_{FW}(E_{BGO})$$

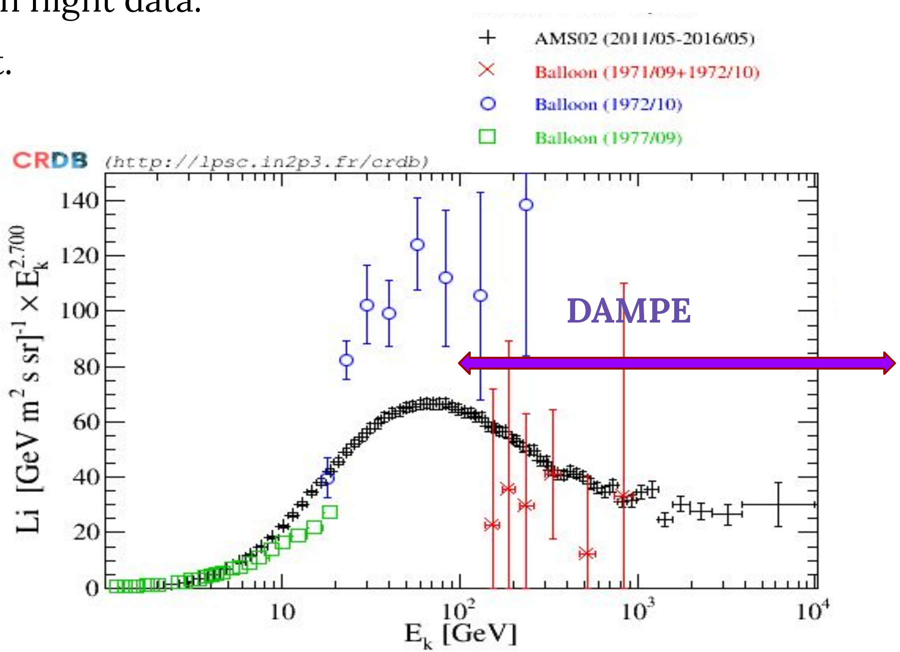
Sample selection is completed, acceptance can be estimated from MC.

Future prospects on Li, Be, B

- Validate MC estimated acceptance with flight data.
- Estimate background with template fit.
- Evaluate systematic contributions.
- Conduct similar analysis for Be, B.

DAMPE aim for Li spectrum:

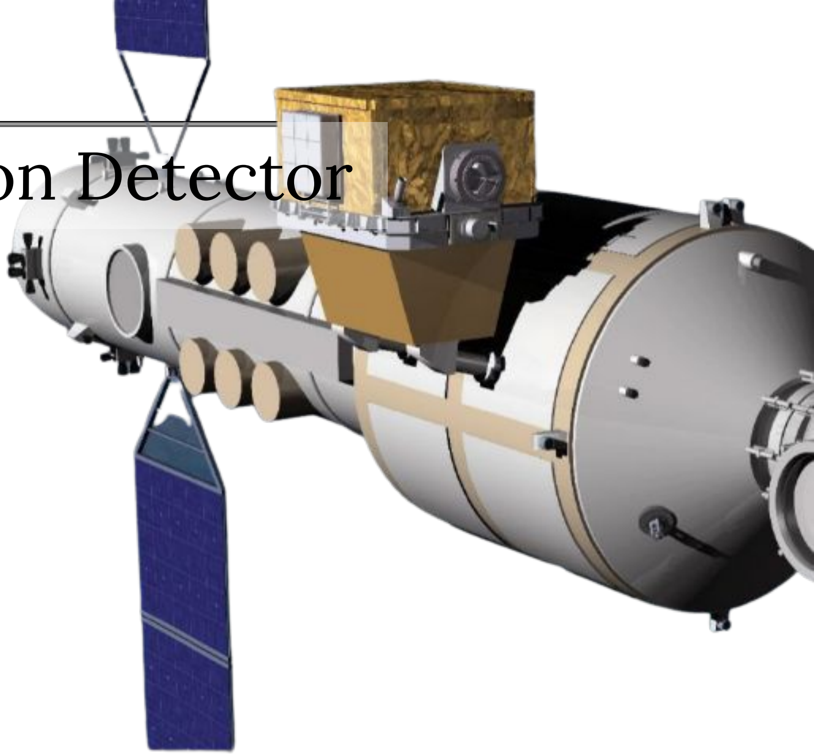
100 GeV - 30 TeV

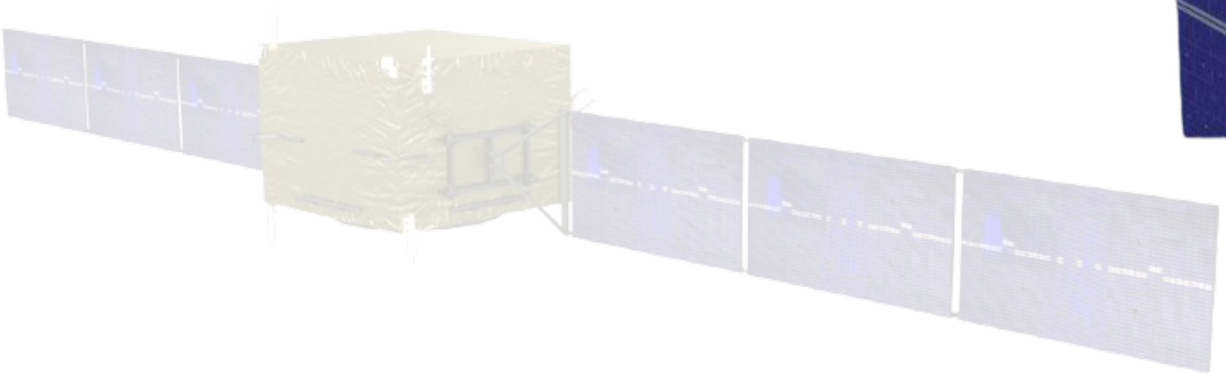


Final aim is to have a spectrum measurement of cosmic Lithium, Beryllium and Boron extending current AMS02 measurements to higher energies.

HERD

High Energy Radiation Detector





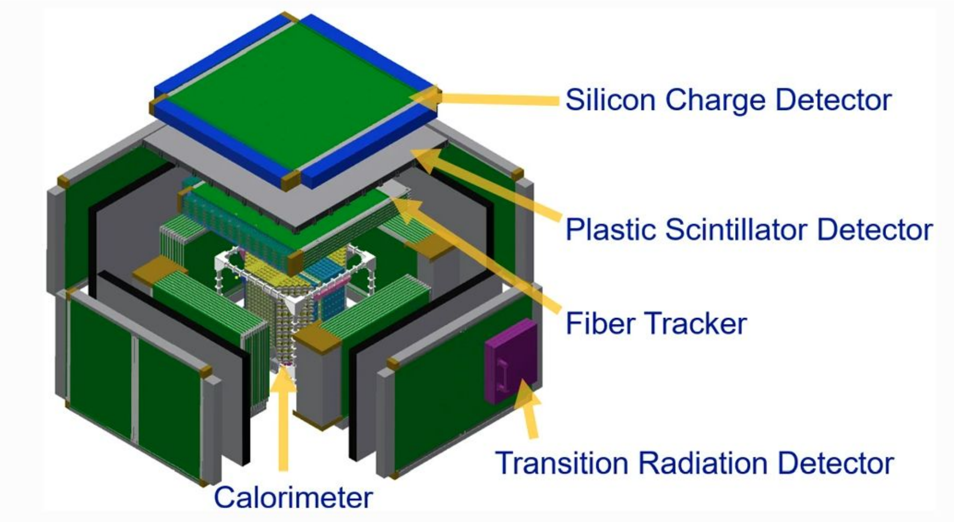
The HERD mission

Detector to be installed on CSS around 2027

- International collaboration between China, Italy, Switzerland and Spain

Science goal:

- Push CR direct detection to the highest energies
- Reach the knee with direct measurement



Detector: 3D design concept

Lifetime	> 10 yr
FoV	± 70°
Geom. Factor (e)	> 3 m^2 sr at 200 GeV
Geom. Factor (p)	> 2 m^2 sr at 100 GeV

The HERD PSD

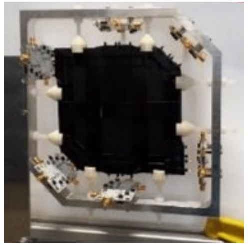
PSD : highly segmented plastic scintillator detector with SiPM-based readout

- Anti-coincidence for gamma-ray detection
- Particle identification for cosmic nuclei
- Two possible geometrical designs: tiles and bars

Solution under study at GSSI / LNGS

Square Tiles

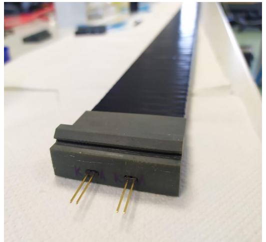
10 x 10 cm^2 tiles, SiPMs possibly an all sides.



- Higher segmentation: reduce backscattering issue.
- Large number of readout channels and higher power consumption, more complicated mechanical instrumentation.

Bars

~150 cm long bars in X and Y layers, SiPMs readout at both ends.



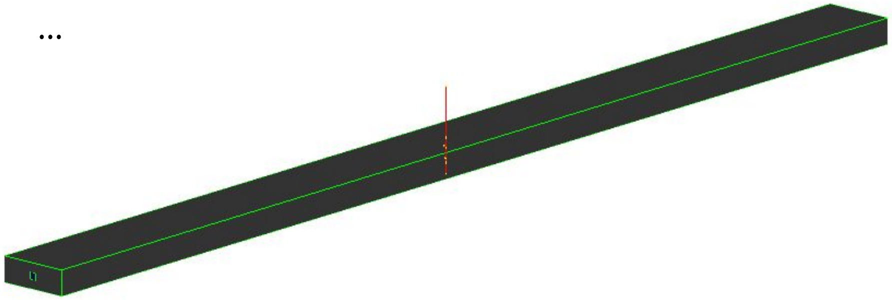
- Lower number of readout channels.
- Light attenuation, more problematic backscattering.

A standalone PSD simulation

***Simulations of the PSD bars** are useful to optimize geometry, design and as a comparison to laboratory measurements.*

A highly customizable **GEANT4 based simulation** was used. Parameters include:

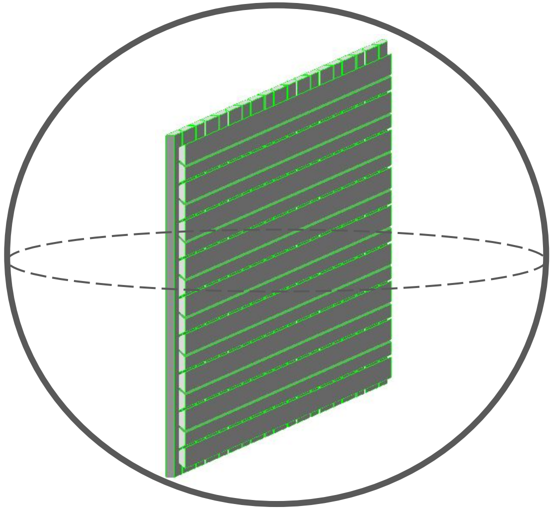
- Bar geometry (length, thickness, shape) and material
- Number and placement of readout SiPMs
- Wrapping material and thickness
- Impinging particle type, energy, direction
- ...



- When energy is released in the detector, scintillation **photons are produced and tracked** until they are absorbed
- SiPM readout simulated taking into account: PDE, crosstalk, dark count, ...

Trapezoidal bars

Hermeticity **:** *key PSD feature for the gamma ray anti-coincidence*

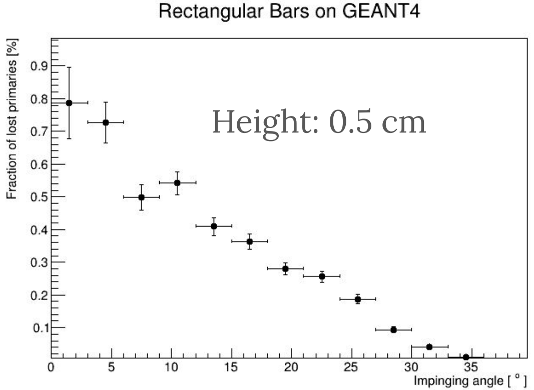


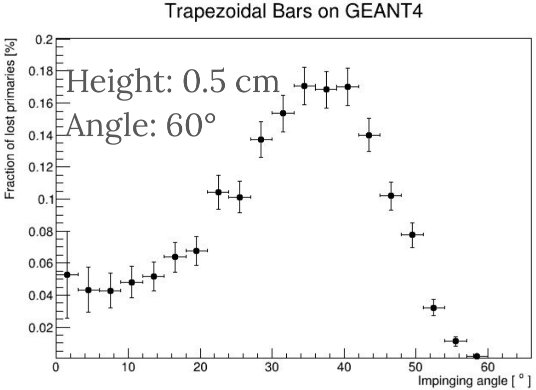
Compare hermeticity of arrays of rectangular and trapezoidal bars:

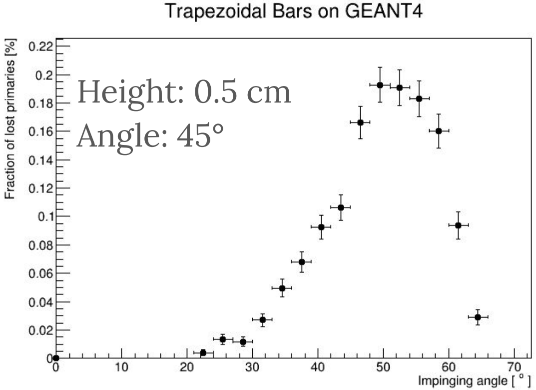
- Modify GEANT4 simulation source code to include trapezoidal geometry
- Generate particles on a **spherical surface** of surrounding the array, with isotropic inward direction .
- 100 GeV protons
- 10M events

Simulate different configurations. For each one count number of particles that pass through the gaps of both layers to estimate the hermeticity performance.

Trapezoidal bars: performance







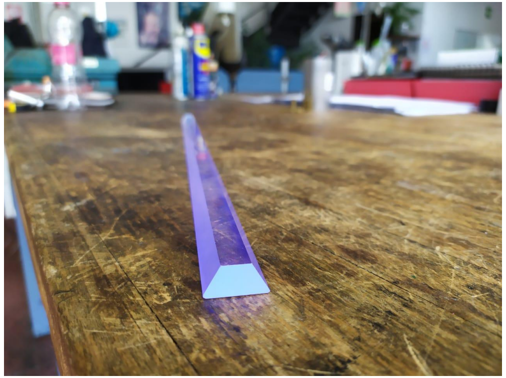
Look at particles that pass through the gaps as a function of the impinging angle.

Include HERD acceptance into results with help of a HerdSoftware simulation.

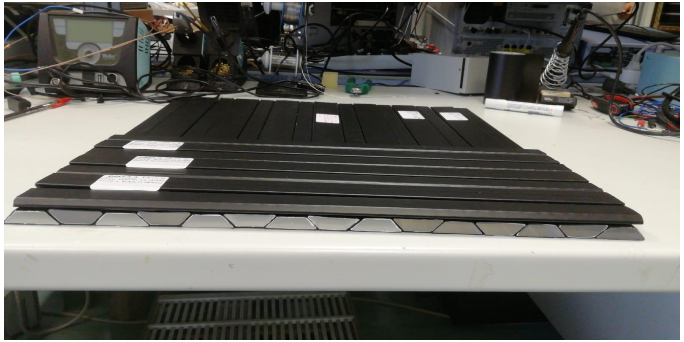
Layout	ε_{loss} **(%)**	ε_{loss} $wHerdSoftware$ **(%)**
Rect - 1 cm	**0.027 ± 0.001**	**0.045 ± 0.003**
Trap - 1 cm - 60°	**0.024 ± 0.001**	**0.032 ± 0.003**
Rect - 0.5 cm	**0.084 ± 0.002**	**0.148 ± 0.006**
Trap - 0.5 cm - 60°	**0.076 ± 0.002**	**0.108 ± 0.005**
Trap - 0.5 cm - 45°	**0.070 ± 0.002**	**0.054 ± 0.004**

HERD PSD simulations: future prospects

- Simulation results led to the choice of trapezoidal bars for the PSD prototype for their improved hermeticity properties.
- 2021 CERN test beam:
  - October, one week at SPS
  - November, one week at PS



- Future simulations will focus on:
  - Prototype built for the test beam
  - Full-scale PSD detector, studying SiPM readout of ~m long scintillation bars.



Conclusions

Li-Be-B analysis with DAMPE:

- Secondary CRs spectra are fundamental to better understand their propagation in the Galaxy
- **Analysis on Li spectrum** with DAMPE mission:
  - Pre-selection
  - p and He background rejection with STK signal
  - PSD charge selection
- Evaluate systematics and background to reach a final spectrum measurement.

Simulations for HERD PSD:

- Future HERD mission on CSS will extend direct CR measurements to the highest energies
- PSD will be an anti-coincidence for gamma-ray detection, simulations are useful to:
  - Assess optimal geometry and readout
  - Study light propagation inside the detector
- Simulation showed better hermeticity performance with trapezoidal bar array, leading to their choice for the PSD prototype.
- Simulations were performed to study the light propagation inside the bar and the collection uniformity.

Activites

Conferences and collaboration meetings:

- 37th International Cosmic Ray Conference ICRC 2021 (12/07/21 - 23/07/21).
- 10th International Conference on New Frontiers in Physics ICNFP 2021 (23/08/21 -03/09/21): gave a **talk** with the title **“Latest results from the DAMPE mission”.**
- 107° Congresso Nazionale SIF (13/09/21 - 17/09/21): presented a **talk** regarding **“Preliminary results on cosmic Li, Be and B with the DAMPE experiment”**.
- Participation in outreach activity **SHARPER** (European Researcher’s night) with a stand in Piazza Duomo, L’Aquila (23/09/21).
- HERD Collaboration Meeting (22/02/21 - 23/02/21).
- Several **presentations** during **internal DAMPE and HERD meetings**.

Scientific publications:

- DAMPE collaboration, “Measurement of the cosmic ray helium energy spectrum from 70 GeV to 80 TeV with the DAMPE space mission”, Phys. Rev. Lett. 126, 201102 (2021)
- L. Wu, M. Cui, D. Kyratzis, A. Parenti and Y. Wei on behalf of the DAMPE
- Accepted for publication: I. De Mitri, A. Parenti and L. Silveri on behalf of the DAMPE collaboration, “Selected results from the DAMPE mission”, Phys. Atom. Nucl.

Backup slides

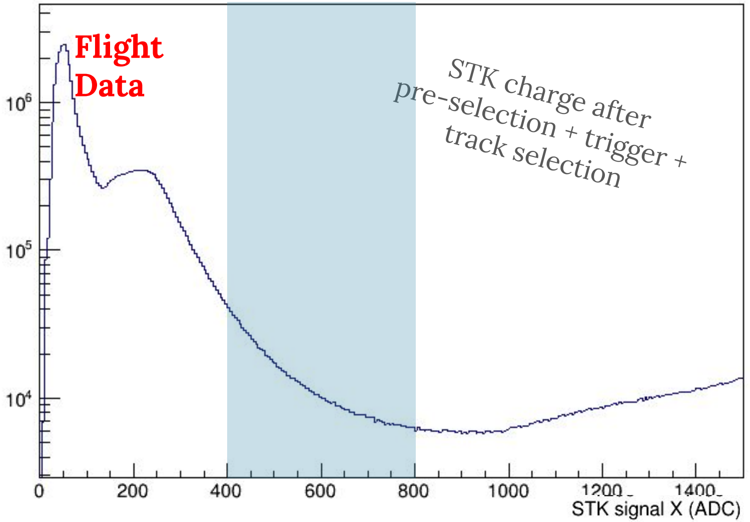
Data and MC samples

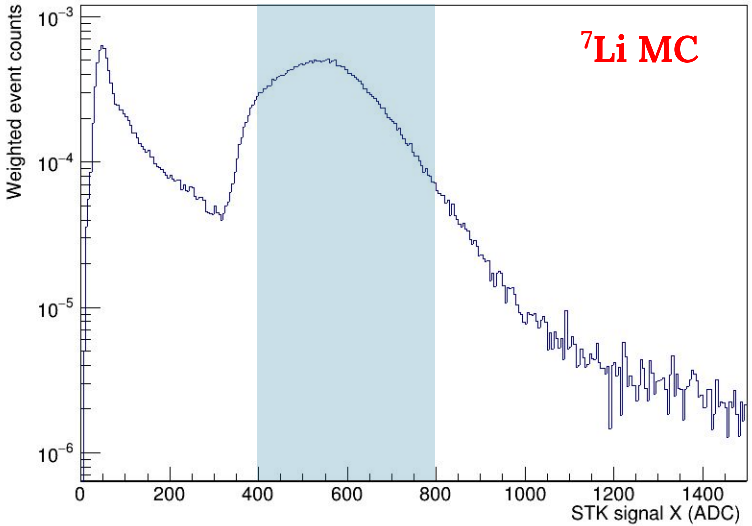
- **Flight Data**:
  - 60 months (5 years):
    - 60 months of flight data in E_{BGO} range [20 GeV, 100 GeV]
    - 60 months of flight data in E_{BGO} range > 100 GeV
- **MC**:
  - MC Li-7 sample in E range [10 GeV, 100 TeV]
  - MC Li-6 sample in E range [10 GeV, 100 TeV] **not included!**

Sample	**Size** (M)	**Sample**	**Size** (M)
Li6_10_100GeV	60	Li7_10_100GeV	60
Li6_100GeV_1TeV	100	Li7_100GeV_1TeV	100
Li6_1_10TeV	10	Li7_1_10TeV	10
Li6_10_100TeV	10	Li7_10_100TeV	10

STK charge selection

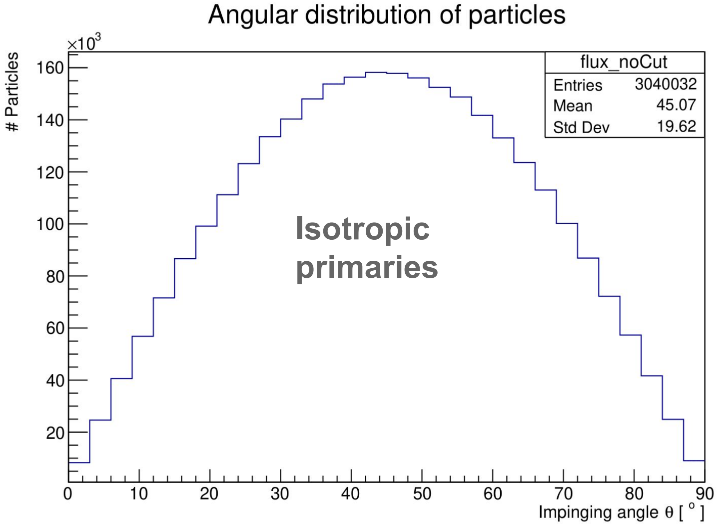
- Use energy deposit in first STK plane (layers along X and Y) to reject p and He background.
  - 400 < STK charge X and Y <800 -> specific to Li

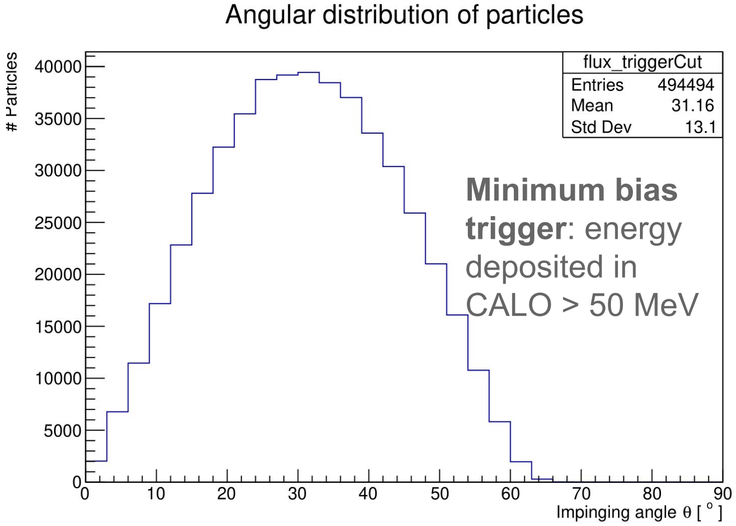




HerdSoftware acceptance

- To better simulate the HERD geometrical acceptance, look at **HerdSoftware** angular distribution of impinging primaries with minimum bias trigger request.





- Divide bin by bin to get some "folding factors":

$$F(\theta_i) = \frac{trigCut \rightarrow Entries(\theta_i, \theta_i + \Delta\theta_i)}{noCut \rightarrow Entries(\theta_i, \theta_i + \Delta\theta_i)}$$

Bar attenuation length

Bulk attenuation length (BAL): pure attenuation length, depends on the scintillator material properties.

Technical attenuation length (TAL): depends on the scintillator material properties, on the bar geometry and on the optical properties of the wrapping.

BAL is given as an input parameter to the simulation.

TAL estimation:

- 1 GeV muon beam impinging on the bar in different position
- Record mean number of absorbed photons by SiPM as a function of the beam position
- Fit with an exponential function