Qualification of CLICpix2 assemblies with planar sensors

Morag Williams, CERN and University of Glasgow

CLIC Detector and Physics Collaboration Meeting

28-29th August 2018

Contents:

- Bump-bonding in hybrid pixel detectors
- CLICpix2 + planar sensor assemblies
- Results of lab measurements of CLICpix2 assemblies:

  1) X-ray images

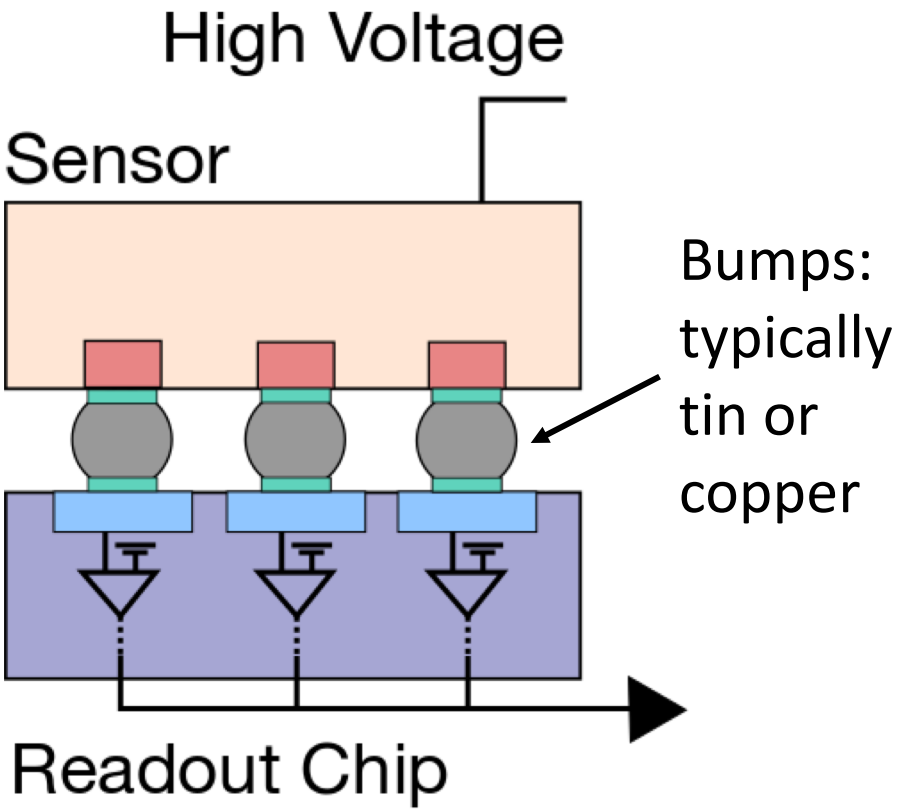
  2) Test pulse measurements

  3) Sr90 source measurements

- Outlook – new assemblies, and test beam results
- Summary

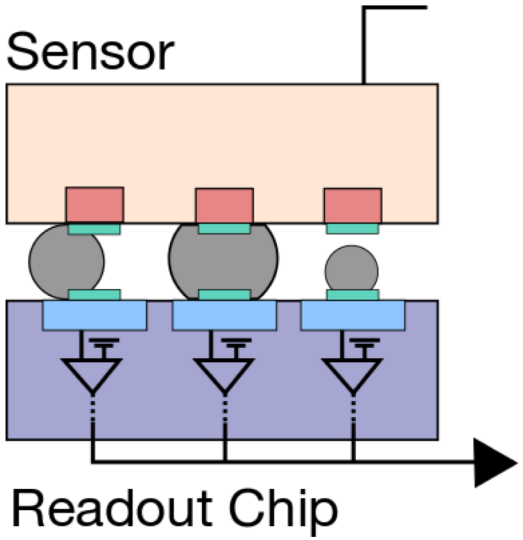
Bump-bonding in hybrid pixel detectors

- Hybrid pixel detectors consist of a sensor layer and readout chip.
- Solder can be used to connect the chips both electrically and mechanically.
- Advantage: Sensor and readout can be optimised separately.
- Disadvantage: Connecting the layers is complicated.

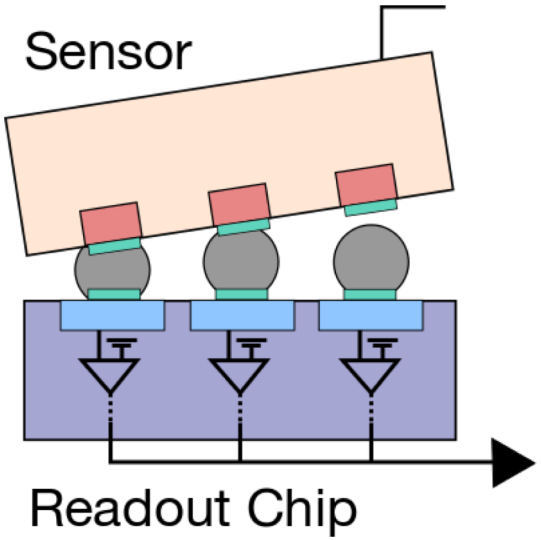


Issues that can arise:

- Solder placement: misalignment or missing bumps
- Solder size: bump=~pitch/2



- Levelling problems: uneven pressure
- Thin chips: temperature dependent bending
- Contamination/defects/splinters
- Testing only one chip on a large support wafer: pixel misalignment



CLICpix2 + planar sensor assemblies

- CLICpix2: pixelated readout chip, 128x128 pixels of pitch 25µm
- 8 bit ToT and 5 bit ToA precision
- 65nm feature size of the CMOS process
- Two CLICpix2 devices tested in our lab
- FBK produced sensor of 130µm, active-edge, UBM (under-bump metallization) processing and bonding at IZM

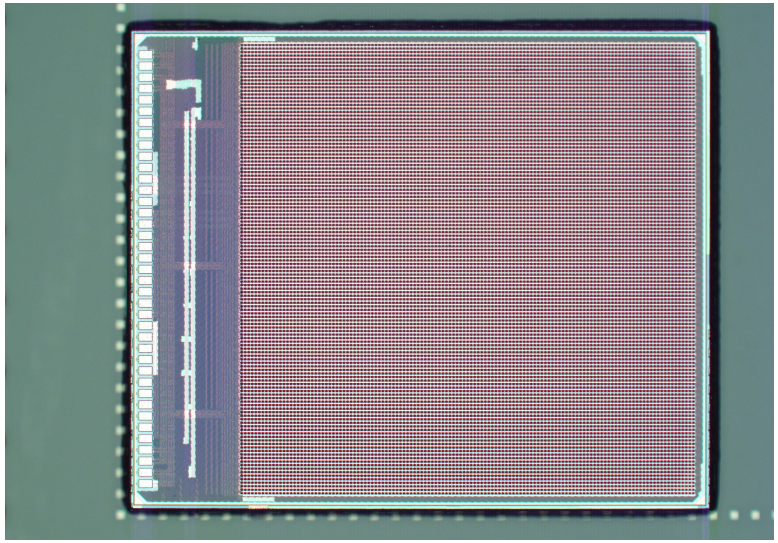


Image of a bumped CLICpix2 ASIC from IZM.

- IZM project aims to deliver 10 assemblies bump-bonded to planar sensors
- 4 have been received so far

Results of lab measurements

Aims of laboratory testing:

Identify:

Missing bumps
Unconnected pixels
'Dead' pixels on the ASIC
Shorts between pixels

Interpret:

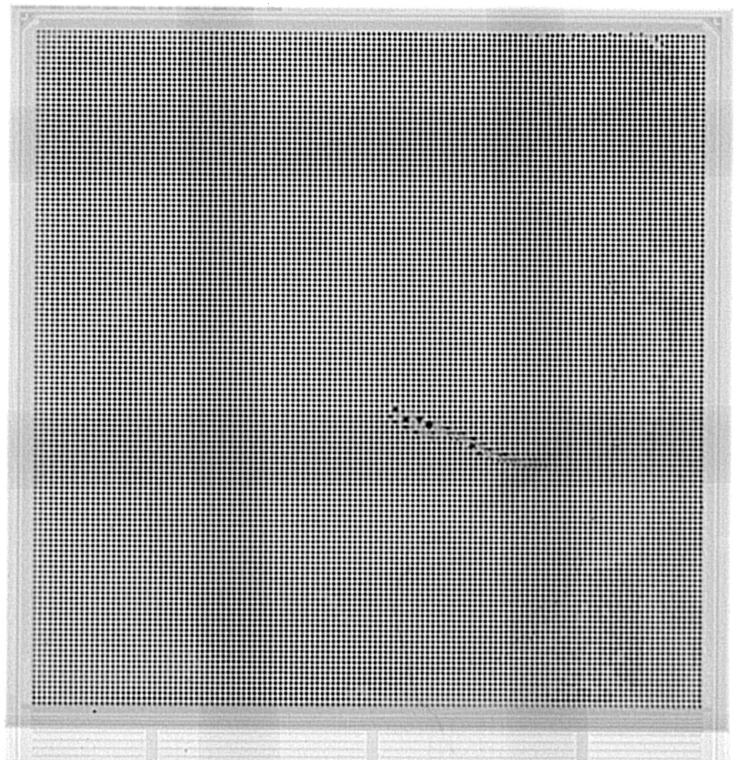
Contamination
Mechanical stresses
Chemical effects

Feedback:

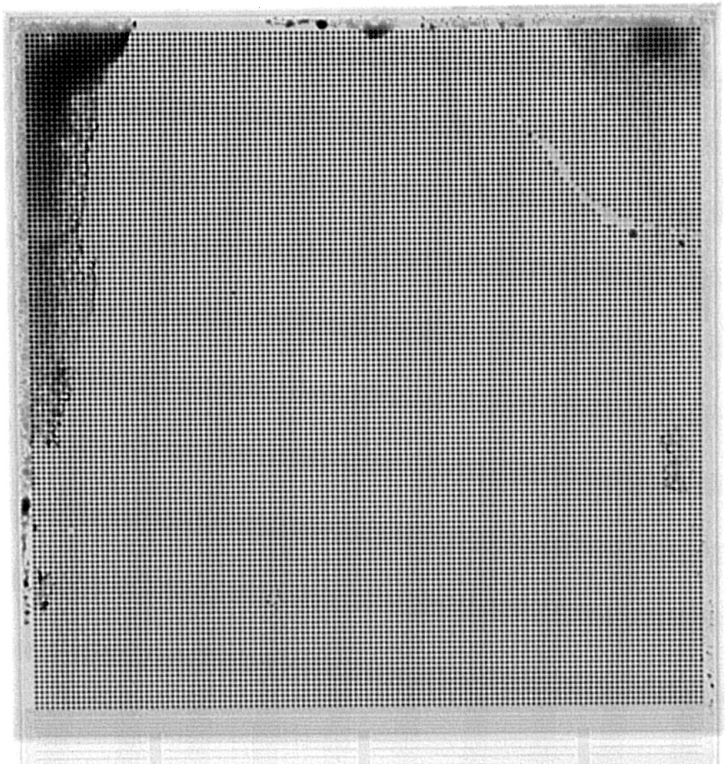
for optimization of processing

1) X-ray images

X-ray images show any missing bumps, mechanical defects, and/or contamination.



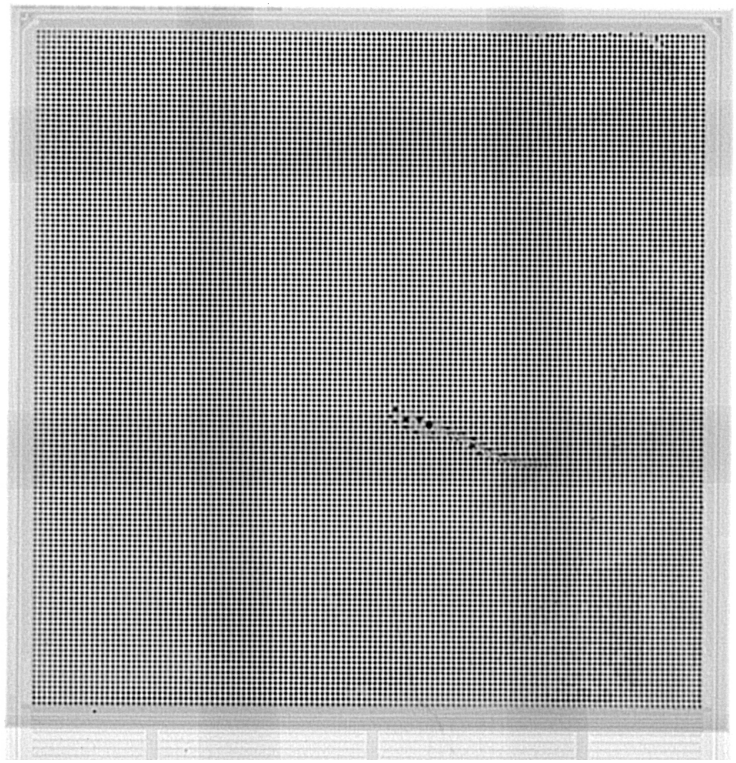
Assembly 14



Assembly 16

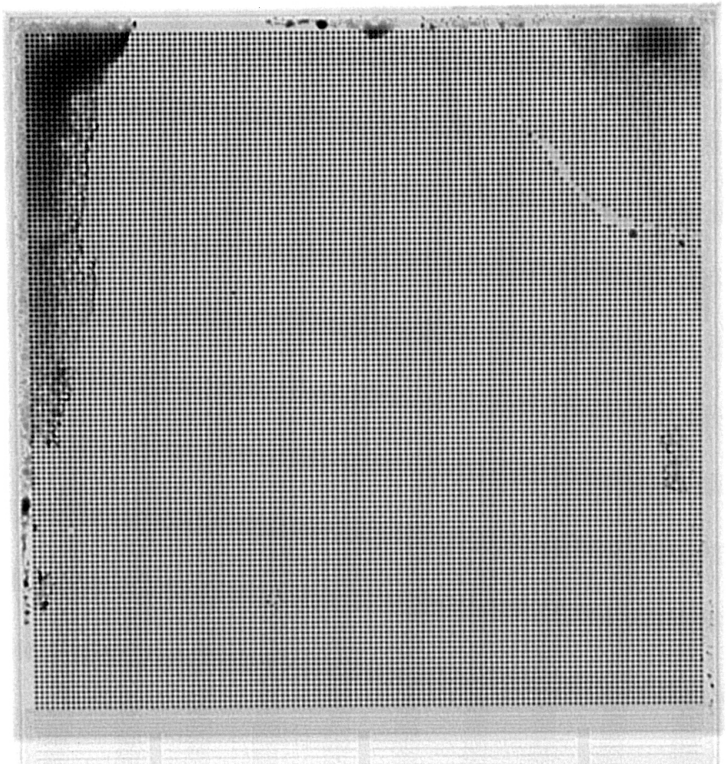
1) X-ray images

Pattern from gel packet for transport
Possible mechanical defect



Assembly 14

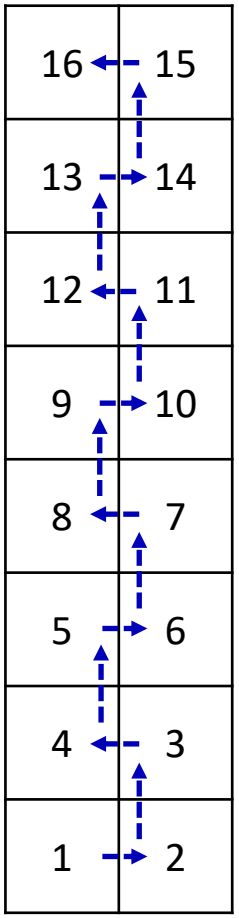
Pattern from gel packet for transport
Black regions due to unknown substance or issue in imaging
Missing bumps due to handling issue



Assembly 16

2) Test pulse measurements

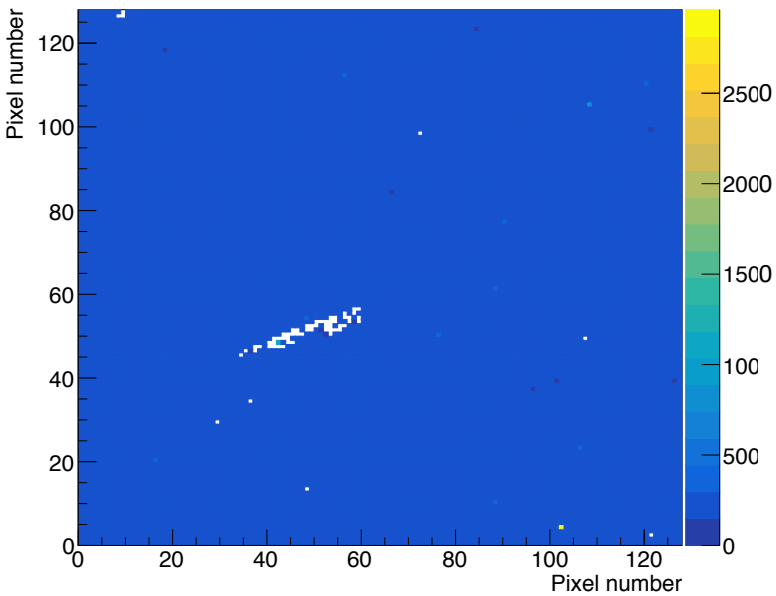
- Shows the number of ‘dead’ or masked pixels on the ASIC and shows possible shorts.
- CLICpix2 ASIC can generate an automatic series of test pulses -> independent of bonding
- Pulse strength = difference in value between two capacitors.
- Test pulses are performed in 16 steps: one pixel in each super pixel is pulsed at a time (1024 pixels pulsed per step).



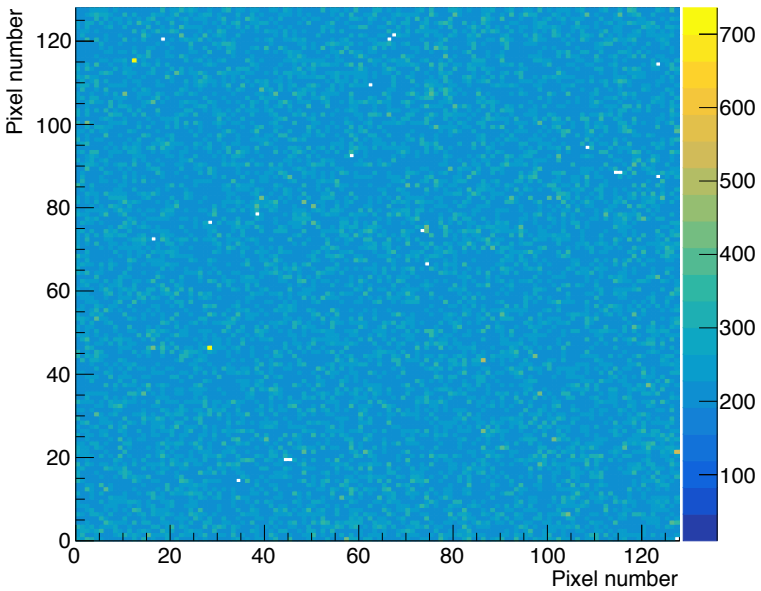
Test pulsing order of a CLICpix2 superpixel (2 columns and 8 rows of pixels).

Test pulsing: All pixel hits, 16 files combined

Combined pixel hits from all 16 steps gives the test pulse performance of every pixel. Shows which pixels never fire and which fire at a lower/higher rate.



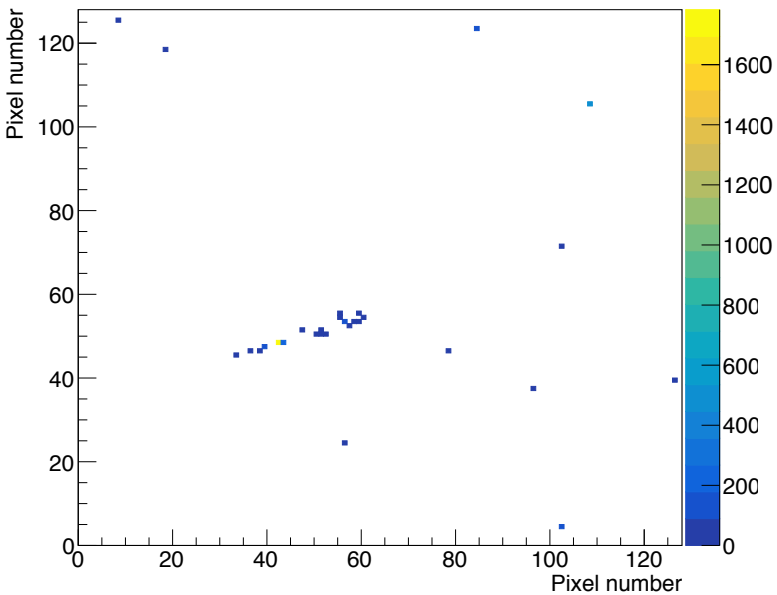
Assembly 14
dead/masked pixels = 62
masked pixels = 59



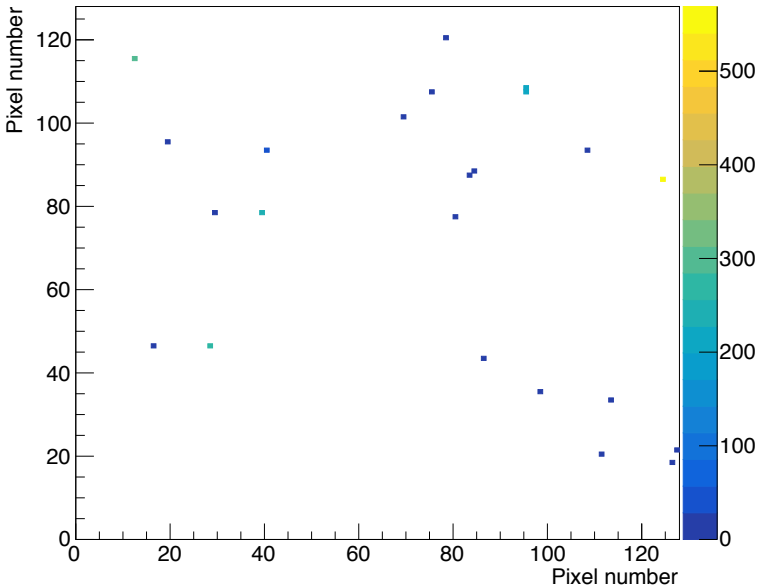
Assembly 16
dead/masked pixels = 19
masked pixels = 18

Test pulsing: Unexpected hits, 16 files combined

Combined unexpected pixel hits from all 16 steps; unexpected = pixel hits recorded from unpulsed pixels.



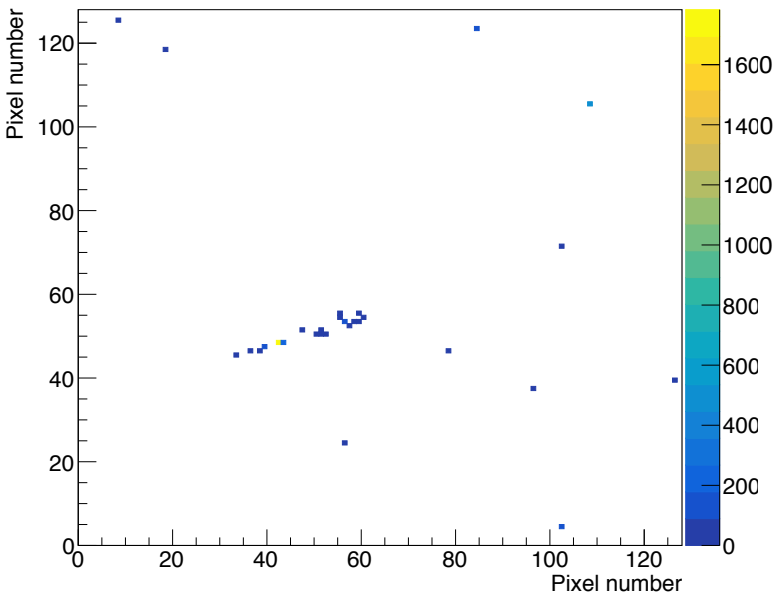
Assembly 14
unexpected pixels = 29



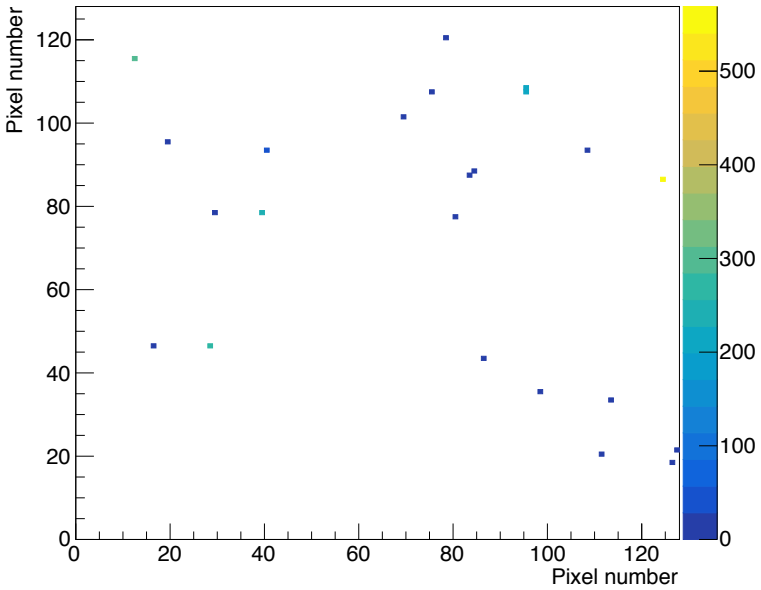
Assembly 16
unexpected pixels = 22

Test pulsing: Unexpected hits, 16 files combined

Other pixels are not masked during test pulsing, hence this measurement shows areas with electrical shorts. Have to distinguish noise from shorts -> look at individual files.



Assembly 14
Small amount of shorts in defect region

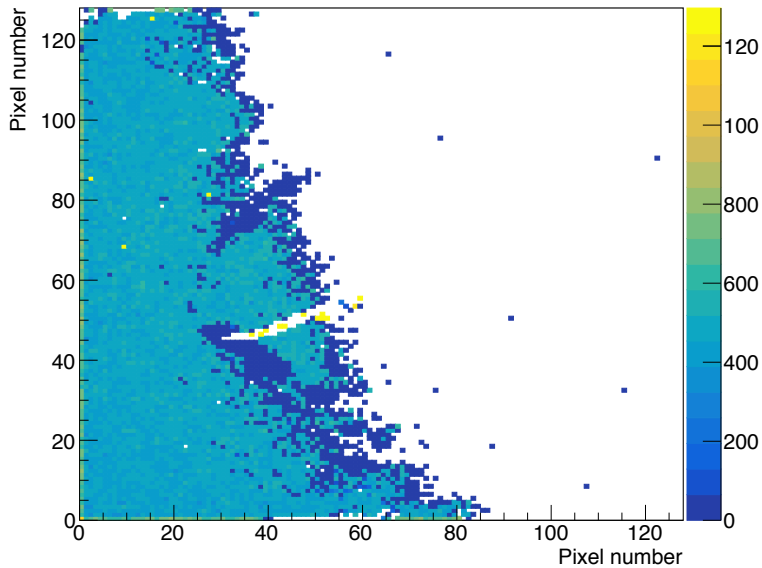


Assembly 16
No shorts observed, all noise hits

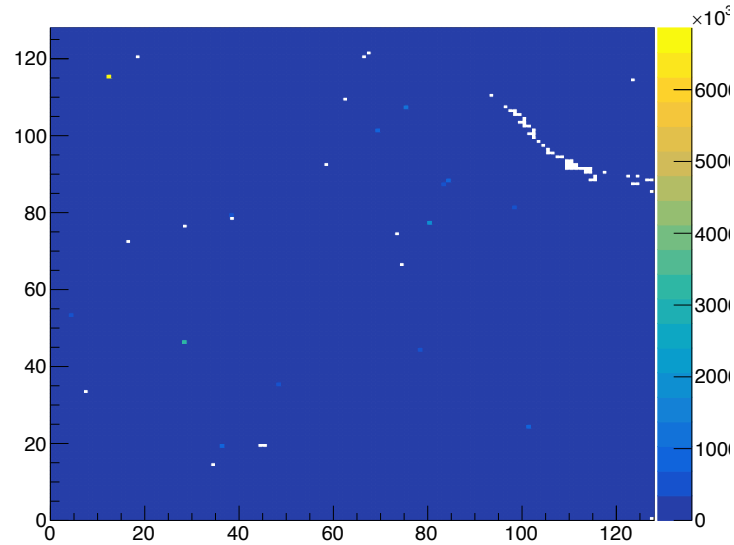
3) Sr90 source measurements

- Shows number unresponsive pixels: particle passes through the sensor layer but there is no signal recorded.
- Either ‘dead’ on the readout ASIC, have been masked, or have bonding problems.
- Combined with the test pulse measurements, you can determine which pixels have bonding issues.
- Sr90 source (beta minus), 20us shutters, -60V bias voltage.

Source measurements: Hitmaps



Assembly 14:
THL = 1250 ADC -> ~700e-
# unresponsive pixels = 10,141
# dead/masked pixels = 62



Assembly 16:
THL = 1189 ADC -> ~540e-
# unresponsive pixels = 62
# dead/masked pixels = 19

Possible cause for assembly 14: a) contamination causing gap between layers, b) bow in sensor, c) combination of the previous and too low a bonding force.

Outlook

Short term:

- Analyse test beam data taken for these assemblies.
- Calibration measurements.

Longer term:

- Obtain new assemblies using improved processing.
- Test these new assemblies in the lab and in a test beam to see improvements.

Summary

- Presented laboratory measurements of two CLICpix2 + planar sensor assemblies.
- Discussed possible problems that can arise while bump-bonding.
- Showed results of X-ray, test pulsing, and source measurements.
- Assemblies show promising results so far.
- Feedback has been given to IZM.

Thank you for your attention

Morag Williams, University of Glasgow and CERN

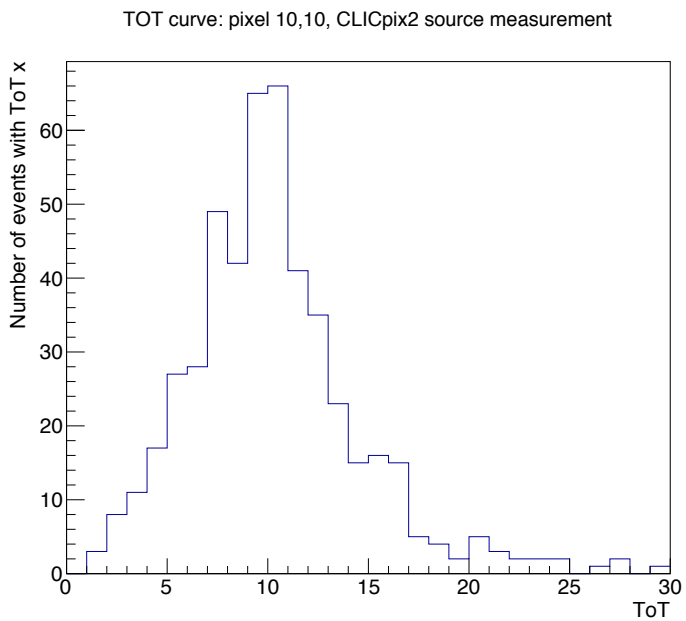
morag.williams@cern.ch

CERN

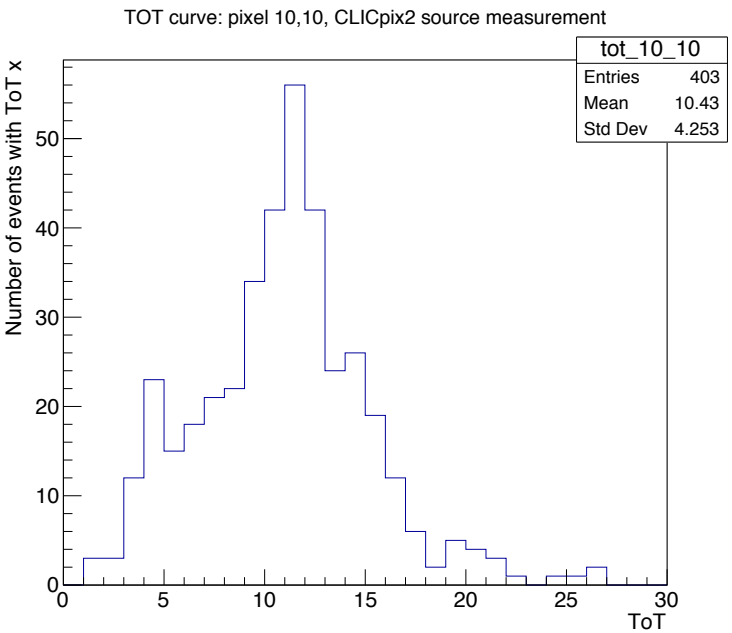
Compact Linear Collider https://clic.cern/

University of Glasgow https://www.gla.ac.uk/schools/physics

Source measurements: ToT pixel 10,10



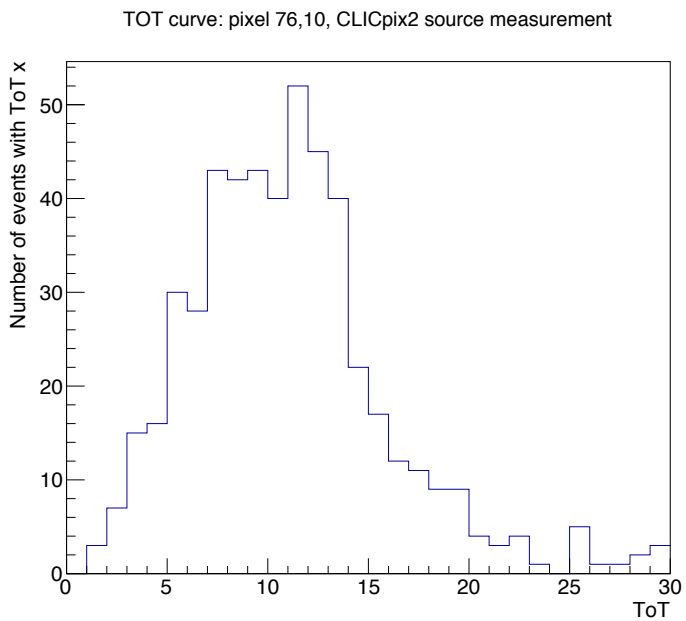
Assembly 14:



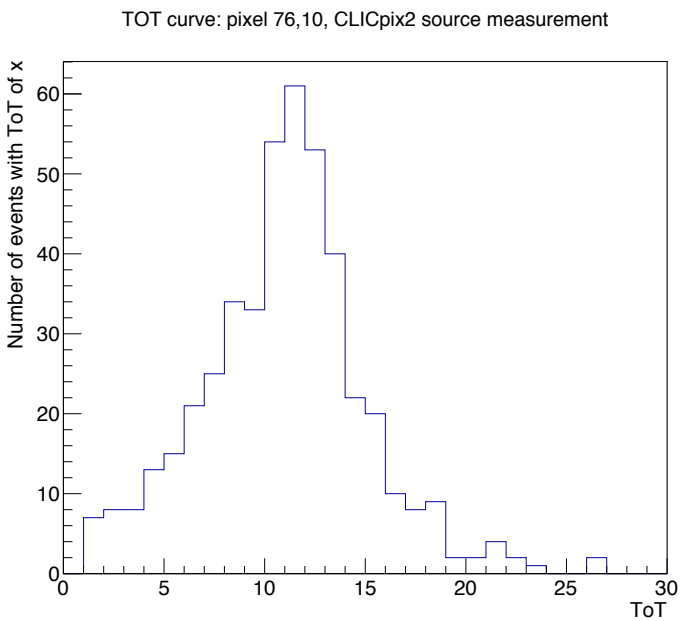
Assembly 16:

These show that ToT circuit works correctly (previous plots were counts only). Calibration can/will be carried out to have a conversion to electrons taking into account the pixel-by-pixel variations.

Source measurements: ToT pixel 76,10



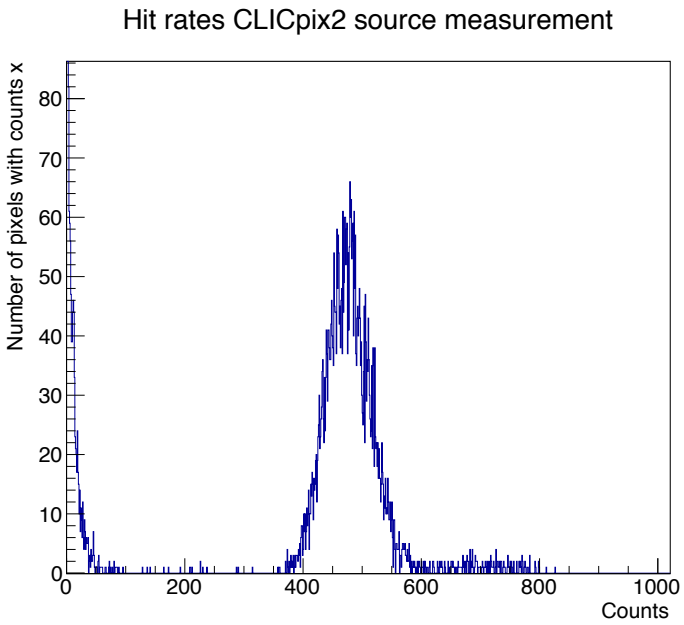
Assembly 14:



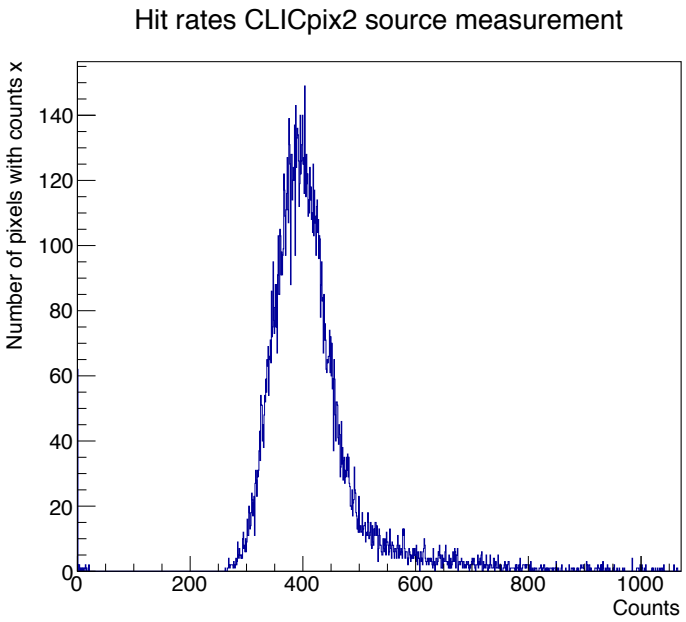
Assembly 16:

These show that ToT circuit works correctly (previous plots were counts only). Calibration can/will be carried out to have a conversion to electrons taking into account the pixel-by-pixel variations.

Source measurements: Hitrates

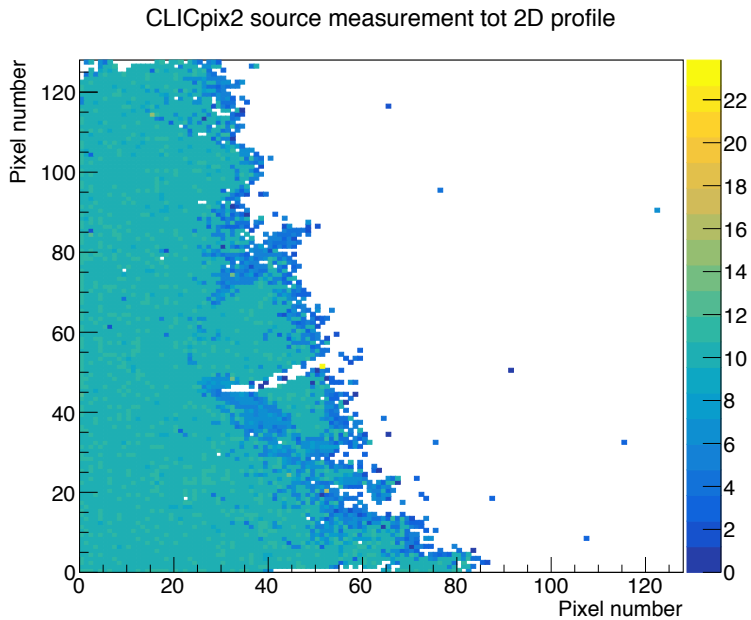


Assembly 14:

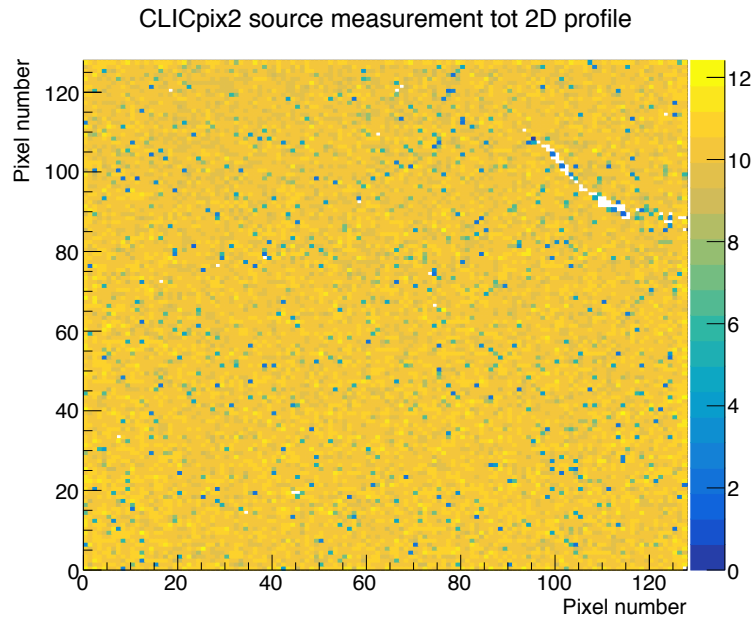


Assembly 16:

Source measurements: ToT 2D

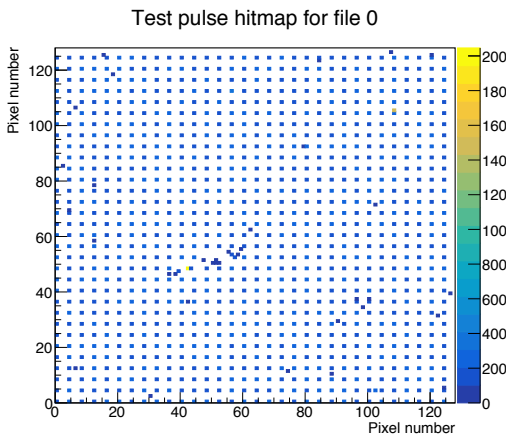


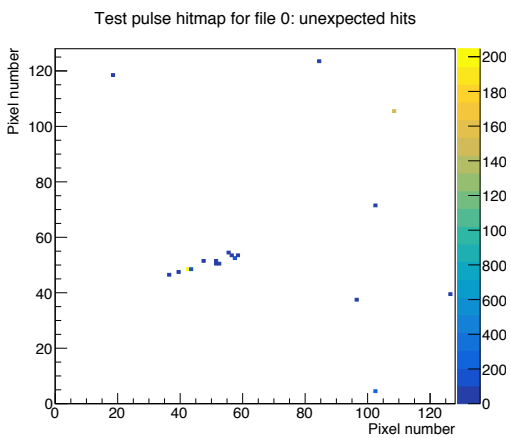
Assembly 14:



Assembly 16:

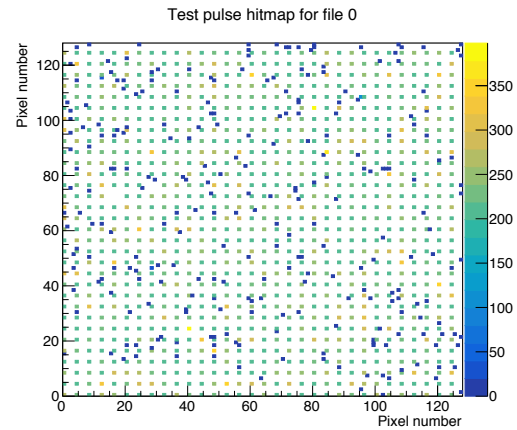
Test pulsing: file 0

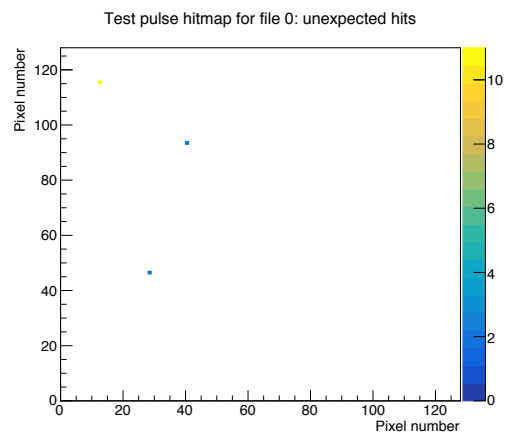




Assembly 14

Assembly 16





To do: Calibration

Part 1:

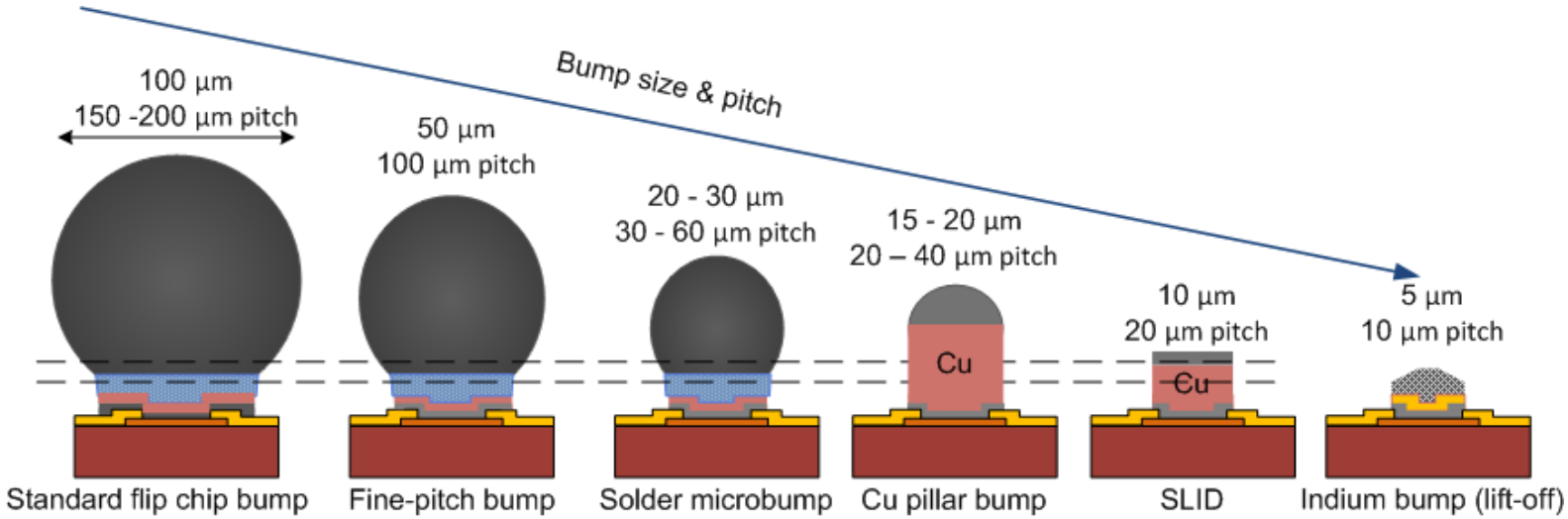
- Test pulse measurements with varying pulse strength.
- Measure counts and ToT per pixel.

Part 2:

- Source measurement with an iron source to measure spectrum peaks.

Combine results to create a plot for each pixel of ToT vs. test pulse strength.

Bump-bonding options

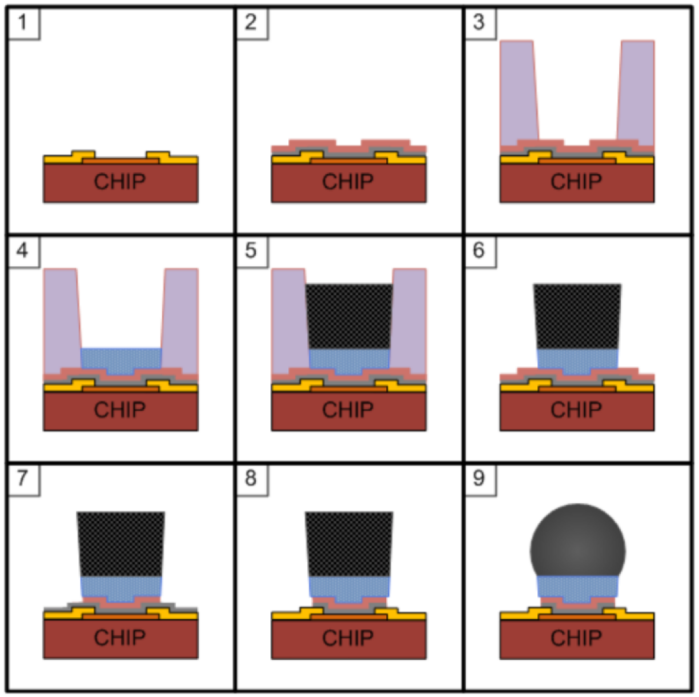
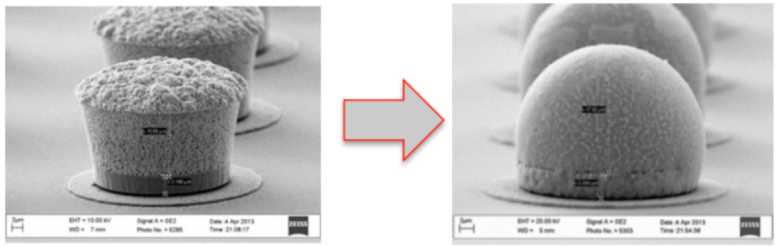


IZM processing for assemblies

- Bump-bonding project with IZM that targets to deliver 10 assemblies with planar active-edge sensors, 4 of which we have received and tested (in the lab and/or in test beam).

- 1) Preparation of carrier wafers with mask alignment marks and bonding layer
- 2) die-bonding of single chips on carrier wafer
- 3) bumping: sputtering of plating base, resist lithography, Cu+SnAg galvanic, resist removal, etching of plating base outside the bumps, reflow of bumps
- 4) removal of chips from carrier wafers
- 5) flip-chip assembly on sensors
- 6) x-ray inspection

Talk slide from Barcelona Techno Week 2018: *Sensors and Interconnects (*Sami VAHANEN)

Electroplating Process

1. Cleaning of wafers
2. Visual inspection of wafers
3. Sputtering of seed layers
4. Adhesion and seed layer deposition
5. Lithography
6. One mask layer process
7. Electroplating
8. Under-Bump Metal (UBM) and solder deposition in sequence
9. Solder bump height measurement
10. Resist removal
11. Etching of the seed layer
12. Etching of the adhesion layer
13. Solder reflow