Fabrication techniques and industrialization of MPGDs.

Zaragoza July/2013

CERN PCB Workshop MPGD history

'96: GEM 50 x 50mm with a gain of 10.

'97: GEM 100 x 100mm with gain of 1000.

'98: GEM 400 x 400mm; 1D and 2D readouts; micro-groove and micro-well detectors.

'00: 3D GEM readout; 1D readout for Micromegas in COMPASS.

'01: PIXEL GEM readout; 2D Micromegas readout.

'03: PIXEL Micromegas readout.

'04: Bulk Micromegas detector 100mm x 100mm. Micro BULK detectors

'06: Half cylindrical GEM detector.

'08: first large GEM 1.2m x 0.4m. First spherical GEM

'09: first large BULK Micromegas 1.5m x 0.5m

'11: First resistive Bulk Micromegas 100mm x 100mm

'12: First 30cm x 30cm NS2 GEM detector

'12: First 1m2 Resistive Micromegas

'12: First 2m2 Resistive Micromegas

'12: First NS2 GEM detector 1.2m x 0.5m

'12: Full cylindrical GEM detector

'13: GEM 2m x 0.5m ?? Micromegas 3.4m x 2.2m ??

OUTLINE

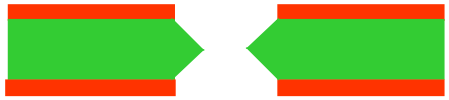
- **GEM**
  - Laser , plasma , chemical
  - Single mask , double mask
  - NS2 assembly
  - Mass production / industrialization status

- Micromegas
  - STD, BULK
  - Protection resistor : foils, groove filling, printed , vacuum deposited
  - Mass production / industrialization status

- Micromegas microbulk
  - std, X/Y, Low mass

- THGEM
  - Last improvements, Pashen curve guide
  - Large size and industry production status

Laser , plasma, chemical etching



- **Chemical etching**
  - -Adjustable angle
  - -Easy inspection
  - -Lowest cost
  - -Mass production in study
  - -Many possible suppliers

  - -Bi-conical shape
  - -Possible charging up
  - -Apical NP only

- **Laser etching**
  - -Cylindrical hole shape
  - -No charging up
  - -Many materials
  - -Mass production in study
  - -Uniformity

  - -Carbonization

  - -One possible supplier
  - -long processing time
  - -High processing cost
  - -Laser cost

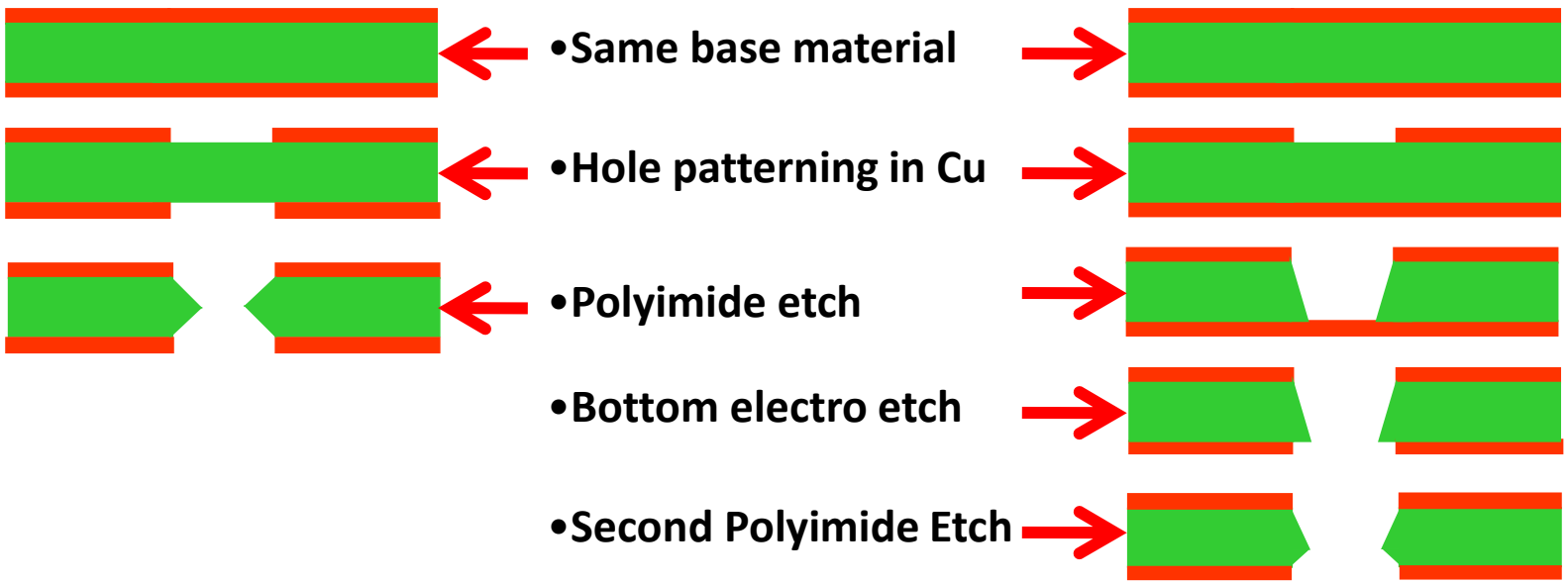
- **Plasma etching**
  - -Many materials
  - -Many techniques

  - -Medium cost
  - -Uniformity

  - -No on going R&D
  - -Isotropic etching
  - -Difficult to clean
  - -Lower breakdown voltage

Chemical etching

- Double mask
- Single mask



- Limited to 40cm x 40cm due to
  - Mask precision and alignment

- Limited to 2m x 60cm due to
  - Base material
  - Equipment

Chemical etching

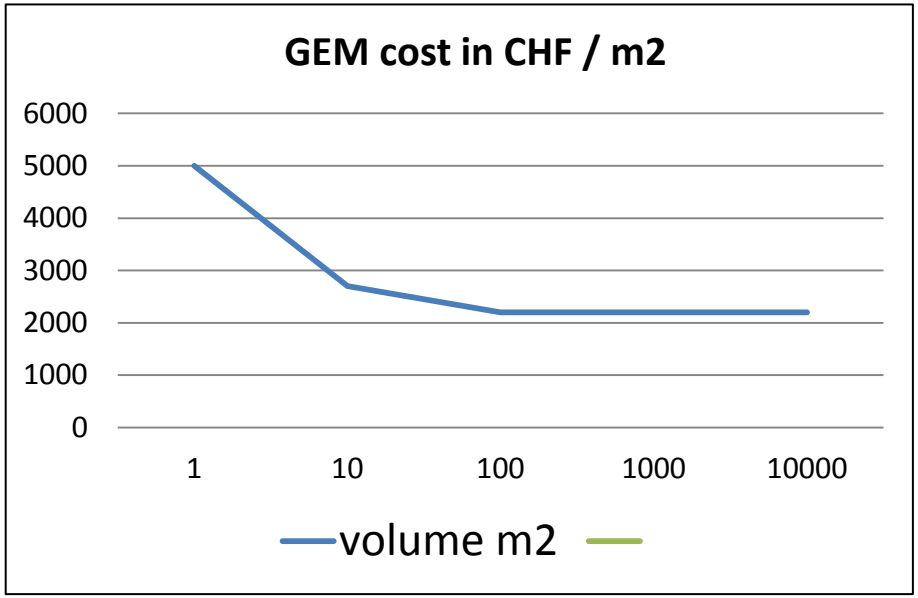
- **Technology offering the best possibilities for cost reduction**

- **For Mass production (1000 m2 or more) most of the steps can be fully done automatically with roll of 50m2**
  - **Roll to roll Lamination**
  - **Roll to roll Exposure**
  - **Roll to roll Copper and polyimide etching**
  - **Roll to roll Stripping**
  - **Still R&D needed for roll to roll Electrochemical etching**
  - **Still R&D needed for roll to roll second Exposure**

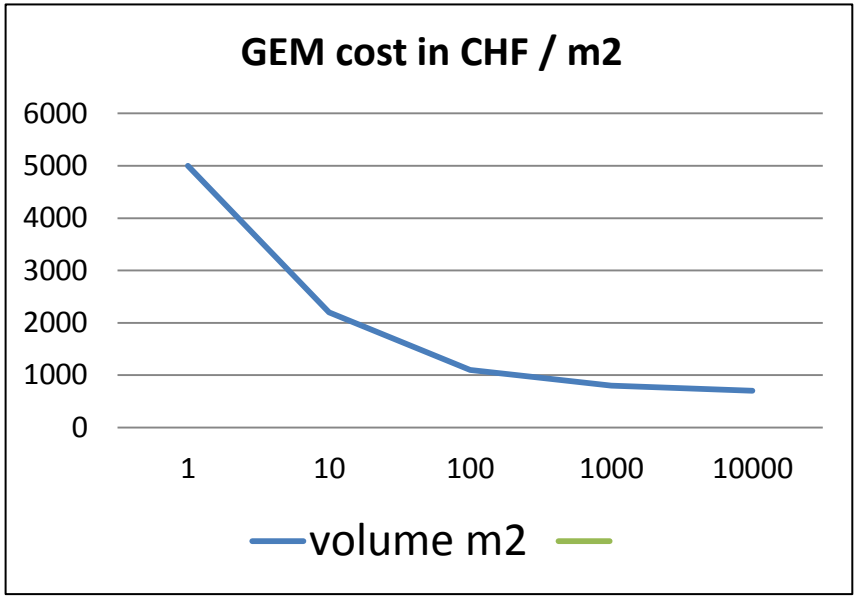
- **For large volume (5000 m2) cost in the range of 700 CHF/m2 can be reached**

Indicative price Vs Volume:

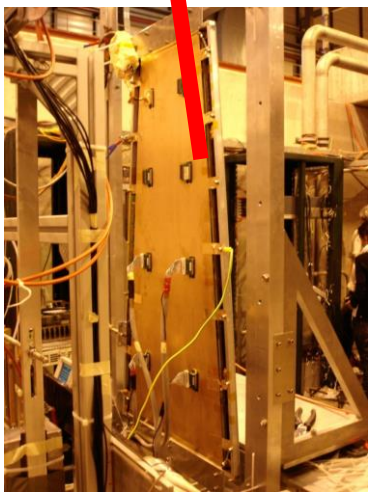
Std technique



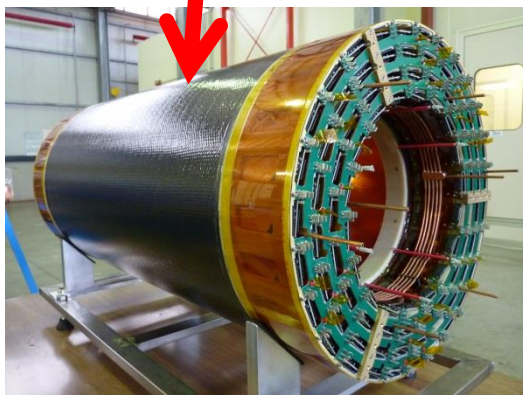
Roll to roll



GEM Single mask examples



- GEM 1.1m x 500mm
- CMS GEM detector GE1/1



- KLOE – Cylindrical 3 GEM Detector
- GEM 800mm x 500mm
- Read-out 2D : 800mmx 500mm

Laser etching

- A new generation of multi beam laser are now available on the market (ORBOTECH)
  - -Laser speed near 2000 holes per sec with 8 beams working in parallel (200 for last laser generation)
  - -Some positive test have been performed (10cm x 10cm)
  - -30cm x 30cm GEM test are in progress

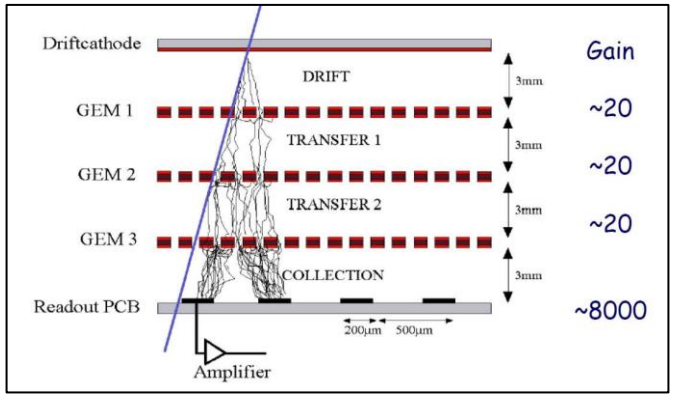
- Laser give the possibility to skip some steps from the full chemical approach.
  - -1 lamination step (out of 2)
  - -1 exposure step (out of 2)
  - -The electrochemical etching step

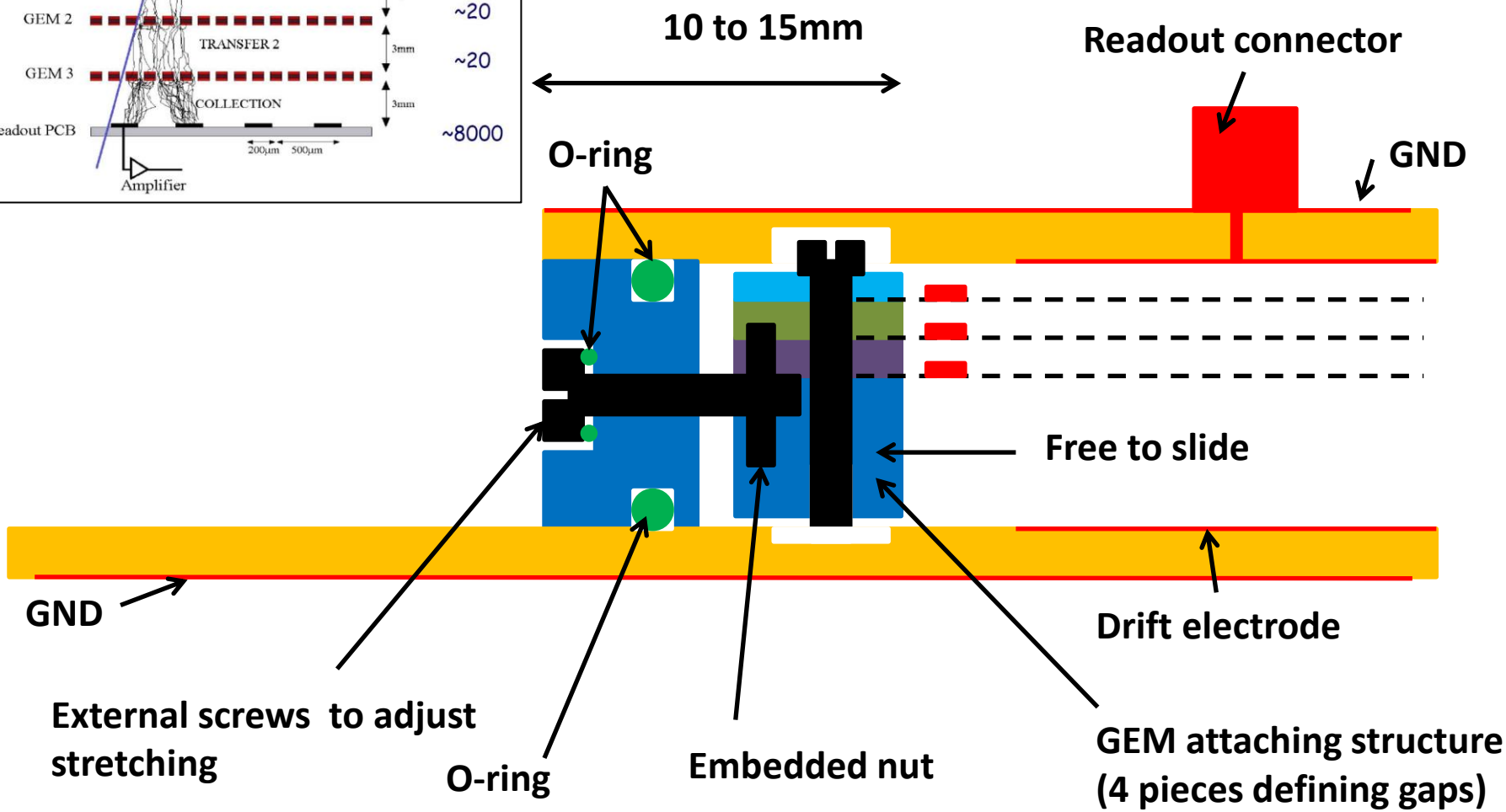
- For large volume (5000 m2) , taking only in account yearly Laser maintenance, prices in the range of 1500 CHF/m2 could be reached.

- The maximum throughput of one machine is approximately 1m2 per day (18 hours). So in case of large volumes many machine should run in parallel.

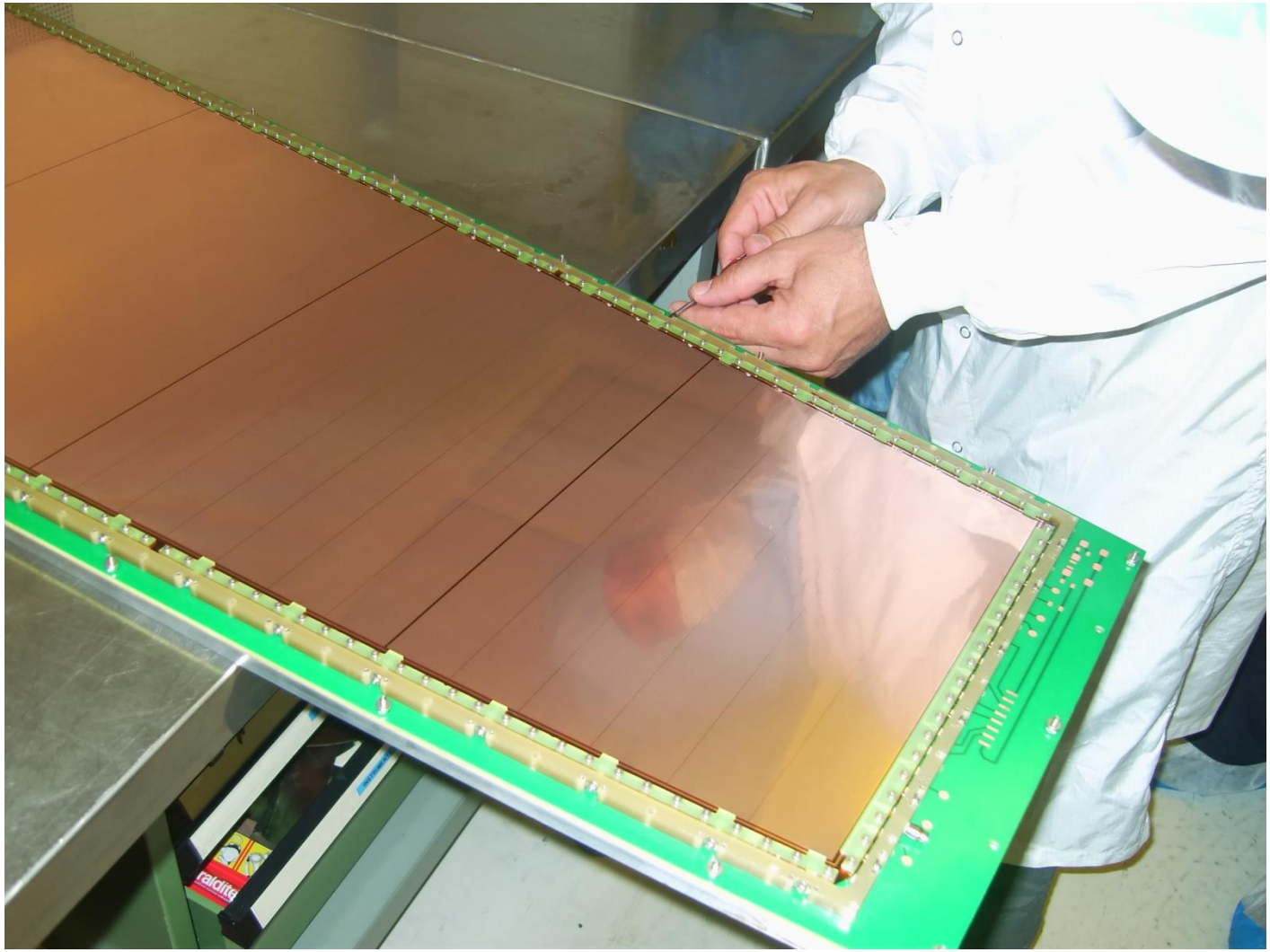
- The machine cost is in the range of 1M CHF!

NS2 assembly





CMS GE1/1 NS2 detector



Already corrected problems:

- **Dust generated during assembly**
  - **No more self threading screws**
  - **Introducing brass inserts and M2 screws**

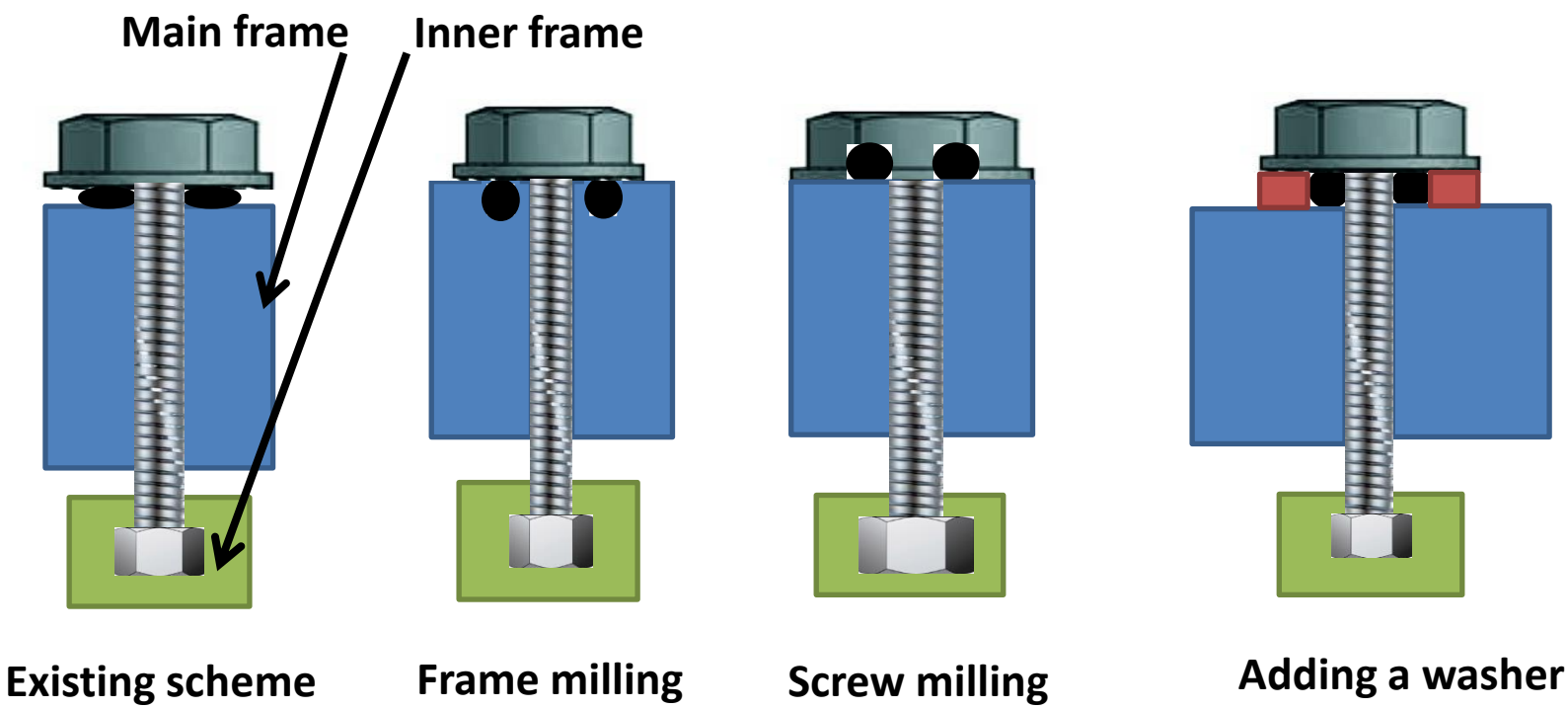
- **Professional Spring for GEMs HV contacts**

- **Board bow due to hard O-ring**
  - **Pre-bended boards**

- **No more gluing steps , the main frame is screwed and made in a single piece**

On going Improvements :

- Tune read-out and drift bending (now 0.2mm→ need better?)
- Test soft o-ring to keep flat boards
- New O-ring scheme for the stretching screws



Comment on the 6 first assemblies:

- **Assembly time below 2.5 hours is realistic**
  - **Exactly 3 hours during the last 2 training sessions**

- **4 detectors version 1 have been produced**
  - **4 tested OK (see RD51talks from Christopher Armaingaud)**

- **6 detectors version 2 are in production**
  - **2 are already assembled (small movie)**
  - **Cosmics and X-Ray test are on going**

NS2 detector advantages:

- **No dead zone in active area**
- **Assembly time**
- **No gluing , no soldering during assembly**
- **Re opening possible**
- **GEM exchange possible**
- **Upgradable.**
    - **The read-out board can be upgraded at any time**
    - **Production can start before final electronic design**

Alternative source of GEM/ technology transfer

- **Techtra**
  - **Polish company**
  - **Making GEM since 10 years**
  - **Licensed by CERN**
  - **Setting up equipment for large GEM production since 1 year**
  - **30cm x 10cm GEMs already produced**
  - **First delivery of 30 GEMs last week**

- **UPLUS/Mecharonics**
  - **Korean company**
  - **Making GEM since a few months**
  - **Licensed By CERN**
  - **30cm x 30cm GEMs already produced (characterization in progress)**
  - **Willing to ramp up to large size**

- **Tech-etch**
  - **US company**
  - **Making GEM since 15 years**
  - **Many small and medium sizes GEM have been produced**
  - **Recently involved in STAR experiment (80 GEMs 40cmx40cm)**
  - **Willing to ramp up to large size**
  - **Licensed by CERN**

- **Scienergy**
  - **Japanese company**
  - **Making GEM since 6 years**
  - **Top quality laser drilled GEM up to 30cm x 30cm**
  - **Licensed by CERN**

Large Drift and read-out boards procurement:

- **Viasystem**
  - **US company**
  - **Single sided boards size: ?**
  - **Double sided boards size?**
  - **Multilayer boards (8 layers) size : 1.2m x 0.5m**

- **ELTOS**
  - **Italian company**
  - **Single sided boards size: 2m x 0.5m**
  - **Double sided boards size: 1.2m x 0.5m**
  - **Multilayer boards size: 700mm x 0.5m**

- **ELVIA**
  - **French company**
  - **Single sided boards size: 2m x 0.5m**
  - **Double sided boards size : 700mm x 0.5m?**
  - **Multilayer boards size: 700mm x 0.5m**

OUTLINE

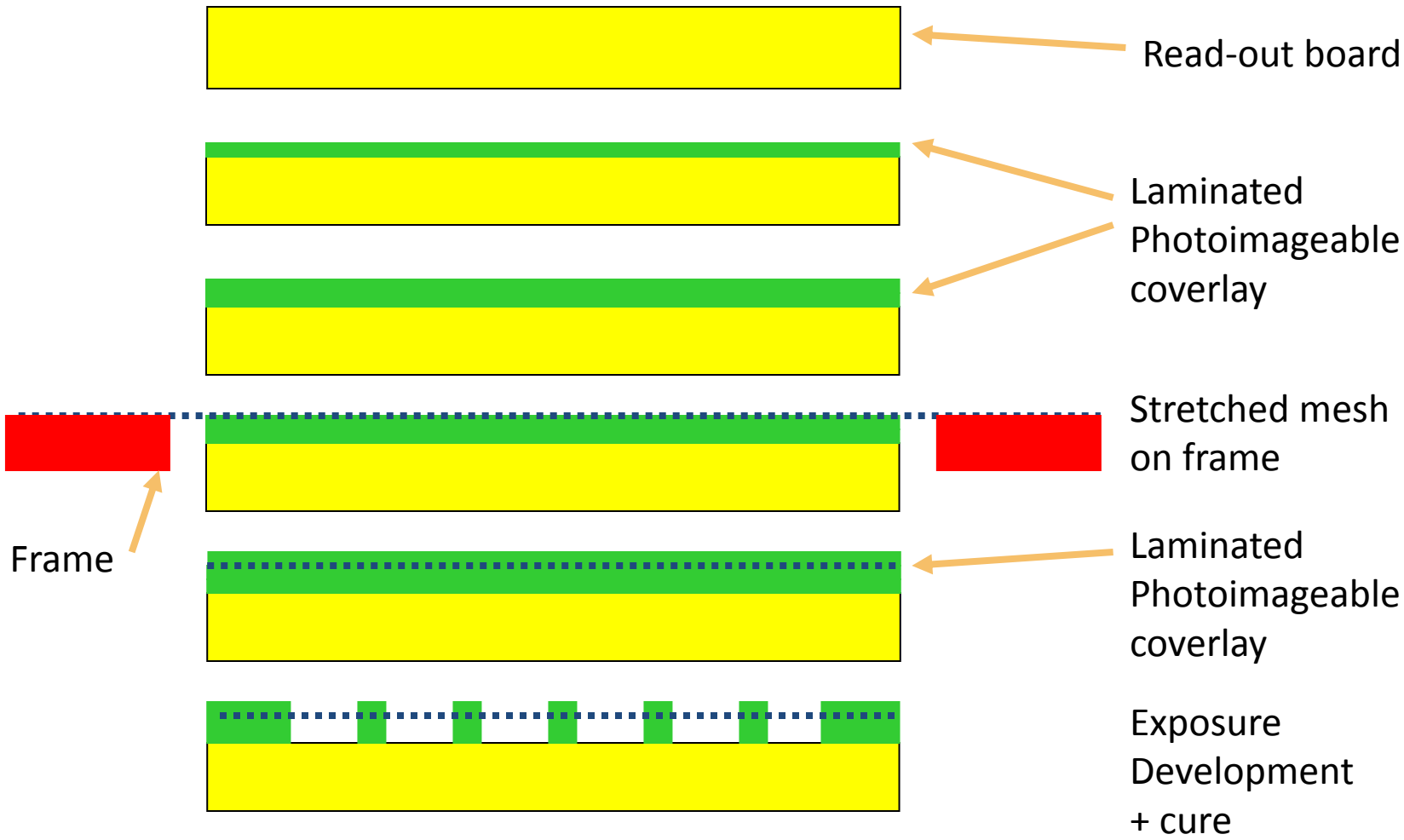
- ***GEM***
  - ***Laser , plasma , chemical***
  - ***Single mask , double mask***
  - ***NS2 assembly***
  - ***Mass production / industrialization status***

- ***Micromegas***
  - ***STD, BULK***
  - ***Protection resistor : foils, groove filling, printed , vacuum deposited***
  - ***Mass production / industrialization status***

- ***Micromegas microbulk***
  - ***std, X/Y, Low mass***

- ***THGEM***
  - ***Last improvements, Pashen curve guide***
  - ***Large size and industry production status***

BULK Micromegas

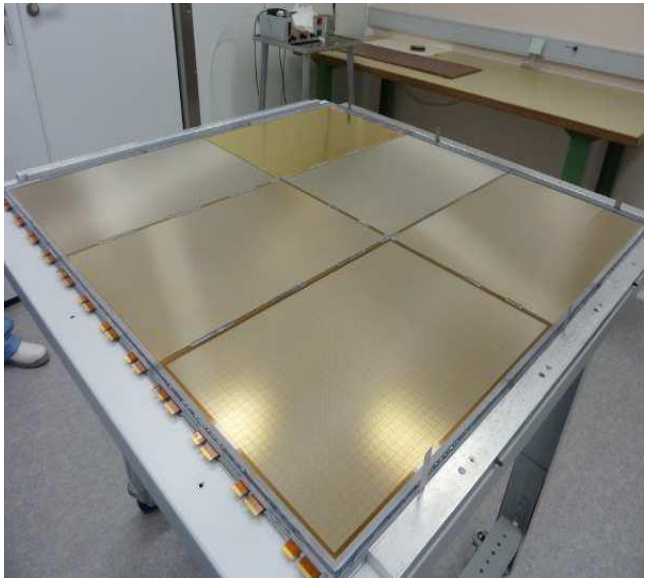


Bulk Micromegas examples

BULK Technology
DUPONT PC 1025 coverlay
BOPP Meshes
SERITEC stretching

Largest size produced:
1.5m x 0.6m
Limited by equipment

Limiting size at CERN is now 2.2mx 1.2m
In a single piece

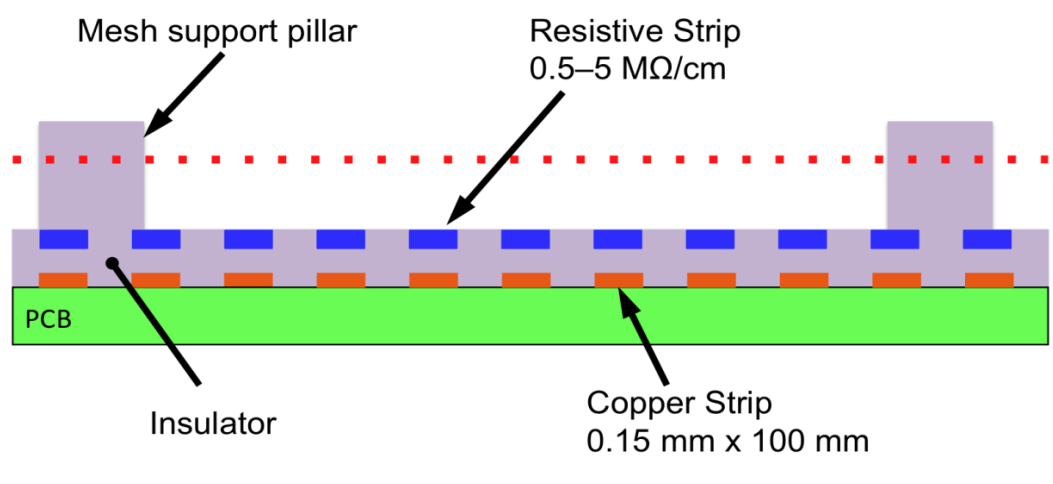


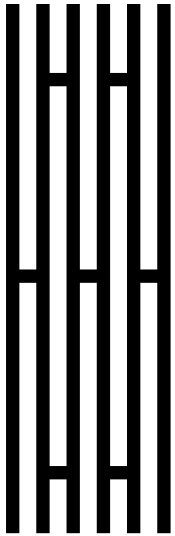
ILC DHCAL

T2K

Resistive Bulk Micromegas

Resistive lines
(see Silvia Franchino &… study)



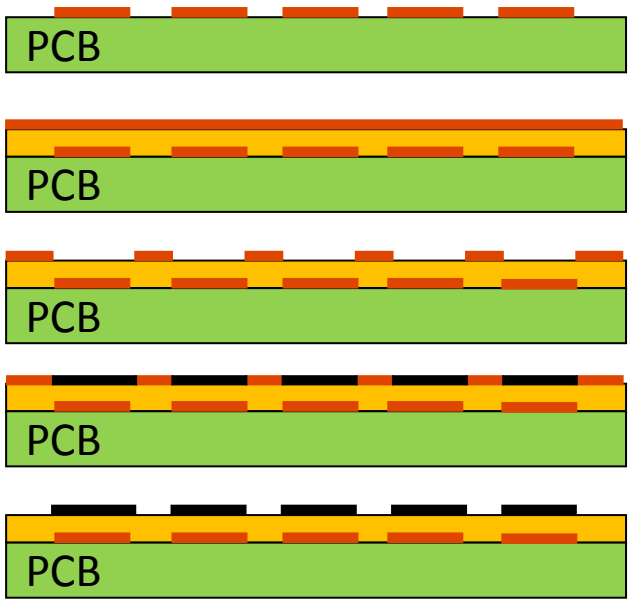


- **Spark protected**
- **Smaller signals by 10-20% related to insulator thickness**
- **Gives the possibility to ground the mesh or the drift**
- **Resistive lines are now connected together**

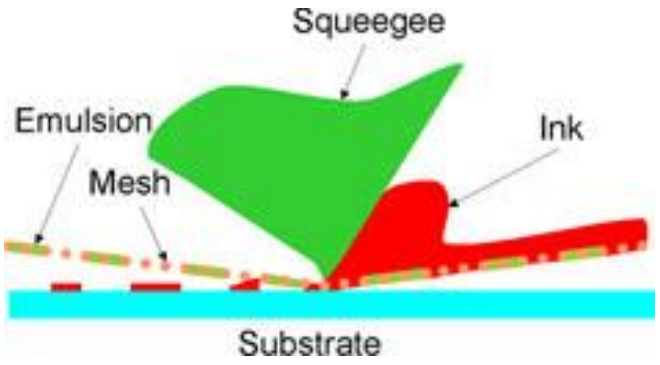
Resistive strips production (on all existing detectors):

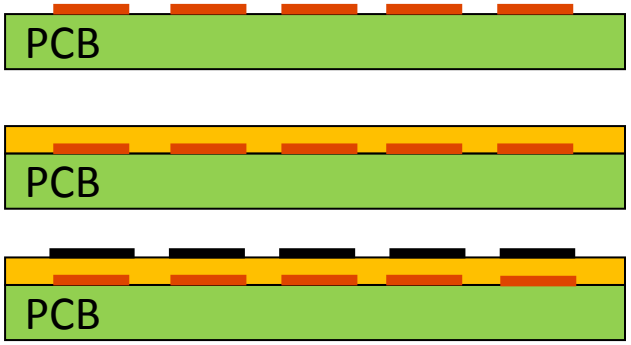
Photolithography

Possibility to go down to 0.1mm pitch

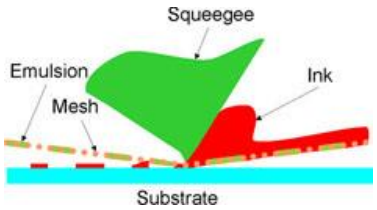


Screen printing





Screen printing :



Semi automatic machine
20 boards/hour
Printing area 1.5m x 0.9m

Full automatic line also available. On going study. Many hundred foils/hour possible rate

Subcontracted to the company Charbonney near CERN

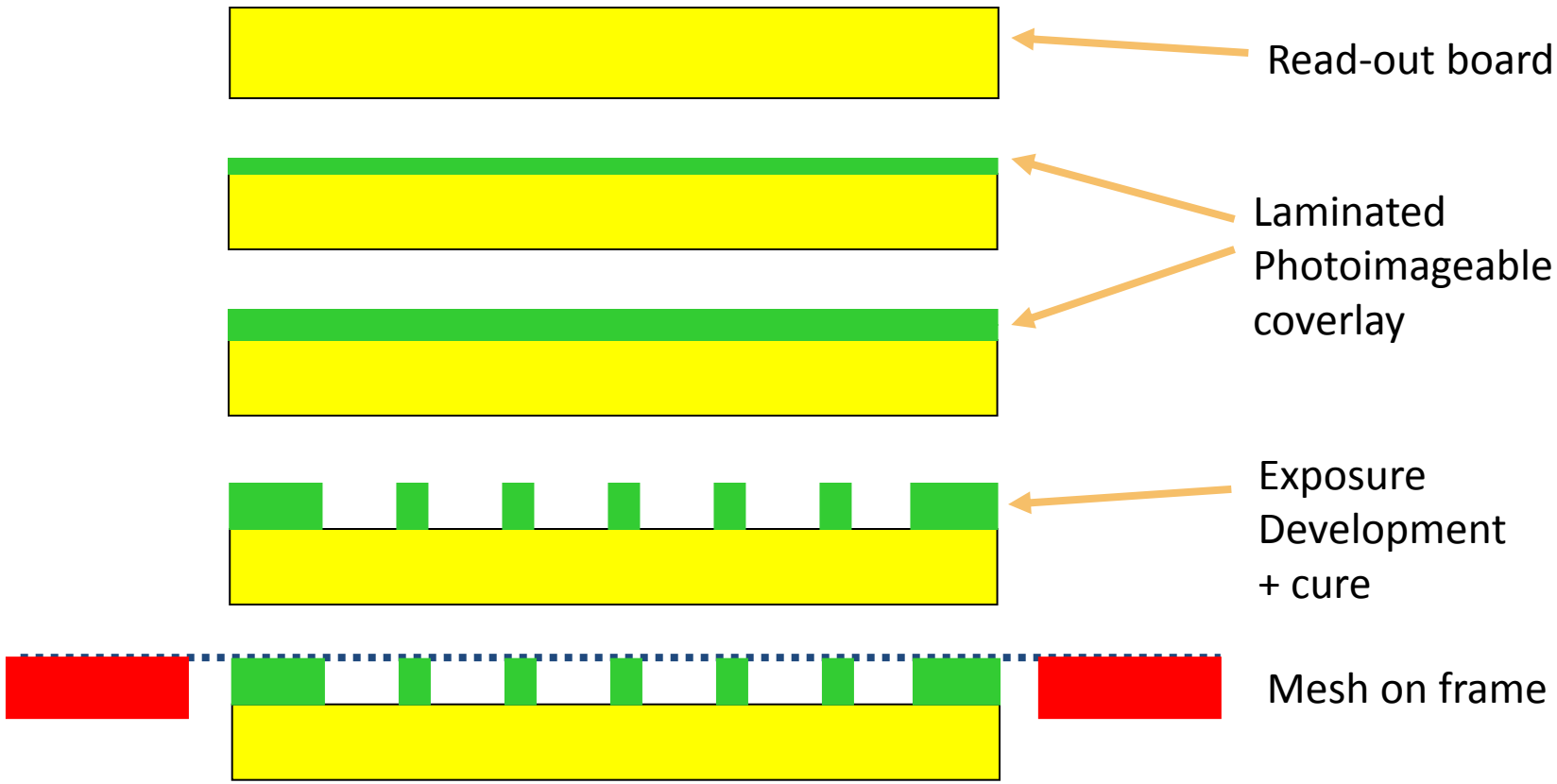
Bulk advantages:

- **Limited dead zones between detectors (TPC application)**
- **Full detector test before final assembly**
- **Lower cost for small and medium size detectors**
- **Perfect for low mass detector**
- **Self supporting**
- **100% available in industry**
- **Cylindrical detectors**

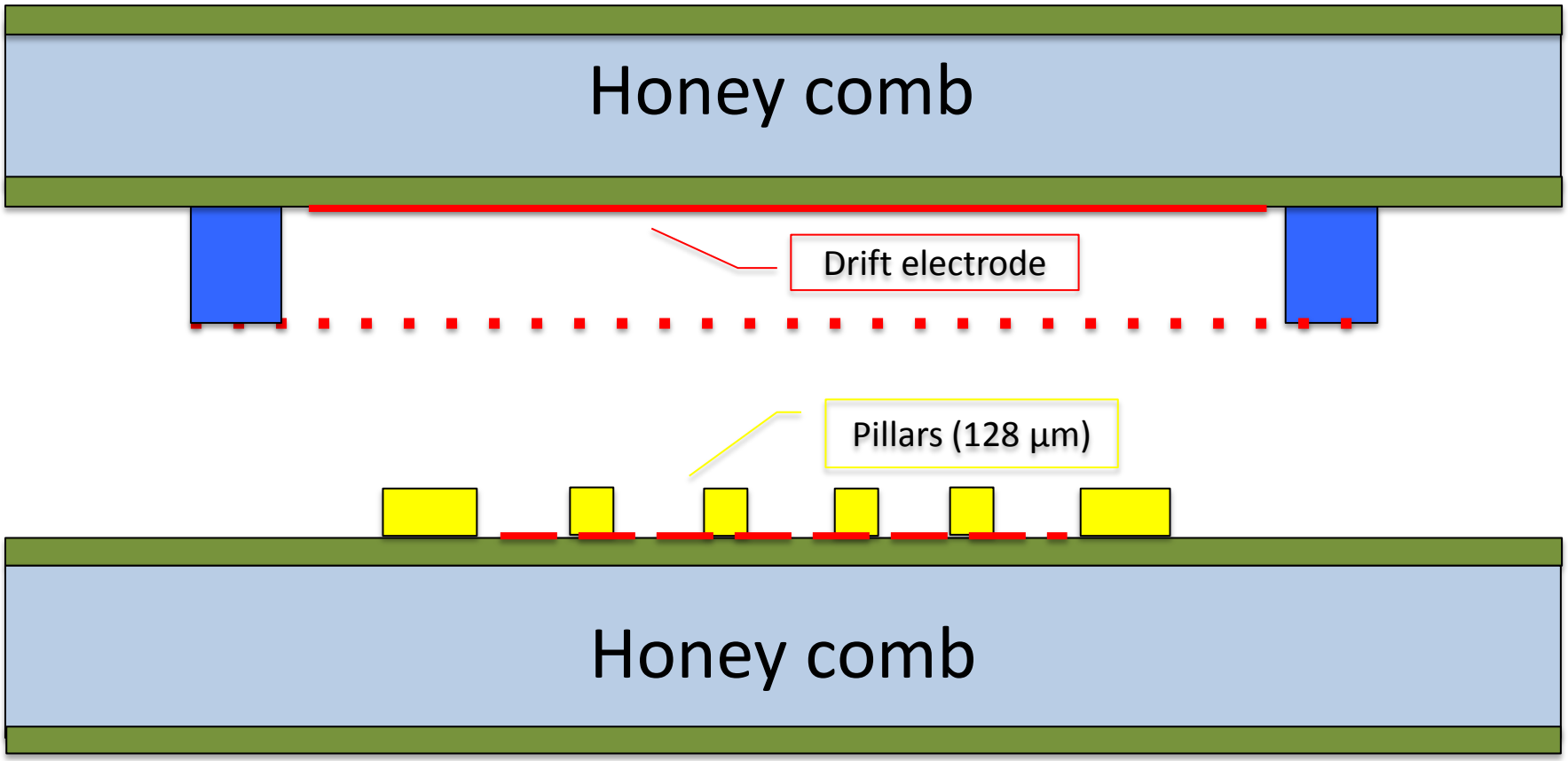
Bulk disadvantages:

- **Large size critical (resistive version): sensitive to dust**
- **Needs temporary frames during production**
- **Limited to 0.6m width in industry (1.2m at CERN)**

STD Micromegas detector (floating mesh):

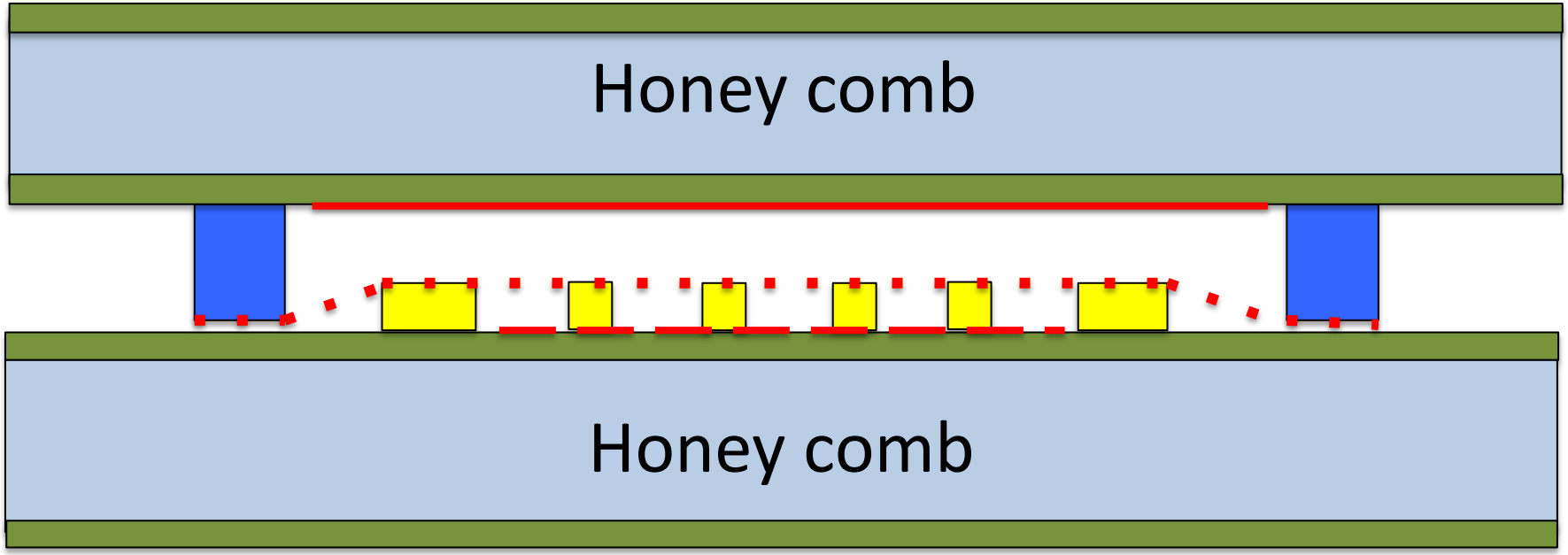


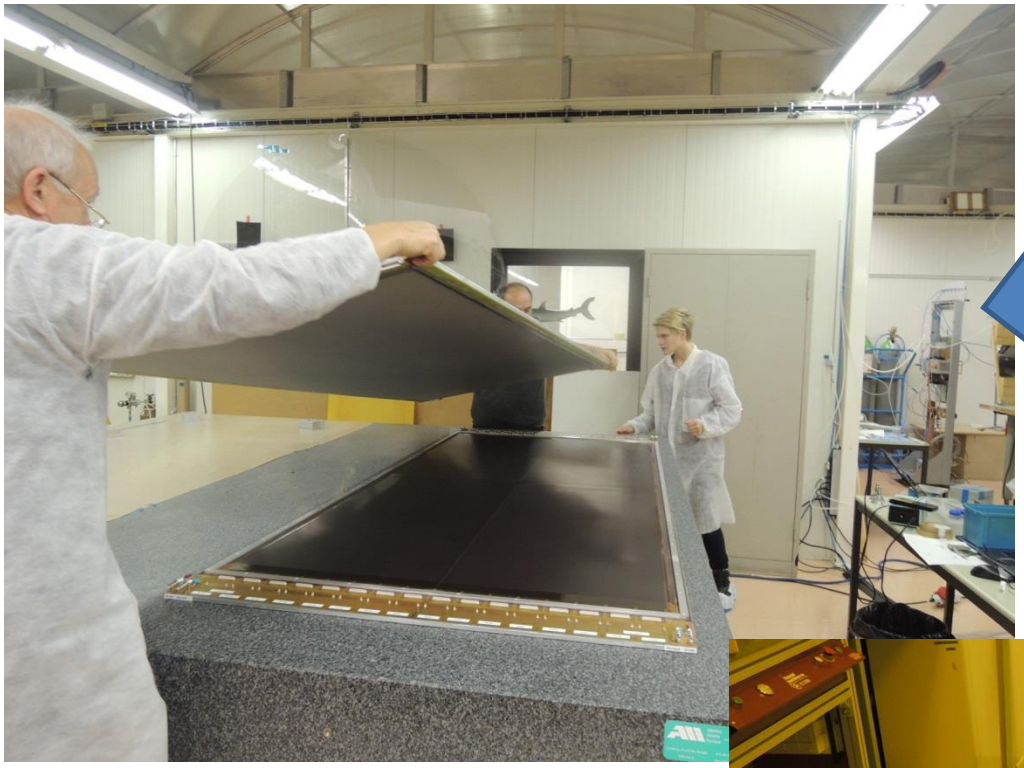
ATLAS prototype 2m x 1m open



STD MicroMegas

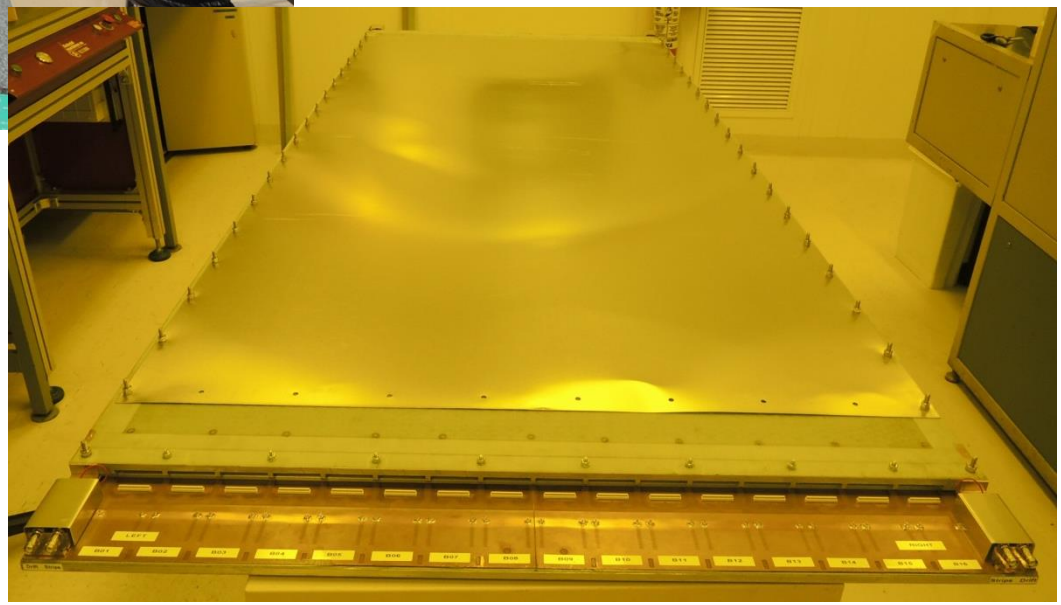
Closed



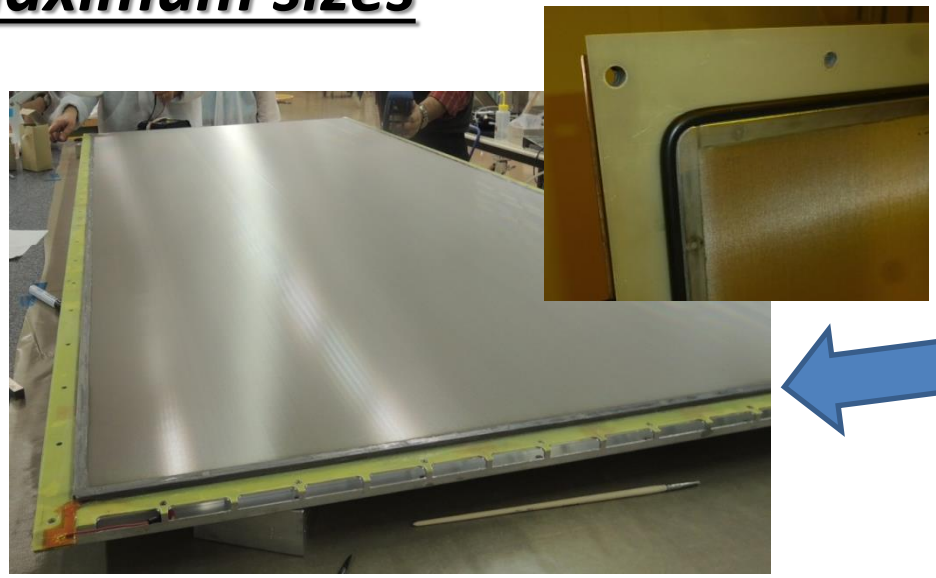


detector opened

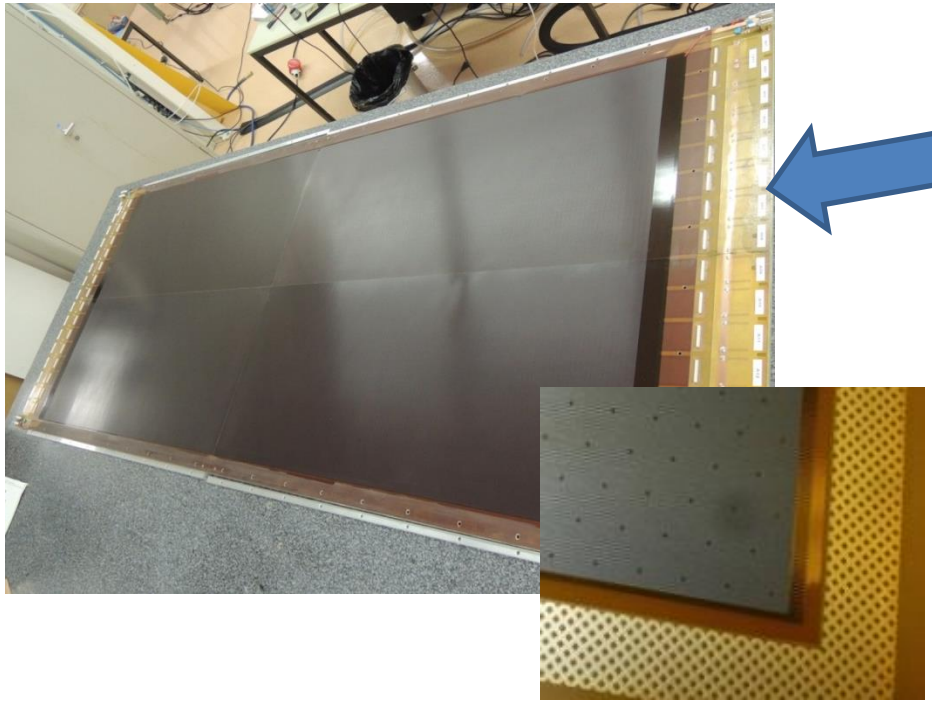
detector closed



Maximum sizes



- Picture : 2m x 1m x 10 mm Aluminum honeycomb drift panel
- Mesh stretched and glued on a frame
- Max size mesh stretching: 3.4m x 2.2m in one piece



- Picture : 2m x 1m x 0.5 mm read-out board with pillars in 4 parts
- 10 mm thick Aluminum honeycomb
- Max size for 1 PCB : 2.2m x 0.6m

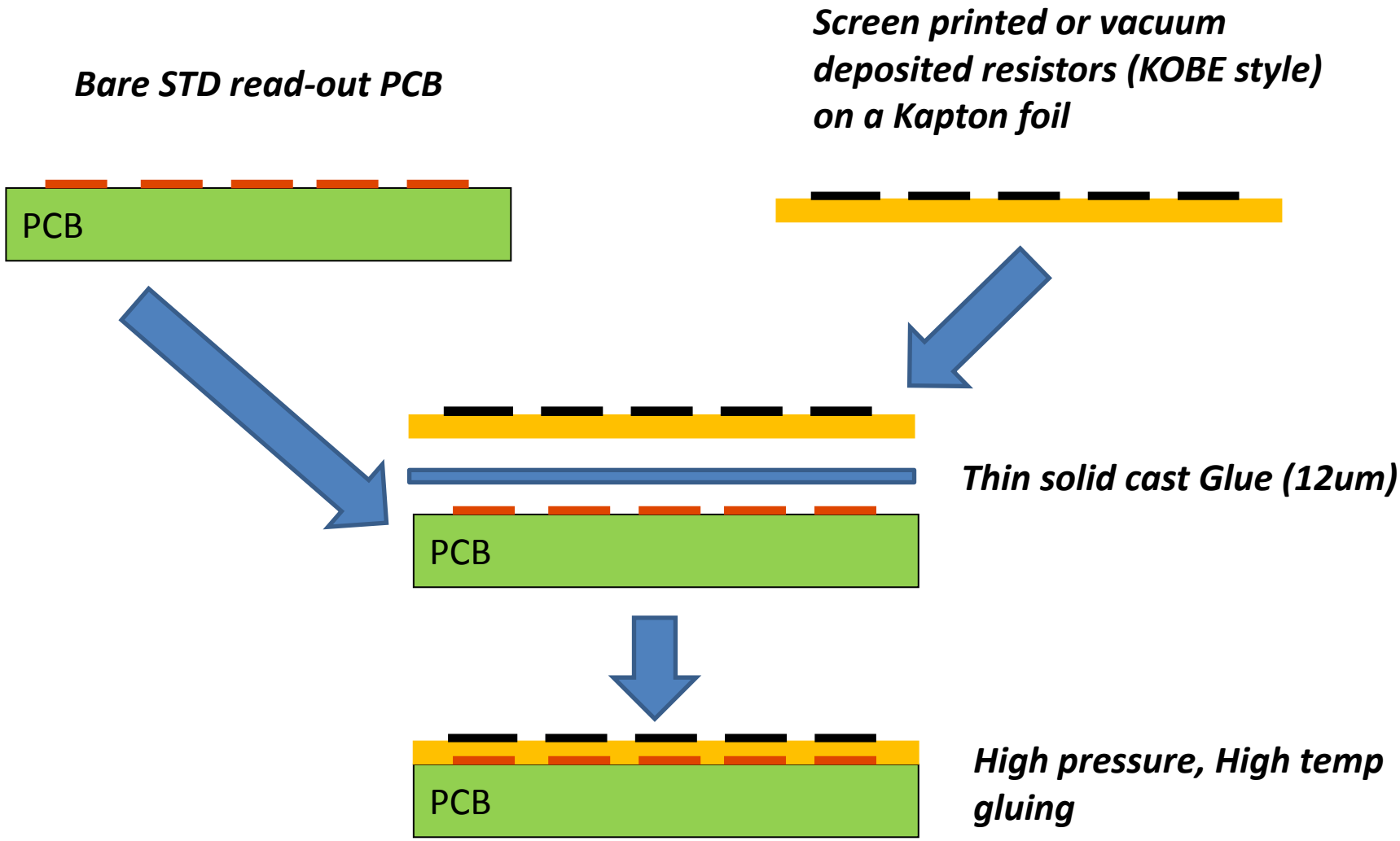
STD advantages:

- **Extra Large possible sizes**
- **The dust problem of the resistive BULK detector is not existing**
- **Lower cost for large detectors**

STD disadvantages:

- **Needs stiff panels for read-out and drift**
- **Planarity below 200um is mandatory (but was easy up to now to reach in all prototypes)**
- **Paradoxically difficult to build in small size**

Resistive layer formation for mass production for future:



Required positioning precision between resistive strips and read-out ?:

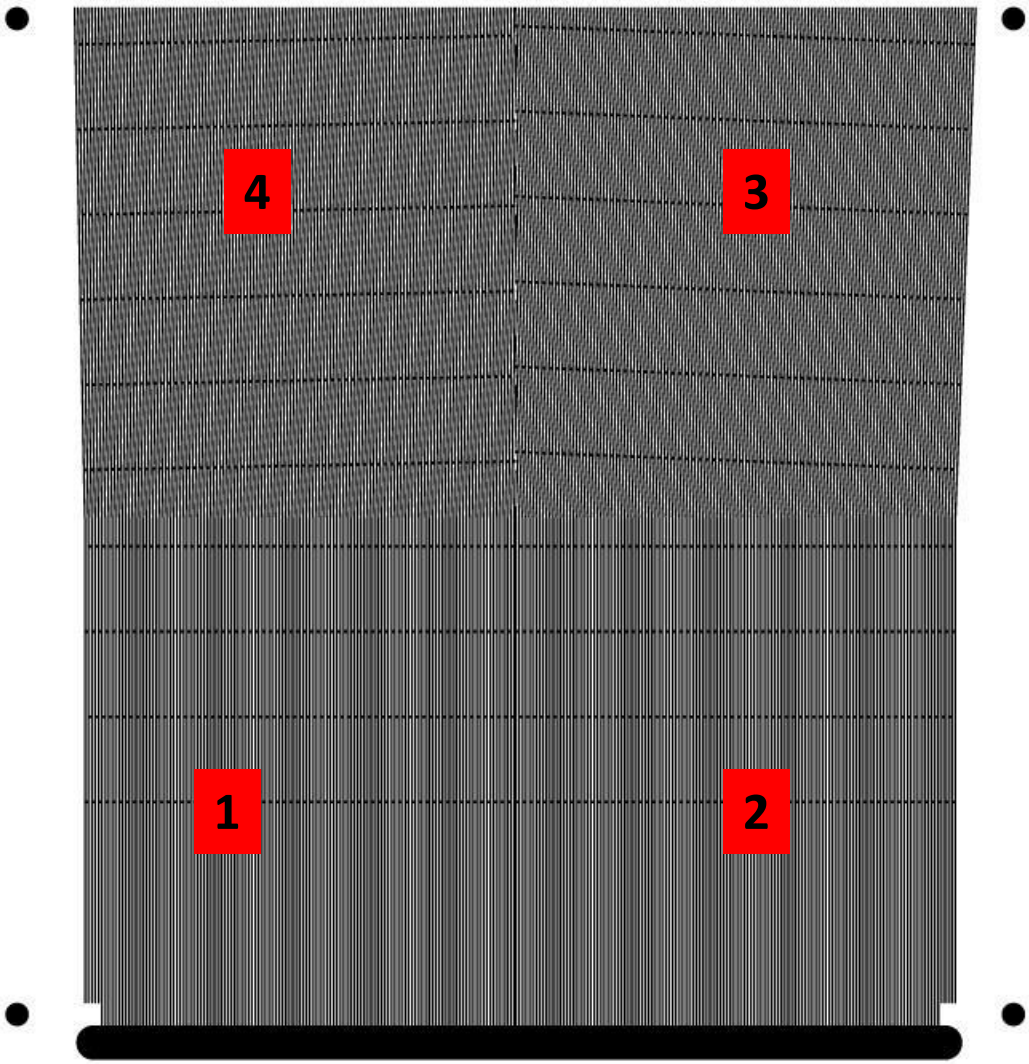
Up to now resistive strips were always aligned with metal strips→ but this is increasing the cost

OK

?

Preliminary slides by Michele Bianco
On behalf of MAMMA collaboration

TQF1 ResistiveStrips Layout



HV Distribution Side

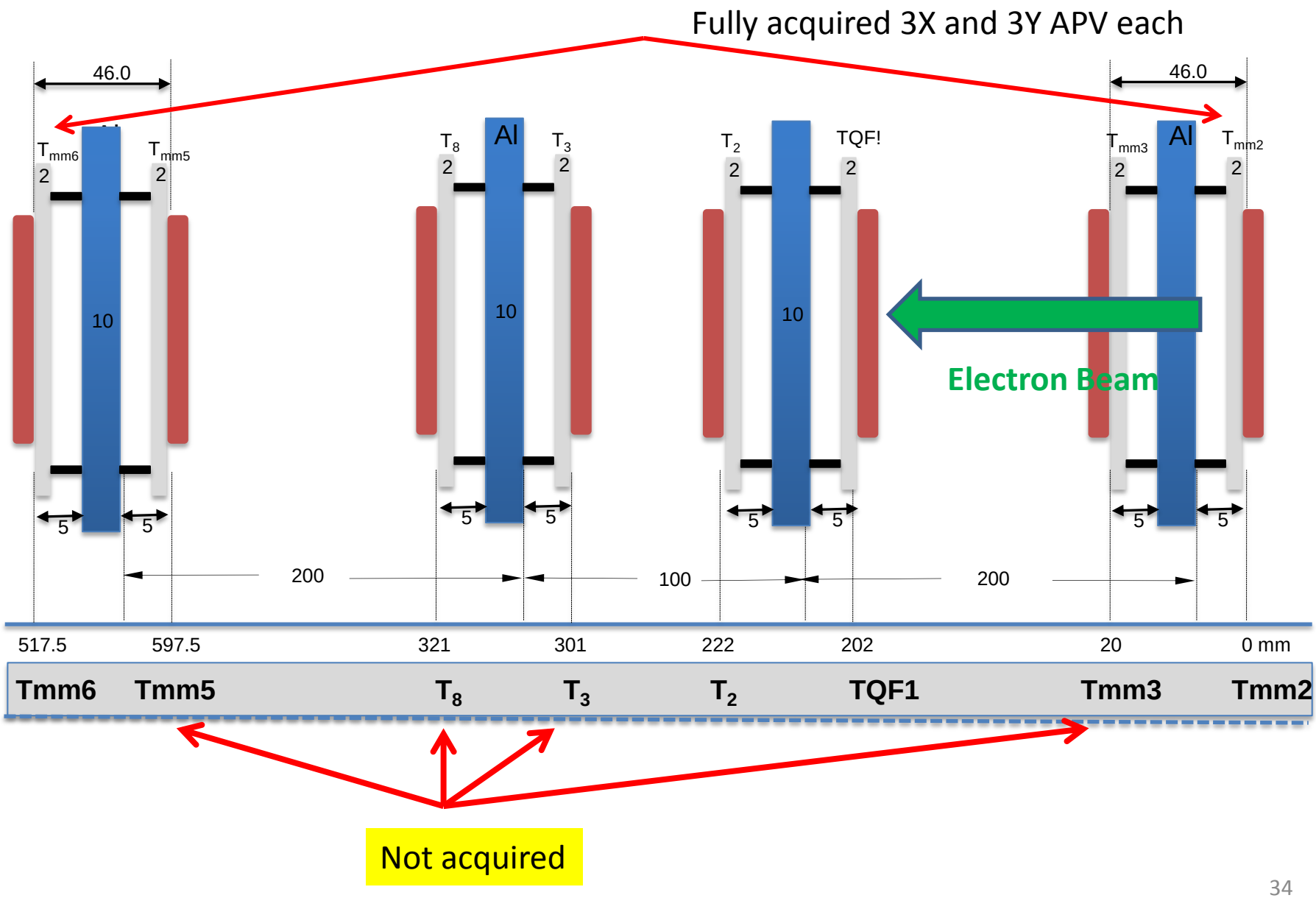
1 Resistive strips aligned with the read out strips

2 Resistive strips shifted by a half pitch, w.r.t. the readout strips

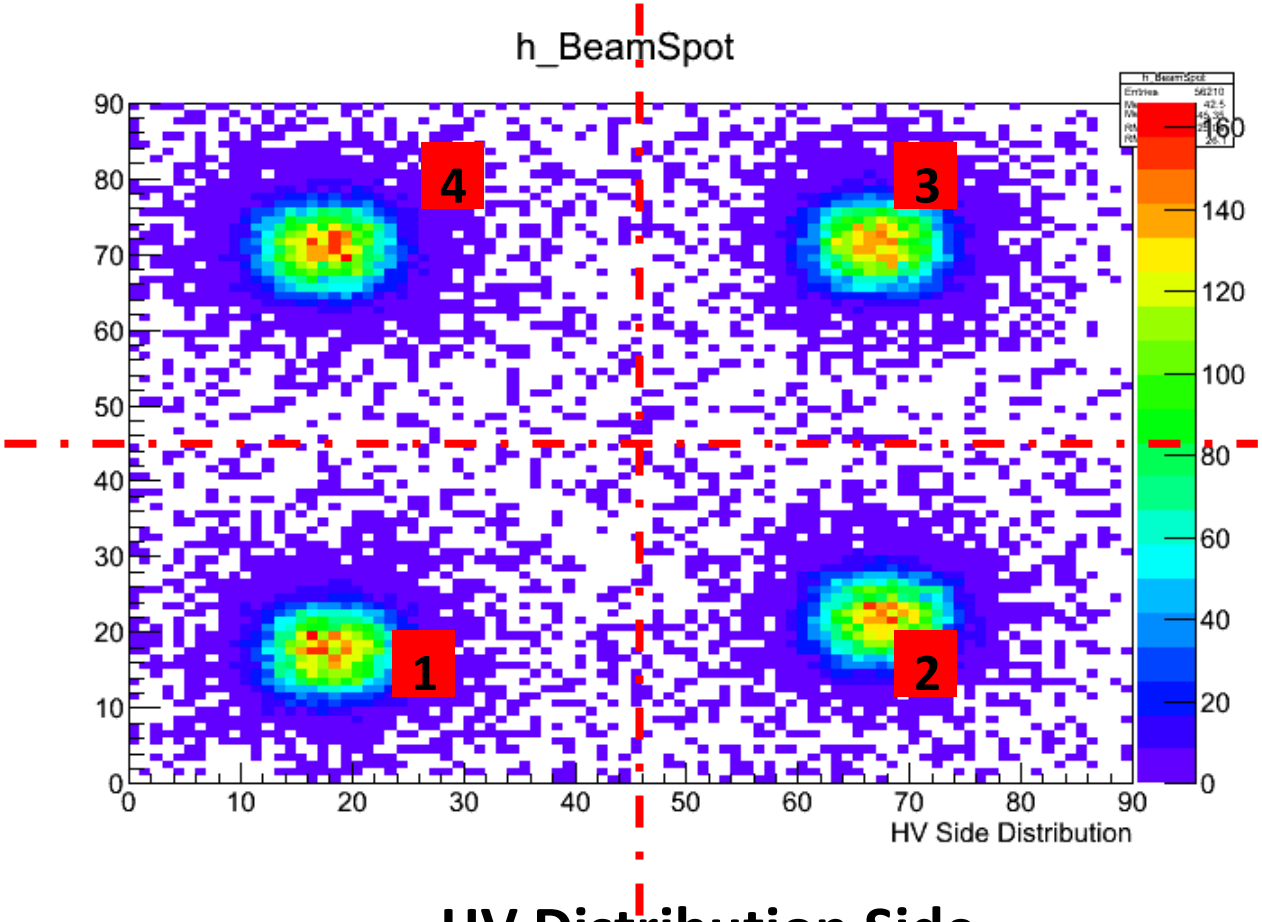
3 Resistive strips rotated by -2°, w.r.t. the read out strips , crossing every cm

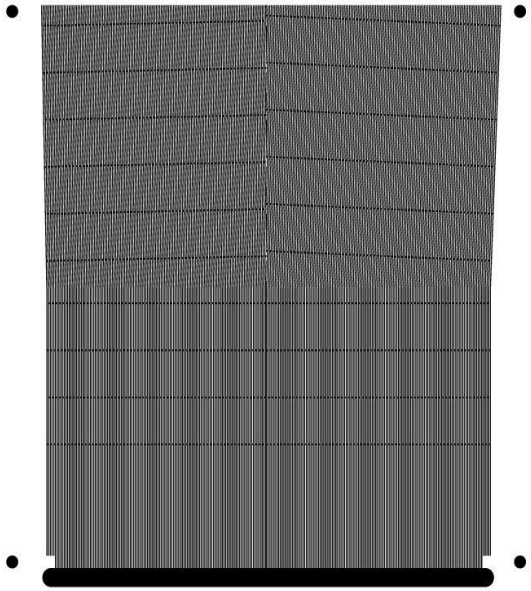
4 Resistive strips rotated by 1°, w.r.t. the read out strips , crossing every 2cm

DESY SETUP FOR TQF1 STUDIES



Beam Spot from Tmm2





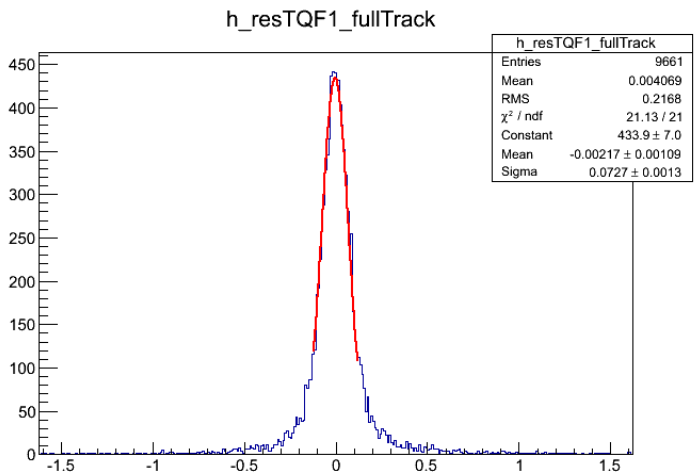
HV Distribution Side

- The chamber frame has been moved by use of the magnet support to allow the beam to illuminate the four different chamber sectors separately.

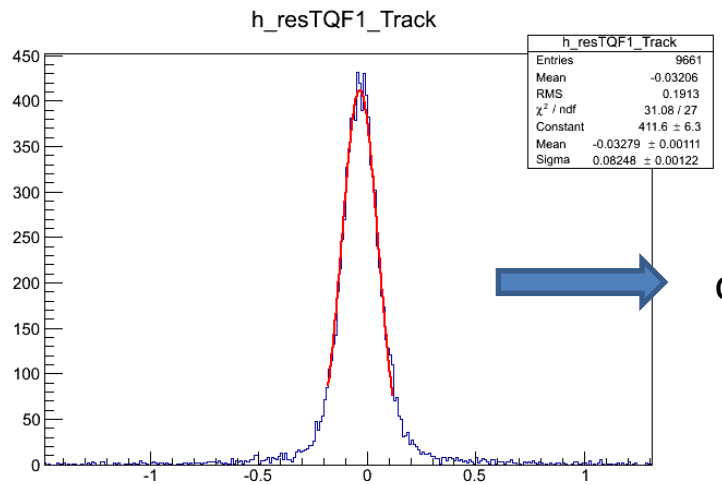
- Two runs for each point has been acquired.

Resolution

Residual from the “Standard” corner



Residual using also TQF1

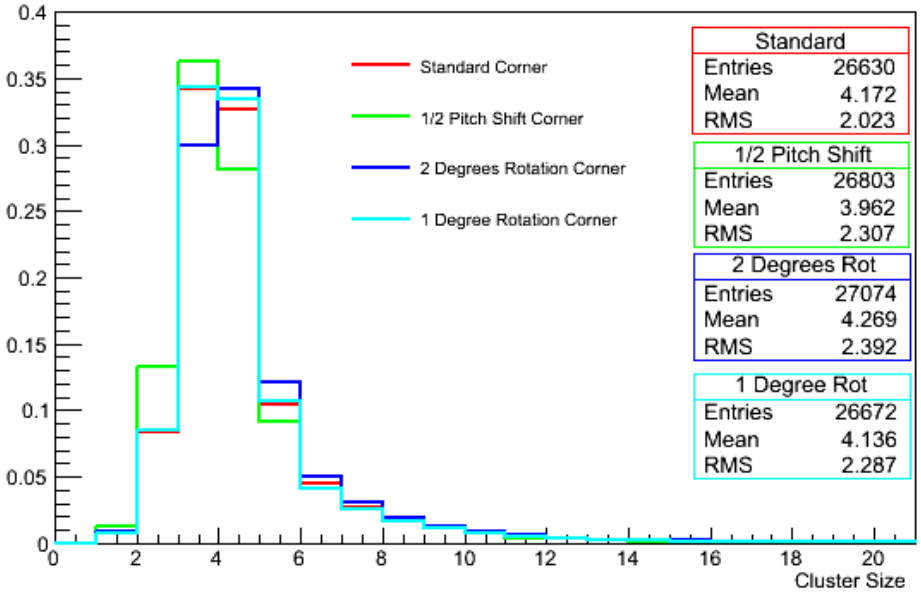


σ = 76.8 µm

Residual without TQF1

Standard Corner	Half pitch Shift	2° rotation	1° rotation
76.8 µm	82 µm	86 µm	81.2 µm

Cluster Size studies



Average Cluster Size measured from the DESY test beam data.
The different corners produce quite similar results, a small increase was noted for the region were the resistive strips are rotated of 2 degrees w.r.t. the readout strip and similarly small reduction for the region were the resistive strips are shifted of half pitch w.r.t. the readout strips.

Industry status

- **ELTOS**
  - **Resistive 10cm x10cm BULK Micromegas → OK**
  - **Large single side read-out boards and drift (2mx0.5m) → OK**
  - **Screen printing of large area → in progress**
  - **Pillars on large area → OK**

- **ELVIA (see Fabien talk in WG6)**
  - **Resistive 40cm x 40cm BULK Micromegas → OK**
  - **Embedded resistor BULK detectors → in progress (see Damien talk WG6)**
  - **Large single side read-out boards and drift (2mx0.5m) → OK**
  - **Screen printing of large area → in progress**
  - **Pillars on large area → OK**

- **Seritec**
  - **Swiss company near CERN**
  - **Stretching 2m x 1m mesh → OK**
  - **Max possible size: 3.2m x 2.2m → to be tested**

- **Charbonney**
  - **Swiss company near CERN**
  - **Printing 1m x 0.5m resistive strips → OK**
  - **Max possible size: 1.5m x 0.9m (print in 2 steps for large boards) → to be tested**

- **MDT**
  - **Italian company**
  - **Press gluing capability 4.2m x 1.6m → to be tested**

OUTLINE

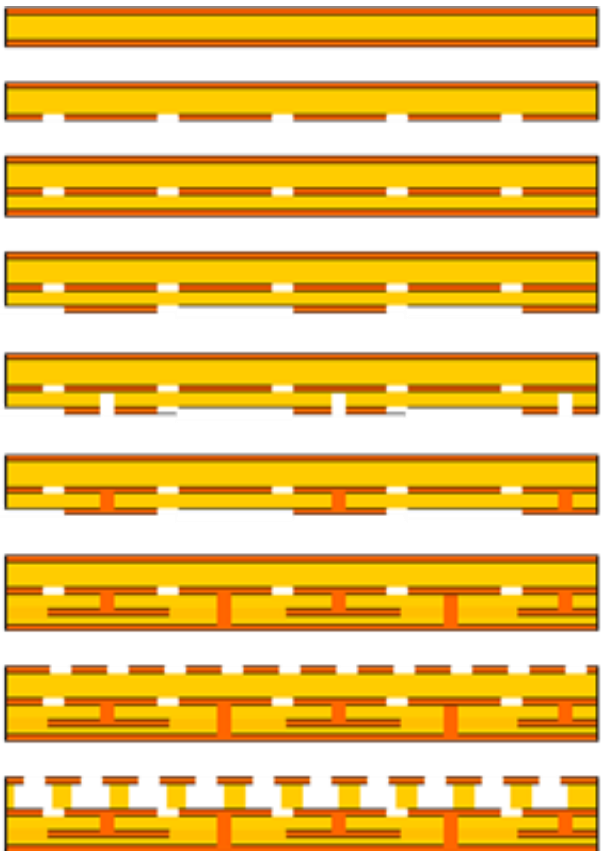
- ***GEM***
  - ***Laser , plasma , chemical***
  - ***Single mask , double mask***
  - ***NS2 assembly***
  - ***Mass production / industrialization status***

- ***Micromegas***
  - ***STD, BULK***
  - ***Protection resistor : foils, groove filling, printed , vacuum deposited***
  - ***Mass production / industrialization status***

- ***Micromegas microbulk***
  - ***std, X/Y, low mass***

- ***THGEM***
  - ***Last improvements, Pashen curve guide***
  - ***Large size and industry production status***

Conventionnal Micro BULK 2D



Double side Cu-coated (5 µm) Kapton foil (50 µm)

Construction of readout strips/pads(photolithography)

Attachment of a single-side Cu-coated kapton foil (25/5 µm)

Construction of readout lines

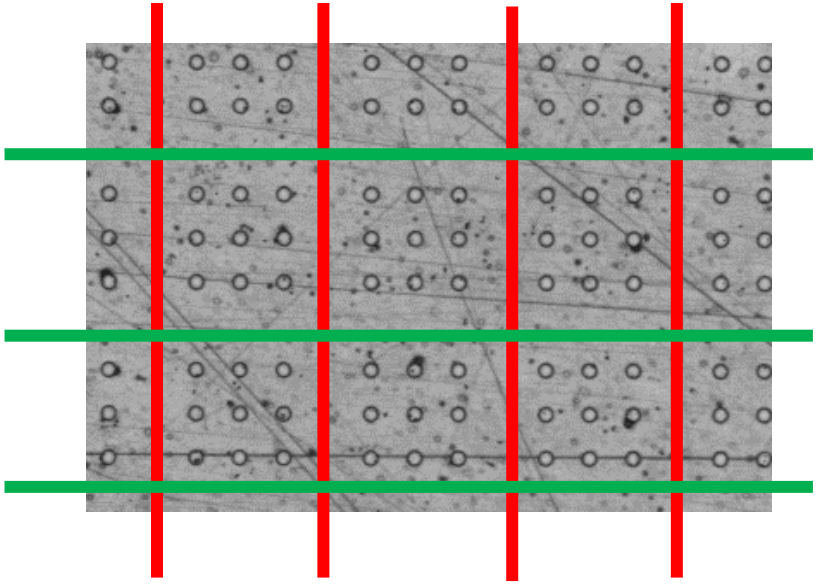
Etching of kapton

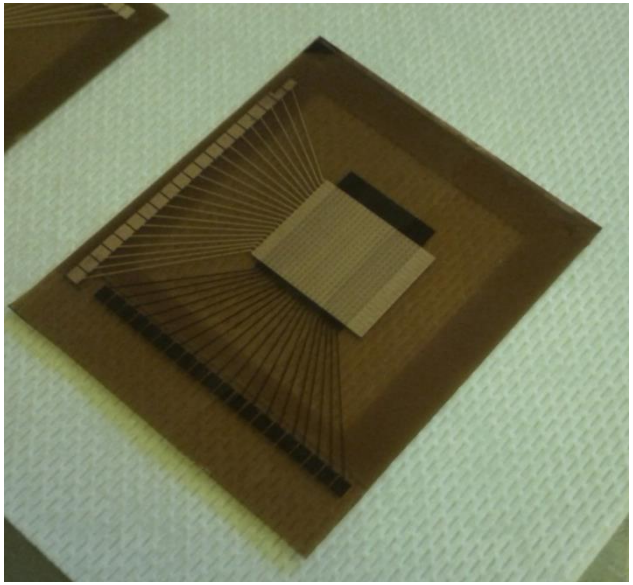
Vias construction

2nd Layer of Cu-coated kapton

Photochemical production of mesh holes
Kapton etching / Cleaning

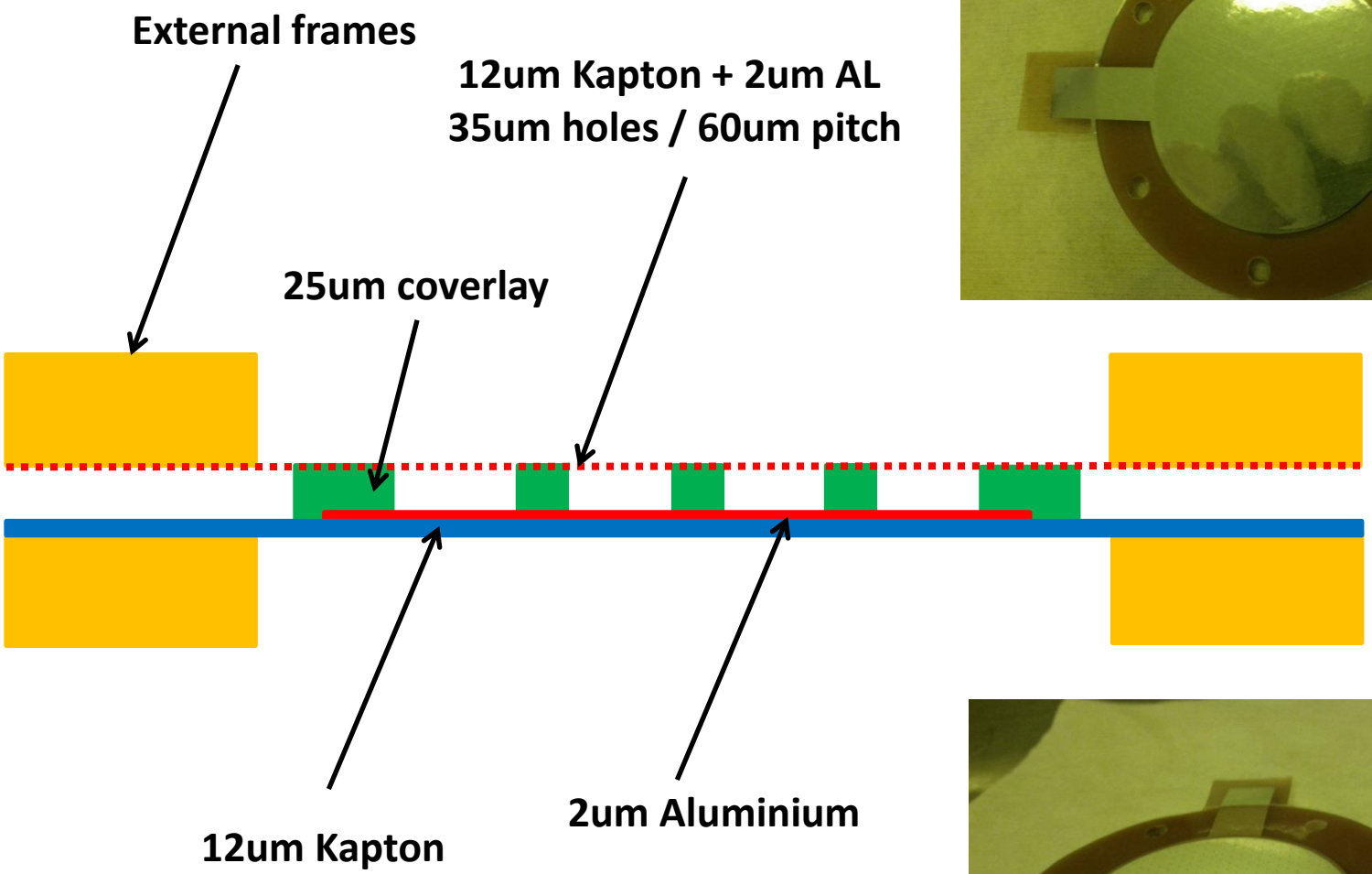
Advanced Micro BULK 2D

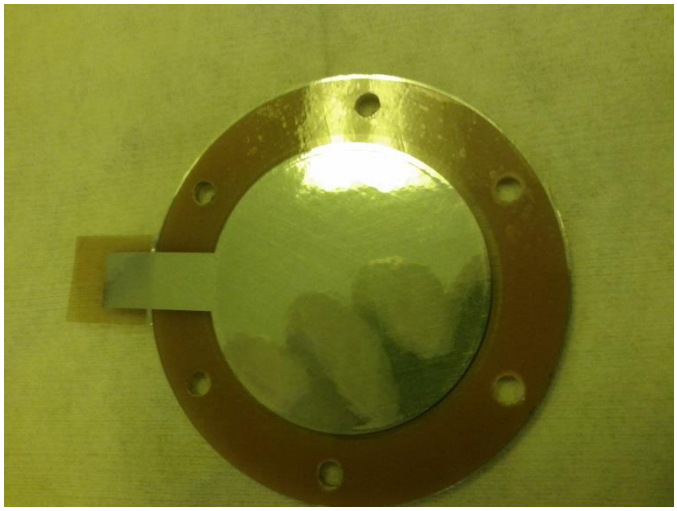


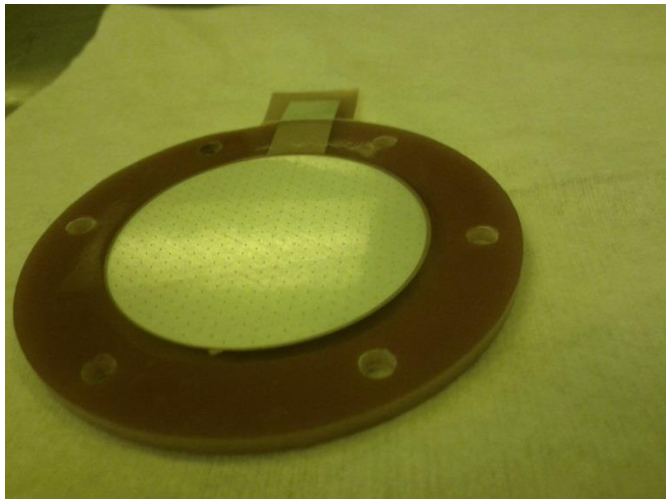


- X/Y read/out with a single 50um foil
- Similar holes and pitch as previous Micro Bulk
- Low mass, Lower cost , better yield expected
- No charge sharing between X and Y pads

Zero Mass Micromegas for n-TOF:







Total : 25um Kapton + 4um Aluminium

OUTLINE

- **GEM**
  - **Laser , plasma , chemical**
  - **Single mask , double mask**
  - **NS2 assembly**
  - **Mass production / industrialization status**

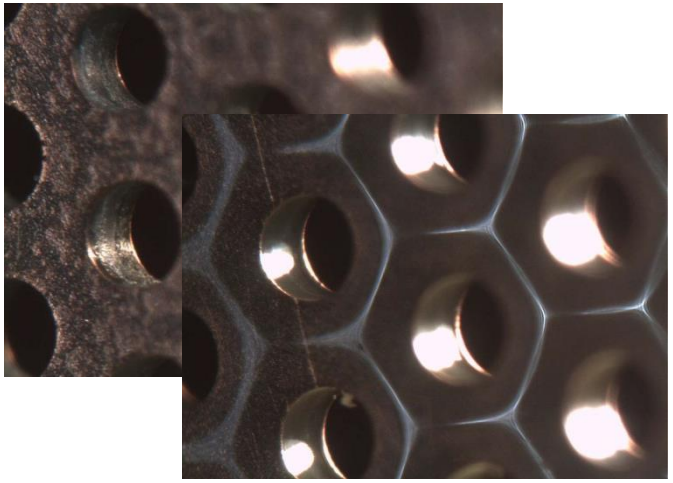
- **Micromegas**
  - **STD, BULK**
  - **Protection resistor : foils, groove filling, printed , vacuum deposited**
  - **Mass production / industrialization status**

- **Micromegas microbulk**
  - **std, X/Y, low mass**

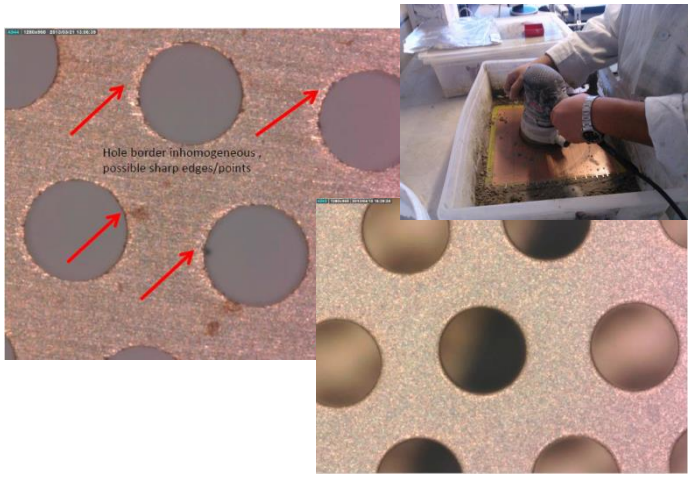
- **THGEM**
  - **Last improvements, Pashen curve guide**
  - **Large size and industry production status**

Last improvements and Paschen curve guide

Polyurethane Treatment



Long polishing (see Last RD51 mini week, Fulvio)



- Breakdown voltages of thick GEM in the past were difficult to predict :
  - Material?
  - Humidity?
  - Shape?
  - RIMs?
- 2 approaches stabilize this breakdown voltages with similar high values
- The values are now consistent with Paschen curves
- The exact explanation is not yet absolutely clear, since the action of the 2 approaches seems to be different

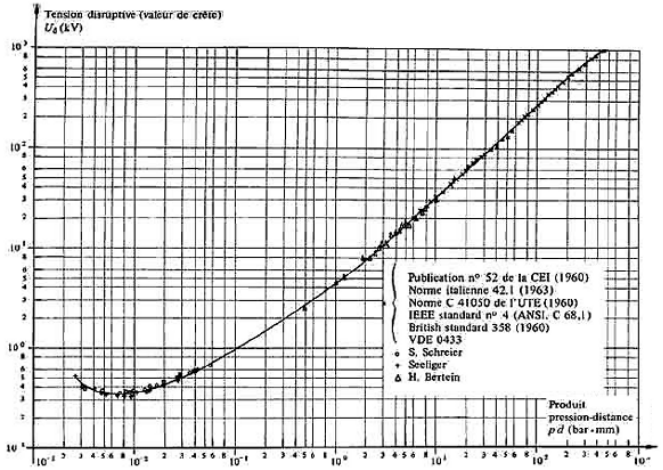
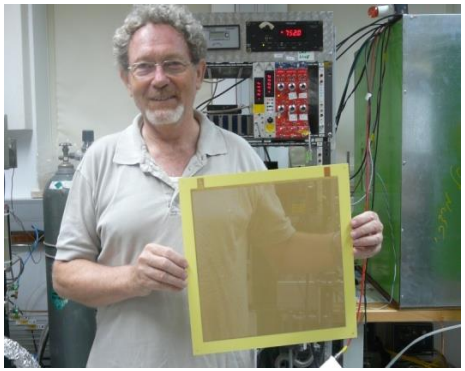


Fig. 9.11 Courbe de Paschen pour l'air en échelles logarithmiques. Température 20 °C [262].

Large size THGEM:



- **ELTOS**
  - **10 holes/ sec drilling machine**
  - **They have produced 60cm x 60cm just for mechanical purpose**
  - **They have produced 80cm x 40cm working THGEM**
  - **They are able to produce RIMs.**
  - **The final cleaning should still be performed by the user or CERN**
  - **Long polishing or PU coating are not yet available in industry**

  - **Mass production costs are still difficult to predict (cleaning technology transfer should be organized)**

- **Print Electronics**
  - **Israel**
  - **Many pieces made for Weismann institute**
  - **Little information on the capabilities**

Conclusions and future:

- **Most of the last improvements were related to production simplification and cost reducing.**

- **The detectors are still growing in size! → GEM 2m x 1m?**

- **Lot of new structures R&D:**
  - **<u>IBF suppressing structure</u>**
    - **Large COBRA structures foils**
    - **Multilayer conical hole ThickGEM**
  - **<u>Liquid Ar experiments</u>**
    - **Polycarbonate THGEM**
    - **Multi electrode THGEM**
  - **<u>Single board detectors (mesh or GEM free)</u>**
    - **PCB resistive MSGC**
    - **2 D resistive spiral structures, preliminary results soon (micro dot like detectors).**

Thank you