Penetrating particle Analyzer (PAN) for deep space exploration

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Penetrating Particle Analyzer

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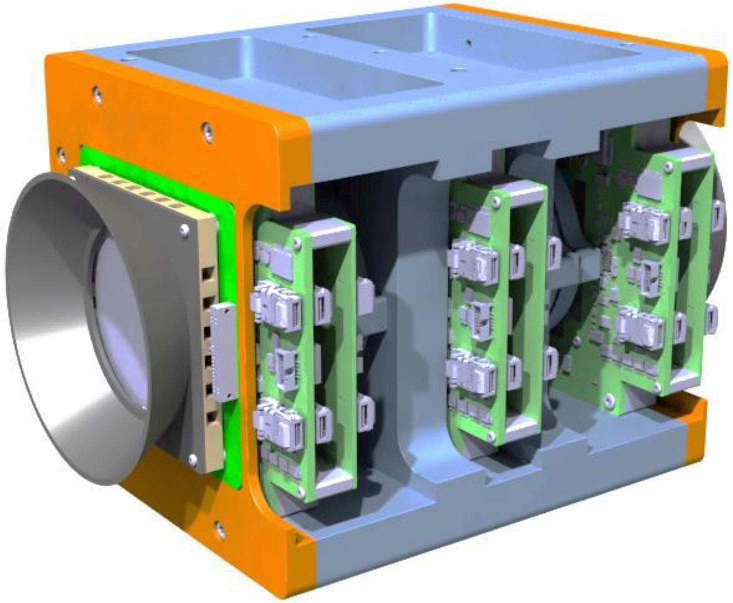
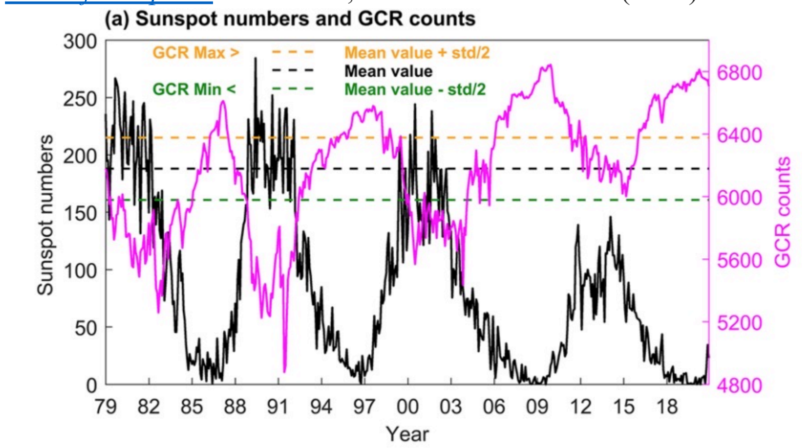
FACULTÉ DES SCIENCES

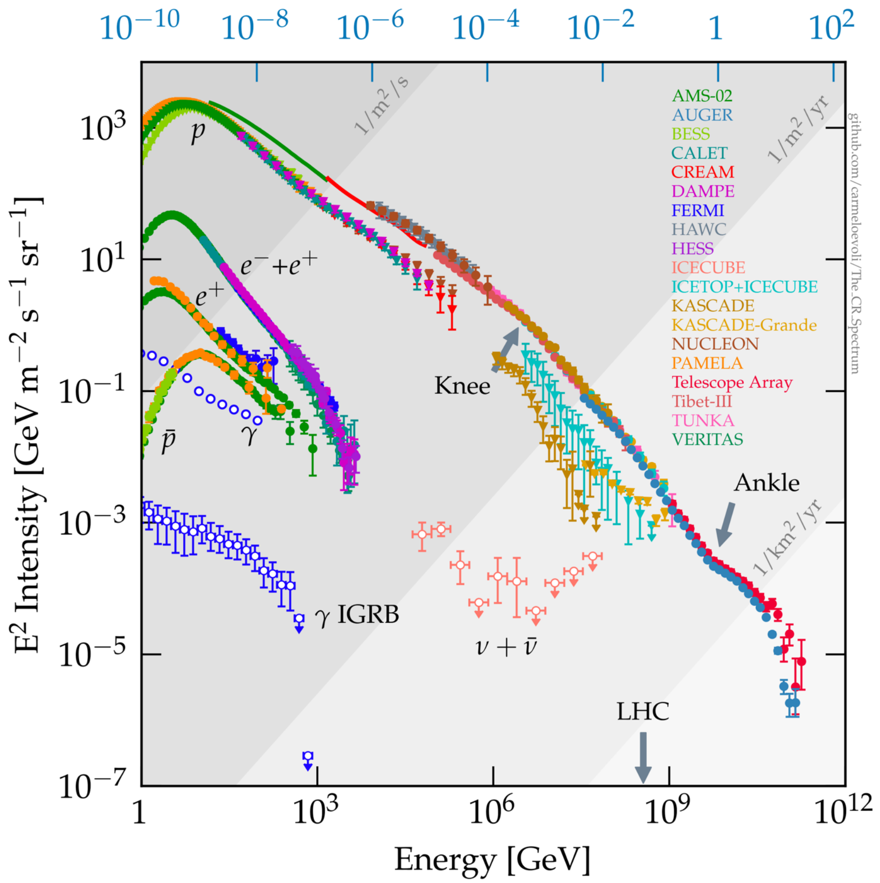


Space radiation environment

- Galactic Cosmic Rays (GCRs):
  - “Static” component, inward diffusion
  - 85% protons, 4% helium particles and 1% heavy ions and 2% electrons
  - Dominant at high energy (Difficult to shield)
  - Modulated by solar activities (Balanced by outward expansion of solar wind)
  - Affected by local magnetic field

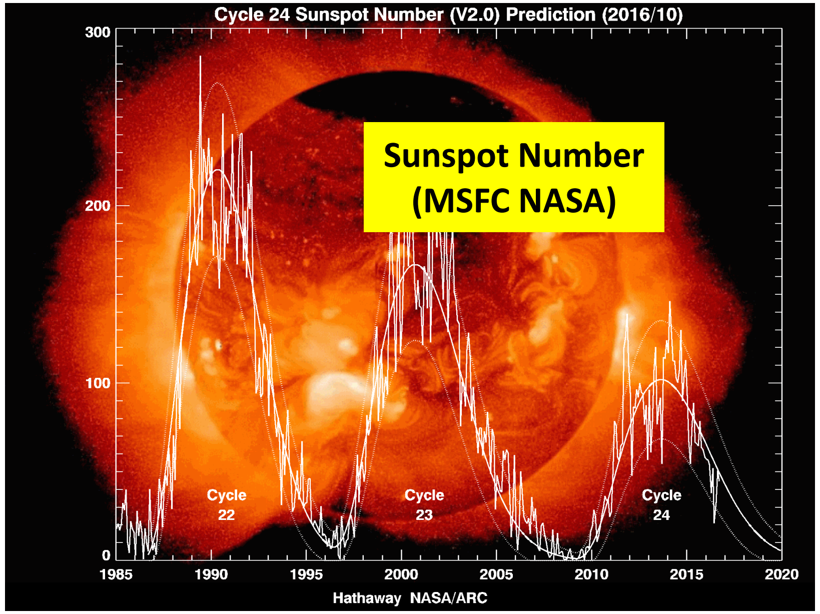
Scientific Reports **volume 13**, Article number: 3707 (2023)

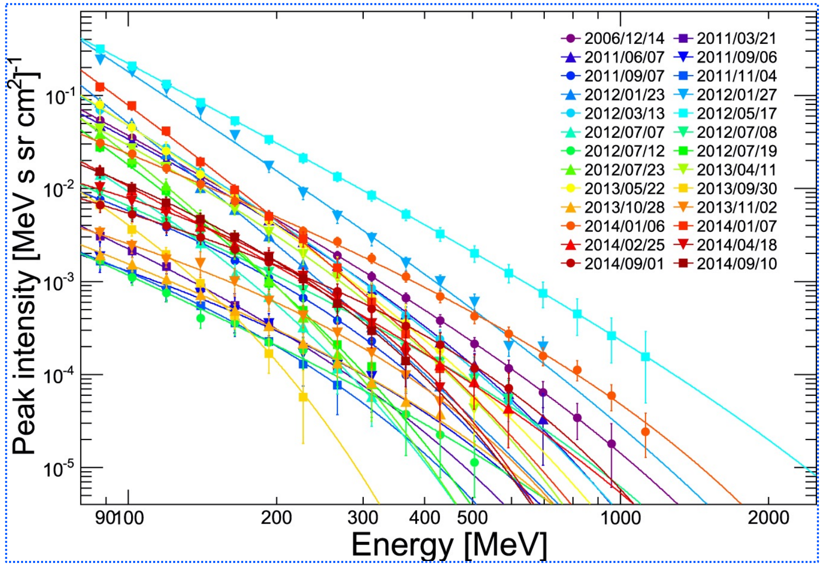




Space radiation environment

- Solar Energetic Particles (SEPs):
  - Rare but intense, largest flux happens during maximum solar activity
  - 92% protons, 6% Helium particles, 2% heavy ions
  - Associate to solar flares, coronal mass ejection (CME)
  - Energy mostly under 1000 MeV
  - Flux can reach > 1000 times of GCR flux
  - Currently not predictable



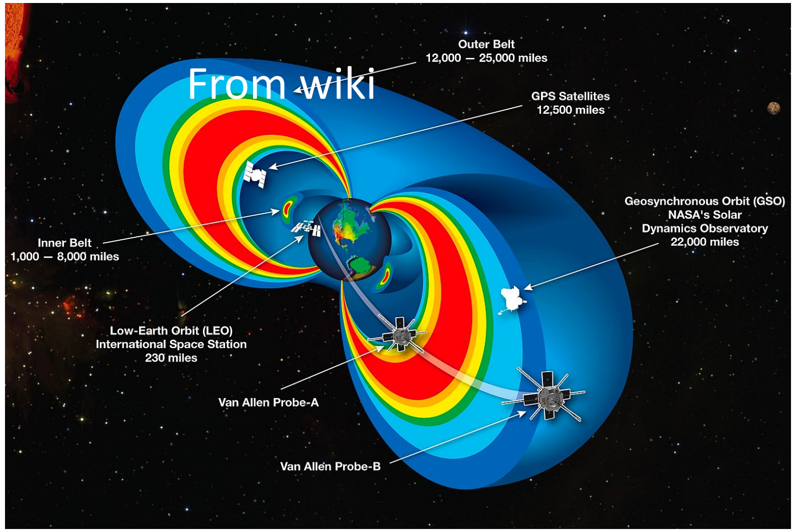


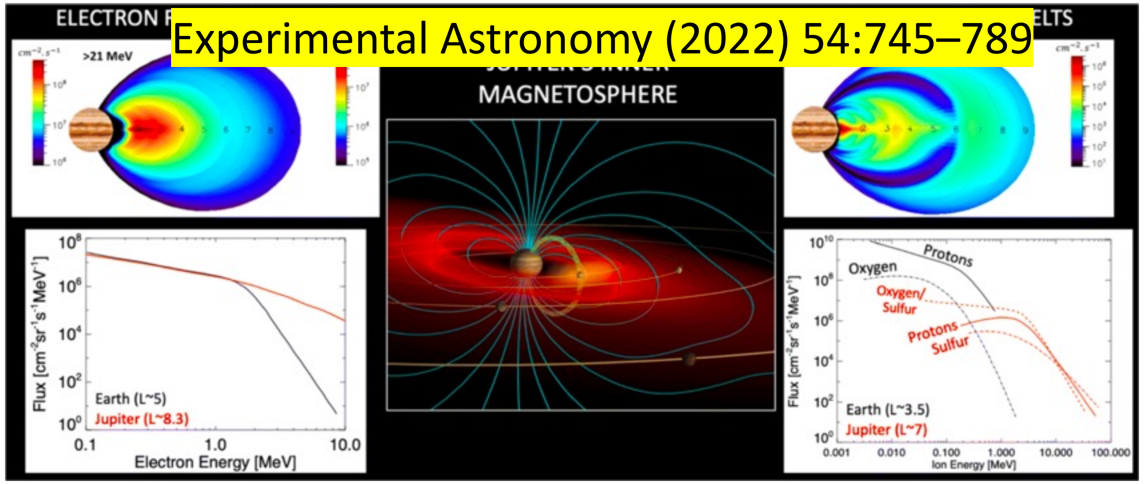
GCR (SPENVIS)

PAMELA SPE 2006-2014
(ApJ 862:97, 2018)

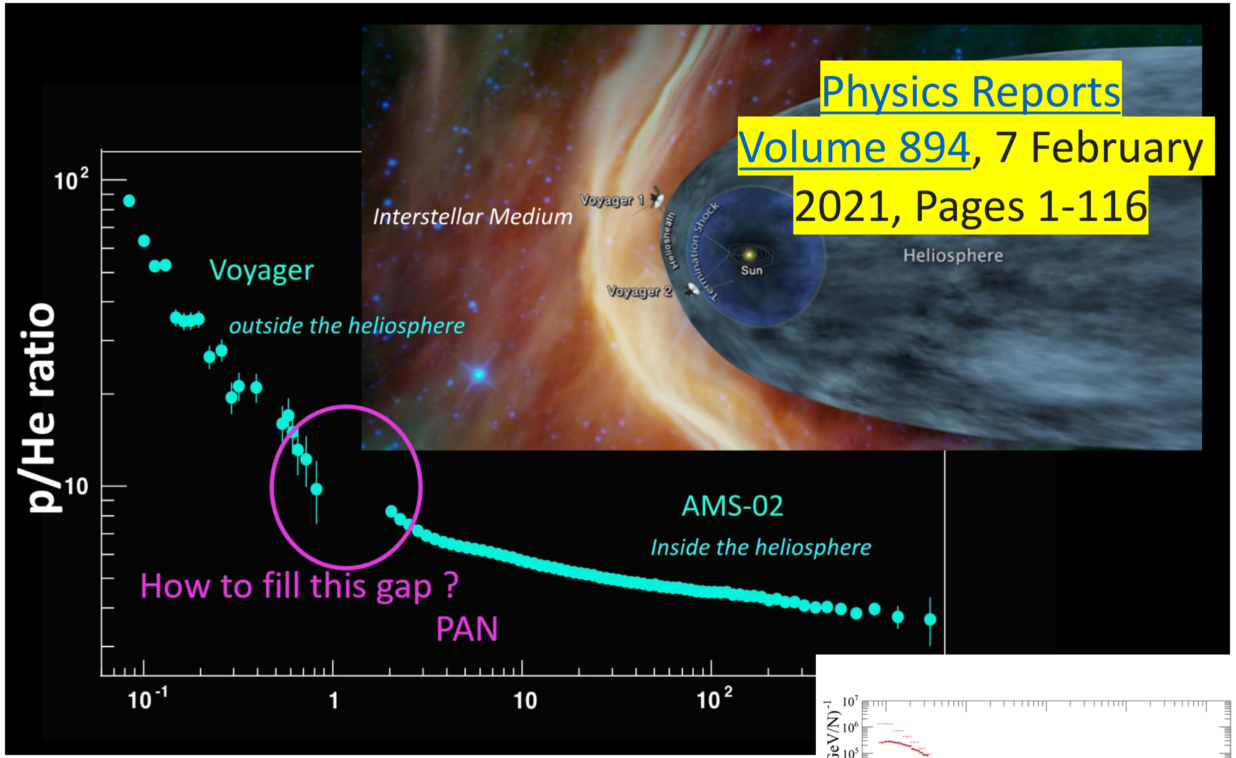
Space radiation environment

- Trapped particles in radiation belts
  - Van Allen belts (keV-100MeV electrons, protons)
  - **Jupiter**, Saturn, Uranus and Neptune
  - Jupiter radiation belt (20000 times stronger than Earth, ~100 GeV protons can be trapped)
- Albedo particles
  - Particles generated at the surface by GCR/SEP (reflection, activation)



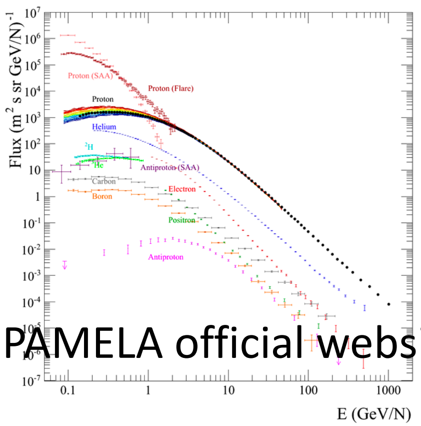


Motivation

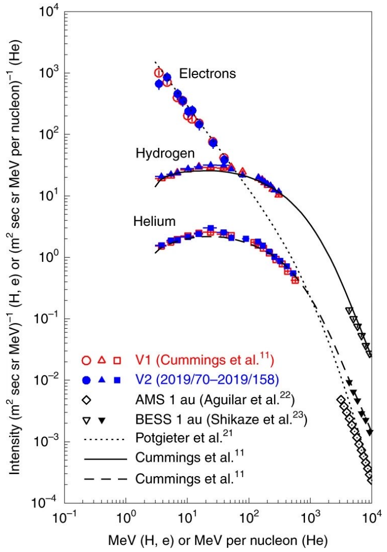


- Many instruments measure GCR flux in deep space ,but only limited to a few 100 MeV/n
  - IMP-8(1973-2006), GEOS (1975-), Voyager 1/2 (1977-), SOHO (1995-), ACE(1997), CRaTER(2009-)…
- ~Geo flux only measured by low earth orbit (LEO)/ balloon missions at high altitude regions
  - AMS-02 (2011-),PAMELA(2006-2016), BESS (1993-2008)
  - Dependence on geomagnetic cutoff evaluation
  - Rate drop below 1 GeV/n

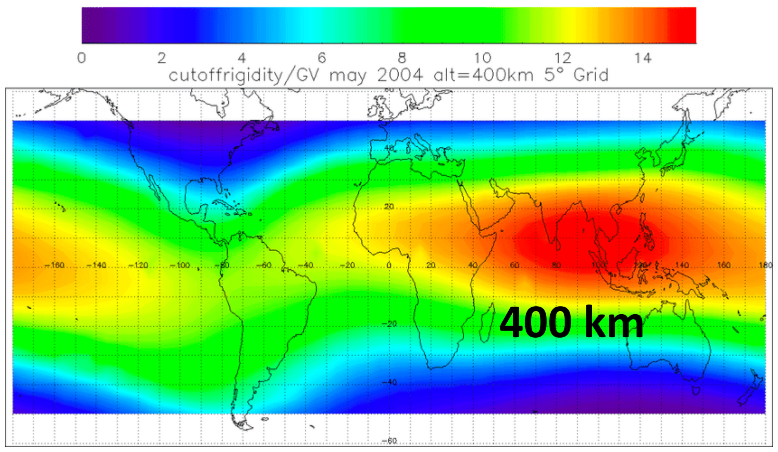
Van allen belt: 640 km - 58,000km
AMS(ISS): 422 km
PAMELA: 350-600 km



PAMELA official website



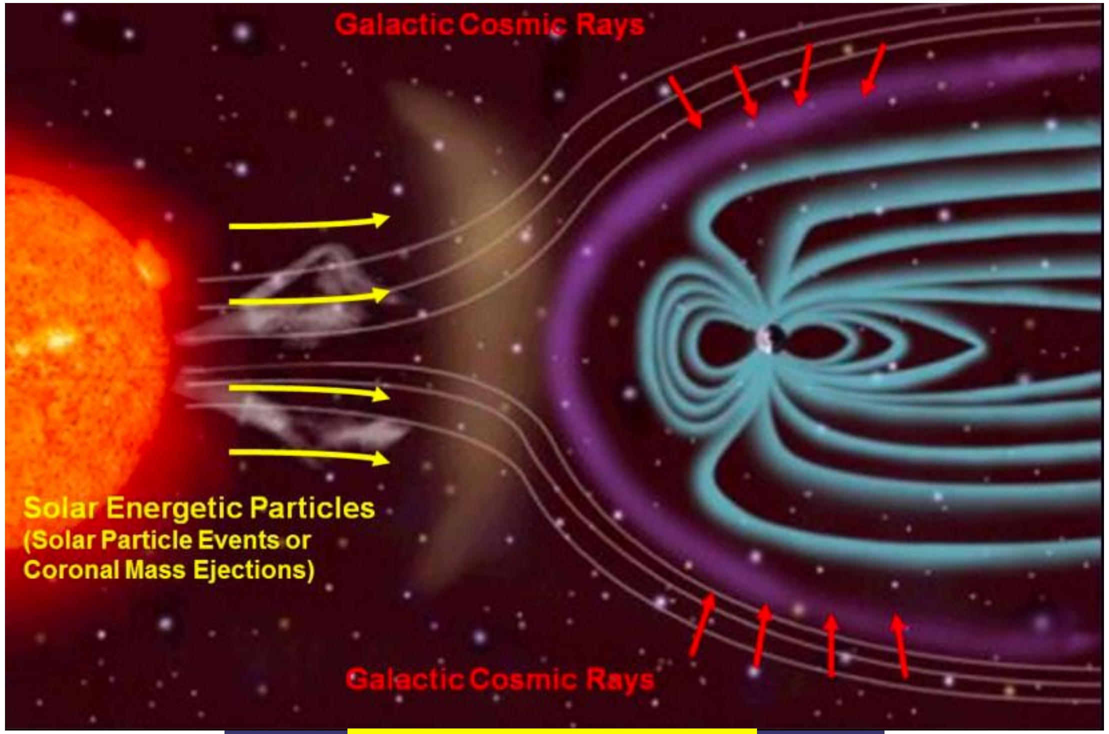
Nature Astro. V3, 1013–1018 (2019)

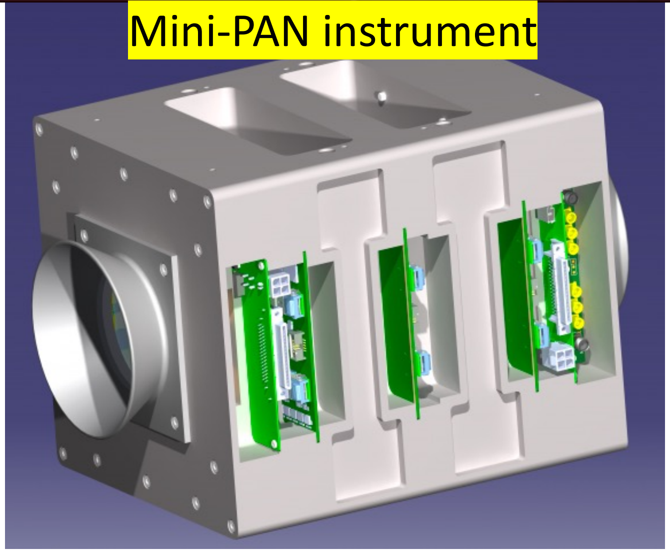


DOI:10.13140/RG.2.2.11166.18246

Objectives

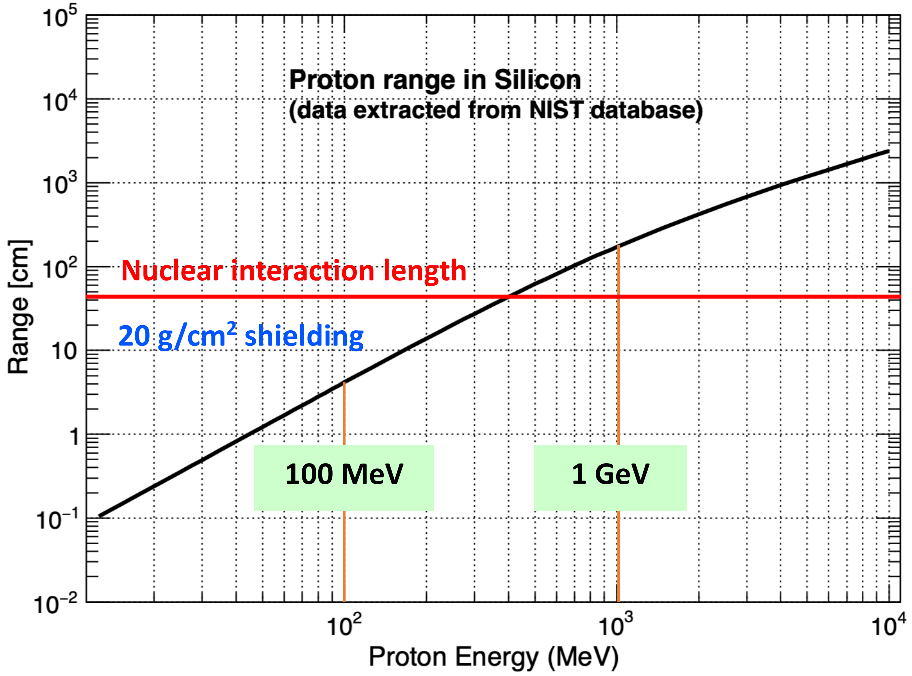
- PAN Versatile multi-disciplinary instrument
  - Precise monitor charged particles from 30 MeV/n to 10 GeV/n
- objective also includes:
  - Solar physics study
  - Space weather model improvement
  - Radiation environment measurement in different planetary system(Lunar, Jupiter)
  - On-board dosimetry for deep space travel
  - Anti-matter search



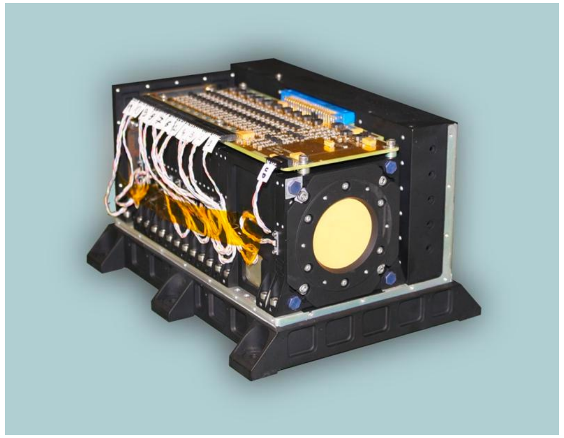


Challenge of measuring penetrating particles

- Energy of penetrating particles cannot be measured by the ΔE-E method
  - ~4 cm of Silicon needed to stop 100 MeV protons completely
    - **To stop 1 GeV protons 170 cm of Silicon is needed!**
  - Silicon nuclear interaction length = 46.52 cm
    - More likely to produce a **shower of secondary particles** (including the dangerous neutrons)
    - Calorimeter method: **very heavy, with bad resolution**
  - Similarly relativistic electrons shower in thick material

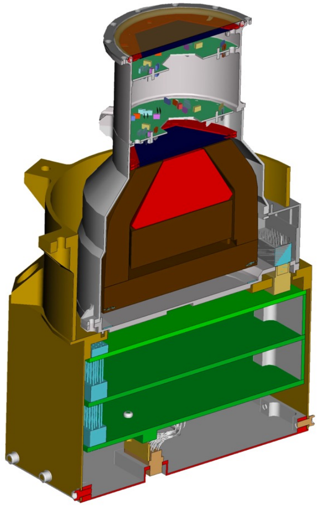


Instruments for space radiation



EPT (Energetic Particle Telescope)
Dimension: 13 × 16 × 21 cm^3
Mass: 4.6 kg
Power consumption: 5.6 W
Dynamic range: proton (9-300 MeV) Helium (36 - 1200 MeV)
Mission: Proba-V

SREM (Standard Radiation Environment Monitor)
Dimension: 9.5 × 12 × 22 cm^3
Mass: 2.64 kg
Consumption: 2.5 W
Dynamic range: electrons from 0.3 MeV to 6 MeV and protons from 8 to 300 MeV
Mission: Integral, Rosseta, Planck, etc

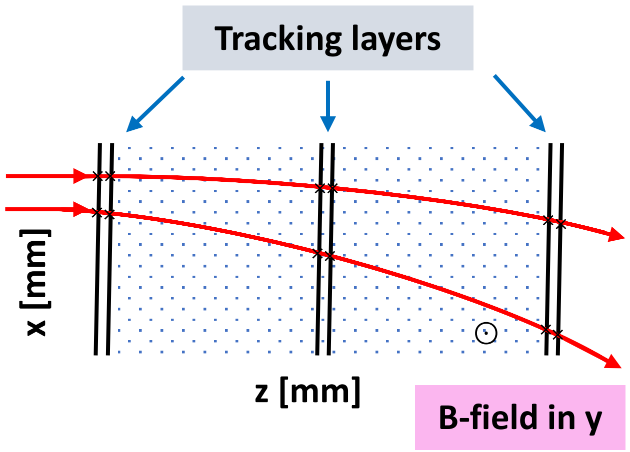


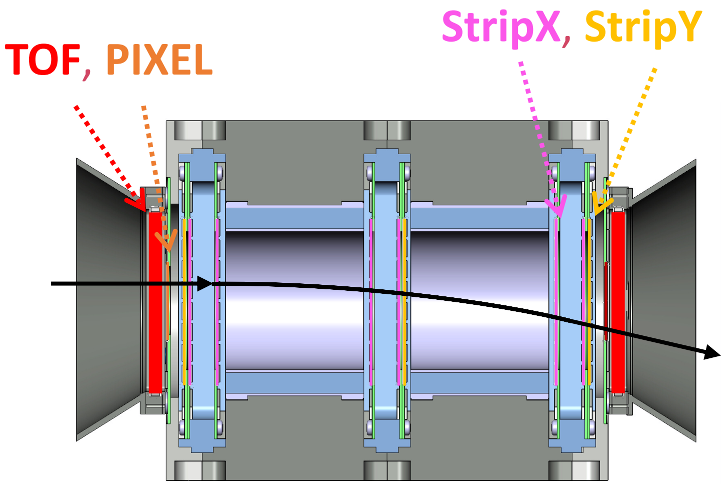
RAD (Radiation Assessment Detector)
Dimension: 240 cm^3
Mass: 1.56 kg
Power consumption: 4.2 W
10-100MeV/n, also measure neutrons and gammas
Mission: Mars Rover

Penetrating Particle Analyzer (PAN)

ASR,V63,2672-2682(2019)

- Instrument featuring a compact magnetic spectrometer to measure the bending of charged particles in the B-field -> rigidity (p/Z)
- Magnetic spectrometer = magnetic field + tracking detectors





PAN Consortium

2nd PAN workshop @ Prague 2021.10

~30 people involved

- University of Geneva (coordinator)
- INFN Perugia
- Czech Technical University in Prague

Magnet design and tests: Pierre Thonet, Carlo, Petrone, M.Liebsch, and Guy Deferne - (CERN)

Mini-PAN demonstrator:
Project funded by EU

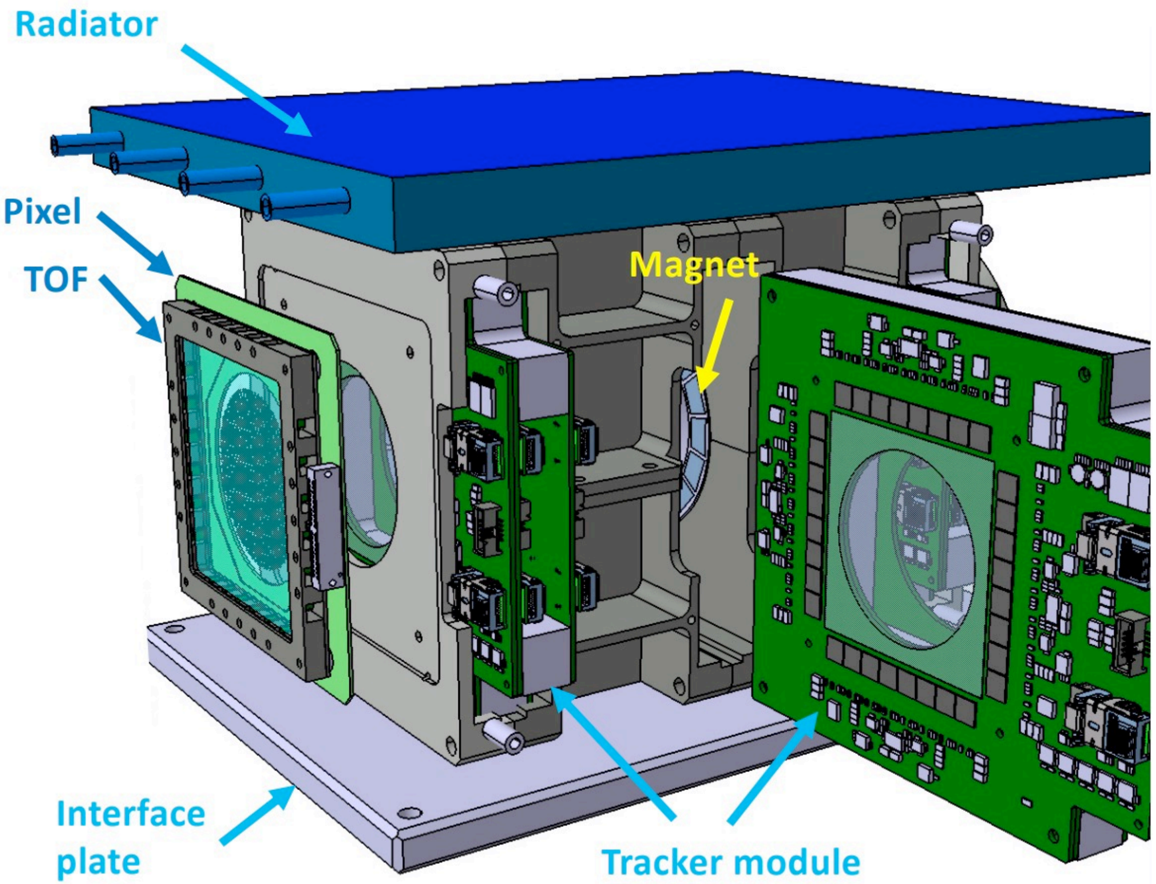
Mini-PAN detector

Magnet (UniGe)
- 2 Halbach permanent magnet sectors
- Dipolar magnetic field of 0.4 Tesla
- Each 5 cm long and 5 cm diameter

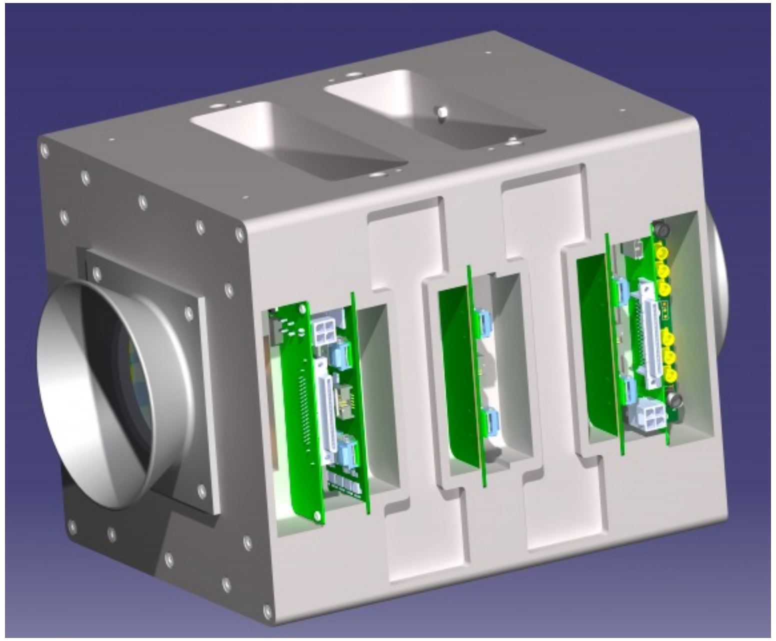
Silicon Strip (UniGe, INFN Perugia)
- 25 um pitch (X) 2048 strips for bending plane
- 400 um pitch (Y) 128 strips for non-bending plane
- Energy measurement and trigger

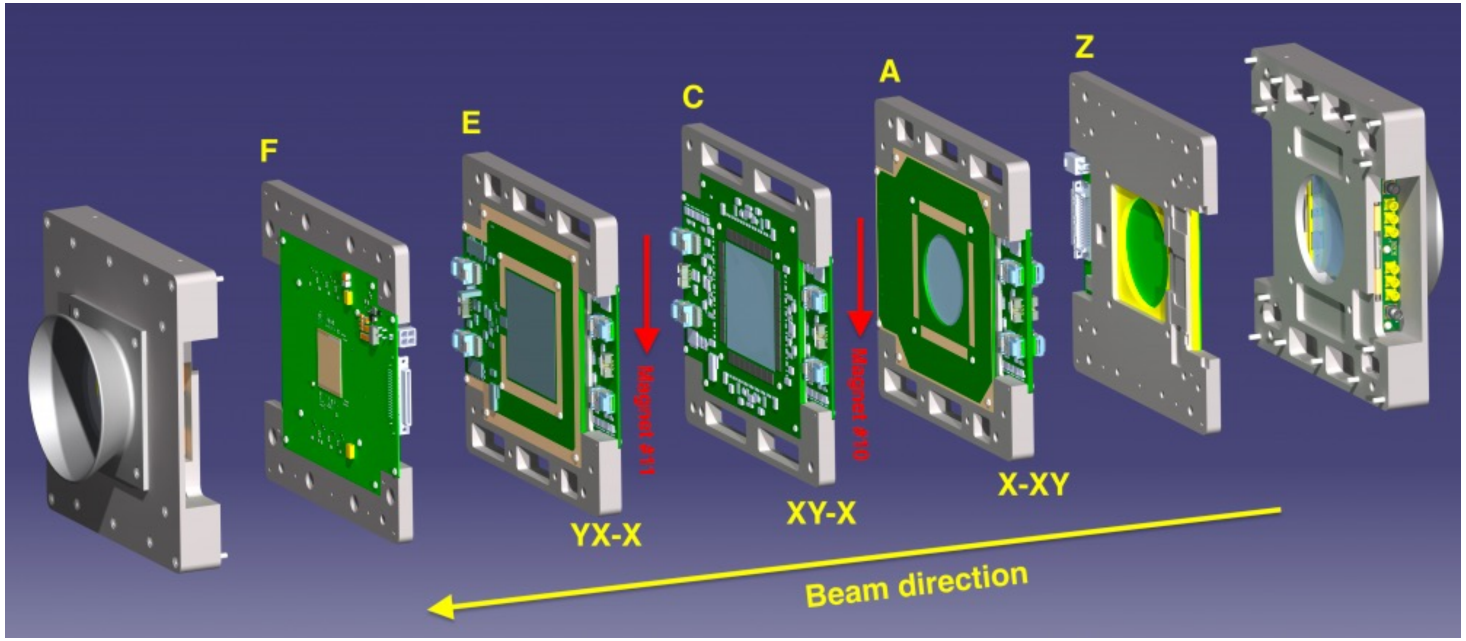
Pixel (CTU)
- Two modules providing Time of Arrival (1.6 ns resolution) and Time over Threshold
- 262, 144 pixels (512 x 512), 55 um Si pixels
- Timepix3 or Timepix4

Time of Flight (TOF) (UniGe)
- Plastic scintillators (EJ-230) readout by SiPMs
- ASIC is TRIROC (Time), CITIROC (Energy)
- Charge Measurement (Z = 1-26)
- Time measurement and trigger



MiniPAN Detector



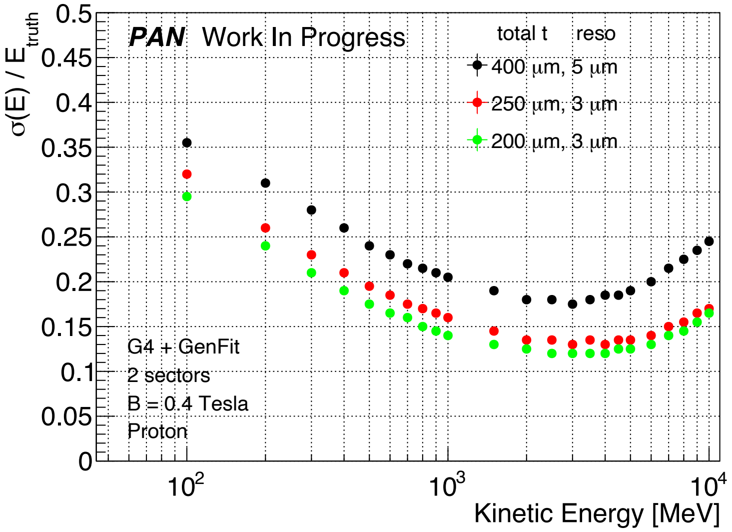


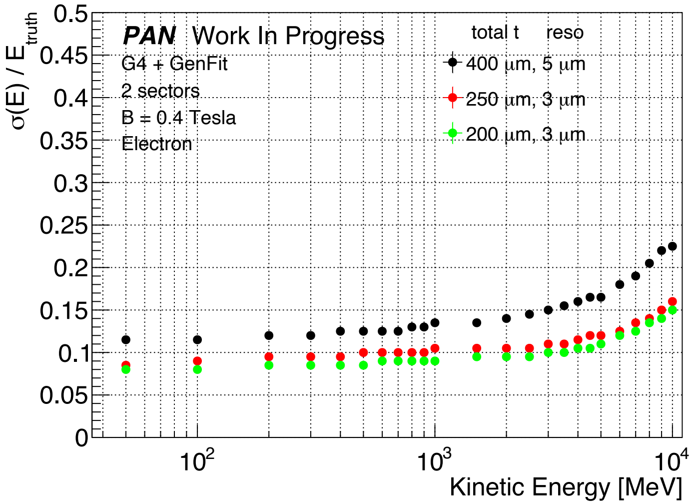
- Weight(Detector): ~9 kg
- Power consumption(front-end electronics):Tracker 6W +Pixel 8W +TOF 3W

TOF->Pixel->Tracker->Tracker->Tracker->Pixel->TOF

MiniPAN Expected performance

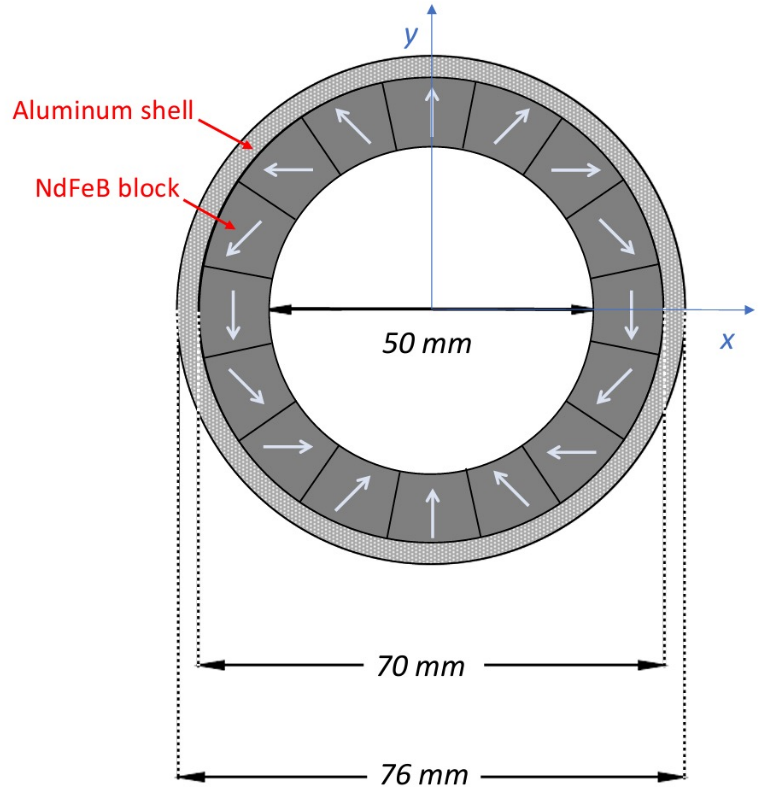
- Excellent energy resolution
  - Aim to reach <5 µm (goal) hit resolution, 15-20% @ 1GeV for protons
  - Acceptance from one end: 2.1 cm^{2}sr for crossing 2 sectors, extra 4.2 for crossing 1 sector
  - ~1 Hz recording rate from GCR with 2-sectors(best precision)
  - 1-1.1 GeV estimated rate: 1 event per 10 seconds(2-sectors)
    - Proton intensity at 1 GeV: 4 m^2 sr s/ MeV(estimated from page 5)





Magnet

Each sector is a 16-block Halback array

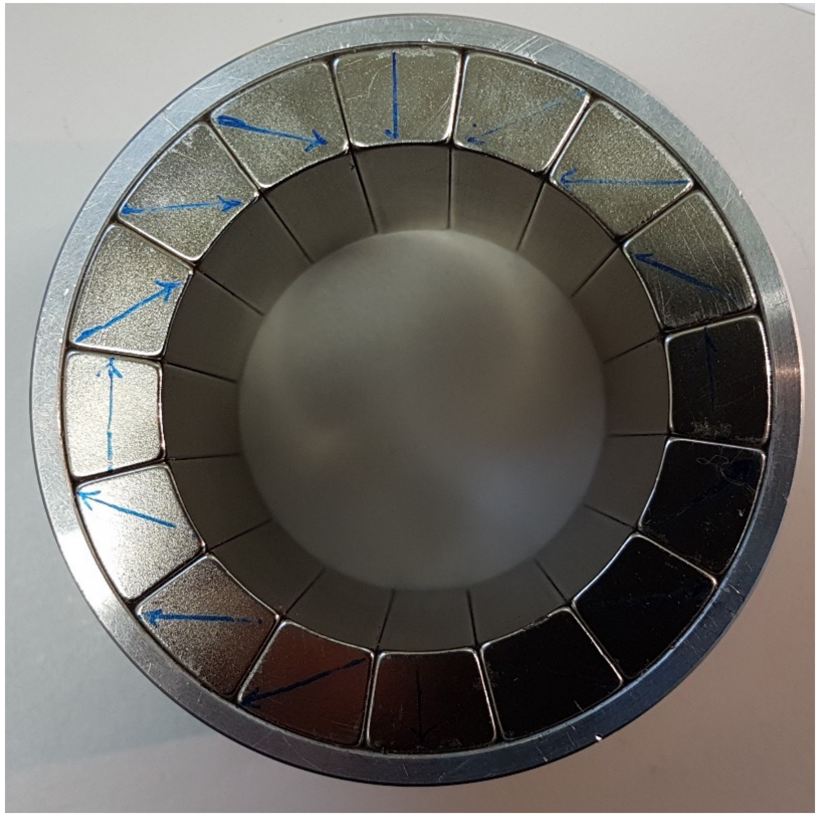


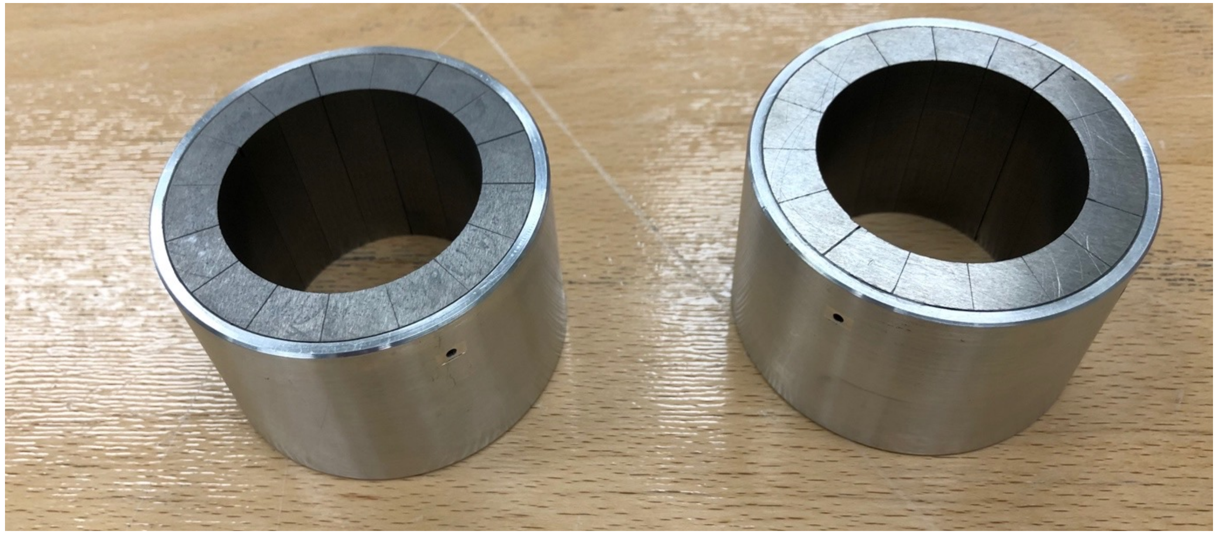
The blocks will be glued with space-qualified epoxy

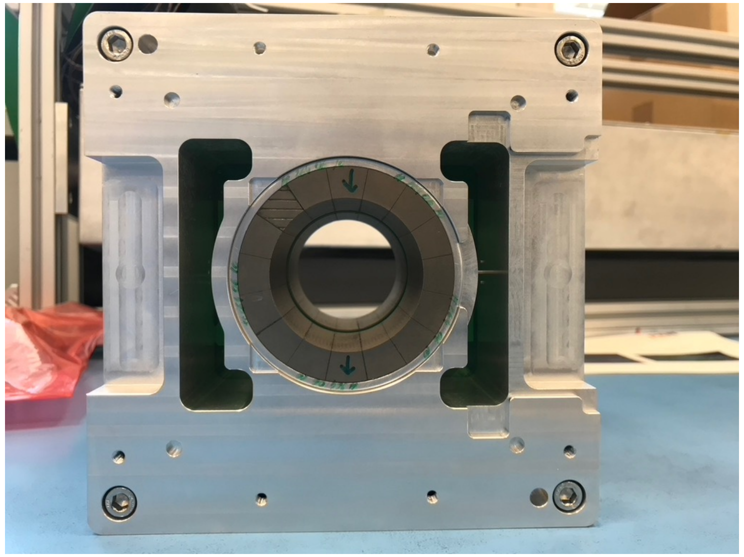
Magnets		
Type	Dipole	
Aperture diameter	50	mm
Length	50	mm
Outer diameter	76	mm
Mass	< 1	kg
Yoke		
Frame / Ring material	Aluminium	
Permanent magnets		
Poermanent magnet material	NdFeB	
BH max	45	MGOe
Magnetic field		
Nominal field at the centre	0.35	T
Nominal integrated field	0.02	Tm
GFR radius	17	mm
Integrated field homogeneity in GFR	≤ 10	%

Table 1 - Main design parameters

Magnet





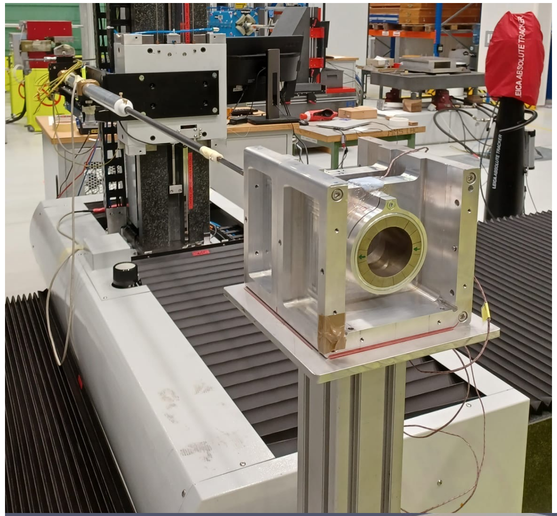


Magnet frame

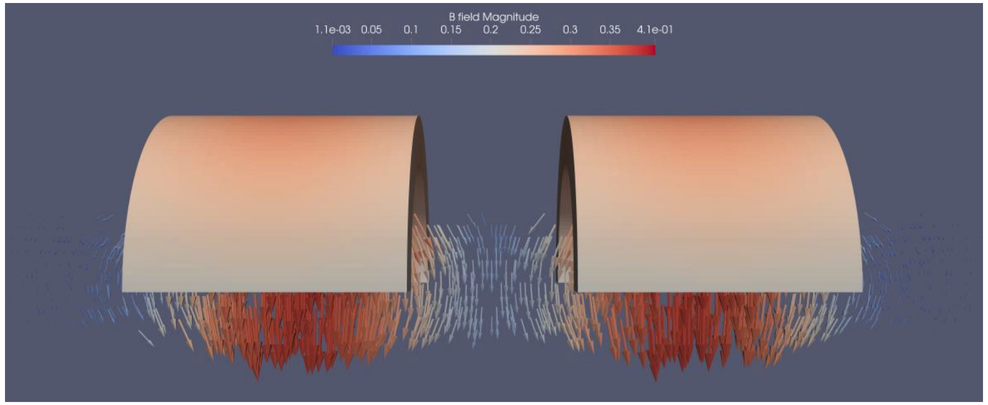
Polarity aligned by pins

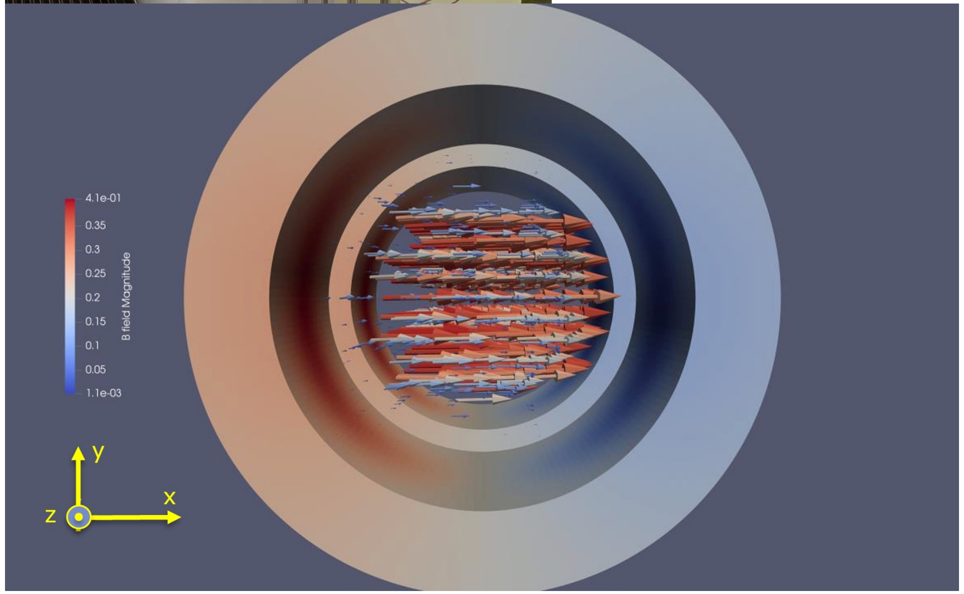
Distance between two units: 12 mm

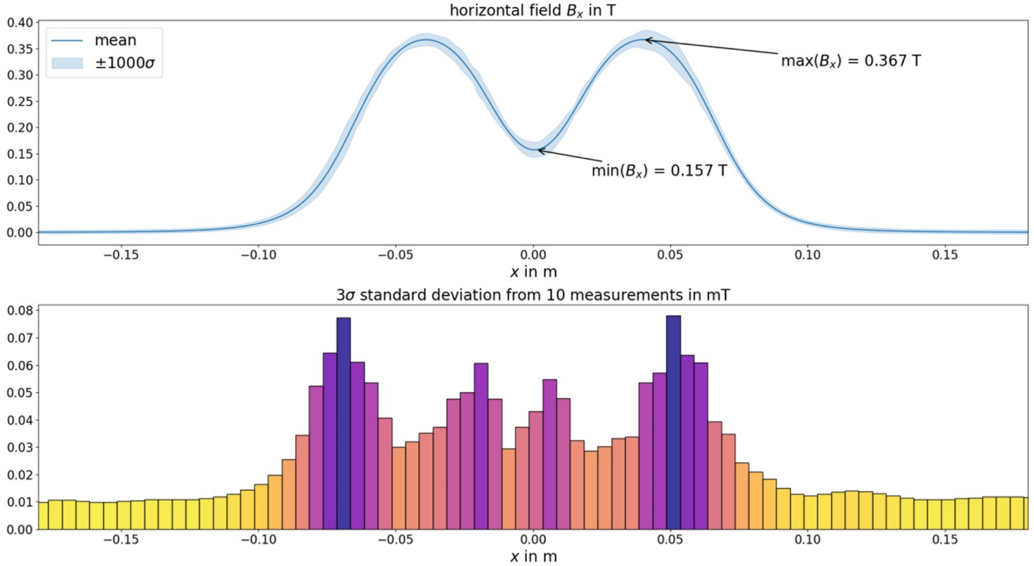
Magnetic Field Meausrement



MiniPAN Magnet at the 3D mapper CERN Magnetic Measurements Lab







Temperature during measurement: 21±0.5 °C

Silicon strip detector

1.Silicon Wafer common properties for both types of silicon strip detectors:

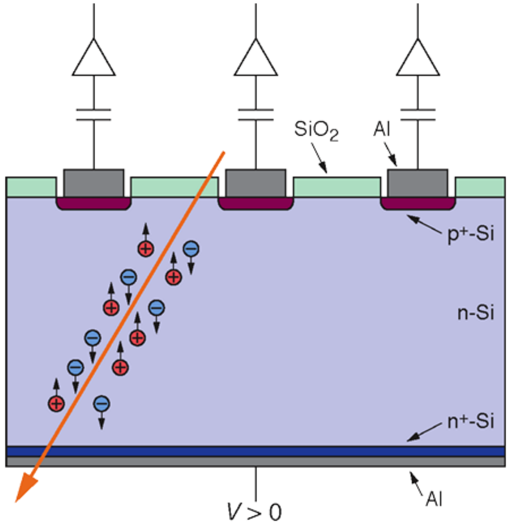
Device type: Single side AC-readout/double metal
Silicon type: N-type, Phosphorus doped
Crystal orientation: <100>
Chip thickness: 150±15µm
Front and back side metal: Al
Full depletion voltage: Max. 50 V
Breakdown voltage: Min. 100 V
Tot. Leakage current (at 1.5V×V_depletion): Max. 3 µA

2. Silicon Strip X sensor properties:

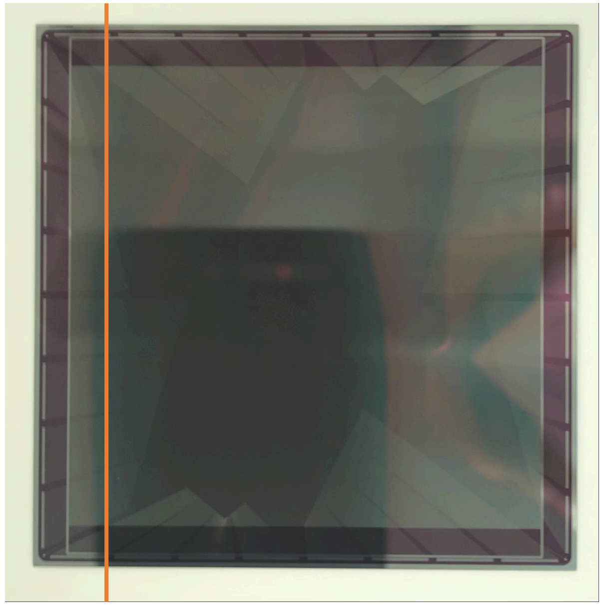
X sensor overall size: 59000±20 × 59000±20 µm
Active Area: 51200 × 51200 µm
Number of Strips: 2048 ch
Strip pitch: 25 µm
Strip width: 13 µm
Readout AL width: 10 µm
Readout PAD pitch: 96 µm

3. Silicon Strip Y sensor properties

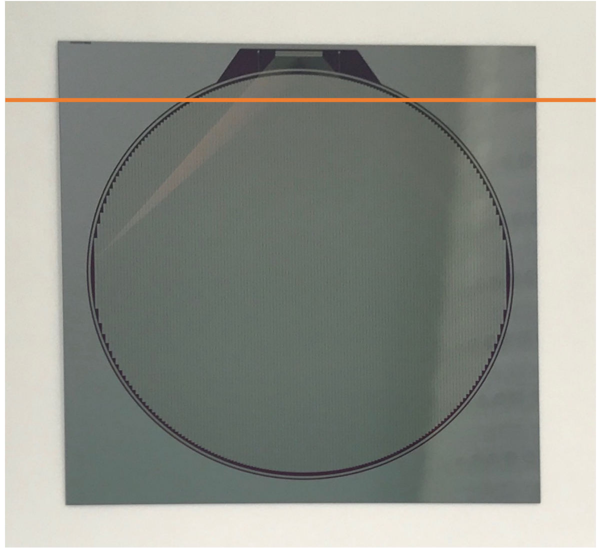
Y sensor overall size: 59000±20 × 59000±20 µm
Active area Circular with D = 51200 µm
Number of Strips: 128 ch
Strip pitch: 400 µm
Strip width: 380 µm
Readout Al width: 10 µm
Readout PAD pitch: 91.2(lines) µm



Strip Orientation



Zigzag shape:
Al routing

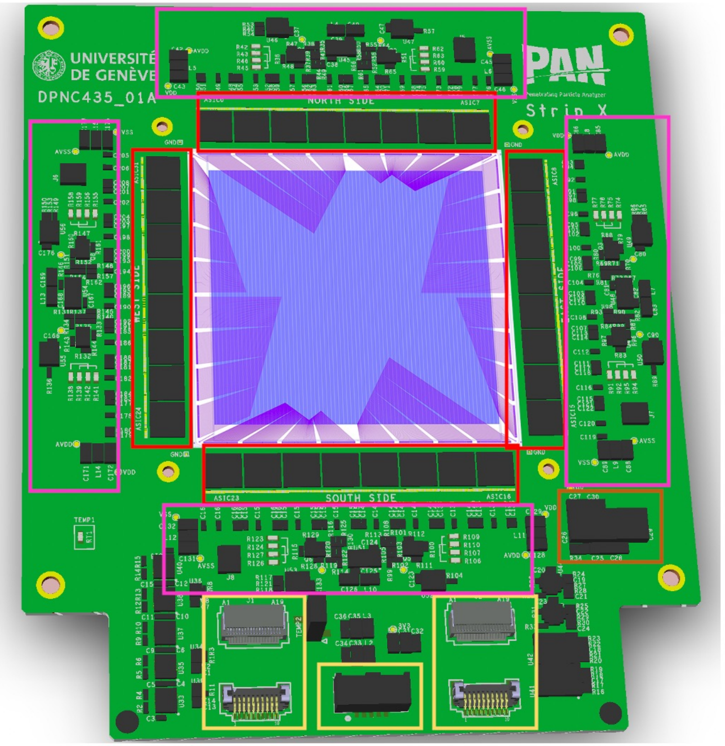


Silicon strip detector

4x2 digitization chains

1x Hamamtsu sensor + routing

DAQ connectors

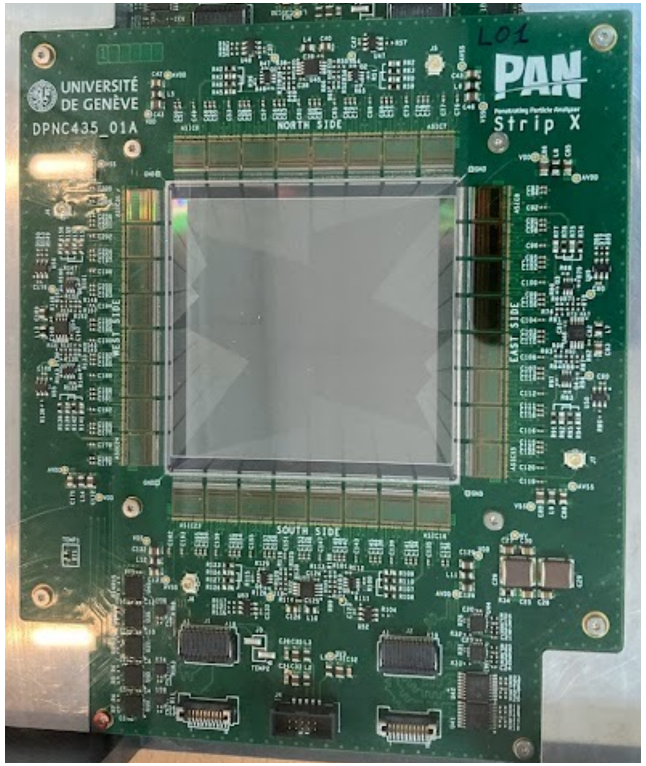


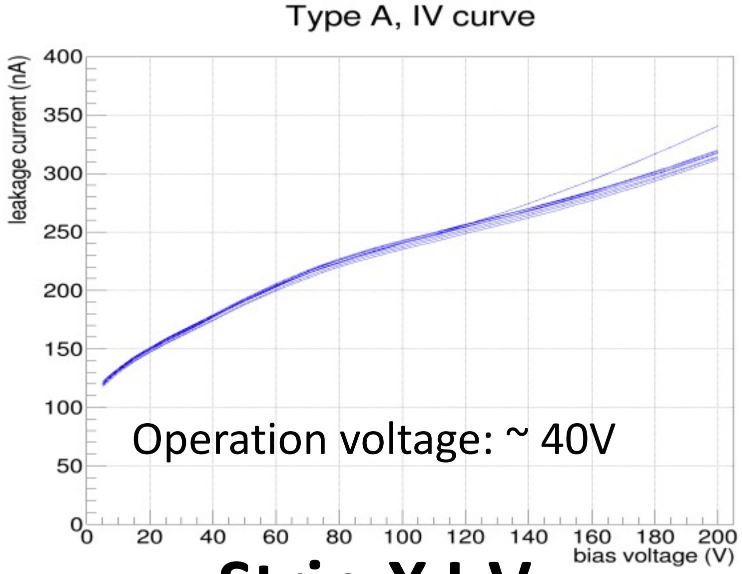
4x8 Ideas IDE1140 VA

0-400 fC
6.5 us
shaping

HV filters

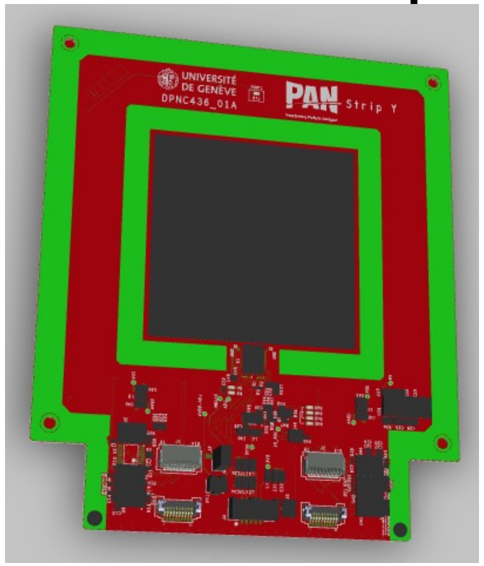
Strip-X FE board



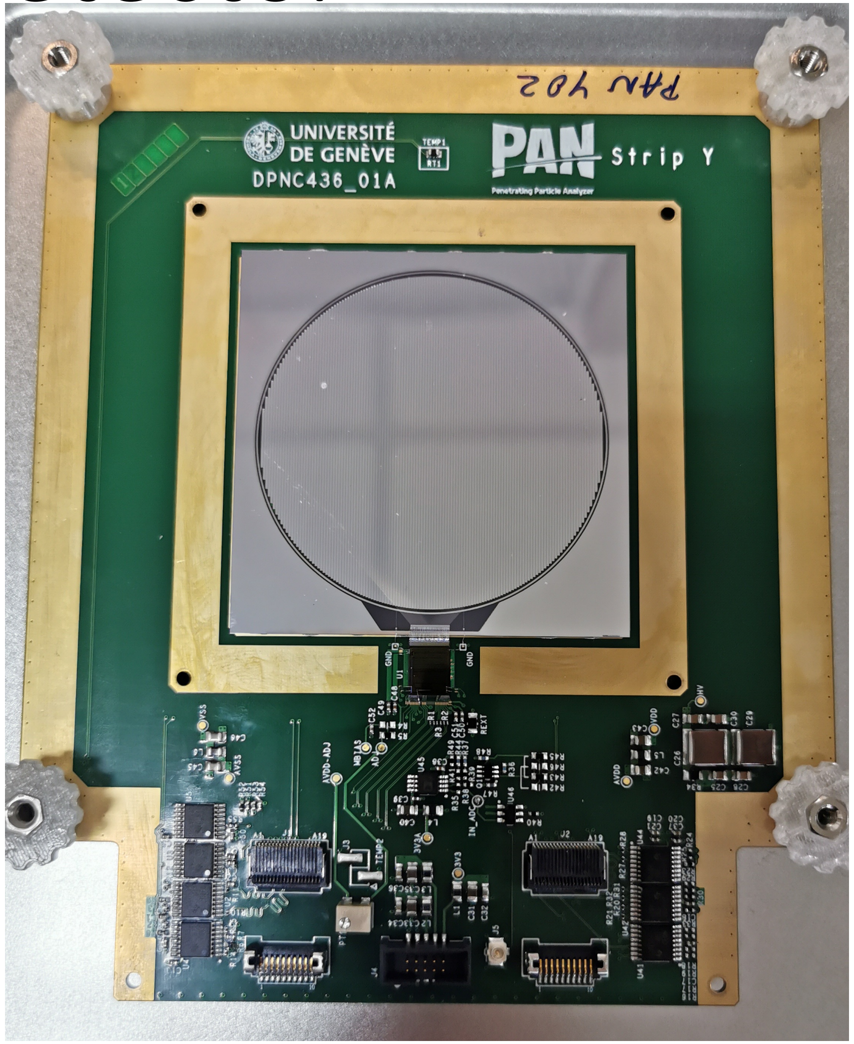


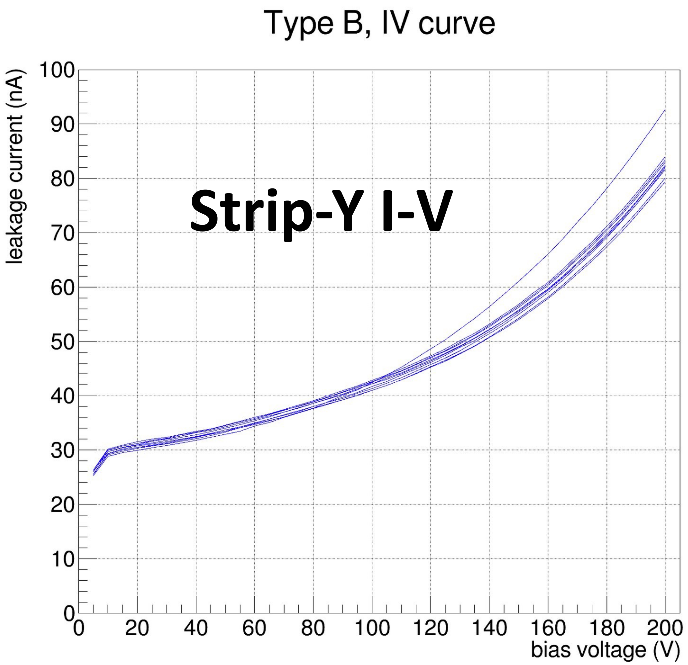
Strip-X I-V

Silicon strip detector

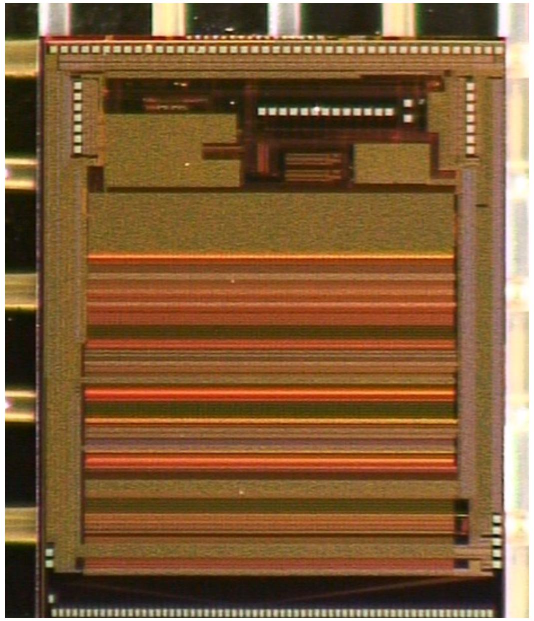


Strip-Y FE board





Read out by VATAGP7
128 channels
500 ns shaping time
Can provide trigger

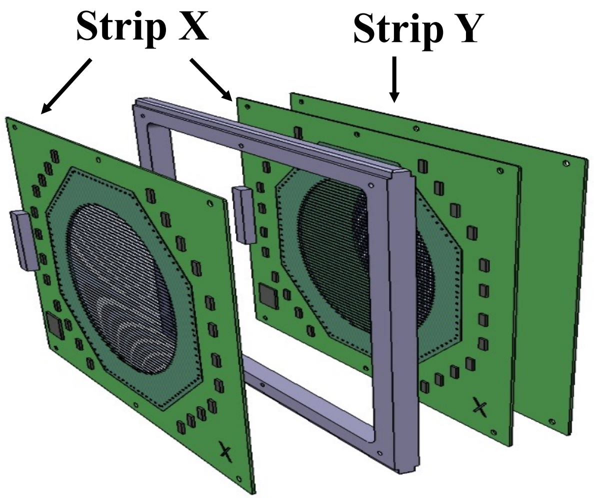


Tracker

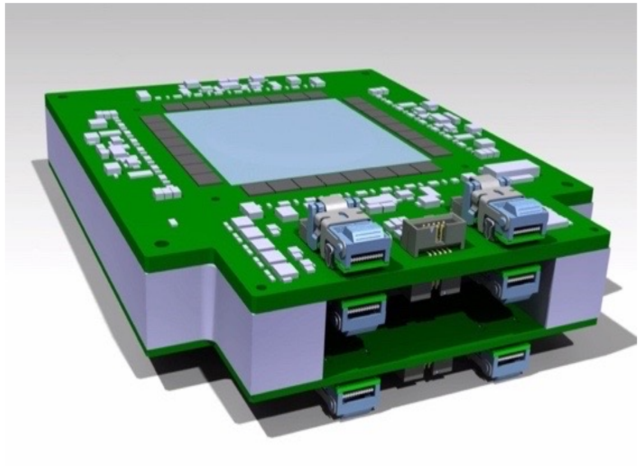
Mini.PAN consists of three tracker modules (two at the extremities of the detector and one between two magnets).

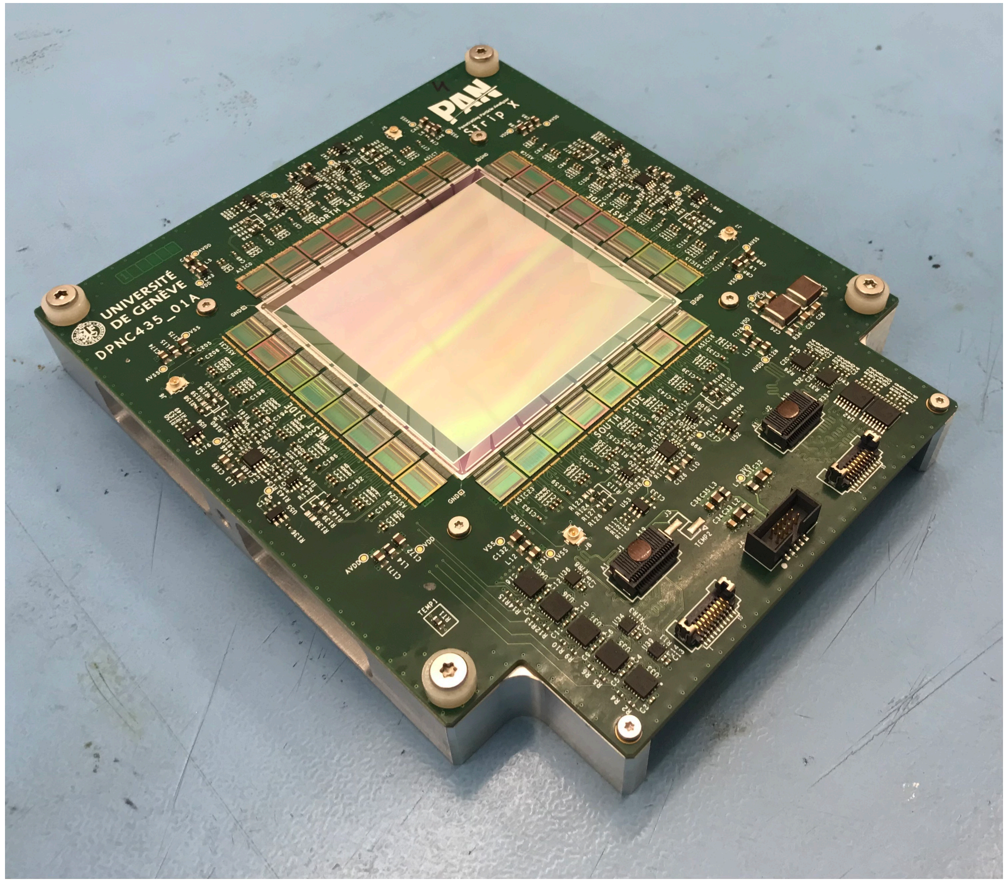
Each tracker module is composed of two Strip-X (bending coordinate) and one Strip-Y detector.

Tracker module

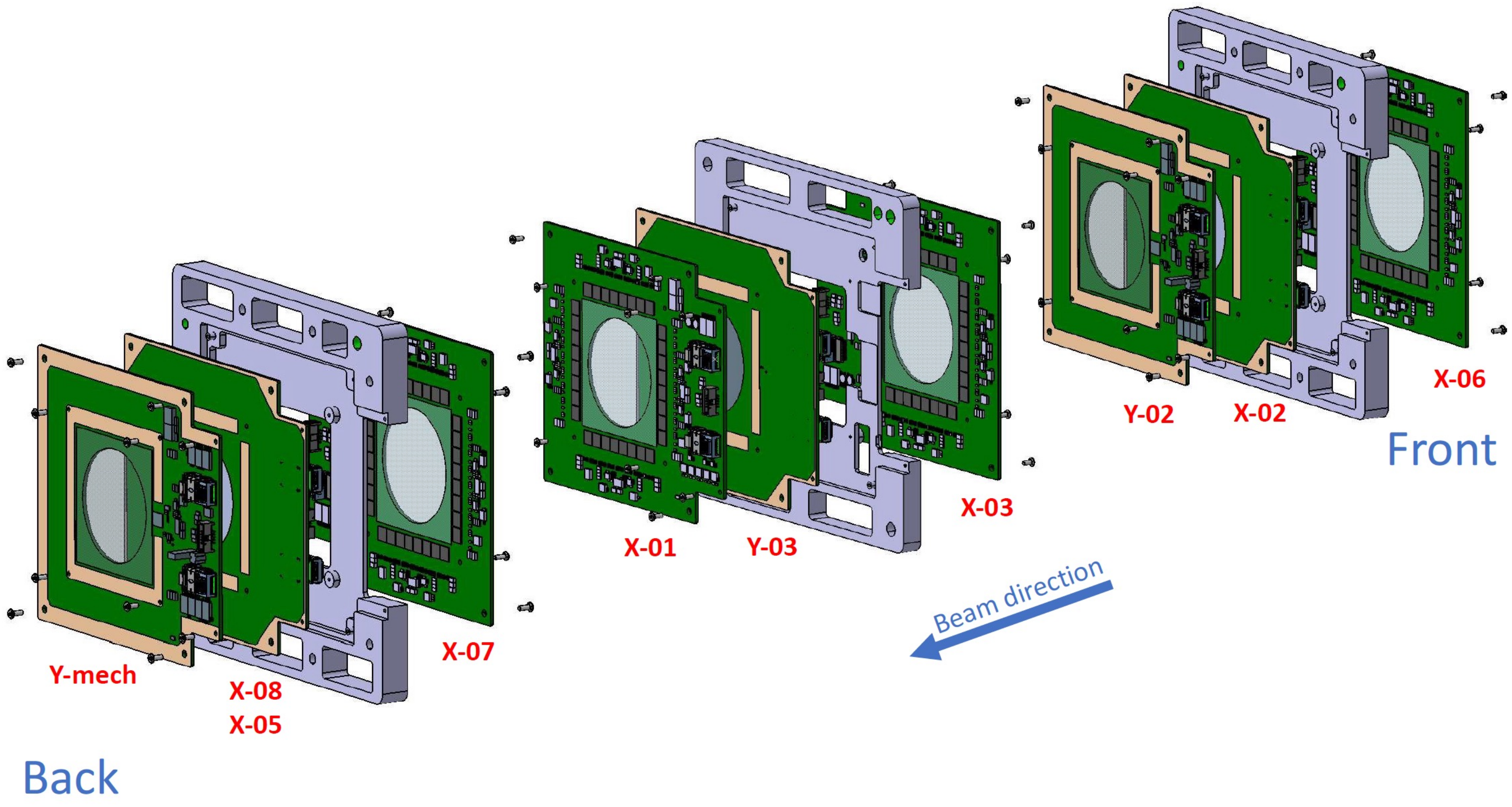


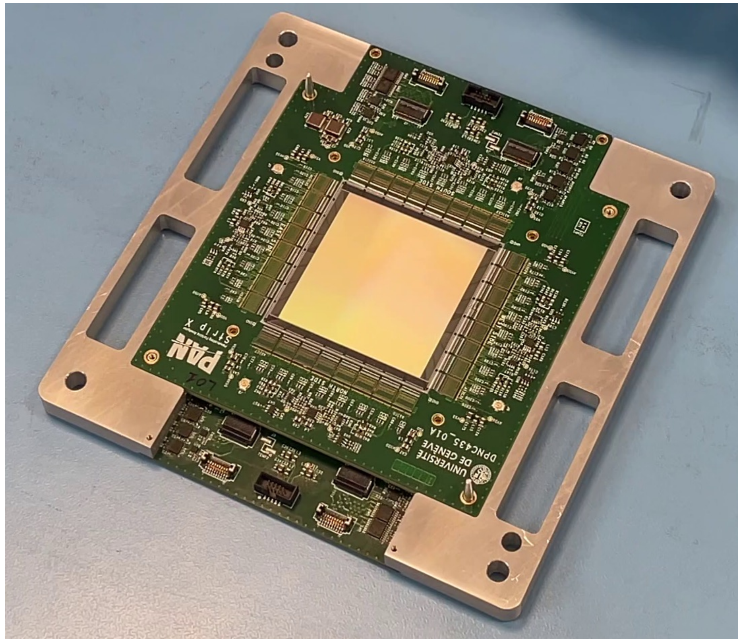
Tracker





Tracker

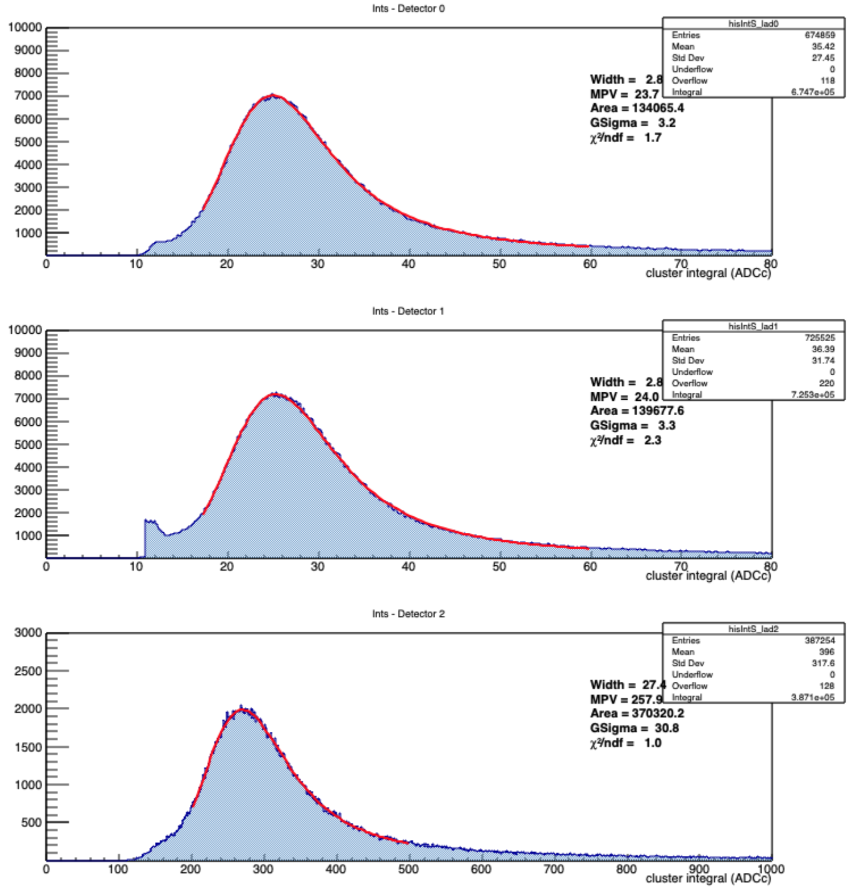




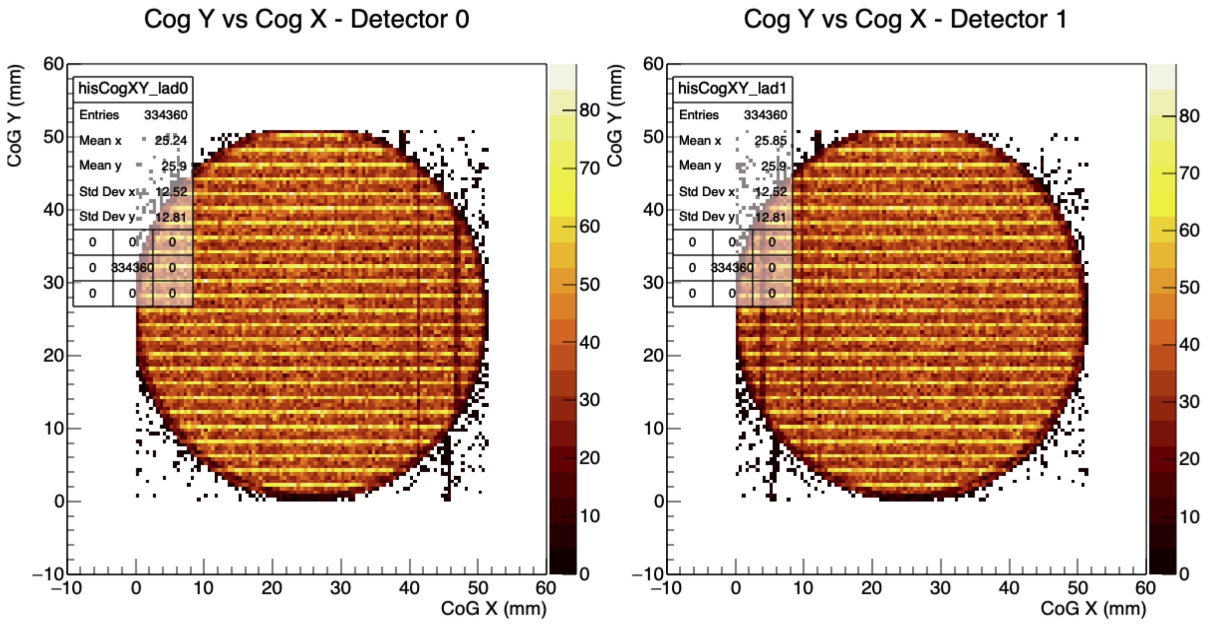
A more compact mechanics for tracker module

Three trackers with different layout

Tracker performance



Position distribution viewed by one tracker module.



Muon beam 2023 Aug.

Beam particle: 120 GeV muon beam

MIP:

Strip-X ~25 ADC

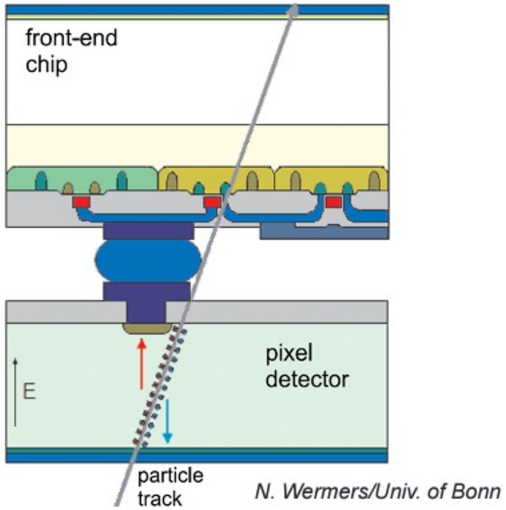
Strip-Y ~250ADC

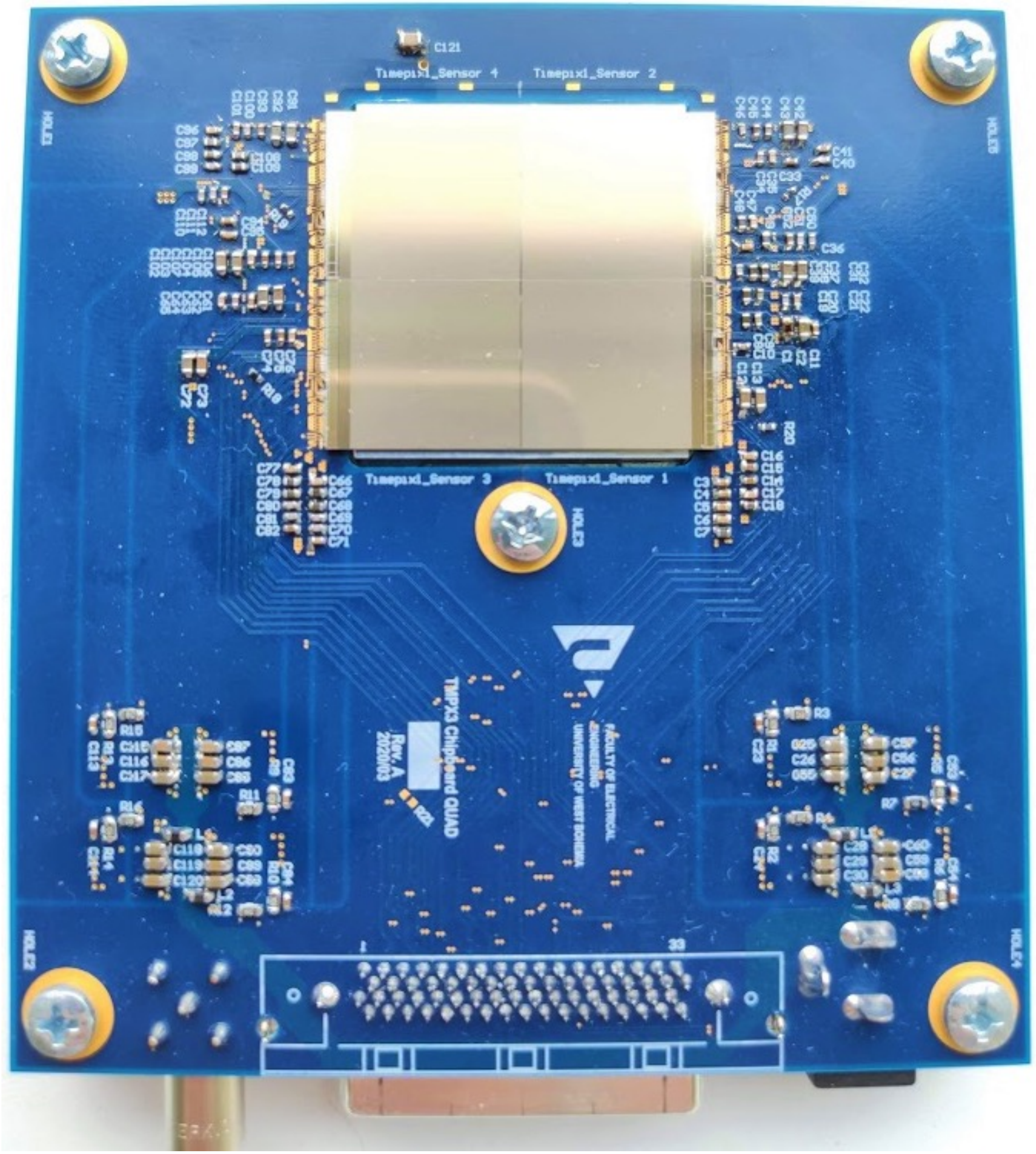
Signal/Noise > 10

Pixels

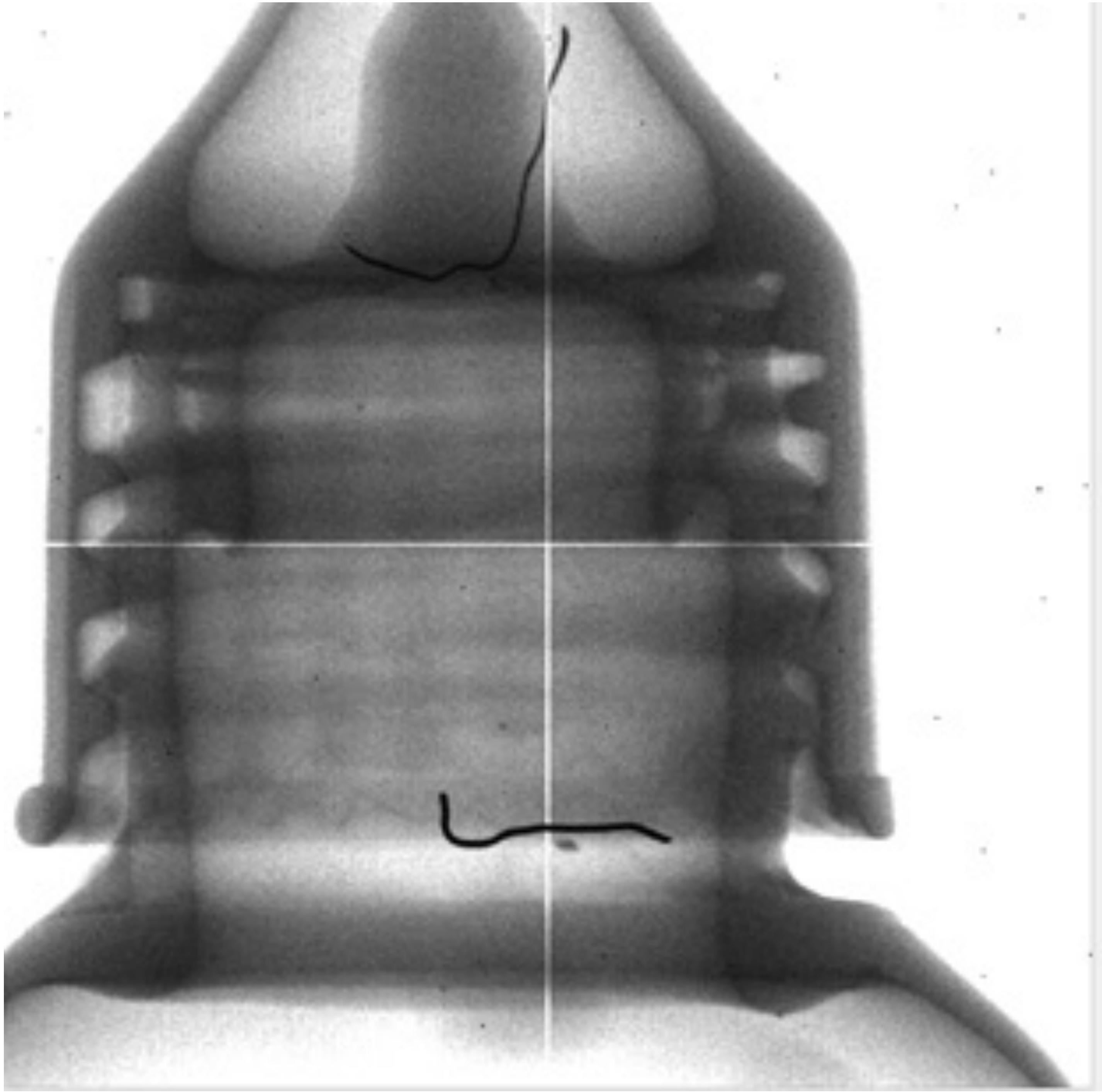
TimePix3 quad detector:

- 262,144 pixels with pixel pitch 55 µm
- 4 Sensors in total 2.8 × 2.8 cm
- Simutaneuously ToA and ToT measurement in each pixel
- Sensor thickness: 300 µm
- ToA binning: down to 1.56 ns



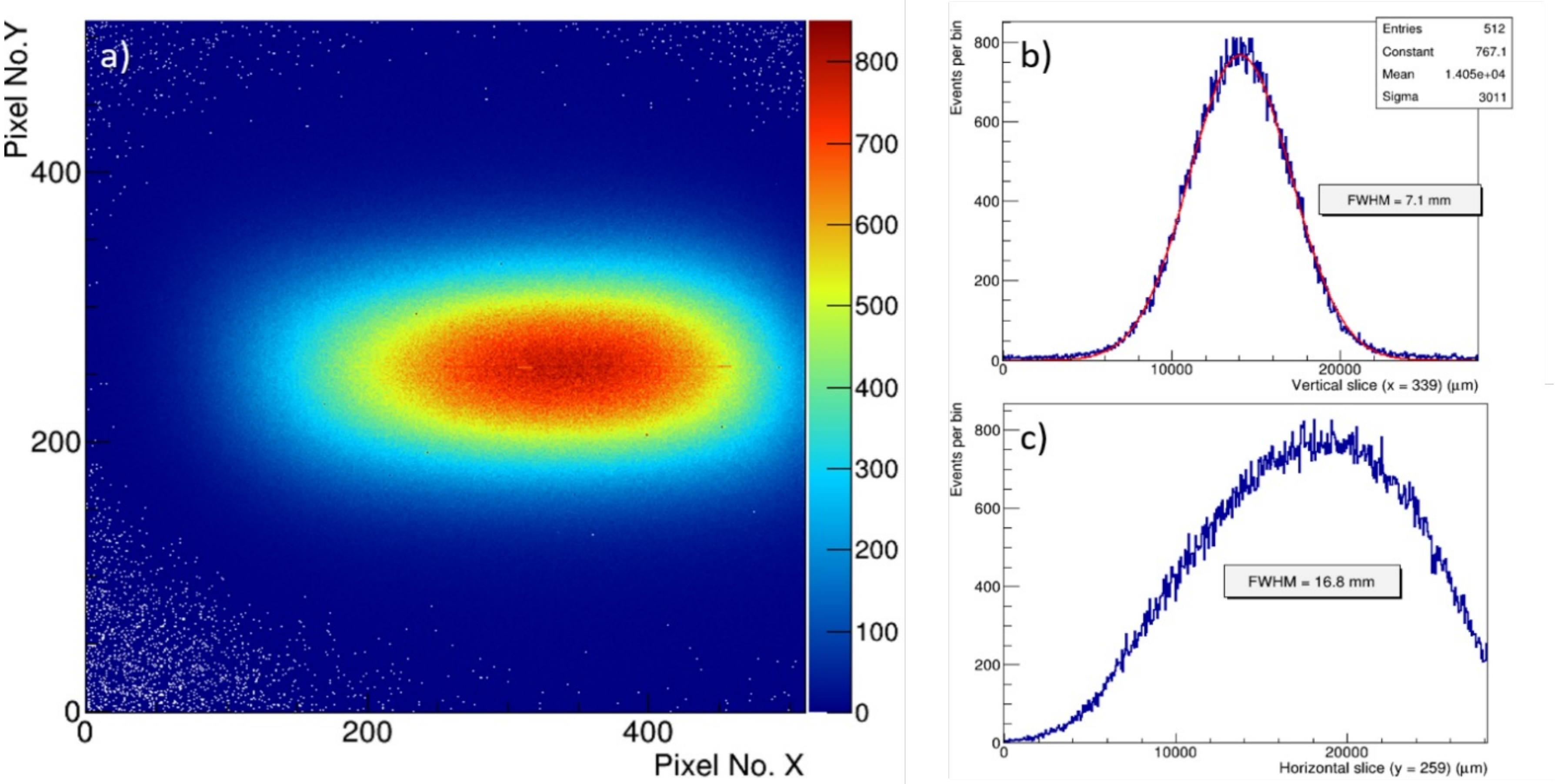


X-ray imaging



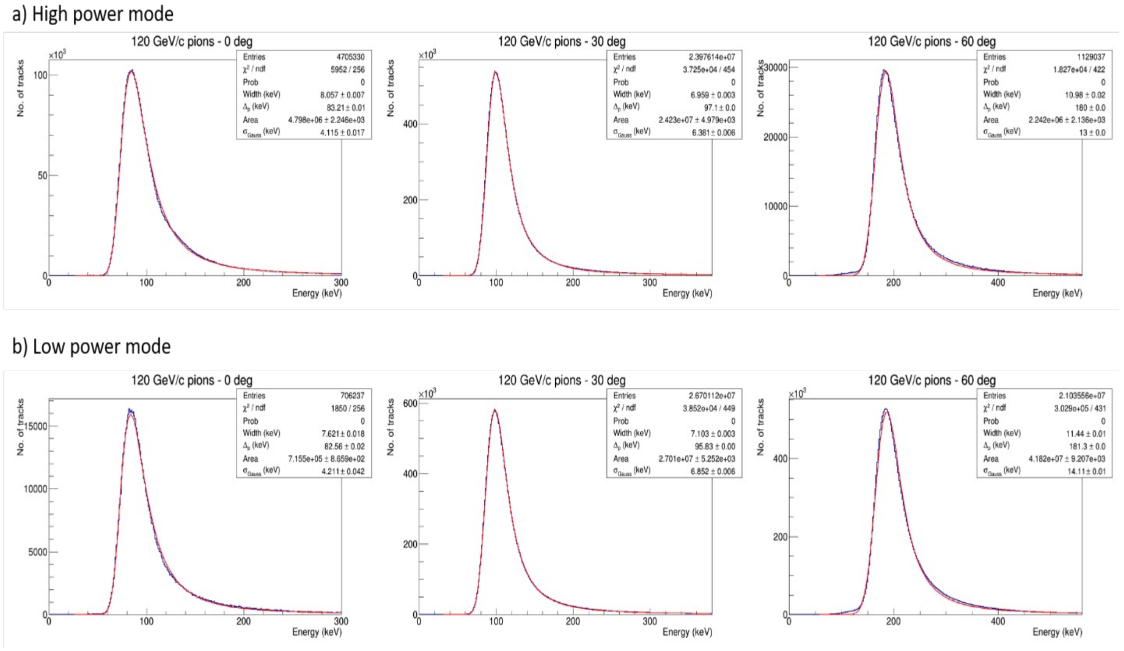
Pixel performance

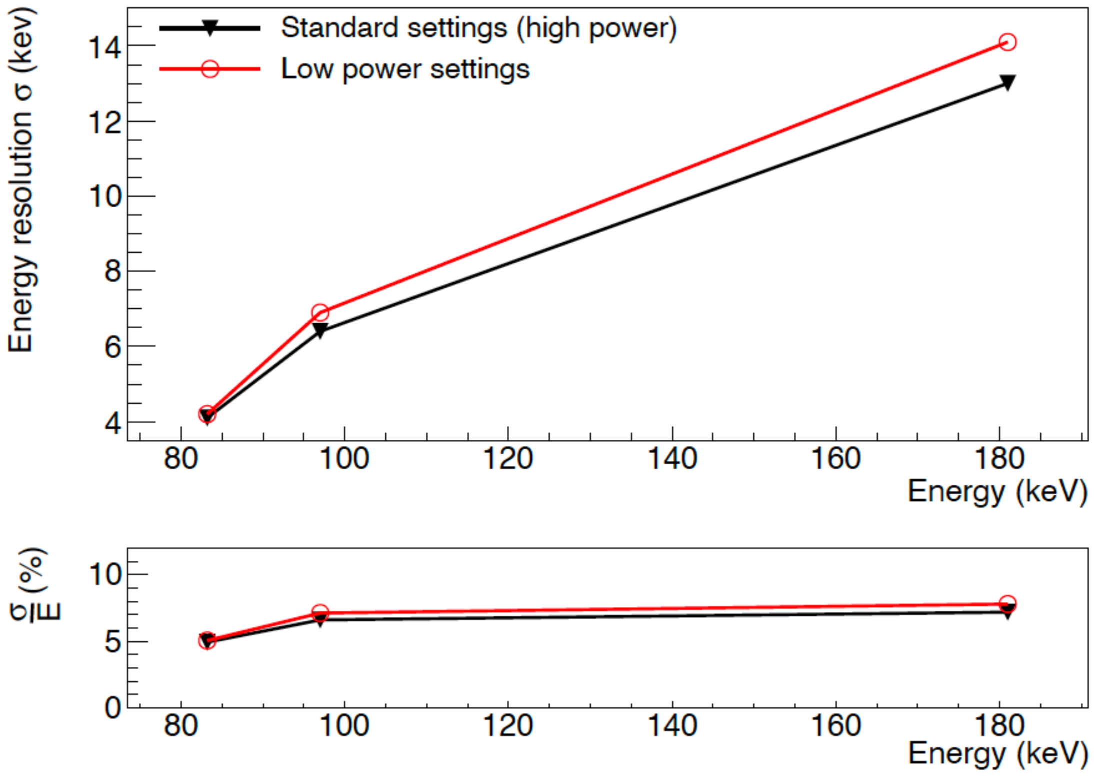
Beam spot



Pixels at beam test
120 GeV pions

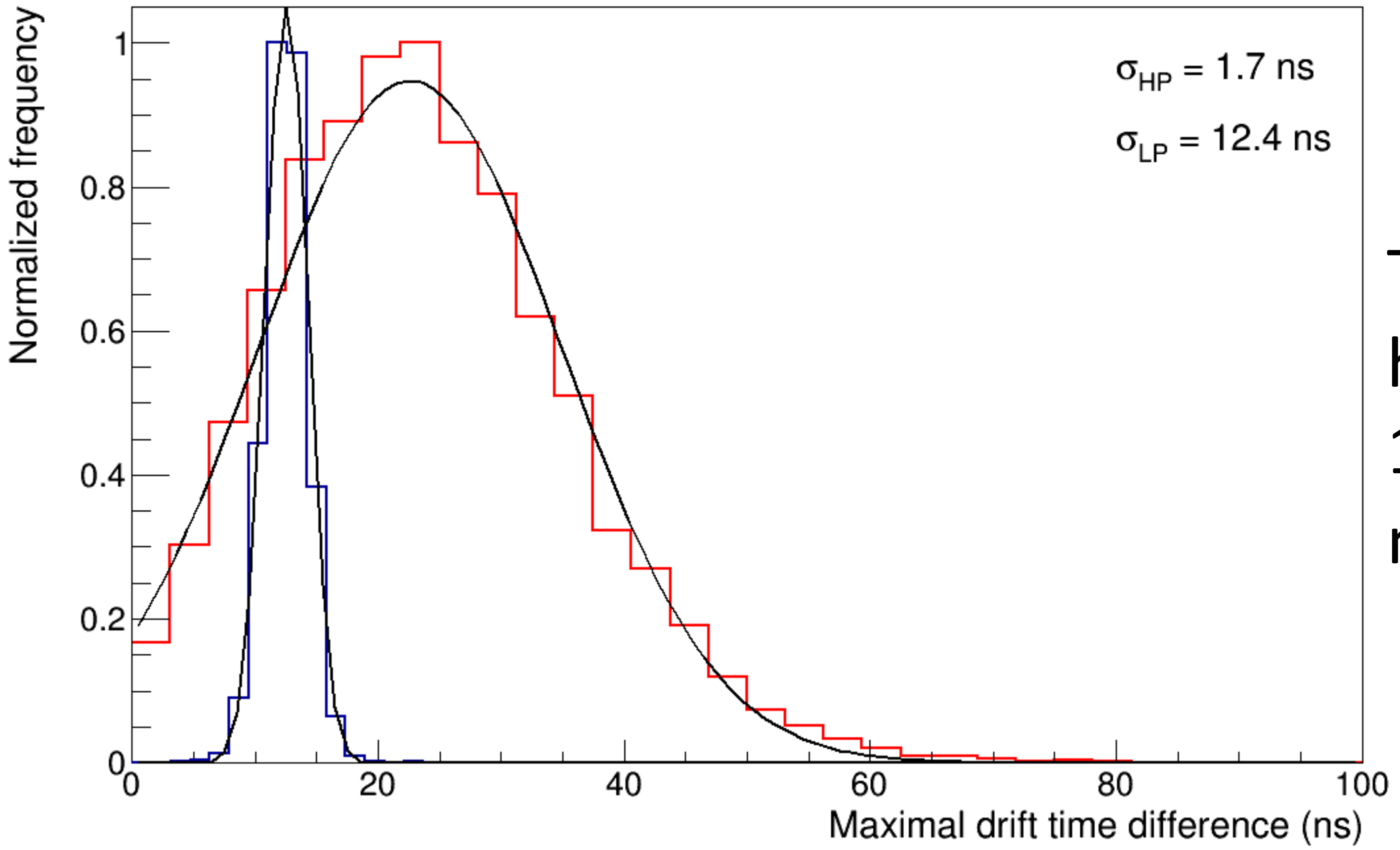
Pixel performance





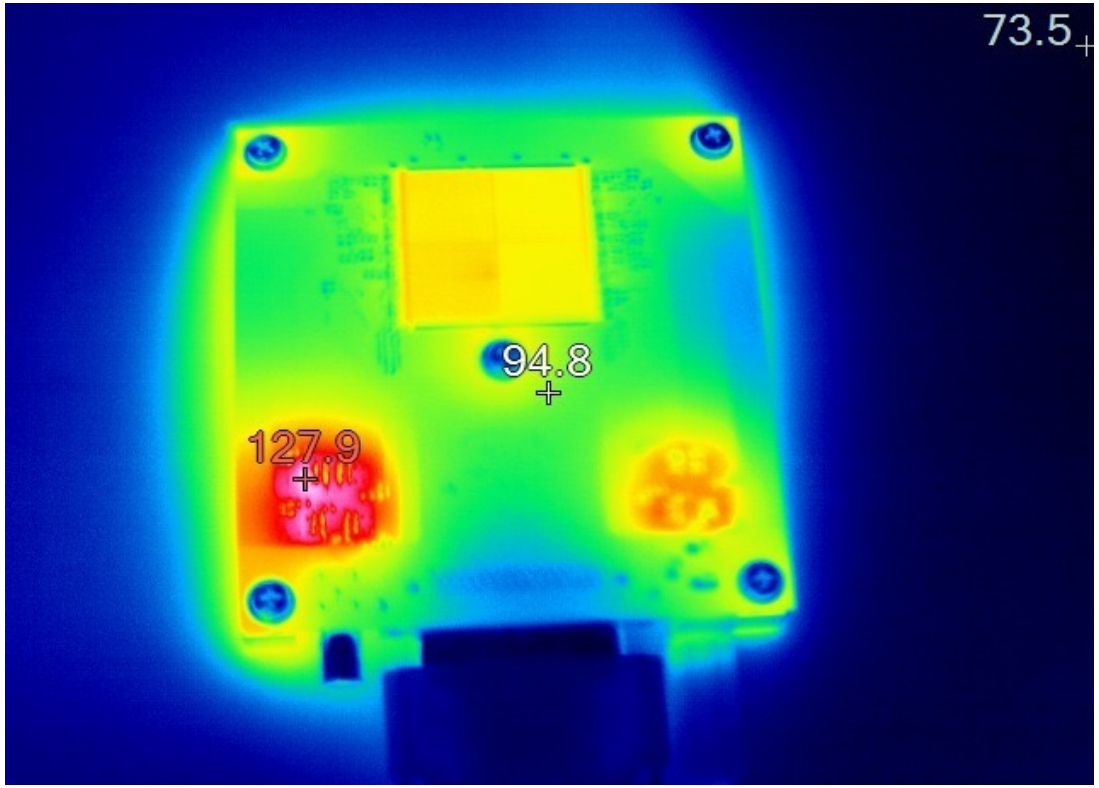
- No significant performance loss in analogue low power mode
- Power consumption/Temperature:
  LP: ~4 W - 50-60°C
  HP: ~6 W - 70-80°C

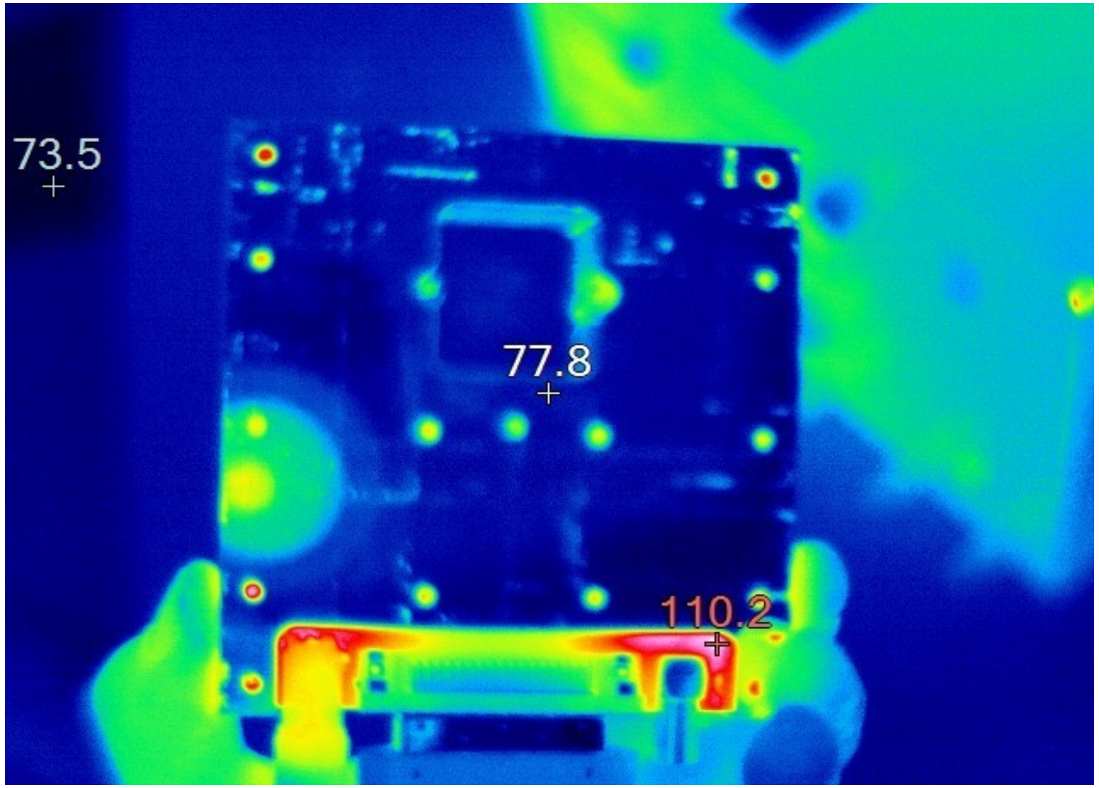
Pixel performance



Time resolution 1.7 ns with high power mode
12.4 ns with low power mode

Challenge for Pixel

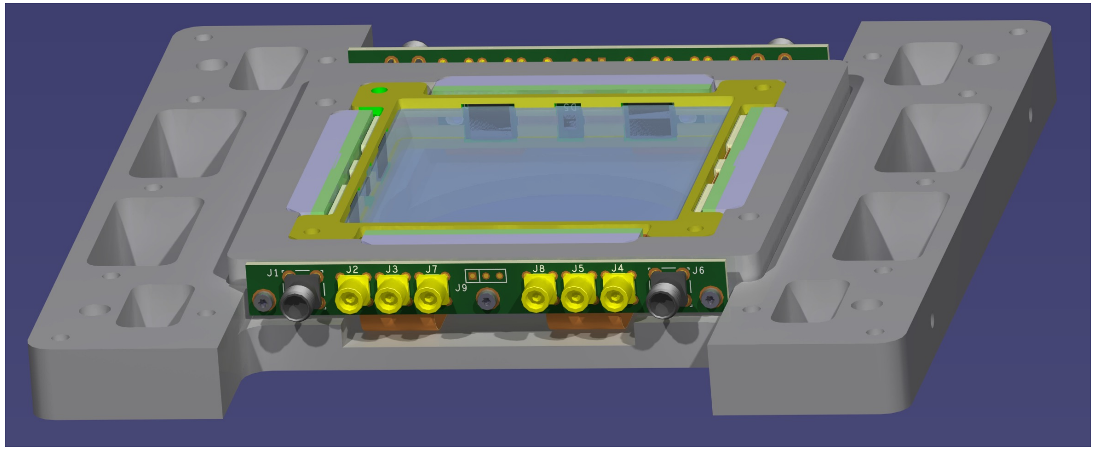


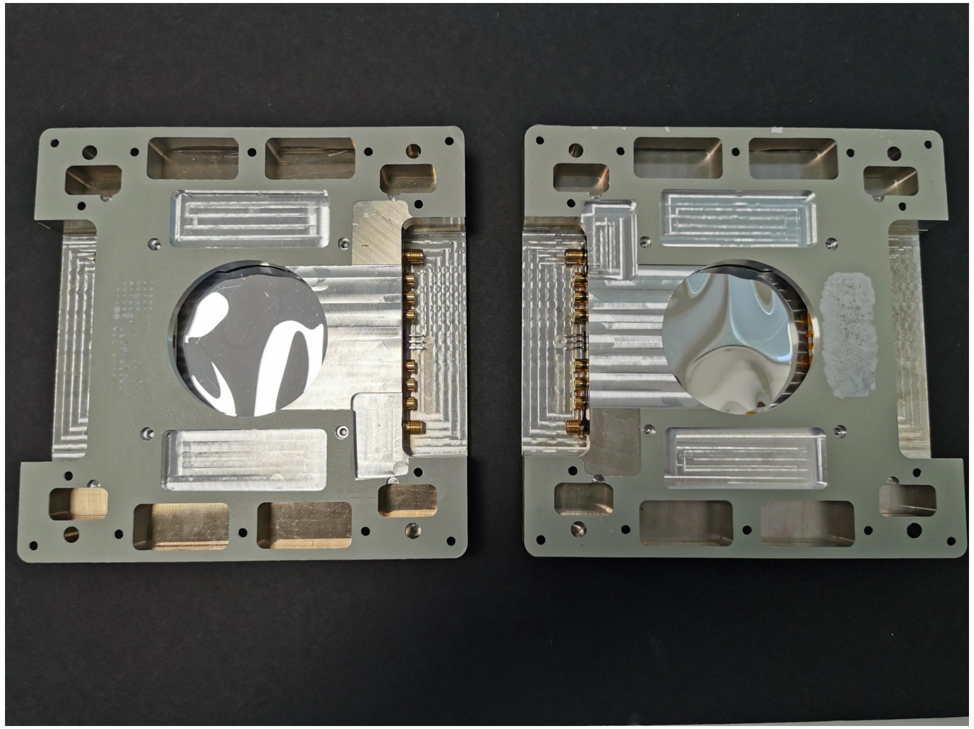


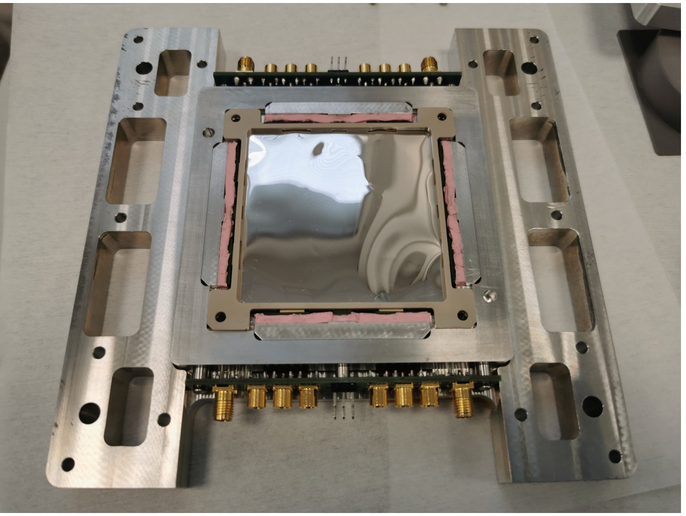
Without cooling, temperature reaches as high as 100 degree

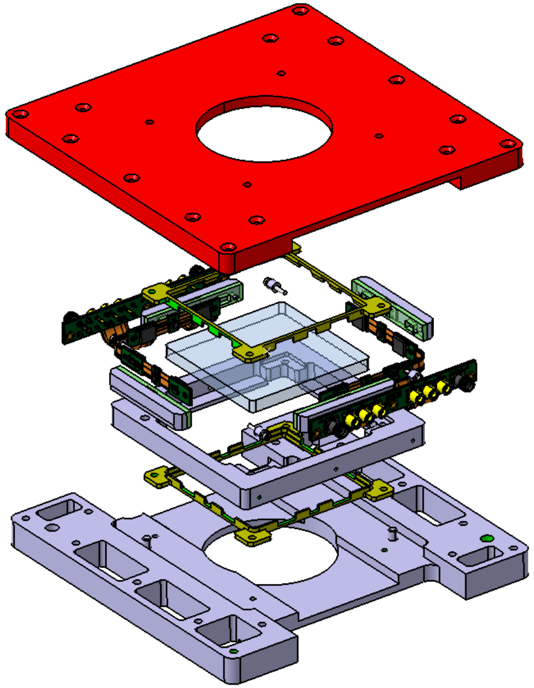
P. Burian *et al* 2019 *JINST* **14** C01001

TOF



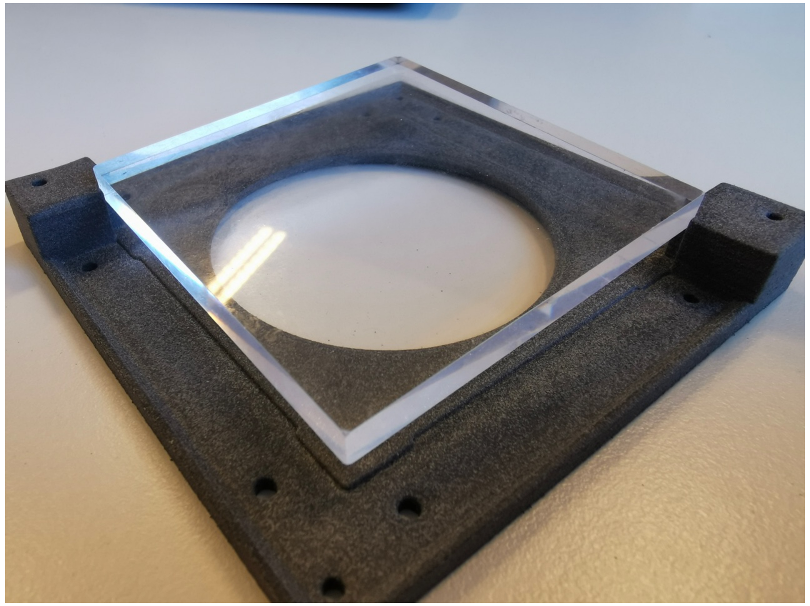






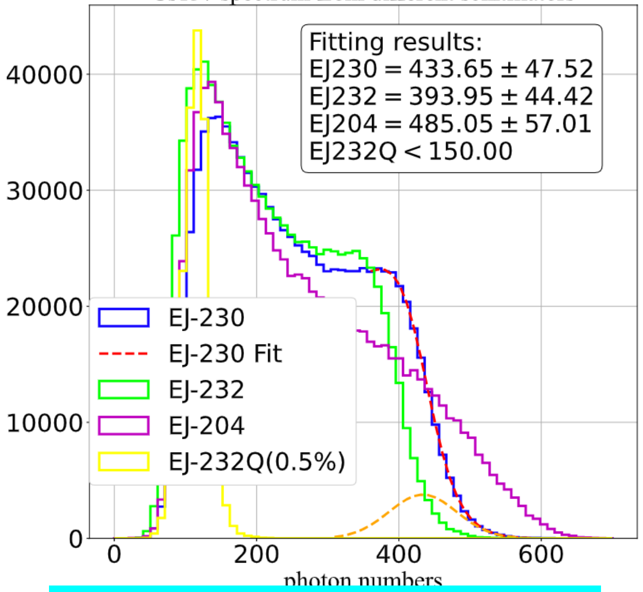
Plastic scintillators(EJ-230)
SiPMs: S13360-6050, 1325, etc
Reflector: 3M ESR
ASICs: Citiroc(Charge), Triroc(Time)

Scintillators

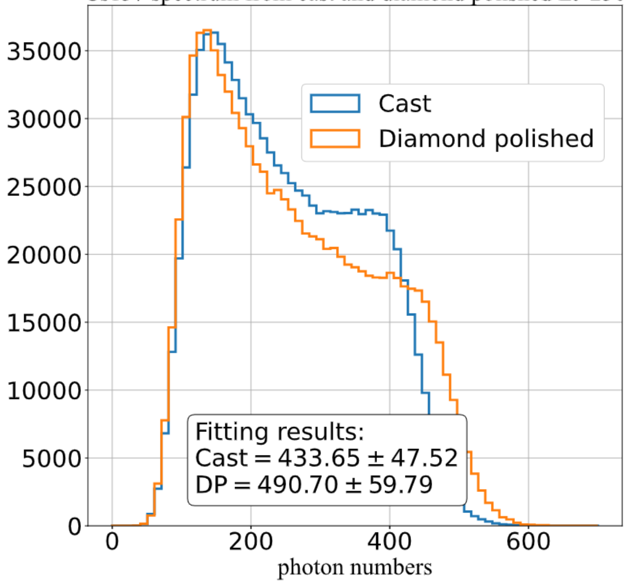


- 65*65*6mm (larger than tracker)
- Trade-off between fast time constant and light yield.
- Trade-off between light yield/time resolution and particle threshold(Minimum energy to cross TOF :~30 MeV for protons).

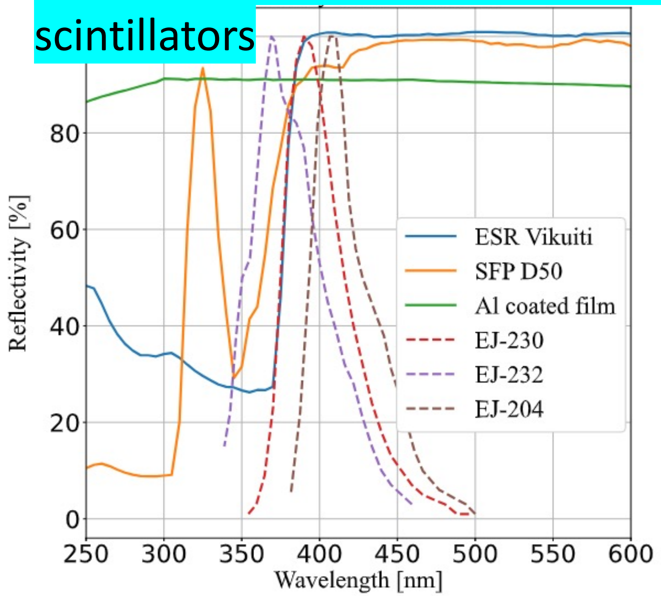
Light yield from different scintillators

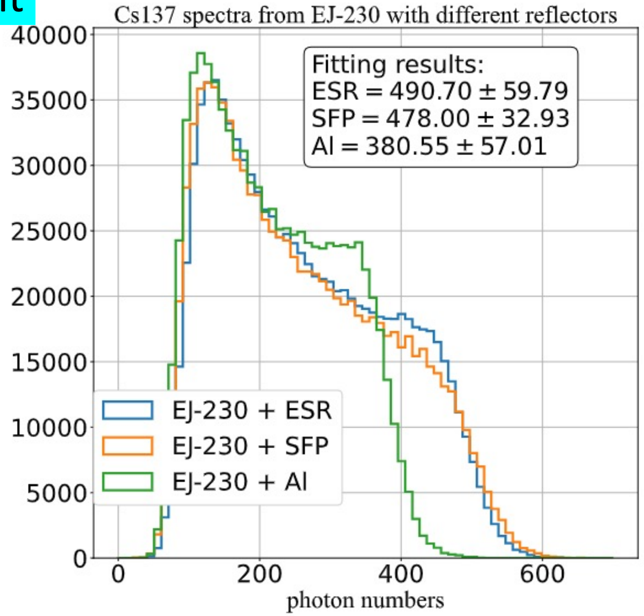


Cast mill
vs diamond polishing



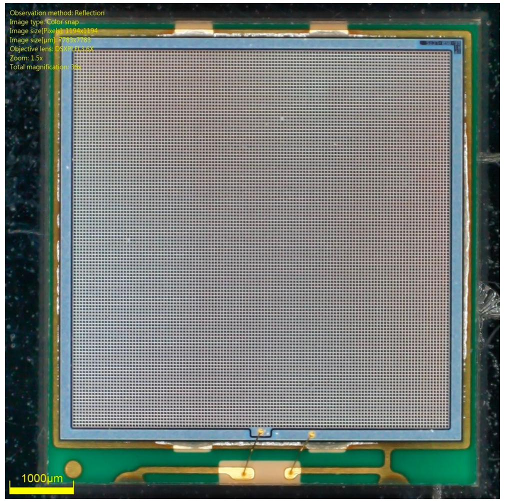
Reflectivity of different films
And emission spectra from different scintillators



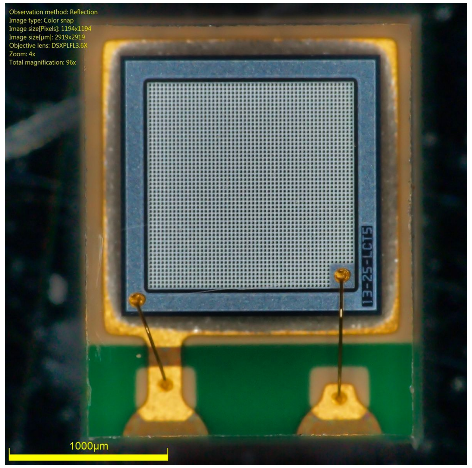


SiPMs

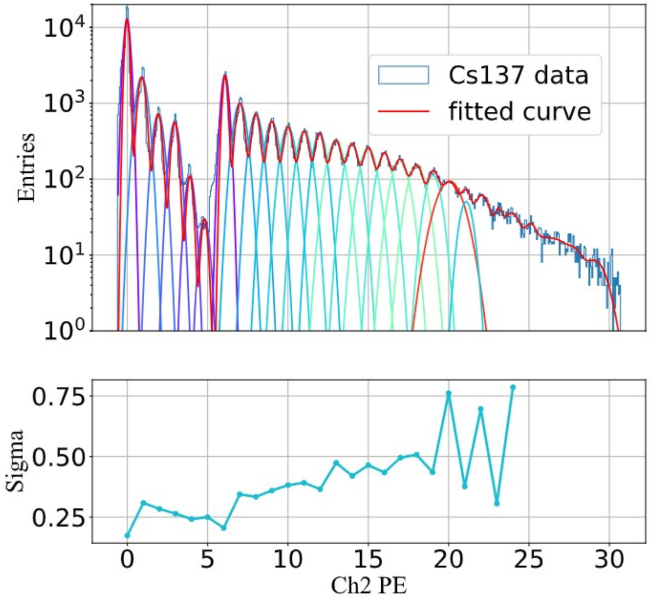
S13360-6050



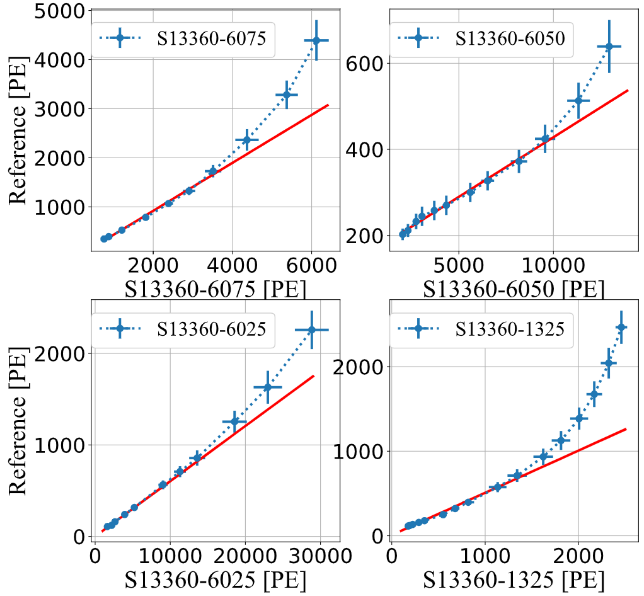
S13360-1325

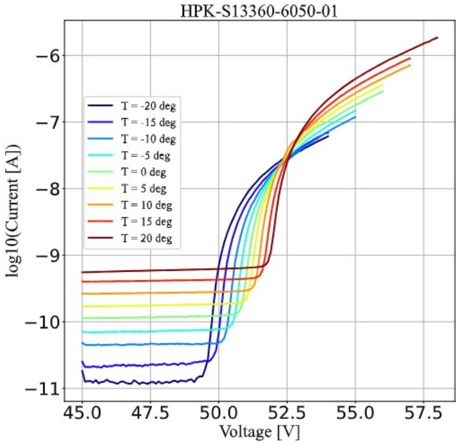


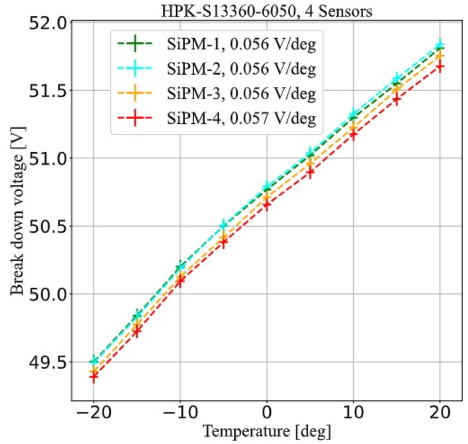
SiPM finger plot measured by Citiroc



SiPM linearity



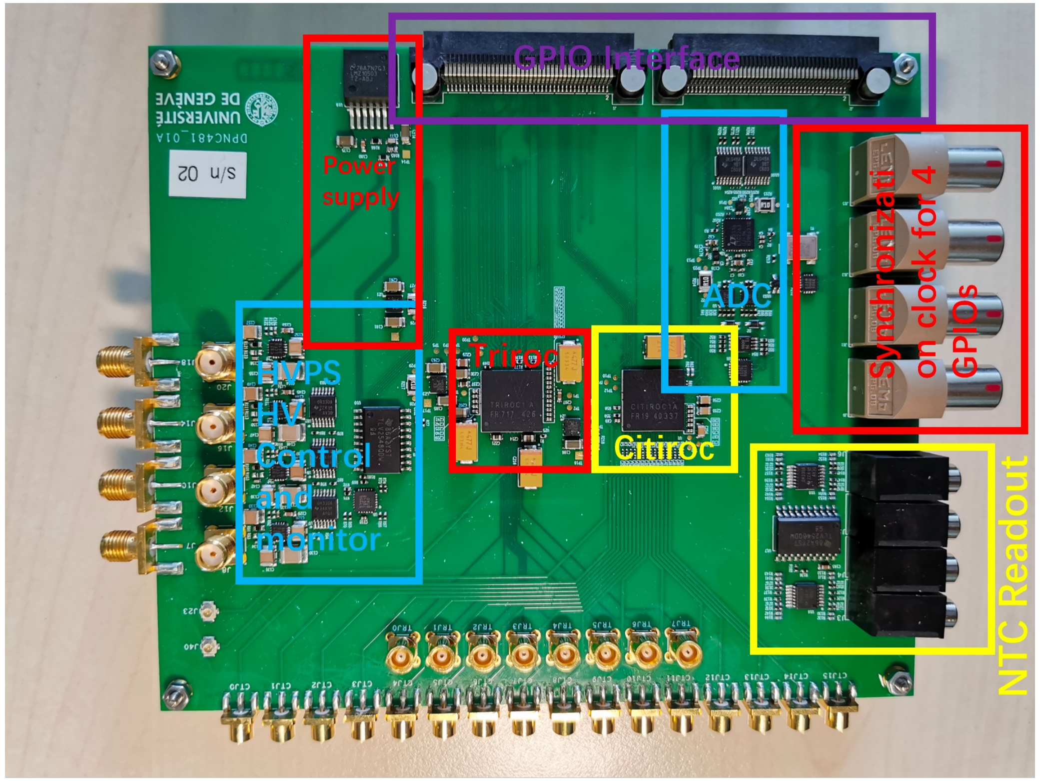


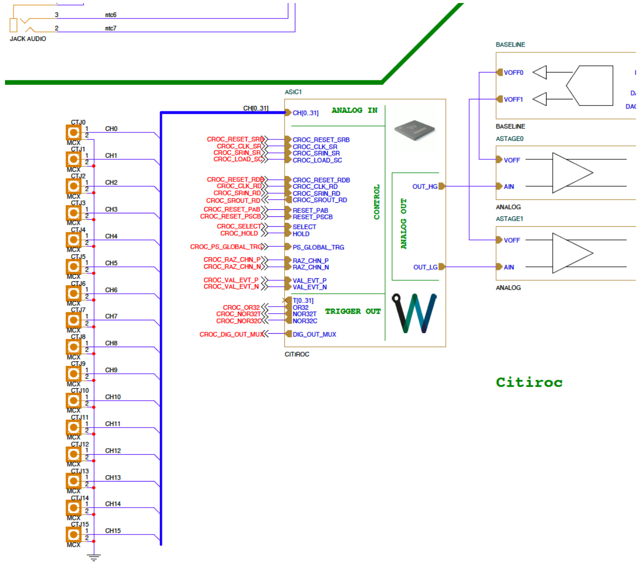


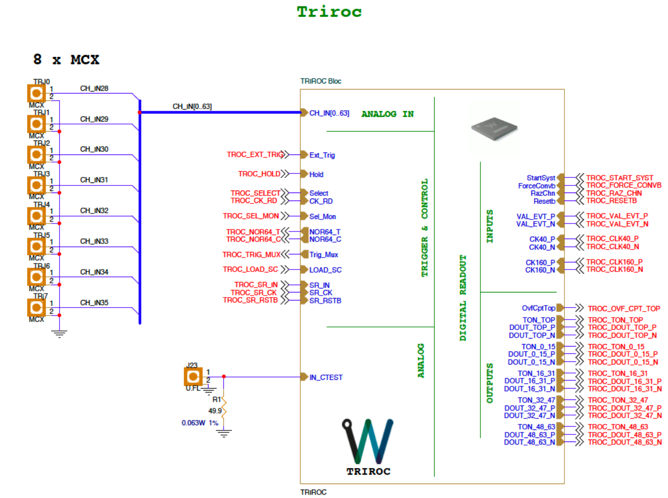
SiPM	Leak current [log10(A)]	V_{bd} [V]	T coeff. [V/°C]
S13360-6075	-9.5±0.1	51.65±0.11	0.055±0.002
S13360-6050	-9.3±0.2	51.85±0.005	0.057±0.001
S13360-6025	-9.2±0.2	51.85±0.06	0.057±0.002
S13360-1325	-10.2±0.2	51.90±0.03	0.054 ±0.002

- Gains are parameterized by temperature, operating voltage in the analysis.
- 1 mm SiPMs (good linearity < 1500 PE) are used for desaturation of 6 mm SiPMs.

TOF Front-end board







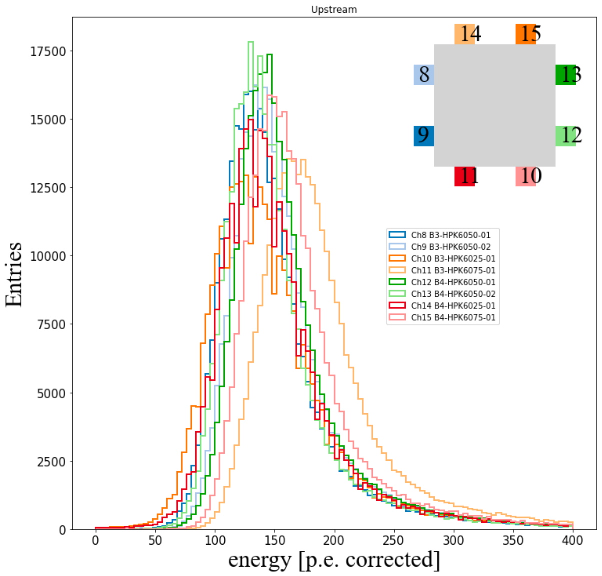
Citiroc:

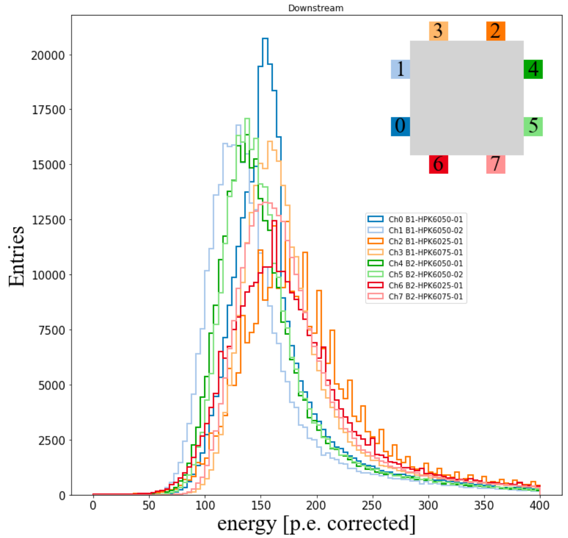
- 0-400 pC
- Can provide trigger
- 4.84 mW per channel
- 16 channels are used

Triroc:

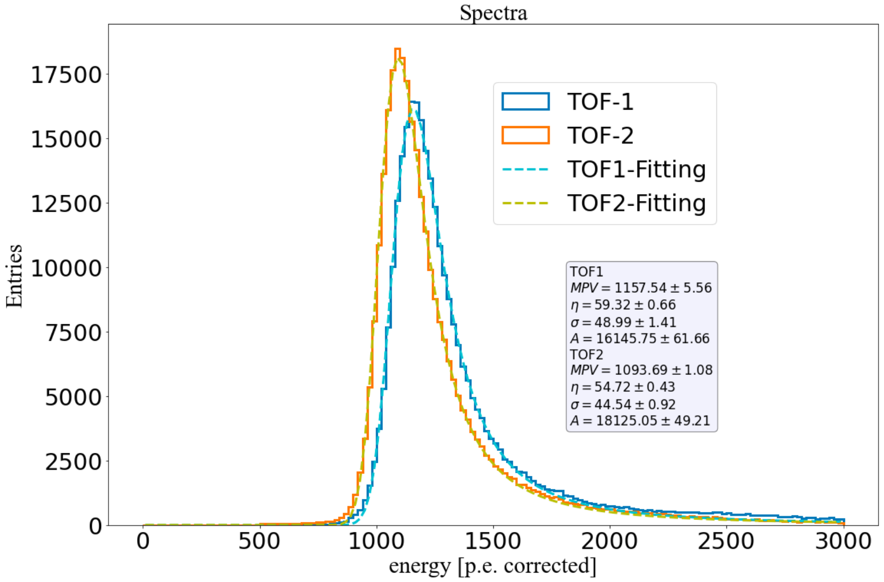
- Time resolution: 88 ps (RMS)
- Provide trigger
- 10 mW per channel
- 8 channels are used

TOF performance

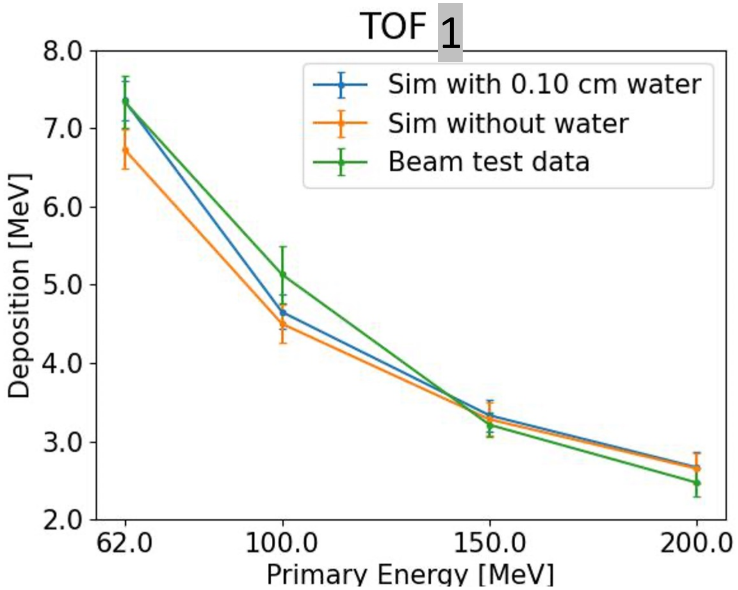




15 GeV proton beam at PS
Fitted by gaussian convoluted landau distribution

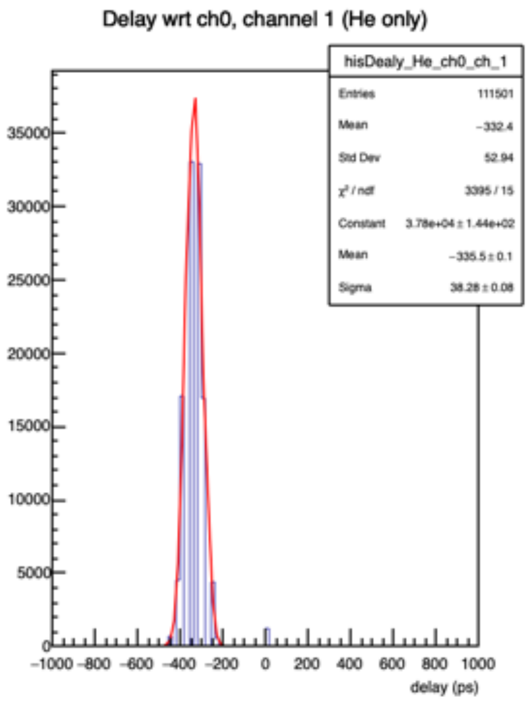


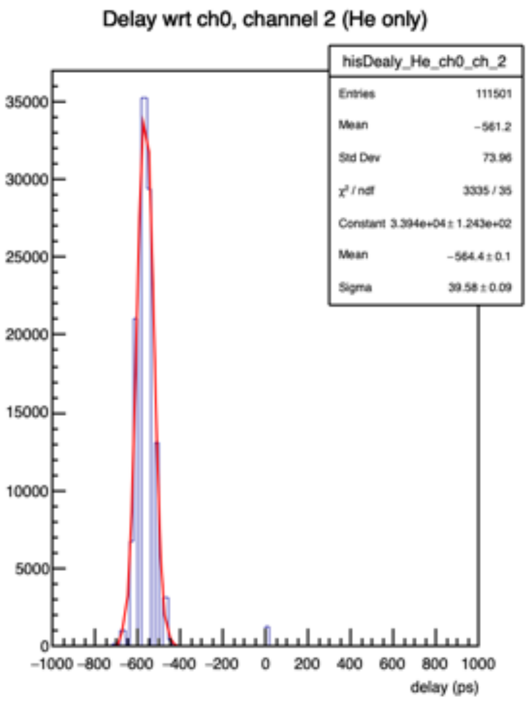
Low energy proton beam at PAVIA

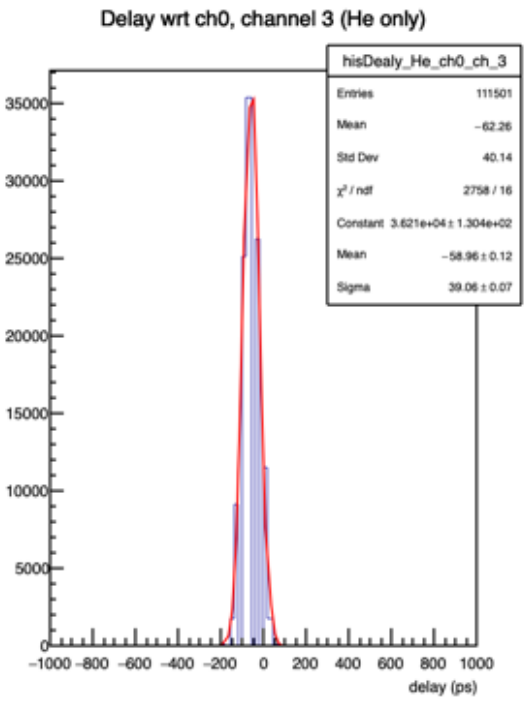


TOF performance

- Time resolution



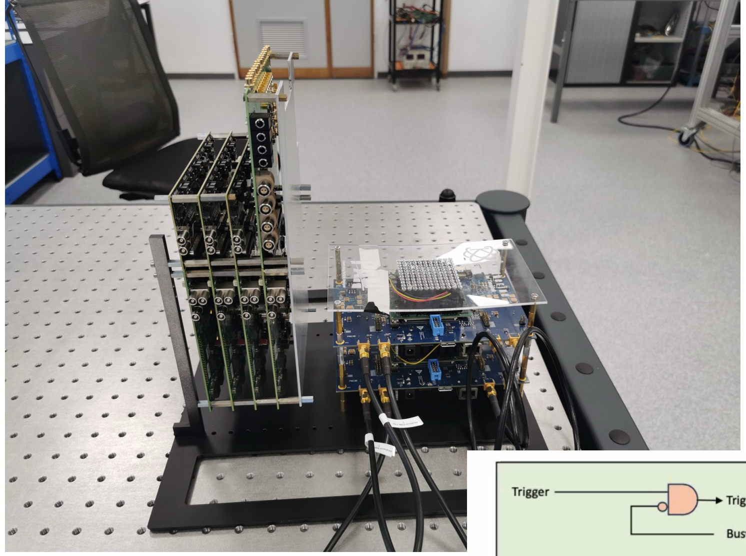


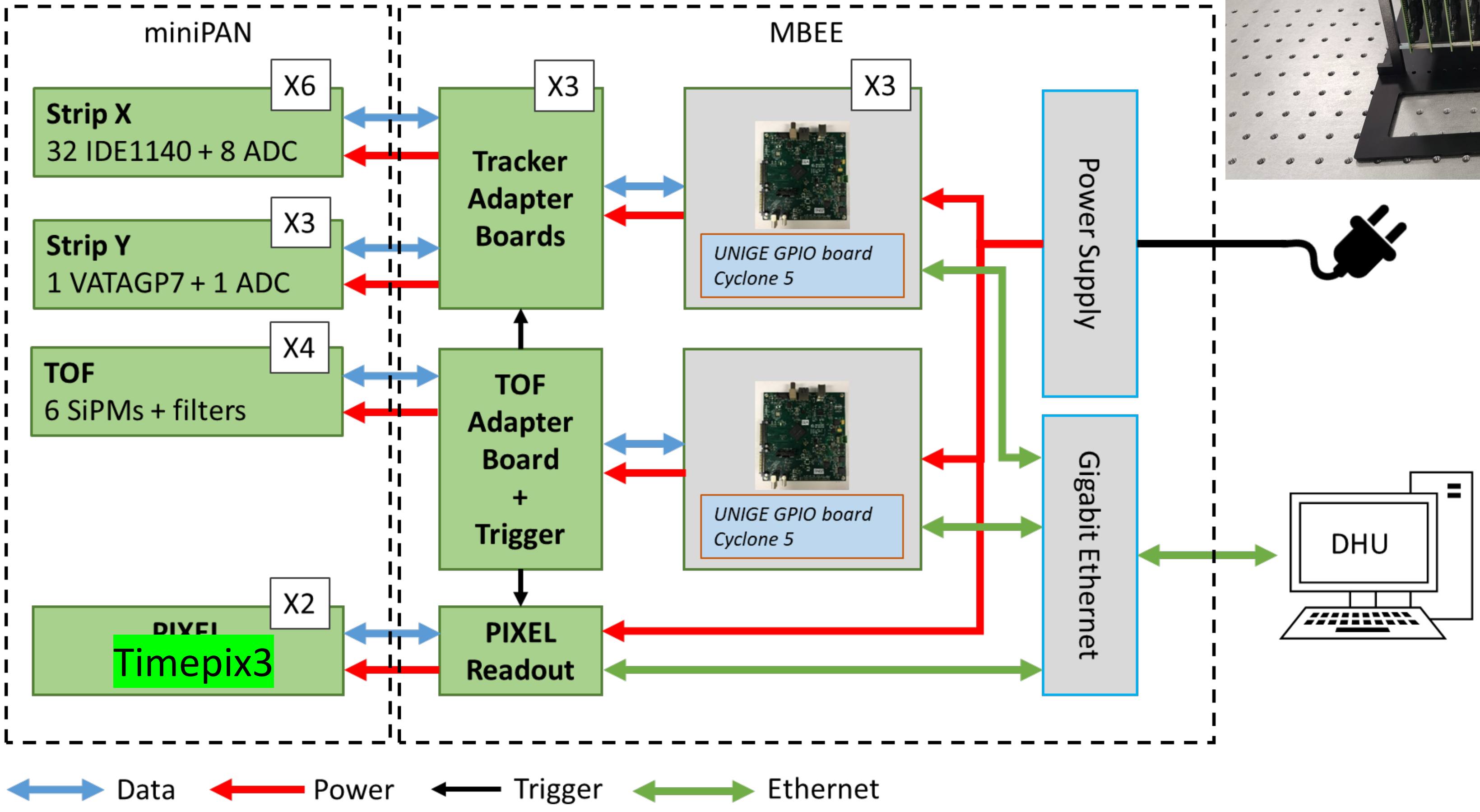


Best time resolution achieved:
40 ps for He particles

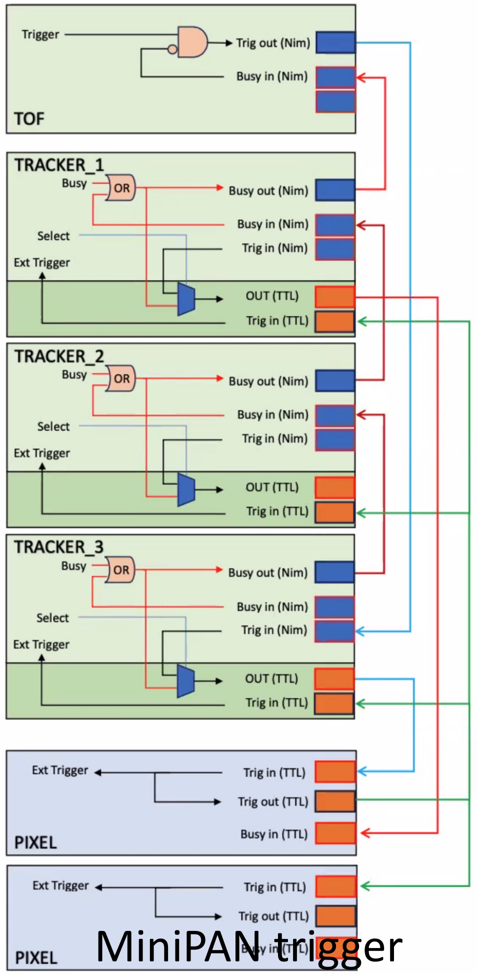
Time resolution $\propto 1/\mathrm{sqrt}(n)$

MiniPAN electronics



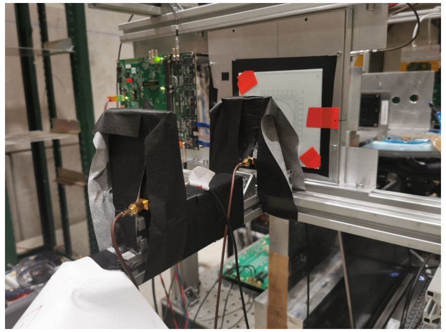


GPIO boards for TOF and each tracker boards
TOF provides trigger for entire system.



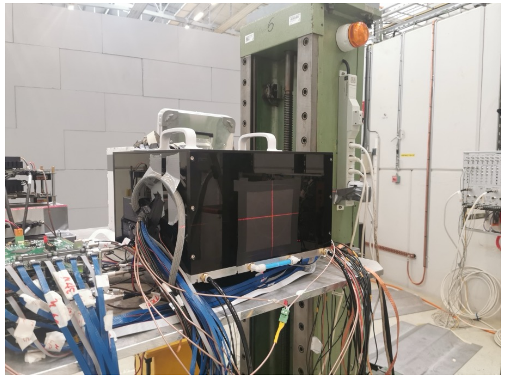
MiniPAN trigger

Beam test

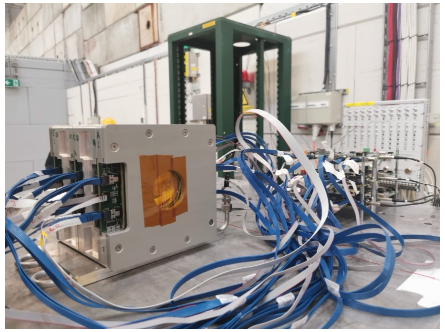


202111 PS
- Three Tracker modules
- first version of mechanics

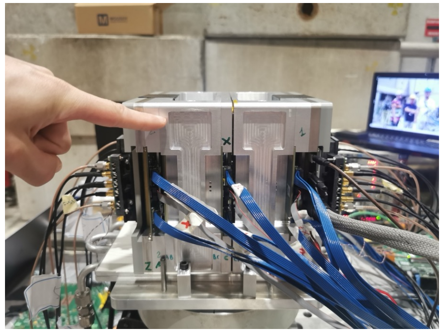
202208 SPS
- Integral pixels in mechanics
- motion control
- integrate magnets



202107/08 SPS
- One tracker module
- 2 TOF scintillator



202206 PS
+
- Pixels
- First TOF modules
- thermal control

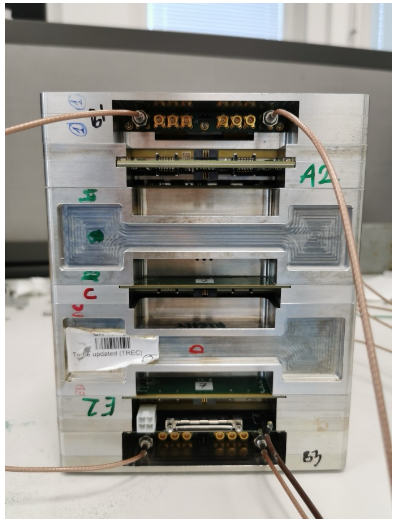


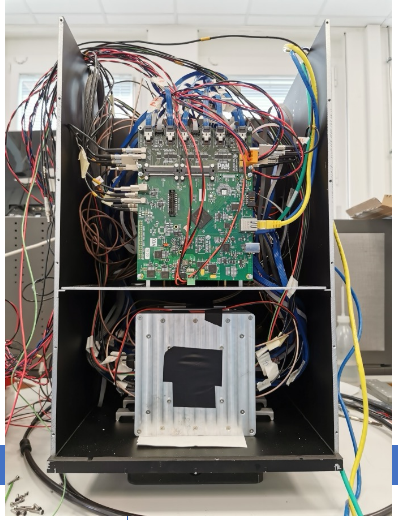
202209 PS
- final TOF modules
- TOF mechanics
- Test box
- **(first assembly of whole miniPAN detector)**

Beam test

202211 SPS

- first ion beam





202304 PS

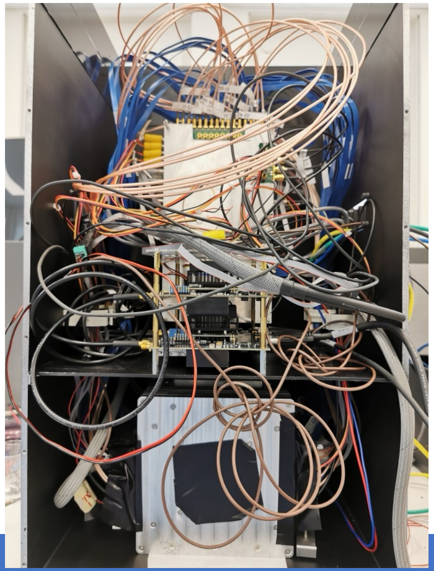
- StripY readout
- compact assembly of front-end electronics and detector

202306 CNAO(Italy)

- 115-400 MeV/n carbon beam
- TOF front-end board integration

202307 CNAO(Italy)

- 62-200 MeV proton beam

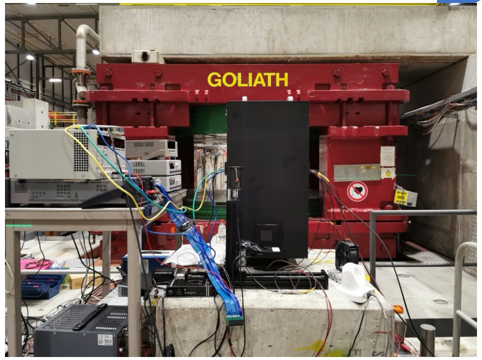


202308 SPS

- Synchronization of miniPAN detector

202310 SPS

- Ion beam
- Time trigger
- DAQ software integration



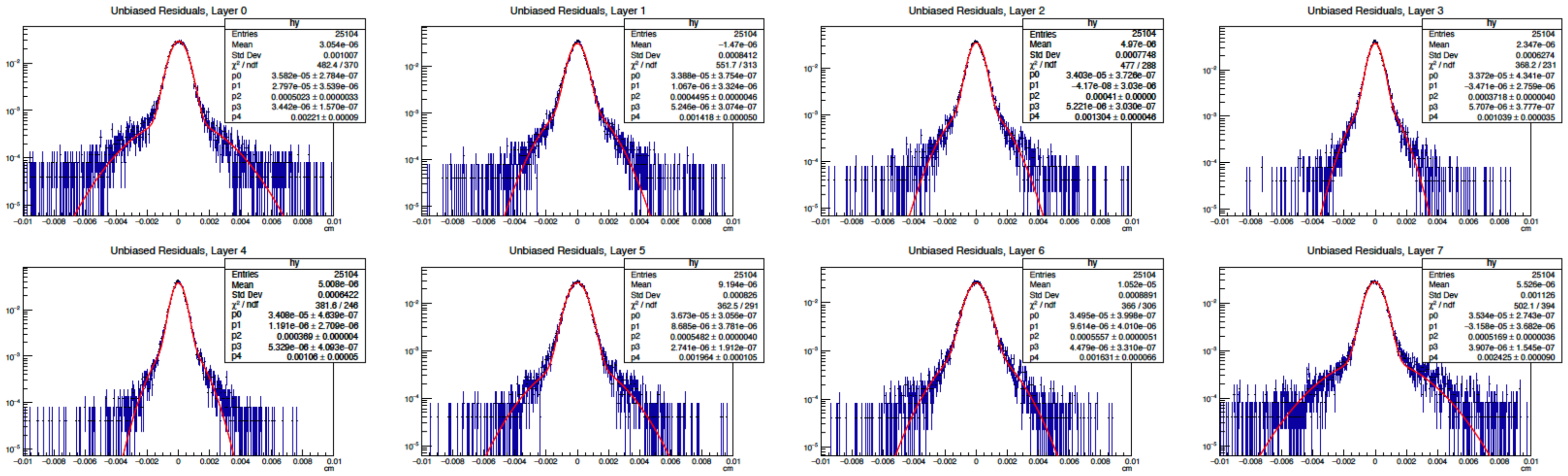
…

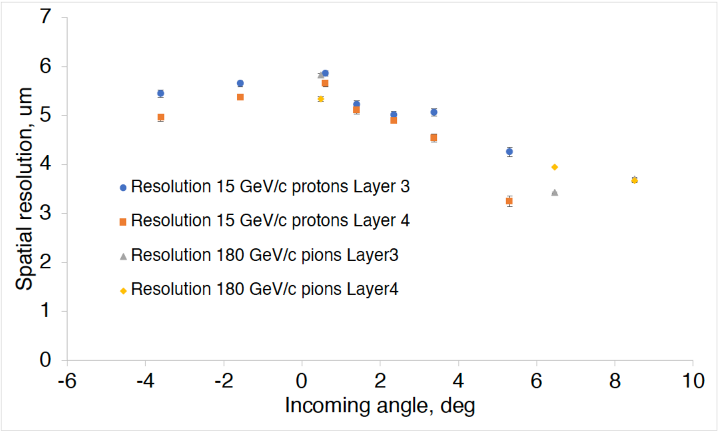
202312 Trento

- Low energy proton beam

Mini-PAN performance

➢Position resolution





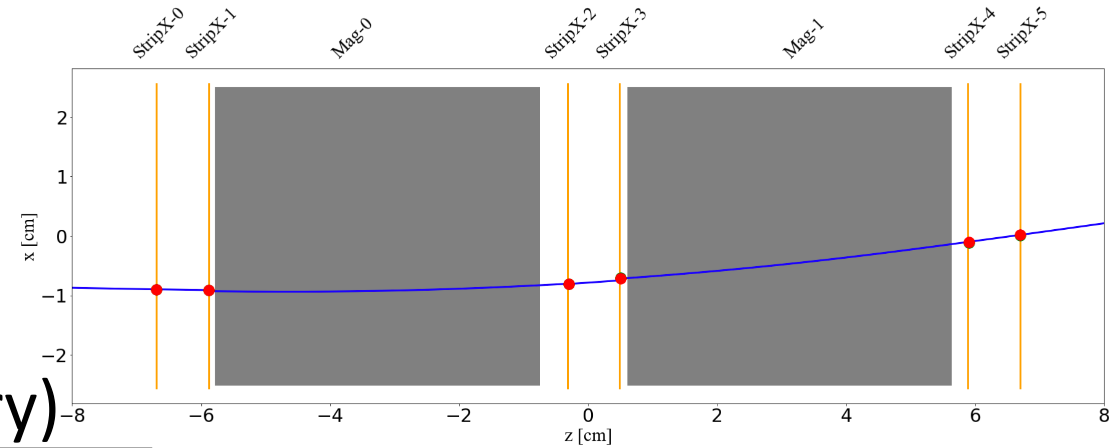
Residual distribution (180 GeV pion beam 2022 Aug)

- Alignment of each detector with 6 parameters (translation and rotation).
- Minimization of global chisquare of reconstructed trackes in the XZ and YZ planes.
- Layer 1,8 pixel detectors
- Layer 2-7 strip-X detectors
- Core vaussian sigma is considered as position resolution.

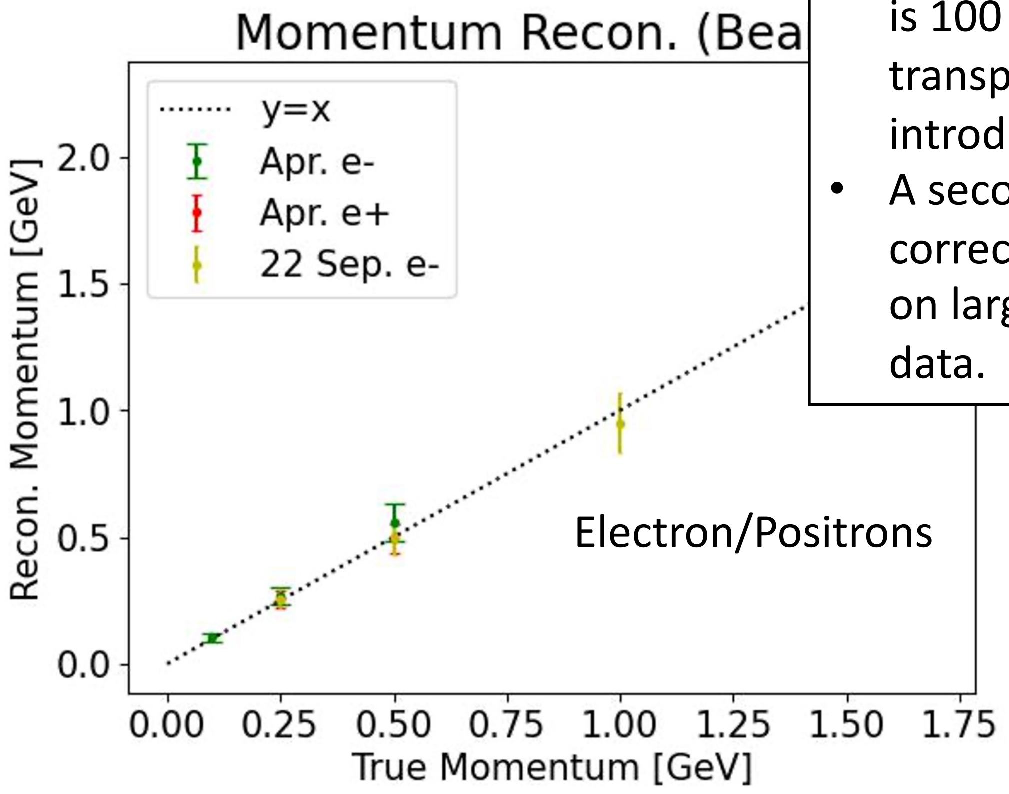
- Spatial dependancy
- Contribution from multiple coulomb scattering is subtracted
- Consistent between 180 pion beam and 15 GeV proton beam

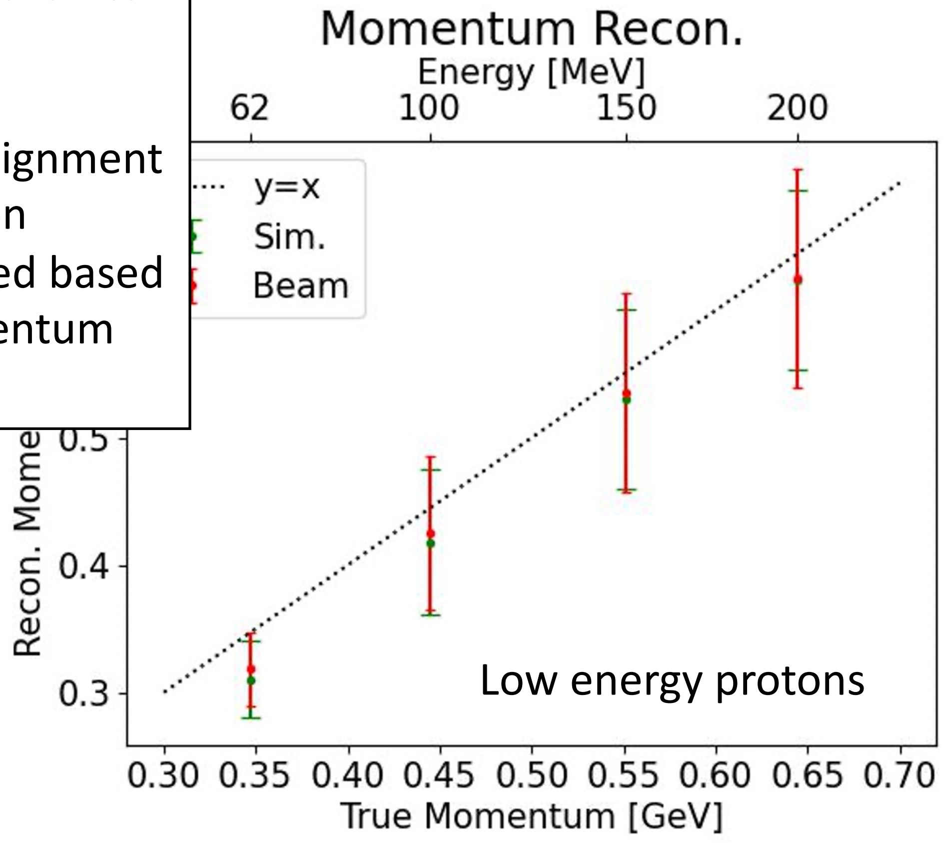
Mini-PAN performance

- Momentum reconstruction (preliminary)



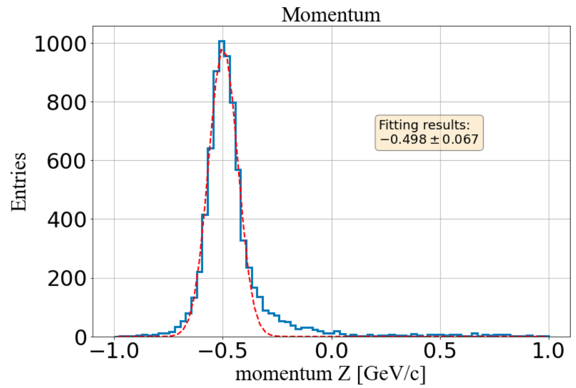
- Precision for mechanics is 100 µm, transportation introduces misalignment
- A second position correction applied based on largest momentum data.



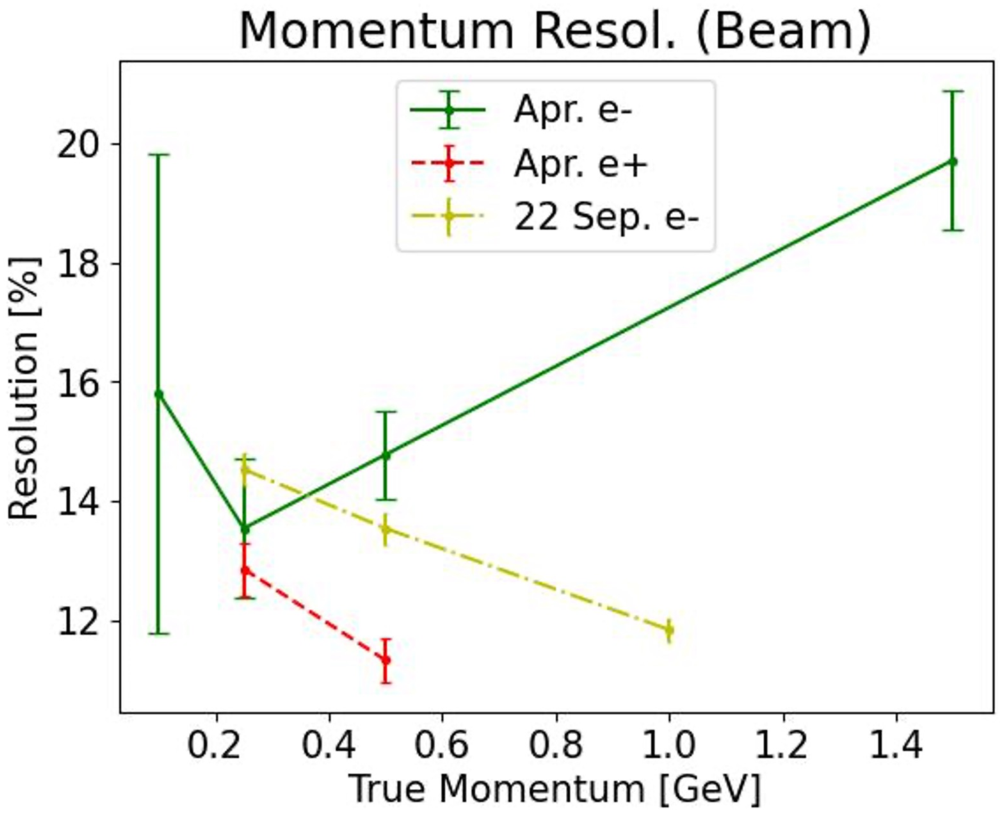


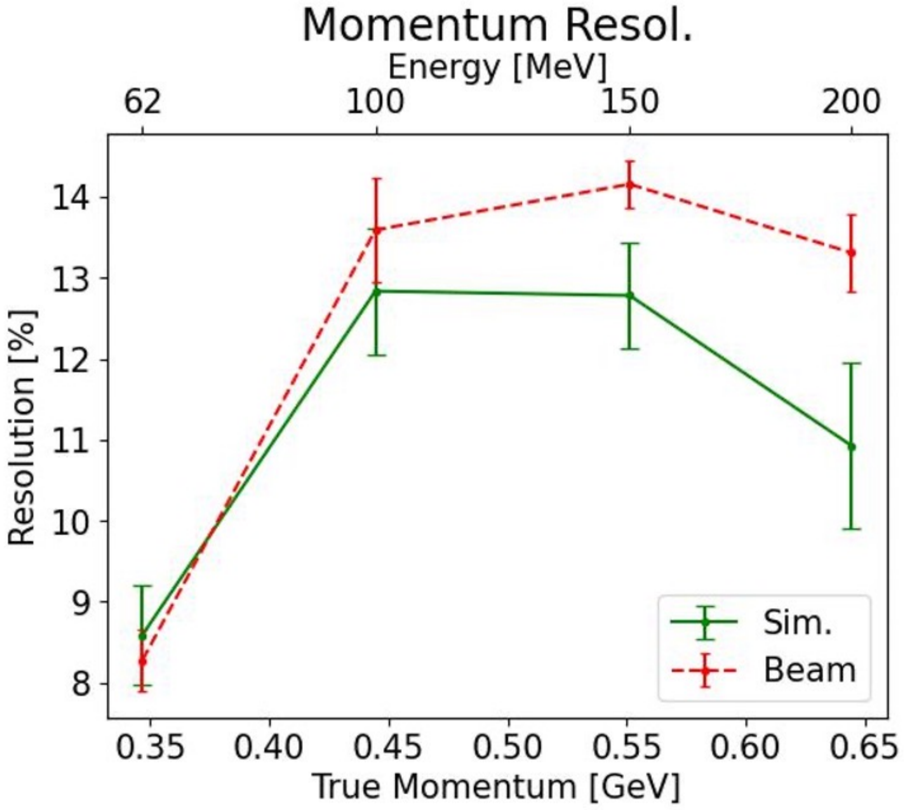
Mini-PAN performance

- Momentum resolution (gaussian sigma)



Gaussian fitting on momentum distribution.

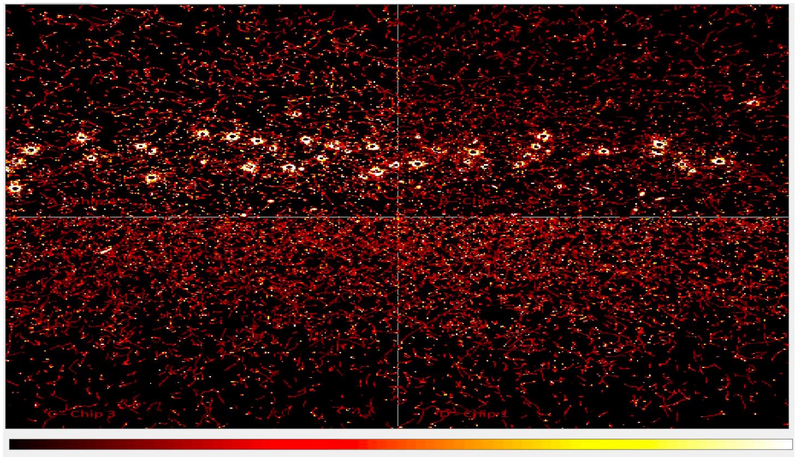


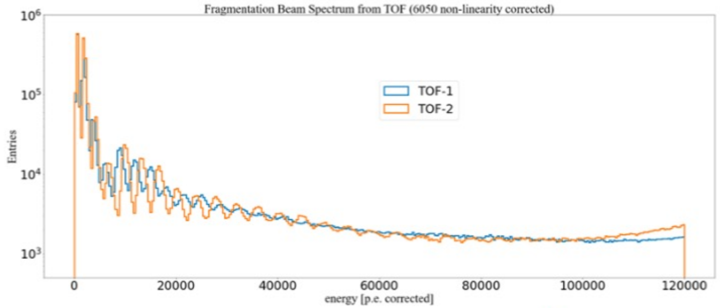


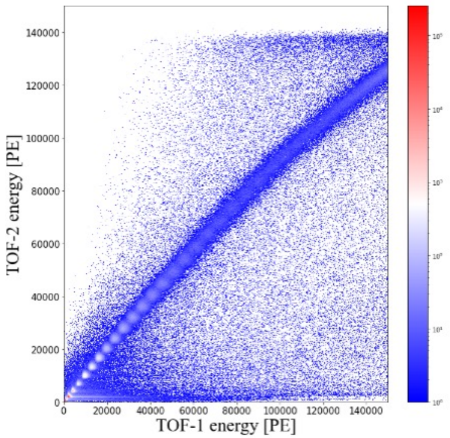
Mini-PAN performance

- Particle identification

Ion beam profile on pixel

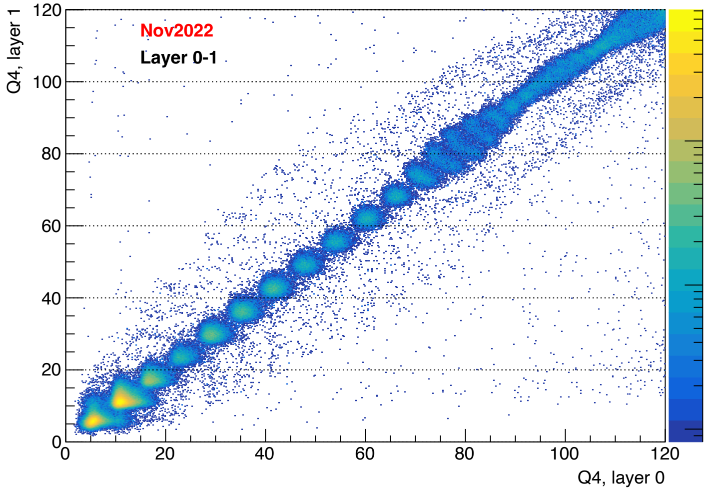






TOF: desaturate by 1 mm SiPMs

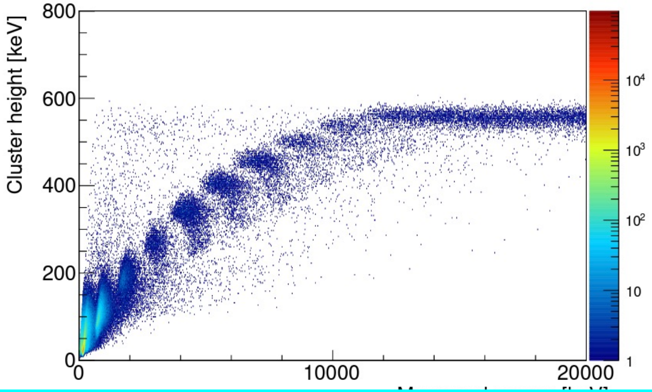
Z up to 7 -> Z up to 20



Strip-X: 5 th largest strip

Z up to 10 -> Z up to 17

Better resolution



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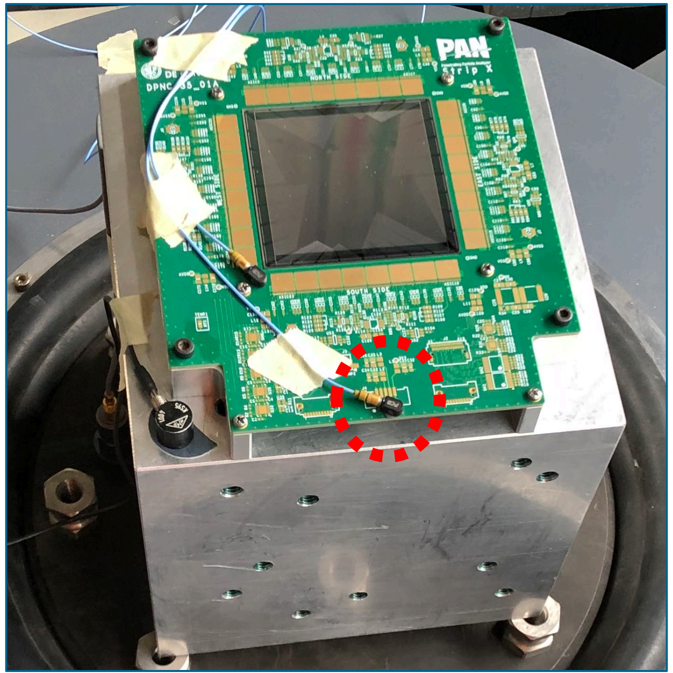
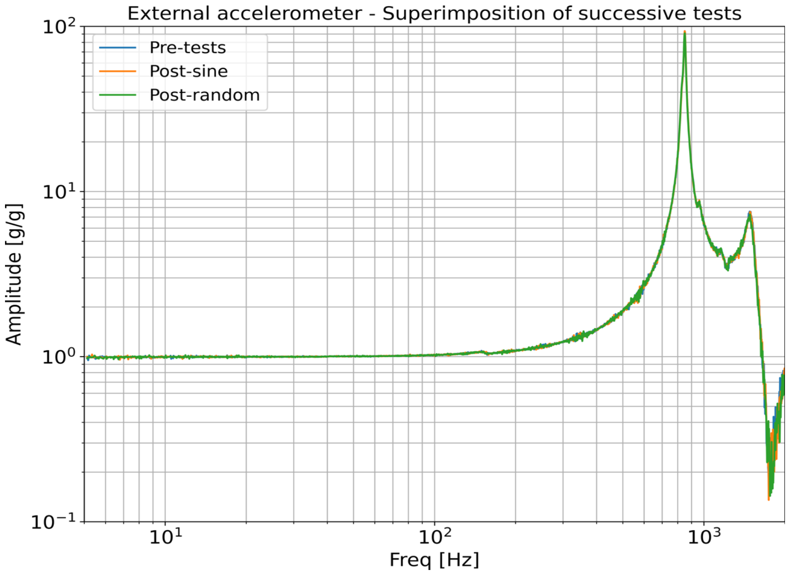
Tracks are different for different particles (e/p/γ)

Spot size correlates with energy deposition

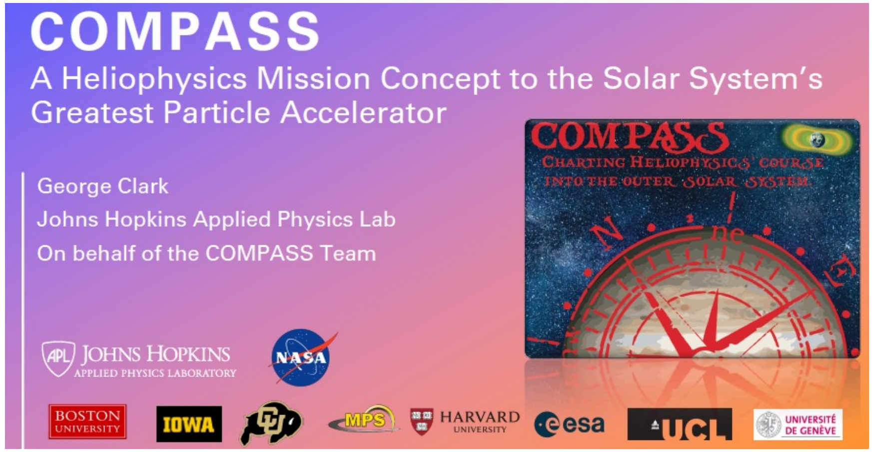
Space qualification

- Vibration and shock tests on mechanical grade detectors completed successfully for the tracker.
- Pixel and TOF tests scheduled later this year.
- Thermal test and thermal vacuum test may be conducted in the end of the year.





Possible application



COMPASS

- Measure particle energy and flux at the Jupiter's radiation belts.
- Targeting sub-GeV/n to GeV/n.
- "Pix.PAN", which consists of 6 silicon pixel detectors is being considered and studied to meet requirements.
- COMPASS Study Reprot: G. Clark et al,, 10.22541/essoar.167751608.84818747/v1
- Pix.PAN white paper: J. Hulsman et al.,Submitted to Exp. Astro., https://doi.org/10.21203/rs.3.rs-2743432/v1

REMEC

- Precisely measure and monitor the flux, composition and particle's direction in deep space outside Earth's magnetosphere.
- Targeting 10 MeV/n – 10 GeV/n.
- Pix.PAN design studied as primarily payload

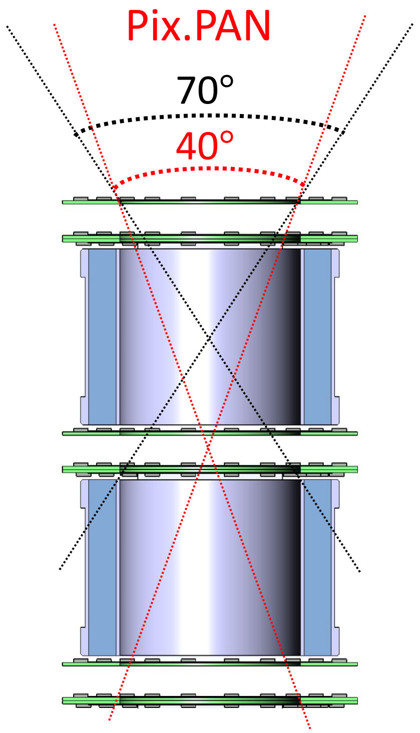
LUNAR Orbital Platform

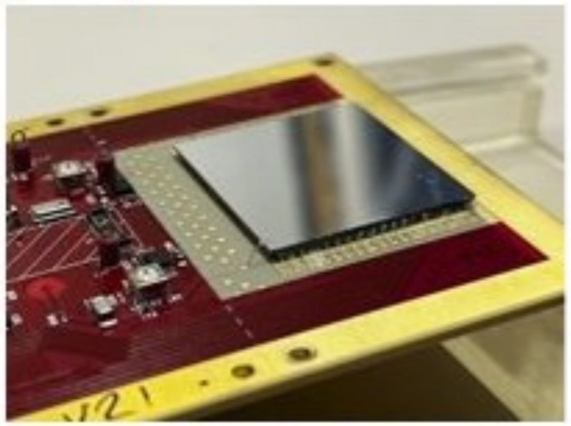
- **Proposed as the Galactic cosmic rays detector on the Lunar Orbital Platform- Gateway**
- Dandouras et al, Front. Astron. Space Sci. Volume 10 - 2023 doi:10.3389/fspas.2023.1120302

Proposed to ESA's call "Reserve Pool of Science Activities for the Moon"

Pix.PAN

- Only 6 layers of Timepix4 detectors.
  - One type of detection element, simplicity in design.
  - Data-driven readout, ADC/TDC integrated in ASIC.
  - 195 ps time resolution
  - High rate capability, no saturation up to a hit rate of 385 Mz/cm^2
  - Customized long pixel: 13.75 µm x 1760 µm ⇒ **hit resolution ≲ 3 µm**





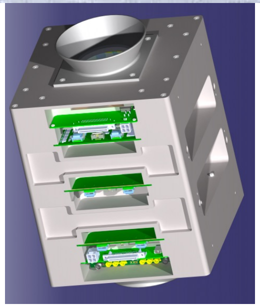
Summary

- Currently penetrating particle precise measurement and monitoring in deep space are still lacking.
- We developed a versatile instrument, miniPAN, with a wide range of potential applications, has potential to fill observation gap of galactic cosmic rays in deep space.
- Extensive tests were carried out to make it a promissing instrument for various scientific endeavours.
- REMEC is a L2/Lunar orbit mission concept currently under Phase0/A/B1 study supported by the Czech Republic and ESA, down selection in 2023
- Wer are actively looking for opportunities for deep space deployment.

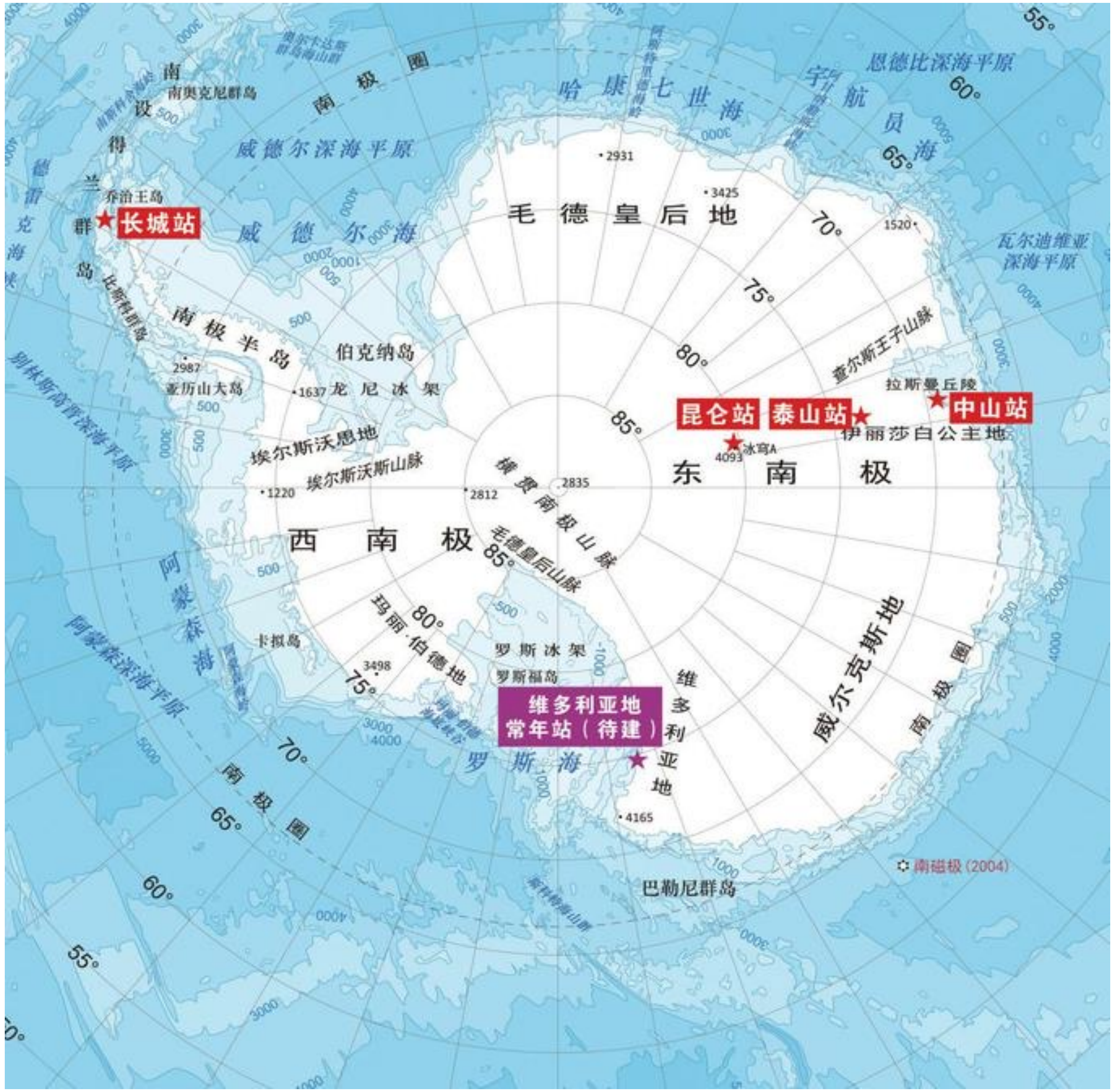
Three open questions

- Possible applications of the miniPAN detector
- Small and compact magnetic spectrometer for deep space (Fill 1 GeV gap)
- Jupiter radiation belt measurement

Mini-PAN



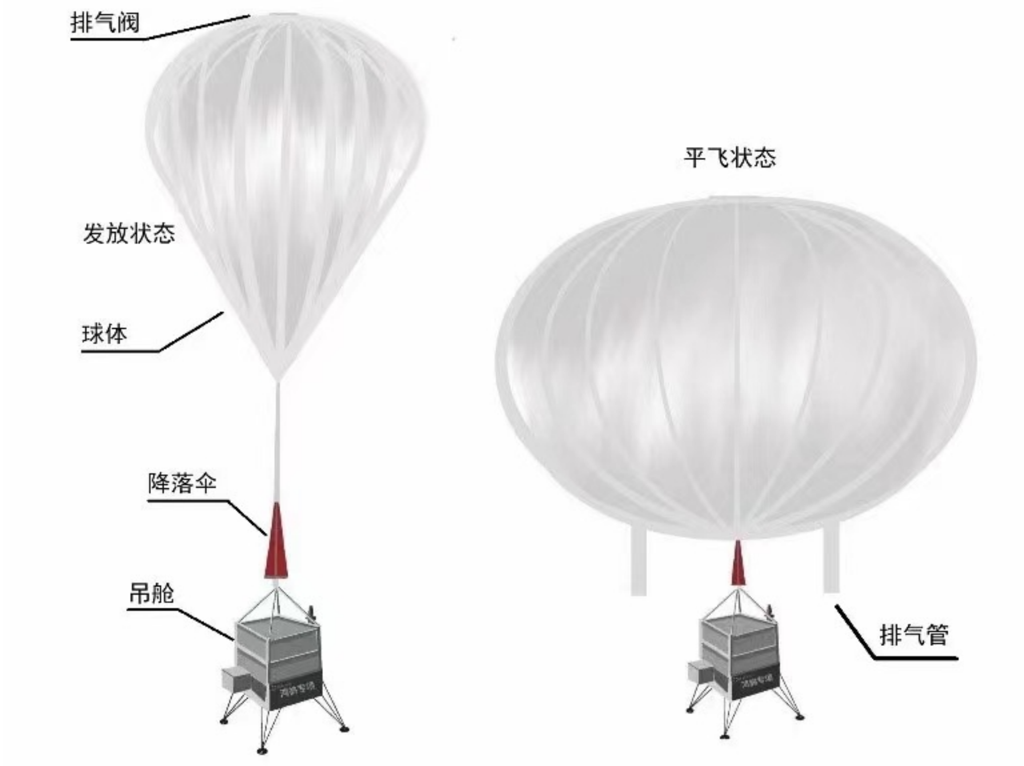
Student based cosmic-ray measurement project with balloon (like GRID)?



There will be a fifth station which is suitable for balloon mission

A good proving place for space detector

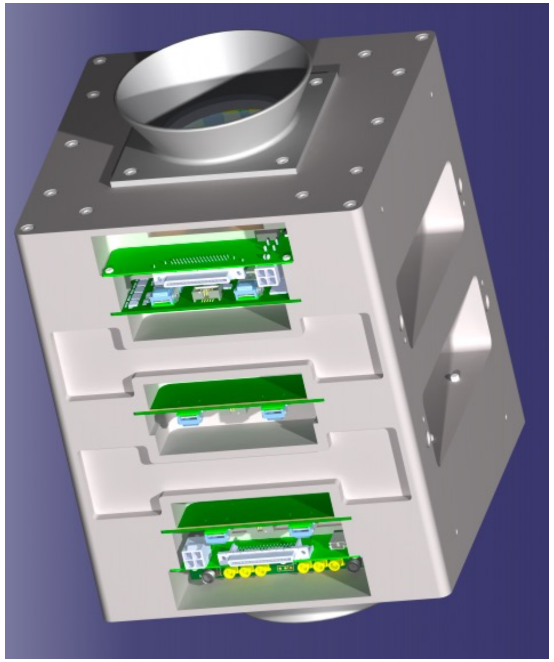
AD



AIRCAS/空天院 is able to produce balloon which can carry 3.6 T payload and fly for >30 days.

They are waiting for scientific projects to explore South Antarctica.

Mini-PAN



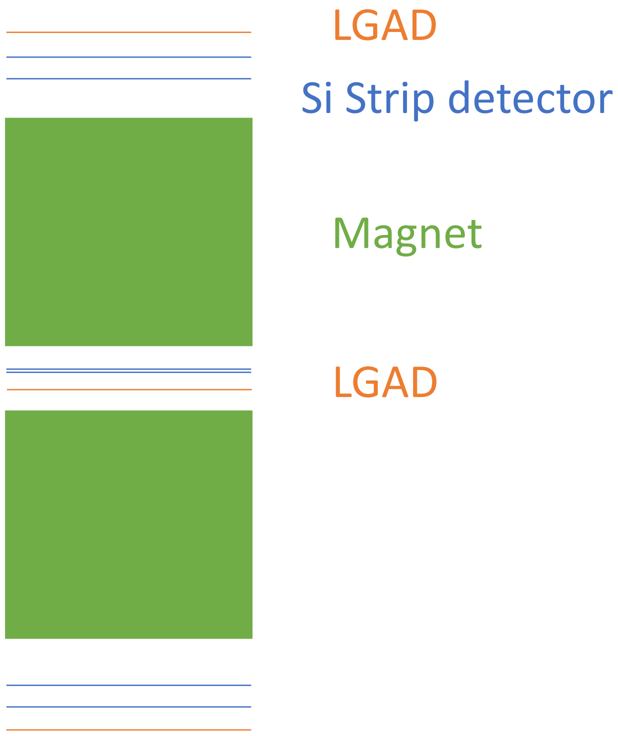
Application in nuclear physics.

- Heavy ion beams in Huizhou.
- Small compact modulized magnetic spectrometer for each sub-beam.

Application in space(Low earth orbit) = Small AMS

- Also for nuclear physics
- Open data to study cross section of different isotopes

Small compact magnetic spectrometer in deep space



- Strip-like LGAD(Time measurement and Y measurement)
- Si Strip detector with space qualified ASIC. (Maybe not important if we operate it inside the space station)
- Magnet(Only one magnet might be enough)

Best application place: Lunar space station/Lunar base.

We can transfer data back to earth periodly.
Off-line analysis cross check with on-line analysis.

Probe Jupiter radiation belt

Deep space exploration

We just arrived at MARS

Tianwen-4 plan to visit Jupiter.

Jupiter missions

- NASA

Jupiter [edit]

- Pioneer program
  - *Pioneer 10*, launched March 1972, completed – first to the asteroid belt and Jupiter
  - *Pioneer 11*, launched December 1974, completed – asteroid belt and Jupiter, first to Saturn
- Voyager program
  - *Voyager 1*, launched September 1977, operational – flybys of Jupiter and Saturn; extended mission to explore interstellar medium; most distant human-made object
  - *Voyager 2*, launched August 1977, operational – flybys of Jupiter, Saturn, Uranus, and Neptune; extended mission to explore interstellar medium; first spacecraft to Uranus and Neptune
- *Galileo*, launched October 1989, completed – Jupiter and its moons
- New Frontiers program
  - *New Frontiers 2 – Juno*, launched August 2011, operational – Jupiter orbiter mission[43]
- *Europa Clipper*, launching 2024, future

From wikipedia

Jupiter missions

- ESA-JUICE

The launch

Launch: 14 April 2023

Launch location: Europe's Spaceport in French Guiana

Launch vehicle: Ariane 5

Destination: Jupiter system

From ESA website

Jupiter radiation belt measurement

Experimental Astronomy (2022) 54:745–789

Table 1 List of past, ongoing, and future missions to Jupiter's magnetosphere and radiation belts

Space missions

Mission	Type	Time	Energetic particle measurements and constraints
Pioneer 10/11	Flyby	1973-1974	Several energetic particle detectors, saturation
Voyager 1/2	Flyby	1979	problems for protons, electrons, radiation damage
Ulysses	Flyby	1992	Several energetic particle detectors, many switched off at Jupiter to avoid radiation damage
Galileo	Orbiter, Atmosphere Probe	1996-2003	Many orbits through the equatorial belts, mostly $>5\ R_J$ several energetic particle detectors, data rate and saturation problems, radiation damage. Limited data from the atmospheric probe
Cassini	Flyby	2000-2001	Distant flyby, synchrotron belts monitored by radar experiment, distant ENA imaging
New Horizons	Flyby	2007	Did not cross into the radiation belts' core, only energetic ions below ∼1 MeV(/n)
Juno	Orbiter	2016-2025	Energetic particle detector, relativistic electrons by monitoring noise in cameras, microwave measurements Inner radiation belt crossings over a wide latitude range.
JUICE	Orbiter	2031-2035	Mostly $>15\ R_J$, energetic particle detectors (<1 MeV), radiation monitor (<40 MeV electrons, <250 MeV protons), ENA imagers
Europa Clipper	Orbiter	2030-2034	$>9\ R_J$, dosimeters, charge monitors for high energy particles

Other observation modes

Type	Example observatories	Characteristics and constraints
Synchrotron Emissions, X-rays	LOFAR, GRMT, VLA	<50 MeV electrons
Aurora (UV, IR, X-rays)	Hubble, XMM-Newton, Chandra, IRTF	Monitoring energetic electrons (<1 MeV), Heavy ions
Io torus remote sensing (UV, X-rays)	HISAKI	Monitoring large-scale flows, Io volcanism, torus composition

Still a glimpse of the radiation belt.

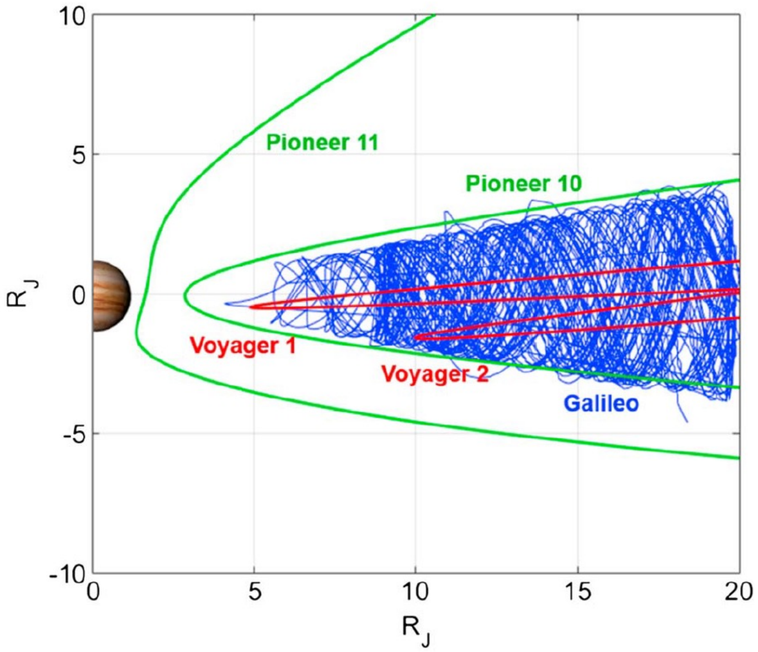
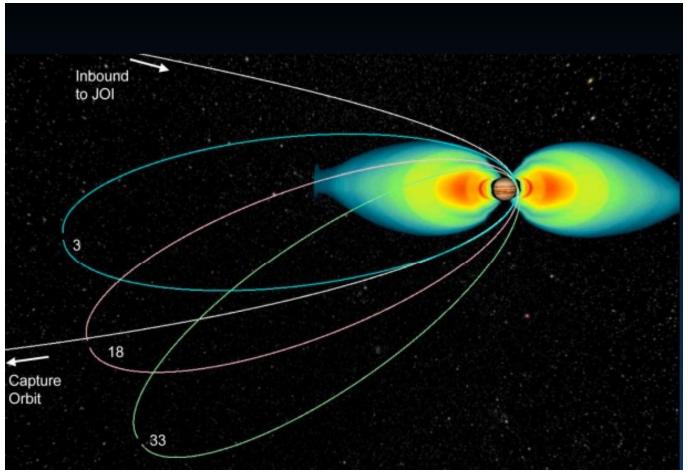
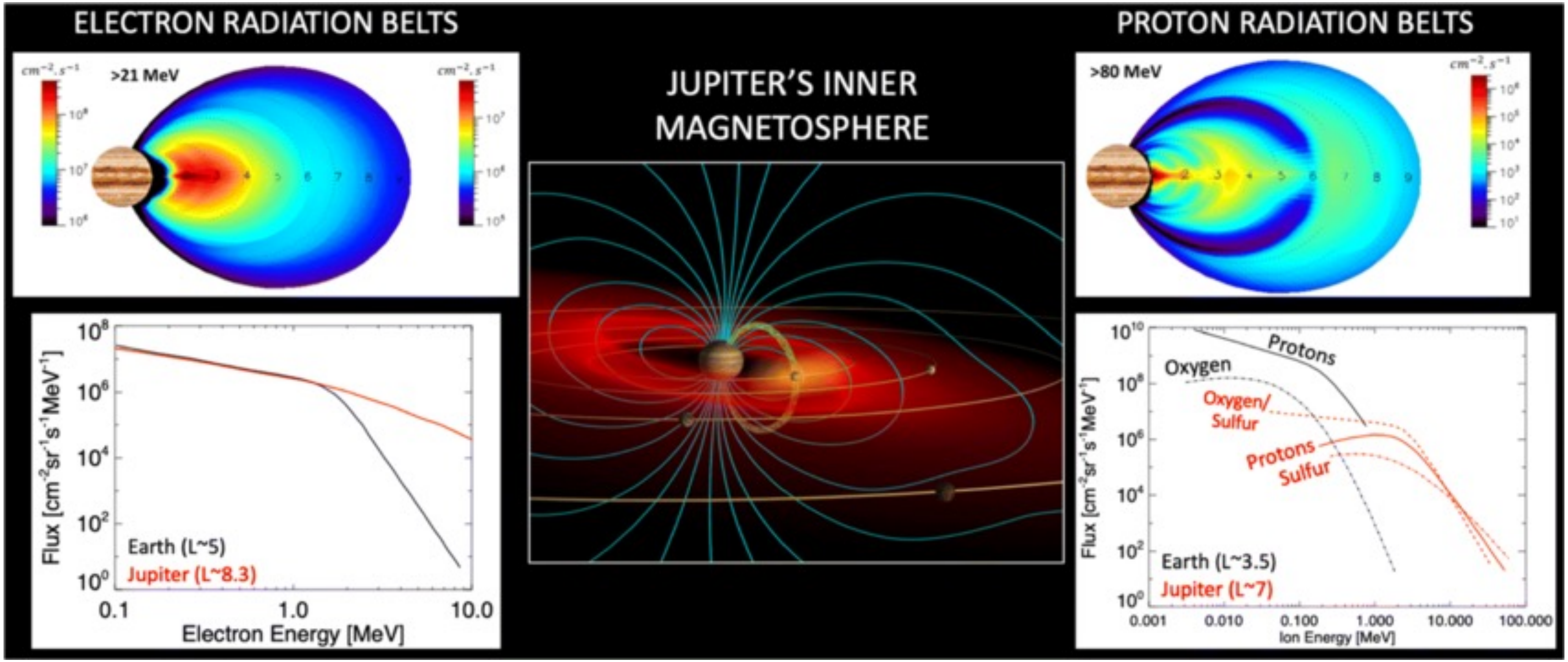


Figure 1. Trajectories of the Pioneer, Voyager 1, Voyager 2 and Galileo missions in a magnetic frame (*x* axis is the magnetic equator) after [*de Soria-Santacruz et al.*, 2016].



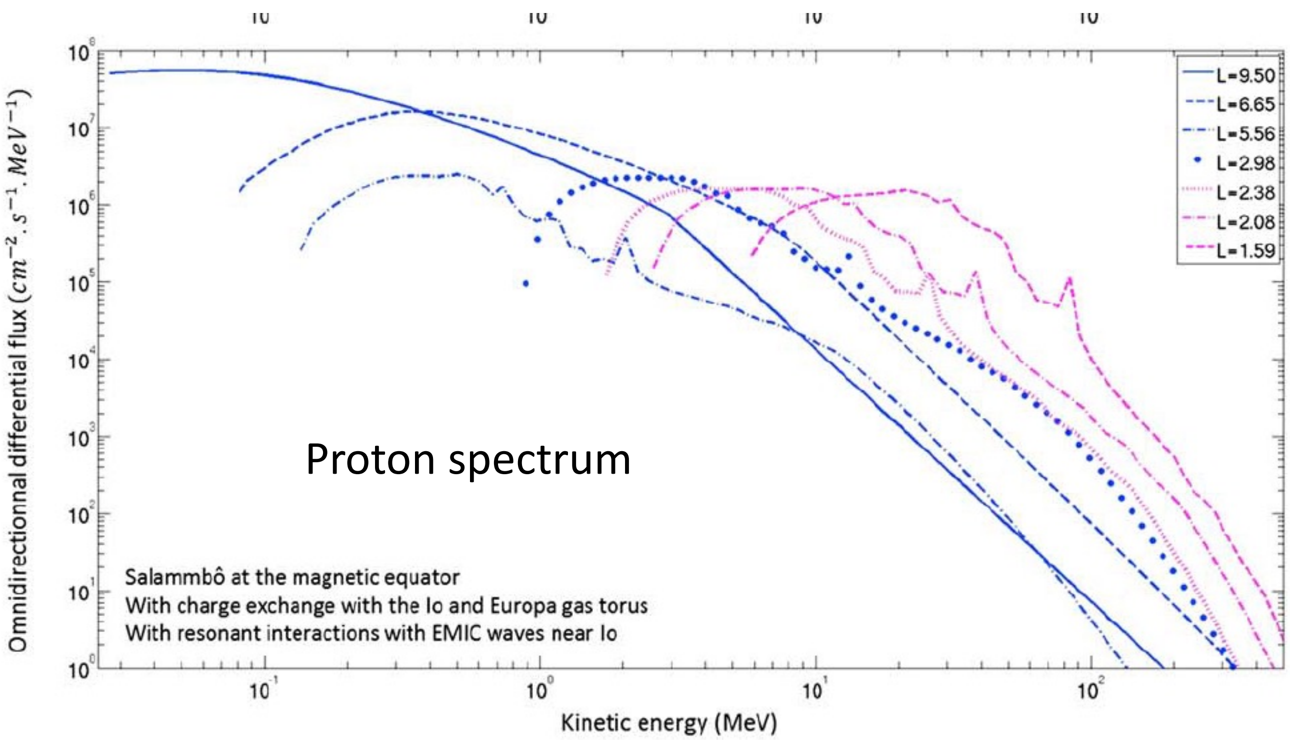
JUNO

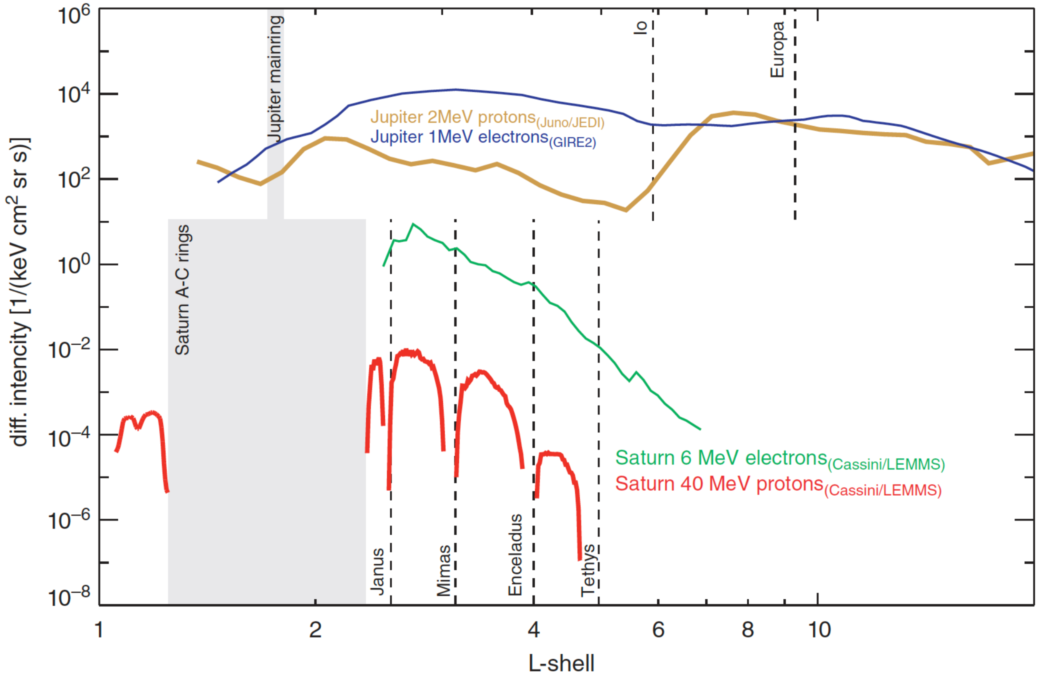
Composition of the radiation belt



Jupiter radius=L=7e4km

Difficulties

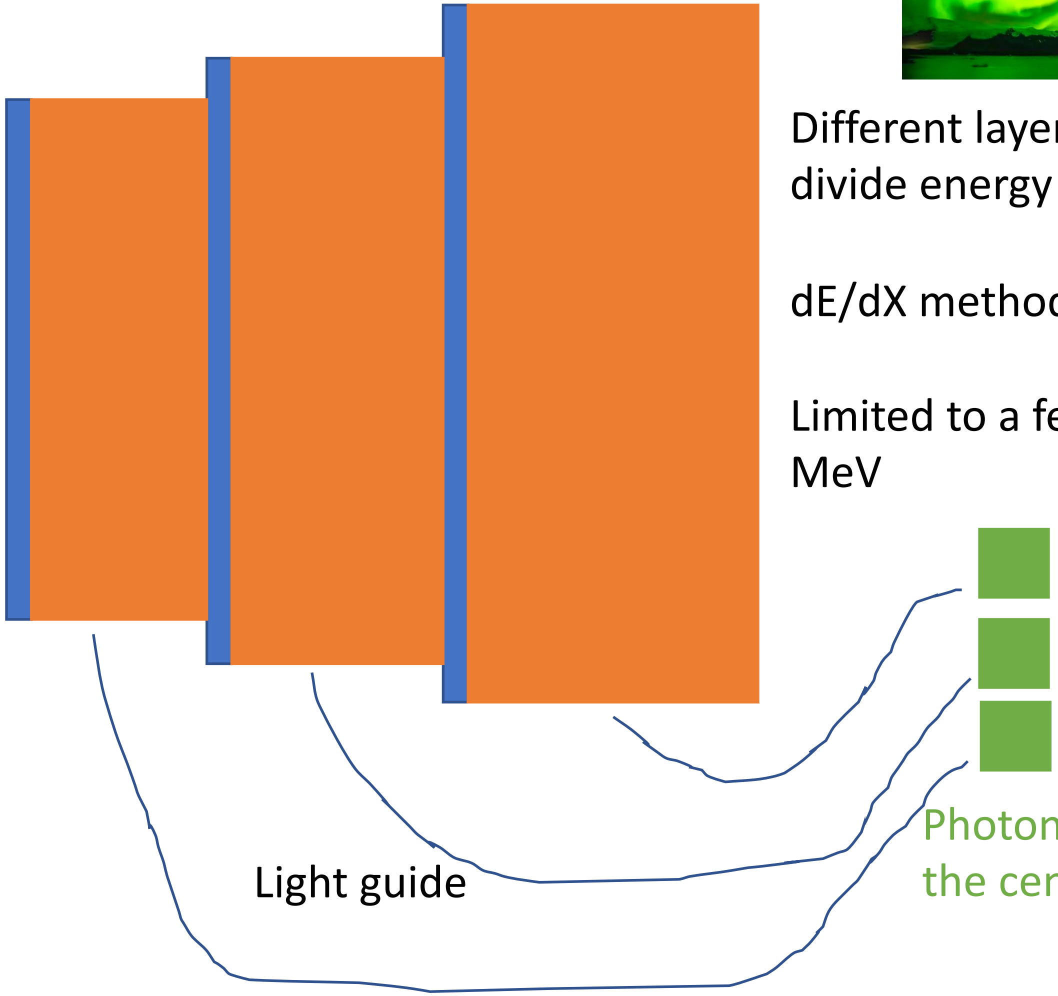




Dust ring around L=1.8

1, Detector saturation
2, Radiation damage

Possible particle detectors for Jupiter radiation belt



Different layer to divide energy bin

dE/dX method

Limited to a few 100 MeV

Insulate electronics from the belt.

Many tunable factors (light production rate by different material or density, light collection, etc) to avoid saturation problem

Radiation damage: Need validation. Maybe we just have to convert lights into current. Current proportional to proton intensity in each layer.

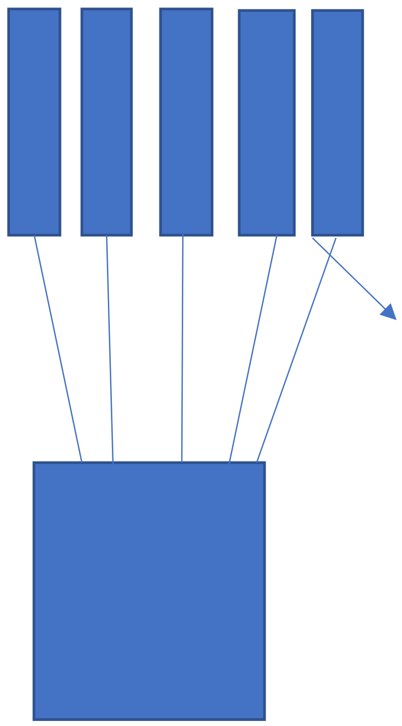
Might be able to disentangle Sulfur and Oxygen with different filling materials.

V1.0

Low energy-customized micro scale pixel detector with readout asics

Micro acceptance

A stack of single pixel detectors



Eg.
50 * 50 * 50um single pixel detector
4 pixels per sensor/layer

Insulation between each two pixels

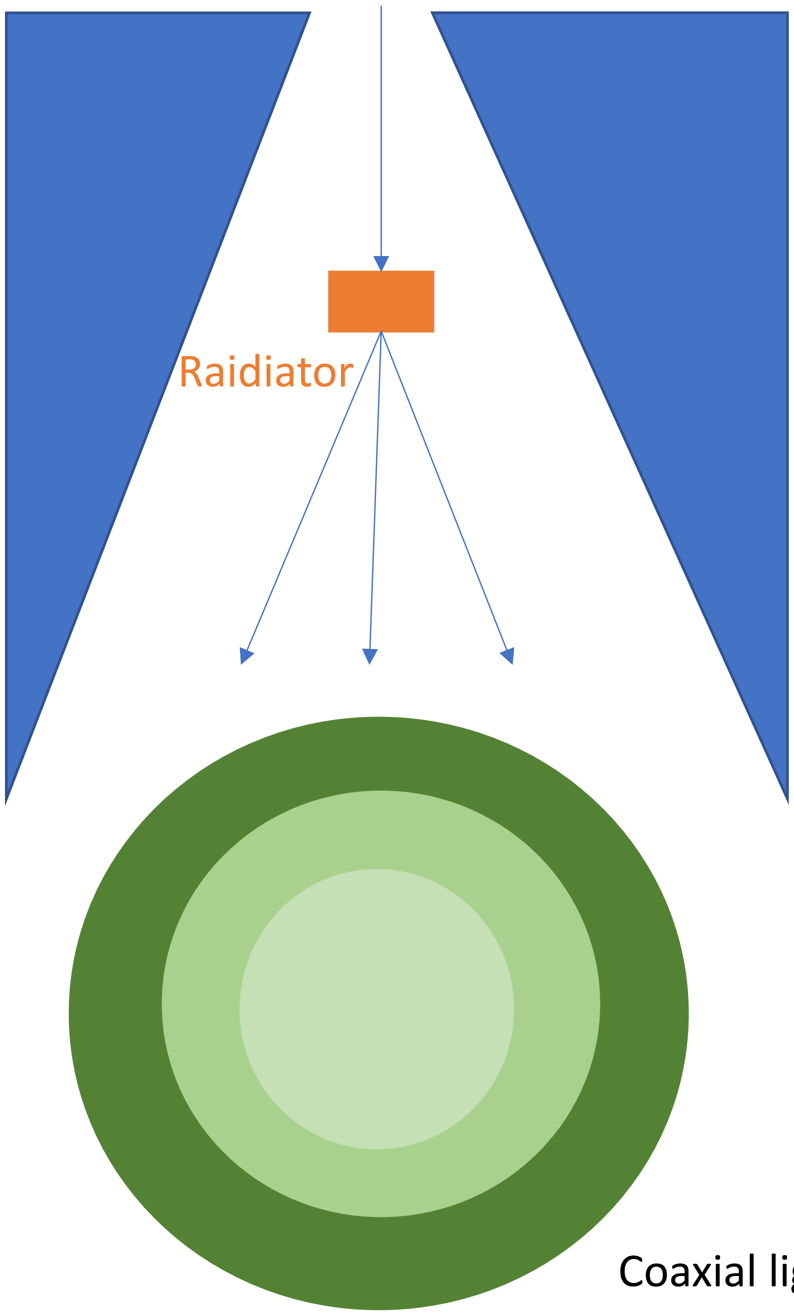
Electronics

No saturation and radiation damage problem.

But the maximum detection energy would be quite limited.

Multiple pixels per sensor help identify electrons and protons

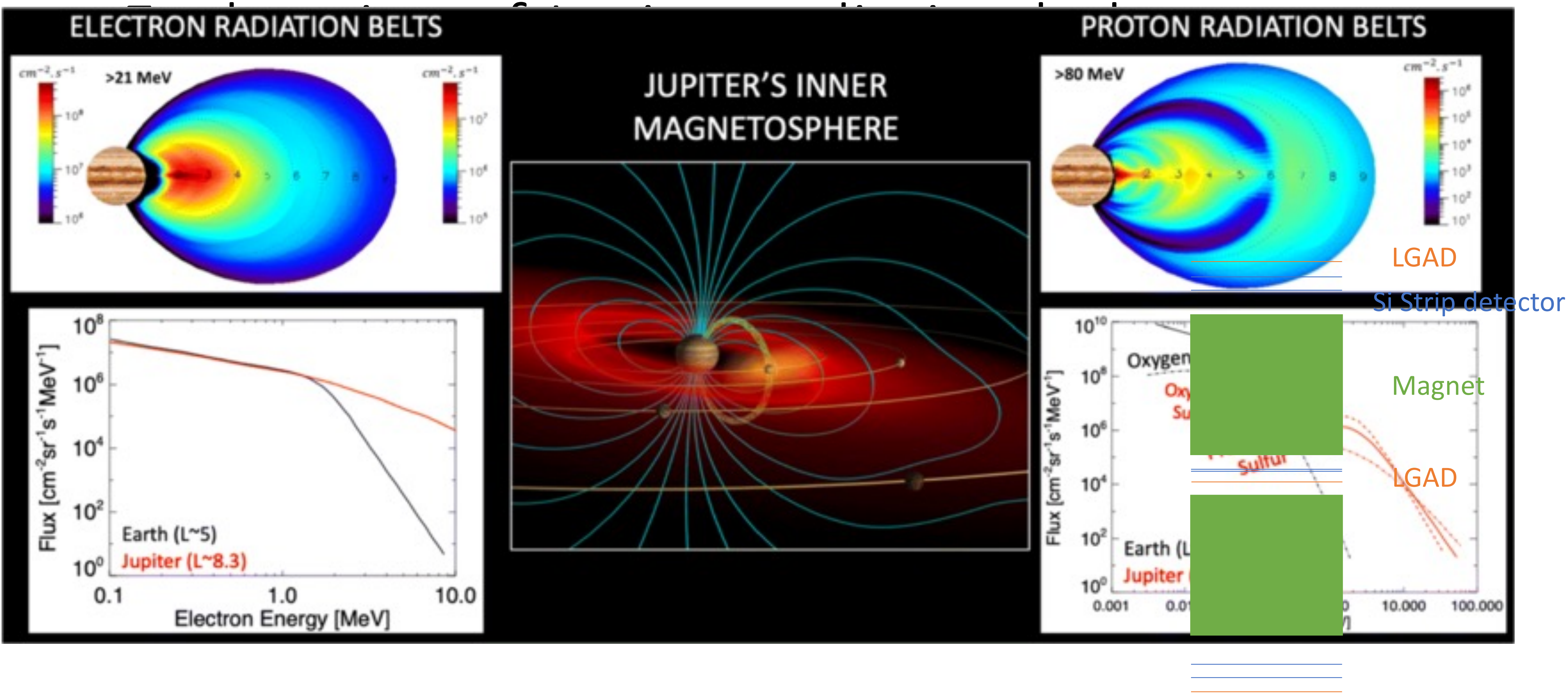
High energy



Ring imaging cherenkov detector(RICH) /Timing of internally reflected cherenkov detector(TORCH) maybe better?

Need more validation.

V1.0

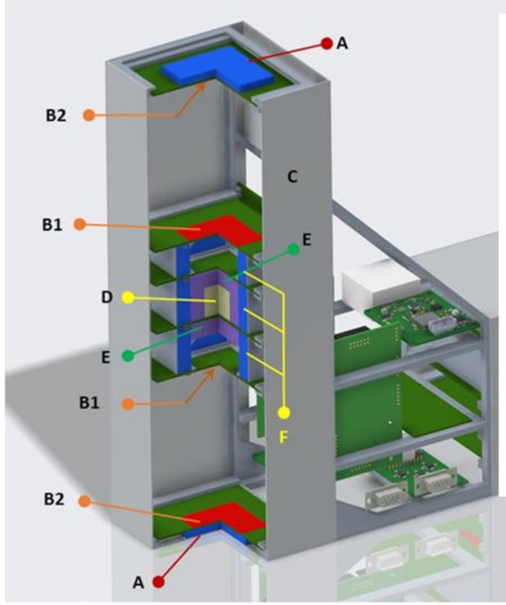


Impossible to probe L<10. Data rate would be too high. No detector/sensor could survive.

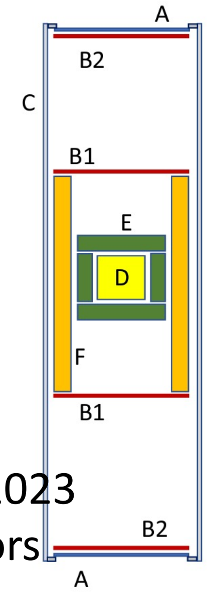
Thank you

GeV detection in deep space

LURAD: Lunar radiation monitor
Group led by university of Athens



A. EJ232Q Fast Scintillator (50x50x5 mm^3)
B. Silicon active pixel detectors
   - B1 (low-gain): 200 x 200 μm^2, 40000 pixels
   - B2 (high-gain): 100 x 100 μm^2, 160000 pixels
C. Aluminum cover
D. Cubic plastic Scintillator (EJ200)
E. Crystalline scintillator CsI(Na)
F. EJ200 Plastic scintillator anticoincidence detector



From spacemon workshop 2023
dE/dx with thicker scintillators

Protons in the energy range from 10 MeV to 2 GeV