INFN PERUGIA
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Silicon Strip Detectors in Physics: From Nuclear Physics to Space Applications

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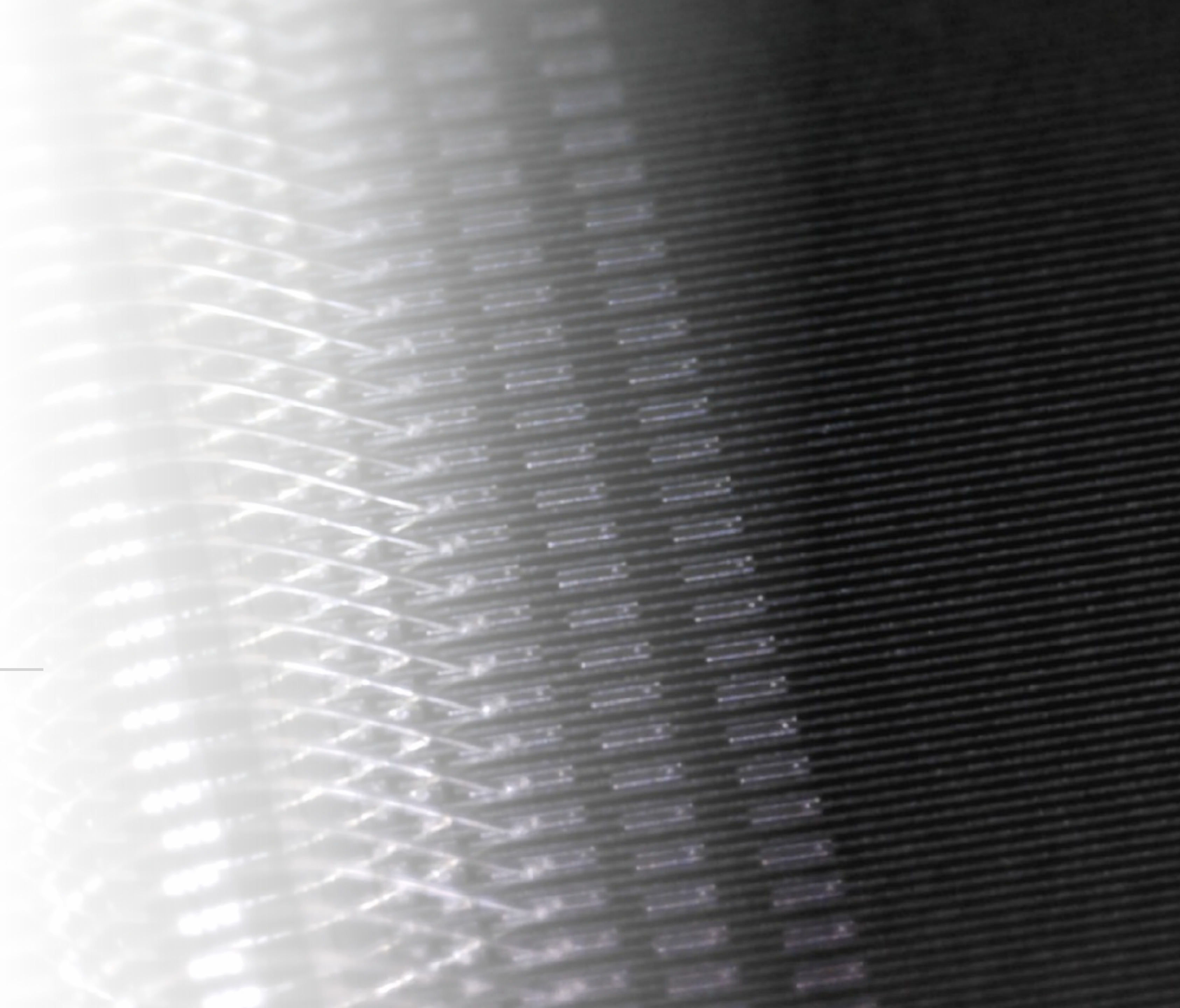
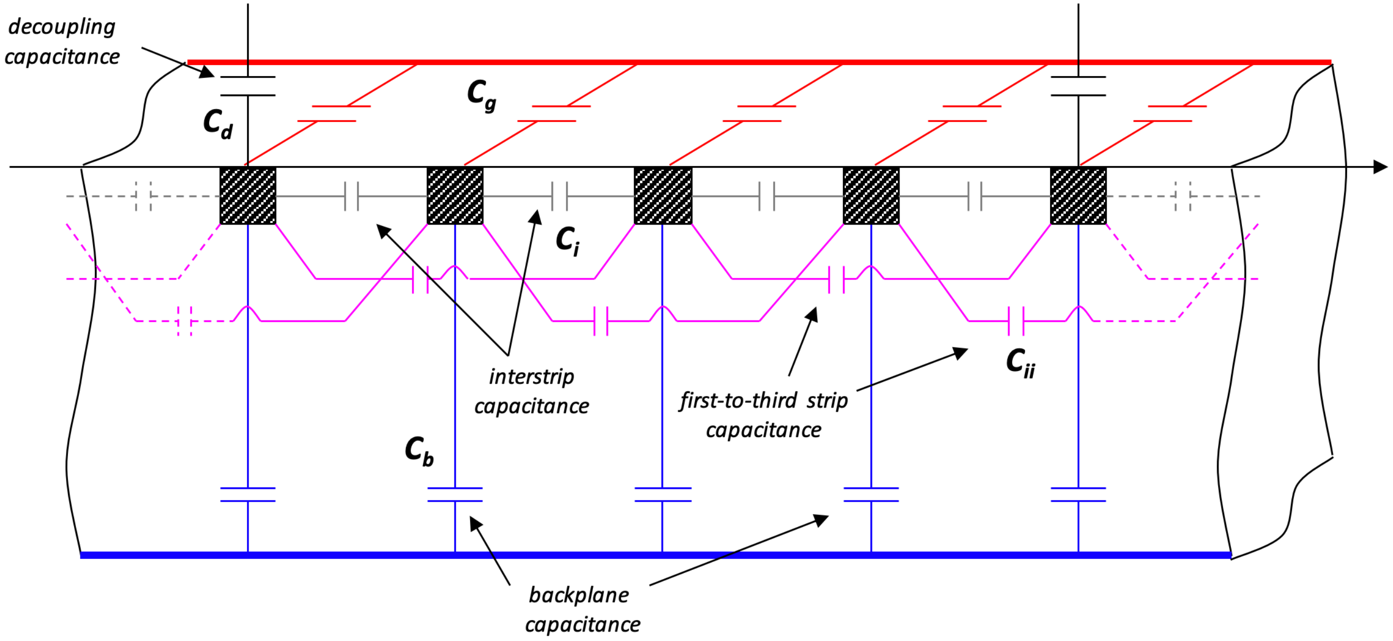


The typical silicon strip detector

- Set of p-n junction diodes operated at reverse bias
- Charged particle crossing induces a current on the segmented electrodes (strips)
- Underlying capacitive coupling network influences the signal behaviour of the detector (charge sharing, backplane charge losses …)



<u>Typical capacitance values</u>

C_i = interstrip capacitance ≈ 1 pF/cm

C_b = backplane capacitance < C_i/5

C_g = guardring capacitance ≈ C_i/20

C_{ii} = first-to-third strip capacitance << C_i

Cd** = decoupling capacitance ≈ 10 pF/cm >> **Ci, Cb, Cg, Cii

One detector, many uses

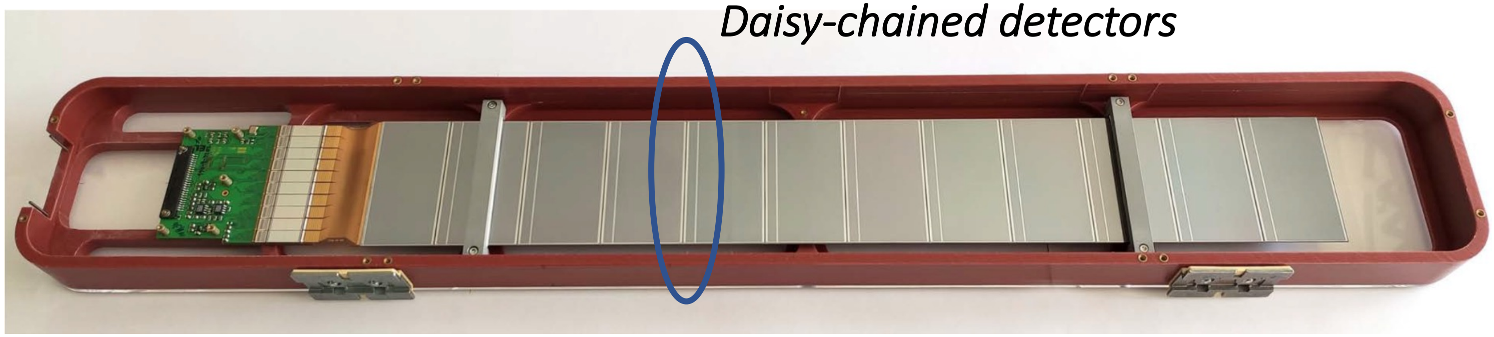
- Proven technology used since the 80s
- Still the natural choice for large area coverage
- Detector parameters can be tuned for the desired performance
- Wide range of applications, from low energy (hundreds of MeV/u) nuclear physics to space-borne experiments

Some applications have very stringent constraints on some of the parameters, for example:

Detector Parameter	Main effect	Constraints
Readout pitch	Spatial resolution	Area to cover, readout input lines footprint ...
Number of channels	Cost	Power consumption, data bandwidth needed ...
Thickness	Deposited charge, charge loss	Mechanical strength, fragmentation and MCS ...
Length	Strip capacitance	Noise levels, production capabilities ...

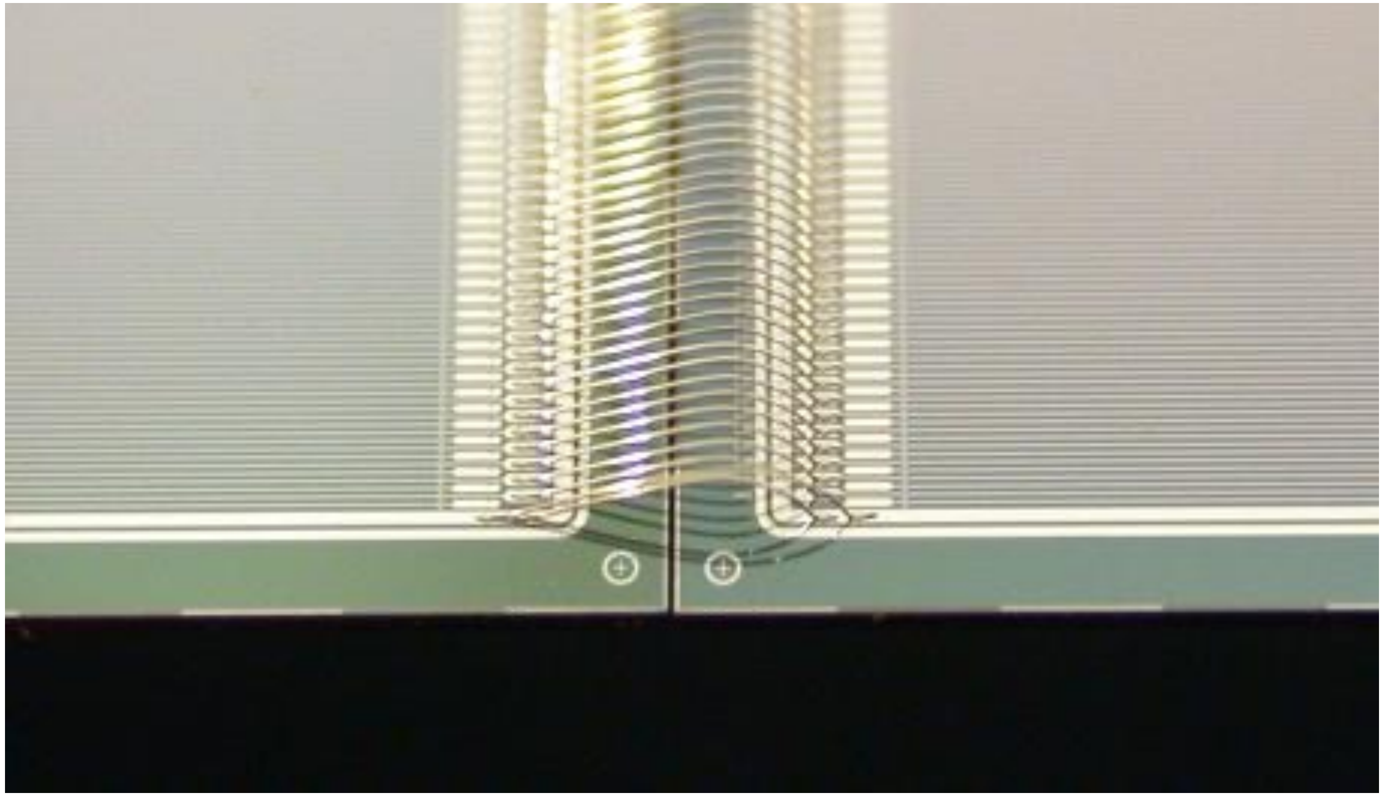
Space application (present): AMS-02 tracker

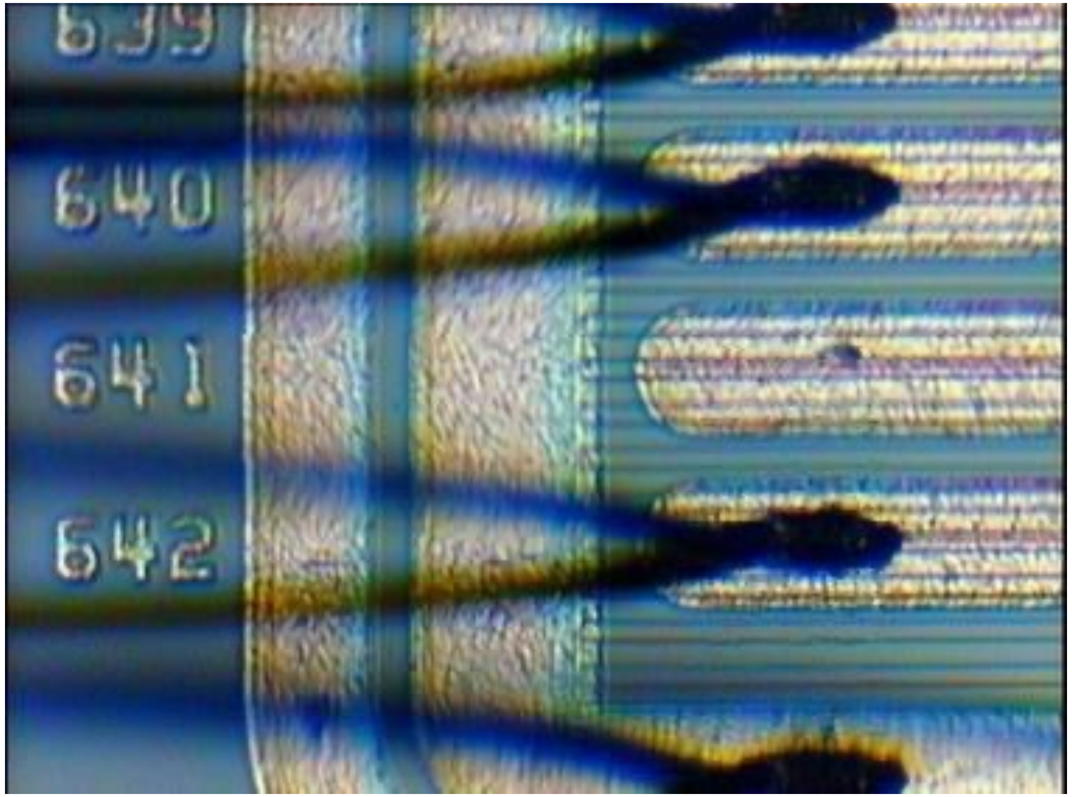
- Nine layers of double sided silicon detectors
- *10 um (30 um) spatial resolution in bending (non bending) plane*
- Momentum resolution ≈10% @10 GeV
- High dynamic range front end for charge measurement
- *Long (28-60cm) "ladders" with daisy-chained sensors*
- *Total covered area approx 7 m^2*
- Total of 200k channels for ≈200 watt



AMS-02 tracker

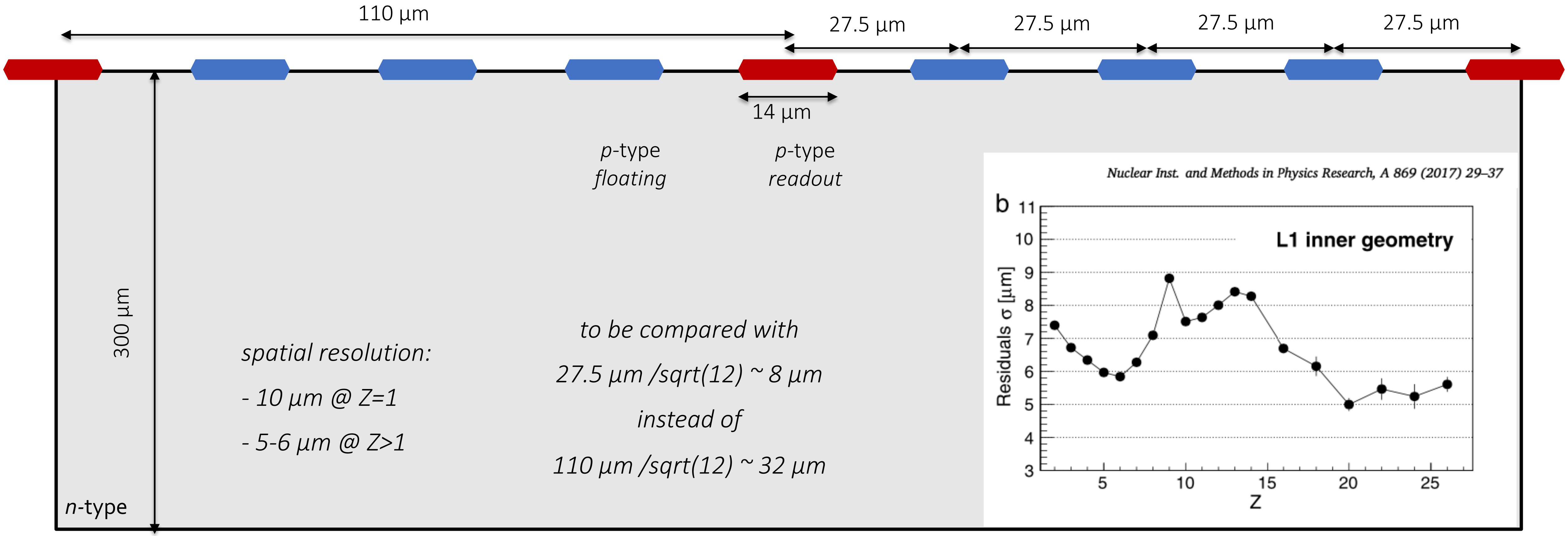
To connect electrically all the sensors in a ladder, all the strips are daisy-chained with a 25 um Al wire through ultrasonic bondings





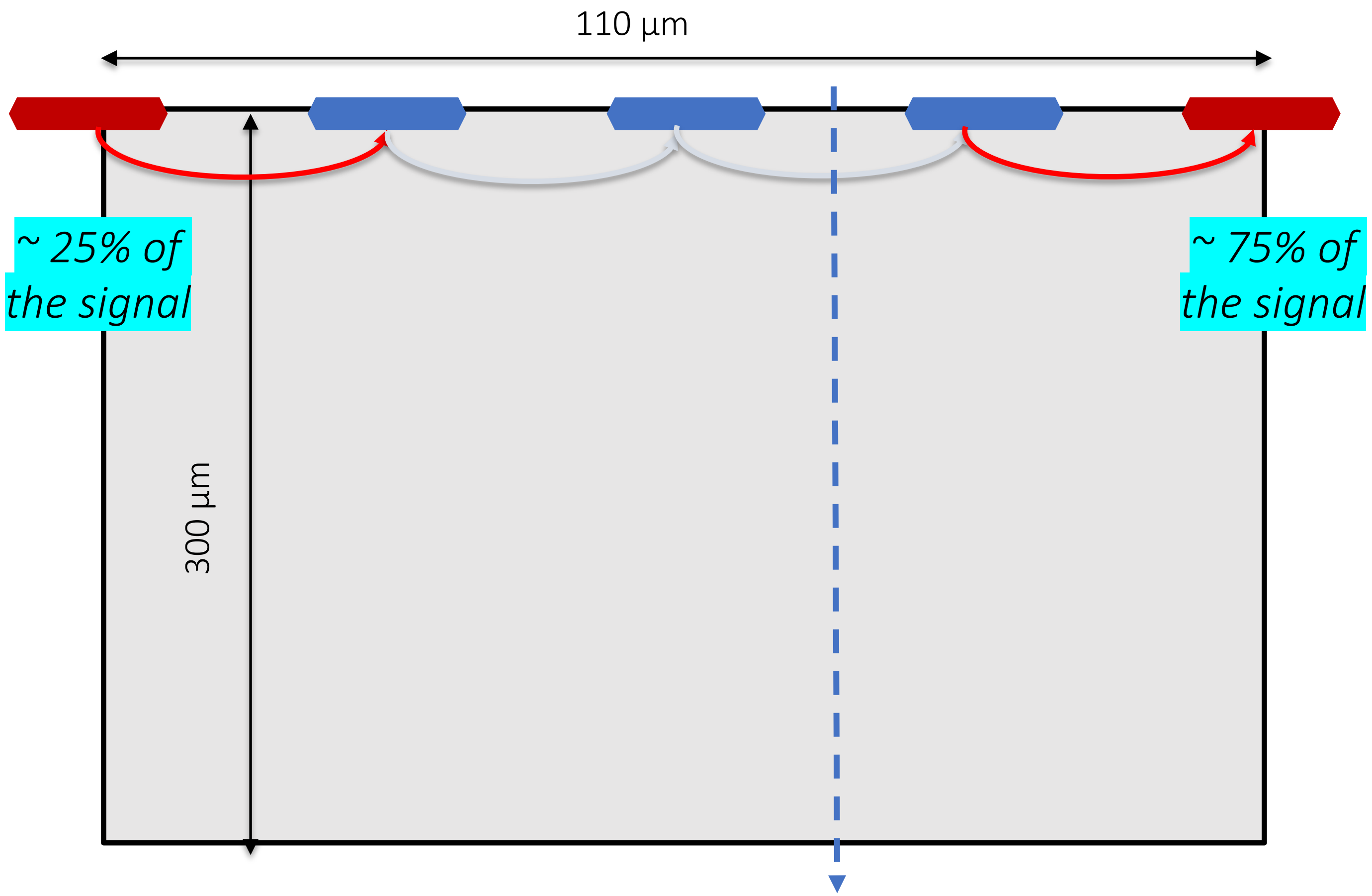
AMS-02 tracker

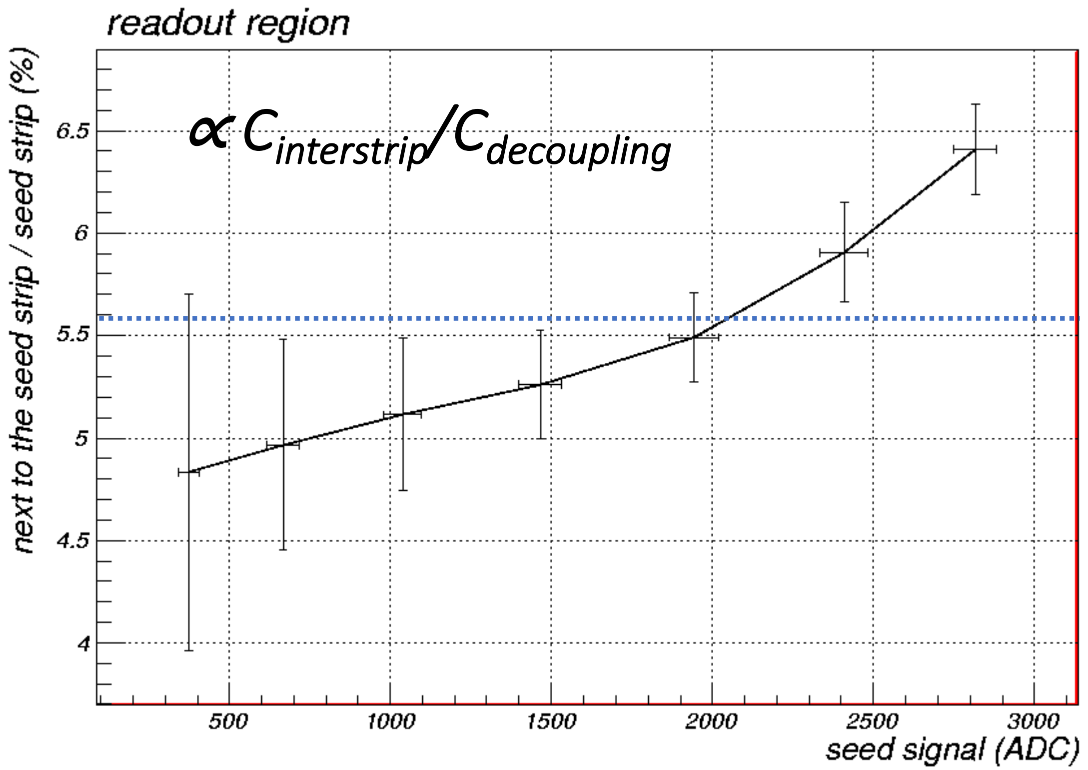
Spatial resolutions of about 10 um can be achieved even with a 110 um readout pitch with the use of "floating" strips: intermediate electrodes implanted but not read-out



AMS-02 tracker

- From Ramo's theorem: only the closest electrode should have signal ("digital" readout)
    - Capacitive coupling of strips shares the signal
    - Impact point can be better evaluated
    - The floating (non-readout) strips helps this charge sharing
- Charge sharing improves spatial resolution and allows to correct for main strip electronic saturation effects

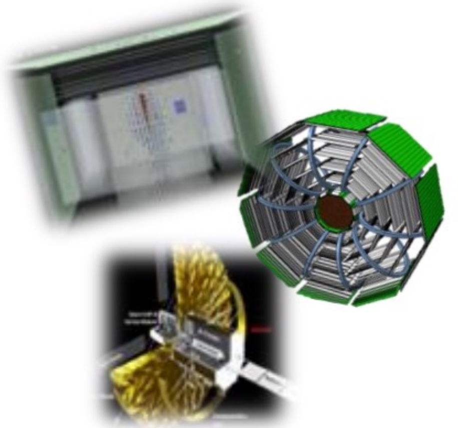




Space application: present and future

Most of space detectors for charged cosmic ray and γ-ray measurements require solid state tracking systems based on Si-µstrip sensors.

Si-µstrip detectors, at the moment, are the only solution to instrument *large area detectors* with larger number of electronics channels coping with the *limitations on power consumption in space*



Operating Missions

	Mission Start	Si-sensor area	Strip- length	Readout channels	Readout pitch	Spatial resolution
Fermi-LAT	2008	~ 74 m^2	38 cm	~ 880 10^3	228 um	~ 66 um
AMS-02	2011	~ 7 m^2	29-62 cm	~ 200 10^3	110 um	~ 7 um
DAMPE	2015	~ 7 m^2	38 cm	~ 70 10^3	242 um	~ 40 um

Future Missions

	Planned operations	Si-sensor area	Strip- length	Readout channels	Readout pitch	Spatial resolution
HERD	2030	~ 35 m^2	48-67 cm	~ 350 10^3	~ 242 um	~ 40 um
ALADInO	2050	~ 80-100 m^2	19-67 cm	~ 2.5 10^6	~ 100 um	~ 5 um
AMS-100	2050	~ 180-200 m^2	~ 100 cm	~ 8 10^6	~ 100 um	~ 5 um

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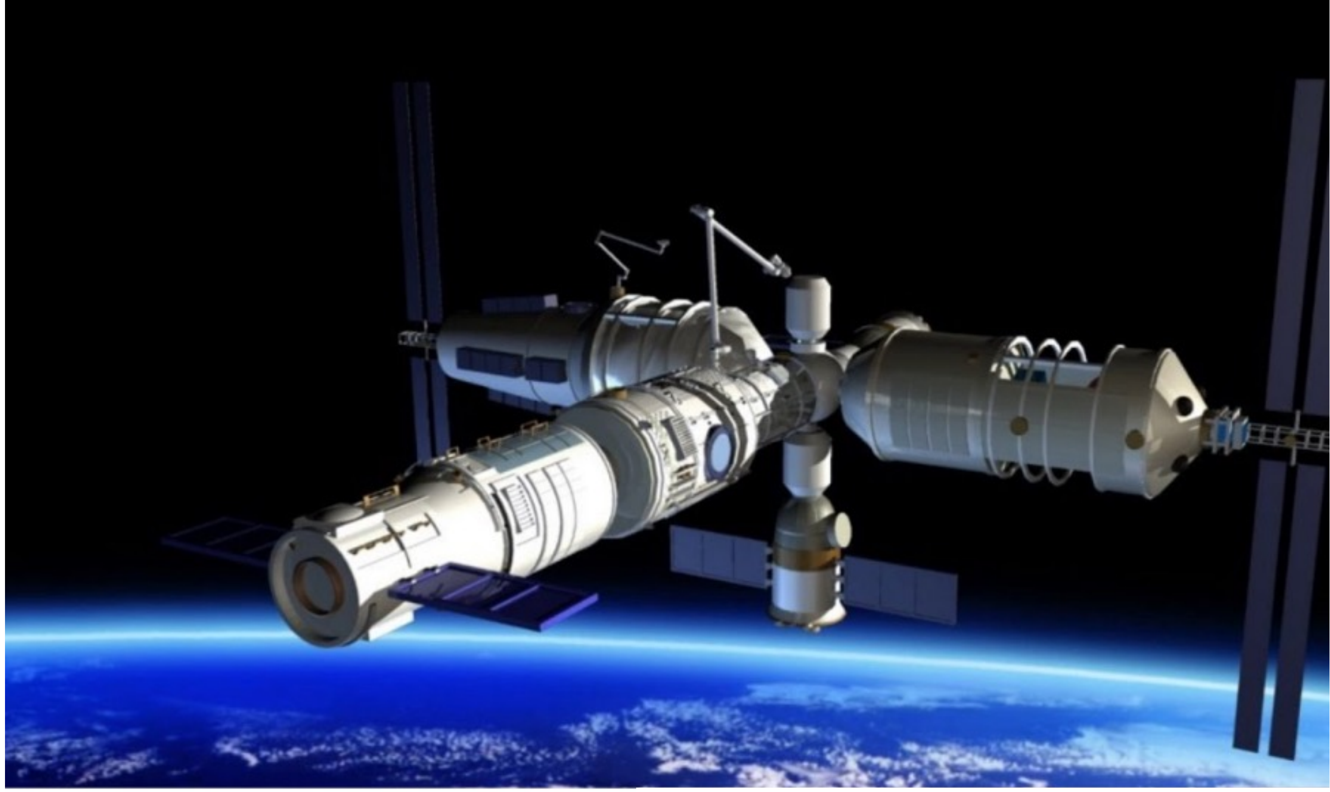
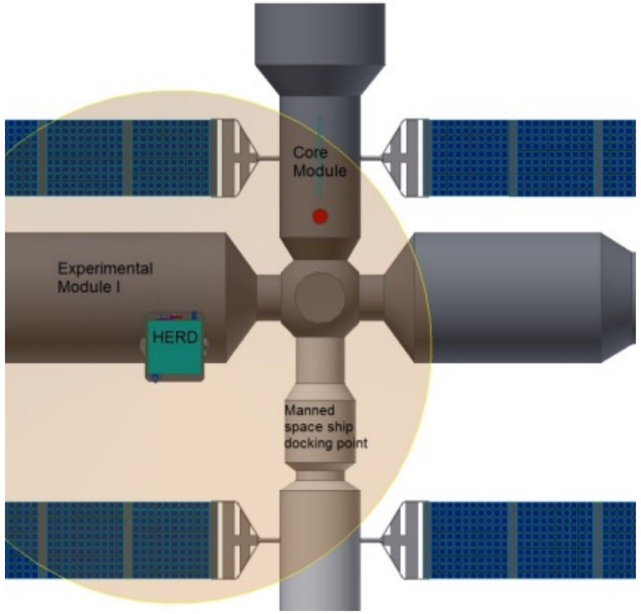
Space application (future): HERD

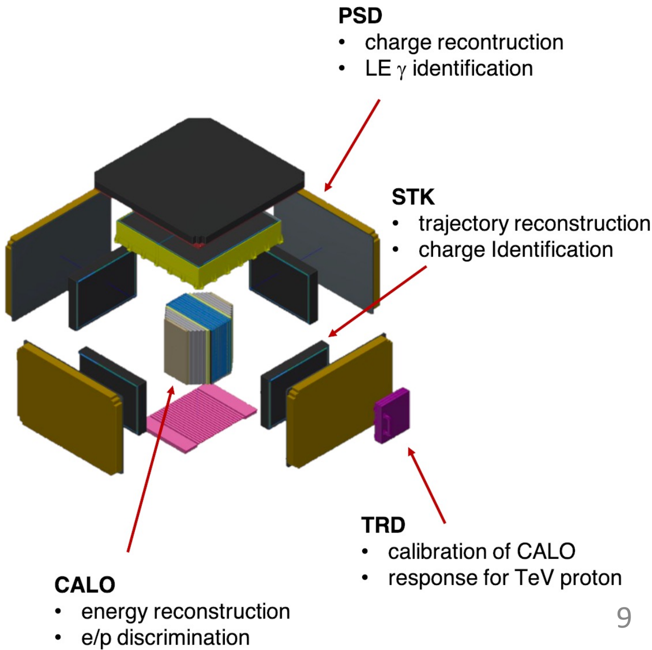
High Energy Radiation Detector (HERD) on the Chinese Space Station (2026-2027)

- LYSO calorimeter
- Small TRD for hadronic energy calibration
- 5 sides PSD

- *5 sides Tracker*
  - 60 m^2 area
  - 200-400k channels
  - ~ 100W for FE
  - ~ 200W for read-out



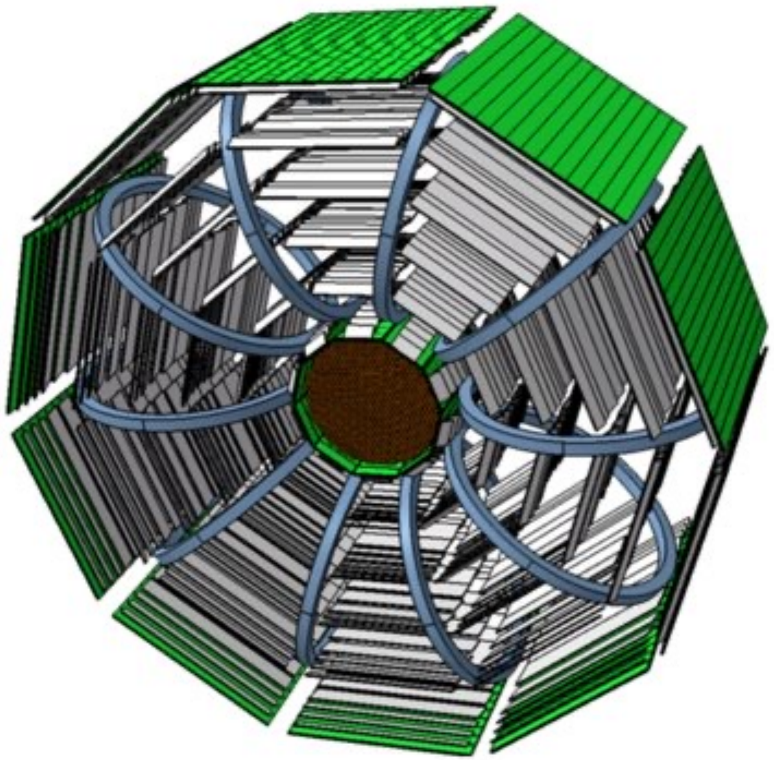


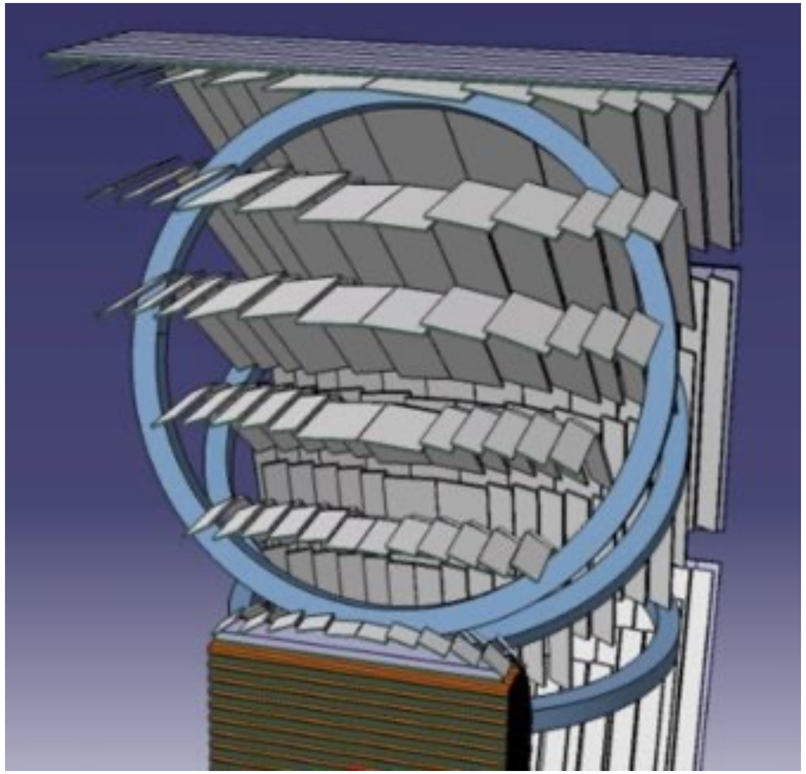


Space application (future): ALADInO

Antimatter Large Acceptance Detector In Orbit (ALADInO)

- Orbiting on L2
- LYSO calorimeter
- 2π PSD and ToF
- 3T (0.8T average) B-field by "hot" super-conducting magnet MgB2



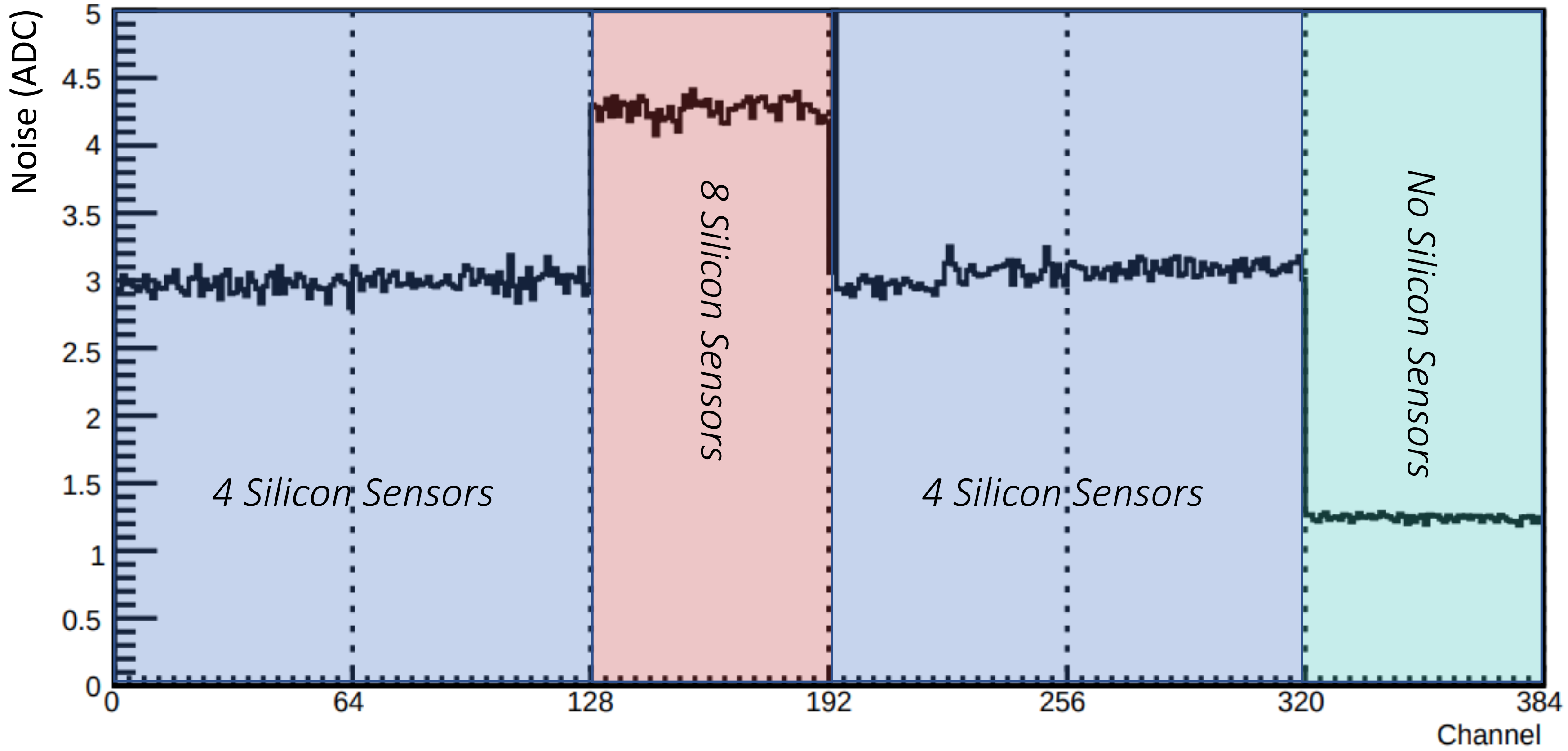


2π Tracker

- *80 m2 area*
- *1.5M channels*
- *~1kW available*

Space application: need for large area coverage

- Daisy-chain of silicon sensors allows for a large area without using any additional electronics
- Increase in noise can be kept under control even for long (≈ 1m) detectors
- Large area can be covered keeping number of channels (and power) under control

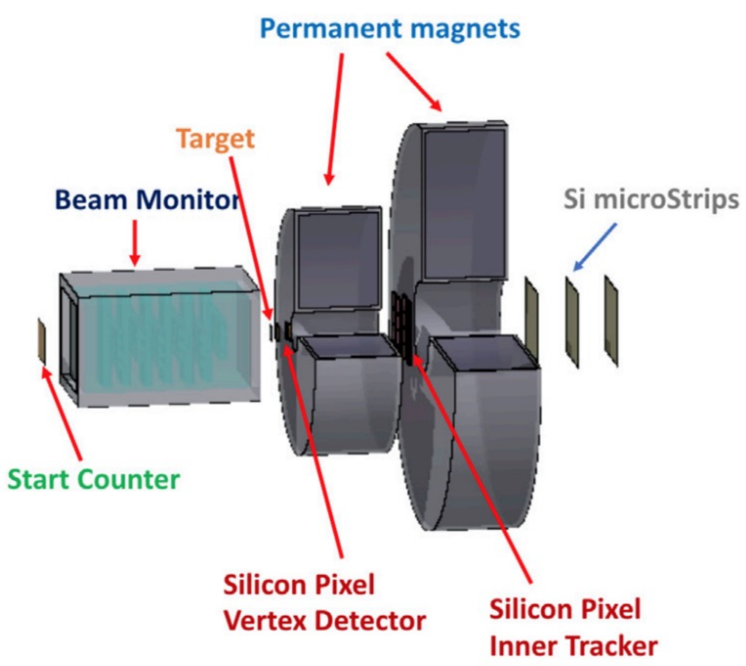


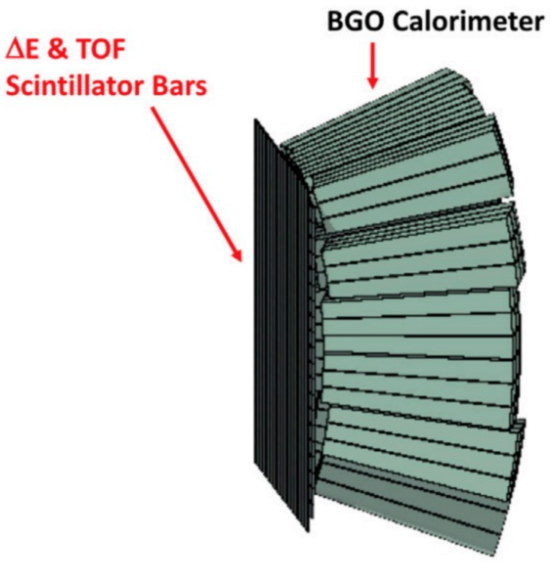
$$C_{eff} = A + B\ \ C_{strip}\ L$$

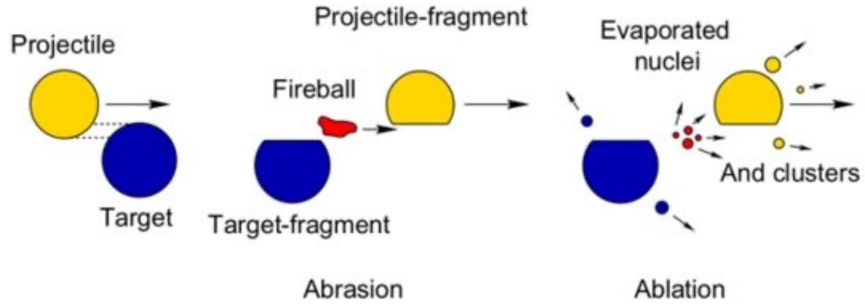
# of silicon sensors	Mean noise value (ADC)
0	≈ 1.2
4	≈ 3.0
8	≈ 4.2

Low energy nuclear physics: the FragmentatiOn Of Target experiment

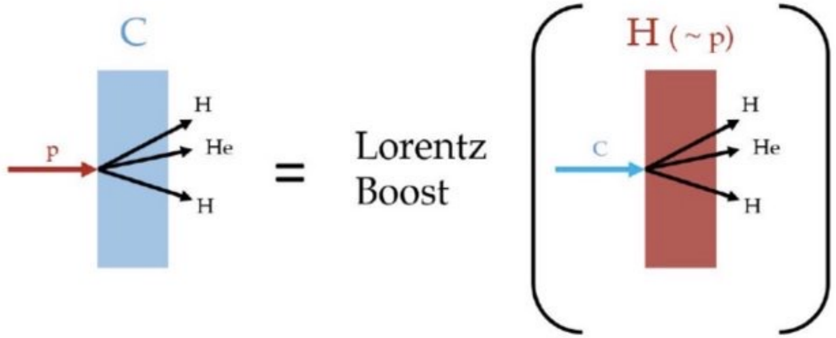
- Hadrontherapy energies (several hundreds of MeV per nucleon)
  - Target (tissue) fragmentation
  - Beam fragmentation
- Contribution of very short range secondary fragments (some um)
  - Non negligible dose deposited in the first part of the particle path
- FOOT will use the inverse kinematics approach







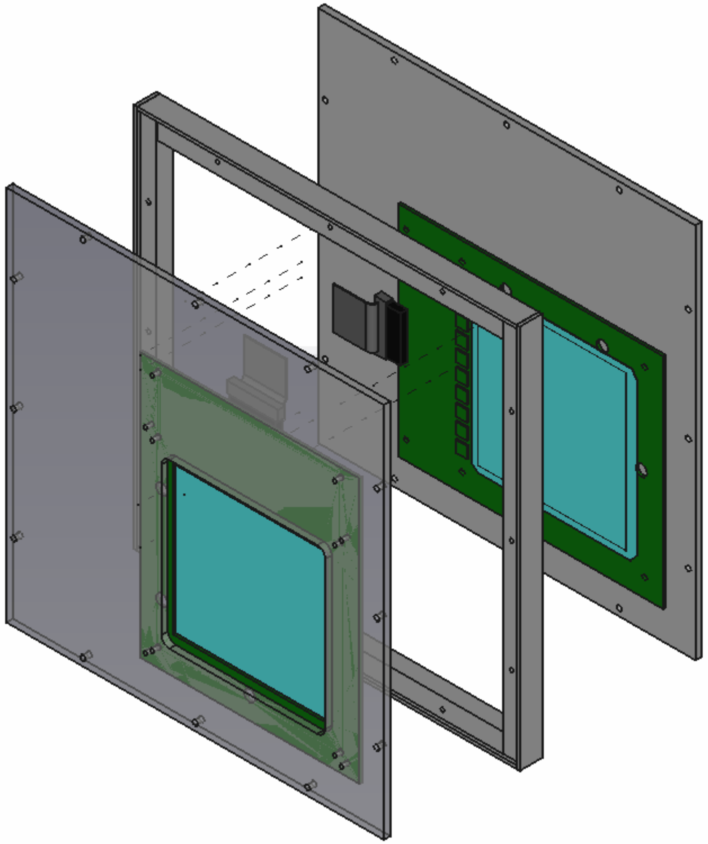
Fragmentation model

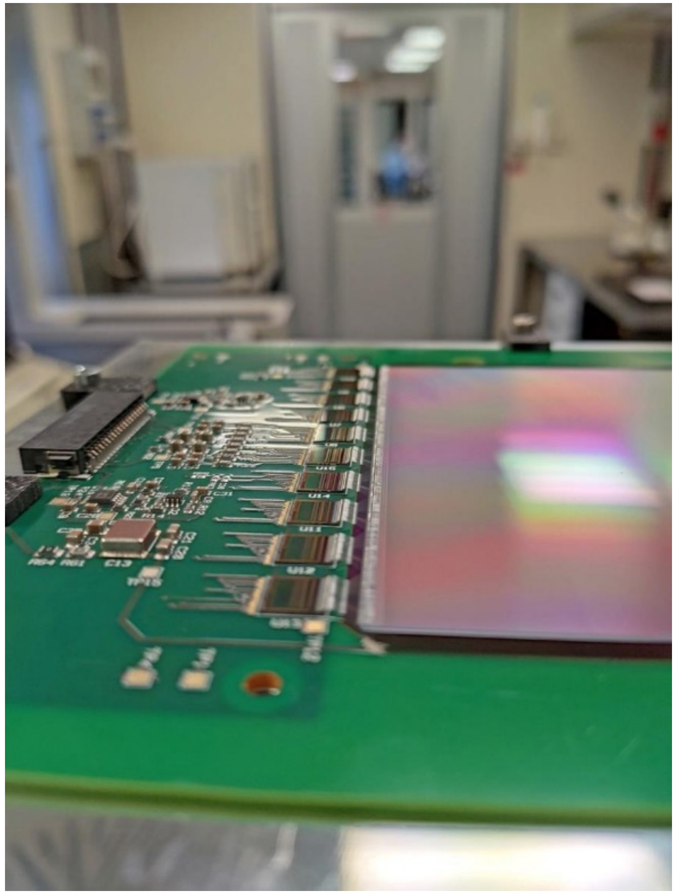


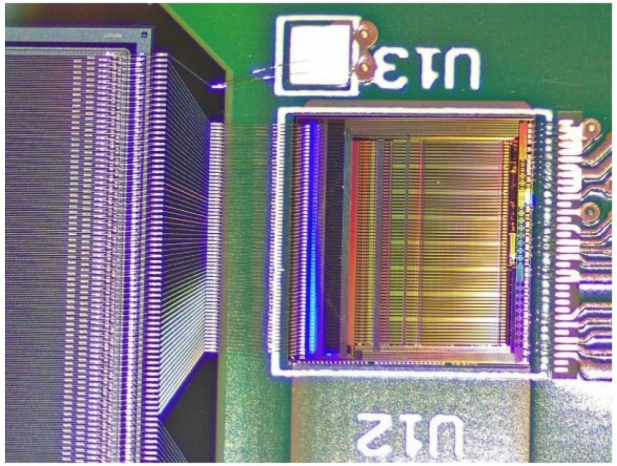
Inverse kinematics approach

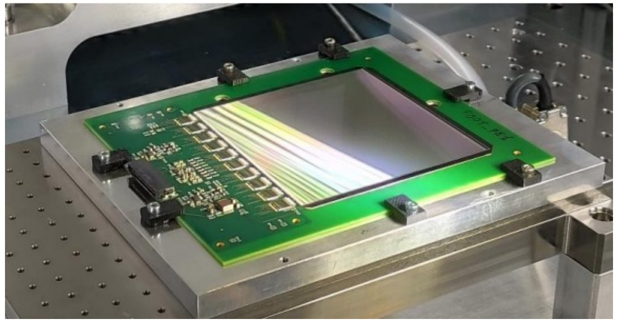
The FOOT silicon strip detector

- Measurement of cross-section of interest for hadrontherapy
  - Strip detectors to track the fragments and estimate their charge
- *Table-top* experiment: data takings in different facilities (CNAO in Pavia, HIT in Heidelberg …)
- Constraints on detector footprint, power consumption and data bandwidth



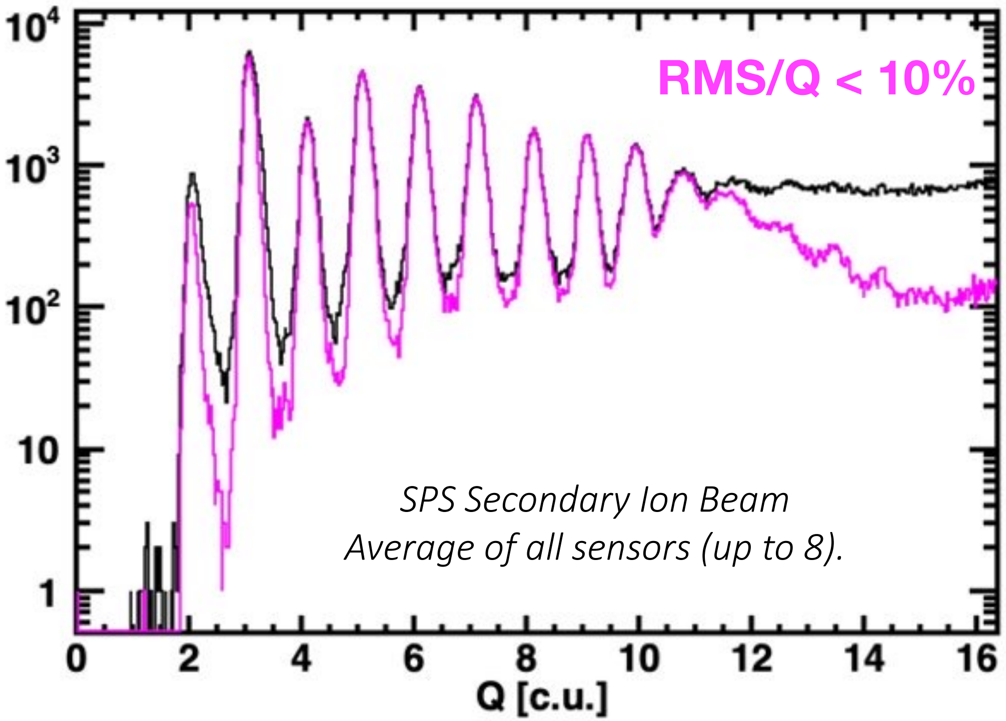


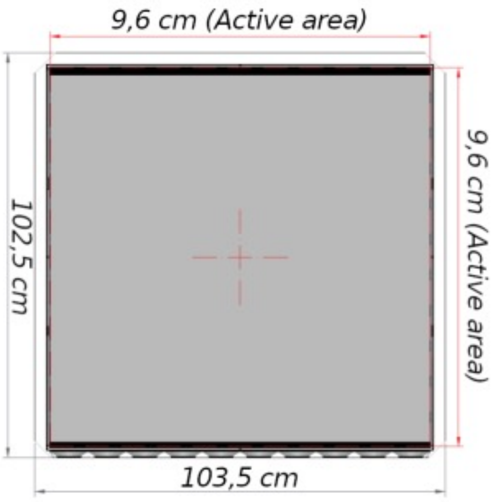


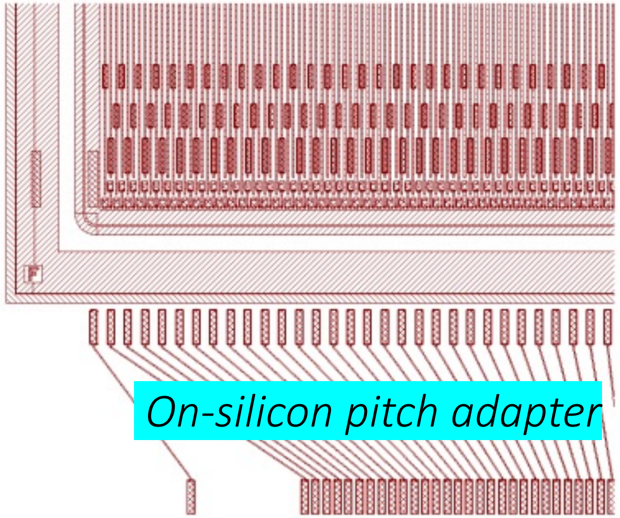


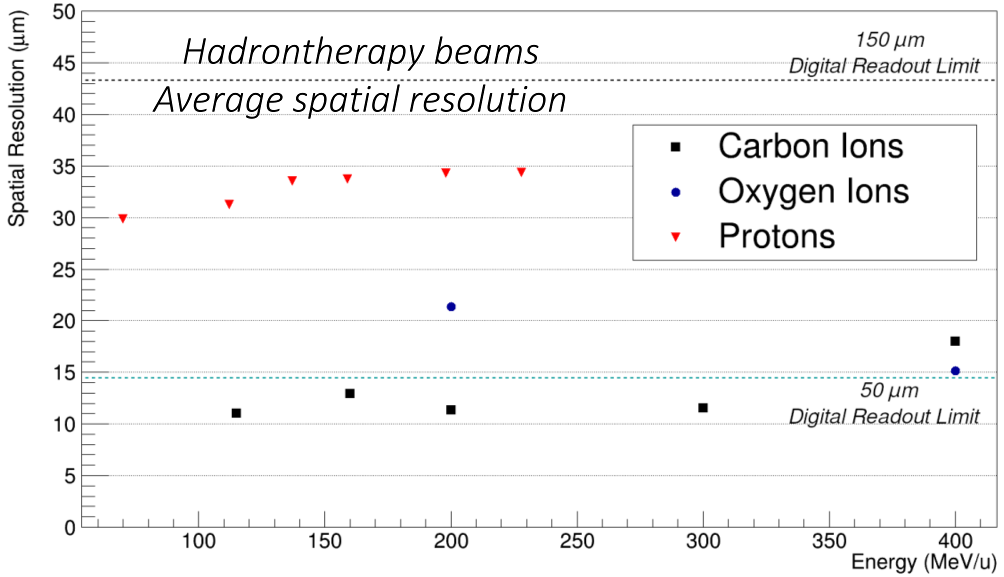
The FOOT silicon strip detector

- Silicon sensors made by Hamamatsu Photonics, 150um thick
- 96 mm × 96 mm active area segmented in 1920 strips with a 50 µm implantation pitch
- *"Floating strip"* approach: readout pitch of 150 µm, with two strips connected to readout every three
- Spatial resolution up to ≈ 10 um with good charge resolution







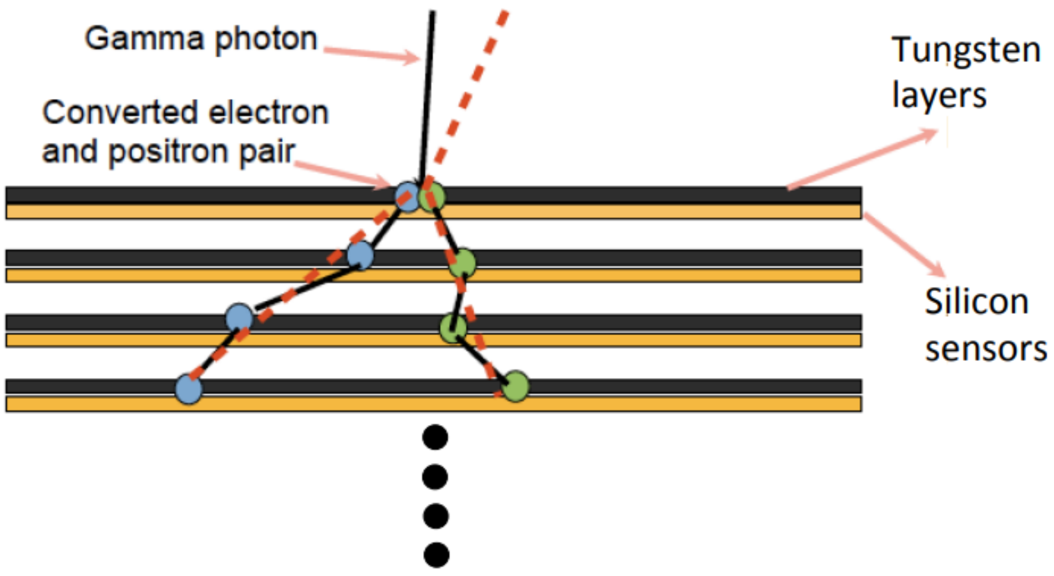


Space application (future): PANGU

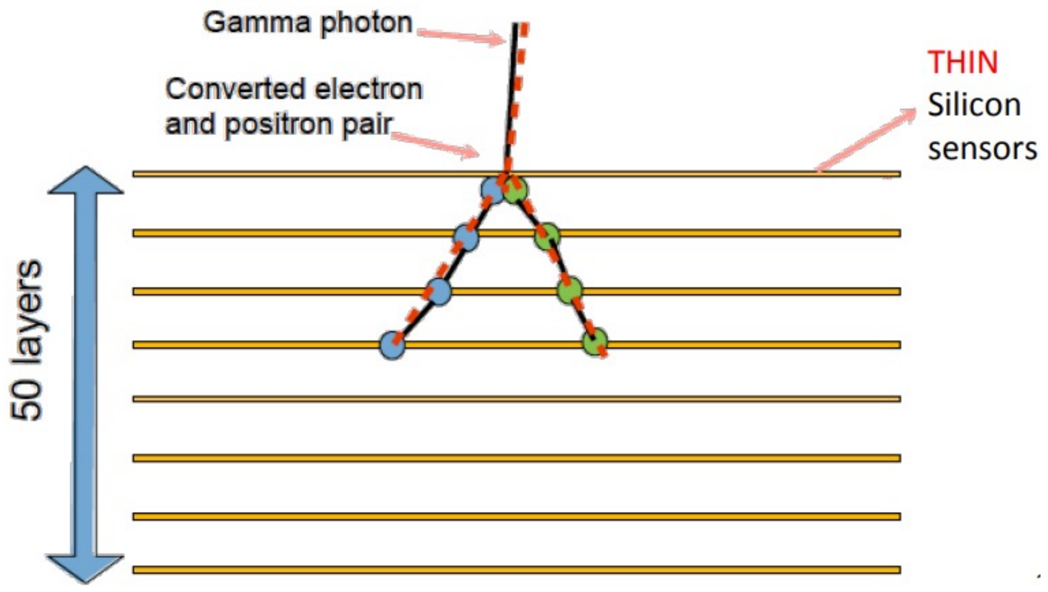
PAir-productioN Gamma-ray Unit (PANGU)

- Sub-Gev γ-ray telescope
- Avoid MCS degradation with less material "Target" (e.g. tungsten for FERMI-LAT)
- Thin silicon sensors act as photon converters and tracker

Detection principle: Fermi-LAT



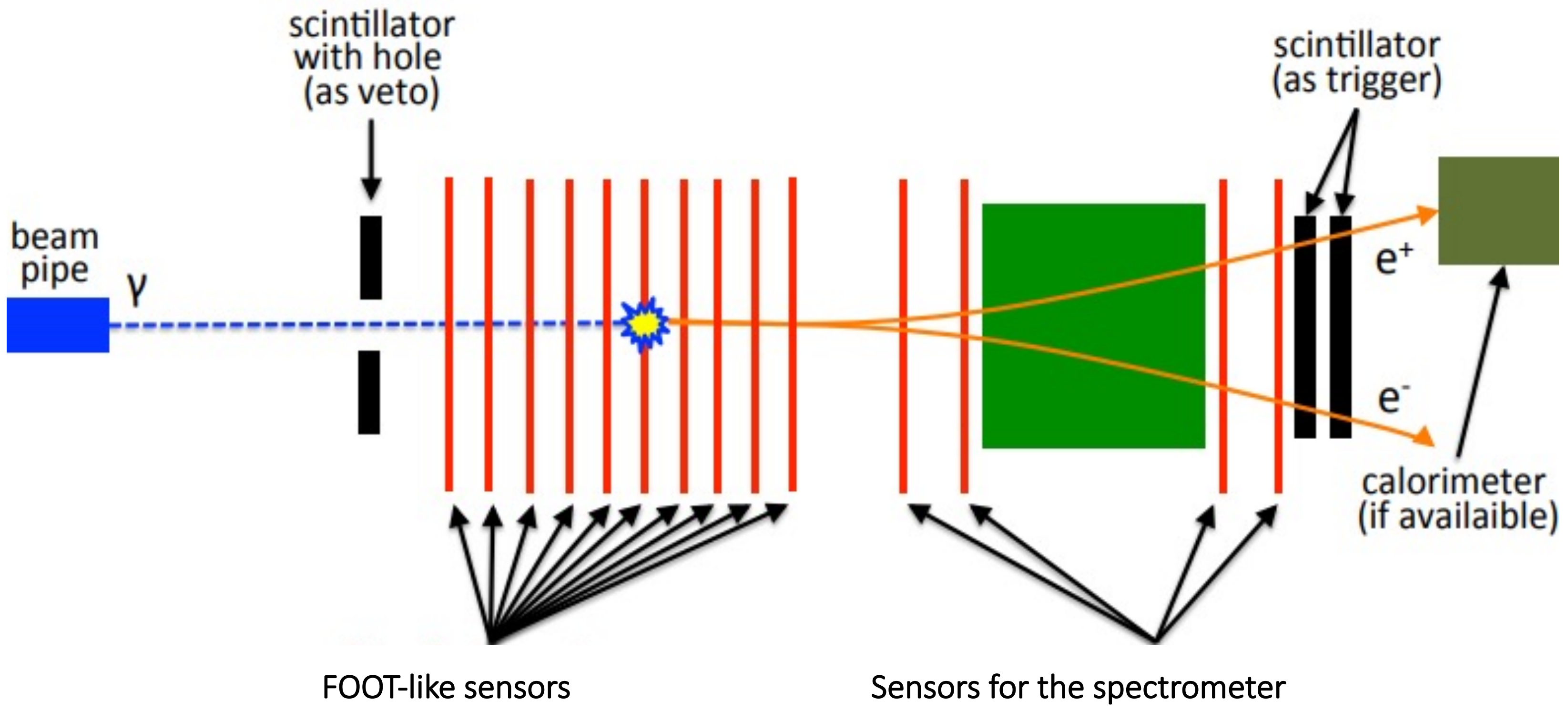
Detection principle: PANGU!



Space application (future): POX

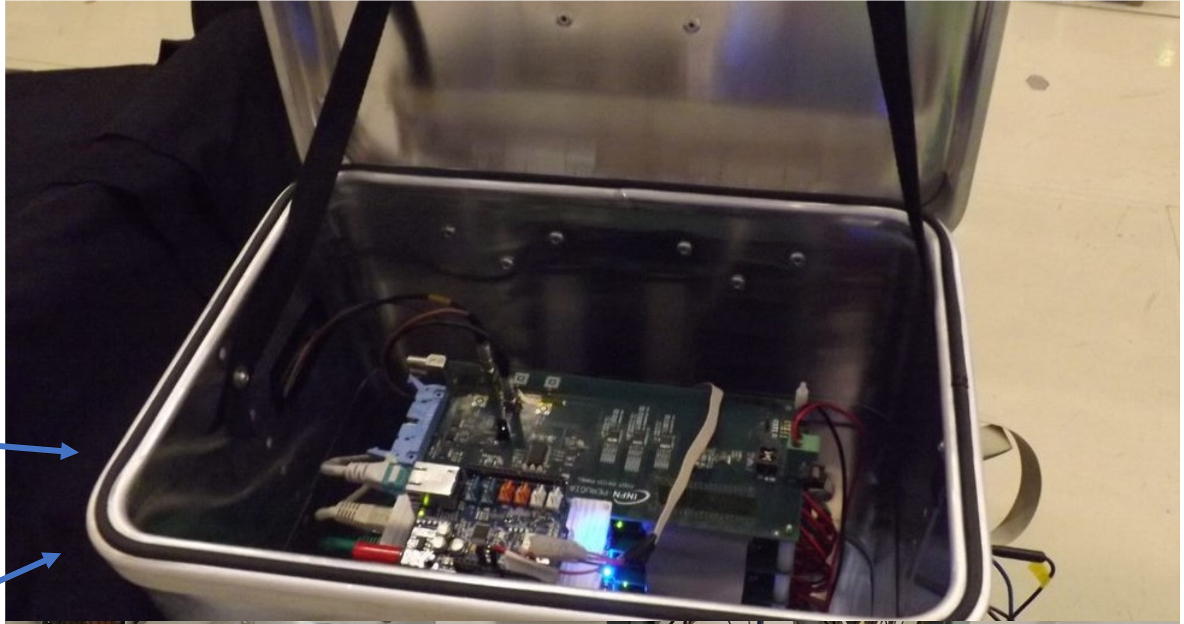
- Synergic development with the FOOT experiment
- Same silicon sensor and DAQ chain can be used
- Experimental verification of a PANGU approach
  - PANGU-like demonstrator (on ground) to validate the experiment (in space)
  - Reduced R&D cost (shared requirements with the FOOT experiment on the detectors)
  - Validation of the expected performance

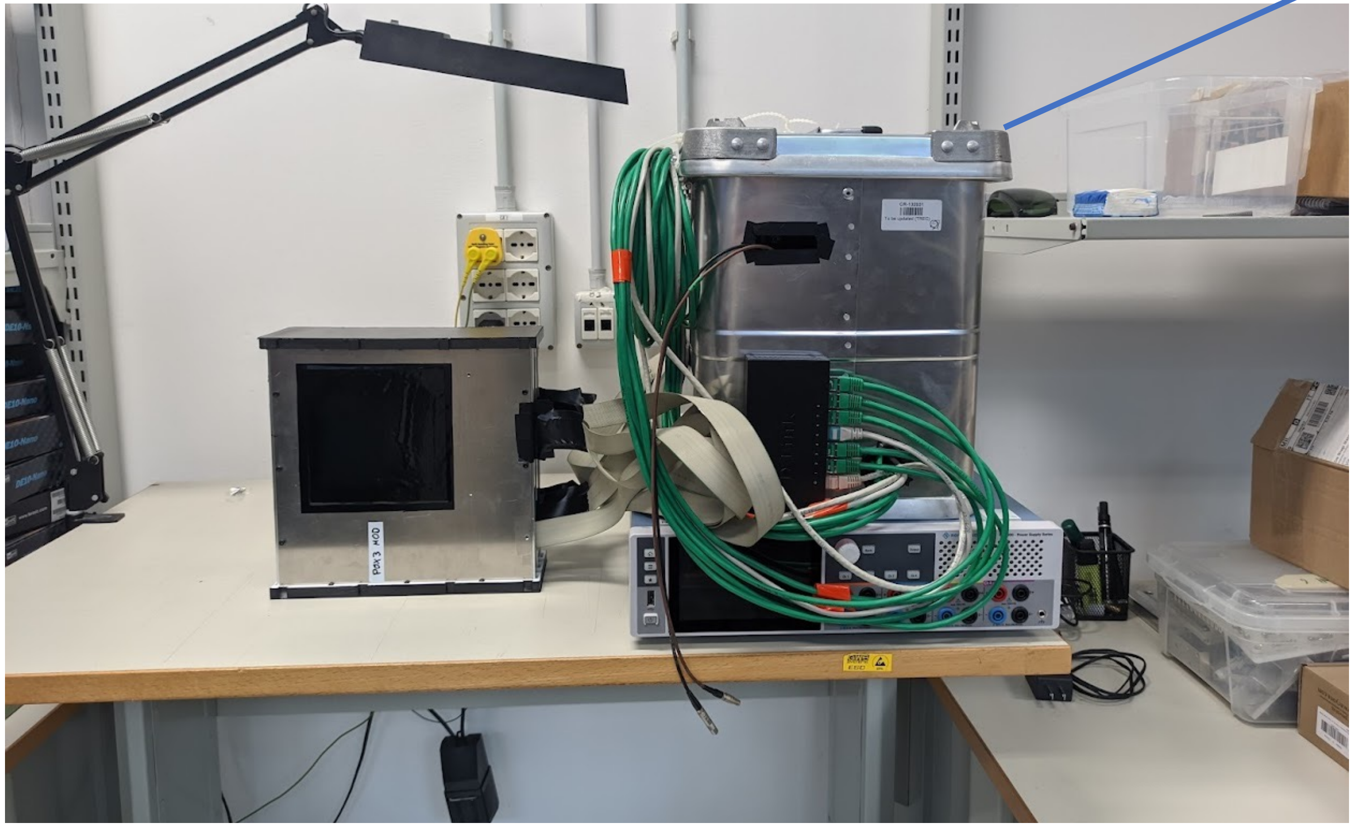
PANGU Optimization and eXperimental verification (POX) setup

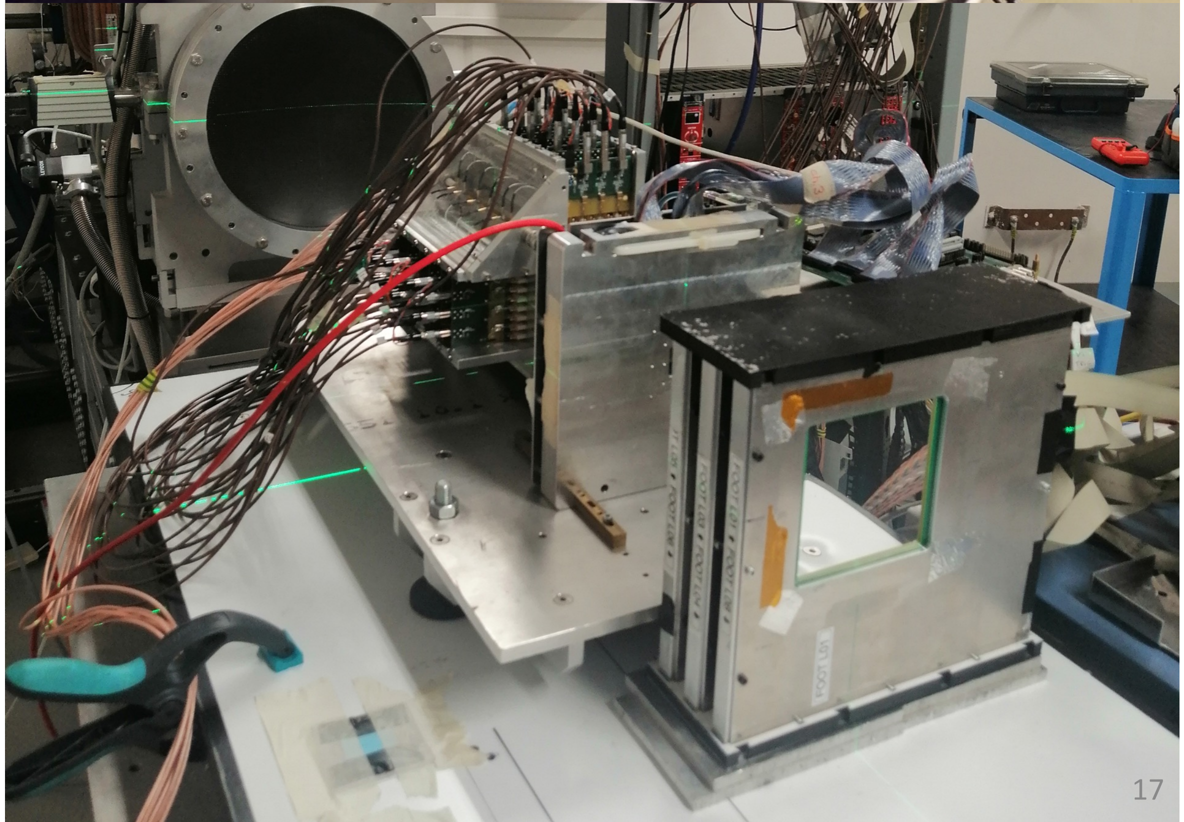


FOOT/POX uStrip Tracker

- Table-top setup
- Modular design
- Modular DAQ electronics



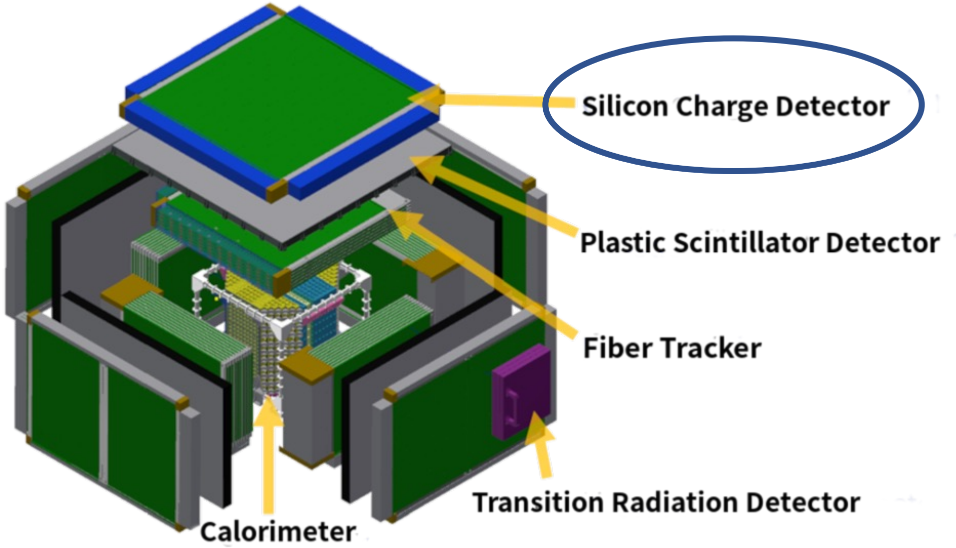


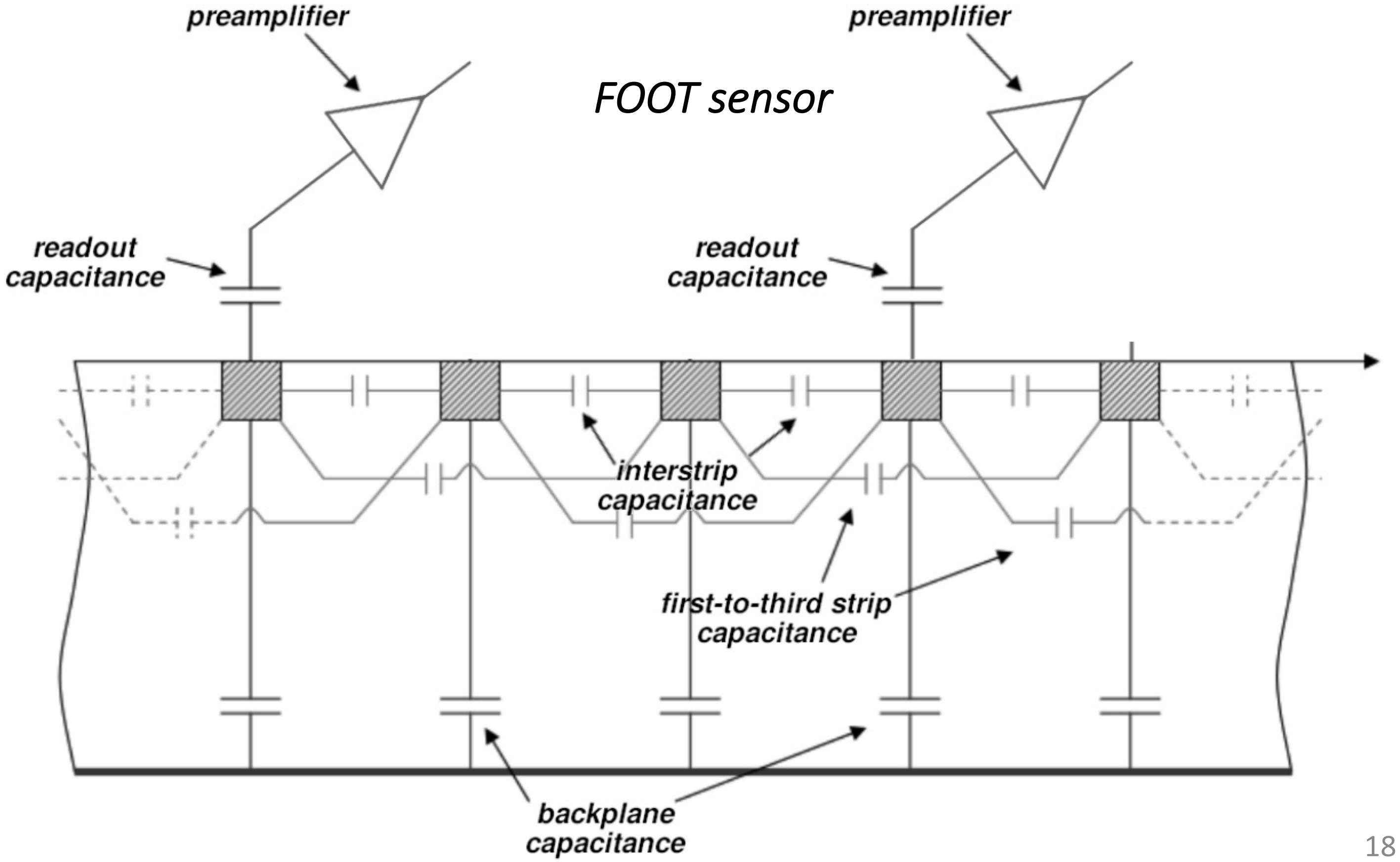


Adapting existing sensors

- Readout parameters can be tuned for each experiment
  - Trade-off between spatial and charge resolution

HERD SCD: charge detector with silicon strips

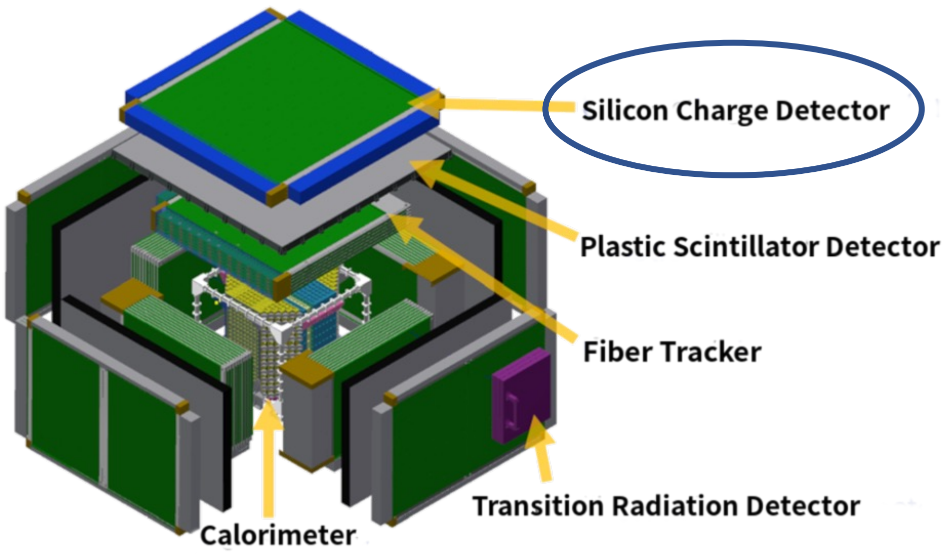


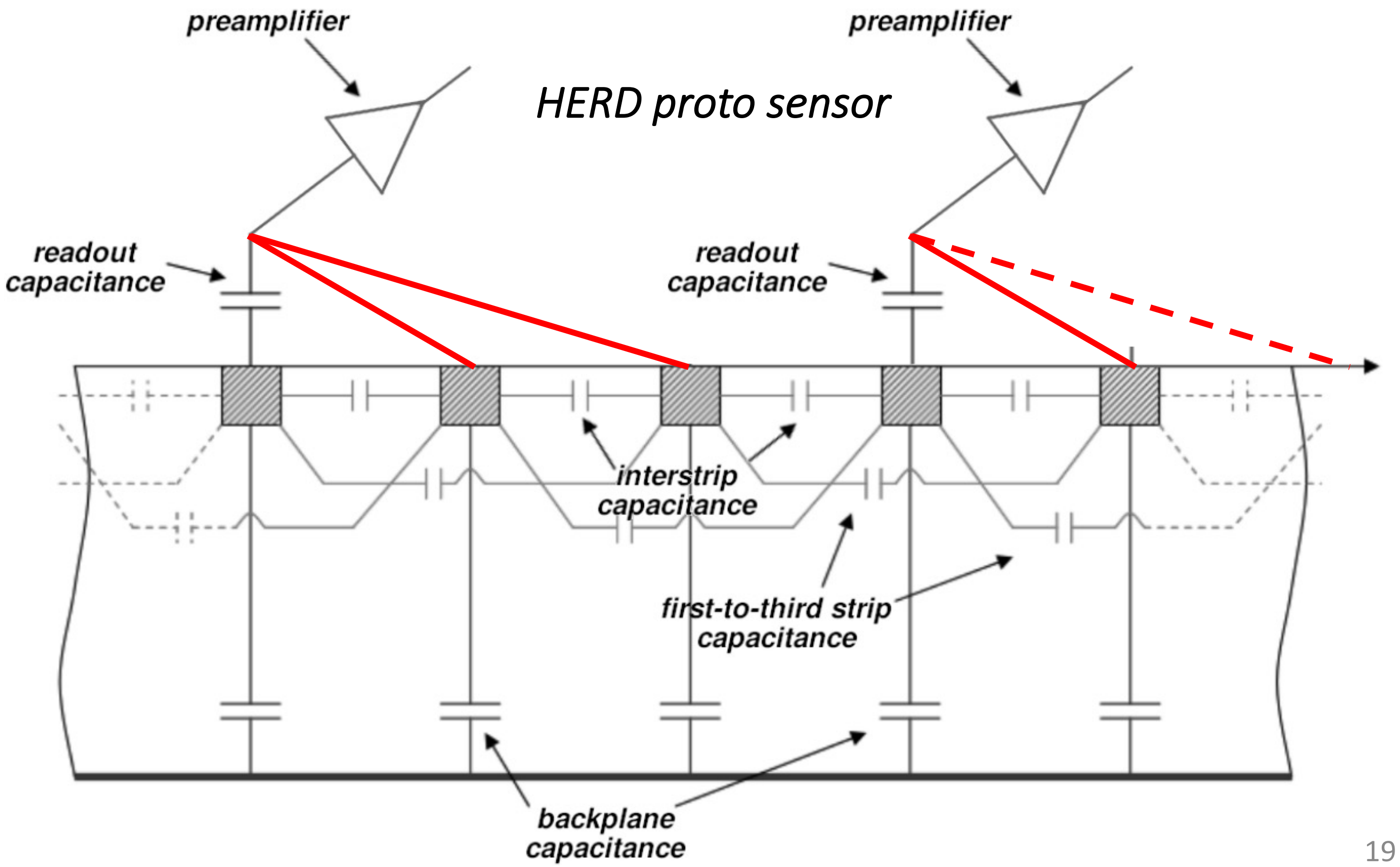


Adapting existing sensors

- Readout parameters can be tuned for each experiment
    - Trade-off between spatial and charge resolution
- Example: better charge resolution from FOOT sensors for HERD Silicon Charge Detector prototyping
    - *No need for a new silicon design and/or production*

HERD SCD: charge detector with silicon strips

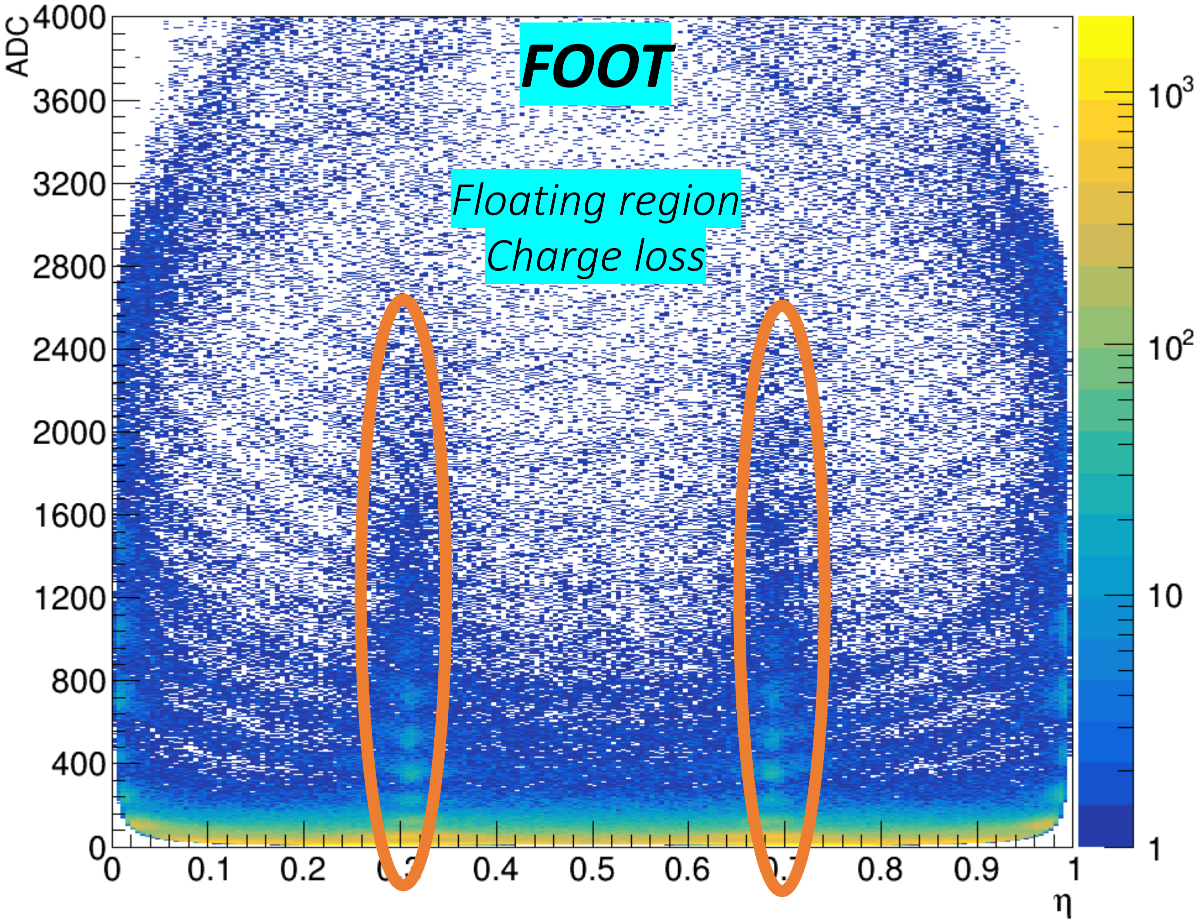


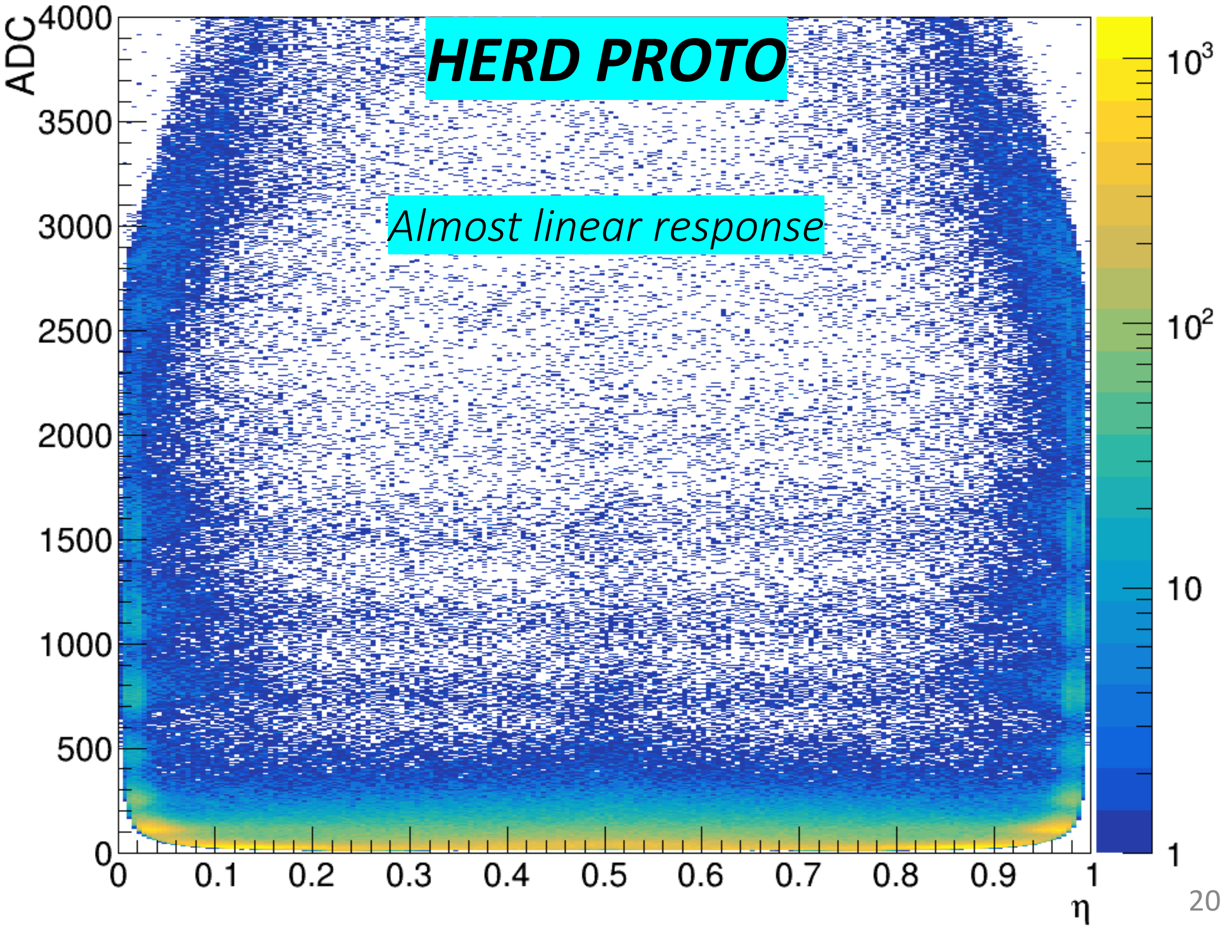


Adapting existing sensors

- The different bonding scheme simulates a detector with same readout pitch, but different strip width
- Charge collection is improved
- Charge non-linearity between readout strips is reduced

$$\eta = \frac{S_L}{S_L + S_R}$$

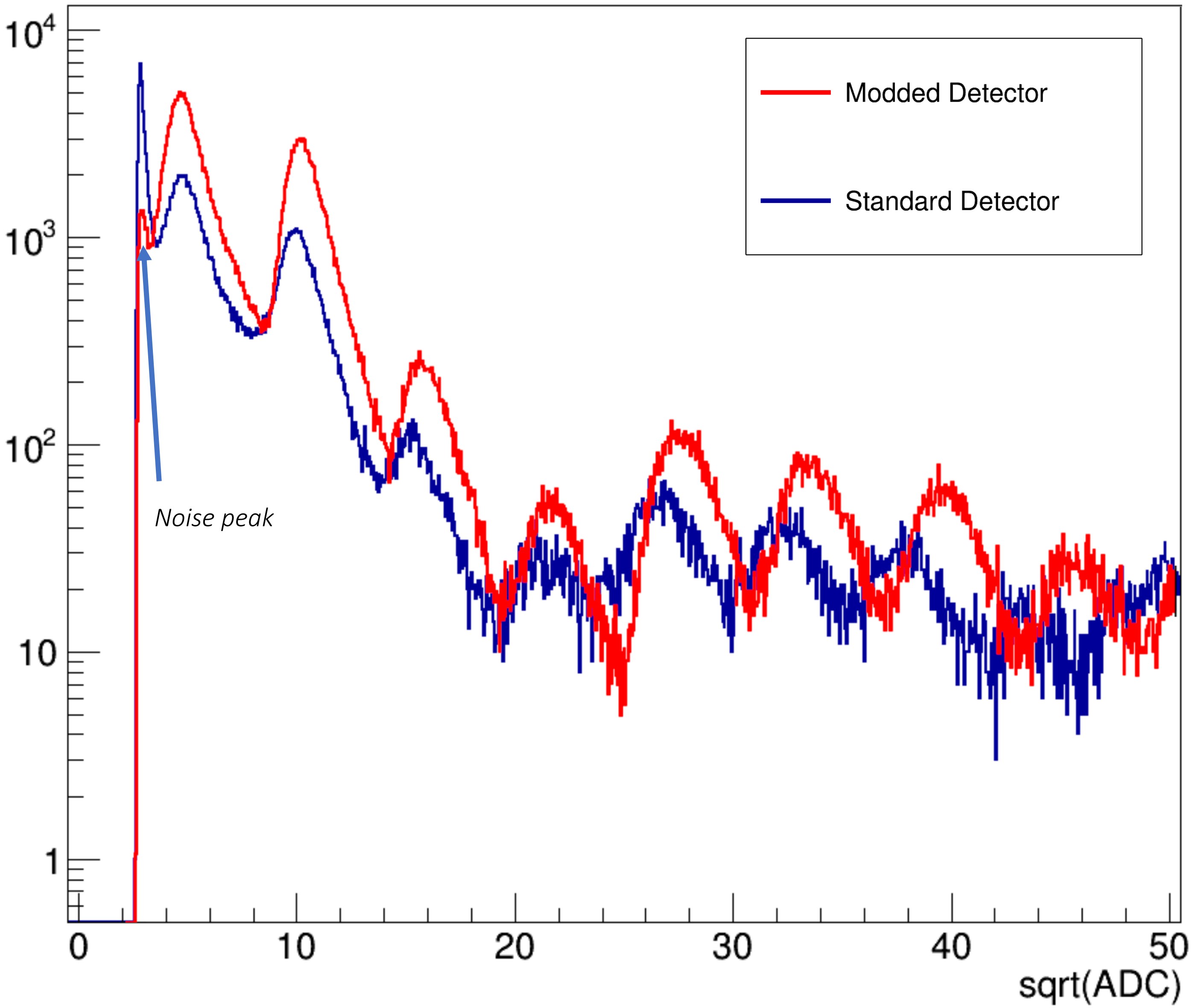




Adapting existing sensors

- Charge discrimination improved
- Higher signal collected
- Improved reconstruction efficiency for lower Z
- Trade-off with spatial resolution and high Z dynamic range

The same thin silicon sensor can be used for the detection of lower signal particles without the need of a new production



Conclusions

- Silicon strip detectors are still the main choice when power consumption and area to cover are crucial
- Good spatial resolutions (less than 10 micrometers) can be obtained exploiting analog readout and charge sharing between strips
- Possibility to estimate the charge (e.g AMS02, HERD …) or the energy (e.g. FOOT) of the particle
- Synergic development (e.g FOOT/POX) can reduce the costs needed
- Adapting existing sensors (e.g. different bonding scheme) allows for low cost prototyping for future experiments