Industrial Production of ATLAS Micromegas Readout Boards

Status, Issues and Solutions

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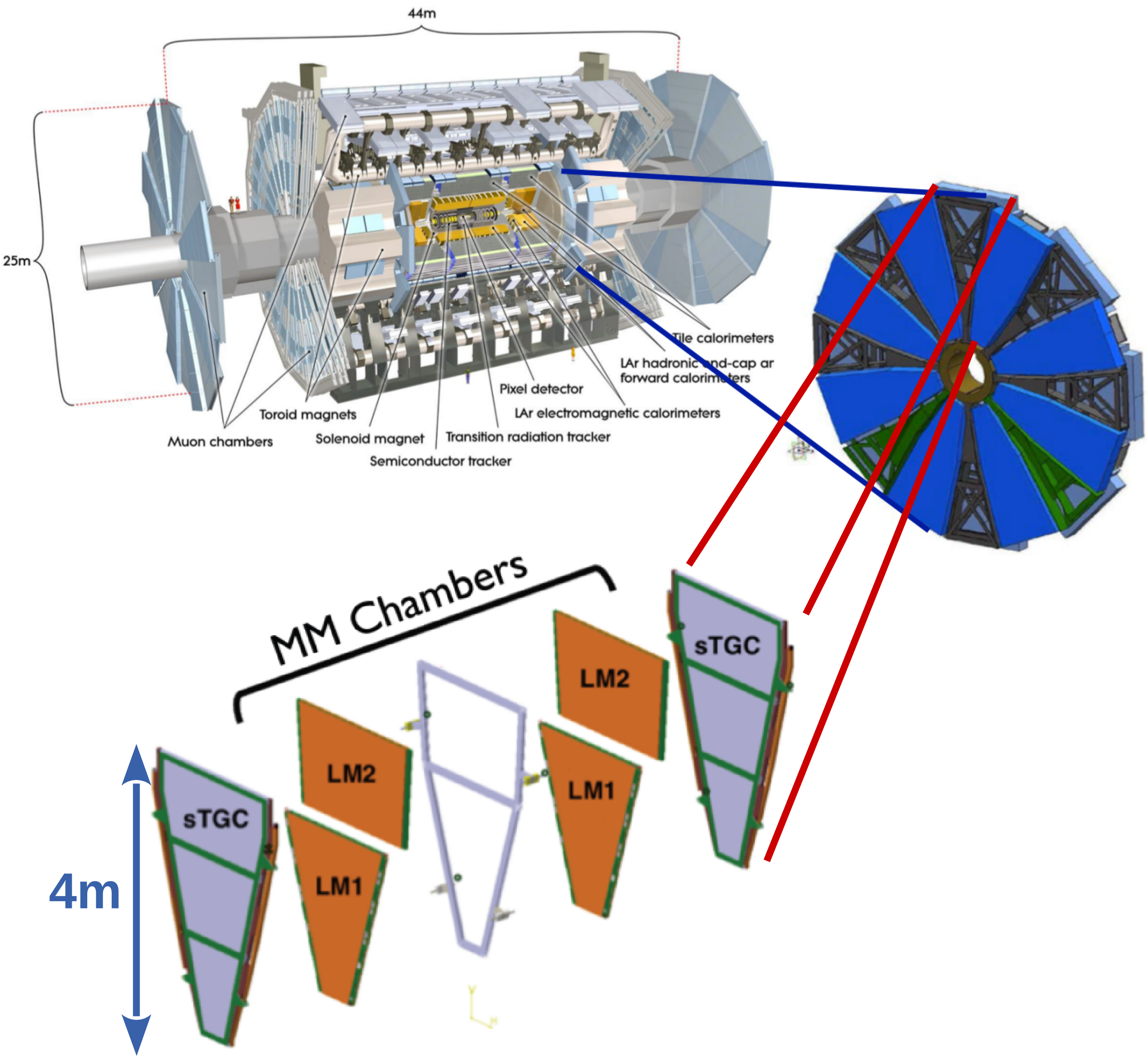
for the ATLAS New Small Wheel collaboration

RD51 Collaboration Meeting
September 28 2017

Motivation: Two New Small Wheels

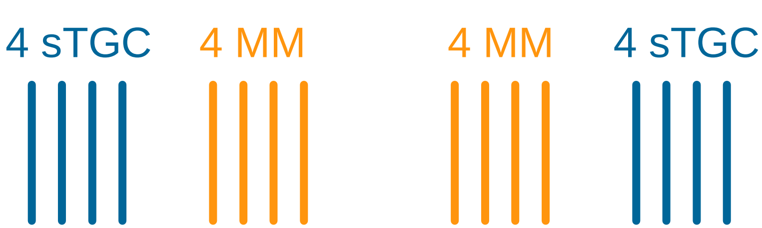


- highest background hit rate in ATLAS muon spectrometer
- $\mathscr{L} > 5\mathrm{x}10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  → excessive hit rates 15kHz/cm^2
  → spatial resolution & efficiency deteriorated
  → trigger bandwidth limit exceeded

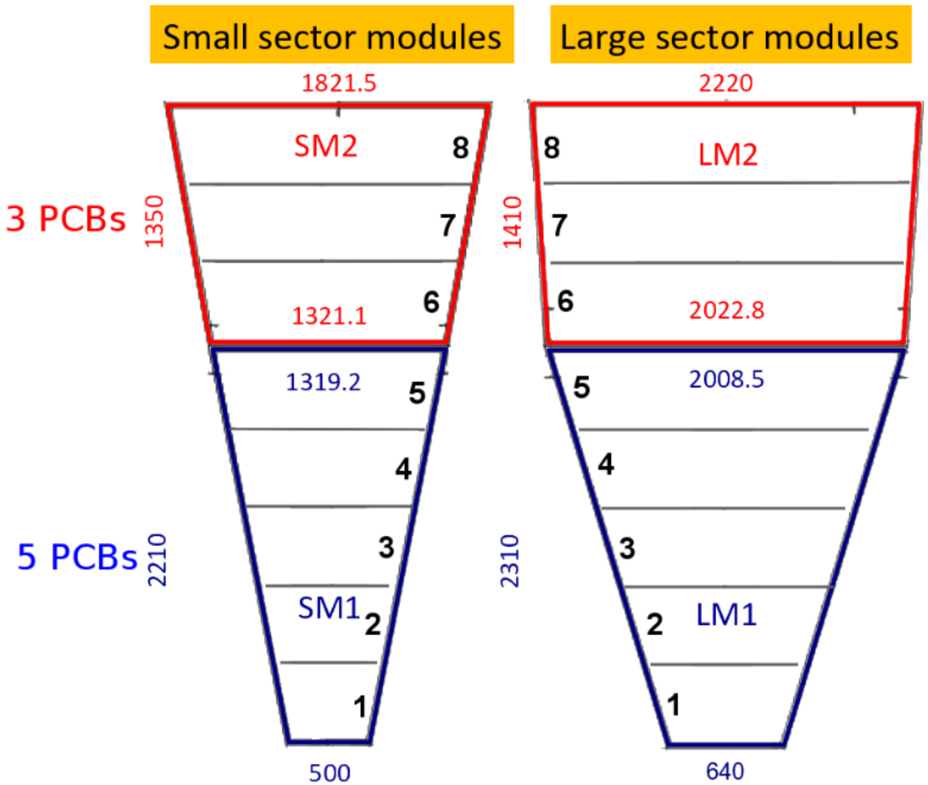
- 2019/20: installation of high rate capable detectors

  small strip Thin Gap Chambers
  triggering (& tracking)

  Micromegas Chambers
  tracking (& triggering)



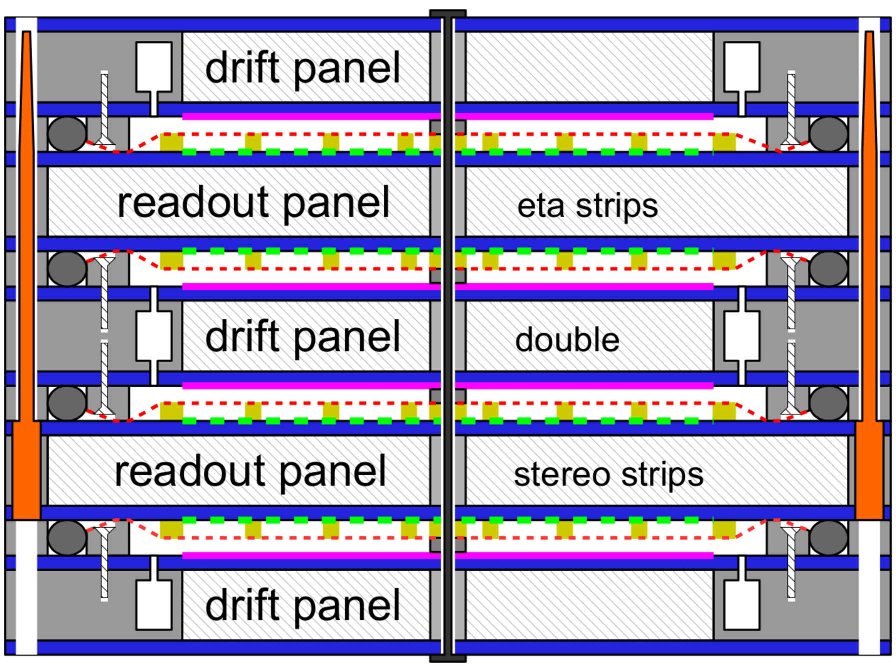
New Small Wheel Micromegas Chambers



quadruplet module:
2 readout layers with parallel strips (eta)
2 readout layers with ±1.5° stereo strips

→ 32 different types of readout boards
→ 2176 boards to be produced

→ 1292 (19/32) produced by Elvia/FR
→ 884 (13/32) produced by Eltos/IT



detector production by 4 different consortia

SM1 Italy INFN (PV, RM, Frasc., CS, LE, NA)

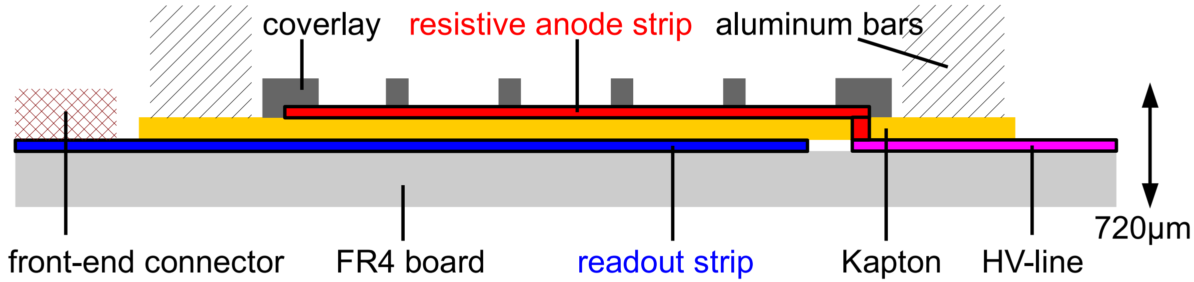
SM2 Germany (LMU, Mainz, Würzburg, Freiburg)

LM1 France (CEA Saclay)

LM2 Russia (Dubna) & Greece (Thessaloniki)

→ 32 quadruplet modules of each type

Resistive Strip Micromegas Readout Structures



1022 copper readout strips

- width 300µm,
  pitch 425µm (SM) or 450µm (LM)
- connection to front-end electronics:
  Zebra-connectors, solderless

resistive strips

- screen-printed on Kapton foil
- width 300µm, pitch 425µm/450µm
- interconnected every 20mm
- connected to HV with
  printed silver line & via

pillars

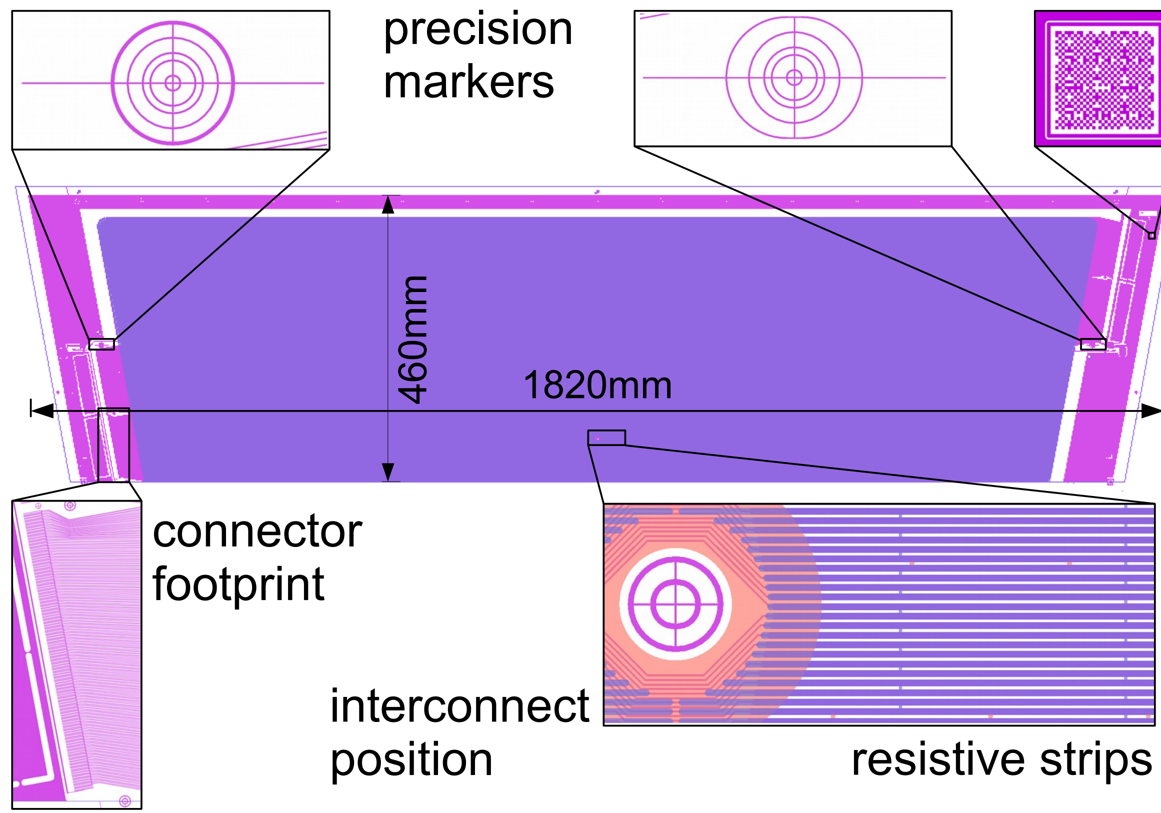
- 128µm height, 200µm x 1200µm
- 7mm pitch

precision markers & rasmasks

- exact w.r.t. strip position

→ optical dimension measurement during QC

→ optical alignment of PCBs during construction



Readout Board Production

I. photolithographic creation of copper pattern
standard process.
complex due to: size of board, required precision & board elongation (humidity).

II. cutting of Kapton foil with resistive pattern
non-standard but simple & required accuracy only ±1mm

III. stacking and high-pressure & temperature gluing of Kapton foil, glue foil and board
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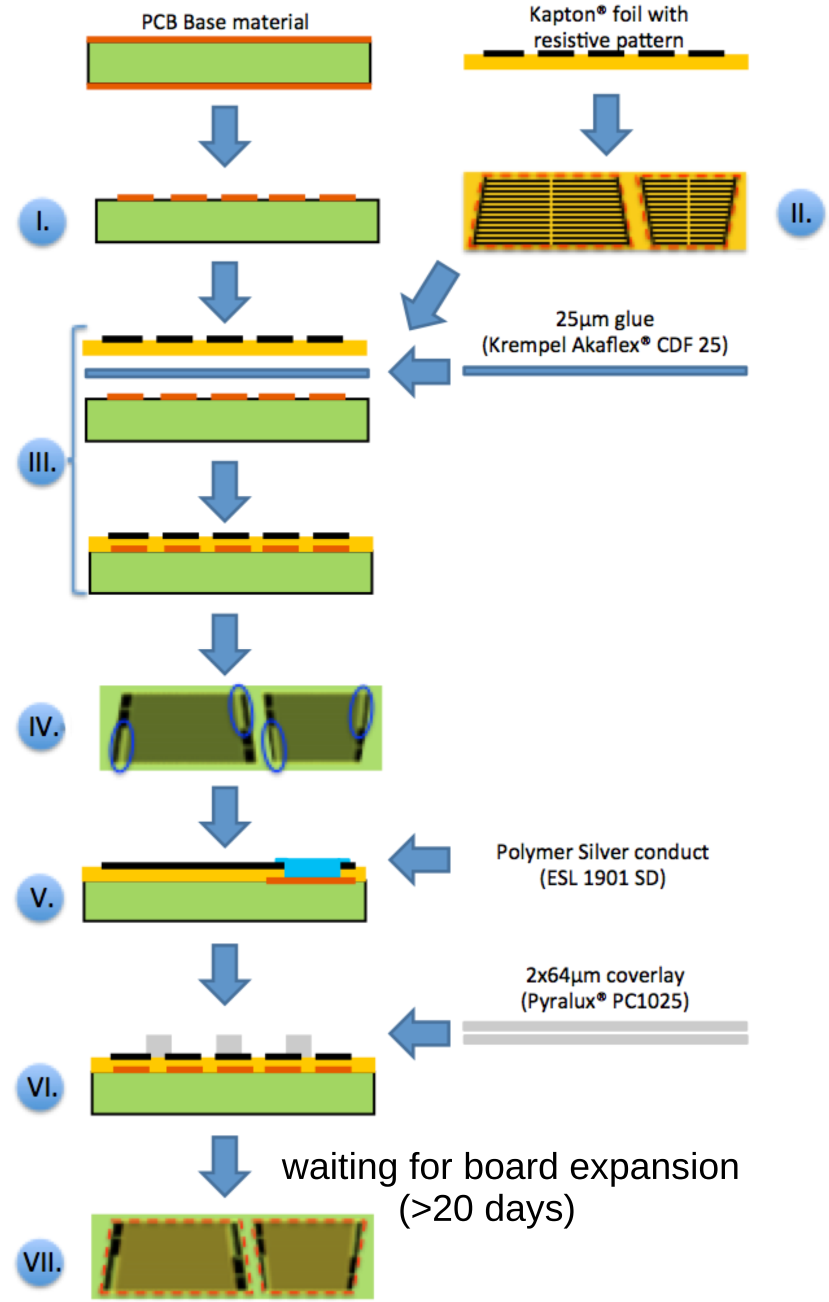


How Detector Industrialization Can Succeed

- central material procurement & logistics
  (base material, coverlay, Ag paste, resistive foils provided by Japan)

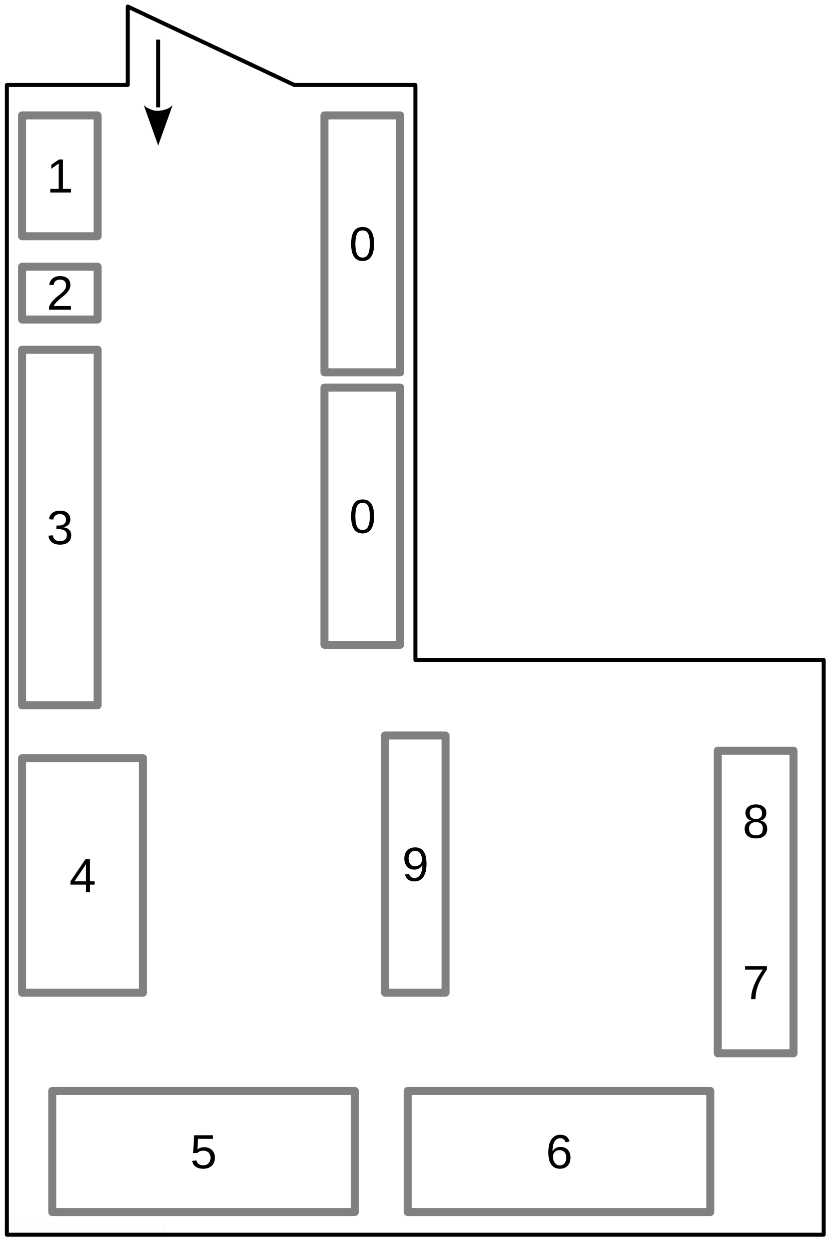
- full knowledge transfer to both companies before production start (Rui et al.)
- very close follow-up of production in companies by us
- thorough quality control of all boards at CERN before distribution

rather complex production with several non-standard steps

→ many things can go wrong

→ several potential problems, that would render the detector degraded or fully unusable

Dedicated Quality Control Lab at CERN



0. shelf & table
   unwrapping
1. computer table
   logistics
2. tool chest
3. top light table
   visual inspection, electrical tests
4. back light table
   agreement btw. holes & Cu pattern,
   edge precision & straightness, pillar pattern
5. rasmask granite table
   absolute dimensions & shape O(30µm)
6. granite table
   pillar height measurement
7. table
   resistivity mapping
8. table
   strip capacitance measurement
9. shelf

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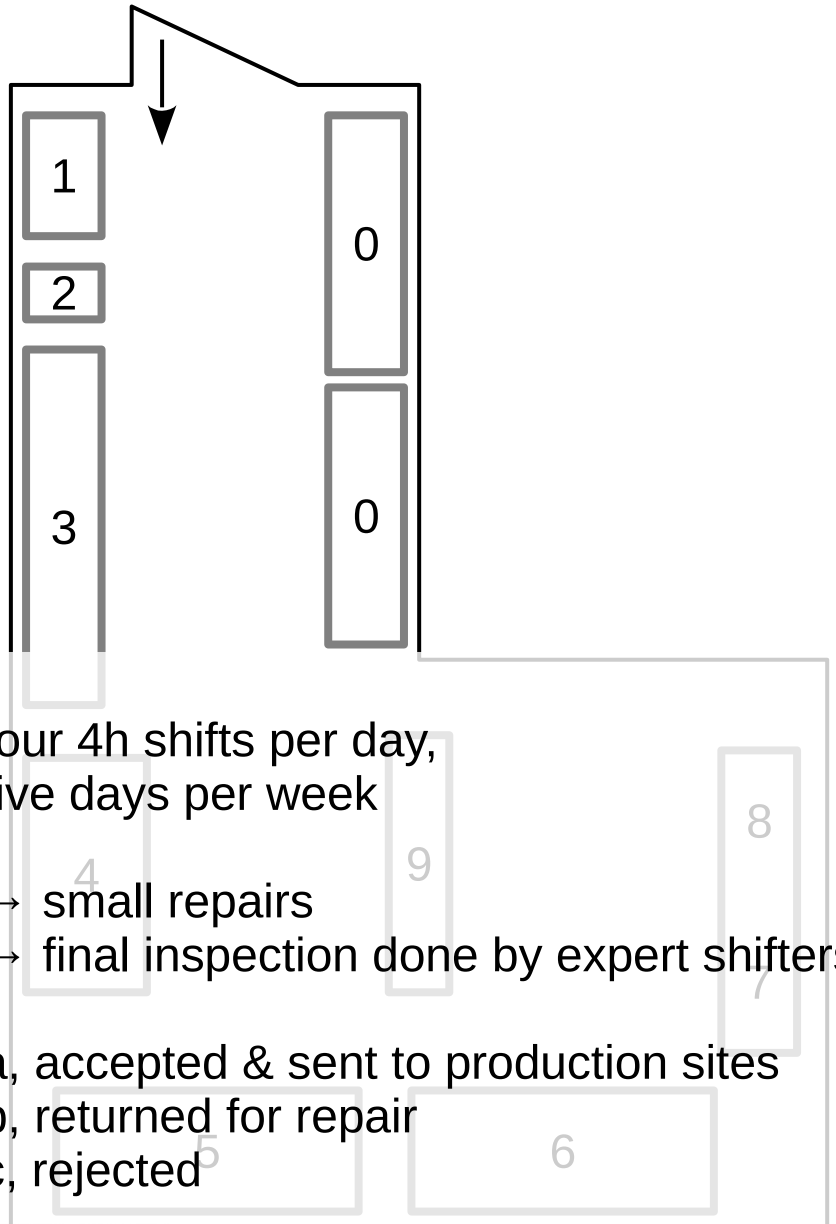

four 4h shifts per day,
five days per week

→ small repairs
→ final inspection done by expert shifters

a, accepted & sent to production sites
b, returned for repair
c, rejected

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Improving Board Quality for Series Production

module 0 boards (2015/16): very poor quality and too large

→ **production procedures reviewed and adjusted**

design changes

pillar pattern

- changed shape from circular 280µm to long: 1200µm x 200µm

inaccuracy of cutting and drilling

- better registration of copper pattern
- removal of strip (1023 → 1022), increase of margin of board rim and between boards

board elongation

- FR4 fully dry before Cu image creation, FR4 exposed to air humidity after Cu etching
  → boards expand by 0.5mm/m
- re-scaled Cu image
  Elvia: -0.48mm/m in short and -0.43mm/m in long direction
  Eltos: -0.43mm/m in short and -0.38mm/m in long direction
- wait four weeks before final cutting and drilling

all production procedures defined, discussed and suppliers are trained

all production problems solved

→ smoothly running series production

→ all boards are usable

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→ smoothly running series production

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hahaha!

Status of PCB Series Production

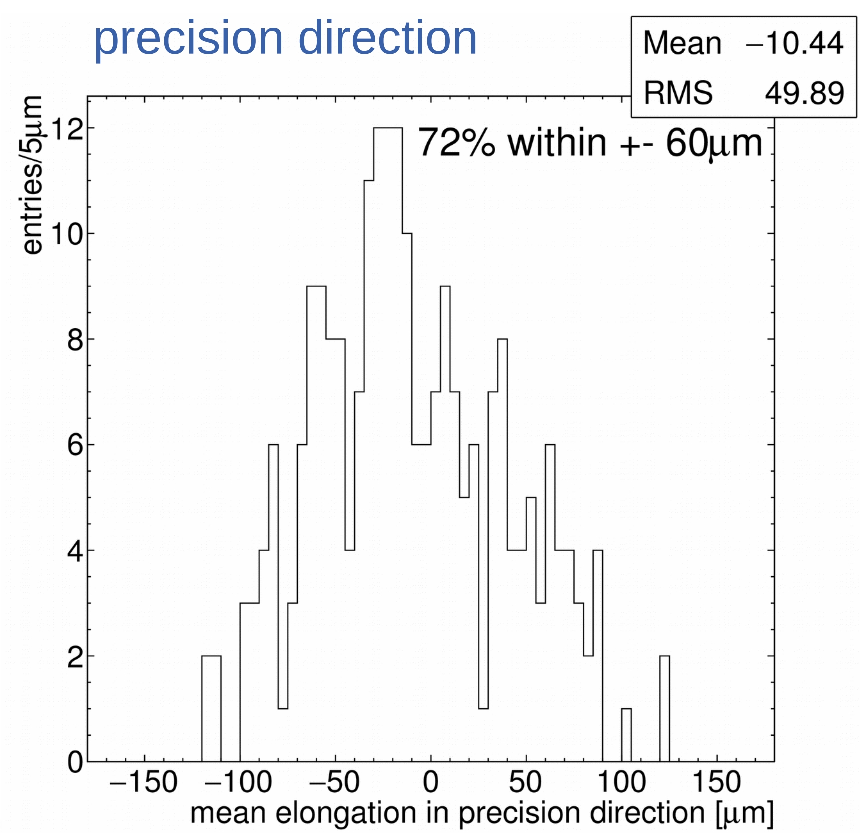
- series production started end of 2016
- already received around 410 boards (20% of order)
- QC at CERN done on 283 boards
- acceptance/rejection decision taken on 145 boards
  → current yield: 70% acceptable
  → value artificially too low: considerable number of boards currently under repair
  → aiming at 80% to 90% final yield (supplier expectation), well achievable
- all construction sites received boards and are producing first series panels & quadruplets
- most module 0 issues are gone after initial iterations
  - good agreement between edges/holes and Cu pattern
  - good Kapton foil cutting and gluing
  - good silver plating quality (although subtle issue → next slides)
  - good silver line printing quality
  - good pillar shape

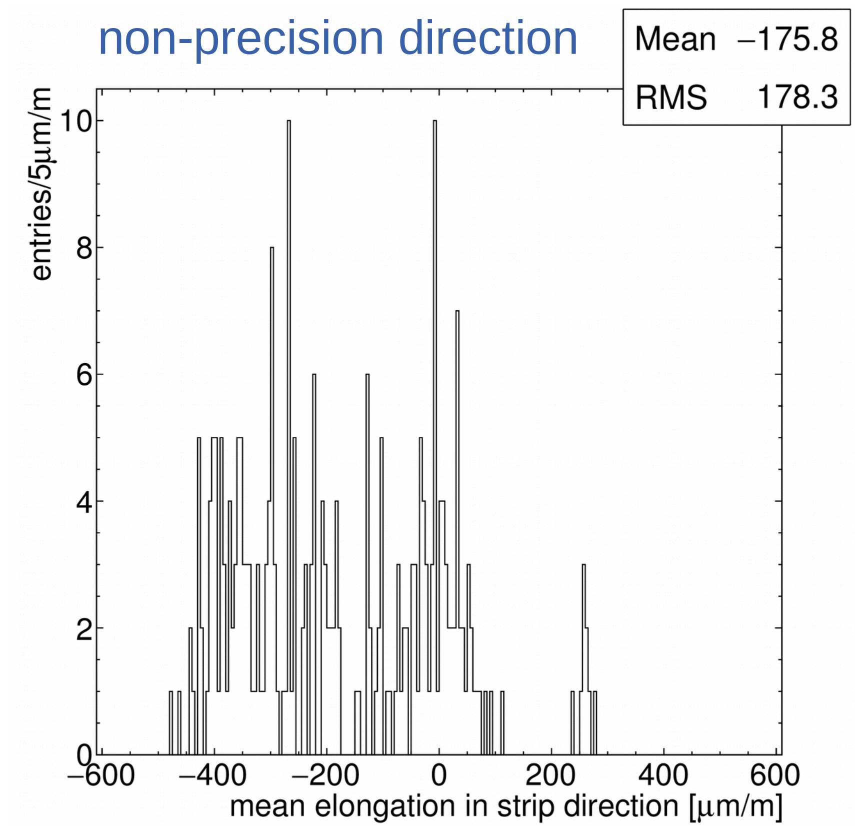
Dimensions of Series Boards

measured with special cameras (Brandeis contact-CCDs) at defined positions on granite table

- setup accuracy ~ 25µm
- humidity in QC lab not controllable (up to 150µm/m increase for 20% RH increase)
- not all boards fully expanded during QC

→ measurements indicative: good board accuracy in precision direction
well tolerable accuracy in strip direction (only mechanical constraints)





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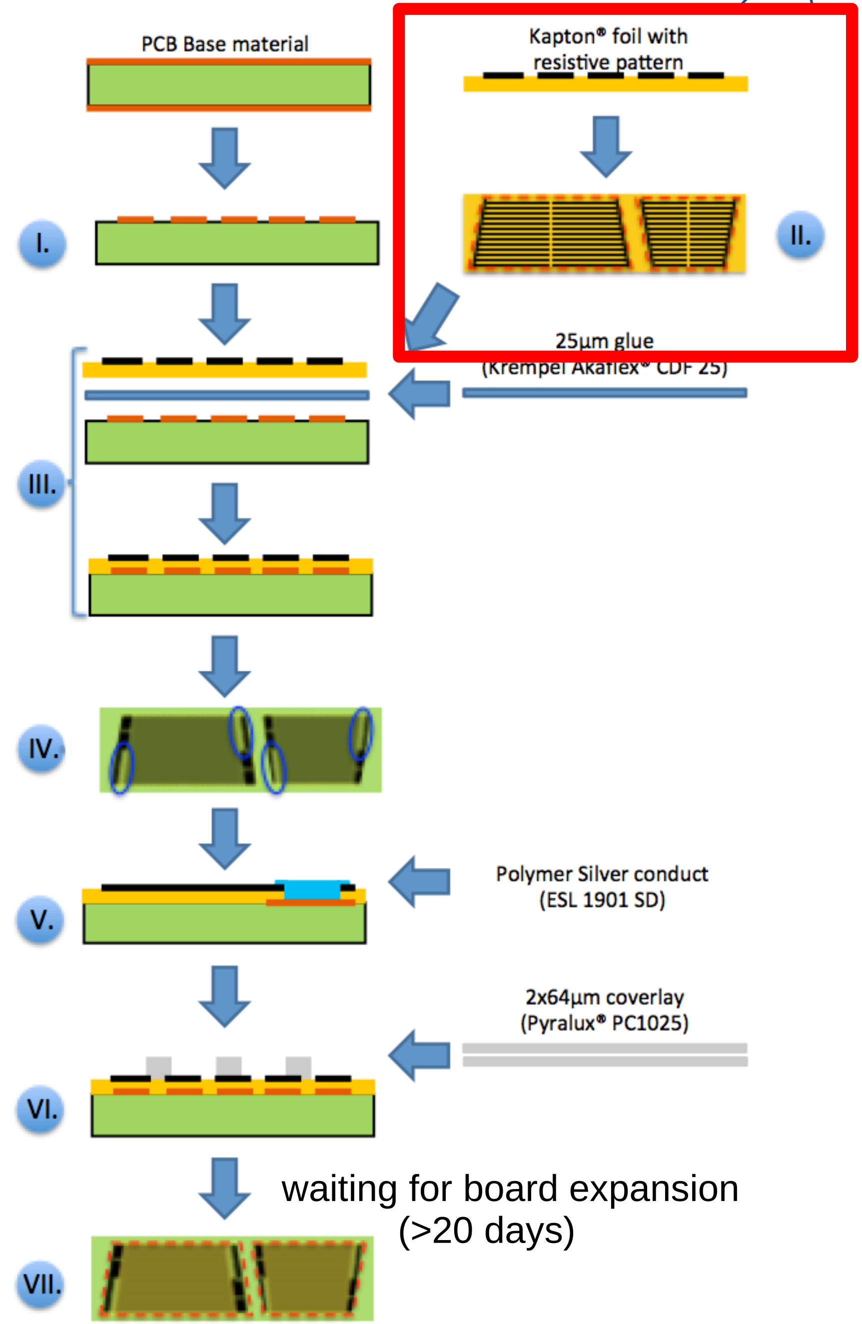
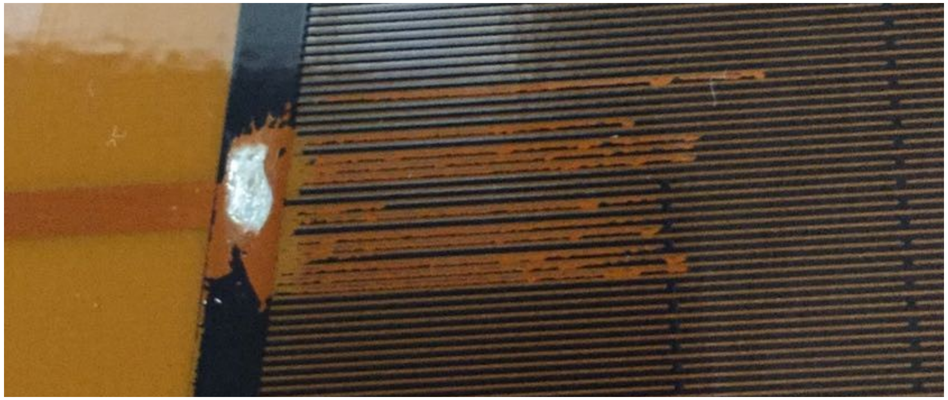


Resistivity and Adhesion of Resistive Strips

low adhesion of resistive strips on some series Kapton foils
→ removed during board production



origin of issue

- June 16: resistivity of recent foils factor 10 too high
- June 16 to August 16: unsuccessful trials by ESL (resistive paste supplier) to correct paste, finally understood, that solvent was changed
- October 16: re-produced paste delivered, resistivity at lower edge of acceptance
  → Matsuda increases resistivity by not fully curing the foils
- November 16: Eltos reports issues with adhesion
- November 16 to December 16: intense effort to find cause, finally realized that indeed curing problem

solution

- re-cure urgently needed foils in oven → adhesion OK
- reproduce most of the affected foils → adhesion good

→ not an issue anymore

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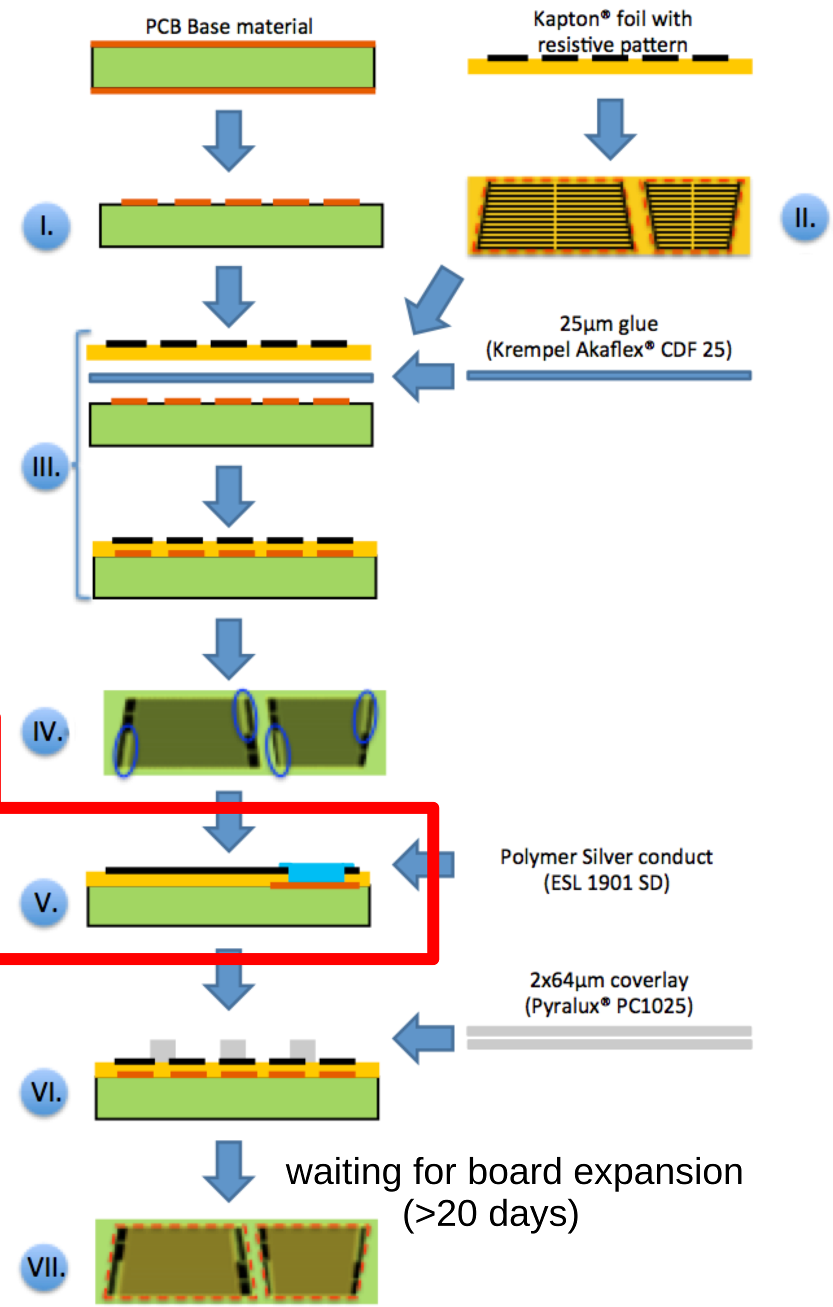
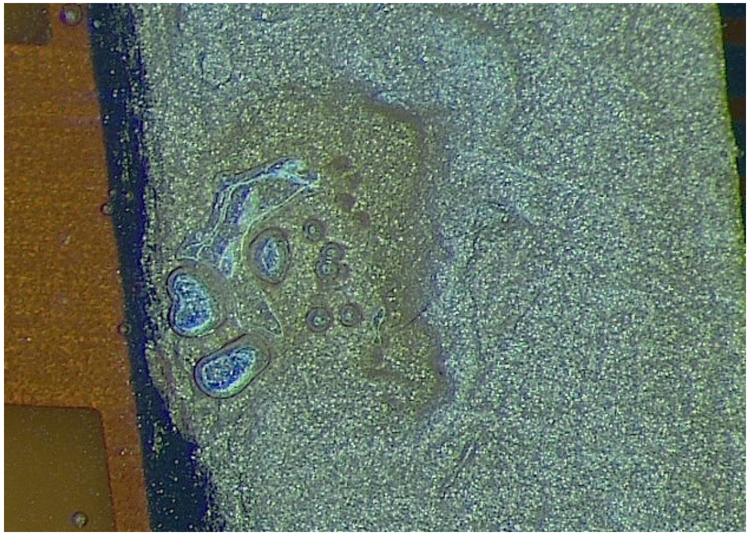


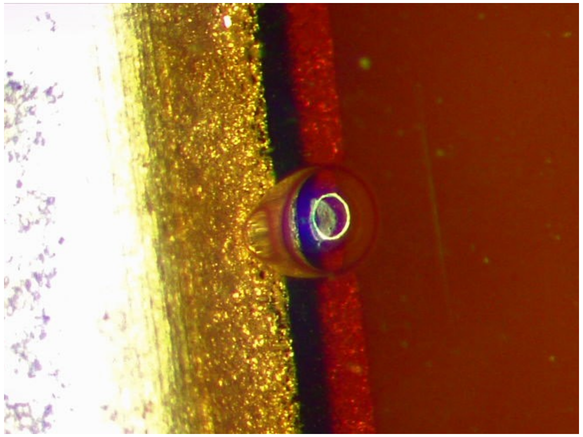
Bubbles underneath Coverlay (Clas12 Issue)

bubbles between coverlay and silver line
→ mesh on top of coverlay
→ can lead to corona discharge in bubble
→ slowly burns coverlay, short circuit after weeks



origin of issue

- HV via (connection between Cu supply line and resistive pattern) not flat (Eltos & Elvia)
- silver line (HV distribution) too thick (Elvia)



solution

- repair at CERN: locally remove coverlay, fill with Araldite 2011
- demonstrated again how to fill and flatten the HV via
- provided screen for screen printing silver line (Elvia)

→ not an issue anymore

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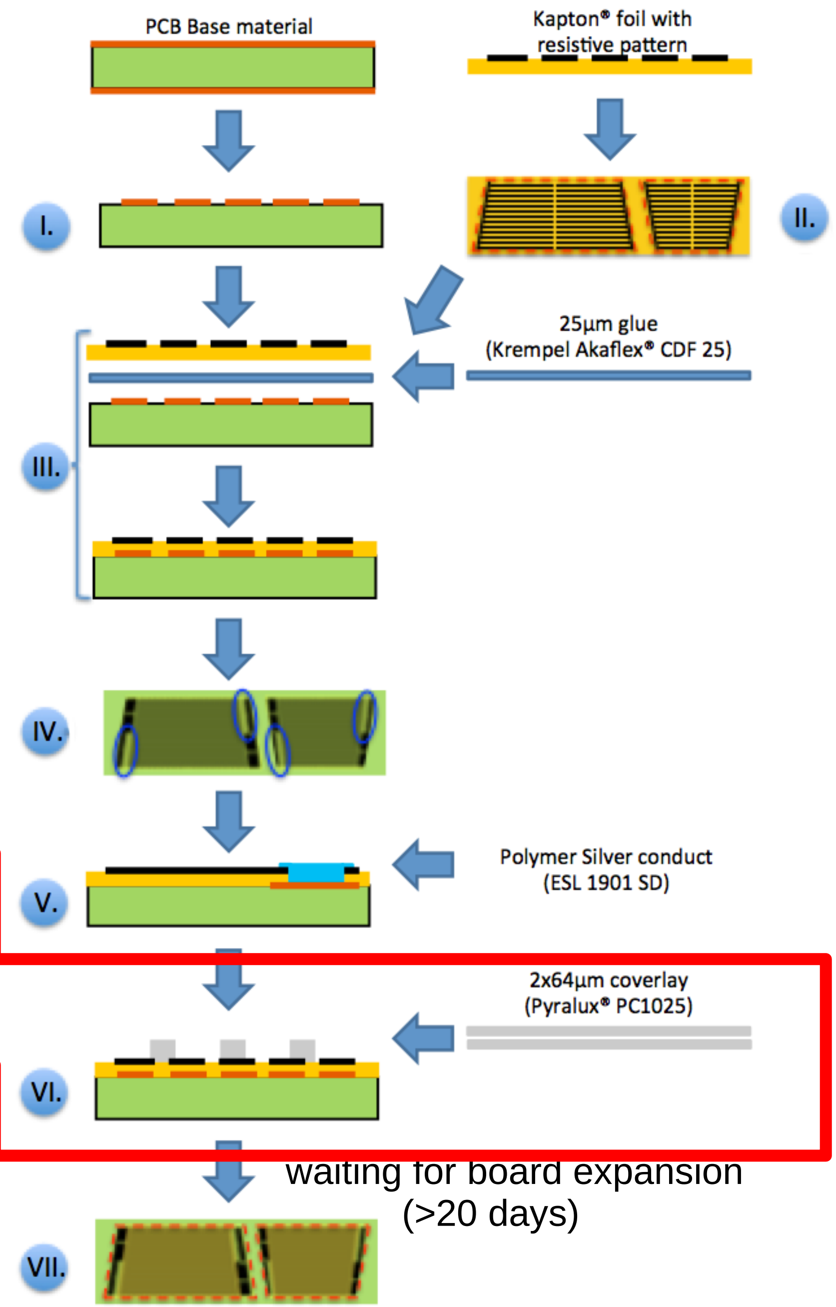
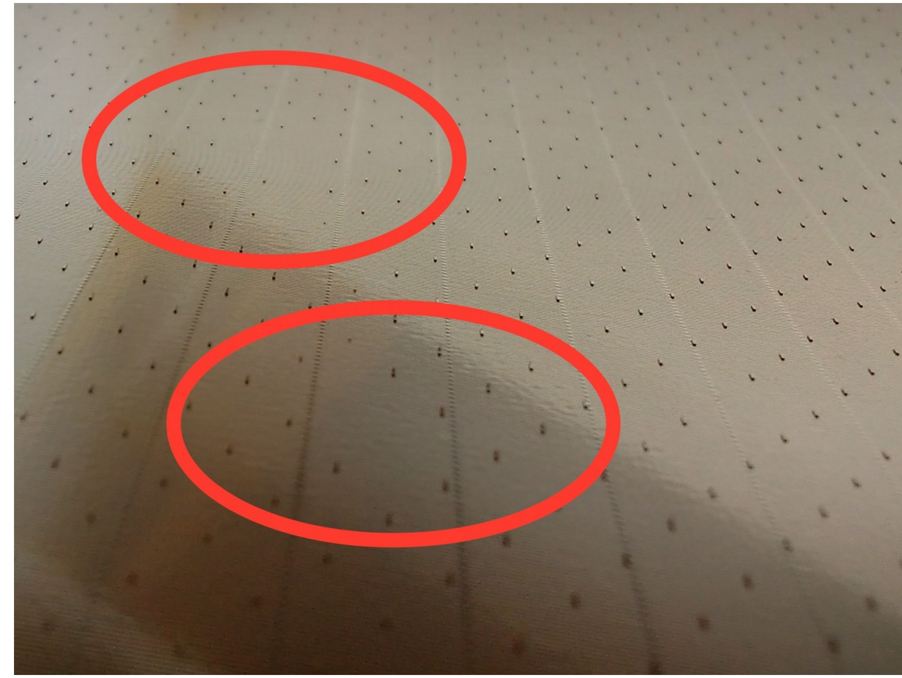


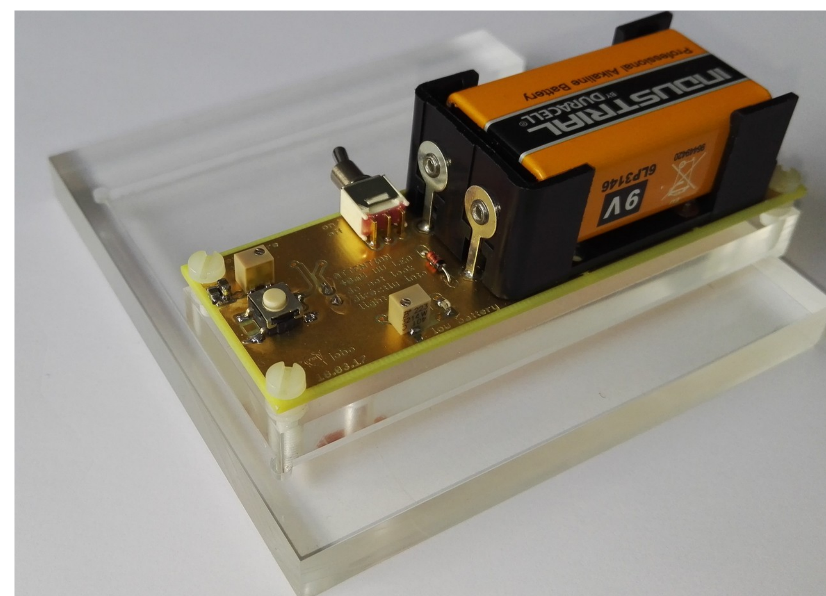
Missing Pillars

some pillars missing (Eltos) or weakly attached (Eltos & Elvia) → non-consecutive missing pillars tolerable during operation



origin of issue

- release film in direct contact with Kapton foil during Kapton foil gluing and pressing
- Eltos dropped polishing (&washing) step after gluing
  → contamination from release film between resistive strips and coverlay
- drying stage after coverlay development too hot (Elvia)



solution

- repair: remove badly attached pillars, clean, re-laminate coverlay, local UV curing, alternatively glue spare pillars with Araldite 2011
- re-introduced mechanical polishing (Eltos)
- reducing temperature during drying (Elvia)

→ not an issue anymore

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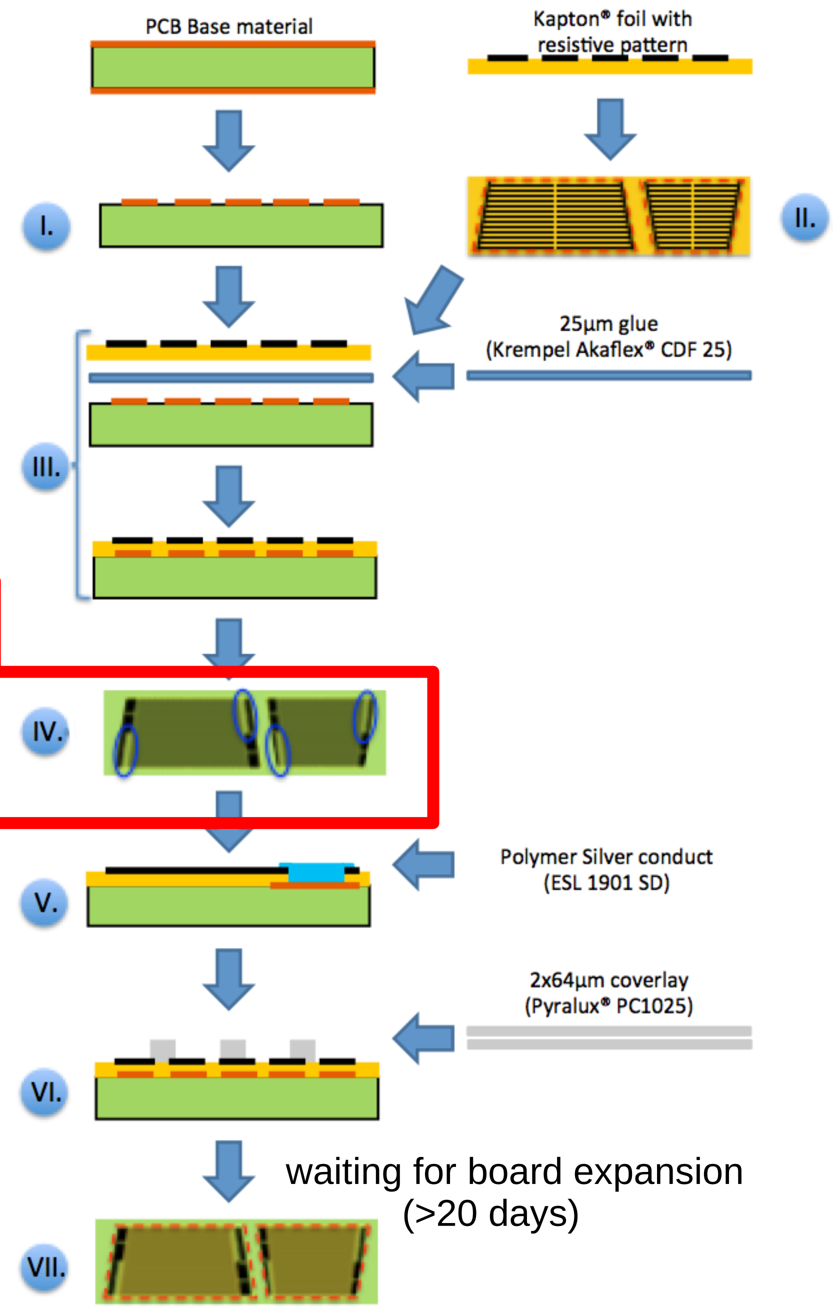
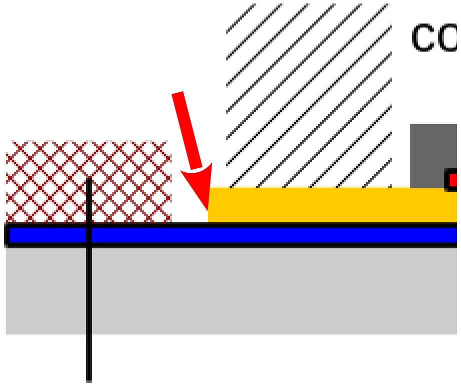


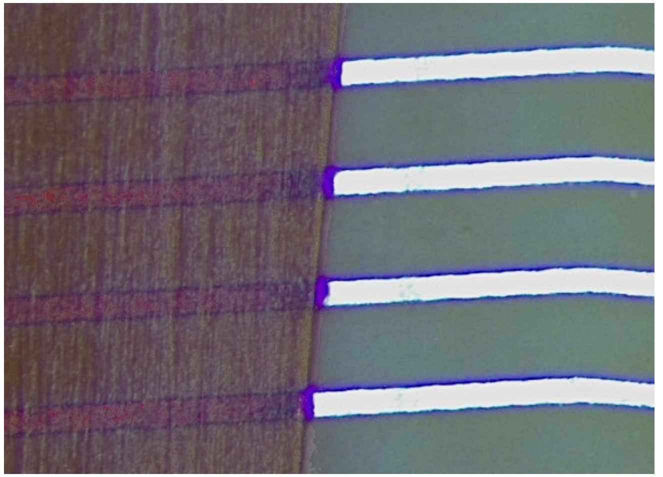
Interrupted Readout Strips

readout strips interrupted below edge of Kapton foil (Eltos)

- impossible to spot visually
- only visible after Kapton removal
  → measure strip to silver line C



before Kapton removal



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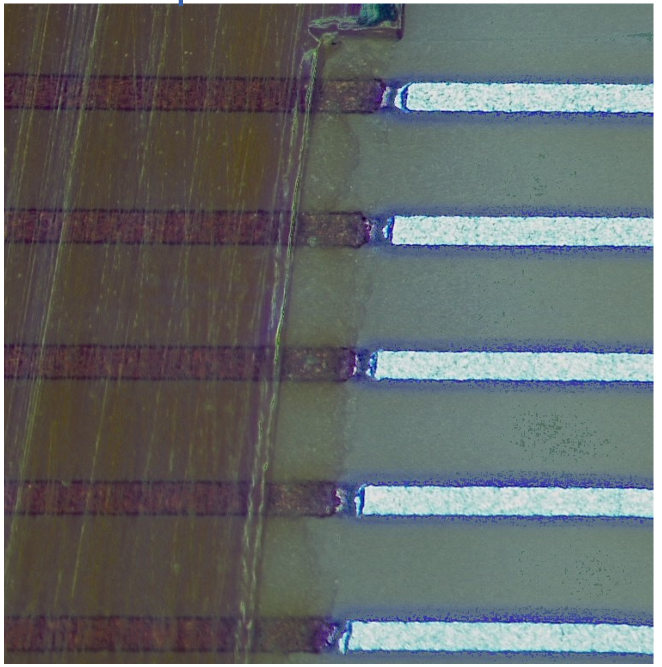

origin of issue

chemical silver deposition on Cu: clean, µ-etch, silver

1. glue between Kapton and board attacked by µ-etch
2. when entering Ag bath, open Cu is immediately coated with Ag
3. glue slowly dissolved by Ag bath chemistry
   → small spots of uncoated Cu appear
4. electro-chemical cell between Ag coated surface (large) & uncoated Cu (tiny)
   → aggressive dissolution of Cu, strong Ag deposition near by

solution

- fast Ag coating (0.1µm) → no damage
- cover Kapton edge with tape
- slow Ag coating (+0.5µm) → no damage since no Cu appears

Summary

ATLAS Micromegas readout board production progressing well

- 20% of boards already produced
- >70% yield → good! will considerably increase in future

thorough QC is essential

- caught all critical problems during QC at CERN
- unexpected defects can appear any time
- known defects can re-appear

very close follow-up at companies during production

- have quickly found and implemented solutions for all appearing problems
- companies are willing to improve/adapt production methods

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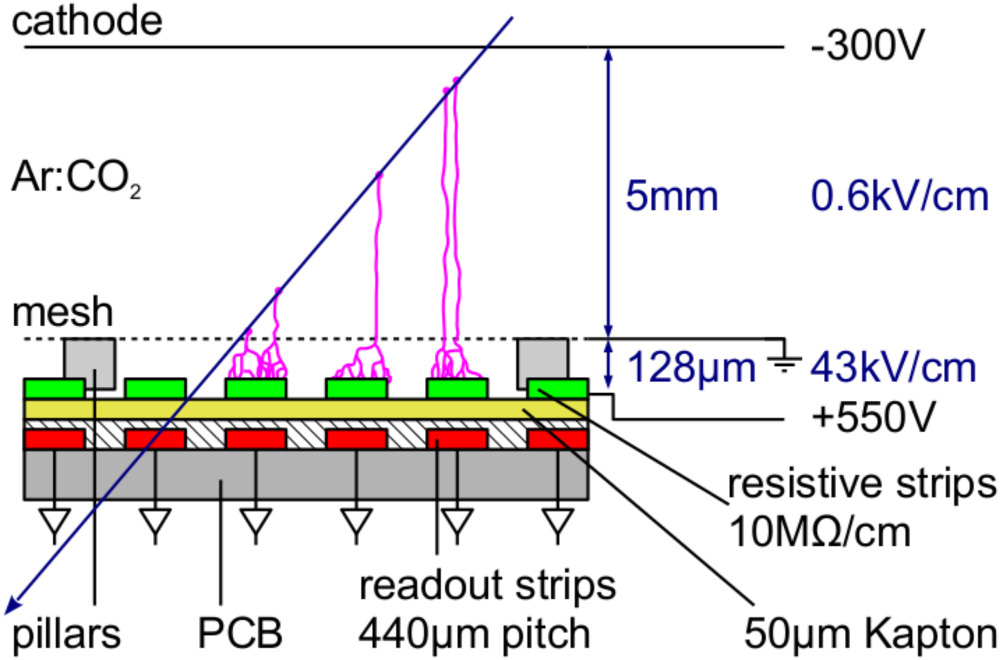
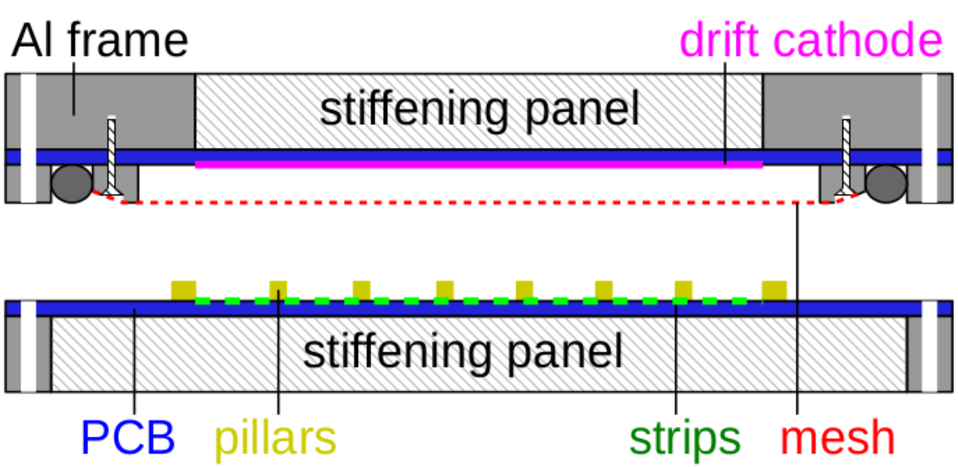
Thank you!

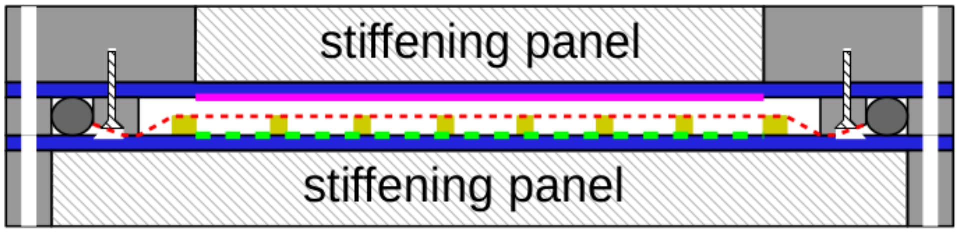
backup

backup - Resistive Strip Micromegas

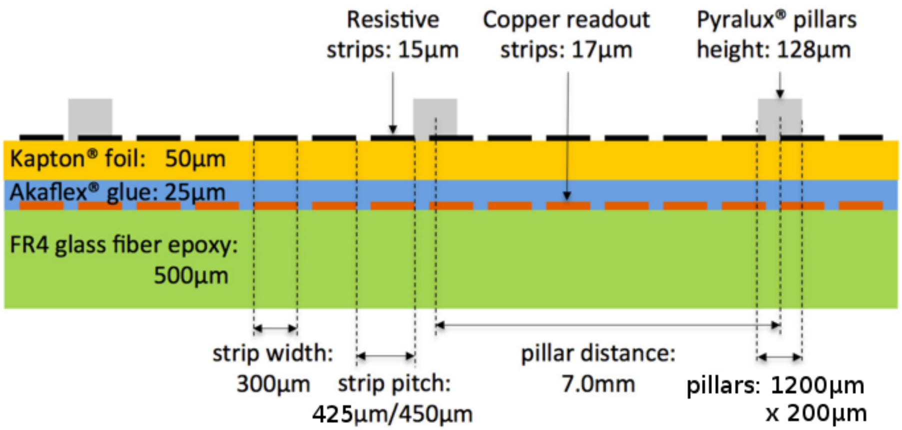


- resistive anode strips
  → suppress discharge influence on efficiency
- floating mesh, attached to cathode
  → facilitate cleaning & simplify commissioning
- large active areas: $2.5 \times 1.5\,\mathrm{m}^2$
- detectors based on stiff but light-weight panels
  → cathode on drift panel
  → mesh attached to drift panel
  → readout structure on readout panel

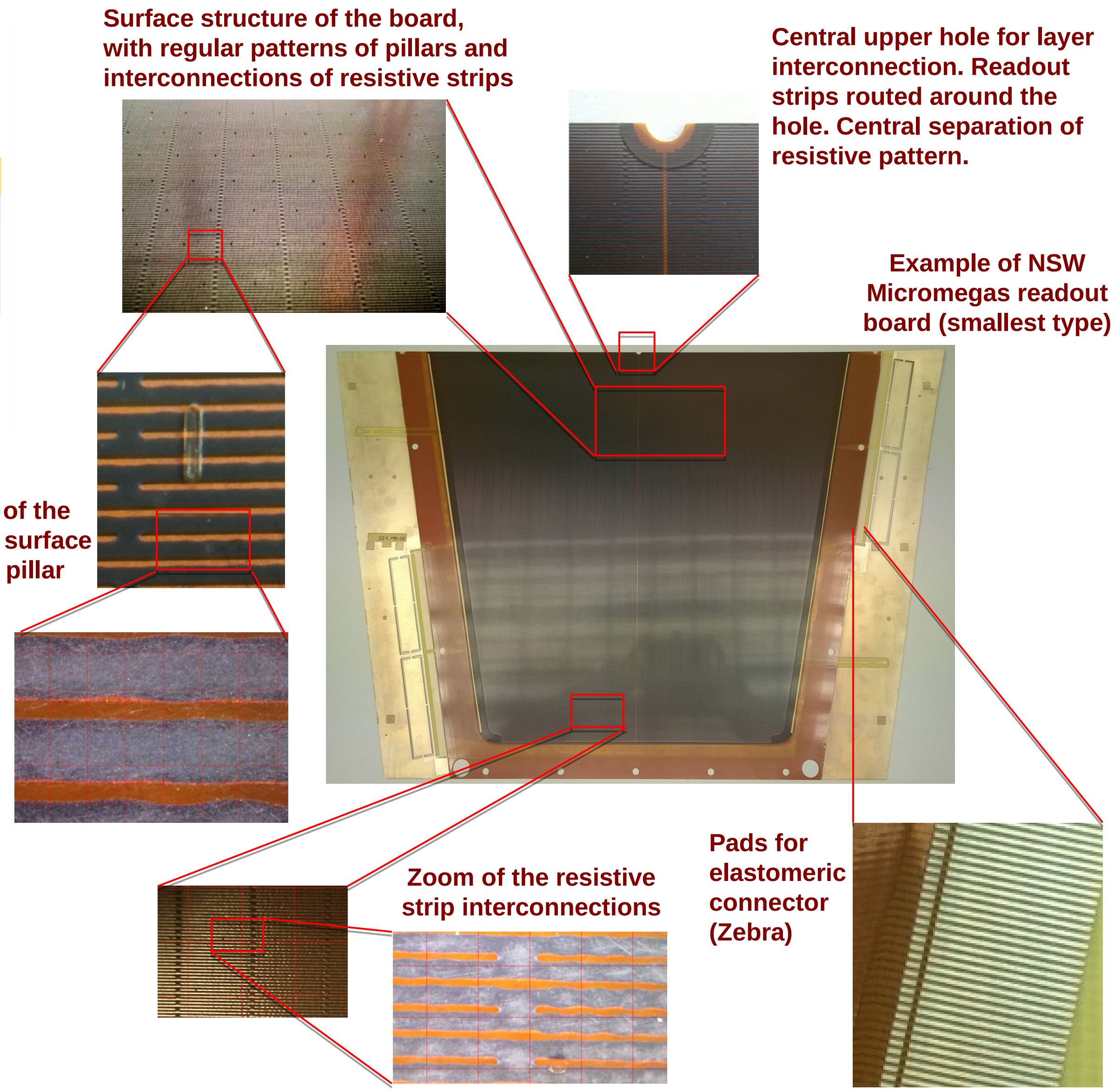




backup - Readout Board Design



- 1022 strips/board
- readout strips: 425 or 450µm pitch
- screen-printed resistive strip pattern with same pitch (Japan)
- HV supply via silver line from the short sides
- resistive pattern interrupted in the center → two HV sectors per board
- elongated pillars: 1200µm x 200µm
- readout strips routed to pads for elastomeric connectors (Zebra)



backup - QC Form – Manual, Storage & Documentation

online QC form

→guide shifter through QC

→easy to use interface to collect & store QC results

→documentation for construction sites (online & print version)

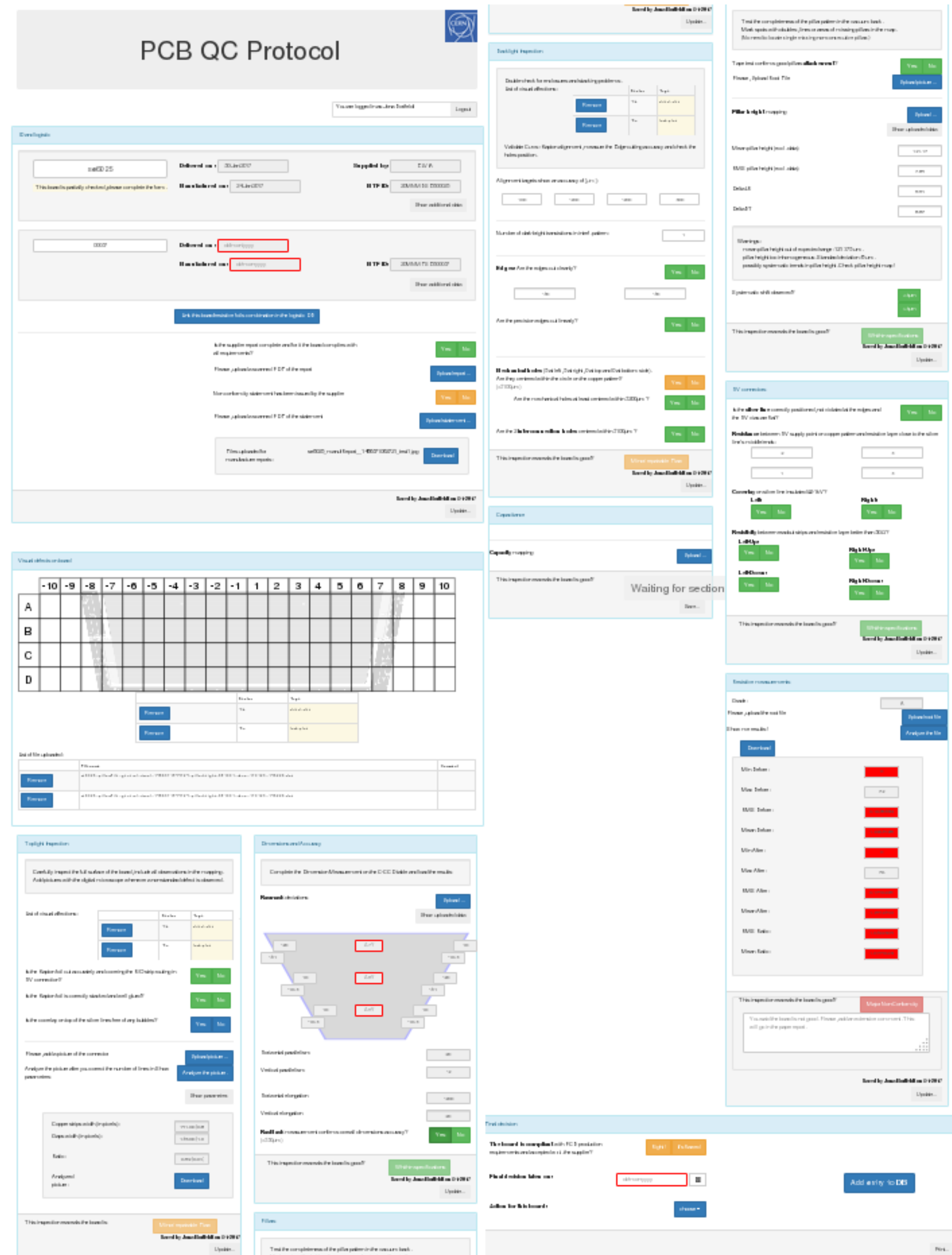
→seamless interface to GUIs (etching, pillar height, dimension, resistivity, strip capacitance)

- logistics (board & foil pairing in log db)
- top light visual inspection
- electrical tests
- back light inspection
- dimensional inspection
- pillar height mapping
- resistivity mapping

→ final QC decision (good, repairable, reject)

→ print QC summary for construction sites

→ save in CERN QC database

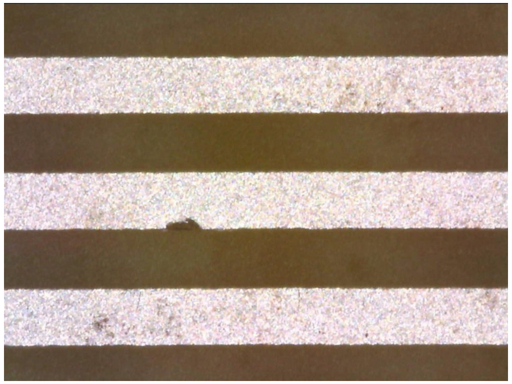


backup - Top Light Inspection

visual inspection

- dirt, damage, obvious problems
- bumps, dents, scratches
- chemical sliver plating
- resistive strips Kapton foil cutting
- unexpected issues

- bumps
- dirt
- coverlay insulation
- readout vs resistive strips insulation



etching quality

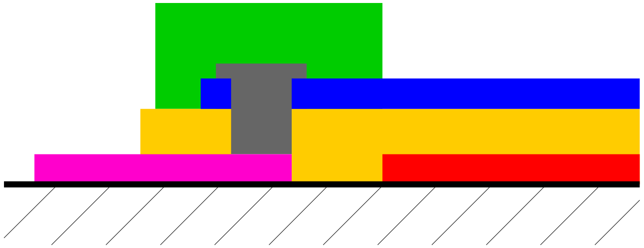
- microscope picture of Zebra footprint, automatically analyzed

electric connectivity

- connectivity HV-contact to resistive pattern (low voltage)

high-voltage integrity

- insulation readout strips vs resistive pattern @ 1kV
- insulation coverlay on silver line vs mesh @ 1kV



Back Light Inspection

edge cutting accuracy

- two target markers per edge
  (100µm line width, 100µm space, 50µm steps)

edge cutting quality

- straightness: press edge against rectified ruler
- cleanliness

agreement between non-precision holes & Cu pattern

- circular markers around holes

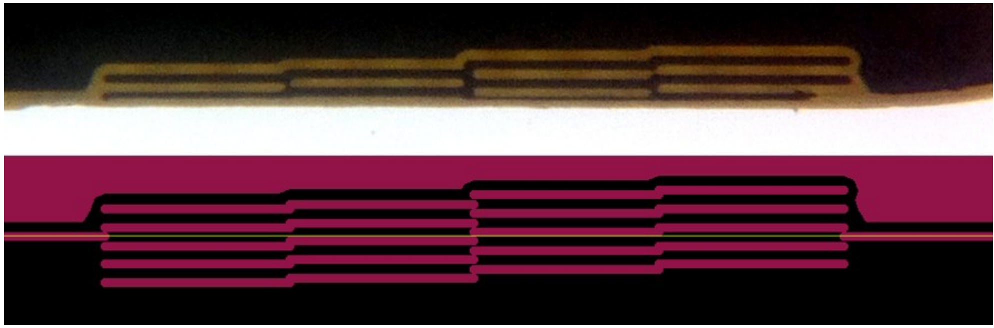
alignment resistive pattern vs Cu pattern

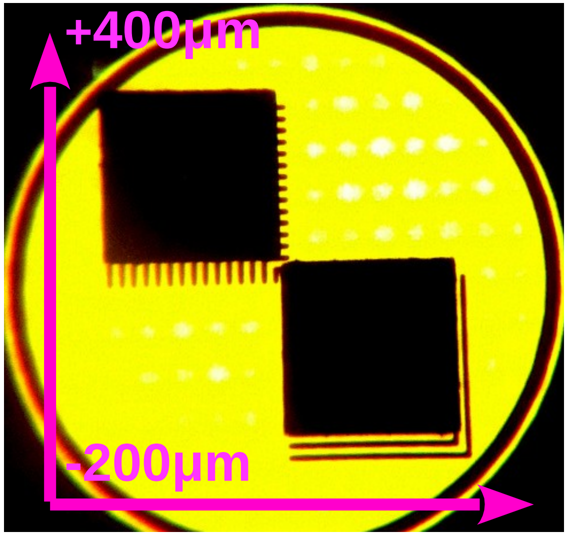
- two markers per board
  (3mm x 3mm squares on resistive pattern vs Cu lines with 100µm width and 100µm space)

pillar pattern

- missing pillars well visible on inclined board
- pillar removal test with adhesive tape

- edge cutting (strips damaged)
- agreement holes vs Cu pattern
- missing pillars



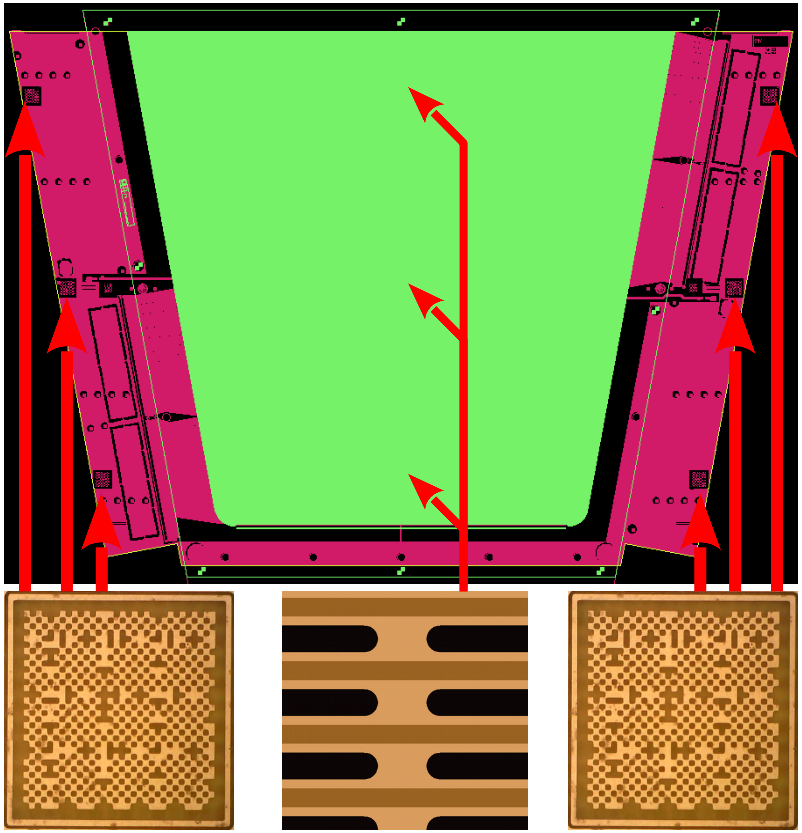


backup - Dimensional Inspection

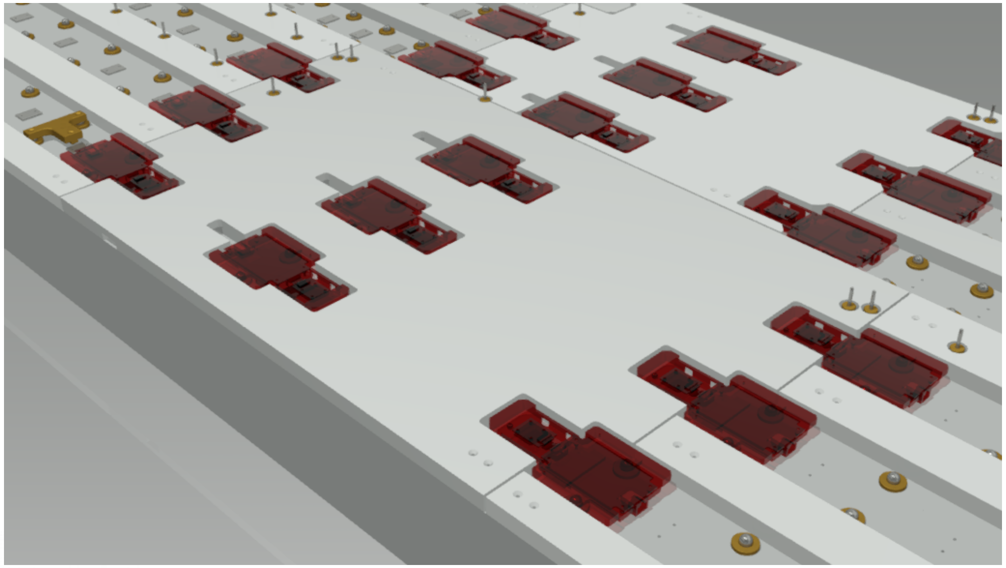
absolute width & length
- six rasmasks per board

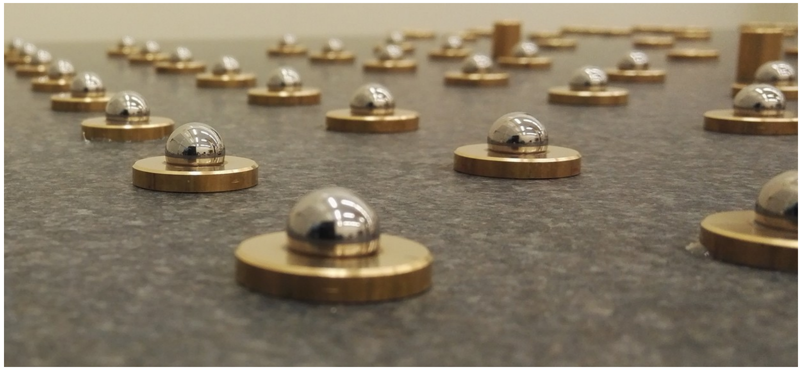
boards too large: 0.4mm/m
→large problems with precision, edges & holes

distortions
- registration of strip position in center + rasmasks



- nine contact CCDs on granite table
- surveyors resting on pairs of precision spheres O(30μm), glued onto table
- fast measurement and analysis with custom GUI with direct interface to QC form (Pavia, Tokyo)
- flexible configuration





backup - Pillar Height Mapping

pillars: two layers of 64µm coverlay laminated onto board
define amplification gap
→height homogeneity important for gas gain homogeneity

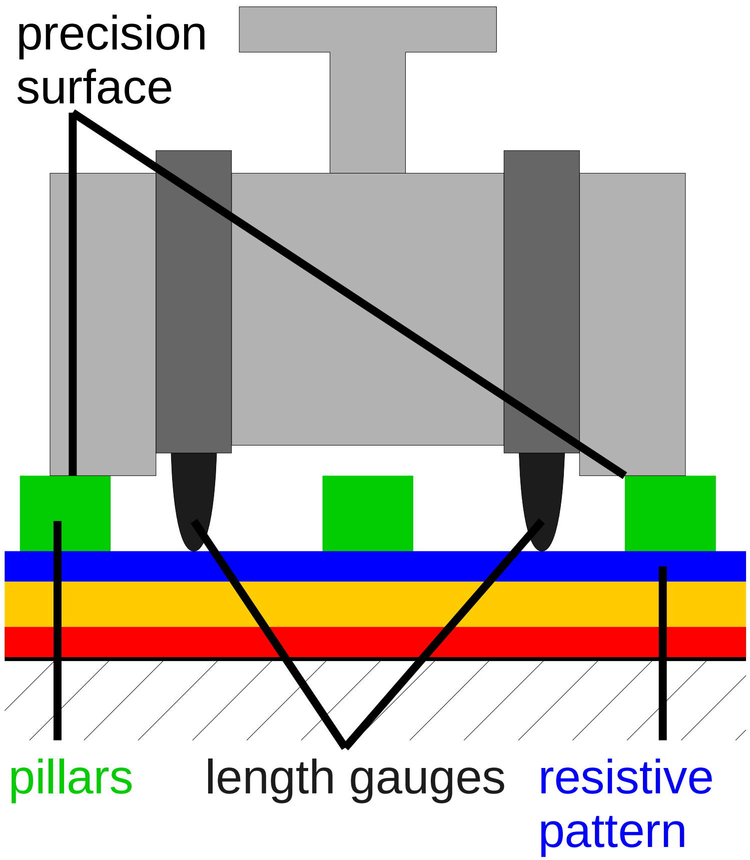
side note: no problems seen during mod 0

height defined by
- coverlay material thickness
- laminator pressure homogeneity
- homogeneous lamination, no waves, wrinkles

pillar height tool
- precision surface, resting on several pillars
- four length gauges, touching anode

→direct measurement of pillar height

pillar height GUI (LMU, Tokyo & CERN)
- acquisition of gauge data & analysis
- direct interface to QC form



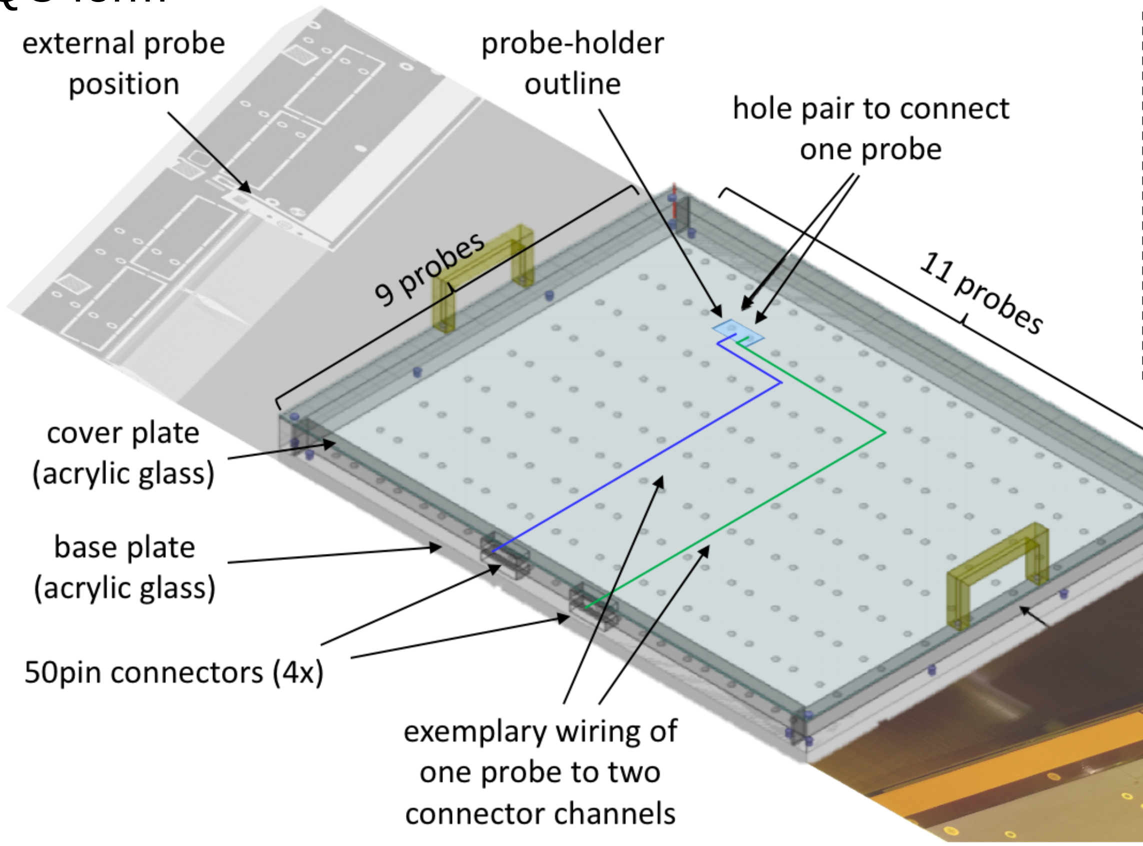
backup - Resistivity Mapping

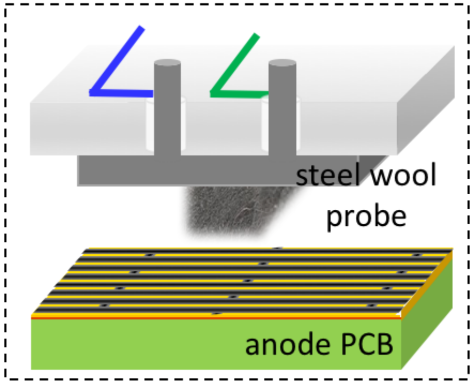
resistivity is mapped during resistive foil QC @ Kobe

change in resistivity during production
- due to pressing & polishing (only Eltos)
- due to problem in production process

automated tool and GUI (Tokyo & Wuerzburg)
- remap resistivity at CERN
- direct comparison before ↔ after
- direct interface to QC form

- occasional large resistivity increase
- issue with resistive paste curing





probe schematic

backup - Strip Capacitance Measurement

automated optical inspection during production
→ readout strip interruptions & shorts

on final board covered with resistive pattern
→ not visible anymore

capacitance of neighboring strips measured
→ 1.15pF/cm for SM1 & SM2
→ 0.8pF/cm for LM1 & LM2

→ tool for automatic measurement of C between neighbor-ing strips with known length → interruptions & shorts