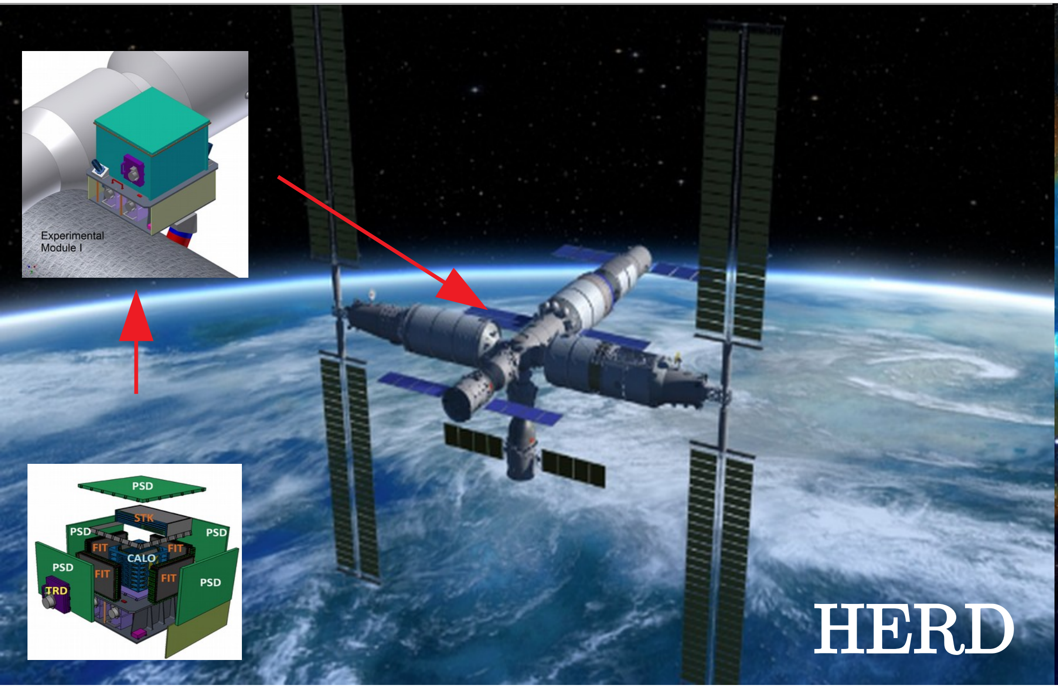
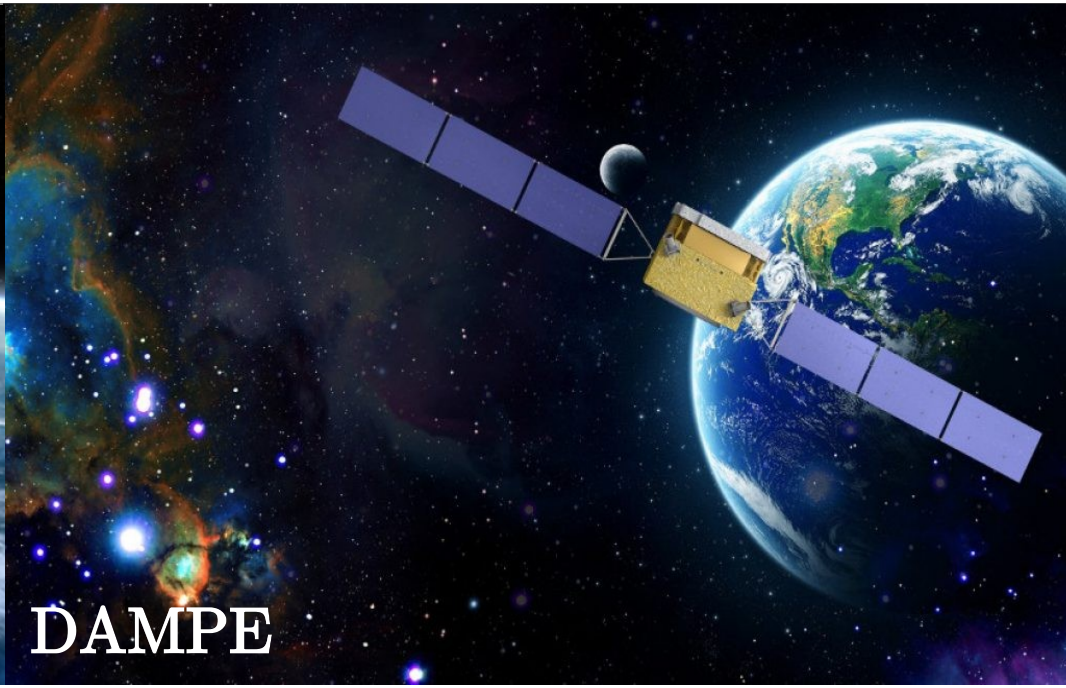
2nd Year Activity Report





Cosmic ray studies with the DAMPE and HERD space missions: medium mass nuclei (BCNO group)

Dimitrios Kyratzis

Advisor: Prof. Ivan De Mitri   Co-Advisor: Dr. Felicia Barbato

Gran Sasso Science Institute (GSSI) & INFN-LNGS

Overview

DAMPE

Physics perspective on BCNO nuclei

The DArk Matter Particle Explorer Space Mission

DAMPE activities

Ongoing BCNO analysis study

HERD

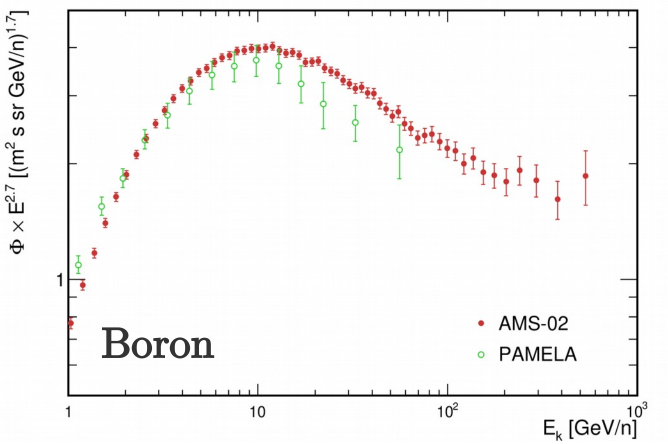
The High Energy cosmic-Radiation Detector space mission

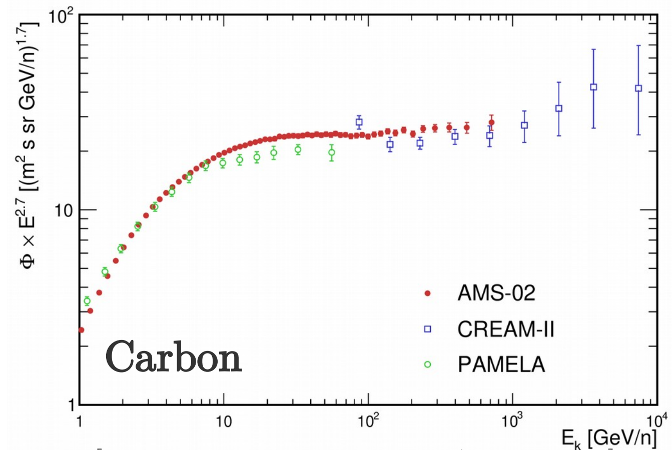
PSD hardware activities at GSSI – LNGS

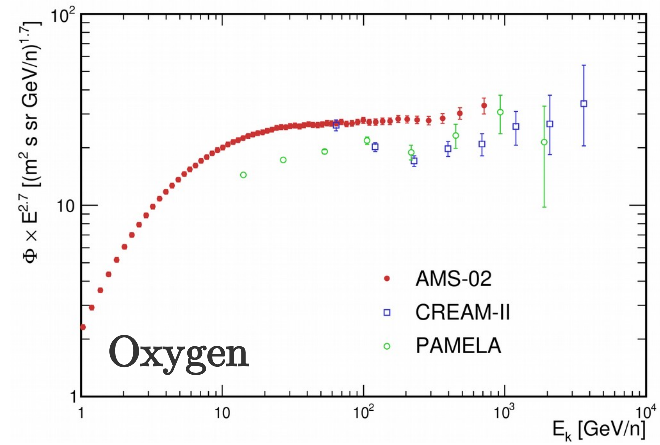
Upcoming activities and future plans

Physics perspective on BCNO physics

Identical rigidity dependence above 60 GV for He, C & O with progressive hardening above 200 GV







[CR data extracted from ASI CRDB]

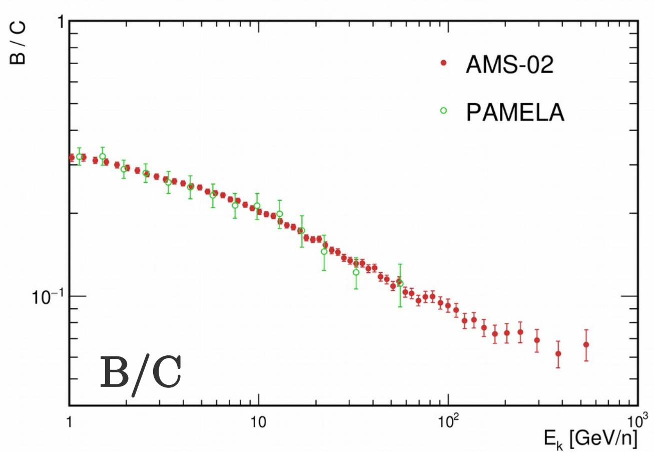
Extending the energy range for BCNO nuclei is important in understanding different aspects of the CR propagation mechanism

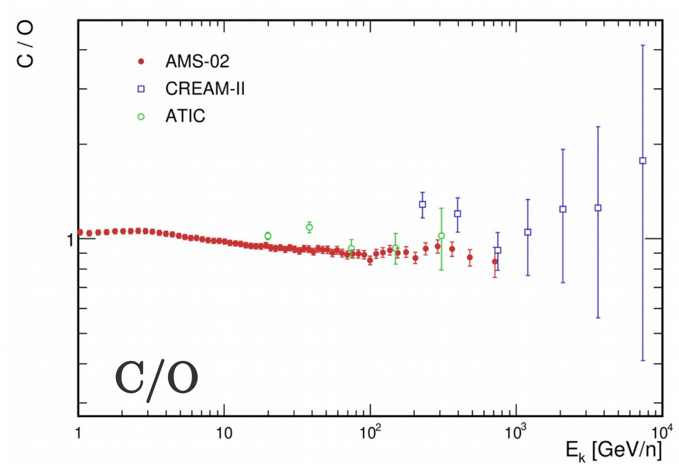
B/C used to quantify the propagation of galactic CRs

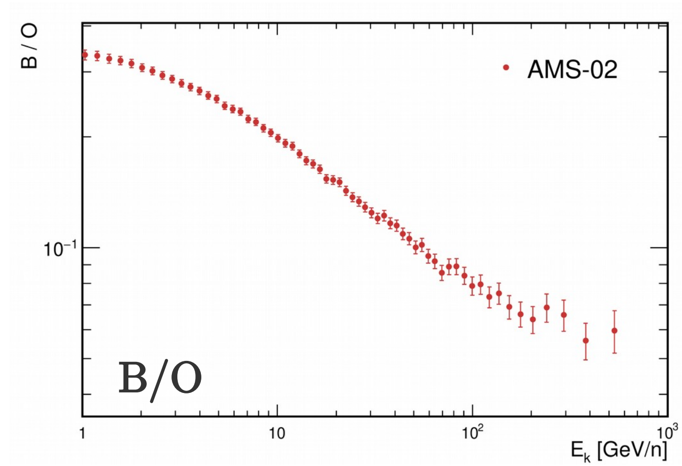
C/O departs from a flat behavior due to:

– Spallation processes more important for heavier nuclei

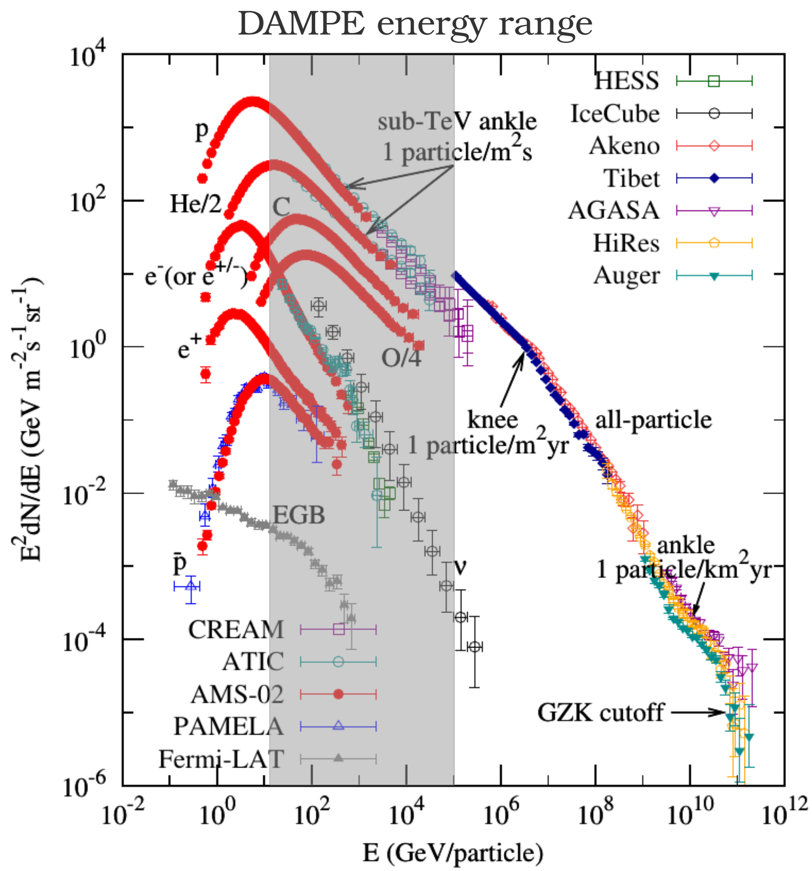
– 20 % of the Carbon flux at low energies contributed by Oxygen spallation.







The DAMPE space mission



Scientific Objectives

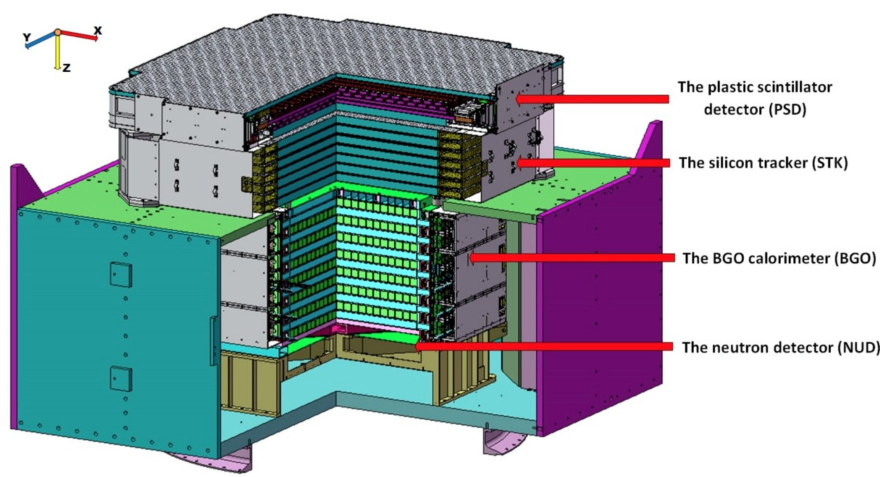
Particle acceleration & propagation of CRs in the Galaxy

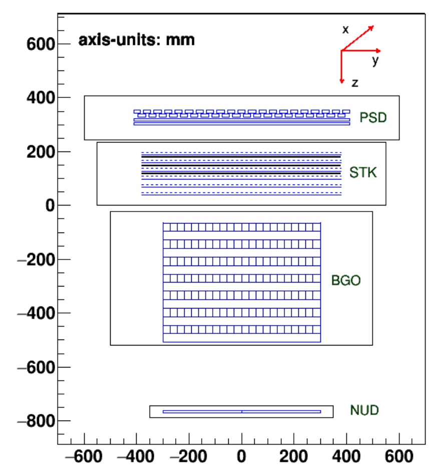
Gamma – ray emission from galactic & extragalactic sources

Indirect Dark Matter studies

Wide energy range
Improved energy resolution
Large acceptance

Astropart. Phys., 95, 6 [2017]





PSD: Anti – coincidence detector

STK: Particle tracker

BGO: Energy measurement

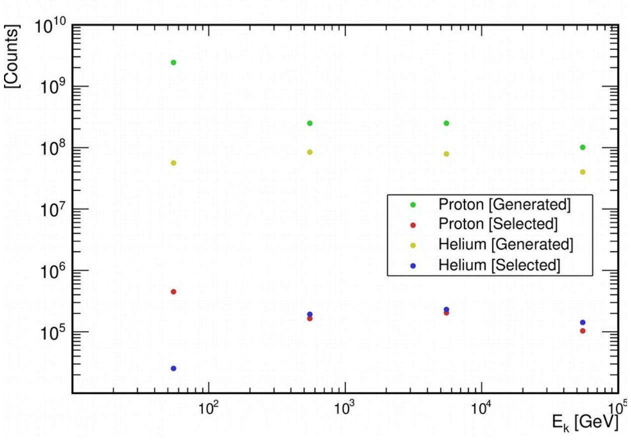
NUD: Further particle ID

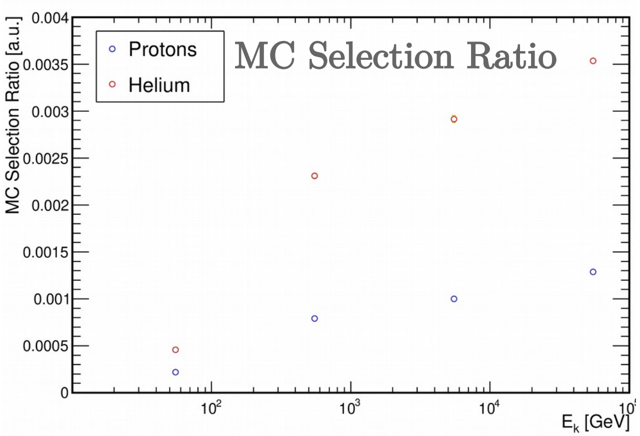
DAMPE activities

MC simulation group

Familiarizing with data-handling techniques

Supervision of multiple samples in computational clusters of Bologna, Bari and Geneva





Hadronic Analyses

Valuable experience gained from previous and ongoing analyses (p, He, p+He)

Calculation of MC events before and after all selections in p + He analyses

Thus receiving insight on the available and proposed additions in BCNO statistics

Preparation for BCNO

Analysis is ongoing

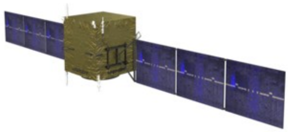
Gathering and verifying all analysis components regarding Flight & MC

Data skimming procedures used in order to boost computational performance

Done Ongoing Proposed	Total / Target [Number of events in Millions]						
Energy Range	B10	B11	C12	C13	N14	N15	O16
100 GeV – 1 TeV	50.85/50	58.4/50	100/100	20/20	20.25/20	21.09/20	100/100
1 – 10 TeV	50/50	50/50	106.9/100	20/20	20/20	20/20	100/100
10 – 100 TeV	50/50	50/50	~20/100	20/20	20/20	20/20	~80/100
> 100 TeV	25	25	50	10	10	10	50

Ongoing BCNO Analysis Study

First look on BCNO nuclei with 44 months of Flight data



Based on selection cuts implemented in the p+He analysis

with minimal additions/changes

Exclusion of SAA flight data and electron events

$E_{BGO} > 100$ GeV

HET activation

BGO pre-selections:

Reconstructed track contained in first & last BGO layer

Shower maximum not in the BGO border

Removal of side entering events

BGO – STK match:

$\chi^2 < 25$, & $\Delta(\theta_{track} - \theta_{BGO}) < 25^0$

At least 1 cluster in X/Y plane 0 of STK

XZ and YZ projections on top of the STK < 200 mm & BGO < 60 mm

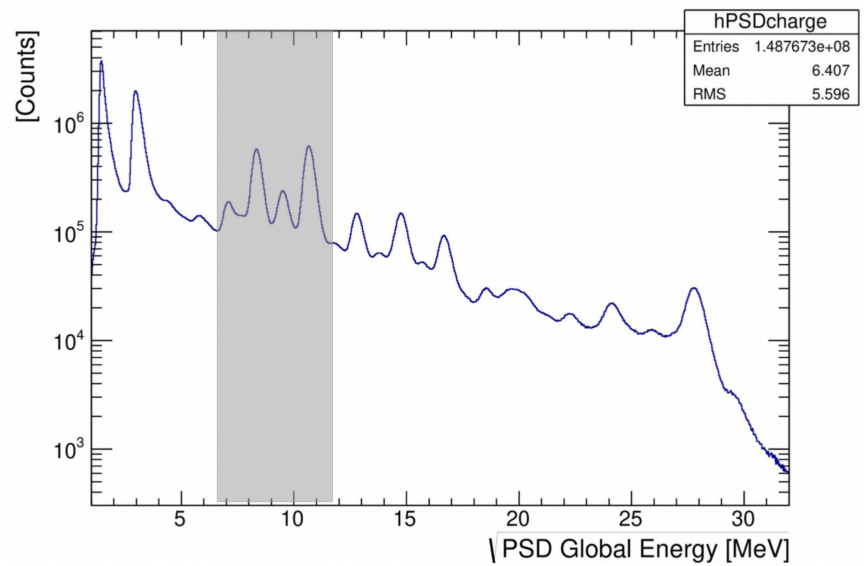
Track ID should be the same for XZ and YZ

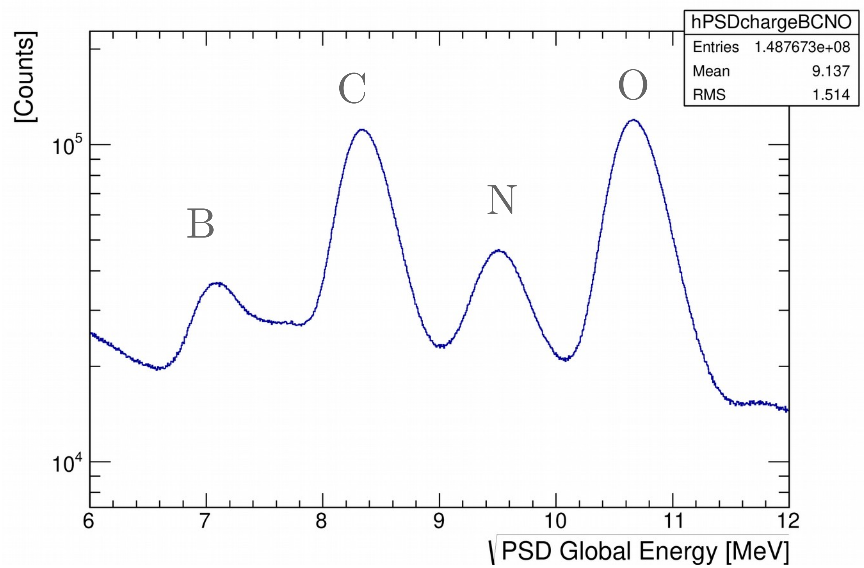
PSD fiducial cut:

Track projection on the first PSD layer < 400 mm

PSD – STK match

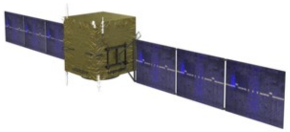
Loop on PSD bars to select the bar crossed by the STK in both XZ and YZ



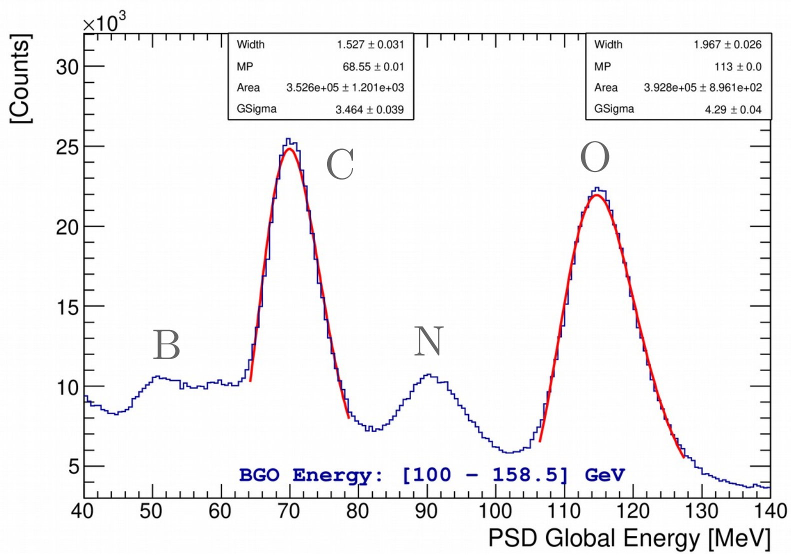


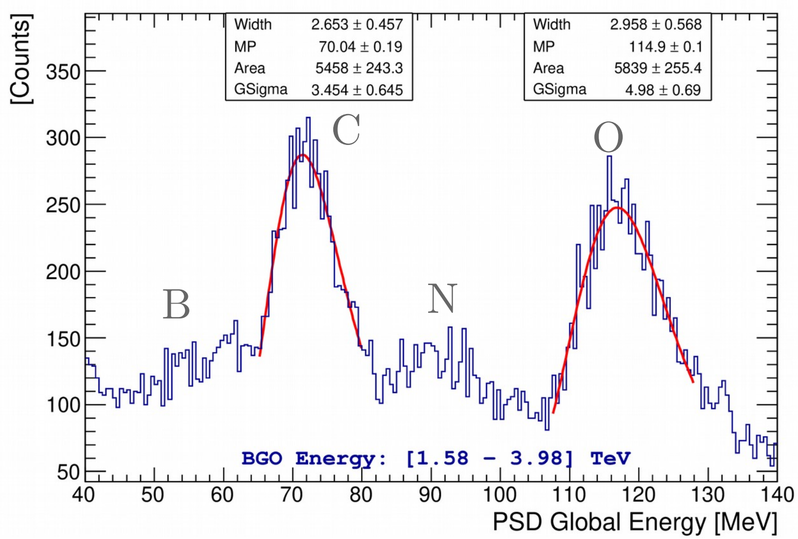
Ongoing BCNO Analysis Study

First look on BCNO nuclei with 44 months of Flight data



Landau convoluted with Gauss fits of C & O nuclei in the PSD charge spectrum

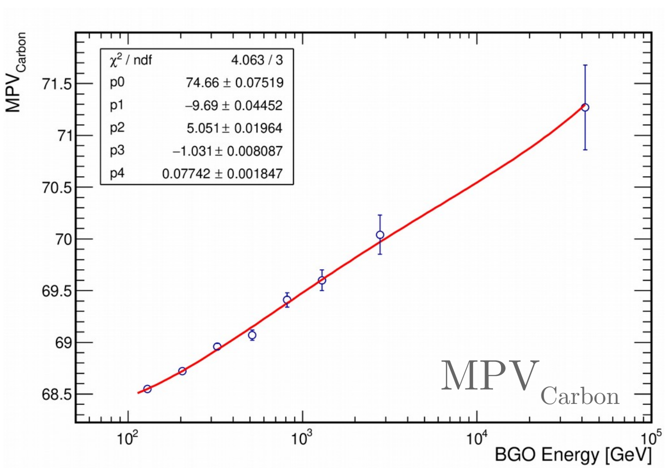


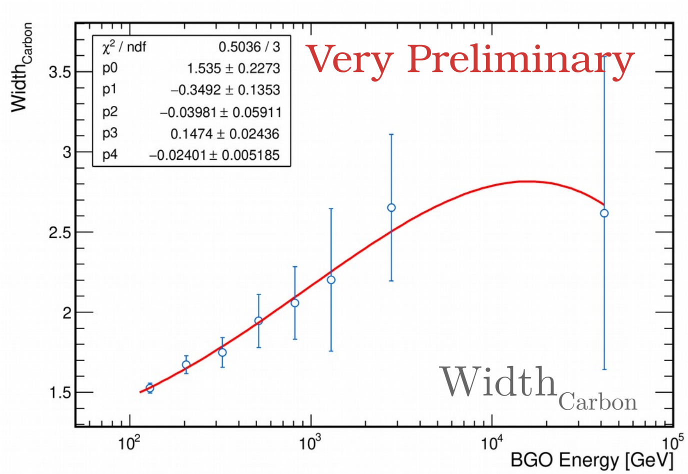


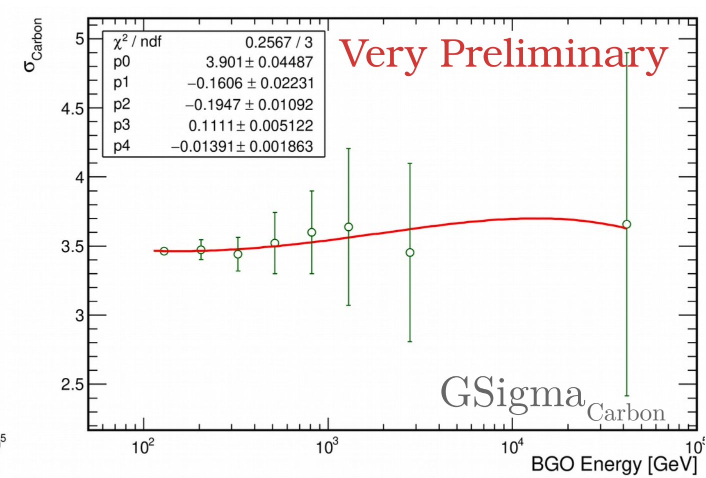
Fits performed in the energy range of 100 GeV to 80 TeV

Ranges referring to energy deposited in the BGO calorimeter

The extracted Landau MPV, width and Gaussian sigma results are used in determining the PSD charge







Ongoing BCNO Analysis Study

Main Goal:

Measuring the BCNO spectra from **100 GeV – 100 TeV** [particle energy]

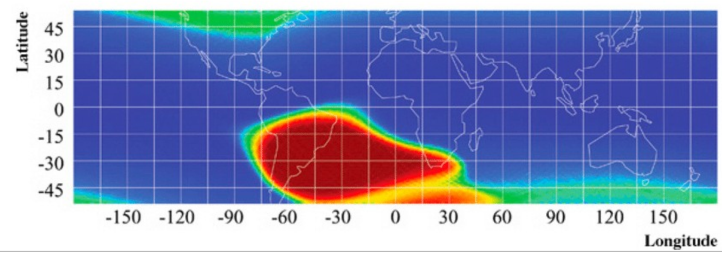
Utilizing flight data from January 1st, 2016 to September 31st, 2020 – **57 months of data**

Pre–selection of events:

Omitting data acquired through the **SAA.**

Elimination of events entering the detector from the **bottom and side**.

Ensuring core containment of the shower in the calorimeter.



Charge selection

CR nuclei should be found in the interval of **$5 < Z < 8$** in order to optimize charge selection and performance.

Track selection

Determining a track **close to the center of the STK cluster.**

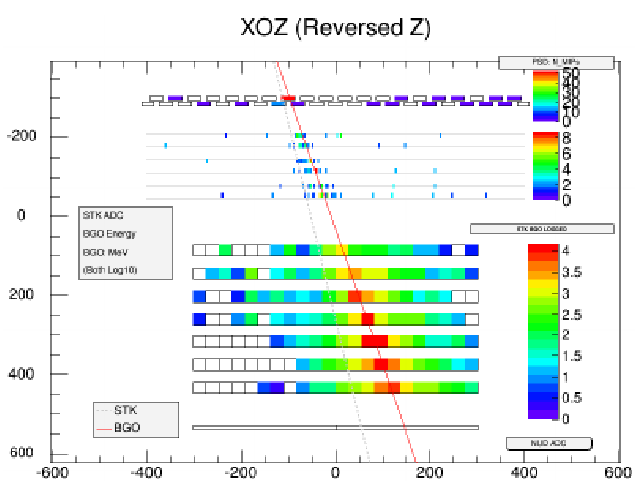
Each candidate STK track should have **maximum energy deposition along its path.**

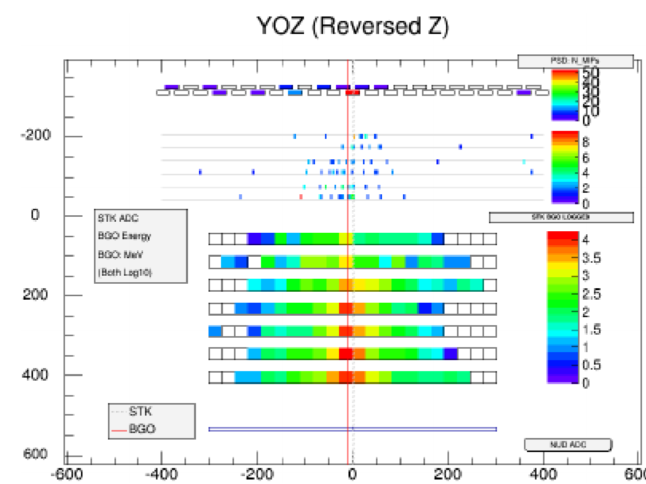
Ongoing and Future work

Ongoing efforts are focused on optimizing all selection cuts according to the BCNO analysis needs

All tests will be applied both on MC and Flight data

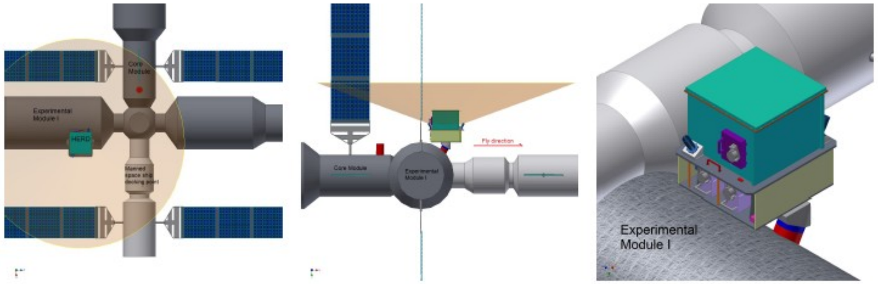
Understanding similarities/differences between different analyses is crucial.





The HERD space mission

The **H**igh **E**nergy cosmic-**R**adiation **D**etector is a novel space-borne experiment to be installed onboard the CSS around 2026 [lifetime 5 – 10 yrs]



(a) Top view (b) Side view (c) Oblique view

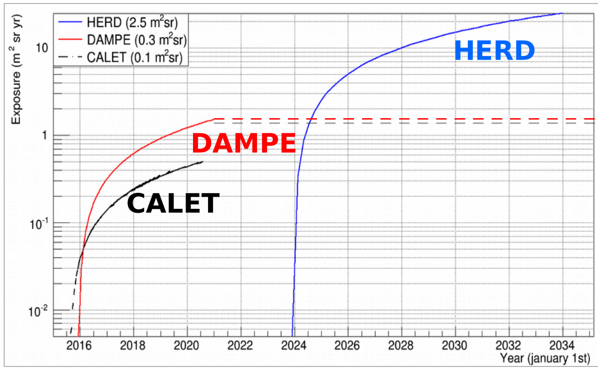
Scientific Goals:

Precise CR spectra and mass composition up to PeV energies

Gamma – ray astronomy and transient studies

Electron spectra up to tens of TeV

Indirect Dark Matter searches



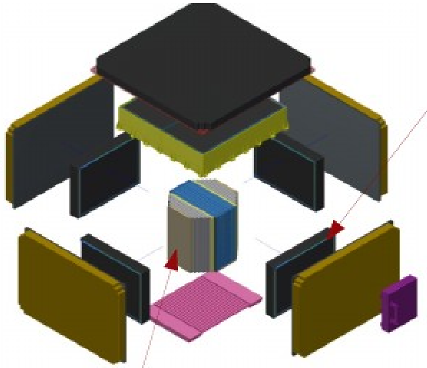
One order of magnitude upgrade in exposure wrt to current gen CR experiments:

15 – 20 m^2 sr yr

D.K., Il Nuovo Cimento 43C (2020) 117

PSD, 5 sides
γ–ray/charged particles' ID
Charge measurement

STK (SSD+W), 5 sides
Charge measurement
CR trajectory
Gamma conv. & tracking



Baseline Design

CALO: 3-D
e/γ/CR Energy
e/p separation

TRD
TeV CR
calibration

Updated Detector Configuration

Featuring **additional CALO readout with photodiodes** (Calocube) for cross-calibration and reduction of systematics

Implementation of **Fiber Trackers (FIT)** as an **alternative to the STK**

Inclusion of **outermost SCD surrounding the PSD layers**

Based on previous experience with AGILE, AMS-02, FERMI & DAMPE missions

PSD Activities at GSSI – LNGS

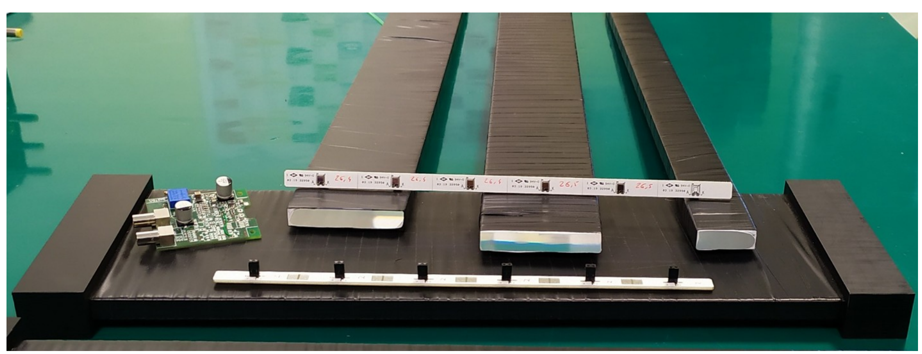
Configuring various scintillator bars coupled with AdvanSiD/Hamamatsu SiPMs.

- Purification, wrapping and coupling procedures carefully carried out at GSSI – LNGS
- Specifically used: [50 x 3 x 1 cm^3] bars coupled with 1 SiPM/side
- Ongoing measurements also include: [50 x 6 x 1 cm^3] bars coupled with 2 SiPMs/side
- Collaboration with other institutes in Italy in order to determine the optimal geometry.

Scintillator bar inventory:

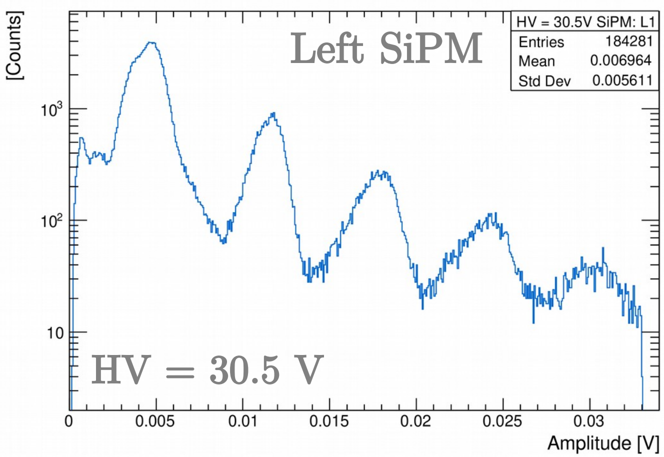
- [50 x 12 x 1 cm] – 3 SiPMs/side
- [40 x 12 x 1 cm] – 3 SiPMs/side
- [50 x 6 x 1 cm] x 2 – 2 SiPMs/side
- [50 x 3 x 1 cm] x 2 – 1 SiPMs/side
- [50 x 2 x 1 cm] x 2 – 1 SiPMs/side

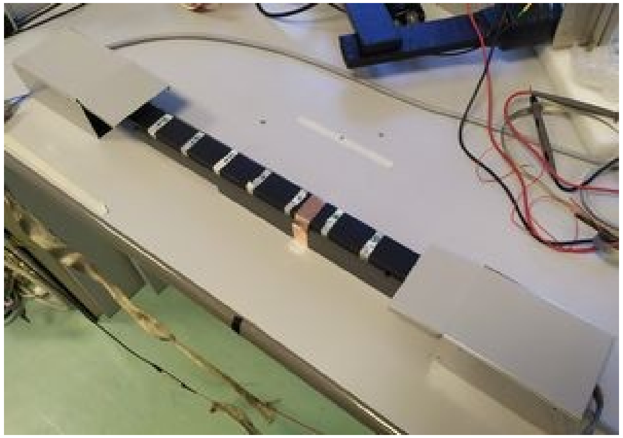
\+ further scintillator & SiPM additions

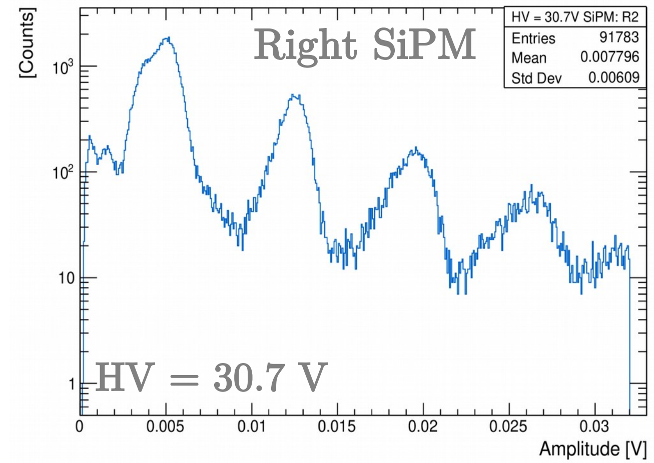


PSD Activities at GSSI – LNGS

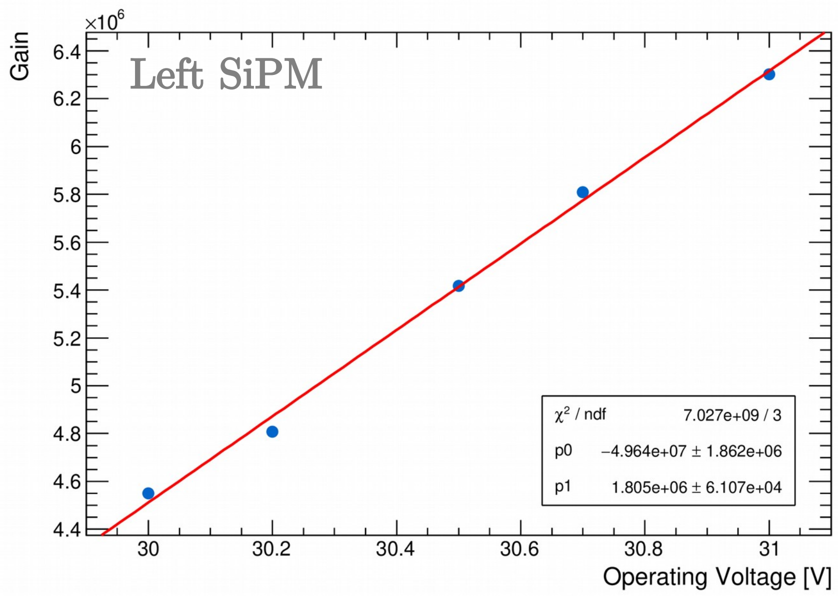
Measurements performed to define the working point, understanding different aspects and characteristics of both **scintillators and SiPMs**



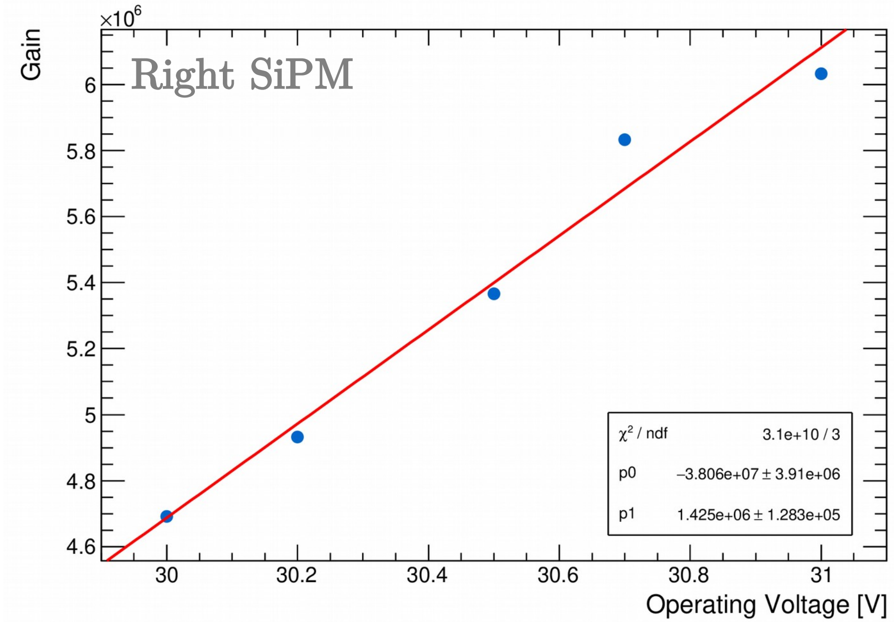




Spectral measurements in a **range of different voltages** in order to define each **SiPM's gain**



SiPM Gain calculation

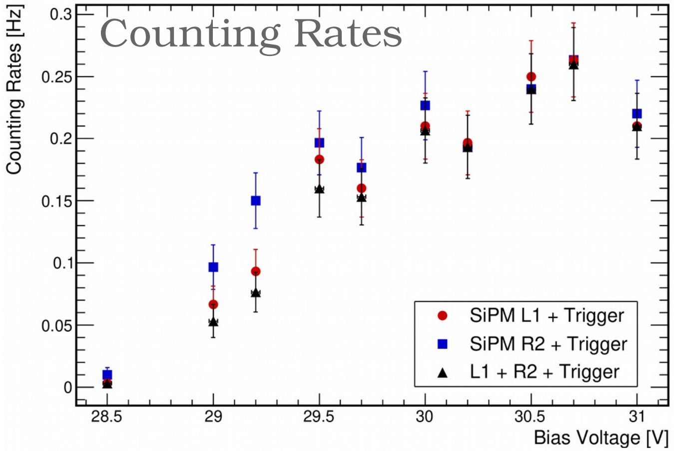


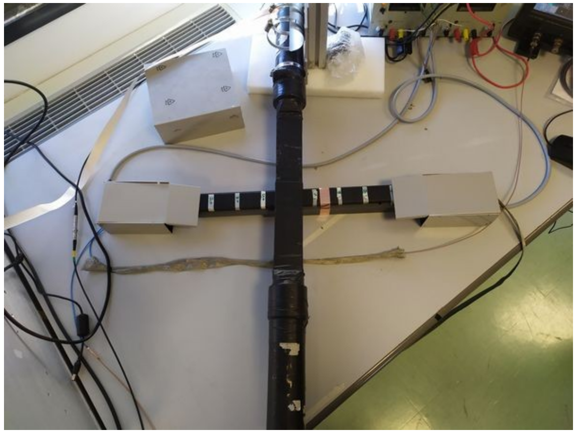
GSSI

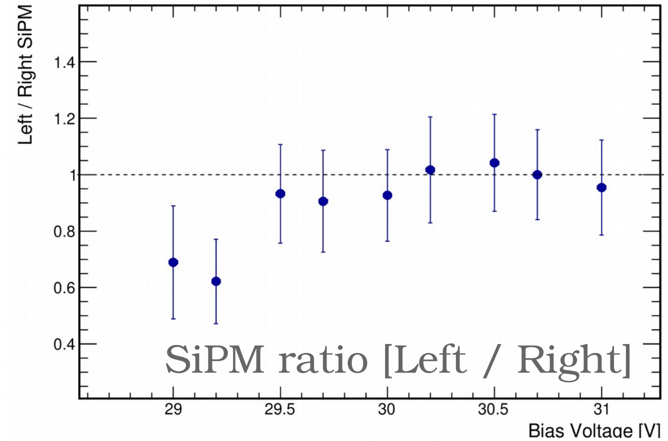
PSD Activities at GSSI – LNGS

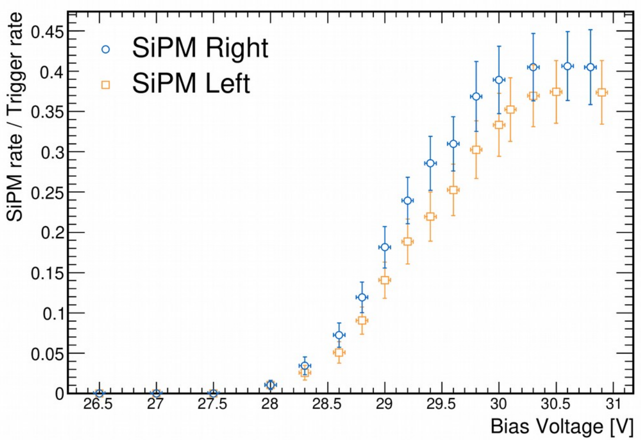
INFN LNGS

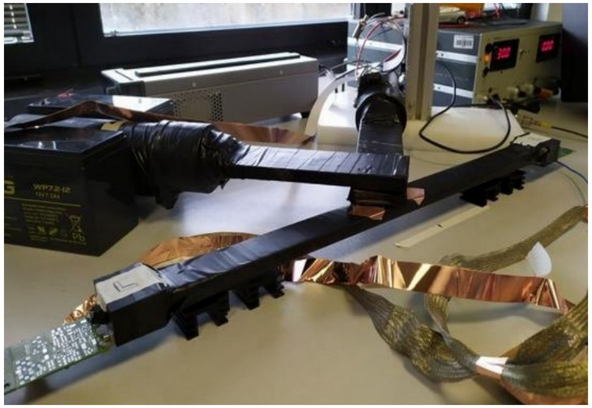
Coincidence setups to obtain the optimal working point

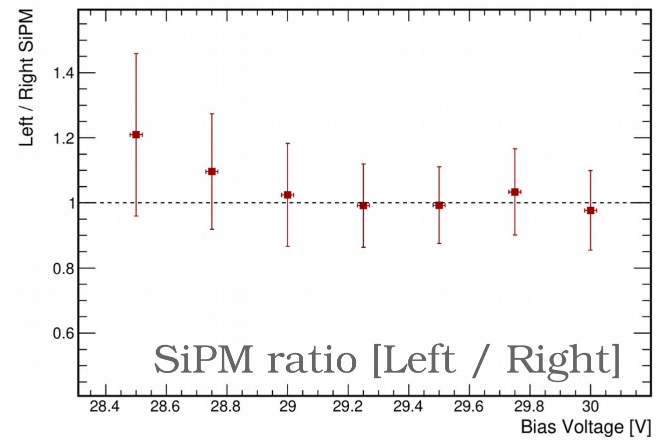


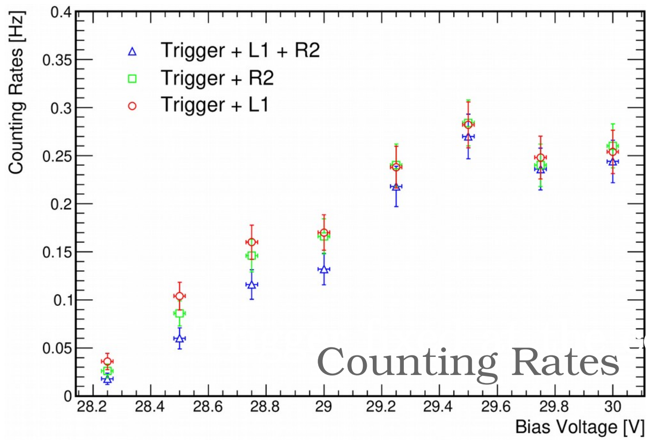






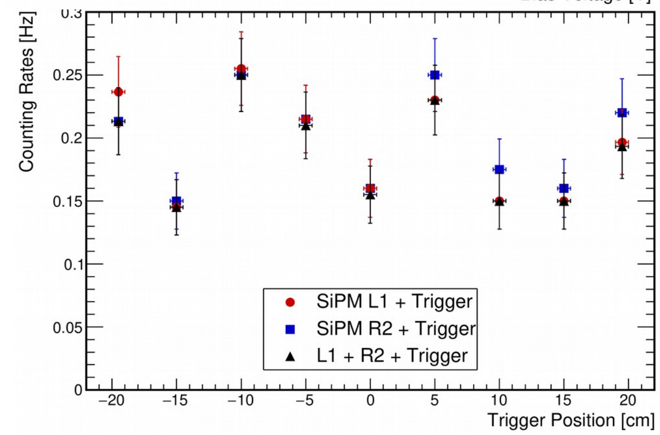






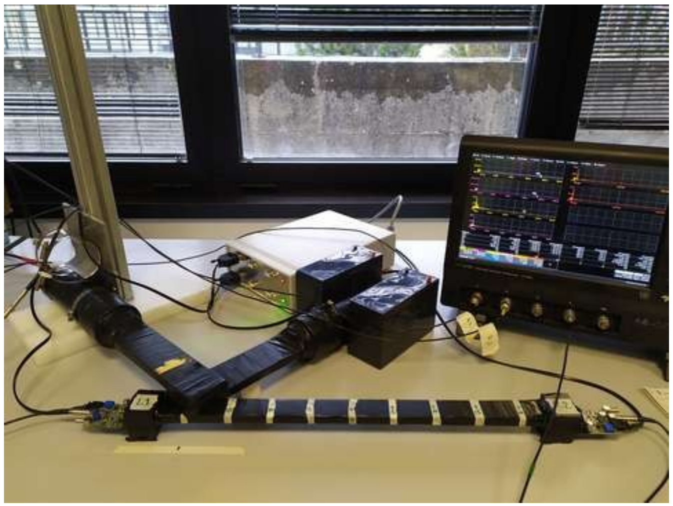
Configuration:
Trigger + left SiPM
Trigger + right SiPM
Trigger + left + right SiPMs

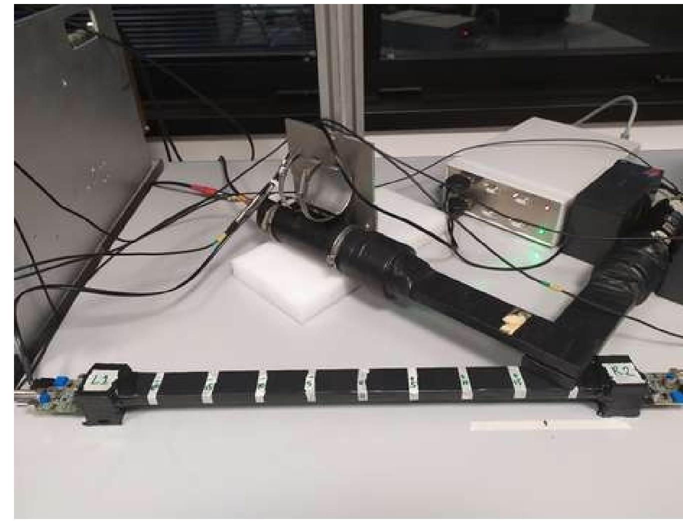
Measurements acquired in different trigger positions along the bar



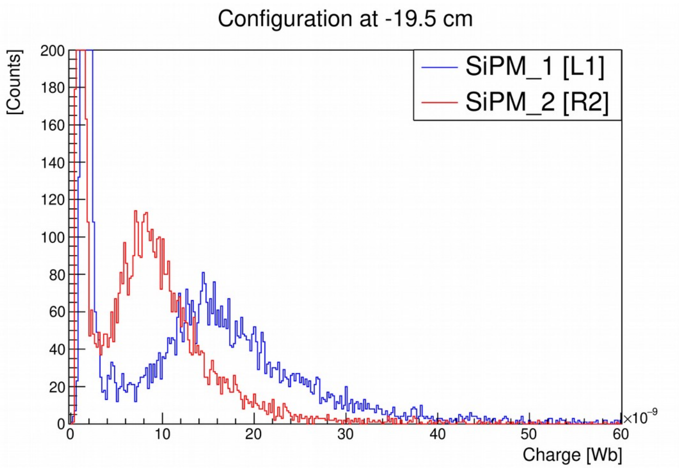
PSD Activities at GSSI – LNGS

Signal distributions produced by CR muons in different positions along the bar

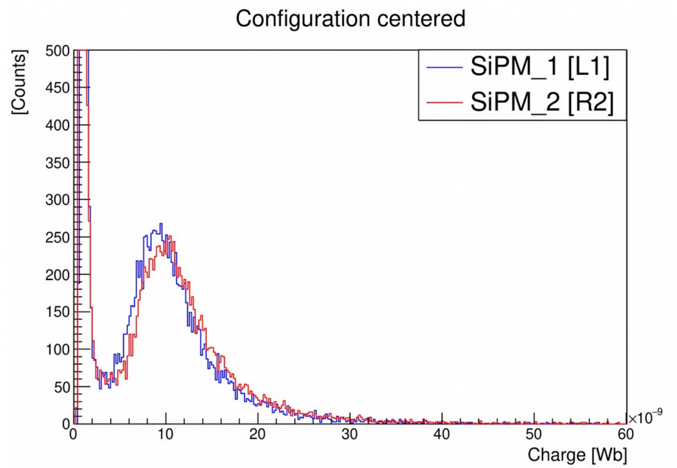




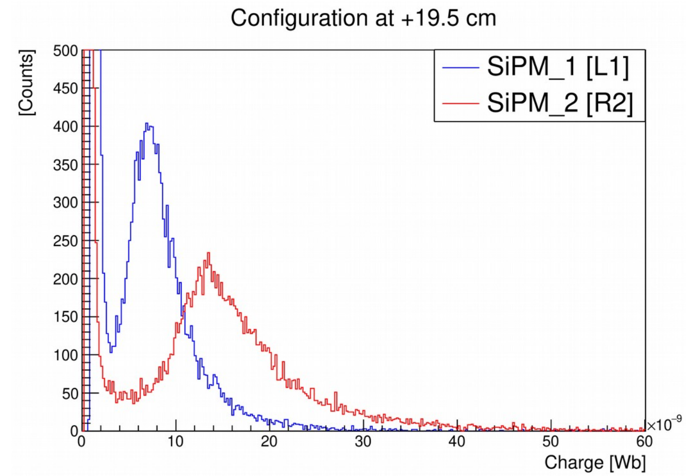
$V_{BIAS} = 30$ V, $V_{BD} \sim 26.5$ V



Trigger placed at -19.5 cm

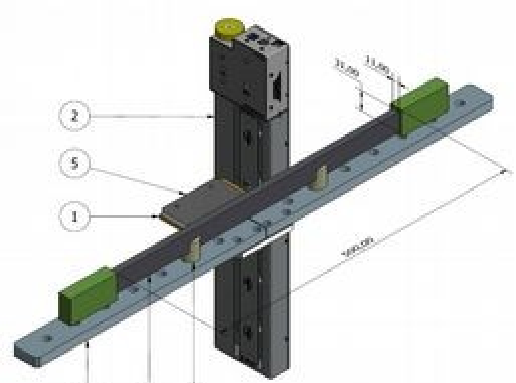


Trigger placed at the center



Trigger placed at +19.5 cm

Upcoming activities & future plans

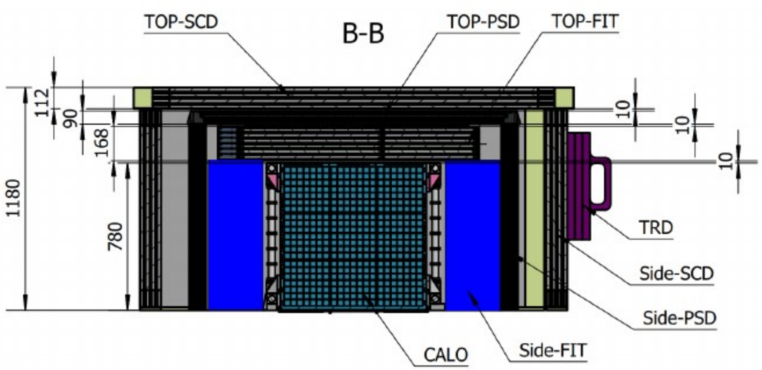


Custom bar support

Verification and preparation of all available bars in order to be tested at the **CNAO synchrotron beamline** in the upcoming days.

CNAO accelerator facility in Pavia

These tests are essential in order to validate scintillator & SiPM performances in view of future HERD prototypes that will be built and verified via beam-tests.



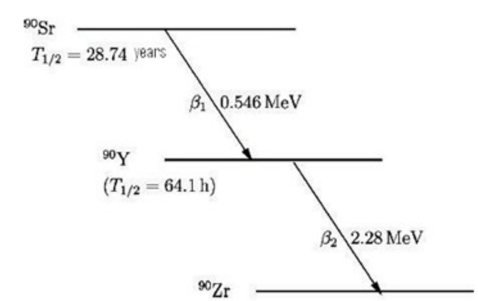
CERN - SPS

The prototypes will be tested at **CERN SPS** in **2021 & 2022**.

Thus examining the optimal payload setup & performance.

Furthermore, **new detector configurations are being built** at GSSI & LNGS as a means of determining the optimal PSD geometry.

All setups will be verified with cosmic rays along with charged particles from radioactive sources



Summary – DAMPE

DAMPE can provide valuable information regarding BCNO nuclei, owing to its wide energy range, large acceptance and improved energy resolution.

Previous and ongoing efforts were focused on **acquiring all the necessary components** for the starting BCNO analysis including MC and Flight data.

First look on BCNO nuclei with minimal changes and additions from previous analyses provides insight regarding the PSD charge spectrum, with further results on the way.

Ongoing and future work will be focused on optimizing the event selection procedure, taking advantage of 57 months of flight data and the valuable experience gained from previous and current analyses.

Summary – HERD

HERD will be one of the prominent space payloads onboard the future Chinese Space Station with its primary objectives residing in the fields of high-energy CRs and gamma-rays along with indirect DM studies.

Previous and ongoing work is dedicated in determining the optimal geometry of the Plastic Scintillator Detector (PSD) utilizing scintillator bars (or tiles) readout by SiPMs in order to provide charge measurements while serving as anti-coincidence for gamma rays.

Great effort has been put towards the preparation, construction and test of various detector configurations in order to improve core performance aspects and verify their capabilities.

A significant part of ongoing and future activities is dedicated to forthcoming beam tests at CNAO that will provide crucial insight for the upcoming realization of HERD prototypes to be examined via beam tests at CERN SPS in 2021 and 2022.

Activities [1/2]

Publications

- D. Kyratzis, *HERD: The High--Energy Cosmic Radiation Detector*, Il Nuovo Cimento **43 C**, (2020) 117
  10.1393/ncc/i2020-20117-1
- C. Yue et al., *Correction Method for the Readout Saturation of the DAMPE Calorimeter*, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 984, (2020) 164645
  10.1016/j.nima.2020.164645
- H. T. Dai et al., *Response of the BGO Calorimeter to Cosmic-Ray Nuclei in the DAMPE Experiment on Orbit*, IEEE Transaction s on Nuclear Science, v.67, n.6, p. 956-961, (2020)
  ieeexplore.ieee.org/document/9090172
- W. Jiang et al., *Comparison of proton shower developments in the BGO calorimeter of the Dark Matter Particle Explorer between GEANT4 and FLUKA simulations*, accepted in Chinese Physics Letters, (September 2020)
  arxiv: 2009.13036
- F. Alemanno, D. Kyratzis et al., *Stage OCRA - Outreach Cosmic Ray Activities*, in preparation.

Award

- *Best presentation award in the section of Astrophysics*, 105th SIF Congress, L'Aquila, 2019
  https://www.sif.it/attivita/congresso/105/comunicazioni

Outreach

- *Participation in the International Cosmic-Ray Day*, LNGS, [Nov 6, 2019]
- *Volunteering work in the 105th SiF 2019*, GSSI, L'Aquila, [Sep 23 – 27, 2019]
- *Participation in SHARPER 2019*, L'Aquila, [Sep 27, 2019]
- *Participation in the OCRA stage - Outreach Cosmic Ray Activities*, L'Aquila, [Apr 14 – 17, 2019]

Activities [2/2]

Schools – Conferences – Workshops

- *Participation in the 106th National Congress of the Italian Physical Society,* online, [Sep 14 – 18, 2020]
  Oral Presentation: Study of the cosmic B, C, N and O nuclei with the DAMPE space mission
- *Multimessenger High Energy Astrophysics in the Era of LHAASO*, online, [Jul 27 – 29, 2020]
- *The DAMPE Collaboration Meeting*, online, [Jul 17, 2020]
  Oral Presentation: Preliminary studies on BCNO spectra
- *CORSIKA Cosmic Ray Simulation Workshop,* online, [Jun 22 – 25, 2020]
- *Astroparticle Physics Scientific Fair,* GSSI, L'Aquila, [Feb 21, 2020]
  Oral Presentation: HERD: The High Energy cosmic-Radiation Detector
  Poster Presentations: 2 Poster presentations regarding DAMPE and HERD activities
- *The 8th HERD International Workshop,* Xi'an, China, [Dec 16 – 18, 2019]
  Oral Presentation: First test measurements on bar-shaped PSD with SiPM readout at GSSI-LNGS
- *DAMPE simulation hands-on meeting,* CERN, Geneva, [Nov 25, 2019]
- *VIII International Geant4 School,* Belgrade, Serbia, [Nov 17 – 22, 2019]
- *HERD software hands-on meeting,* Bari, [Oct 16 – 18, 2019]
- *Cosmic Ray Anisotropy Workshop, CRA 2019,* GSSI, L'Aquila, [Oct 7 – 11, 2019]
- *SiPM workshop: from fundamental research to industrial applications,* Bari, [Oct 2 – 4, 2019]
- *Participation in the 105th National Congress of the Italian Physical Society,* GSSI, L'Aquila, [Sep 23 – 27, 2019]
  Oral Presentation: HERD: The High Energy cosmic-Radiation Detector
- *Joint 9th IDPASC SCHOOL "Francesco Romano"*, Otranto, [May 27 – June 4, 2019]
  Oral Presentation: Study and detection of Solar Neutrons on ground level with the Spherical Proportional Counter
- *The 8th International DAMPE workshop,* GSSI, L'Aquila, [Dec 10 – 12, 2018]