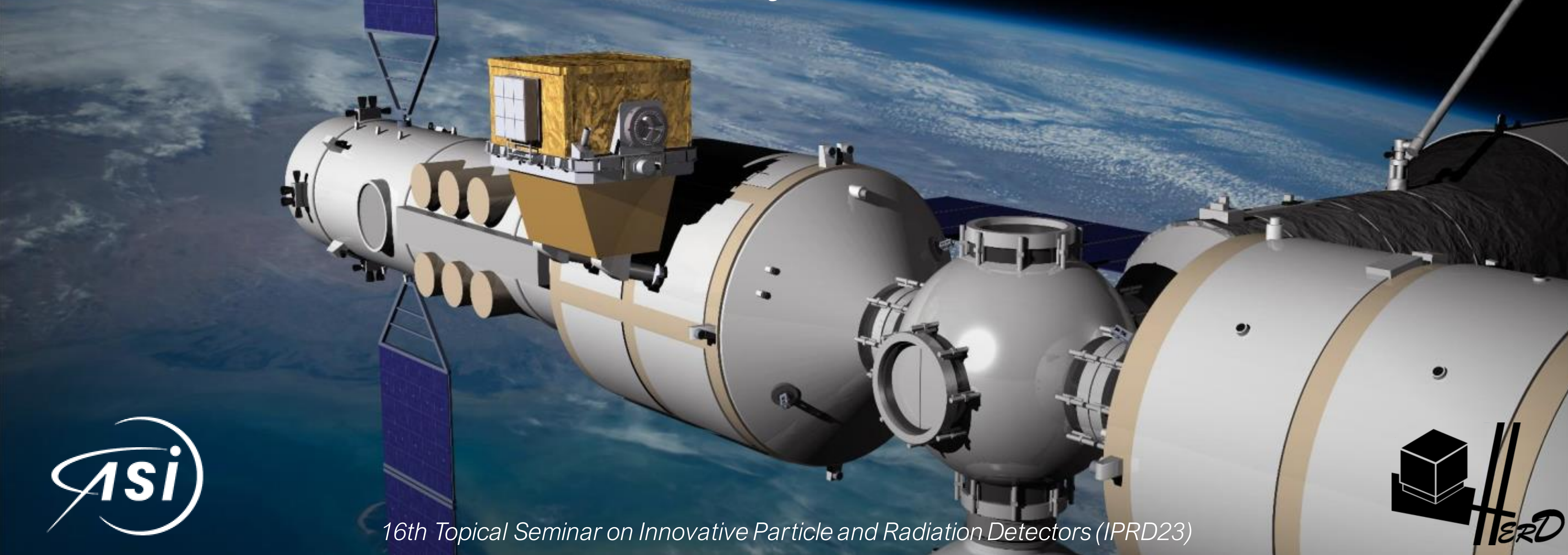
The ***Silicon Charge Detector*** *of the* ***High Energy Cosmic Radiation Detection*** *experiment*

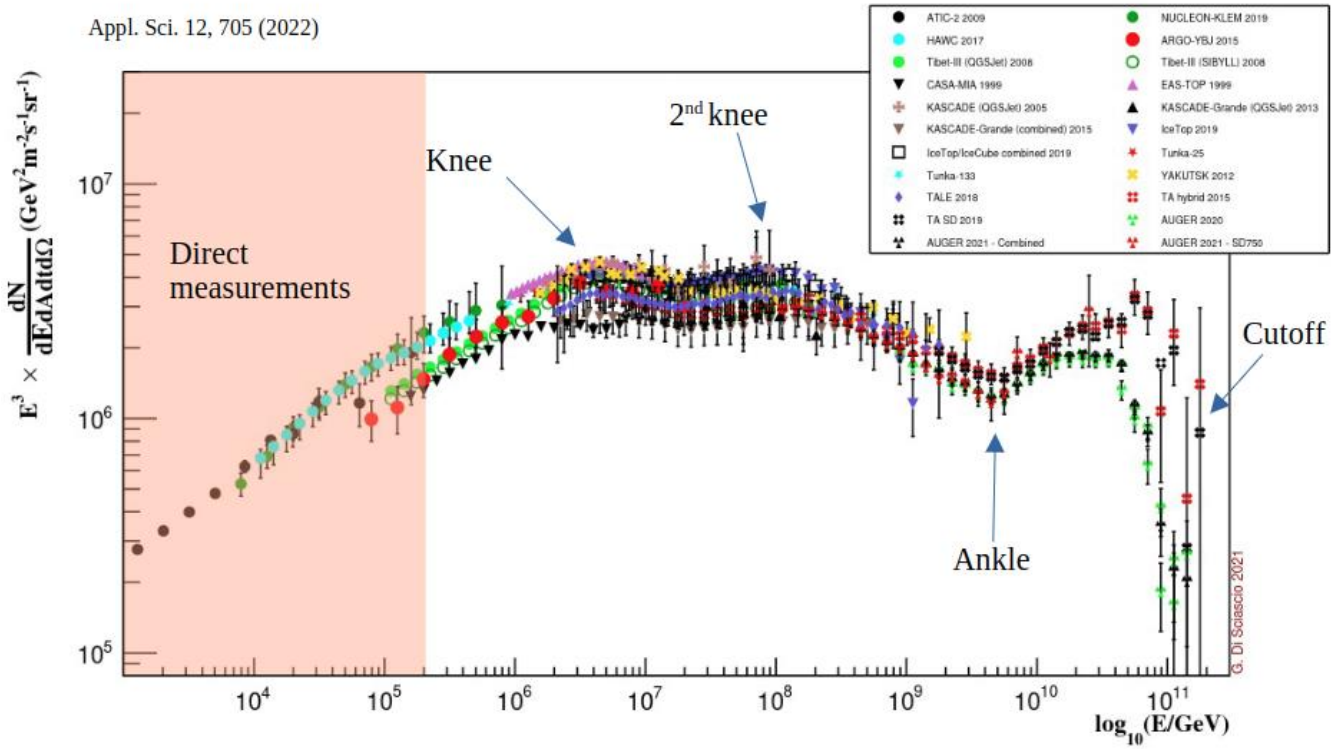
Gianluigi Silvestre on behalf of the HERD SCD Collaboration



16th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD23)

Physics Motivations

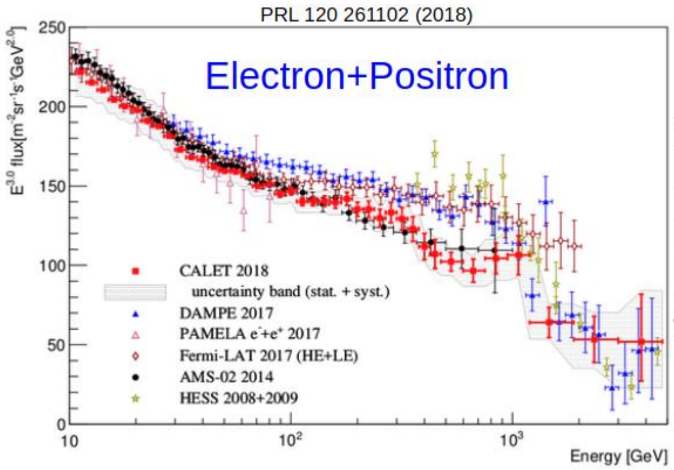
- All–particle energy spectrum of primary cosmic rays show evident features
    - Indications for particle-dependent knee energy
    - Large systematics due to indirect detection techniques

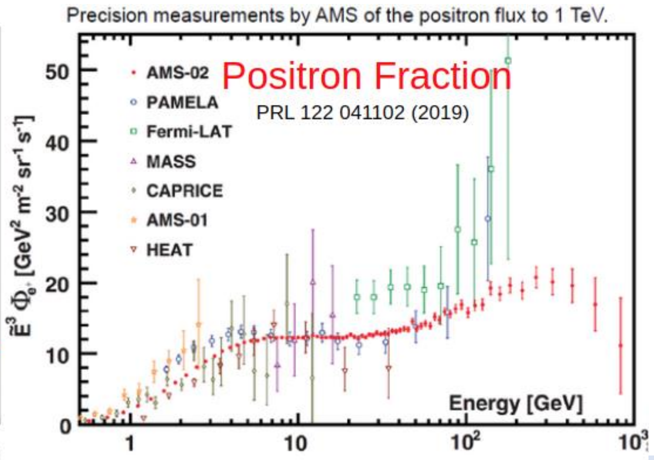


- Large deviation among the different measurements (Fermi-LAT, CALET, DAMPE) for electron/positron fluxes

- Positron excess respect to pure secondary production (PAMELA, AMS-02)

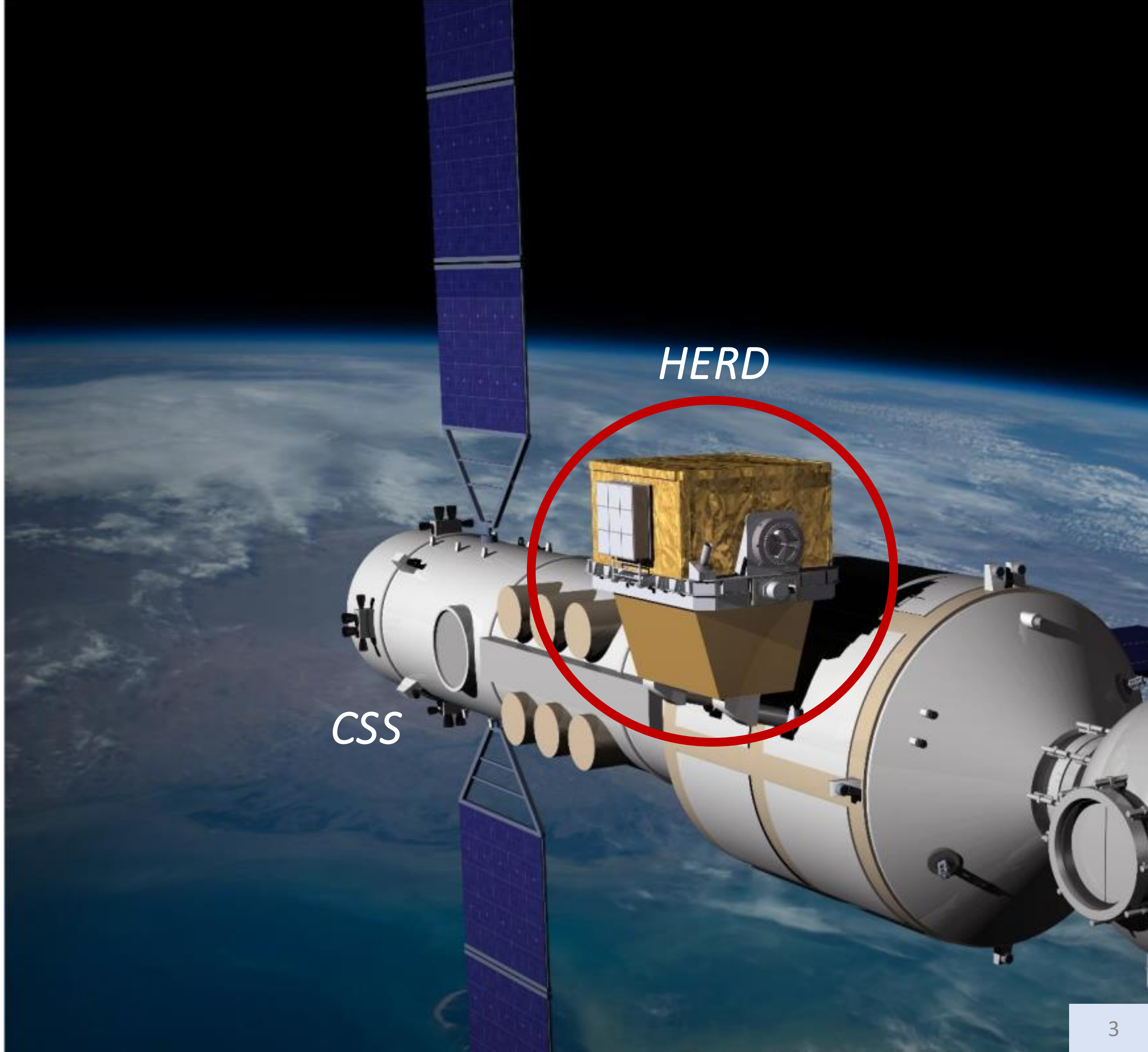
- One possible hypothesis for the discrepancies is Dark Matter (DM) annihilation



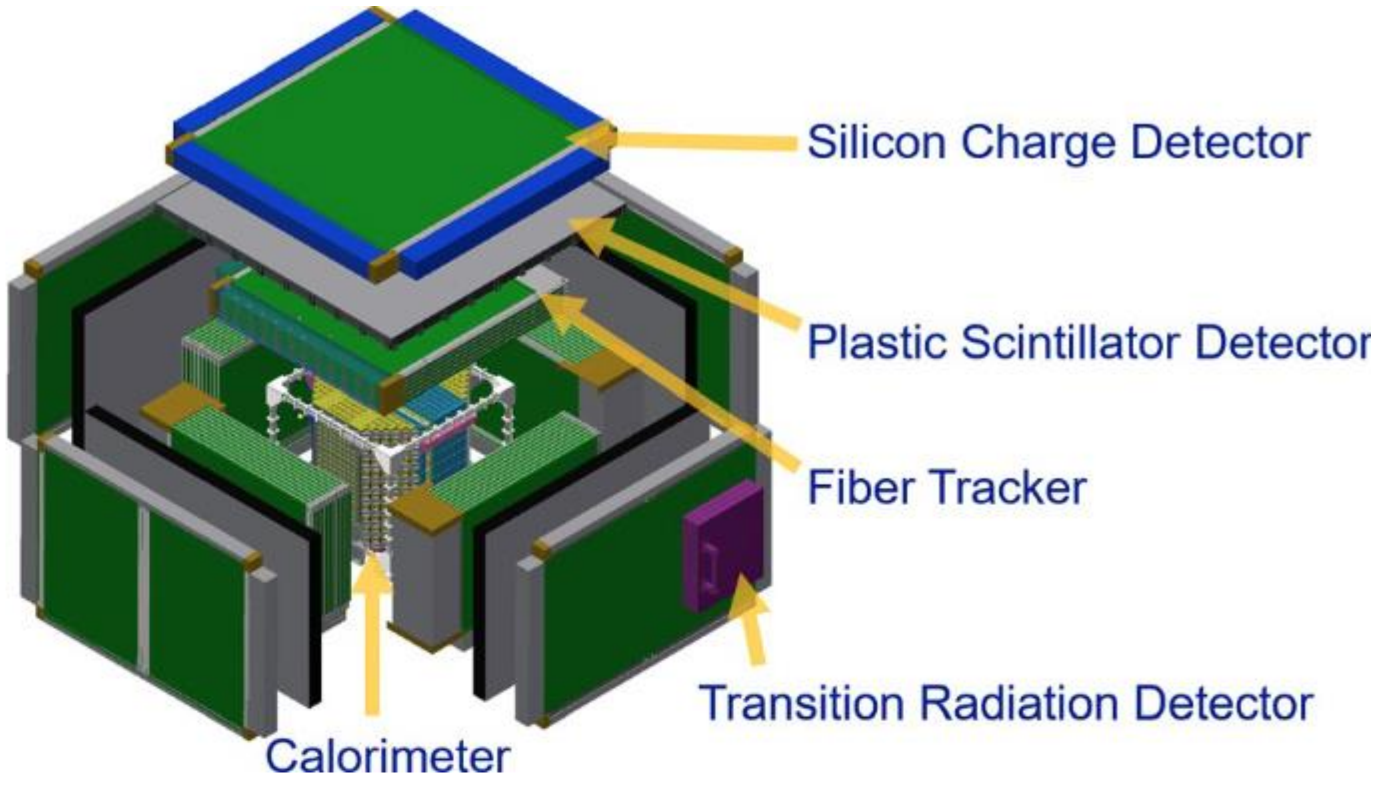


The High Energy cosmic-Radiation Detection (HERD) facility

- Space-borne high-energy physics experiment to be installed on the Chinese Space Station (CSS) in 2027
- Search for signatures of dark matter particles in the energy spectra and anisotropy of electrons
  from 10 GeV to 100 TeV and in the γ-ray spectrum from 500 MeV to 100 TeV;
- Study the cosmic rays (CRs) knee measuring directly the energy spectra and chemical composition of CRs up to PeV
- Monitor the high-energy γ-ray sky, starting from 100 MeV, in a wide field-of-view (FOV)



HERD design

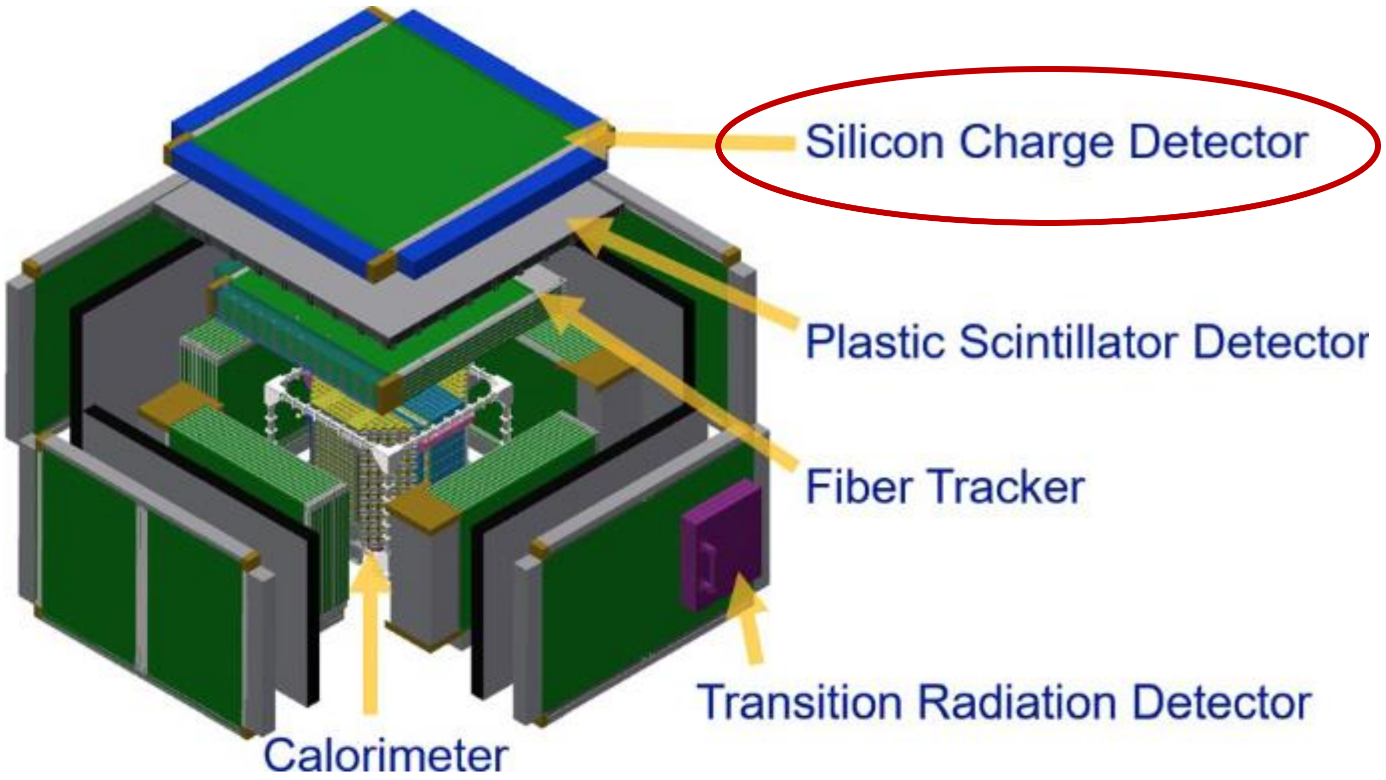


Schematic view of the HERD system

- Wide FOV novel design: particles accepted from 5 of the 6 available faces of the system
- Homogeneous, 3D segmented, LYSO imaging calorimeter (CALO) as the main subsystem
- Scintillating Fiber Tracker (FIT) for tracking and g-rays conversion
- Plastic Scintillator Detector (PSD) as anti-coincidence shield for g-ray measurements and as a charge detector for charged-particle identification
- Silicon Charge Detector (SCD) for charge identification and particle tracking with minimal material traversed before the interaction
- Transition Radiation Detector (TRD) on one of the lateral sides to calibrate the overall response of the calorimeter with flight data.

See more on L. Silveri's talk

HERD design



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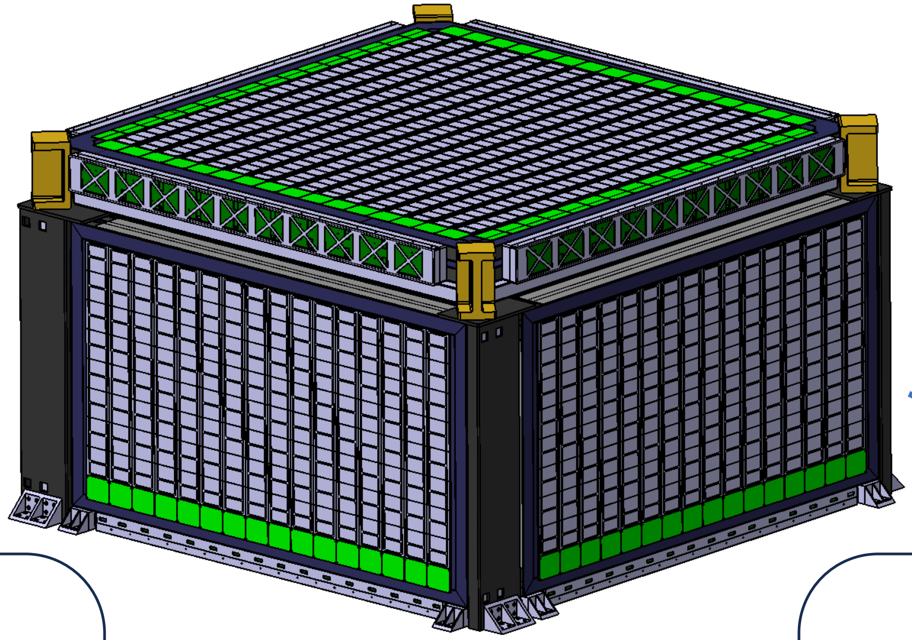
The Silicon Charge Detector (SCD)

- Outermost detector of the experiment
- Covers 5 of the 6 available faces of the experiment assembly
- Composed of silicon microstrip detectors mounted on an aluminium honeycomb and carbon fibre structure



Charge Measurement

Charge of incident particles up to Z = 26

Reduced systematic uncertainty on reconstructed charge

Measures particle charge before interaction with other materials

Particle Tracking

Incident particle track reconstruction

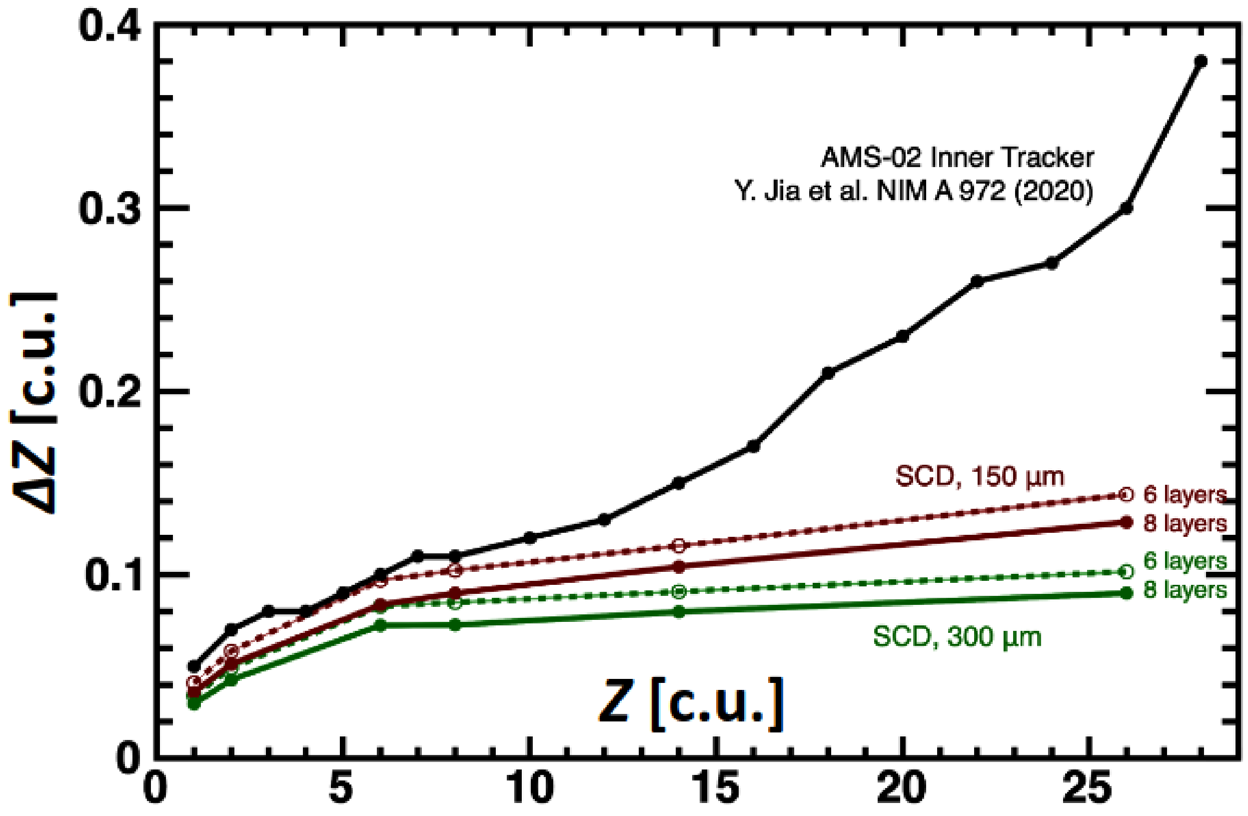
Spatial resolution on single measurement better than 40 µm

Reduces effects of backscattered secondary particles from the calorimeter

SCD Charge Measurement Performance

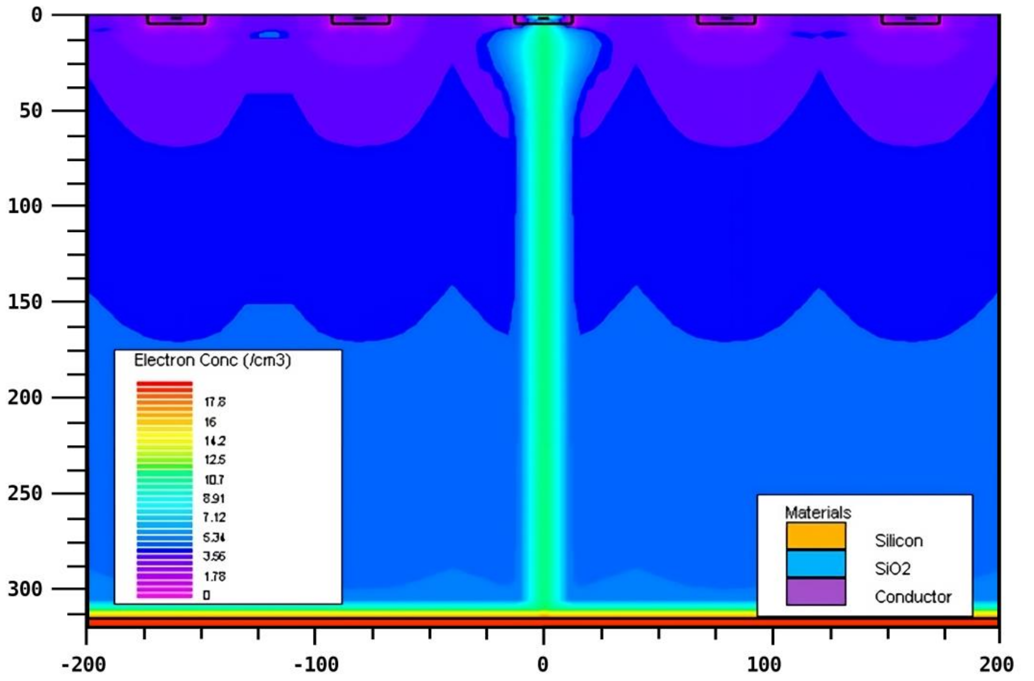
- Full HERD detector GEANT4 simulation conducted
- Evaluation of charge resolution using different sensor configurations
- Effect of detector parameters (implantation pitch, implantation width, readout pitch and decoupling capacitance) on the performance
- Evaluation of the effects on
  - Charge Collection Efficiency (CCE)
  - Charge Sharing Ratio (CSR)

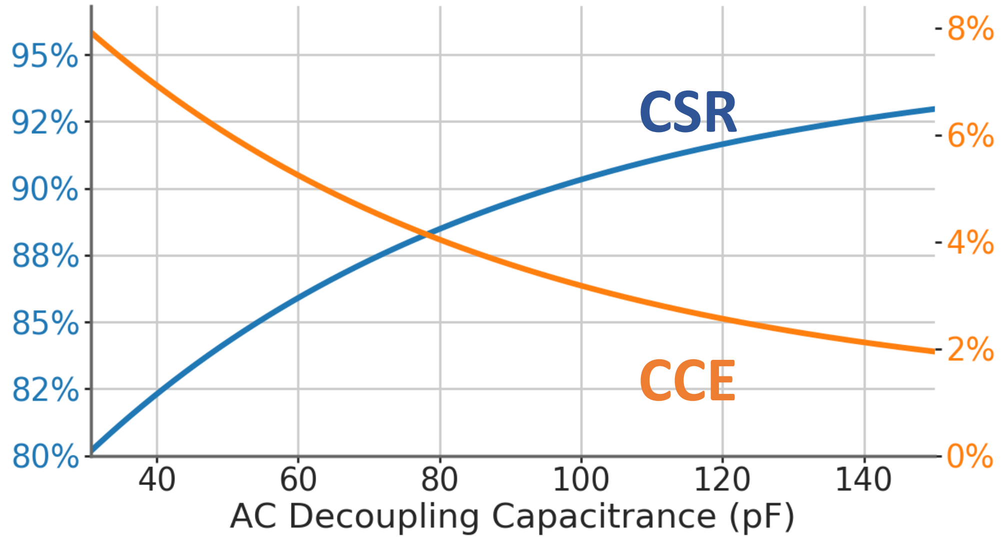
Expected charge resolution



SCD Charge Measurement Performance

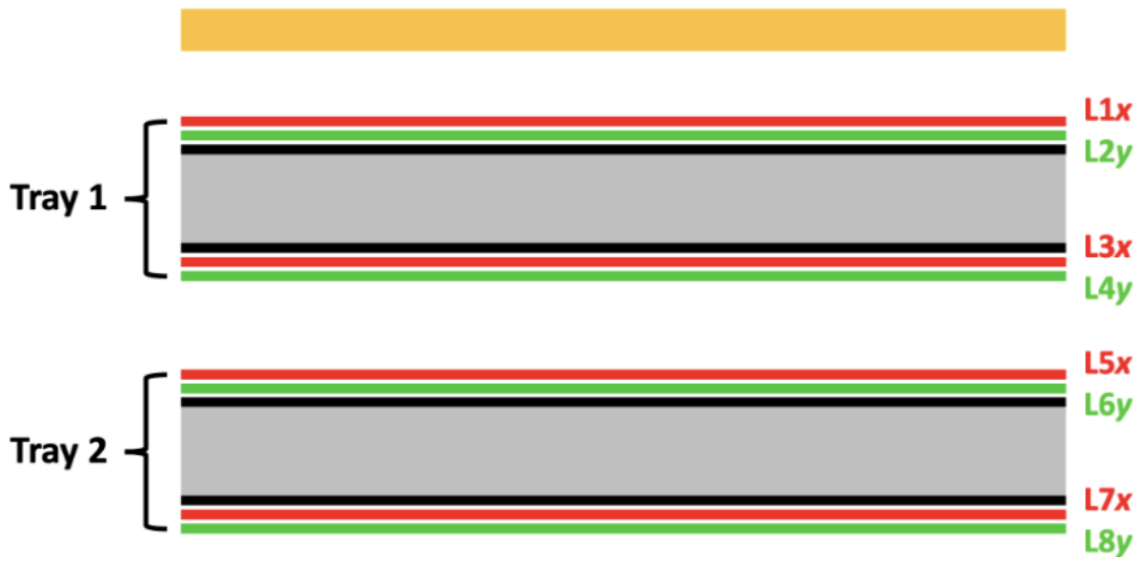
- Charge Collection Efficiency (CCE): the amount of signal collected summing all readout strips
- Charge Sharing Ratio (CSR): the ratio between signal on the readout strips next to the injection with respect to the one on the injection
  - Signal is redistributed on strips far away from the charge migration region due to capacitive coupling among strips.
  - Signal on strips next to the ionisation region can be used as "low-gain" estimators of the nearby strip
  - Dynamic range of the SCD charge measurement is effectively extended

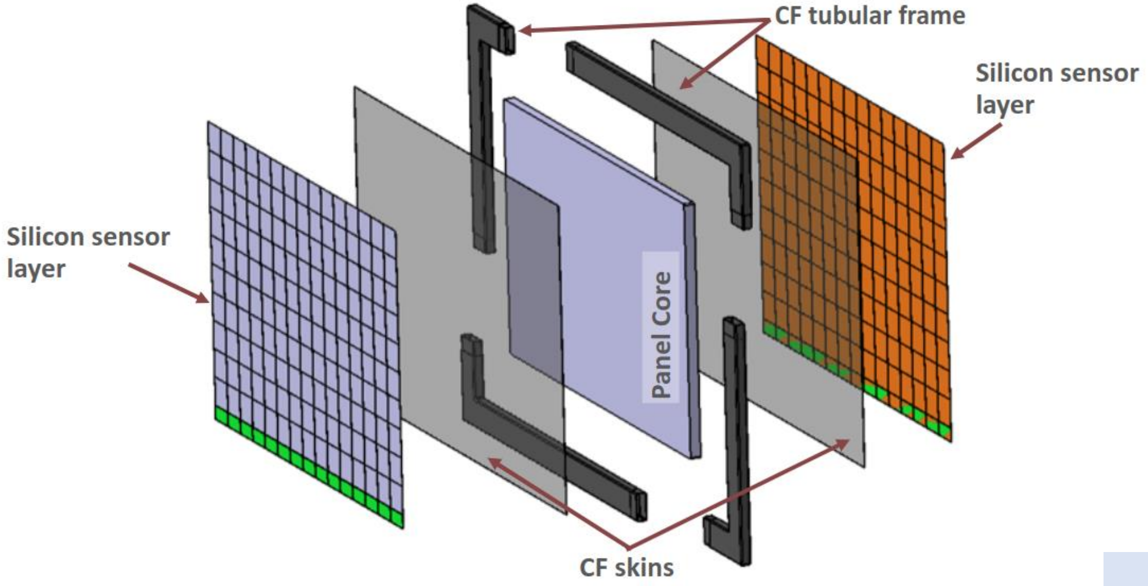




The SCD Design

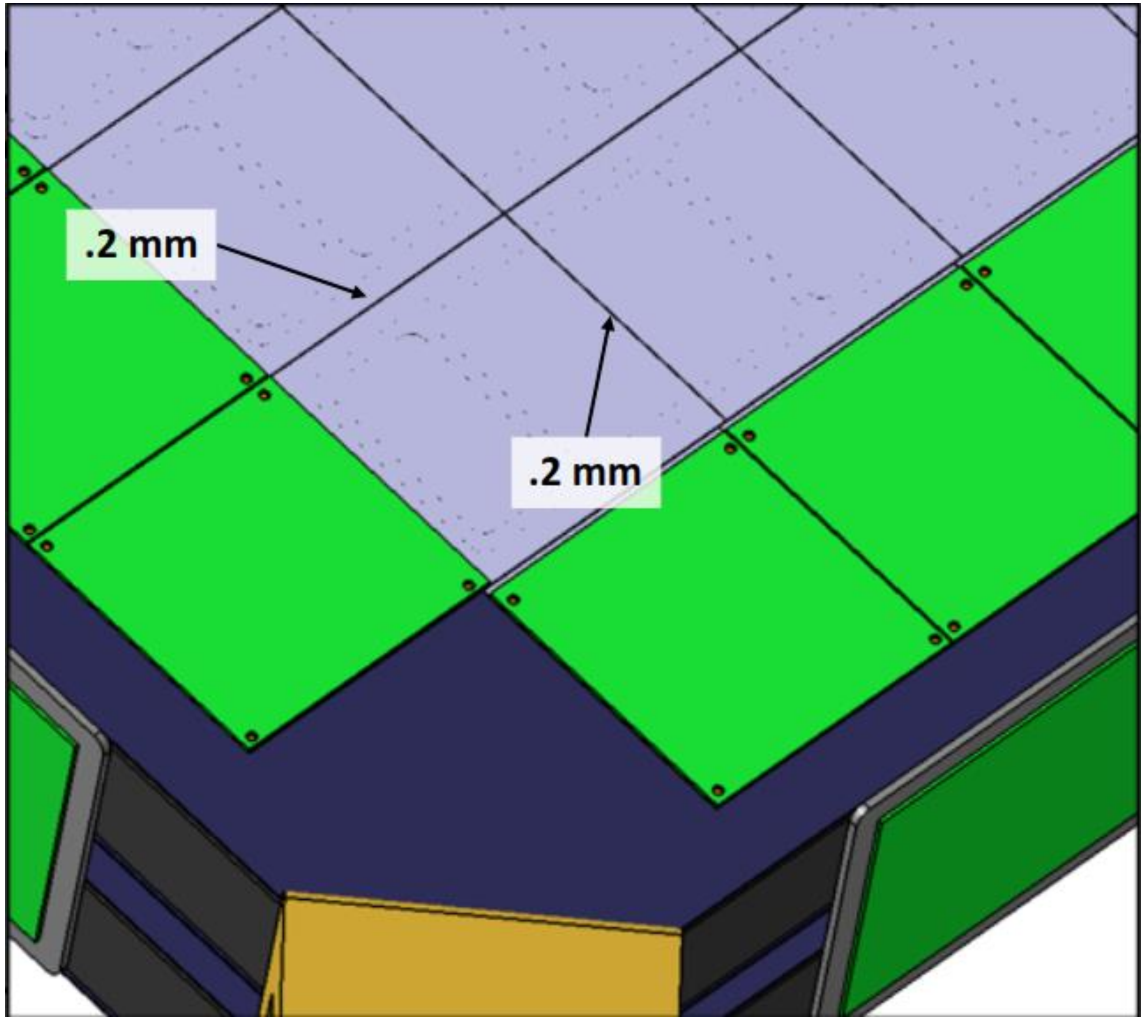
- Flight configuration of the SCD: five thin detector units
  - 1 x TOP side: 1.8 × 1.8 m2 area
  - 4 x SIDE: 1.6 × 1.1 m2 area
- Each of the unit contains 8 layers silicon microstrip detectors
- Layers mounted alternately in orthogonal directions.
- Each XY pair is composed of a supporting structure
  - Woven carbon fiber frame
  - High modulus unidirectional carbon fiber skins
  - Aluminum honeycomb core





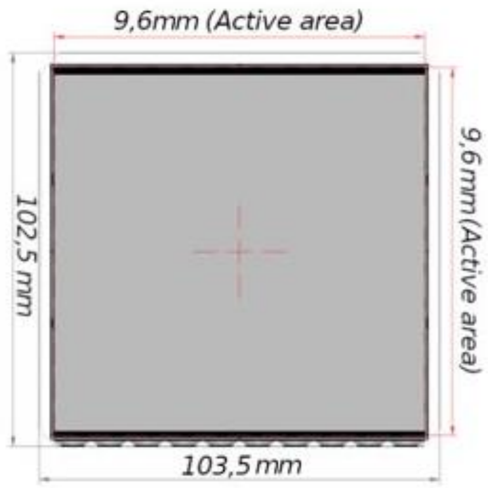
The SCD Design

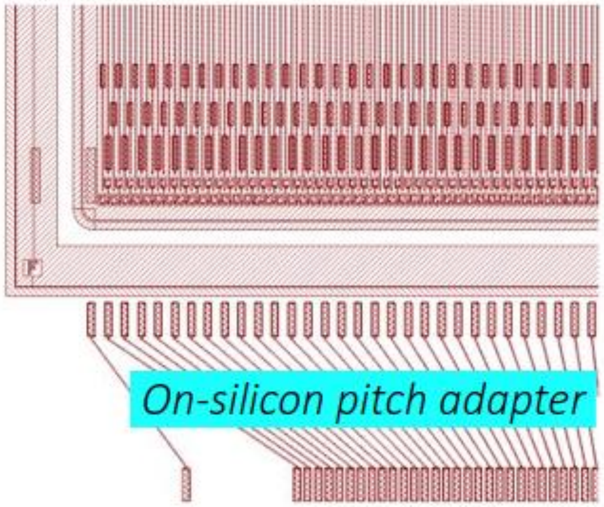
- Silicon detector “ladders” to cover the whole area of each of the SCD detector units
    - Silicon sensors are daisy chained and read-out from one side by dedicated electronics
- Side units contain 1024 silicon tiles, top unit contains 2048: total of 6144 tiles.
- For the designed 95 x 95 mm2 silicon sensors this gives rise to a total silicon area of about 60 m2.
- Various options are under evaluation for the read-out electronics for the sensor.
    - Commercial option: IDEAS IDE1140, as previously used for space experiment silicon trackers
    - In-house developed INFN-To ASTRA ASIC by INFN (Istituto Nazionale di Fisica Nucleare)

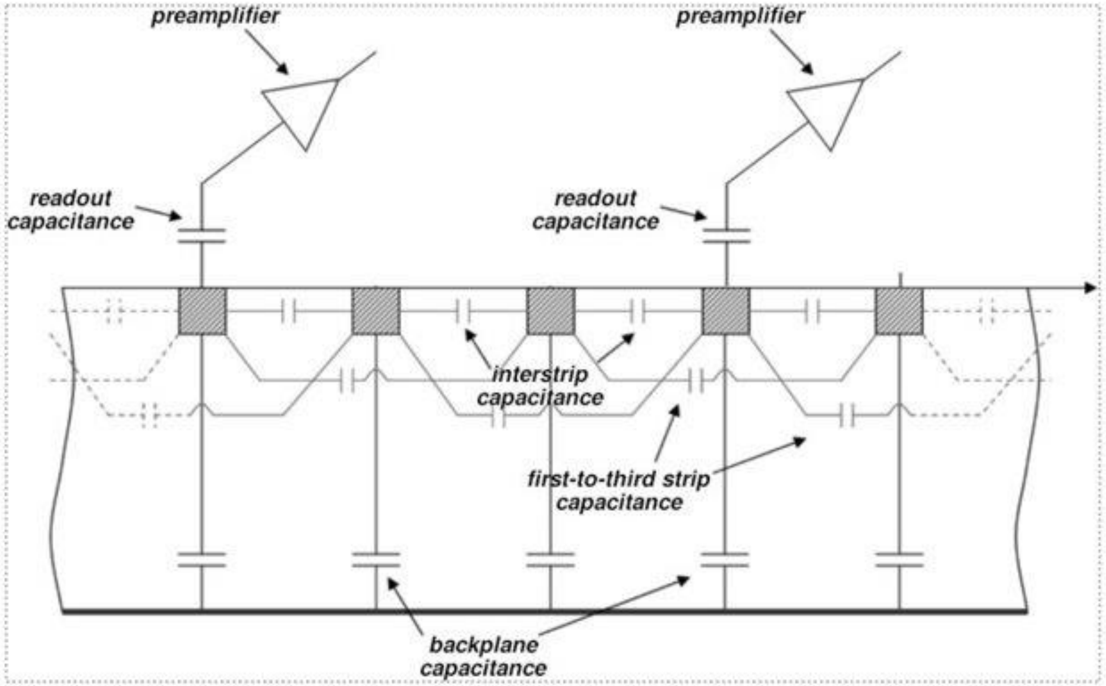


The First SCD Prototype

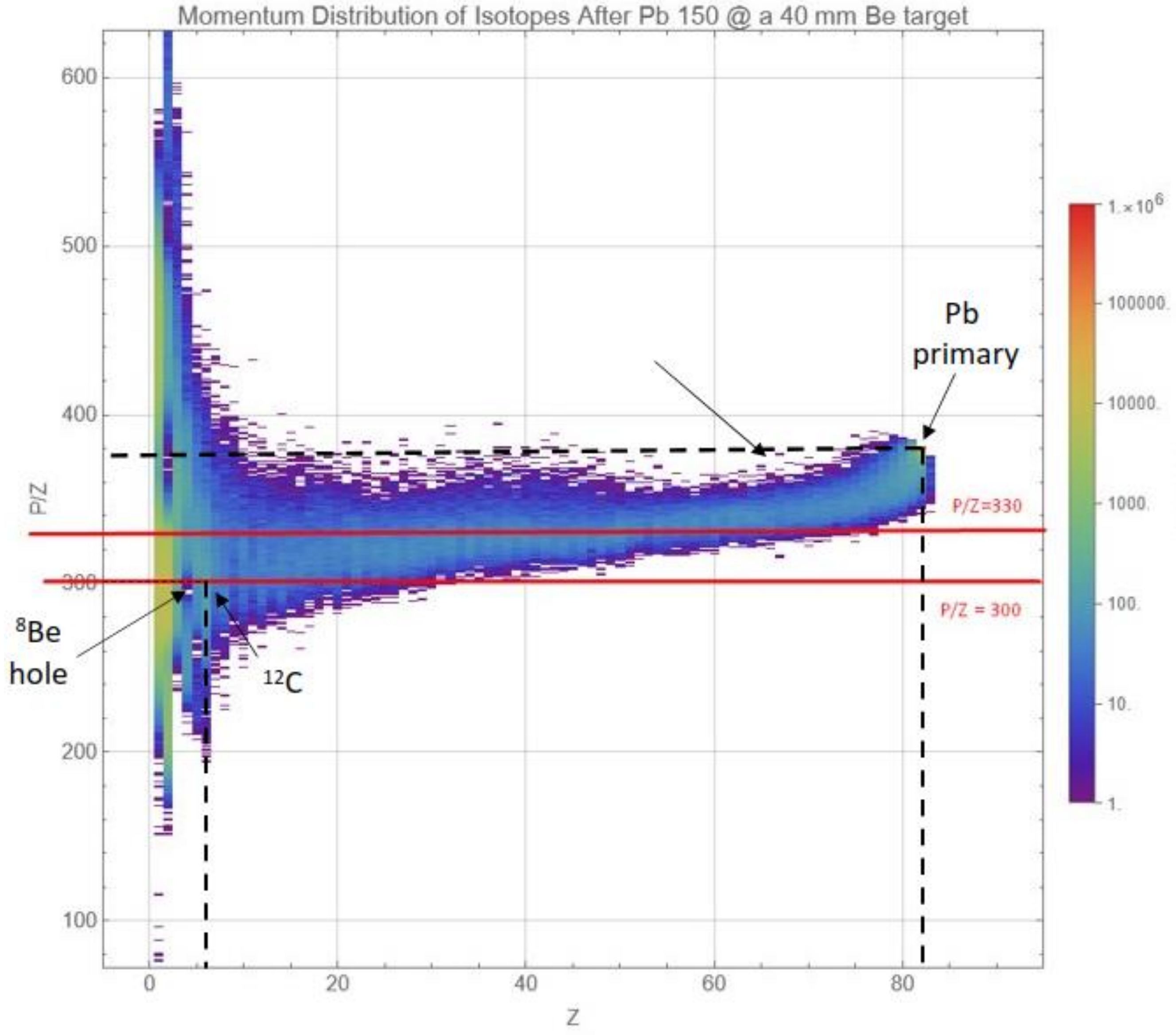
- Silicon sensors made by Hamamatsu Photonics, 150um thick
- 96 mm × 96 mm active area segmented in 1920 strips with a 50 µm implantation pitch
- Readout by ten IDE1140 ASIC chips
- On-silicon pitch adapter from strips to ASIC channels to simplify the assembly procedure
- *"Floating strip"* approach: readout pitch of 150 µm, with two strips connected to readout every four
    - Total number of readout channel for each detector: 640







SCD Prototype @ CERN SPS



- Pb (150 A GeV/c or 379 GV/c) + Be (40 mm) target
- Fragments selected magnetically
- Rigidity interval of few % around 300 GV/c
- Approx A/Z=2.2
- Possible to get very high Z particles
- Data taking with other prototype detectors of the HERD experiment
- Tracker system composed of 4 XY stations
- Goal: detector response/resolution to a wide range of ions and η calibration
  - Desiderata: fragmented ion beam with different Z covering a wide area with high statistics

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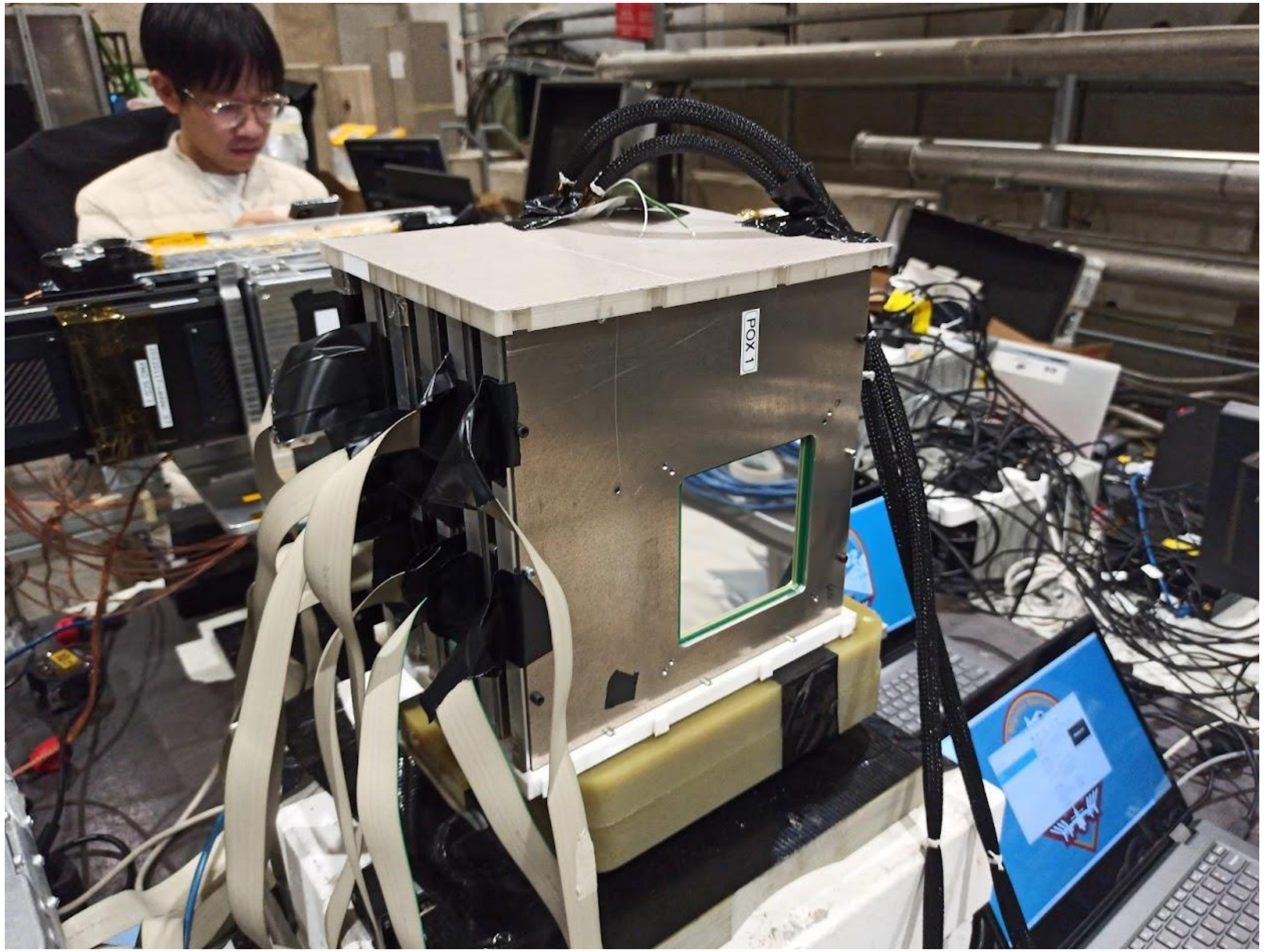

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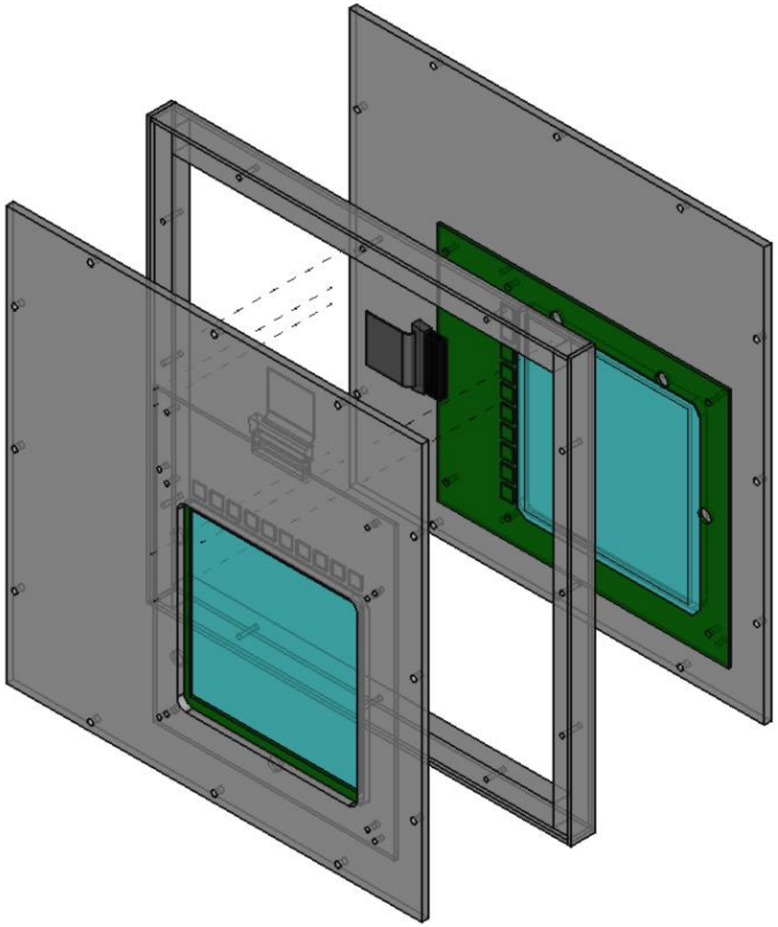

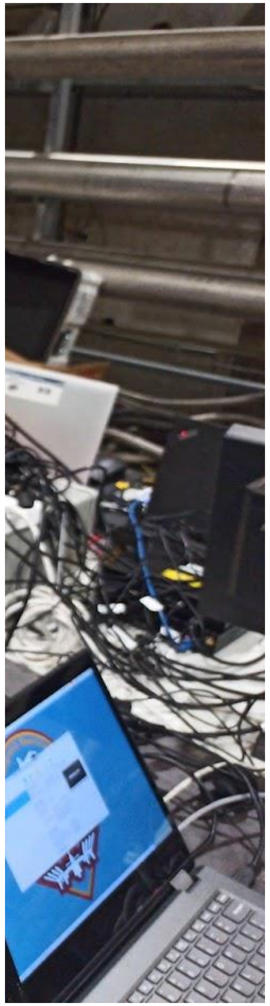

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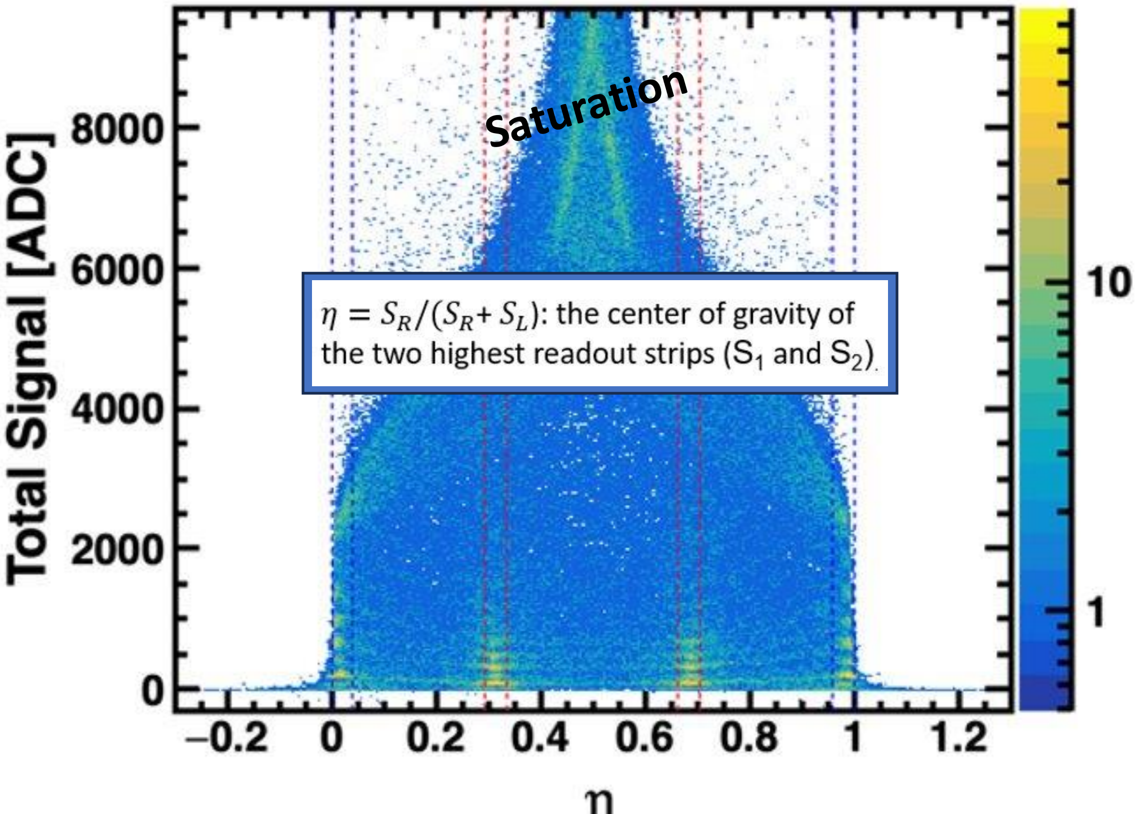
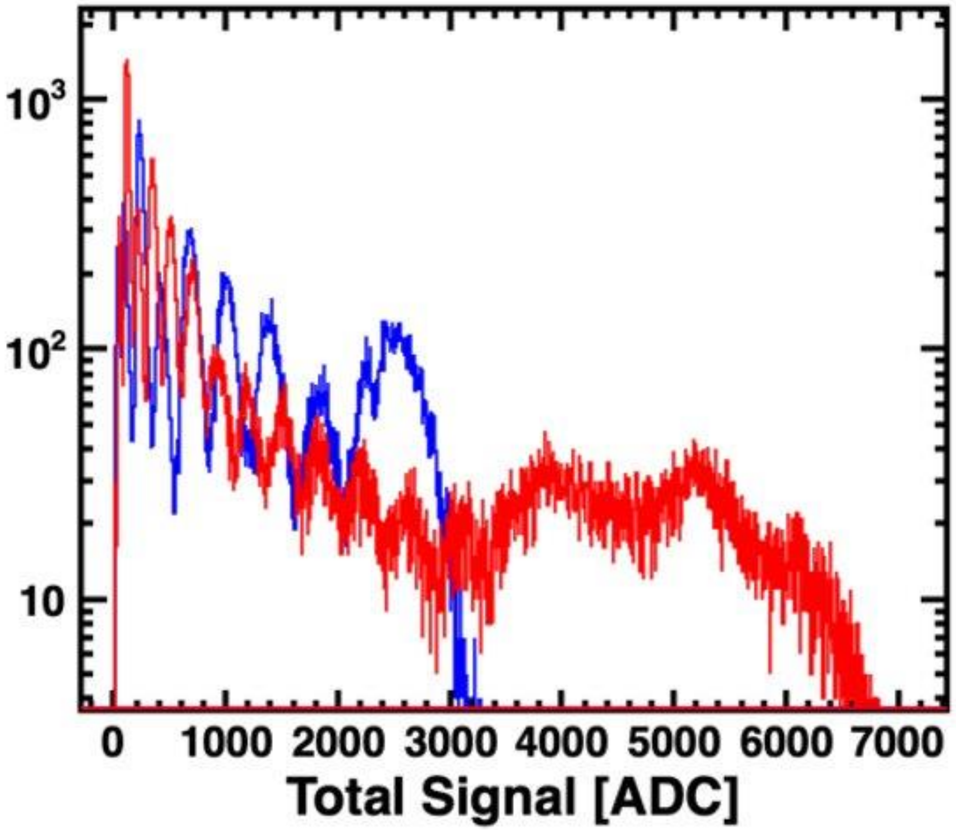
Charge Reconstruction

- Eta parameter: relative signal fraction of the 2 highest strips in the cluster
  - Equivalent to centre of gravity in units of the readout strip pitch
  - Capacitive coupling gives rise to the presence of peaks in the η distribution
  - Non linear charge division between strips

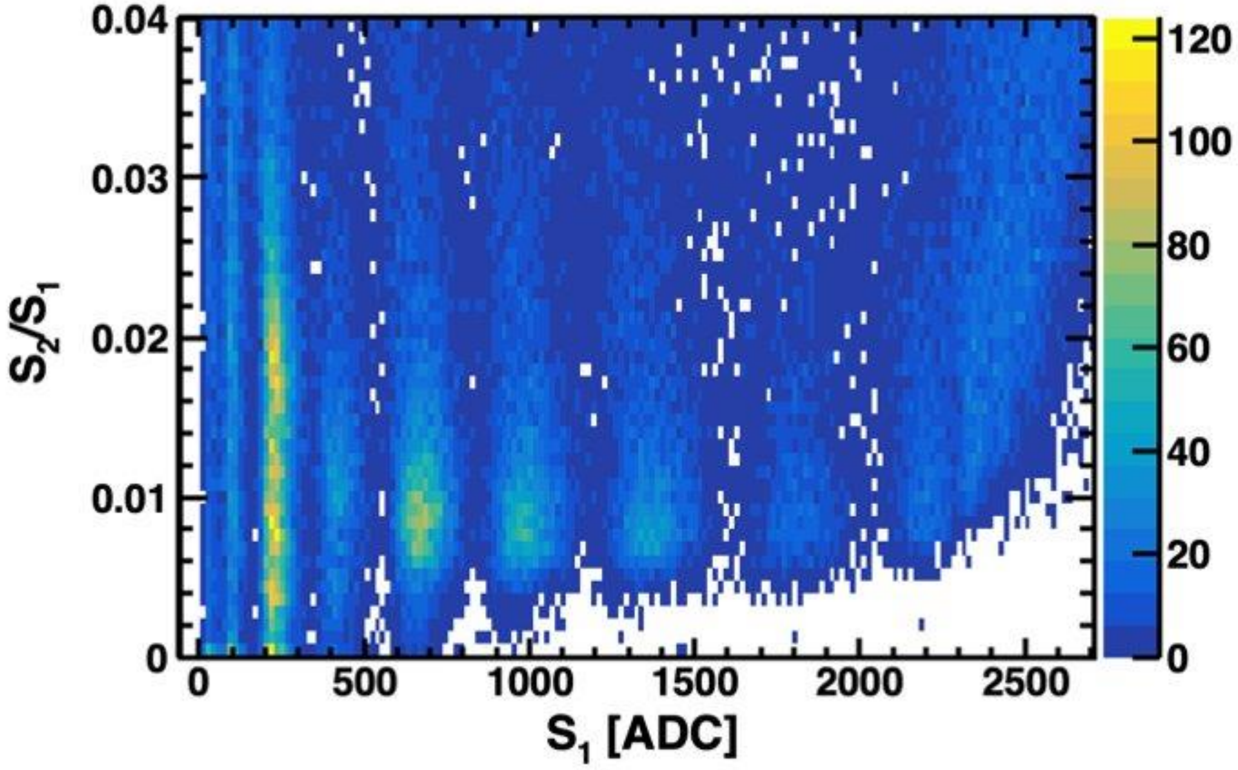
- The η-distribution shows 2 extra-peaks at about 1/3 and 2/3 as expected from the presence of 2 floating strips.

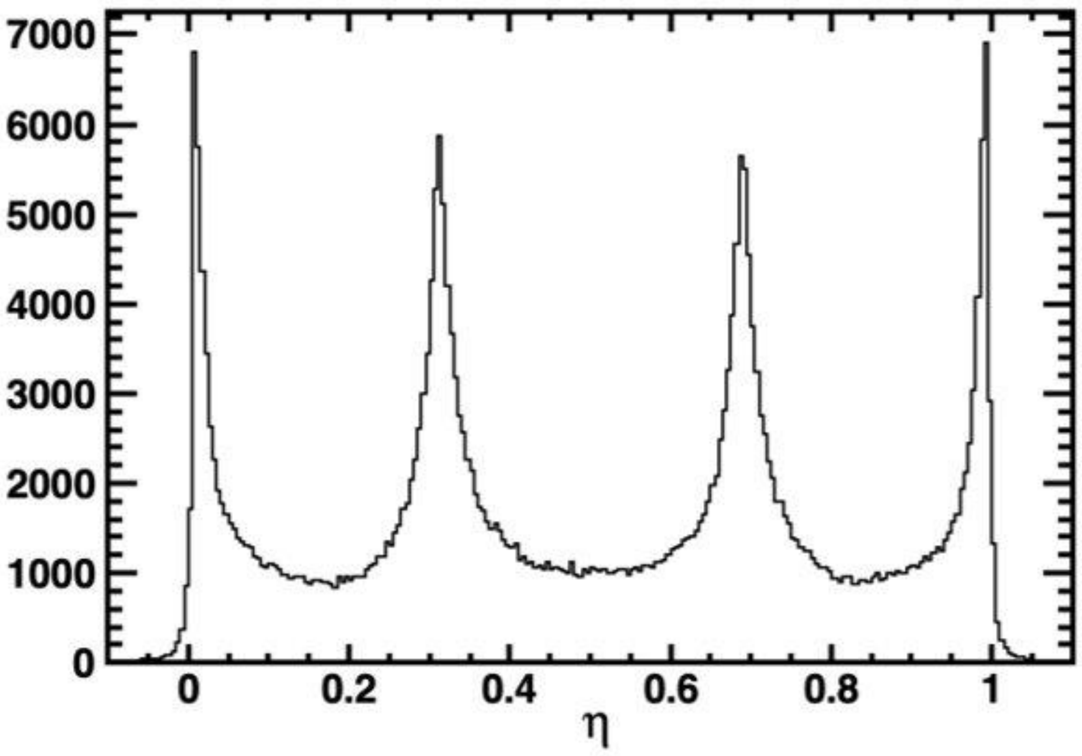




Charge Reconstruction

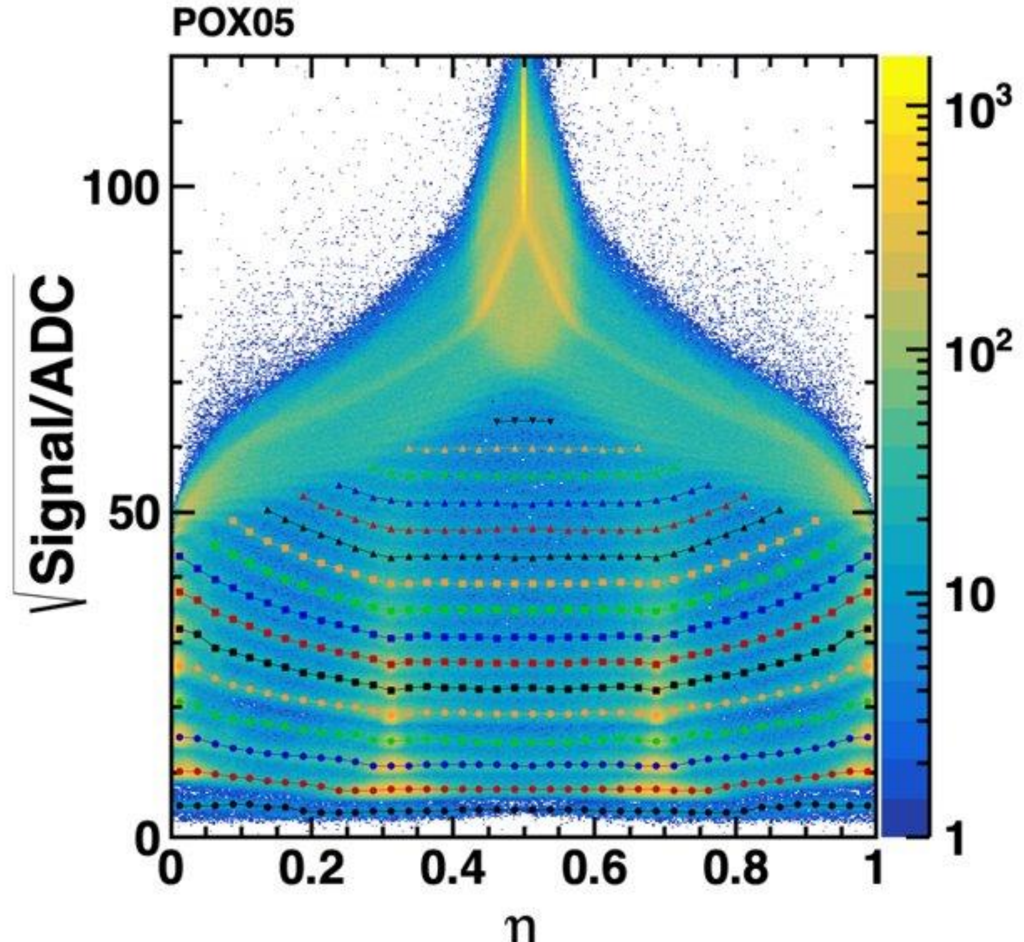
- Both η-distribution and/or S_2/S_1 ratio show a charge coupling of about **0.8%**
- The interstrip region effectively acts as a "low gain" region
- Possible to reconstruct up to Z=8 with readout region, and up to Z=14 with floating using total cluster signal
- The use of external strips of the cluster should give capabilities in reconstructing Z>14 particles

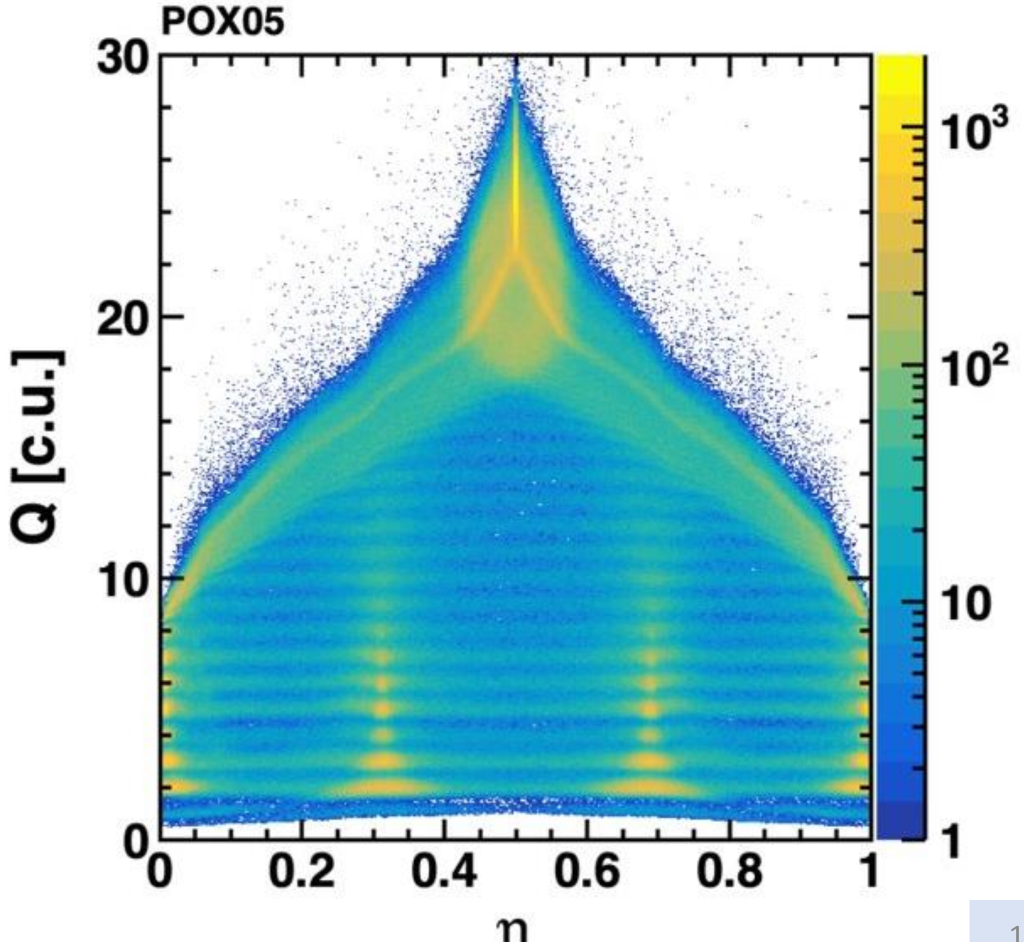




Charge Reconstruction

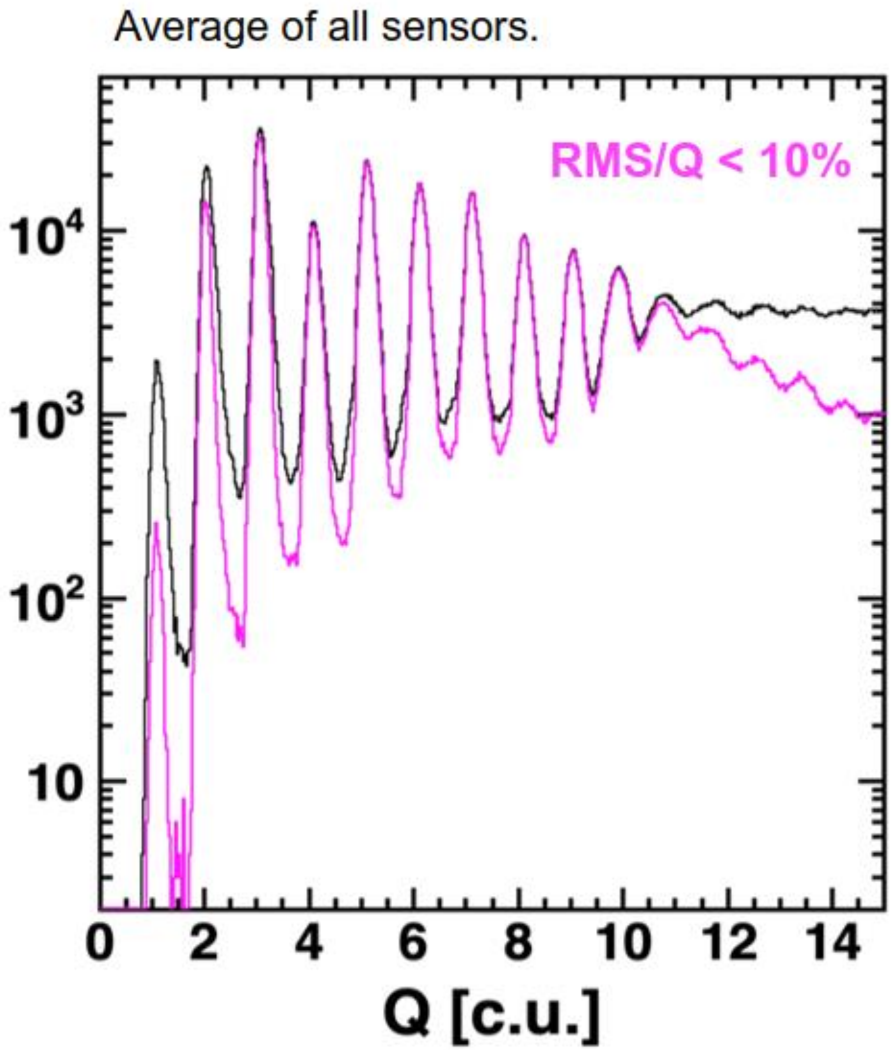
- Evaluate the peak position for each Z (from 1 to 8) in the readout region to evaluate the gain of each VA
- VAs of the same sensor are put together (after gain correction). For fitting a “η-folding” is applied.
- Apply a handwritten peak finding procedure to characterize the signal variation with η

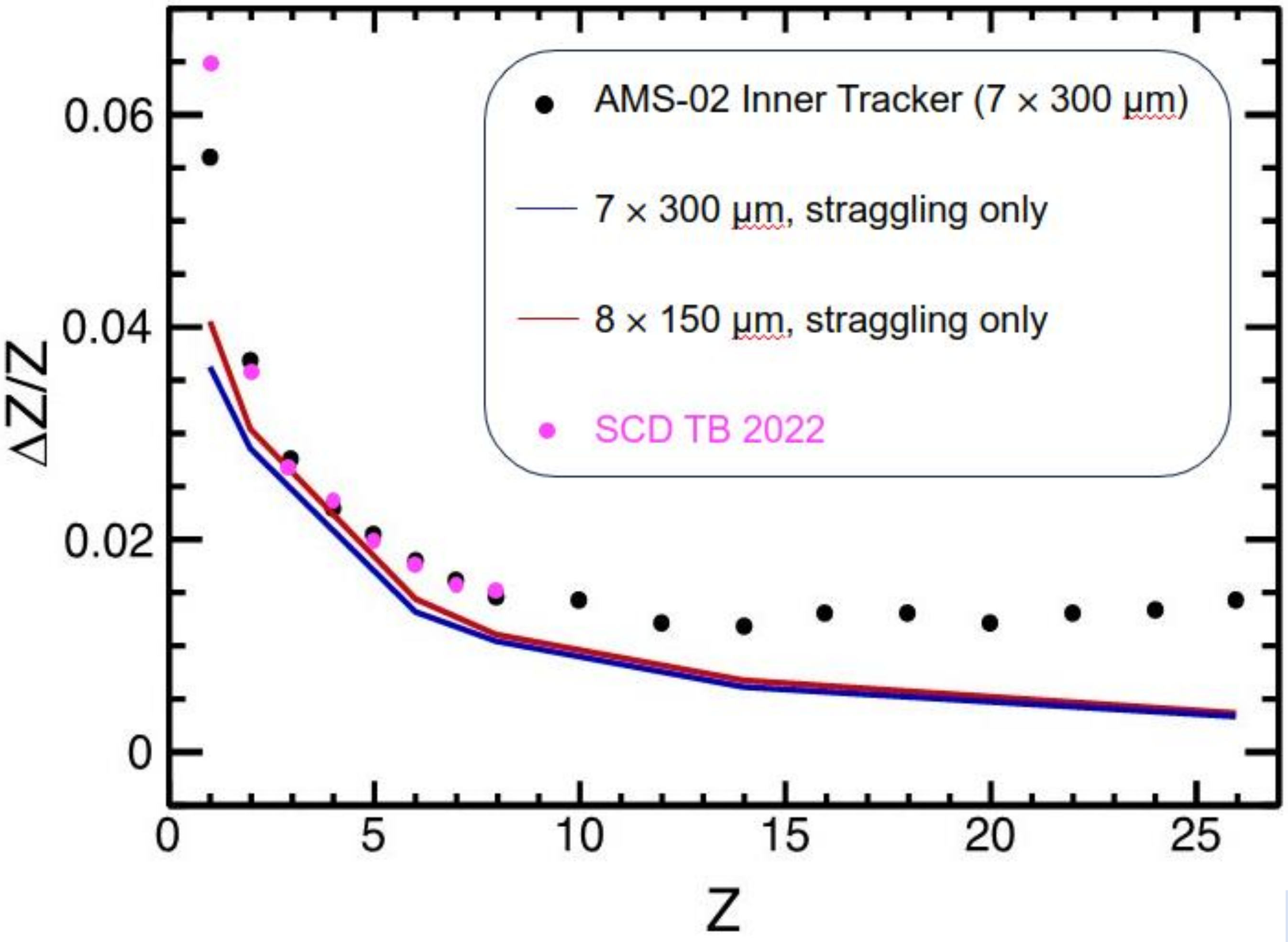




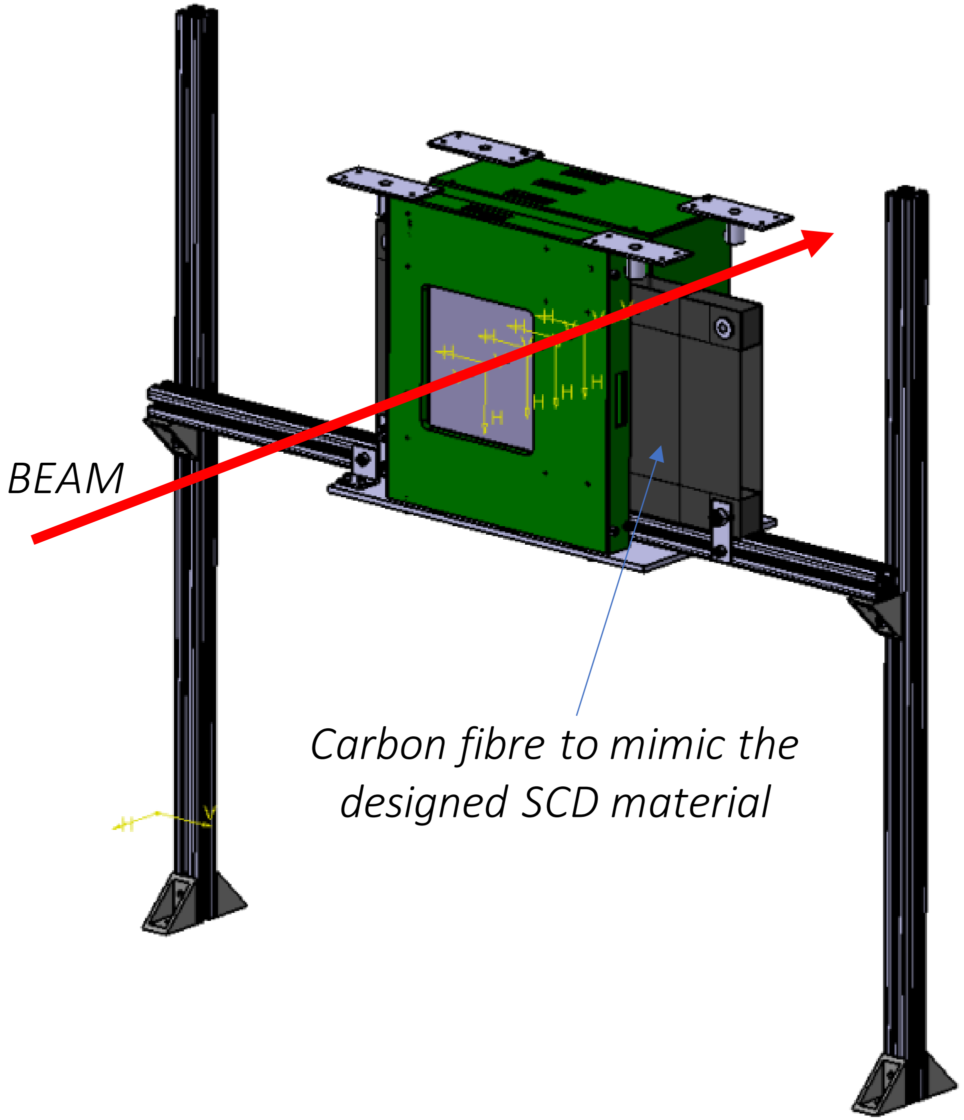
Charge Reconstruction

- After eta correction it is possible to get from the raw cluster ADC content to reconstructed charge
- Info from all the sensors is combined to estimate the fragment reconstructed charge

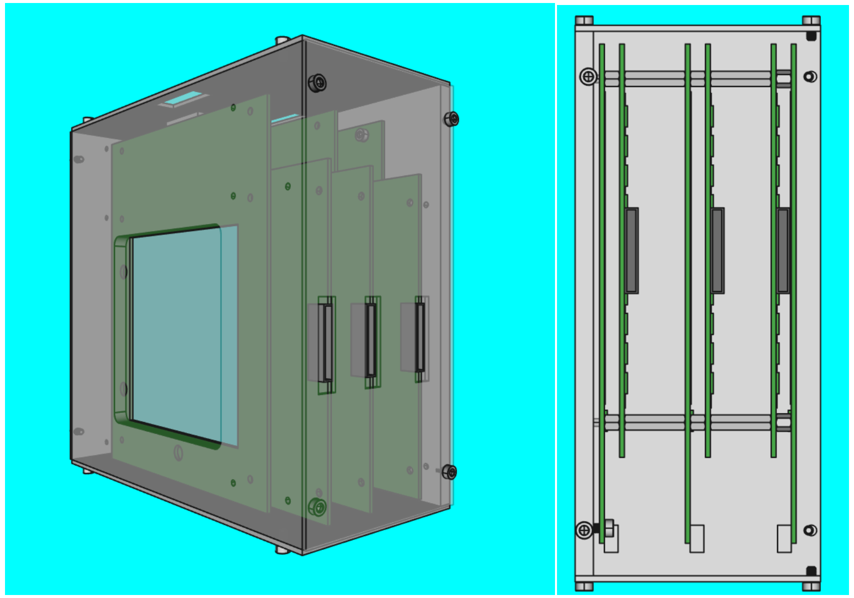




2023 Data Campaign @ CERN



Carbon fibre to mimic the designed SCD material



Single box solution containing 3 pairs of detectors (to be put downstream), same idea for the single pair upstream

300um detectors (instead of 150um of the first prototype)

Conclusions

- The High Energy cosmic-Radiation Detection (HERD) facility will be installed on the Chinese Space station in 2027
  - It will search for signatures of DM particles and study the CRs knee up to the PeV
  - Novel design with wide FOV based around an highly segmented LYSO calorimeter
- The Silicon Charge Detector will be used for charge identification and particle tracking
  - Large area coverage (approx. 60 m2) with silicon strip detectors arranged on 5 of the 6 faces of the experiment
  - Charge measurement up to Z=26 and tracking resolution better than 40um
- Tested a first 150um prototype developed at CERN SPS in October 2022 with fragmented ion beam
  - Evaluated the corrections to be applied to the charge reconstruction algorithm
  - Combined info of several detectors to reconstruct charges up to Z=16 with good charge and spatial resolution
    - Use of external detectors (scintillators) is needed to study spatial resolution and charge reconstruction for Z > 16
- Second 300um prototype soon to be tested at CERN SPS

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Thanks for your attention

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