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

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Co-Advisor: Adriano Di Giovanni

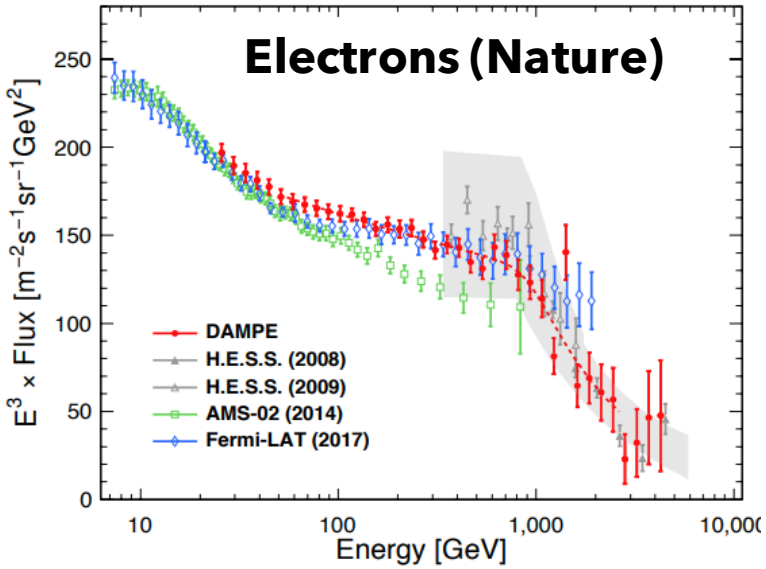
Contents

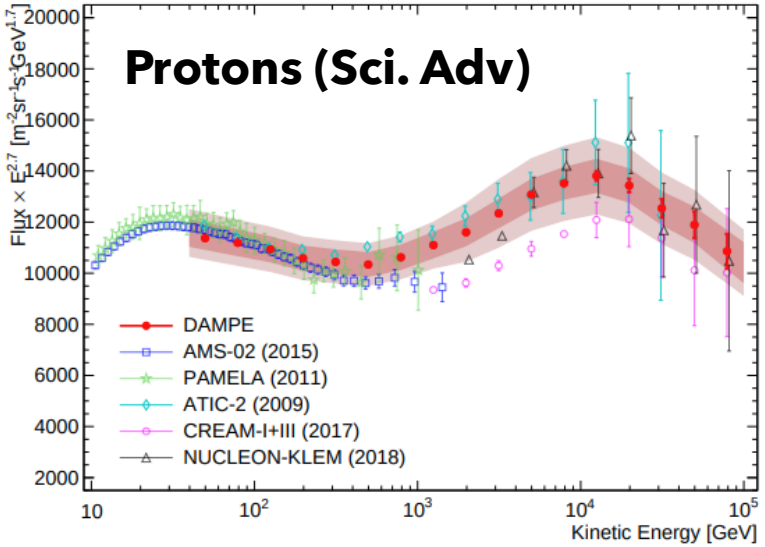
DAMPE

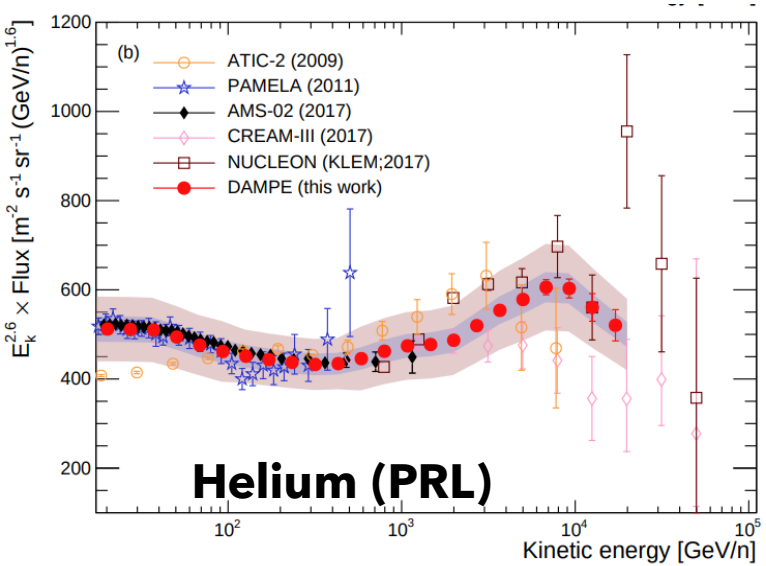
Dark Matter Particle Explorer

- Launched in 2015
- Deepest calorimeter in space

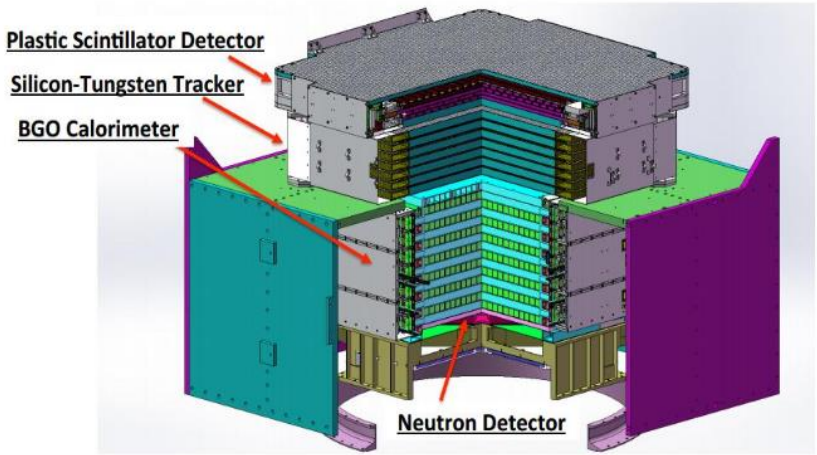
- Main scientific goals:
  - Measurement of cosmic ray nuclei and electrons spectra
  - Search for gamma ray lines related to dark matter processes
  - Gamma sources and transient events







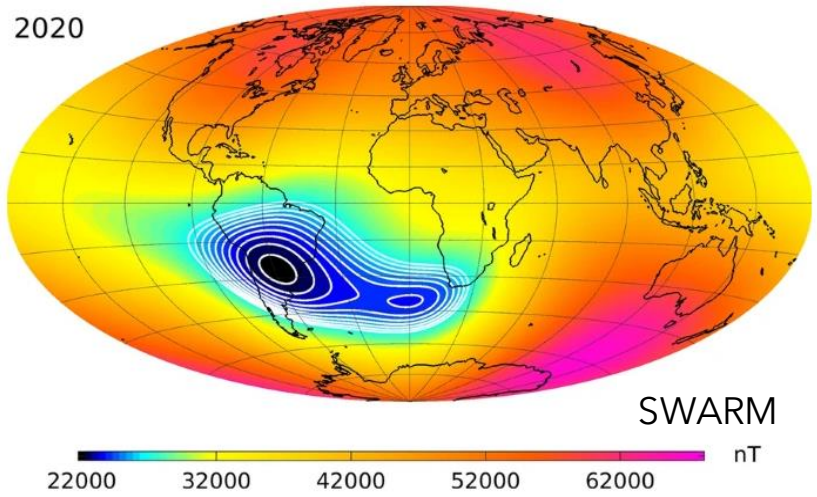
The DAMPE Experiment



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

Events Preselection:

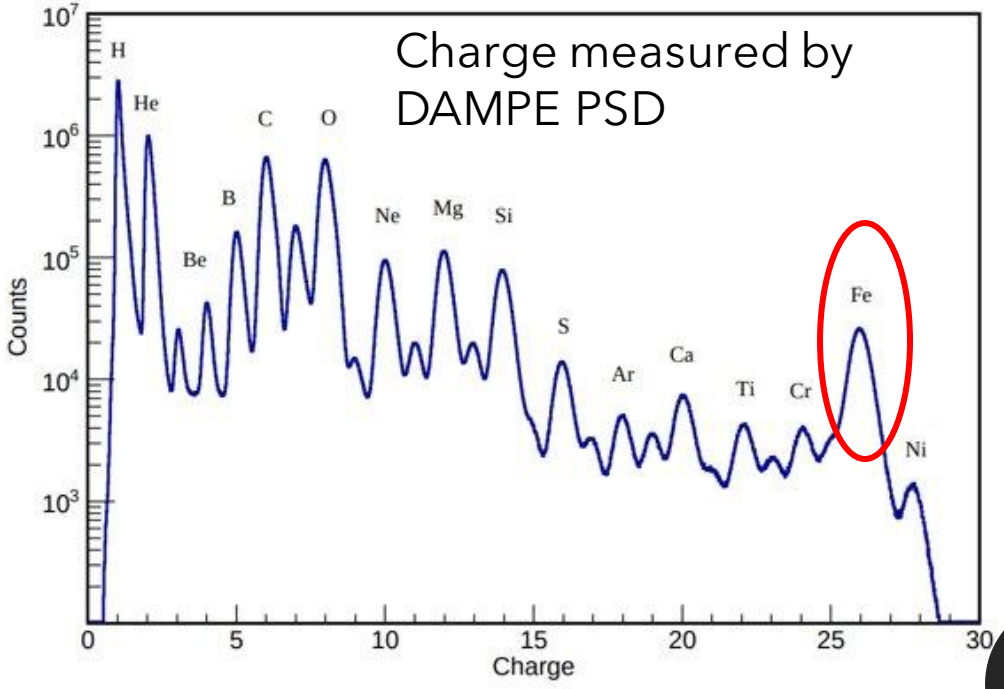
- Trajectory correctly reconstructed and fully contained in the detector
- Threshold for reconstructed energy (*BGO Energy*) at 20 GeV
- South Atlantic Anomaly excluded



Direct measurement of Iron in cosmic rays

- Most abundant among the nuclei heavier than Si
- Primary (accelerated in astrophysical sources)

- Possibility of accurate measurements to better understand how acceleration and propagation mechanisms behave at high Z



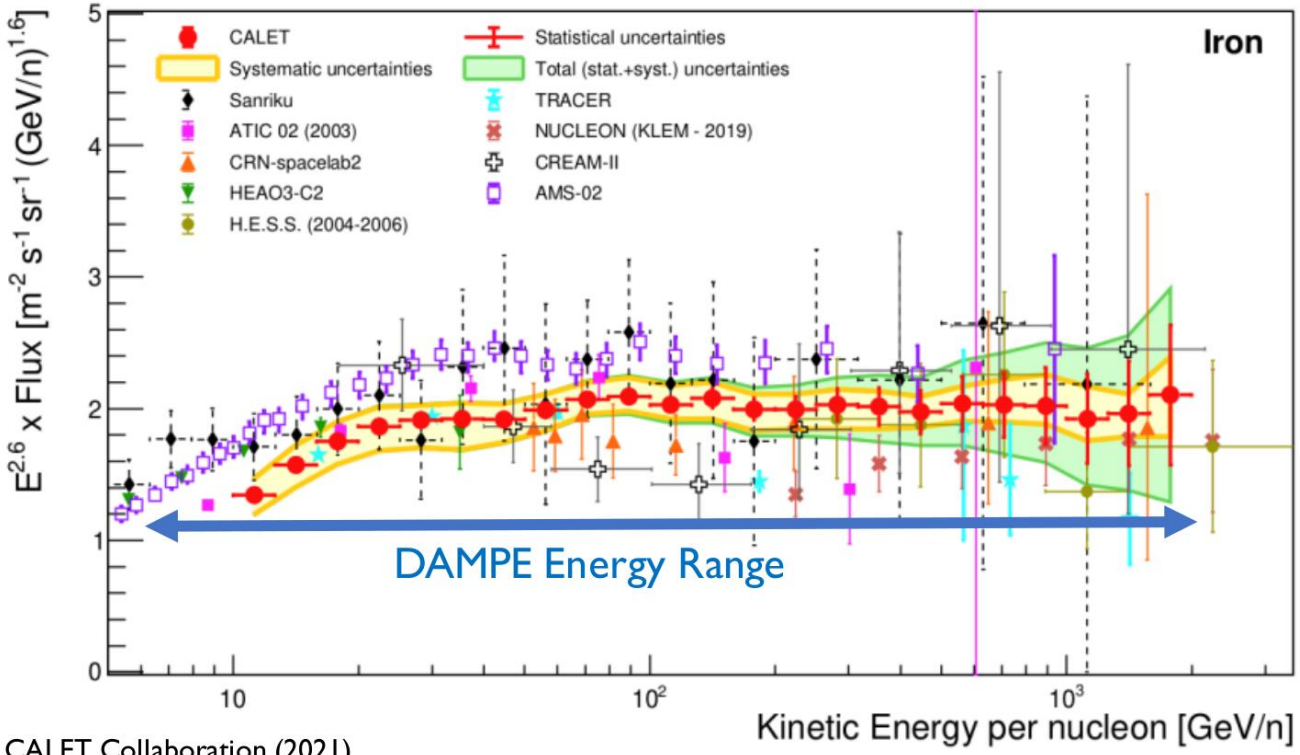
The Iron flux

- Spectrometers => Rigidity (p / Z)
- Calorimeters => Energy

- Fe AMS-02 energy range is very close to calorimetric one because of high Z

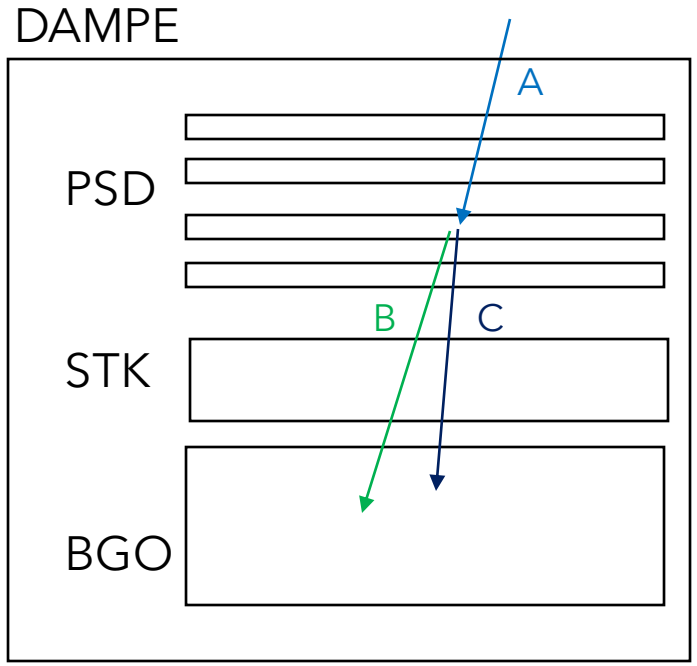
- **Difference** between AMS-02 and CALET fluxes below 70 GeV / n

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

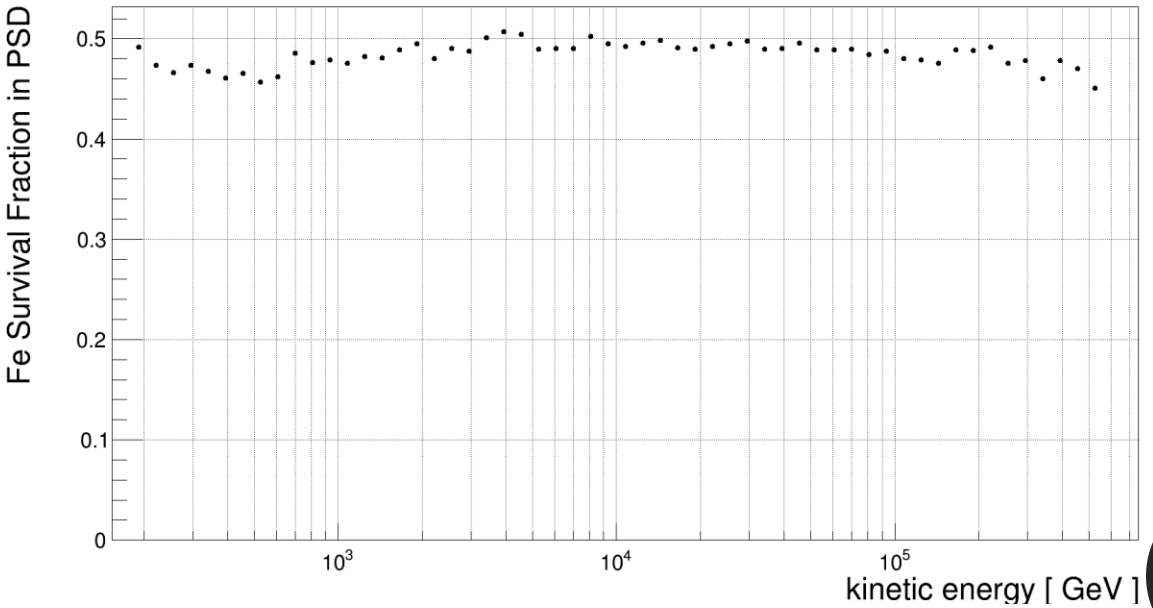


CALET Collaboration (2021)

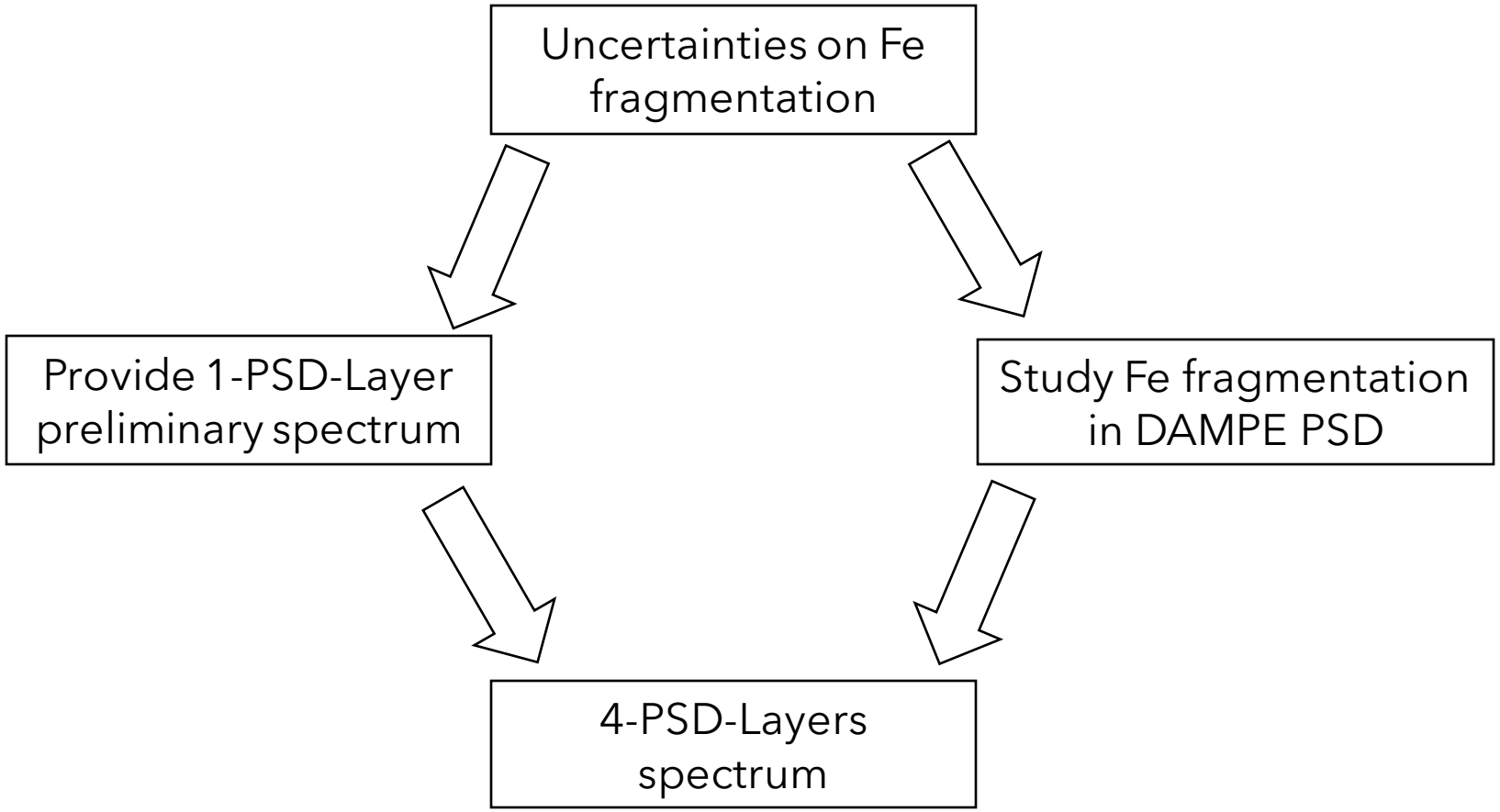
The Iron fragmentation



- In DAMPE, nuclei are identified by the energy deposit inside 4 layers of PSD ($\propto Z^2$):
  - Nuclei fragmented before hitting last layer are **not** correctly identified: $Z_A = Z_B + Z_C \Rightarrow Z_A^2 > Z_B^2 + Z_C^2$
- ~50% of Fe nuclei fragment inside DAMPE PSD
- Likely to have a significant difference between real data and Montecarlo
- Detector efficiency affected by fragmentation cross section uncertainties
- **Systematics propagated to flux**



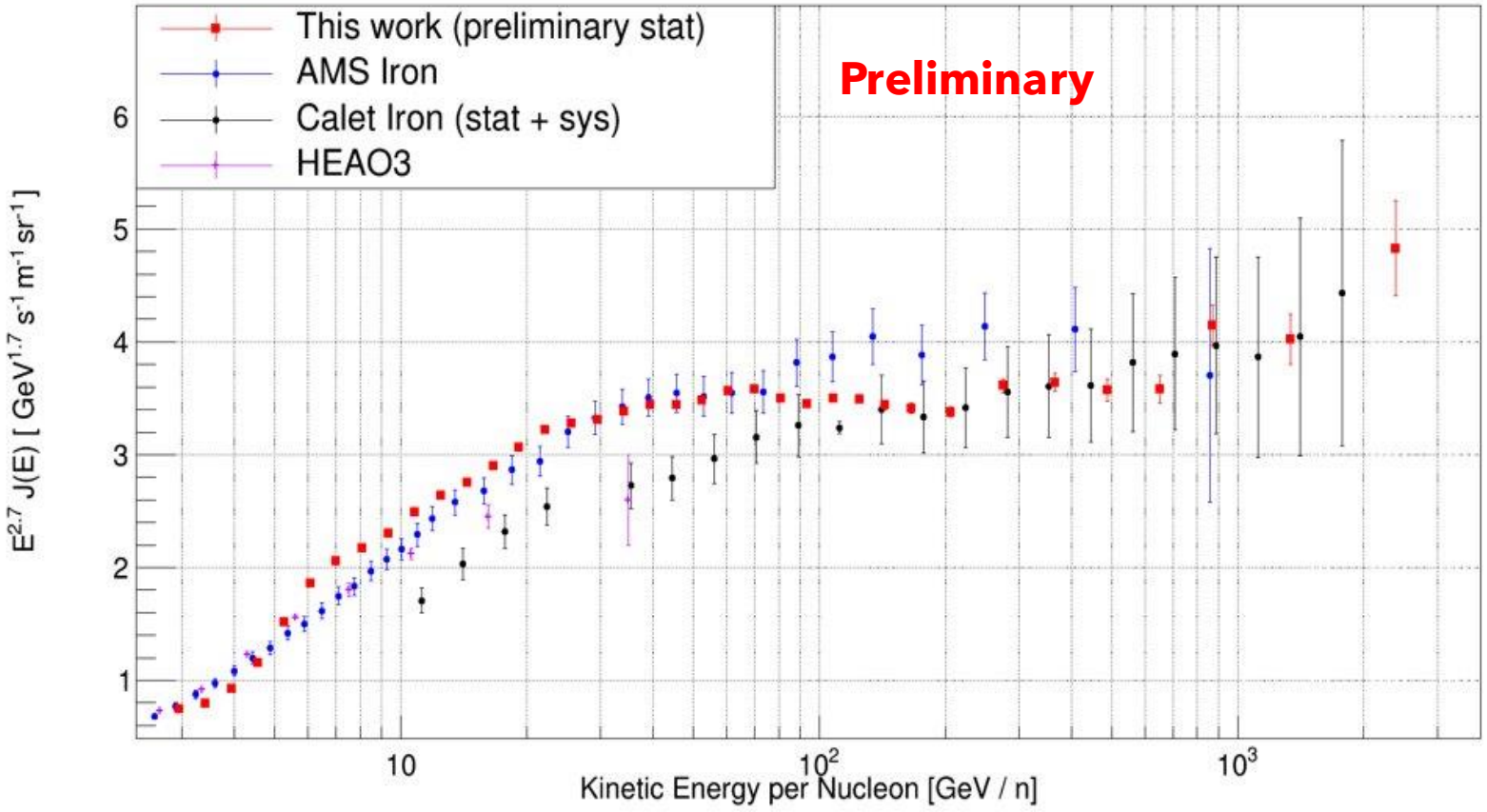
How to deal with it



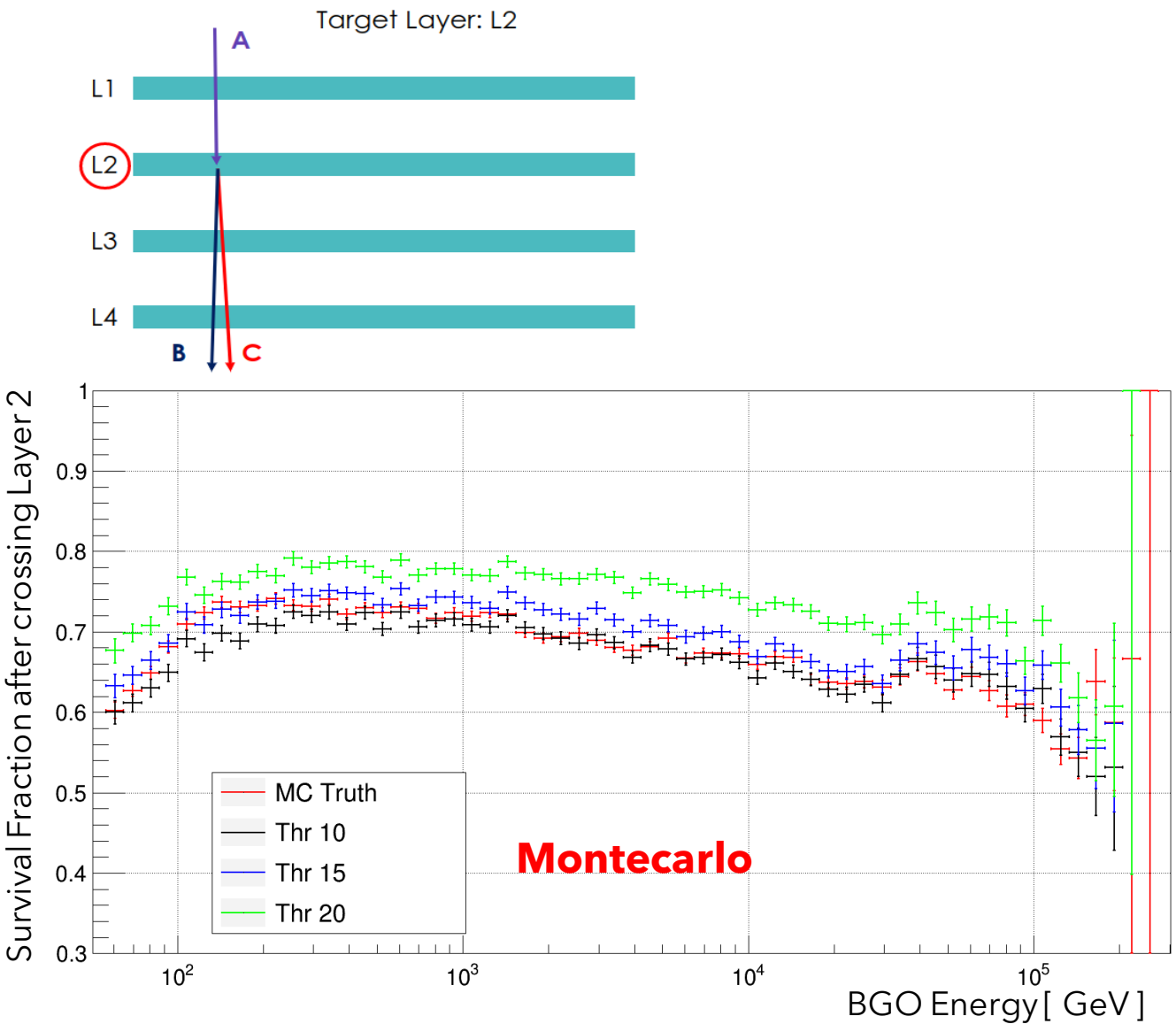
Status of 1-PSD-Layer analysis

Preliminary Flux:

- Compatible with AMS below 100 GeV / n
- Compatible with CALET above 100 GeV / n
- Systematics to be evaluated



Status of Fe fragmentation study



Steps for the study:

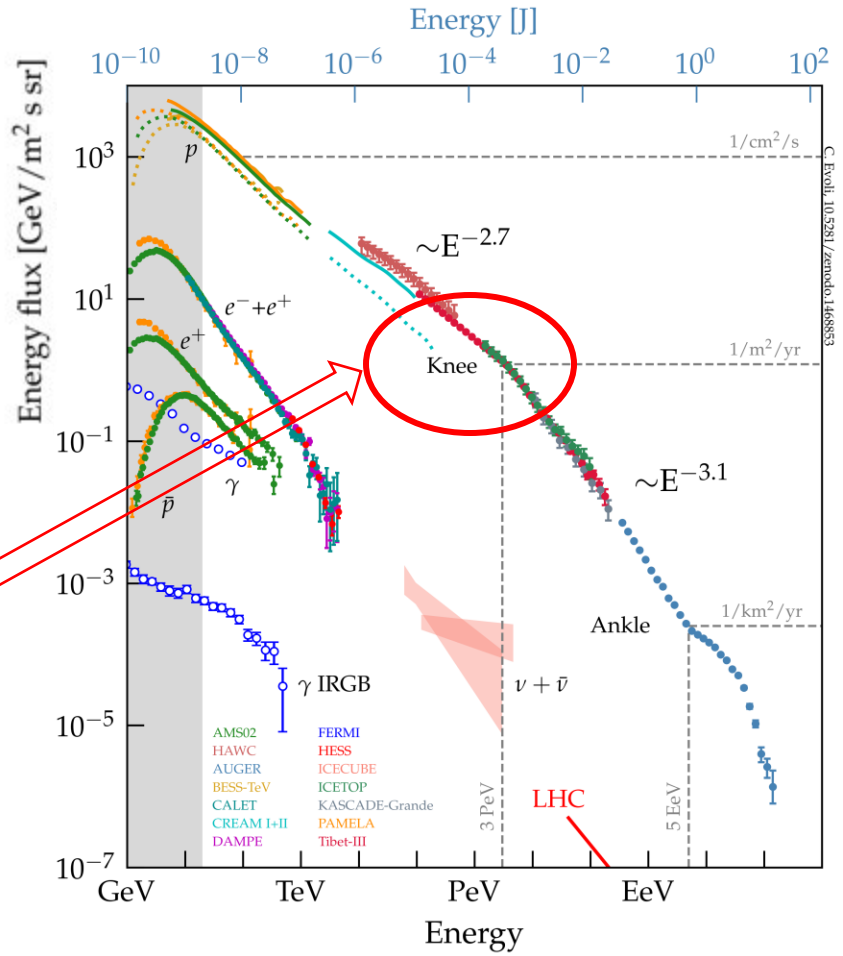
- Count events compatible with Fe signal in Layer 1 AND Layer 3 (~survived after L2)
- Count events compatible with Fe signal in Layer 1, releasing a signal on Layer 3 above a given threshold on measured Z (~all Fe events in L1 also crossing L3)
- Comparison with MC Truth: behaviour seems to be well replicated by setting threshold on Z within 10 and 15
- Working on apply same procedure to the flight data and FLUKA model

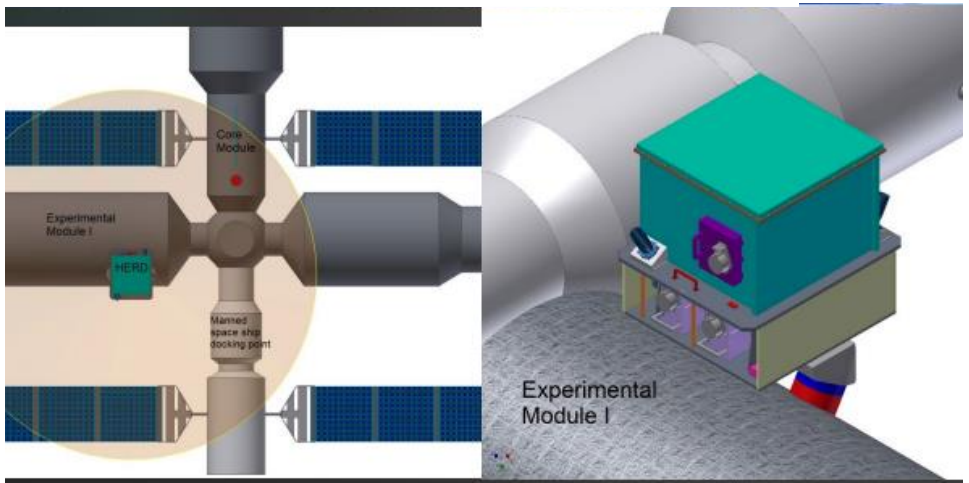
HERD
High Energy Radiation Detector

The HERD Experiment

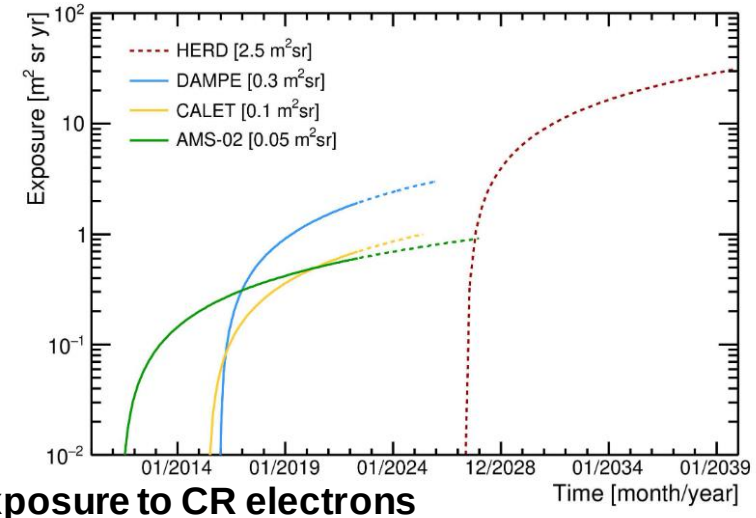
- To be launched in 2027
- Will be operative onboard the Chinese Space Station
- 5 sensitive faces

- Scientific goals:
  - Measurement of CRs up to the *knee* (PeV scale)
  - Measurement of electron spectrum up to 10 TeV
  - Gamma monitor and full sky survey
  - Indirect dark matter searches





The HERD Experiment

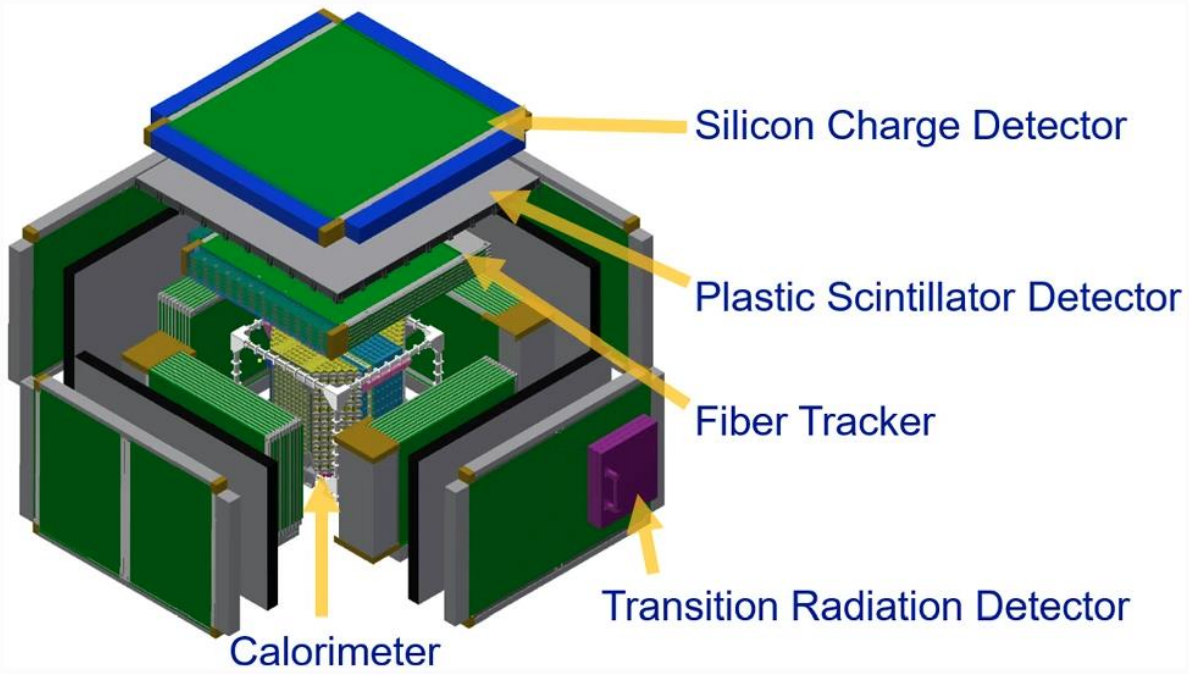


Exposure to CR electrons

	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 detector response to TeV protons
- SCD -> charge measurement
- PSD -> photon anticoincidence + redundancy on charge measurement (**R&D in GSSI/LNGS**)
- FIT -> track reconstruction
- CALO -> energy measurement and shower imaging (LYSO cubes)

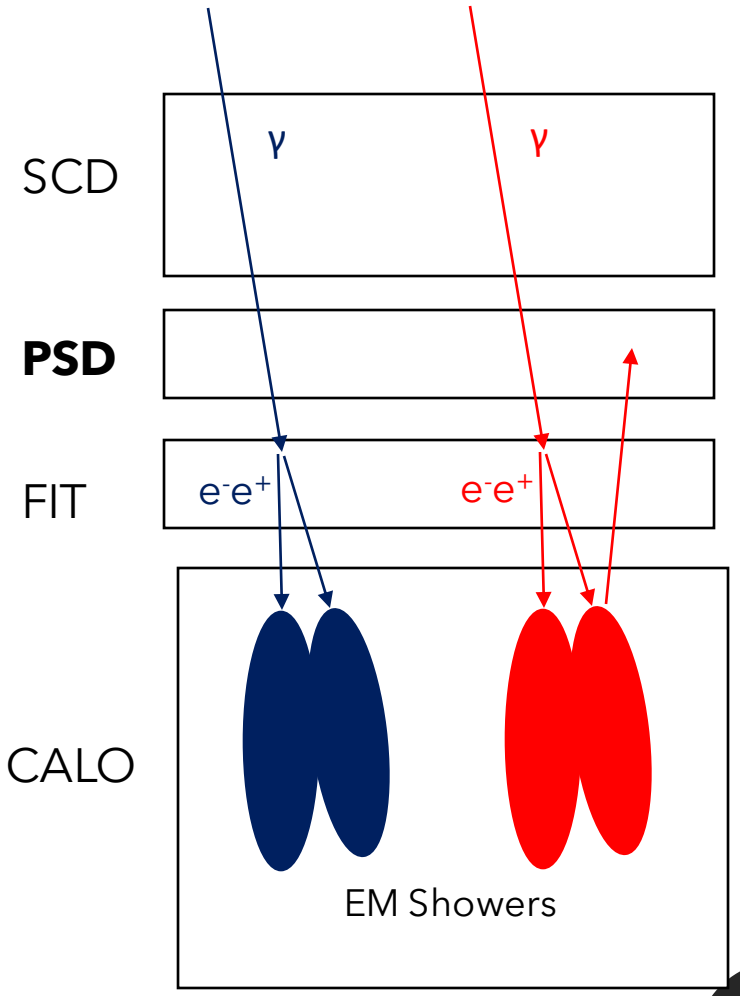


PSD Backsplash study

- **Backsplash** can affect PSD charge measurements
  - Fake Vetoes in Low Energy Gamma trigger (50 MeV- 10 GeV)
  - Systematically increasing nuclei charge measurements

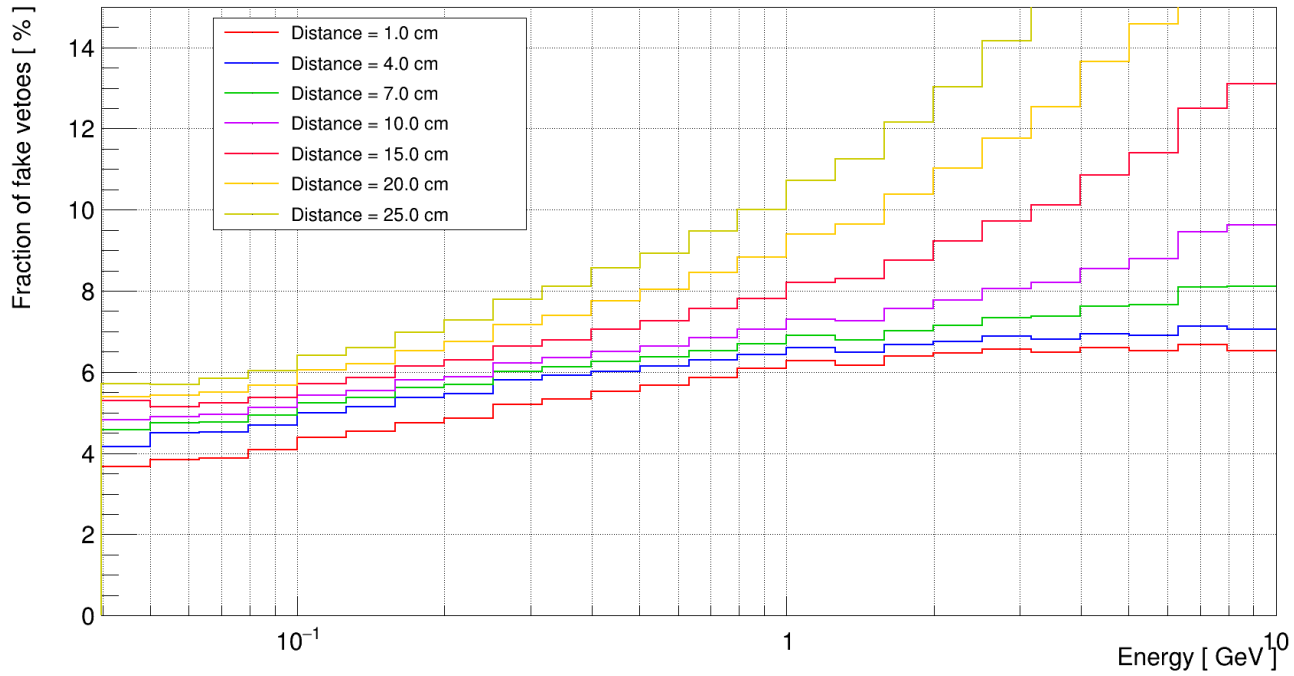
- Find optimal PSD layout for backsplash reduction while keeping trigger busy time as low as possible

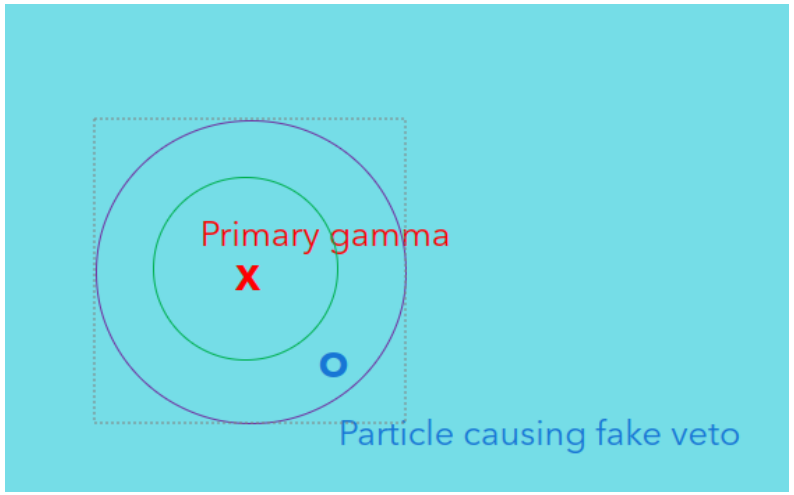
- Preliminary results for γ



PSD Backsplash study

- Find particles releasing signal over threshold (1/3 MIP) within defined radii from primary particles' impinging point
- Latter definition also includes electron-positron pairs converted in the material from sub-detectors placed on top of PSD





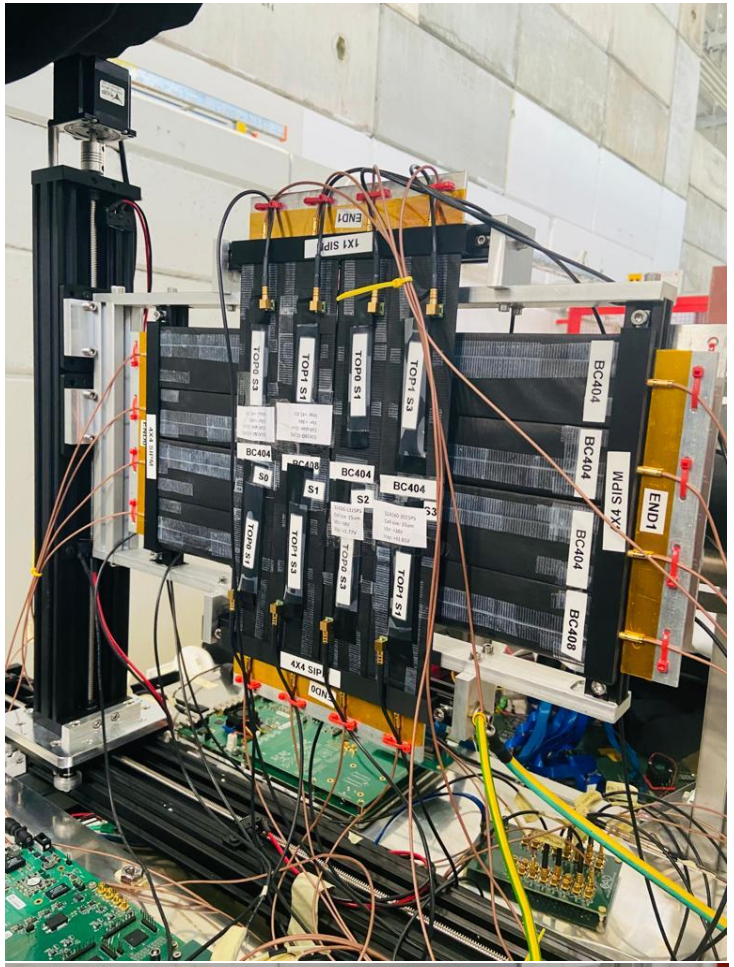
- LEG Trigger should look for charged particles within a surface of ~300 cm^2

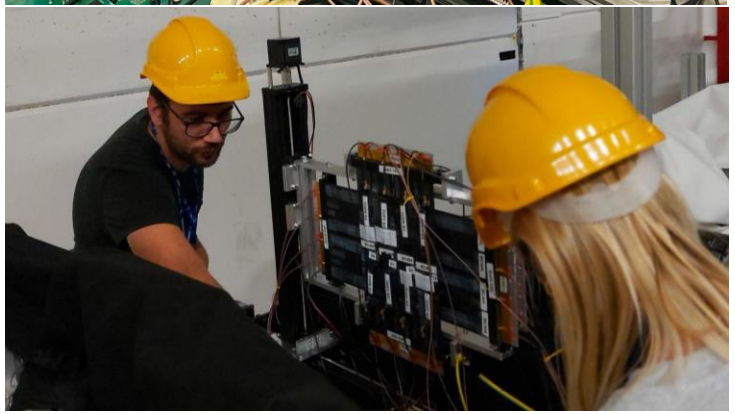
Lab Activities

- Prototype construction for the beam tests 2021
- Worked with DAQ (Data AcQuisition) board firmware and data processing
- Shifter for Beam Tests @ CERN PS in November 2021 and September 2022

Assembled Prototype
Beam Test 2021

Beam Test @CERN PS
September 2022





Summary

- I'm involved in both DAMPE and HERD experiments

- DAMPE:
  - Obtained preliminary Iron spectrum with further study in progress
  - Study of how Iron fragmentation affect it

- HERD: Full detector simulations and analyses:
  - PSD Backsplash (in progress)
  - Lab activities, PSD Prototype
  - HERD Software Framework, implementation of trapezoidal shaped bars
  - PSD Bar Hermeticity study

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, **poster** on DAMPE Iron analysis
7. 107th Congresso SIF, 13–17 September 2021, **talk** on DAMPE Iron analysis
8. Radiation Protection security course by LNGS on 22 Sept. 2021
9. SiPM Radiation Workshop, 25-29 April 2022
10. INFN School of Statistics 2022, 16-20 May 2022
11. 21st Int. Symp. on VHE Cosmic Ray Interactions, 23-28 May 2022 **talk** on DAMPE results
12. 12th Cosmic Ray International Seminar, 12–16 September 2022, **talk** on HERD R&D
13. 6th International Symposium on Ultra High Energy Cosmic Rays, local phd&postdoc **staff**
14. CERN **beam test shifter**, November 2021 and September 2022
15. DAMPE **simulation shifts** for a total of 14 weeks
16. Collaboration meetings (DAMPE 2020&2022, HERD 2022, NUSES 2022)
17. AP student representative in ***Commissione Paritetica Docenti-Studenti*** since 8 Jan. 2020
18. Participation in **SHARPER** (European researcher night) on 24 Sept. 2021 and 30 Sept. 2022

Publications

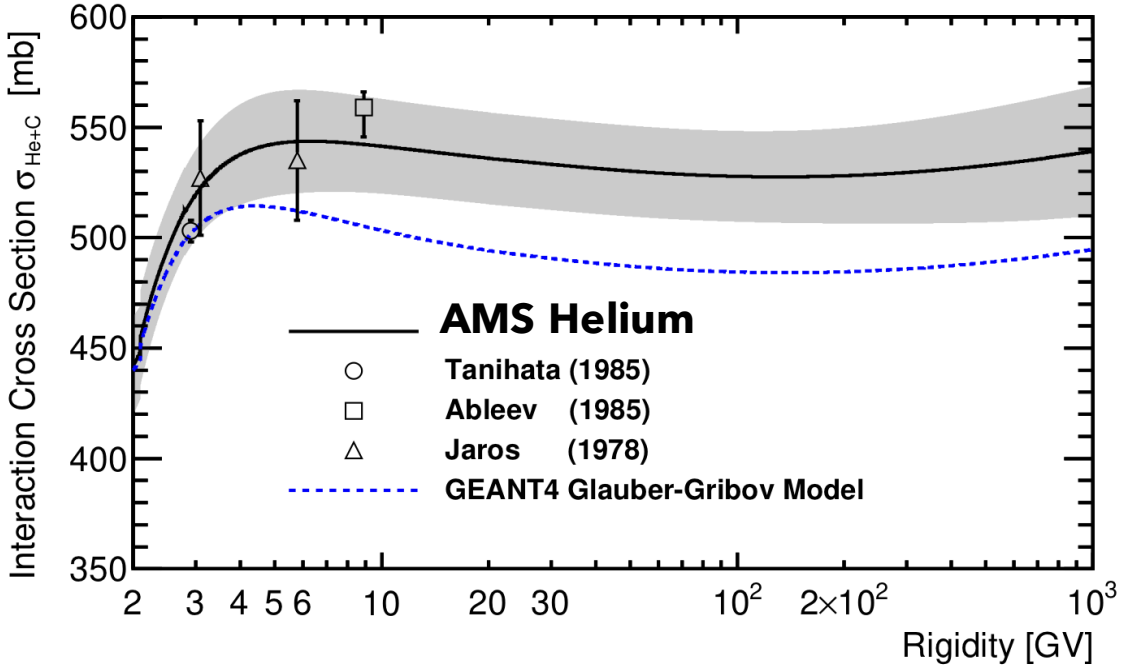
1. H. Menjo et al, *The results and future prospects of the LHCf experiments*, PoS ICRC2019 (2019) 349
2. F. Alemanno et al, *Measurement of the Cosmic Ray Helium Energy Spectrum from 70 GeV to 80 TeV with the DAMPE Space Mission*, Phys. Rev. Lett. 126 (2021) 201102
3. D. Kyratzis et al, *The Plastic Scintillator Detector of the HERD space mission*, PoS ICRC2021 (2021) 054
4. L. Fariña et al, *Gamma-ray performance study of the HERD payload*, PoS ICRC2021 (2021) 651
5. Z. Xu et al, *Direct measurement of the Cosmic Ray Iron Spectrum with the Dark Matter Particle Explorer,* PoS ICRC2021 (2021) 115
6. F. Alemanno et al, *Observations of Forbush Decreases of Cosmic-Ray Electrons and Positrons with the Dark Matter Particle Explorer,* ApJL 920 (2021) L43
7. I. De Mitri et al, *Selected results from the DAMPE space mission*, Phys. Atom. Nucl. 84 (2021) 947-955
8. S.C. Wen et al, *The sensitive unit calibration of the EM calorimeter for Dark Matter Particle Explorer in orbit*, NIM A 1028 (2022) 166390
9. F. Alemanno et al, *Search for gamma-ray spectral lines with the Dark Matter Particle Explorer*, Sci. Bull. 67 (2022) 679-684
10. F. Alemanno et al, *Search for relativistic fractionally charged particles in space,* Phys. Rev. D 106 (2022) 063026
11. L. Silveri, *Results on high energy galactic cosmic rays from the DAMPE space mission,* accepted Sci. Post. Proc.

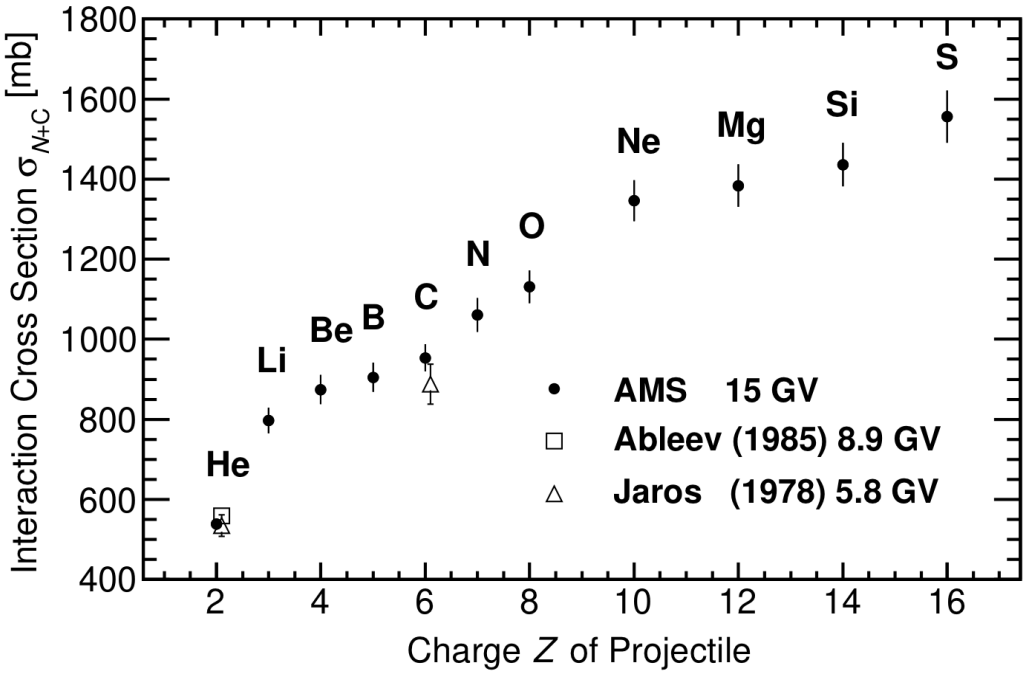
Backup

The Iron fragmentation

- Nuclei interaction models at high energy are not well verified by the experiments: cross section of interaction with materials affected by large uncertainties

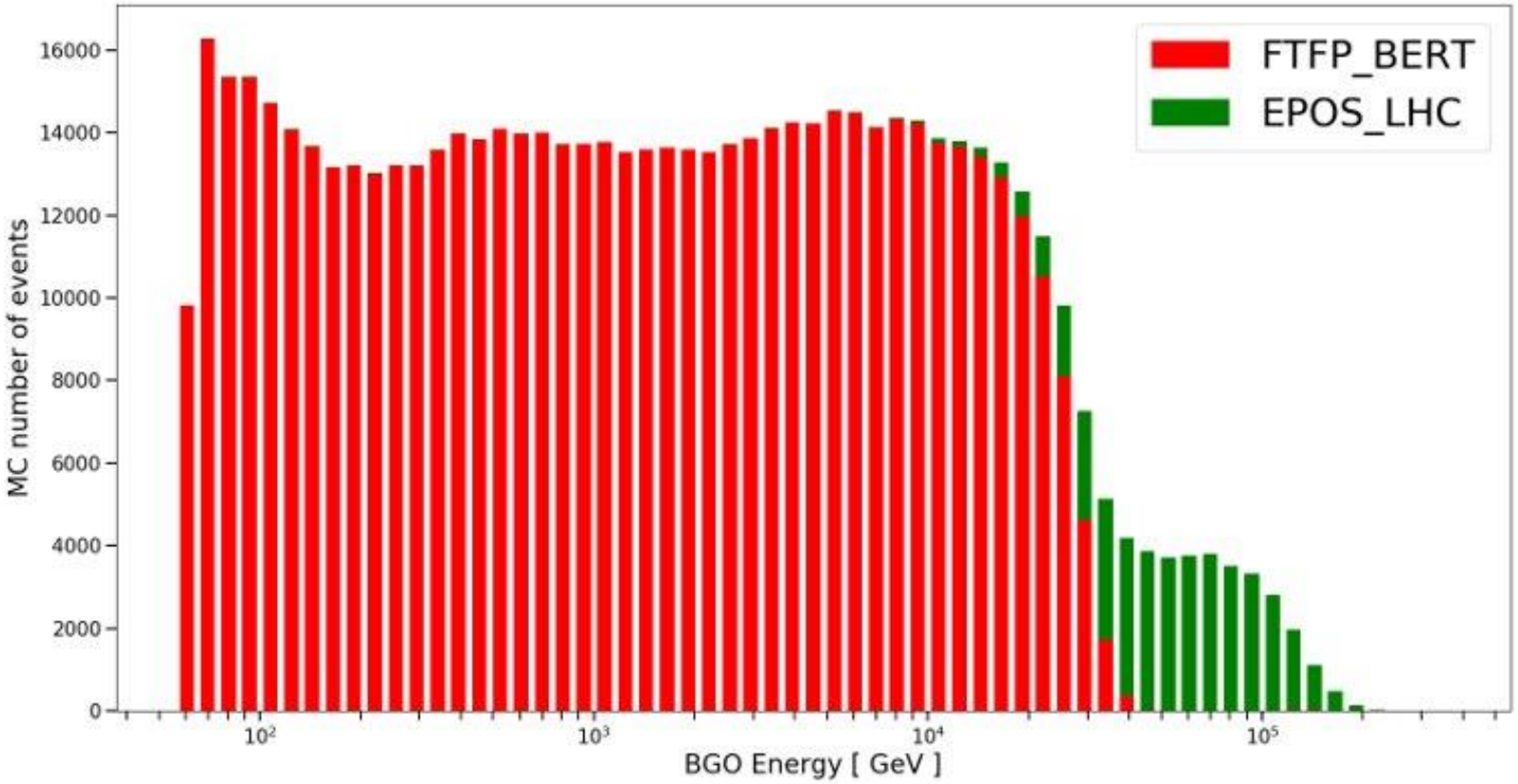
- Heavier nuclei have larger interaction cross section with respect to lighter ones





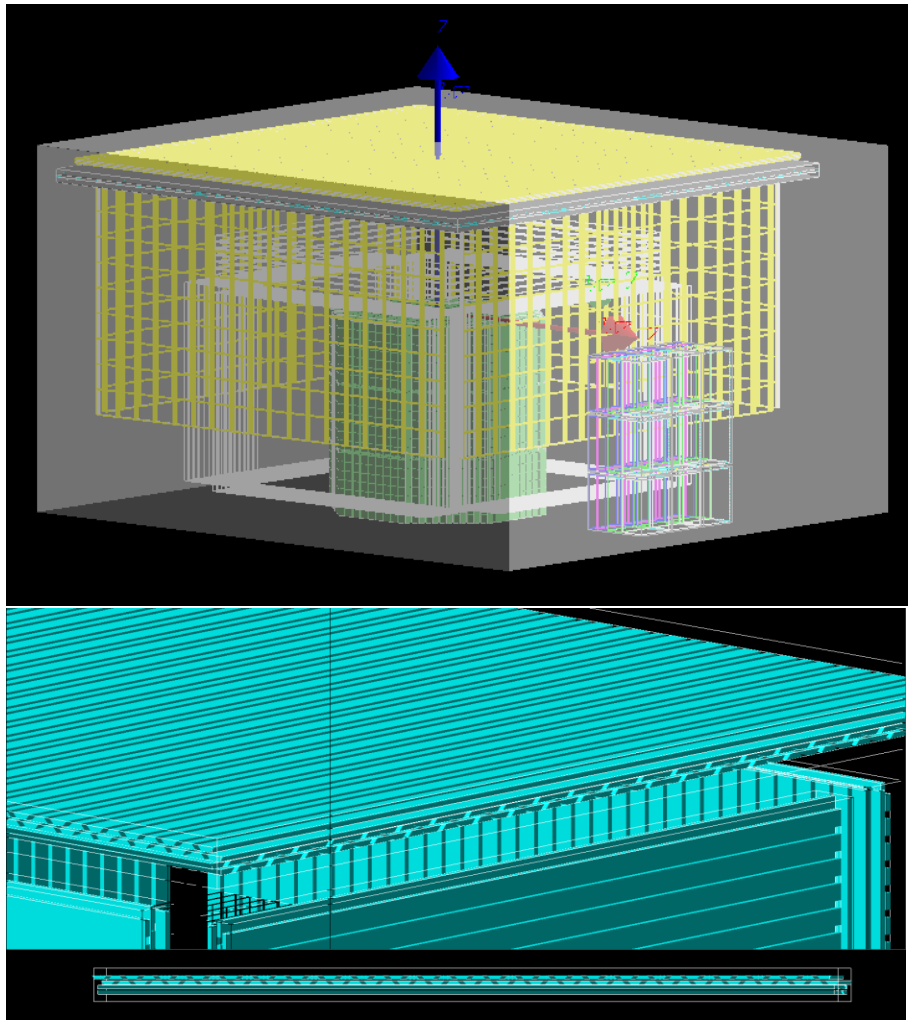
MC Models used in Fe analyses

Number of events after preselection cuts



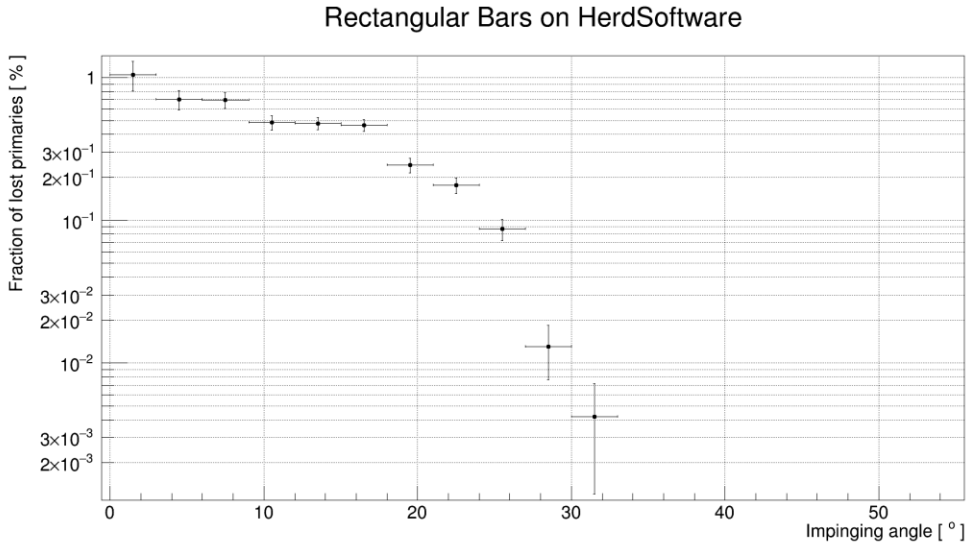
HERDSoftware

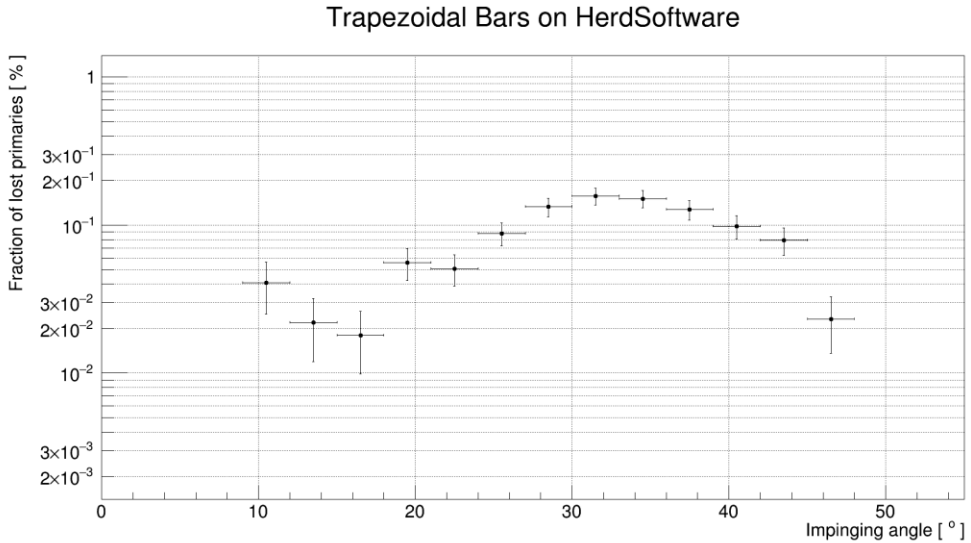
- Simulation and analysis framework
- Developed and maintained within the collaboration
- Provides interfaces to GEANT4 and ROOT
- Provides routines to retrieve energy deposit in each subdetectors and track reconstruction
- I **developed parts of the code used for bars** (together with A. Parenti)



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°