Penetrating Particle Analyzer

Development of a Penetrating particle ANalyzer for high-energy radiation measurements in space

Philipp Azzarello on behalf of the PAN consortium

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département de physique nucléaire et corpusculaire

The Penetrating particle Analyzer

- PAN is a generic instrument technology for deep space and interplanetary missions.
- Capable of precisely measure and monitor in real time the flux, composition, direction of penetrating particles (> ~100 MeV/nucleon)

- Consortium of three institutes:
  - Department of nuclear and particle physics, University of Geneva
  - INFN sez. di Perugia
  - Institute of Experimental and Applied Physics, Czech Technical University in Prague

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Particle environment in deep space

- Particles trapped in planetary magnetic fields
  - Only dominant in the radiations belts near the planets
  - Important topic in planetary science (e.g. Jupiter's large magnetosphere)
- Steady flux: Galactic Cosmic Rays (GCR)
  - Dominant at energy > 100 MeV/n, peaking at ~1 GeV/n
  - *Mainly protons and Helium ions*
  - Modulated by solar activities
  - Important contributor to shielded TID (Total Ionization Dose) for long missions
- Transient flux: Solar Energetic Particle (SEP)
  - Particles from solar eruptions (flare and Corona Mass Ejection)
  - Rare and intense "GeV" Solar Particle Events are highly damaging/dangerous
    - Could be 1000s times more intense than GCR

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PAN Science goals

- Cosmic ray physics: fill an in situ observation gap of galactic cosmic rays (GCRs) in the GeV region in deep space
  - Understanding of the origin of the GCRs and their interplay with solar activities
  - Antimatter searches
- Solar physics: provide precise information on solar energetic particles
  - Study the physical process of solar events, in particular those producing intensive flux of energetic particles.
- Space weather
  - Improve space weather models from the energetic particle perspective.
- Planetary science: measure and monitor energetic particles
  - Develop a full picture of the radiation environment of a planet/moon, in particular as a potential habitat.
- Deep space travel: penetrating particles are difficult to shield
  - PAN can monitor the flux and composition of penetrating particles during a space voyage.
  - PAN can be part of a standard on-board instrument suit for radiation monitoring for deep space travel.

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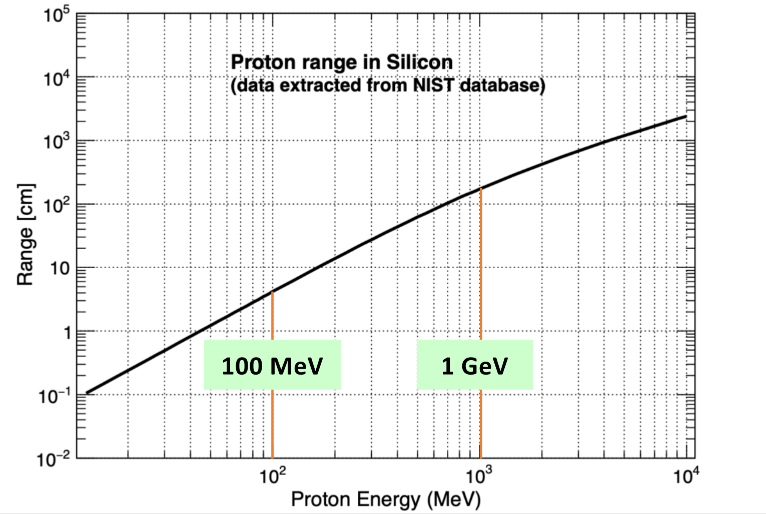
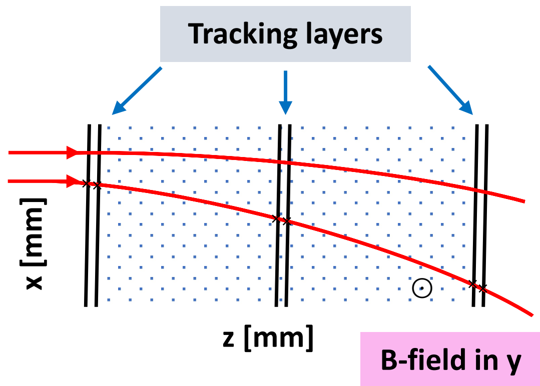
Measuring Gev protons

- The energy of GeV protons cannot be measured by the ΔE – E method as used for low E protons.
  - 170 cm of Si needed to stop 1 GeV protons
  - The nuclear interaction length in Si is 46.52 cm, thus with 170 cm of Si, it is likely to produce a hadronic shower before losing all the energy by dE/dx
  - A calorimeter is too thick/heavy and has bad resolution (~30-40%)
- The solution is to use a magnetic spectrometer
  - Measure the bending of charged particles in the B-field ⇒ rigidity (p/Z)
  - Then infer the momentum and energy with independently measured particle charge Z





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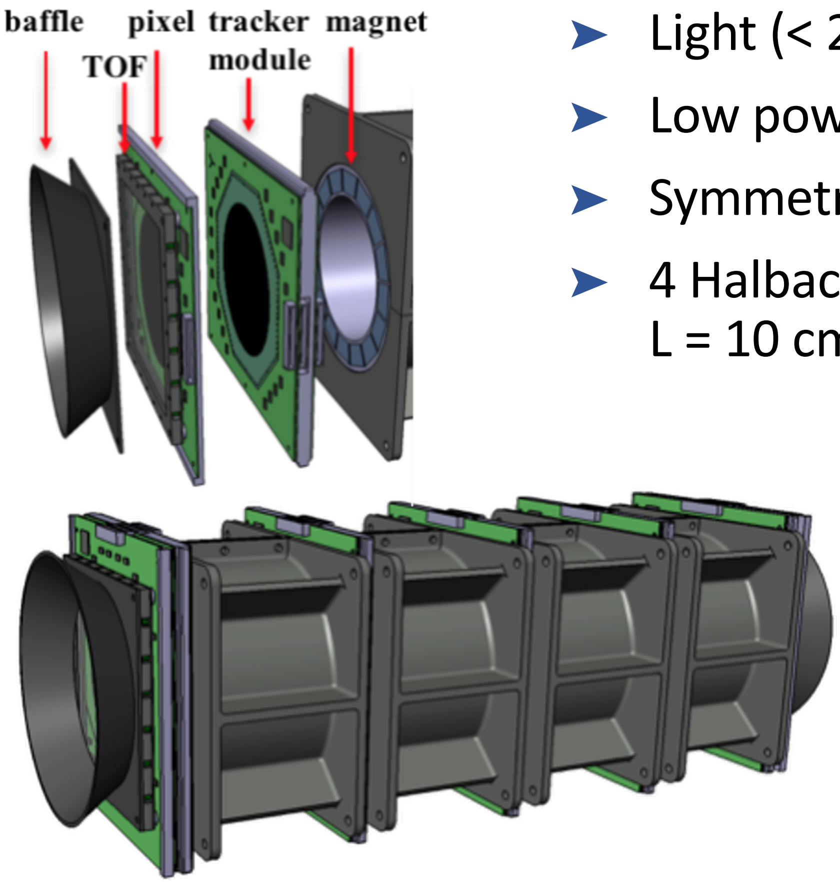
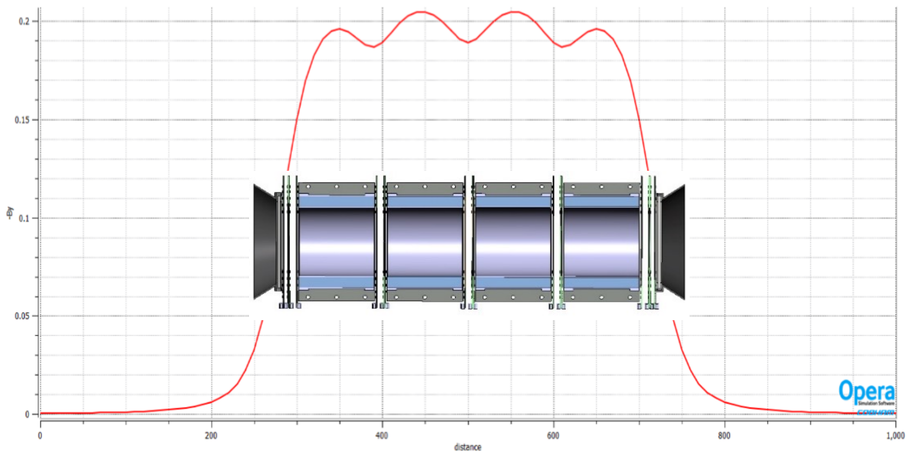
The PAN instrument

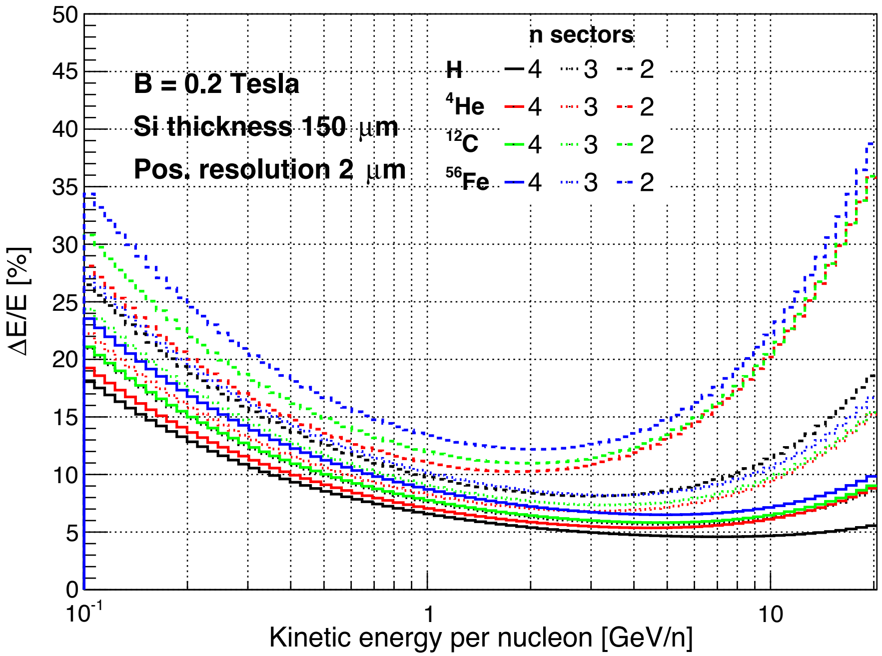
- Light (< 20 kg)
- Low power (< 20 W)
- Symmetric: measure particles coming in from both ends
- 4 Halbach permanent magnet sectors, each (⌀= 10 cm, L = 10 cm) →dipole magnetic field of ~0.2 Tesla

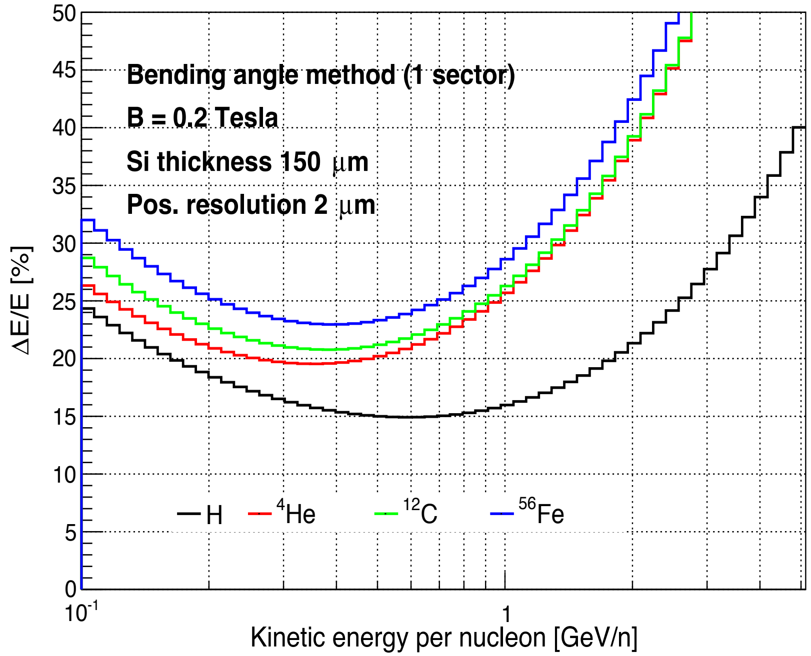




Expected performance: energy resolution

- <10% for protons of 0.4 – 20 GeV for 4-sector acceptance
- <20% for protons of 0.2 – 2 GeV for 1-sector acceptance





The Mini.Pan project

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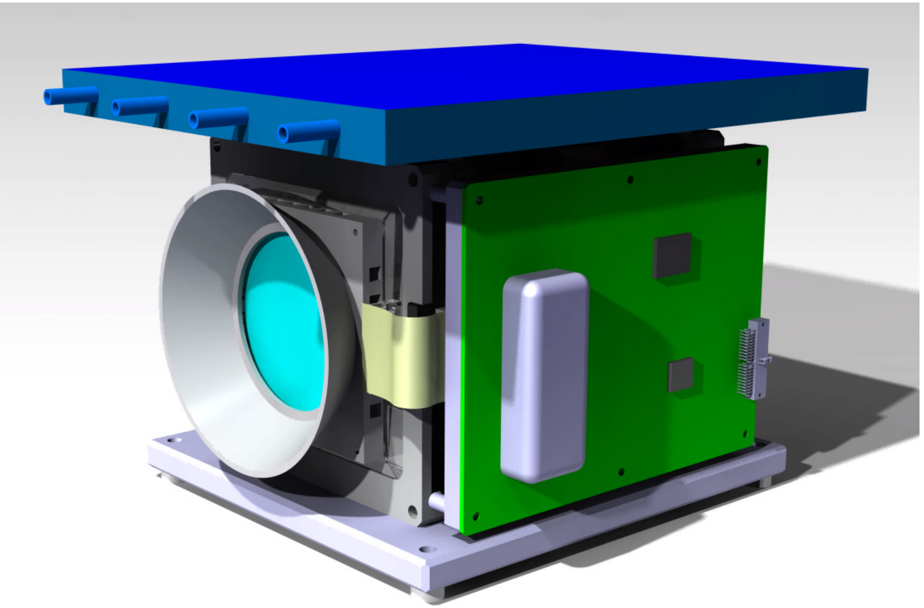
Horizon 2020
European Union Funding
for Research & Innovation

- Funded by the EU H2020 FETOPEN program to develop a demonstrator (Mini.PAN) in 3 years (2020-2022)
- Suitable for space weather and planetary applications (5-8 kg)
- 2 Sectors with smaller dimensions with the same instrumentation (ToF, pixel, tracker)
- The shorter sector length (5 cm) is compensated by a stronger magnetic field.
- It is a demonstrator for the PAN technology.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862044.

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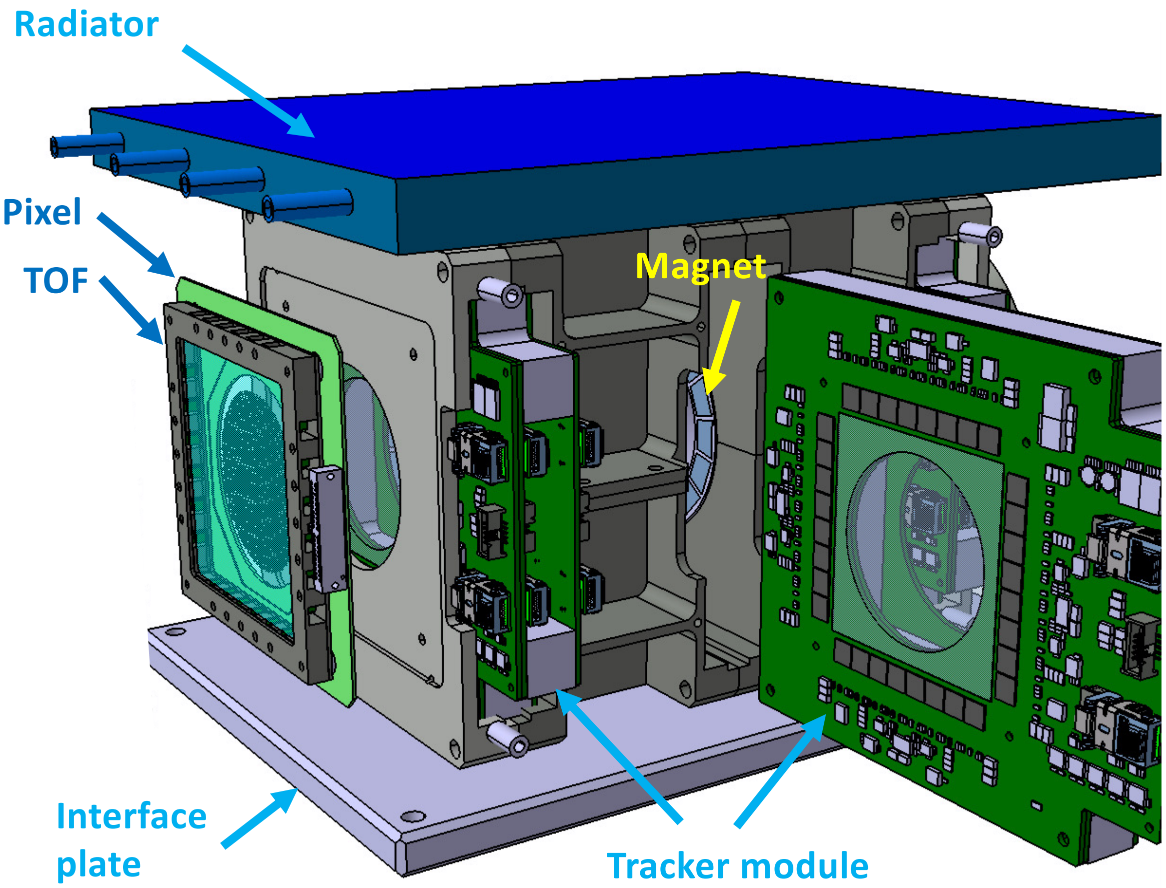
The Mini.Pan instrument

- 2 magnets (⌀ = 5 cm, L = 5 cm)
- Three tracker modules
  - StripX: Measure bending radius and angle
  - StripY: Measure position and time stamp
  - Charge measurement
- Two pixel detector modules
  - Avoid measurement degradation for high rate solar events
  - Extra charge and 3D point measurement
- Two TOF modules
  - Trigger, particle counter
  - Charge and time measurement



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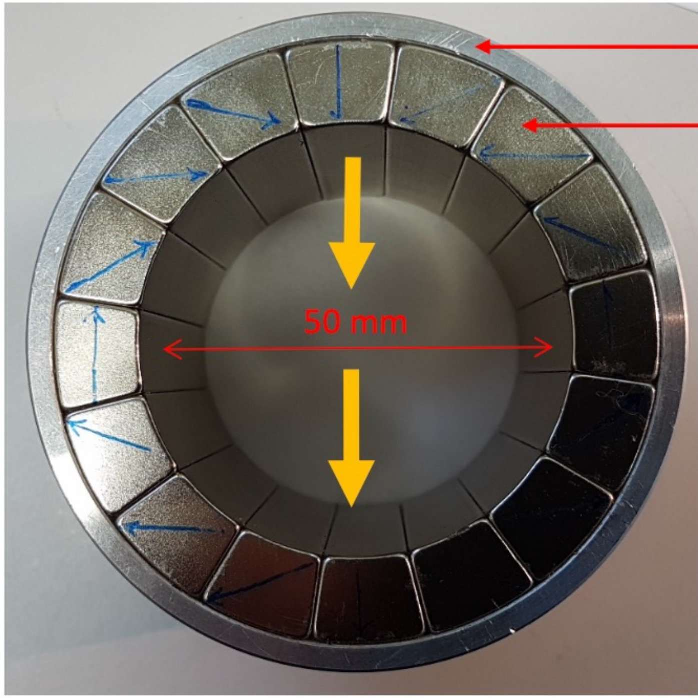
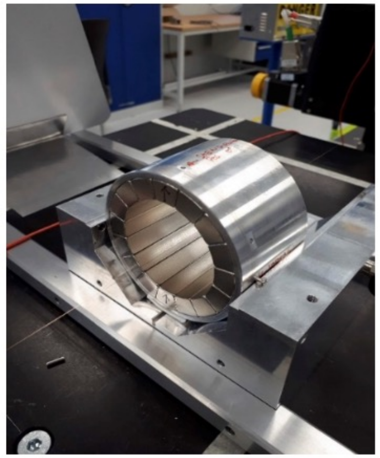
Magnets

- Three prototype magnets have been designed (P. Thonet, CERN) and produced.
- Each magnet is ~0.8 kg;
  Central field 0.4 T,
  Field homogeneity ~ 10 %.
  (Field measurements: C. Petrone, G. Deferne, CERN)
- Two new magnets have been delivered, and will be tested in the coming weeks at CERN.





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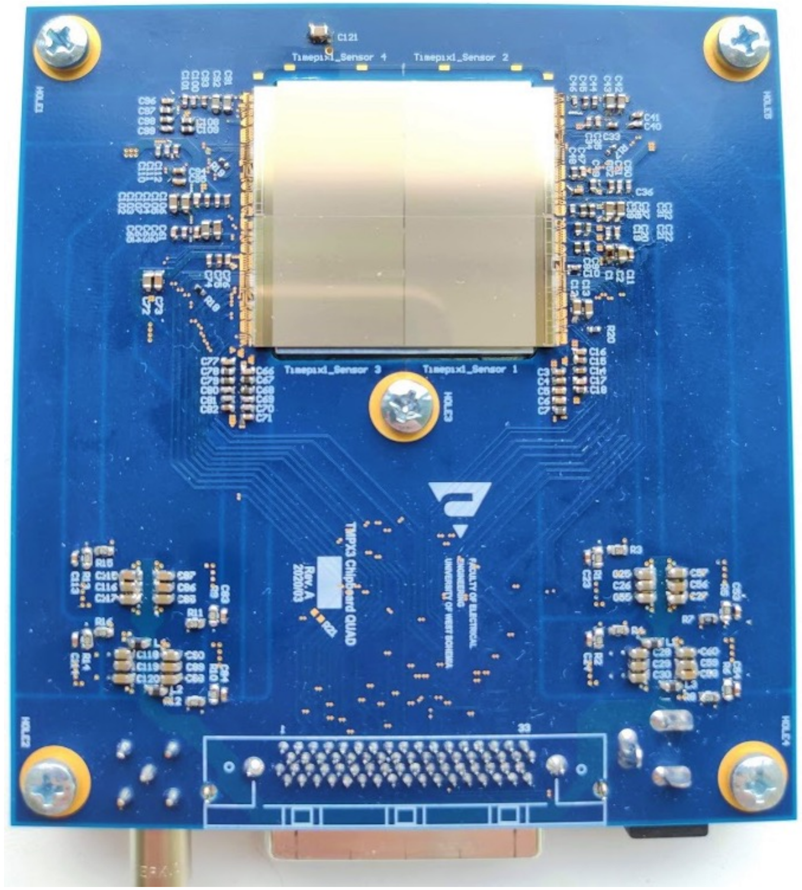
Pixel module: breadboard design

Timepix3 quad detector:

- 262’144 pixels with pixel pitch 55 µm (2.8 x 2.8 cm)
- Simultaneous time of arrival (ToA) and time over threshold (ToT) measurement in each pixel.
- Sensor thickness 300 µm
- ToA binning: down to 1.56 ns



Challenges:

- Power consumption (currently: 4 W, goal: 2.5 W)
- Temperature management (w/o cooling in air: ~55°, in vacuum <~ 80°)

- Two pixel modules will be produced for integration in April 2022.

Pixel module – beam test - ^{3}He 36 MeV

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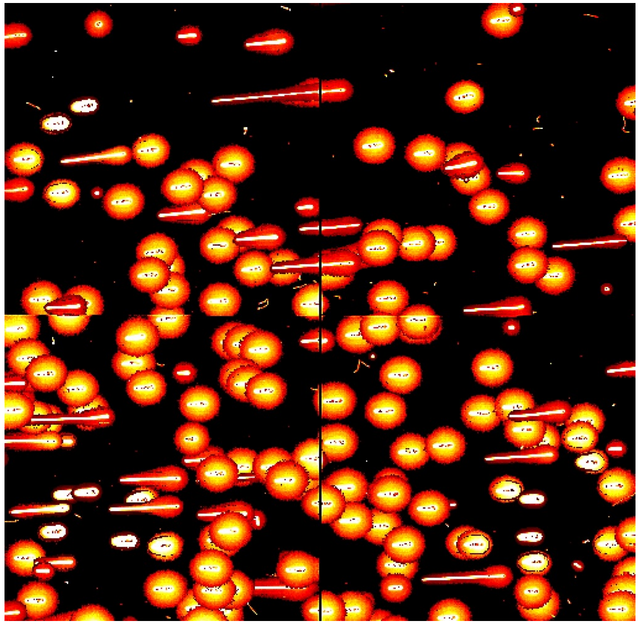
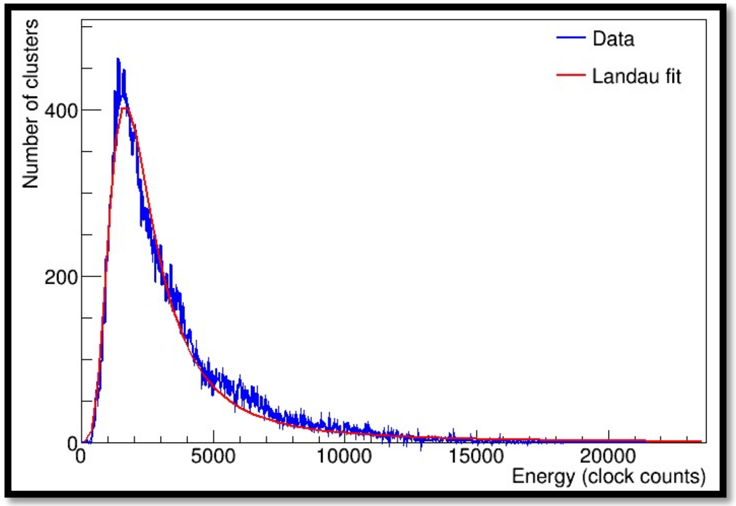
- Beam test at UJV Rez facility, Czech Republic
- Particles: ^{3}He - 36 MeV





Example data: Particle impact at 75°

Tracker detector

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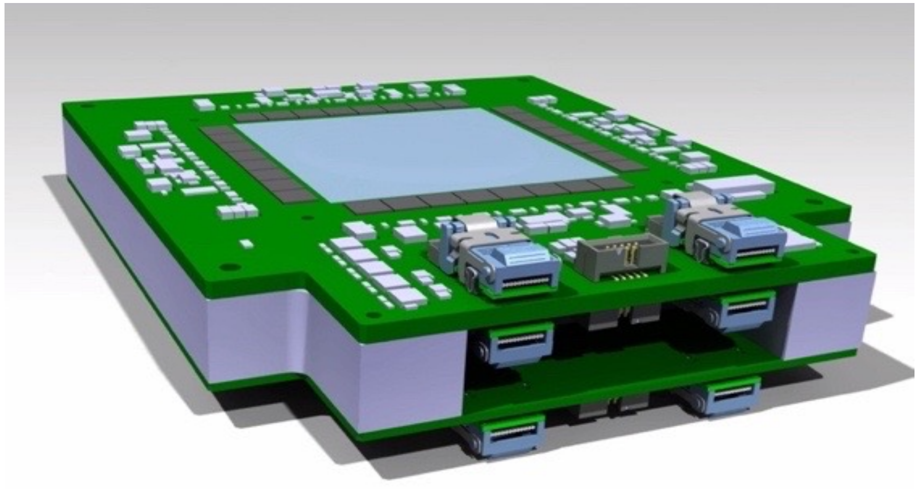
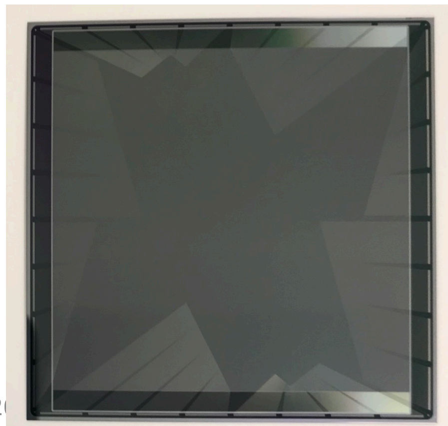
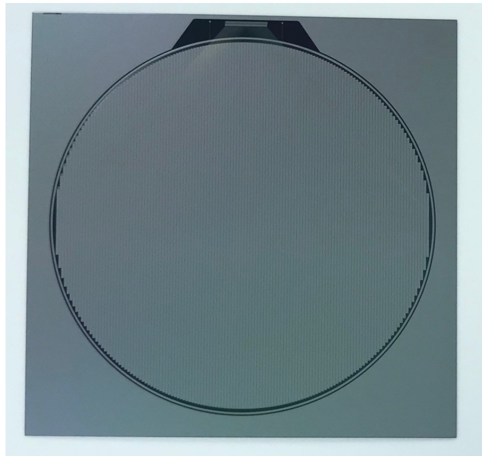
- Mini.PAN will be equipped with three tracker modules
- Each module hosts three sensors.
- Two to measure the X-coordinate (“StripX”)
  - 150 µm thickness, 25 µm pitch, 2048 strips, all read out.
  - 32 IDEAS IDE1140 ASICs to read out one sensor.
  - Double metal layer to route the signals all around the sensor (pitch 96 µm to connect to the ASICs).
  - Active area: 5 cm x 5 cm
- One to measure the Y-coordinate (“StripY”)
  - 150 µm thickness, 400 µm pitch, 128 strips, all read out.
  - 1 IDEAS VATA GP 7.2 ASIC to read out one sensor.
  - Active area: disk of 5 cm diameter.
- Sensors external dimension 6 cm x 6 cm
- Produced by Hamamatsu.







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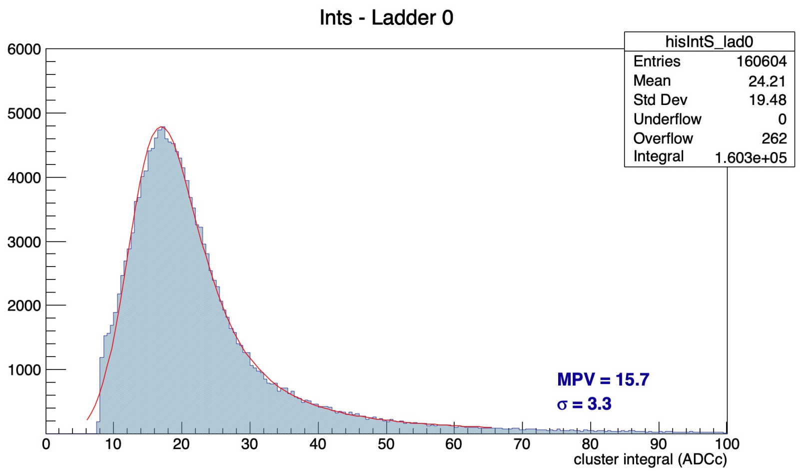
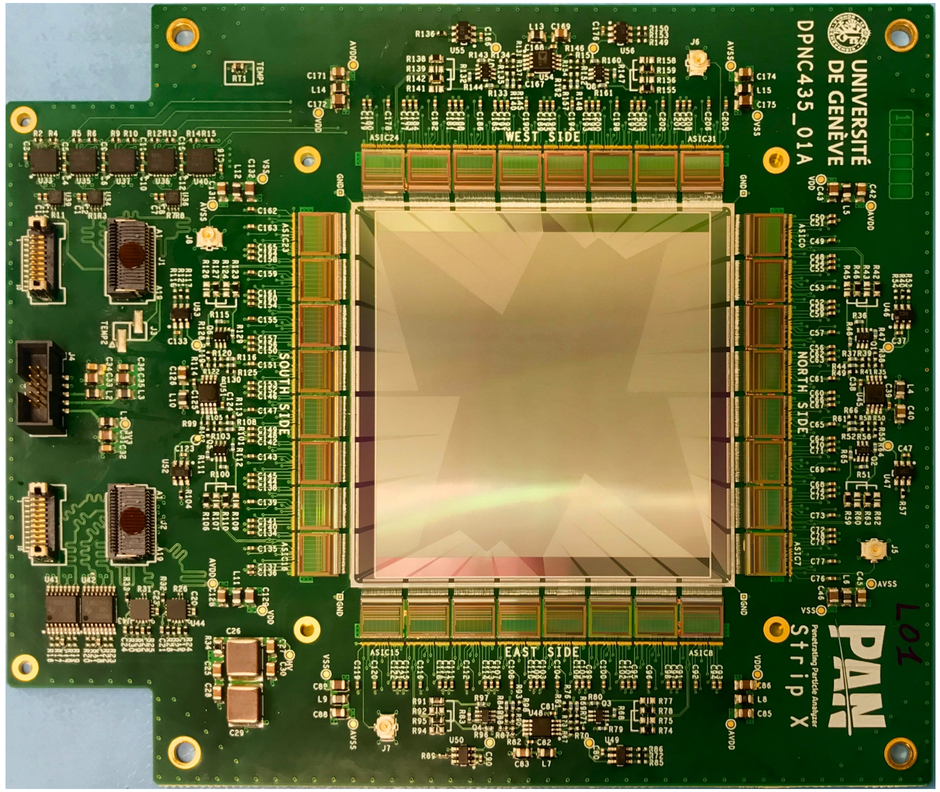
Tracker board

- Three StripX sensors have been tested during various beam tests.
- Analysis of the spacial resolution and signal response is ongoing.





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Summary

- The Mini.PAN project is in good progress.
- The integration of the various detectors into the final instrument is foreseen for April 2022.
- Modules of each subdetector (Pixel, Tracker, TOF) will be studied in the coming weeks at various beam tests at CERN.
- The integrated instrument will then be tested in beams and have partial space qualification tests (in particular thermal and thermal vacuum).
- We are actively looking for flight opportunities (from 2023):
  - Lunar Gateway
  - CubeSat missions
  - Jupiter radiation belt exploration
  - European Large Logistic Lander (EL3) for Moon exploration