ICHEP 2022
BOLOGNA

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XLI
International Conference
on High Energy Physics
Bologna (Italy)

6
13 07 2022

CERN

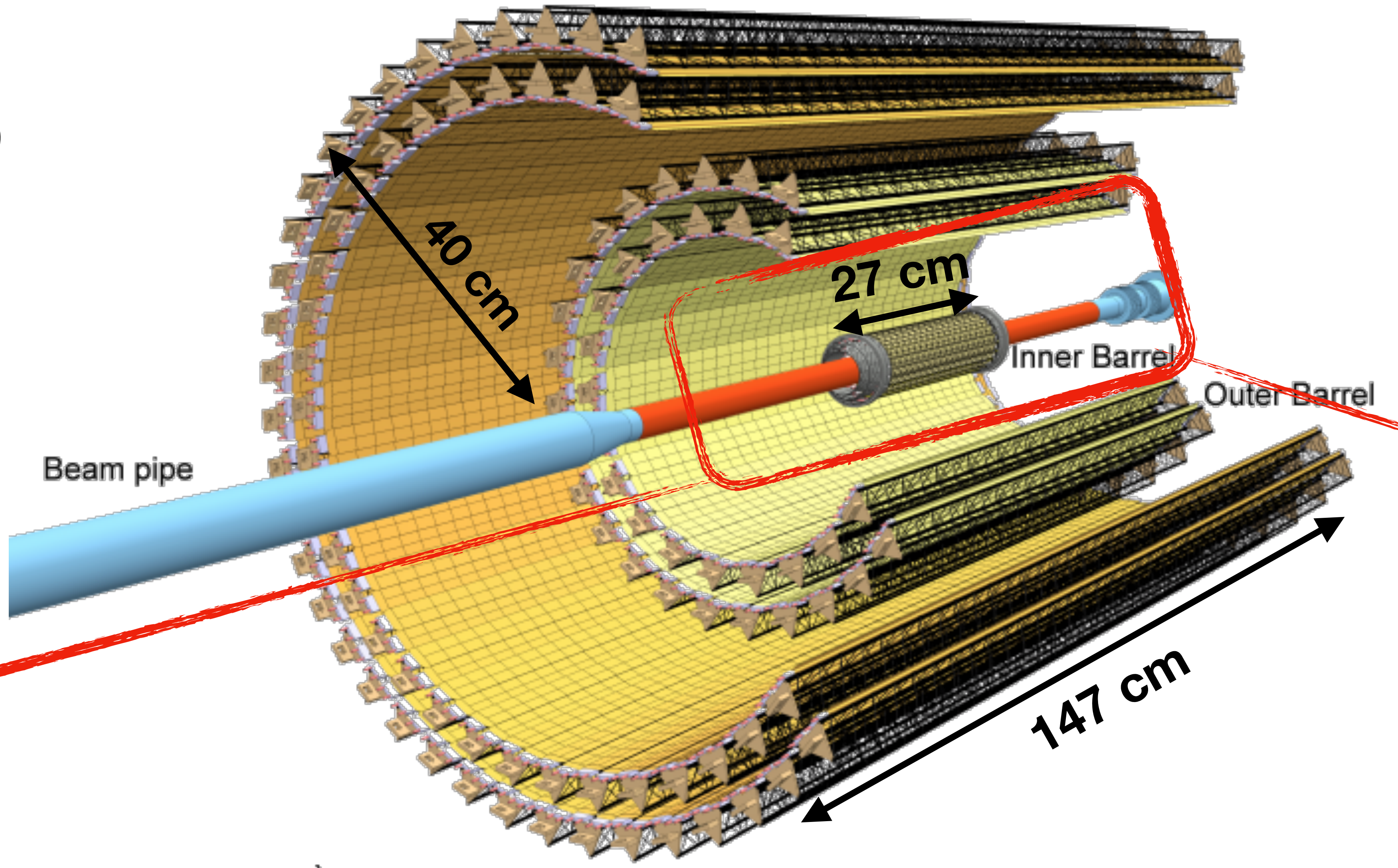
ALICE

# A truly cylindrical inner tracker for ALICE

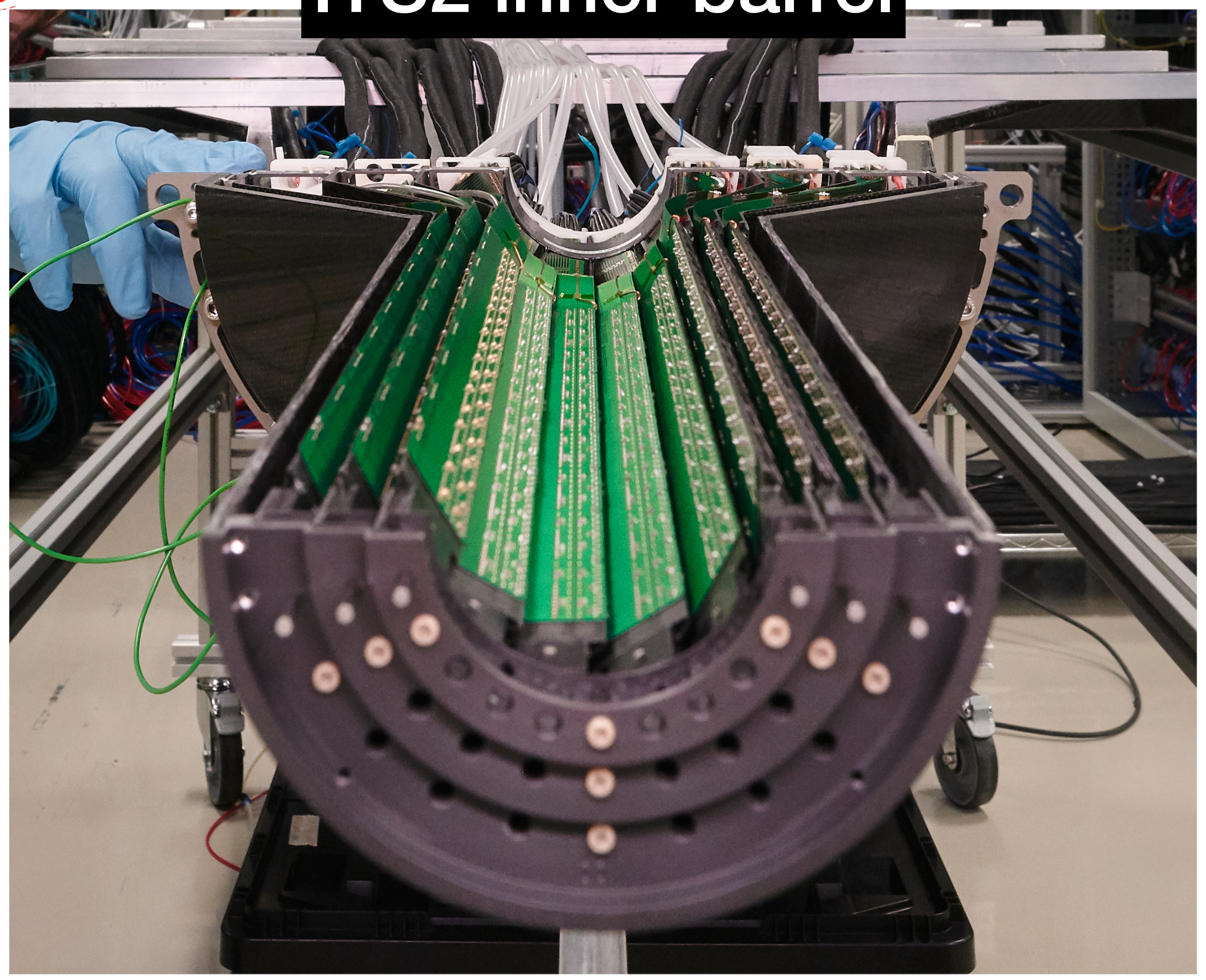
**Magnus Mager (CERN)**
***on behalf of the ALICE collaboration***

# ITS2 → ITS3

→ tomorrow, 9:00:
Robert H. Münzer
*Preparation of ALICE for Run 3*

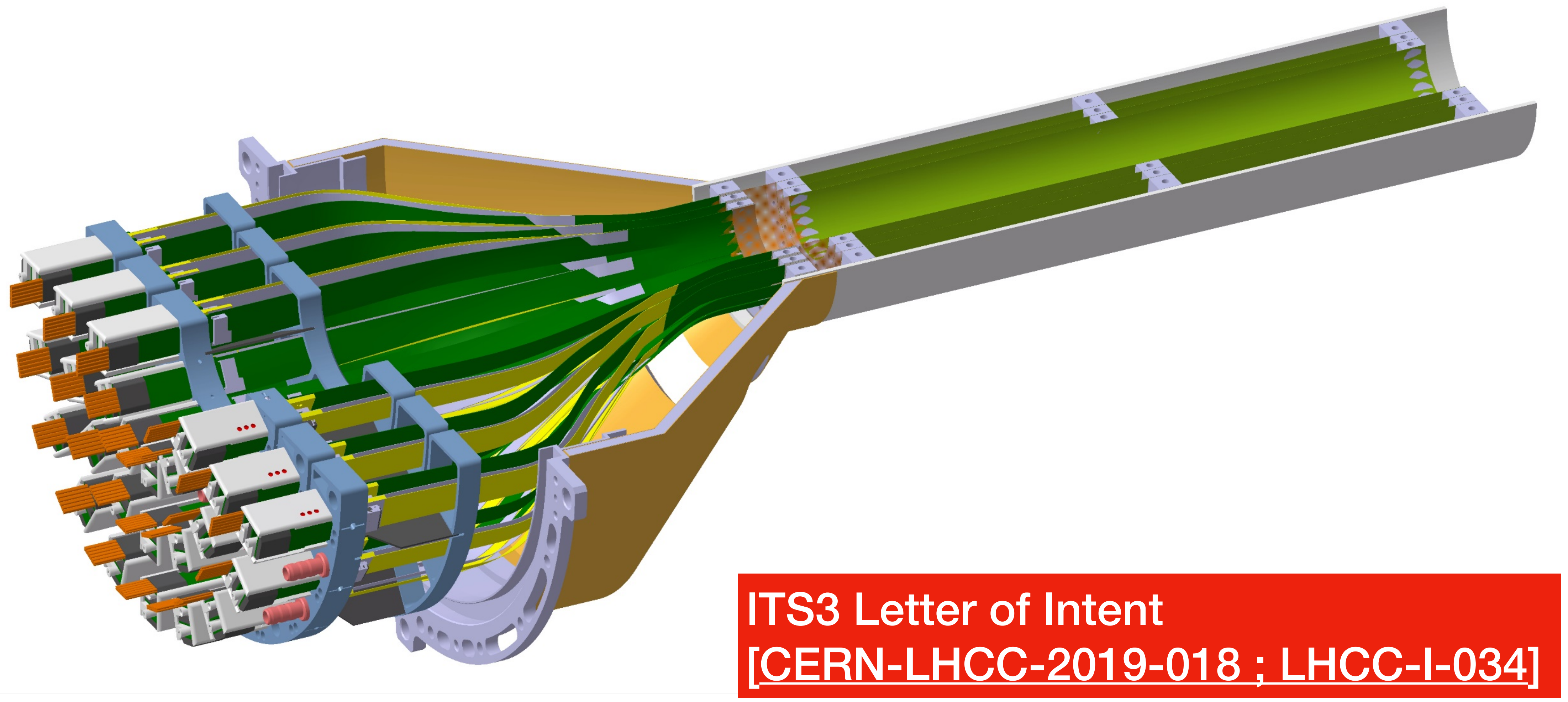



ITS2 inner barrel



**LS3 replacement of inner barrel**

ITS3



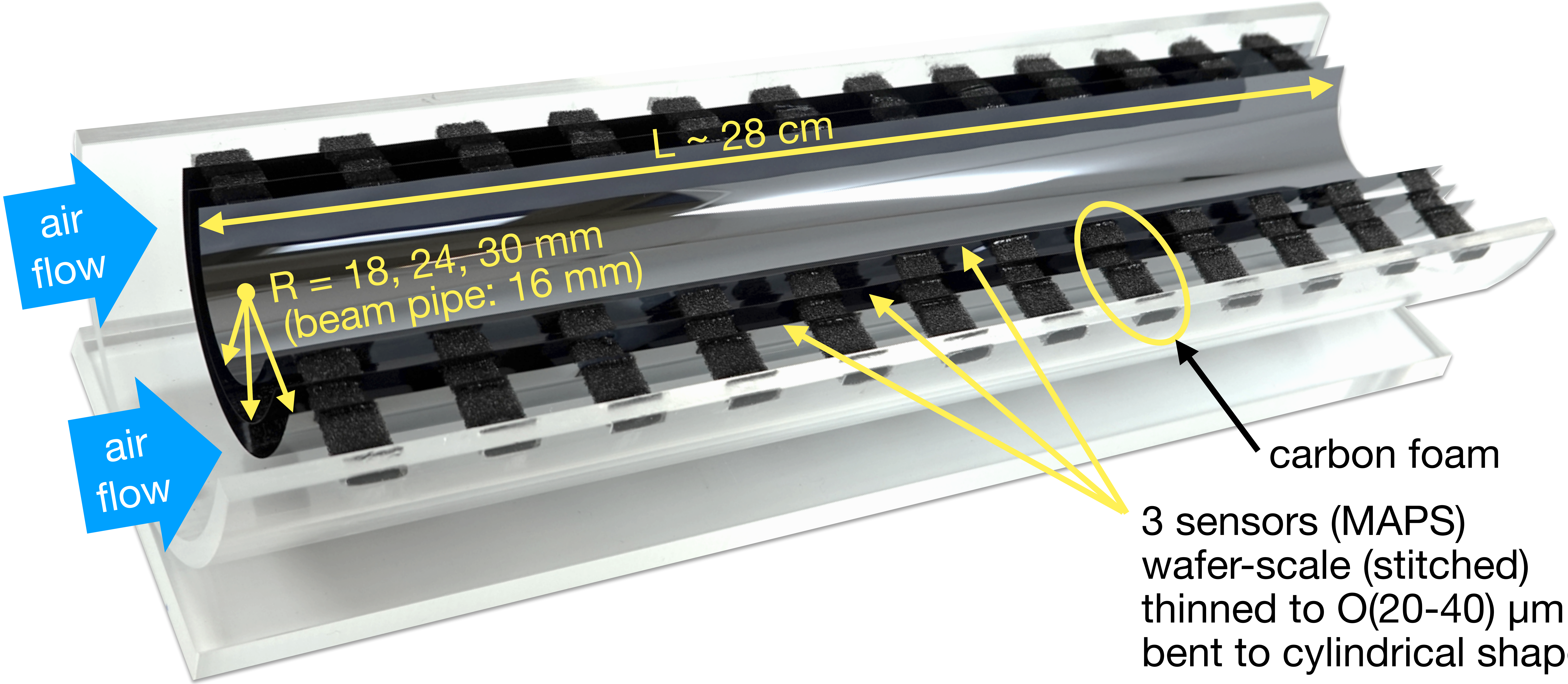
ITS3 Letter of Intent
[CERN-LHCC-2019-018 ; LHCC-I-034]

| | Run 3 | | | | LS3 | | | Run 4 | | | | LS4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 |

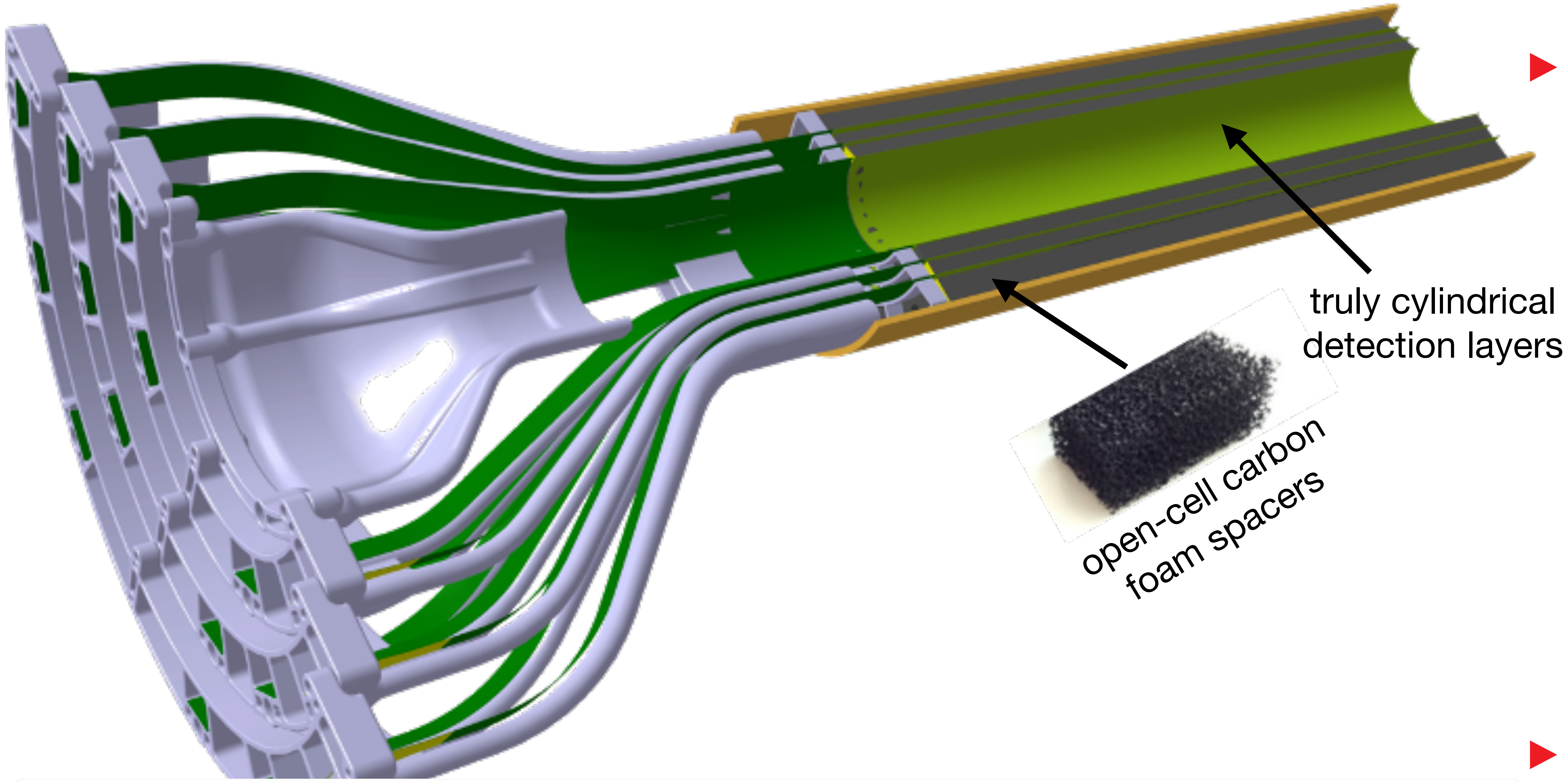
[LHC timeline]

# ITS3 detector concept (1)

## mechanical mockup using silicon dummies



# ITS3 detector concept (2)



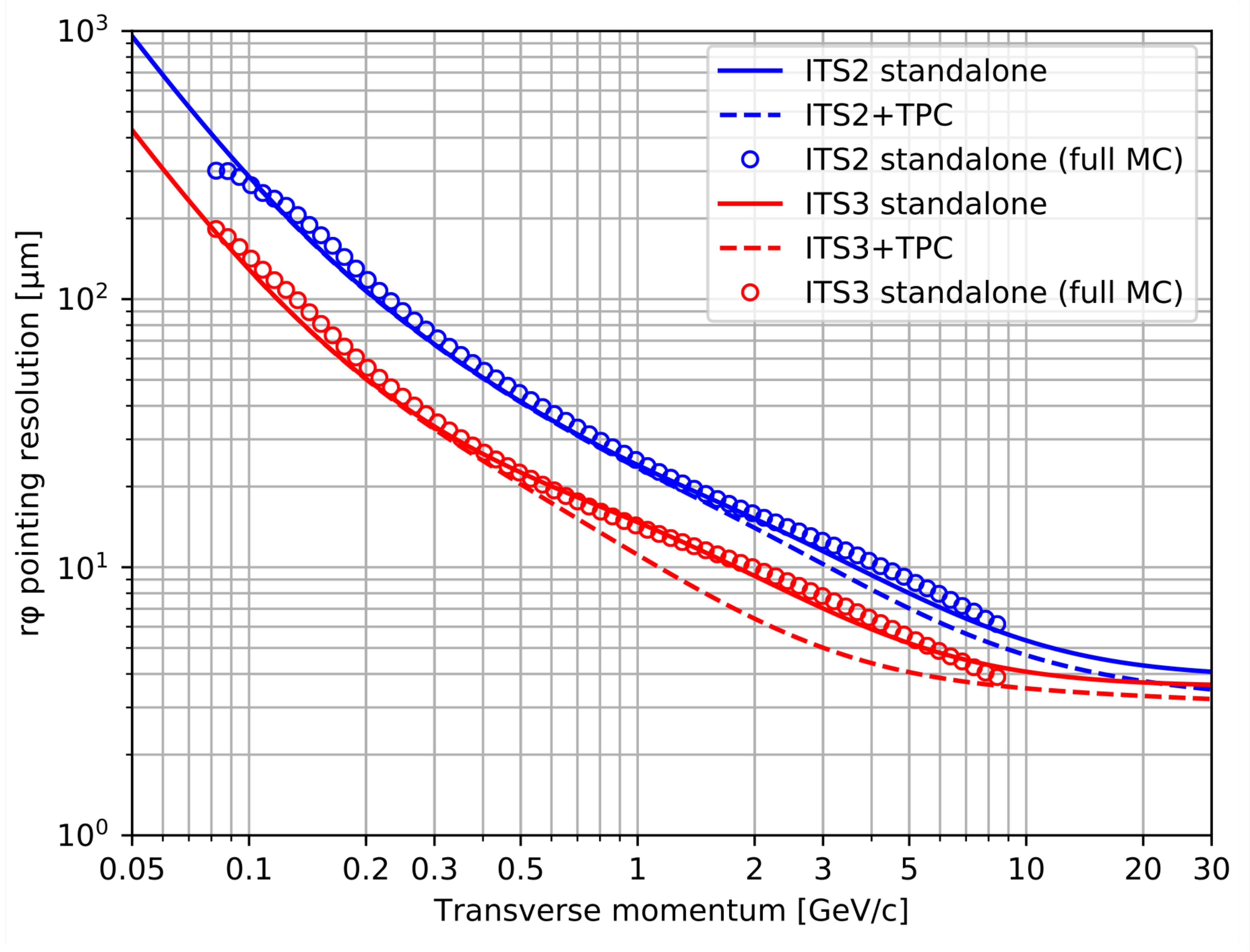

| | | | |
|---|---|---|---|
| Beam pipe Inner/Outer Radius (mm) | 16.0/16.5 | | |
| IB Layer Parameters | Layer 0 | Layer 1 | Layer 2 |
| Radial position (mm) | 18.0 | 24.0 | 30.0 |
| Length (sensitive area) (mm) | 300 | | |
| Pseudo-rapidity coverage | ±2.5 | ±2.3 | ±2.0 |
| Active area ($cm^2$) | 610 | 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 ($\mu m^2$) | O (10 x 10) | | |

- Key ingredients:
  - 300 mm wafer-scale sensors, fabricated using stitching
  - thinned down to 20-40 µm (0.02-0.04% $X_0$), 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% $X_0$ (beampipe: 500 µm Be: 0.14% $X_0$)
  - homogeneous material distribution: negligible systematic error from material distribution

**The whole detector will consist of six (!) sensors (current ITS IB: 432) – and barely anything else**

# Performance improvement

pointing resolution




[ALICE-PUBLIC-2018-013]

improvement of factor 2 over all momenta

- Improvement of pointing resolution by:
  - drastic reduction of **material budget** (0.3 → 0.05% $X_0$/layer)
  - being **closer** to the interaction point (24 → 18 mm)
  - thinner and smaller and **beam pipe** (700 → 500 µm; 18 → 16 mm)
- Directly boosts the ALICE core physics program that is largely based on:
  - low momenta
  - secondary vertex reconstruction
- E.g. $\Lambda_c$ S/B improves by factor 10, significations by factor 4

# Main R&D lines towards ITS3

## Ultra-light mechanics and cooling

- mechanical concept to hold thin sensors “without” material
  - development of assembly procedure
  - qualification of carbon foams
- verification and optimisation of air cooling concept

## Thinning, bending, interconnection

- development of procedures to handle and bend large thin chips
- characterisation of electrical and mechanical properties of sensors after bending
- development of electrical interconnection to bent chips

## Wafer-scale sensor development

- switch to 65 nm technology (TPSCo)
  - verification of the technology for radiation tolerance and charge collection
- stitched sensor design
  - chip architecture
  - optimisation for yield

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# Bending of wafer-scale sensors

## procedure

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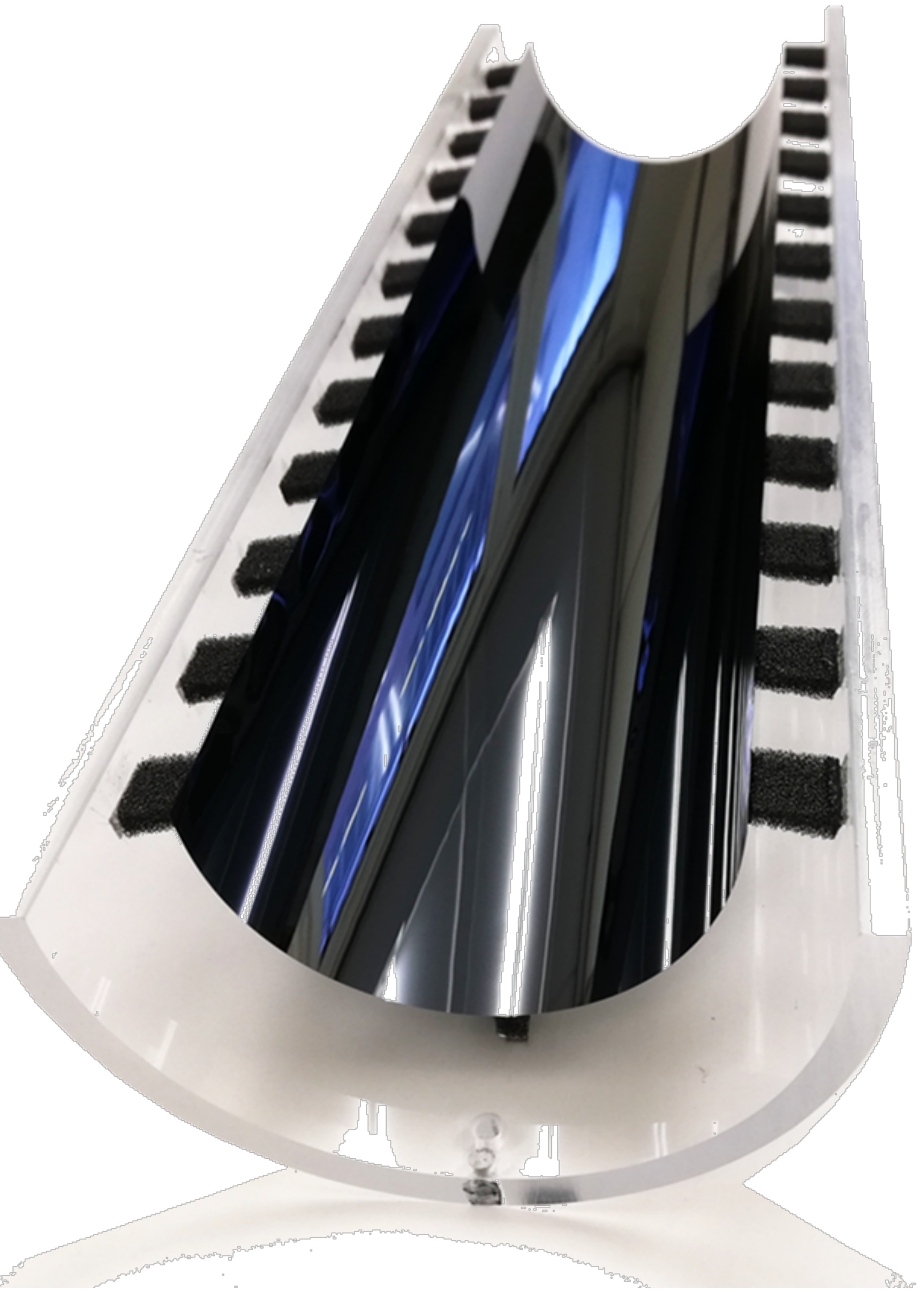
## procedure

# Layer assembly

## Layer 2



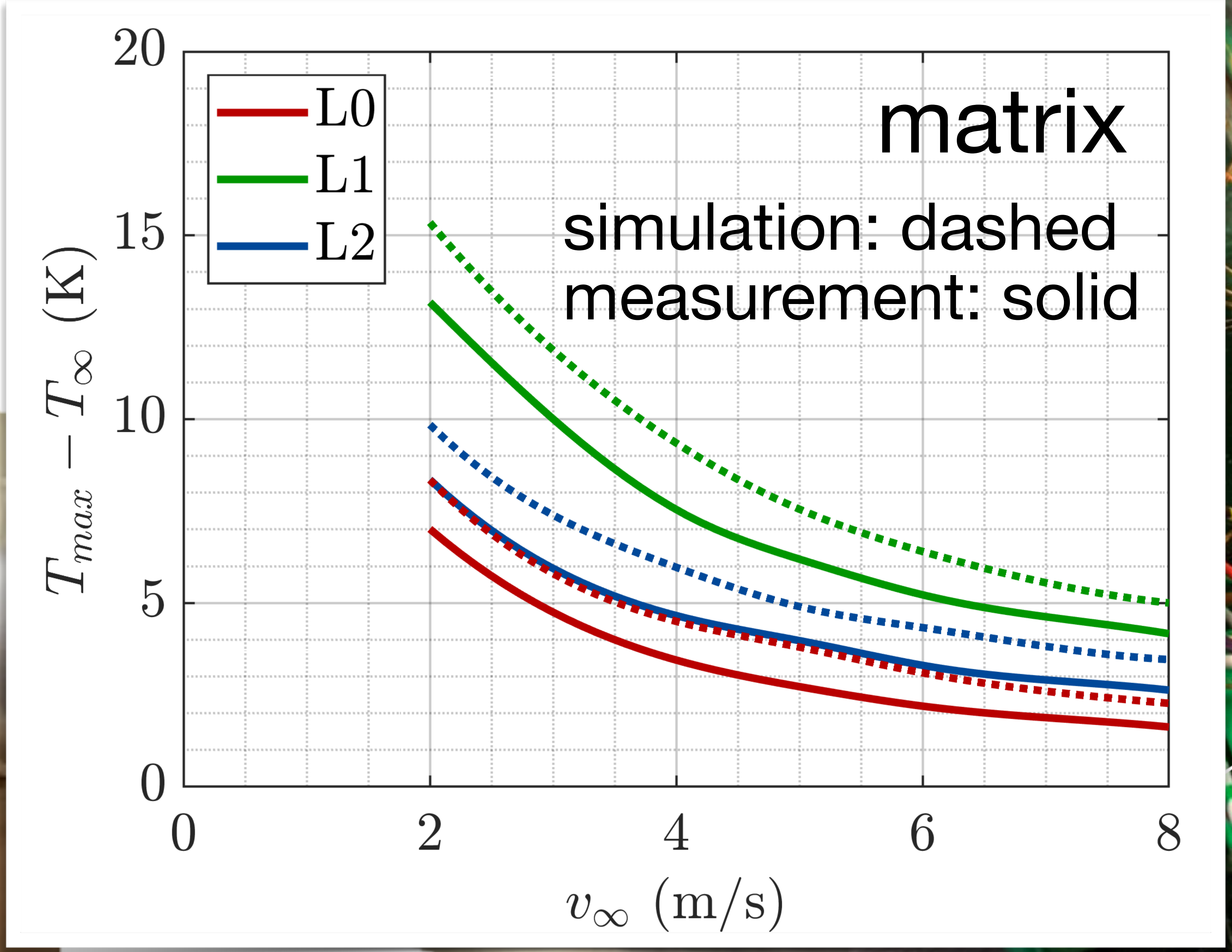
## Layers 2+1

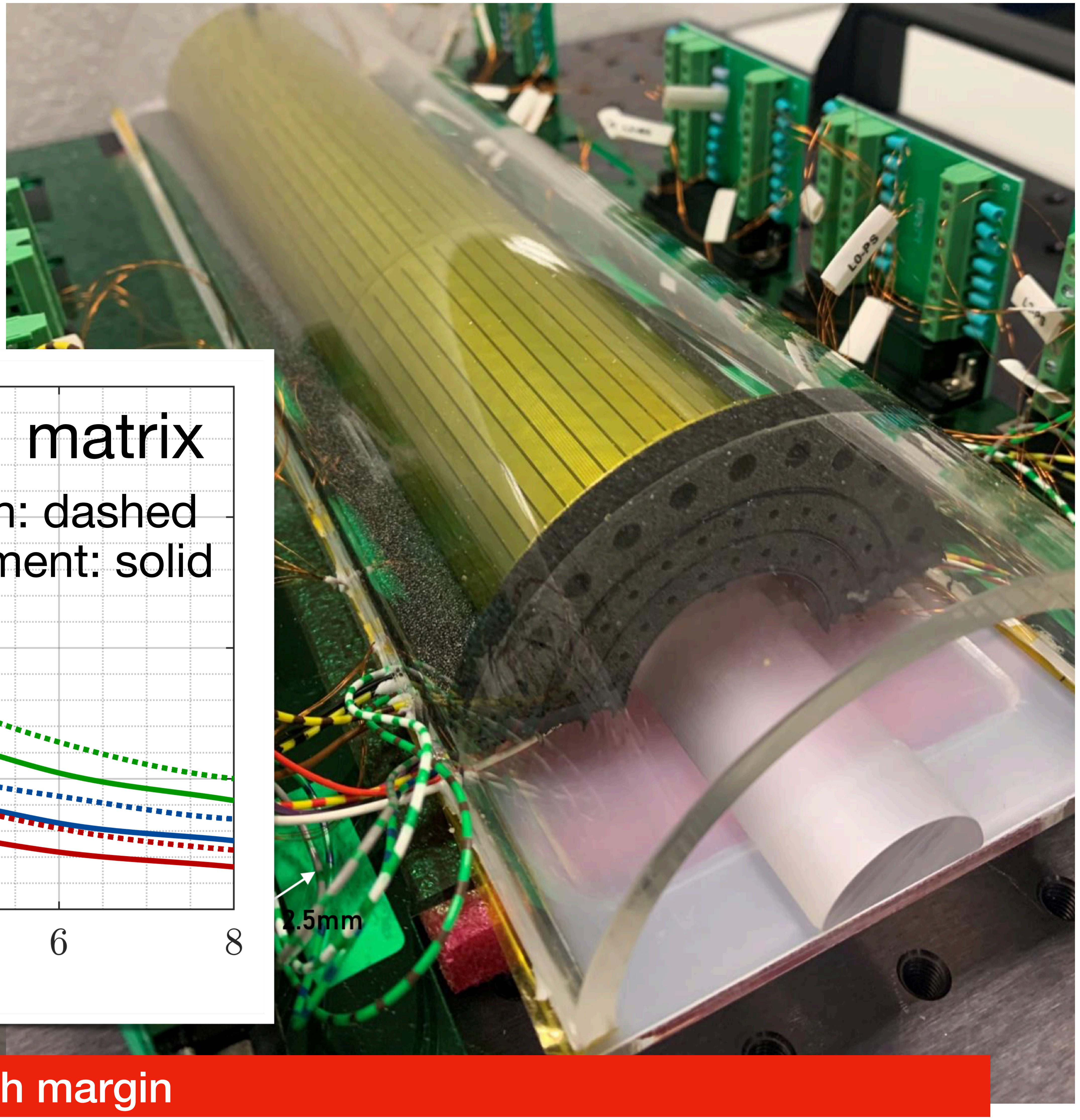
## Layers 2+1+0

**Mechanically, the integration is very feasible – now the assemblies are characterised and optimised**

# R&D on air cooling

- A set of models based on heating elements are being developed
- Placed in a custom wind tunnel, thermal and mechanical properties are studied



**Air cooling is feasible with margin**

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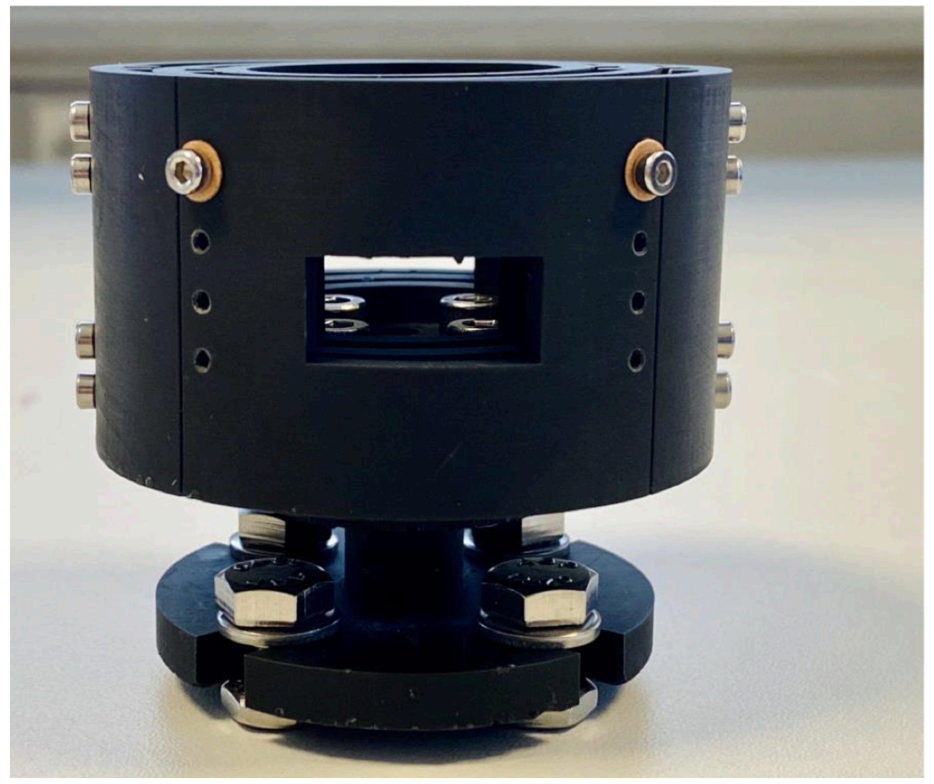
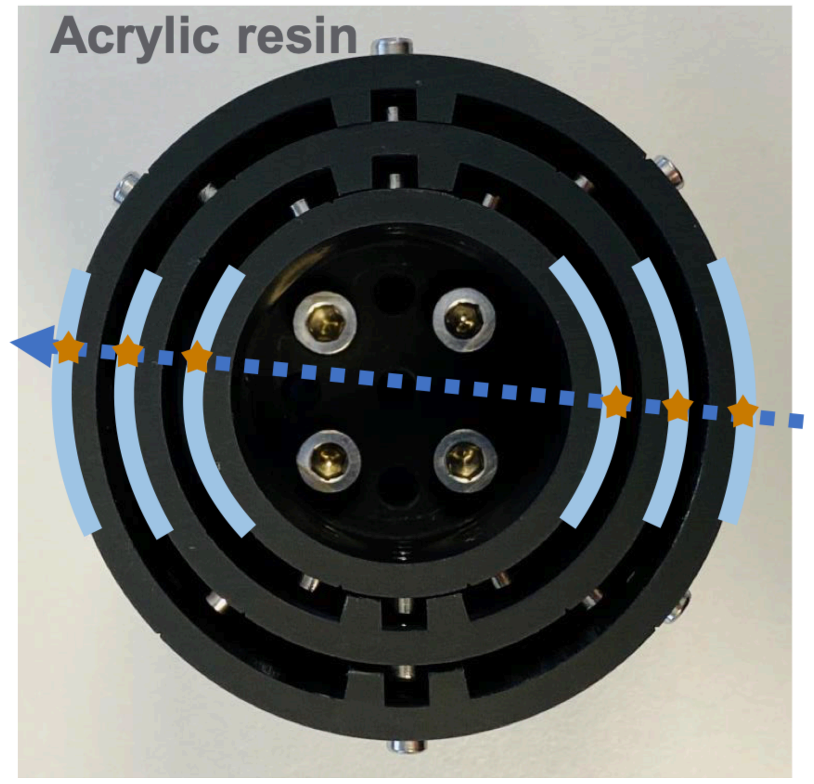
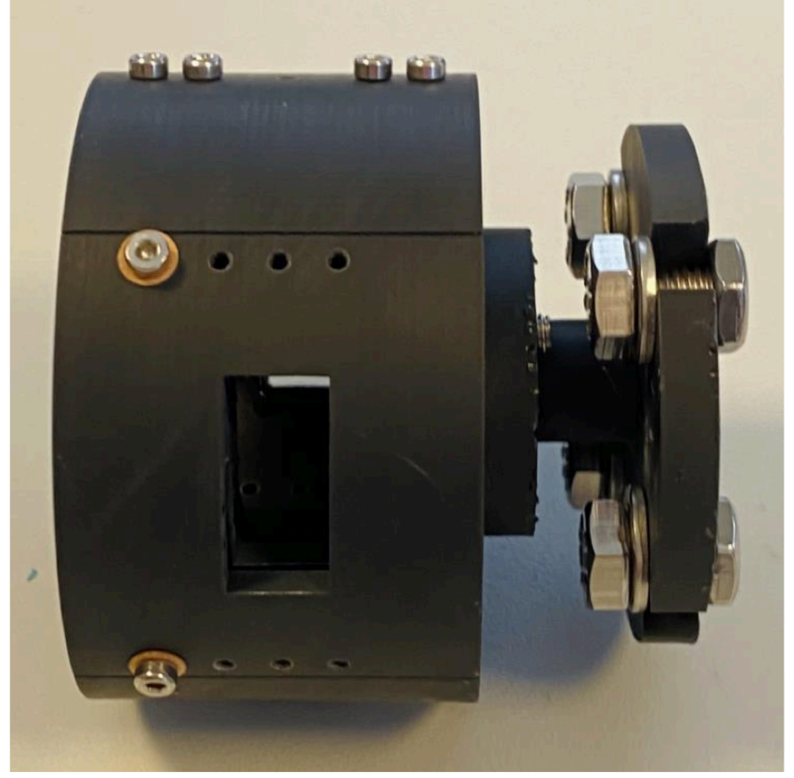
# Bent ALPIDEs

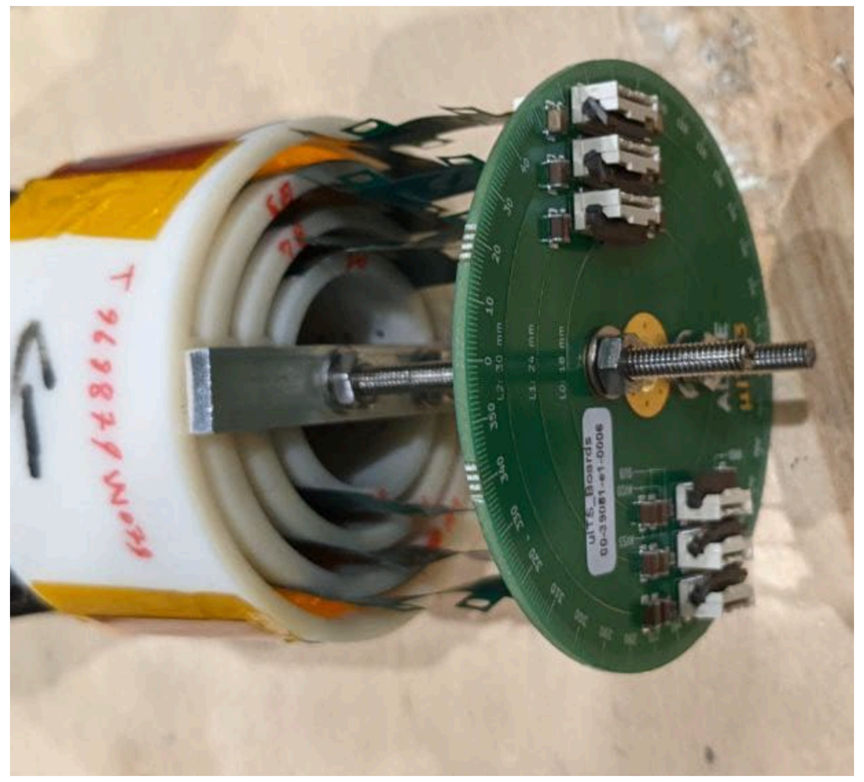
[doi:10.1016/j.nima.2021.166280]

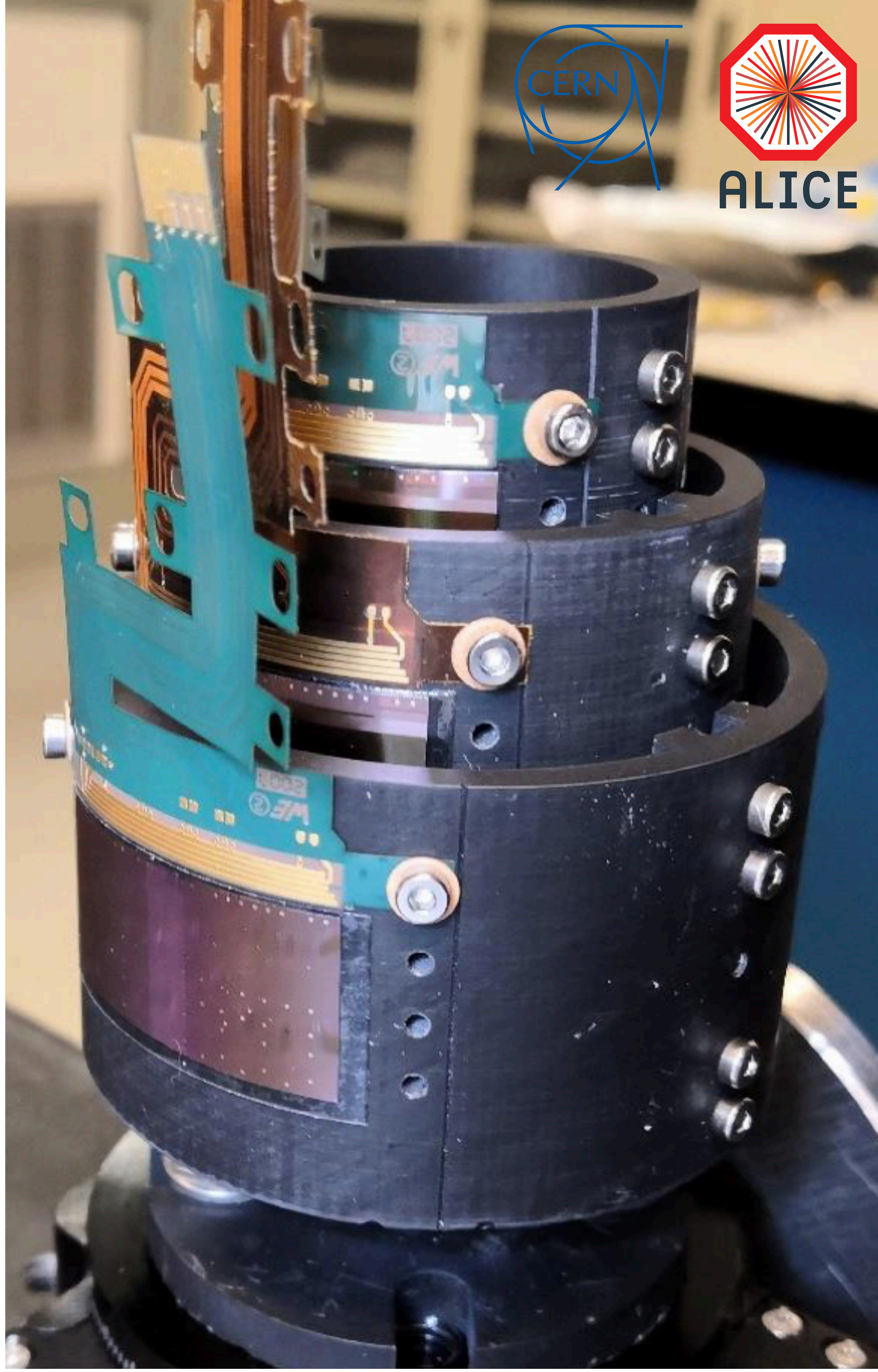
- Functional chips (ALPIDEs) are bent routinely
  - several different ways were explored (bending before bonding, or vice versa, different jigs)
  - all radii of ITS3 are easily achievable
- Chips continue to work
  - tested at several beam campaigns
- By now, we have a full mock-up of the final ITS3, called "μITS3"
  - 6 ALPIDE chips, bent to the target radii of ITS3





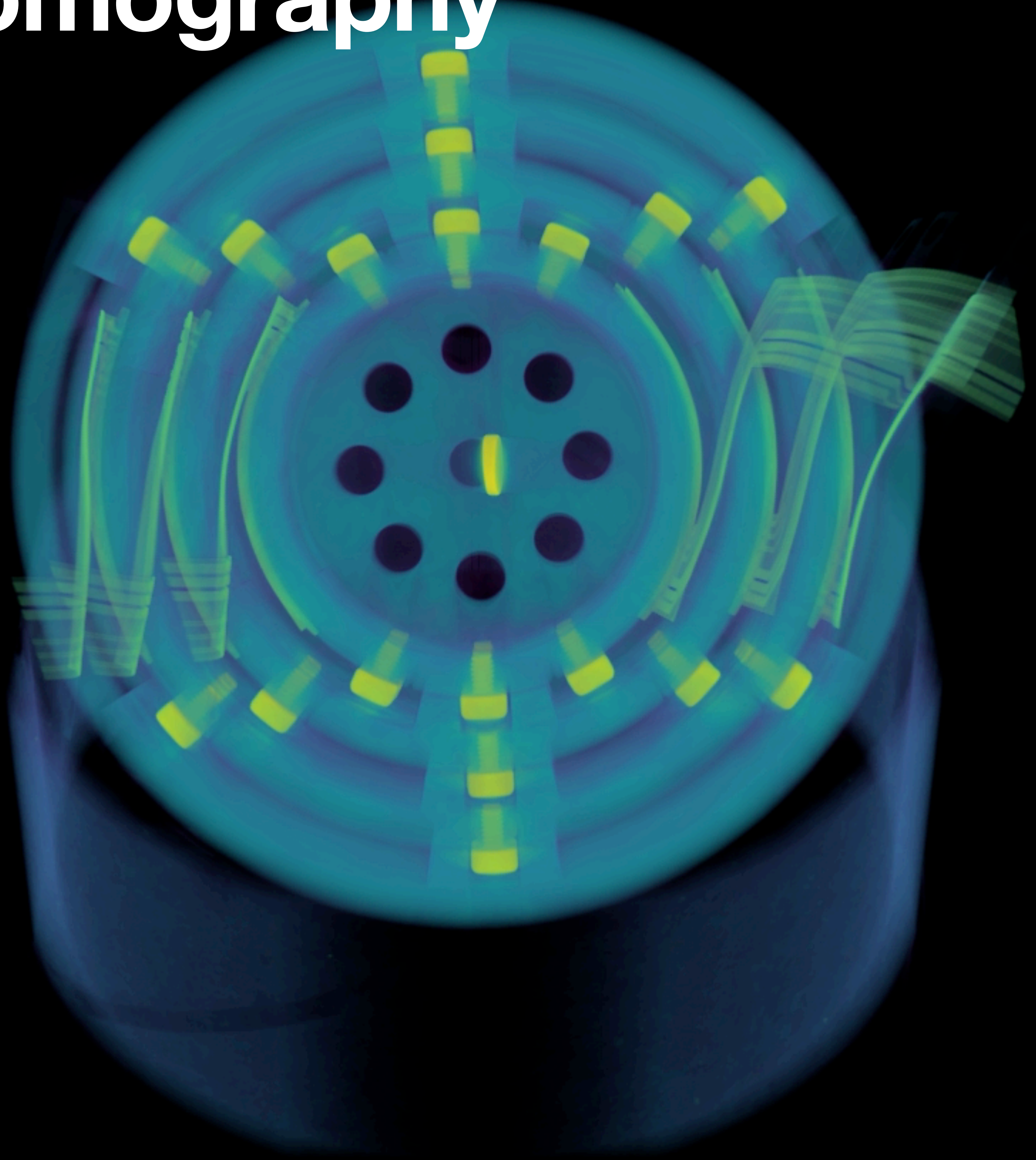







**Mechanically, the integration is very feasible – now the assemblies are characterised and optimised**

# µITS3 X-ray tomography



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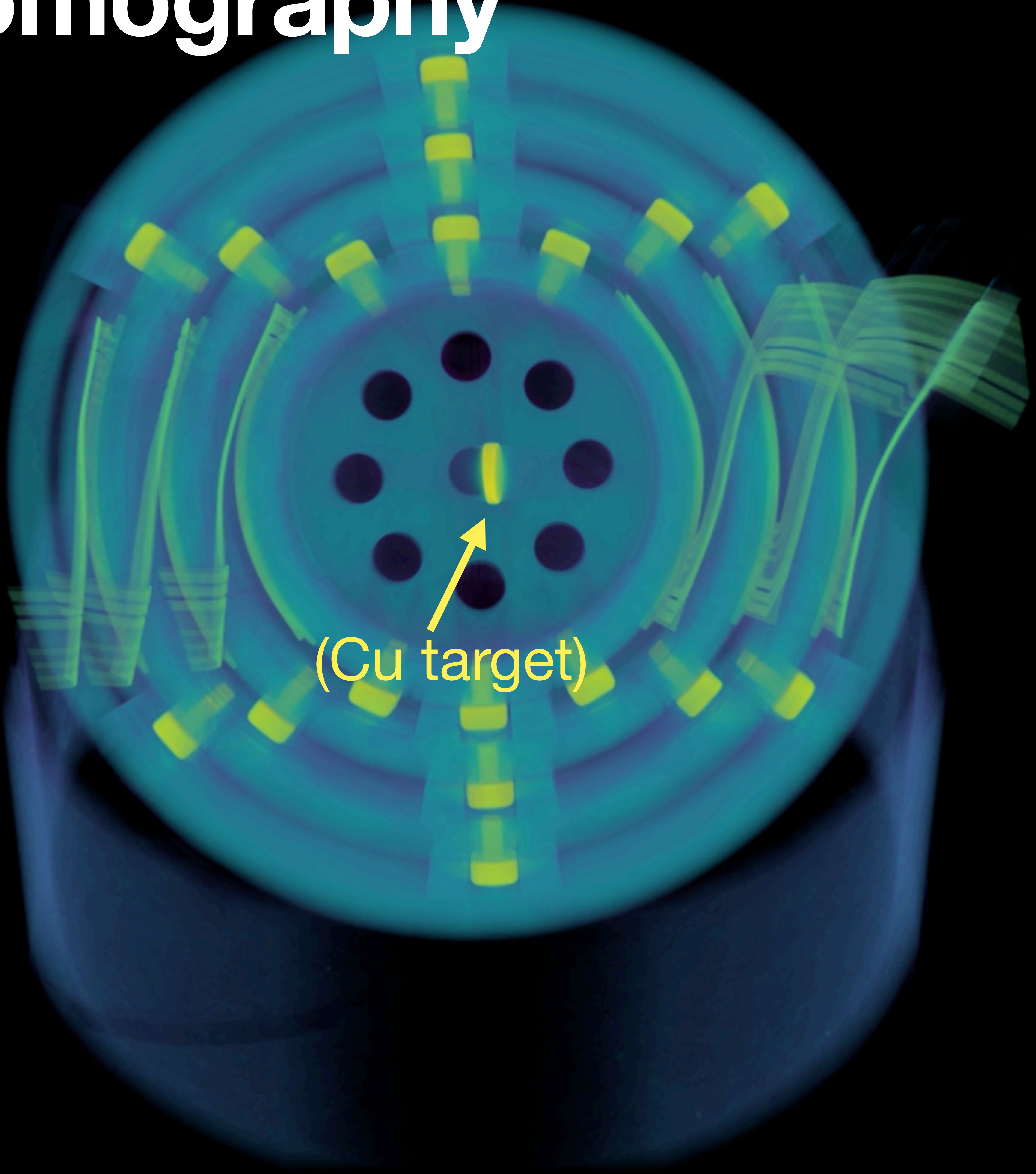

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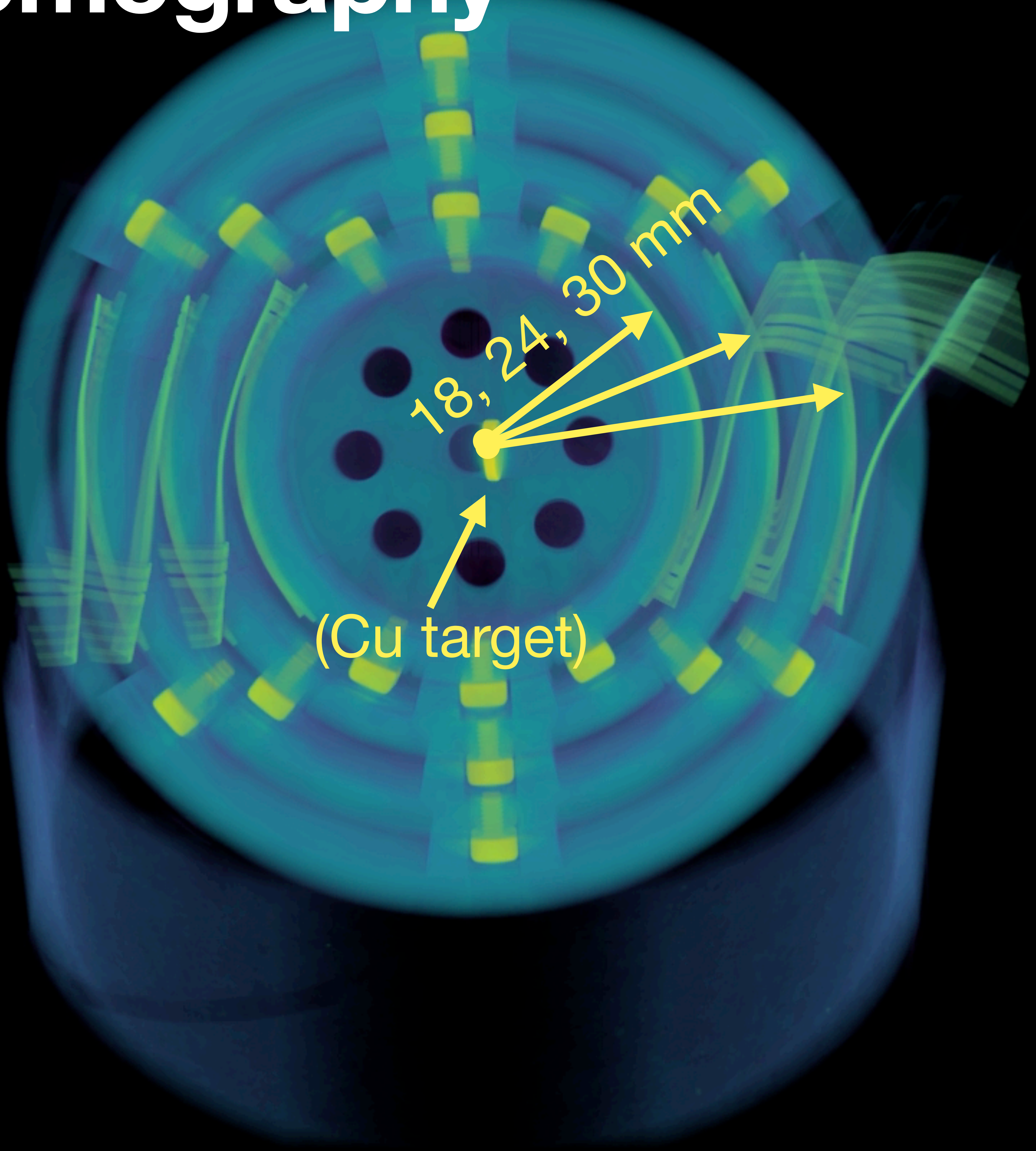

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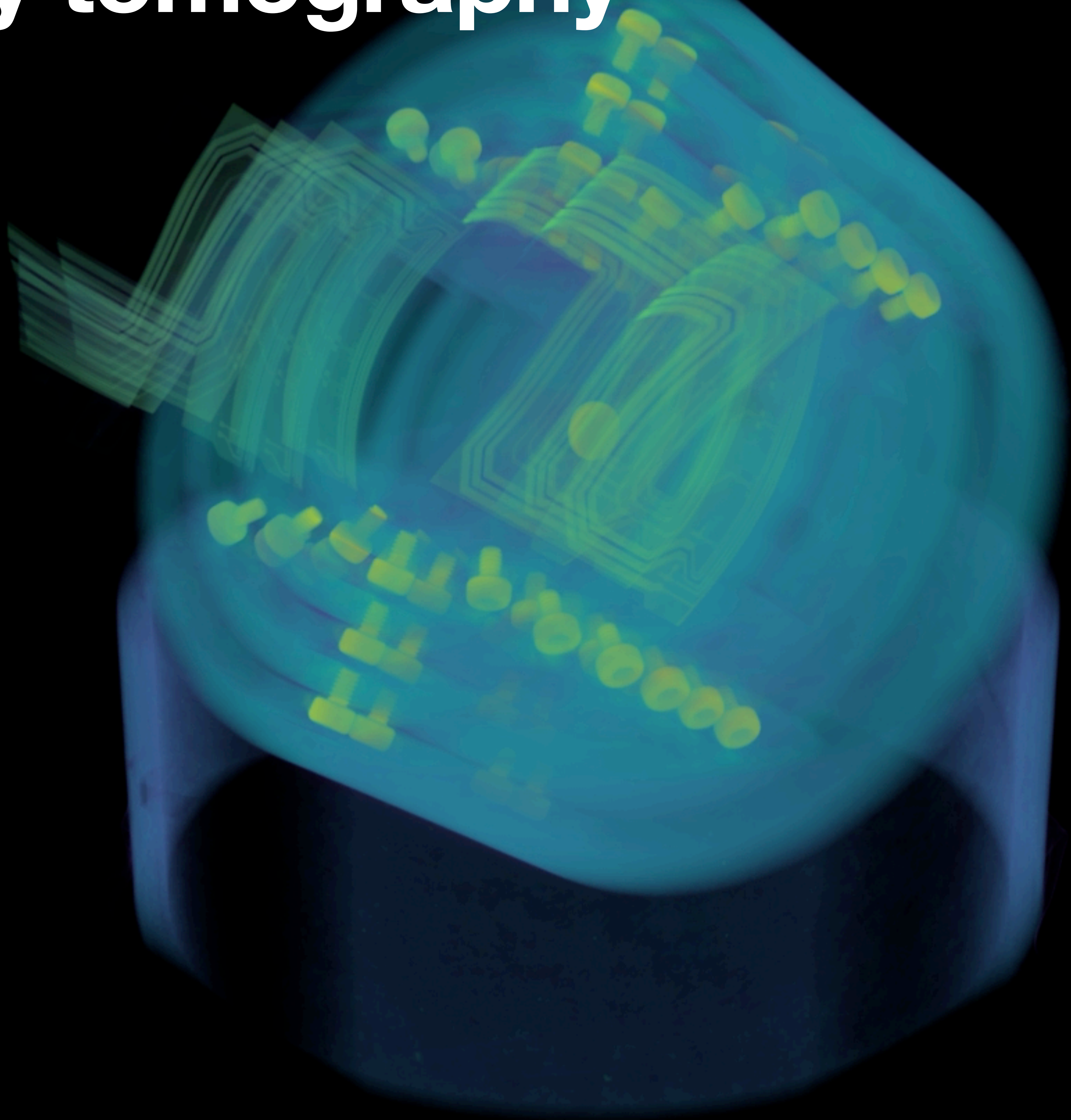

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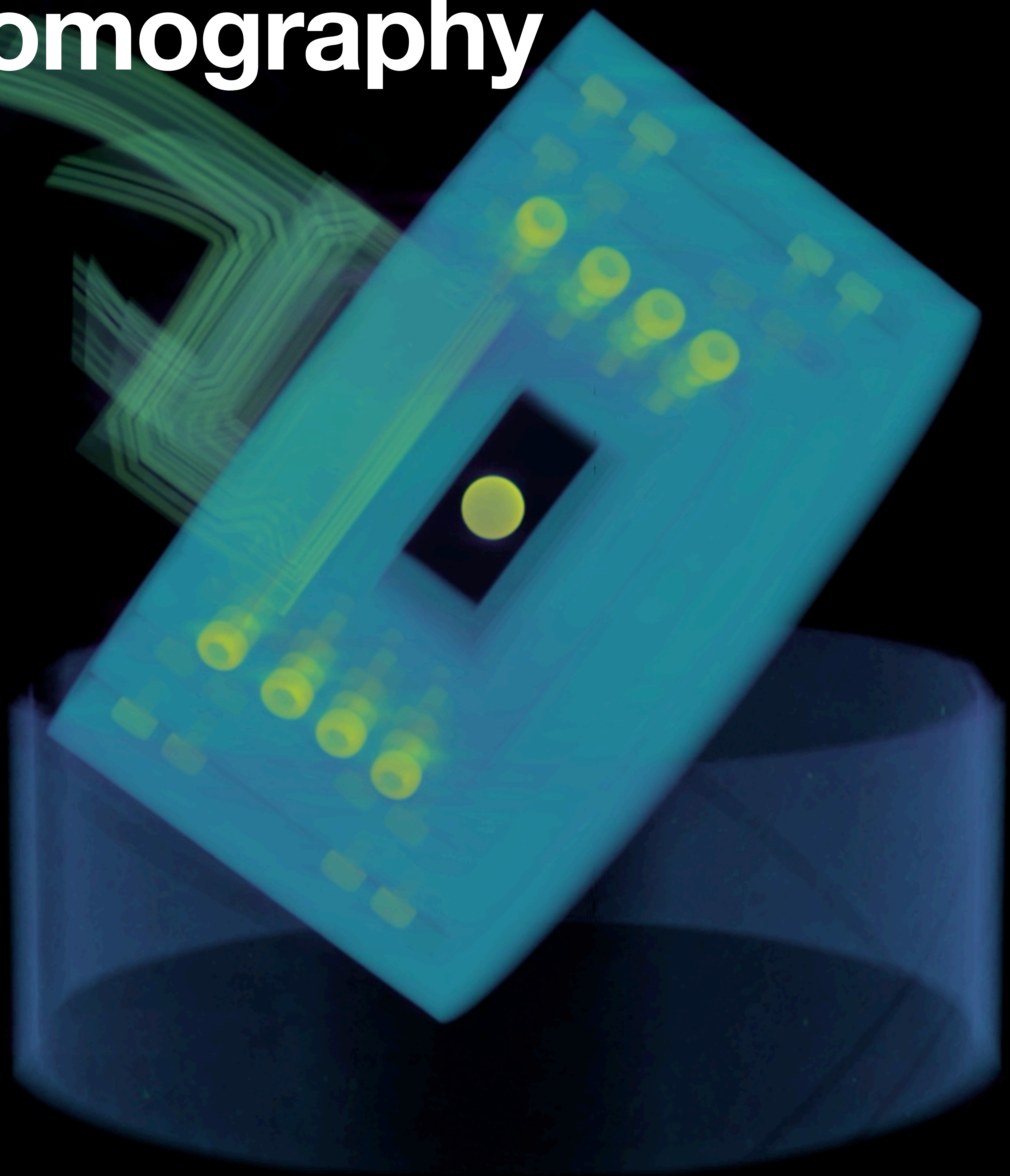
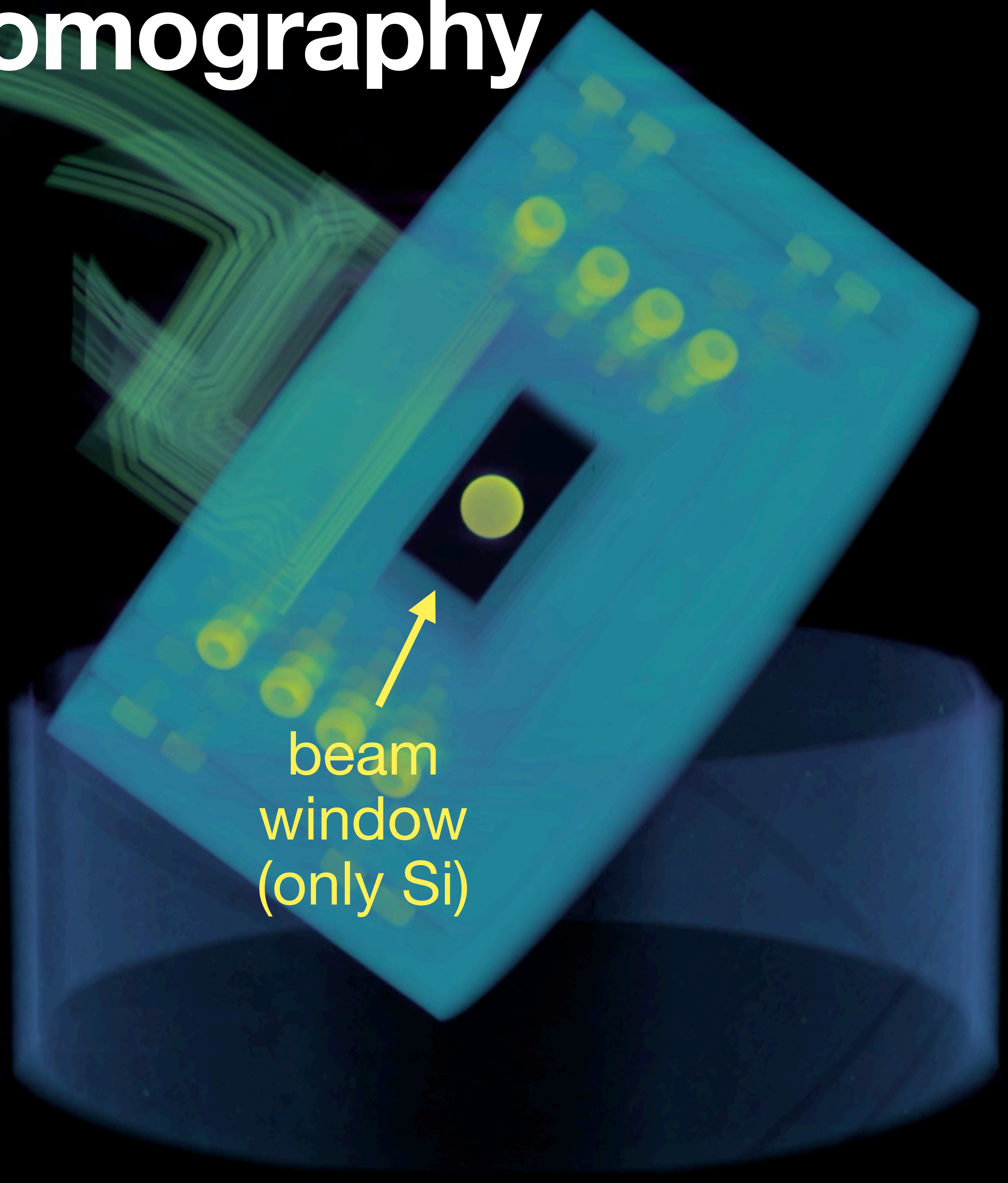


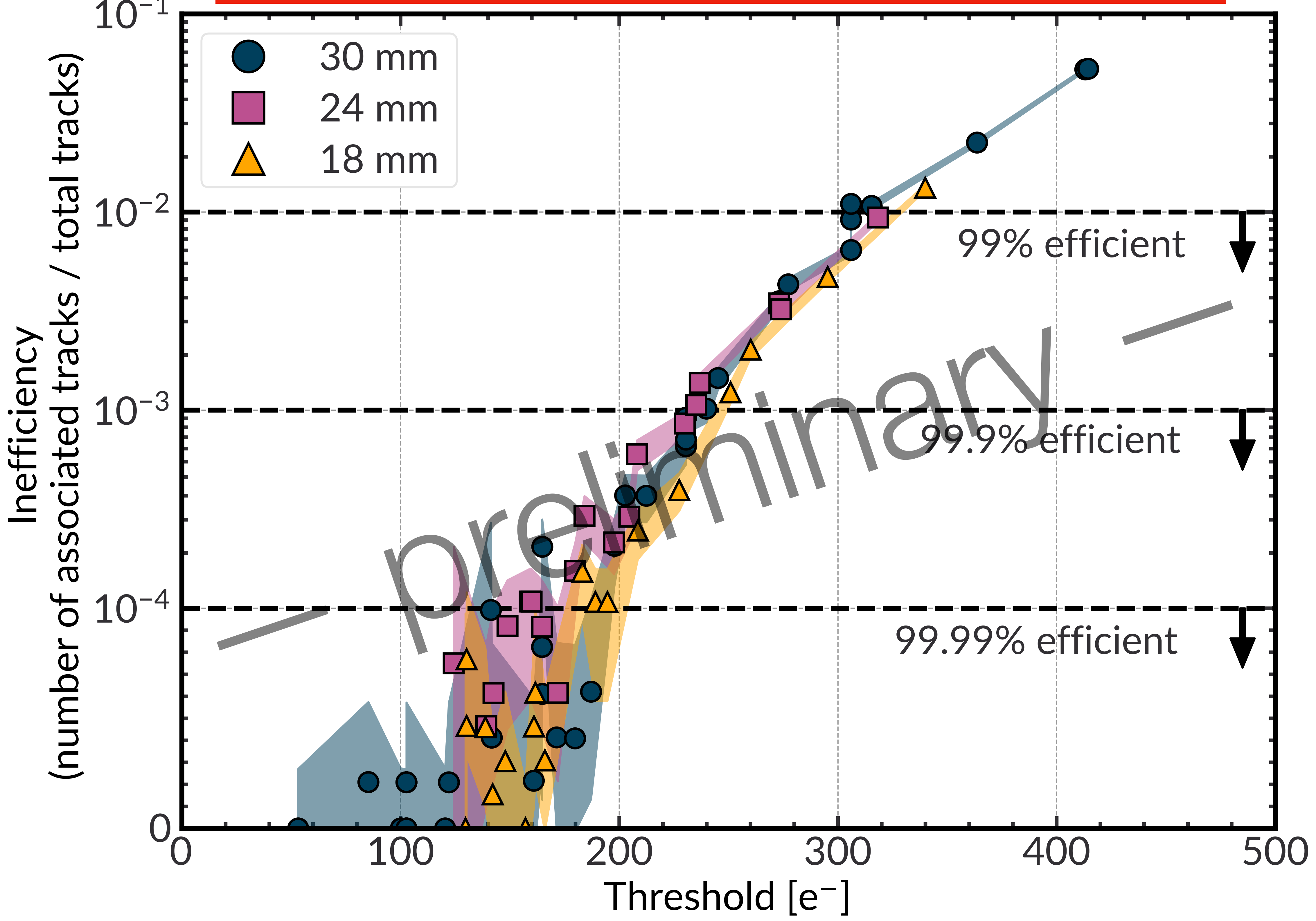
# µITS3 X-ray tomography



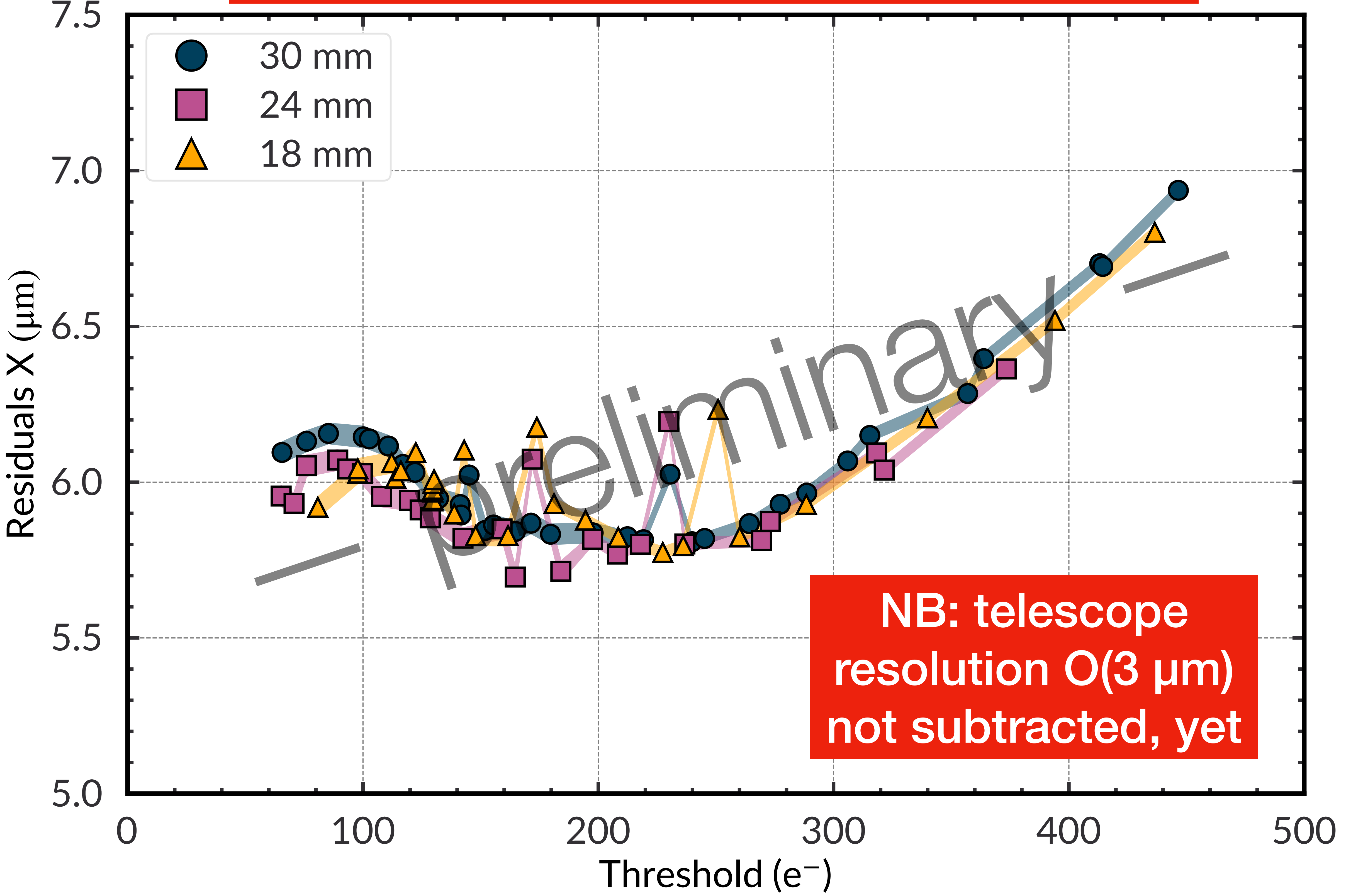
# Bent ALPIDEs — beam test results

## at all nominal ITS3 radii

Inefficiency




Residuals




NB: telescope resolution O(3 µm) not subtracted, yet

Bent MAPS "just" continue to work! – bending is not visible in main performance figures

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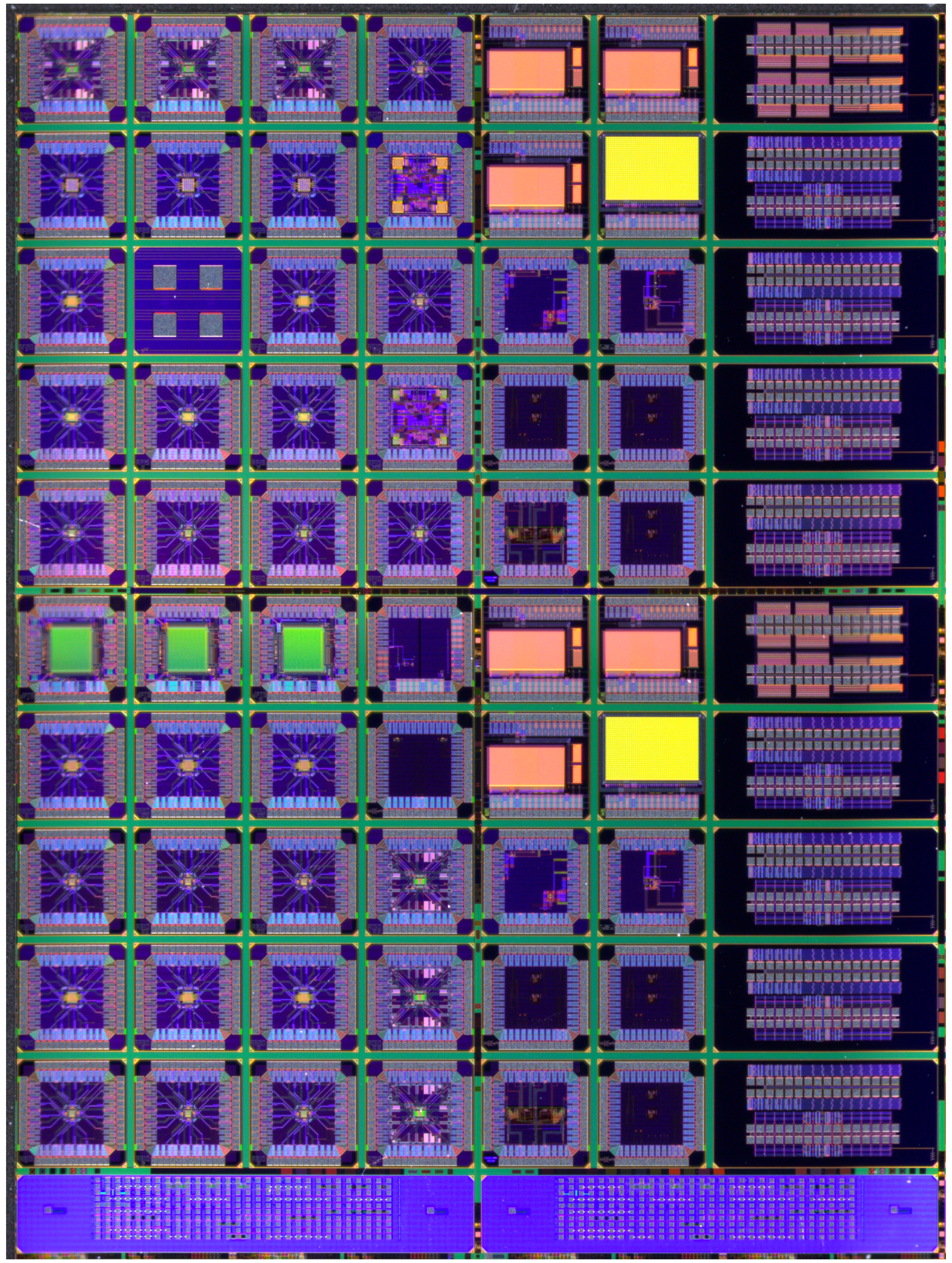
# Sensor design: advancing the technology

## qualifying the TPSCo 65 nm CMOS Imaging Technology

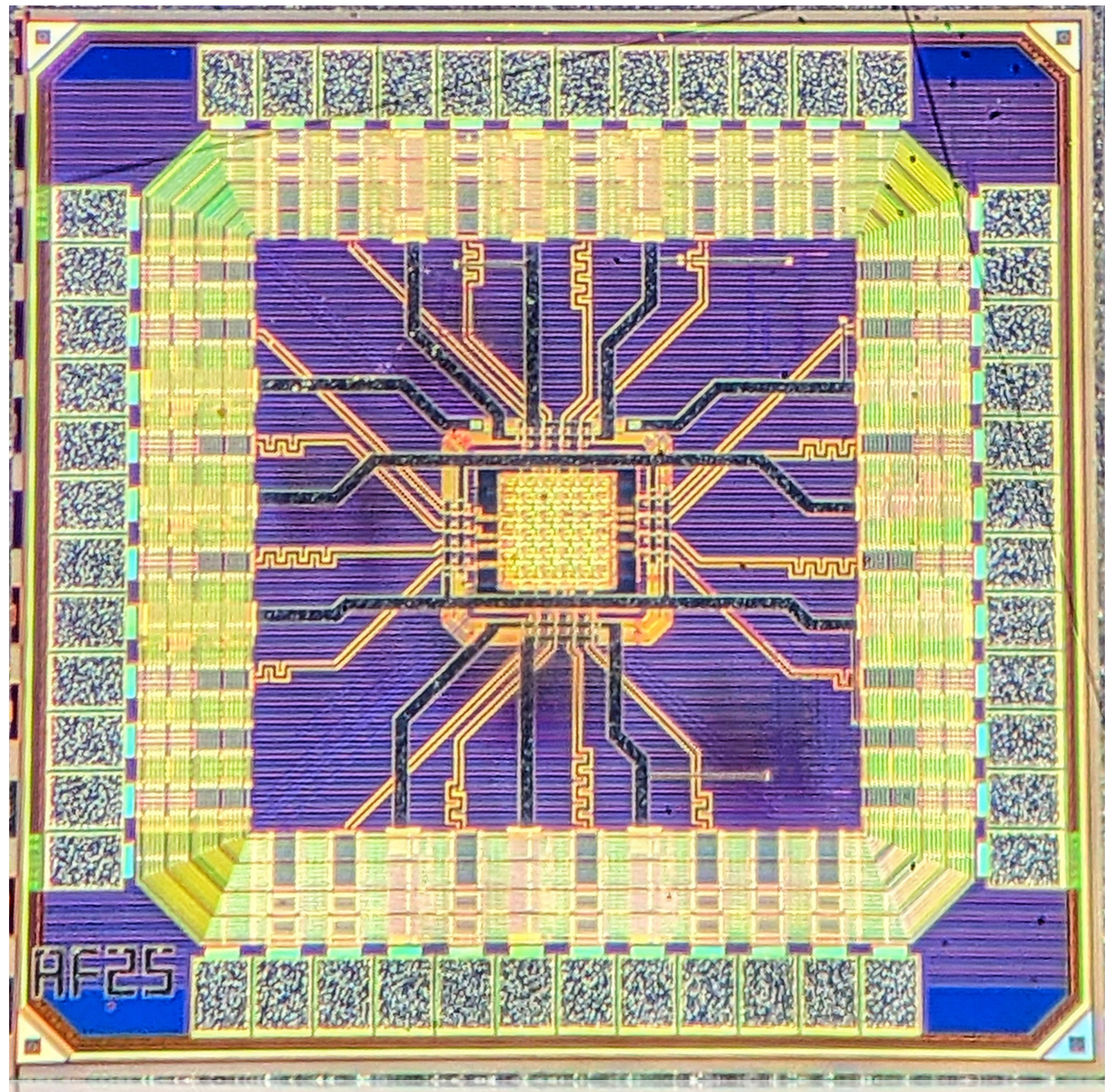
- Together with CERN EP R&D
- Leverages on experience with 180 nm process (ALICE ITS2 an beyond)
  - excellent links to foundry
- Comprehensive *first* submission: **55** prototype chips
  - different processing flavours were tried
- Immense dataset for ITS3 and the community at large



**This technology has a large potential for the field, not only because it is done on 300 mm wafers!**

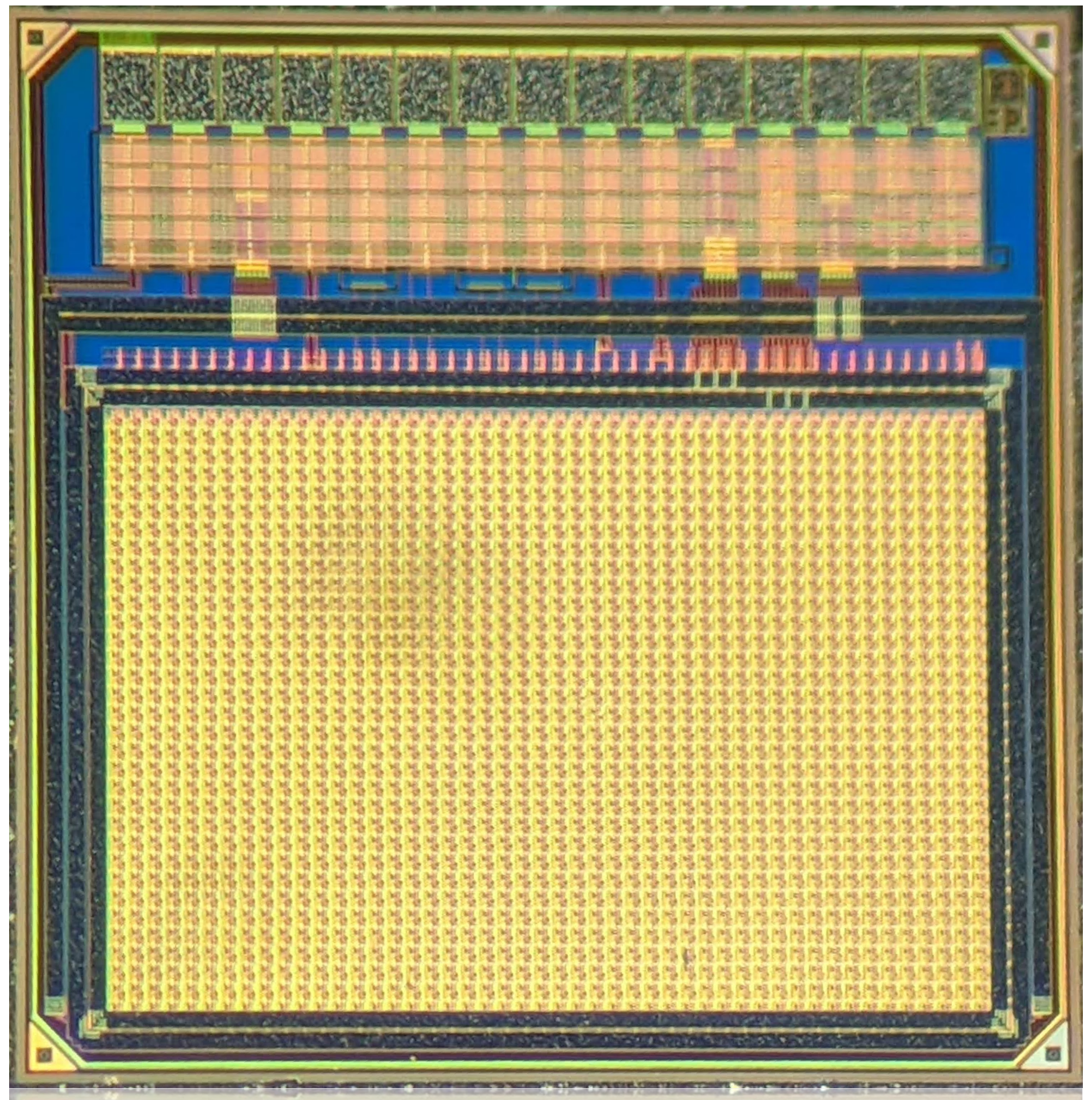
# Pixel prototype chips (selection)

## APTS



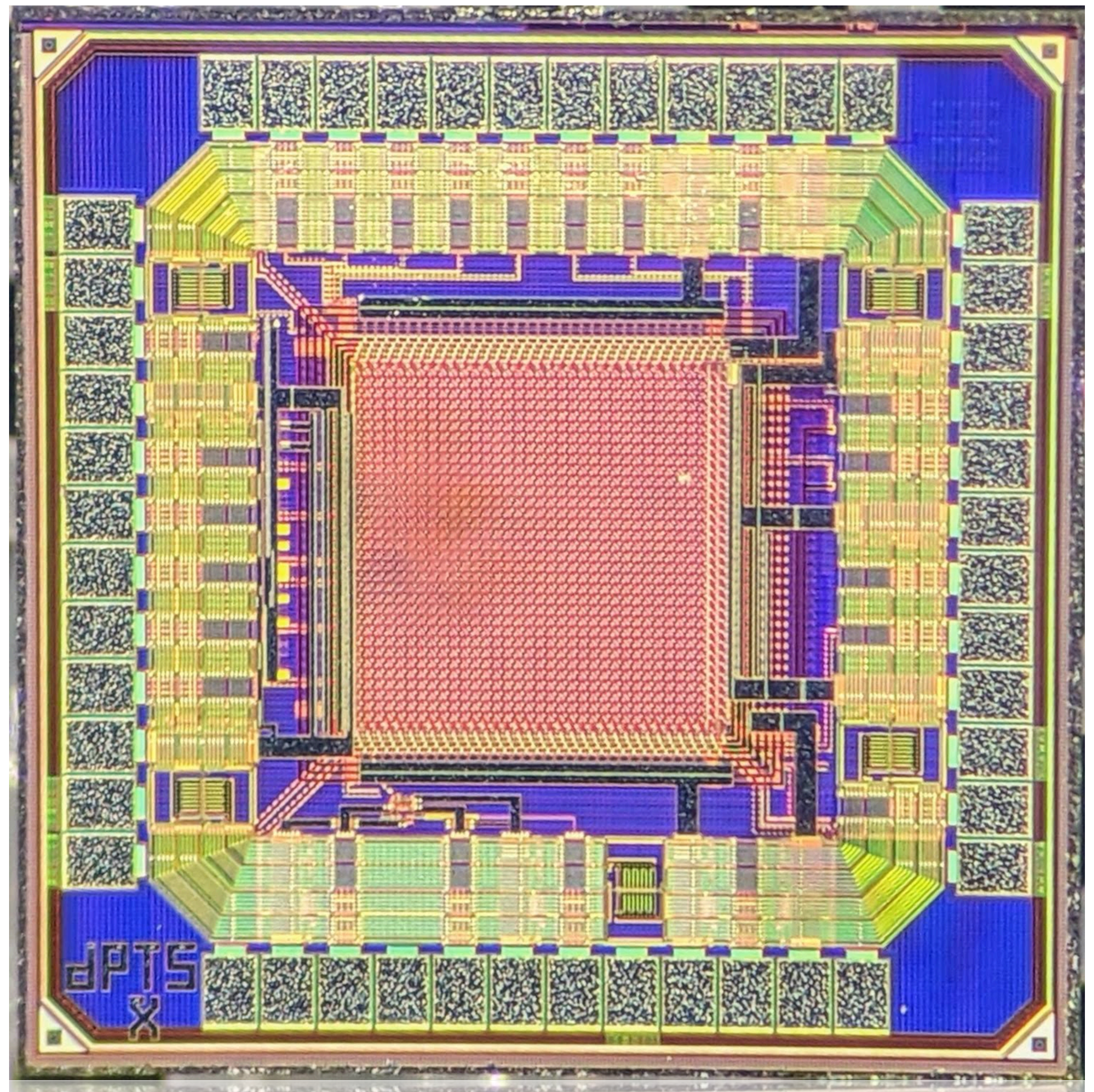

- **matrix:** 6x6 pixels
- **readout:** direct analog readout of central 4x4
- **pitch:** 10, 15, 20, 25 µm
- **total:** 34 dies

## CE65



- **matrix:** 64x32, 48x32 pixels
- **readout:** rolling shutter analog
- **pitch:** 15, 25 µm
- **total:** 4 dies

## DPTS

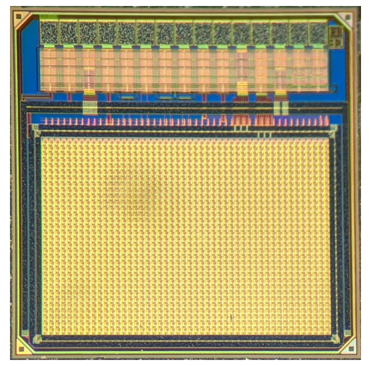



- **matrix:** 32x32 pixels
- **readout:** async. digital with ToT
- **pitch:** 15 µm
- **total:** 3 dies

Comprehensive set of prototypes and variants to explore the technology for particle detection

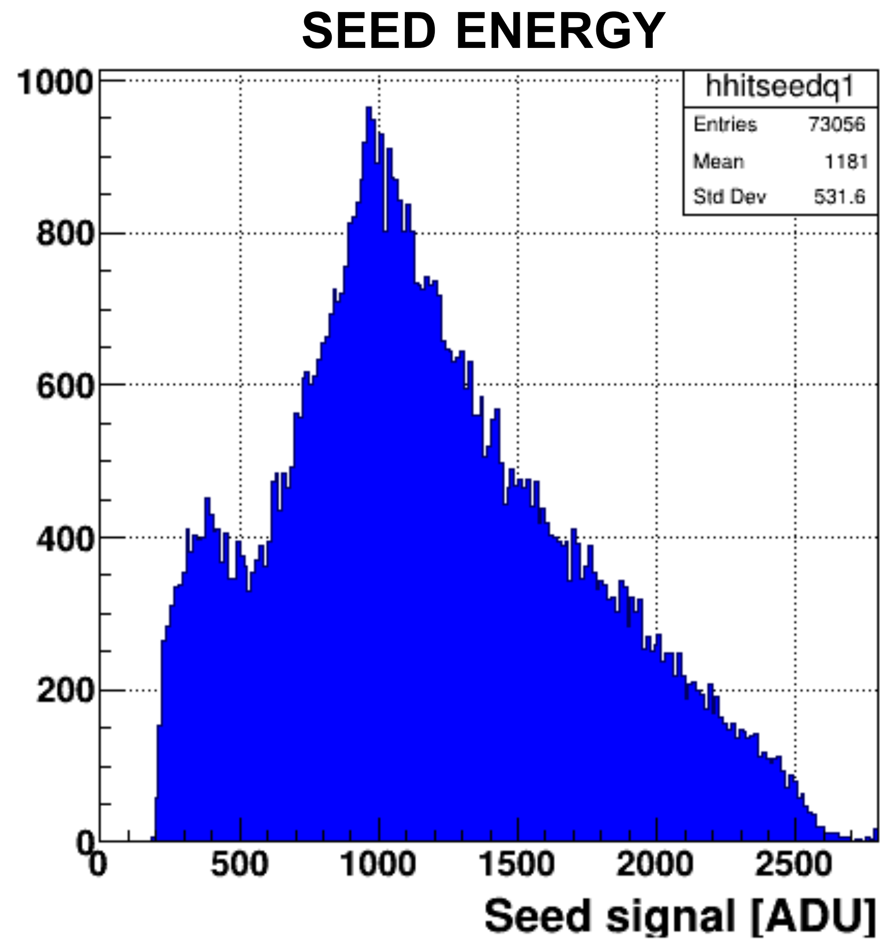
# CE65 – Fe-55 lab tests

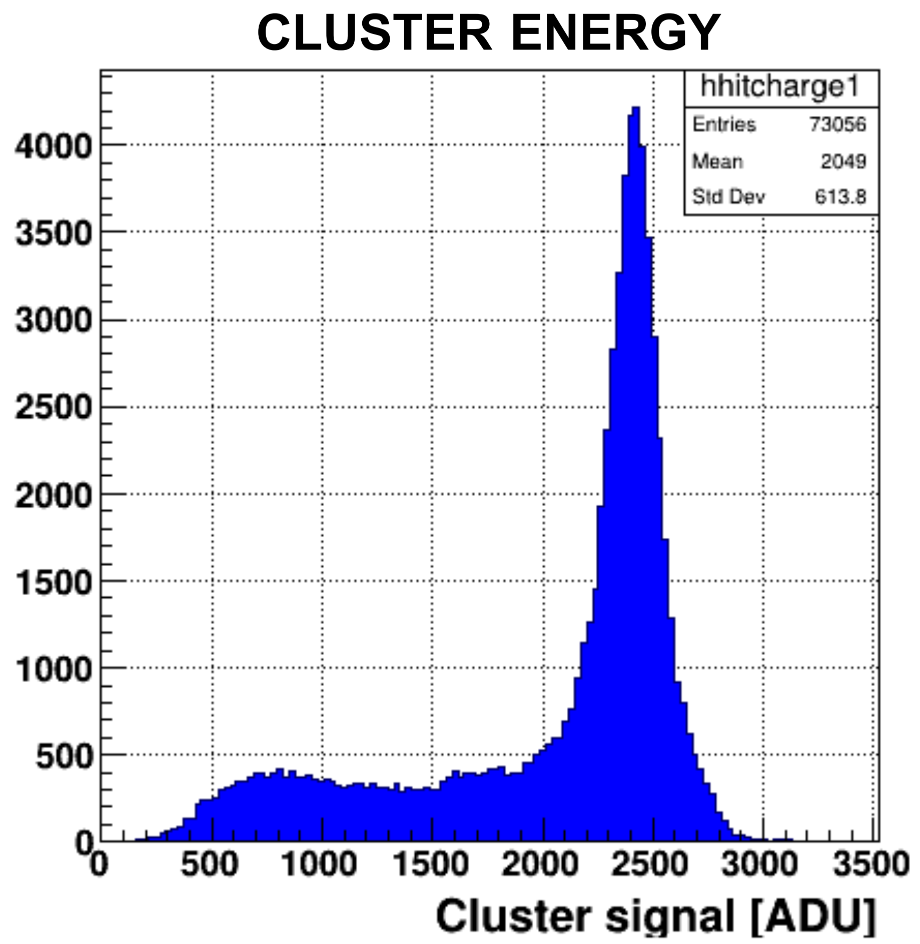
## charge sharing

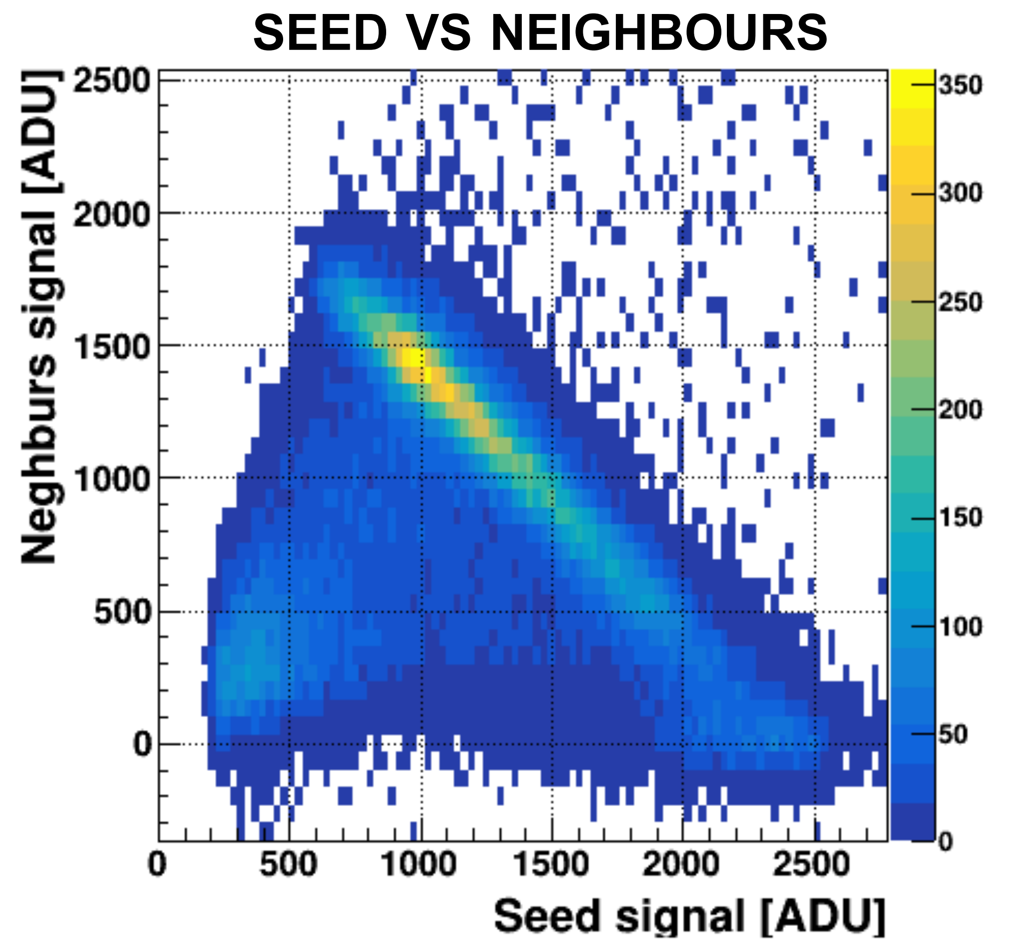


- Very good charge collection properties
- Effect of different optimisation can be seen very clearly
- Now being also verified
  - after irradiation
  - in beam tests

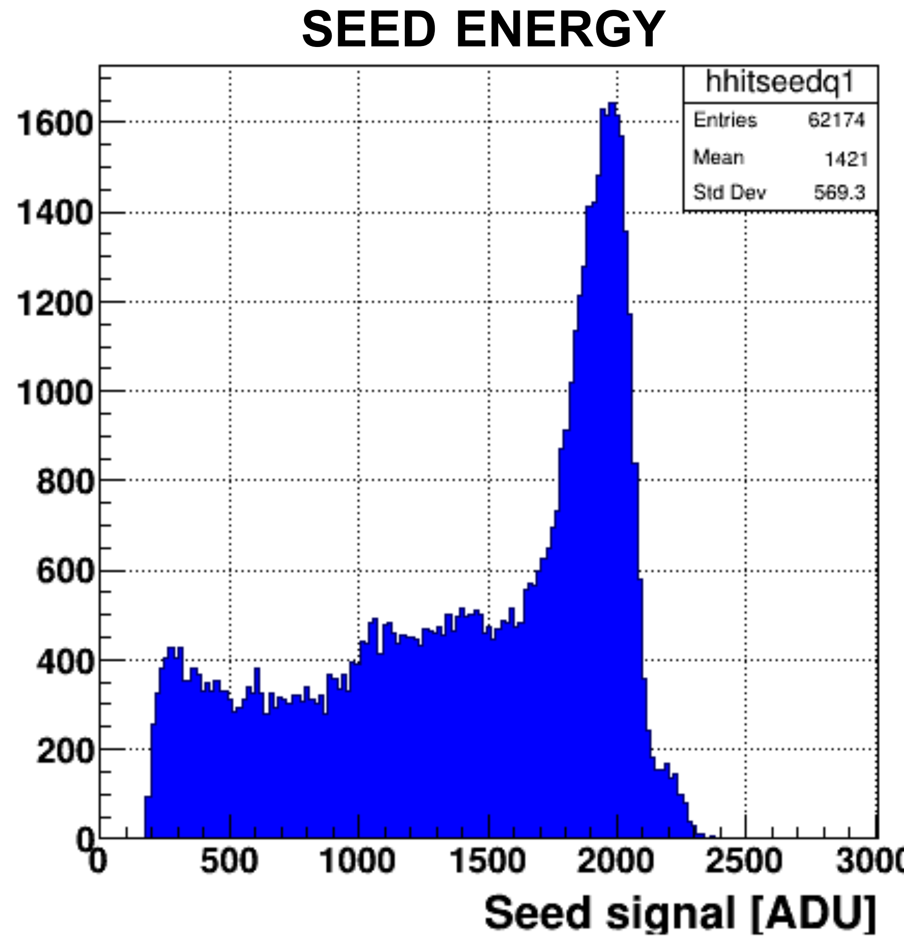
**BASIC DIODE [A4]:**

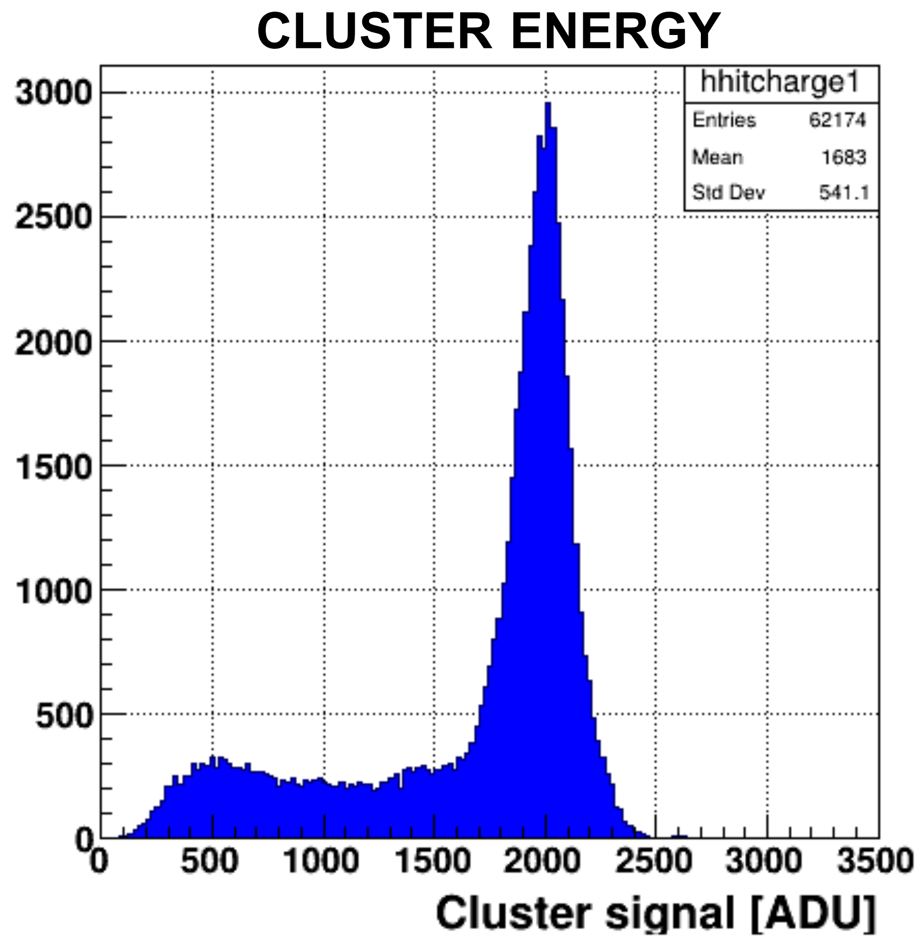


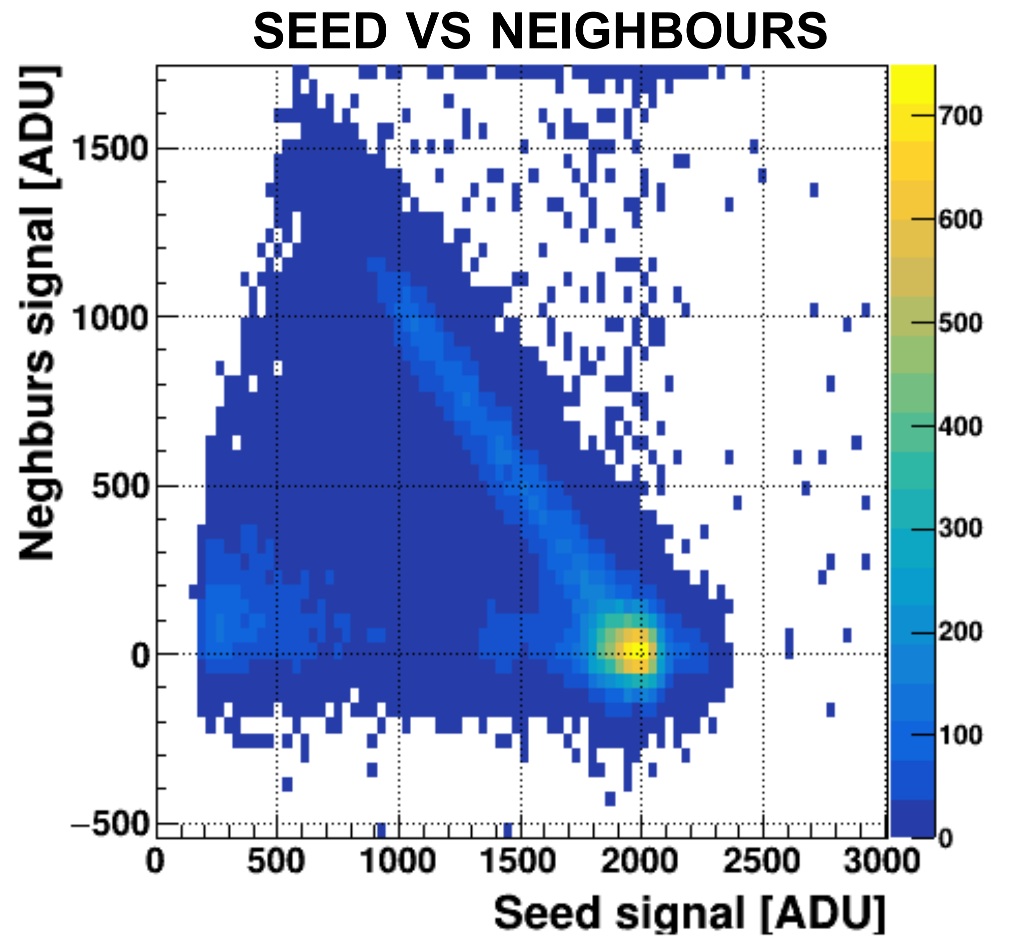



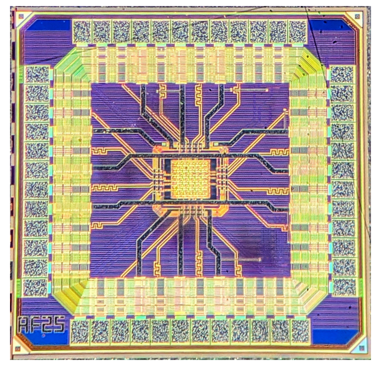

**OPTIMIZED DIODE [B4]:**



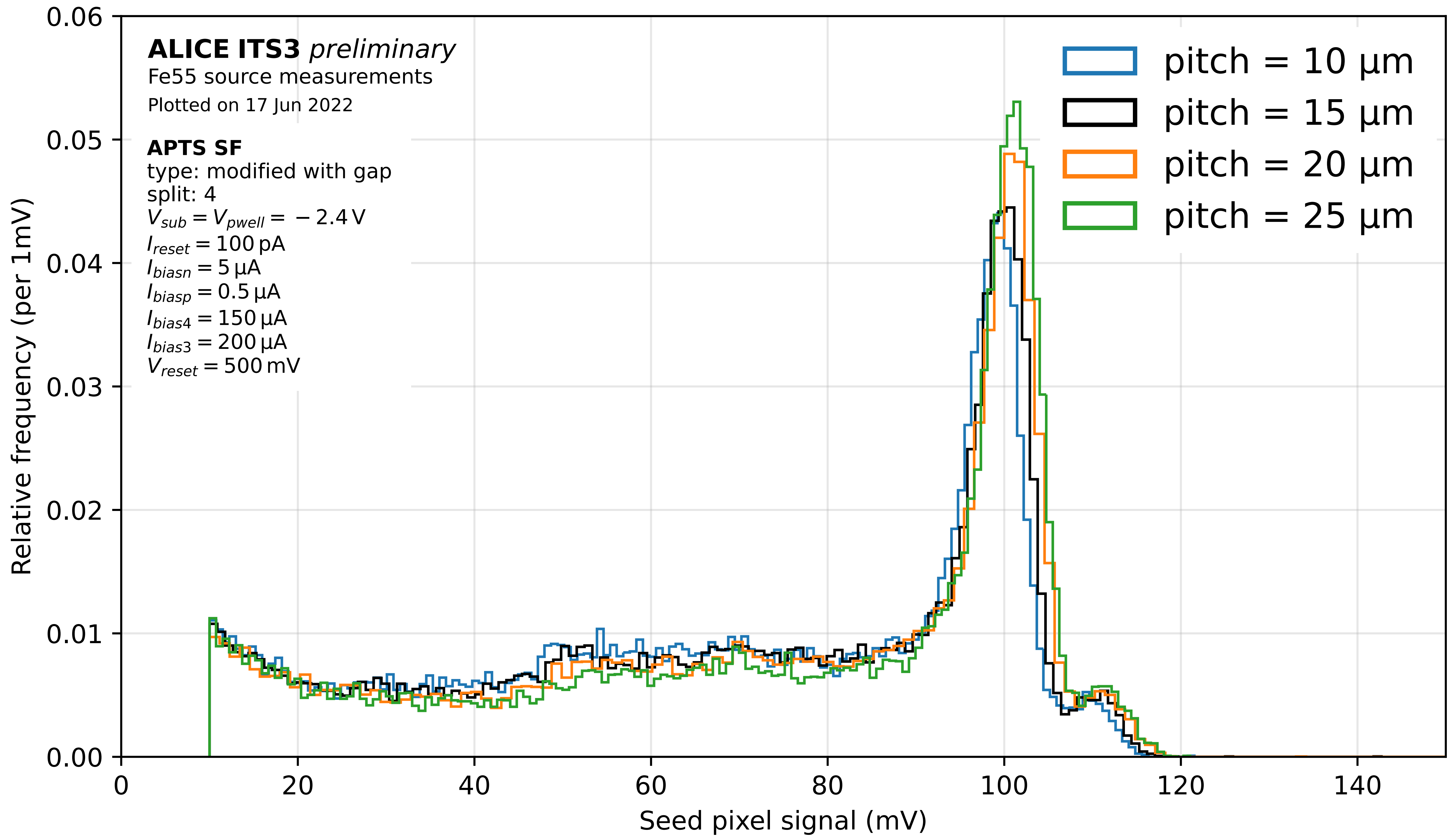



# APTS – Fe-55 lab tests



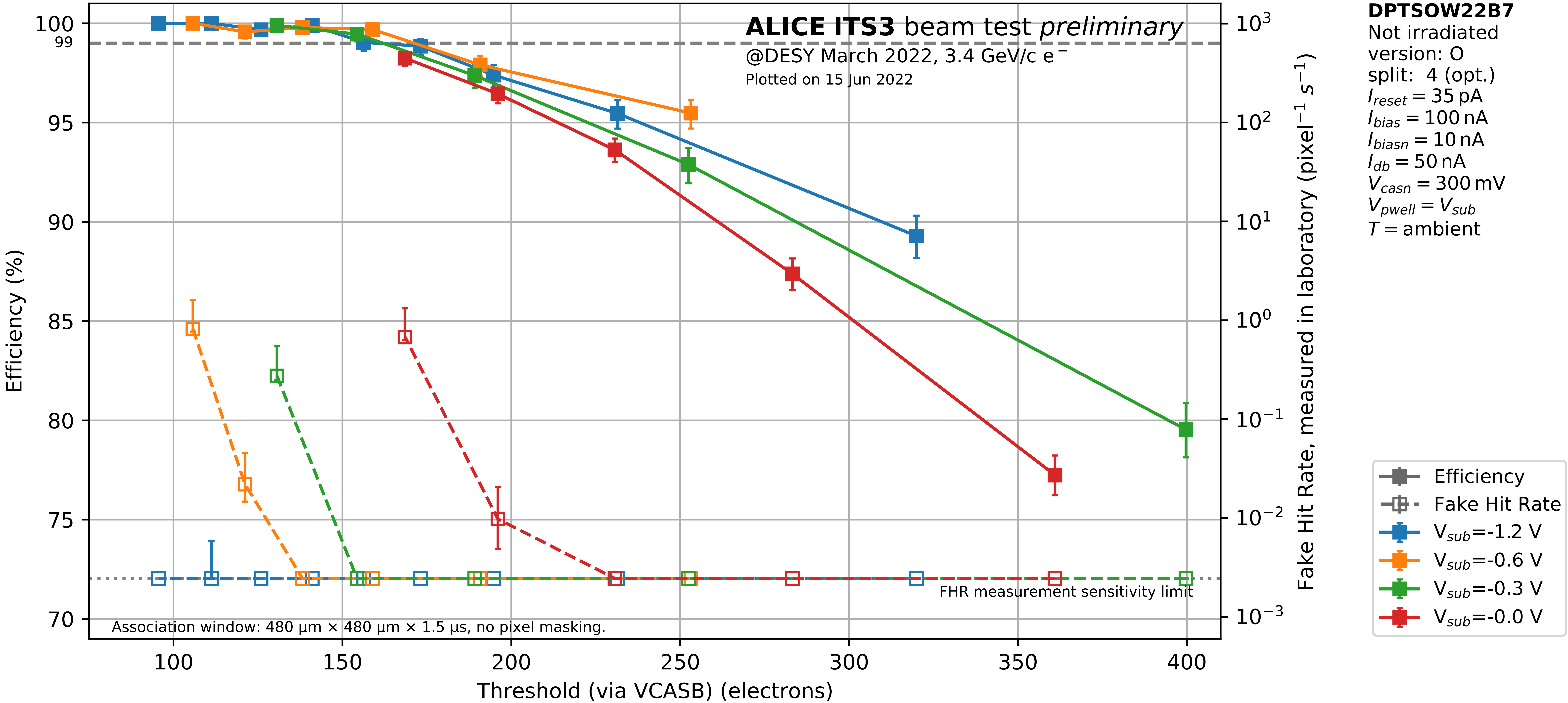
## comparison of pixel pitches

- Process modification was introduced:
  - full depletion of sensors
  - electric field pointing to collection electrodes
- Pixels of pitches of 10-25 µm show similar results
  - indicates that the charge collection is very efficient
- Allows to *choose* optimal pitch for the final sensor




**This is a remarkable result — now being verified with beam tests**

# DPTS – beam tests
## efficiencies and fake hit rates

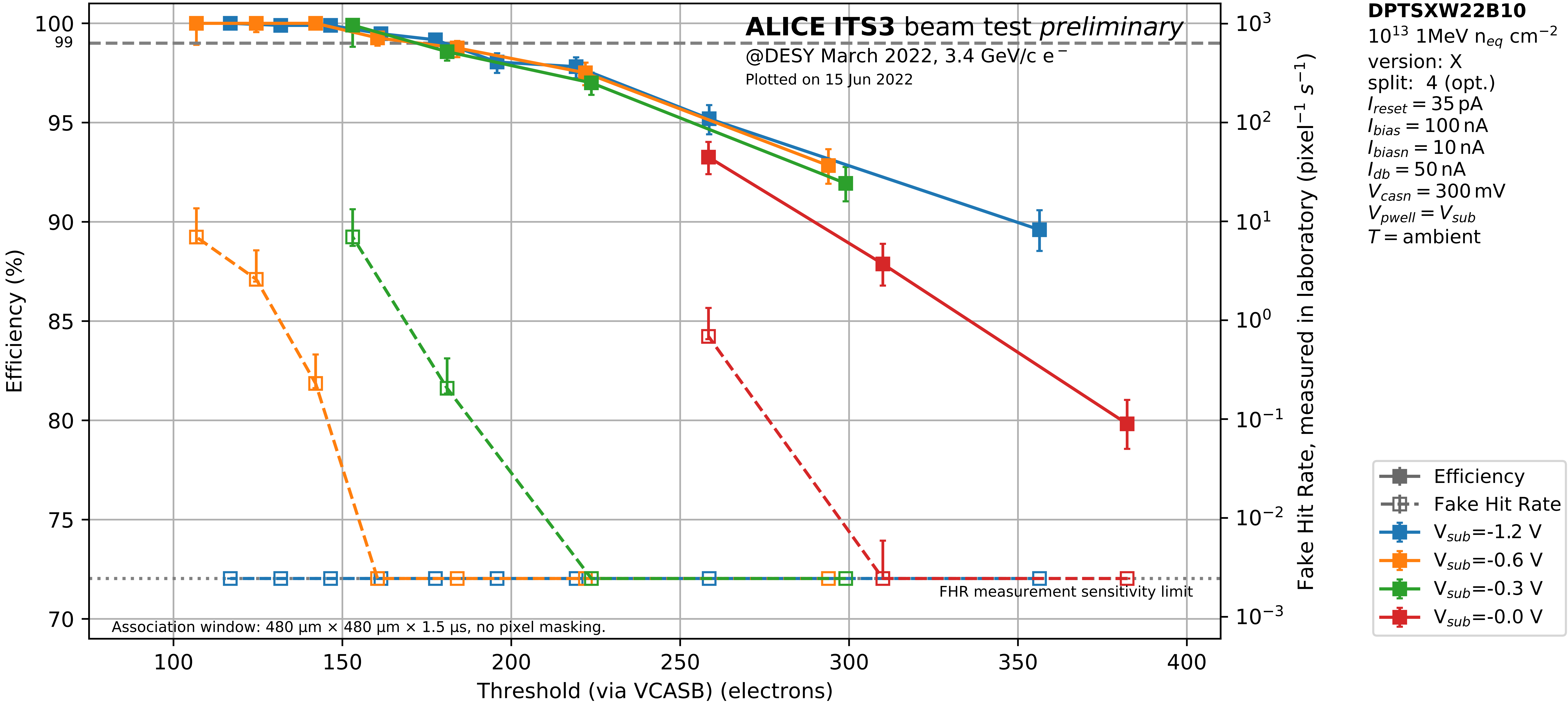



**DPTSOW22B7**
Not irradiated
version: O
split: 4 (opt.)
$I_{reset} = 35\,\mathrm{pA}$
$I_{bias} = 100\,\mathrm{nA}$
$I_{biasn} = 10\,\mathrm{nA}$
$I_{db} = 50\,\mathrm{nA}$
$V_{casn} = 300\,\mathrm{mV}$
$V_{pwell} = V_{sub}$
$T = \mathrm{ambient}$

**Excellent detection efficiency at very low fake hit rates over large threshold range!**

# DPTS – beam tests

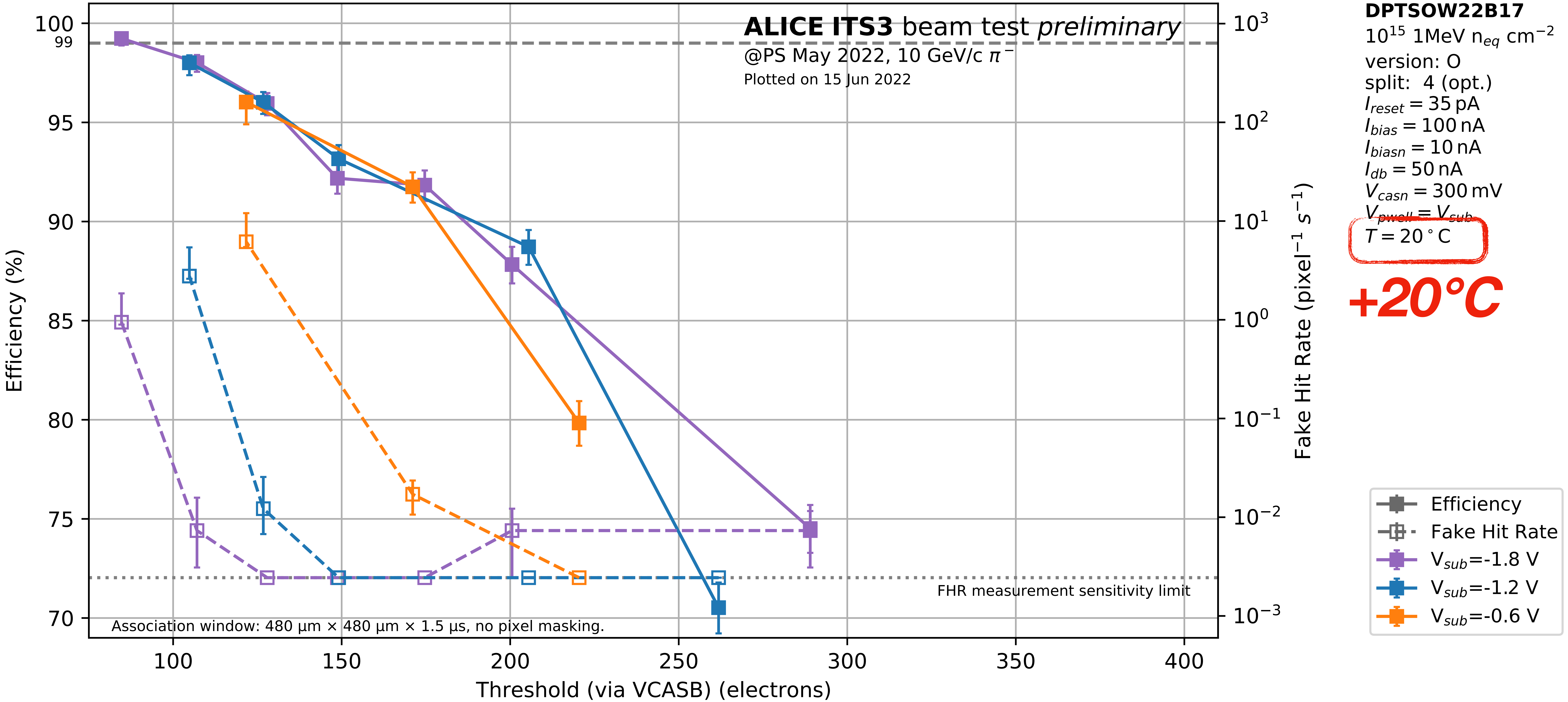
## after irradiation: “$10^{13}$ NIEL”




**At ALICE conditions: slightly larger fake rates, but still large operational margin**

# DPTS – beam tests

## after more irradiation: "$10^{15}$ NIEL"



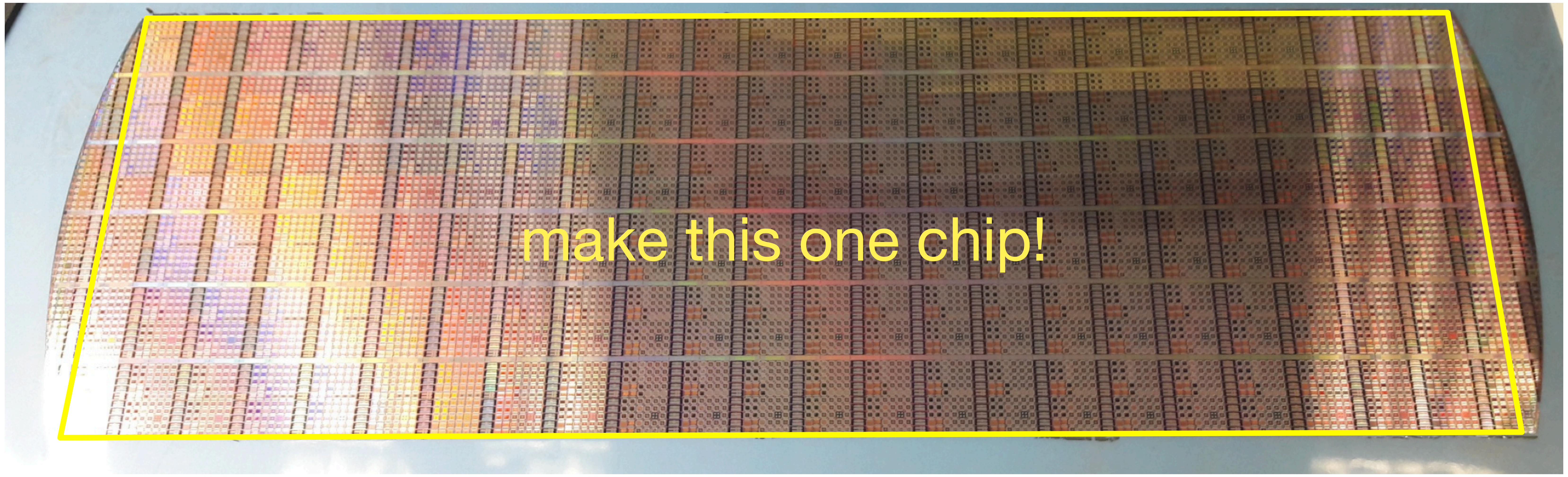

**DPTSOW22B17**
$10^{15}$ 1MeV $n_{eq}$ $cm^{-2}$
version: O
split: 4 (opt.)
$I_{reset} = 35$ pA
$I_{bias} = 100$ nA
$I_{biasn} = 10$ nA
$I_{db} = 50$ nA
$V_{casn} = 300$ mV
$V_{pwell} = V_{sub}$
$T = 20^\circ$C

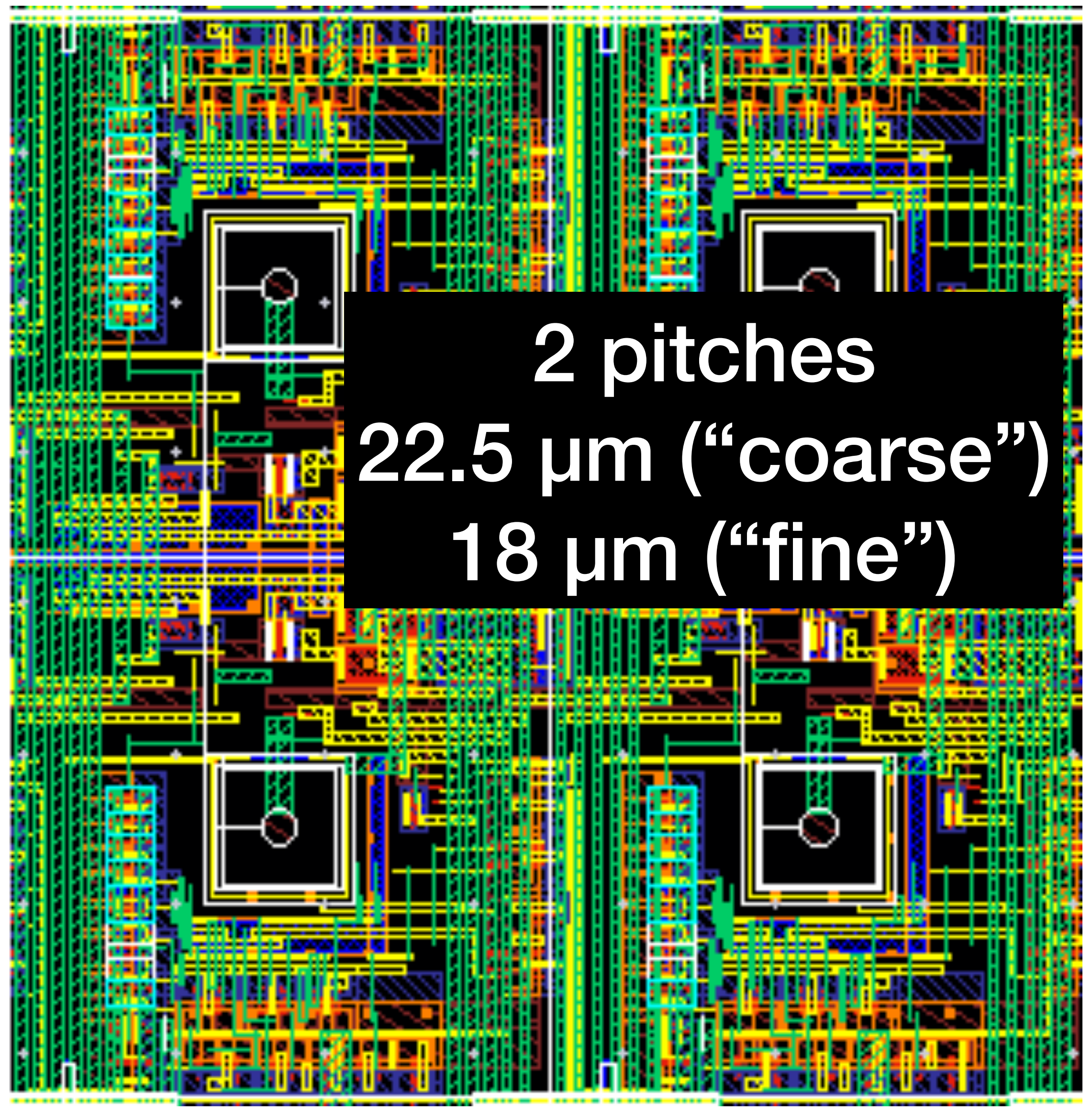
**+20°C**

**At $10^{15}$: still possible to attain 100% detection efficiency at room temperature w/o being flooded in noise**

# Next chip submission: stitching

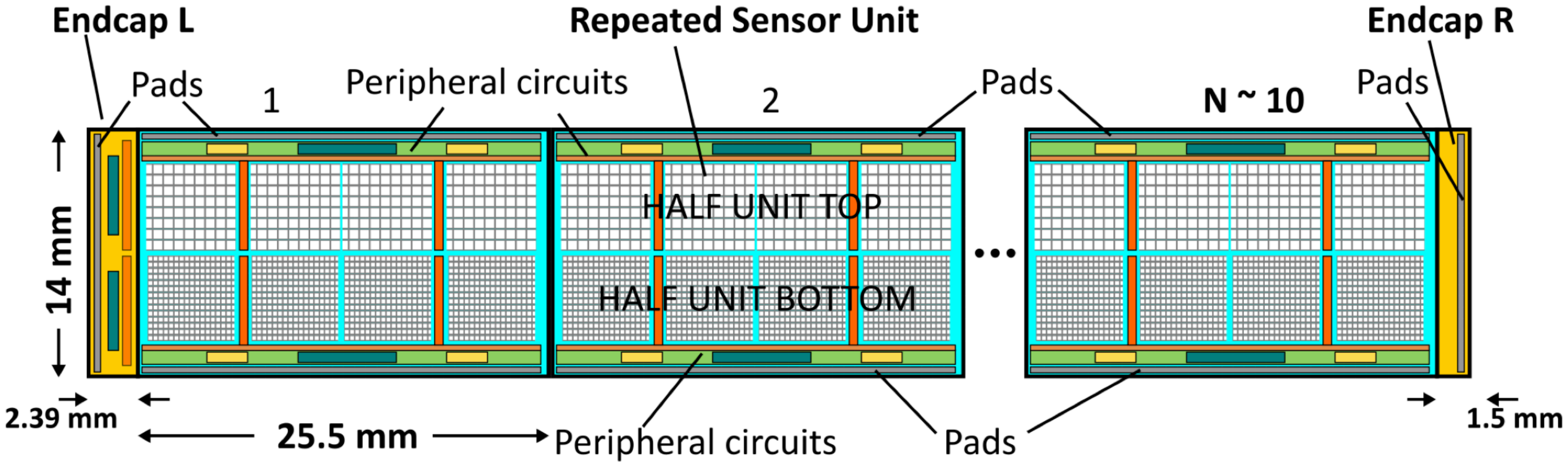
- Next goal (submission this summer, "ER1"):




Requires dedicated design effort:

- understanding of "stitching" rules
- incorporation of redundancy, fault tolerance




- Crucial exercise to understand:
  - yield
  - uniformity

**We are taking the next and last critical step!**

# Summary & Outlook

- **ALICE** is carrying out the R&D for a **new class** of vertex detectors
  - target: installation of new inner layers, **ITS3**, for LHC **LS3**
- Large improvement in tracking **precision** by:
  - new material budget record: **< 0.05% $X_0$** per layer
  - radial distance from IP: only **18 mm**
- **Advancing MAPS** technology towards:
  - deeper sub micron technology node: **65 nm**
  - wafer-scale sensors: **stitching**
- **Ultra-thin, bent, wafer-scale MAPS** are becoming a reality!
  - for ALICE ITS3, *and beyond!*

→ next talk:
Nicolo Jacazio
***ALICE 3***

# Thank you!