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The high resolution PAN detector for deep space cosmic rays particles measurements

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Abstract: The **P**enetrating particle **AN**alyzer, an instrument designed to operate in space, will provide precise measurements and monitoring of the flux, composition, and direction of highly penetrating particles with energy ranging from 100MeV/n to 20 GeV/n. The concept of the detector is based on a modular magnetic spectrometer of small size, reduced power consumption and low weight to make the instrument suitable for deep space and interplanetary missions. The magnetic spectrometer module consists in high-field permanent magnet sectors, high resolution silicon micro-strip detectors, Time-Of-Flight counters readout by SiPMs, and active Pixel detectors to maintain the detection capabilities in high rate conditions occurring during solar energetic particle events and traversing radiation belts around planets.
Here we report on the concept of the experiment and the development of a small demonstrator Mini.PAN for the in-orbit validation of the key functionalities of the instrument.

Scientific Goals of PAN experiment

PAN - a generic instrument technology for deep space and interplanetary missions
- Capable of precisely measure and monitor in real time the flux, composition, and direction of penetrating particles (>~100MeV/nucleon) in deep space, moons, planets,…
- Impact on Multidisciplinary science and technology potentials

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.

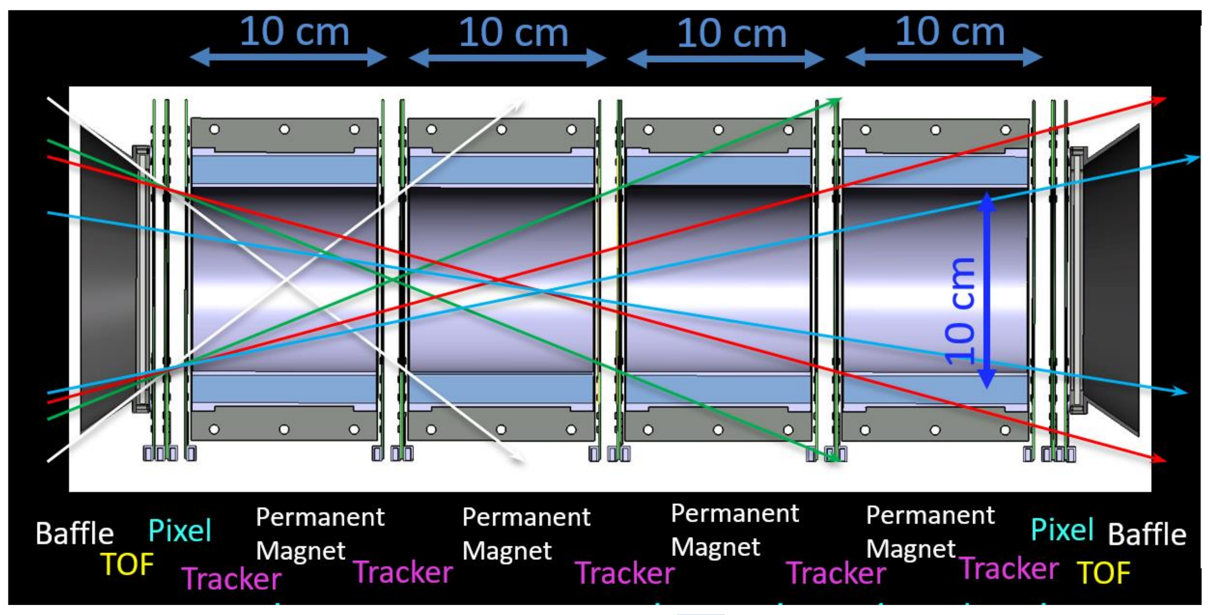
Space weather:
- improve space weather models from the energetic particle perspective

Planetary science:
- Develop a full picture of the radiation environment of a planet, 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 become a standard on-board instrument for radiation monitoring for deep space travel.

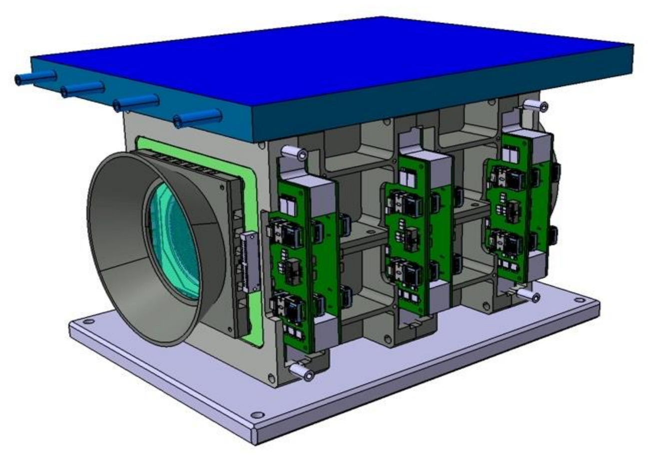
Concept of the PAN Instrument and Measurements

PAN use a magnetic spectrometer (magnetic field + tracking detectors) to measure the bending of charged particles in the B-field → rigidity (p/Z);
PAN aims to achieve unprecedented precision by pushing the technology limits for space application



- **Tracker:** made of five silicon modules will provide excellent rigidity resolutions, particle direction measurement with an angular resolution of 0.2deg, a trigger and the measurement of Z
- **The Magnet:** made of four permanent magnet sectors with a 0.2T magnetic field. Each sector will be 10cm long with diameter of 10cm
- **TOF detectors:** made of plastic scintillator readout by SiPM will provide a trigger, particle counter (max. ~10 MHz), charge measurement (Z = 1 - 26), and time measurement (< 100 ps)
- **Pixel Detector:** made by two modules providing Time of Arrival (ToA) and Time over Threshold (ToT) measurement, will avoid measurement degradation for high rate solar events and at lower rate solar events gives one extra 3d point with 55um Si pixels

From PAN Instrument to mini.PAN Demonstrator



Funded by the EU H2020 FETOPEN program for design and construction a ground demonstrator (Mini.PAN) in three years (2020-2023)
Grant Agreement Nr. 862044 –PAN: http://www.pan-space.eu/

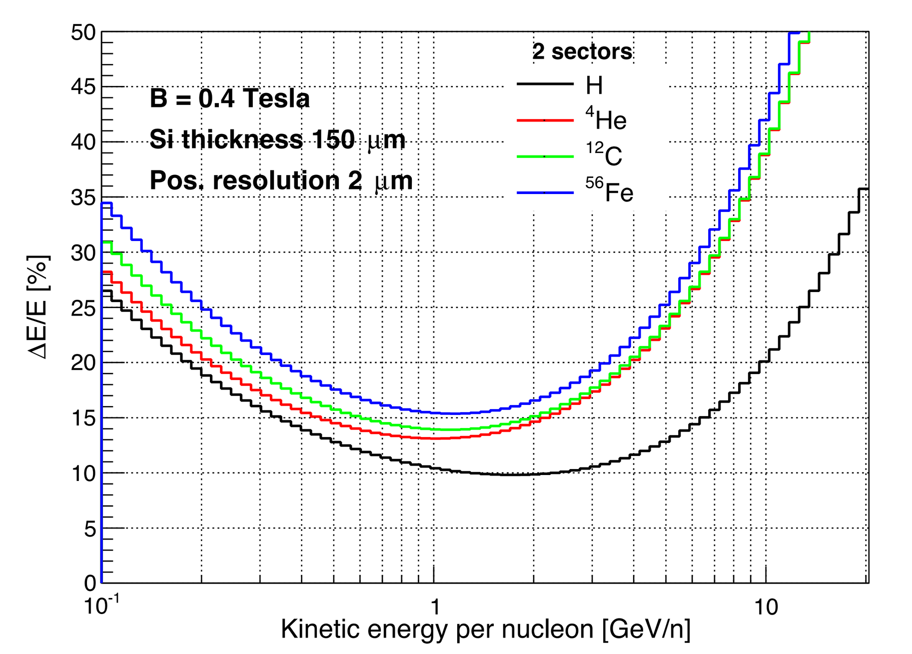
MiniPAN demonstrator overall characteristics:
- Total dimensions: 20cm x 30cm x 20cm
- Weight: max. 10kg
- Power consumption: < 30W

Mini.PAN DEMONSTRATOR

Expected Performance of mini.PAN

Energy resolution <20% for protons of 0.2 – 10 GeV for 2-sector acceptance

Energy resolution for 1-sector acceptance same as PAN (<20% for protons of 0.2 – 2 GeV) Shorter sector length (5 cm instead of 10 cm) compensated by stronger B field



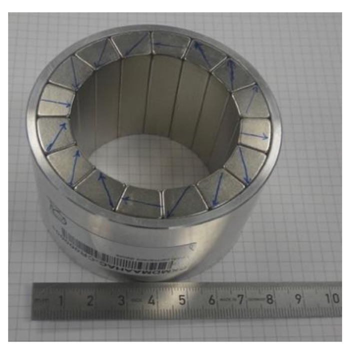
Mini.PAN TOF

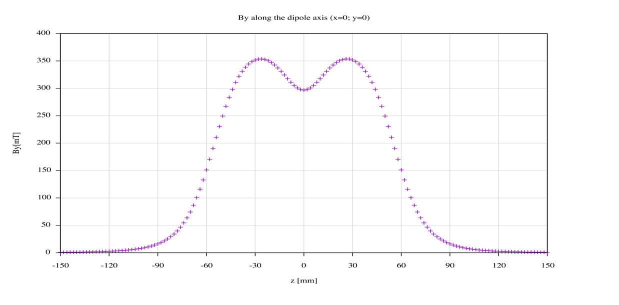
made by plastic scintillators optically coupled with SiPMs which are read-out by the front-end electronics. Total power budget cca. 1W

TOF detectors provide:
- Trigger
- Measurement of Z
- Measurement of Time of Flight
- Low energy particle counter

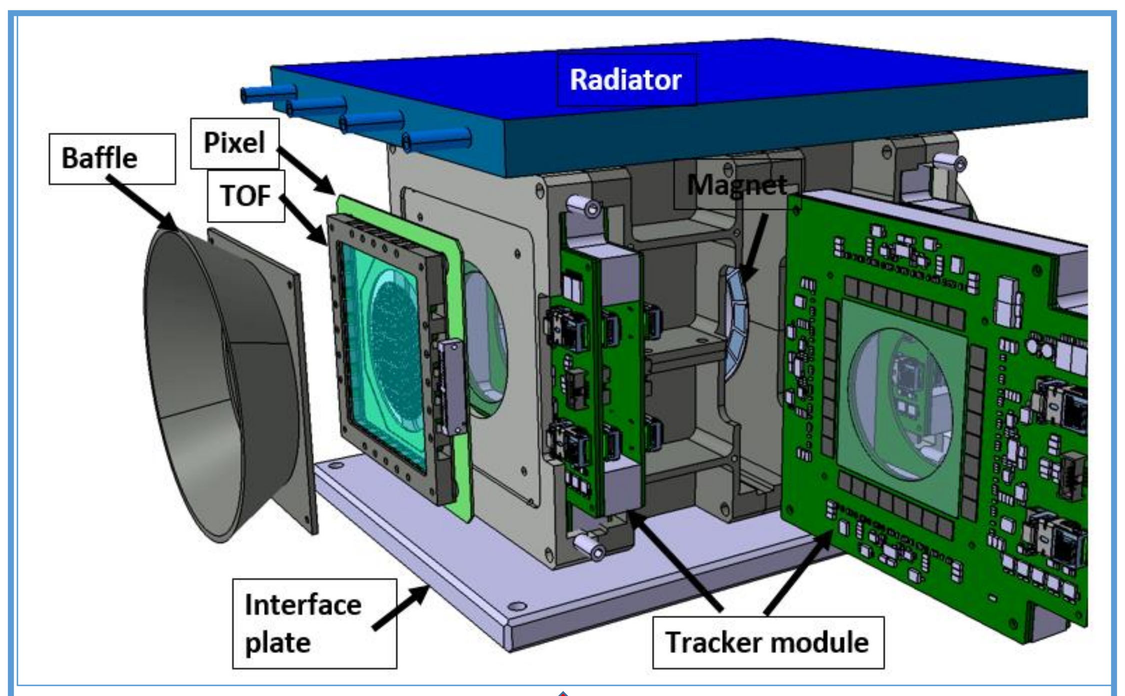
Mini.PAN MAGNET

Two-sector permanent magnet providing a dipolar field perpendicular to particles incoming direction; Each sector is a dipole-type Halbach array made of 16 blocks of NiFeB glued together. The inner diameter for the miniPAN magnet is 5cm.





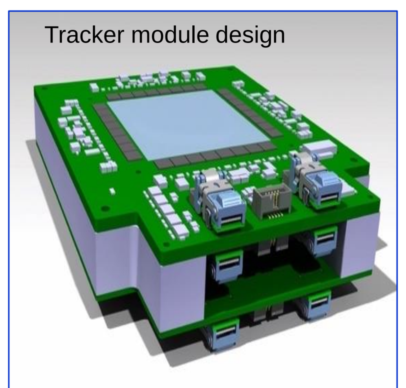
MiniPAN simulated magnetic field By component at the center of the magnet as a function of the position along the dipole axis



An important advantage of the minPAN instrument is the **modularity** of the apparatus: more magnet blocks can be added, more silicon tracker modules can be inserted

Mini.PAN TRACKER

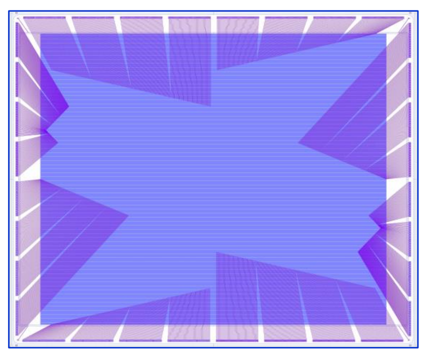
- Thin (150 µm) Silicon Strip Sensors
- Pitch adapter to fan-out to bonding pads directly implemented o the silicon wafer with double metal layer
- Low noise ASIC and analog readout electronics to allow CoG reconstruction
- Robust module design and assembly to survive manipulation and space qualification
- Thermal/mechanical system that ensures stability during operation



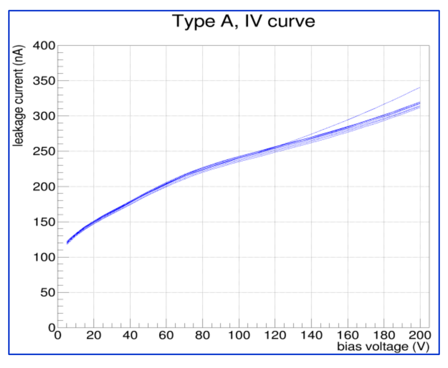
Tracker module design

Mini PAN Tracker will have three modules. Each module made of three silicon strip detectors:
- Two "X-coordinate reading sensor" with 25 µm readout pitch, mounted back to back on a mechanical support, with a 2 µm spatial resolution, read out by 32 VA1140, 2048 readout channels
- One "Y-coordinate reading sensor" with 500mm readout pitch, providing 115 µm spatial resolution readout by a high dynamic range VATA GT7.2 chip with 128readout channels
- Total Tracker power consumption 8W

Strip X detector assembly in INFN – Perugia Clean Room



Strip X sensor (type A) design

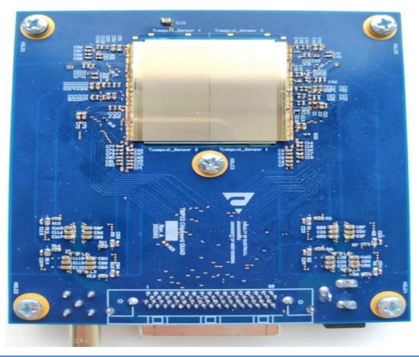


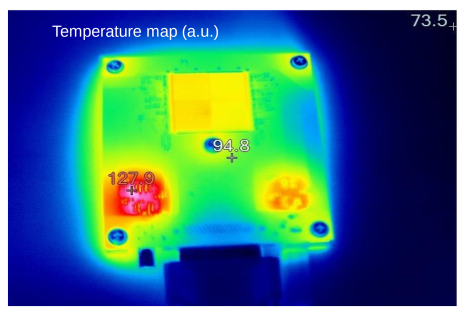
Strip X sensors characterization

Mini.PAN PIXEL

four Timepix3 pixel detector assemblies in a 2 x 2 (quad) arrangement.
A Timepix3 quad PCB contains four Timepix3 ASICs and a 300mm thick silicon sensor bump bonded

PIXEL detector provides:
- A high rate particle counter
- Improvement of tracking (a fraction of events)
- Measurement of Z (a fraction of events)





> 260K 55um pixels Area cca 8cm^2

Chalenges:
- Power consumption (currently: 5.5 W → goal: 2.5 W)
- Temperature management

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