Photo analysis for QA/QC of CRP anodes

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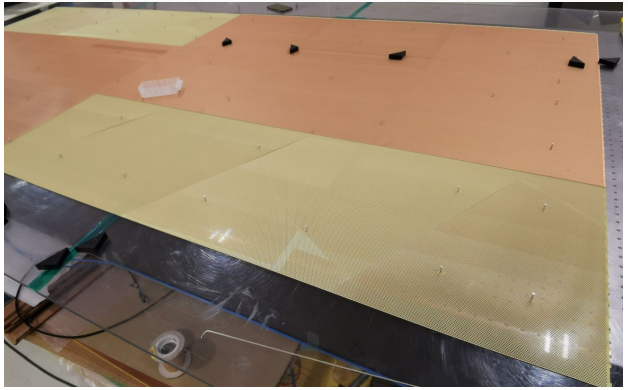
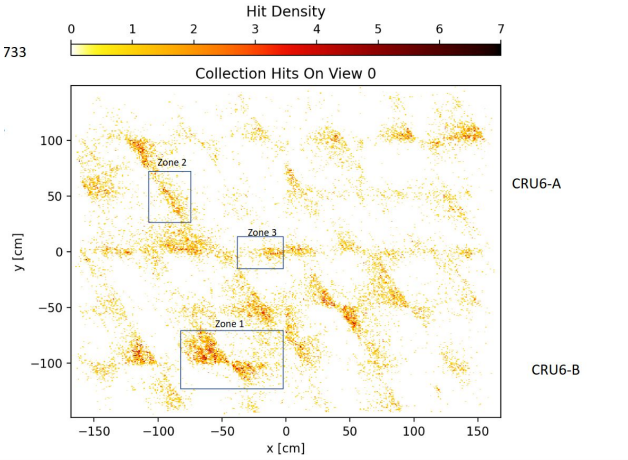
LAPP

Context

- DUNE CRP anodes fabricated by gluing perforated PCBs
  - Need very good precision in hole dimension and pitch
  - Ideally we would like to have a QC/QA process to verify hole dimension and pitch in all PCBs and assembled anodes
    - Or at least samples of each anode
    - Automate process
    - Keep track of information in a database
- Cold Box test of CRP6
  - Laura analysis showed strange behaviour with **reduced charge** in some regions of **collection view** and apparent **collection of charge in induction 1 view**
  - What is the origin of this behaviour?



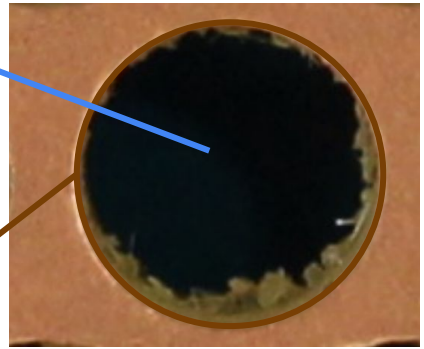


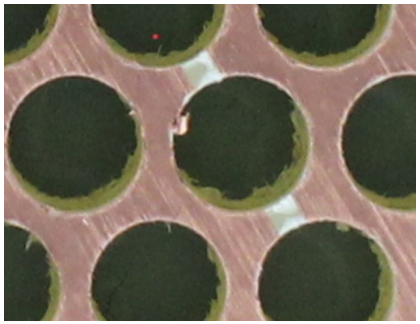
Parameters for QA/QC

- Different parameters can be studied with photo analysis
  - **Hole diameter:** Taking copper as reference
  - **Effective hole diameter:** “real” diameter of holes that electrons will go through, including effects of misalignment, glue/paper/copper residuals
  - **Pitch:** Distance between holes in a given direction
  - Cu and drilling quality

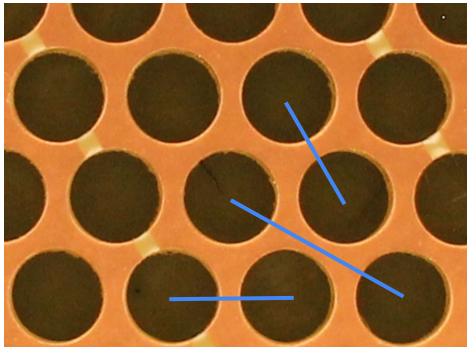
Effective hole diameter (from black region)

hole diameter (copper region)





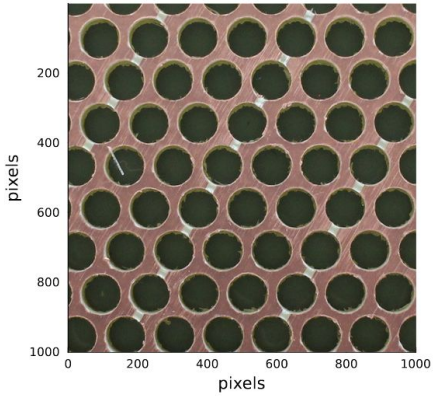
Bad Cu/drilling quality

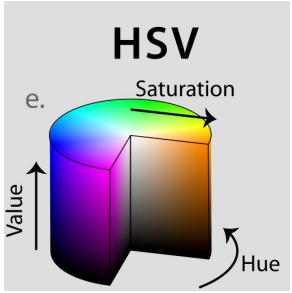


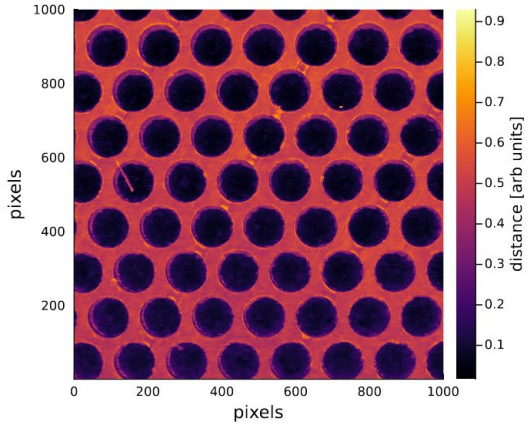
Pitch

Methodology

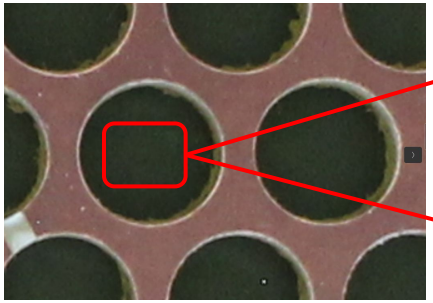
- Images/photos can be converted to HSV color space (cylindrical coordinates)
- PCBs have regular structure that can be used to identify components by using the different colors (copper, glue, etc)
  - Different parts (holes, copper, glue) can be separated defining a metric (distance in HSV space) to a reference color (copper, glue, paper on background, etc)
  - Once holes are identified the area/diameter of each hole can be calculated (in pixels)
    - The center of the holes can be used to measure the pitch





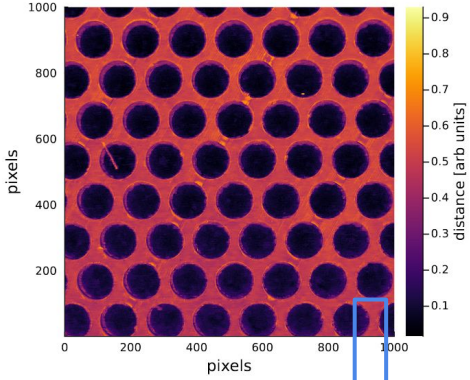


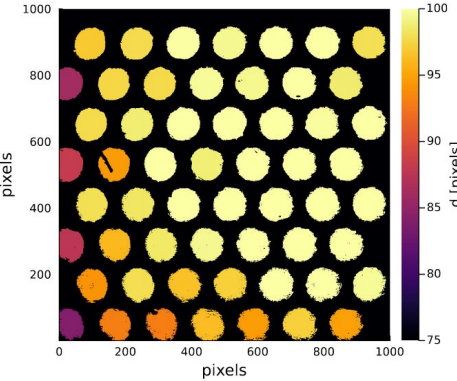
Methodology



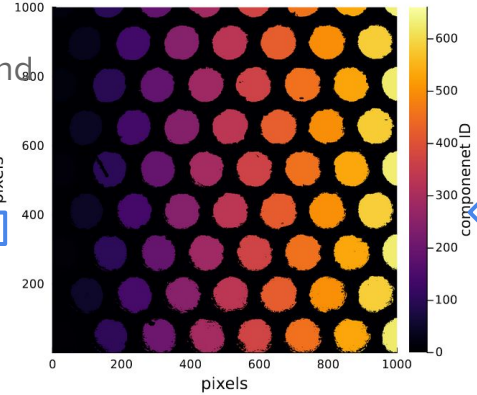
Average hole color

Compute distance

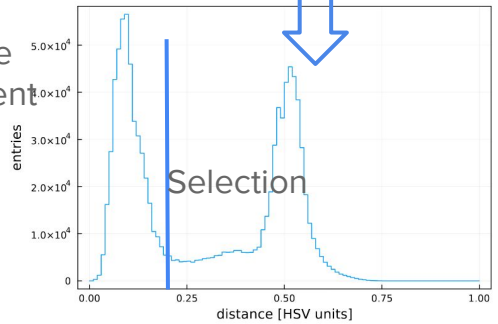




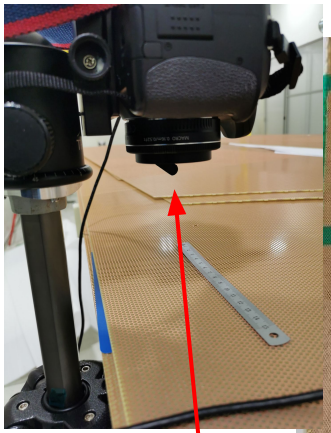
Compute hole area and diameter in pixels

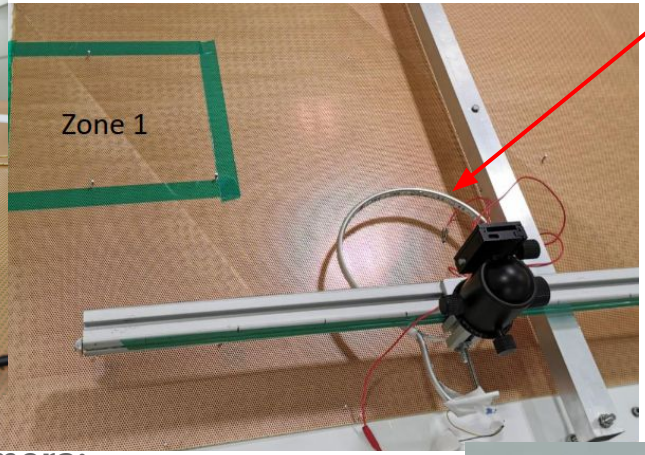


Binary image for component analysis



The setup

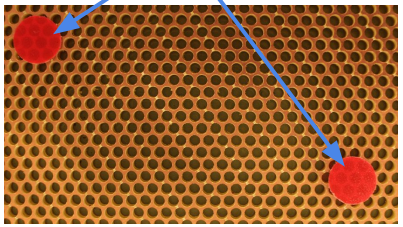




Need uniform light to improve precision: Using **Chris M. idea/setup** of ring of LEDs around camera

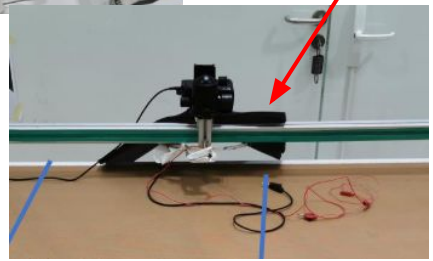
Black coverage to reduce light variations from clean room illumination

10 mm diameter red circles for pixel to mm calibration factor



Dominique's camera:
CANON APSC (3456 x 5184) pixels
24 mm LENS in macro mode
Lens geometrical correction applied by Dominique using dedicated image software (rawtherapee)

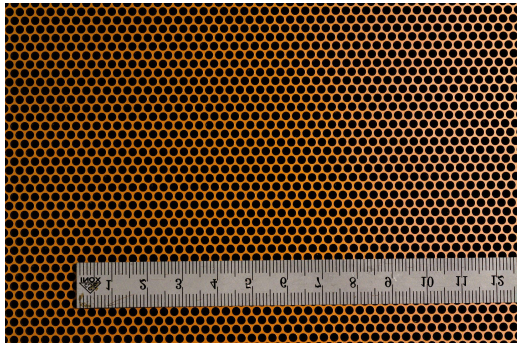
+

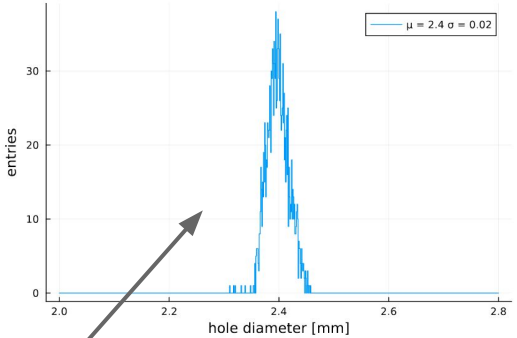


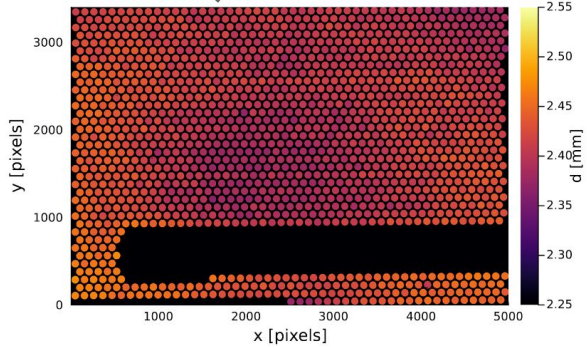
Several photo-taking campaigns performed by Dominique, Luis, Chris...

Results CRP7 - hole diameter

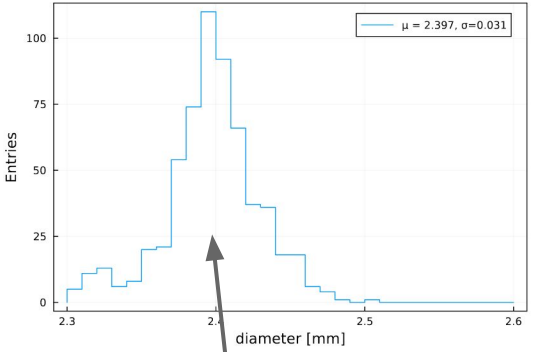
- Hole diameter according to what is expected:
  - 2.4 mm hole diameter (taking cu as reference)
    - Two calibration methods
      - ruler or red circles
  - Homogeneous distribution

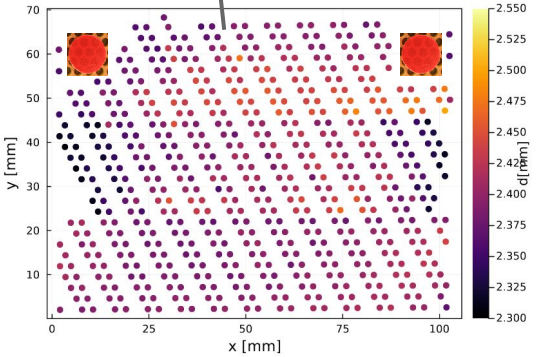






Shield

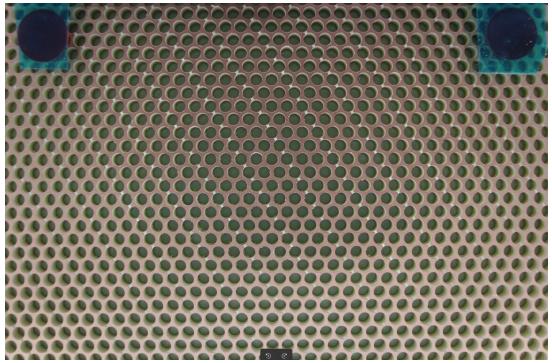


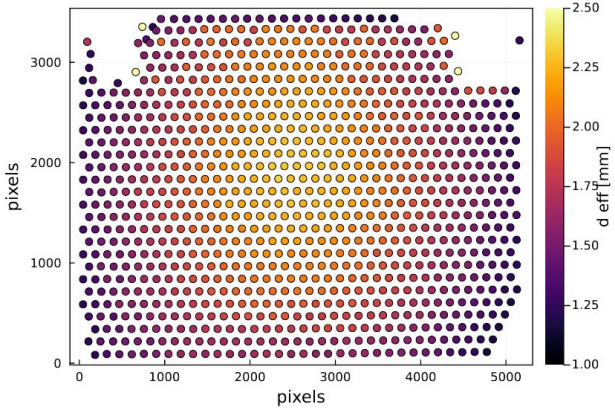


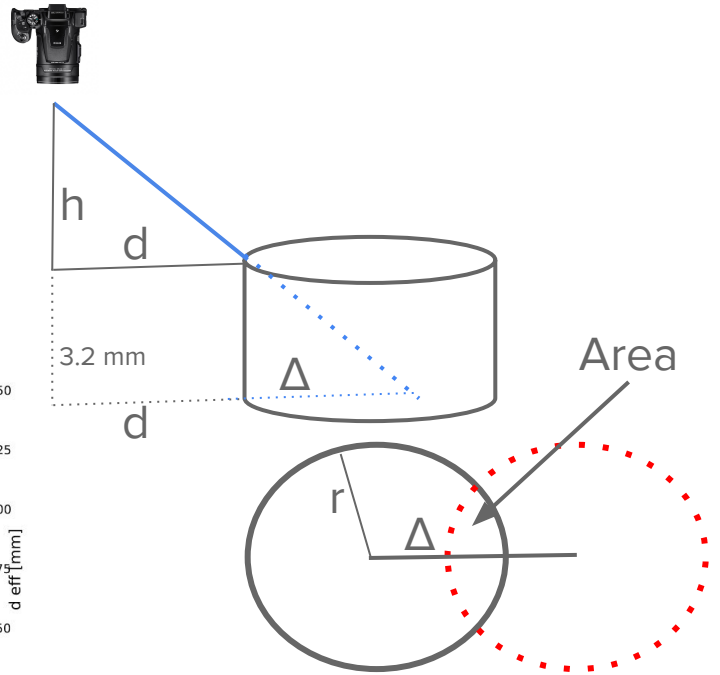
Induction

Results CRP7 - effective hole diameter

- Camera is placed above center of each photo
  - Shadow effect if go far away from the center
    - Given by distance of camera to anode and anode thickness
    - To look for small effects a correction is needed

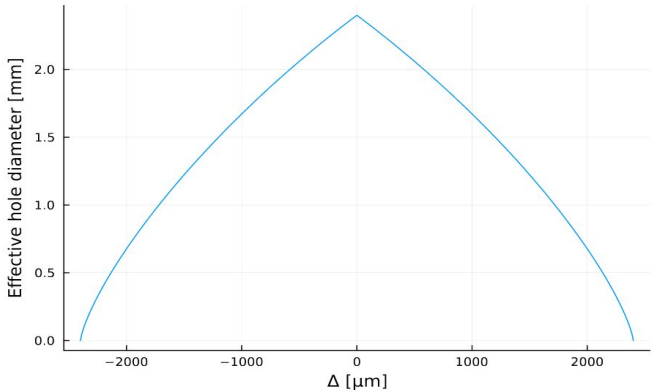


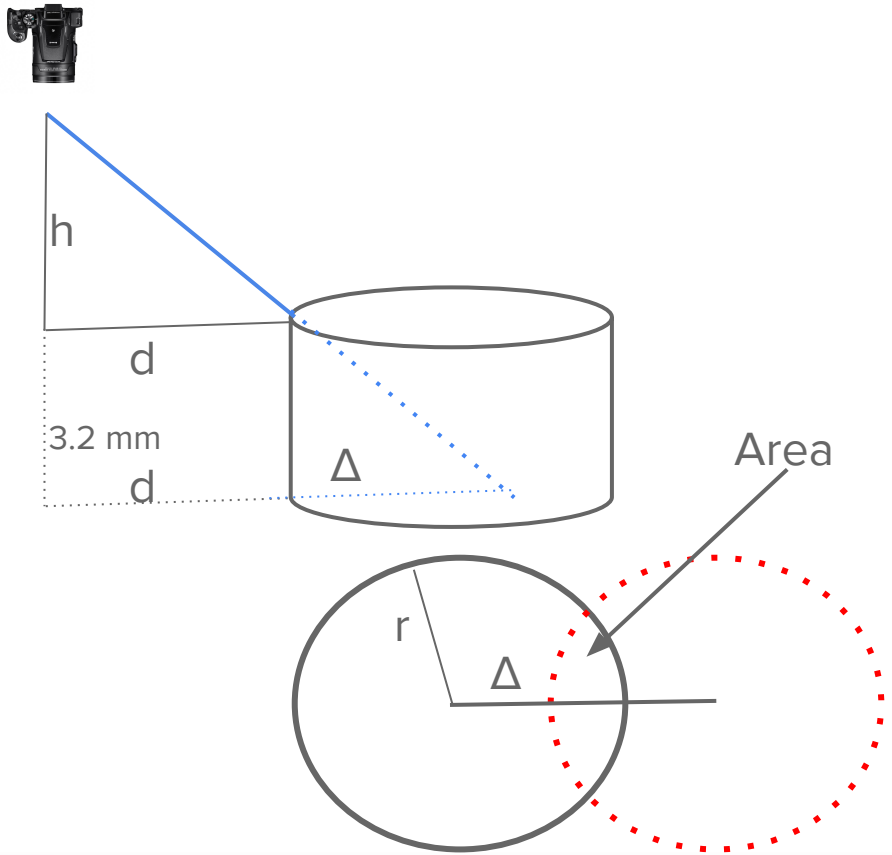




Shadow correction

- The expected area is given by intersection of two circles
  - Area = 2*r^2*acos(Δ/2*r) - Δ*sqrt(r^2 - (Δ/2)^2)
  - with Δ = (Anode_tickness/h)*d
  - Correction: sqrt(Area/(πr^2))
  - The same effect is produced by a real shift of the two glued PCBs
    - In this case dependence of only Δ

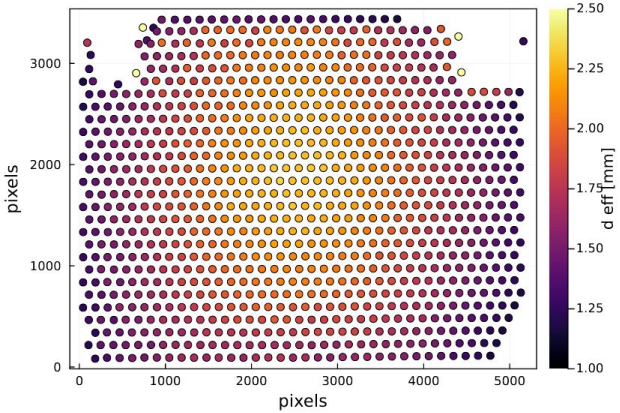




Shadow correction results

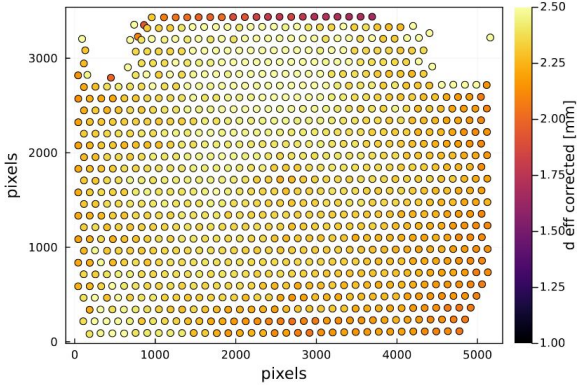
- Introduce a correction as described in previous slide
- If no problem we should have a ~homogenous distribution

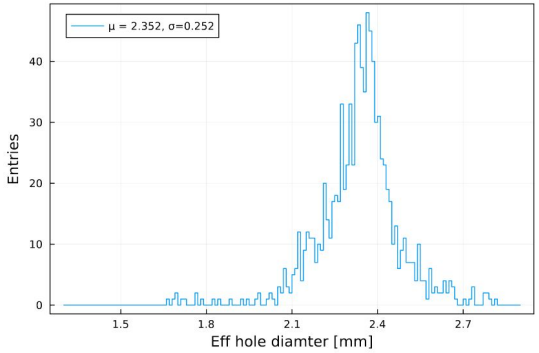
Before correction



shadow correction

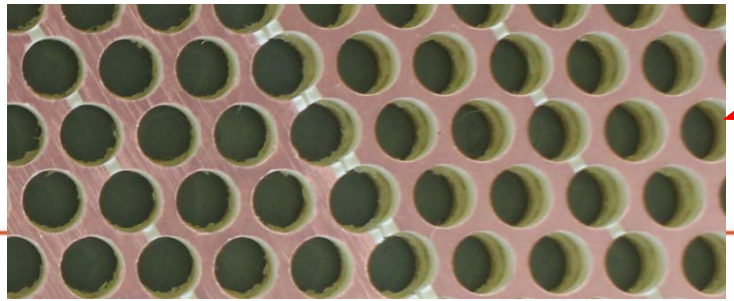
After correction

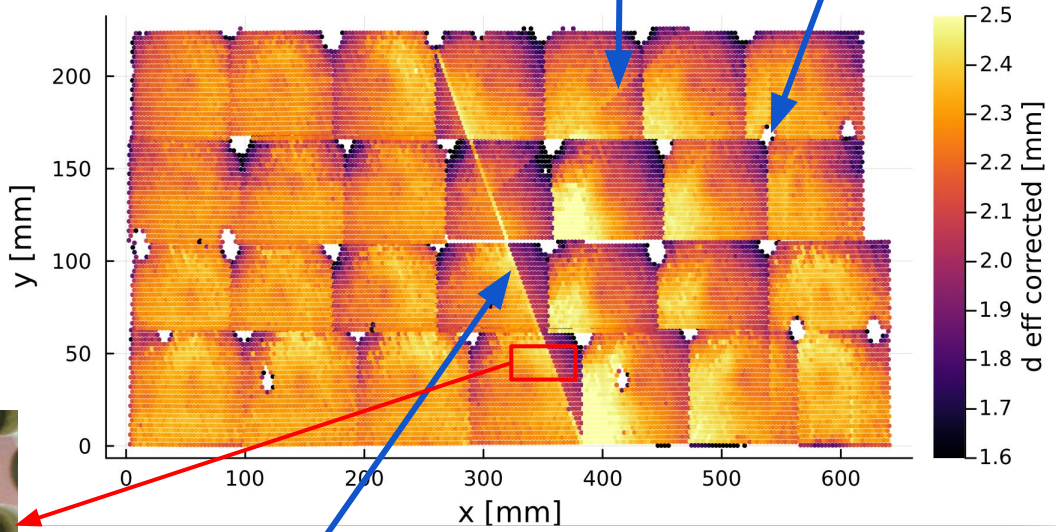




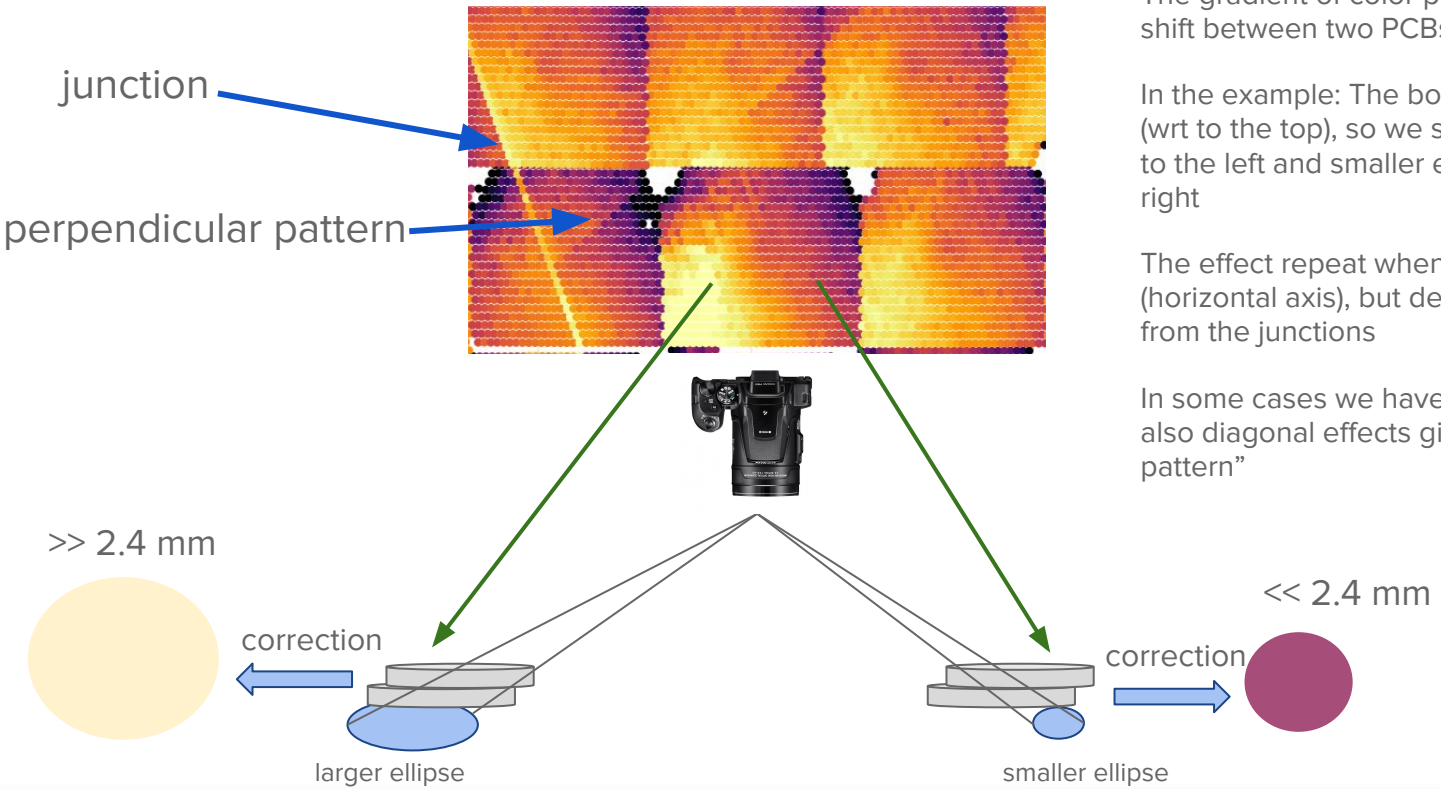
Results in a large area

- Two large sections were photographed
  - Photos can be merged using reference points (red circles)
    - Allows to check for variations
  - Shift clearly visible in the junction of two PCBs





Observed effects



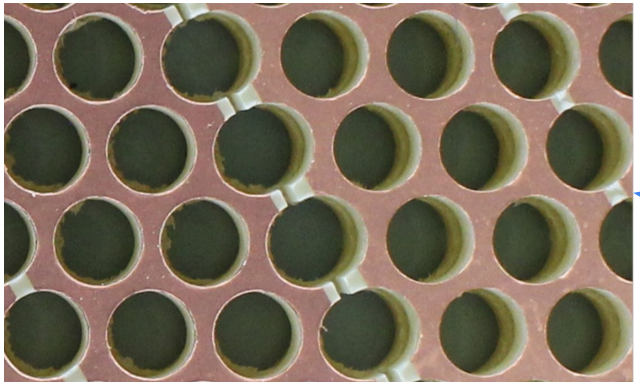
The gradient of color provides information about the shift between two PCBs

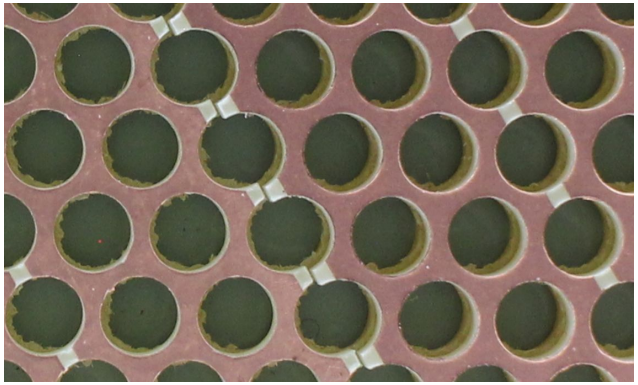
In the example: The bottom PCB is shifted to the left (wrt to the top), so we see larger ellipses when we look to the left and smaller ellipses when we look to the right

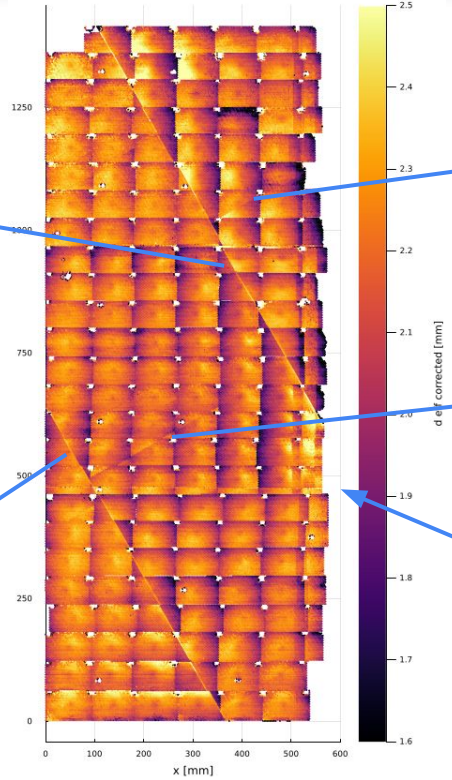
The effect repeat when we move to the next photo (horizontal axis), but decrease as we move far away from the junctions

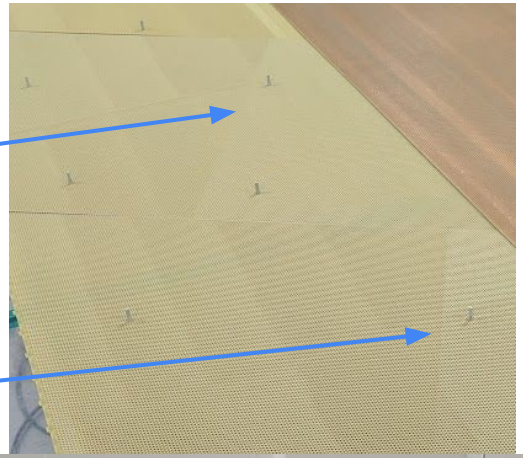
In some cases we have shift in both directions and also diagonal effects given by the “perpendicular pattern”

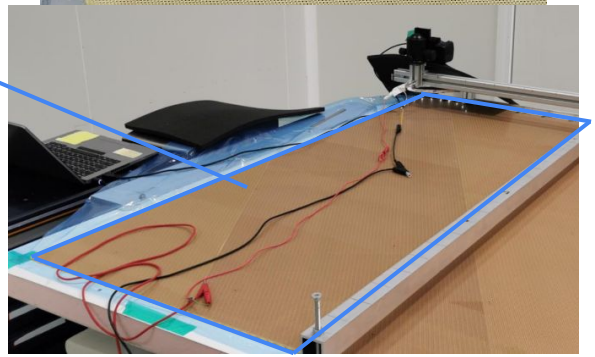
Results large area 2



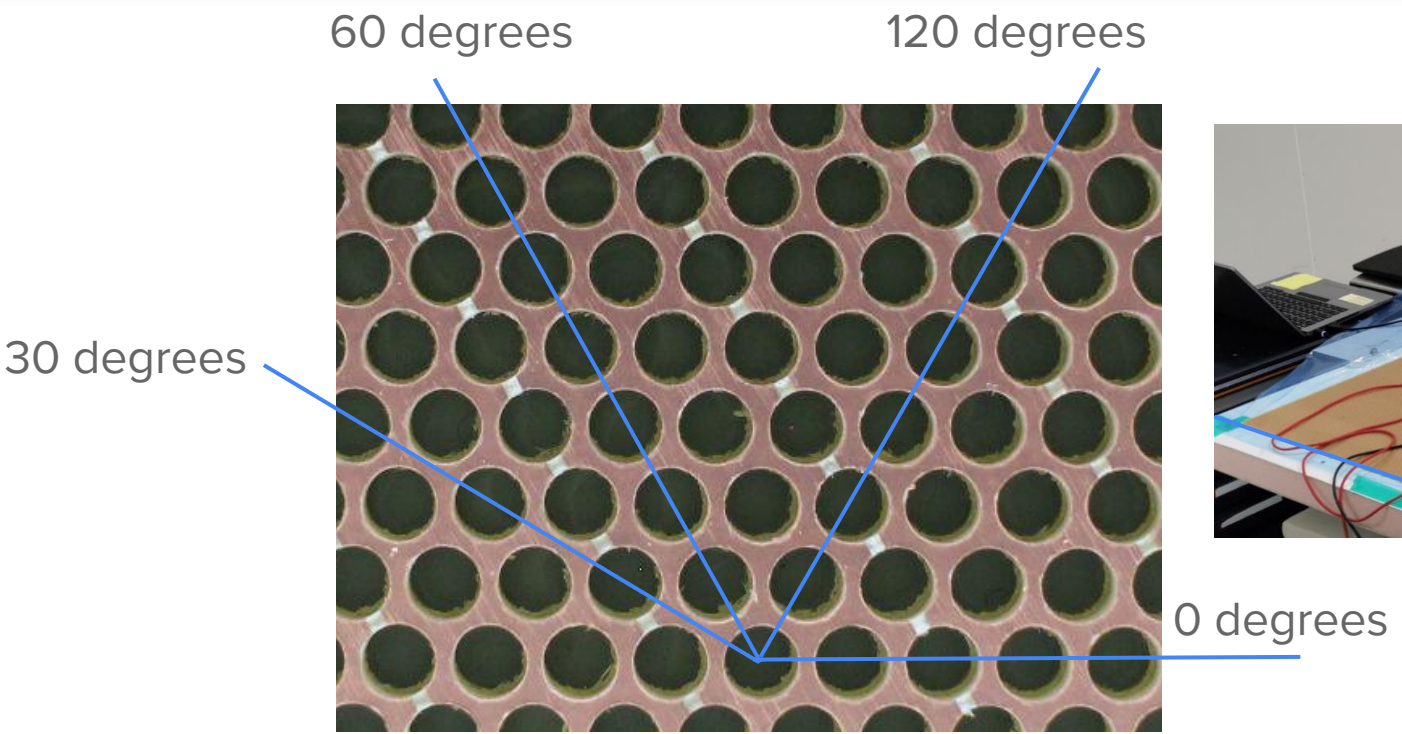


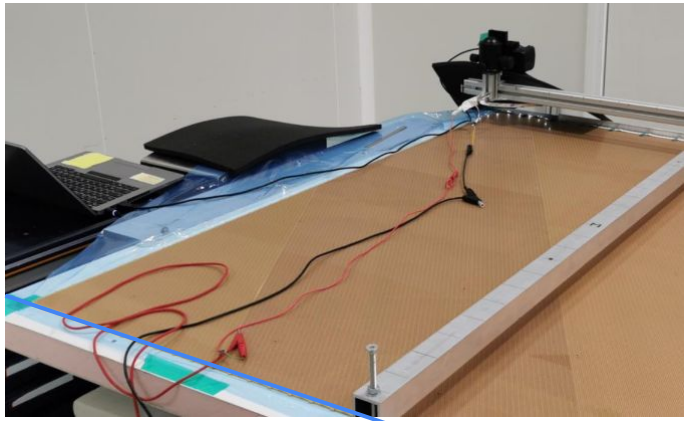




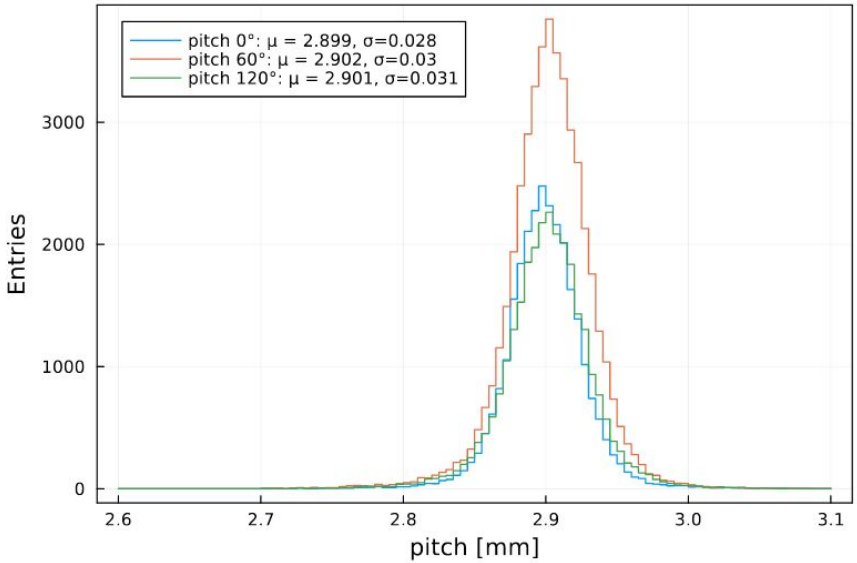


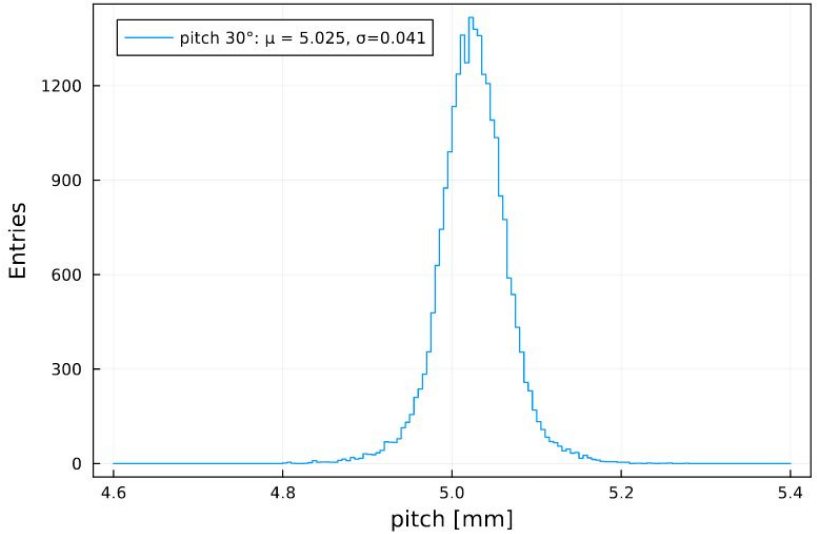
CRP7 Pitch





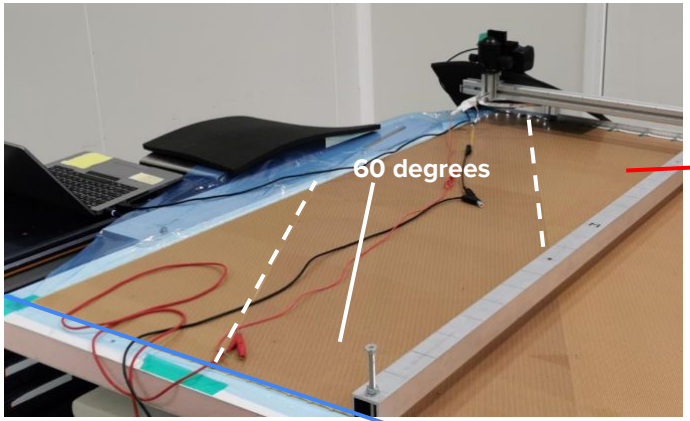
Pitch distribution

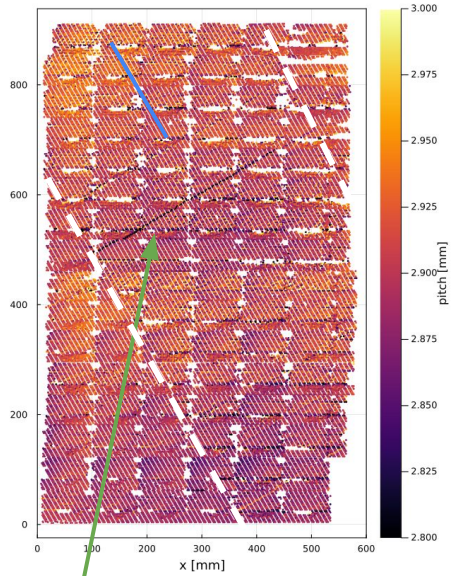




In general homogeneous everywhere

Pitch over large area

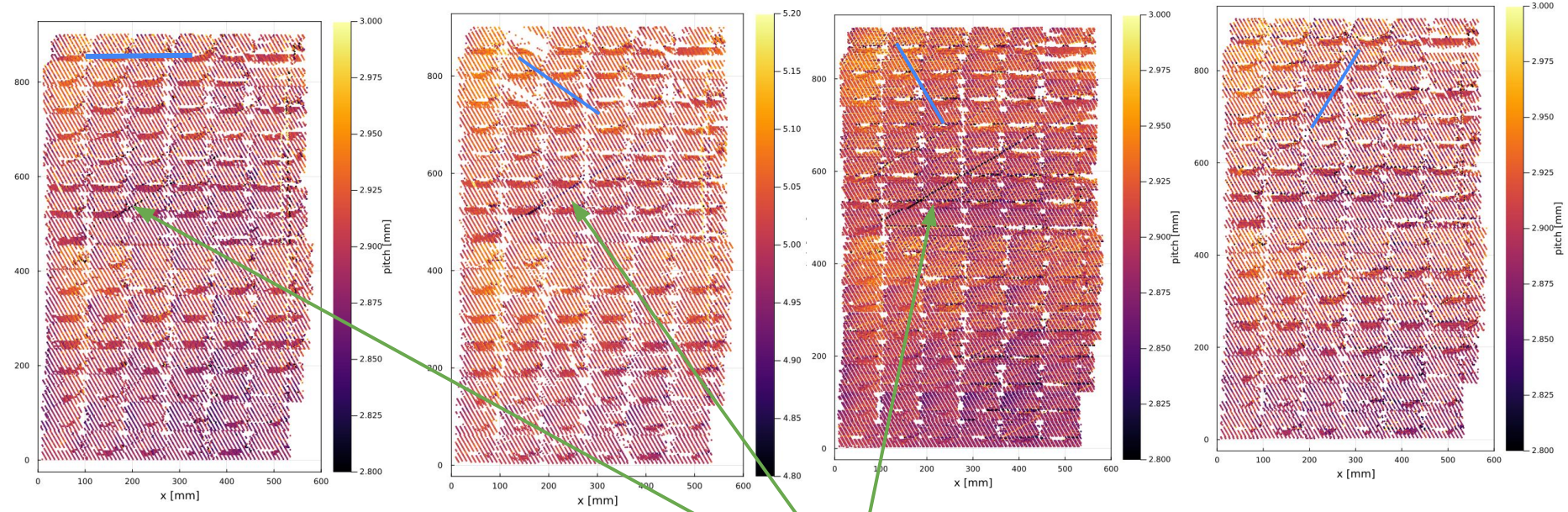




60 degrees

About 150 µm smaller pitch in “longitudinal” direction

Pitch over large area



0 degrees

30 degrees

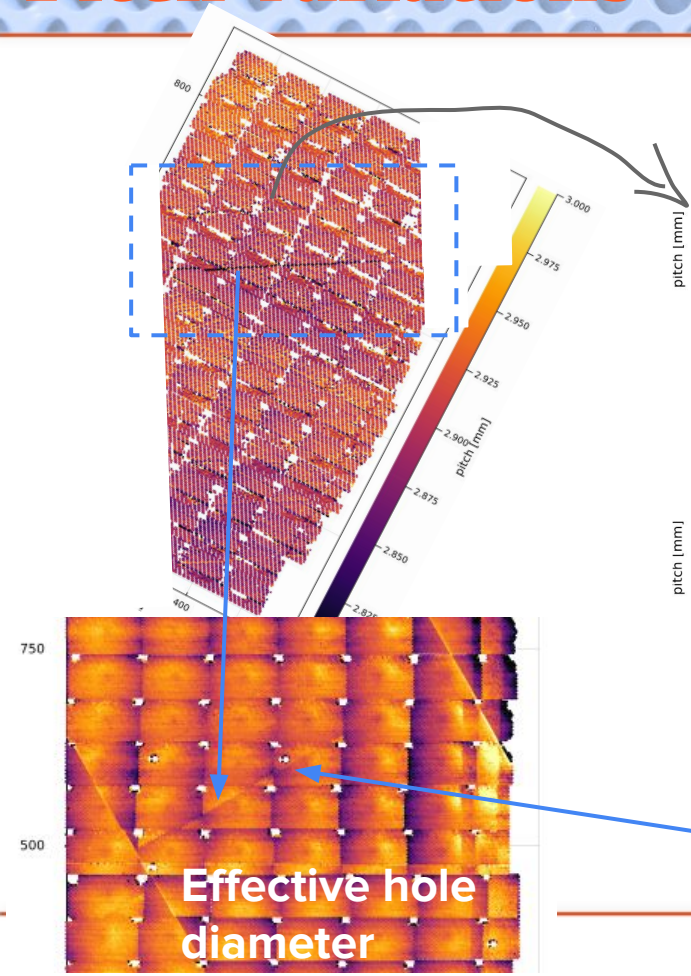
60 degrees

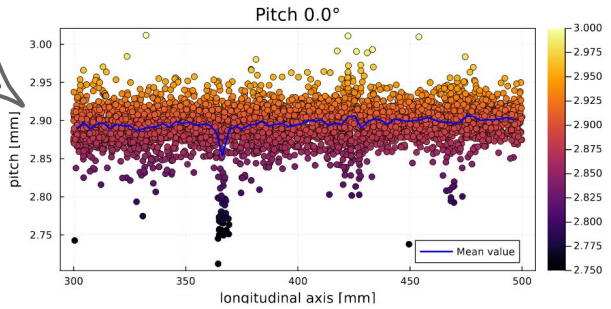
120 degrees

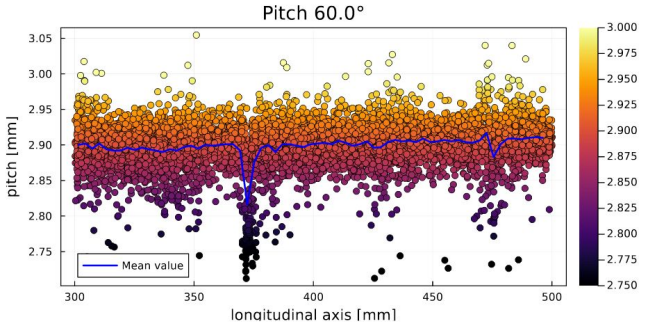
About 150 µm smaller pitch in “longitudinal” direction

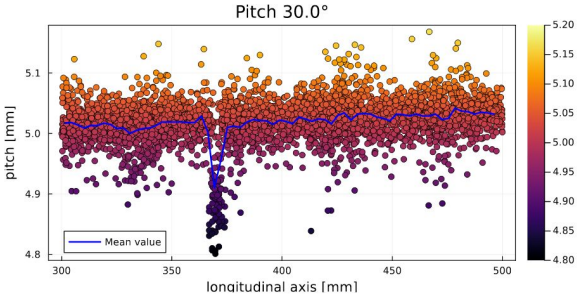
*Blue line indicates the direction that was considered for the pitch measurement

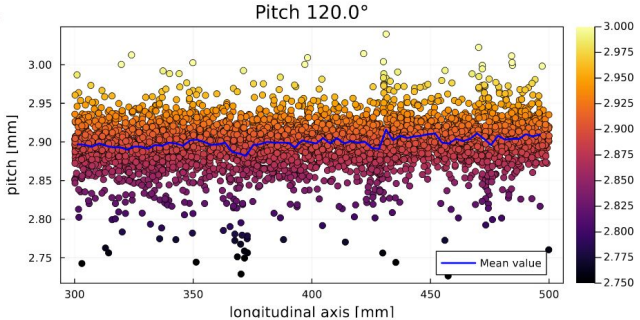
Pitch variations











About 150 um pitch reduction: This produce a shift and will introduce a rotation of the PCBs
Can we see this effect in the photos?

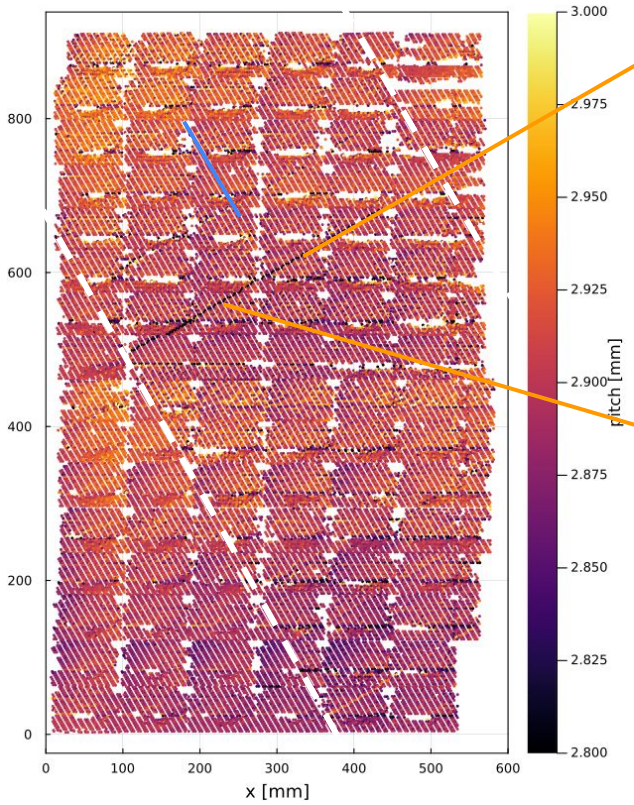

0
200
400
600
800
0
100
200
300
400
500
600
x [mm]
3.000
2.975
2.950
2.925
2.900
2.875
2.850
2.825
2.800
pitch [mm]

Photo 111

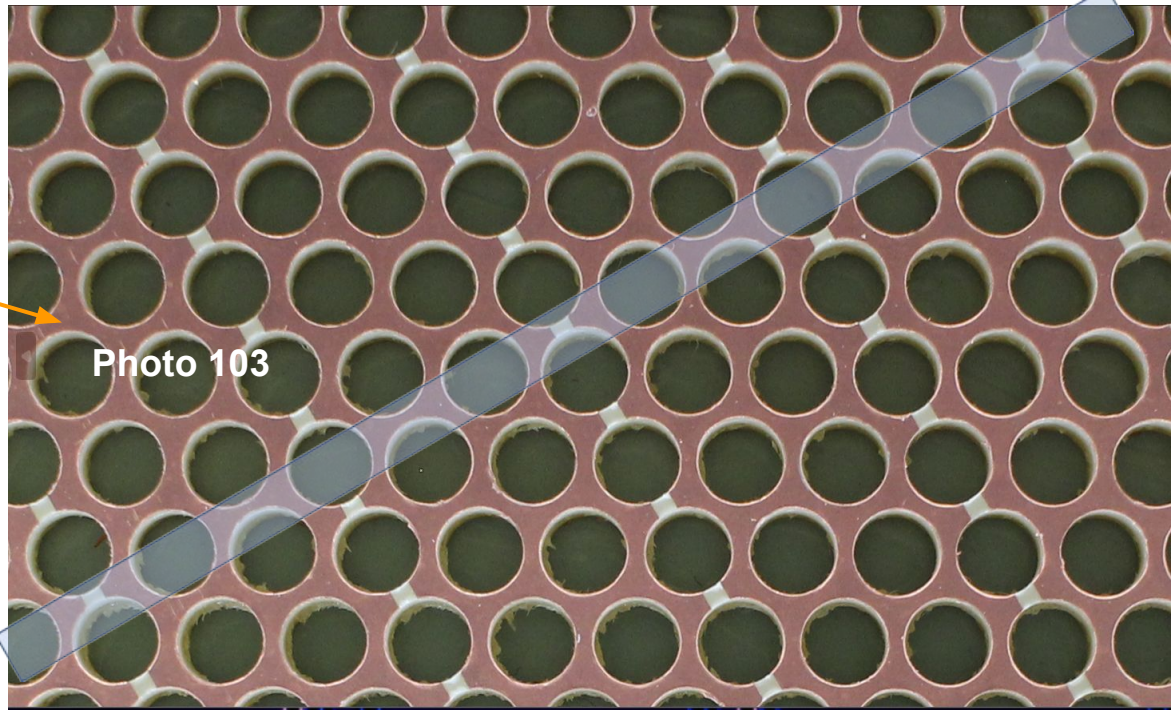


Photo 103

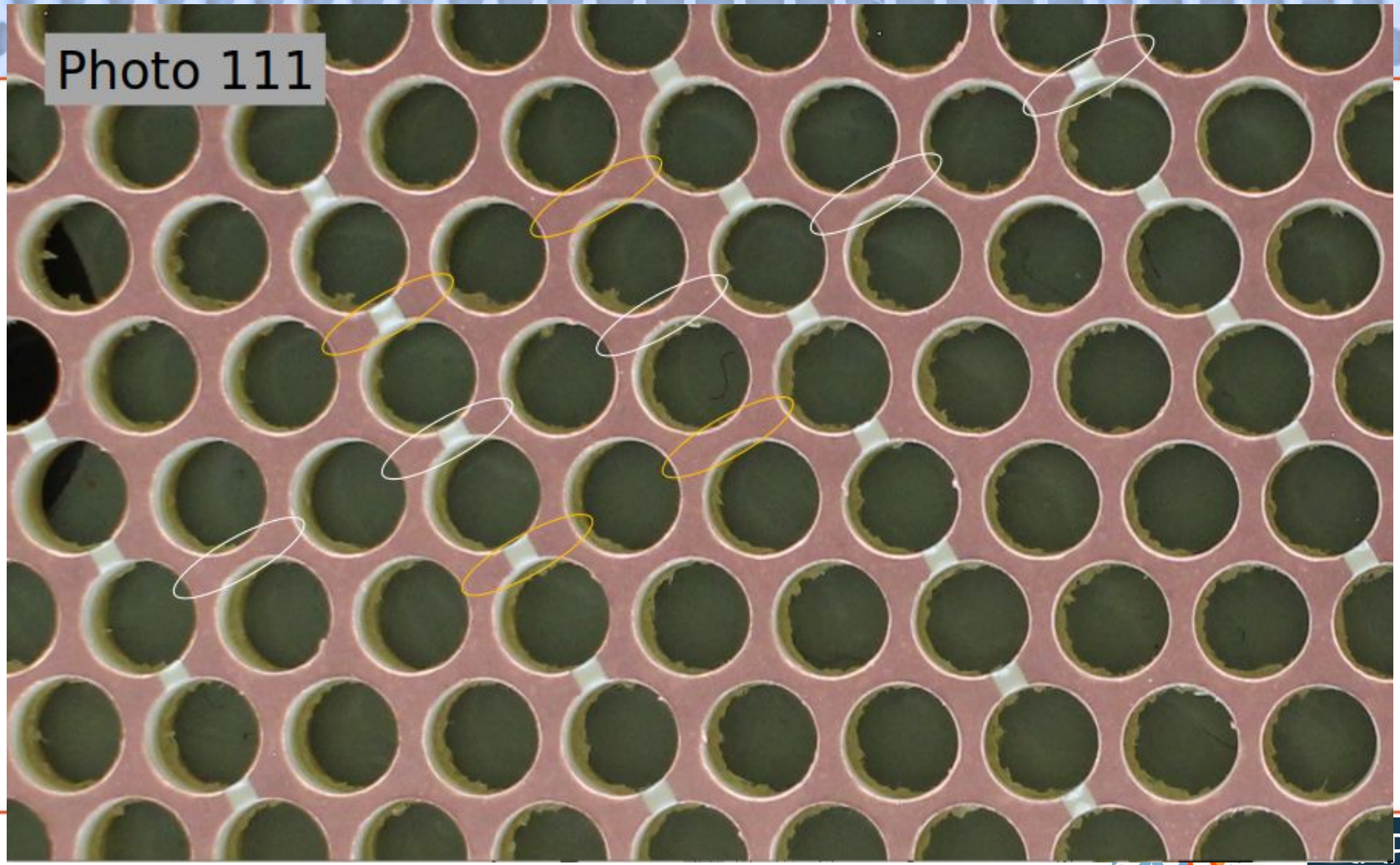
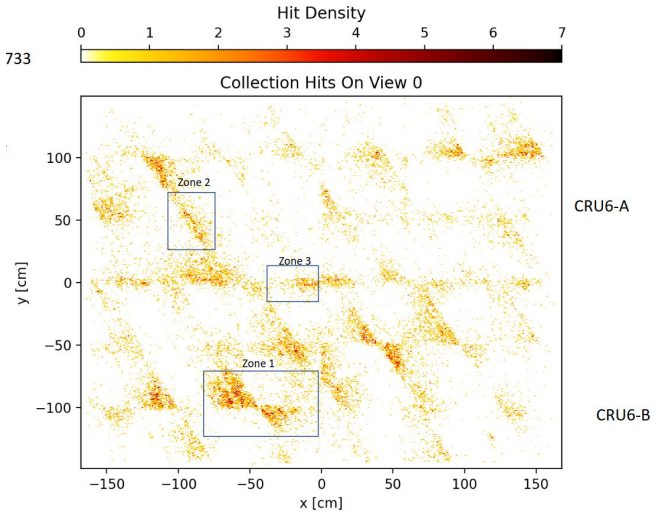


Photo 111

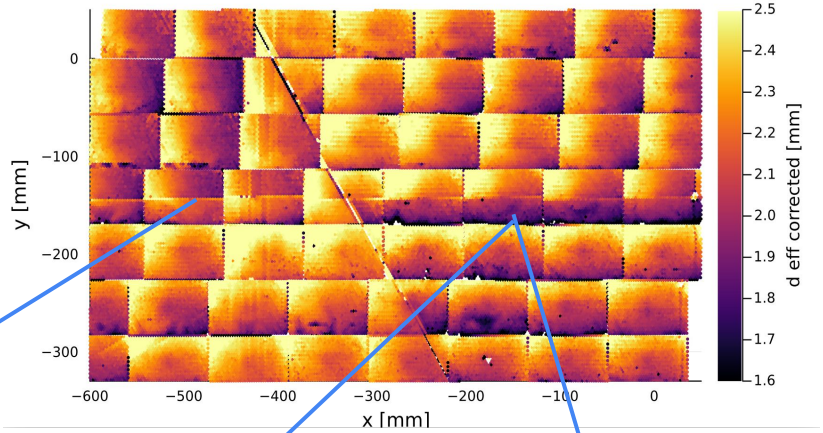
CRP 6

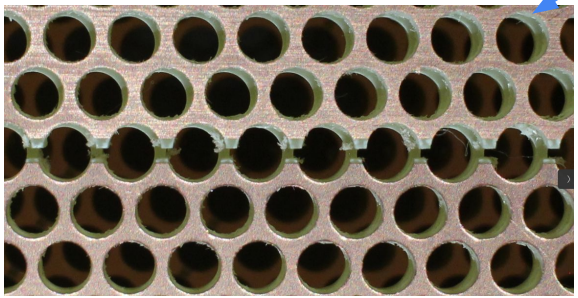
- Dominique photographed 3 regions of shield PCB of CRP 6 when suspended in Faraday cage after second cold box run
- Use analysis to confirm shift of PCBs in problematic regions

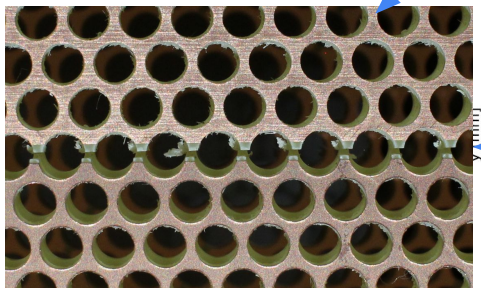


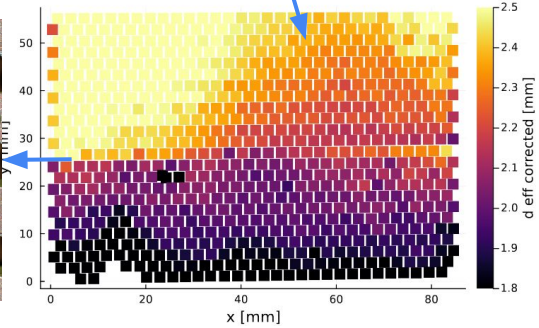
CRP6: Zone 1

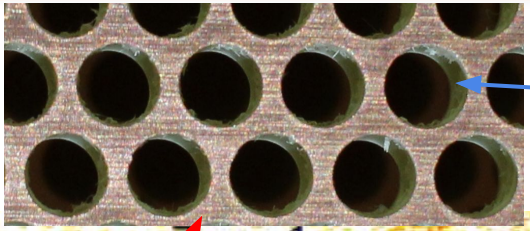
- Conditions less well controlled than when using setup in clean room
- Nevertheless:
  - **A shift is clearly visible**
  - Corresponds with pattern observed by Laura
  - The effective hole diameter in the worst part is about 1.9 mm



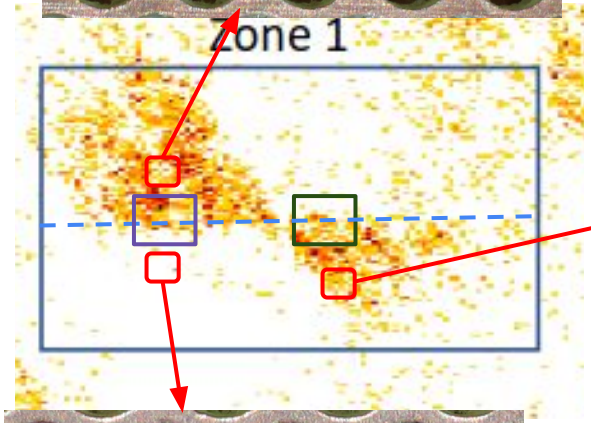


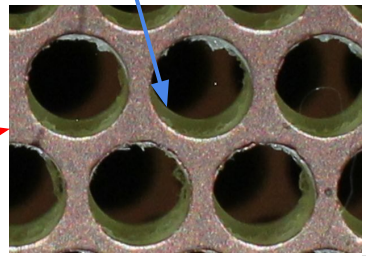


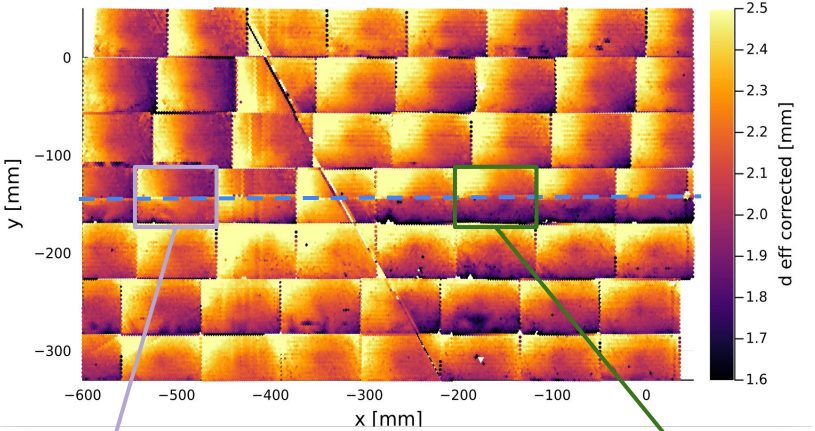


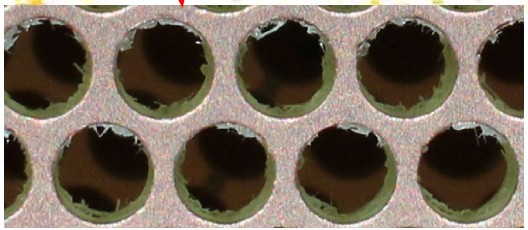


PCB shift

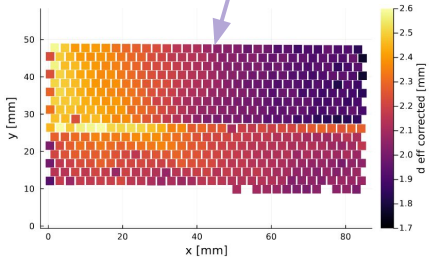


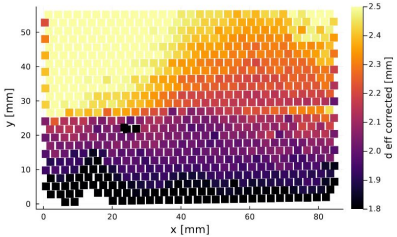




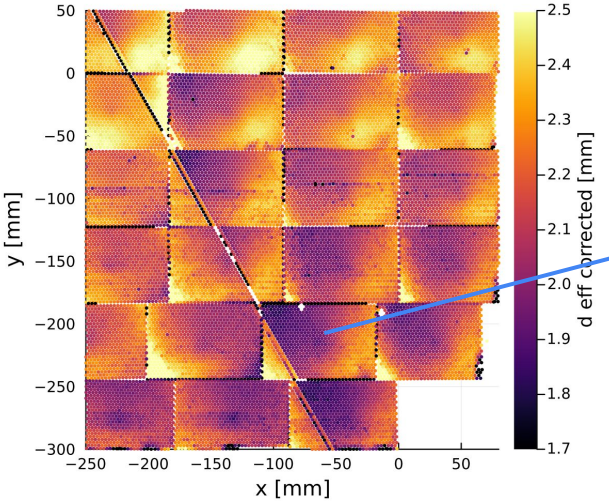


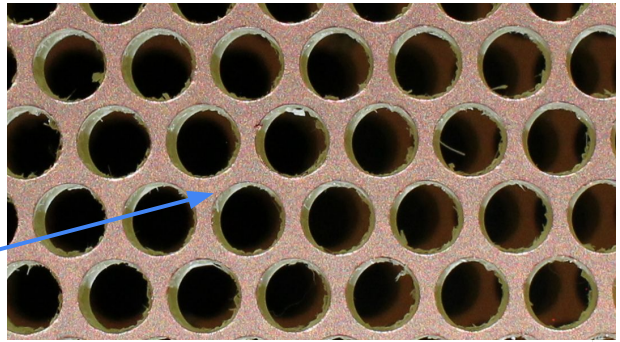
Mostly glue residuals

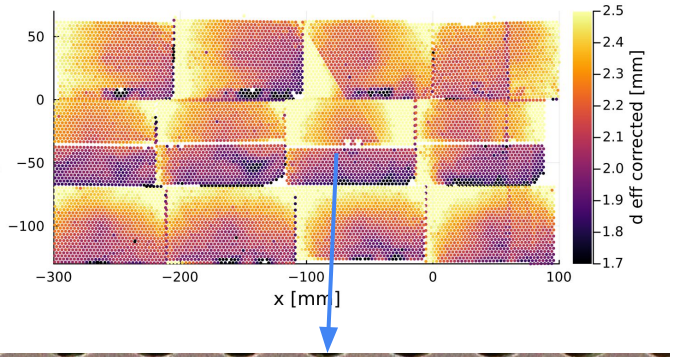


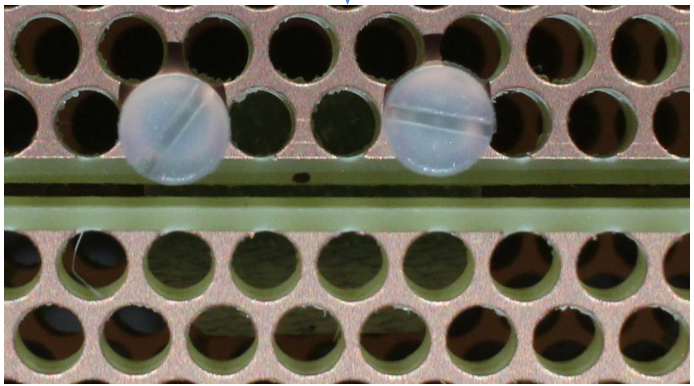


CRP6: Zone 2 and 3





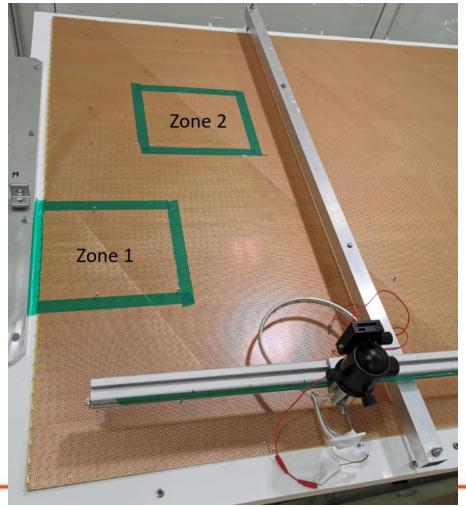


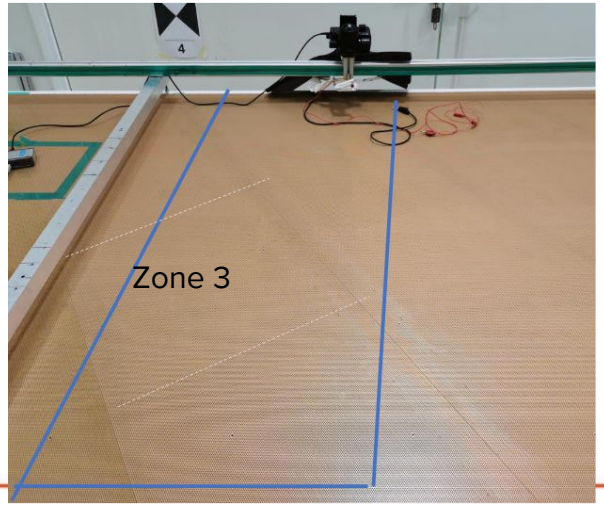


- Same effect as in Zone 1
- Shift clearly visible

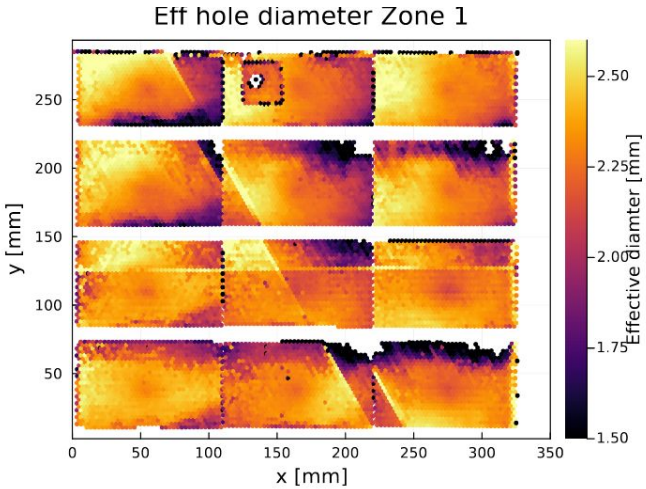
New anode for CRP6

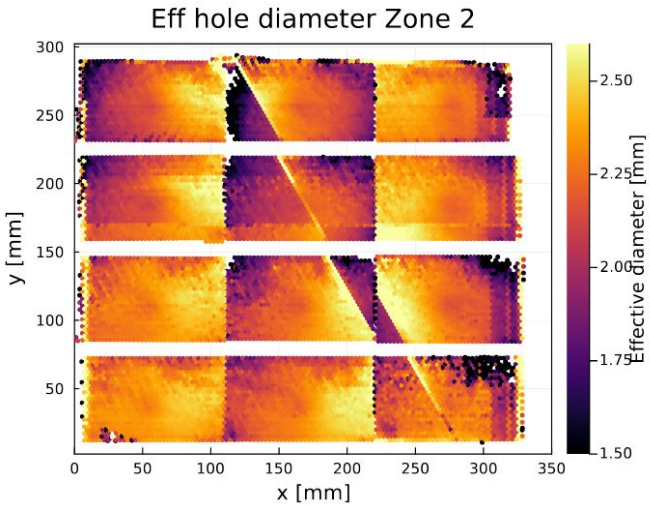
- Clear evidence that a **misalignment/shift** in the PCBs is at the origin of **decrease of charge collection**
  - **It affects mostly the electron diffusion ; simulations are ongoing, first estimate by FP shows possible significant effect**
  - **Additional analysis ongoing by JP.**
- The effect is larger in PCB junctions
  - If border of PCBs is reduced (sanded) this should reduce constraints and might improve alignment?
  - New anode builded to check effect
    - Zone 1 and 2 above junctions: shielding + induction
    - Part of Zone 2 is the continuation of PCB in Zone 3
    - Zone 3: large area allowing to check pitch variations

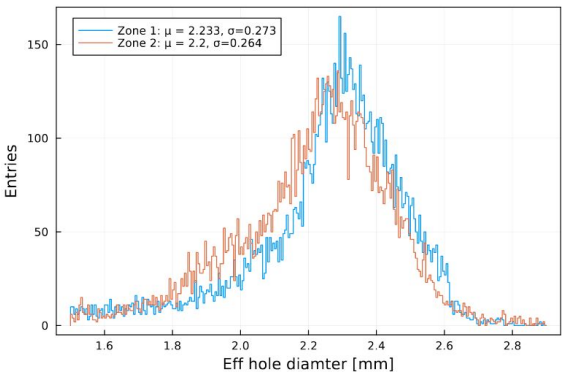




Effective hole diameter Zones 1 and 2

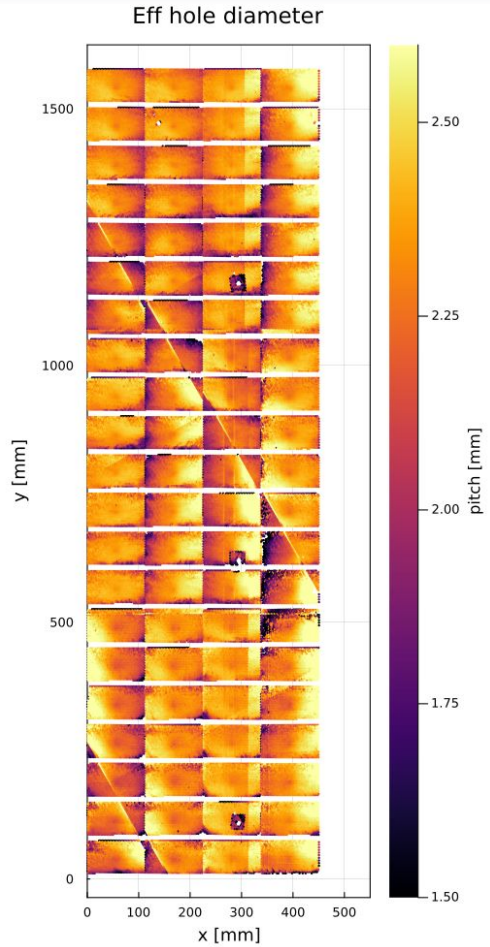




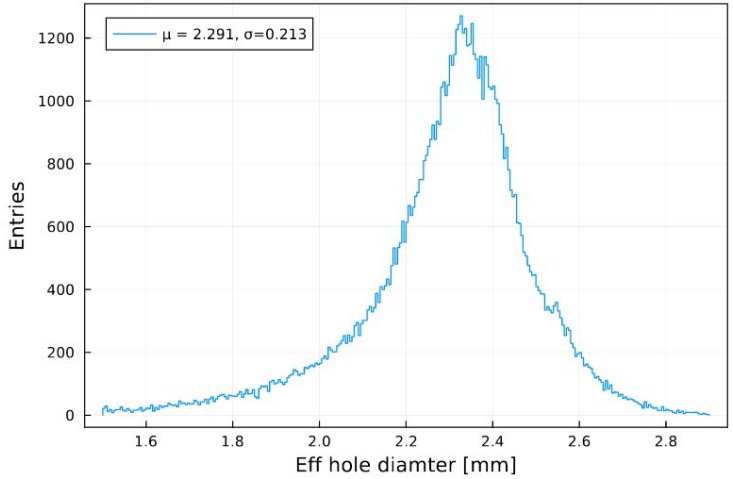


- Shift still present in both zones: Larger in Zone 2
  - Sanding the border of the PCBs seems to improve the alignment but shift still present
- Small rotation produces such a shift
  - If systematic reduced pitch (~150 um) pattern ~each 50 cm in all PCBs, then this can produce a rotation resulting in a shift (misalignment)
  - Do we have everywhere this reduced pitch pattern? -> Check Zone 3 of this new PCB to confirm effect

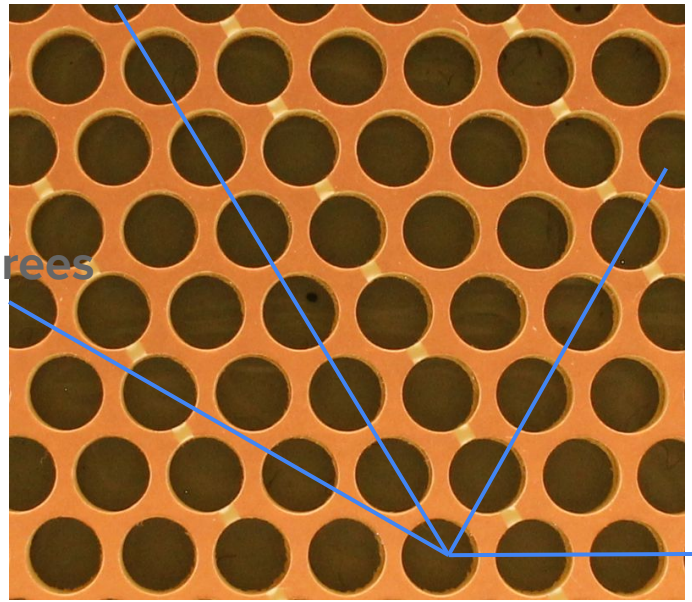
Effective hole diameter Zone 3

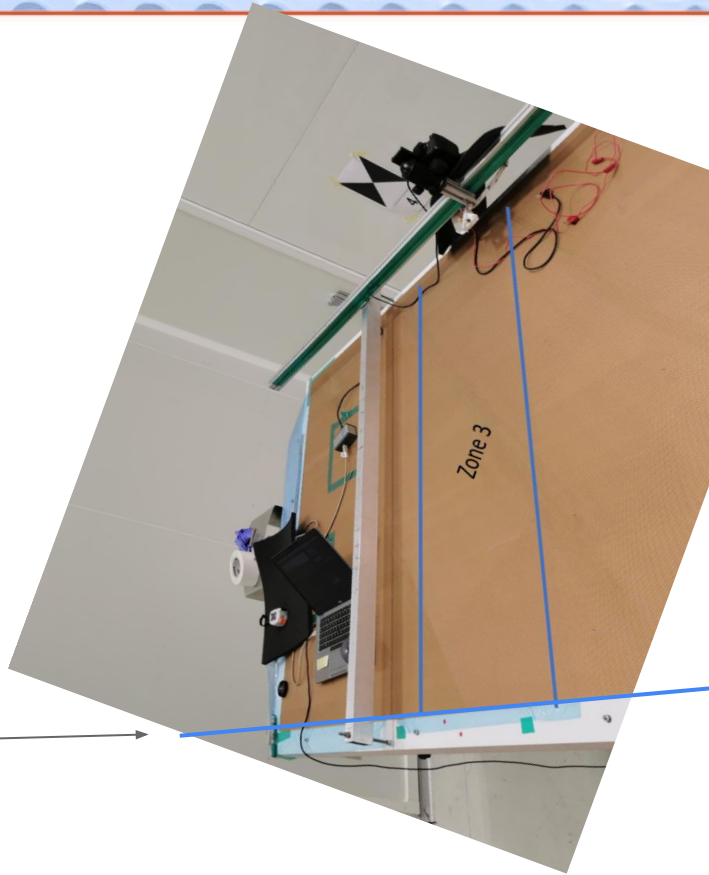


- Most of the regions show a very homogenous response
- Some shift is present but smaller than Zones 1 and 2
  - Effect might depend on the order of gluing: more shift in the parts glued at the end?



Zone 3 pitch



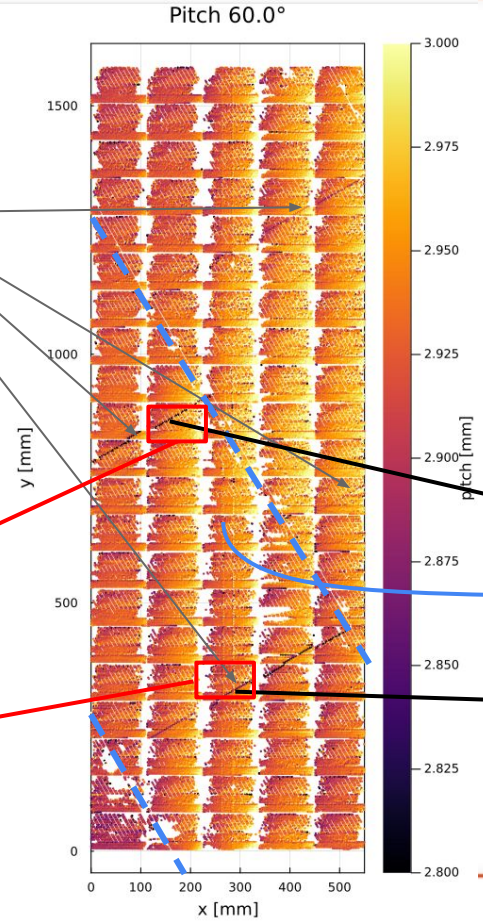


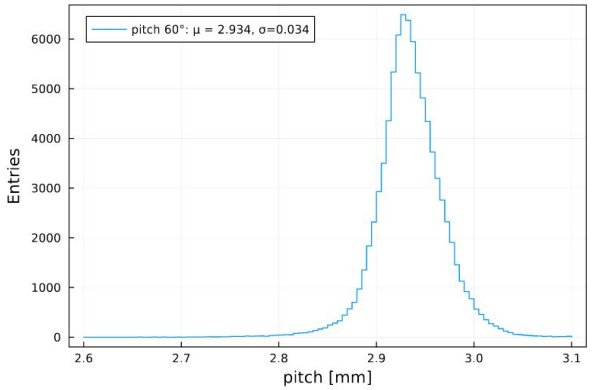
Pitch Zone 3

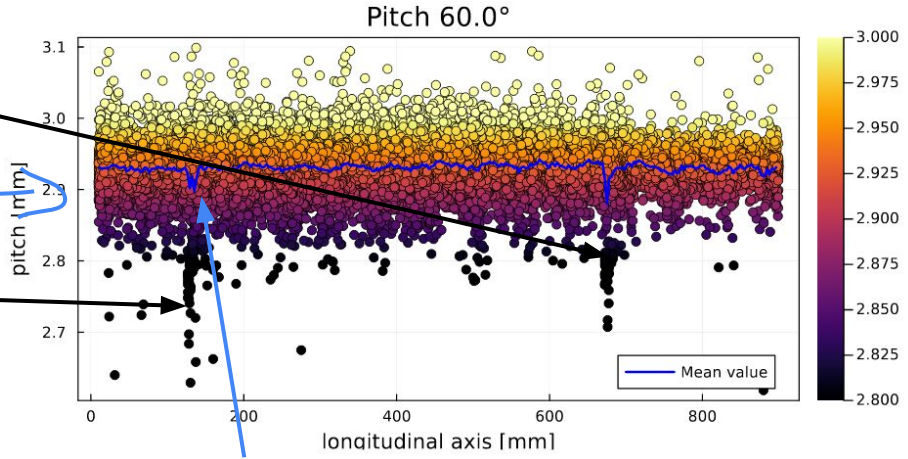
reduced pitch ~150 um smaller

Photo 66

Photo 86







Looks wider because alignment is not perfect

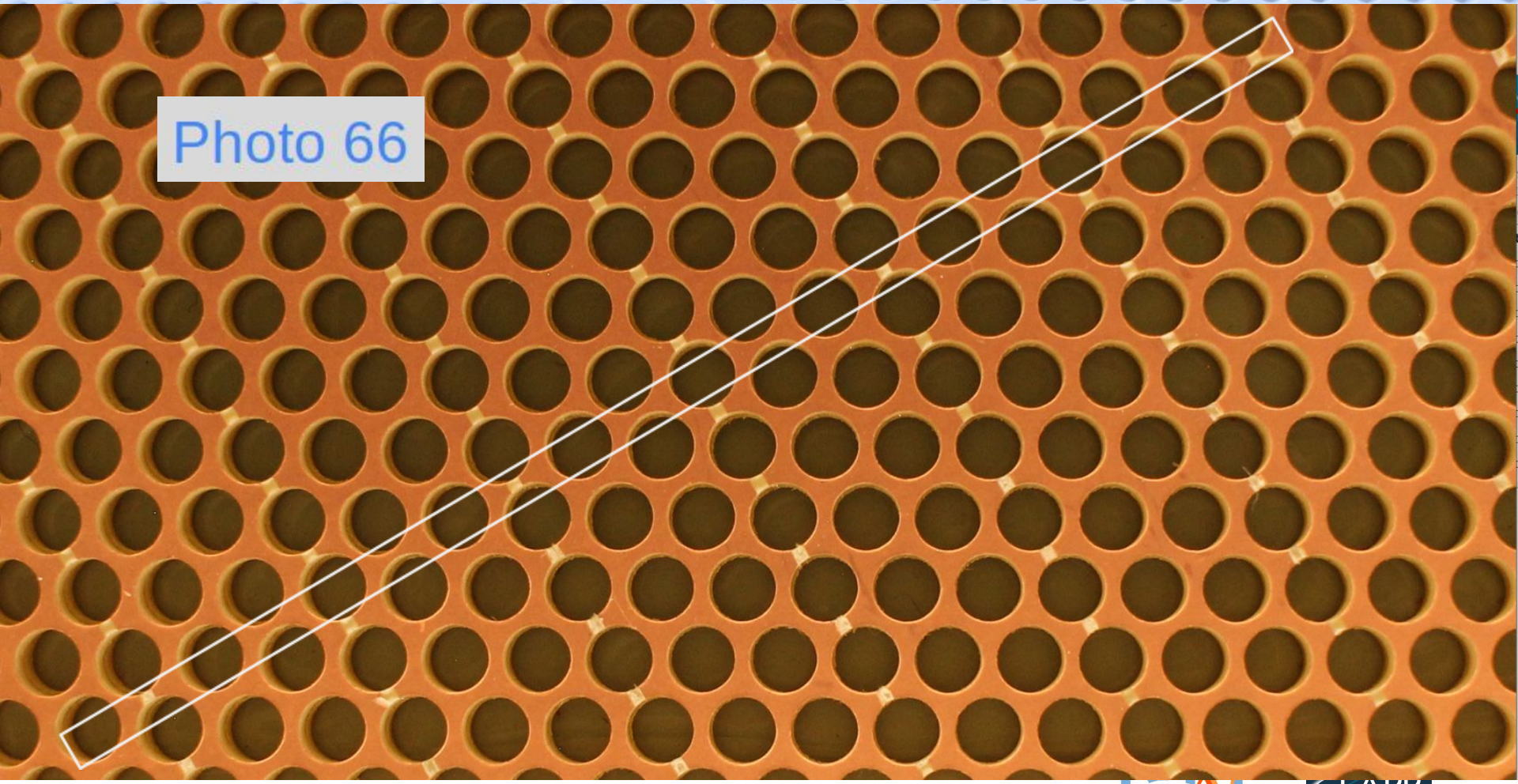


Photo 66

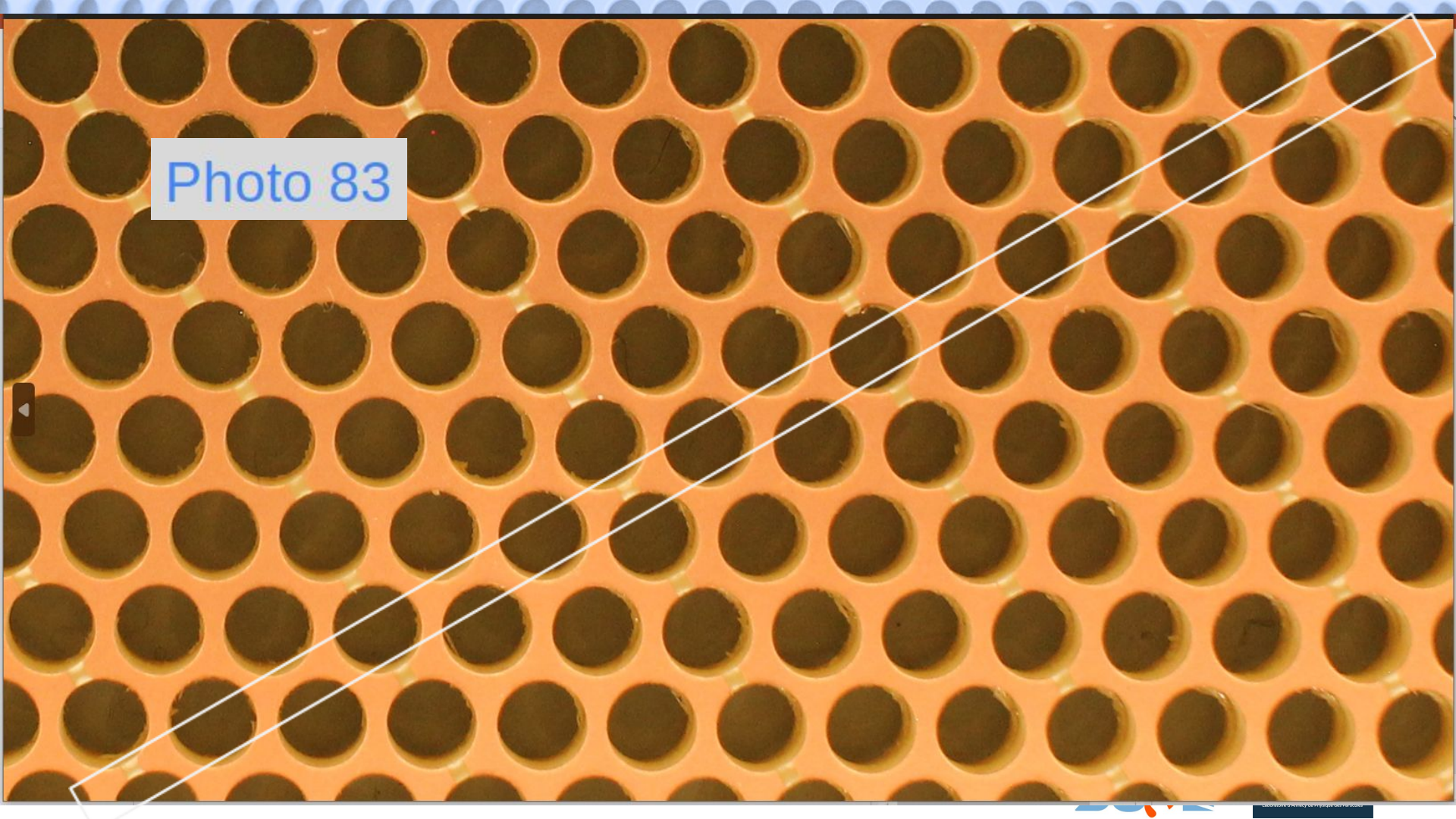
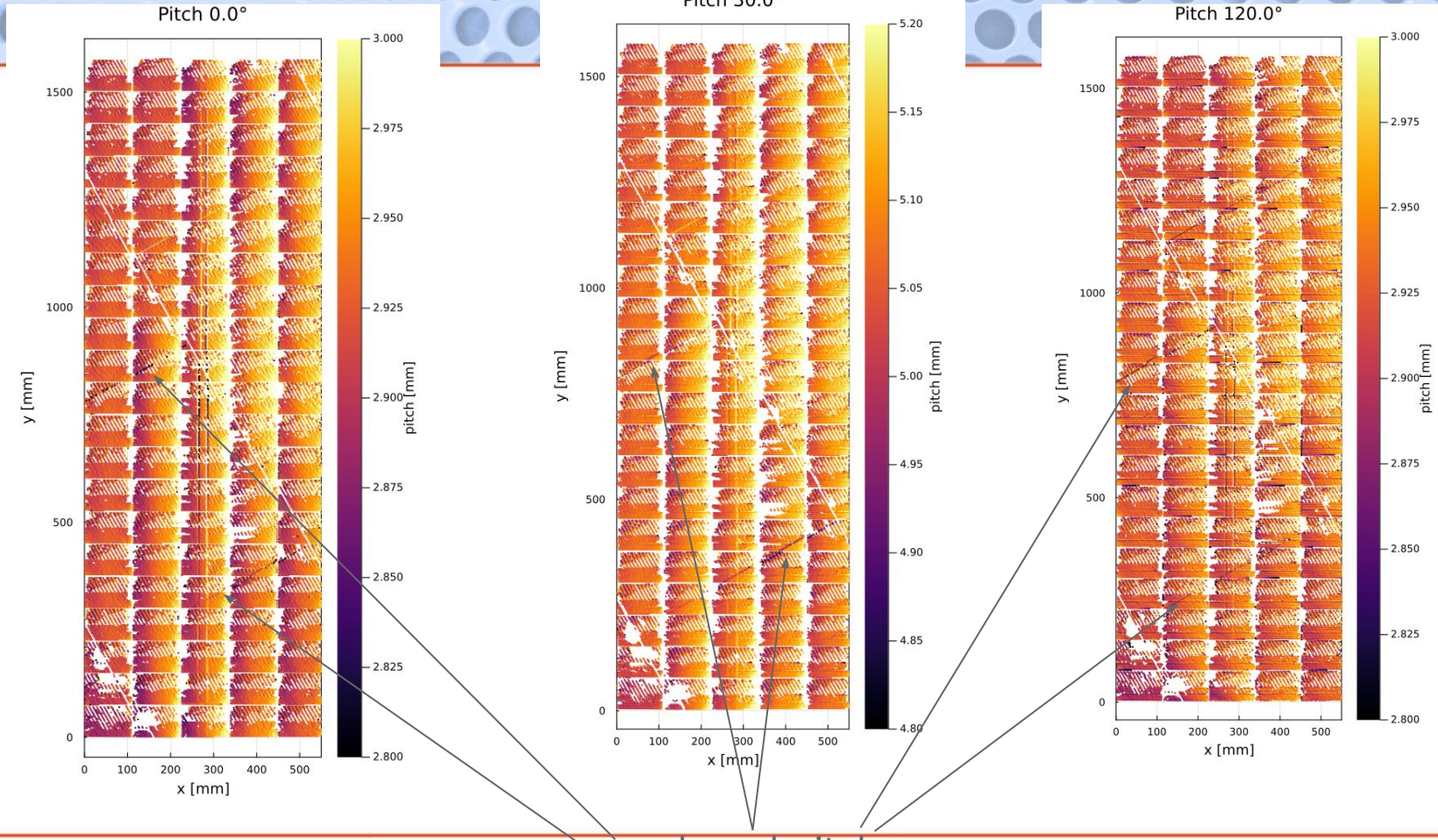


Photo 83


Pitch 0.0°
Pitch 30.0°
Pitch 120.0°
y [mm]
x [mm]
pitch [mm]
reduced pitch

Conclusions

- We have developed a method for QA/QC of CRPs anodes based on analysis of photos
  - PCBs can also be checked individually before anode assembly
  - Qualitative and quantitative results have been obtained
  - Hole diameter according to specifications
- Problems observed
  - Misalignment of holes in some regions after anode assembly ➔ reduced effective hole diameter
    - Origin most likely coming from a small rotation produced by a systematic reduced pitch pattern each 50 cm
  - Effective hole diameter also reduced by remaining glue inside the holes
- Results allowed to provide feedback to manufacturer
  - Improvement of production should solve these issues and improve quality of anodes
- QA/QC method can be improved and fully automated for full anode production