

# 15<sup>th</sup> Trento Workshop

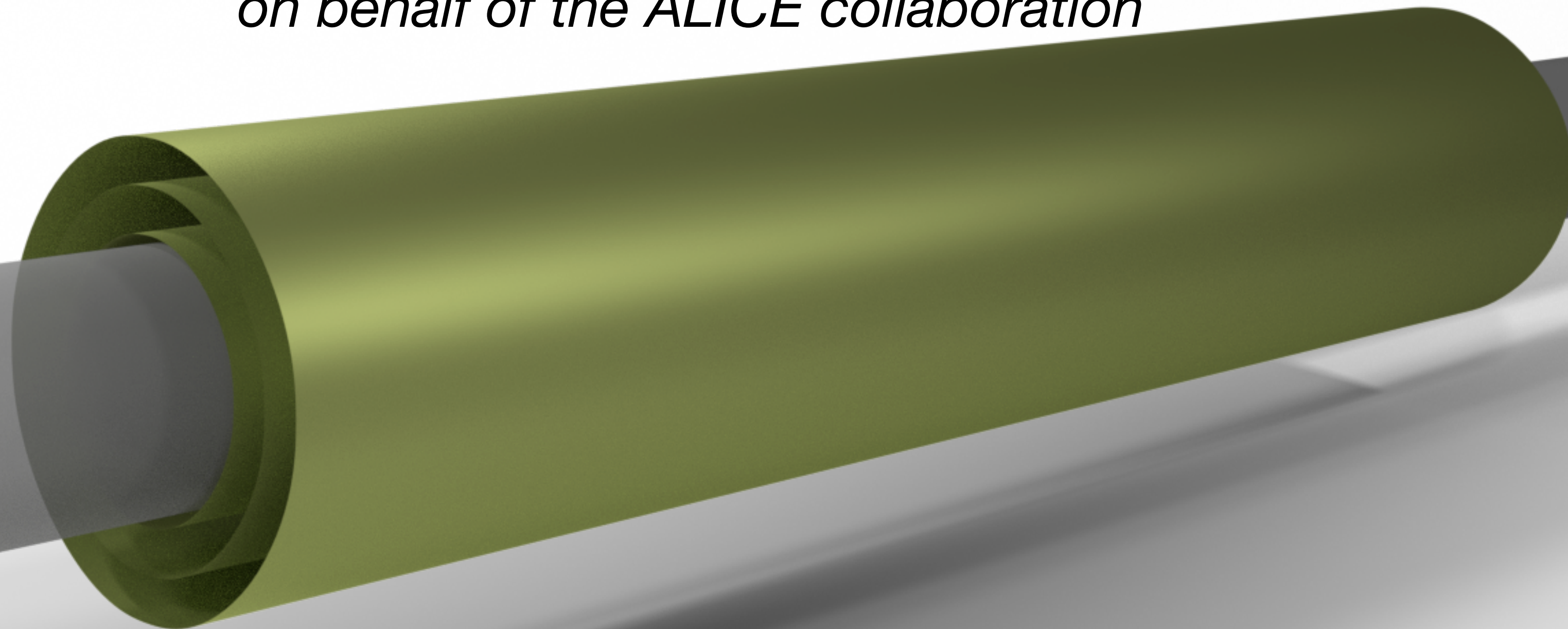
on Advanced Silicon  
Radiation Detectors

17-19 February 2020 TU Wien



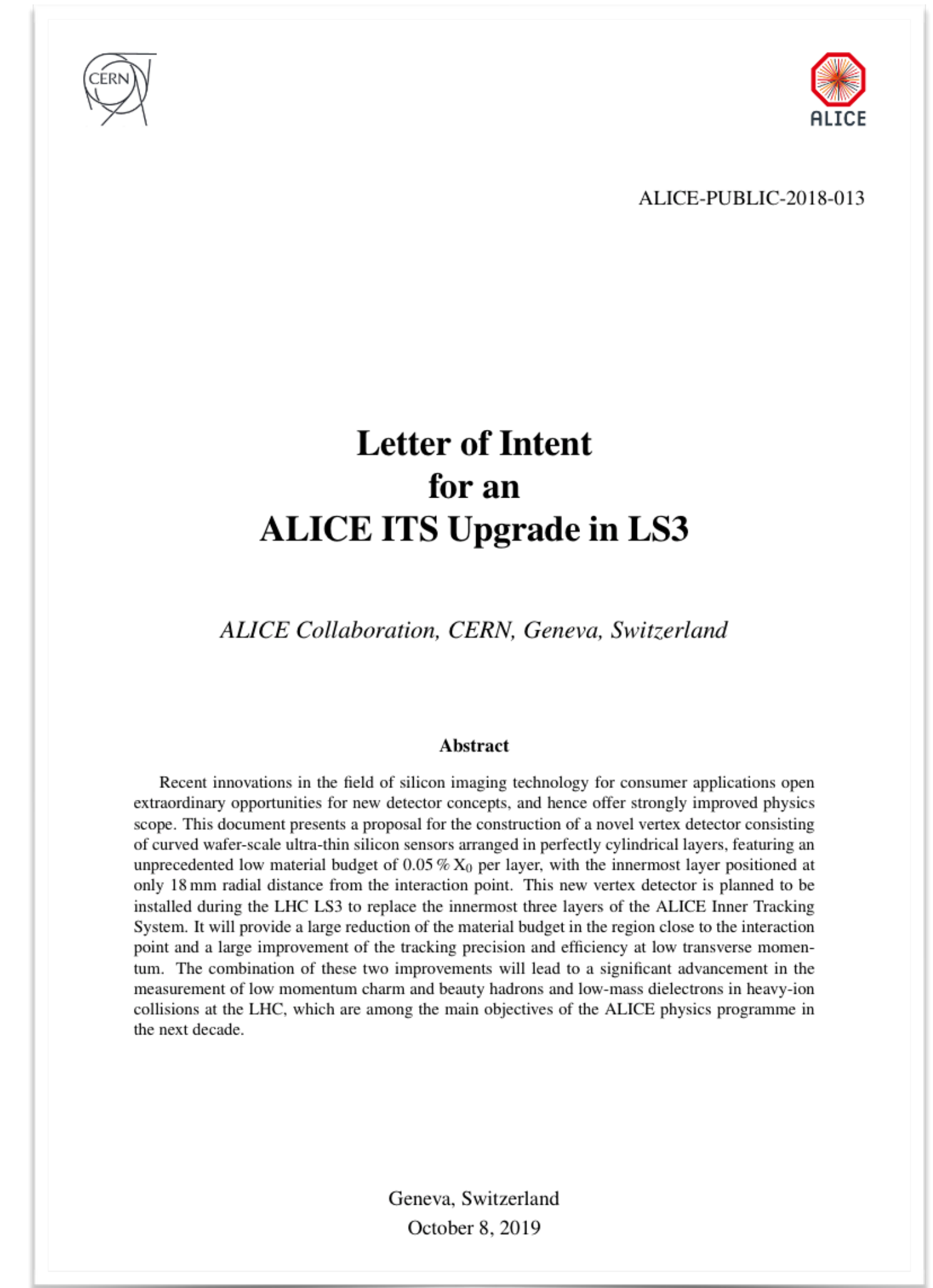
## The LS3 upgrade of the ALICE Inner Tracking System based on ultra-thin, wafer-scale, bent Monolithic Active Pixel Sensors

Magnus Mager (CERN)  
*on behalf of the ALICE collaboration*



# Contents

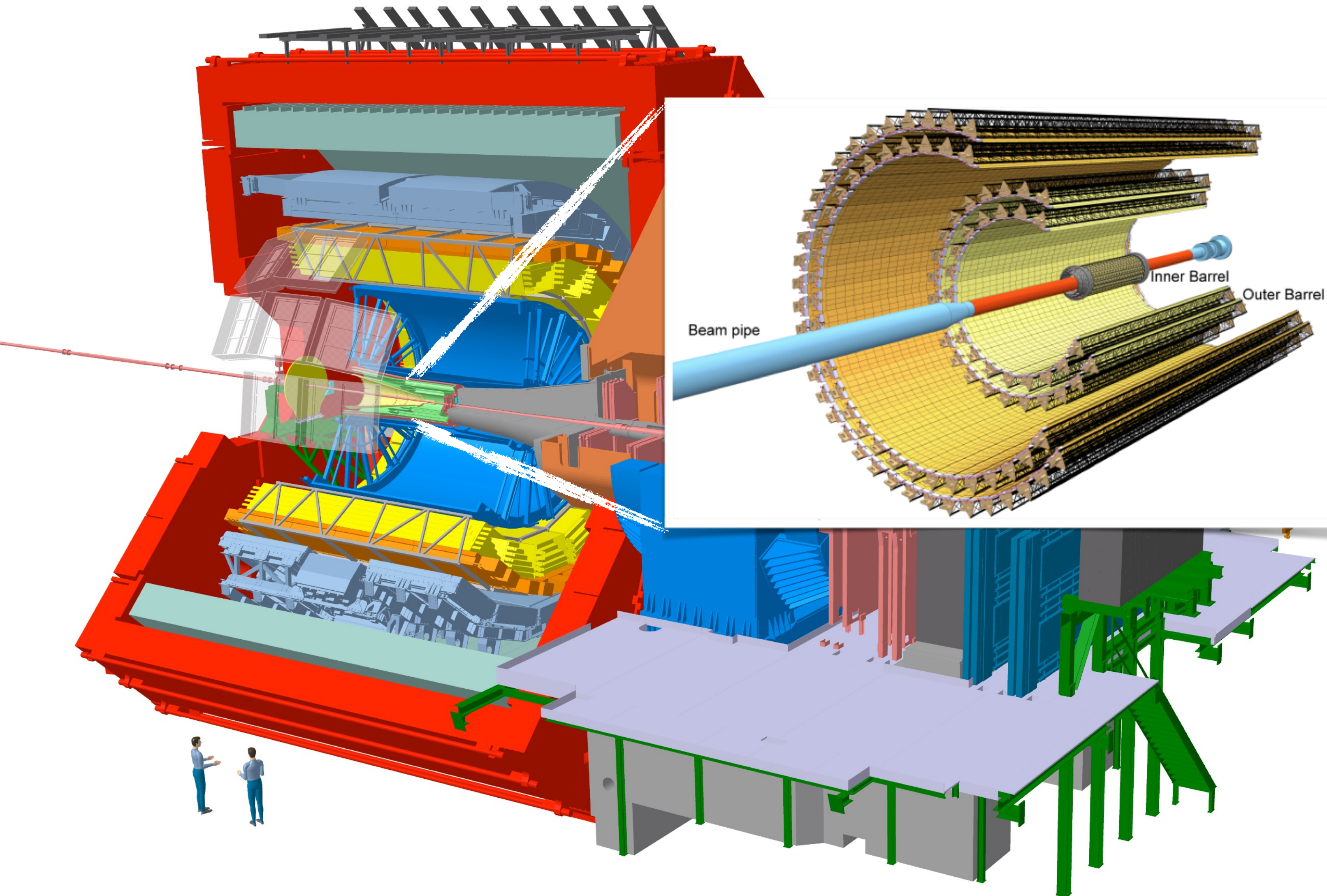
- ▶ ALICE ITS2 + motivation to go further
- ▶ ITS3 layout and integration
- ▶ R&D topics (selection):
  - Wafer scale chip (300 mm, 65 nm)
  - Thinning/bending
  - Interconnection
- ▶ Performance projections
  - tracking performance
  - physics projections
- ▶ R&D + Construction Timeline



[ALICE-PUBLIC-2018-013]

# ▶ ALICE ITS2 + motivation to go further

# ALICE in Run3 (LS2-LS3)



- ▶ ALICE had a very successful ITS in Run1+Run2
- ▶ ALICE will get a novel MAPS-based ITS2 in LS2 (i.e. right now), see:
  - Jian Liu: “The Inner Tracking System upgrade for ALICE”
- ▶ ***This* upgrade aims at replacing the inner-most part of ITS2 with an even better detector**

# ITS2 commissioning



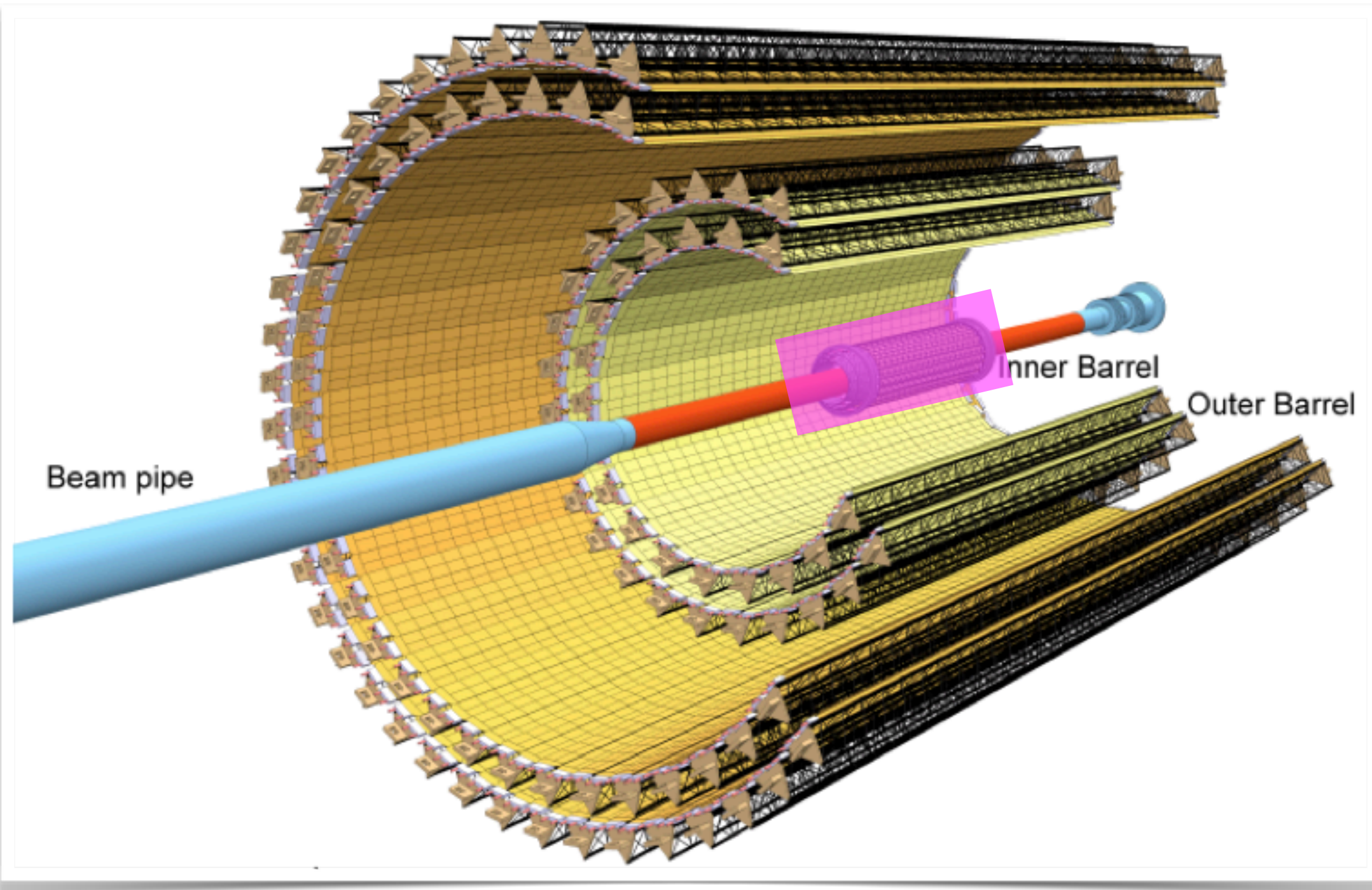


# ITS2 Inner Barrel

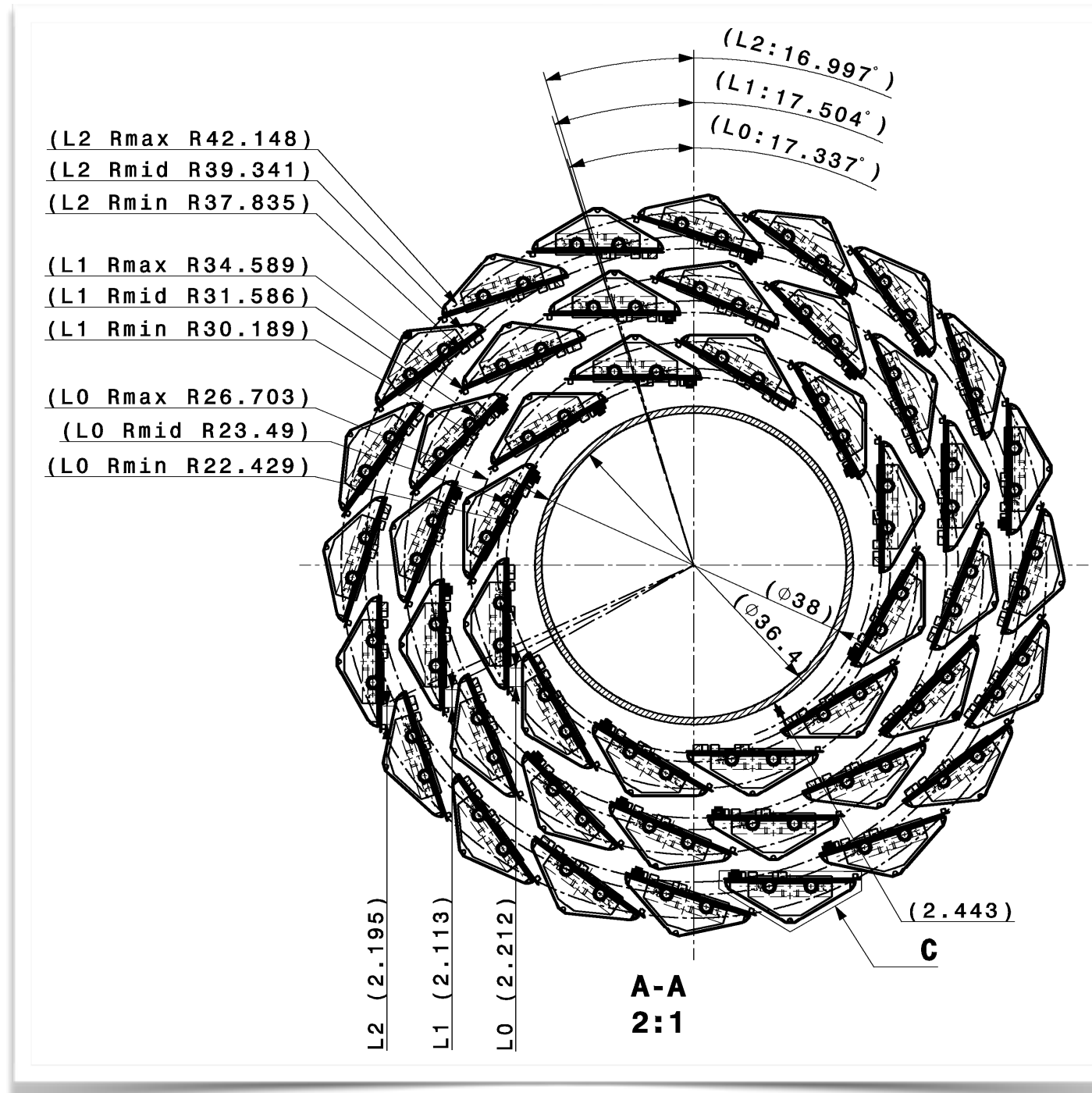


# ITS2 overview

ITS2 layout



Inner barrel

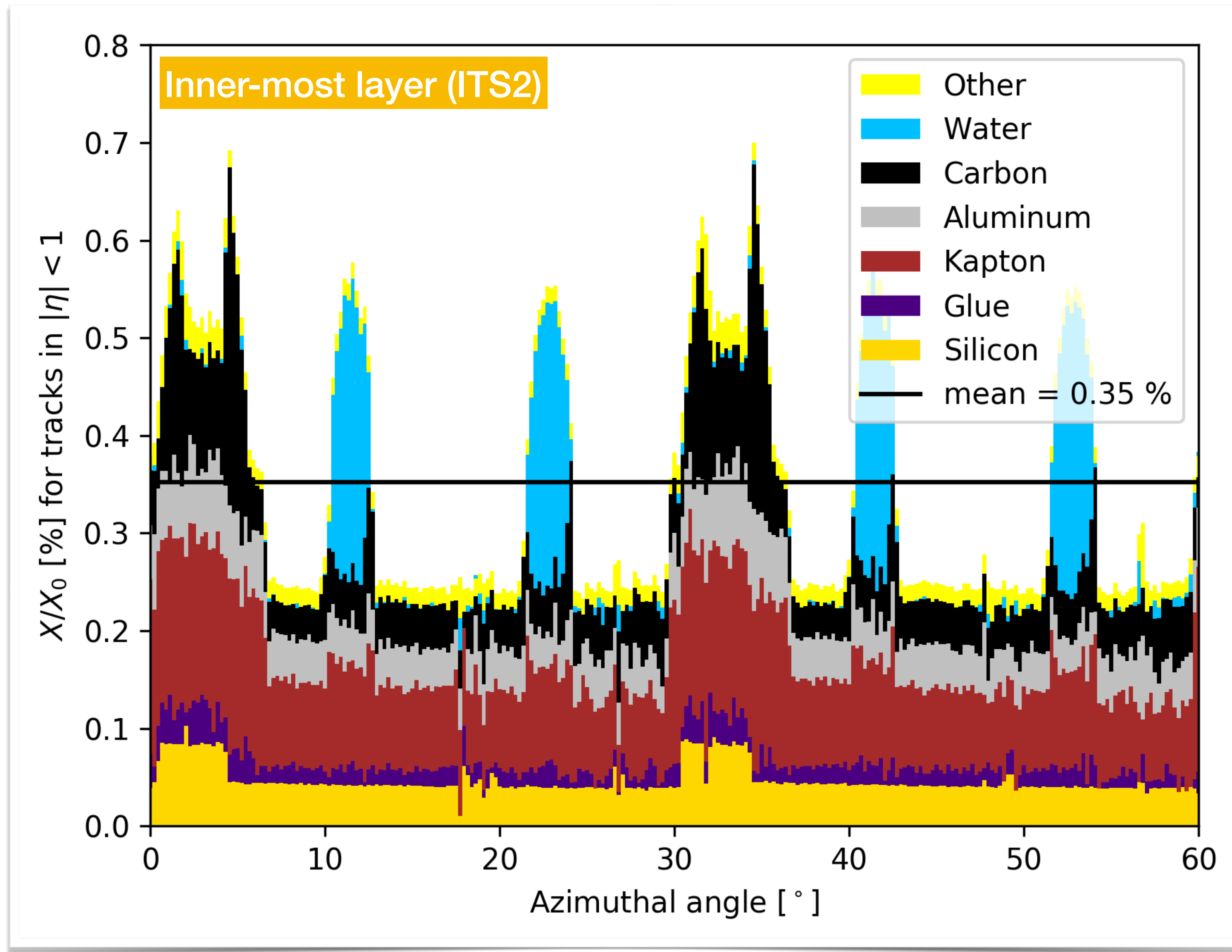


Layer 2 (20 staves)



- ▶ ITS2 will already have unprecedented performance
- ▶ The Inner Barrel is ultralight but rather packed → further improvements seem possible
- ▶ **Key questions: Can we get closer to the IP? Can we reduce the material?**

# Material budget

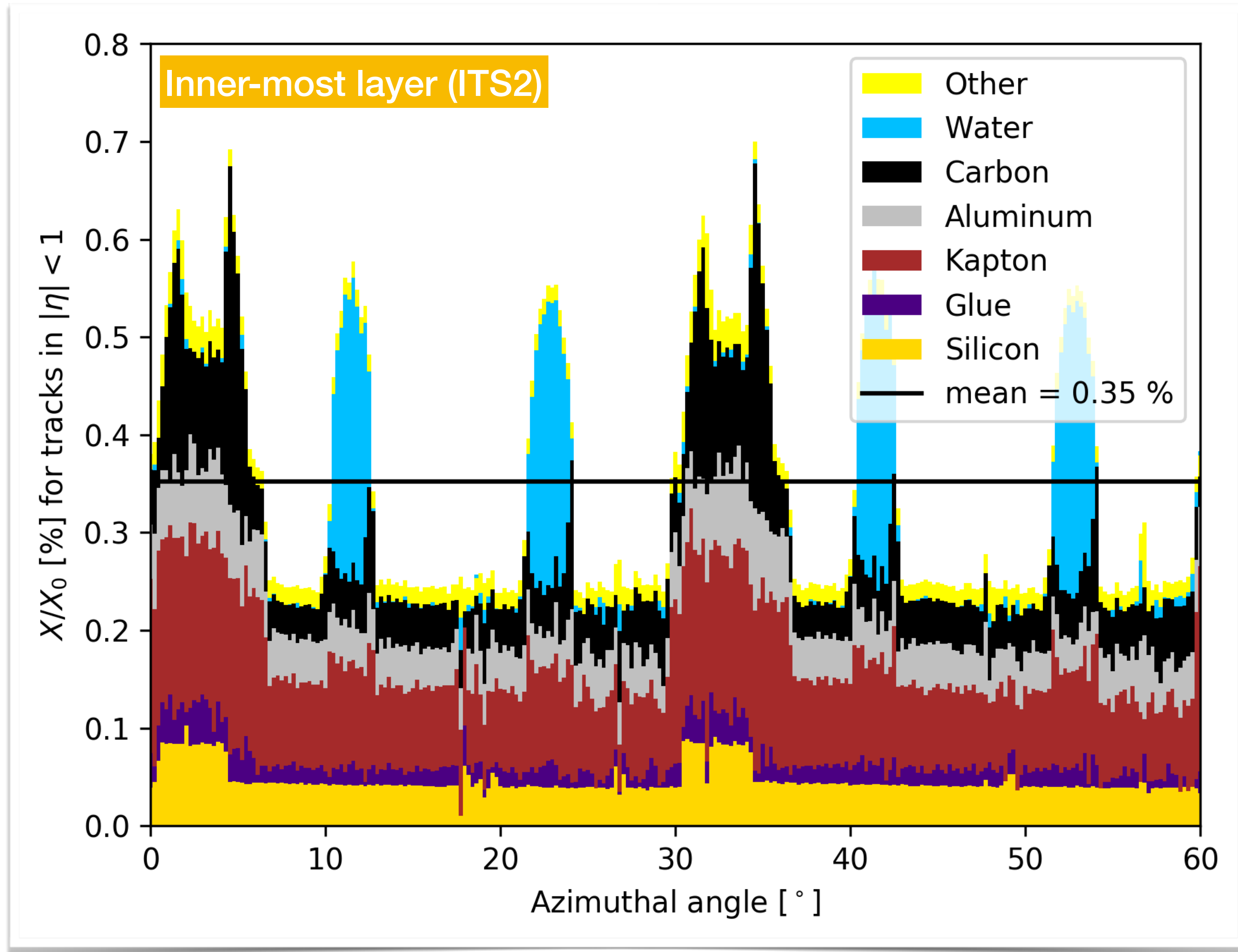


► Observations:

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

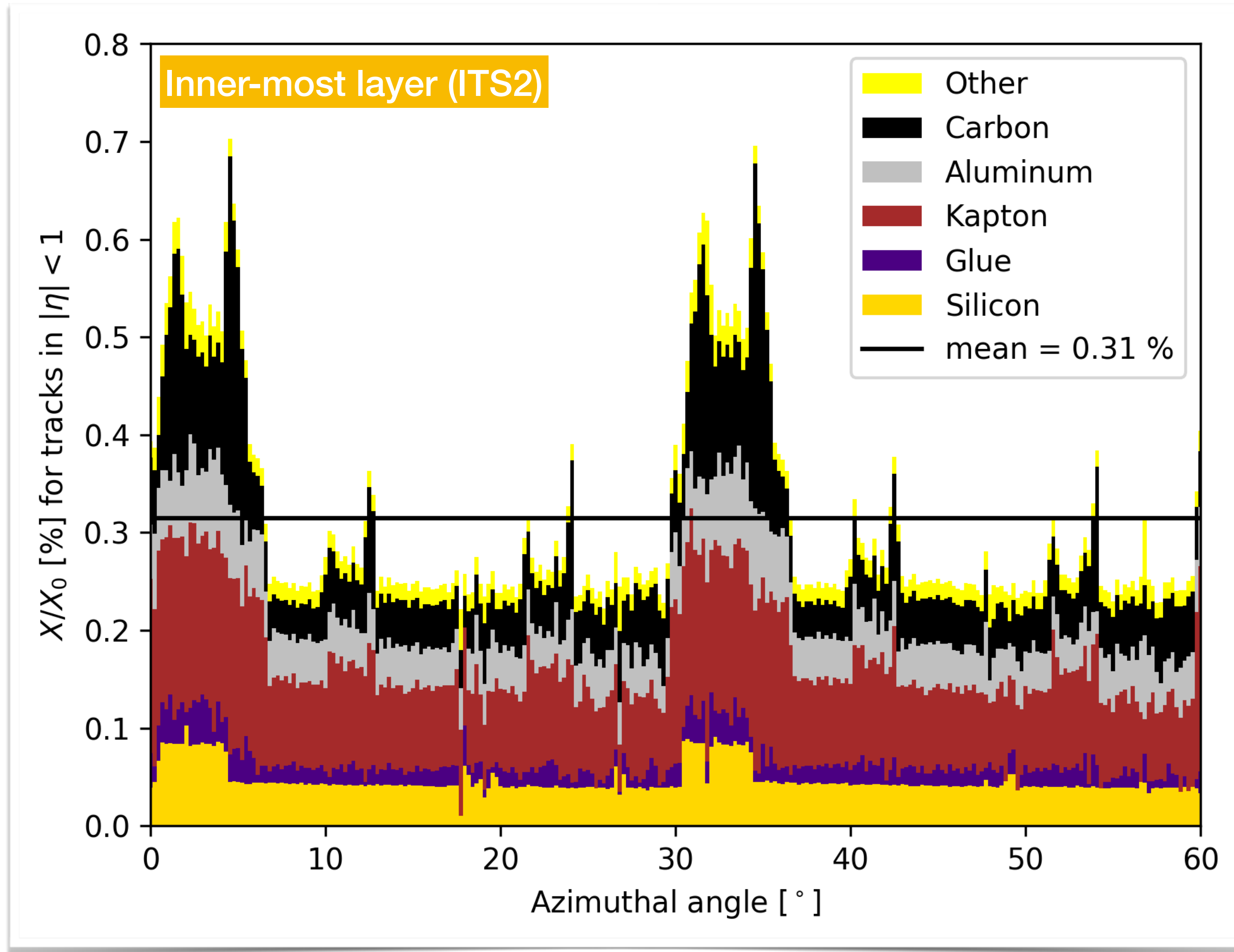


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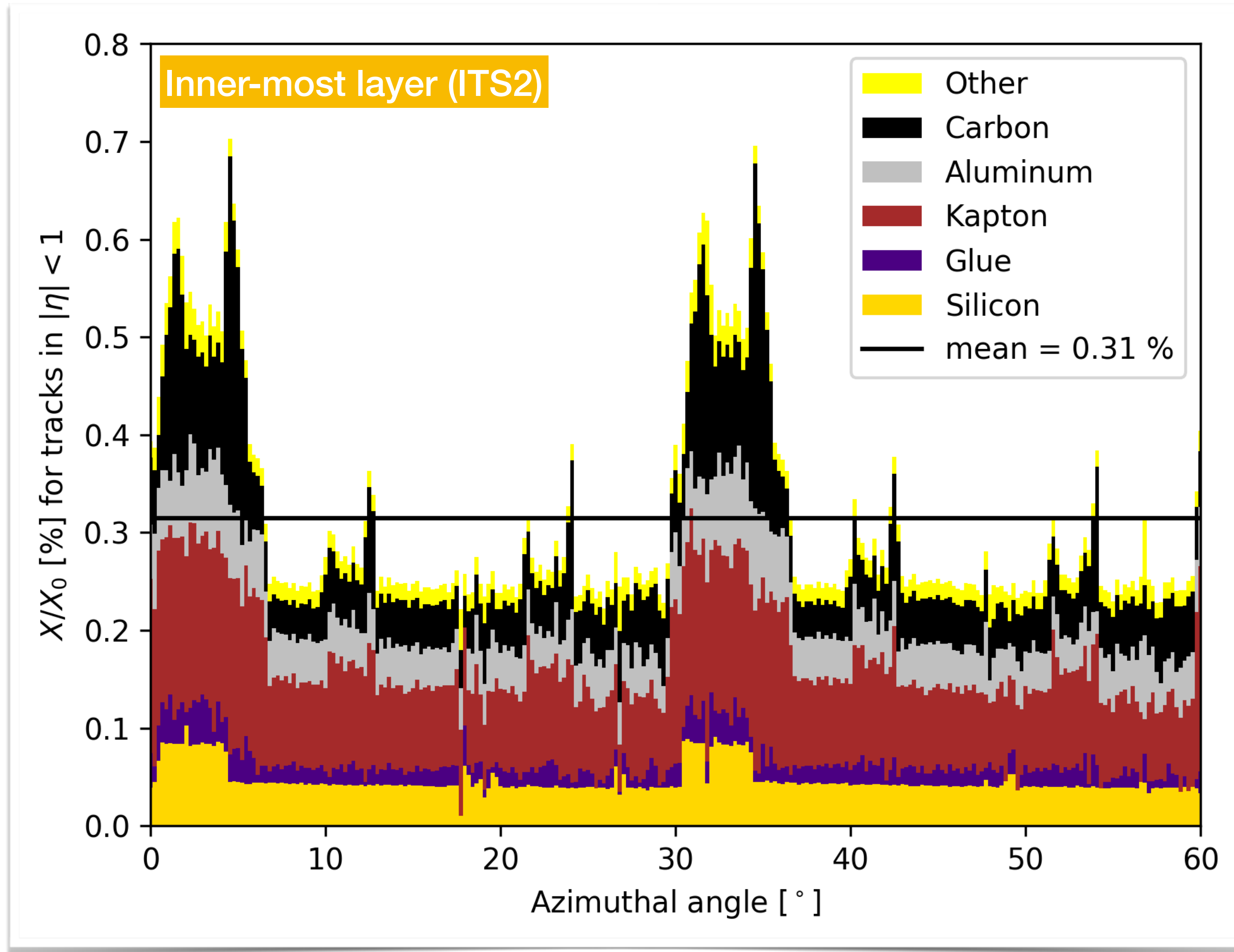
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- ▶ Removal of water cooling
  - **possible** if power consumption stays below 20mW/cm<sup>2</sup>

# Material budget



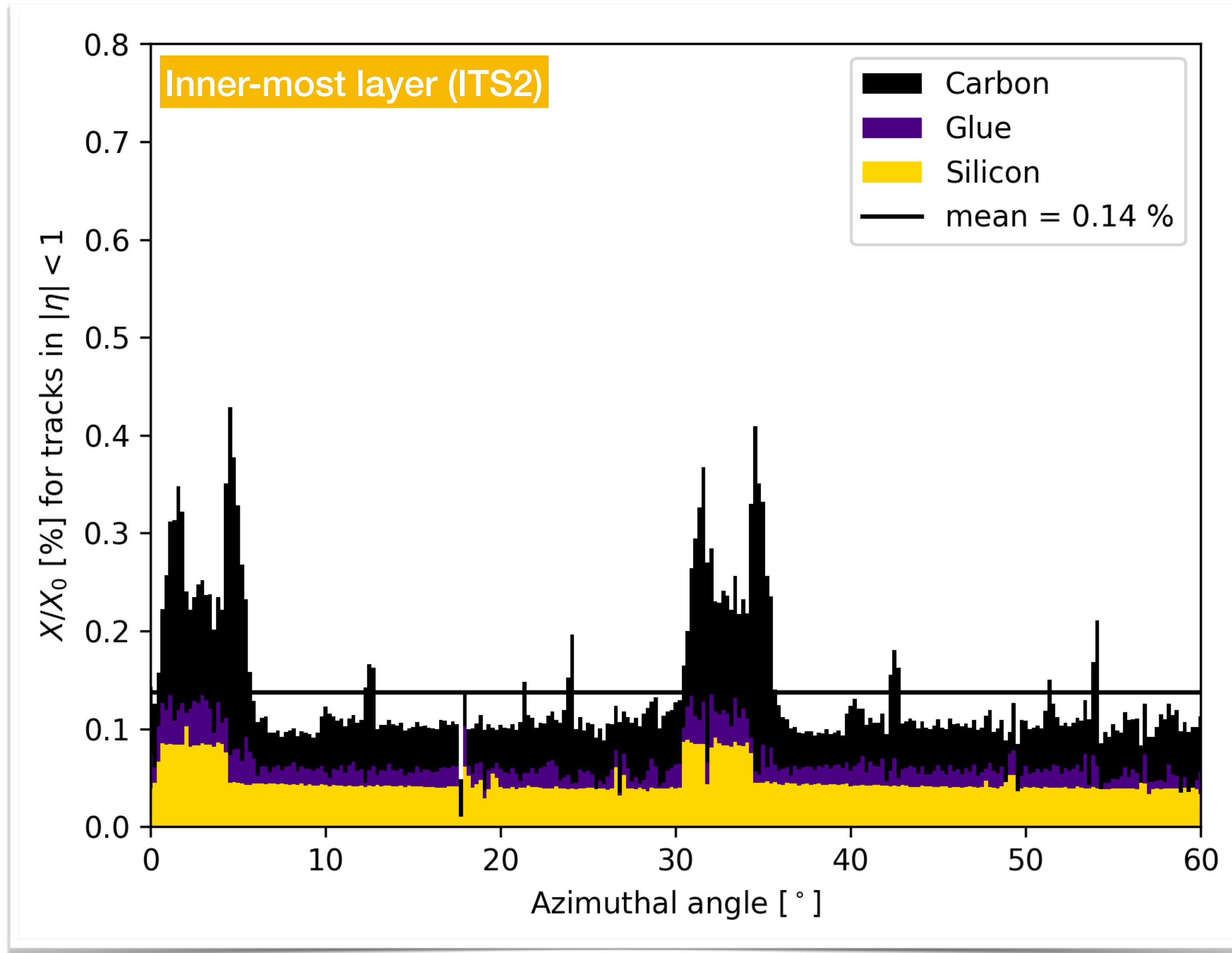
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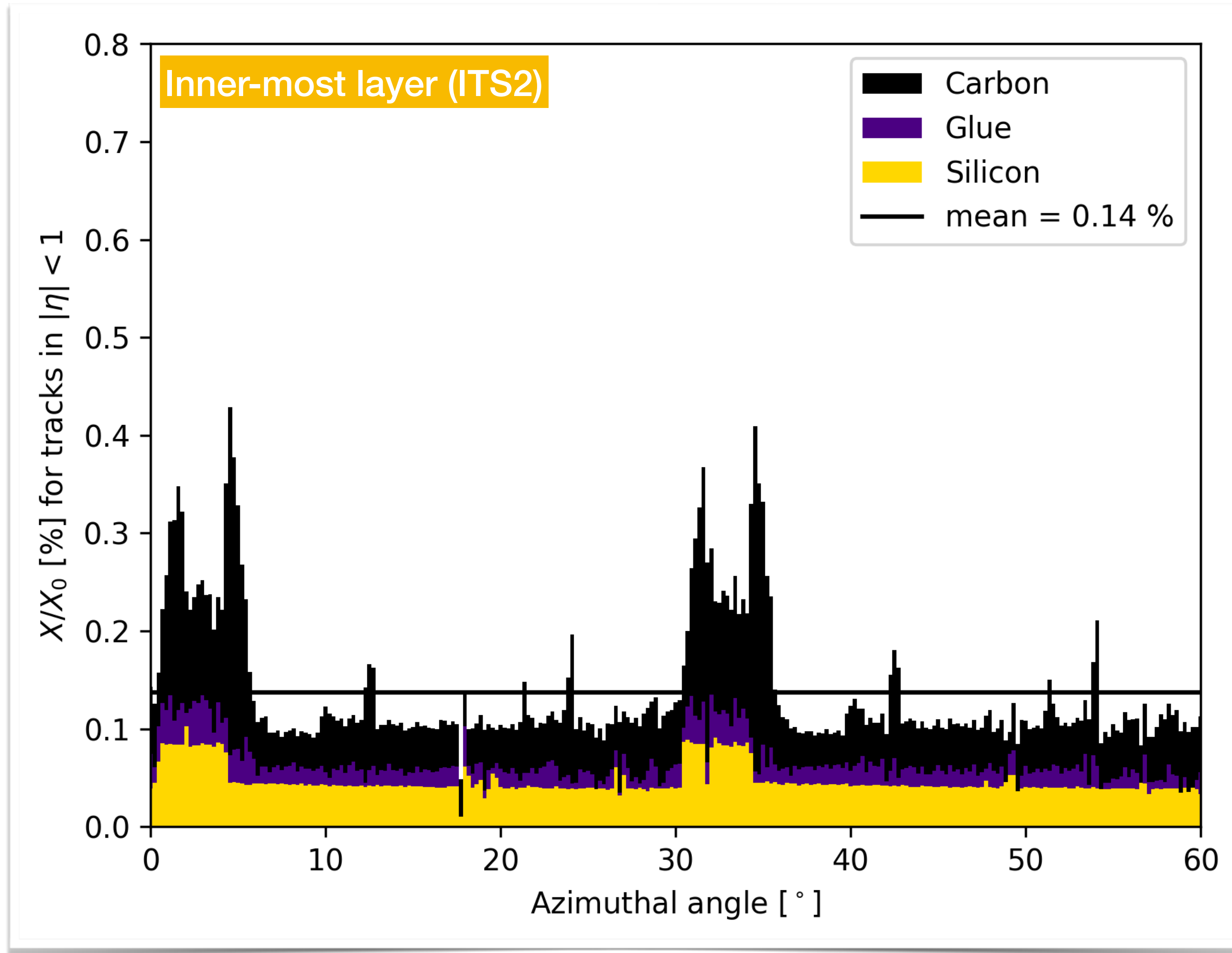
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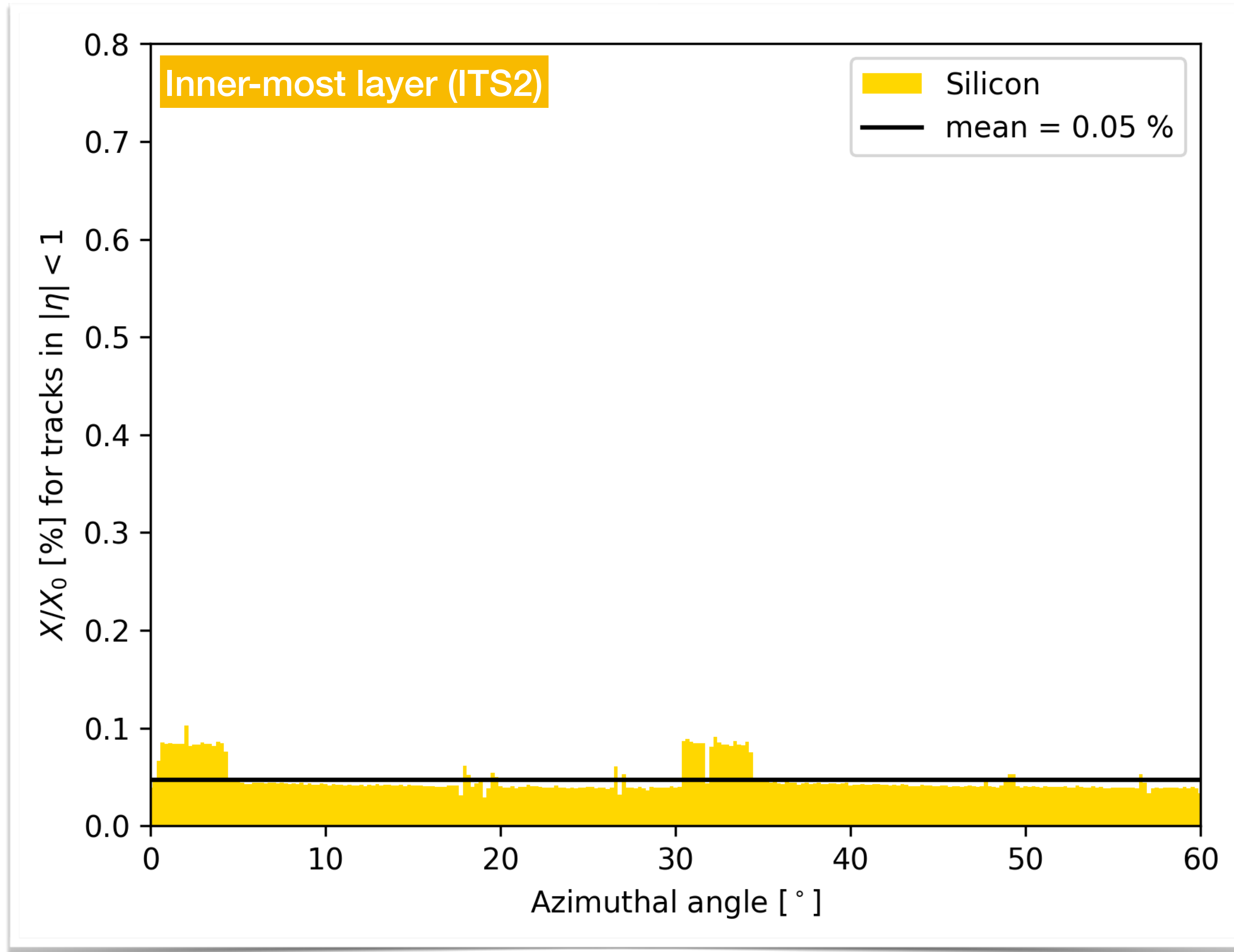
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- ▶ Removal of mechanical support
  - **benefit** from increased stiffness by rolling Si wafers

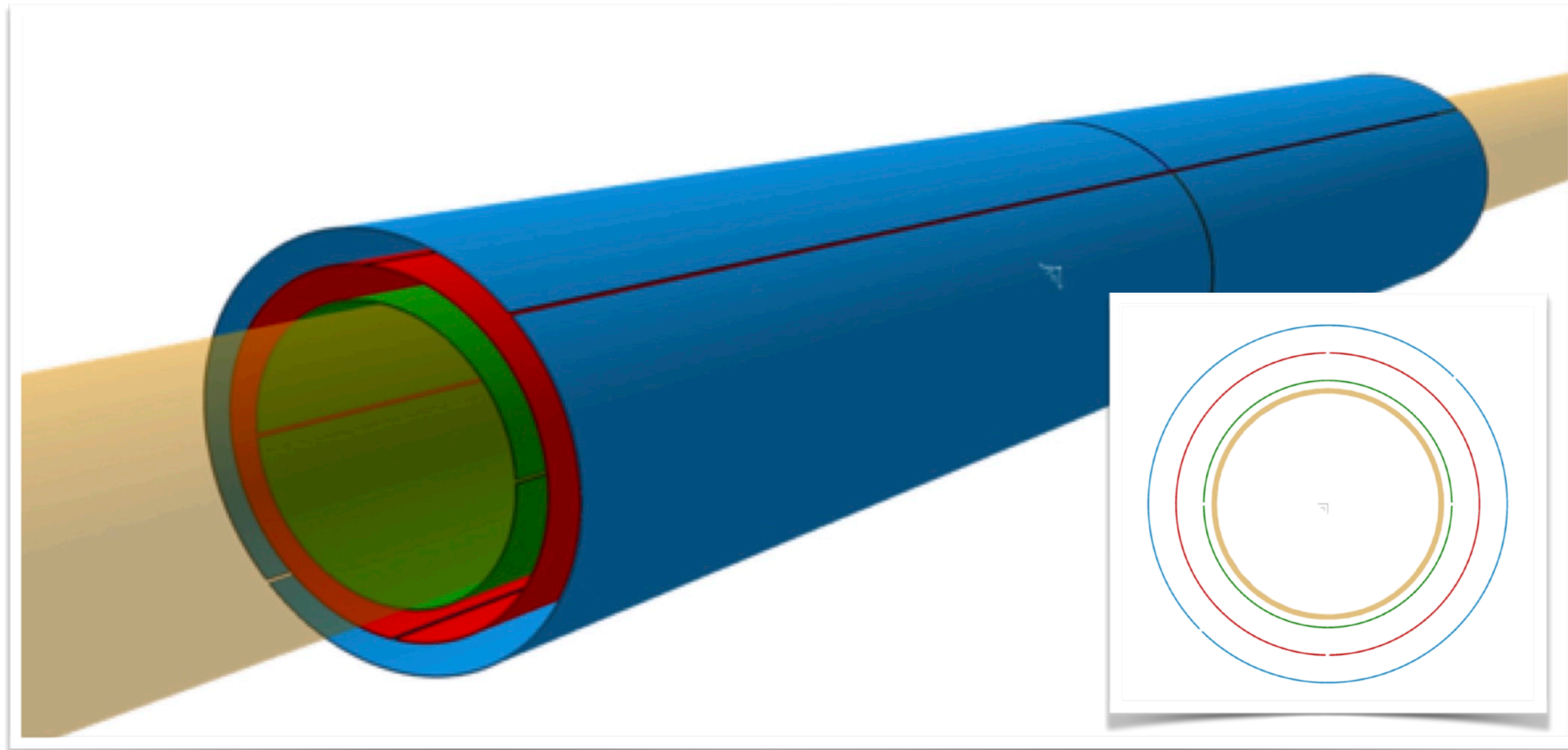
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## ▶ ITS3 layout and integration

# Layout

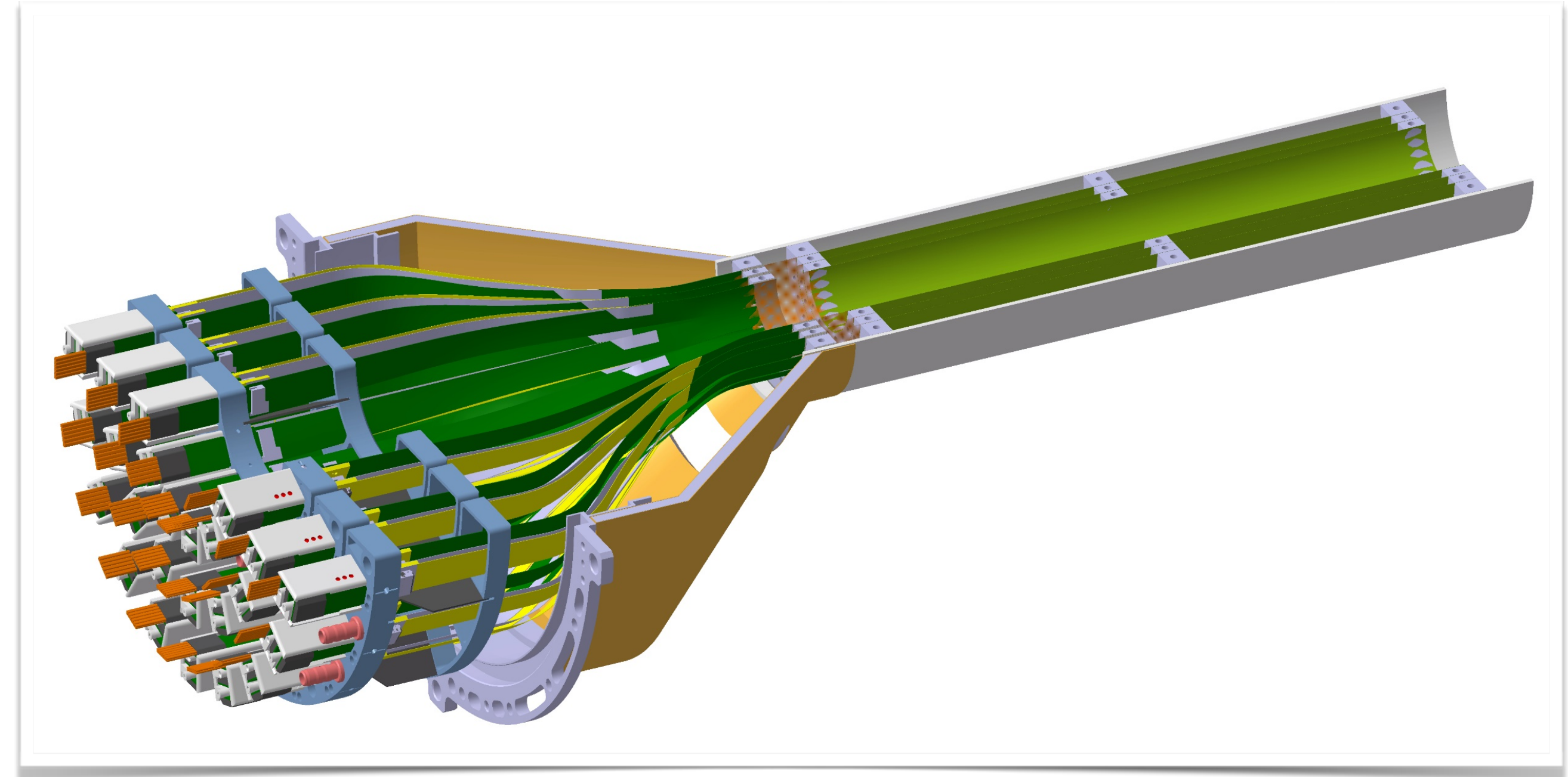
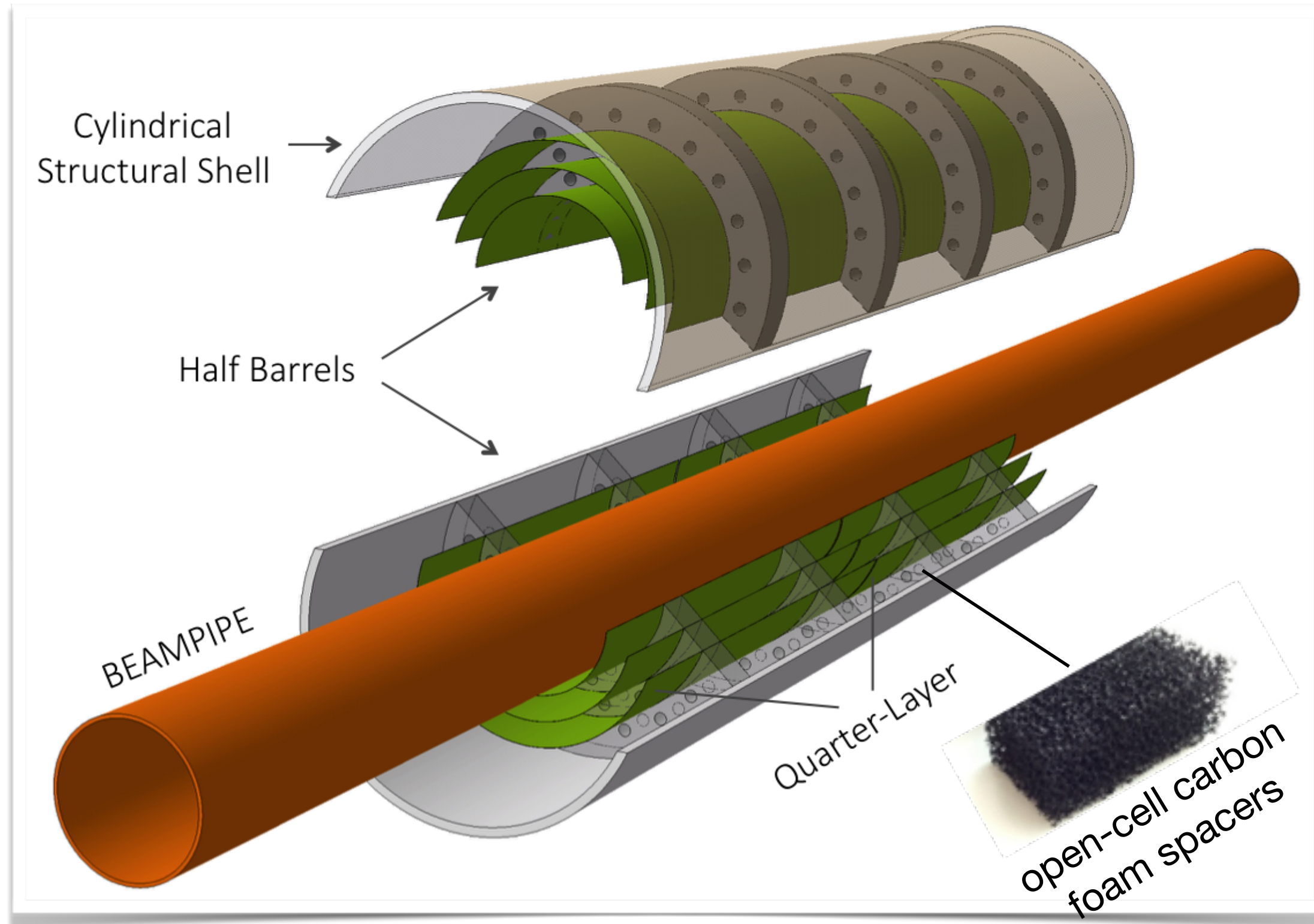


- ▶ New beam pipe:
  - “old” radius/thickness: 18.2/0.8 mm
  - new radius/thickness: 16.0/0.5 mm
  
- ▶ Extremely low material budget:
  - Beam pipe thickness: 500  $\mu\text{m}$  (0.14%  $X_0$ )
  - Sensor thickness: 20-40  $\mu\text{m}$  (0.02-0.04%  $X_0$ )
  
- ▶ Material homogeneously distributed:
  - essentially zero systematic error from material distribution

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	$\pm 2.5$	$\pm 2.3$	$\pm 2.0$
Active area (cm <sup>2</sup> )	610	816	1016
Pixel sensor dimensions (mm <sup>2</sup> )	280 x 56.5	280 x 75.5	280 x 94
Number of sensors per layer	2		
Pixel size ( $\mu\text{m}^2$ )	O (10 x 10)		



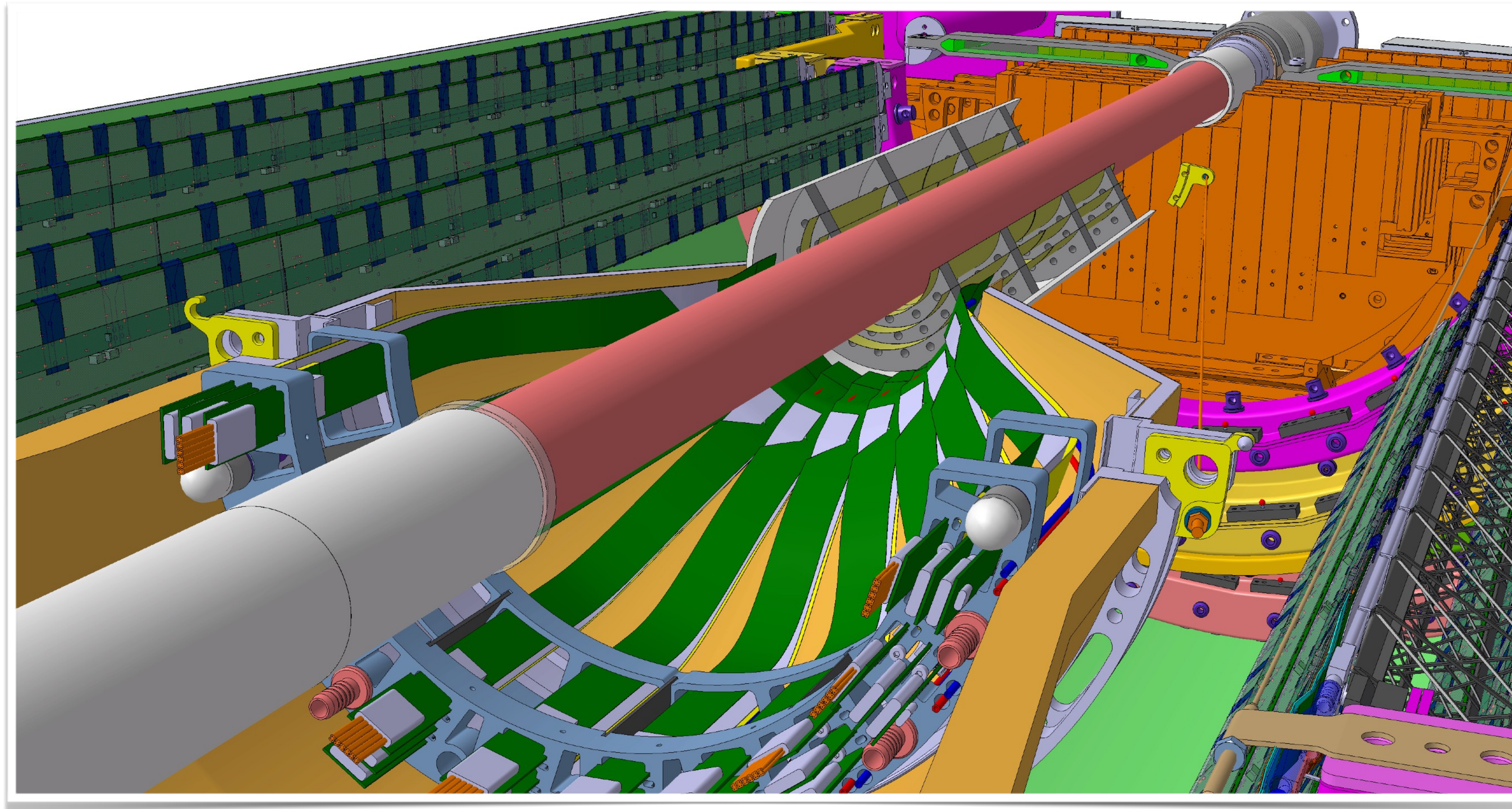
# Integration



- ▶ Possible layout based on air-cooling
- ▶ Sensors held in place with low-density carbon foam

- ▶ Fixation into the experiment by surrounding support structure, as well as at both ends
- ▶ Cooling at the extremities (chip peripheries)

# Integration (2)



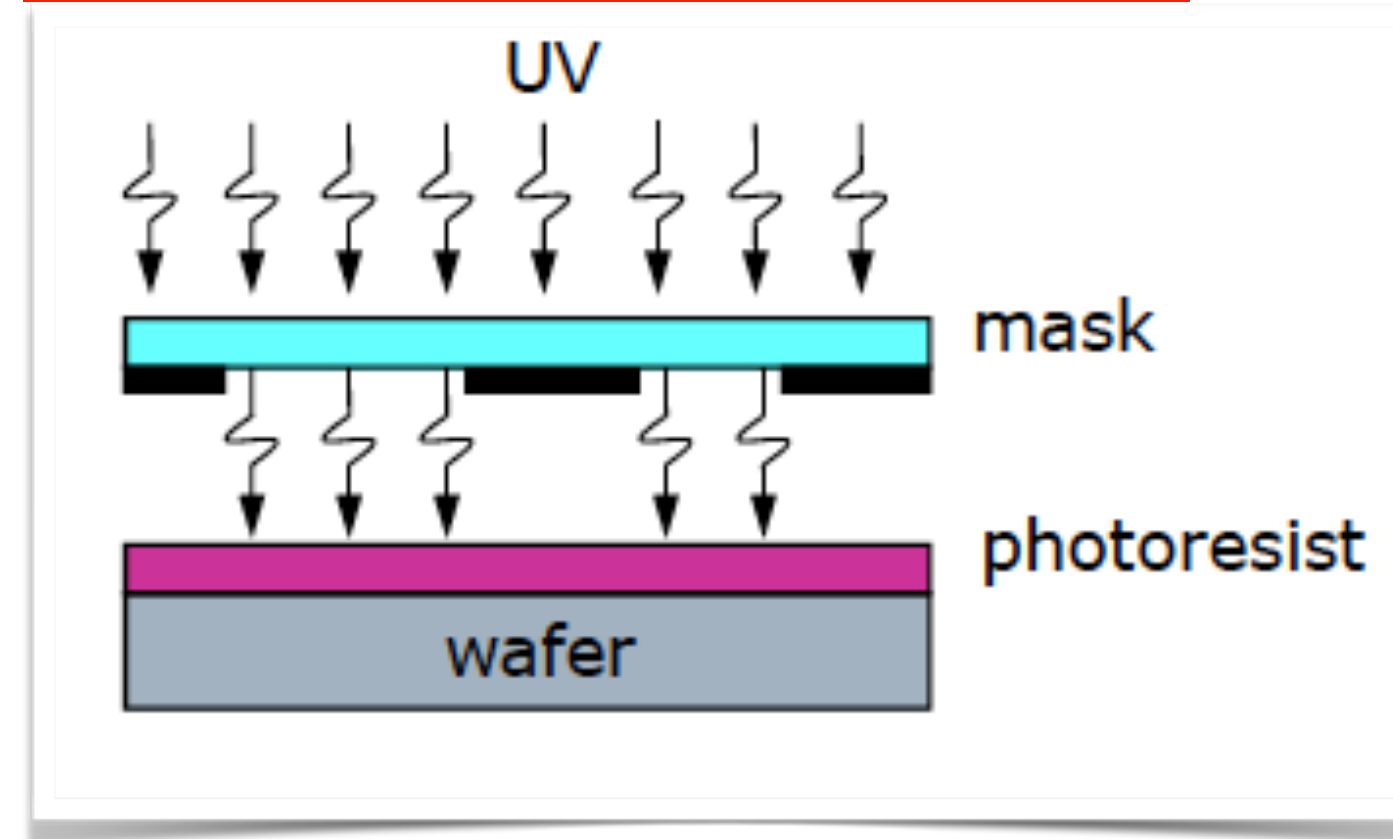
- ▶ Simply **replaces** the “old” Inner Barrel, **reuses** services (power, readout, cooling)
- ▶ Remaining ITS2 stays in place as is

## ▶ R&D topics (selection)

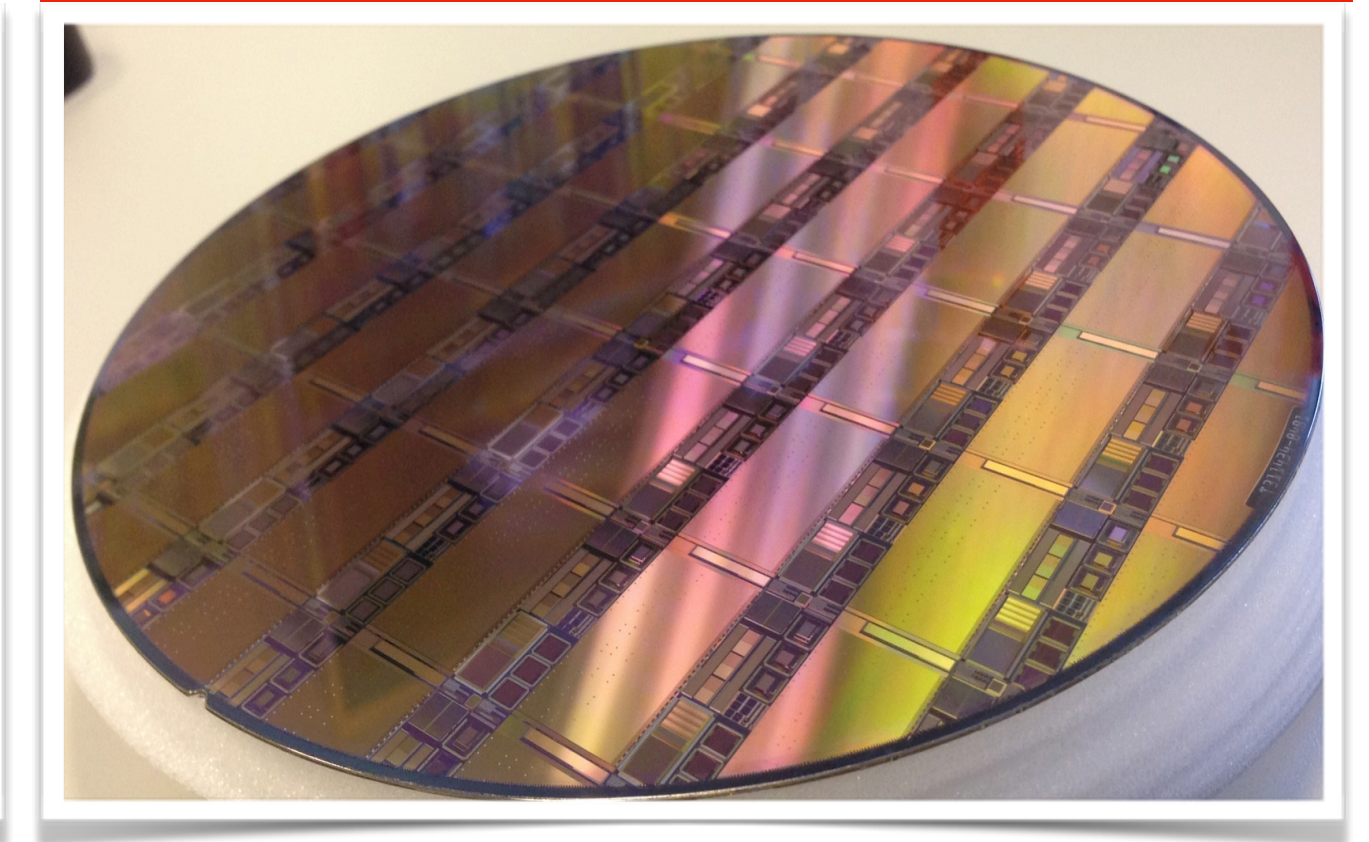
# Wafer-scale chip

- ▶ Chip size is traditionally limited by CMOS manufacturing (“reticle size”)
  - typical sizes of few cm<sup>2</sup>
  - modules are tiled with chips connected to a flexible printed circuit board

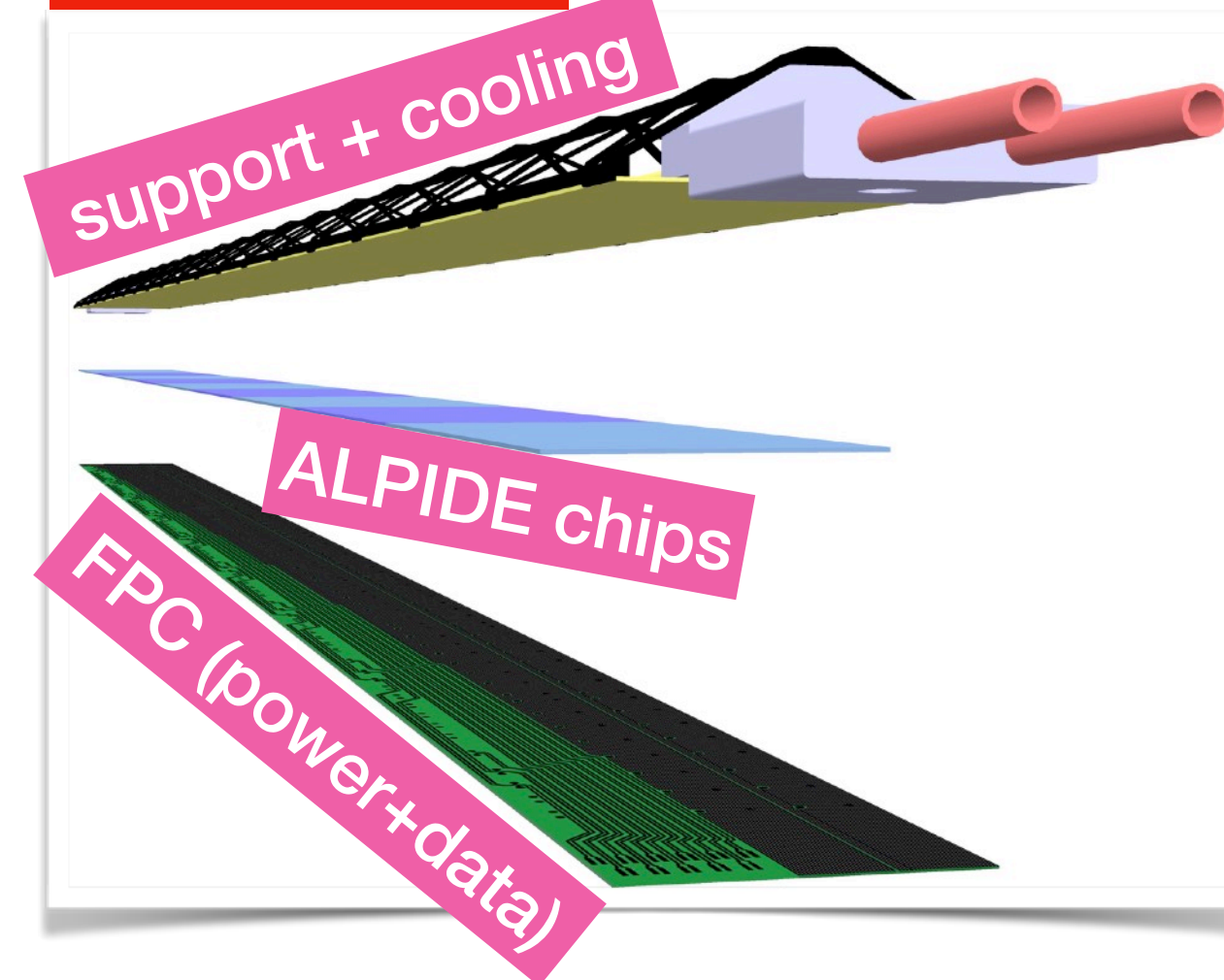
Principle of photolithography



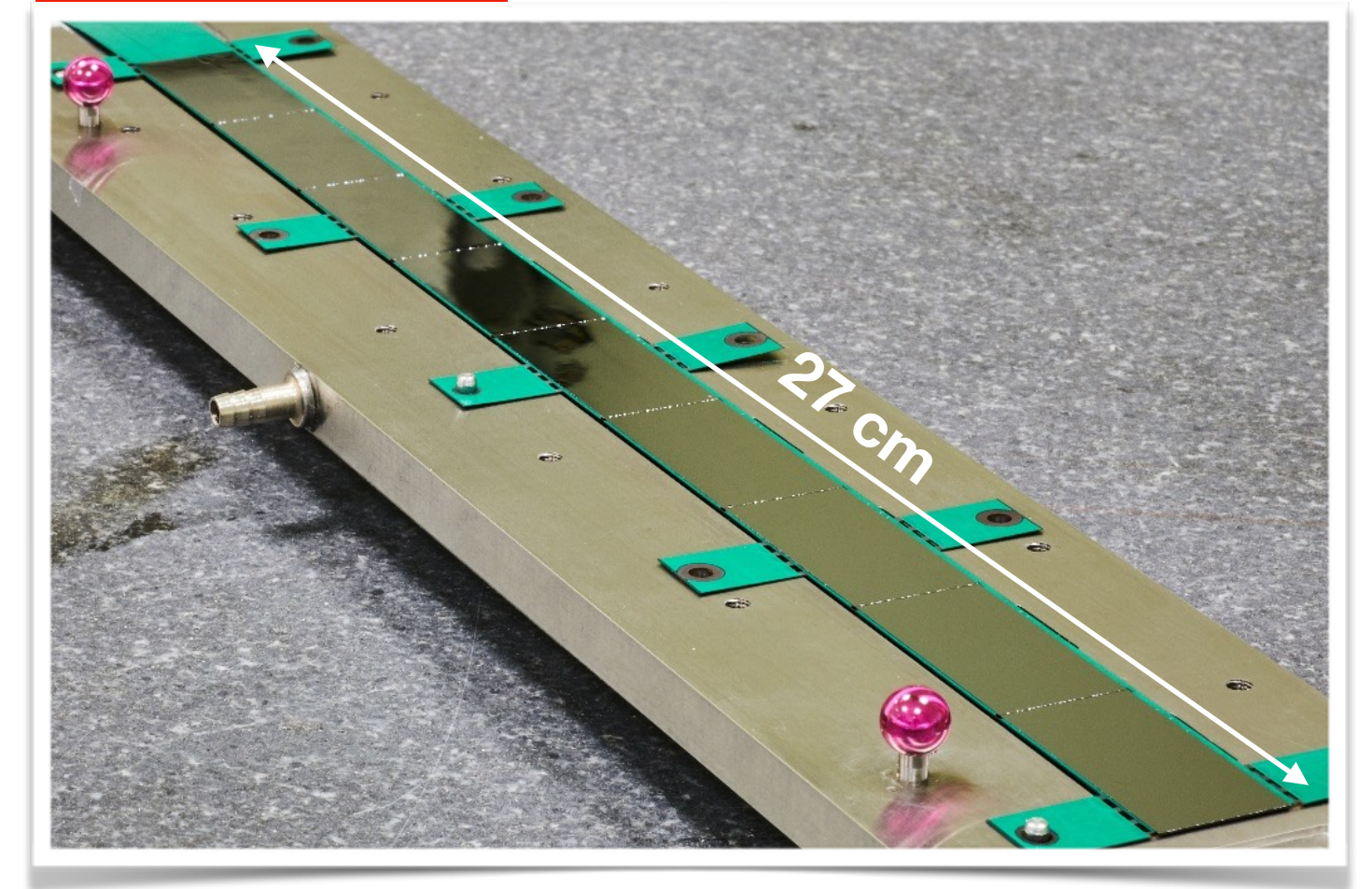
200 mm ALPIDE prototype wafer



Stave design



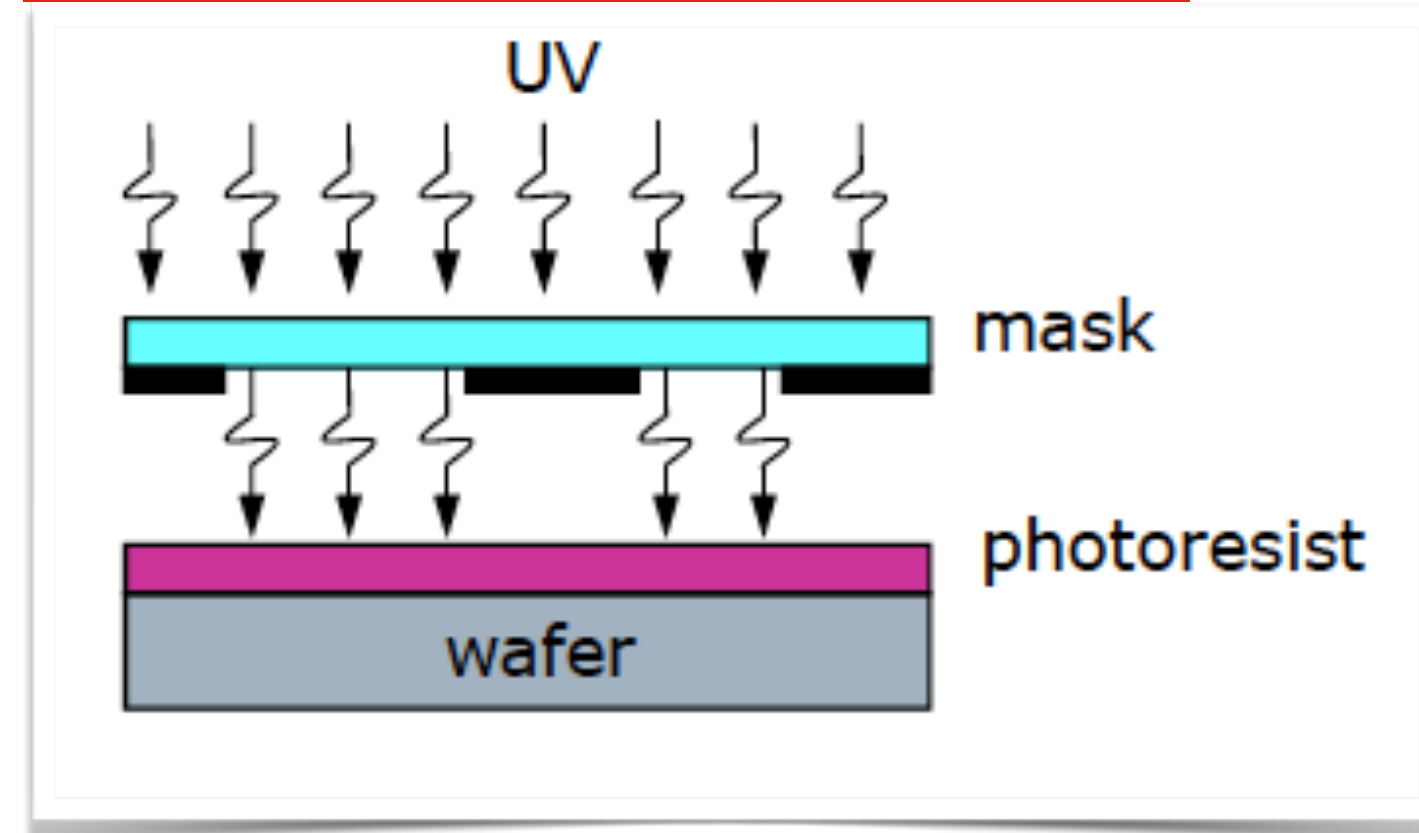
FPC + chips



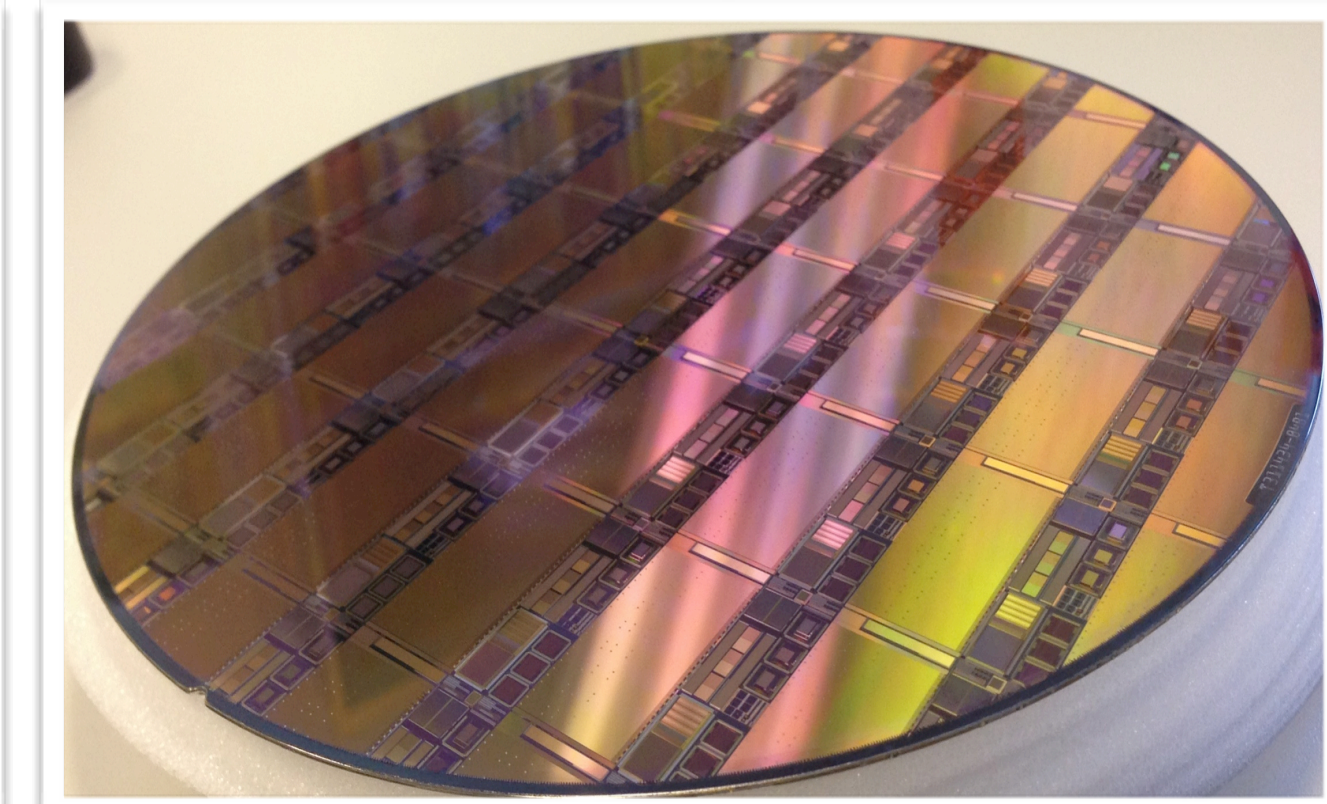
# Wafer-scale chip

- ▶ Chip size is traditionally limited by CMOS manufacturing (“reticle size”)
  - typical sizes of few cm<sup>2</sup>
  - modules are tiled with chips connected to a flexible printed circuit board
  
- ▶ New option: stitching, i.e. aligned exposures of a reticle to produce larger circuits
  - actively used in industry
  - a 300 mm wafer can house a chip to equip a full half-layer
  - *requires dedicated chip design*

## Principle of photolithography

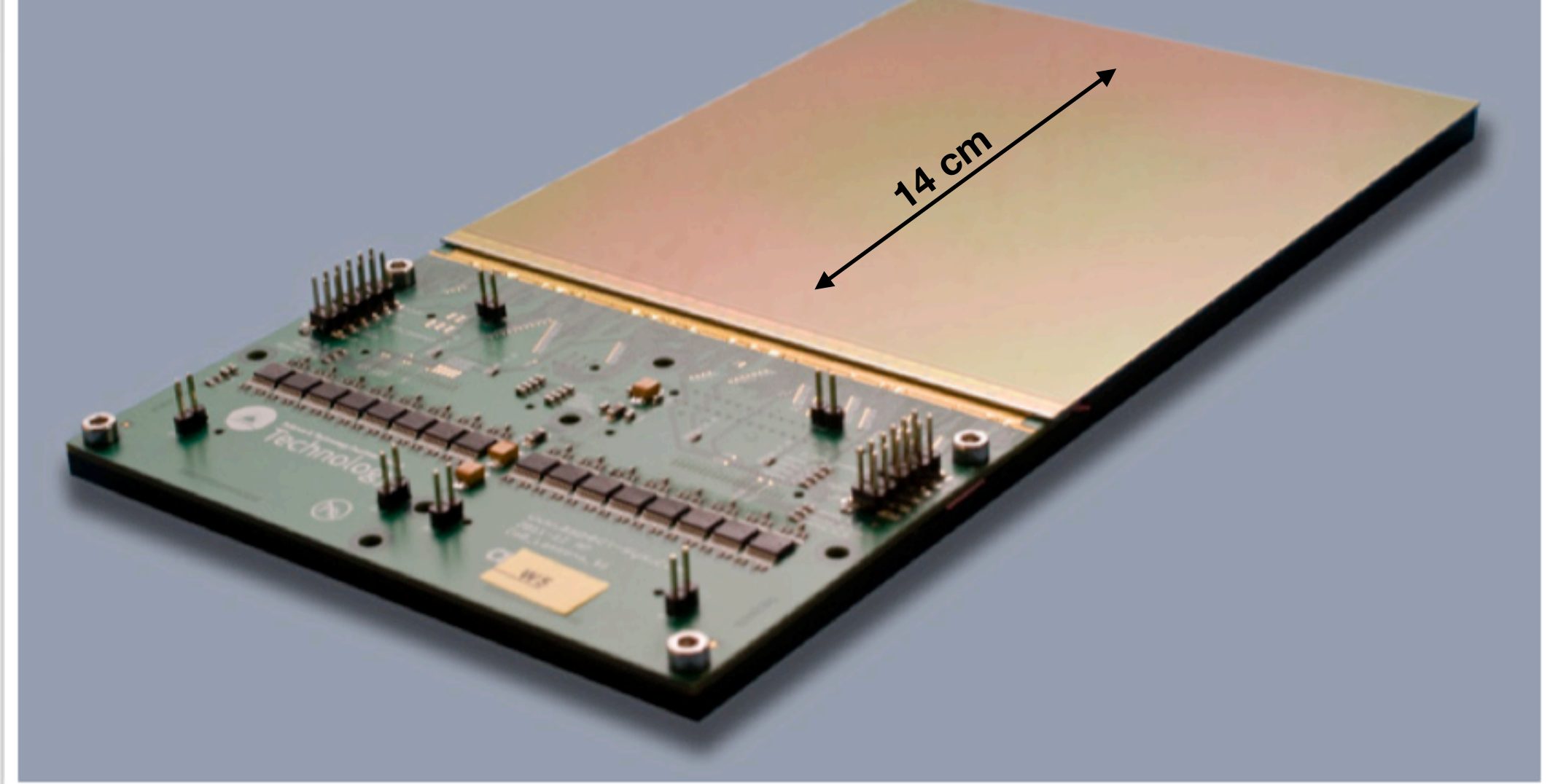


## 200 mm ALPIDE prototype wafer



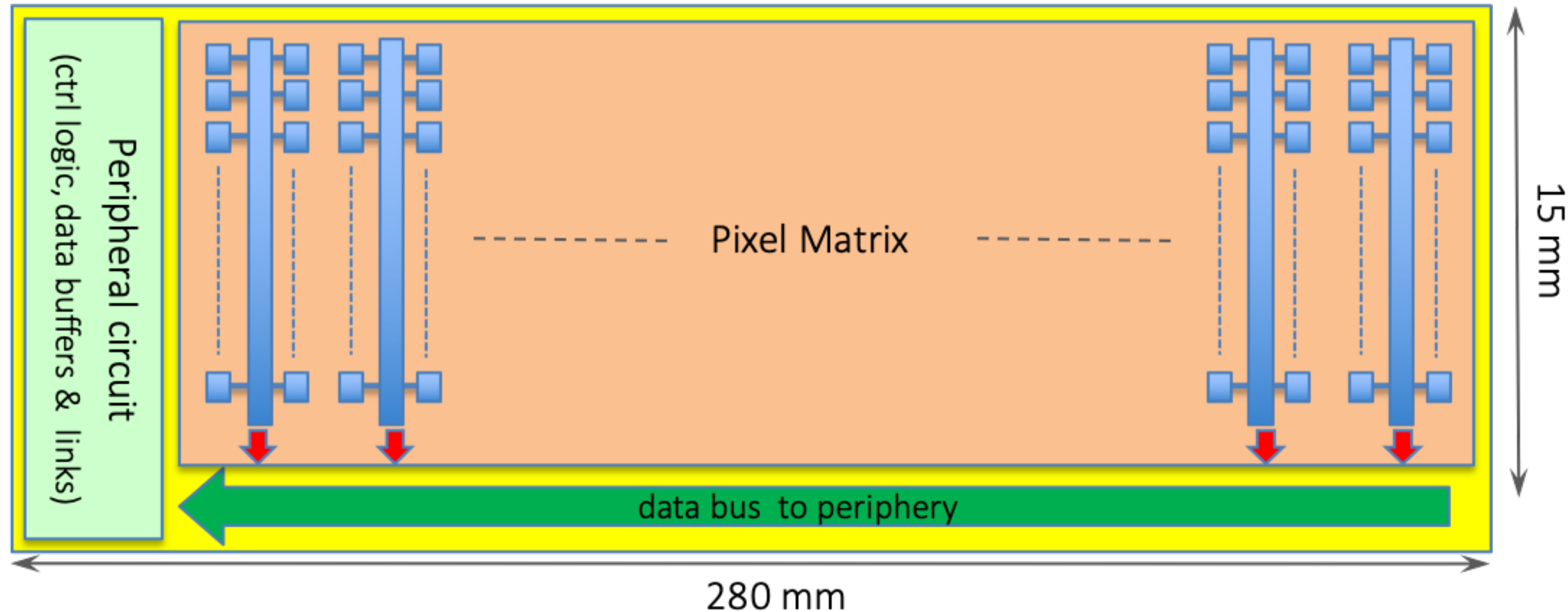
## Wafer-scale sensor

Courtesy: R. Turchetta, Rutherford Appleton Laboratory



# Wafer-scale chip (2)

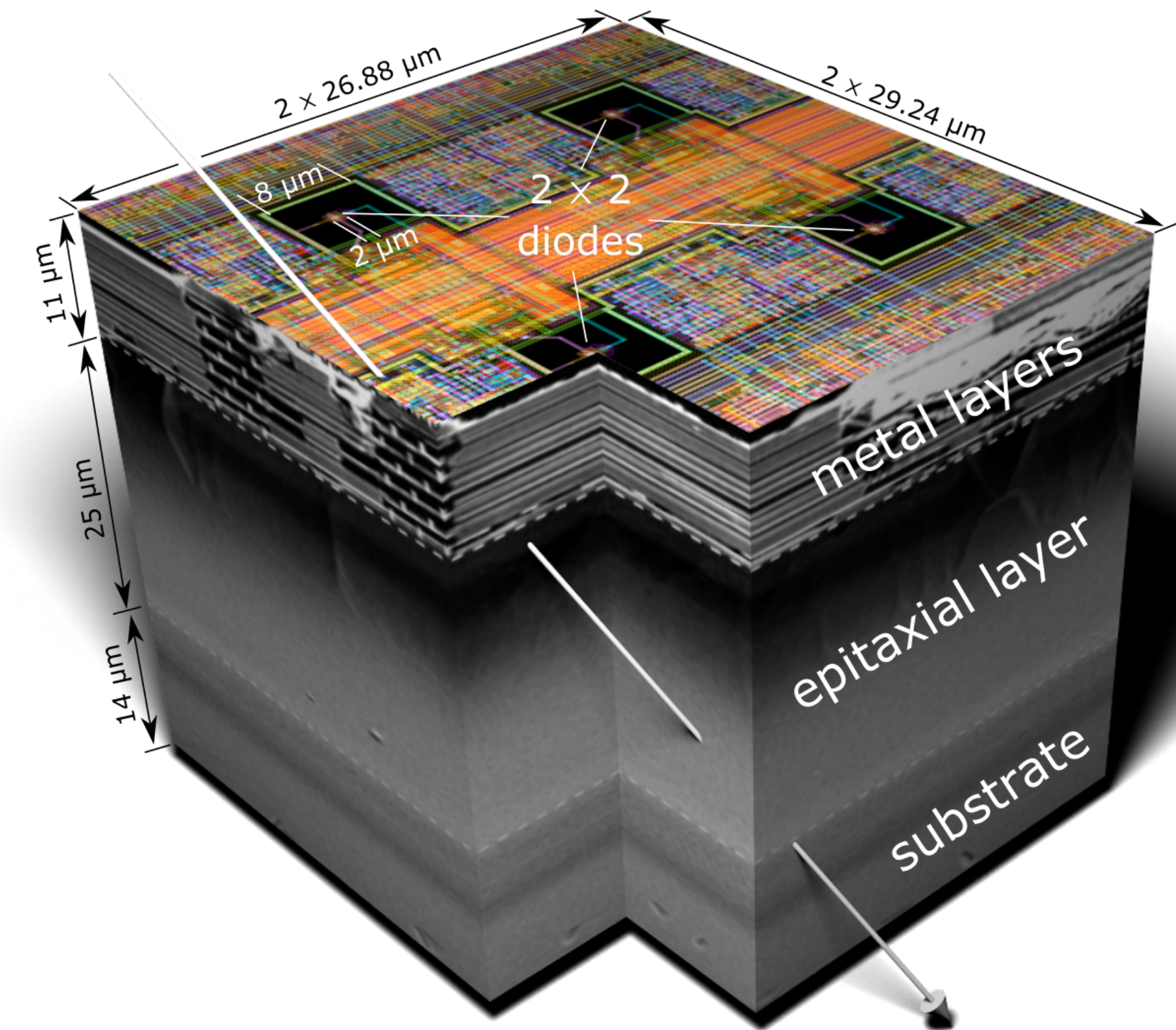
## Possible architecture



- ▶ Starting from ALPIDE architecture
- ▶ Porting to 65 nm technology node
  - smaller pixels
  - larger wafers (300 mm instead of 200 mm)
- ▶ Basic building block of 15 mm height
  - to be repeated n times in vertical direction to obtain the sizes needed per layer

# Thinning and bending silicon

- ▶ CMOS sensors are already very thin
  - ALPIDE is 50  $\mu\text{m}$  thick
  - it uses an epitaxial layer of 25  $\mu\text{m}$  as sensing layer, i.e. 50% of volume is active
  - thinner (18, 20  $\mu\text{m}$ ) epitaxial layers were also tried and yield similar performances
  
- ▶ Realistically heights of  $\approx 30\text{-}40$   $\mu\text{m}$  are already possible
  - The 65 nm process has even thinner metal stack
  - smaller pixels would likely allow for even thinner epi-layers
  
- ▶ Below 50  $\mu\text{m}$ , Si wafers become flexible, “paper-like”



schematic cross-section of ALPIDE

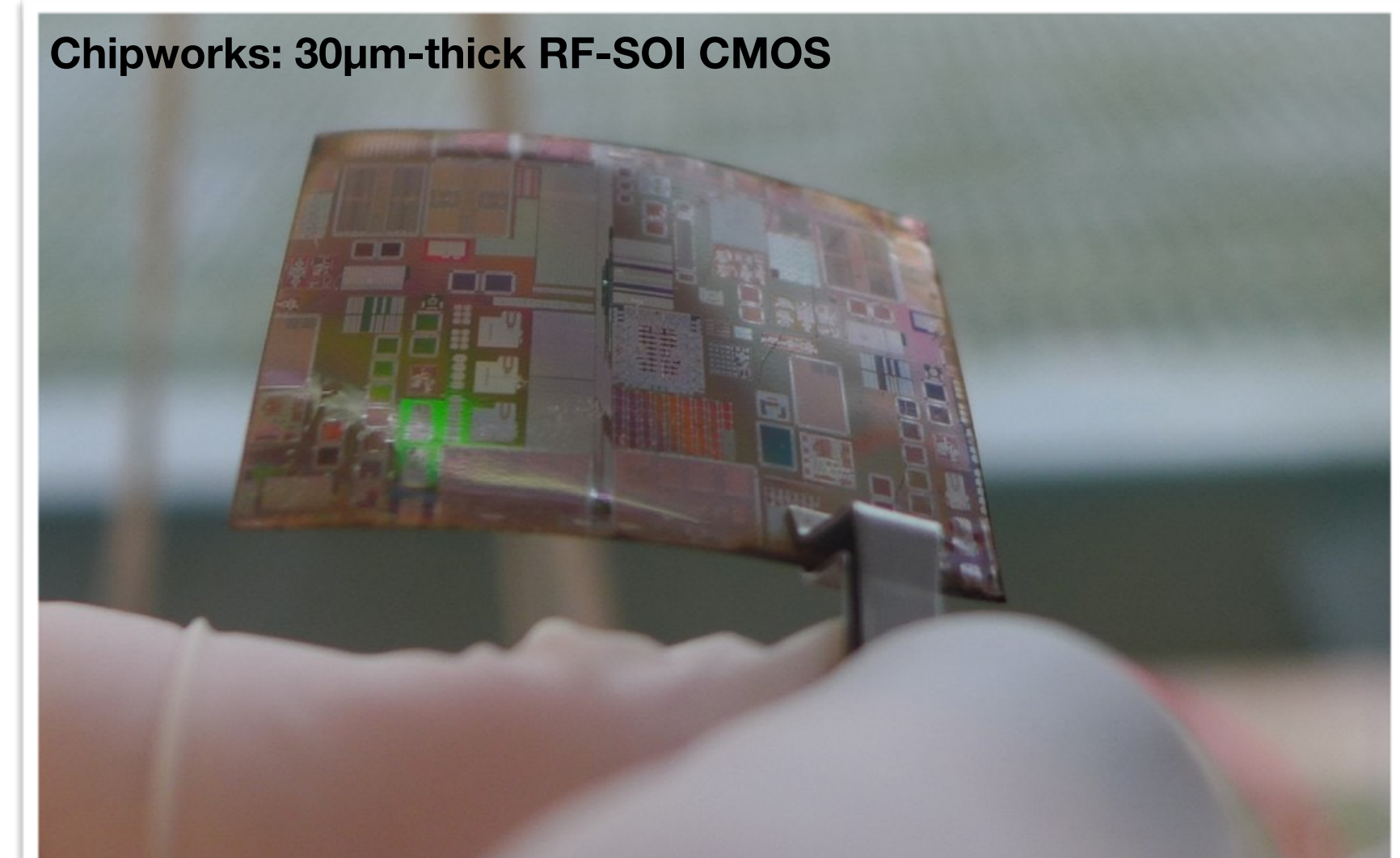
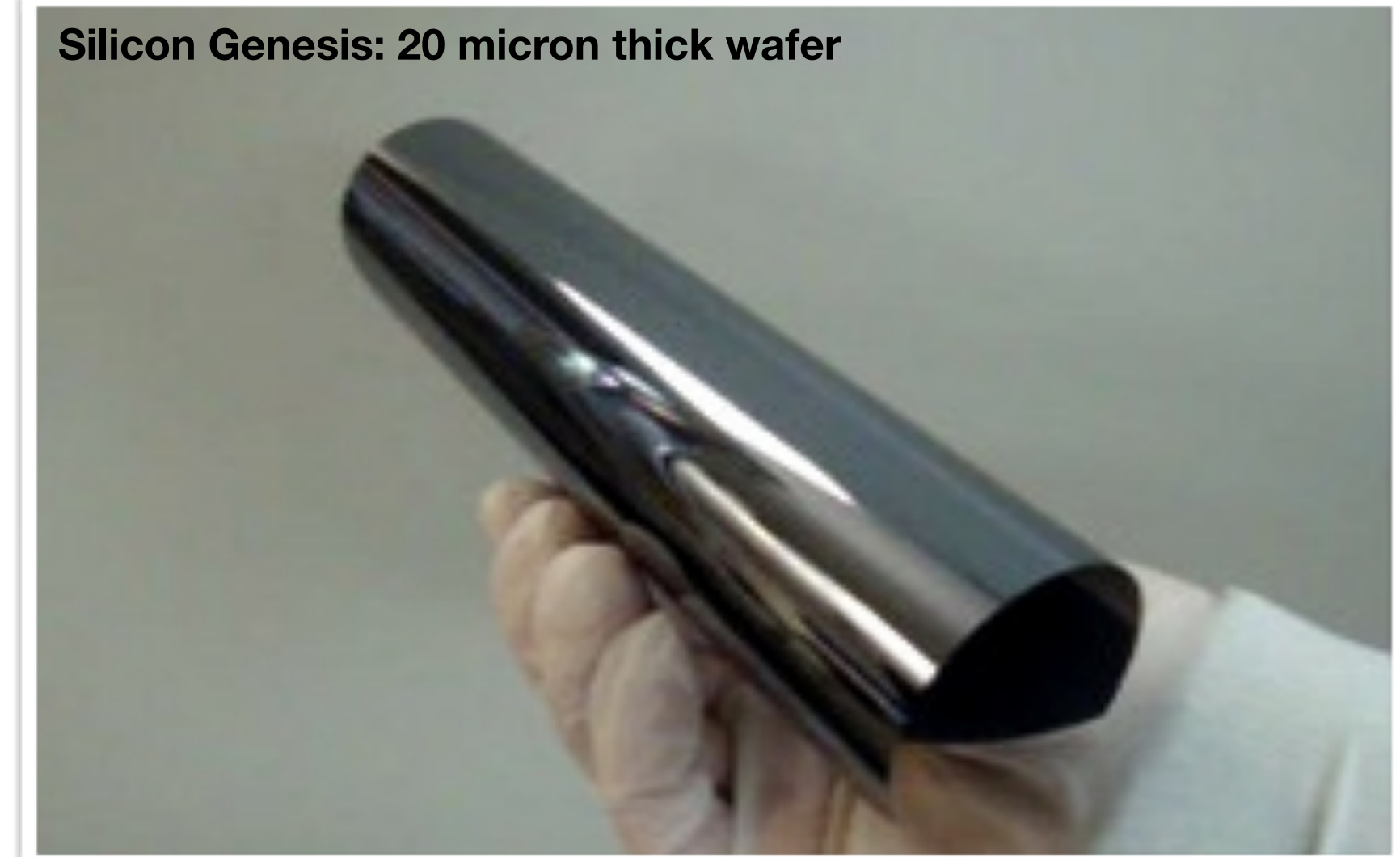
# Thinning and bending silicon (2)

- ▶ Bending Si wafers and circuits is generally possible and done in industry
- ▶ Radii *much* smaller than our needs have been achieved
- ▶ Results can depend on circuitry
  - Demonstration with ALPIDE wafers under way
- ▶ Interconnection options to be studied

Die type	Front/back side	Ground/polished/plasma	Bumps	Die thickness ( $\mu\text{m}$ )	CDS (MPa)	Weibull modulus	MDS (MPa)	$r_{\text{min}}$ (mm)
Blank	Front	Ground	No	15–20	1263	7.42	691	2.46
Blank	Back	Ground	No	15–20	575	5.48	221	7.72
IZM28	Front	Ground	Yes	15–20	1032	9.44	636	2.70
IZM28	Back	Ground	Yes	15–20	494	2.04	52	32.7
Blank	Back	Polished	No	25–35	1044	4.17	334	7.72
IZM28	Back	Polished	Yes	25–35	482	2.98	107	24.3
Blank	Back	Plasma	Yes	18–22	2340	12.6	679	2.50
IZM28	Front	Plasma	Yes	18–22	1207	2.64	833	2.05
IZM28	Back	Plasma	Yes	18–22	2139	3.74	362	4.72

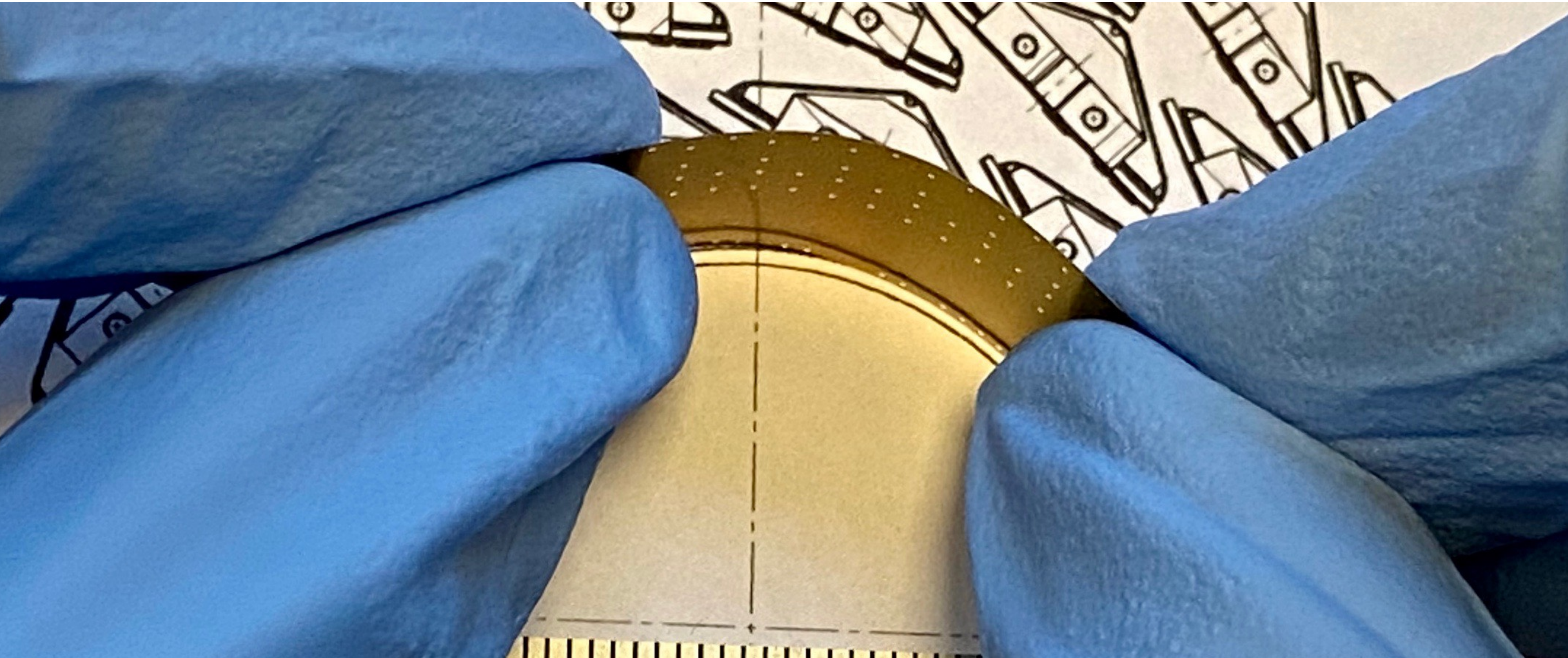
<http://dx.doi.org/10.1016/j.microrel.2014.07.125>

D.A. van den Ende et al., *Microelectronics Reliability*, vol. 54, pp. 2860–2870, 2014



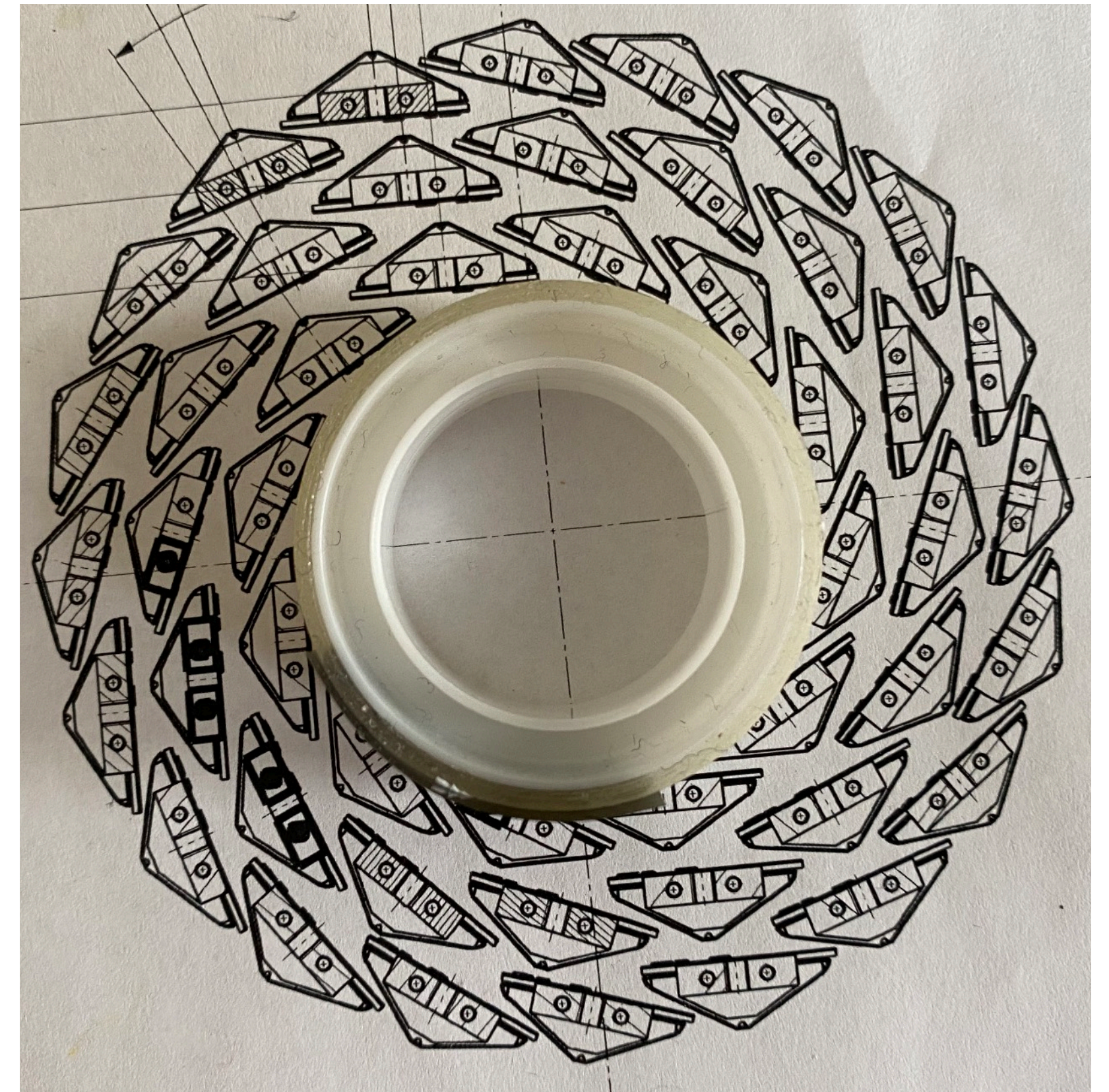


# First trials with ALPIDE



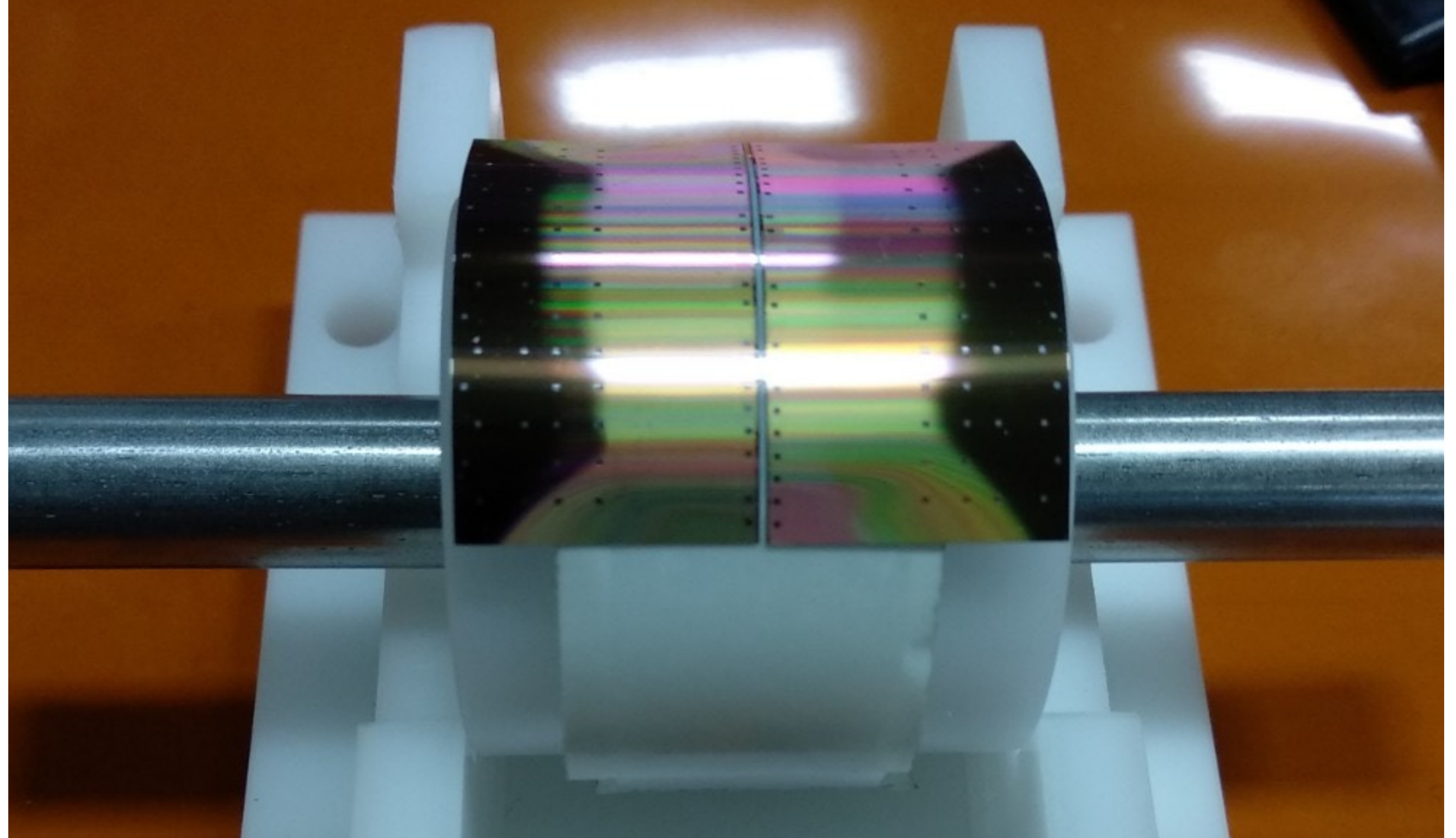
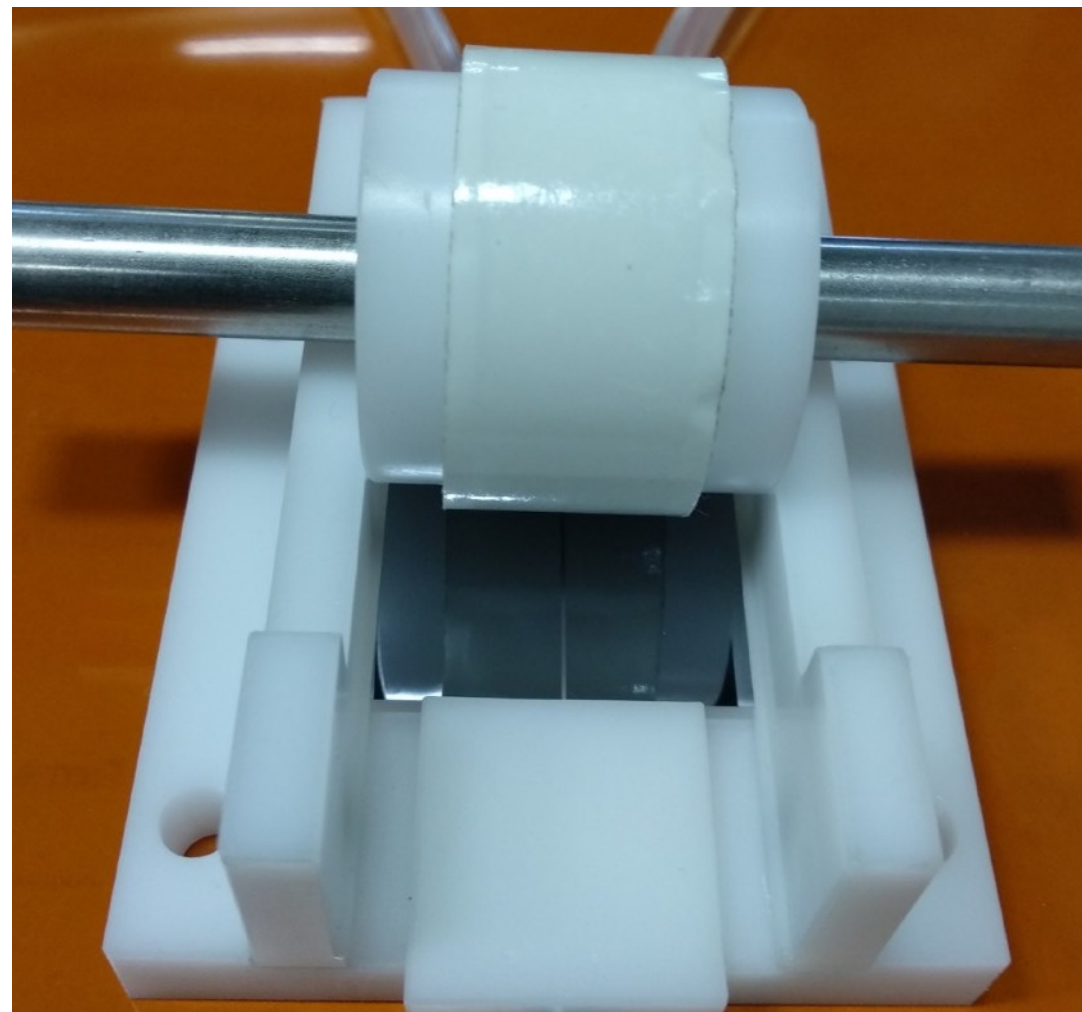
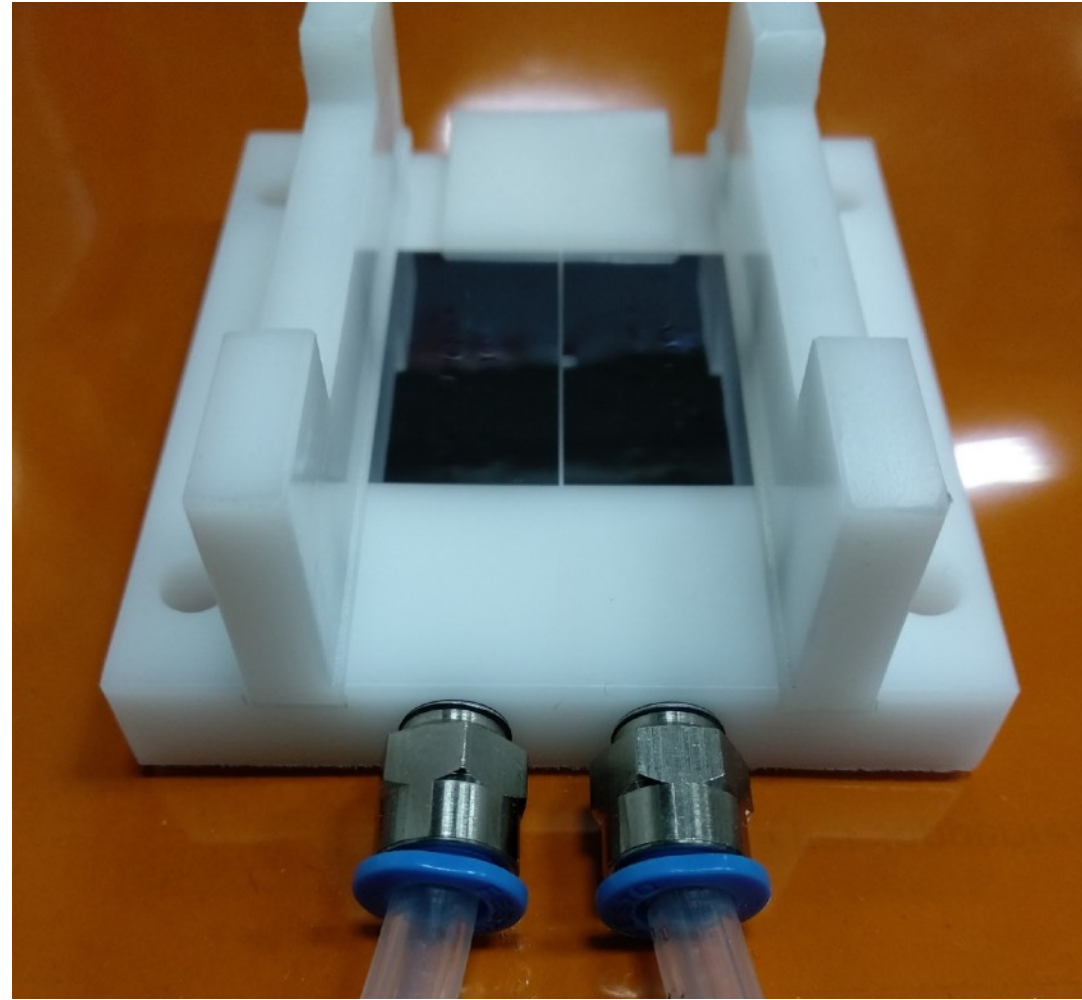
**“Standard”, 50  $\mu\text{m}$  thick ALPIDEs as used for the ITS2 IB, are already quite flexible!**

# First trials with ALPIDE (2)



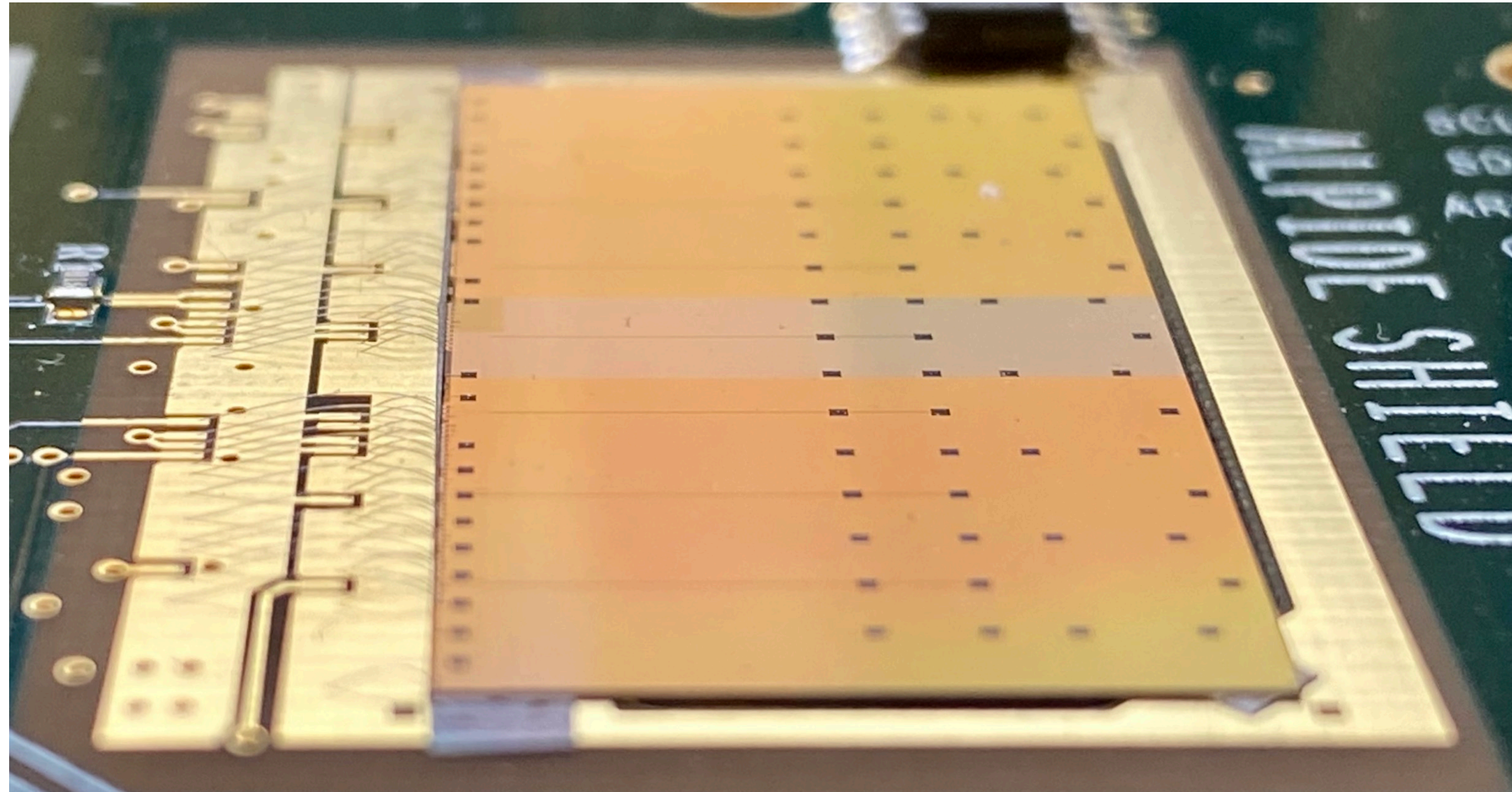
“Office supply” material as motivation for more appropriate mechanics

# First trials with ALPIDE (3)



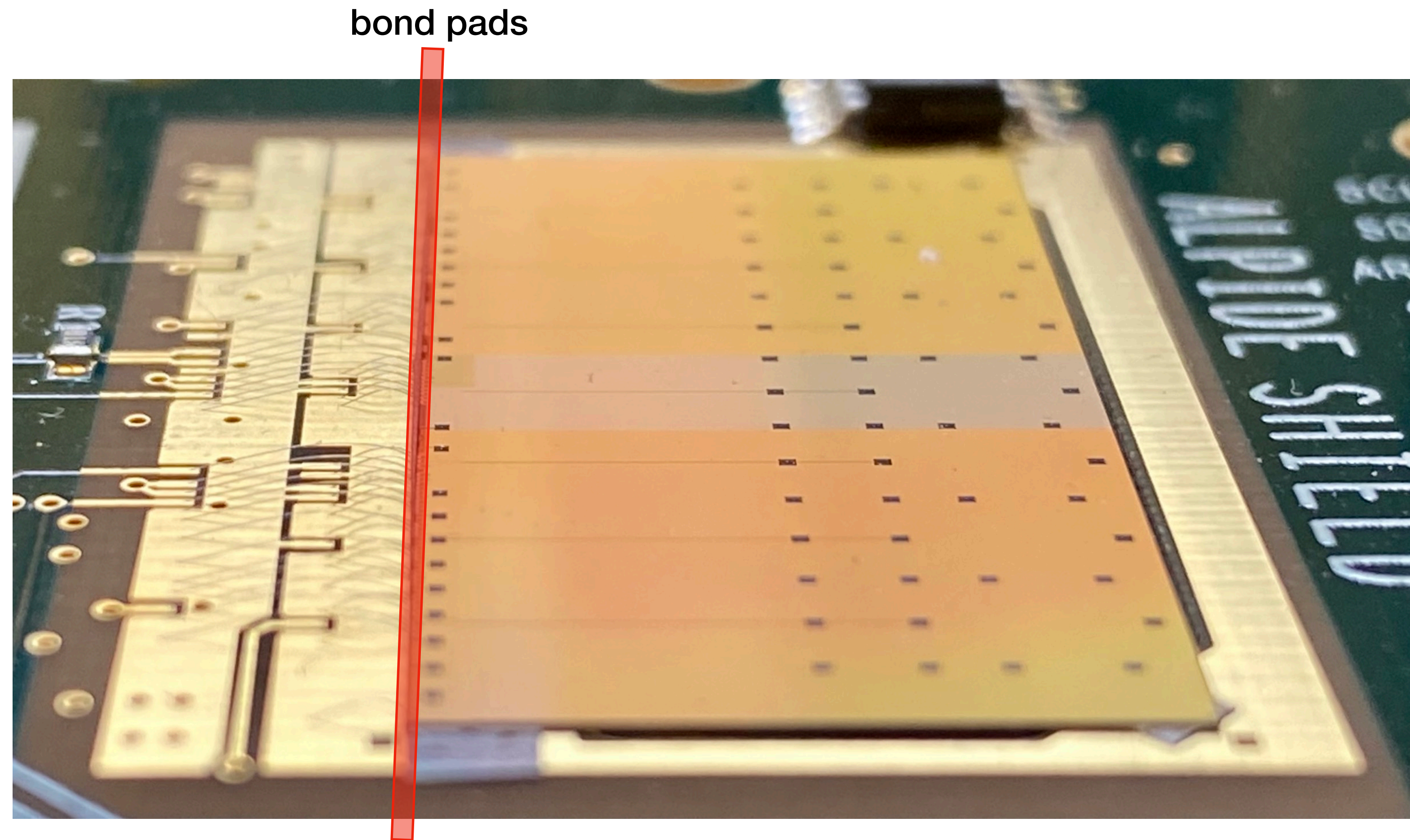
More adequate tools are being prepared

# First trials with ALPIDE (4)



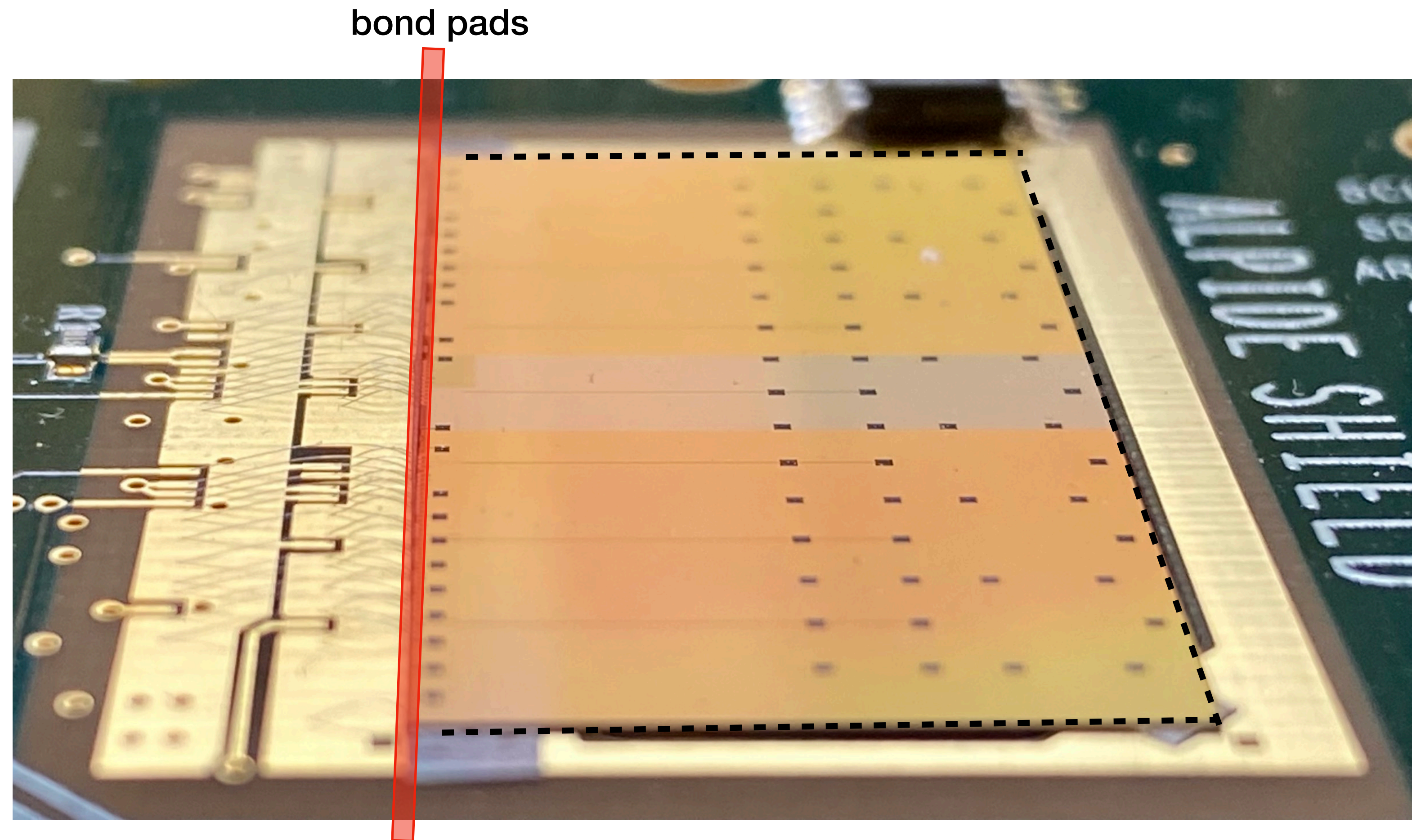
Sketch of how ALPIDEs could be bent based on existing test systems

# First trials with ALPIDE (4)



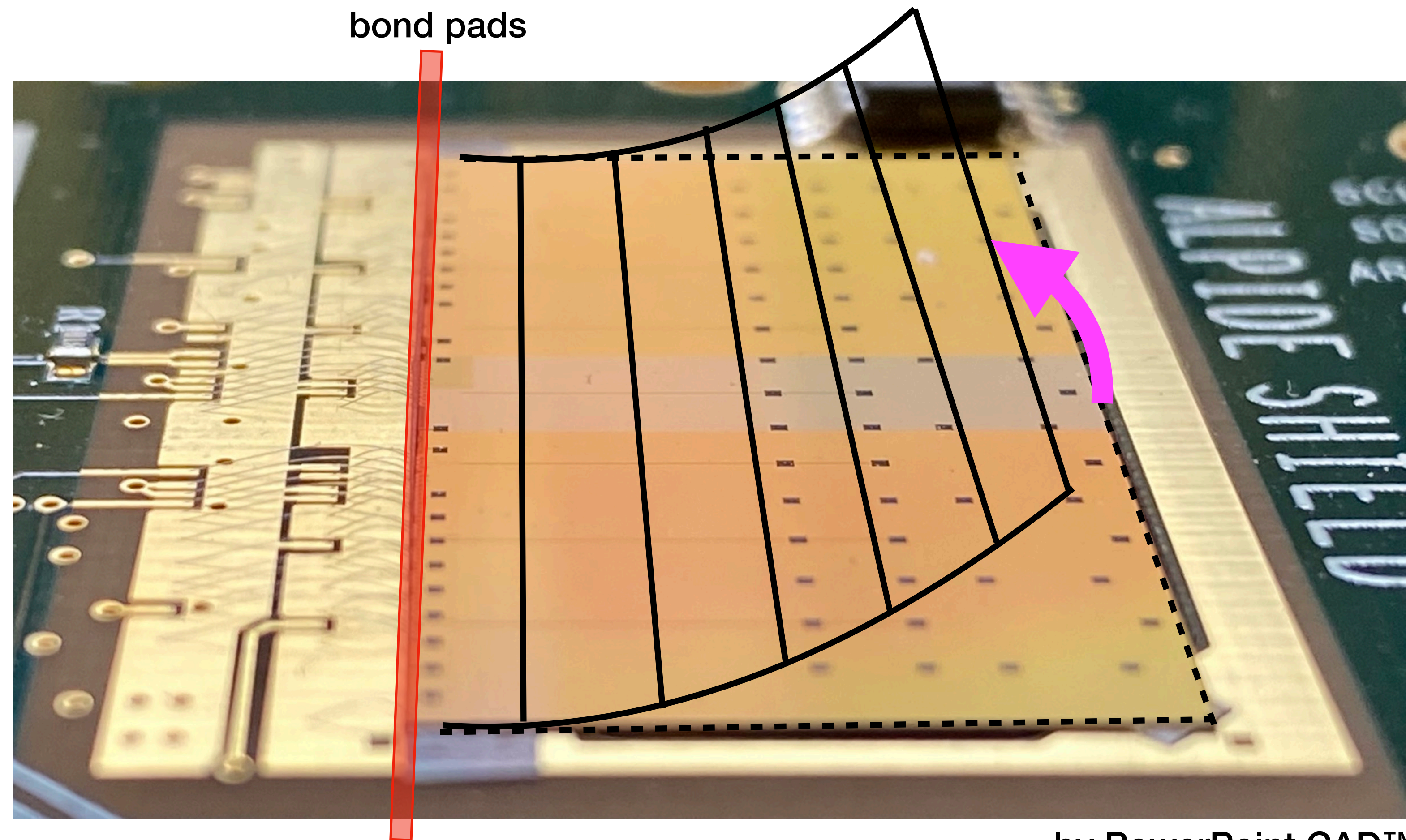
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# First trials with ALPIDE (4)



Sketch of how ALPIDEs could be bent based on existing test systems

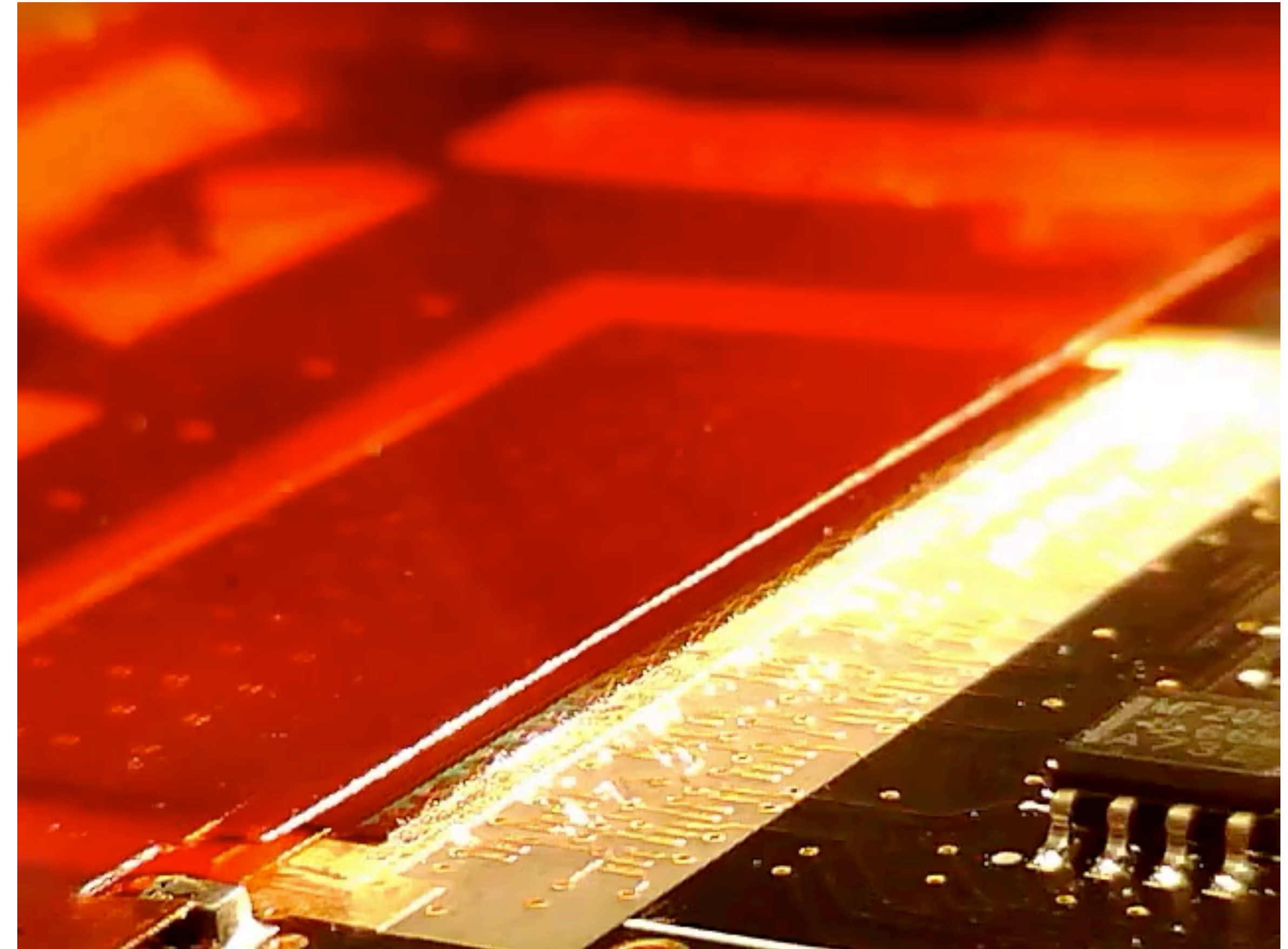
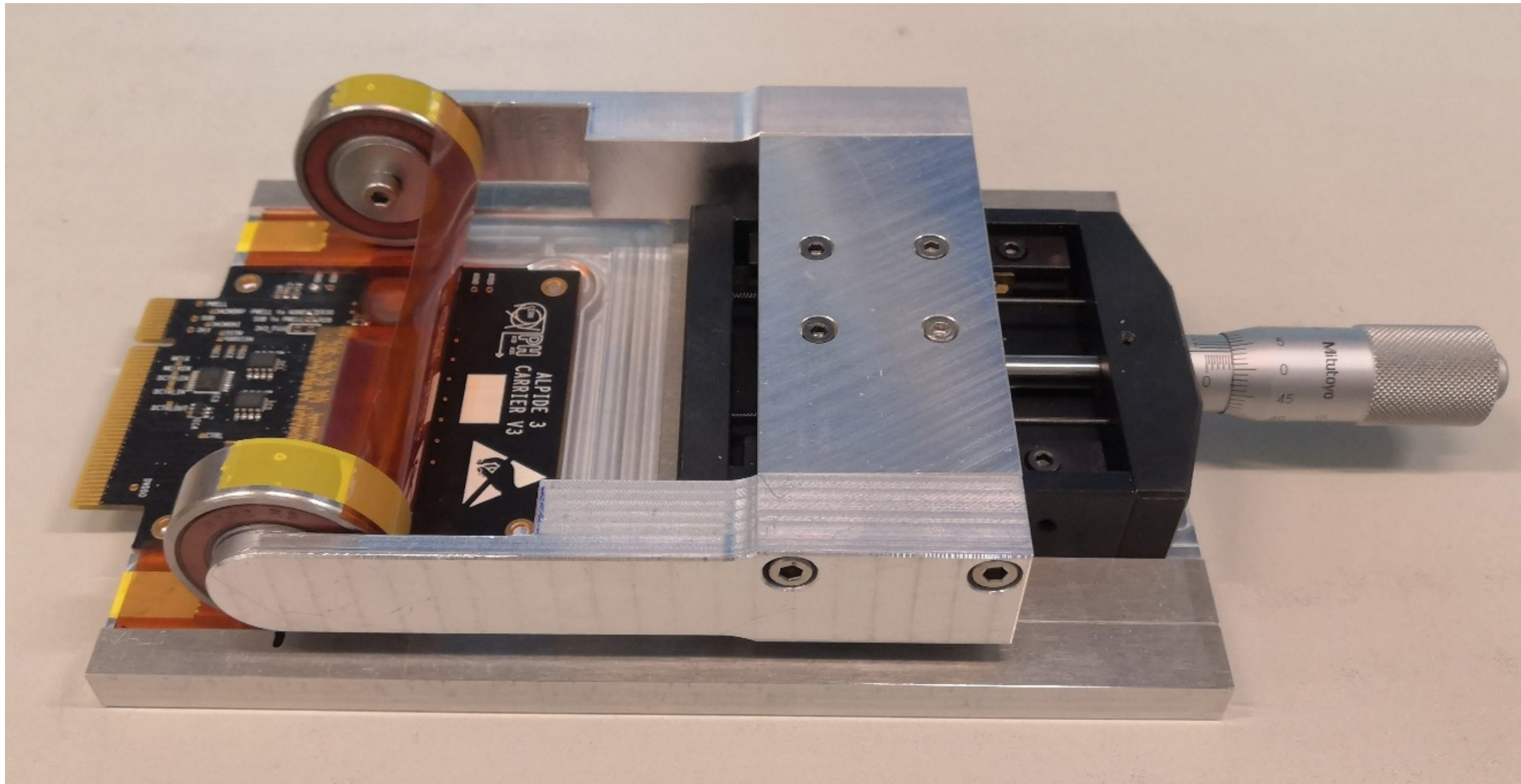
# First trials with ALPIDE (4)



by PowerPoint CAD™

Sketch of how ALPIDEs could be bent based on existing test systems

# First trials with ALPIDE (5)

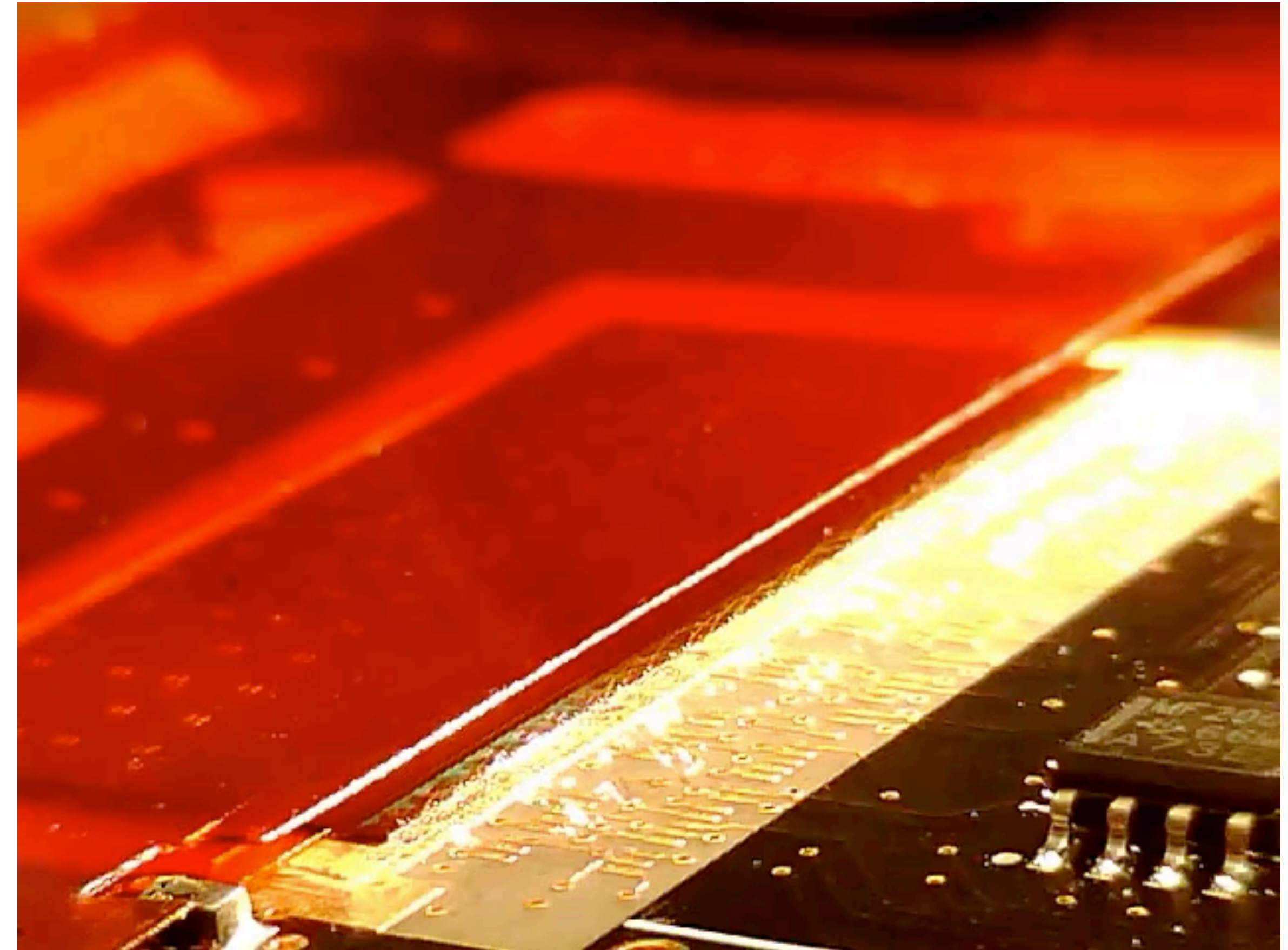
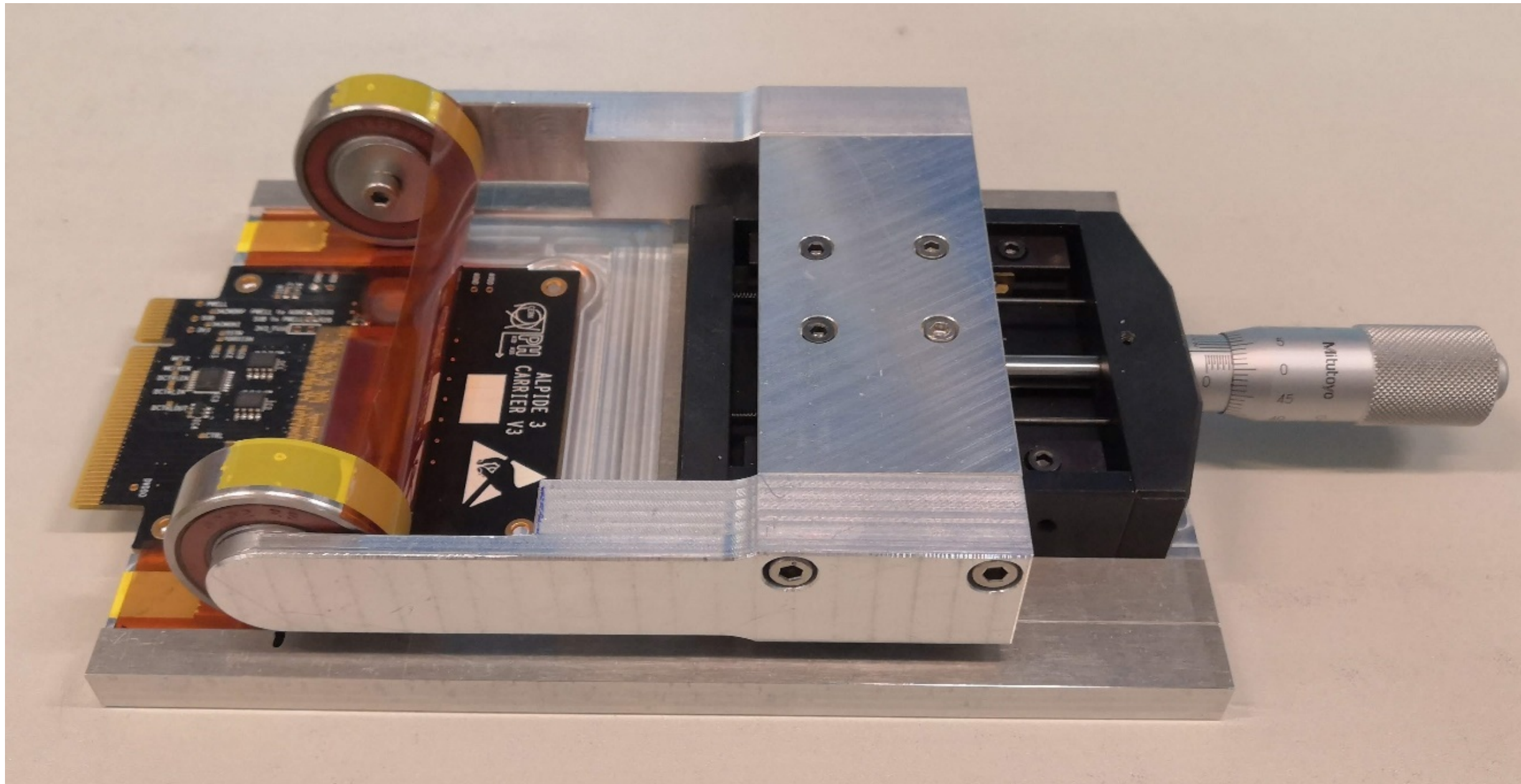


... mechanically this works!

electrical tests underway



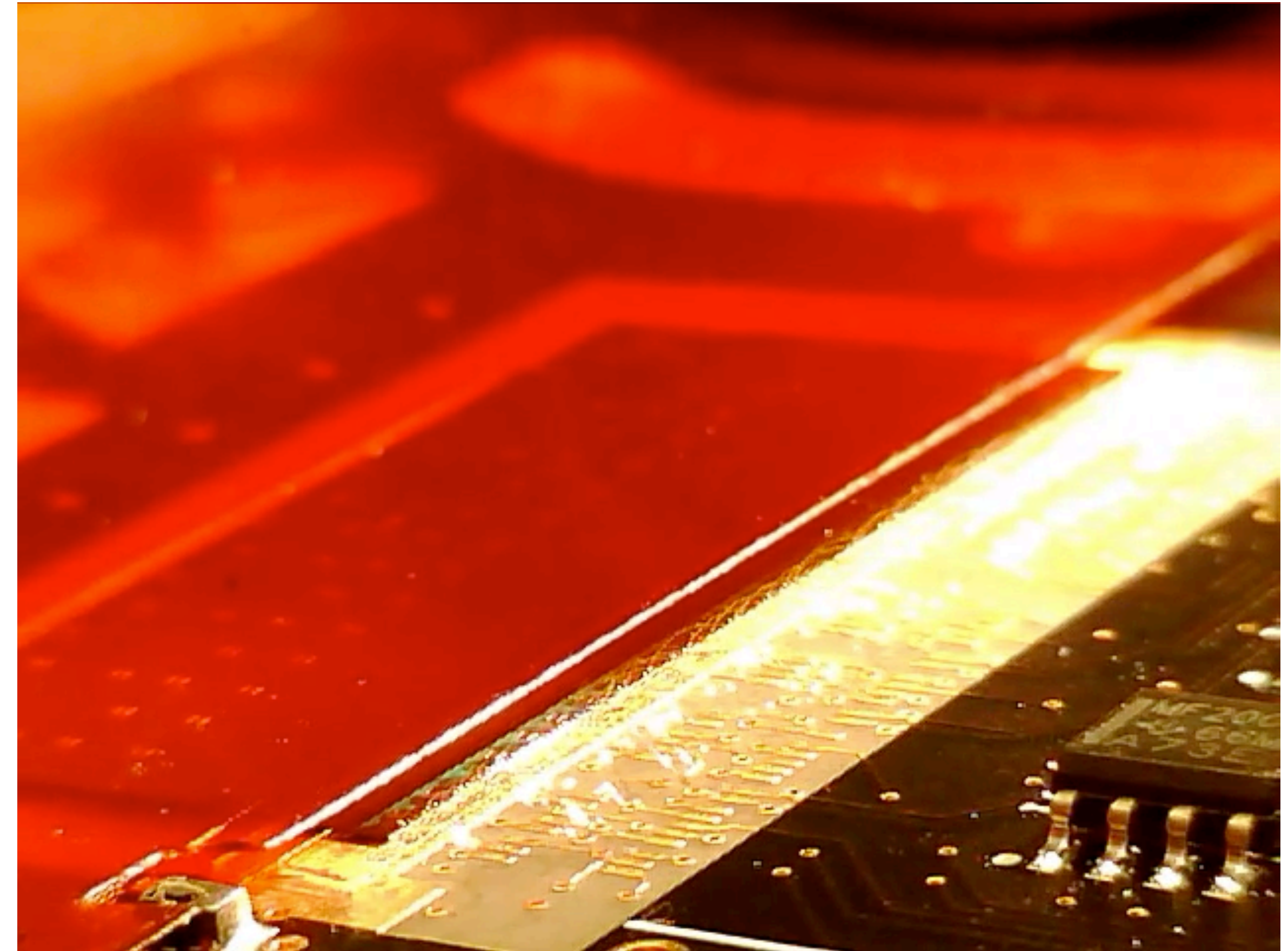
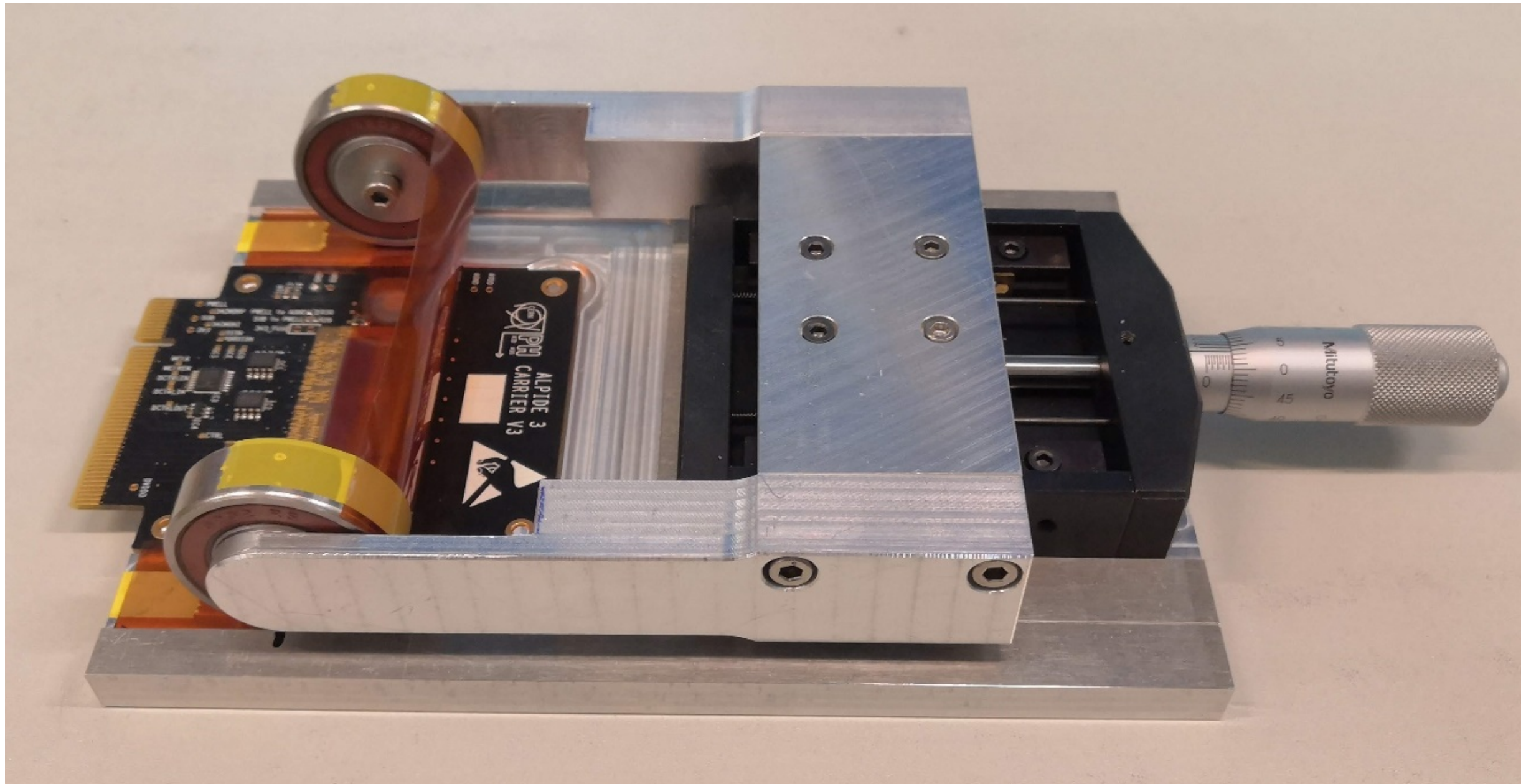
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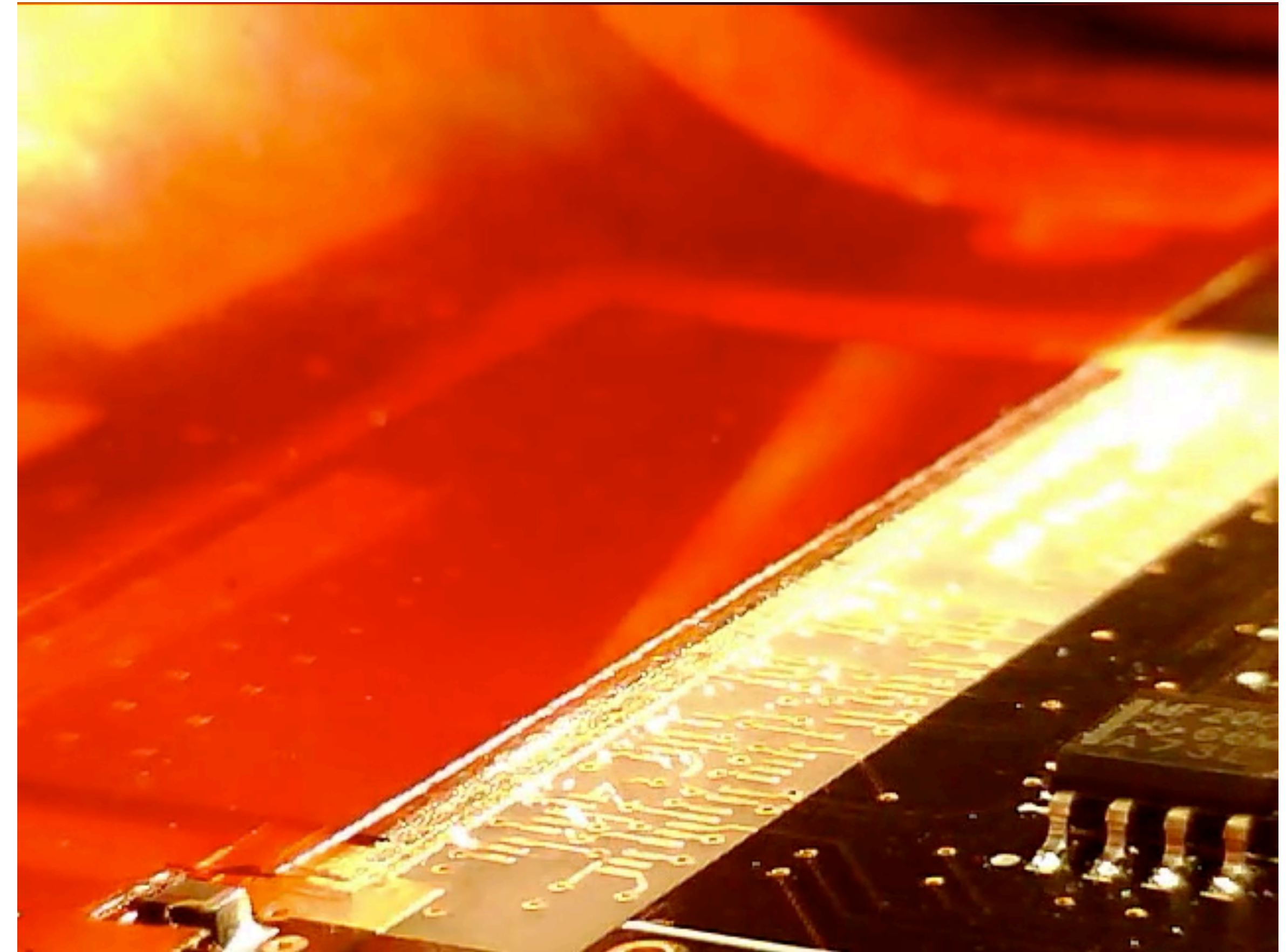
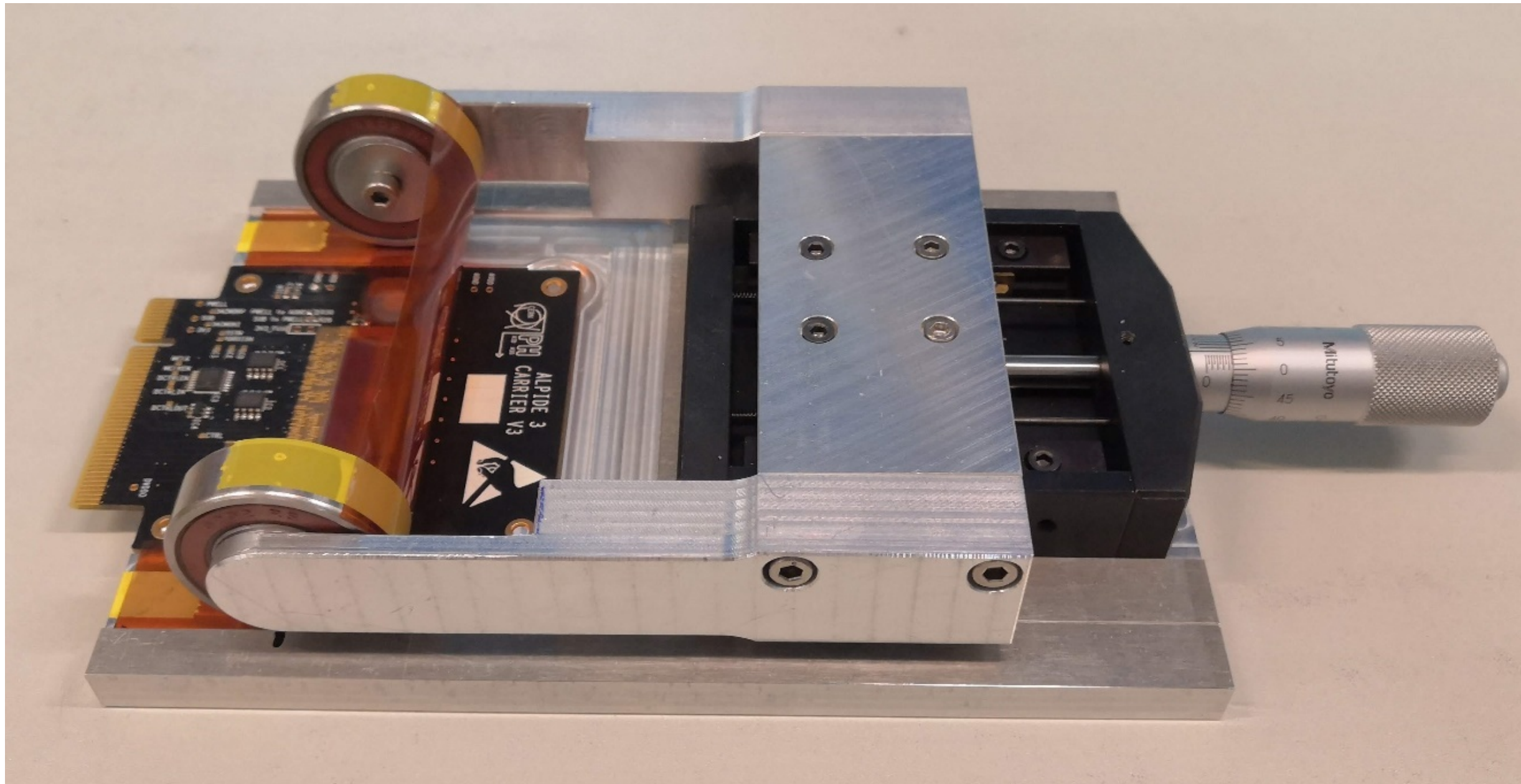
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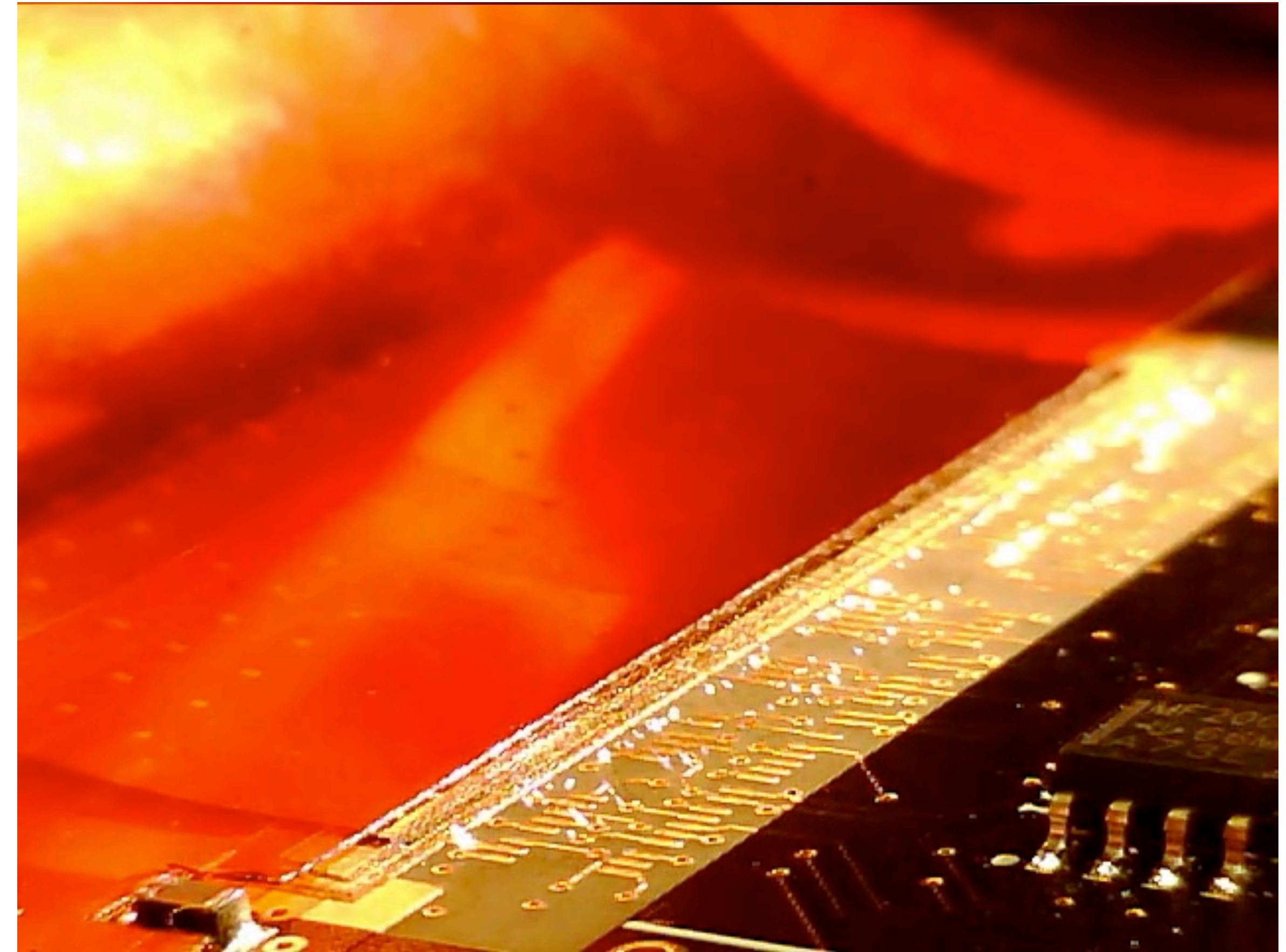
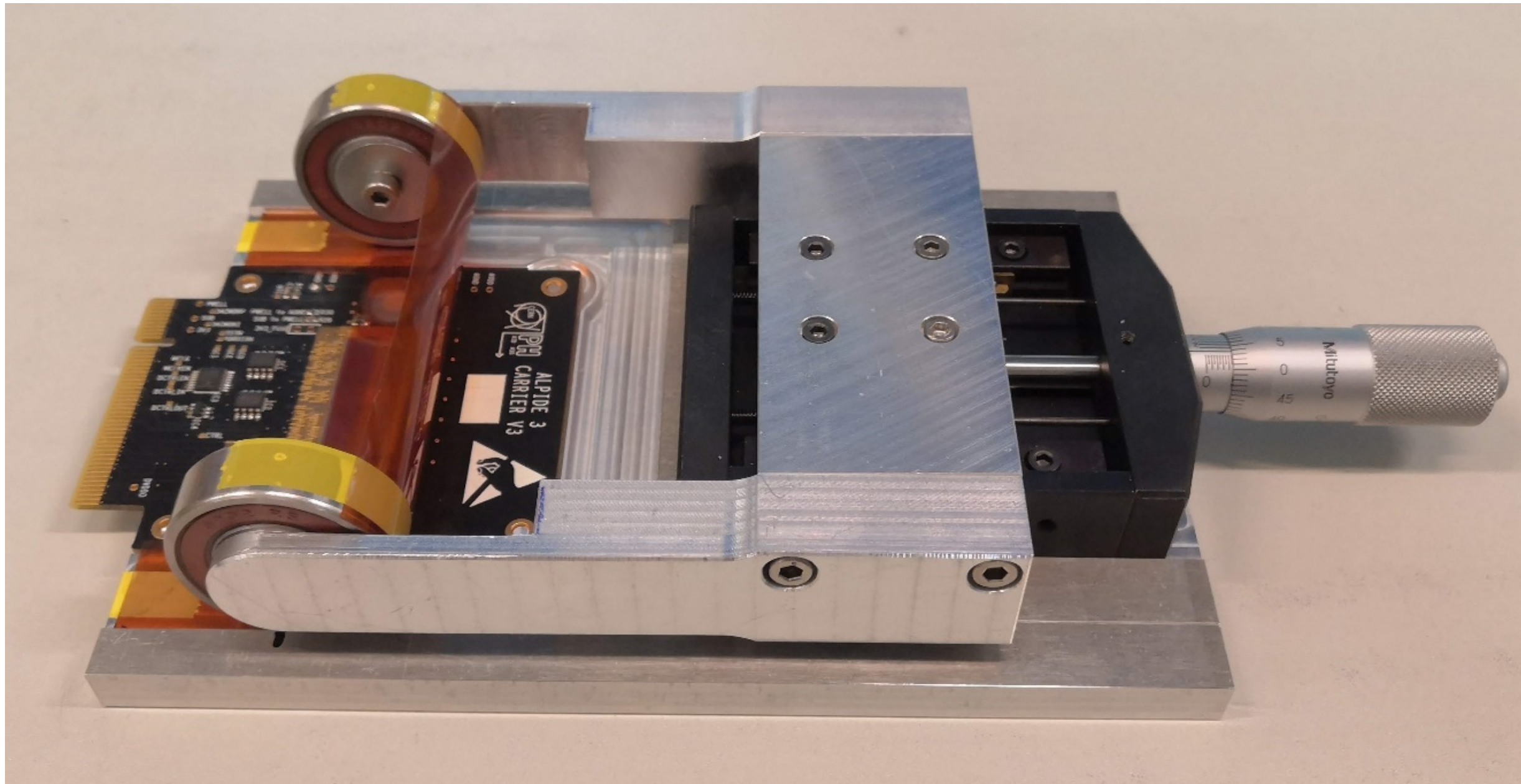
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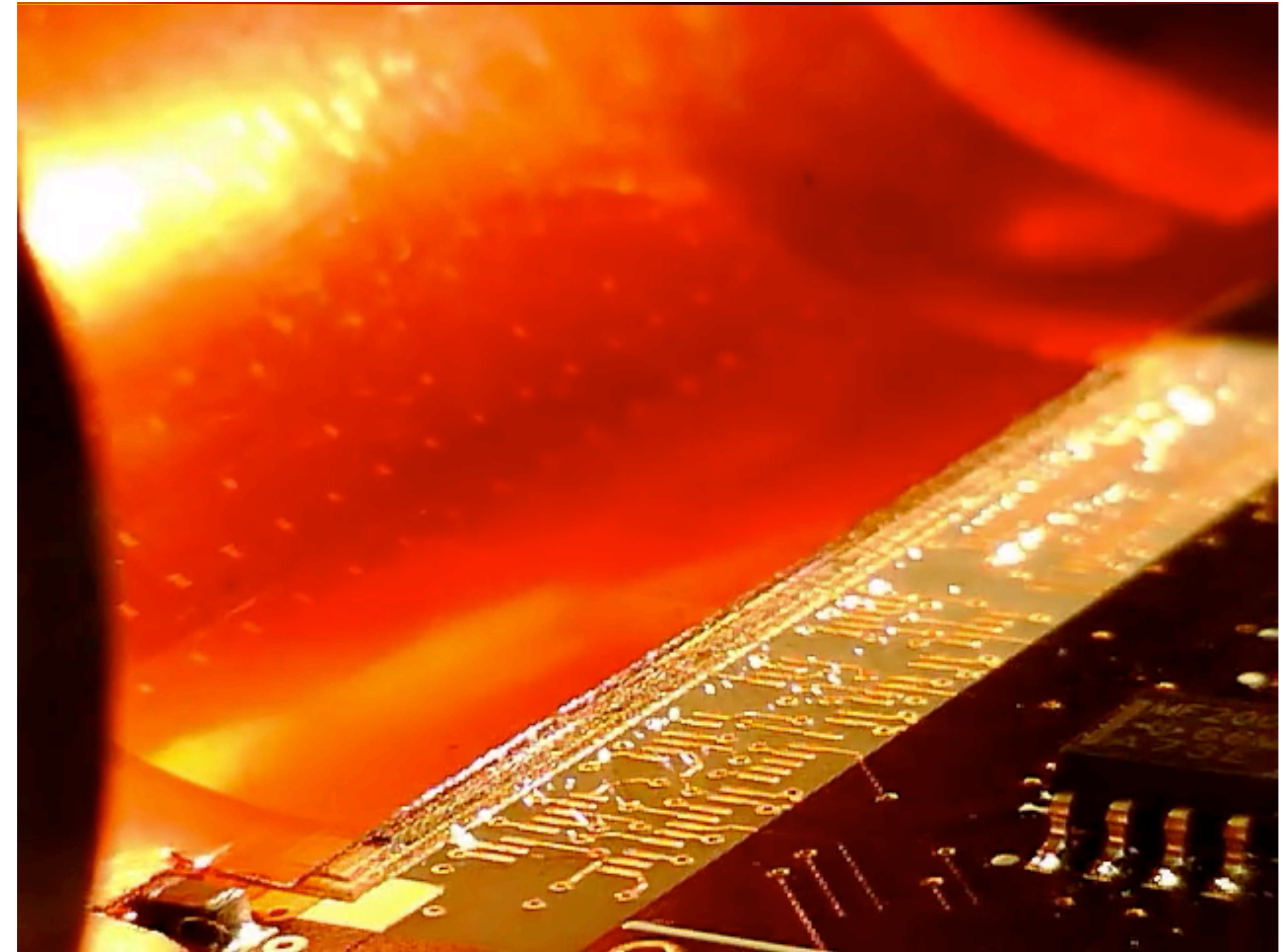
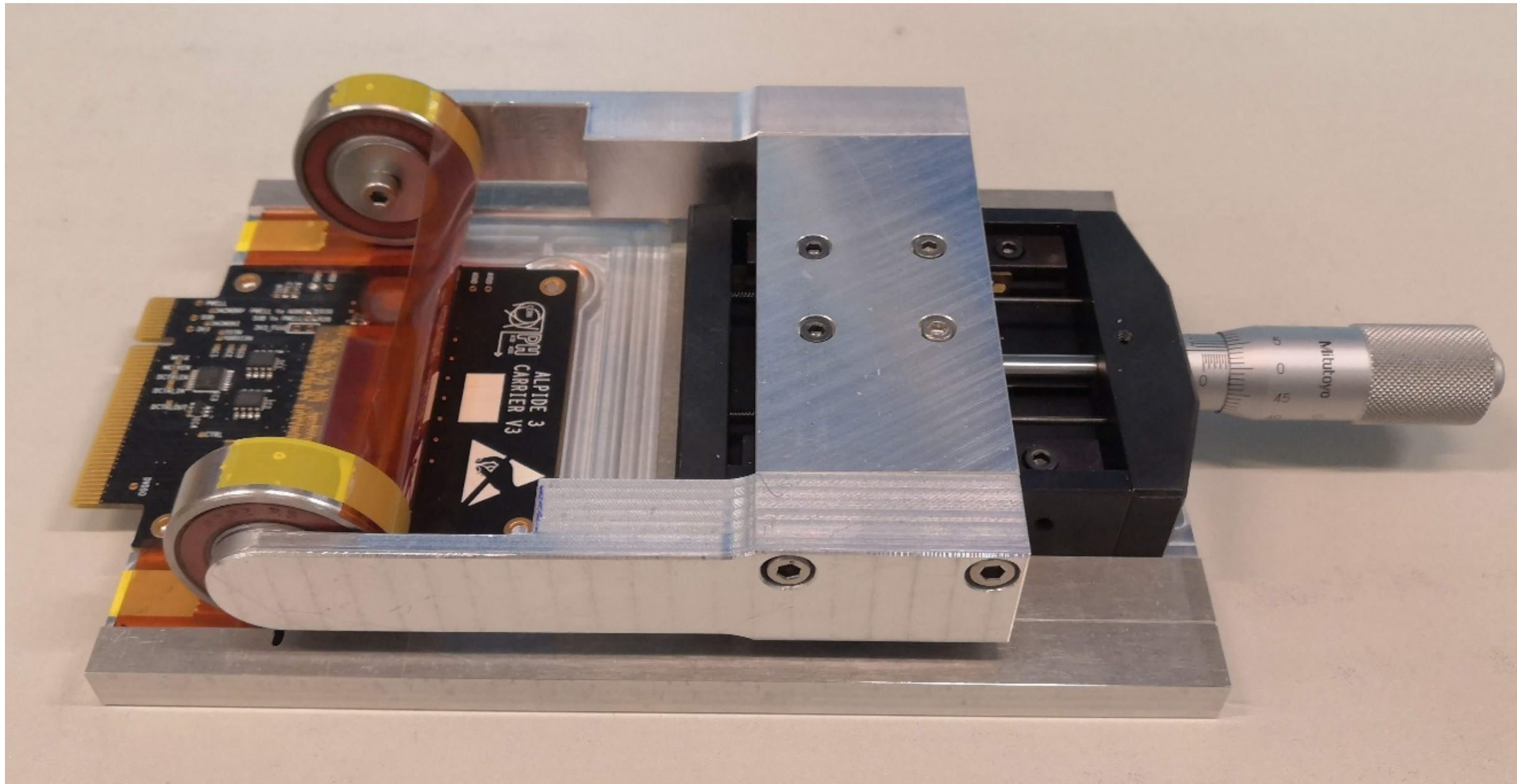
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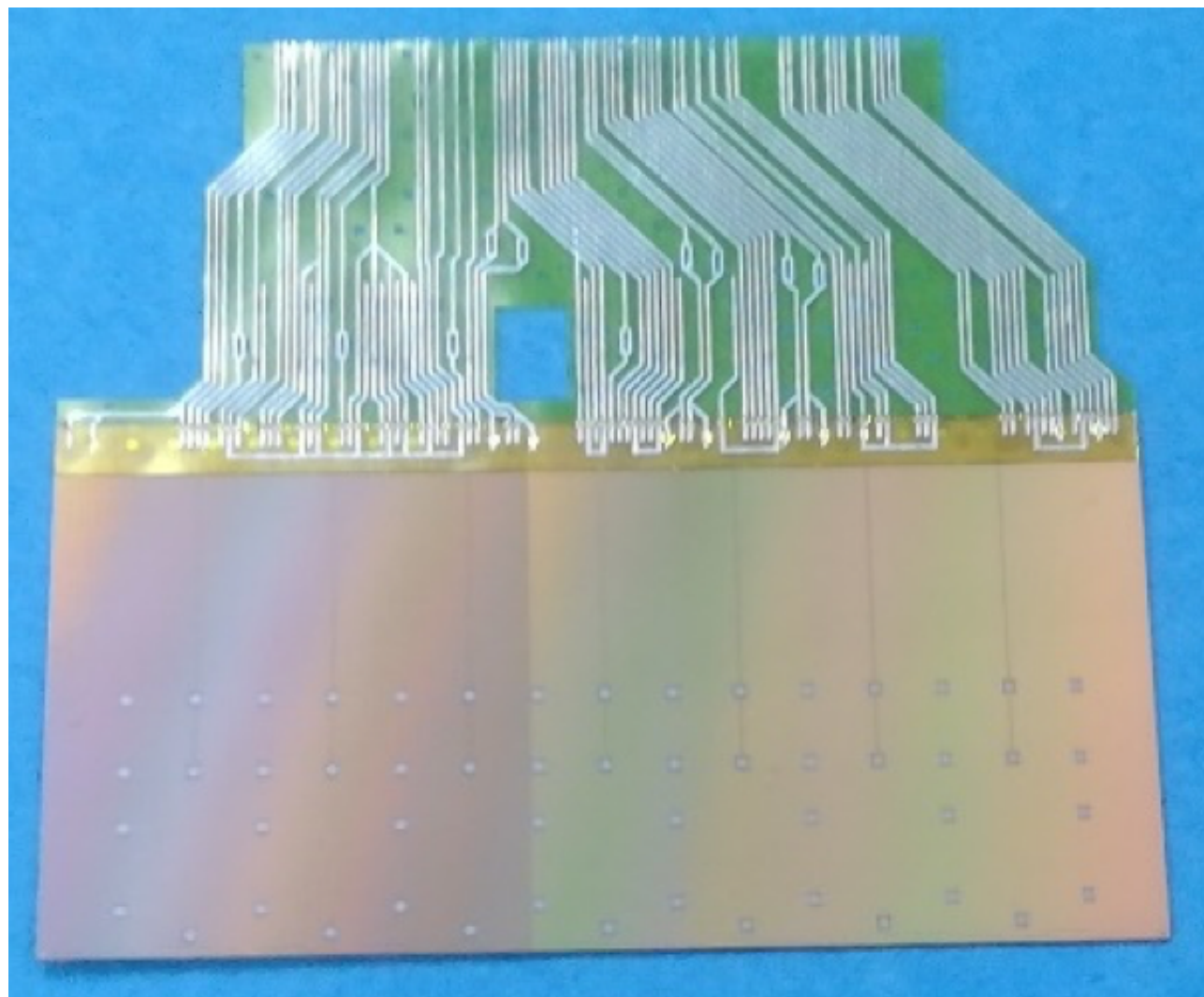
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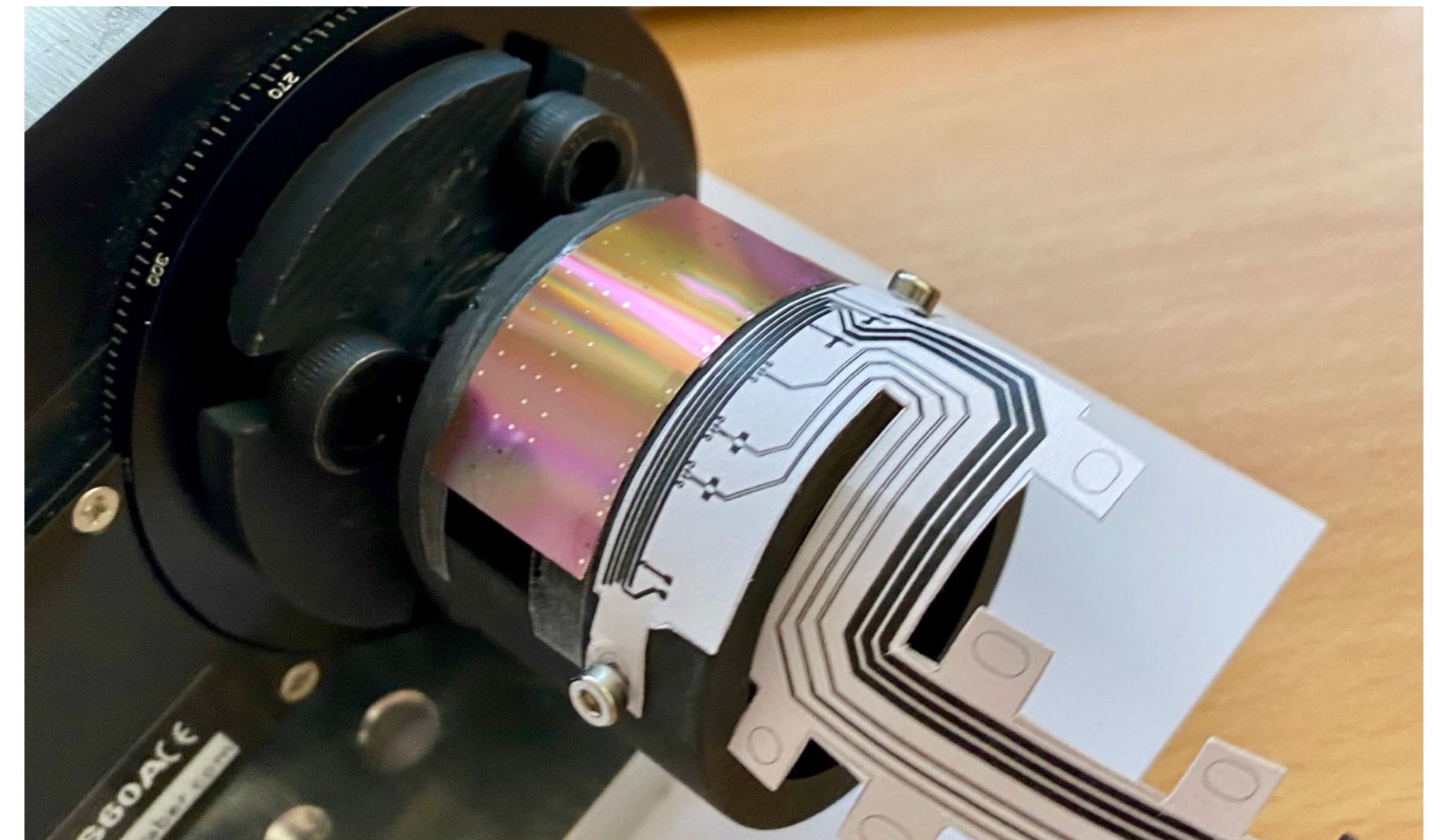
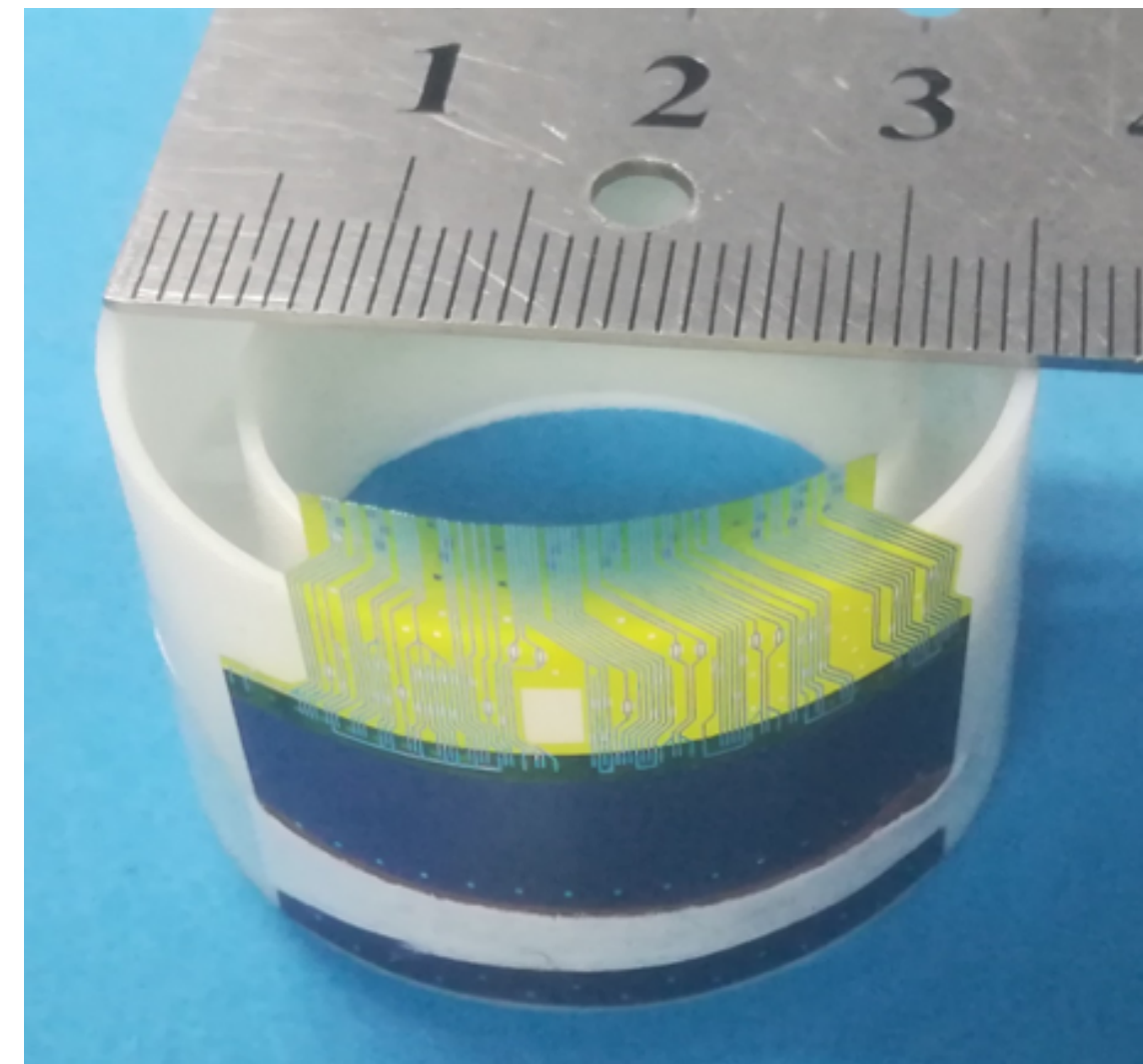
# Interconnection

- ▶ Different concepts under study
  - main question: bond or bend first?
- ▶ Possibly different options for final integration and sensor R&D

## R&D examples



**SpTAB bonding then bending**

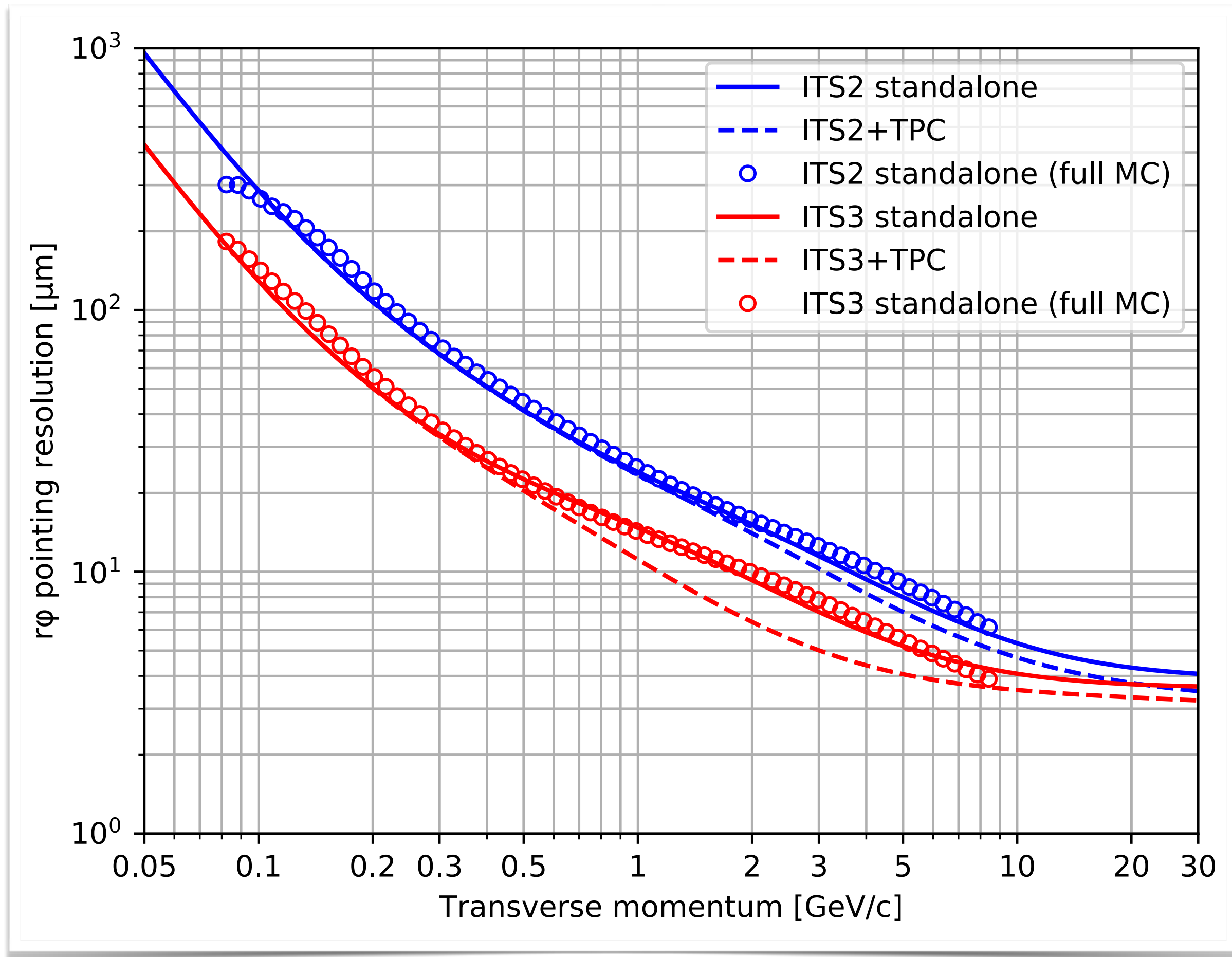


**Wire bonding on cylindrical bonding jig**

# ▶ Performance projections

# Performance figures

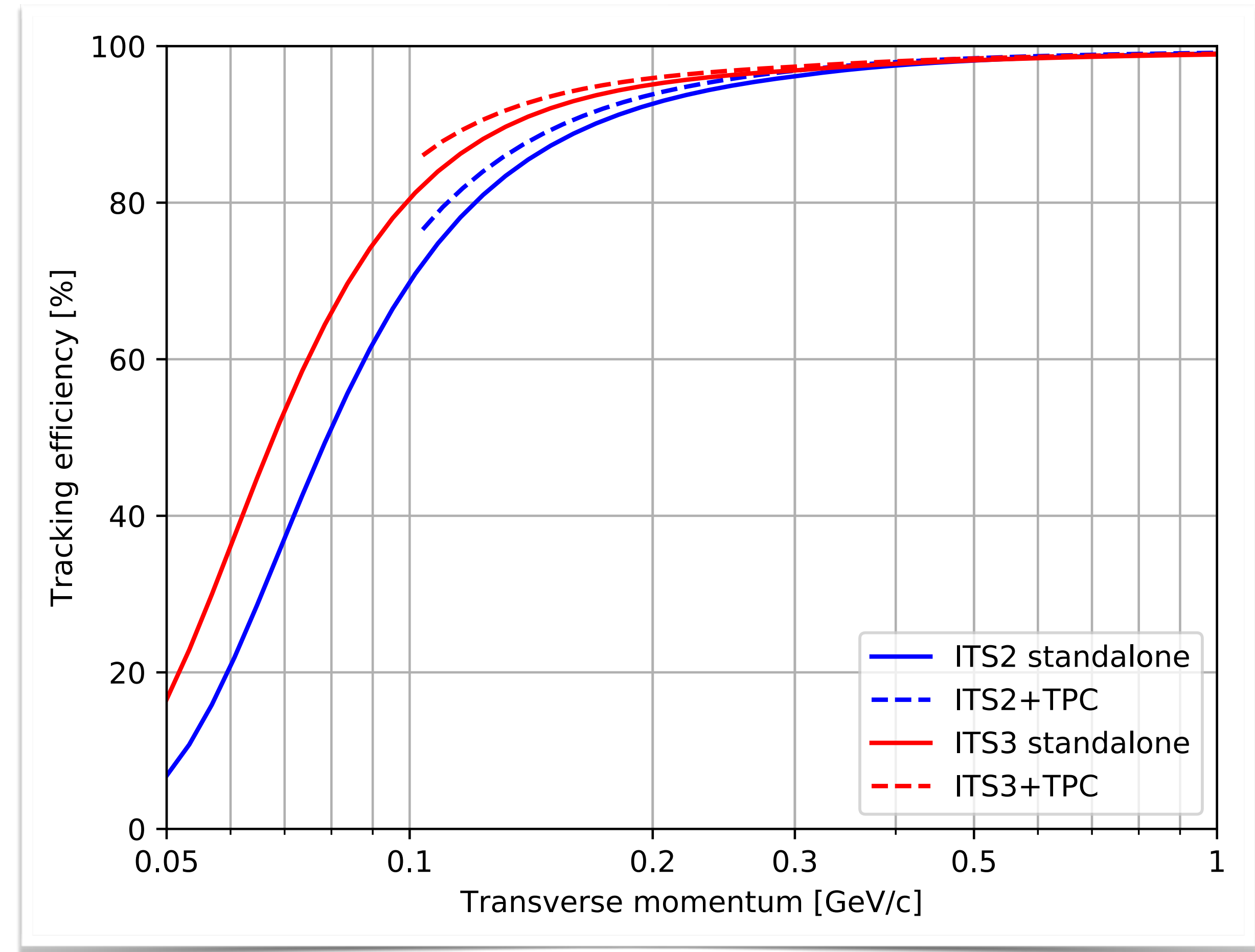
pointing resolution



[ALICE-PUBLIC-2018-013]

improvement of factor 2 over all momenta

tracking efficiency



large improvement for low transverse momenta



# Impact on physics

## ▶ **Low-mass di-electrons**

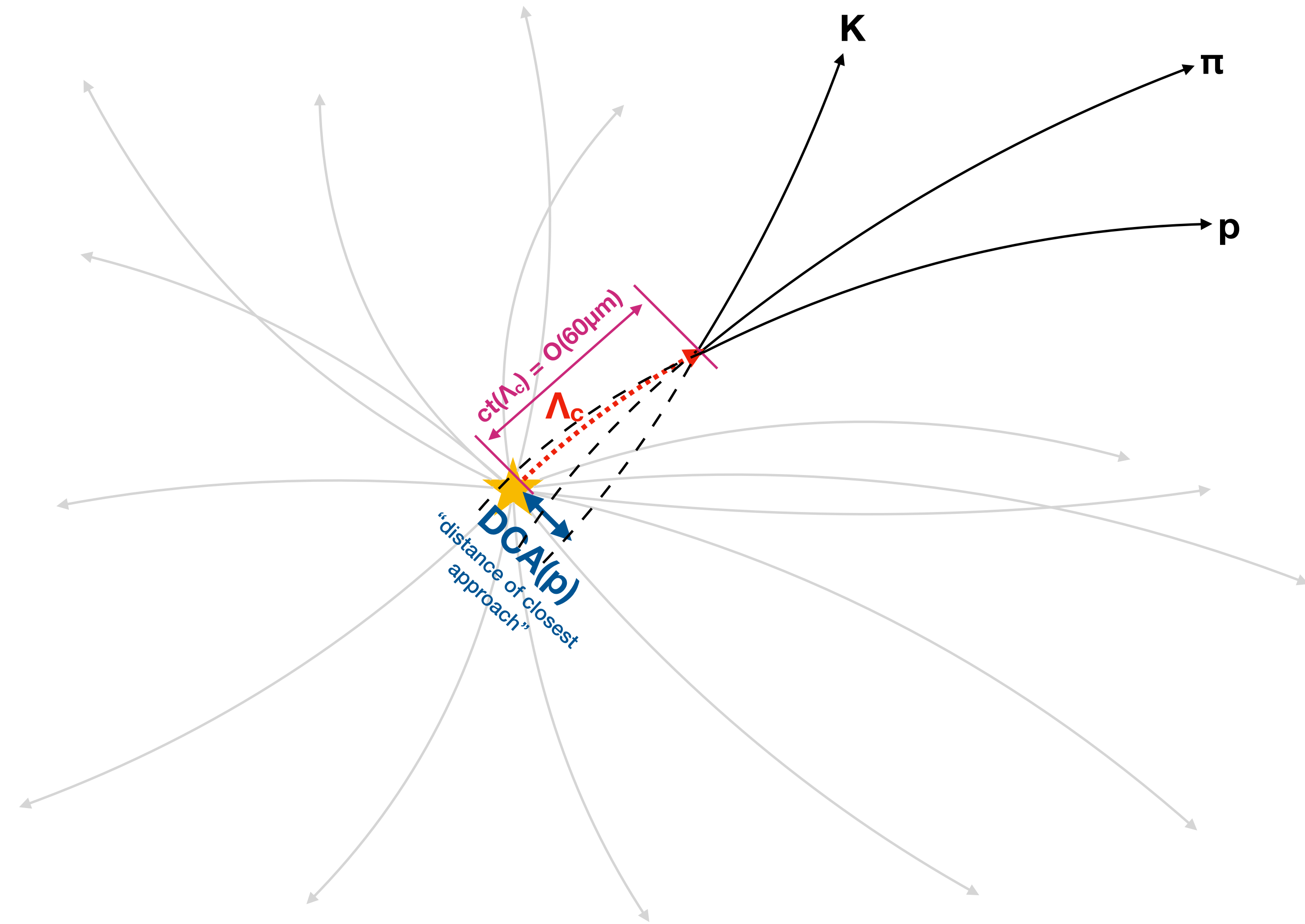
- Less conversions ( $\times 1/3$ ), one of the main “soft” backgrounds
- Better low- $p_T$  standalone efficiency to reconstruct and reject conversions
- Better precision to reject or subtract conversion and charm-decay electrons (displaced)

## ▶ **Heavy flavour** in particular those with small $c\tau$ ( $\Lambda_c \approx 60 \mu\text{m}$ , $D_s \approx 150 \mu\text{m}$ )

- Better precision to separate secondary vertex
- Increased efficiency also helps in multi-prong decays

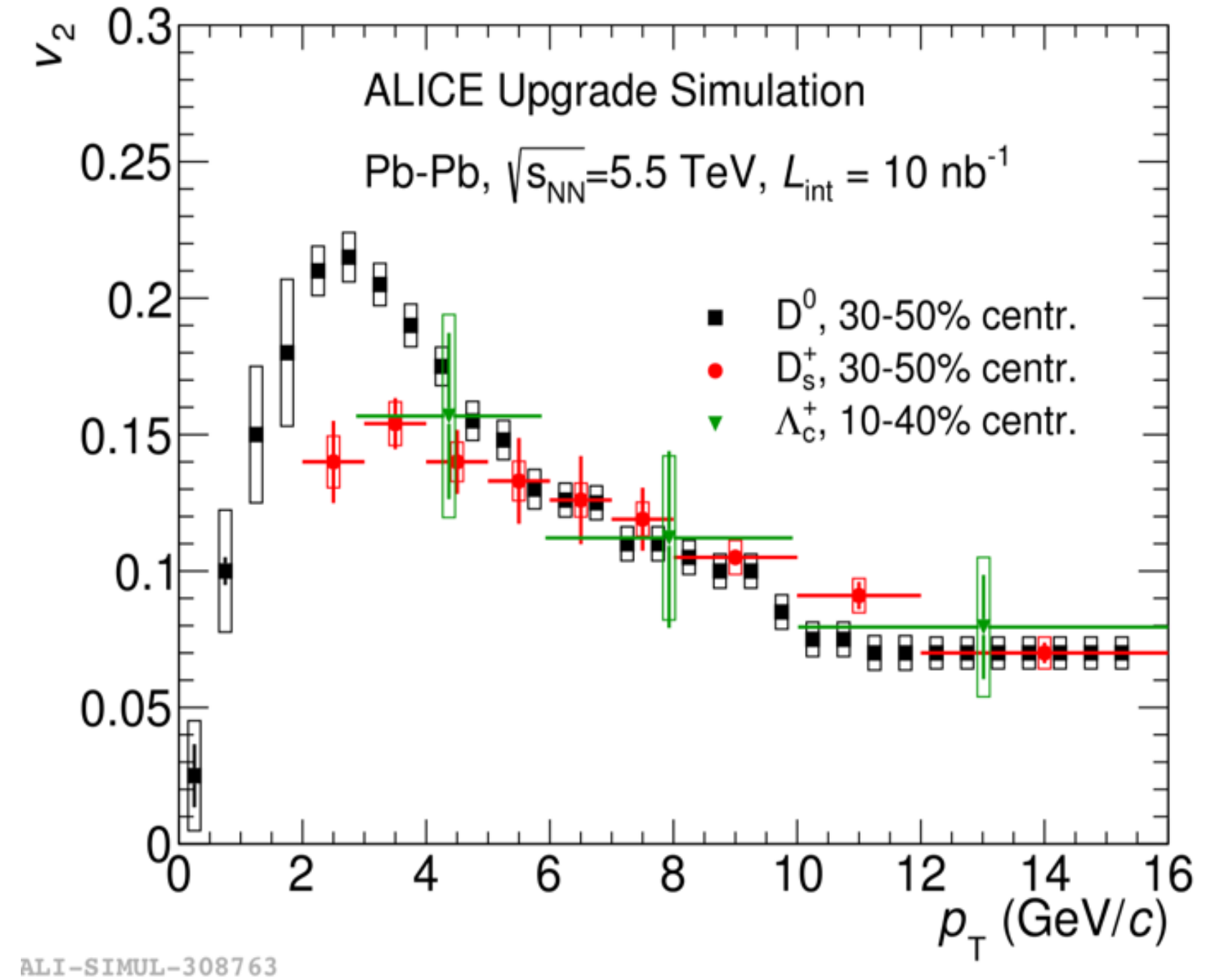
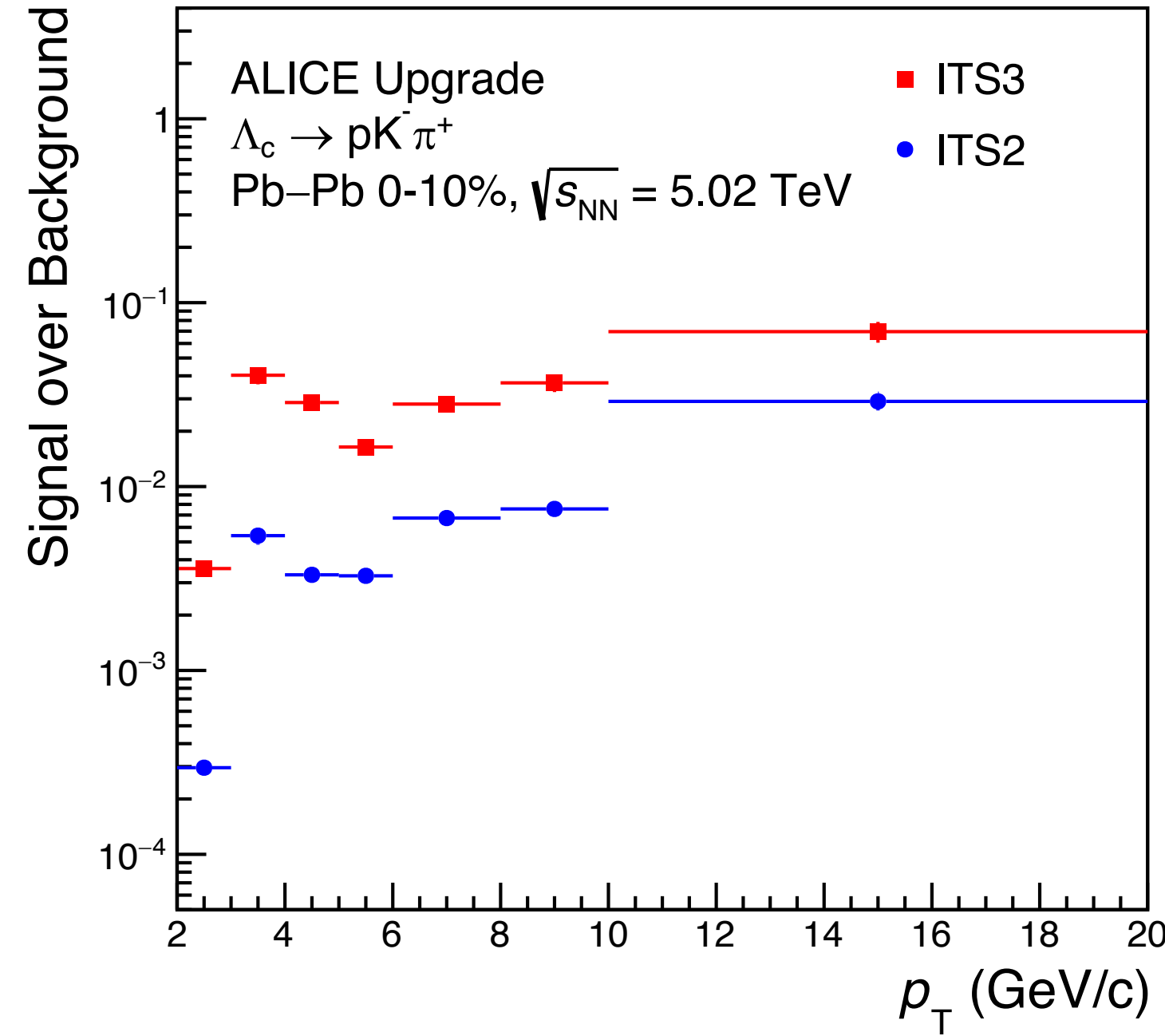
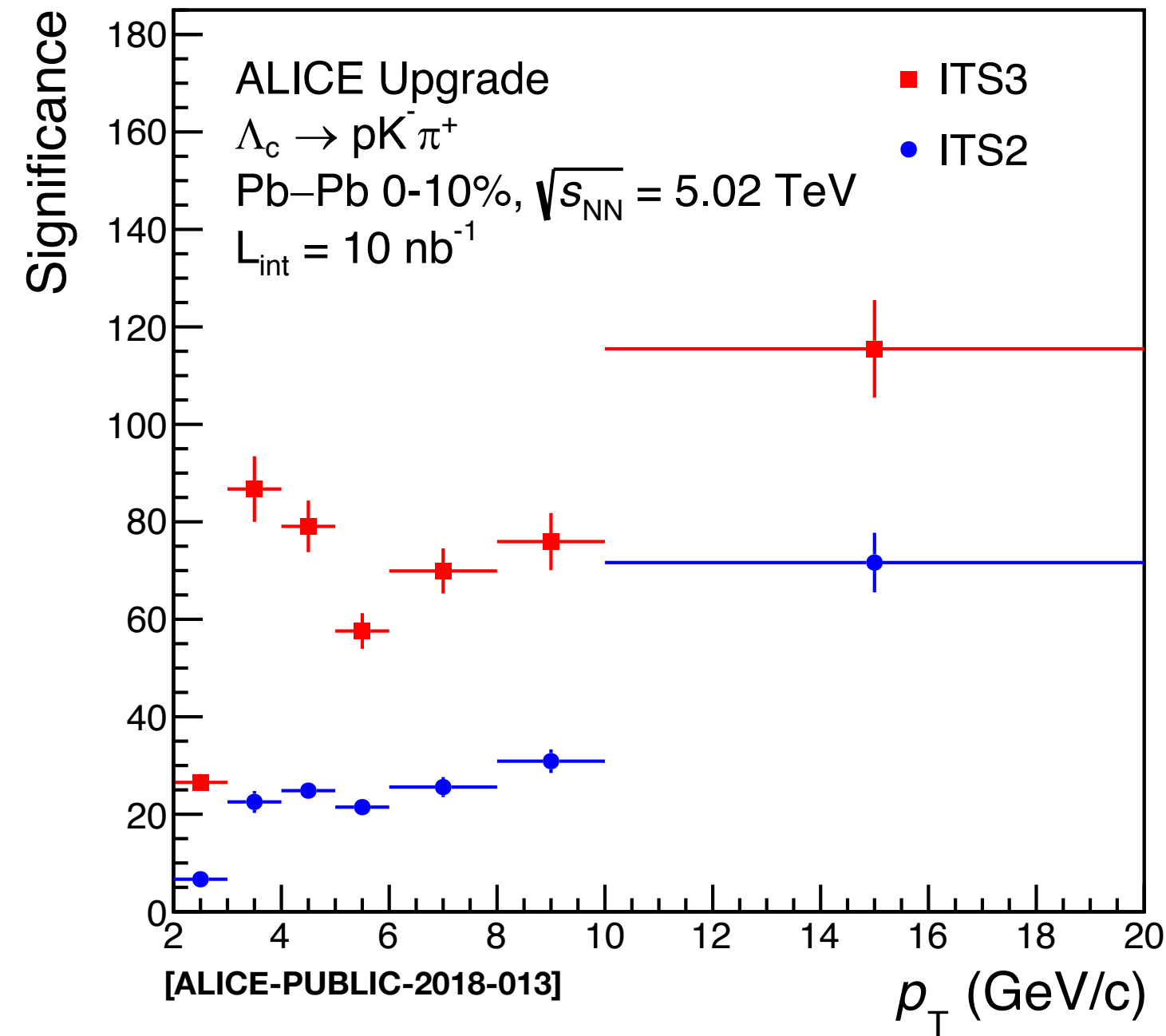
# Lambda-c ( $\Lambda_c$ )

schematic view of a  $\Lambda_c$  decay



- ▶ Analysis difficult due to large combinatorial background:
  - O(10k) charged particles in a central Pb-Pb collision
- ▶ Discrimination of background via:
  - Particle identification (relatively low yield of protons and Kaons wrt. pions)
  - **Topology:** cut on DCA of single tracks (before making the combinations) and decay vertex position (needs combinations)

# Lambda-c ( $\Lambda_c$ ) (2)



- ▶ Large improvement of S/B + significance due to better separation power of secondary decay vertex ( $\Lambda_c \approx 60 \mu\text{m}$ )
- ▶ Allows for precision measurements over a wide  $p_T$  range

$\Lambda_c$ yield	S/B	Significance
ITS3 / ITS2	10	4

# There is much more

## ▶ Beauty baryon $\Lambda_b$

- b quark recombination in QGP?
- $\Lambda_b \rightarrow \Lambda_c \pi$
- Limited to  $p_T > 4$  GeV/c with ITS2
- Expected improvement from better  $\Lambda_c$  S/B

## ▶ Charm-strange baryons

- Interplay of c recombination and s “enhancement” in QGP
- $\Xi_c$  ( $c\tau \approx 80 \mu\text{m}$ )  $\rightarrow pK\pi, \Xi p$
- $\Omega_c$  ( $c\tau \approx 130 \mu\text{m}$ )  $\rightarrow \Omega p$

## ▶ Non-prompt $D_s$ and $\Lambda_c$

- From impact parameter fits of inclusive  $D_s$  and  $\Lambda_c$
- Give access to  $B_s$  and  $\Lambda_b$
- Try  $B_s \rightarrow D_s \pi$  as well

## ▶ c-deuteron search

- $\Lambda_c n$  bound state
- Would be the lightest hyper-nucleus with charm
- Statistical hadronisation model:  
 $dN/dy \approx 104$  with  $L_{\text{int}}=10 \text{ nb}^{-1}$  Pb-Pb
- Similar  $c\tau$  and decays as  $\Lambda_c$ :  
 $\approx 60 \mu\text{m}$ ,  $\rightarrow pK\pi$ ,  $\rightarrow dK^0_s$

## ▶ Charm correlations and jets

- DD correlations & c-tagged jets sensitive to details of charm energy loss mechanisms (radiative, collisional,...)
- Expect with improvement with ITS3 (short  $D_0$  decay length)

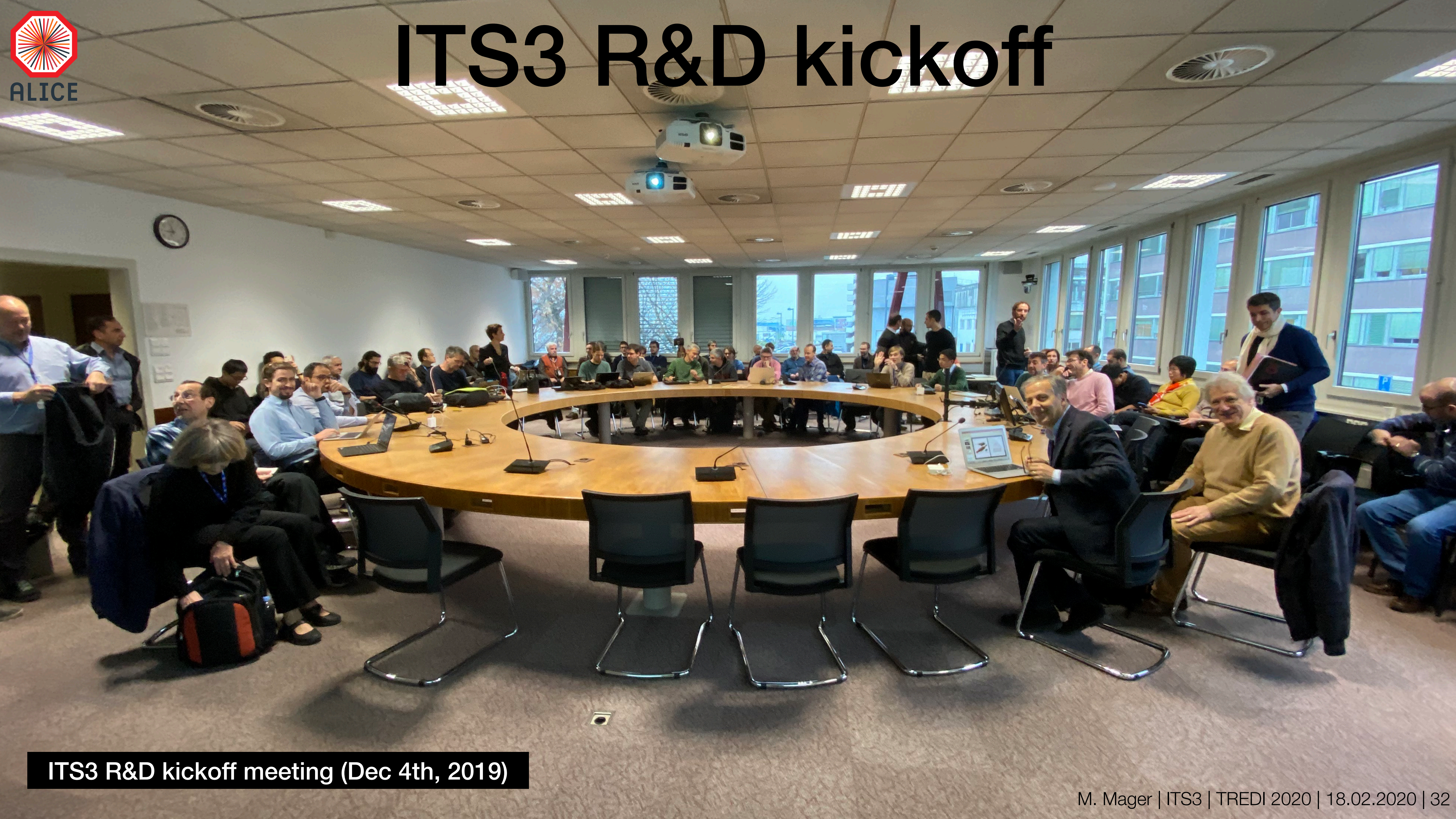
## ▶ ... many more under study

# ▶ R&D + Construction Timeline

### LHCC-139 (Sep 2019)

The **LHCC is impressed** by the new concept for the ITS3 with significantly reduced material budget, recognises the physics case presented in the LoI and in the dedicated ITS3 session and appreciates the on-going simulations on various physics channels to further demonstrate the expected gain from better resolution and efficiency at low transverse momentum. The **LHCC endorses** the plan of ALICE to carry out the necessary R&D studies to demonstrate the technical feasibility of this upgrade project. A TDR to be submitted on a timescale compatible with installation in LS3 will have to include in addition a comprehensive study of its physics gains with respect to the ITS2 detector.

# ITS3 R&D kickoff



# Project milestones

- ▶ EoI details milestones for all activities, grouped by:
  - Sensor Chip
  - Thinning and bending
  - Mechanics and cooling
  - Beam pipe
- ▶ R&D is ongoing
- ▶ TDR is foreseen for 2022

## example: chip design

Milestone	Description	Production <sup>a</sup>	Date
1	<b>Technology test structures</b> single pixels, transistors, small memory cell array for studying the radiation hardness of the technology	MPW	Q4 2019
2	<b>Pixel test vehicle</b> optimization of pixel and diode geometries	MPW	Q3 2020
3	<b>Large area prototype</b> basic blocks: pixel matrix, periphery, output serial links exercising of stitching different parts	ER	Q4 2021
4	<b>Full-scale prototype</b> prototype of final chip with all functionality	ER	Q4 2022
5	<b>Final Chip</b> possible minor adjustments wrt milestone 4	ER	Q4 2023

[ALICE-PUBLIC-2018-013]



# Summary and Outlook

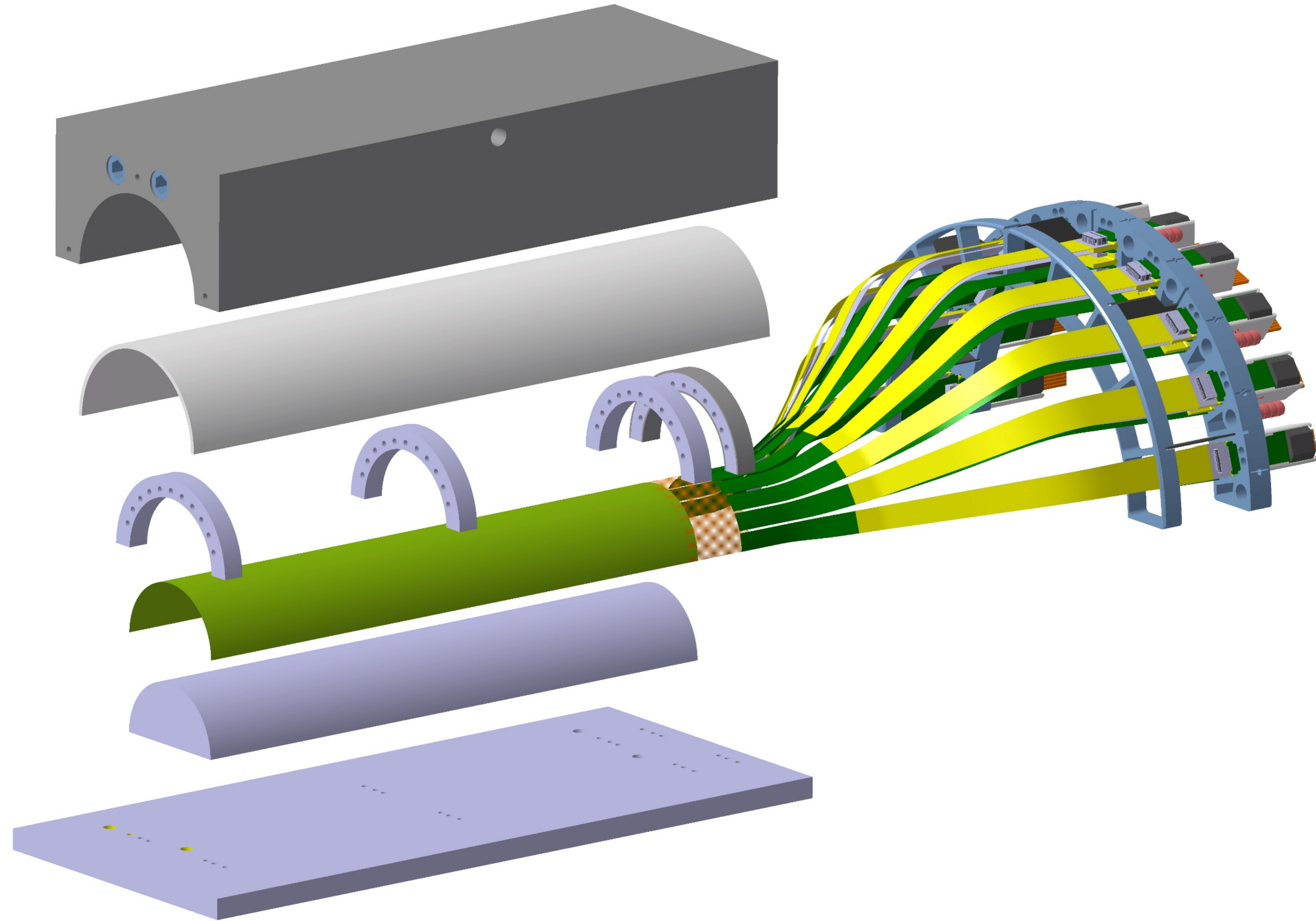
- ▶ ALICE is starting the R&D for a **nearly massless, truly cylindrical, Si-only, wafer-scale** Inner Tracking System
- ▶ **Unprecedented performance figures**, especially for **low-momentum** particles, will largely increase the ALICE physics yield
- ▶ Needed **technology is within reach**
- ▶ At its 139<sup>th</sup> meeting (Sep 2019), the **LHCC endorsed** the R&D with the goal of presenting the **TDR in 2022**
- ▶ An **intense R&D phase** has just started and already **gained momentum**
- ▶ **Installation** is foreseen for **LS3**

*Thank you!*

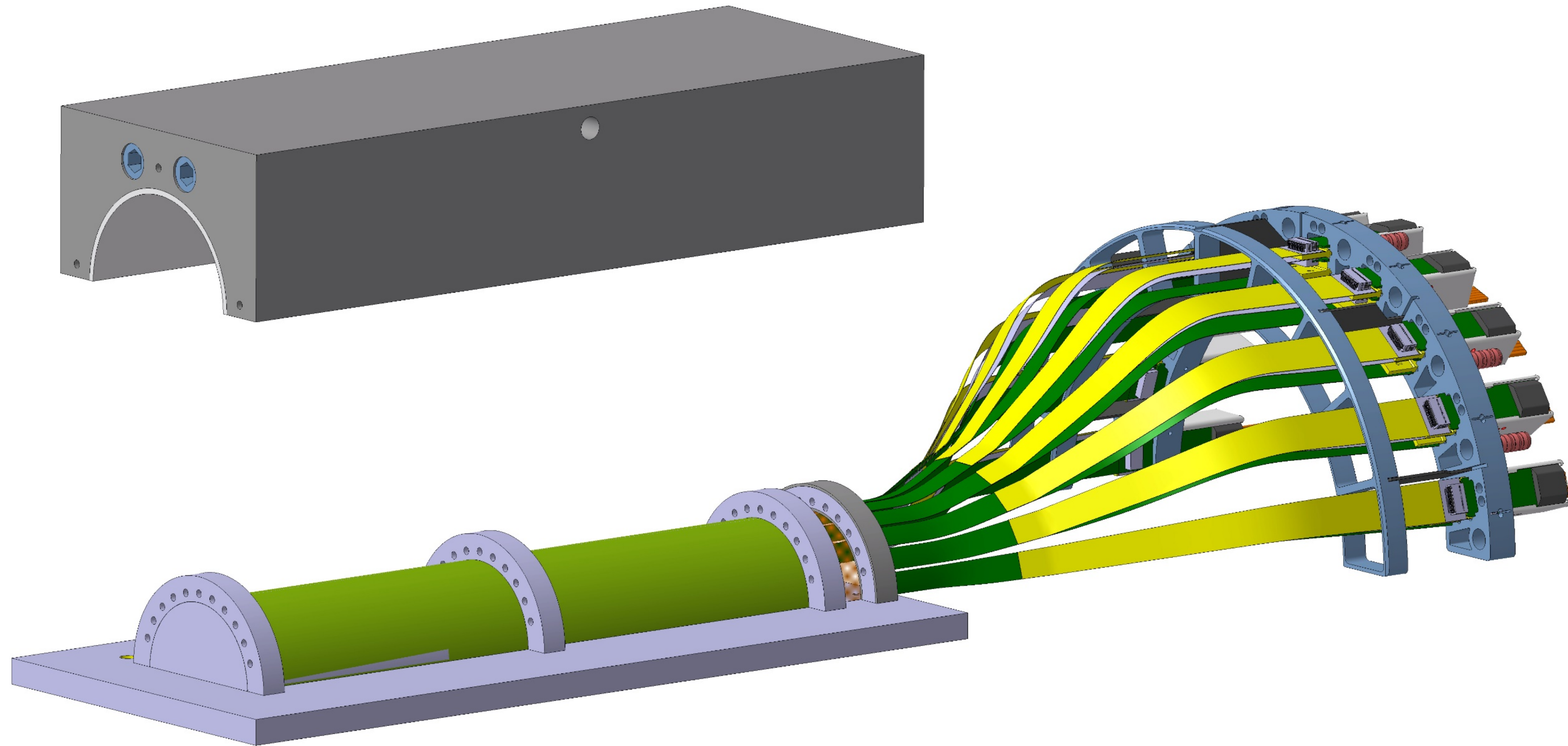


# ▶ Supplemental material

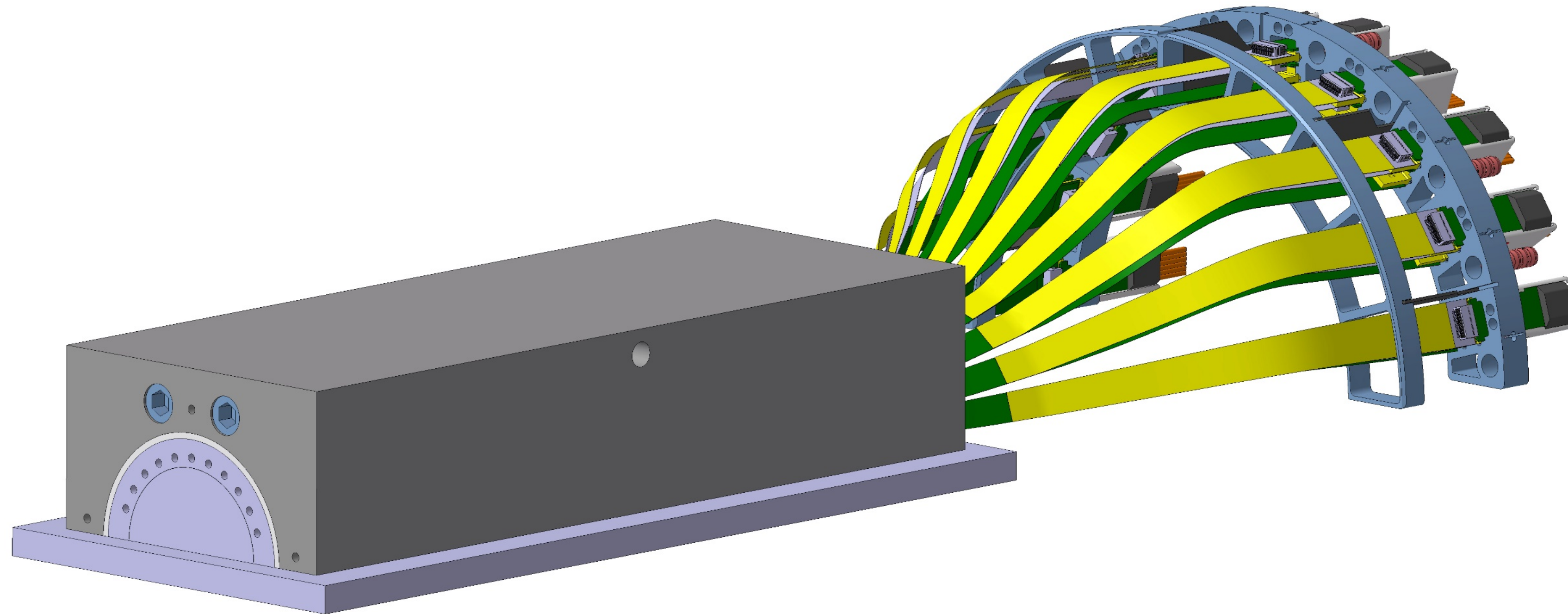
# Assembly procedure



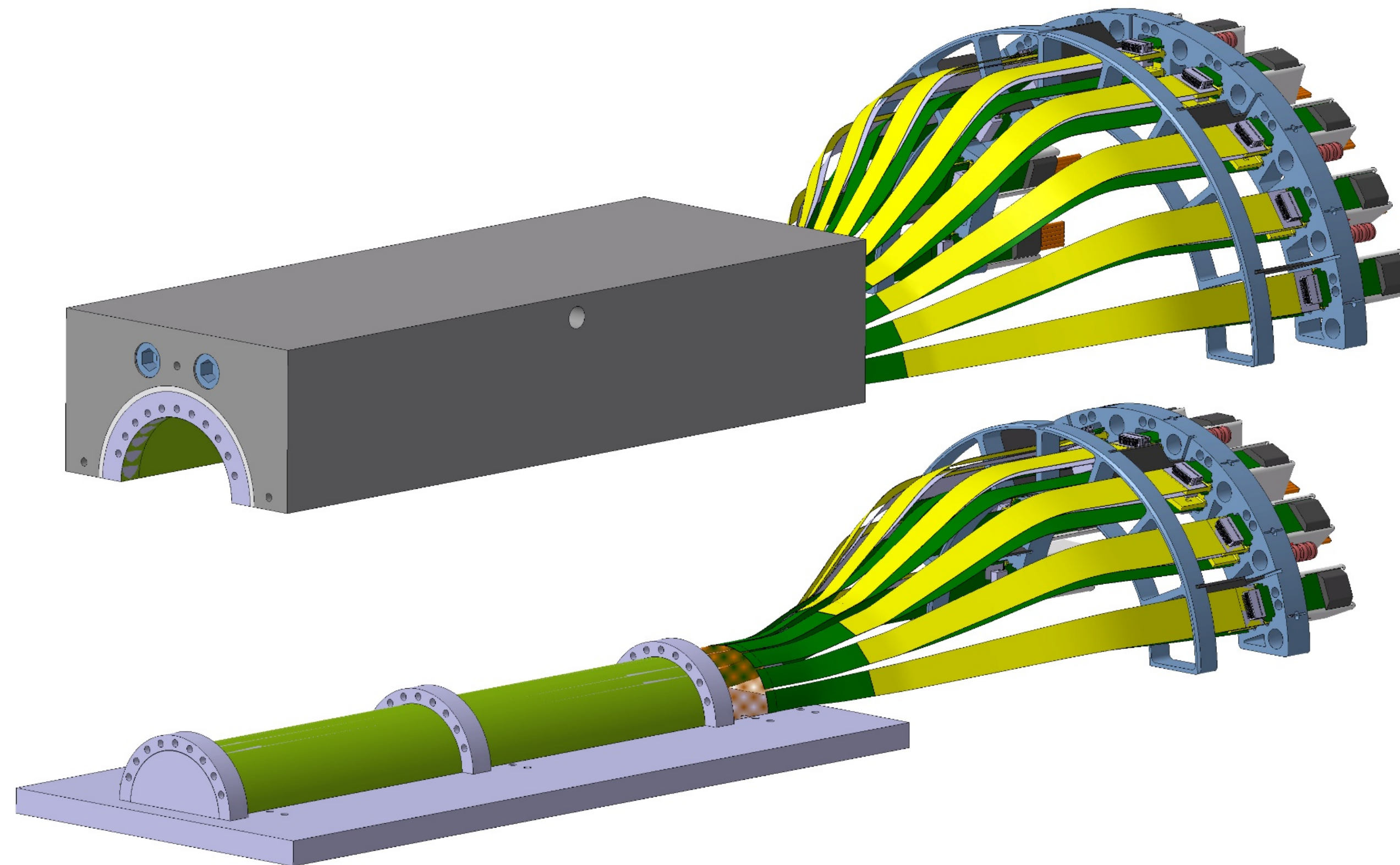
# Assembly procedure



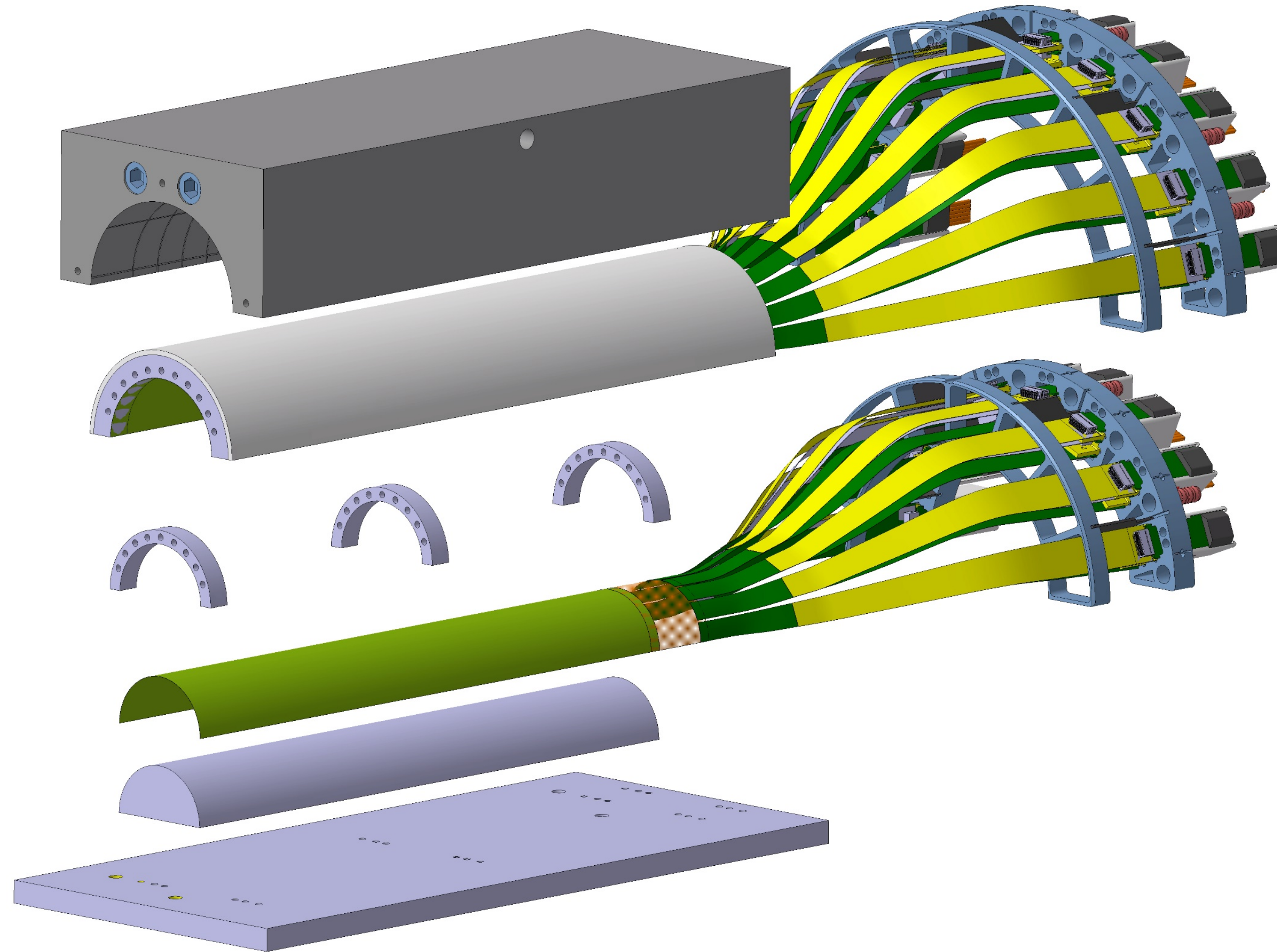
# Assembly procedure



# Assembly procedure

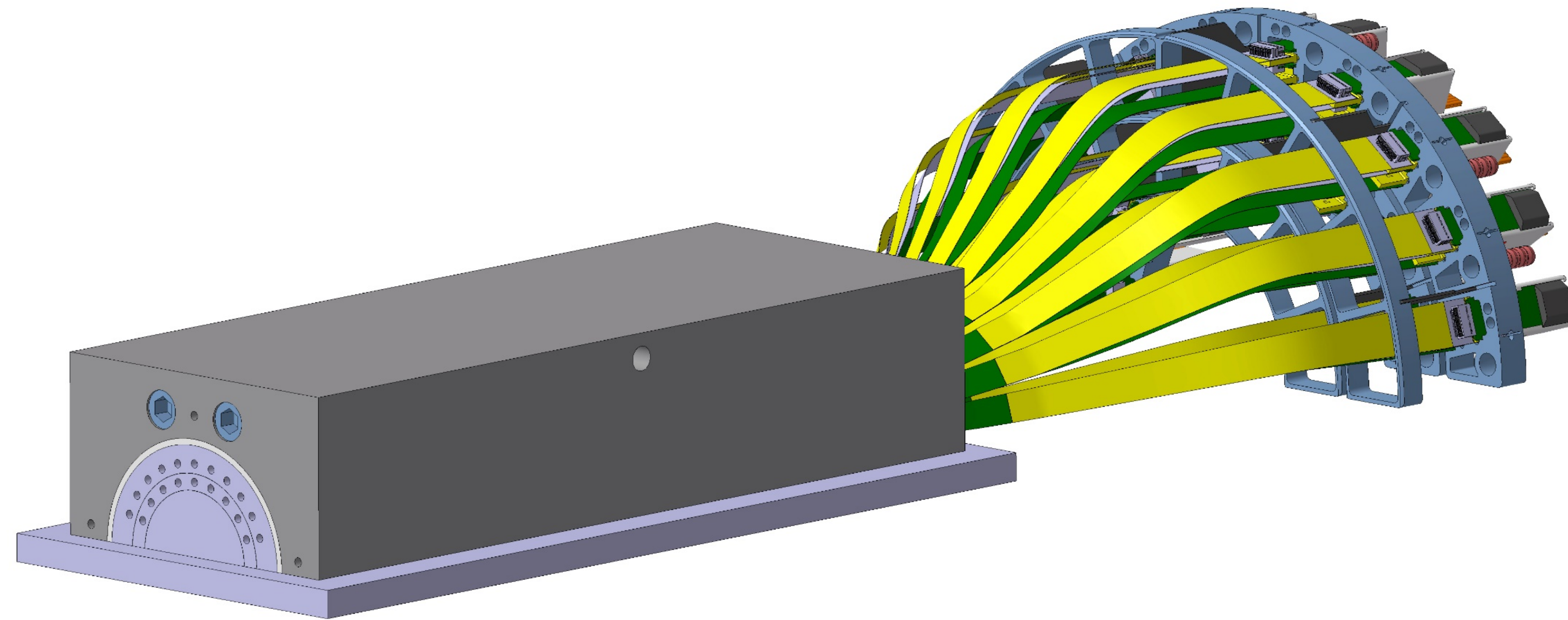


# Assembly procedure

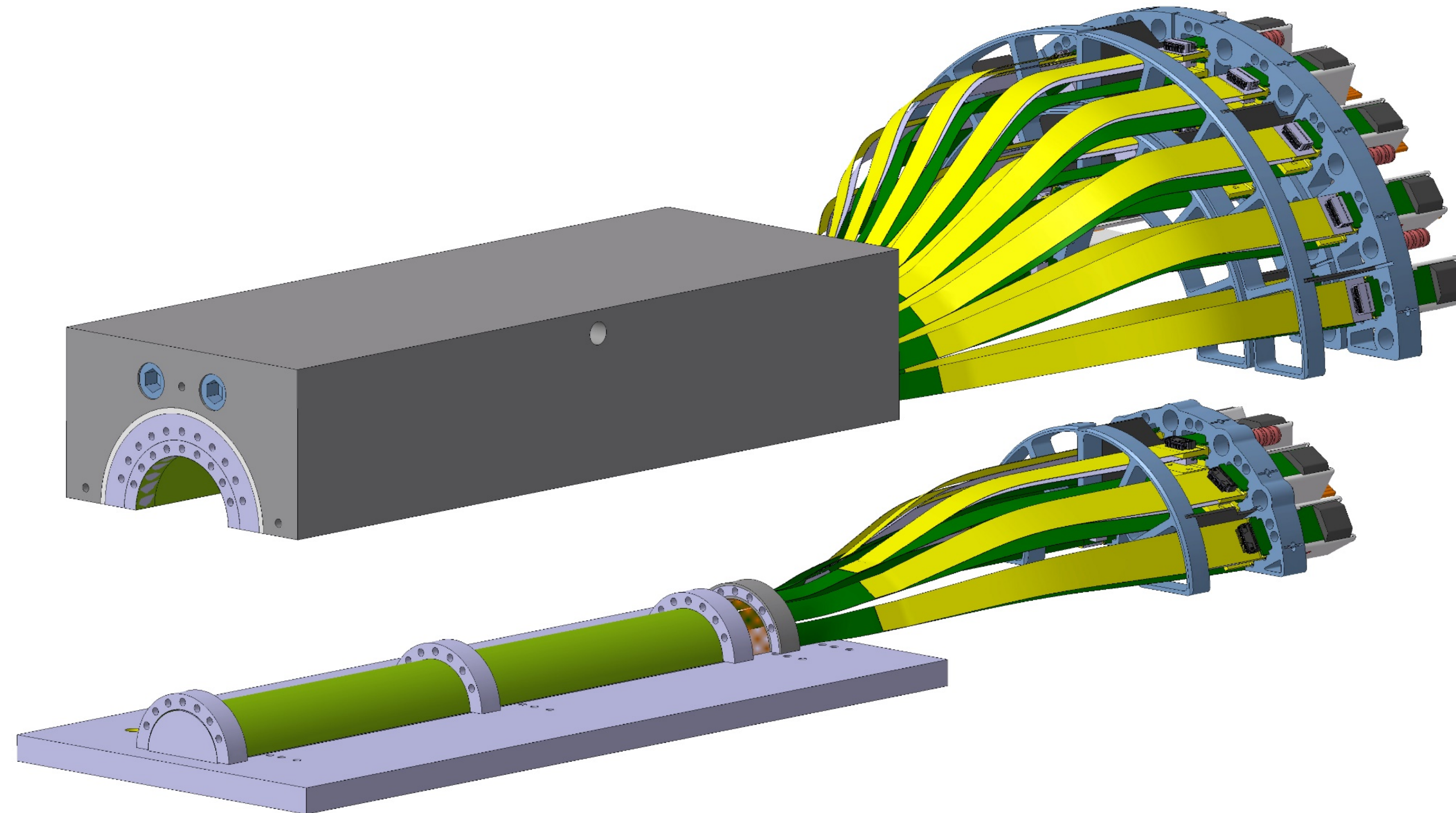




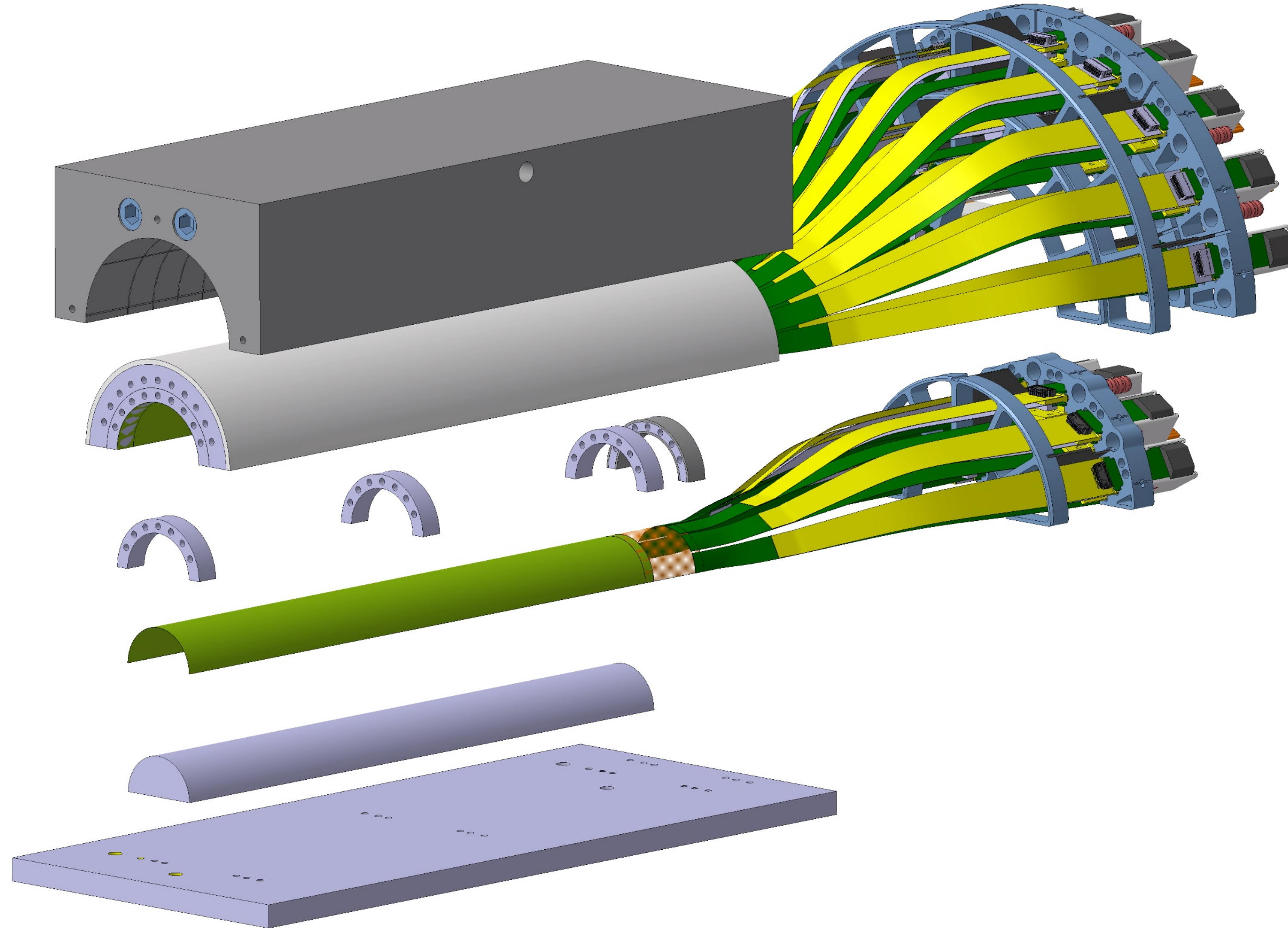
# Assembly procedure



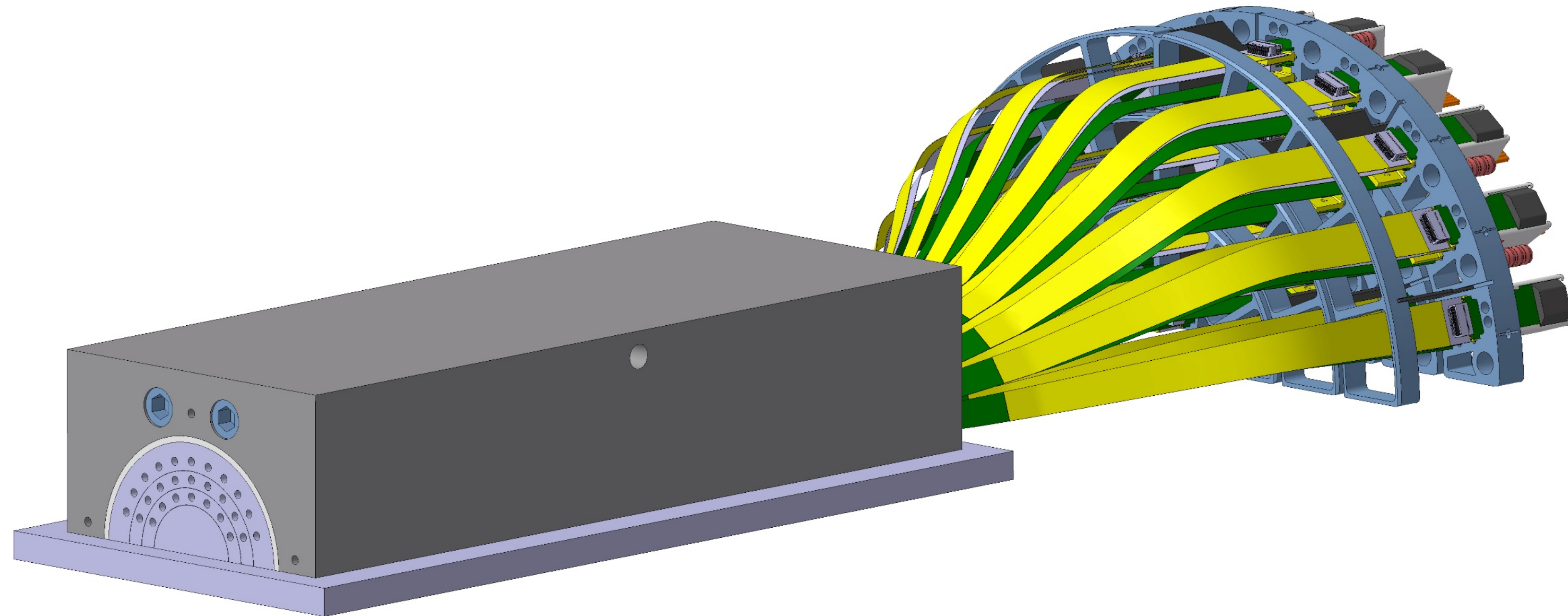
# Assembly procedure



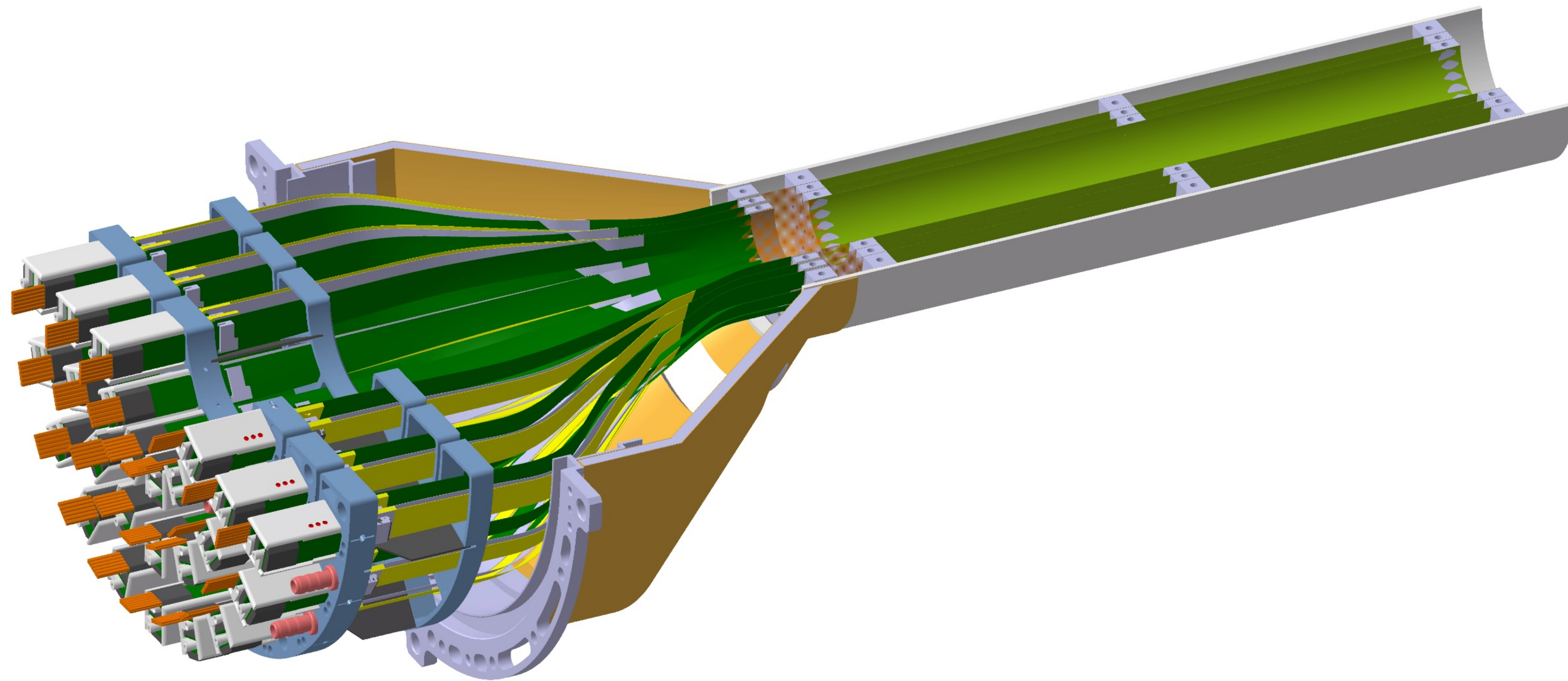
# Assembly procedure



# Assembly procedure

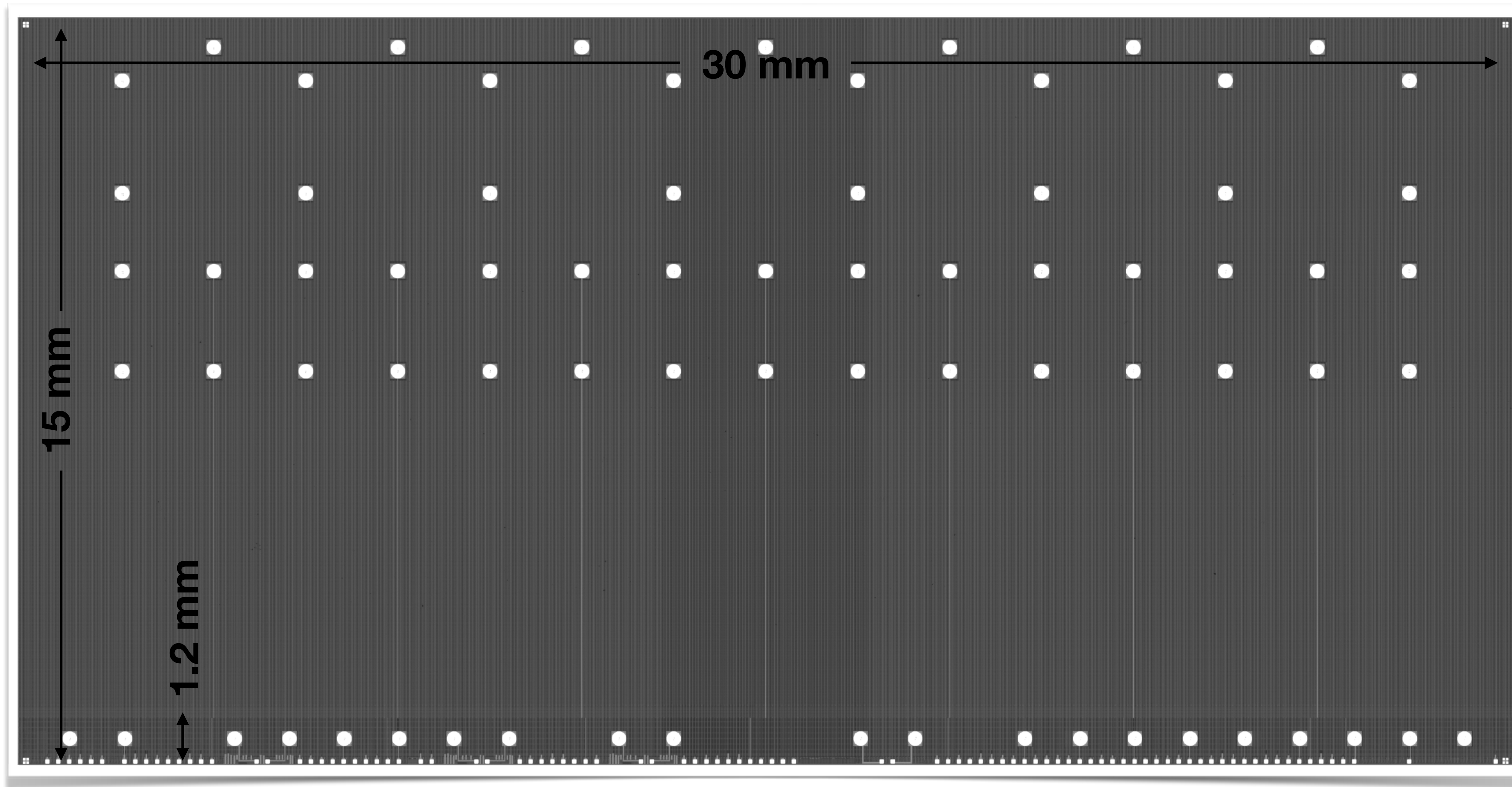


# Assembly procedure



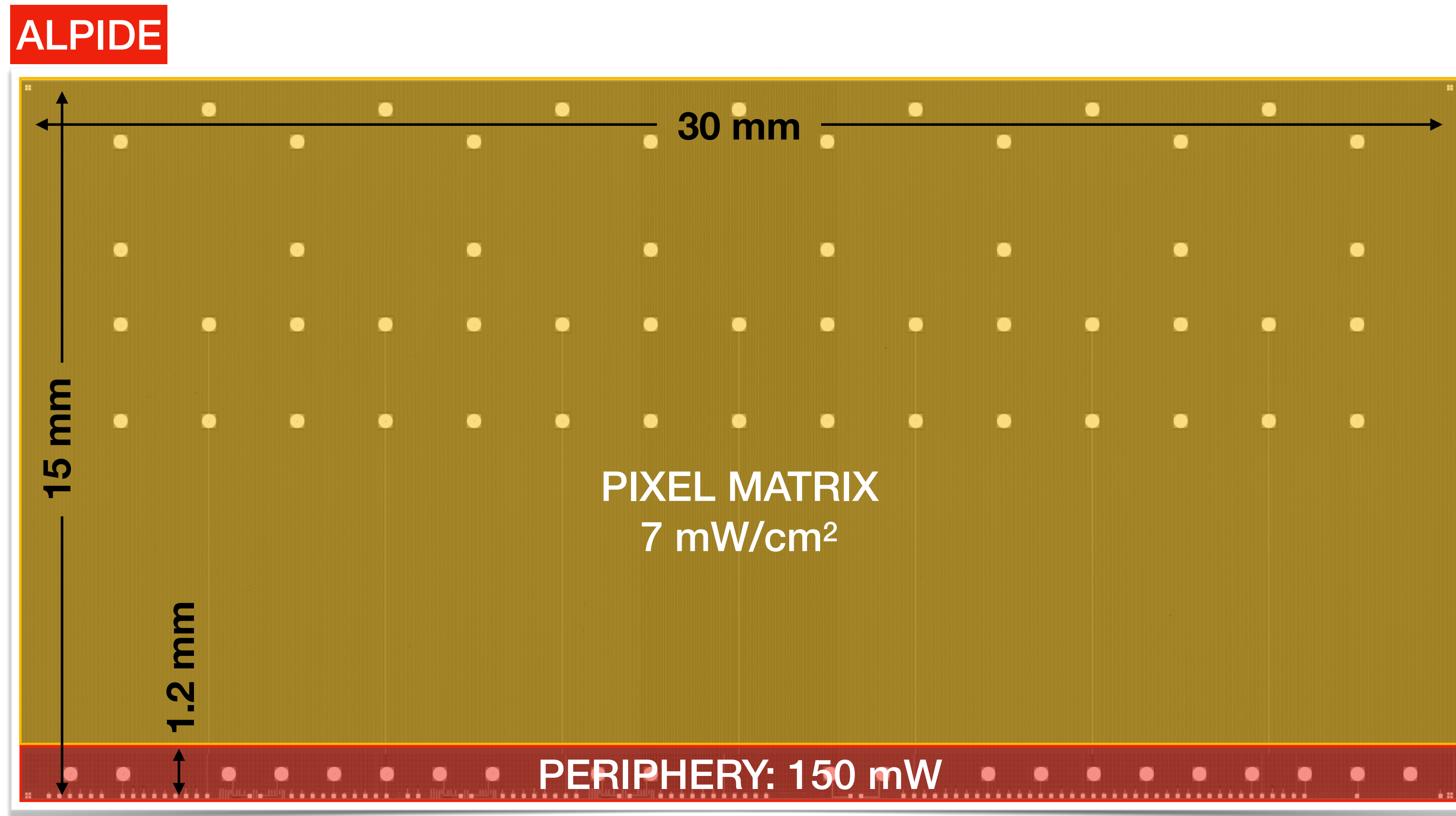
# Air cooling

ALPIDE



- ▶ air cooling possible from 20 mW/cm<sup>2</sup> (was indeed studied as option for ITS2)
- ▶ ALPIDE is already close:  $\approx 40$  mW/cm<sup>2</sup>

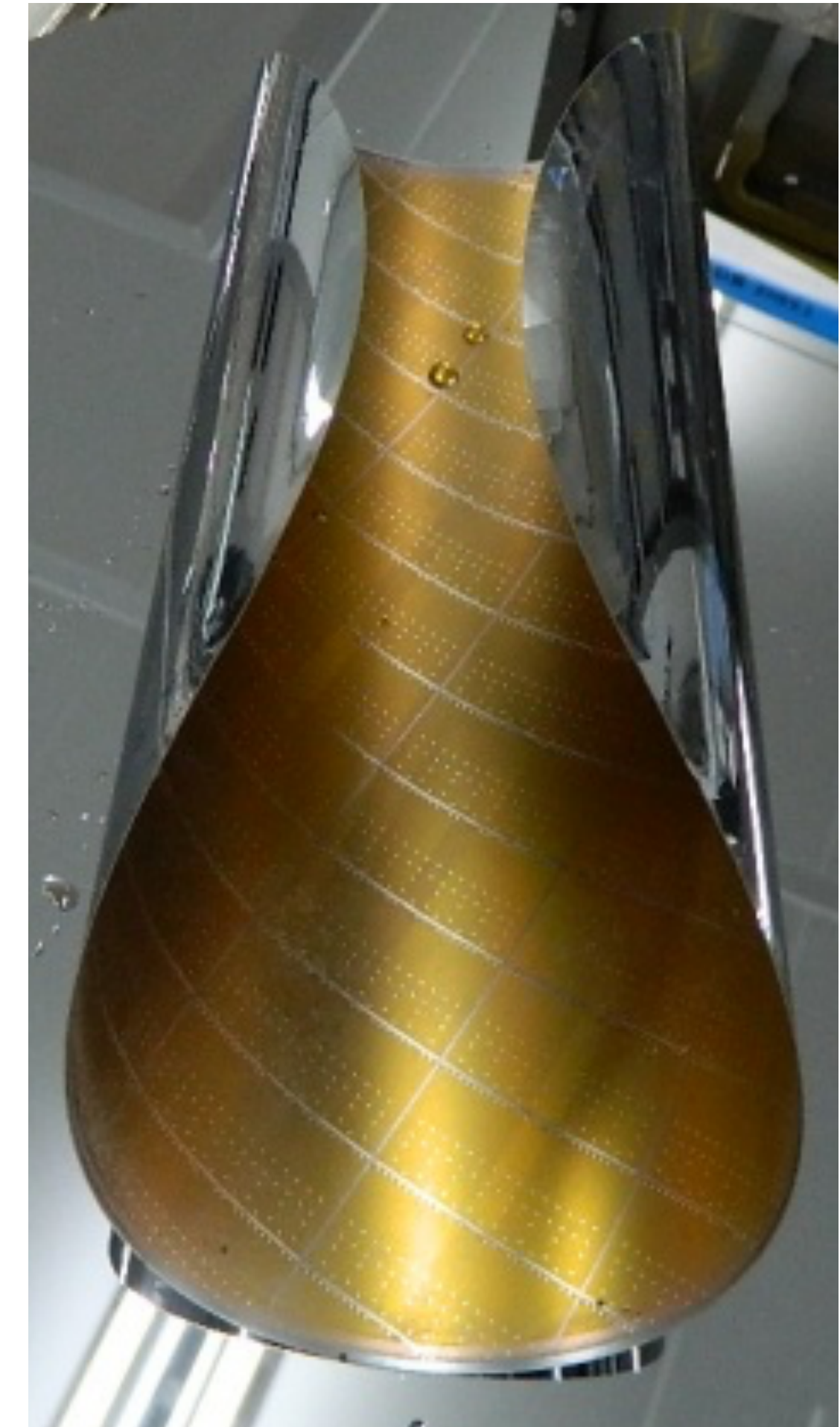
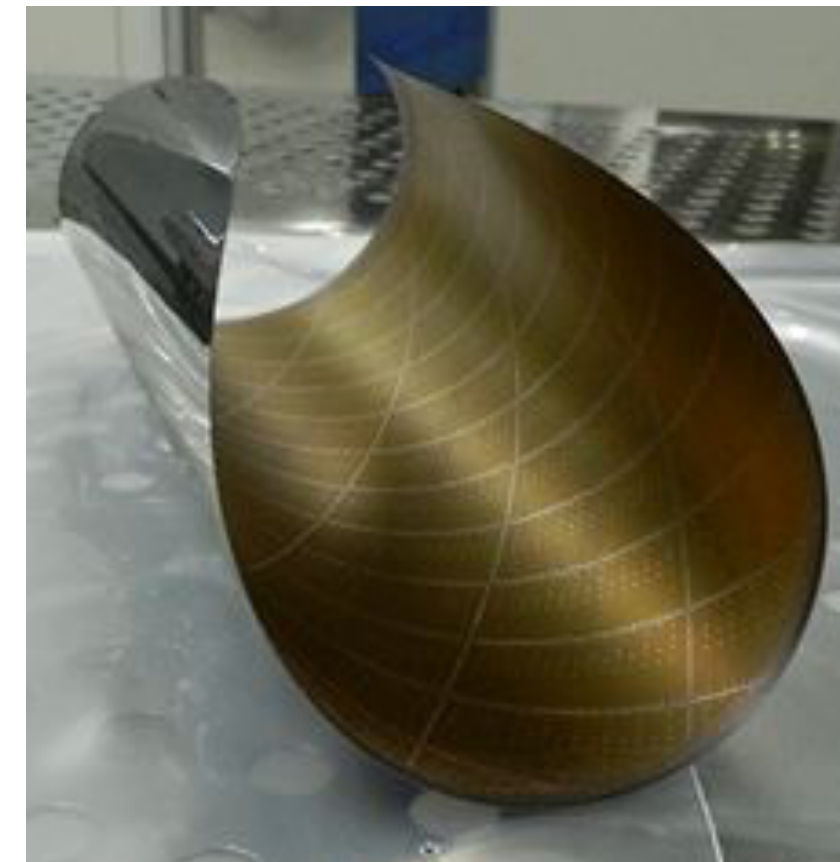
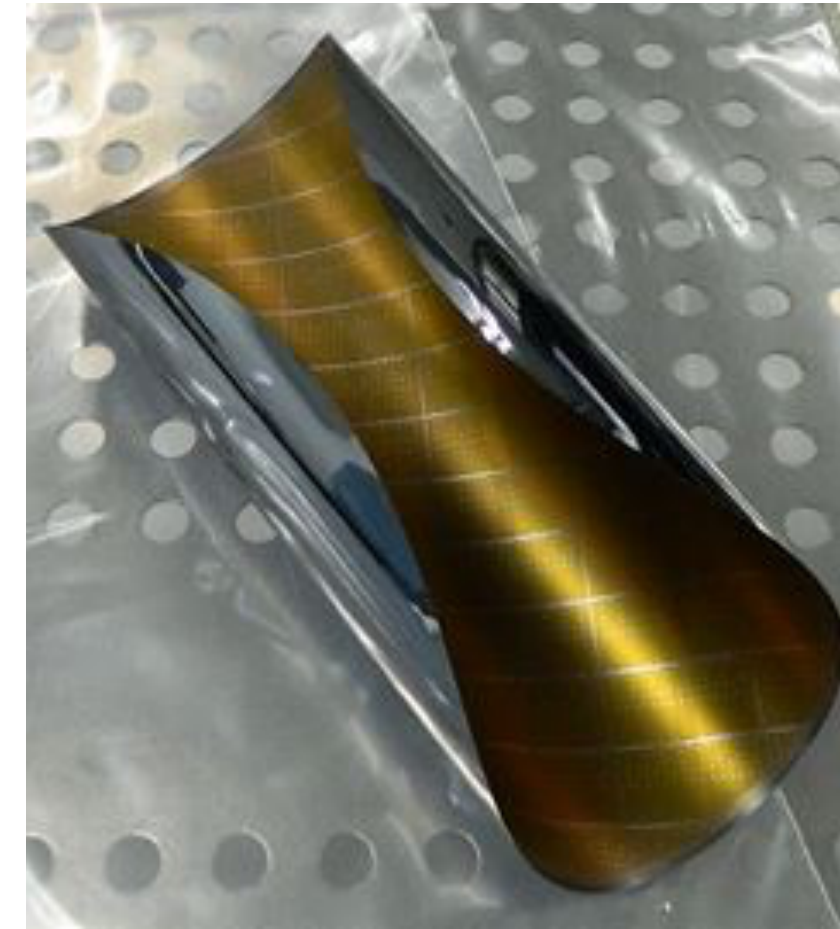
# Air cooling



- ▶ air cooling possible from 20 mW/cm<sup>2</sup> (was indeed studied as option for ITS2)
- ▶ ALPIDE is already close:  $\approx 40 \text{ mW/cm}^2$
- ▶ Actually, already largely sufficient *if* its periphery can be placed outside the fiducial volume

# ... it was already done...

- ▶ Indeed “warpage” is omnipresent when working with thin sensors
- ▶ We accidentally produced curved ALPIDEs
- ▶ On chip and on wafer level





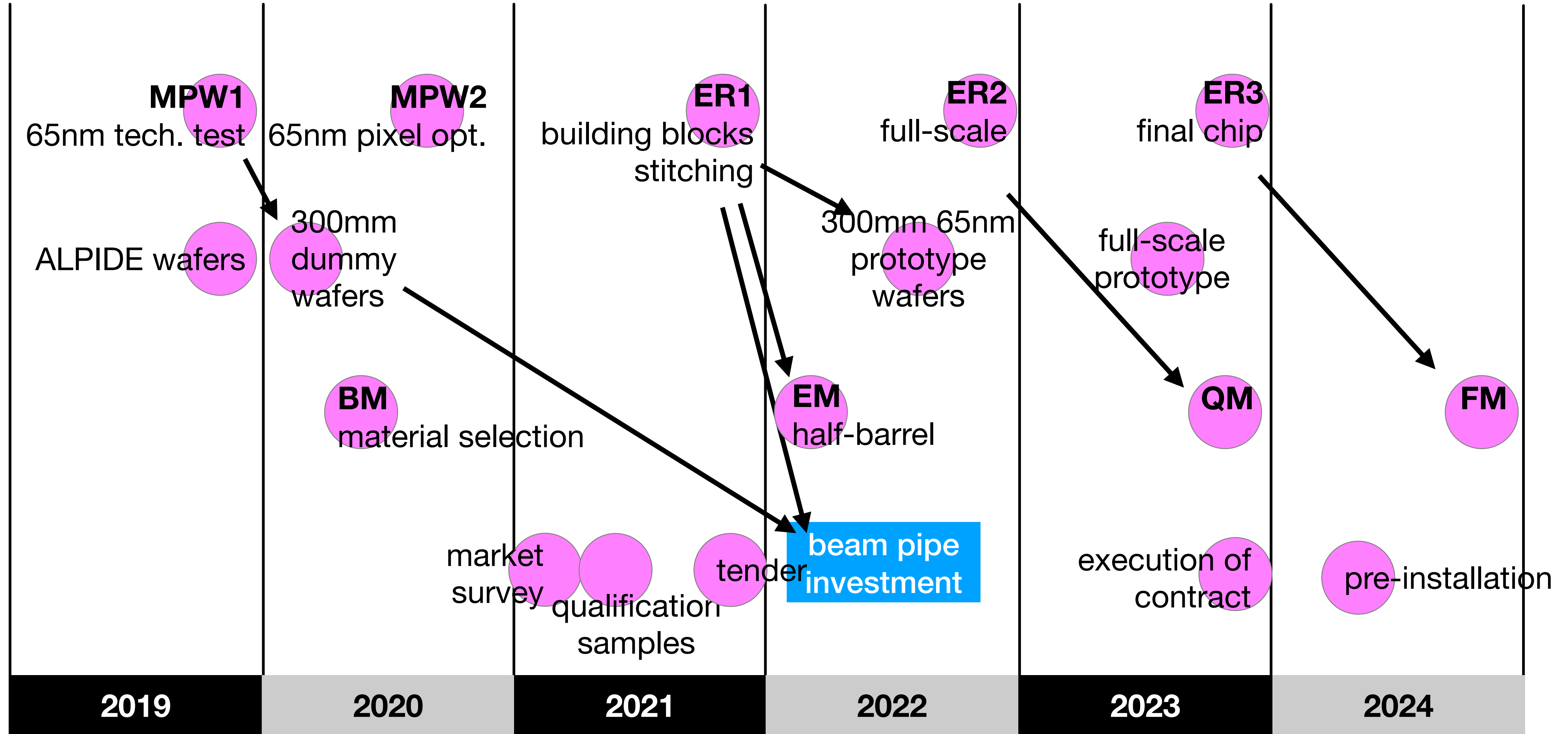
# Milestone summary

**Sensor  
(submissions)**

**Thinning  
Bending**

**Mechanics  
Cooling**

**Beampipe**



**MPW:** multi-project wafer run, **ER:** engineering run, **BM:** breadboard module, **EM:** engineering module, **QM:** qualification module, **FM:** final module

# Project milestones

Milestone	Description	Date
1	<b>Market survey</b> preparation of beampipe technical specifications definition of technical and commercial criteria for the selection of suppliers preparation of technical specifications for the qualification samples <sup>a</sup> selection of candidate supplier	Q1 2021
2	<b>Evaluation of candidate suppliers</b> production of qualification samples (by candidate suppliers) evaluation of qualification samples (by CERN)	Q2 2021
3	<b>Tender</b> preparation of technical specification document invitation to tender	Q4 2021
4	<b>Execution of contract</b> R&D phase (until Q2 2022) production	Q4 2023
5	<b>Pre-installation phase (CERN)</b> Acceptance and post production activities	Q2 2024

Milestone	Description	Date
1	<b>Breadboard Module (BM)</b> selection of carbon materials based on structural and thermal properties production of samples for material characterization development of FE and CFD models for structural and thermal simulations	Q2 2020
2	<b>Engineering Module (EM)</b> production of one half-layer with dummy chips thermal and dynamic stability tests (including wind tunnel) development of half-barrel assembly procedures and jigs production of first half-barrel with dummy chips thermal and dynamic stability tests (including wind tunnel) drawings, FE and CFD analysis reports	Q1 2022
3	<b>Qualification Module (QM)</b> production of two half-barrels with prototype chips thermal and dynamic stability tests (including wind tunnel) electrical functional test final assembly and test procedures, technical specifications and drawings	Q4 2023
4	<b>Final Module (FM)</b> production of four half-barrels with final chips electrical and mechanical acceptance tests	Q4 2024

Milestone	Description	Date
1	<b>ALPIDE wafers</b> based on existing 200 mm ALPIDE wafers characterization of mechanical stability characterization of sensor performance	Q4 2020
2	<b>300 mm dummy wafers</b> based on pad wafers (top metal only) characterization of mechanical and thermal properties	Q1 2021
3	<b>Wafers with large prototypes</b> using ER with larger arrays (milestone 3 of Tab. 3) characterization of influence of realistic circuitry onto mechanical properties beam tests	Q3 2022
4	<b>Full-scale prototype</b> using full-scale prototype (milestone 4 of Tab. 3) validation of mechanical, electrical, and detection properties beam tests	Q3 2023

Milestone	Description	Production <sup>a</sup>	Date
1	<b>Technology test structures</b> single pixels, transistors, small memory cell array for studying the radiation hardness of the technology	MPW	Q4 2019
2	<b>Pixel test vehicle</b> optimization of pixel and diode geometries	MPW	Q3 2020
3	<b>Large area prototype</b> basic blocks: pixel matrix, periphery, output serial links exercising of stitching different parts	ER	Q4 2021
4	<b>Full-scale prototype</b> prototype of final chip with all functionality	ER	Q4 2022
5	<b>Final Chip</b> possible minor adjustments wrt milestone 4	ER	Q4 2023



# LHCC

CERN/LHCC-2019-010  
LHCC-139  
September 2019

## LARGE HADRON COLLIDER COMMITTEE

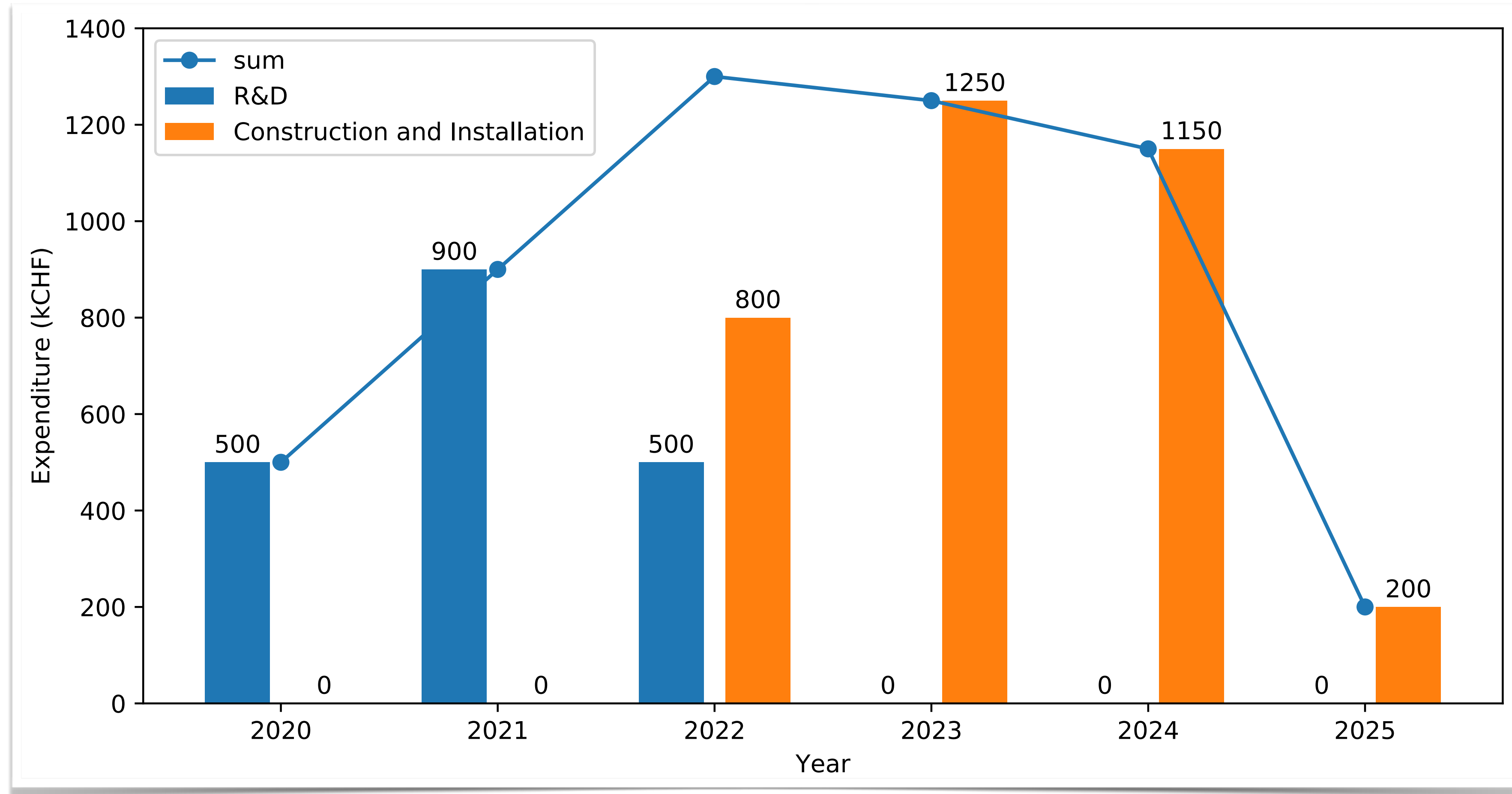
Minutes of the one-hundredth-and-thirty-ninth meeting held on  
Wednesday and Thursday, 11-12 September 2019

- The **LHCC is impressed** by the new concept for the ITS3 with significantly reduced material budget, recognises the physics case presented in the LoI and in the dedicated ITS3 session and appreciates the on-going simulations on various physics channels to further demonstrate the expected gain from better resolution and efficiency at low transverse momentum. The **LHCC endorses** the plan of ALICE to carry out the necessary R&D studies to demonstrate the technical feasibility of this upgrade project. A TDR to be submitted on a timescale compatible with installation in LS3 will have to include in addition a comprehensive study of its physics gains with respect to the ITS2 detector.

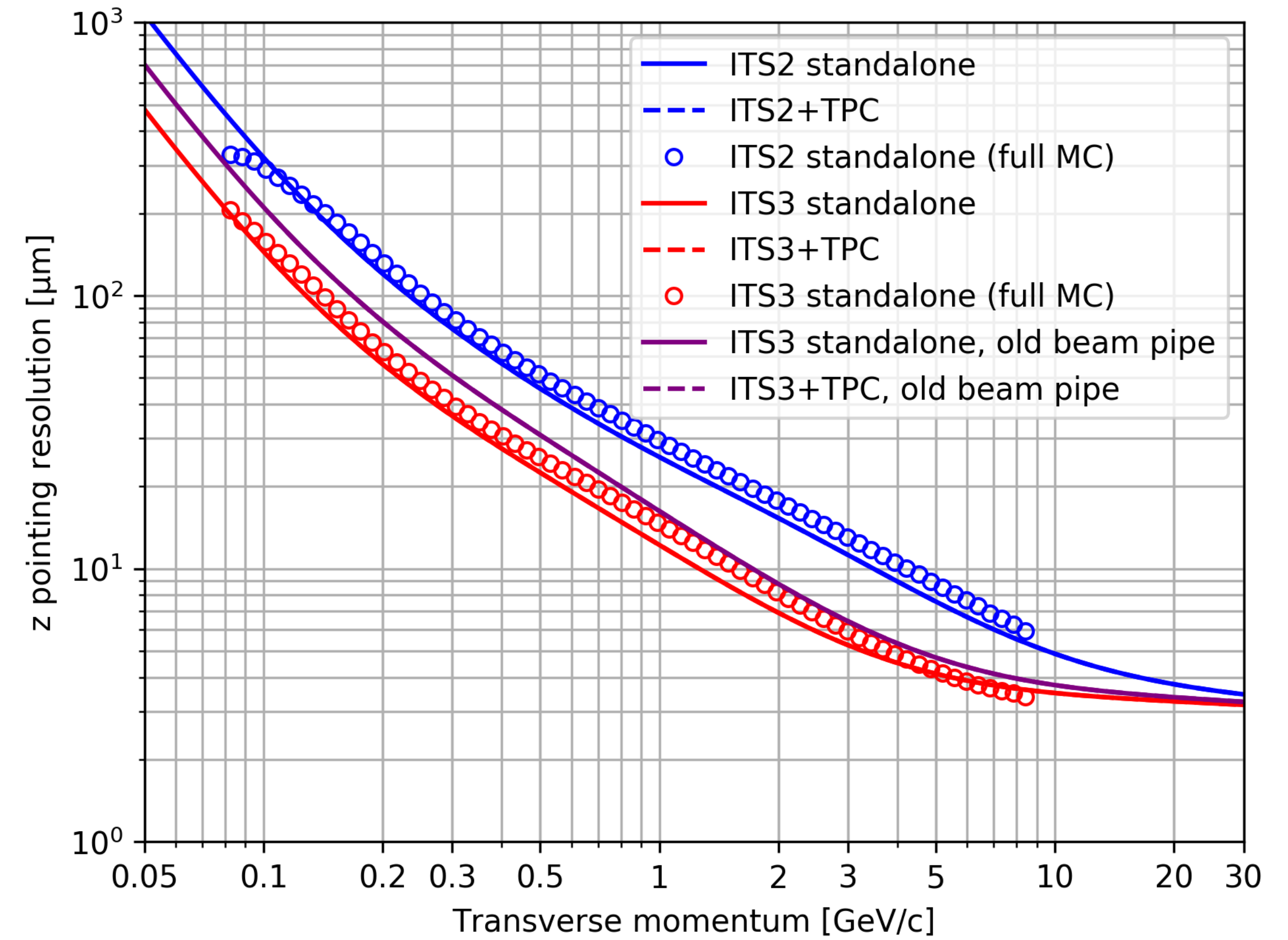
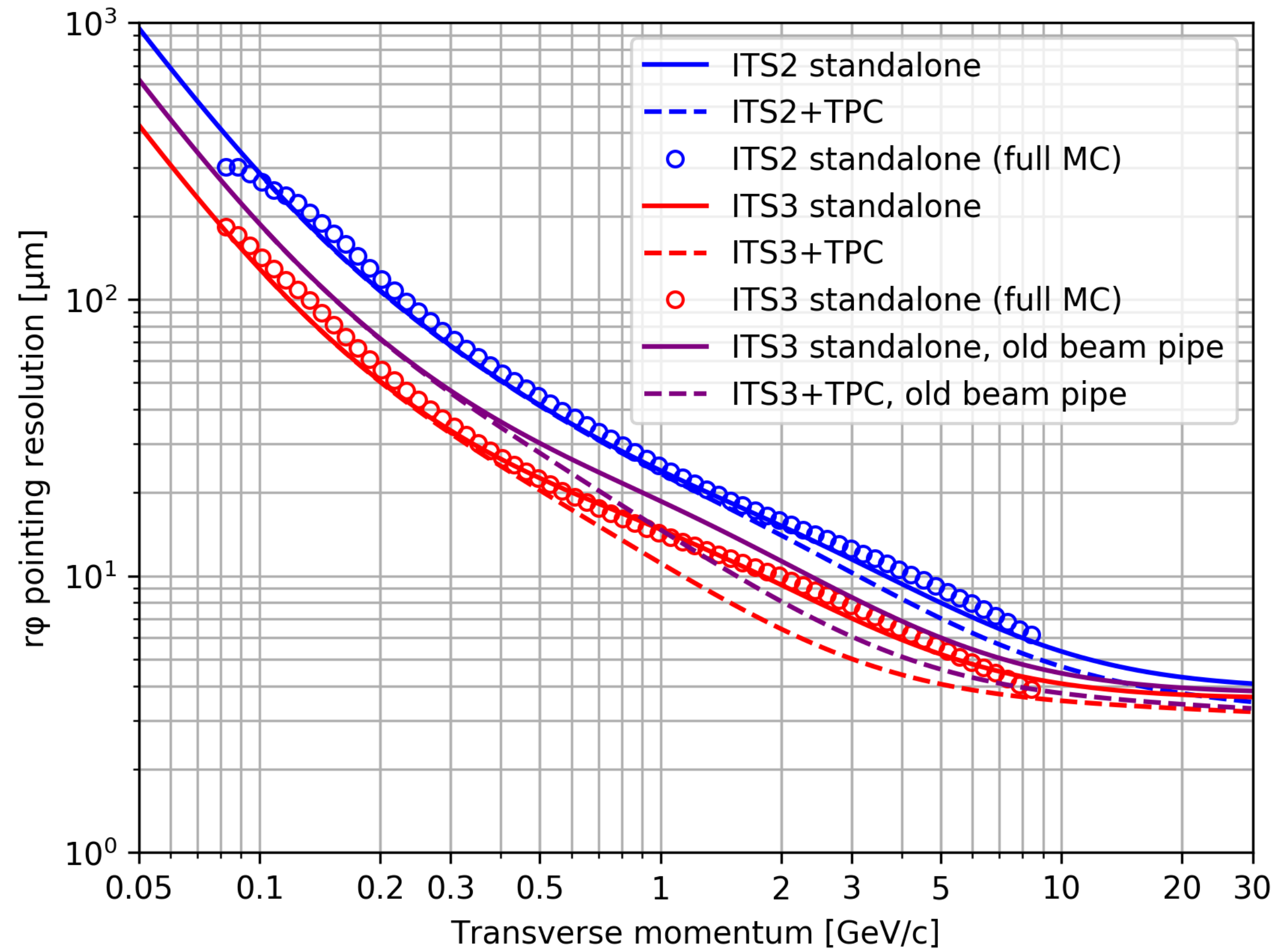
# Chip specifications

Parameter	ALPIDE (existing)	Wafer-scale sensor (this proposal)
Technology node	180 nm	65 nm
Silicon thickness	50 $\mu\text{m}$	20-40 $\mu\text{m}$
Pixel size	27 x 29 $\mu\text{m}$	O(10 x 10 $\mu\text{m}$ )
Chip dimensions	1.5 x 3.0 cm	scalable up to 28 x 10 cm
Front-end pulse duration	$\sim 5 \mu\text{s}$	$\sim 200 \text{ ns}$
Time resolution	$\sim 1 \mu\text{s}$	$< 100 \text{ ns}$ (option: $< 10 \text{ ns}$ )
Max particle fluence	100 MHz/cm <sup>2</sup>	100 MHz/cm <sup>2</sup>
Max particle readout rate	10 MHz/cm <sup>2</sup>	100 MHz/cm <sup>2</sup>
Power Consumption	40 mW/cm <sup>2</sup>	$< 20 \text{ mW/cm}^2$ (pixel matrix)
Detection efficiency	$> 99\%$	$> 99\%$
Fake hit rate	$< 10^{-7}$ event/pixel	$< 10^{-7}$ event/pixel
NIEL radiation tolerance	$\sim 3 \times 10^{13}$ 1 MeV $n_{\text{eq}}$ /cm <sup>2</sup>	$10^{14}$ 1 MeV $n_{\text{eq}}$ /cm <sup>2</sup>
TID radiation tolerance	3 MRad	10 MRad

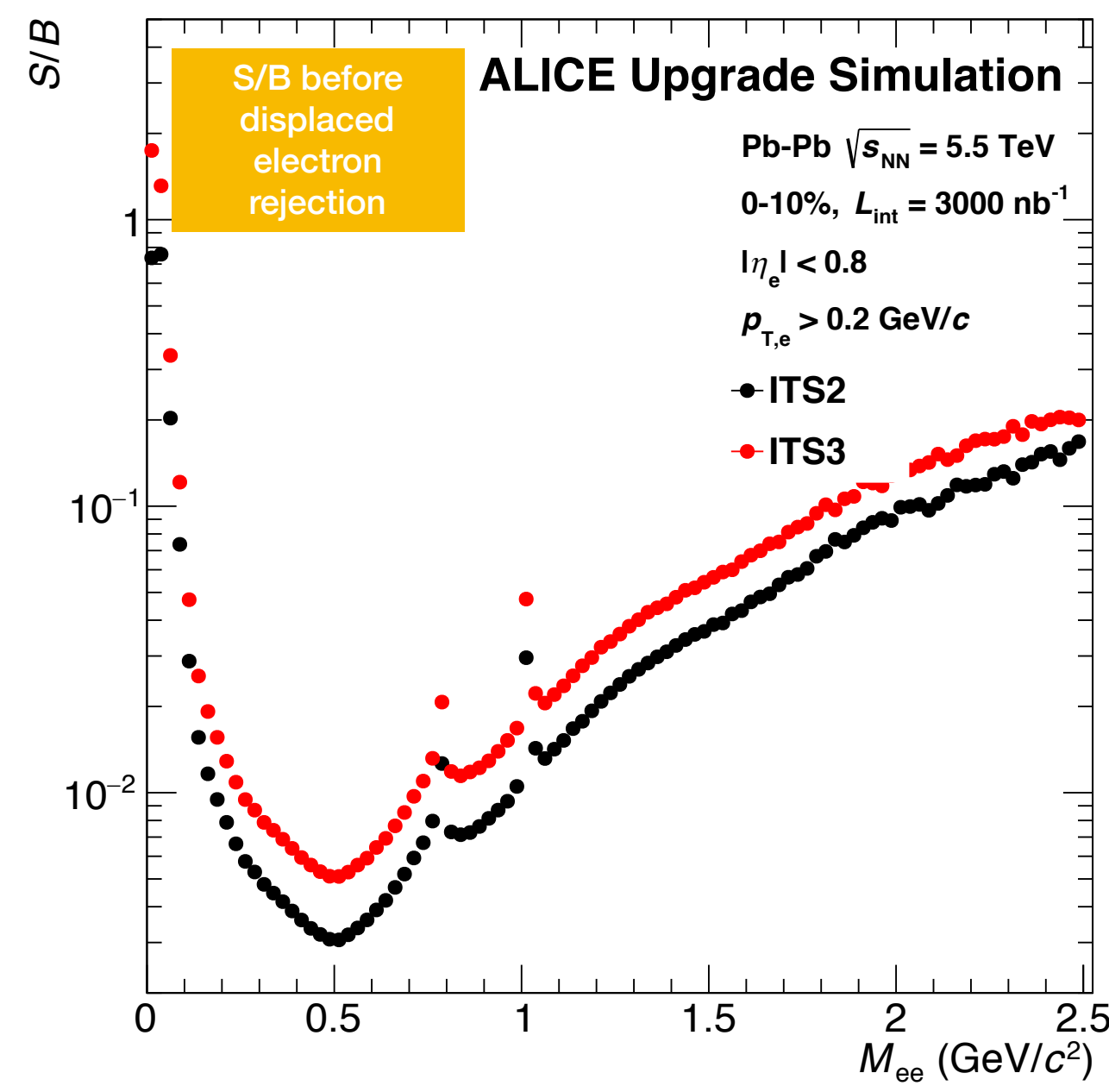
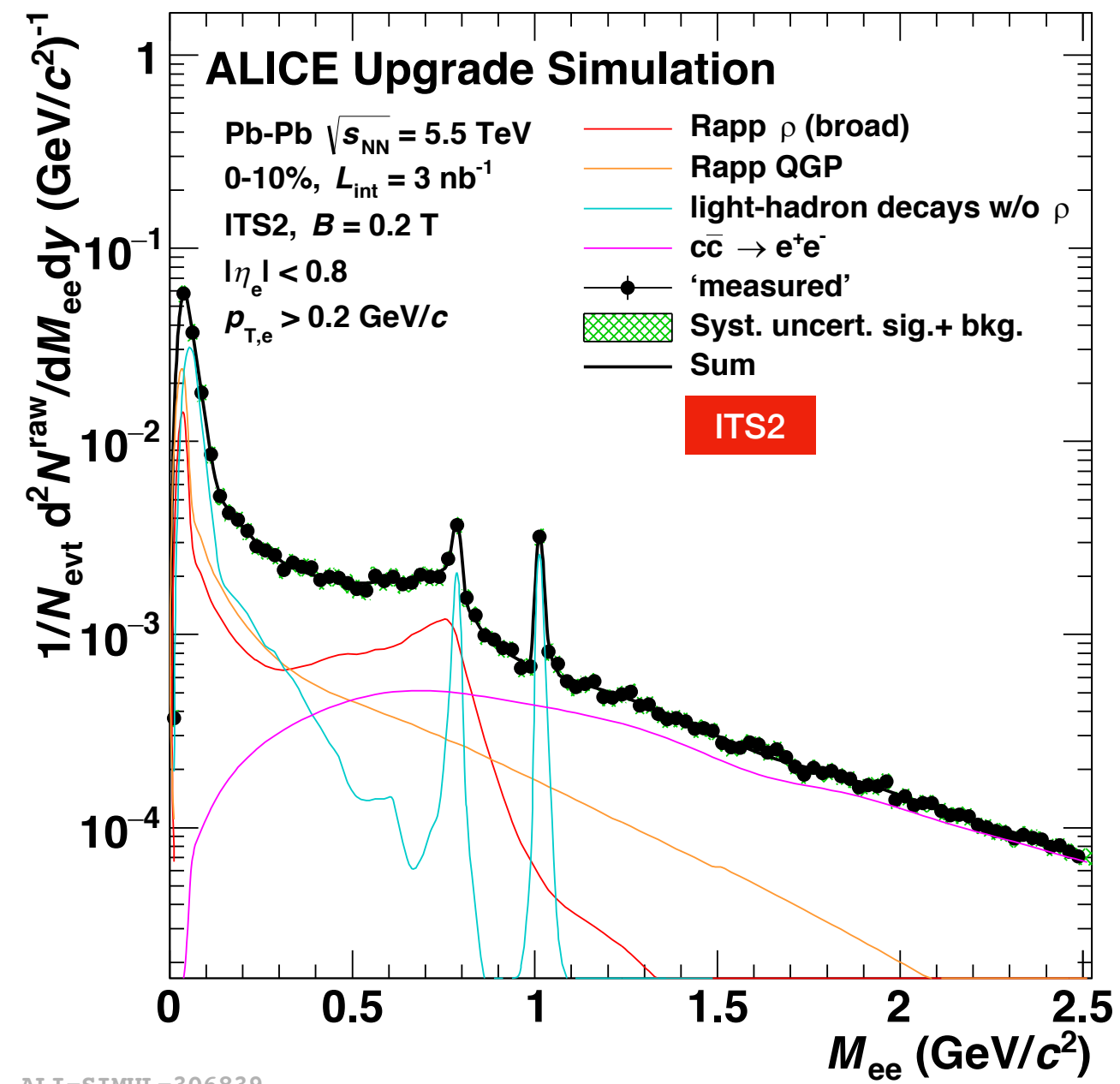
# Spending profile



# Old beam pipe, new ITS



# Low-mass di-leptons

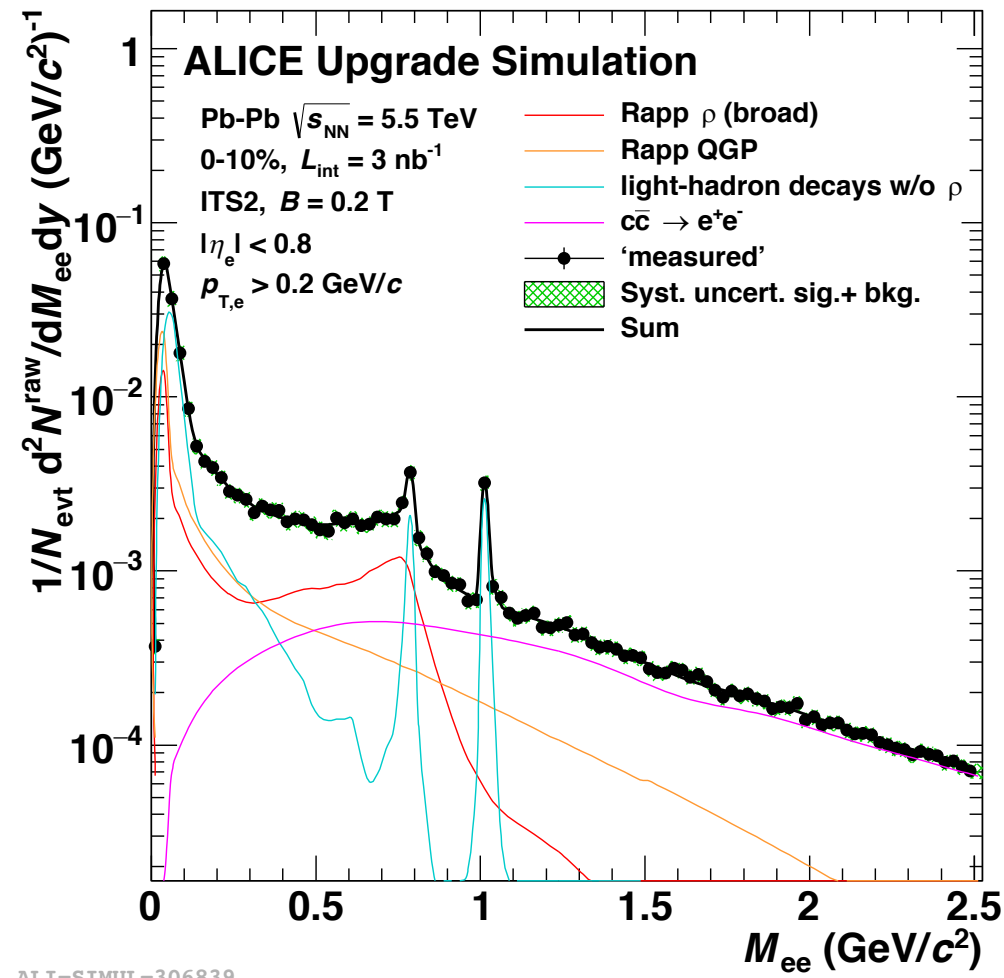


- ▶ background: all pairs of particles,
- ▶ dominated by conversions, i.e. material
- ▶ reduction by 50% due to lower material

# Low-mass di-leptons (2)

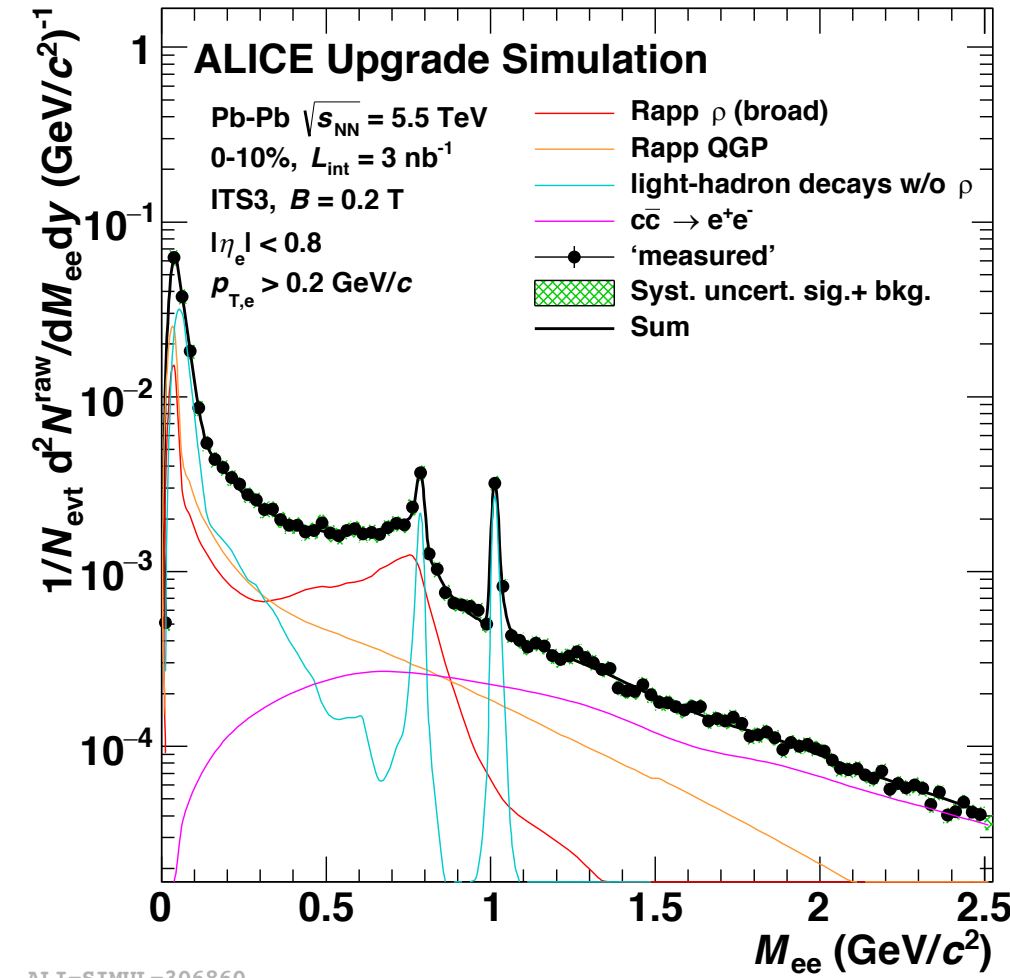
## Signals

ITS2



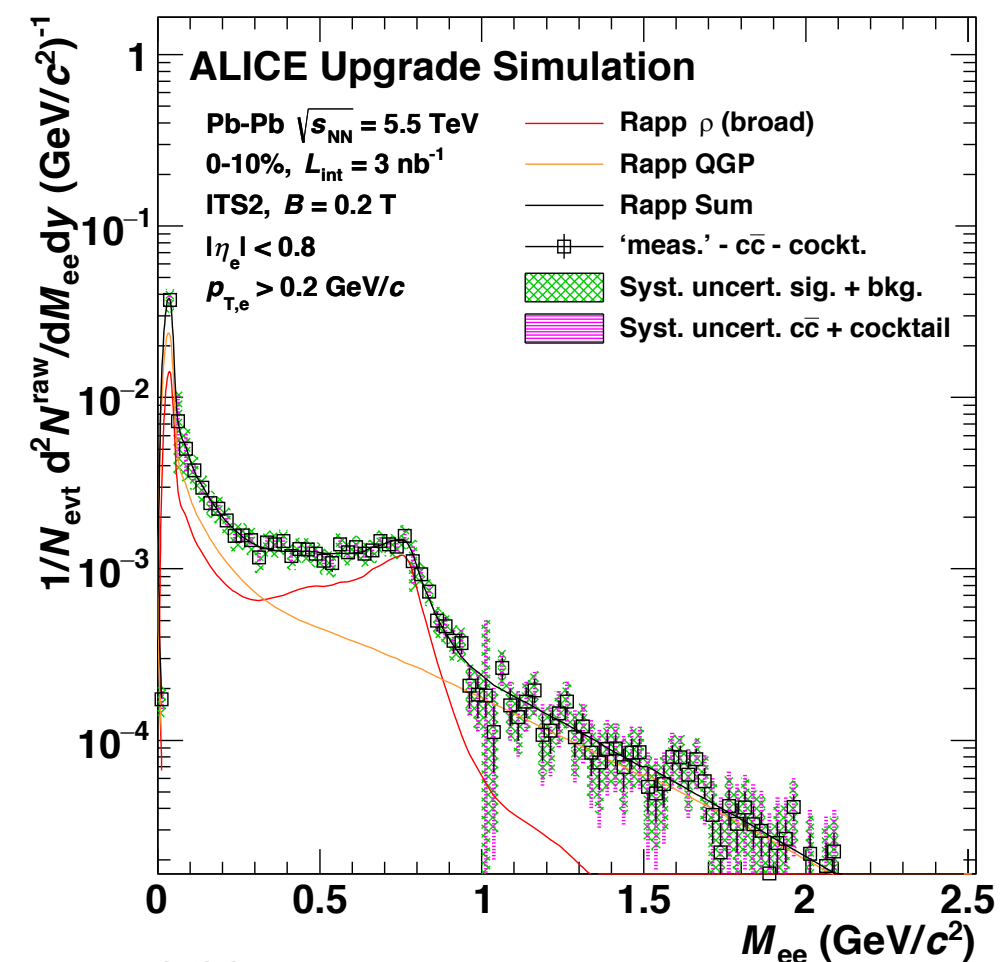
ALI-SIMUL-306839

ITS3

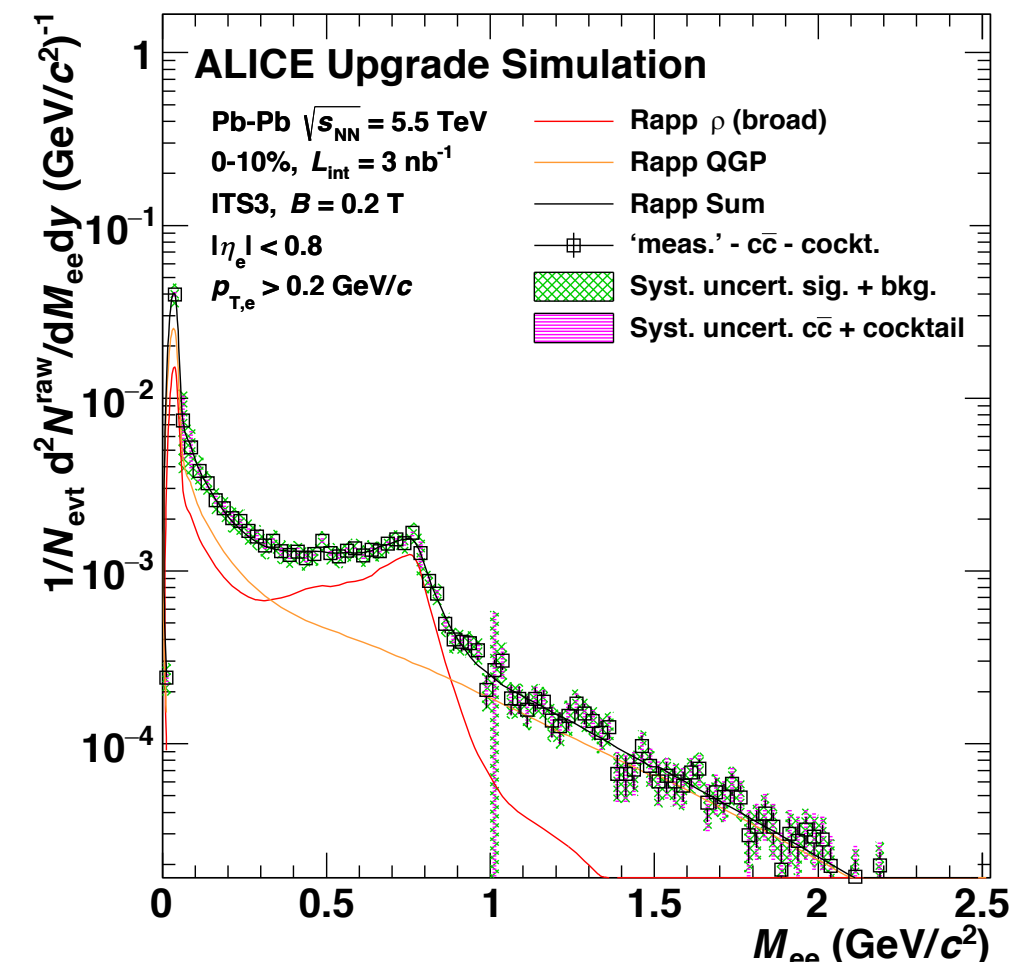


ALI-SIMUL-306860

- ▶ In addition benefit from better reconstruction of charm



ALI-SIMUL-306843



ALI-SIMUL-306856

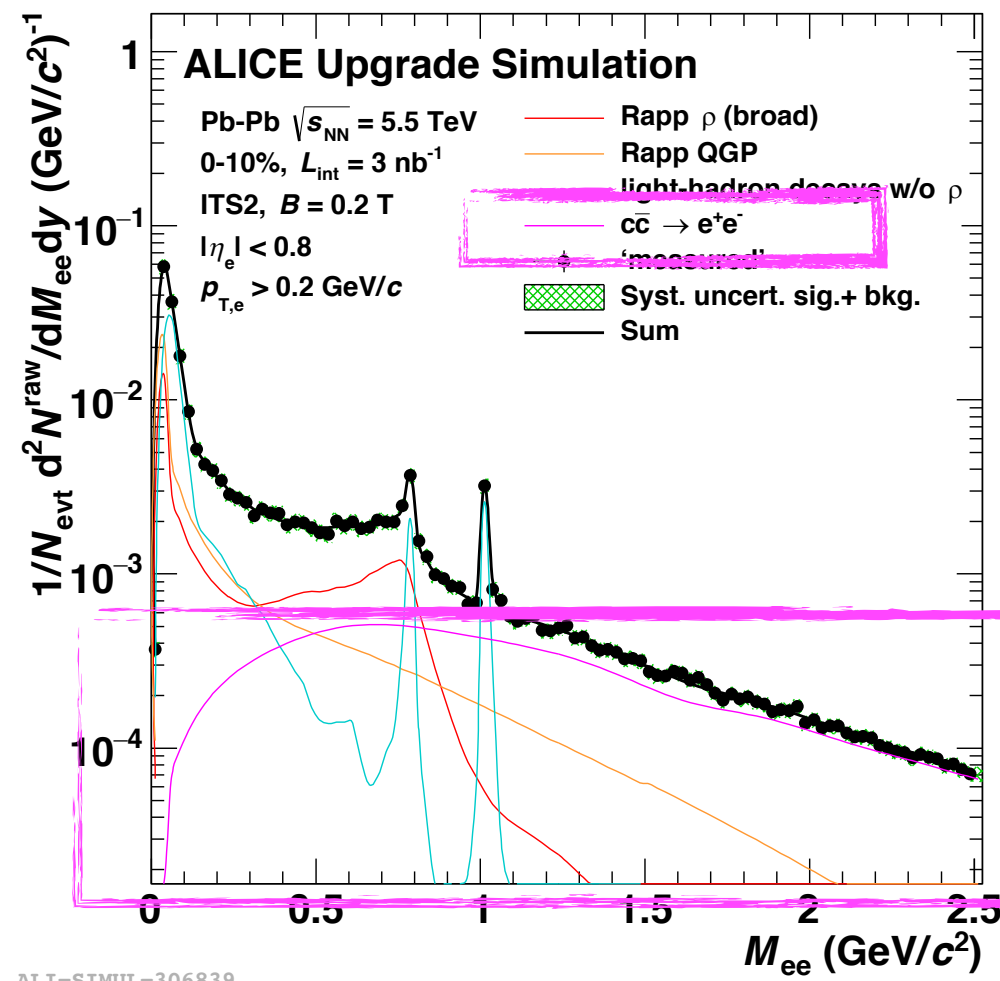
T(QGP)	stat. err.	sys. err. (bkg)	sys. err. (charm)
ITS3 / ITS2	1/1.3	1/2	1/2



# Low-mass di-leptons (2)

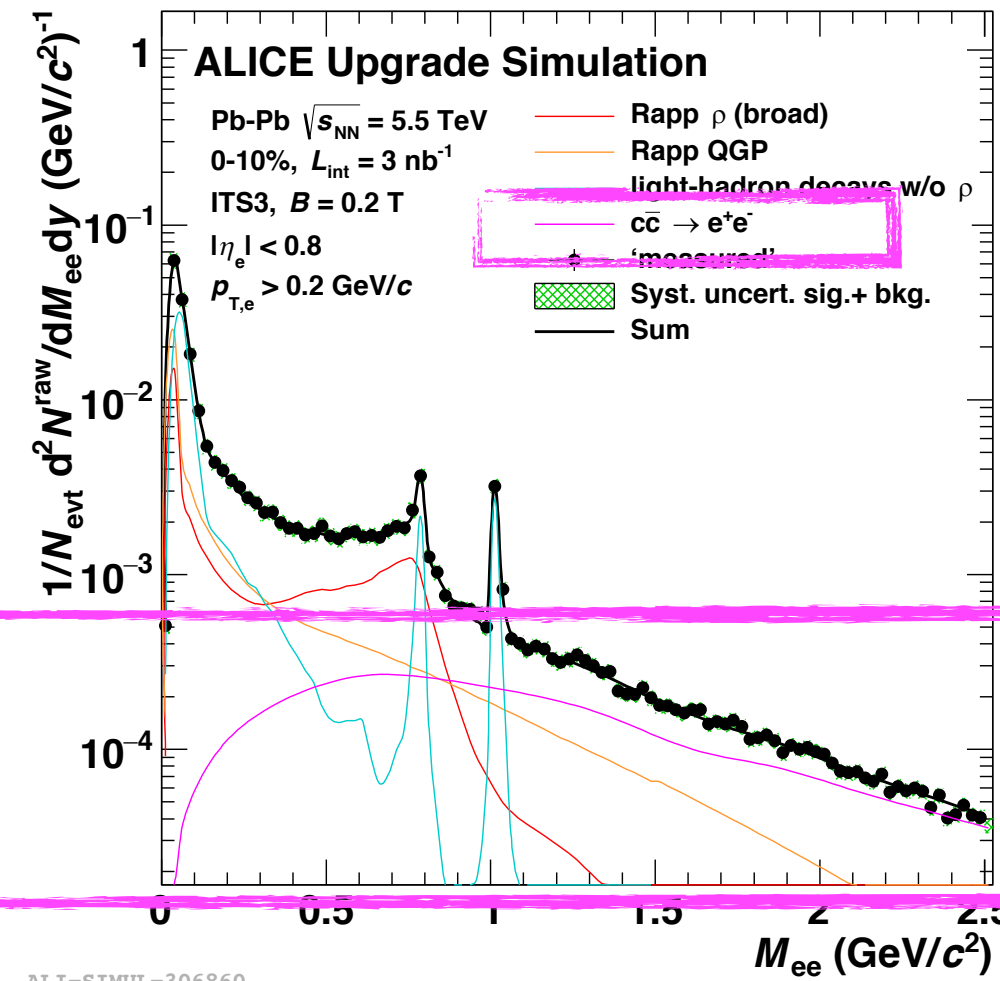
## Signals

ITS2



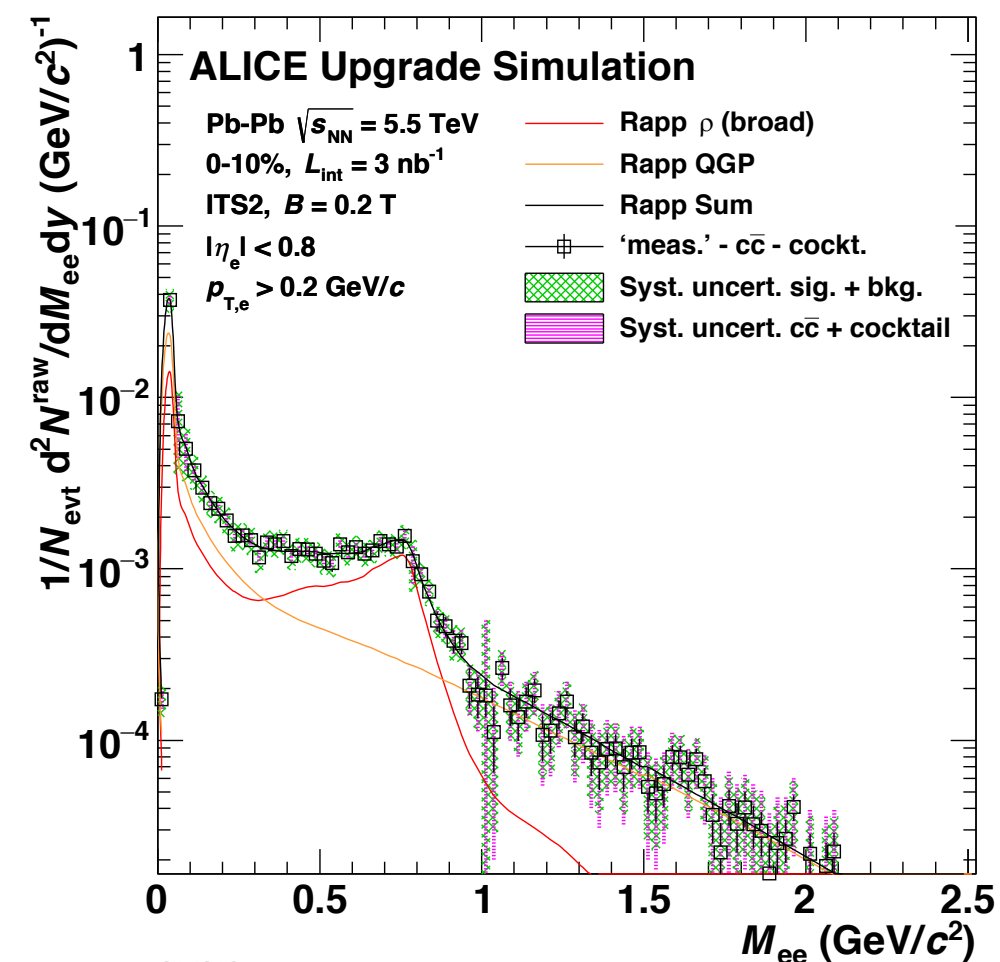
ALI-SIMUL-306839

ITS3

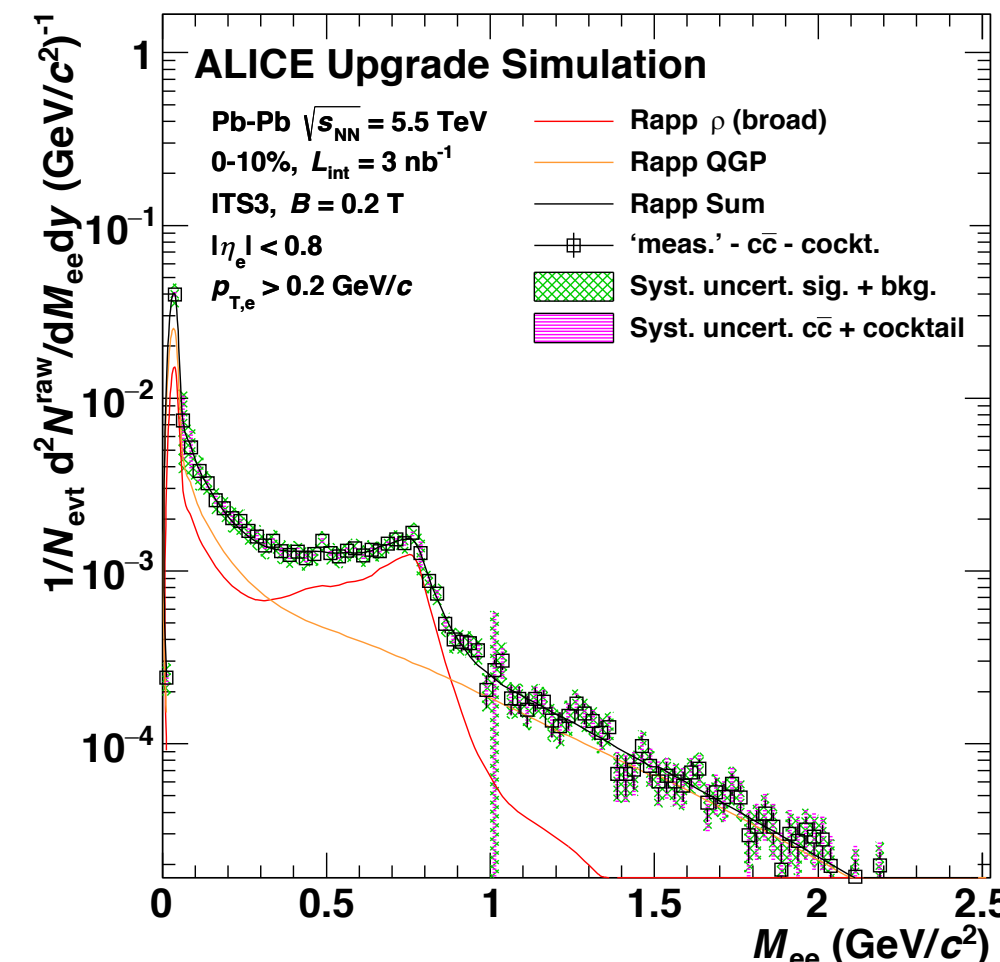


ALI-SIMUL-306860

- ▶ In addition benefit from better reconstruction of charm
- ▶ (Unidentified) charm background is reduced by 50%



ALI-SIMUL-306843



ALI-SIMUL-306856

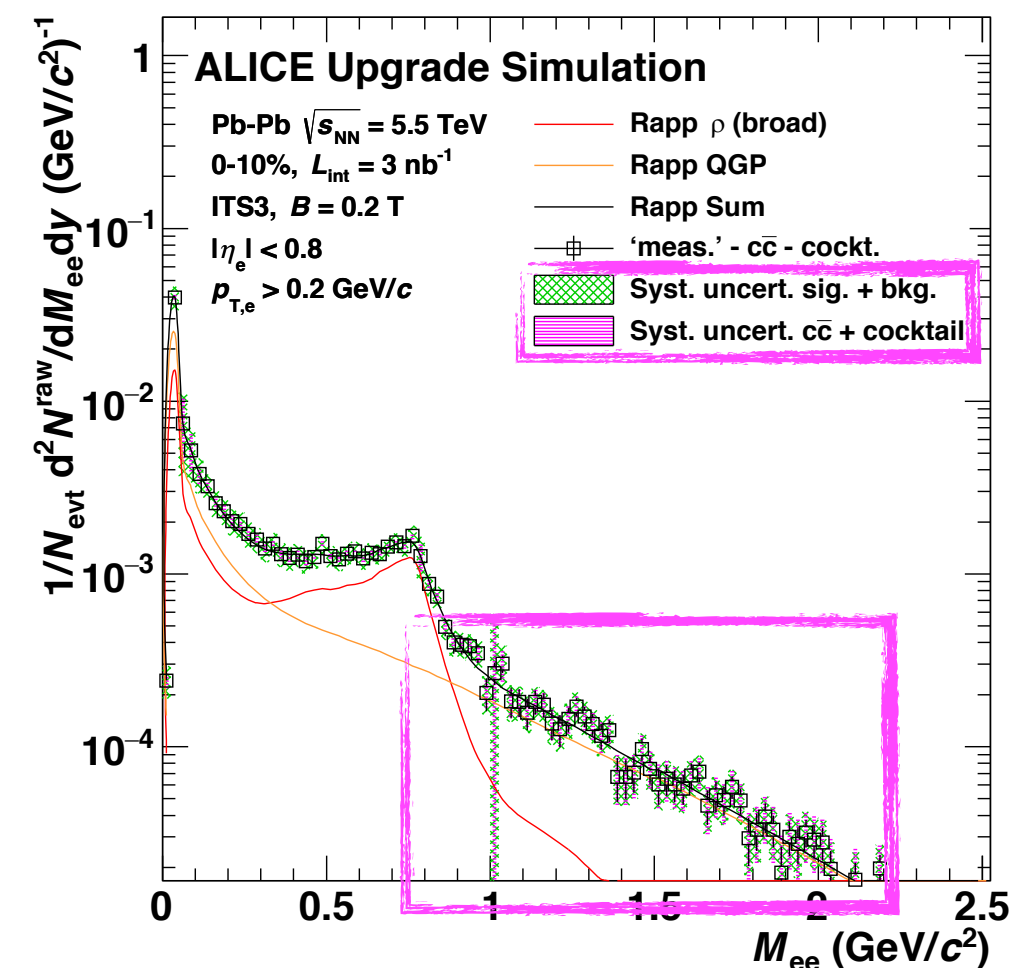
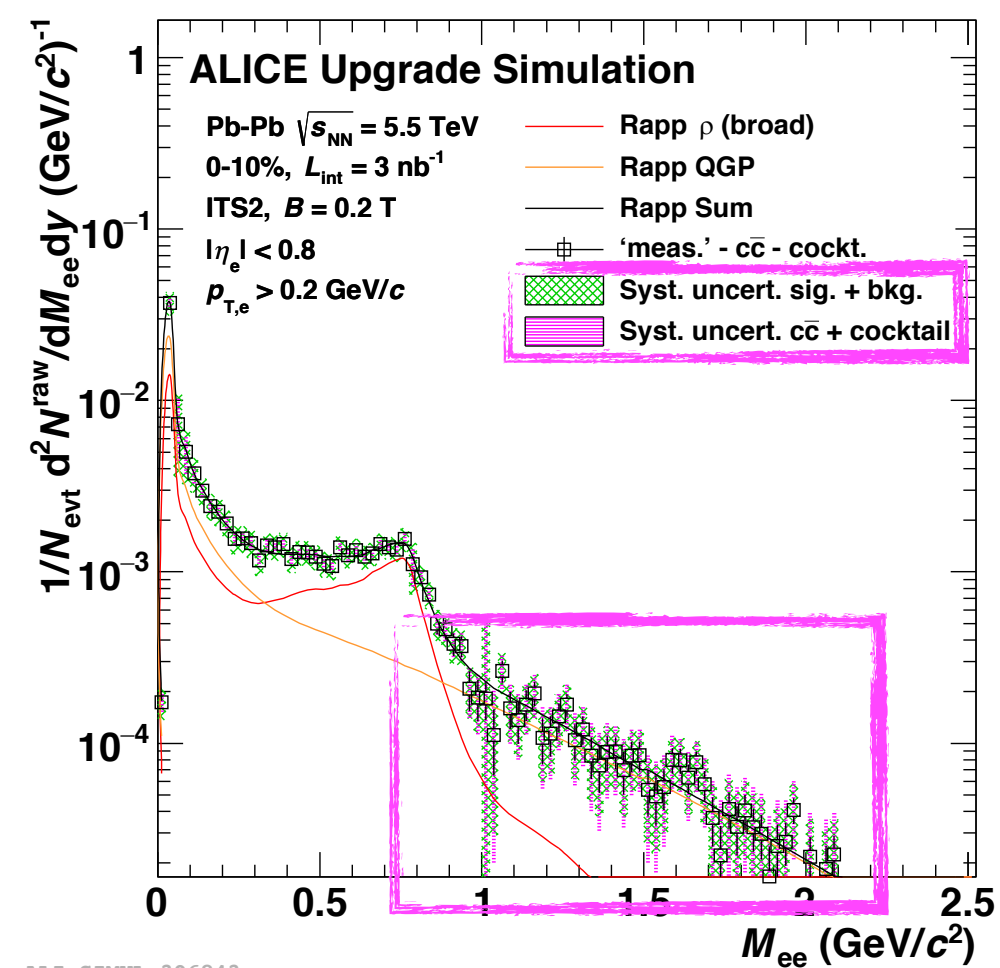
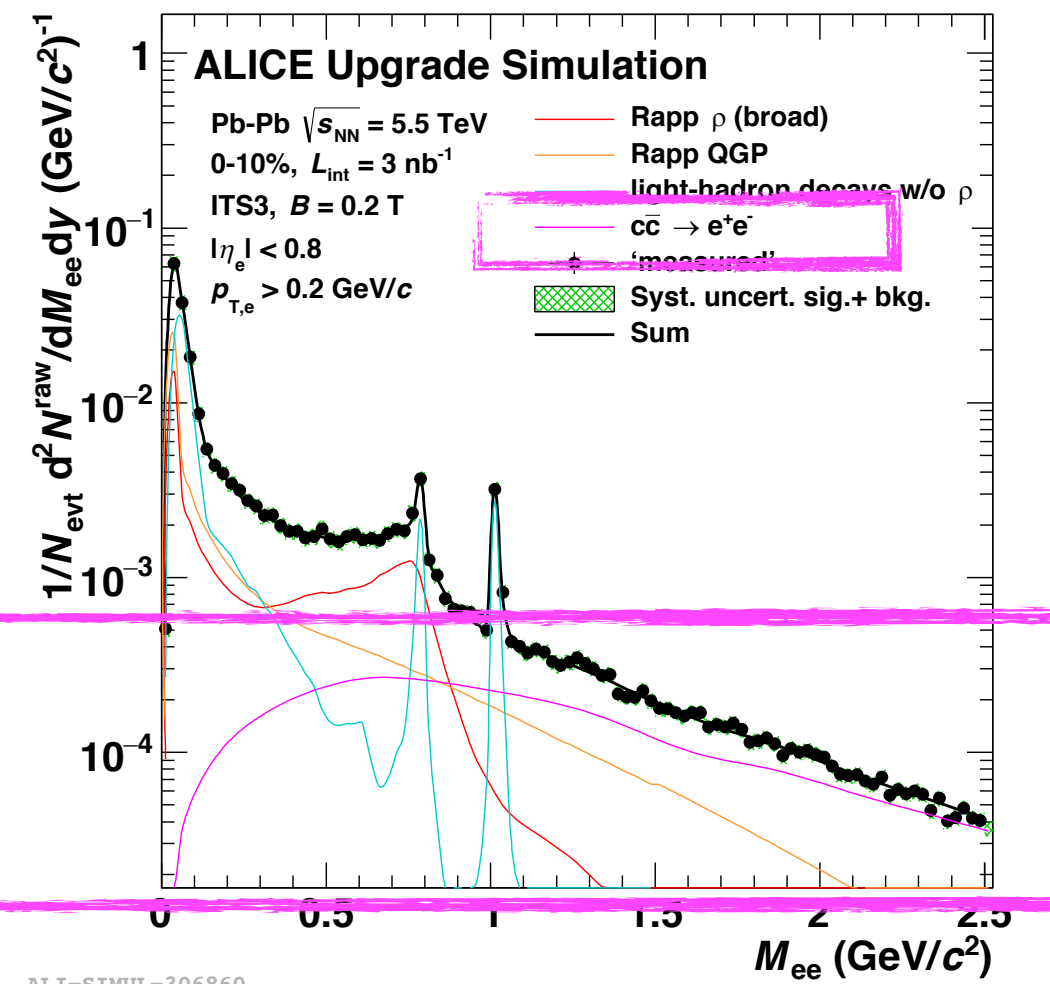
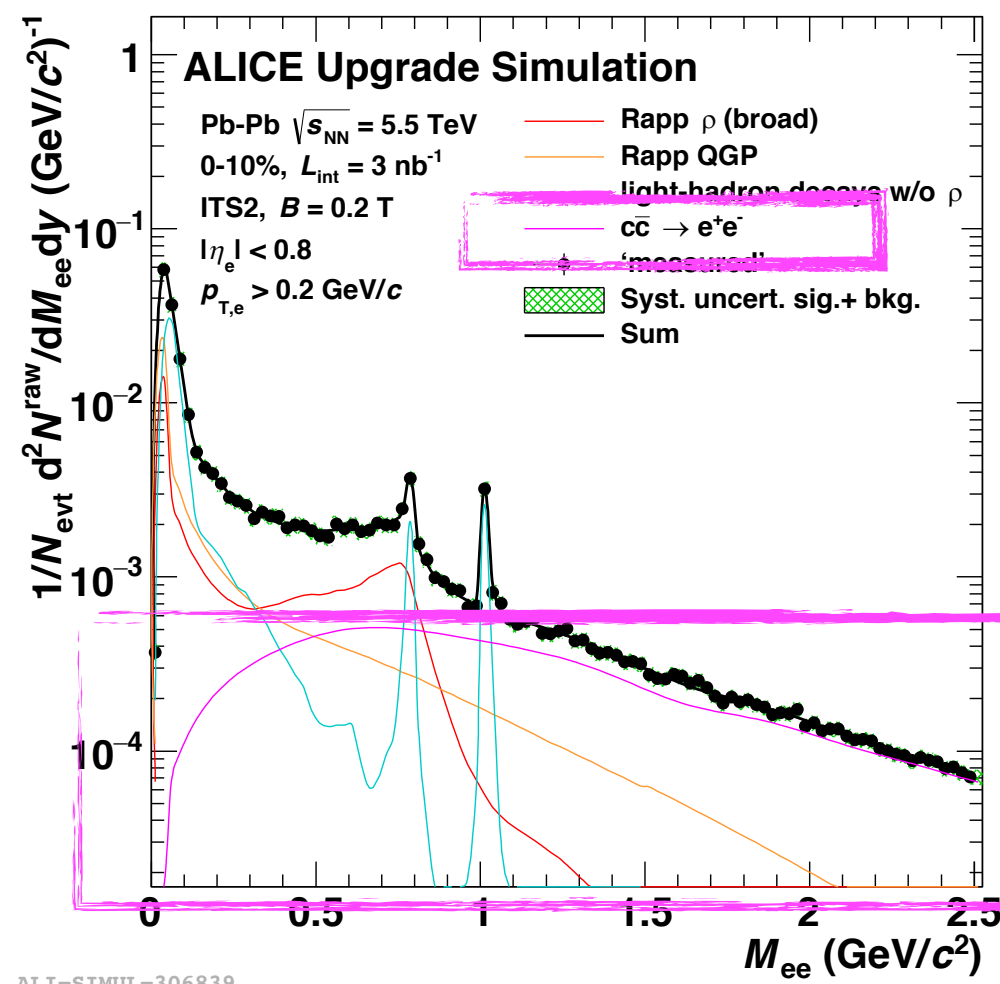
T(QGP)	stat. err.	sys. err. (bkg)	sys. err. (charm)
ITS3 / ITS2	1/1.3	1/2	1/2

# Low-mass di-leptons (2)

## Signals

ITS2

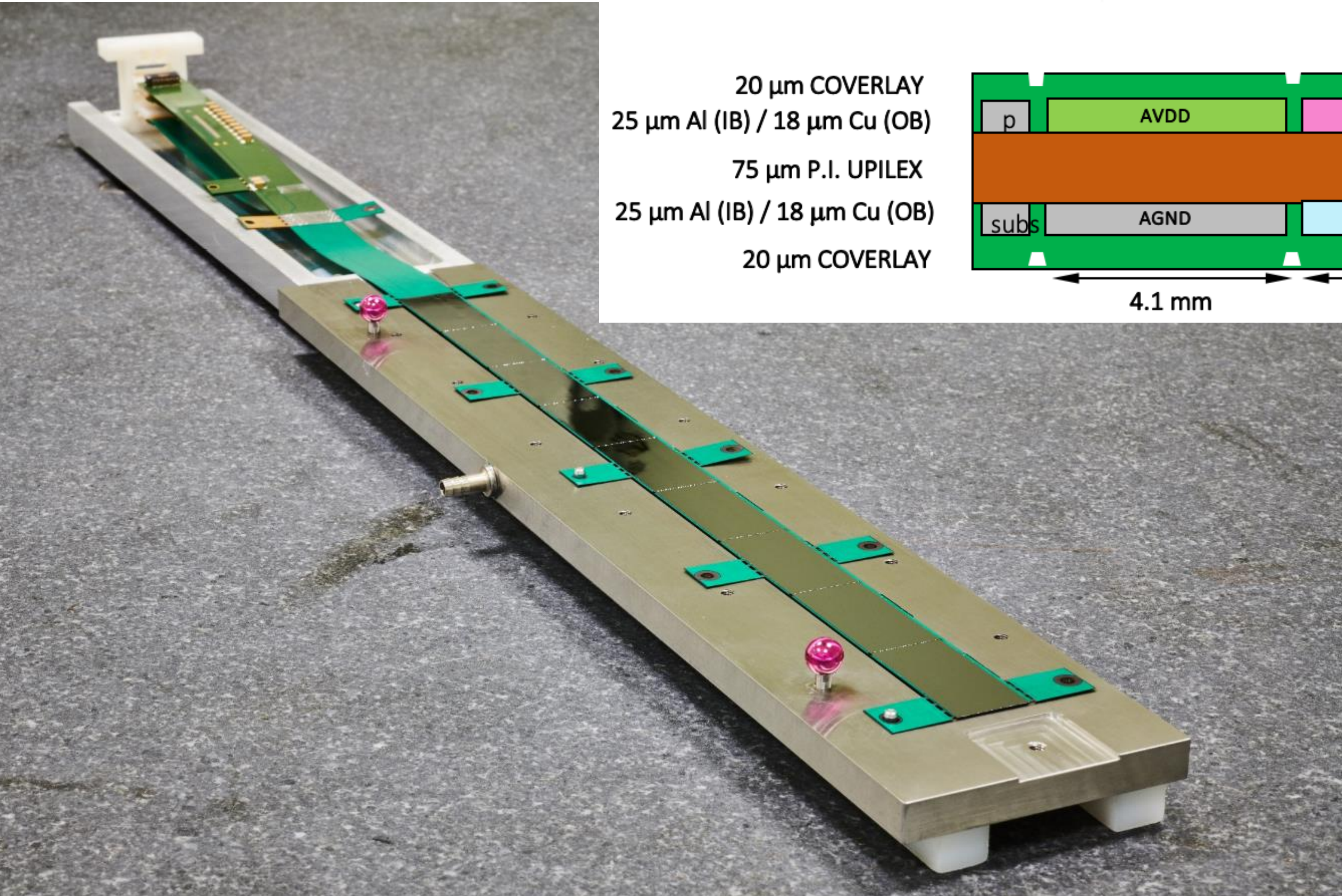
ITS3



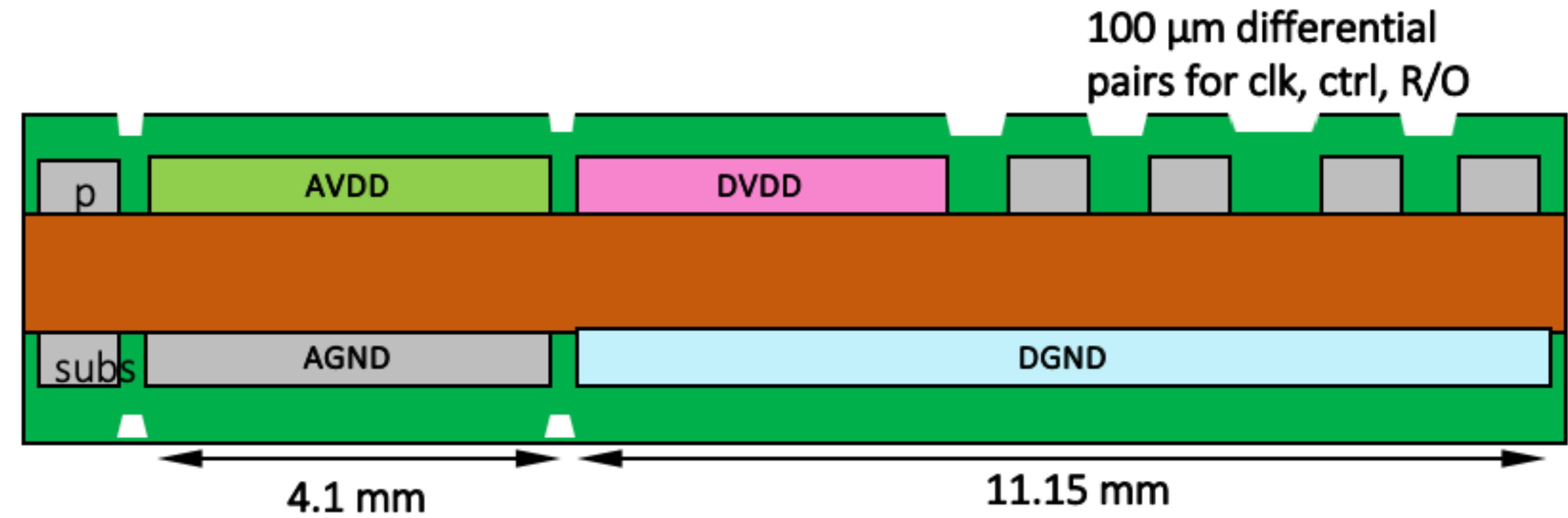
- ▶ In addition benefit from better reconstruction of charm
- ▶ (Unidentified) charm background is reduced by 50%
- ▶ Temperature fit:
  - $dN_{ee}/dM_{ee} \propto M_{ee}^{3/2} \exp(-M_{ee}/T_{fit})$
  - Systematic uncertainties of temperature fit reduced significantly

T(QGP)	stat. err.	sys. err. (bkg)	sys. err. (charm)
ITS3 / ITS2	1/1.3	1/2	1/2

# Hybrid Integrated Circuit

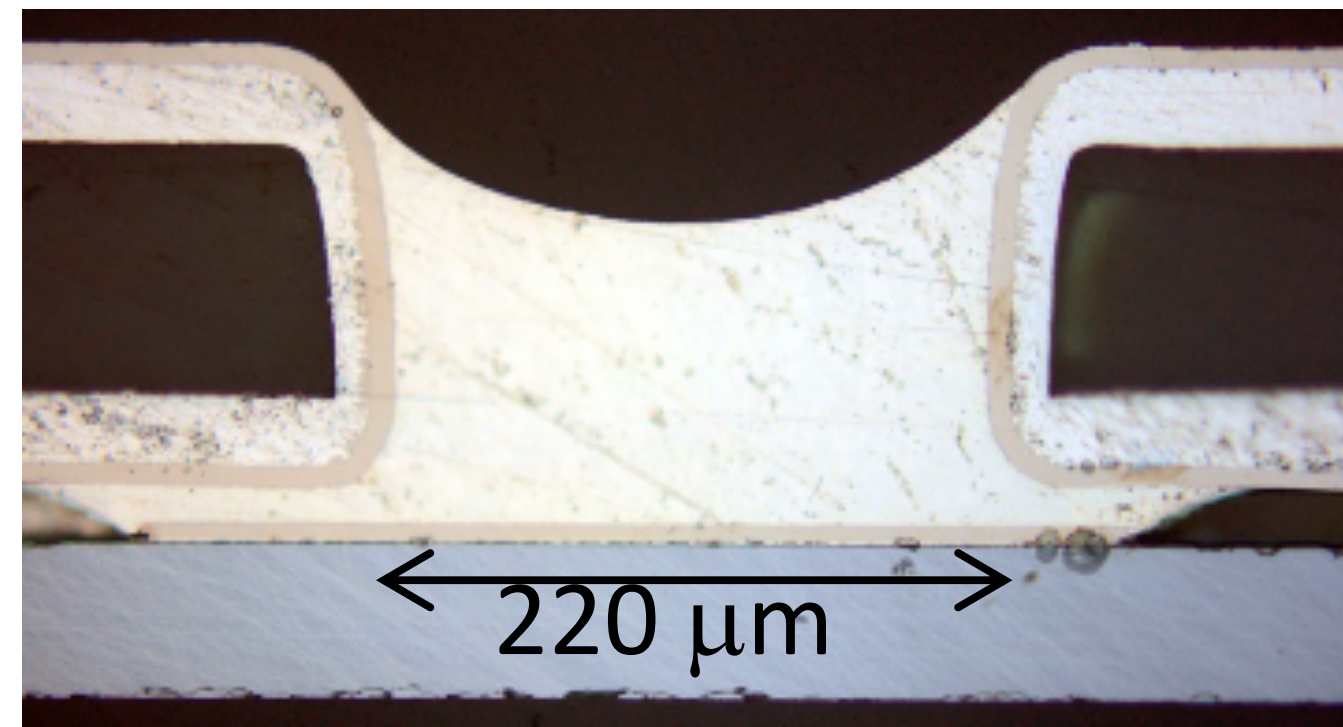
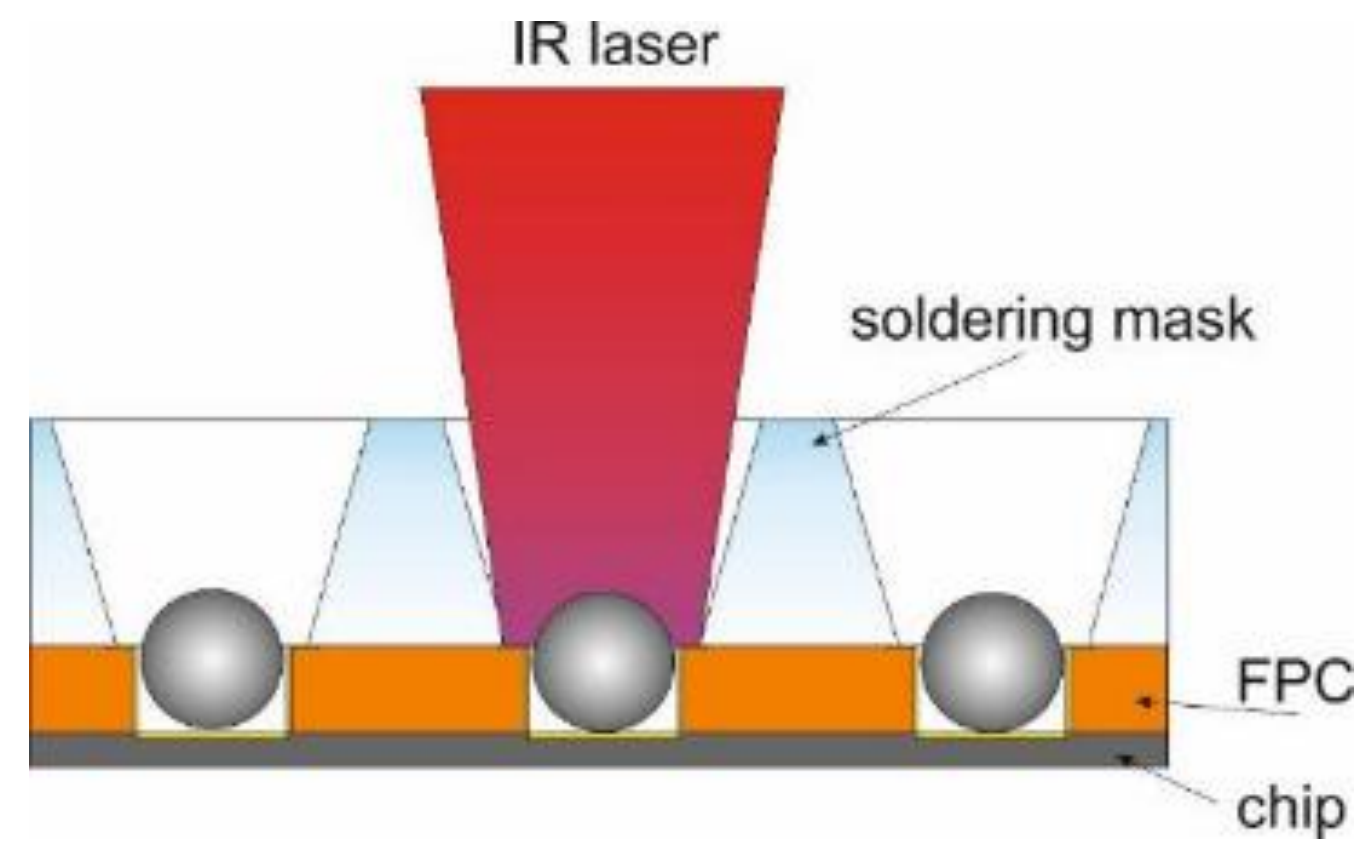


20  $\mu\text{m}$  COVERLAY  
 25  $\mu\text{m}$  Al (IB) / 18  $\mu\text{m}$  Cu (OB)  
 75  $\mu\text{m}$  P.I. UPILEX  
 25  $\mu\text{m}$  Al (IB) / 18  $\mu\text{m}$  Cu (OB)  
 20  $\mu\text{m}$  COVERLAY

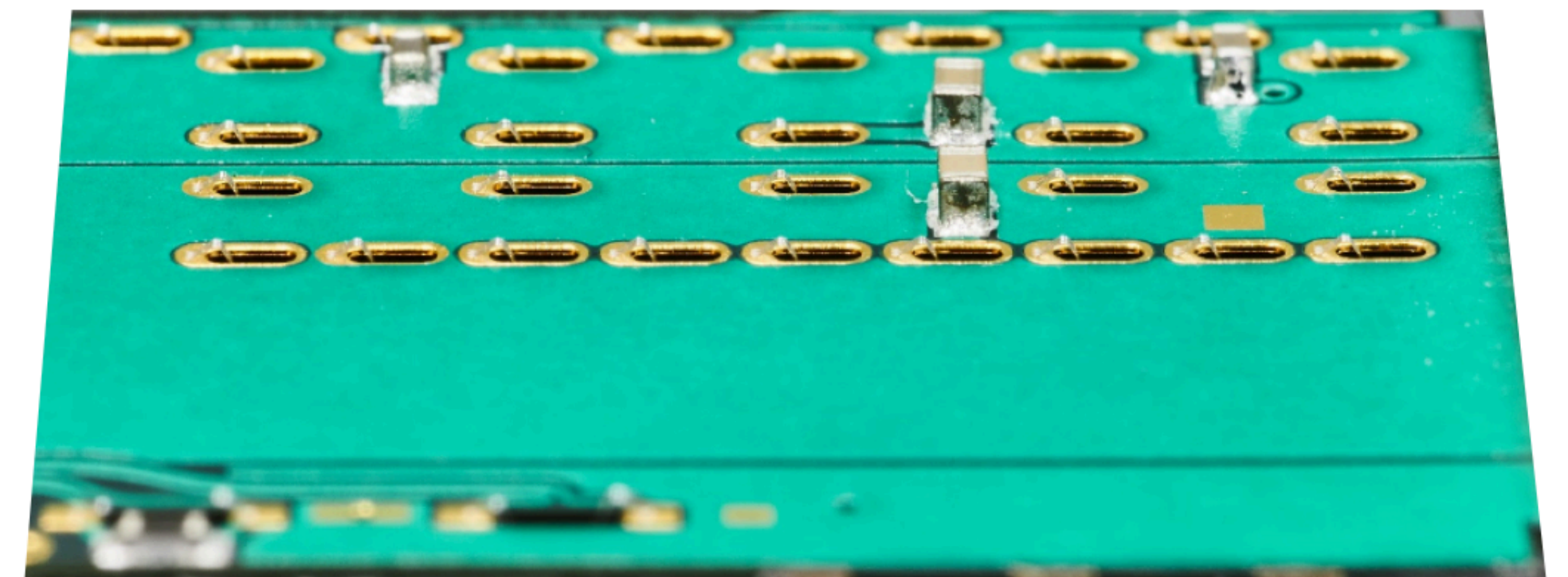
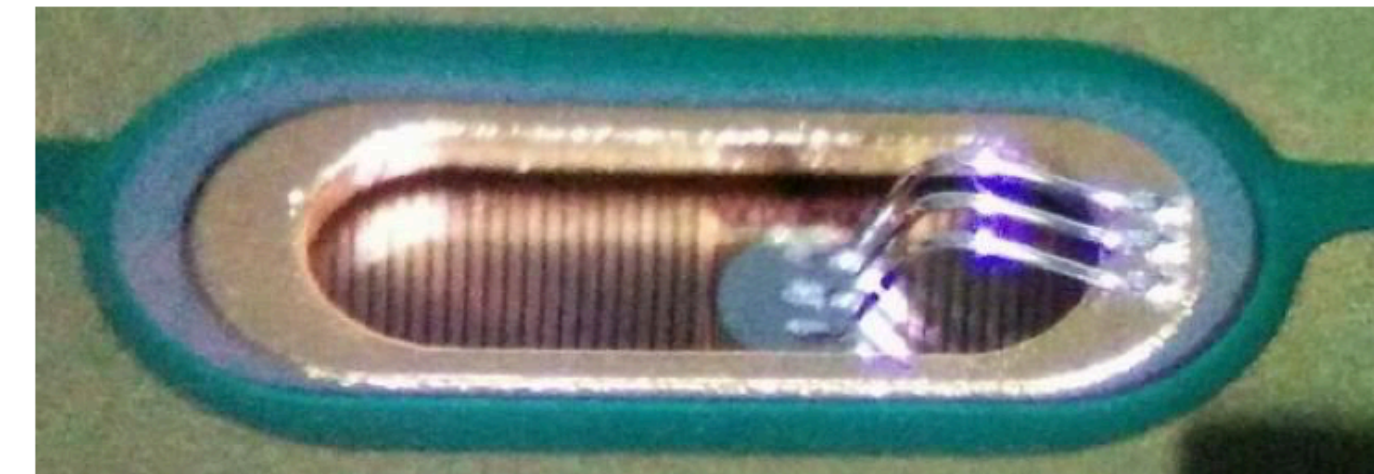
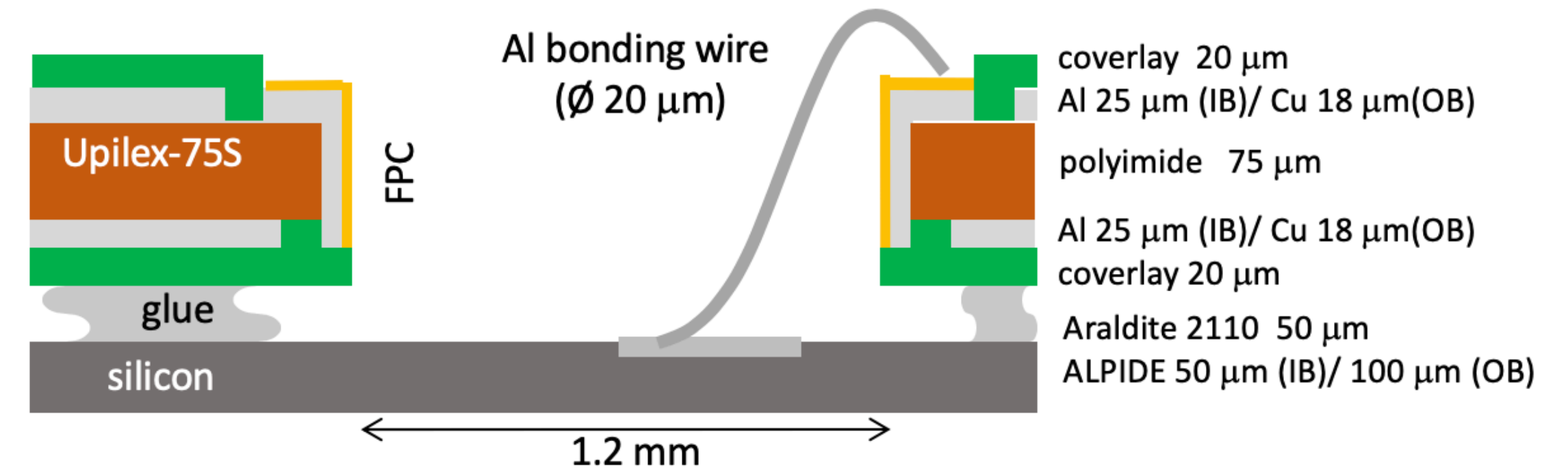


# Interconnection technology

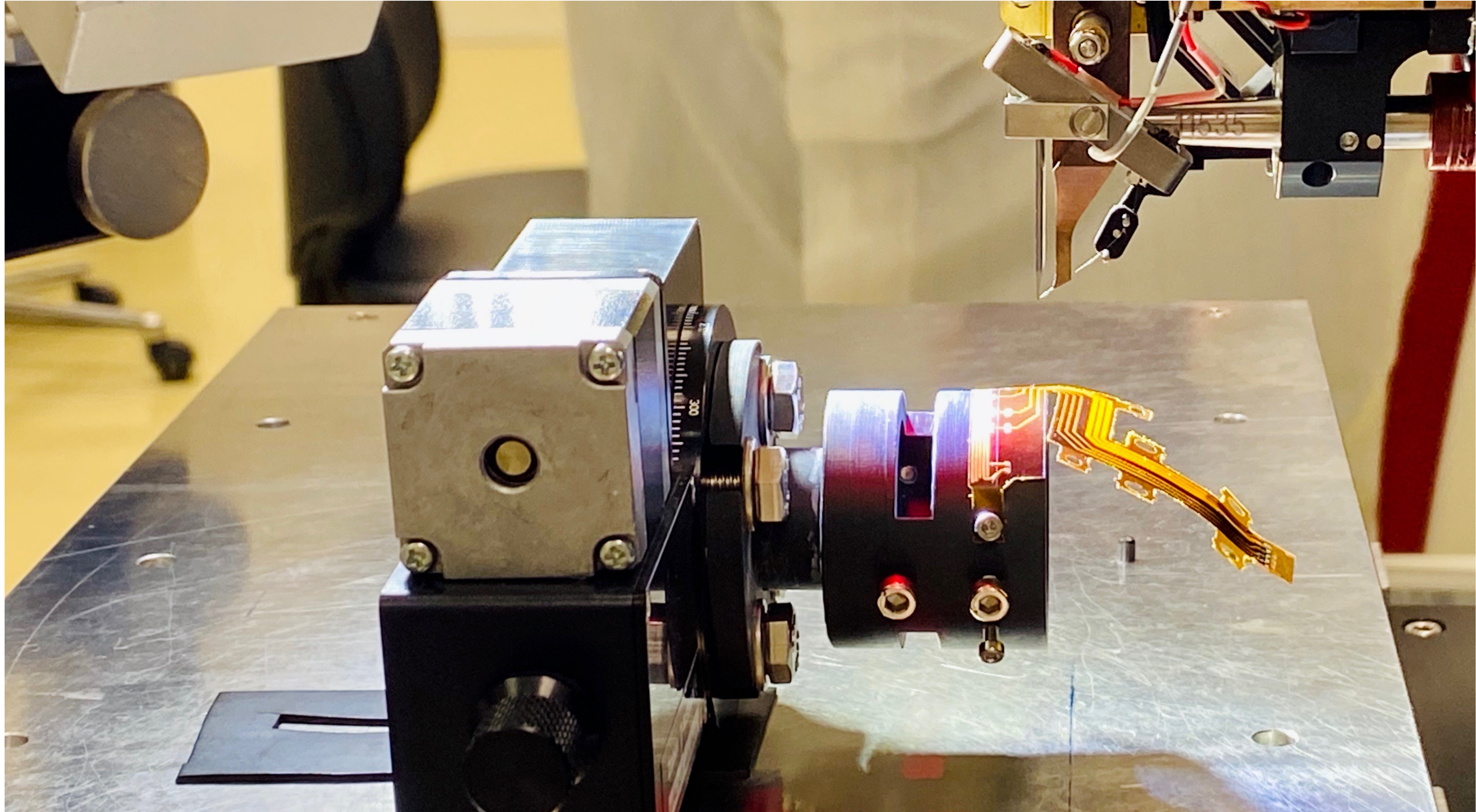
## Selective laser soldering



## Wire bonding

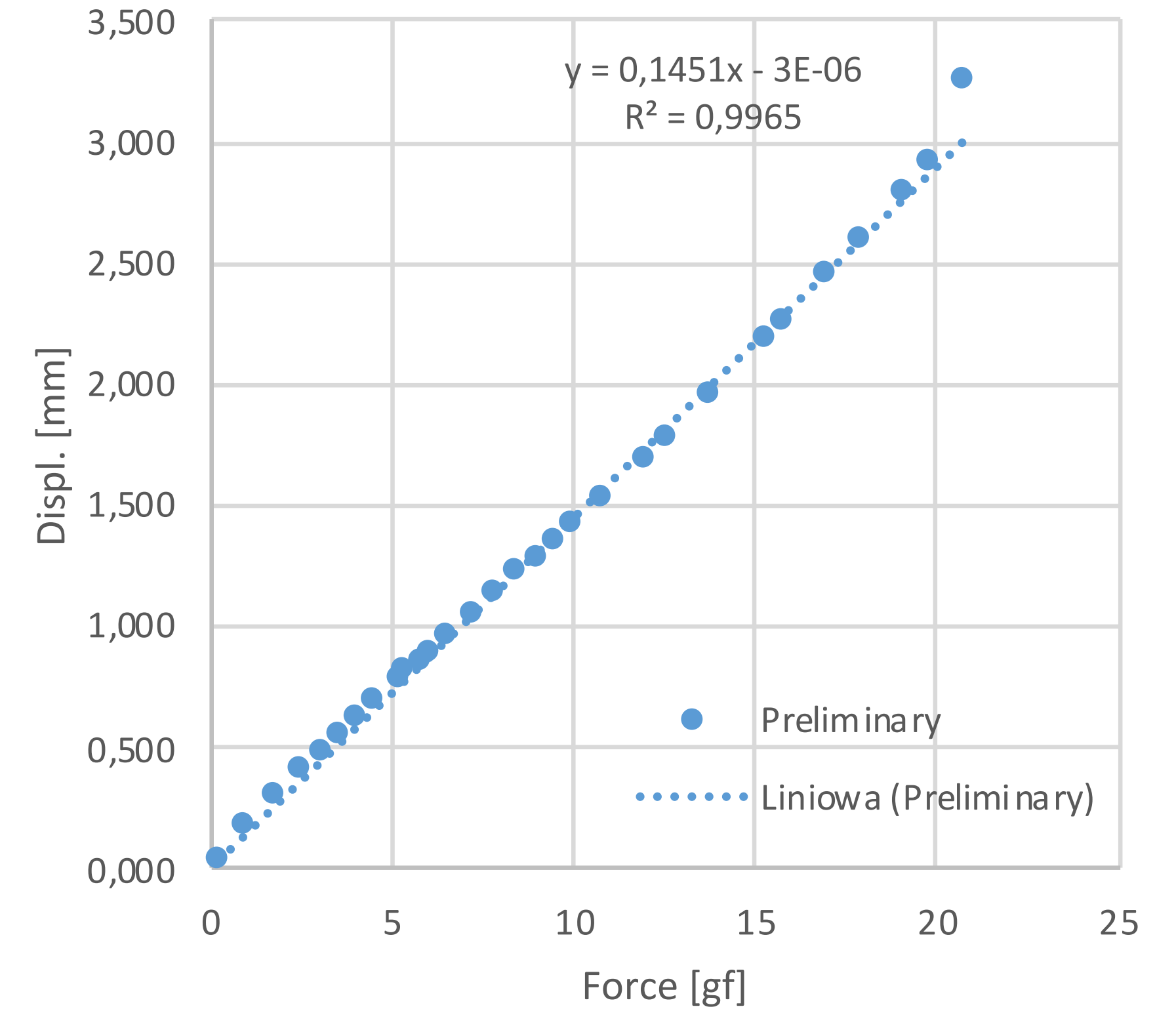
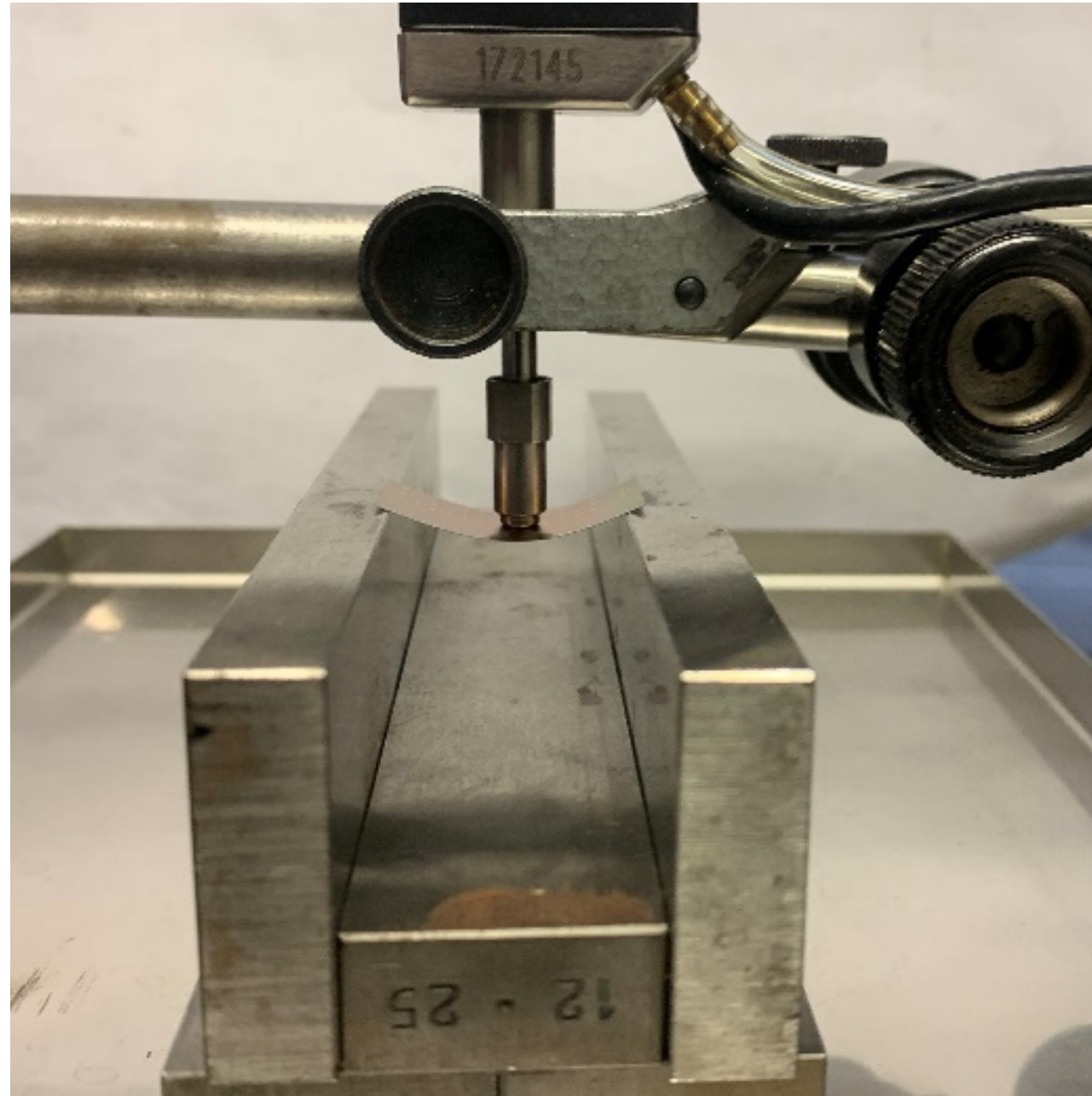


# Bonding



# Bending tests

Preliminary



- ▶ 50  $\mu\text{m}$ -thick ALPIDE
- ▶ Extracted Youngs Modulus:  $\sim 140$  GPa (literature Si: 140-180 GPa)