Quality Control (QC) preparation for the NSW Micromegas anode board production

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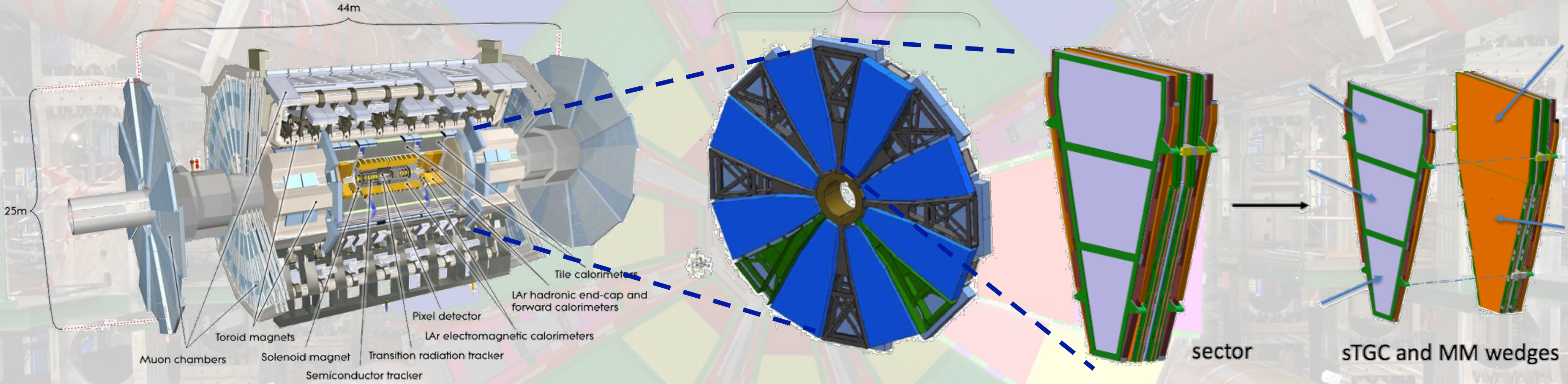
sponsored by the

The ATLAS NSW Upgrade

The innermost forward detector wheels of the ATLAS Muon system will undergo an upgrade during LHC Long Shutdown 2 (2019/2020) → **New Small Wheels (NSW)**

9.3 m

2 x 4 layers (Quadruplets) of Micromegas and sTGC detectors / NSW Sector

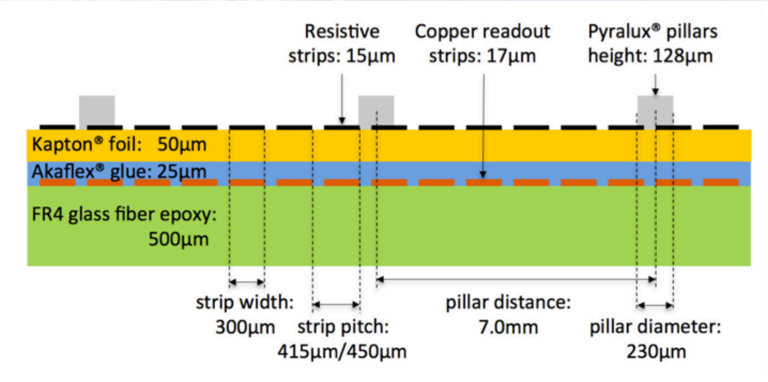


The NSWs will comprise an active detector area of **2x1280m^2**, divided in **128 MM Quadruplets** of 4 different types and **192 sTGC Quadruplets** of 6 different types with more than **2 M channels**.

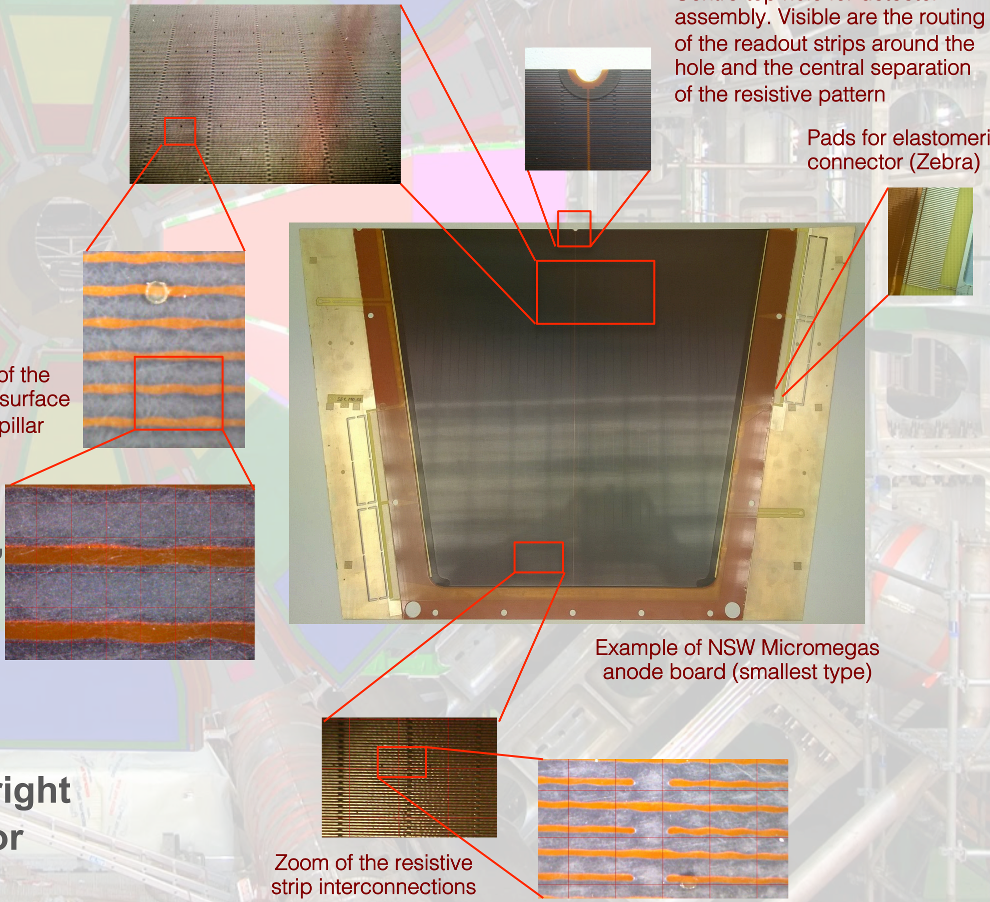
The NSWs shall provide Muon p_T measurement with **10% resolution at 1 TeV** (offline) and contribute to the improved **Level 1** (1mrad accuracy).

NSW MM anode boards

The readout PCBs are the critical item for the Micromegas construction, which have to be produced in industries



- 415/450 µm strip pitch 300 µm width
- 1022 strips/board
- Screen-printed resistive pattern (~1 MΩ/□, 415/450 µm pitch 300 µm width, interconnections every 10 mm)
- Two HV sectors for each board: resistive strips interrupted in the middle
- Pillars 128 µm height, 280 µm diameter
- Strips routed to the left (bottom half) and right (top half) to pads for elastomeric connector (Zebra)



Surface structure of the board, with regular patterns of pillars and interconnections of resistive strips

Centre-top hole for detector assembly. Visible are the routing of the readout strips around the hole and the central separation of the resistive pattern

Pads for elastomeric connector (Zebra)

Zoom of the board surface with a pillar

Example of NSW Micromegas anode board (smallest type)

Zoom of the resistive strip interconnections

NSW MM anode boards

- All production steps are standard in industries, still
    - the combination of these steps is rather uncommon,
    - the **large size** (0.6 x $2.2m^2$) complicates production,
    - the **stringent quality requirements** result in a considerable challenge for PCB producers.

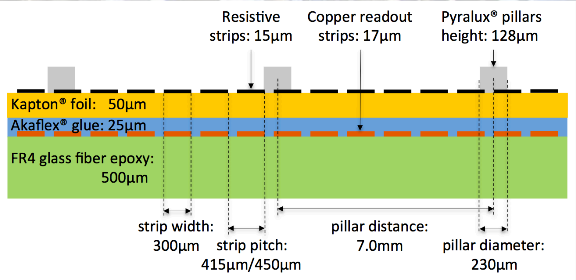
→ Significant delays for Module-0 PCB order due to production faults / insufficient quality / very low yield.

Lessons learned and **actions taken** on the PCB production:

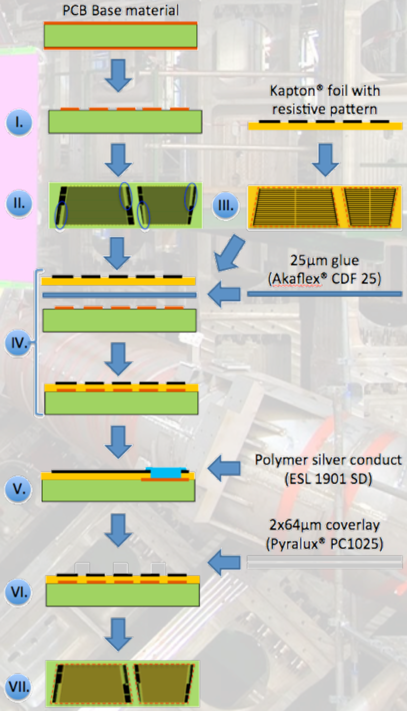
→ Strengthen the In-Industry QC (→ increase yield)

→ Insist on quality requirements, delivery schedules (Improved situation in pre-series / full production contract)

→ Follow-up more closely and more regularly at the producers premises. (Module0, Pre-series, full production)



Schematic of the **NSW Micromegas anode board** layers and dimensions of its main structures (not to scale).



Process chart of the anode board construction:
I. Copper pattern creation; II. Connector pad plating; III. Kapton® foil cutting; IV. Kapton® -PCB gluing; V. Silver conduct application; VI. Pillar pattern creation; VII. Cutting and drilling.

QA/QC scheme for MM anode board production

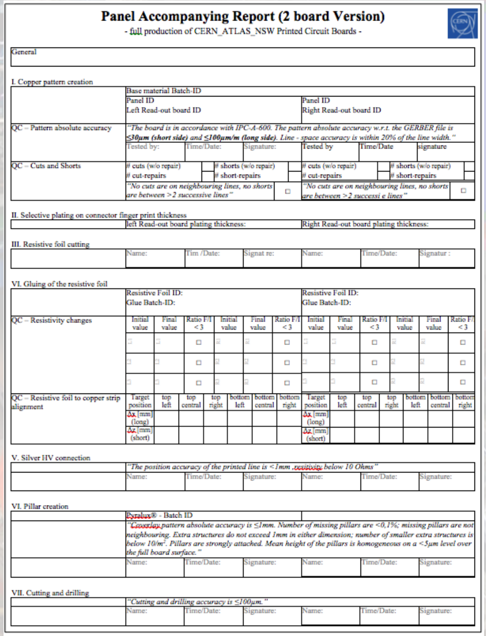
A multi-step QC scheme is applied **prior to, during** and **after** anode board production:

1. PCB Base material QC (CERN)

- Thickness QC (Requirement: 500±50µm) on defined sample per batch
- In case of any deviation: Extension of the sample.

2. Resistive Layer QC (JAPAN)

- Scan & Pattern recognition on each foil to identify pattern blemishes
- Resistivity mapping on each foil



Panel Accompanying Report (2 board Version)

- full production of CERN_ATLAS_NSW Printed Circuit Boards -

General

I. Copper pattern creation

Base material Batch-ID

Panel ID
Left Read-out board ID | Panel ID
Right Read-out board ID

QC – Pattern absolute accuracy: *"The board is in accordance with IPC-A-600. The pattern absolute accuracy w.r.t. the GERBER file is* ***≤30µm (short side) and ≤100µm/m (long side)****. Line - space accuracy is within 20% of the line width."*

Tested by: | Time/Date: | Signature: | Tested by | Time/Date | signature

QC – Cuts and Shorts: # cuts (w/o repair) | # shorts (w/o repair) | # cut-repairs | # short-repairs | *"No cuts are on neighbouring lines, no shorts are between >2 successive lines"* ☐ | # cuts (w/o repair) | # shorts (w/o repair) | # cut-repairs | # short-repairs | *"No cuts are on neighbouring lines, no shorts are between >2 successi e lines"* ☐

II. Selective plating on connector finger print thickness

left Read-out board plating thickness: | Right Read-out board plating thickness:

III. Resistive foil cutting

Name: | Tim /Date: | Signat re: | Name: | Time/Date: | Signatur :

VI. Gluing of the resistive foil

Resistive Foil ID:
Glue Batch-ID: | Resistive Foil ID:
Glue Batch-ID:

QC – Resistivity changes

Initial value	Final value	Ratio F/I < 3	Initial value	Final value	Ratio F/I < 3	Initial value	Final value	Ratio F/I < 3	Initial value	Final value	Ratio F/I < 3
		☐			☐			☐			☐
		☐			☐			☐			☐
		☐			☐			☐			☐

QC – Resistive foil to copper strip alignment

Target position	top left	top central	top right	bottom left	bottom central	bottom right	Target position	top left	top central	top right	bottom left	bottom central	bottom right
Δx [mm] (long)							Δx [mm] (long)						
Δz [mm] (short)							Δz [mm] (short)						

V. Silver HV connection

"The position accuracy of the printed line is <1mm ,resitivity below 10 Ohms"

Name: | Time/Date: | Signature: | Name: | Time/Date: | Signature:

VI. Pillar creation

Pyralux® - Batch ID

"Coverlay pattern absolute accuracy is ≤1mm. Number of missing pillars are <0,1%; missing pillars are not neighbouring. Extra structures do not exceed 1mm in either dimension; number of smaller extra structures is below 10/m². Pillars are strongly attached. Mean height of the pillars is homogeneous on a <5µm level over the full board surface."

Name: | Time/Date: | Signature: | Name: | Time/Date: | Signature:

VII. Cutting and drilling

"Cutting and drilling accuracy is ≤100µm."

Name: | Time/Date: | Signature: | Name: | Time/Date: | Signature:

3. In-Industry QC (PCB producer)

Suppliers are obliged to fill a QC-**report** for each PCB, stating **results from QC tests** on:

- #Cuts & #Shorts
- Plating Quality & Thickness
- Change of Resistivity during gluing
- Alignment accuracy

Additionally they will sign **compliance statements** on:

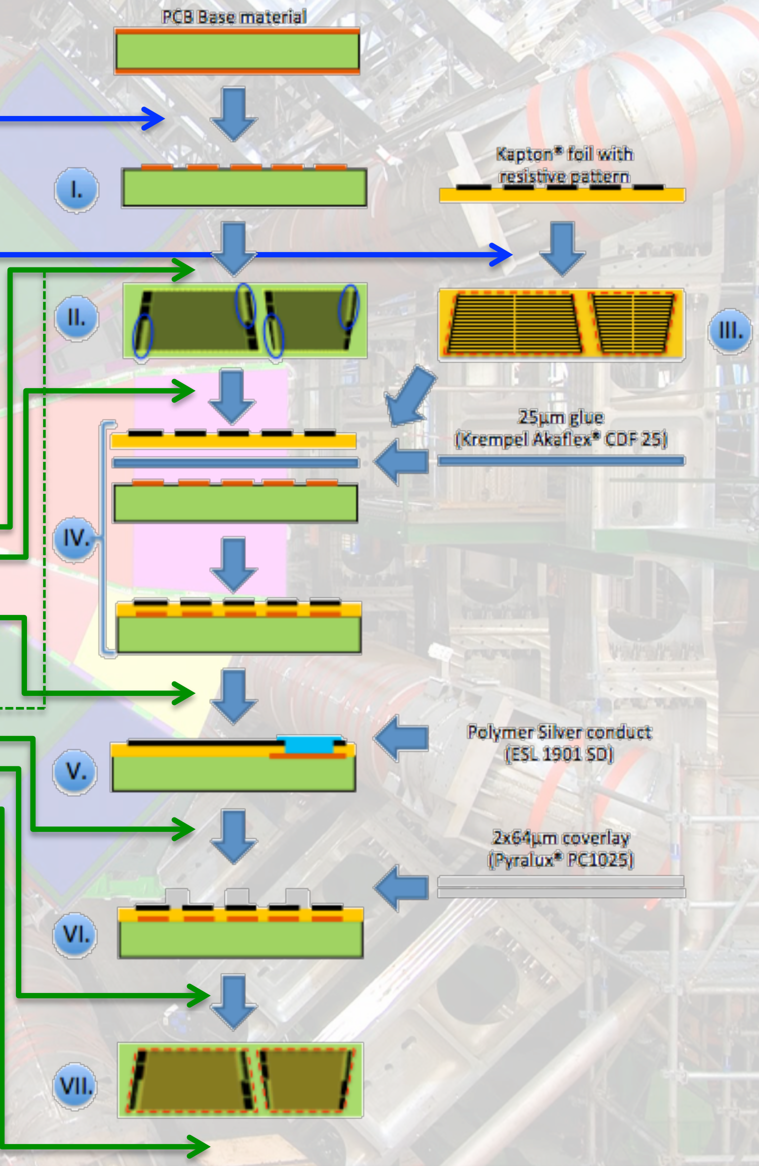
- PCB overall dimensions & Line width accuracy
- Positioning & Quality of the Silver conduct line
- Quality of the Pillar Pattern
- Accuracy of the drilling & cutting

4. Interfering QC (CERN)

- Double-Check Dimensions, #Cuts & #Shorts on samples

\+ Whichever additional QC we want to do.

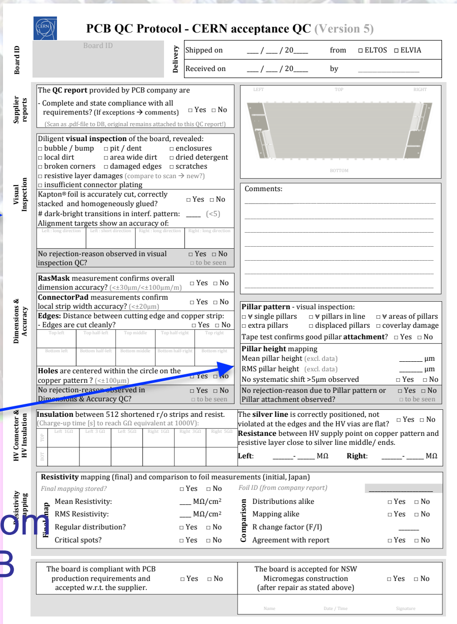
5 . Final Acceptance QC (CERN)



Final Acceptance QC at CERN (Module-0)

The multitude of QC tests for final anode PCB acceptance at CERN can be grouped in:

- **Visual inspection**
- **Dimension validation**
- **Drilling and Cutting Accuracy tests**
- **Electrical properties and Resistivity**
- **Pillar pattern & - height**



PCB QC Protocol - CERN acceptance QC (Version 5)

Board ID: Board ID

Delivery
Shipped on ___ / ___ / 20____ from ☐ ELTOS ☐ ELVIA
Received on ___ / ___ / 20____ by ________________

Supplier reports
The **QC report** provided by PCB company are
- Complete and state compliance with all requirements? (If exceptions → comments) ☐ Yes ☐ No
(Scan as .pdf-file to DB, original remains attached to this QC report!)

Visual Inspection
Diligent **visual inspection** of the board, revealed:
☐ bubble / bump ☐ pit / dent ☐ enclosures
☐ local dirt ☐ area wide dirt ☐ dried detergent
☐ broken corners ☐ damaged edges ☐ scratches
☐ resistive layer damages (compare to scan → new?)
☐ insufficient connector plating
Kapton® foil is accurately cut, correctly stacked and homogeneously glued? ☐ Yes ☐ No
dark-bright transitions in interf. pattern: ____ (<5)
Alignment targets show an accuracy of:

Left : long direction	Left : short direction	Right : long direction	Right : long direction

No rejection-reason observed in visual inspection QC? ☐ Yes ☐ No ☐ to be seen

LEFT TOP RIGHT BOTTOM

Comments:
____
____
____
____
____
____
____

Dimensions & Accuracy
RasMask measurement confirms overall dimension accuracy? (<±30µm/<±100µm/m) ☐ Yes ☐ No
ConnectorPad measurements confirm local strip width accuracy? (<±20µm) ☐ Yes ☐ No
Edges: Distance between cutting edge and copper strip:
- Edges are cut cleanly? ☐ Yes ☐ No

Top left	Top half-left	Top middle	Top half-right	Top right
Bottom left	Bottom half-left	Bottom middle	Bottom half-right	Bottom right

Holes are centered within the circle on the copper pattern ? (<±100µm) ☐ Yes ☐ No
No rejection-reason observed in Dimensions & Accuracy QC? ☐ Yes ☐ No ☐ to be seen

Pillar pattern - visual inspection:
☐ ∀ single pillars ☐ ∀ pillars in line ☐ ∀ areas of pillars
☐ extra pillars ☐ displaced pillars ☐ coverlay damage
Tape test confirms good pillar **attachment**? ☐ Yes ☐ No
Pillar height mapping
Mean pillar height (excl. data) ______ µm
RMS pillar height (excl. data) ______ µm
No systematic shift >5µm observed ☐ Yes ☐ No
No rejection-reason due to Pillar pattern or Pillar attachment observed? ☐ Yes ☐ No ☐ to be seen

HV Connector & HV Insulation
Insulation between 512 shortened r/o strips and resist.
(Charge-up time [s] to reach GΩ equivalent at 1000V):

	Left 1GΩ	Left 3 GΩ	Left 5GΩ	Right 1GΩ	Right 3GΩ	Right 5GΩ
TOP						
BOT						

The **silver line** is correctly positioned, not violated at the edges and the HV vias are flat? ☐ Yes ☐ No
Resistance between HV supply point on copper pattern and resistive layer close to silver line middle/ ends.
Left: ______- _____ MΩ **Right**: ______- _____ MΩ

Resistivity mapping
Resistivity mapping (final) and comparison to foil measurements (initial, Japan)
Final mapping stored? ☐ Yes ☐ No *Foil ID (from company report)* ________________

Final map
Mean Resistivity: ___ MΩ/cm²
RMS Resistivity: ___ MΩ/cm²
Regular distribution? ☐ Yes ☐ No
Critical spots? ☐ Yes ☐ No

Comparison
Distributions alike ☐ Yes ☐ No
Mapping alike ☐ Yes ☐ No
R change factor (F/I) ______
Agreement with report ☐ Yes ☐ No

The board is compliant with PCB production requirements and accepted w.r.t. the supplier. ☐ Yes ☐ No
The board is accepted for NSW Micromegas construction (after repair as stated above) ☐ Yes ☐ No

Name Date / Time Signature

Copying results from paper report to DB

Module-0 PCB QC was based on paper forms:

\+ Copy of the report 'travels' with the board to ensure information transfer before DB setup

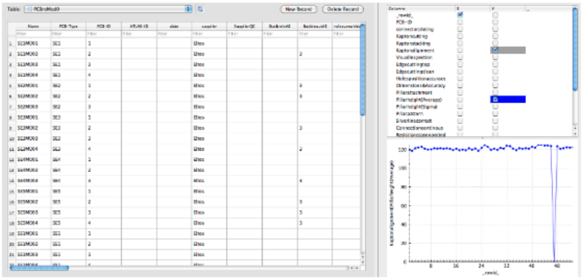
\+ Changes are quickly implemented (6 Iterations)

− Systematic search for faults is difficult

− Waste of time in copying to DB

For Module0:

- QC reports are stored together with the pillar height maps and published on a dedicated twiki to be easily accessible for construction sites
- Results are summarized in a (local) SQLite DB for bookkeeping

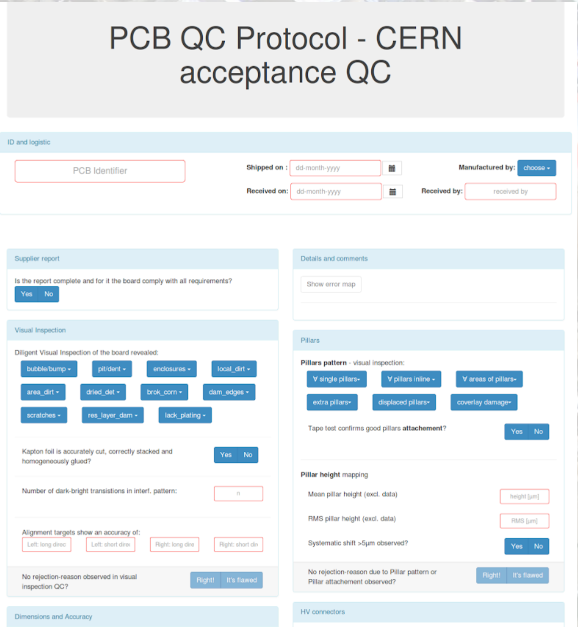


Final Acceptance QC at CERN (NSW production)

The testing structure is maintained (although more elaborated in some details) during *NSW production.*

- **Visual inspection**
- **Dimension validation**
- **Drilling and Cutting Accuracy tests**
- **Electrical properties and Resistivity**
- **Pillar pattern & - height**

The reports will be filled digitally with a custom User Interface, providing a direct link to measurement software (speeding up QC) and to the DataBase (proper storing).



PCB QC Protocol - CERN acceptance QC

ID and logistic

PCB Identifier

Shipped on : dd-month-yyyy

Manufactured by: choose

Received on: dd-month-yyyy

Received by: received by

Supplier report

Is the report complete and for it the board comply with all requirements?

Details and comments

Visual Inspection

Diligent Visual Inspection of the board revealed:

Kapton foil is accurately cut, correctly stacked and homogeneously glued?

Number of dark-bright transistions in interf. pattern: n

Alignment targets show an accuracy of: Left: long direc | Left: short direc | Right: long dire | Right: short dir

No rejection-reason observed in visual inspection QC?

Pillars

Pillars pattern - visual inspection:

Tape test confirms good pillars **attachement**?

Pillar height mapping

Mean pillar height (excl. data): height [µm]

RMS pillar height (excl. data): RMS [µm]

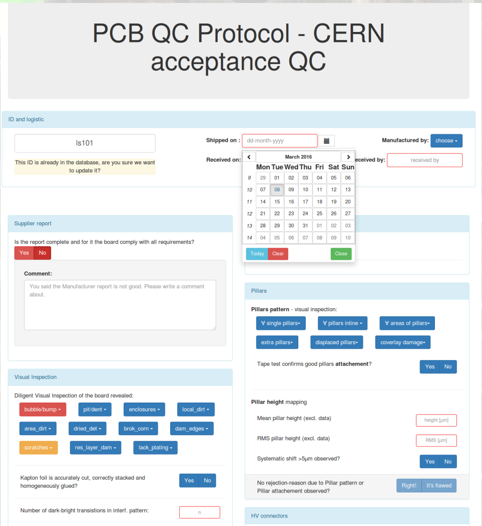
Systematic shift >5µm observed?

No rejection-reason due to Pillar pattern or Pillar attachement observed?

Dimensions and Accuracy

HV connectors

Online report to be filled



PCB QC Protocol - CERN acceptance QC

ID and logistic

ls101

This ID is already in the database, are you sure we want to update it?

Shipped on : dd-month-yyyy

Manufactured by: choose

Received on:

Received by: received by

Supplier report

Is the report complete and for it the board comply with all requirements?

Comment:

You said the Manufacturer report is not good. Please write a comment about.

Visual Inspection

Diligent Visual Inspection of the board revealed:

Kapton foil is accurately cut, correctly stacked and homogeneously glued?

Number of dark-bright transistions in interf. pattern: n

Pillars

Pillars pattern - visual inspection:

Tape test confirms good pillars **attachement**?

Pillar height mapping

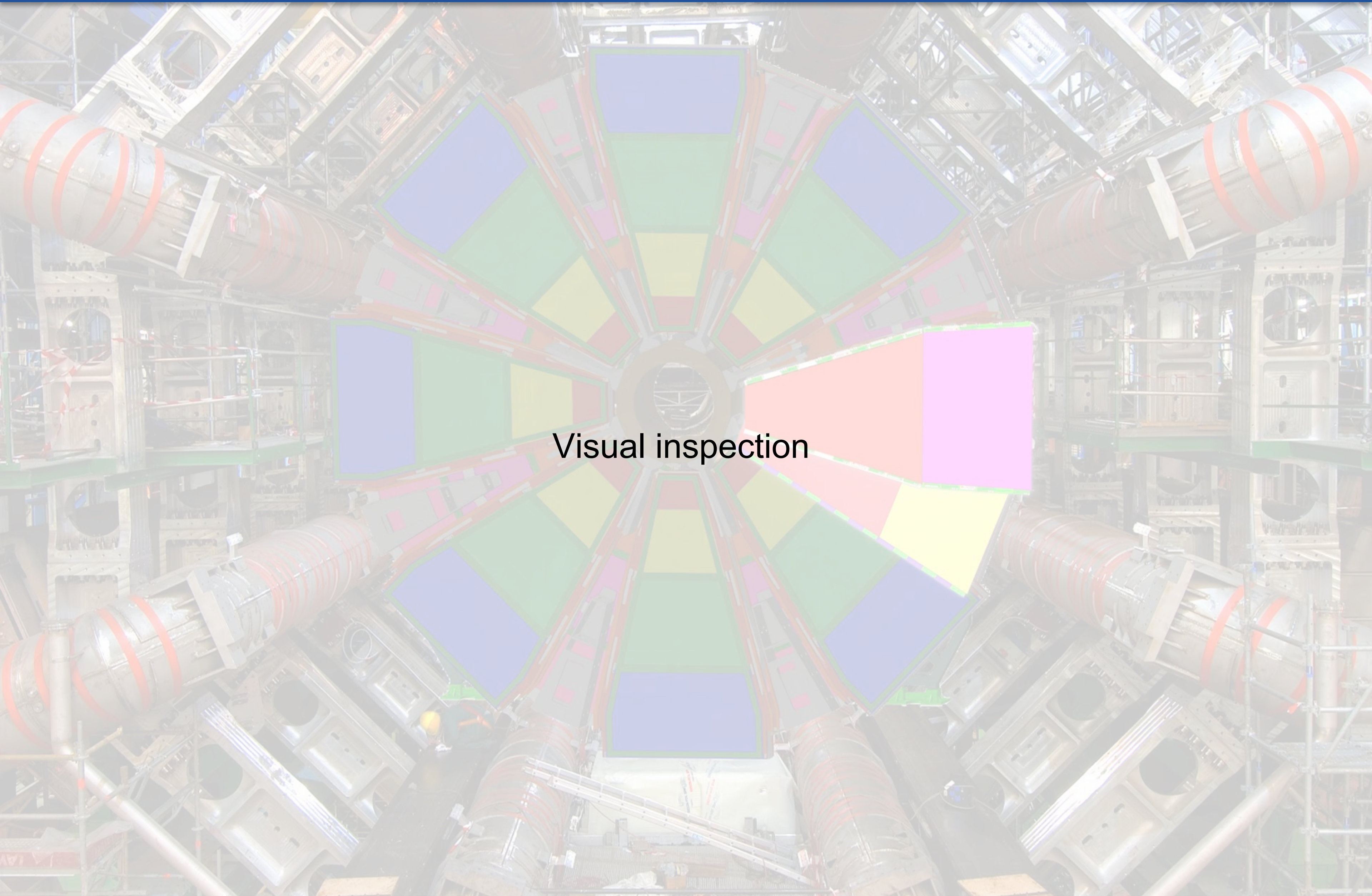
Mean pillar height (excl. data): height [µm]

RMS pillar height (excl. data): RMS [µm]

Systematic shift >5µm observed?

No rejection-reason due to Pillar pattern or Pillar attachement observed?

HV connectors



Visual inspection

QC – Visual inspection (Module-0)

A large variety of defects has been observed on the Module-0 anode boards.

They are rated case-by-case as either:

- **Minor**: if repairable or only localized effect on the detector, if any

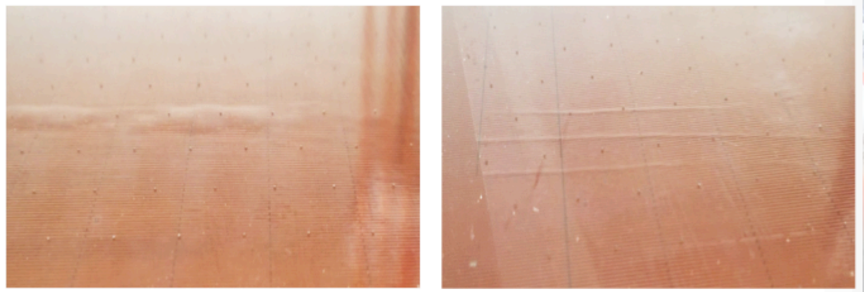
→ Non-conformity acceptance considered

- **Major**: non-repairable and effect on the full detector / plane / larger area

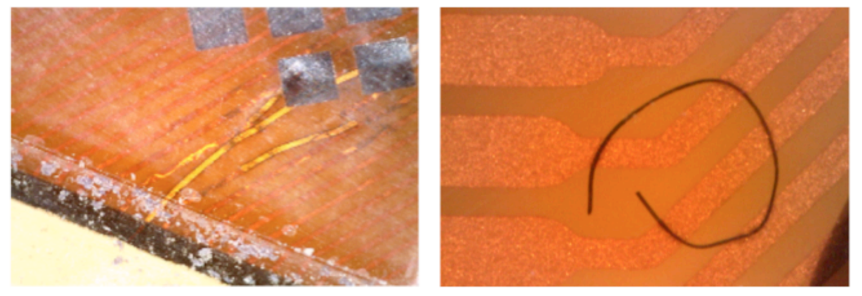
→ Rejection mandatory

Only a careful visual inspection by a trained operator can reveal all kind of occurring imperfections.

Localization and classification (if possible) is mandatory.



Bubbles on the resistive surface, caused by air enclosures between the PCB and the Kapton foil (left) and a series of folds in the foil.

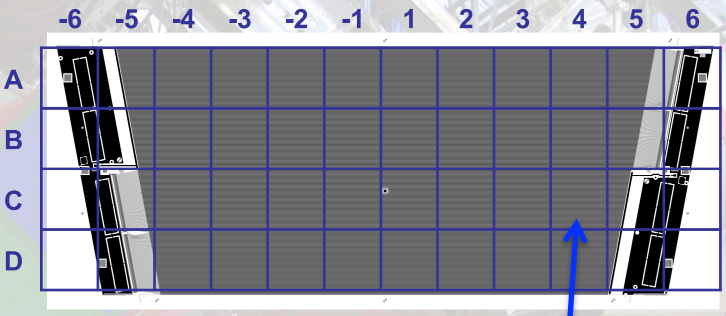


Strip repairs causing a bump in the active area (middle) and fiber enclosed in the glue between PCB and Kapton (right).

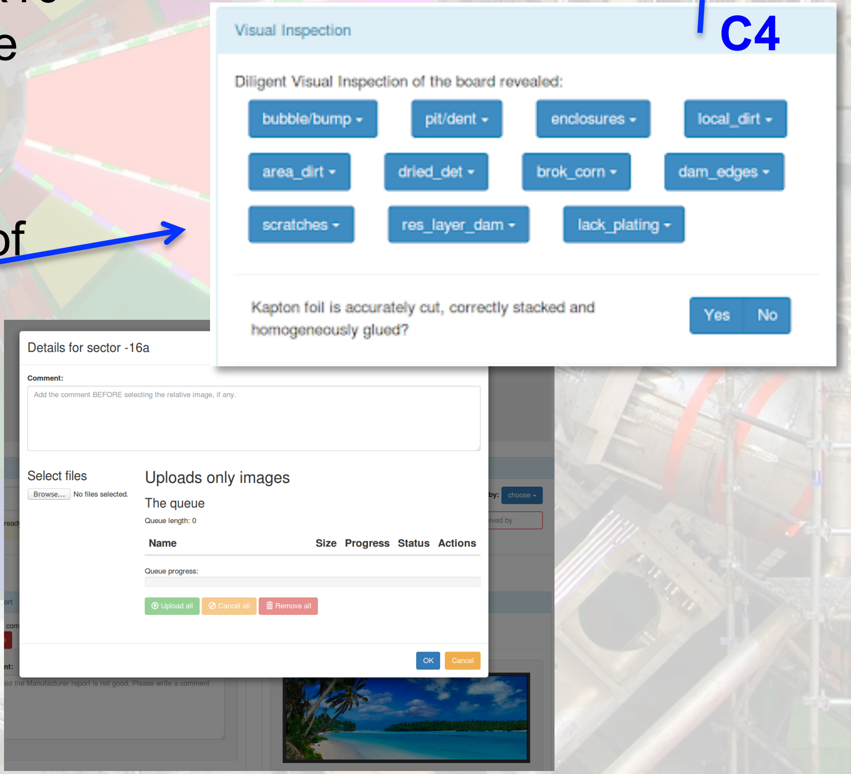
Two examples of contaminations: A piece/drop of metalized glue or silver printing paste (left), detergent remnants (right).

QC – Visual inspection (NSW production)

- Visual inspection remains a key QC, although a lower number of ‘new’ defects is expected.
  (valuable experience from Module-0 in classification of blemishes and test on repair possibilities)
- Localization is done with a coarse ≈10x10 cm^2 ‘coordinate system’, referring to the center of each board.
- Classification is supported by choices of known / observed blemishes
- For in-classifiable cases (microscope) pictures can be added



Simplified ‘square-coordinate system’ for localization of defects on NSW MM anode boards



Visual Inspection

Diligent Visual Inspection of the board revealed:

Kapton foil is accurately cut, correctly stacked and homogeneously glued?

Details for sector -16a

Comment:

Add the comment BEFORE selecting the relative image, if any.

Select files

No files selected.

Uploads only images

The queue

Queue length: 0

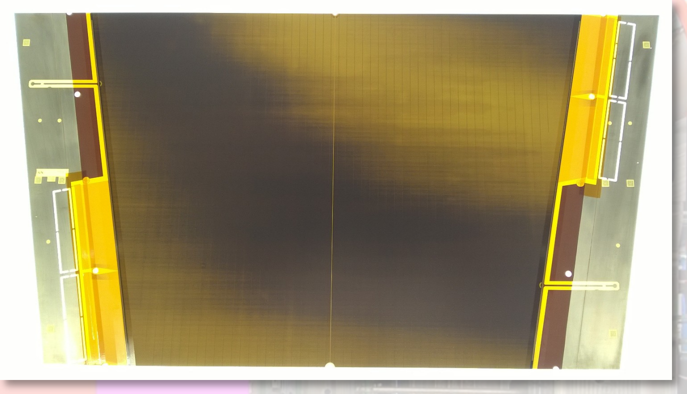
Name	Size	Progress	Status	Actions

Queue progress:

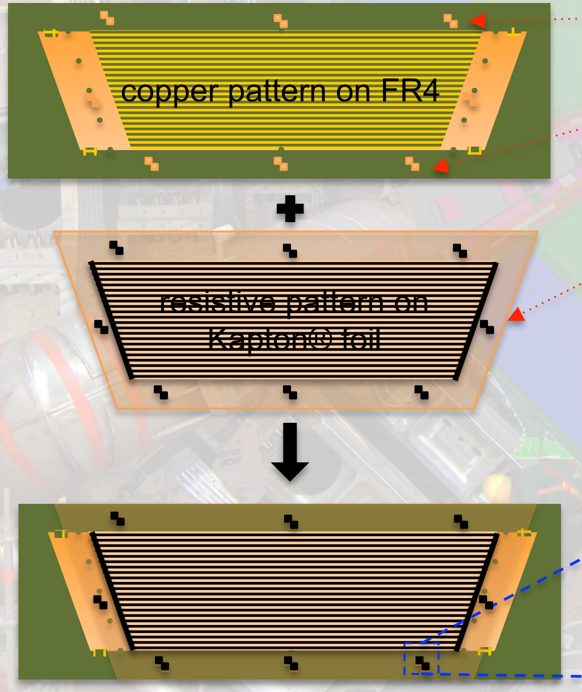
QC – Visual inspection (NSW production)

The Alignment between resistive pattern and readout strips can be checked:

- Very quick by looking at the interference pattern on a light table
- Measured visually by using Alignment Markers on the foil and board



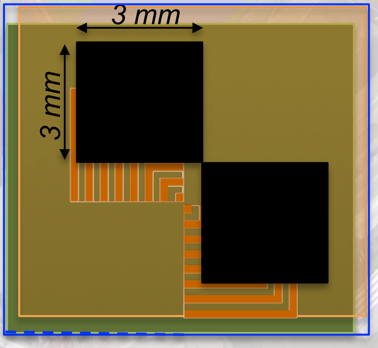
Backside Illuminated PCB showing the interference pattern between resistive layer and readout strips, corresponding to a ≈600μm left-right misalignment.



Module0: 2x3 for use in company

New: +2 targets for CERN QC

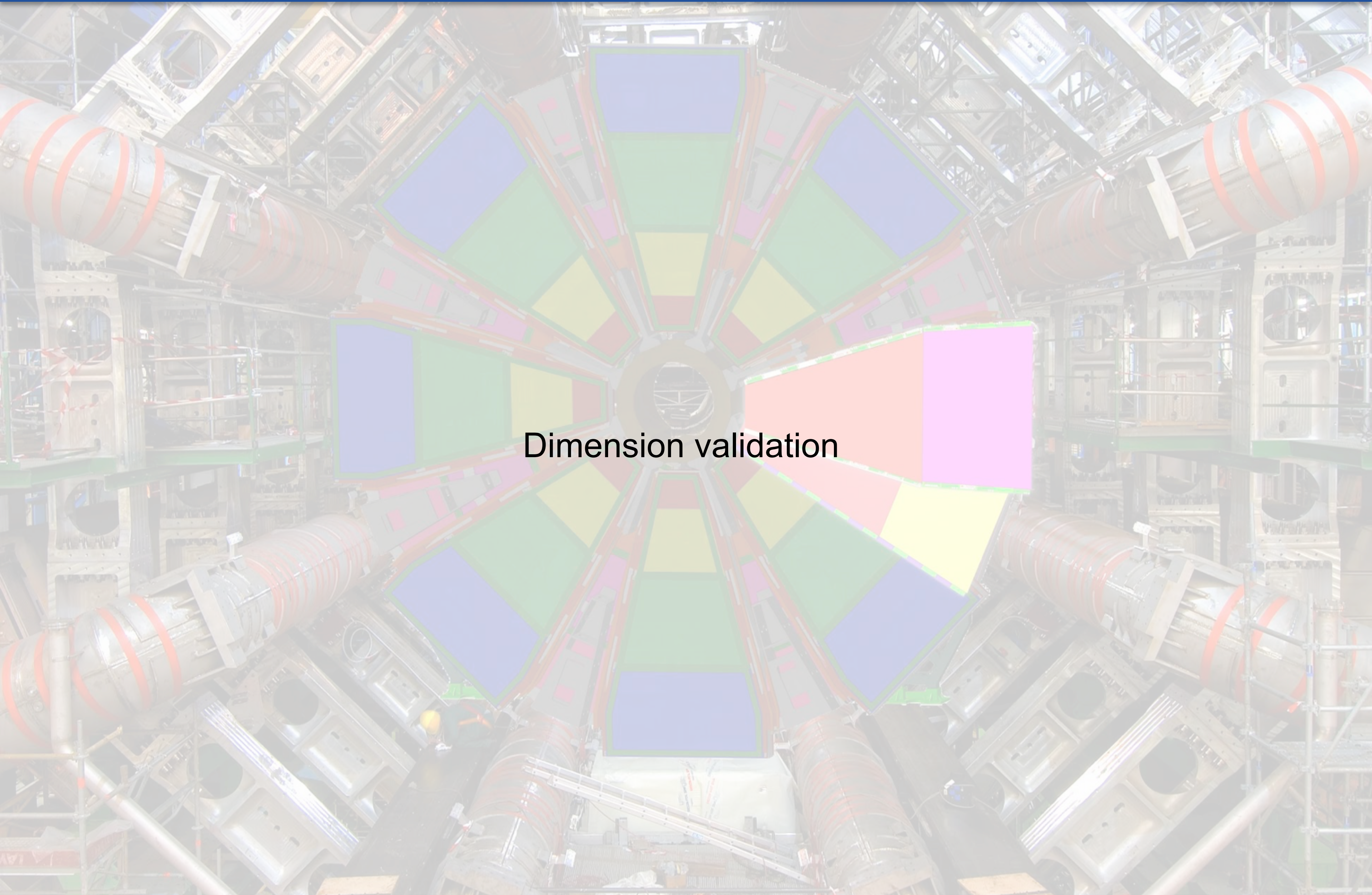
Alignment of copper- to resistive pattern is directly measureable counting 200μm wide lines / spaces.



In this example:

Δx = +1.0mm

Δy= +0.4mm

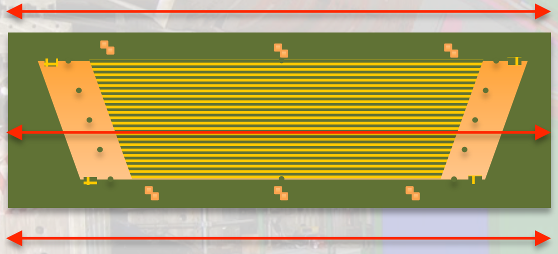


Dimension validation

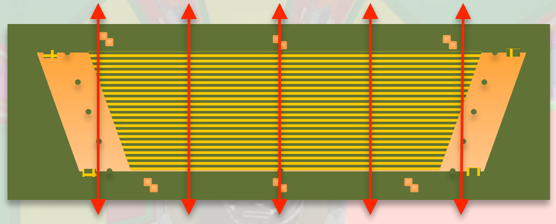
QC – **Dimension** (global)

Inaccuracy / deformations in the cu pattern are critical blemishes of the boards. Although measurement during production (AOI) are required we need a method to cross-check these results.

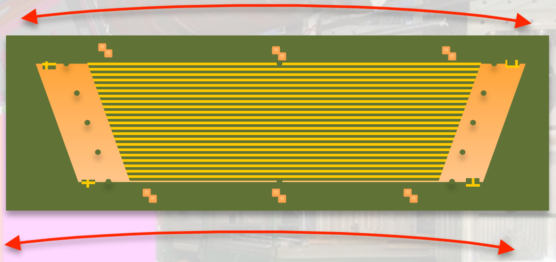
Only ‘global’ pattern deformations are likely, not local displacements



Linear shrink or elongation in long direction (<100µm/m)



Linear shrink or elongation in Short direction (<100µm/m)



‘banana-shape’ deformation
→ Non linearity of the strips

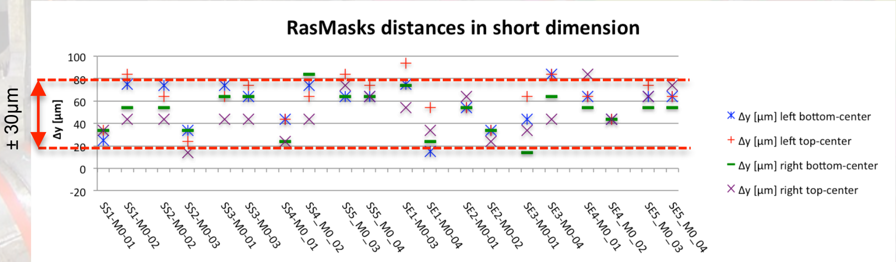
Testing the three parameters: x-elongation, y-elongation and strip linearity (on with sufficient high granularity) could identify all modes of global deformation

QC – **Dimension** (global) (Module-0)

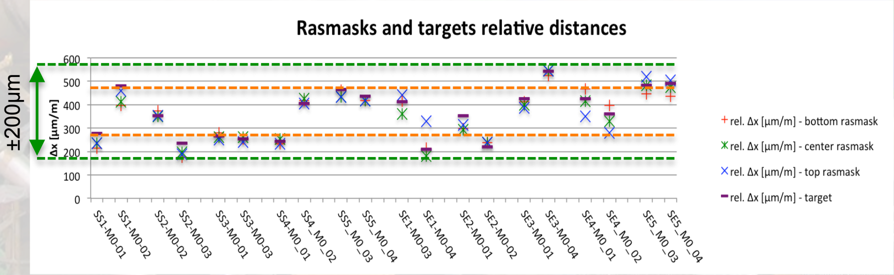
During *Module-0 PCB* QC dimensions have been measured using a microscope table (1,80 x 1,20) with an accuracy of ±20µm.

→ Very time consuming (≈ 30min / board)

→ Repeatability of measurements is limited, accordingly only distances are measured.



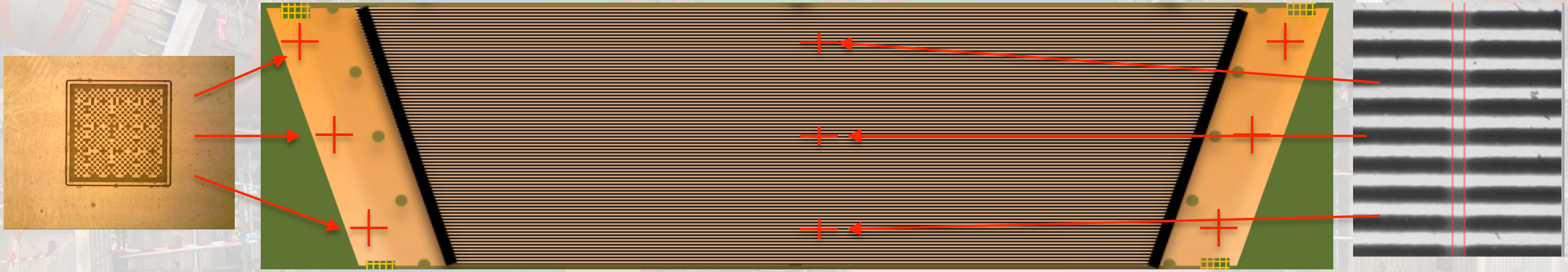
RasMasks distances in short dimension



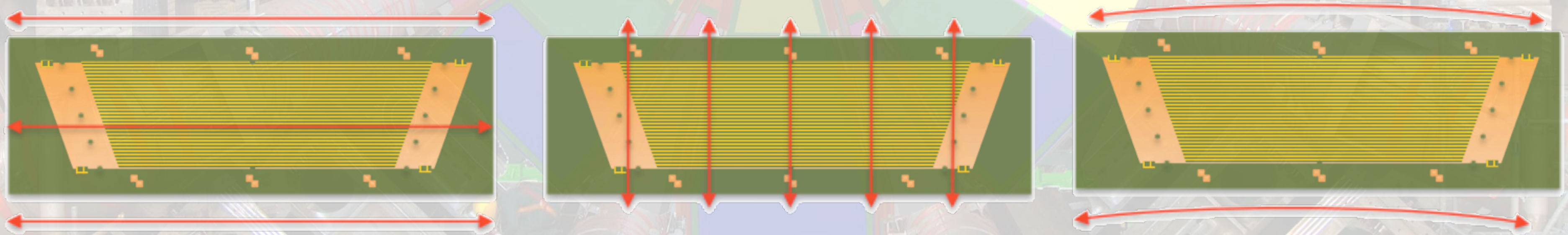
Rasmasks and targets relative distances

QC – **Dimension** (global) (NSW production)

For *NSW production* the position of Rasnik Masks (3x left, 3x right – both coordinates) + Anode strips in the center (one coordinate only) are measured simultaneously using a precision table with in-build C-CCDs.



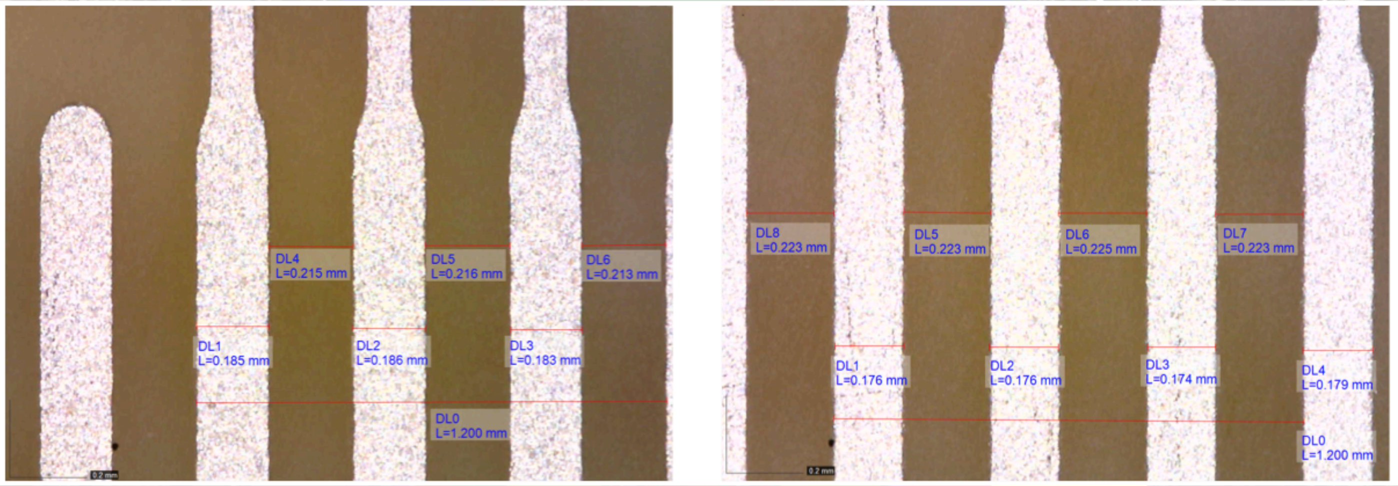
In this configuration we have good control over x-elongation, y-elongation and 'limited' access to and strip linearity (3 points over up to 2m length)



Tooling and Software development is ongoing, expected time <3min / board.

QC – Dimension (local) (NSW production)

Additionally the **local strip / gap width accuracy** has to be checked.
(e.g. on the Zebra-Connector Pads an accuracy of ±20μm is required.)

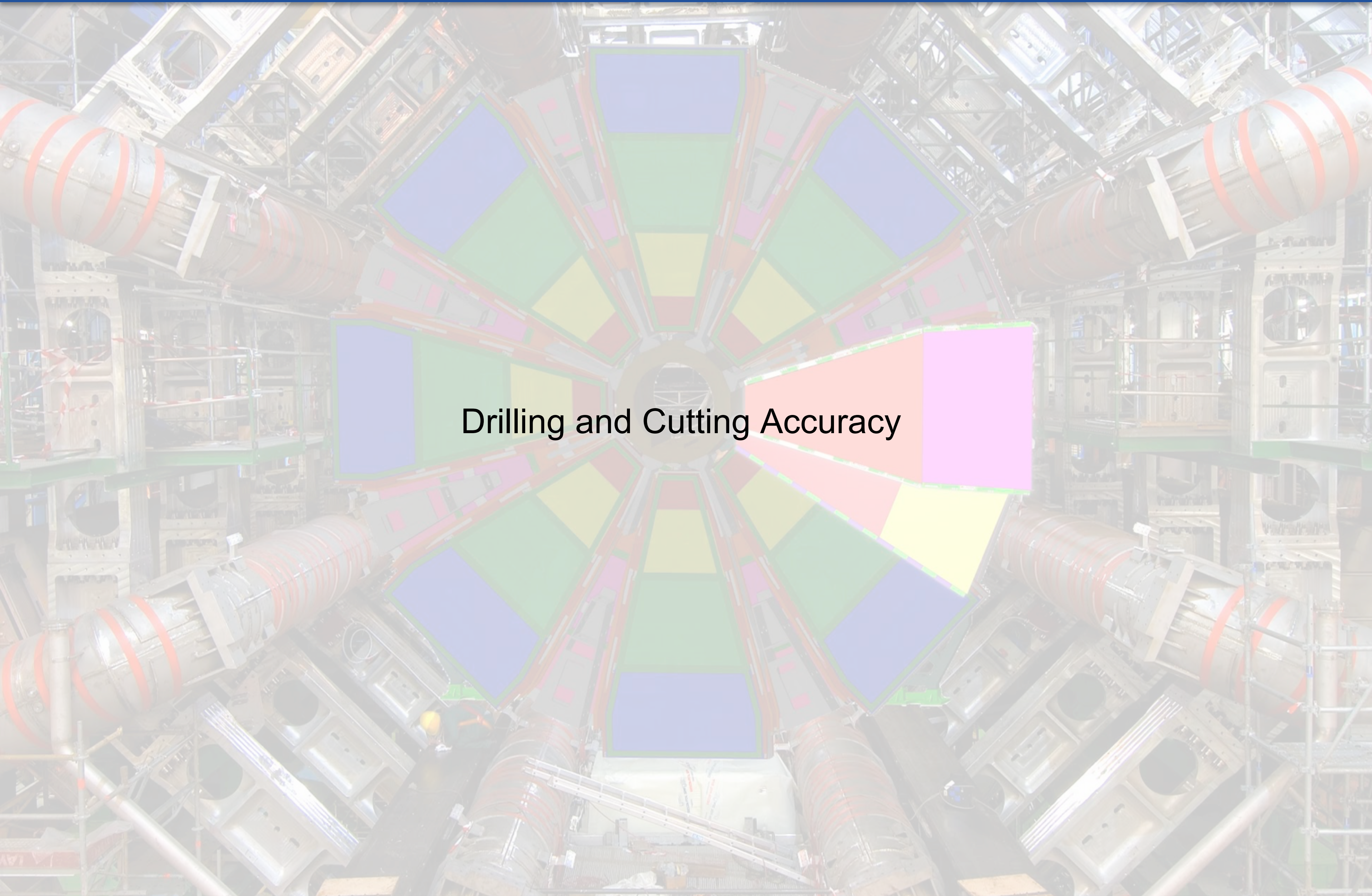


Systematic width deviation
of 15μm → acceptable

Width of by 24μm
→ Not within specification

Module-0: Measurements with a calibrated Microscope and manual image evaluation has been performed (2-3min / picture → >5min / board)

NSW production: Pattern recognition for automatized measurements (c-CCD)
(<1min per point → 1-2min / board)



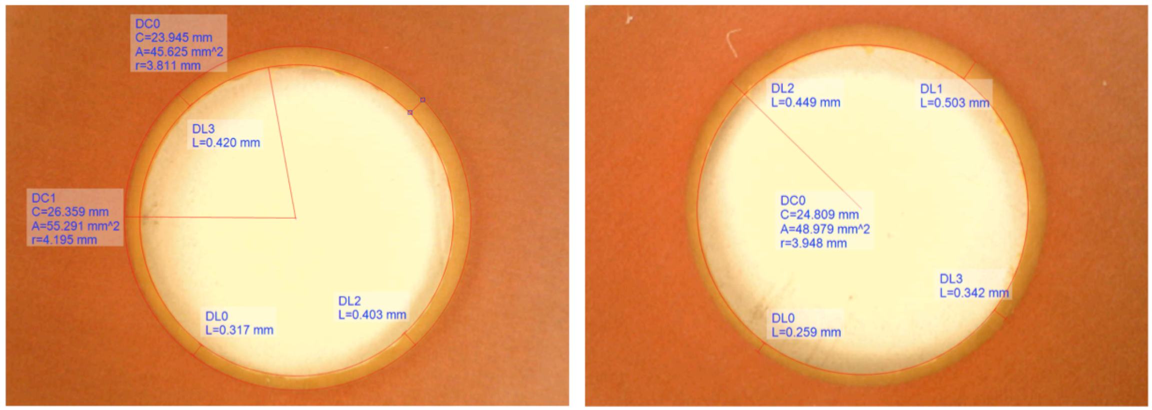
Drilling and Cutting Accuracy

QC – Drilling accuracy (Module-0)

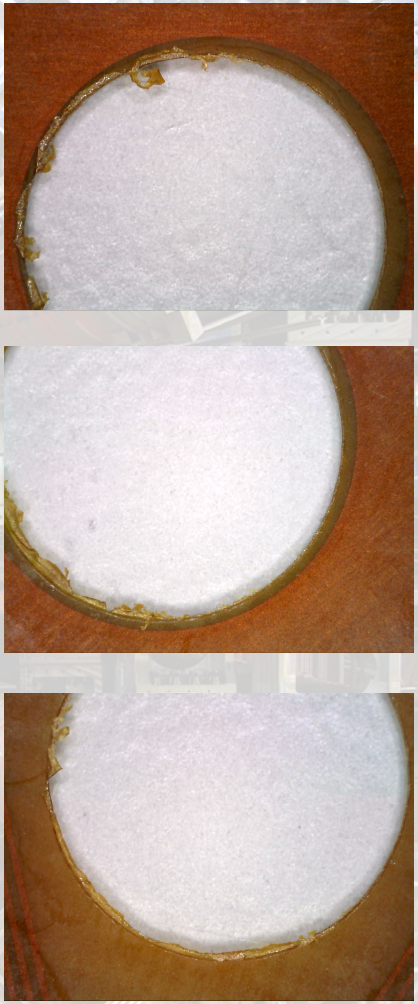
The position of the (no-precise / mechanical) holes in the PCB is required to be accurate to ±100µm.

Judging this visually is difficult, especially in regions where no concentric Cu-pattern is around.

Measurements with a calibrated microscope are time consuming >1min / hole.



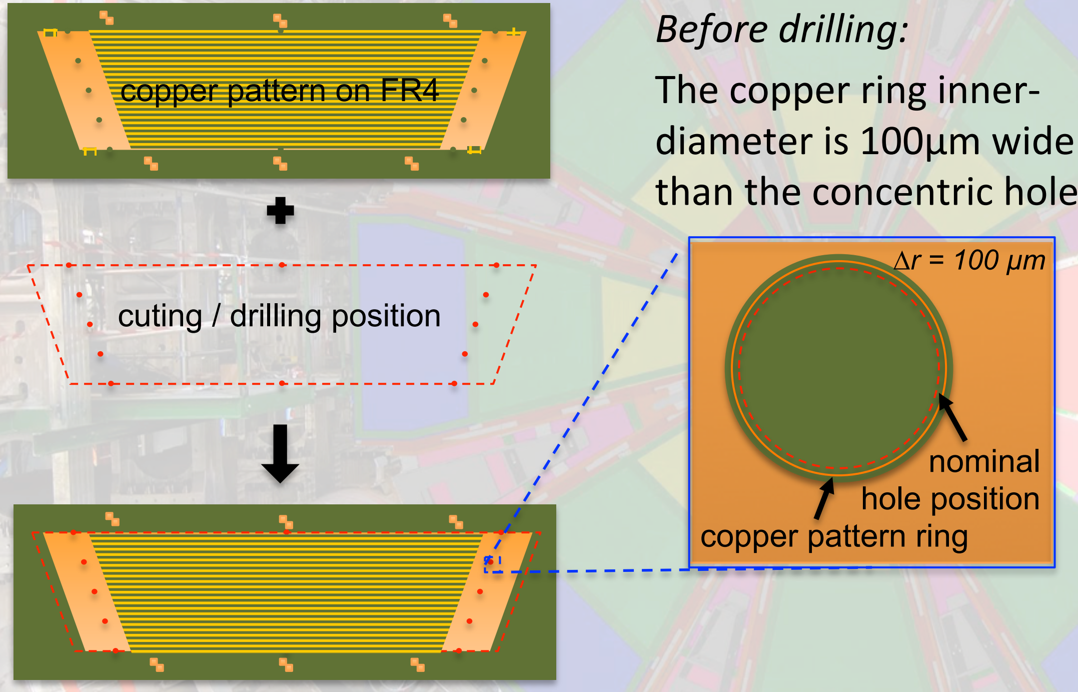
Example measurements of the hole accuracy: The distance between copper pattern hole and drilled hole varies between 300-420µm (left) resp. 250-510 µm (right), equivalent to a ≈ 60 µm (accepted) resp. 130 µm (non-conform) displacement of the hole centers.



Examples of inaccurately drilled holes on Module-0 PCBs.

QC – Drilling accuracy (NSW production)

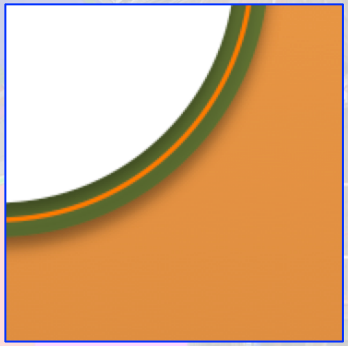
For *NSW production* we added an extra ring in the Cu pattern around the nominal hole position allows for quicker visual QC tests:



Before drilling:

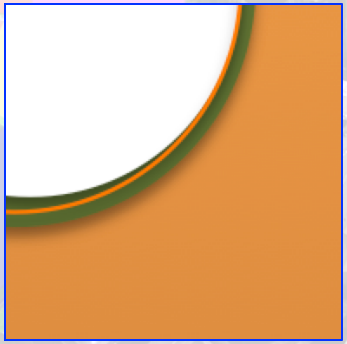
The copper ring inner-diameter is 100µm wider than the concentric hole

After drilling:



The hole is either within the ring,

→ acceptable



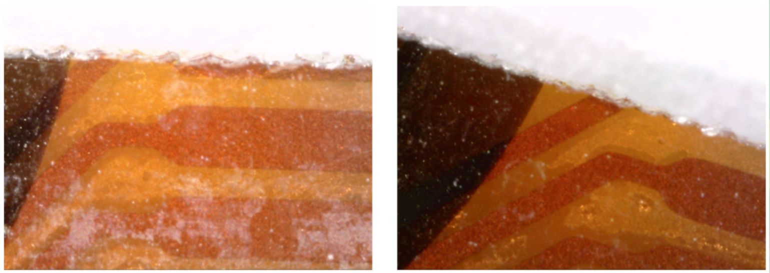
… or touching / violating it

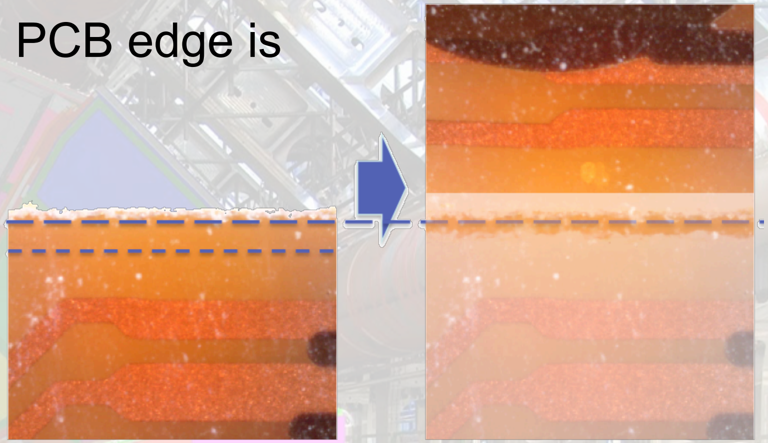
→ Not within specification

During *NSW production* all hole positions can be checked visually to be within / out of specifications in less than 1min.

QC – Cutting Accuracy (Module-0)

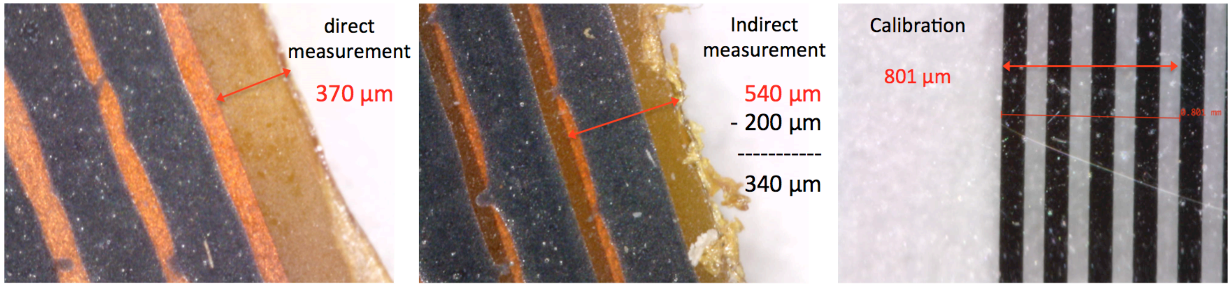
The distance between the last r/o strip and the PCB edge is required to be 300 ± 100µm.





Cutting Edge too close (left) to the last strip, violating or removing a r/o strip or too far (right) causing interference when joining two boards.

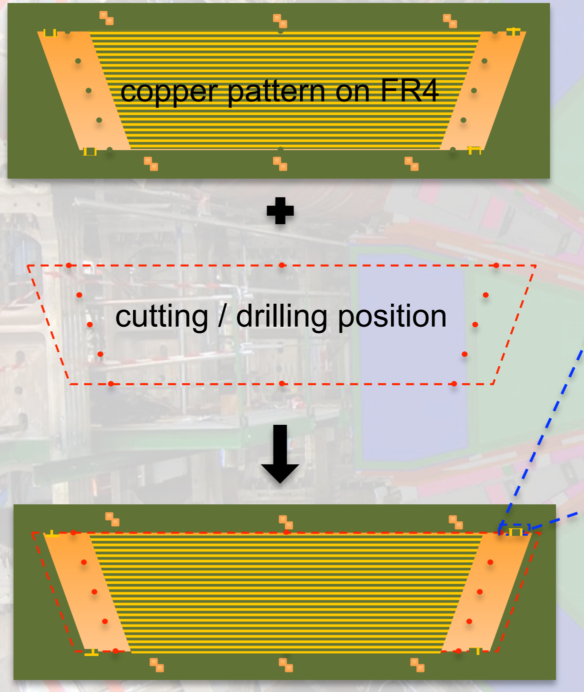
During *Module-0 PCB* QC the distance between last r/o strip and PCB edge has been measured with a calibrated microscope manual image evaluation has been performed (≈1/2 min / picture → 5 min / board)



Examples for direct (left) and indirect (middle) strip-edge to cutting-edge measurement and a calibration measurement (right). The left picture shows a clean cut while in the middle picture the cut is full of Kapton splinters.

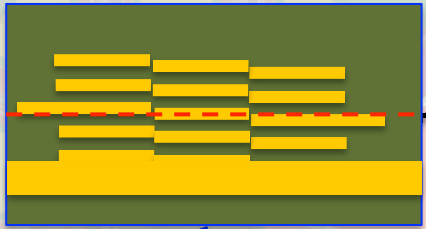
QC – Cutting Accuracy (NSW production)

To speed up this procedure additional QC markers have been added on the Cu-pattern for *NSW production*.



Before cutting:

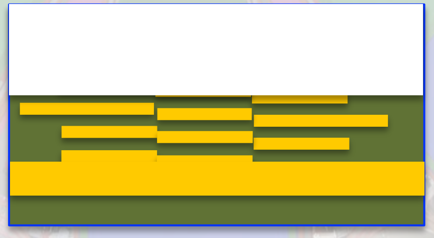
The nominal cutting line goes through the center of the pattern



Line /gap width 100µm, shift of 50 µm

After cutting:

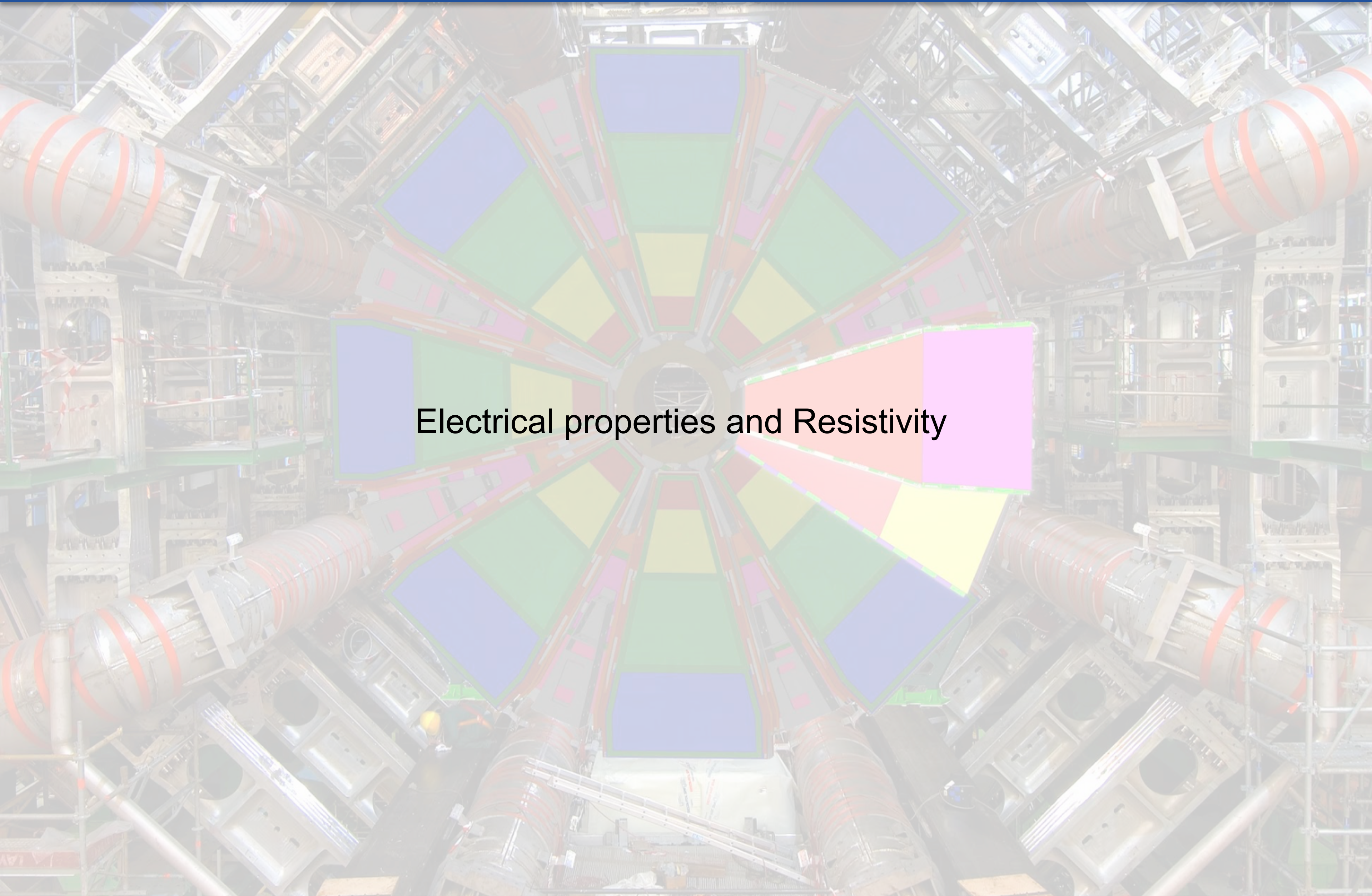
The cut chops part of the pattern away and the deviation can be counted by counting lines



One line on the right the full gap in the middle are visible, indicating an ≈150µm shifted cut.

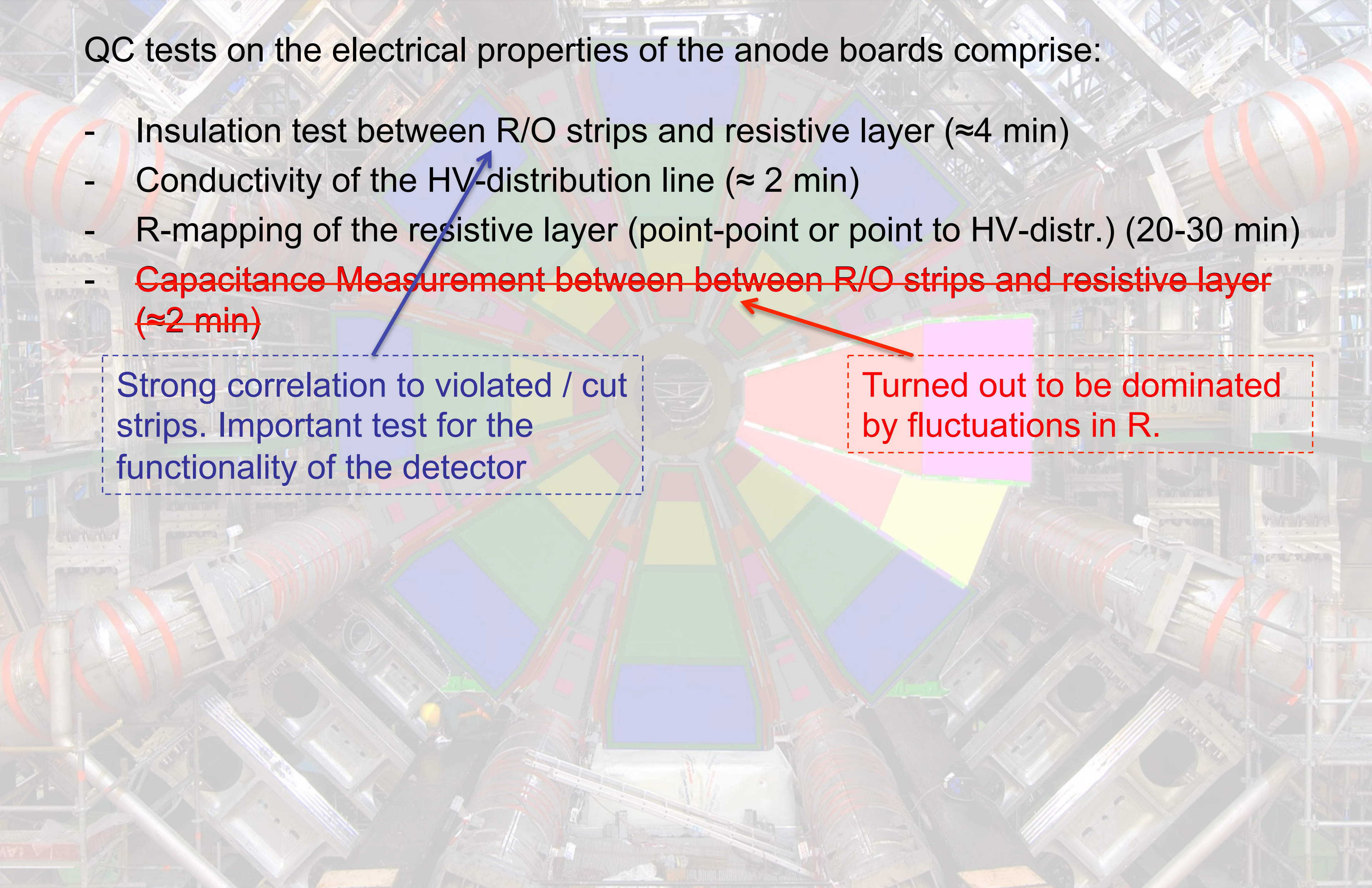
The cut position is checked on the sides and the linearity of the cut is tested by pressing against a rectified bar on an illuminated table.

→ A quick acceptance decision can be taken visually within < 1min.



Electrical properties and Resistivity

QC - Resistivity & Electrical properties (Module-0)



QC tests on the electrical properties of the anode boards comprise:

- Insulation test between R/O strips and resistive layer (≈4 min)
- Conductivity of the HV-distribution line (≈ 2 min)
- R-mapping of the resistive layer (point-point or point to HV-distr.) (20-30 min)
- ~~Capacitance Measurement between between R/O strips and resistive layer (≈2 min)~~

Strong correlation to violated / cut strips. Important test for the functionality of the detector

Turned out to be dominated by fluctuations in R.

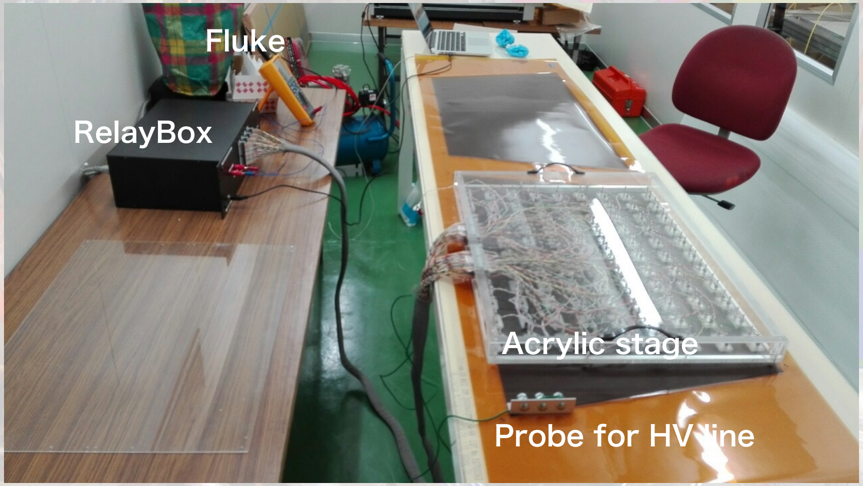
QC - Resistivity & Electrical properties

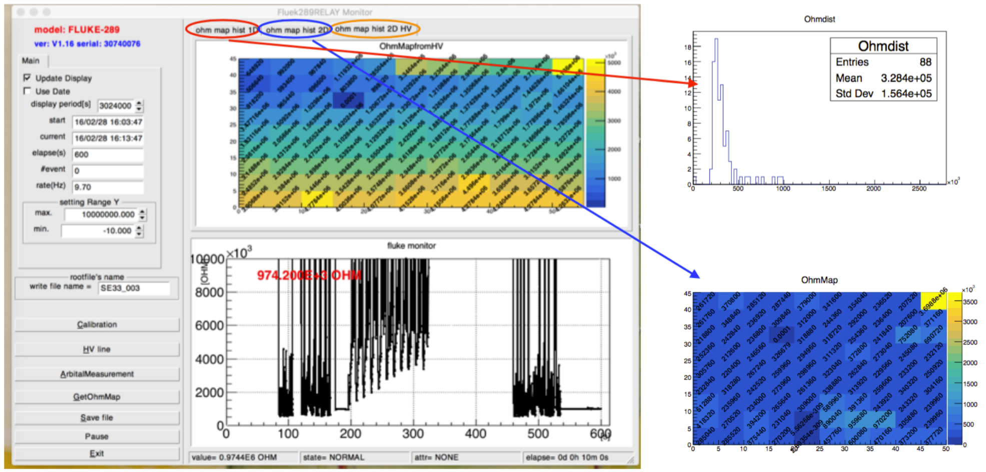
QC tests on the electrical properties of the anode boards comprise:

- Insulation test between R/O strips and resistive layer
- Conductivity of the HV-distribution line
- R-mapping of the resistive layer (point-point or point to HV-distr.)
- Capacitance Measurement between between R/O strips and resistive layer

Combined in one measurement

Fruitful collaboration between Kobe (Japan), Würzburg (Germany) and CERN resulted in a very elaborated R-mapping tool & software.
→ **< 5 min / foil or board** (both mappings)





model: FLUKE-289
ver: V1.16 serial: 30740076

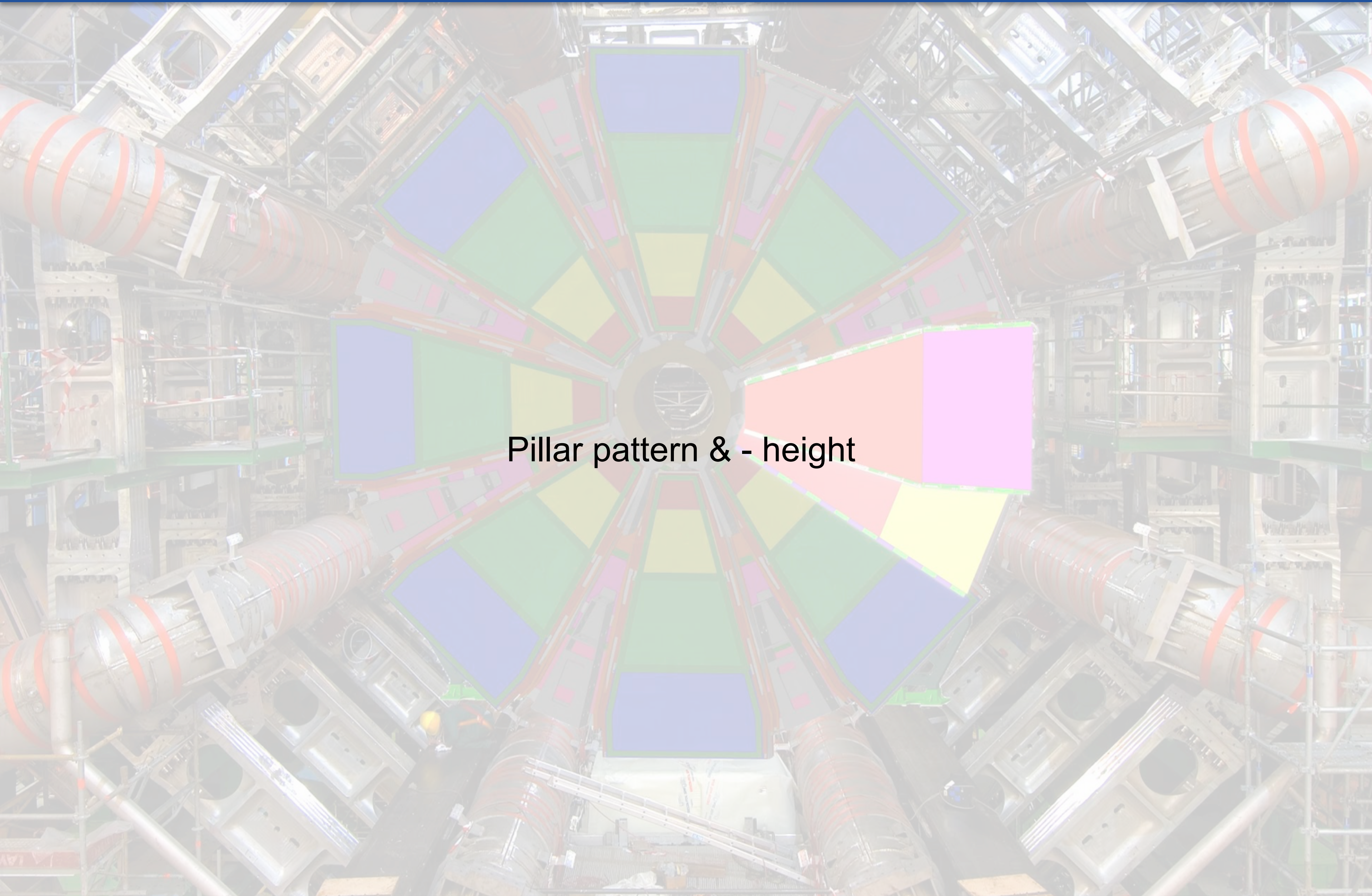
☑ Update Display
☐ Use Date
display period[s] 3024000
start 16/02/28 16:03:47
current 16/02/28 16:13:47
elapse(s) 600
#event 0
rate(Hz) 9.70

setting Range Y
max. 10000000.000
min. -10.000

rootfile's name
write file name = SE33_003

value= 0.9744E6 OHM
state= NORMAL
attr= NONE
elapse= 0d 0h 10m 0s

Ohmdist	
Entries	88
Mean	3.284e+05
Std Dev	1.564e+05



Pillar pattern & - height

QC – **pillar pattern** & - height

Missing pillars turned out to be one of the major problems during Module-0 PCB production.

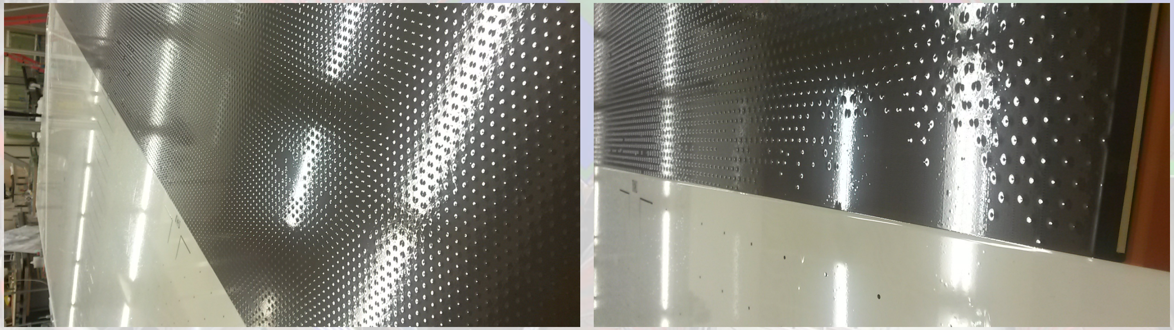
Completeness of the pillar pattern can be best checked visually using light reflection.

- The test can be simplified by using **UV-light**.

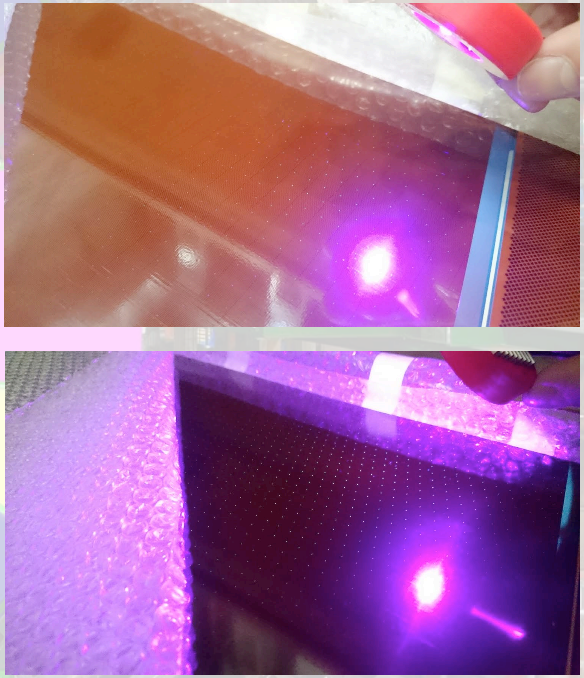
(requiring darkness, difficult to achieve homogeneous UV illumination over the full PCB surface)

- With normal light, the reflection can be magnified with a foil sucked over the PCB

(vacuum bag / vacuum table)



Enhanced visibility of the pillar pattern under a vacuum sucked Mylar foil.

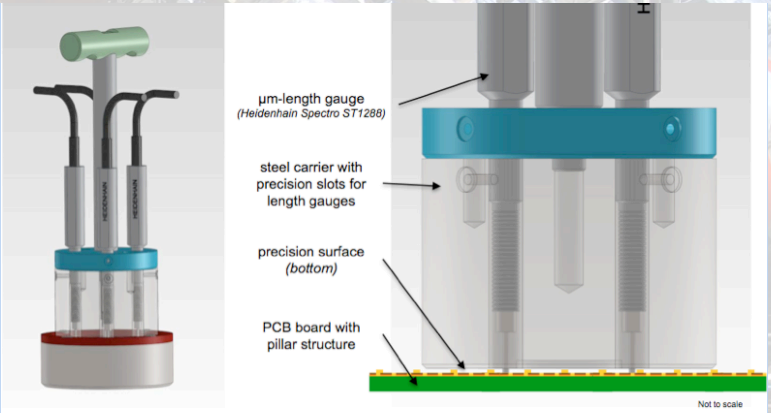


Pillar visibility under UV illumination.

QC – **pillar** pattern & - **height**

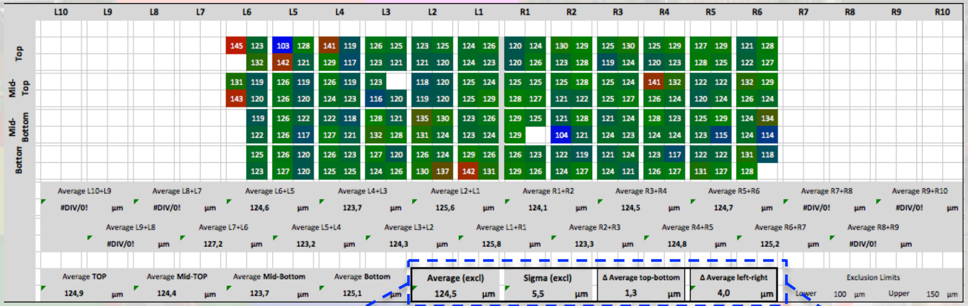
The height of the pillars defined the Micromegas amplification gap and accordingly the gas gain of the chamber.

Few µm variation can have a large impact on the response-homogeneity / efficiency.



The mean pillar height is mapped over the full surface of each board:

Module-0: 3-6min (measurements)
+ 3-4min (data processing)
per board



	L10		L9		L8		L7		L6		L5		L4		L3		L2		L1		R1		R2		R3		R4		R5		R6		R7		R8		R9		R10	
Top									145	123	103	128	141	119	126	125	123	125	124	126	120	124	130	129	125	130	125	129	127	129	121	128								
										132	142	121	129	117	123	121	121	120	124	123	120	126	123	128	119	124	120	123	128	125	122	127								
Mid-Top									131	119	126	119	126	119	123		118	120	125	124	125	125	125	128	125	124	141	132	122	122	132	129								
									143	120	126	120	124	123	116	120	119	120	125	129	128	127	121	122	125	127	126	124	120	124	126	124								
Mid-Bottom										119	126	122	122	118	128	121	135	130	123	126	129	125	121	128	121	124	128	123	125	129	124	134								
										122	126	117	127	121	132	128	131	124	123	124	129		104	121	124	123	124	124	123	115	124	114								
Bottom										125	126	120	126	123	127	120	126	124	129	126	126	123	122	119	121	124	123	117	122	122	131	118								
										123	127	120	125	125	124	126	130	137	142	131	129	126	124	127	124	121	126	127	131	127	128									

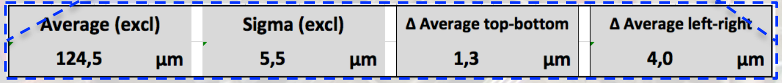
Average L10+L9	Average L8+L7	Average L6+L5	Average L4+L3	Average L2+L1	Average R1+R2	Average R3+R4	Average R5+R6	Average R7+R8	Average R9+R10
#DIV/0! µm	#DIV/0! µm	124,6 µm	123,7 µm	125,6 µm	124,1 µm	124,5 µm	124,7 µm	#DIV/0! µm	#DIV/0! µm

Average L9+L8	Average L7+L6	Average L5+L4	Average L3+L2	Average L1+R1	Average R2+R3	Average R4+R5	Average R6+R7	Average R8+R9
#DIV/0! µm	127,2 µm	123,2 µm	124,3 µm	125,8 µm	123,3 µm	124,8 µm	125,2 µm	#DIV/0! µm

Average TOP	Average Mid-TOP	Average Mid-Bottom	Average Bottom	Average (excl)	Sigma (excl)	Δ Average top-bottom	Δ Average left-right
124,9 µm	124,4 µm	123,7 µm	125,1 µm	124,5 µm	5,5 µm	1,3 µm	4,0 µm

Exclusion Limits
Lower 100 µm Upper 150 µm

NSW production:
Direct interface between analysis program and measurement tool speeds up the Measurement significantly. (<5min / board)

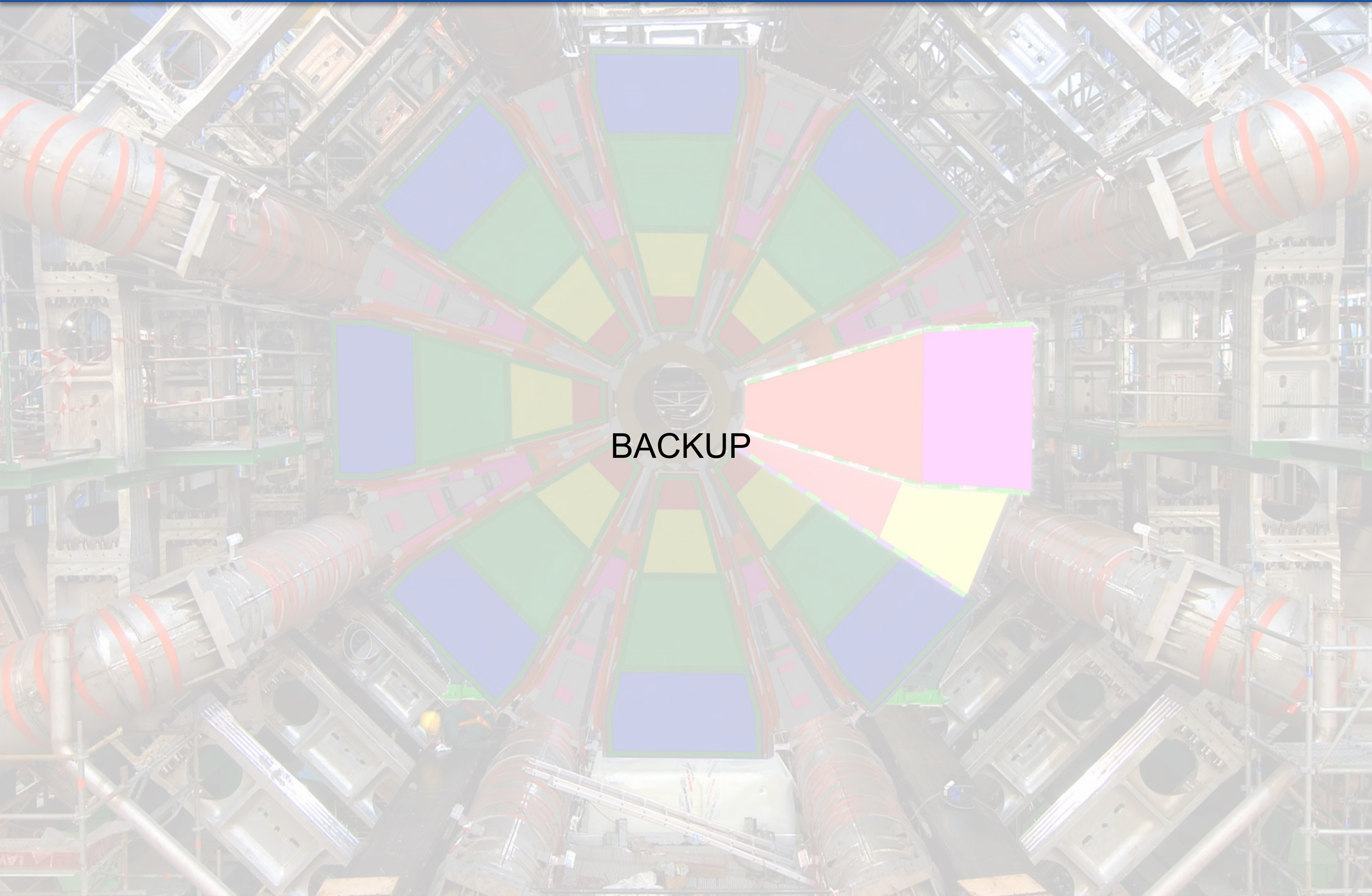


Average (excl)	Sigma (excl)	Δ Average top-bottom	Δ Average left-right
124,5 µm	5,5 µm	1,3 µm	4,0 µm

Summary – Anode PCB QA/QC at CERN

- Module-0 experience has proven very valuable in terms of QC optimization
  - Measurement ideas have been tested (HV insulation, C-measurement…)
  - Visual inspection has become more systematic and 'more objective'
  - Methods have been optimized (R-measurements, pillar height…)
- Introduction of QC-Markers in the PCB design facilitates QC significantly
- All QC methods/ processes are 'speeded up'

  (≈2h / board for Module-0 → 30-40 min / board envisaged during NSW production)
- Last tools are currently build and will become available in the next months
- Digitalization (+ DB interface) of all processes is ongoing and will be ready before start of NSW mass production.



BACKUP

Backup – NSW MM anode boards production steps

I. Copper pattern creation by photolithography

→ Standard operation for PCB manufacturer except for board size (length; width is standard)

II. Selective plating on connector pads

→ Standard operation for PCB manufacturer

III. Cutting of Kapton foils with resistive pattern

→ Non-standard operation but not critical (accuracy ±1 mm)

IV. High pressure Gluing of Kapton foil on the PCB

→ High pressure gluing is part of PCB manufactures, complexity arises from board size and non-standard material (Kapton with resistive pattern)

V . Connection between HV input line and resistive strips (screen printed: silver conductive paste)

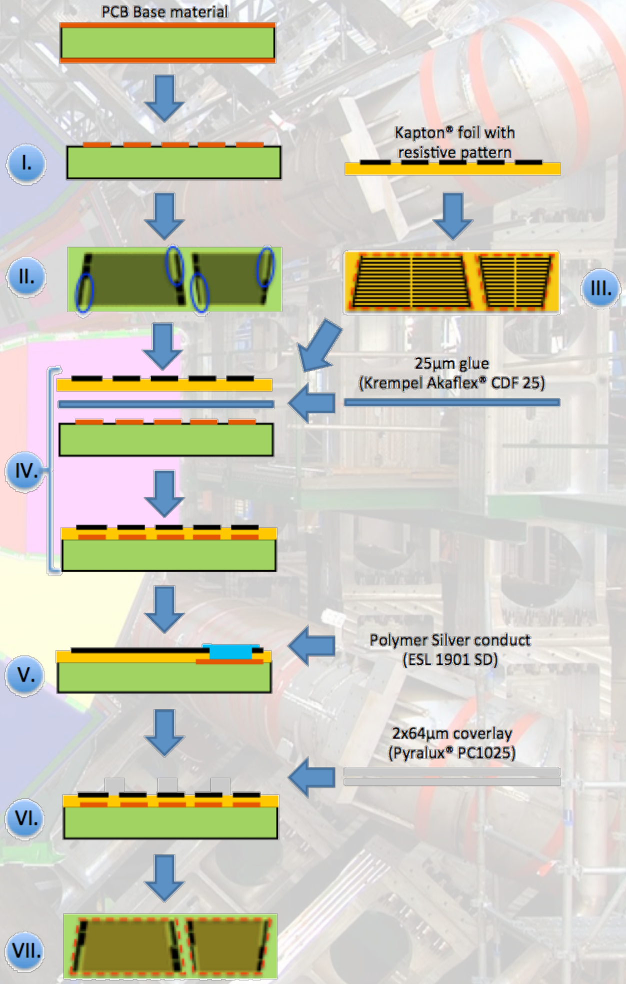
→ Simple operation to be done manually

VI. Pillar creation (2x 64µm Pyralux coverlay)

→ Standard operation with a highly ‘non-standard’ pattern (pillars)

VII. Cutting of the boards and drilling of the non-precision holes (holes for mechanical assembly and alignment)

→ Standard operation on CNC machine



Backup – NSW MM anode board Quality requirements

Production done in industry – stringent requirements

I. Copper pattern creation by photolithography

- Copper pattern absolute accuracy: <30 µm for the short side and <100 µm/m for the long side
- Line and space accuracy 20% w.r.t. the design file
- Maximum 1% of cut on the copper lines, as long as cuts are not on neighboring lines
- Maximum of 0.1% of shorts between two lines, as long as no more than two successive lines are shorted

II. Selective plating on connector pads

- Layer thickness depending on plating choice: Au/Ag/Pd

III. Cutting of Kapton foils with resistive pattern

- Cutting accuracy shall be better than ±1mm

IV. High pressure Gluing of Kapton foil on the PCB

- Alignment accuracy shall be better than ±0.5mm

V . Connection between HV input line and resistive strips (screen printed: silver conductive paste)

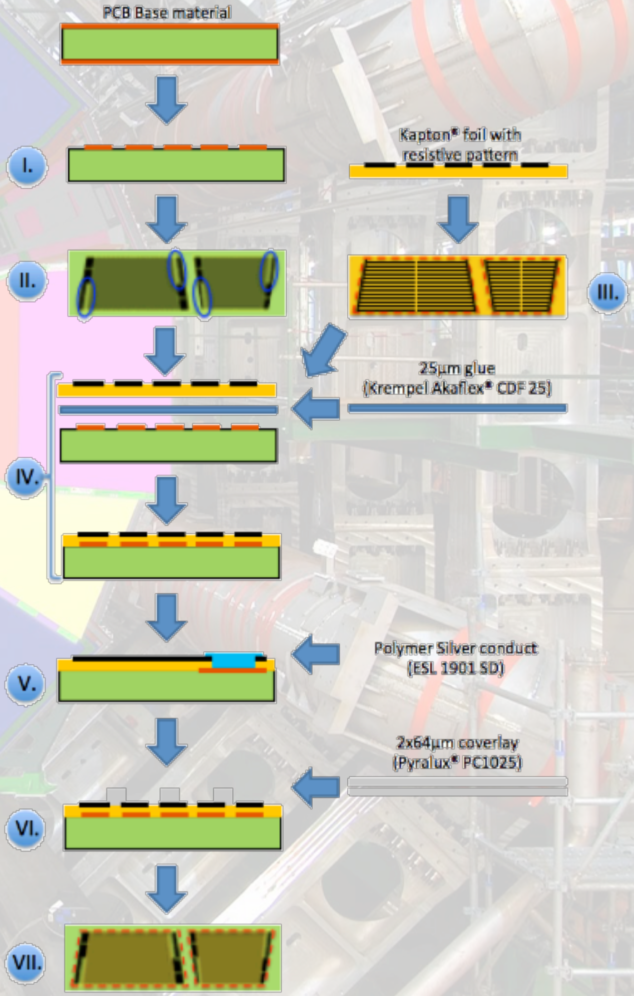
- Position accuracy w.r.t. the copper pattern < ±1m
- Resistance of the silver HV connection line < 10Ω

VI. Pillar creation (2x 64µm Pyralux coverlay)

- Coverlay pattern absolute accuracy < ±1 mm
- Accuracy of the diameter of the pillars ±25 µm
- Missing pillars maximum 0,1% of the total number, as long as no neighboring pillars are missing
- Max. 10 extra coverlay structures of a size < 1mm in each dimension are tolerated per square meter
- The mean height of the coverlay layer / pillars in different 25x25 cm^2 regions has to be homogeneous on a level of <5µm over the full surface of the board

VII. Cutting of the boards and drilling of the non-precision holes (holes for mechanical assembly and alignment)

- Cutting absolute accuracy w.r.t. the copper pattern shall be better than ±100µm
- Holes absolute position accuracy referring to the copper pattern shall be at least ±100µm



Concept of readout PCB QA/QC

- **Conduct QC tests as fine-meshed as possible**

  The complexity of the process and lacking experience of large-area PCB production in industries requires **multiple QC steps** during the different steps of PCB production. This as well avoids unqualified parts to be further processed.

- **Shifting QC as close to industries as possible**

  QC/QA shall be performed in industries and by industries personal whenever possible.

  This requires setups to be exported to industries which are **reliable** , **simple** and **time efficient to use** and provide accurate and repeatable QC results independent of the testing person.

  These requirements lead to largely automatized measurements, minimizing processes involving human handling.

- **Keeping track of QC tests and results**

  Giving QC measurements to industries fortifies the need of proper bookkeeping. A database developed centrally by the NSW collaboration will be used to store all the information and results of each QC steps, including visual inspection of components with passed/not passed results.

- **Maintaining QC pressure on industries**

  Minimizing the risk of negligent performed test in industries, CERN will requiring the possibility

  to re-test individual batches. This requires producing **two sets of testing tools** and manpower/ responsible to keep track of the production and QA/QC. **Regular visits** to the industry premises are also foreseen to verify the respect of the defined procedures.