INFN
LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

GSSI
GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

Study of cosmic Iron flux with DAMPE and R&D for HERD

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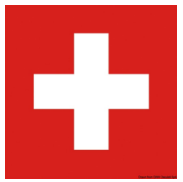
Advisor: Ivan De Mitri

Contents

- **DAMPE**
  - The heavy component of cosmic rays
  - Detector Layout
  - Iron Fragmentation Study

- **HERD**
  - Detector layout
  - Study of backsplashed particles
  - Study of hermeticity of PSD bars
  - Lab activities

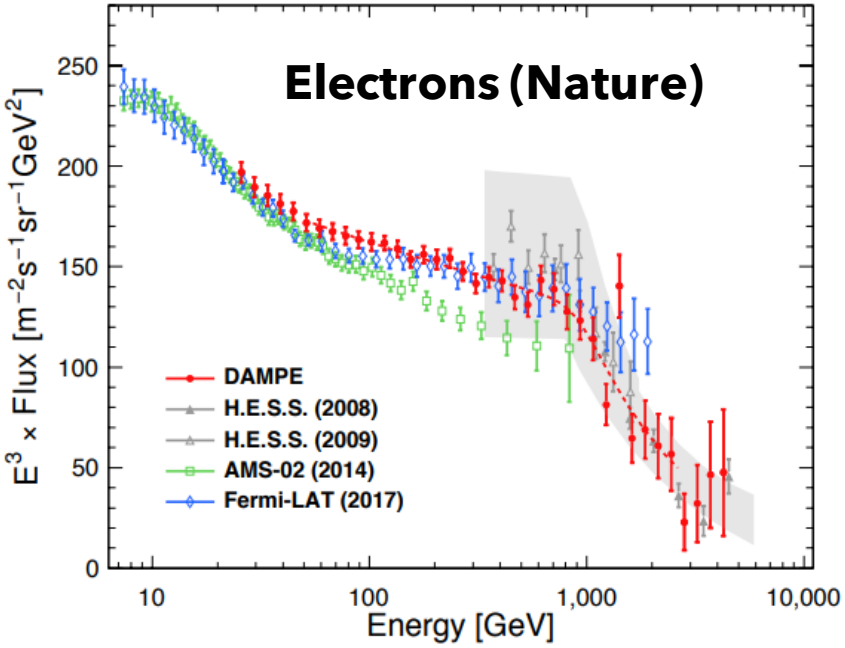


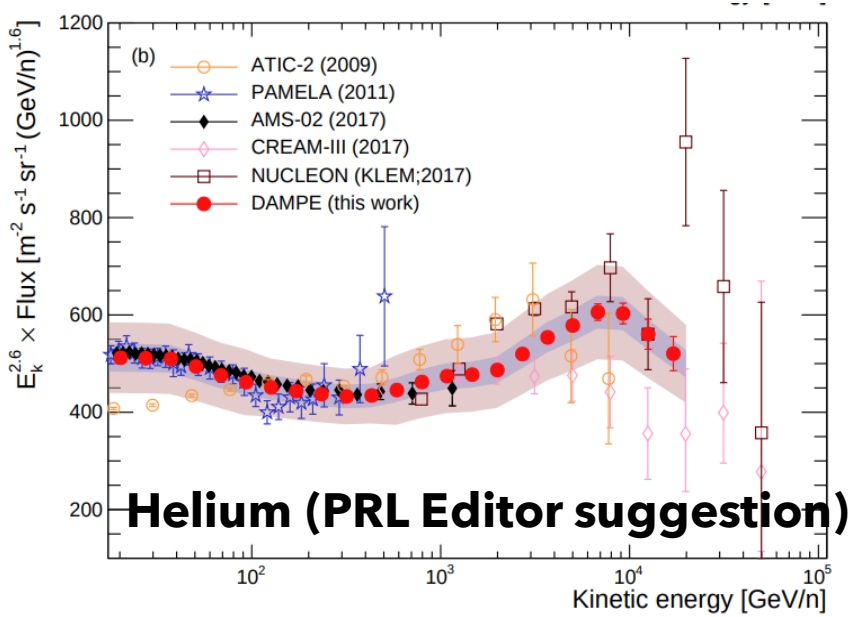


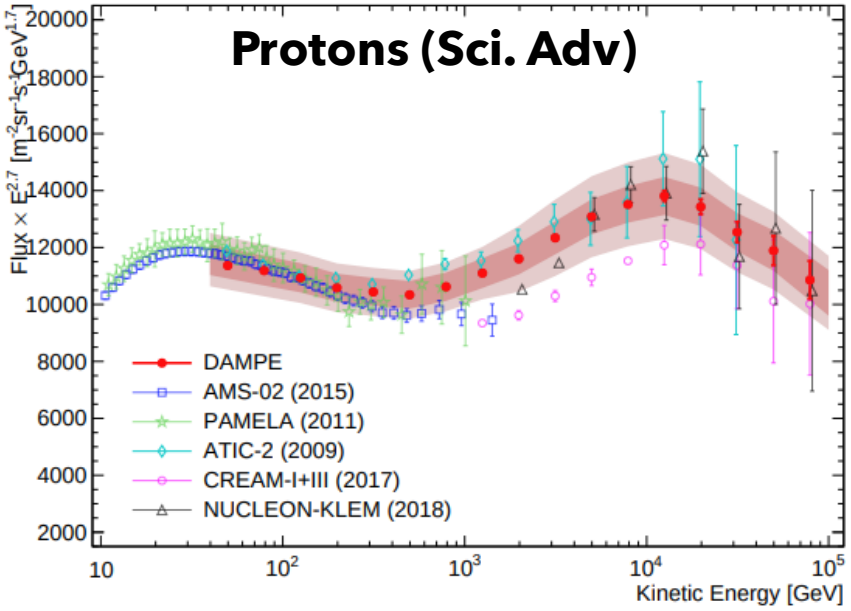
DAMPE

Dark Matter Particle Explorer

On orbit since December 15th, 2015

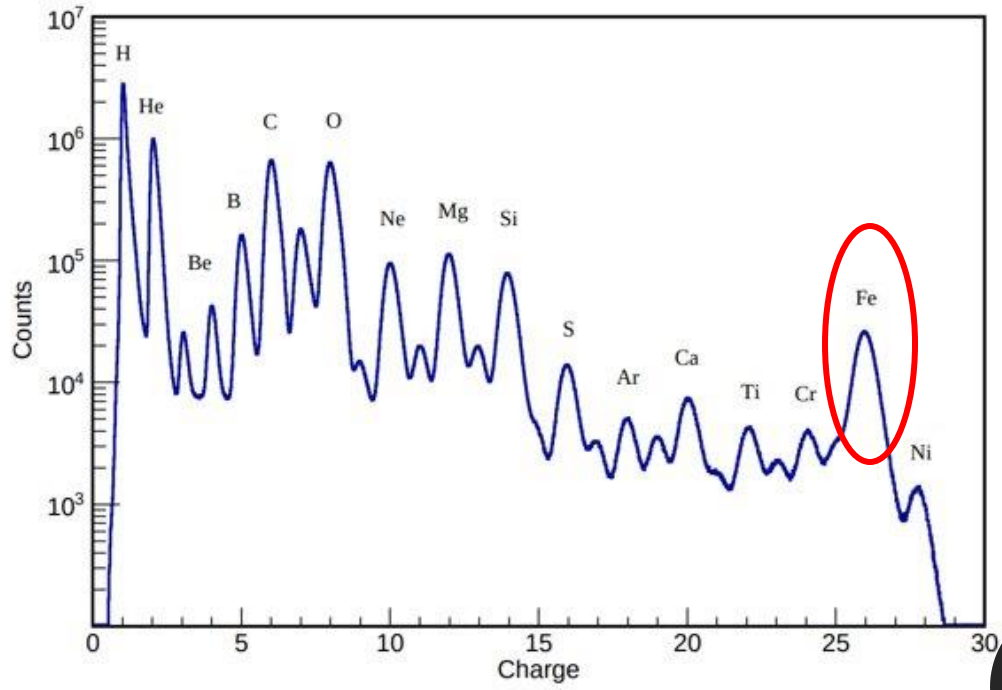






Direct measurements of heavy component of cosmic rays

- High Z nuclei fluxes can probe models
- Only direct detection can well discriminate nuclear species
- Among these nuclei, Iron is the most abundant



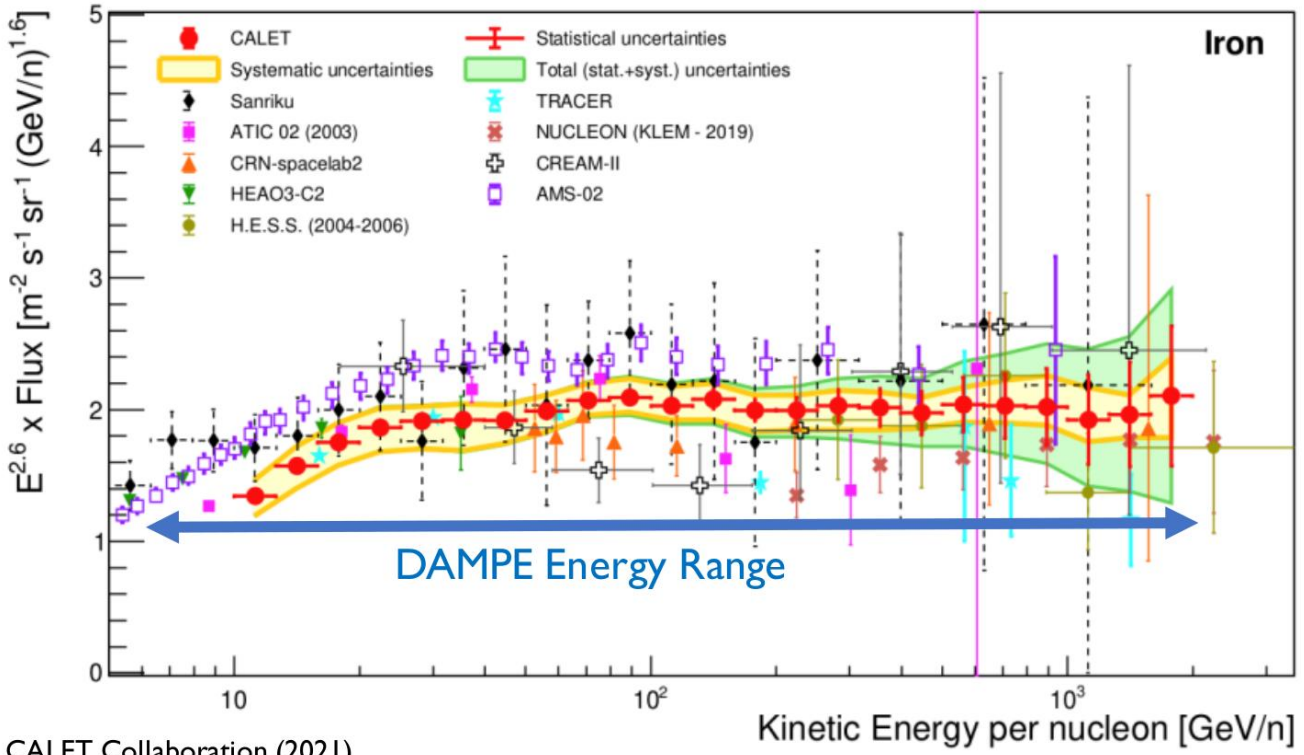
The Iron flux

- Spectrometers => Rigidity (P / Z)
- Calorimeters => Kinetic energy

- In the Fe case (Z=26) same energy scale in current experiments

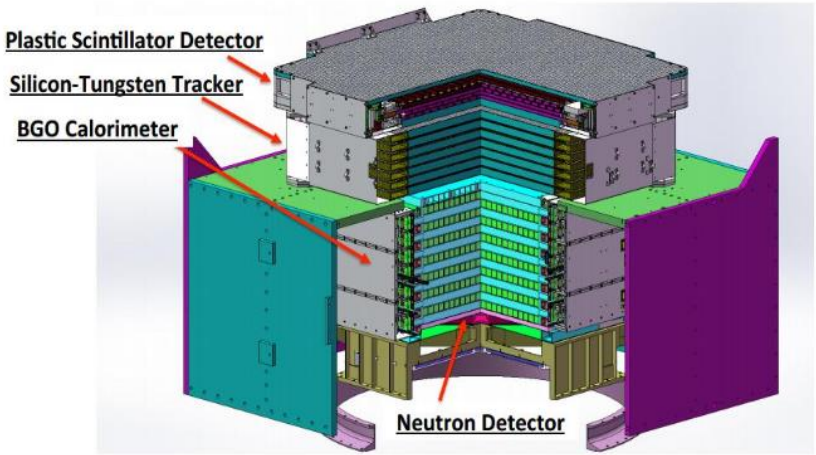
- **Significant difference** in AMS-02 and CALET fluxes

- **Our results will help understanding this difference, and better constrain the models**



CALET Collaboration (2021)

The DAMPE Experiment

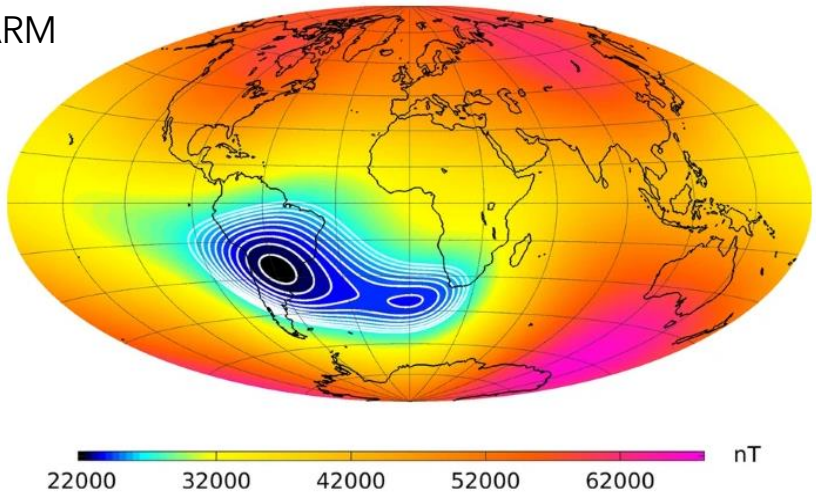


- **PSD** -> Particle Identification (4 layers)
- **STK** -> Track Reconstruction
- **BGO** -> Energy measurement and shower image
- **NUD** -> Shower produced neutron detection

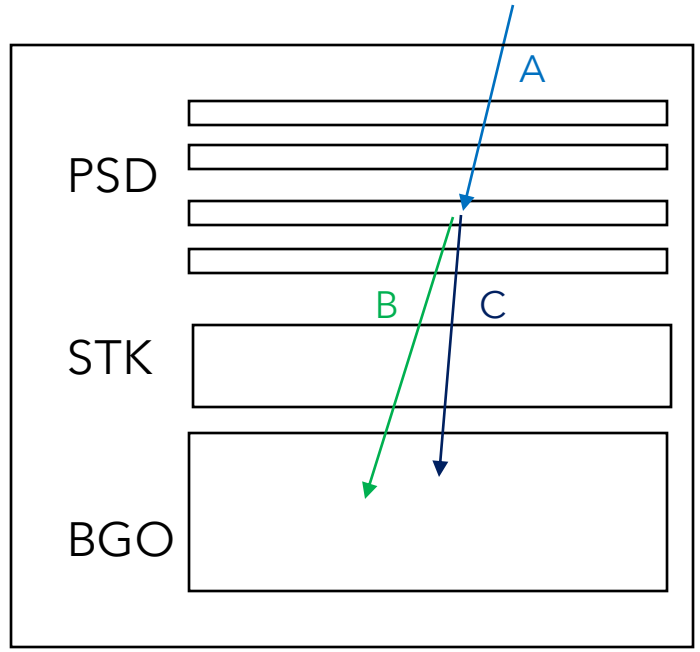
Events Preselection:

- Trajectory correctly reconstructed and fully contained in the detector
- Threshold for reconstructed energy (*BGO Energy*) at 20 GeV
- South Atlantic Anomaly excluded

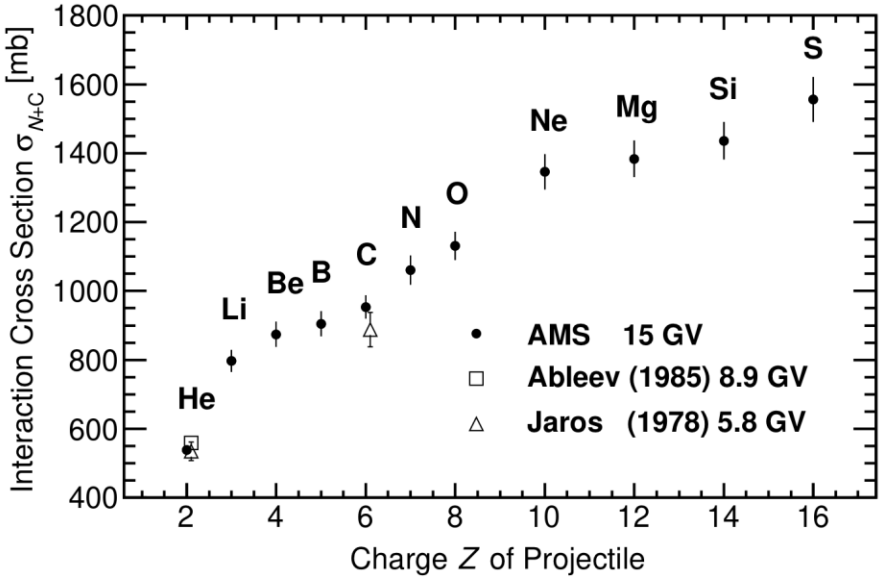
SWARM



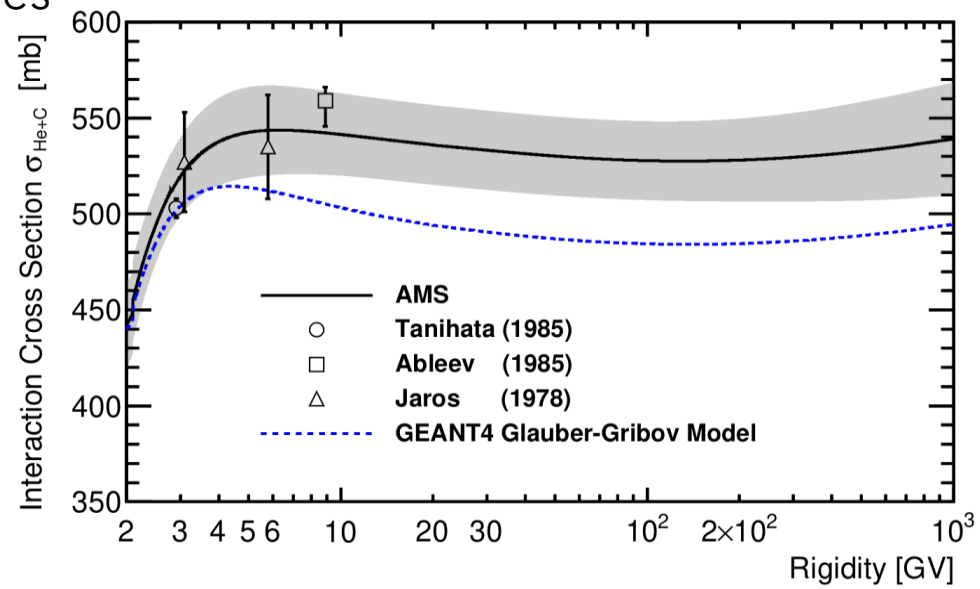
The Iron fragmentation



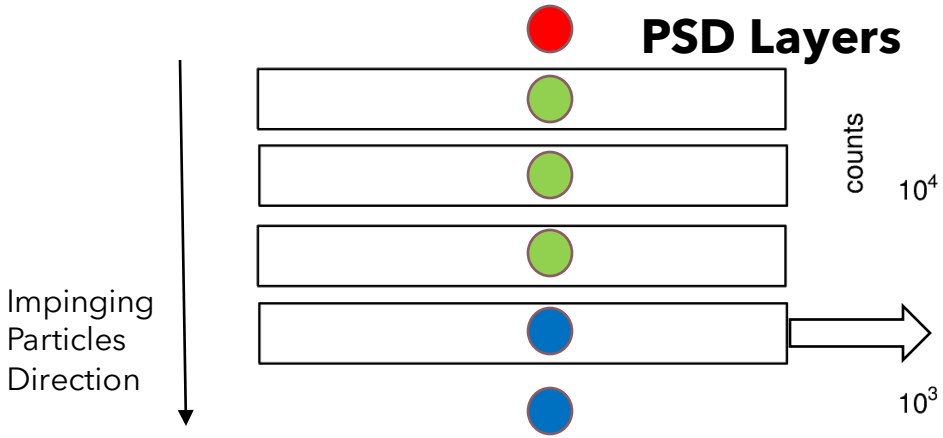
- Nuclei event reconstruction:
  - Charge Measurement by PSD (energy deposit ∝ Z^2)
  - Track reconstruction by STK
  - Energy Reconstruction by BGO
- Nuclei are identified by the PSD signal



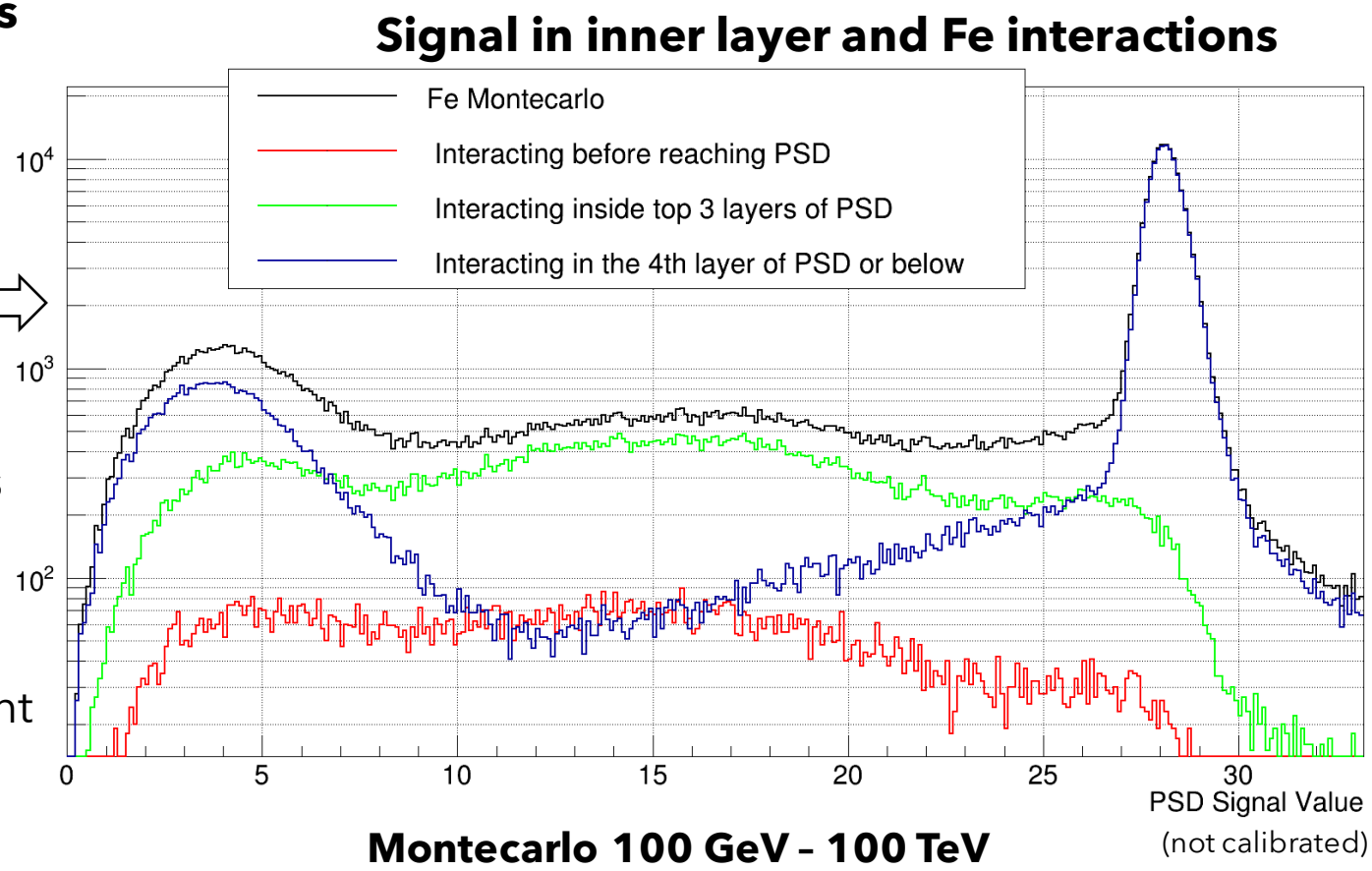
- Fragmented nuclei are not correctly identified
- Detector inefficiency ∝ misidentified particles
- Detector efficiency affected by fragmentation cross section uncertainties



The Iron fragmentation



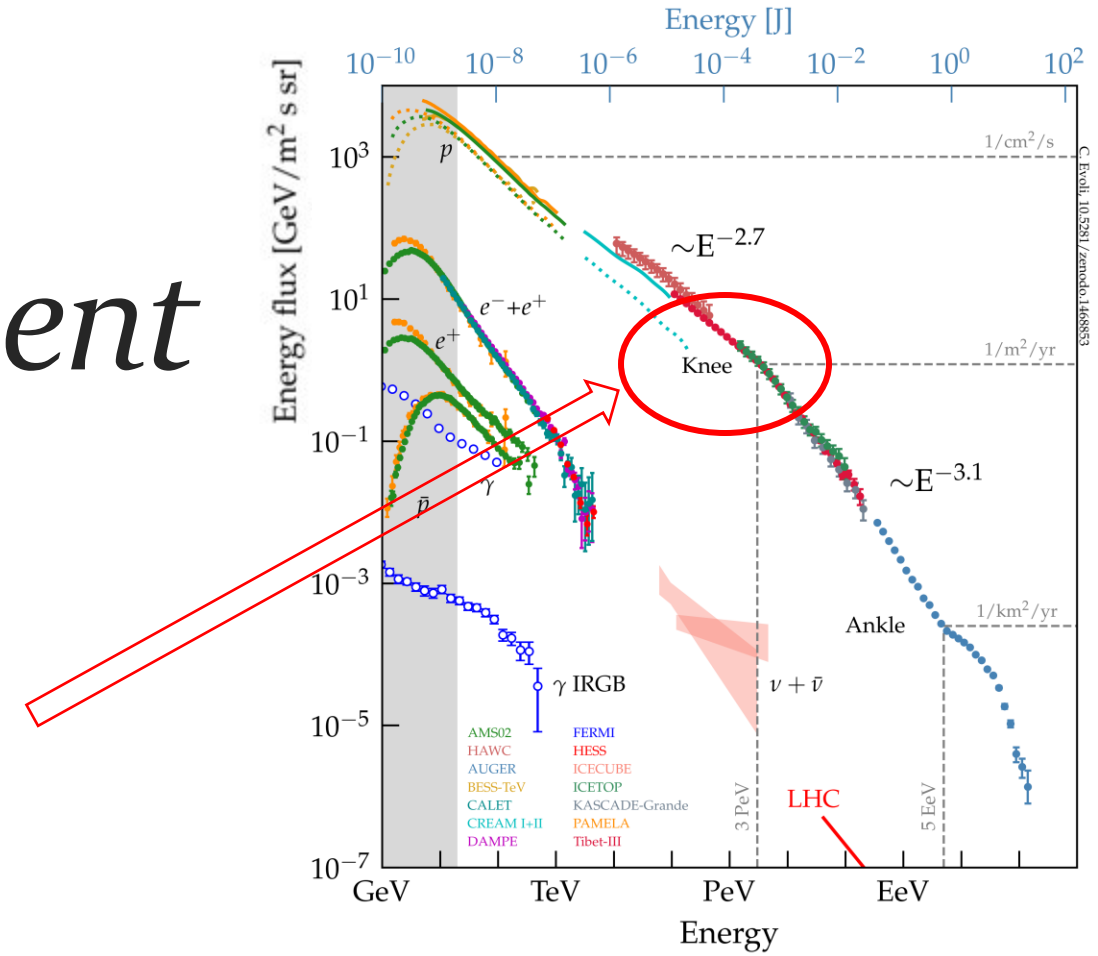
- 34% of events fragmenting in layers
- Most of misidentified nuclei
- Identifying "fragmentation layer" might give us a tool to cross check the Montecarlo and measure iron fragmentation

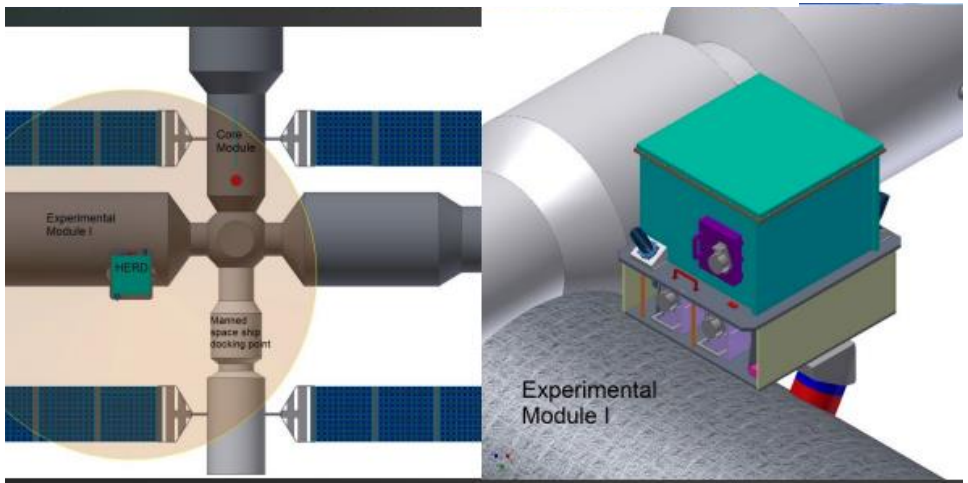


HERD
High Energy Radiation Detector

The HERD Experiment

- To be launched in 2027 to Chinese Space Station
- 5 sensitive faces
- Scientific goals:
  - Measurement of CRs up to their *knee* (PeV scale)
  - Electron up to 10 TeV and nearby sources
  - Gamma monitor and full sky survey
  - Indirect dark matter searches





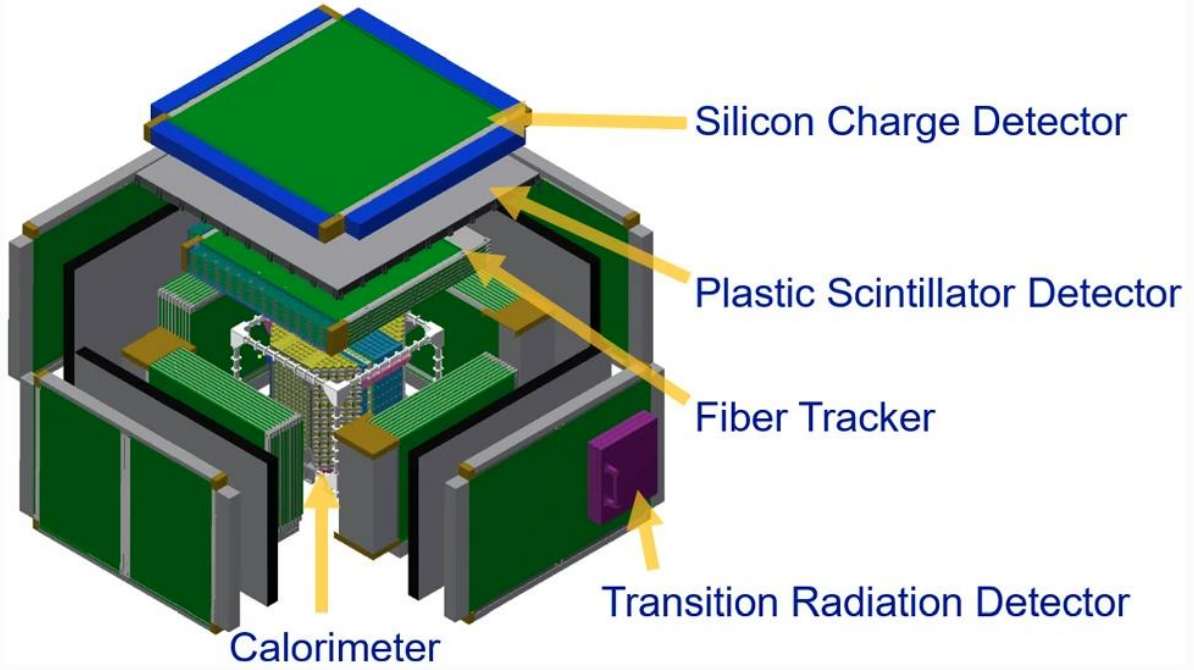
The HERD Experiment

- Design specification

	HERD	DAMPE	CALET	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	<1	<1.5	2	3	10
e/γ Angular res.@100 GeV (deg.)	< 0.1	<0.2	0.2	0.3	0.1
e/p discrimination	$>10^6$	$>10^5$	10^5	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	55	32	27	17	8.6
Geometrical accep. (m^2sr)	>3	0.3	0.12	0.09	1

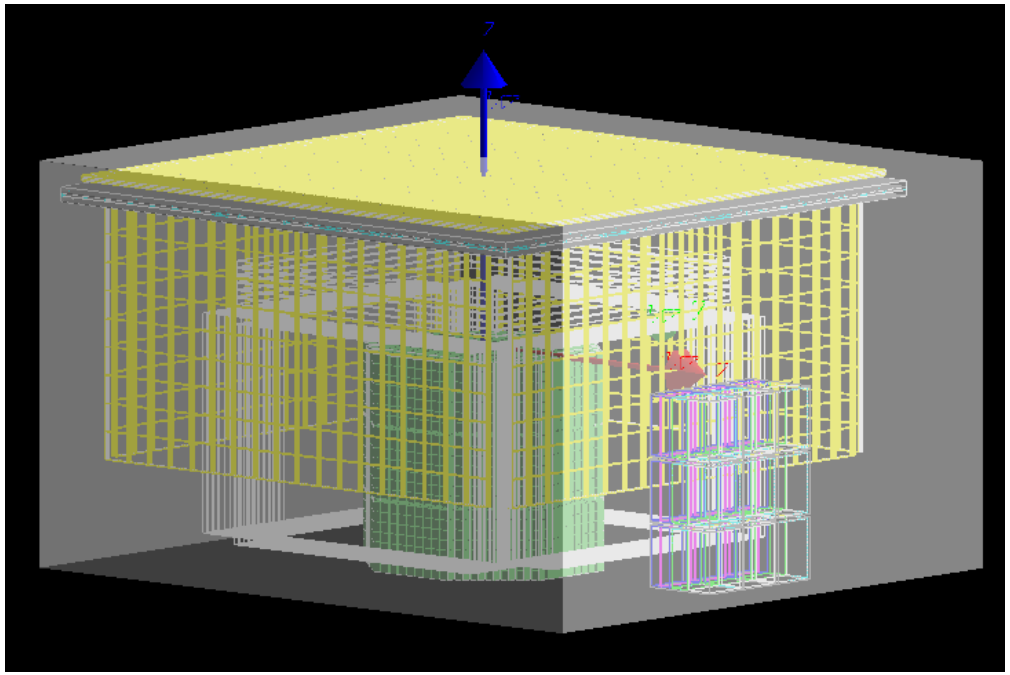
The HERD Experiment

- TRD -> calibration for TeV protons (foam / foils radiator + Xe detector)
- SCD -> charge measurement
- PSD -> photon anticoincidence + redundancy on charge measurement (tiles and bars configurations under study: bars **R&D in GSSI/LNGS**)
- FIT -> tracking system
- CALO -> energy measurement and shower imaging (LYSO cubes)



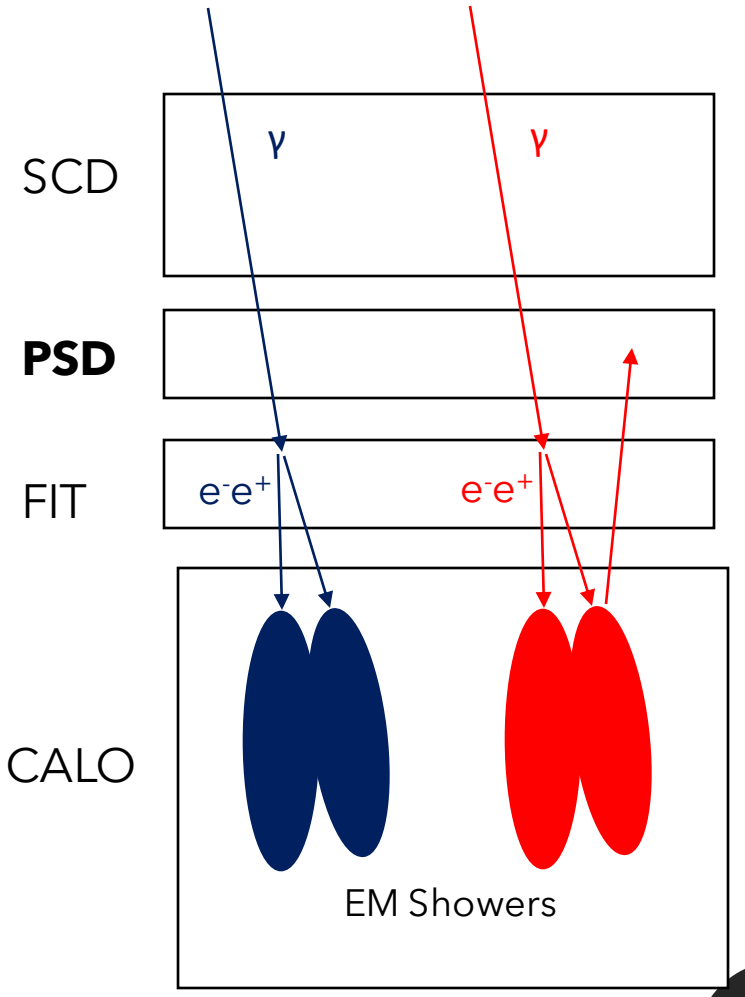
HERDSoftware Framework

- Simulation and analysis
- Developed in C++ and maintained within the collaboration
- Provides interfaces to GEANT4 and ROOT
- Provides routines to retrieve energy deposit in each subdetectors and track reconstruction
- Results from these simulations can be used to **optimize the PSD layout**



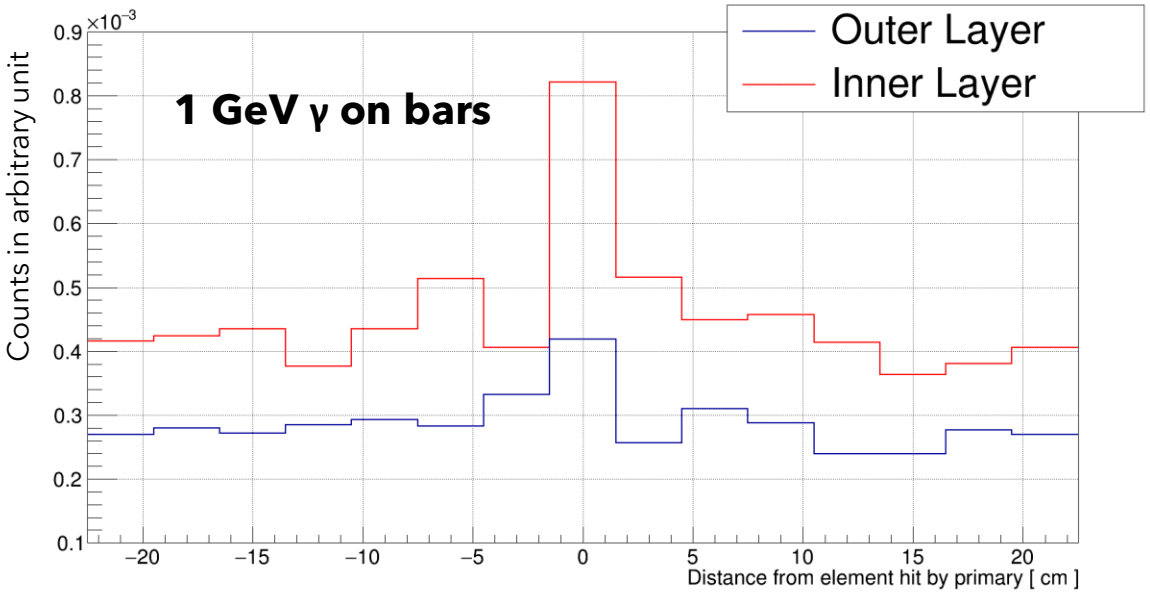
PSD Backsplash study

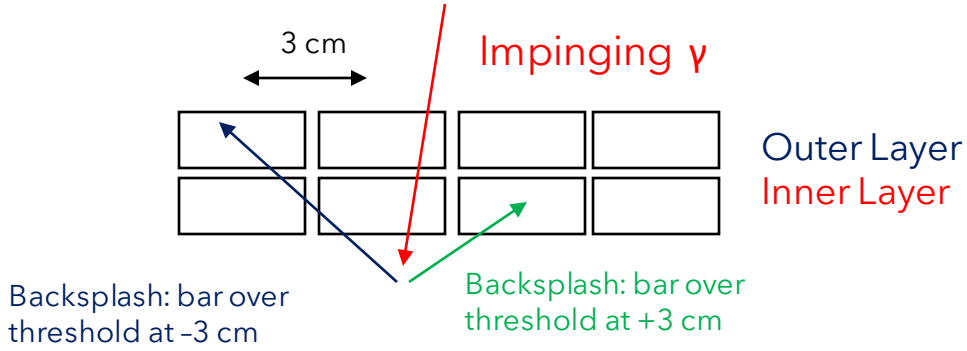
- **Backsplash** can affect PSD charge measurements
  - Fake Vetoes in gamma measurements
  - Systematically increasing charge measurements for nuclei
- Find optimal layout for backsplash reduction via simulation (bars and tiles configurations)
- Preliminary results for γ



PSD Backsplash study (bars)

- Set threshold at 0.25 MeV (1 / 3 MIP in 0.5 cm)
- Bars over threshold => Fake veto
- Fake vetoes could be reduced by selecting a region of interest of PSD using particle track
- We need to know where backsplash hits





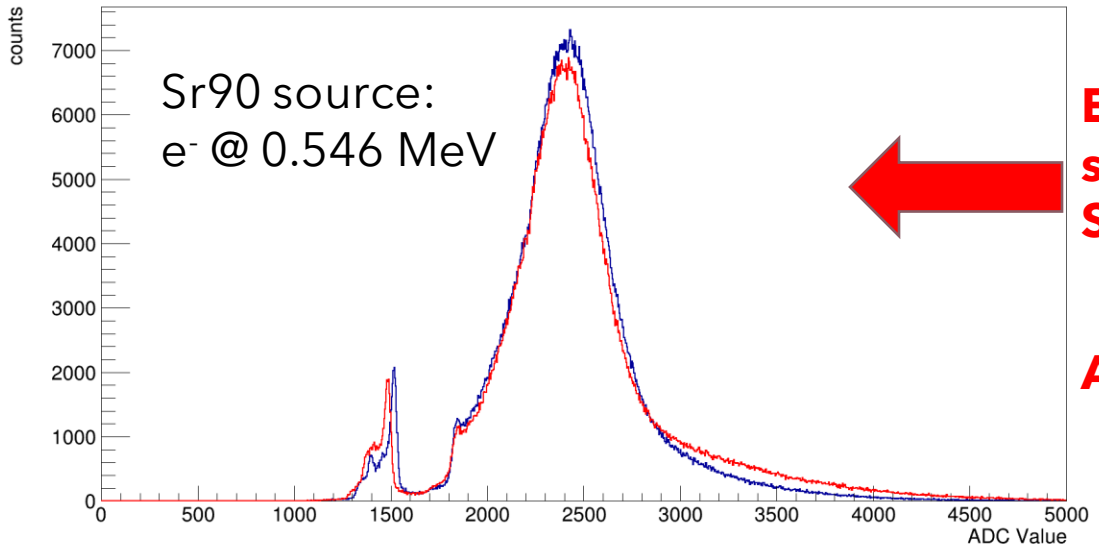
EXEMPLARY DRAWING: IN REALITY OUTER LAYER AND INNER LAYER ARE ORTHOGONAL TO EACH OTHER

Future work:

- Providing more studies on this background
- Studying a cut based on the particle track
- Studying protons and heavy nuclei

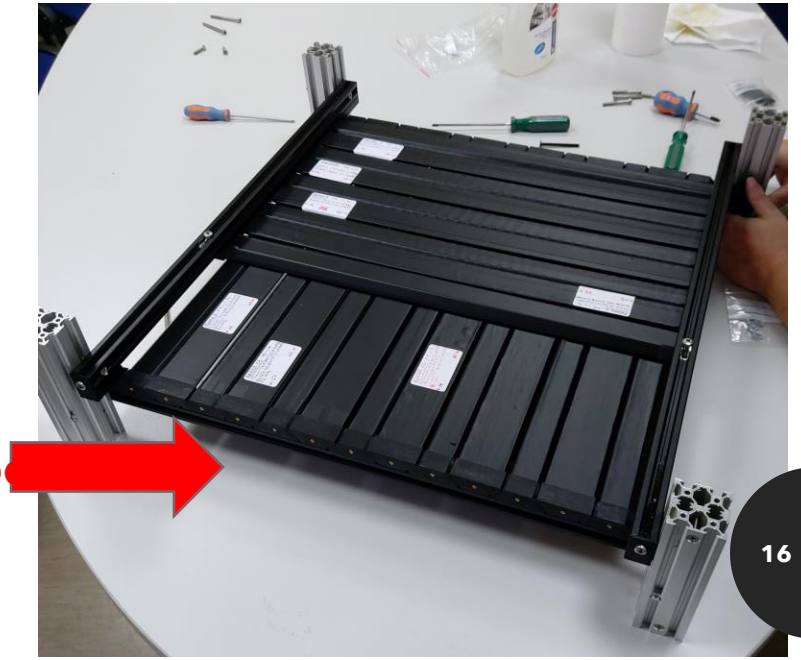
Lab Activities

- Prototype construction for the test beam
- Worked with DAQ (Data AcQuisition) board firmware and data processing
- DAQ data conversion to ROOT file format
- Shifter for Test Beam @ CERN PS (1st week November)



Example of a bar signal taken with SiPM at both end

Assembled Prototype



Summary

- I'm involved in both DAMPE and HERD experiment
- DAMPE: Study of nuclei fragmentation and Iron spectrum (in progress)
- HERD: Full detector simulations and analyses:
  - HERDSoftware Framework
  - PSD Backsplash (in progress)
  - PSD Bar Hermeticity study
  - Lab activities, PSD Prototype

Activities

1. Physical Sensing and Processing, 20 – 24 July 2020
2. Cosmic Rays and Neutrinos in the Multi-Messenger Era, 7 – 11 December 2021
3. Security and safety in the workplace course, attended on 8 March 2021
4. PyHEP 2021 (virtual) workshop, 5 - 9 July 2021
5. 37th International Cosmic Ray Conference (ICRC), 12 - 23 July 2021
6. 10th IDPASC School, 6 - 17 September 2021
7. 107th Congresso SIF, 13 – 17 September 2021, presentation on DAMPE Iron analysis
8. Outreach activities in Sharper 2021
9. AP Student representative in "Commissione Paritetica Docenti-Studenti"

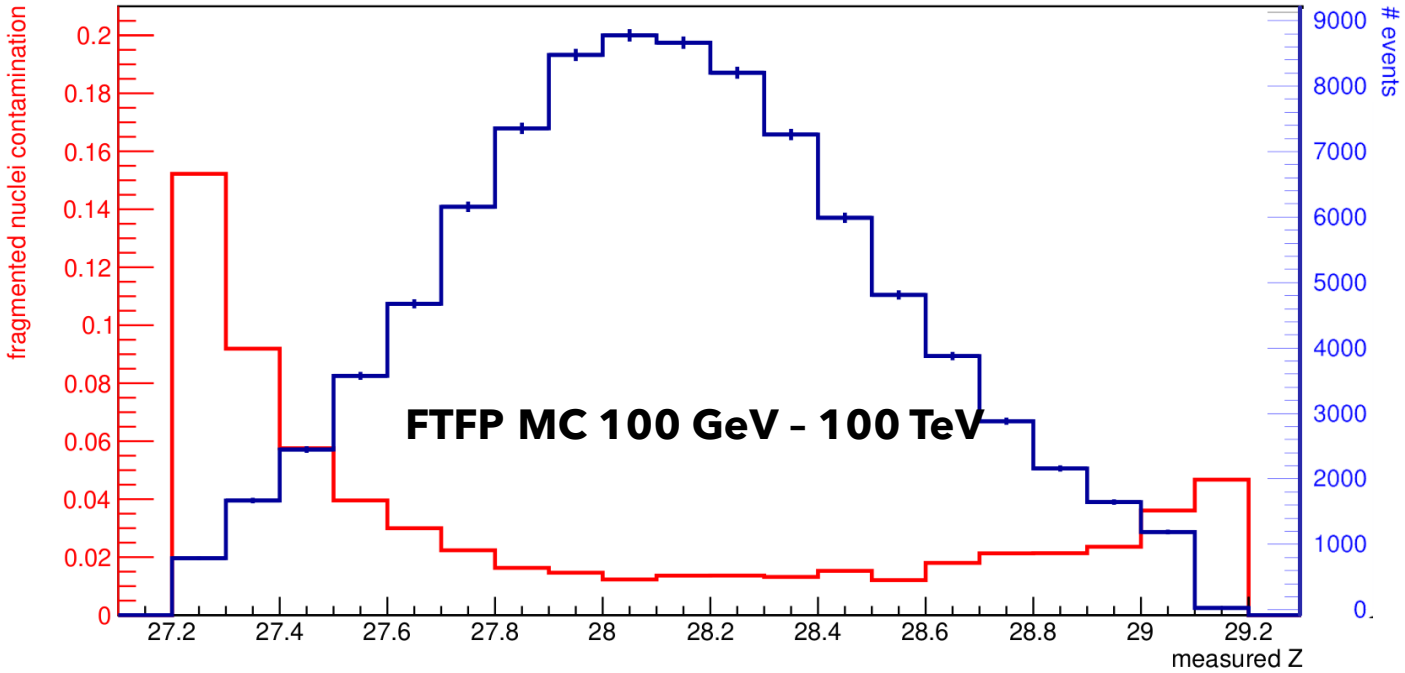
Publications

1. The results and future prospects of the LHCf experiments, Proc. of Science ICRC2019, 349
2. Measurement of the Cosmic Ray Helium Energy Spectrum from 70 GeV to 80 TeV with the DAMPE Space Mission, Phys. Rev. Lett. 126, 201102
3. The Plastic Scintillator Detector of the HERD space mission, Proc. of Science ICRC2021, 54
4. Gamma-ray performance study of the HERD payload, Proc. of Science ICRC2021, 651
5. Direct measurement of the Cosmic Ray Iron Spectrum with the Dark Matter Particle Explorer, Proc. of Science ICRC2021, 115
6. Selected results from the DAMPE space mission, Phys. Atom. Nucl. (Accepted for publication)
7. Observations of Forbush Decreases of cosmic ray electrons and positrons with the Dark Matter Particle Explorer, ApJ Lett. (Accepted for publication)

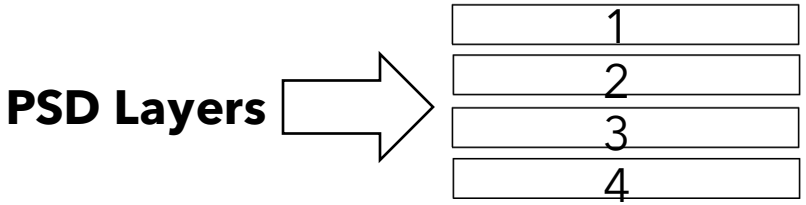
Backup

The Iron fragmentation

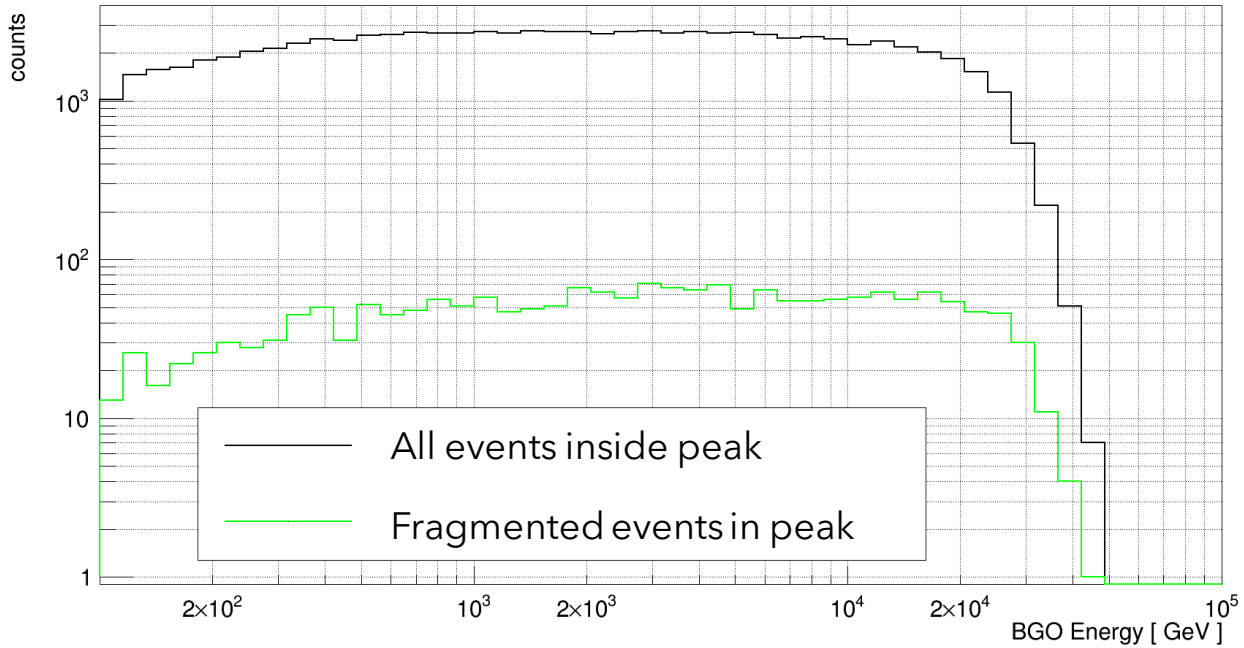
- Events are required to be inside peak in both 1st and 4th layers of PSD
- Particles in these charge range are rarely fragmenting



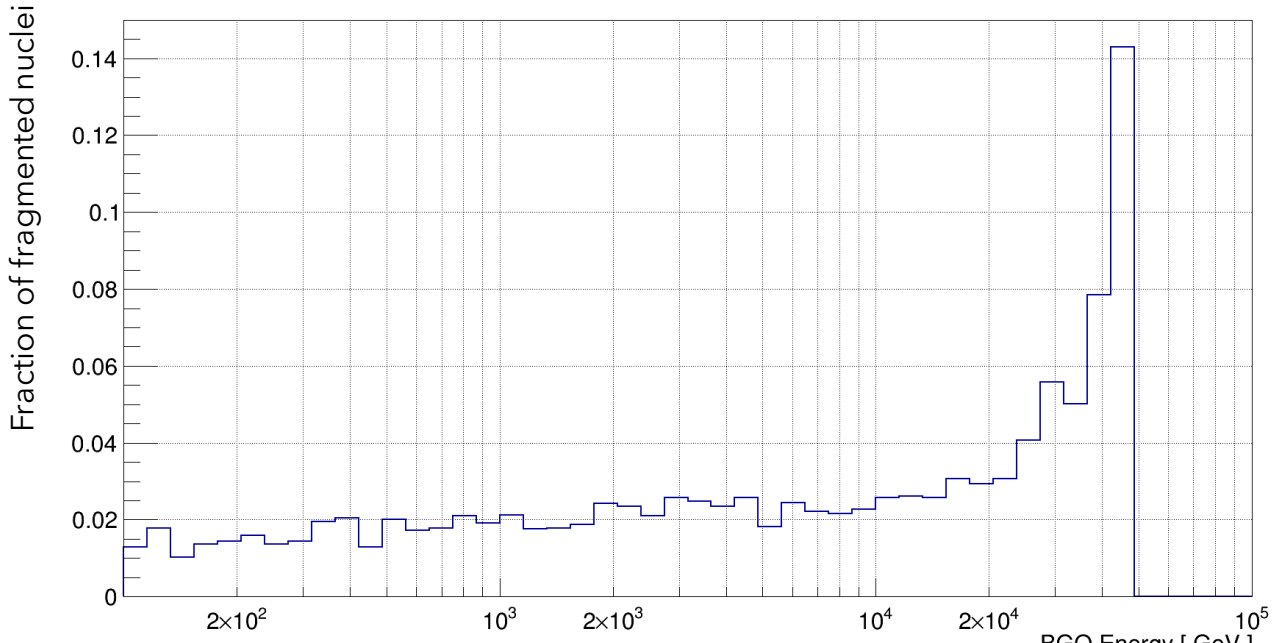
The Iron fragmentation

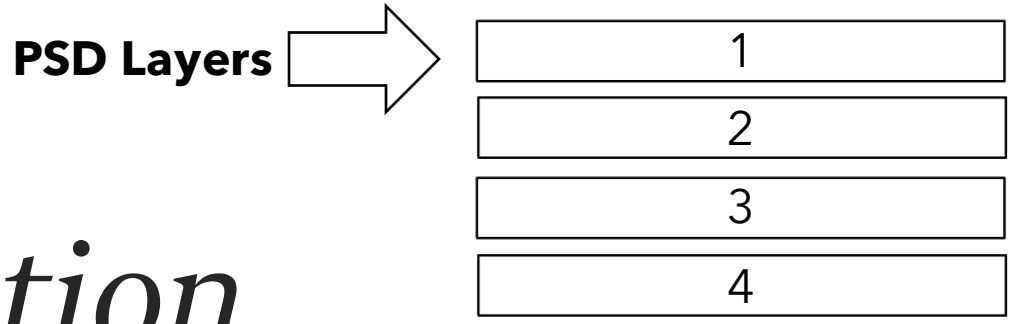


- Events with signal inside the Iron peak of layers 1 and 4
- Preliminary cut, need to be extended to high energy



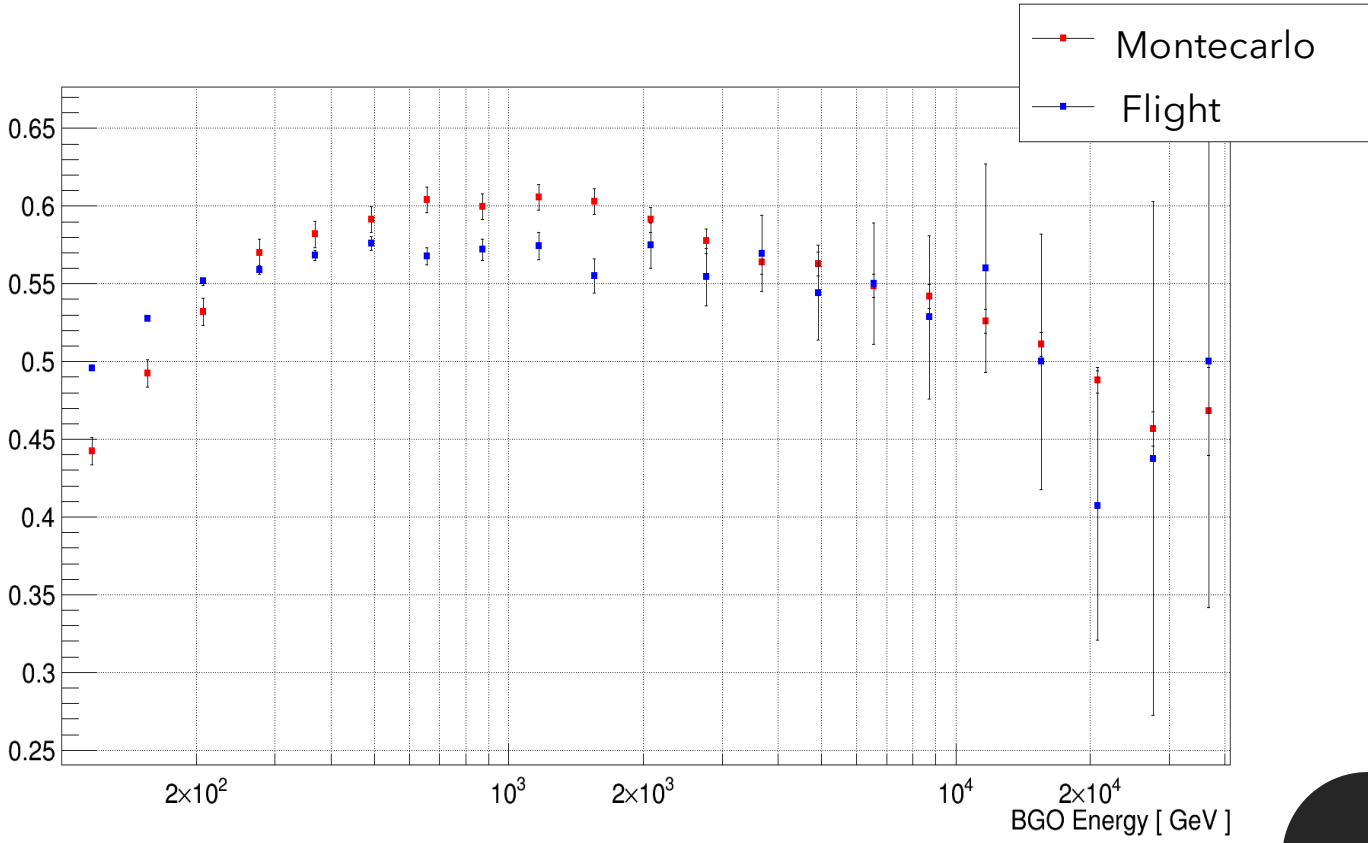
FTFP MC 100 GeV – 100 TeV





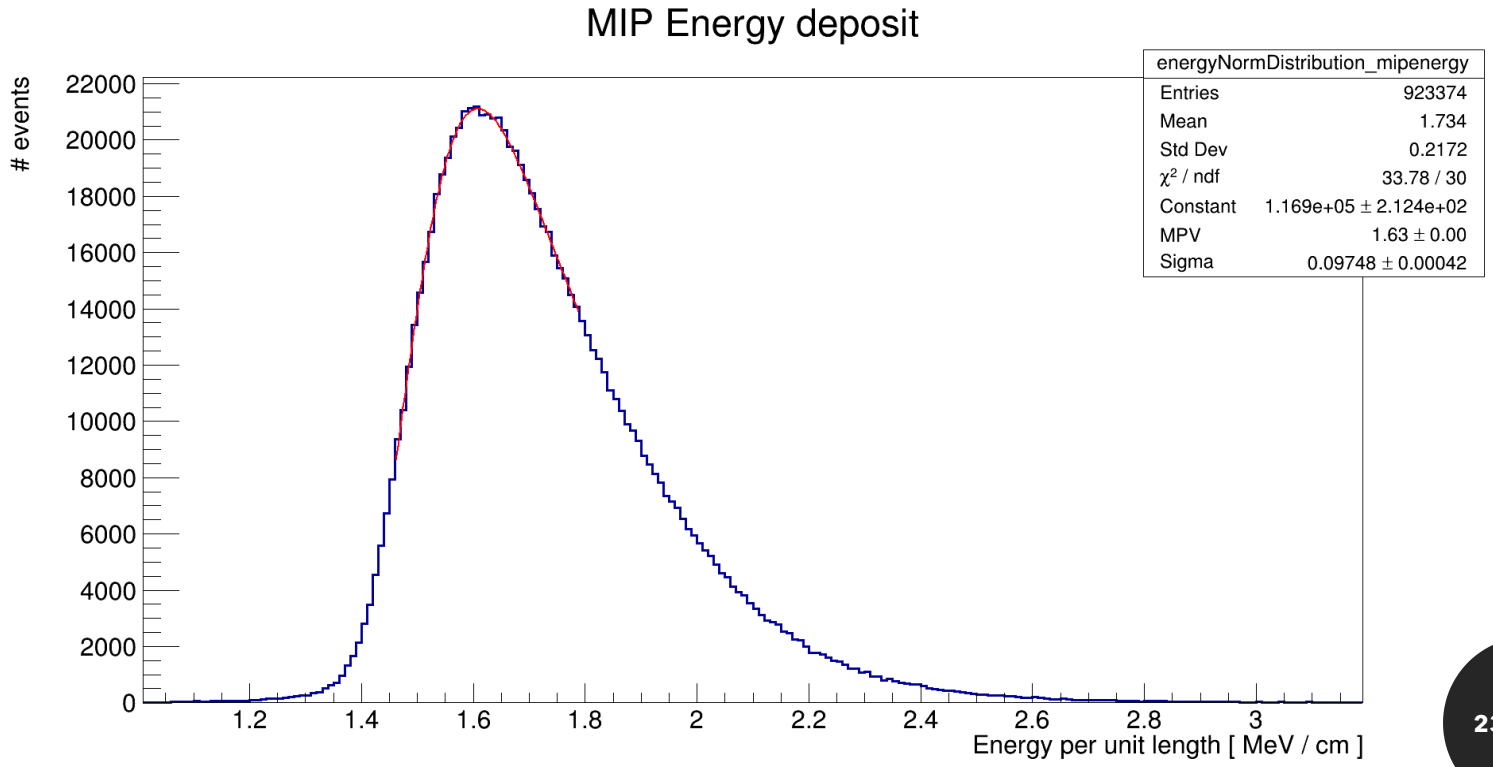
The Iron fragmentation

- Fraction of nuclei fragmenting in 3 layers of PSD (2, 3 and 4)
- Extend this to all layers pair
- Iron spectrum corrections and details on iron cross section



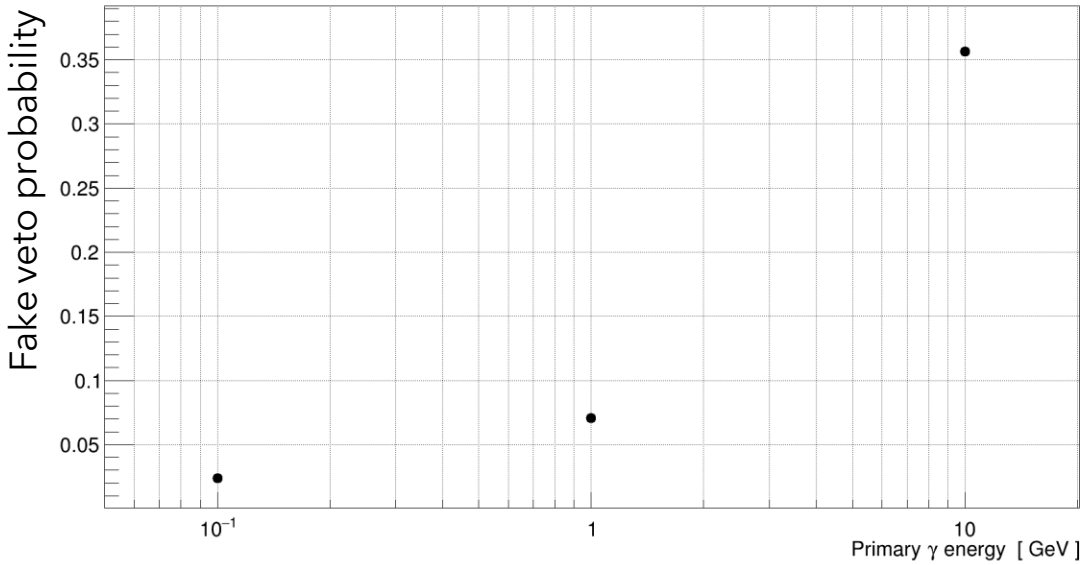
PSD MIP Energy Deposit

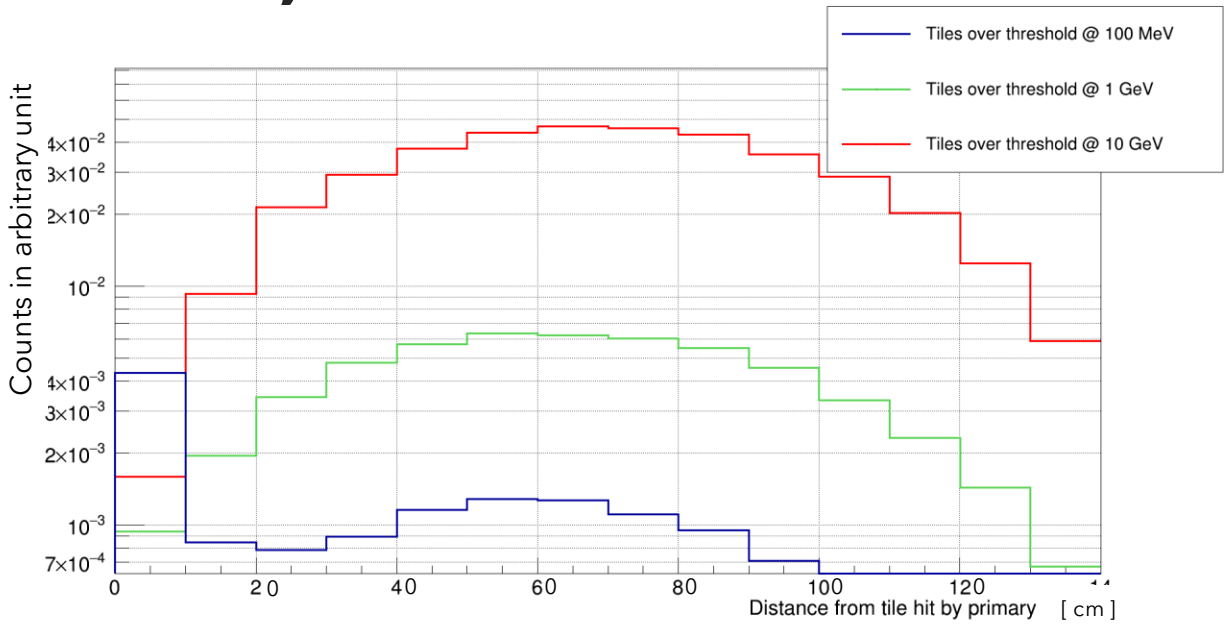
- Simulation with 10^6 μ^- @ 100 GeV
- Energy deposit / track length
- Landau fit
- MPV: 1.63 MeV / cm



PSD Backsplash study

Tiles results





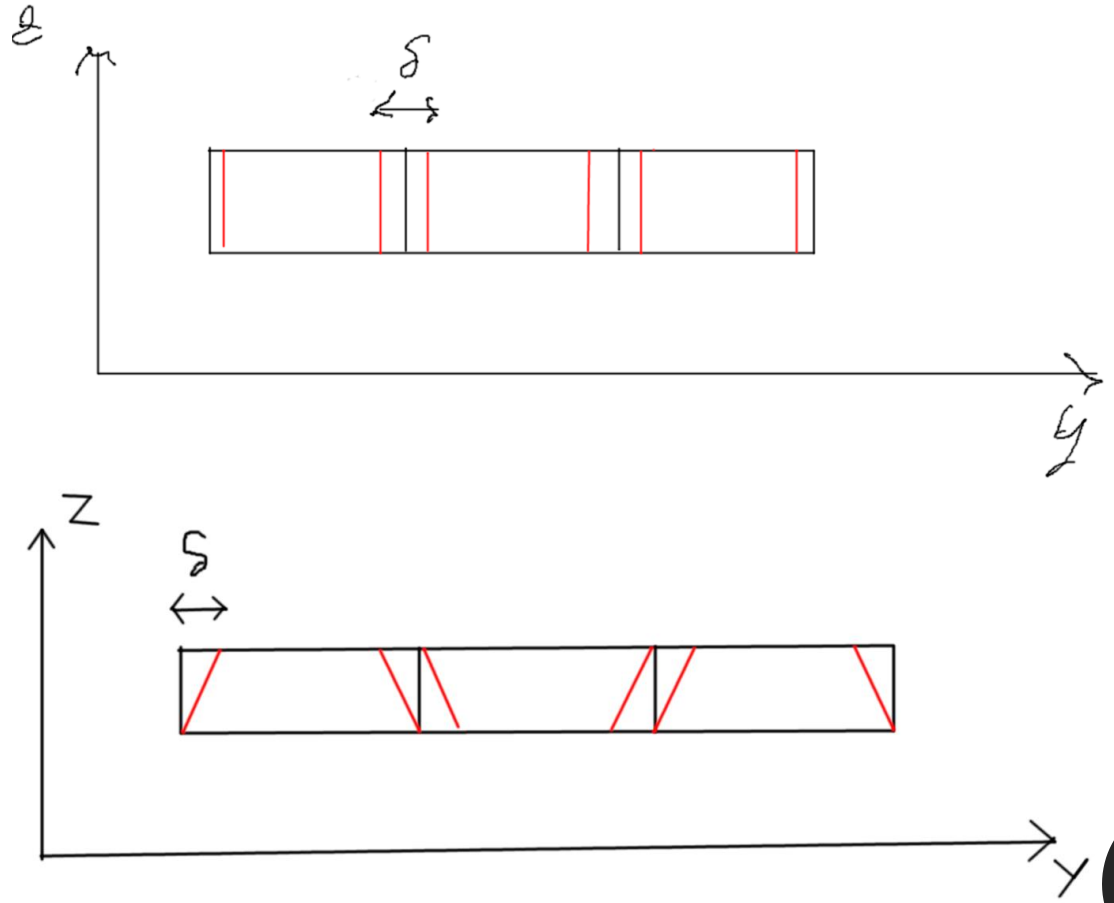
Distance is $(\Delta X^2 + \Delta Y^2)^{1/2}$
Tiles' size is 10 cm x 10 cm

PSD Hermeticity study

- Trapezoidal vs Rectangular bars shape
- 2 layers of bars orthoganal
- Simulations made on full detector (HERDSoftware)
- Isotropic flux of 100 GeV muons

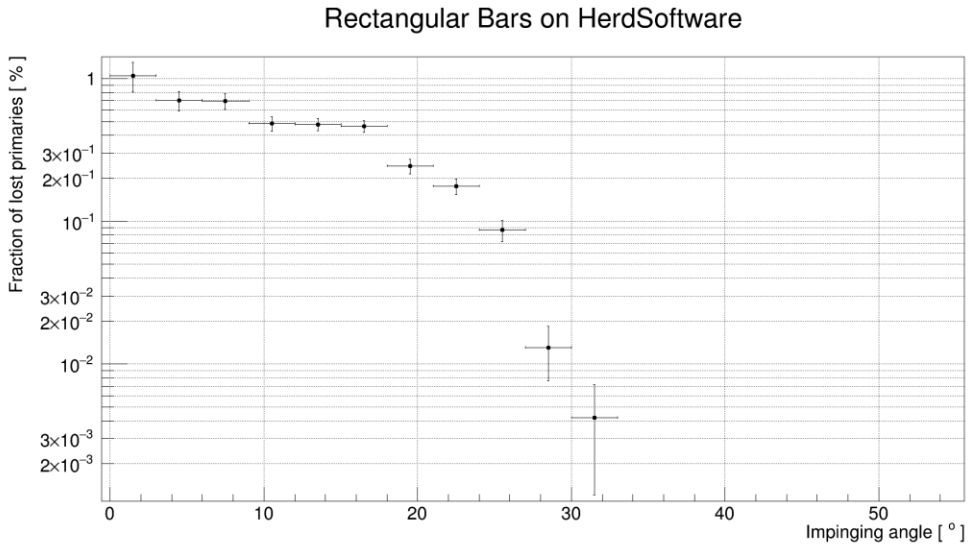
PSD Hermeticity study

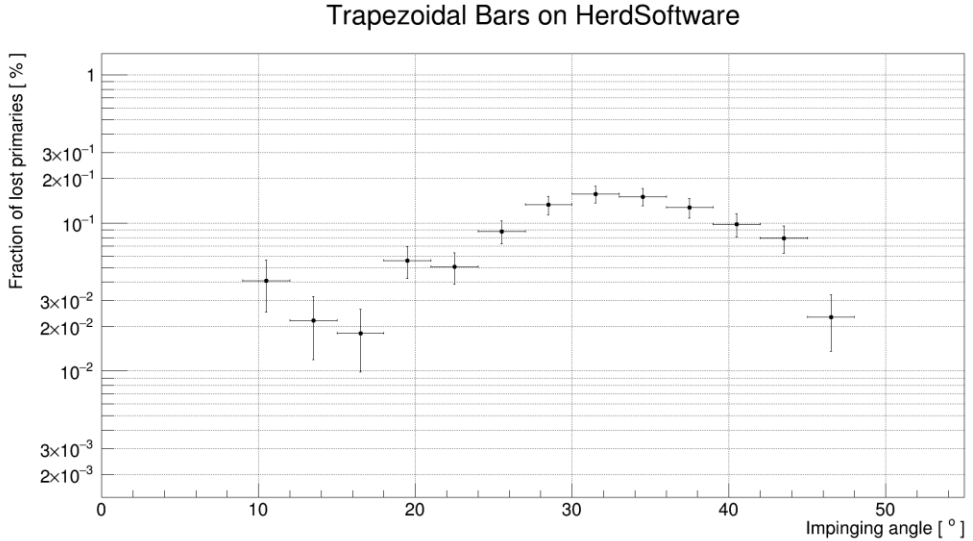
- Simulation of bars wider than needed
- We can see what happens in the gaps



Hermeticity study

- Particles not releasing signal in the detector in function of the angle for trapezoidal and rectangular shaped bars
- Flatter and in general lower distribution for trapezoidal shapes
- Fraction of all lost primaries is 0.024% for trapezoids against 0.027% of rectangles
- Difference is small because the acceptance is peaked at ~30°





Hermeticity study: acceptance

- Angular distribution of impinging particles: peak is about 30°