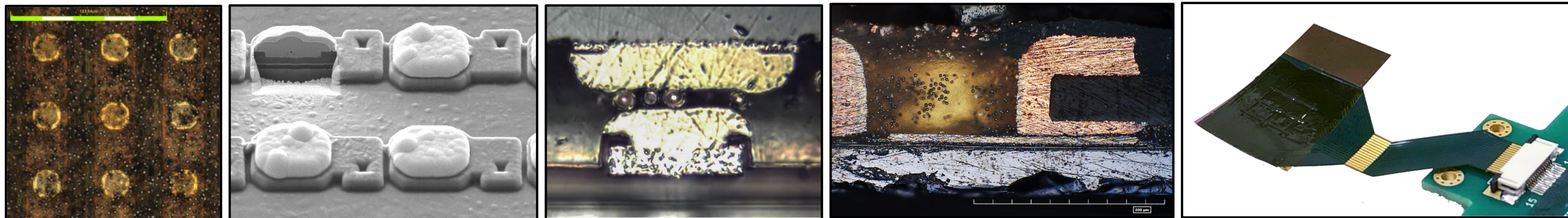
EP-DT
Detector Technologies

EP R&D

Pixel detector hybridization and integration with Anisotropic Conductive Films



Linear Colliders Workshop 2021
17/03/2021

Mateus Vicente (CERN)

Introduction

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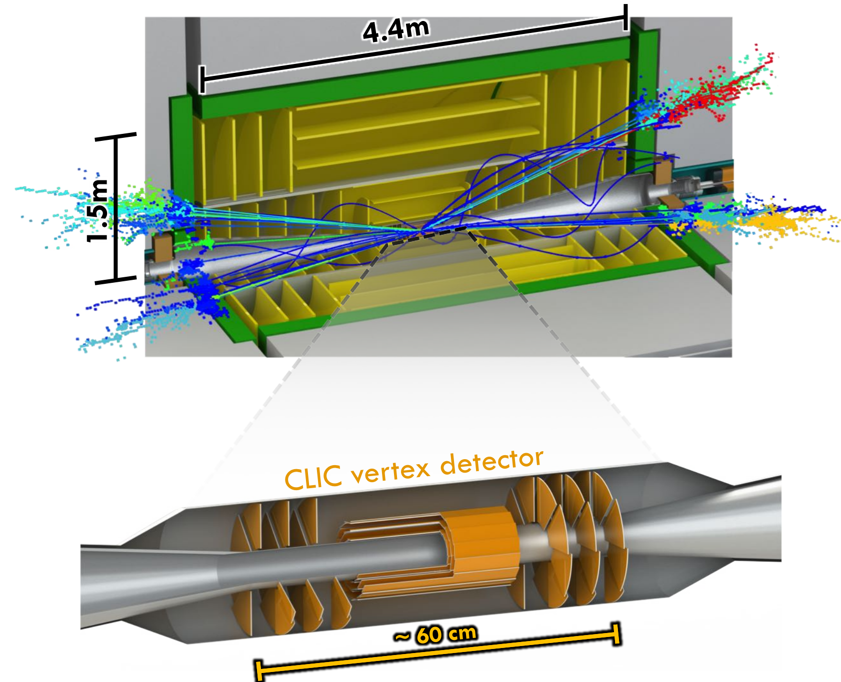
Work performed within the **EP R&D** program, supported by **AIDA 2020, AIDAinnova, CLICdp, Medipix3, ATLAS,** and **ALICE** collaborations + **industrial** support from **Conpart** and **Dexerials**

Linear Colliders are pushing the limits on measurement precisions

- Vertex detector with high demands for the pixel modules
  - **0.2 % X_0** per detection layer ➔ Extremely low mass modules
  - Single hit resolution of **~3 µm** ➔ Fine-pitch pixels (**<25 µm**)

- Use of anisotropic conductive adhesives in detector modules
  - Anisotropic conductive films (ACF) for pixel detector hybridization
  - ACF for detector integration



ACF in the industry

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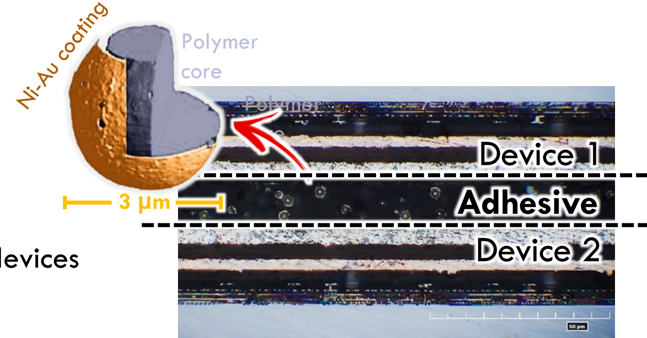
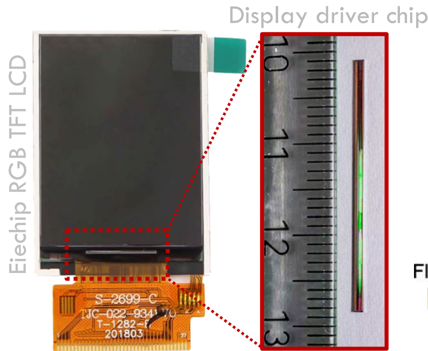
ACF is the **dominating interconnection** technology in the **display industry**

- **Adhesive film** embedded with **conductive micro-particles** (CP)
  - Particles are **compressed** (only vertically) and connect electrically the pads of the devices
    - **Mechanical attachment** is achieved with the thin adhesive layer



Display driver chip



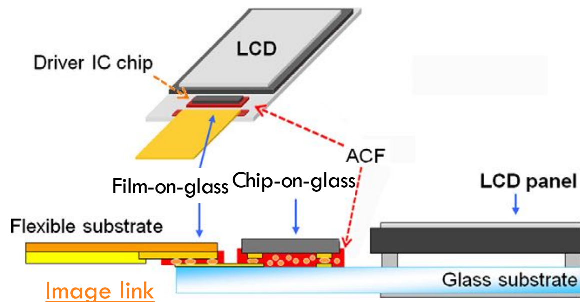
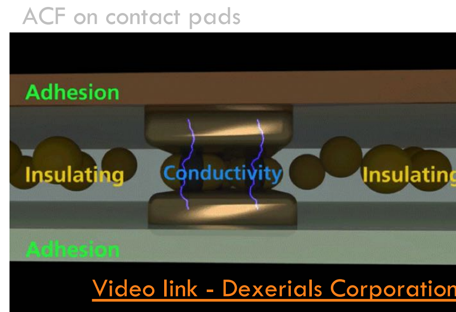


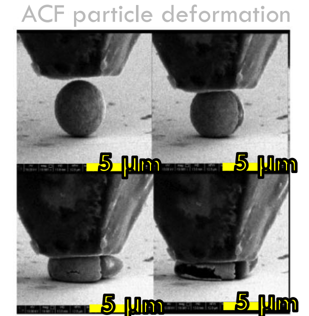
Image link

ACF on contact pads



Video link - Dexerials Corporation

ACF particle deformation



ACF for pixel detector hybridization

Electroless Nickel Immersion Gold for UBM

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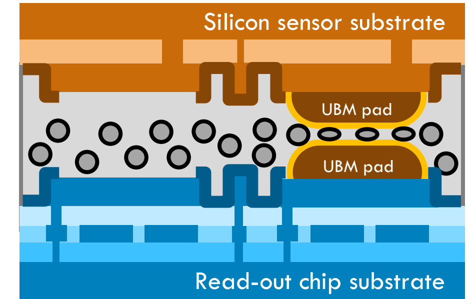
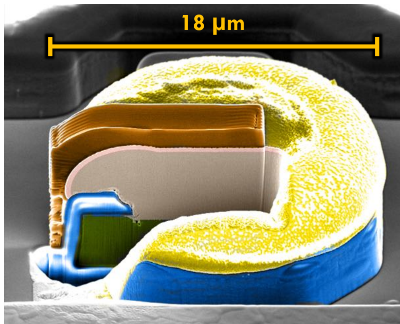
- **Under Bump Metalization (UBM)** is applied to ensure the CP compression
  - **ENIG** is a **wet chemical** deposition of **Ni** and **Au** (without external electrical current)
    - **Maskless process ➔ lower cost**
- Qualified an industrial ENIPIG process for **full wafers** (Timepix3 and sensor)
  - **In-house** ENIG UBM plating on CLICpix2 (**single devices**) as first small-pixel plating test

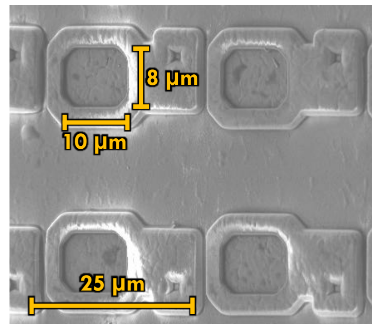
Unplated (left) VS Plated (right) pixels



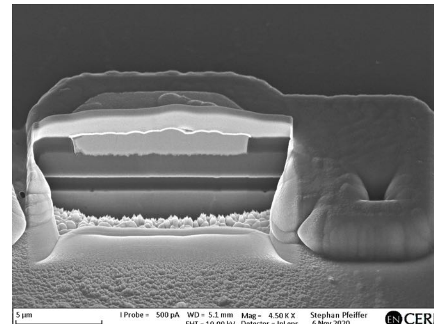
Timepix3 UBM cross-section



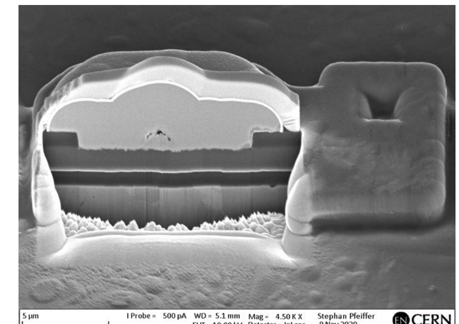
Bare CLICpix2 pixel matrix



CLICpix2 after 3 min in the Ni bath



CLICpix2 after 7 min in the Ni bath



In-house flip-chip hybridization

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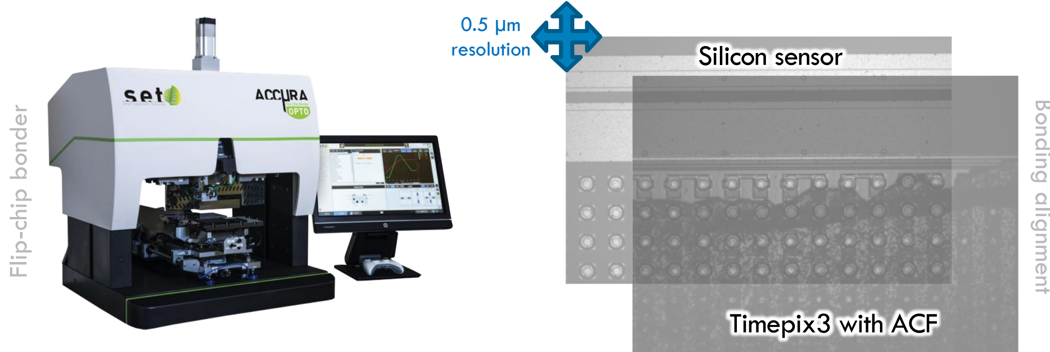
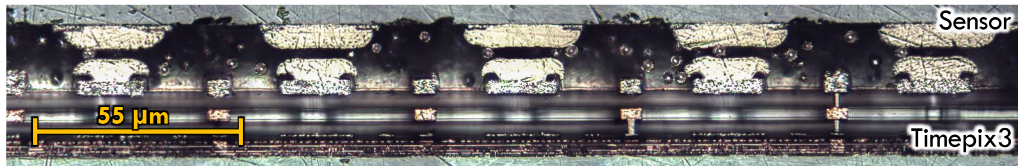
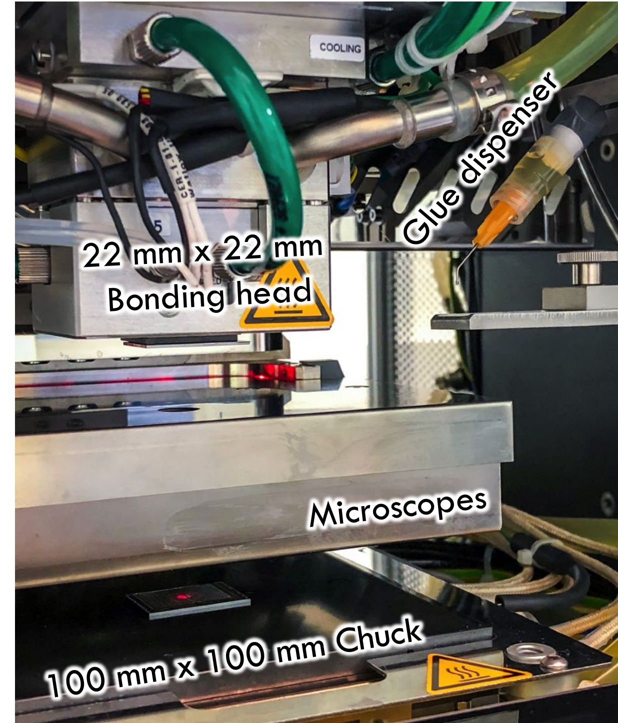
- **Semi-automatic flip-chip** bonder, installed at Geneva University
  - Post-bonding accuracy **1-2 µm** achieved and planarity **< 100's µrad**
  - Heating up to **400 ℃** and force applied by bonding arm up to **100 kg**



Timepix3-ACF-sensor assembly cross-section





ACF bonding

resistance measurement with test-structure

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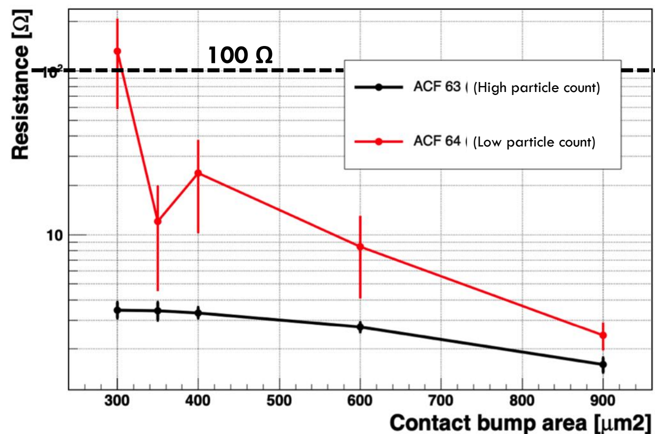
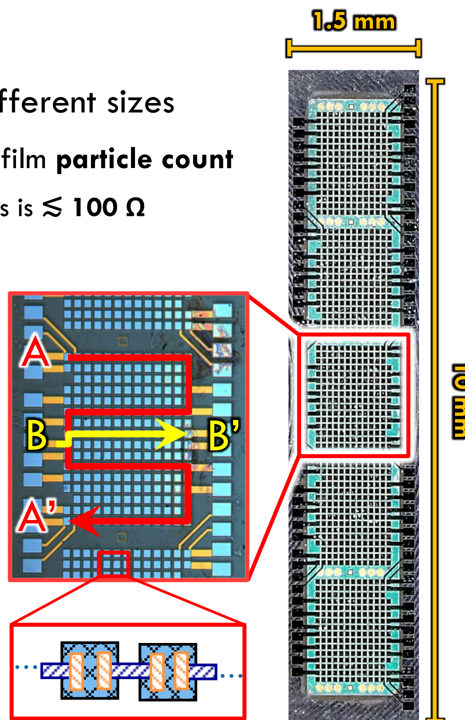
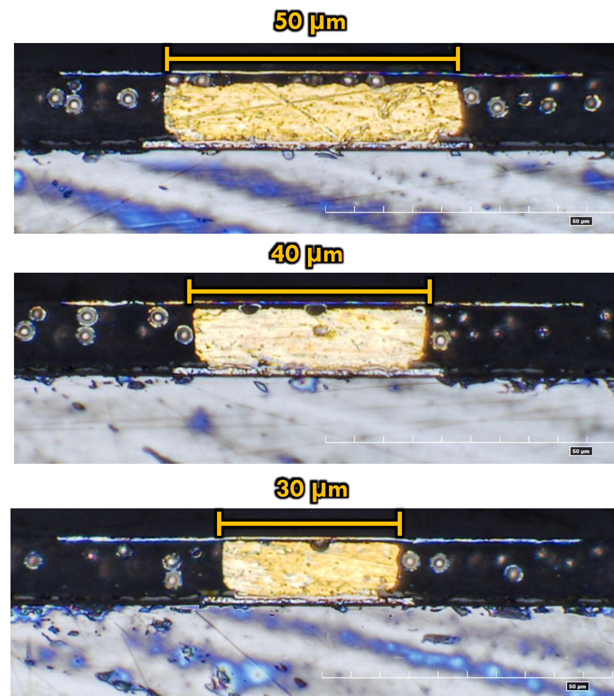
- Test structure with 5 matrices of pads with different sizes
  - Resistance scales with the (pixel) **pad size** and film **particle count**
    - Acceptable resistance in hybrid pixel detectors is ≲ **100 Ω**







Timepix3 hybridization with ACF

first tests – Bonding optimization

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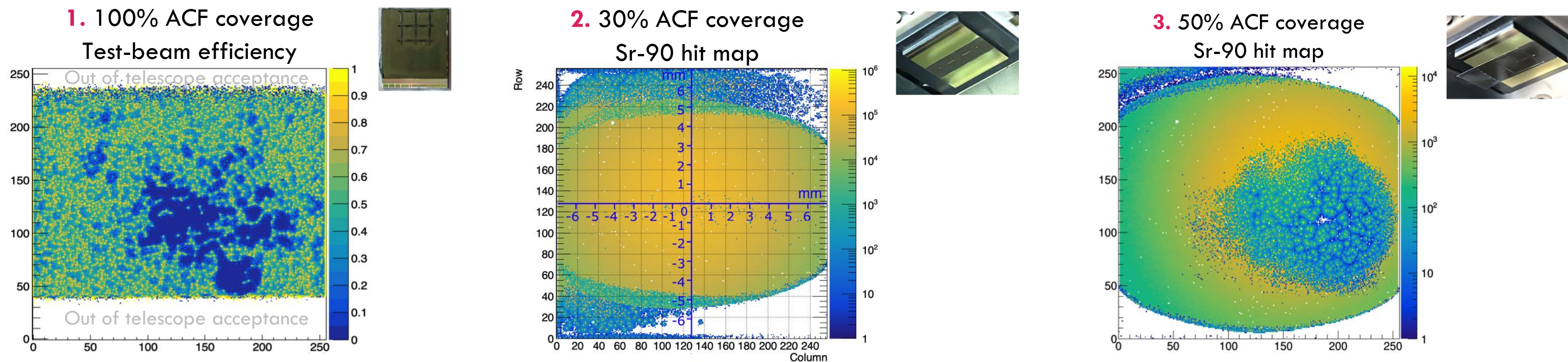
18 µm ACF with **3 µm** CPs: requires curing at **150 ℃** and **bonding** pressure of **300~800 kgf/cm²**

- Timepix3: 256x256 * 320 $\mu m^2 \approx 0.20\ cm^2$ ➔ **61~163 kgf**

1. Timepix3 matrix **fully covered** with ACF (test-beam in Aug. 2020) ➔ Low connectivity yield (<500 pixels)
2. sample covering **~30%** of the matrix ➔ **Uniform** and **high yield** connectivity (at DESY for test-beam soon)
3. sample with **~50%** coverage ➔ **Large area** with **good connectivity,** low yield in the central region (as 1st sample)

Proof-of-concept achieved: Successful pixel matrix bonding of **up to 1 cm²** (so far)

- Optimization on going to reduce the necessary bonding force



Fine-pitch pixel hybridization with ACF

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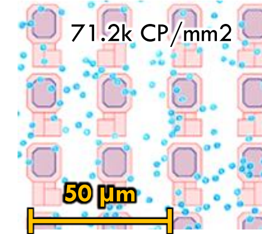
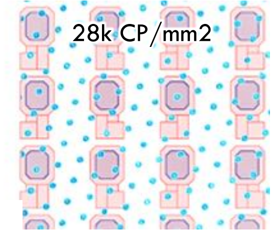
- First **mechanical** samples of 25-micron pitch **CLICpix2 ASICs** and **Advacam edgeless sensors**
  - Smaller matrix area results in higher bonding pressure
    - Better particle compression compared to the Timepix3 case
  - Smaller pitch and pad area requires uniform particle distribution
    - Tests with new **particle aligned** ACF

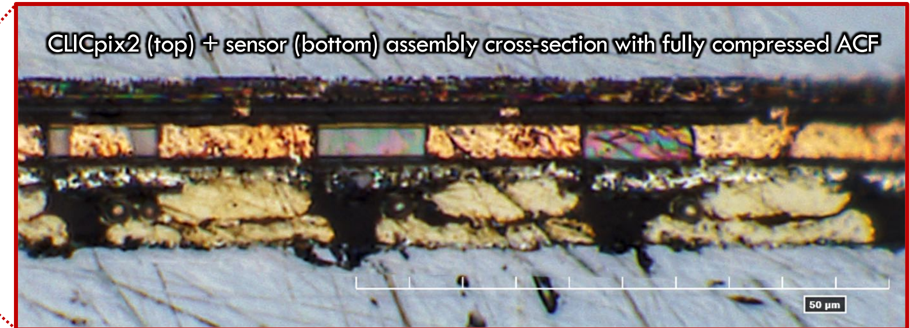
Currently available ACF
Minimum bonding area: 1000 μm^2



Particle aligned ACF
Minimum bonding area: 300 μm^2



Picture of the ACF CPs (light blue) overlaid with the CLICpix2 pads (red) layout



Module integration with ACF

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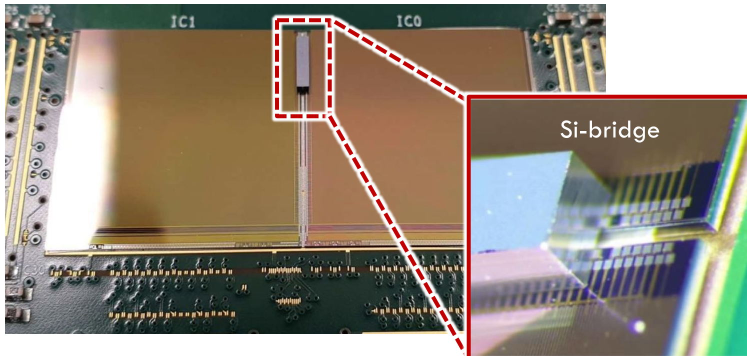
ACF is also suitable for **module integration** of readout ASICs / **monolithic** sensors (**alternative** to wire bonding)

- Si-bridge connecting IOs in **MALTA** modules: minimum gap between chips (and possibly future module functionalities)
  - Successful tests with industrially bump-bonded Si-bridges, can be alternatively bonded **in-house** using ACF

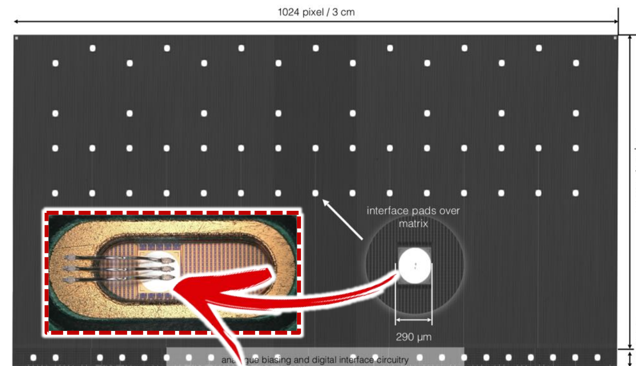
The possibility to use the ACF to make flexible modules is also being investigated together with the ALICE ITS3 R&D

- Initial tests with a **50-µm thin ALPIDE** (ALICE ITS upgrade) monolithic pixel detector
  - ALPIDE-ACF-Flex connected via **~300 µm** diameter pads (intended for wire-bonding)

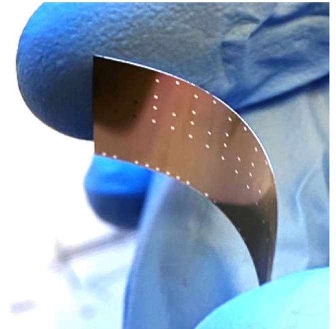
MALTA double module with Si-bridge chip



ALPIDE monolithic chip, courtesy of the ALICE ITS upgrade



Bent 50 µm thick ALPIDE chip, courtesy of ALICE ITS3



ALPIDE ACF bonding tests

ALPIDE flex, ENIG and bonding

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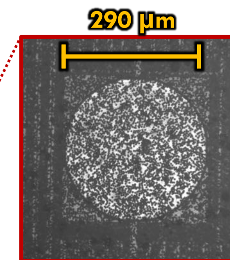
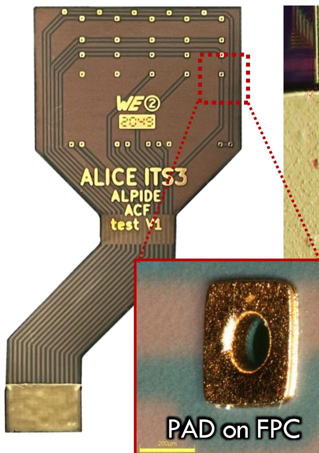
- Produced a flex printed circuit (**FPC**) for the ACF bonding trials
- **In-house ENIG** plating on the ALPIDE chip for higher bonding pads
- Lower force (**20 kgf**) and reduced bonding time required (low interconnect density)

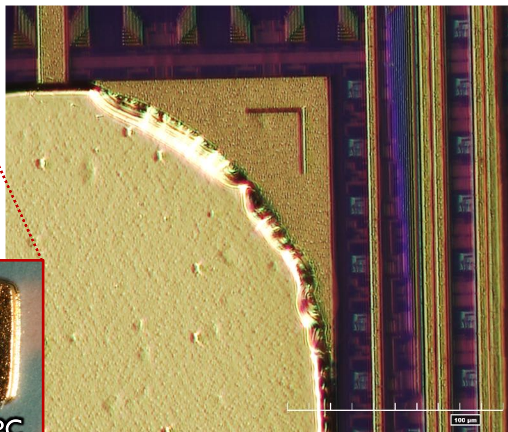


ACF particles over ALPIDE pad

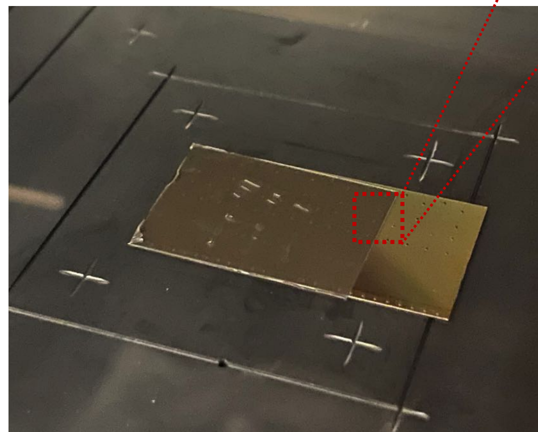
ALPIDE flex V1



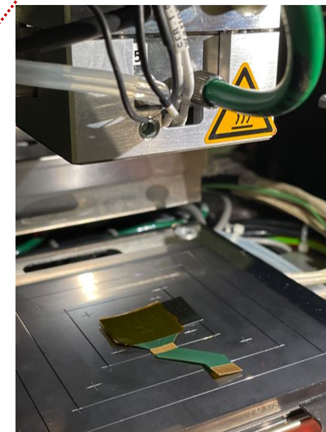
ENIG grown on ALPIDE interface pad



ALPIDE with ACF (partially) laminated



ALPIDE/flex after bonding



ALPIDE ACF bonding tests

Sr^{90} illumination test and next steps

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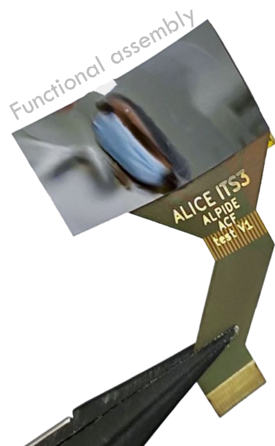
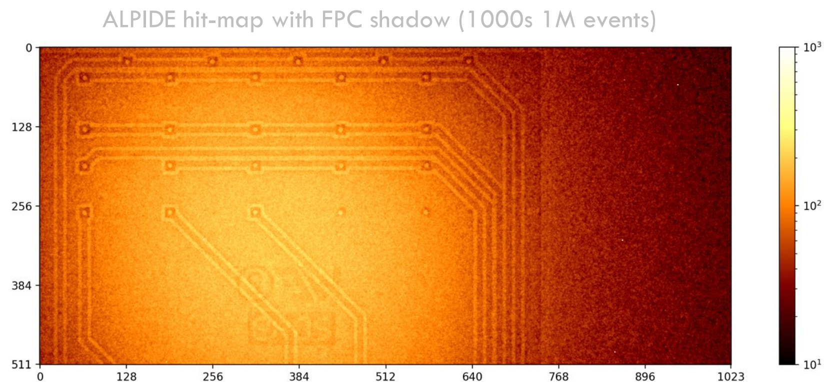
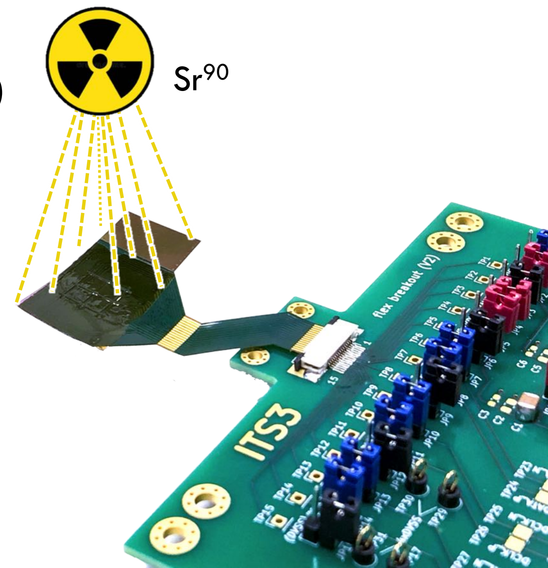
- 4 samples produced so far. Read-out works and shows good results
  - Good communication/interconnection between ROC and Flex
  - Very good electrical contact (**<1 Ohm** contact resistance). Nominal power consumption
  - Assembly flexibility and connection reliability to be tested
- Next iteration with optimized FPC for 3x3 ALPIDE tiling

Towards: Development of ultra-thin and large flexible modules with seamless tiling (gap < 20 μm)







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Summary

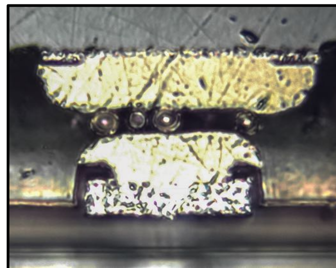
Encouraging first hybridization and interconnection results

- **In-house** UBM plating and ACF flip-chip process under development
- (Partially) Successful **Timepix3 ACF hybridization**
  - Work-in-progress for 100% matrix coverage and high connectivity yield

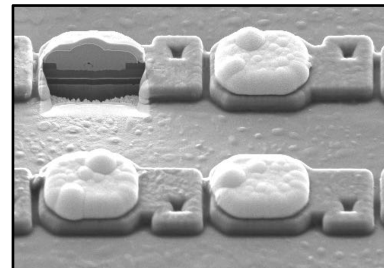
  Towards: **Fine pitch** hybridization (25 µm pitch)
- Planning and first tests of MALTA/Si-bridge integration ongoing
- First successful **ALPIDE-flex integration** with **ACF**

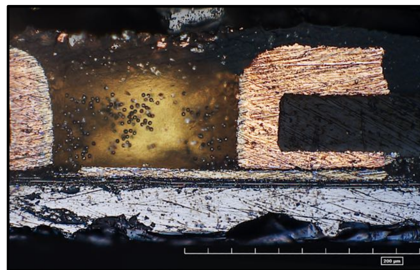
  Towards: Larger 3x3 flexible module assembly w/ new flex design

Timepix3-ACF-sensor cross-section

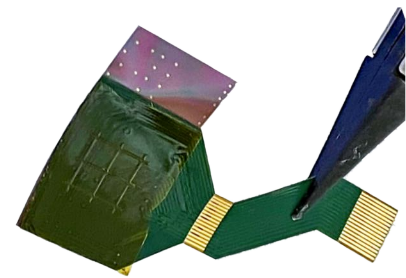


ENIG UBM on CLICpix2 pixels





ALPIDE-ACF-FPC assembly cross-section



ALPIDE-ACF-FPC (+Kapton) assembly