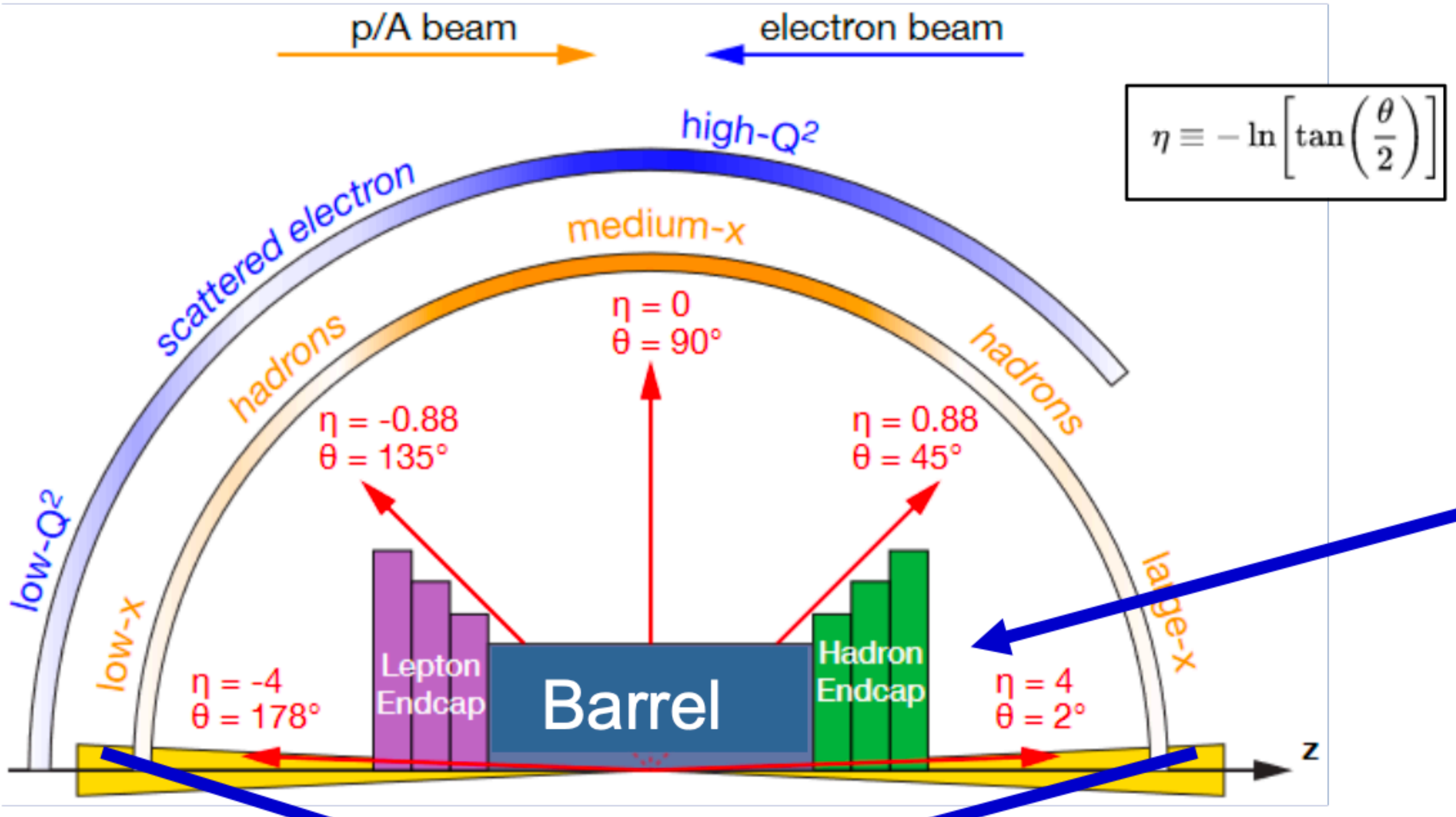
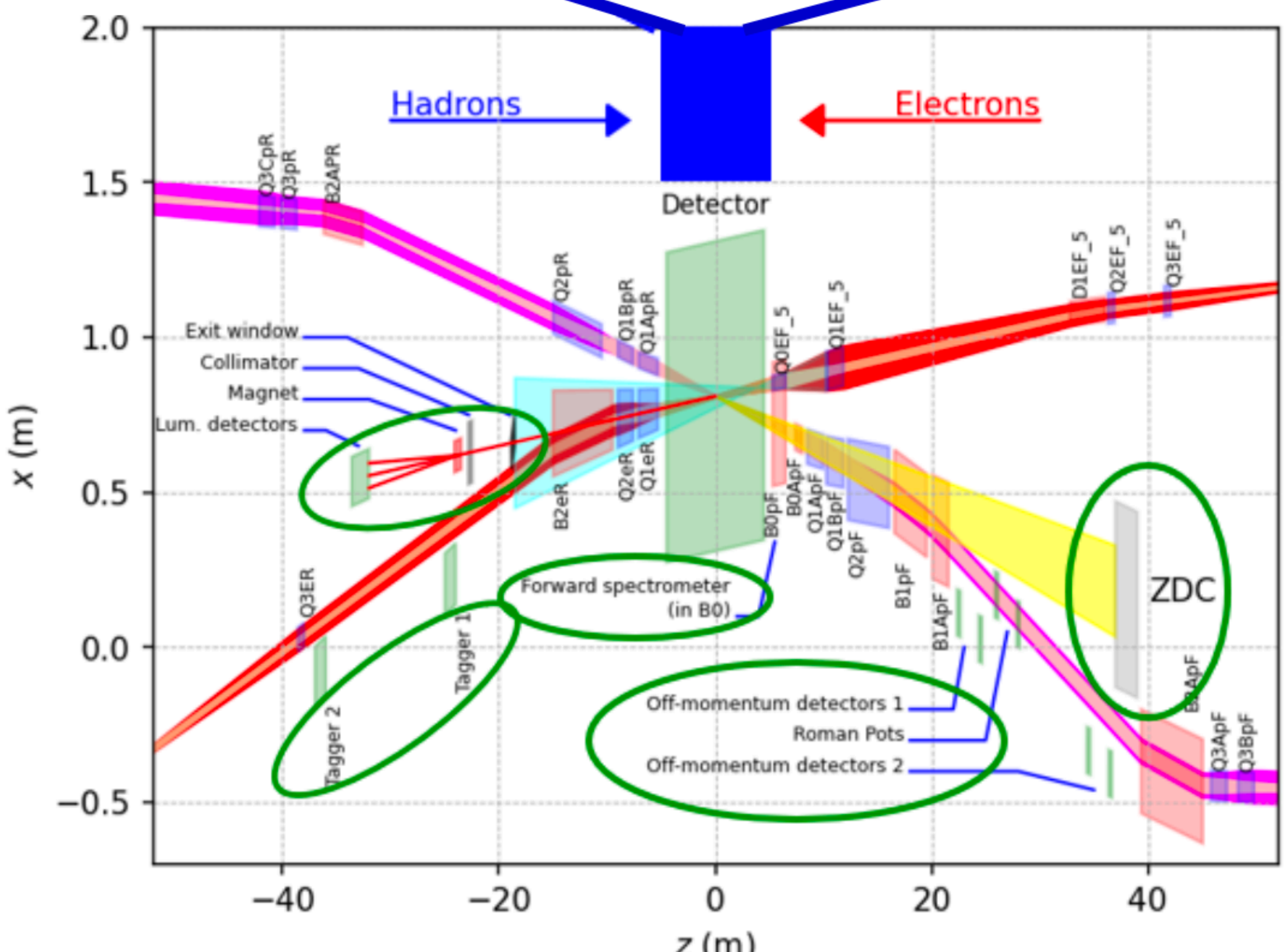
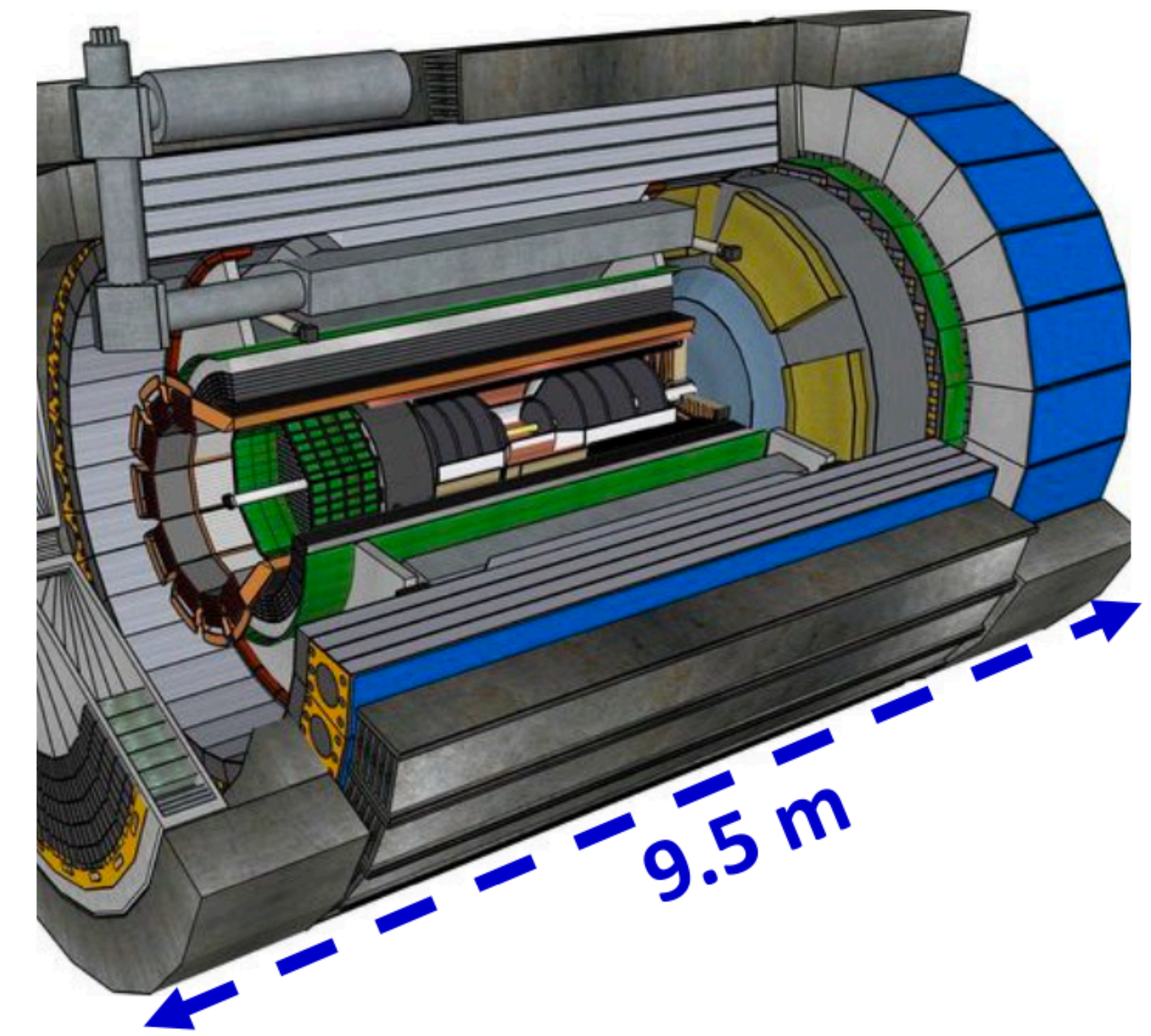
The SVT for the ePIC experiment
project overview and plans for the MIT group

MITHIG group meeting
August 23nd 2023

The ePIC detector at the Electron–Ion Collider





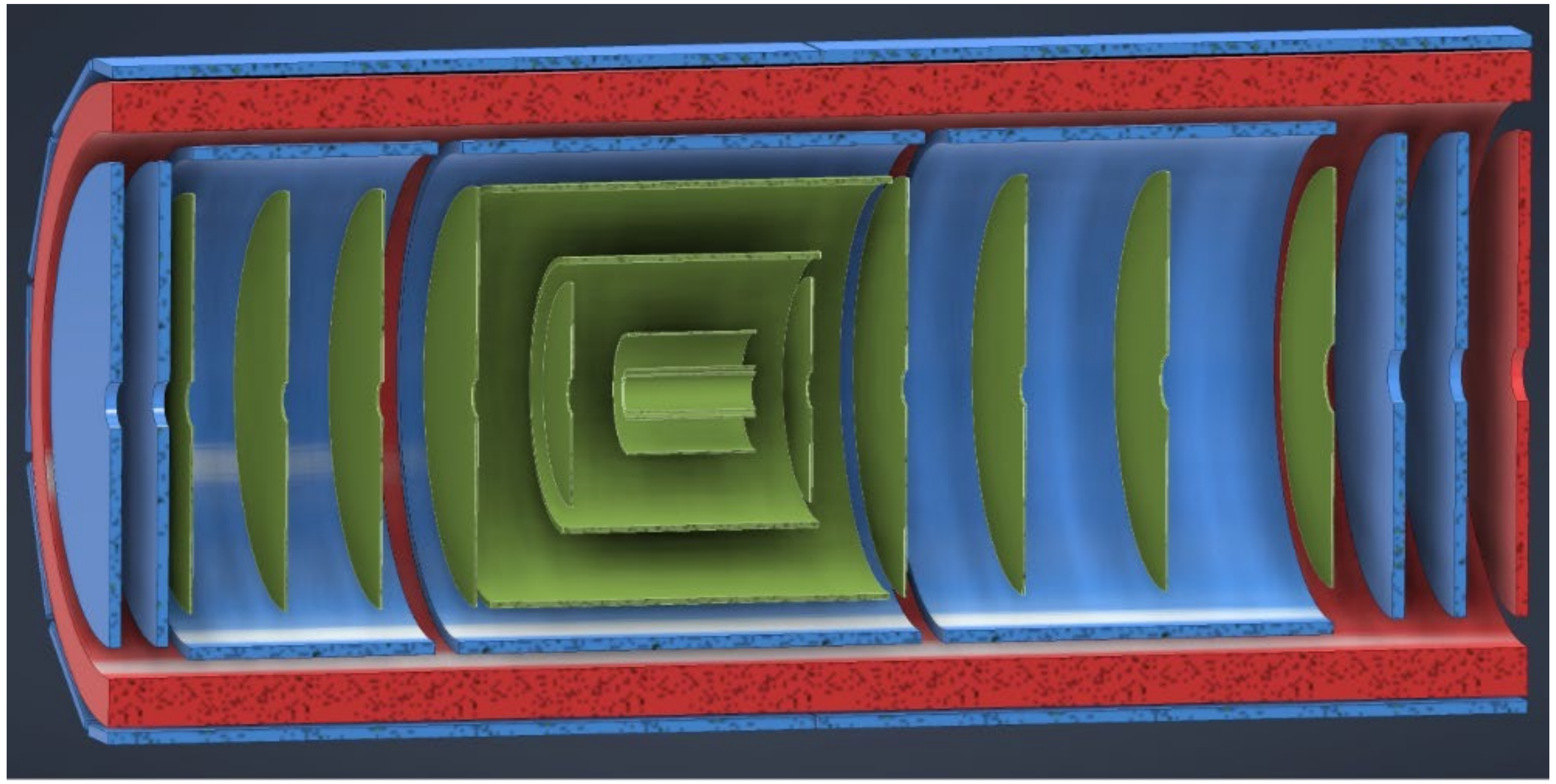


- **Total size detector**: ~75m
- **Central detector:** ~10m
- **Far Backward** electron detection: ~35m
- **Far Forward** hadron spectrometer: ~40m
- Auxiliary detectors to tag particles at small angles in the lepton and hadron outgoing direction

ePIC tracking: challenges and strategies

Challenges:

- Complex pattern recognition
- Strong requirements on material budget
- large background with “low” interaction rate (< 0.5 GHz)



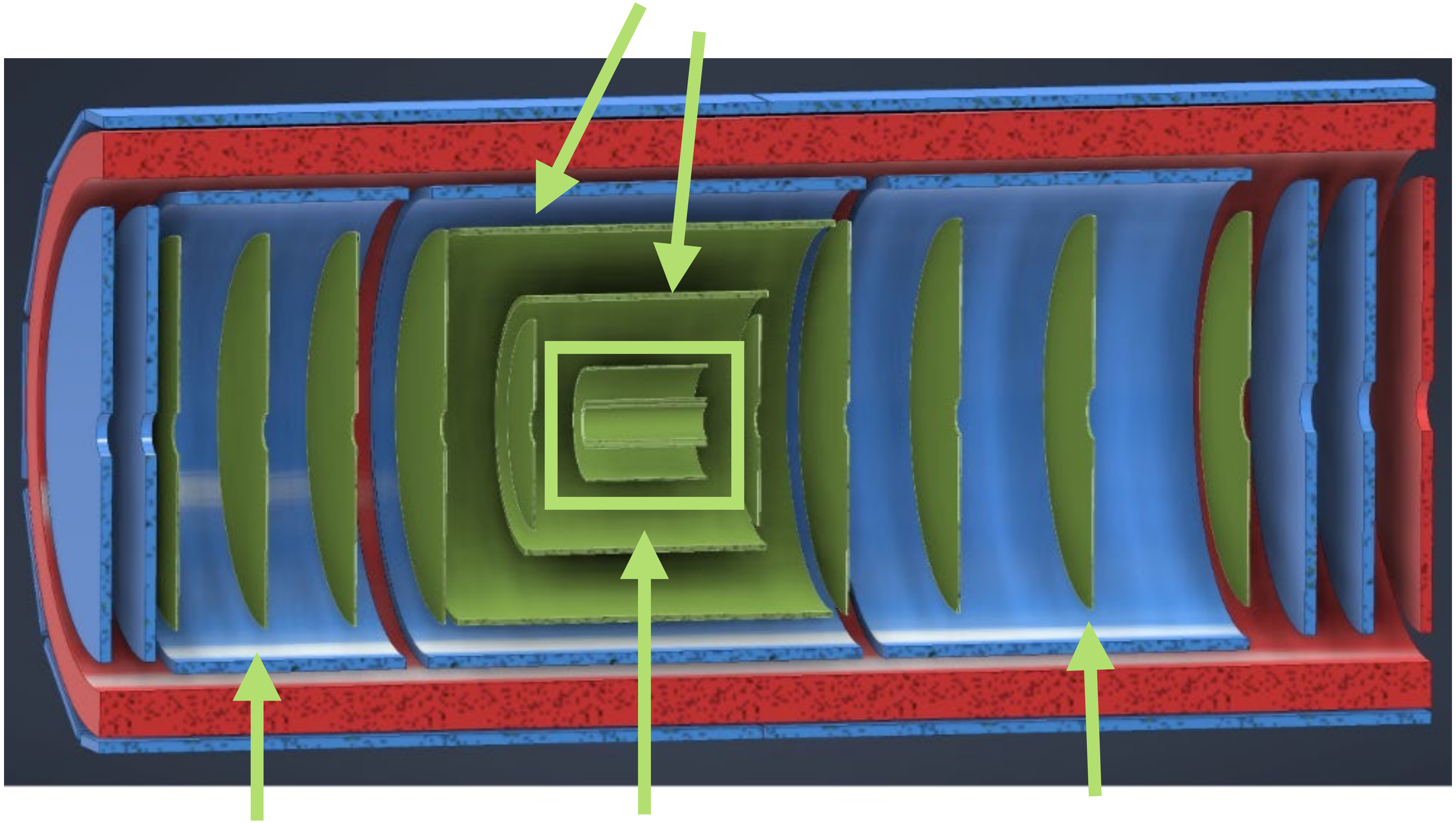
SVT MPGDs ToF (fiducial volume)

Strategy:

- Redundancy of the measured space point coordinates
- Extra time resolution from ECal, barrel ECal, RICH:
  → disentangle signal and background
- **Silicon Vertex Tracker:** “fast” Monolithic Active Pixel Sensors (MAPS) for high-resolution and low material budget

The SVT ePIC detector (in green)

total area of ~8.5 m^2



SVT outer layers

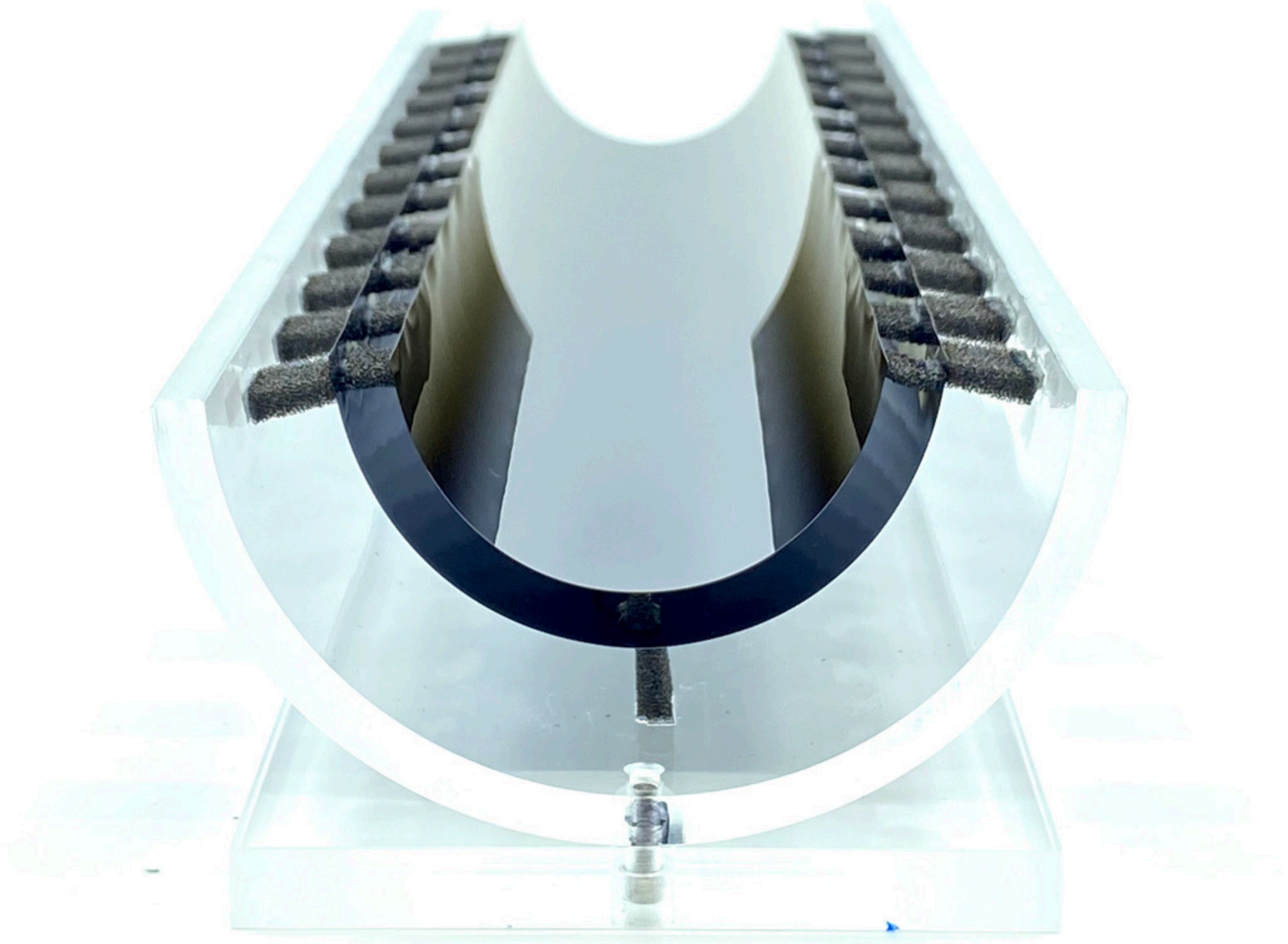
SVT disks

SVT inner barrel

SVT disks

The ITS3 pixel technology for the SVT

ALICE ITS3 Letter of Intent: ALICE-PUBLIC-2018-013
ALICE ITS3, arXiv.2105.13000
ALICE ITS3, arXiv.2212.08621



Prototype for the
ITS3 upgrade

ITS3: ultra-light ("massless") sensors with <0.05 X_0

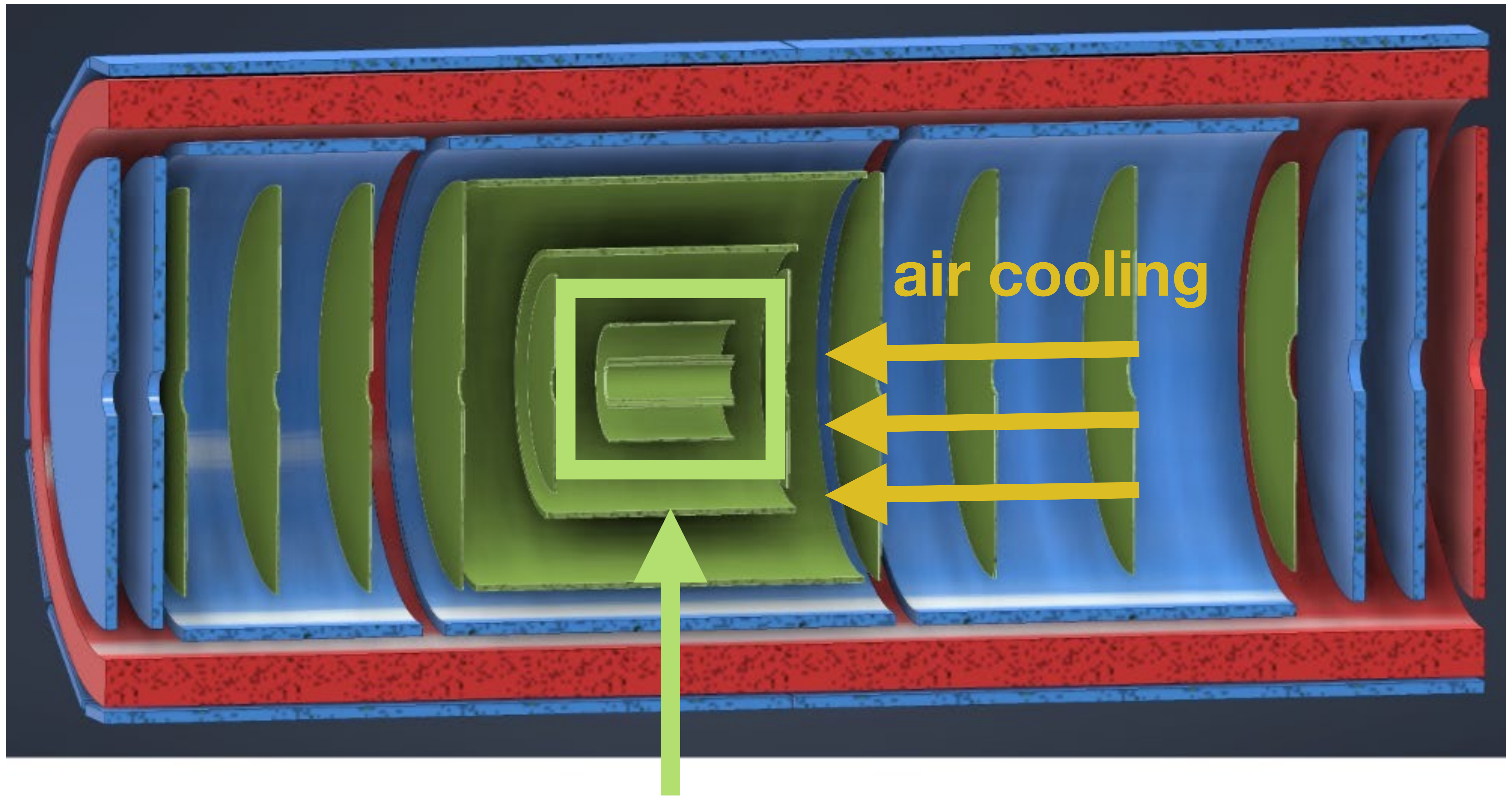
- large sensors **with "stitching" techniques**
- **"bendable" when thinned** below ~20-40 µm

→ Impact parameter resolution of a few µm for $p_T \sim 1$ GeV

ITS3 fulfills ePIC requirements in terms of spacial resolution and material budget:

→ **Challenge:** ITS3 readout is "slow" for ePIC, dedicated R&D is needed!

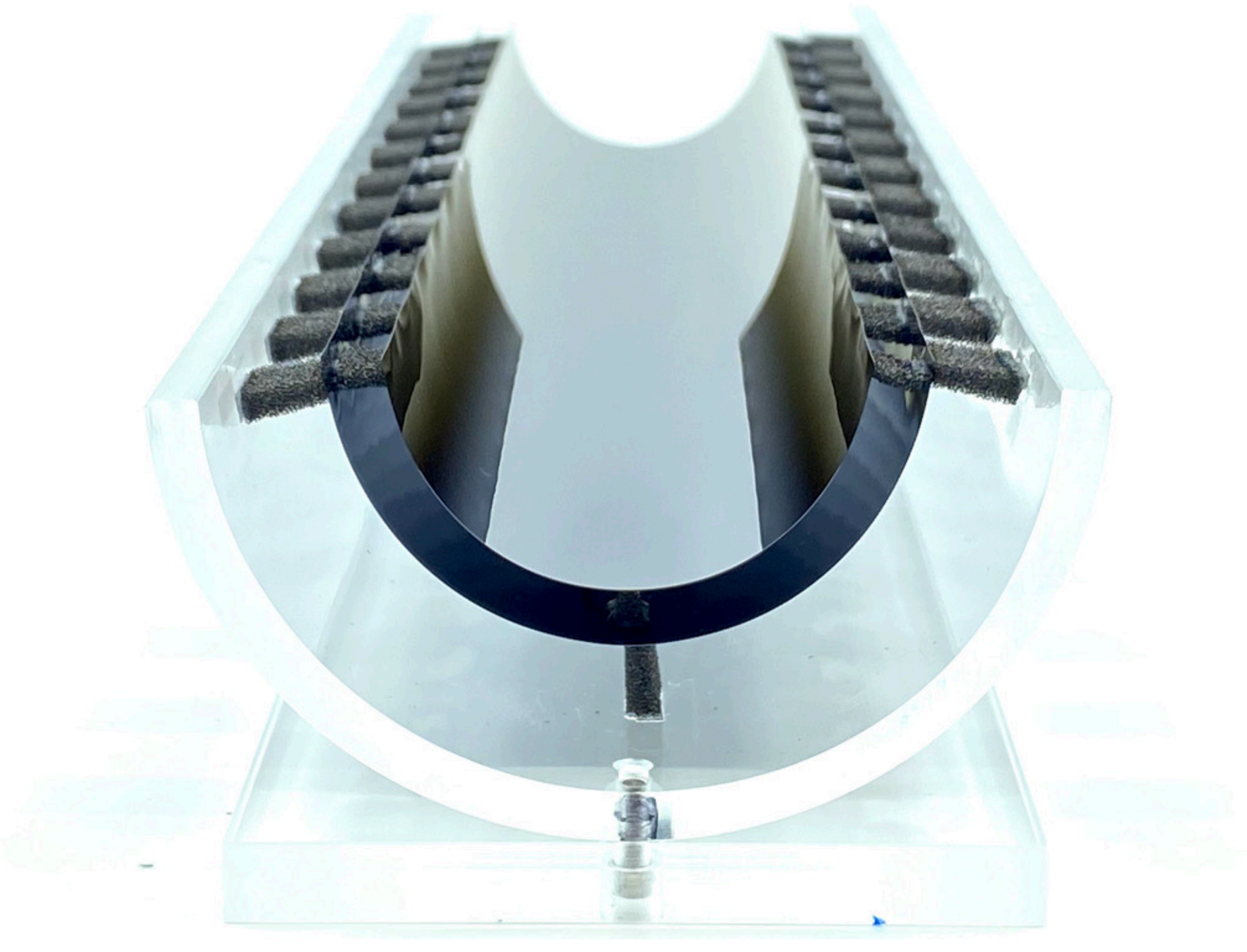
The SVT inner barrel ("bent" layers 0, 1, 2)



SVT inner barrel

- built with **bent ITS3 wafer-size sensors**
- minimal support structure (carbon foam)
- air cooling (~ few m/s)

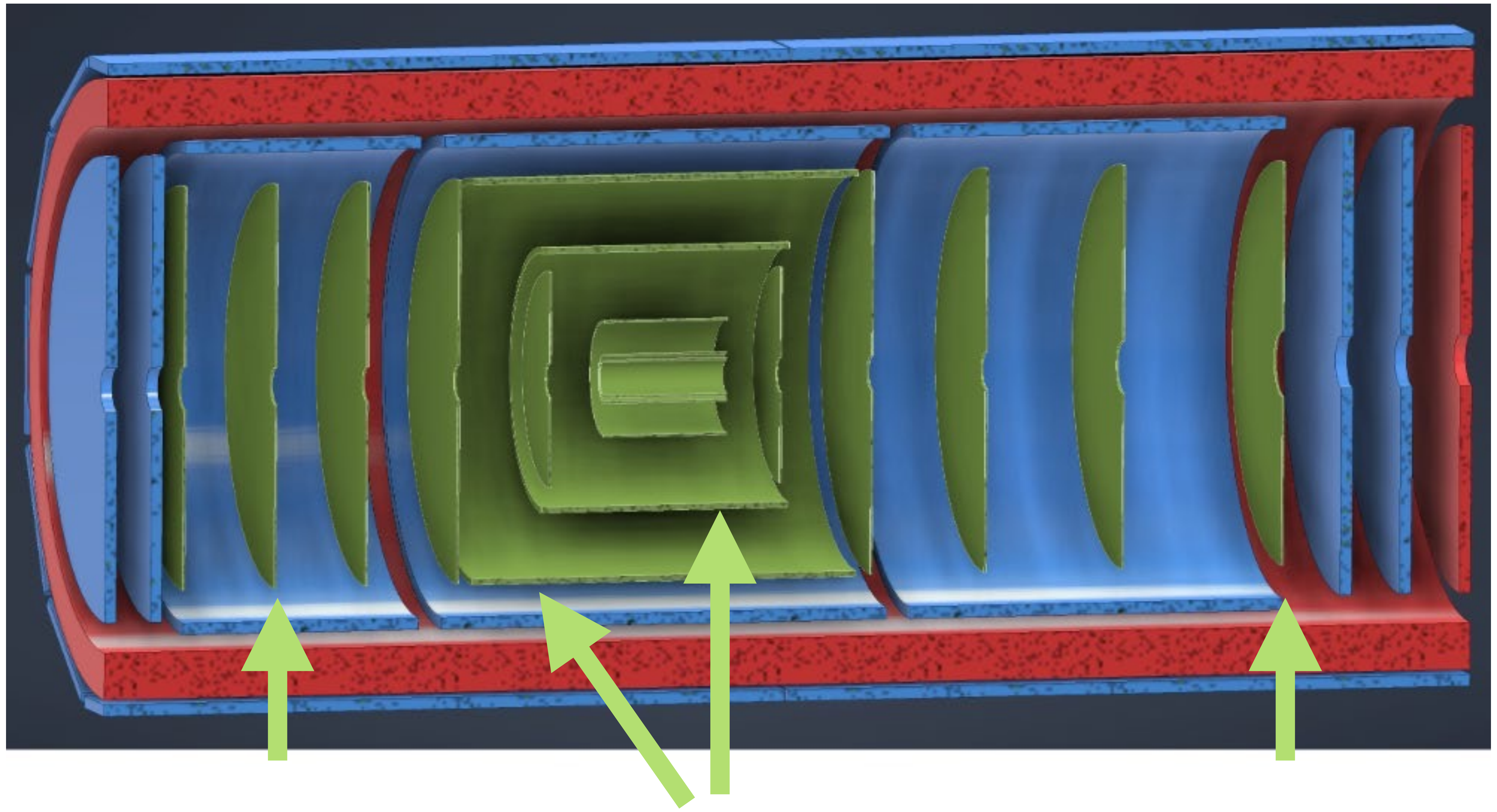
- **Radii = 3.6, 4.8, 12 cm**
- **Lengths = 27 cm**



ePIC specific needs:

- reduce services at forward/backward
- Mechanical stability ($R_{\mathrm{ITS3}}^{\mathrm{max}}$ is only 4 cm!)
- air cooling strategy is more challenging due to the presence of the disks

The SVT outer barrel (layers 3, 4) and disks



SVT disks SVT outer layers SVT disks

“Flat” Large Area Sensors (LASs) derived from ITS3 optimised for covering large surfaces

- **traditional staved** structure (not bent)
- carbon fibre support
- integrated cooling (liquid or air)

Challenges:

- keep low material budget in the presence of carbon fiber supports and services
- disk geometry can obstruct air cooling for the inner barrel
- tight schedule for a new sensor development!

MIT plans for the SVT detector

Long-term plan

Stage 1) ALICE - SVT R&D effort at CERN → characterization of the ITS3 sensors

Stage 2) R&D for the ITS3/SVT readout and SVT mechanics of the inner layers with contributions to the sensor design

Stage 3) Production and testing, installation, and commissioning of the three innermost layers

EIC first collisions

EIC data-taking for physics

Stage 3

Stage 2

Stage 1

2023

2024

2025

2026

2027

2028

2032

2035

ER1 sensor on bench

ER2: full sensor available

ER3: full detector available

← **Timeline for the ITS3 ALICE**

An engineering run (ER) is a prototype used to benchmark the sensor performance and test new solutions

Plans for 2023: past and current

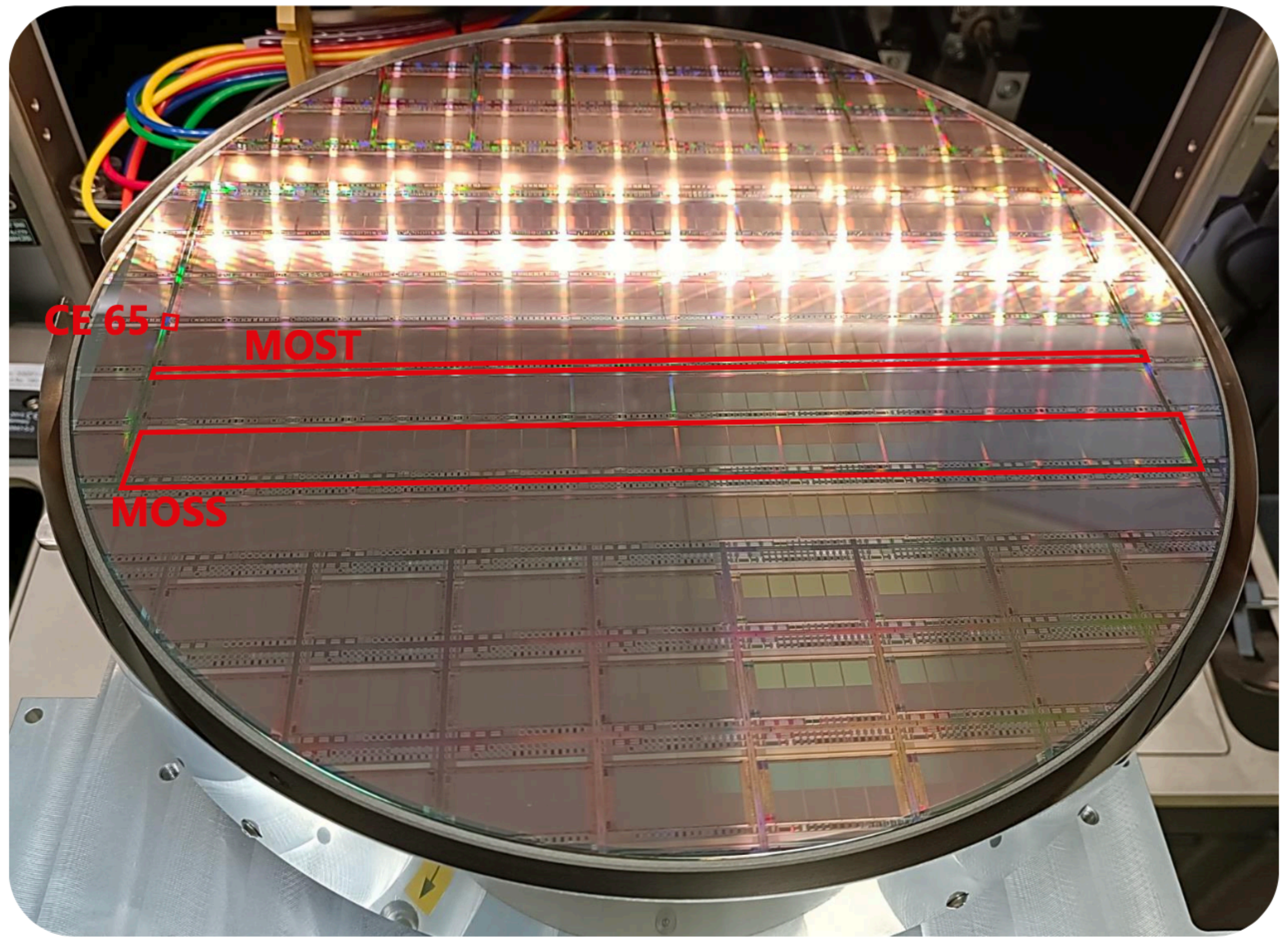
(Past few months) **Equip a MIT-pixel laboratory at CERN**

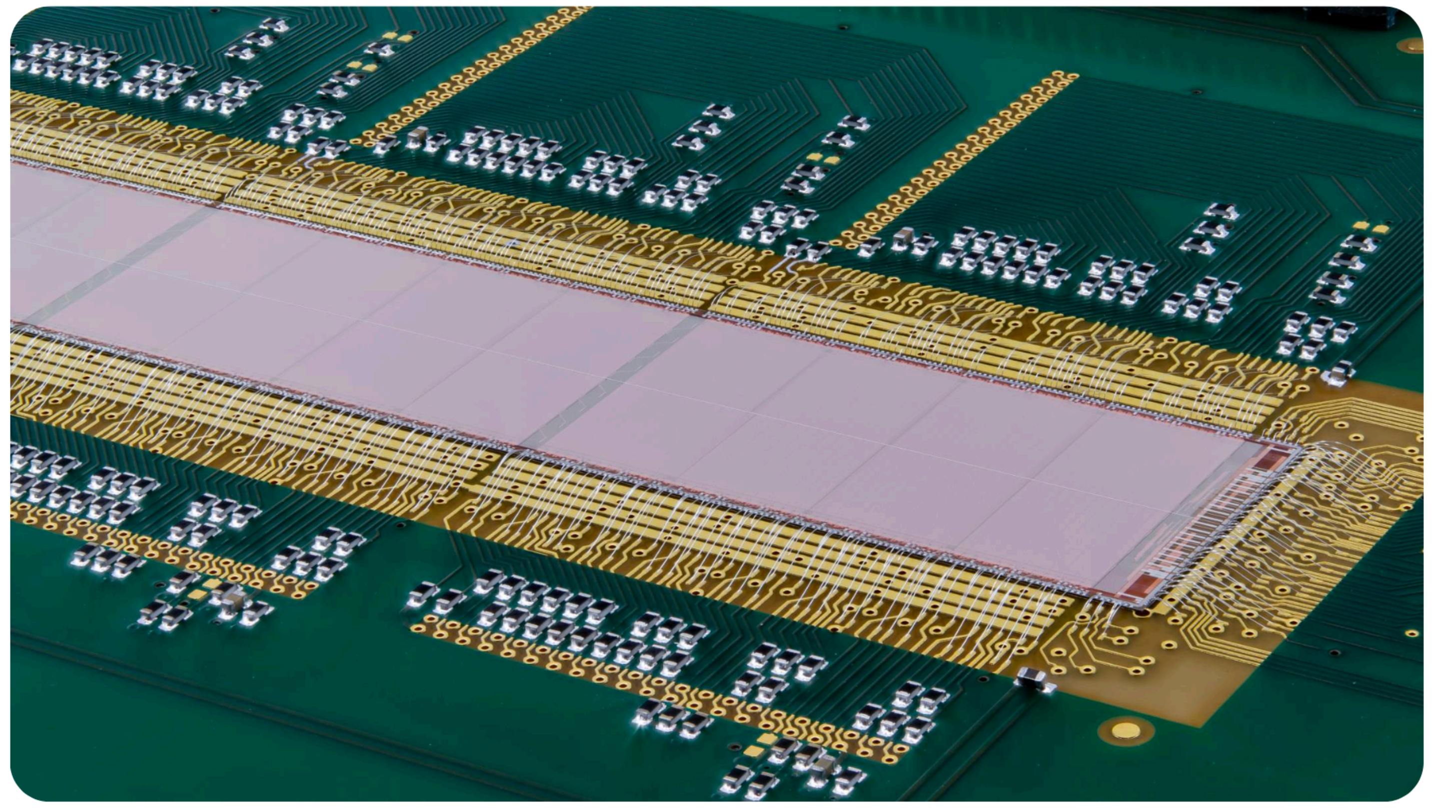
- **Lab equipment purchased or being purchased:**
  - Power supplies, cables, photosensors, phototubes
  - trigger board, test beam setup, …
  - **A state-of-the-art wafer probe machine** to test 300mm silicon wafers (“readiness” for fully automatic tests at low/high temperature)

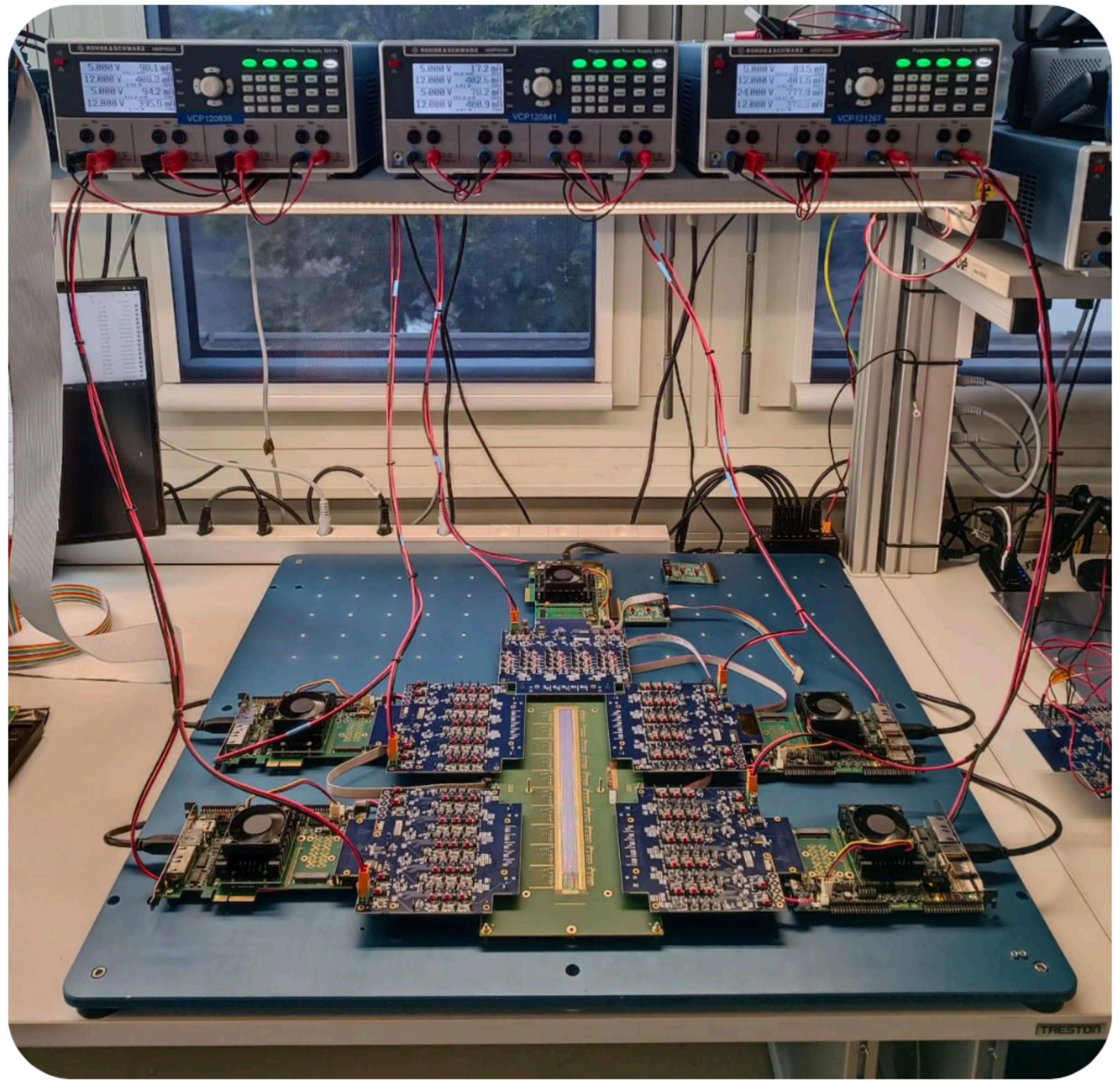
- **(June-July 2023)** **Integration of the MOSS readout in the test-beam software** (MOSS = new bendable chip from the latest stiched bent sensor production, ER1)

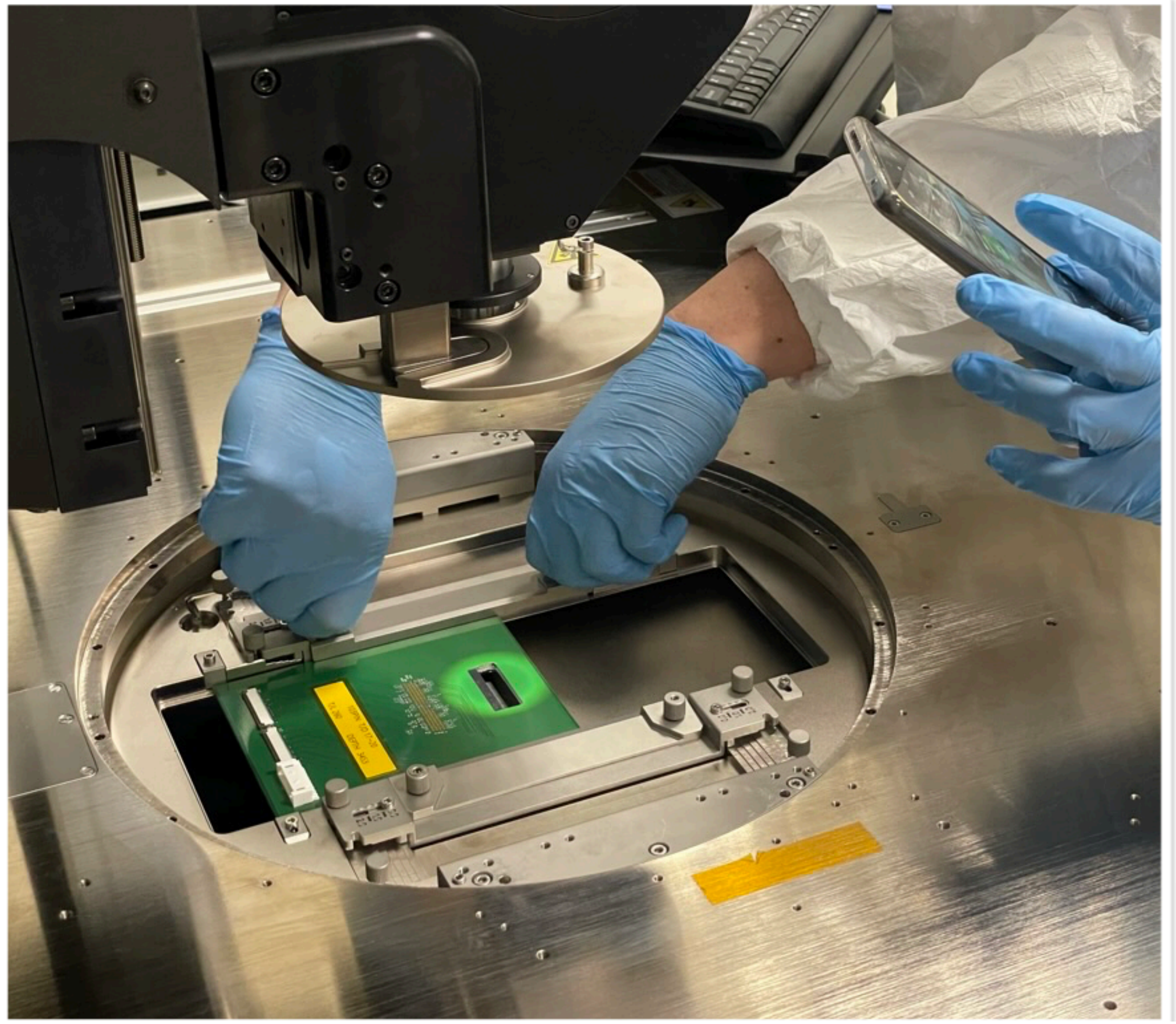
- **(August 2023 -December 2023)** **Lead the first test beams with the MOSS chip**
  - Beam tests in different facilities (PS, DESY)

Plan for 2024-2025: ER1/ER2 sensor characterization at CERN









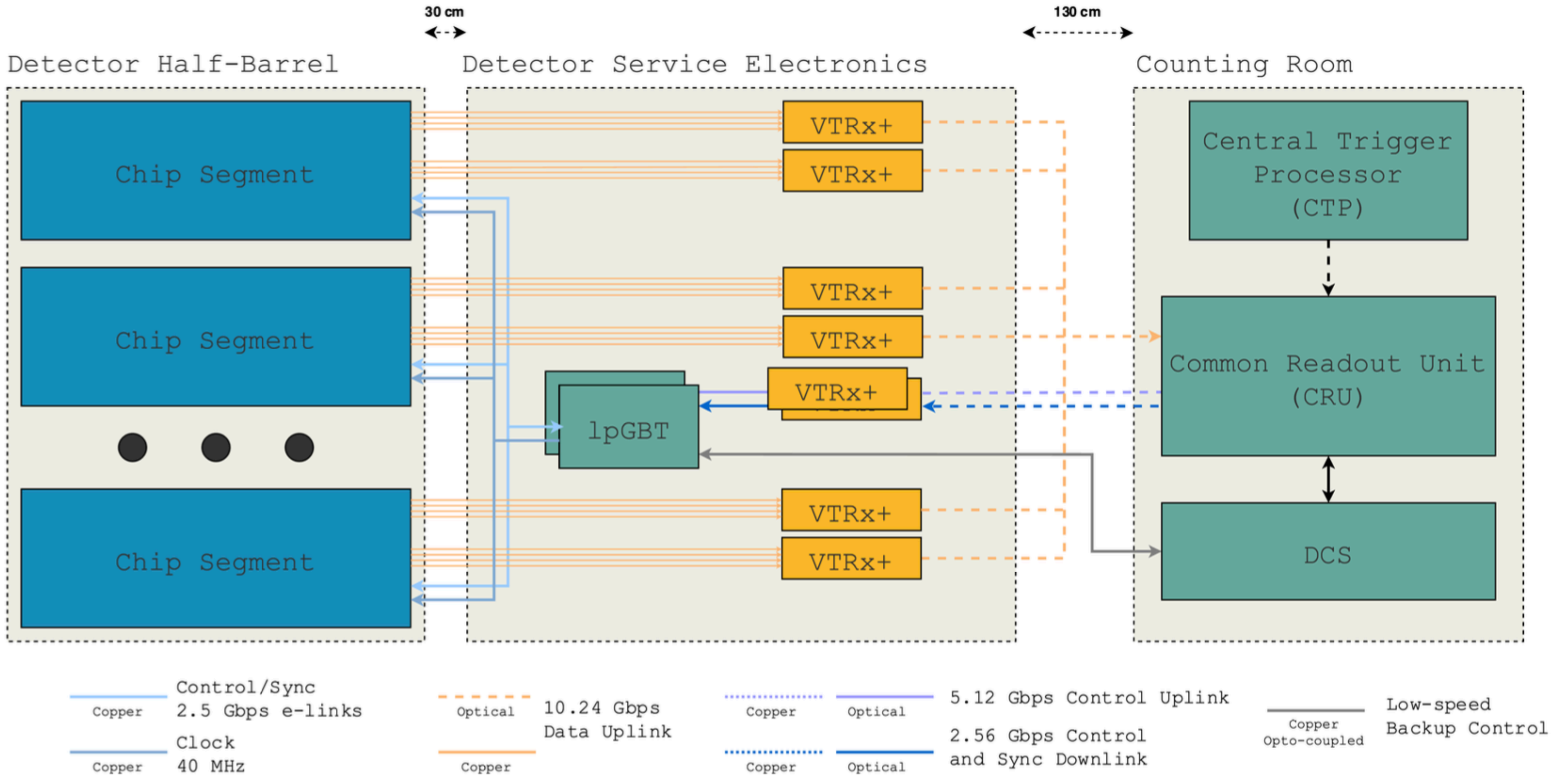
with **DAQ setup**, **wafer probe station** and test beams

Goals

- Test powering/communication and basic readout
- Characterize performance in terms of signal yields, resolution, efficiency, cluster size before and after irradiation

G. H. Eberwein, ITS3 WP3 weekly 11 Jul 2023
V. Sarritzu, ITS3 WP3 weekly 11 Jul 2023

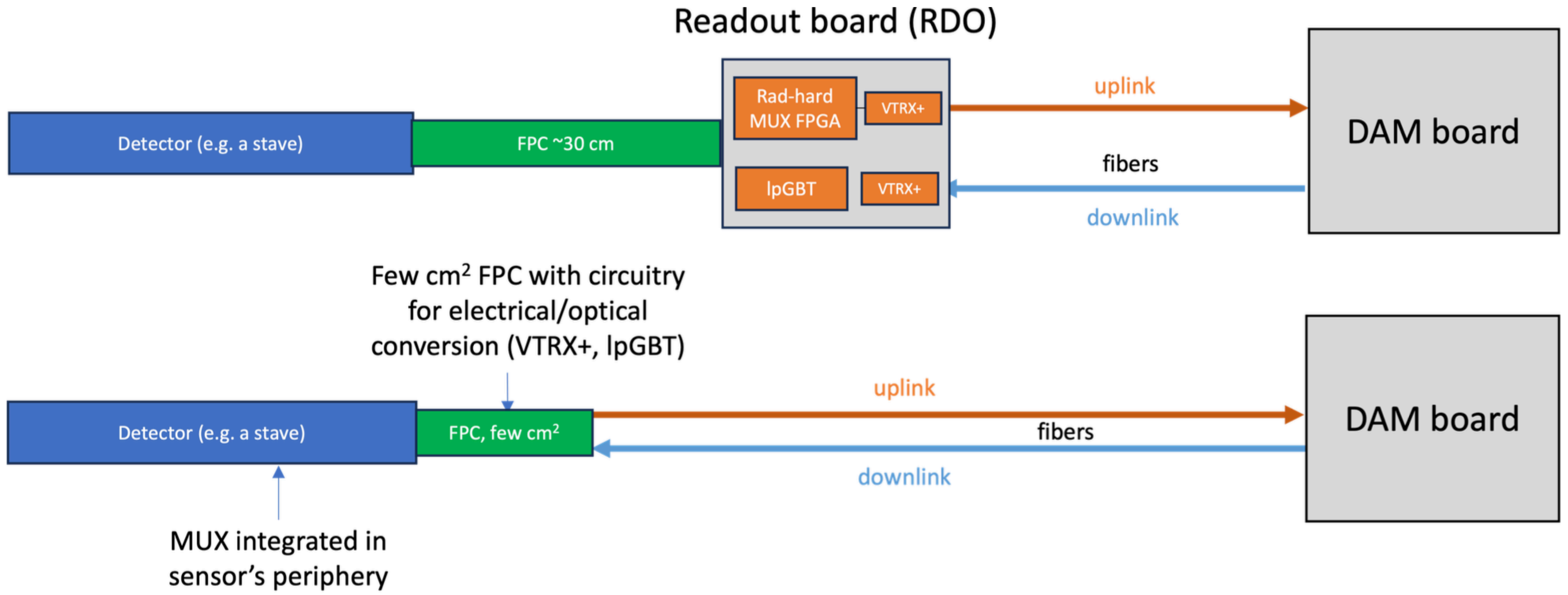
Plan for 2024–2025: readout for ITS3 and SVT



Contribute to the R&D for ER2 readout at CERN

- Control board (PCB)
- Interface board (VTR+)

F. Reidt, ITS3 Plenary 30 June 2023



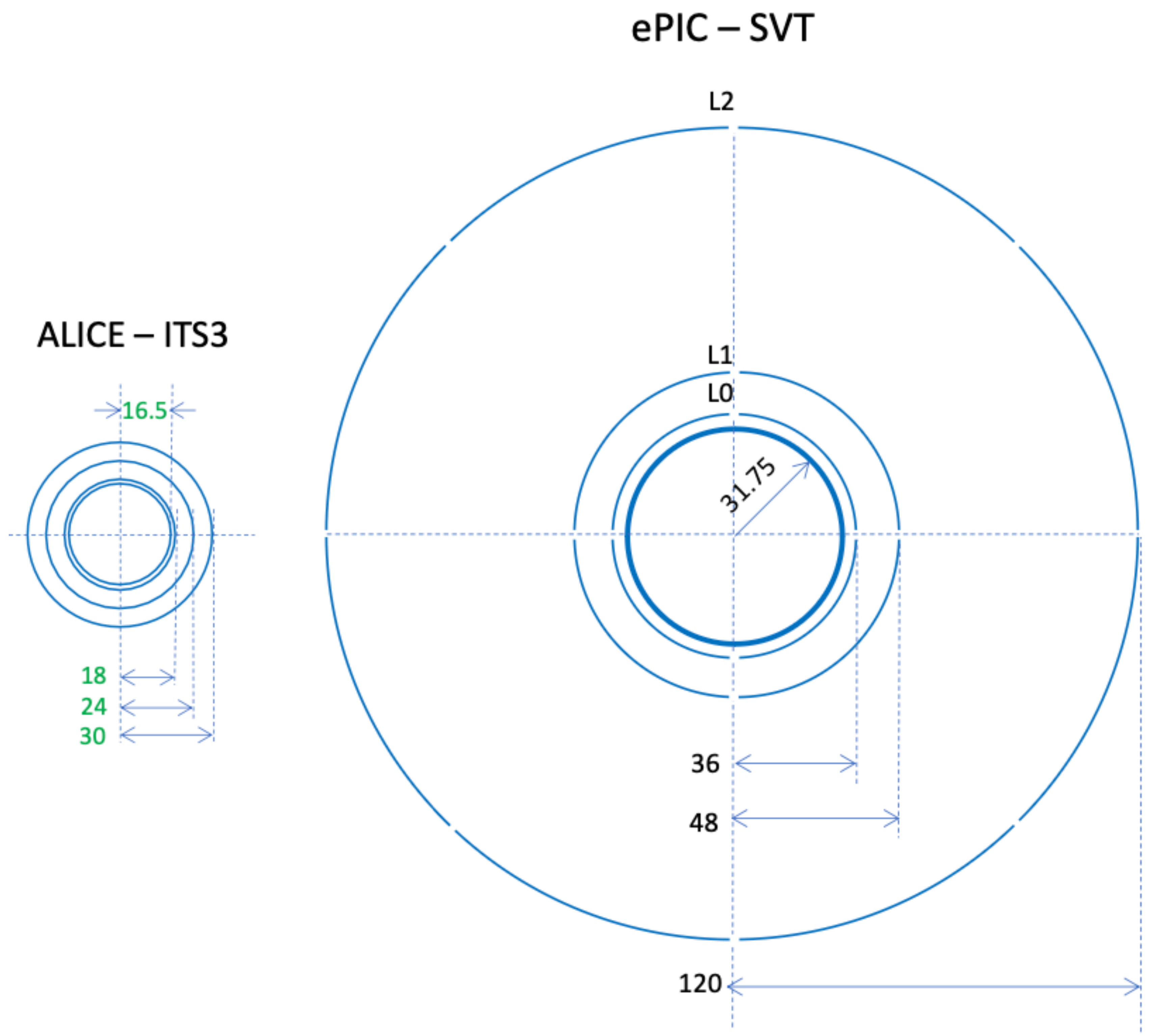
L. Gonella, ePIC collaboration meeting, 27 July 2023

Design and optimize the SVT readout strategy

- multiplexing strategy for the output links of the EIC LAS
- Multiple 10 Gbps links (ITS3), not needed for the (much lower) data rates at ePIC

Plan for MIT contribution to the SVT mechanics

Task: Design for the support structure of the inner barrel:
- stability for sensors bent at large radii (R=12cm). Bending and interconnection for R=12 is a challenge:
  - **is it enough to have additional ring-like structures or or do we need a whole cylindrical structure?**
- space for services
- Test each solution also in terms of alignment capabilities (challenging due to the absence of areas of sensor overlaps).



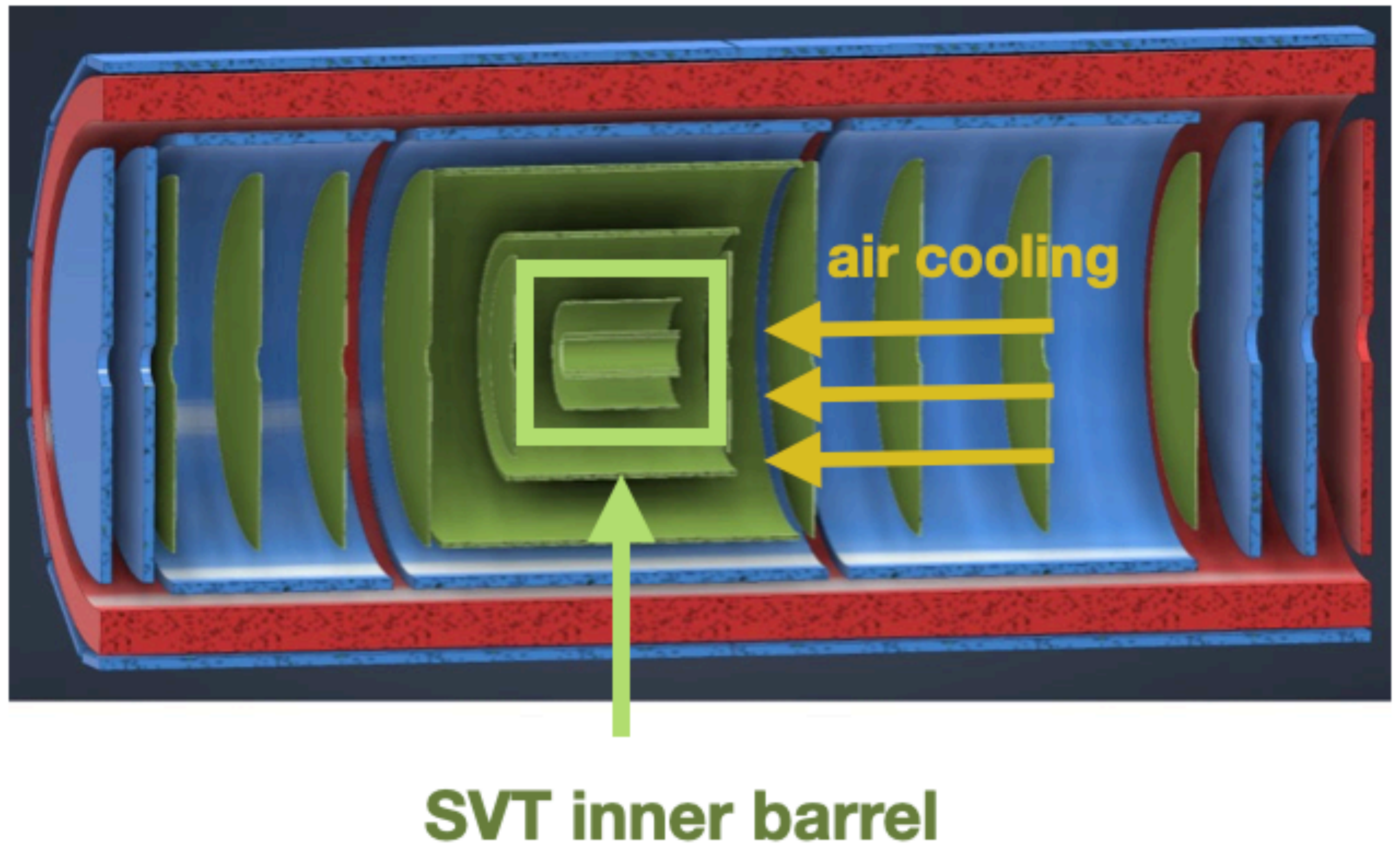
Plan for MIT contribution to the SVT mechanics

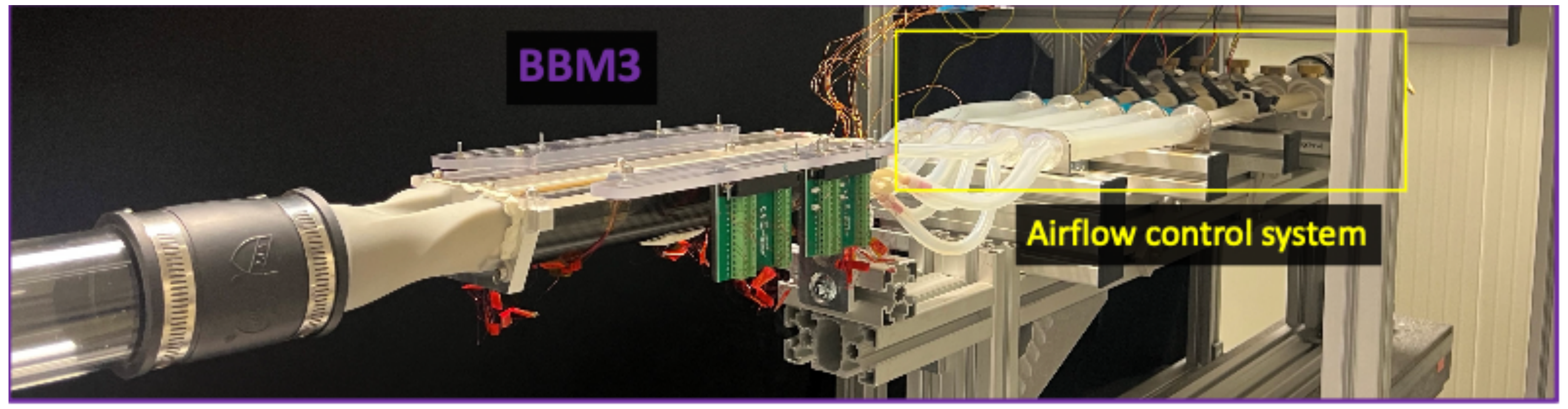
Task: Mechanical characterization of the sensor and impact of vibrations

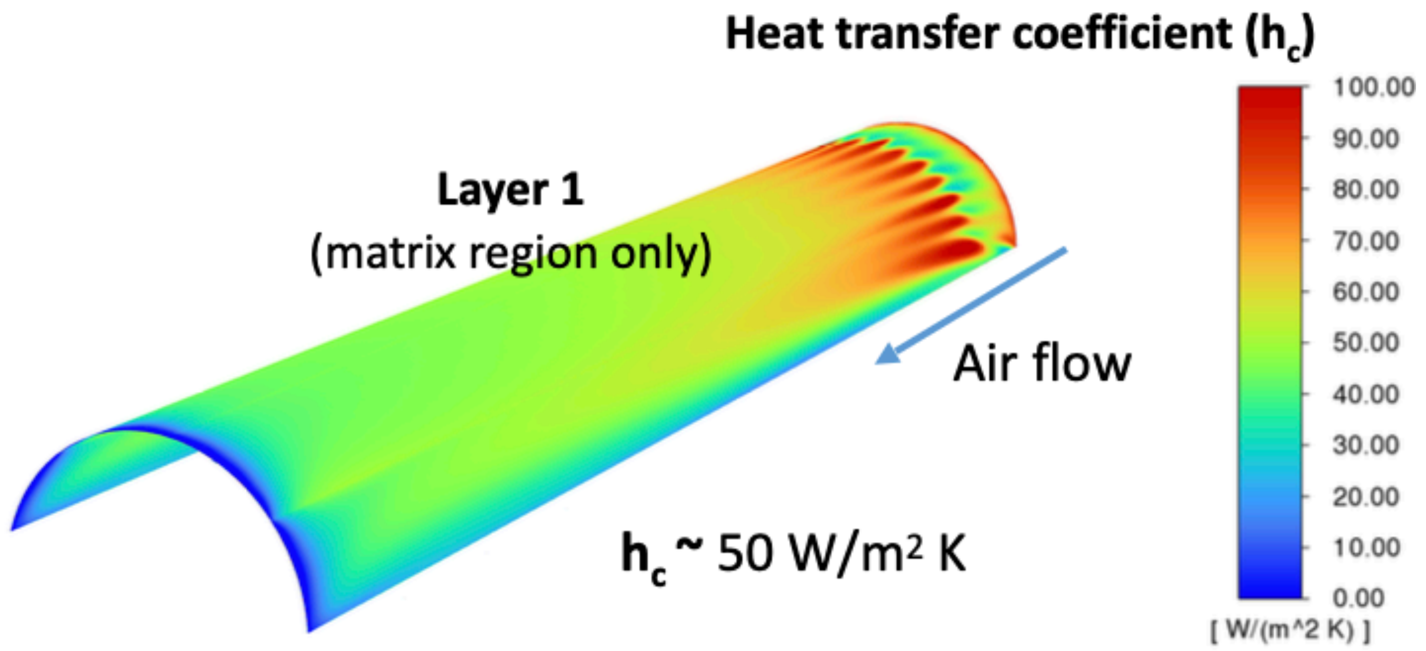
- **simulations to characterize the mechanical properties** of the sensor and evaluate impact of vibrations
- realize a dedicated **experimental setup (with a realistic silicon wafer placed in a wind tunnel) to test it in the lab**

Task: finalization of the cooling strategy.

- Realize a prototype of the inner barrel and the forward disks.
- Dedicated cooling tests will be performed in a wind channel
  → **how to channel air cooling for the inner barrel in the presence of disks?**
- By exploiting the same experimental setup, the group can provide help for the thermal characterization of the SVT detector.





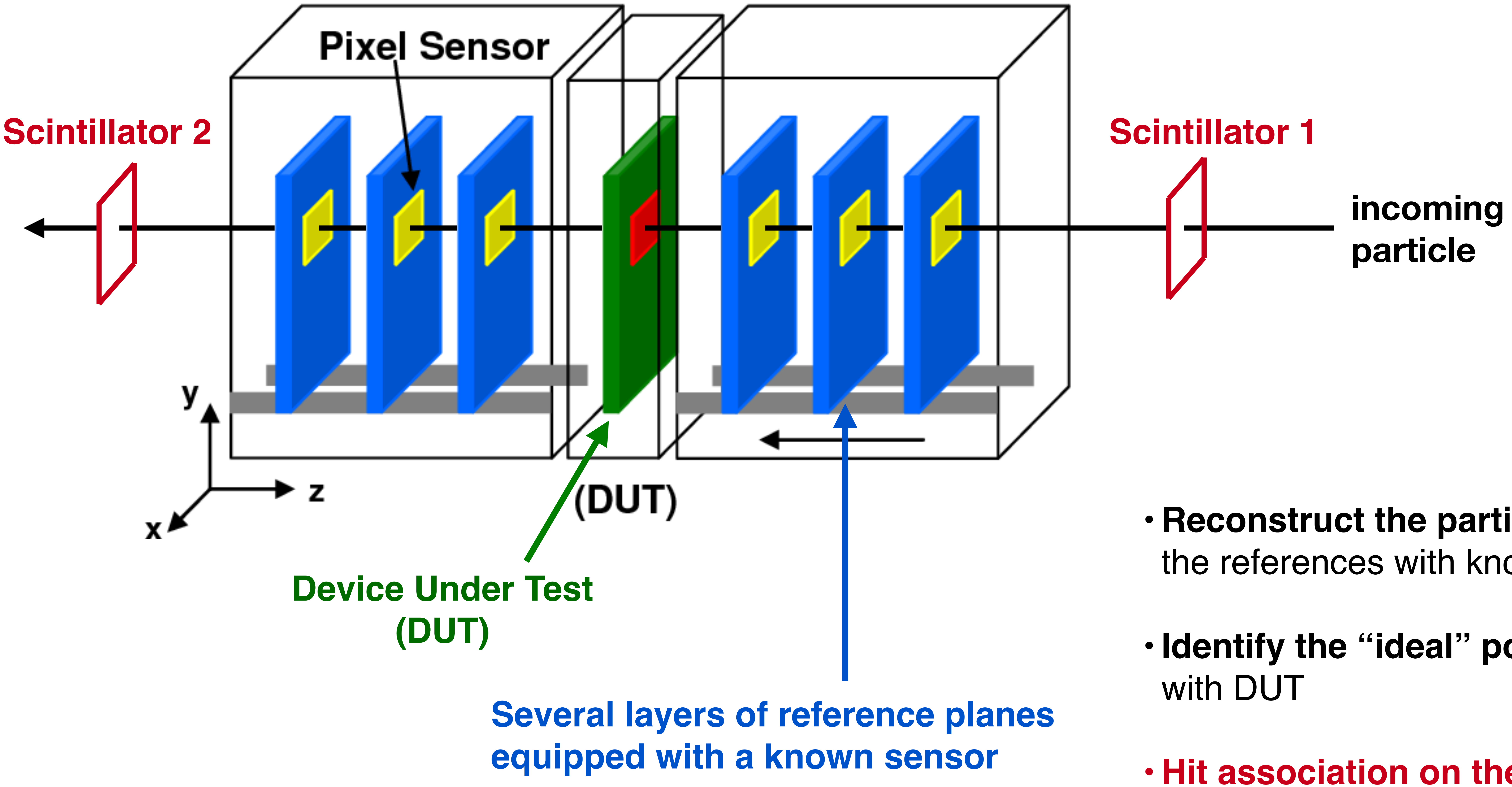


C. Gargiulo, ITS3 Plenary 30 June 2023

Additional material

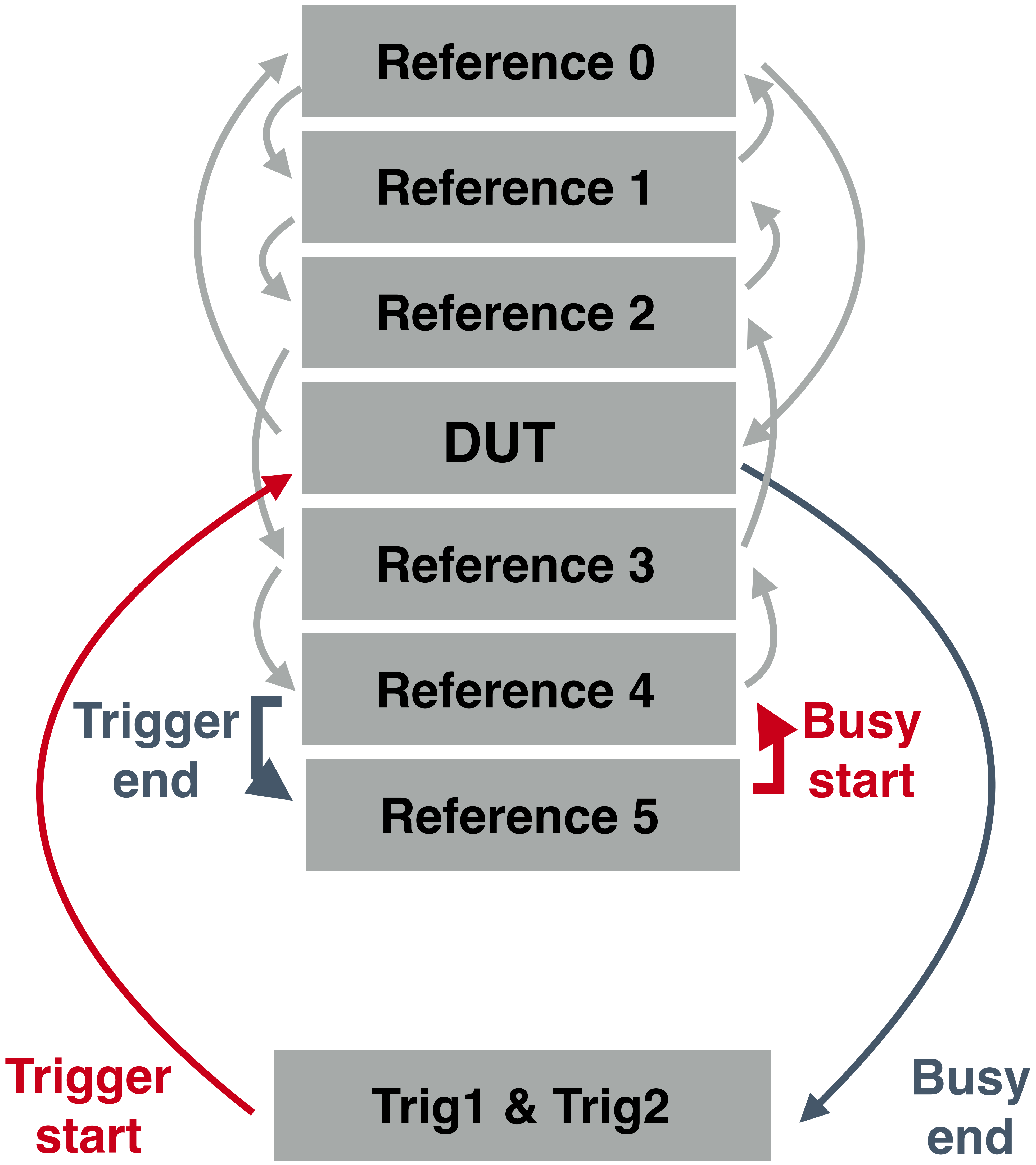
test beams with ALPIDE telescope

What is a telescope and how does it work?



- **Reconstruct the particle trajectory** using the references with known resolution
- **Identify the "ideal" point of intersection** with DUT
- **Hit association on the DUT** to estimate the DUT resolution and efficiency

Trigger/busy logic

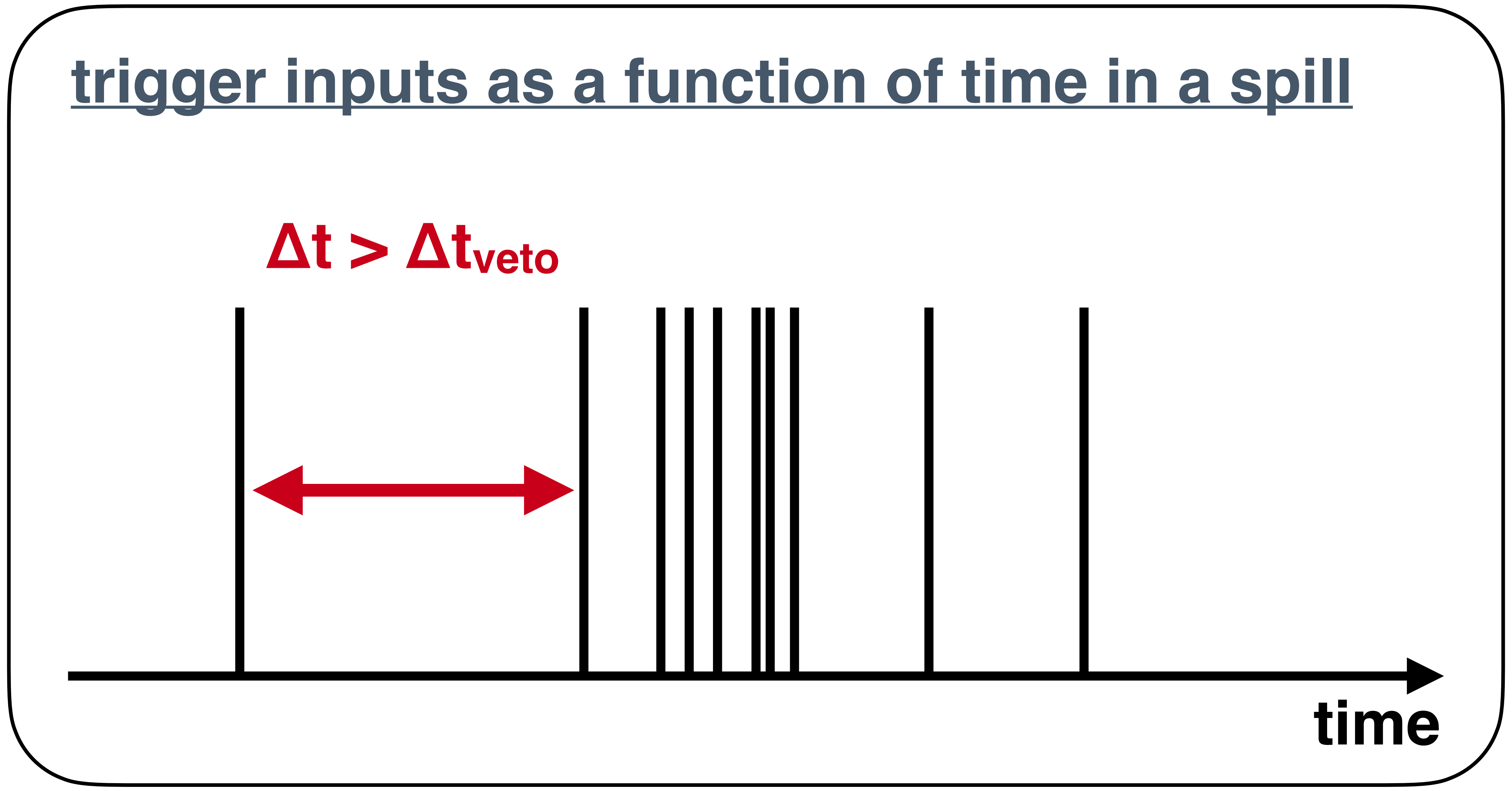


Trigger coincidence (PMT1 AND PMT2):

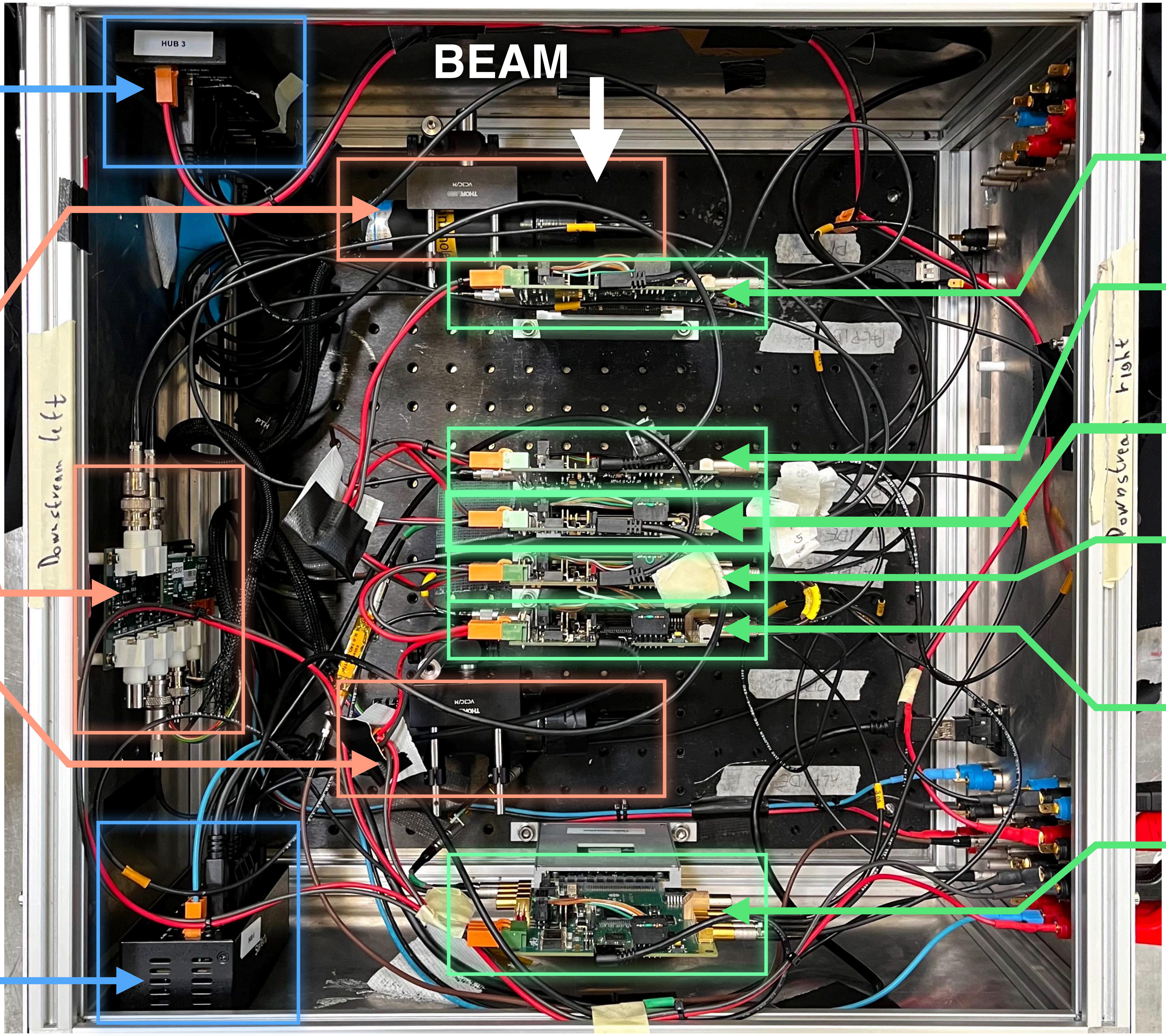
- logic end between the signals coming from the two PMTs

Trigger veto to mitigate pileup:

- accept a trigger only if no trigger input were received was received in a given time windows



Telescope setup



USB Hub

PMT2

Trigger Board
+ IceStick

PMT1

USB Hub

ALPIDE 5

ALPIDE 4

ALPIDE 3
(DUT)

ALPIDE 2

ALPIDE 1

ALPIDE 0

Telescope calibration, alignment and operation (summary)

Telescope installation at PS test-beam

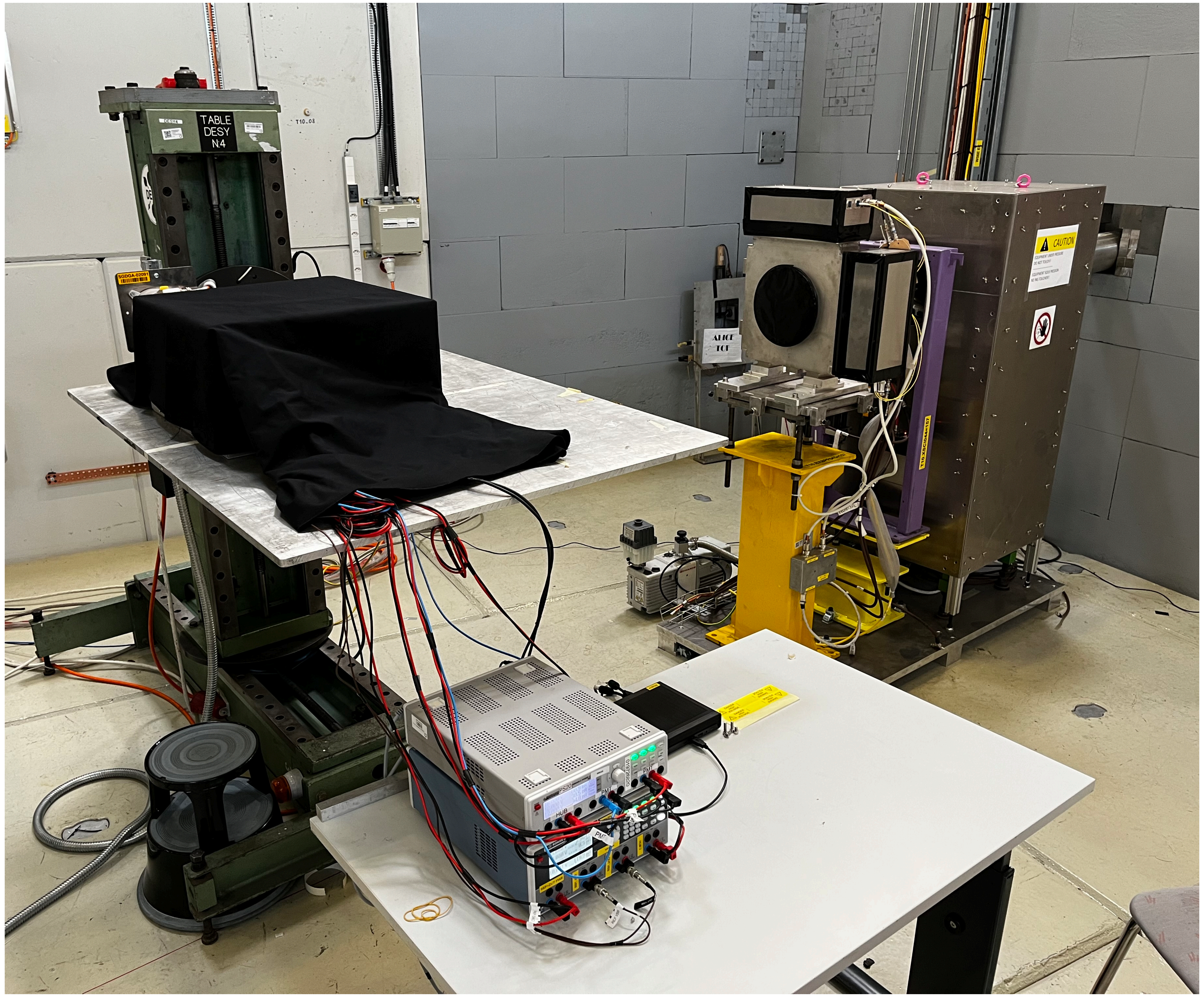
- First “manual” alignment with a laser
- Connect power, connect to the PC
- Refine alignment with beam + eudaq hit display

Calibration of the PMTs

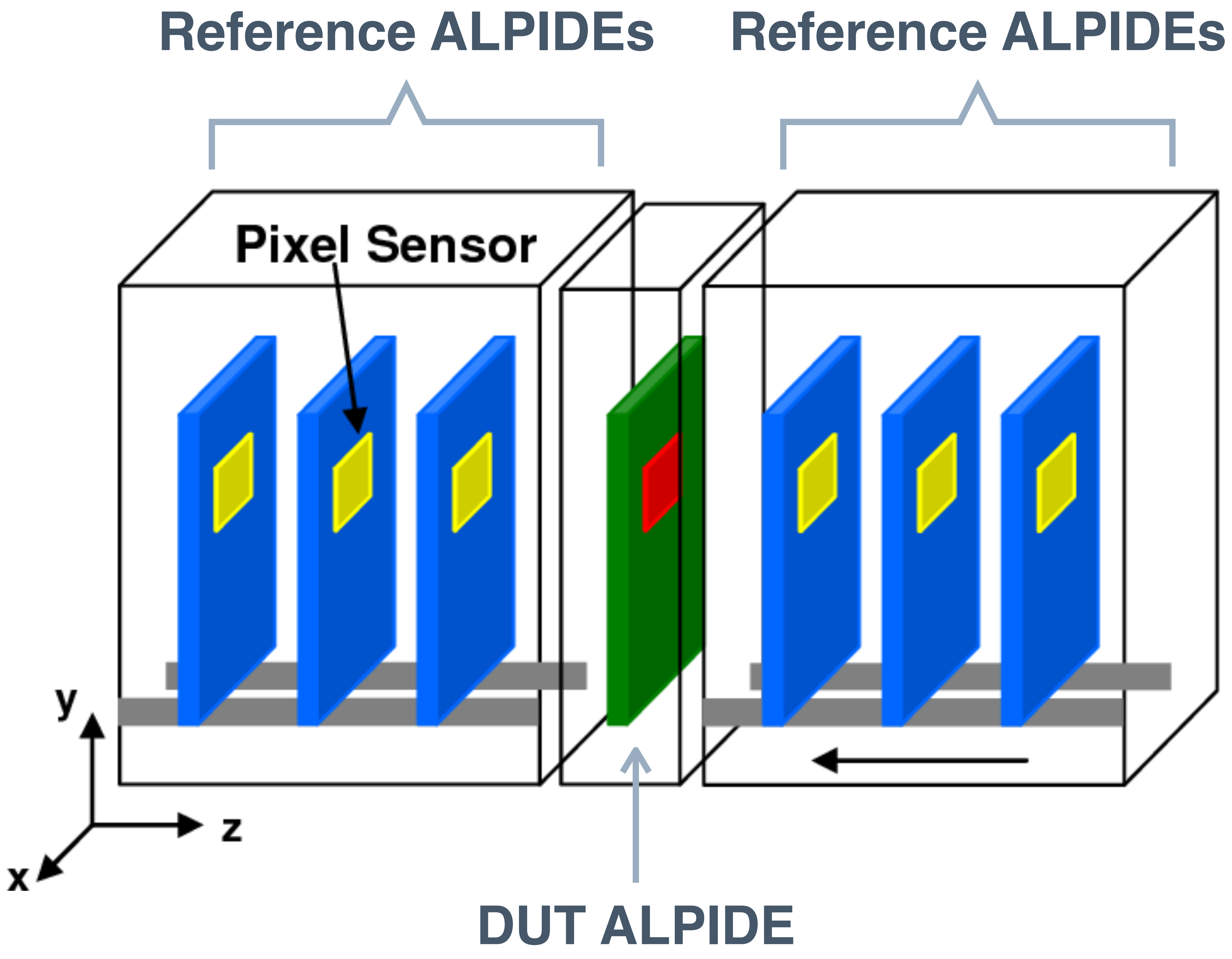
- Gain and threshold adjustment

Optimization of the veto time

- Improve rate of data taking
- Reduce pile-up in the reference + DUT planes



Data analysis: primary goals



1) ALPIDE VCASN scans (internal threshold)

- Data for range of VCASN values with vbb at 3V and 0V

2) ALPIDE data with vbb = 0V

- New data! ALPIDEs have not been characterized with this bias

3) Experiment and optimize process for MOSS test-beam

- Prepare for MOSS telescope
- Establish data collection and analysis pipeline

Overview of the data taking strategy

During Run: Checks with EUDAQ2

- Hit maps → Is telescope aligned to beam?
- Correlations → Are DUT + references working together?
- Hits per event → Reasonable? Pileup issues?

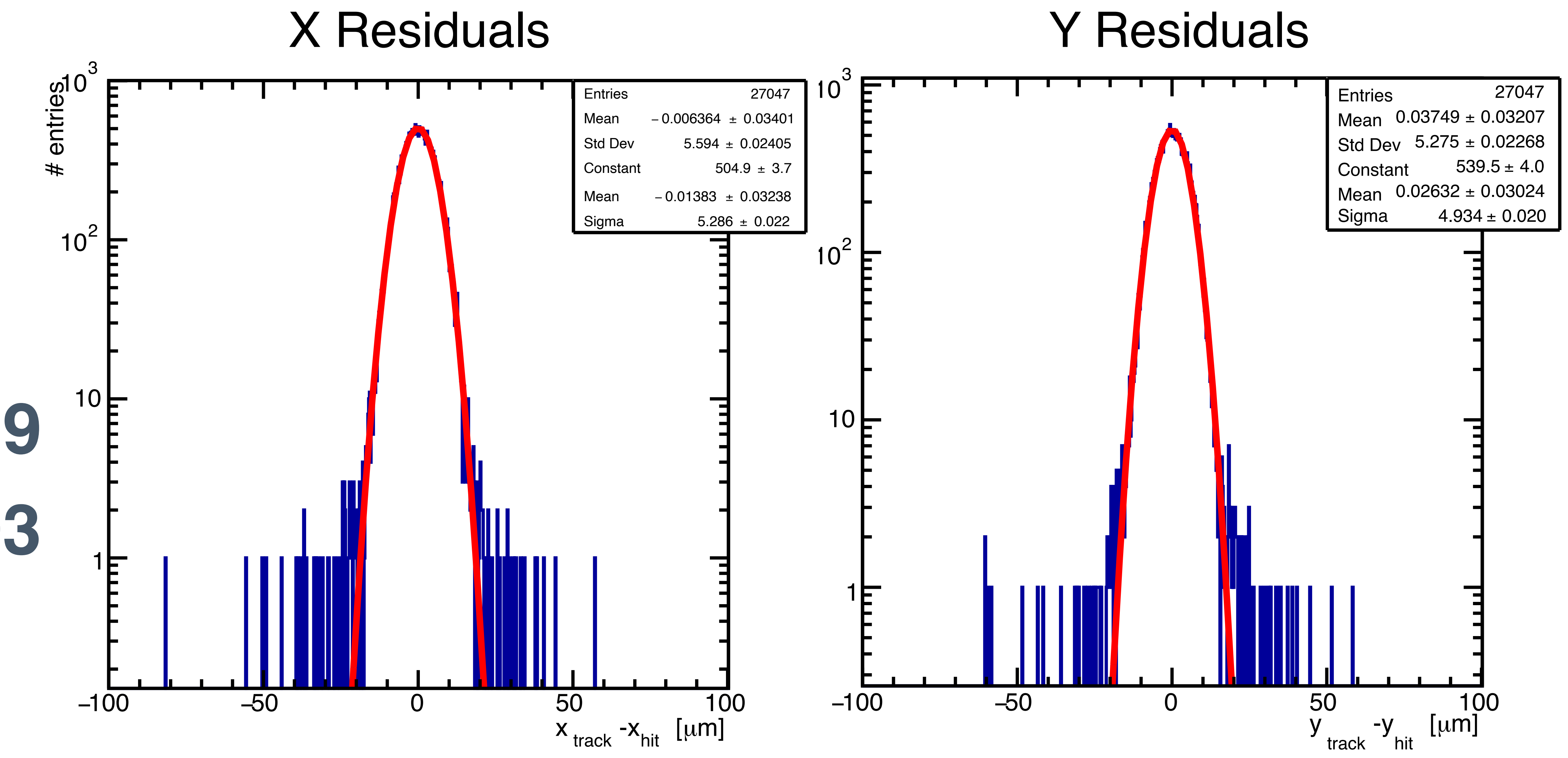
After Run: Analysis with Corryvreckan

- Align DUT ALPIDE with reference ALPIDE
- Ensure usable tracks with data
- Residuals → Alignment between refs & DUT
- Clusters, cluster sizes → DUT performance, noise

3V

x: 5.29

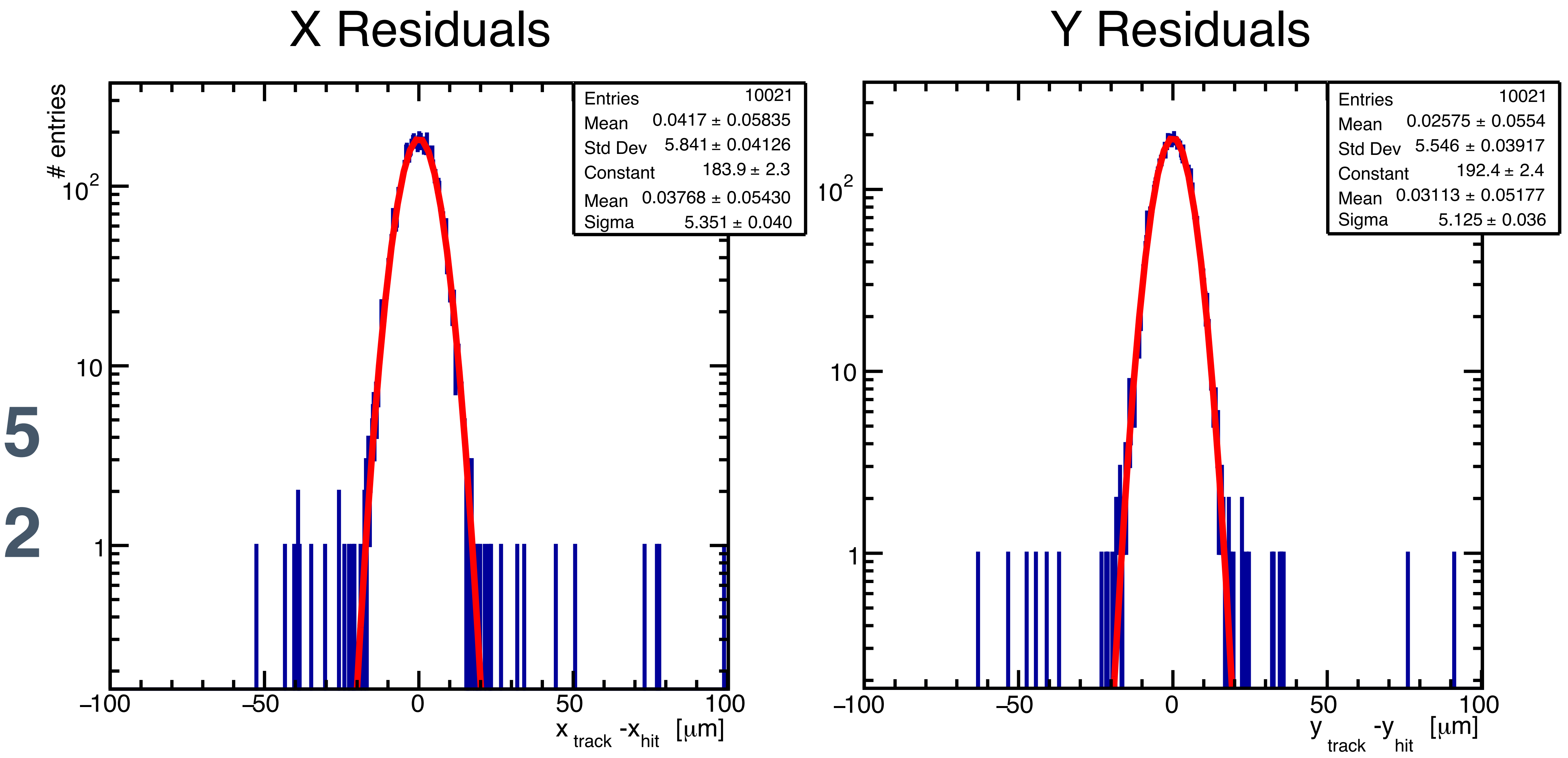
y: 4.93



0V

x: 5.35

y: 5.12



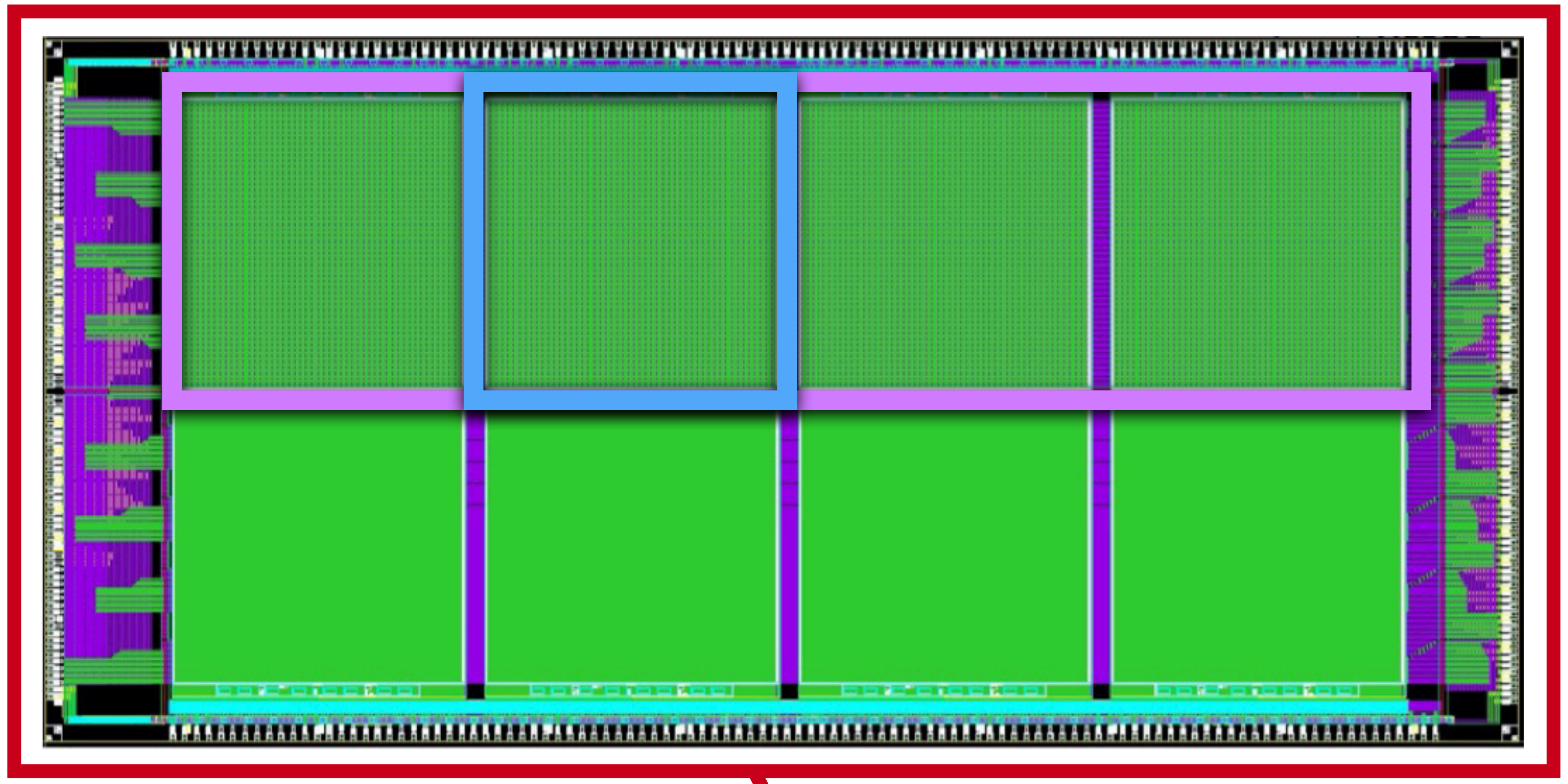
Additional material

first test beams with the MOSS!

Overview of the MOSS

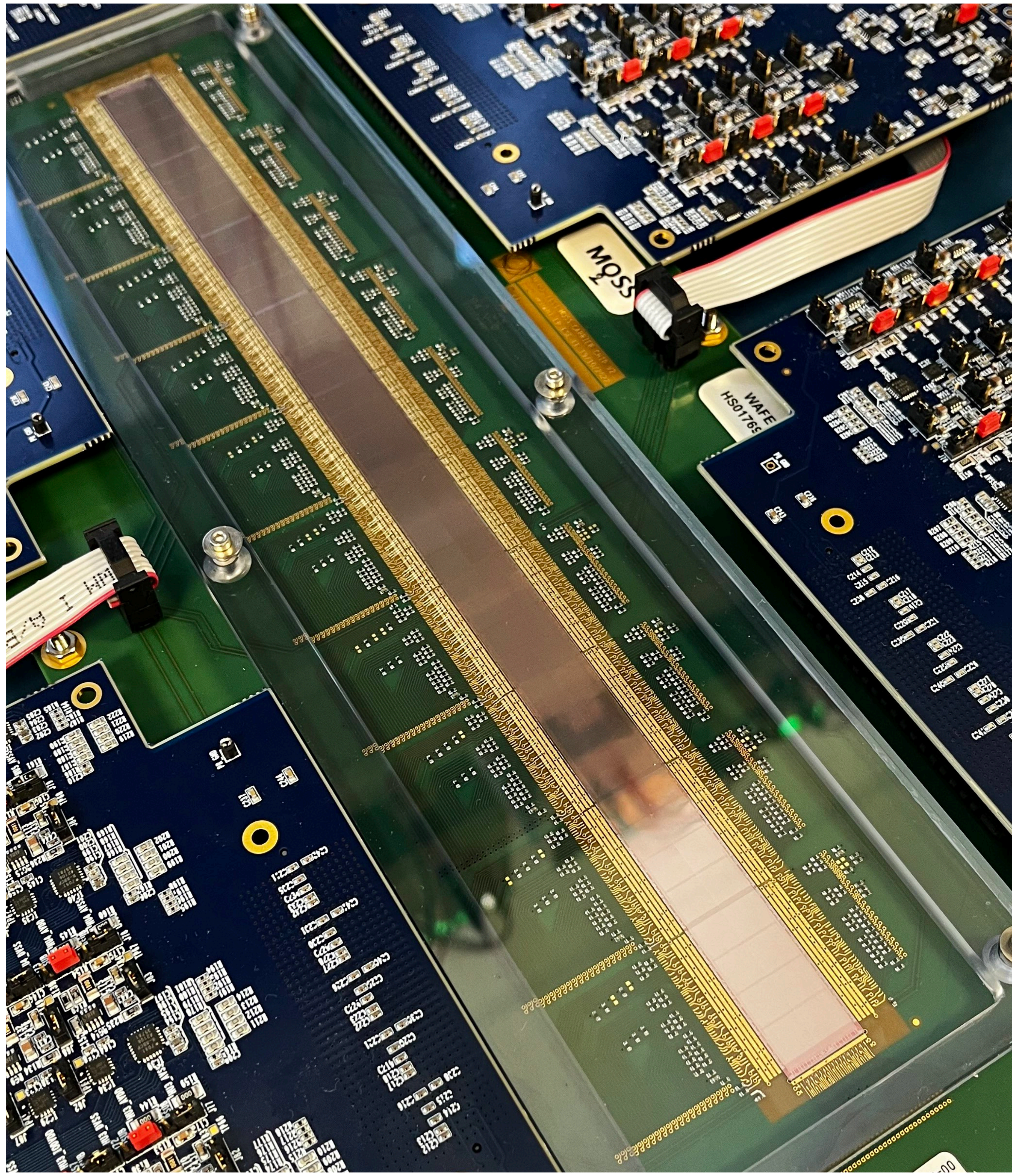
(**Mo**nolithic **S**titched **S**ensor)

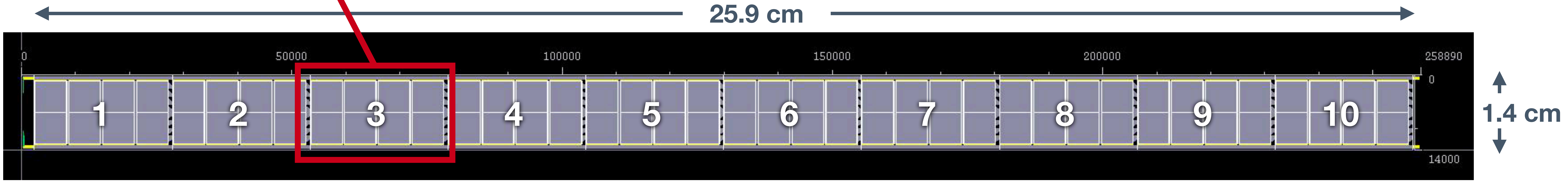
10 Repeated Sensor Units (RSU)
↳**2 Half-Units (HU)** per RSU (top & bottom have diff. pitch)
  ↳**4 Regions** per HU (each with diff. transistors)



Top:
256 x 256 pixels
Pitch: 22.5 µm

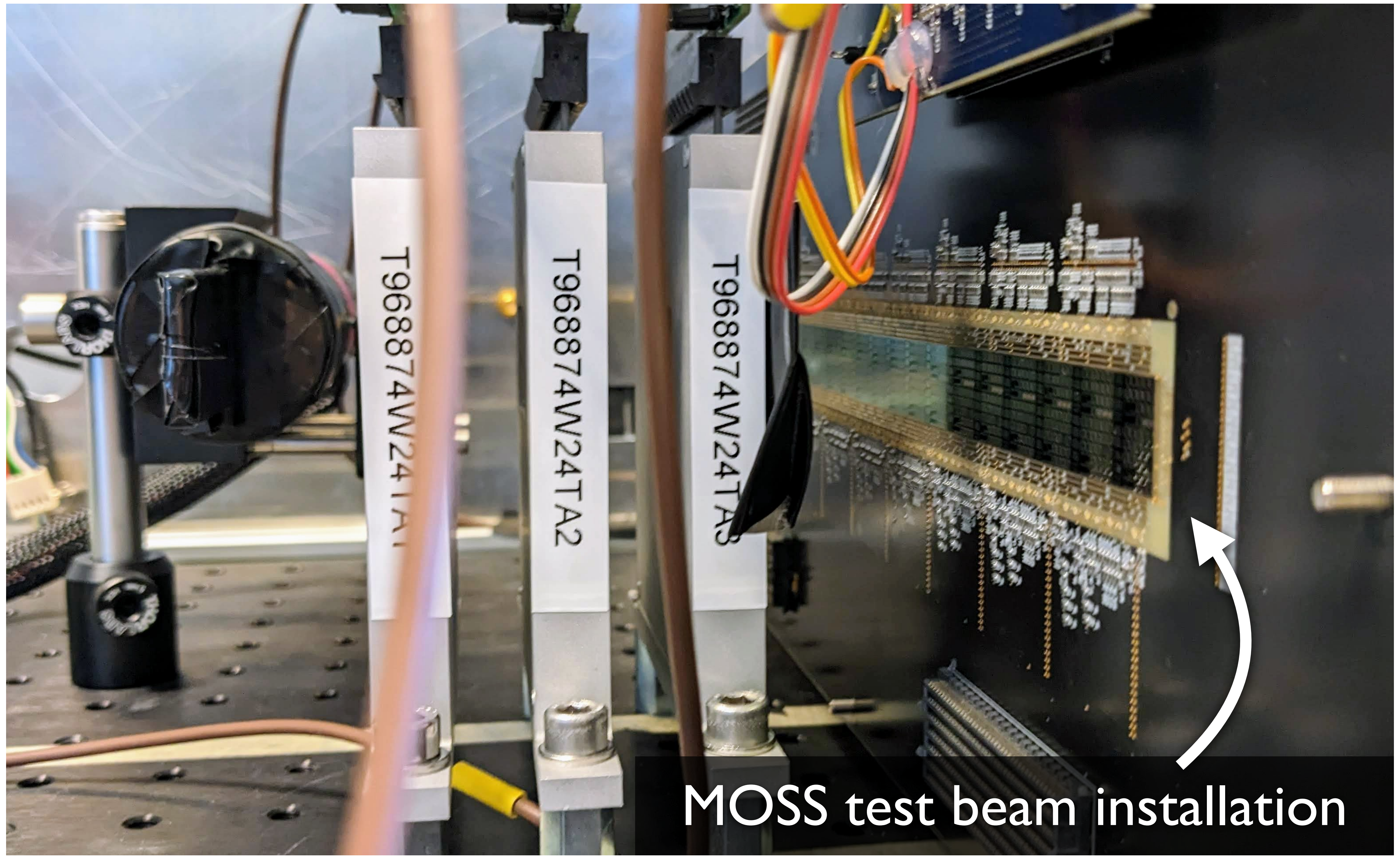
Bottom:
320 x 320 pixels
Pitch: 18 µm



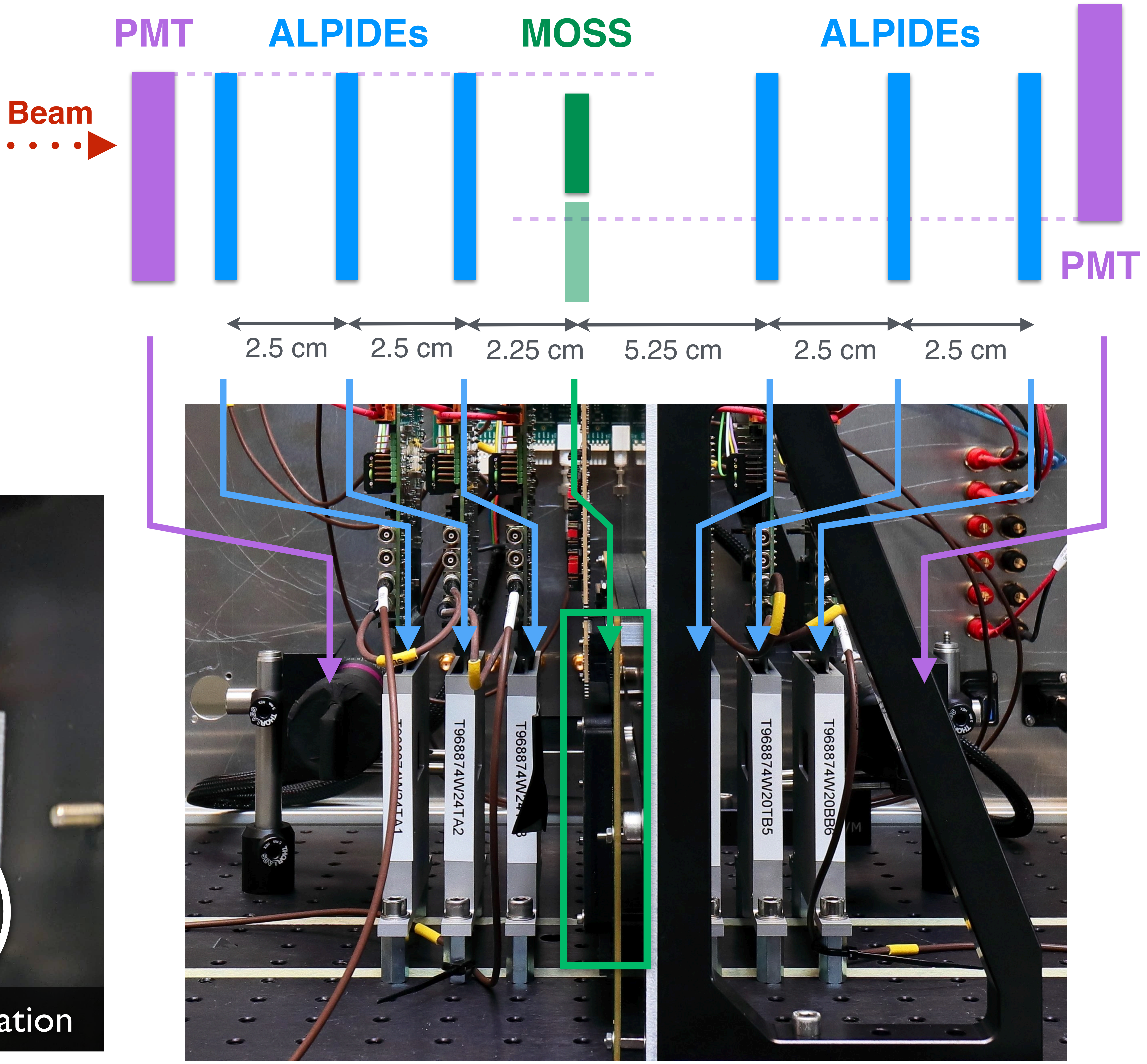


MOSS telescope setup

- **6x ALPIDE reference planes**
- Trigger: **2 PMTs in coincidence**
- **1 MOSS as DUT**



MOSS test beam installation



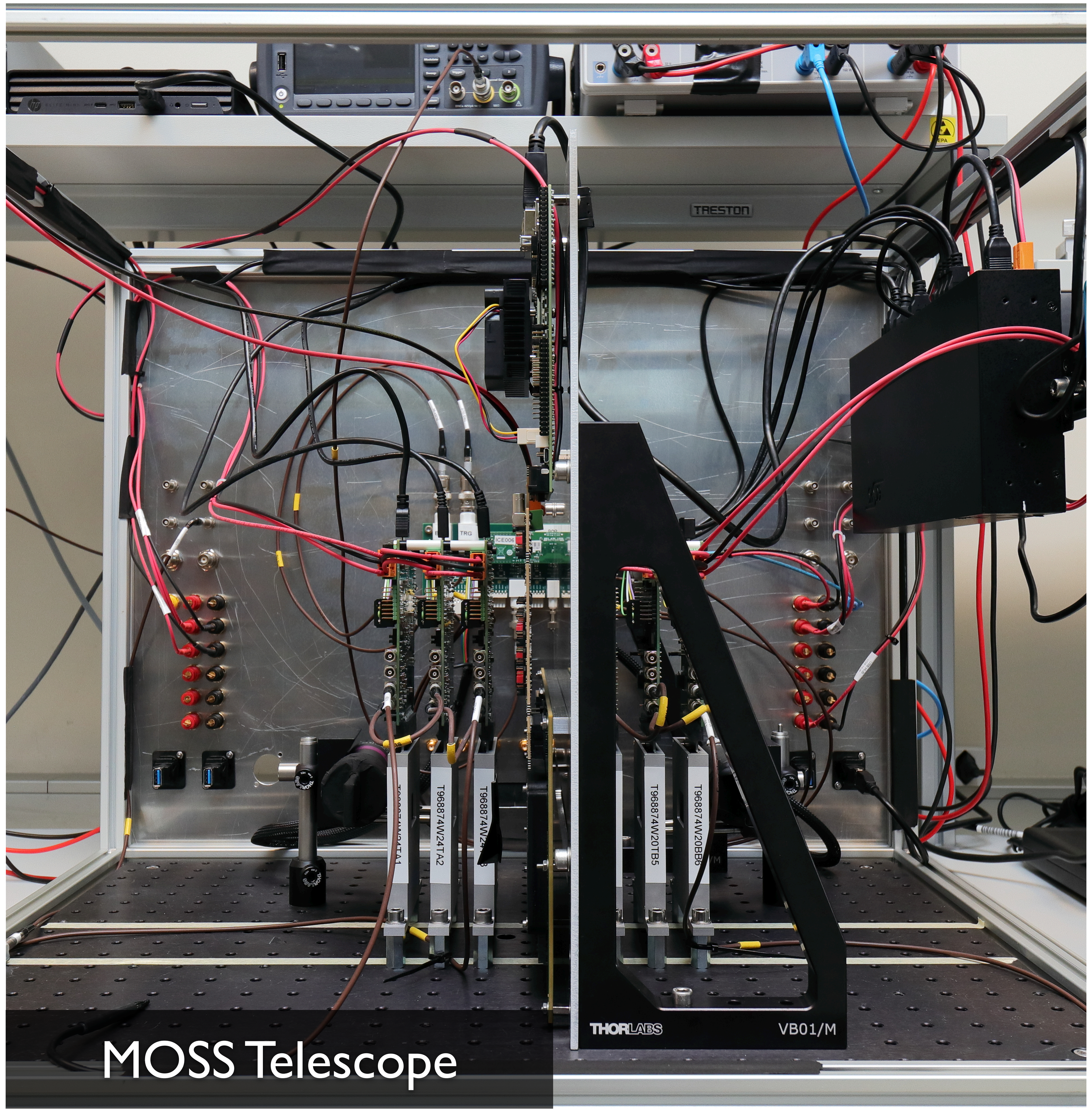
Test beam at the PS: plan and schedule

Timetable:

- PS test beam 5 - 19 July
- MOSS in beam since 14 July
- Just 5 weeks after the bonded MOSS arrived at CERN!

Beam configuration:

- T10@PS: **10 GeV negative hadrons**
- both low-intensity and high-intensity runs



Goals of the test:

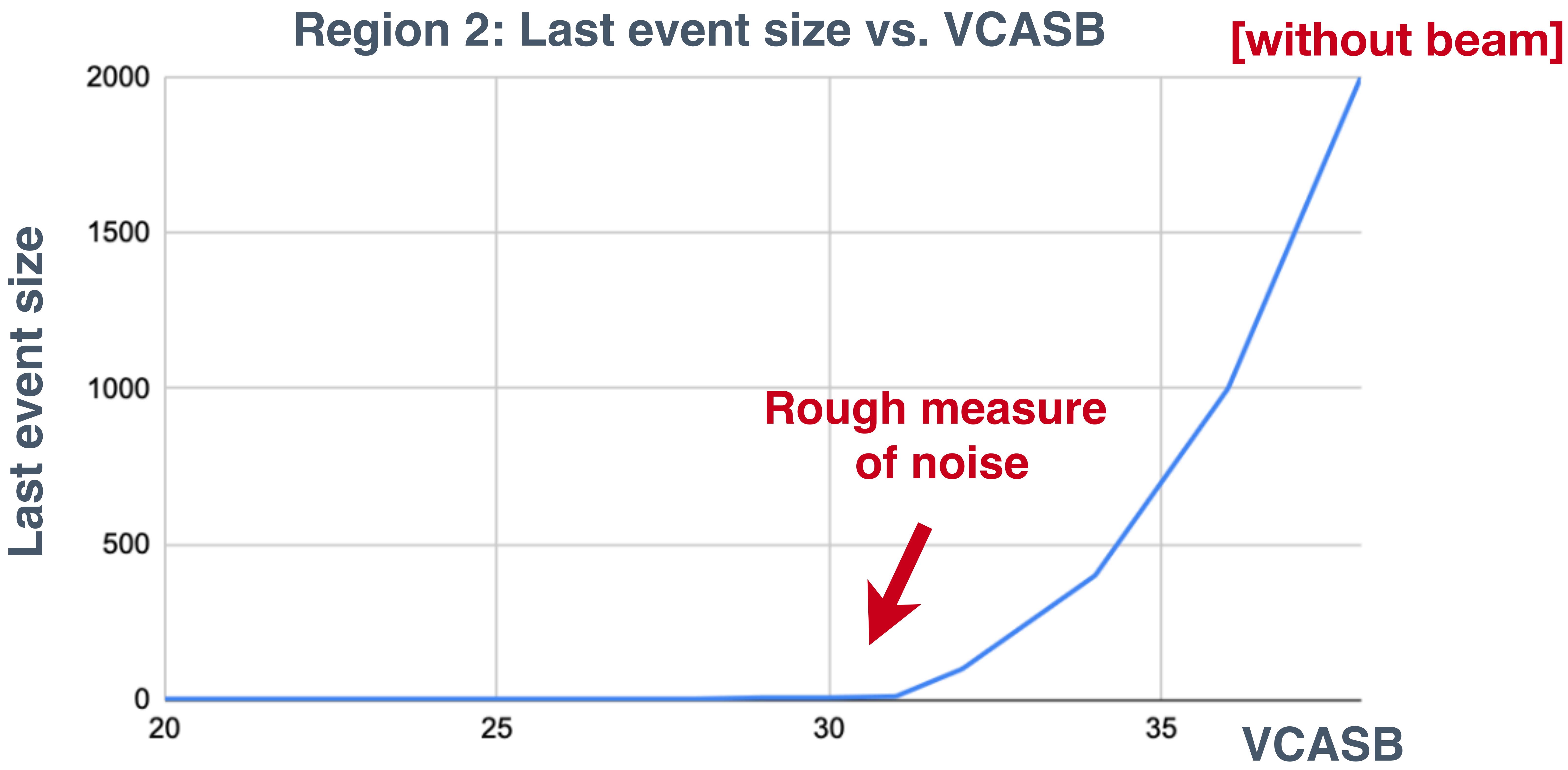
- Observe and characterize the very first signals in the MOSS
- Characterize efficiency and resolution as a function of tension VCASB **(see next slide)**

MOSS 'Word scan' vs VCASB → noise level

Number of words of the last event recorded by the online DAQ system **(4 words = empty event)**

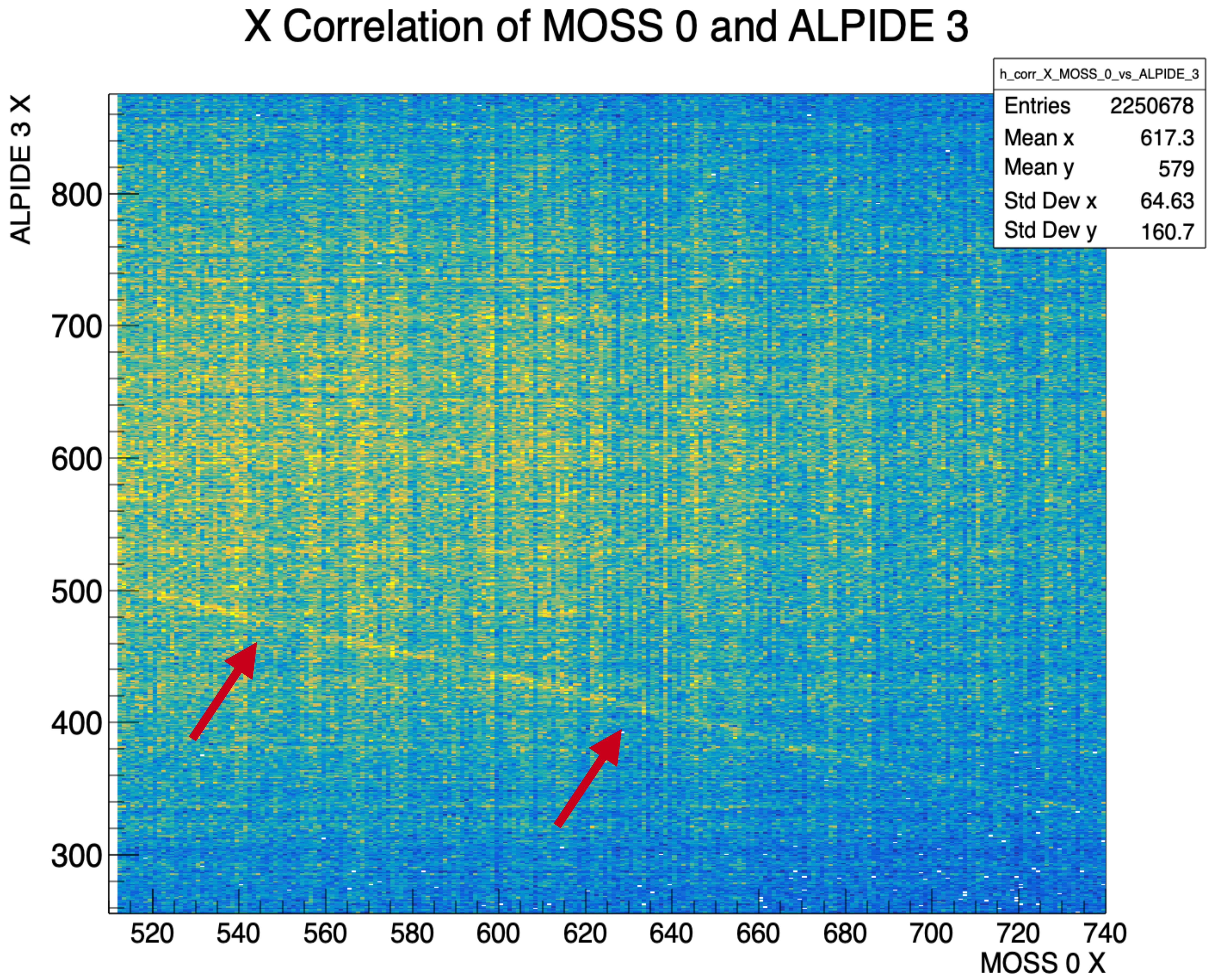
→ rough estimation of the noise level of the MOSS

VCASNB	Last event size (n. of words)
36	~ 1000
34	~ 400
32	~ 100
31	12
30	8
29	8
28	4
26	4
24	4
22	4
20	4

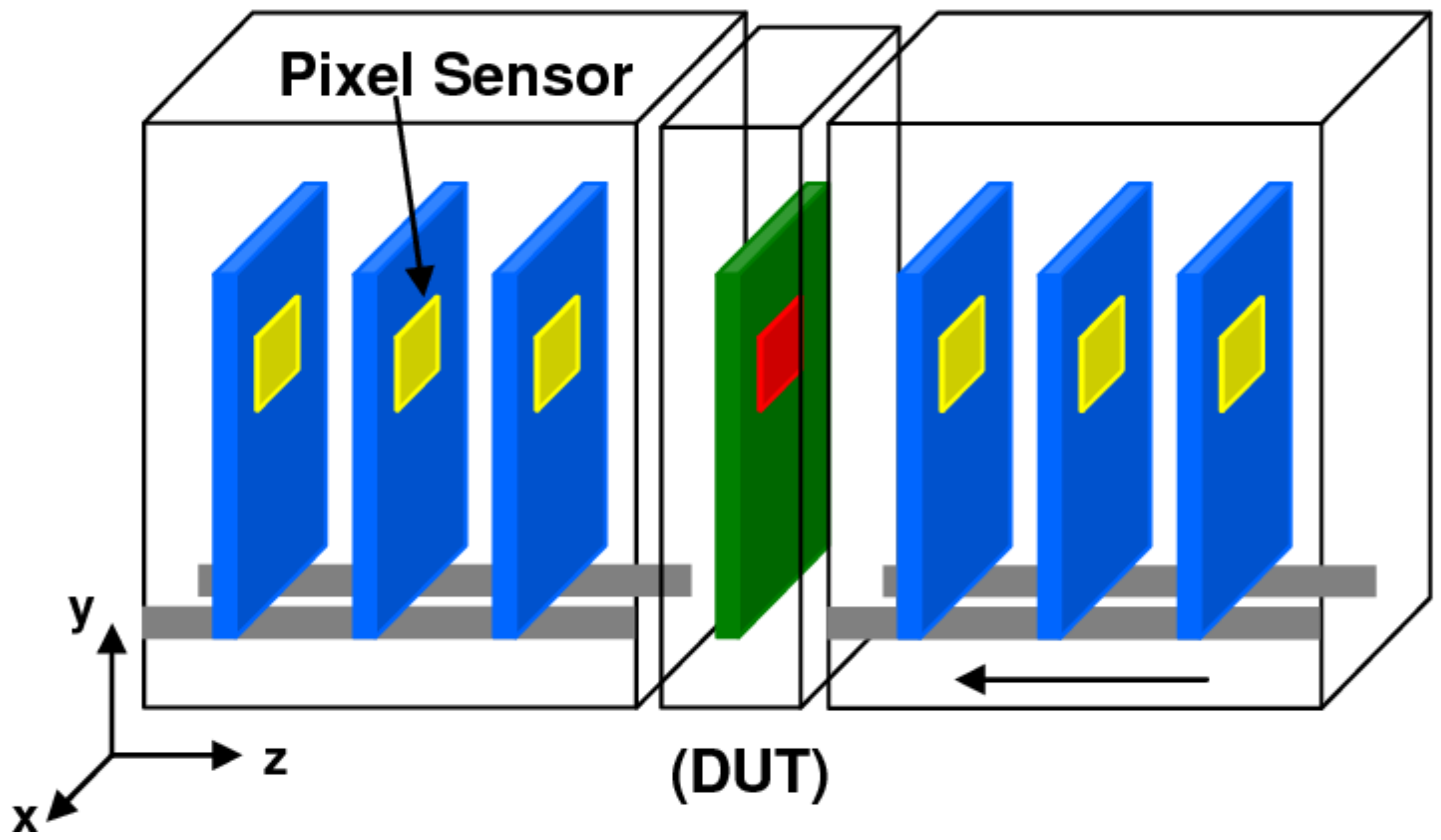


First correlation seen on ALPIDE(s)–MOSS!

(with high-intensity beam)



Region 2, VCASB=26



Correlation between the MOSS signal and the one in <u>any</u> of the ALPIDE reference planes:

- both ALPIDEs and MOSS are “seeing” the passage of the same particle trajectory

Data taking strategy and collected samples

Large datasets collected in low-intensity mode:

- Low-intensity runs → collimators ± 3.0 cm
  - Cleaner and higher-luminosity samples (milder trigger veto)
- 20k trigger events per VCASB level
  - ~1 MOSS hit per event
  - ~18k ALPIDE tracks per set → ~10% through MOSS

	good set		**good set**	
REGION	**0**	**1**	**2**	**3**
VCASB steps	[3,25] in steps of 2	[7,23] in steps of 2	[4,30] in steps of 2	-
Statistics	12 x 20k	9 x 20k	13 x 20k	-
Beam Intensity	low	high*	low	

**Different beam settings - data is not reliable*

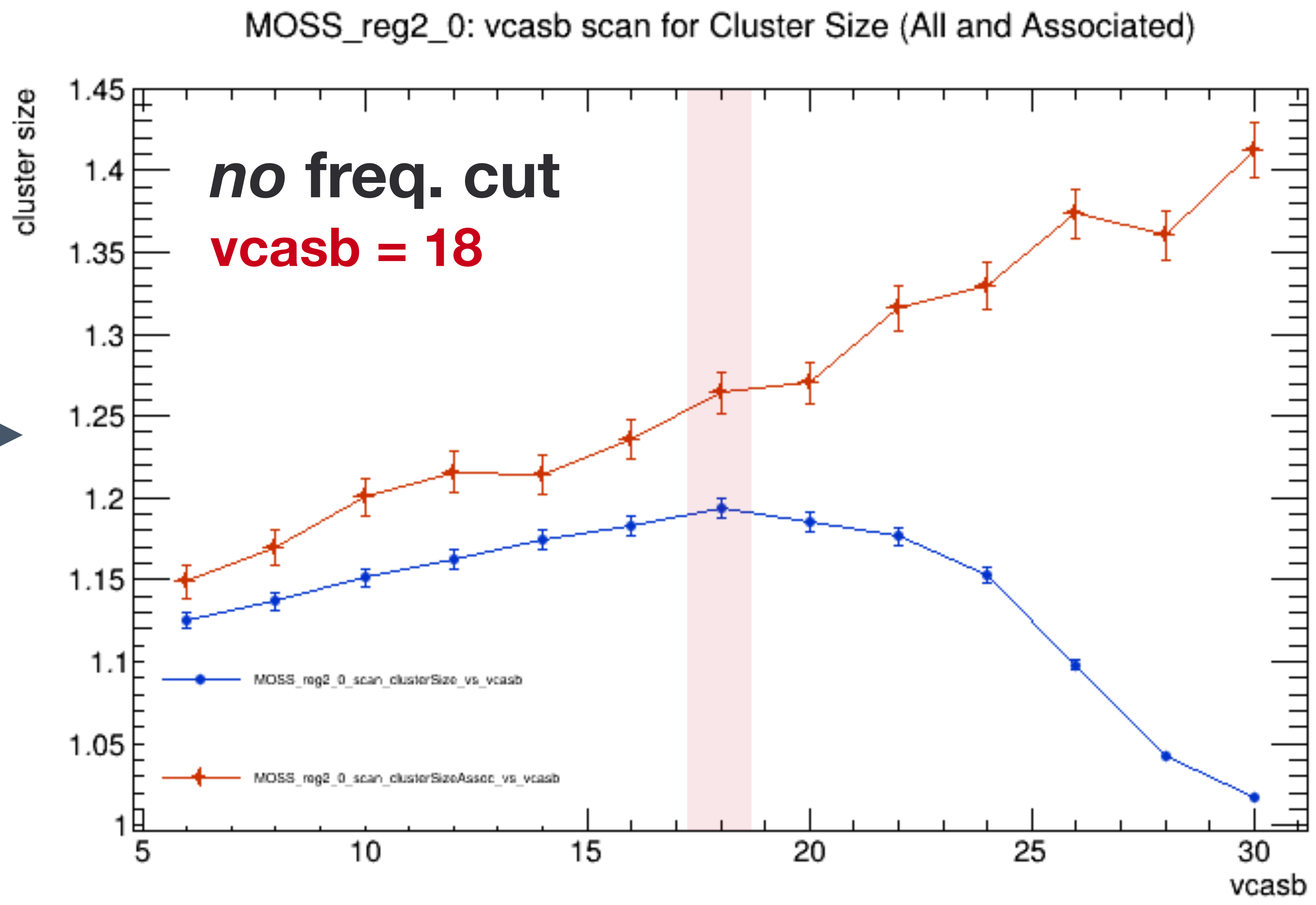
MOSS analysis: masking noisy pixels

Apply frequency cut to automatically mask

- Pixel is masked if it satisfies:

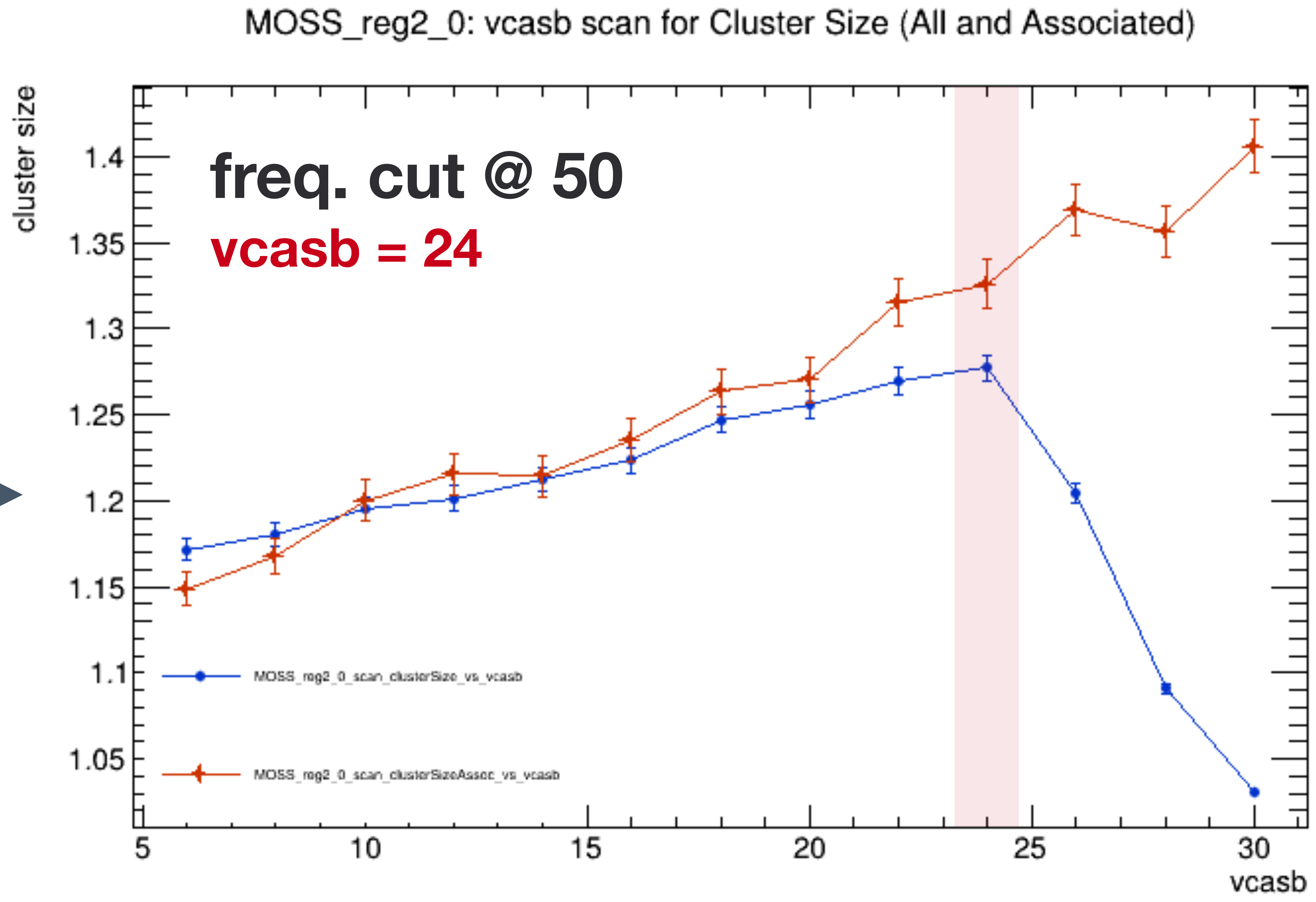
  [#hits] ≥ [freq] x [avg. hits per event]
- Peak cluster size **without cuts** is at vcasb = 18
  - Much lower than expect, **but…**
- For frequency ≥ 50, **peak shifts to vcasb = 26**
  - **This is close to “manual scan” results!**

	Manual	No Cut	Cut @ 50
Region 2	**~26**	**18**	**24**
Region 0	~16	13	13



***no* freq. cut**

vcasb = 18



freq. cut @ 50

vcasb = 24

MOSS analysis: alignment process

- Set MOSS at origin in Z
- Use ALPIDE 2 as “reference” (stays ~fixed, closest to MOSS)
- Time cuts with MOSS are set to 1e99 or turned off

Corryvreckan Steps

1. Masking

Mask with:

`frequency_cut=-1`

2. Prealignment

Broader settings:

`max_rms=15mm`

`range_abs=20mm`

3. Alignment 1

Excludes DUT, aligns ALPIDEs only (Tracking4D & AlignementMillipede)

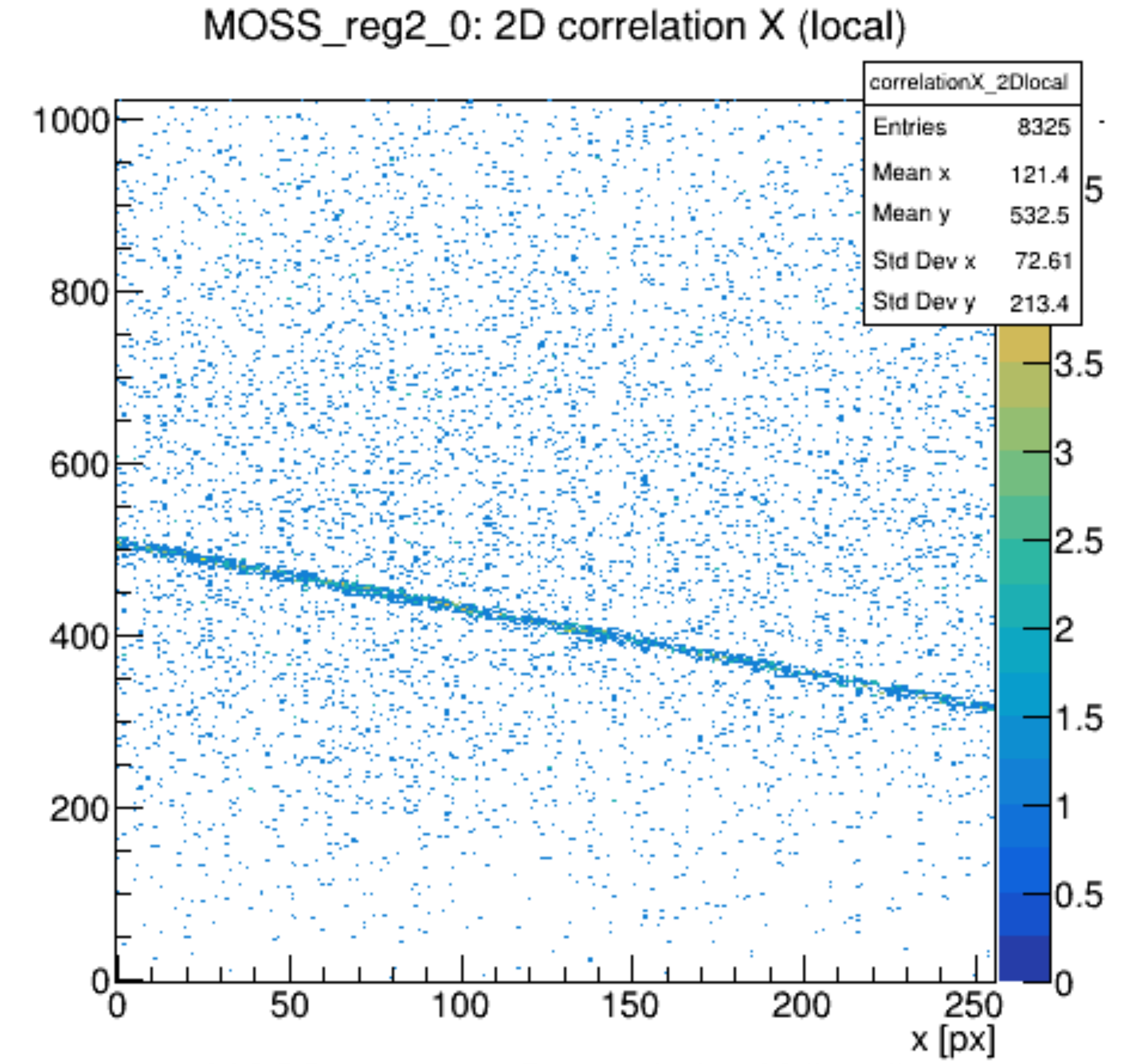
4. Alignment 2

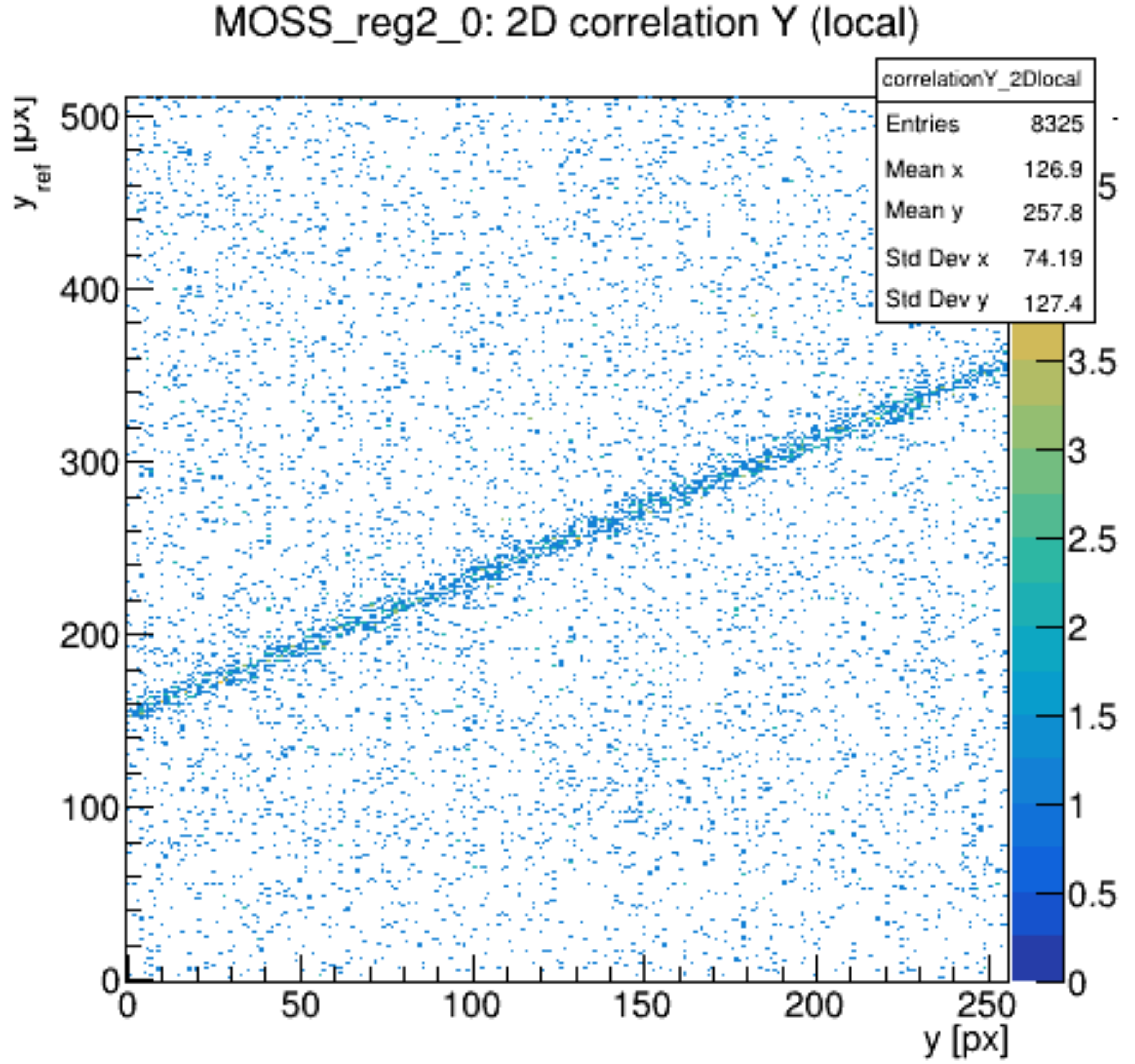
Includes DUT, aligns MOSS with ALPIDEs (Tracking4D & AlignementMillipede)

5. Analysis

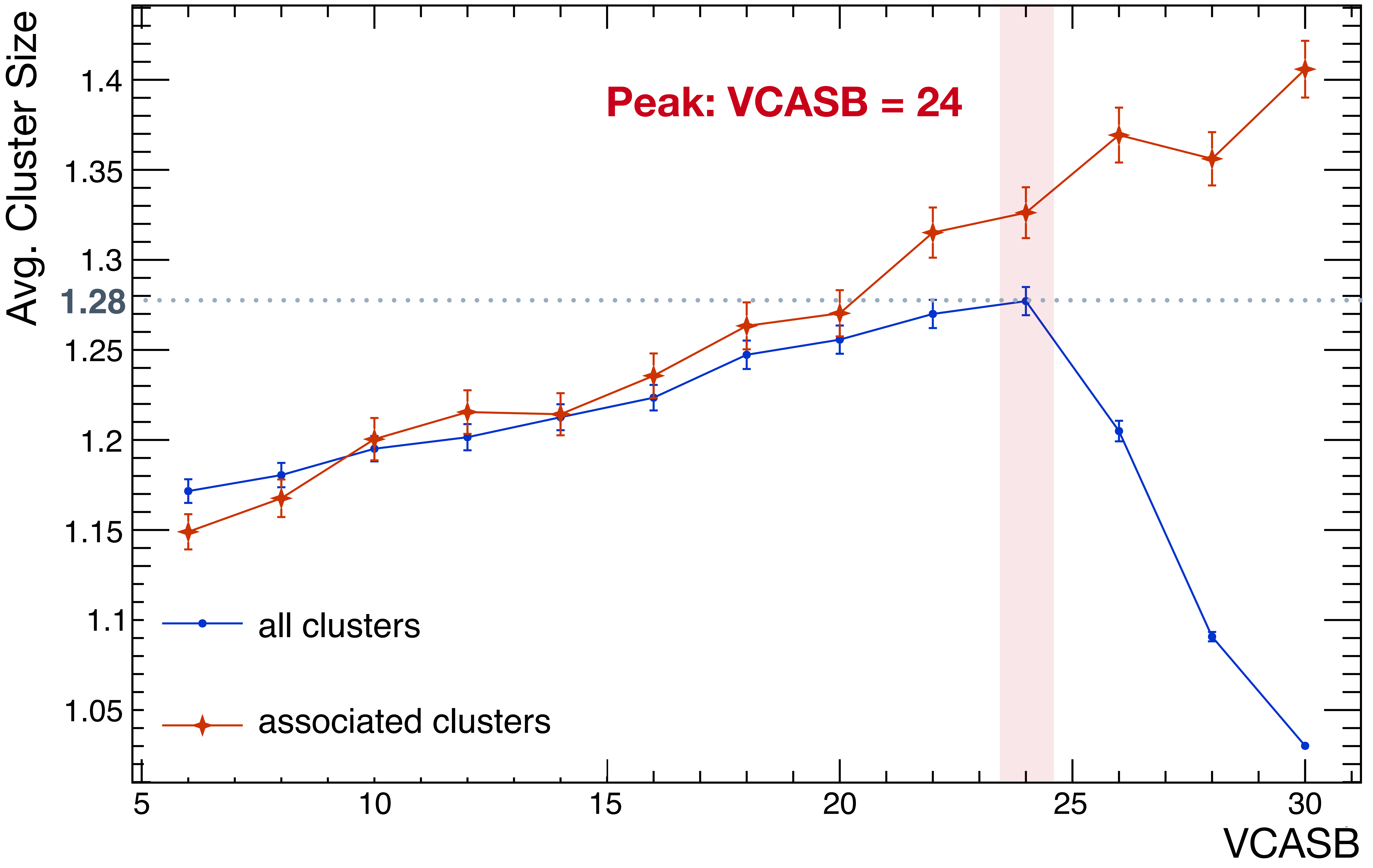
No major changes

Two Alignment Steps





Region 2: ⟨Cluster size⟩ vs VCASB



Peak: VCASB = 24

Increasing VCASB

Decreasing **Threshold**

VCASB is
inversely proportional
to threshold

Why the peak?

- Associated cluster size increases as threshold decreases (charge on neighboring pixels)
- At a point, pixels become noisy and 1-pixel cluster noise dominates

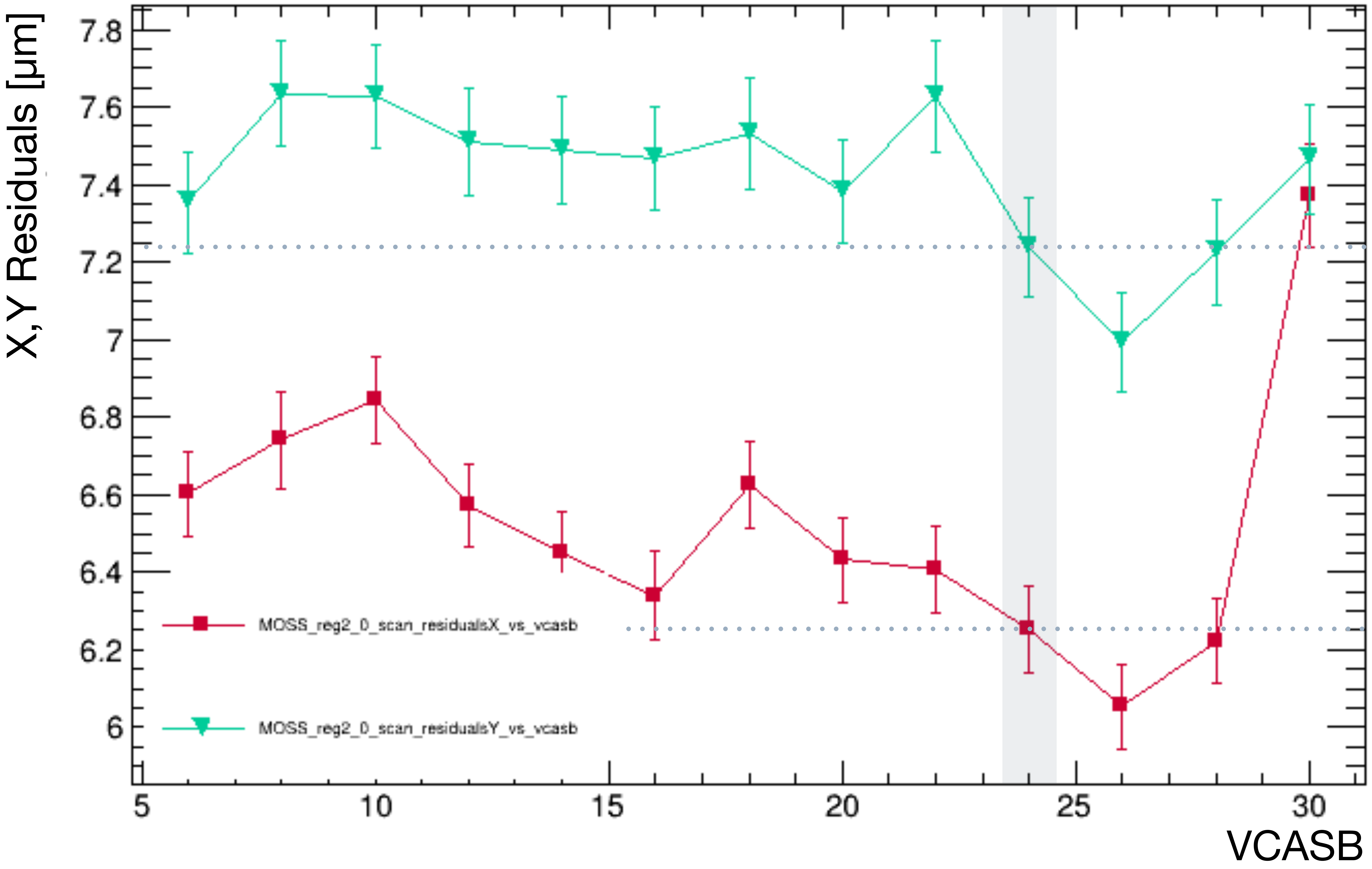
MOSS Alignment: Region 2 Residuals

Region 2 (for VCASB = 24)

- X Residuals: **6.25 µm**
- Y Residuals: **7.25 µm**

Significant asymmetry between X & Y

- Expected cause: ALPIDE pixels have difference X, Y pitch
- Still need to subtract telescope residuals



Summary and next steps

- **Major contribution to the R&D, construction, installation and commissioning of the SVT innermost layers**

→ ITS3 as the technological baseline, but with a lot of additional challenges!

- **MIT will profit from a CERN-based laboratory to maximize the knowledge transfer from ALICEITS3 to ePIC SVT**

- **Good plan from the near to the far future, with several aspects are still being optimized/finalized.**

→ any feedback/suggestion is very welcome

- **Already delivering good results!**

→ Our CERN team is providing major contributions to the MOSS first test beam
→ Ramping up the activities at Bates for the mechanical design and R&D
→ A lot of opportunities for students and postdocs to have an impact on the project!

BACKUP slides