Pixels in CBM

The Micro Vertex Detector and Beyond

Franz A. Matejcek for the CBM Collaboration

1st GSI Pixel Platform Workshop, GSI, 23.03.2026

Chapter 0

Introduction

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Compressed Baryonic Matter Experiment

Fixed Target A-A at $\sqrt{s_{NN}} = 2.9, \ldots, 4.9$ GeV

→ First-order chiral phase transition

→ Exotic phases (soft deconfined, quarkyonic, …)

→ EoS at neutron star core densities

→ In-medium properties of hadrons

→ Strangeness and Charm production, properties

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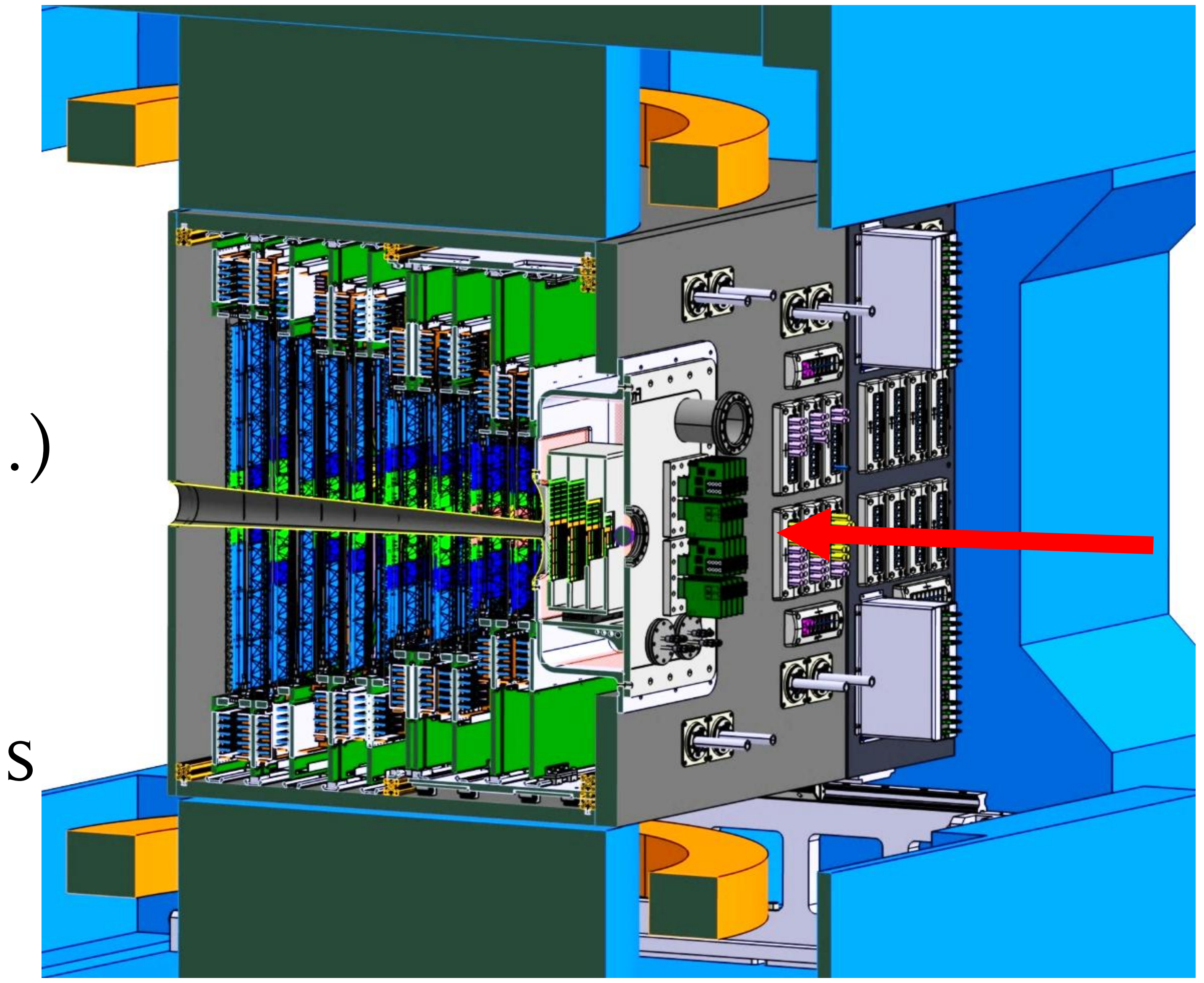


The Inner Tracker

Inside 1 T·m magnet dipole field

2.5 – 25° polar acceptance (full azimuth)

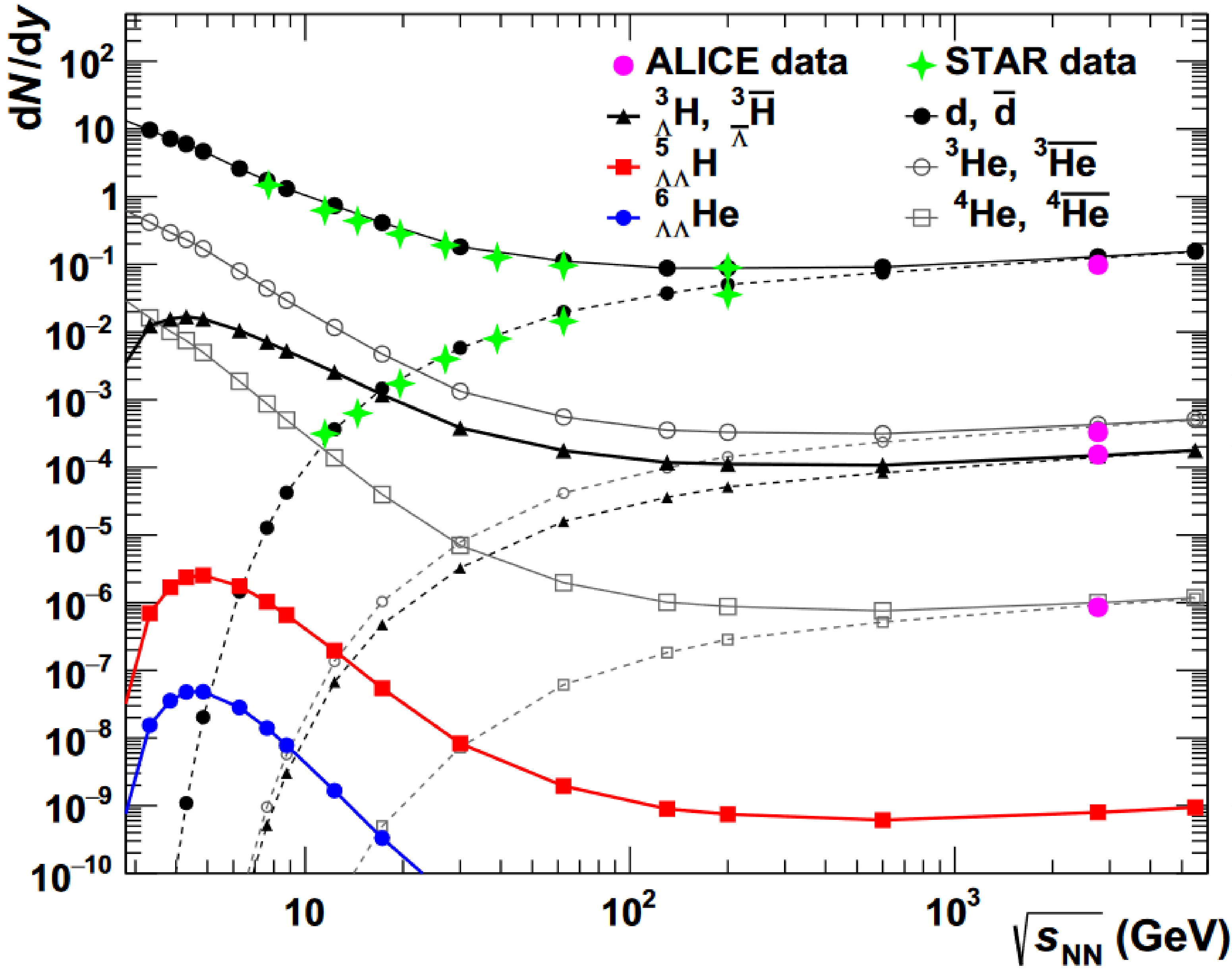
MVD: 4 layers CMOS MAPS

→ $z = 8 - 20$ cm (in vacuum)

STS: 8 layers Si-strips

→ $z = 30 - 100$ cm (in air)

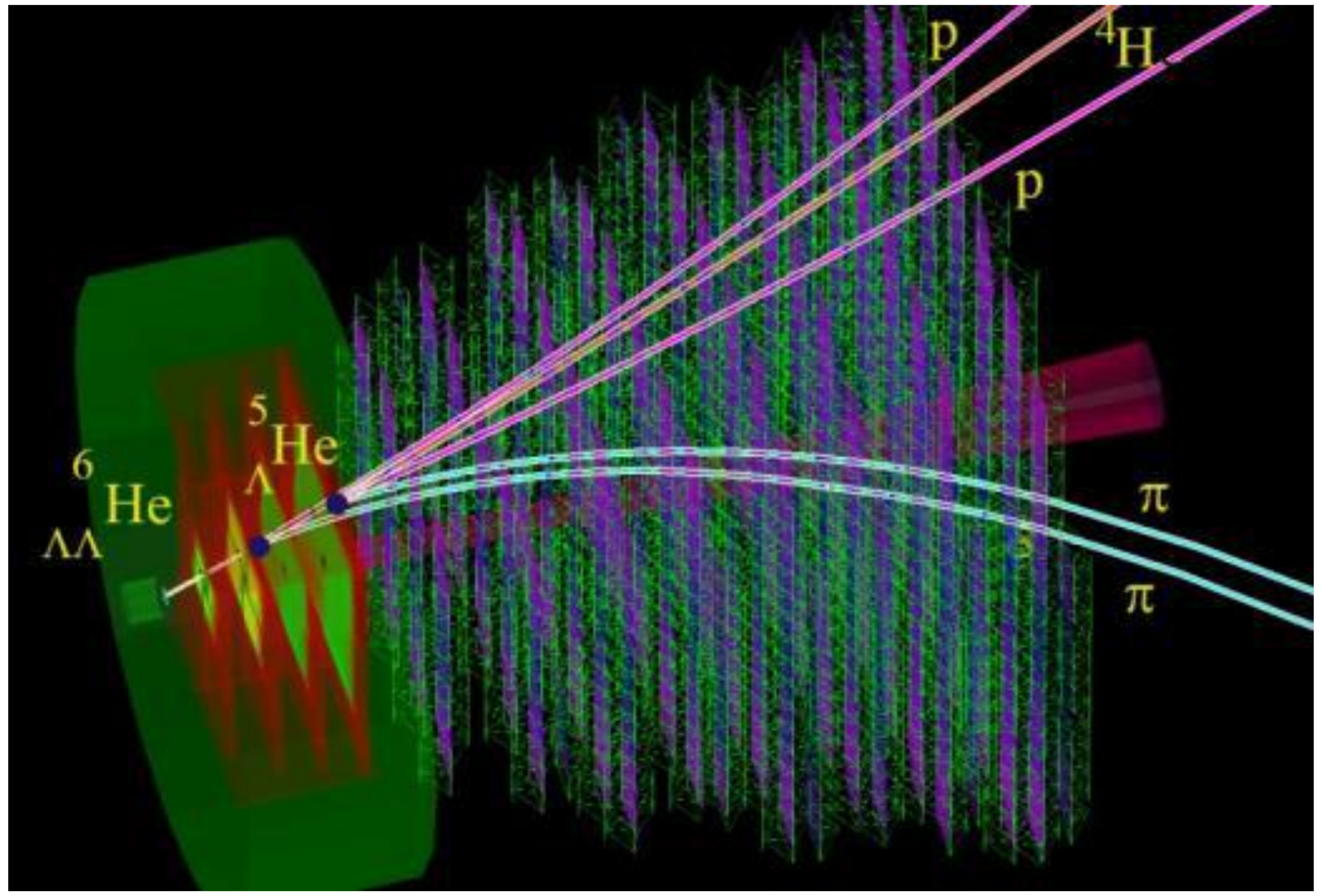
Physics with the MVD



Taken from B. Dönigus, modified from A. Andronic et al.

Hypernuclei production

Selection w/ KFParticle Finder in CBM



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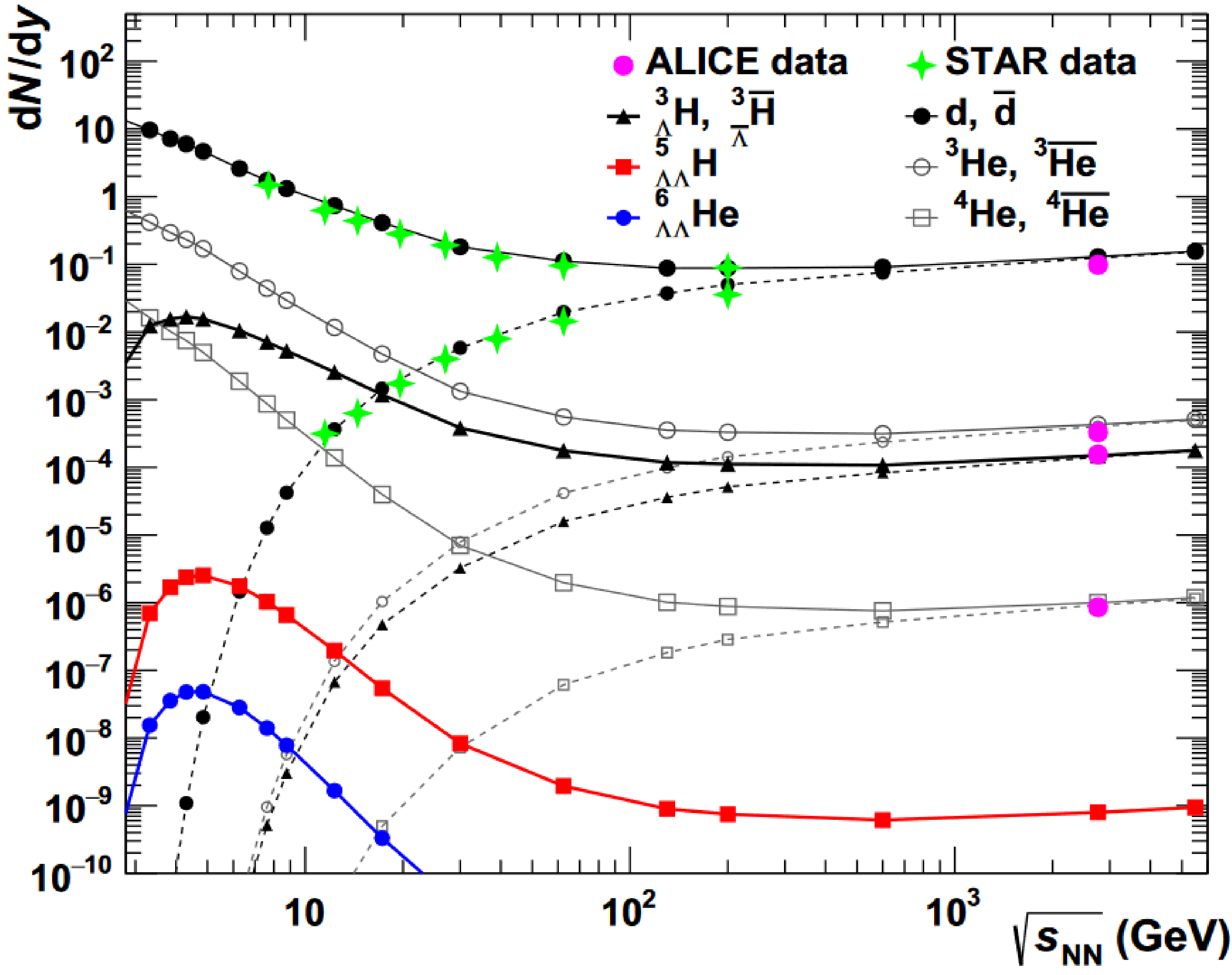

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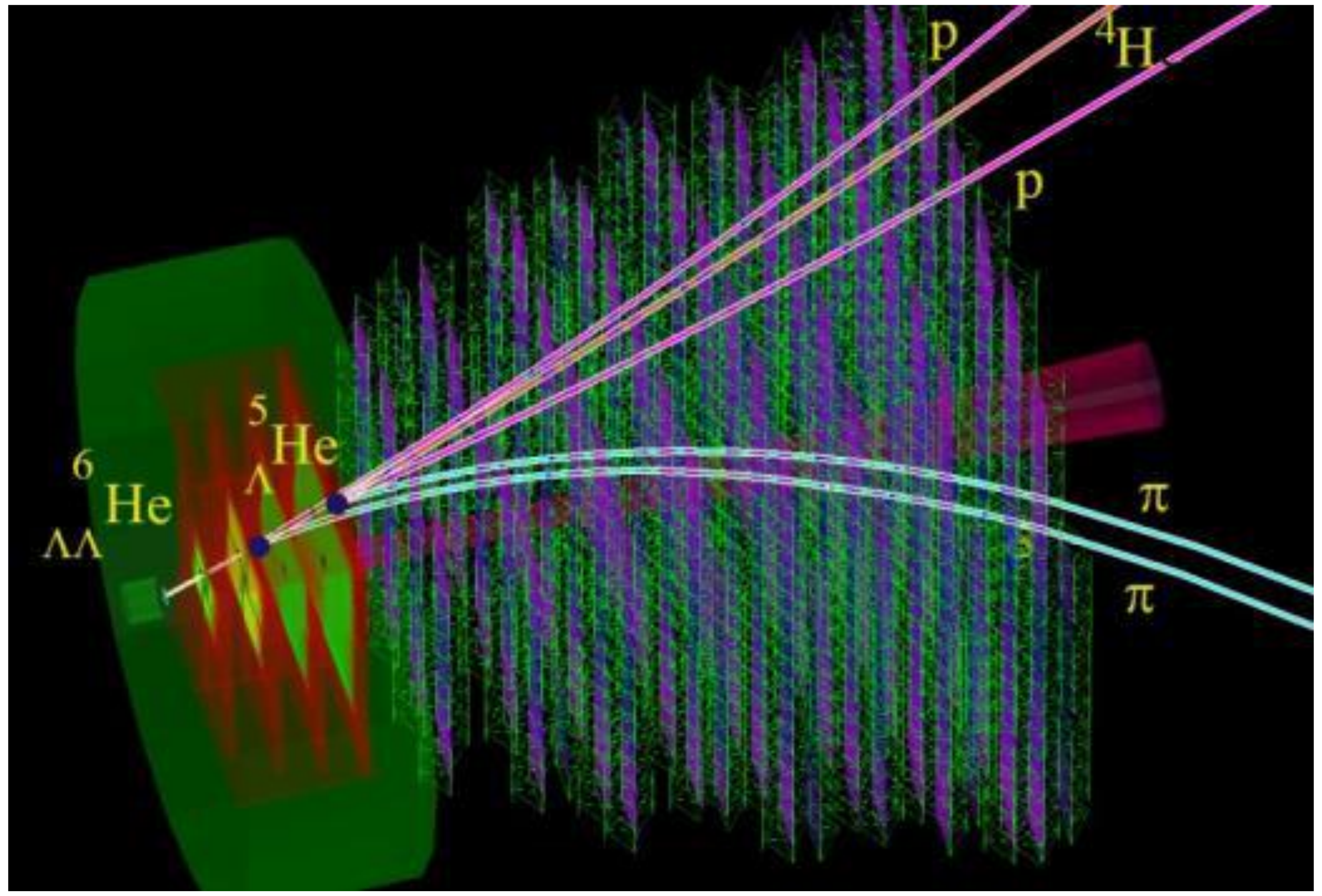
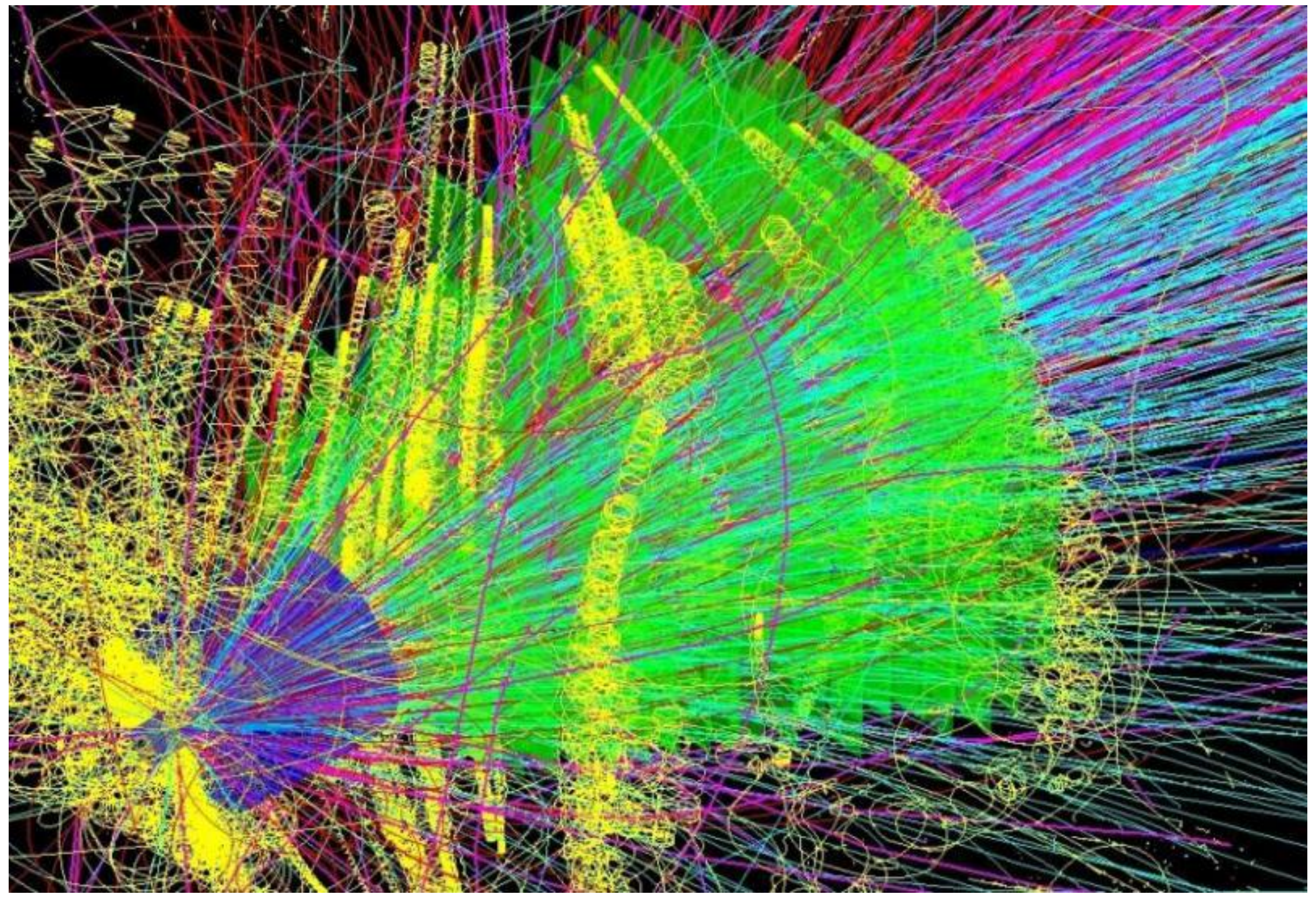


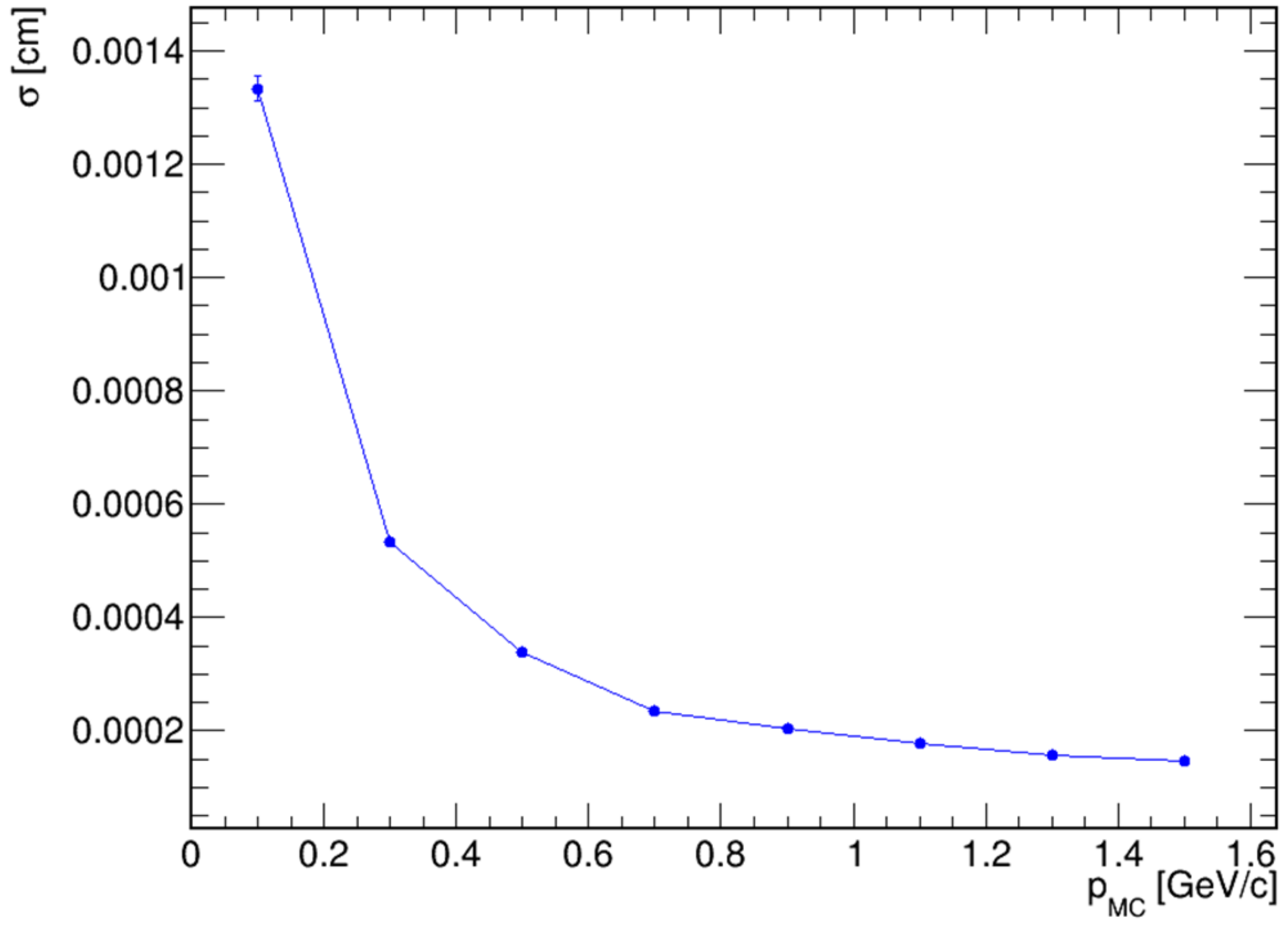


High track density in the Inner Tracker

MVD track seeds minimizing STS ambiguities

Pointing Precision

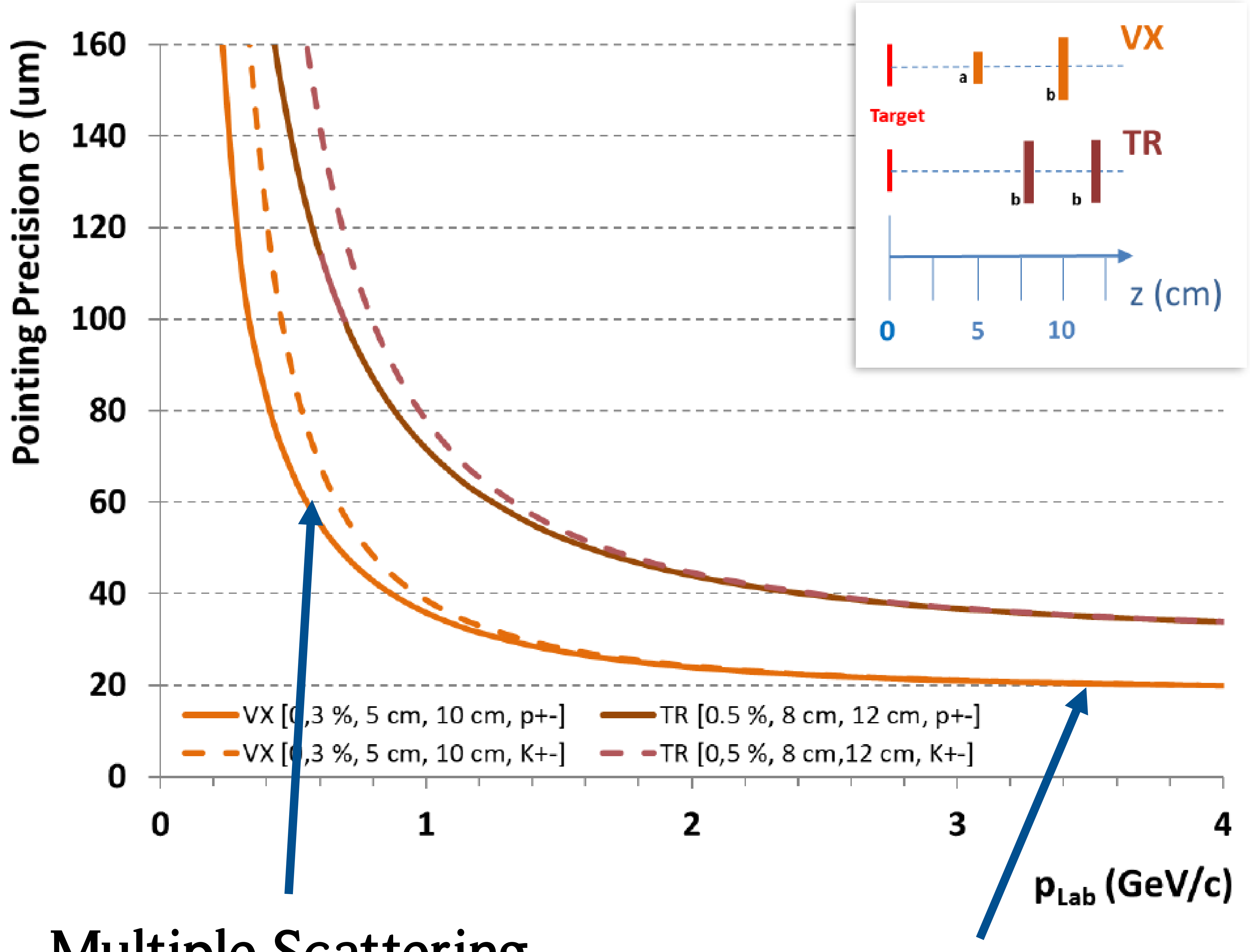
x-Distance for z=0 [cm]



Requirements for Low-p Tracking

$$\boxed{\sigma_{MS} \sim \frac{1}{\beta \cdot p_{lab}} \sqrt{\frac{x}{X_0}}}$$

Generic 2-station pointing precision



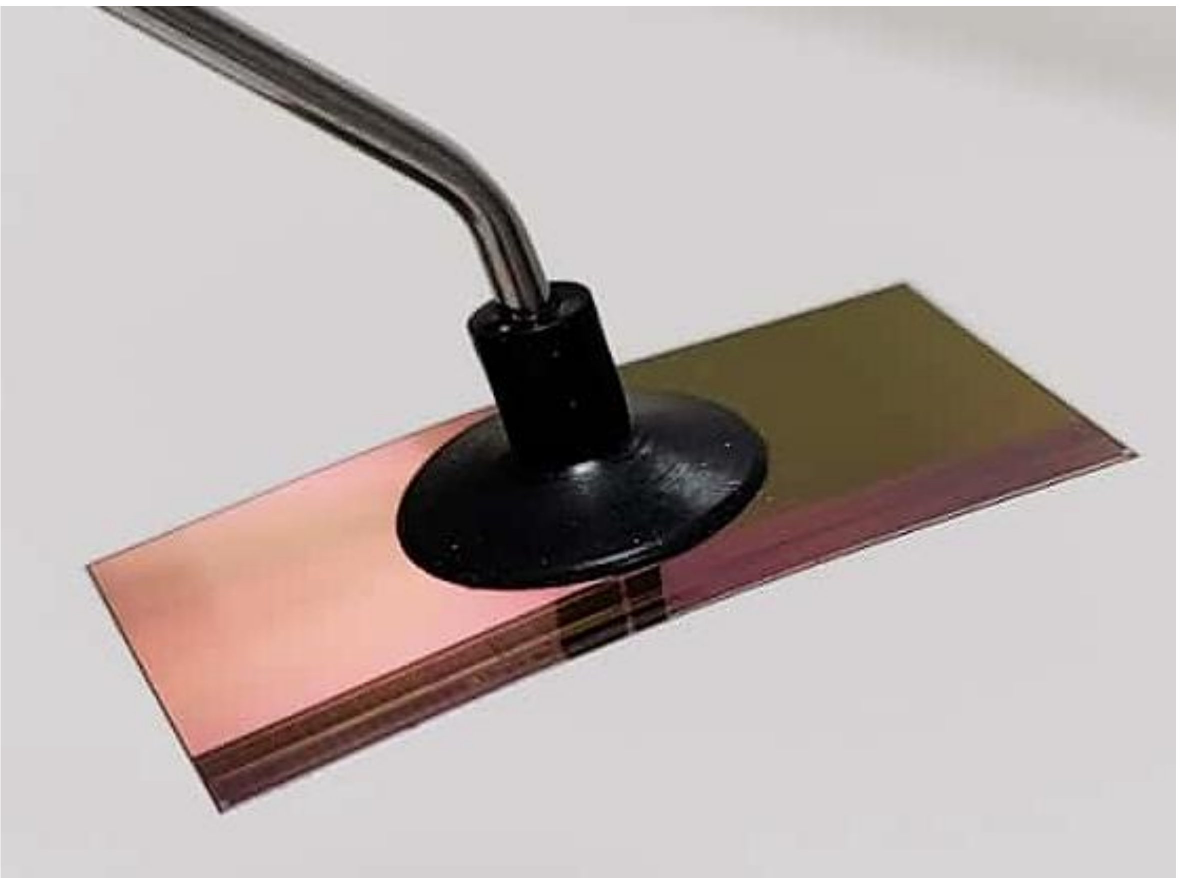
Multiple Scattering dominates

Geometry dominates

Requirements for Low-p Tracking

Design driven by material budget

→ Multiple Scattering dominated regime
→ Technology: (thinned) CMOS MAPS
→ Tracking **before** beam window (vacuum operation)



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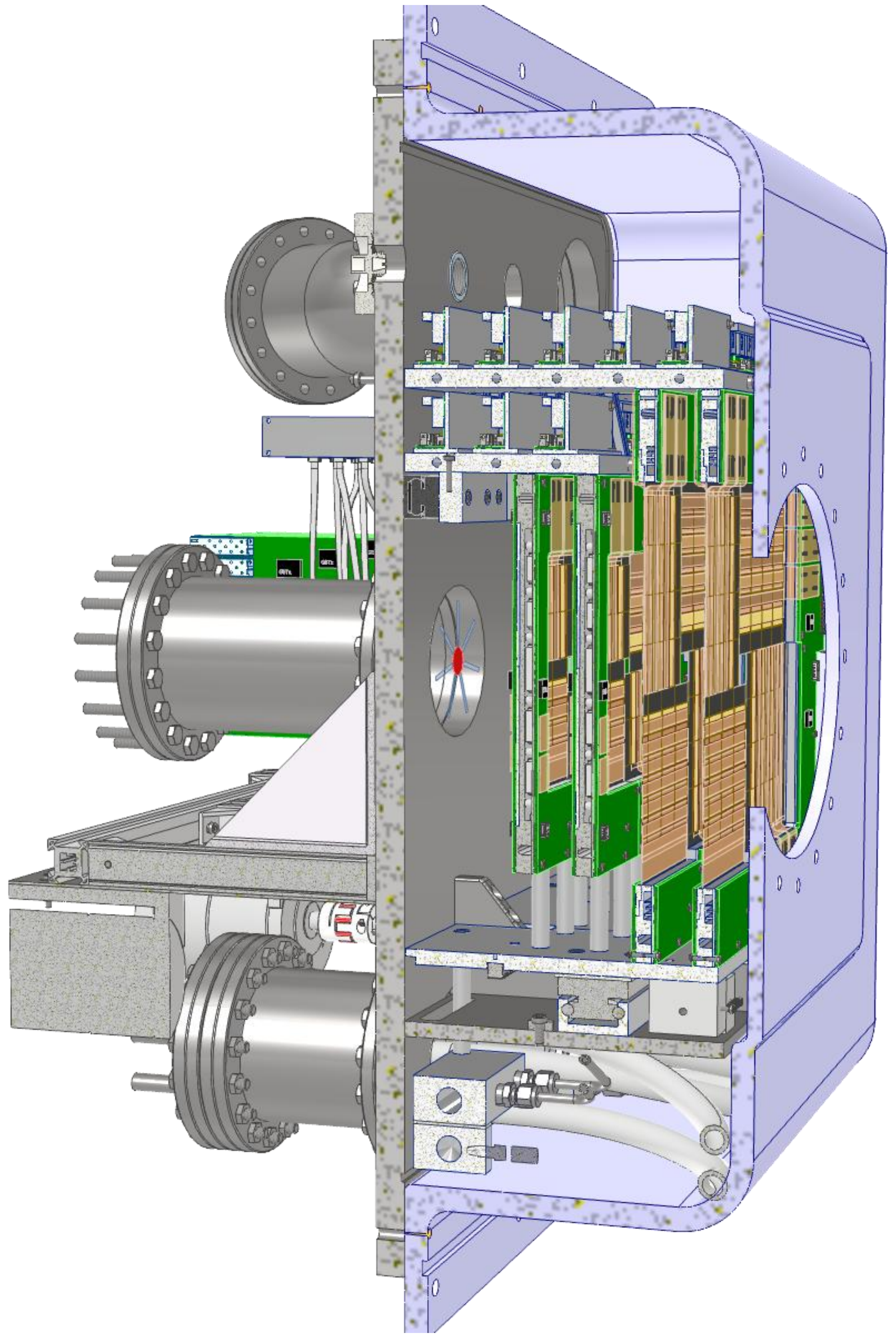

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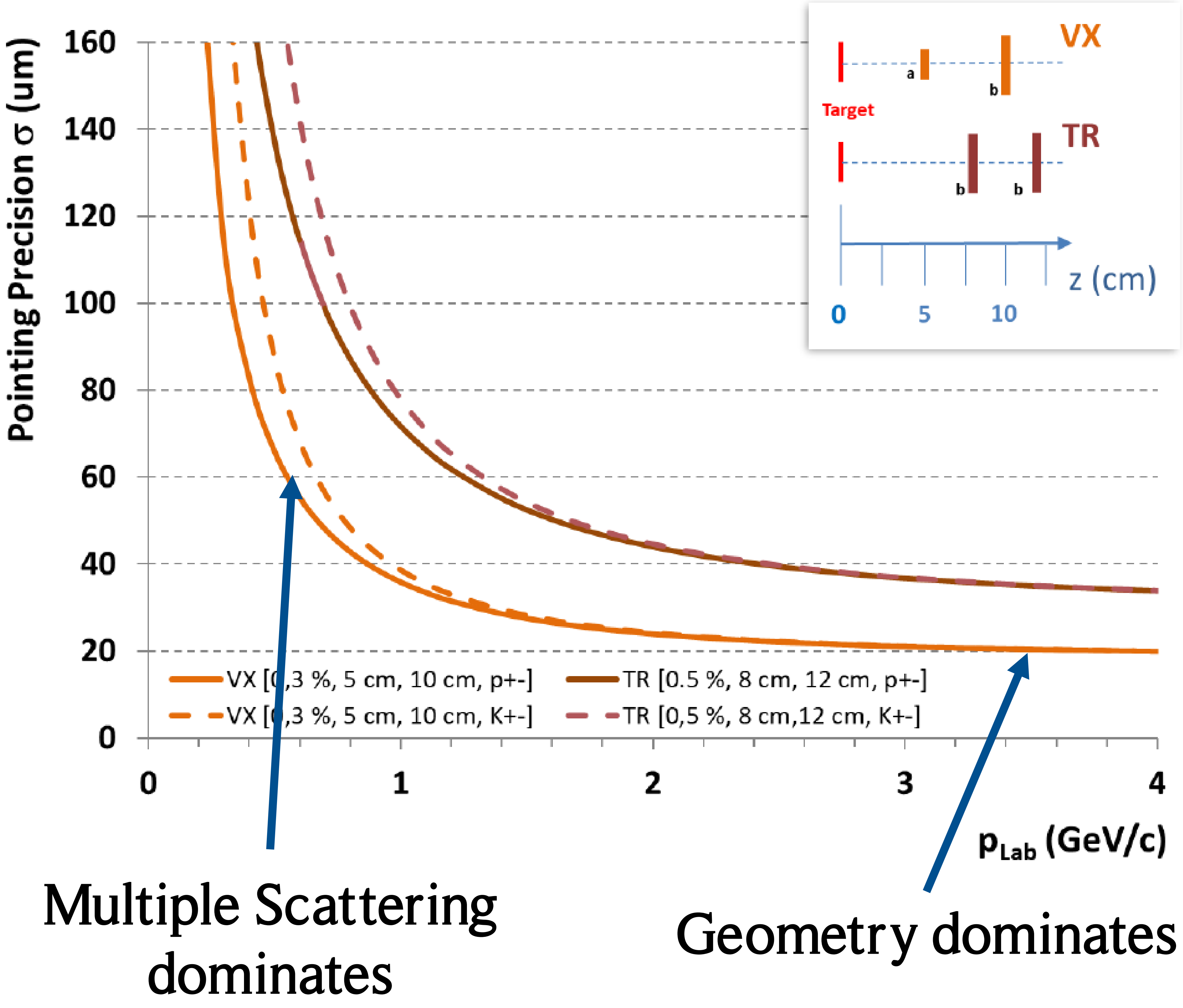

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Requirements for Low-p Tracking

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→ Multiple Scattering dominated regime

→ Technology: (thinned) CMOS MAPS

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But: No lunch for free

→ MVD rate limited to 100 kHz Au+Au (10 MHz pp)

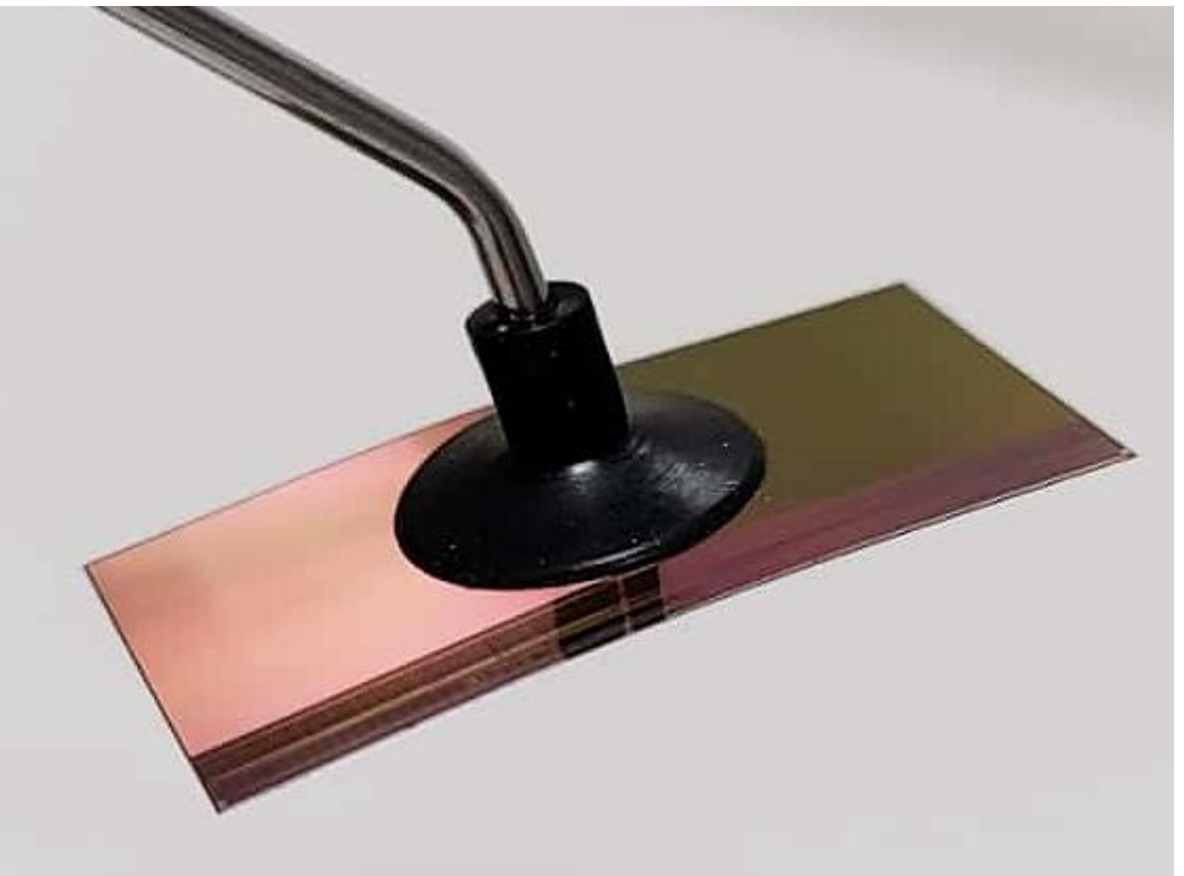
Readout speed, radiation hardness

1st station needs annual exchange

→ Passive cooling in acceptance

Large modules for mechanics and cooling

→ Double-sided integration



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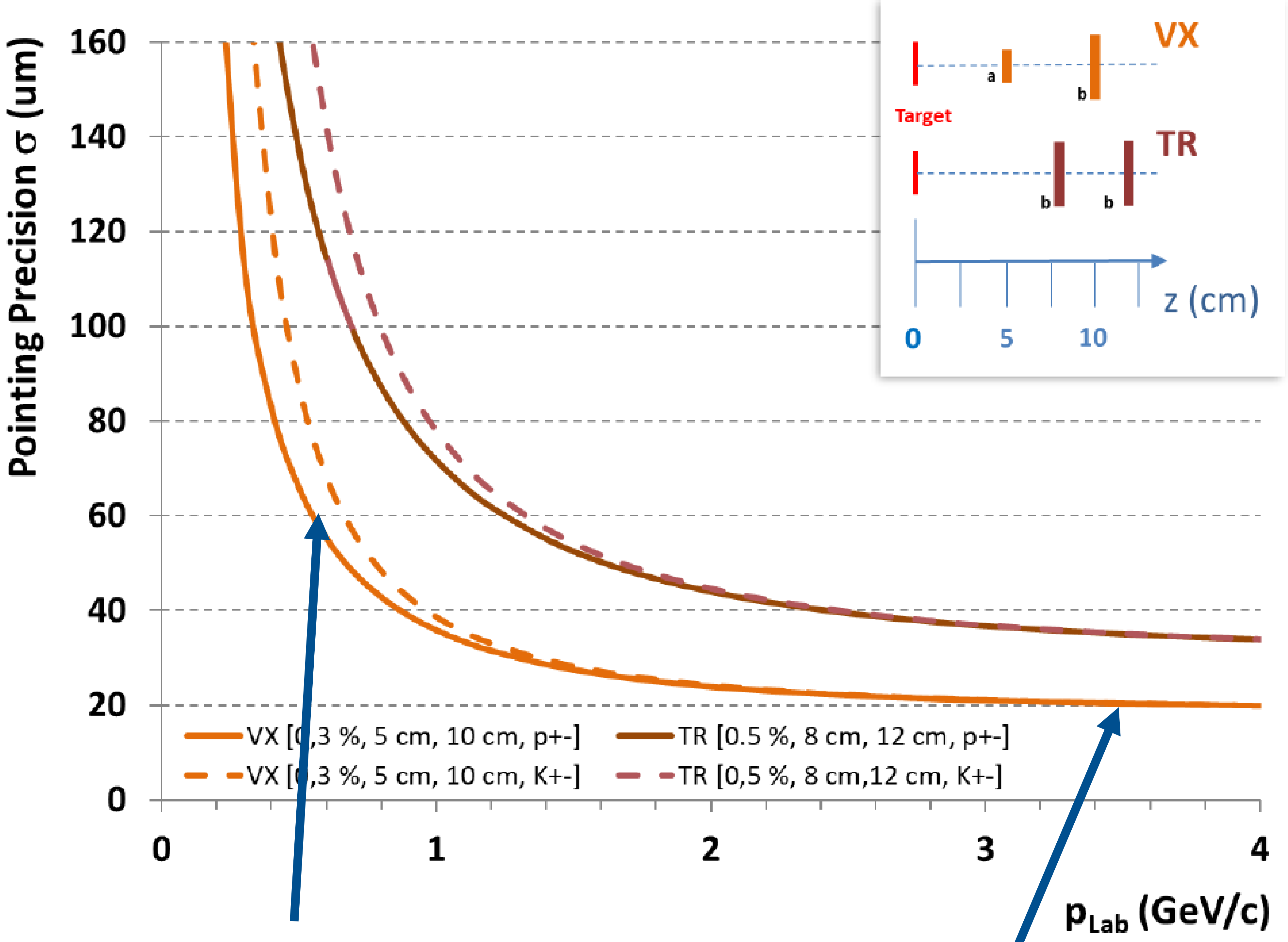

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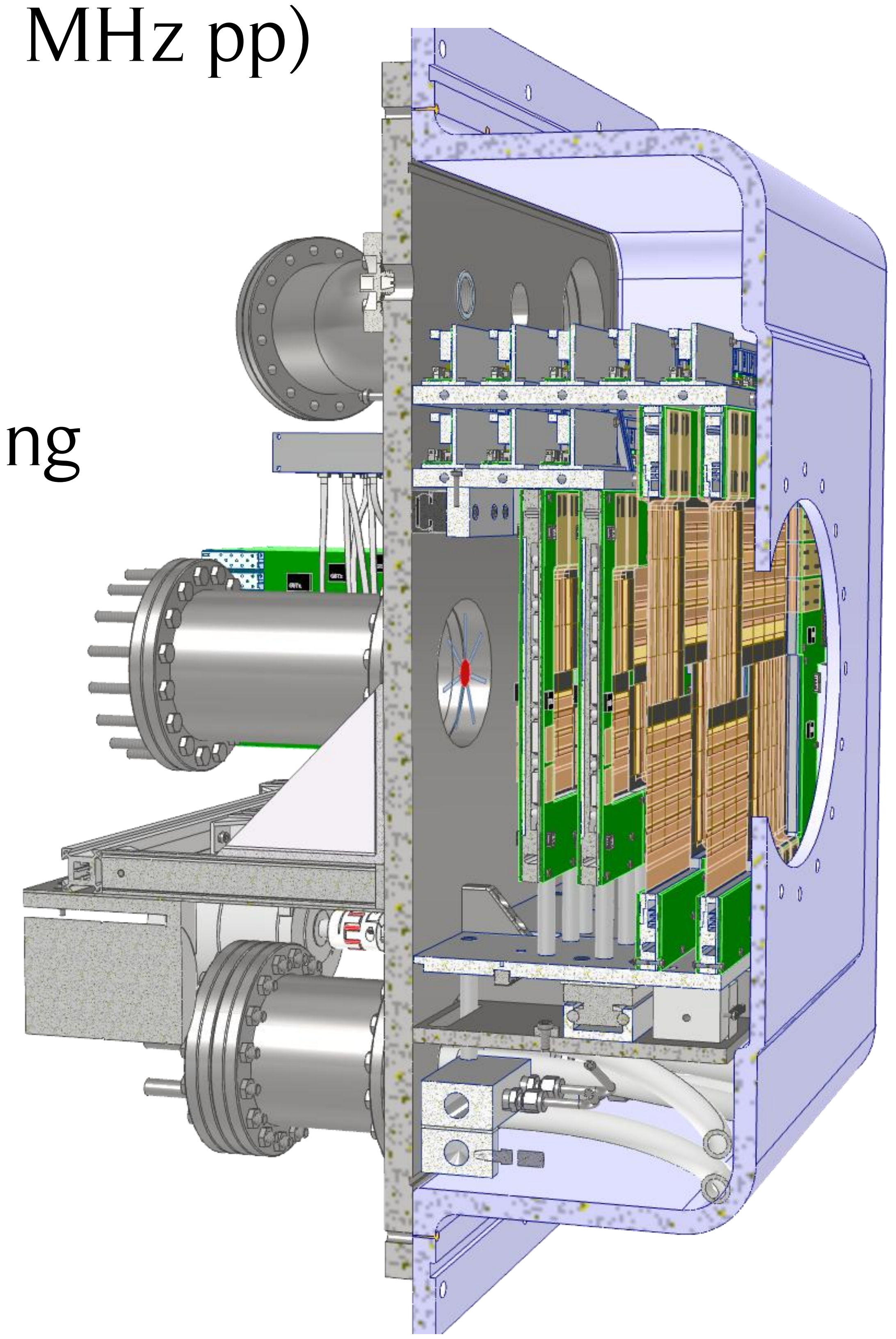
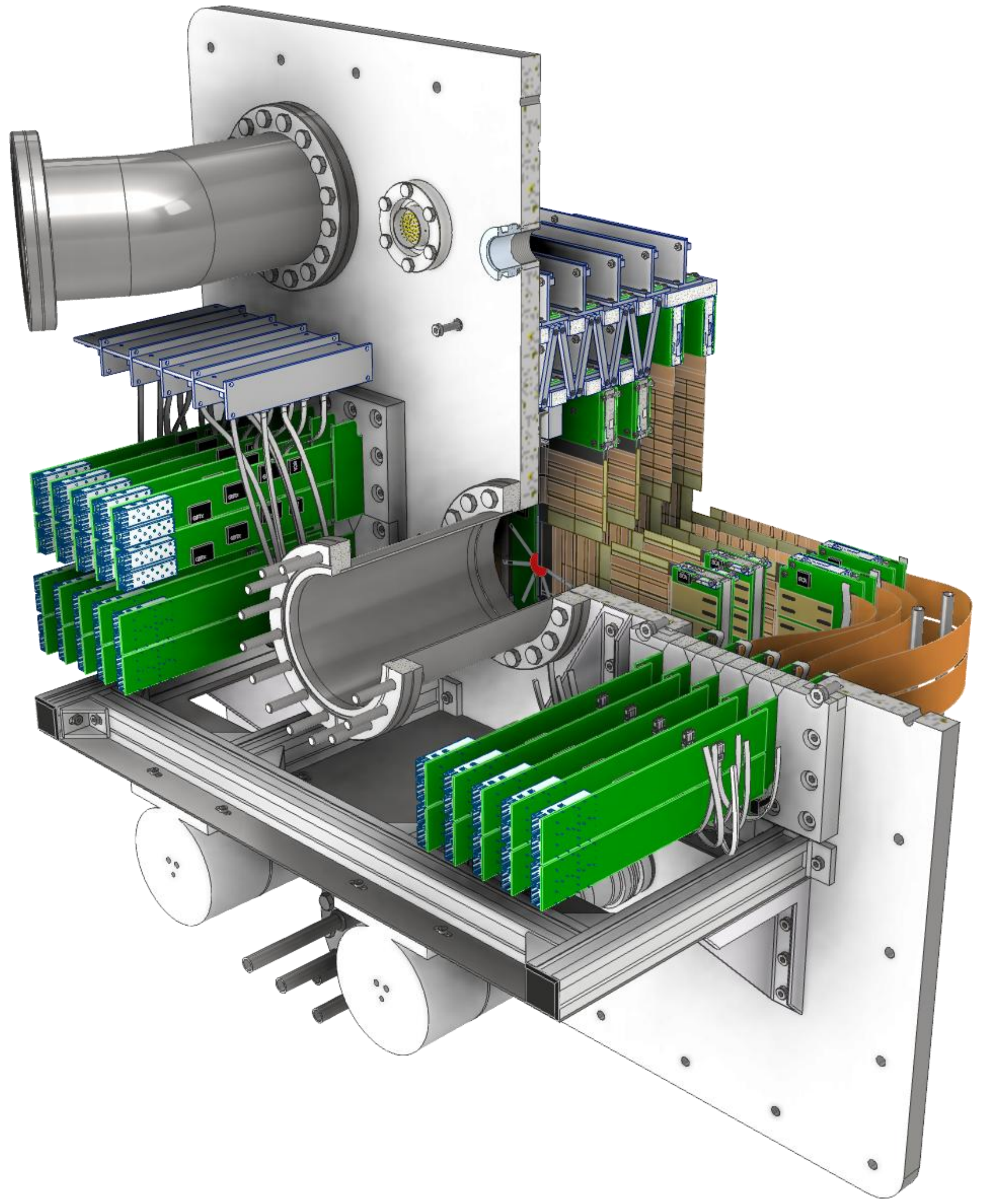
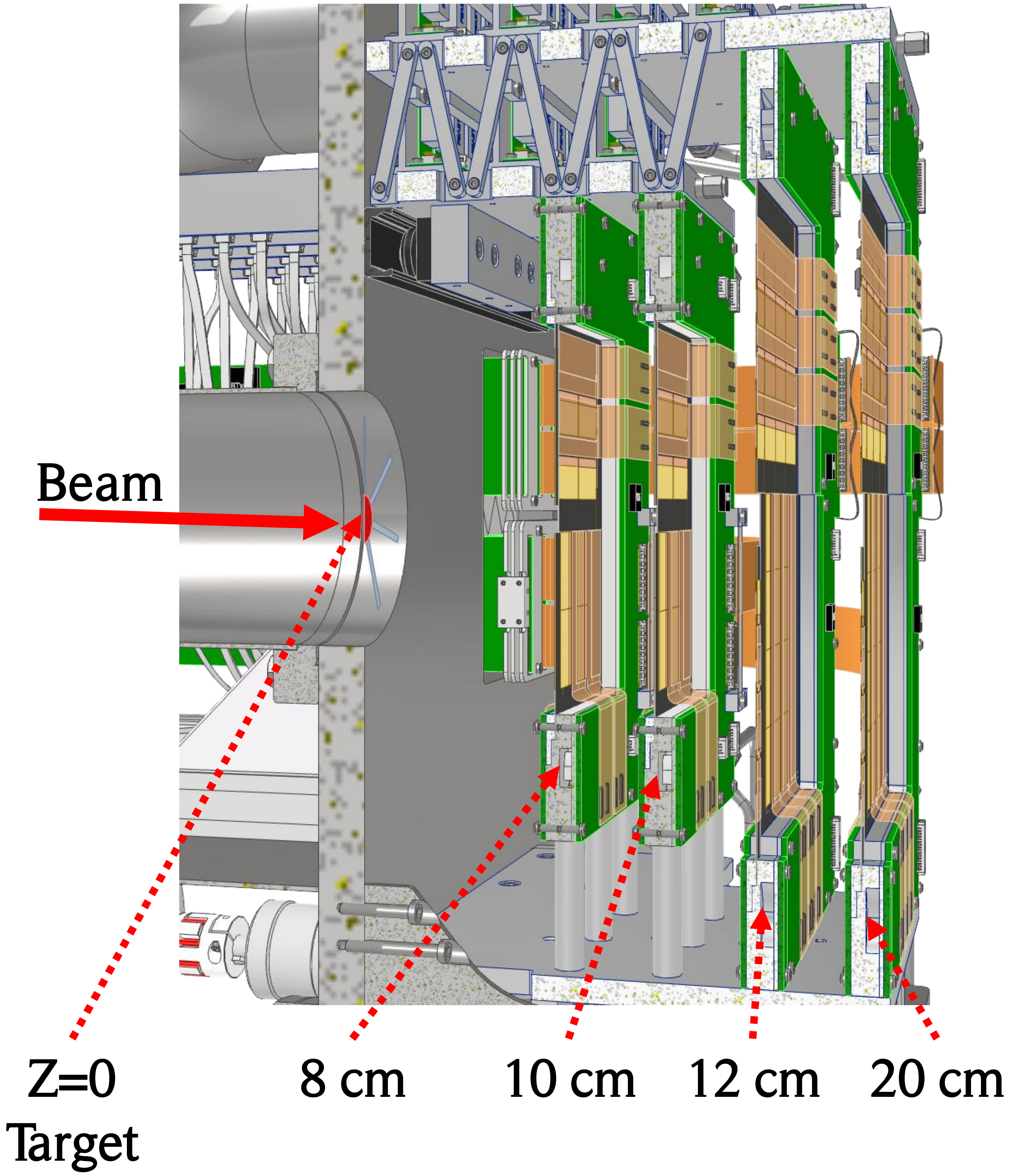


Overview Micro Vertex Detector

4 planar tracking stations, ~300 sensors
→ 8 – 20 cm downstream of target





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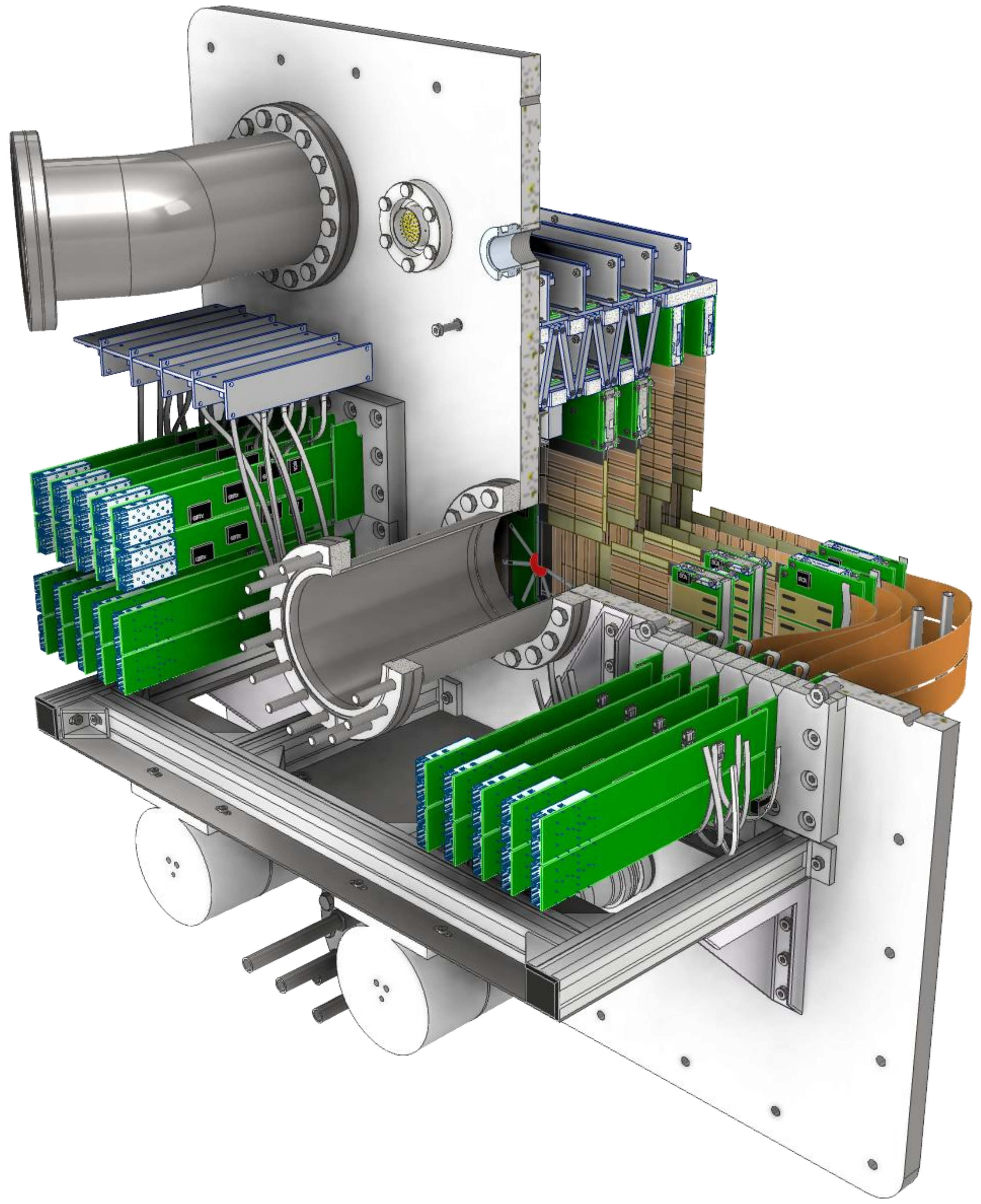
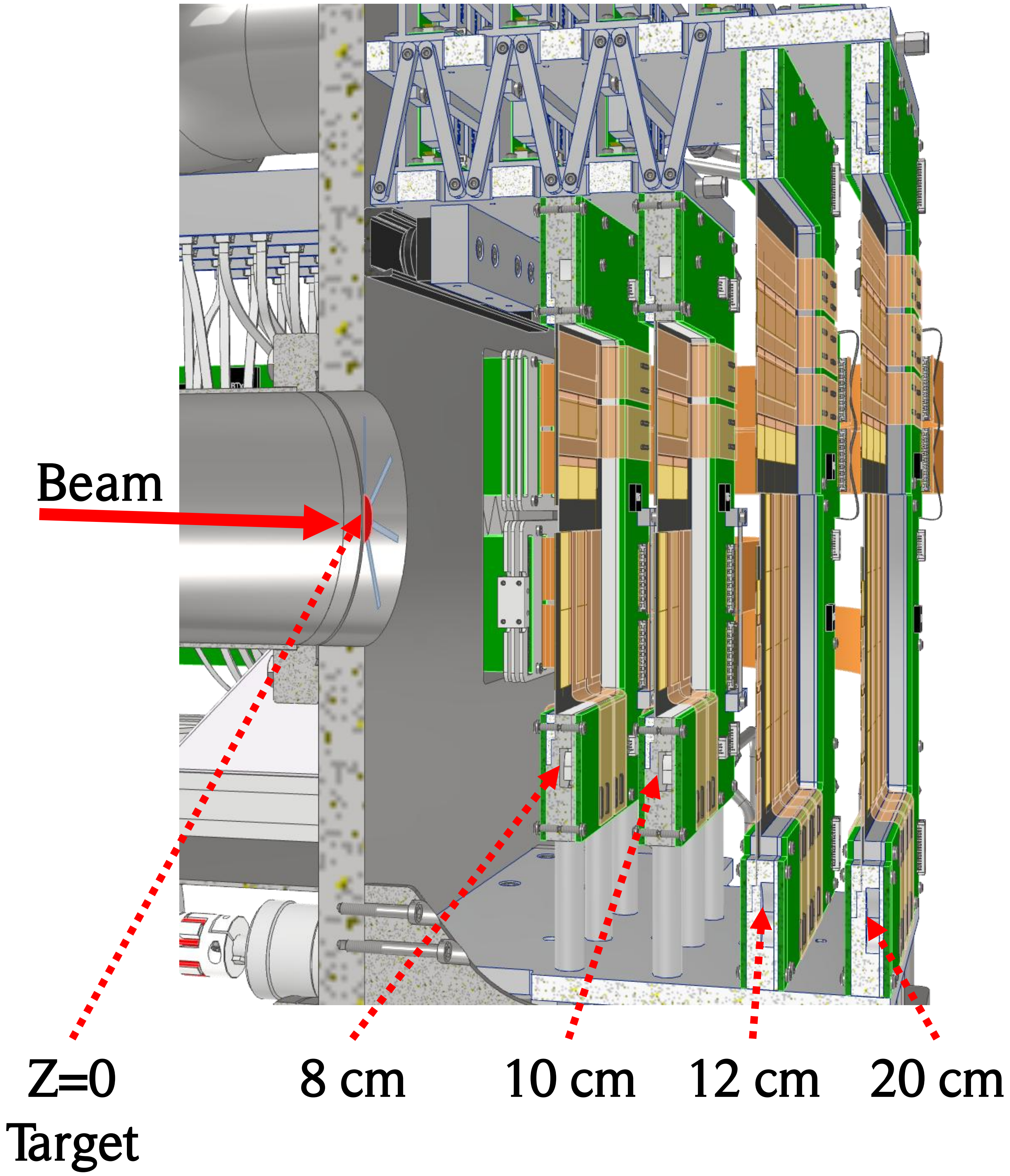
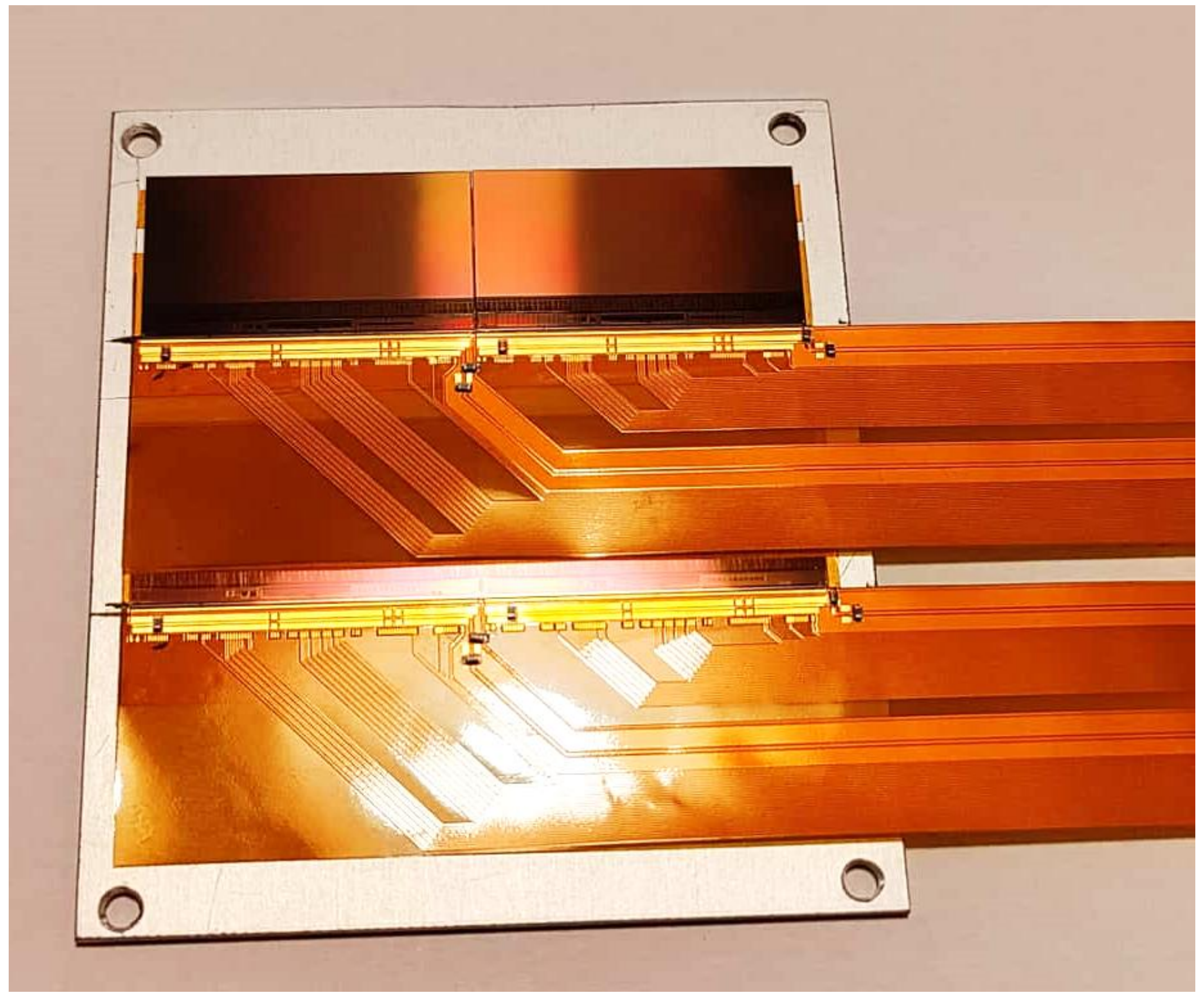
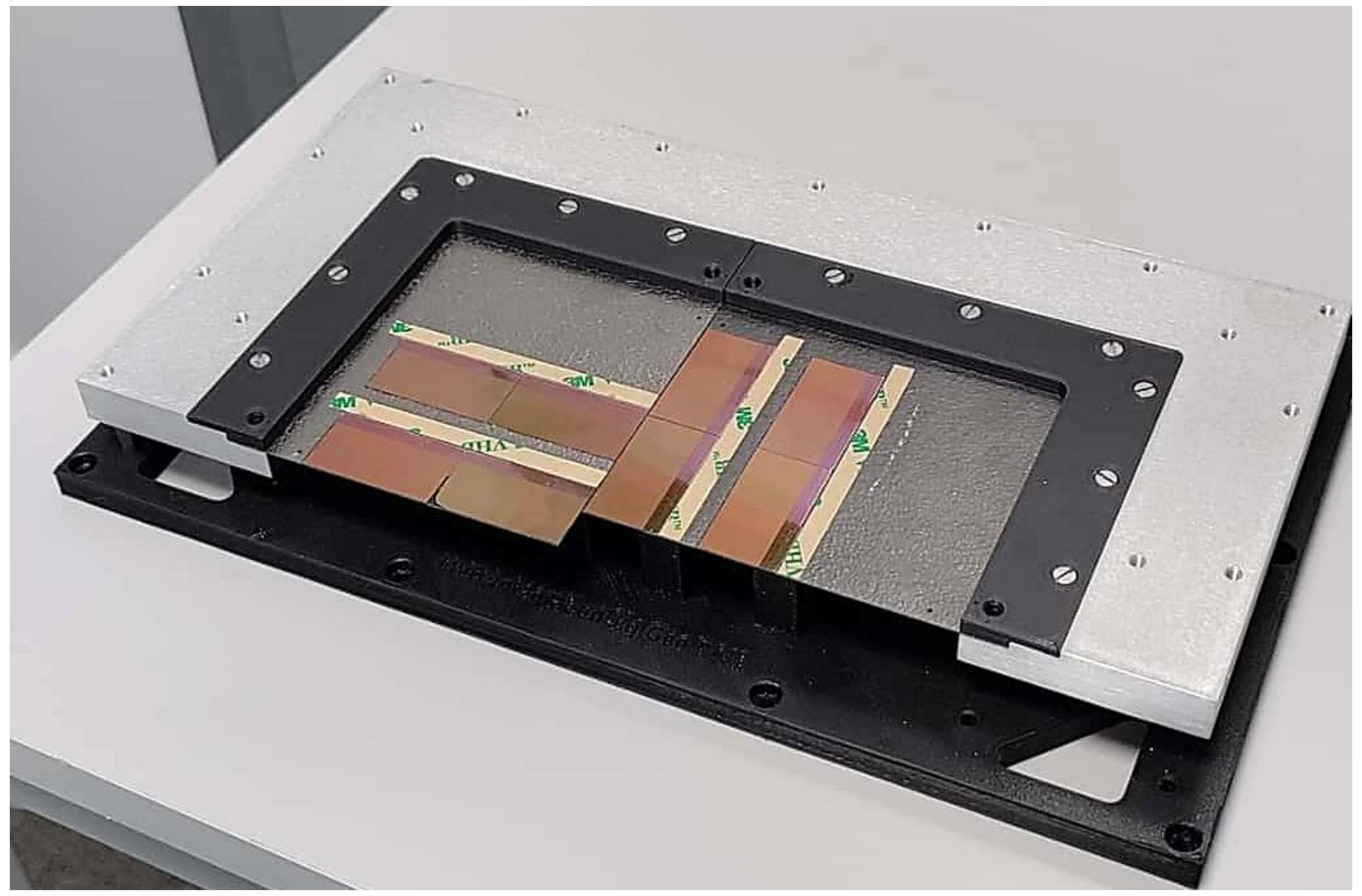






MIMOSIS-2.1 with MVD FPC

MIMOSIS-2 on TPG



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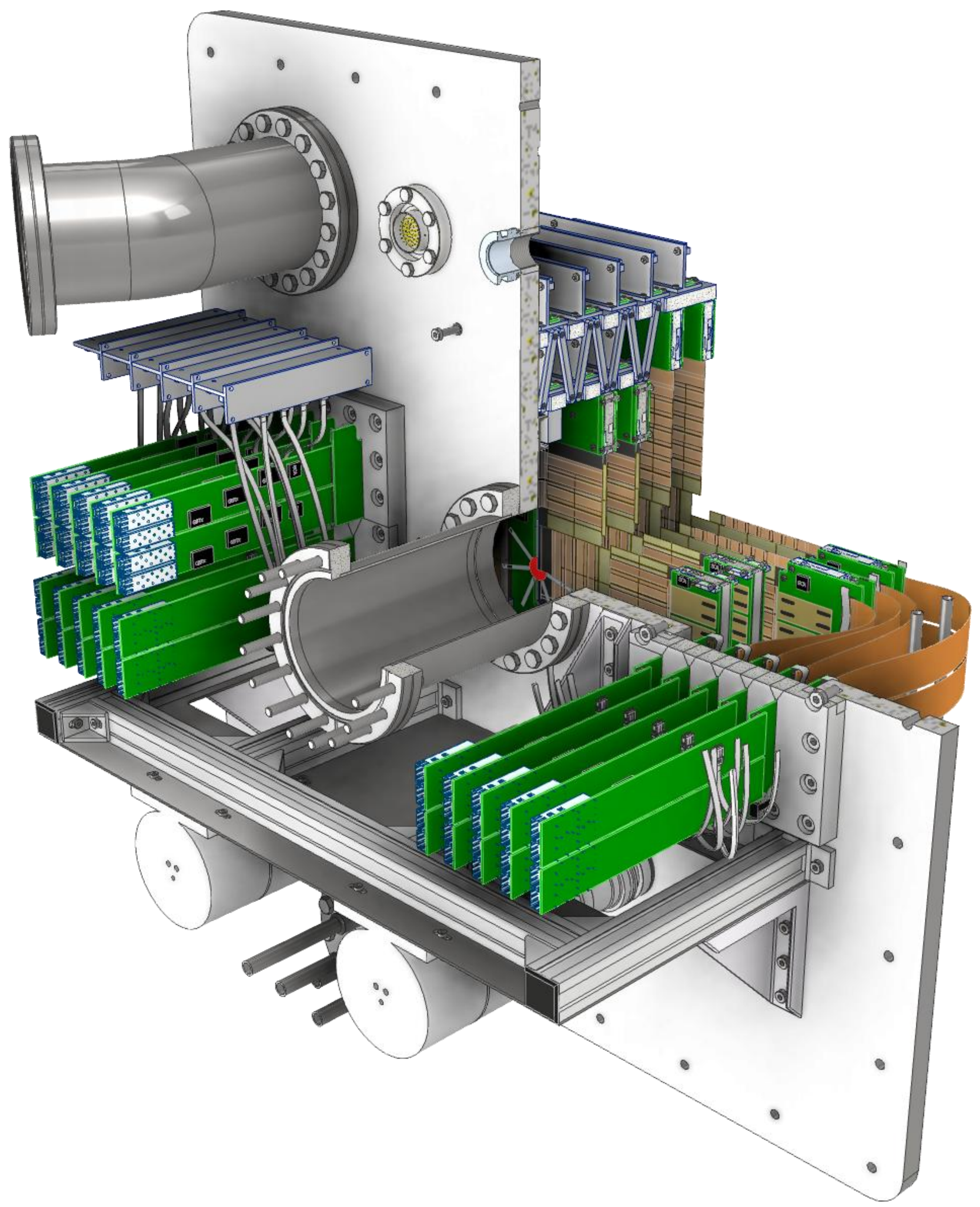
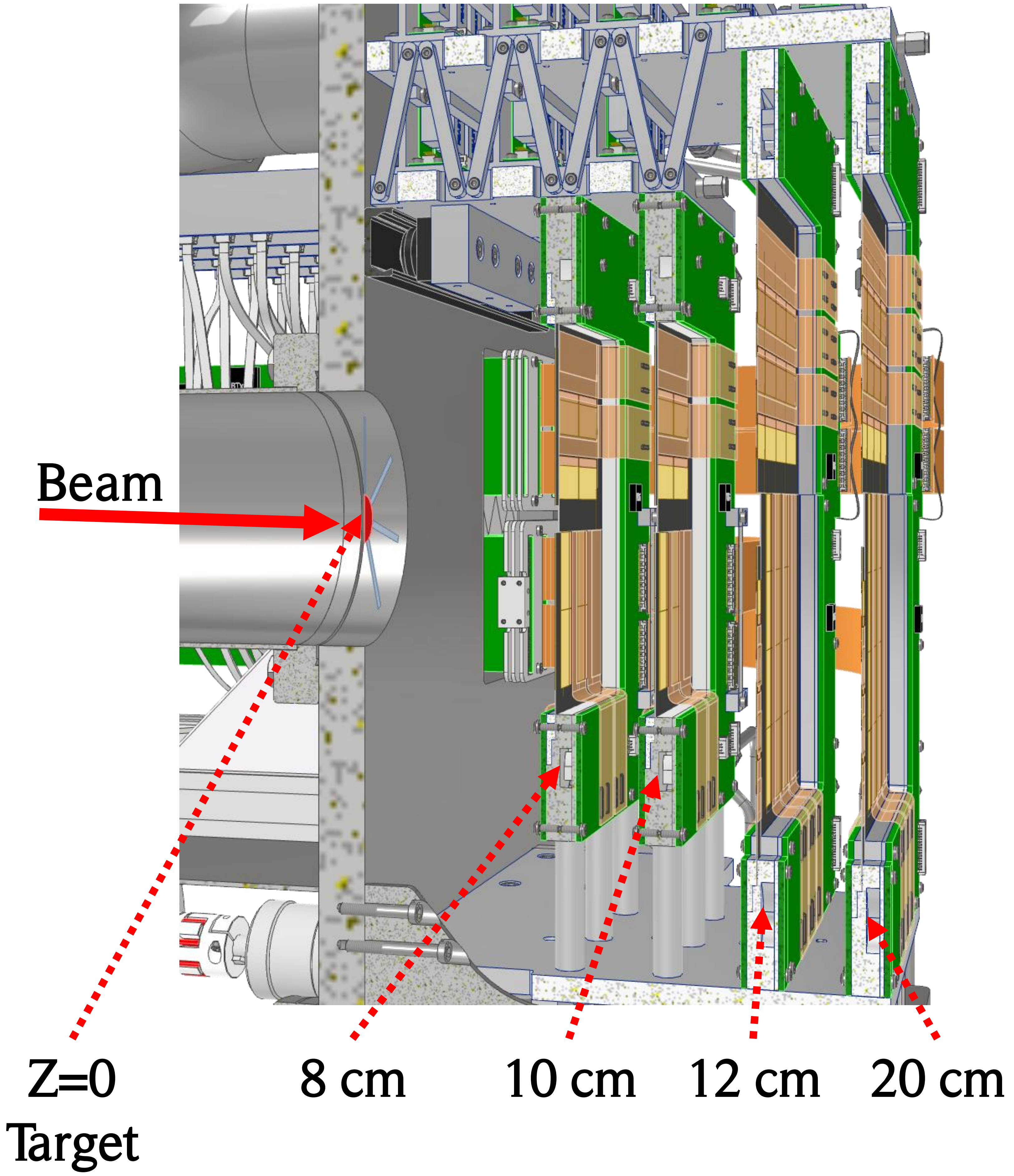
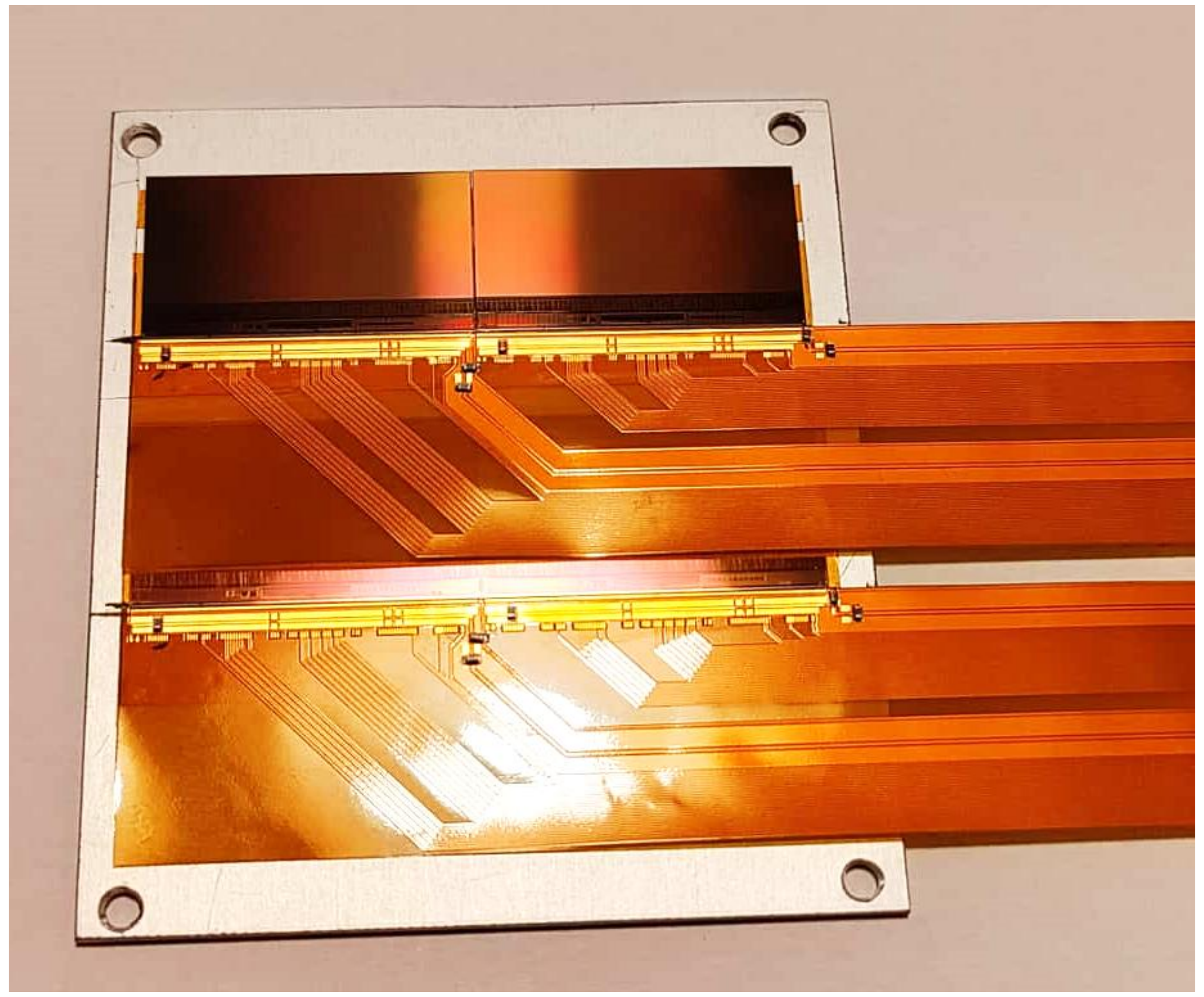
Overview Micro Vertex Detector

4 planar tracking stations, ~300 sensors
→ 8 – 20 cm downstream of target

Key challenges:
→ Magnetic field and vacuum operation
→ Material budget (0.3% – 0.5% X_0)
→ Double-sided integration







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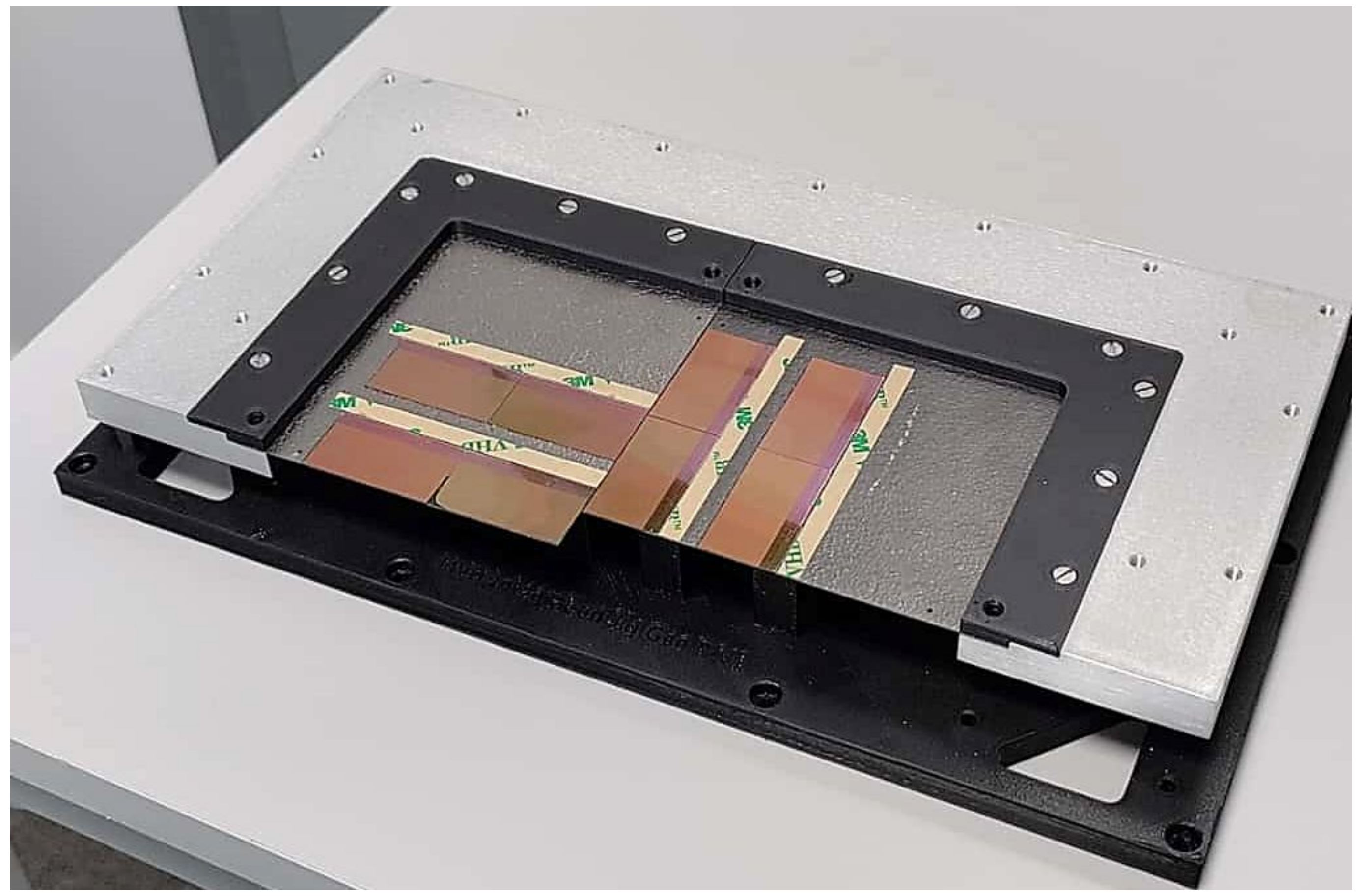

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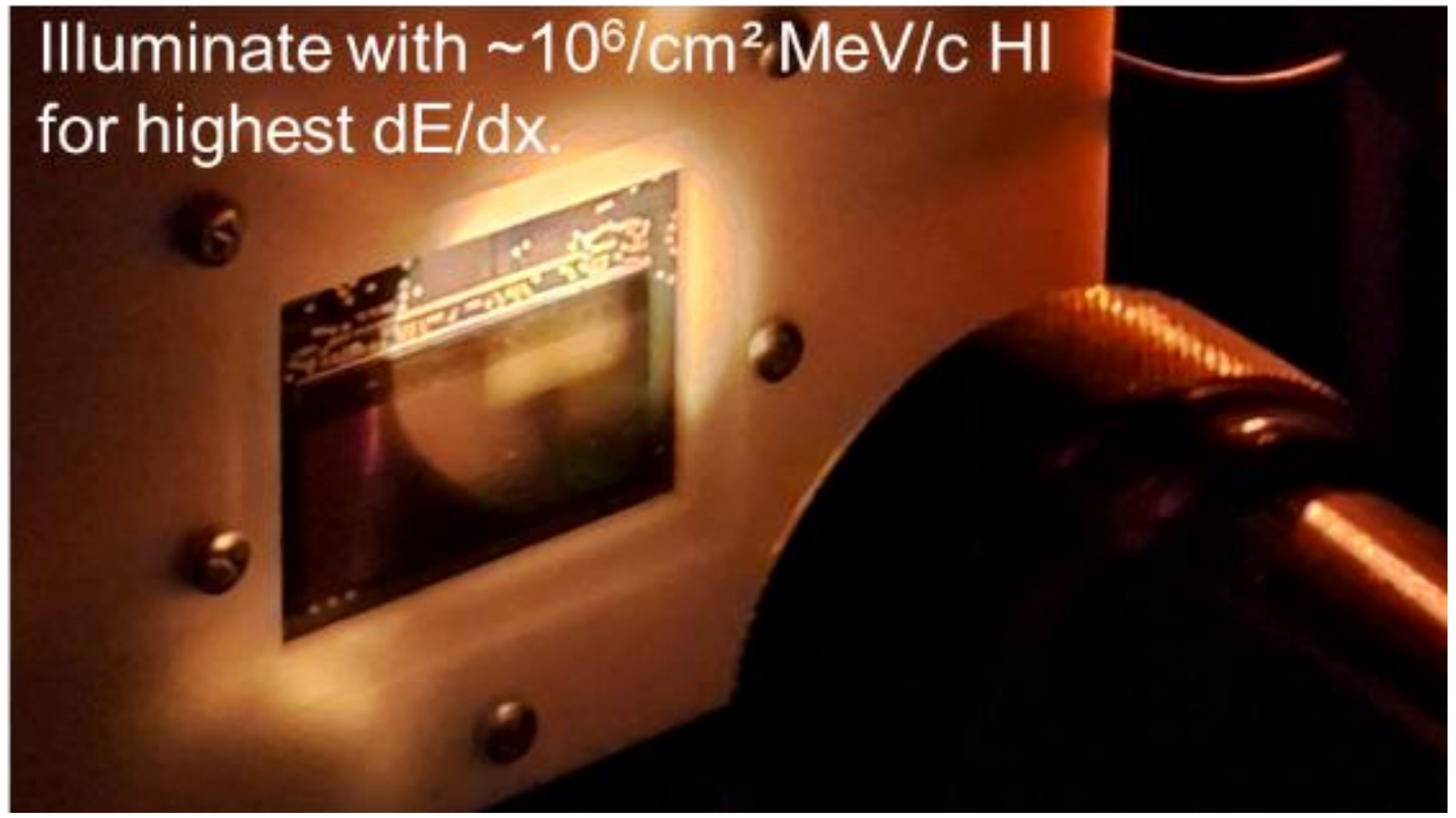
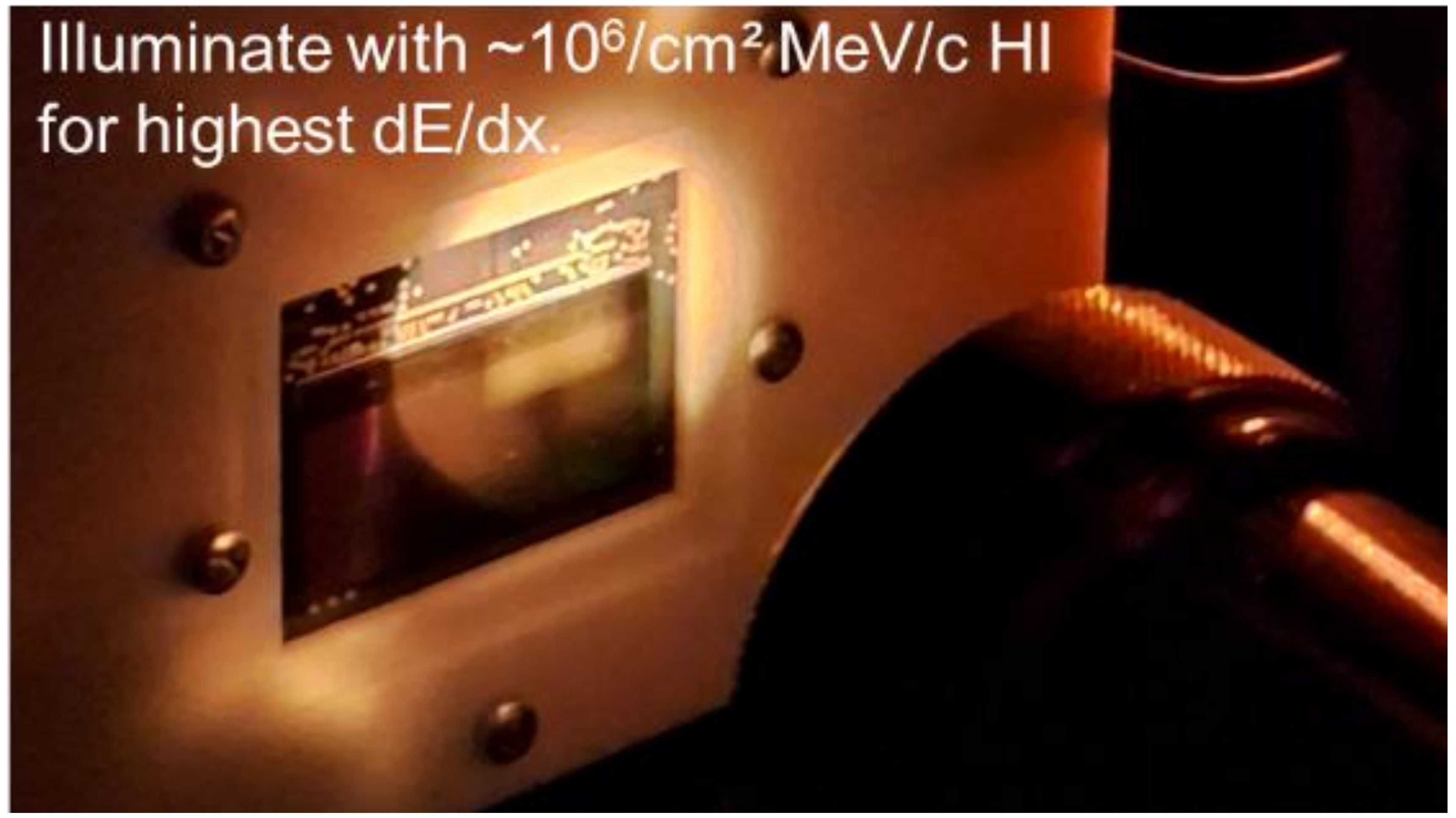
CBM and the GSI Pixel Platform


Illuminate with ~10^6/cm² MeV/c HI for highest dE/dx.

Sensor validation infrastructure (SEE tests at UNILAC, mCBM@SIS18, …)

CBM and the GSI Pixel Platform



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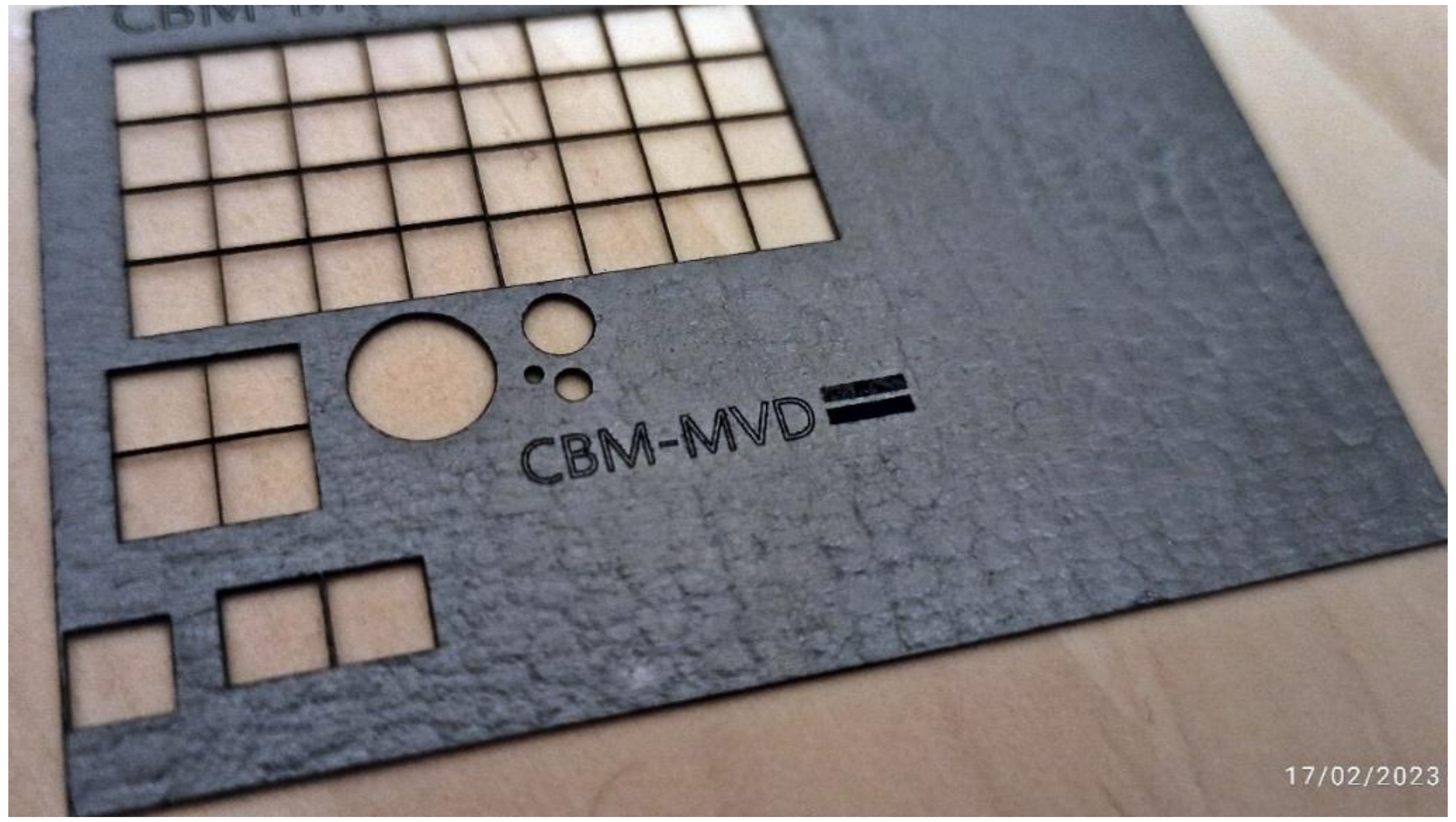

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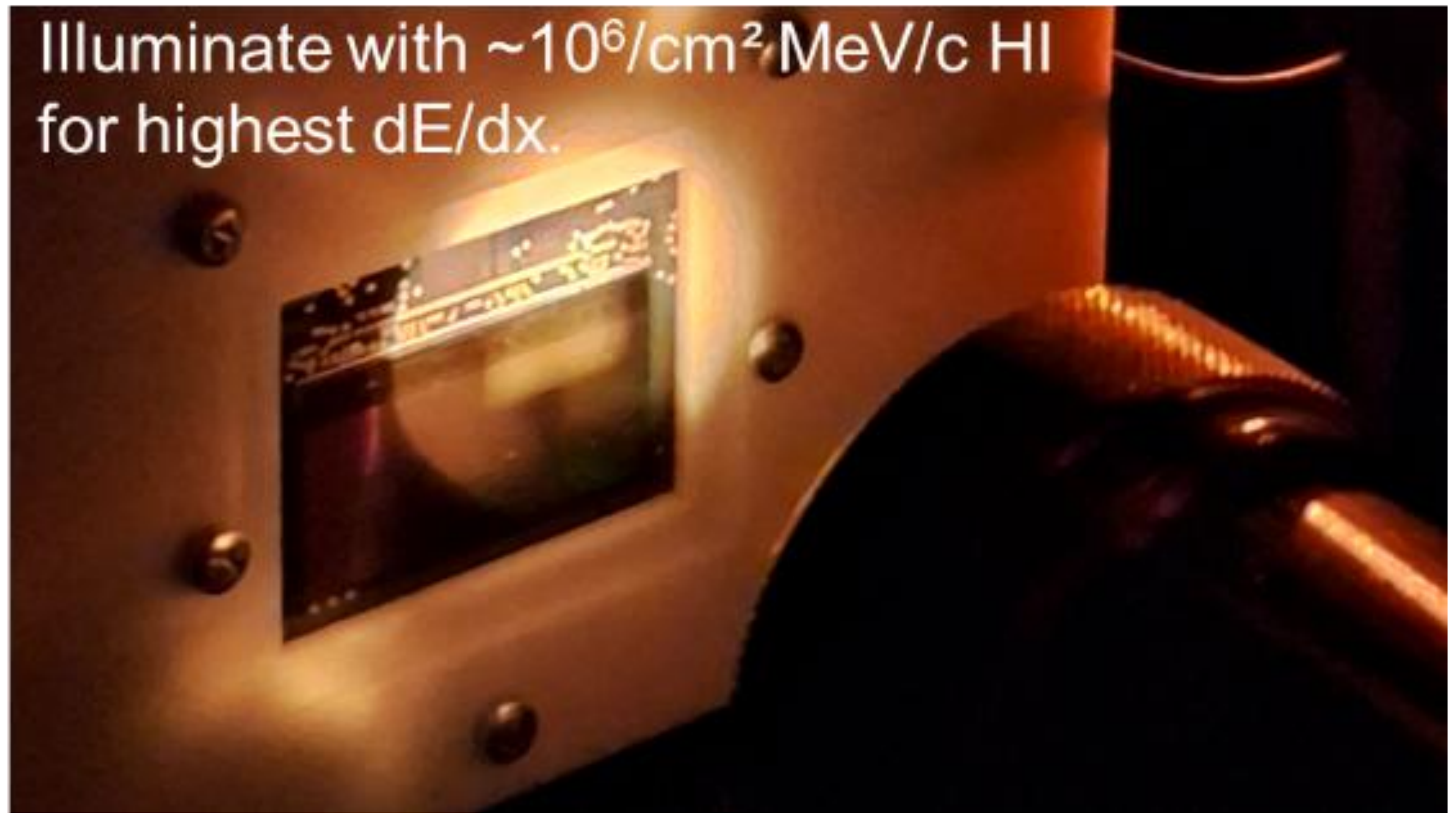

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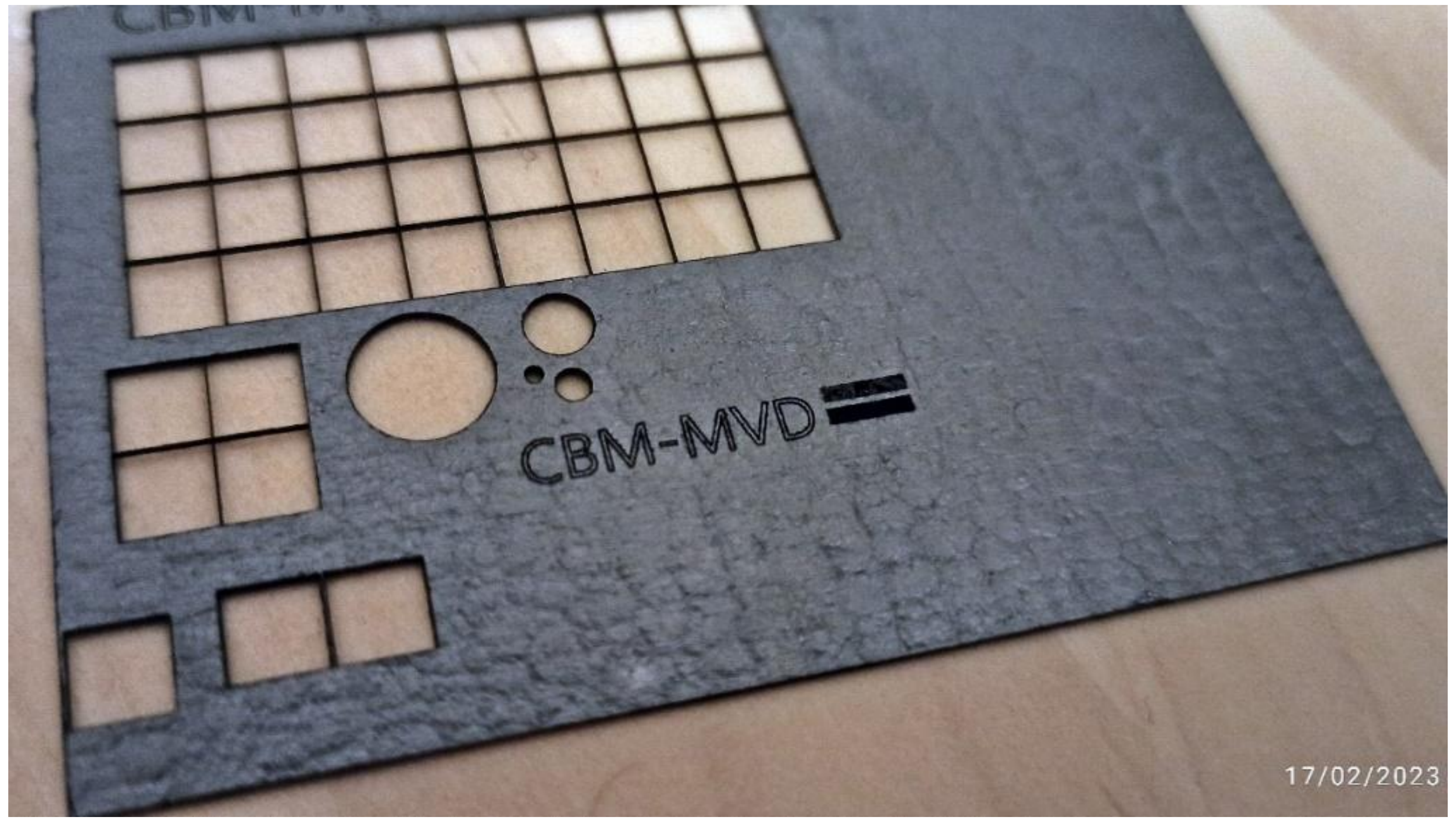

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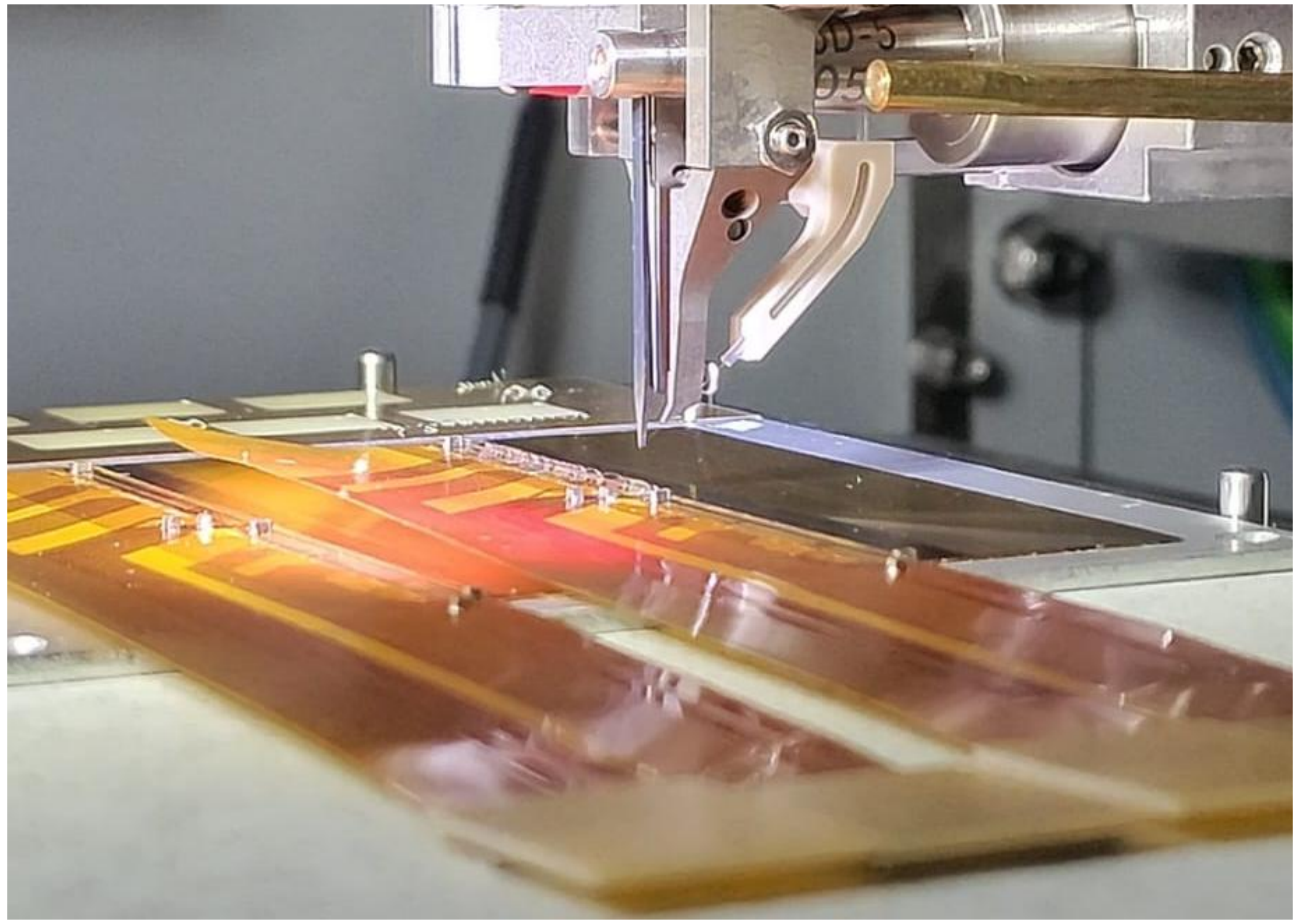

Integration expertise
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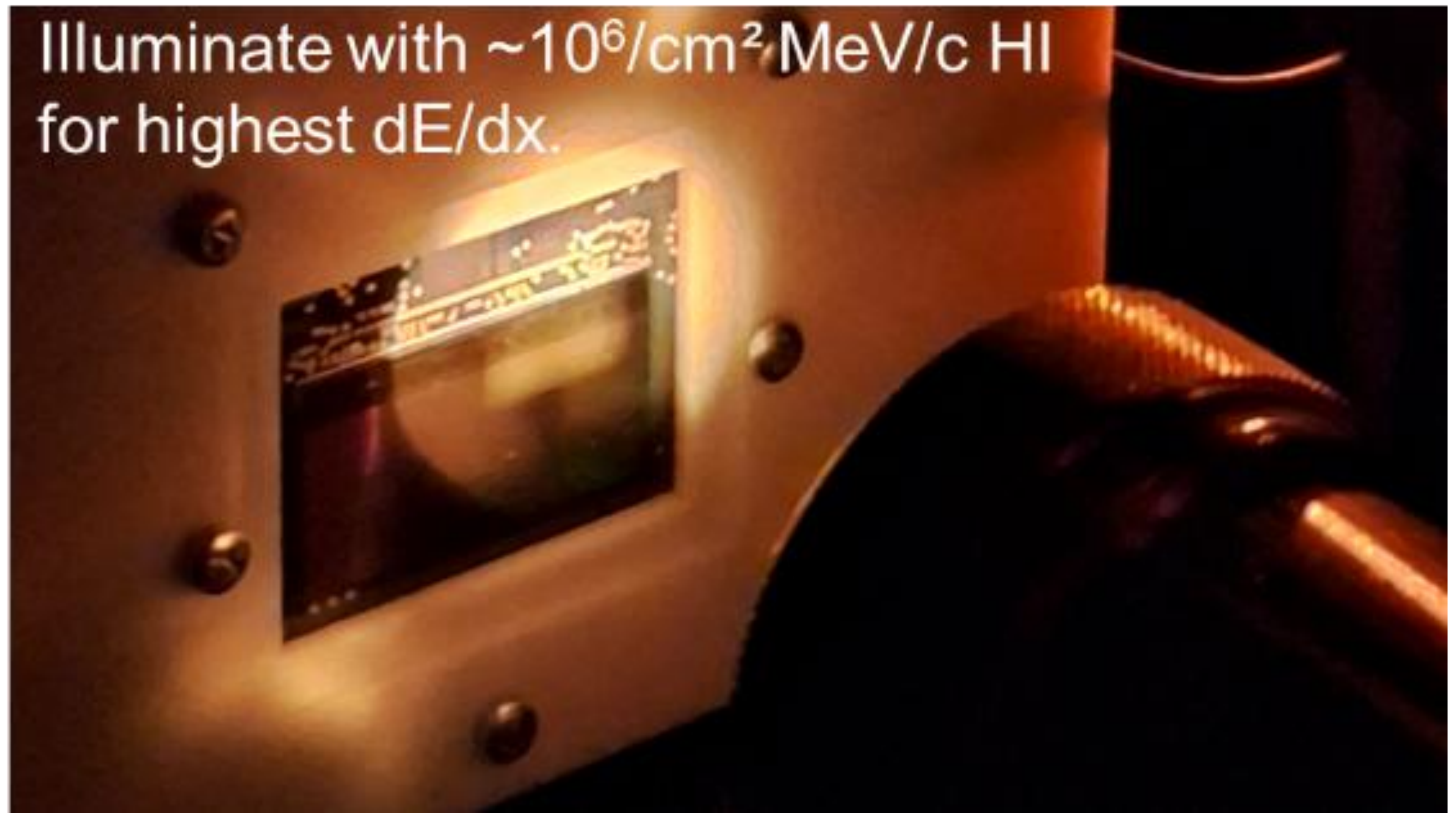

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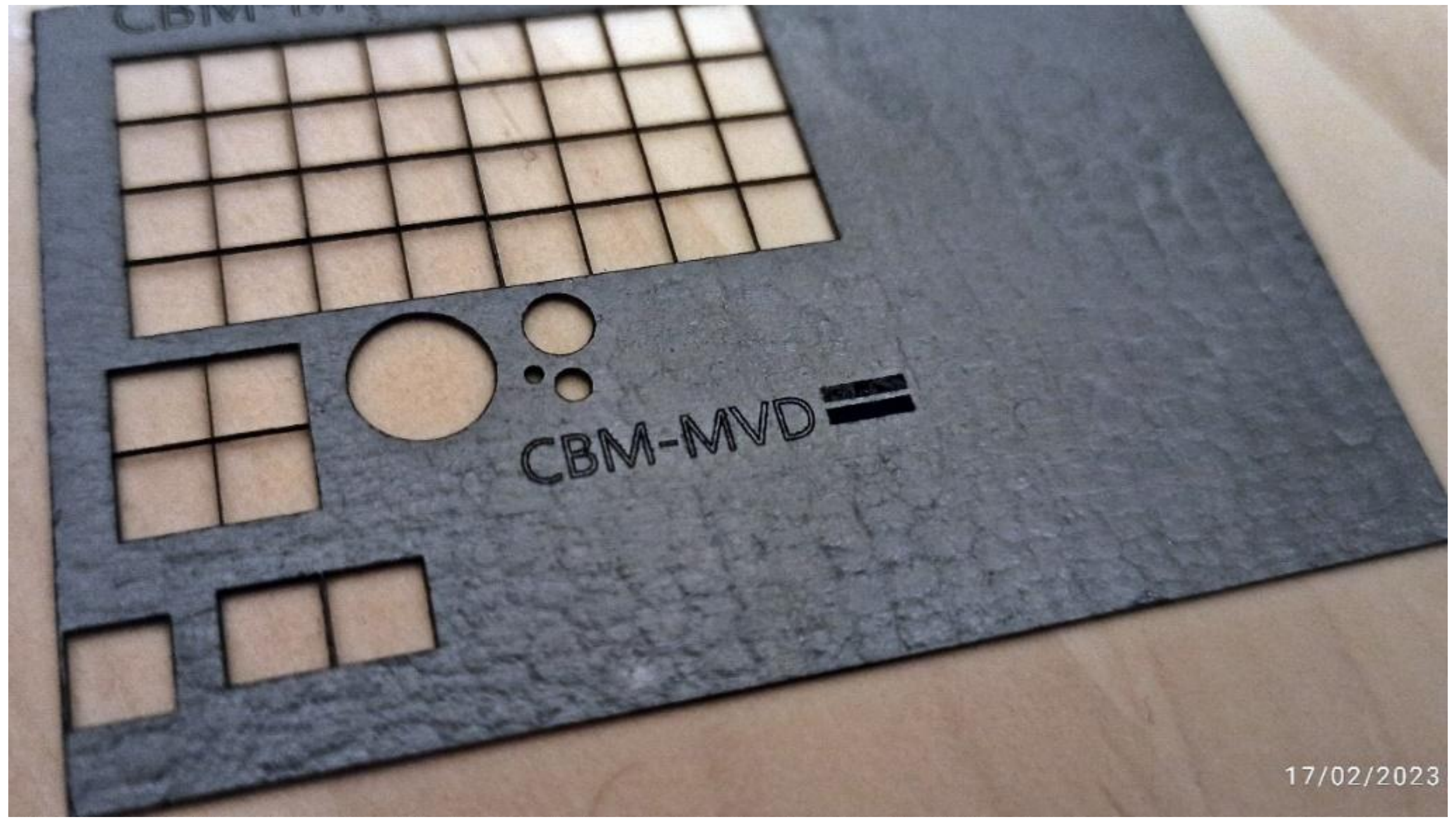

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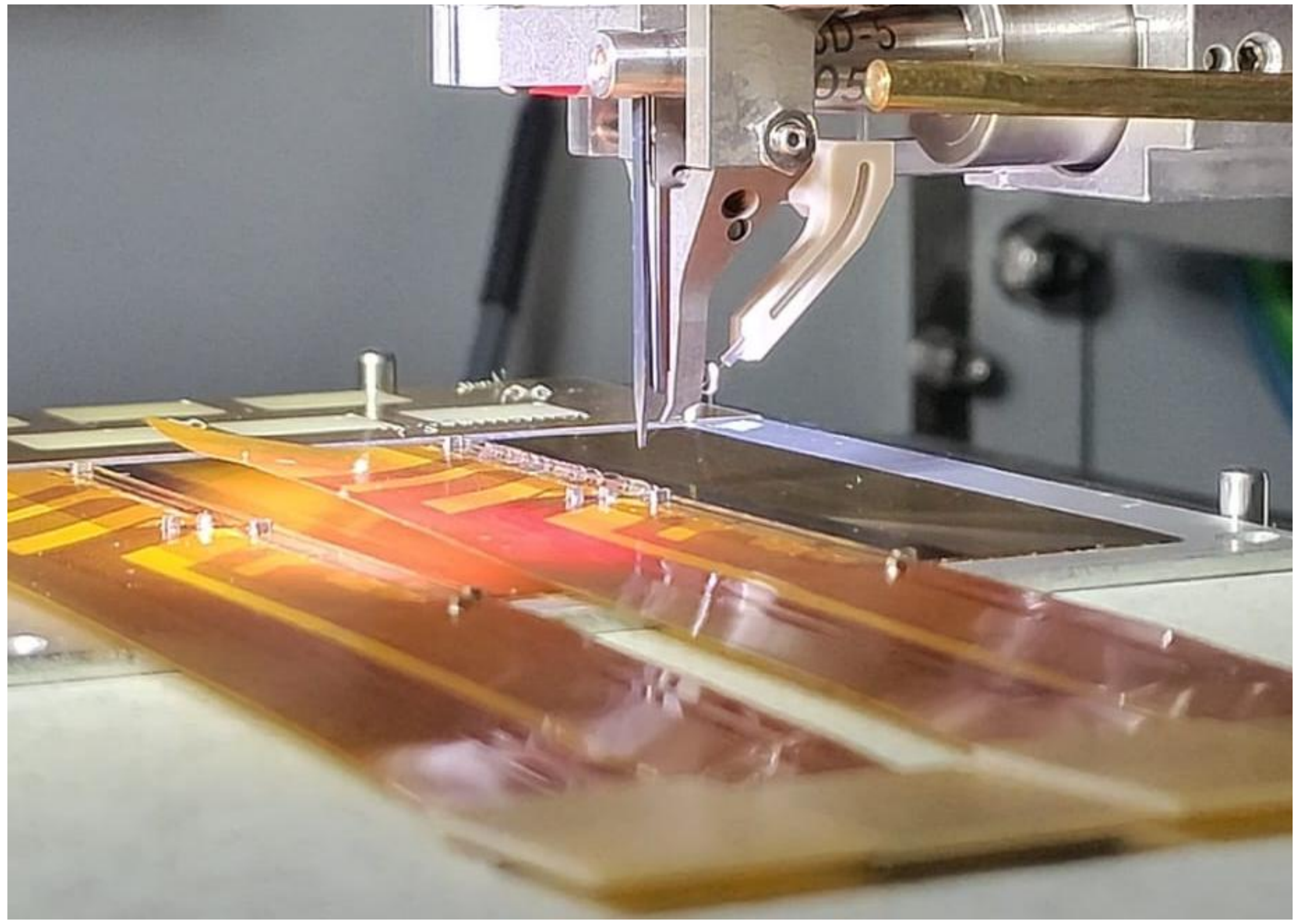
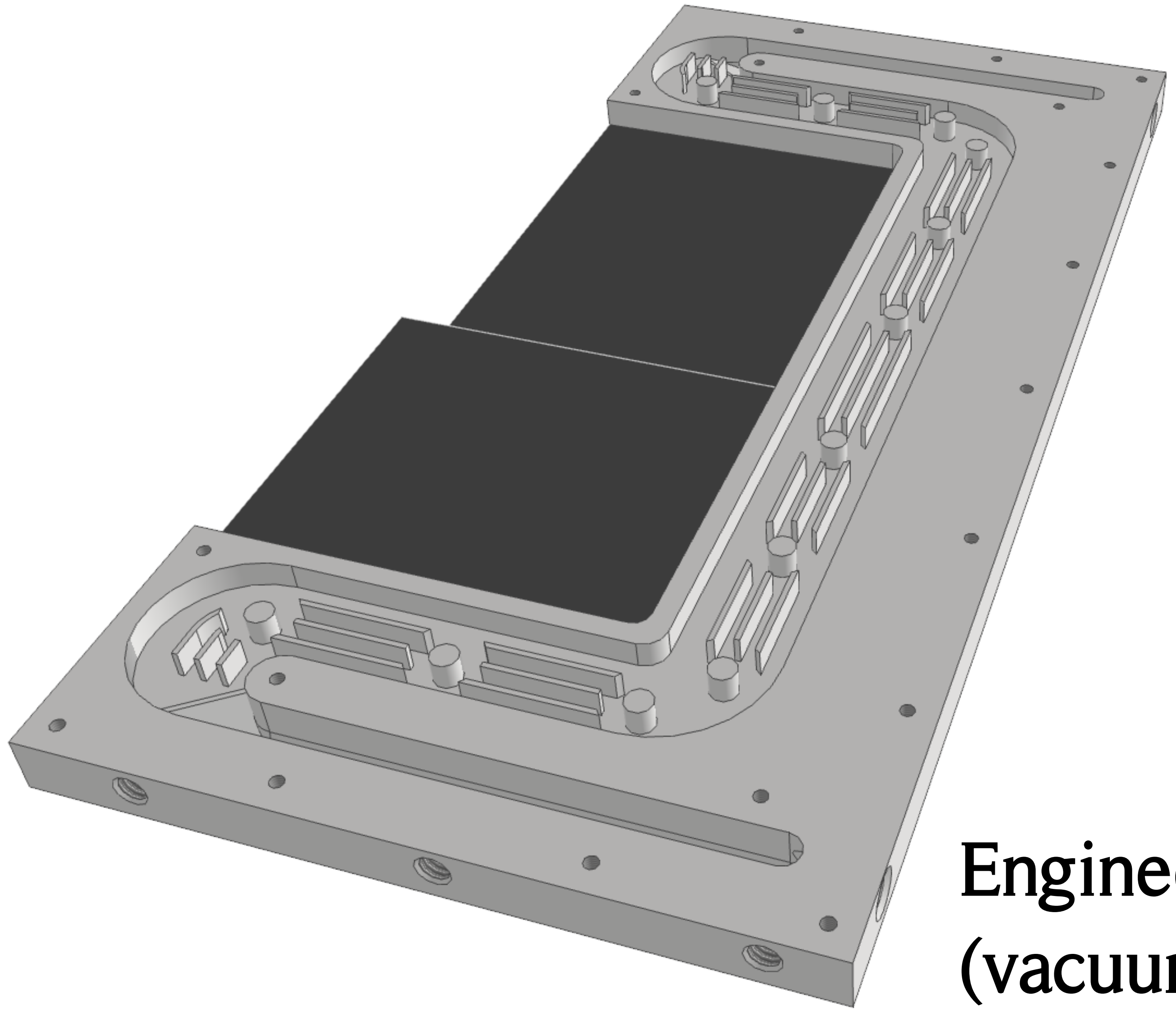


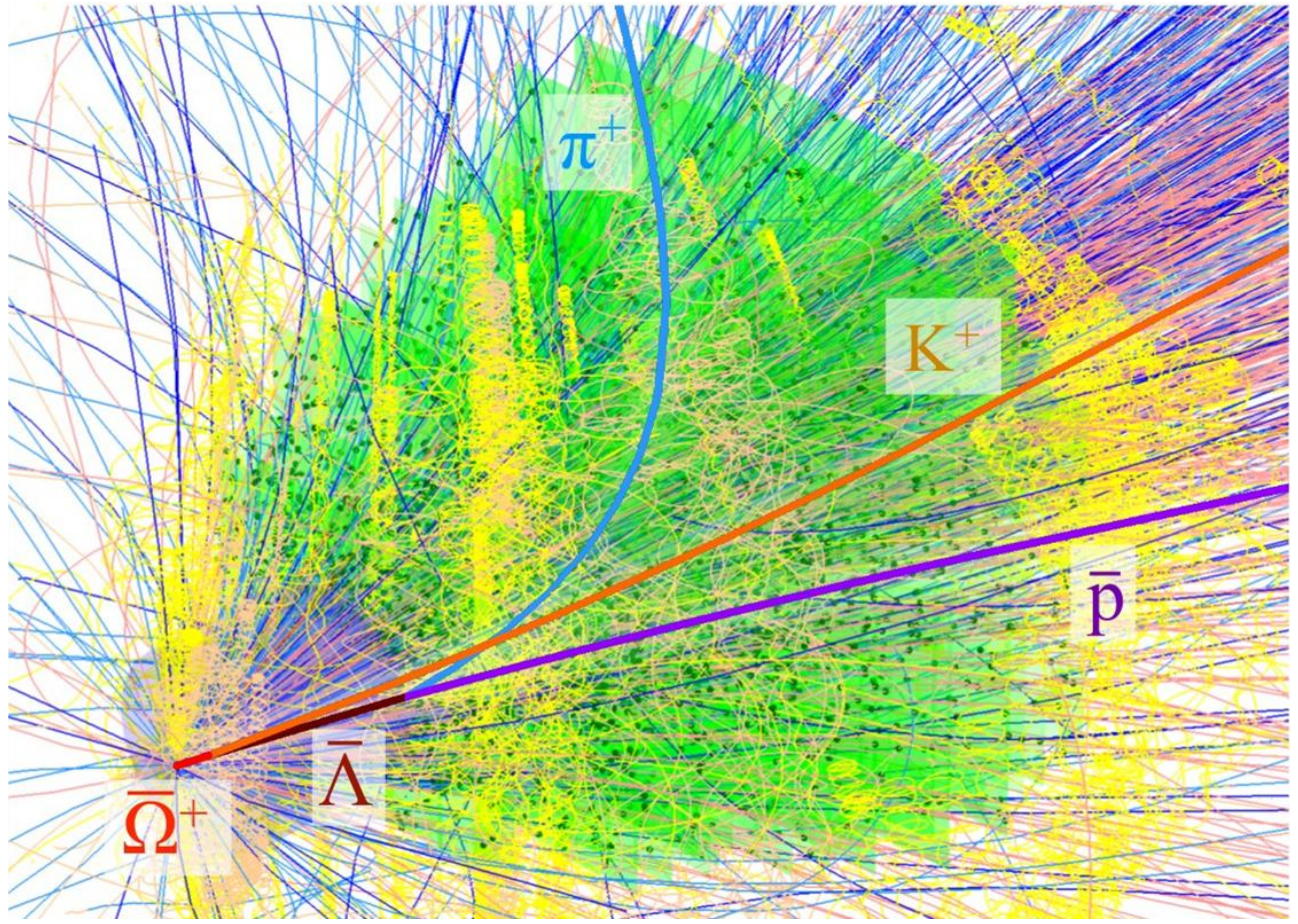


Engineering expertise
(vacuum feedthroughs, heat sinks, …)

Chapter 1

MIMOSIS

The MIMOSIS Story



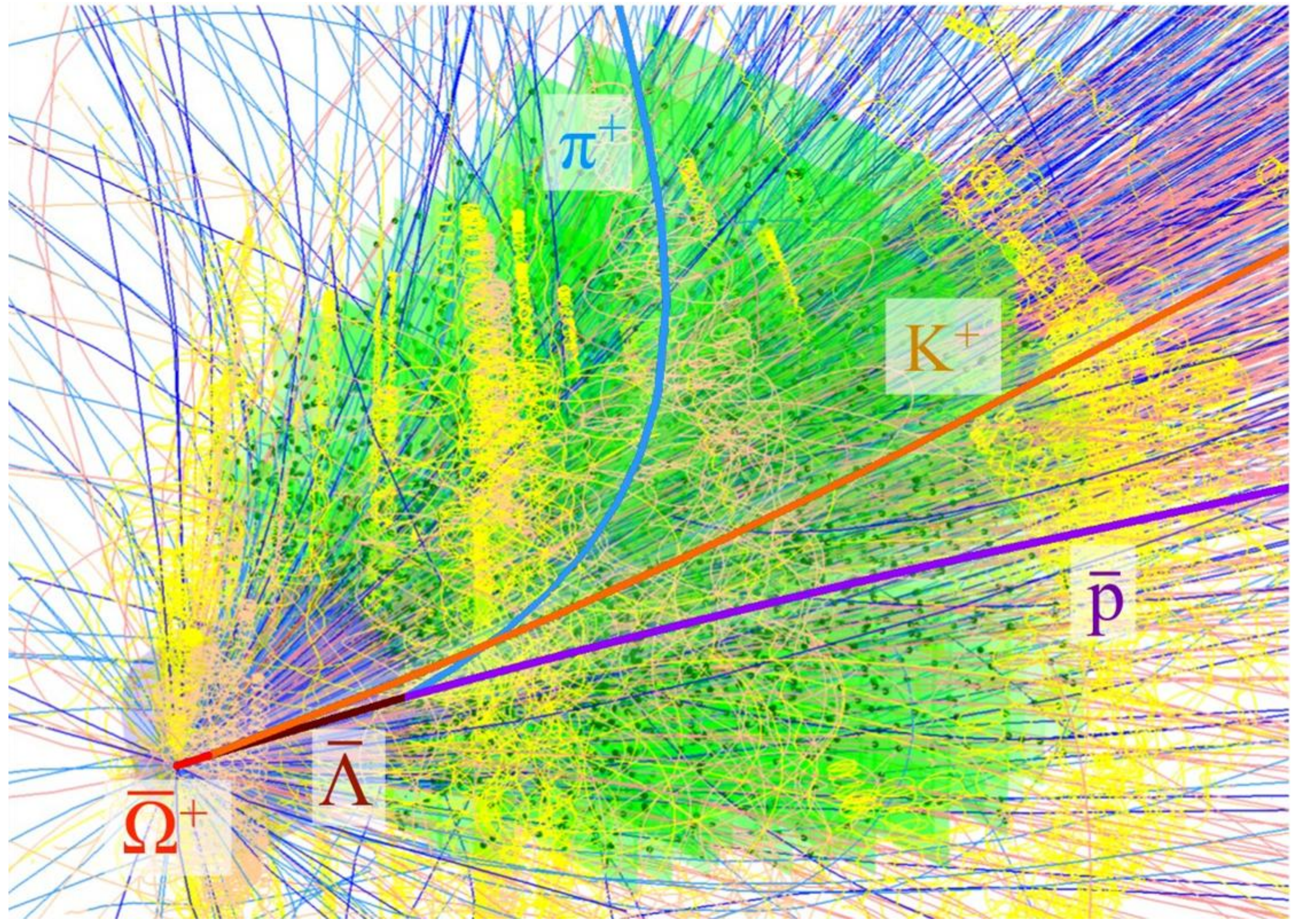
“The needle in the haystack”
Anti-Ω in12 *A*GeV Au-Au collisions
in the Inner Tracker

	Requirement
Spatial precision	~5 µm
Time resolution	~5 µs
Thickness	~50 µm
Power dissipation	< 100 mW/cm^2
Radiation doses (non-ionizing)	**> 7x10^{13} n$_{eq}$/cm^2**
Radiation doses (ionizing)	**> 5 Mrad**
Radiation gradient on chip	**~100%**
Rate capability avg. (peak)	20 (80) MHz/cm^2
HI-tolerance	10 Hz/mm^2

~10x ALPIDE

~20x ALPIDE

The MIMOSIS Story



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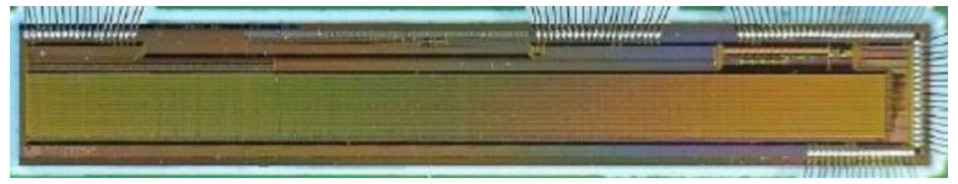
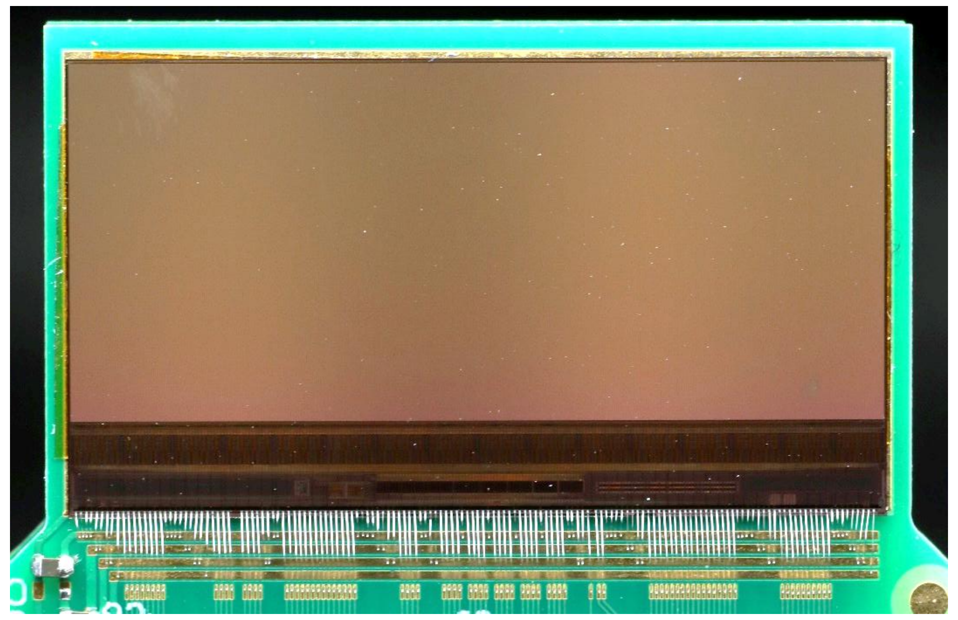
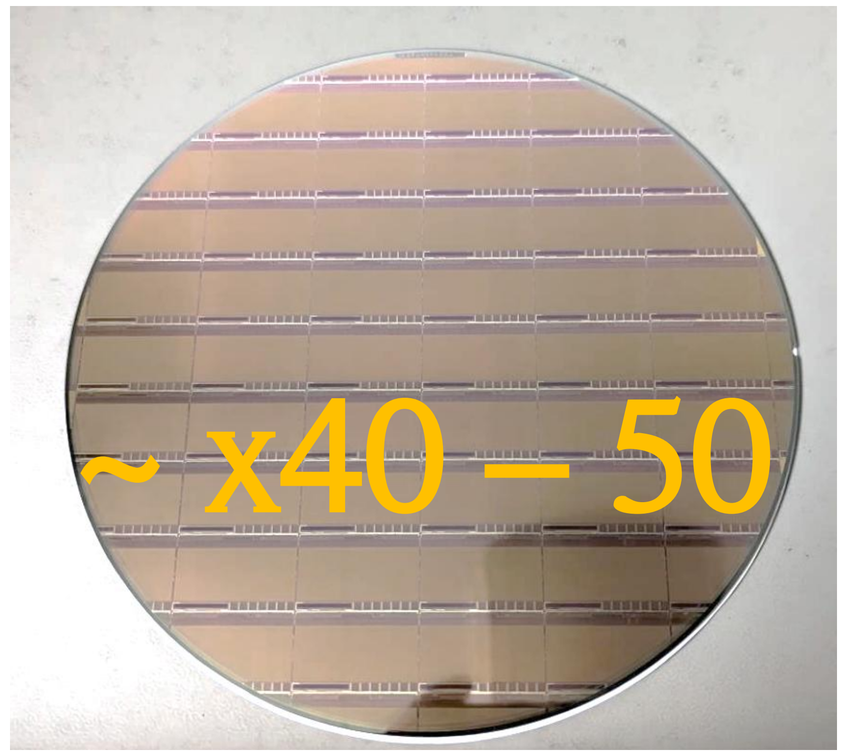


MIMOSIS-0 (2018)

MIMOSIS-1 (2020)



MIMOSIS-2/2.1 (2024)

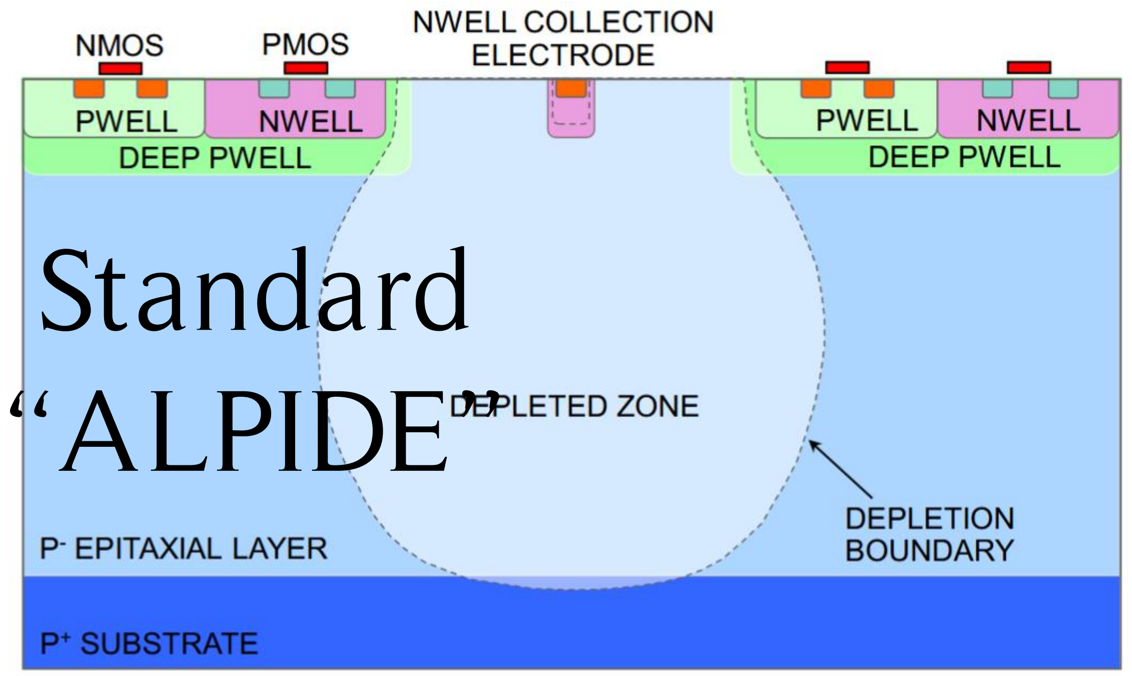


MIMOSIS-3 (2026)

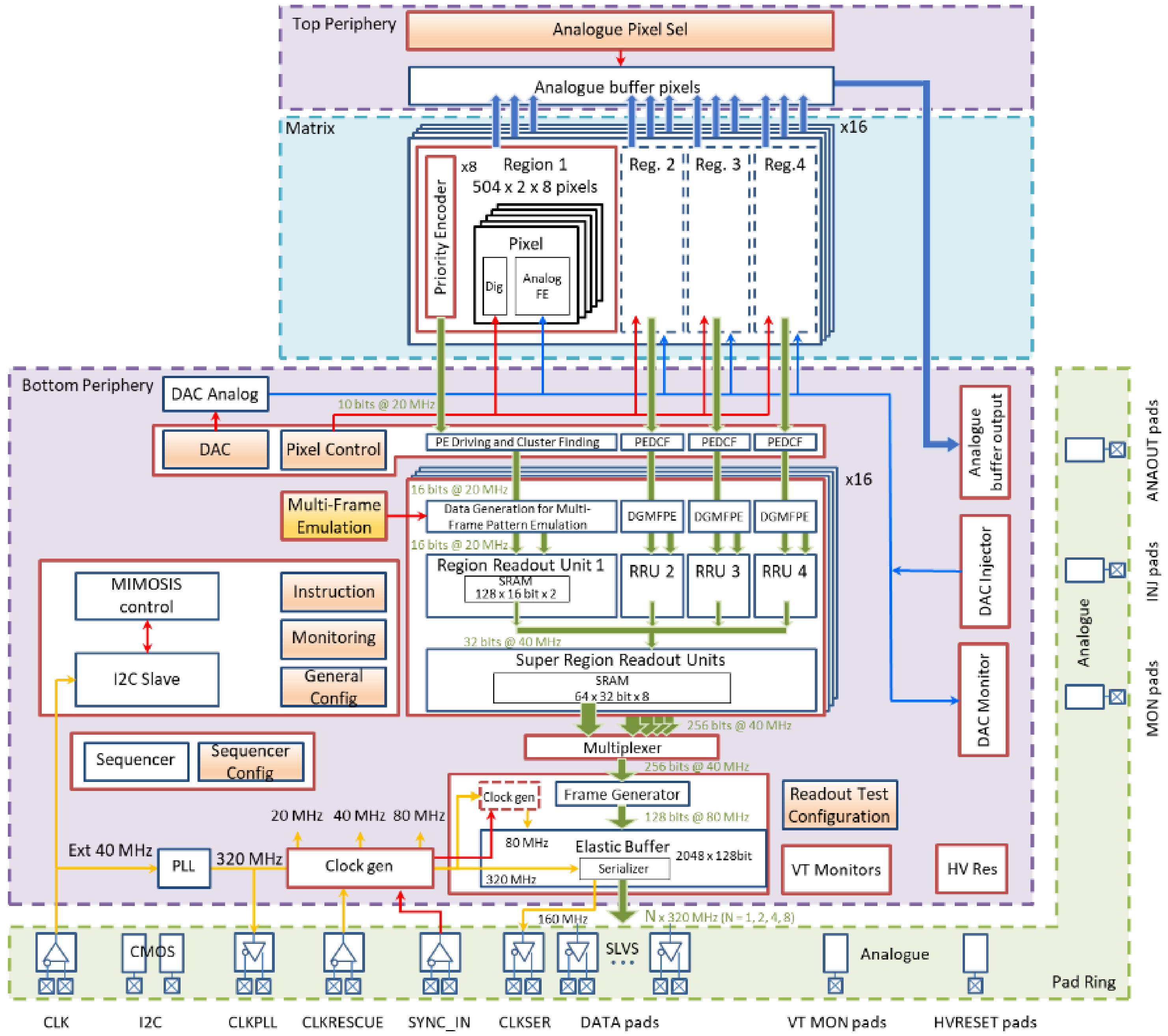
The MIMOSIS Story

Joint venture: IPHC Strasbourg, University Frankfurt, GSI

→ Starting point: ALPIDE pixel, fully custom digital front-end



Standard
“ALPIDE”



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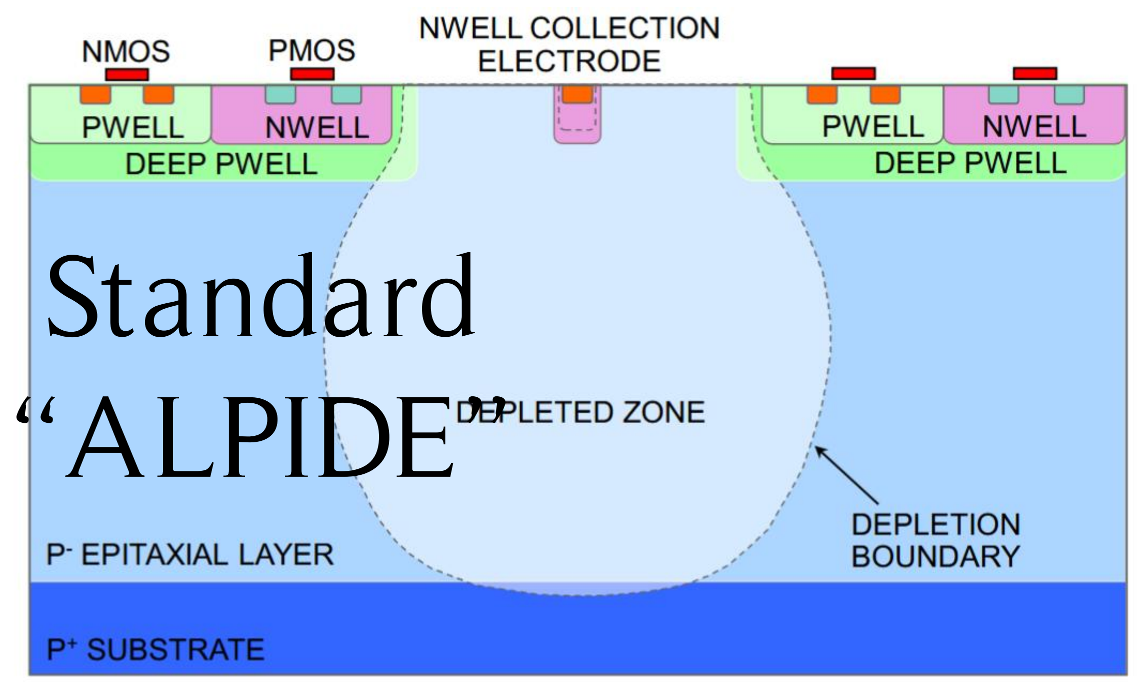
Improved radiation hardness
→ Modified epitaxial layer (“p-stop”)
→ Increased diode bias (AC-coupling)



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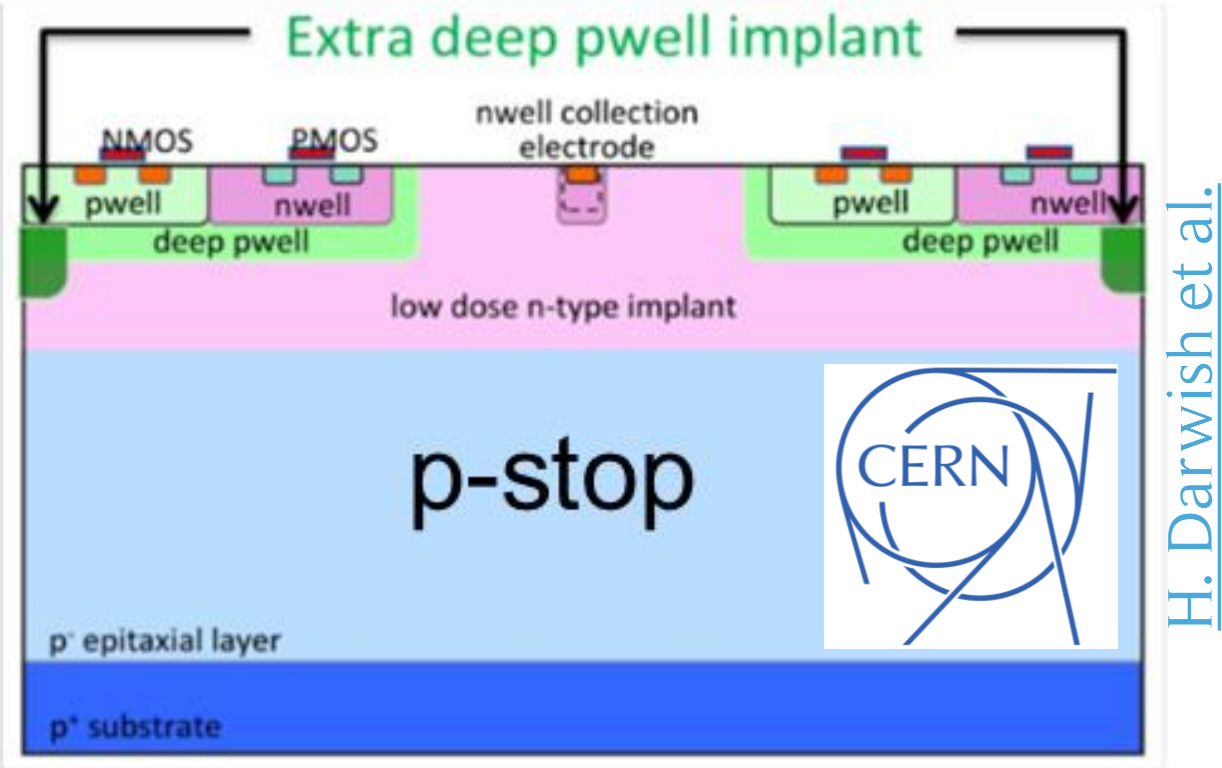

p-stop

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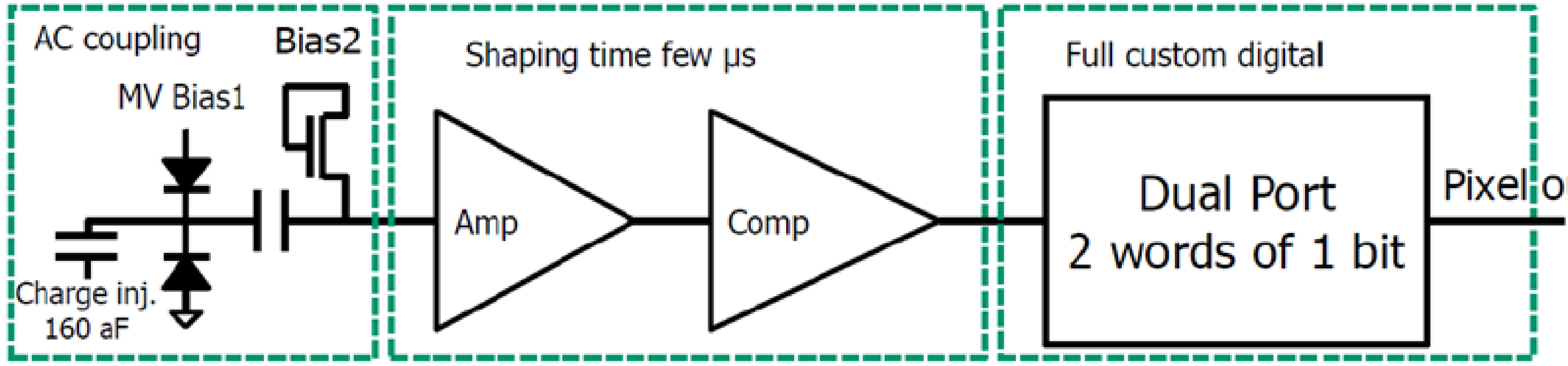
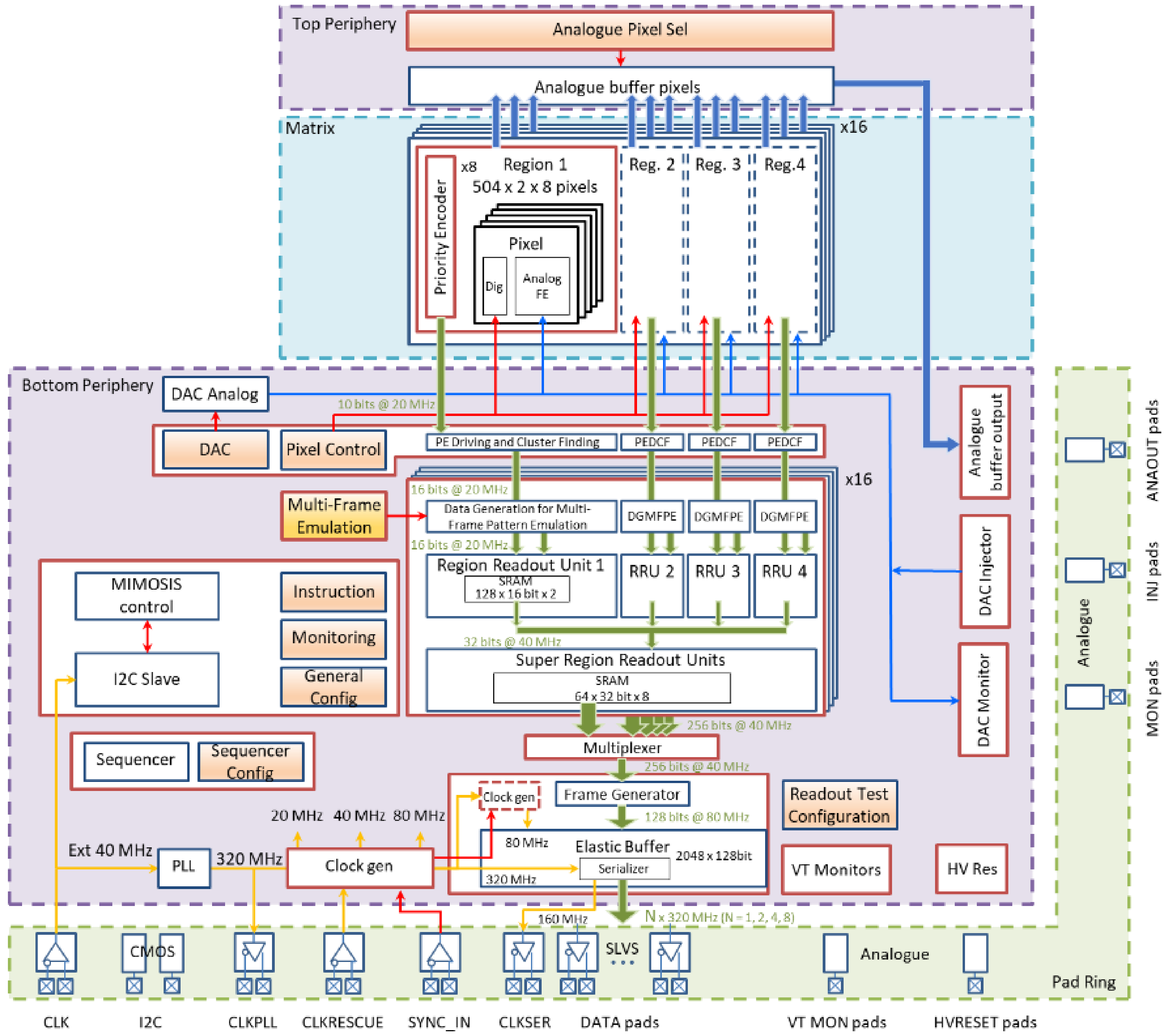


F. Morel



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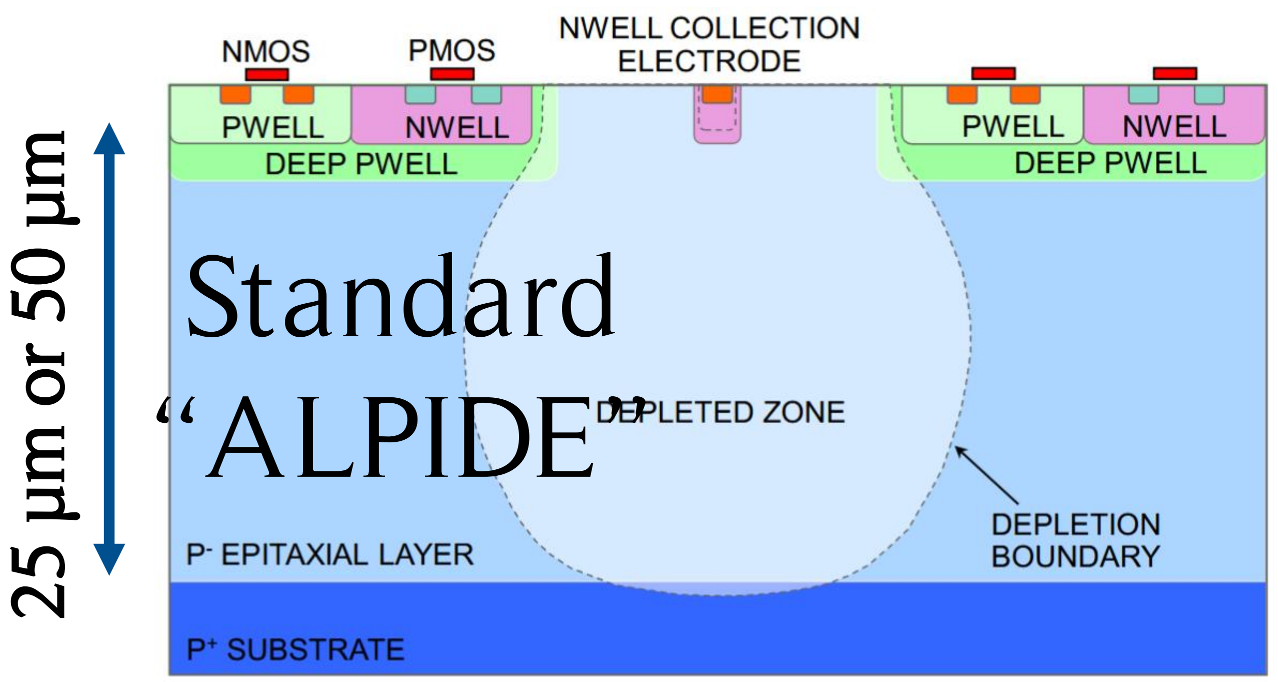
Improved operation range (signal)
→ 50 µm epi thickness



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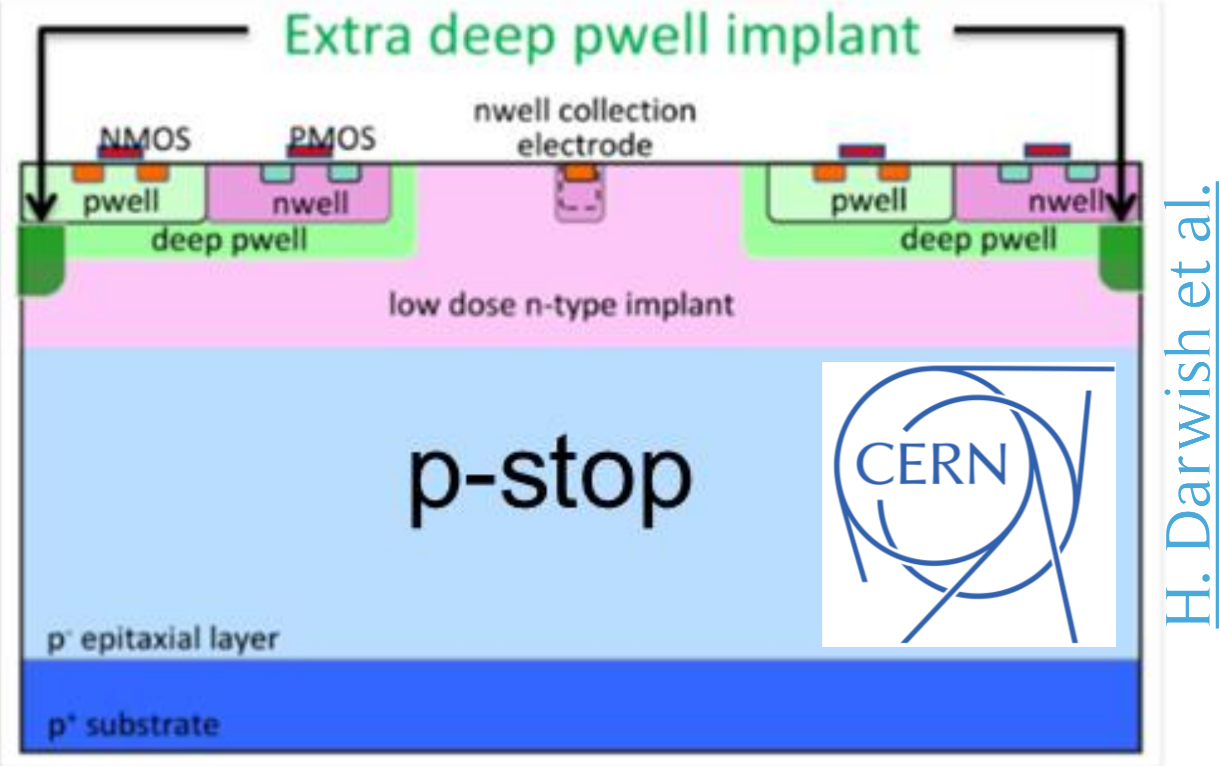

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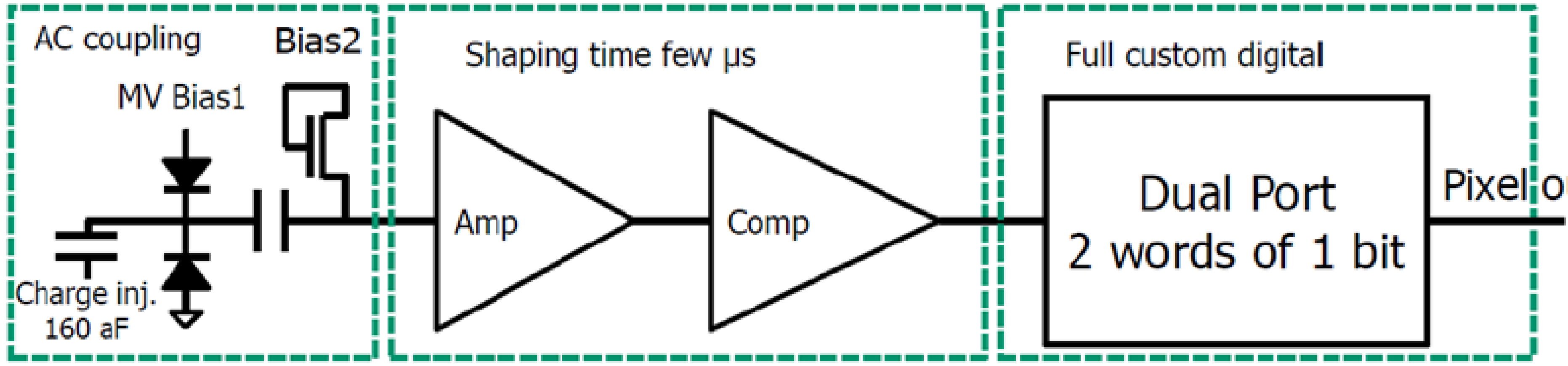

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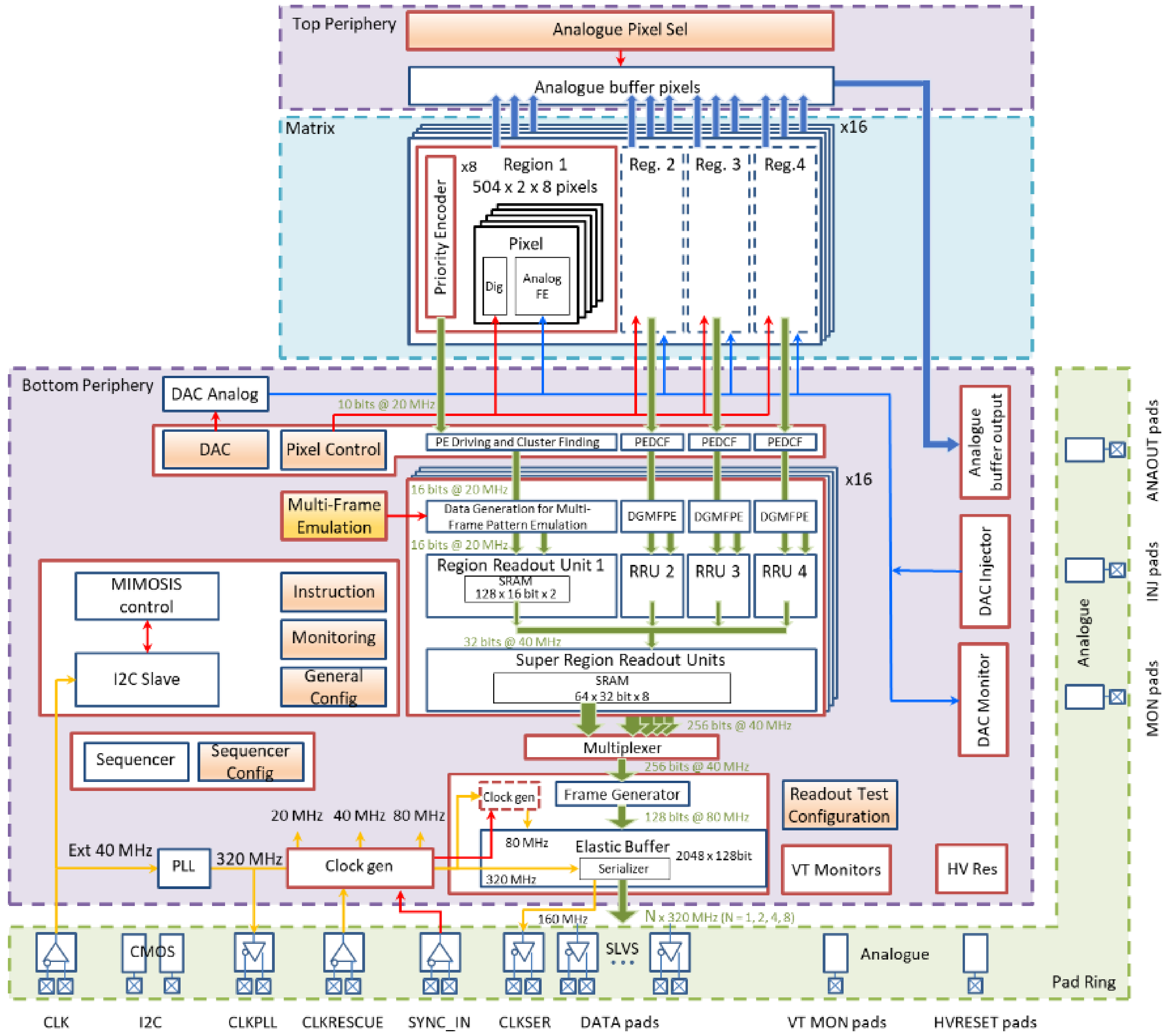

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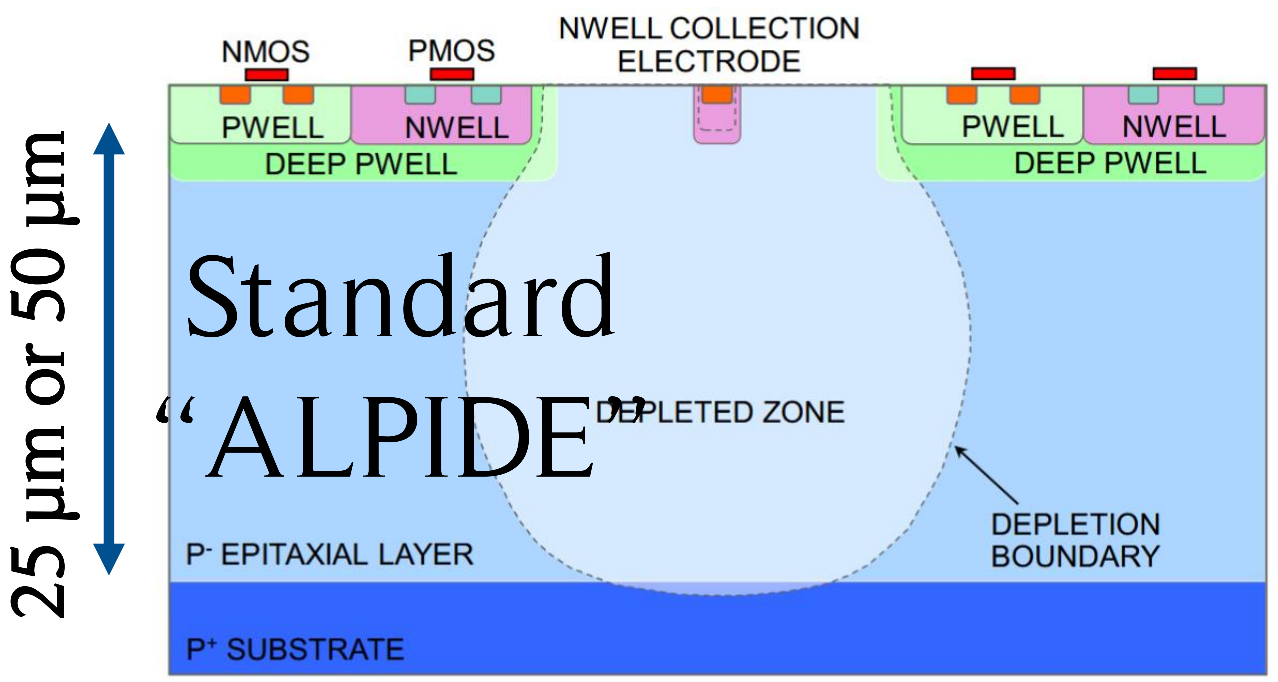
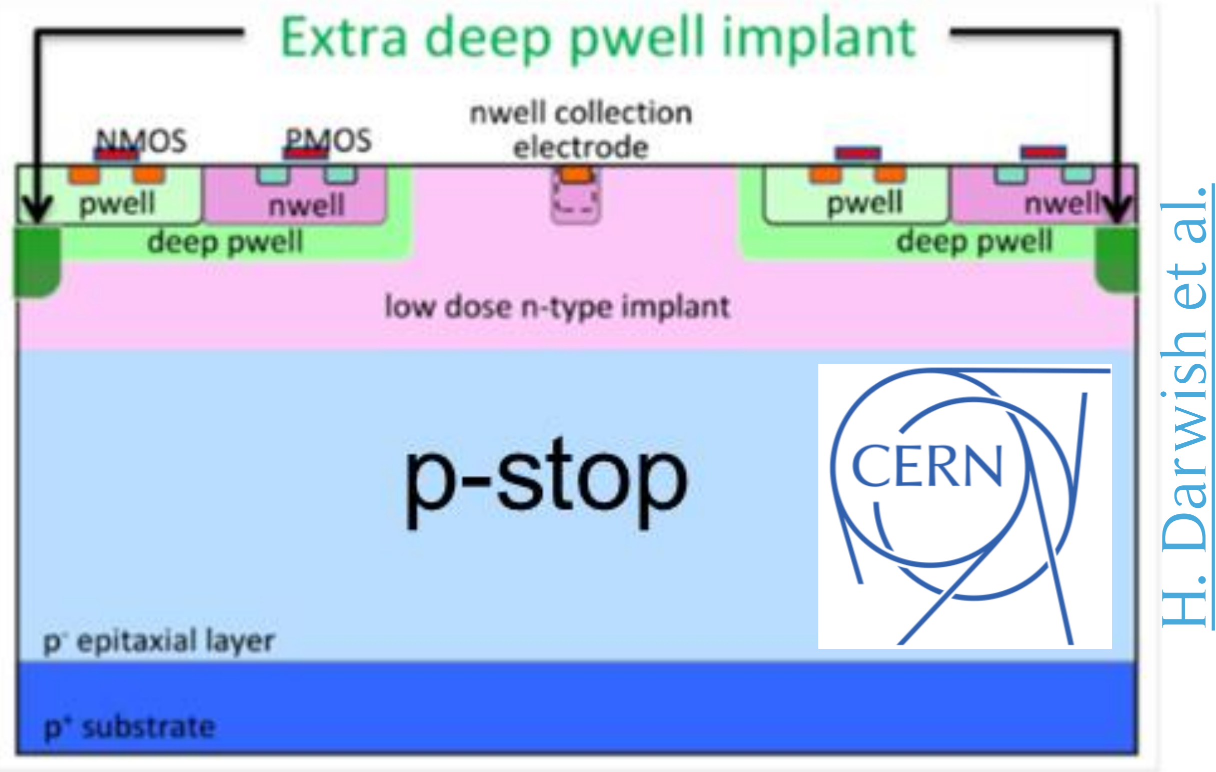
Improved readout speed

→ 8 x 320 Mbit/s





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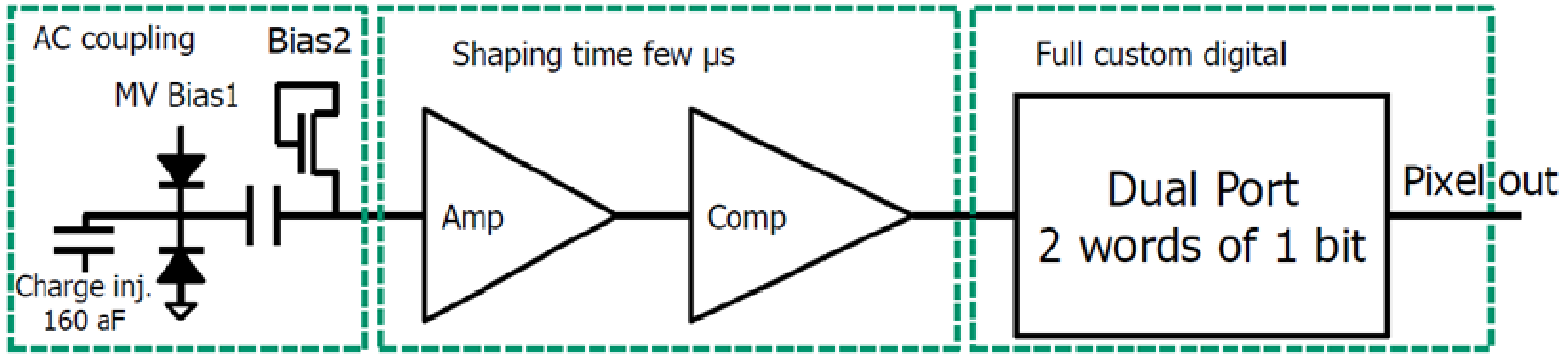

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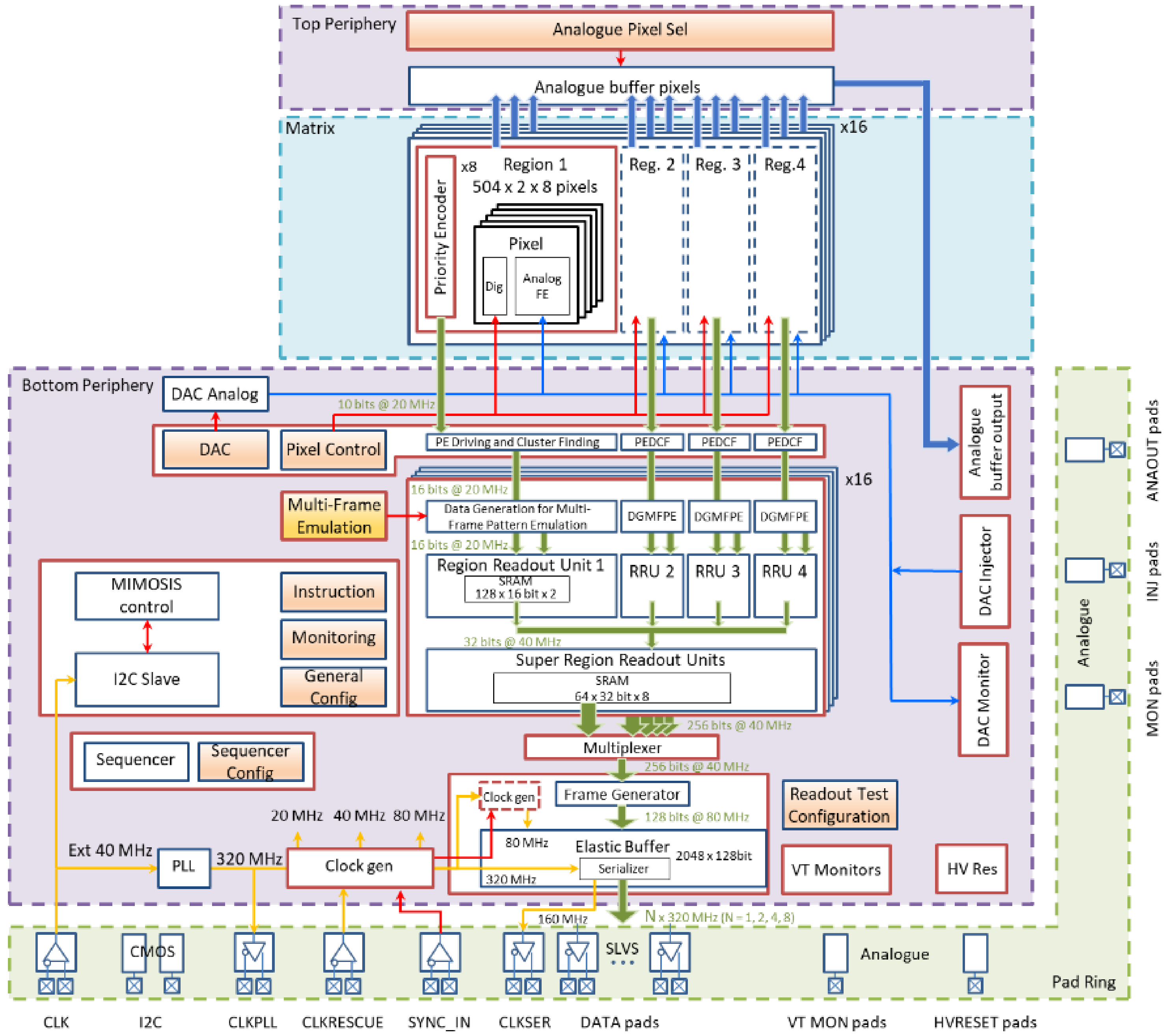

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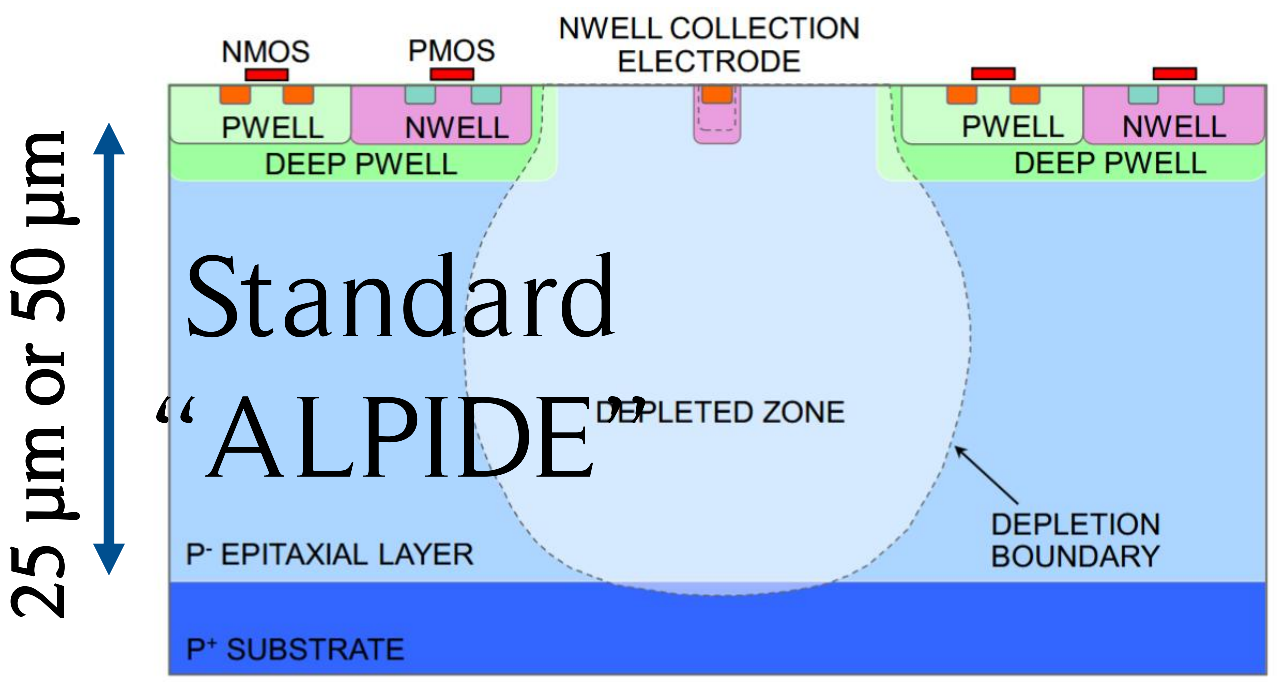
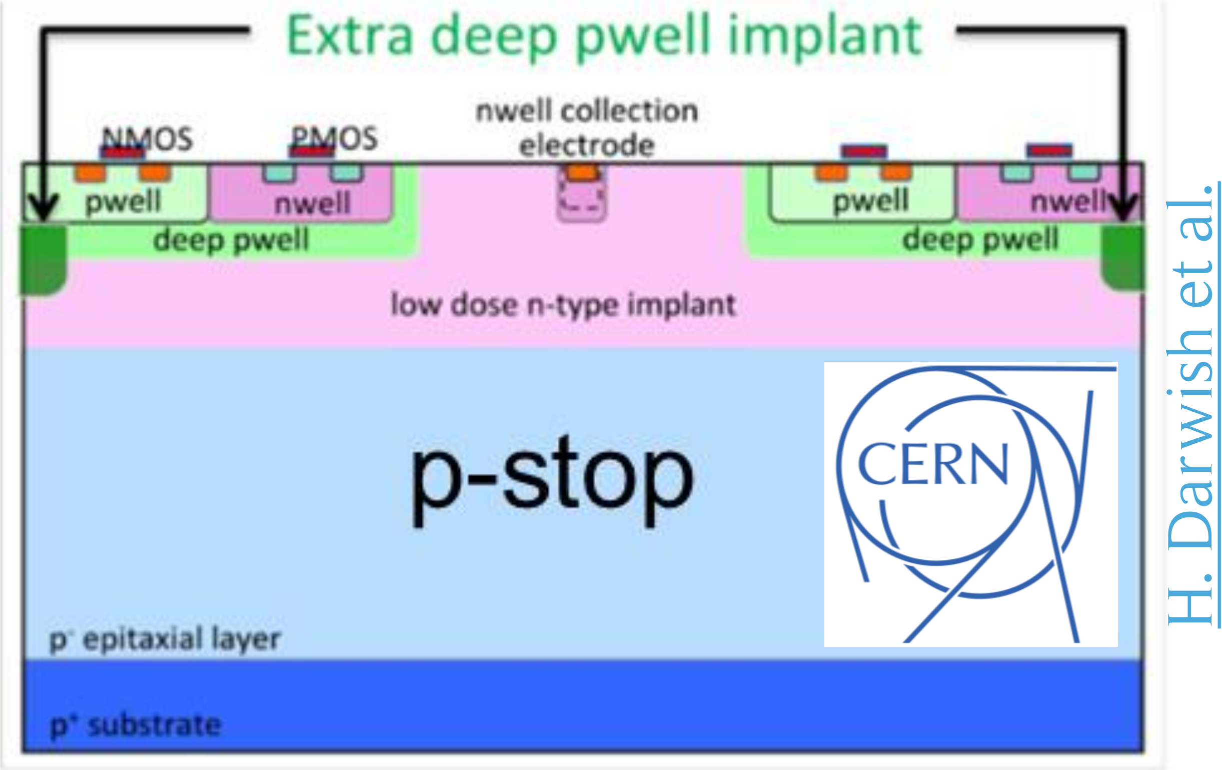
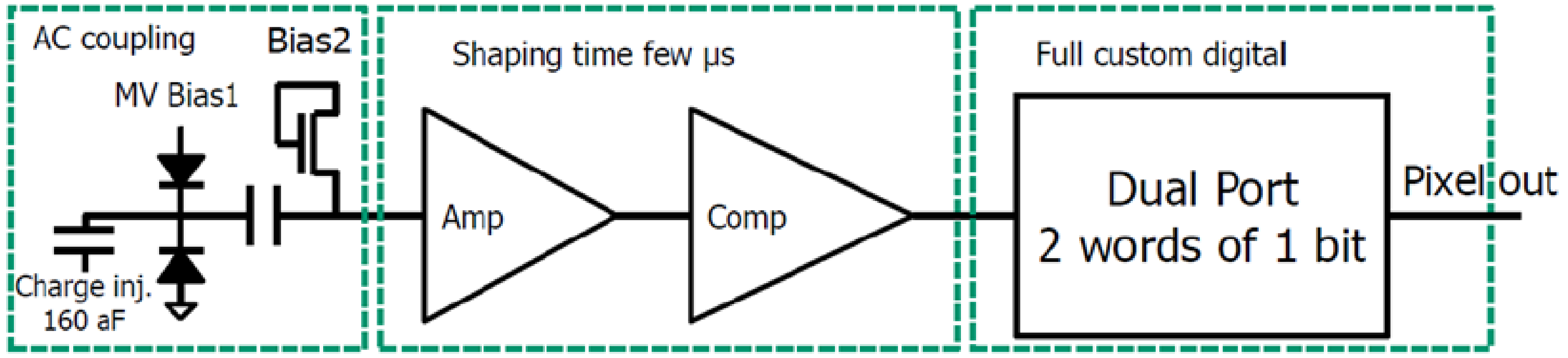
Improved SEE hardening
→ Hamming encoding (DACs)
→ Triple Modular Redundancy

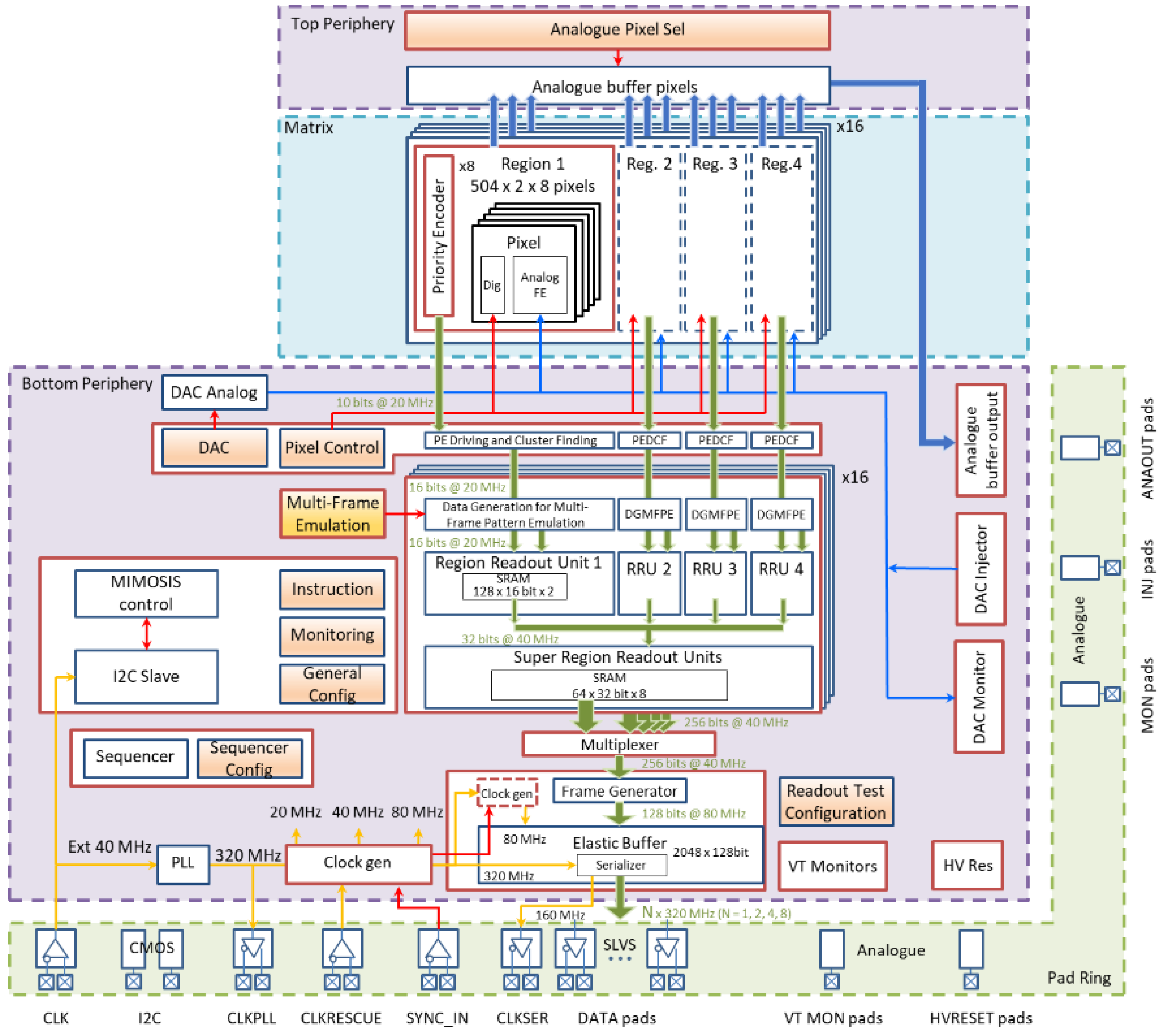




H. Darwish et al.



F. Morel



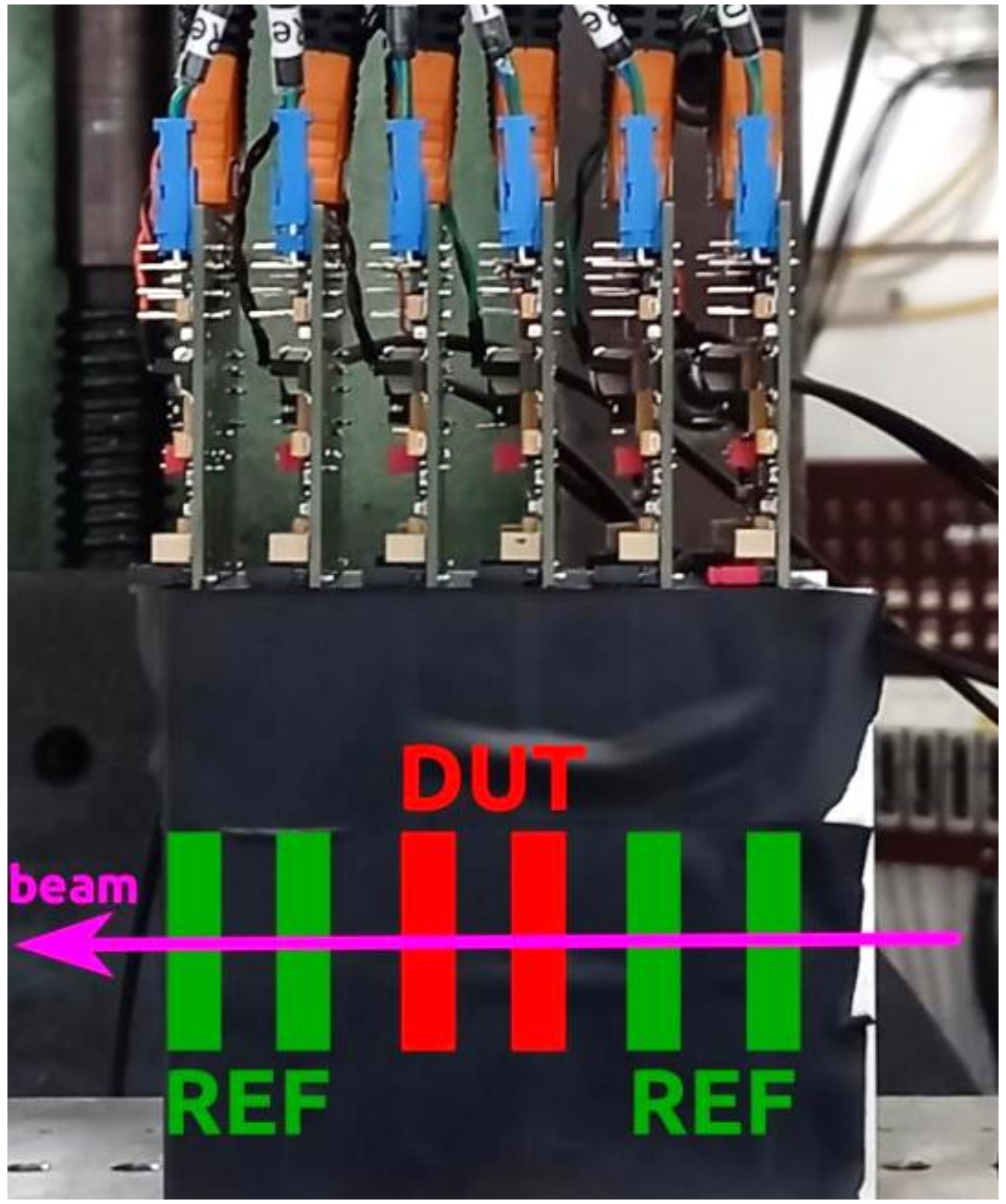
MIMOSIS-2.1 Performance

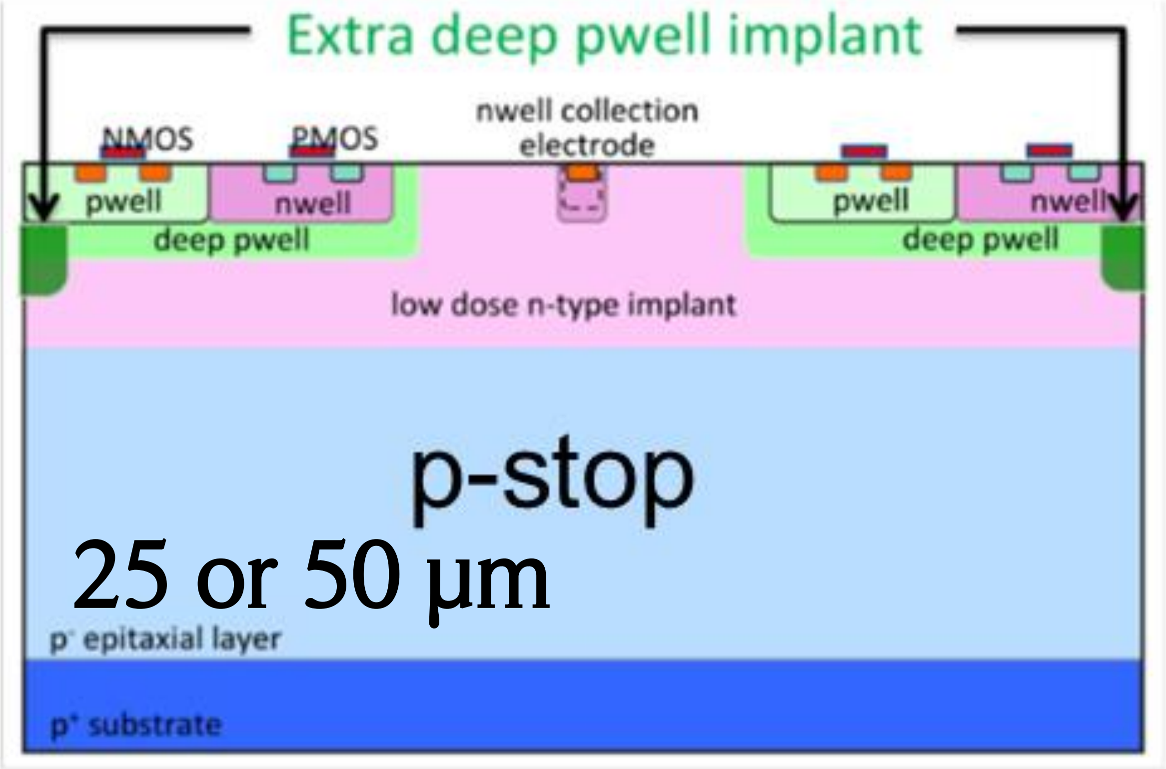
All–MIMOSIS beam telescope

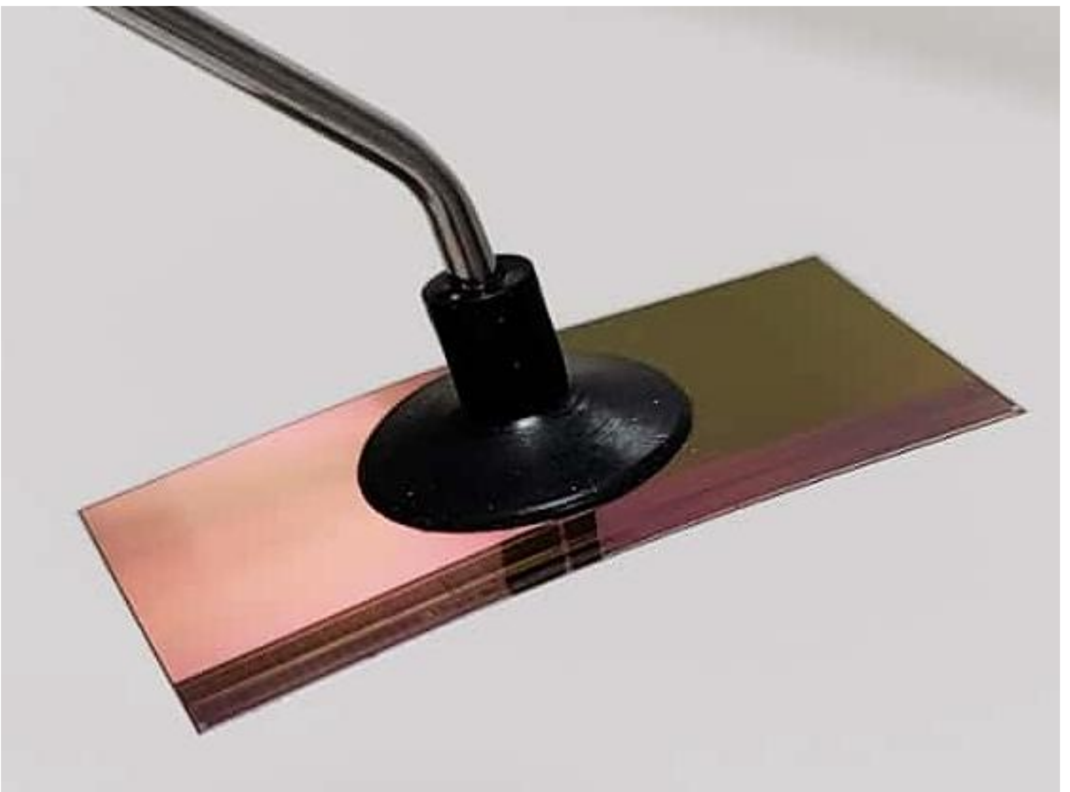
→ 4 reference sensors, 2 DUTs

→ Controlled room temperature

→ Dark rate $<10^{-10}$/pixel/frame







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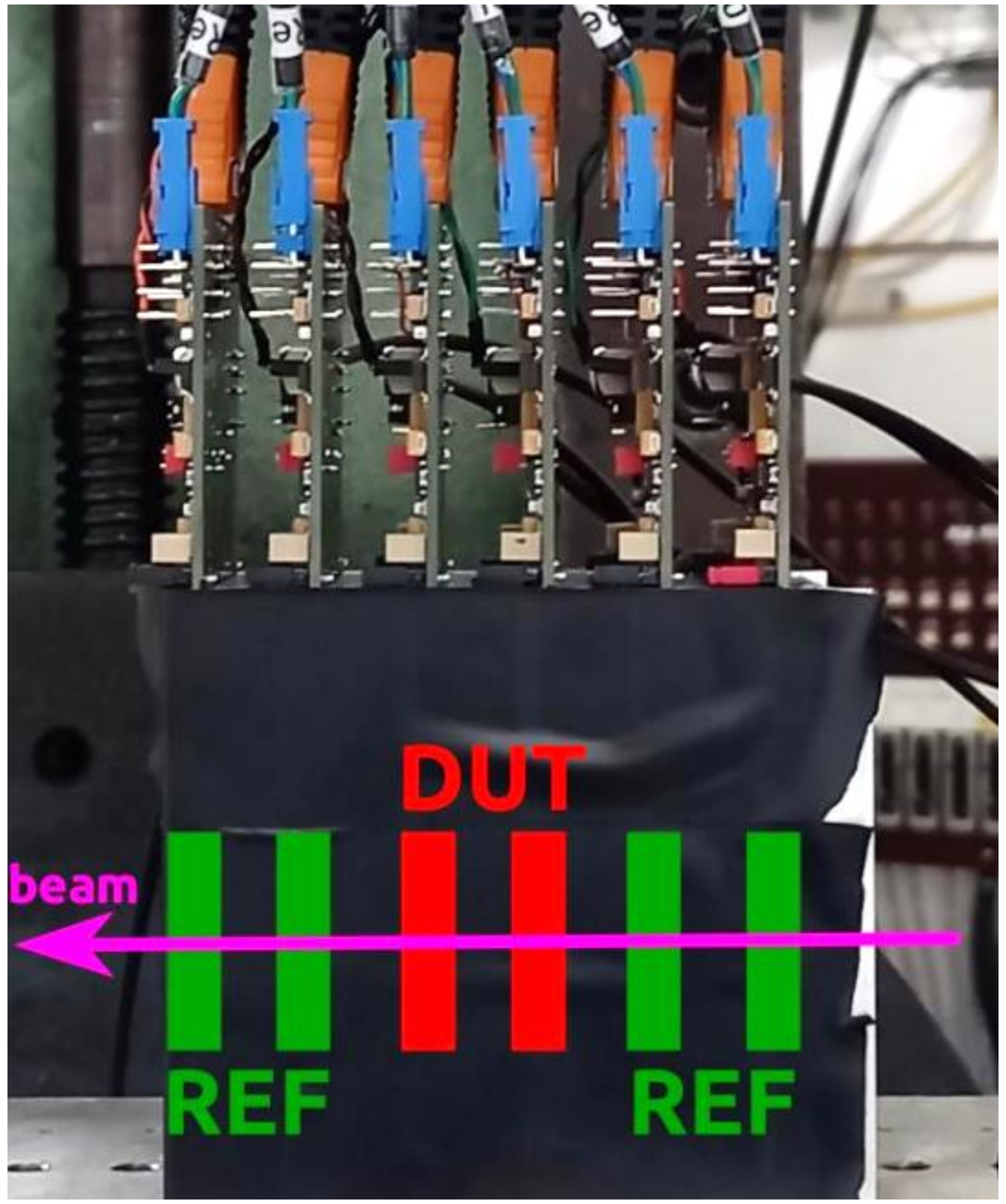
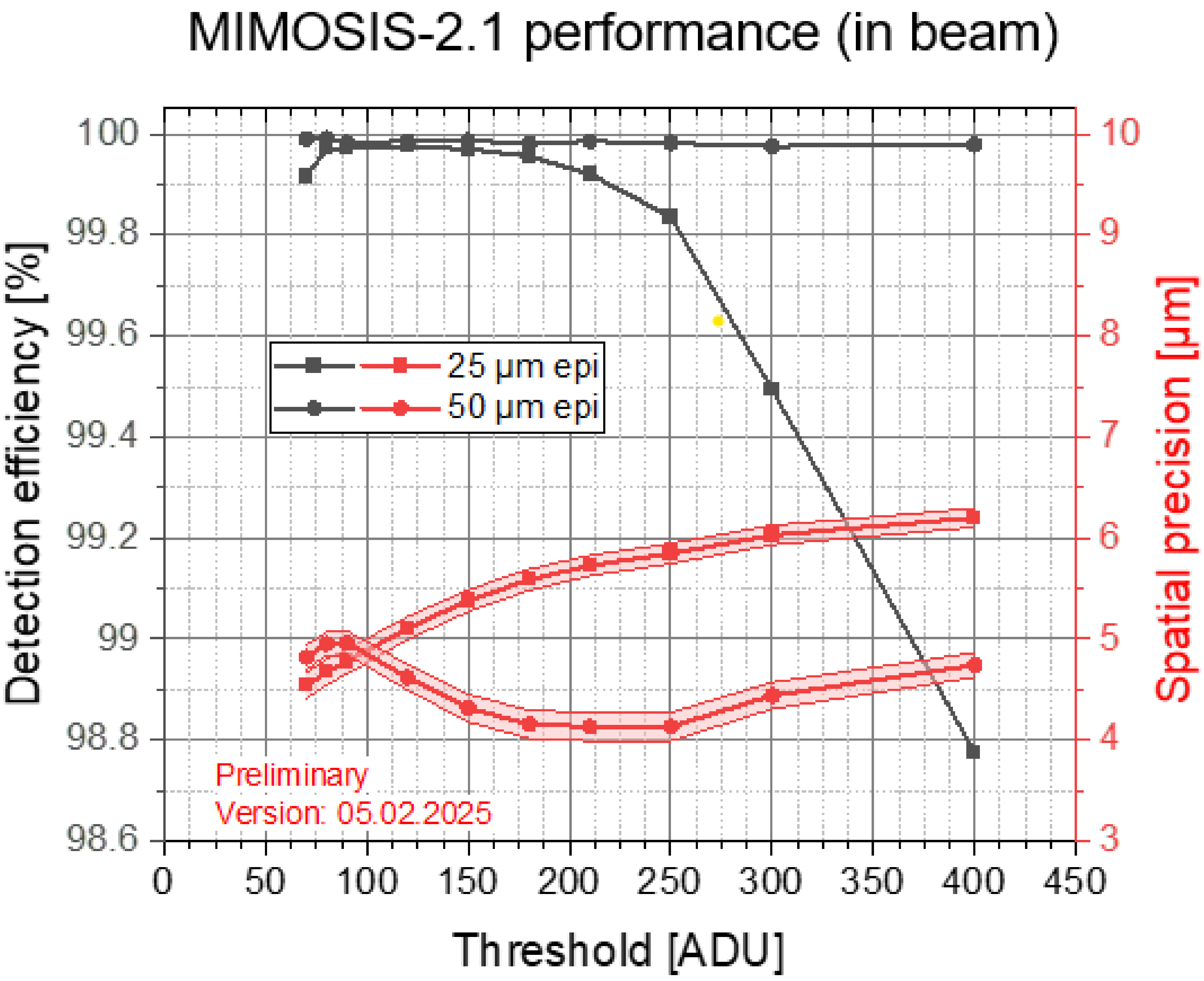
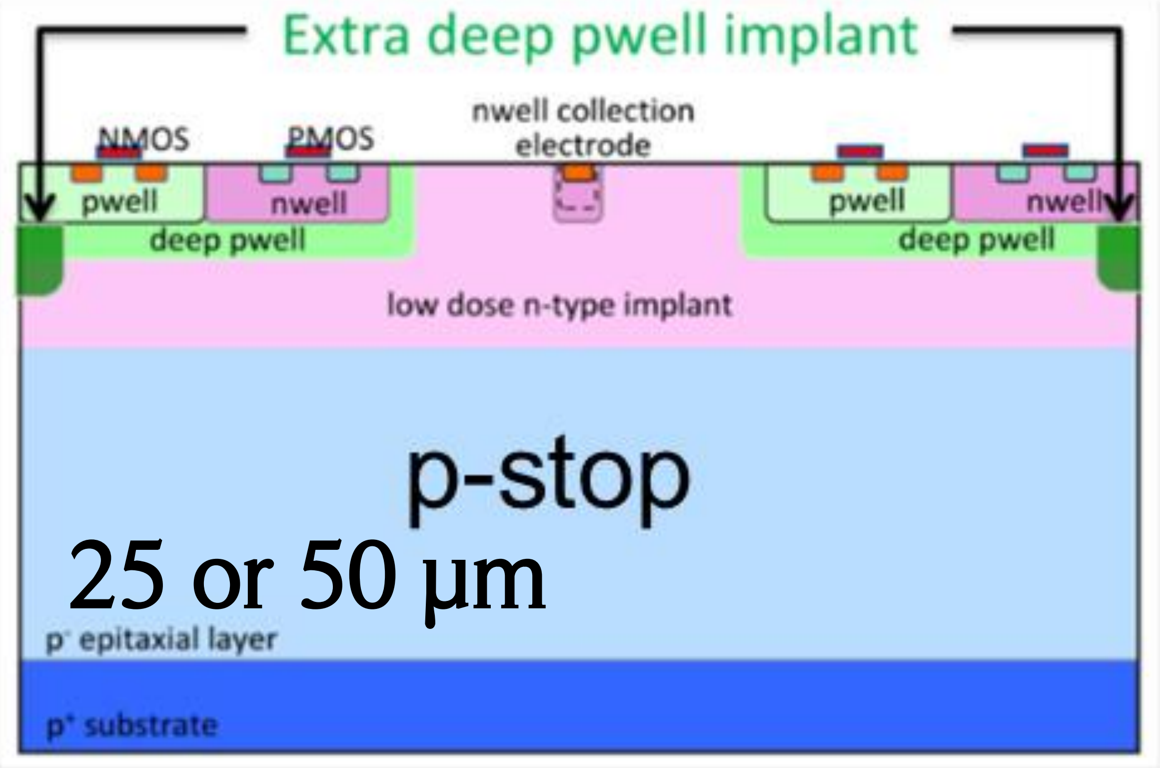
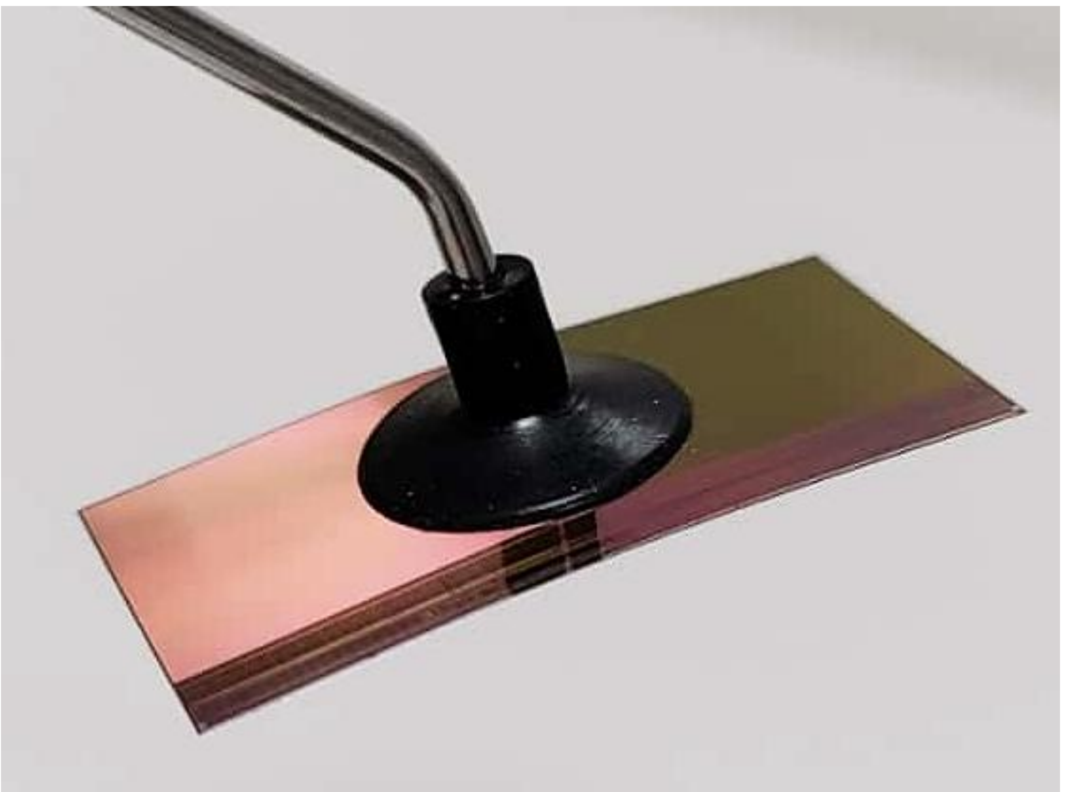








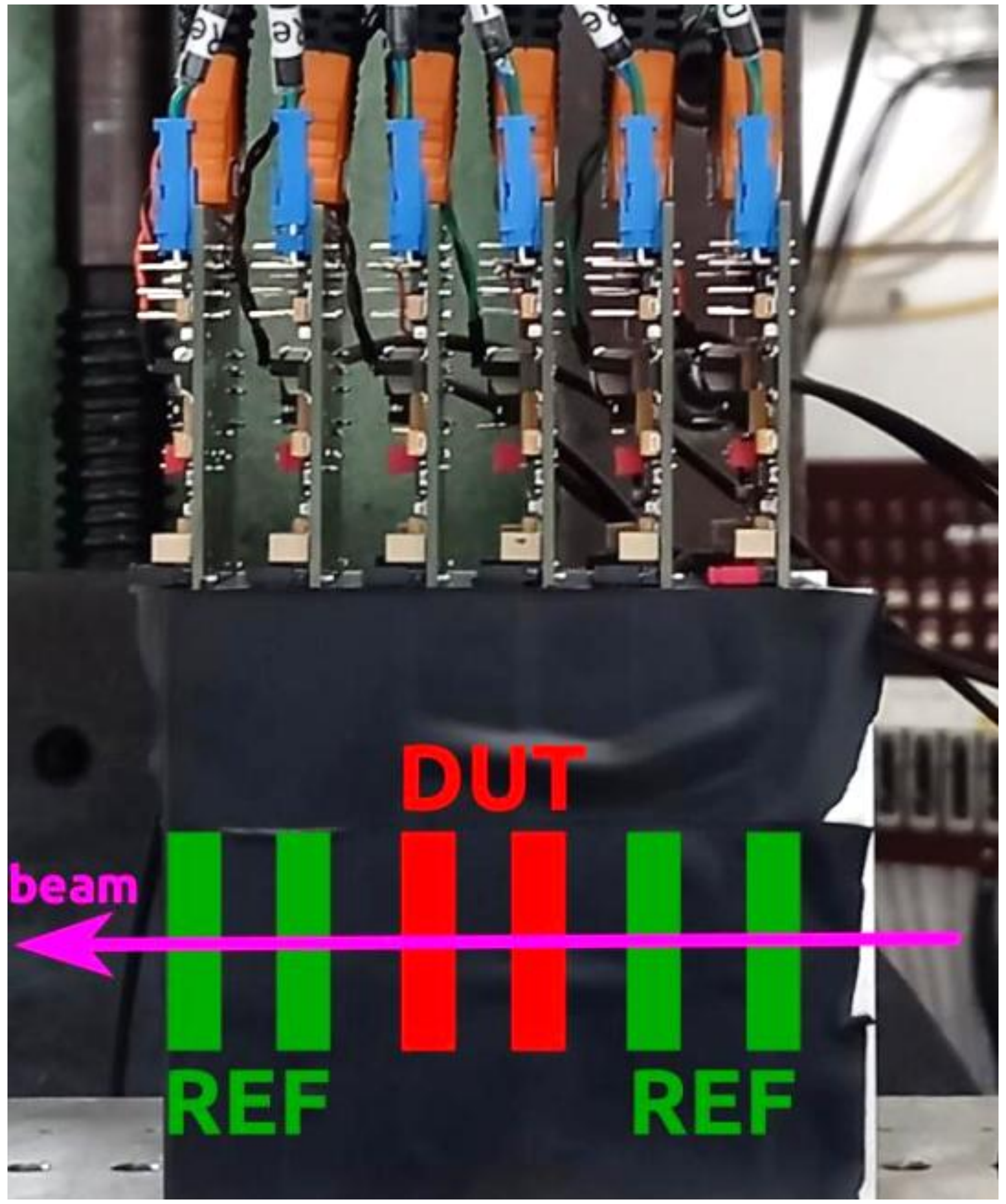
… after Irradiation

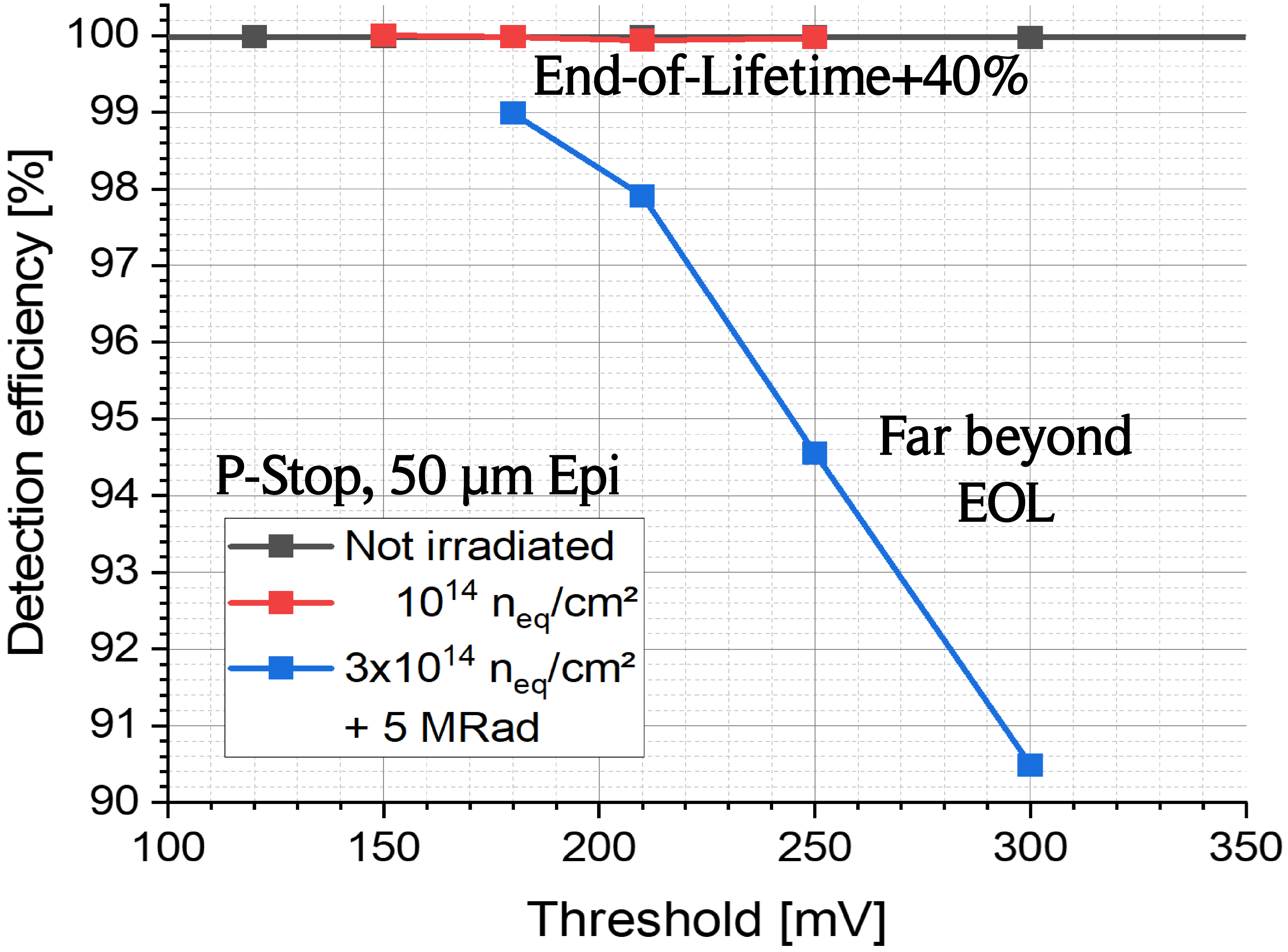
Induced radiation damage

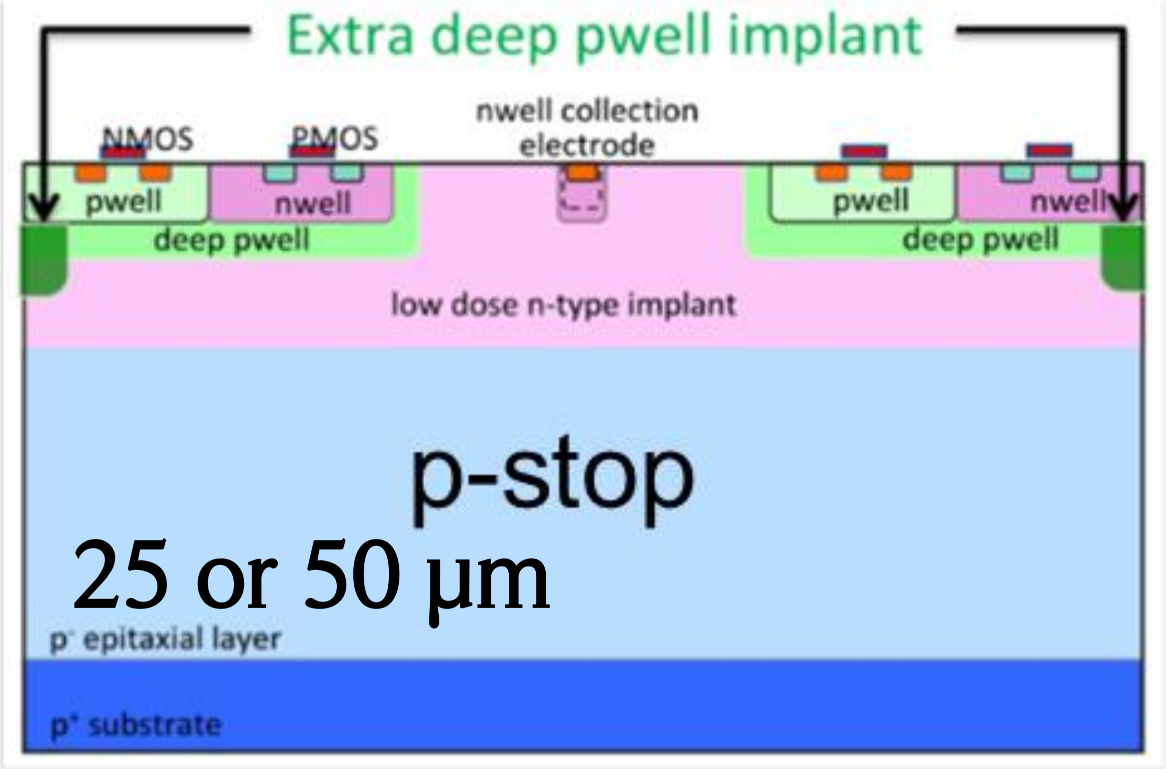
→ Reactor neutrons, 60 keV X-rays

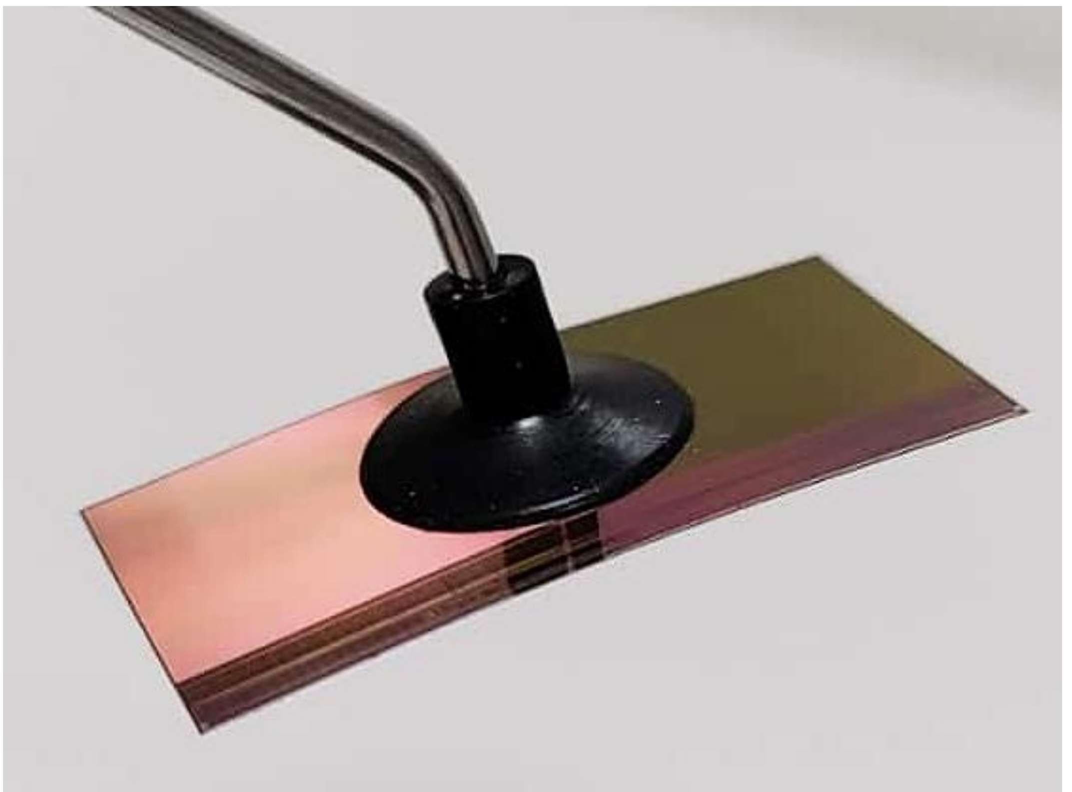
→ EOL dose + safety margins

→ Dark rate $<10^{-6}$/pixel/frame









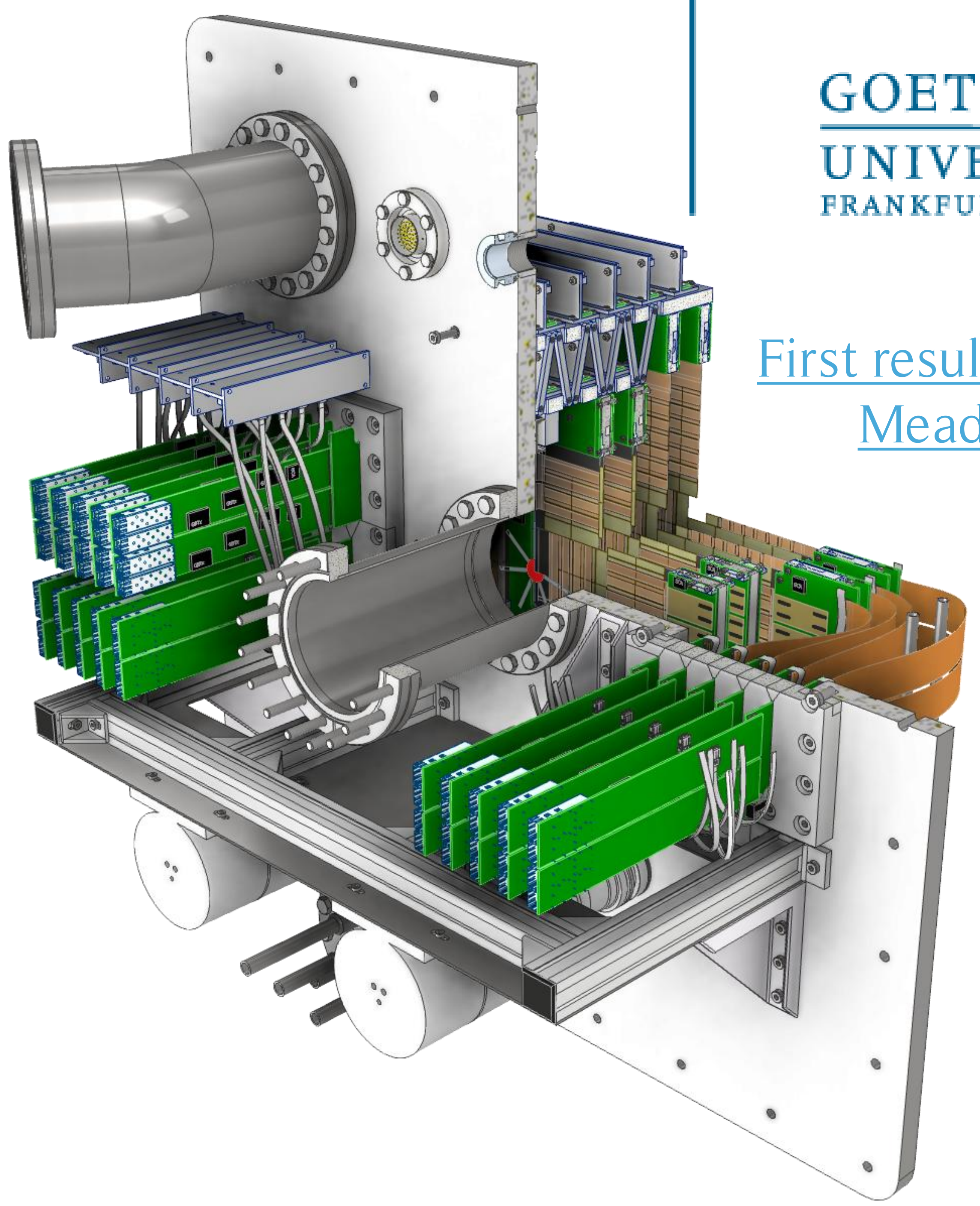
Challenge: Fixed Target (SEE)

Single Event Effects from beam halo, target fragments, direct beam impact

→ 5.4 mm next to the beam!

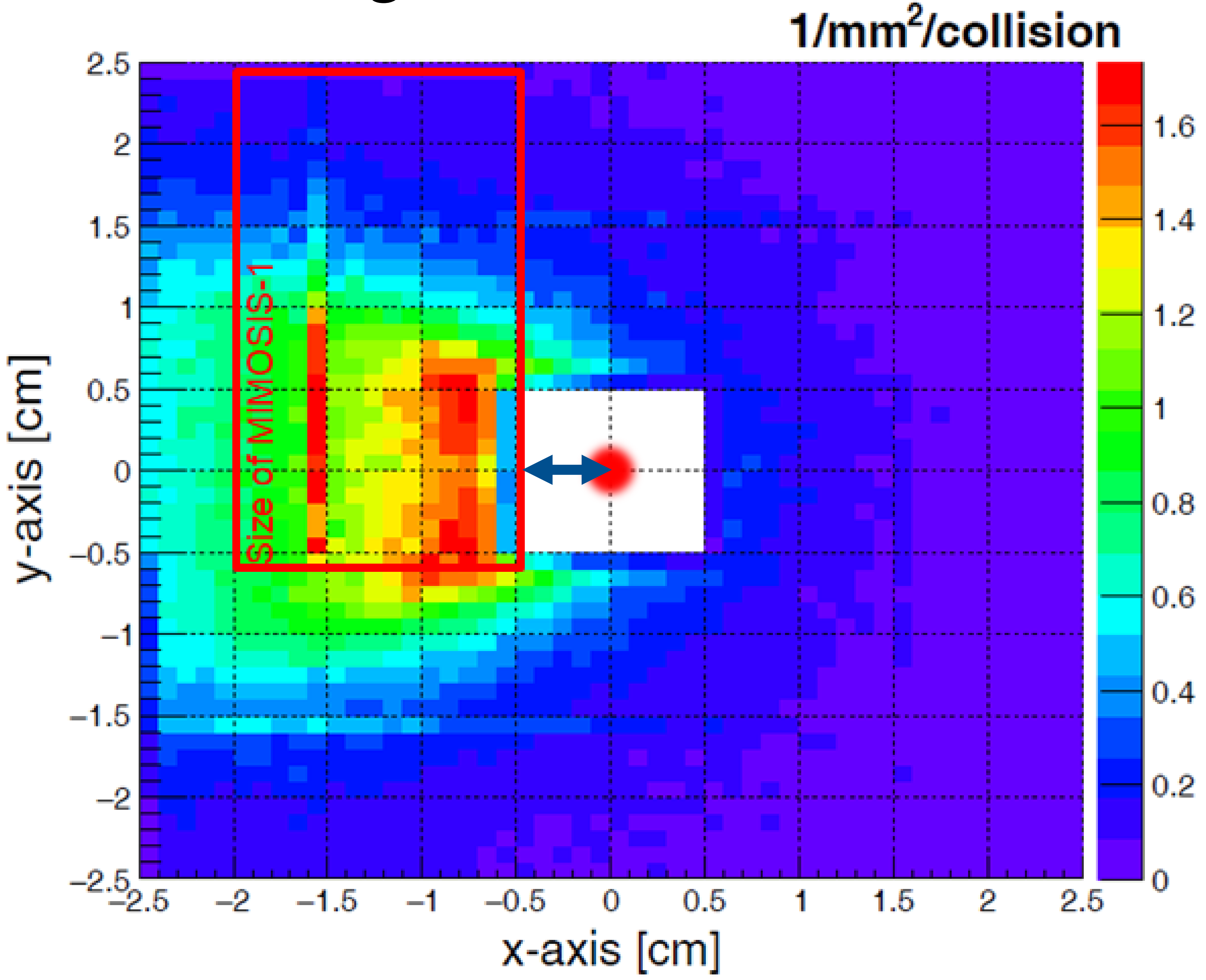
ALICE: ITS2 23 mm, ITS3: 19 mm, IRIS: 5 mm

→ Validate with ~4 *A*MeV Au @GSI



First results: B. Arnoldi-Meadows et al.

Hit gradient 1st MVD station



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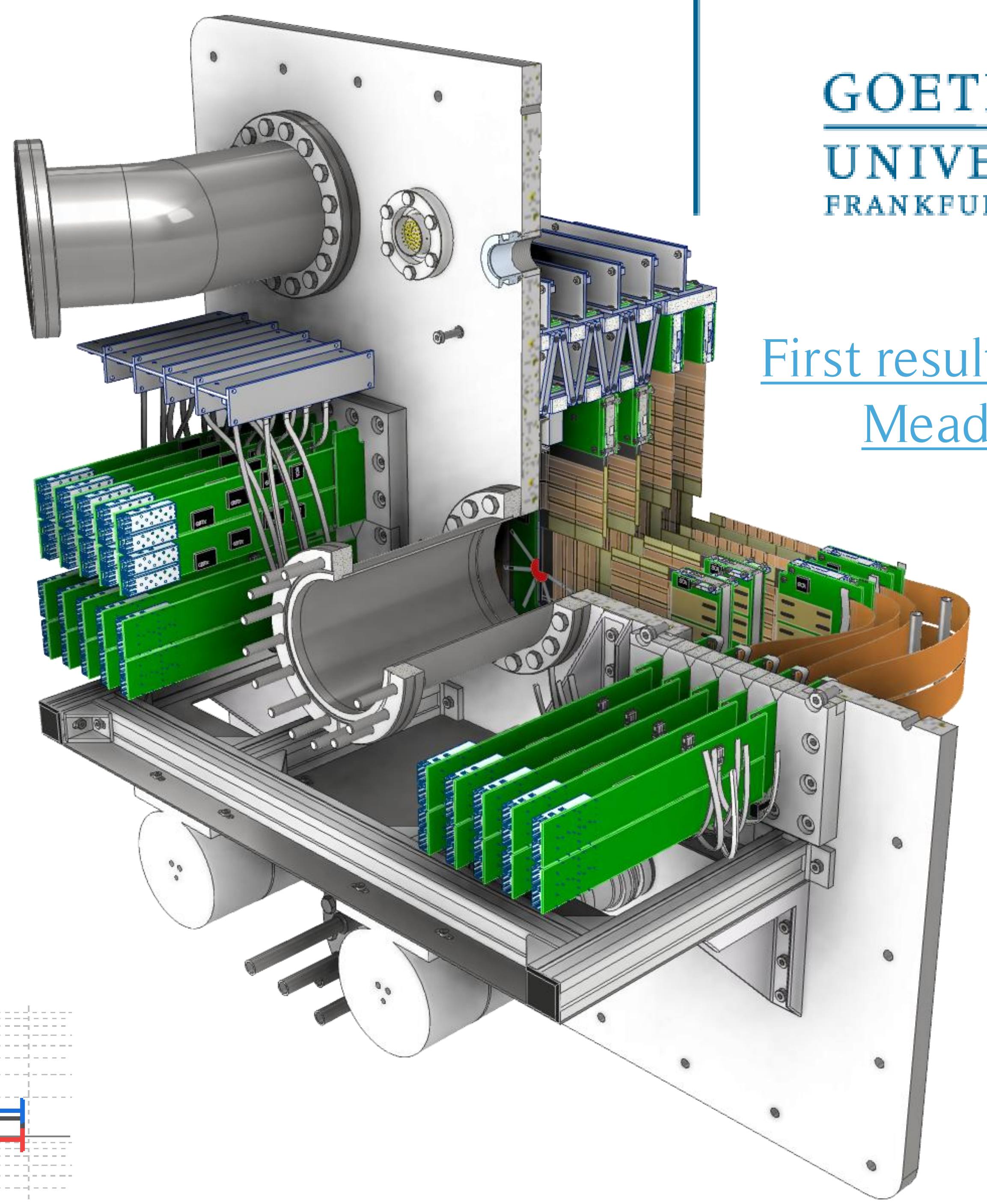

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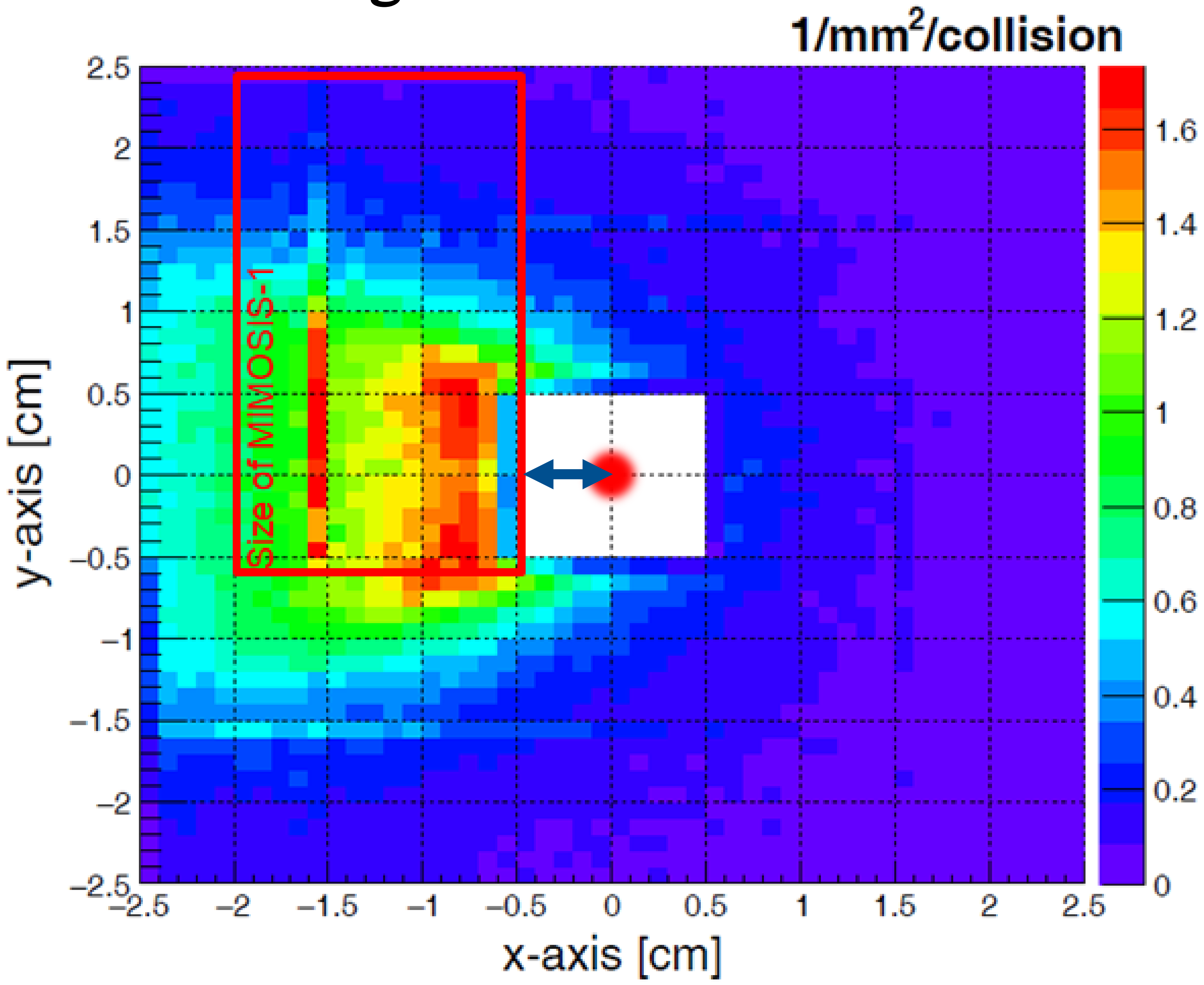

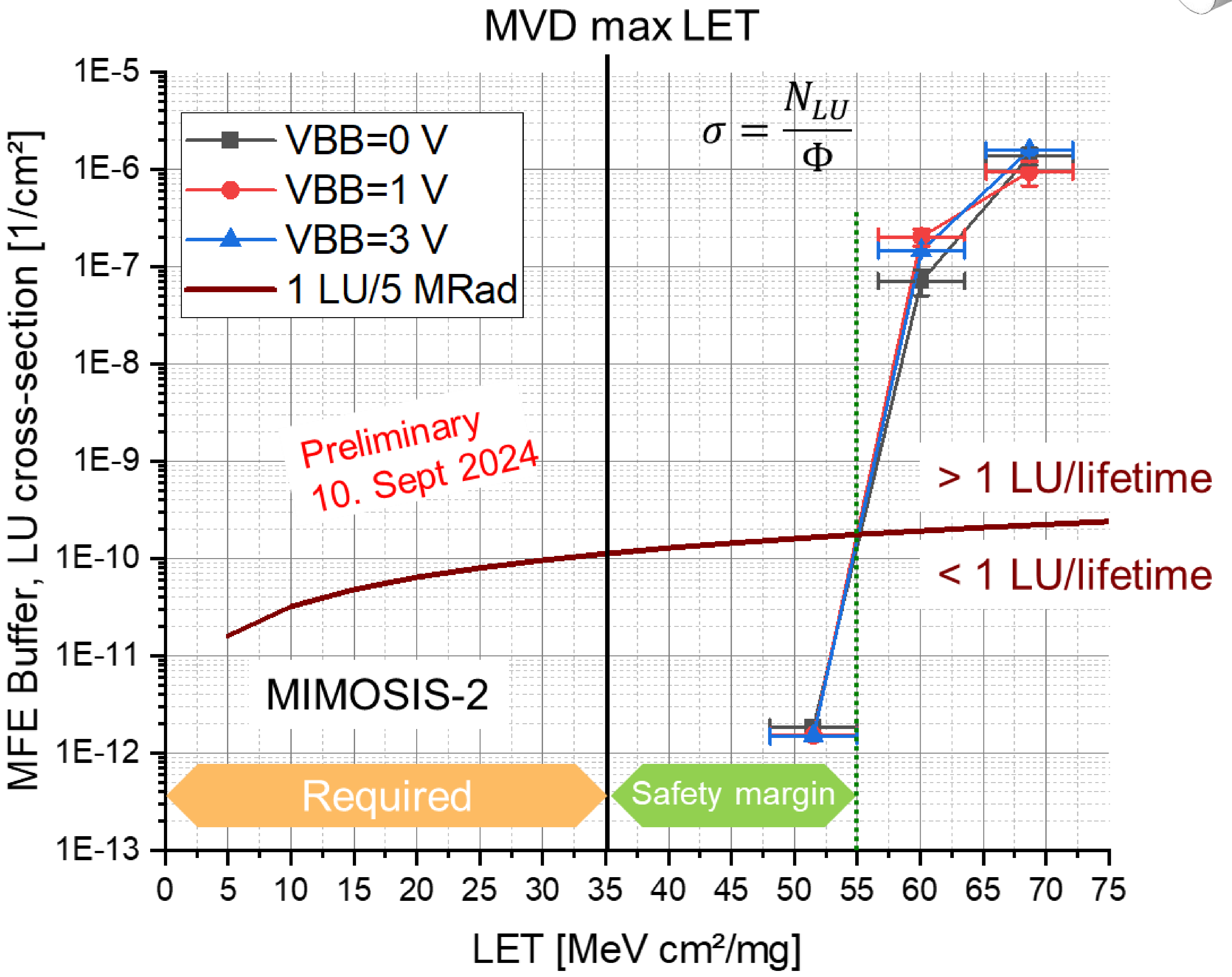

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GOETHE
UNIVERSITÄT
FRANKFURT AM MAIN

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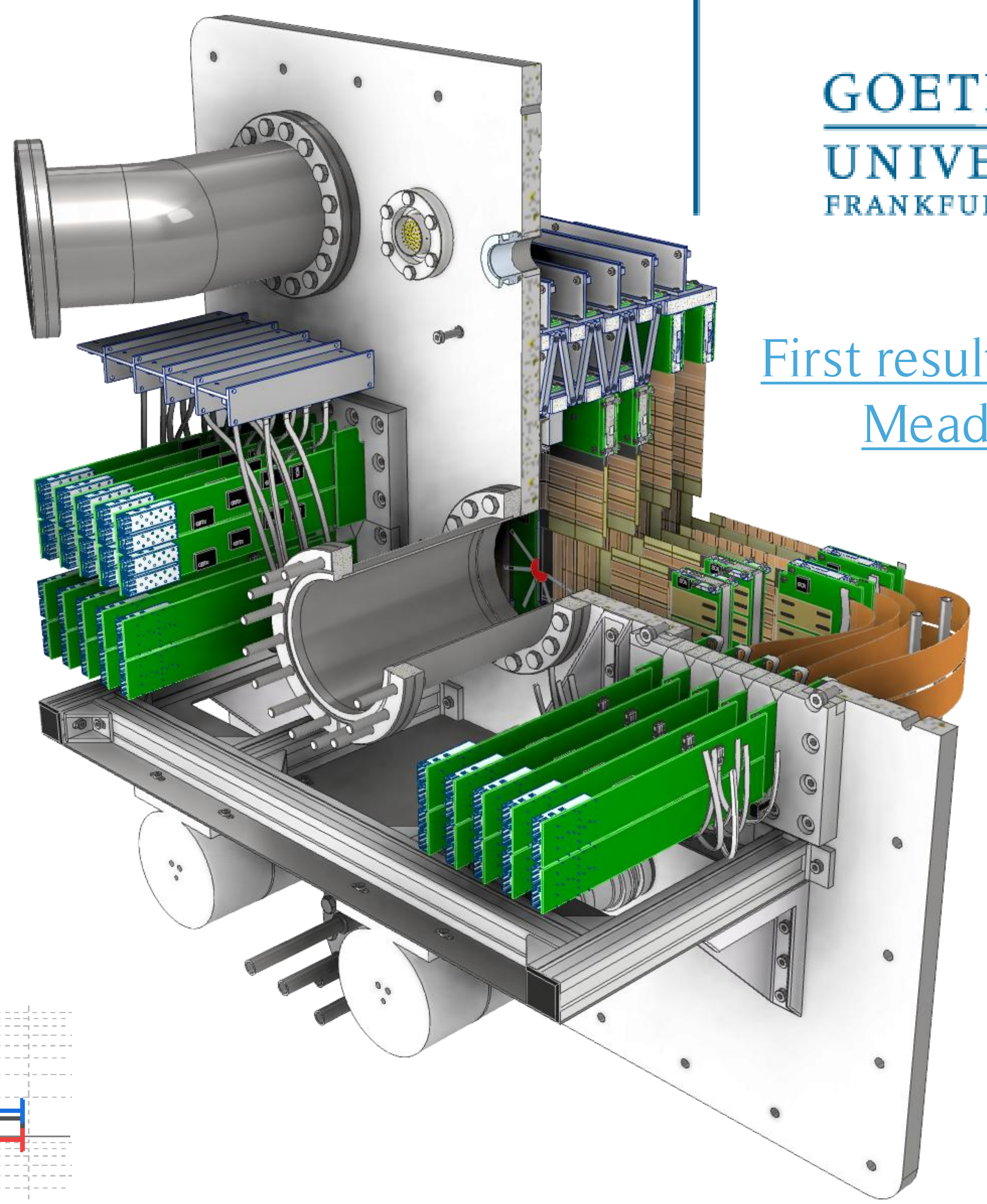

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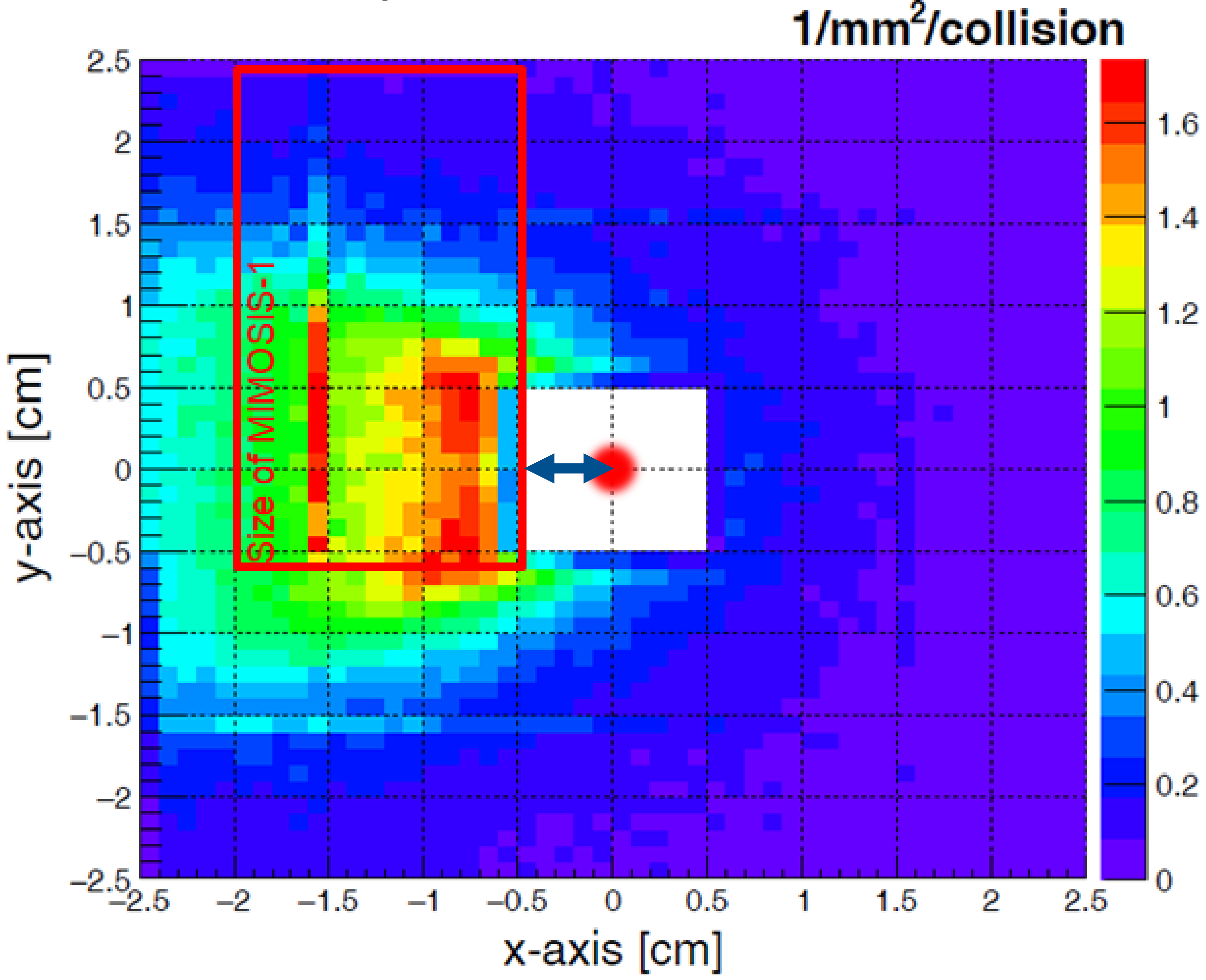
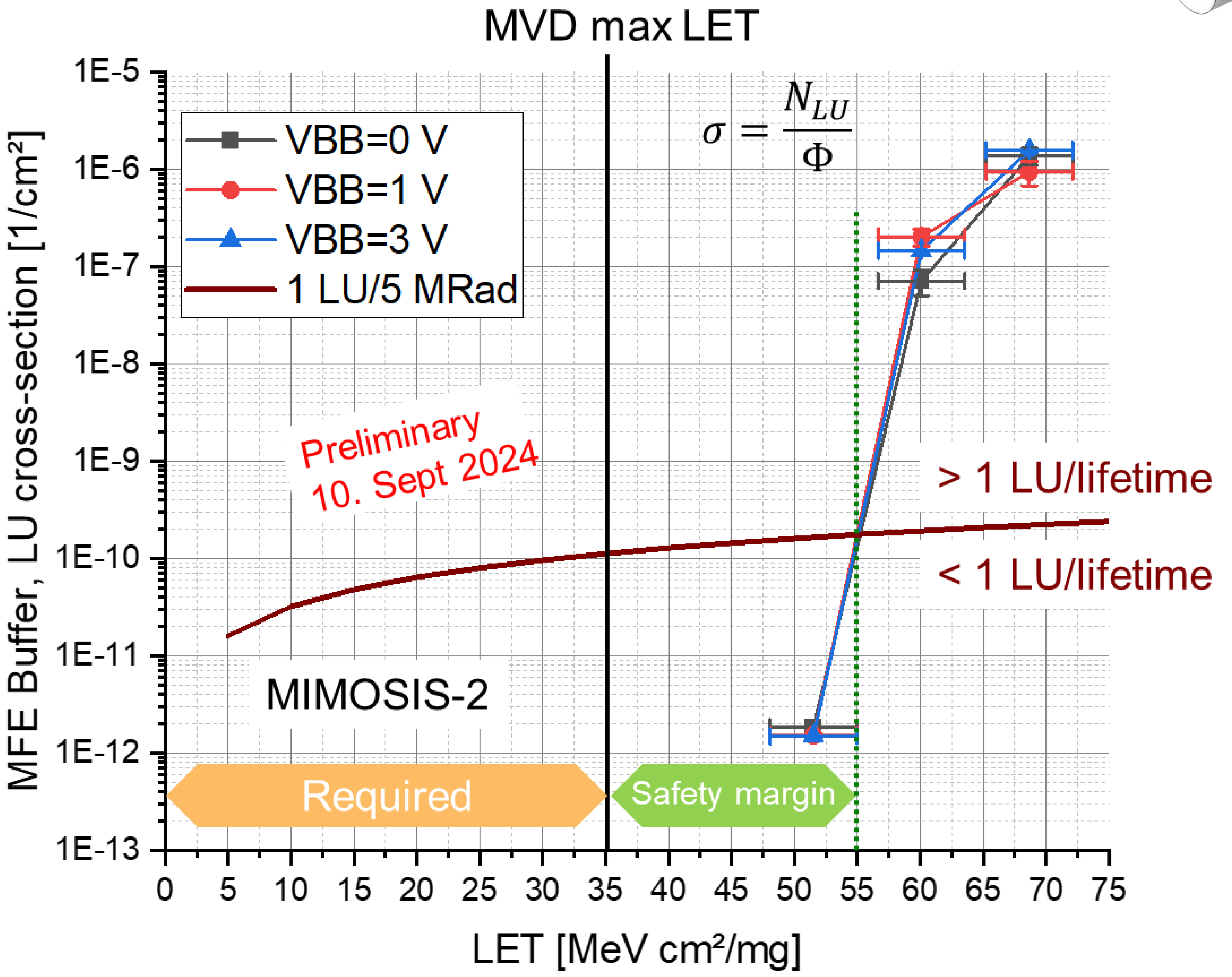
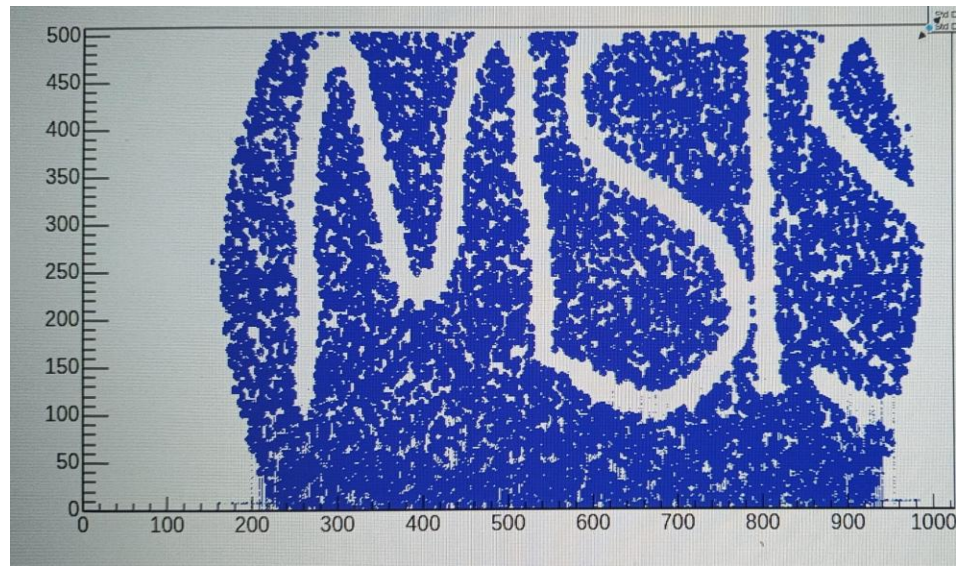
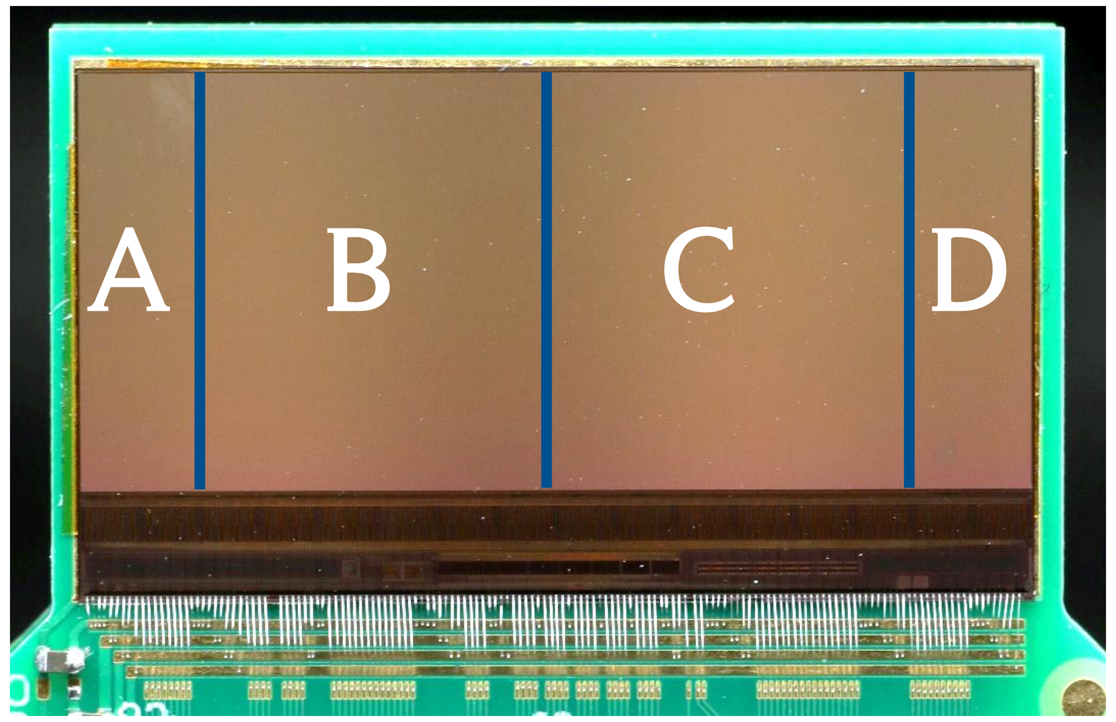






Challenge: Fixed Target (Deltas)



δ-e⁻ (+ dipole field: irradiation gradient)

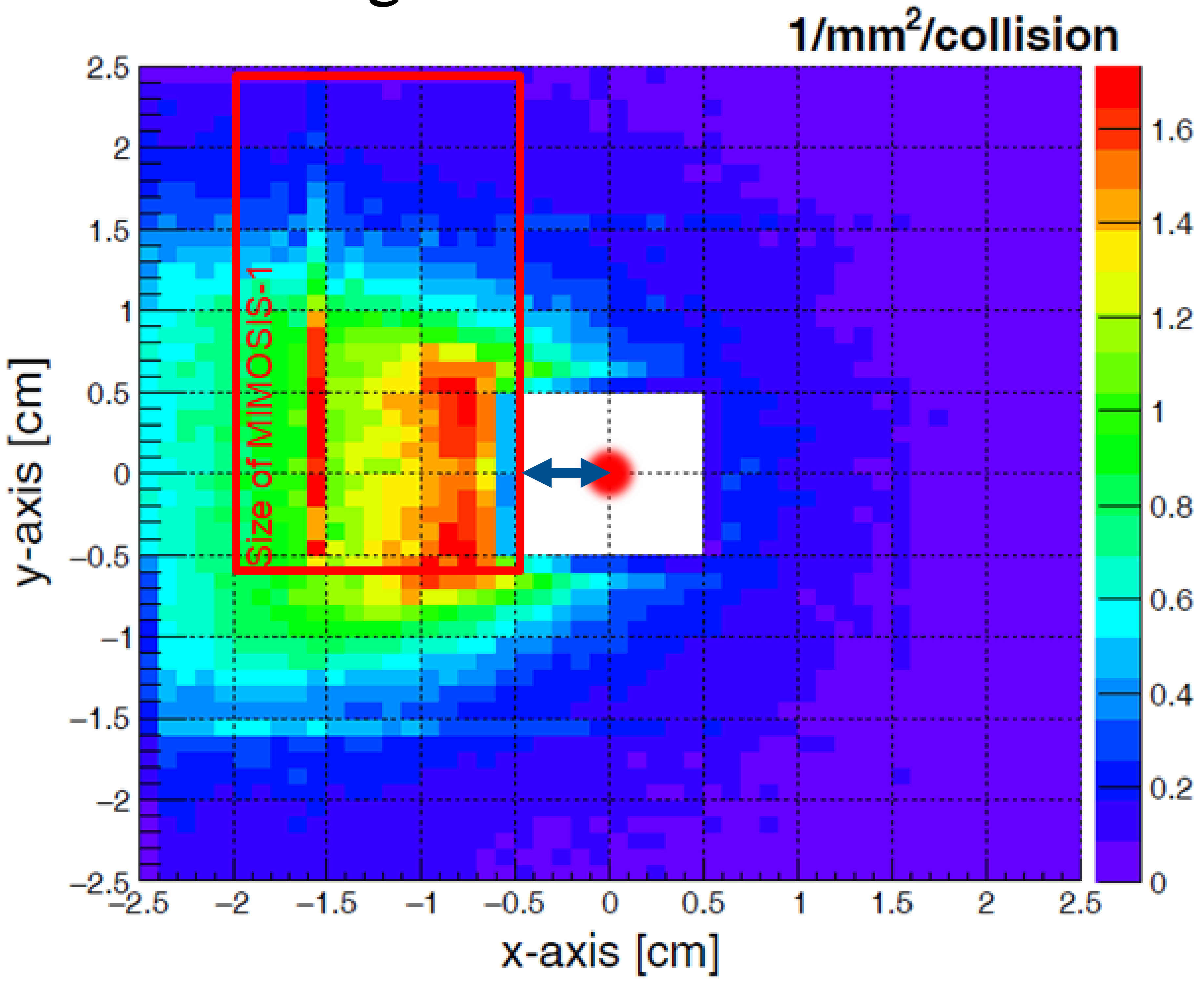
→ Load uncorrelated to physics events (tracking ambiguity)

Threshold shift from TID (charge build-up in gate oxide)

→ Saturates (~1 Mrad if biased, 3 Mrad if unbiased)

→ Pre-irradiation to homogenize pixel response (^{60}Co γ)

Hit gradient 1st MVD station



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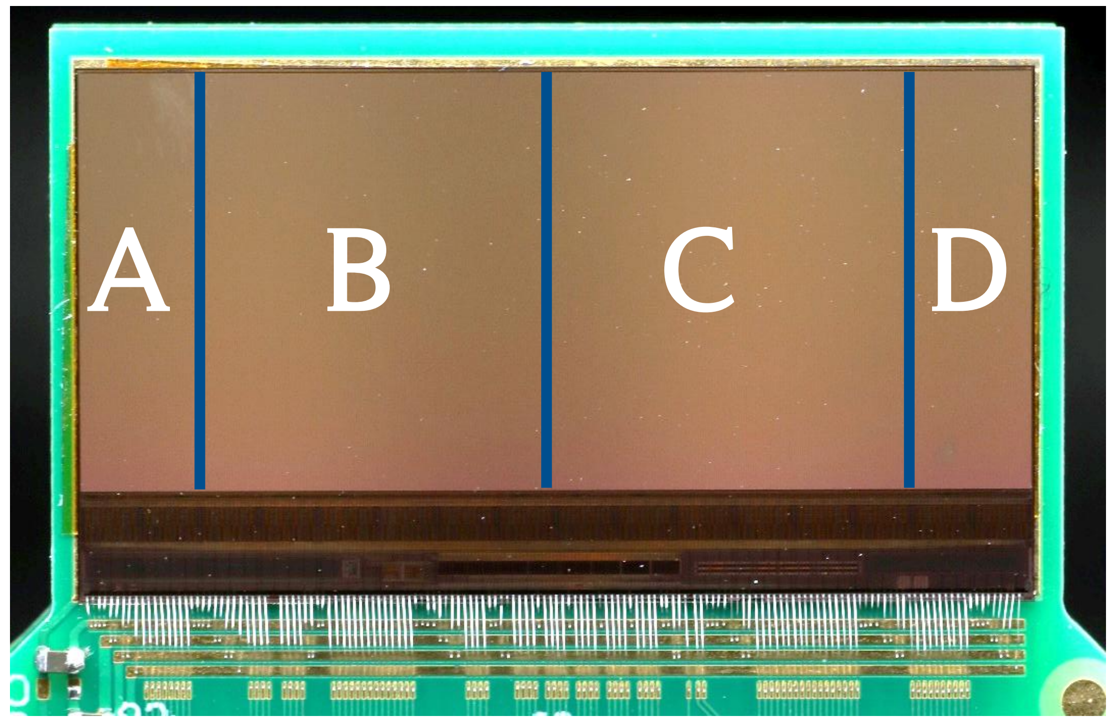

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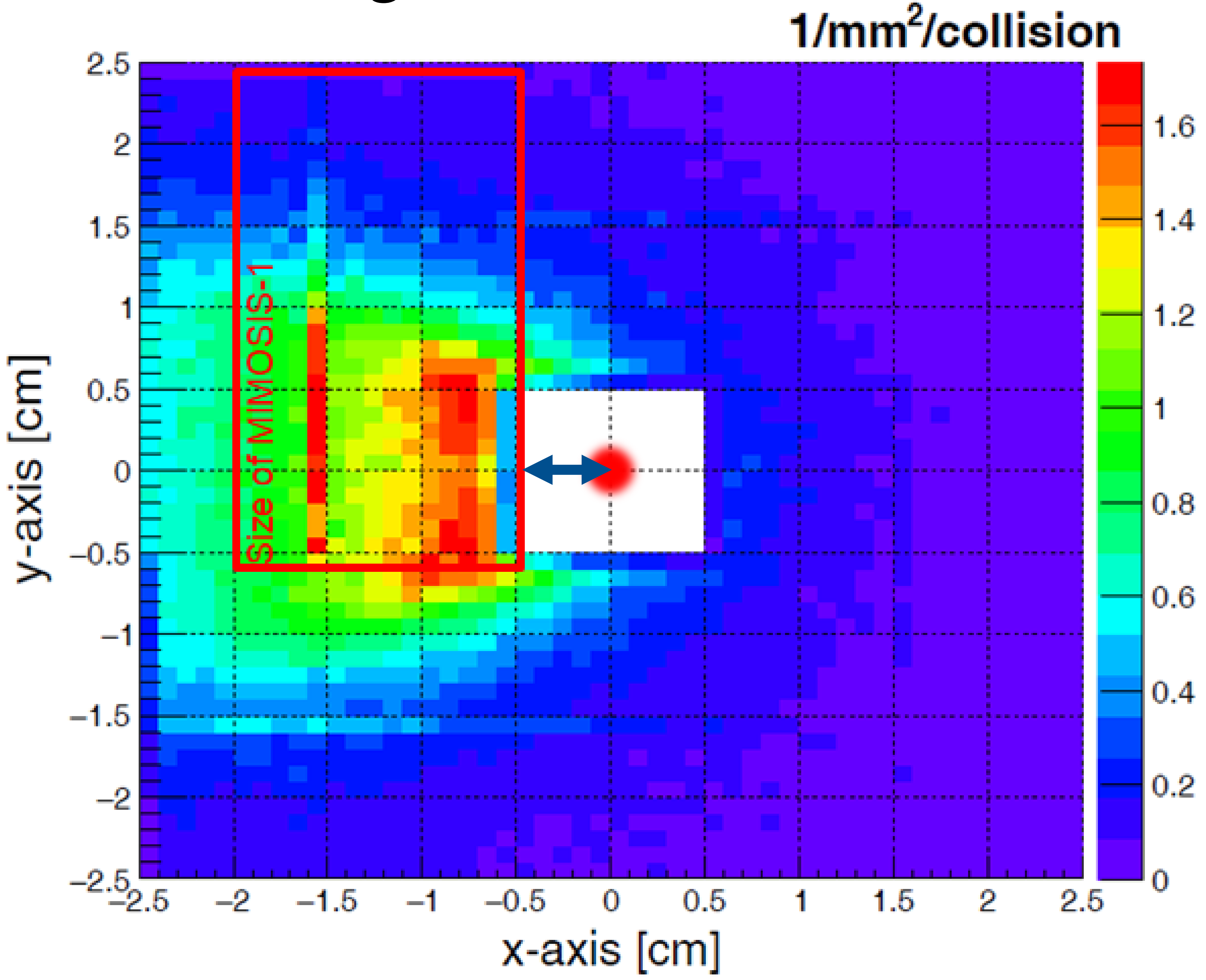
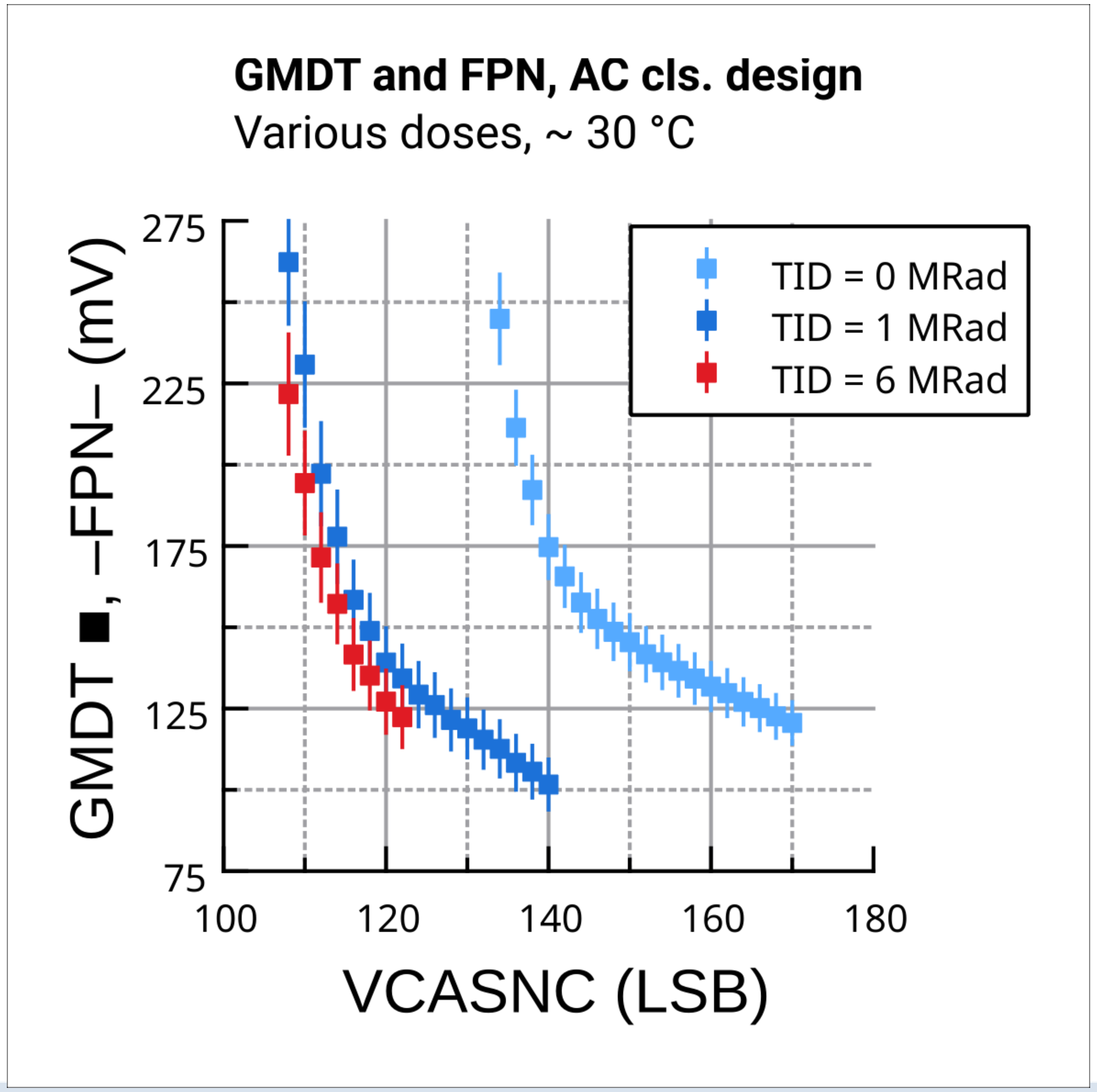
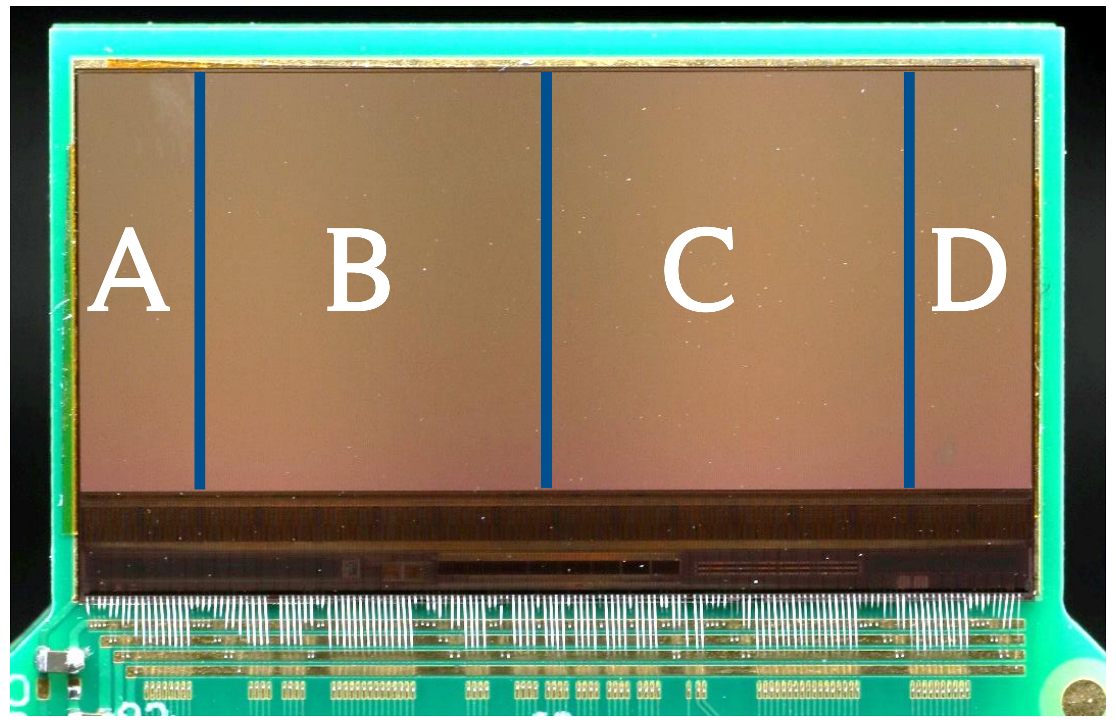


Threshold shift biased MIMOSIS-1



Challenge: Fixed Target (Deltas)



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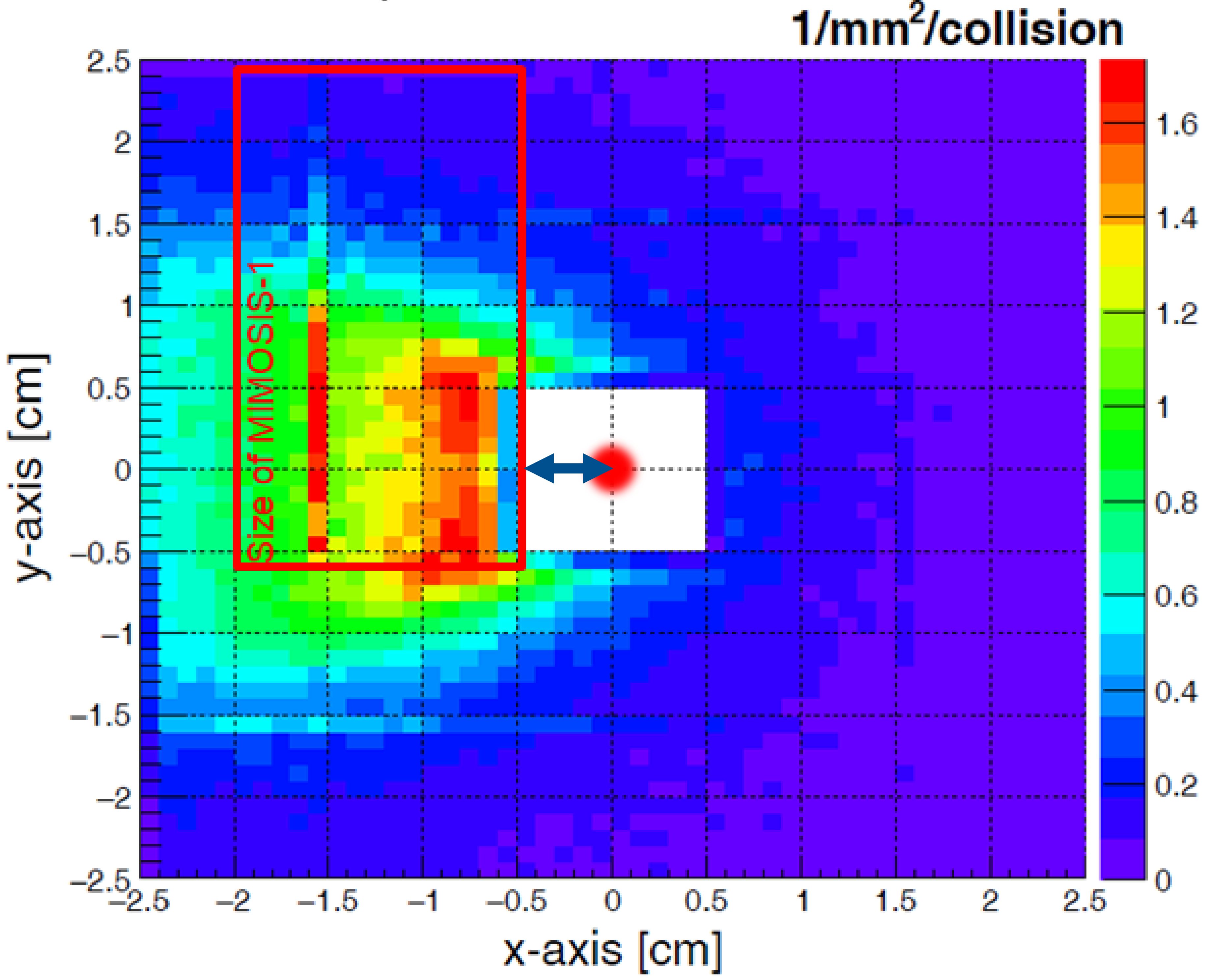
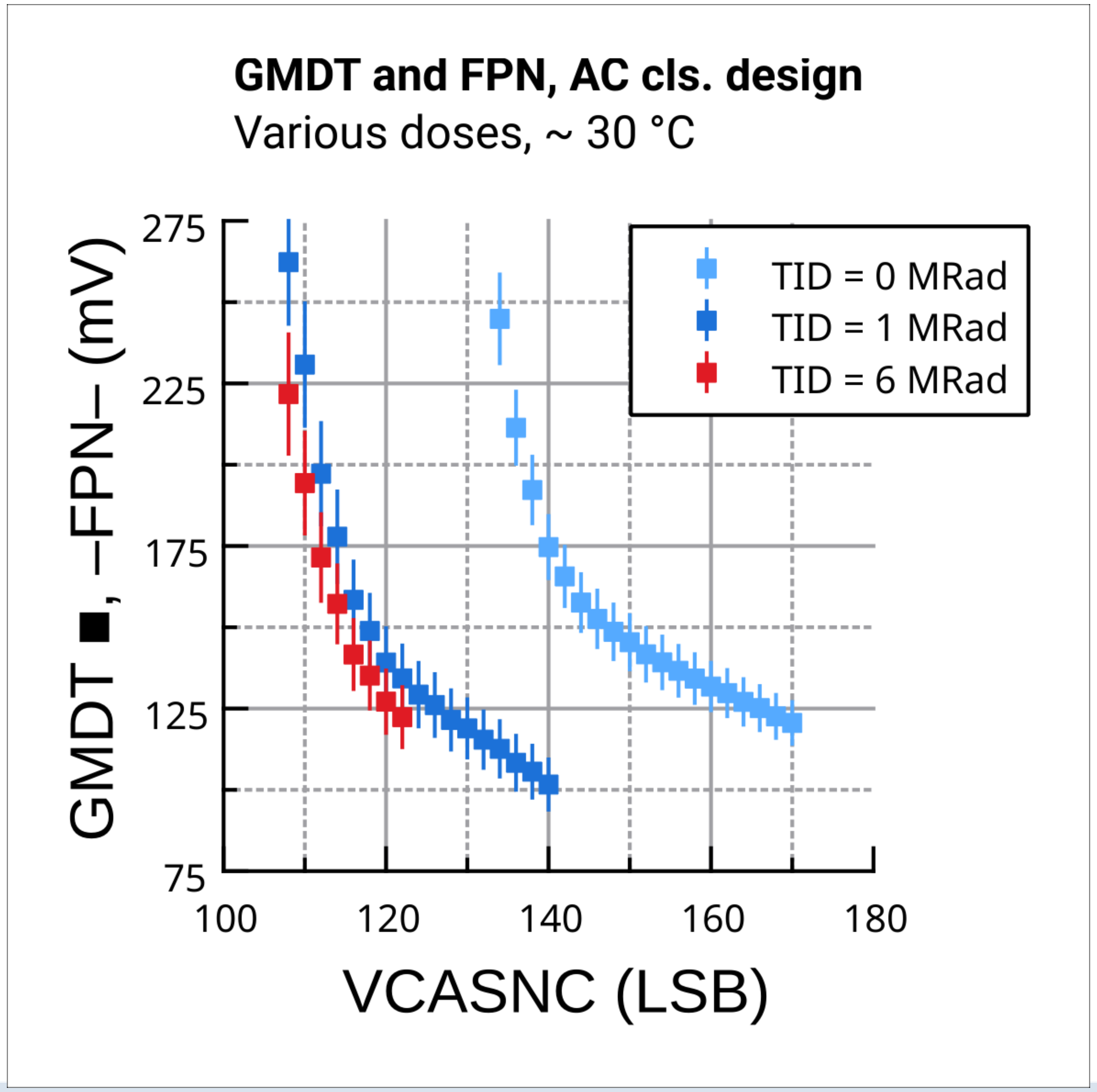
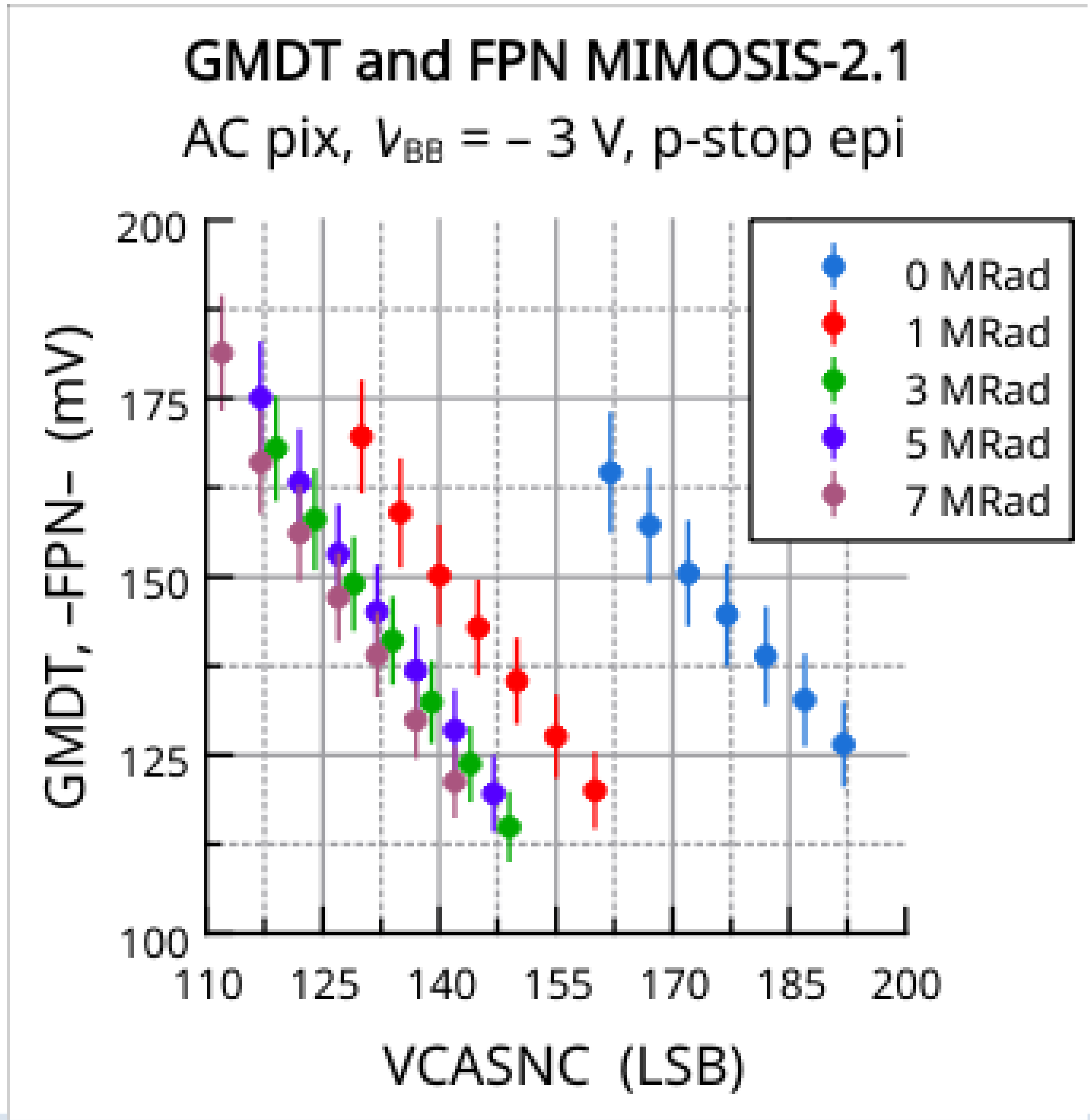


Threshold shift biased MIMOSIS-1



Threshold shift unbiased MIMOSIS-2.1



Challenge: Fixed Target (Intensitiy Fluctuations)

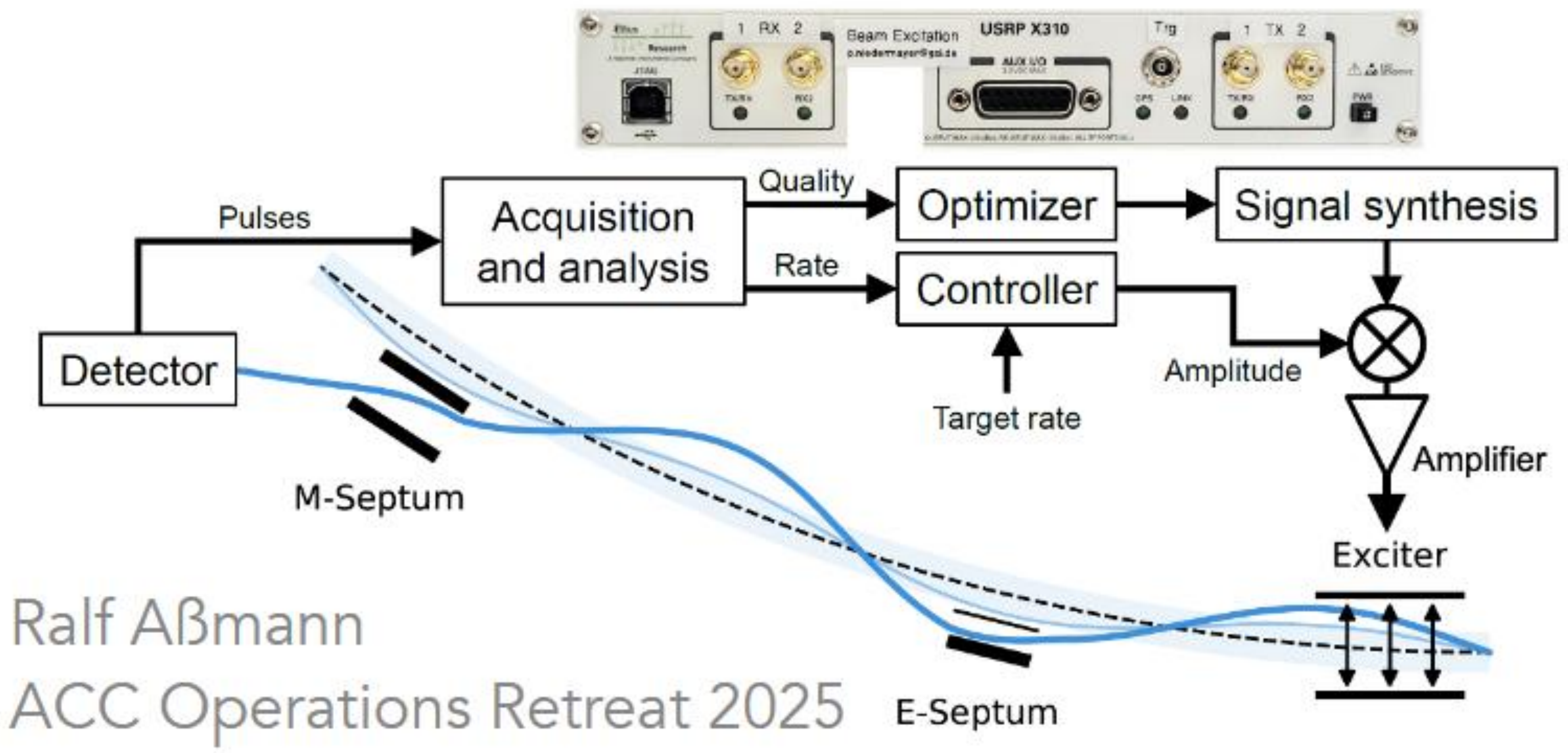
Non-ideal spills in realistic accelerators (SIS100)

→ Global spill: 0.5 s synchrotron refill, 10 s slow extraction

→ μ-spill structure (known from SIS18)

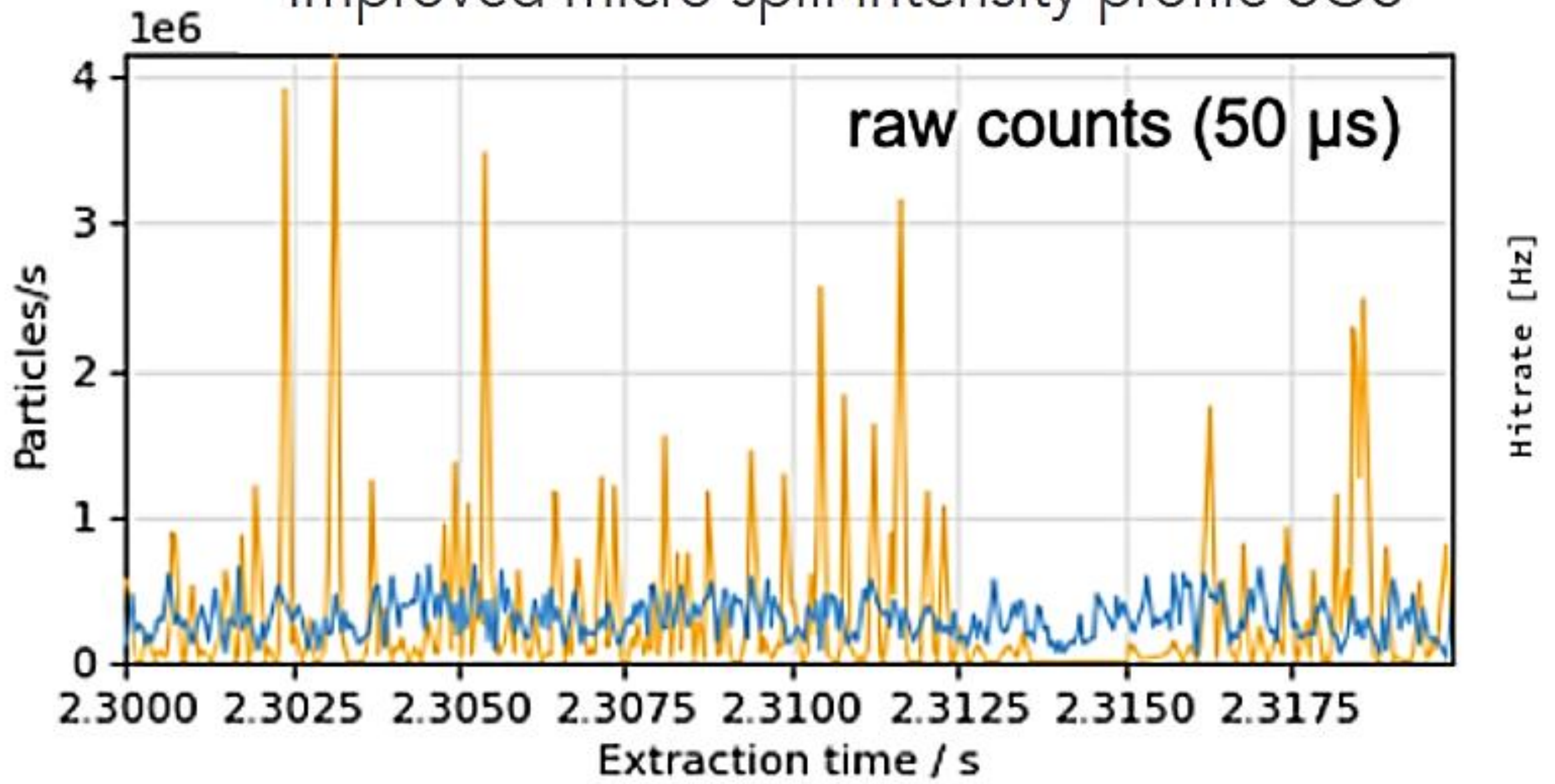
→ Substantially improved with Spill Optimization System (SOS)

Spill optimisation system (SOS)



Ralf Aßmann
ACC Operations Retreat 2025

Improved micro spill intensity profile SOS



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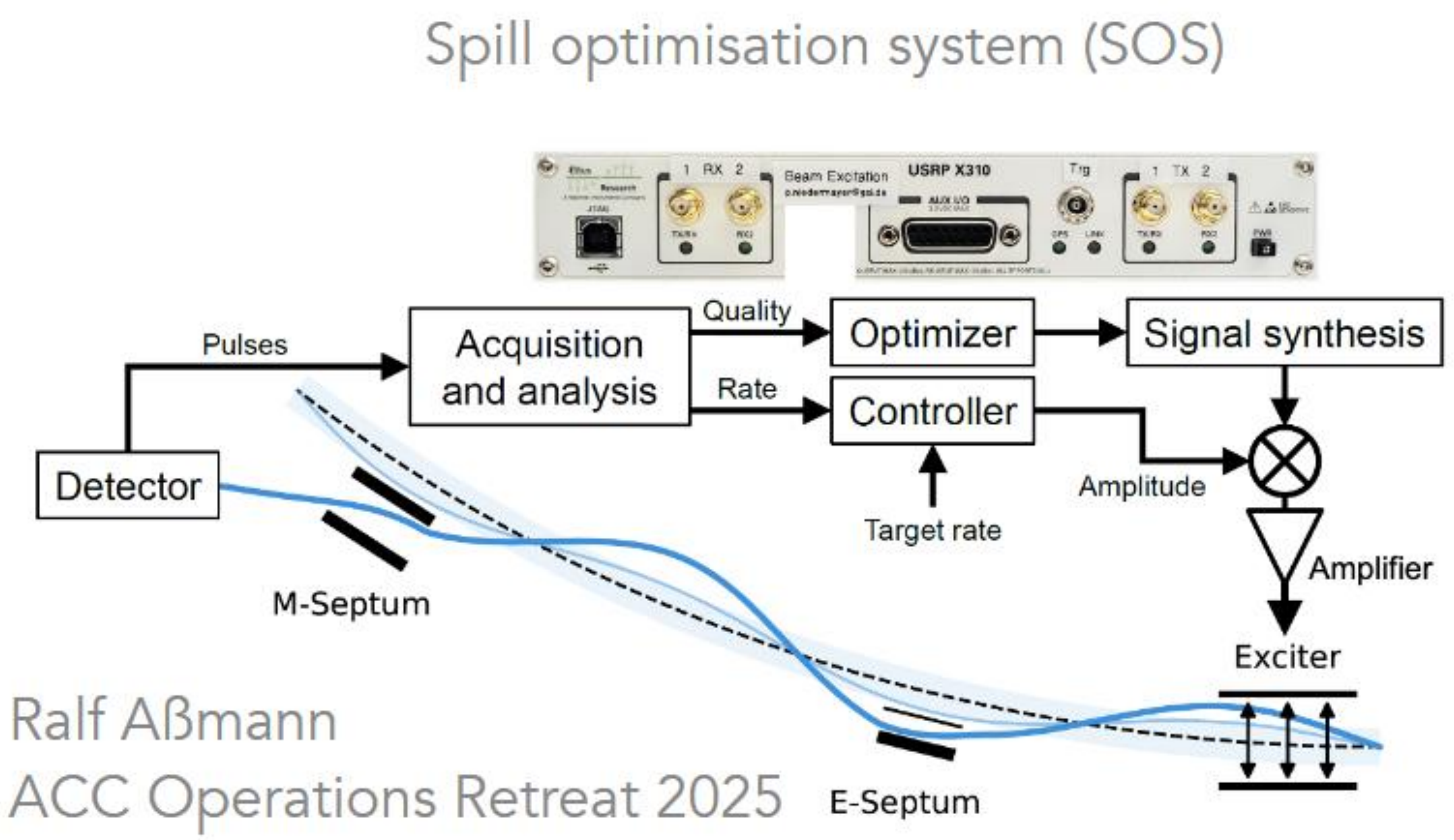
Elastic buffer in MIMOSIS

→ Peak/average >3 for 50 μs

→ Write speed 10.24 Gb/s > Read speed 2.56 Gb/s (for 8 links)



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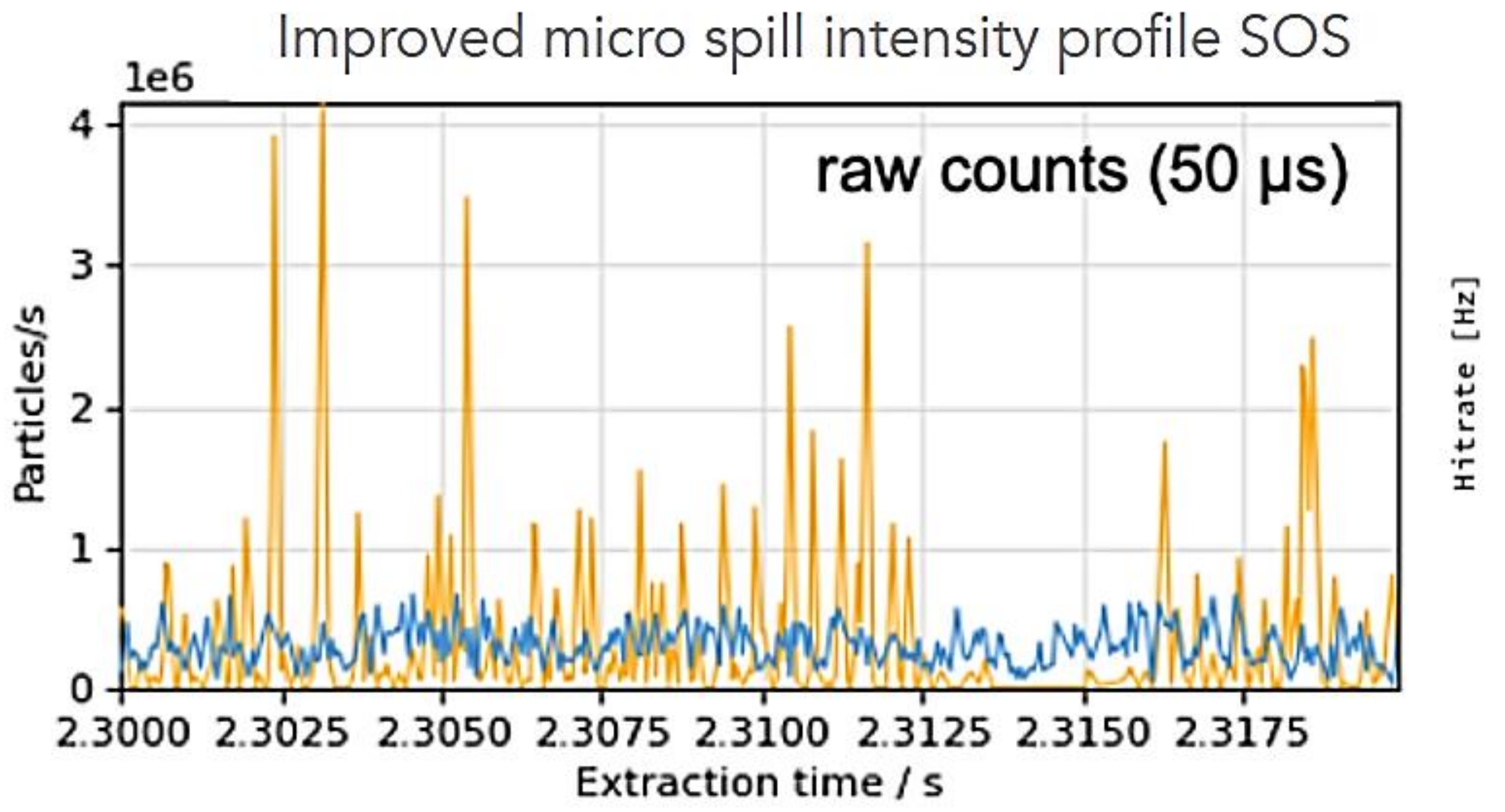
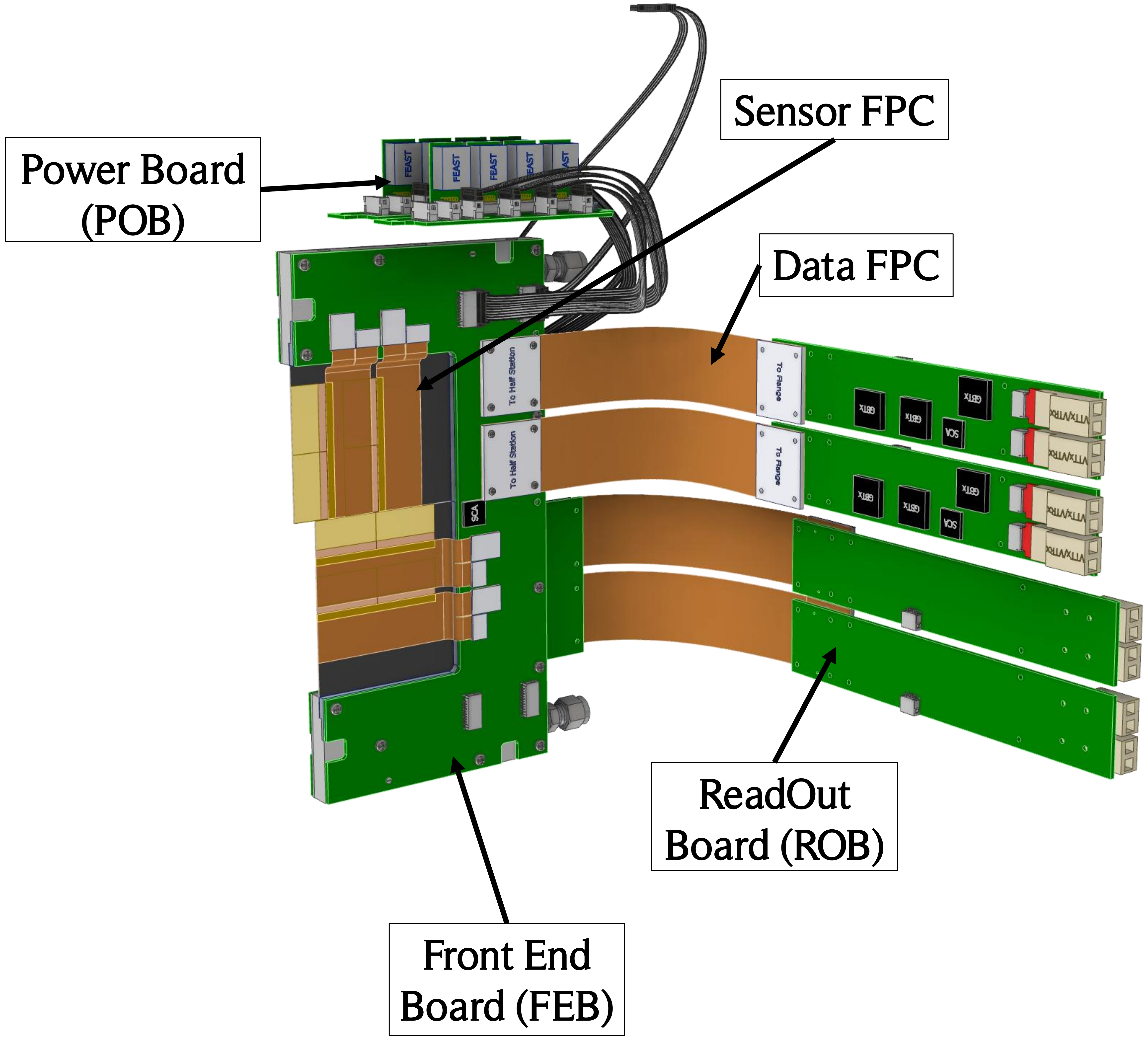
ACC Operations Retreat 2025



Chapter 2

Integration

Front-End Electronics



Power Board (POB)

Sensor FPC

Data FPC

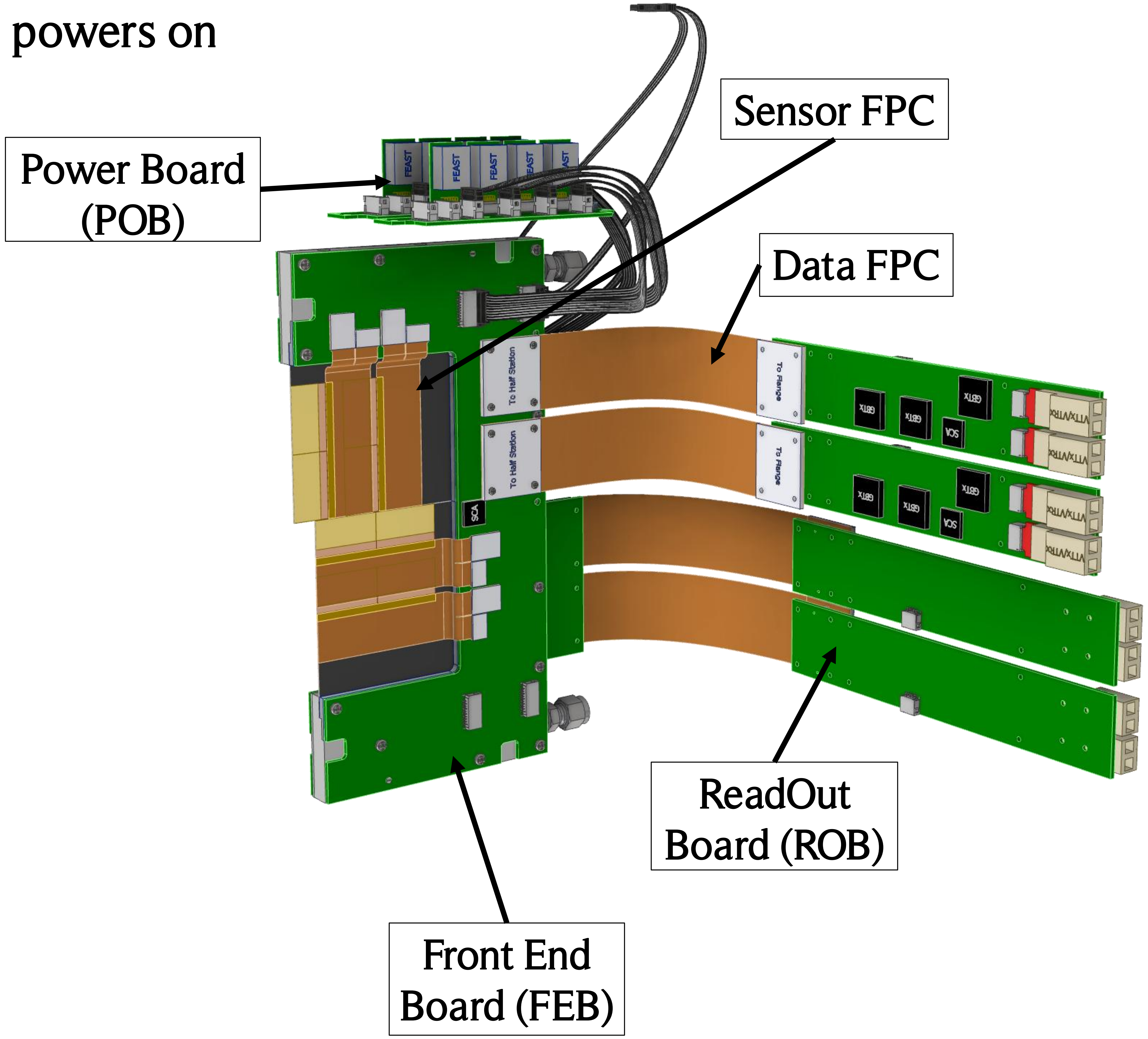
ReadOut Board (ROB)

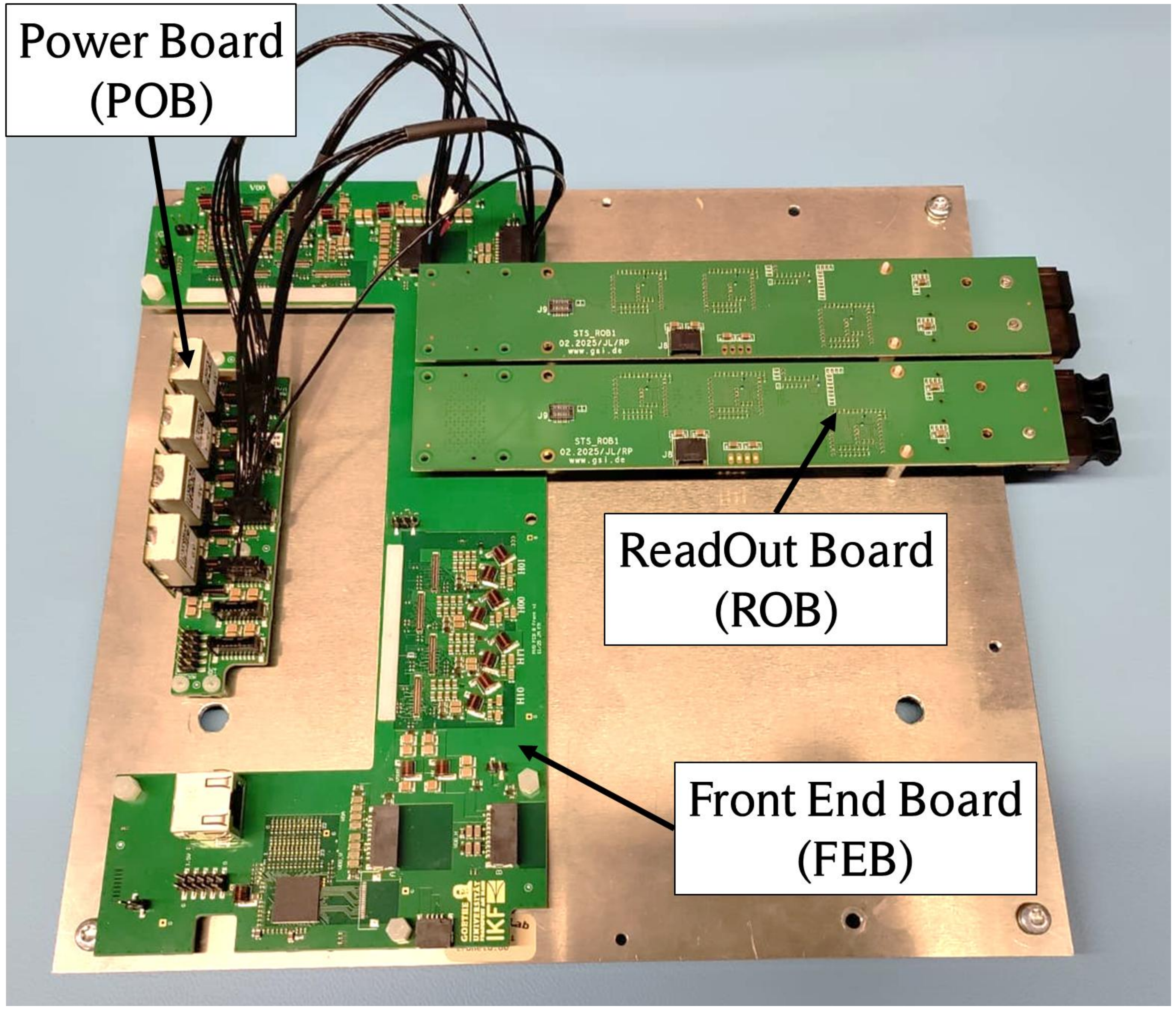
Front End Board (FEB)

Front-End Electronics

ROB and POB fully functional

FEB powers on



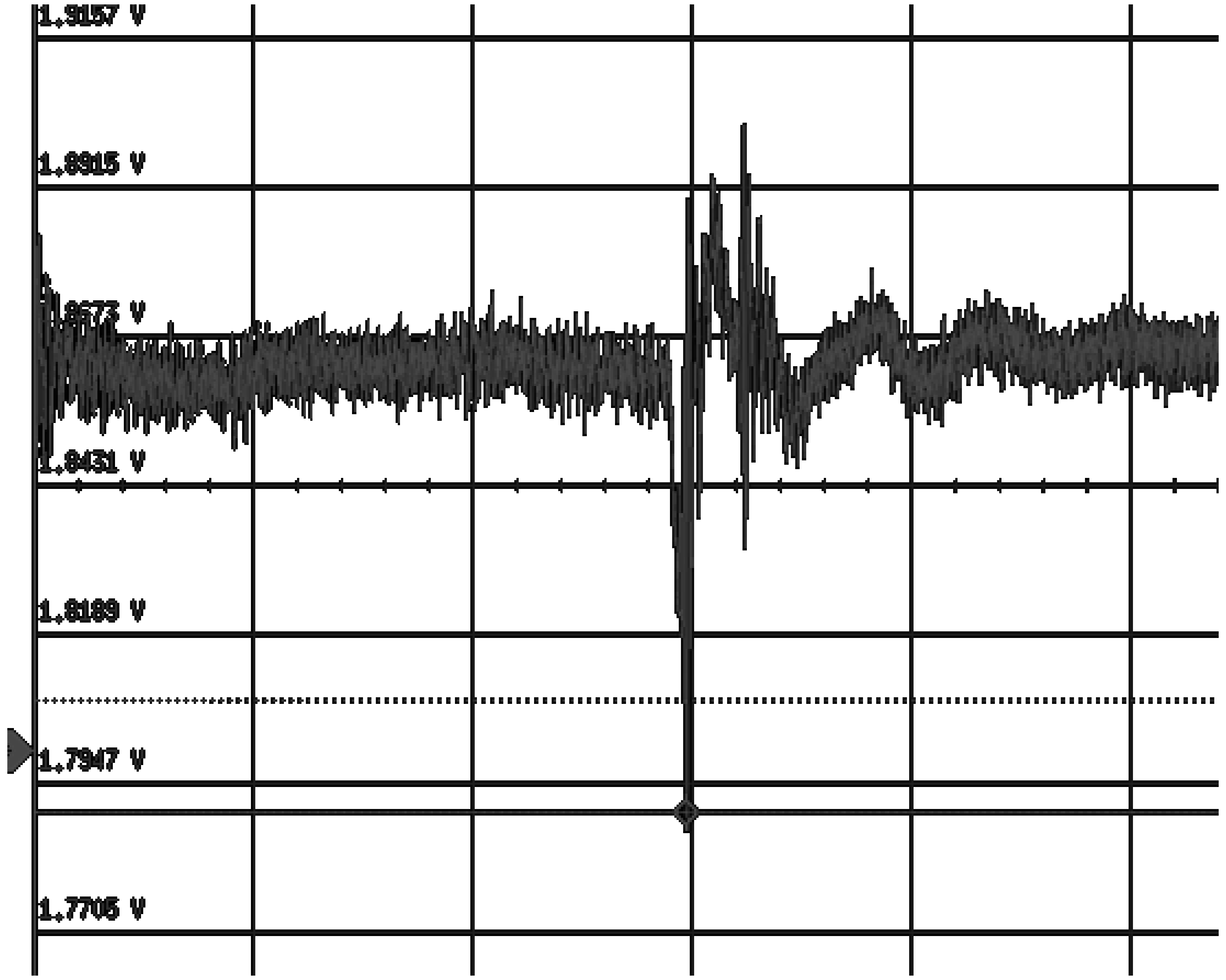


Challenge: Powering

Optimize power distribution network (on-chip and in-detector)

→ Static and dynamic voltage drops on all time scales

$\lessapprox$ 100 mV voltage fluctuations on VDD every frame (5 µs)



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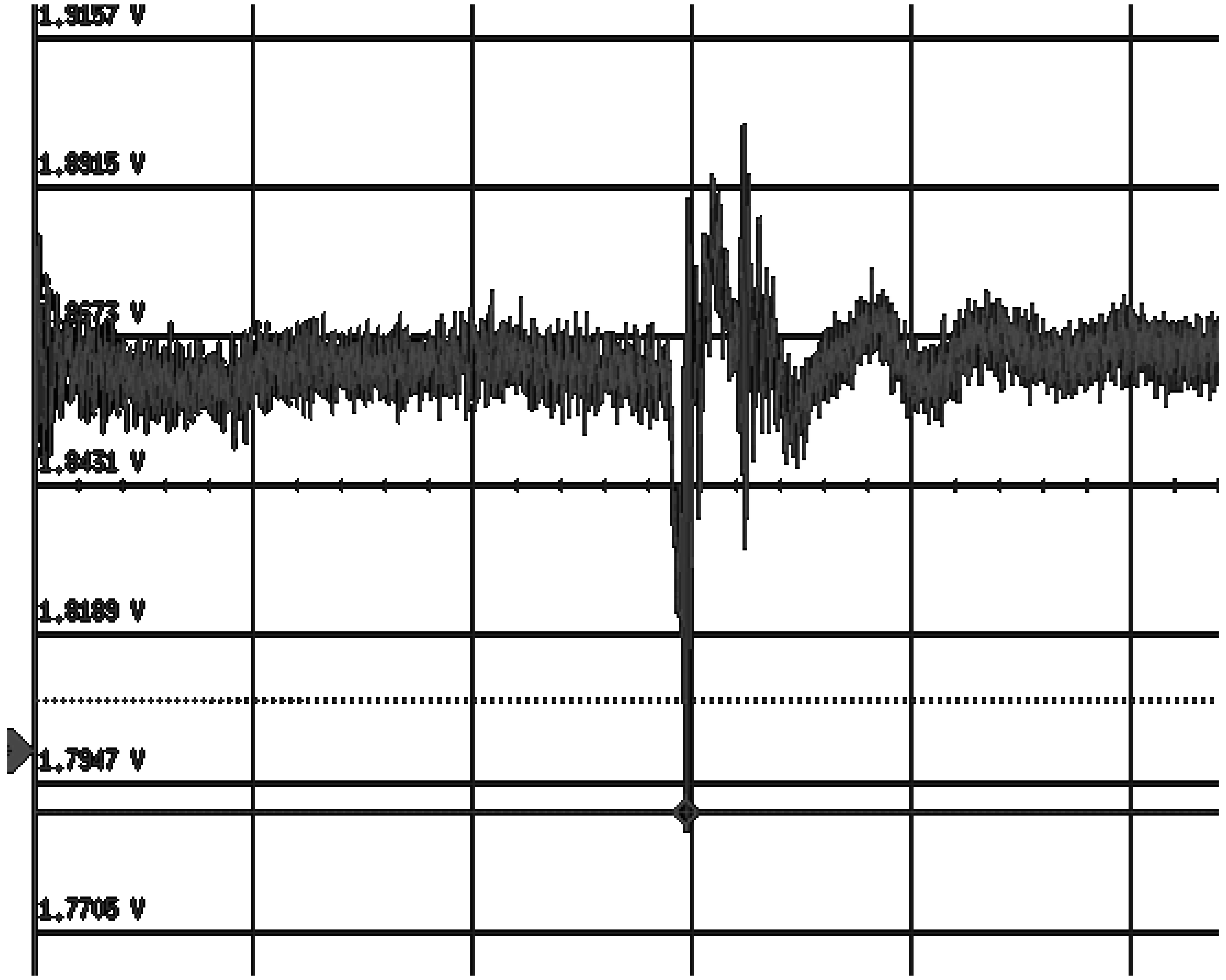
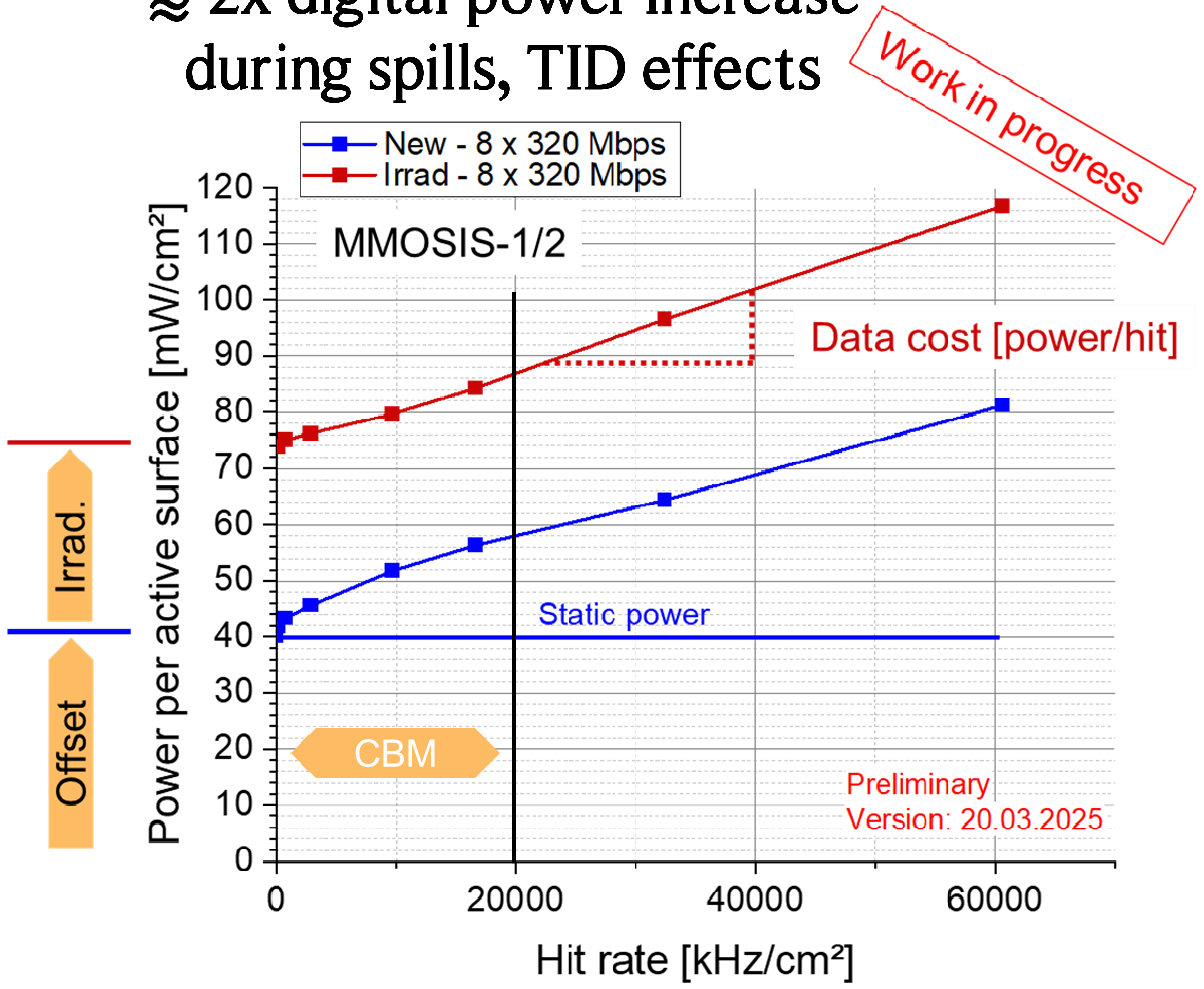


≲ 2x digital power increase during spills, TID effects



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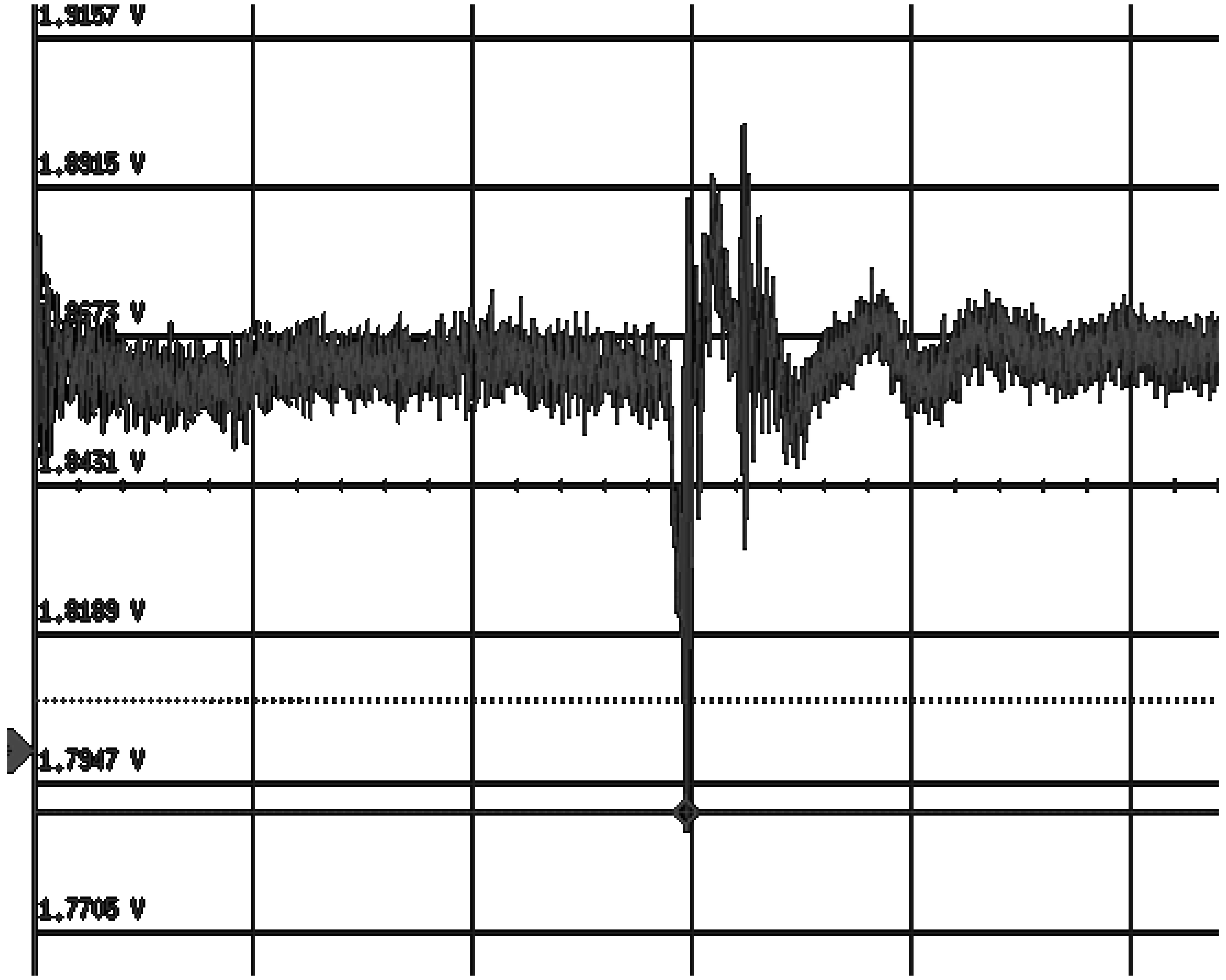

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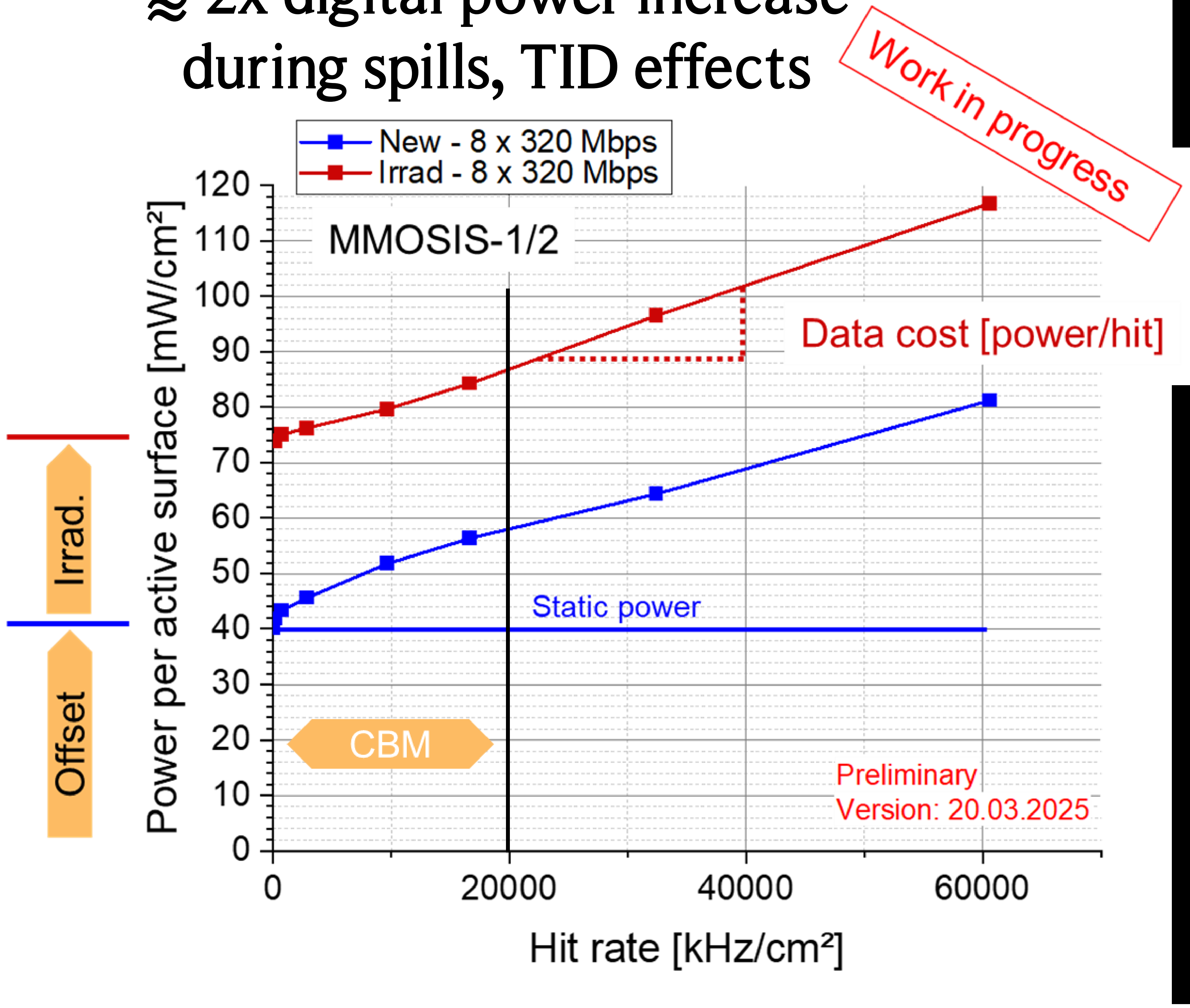
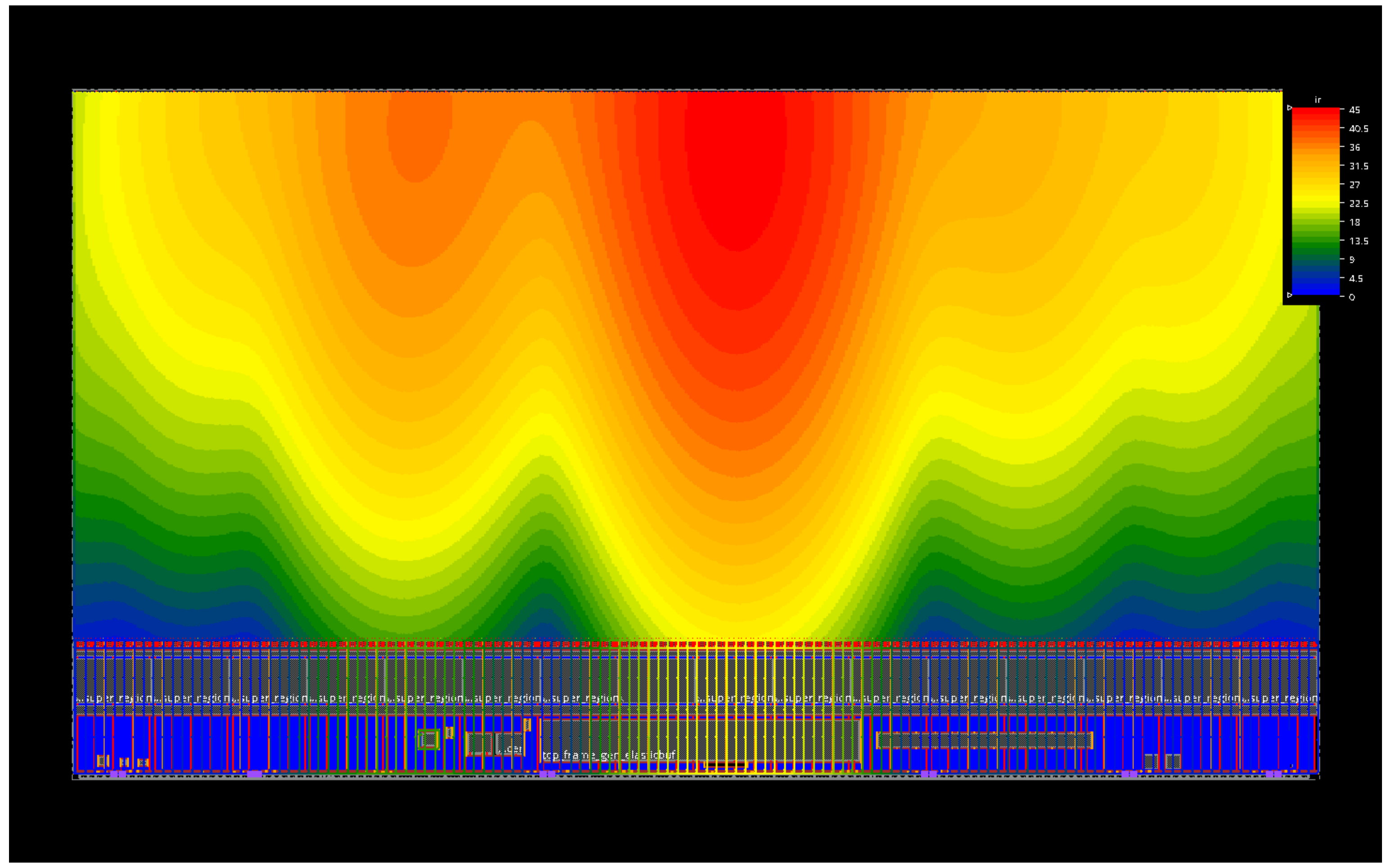
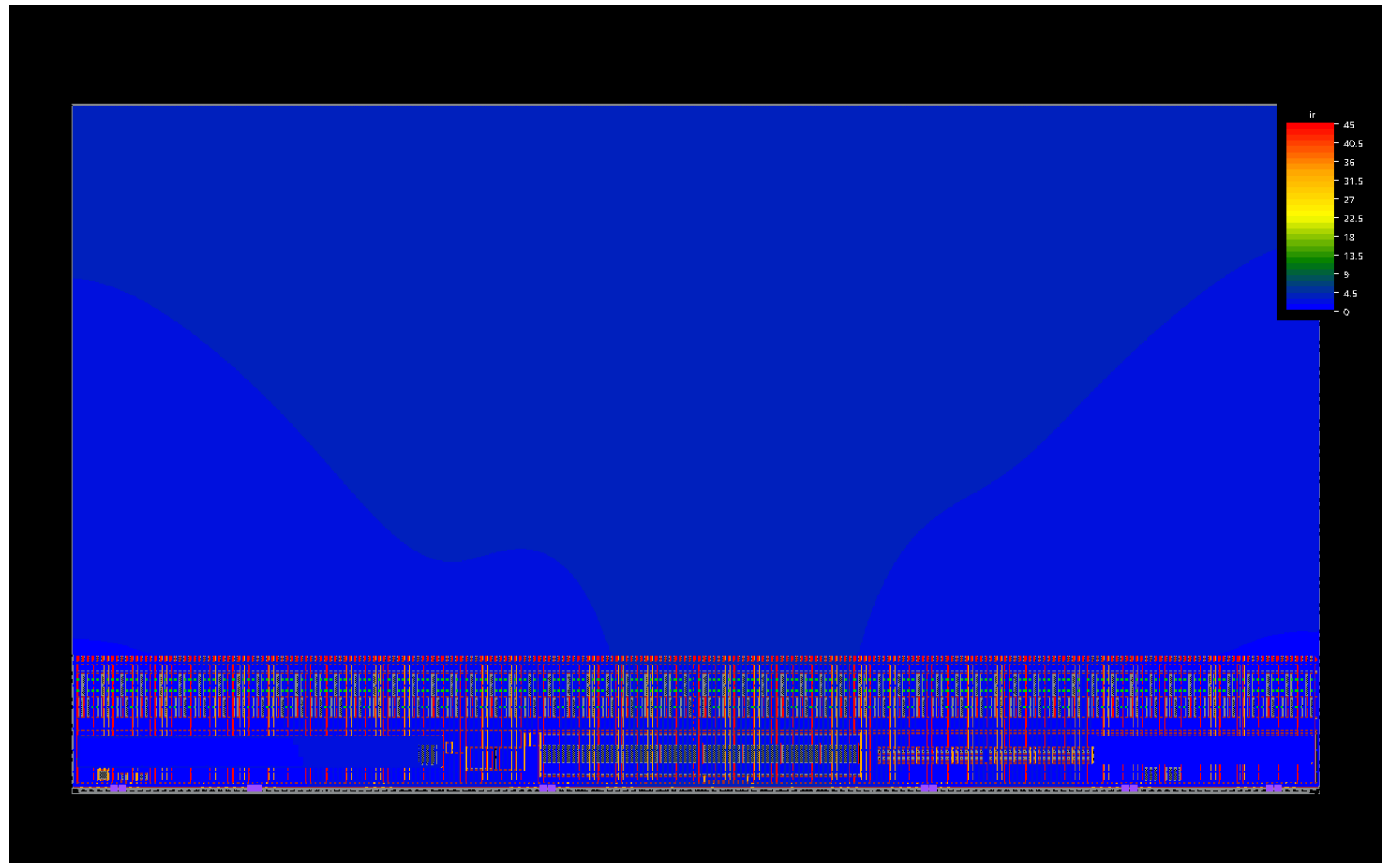




~4x improvements in analog power grid from M1 to M2



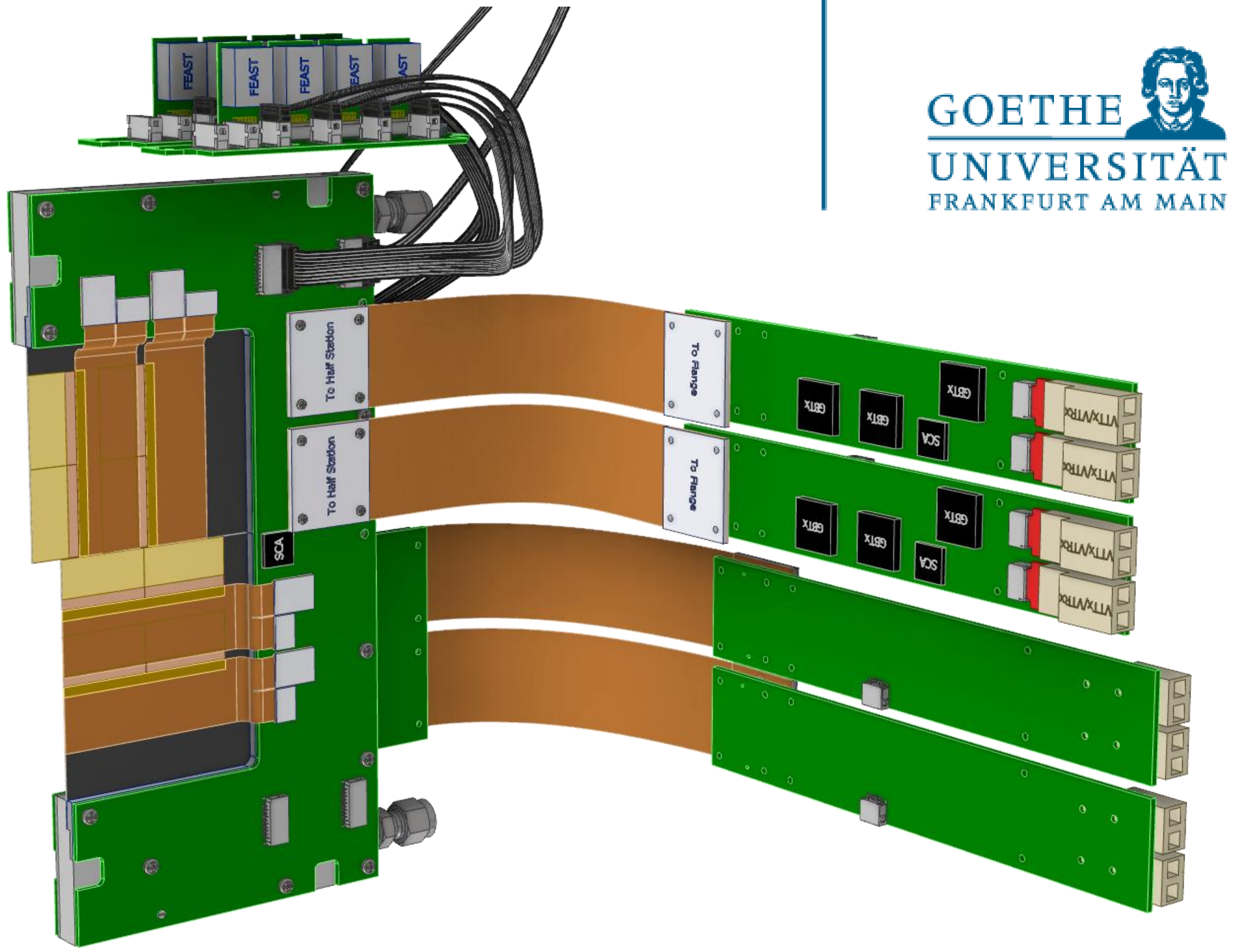
Challenge: Powering

Note: This is an “easy” system

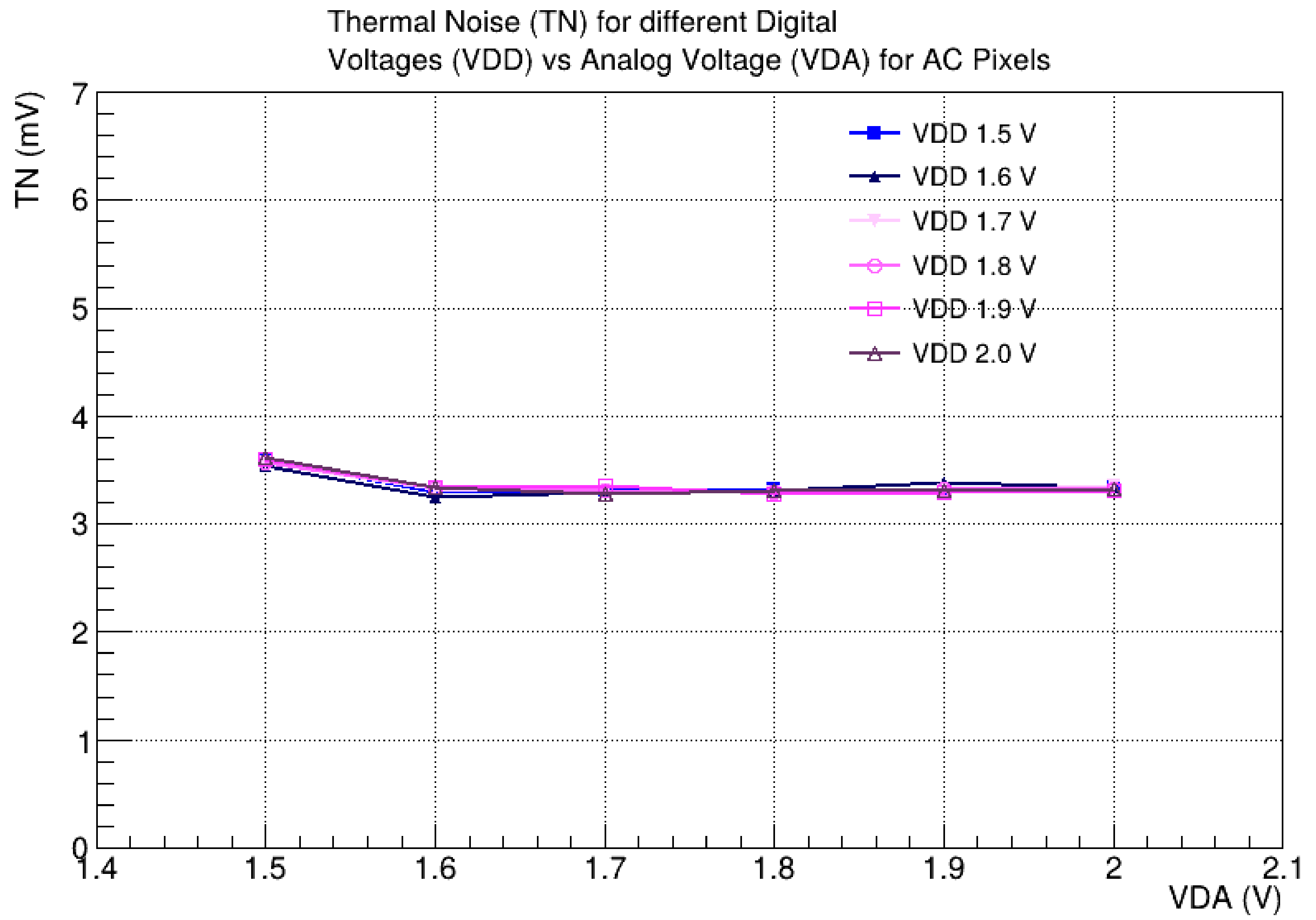
→ Parallel powering

→ Cross-powering and latch-ups not observed

→ Sufficient stable operation voltage range



Stable operation voltage range



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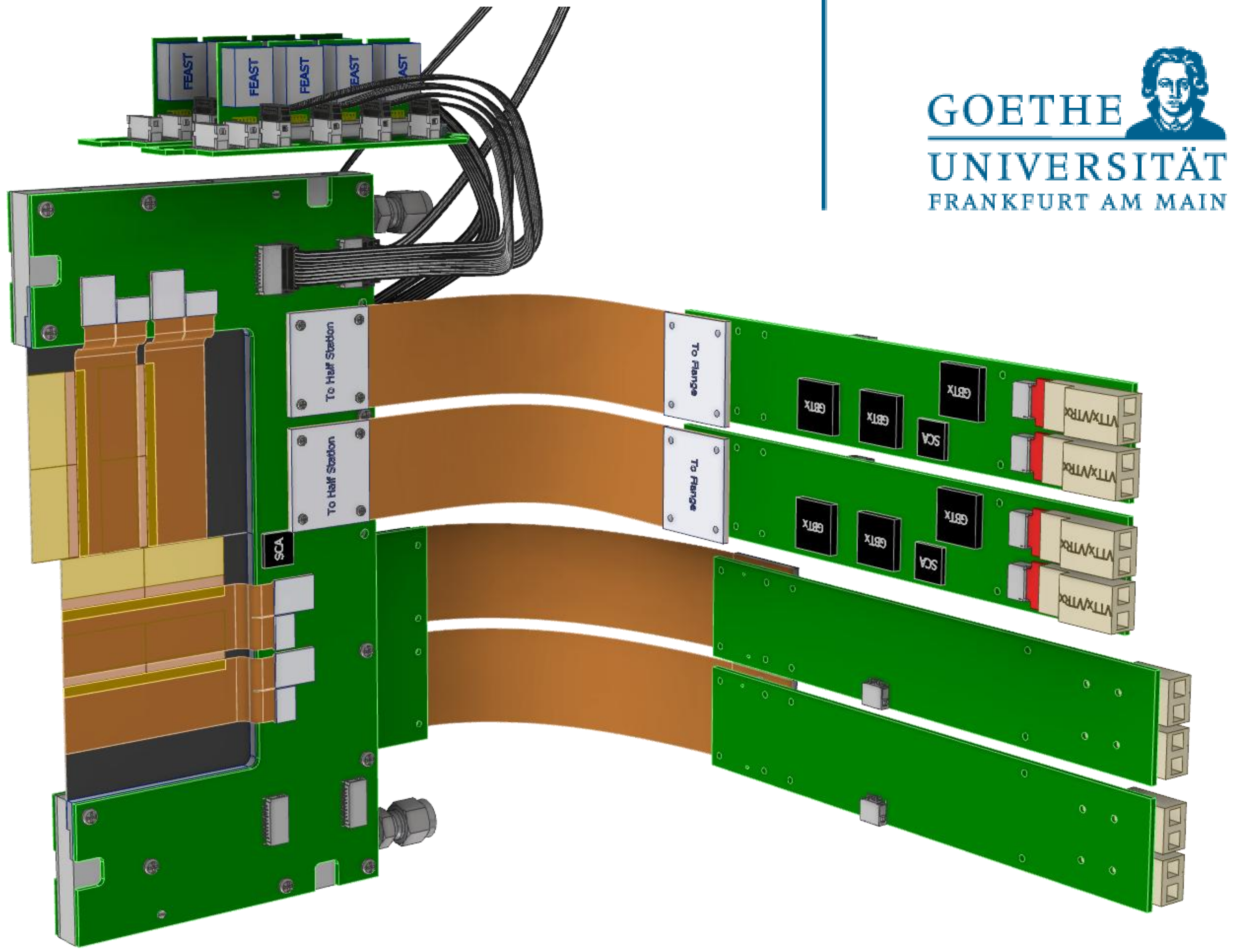
Detector PDN

→ LV distribution in vacuum (FEAST DC/DC)

→ Low R cabling

→ >50% of FPC area for powering

→ Separated power domains



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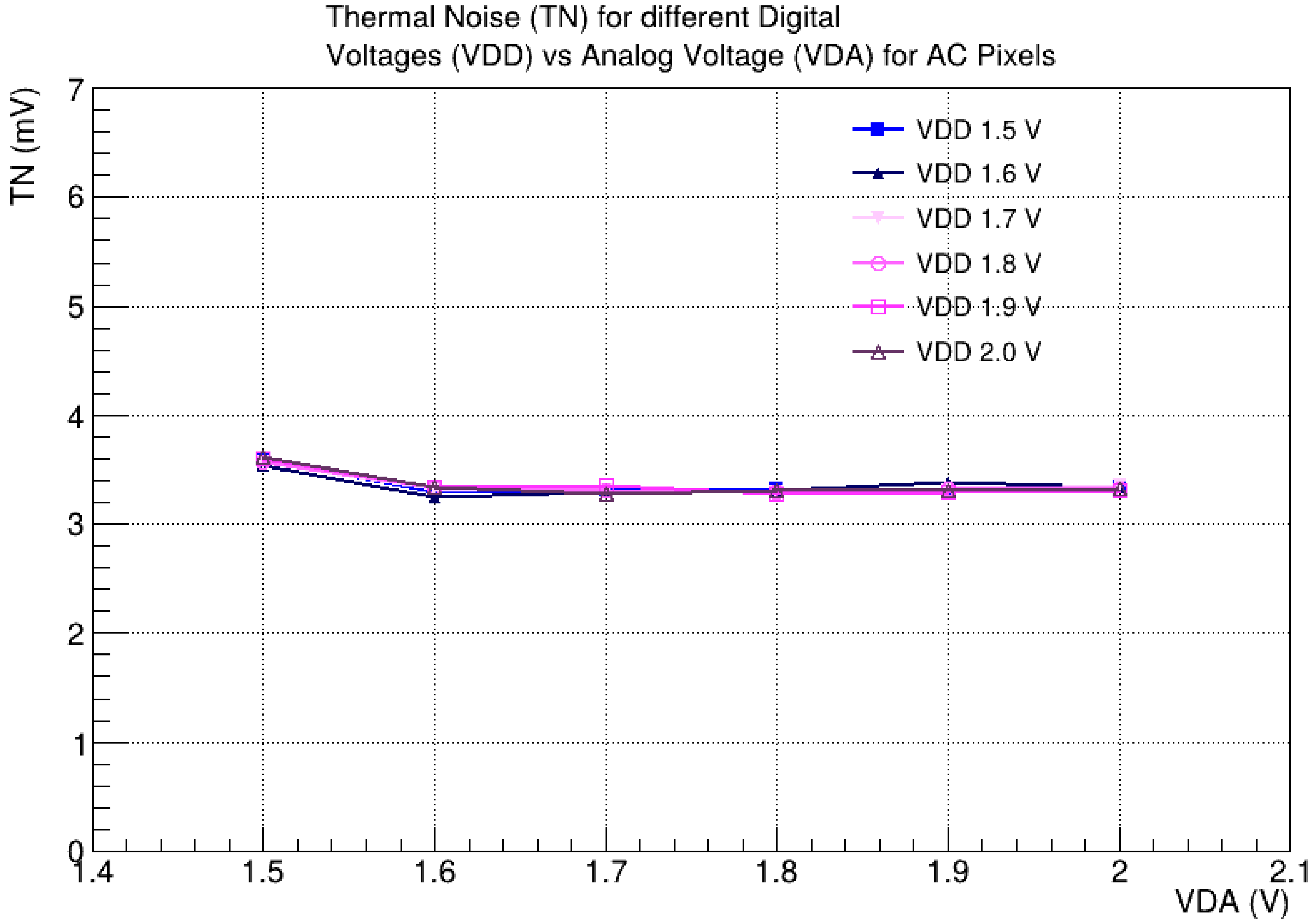

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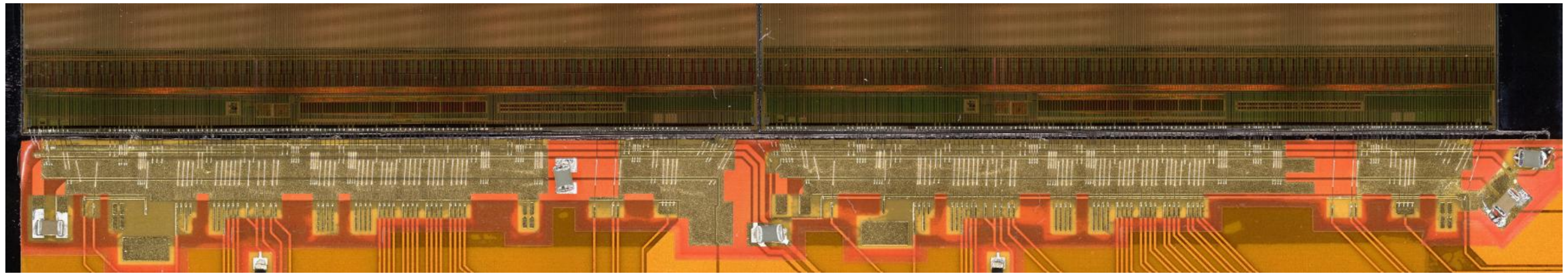
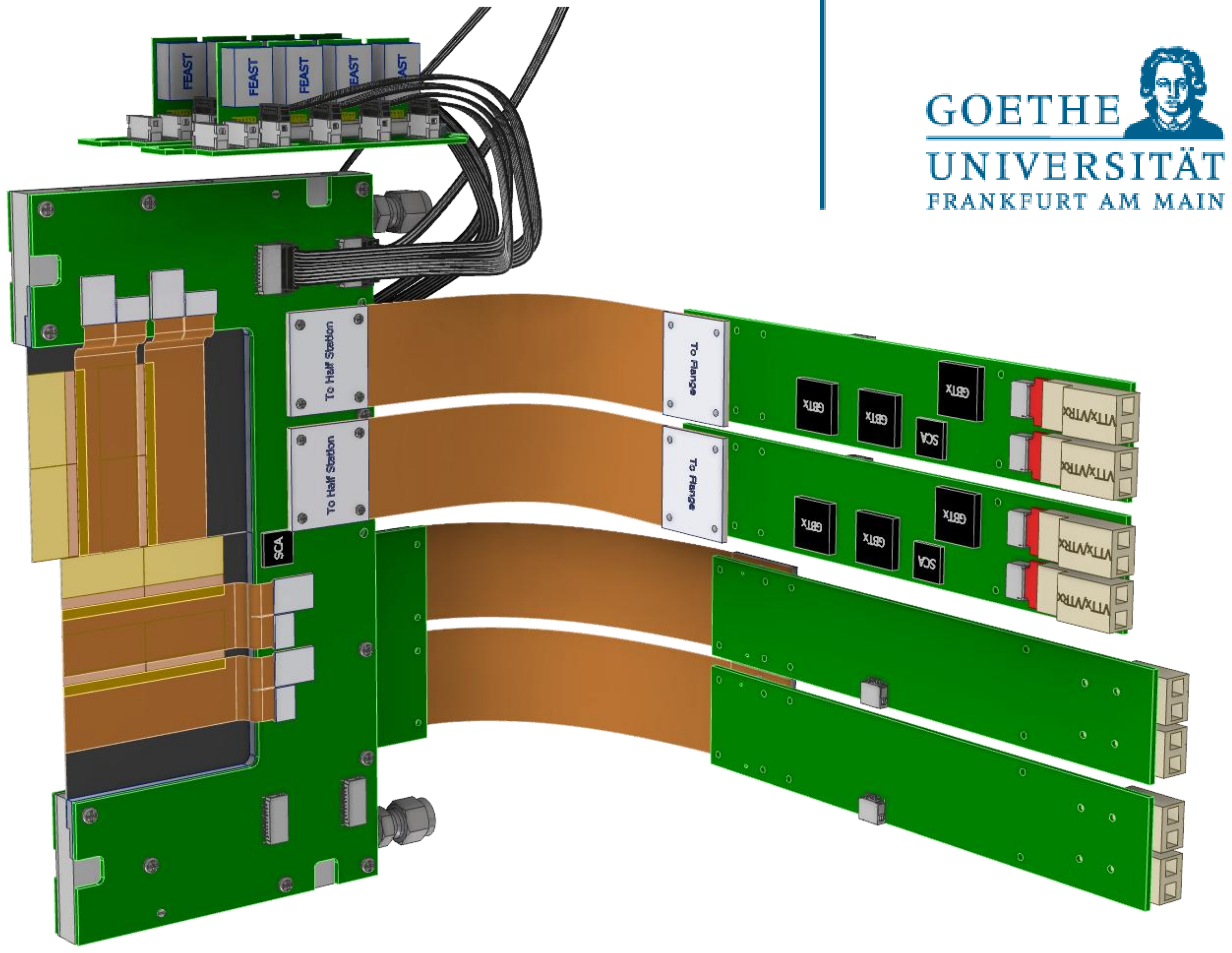
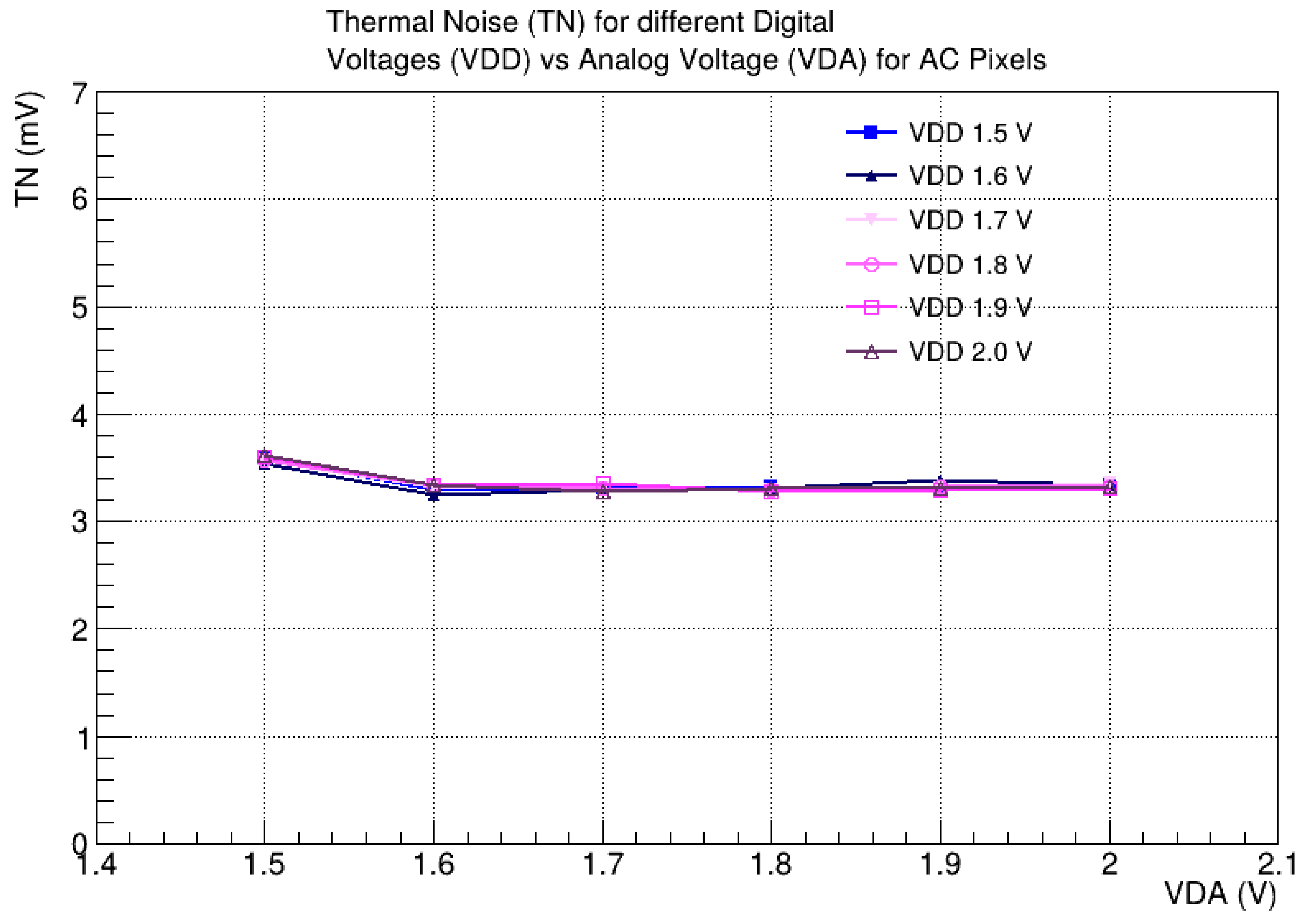
But: Capacitors in acceptance
But: Grouping of components
But: External biasing (20 m)
But: ~40 mV GND shift (biasing, SLVS)

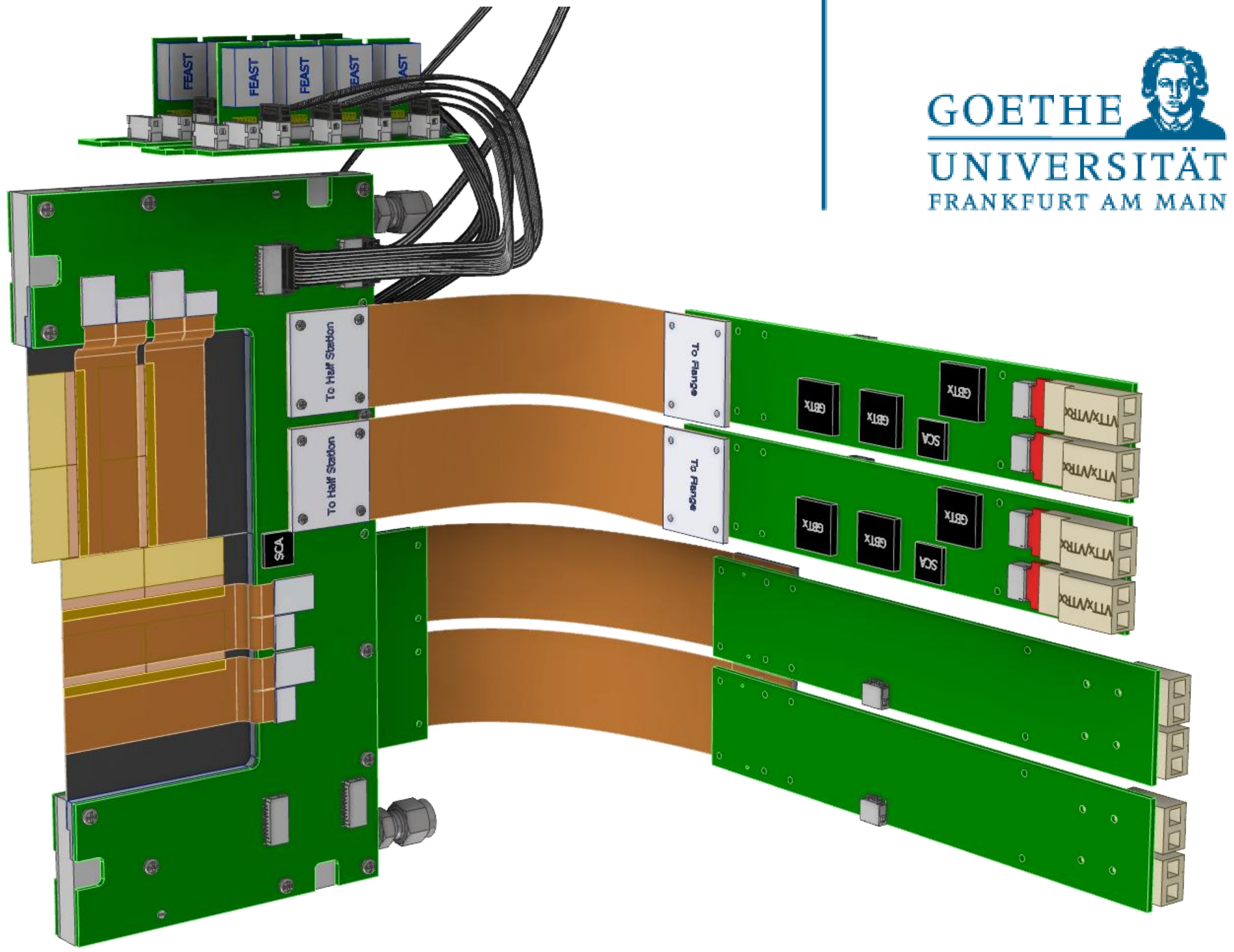




Stable operation voltage range



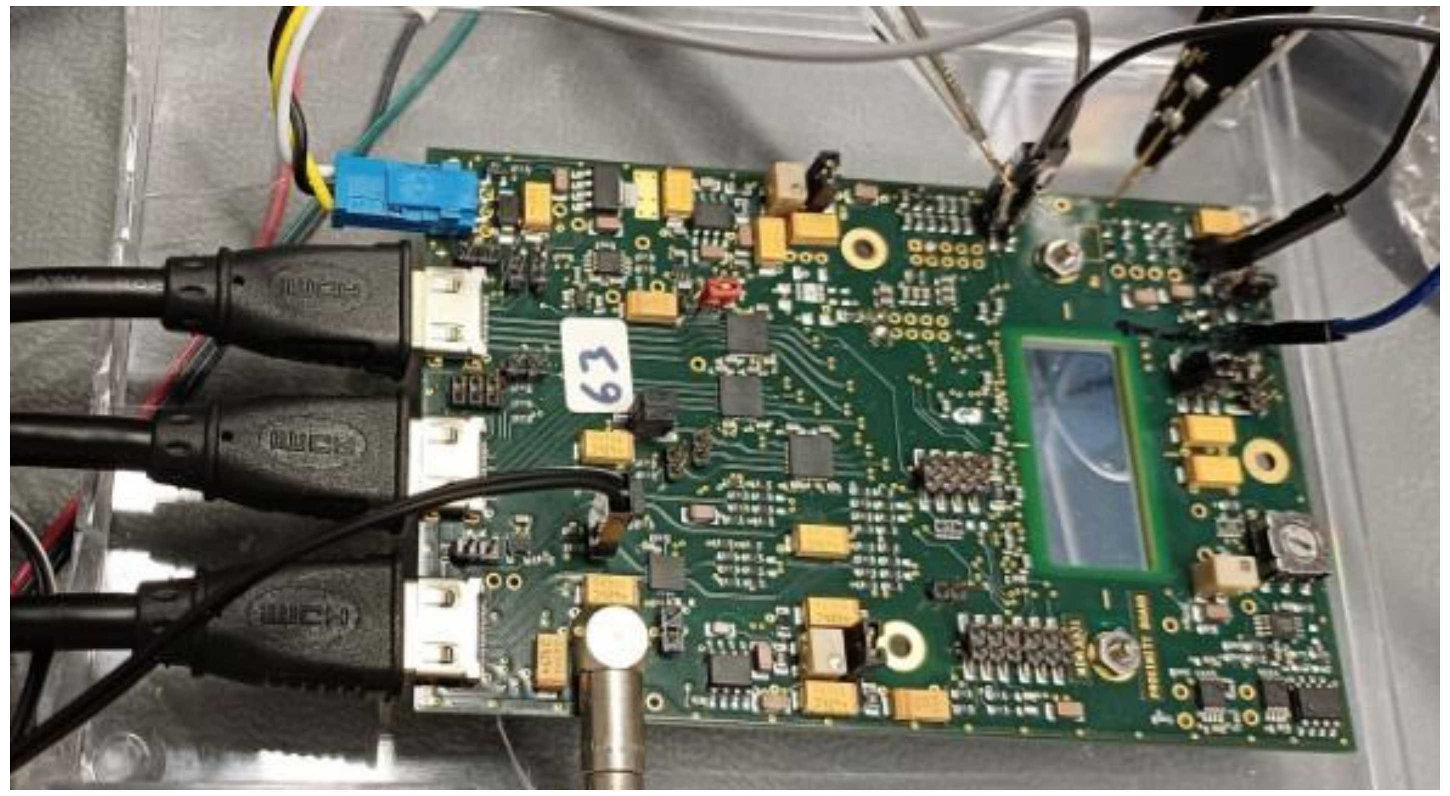
Challenge: Data Integrity

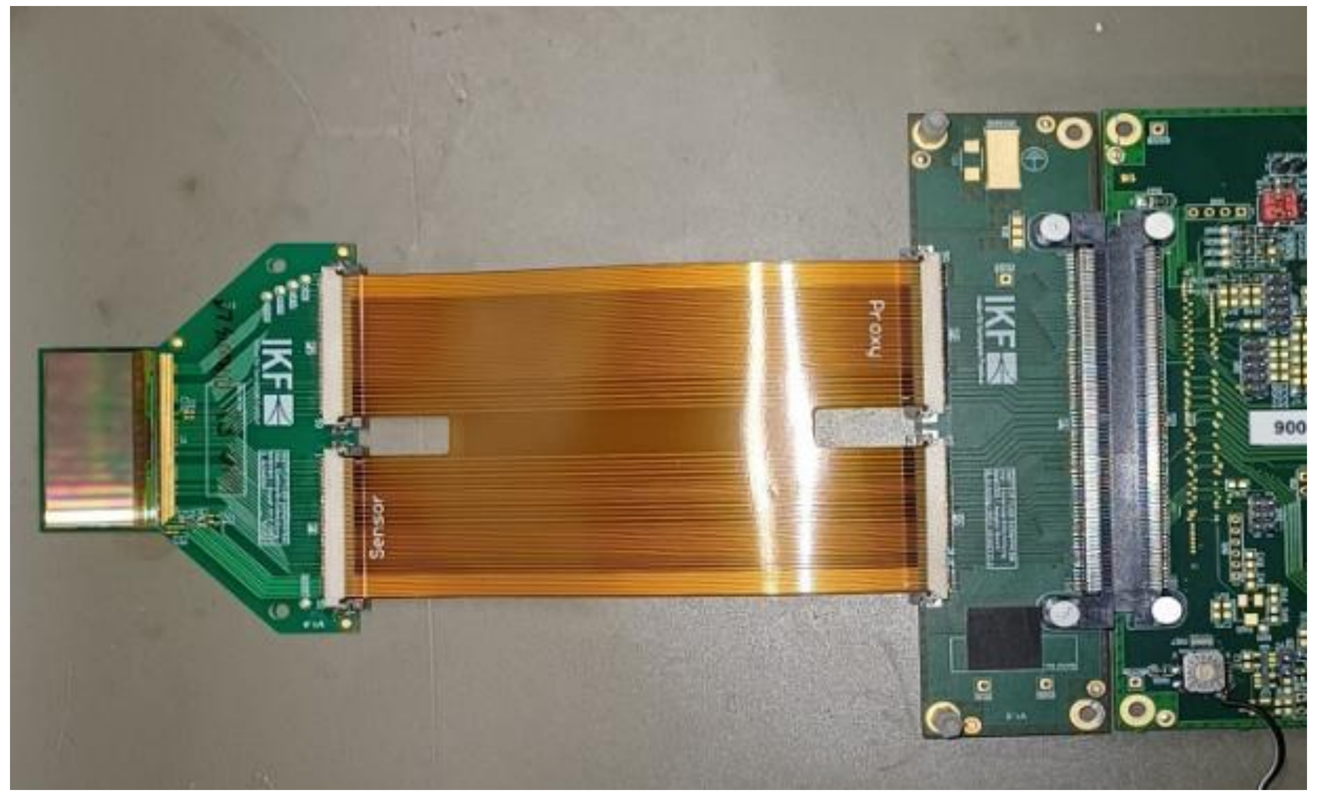


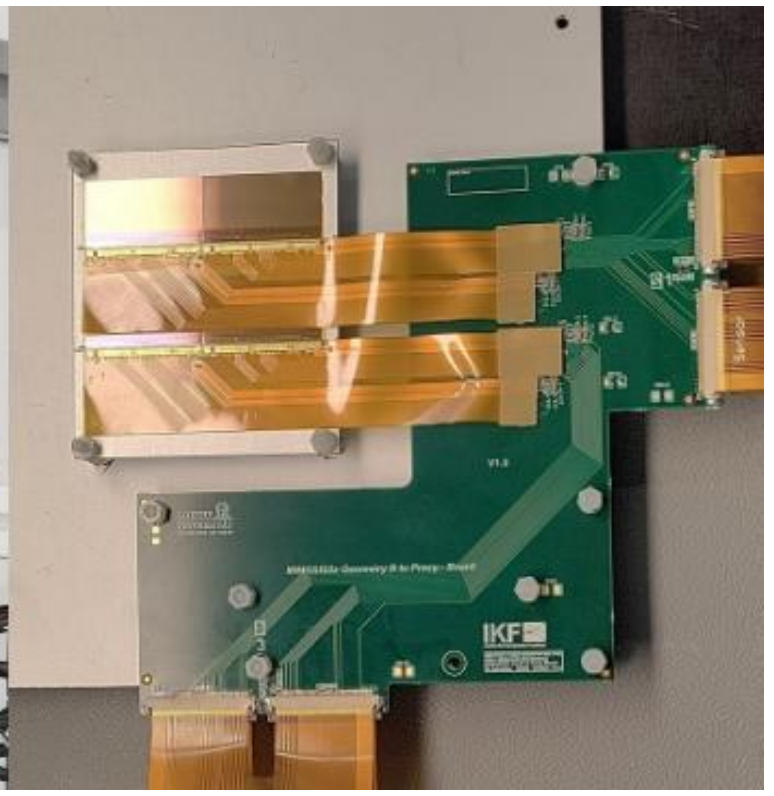
High-speed signals over imperfect transmission path
→ 320 Mb/s SLVS, up to 90 cm FPCs + PCBs
→ Three connectors (discontinuities) in data path
→ Single-layer, unshielded FPCs
→ SLVS CM (200 mV) shifts due to GND shift (40 mV)
→ Dynamic phase shifts due to power fluctuations

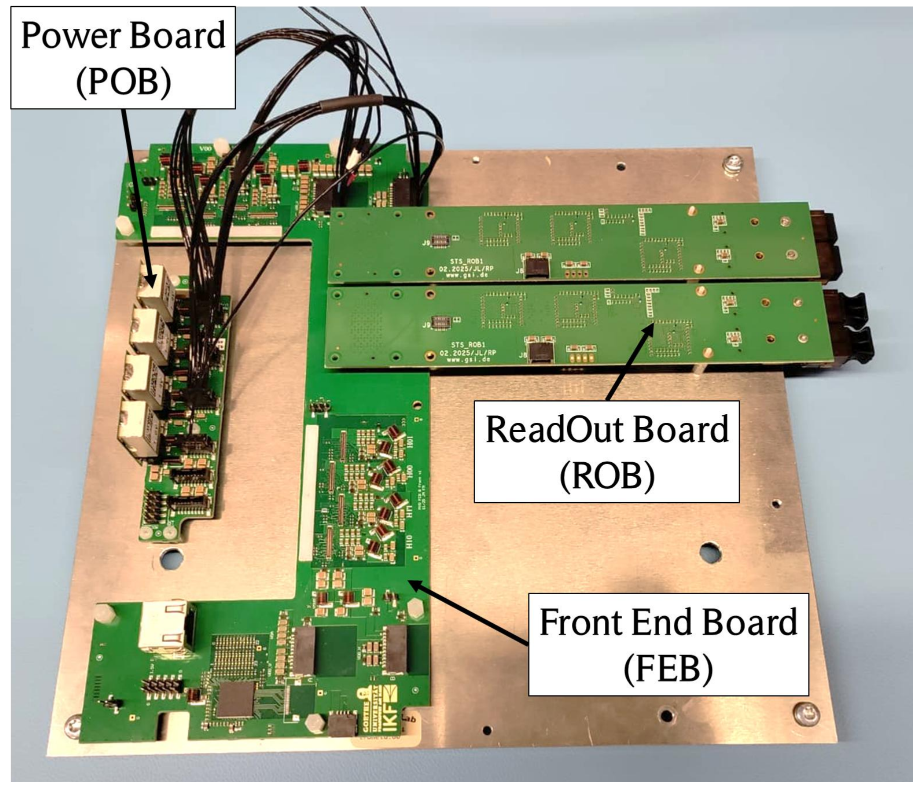
Various aspects validated, full system test in preparation

Ideal operating conditions → MVD operating conditions









FEE Validation: Next Steps

Control functionality and Data Integrity

→ Sensor FPCs, wire-bonded MIMOSIS 2.1

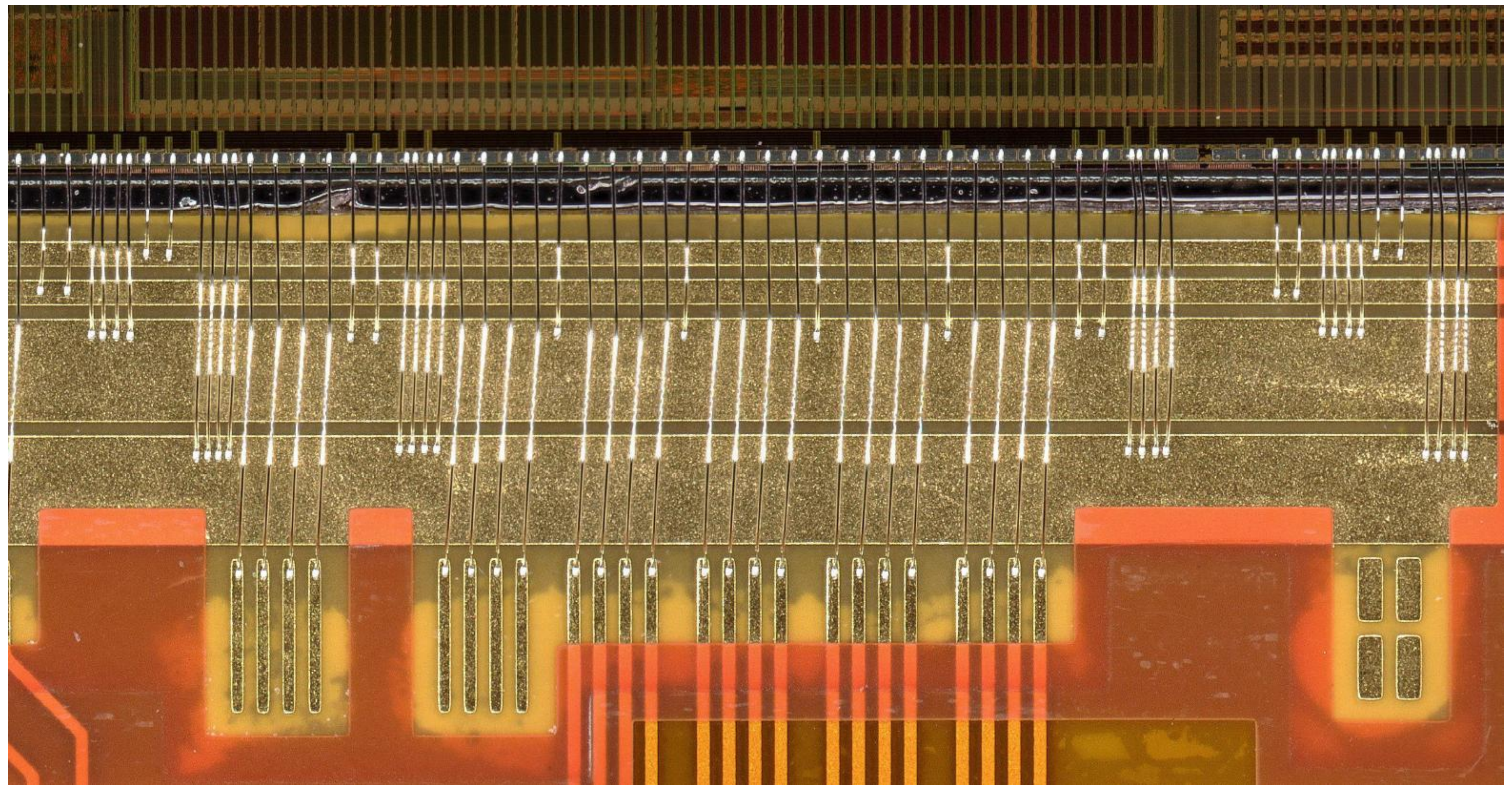
→ Full-system tests w/ final powering, cable lengths, …

Sensor FPC

→ Not final ultra-thin design

→ Now 18 µm, later 12 µm copper

→ Validate FEB, next iteration



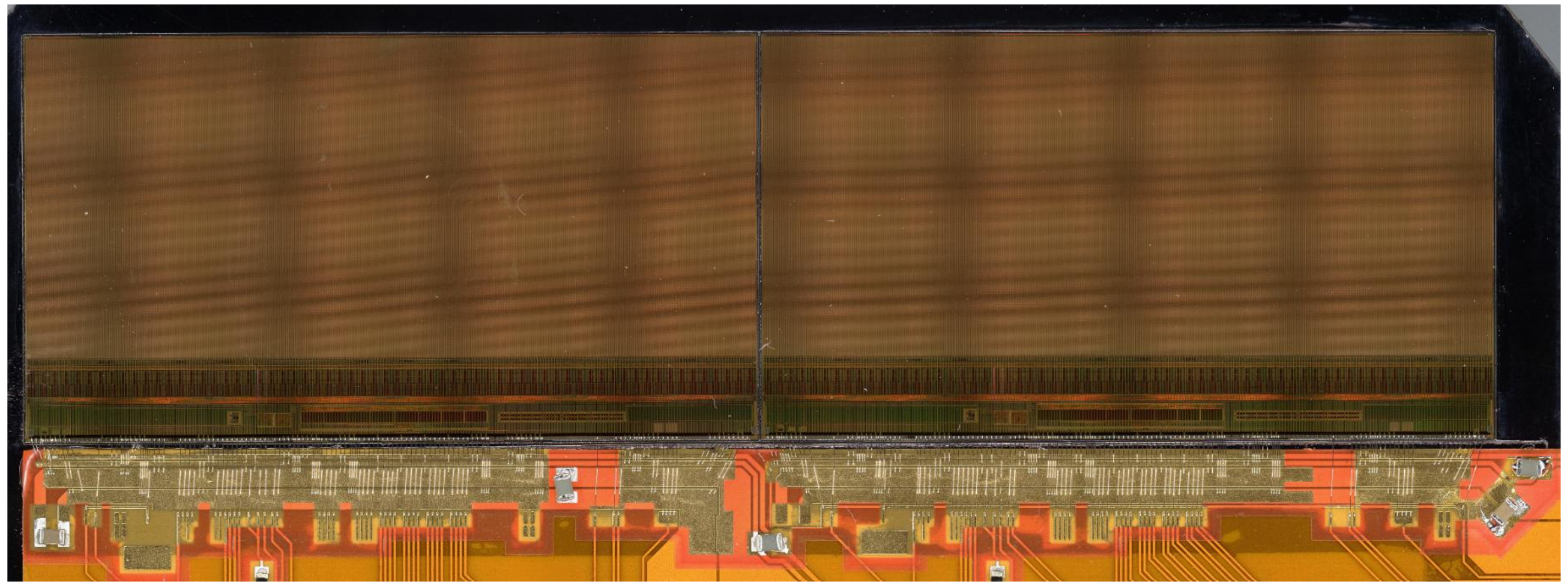
Wire Bonding

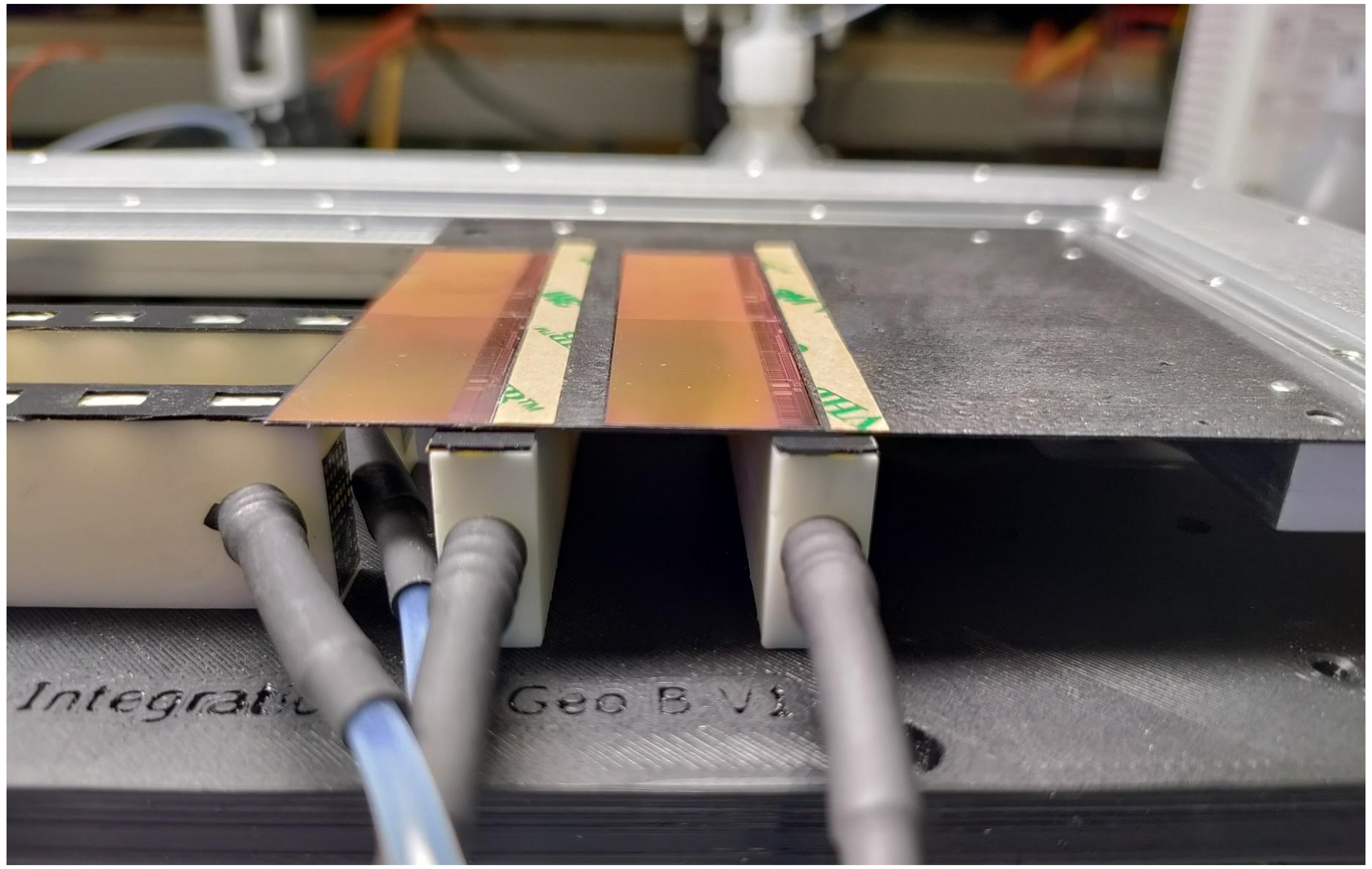
Double-sided integration

→ Wire-bonding: Challenging integration step

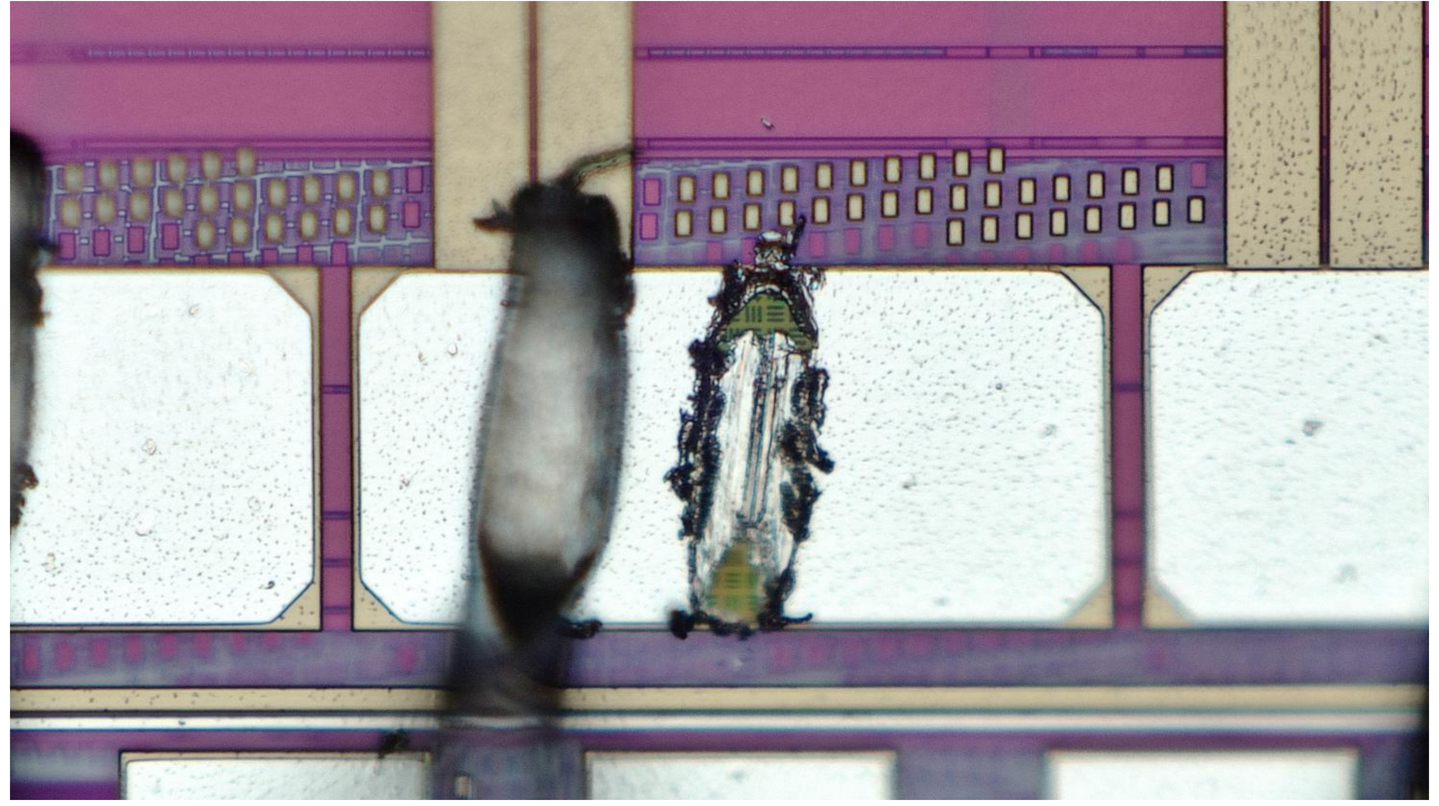
→ Dedicated vacuum jig (Under validation)

Full-automatic bonding @GSI Detector lab





Pad rupture after bonding



Chapter 3

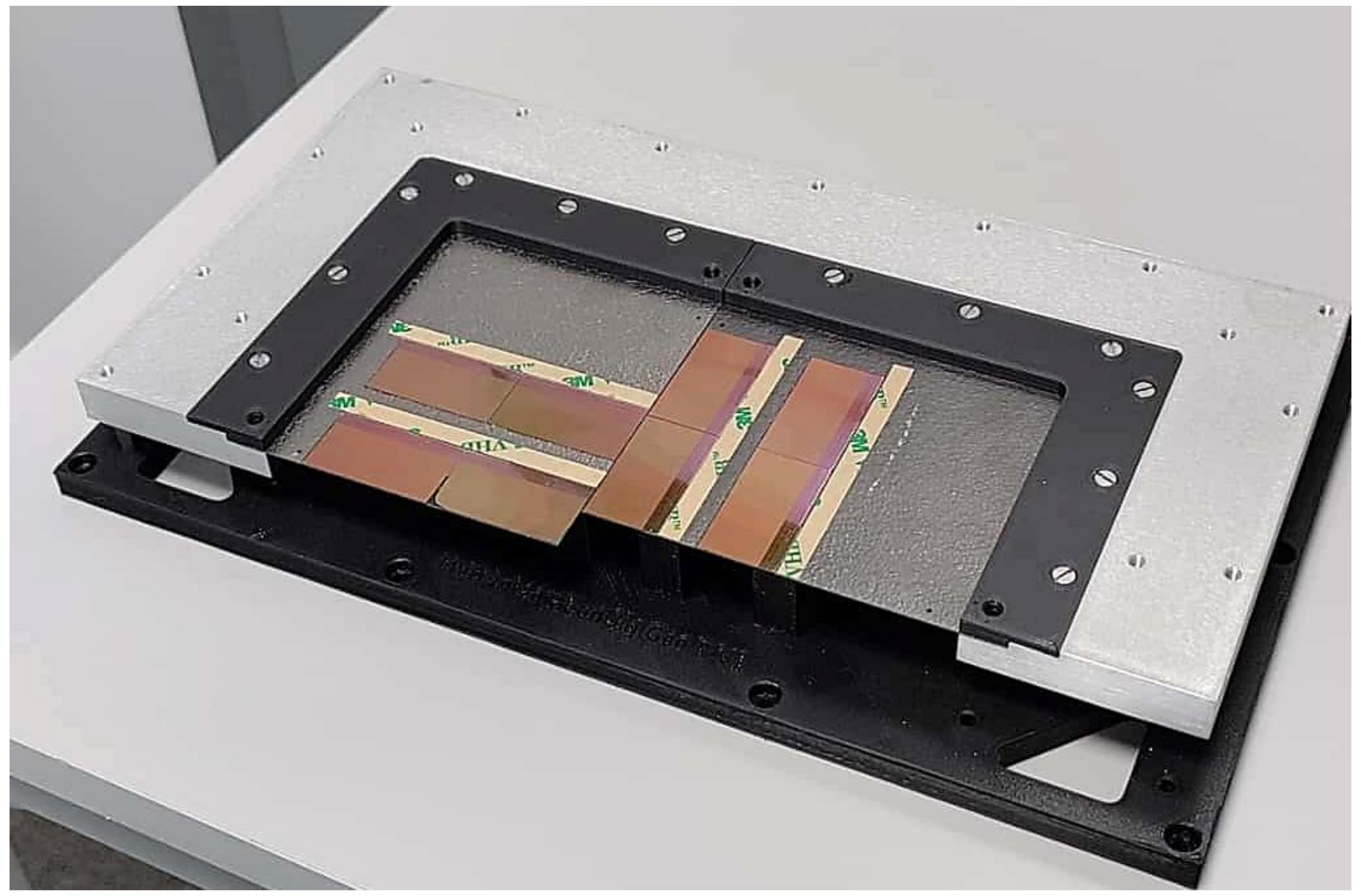
Upgrades

Pixel Upgrade

MVD is CBM rate bottleneck

→ 0.1 MHz Au+Au w/ MVD, up to 10 MHz w/o

→ Annual exchange of MVD planned



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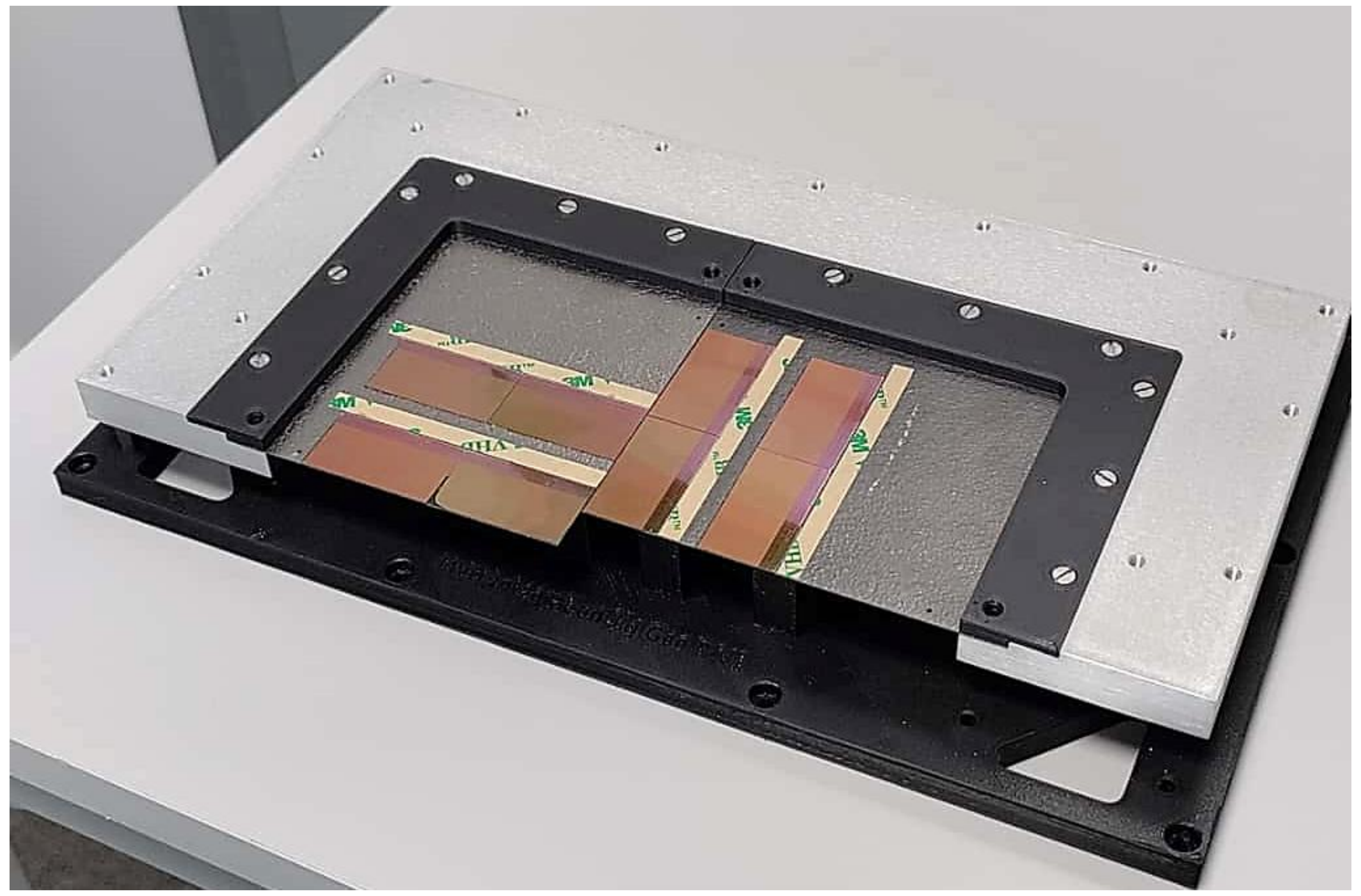

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Material budget improvement
→ MVD concept with early MAPS: limited by cooling
→ Now: Limited by mechanics

Rate improvement
→ 1 MHz Au+Au w/ next-gen MAPS

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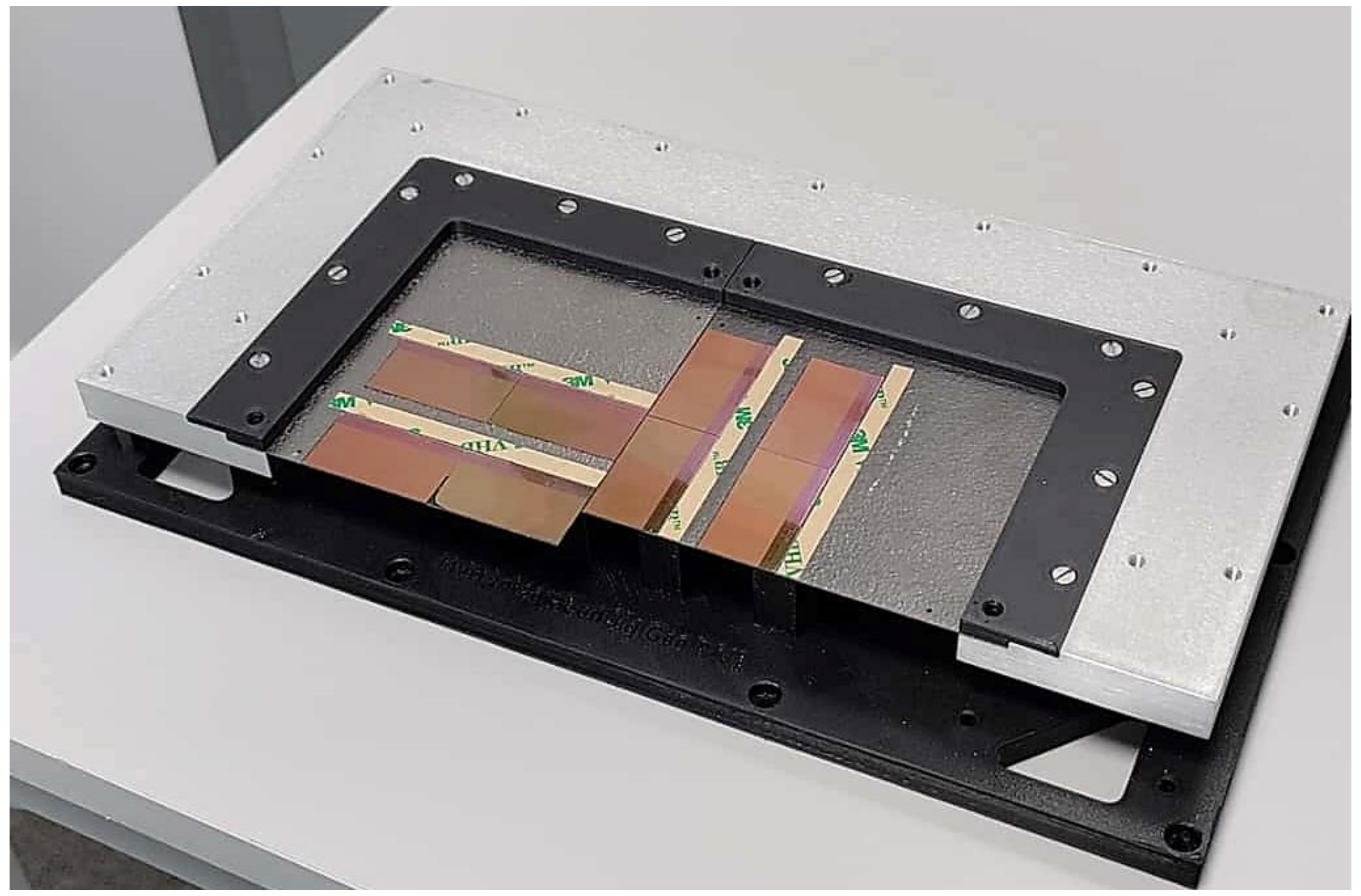

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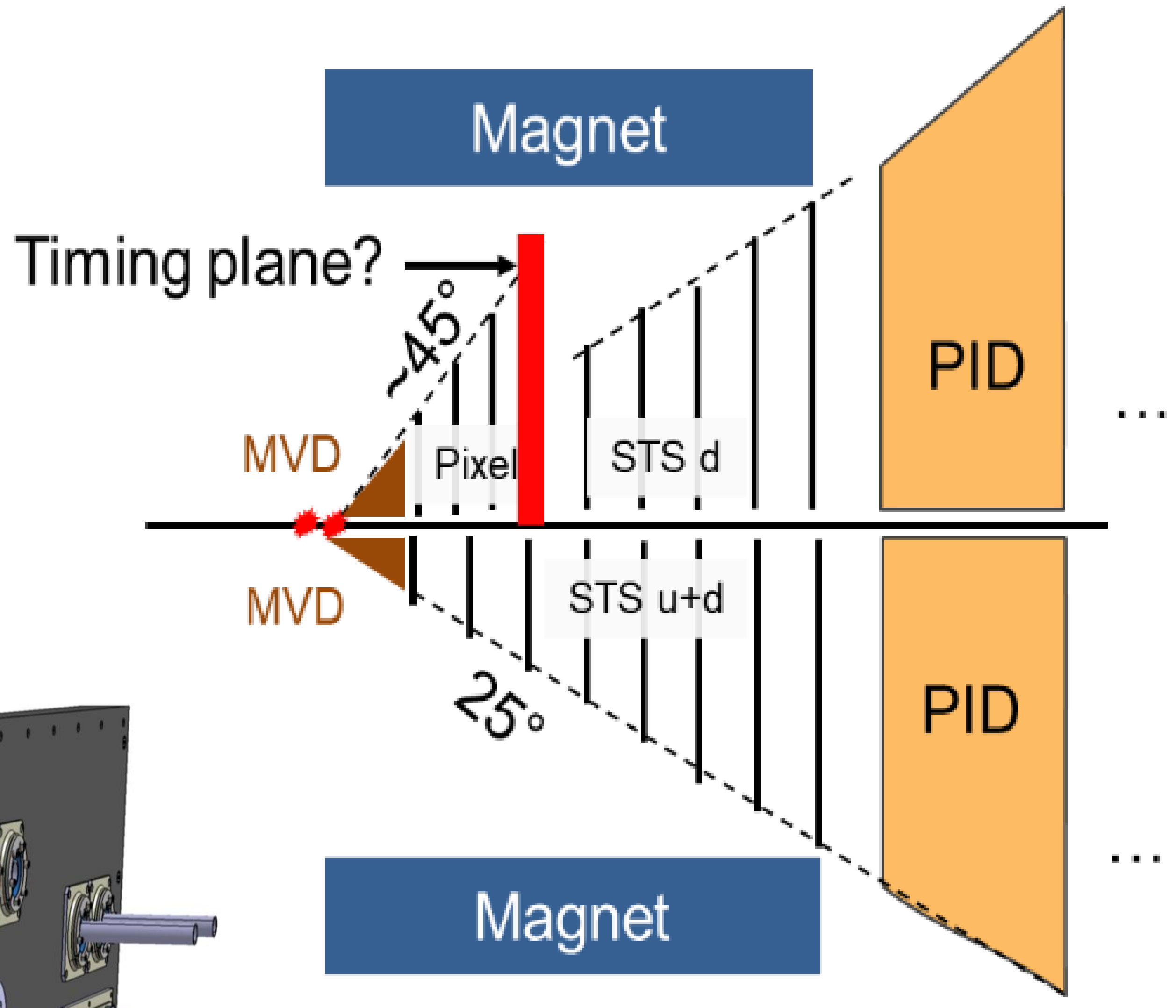

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Full Inner Tracker Upgrade

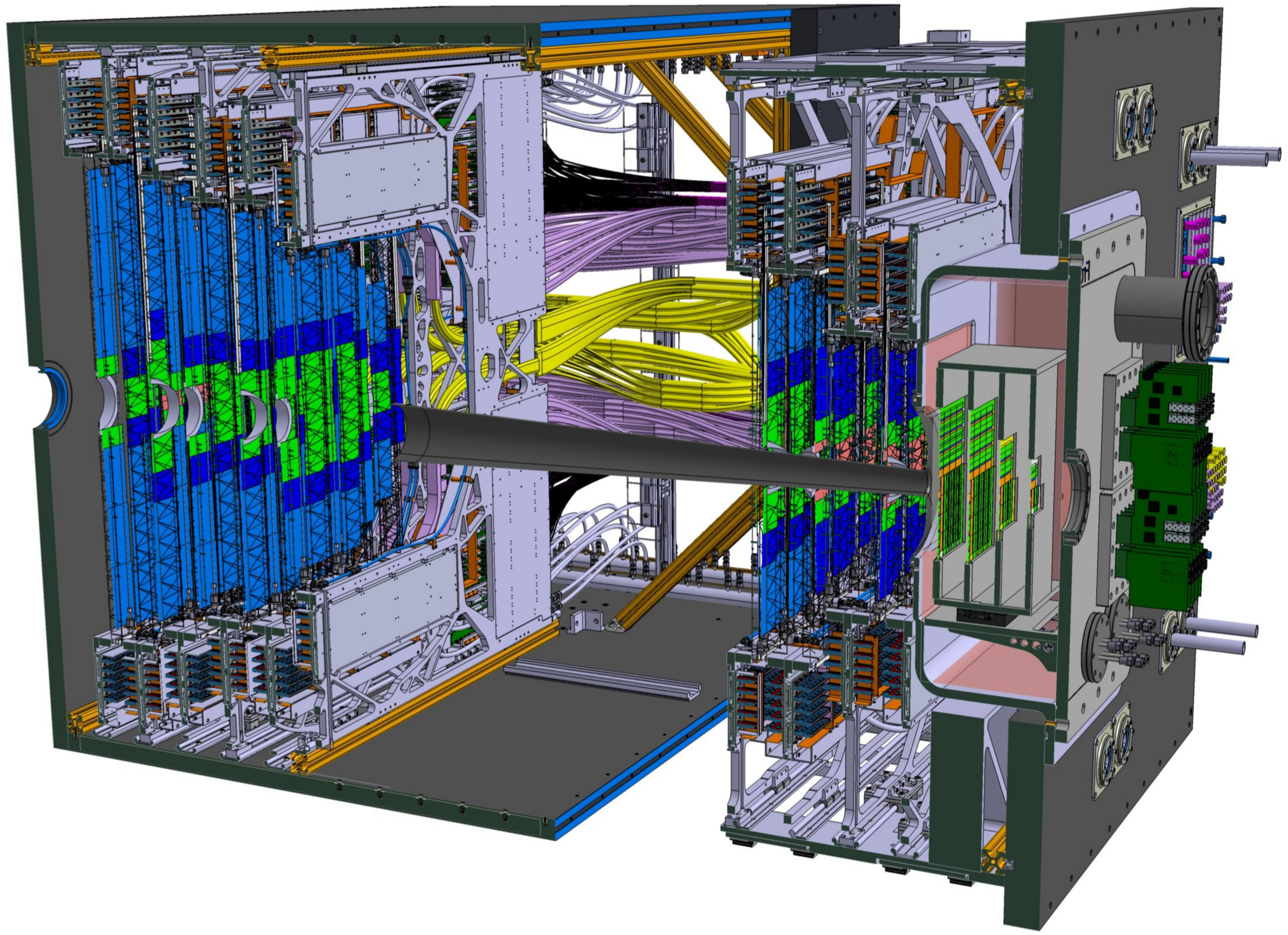
→ Next-gen MAPS MVD, Pixelized STS-U

→ Extend acceptance from 25° to 45°?

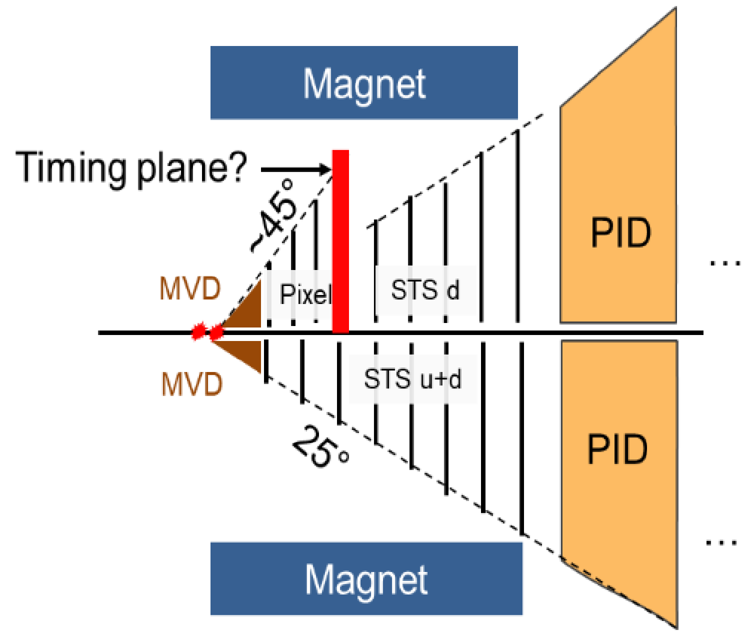
→ Material budget reduction?

→ Added timing plane?

In-beam T0 limited to 0.1 MHz Au+Au



Requirements Next-Gen MAPS



Back-of-the-envelope, to be scrutinized

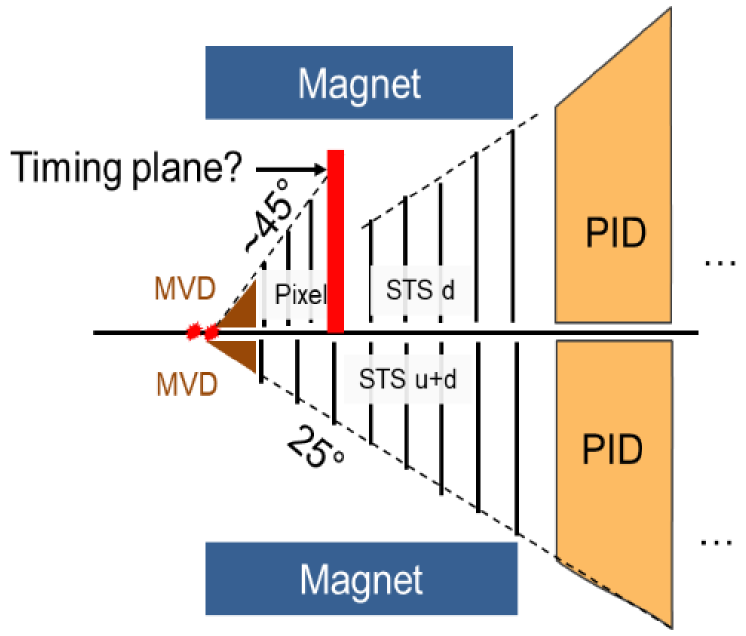
Requirement	MIMOSIS	CBM STS Upgrade	CBM MVD Upgrade
Spatial precision (µm)	~5	~10	~5
Time binning (ns)	5000 →	~10	~ 10
Power dissipation (mW/cm^2)	~70	~ 50	~100
Annual NIEL dose (n_{eq}/cm^2)	~ 3x10^{14} →	~ 2x10^{14}	~ 10^{15}
Annual TID (Mrad)	~ 5	~ 17	~ 50
Rate capability (MHz/cm^2)	20 (80) mean (peak) →	~10 + margin	~ 90 + margin

Requirements Next-Gen MAPS

Move from TJ180 nm to TPSCo 65 nm

New readout philosophy
→ Abandon frame-based readout
→ Time walk correction mandatory for timing

Serial powering



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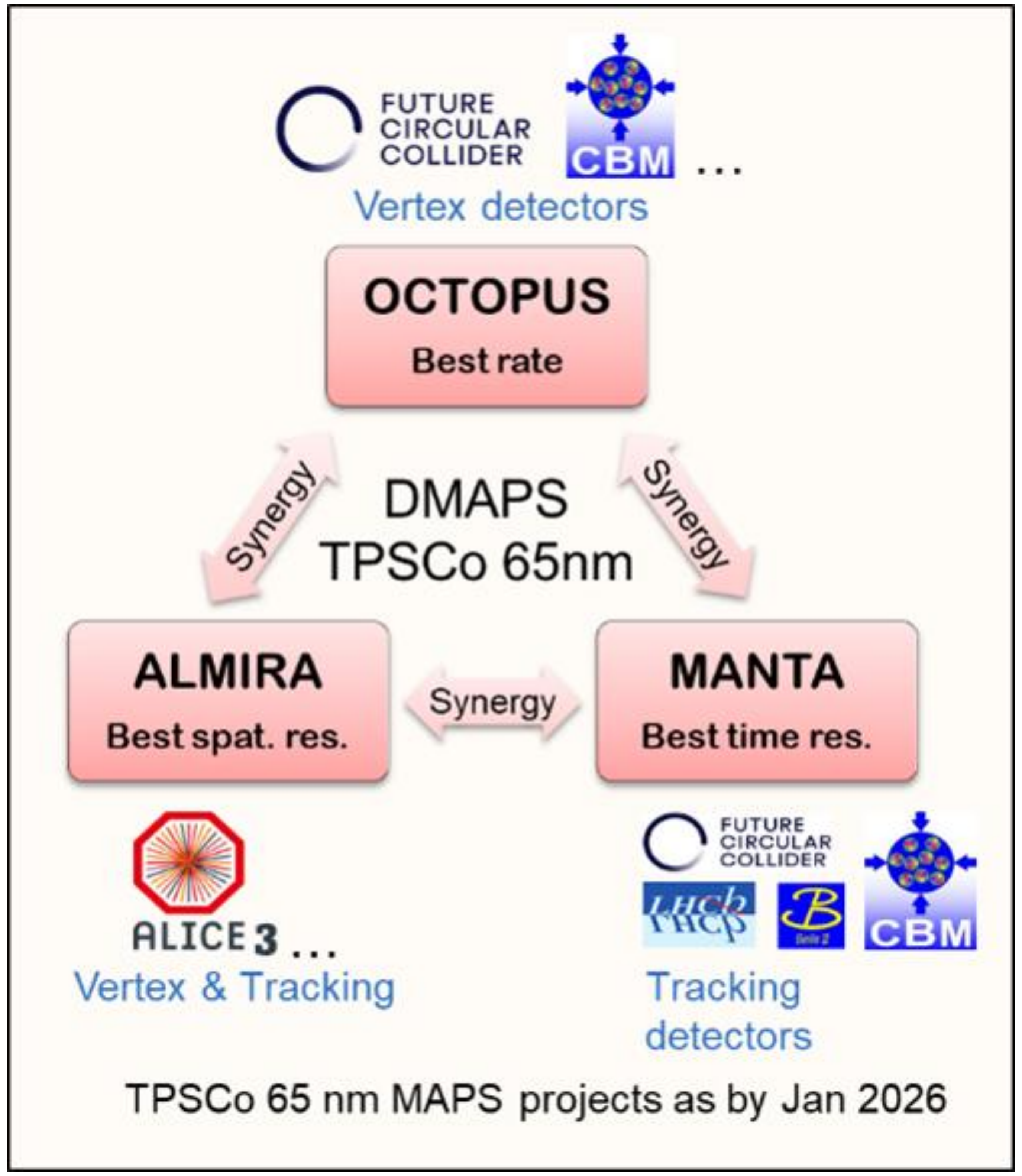

Vertex detectors

OCTOPUS
Best rate

Synergy

DMAPS
TPSCo 65nm

Synergy

ALMIRA
Best spat. res.

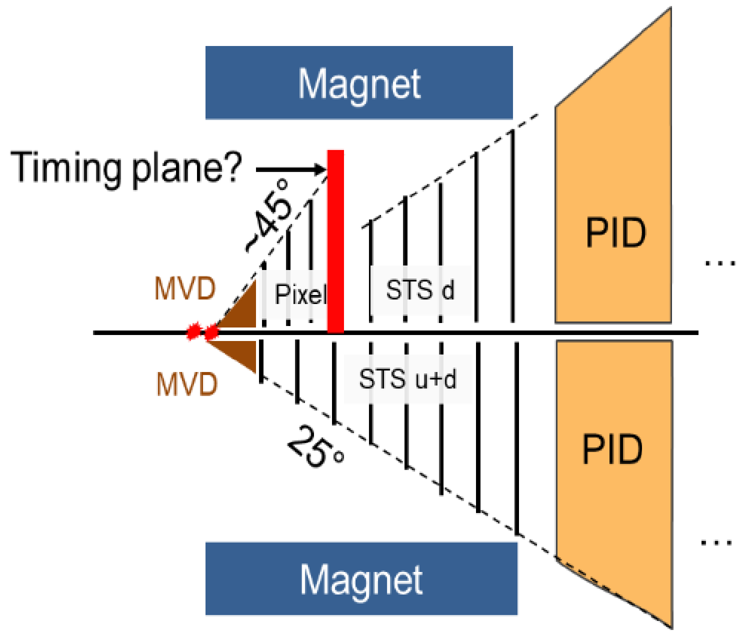
Synergy

MANTA
Best time res.

ALICE 3 …
Vertex & Tracking

Tracking detectors

TPSCo 65 nm MAPS projects as by Jan 2026



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OCTOPUS and MANTA

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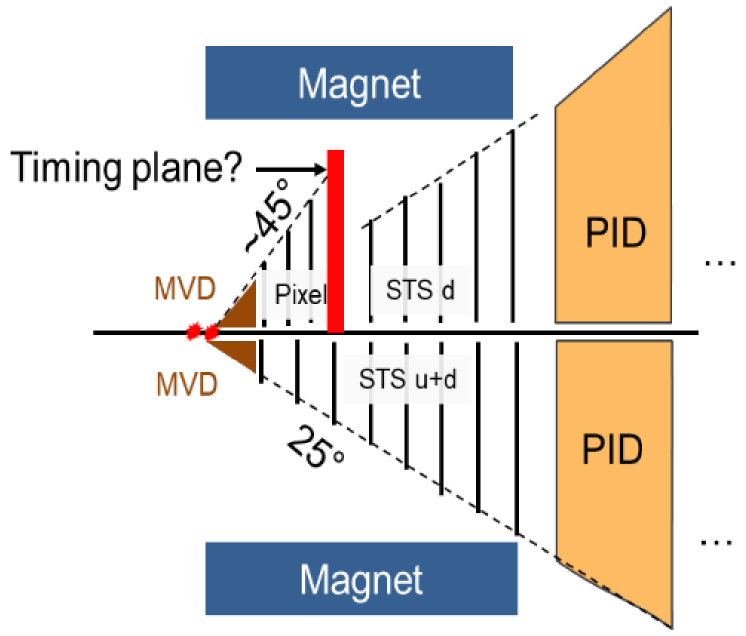
→ DRD3 recognized functional collaboration
→ Sensor R&D ongoing

MANTA

→ Collaboration under preparation
→ Sensor R&D started, regular design meetings



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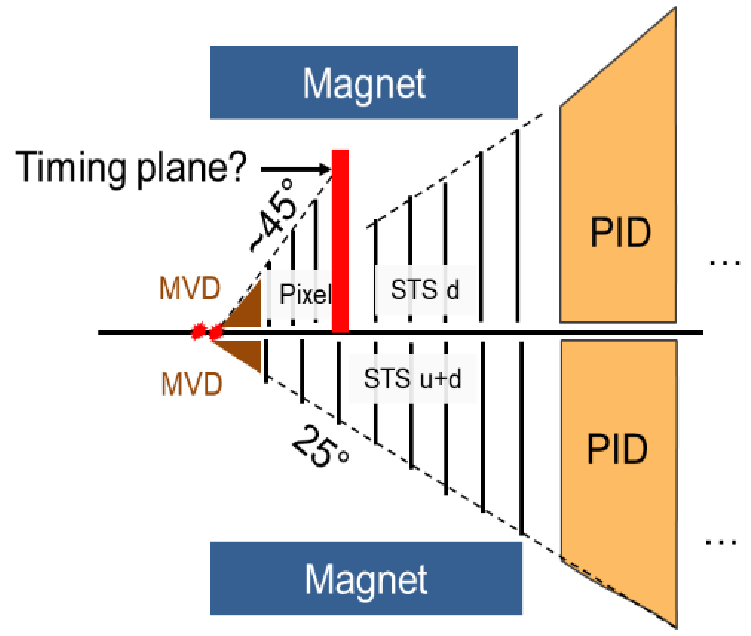
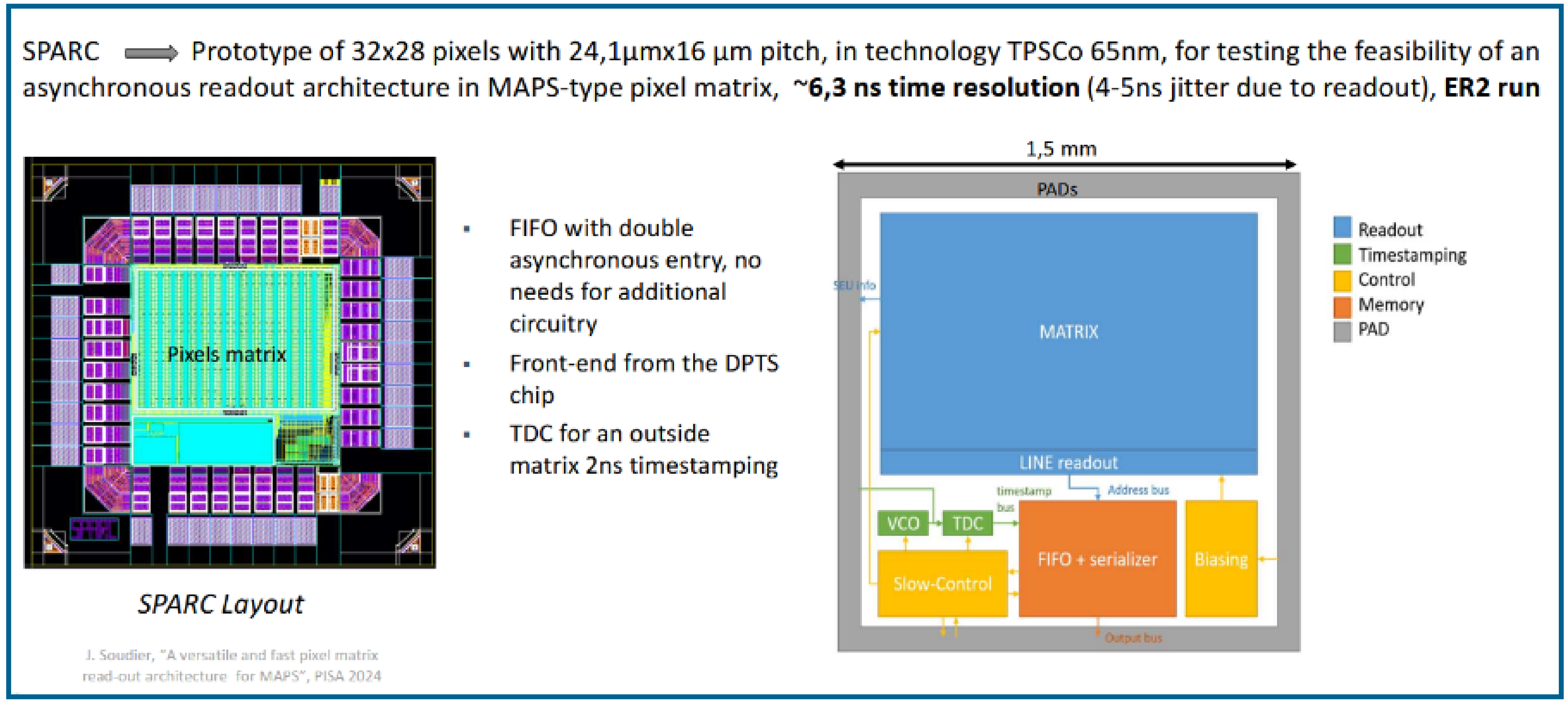


SPARC (IPHC) prototype on ALICE/ER2

→ 1.5x1.5mm², novel readout, ~6ns time precision expected
→ Beam test planned (DESY, 22. May – 05. June)
→ Joint OCTOPUS/MANTA team
→ Mini-structure on ALICE/ER3 planned



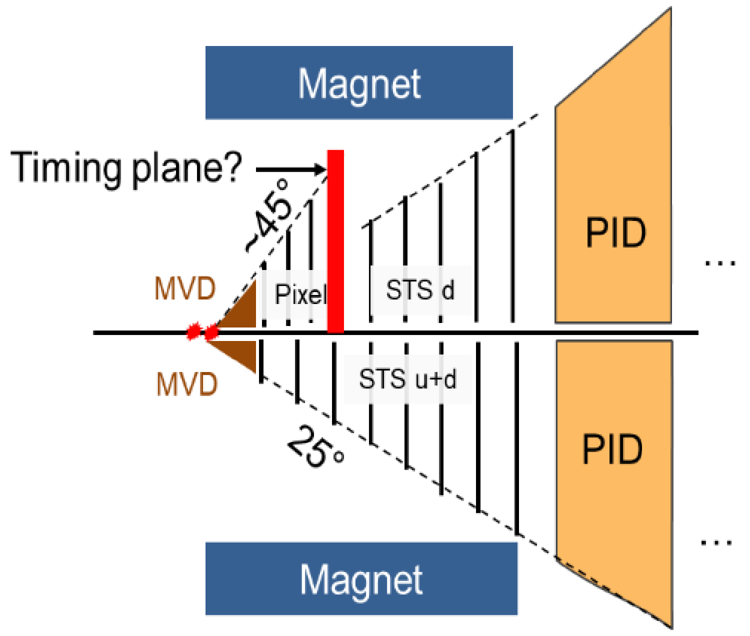
SPARC ⟹ Prototype of 32x28 pixels with 24,1µmx16 µm pitch, in technology TPSCo 65nm, for testing the feasibility of an asynchronous readout architecture in MAPS-type pixel matrix, **~6,3 ns time resolution** (4-5ns jitter due to readout), **ER2 run**

SPARC Layout

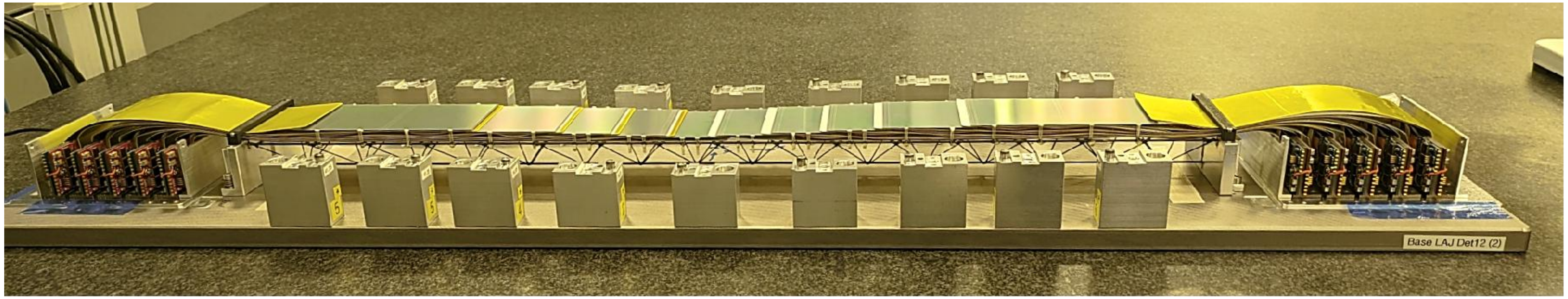
J. Soudier, "A versatile and fast pixel matrix read-out architecture for MAPS", PISA 2024

- FIFO with double asynchronous entry, no needs for additional circuitry
- Front-end from the DPTS chip
- TDC for an outside matrix 2ns timestamping

First Draft of STS Upgrade Ladder



CBM-STS Ladder
→ Silicon Strips



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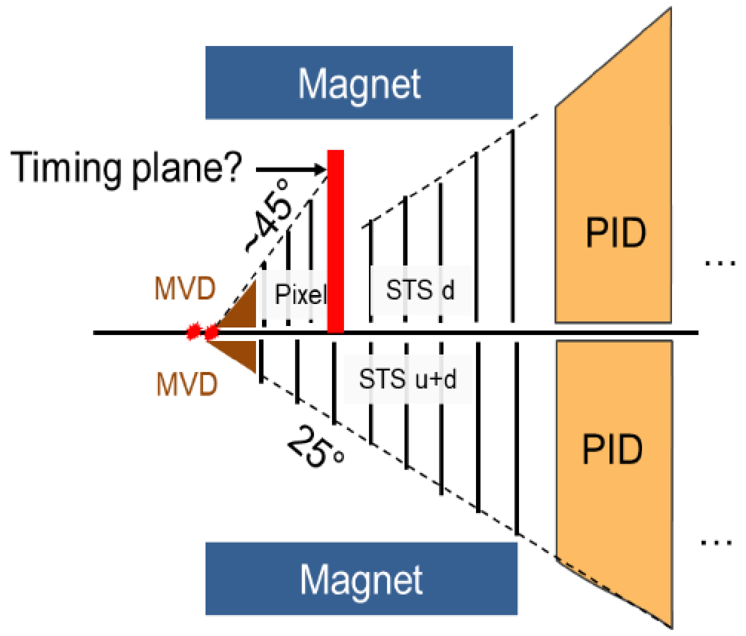
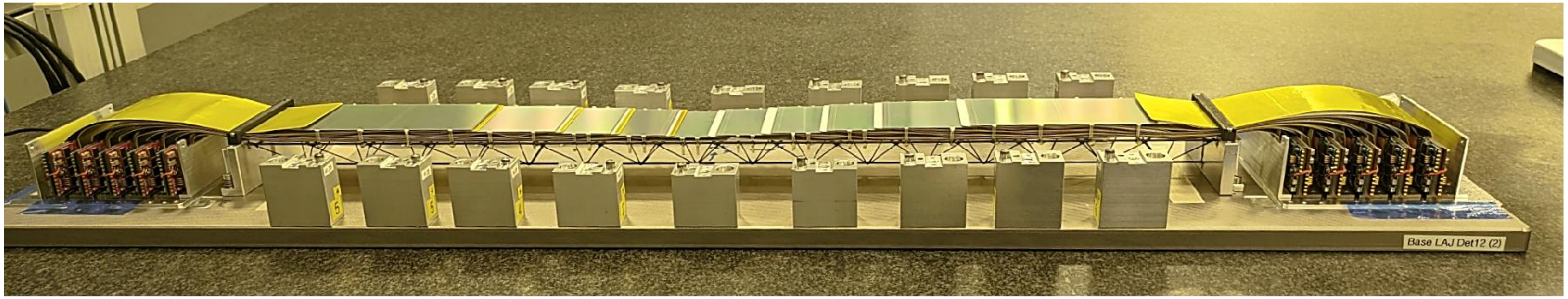


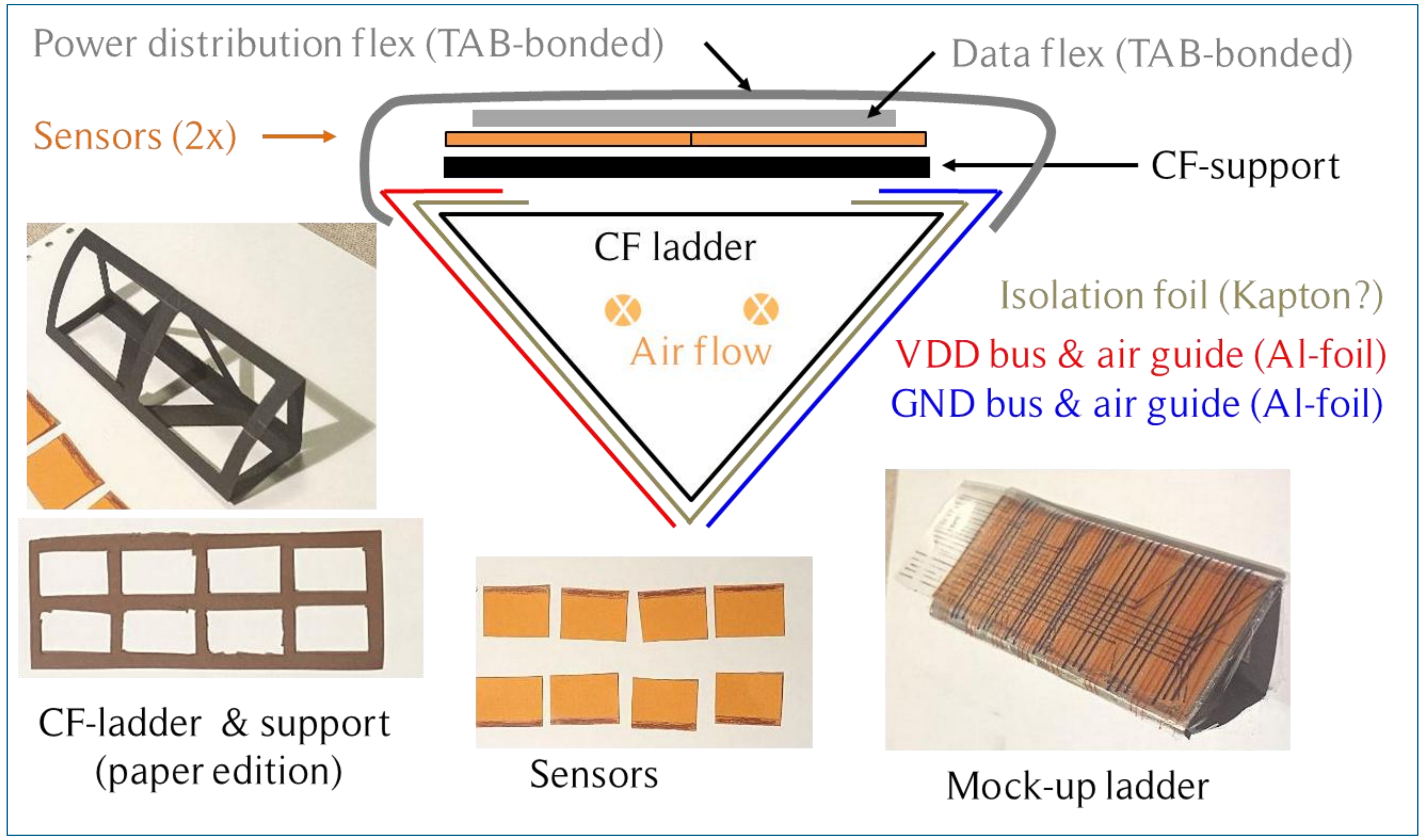
STAR-HFT
→ ~150mW/cm²
→ Air-guide

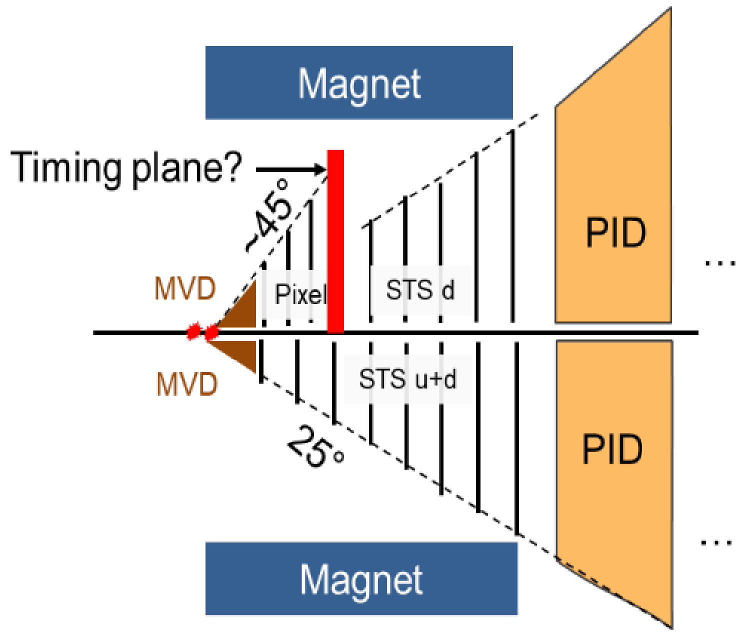
CBM-STS Ladder
→ Silicon Strips



First Draft of STS Upgrade Ladder

Air cooling concept similar to STAR-HFT
→ Power distribution flex as part of air guide
→ CF modules + PGS, assembled on STS ladder





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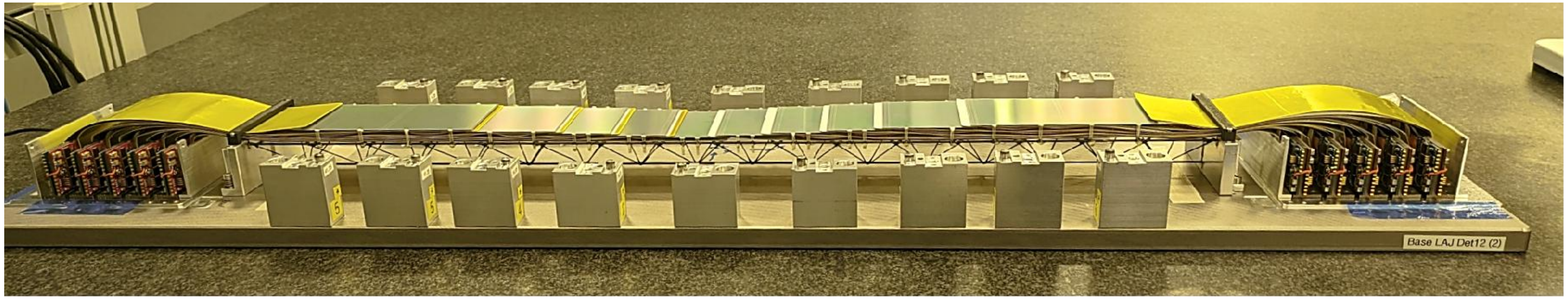

Summary

MIMOSIS CMOS MAPS R&D concluded

→ Performance validated

→ M3 submission now, FOS Q4/26

MVD full-system tests in preparation

→ Pre-requisites done

→ Pre-production module(s) Q2/26

Upgrade project started

→ Common resources, ideas, …

→ GSI pixel platform

Silicon@GSI: Kick-off event 31 January 2025

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… exciting times for CBM, GSI, and the MAPS community!