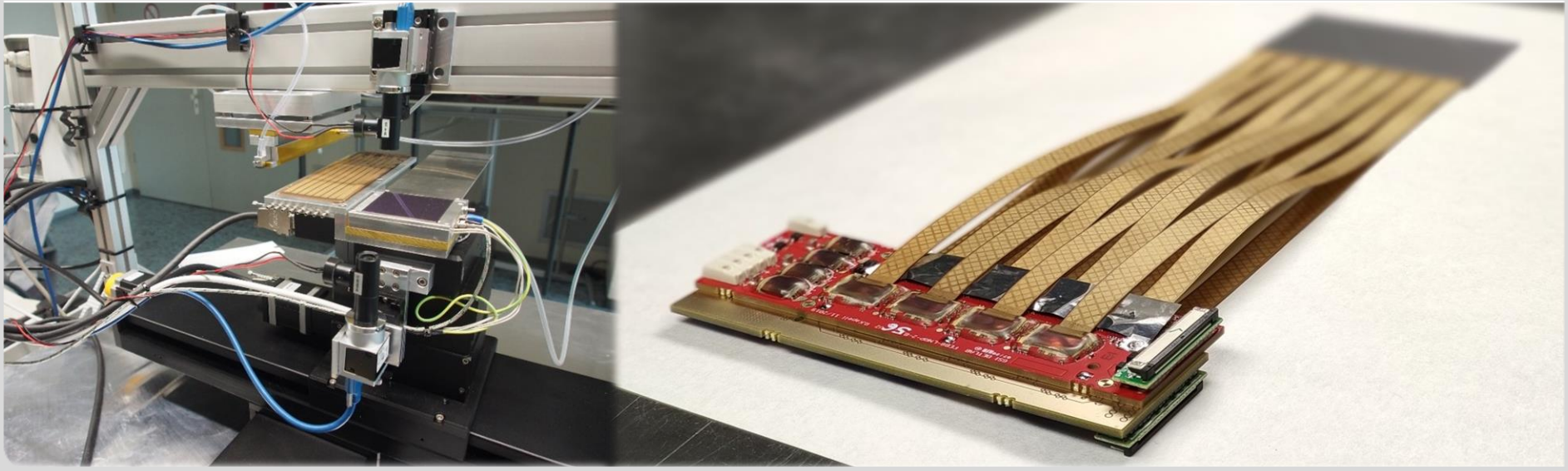
Karlsruhe Institute of Technology

CBM

Development and characterization of a novel high-density interconnection technology for the CBM Silicon Tracking System at FAIR

Patrick Pfistner, Thomas Blank, Michele Caselle,
for the CBM collaboration

Institute for Data Processing and Electronics

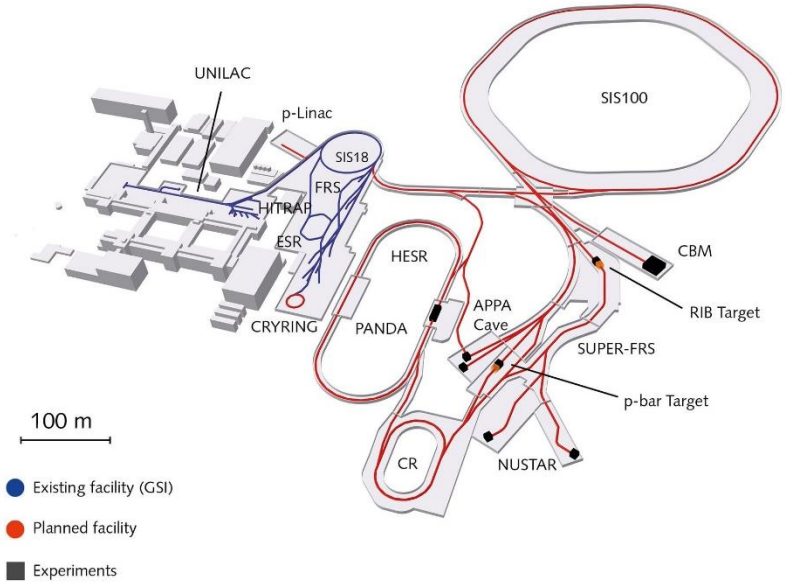


Outline

- Compressed Baryonic Matter (CBM) experiment @ FAIR
- Silicon Tracking System (STS)
- STS detector module
- High-density interconnection based on aluminum microcables and TAB
- Novel high-density interconnection technology based on Gold stud – solder bump bonding
- Characterization of prototype modules in copper technology

CBM @ FAIR

- CBM is one of the major scientific programs at FAIR
- Investigation of QCD phase diagram at high net-baryon densities and moderate temperatures



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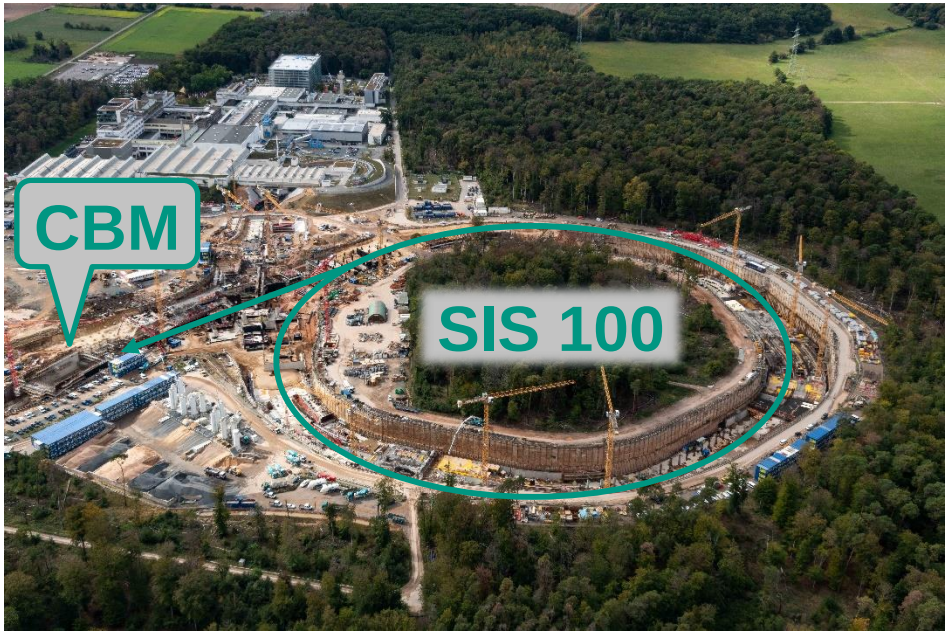
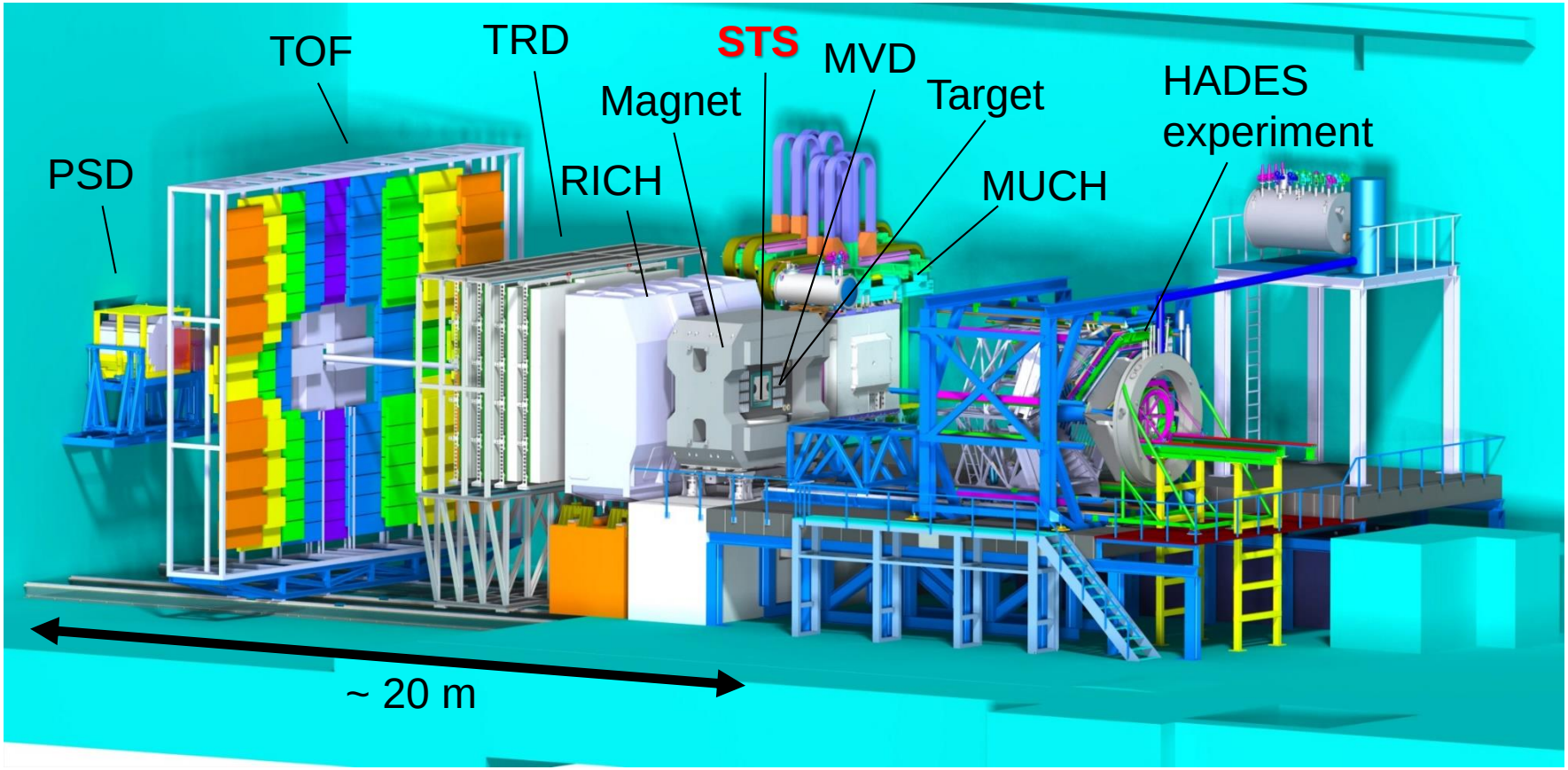


Image: D. Fehrenz/GSI/FAIR

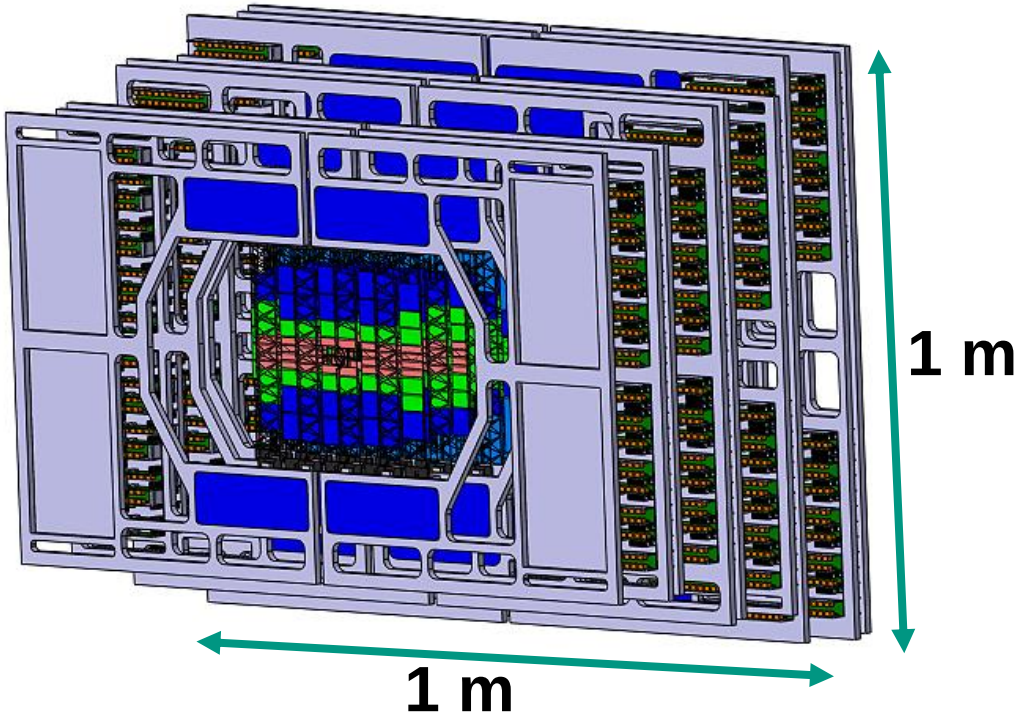
Drone video of FAIR construction site:
https://www.youtube.com/watch?v=8cSLI557CQk

CBM experimental setup

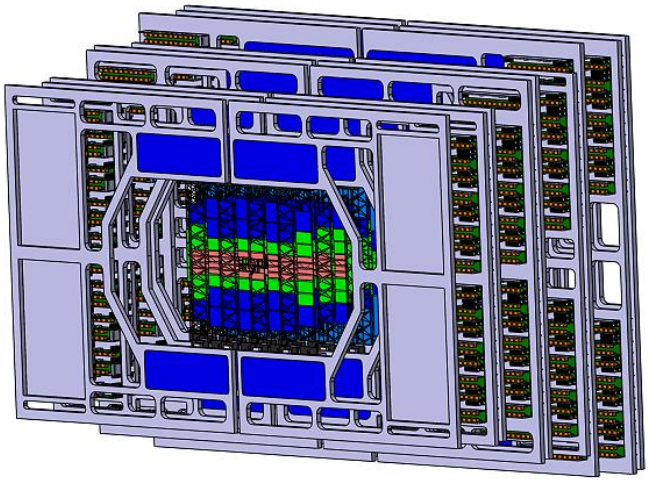


Silicon Tracking System (STS)

- Track identification and momentum determination of charged particles
- Track mult. ≤ 700 per central Au+Au collision in aperture $2.5° < \theta < 25°$
- Lifetime fluence up to $1 \text{ x } 10^{14} \text{ n}_{\text{eq}} \text{cm}^{-2}$
- Momentum resolution Δp/p < 2%



STS conception



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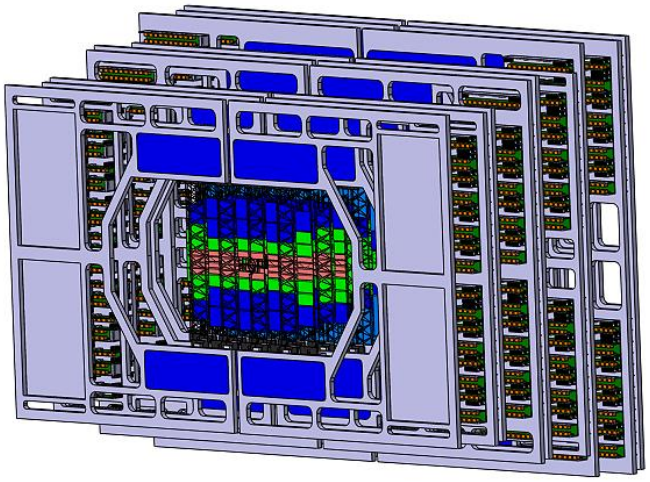
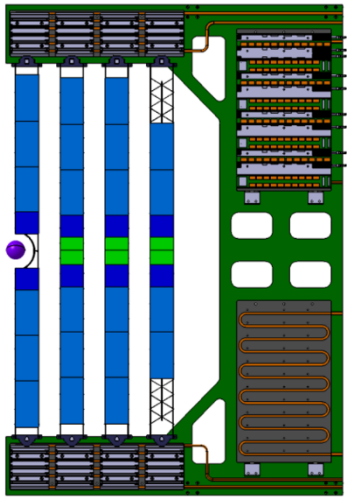


Half-station



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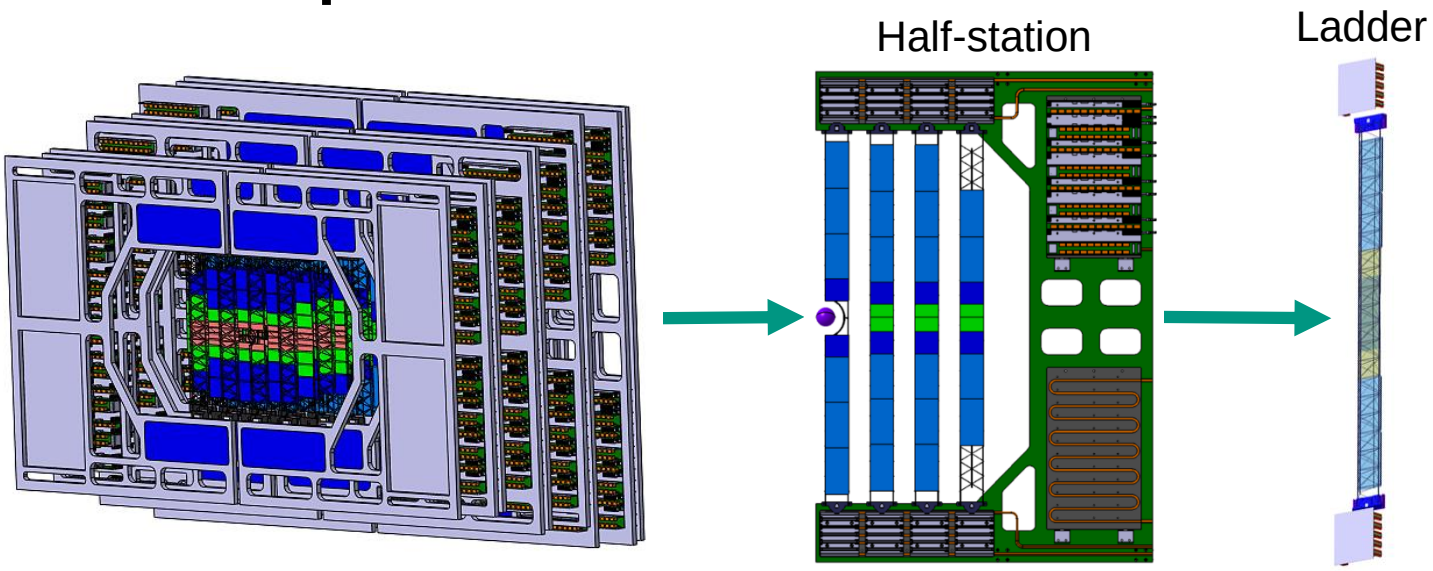

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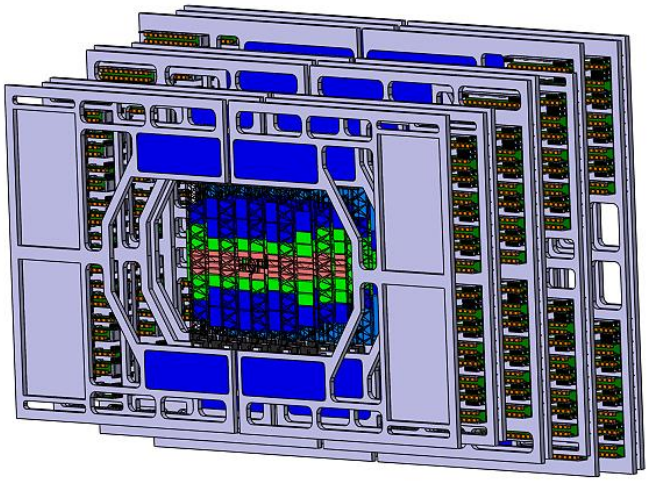
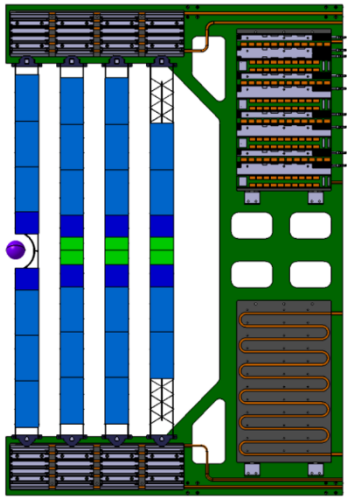
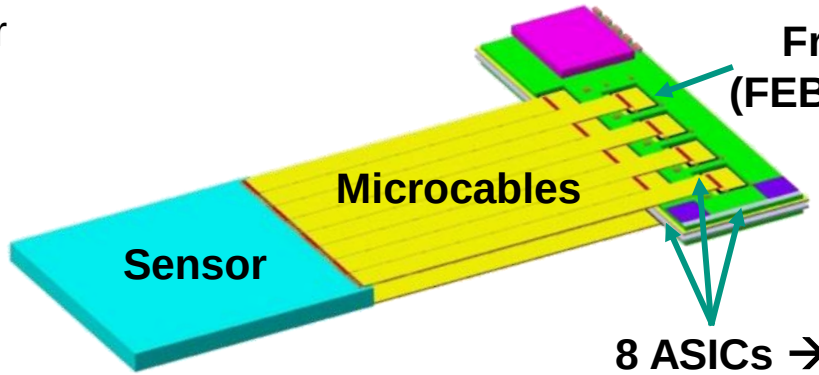




Detector module

- Double-sided microstrip sensor
  - Pitch: 58 µm
  - 2 x 1024 channels
- 2 x 8/16 low mass microcables
- 2 x FEB-8
- 2 x 8 STS-XYTER ASICs



TAB interconnection

ALUMINUM TECHNOLOGY

Aluminum microcables

Aluminum microcable

- 15 µm Al on 10 µm Polyimide
- Meshed PI spacer
- 64 signal lines
- Pitch: 116 µm
- Capacitance ~ 0.35 pF/cm
- $X/X_0 \sim 0.03$ %
- 32 microcables per sensor

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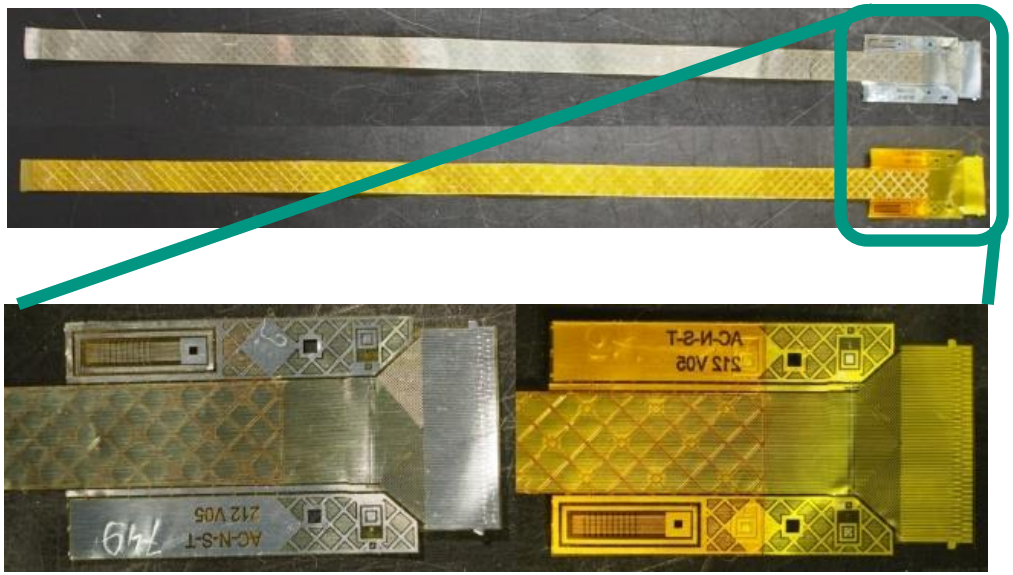

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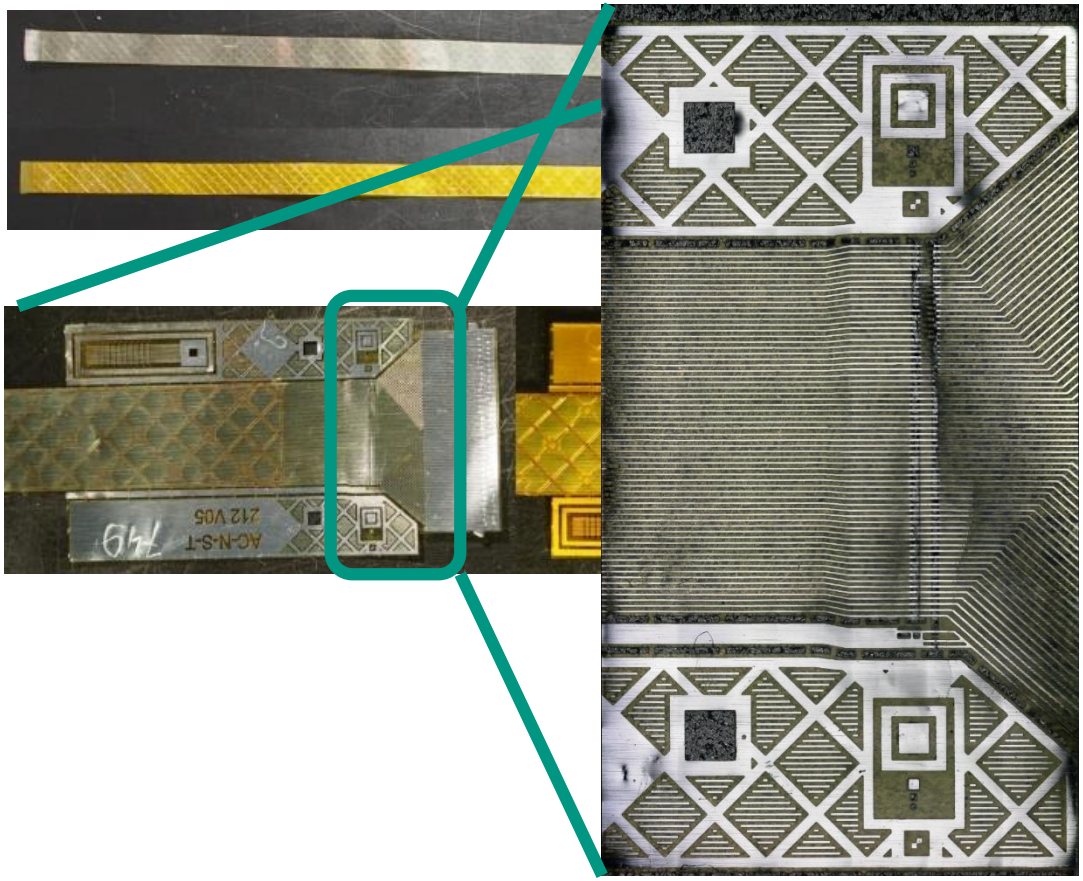
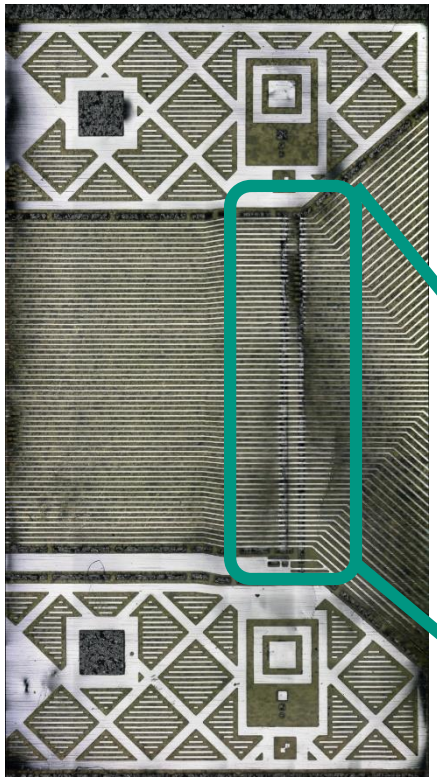


Interconnection by TAB process



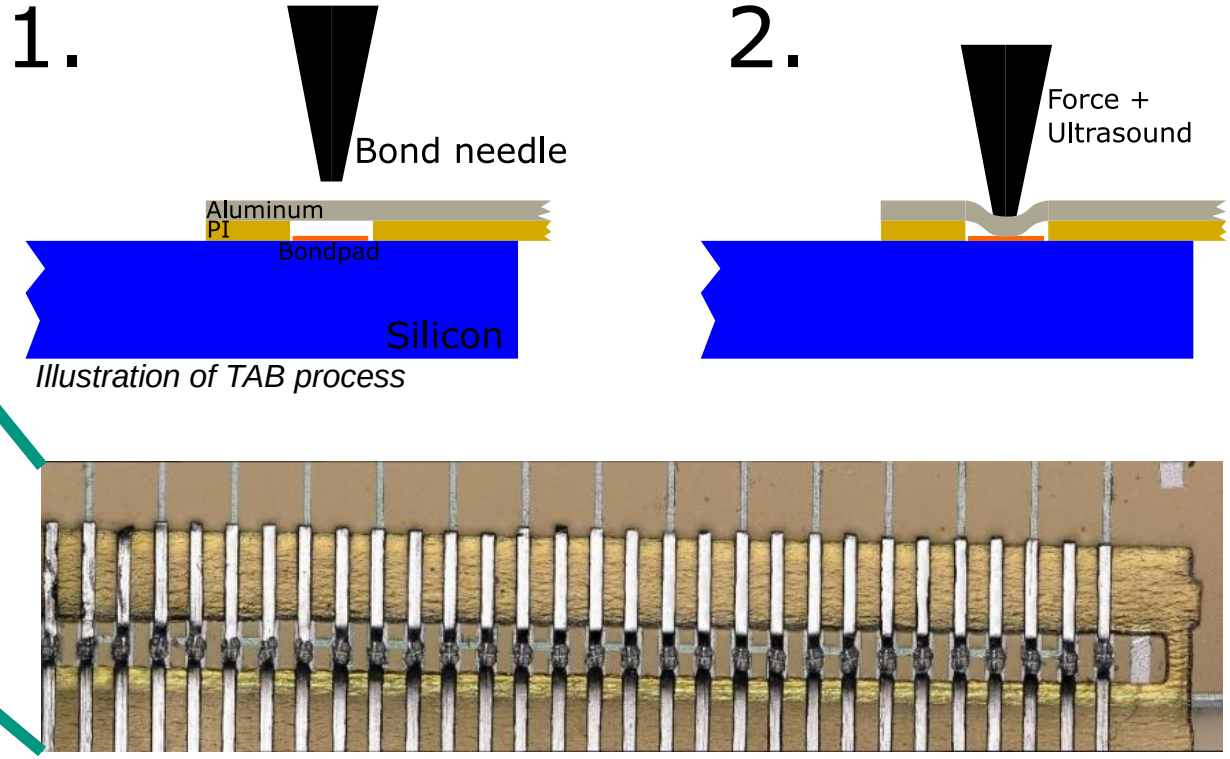


Illustration of TAB process

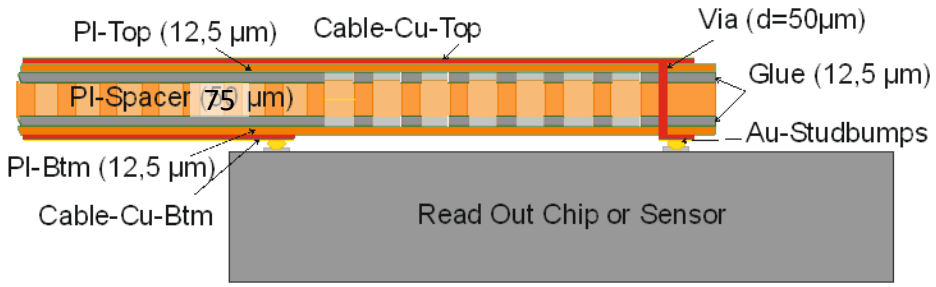
- Room temperature process
- Well-established, proven to work
- Manual and time-consuming
- Single supplier of aluminum microcables (LTU Ltd, Kharkov, Ukraine)

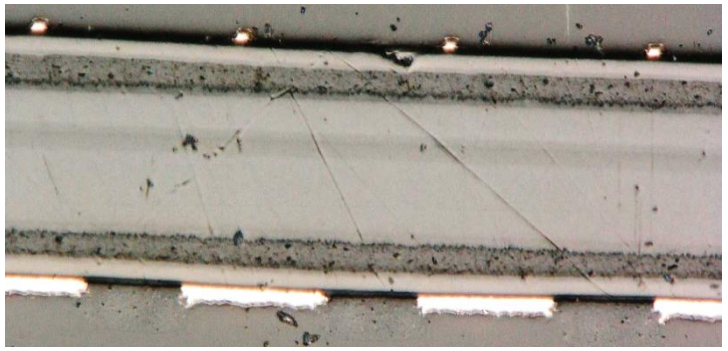
Gold stud – solder bump bonding

COPPER TECHNOLOGY

Copper microcables for Au-solder process

- Two signal layers: 2 x 64 channels
- Bond pitch 116 µm
- Thickness 140 µm
- Capacitance ~ 0.38 pF/cm
- X/X_0 ~ 0.05 %





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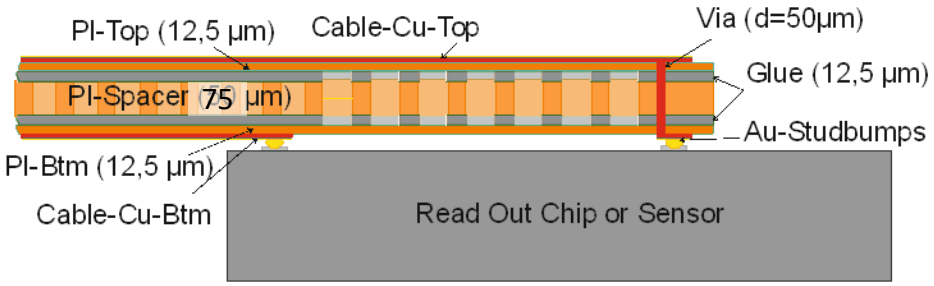
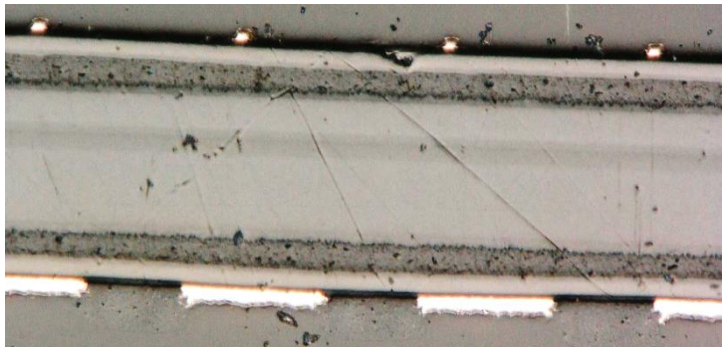
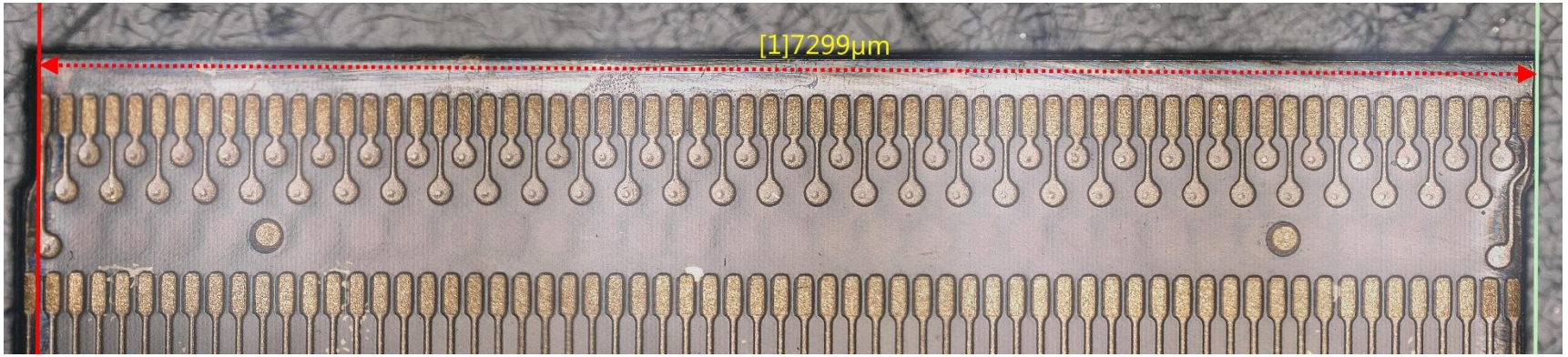


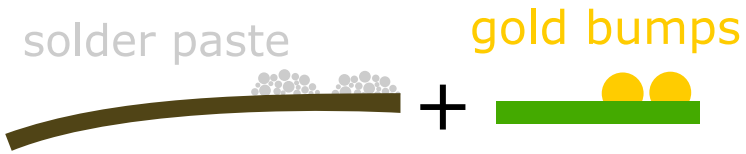




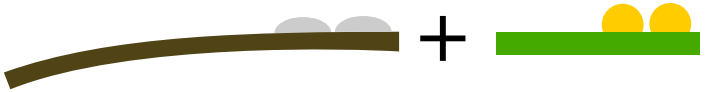
Novel approach: Gold stud – solder process

1. cable and chip

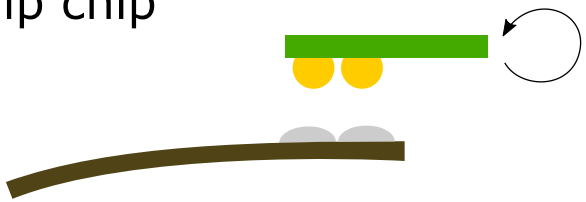
2. place bumps on chip and solder paste on cable



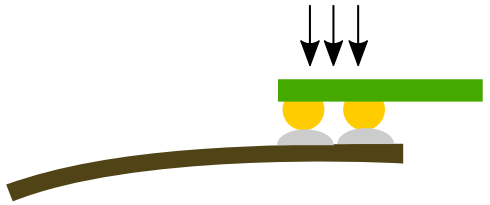
3. reflow



4. flip chip

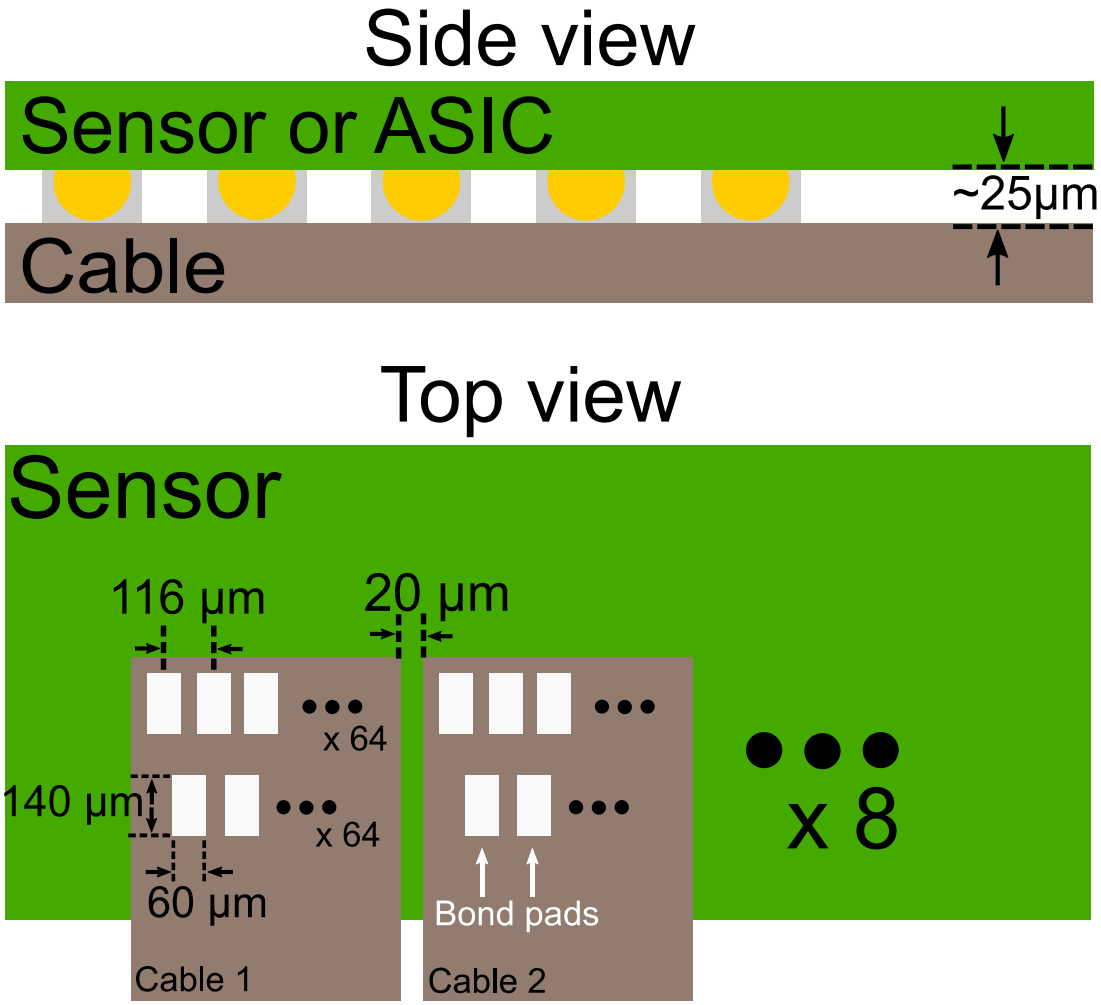


5. thermocompression bonding

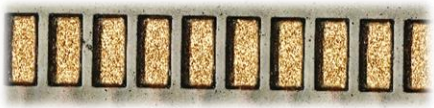


6. underfill

Important dimensions

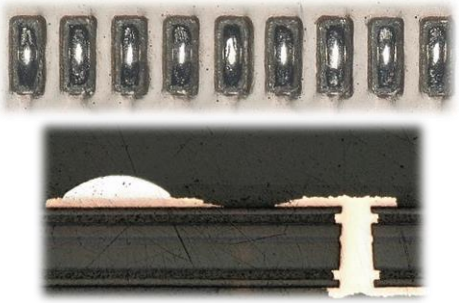


Realization of Au stud – solder process



Bond pads

Print solder paste



Reflow solder paste

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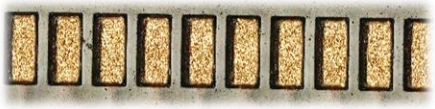

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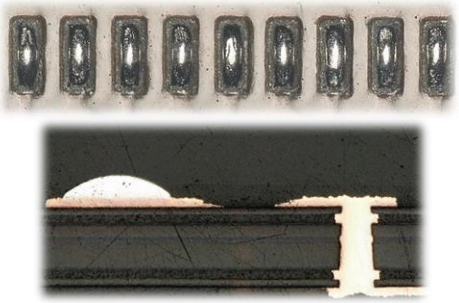
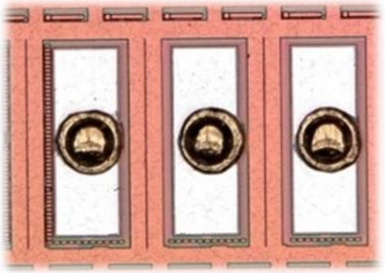
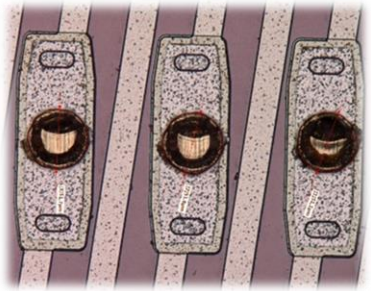


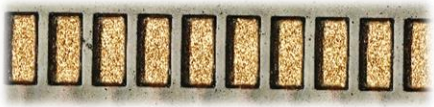
Reflow solder paste





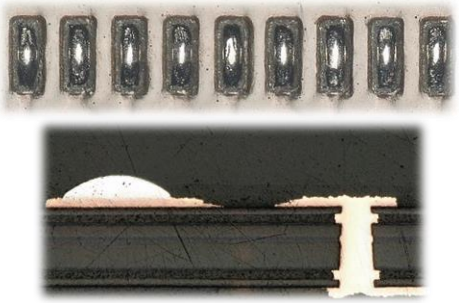
Place gold bumps

Realization of Au stud – solder process

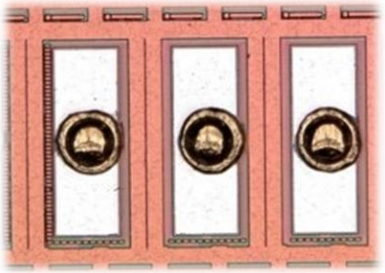


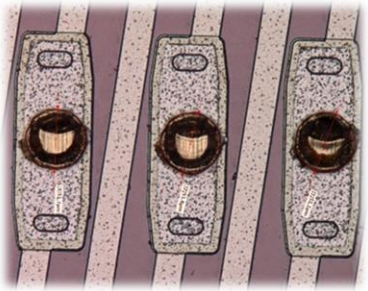
Bond pads

Print solder paste



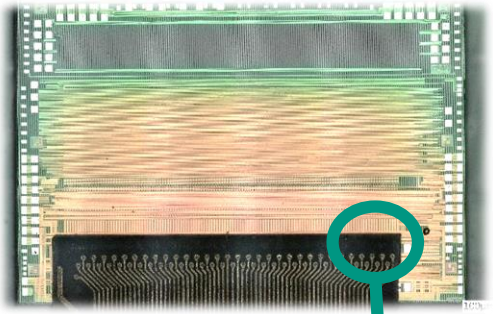
Reflow solder paste

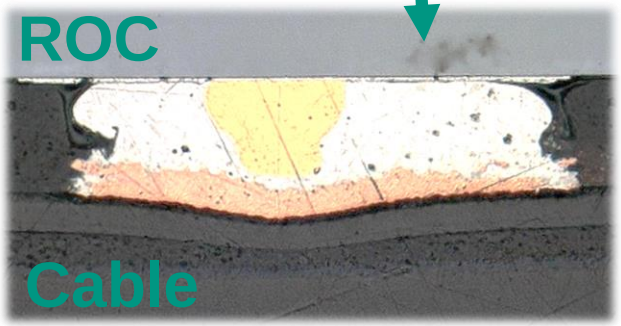




Place gold bumps

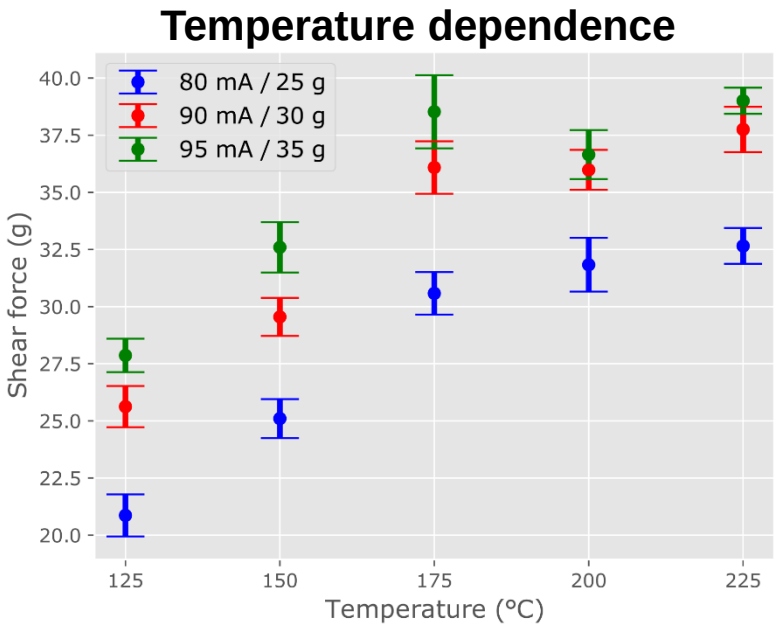
Bonding





Gold stud bumping process optimization

- Gold bumping parameter scan
  - Temperature
  - Bond force
  - Ultrasonic current (USG)



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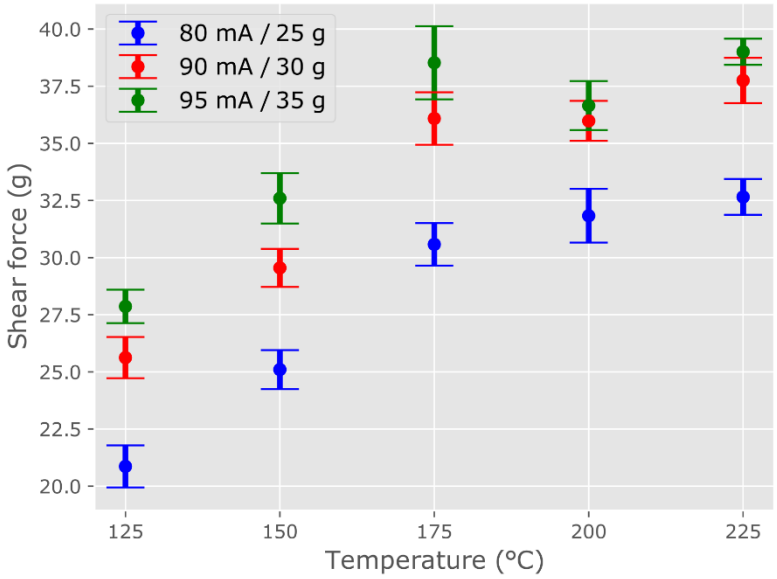
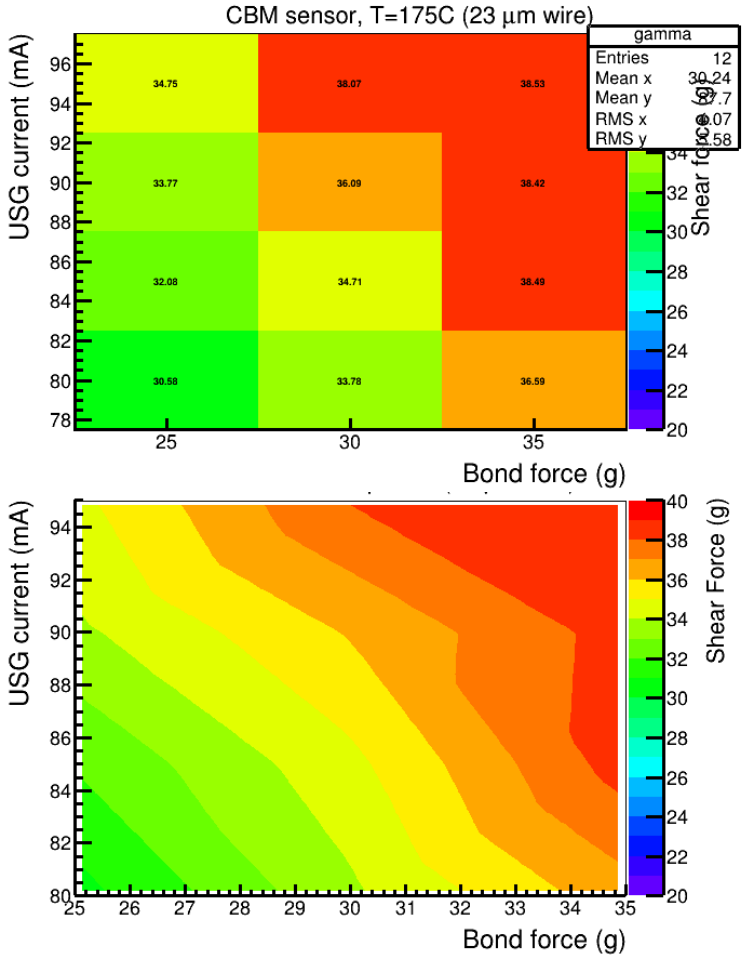
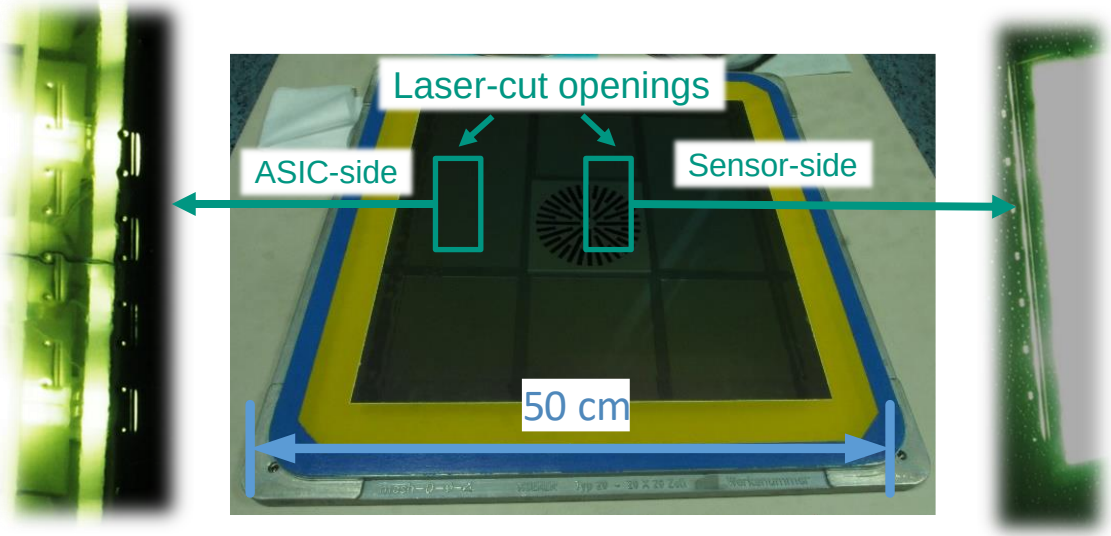
Temperature dependence

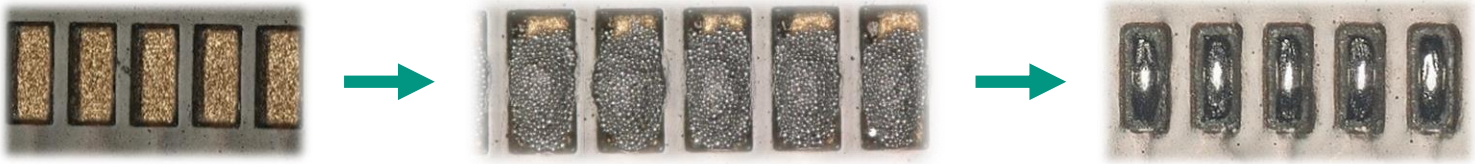


Bond force – USG scan

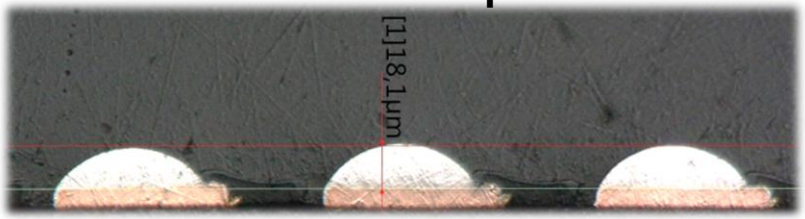


Solder paste type 7/8 printing and reflow





Uniform solder deposition



Tackling the thermal mismatch

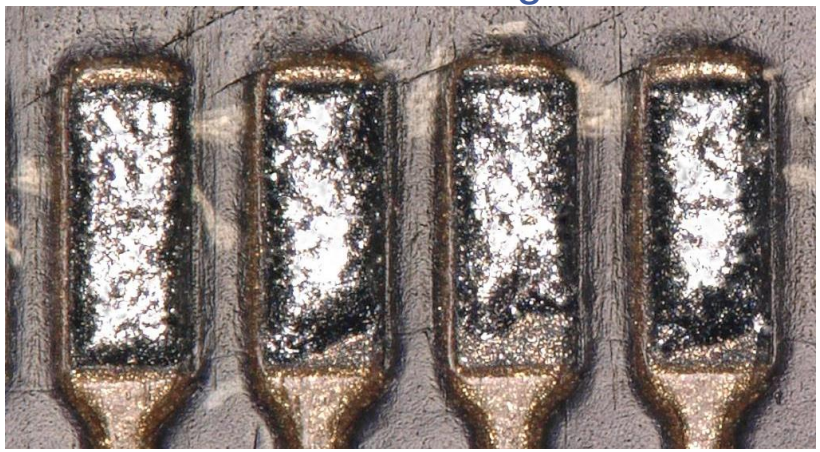
- Process temperature reduction
- Downscaling of microcable pitch

Solder paste type 7/8

Alloy	T_{melt} (°C)
Sn96.5Ag3.0Cu0.5 (SAC305)	217
Sn63Pb37	183
Sn42Bi58	138
Sn42Bi57.6Ag0.4	131

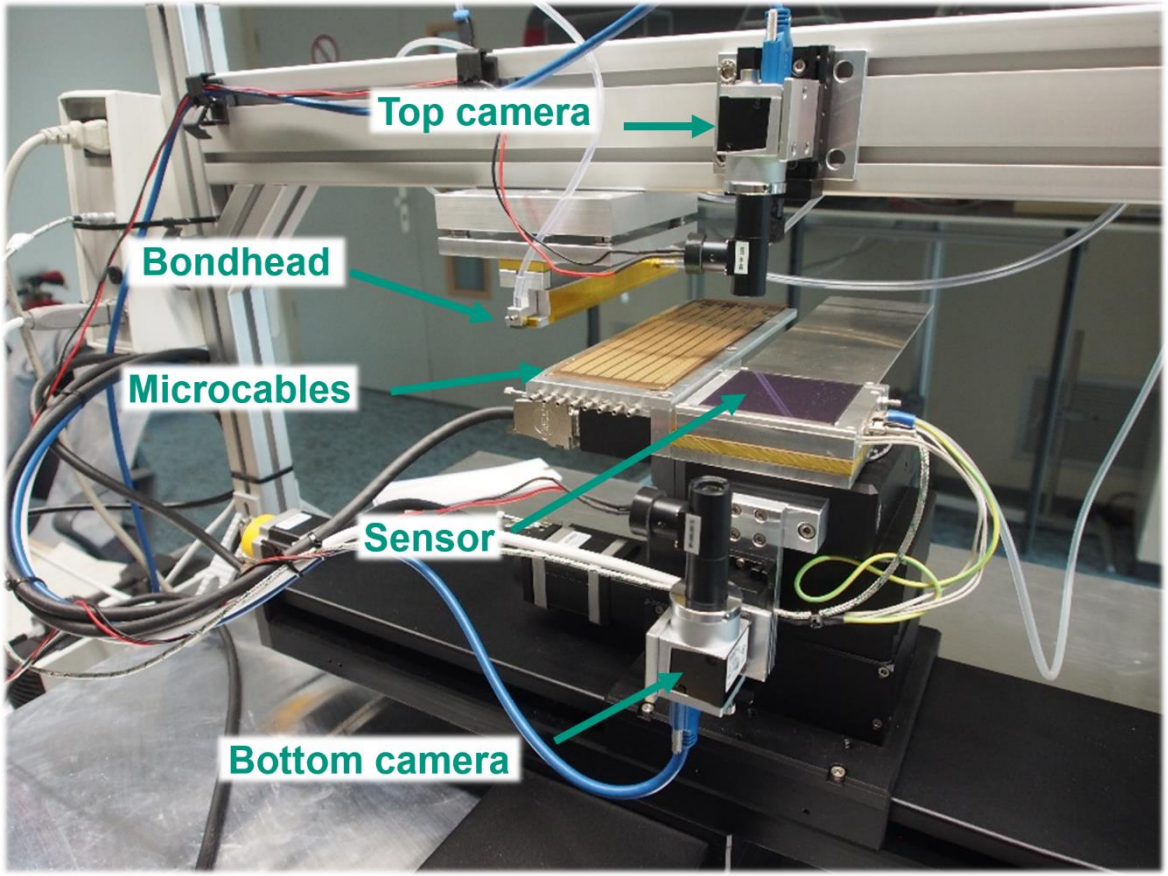
SAC305

Sn42Bi57.6Ag0.4

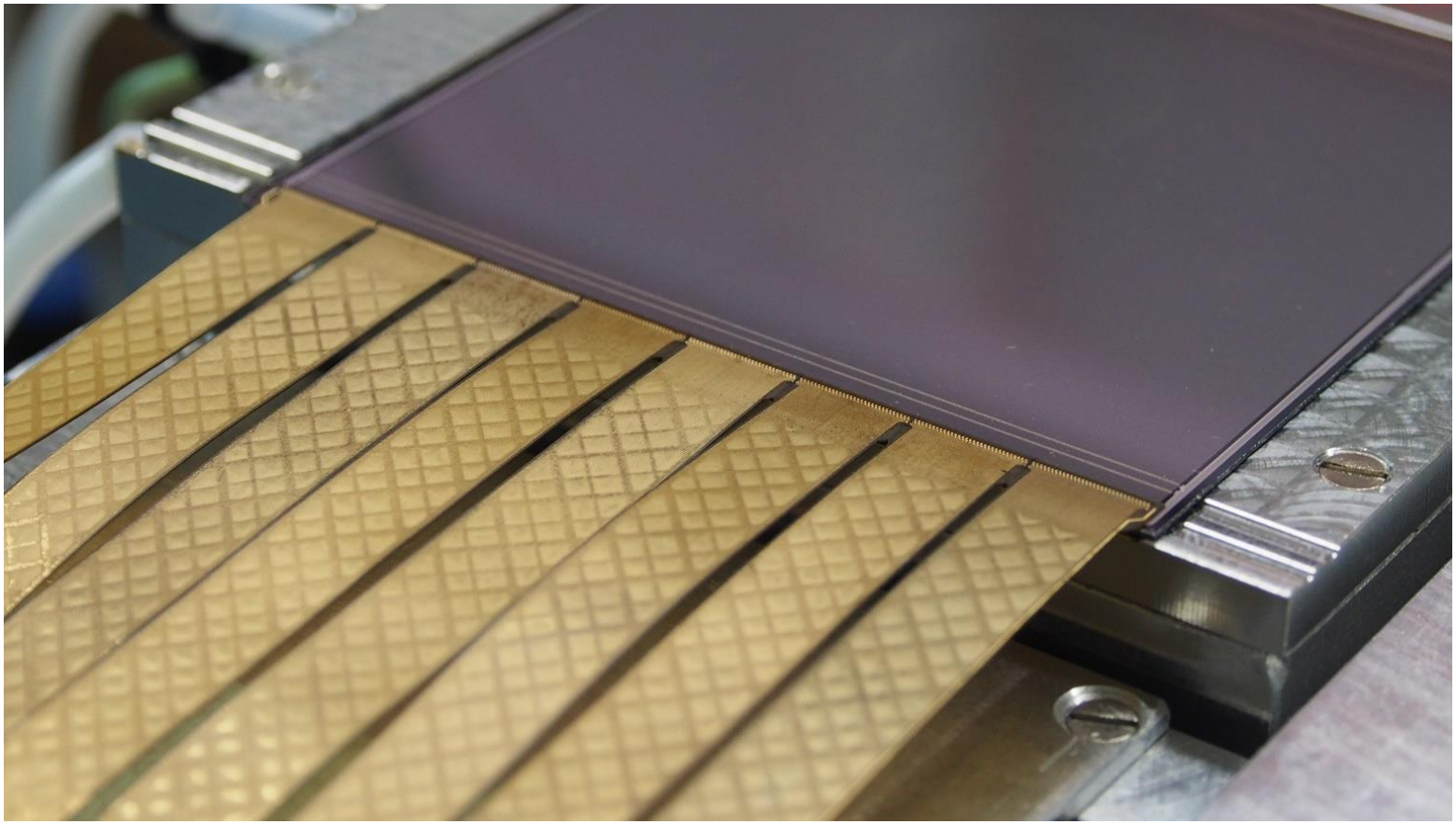


In-house bonding machine for sensor-side interconnection

- Four stepper motors (x,y,z,φ) with sub-micron resolution
- Temperature regulated heatable bond head and sensor plate
- Dual-camera optical system
- Automated vacuum control



Complete single-sided assembly



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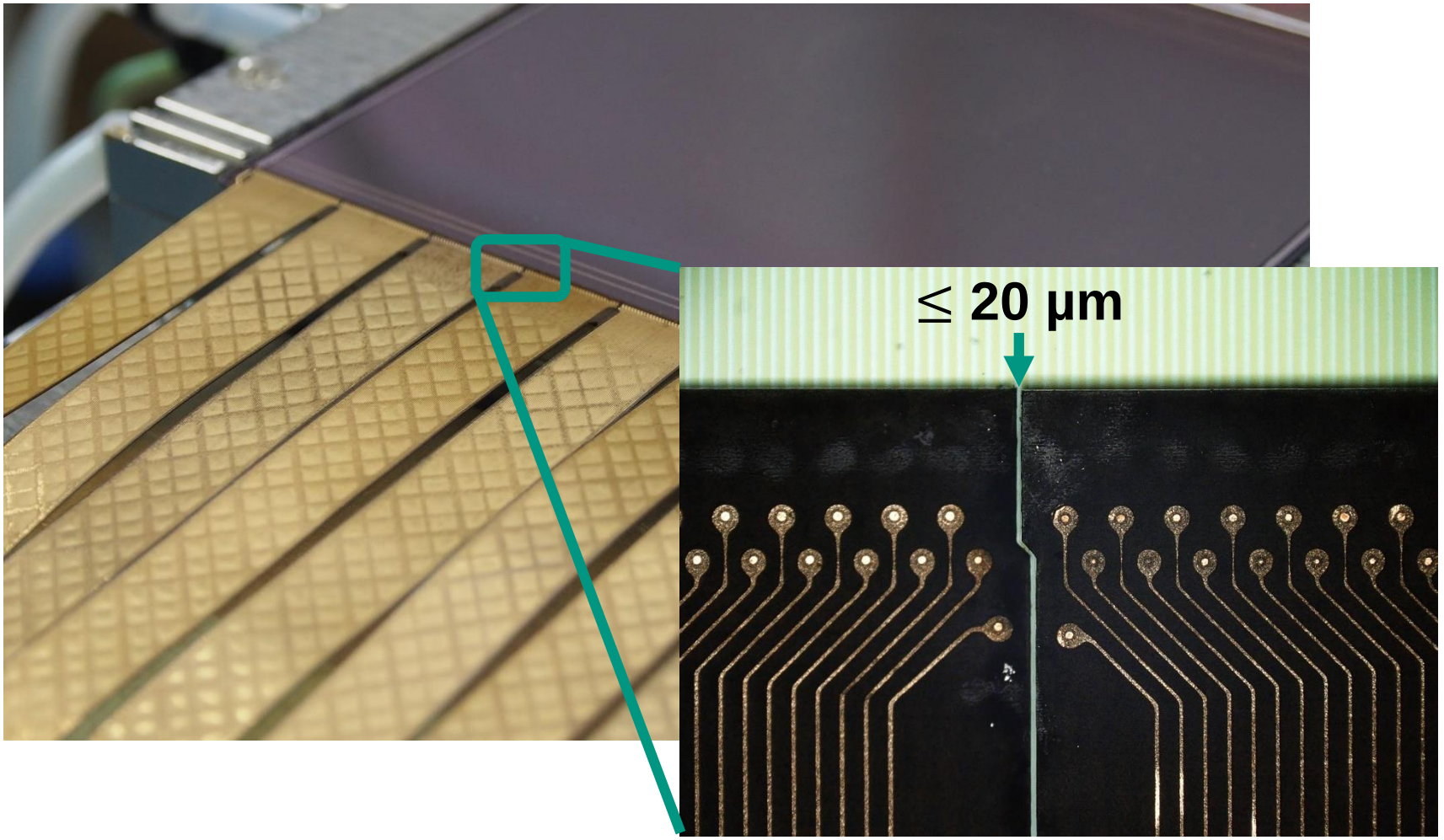
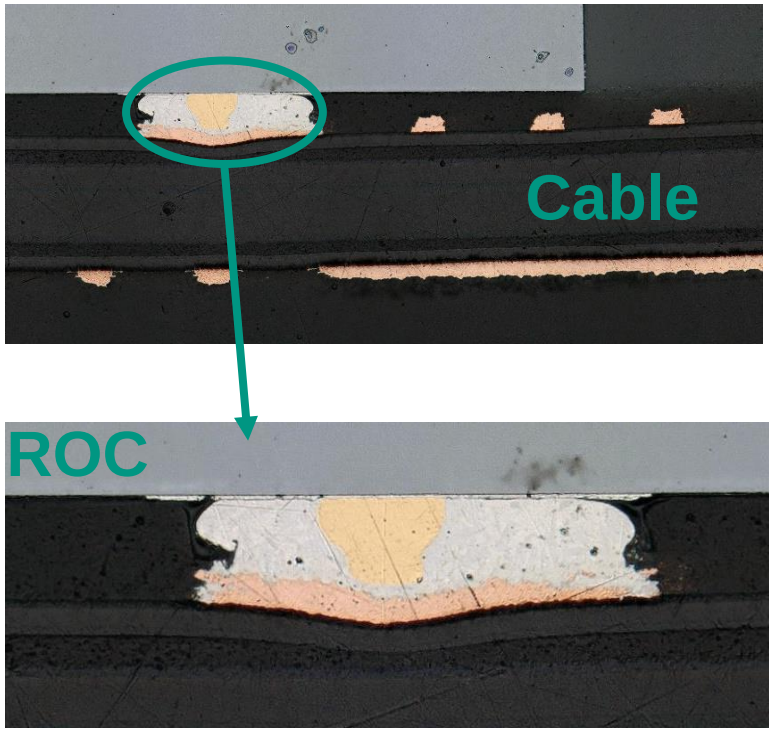
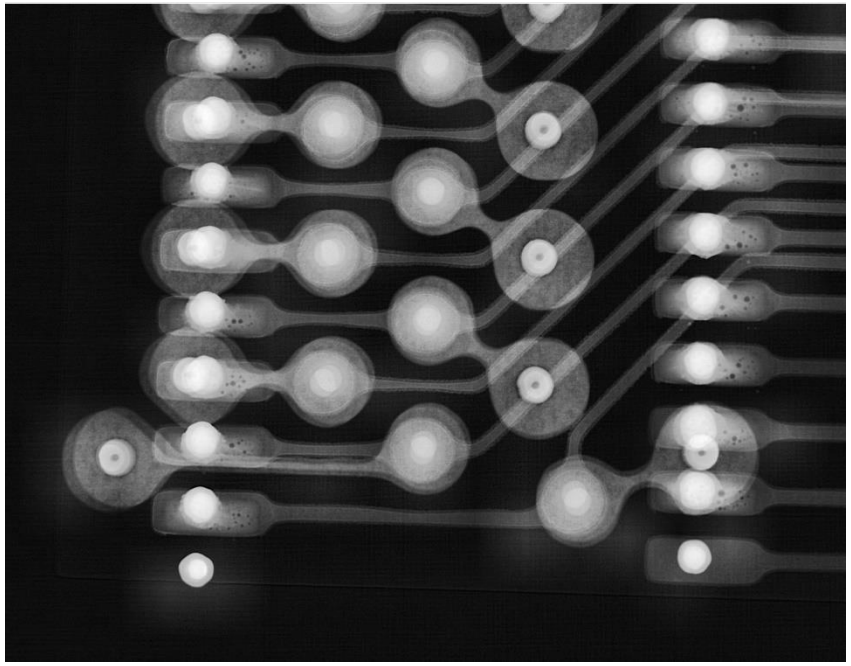


Quality assurance

Cross-sections

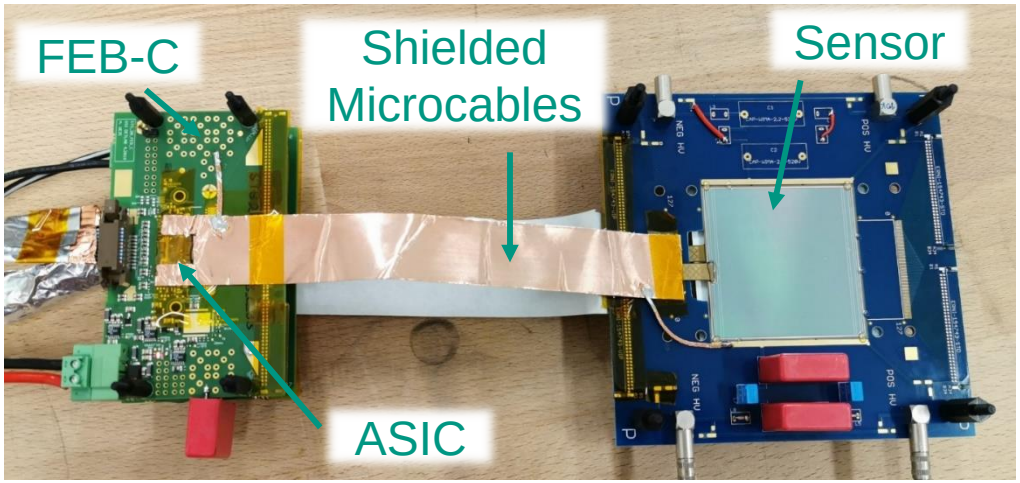


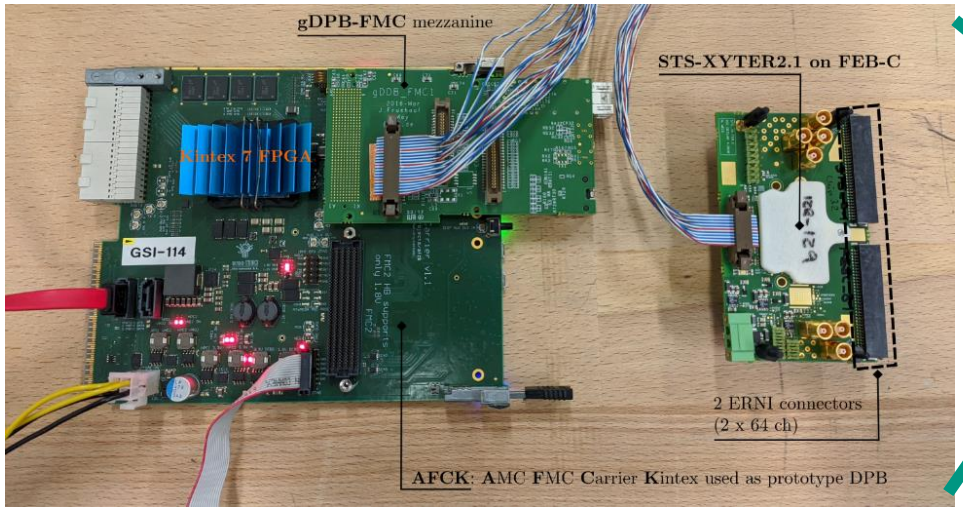
X-ray inspection

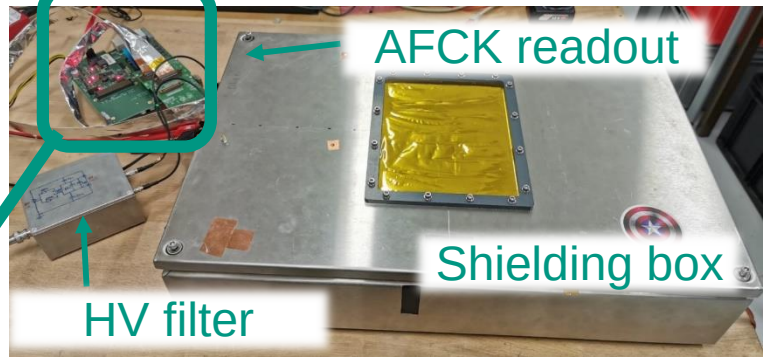


Test setup small-scale prototypes

- Asymmetric bias at 150 V
- One microcable each on n- and p-side
- 2 x FEB-C each hosting one readout ASIC
- Readout via AFCK hosting Kintex7 FPGA controlled by IPbus protocol







ENC evaluation on prototype modules

- Simple ENC parametrization based on capacitive load seen by CSA

$$\text{Alu: } \underbrace{460\ \mathrm{e^-}}_{\textbf{ASIC}} + \Big(\underbrace{0.35\ \frac{\mathrm{pF}}{\mathrm{cm}} * 25\ \mathrm{cm}}_{\textbf{Cable}} + \underbrace{1.52/1.74\ \frac{\mathrm{pF}}{\mathrm{cm}} * 4.2\ \mathrm{cm}}_{\textbf{Sensor}}\Big) * 27.4\ \frac{\mathrm{e^-}}{\mathrm{pF}} = \mathbf{875/900\ e^-}$$

$$\text{Cu: } 460\ \mathrm{e^-} + \Big(0.38\ \frac{\mathrm{pF}}{\mathrm{cm}} * 20\ \mathrm{cm} + 1.52/1.74\ \frac{\mathrm{pF}}{\mathrm{cm}} * 6.2\ \mathrm{cm}\Big) * 27.4\ \frac{\mathrm{e^-}}{\mathrm{pF}} = \mathbf{926/964\ e^-}$$

ENC evaluation on prototype modules

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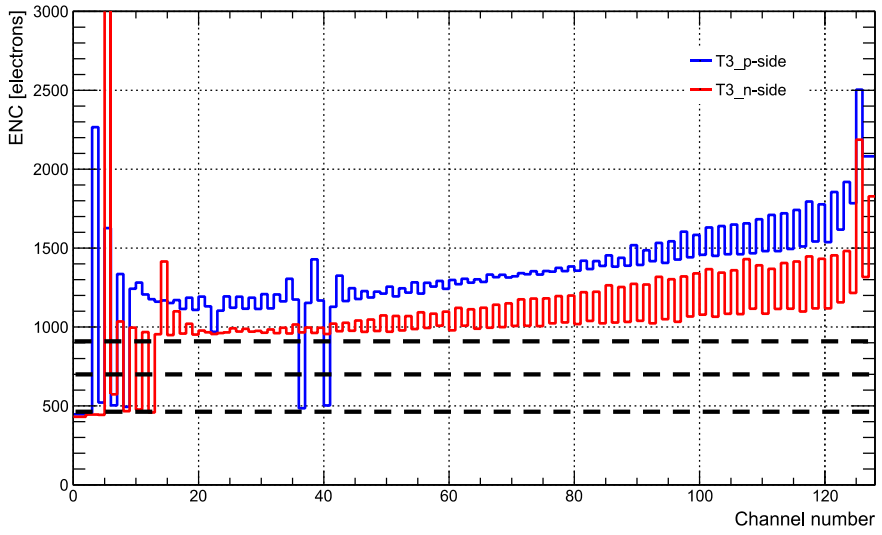
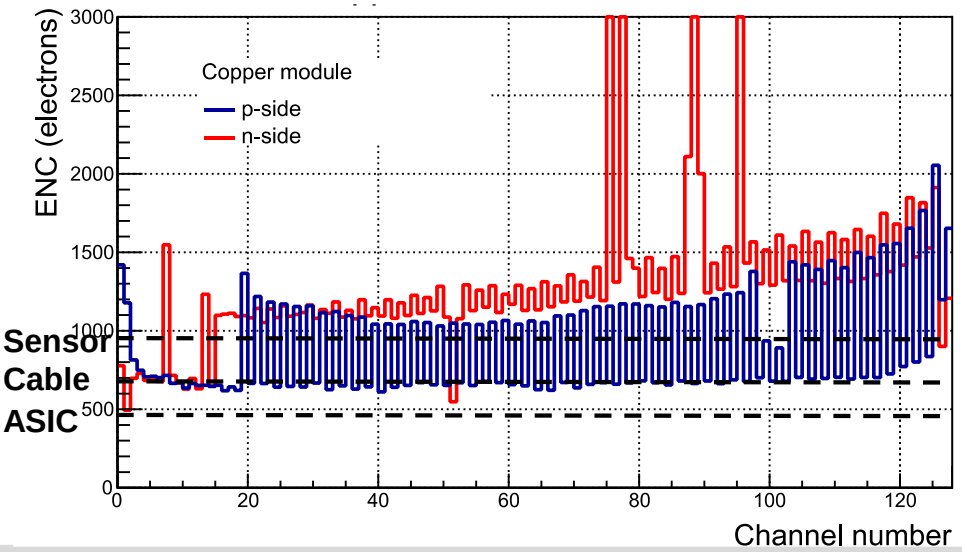
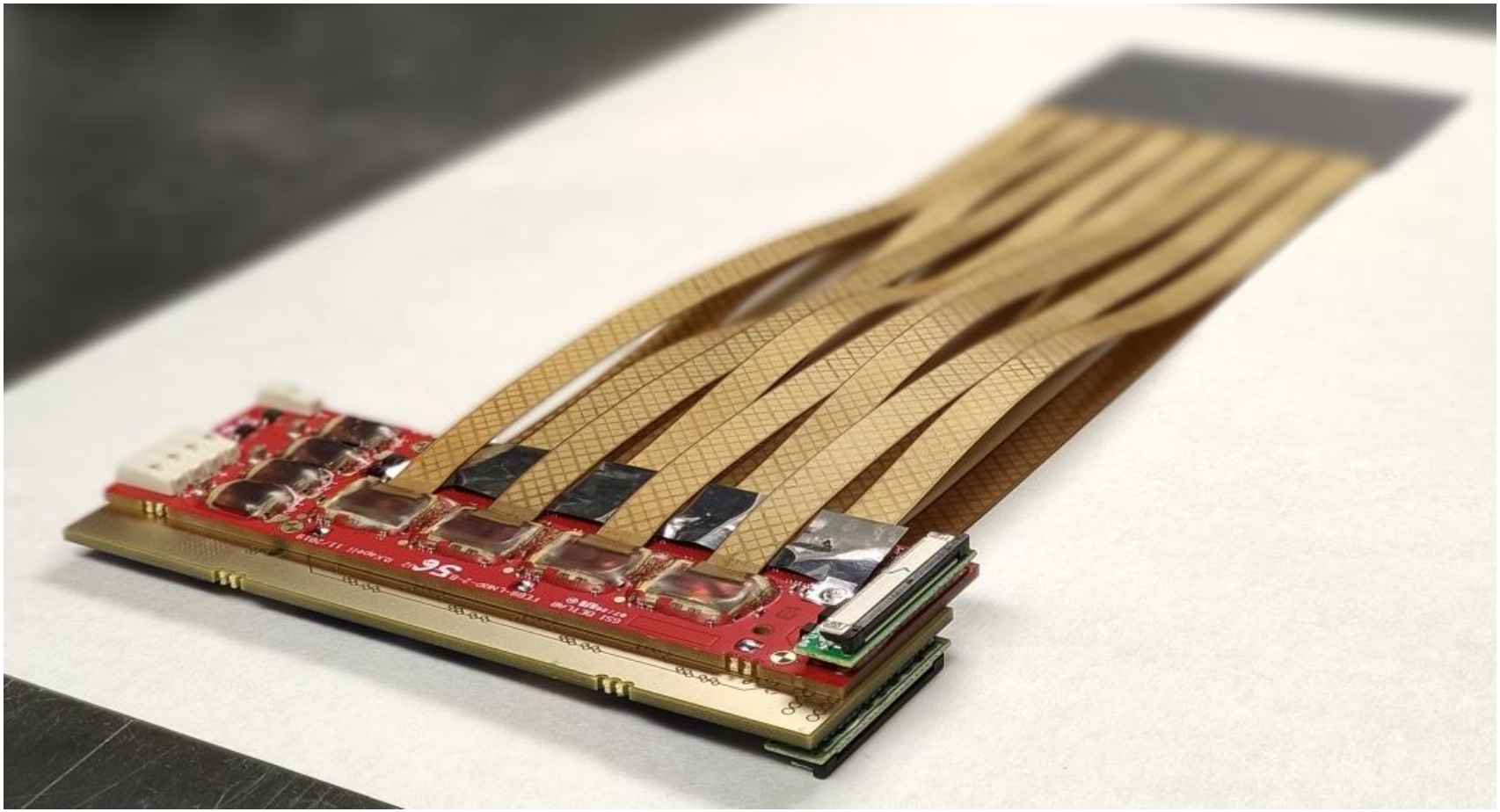
Alu



Cu

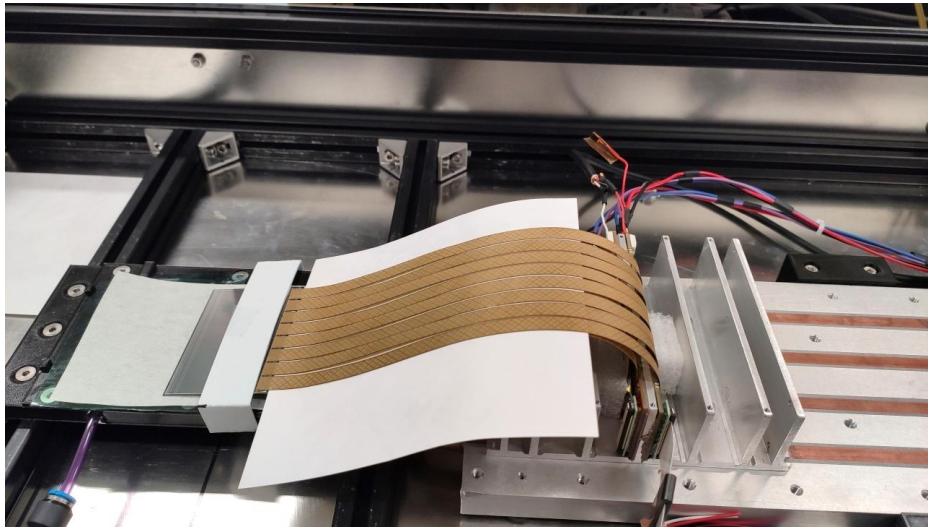


Full-scale prototype

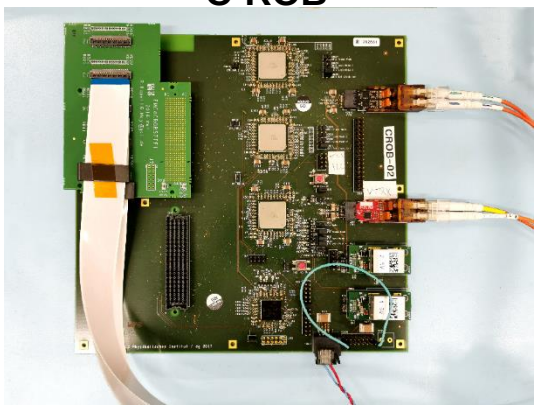


Full-scale prototype testing

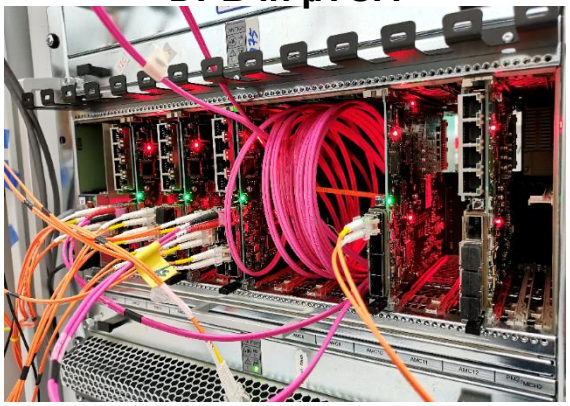
- Light-tight shielding box
- Symmetric bias $\pm$ 75 V
- Water cooling system
- Readout chain
  - 1. FEB-8
  - 2. C-ROB: data aggregation, electrical to optical interface
  - 3. Data Processing Board (DPB) based on AFCK



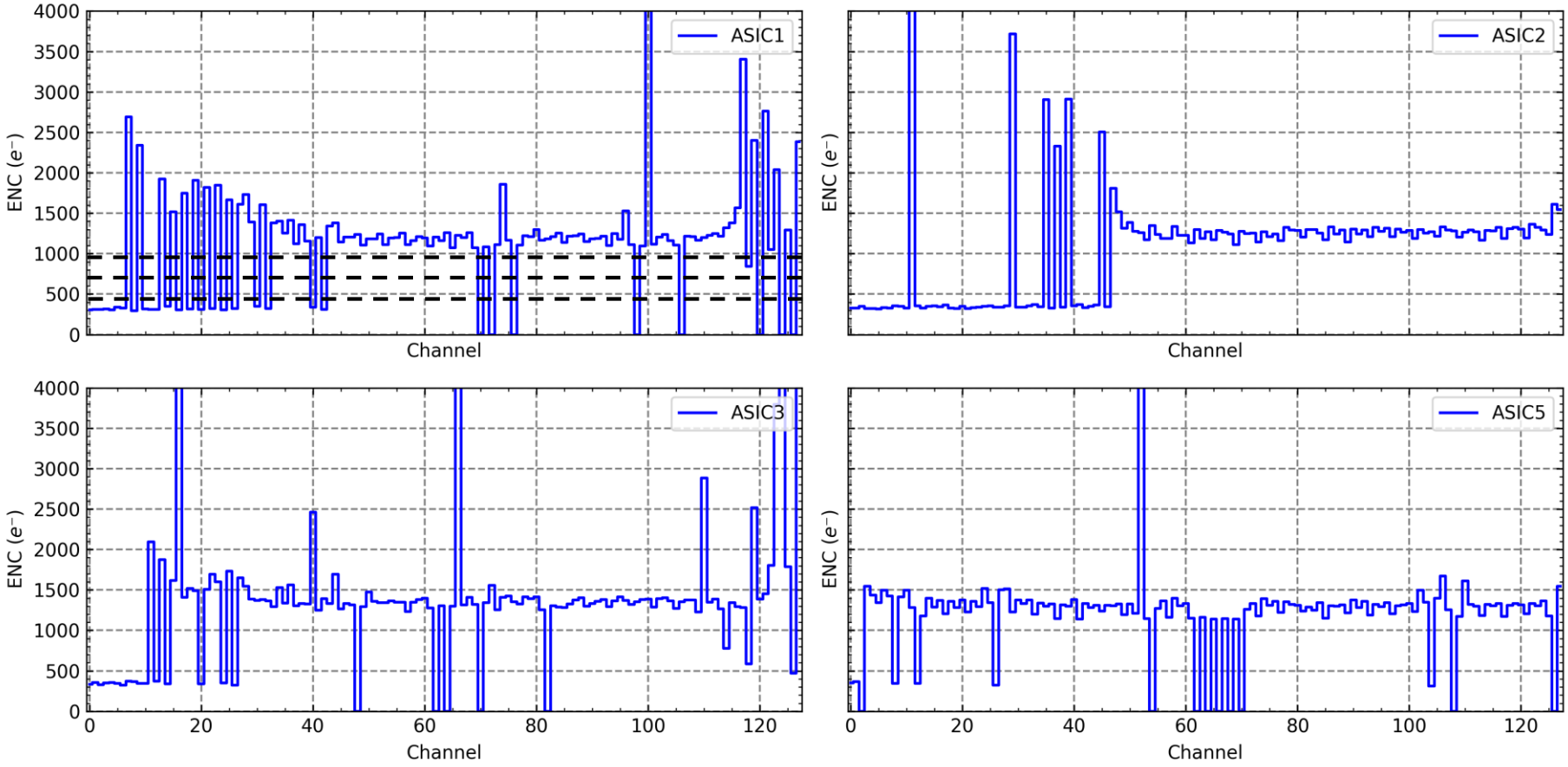
C-ROB



DPB in µTCA



ENC full-scale prototype: ASICs 1,2,3,5 n-side



Challenges

- Double-layered fine-pitch flex technology on the edge of manufacturing capabilities (yield, cost)
- High demands on precision solder printing
- High demands on planarity between die and cable
- Copper microcable stiffness complicates assembly
- Thermal mismatch due to need for elevated process temperature
- Slightly higher capacitance and material budget compared to aluminum cables

Summary

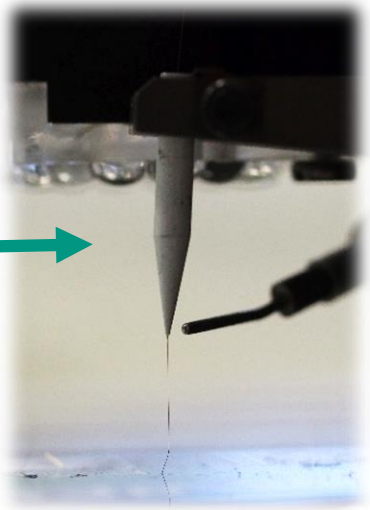
- A double-layered (2x64 channels) fine-pitch copper cable was developed and characterized
  - Capacitance: 0.38 pF/cm (Alu: 0.35 pF/cm)
  - Material budget: X/X_0 = 0.05% (Alu: 0.03%)
- A novel high-density interconnection technology has been established
  - Gold stud bumping on the die combined with precision solder printing on the cable assembled in a flip-chip process
  - High degree of automization achievable
- Prototype modules show electronic performance comparable to established aluminum TAB modules

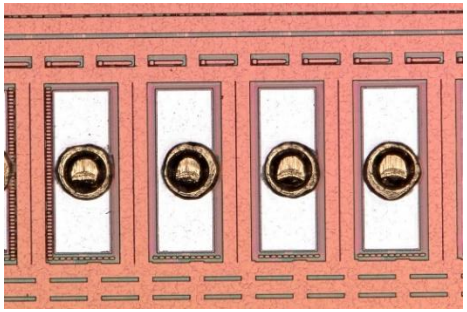
Thank you for your attention!

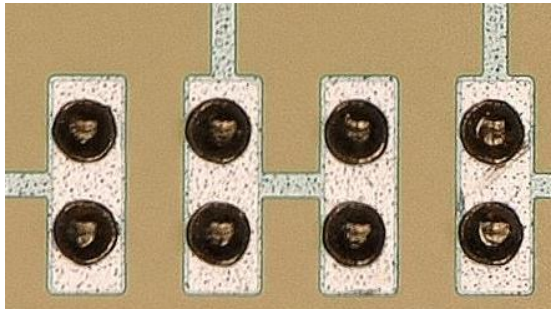
BACKUP

ASIC and sensor: Gold stud bumping

- Iconn ball wire bonder
  - 20 bumps/s
- STS parameters
  - 23 µm Au wire
  - Bump diameter 55 µm
  - Bump height: 30 µm

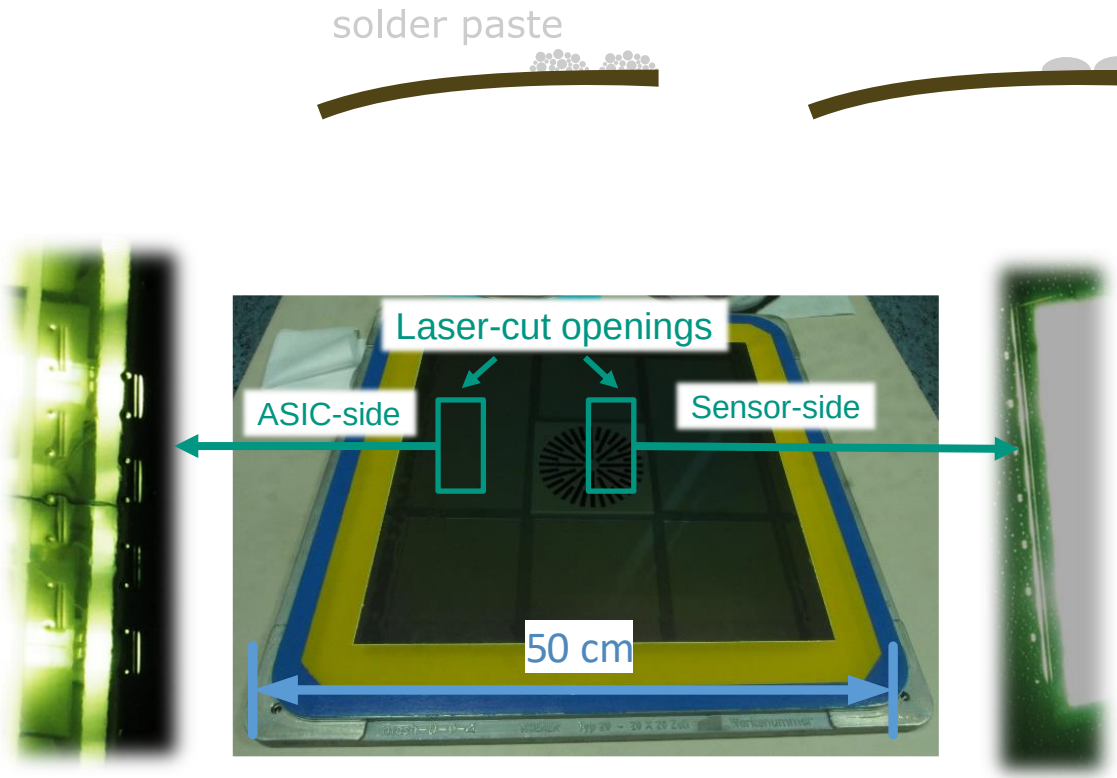






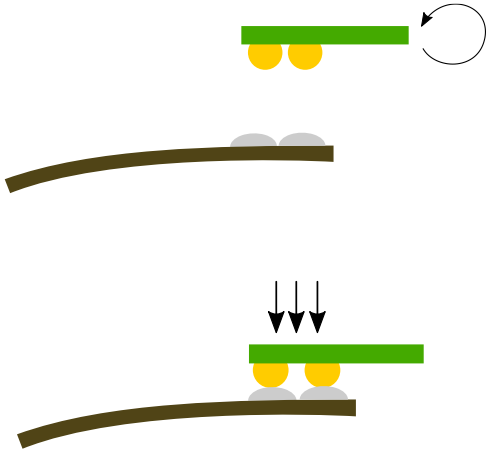
Fast, flexible, reliable

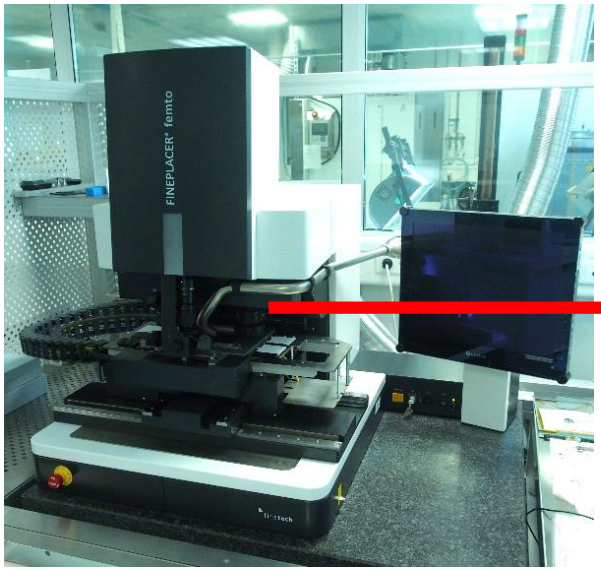
Solder paste type 7/8 printing and reflow

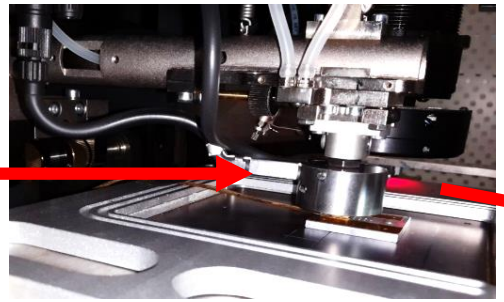


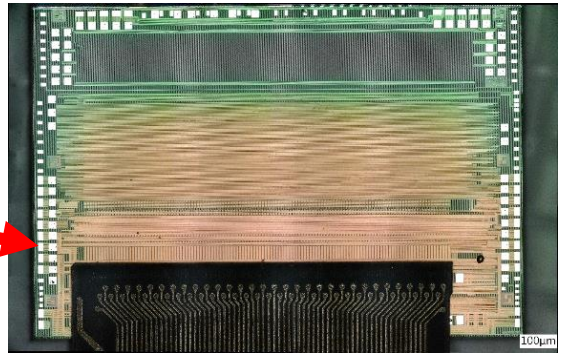
ASIC – microcable interconnection

- Fineplacer femto flip chip machine with 0.5 µm alignment accuracy
- Thermocompression bonding process
  - F = 40 N
  - T = 230 °C



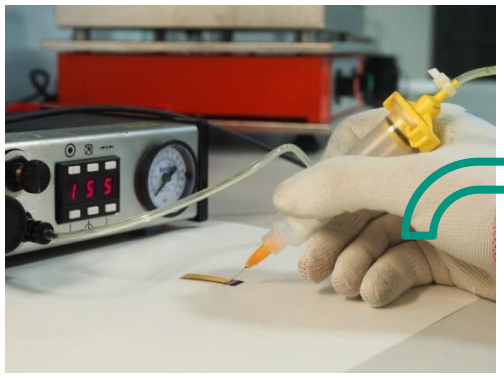


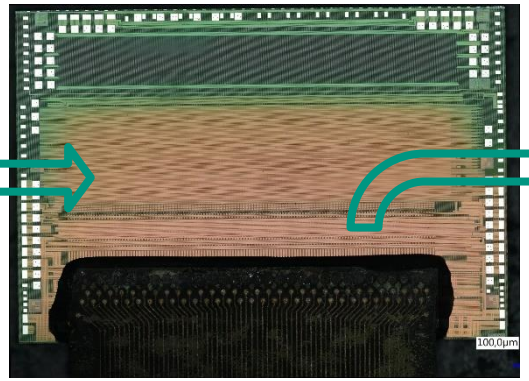


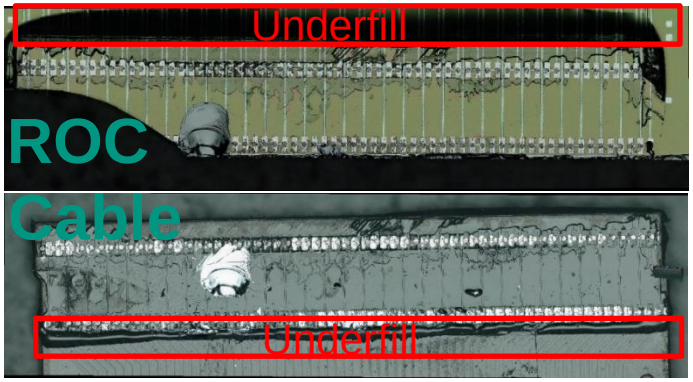


Underfill application

- Improves mechanical strength to survive CBM lifetime of 10 years
- Spark protection between LV microcable and HV sensor edge
- Gap height ~ 25 µm, obstructions by gold bumps
- Polytec EP601-LV ()

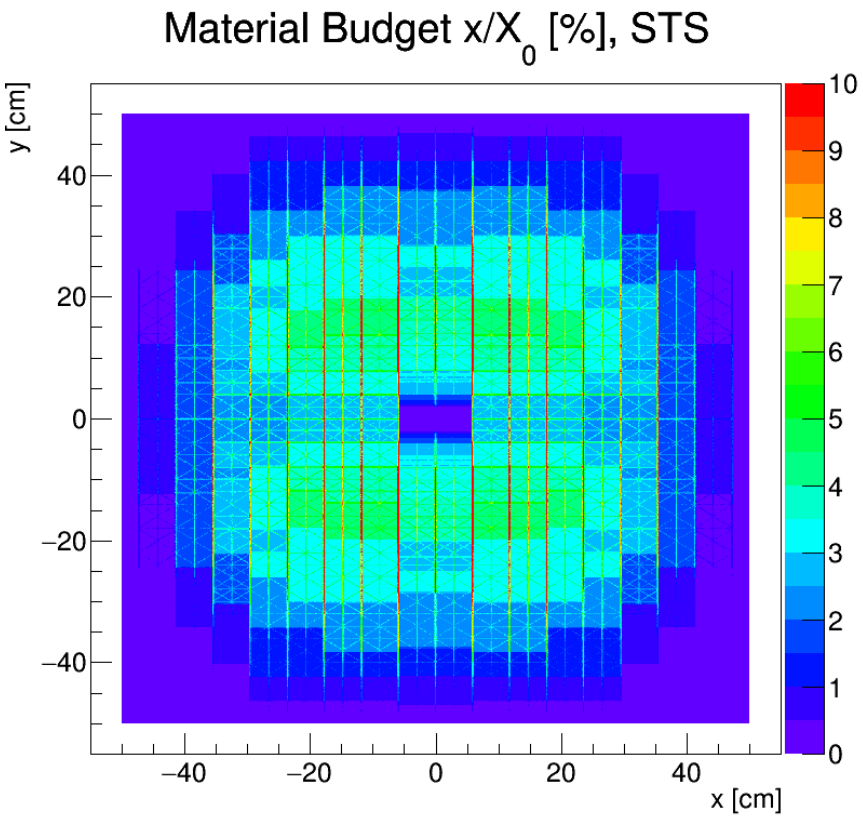




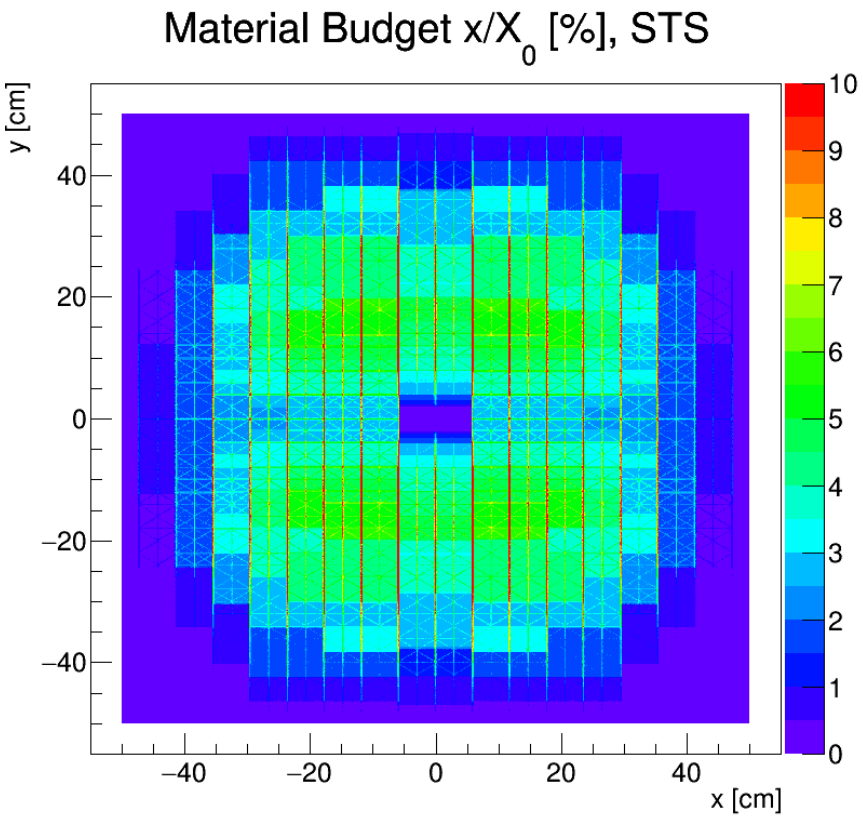


STS material budget simulations

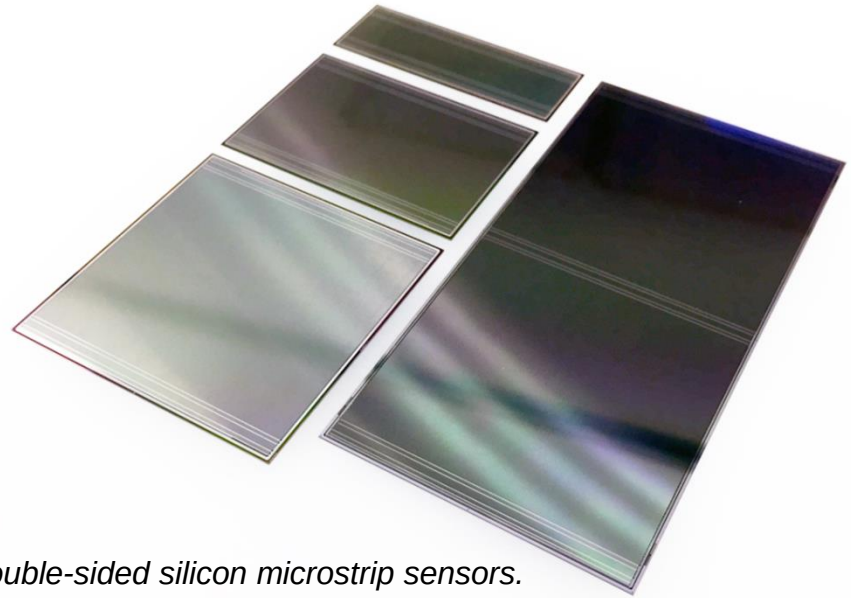
Aluminum microcables



Copper microcables

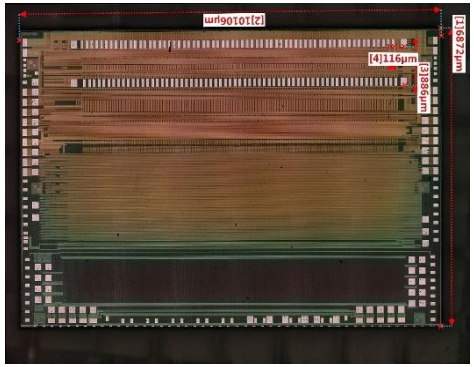


Module components

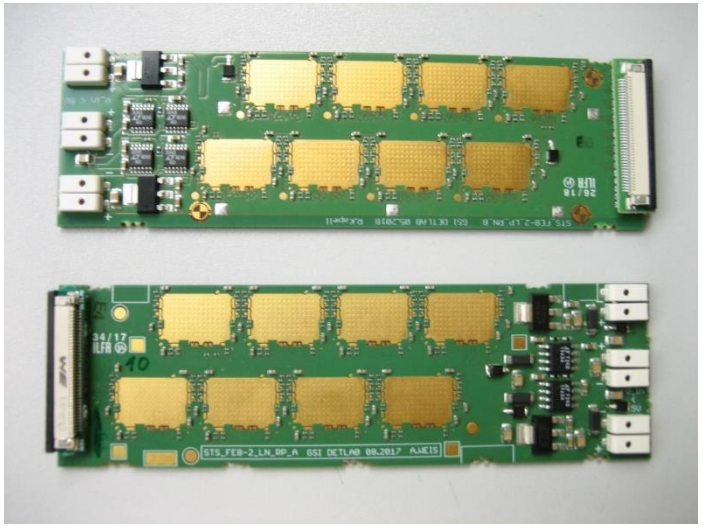


Double-sided silicon microstrip sensors. Thickness: 300 µm. Sizes: 62 mm x 22, 42, 62, 124 mm

Low mass microcables with varying length. Top: single cable. Bottom: sheet of 8 cables.



STS-XYTER

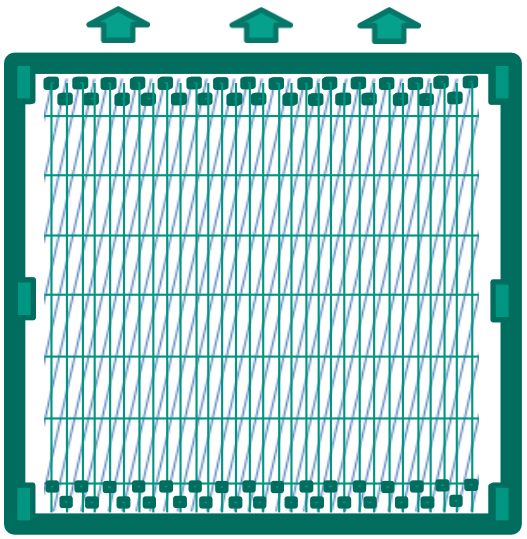


FEB-8 for p- and n-side

Silicon microstrip sensors

- 285/320 ± 15µm thick
- n-type silicon
- double-sided segmentation
- 1024 strips of 58 µm pitch
- strip length 2/4/6/12 cm
- angle front/back: 7.5/0 deg
- n-side strip insulation: modulated p-spray
- read-out from top edge
- double-metal routing on p-side
- rad. tol. up to 10^{14} n_{eq}/cm^2
- rad tol. w.r.t. TID?

r/o electronics



n-side

p-side