The development of a demonstrator of the Penetrating Particle Analyzer for space missions

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Scientific applications of PAN

- Spectroscopy of high energy particles (0.1-10 GeV/n) in deep space – not yet achieved
- **Magnetic spectrometer** utilizing bending of charged particles in magnetic field
- Aiming on **low weight** and **low power consumption** – target mass below 10 kg and target power around 20 W
- **Trapped particles in planetary magnetic fields** - protons, ions, electrons
  - Van Allen belts, Jupiter's radiation belts, …
- **Galactic cosmic rays (GCR)** – protons, all sorts of ions
  - Understanding origin of GCR and their interplay with solar activities
- **Solar energetic particles (SEP)** – high energy particles (up to several GeV) ejected from the Sun during solar particle events
  - Rare events, but very high rate of particles
  - Understanging processes that create SEP
- **Albedo particles** from Solar system bodies – secondary particles created by high energy cosmic rays bombarding the bodies
  - Lunar albedo particles = potential danger for future human missions
- **Deep space travel** – measurements of radiation environment in deep space and near Moon are important for improving radiation exposure models
  - High energy cosmic rays cannot be shielded
  - PAN can be standard part of radiation monitoring equipment

MiniPAN demonstrator

- **Modular design** – tracker modules and magnet segments (figure 1)
- **Magnets** – 2 units
  - 16 permanent NdFeB magnets in Halbach geometry (figure 2)
  - Magnetic flux density 0.35 T in the middle
- **Tracker** – 3 modules, silicon strip detectors
  - In each module: 2 stripX detectors (strip pitch 25 µm; figure 3) in the bending direction and 1 stripY detector (strip pitch 400 µm)
  - 150 µm thickness of the sensors
- **Pixel detector** – 2 units of silicon Timepix3 Quad pixel detectors (figure 4)
  - Precise determination of the particle entry point in x and y axes
  - 55 µm pixel pitch, 512×512 pixels, 300 µm thickness of the sensor
  - Operated in low-power mode
- **Time-of-Flight (TOF)** – 2 units on very ends of MiniPAN; provides trigger
  - Required charge resolution from Z=1 to Z=26
  - EJ-230 scintillator coupled with 12 SiPMs (figure 5)
  - Precise time measurement (error ~190 ps) to get particle's direction of travel

MiniPAN results

- Verification of the performance in known particle beams
  - StripX **spatial resolution** ~5 µm (figure 6)
  - Best energy resolution ~15 % for **protons** @ 1 GeV (figure 7) and ~10 % for **electrons** @ 0.1 GeV (figure 8)
  - TOF charge resolution from Z=1 to Z=20 (figure 9), timing resolution ~190 ps
  - StripX detectors can also be used for charge determination, resolution up to Z=22 (figure 10)
- Testing mechanical endurance in **shock and vibration tests**
  - MiniPAN passed the tests

Future of PAN

- **PixPAN** – unification of detector technology
  - Tracker based on **Timepix4** pixel detectors
  - Timepix4 can measure in data-driven mode with time-of-arrival precision 195 ps – no need for TOF
- Accepted for:
  - **ESA Moon Reserve Pool** – in reserve (ongoing)
  - **REMEC**, Phase0/A/B1 in ESA – not selected for mission launch (completed)
  - **COMPASS**, finished pre-Phase A in NASA – detector for probing radiation belts of Jupiter (under evaluation)
  - **LunPAN**, pre-Phase A in ESA – mission for measurement of radiation environment on Gateway-like orbit; including detectors optimized for detection of lunar albedo neutrons and gammas (ongoing)

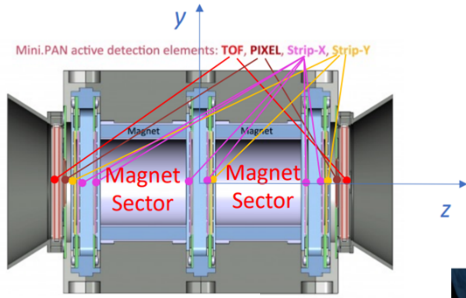

Figure 1 Side sketch of MiniPAN components. TOF and pixel detectors are on the edges of MiniPAN. Magnet sectors and tracker modules with StripX and StripY detectors are modular – more of them can be put together.

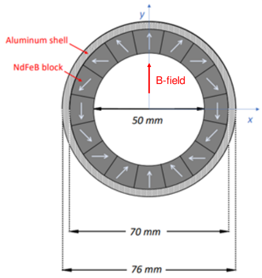

Figure 2 Sketch of magnets in Halbach array used in MiniPAN.

Figure 3 StripX detector.

Figure 4 Assembly of MiniPAN. Timepix3 Quad is on the top. TOF scintillator has not been installed, yet.

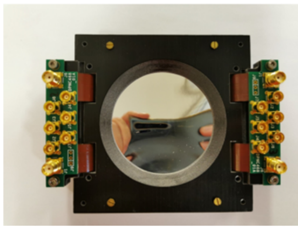

Figure 5 TOF scintillator wrapped in a reflective foil and black casing ready to be installed on MiniPAN.

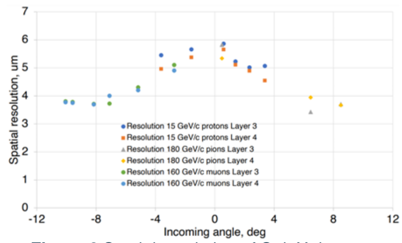

Figure 6 Spatial resolution of StripX detector – beamtest data at various incident angles.

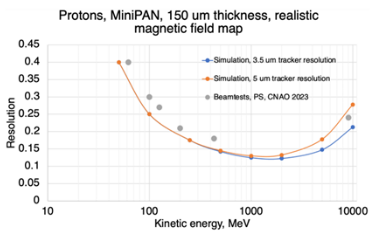

Figure 7 Resolution of proton energy by MiniPAN – simulation and beamtest data.

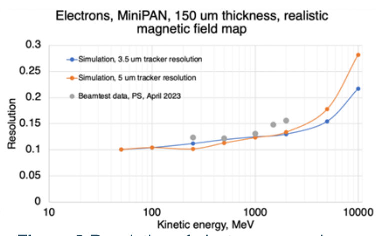

Figure 8 Resolution of electron energy by MiniPAN – simulation and beamtest data.

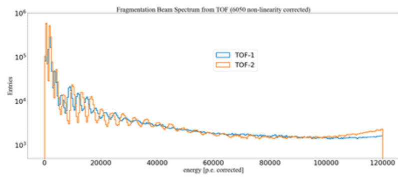

Figure 9 Charge resolution of TOF in heavy ions beam test. TOF can resolve charge up to Z=20.

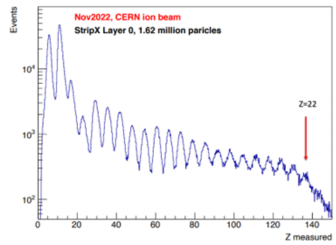

Figure 10 Charge resolution of StripX in heavy ions beam test. StripX can resolve charge up to Z=22.

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