HV-CMOS Test Beam Campaigns

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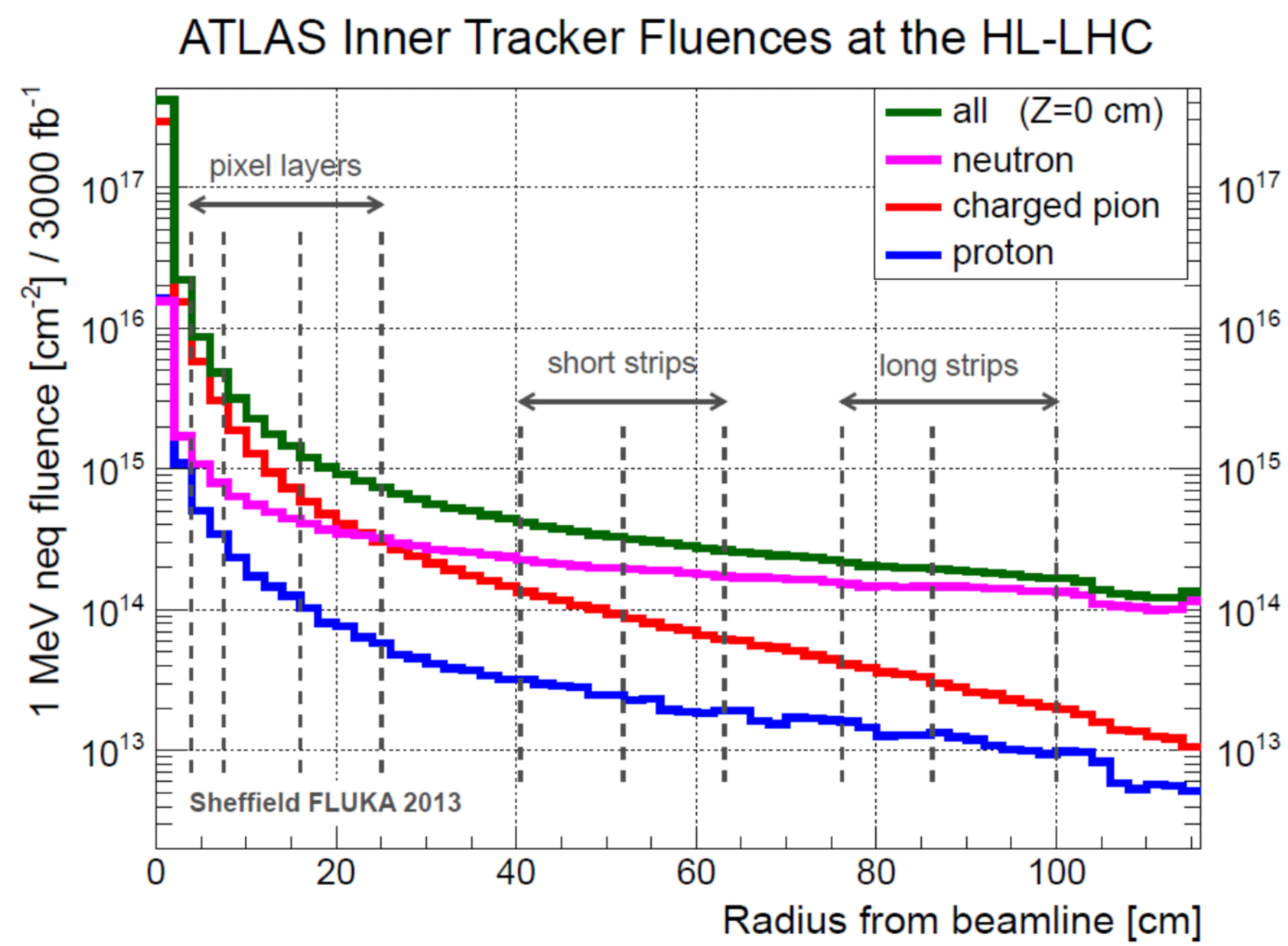
ITk: Inner Tracker Upgrade of ATLAS

- LHC upgrades planned to increase luminosity
- Significantly more radiation

- **Replacement of Inner Tracker (ITk Upgrade):**
  > large area
  > extremely radiation tolerant silicon pixel detectors i.e. outer-pixel layers ($\sim 10^{15}$ 1 MeV n_{eq} /cm^2)



- **HV-CMOS Technology is a promising candidate:**
  > high bulk bias voltage ⟶ fast charge collection
  > radiation tolerant technology
  > affordable commercial production costs

- **R&D on variations of technology underway to determine suitability**

Test Beam: Characterisation

- Sensors in ATLAS for 10 years receiving an integrated luminosity of 4000 fb^{-1}
- Need to prove their performance both during and after such conditions

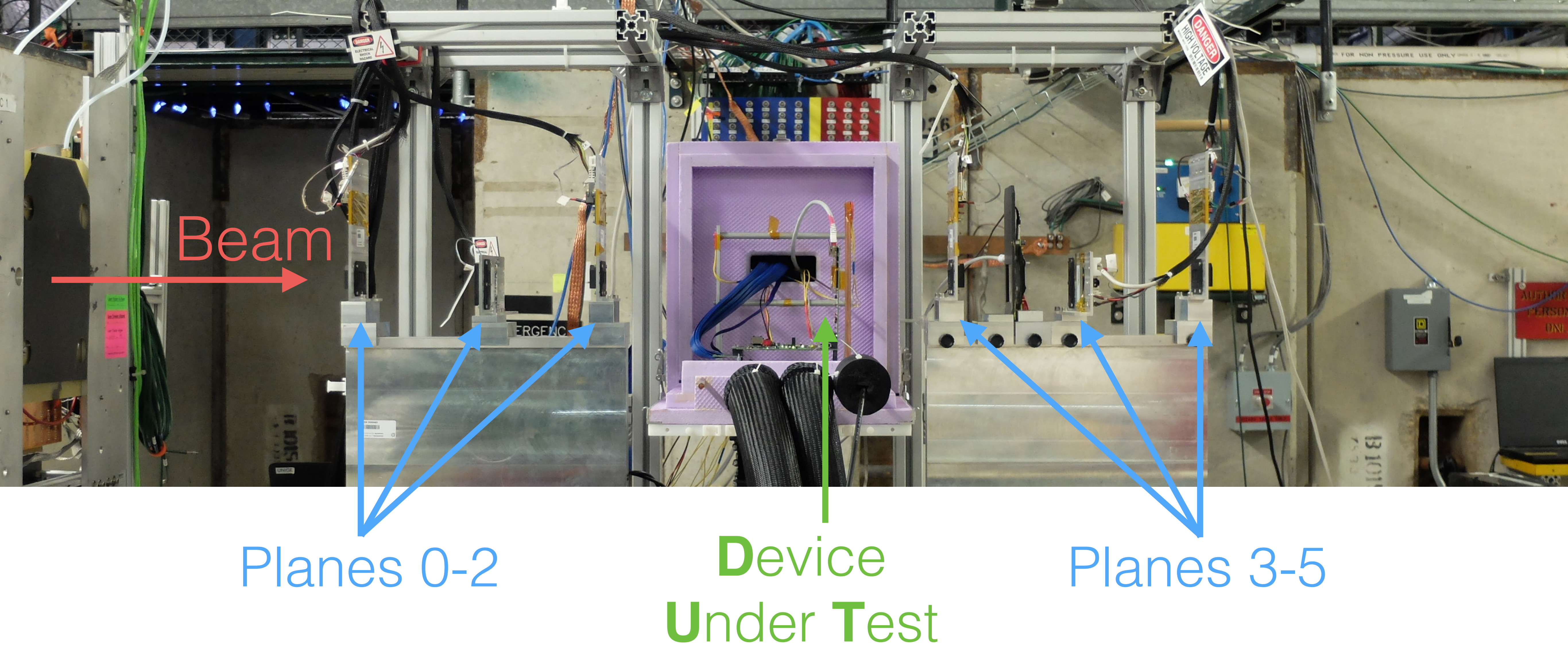
→ **Test Beam Campaigns**
SPS 16 and FNAL 17

- Expose sensors to Beam
- Detect particles
- Compare to detection using **Telescope**

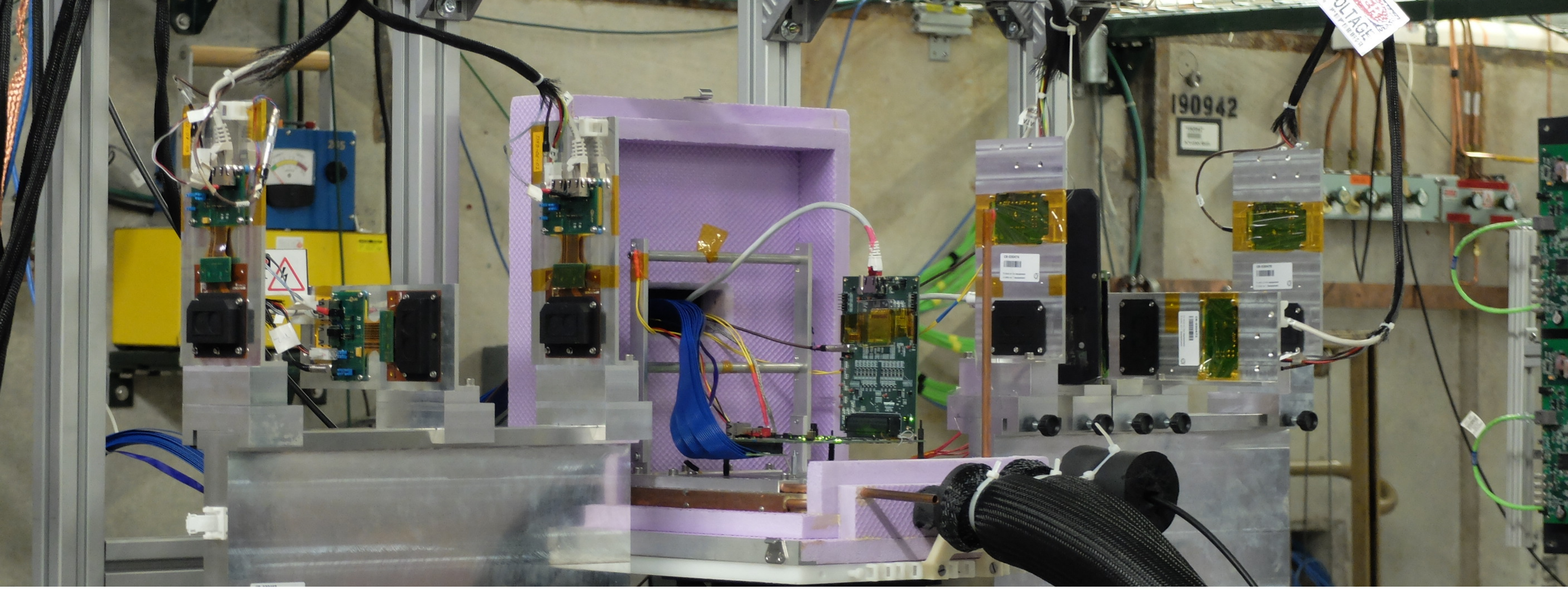
FE-I4 Telescope - Université de Genève
https://arxiv.org/pdf/1603.07776.pdf

- **Irradiation Campaign:**
  Irradiated in increments with 18 MeV protons at the Bern Cyclotron
  (see A. Fehr's presentation)

- Test at various irradiations to observe change in performance over lifetime



- Test Beam Campaign at Fermilab using 120 GeV pion beam
- 6 IBL planar pixel sensors: pixel pitch of (250 x 50) μm
- Trigger was given by the coincidence of plane 0 and 5
- DUT situated in the middle of the telescope planes

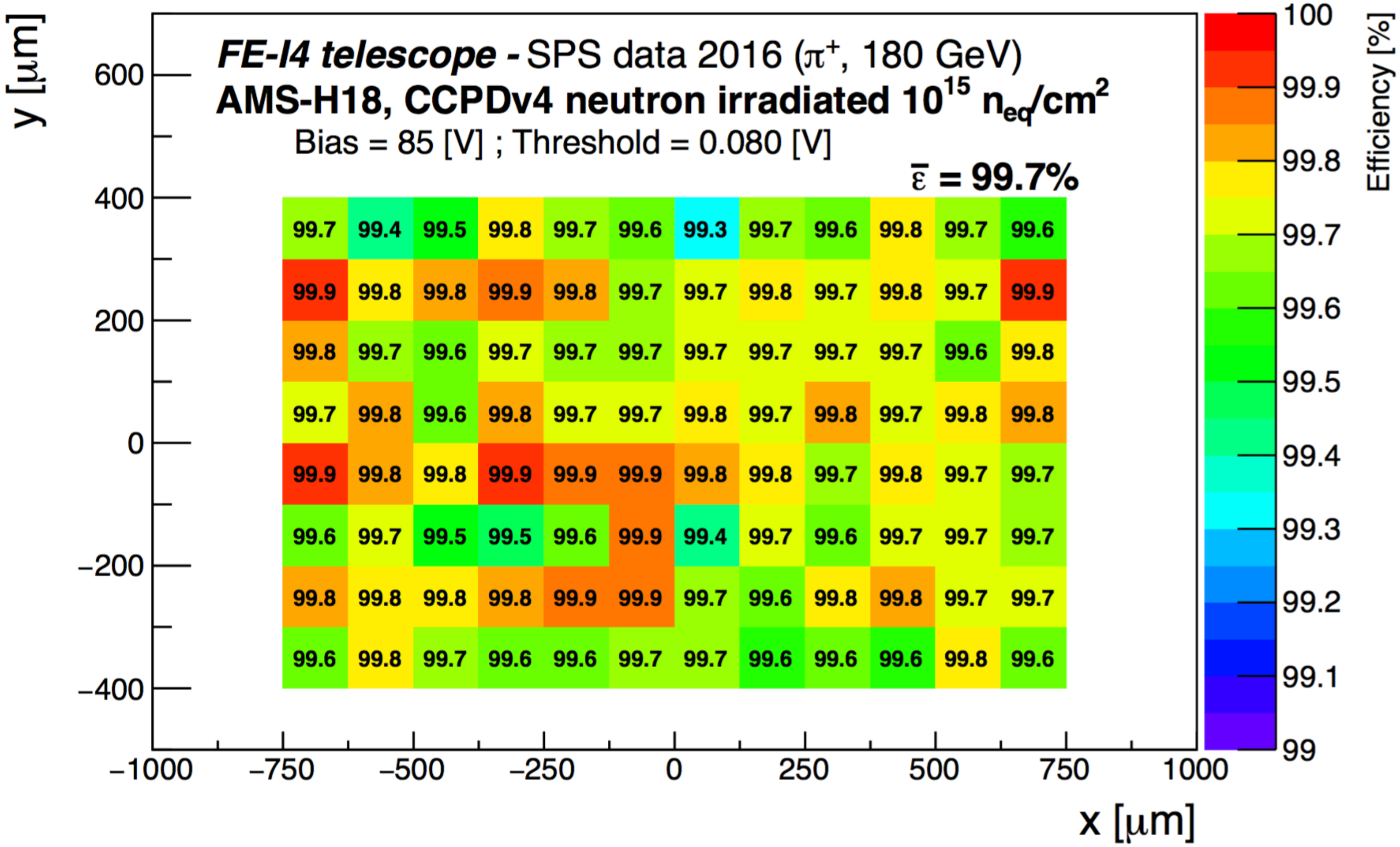


- Hit information of telescope ⟶ track reconstruction
- Expected hits in DUT

$$\text{Hit Efficiency} = \frac{\#\ \text{matching hits in DUT}}{\#\ \text{expected hits in DUT}}$$

- Timing measurements
- Cluster Size (how many pixels fired during one event)

Test Beam Results: Example

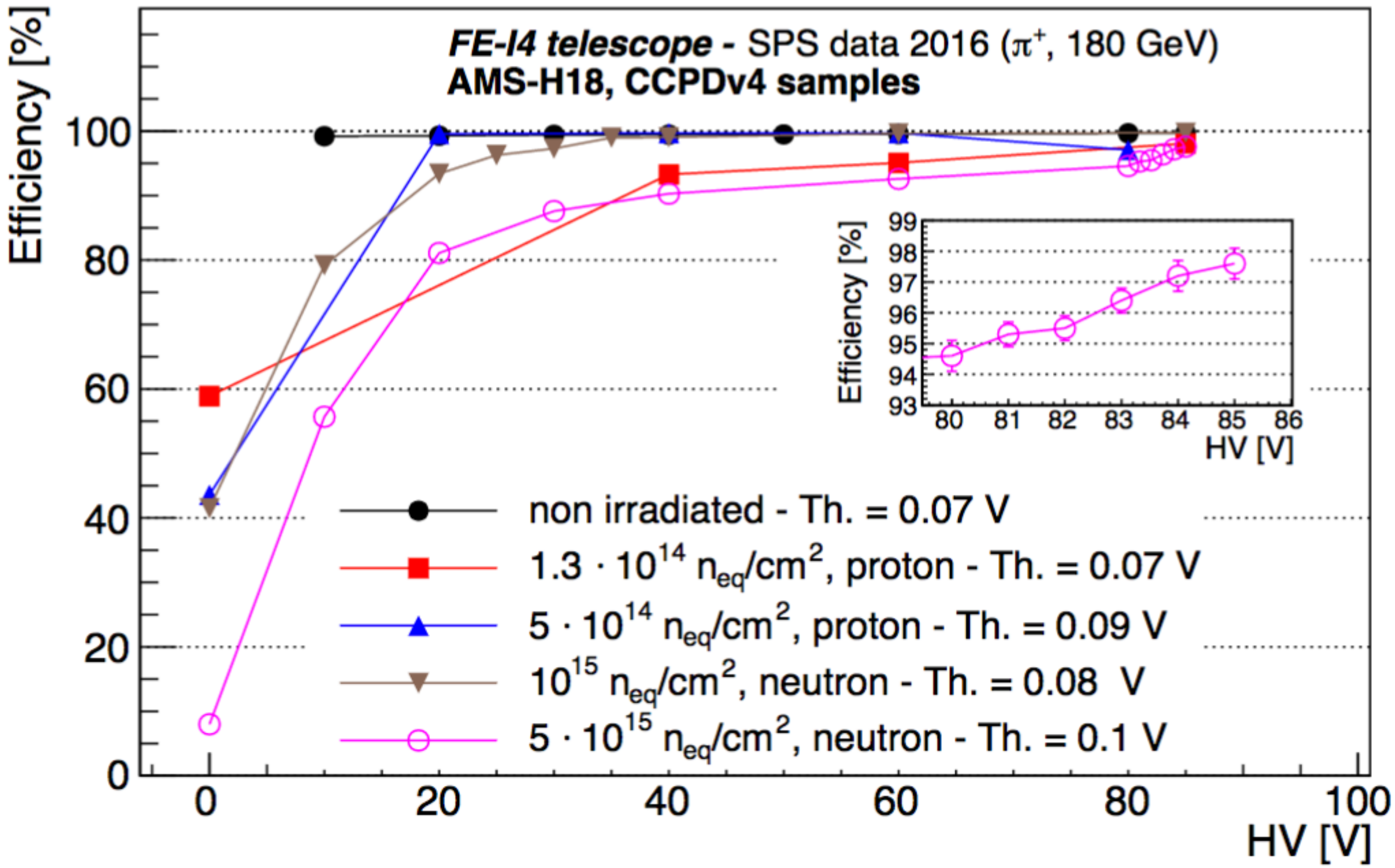


- Hit efficiency across geometry of sensor
- Average efficiency of **99.7%**

- Results are for one irradiation step and for specific parameters: Bias (High) Voltage and Threshold

https://arxiv.org/pdf/1611.02669v1.pdf

Test Beam Results: Example



- Efficiency measurements vs. sensor parameter for different fluences

- Used to map change in performance of sensor across it's lifetime in ATLAS
- Optimise values of sensor parameters

- For more in depth results, refer to F. Di Bello's presentation

https://arxiv.org/pdf/1611.02669v1.pdf

Telescope Development

- Results of sensors dependent on performance of telescope
- Spatial resolution? Active area? …

- Improvements to telescope could better understand results of test sensors

Highlighted Features:

- Control of plane environment
- Cooling systems - planes and DUT
- Large active area
- Portability
- ITk compatibility

ITk Compatibility

Compatibility with ITk:

- Compatible with latest hardware of ATLAS
- Benefits from substantial R&D work in collaboration

Relevant Features of ITk:

- **QUAD modules**
  Large active area
- **Readout System: FELIX**
  New modules compatible with current RCE and FELIX
- **Flex Design**
  Responsible for the housing of the sensors and electrical connections to the sensor - data lines, powering etc

Planes and Modules

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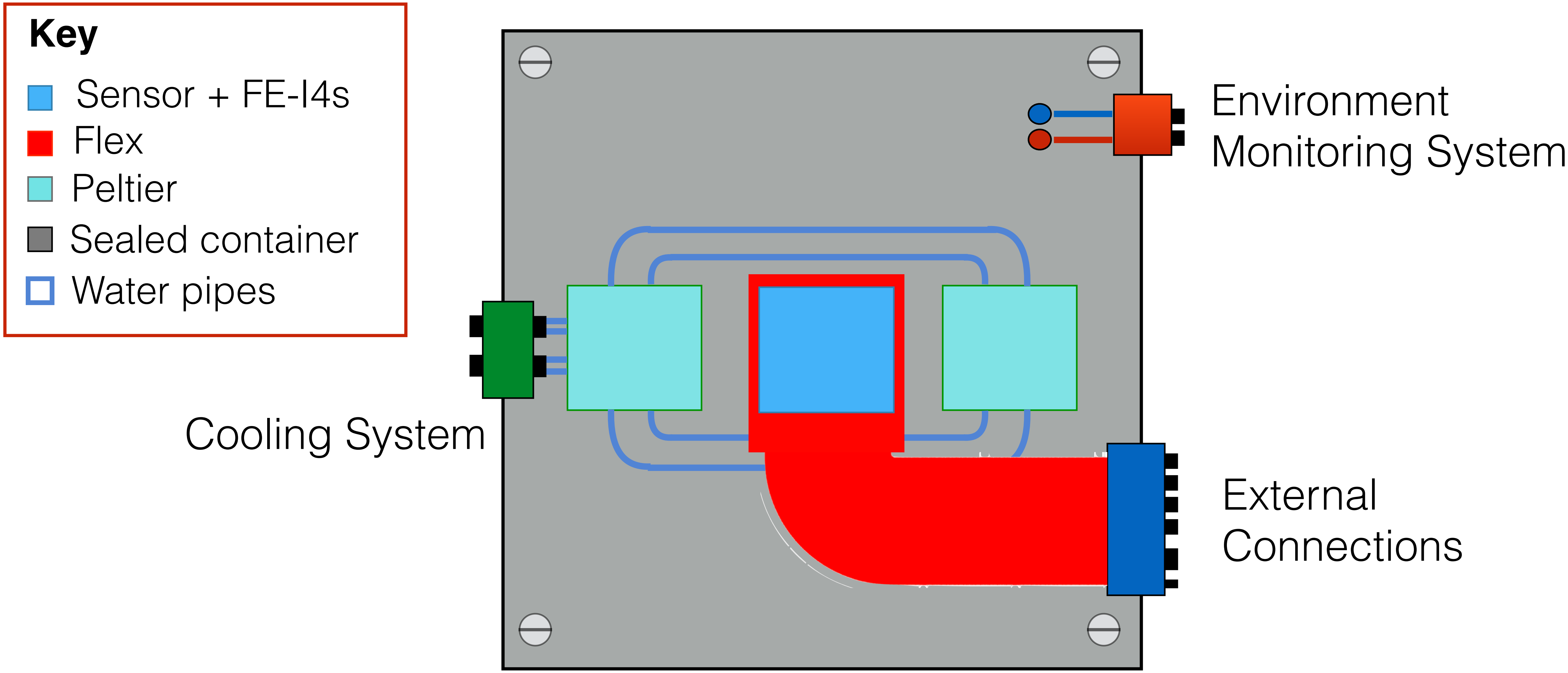

- Sealed container to ensure constant environment
- Integrated cooling system and environment monitoring - temperature and humidity
- Exposed connections to flex - Data lines, powering etc
- Symmetrical for easy use after rotation of plane

Plane Cooling System

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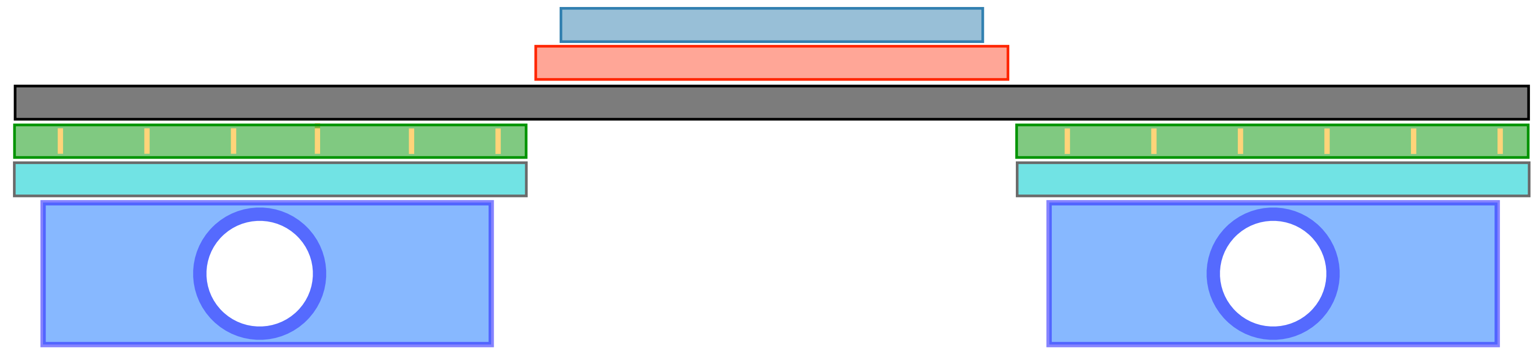
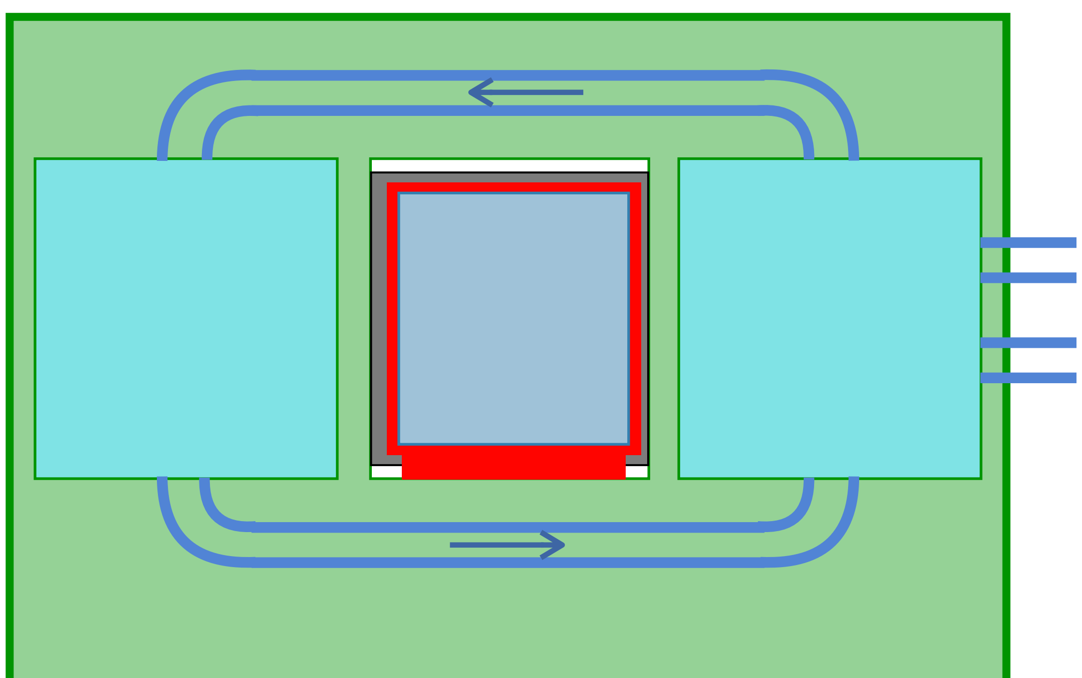
Key

- Active Sensor
- FE-I4 + Flex
- Graphite
- PCB with conductive via's
- Peltier
- Cooling Block and connecting water pipe

Top



Rear



- Beam only passes through sensor, FE-I4, Flex and graphite
- Cooling system incorporated in container, isolated from electronics

$1.742\ \text{MeV g}^{-1}\,\text{cm}^{2}\ \times\ 2.210\ \text{g cm}^{-3}\ =\ 3.850\ \text{MeV cm}^{-1}$

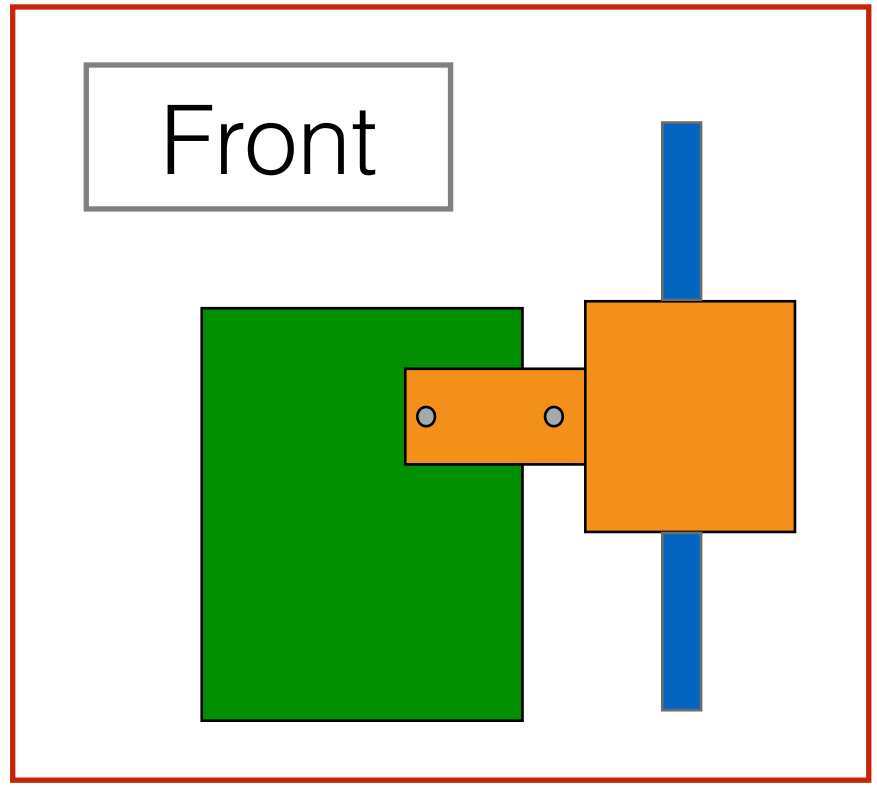
thickness ~ 500 um —> ~ 0.2 MeV

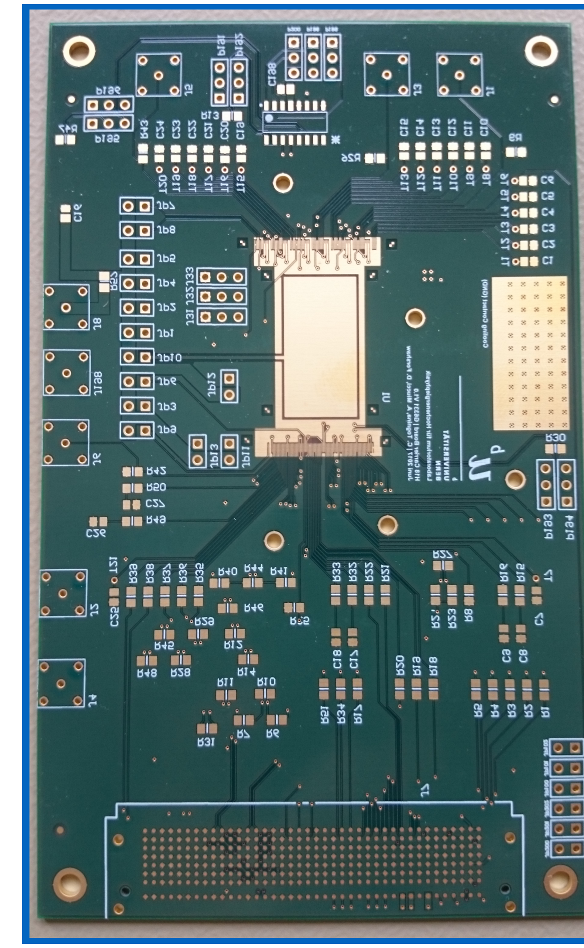
0.2 MeV / 180 GeV = 0.0001% Beam Energy Loss

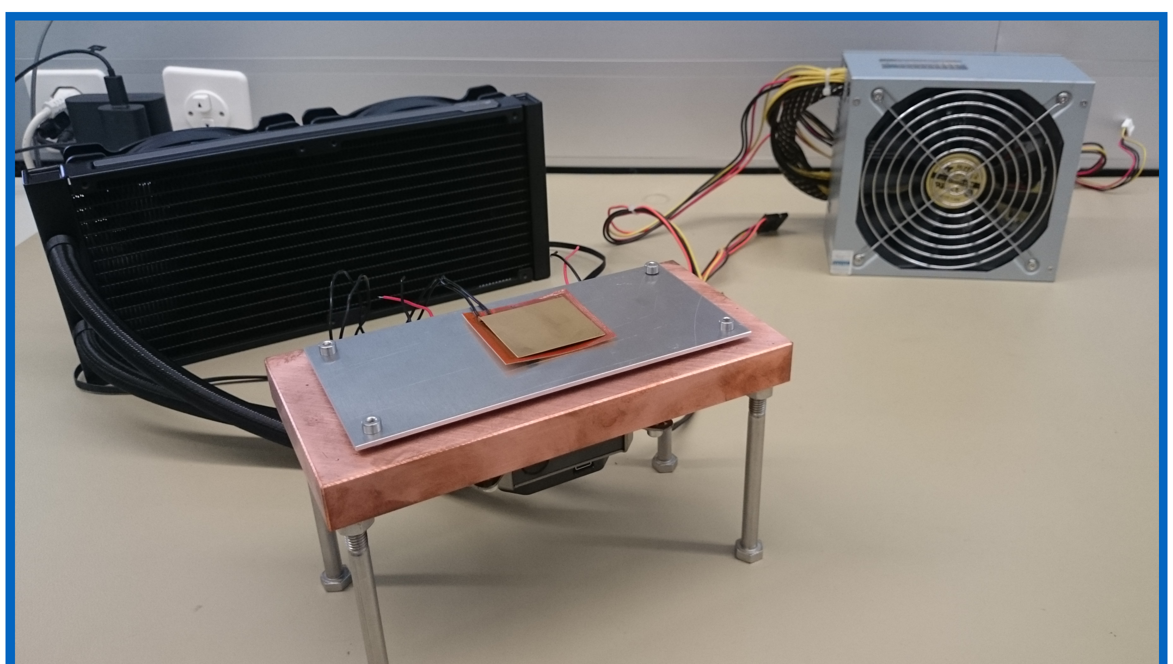
Graphite in beam is negligible

DUT Cooling System

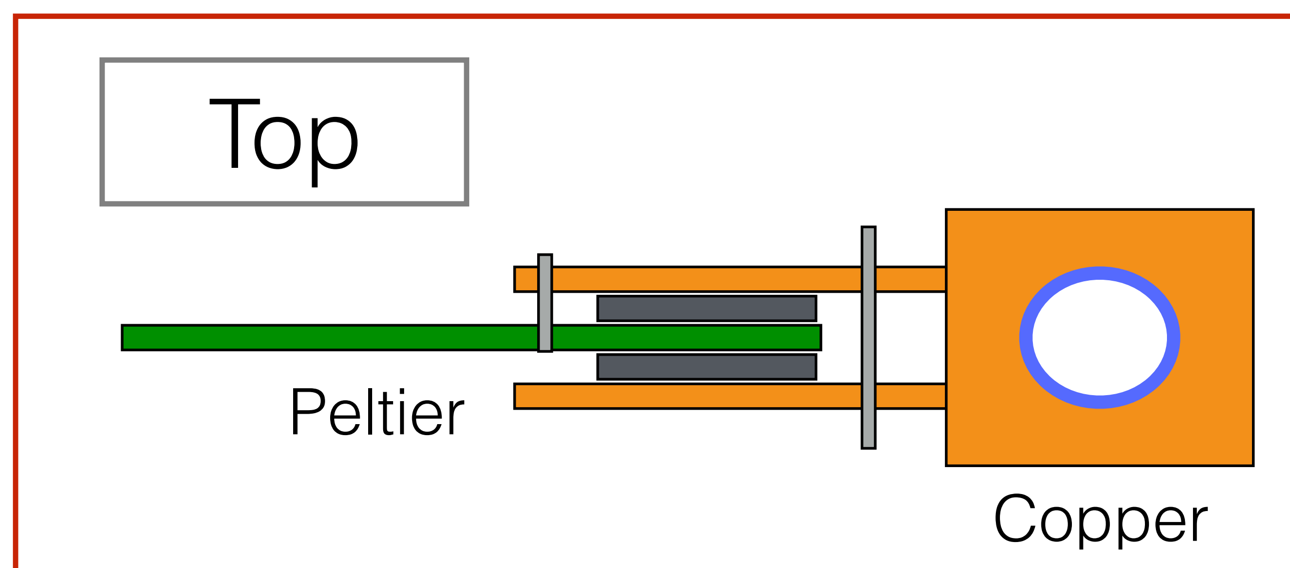
- Generic system in the future
- Specific system to new HV-CMOS sensors
- Exposed metal GND pads cools entire GND layer
- Testing in laboratory
- Ready for upcoming test beam







Cooling Tests in Laboratory



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Conclusions and Future Plans

Test Beam Campaigns:

- Introduction and Concepts of Test Beam Campaigns

Telescope as Tool for Test Beams:

- Vital equipment
- Results dependent on performance of telescope

Telescope Development:

- Improvement to existing designs

- Currently in design phase
- Assembly of a full prototype in the coming months

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ATLAS
EXPERIMENT

Thanks for listening

Backup

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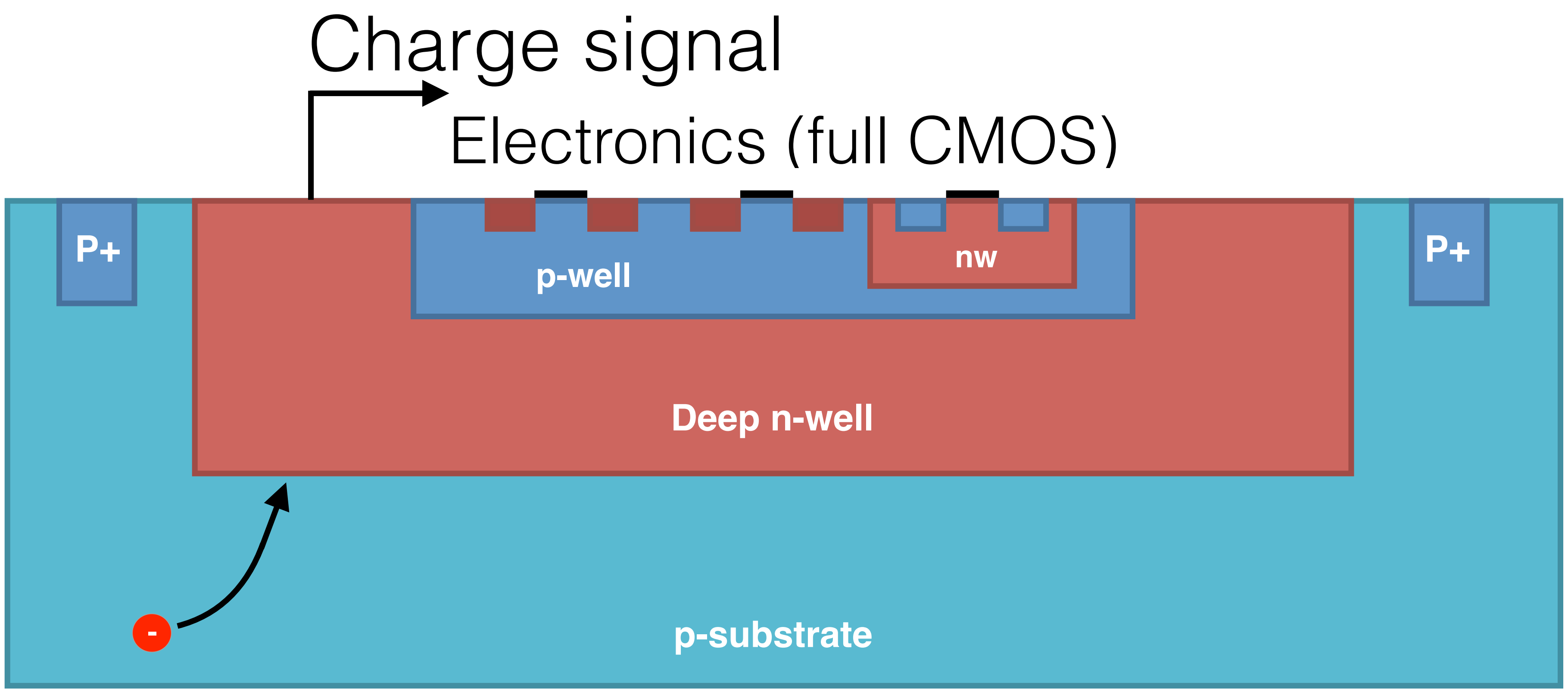
HV-CMOS Technology: Concept



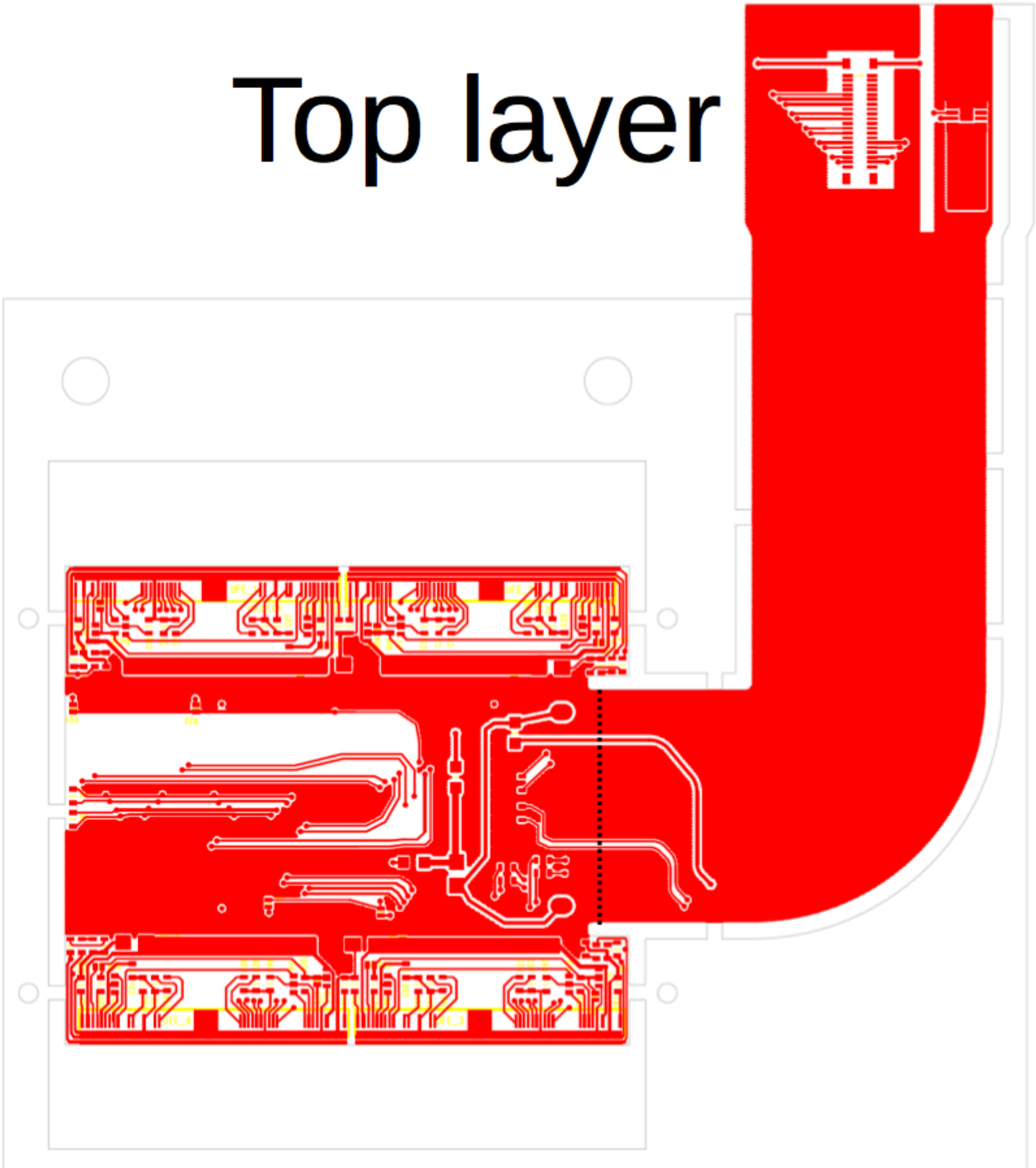
- High E field + low resistivity ⟶ fast charge collection & radiation hard
- Collection electrode (Deep n-well) with **large fill factor**
  - no low field regions
  - on average short(er) drift distances

Quad Modules and Flex

- FE-I4 Quad Modules
- Naturally provide a large surface area
- sealed environment for each module to ensure constant temperature and humidity

- Current flex design likely not to change
- Quad attached to flex which is mounted to a PCB
- PCB for connection at opposite end

- In production end of July

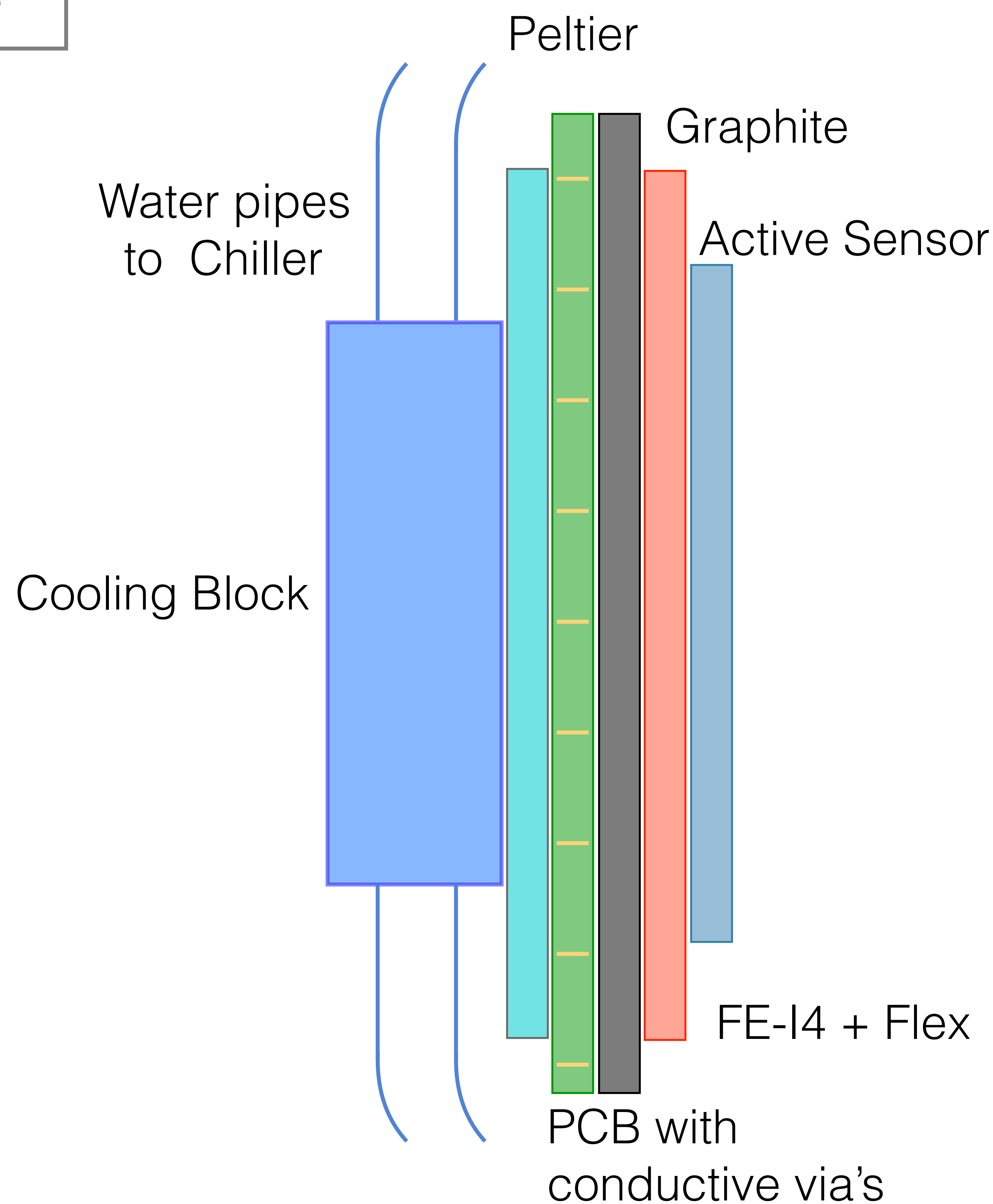


https://indico.cern.ch/event/642037/

Quad Structure + Cooling

Side

** not to scale*



Quad Structure + Cooling

Top

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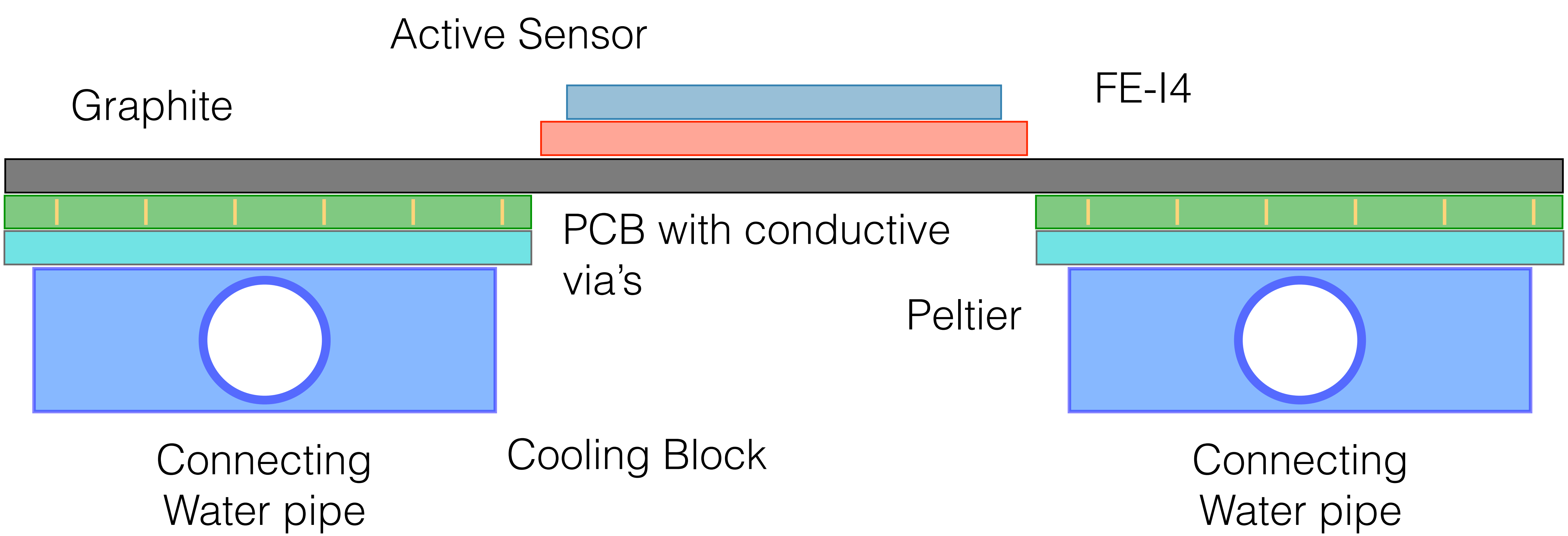

Cooling blocks and water pipes integrated into container to isolate from electronics
PCB screws into container

Quad Structure + Cooling

Rear

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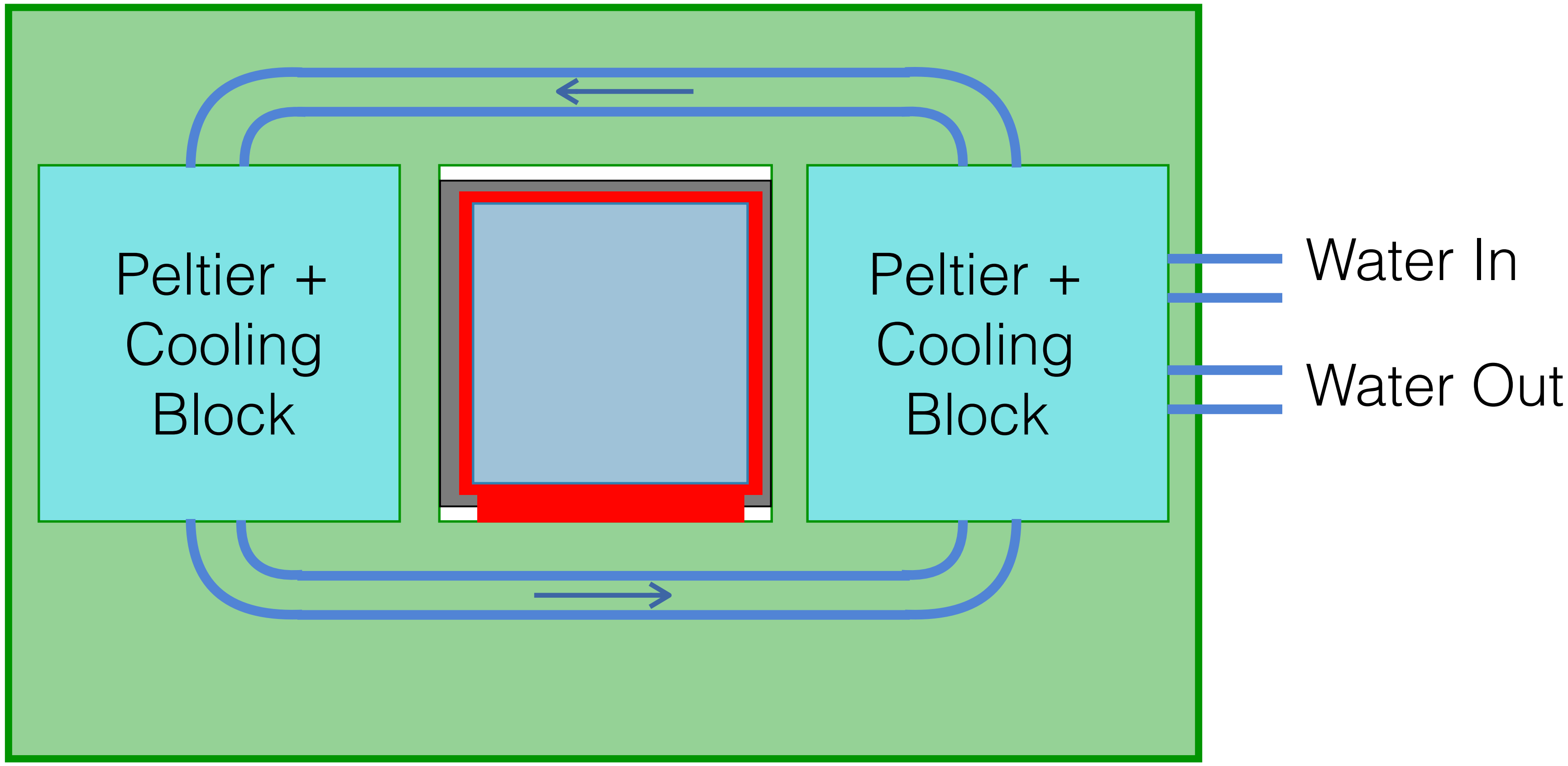

Beam only passes through sensor, FE-I4 and graphite
Important to isolate the water pipes from the electronics

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Module Container and Connections

Container

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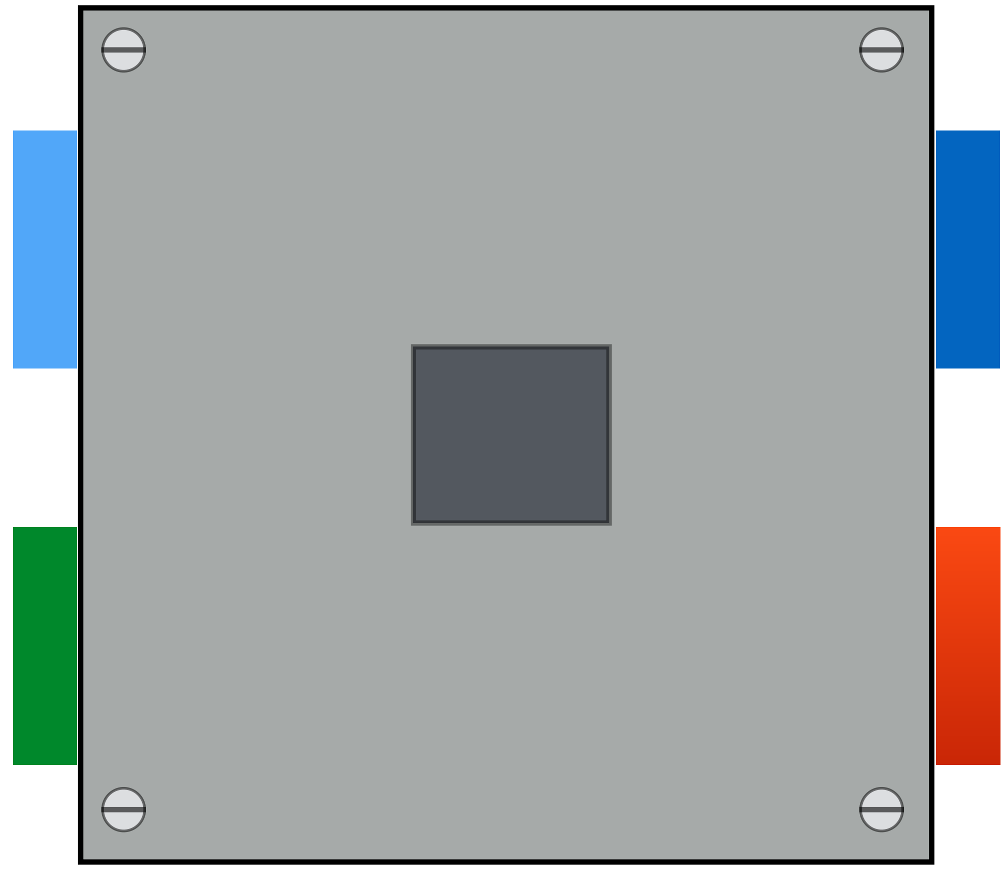
Window

Cooling System

Water In
Water Out

Pressure Valves

Valve Flush
Valve Exhaust



Quad Connection

4 x RJ45 Data lines
1 x LV Molex connector
1 x Lemo HV connector
4 x Lemo HitOr lines

Environment Monitoring

NTC temp sensor
SHT15 humidity sensor

Front and back plate of container screw together to seal environment, but expose ‘blocks’ containing required connectors

Mechanism on two sides to connect directly to ‘slide system’.
—> Symmetry allows for easy rotation

Cooling Test Experiment

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