ALICE ITS upgrade for LS3

Magnus Mager (CERN)

13th Terascale Detector Workshop

07.04.2021

PHYSICS AT THE TERA SCALE

Helmholtz Alliance

CERN

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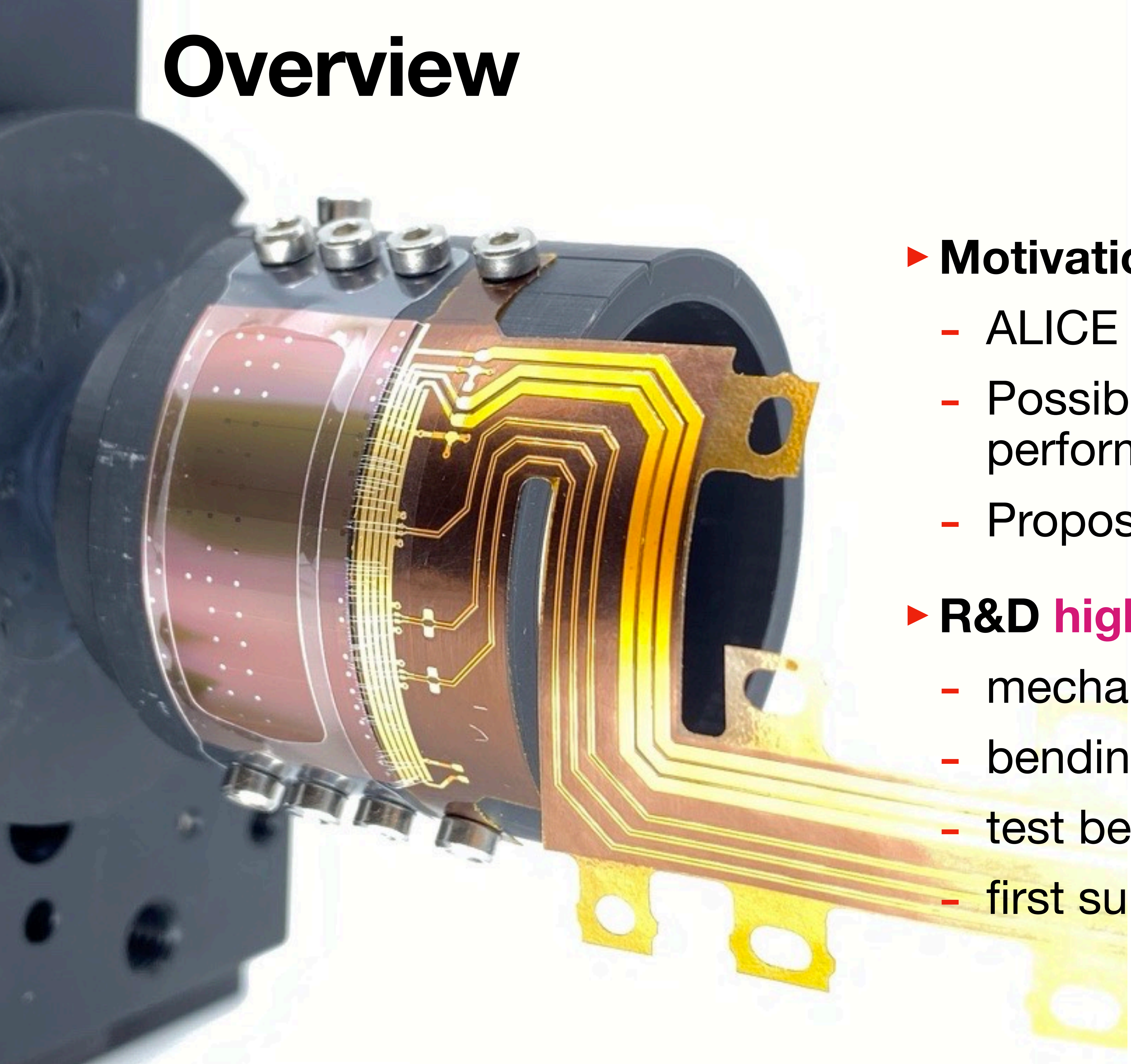
Overview



- **Motivation + Design**
  - ALICE + ITS2
  - Possible improvements and performance projections
  - Proposal for **ITS3**
- **R&D highlights**
  - mechanics with wafer-scale chips
  - bending and interconnection
  - test beam results from bent MAPS
  - first submission in 65 nm

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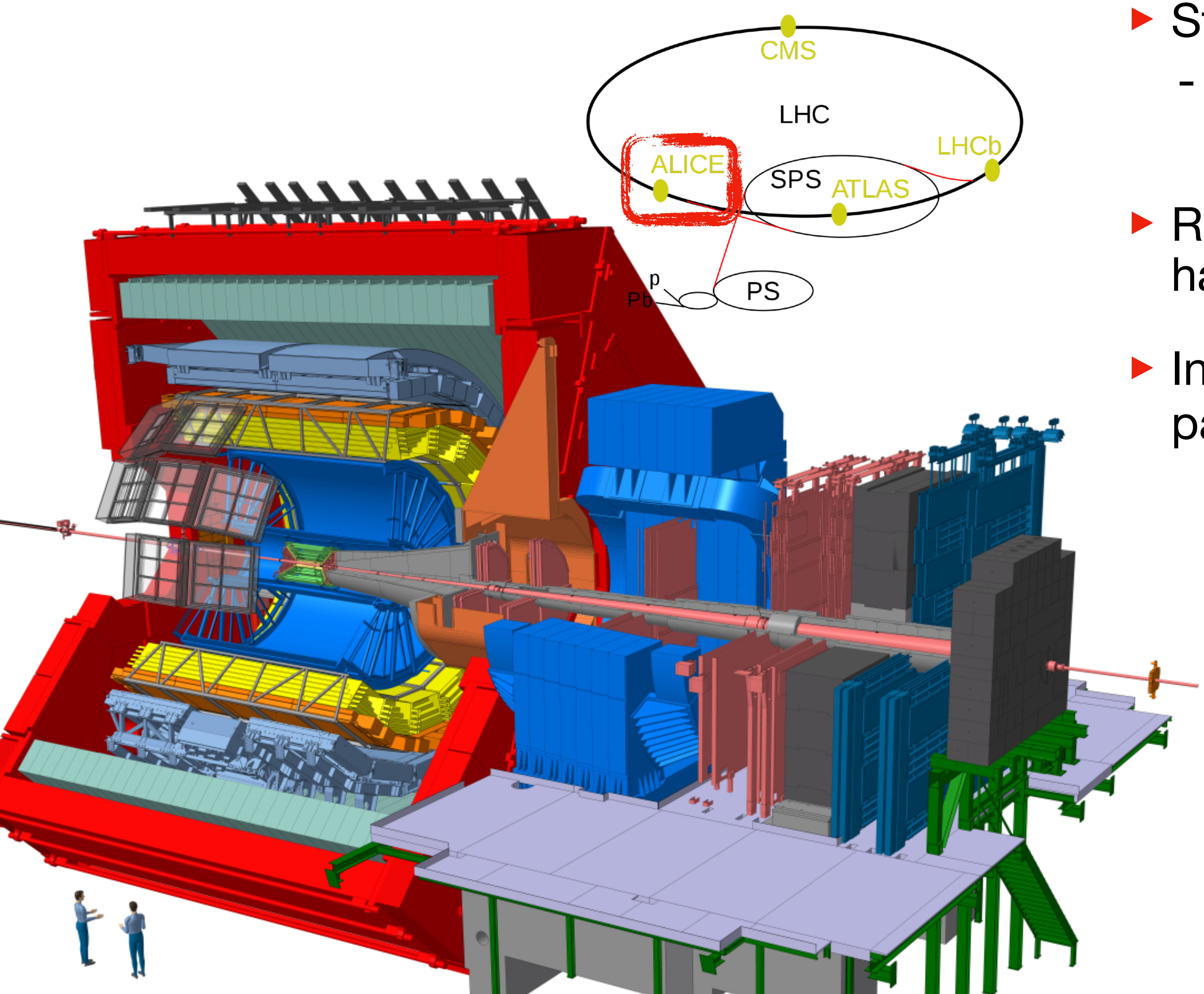
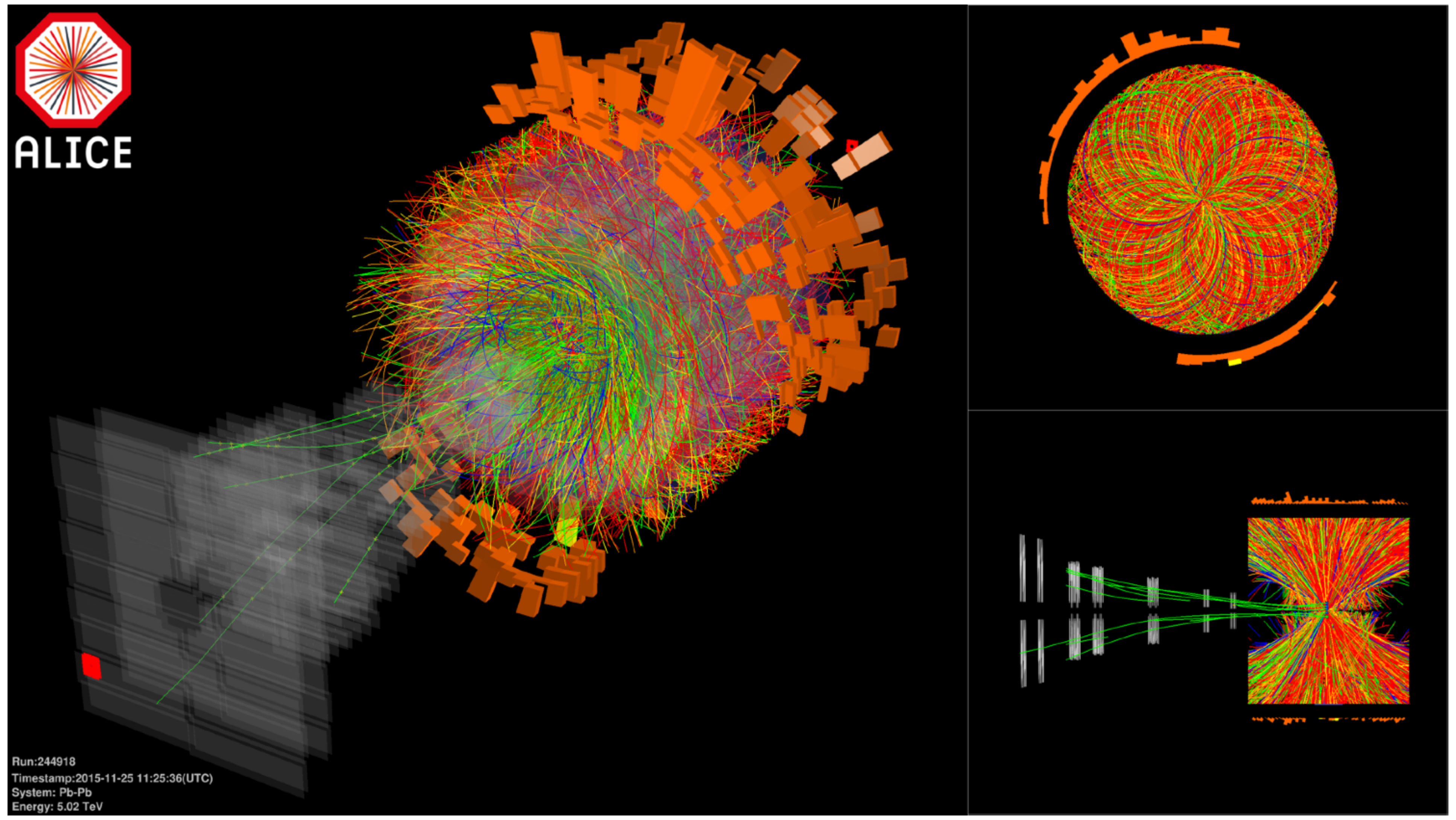
Detector and main goals

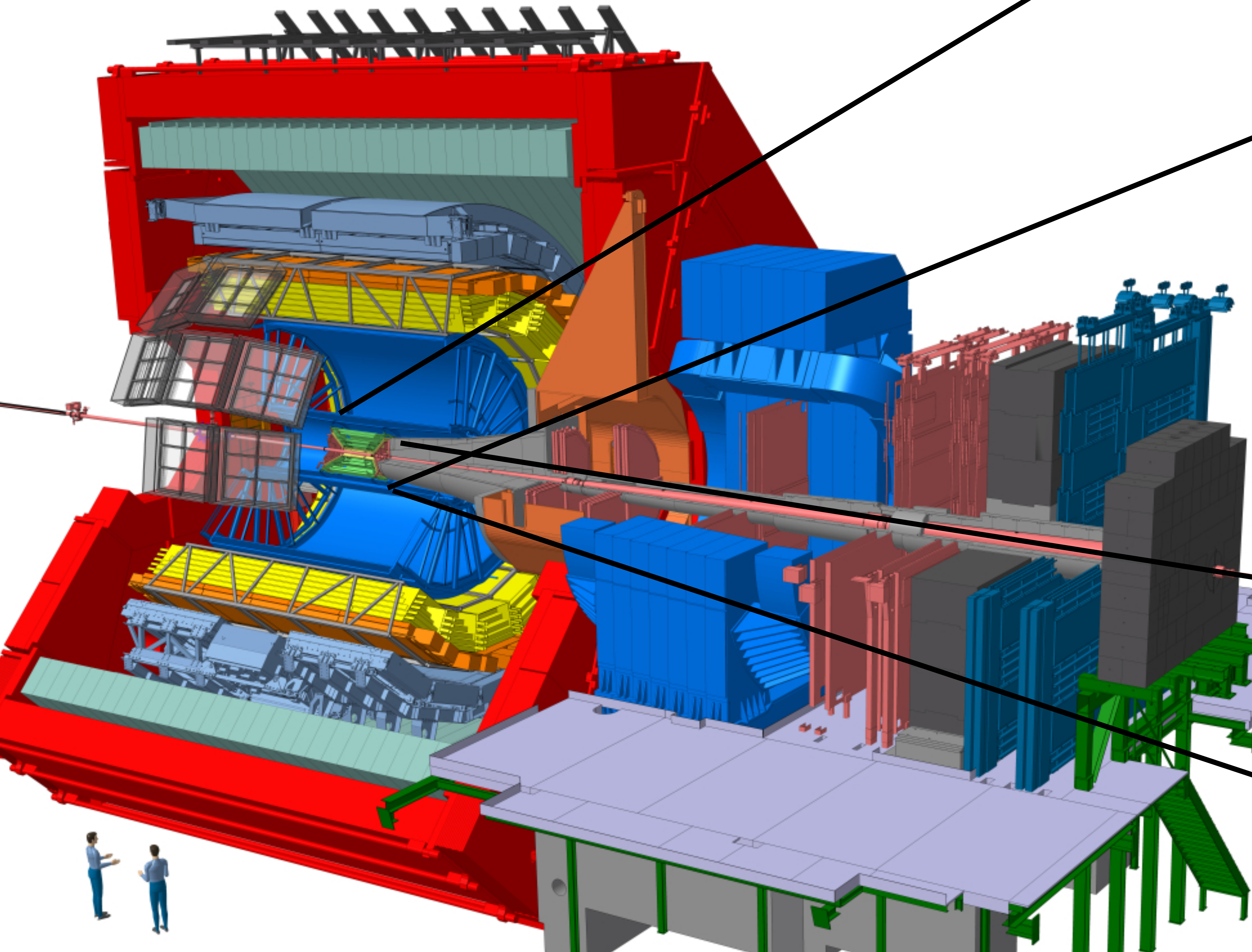


- Study of QGP in heavy-ion collisions at LHC
  - i.e. up to O(10k) particles to be tracked in a single event
- Reconstruction of charm and beauty hadrons
- Interest in low momentum (≲1 GeV/c) particle reconstruction

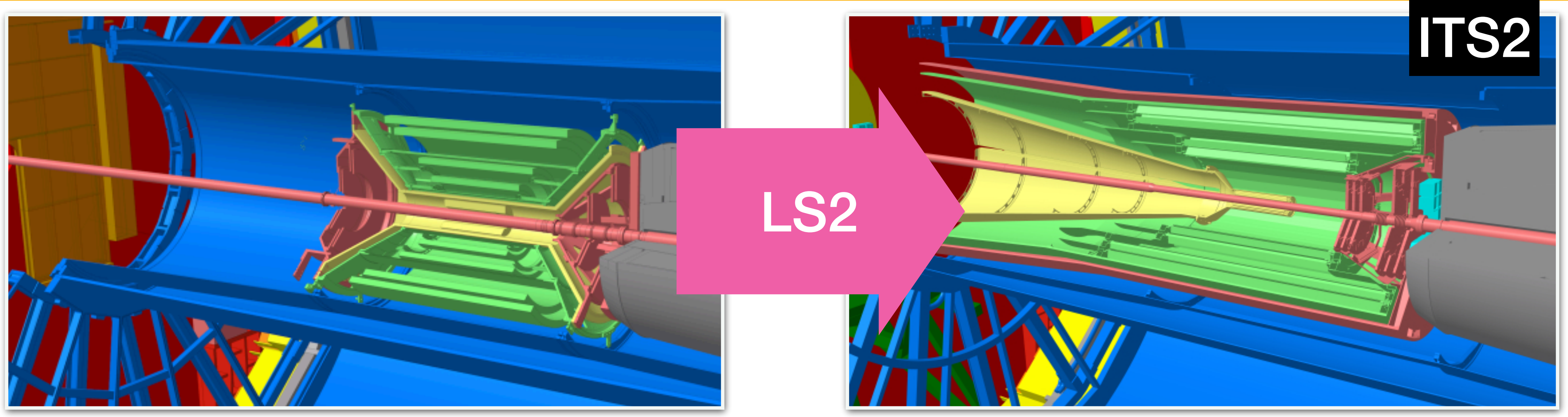


ALICE today

LS2 upgrades with Monolithic Active Pixel Sensors (MAPS)

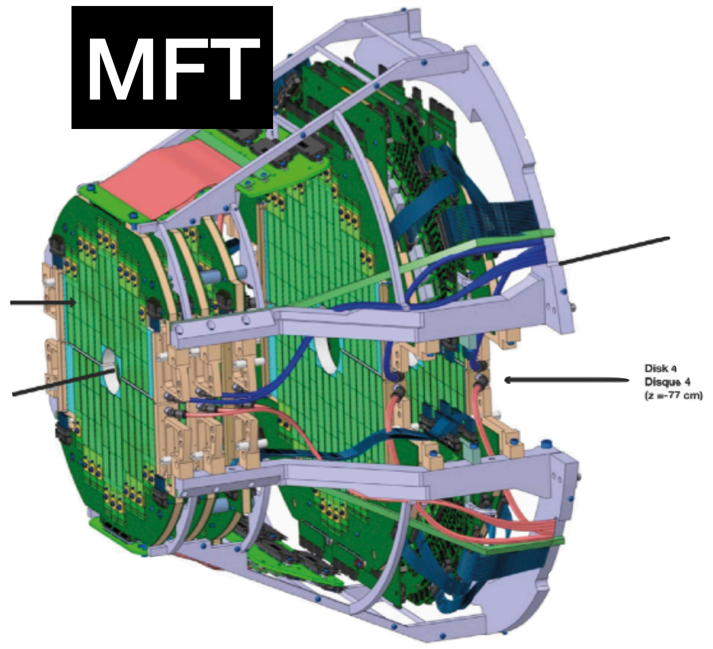


Inner Tracking System



6 layers:	7 layers:
2 hybrid silicon pixel 2 silicon drift 2 silicon strip	all MAPS
Inner-most layer:	**Inner-most layer:**
radial distance: 39 mm	radial distance: 23 mm
material: $X/X_0 = 1.14\%$	material: $X/X_0 = 0.3\%$
pitch: $50 \times 425\ \mu m^2$	pitch: $O(30 \times 30\ \mu m^2)$
rate capability: 1 kHz	**rate capability:** 100 kHz (Pb-Pb)

Muon Forward Tracker

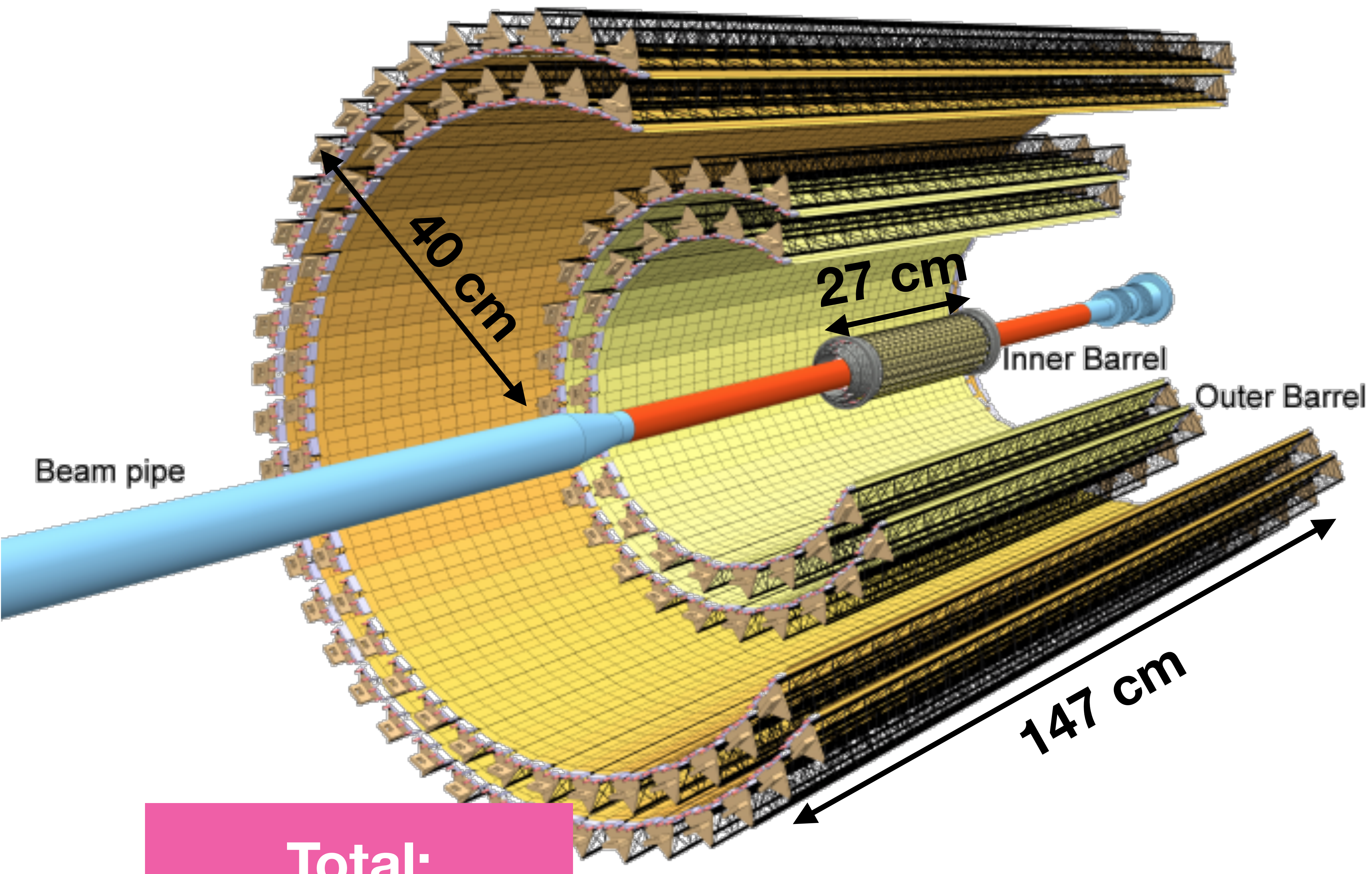


new detector

5 discs, double sided:
based on same technology as ITS2

ITS2 overview

Layout



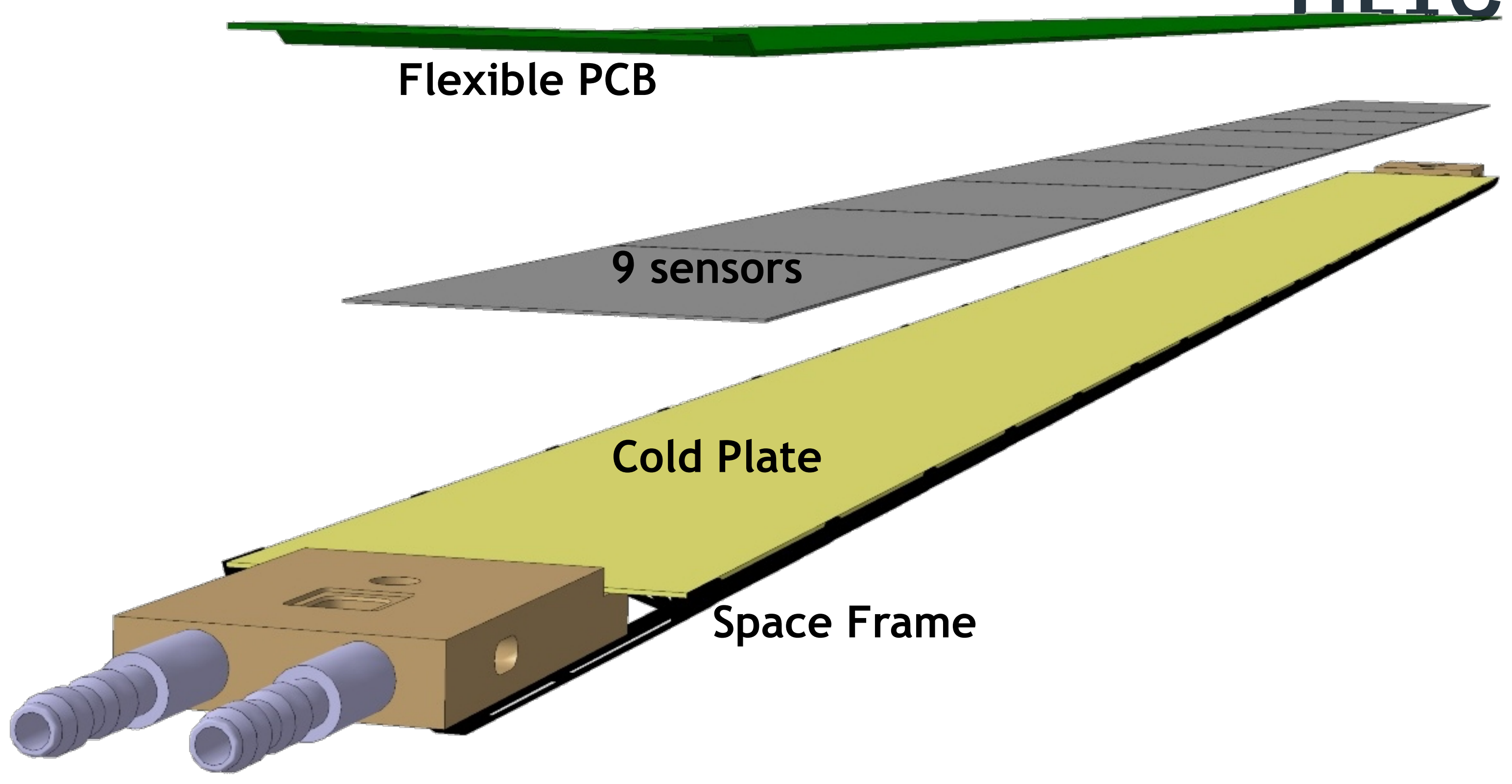
Total:
- 24k chips
- 10 m²
- 12.5 GPixel

Inner Barrel (IB)

3 Inner Layers: 12+16+20 Staves
1 Module / Stave

9 sensors per Module

96 Modules to be produced

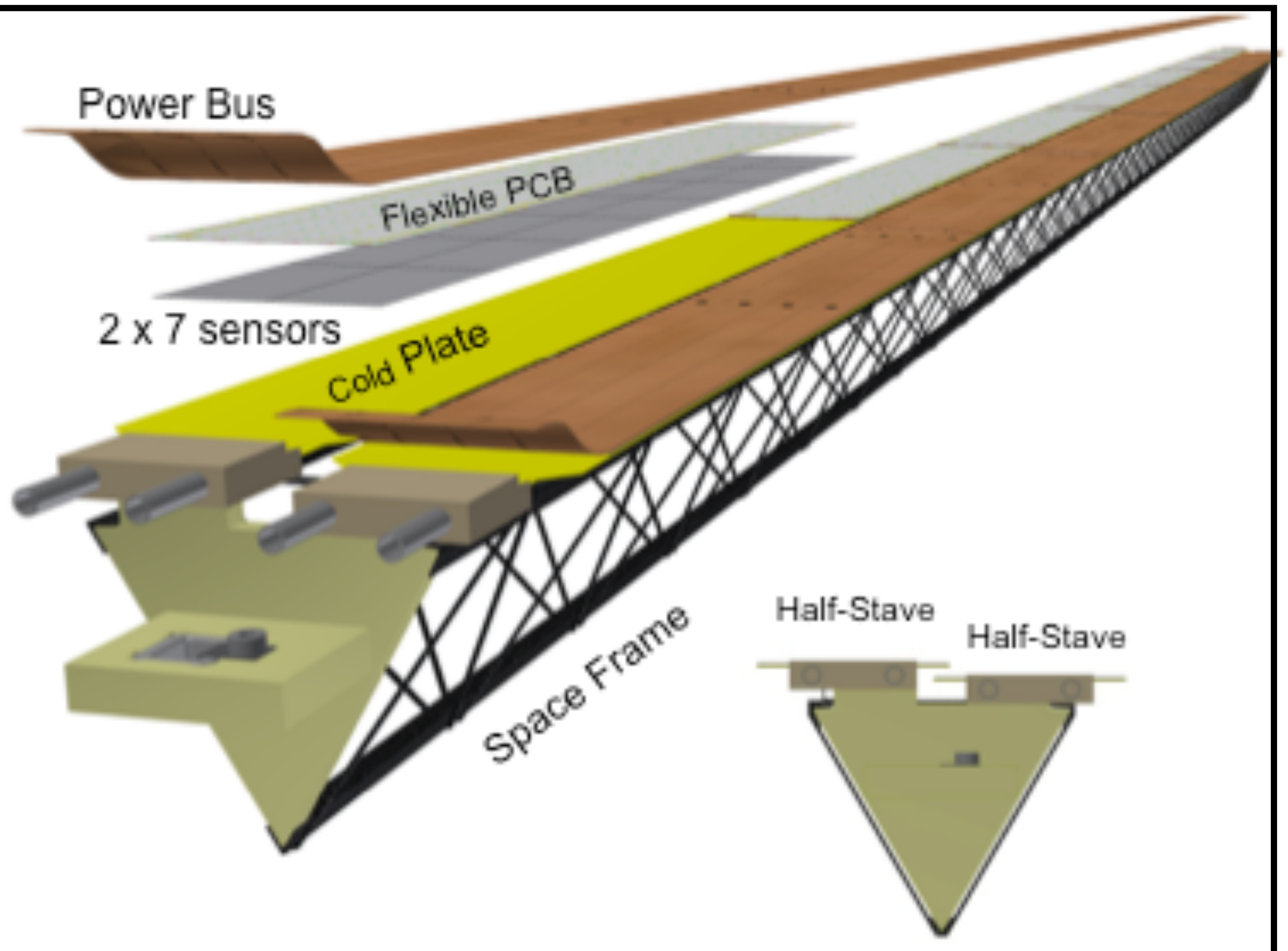


Outer Barrel (OB)

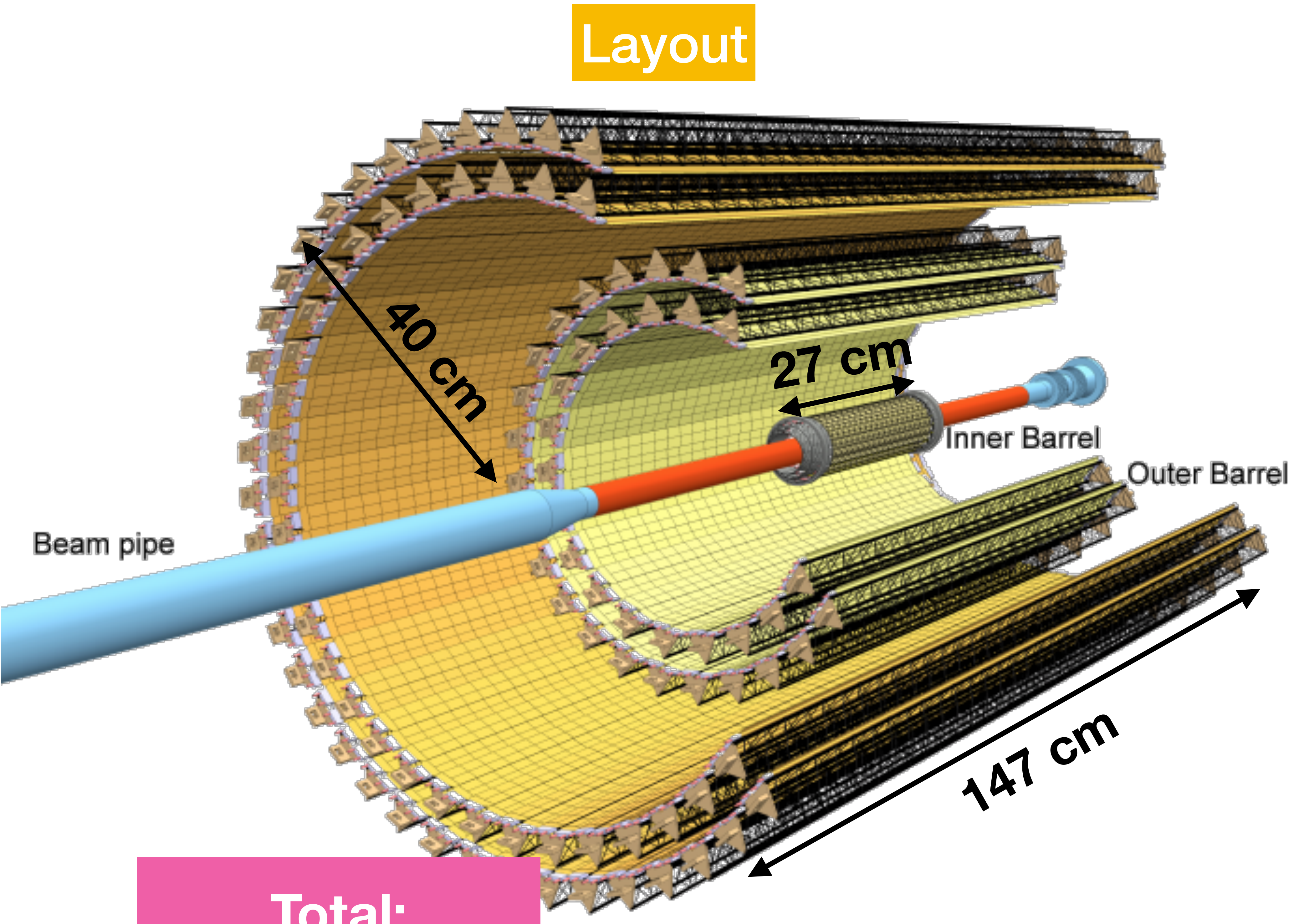
2 Middle Layers: 30+24 Staves
2×4 Modules / Stave
2 Outer Layers: 42+48 Staves
2×7 Modules / Stave

2×7 sensors / Module
(Middle and Outer Layers are equipped with the same Module Type)

1880 Modules to be produced (including spares)



ITS2 overview



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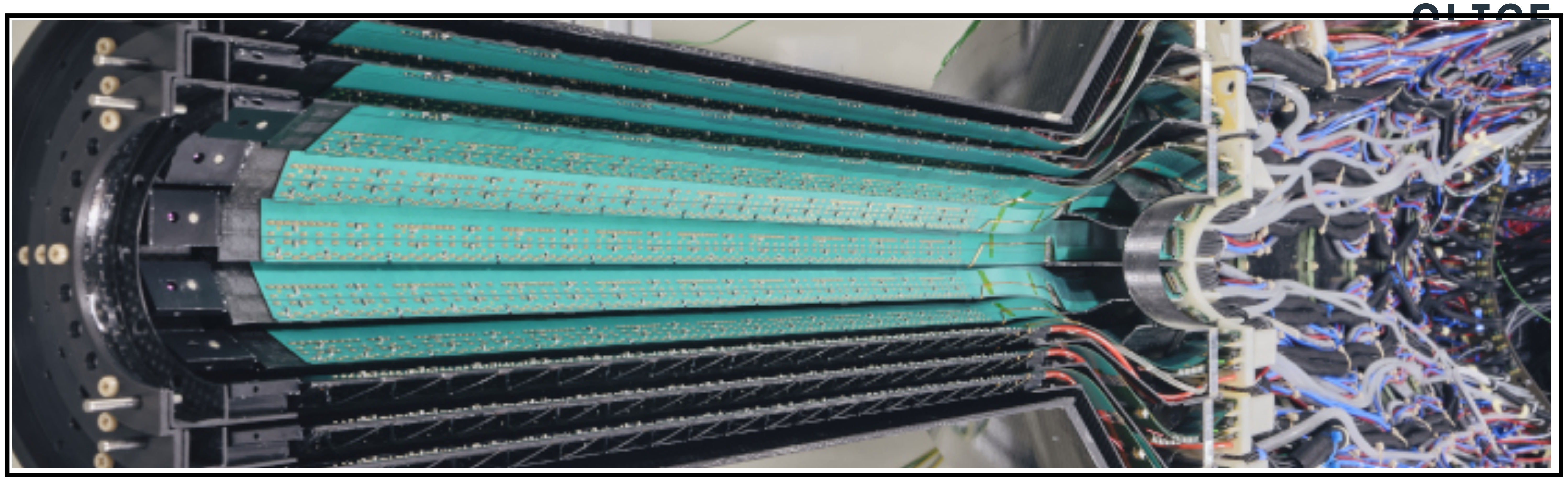
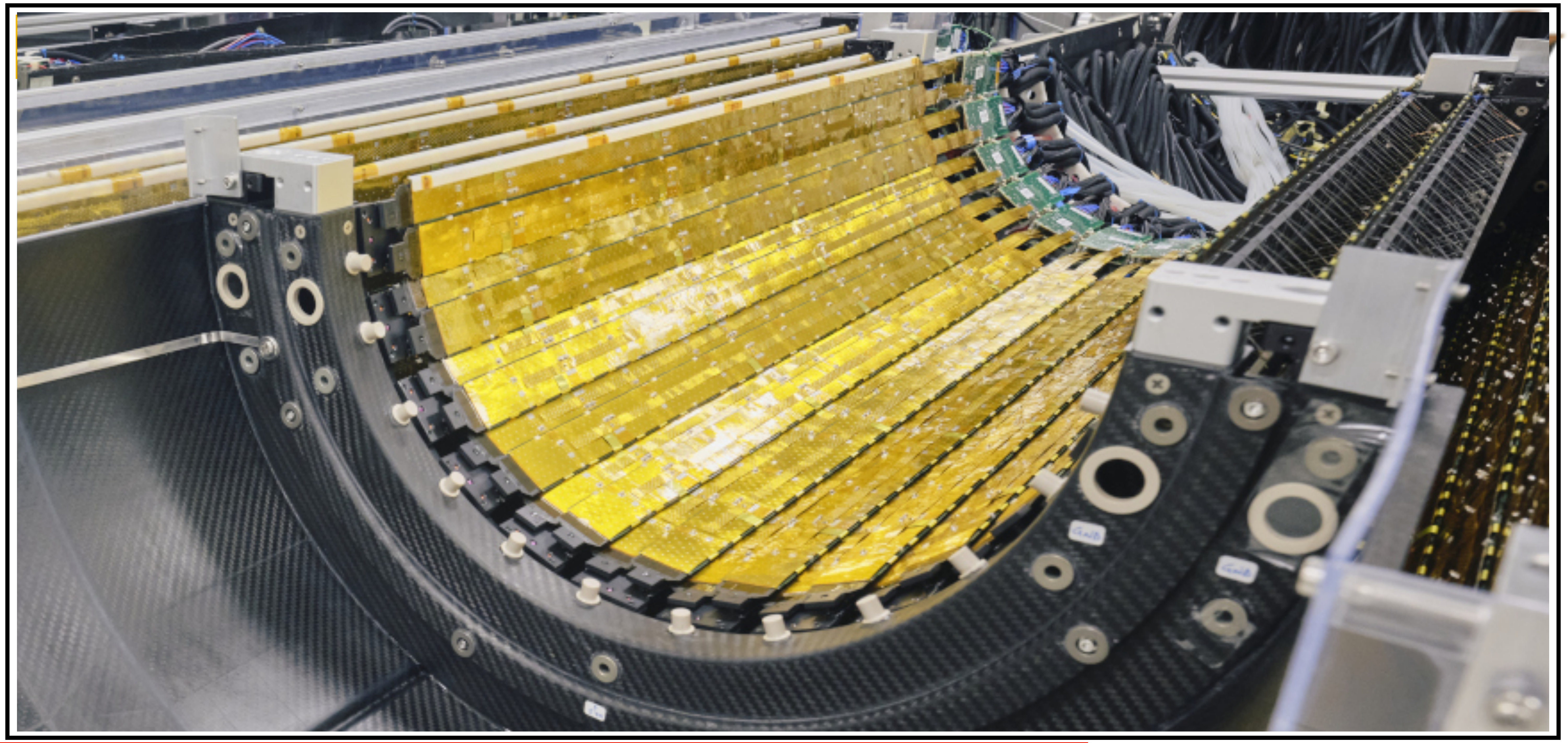




Good news: it was all built, assembled and tested!

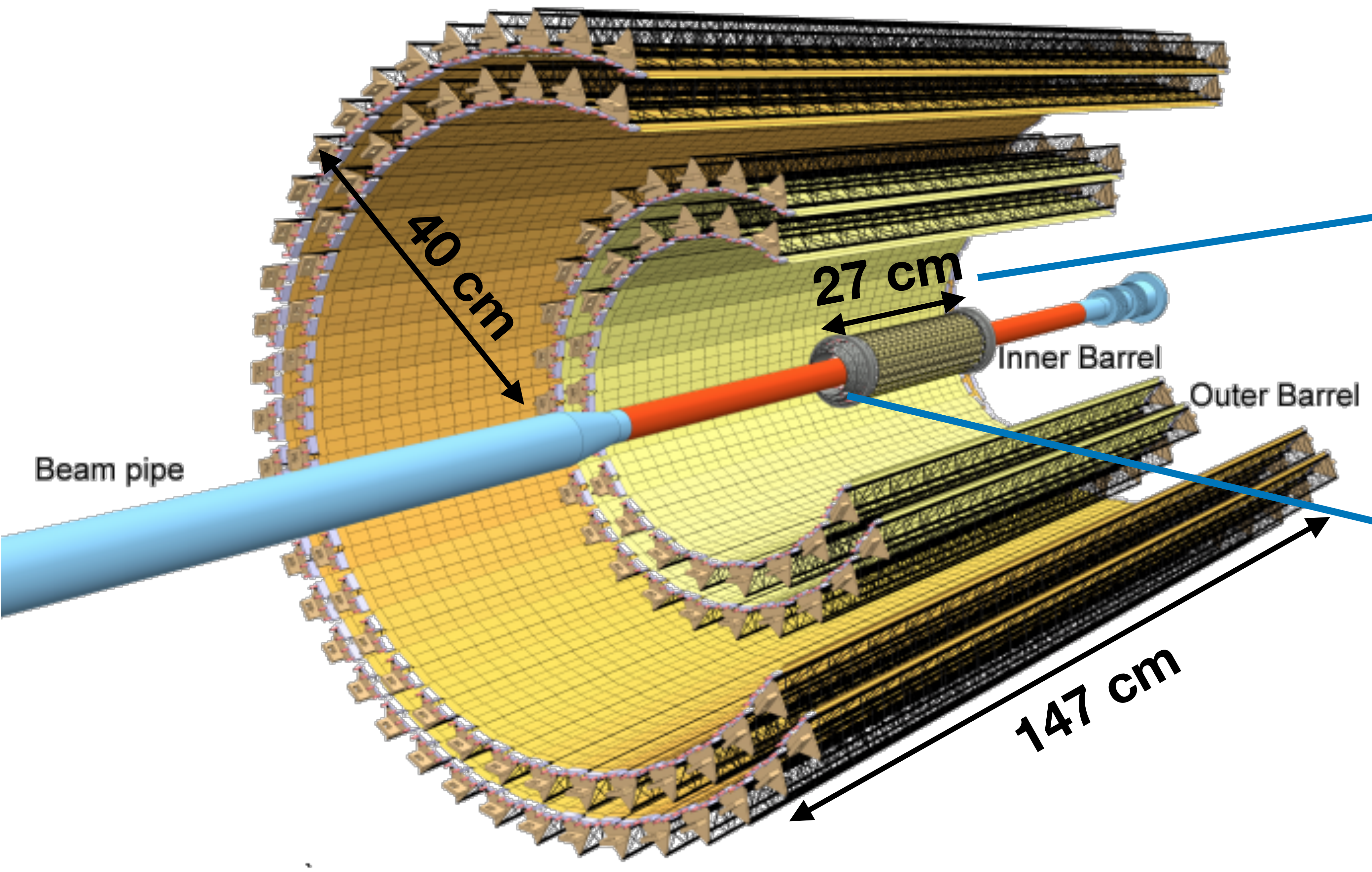
ITS2 installation

Insertion of first Outer Half-Barrel

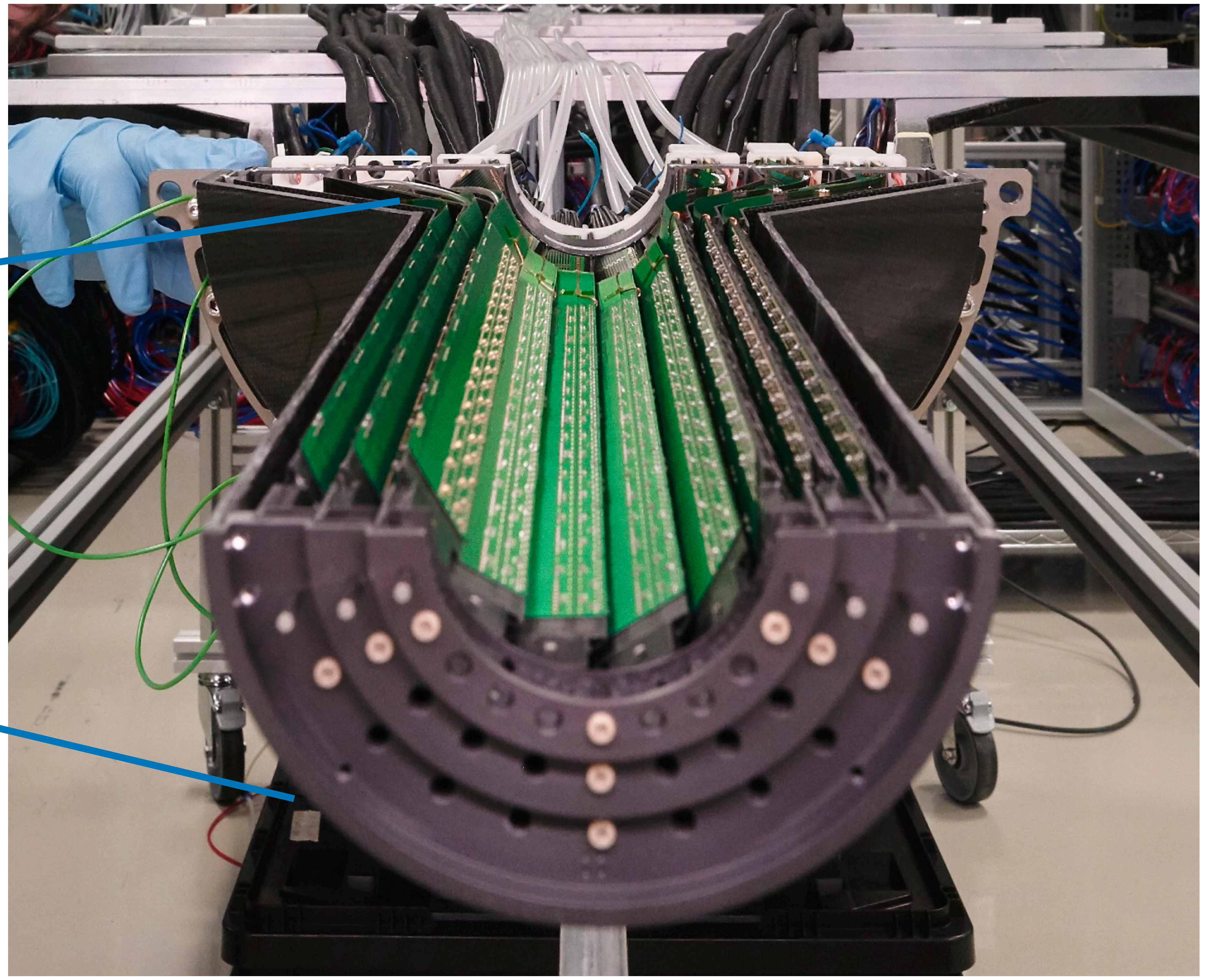
Status today: Outer Barrel is completely installed

ITS2 inner barrel

Layout

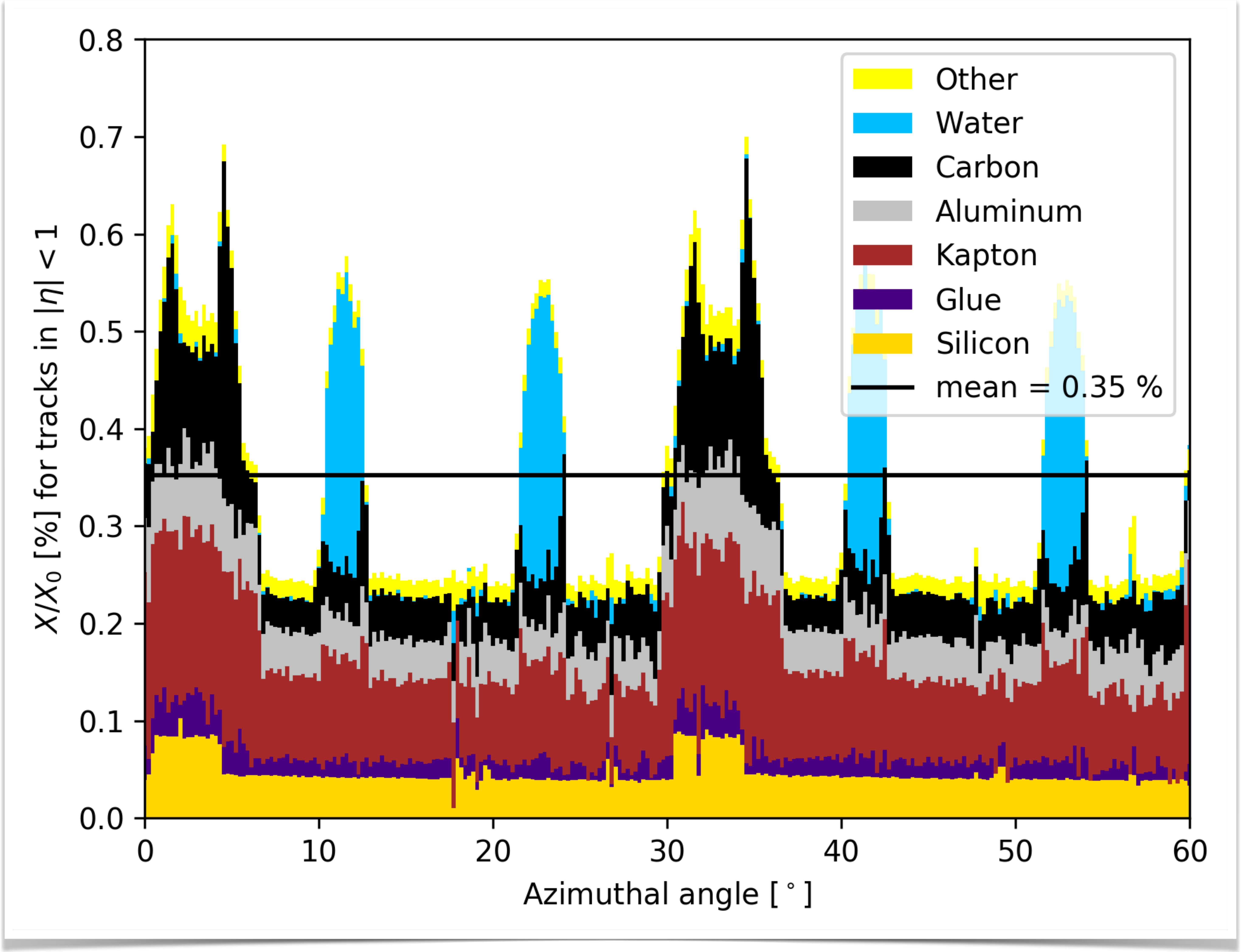


ITS2: assembled three inner-most half-layers



- ITS2 is expected to perform according to specifications or even better
- The Inner Barrel is ultra-light but rather packed → further improvements seem possible
- **Key questions: Can we get closer to the IP? Can we reduce the material further?**

Motivation for ITS3



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  - Si makes only **1/7th** of total material
  - **irregularities** due to support/ cooling

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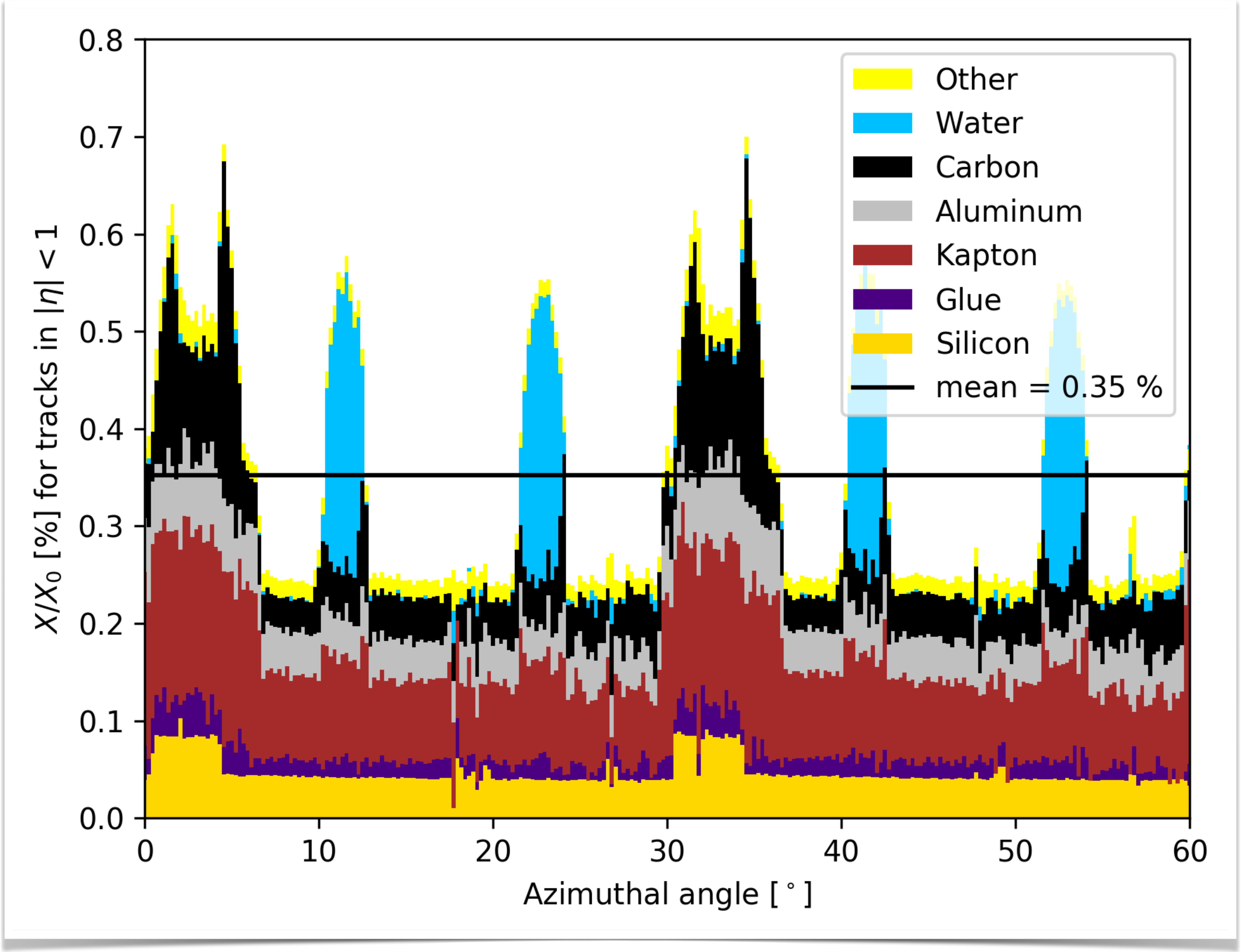

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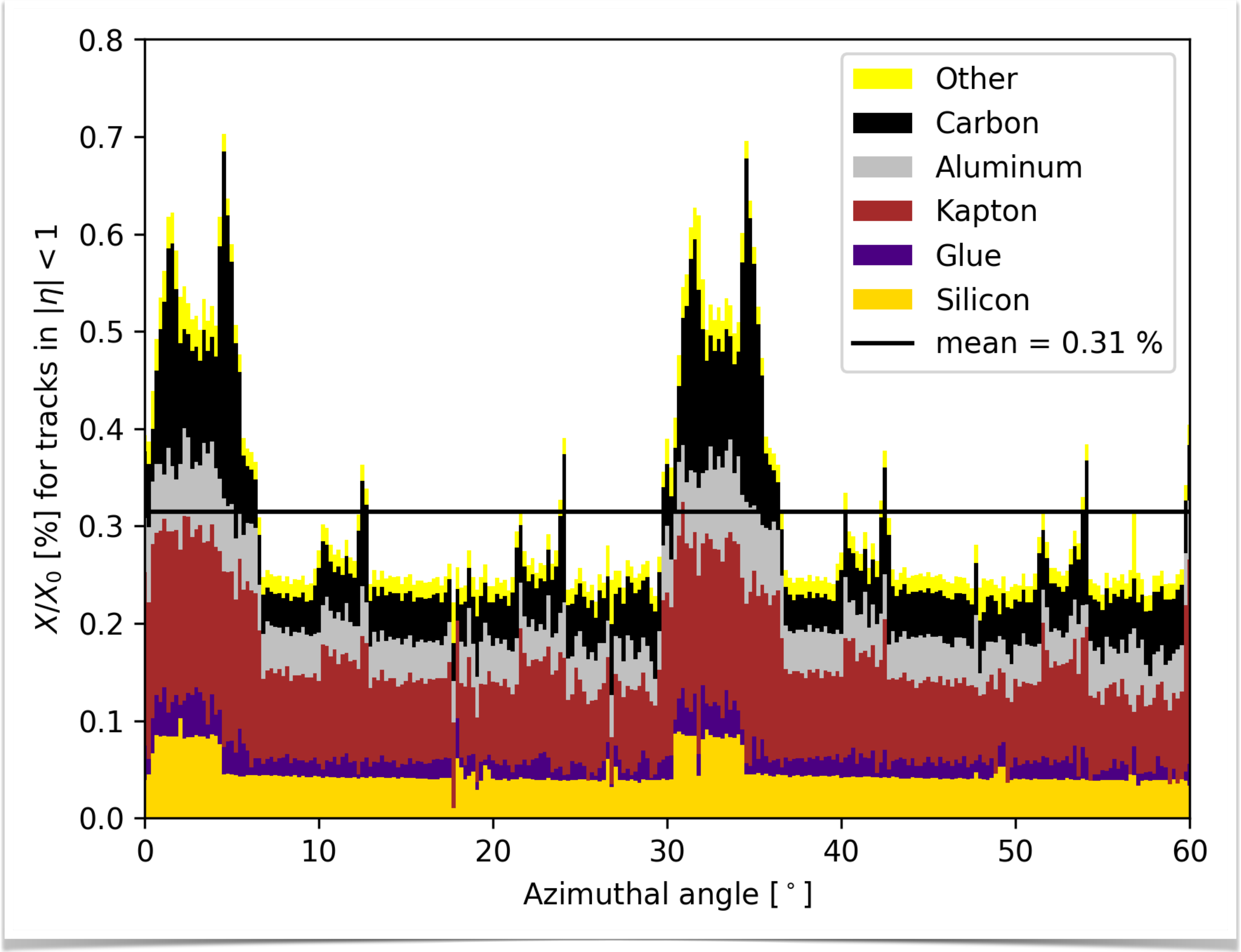

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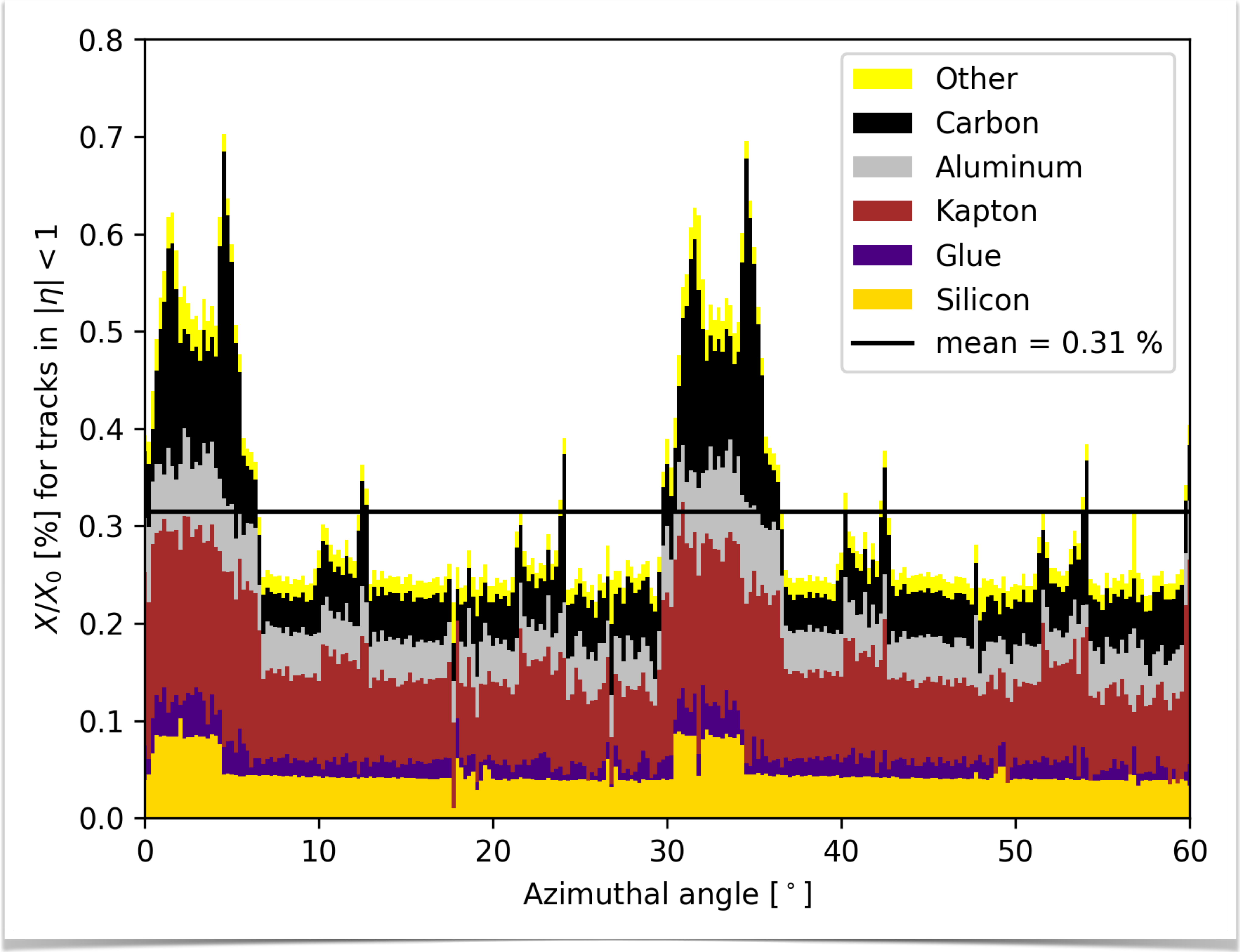

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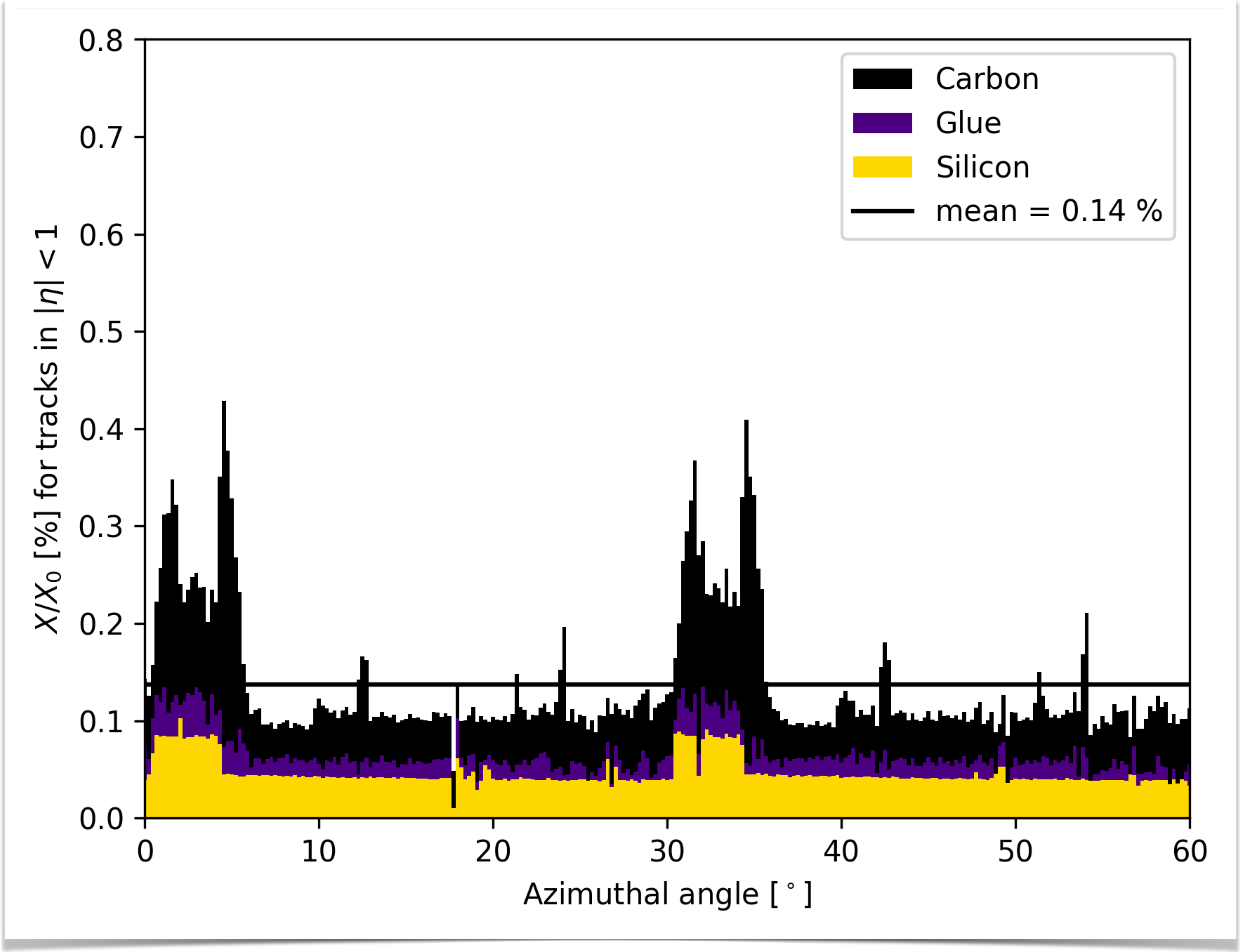

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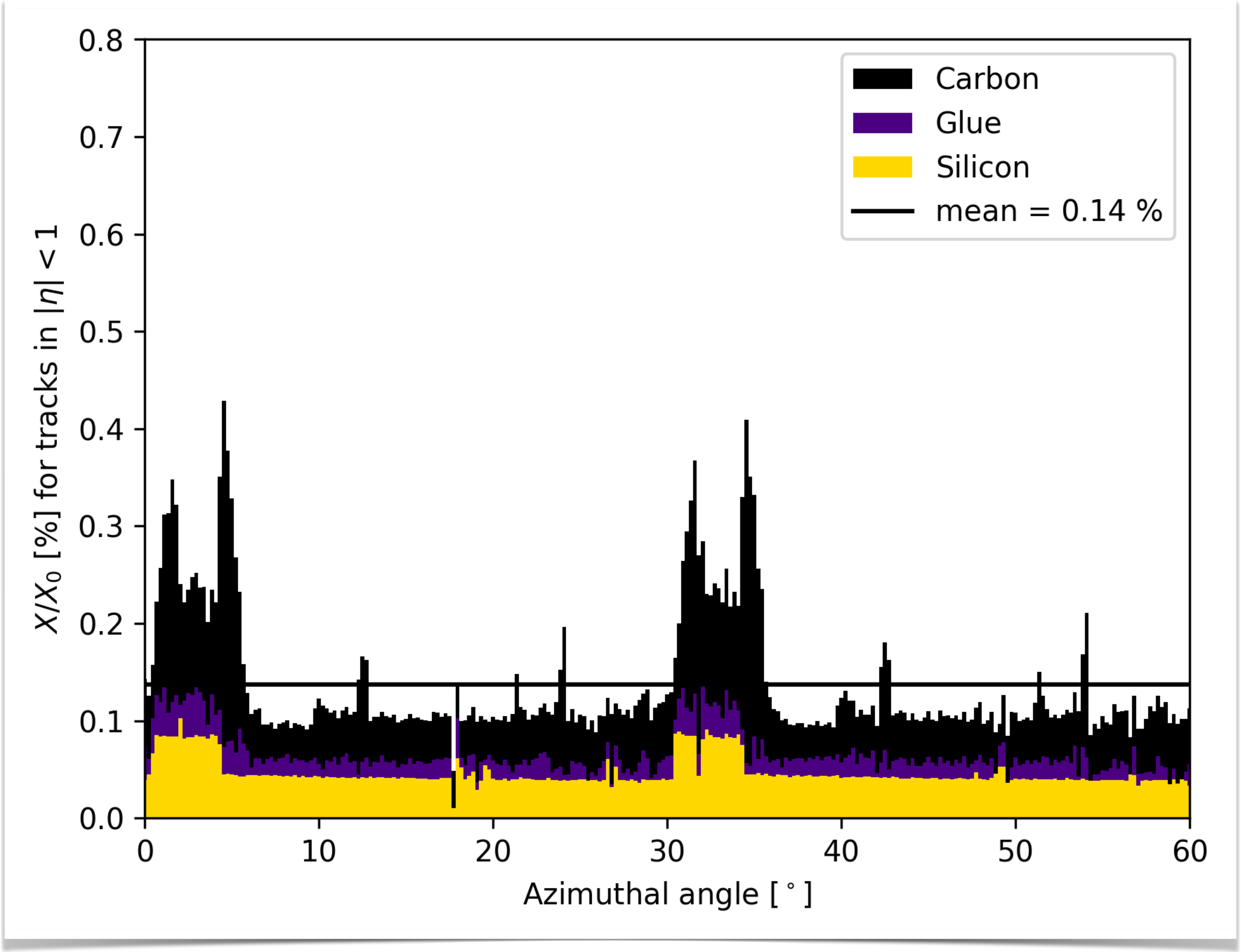

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- Removal of mechanical support
  - **benefit** from increased stiffness by rolling Si wafers

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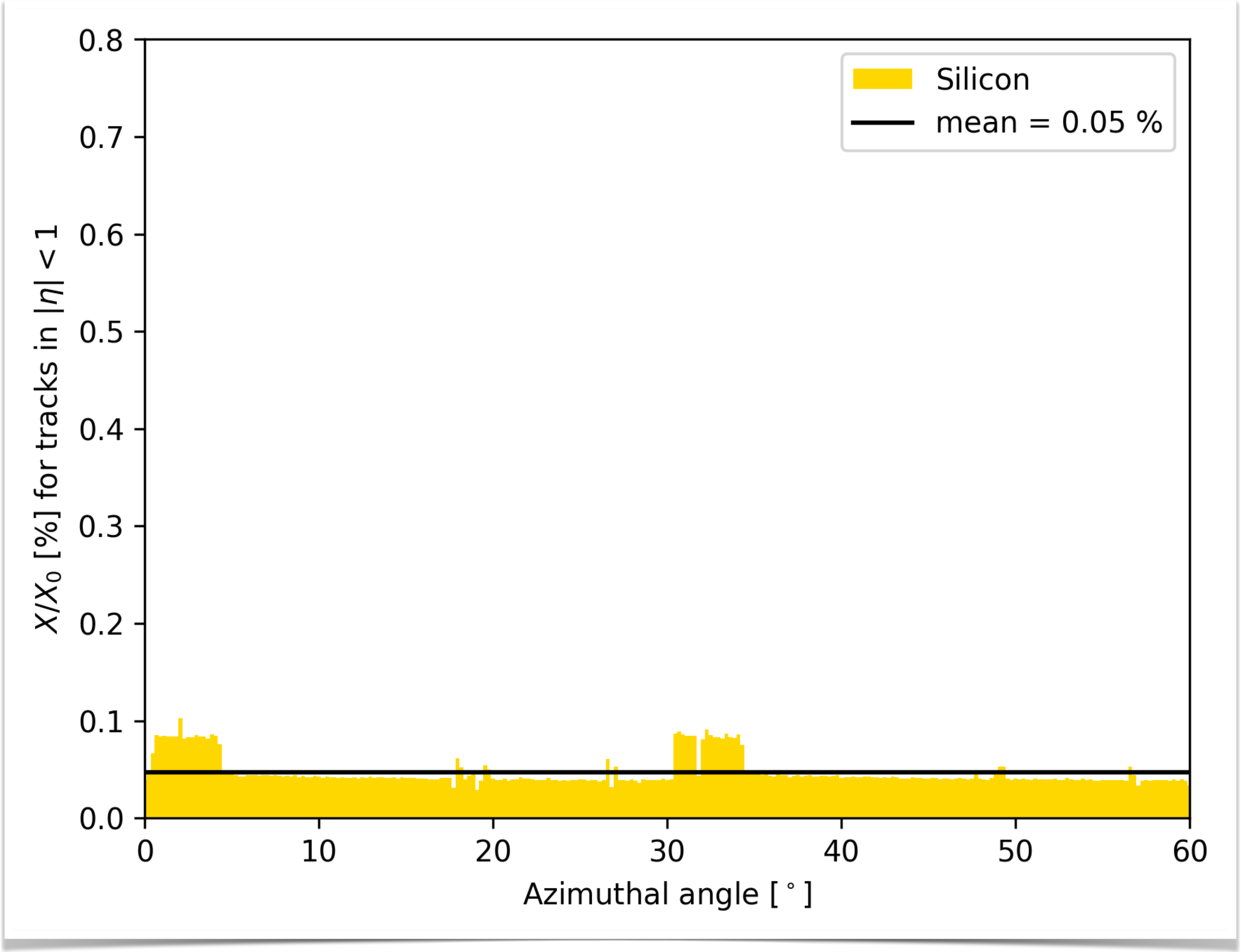

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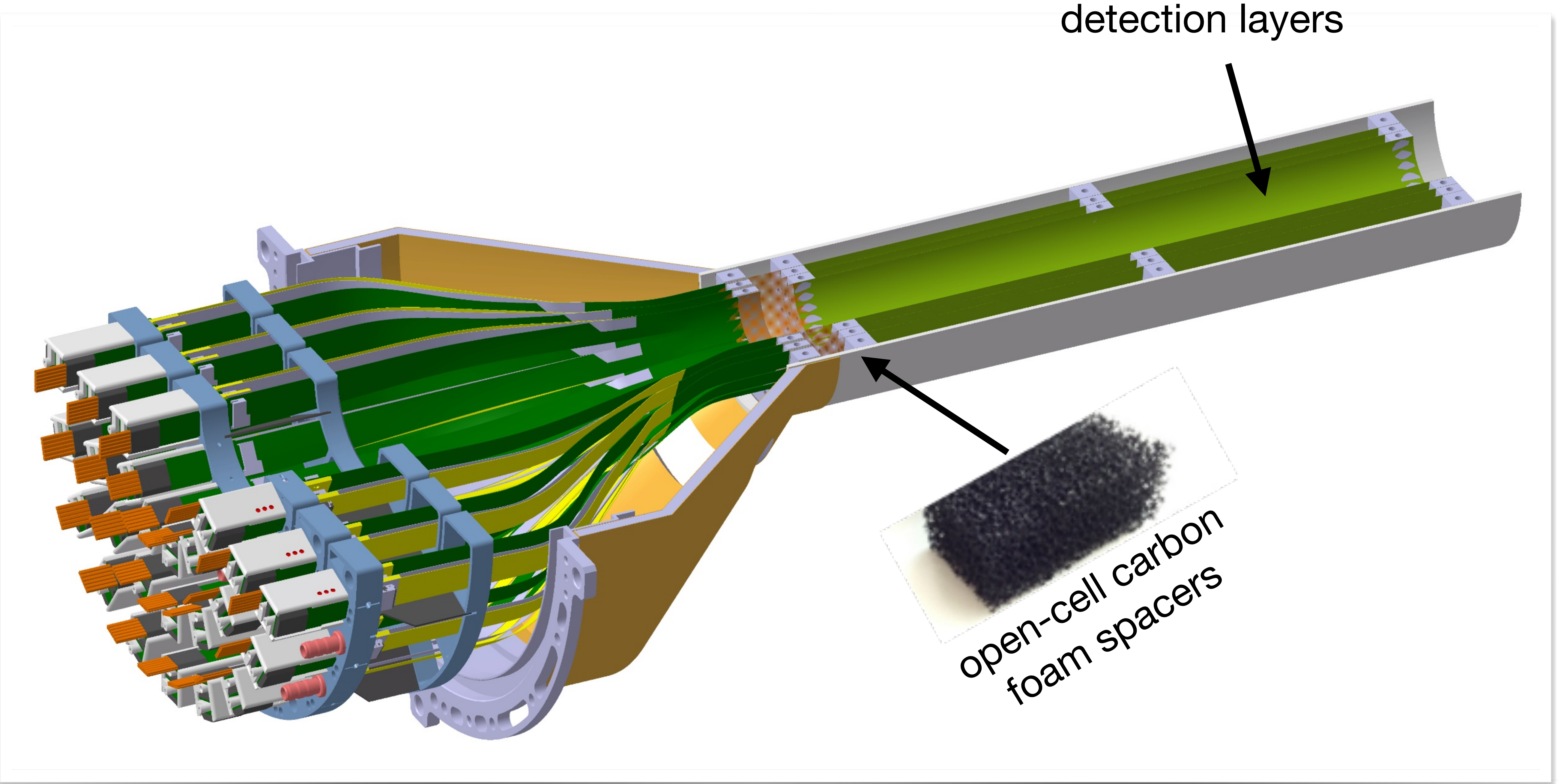
ITS3 detector concept



Beam pipe Inner/Outer Radius (mm)	16.0/16.5		
IB Layer Parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	300		
Pseudo-rapidity coverage	±2.5	±2.3	±2.0
Active area (cm^2)	610	816	1016
Pixel sensor dimensions (mm^2)	280 x 56.5	280 x 75.5	280 x 94
Number of sensors per layer	2		
Pixel size (μm^2)	O (10 x 10)		

- Key ingredients:
  - 300 mm wafer-scale chips, fabricated using stitching
  - thinned down to 20-40 µm (0.02-0.04% X0), making them flexible
  - bent to the target radii
  - mechanically held in place by carbon foam ribs
- Key benefits:
  - extremely low material budget: 0.02-0.04% X0 (beampipe: 500 µm Be: 0.14% X0)
  - homogeneous material distribution: negligible systematic error from material distribution

The whole detector will comprise six (!) chips (current ITS IB: 432) – and barely anything else

ITS3 performance figures

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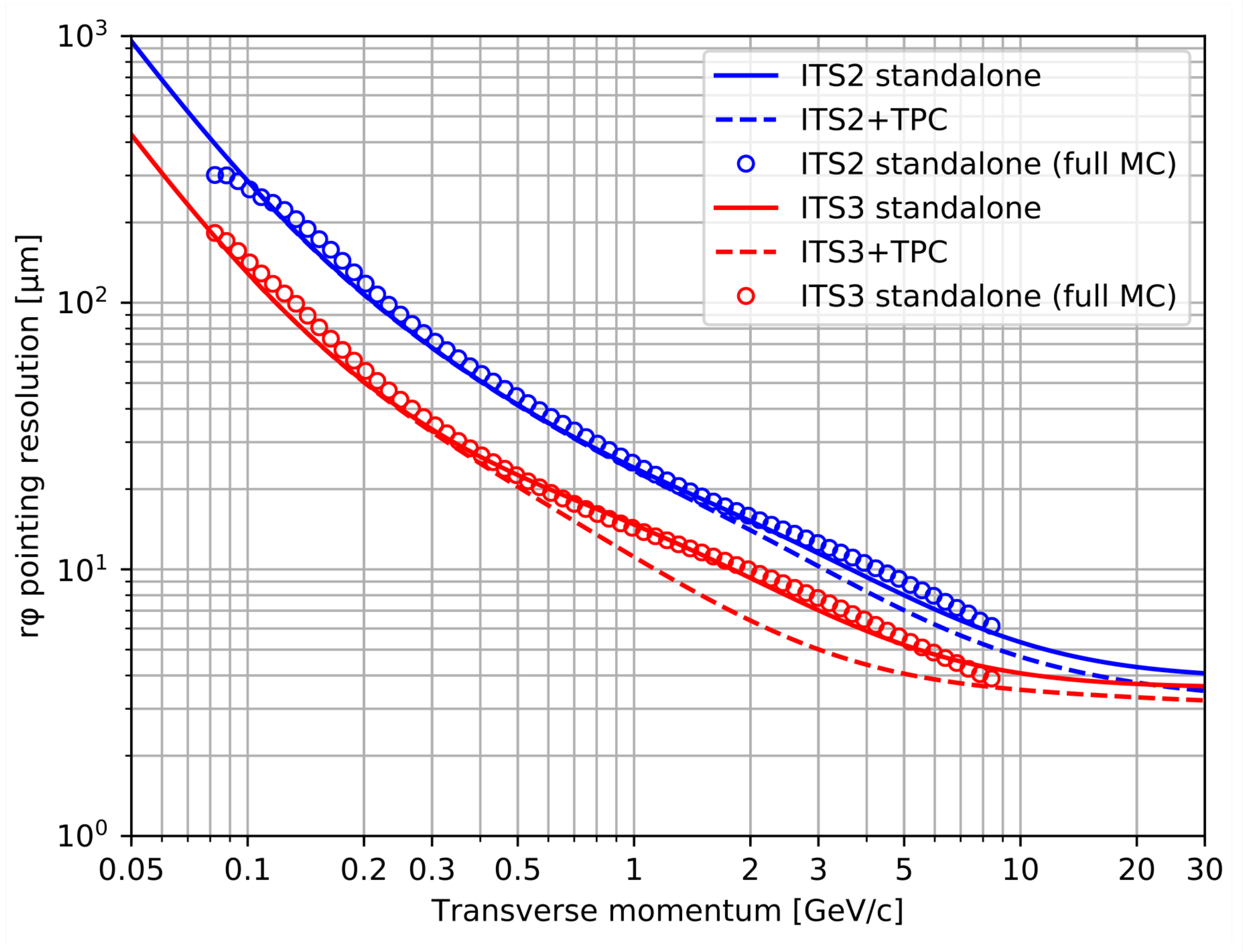
pointing resolution



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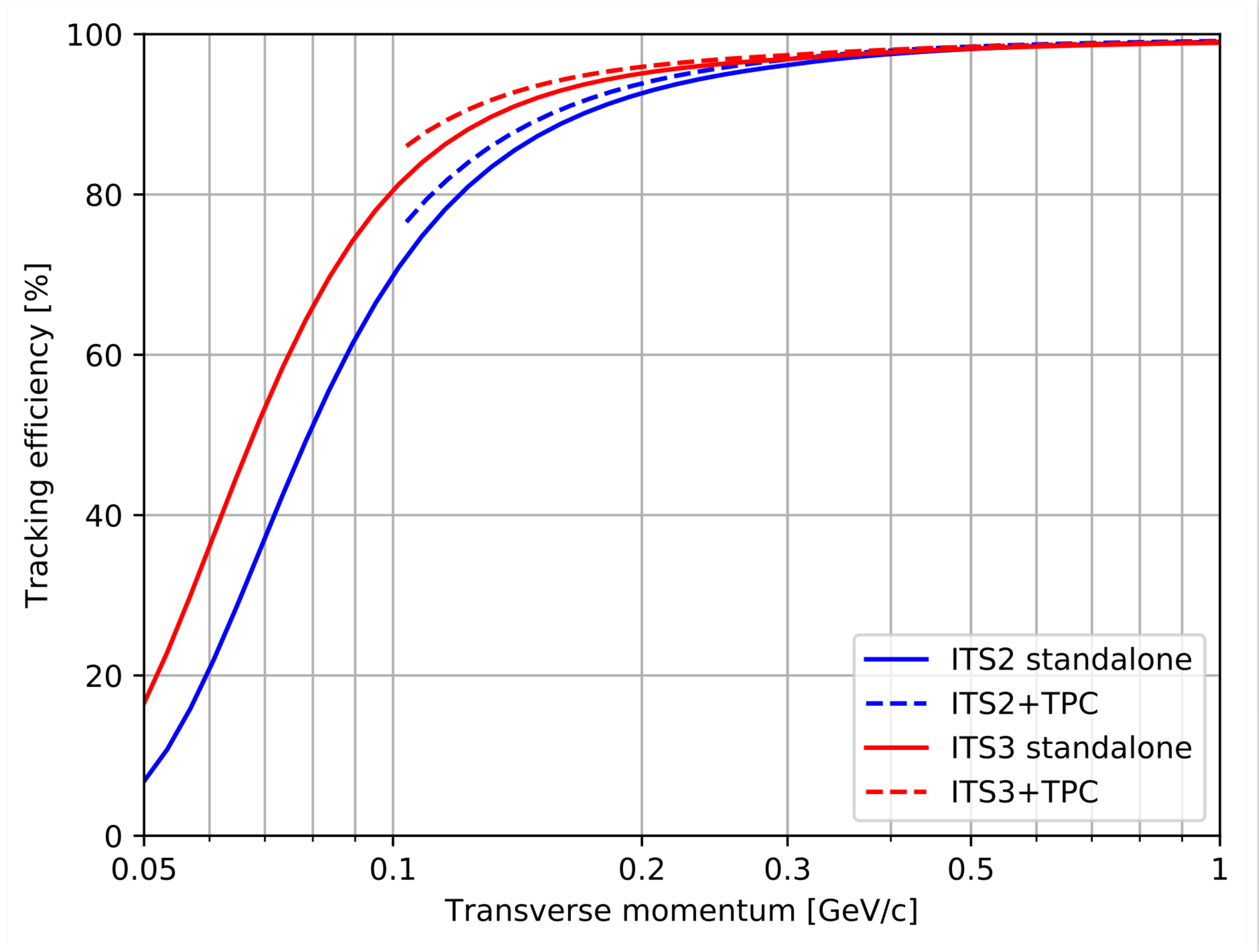
improvement of factor 2 over all momenta

tracking efficiency



large improvement for low transverse momenta

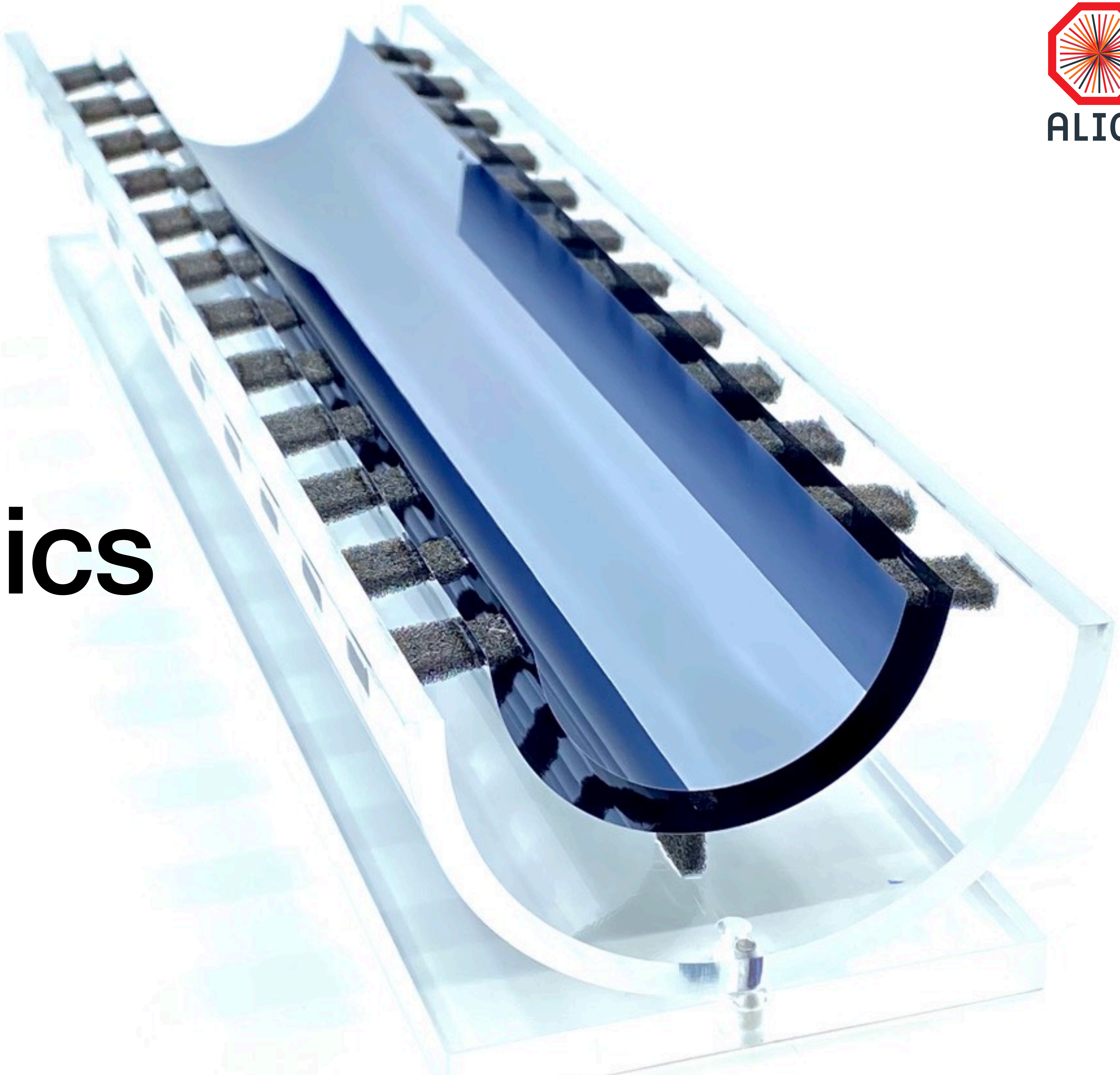
Timeline

main milestones

We are on track!

MLR: multiple layer per reticle, **ER:** engineering run,
BM: breadboard module, **EM:** engineering module, **QM:** qualification module, **FM:** final module

R&D: mechanics



Bending of wafer-scale chips

procedure

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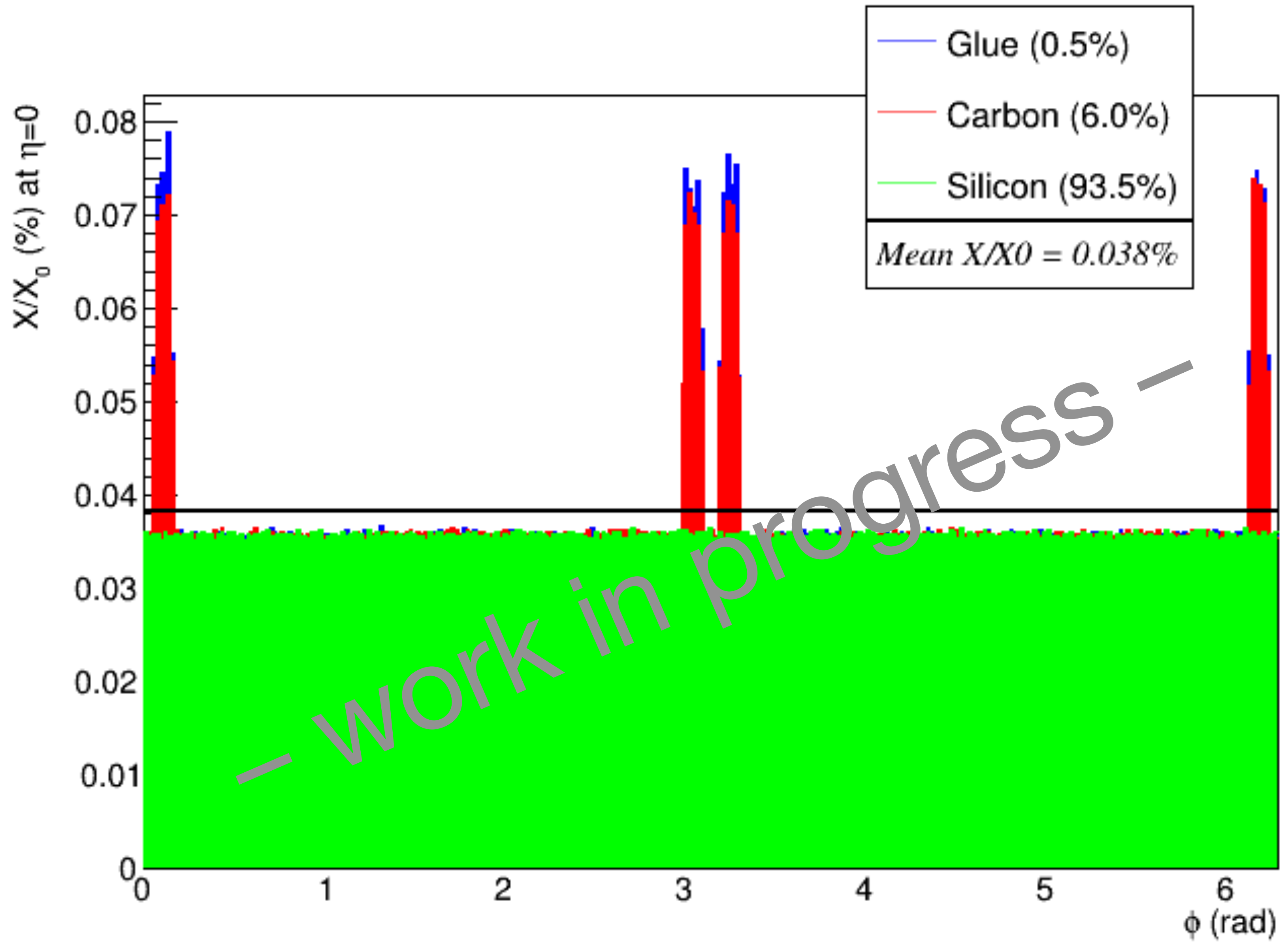
30 mm (L2)

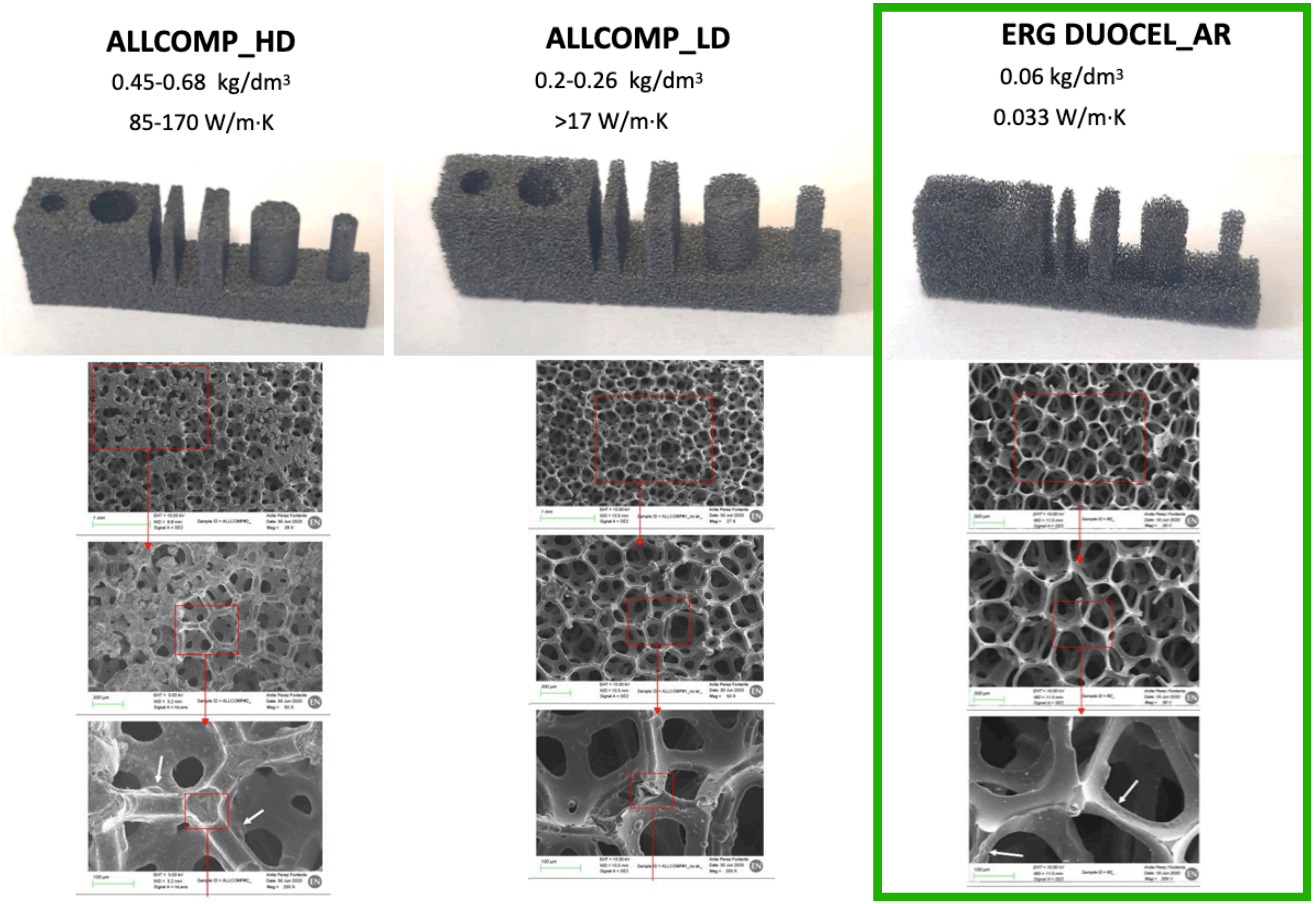
50 µm dummy chip

Carbon foam

selection complete

- Different foams were characterised for machinability and thermal properties
- Baseline is
ERG DUOCEL_AR,
which also features the largest radiation length



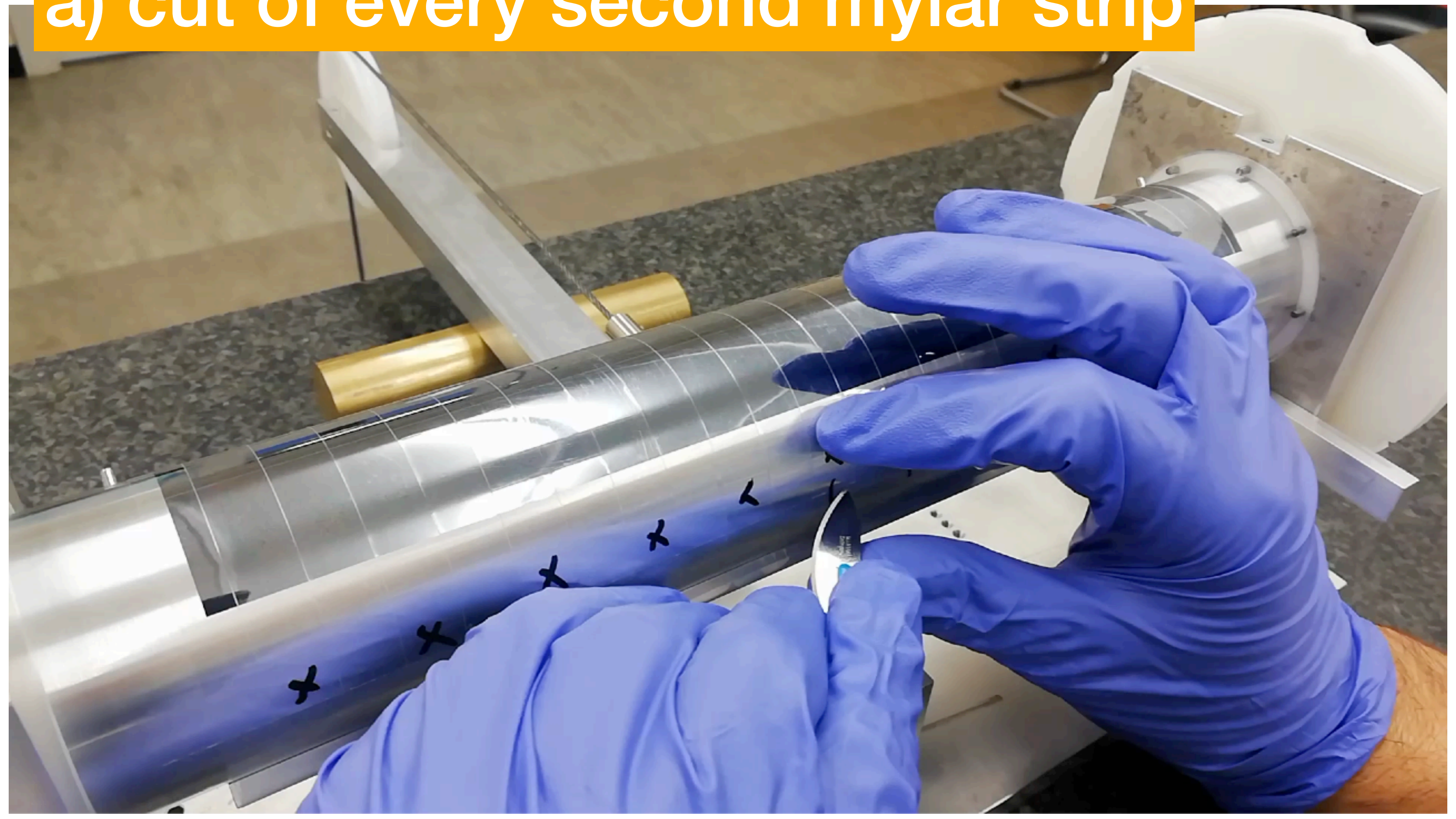


Attachment of foam supports

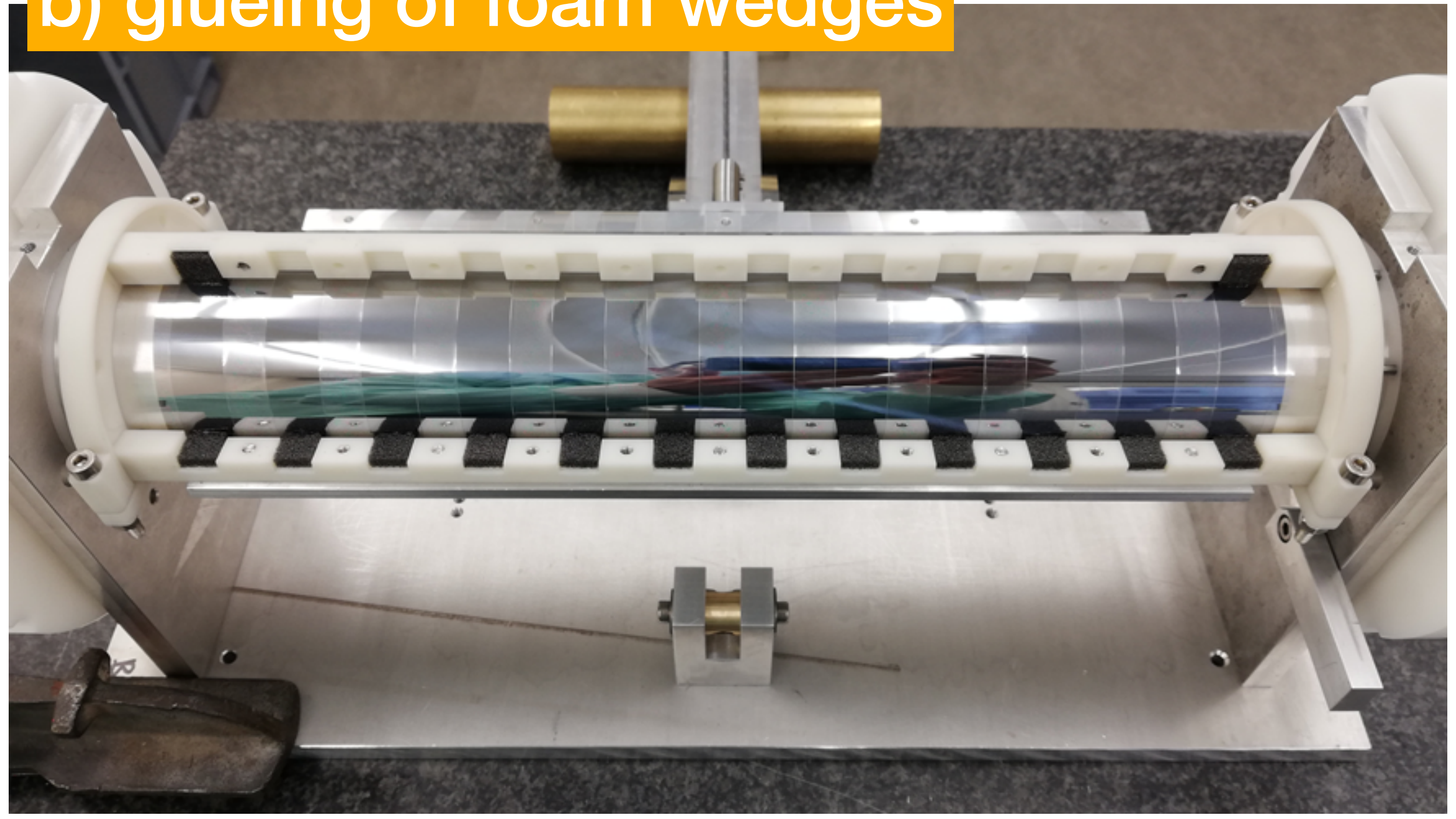
procedure

- Assembly process being developed
- Different options under study (incl. vacuum clamping)
- Currently working solution based on segmented mylar foil

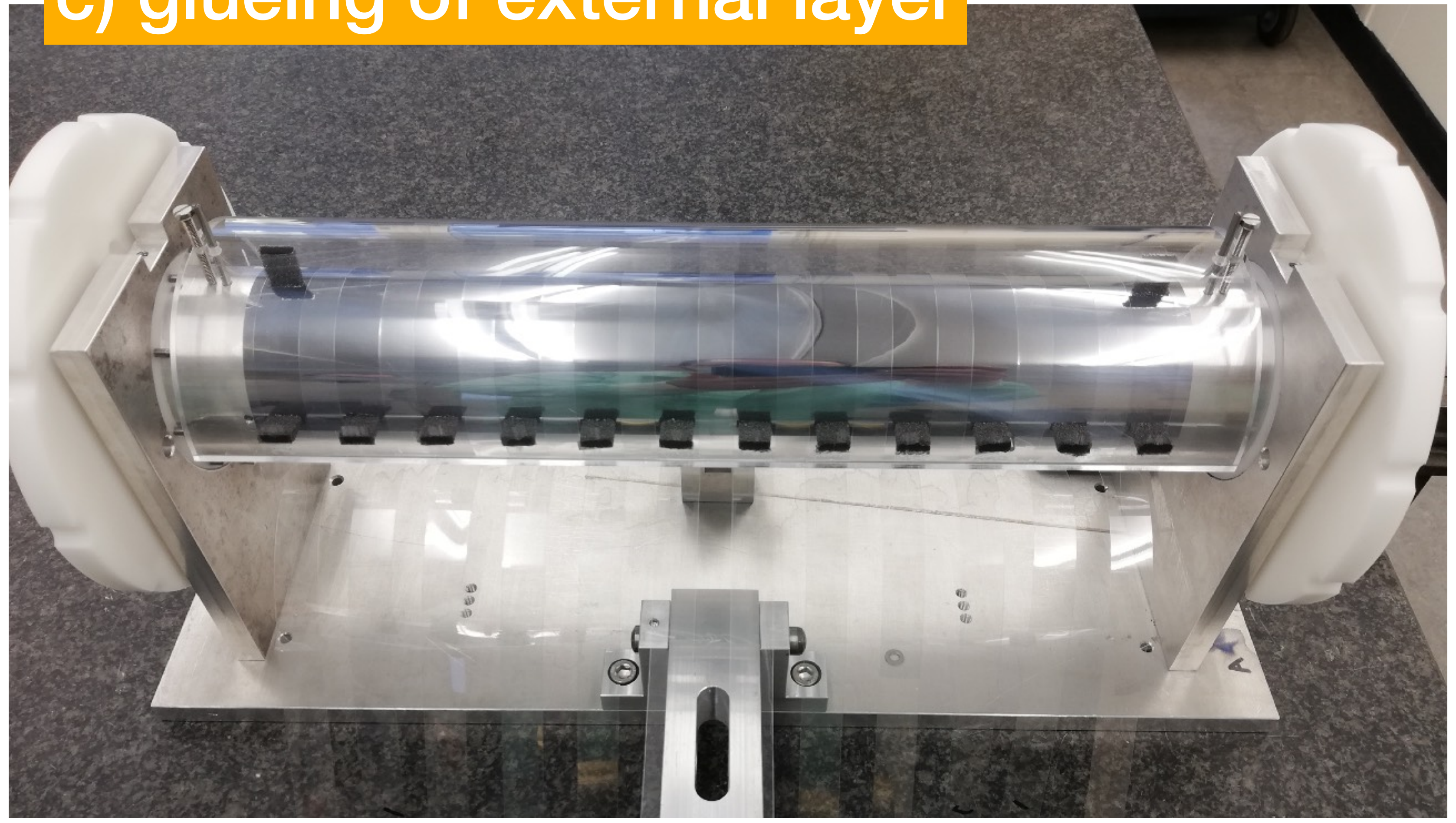
a) cut of every second mylar strip



b) glueing of foam wedges

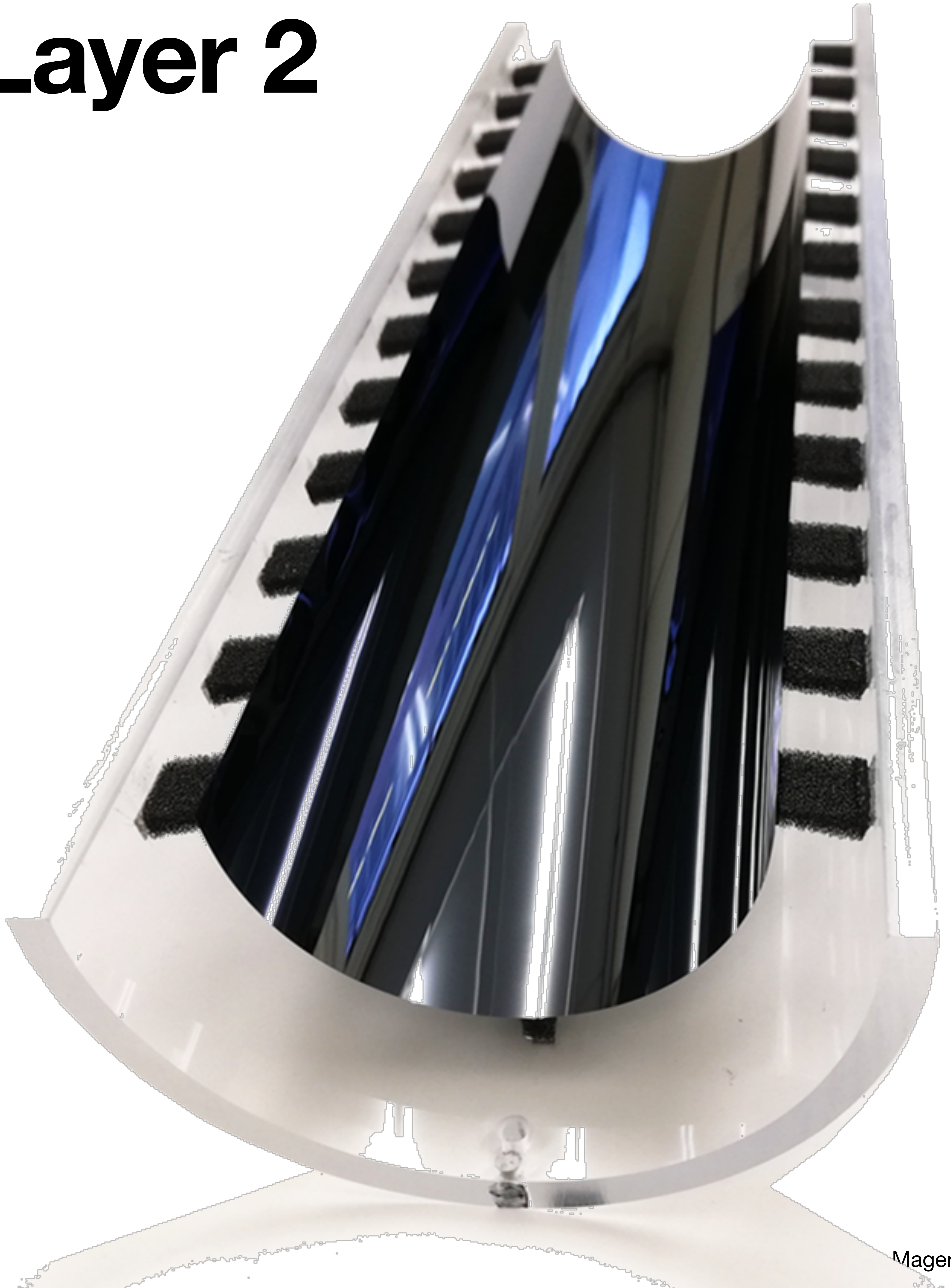


c) glueing of external layer



d) removal of remaining strips

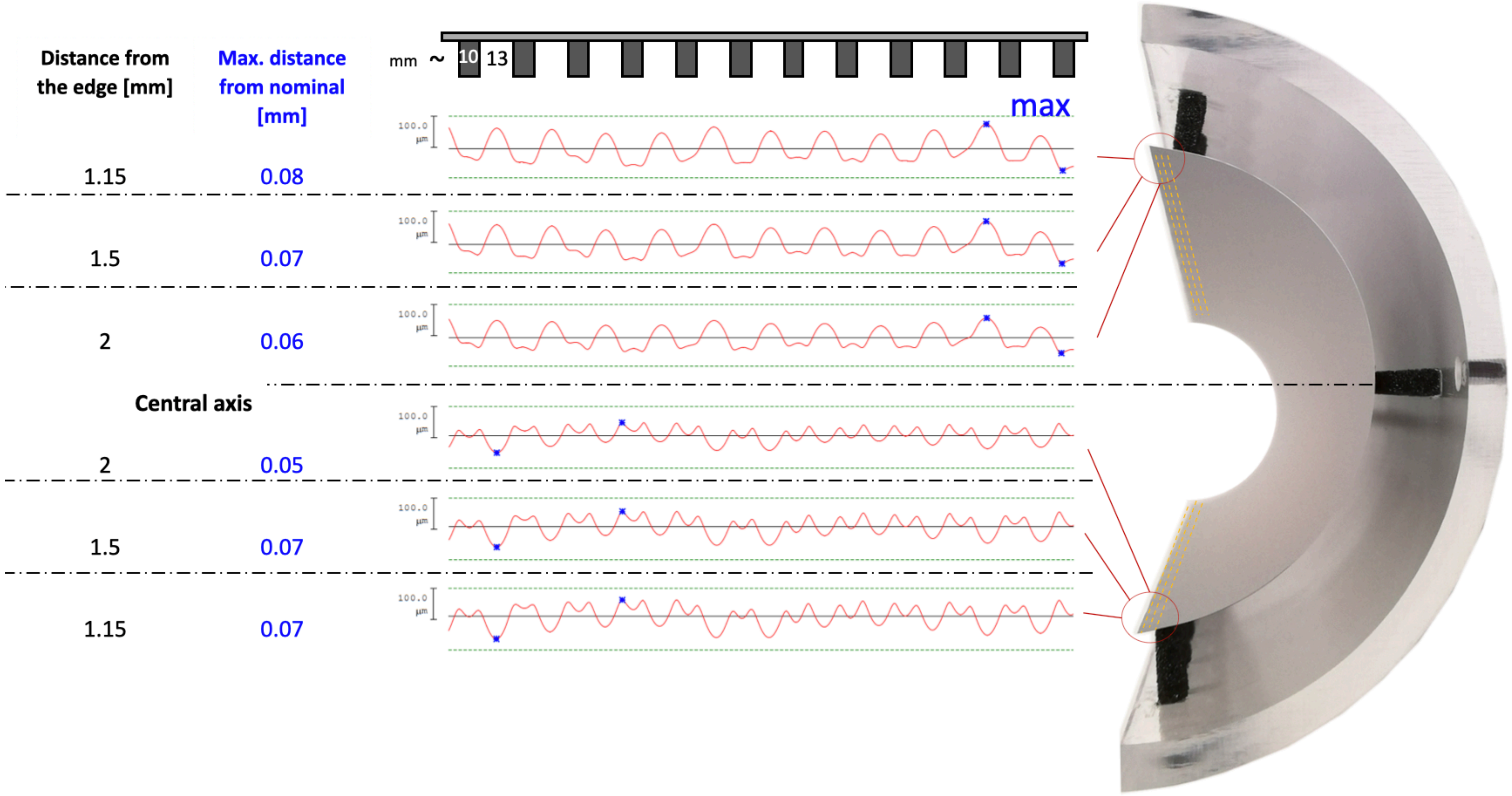
Assembled Layer 2



Metrology

Layer 2

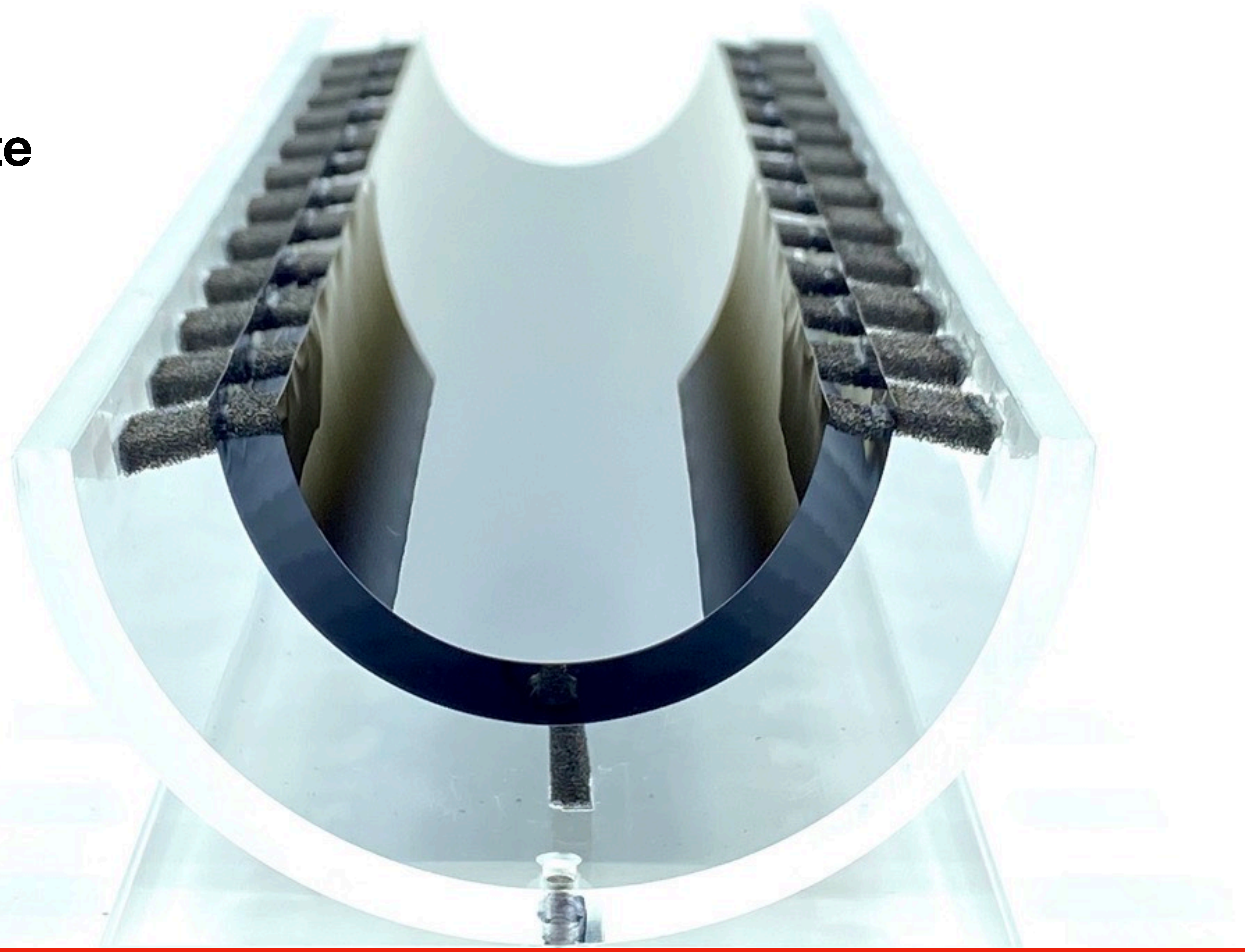
- Reflective, mirror-like, surface fo the Si chip allows for precise measurement of deflections
- Very small off-shape variation: <100 µm
- Further optimisation of carbon support placement and shape on going



Pretty much perfect in shape at first attempt!

Layer 1

Recent update



... works! ... now continuing with Layer 0 ... stay tuned!

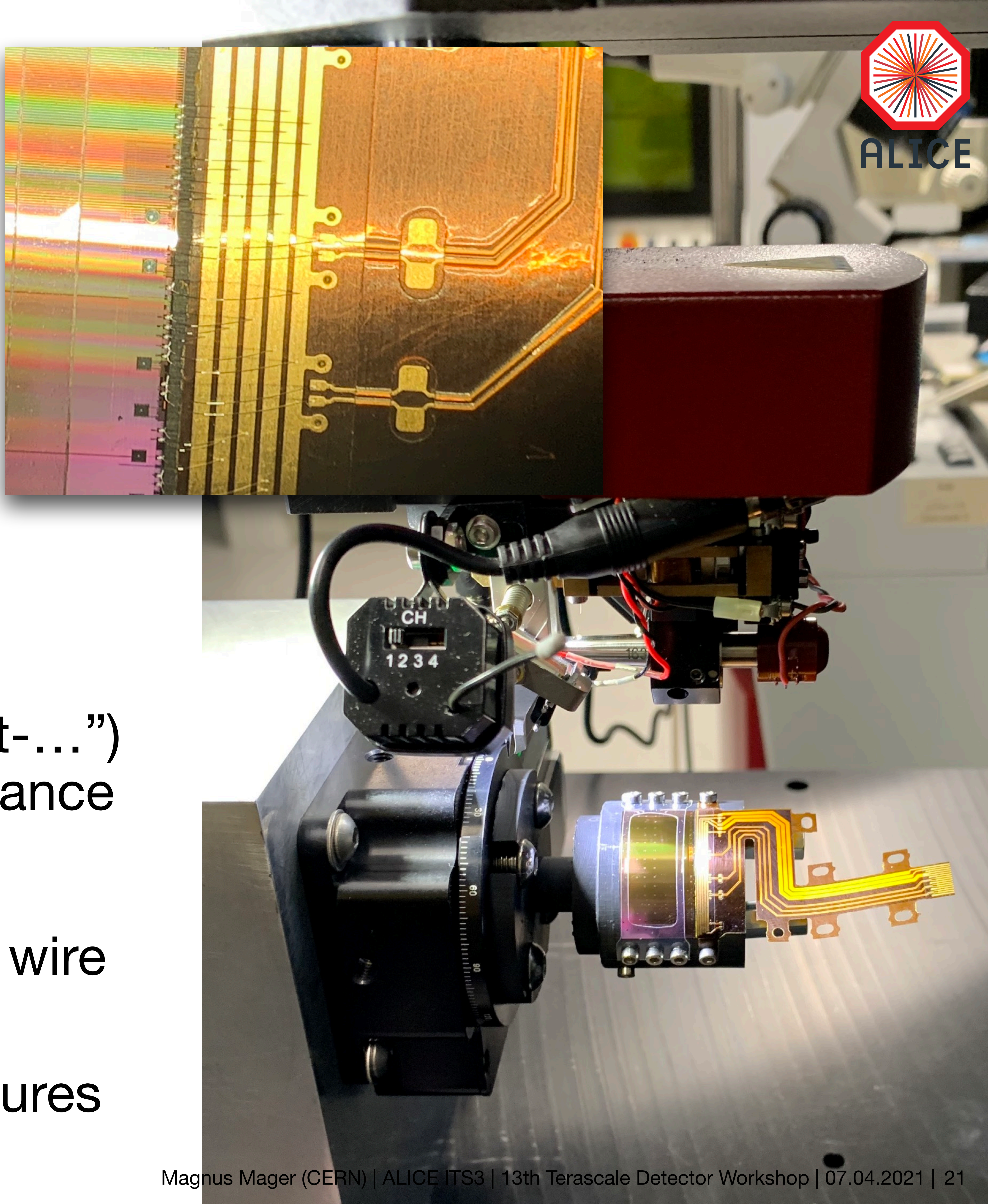
R&D: bent MAPS

Bending ALPIDE

example

Interconnection

now done routinely at different laboratories



- We exercised different options:
  - wire bonding before bending
  - wire bonding after bending
  - SpTAB bonding
- Very important for the R&D phase:
  - flexible (in sense of “flat-bent-flat-bent-flat-…”) are a good vehicle to make direct performance comparisons
- Baseline for final detector implementation is wire bonding after bending
  - will be exercised soon also on large structures

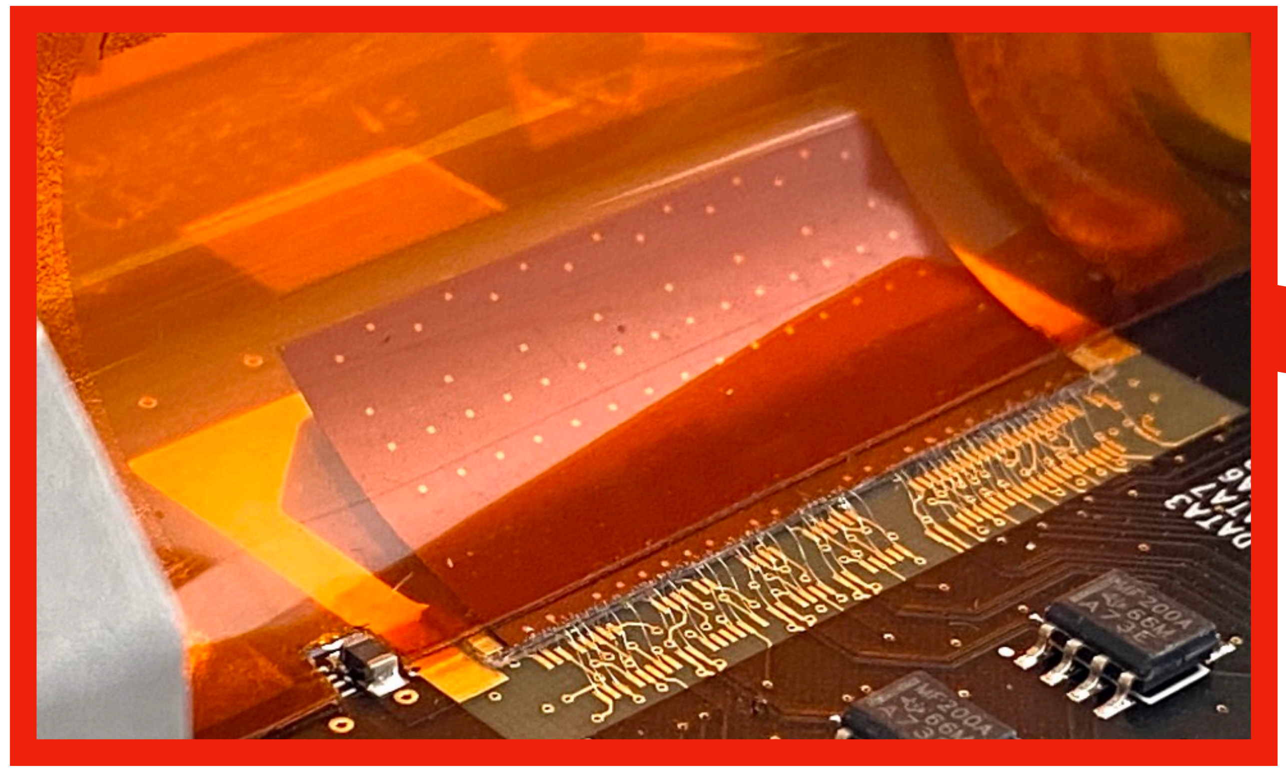
Test beams

overview

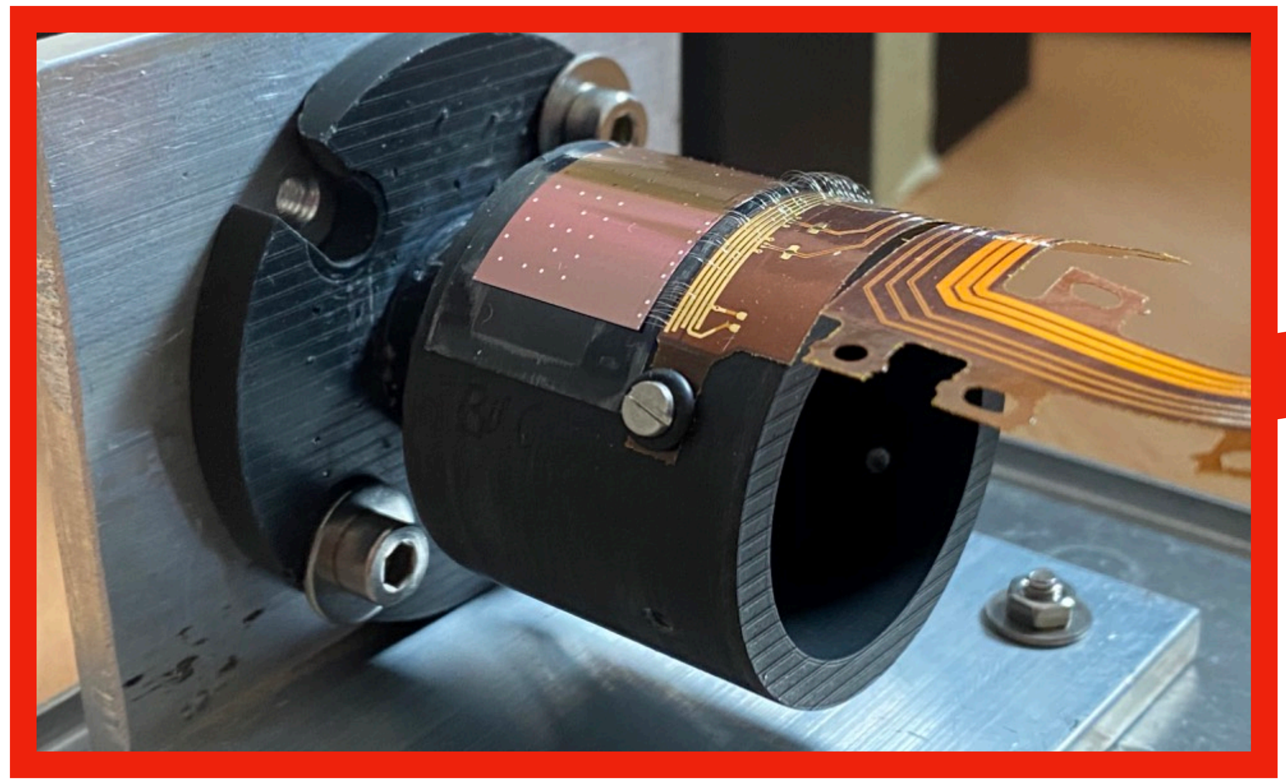
- 3 beam tests at DESY in 2020
- different DUTs
- comprehensive data set

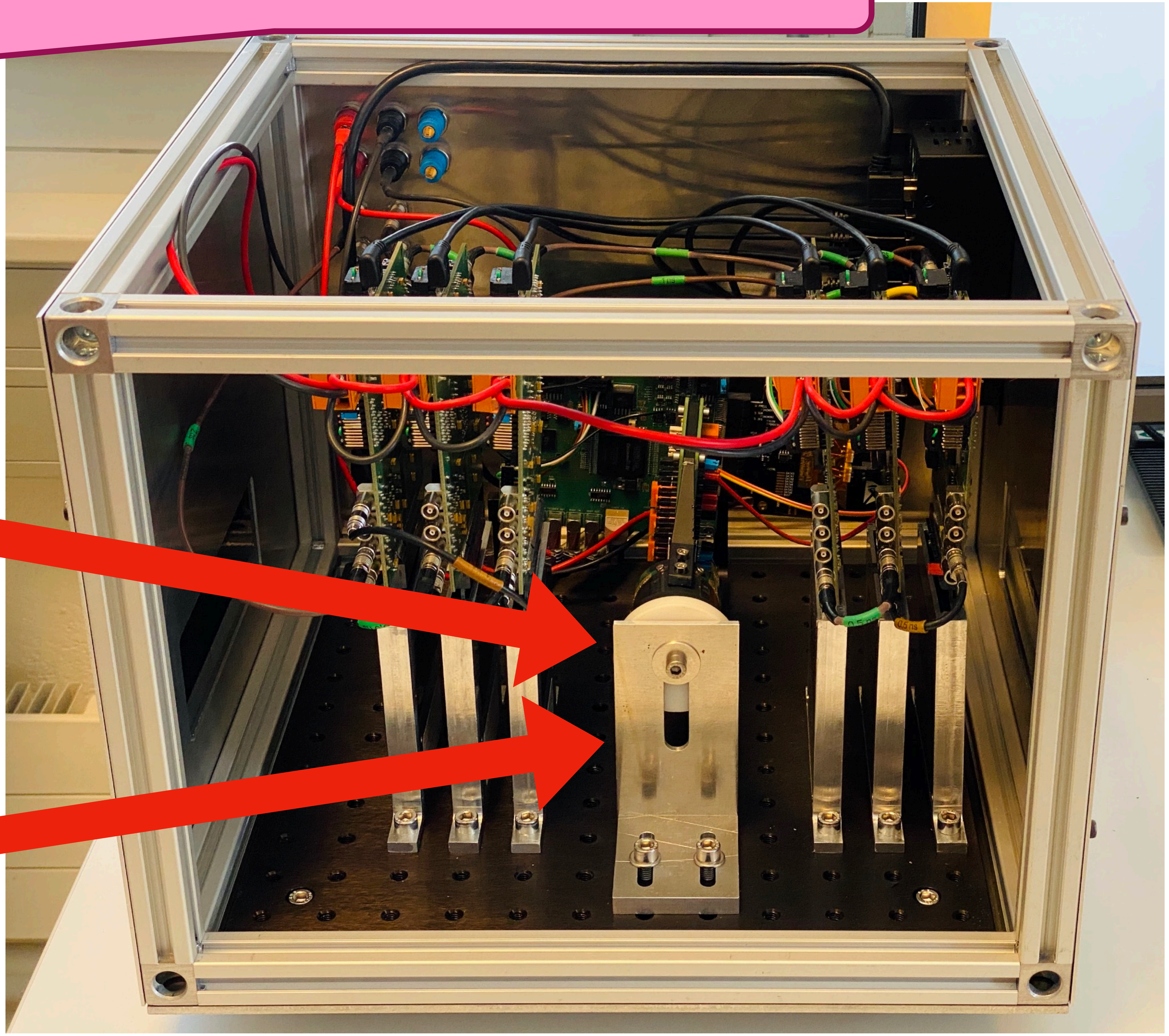
Many thanks to Helmholtz!!

a) Jun 2020
first bent ALPIDE
on "standard carrier"



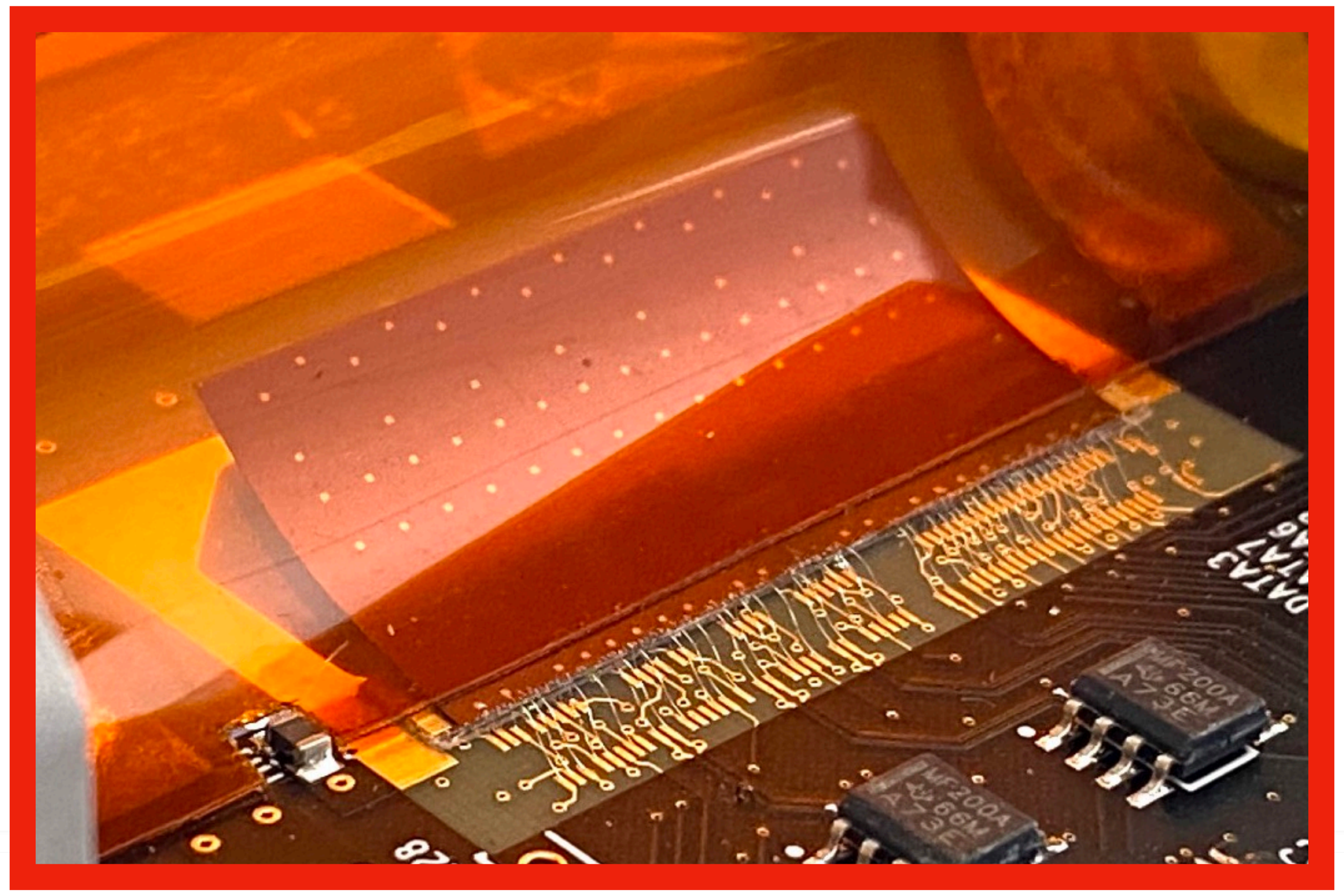
b) Aug/Dec 2020
bent ALPIDE
on cylindrical mount

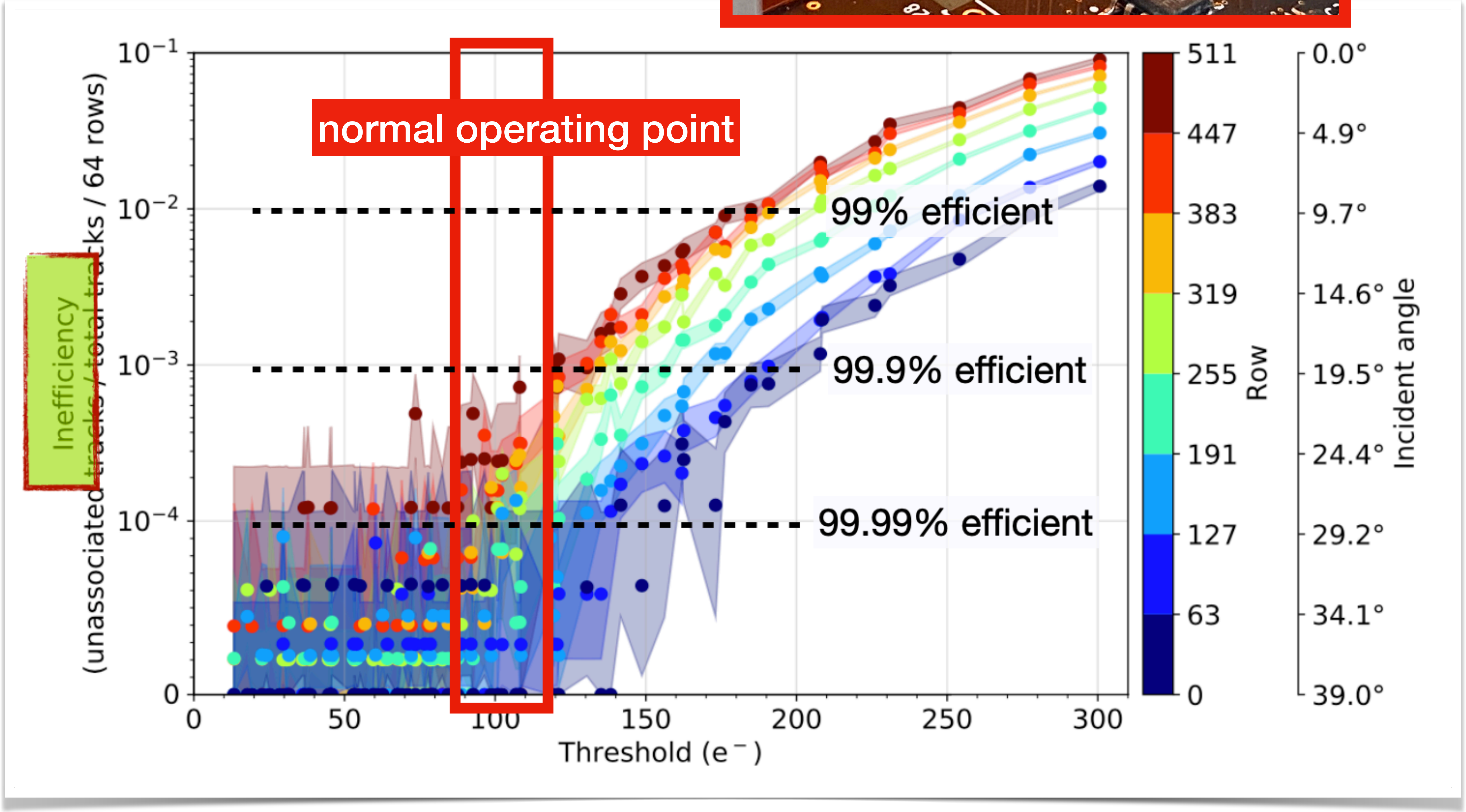




Test beams

1st paper (draft)





- Based on analysis of Jun 2020 test beam data, we concluded that:
- **Bent MAPS work perfectly**
  - actually, no deviation from the flat performance could be seen
- A publication on this important milestone has been drafted and is under internal review

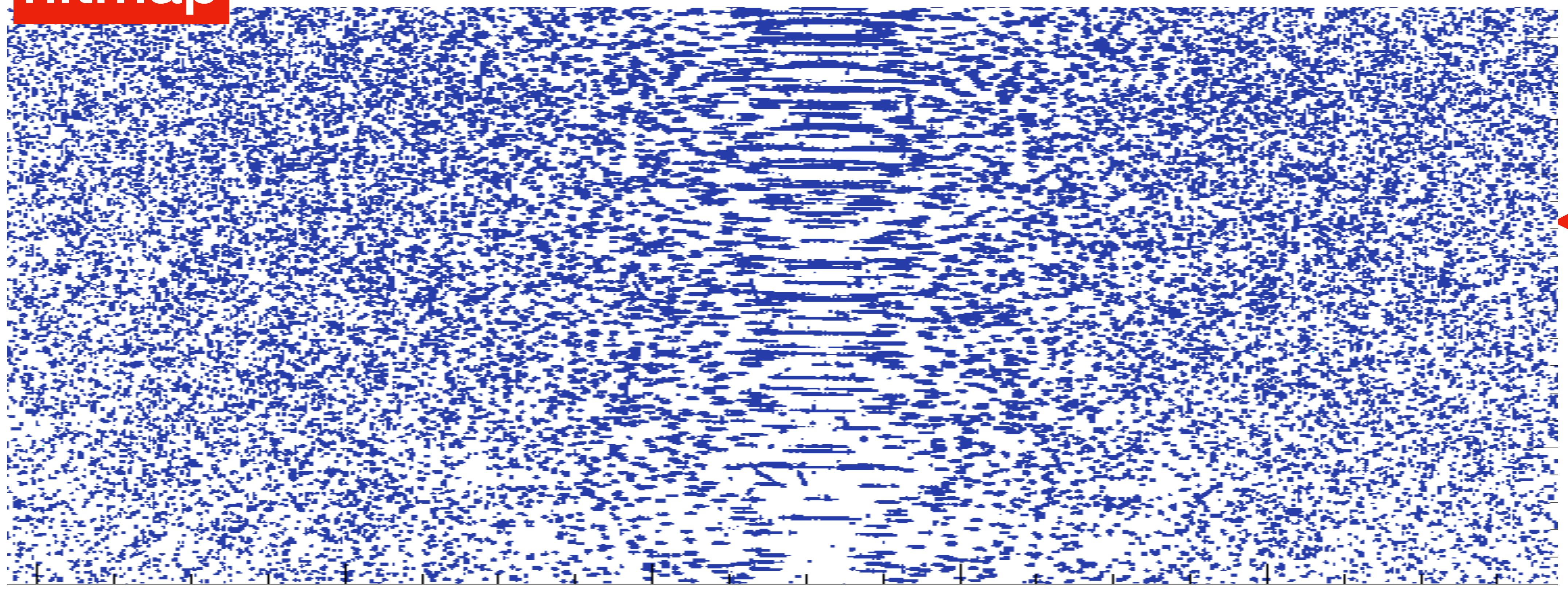
The chips just continue to work!

Test beams

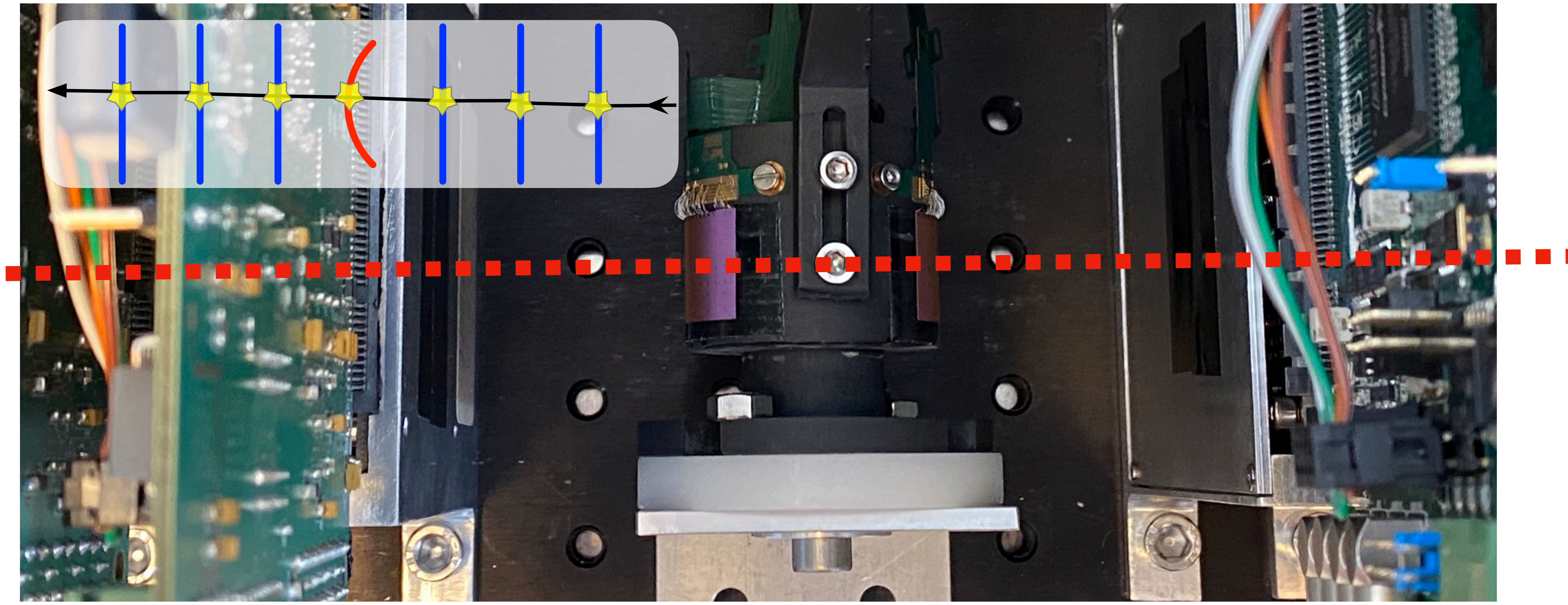
more data

- Very interesting geometries are becoming possible
- Analysis ongoing

hitmap

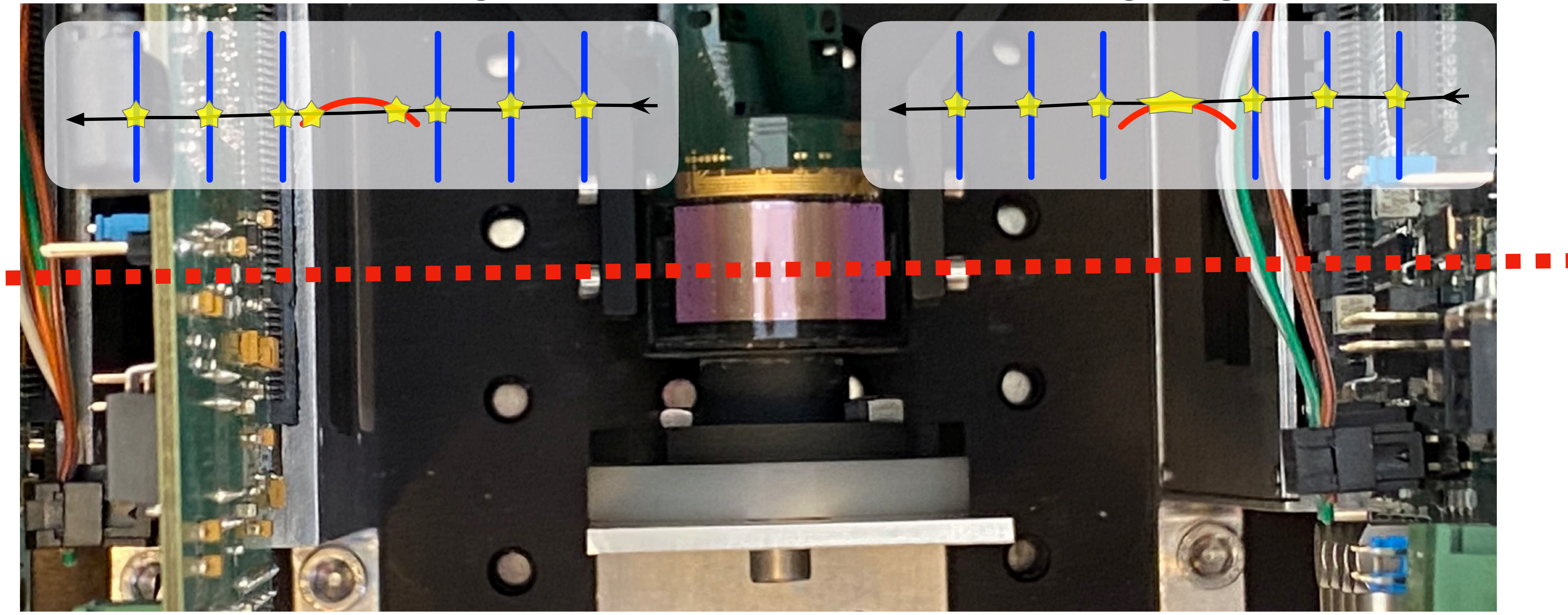


"ordinary"



double-crossing

grazing



Example event

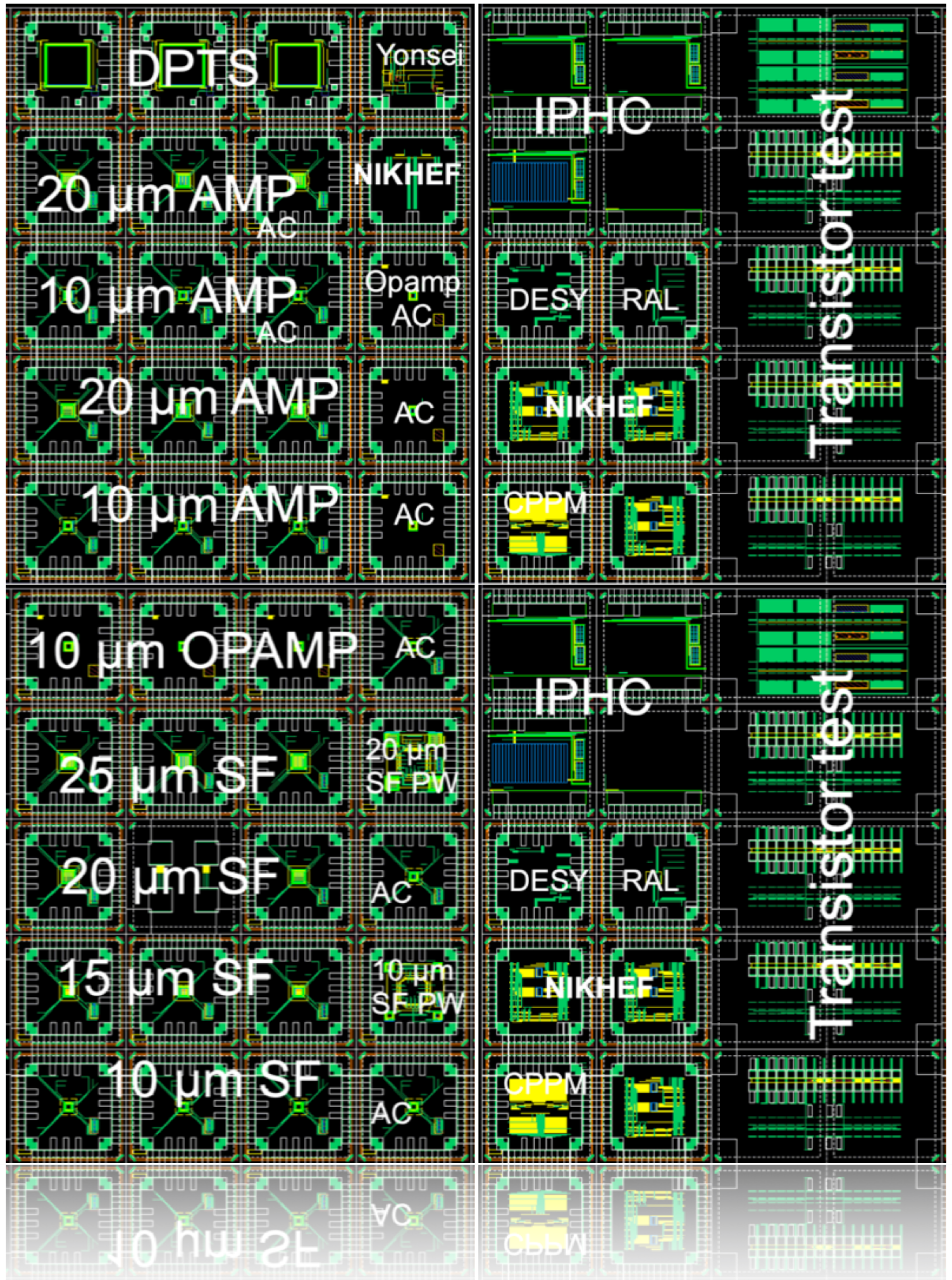
- ALPIDE bent to R = 18 mm
- beam crossing sensor twice
- shallow incident angles

Example event

closeup

- first crossing

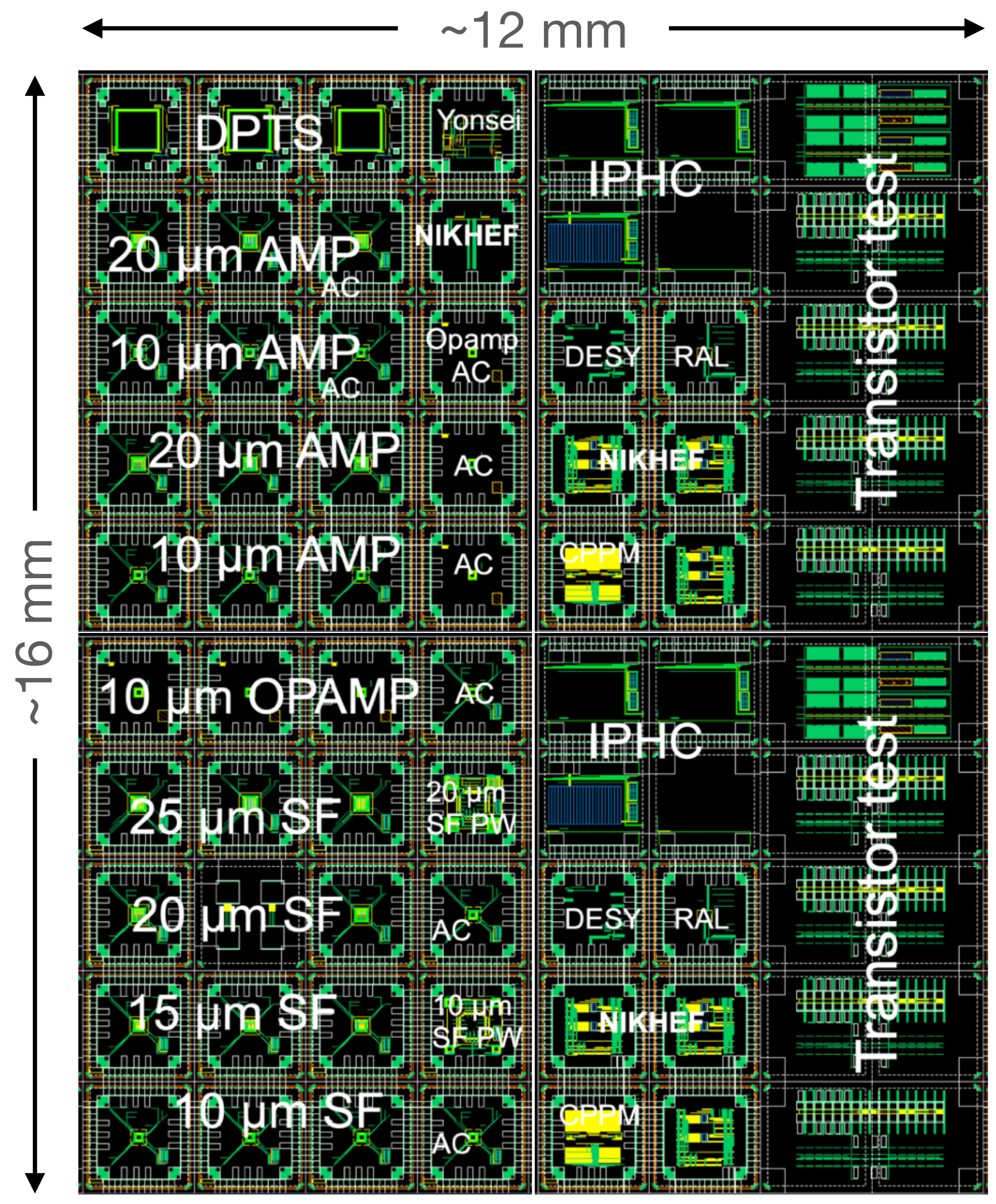
R&D: chip design



Chip submissions

MLR1 submission

- MLR1 is the first submission in the TowerJazz 65nm technology
  - scoped within CERN EP R&D WP1.2, but significant drive from ITS3
- Actually much more than what we thought of *“first test structures”, to* give it full justice:
  - transistor test structures
  - analog building blocks (band gaps, LVDS drivers, etc)
  - various diode matrices (small and large)
  - digital test matrices
  - ➡ Essentially covers the initial goals of MPW1 and MPW2
- Estimated end-of-line: May 2021

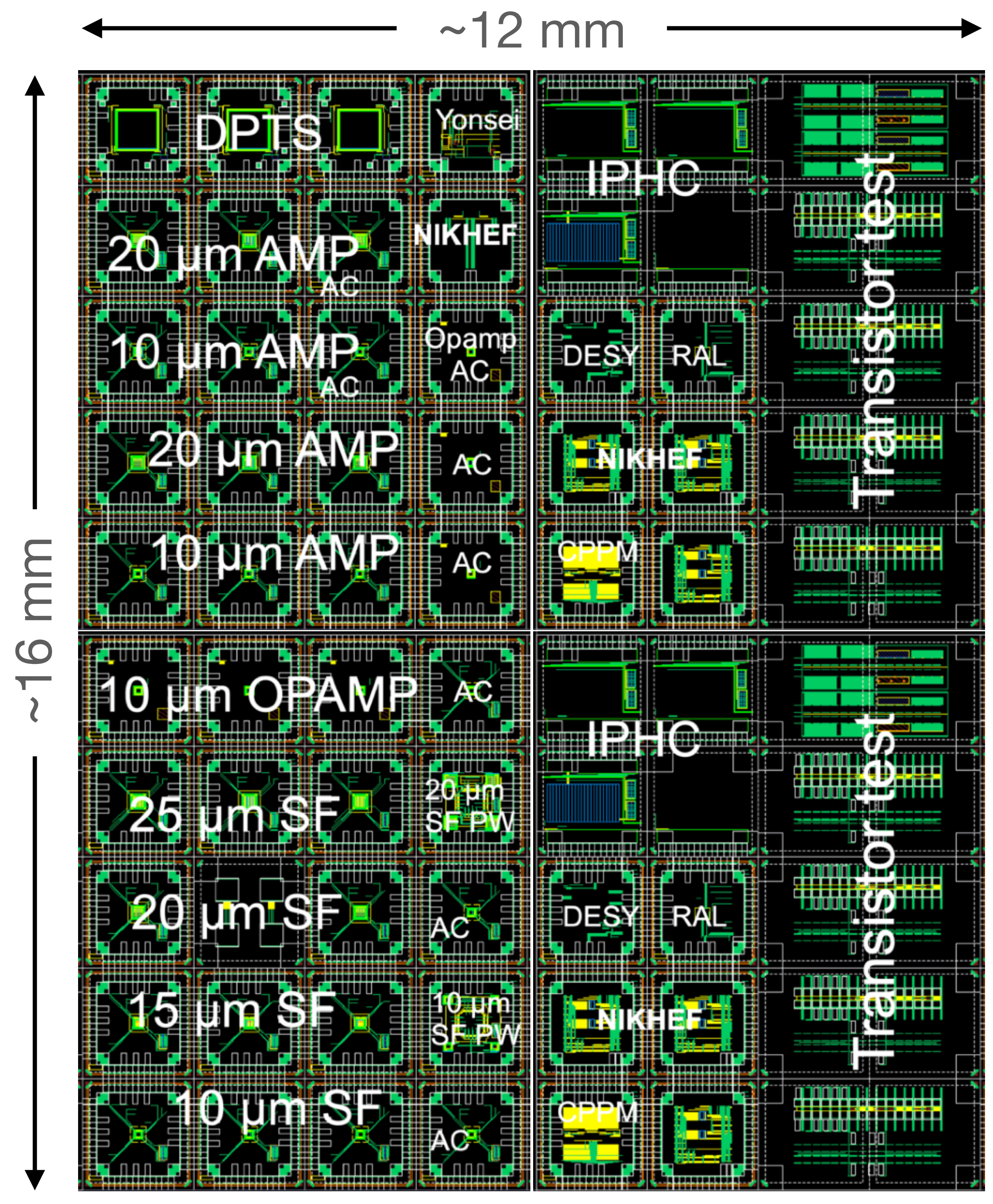


expect O(300) dies per wafer

Chip submissions

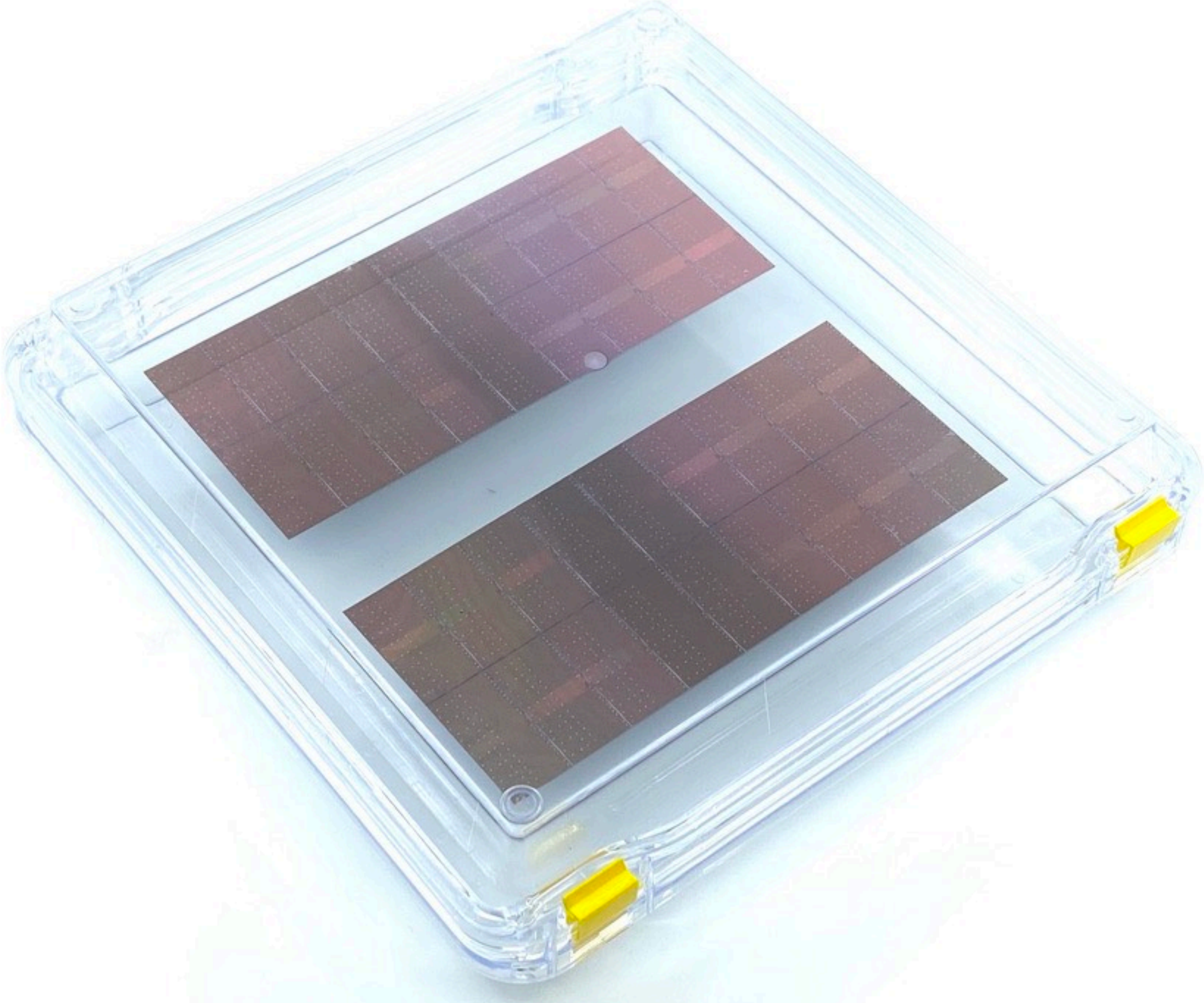
MLR1 testig preparation

- Several groups are preparing for the testing and characterisation of the first prototypes
  - dedicated test system is being developed to equip a large number of institutes
- Goals vary from:
  - radiation hardness validation of the technology
  - characterisation of charge collection properties
  - mechanical characterisation of processed, large chips
- Common irradiation plan is being set up



expect O(300) dies per wafer

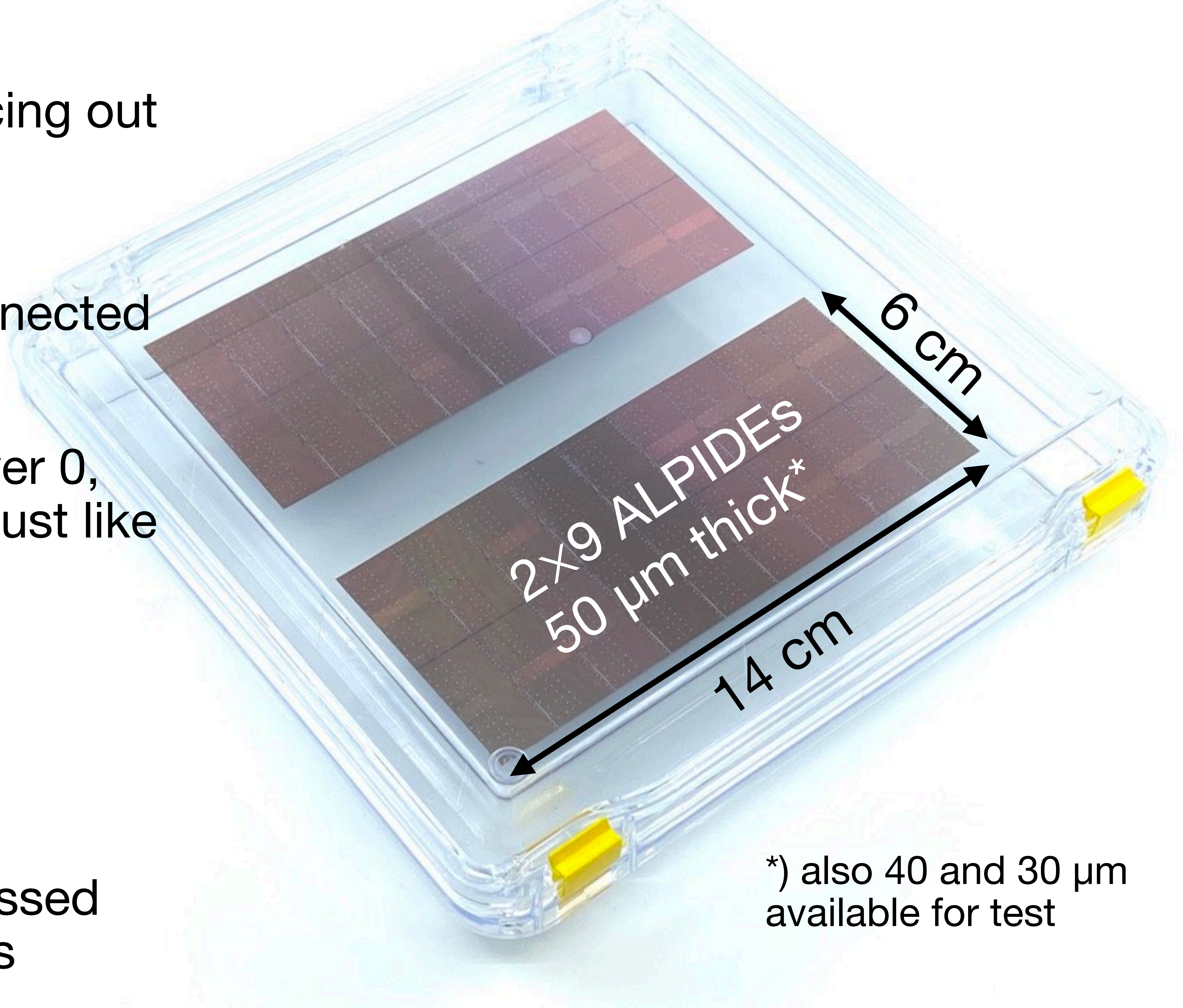
R&D: outlook



Outlook 2/2: “super-ALPIDE”

the first large-scale detector based on bent MAPS ever

- Starting from ALPIDE wafers, instead of dicing out single chips, large areas are cut
  - the super-chip contains 18 ALPIDE dies
  - they are not stitched but can be interconnected individually
- Size matches closely the target size for Layer 0, only that it is shorter (14 instead of 28 cm, just like the 180 nm fallback solution)
- Will allow us to study:
  - handling of large chips
  - the electrical integration
  - the mechanical properties of large processed wafer-scale chips of different thicknesses

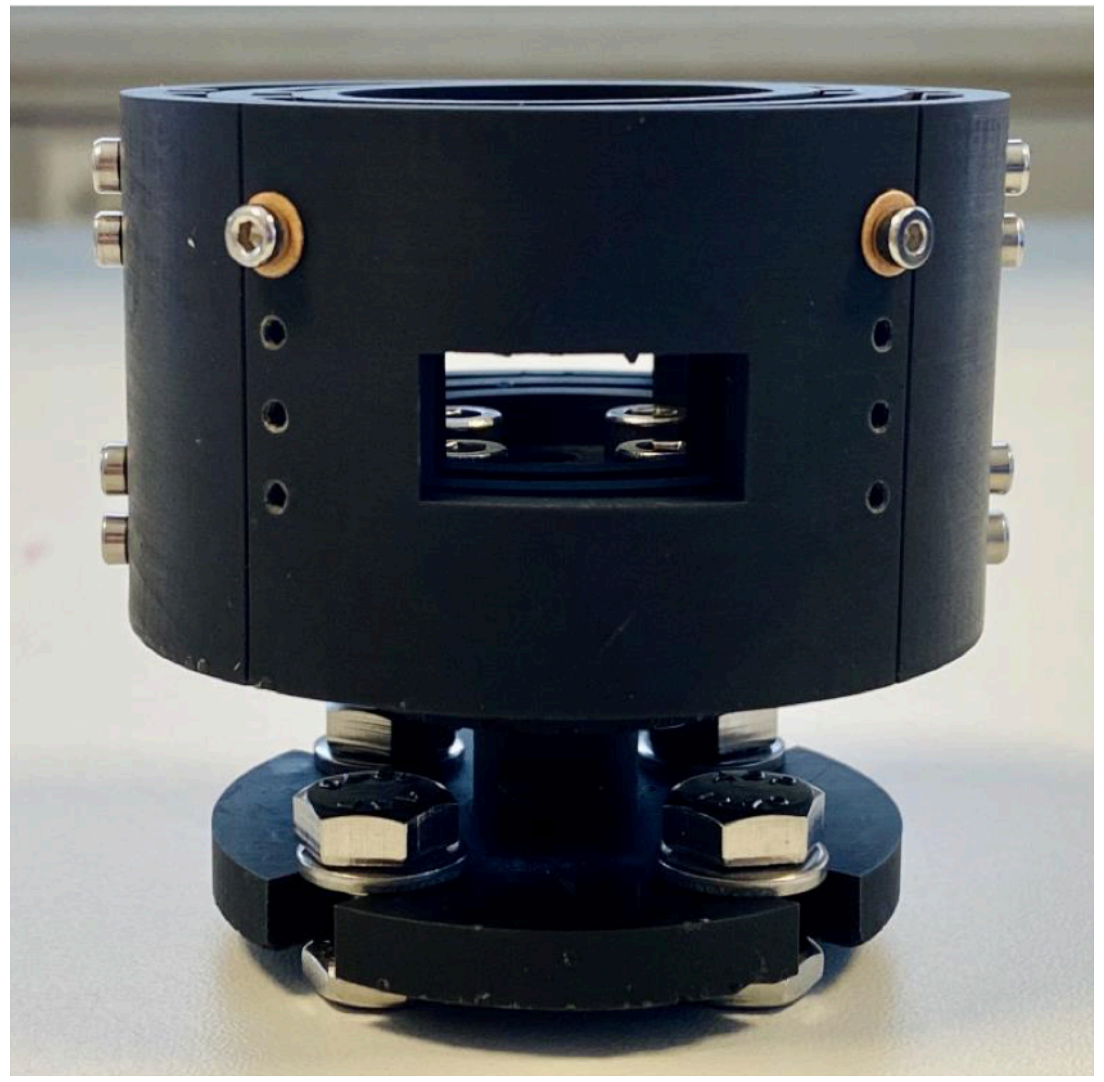


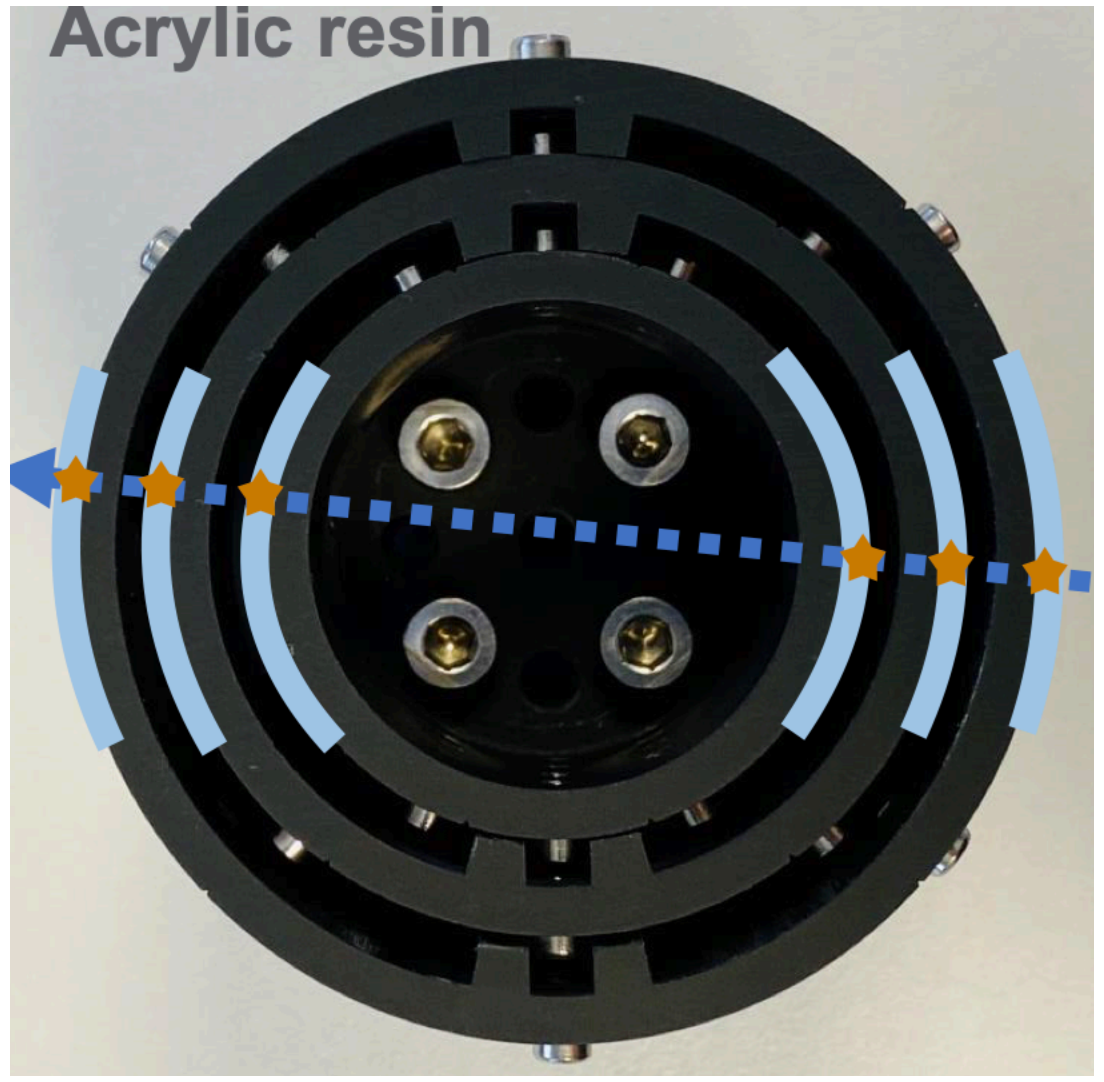
*) also 40 and 30 µm available for test

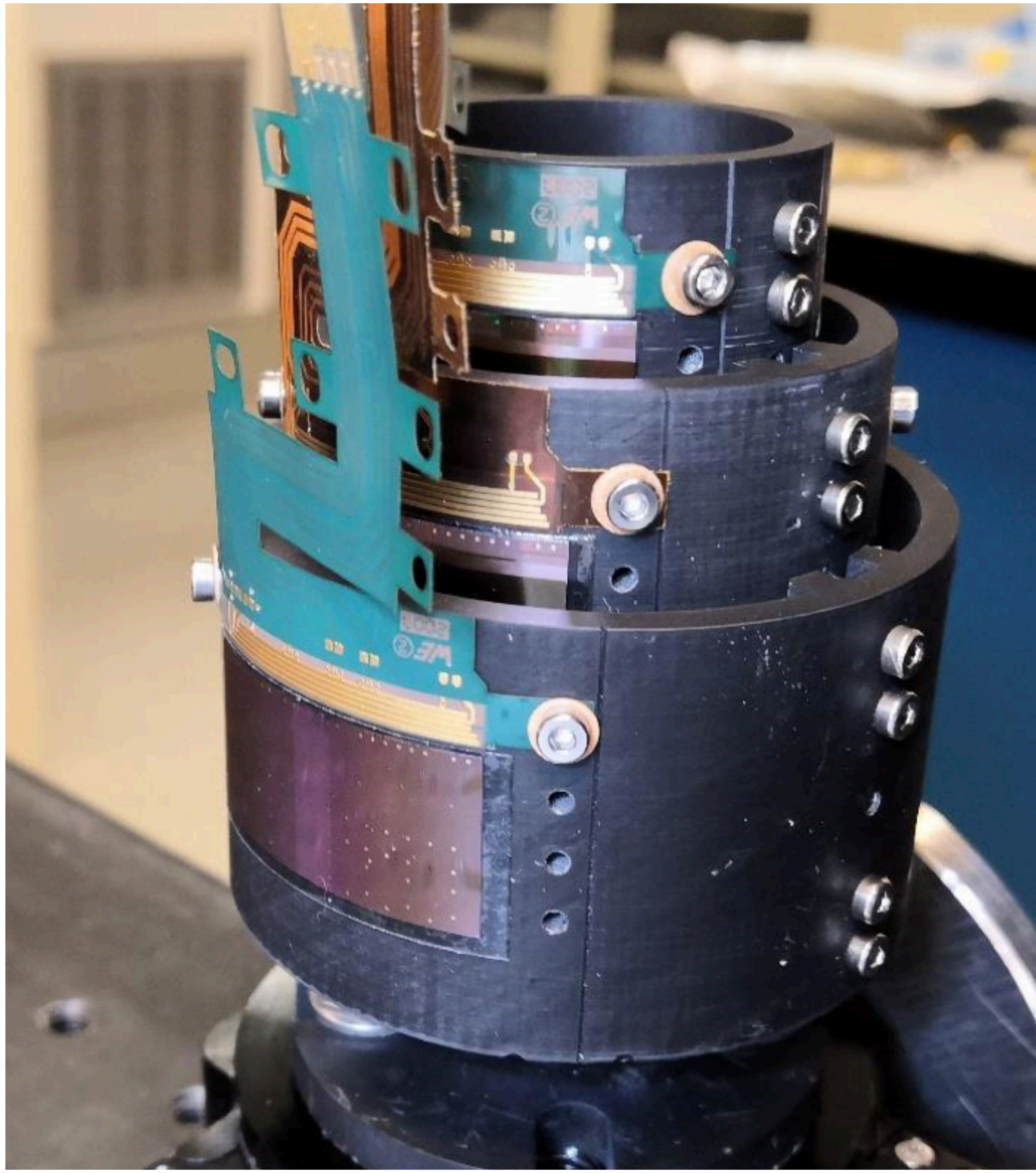
Outlook 1/2: “µITS3”

for the next test beam

- 3 layers of with bent ALPIDEs
- Mimics ITS3:
  - same radii (18, 24, 30 mm)
  - no extra material (opening in jig along particle trajectory)
- Up to six track points
  - probably one of the smallest beam telescopes ever built
- Will allow us to learn a lot about reconstruction





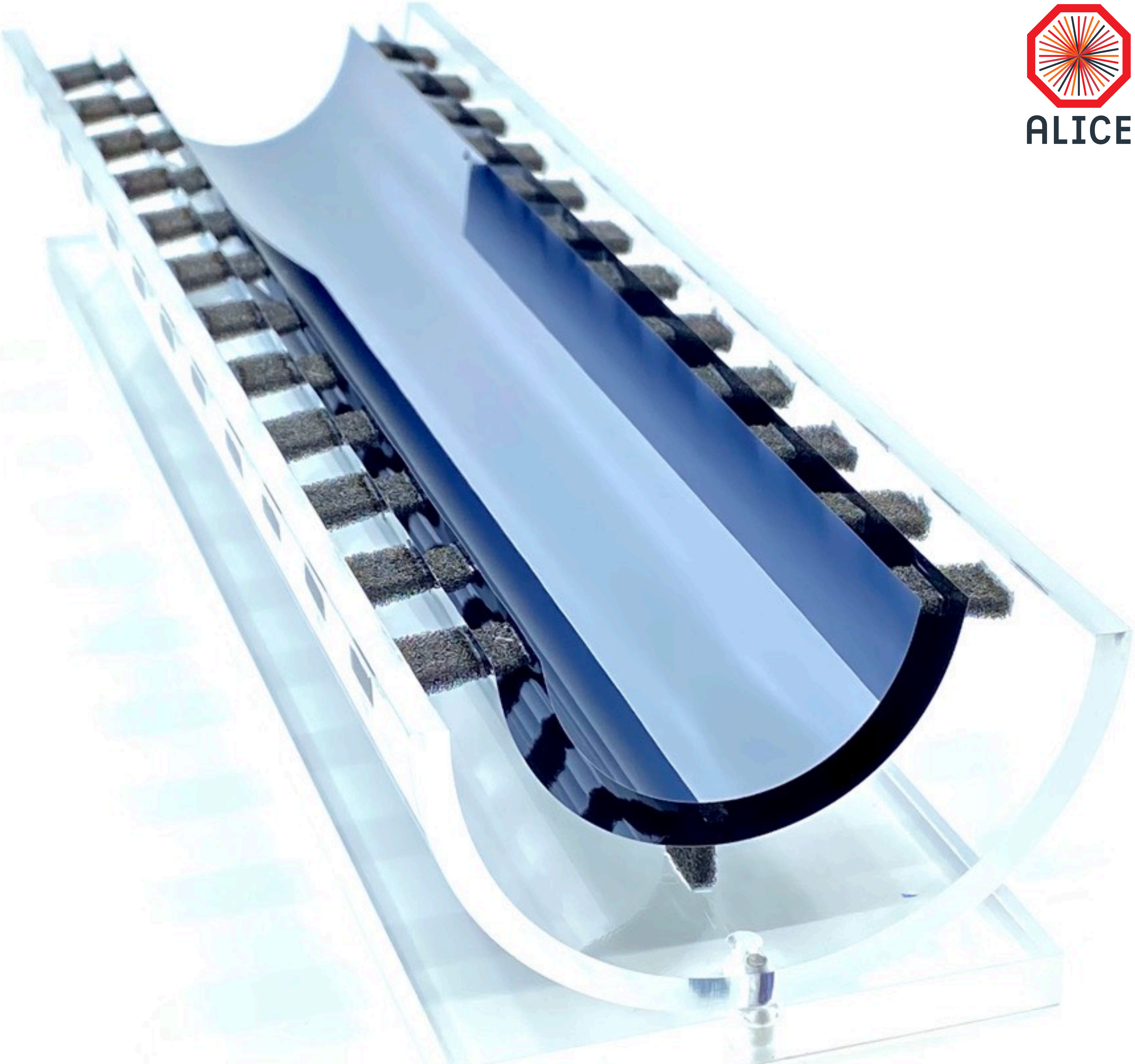


Summary

- ALICE proposes to build the next-generation Inner Tracking System, based on **300 mm-wafer-scale**, **20-40 µm-thin**, **bent MAPS**
- Large **momentum** has been gathered and maintained during 2020
  - many groups (also ALICE-externals) joined the effort
  - large interest in the technology (65 nm, wafer-scale sensors, bent geometries) from other experiments/future interests
- **R&D** is making rapid progress on all fronts, in particular:
  - successful **in-beam verification of bent MAPS** (3 campaigns in 2020)
  - **full-size mechanical mockups**
- **First prototype chips** fabricated in **65 nm** are about to return for testing
  - significant drive from the ITS3 community to push this technology
- **Bent detectors have become a reality!**

ALICE

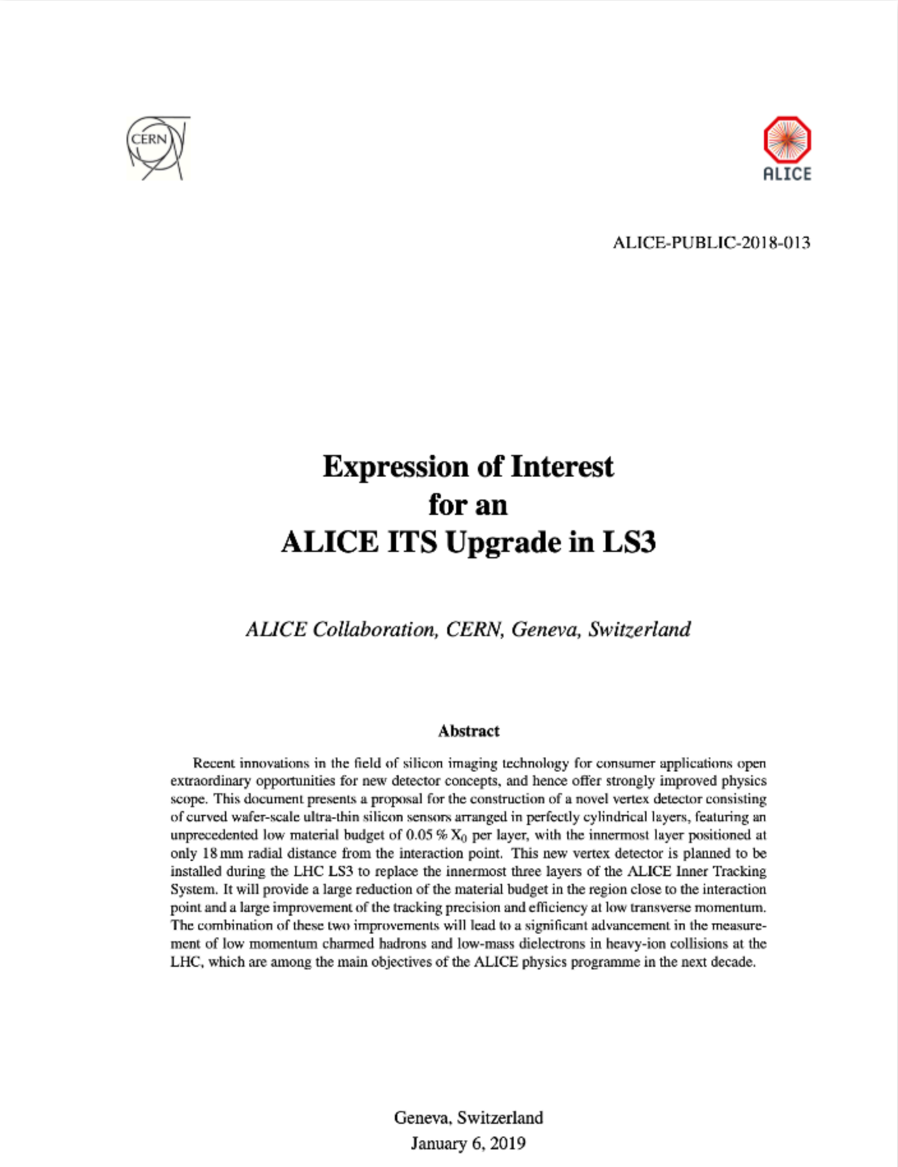
Thank you!



Supplemental material

ITS3 project startup

EoI, LoI, start of R&D


ALICE-PUBLIC-2018-013

Expression of Interest
for an
ALICE ITS Upgrade in LS3

ALICE Collaboration, CERN, Geneva, Switzerland

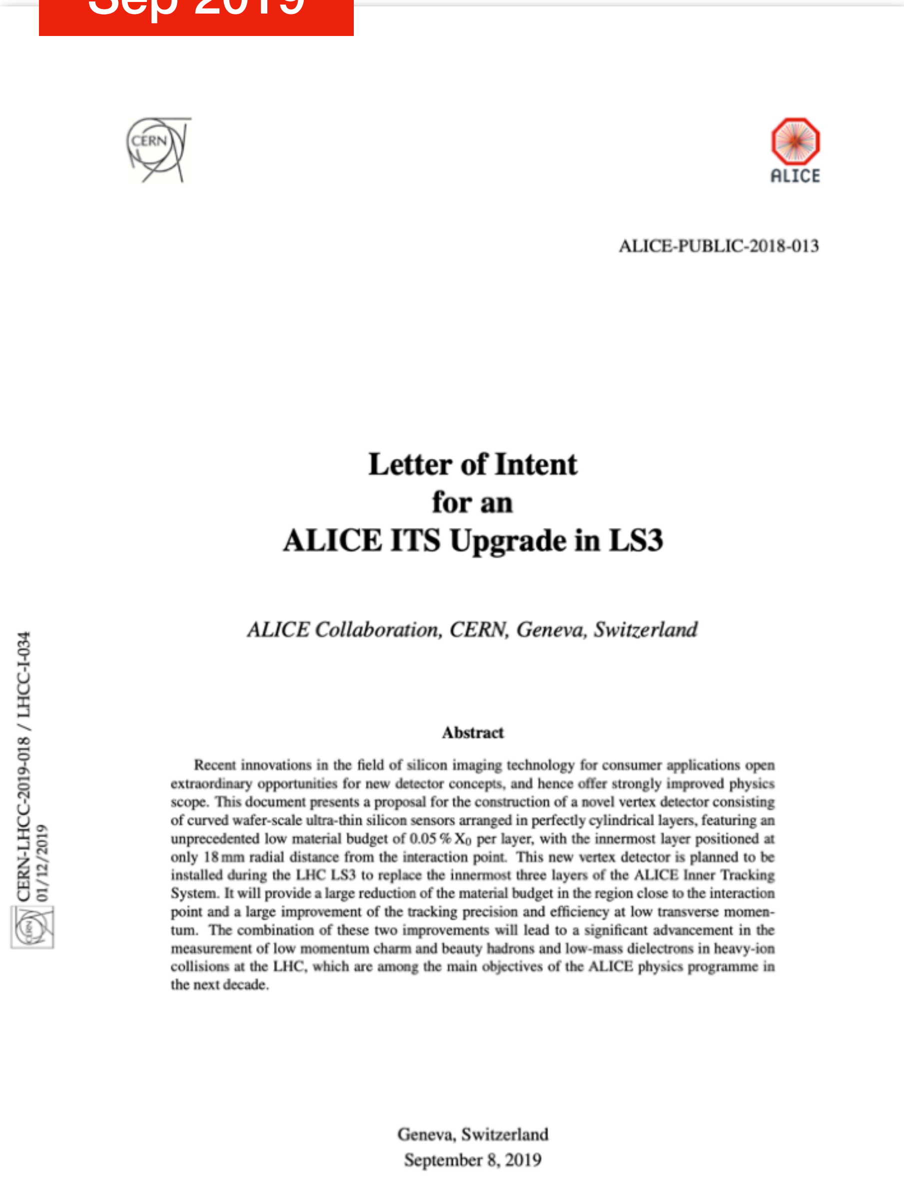
Abstract

Recent innovations in the field of silicon imaging technology for consumer applications open extraordinary opportunities for new detector concepts, and hence offer strongly improved physics scope. This document presents a proposal for the construction of a novel vertex detector consisting of curved wafer-scale ultra-thin silicon sensors arranged in perfectly cylindrical layers, featuring an unprecedented low material budget of 0.05 % X_0 per layer, with the innermost layer positioned at only 18 mm radial distance from the interaction point. This new vertex detector is planned to be installed during the LHC LS3 to replace the innermost three layers of the ALICE Inner Tracking System. It will provide a large reduction of the material budget in the region close to the interaction point and a large improvement of the tracking precision and efficiency at low transverse momentum. The combination of these two improvements will lead to a significant advancement in the measurement of low momentum charmed hadrons and low-mass dielectrons in heavy-ion collisions at the LHC, which are among the main objectives of the ALICE physics programme in the next decade.

Geneva, Switzerland
January 6, 2019

[ALICE-PUBLIC-2018-013]

Sep 2019


CERN-LHCC-2019-018 / LHCC-I-034
01/12/2019

ALICE-PUBLIC-2018-013

Letter of Intent
for an
ALICE ITS Upgrade in LS3

ALICE Collaboration, CERN, Geneva, Switzerland

Abstract

Recent innovations in the field of silicon imaging technology for consumer applications open extraordinary opportunities for new detector concepts, and hence offer strongly improved physics scope. This document presents a proposal for the construction of a novel vertex detector consisting of curved wafer-scale ultra-thin silicon sensors arranged in perfectly cylindrical layers, featuring an unprecedented low material budget of 0.05 % X_0 per layer, with the innermost layer positioned at only 18 mm radial distance from the interaction point. This new vertex detector is planned to be installed during the LHC LS3 to replace the innermost three layers of the ALICE Inner Tracking System. It will provide a large reduction of the material budget in the region close to the interaction point and a large improvement of the tracking precision and efficiency at low transverse momentum. The combination of these two improvements will lead to a significant advancement in the measurement of low momentum charm and beauty hadrons and low-mass dielectrons in heavy-ion collisions at the LHC, which are among the main objectives of the ALICE physics programme in the next decade.

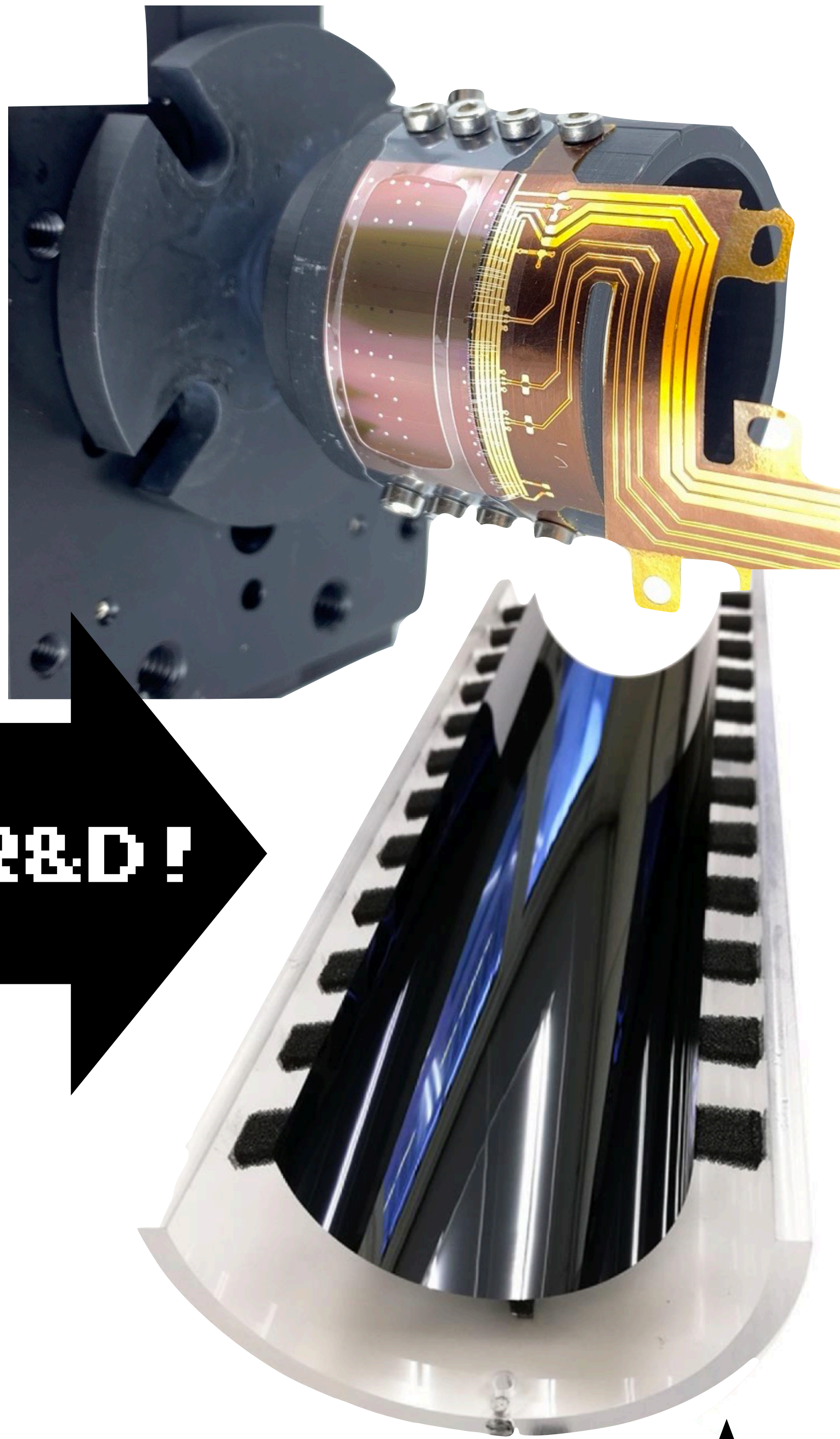
Geneva, Switzerland
September 8, 2019

[CERN-LHCC-2019-018 ; LHCC-I-034]

Dec 4th 2019

[ITS3 R&D kickoff meeting]

R&D!



[...]
The **LHCC is impressed** by the new concept for the ITS3
[...]
The **LHCC endorses** the plan of ALICE to carry out the necessary R&D
[...]
[LHCC minutes: CERN-LHCC-2019-010 ; LHCC-139]

[...]
The **LHCC congratulates** the ITS3 groups for the successful start of the project.
[...]
[LHCC minutes: CERN-LHCC-2020-008 ; LHCC-142]

[...]
according to schedule with rapid progress on the bending of sensors, interconnection and mechanics
[...]
[LHCC minutes: CERN-LHCC-2021-005 ; LHCC-145]