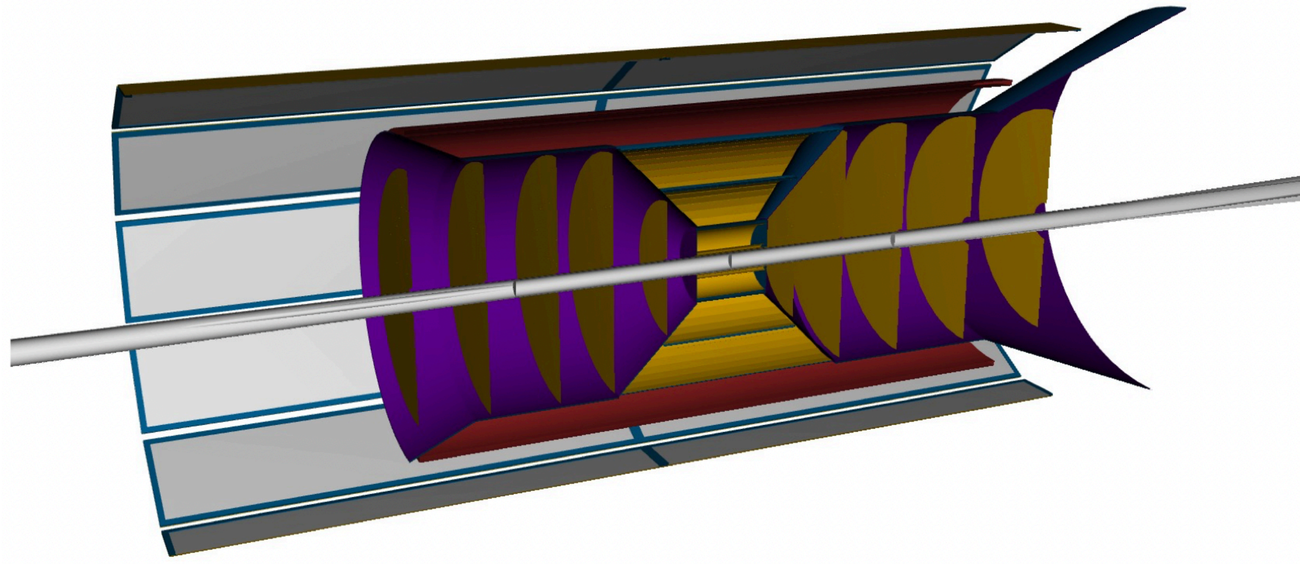


Characterization of the SVT sensors and ancillary IC

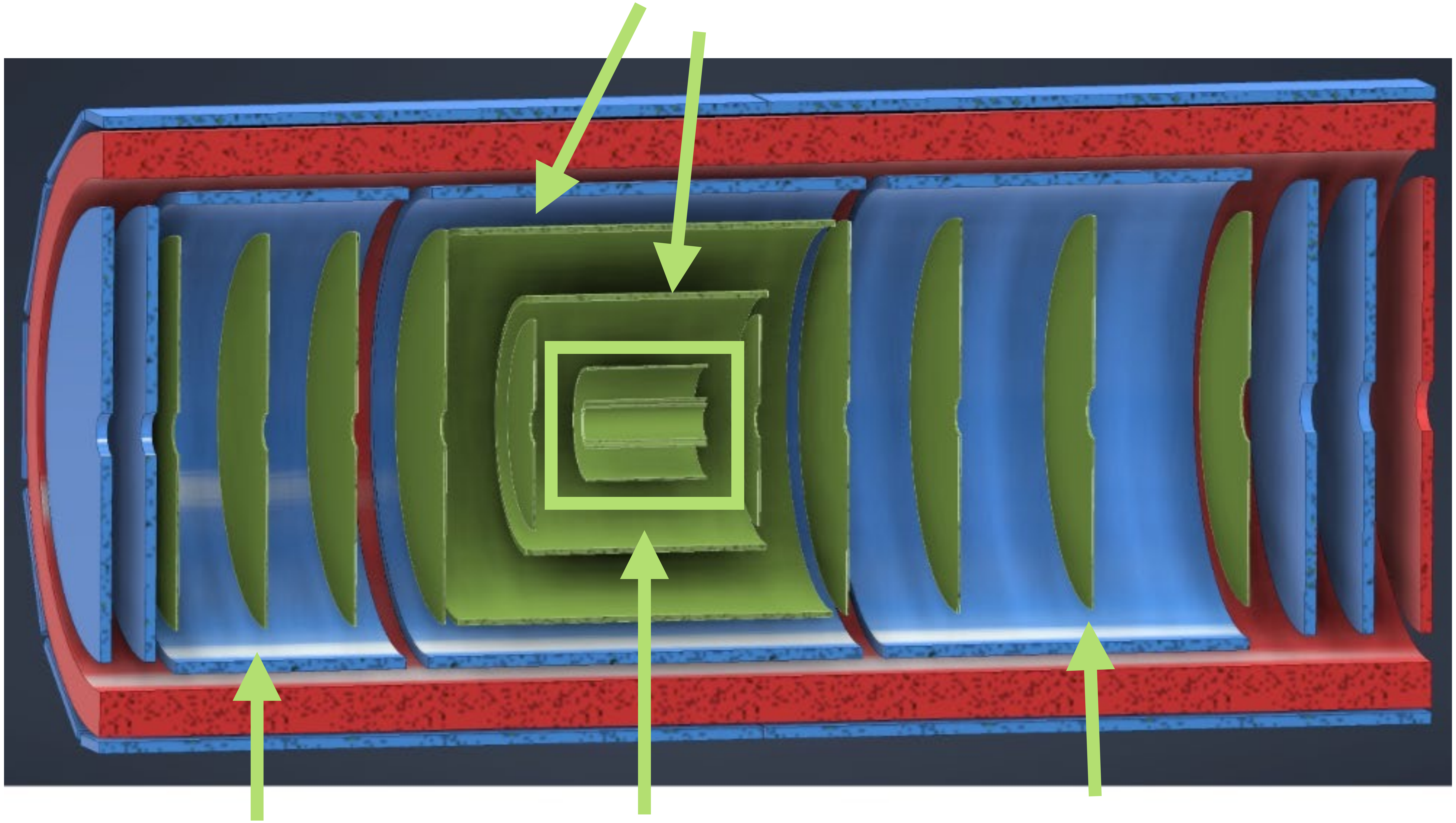
EPIC COLLABORATION MEETING

Argonne National Laboratory (9-13 January 2023)

Lukas Tomasek (CTU, Prague)
Gian Michele Innocenti (MIT, Boston)

The SVT ePIC detector (in green)

total area of ~8.5 m²



SVT outer layers

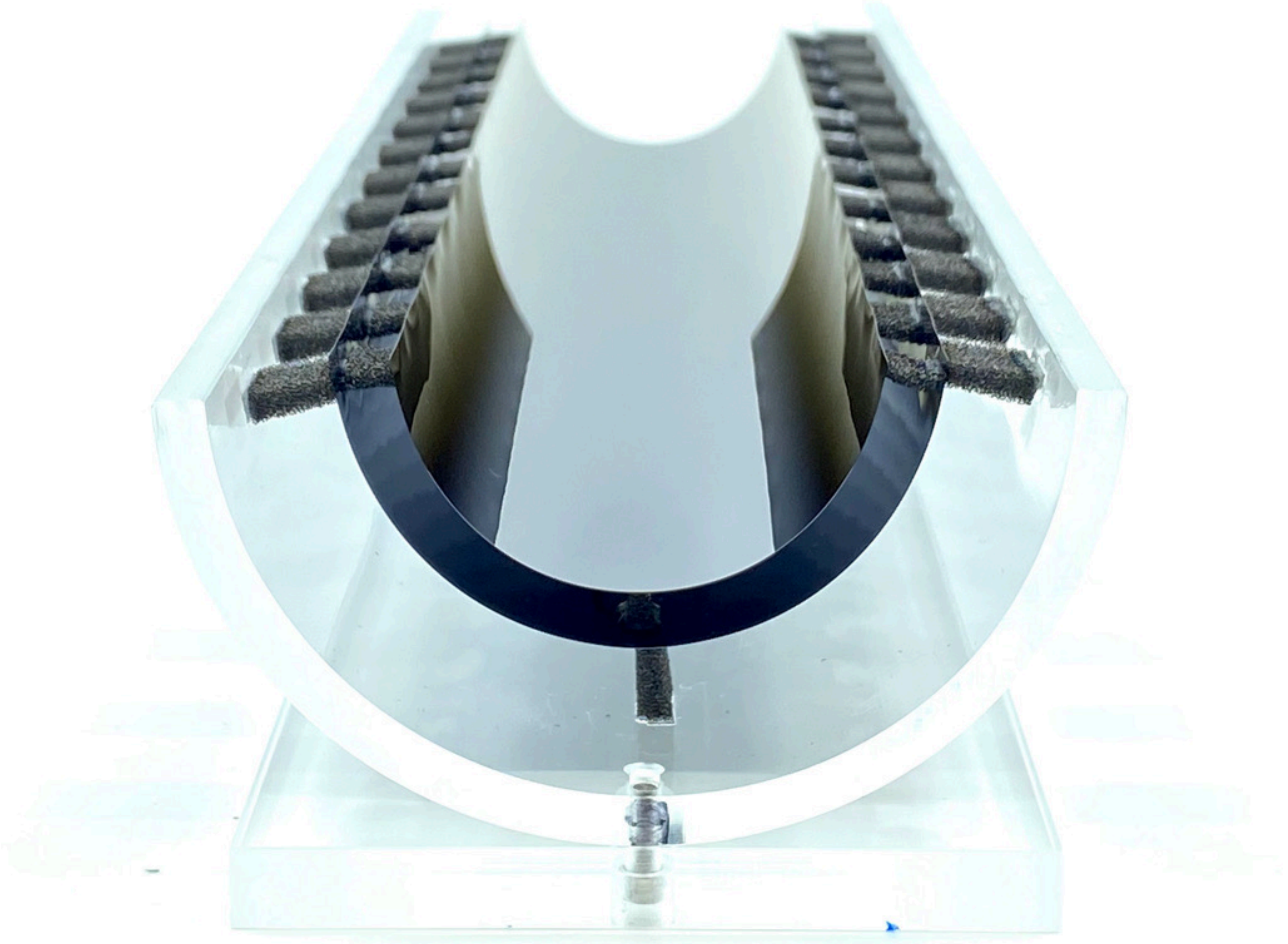
SVT disks

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



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

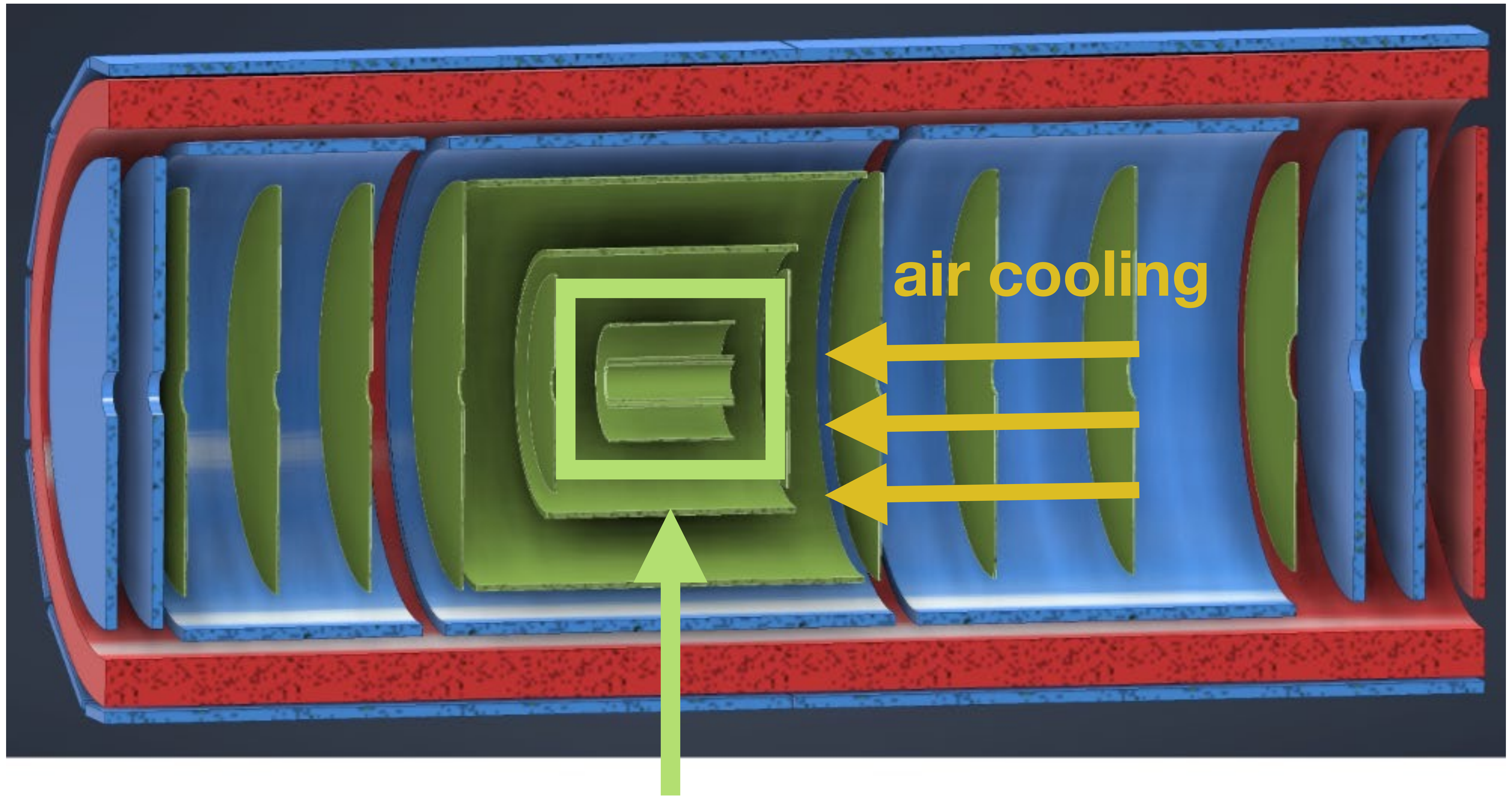
- large sensors **with "stitching" techniques**
- **"bendable" when thinned** below ~20-40 µm

→ 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:** ePIC has stronger requirements in terms of integration time!

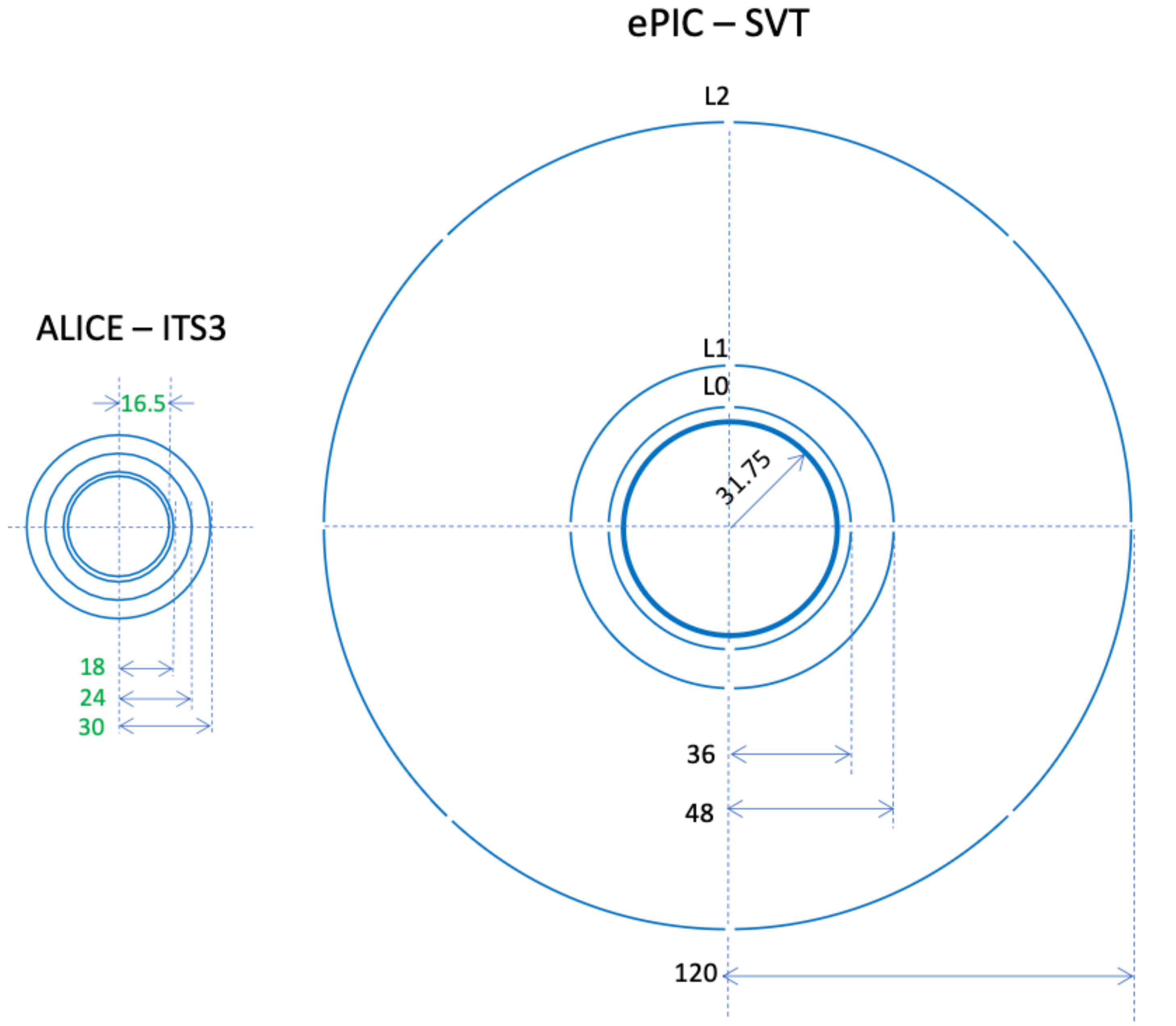
The SVT inner barrel (“bent” layers 0, 1, 2)



SVT inner barrel

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

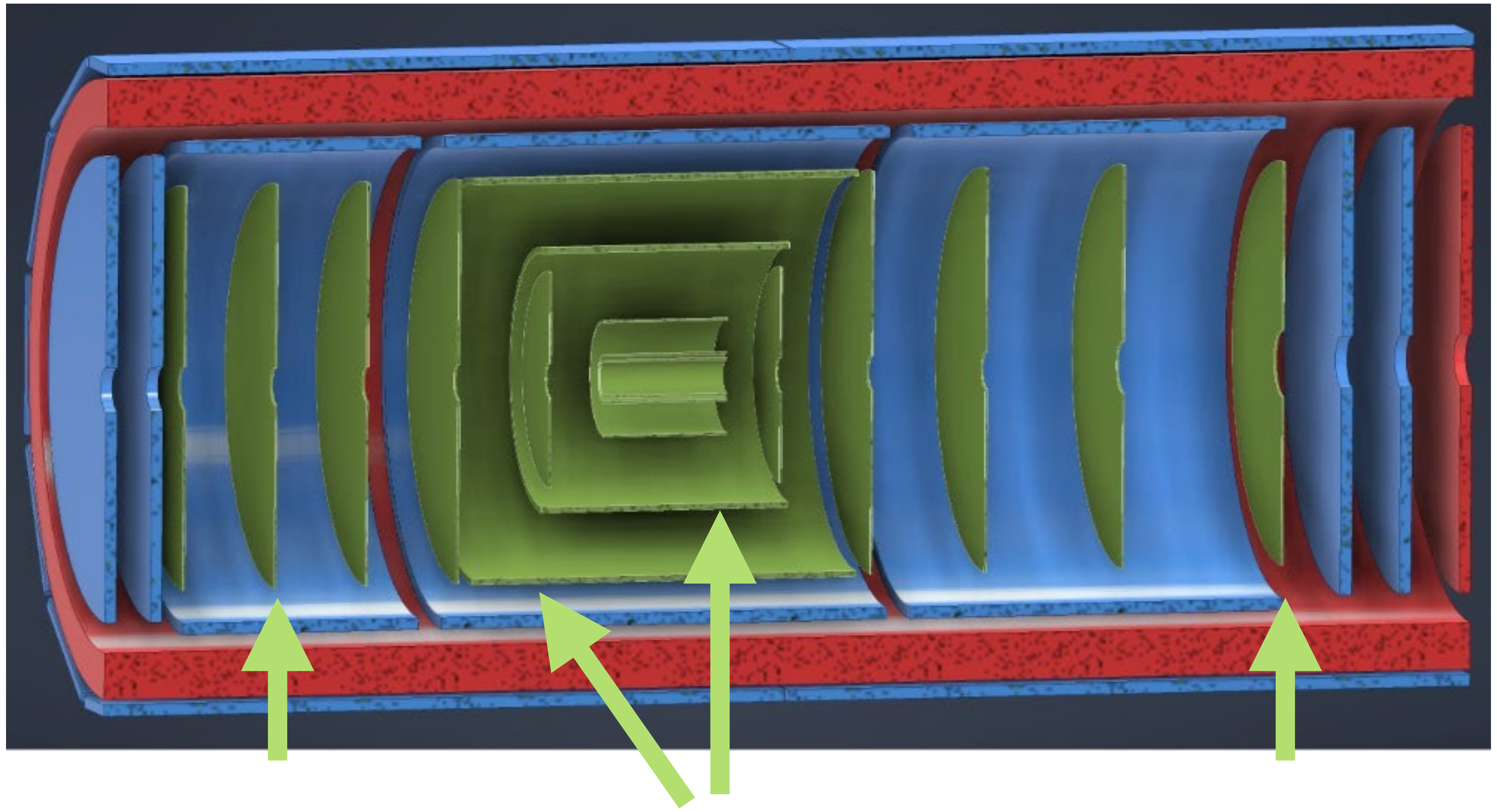
- **Radii = 3.6, 4.8, 12 cm**
- **Lengths = 27 cm**



ePIC specific needs:

- reduce services at forward/backward
- Mechanical stability in the presence of a R=12 cm layer (R^{max}_{ITS3} is < 4 cm!)
- air cooling strategy is more challenging due to the presence of the disks

The SVT outer barrel (layers 3, 4) and 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

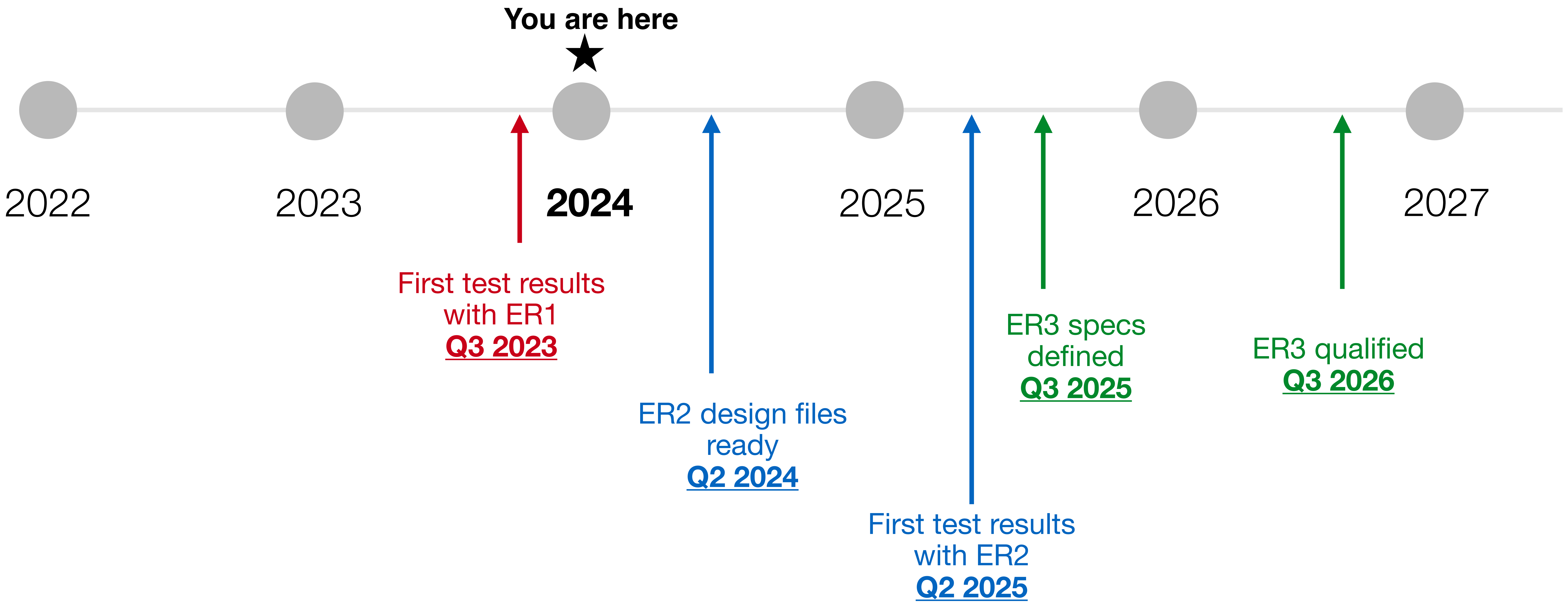
ITS3 sensor: development phases and timeline

MLR1: qualification of CMOS 65nm technology, prototype for circuit blocks

ER1: stitching technology demonstrator (MOSS and MOST sensor), yield studies

ER2: fully functional sensor that satisfy ITS3 requirements

ER3: final production and design (bug fixes from ER2)



You are here ★

2022

2023

2024

2025

2026

2027

First test results with ER1
Q3 2023

ER2 design files ready
Q2 2024

First test results with ER2
Q2 2025

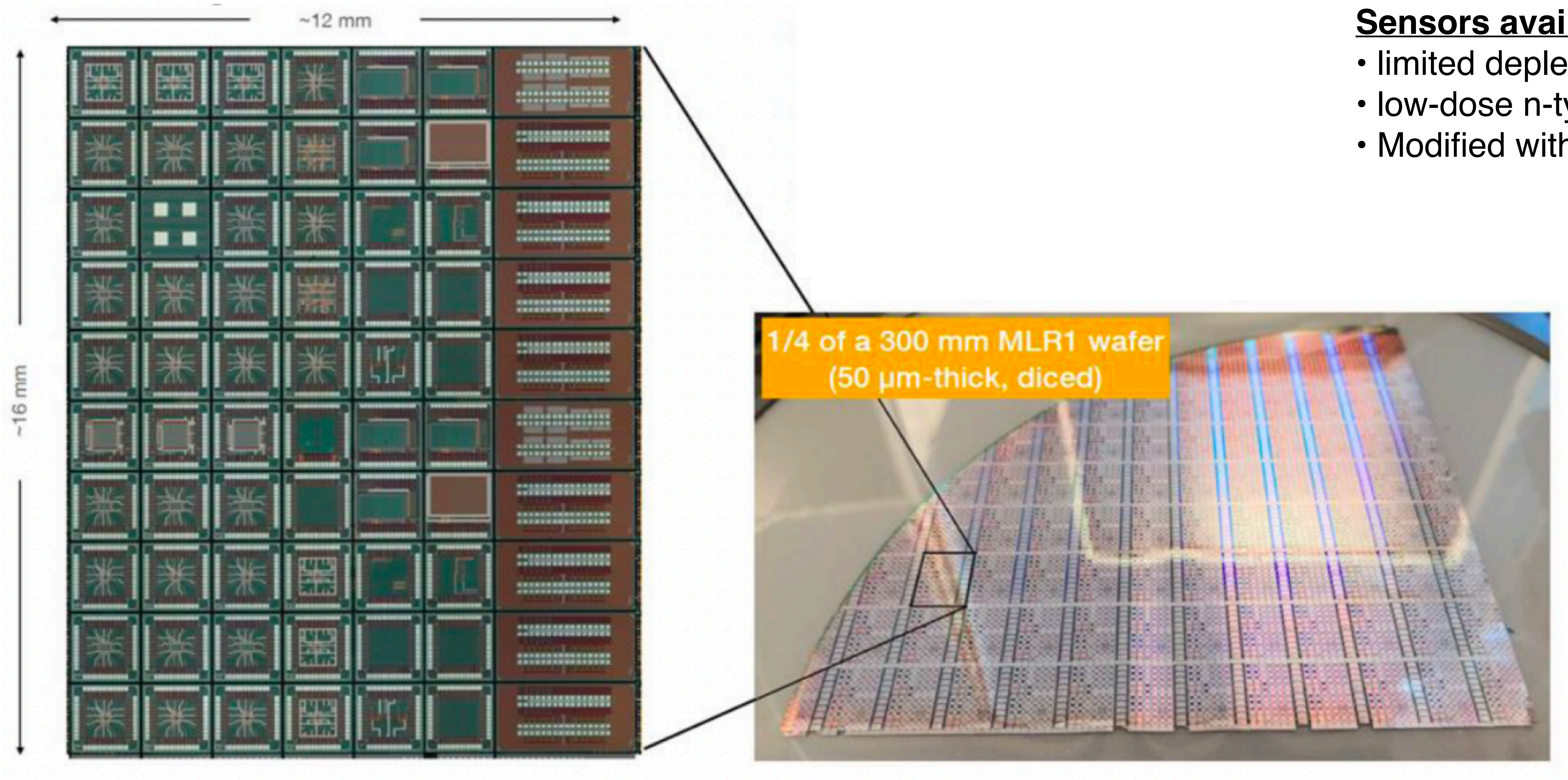
ER3 specs defined
Q3 2025

ER3 qualified
Q3 2026

SVT past/current contributions to the ITS3 project

MLR1 sensors: designs and goals

MLR1 reticule prototype to “validate” the 65 nm CMOS imaging sensor technology
→ different implant geometries, pitches, depletion regions



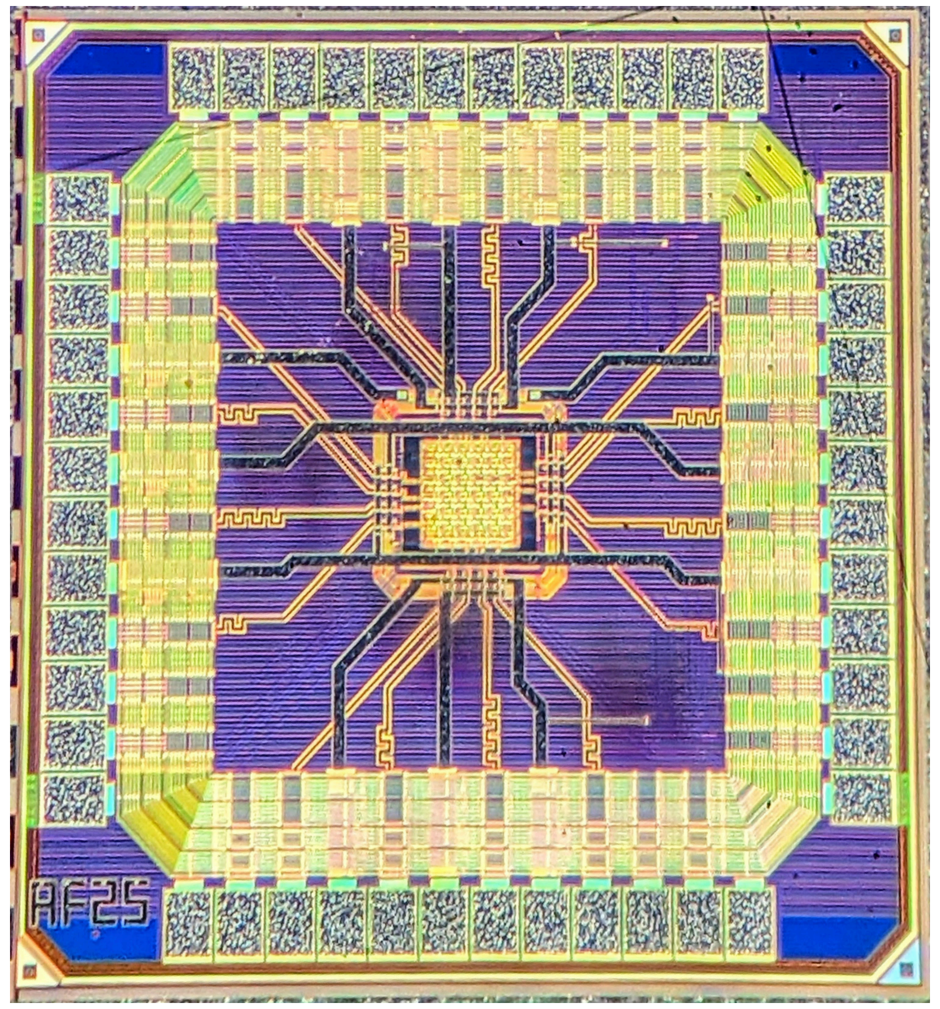
1/4 of a 300 mm MLR1 wafer (50 μm-thick, diced)

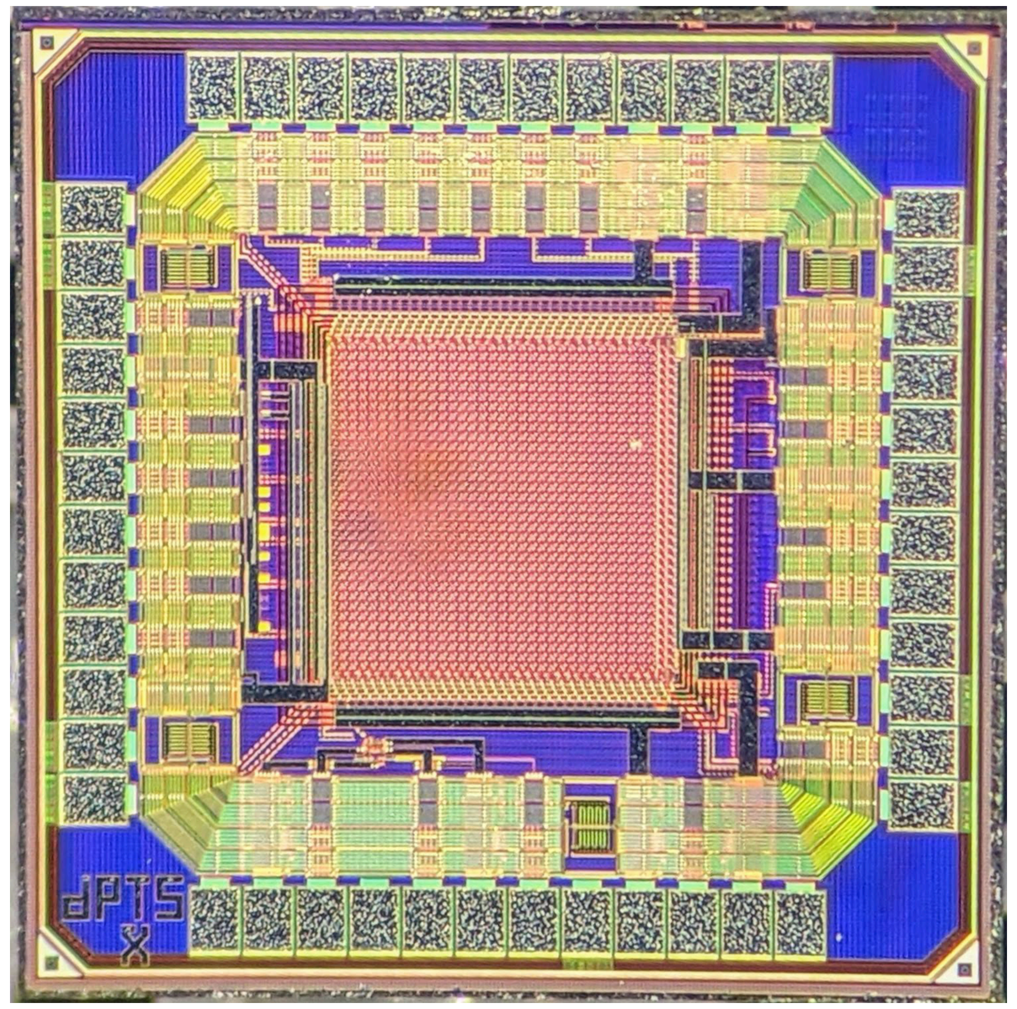
Sensors available in 3 different types:

- limited depleted region
- low-dose n-type implant + fully depleted zone
- Modified with a gap

ALICE ITS3: https://doi.org/10.1016/j.nima.2023.169000

MLR1 Sensor Test Structures





APTS (Analogue Pixel Test Structure)

→ explore different pixel designs

- **matrix**: 6x6 pixels
- **readout**: direct analog readout of central 4x4
- **pitch**: 10,15,20,25 µm
- **total**: 34 dies

DPTS (Digital Pixel Test Structure

→ study in-pixel discrimination

- **matrix**: 32x32
- **readout**: async digital with ToT
- **pitch**: 15, 25 µm
- **total**: 3 dies

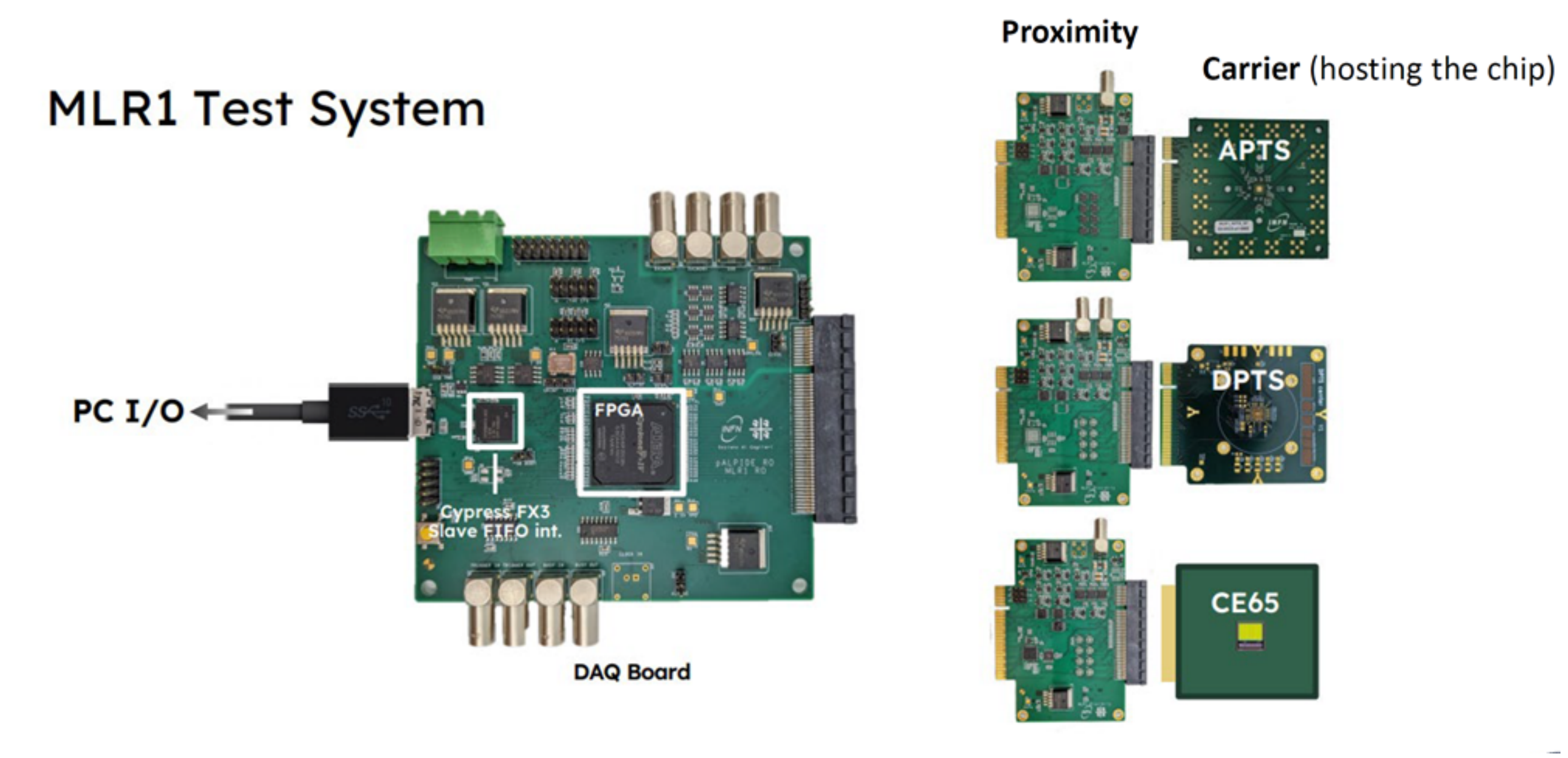
ALICE ITS3: https://doi.org/10.1016/j.nima.2023.169000

Characterization of the MLR1 prototypes

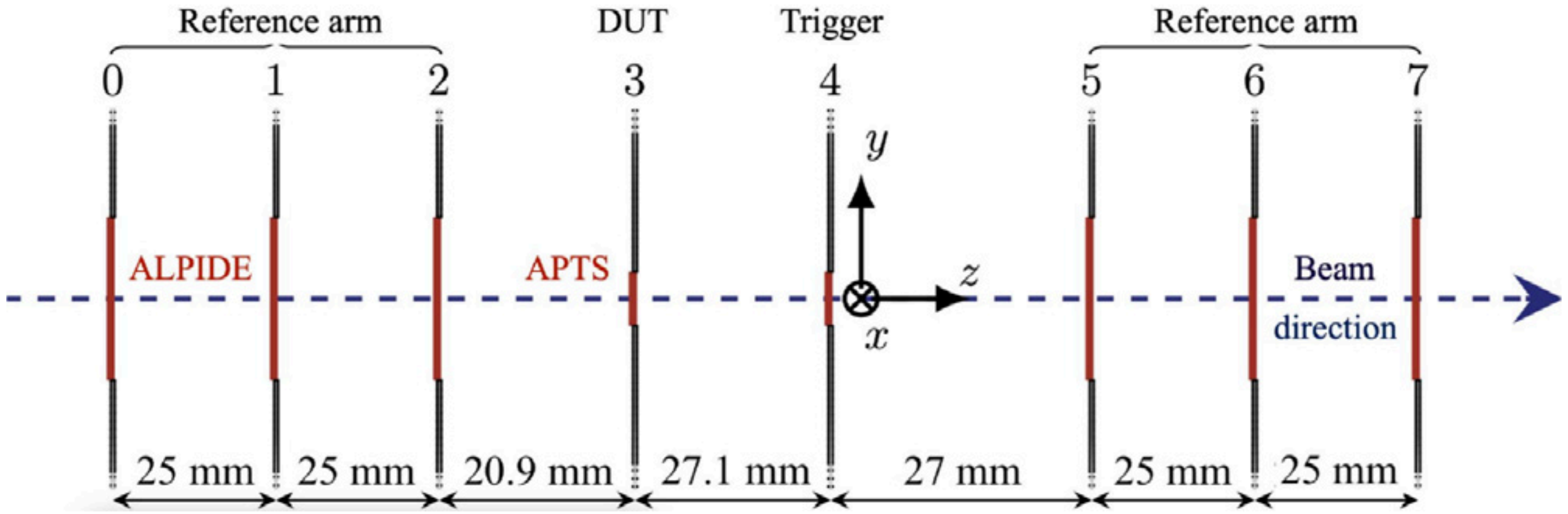
ALICE ITS3: arXiv.2212.08621

Laboratory measurements: Noise, charge collection efficiency and cluster size characterized with 55Fe source before and after TID and NIEL irradiation.

Common test system: DAQ + Proximity + Carrier



Test beam measurements at CERN SPS and DESY: tracking and resolution performance tested before/after irradiation using telescope setups

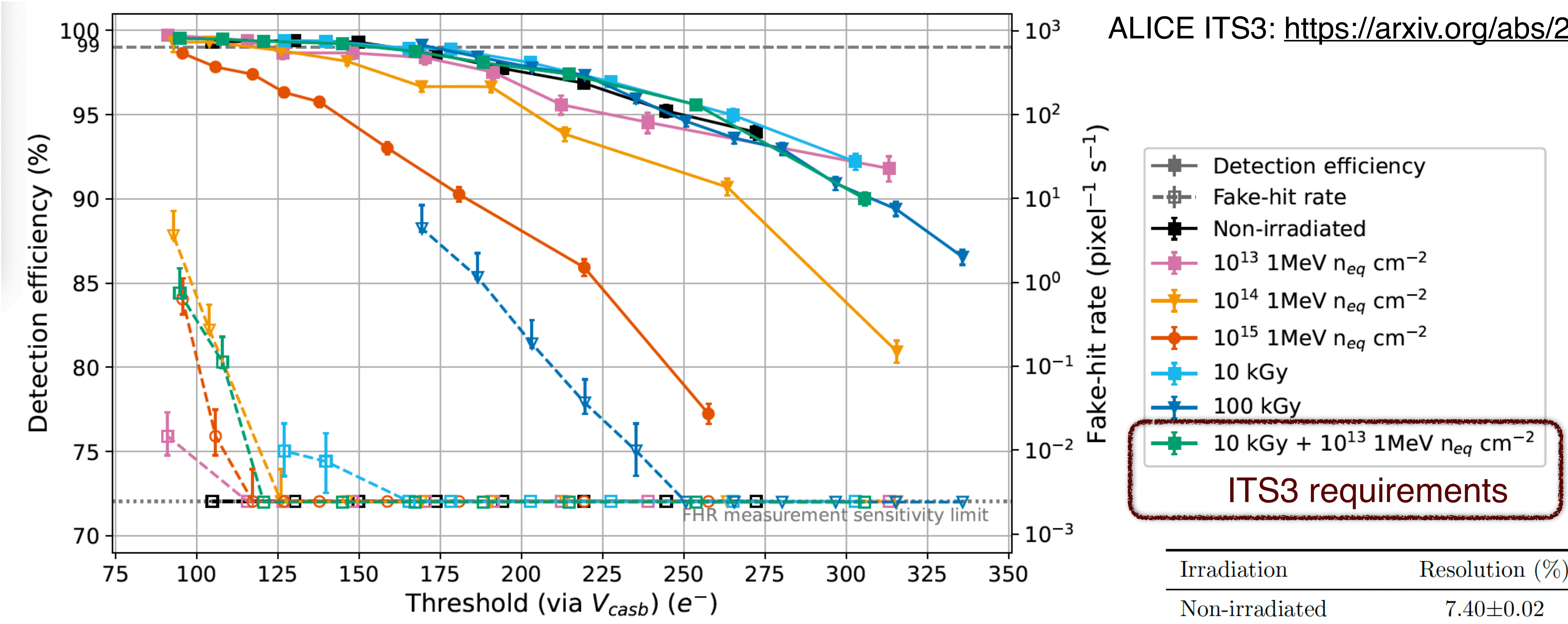


ALICE ITS3: https://doi.org/10.1016/j.nima.2023.169000

Overview of MLR1 performance studies: DPTS

Detection efficiency and fake-hit rate as a function of average threshold, measured with 10 GeV/c positive hadrons ***for different levels of irradiation***

ALICE ITS3: https://arxiv.org/abs/2212.08621



ITS3 requirements

Irradiation	Resolution (%)
Non-irradiated	7.40±0.02
10^{13} 1 MeV n_{eq} cm^{-2}	7.42±0.03
10^{14} 1 MeV n_{eq} cm^{-2}	8.73±0.02
10^{15} 1 MeV n_{eq} cm^{-2}	12.05±0.07

Qualification of the technology has been achieved!

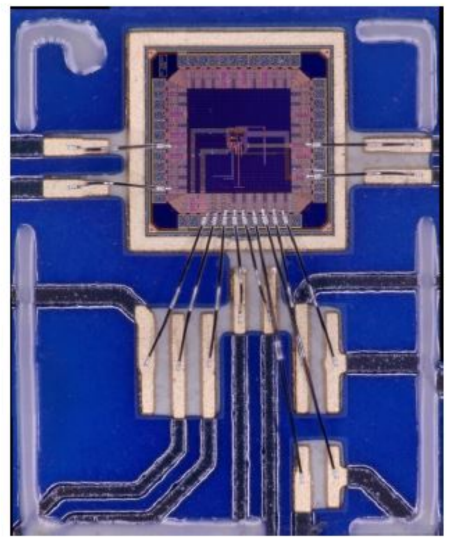
Overview of MLR1 ancillary IC designs and tests by UK institutes

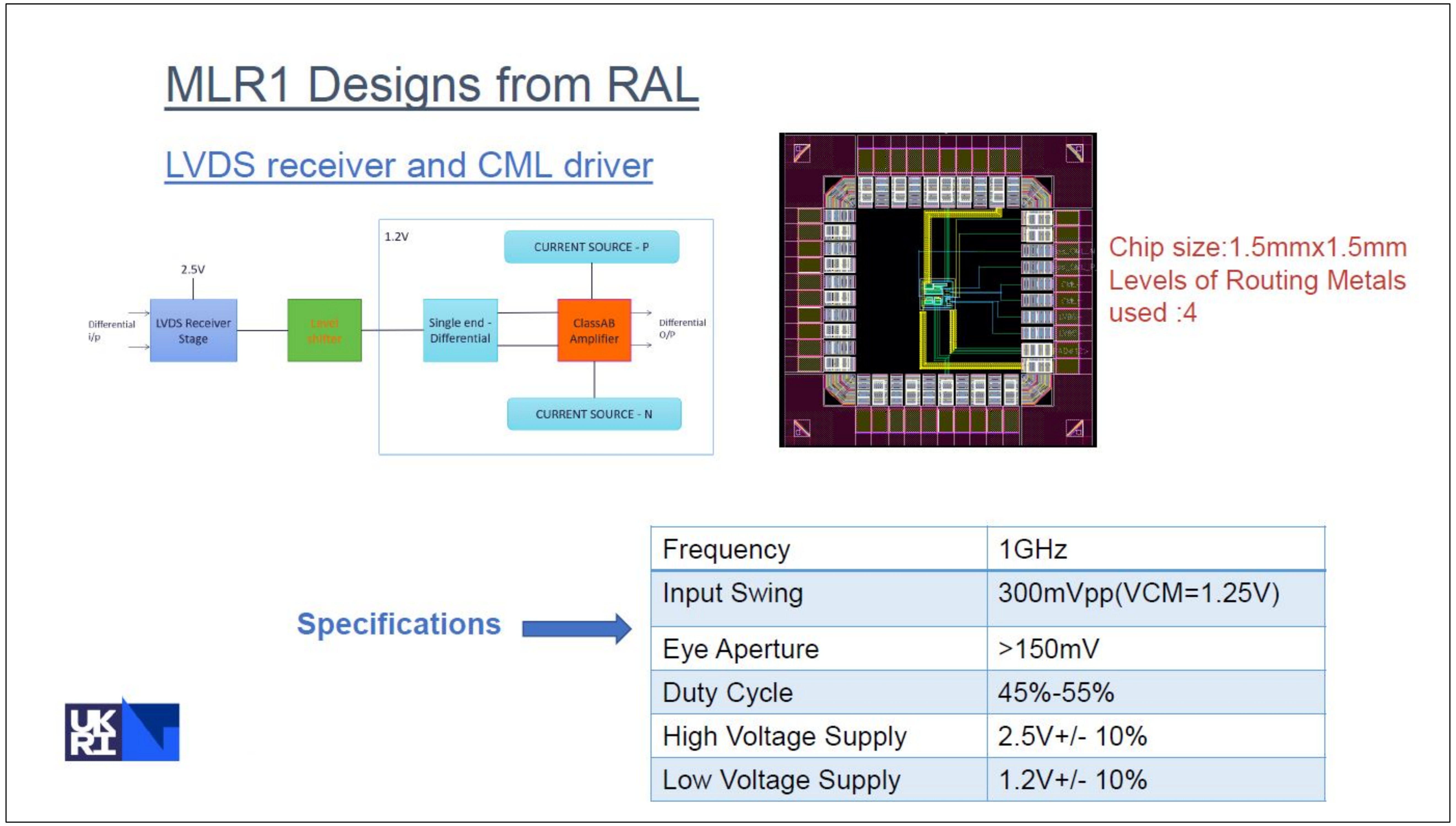
As part of MLR1, the STFC CMOS group designed an LVDS receiver and CML driver.

5 ASICs have been wire bonded to carrier boards and tested.

The test structures were operated successfully with a clock-like input-signal (bit rate 1.5Gb/s) up to ~10 Mrad.

LVDS receiver and CML driver
Bonded (MLR1)





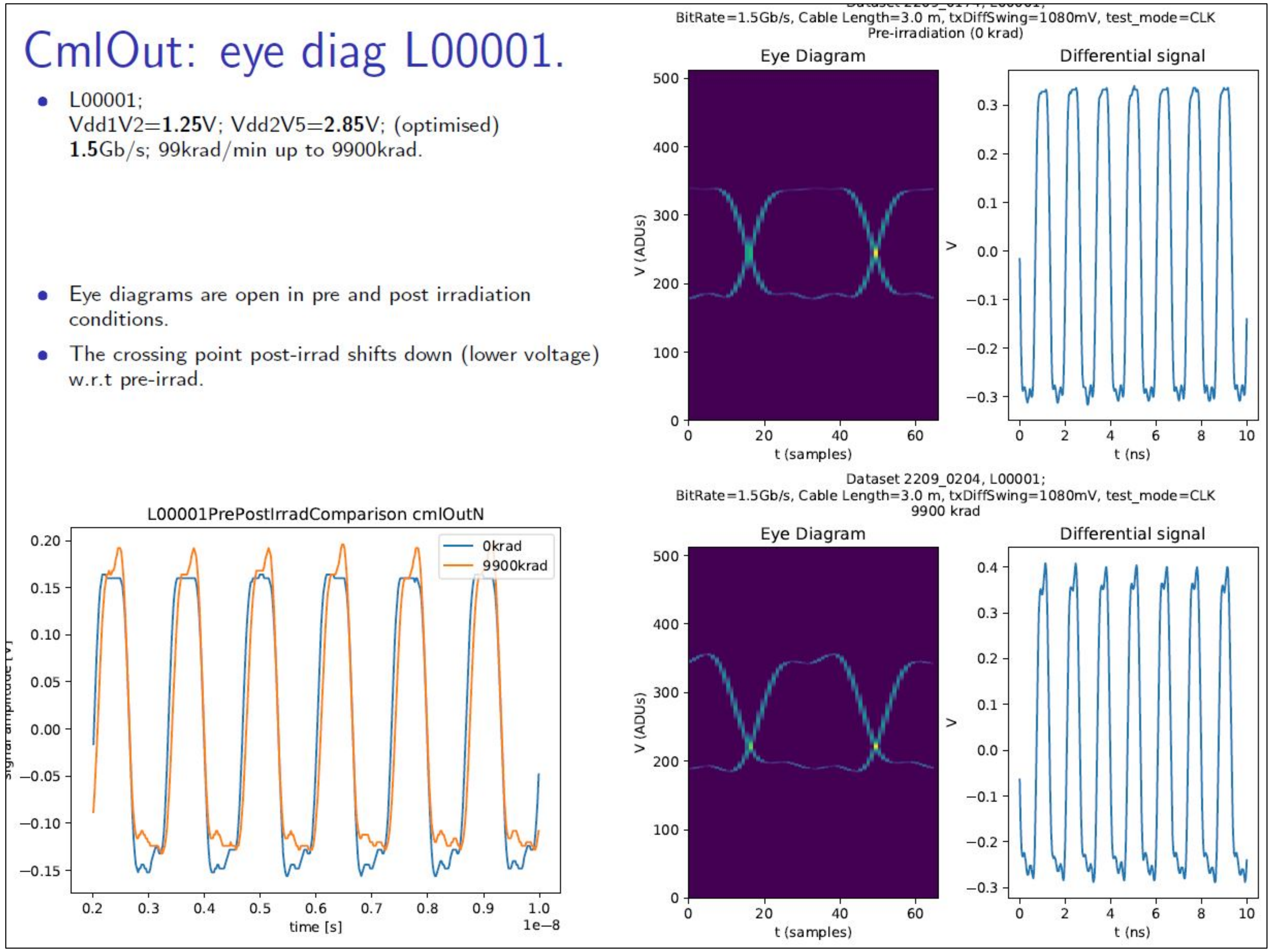
MLR1 Designs from RAL

LVDS receiver and CML driver

Chip size:1.5mmx1.5mm
Levels of Routing Metals used :4

Specifications

Frequency	1GHz
Input Swing	300mVpp(VCM=1.25V)
Eye Aperture	>150mV
Duty Cycle	45%-55%
High Voltage Supply	2.5V+/- 10%
Low Voltage Supply	1.2V+/- 10%



CmlOut: eye diag L00001.

- L00001;
  Vdd1V2=**1.25**V; Vdd2V5=**2.85**V; (optimised)
  1.5 Gb/s; 99krad/min up to 9900krad.

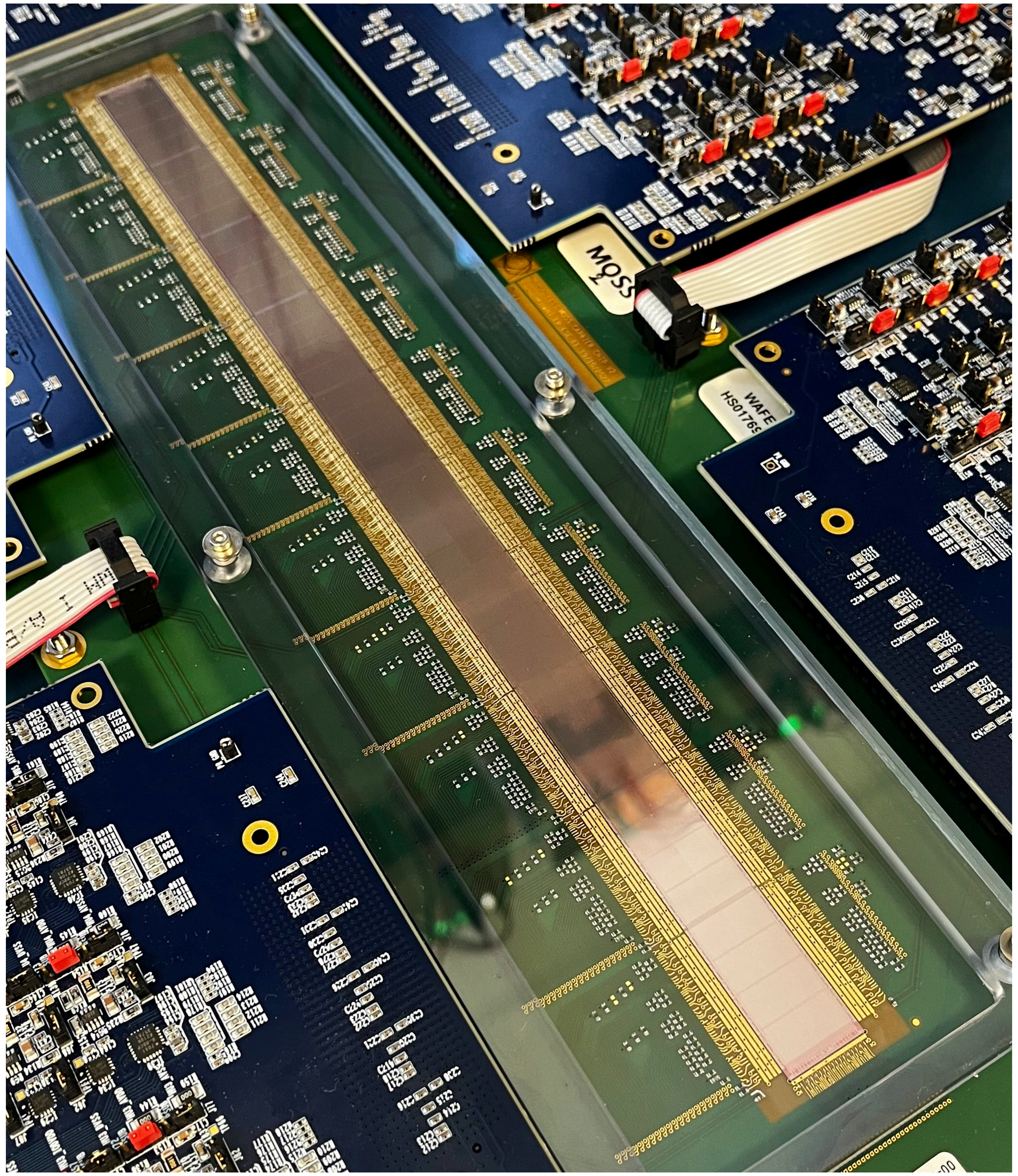
- Eye diagrams are open in pre and post irradiation conditions.
- The crossing point post-irrad shifts down (lower voltage) w.r.t pre-irrad.

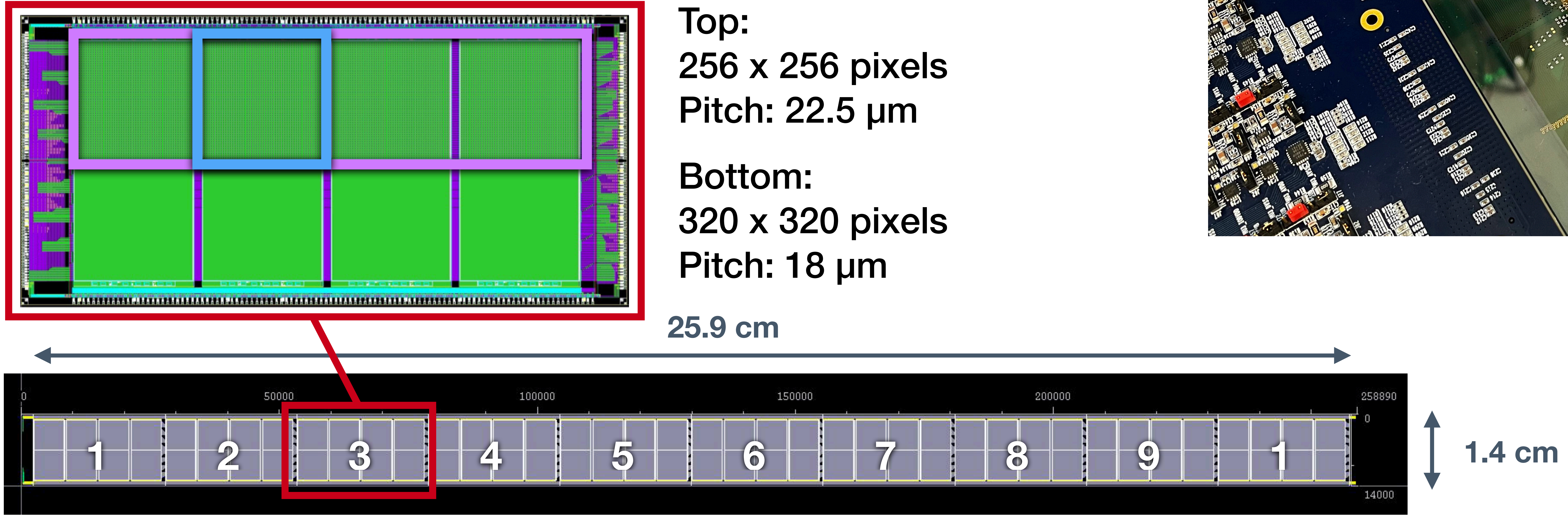
BitRate=1.5Gb/s, Cable Length=3.0 m, txDiffSwing=1080mV, test_mode=CLK
Pre-irradiation (0 krad)

Dataset 2209_0204, L00001;
BitRate=1.5Gb/s, Cable Length=3.0 m, txDiffSwing=1080mV, test_mode=CLK
9900 krad

First in-beam characterization of MOSS

Goals:
- efficiency and spacial resolution characterization for different sensor regions
- Scan of the sensor performance in different voltage conditions



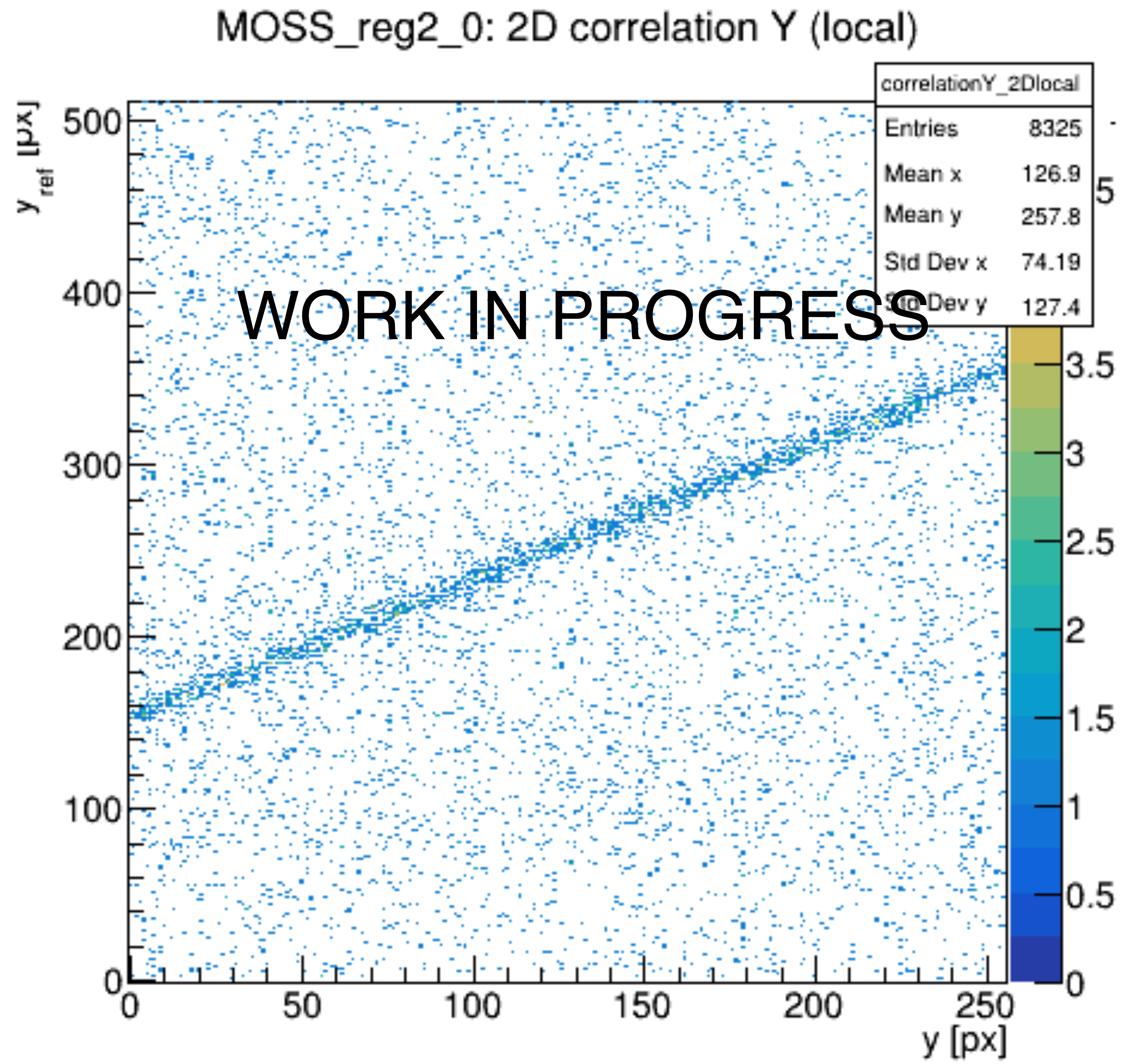


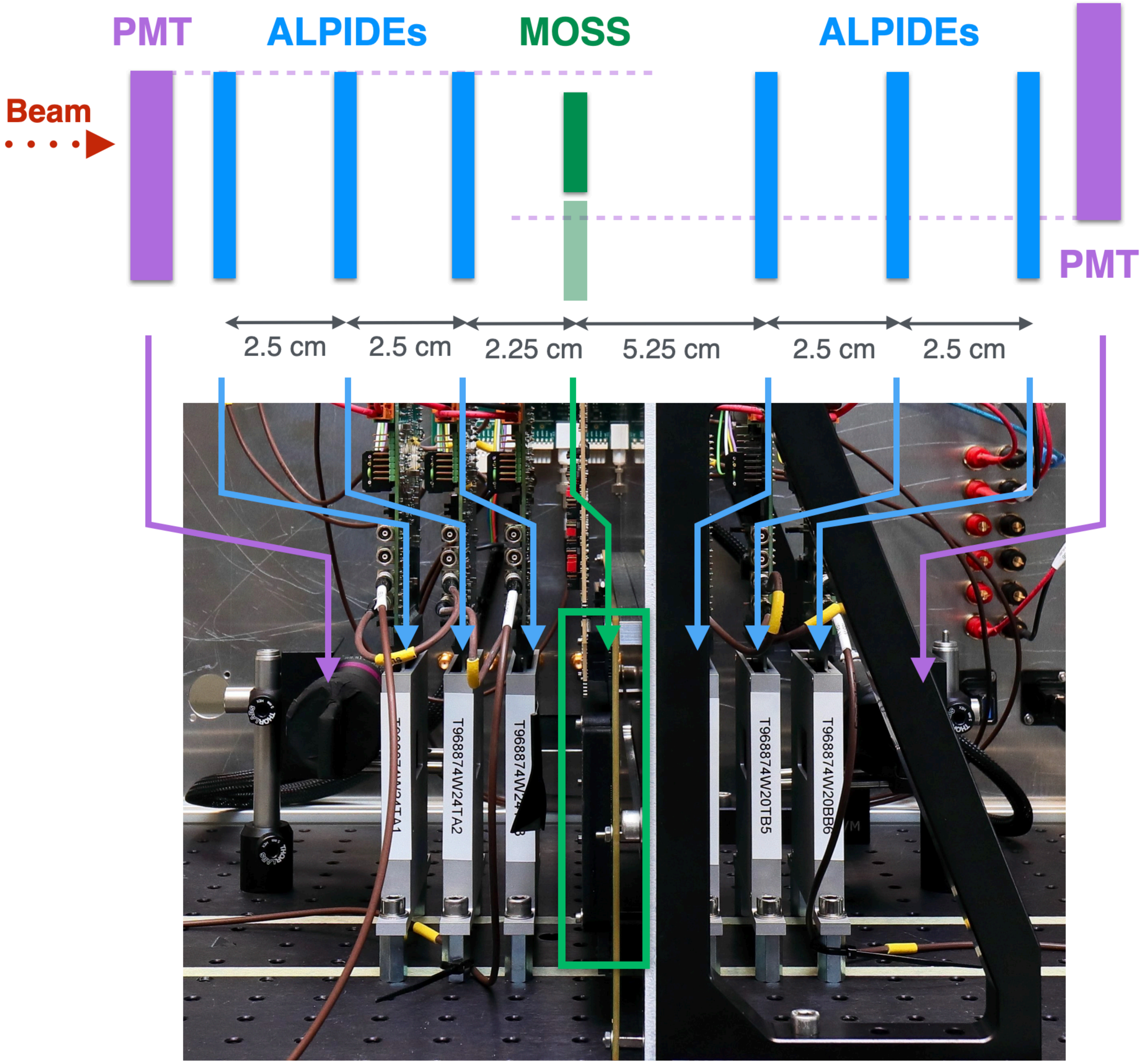
Top:
256 x 256 pixels
Pitch: 22.5 µm

Bottom:
320 x 320 pixels
Pitch: 18 µm

MOSS test beams at PS at CERN

- Optimization the data-taking software for data acquisition to operate with the MOSS sensor
- Installation/setup of the telescope at PS
- Optimization of the Corryvreckan analysis framework
- First characterization of efficiency and resolution:
  (updated versions of these results will be included in the ITS3 TDR)





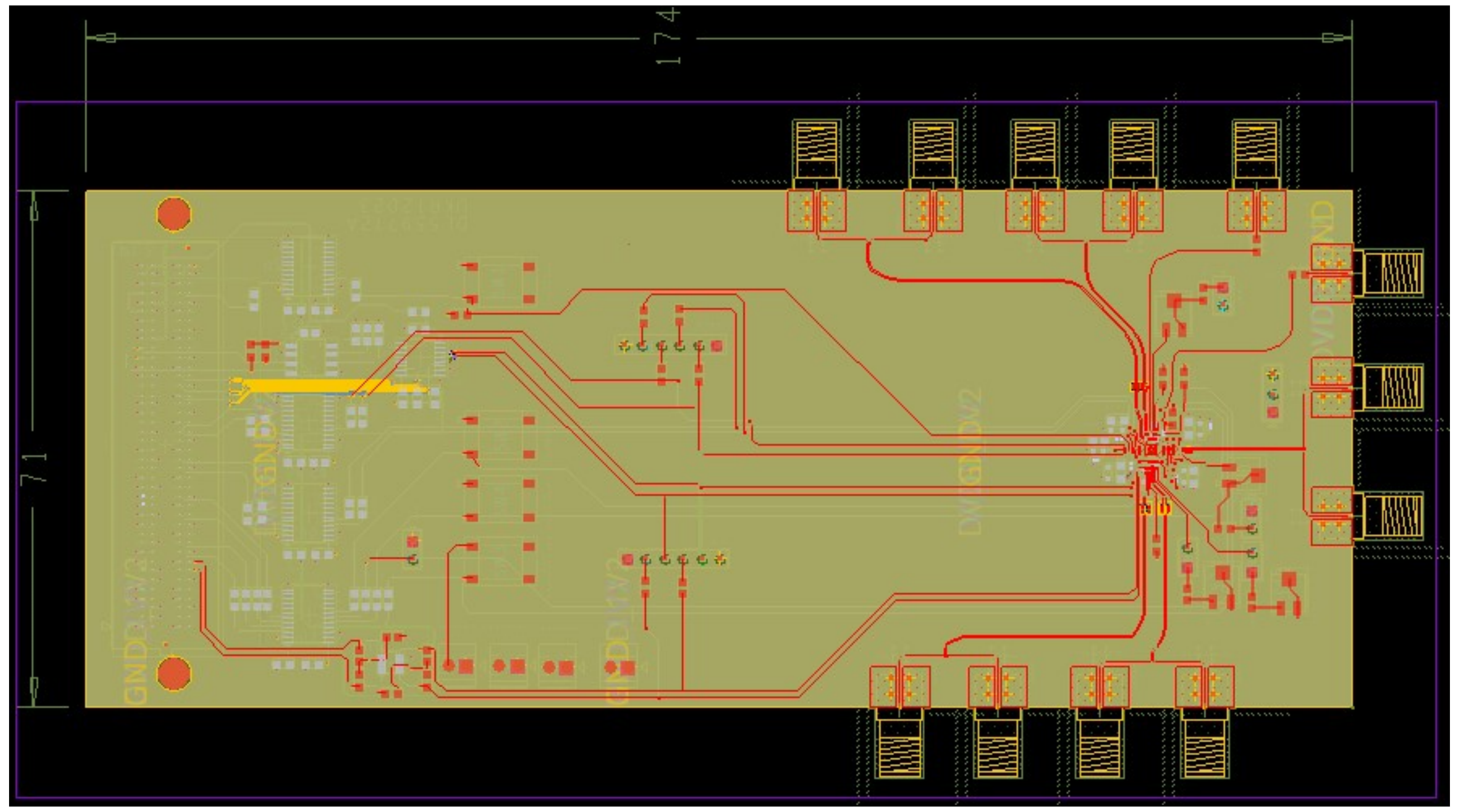
Overview of ER1 ancillary IC designs and tests by UK institutes

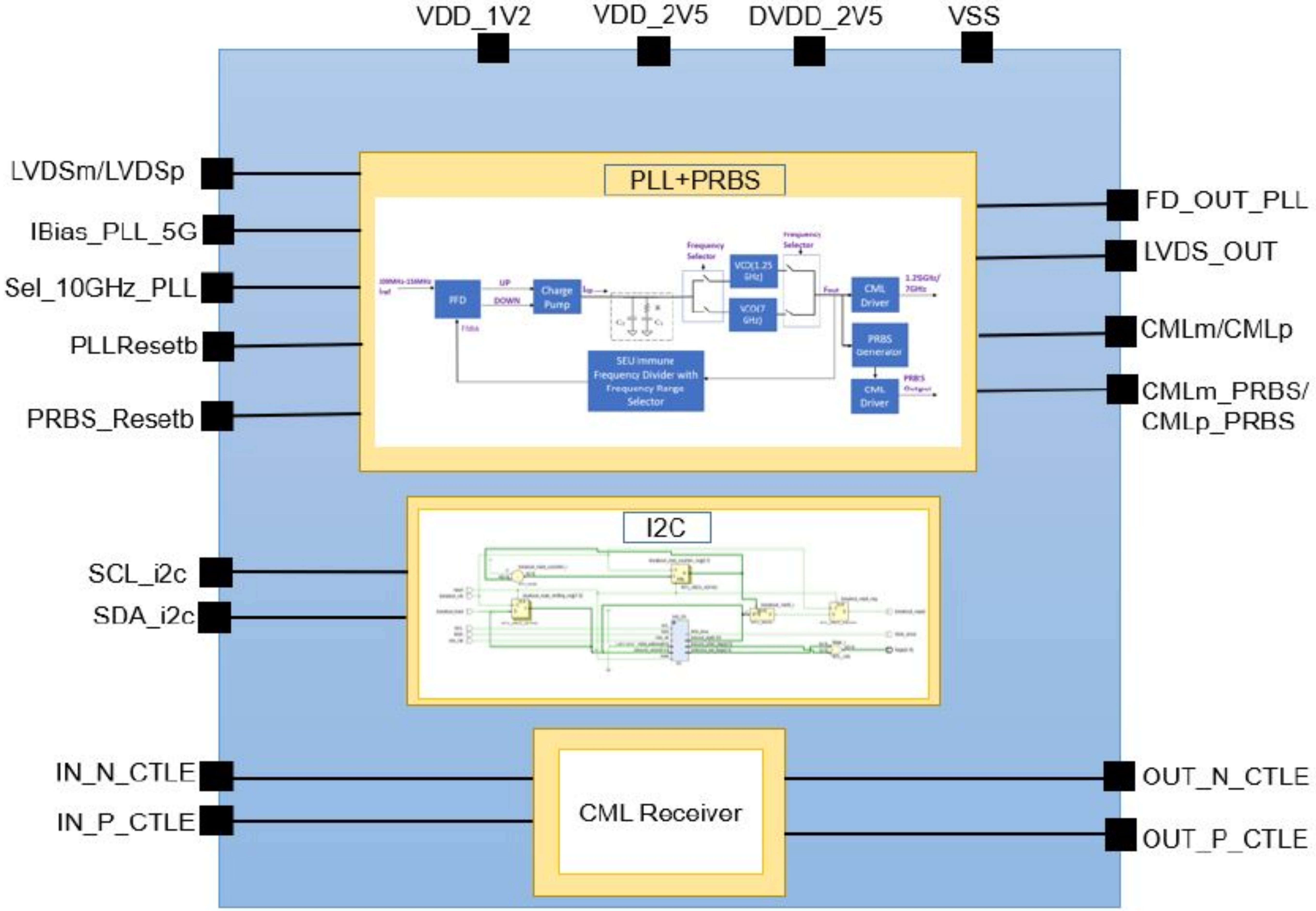
As part of ER1, the STFC CMOS group designed an ASIC consisting of:

- a dual mode PLL which can operate in two different frequency modes;
- 5GHz PRBS Generator;
- 10GHz CTLE based CML Receiver;
- I2C block;

One unit has been wire-bonded to a custom-made carrier-board, and communication to I2C block has been validated.

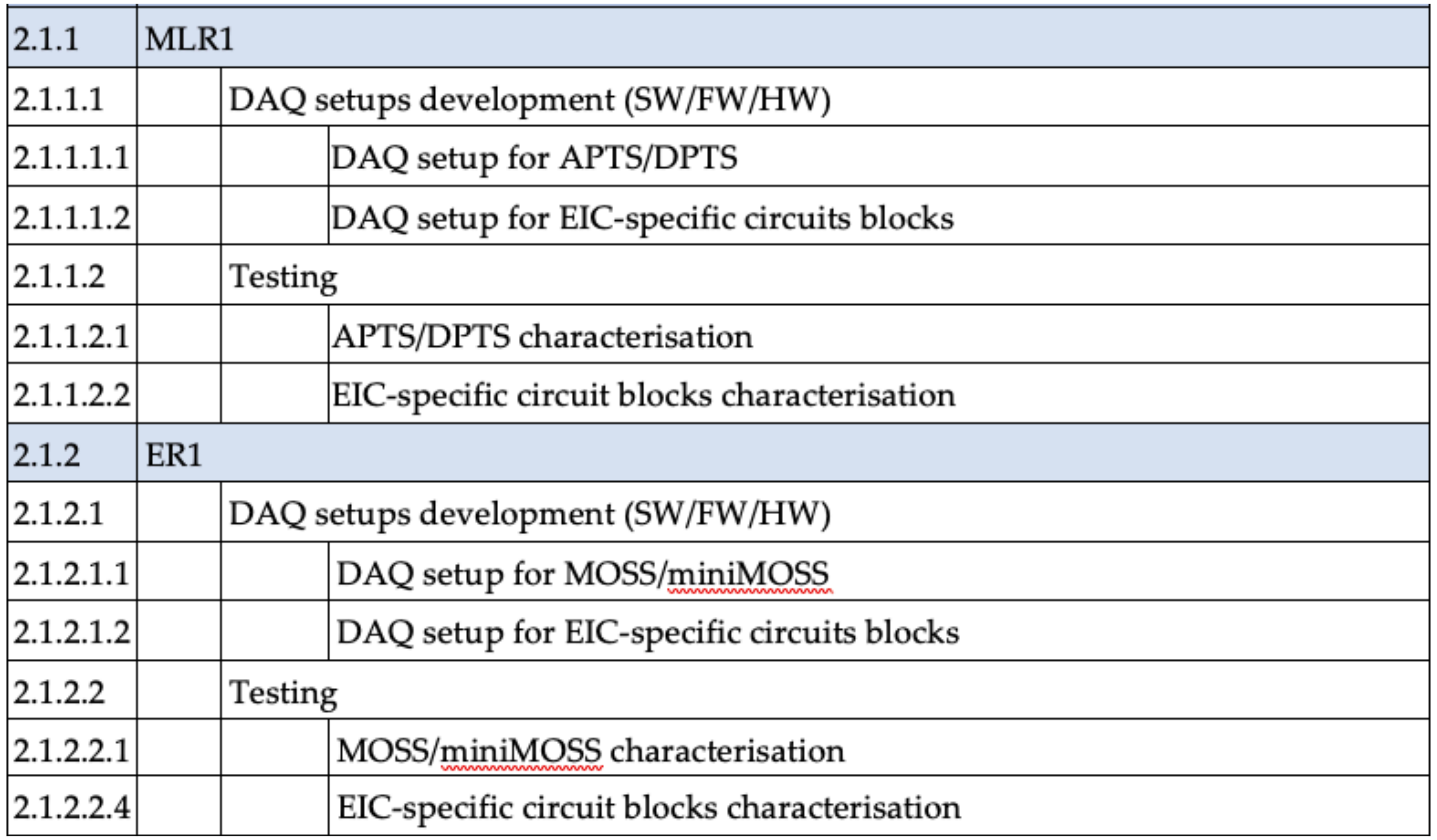
Smoke testing is ongoing and a detailed test plan is under discussion.



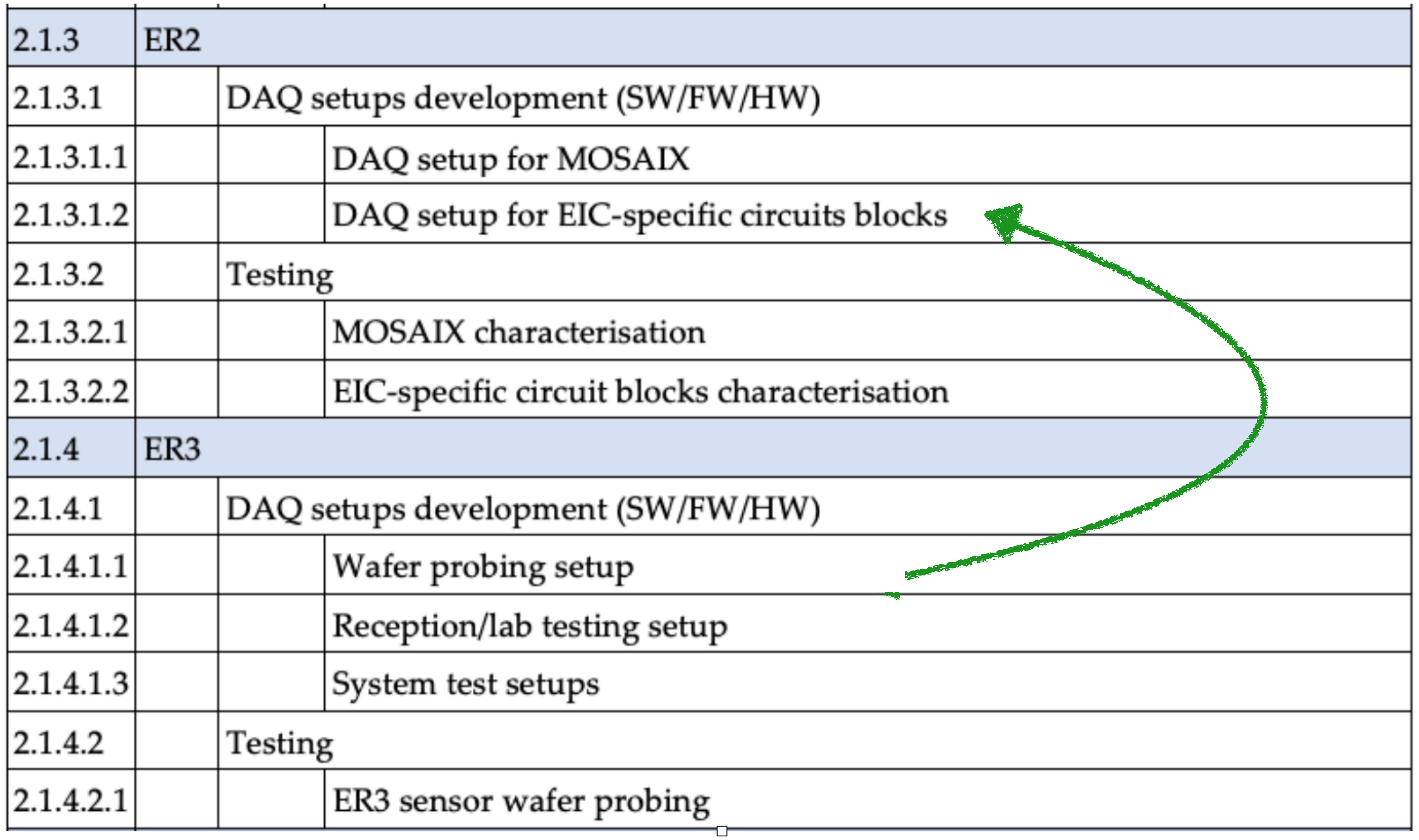


Objectives of the Working Group 2

WP2 working plans and milestones (“ITS3” phase)



2.1.1	MLR1		
2.1.1.1		DAQ setups development (SW/FW/HW)	
2.1.1.1.1			DAQ setup for APTS/DPTS
2.1.1.1.2			DAQ setup for EIC-specific circuits blocks
2.1.1.2		Testing	
2.1.1.2.1			APTS/DPTS characterisation
2.1.1.2.2			EIC-specific circuit blocks characterisation
2.1.2	ER1		
2.1.2.1		DAQ setups development (SW/FW/HW)	
2.1.2.1.1			DAQ setup for MOSS/miniMOSS
2.1.2.1.2			DAQ setup for EIC-specific circuits blocks
2.1.2.2		Testing	
2.1.2.2.1			MOSS/miniMOSS characterisation
2.1.2.2.4			EIC-specific circuit blocks characterisation



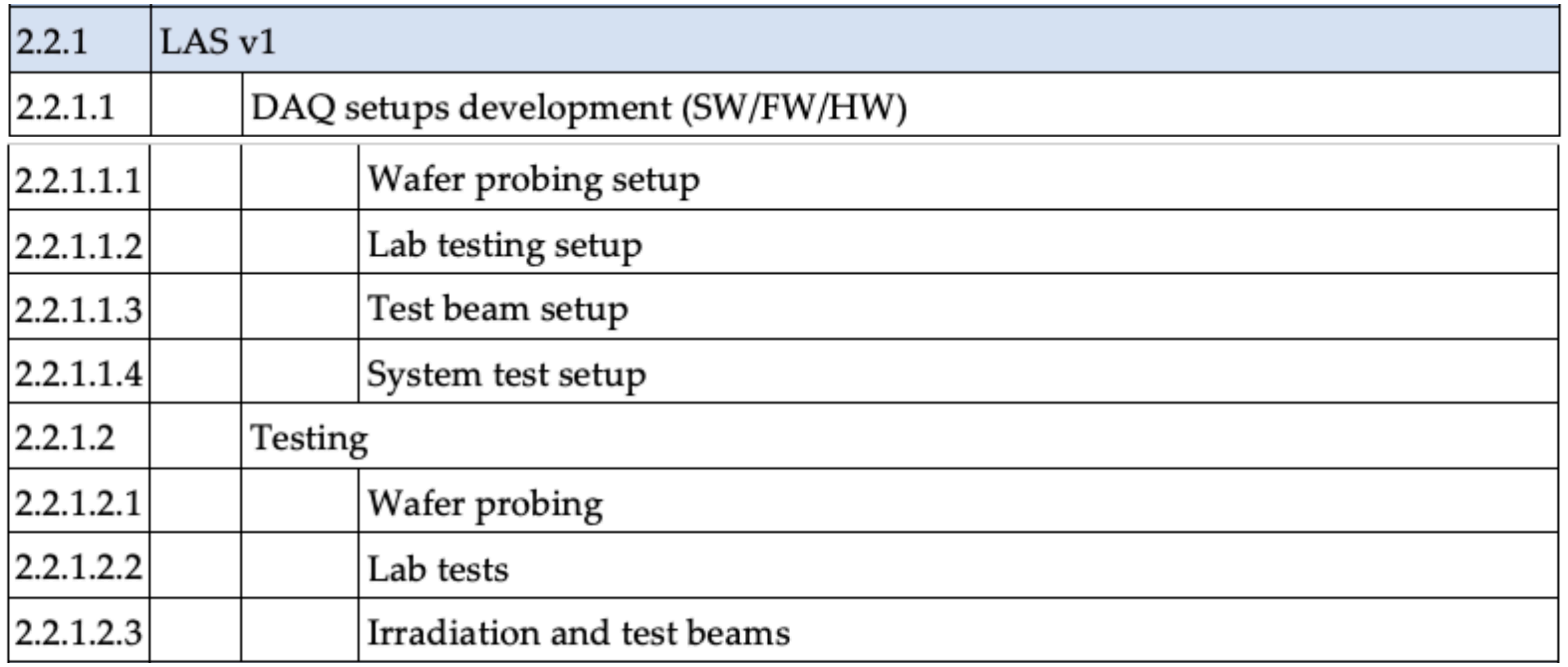
2.1.3	ER2		
2.1.3.1		DAQ setups development (SW/FW/HW)	
2.1.3.1.1			DAQ setup for MOSAIX
2.1.3.1.2			DAQ setup for EIC-specific circuits blocks
2.1.3.2		Testing	
2.1.3.2.1			MOSAIX characterisation
2.1.3.2.2			EIC-specific circuit blocks characterisation
2.1.4	ER3		
2.1.4.1		DAQ setups development (SW/FW/HW)	
2.1.4.1.1			Wafer probing setup
2.1.4.1.2			Reception/lab testing setup
2.1.4.1.3			System test setups
2.1.4.2		Testing	
2.1.4.2.1			ER3 sensor wafer probing

Overall strategy is to contribute to the best of our capacity to the activities of the ITS3 team:
- DAQ developments for ER1/2/3 sensors and EIC specific blocks
- characterization in lab with DAQ setups and wafer-probe stations and with test beams before and after irradiation

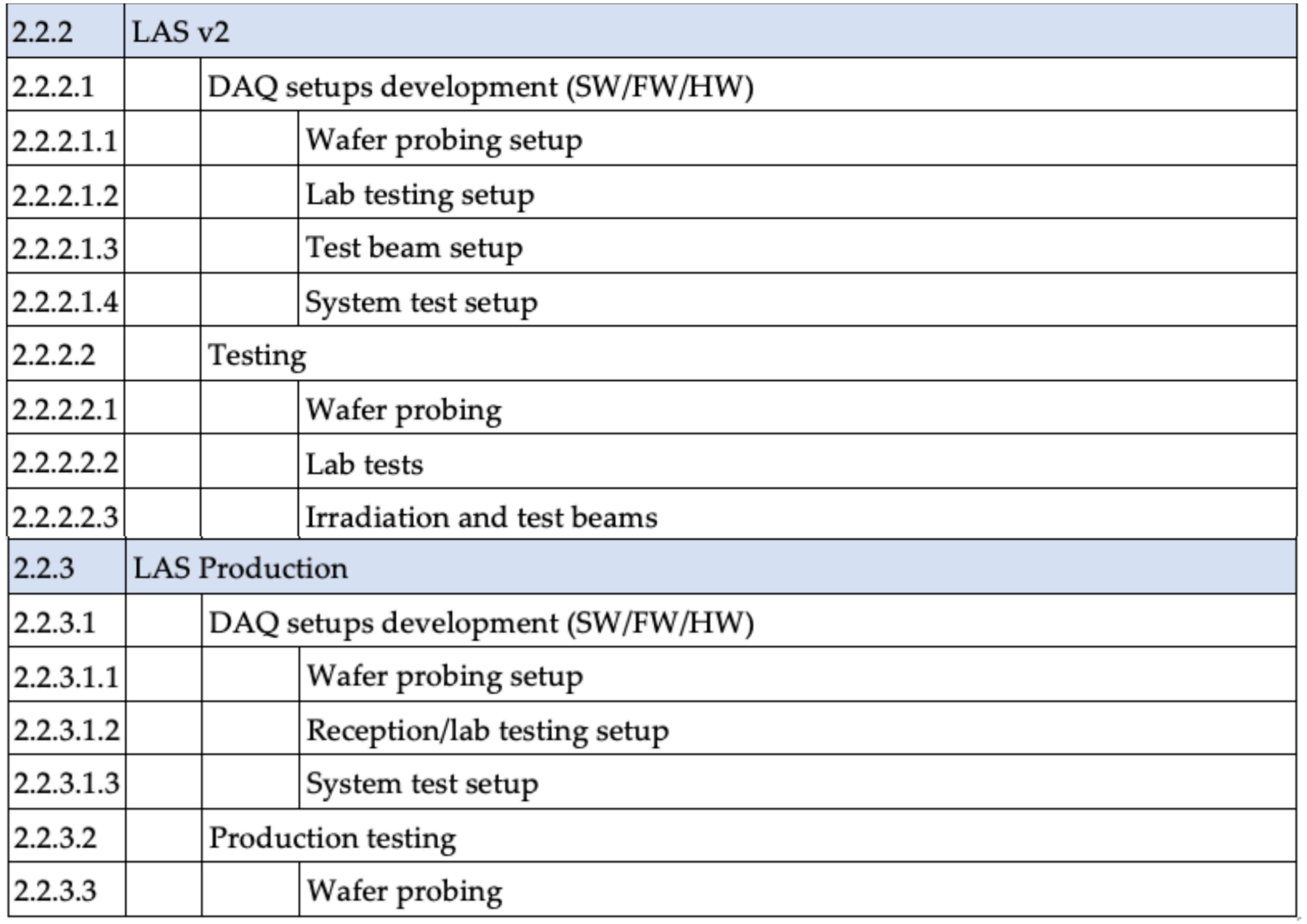
by combining a stable presence of SVT groups at CERN with the activities carried out in SVT labs and institutes

IMPORTANT: we need to optimize an effective collaboration strategy for SVT groups which are not in ALICE!

WP2 working plans and milestones ("LAS" phase)



2.2.1	LAS v1		
2.2.1.1		DAQ setups development (SW/FW/HW)	
2.2.1.1.1			Wafer probing setup
2.2.1.1.2			Lab testing setup
2.2.1.1.3			Test beam setup
2.2.1.1.4			System test setup
2.2.1.2		Testing	
2.2.1.2.1			Wafer probing
2.2.1.2.2			Lab tests
2.2.1.2.3			Irradiation and test beams



2.2.2	LAS v2		
2.2.2.1		DAQ setups development (SW/FW/HW)	
2.2.2.1.1			Wafer probing setup
2.2.2.1.2			Lab testing setup
2.2.2.1.3			Test beam setup
2.2.2.1.4			System test setup
2.2.2.2		Testing	
2.2.2.2.1			Wafer probing
2.2.2.2.2			Lab tests
2.2.2.2.3			Irradiation and test beams
2.2.3	LAS Production		
2.2.3.1		DAQ setups development (SW/FW/HW)	
2.2.3.1.1			Wafer probing setup
2.2.3.1.2			Reception/lab testing setup
2.2.3.1.3			System test setup
2.2.3.2		Production testing	
2.2.3.3			Wafer probing

- **Adjust the existing HW/SW/FW tools developed for the ITS3 sensors to the ePIC-specific LAS sensor** (wafer-probe, test beam, DAQ, test beams tools for both characterization and production phase)
- **Characterization with lab tests and test beams before and after irradiation:**
  - dedicated irradiation studies needed for LAS sensor, support chip, COTS, optic cables, FPC, …

A focus on wafer-probe testing for ER2, ER3 and LAS

→ test the wafers before thinning and dicing to select the good segments and subsequent dicing and thus improve the yield.

Standard testing sequence with wafer prober:

1. Visual inspection and metrological measurements
2. Electrical and functional test sequence:
    - basic electrical test, power supply and currents
    - test of I/O connection (writing and reading configuration)
    - noise run to identify noisy pixels in the matrix;
    - test of the digital part (e.g. using a test pulse pattern)
    - sensor response using light or a radioactive source.

The WP2 working group has three 12-inches wafer-prober available:

- one at CERN from MIT group (which will be made available to the ITS3 team to characterize the ER2/3 sensors)
- two in other SVT institutes (Prague and ORNL)

→ ***Plan is to hire at least one postdoc/technician that could contribute to the ITS3 sensor testing directly at CERN***

Overview of past SVT contributions to ITS3 effort

✦**MIT**

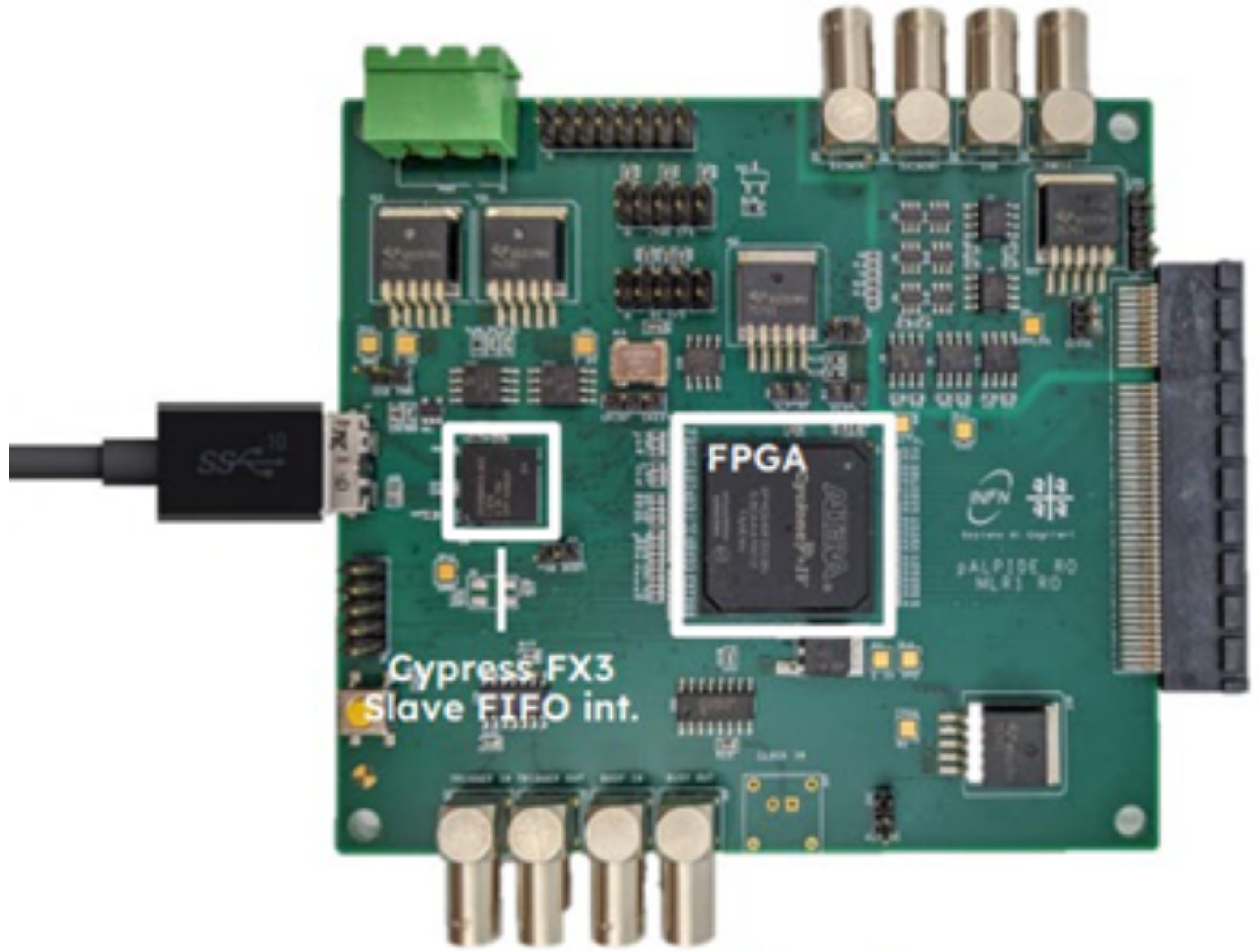
- participated to the first test beams of the ER1 MOSS sensor to extract efficiency and space resolution.

✦**LBNL and UC Berkeley**

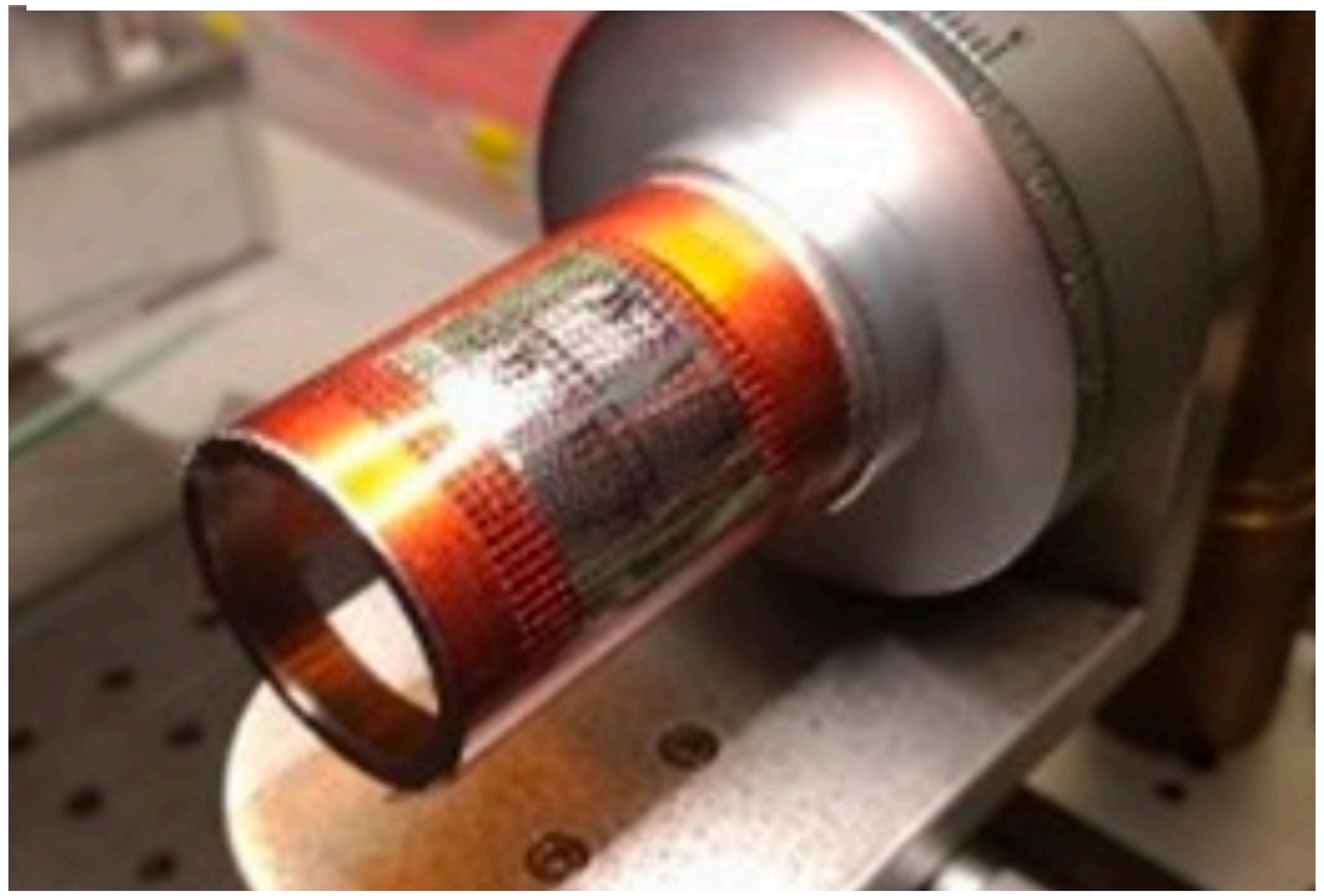
- contributed 20 assembled DAQ boards to ITS3 for sensor characterization to help overcome supply-chain shortages;
- contributed to ITS3 MLR1 sensor DPTS characterization and test beam data taking and analysis, multiple studies including ToT;

✦**INFN**

- testing/optimization of the MLR structures for EIC specific applications, define the configuration settings that minimize integration time and noise hit level;
- contribution to the development of DAQ system and test the ER1 stitched sensor yield.



DAQ Board



Overview of past SVT contributions to ITS3 effort

✦LANL

- 8 ALPIDE stave telescope has been setup at LANL, which will be used to characterize the ER1, ER2 and potentially EIC LAS sensors.

✦ORNL

- characterization of the ITS3 MLR1 DPTS sensor via calibration of the pixels with radioactive sources and X ray fluorescence,
- CML buffer parameter scan, time-over-threshold studies, pixel-per-pixel variations

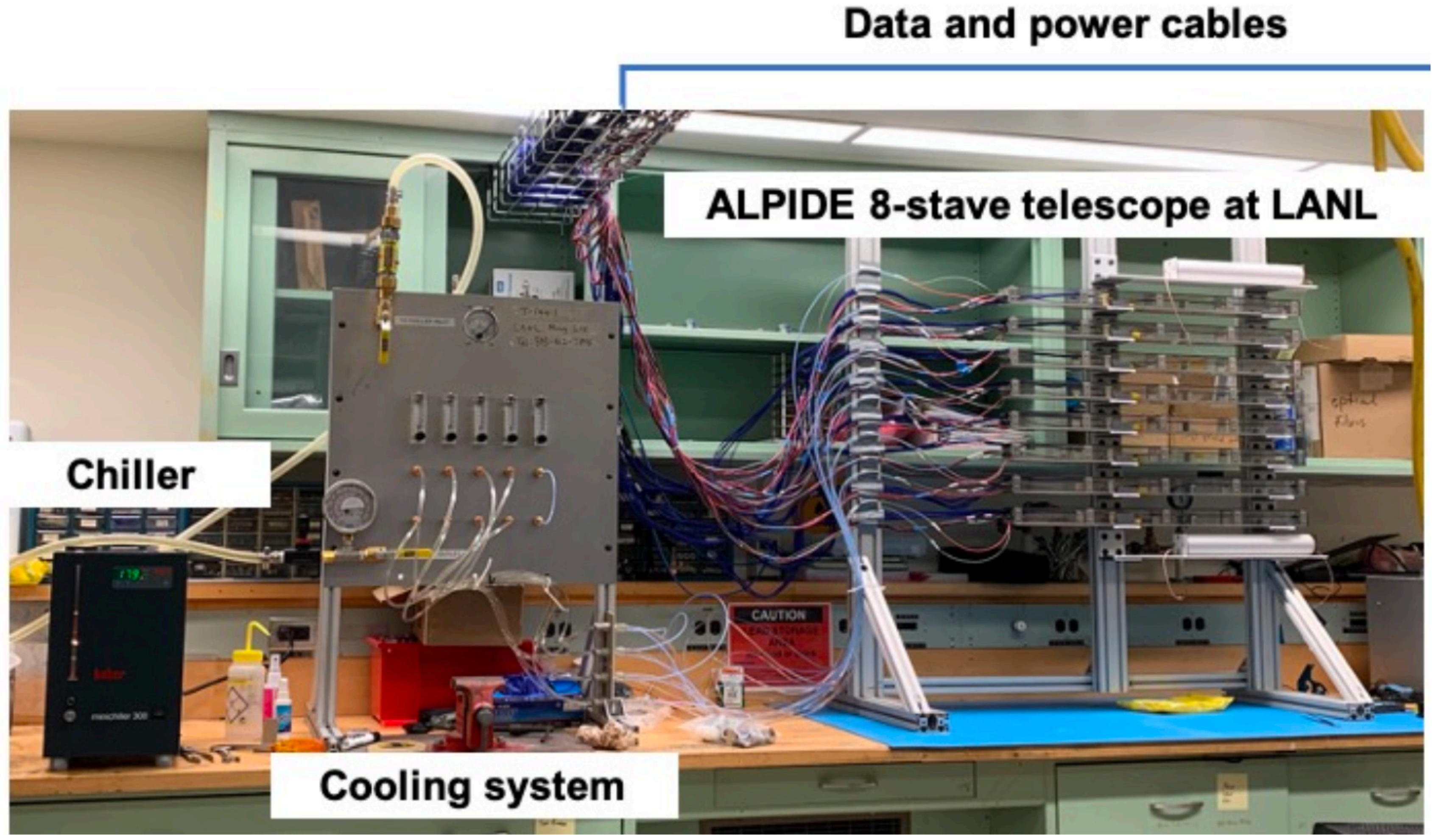
✦UK groups

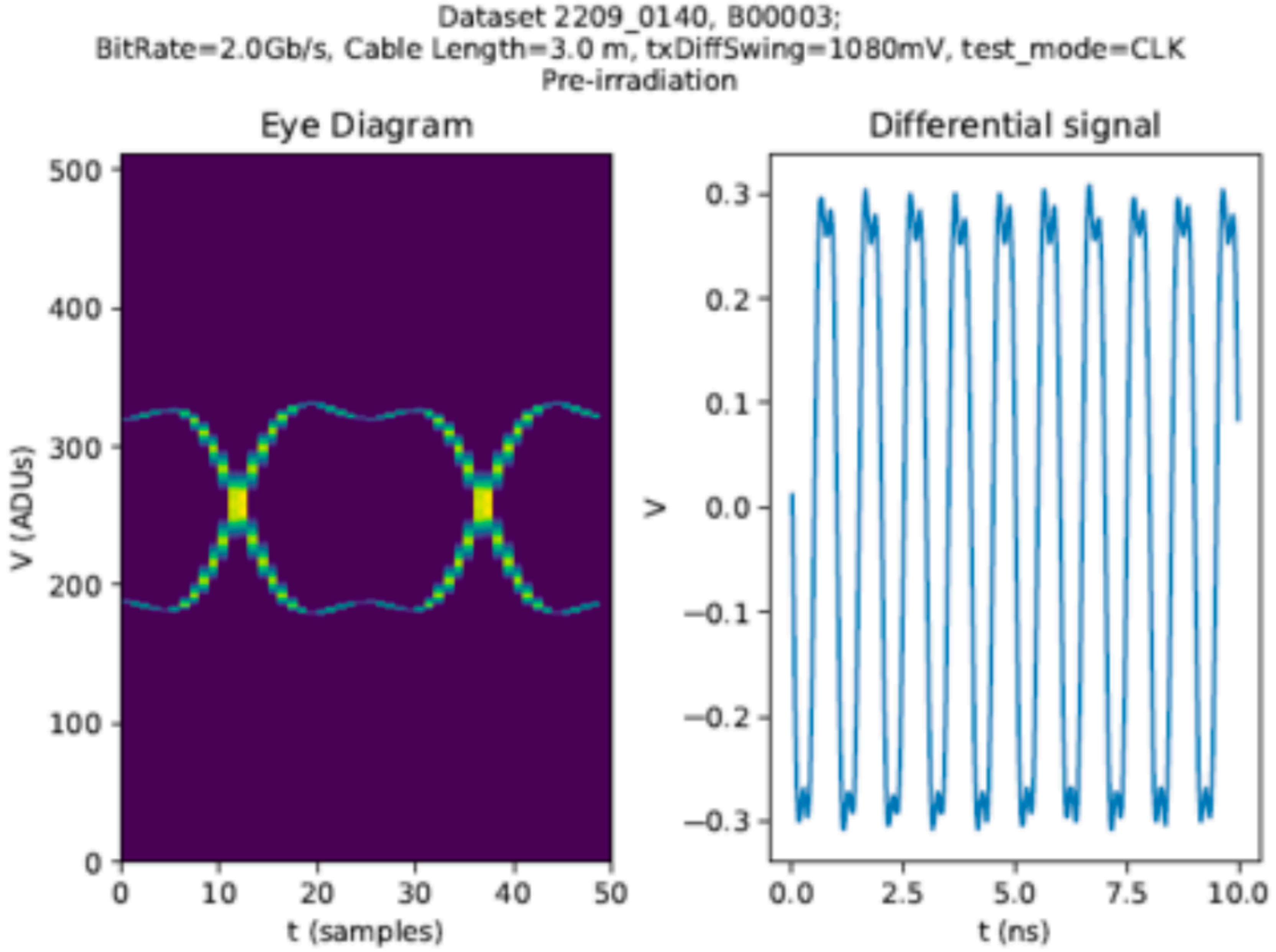
- full characterization of the MLR1 circuits blocks commissioned by RAL;
- involved in testing of APTS and DPTS

✦CTU Prague

- participation on ITS3 MLR1 and ER1 CE65 test structures characterisation with Fe55 source and X-ray fluorescence.

New groups to join testing activities are very welcome!





Inputs for discussion

Discussion: additional technical challenges

Temperature-dependent studies with climatic chamber/wafer probe?

- According to the current strategy, the sensor will operate at room temperature
- But temperature-dependent studies could provide useful information about the sensor behavior when when the beampipe is being baked out in situ with hot gas flowing.
- Synergies with the ALICE3 first temperature-dependent studies

I**rradiation/test beam plans for LAS sensor, support chip, COTS, optic cables, FPC…**

- one of the goals of this workfest is to define a coherent plan inside the WG2 that uses all the existing facilities (CERN, DESY, …)
- Need to consider also the planned shut-down periods foreseen for each facility

Discussion: collaboration with ITS3/microelectronic CERN team

Status:

- the EIC-CERN agreement (in brief) will give access to the ITS3 sensor, use it and modify it to design the LAS.
- proposing modifications to the agreement does not look feasible at this stage
- possible collaborations between SVT groups and the CERN ITS team is not covered in the agreement

→ The contribution of non-ALICE members to the ITS3 R&D and test is potentially very challenging (access to the sensor, to the software and the documentation, ….)

→ Any collaboration between non-ALICE SVT groups and the ITS3 group would go through "individual" agreements which however poses issues in terms of paper authorship, conferences, ..

How to maximize the impact of the SVT community on the ITS3-sensor characterization? Some considerations

- **need for a strong coordination between the WP2 SVT groups** with regular WP2 discussions and in-person meetings/workshops/retreats
- **Concentrate the effort:** less likely to make a strong impact on such a time-sensitive project with a scattered effort on several projects. It could be more effective to cluster SVT teams that could take the lead in some specific areas of the development'
- **Increase the presence at CERN** would improve the quality of the collaboration with the CERN teams
  - can we foresee to have a SVT "lab" and team at CERN?

Discussion: collaboration with ITS3/microelectronic CERN team

Possible goals for this workfest:

- agree on an effective mode of operation for the WP2 (meeting time, next workfest, …)
- identify a few areas of work (and corresponding workforce) where the SVT can provide a leading contribution over the next year
  → **with this “package” in hand, propose an ad-hoc collaboration plan to the ITS3 team**
- elaborate on the plan for ePIC-specific testing activities

Mattermost channel for the SVT WP2. Join if you are interested!!
https://chat.epic-eic.org/main/channels/svt-wp2-sensor-testing