

# SiPM-on-Tile Technology

## Status and Developments

Run: 60225 Event: 2829 Date: 09.05.2018 Time: 14:27:33.000000000

6th DUNE Near Detector Meeting.2019

DESY, Hamburg, October 22, 2019

Felix Sefkow  
DESY



# Outline

for this talk

**Calorimeter prototypes for future  $e^+e^-$  colliders**

**Production procedures**

**Electronics directions**



# Prototyping Experience for an $e^+e^-$ Detector

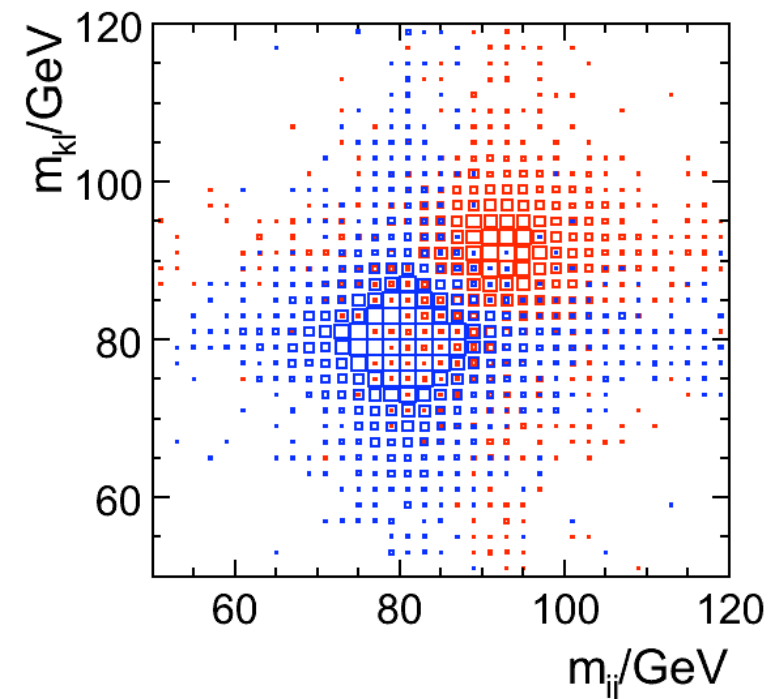
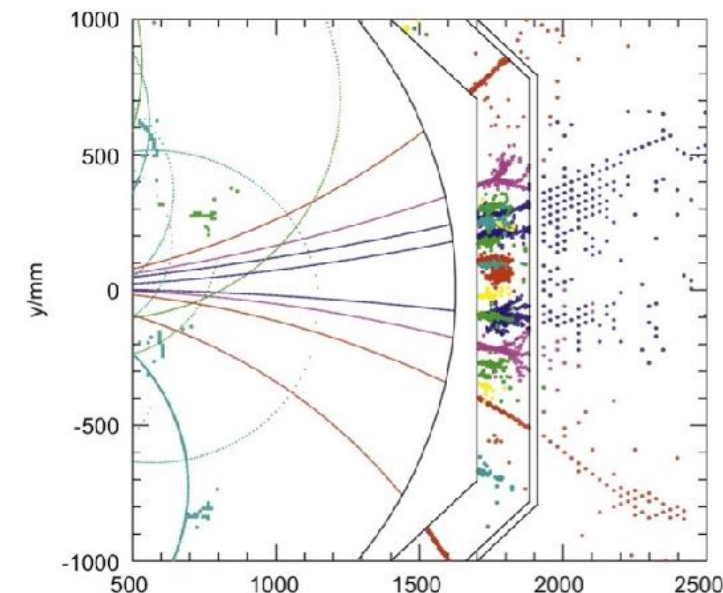
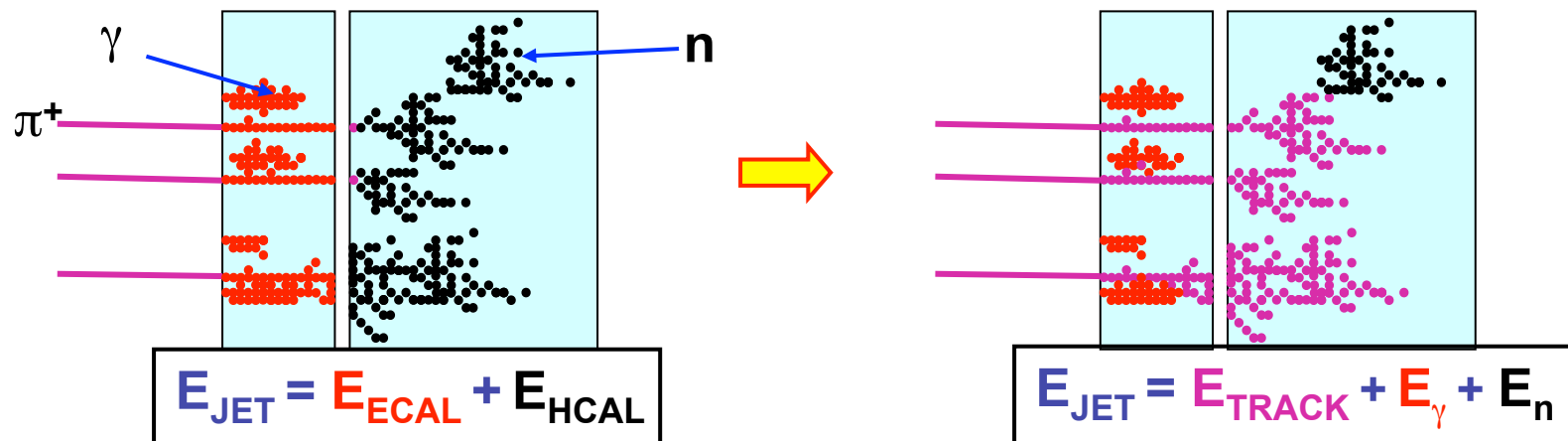
# Particle Flow Paradigm

Tackle the jet energy challenge.

Reconstruct each particle individually and use optimal detector

Requires fine 3D segmentation of and sophisticated software

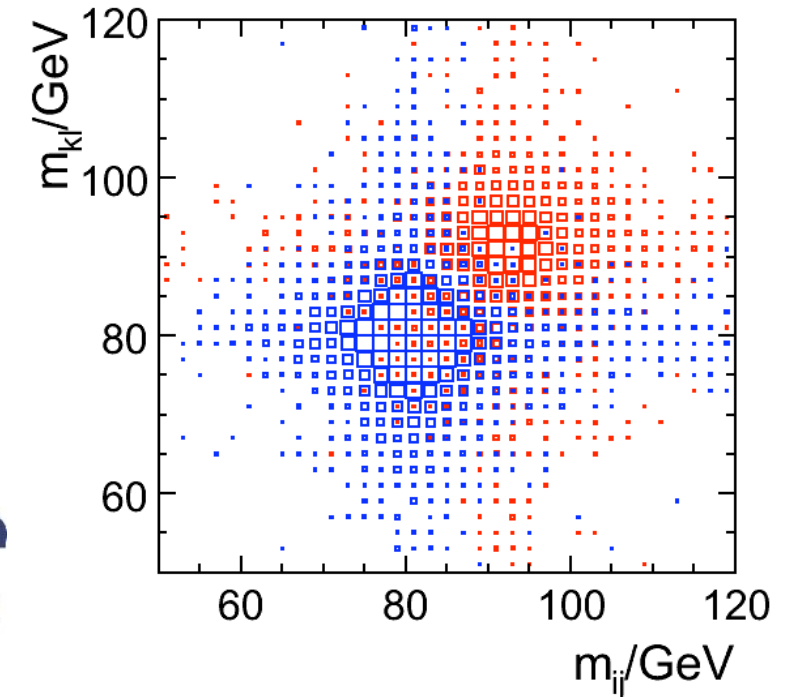
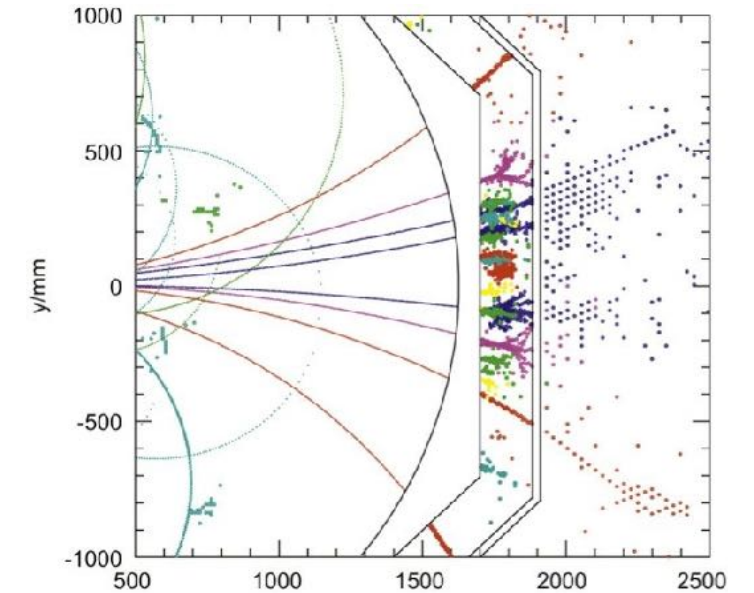
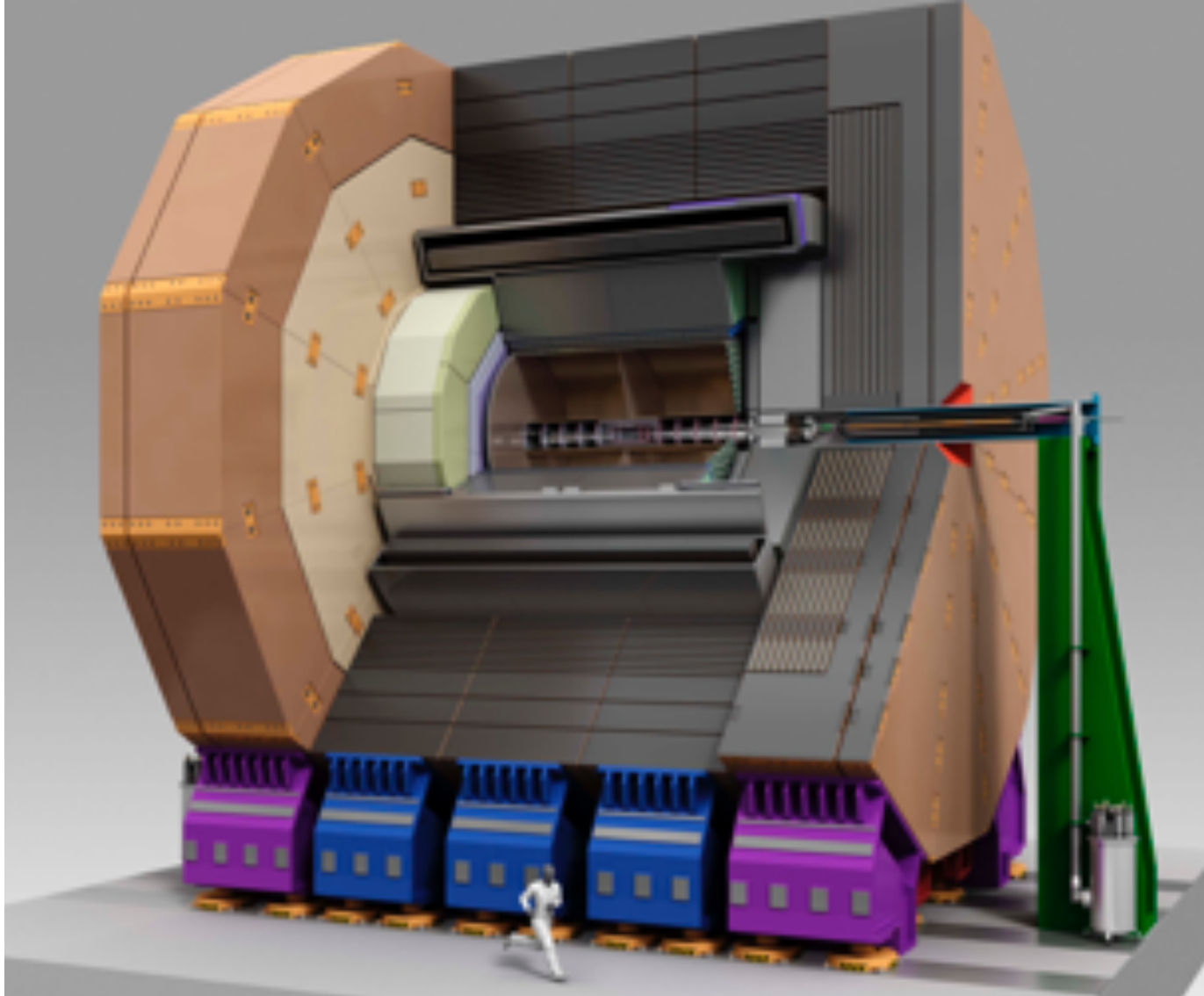
Today all linear collider detector concepts follow particle flow concept





# Particle Flow Paradigm

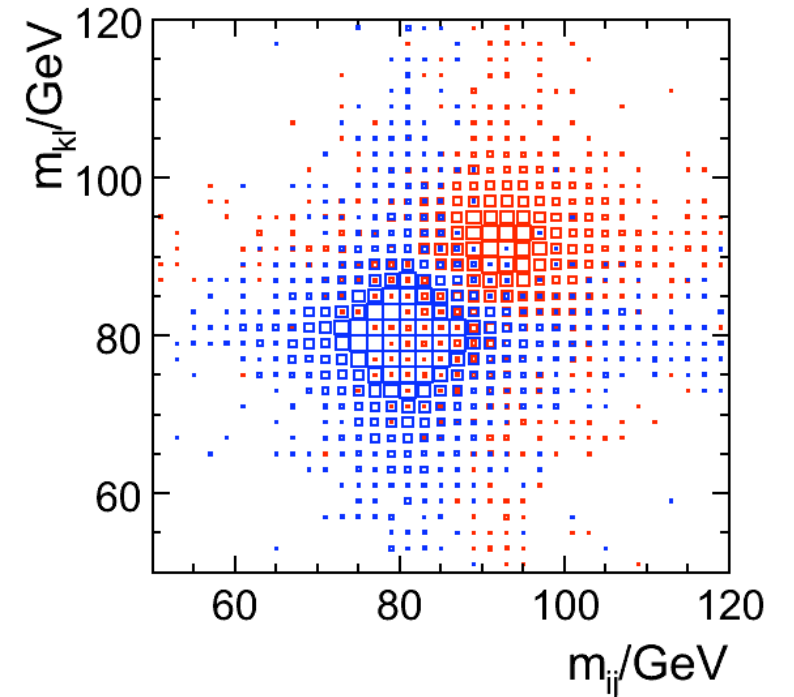
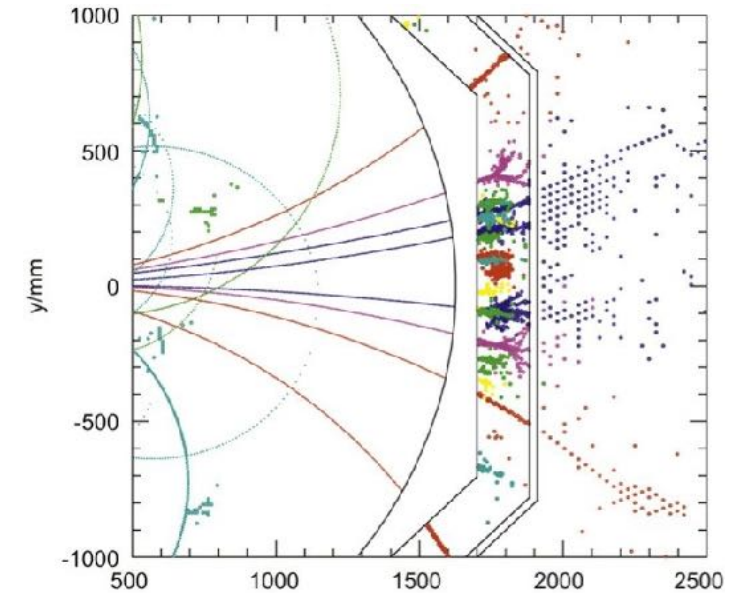
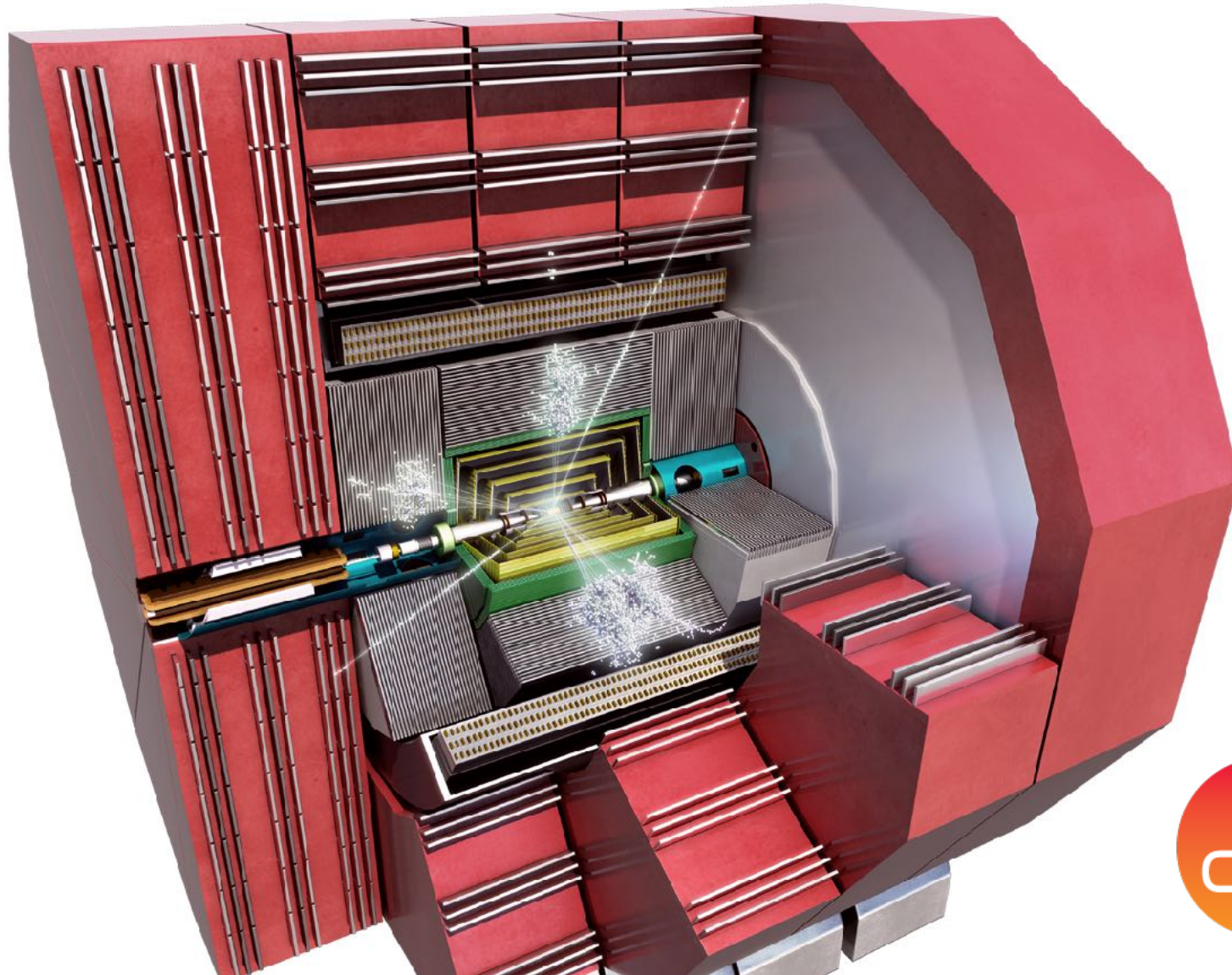
Tackle the jet energy challenge.



ilc

# Particle Flow Paradigm

Tackle the jet energy challenge.





# Technologies for Highly Granular Calorimeters

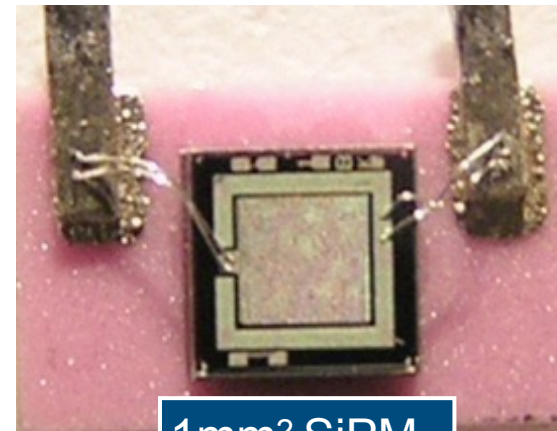
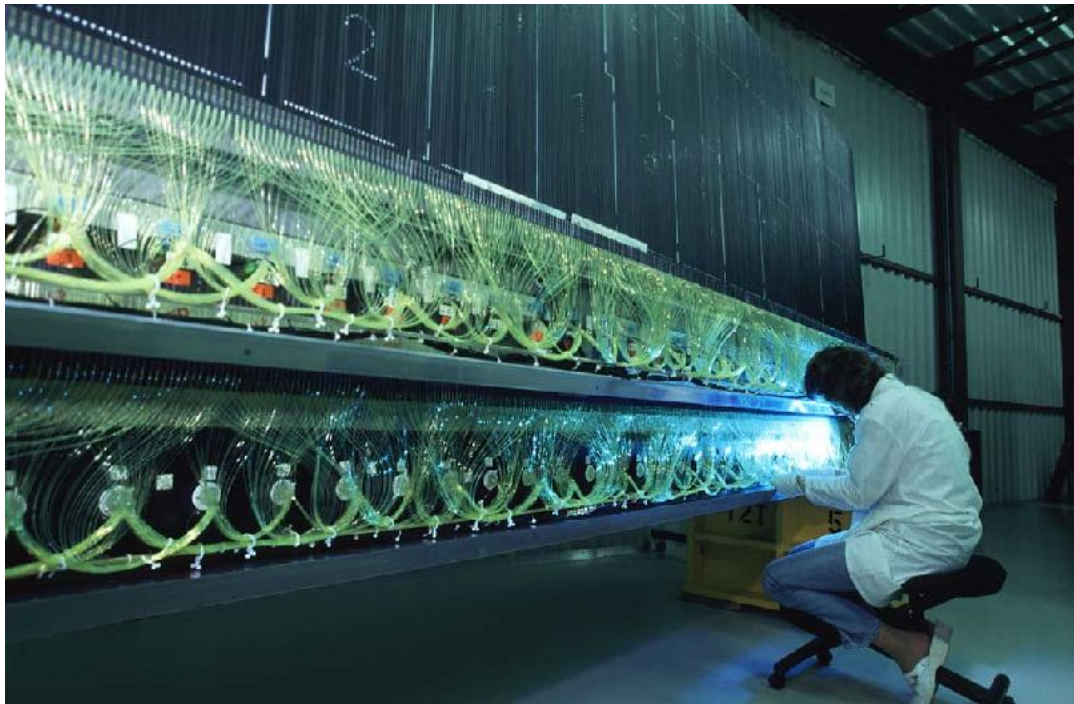
Because we can.

## Large area silicon arrays

- silicon calorimetry grows out of the domain of small plug devices

## New segmented gas amplification structures (RPC, GEM, $\mu$ Ms)

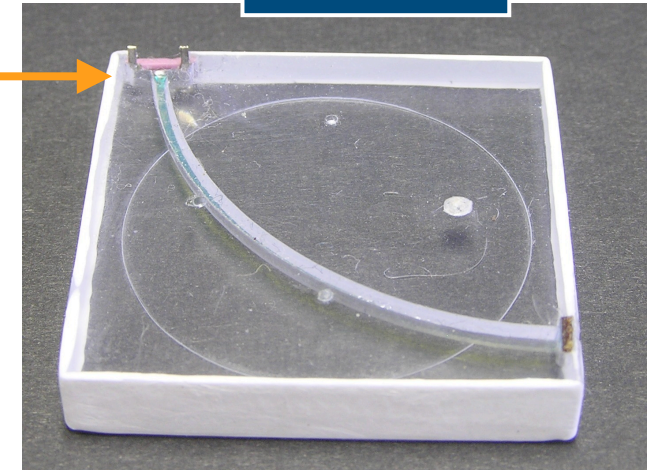
## Silicon photomultipliers on scintillator tiles or strips



1mm<sup>2</sup> SiPM

2004

3x3cm<sup>2</sup> tile

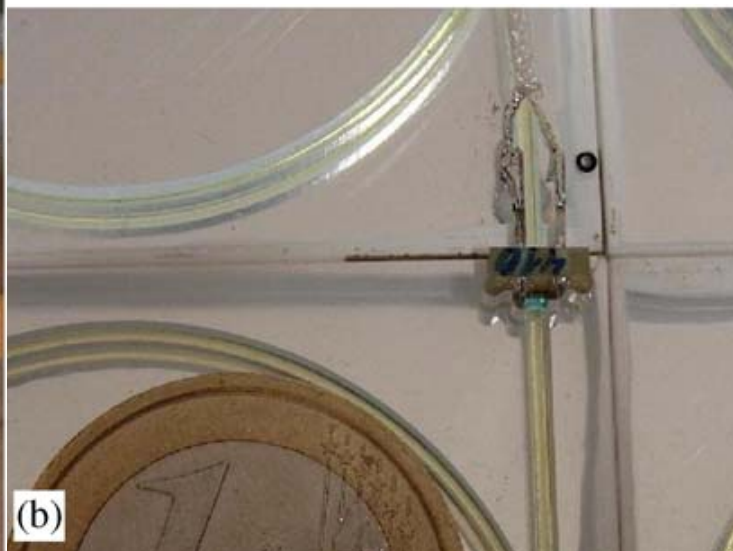
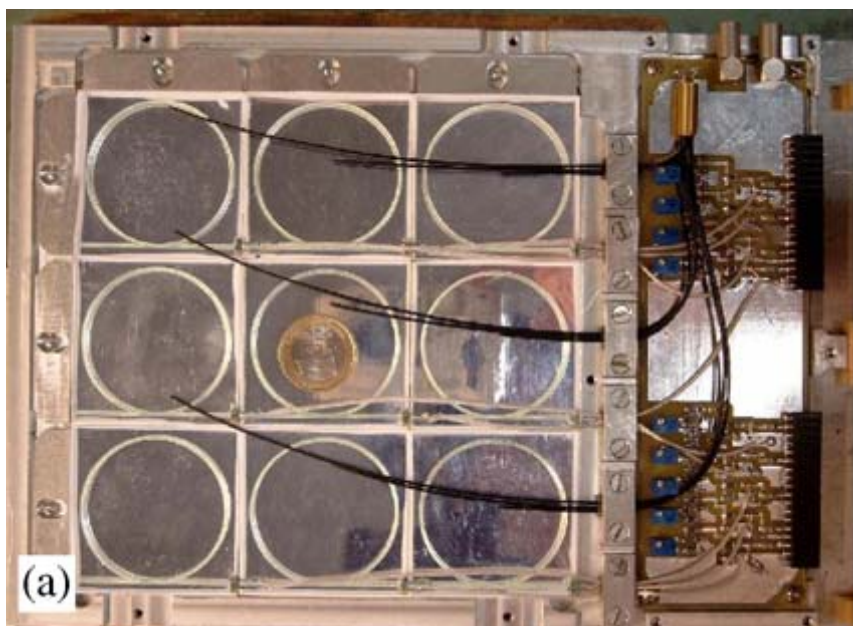


small, B-insensitive, cheap, robust

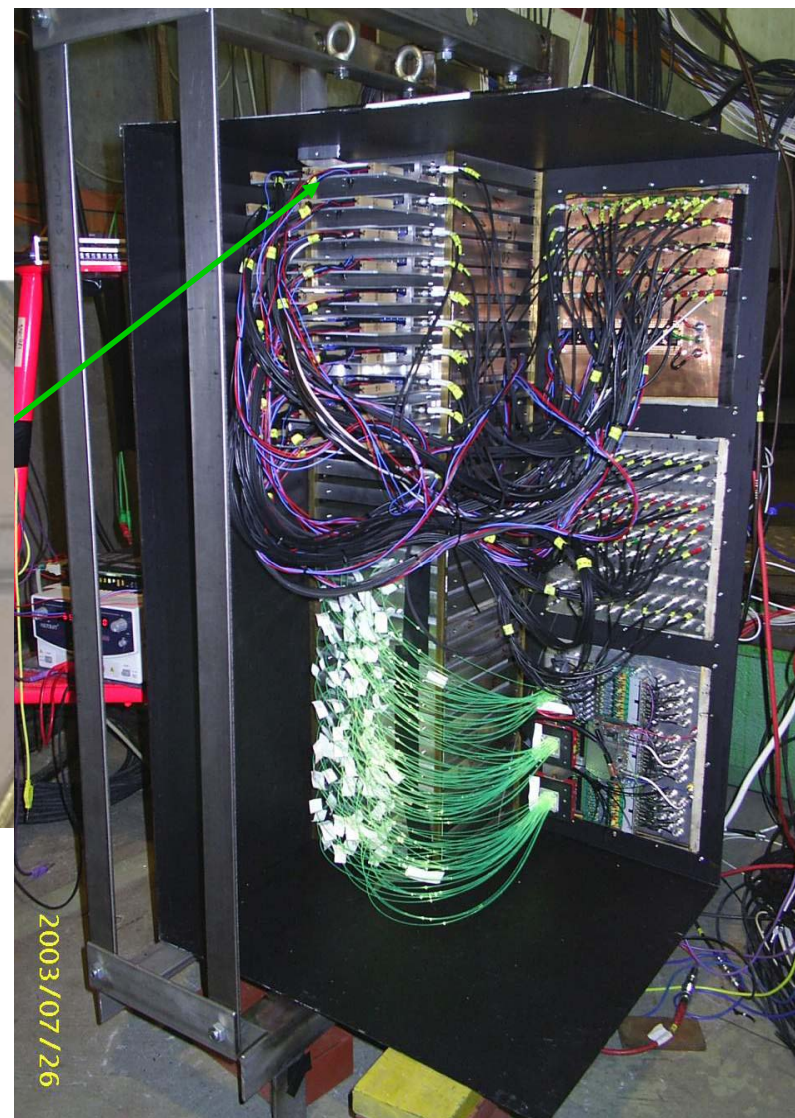


# SiPM-on-Tile Evolution

A long way



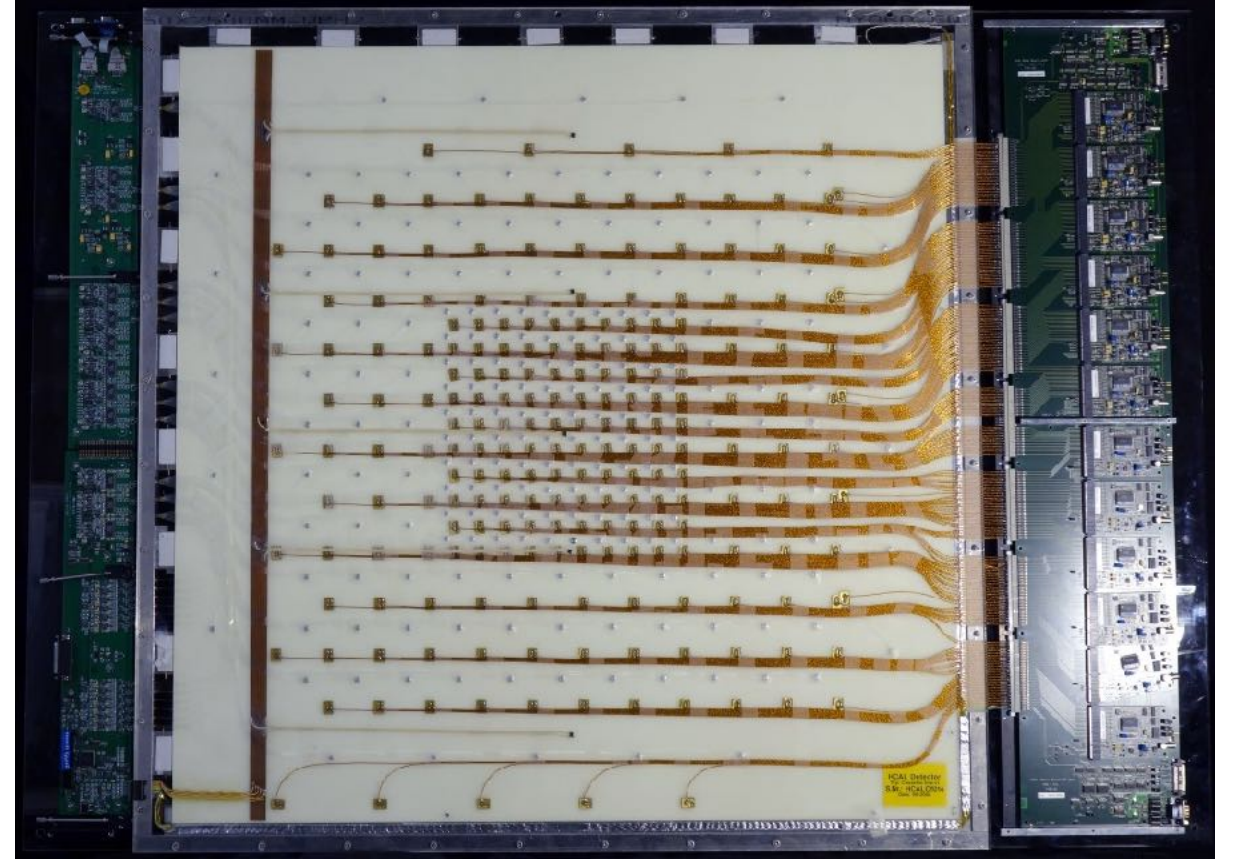
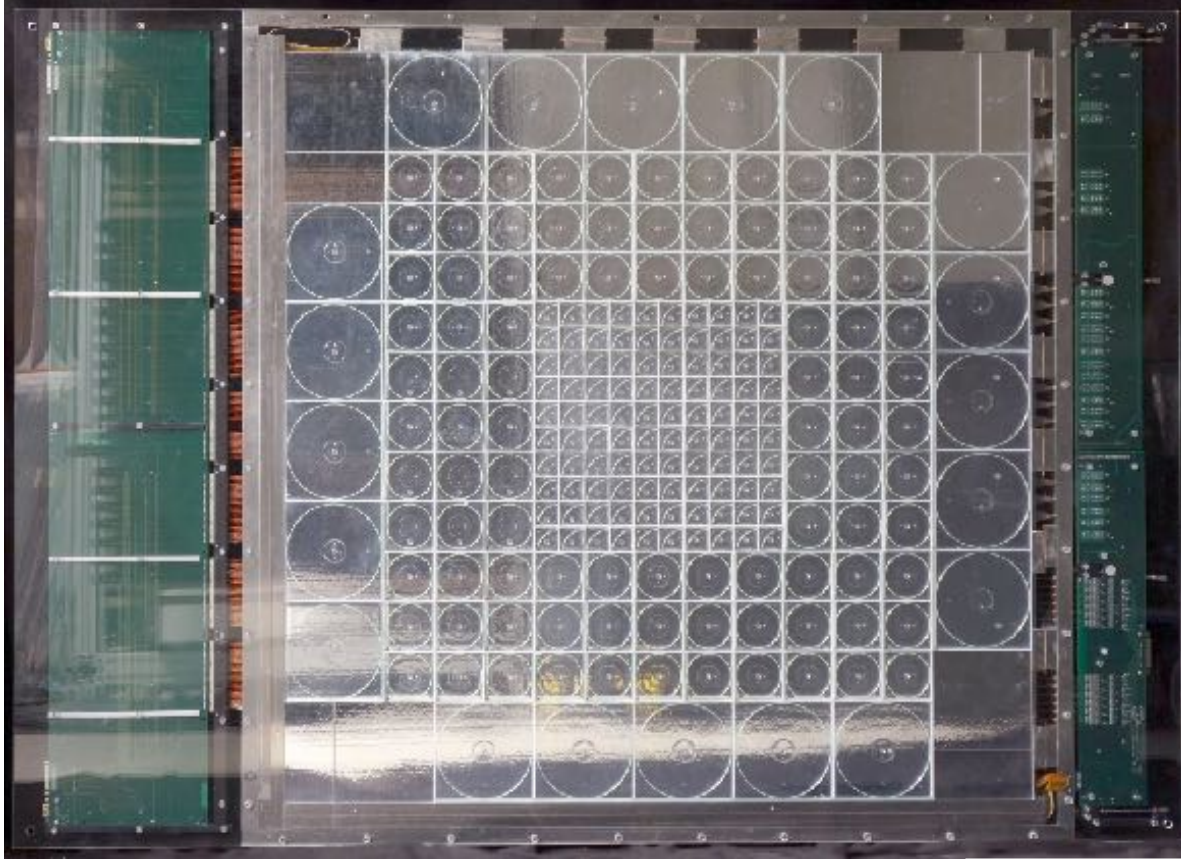
2003: MiniCal





# SiPM-on-Tile Evolution

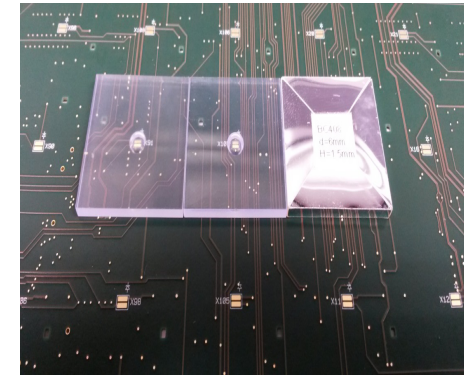
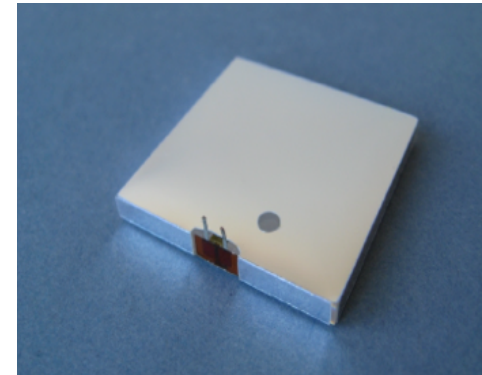
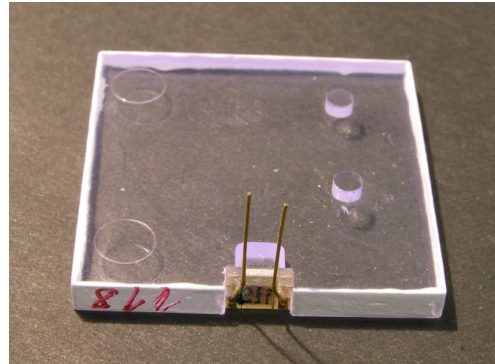
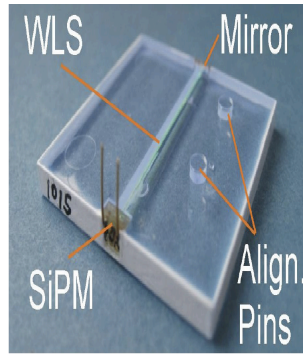
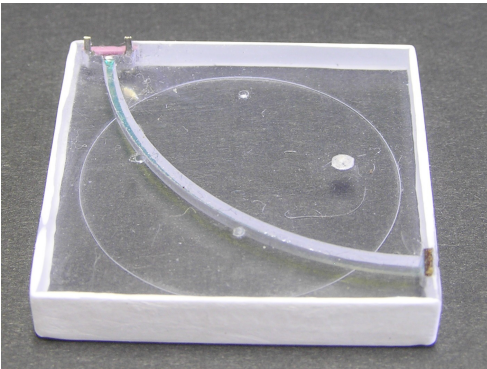
A long way



2006: Physics Prototype

# SiPM-on-Tile Evolution

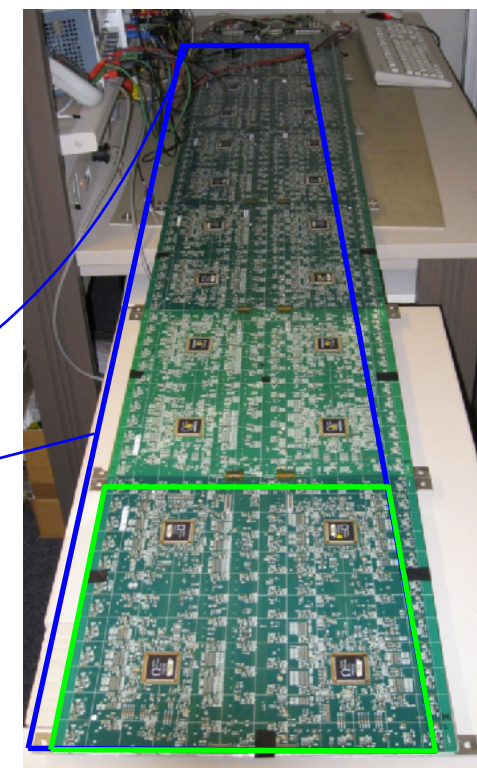
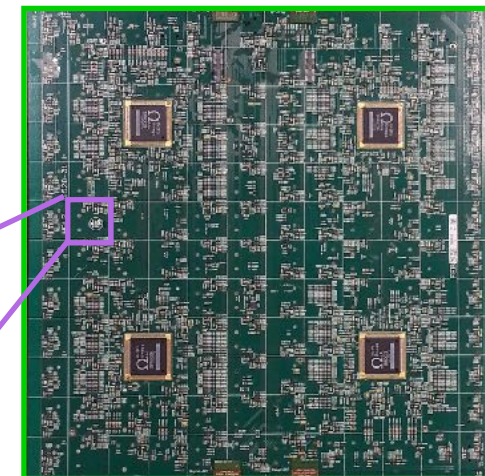
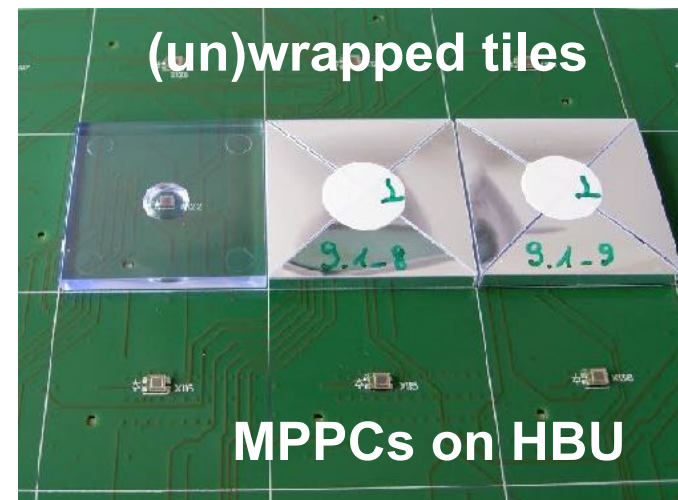
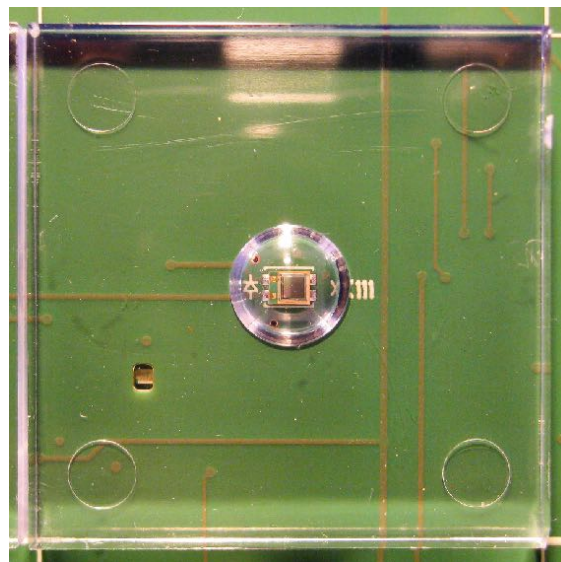
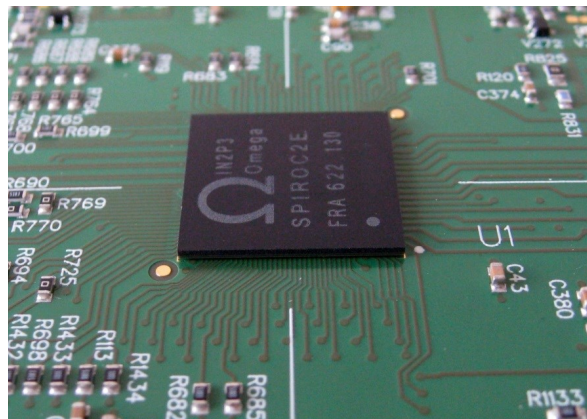
A long way



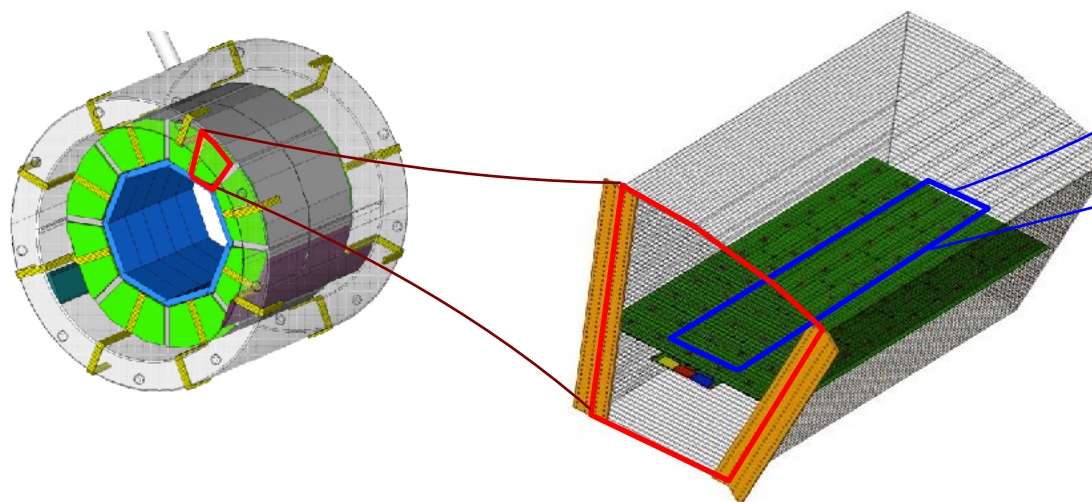


# The Next Step: Scalability

Technological prototypes.



- 1000's of channels per  $m^2$
- 1000's of  $m^2$
- must embed electronics and go digital as early as possible; power pulsing
- Integrate SiPMs in read-out board, too



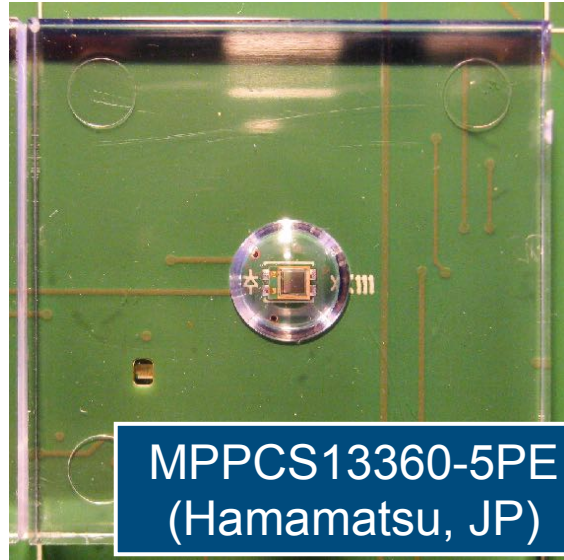


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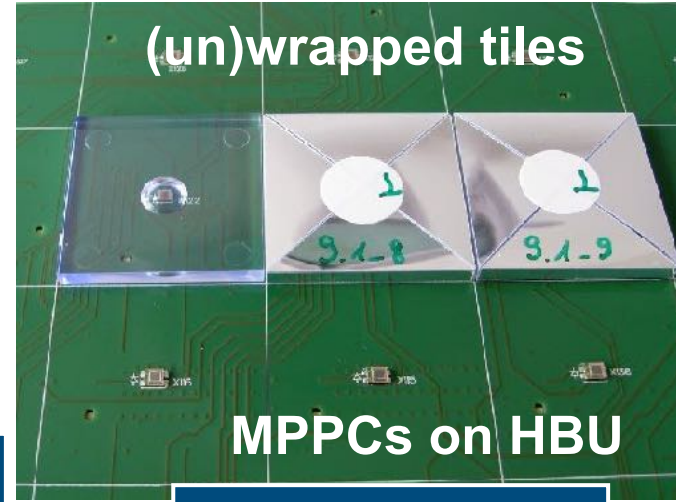
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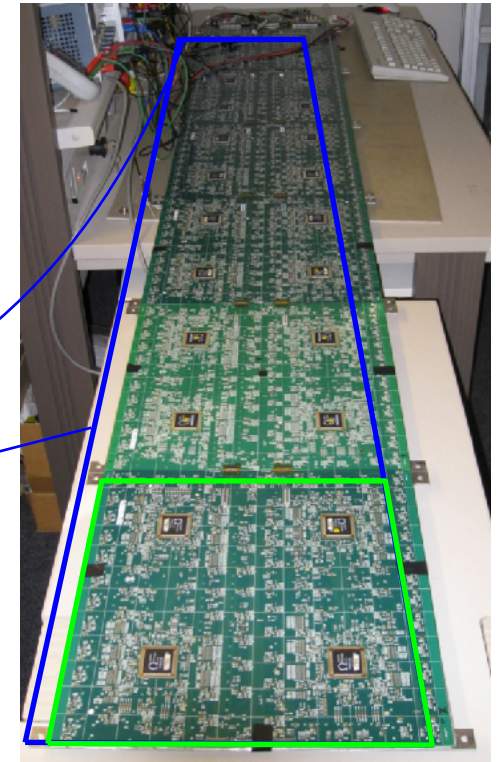
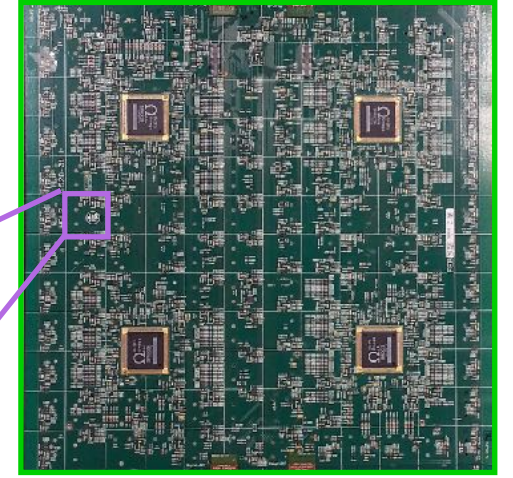
SPIROC2E  
(OMEGA, F)



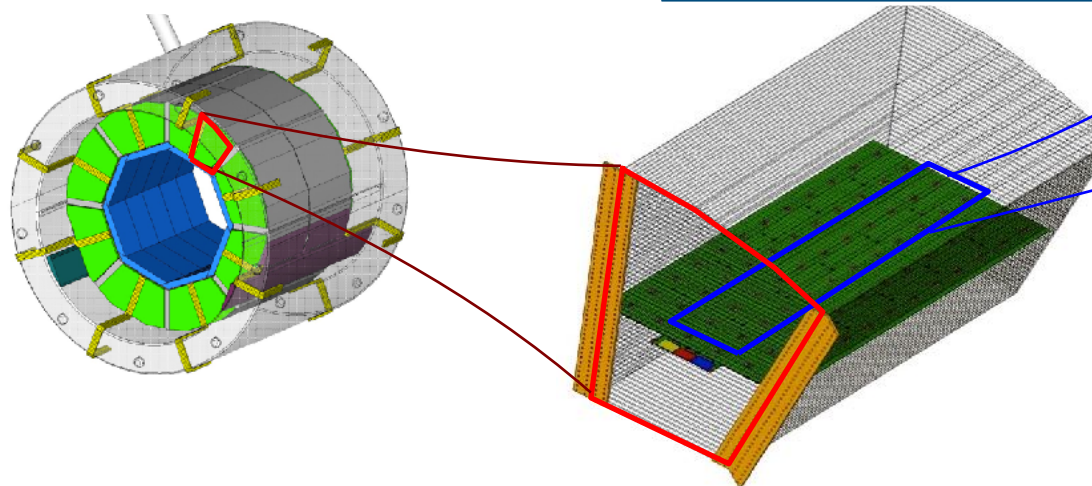
MPPCS13360-5PE  
(Hamamatsu, JP)



polystyrene tiles  
(Uniplast, RU)  
with ESR film



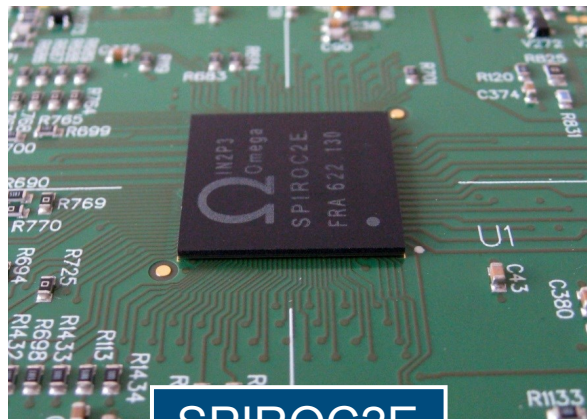
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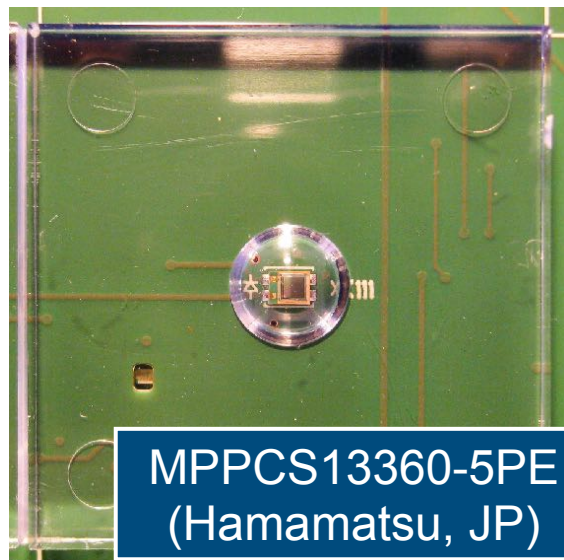


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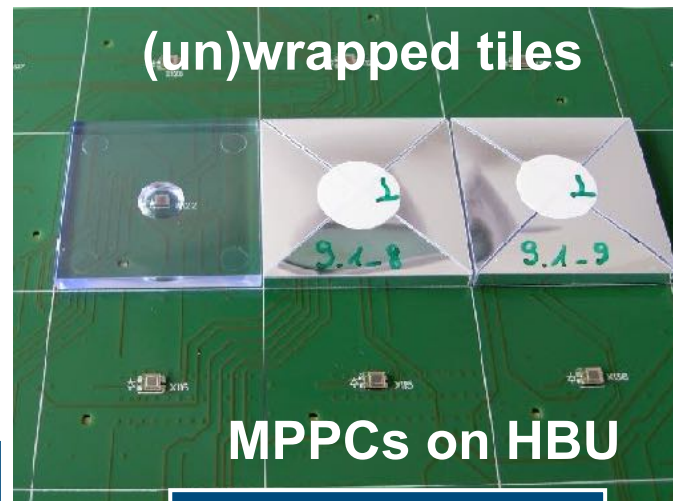
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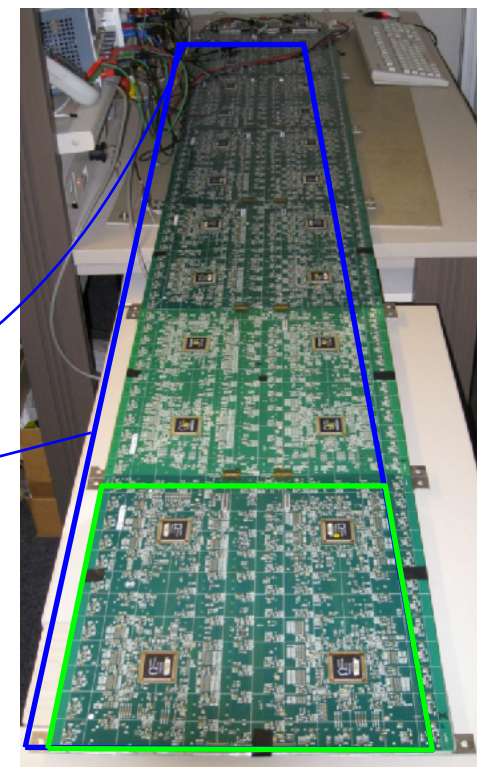
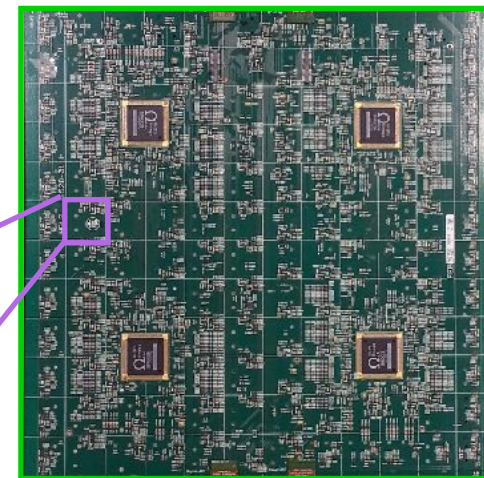
SPIROC2E  
(OMEGA, F)



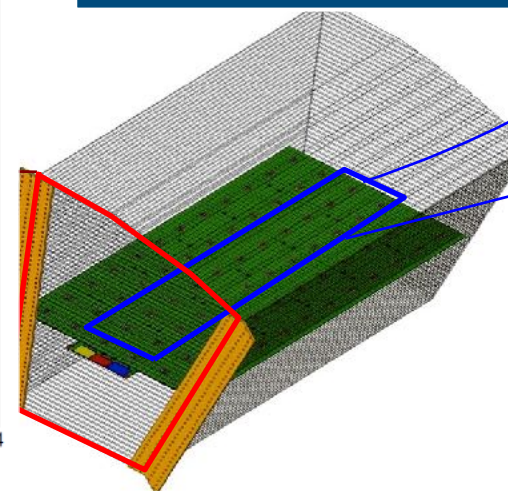
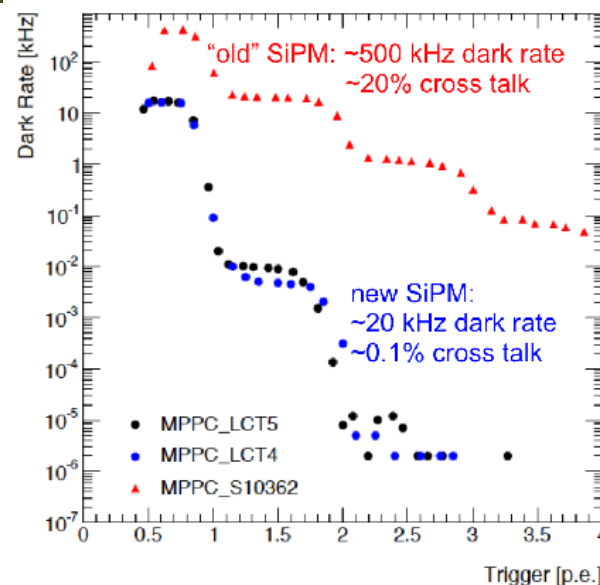
MPPCS13360-5PE  
(Hamamatsu, JP)



polystyrene tiles  
(Uniplast, RU)  
with ESR film



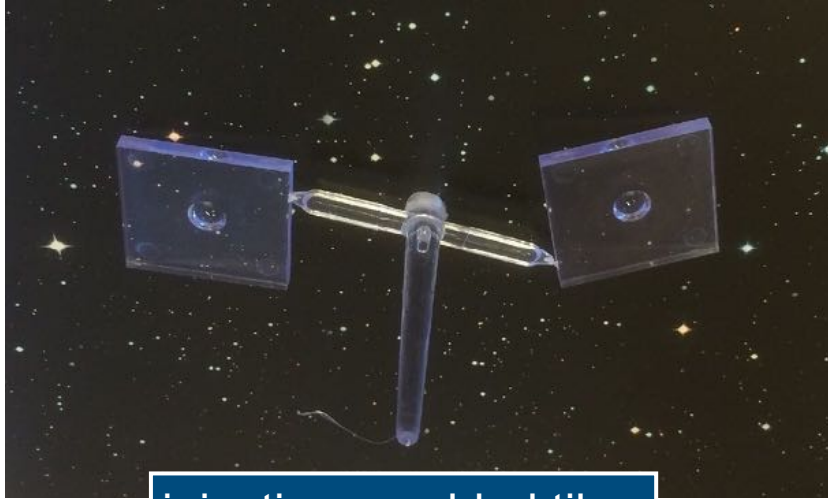
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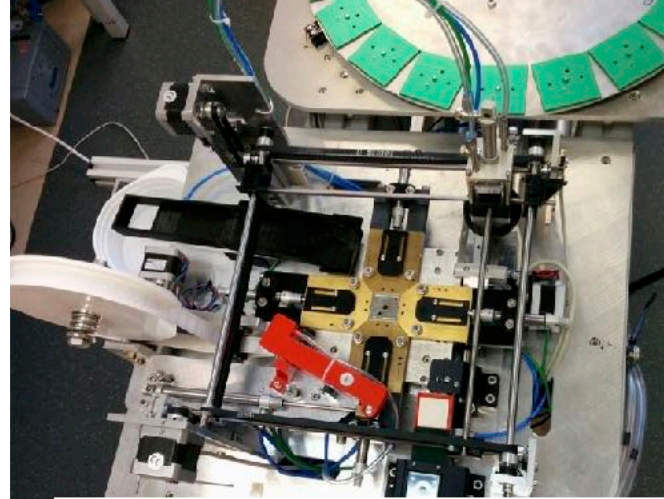


# Automated Production and Quality Assurance

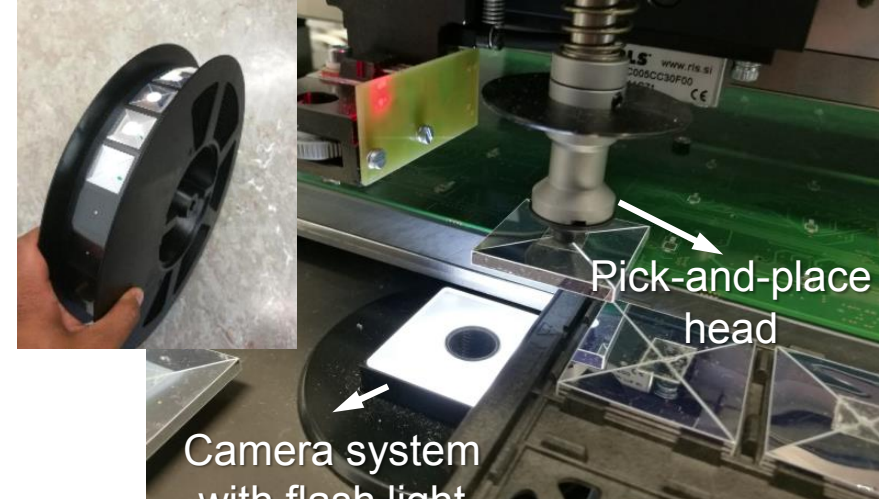
Establishing the concept.



injection-moulded tiles



reflector wrapping machine



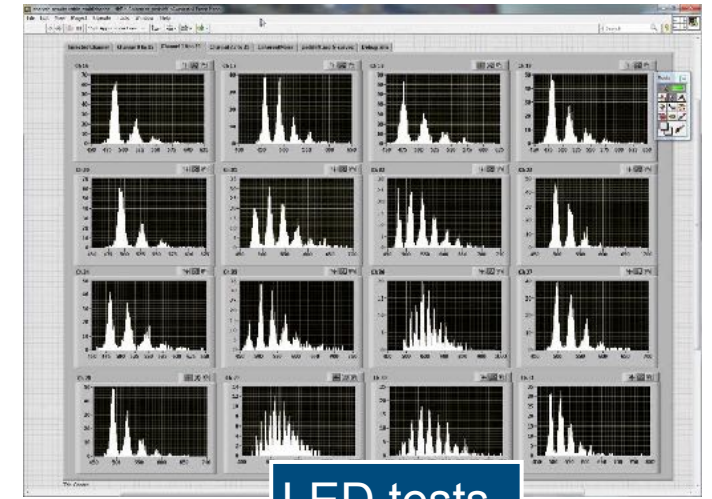
tile-board assembly

In addition test infrastructures:

- Multi-channel SiPM tests
- Automated ASIC tests
- PCB tests using LEDs
- Cosmic tests after tile assembly



read-out boards



LED tests



# Mechanical Structure and System Integration

Prototyped.

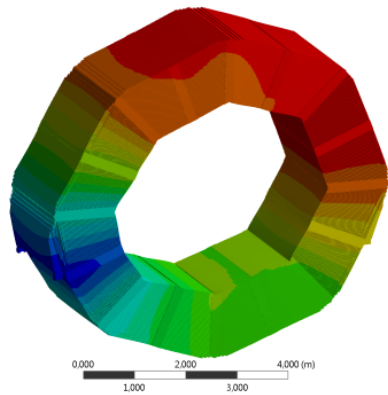
**Stack services dimensioned for full collider detector**

- Data concentration
- Power distribution
- Cooling

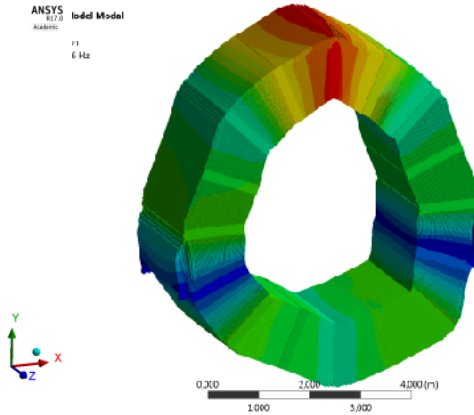
**Dynamic stability studies: simulate seismic shocks and optimise**

1: 2016 03 11 Shell-Model Model  
Total Deformation  
Type: Total Deformation  
Frequency: 2.826279326 Hz  
Unit: m

0.0027313 Max  
0.0025362  
0.0023411  
0.002146  
0.0019509  
0.0017559  
0.0015608  
0.0013657  
0.0011706  
0.00097547  
0.00078038  
0.00058528  
0.00039019  
0.00019509  
0 Min



ANSYS  
161.0  
Academic  
11  
6 Hz



ANSYS  
161.0  
Academic



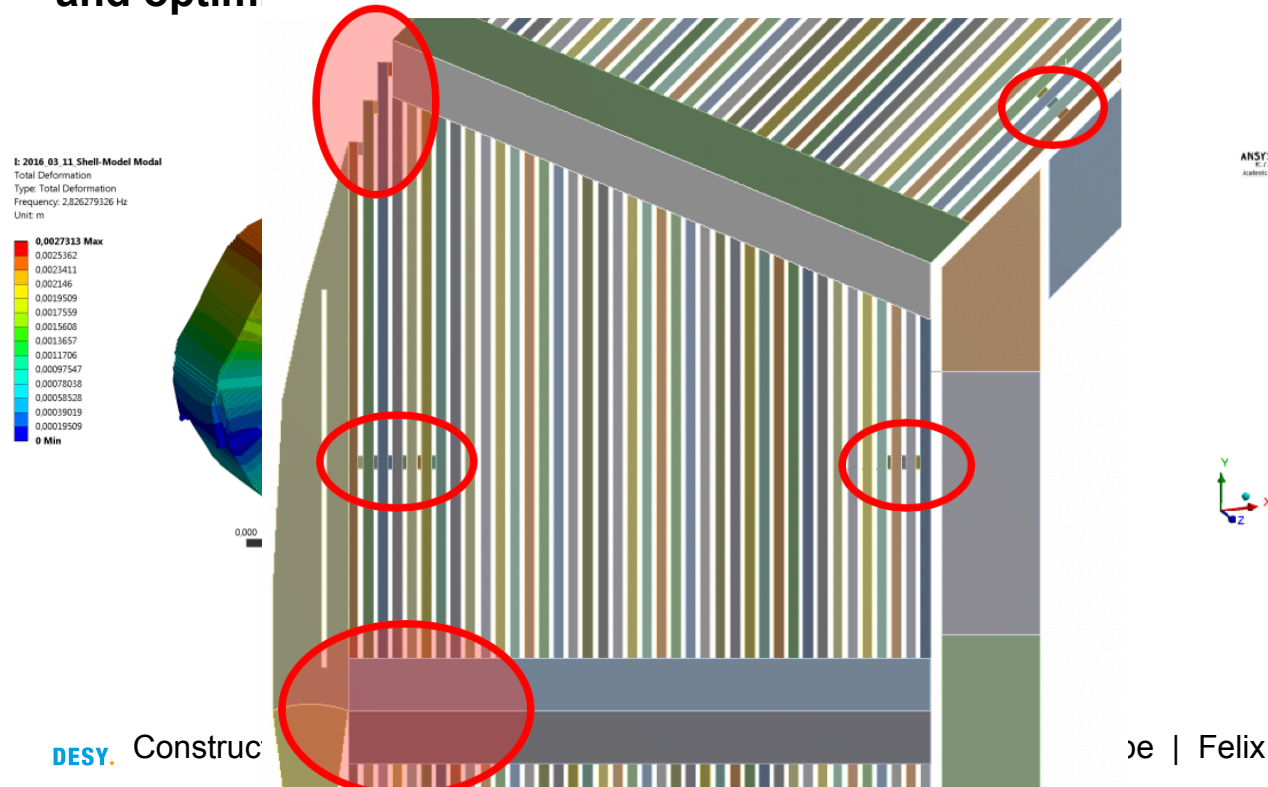
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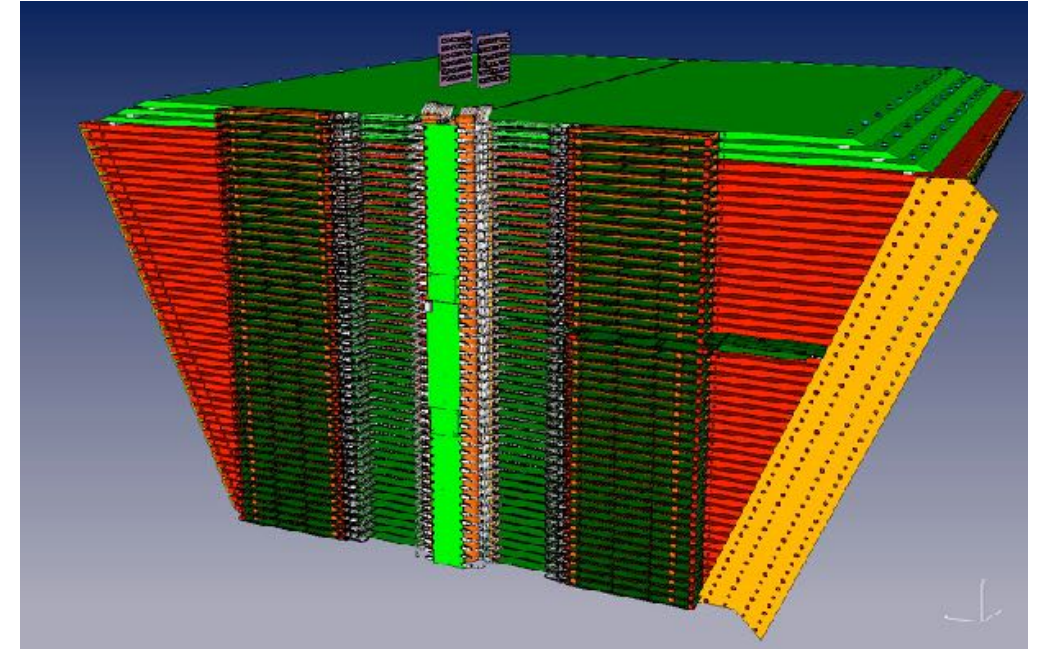
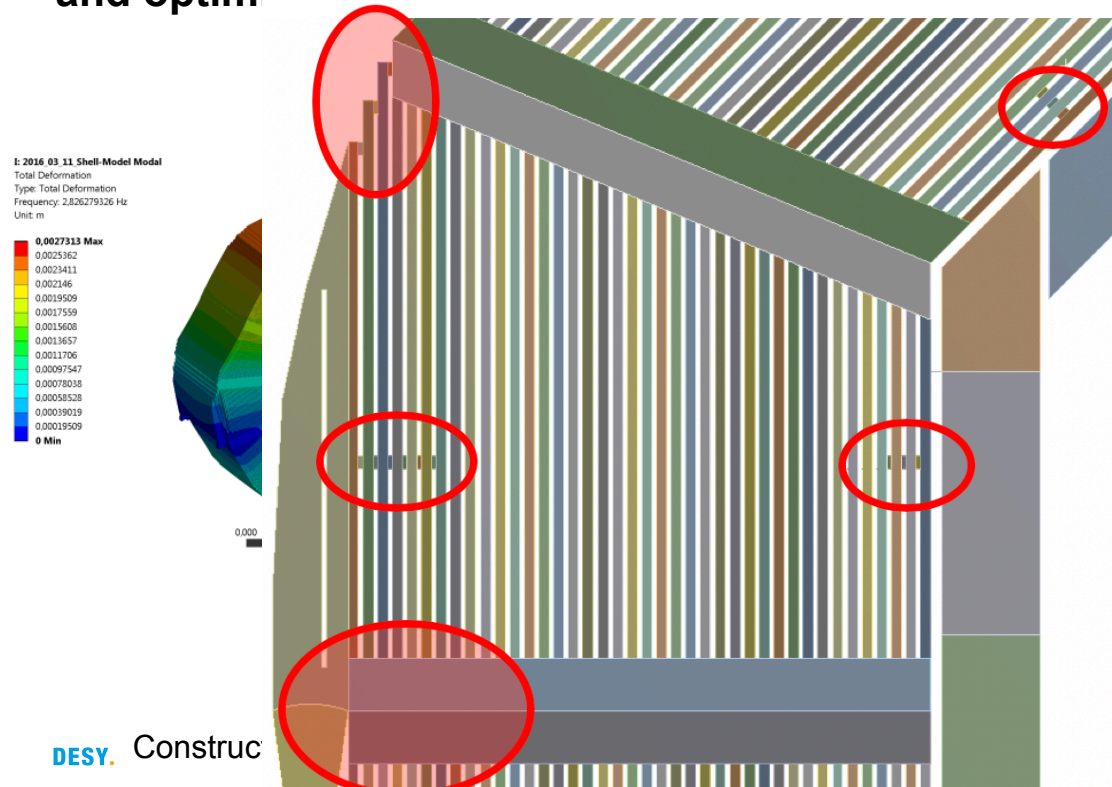
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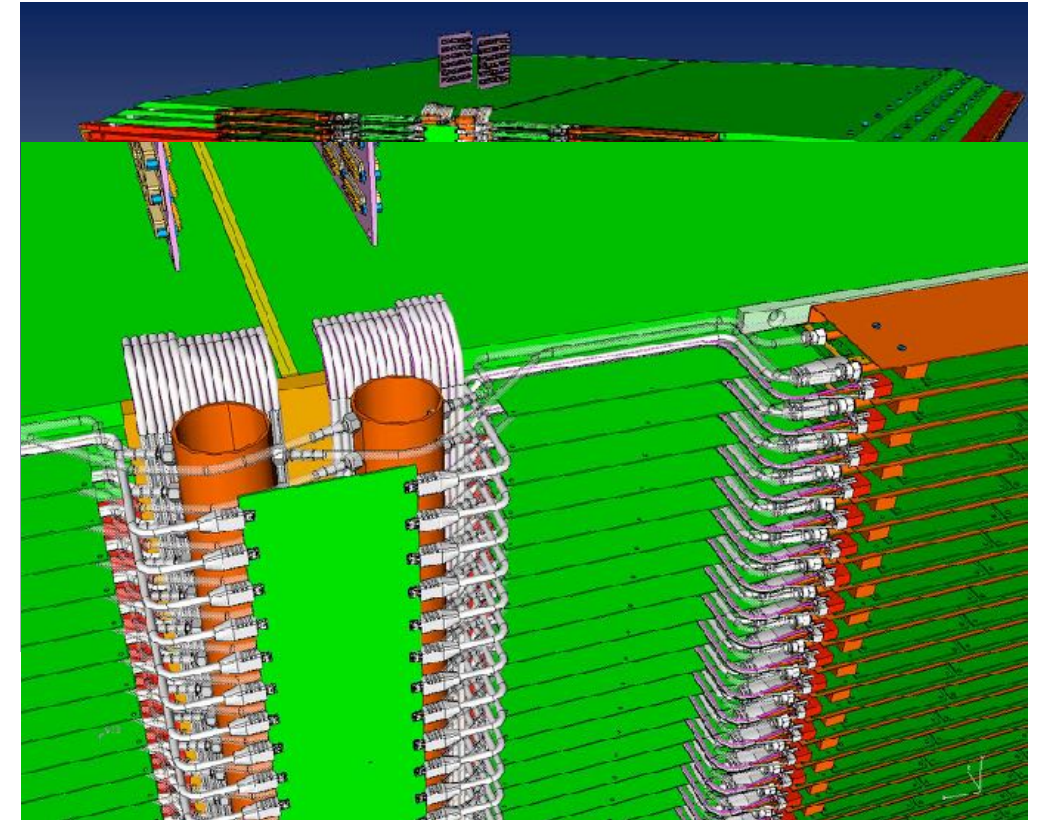
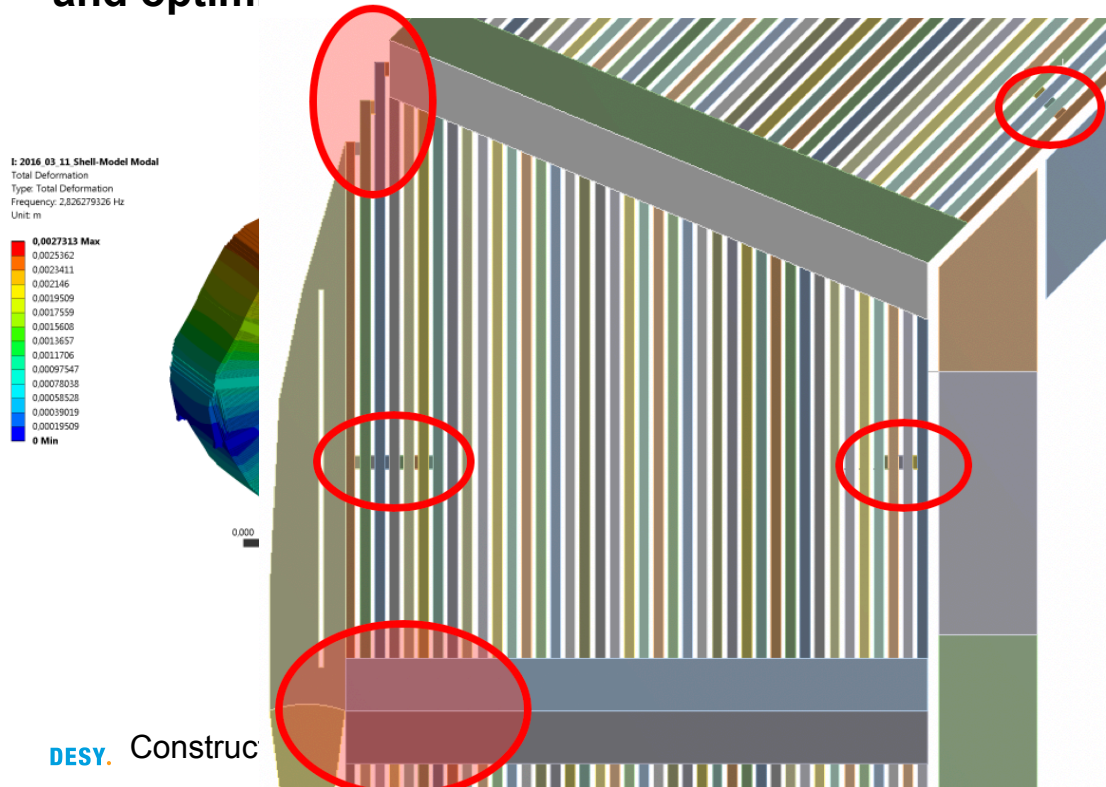
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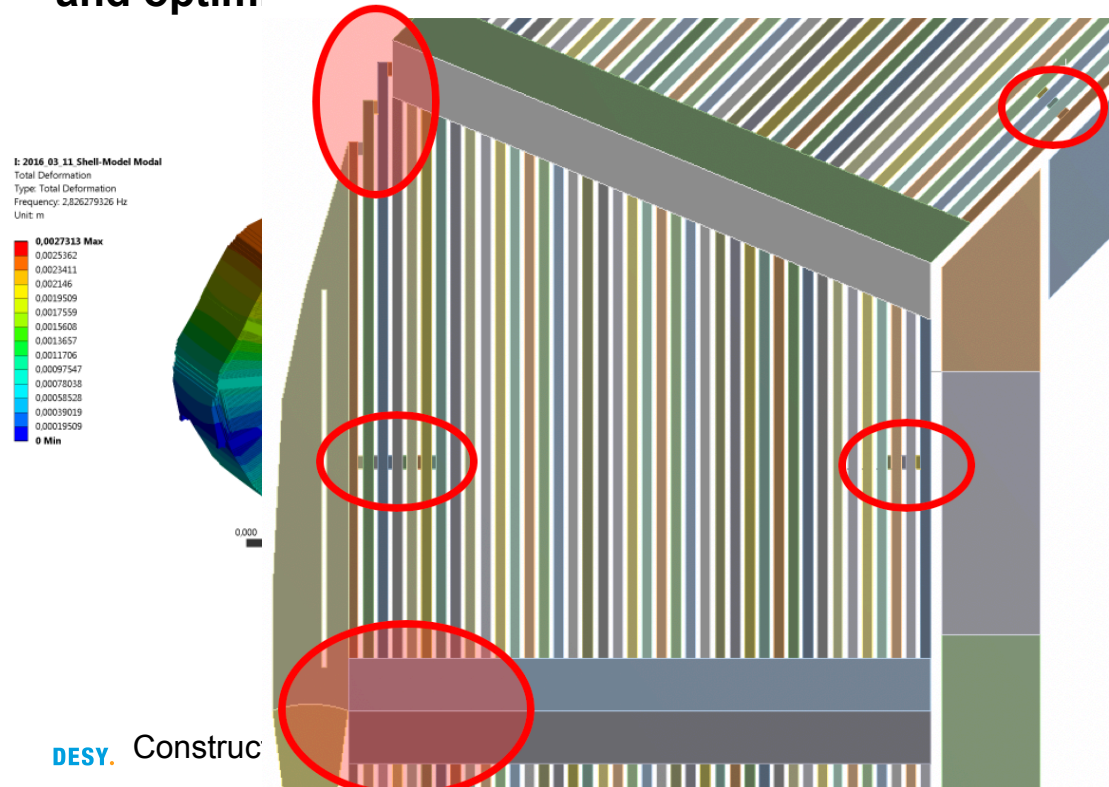
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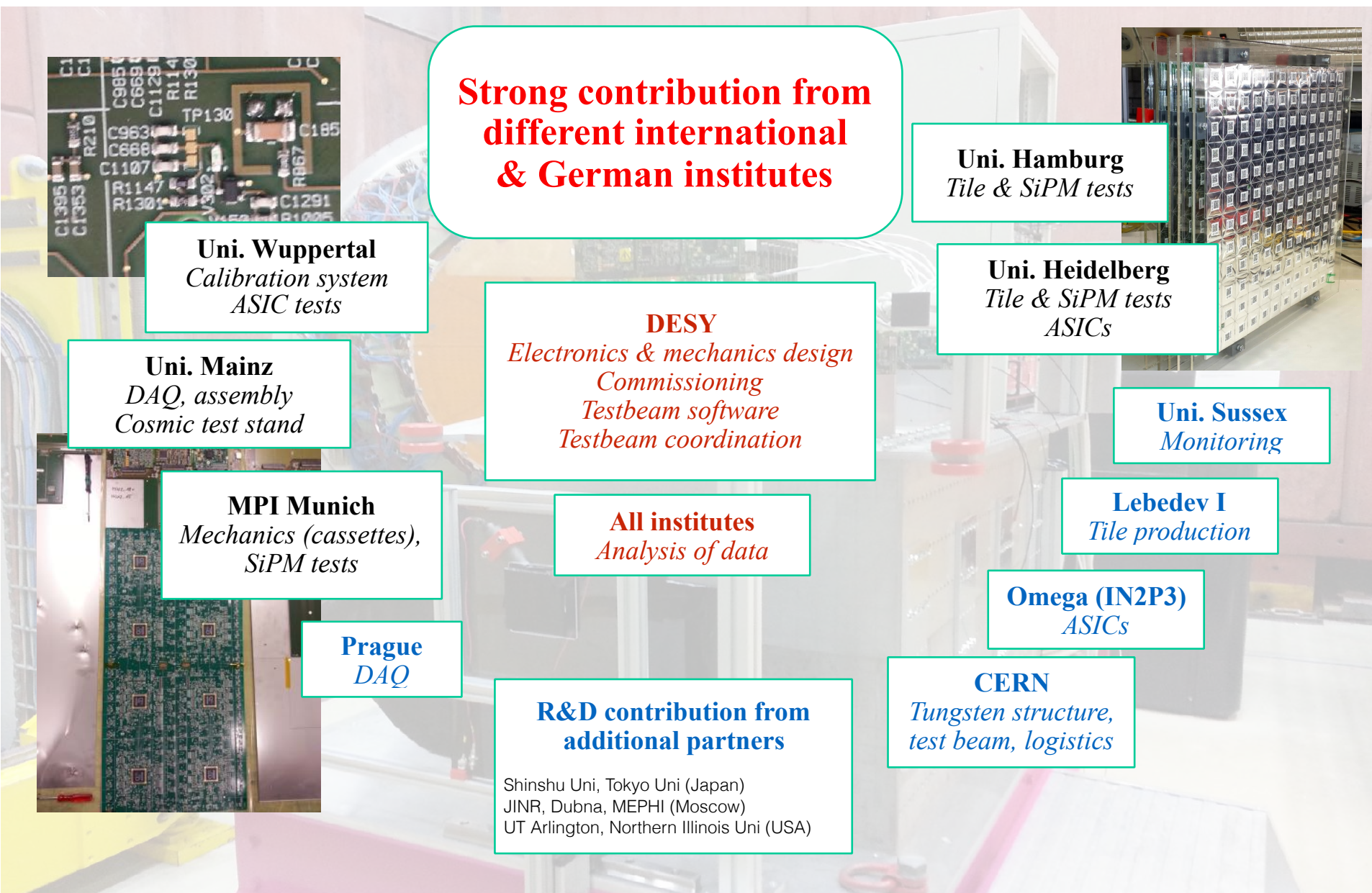
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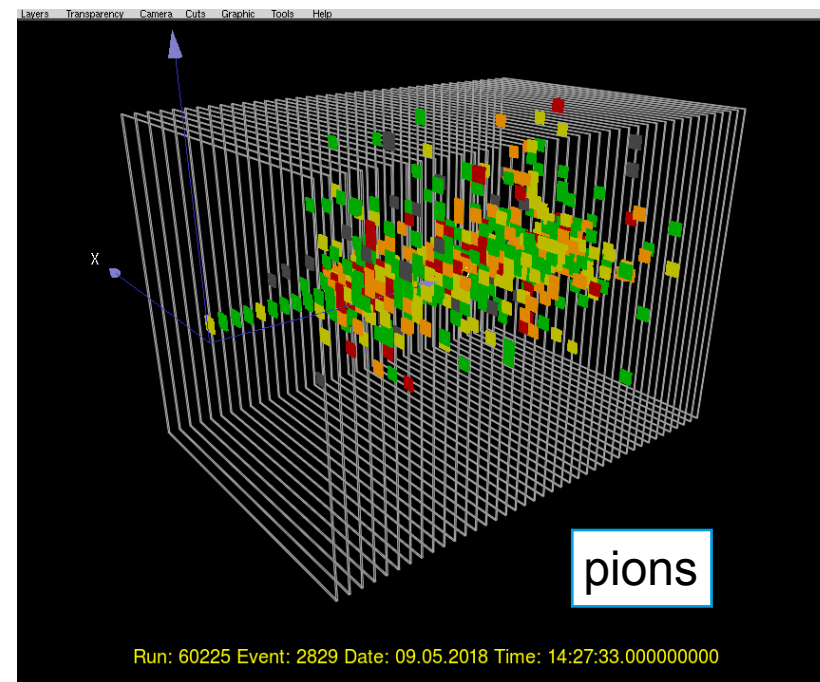
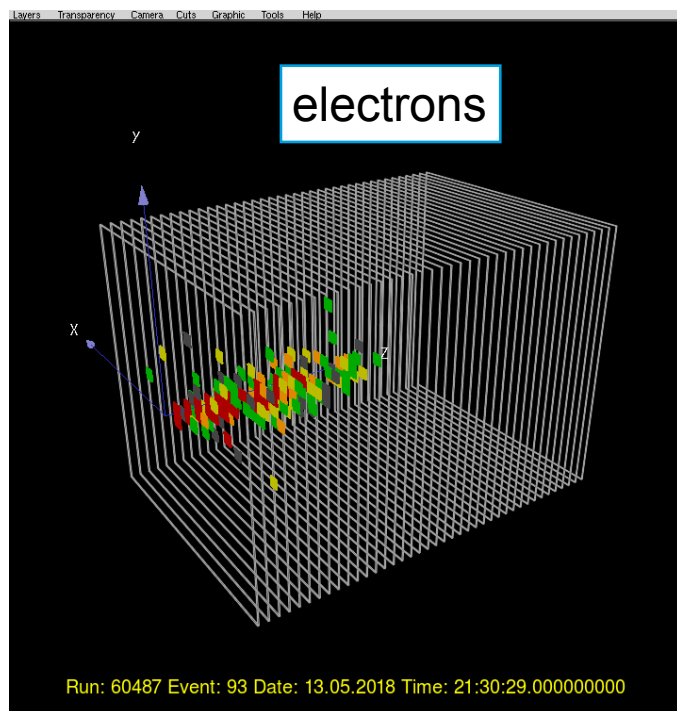




# Electrons and Hadrons

## Mixed Beams

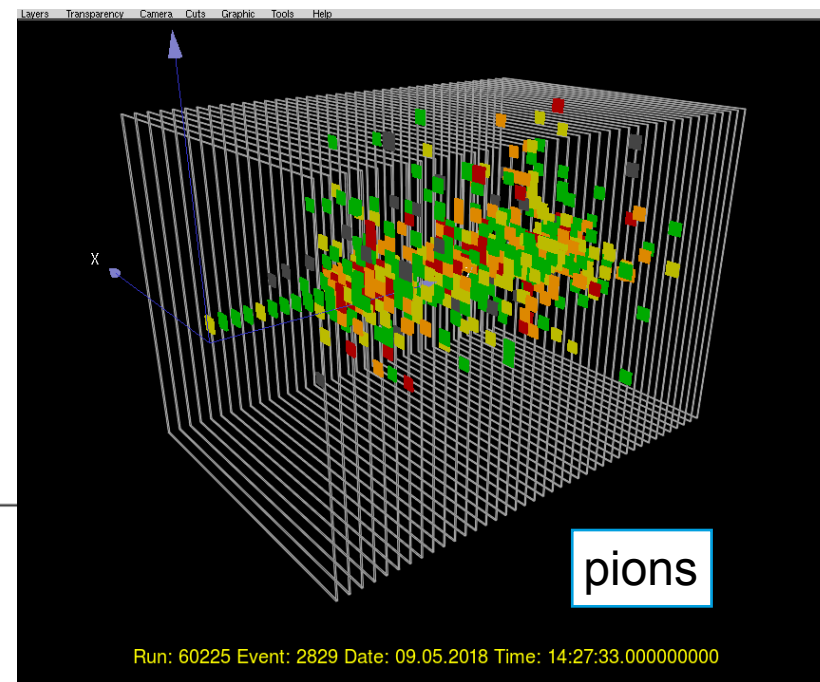
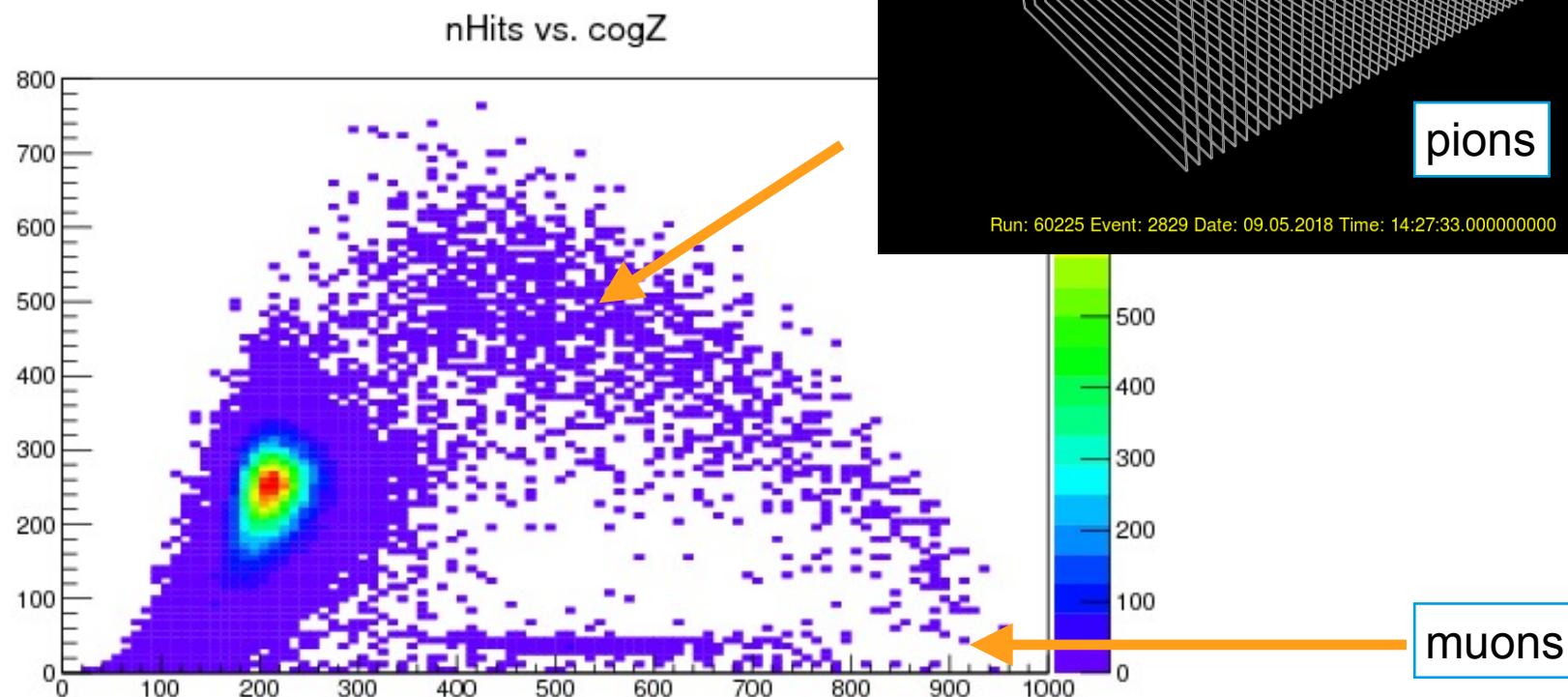
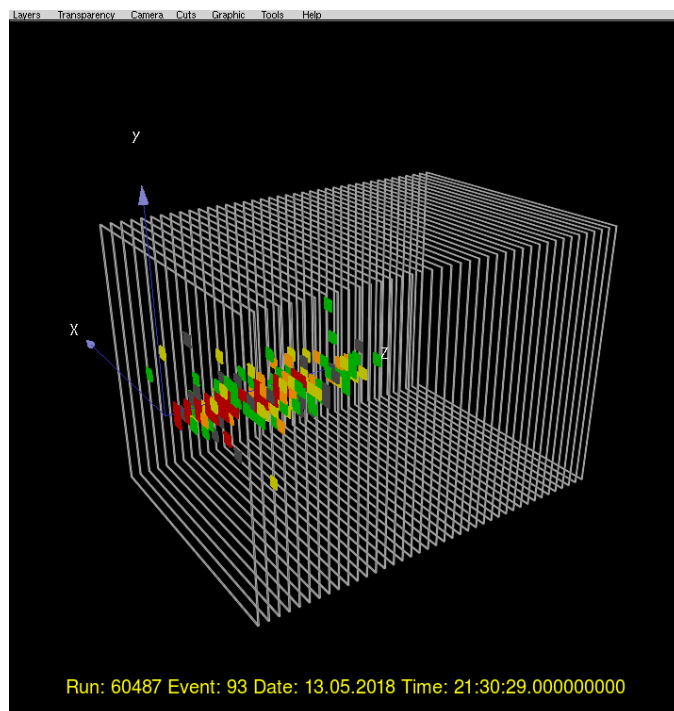
- Electron data 10 - 100 GeV
- Hadron data 10 - 160 GeV



# Electrons and Hadrons

## Mixed Beams

- Electron data 10 - 100 GeV
- Hadron data 10 - 160 GeV





# Temperature compensation

Online - Used routinely throughout 2018

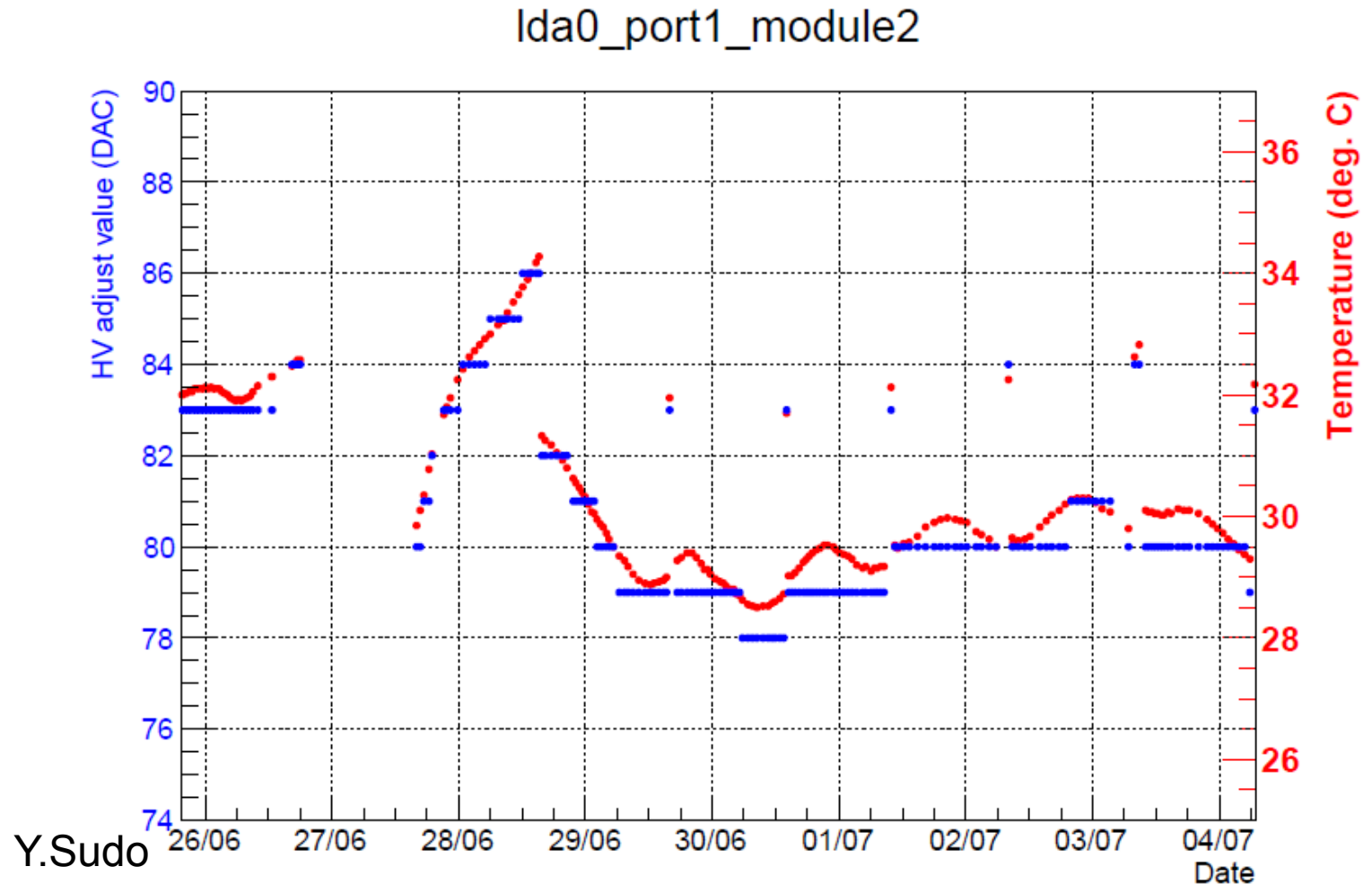
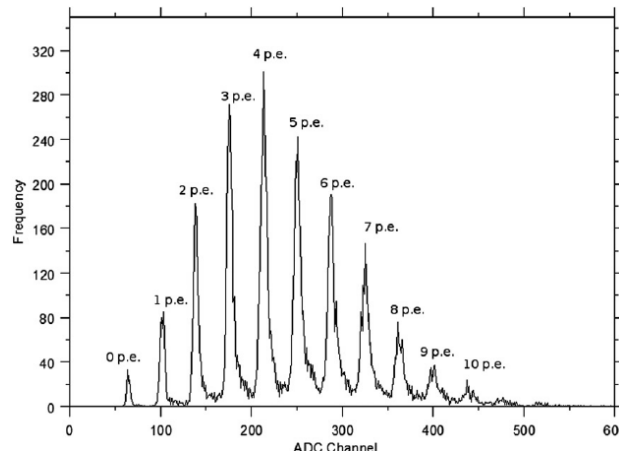
SiPM parameters (almost all)  
depend on over-voltage

$$\Delta V = V_{\text{bias}} - V_{\text{breakdown}}(T)$$

$V_{\text{breakdown}}$  depends on  
temperature, very uniformly

Adjust  $V_{\text{bias}}(T)$  to stabilise  $\Delta V$

Use gain (from single photo-  
electron peak spacing to monitor  
stability



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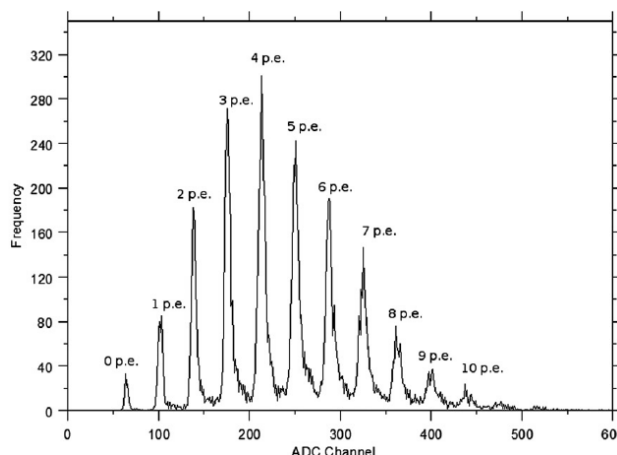
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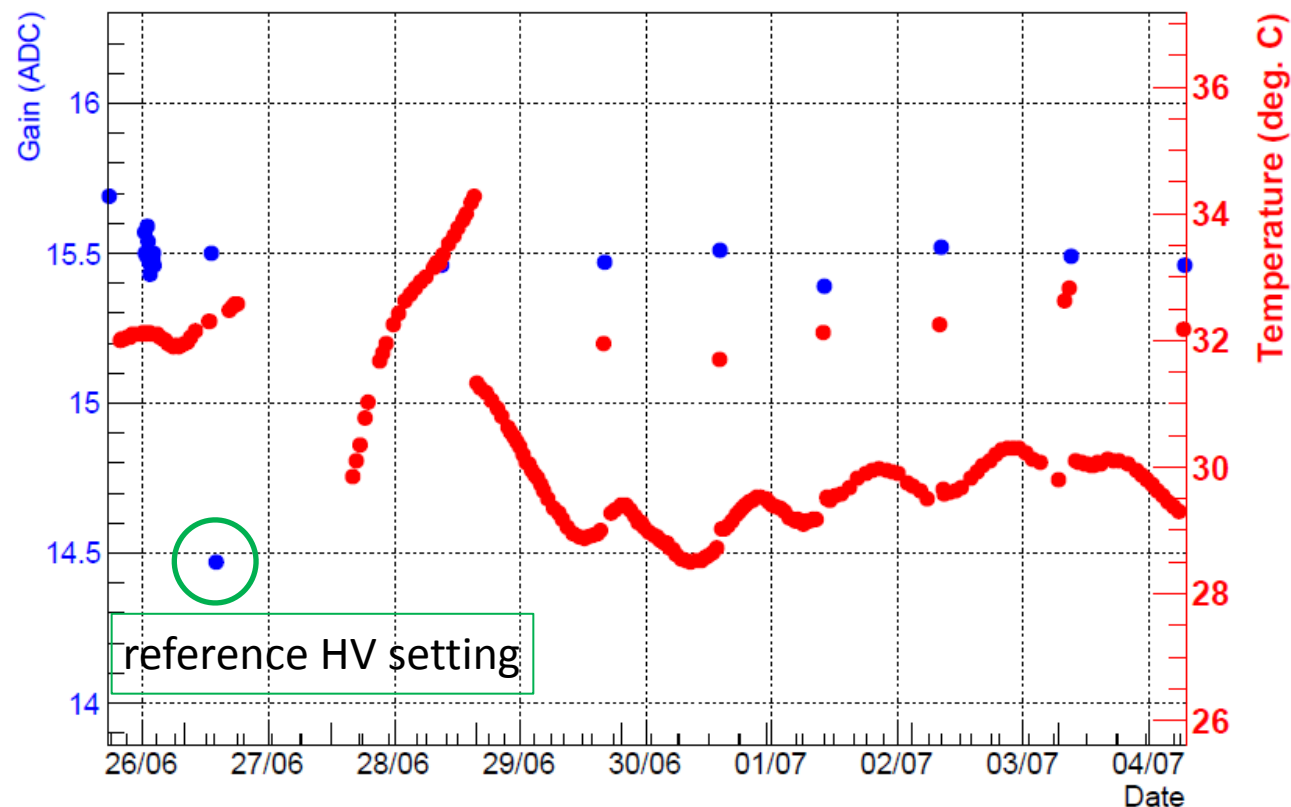
**Use gain (from single photo-  
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stability**



no HV adjust  
(same setting  
as the last  
configuration)

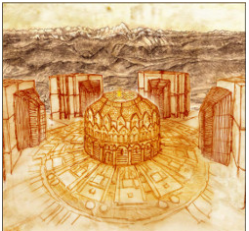
Y.Sudo

lda0\_port1\_module2\_chip512\_chn0





# Construction Techniques for the CMS Upgrade



# HGCal Overview

## Key Parameters (updated from the TDR):

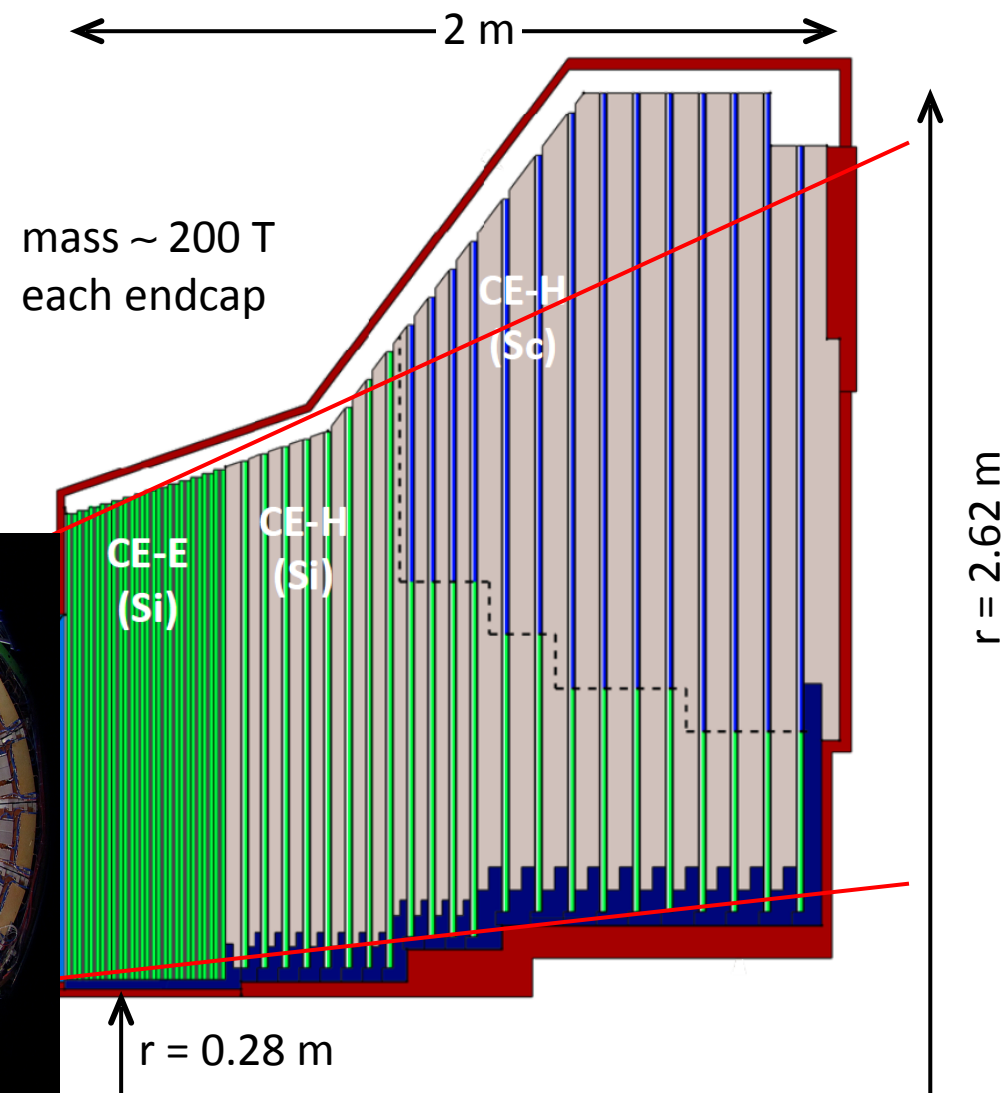
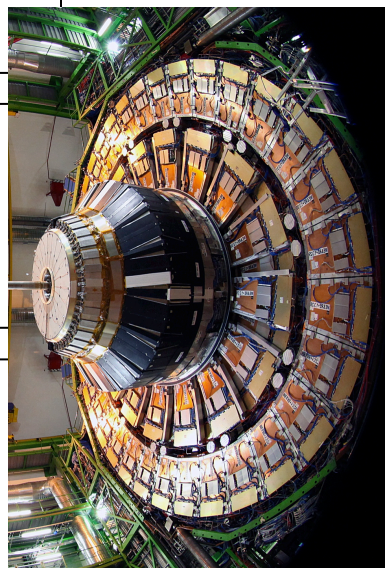
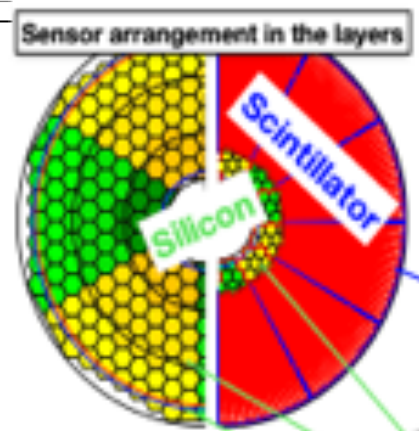
- HGCal covers  $1.5 < \eta < 3.0$
- **Full system maintained at  $-30^{\circ}\text{C}$**
- **$\sim 640 \text{ m}^2$**  of silicon sensors
- **$\sim 370 \text{ m}^2$**  of scintillators
- 6.1M Si channels, 0.5 or 1.1  $\text{cm}^2$  cell size (6M)  
240k scint-tile channels ( $\eta$ - $\phi$ )
  - Data readout from all layers
  - Trigger readout from alternate layers in CE-E and all in CE-H
- $\sim 31000$  Si modules (incl. spares)

## Active Elements:

- Si sensors (full and partial hexagons) in CE-E and high-radiation region of CE-H.
- SiPM-on-Scintillating tiles in low-radiation region of CE-H

Electromagnetic calorimeter (**CE-E**): **Si**, Cu/CuW/Pb absorbers, 28 layers,  $25.5 X_0$  &  $\sim 1.7\lambda$

Hadronic calorimeter (**CE-H**): **Si & scintillator**, steel absorbers, 22 layers,  $\sim 9.5\lambda$  (including CE-E)





# Tileboard

## Prototyping

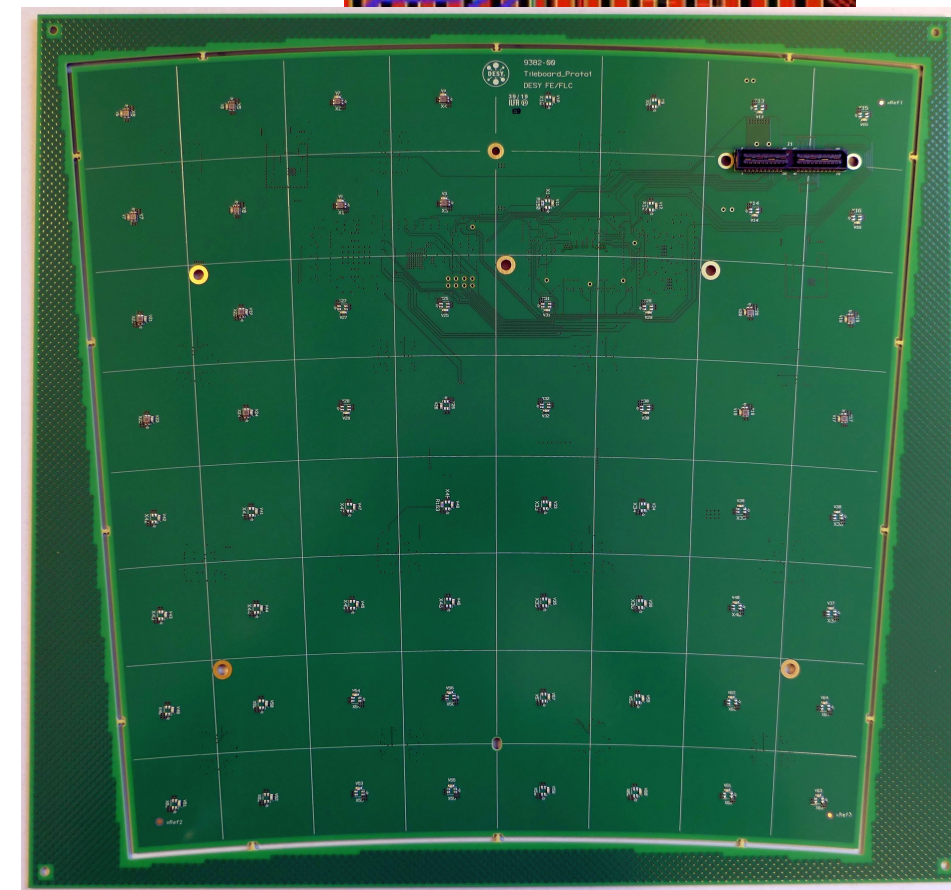
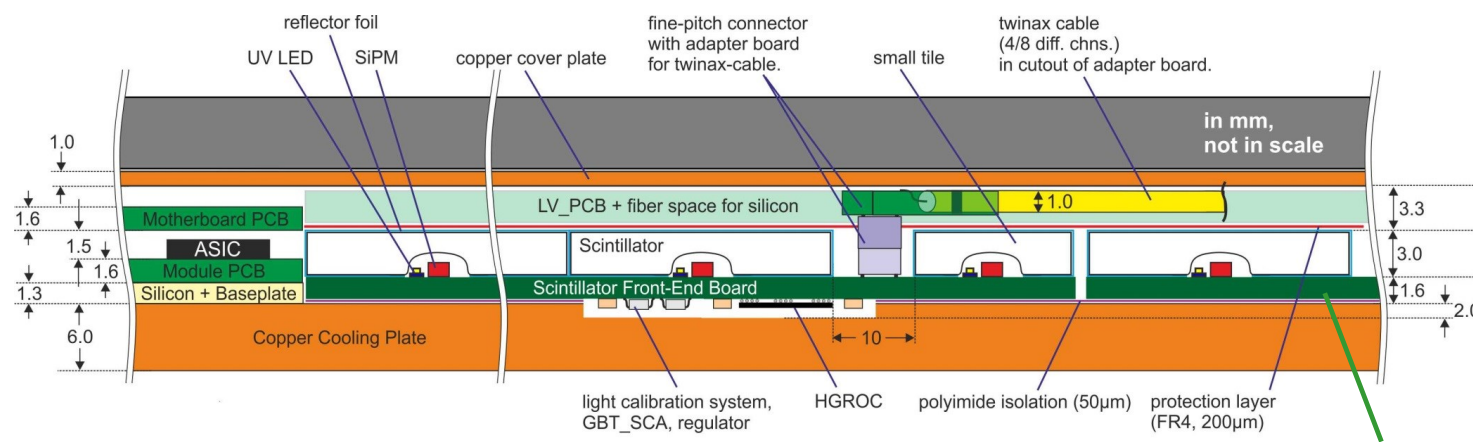
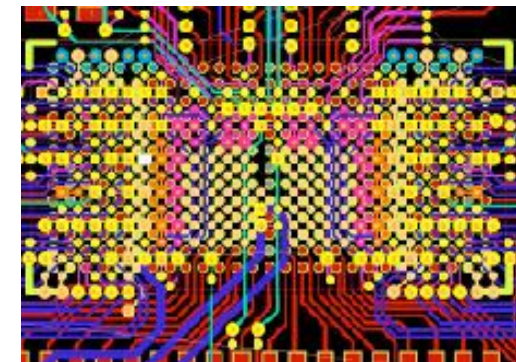
Prototype TB-1 produced last week

64 SiPMs, HGCROC ASIC, DCDC converters, LEDs

Complex layout, HGCROC in 0.6mm pitch BGA package

Thermal vias for SiPM cooling

Test environment in preparation





## Prototyping

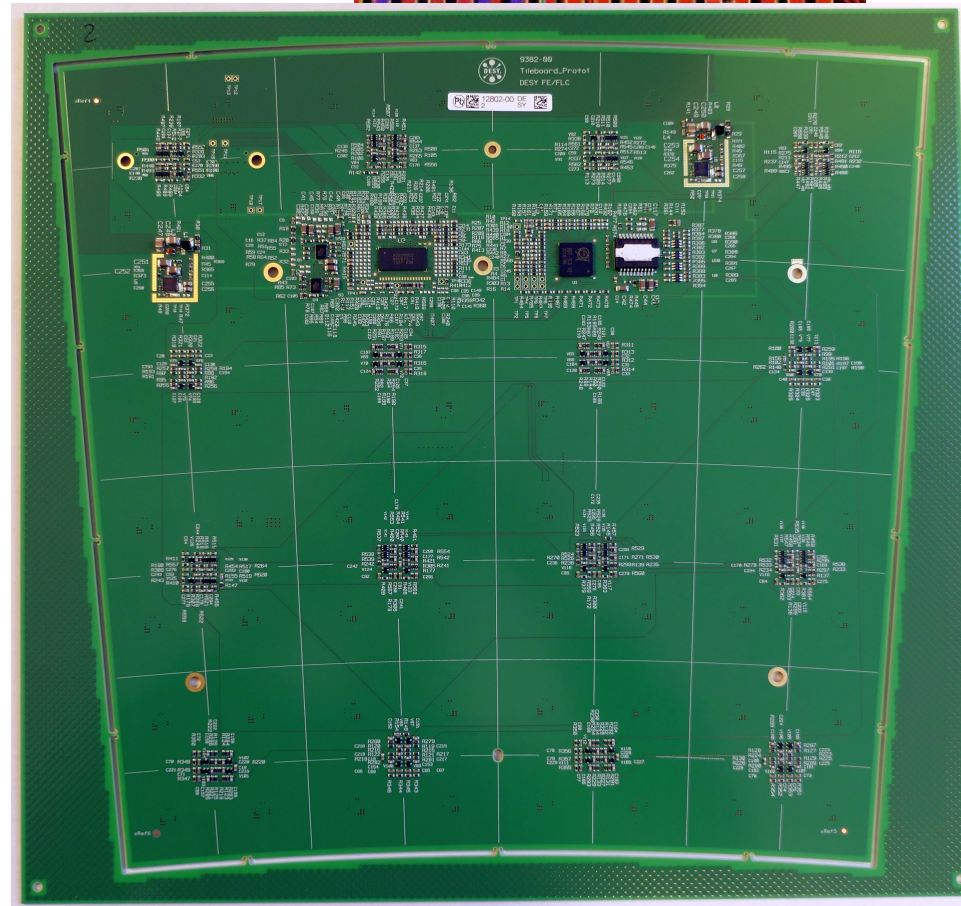
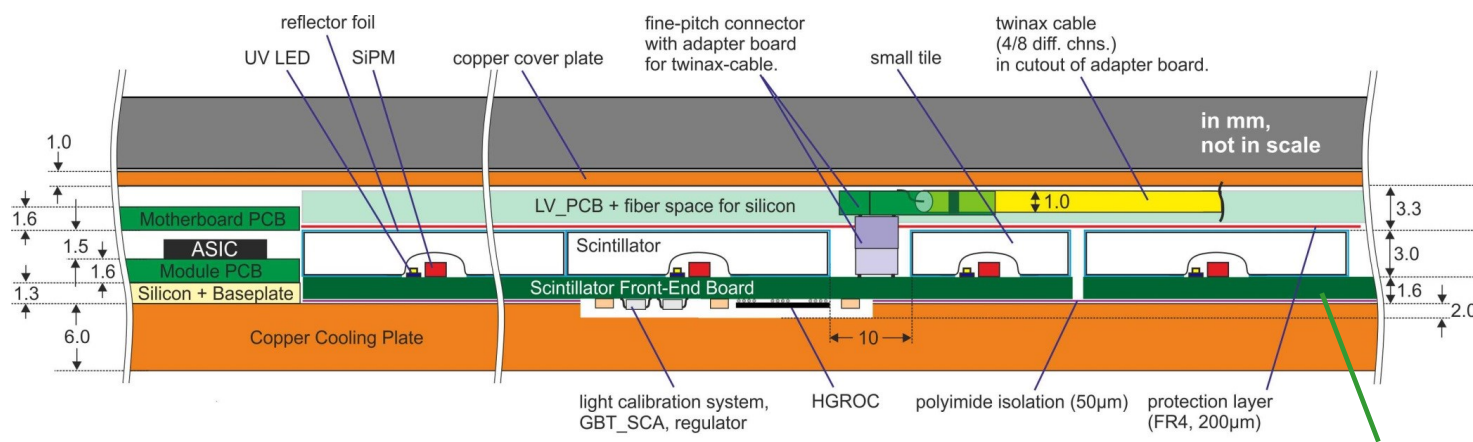
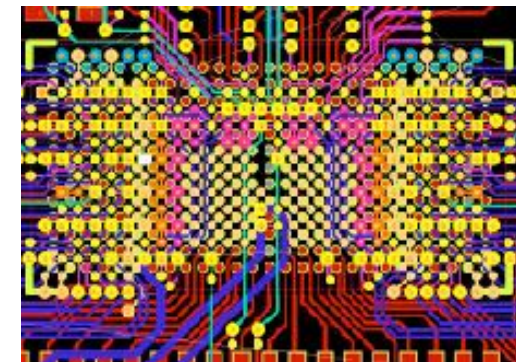
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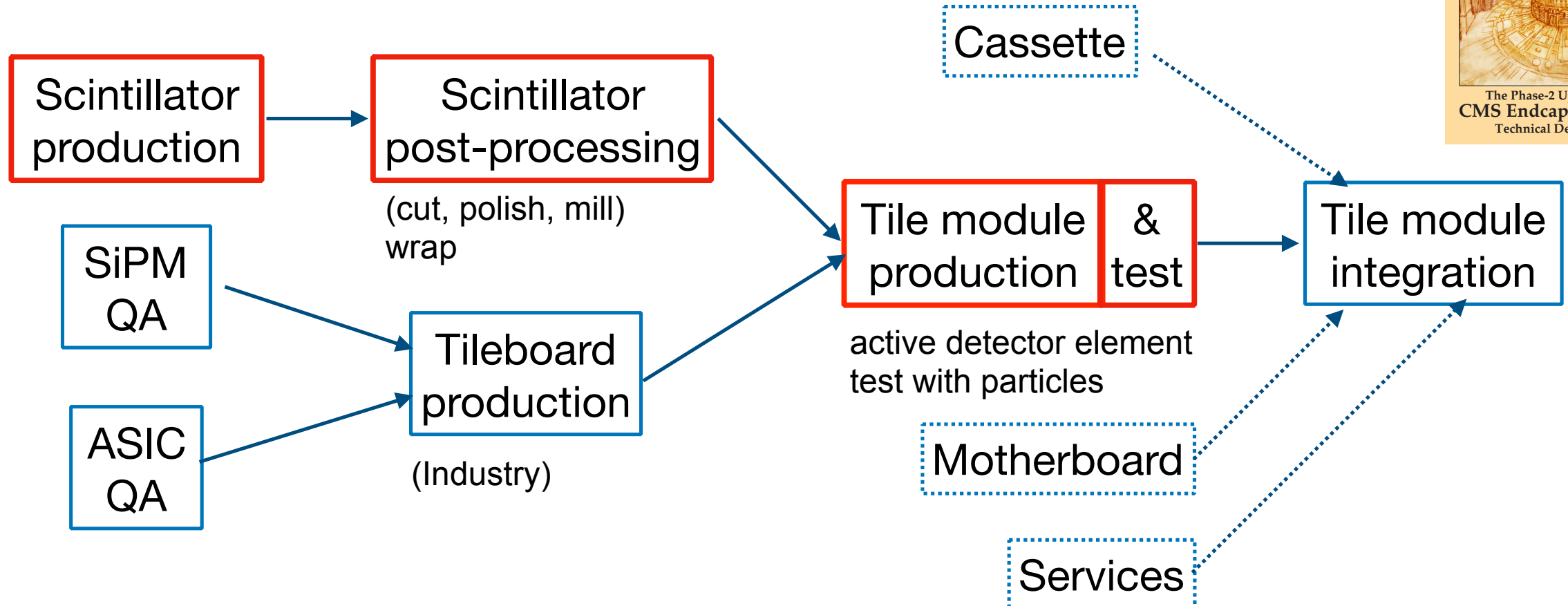
## Test environment in preparation





# Tile Module Assembly Flow Diagram

## Production and QC



- Quality assurance and quality control after each step

# Foil Cutting Alternative

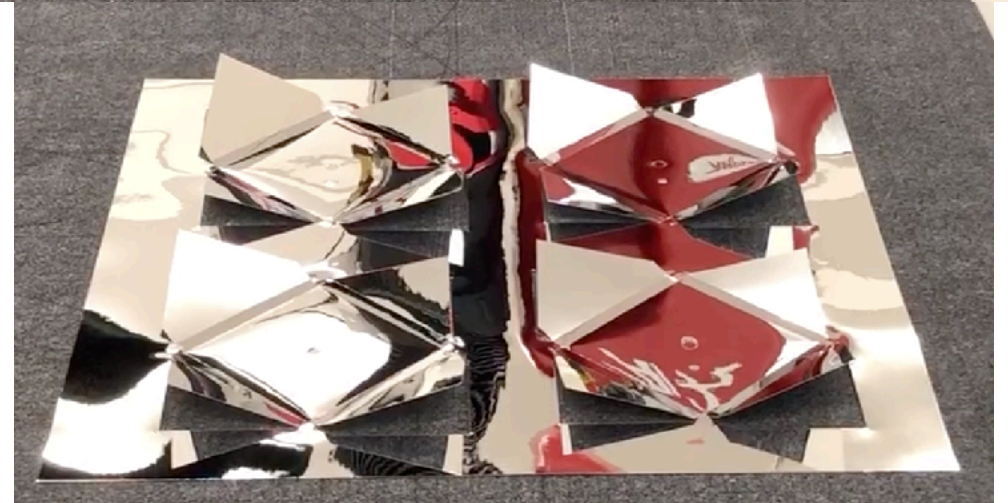
To replace laser cutter



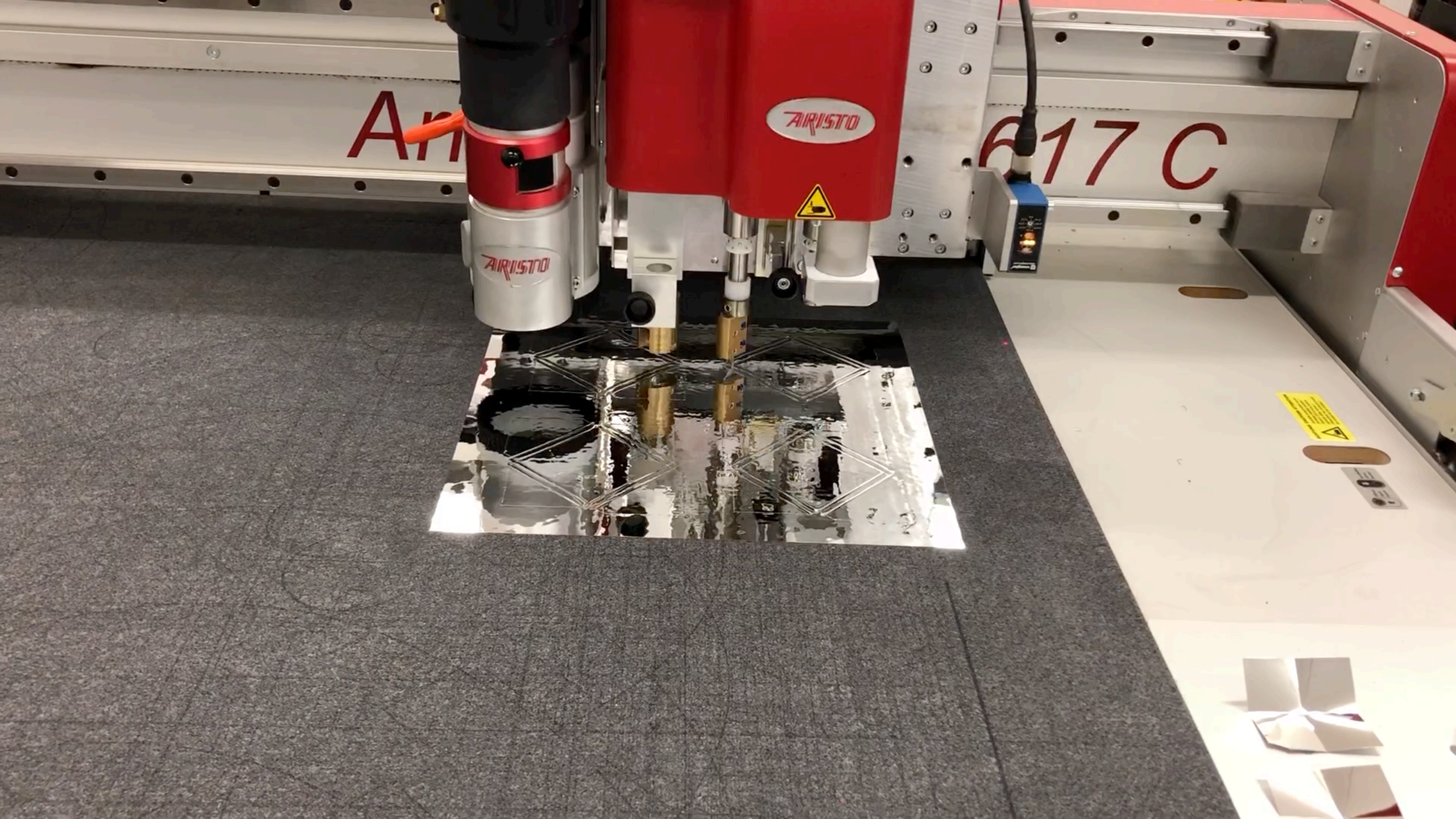
**Computer-controlled creasing wheel and knife**

easy to program: reads drawings in dxf format

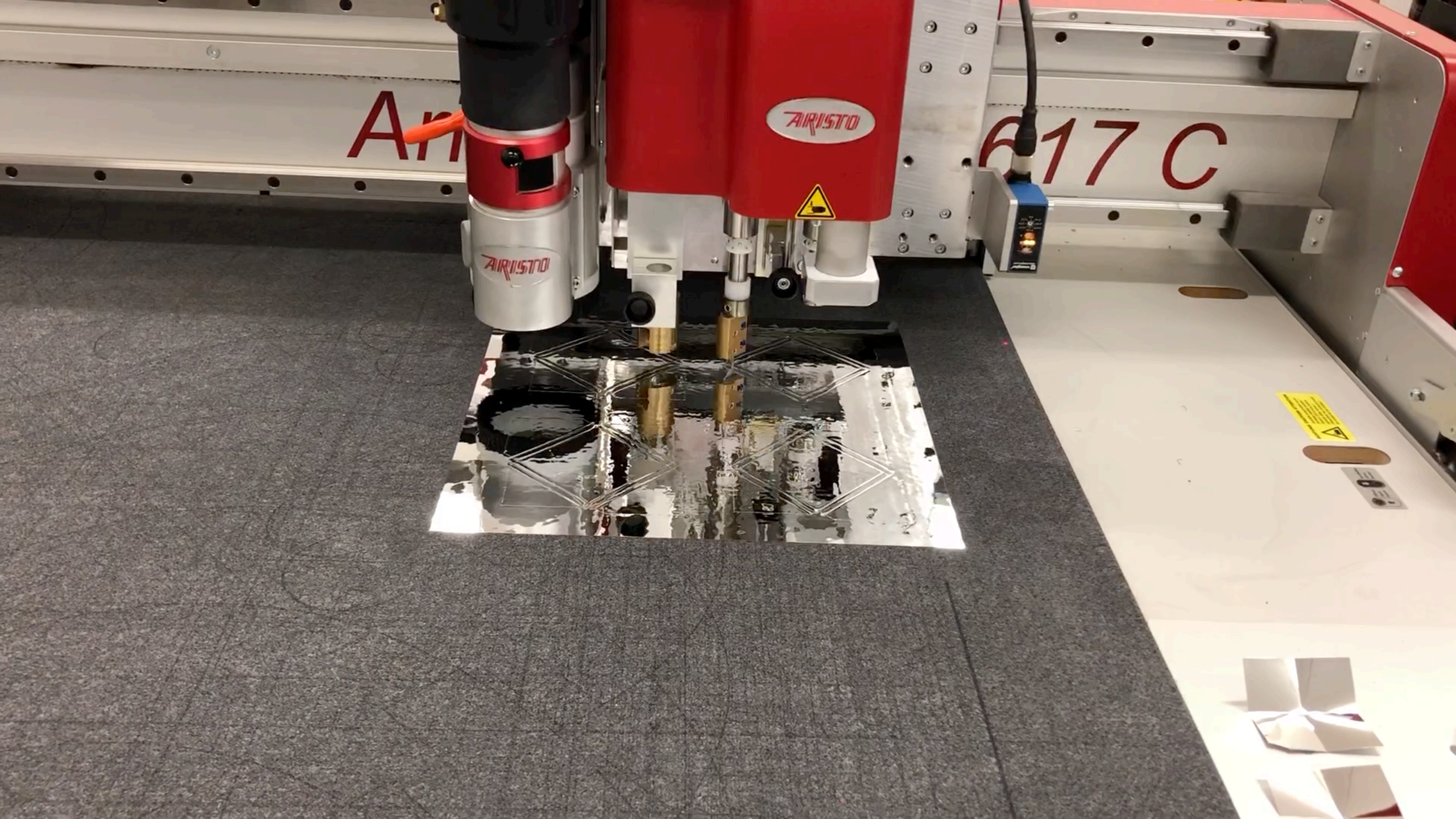
Reproducibility (spec) 0.02 mm











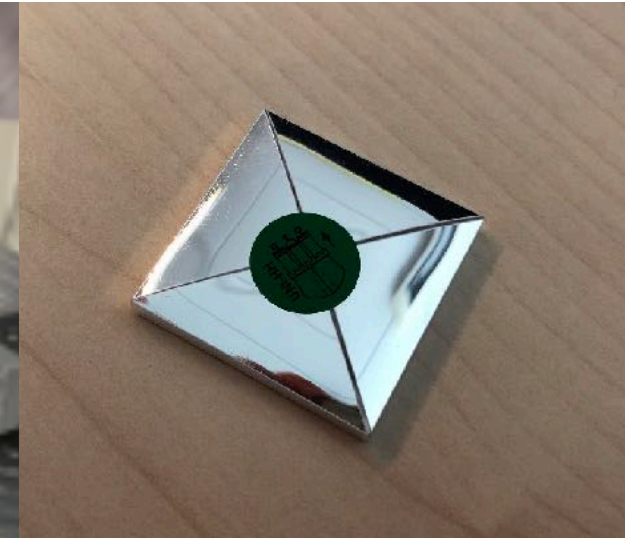
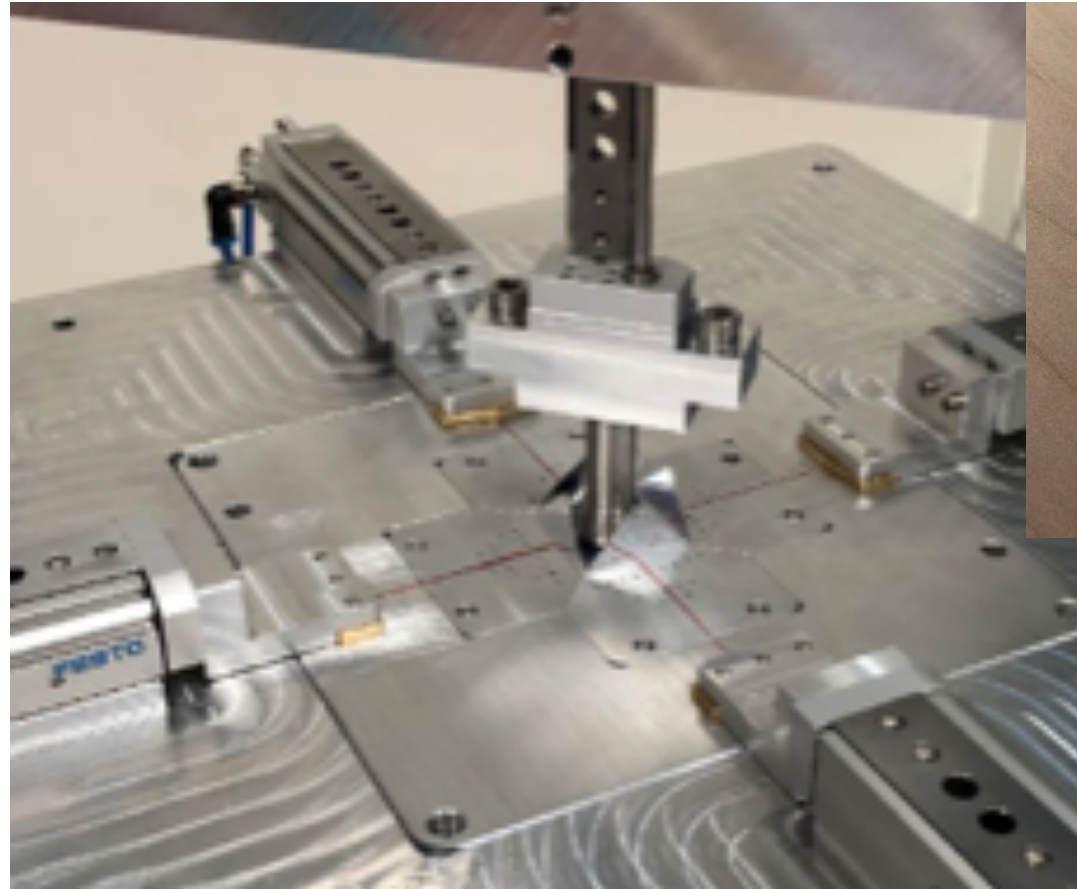


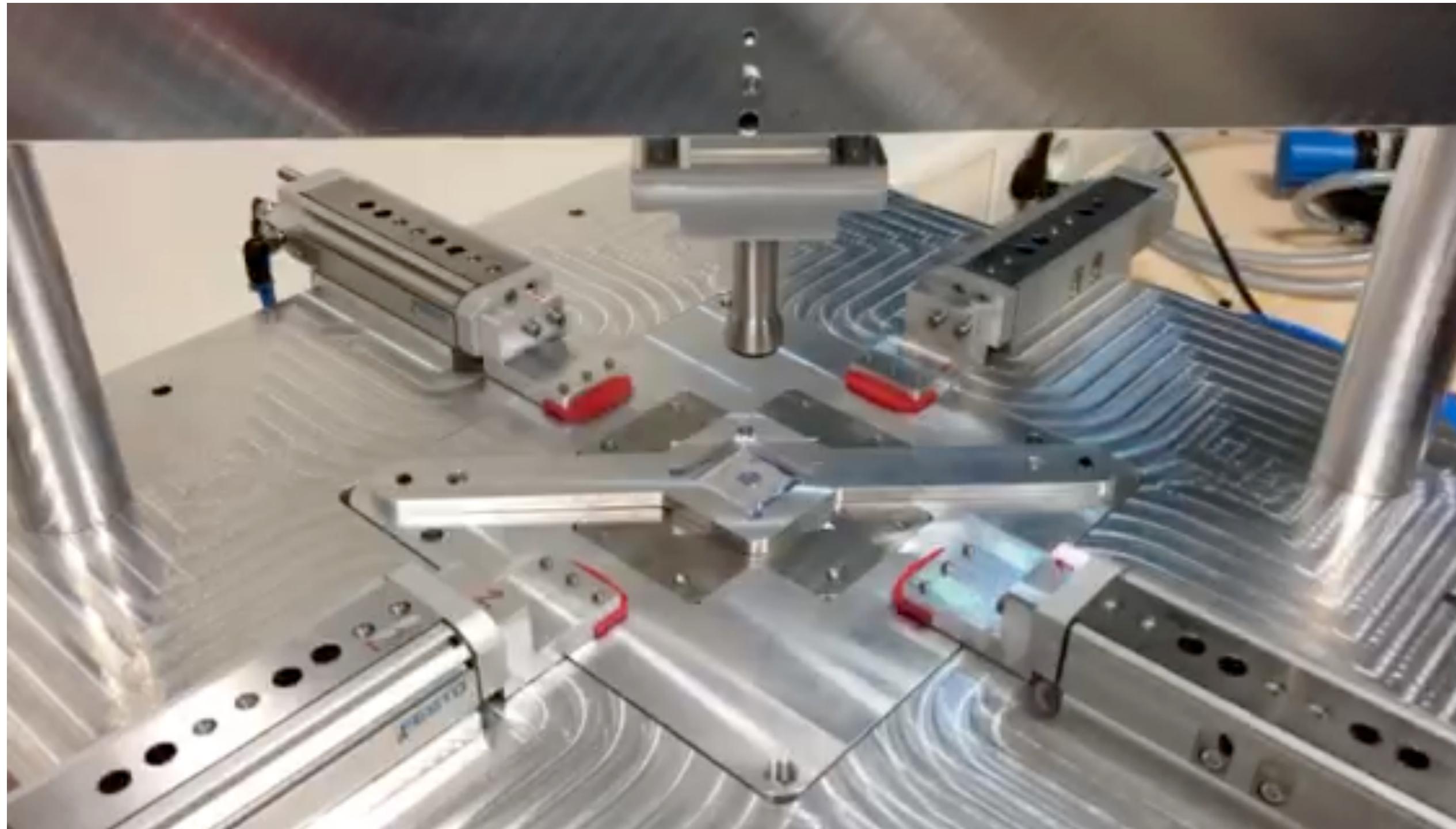
# Tile Wrapping Tool

Ongoing work: DESY

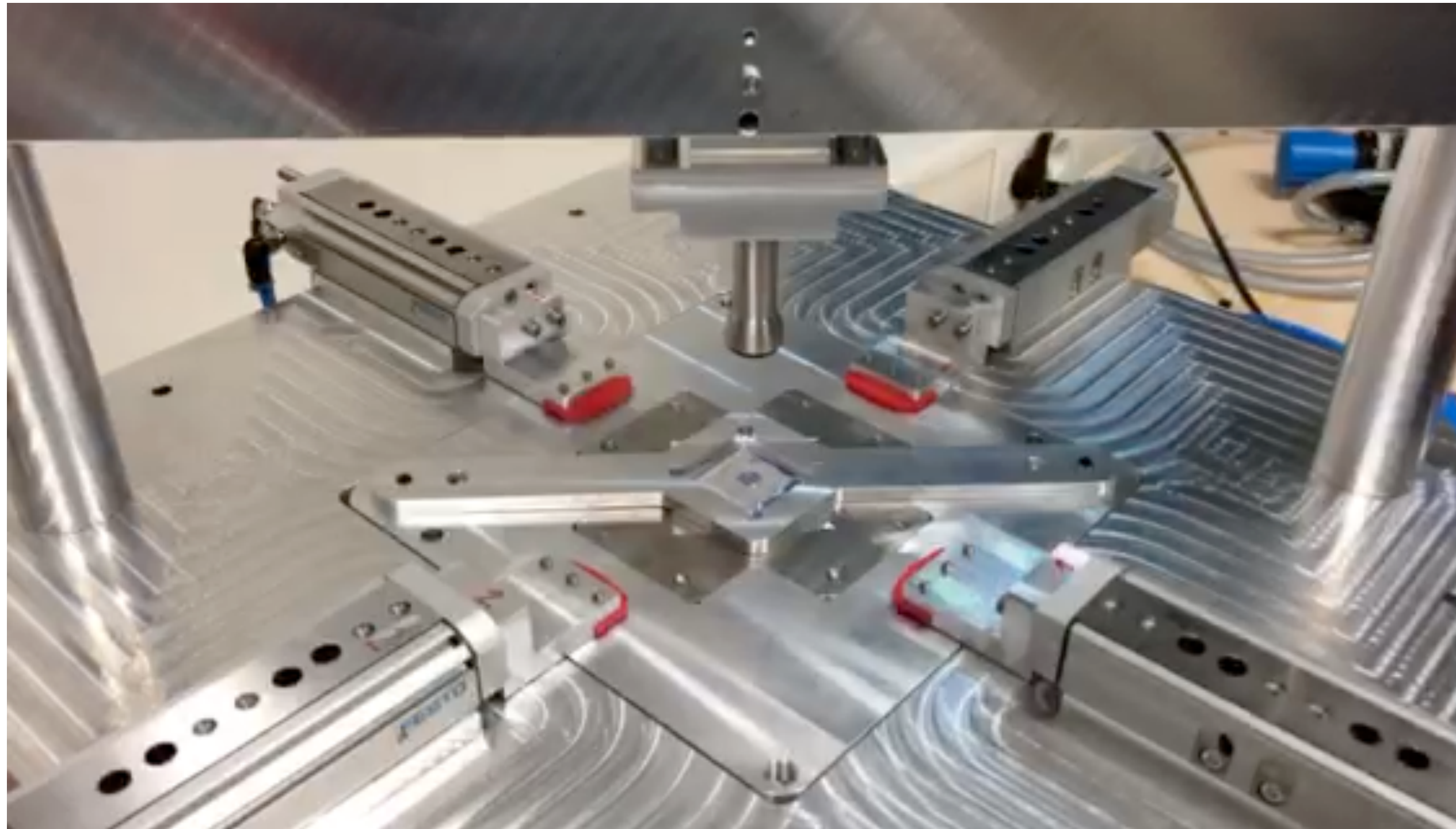
**Machine built, first tests done**

Commercial pneumatic actuators, rest built in-house









# Wrapping Machine Status

As of Today

**Central part ready, feeders in production**

expected for mid October

**Size-dependent parts**

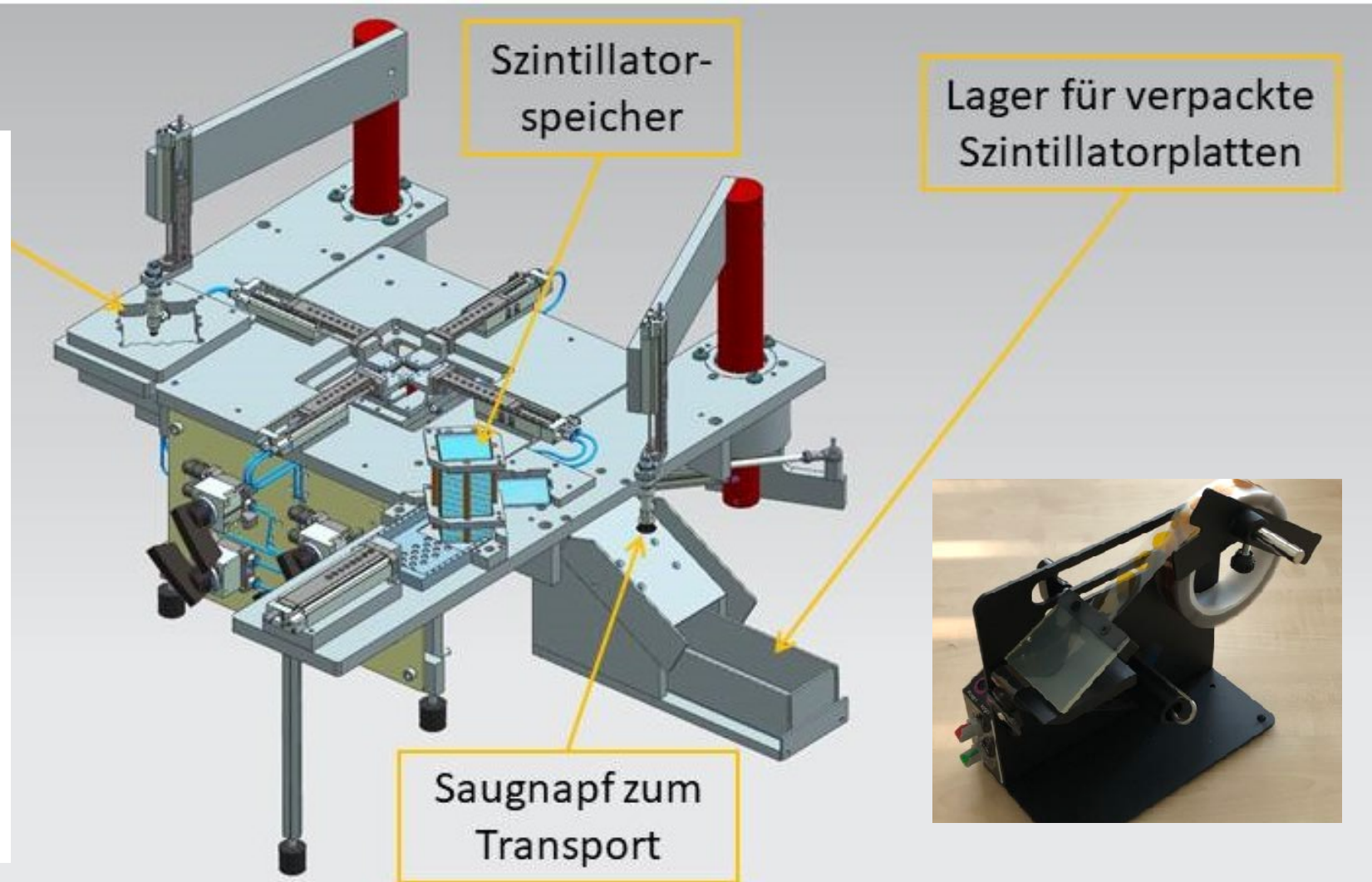
existing for square CALICE tiles,  
used for assembly tests

ready for the 4 sizes of  
Tileboard-1

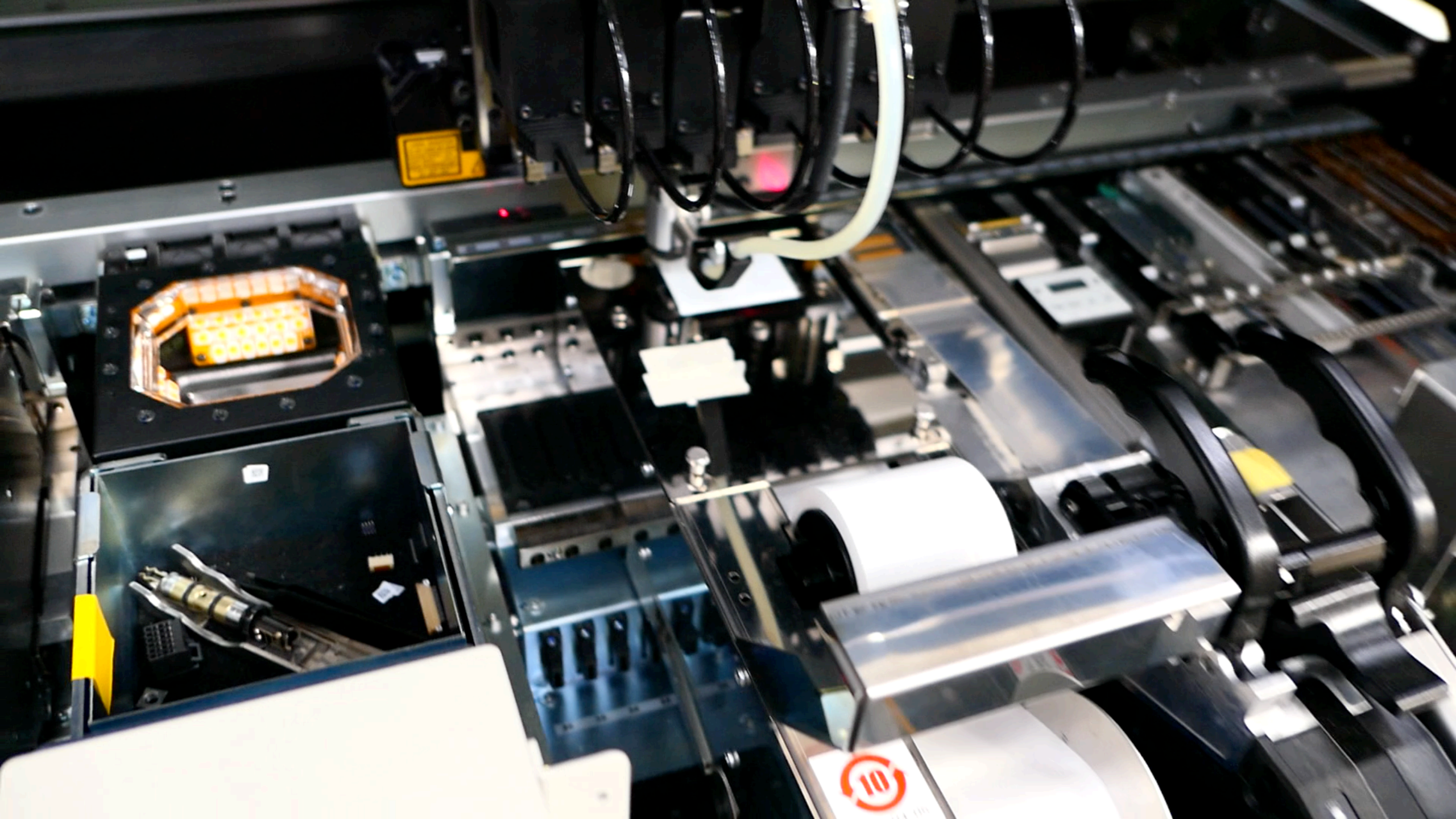
**Figures:**

Cost: 8k + 160 hrs w/s time

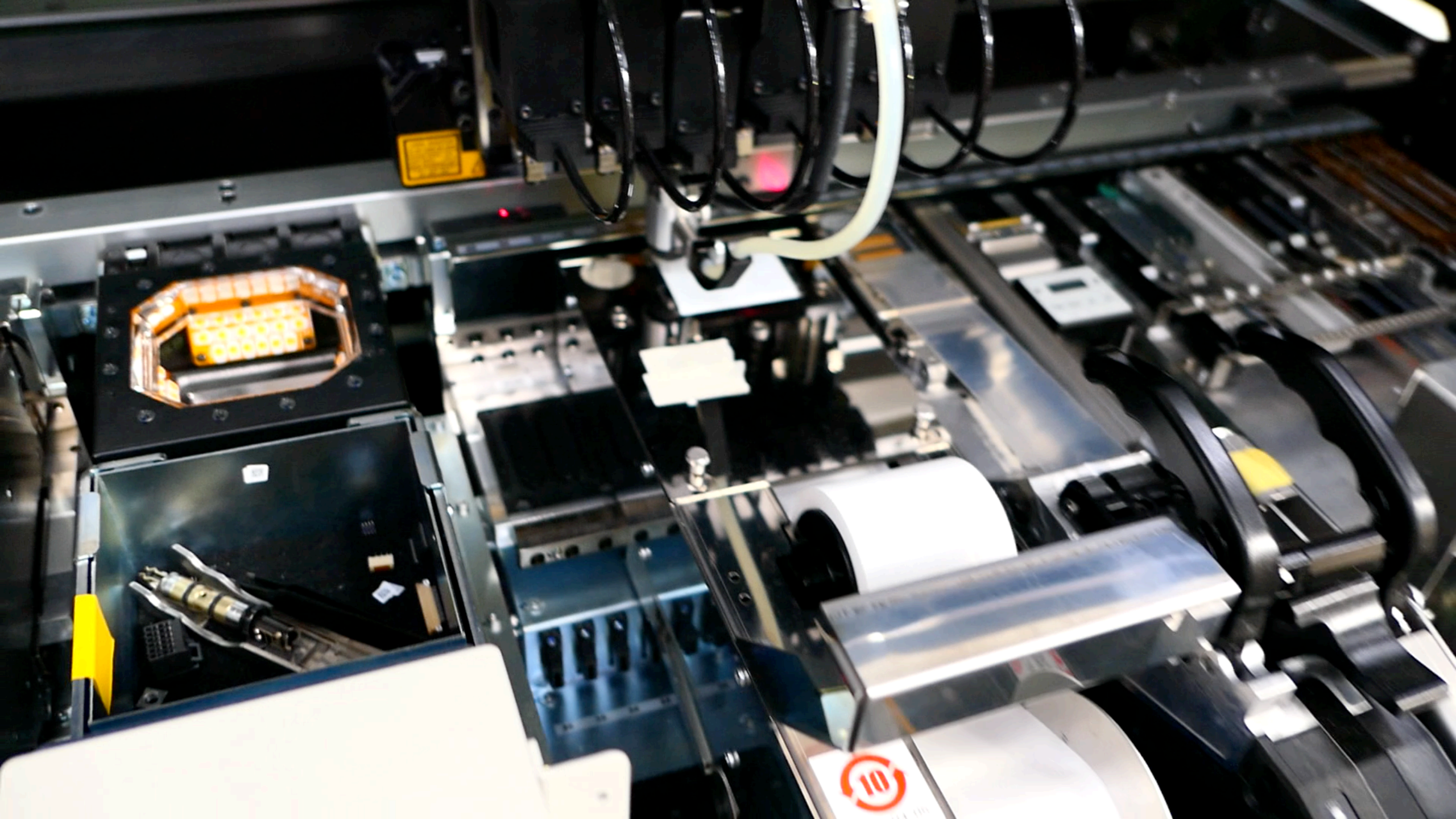
Speed: 3-4 tiles / min



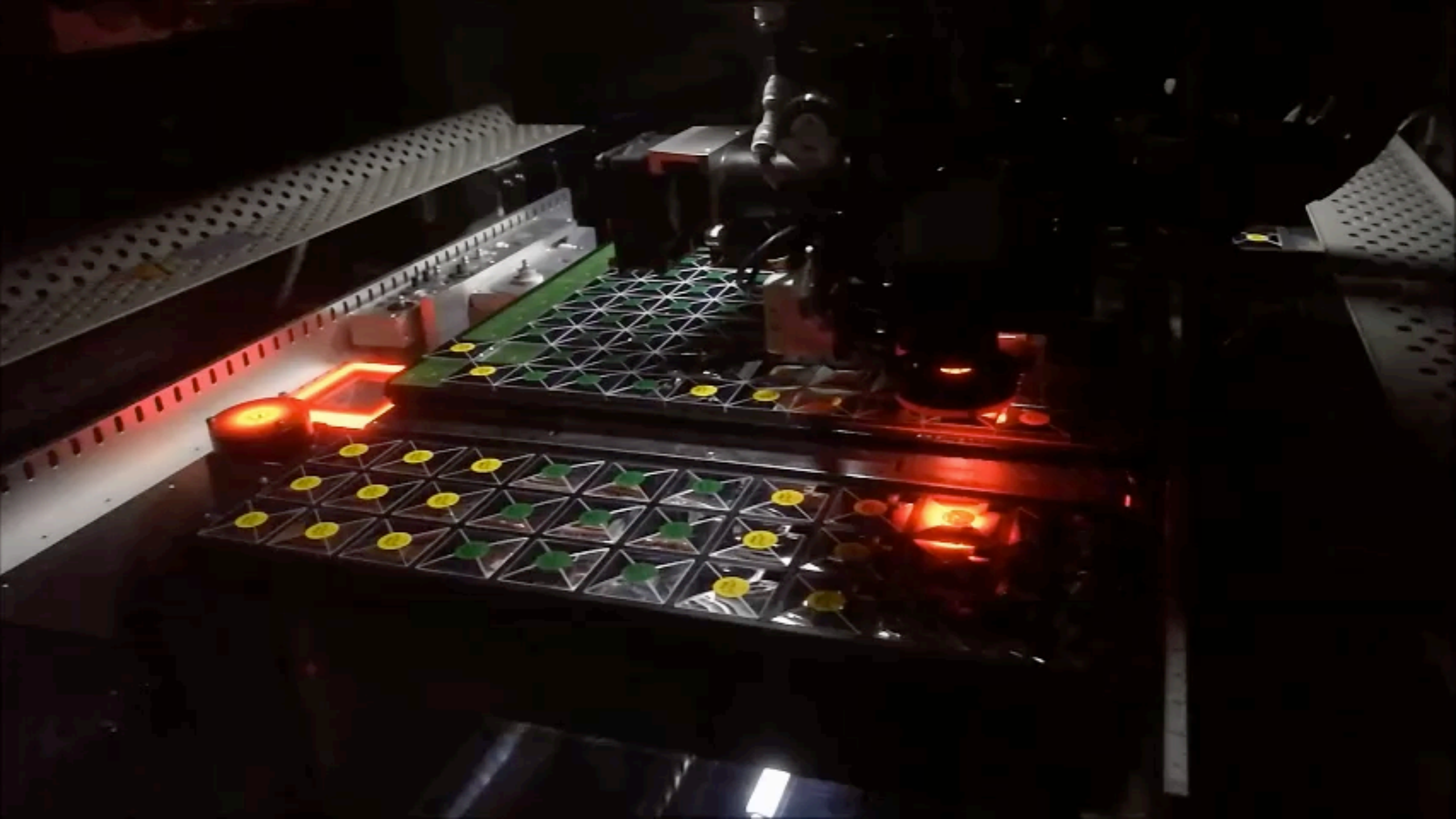


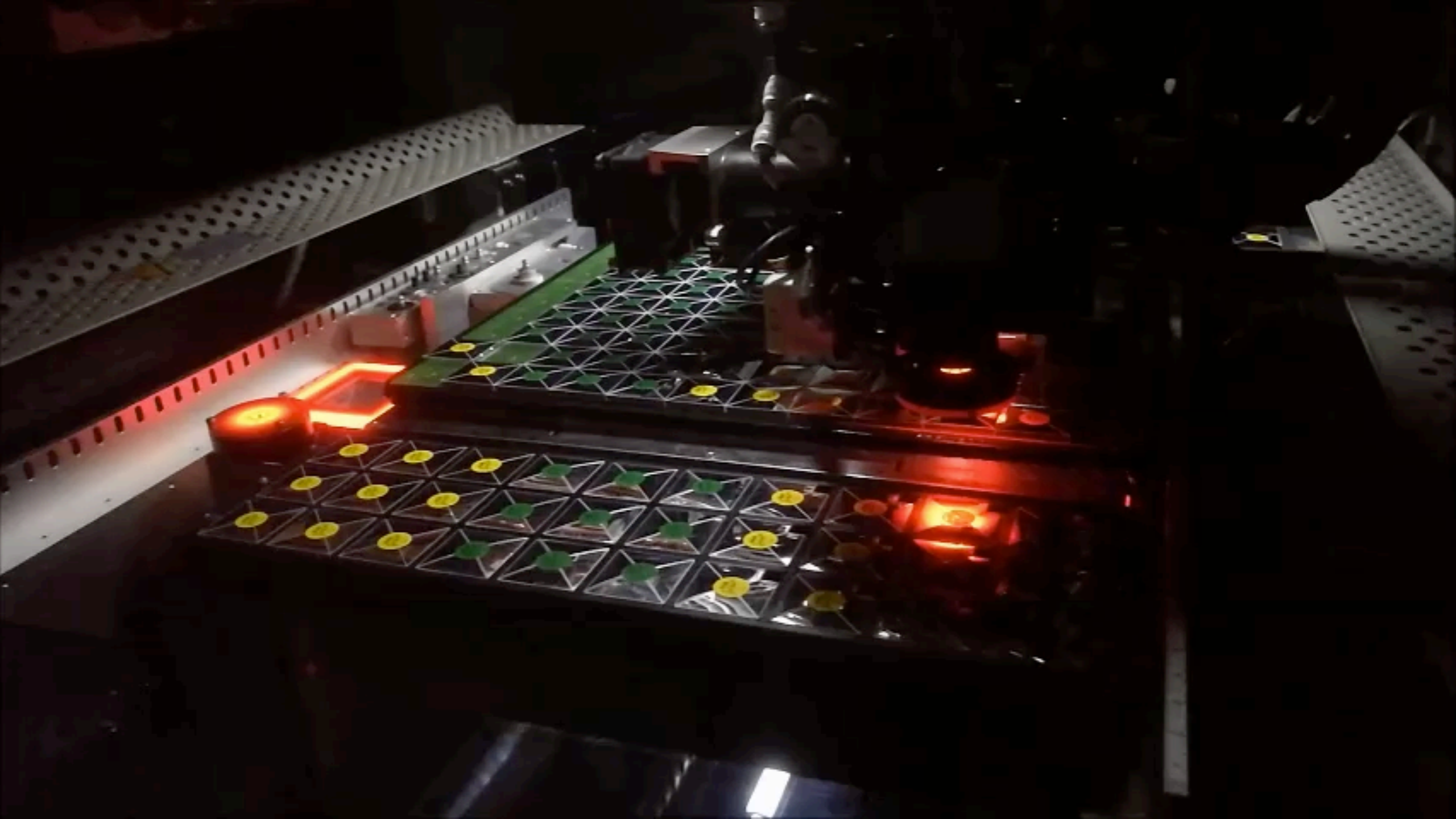












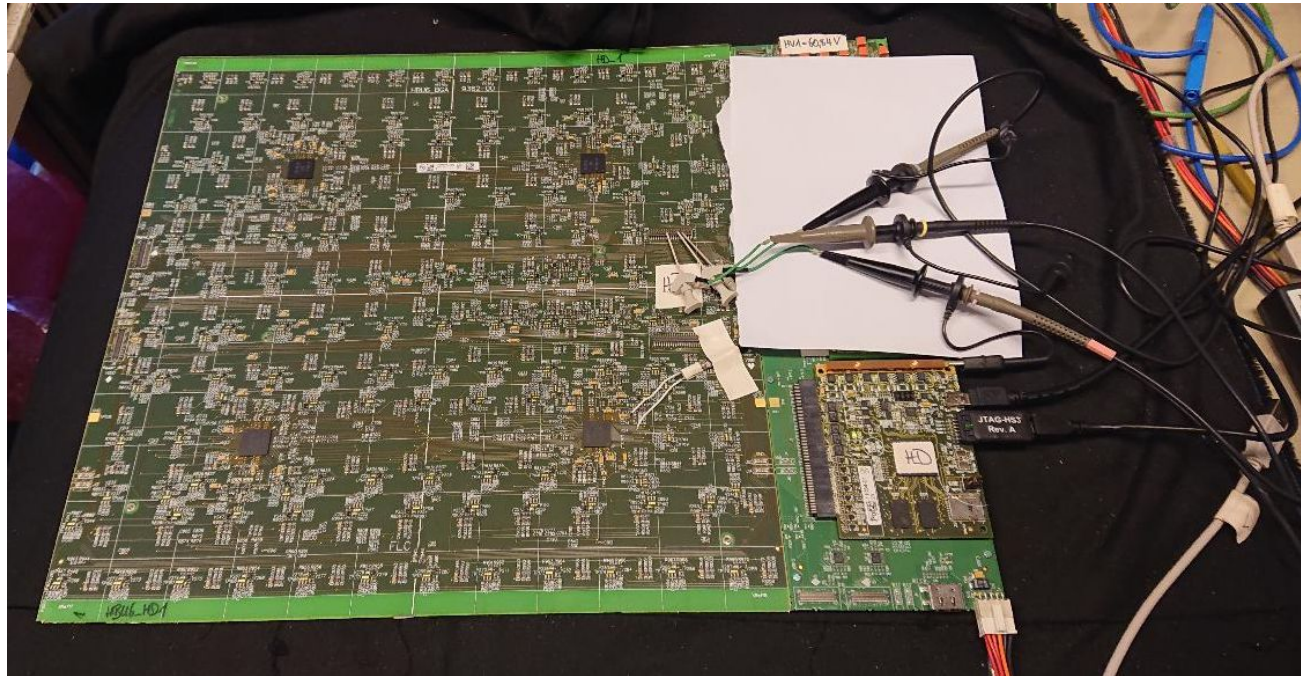


# Electronics Developments

# Status Commissioning HBU6\_HD

- New child in HBU family: HBU6\_HD with KLauS ASICs (cooperation Uni Heidelberg, DESY)
- Two HBU6\_HDs with KLauS5 ASICs, 4 new POWER4 boards completed.
- First commissioning at DESY Sept. 2019: Zhenxiong, Mathias.

see Wei Shen's talk



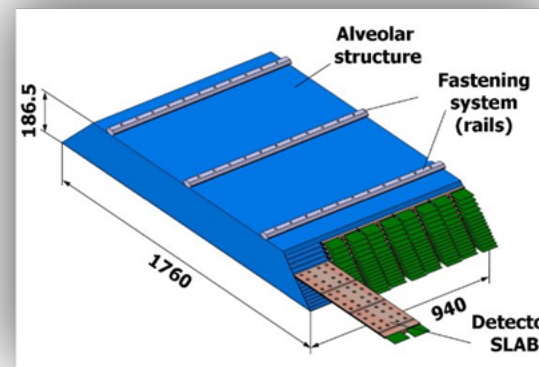
KLAUS ASIC:  
optimised input stage  
for SiPMs with smaller  
gain, larger dynamic  
range  
continued read-out  
timing



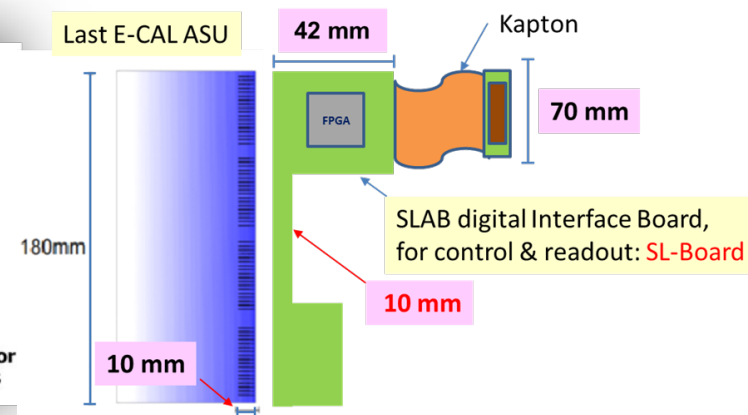
## Constraints for the Slab Interface Board ( SL-Board)

- The SI-board will be installed between ECAL and HCAL, separated by only 67 mm
- L-shape because of the cooling system
- Maximum Height : **6 to 12 mm depending on the location**
- Control & Readout electronics at the extremity of the Slab
- Signal Integrity over a Slab : up to 15 interconnected ASUs
- Very low Power consumption ( $\sim 150$  mA/ Slab) : needs to run in **power pulsing mode**

Alveolar structure for ILD SiW ECAL

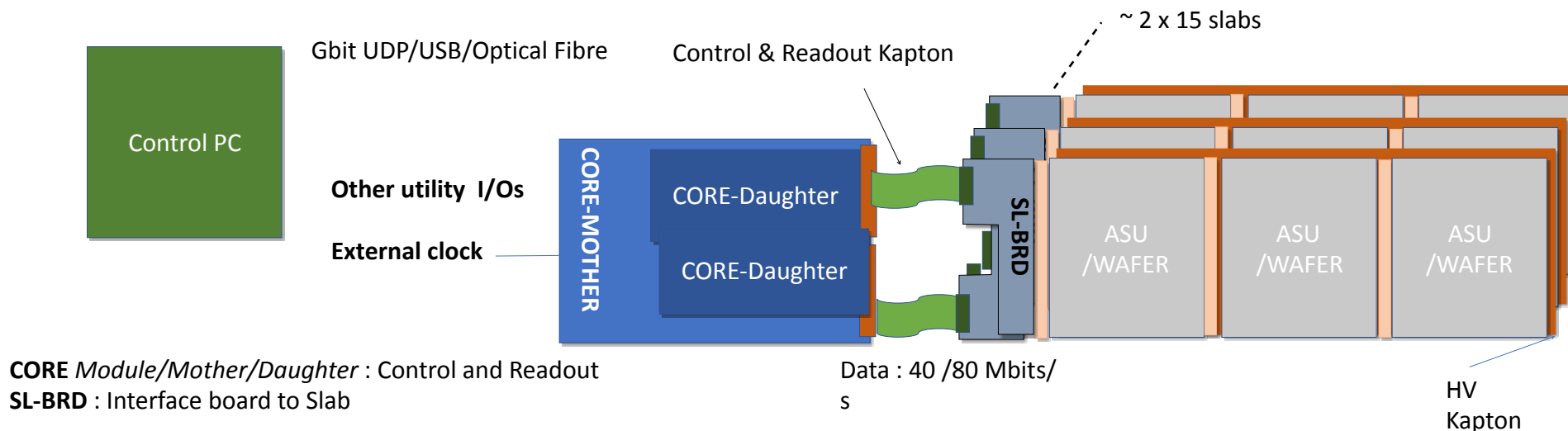


Scheme of layer extremity



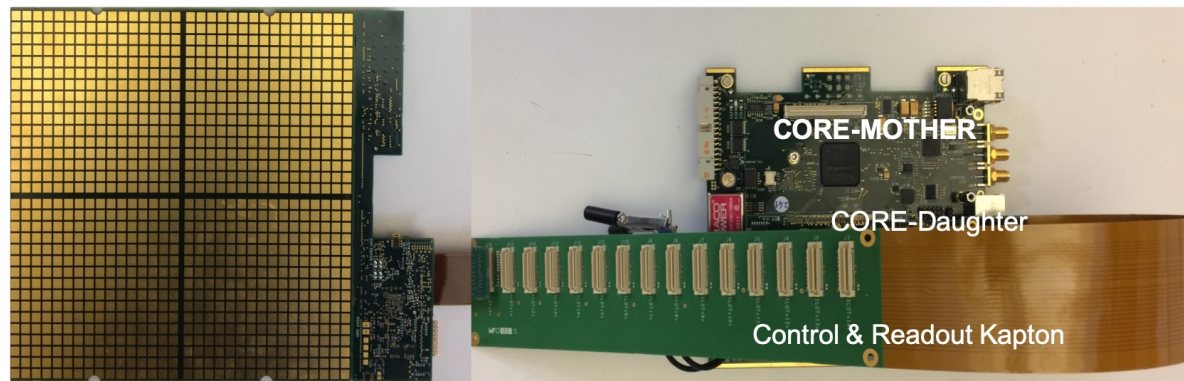
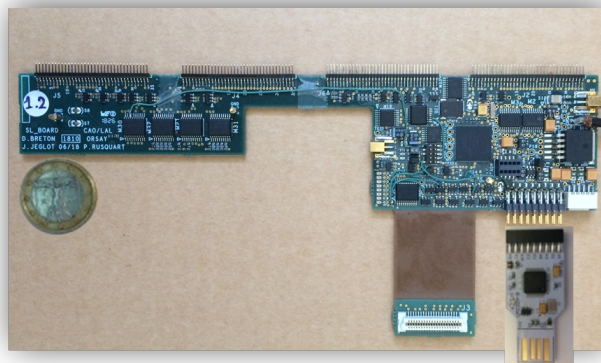
... similar to DUNE Structure

## Readout scheme of CALICE SiW ECAL technological prototype



External clock and Utility I/Os : possibility to be synchronised with other systems!

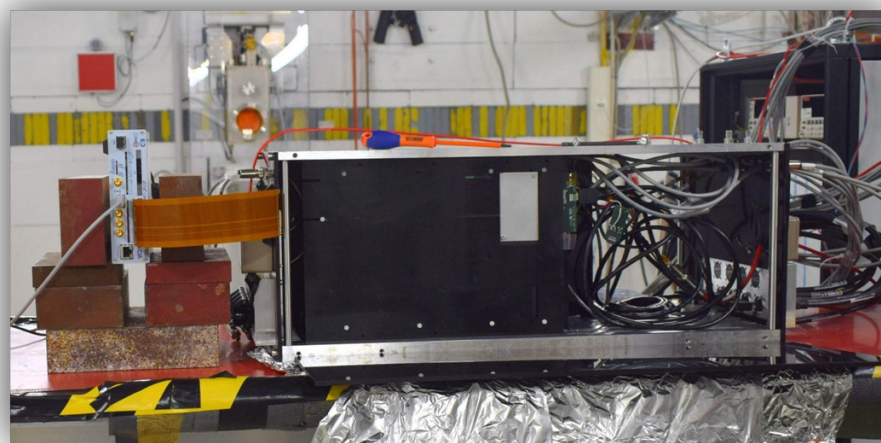
SL-Board for up to 10000 cells and connection to concentrator unit via flat kapton cable



Service for  
up to 15 layers

Elegant space economic solution  
 Seamless operation in DESY beam test 2019

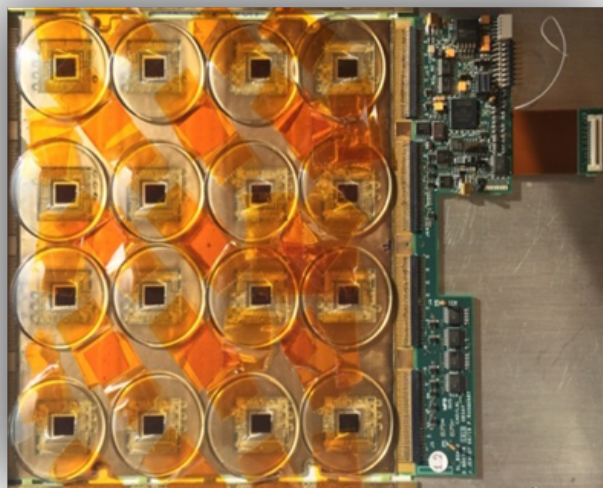
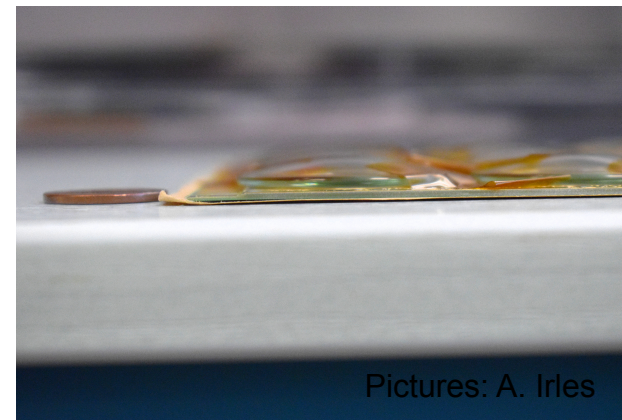
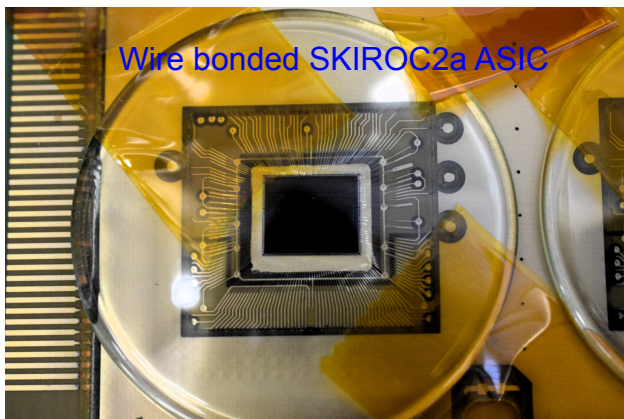
2019:  
 One flat cable  
 leaving the  
 detector



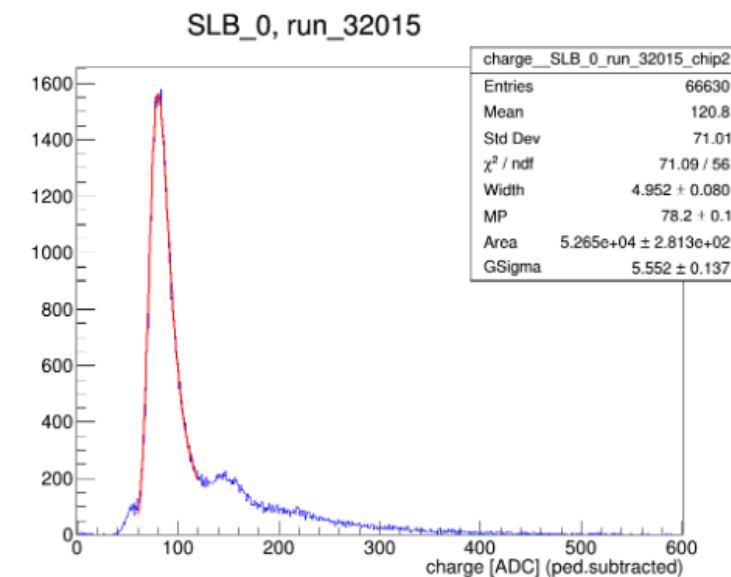
< 2019:  
 “Jungle” of bulky  
 cables



## Thin PCB for compact detector solutions



- Height 1.2mm (for a 9 layer board!!!)
- Challenges in terms of planarity
- were overcome in
- close collaboration with Korean Company
- First beam test 2019 at DESY



- “Dead space free” granular calorimeters put tight demands on compactness
- Current developments within CALICE for SiECAL meet these requirements
- Can be applied/adapted wherever compactness is mandatory
- Components will/did already go through scrutiny phase in beam tests



# Summary

no Outlook

**SiPMs are a mature technology meanwhile**

**SiPM-tile integration concepts suitable for large systems developed for e<sup>+</sup>e<sup>-</sup> colliders**

**Now being applied to CMS: production techniques for 240'000 channels**

**Electronics for compact ECAL designs and continuous readout under development**

**Established network of institutes and task sharing**

# Back-up