PS Module Assembly @DESY

for the Phase 2 Upgrade of the CMS Outer Tracker

Paul Schütze
for the DESY CMS Outer Tracker Team
SiDet R&D Meeting
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Context: The HL-LHC

- Ever seen this one?
- High Luminosity LHC nutshell:
  - More data in less time (compared to LHC)
- More scientific:
  - Higher instantantaneous & integrated luminosity
  - At the same bunch repetition rate this means higher pileup*

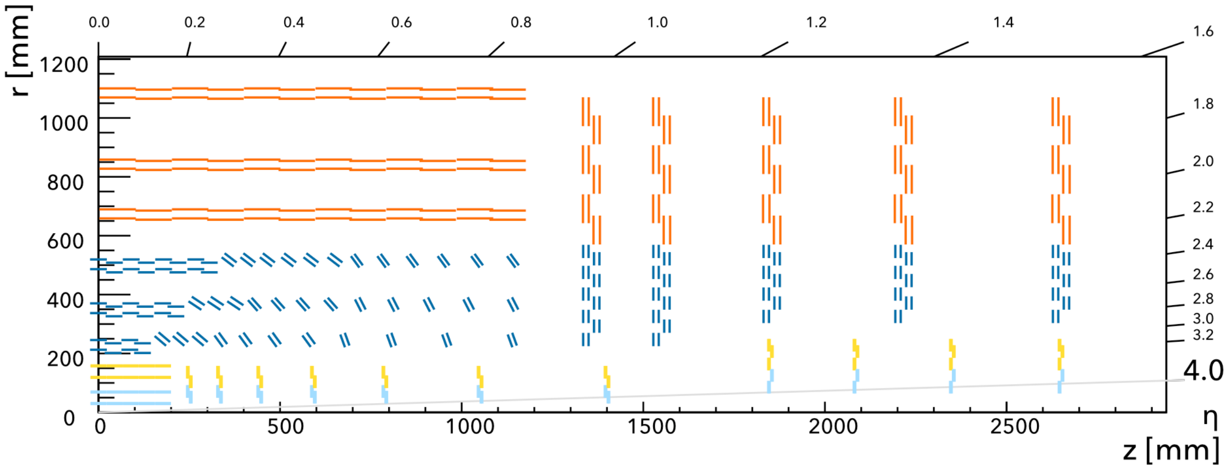
* number of proton-proton interactions in single bunch crossing

➔ Challenging environment for all detector systems → most systems require a replacement

  ➔ This presentation: CMS Outer Tracker

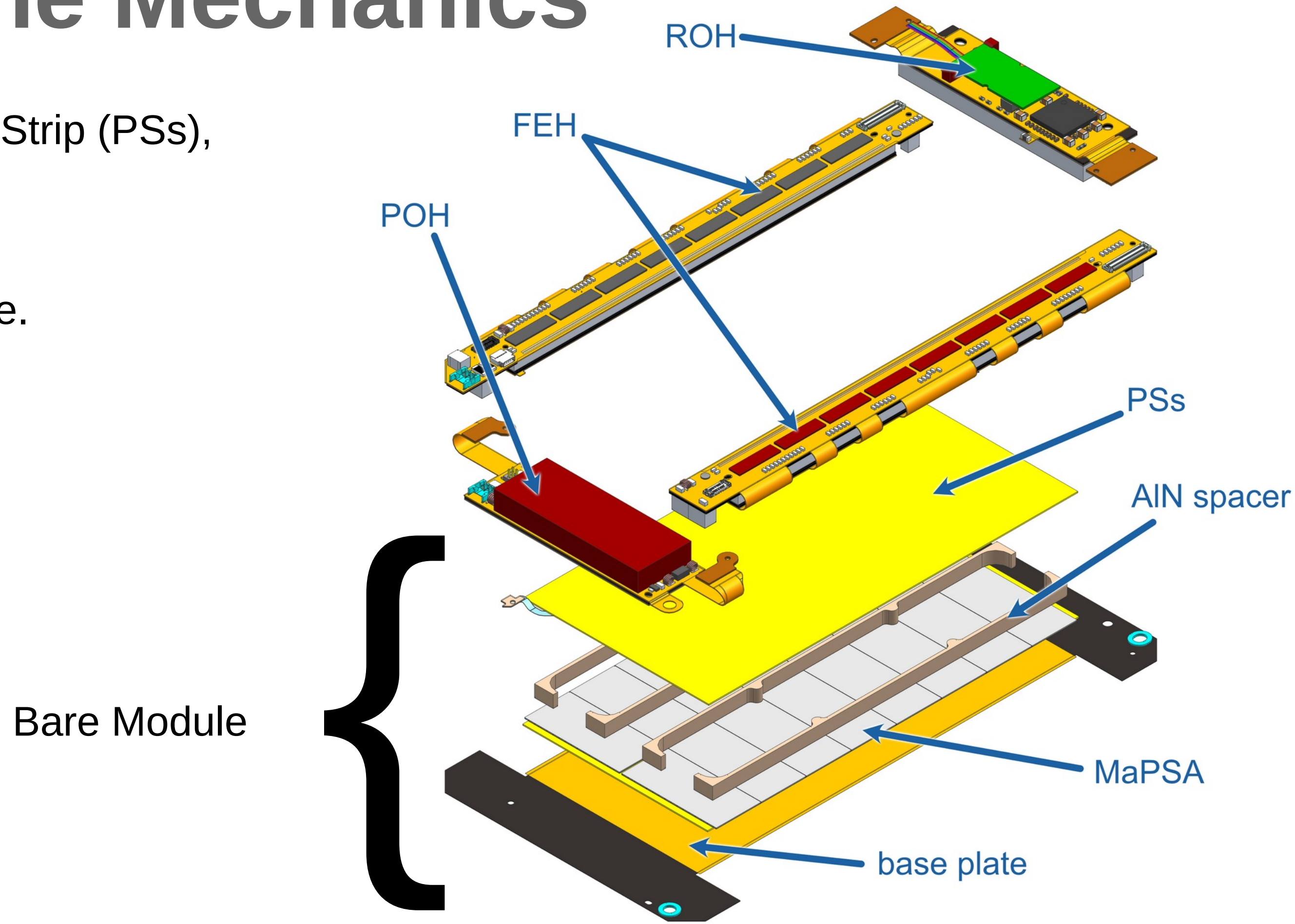
Context: The CMS Outer Tracker

- CMS Tracking Detector for the HL-LHC phase:
  - Inner Tracker:
    - 3D Si sensors (innermost barrel layer) & planar n-in-p else
    - Blue&Yellow: different module dimensions
  - Outer Tracker:
    - Based on modules with two sensors each
    - Blue: Pixel-Strip (PS) modules
    - Orange: Strip-Strip (2S) modules



PS Module – The Mechanics

- Two sensors, Pixel (MaPSA) + Strip (PSs),
- … are separated by spacers
- … and mounted on a base plate.



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- Two sensors, Pixel (MaPSA) + Strip (PSs),
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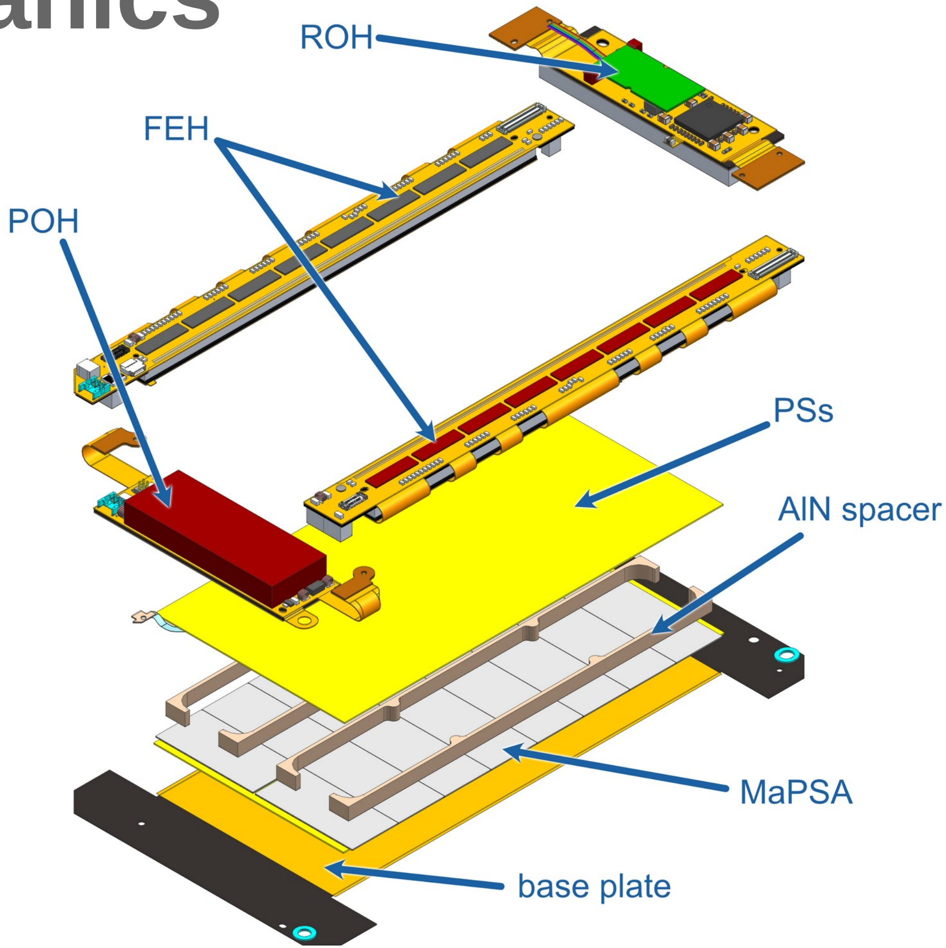
- The signals are processed by Front-end hybrids (FEH)
- Power is supplied via the Power hybrid (POH)
- Data is transmitted via the readout hybrid (ROH)



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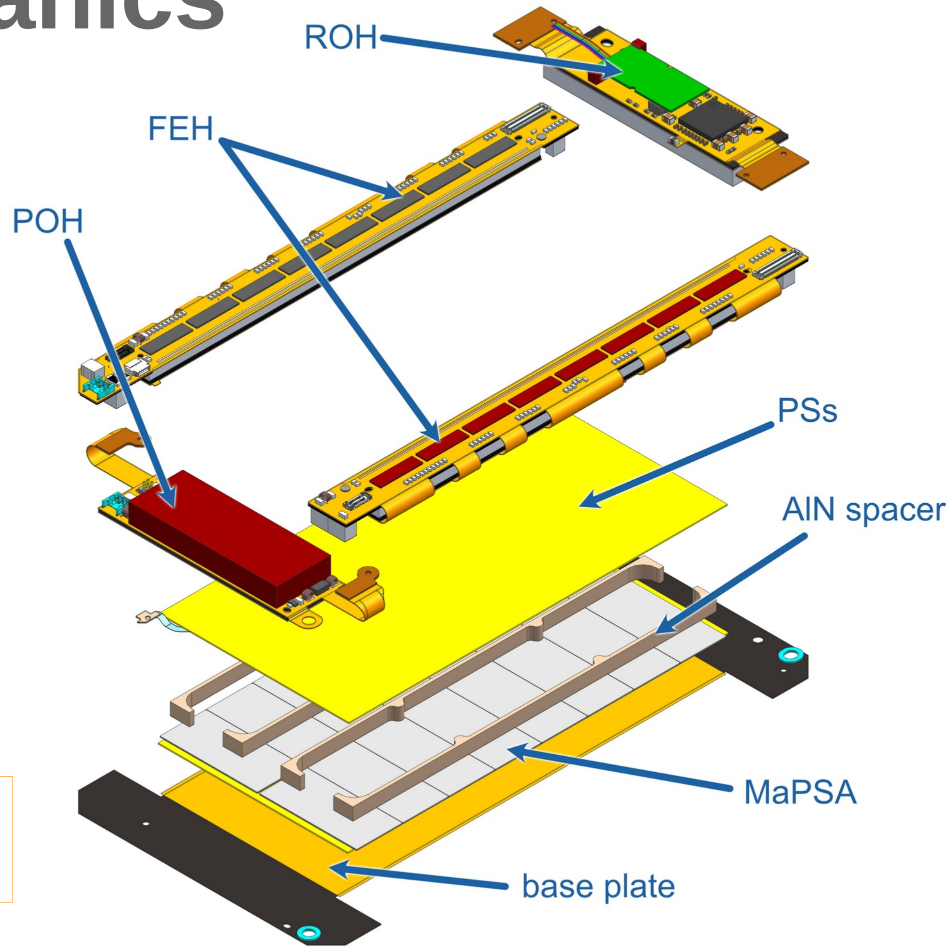
DESY will build > 1150 PS modules for the Phase II (HL-LHC) upgrade!



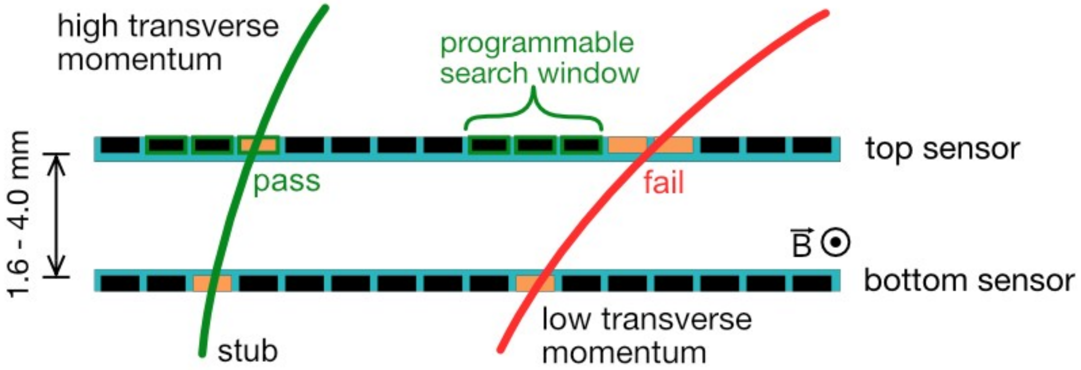
PS Module – The Track Trigger

- Track based triggering is challenging:
  - Tracker: huge number of channels
  - Data transfer & tracking algorithms usually too time consuming for triggering
- CMS OT Track Trigger:
  - The hits in the two sensors in one module are combined to form *stubs*, if they are closer (in *x*) than a configurable distance

  ➔ This provides *fast* information on the track angle

  ➔ Track angle correlates to the transverse momentum $\mathrm{p_T}$

  ➔ Information is sent to L1 trigger



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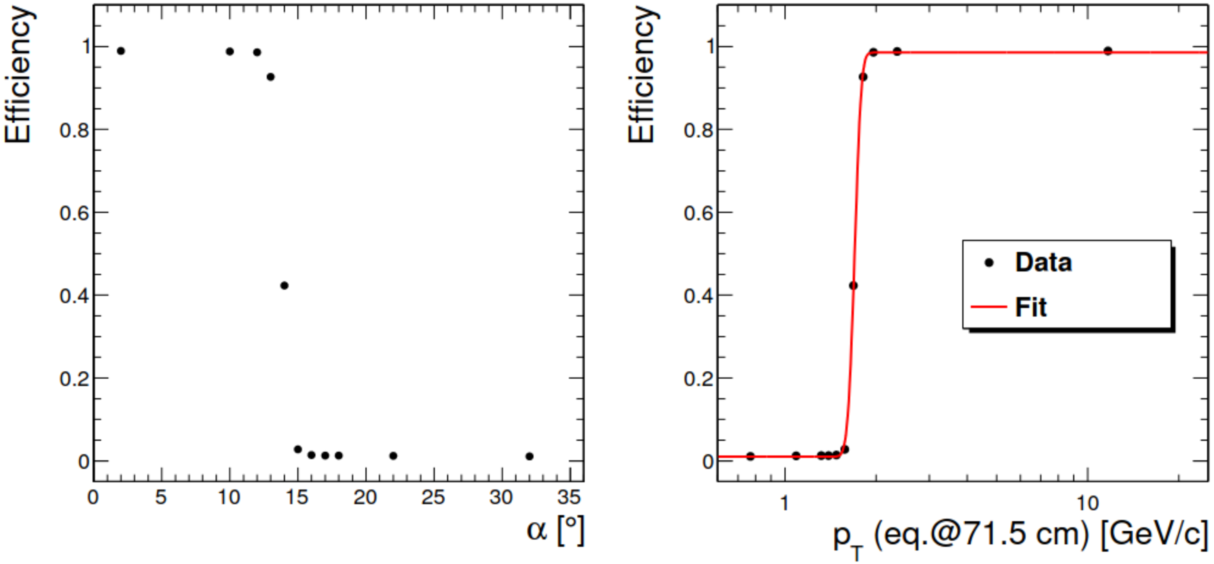
A. Harb
2S prototype module



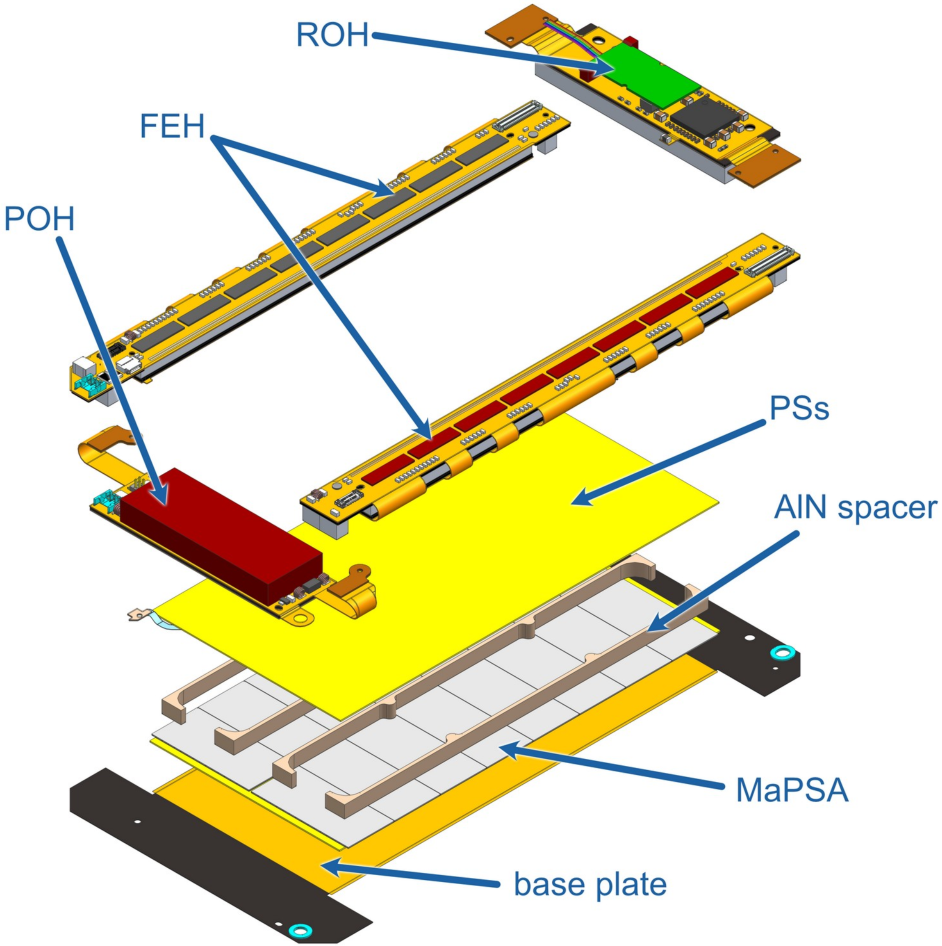
Great Plan, let's build these things

- DESY will build one entire endcap
- DESY plans to produce > 1150 PS modules
  - All of these will be *integrated* onto the support structures at DESY*
- The endcap built at DESY also holds a similar amount of 2S modules, which will be produced at KIT (Karlsruhe)

* Disclaimer: I will only cover the module assembly as such – not the integration on support structures

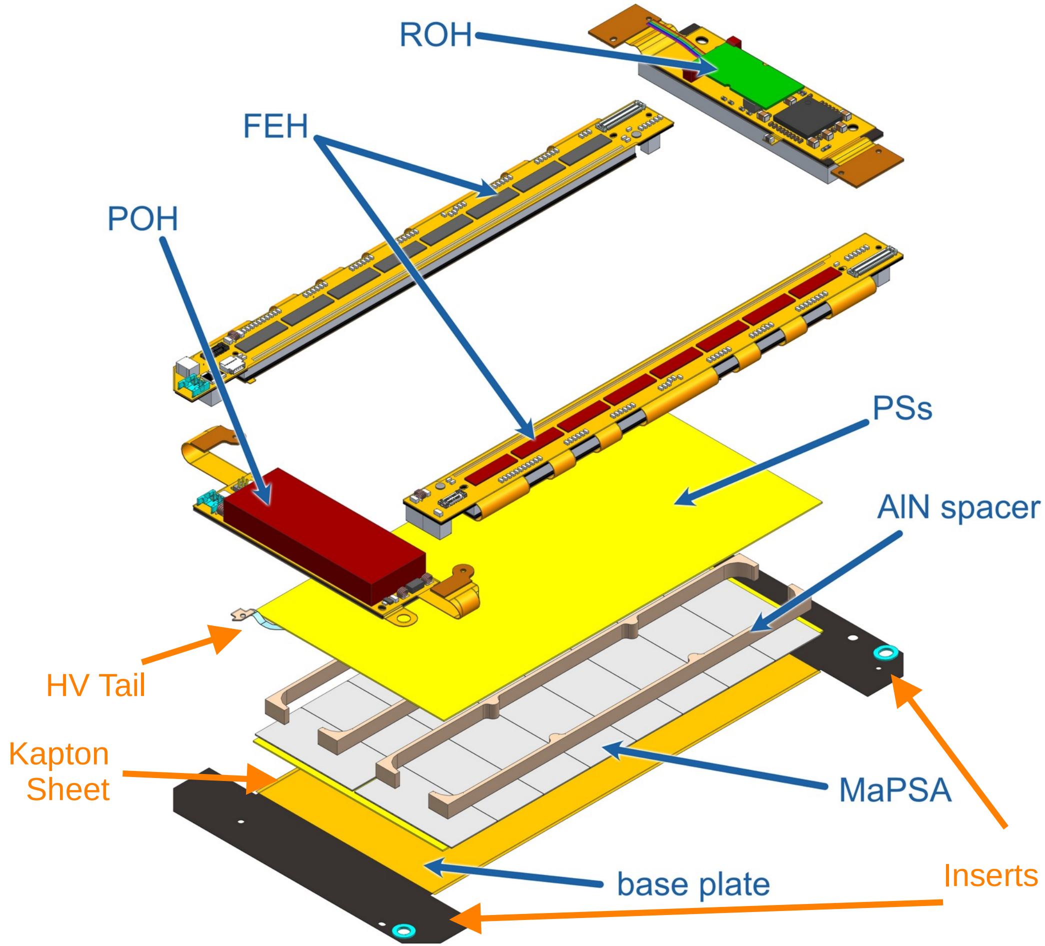
Module Production

- Components are purchased from industrial manufacturers
  - Centralised via CERN, then delivered to production sites
  - Sensors purchased from HPK (Hamamatsu)
- *Assembly*:
  - Join all components to a functioning module
- *Quality assurance/control**:
  - Components are tested and inspected at many steps during the assembly to verify good quality and to prevent waste of components



* Disclaimer: Also not covered here

The Components



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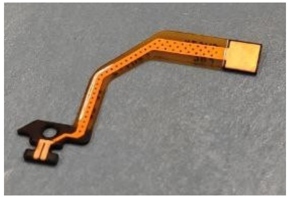
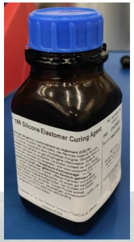
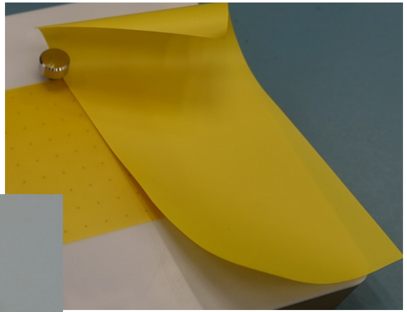
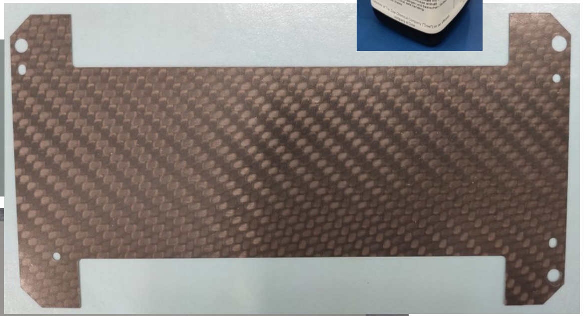
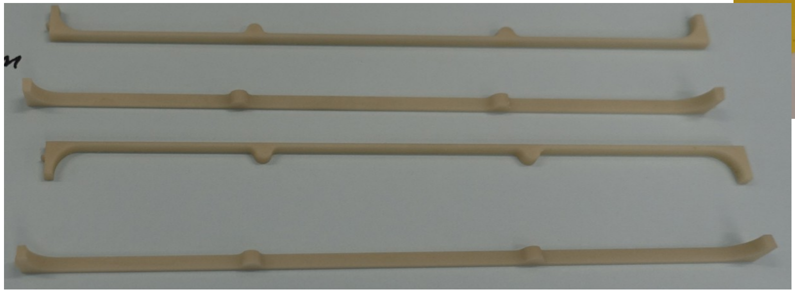
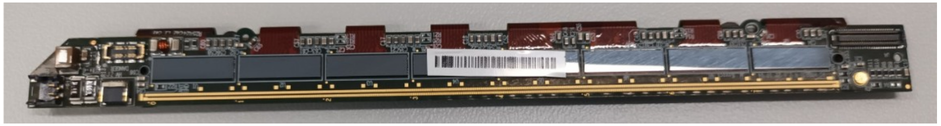









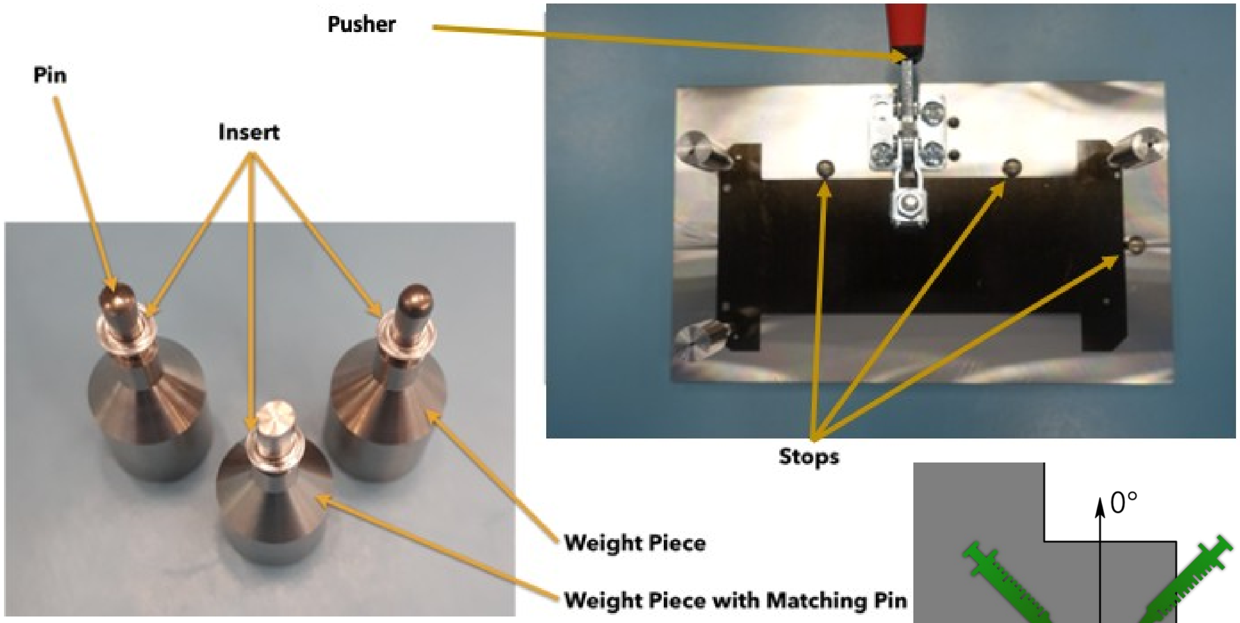



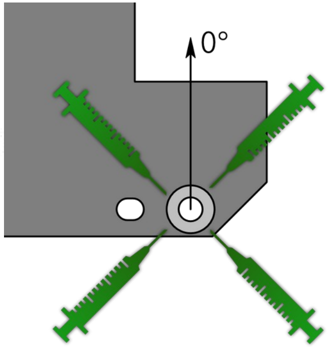

Assembly Steps

Preamble

- Large number of assembly steps required
  - Many of them don’t seem too challenging, but they require a high precision, high reproducibility and a *fast* throughput
- The development of individual assembly steps is distributed over the assembly centres
  - This includes the design, testing, manufacturing and distribution of jigs to other centres

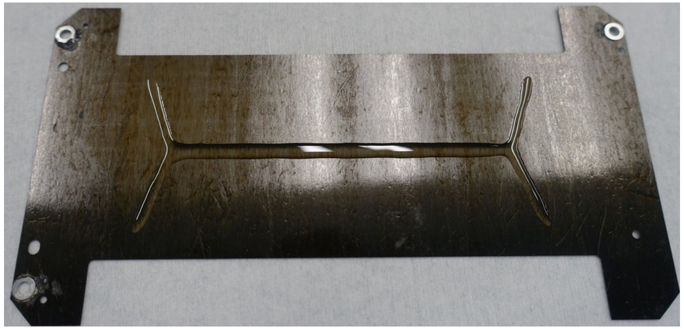
Baseplate + Inserts



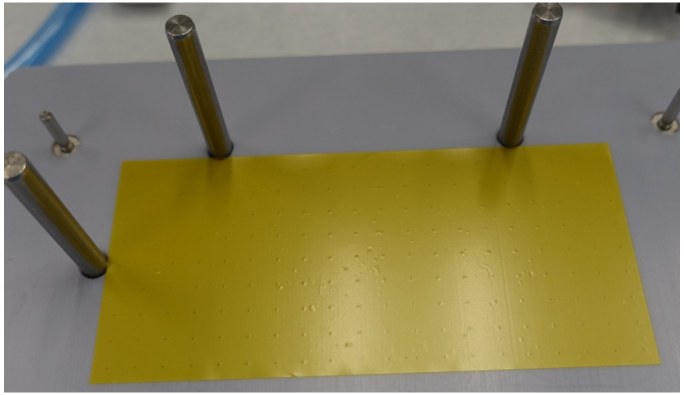


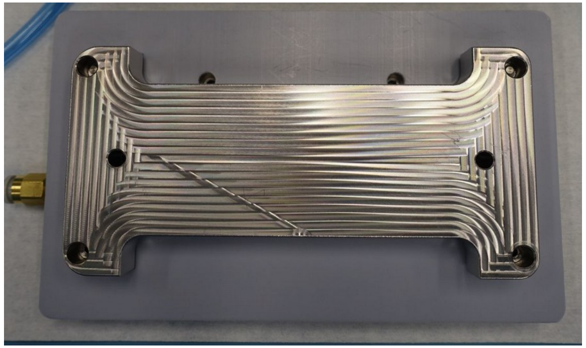
- Baseplate:
  - Carbon fibre reinforced plastic, 200 um thickness
  - Support for all other components (though not rigid)
- Inserts:
  - Aluminum *washers* with sleeves
  - Required for positioning of components and mounting on the support structure (disks)
  - Important for grounding
- Jig-based assembly

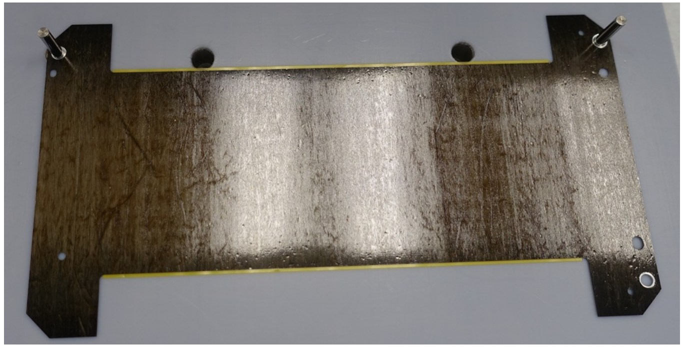
Baseplate + Isolator



- Kapton sheet (KS, ~20 um) as isolator between sensor backside (HV) and Baseplate
- Apply glue on Baseplate+Inserts
- Push KS against stops & fix via vacuum
- Flip Baseplate and position on KS via pins
- Place weight piece on top
- Leave for glue distribution & curing for ~24 h

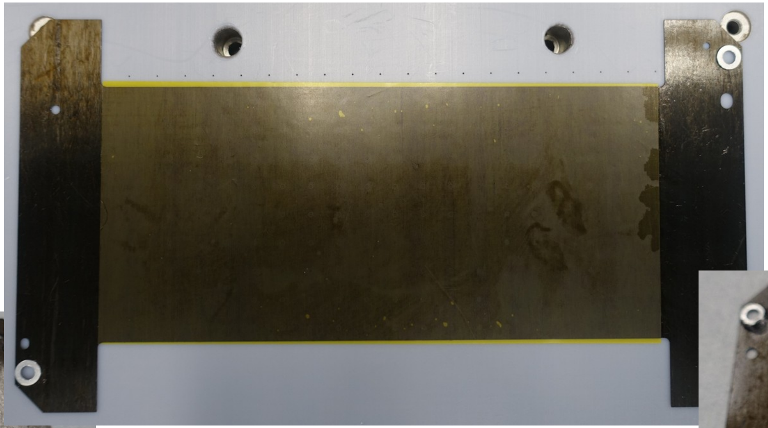


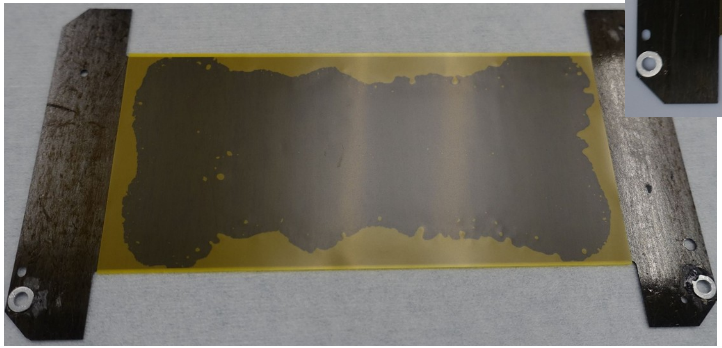


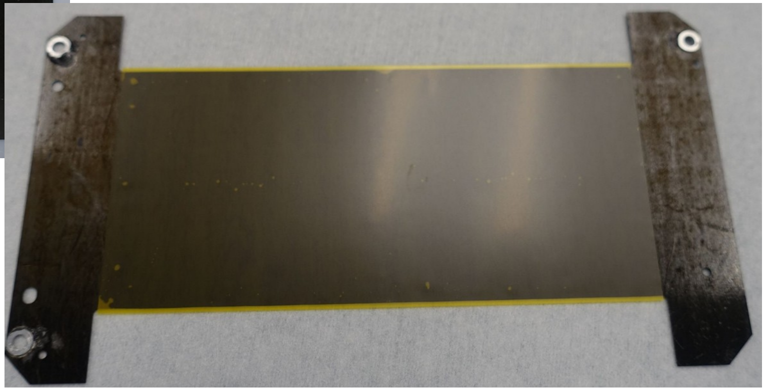


Reproducibility – Glue Application

- Good reproducibility is essential for a production of more than a thousand modules: positioning of components, **glue volume**, …

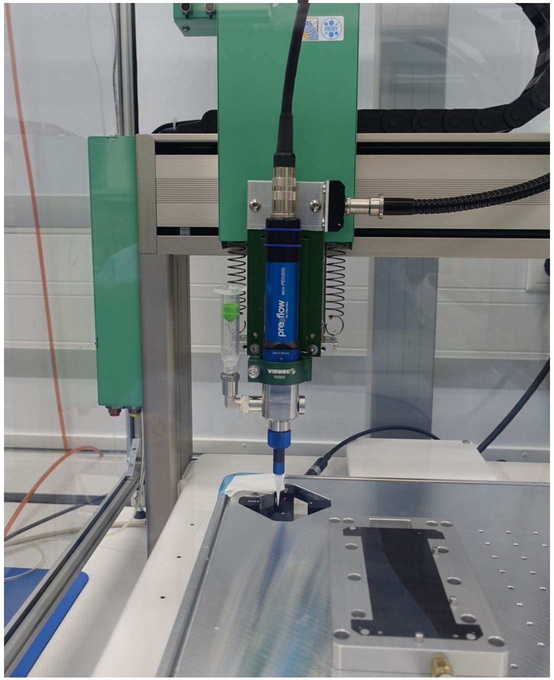






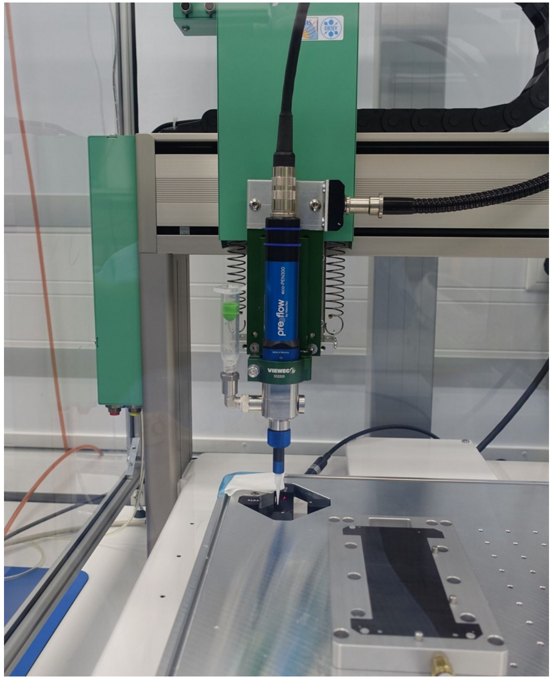
Volumetric Dispensing I

- Status Quo: purely pneumatic application of glue (Polytec 601-LV) via glue dispensing robot
- Issue:
  - Minimal changes in ratio of glue components ($\mathcal{O}(1\%)$) leads to viscosity variations
  - ➔ Significant variation in dispensed volume leads to spillage or lack of glue
- Solution:
  - Volumetric dispensing unit: *preeflow eco-PEN 300 SS & eco-CONTROL EC200*
  - Flow range: < 1.48 ml/min



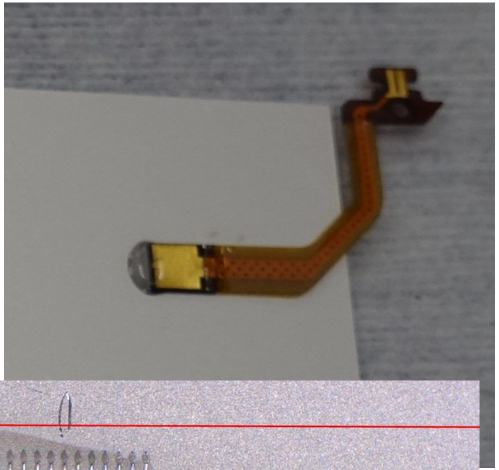
Volumetric Dispensing II

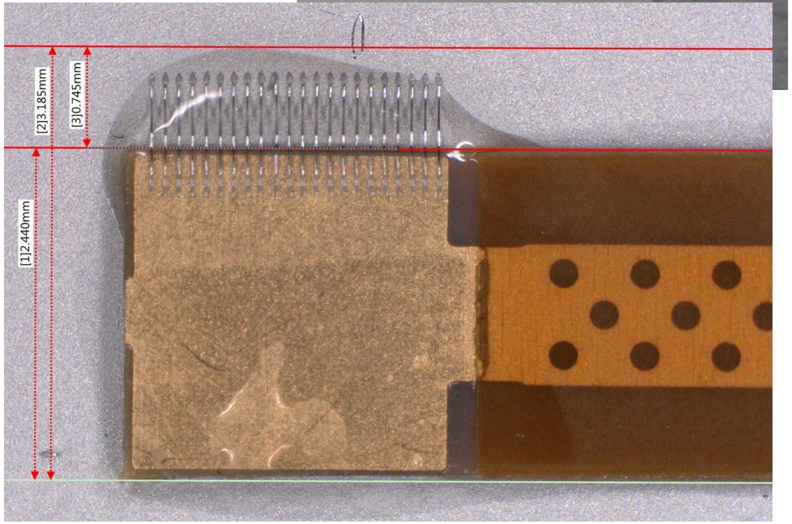
- Flow defined via eco-CONTROL (volume per time),
  kept the same for all assembly steps (0.04 ml/min)
- As before: programme defined via PC enables/disables the dispensing during motion
  - ➔ Line density defined via velocity
- High reproducibility in glue volume (e.g. $\mathcal{O}(2\ \mathrm{mg})$ in PI to BP)
  ($\rightarrow$ scale uncertainty)
- Higher reproducibility in needle position calibration (drop at needle tip)



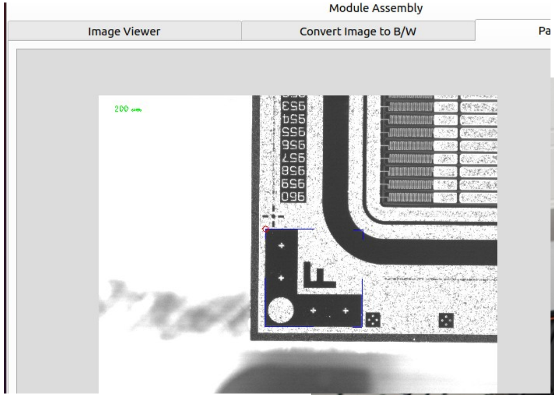
PSs + HV Tail

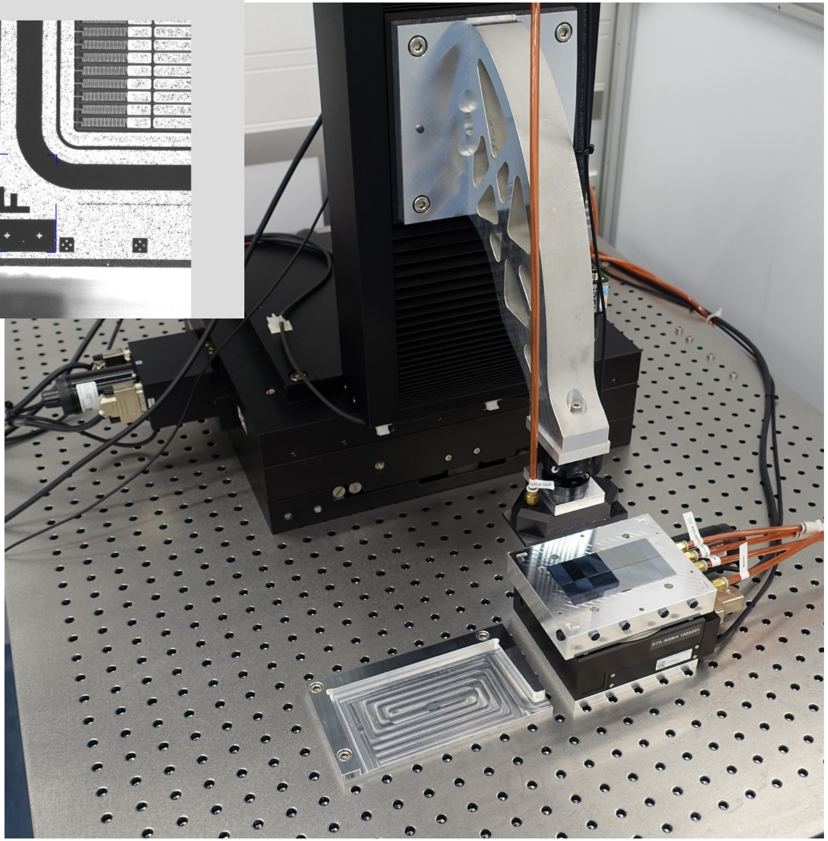
- HV Tail supplies backside of strip sensor with bias voltage
- Multiple steps:
  - Jig-based gluing of HV Tail to sensor
  - Wire bonding of HV Tail to sensor
  - Encapsulation of wire bonds





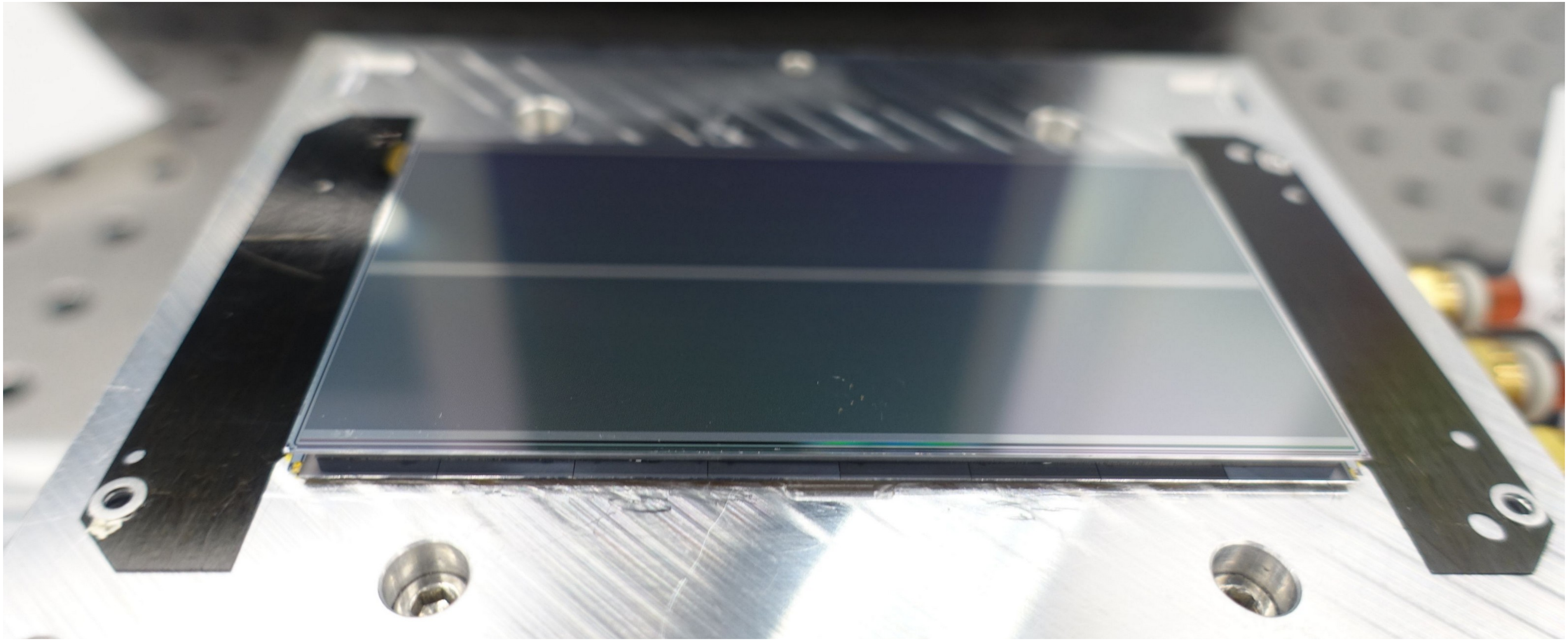
Bare Module *Automated* Assembly





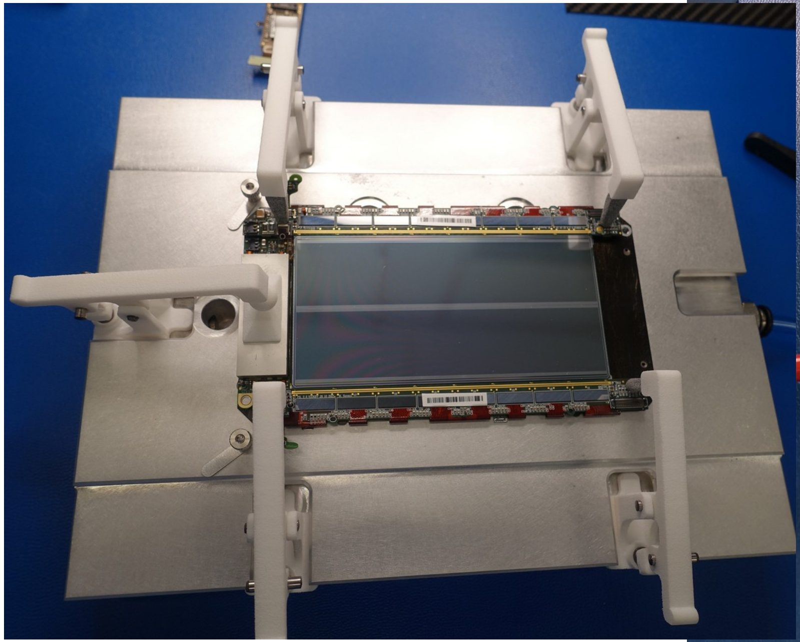
- Robotic assisted assembly of …
    - Baseplate (+Inserts+Isolator)
    - PSp (MaPSA, pixel sensor)
    - Spacers
    - PSs (strip sensor)
- High relative precision essential for this routine
    - Motion stages: ~ 4 um precision
    - Rotation stage: ~ 175 urad precision
    - Microscope camera: 1.2 um resolution
- Pattern recognition on fiducial markers on sensors guides the relative alignment of components
- Vertical stage with vacuum tool picks up and places components based on provided parameters and PatRec

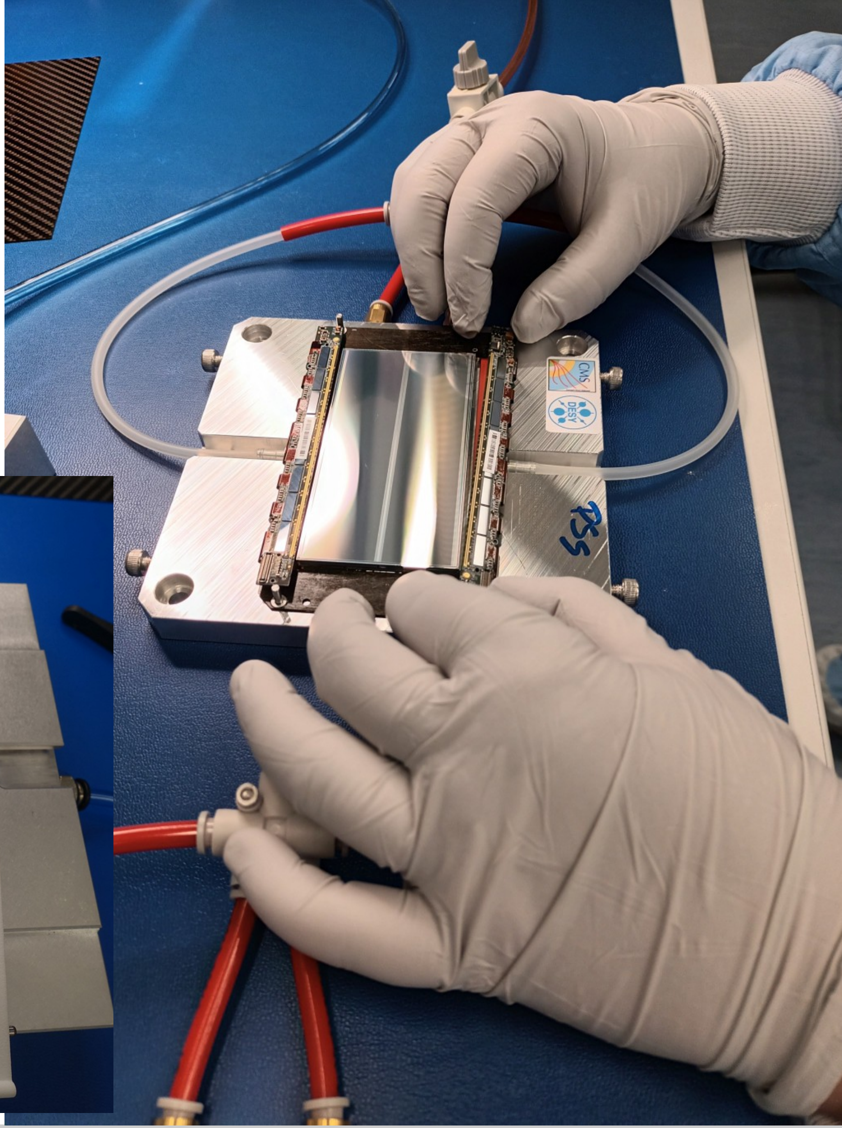
Bare Module *Automated* Assembly



Hybrid Gluing

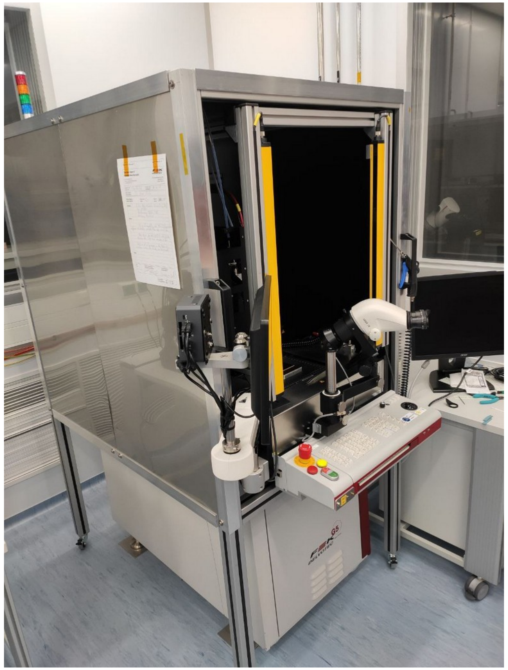
- Hybrids for signal collection, data aggregation, communication to services, power distribution
- Hybrids positioned via pins and fixed via pushers during glue curing

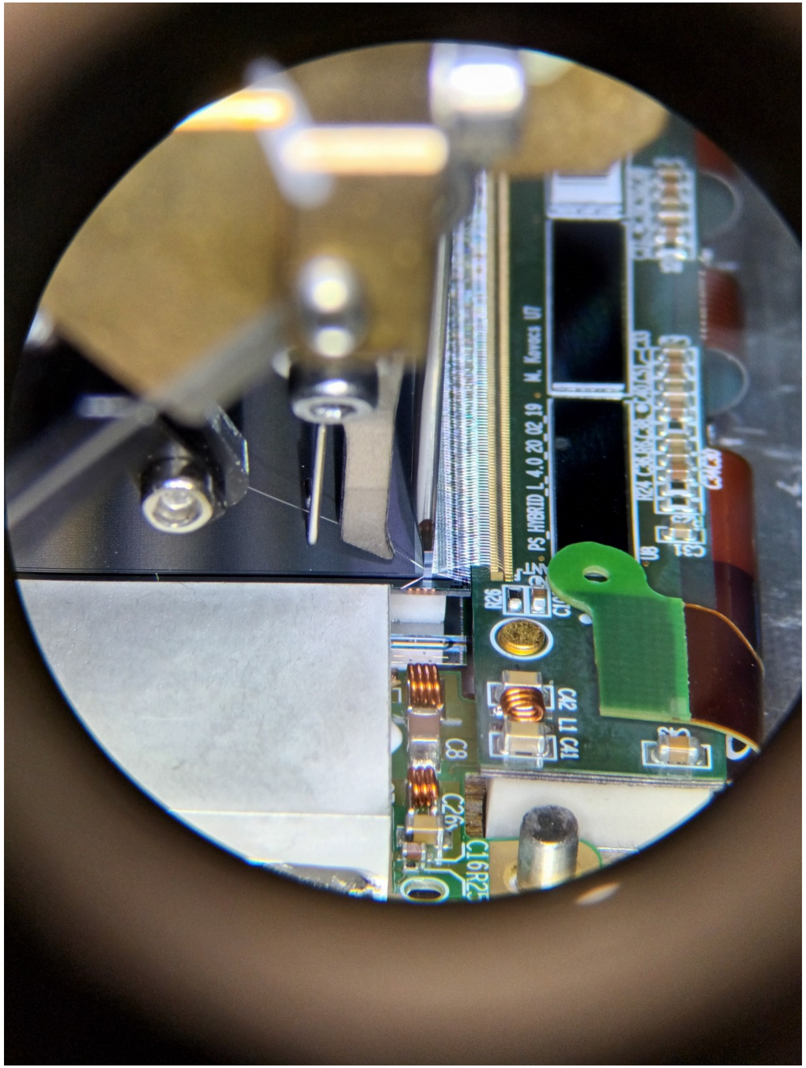




Wire bonding

- Wire bonds (25 um aluminum wire) to connect …
  - Sensors to hybrids
  - PSp to bias voltage
- Currently the bottleneck of the production:
  - ~ 2 h per module
  - Single machine available

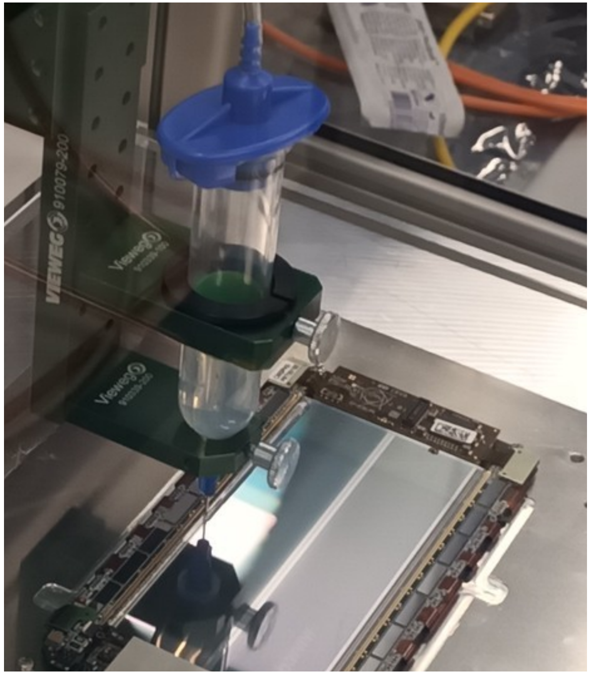


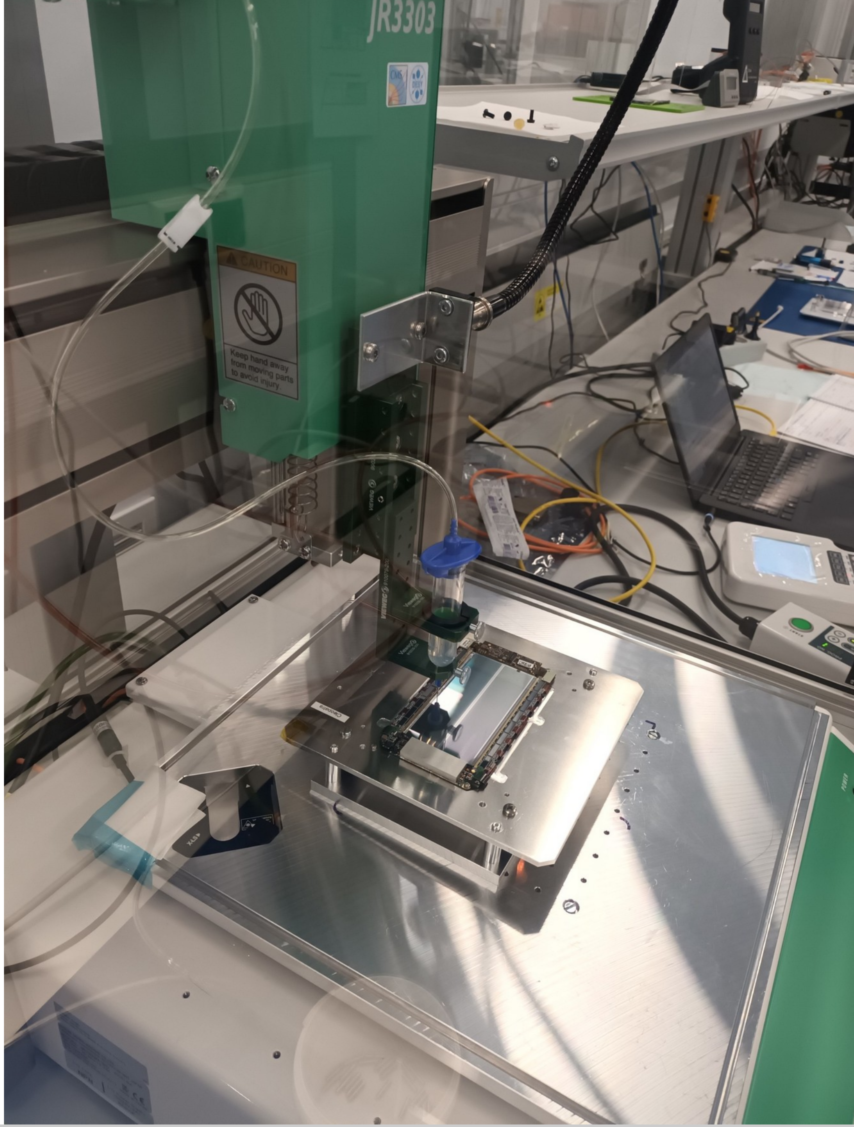


Wire bond Encapsulation

- Wire bonds are encapsulated for protection against physical damage and resonant vibrations in the magnetic field

- Glue dispensing robot: application of lines of Sylgard 186 (silicone elastomer)





Single Module Assembly Flow & Timeline

Assembly Step	Min. (curing) Time
Baseplate + Inserts	1 d
Baseplate + Isolator	1 d

Assembly Step	Min. (curing) Time
PSs + HV Tail (glue)	1 d
PSs + HV Tail (encap.)	1 d

Assembly Step	Min. (curing) Time
Automated Assembly	1.5 h + 1 d
Hybrid Gluing	1 d
Wire bonding (PSs)	1 h
Wire bonding (PSp)	1 h
Encapsulation (PSs)	1.5 d
Encapsulation (PSp)	1.5 d
Total	**~ 8 d**

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Electrical Test

Metrology

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Module Tests

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- Note: **These** are only the time-critical tests
- Additional reception tests on individual components

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- Another note:
  This is an ideal world scenario – permanent availability of personnel, tools and components
- More realistic: en-bloc preparation, delays …

PS Module Assembly @DESY
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Status

Kickoff Modules

- *Kickoff Batch*: ~ 5 modules to be built per assembly centre in Q3/4 2023
- Status @DESY:
  - Bare module assembly completed
  - Waiting for hybrid delivery
- Special case:
  - Module equipped with on-silicon temperature sensors for thermal studies on PS modules
  - Different workflow required
    - ➔ Strong angular misalignment of sensors

Kickoff Modules – Bare Module Metrology

- Metrology performed via SmartScope Flash CNC 300

Module ID	Δx [µm]	Δy [µm]	Δz [mm]	|α| (PSp-PSs) [µrad]
PS_26_05_DSY-00006	3	14	2.605	309
PS_26_05_DSY-00101	-3	-1	2.598	18
PS_26_05_DSY-00102	-23	-34	2.642	2590
PS_26_05_DSY-00103	-13	9	2.639	29
PS_26_05_DSY-00104	2	-162	2.597	91
PS_26_05_DSY-00105	1	-5	2.599	47

Temperature module

- Incident: in consequence to a software bug, the PSs+Spacers subassembly was (at the correct time and transverse position) moved onto the PSp+BP subassembly without braking. PSs+Spacers was subsequently moved up by 20 µm (glue joint).
  - ➔ Substantial force was applied on sensors and glue joints
  - ➔ Misalignment along y, IV measurement of PSs normal, PSp impossible to measure

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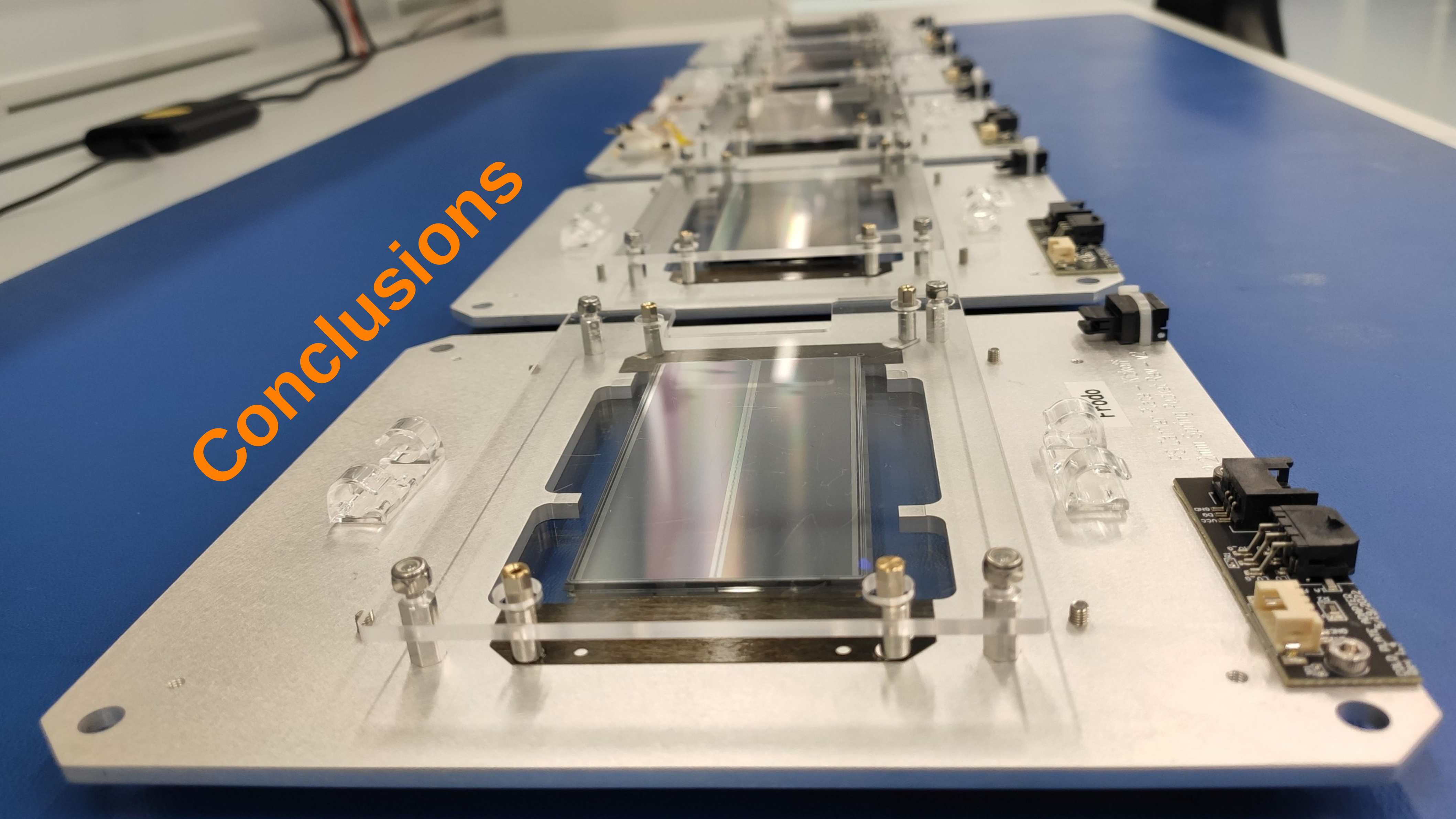
➔ Demonstrates ability to assemble PS modules well within specifications despite two issues with known causes


Conclusions

Conclusions

- Assembly workflow for PS modules presented
  - Kickoff (bare) modules assembled: positive results despite few issues
  - Looking forward to hybrid reception
- Assembly workflow established for single modules
  - ➔ Upscaling required for production (tools, personnel, schedules)
- Preproduction of PS modules to start in early 2024
  - Begin with reduced production throughput
- Series production to start in Summer 2024

- Feel free to visit us in 25c and take a look