UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

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# Space Missions with Silicon Detectors

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# University of Geneva

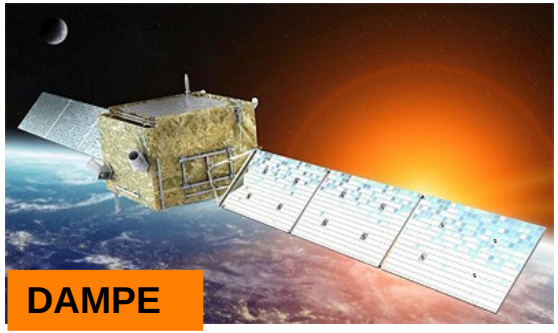
UNIVERSITÉ DE GENÈVE

- Founded in 1559
- 3rd largest university in Switzerland by student number (+17,000)
- Key research sectors are
  - elementary physics, astrophysics, economics, social sciences, psychology, chemistry, biochemistry and biophysics
- 10 Nobel Prizes won over the years (most recent in 2019)
- 10km from CERN


# The Space Astroparticle Physics Group

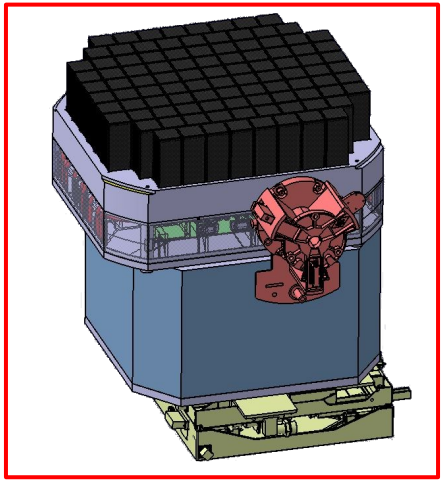
- Group has designed and produced major detector components for space missions at NASA (AMS-02), ESA (POLAR) and Chinese Space Agencies (DAMPE, POLAR)





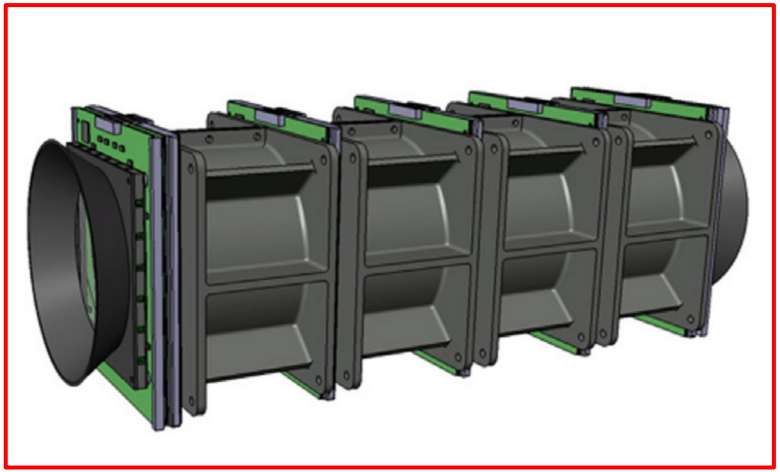

# The Space Astroparticle Physics Group

- Actively participating in the development of future missions, including POLAR-2, HERD, PAN and eXTP



**POLAR-2**

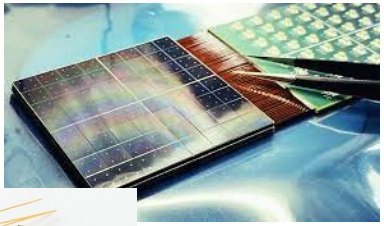
**HERD**

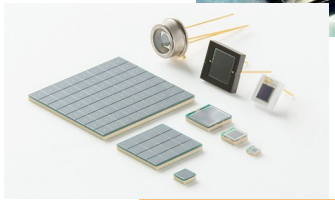


**PAN**

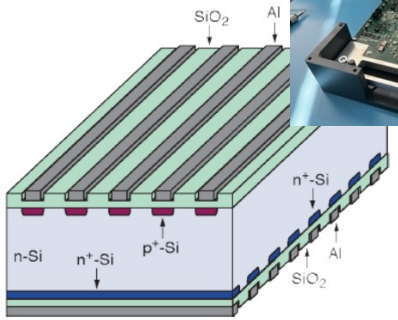
# The Space Astroparticle Physics Group

- Key silicon detector technologies are the SiPMs, silicon strip detectors and pixel detectors
- SiPMs: array of diodos detecting photons from fibers/scintillators
- Pixel/Strip : array of diodes bonded to ASIC to detect ionzing particles (and neutrons through conversions layers)



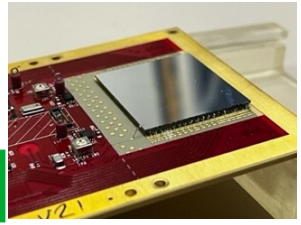


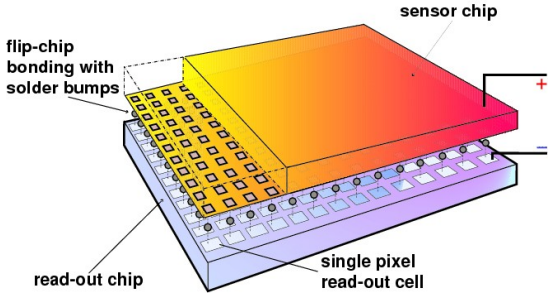
**SiPMs**




**Strip Detector**


See Ada's presentation





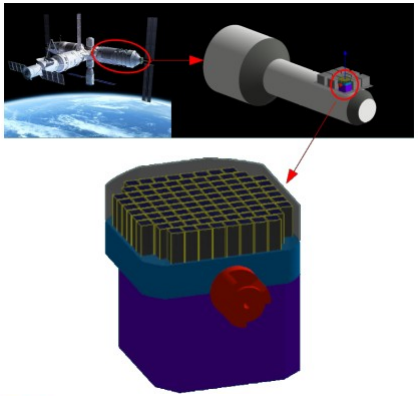

**Pixel Detector**

# POLAR-2

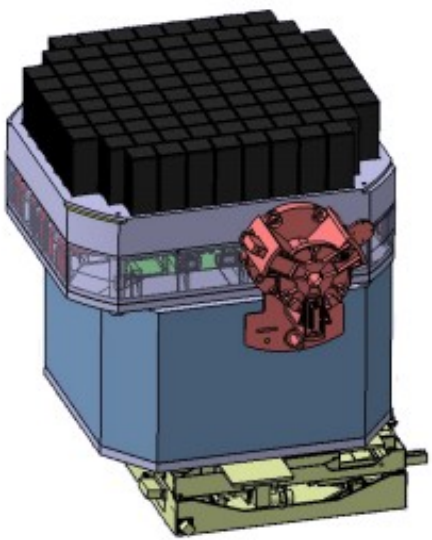

- **Instrument Goal:**
  - Perform polarization measurements of photons from GRBs
  - Higher measurment precision compared to POLAR and extend lower energy range
  - Sensitive from 20keV to 800keV
  - Longer mission (>2 years)
- **Science Goals:**
  - larger catalogue
  - detailed temporal & energy resolved analyses

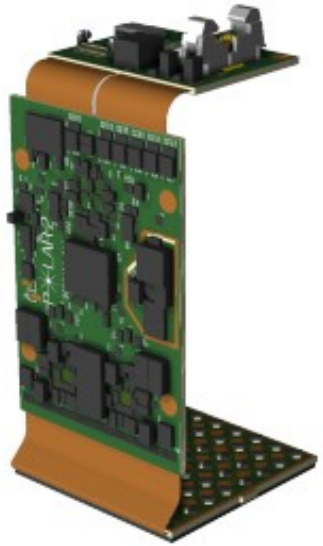
- Simulate full instrument (mechanics + signal response)
- Prototype testing
- Irradiation campaigns
- Data Analysis

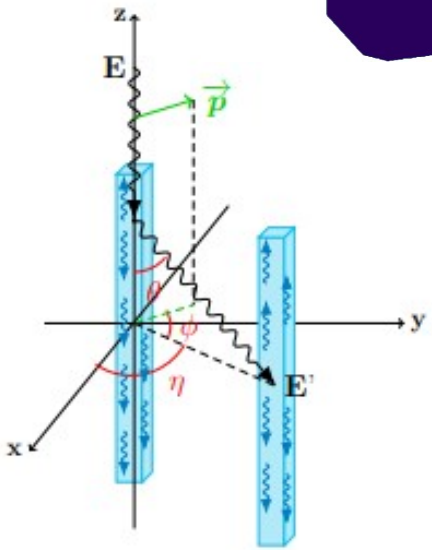
# POLAR-2



- **Instrument Design**

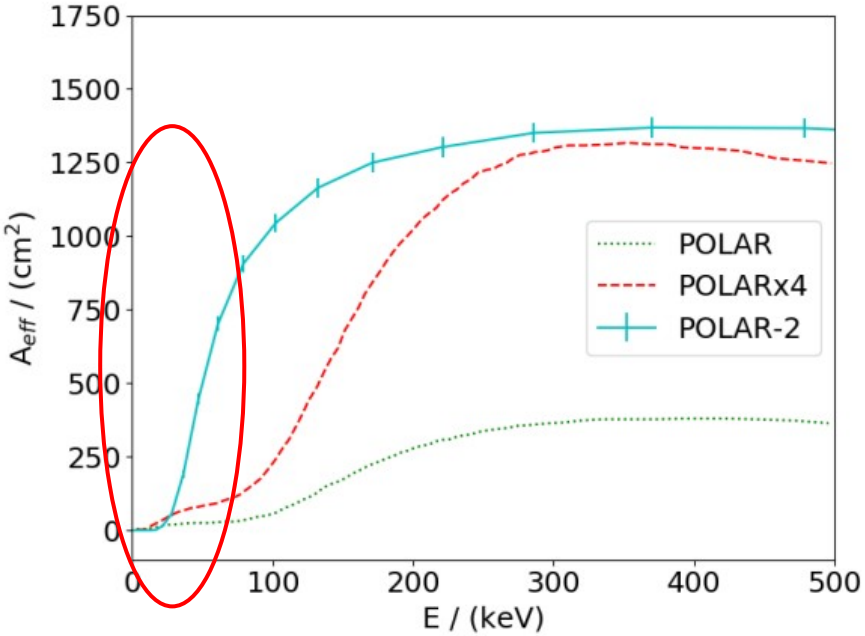


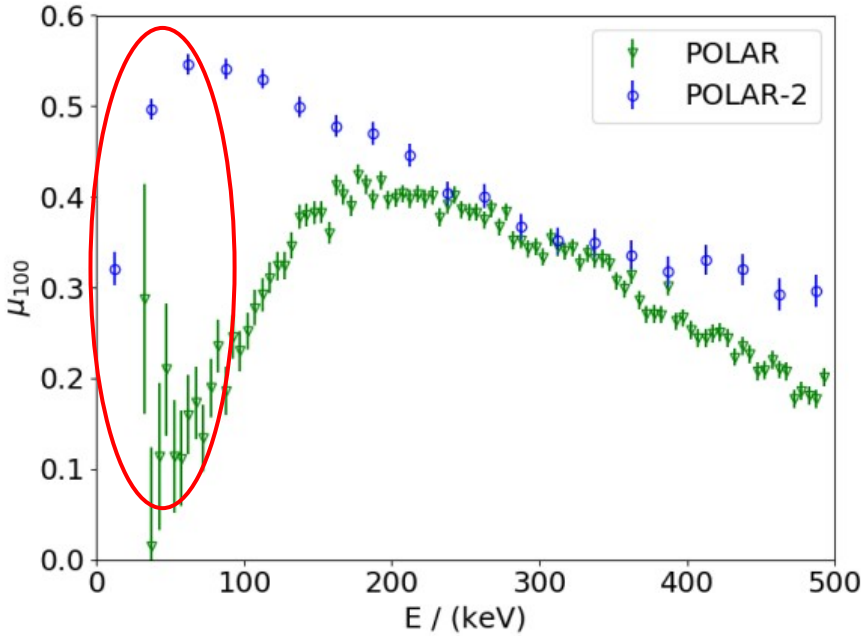





- 100 modules → each with 64 scintillator bars → coupled to 64 channel S13361-6075PE SiPM

# POLAR-2

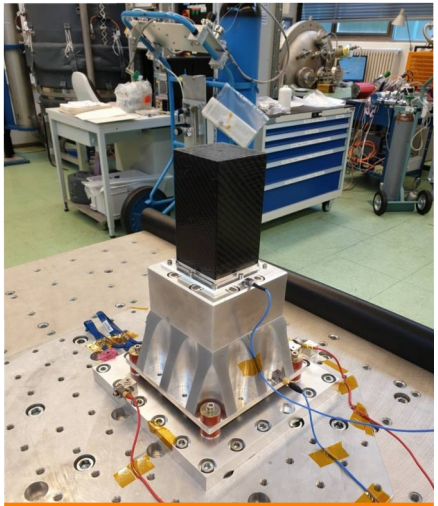



Upgrades necessary for greater sensitivity at low energies

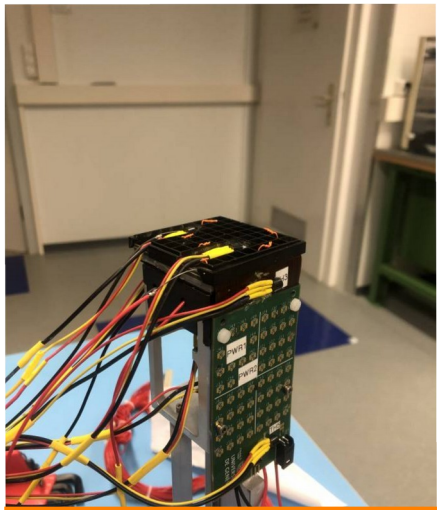
# POLAR-2

- Upgrades allows us to achieve scientific goals
- Space Qualification necessary to ensure components do not fail



Shock & Vibration

Radiation

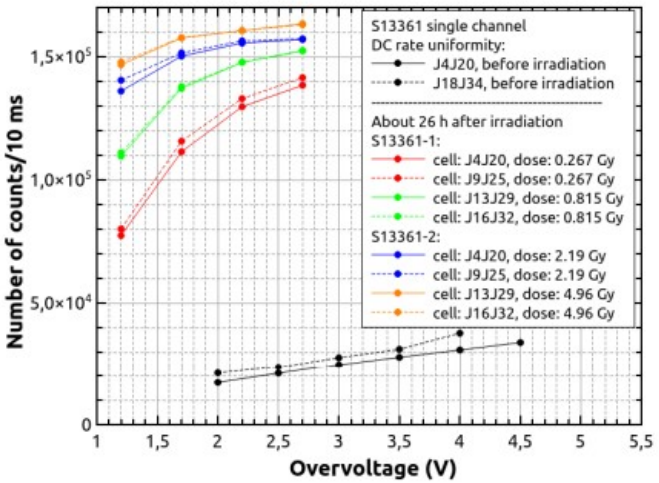


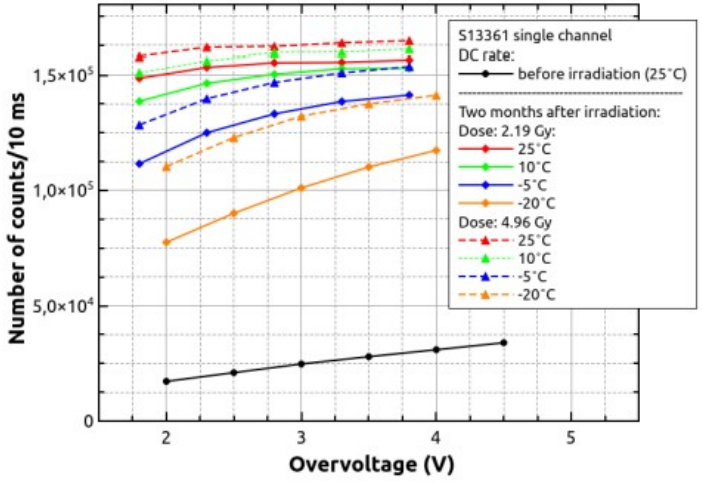
Thermal

# POLAR 2

Need for systematic radiation campaigns!! (campaign next week at RA1)

- Particles damage lattice crystal structure of Silicon
  - Electrons, gamma, neutron and protons all damage the SiPM different
  - Organization of a dedicated workshop to discuss/understand this https://indico.cern.ch/event/1093102/



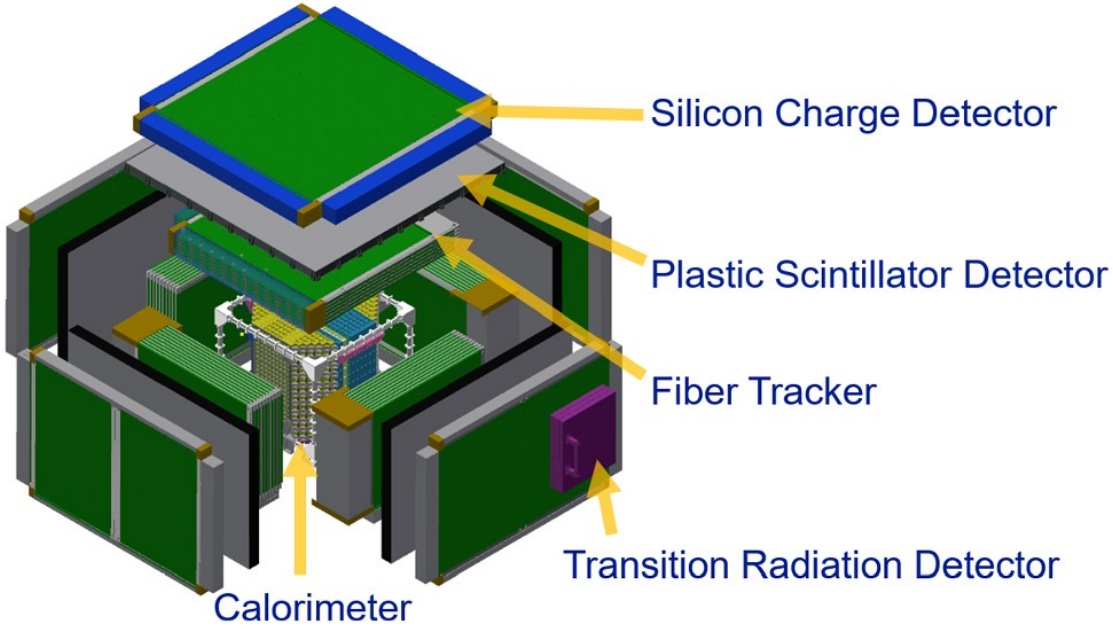

Custom framework designed to estimate dose from radiation campaigns correlation to “time in space”

# HERD

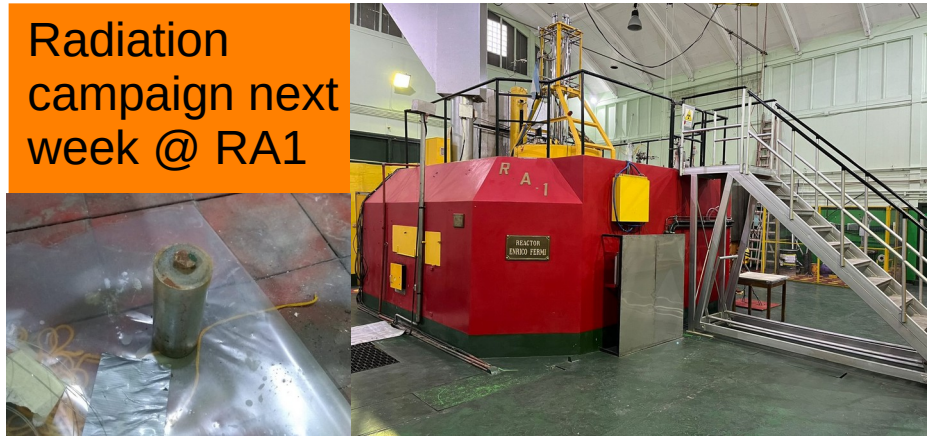
- **Instrument Goal:**
  - CR measurements
  - Sensitive from 10GeV to  3PeV (depending on particle type)
  - Long mission (>10 years)
- **Science Goals:**
  - Indirect dark matter search with unprecedented sensitivity
  - precise cosmic ray spectrum and composition measurements up to the knee energy
  - Gamma-ray monitoring and full sky survey

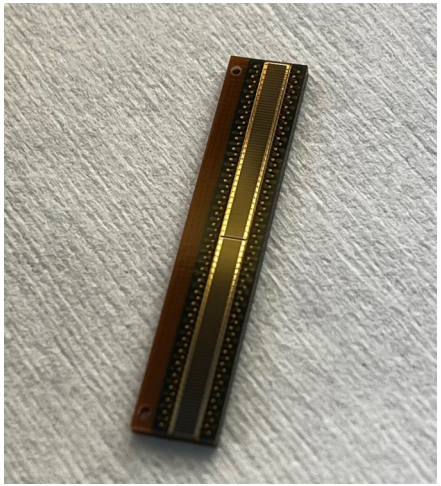
Analysis on radiation damage of Fiber Tracker SiPMs (**UniGe, UTN & LAHN-CNEA**)

# HERD




Radiation campaign next week @ RA1





Comisión Nacional de Energía Atómica
LAHN LABORATORIO ARGENTINO DE HACES DE NEUTRONES

UNIVERSITÉ DE GENÈVE

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FACULTAD REGIONAL BUENOS AIRES

# PAN

Penetrating Particle Analyzer

- **Instrument Goal:**
  - measure the flux, composition and arrival direction of highly penetrating particles in space of energy ranging from 100 MeV/n to 20 GeV/n
  - High rate capability
  - Low power consumption (<20W)
- **Science Goals:**
  - Measure energetic particles in space that are from the Sun (Solar Energetic Particles), Galactic Cosmic Rays and/or trapped populations in planetary magnetospheres.
  - help improve Space weather models for Deep Space travels
  - Study of particle production mechanism

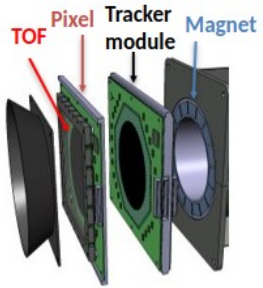
- Prototype testing
- Beam Test campaigns
- Data Analysis
- DAQ Pipeline
- Science Analyses

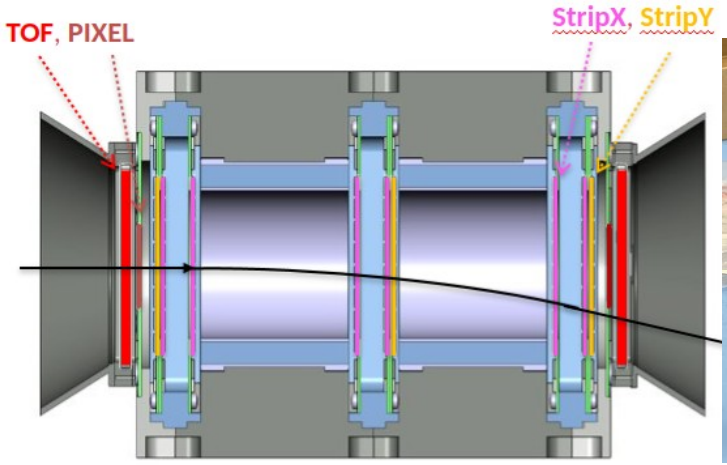
# Mini.PAN

Penetrating Particle Analyzer

## Mini.PAN is the technology demonstrator of the PAN concept

- Mini.PAN: 9 tracker layers (6 **Strip**X, 3 **Strip**Y), 2 TOF modules, 2 **Timepix**3 modules

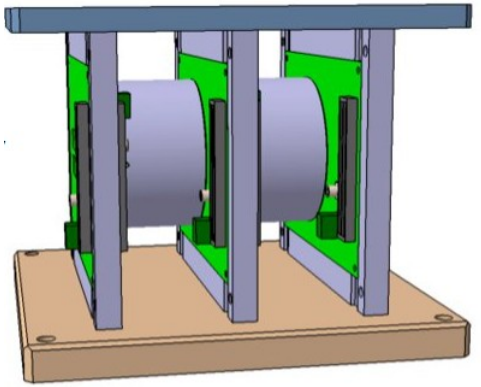


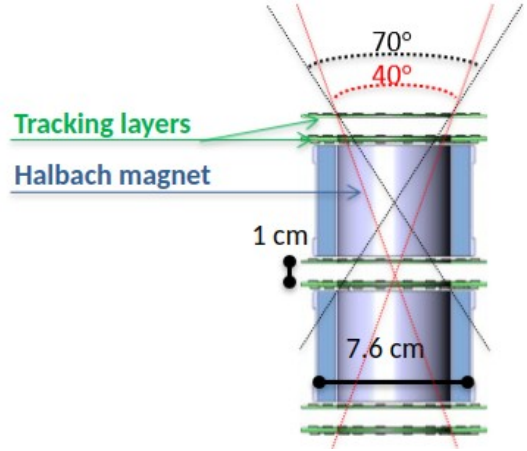

- Pipeline developed to merge instrument response to common trigger
- Global Instrument DAQ underway

# Pix.PAN

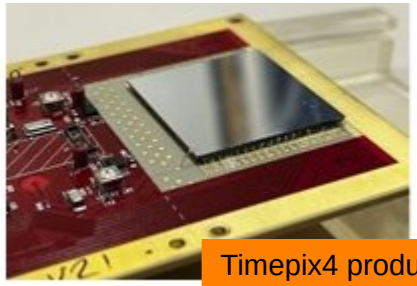
**2 magnets + 6 layers of quad Timepix4 detectors grouped in 3 tracking stations**



- **High rate capability**, no saturation up to most intensive SPE storms
- Single type of active component: Timepix4 Si pixel sensor in quad assembly
- Data-driven readout (no trigger needed)
- Full analog readout: **particle identification with dE/dx**
- 195 ps timestamp ⟹ **Time-Of-Flight** as additional handle for **particle ID**



# Pix.PAN

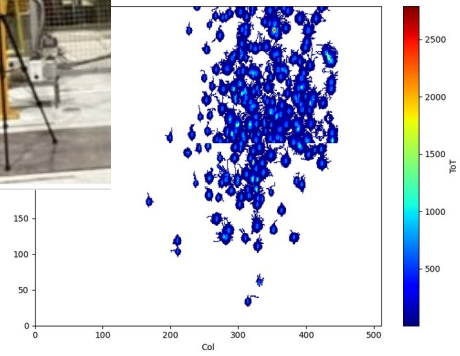


Timepix4 produced and validated in 2021 (Llopart et al., Journal of Instr, 17, C01044, 2022)

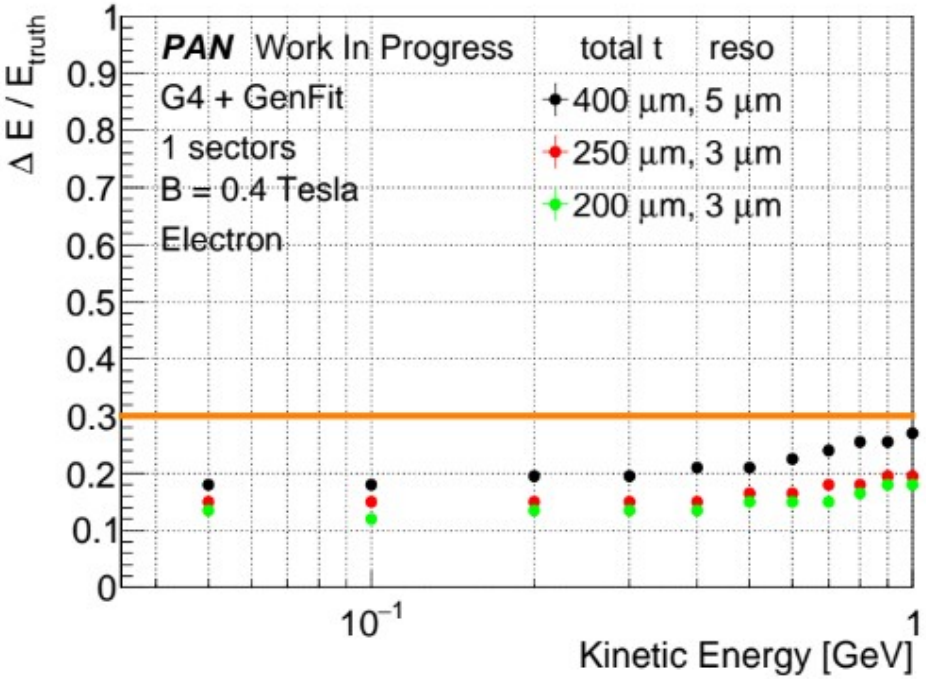
Optimized pixel geometry for good hit resolution in bending direction

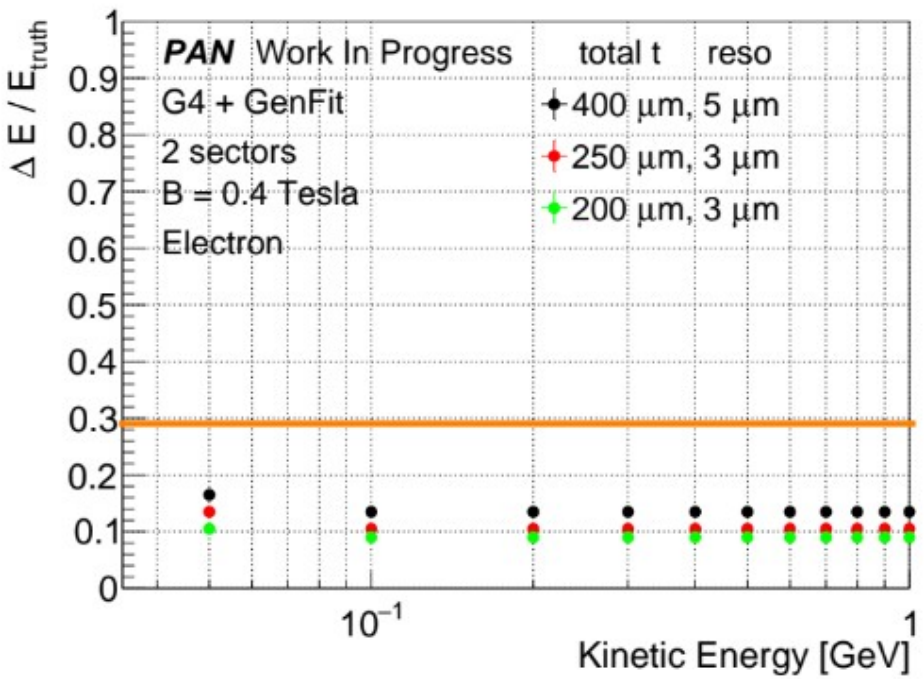
- “long” pixel: 13.75 µm x 1760 µm -> **hit resolution ≲ 3 µm**, only 1/8 of Timepix4 cells used
- **Save 7/8** of front-end analog **power consumption** plus some part of digital power
- Goal is to reach **~20W** for the spectrometer

Timepix4 at beam test



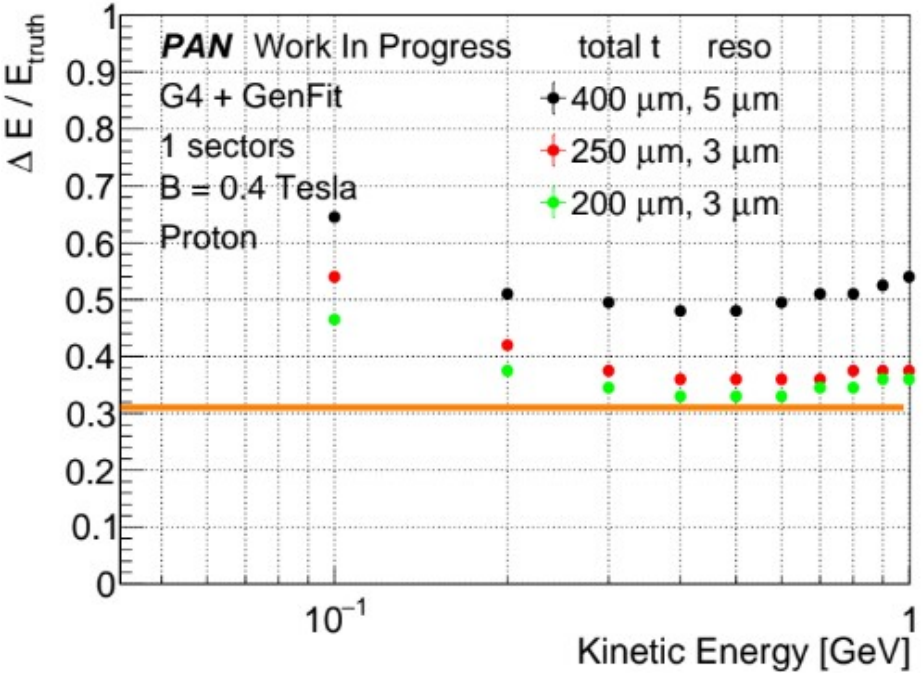
# Expected Energy Rec. Performance

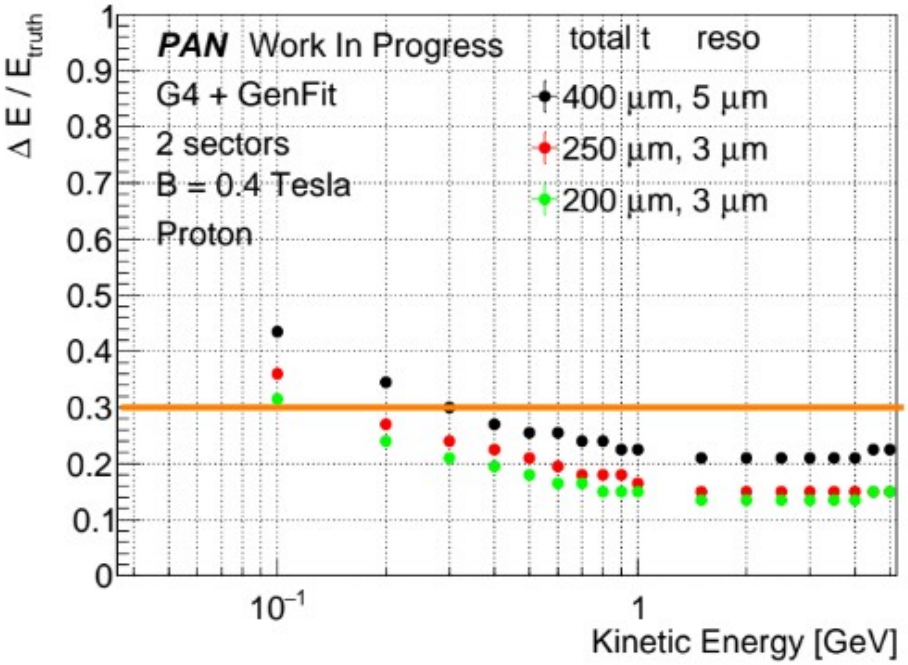



Electron energy resolution better than 30% for 1 and 2 sectors in energy range of interest

# Expected Energy Rec. Performance

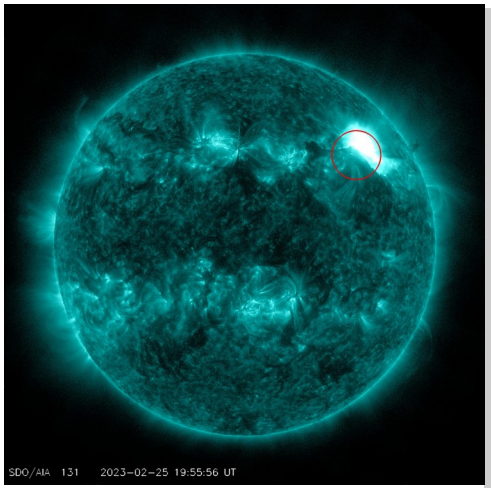


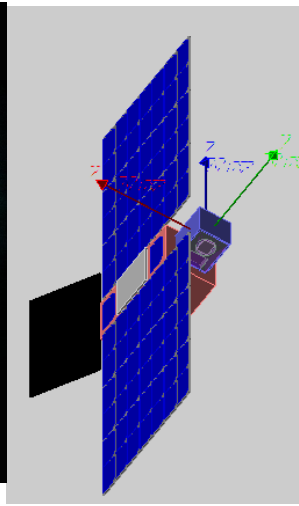




Proton energy resolution better than 30% for 2 sectors in energy range of interest

# Pix.PAN - REMEC

- **Instrument Goal:**
  - measure the flux, composition and arrival direction of highly penetrating particles in space of energy ranging from 10 MeV/n to 10 GeV/n at L2
  - High rate capability
  - Low power consumption (<20W)
  - >3 years of operation
- **Science Goals:**
  - first precise measurements of the flux, composition and arrival time of SEP in the energy range
  - improve space weather models outside the magnetosphere

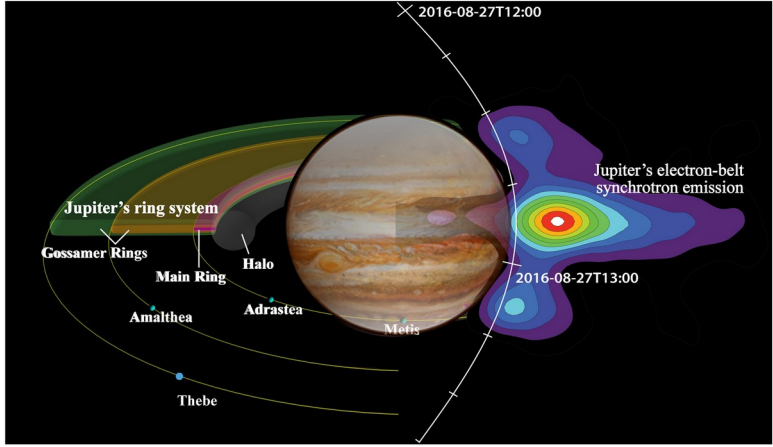


- Project Scientist
- Payload (Interface) Definition
- Feasibility studies
- TID Simulations

# Pix.PAN - COMPASS

- **Instrument Goal:**
  - measure the flux, composition and arrival direction of highly penetrating particles in space of energy ranging from 10 MeV/n to 10 GeV/n at Jupiter
  - Very High rate capability (at least 44MHz/cm$^2$)
  - Low power consumption (<20W)
- **Science Goals:**
  - origin of the heavy and light ion radiation belts
  - CRAND as universal proton radiation belt source
  - High latitude charged particle acceleration as a universal radiation belt source

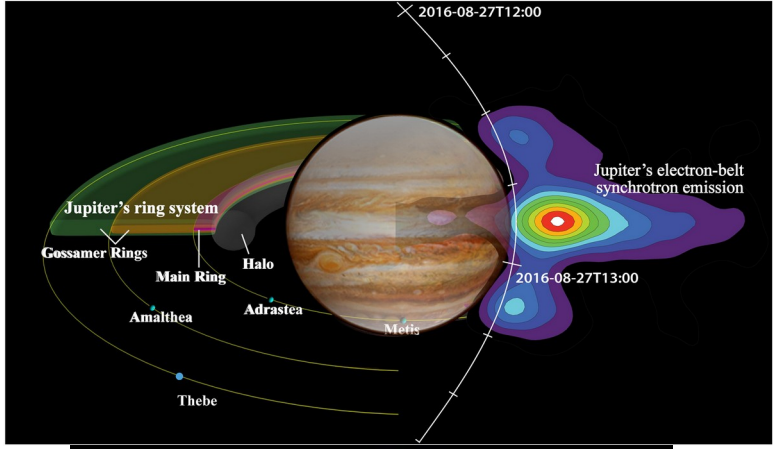



- Instrument design concept
- Technological feasibility studies

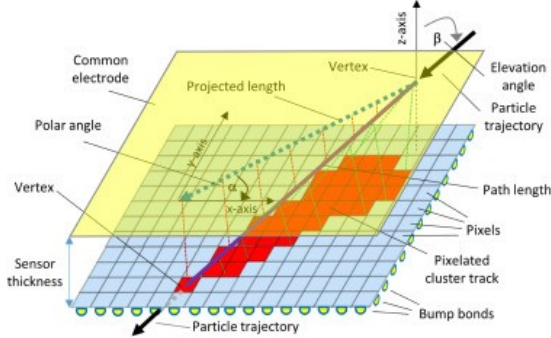
# Status on Radiation Belts

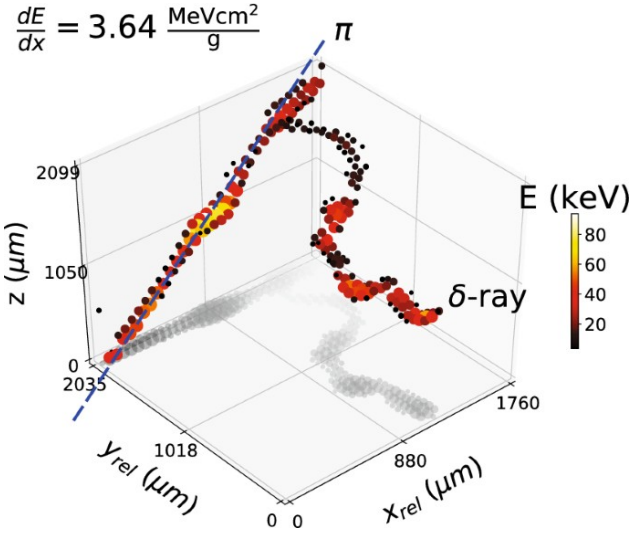
- What makes them so interesting
  - Space weather predictions
  - Understanding of fundamental processes could be extrapolated to more powerful astrophysical laboratory
- Jupiter radiation belts
  - magnetic moment is <u>20,000 times stronger</u> than that of the Earth
  - could trap particles up to <u>few GeV/nuc</u>

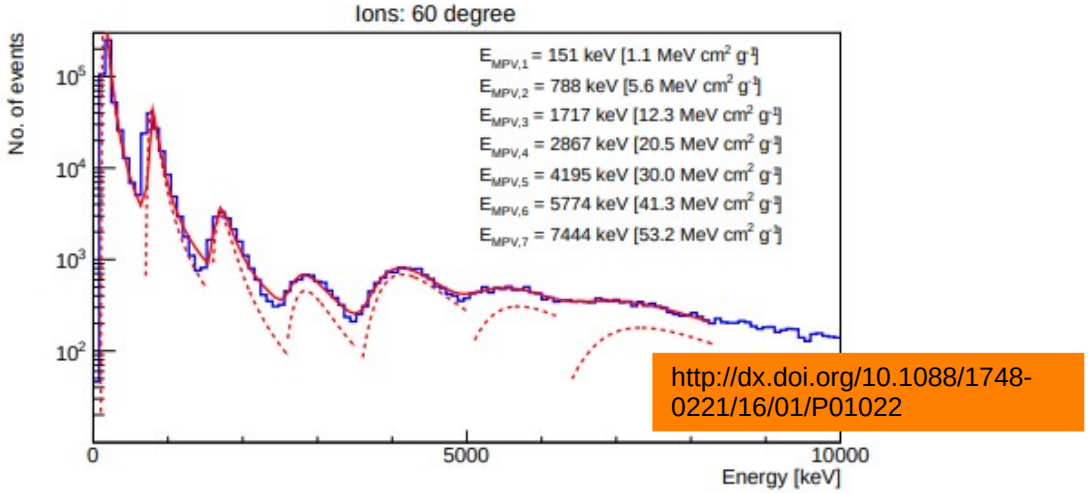
Earth is cool but Jupiter is event better! :)




# TimePix4 Cluster Analysis




http://dx.doi.org/10.1088/1748-0221/16/01/P01022

Work underway to develop a common TimePix4 data analysis software tool (**UTN & UniGe**)

# Further Work in...

- New TimePix4 data from beam tests and subsequent analyses
- Continuation of SiPM radiation tests and analyses
- Innovative outreach setups with MiniPix
- Standardizing measurement campaigns for large SiPM batches
- Strengthening of UniGe-UTN scientific collaboration agreement