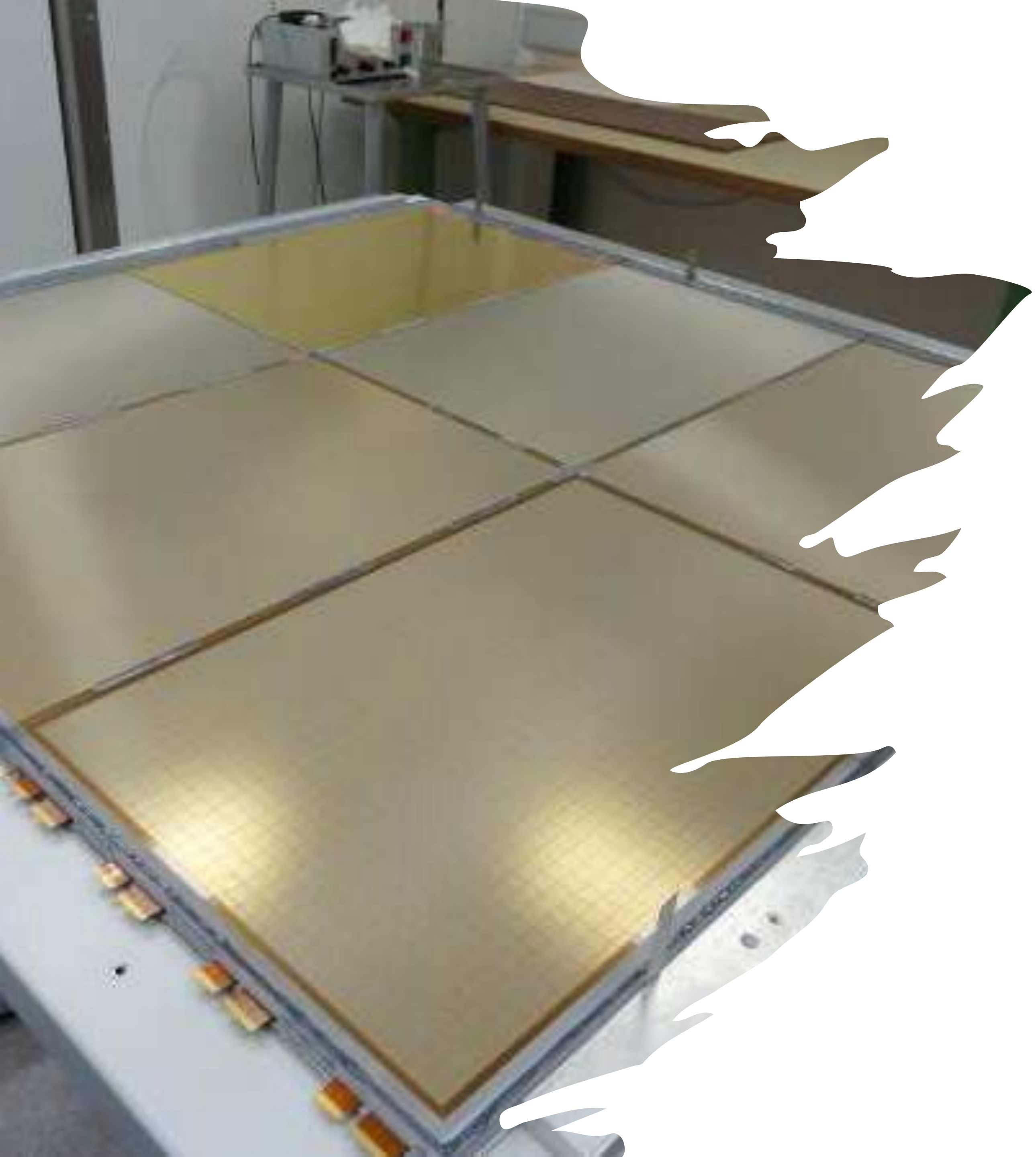
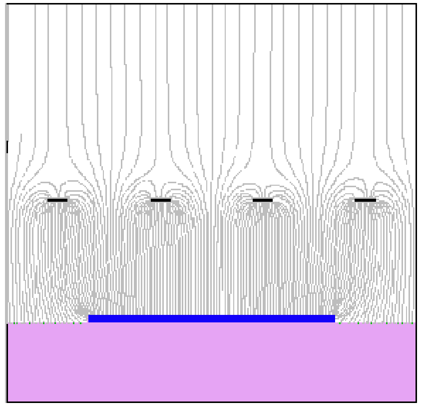
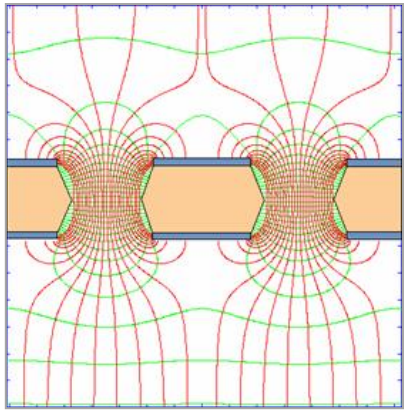


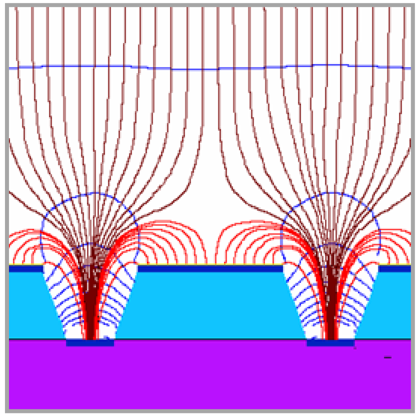
Micromegas detectors

- MPGD situation at the end of the nineties
- Initial Micromegas and evolutions
- Introduction of resistive layers
- Micromegas today

End of nineties , 3 main MPGD structures emerged !


Mesh with spacers


Holes

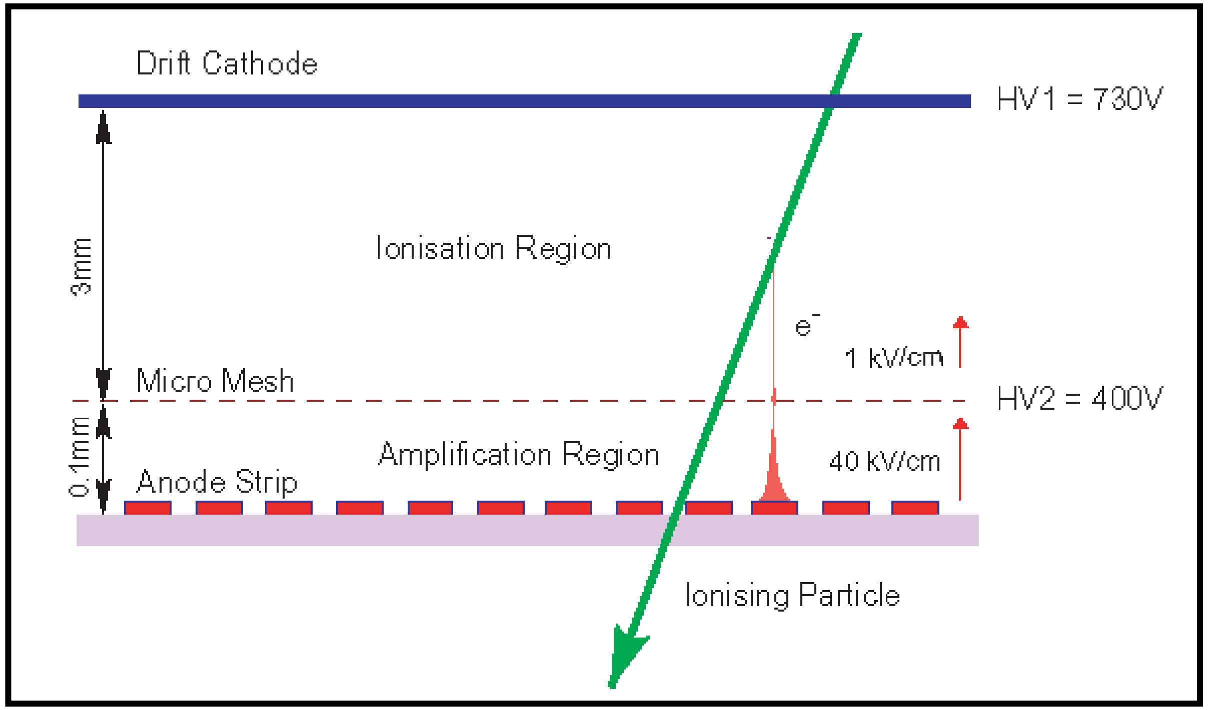

Wells

It is interesting to observe that in these 3 options the amplification gaps are precisely defined by industrial materials, not by photolithography:

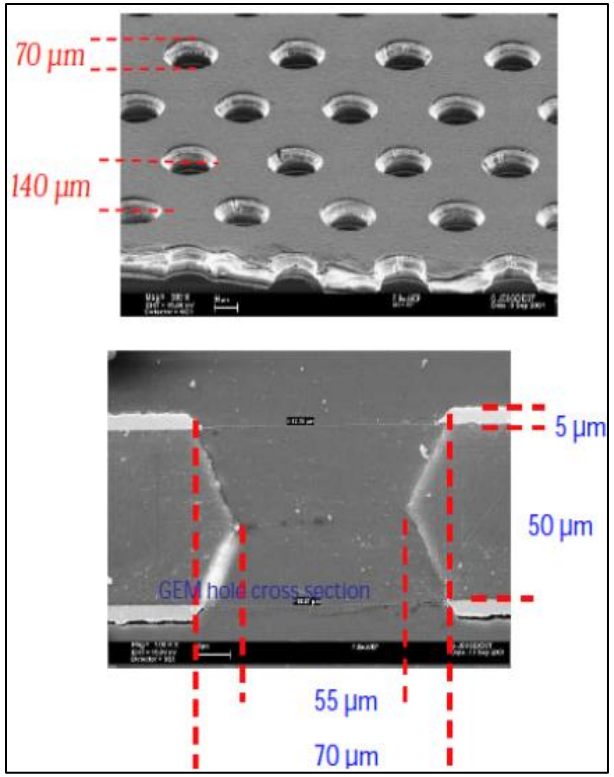
-Polyimide 50um +/-0.1um

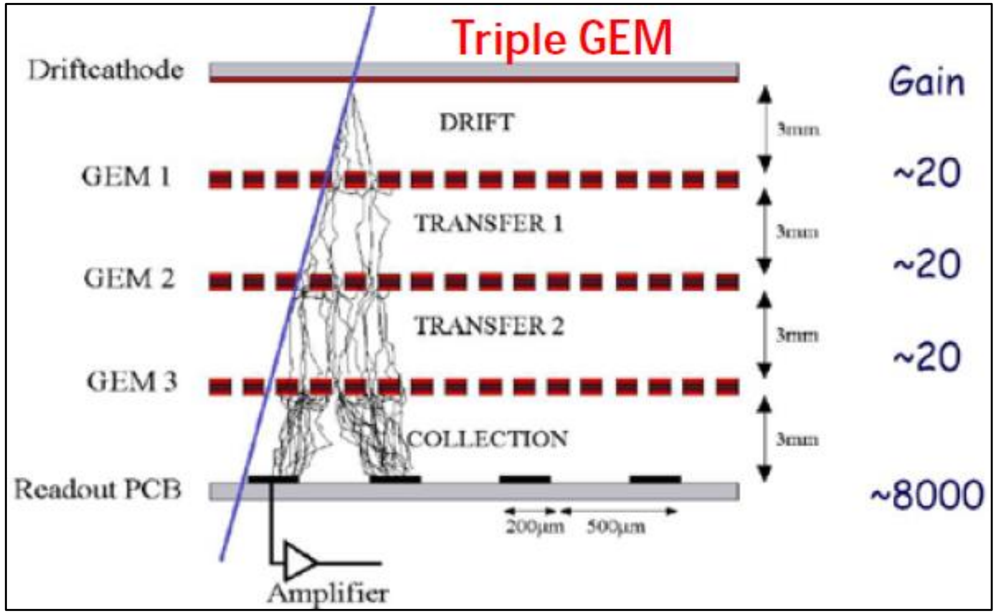
-Photo-imageable coverlay spacer 128um +/-2um

1997→Micromegas (Yannis)



1998→GEM foil and then triple GEM detector (Fabio Sauli)





Spark problem solved by stacking 3 GEMs:

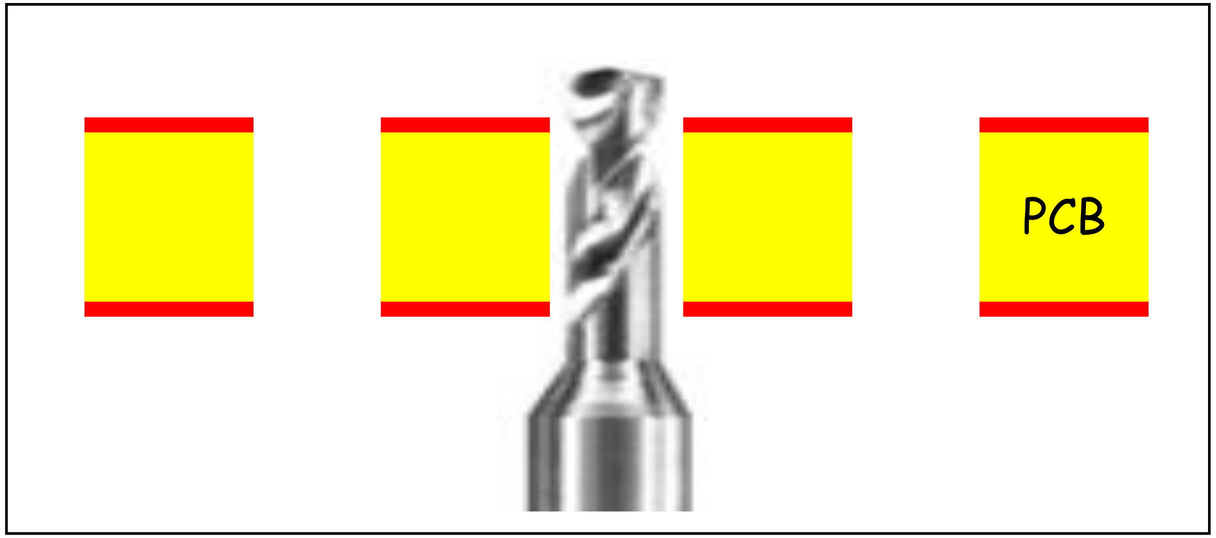
The size of the detector do not affect the performance.

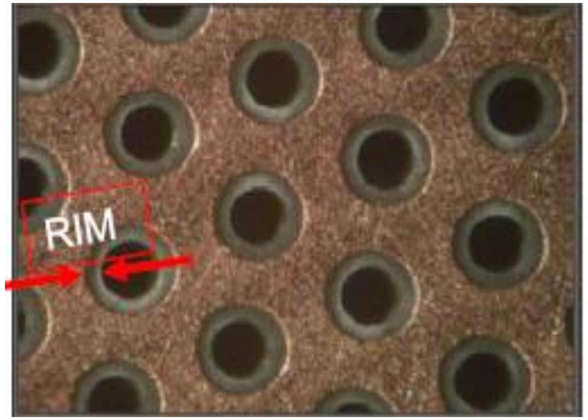
A GEM is only made with Photolithographic processes. Industrial by nature.

The technology was spread rapidly.

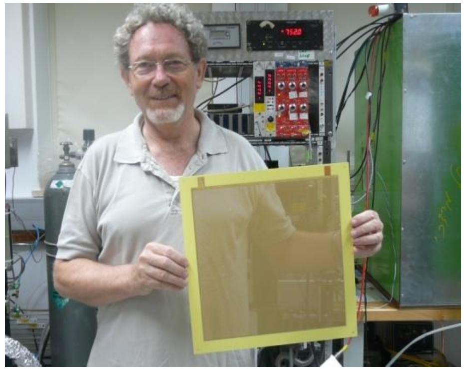
1998→first LEM or THGEM (Pio Picchi and his team)

Mechanical Drilling : FR4, PMMA etc..
More recently:
- Multi electrode THGEM
- Sand blasting on glass
- Photo imaged glass





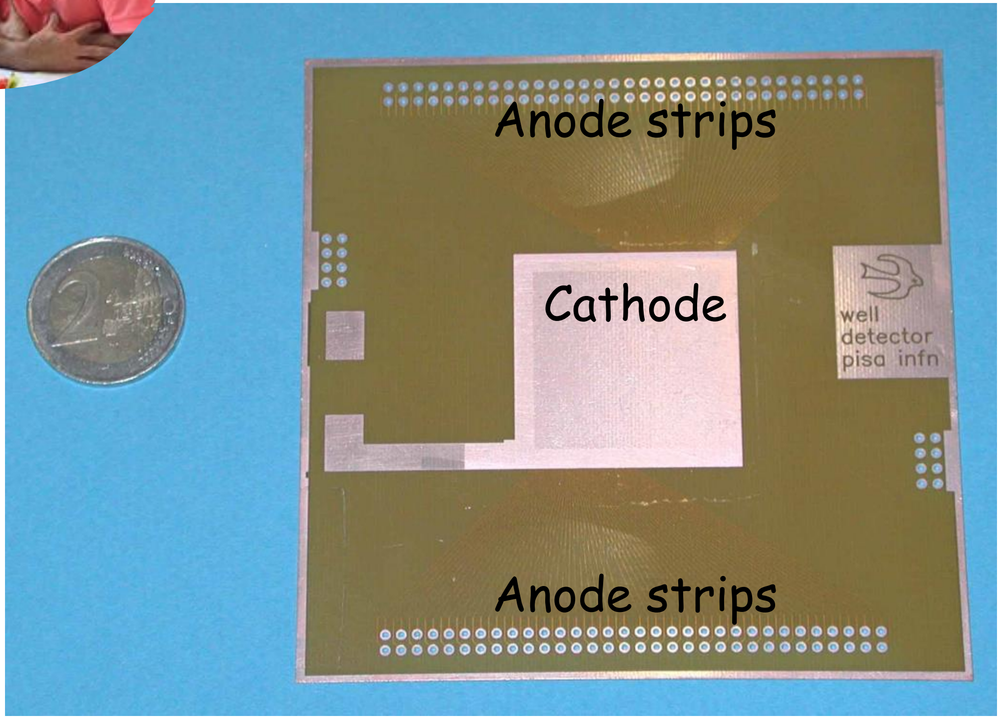
Eltos (IT)
Hold by
Fulvio Tessarotto

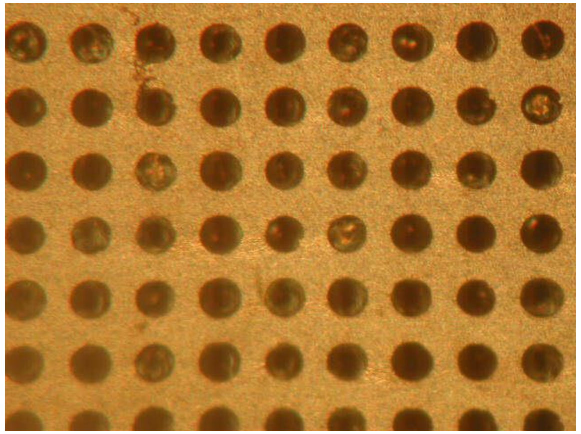


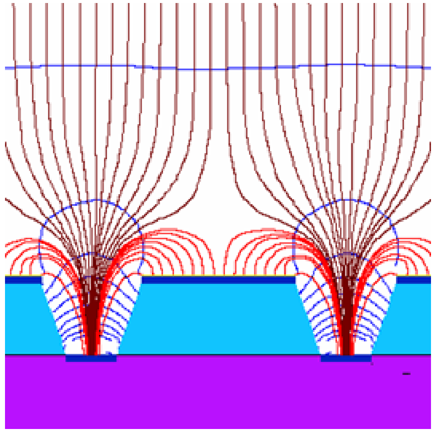
Print electronics (IS)
Hold by
Amos Breskin

CERN
Hold by
Serge Ferry

1999→Micro-Well (Ronaldo Bellazzini)

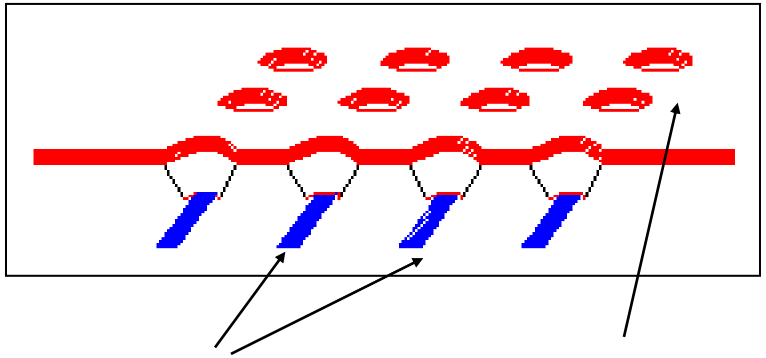






Close-up view
Square pattern used
in the early days

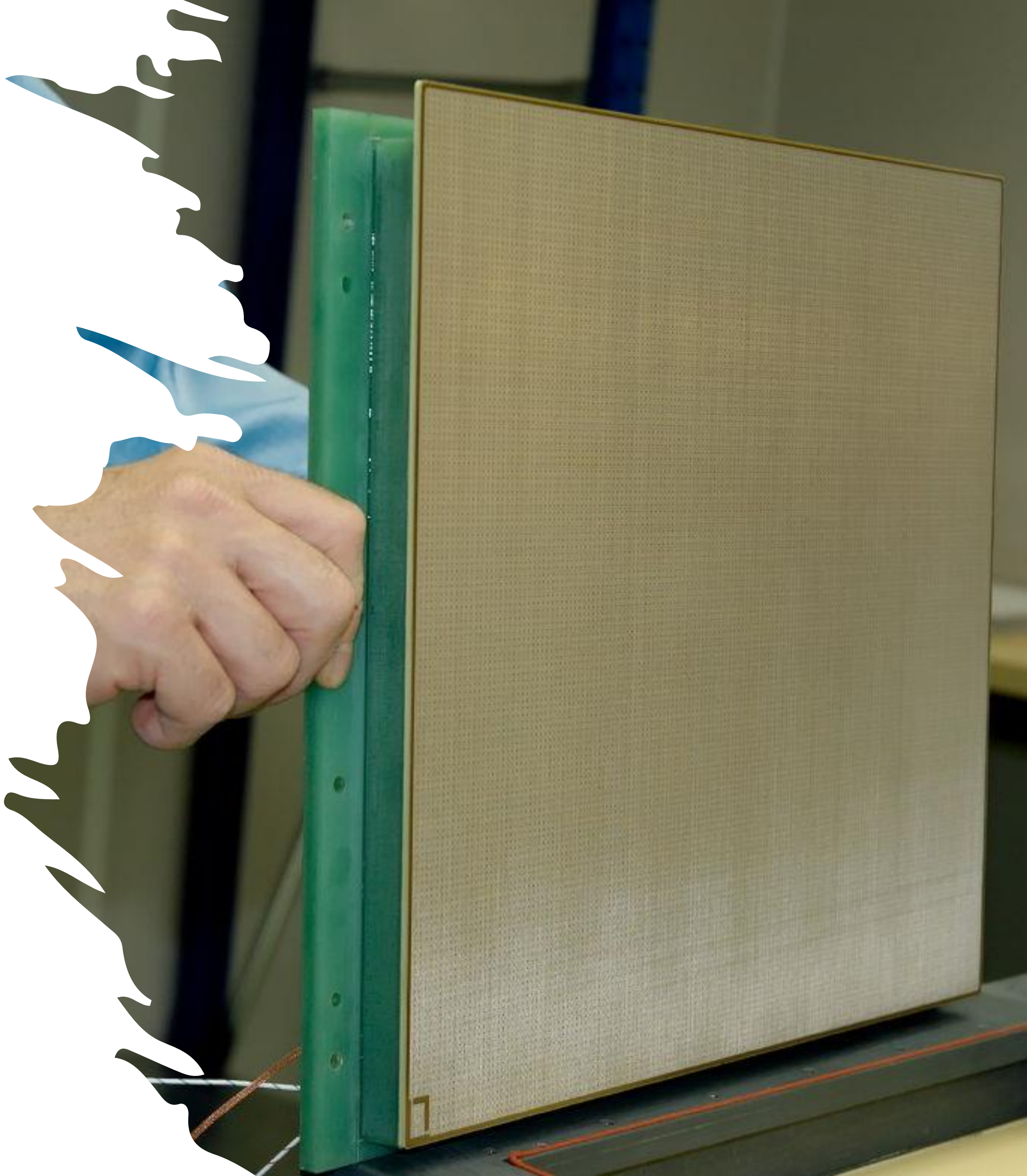
-3 x 3 cm Micro-well detector
-Produced with GEM processes
-Really simple but abandoned for a while
due to the difficulty to mitigate sparks



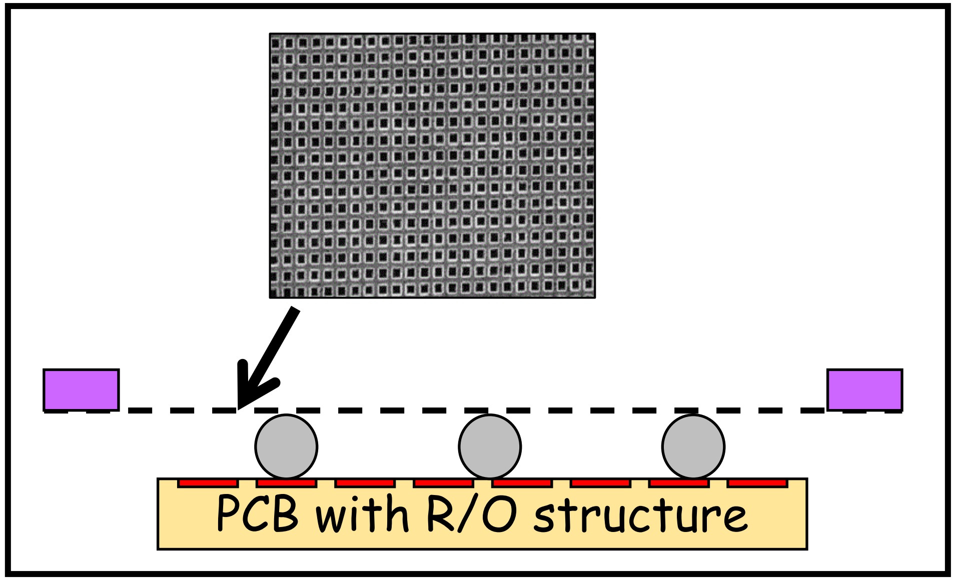
R/O lines
Anode

cathode

But let's come back to MM



1997 First Micromegas (Yannis)



-Ni electroformed mesh stretched on a frame.

-Spacers done with fishing wires.

-Spark protection done with added discrete components.

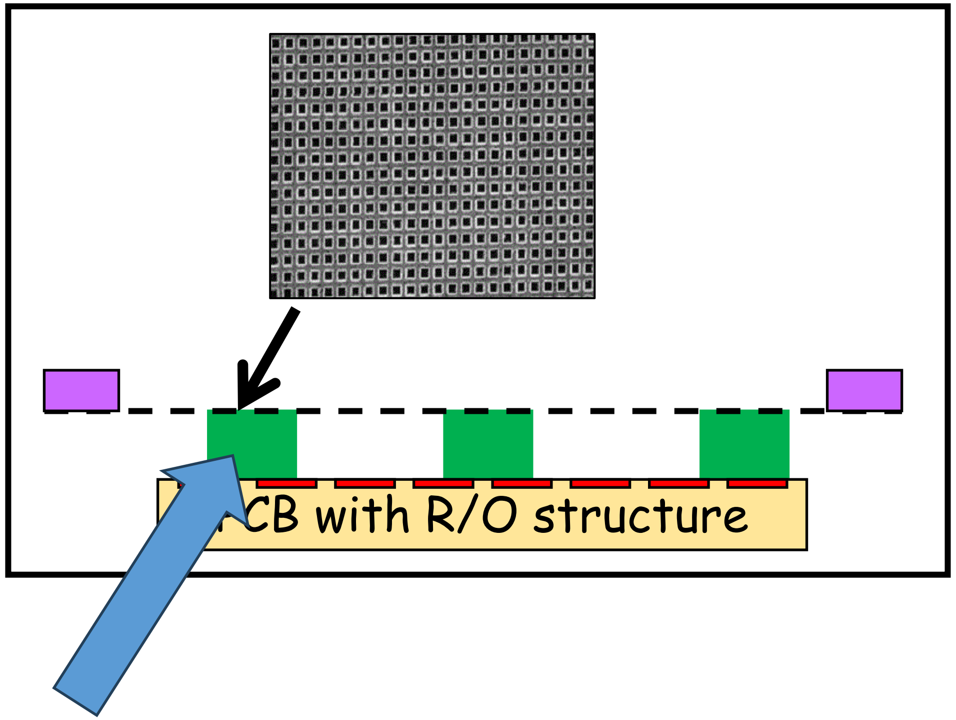
-The size of the detector have an impact on the spark current.

-The Ni mesh is fragile.

-The production steps are mainly relying on manual artisanal skills .

-Challenge to produce a 30cm x30cm detector

2000 First Evolution (Yannis) → Photo imaged pillars



-Still fragile Ni Electroformed mesh stretched on a frame.

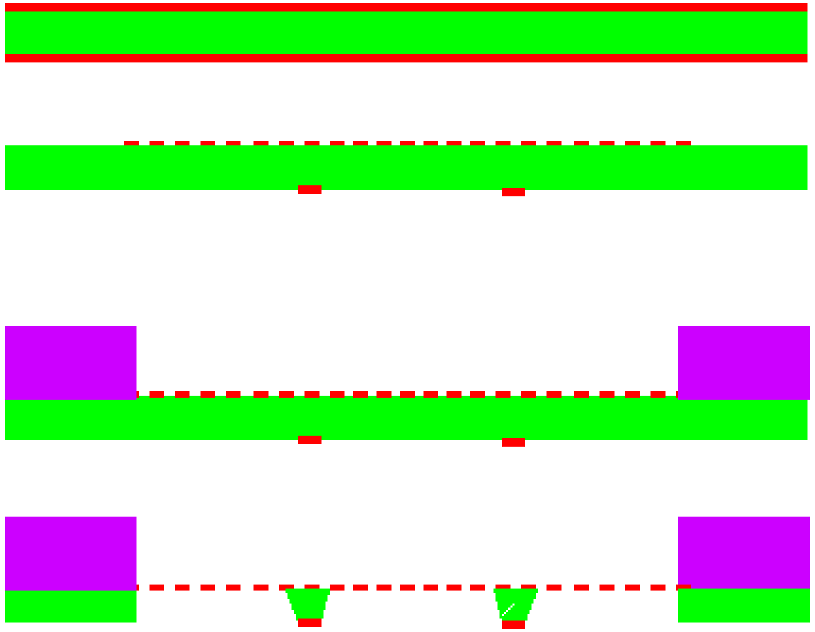
-Spacers deposited on the PCB by photo lithographical processes.

-Still production steps relying to much on manual artisanal skills .

-Structure used initially for Compass.

-30cm x 30cm challenging

2001 Second evolution (CERN)
→ Dots on mesh



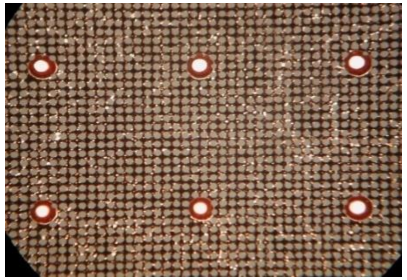
-Copper Mesh done by photolithography

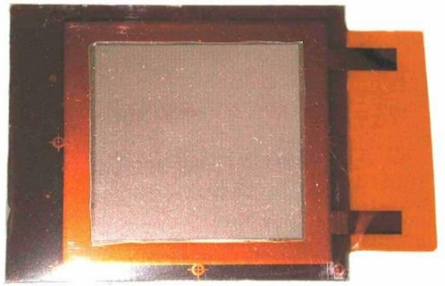
-Spacers are attached to the mesh and done by photolithography.

-This structure is still fragile due to the thin copper mesh .

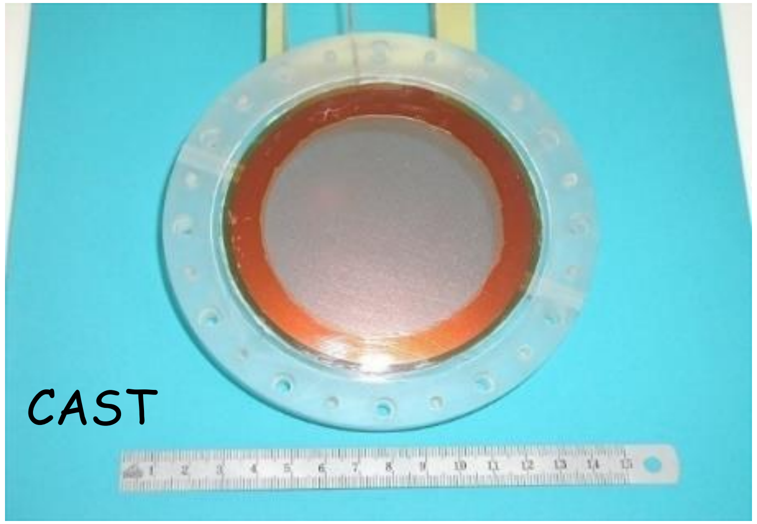
-Structure used for KABES and CAST

-30cm x30cm challenging

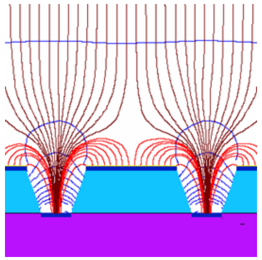




KABES



Right after with similar process →Micro bulk
Yannis and CERN



S Andriamonje *et all* 2010 *JINST* **5** P02001

Figure 1. Kapton pillars are created below the copper in each mesh step.

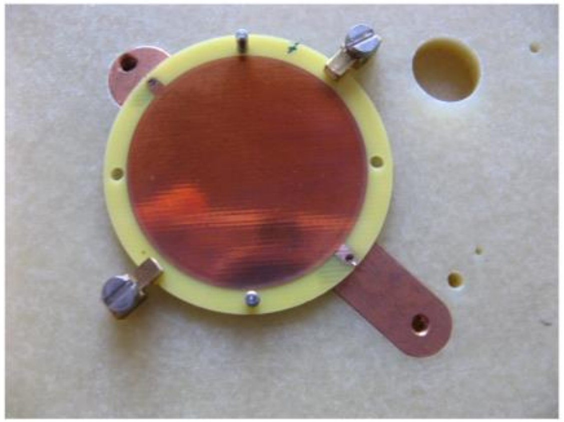
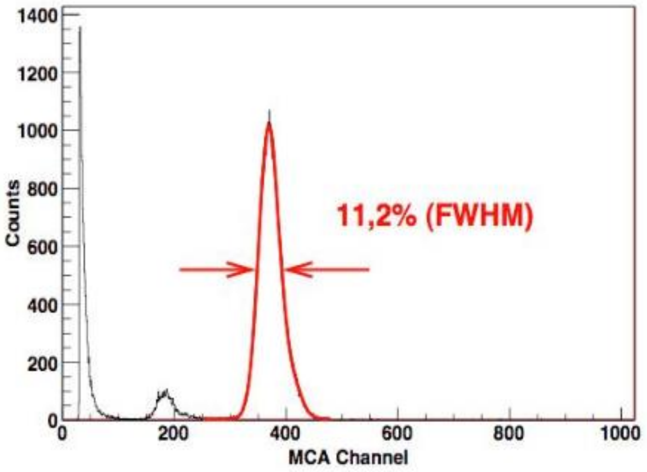
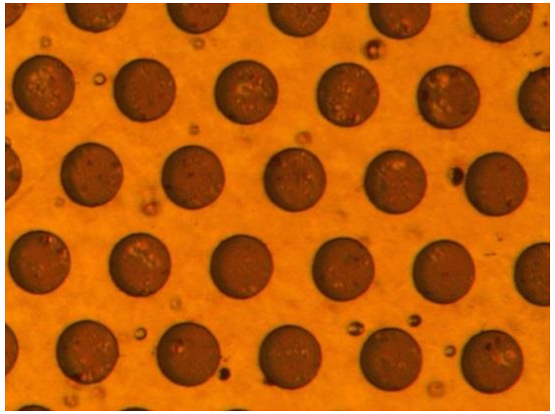


Figure 3. Photo of the 3.5 cm diameter circular Micromegas.

Same material as GEM (kapton + Cu)
Holes created etching copper and kapton (like a GEM)
Amplification in the small holes (field ~ uniform)

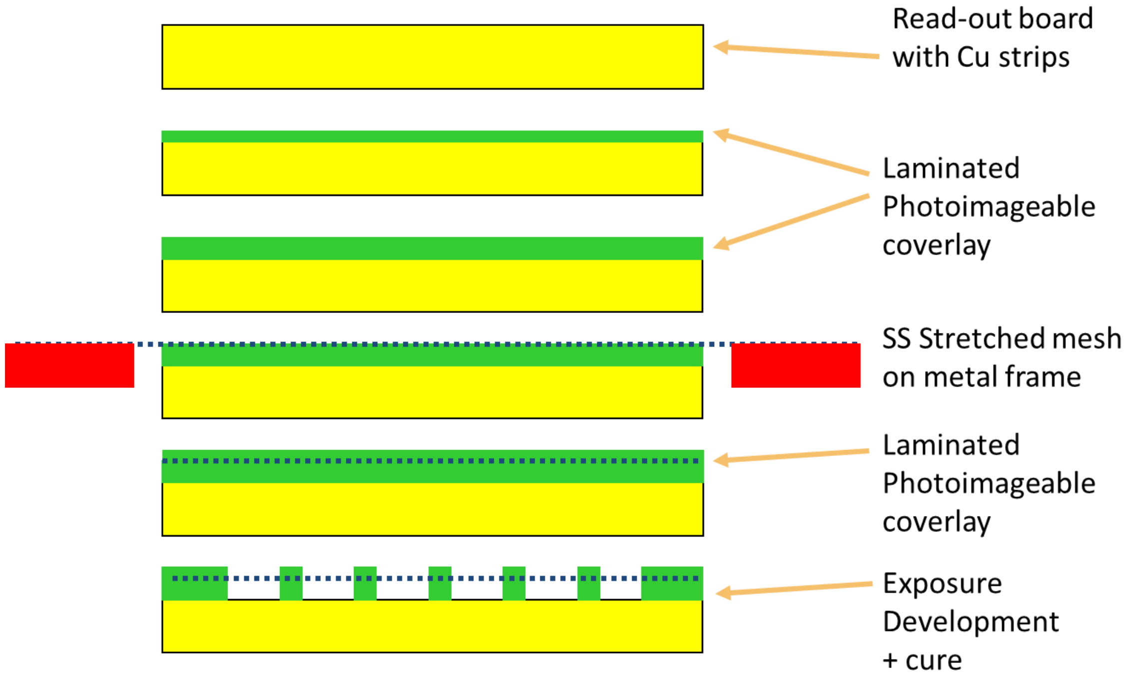


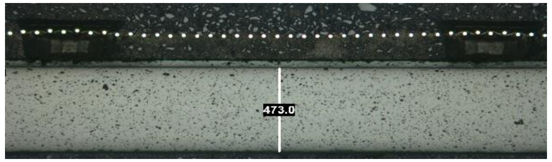
Best energy resolution among MPGD



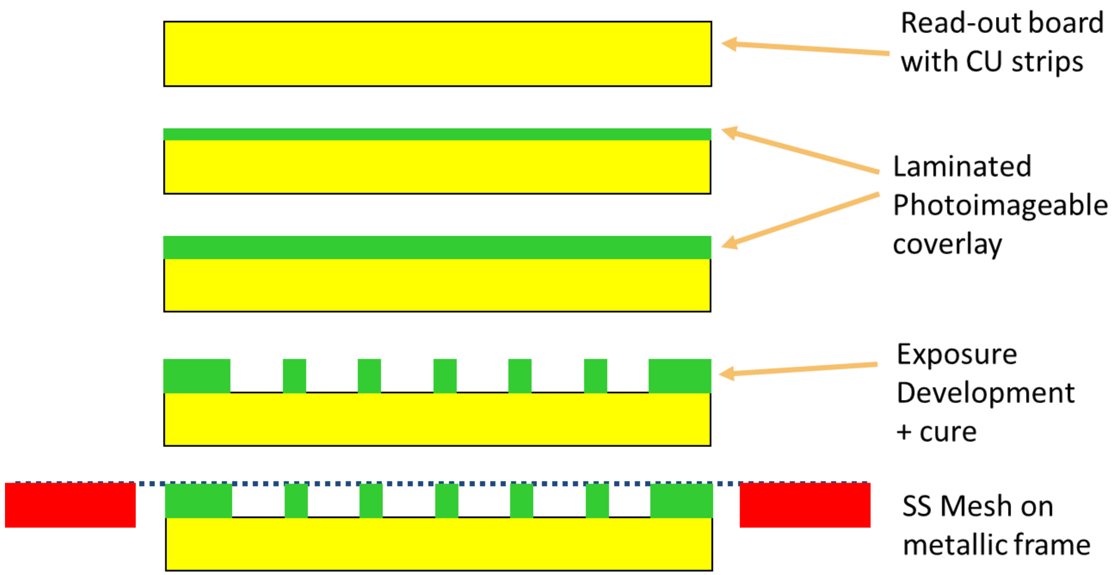
2004 Third evolution (Yannis and CERN) → use of stainless-steel woven mesh

BULK Micromegas





Floating mesh Micromegas

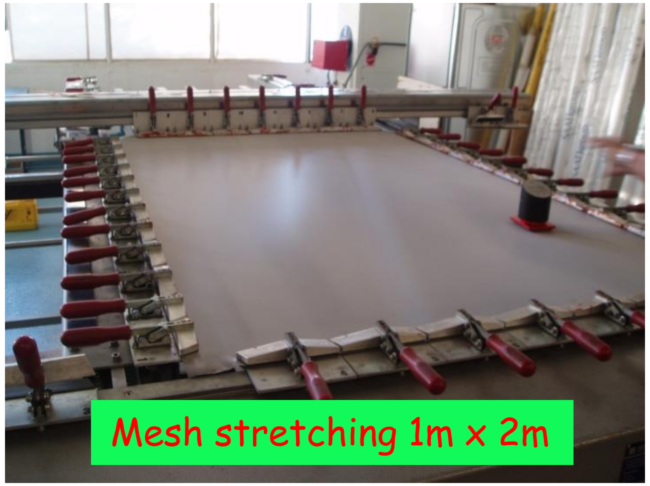


5

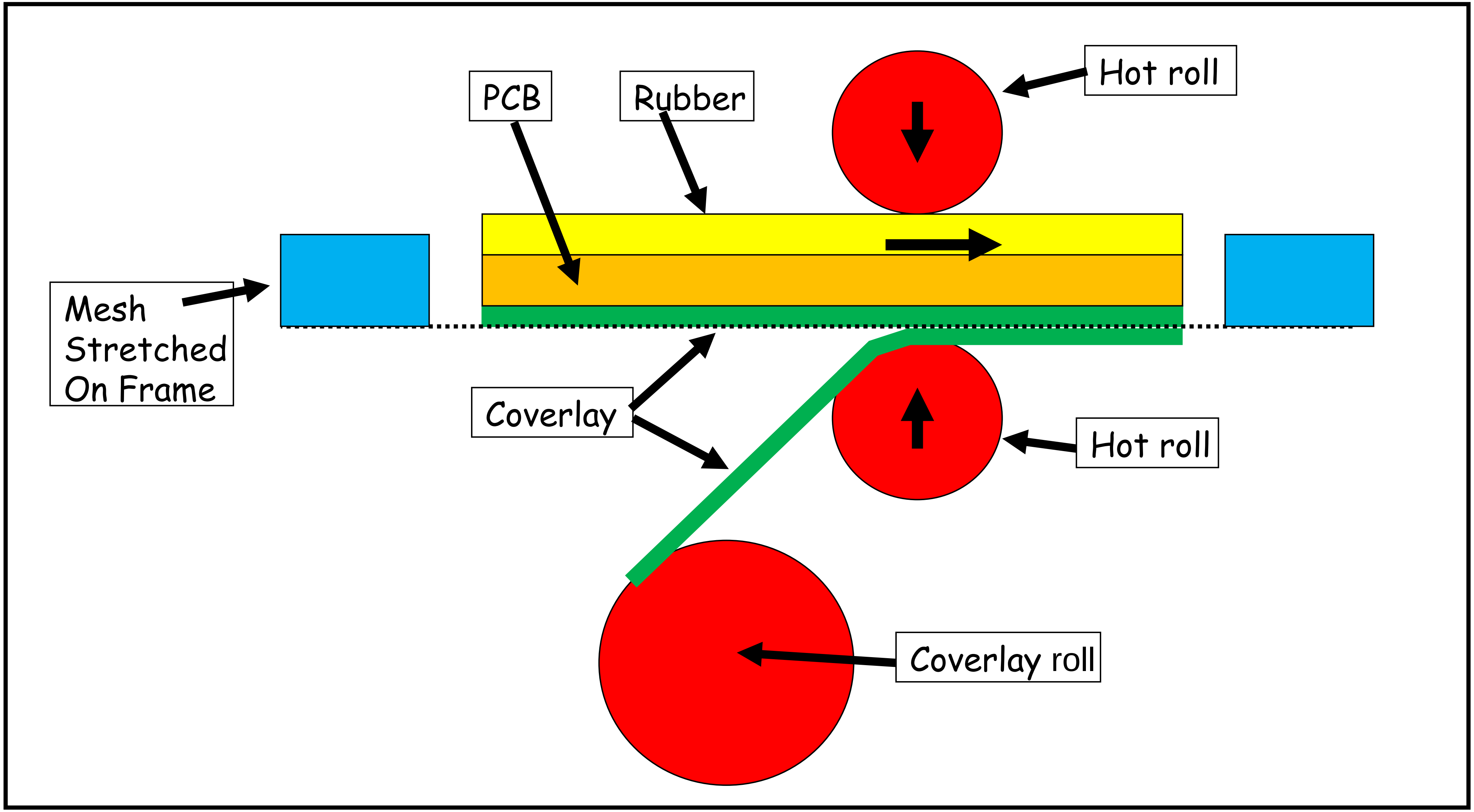
7

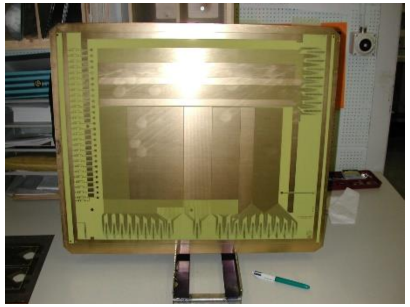
Robust mesh
Repeatable industrial processes.
Possibility to make large detectors of 2m x 1m
The technology spread was then rapid.

Mesh stretching

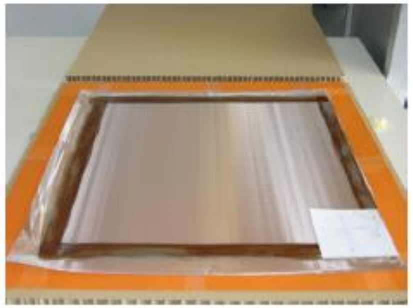


Hot roll lamination details



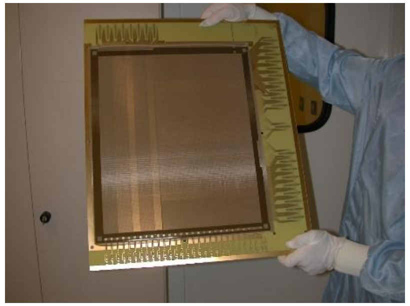


Read-out board



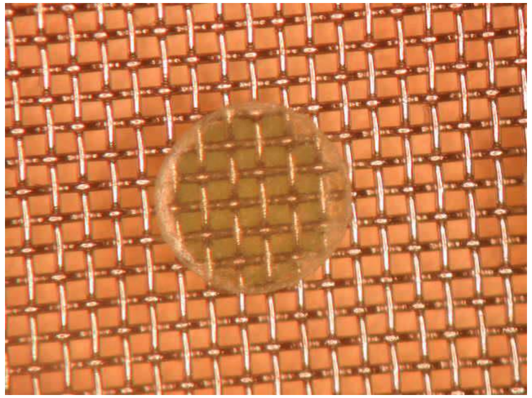
Mesh stretched on frame

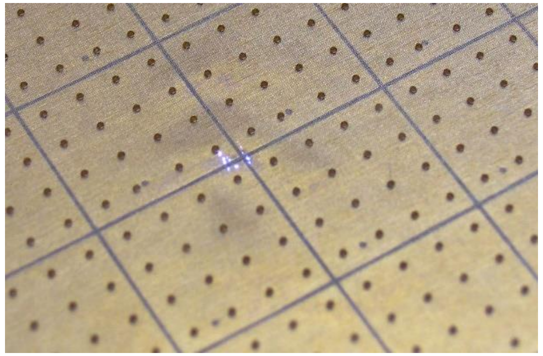
Coverlay lamination



Detector developed / cured / tested

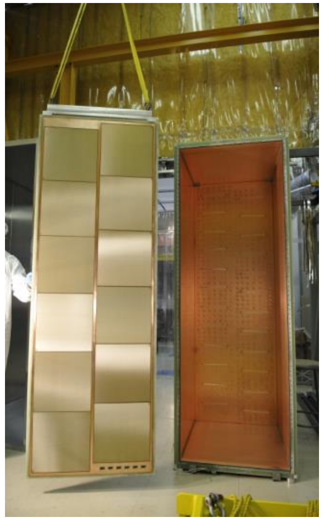
400um pillar



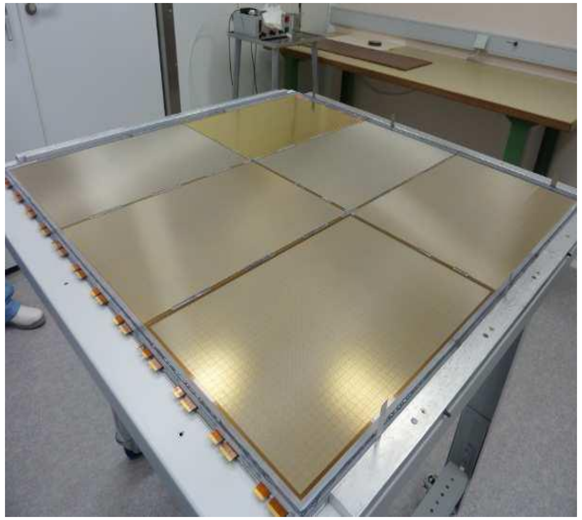


Pillar matrix
on 1cm x 1cm pads

BULK Micromegas detectors

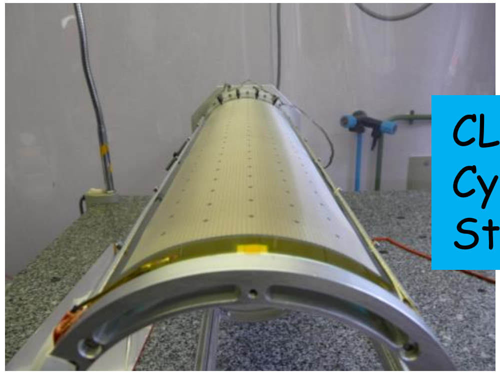


T2K TPC
Alain Delbart

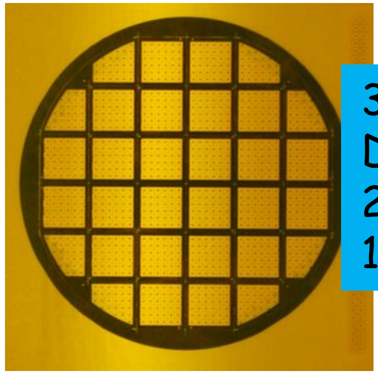


ILC DHCAL ,
Max Chefdeville
1m x 1m plane
With 6 detectors

Early ATLAS NSW R&D
Joerg Wotschack
1.5m x 0.5m plane
Single panel



CLAS 12
Cylindrical Micromegas bulk
Stefan Aune



33 sectors , 12cm diameter
Damien Neyret
2.5mm dead space for sectorizing
1mm hole for HV connection

- Resistive layer introduction.
  A long path, I think not yet fully explored !

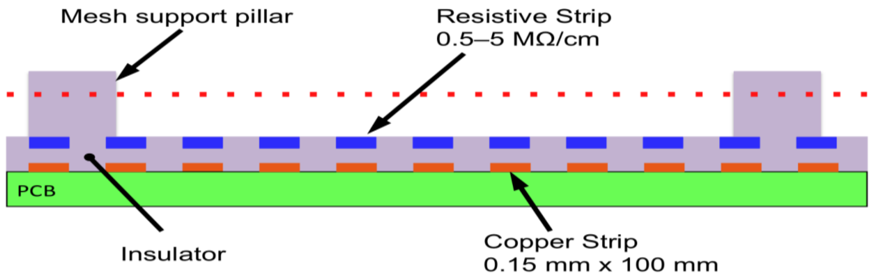
The first person who came to our workshop asking for resistive layers was again Yannis. The idea at that time was to dilute carbon powder in epoxy resin and cover read-out strips.

In 2012 during the early phase of ATLAS NSW R&D it became clear that the resistive layers are crucial.

With LHC background the single amplification stage detectors were continuously sparking, they were not damaged but simply constantly stopped due to the spark rate.

In close collaboration with Joerg Wotschack we dive in resistive layers.

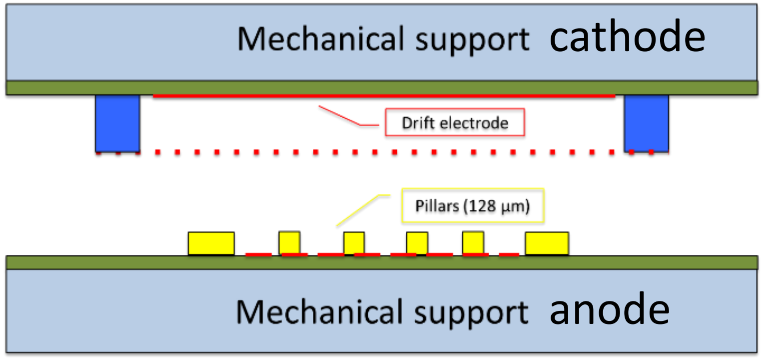
It took us 12 iterations to find the right structure.



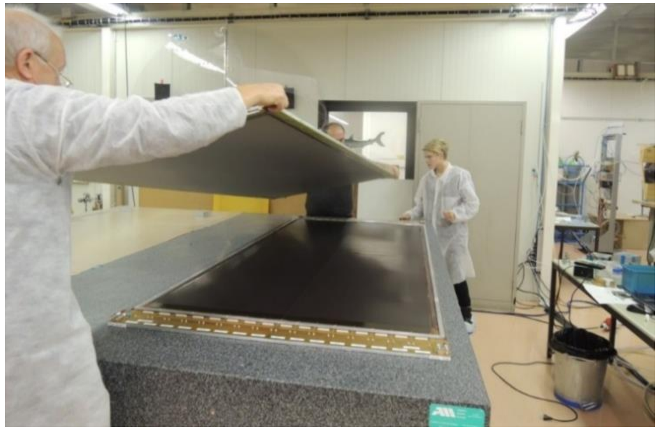
Screen printed resistive strips (ATLAS NSW)

ATLAS NSW prototype 1m x 2m → Floating mesh

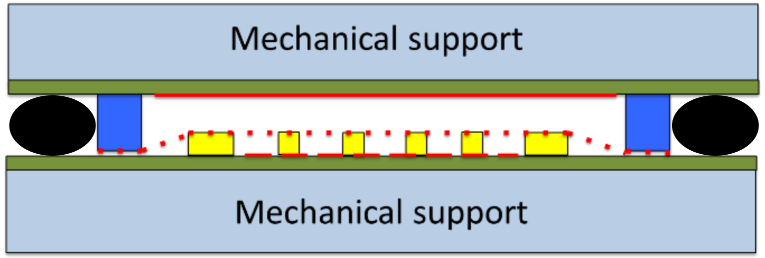
Open



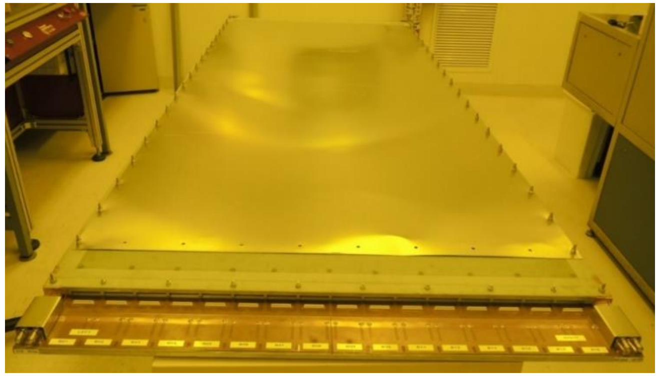
Open



Closed

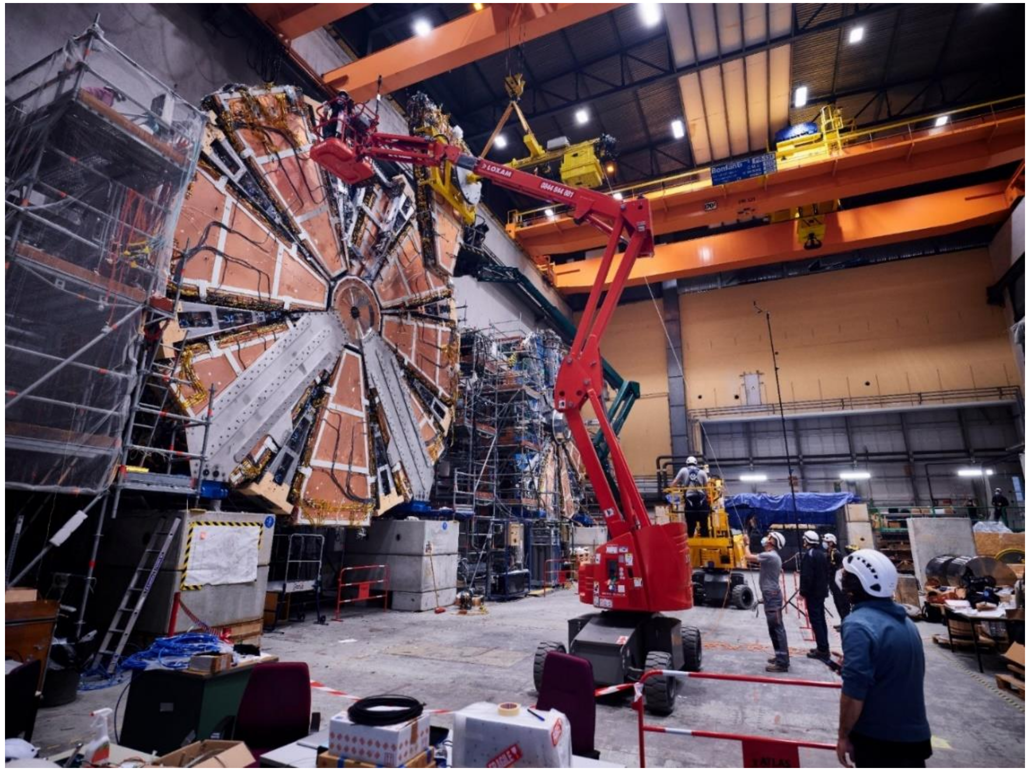


Closed



Atlas NSW

Joerg Wotschack



Close to 2000 Micromegas detectors produced with modules sizes up to 2m x 0.5m

PCBs with pillars built at ELTOS (IT) and ELVIA (FR)

Meshes stretched and glued on frame in Thessaloniki

Honey-comb panels construction and detector Assembly :
- Dubna
- INFN Frascati
- CEA Saclay (Fabien Jeanneau's gang)
- LMU Munich

MPT participated to the R&D and was also involved in the mass production with industry
- Specification
- Companies selection
- Technology transfer

Right after we did a Survey on existing resistive layers to take a direction for the future

Polymer paste 10Kohms to 100K/Square	Too low values (but strips can artificially increase the value)
RuO Thick film paste 10K to 100M/square	Perfect range , but the substrate must be ceramic
Resistive ceramics or glass	Limitation on resistive values and size
Resistive Kapton	Limitation on resistive values
Dissipative films	Too high values
DLC: Diamond Like Carbon	Perfect range 100K to 1T→ chosen direction

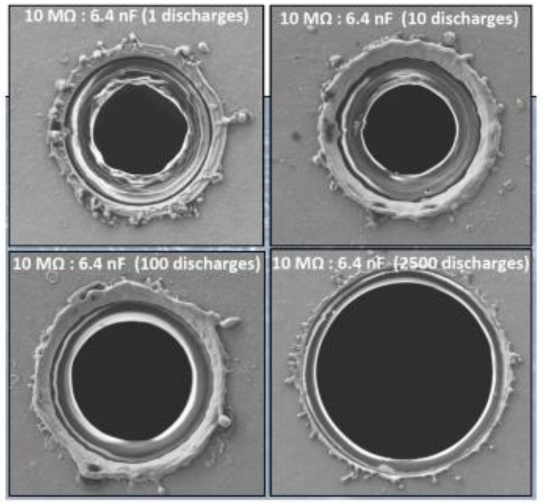
First benefit coming from resistive layers : Spark protection

No structural defect
No process above 100deg
No effect on metals or Polymers

- Spark energy : ½ CV2
  - 600 uJ in a 10cm x 10cm GEM.
  - 30 uJ with a classical MM 10cm x10cm.
  - 0.06 uJ with a 10M resistive layer.

- Below 10M/square.
  - We can still create some visible compounds.
  - There is still enough energy to slightly deteriorate dielectrics.

- Above 10M/square
  - No visible compounds.
  - The structure is never damage.
  - But low Humidity and High cleanliness are mandatory !



© J. Merlin et al.
https://indico.cern.ch/event/709670/contributions/3008626/

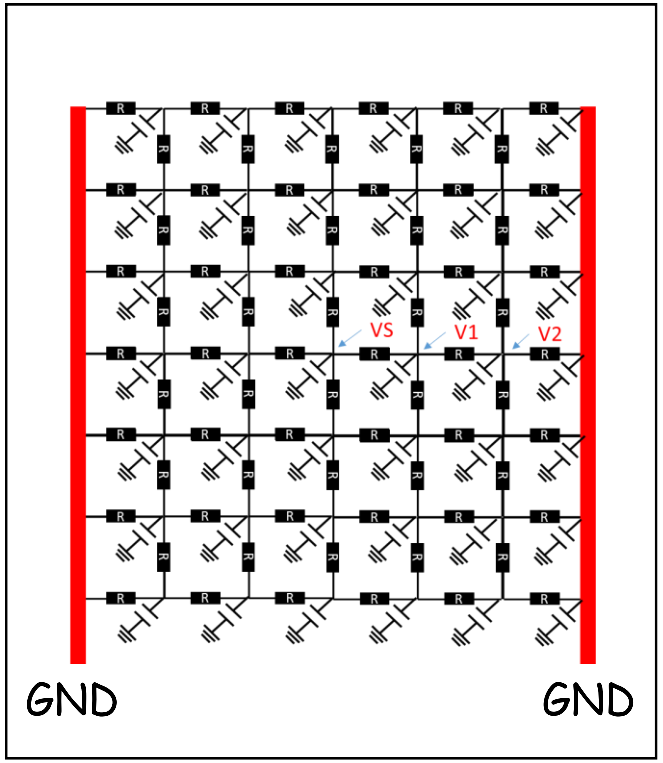
Massive structural effects
Metal melting
Kapton evaporation
Processes happening above 1000 deg

But thanks to Triple GEM structure this is not happening

second benefit : Resistive spreading

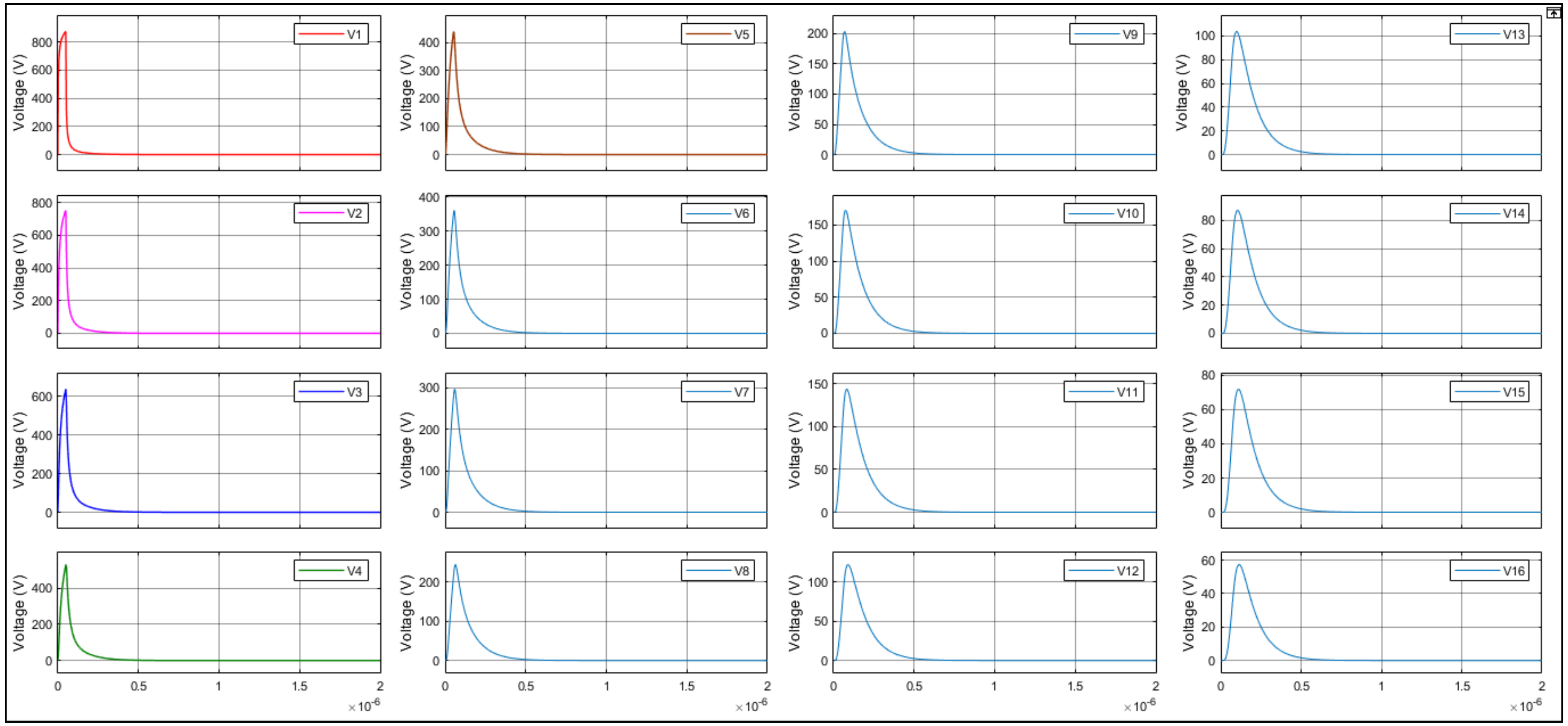
spice simulation Virginia university collaboration

Resistive layer model

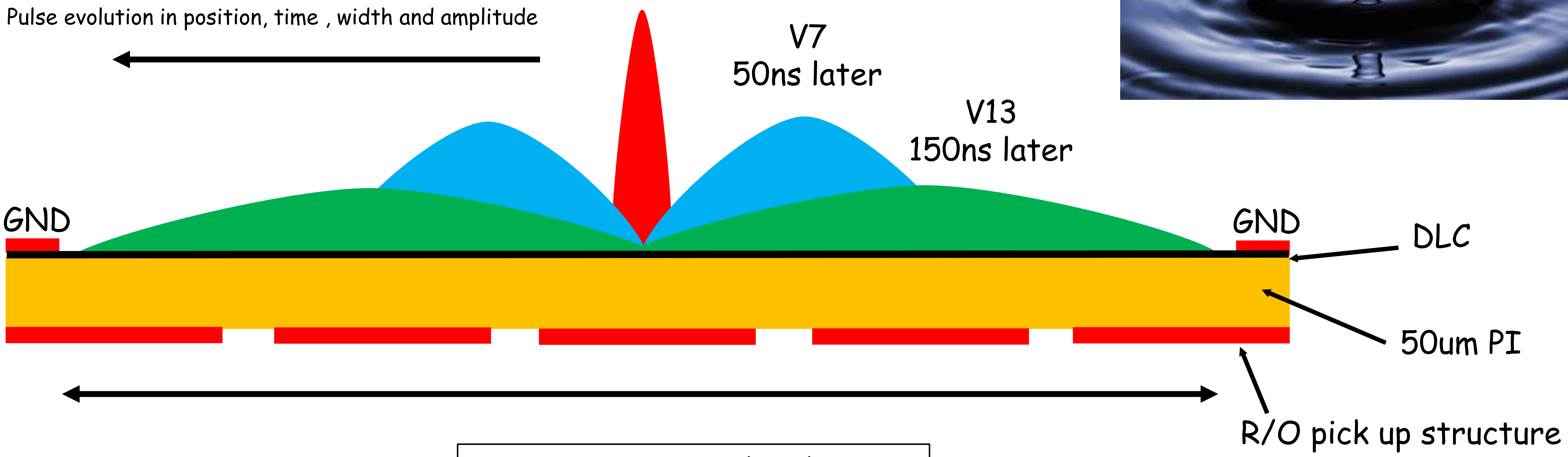


1600 cells
0.125mm x 0.125mm

Pulse amplitude and time shift with a 1MOhms/SQR layer

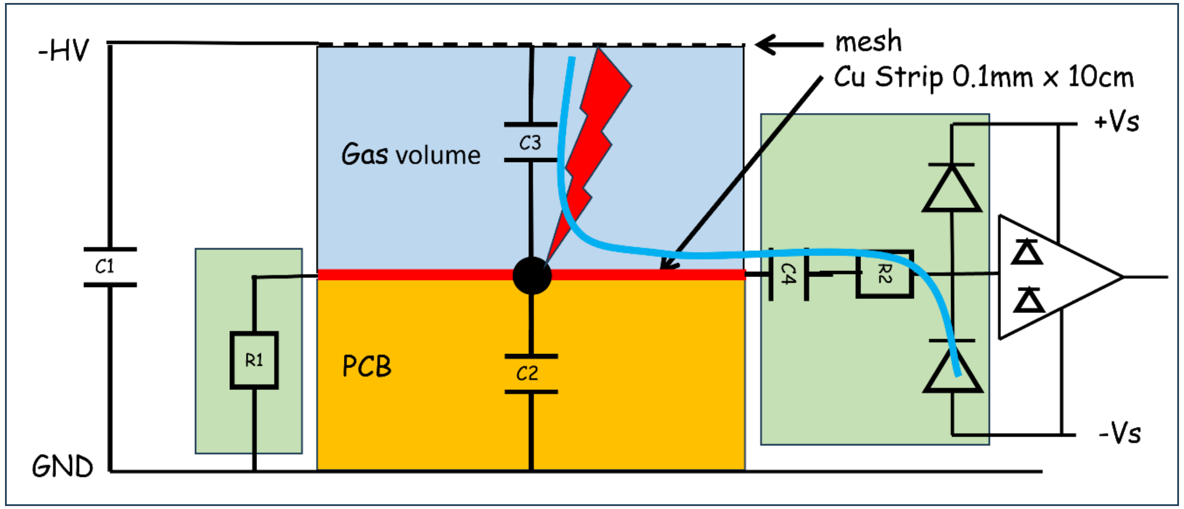


Resistive spreading

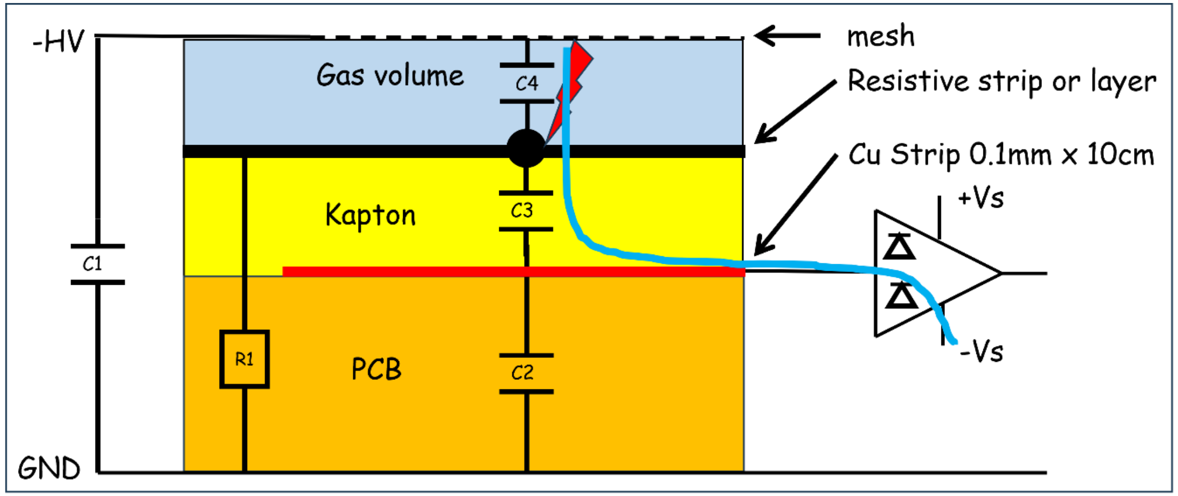


Approximative spreading diameter
- -3mm for 1M
- -1.25mm for 10M
- -0.25mm for 100M
- -less than 0.1mm for 1G

Third benefit : The FE protections are useless



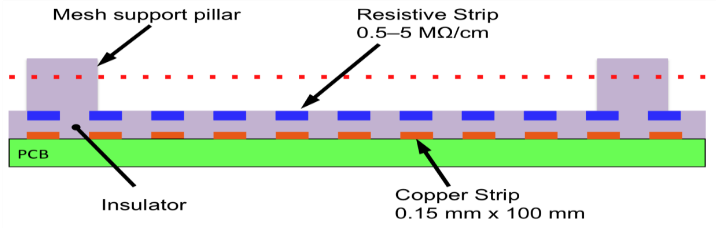
Classical MM
C4 is defining the Spark current
C4 is in the range of 300pF



Resistive MM
C3 is defining the Spark current
and C3 is less than 1pF

2013-2023→MM with resistive layers

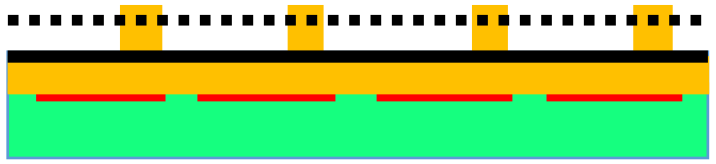
Medium-rate detectors 100kHz/cm2
Side evacuation of the charges



Screen printed resistive strips (ATLAS NSW)

2013

or

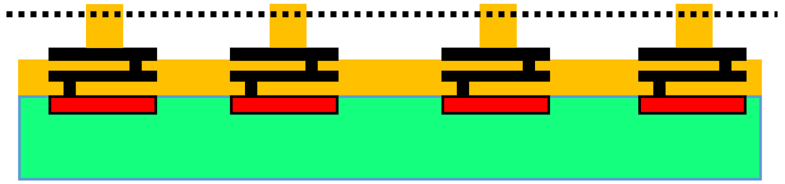


1 full DLC or resistive kapton layer

2015

Joerg Wotschack — CERN
Alain Delbart — Saclay
Paul Colas — Saclay

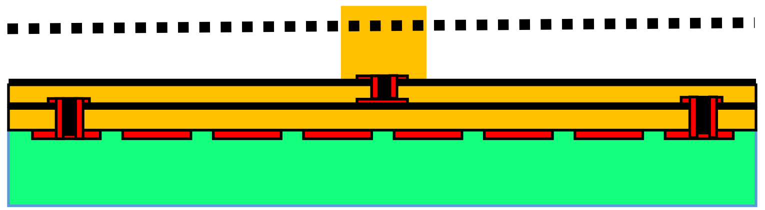
High-rate detectors 10Mhz/cm2
Charge evacuation inside active area



2 layers with screen printed pads

2015

or



2 DLC layers without patterns

2020

Damien Neyret — Saclay
Max Chefdeville — Lapp Annecy
Renaud Gaglionne — Lapp Annecy
Mauro Iodice — INFN Roma

2016→PicoSec precise timing with Micromegas

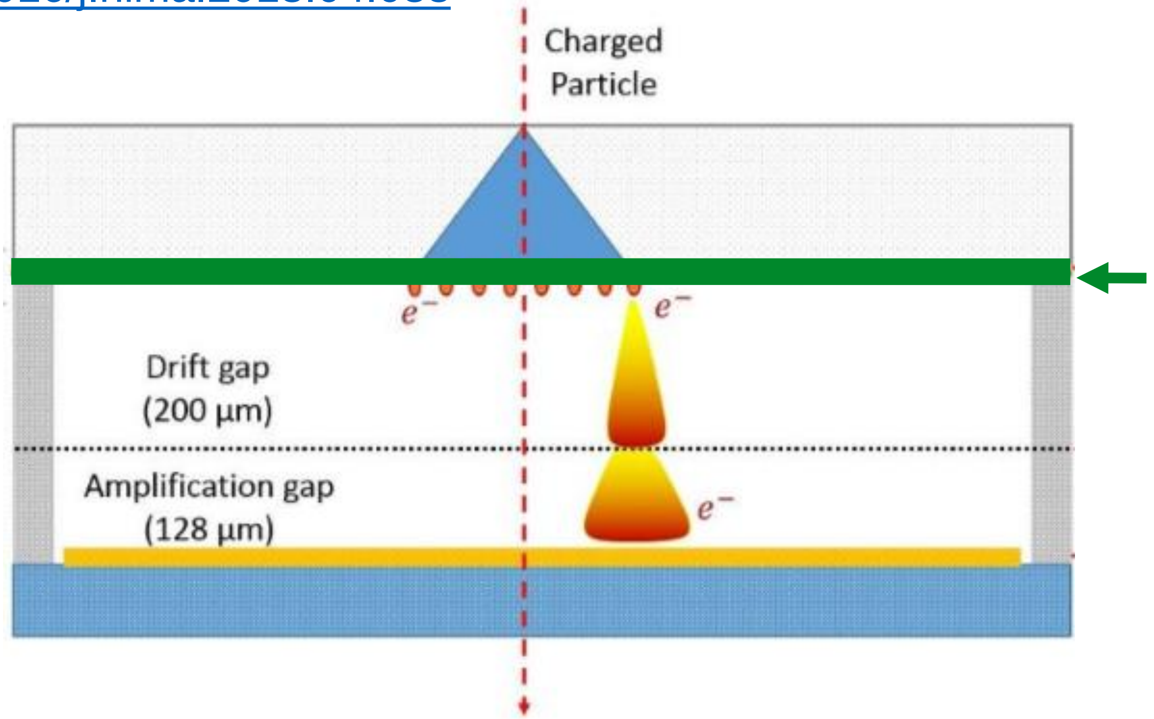
PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector
J. Bortfeldt et. al. (RD51-PICOSEC collaboration), NIM A (903), 2018,
https://doi.org/10.1016/j.nima.2018.04.033

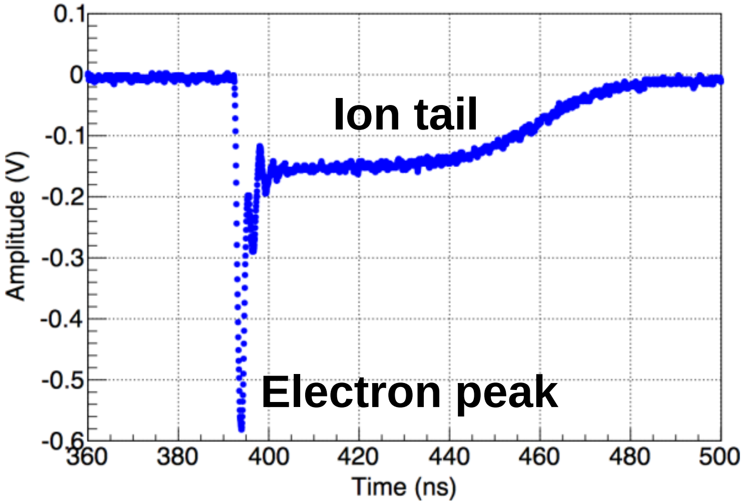
Cherenkov radiator
(3 mm MgF_2)

Photocathode
(3 nm Cr + 18 nm CsI)

Drift gap
(Pre-amplification)

Micromegas
(Amplification)





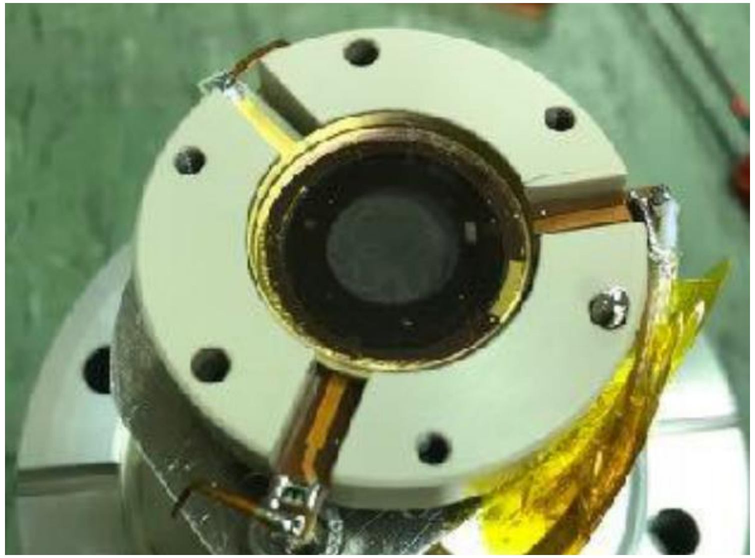
- **Signal with two distinct components:**
  Electron peak: fast (≈0.5 ns)
- Ion tail: slow (≈100 ns)

Gas mixture: 80% Ne + 10% C_2H_6 + 10% CF_4 (COMPASS gas)

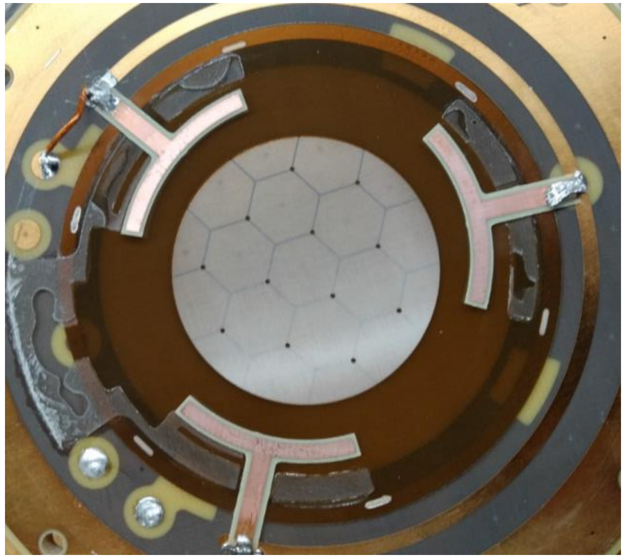
Schematic not drawn to scale

X. Wang et al., Study of DLC photocathode for PICOSEC detector, RD51 collaboration meeting, October 2018

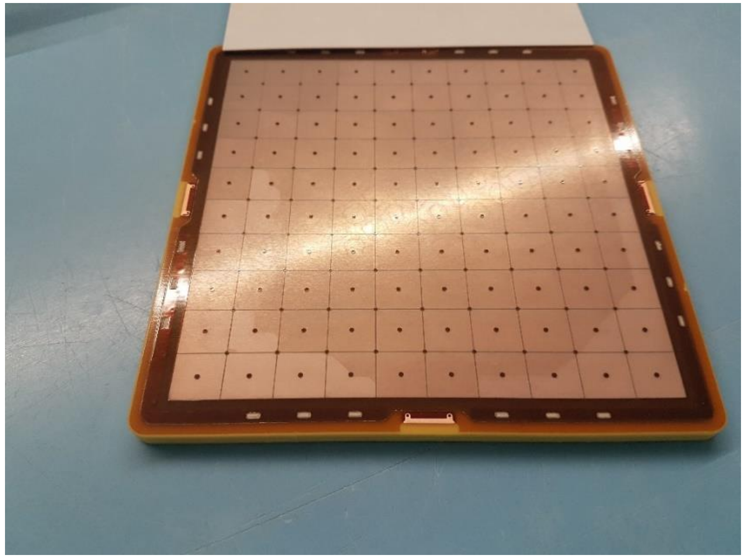
PicoSec detector modules



Single pad (2016)
Pads ⌀1 cm



Multi pad (2017)
Pads ⬡ 1 cm



10x10 module (2022)
Pads □ 1 cm

Conclusion

Yannis have triggered nearly all the major MM improvements

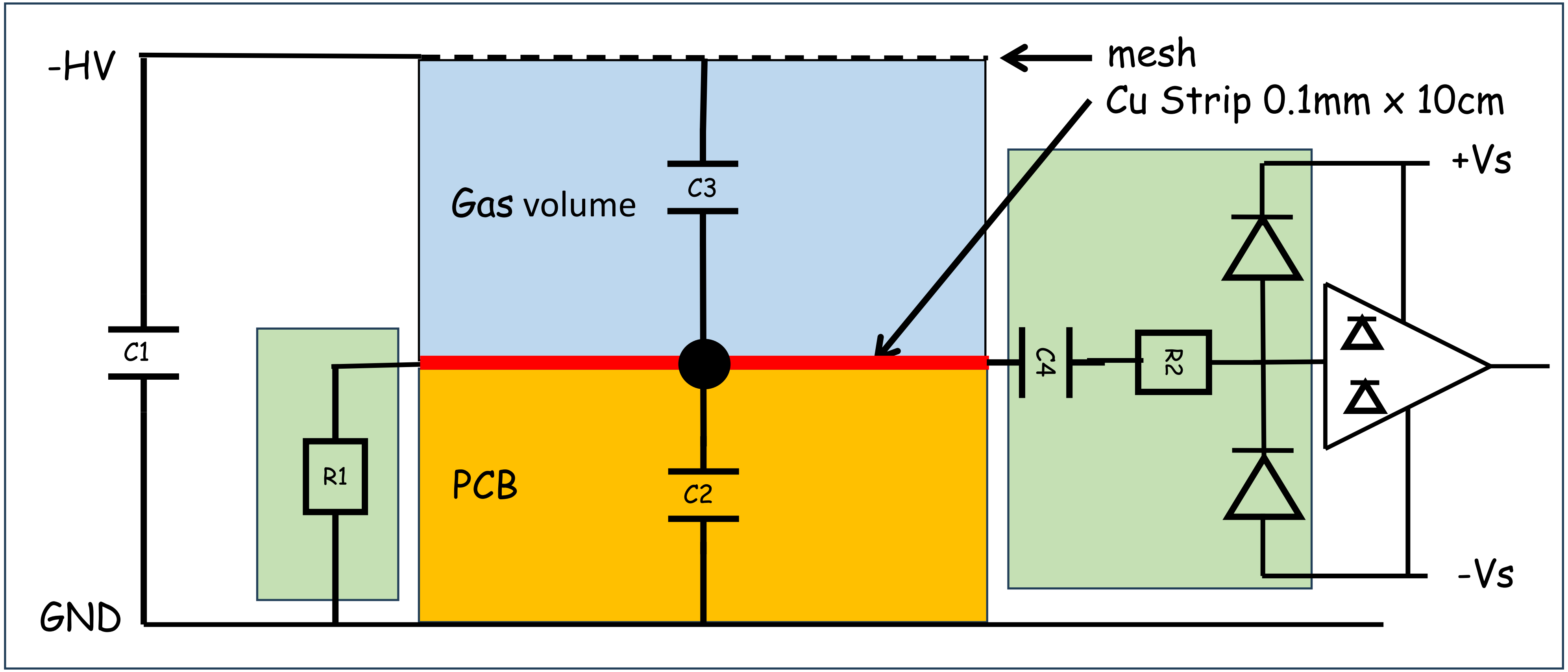
There is now a solution for nearly all applications:

large size, shape, protection , rate , space resolution, mass production , time resolution etc.

Yannis could you help us to face our last problem :

Improving the robustness of photocathode layers for precise timing detectors

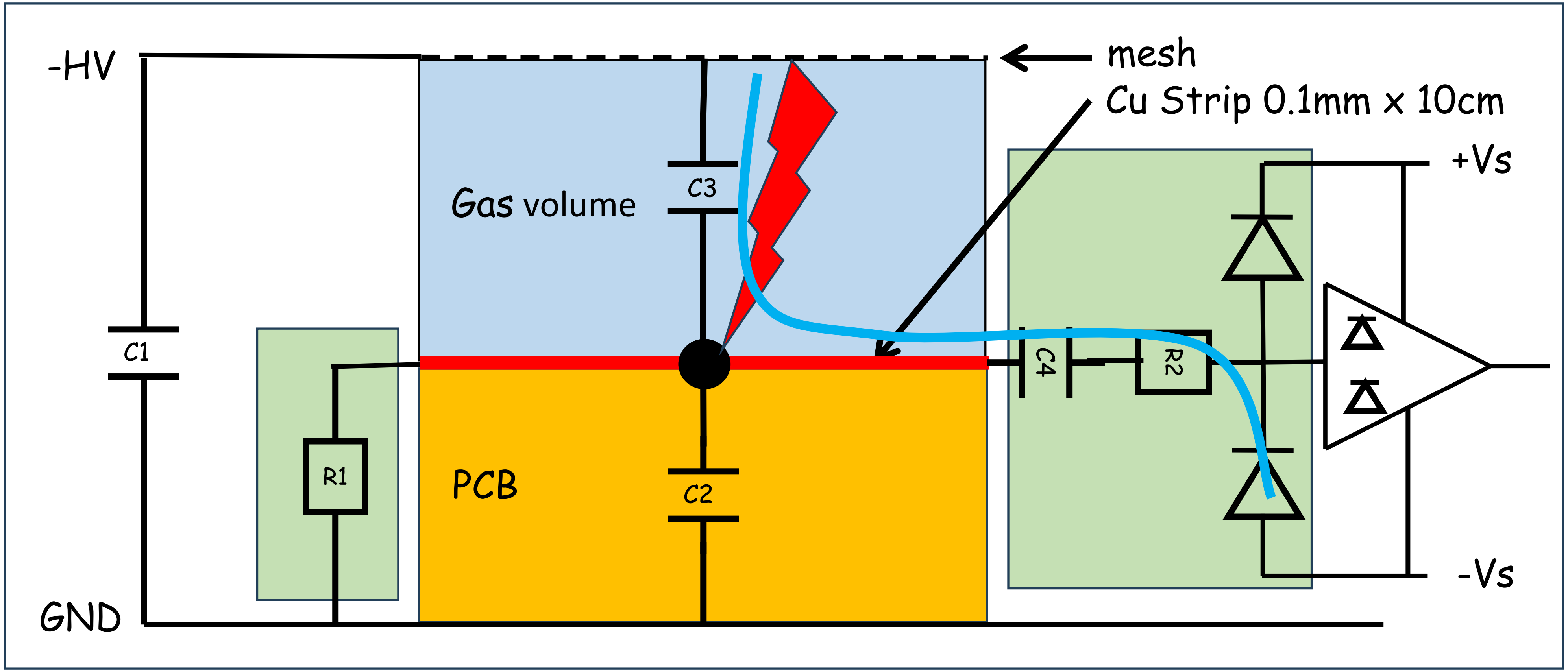
Third benefit : The FE protections are useless



C1 : capacity mesh to GND	many nF
C2 : strip capacity to GND	in the range of 20 pF
C3 : strip capacity to mesh	in the range of 10pf
C4 : spark protection capacitor	in the range of 300pF → 10 x (C2//C3)
R1 : polarization resistor	1M
R2 : peak spark current limitation	20 Ohms to protect the external diodes

Third benefit : The FE protections are useless

MM with classical discrete components protection (In green)

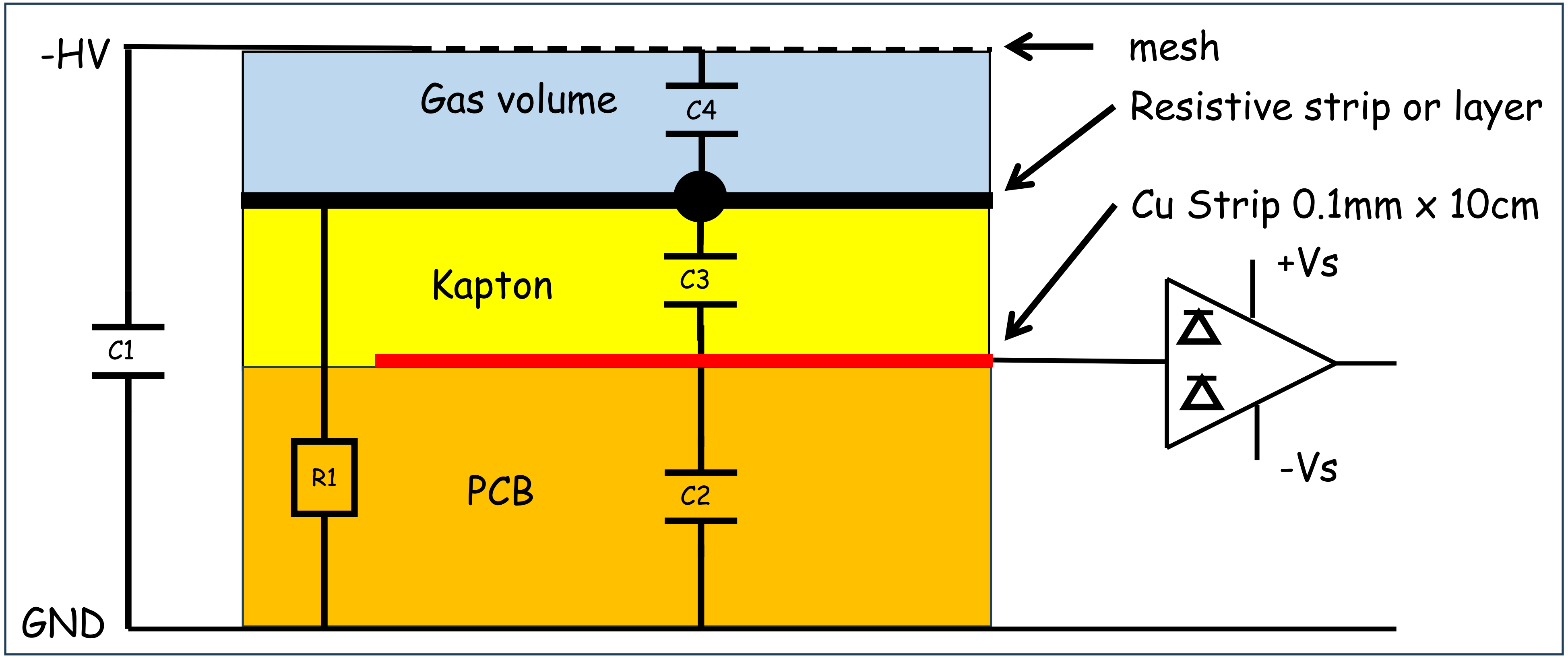


C1 : capacity mesh to GND many nF
C2 : strip capacity to GND in the range of 20 pF
C3 : strip capacity to mesh in the range of 10pf
C4 : spark protection capacitor in the range of 300pF → 10 x (C2//C3)
R1 : polarization resistor 1M
R2 : peak spark current limitation 20 Ohms to protect the external diodes

The spark current is defined by C4 serial to R2 through outer diodes.
This spark current do not flow through the amplifier.
Without external diodes the inner diodes would have been damaged.
Without C4 , C1 defines a so large current that the outer diodes would have been damaged, melting also the mesh.

Third benefit : The FE protections are useless

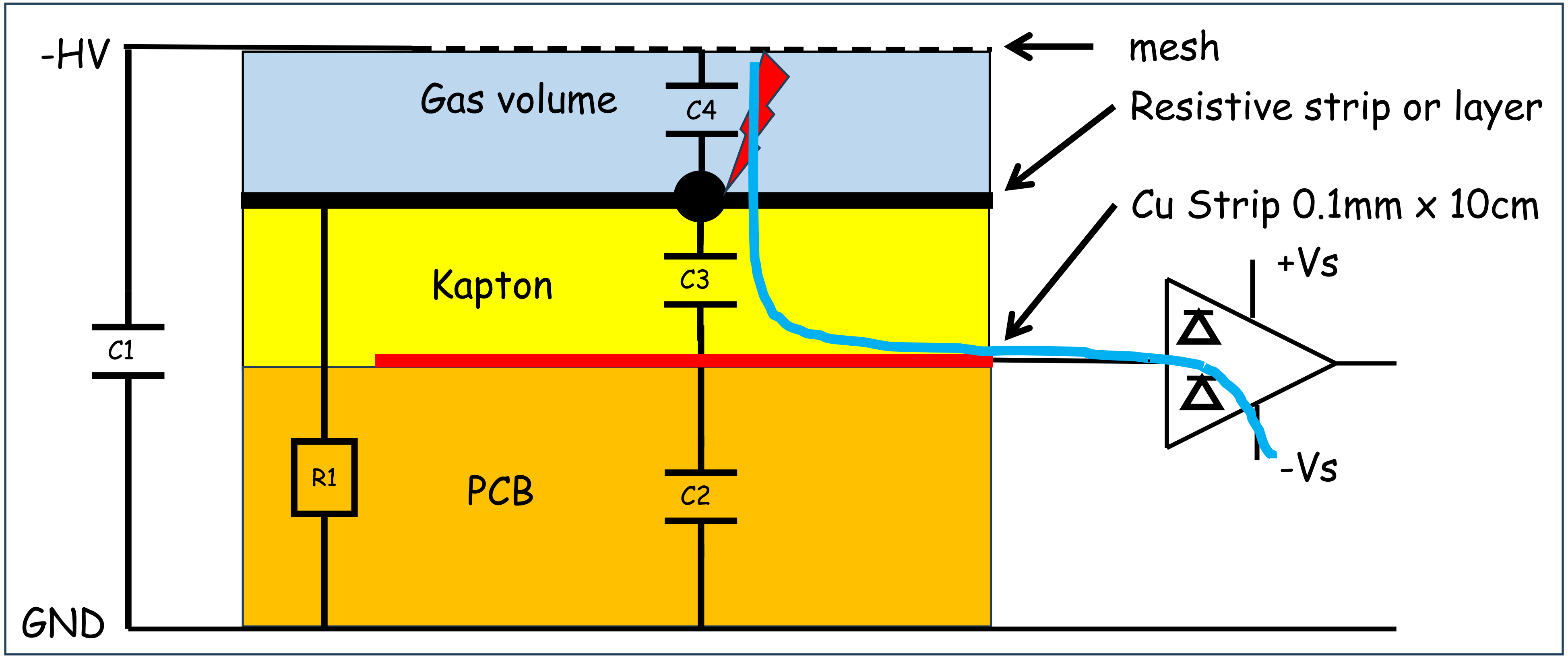
MM with Resistive protection



C1 : capacity mesh to GND	many nF
C2 : strip capacity to GND	in the range of 20 pF
C3 : local capacity res layer to mesh	below the pF
C4 : local capacity res layer to strip	below the pF
R1 : embedded resistor	part of the resistive strip or layer

Third benefit : The FE protections are useless

MM with Resistive protection



C1 : capacity mesh to GND	many nF
C2 : strip capacity to GND	in the range of 20 pF
C3 : local capacity res layer to mesh	below the pF
C4 : local capacity res layer to strip	below the pF
R1 : embedded resistor	part of the resistive strip or layer

The peak spark current flowing in the amplifier is defined by C3 and the amplifier internal diodes.
Approximately 1000 time less the previous scheme.
External diodes are not necessary.