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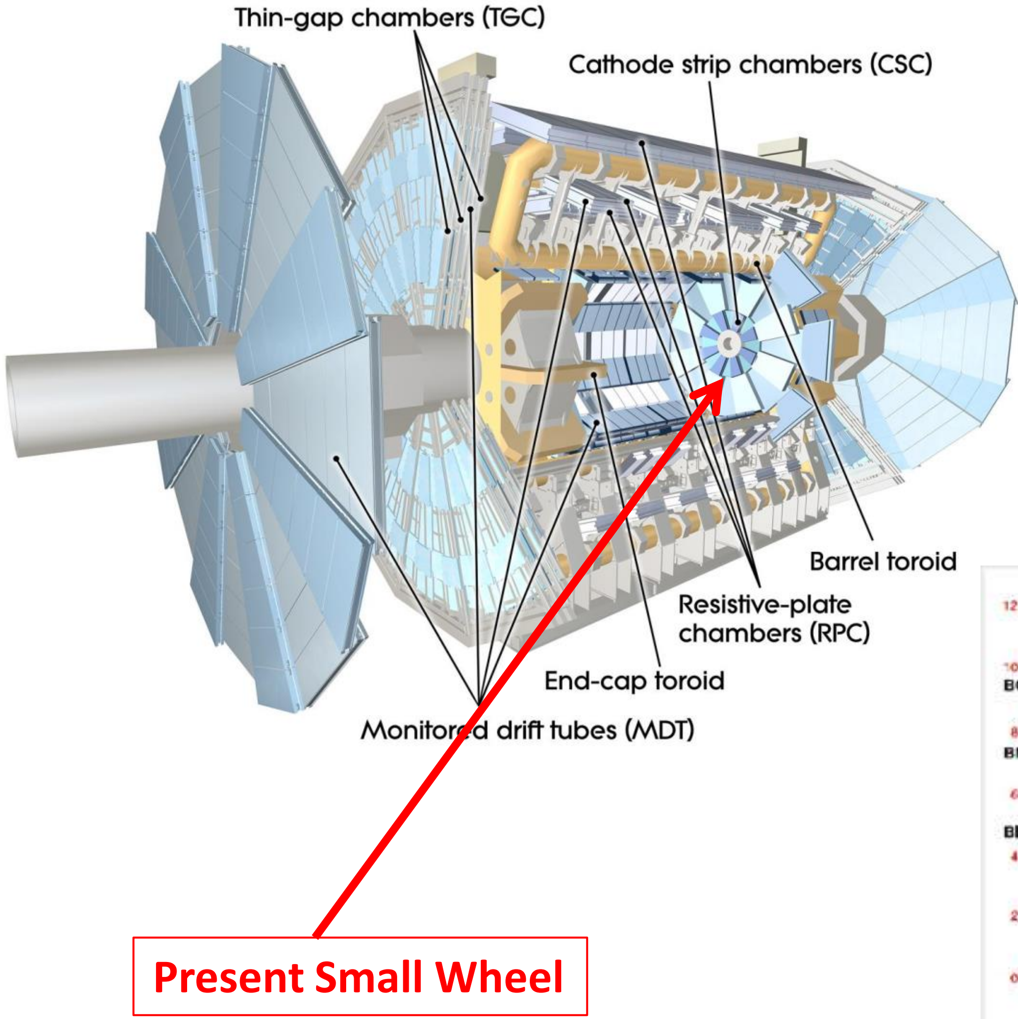
On behalf of the MAMMA Collaboration

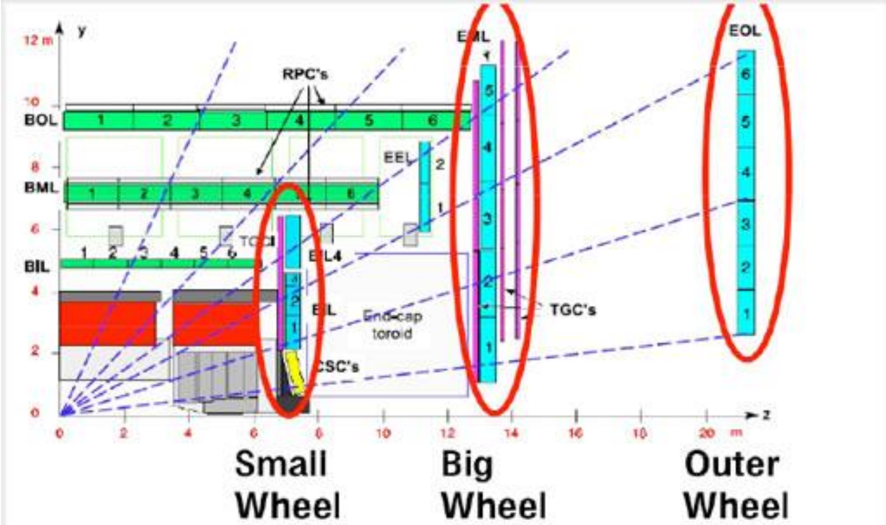
Micromegas for the ATLAS Muon System Upgrade

Outline

- The ATLAS Muon System upgrade
- The micromegas technology
- Making micromegas spark-resistant
- Performance & ageing studies
- Large-area micromegas chambers
    - Construction: problems and solutions
- Large chambers characterization

ATLAS Muon System





ATLAS upgrade for the s-LHC

LHC upgrade to happen in three phases:

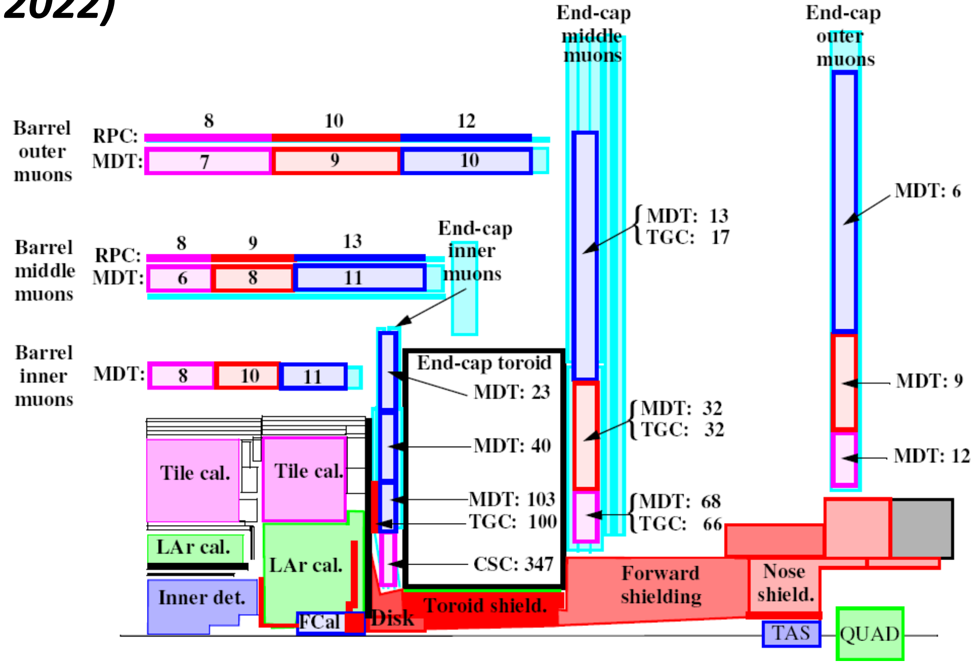
$L_{phase\ 0}$ *~ 1x10^{34} cm^{-2} s^{-1} (~2015)*
$L_{phase\ 1}$ *~ 2-3 x10^{34} cm^{-2} s^{-1} (~2018)*
$L_{phase\ 2}$ *~ 5x10^{34} cm^{-2} s^{-1} (with luminosity leveling~2022)*

Muon Spectrometer affected regions :

- **End-Cap Inner (CSC,MDT,TGC)**

Total area ~150 m2

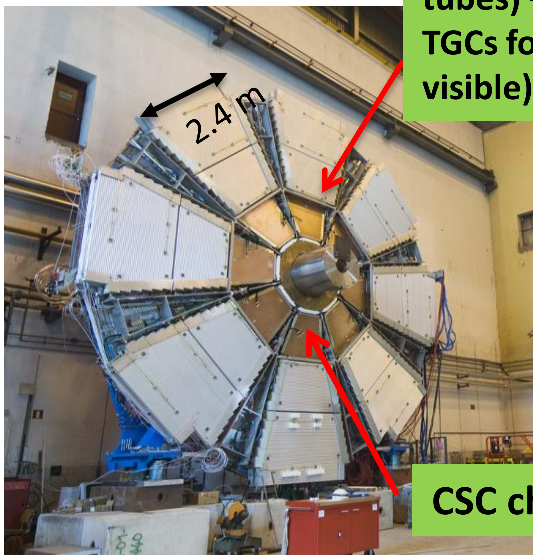
Micromegas have been chosen as precision measurement detectors (but also trigger) of the New Small Wheel of ATLAS



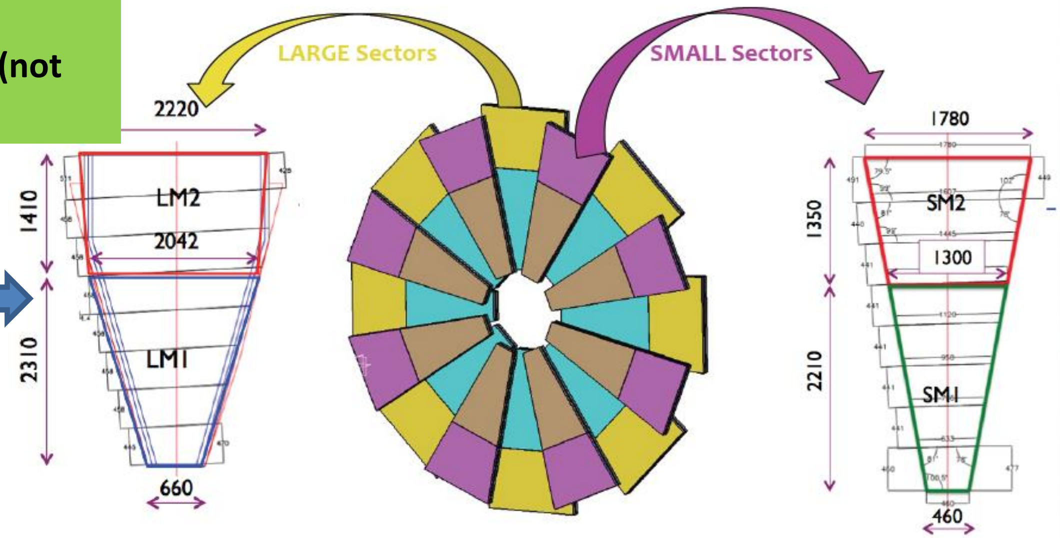
Average single plane counting rate (Hz/cm^2) at the 10^{34} nominal LHC luminosity (CERN-ATL-GEN-2005-001)

ATLAS Small Wheel upgrade project

Today: MDT chambers (drift tubes) +
TGCs for 2nd coordinate (not visible)



CSC chambers



New Small Wheel Layout

Equip the New Small Wheels with sTGC and MicroMegas (MM) detectors

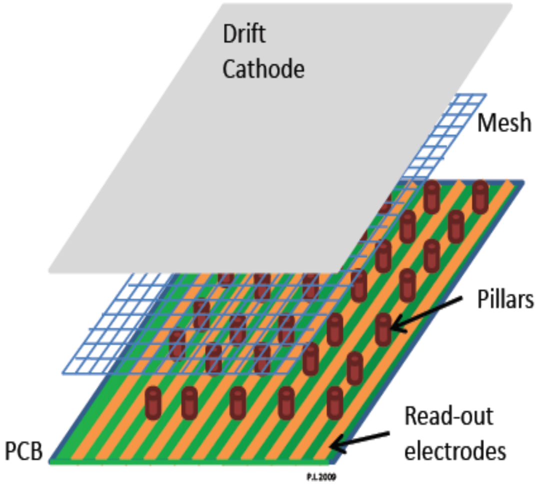
MM parameters:

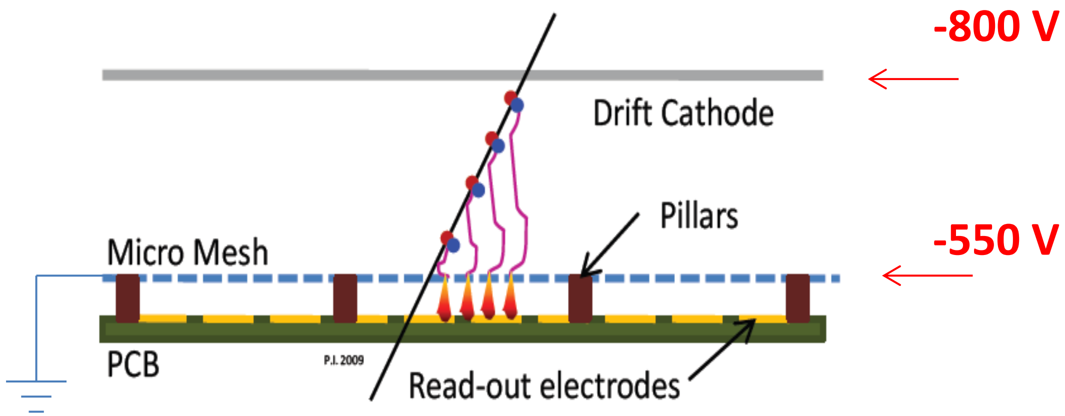
- ✓Detector dimensions: 1.5–2.5 m^2 per detector.
- ✓Combine precision and 2^{nd} coord. measurement as well as trigger functionality in a single device
- ✓Each detector technology comprises eight active layers, arranged in two multilayers
- ✓MM 2^{nd} coord will be achieved by using $\pm$ 1.5° stereo strips in half of the planes.
  - 2M readout channels
  - A total of about 1200 m^2 of detection layers

The micromegas technology

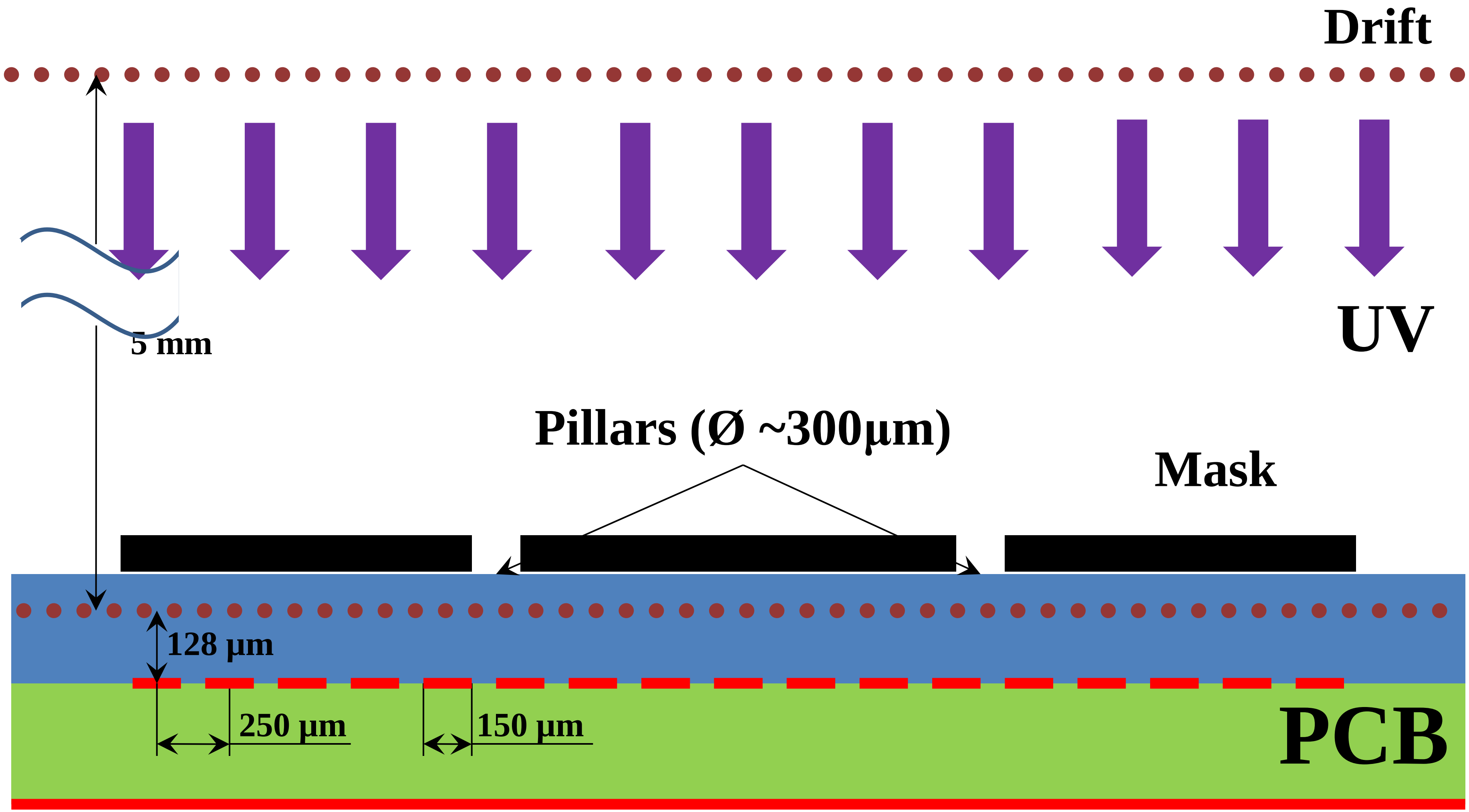
What are Micromegas ?

- Micromegas are parallel-plate chambers where the amplification takes place in a thin gap, separated from the conversion region by a fine metallic mesh
- The thin amplification gap (short drift times and fast absorption of the positive ions) makes it particularly suited for high-rate applications



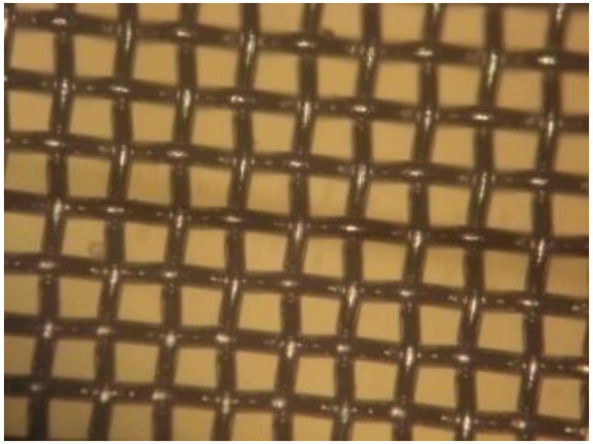


Micromegas: The bulk technique



Micromegas: The bulk technique

Pillar distance on photo: 2.5 mm

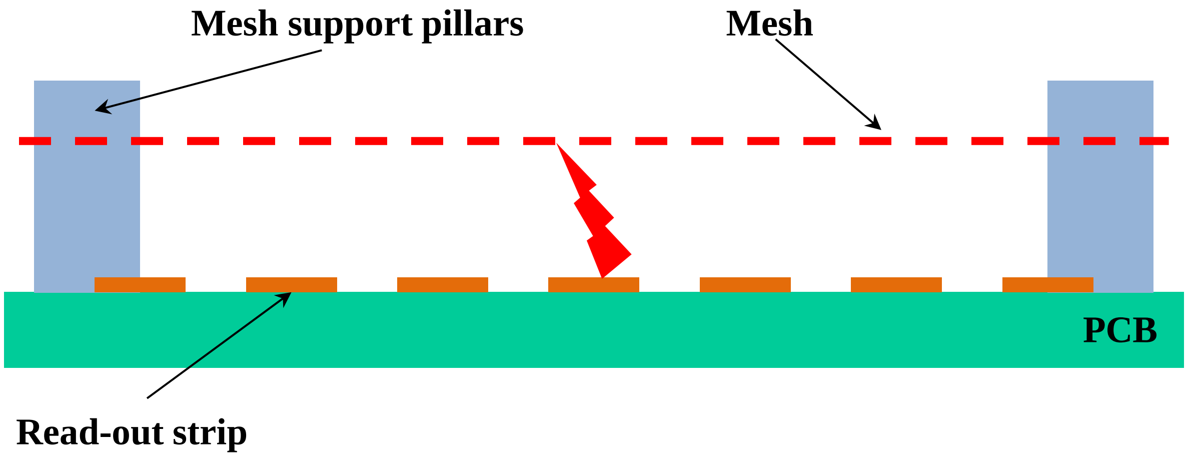


Standard configuration

- Pillars every 2.5 (or 5) mm
- Pillar diameter ≈350 µm
- Dead area ≈1 %
- Amplification gap 128 µm
- Mesh: 325 lines/inch

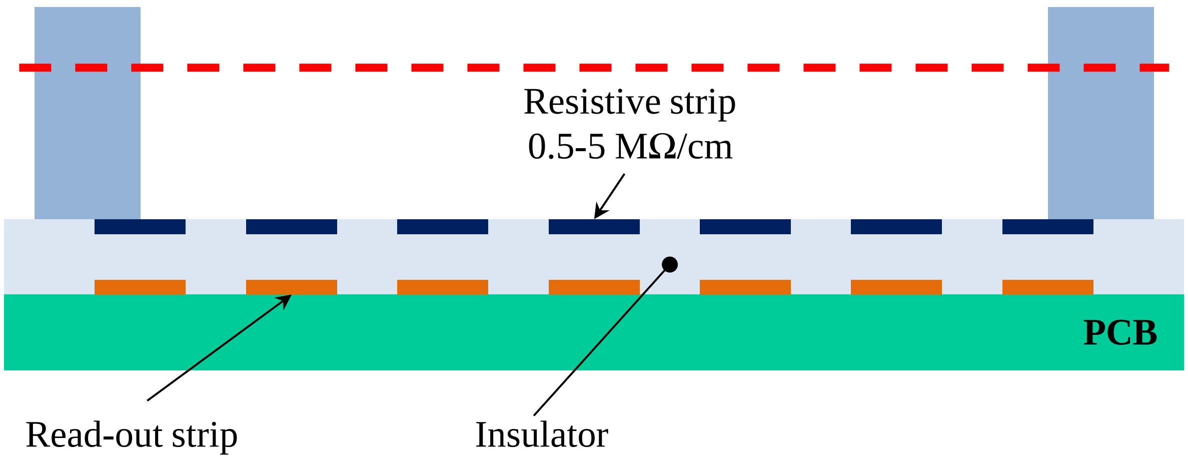
Making MMs spark resistant

Making MMs spark resistant

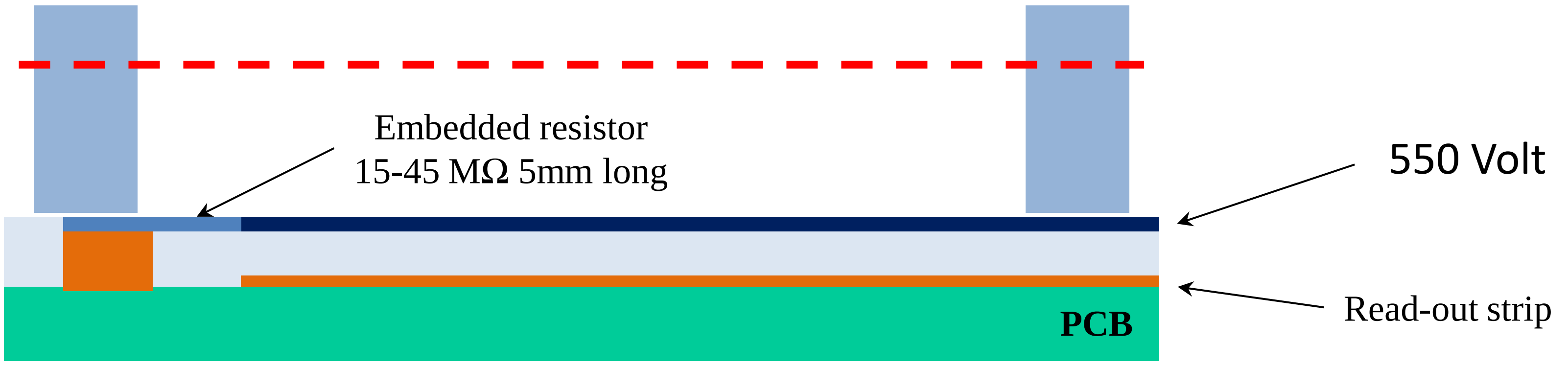


- Sparks between mesh and readout strips may damage the detector and readout electronics and/or lead to large dead times as a result of HV breakdown
- Several protection/suppression schemes tested
  - A large variety of resistive coatings of anode
  - Double/triple amplification stages to disperse charge, as used in GEMs (MM+MM, GEM+MM)
- Finally settled on a protection layer with resistive strips
- Tested the concept successfully in the lab (^{55}Fe source, Cu X-ray gun, cosmics), H6 pion & muon beam, and with 5.5 MeV neutrons

Making MMs spark resistant



To avoid spark effect the readout strips were covered with the 64 μm thick insulator layer with resistive strips on top of it connected to the +HV via discharge resistor and mesh is connected to GND

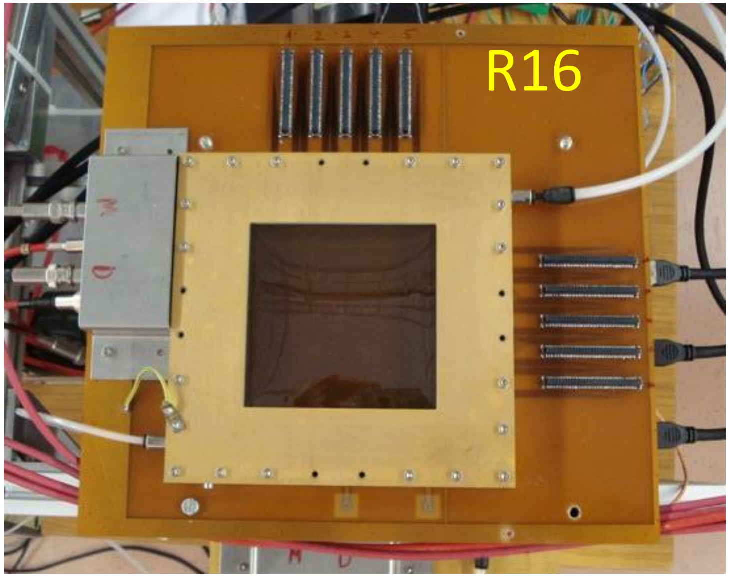


Making MMs spark resistant

- Several resistive-strips detector tested
- Small 10 x 10 cm^2 chambers with 250 μm readout strip pitch
- Various resistance values

Chamber	R_{GND} (MΩ)	R_{strip} (MΩ/cm)	$N_R:N_{ro}$
R11	15	2	1:1
R12	45	5	1:1
R13	20	0.5	1:1
R14	100	10	1:1,2,3,4,72
R15	250	50	1:1,2,3,4,72
R16	55	35	x-y readout
R17	100	45	x-y readout
R18	200	100	x-y readout
R19	50	50	xuv readout

- Gas mixtures
  - $Ar:CO_2$ (85:15 and 93:7)
- Gas gains
  - 2–3 x 10^4
  - 10^4 for stable operation



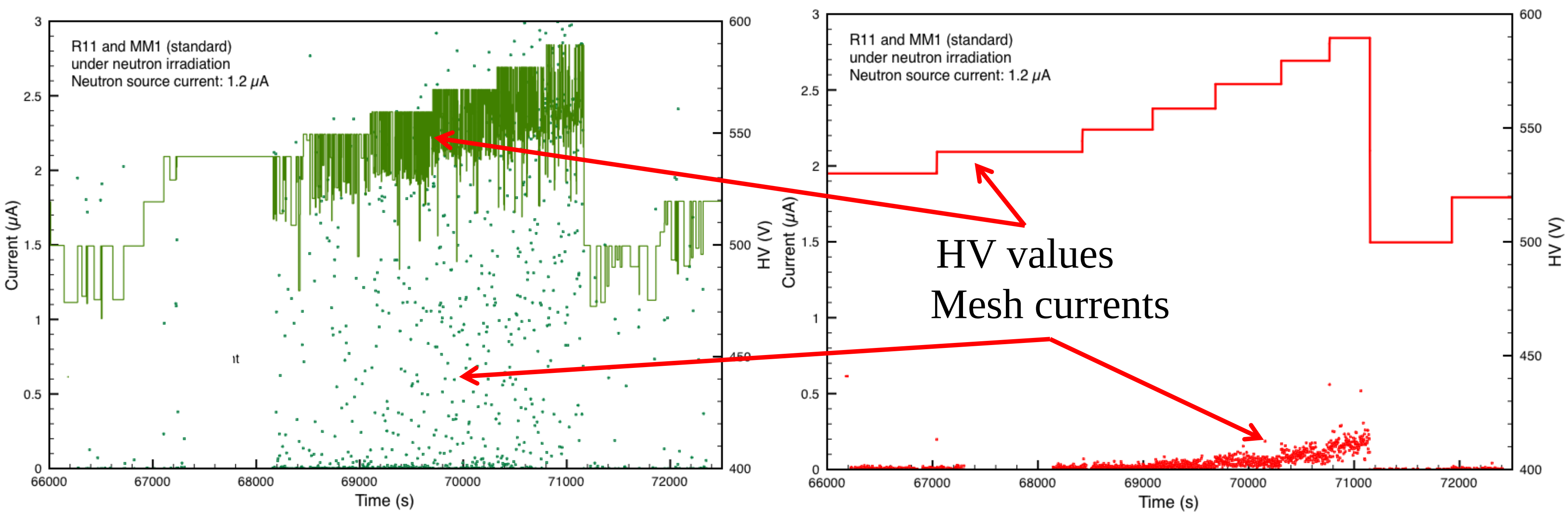
Making MMs spark resistant

MicroMegas mesh currents and HV drop
in neutron beam

Gas: Ar:CO_2 (85:15) Neutron flux: ≈ 10^6 n/cm^2/sec

Standard MM:
Large currents
Large HV drops, recovery time O(1s)
Chamber could not be operated stably

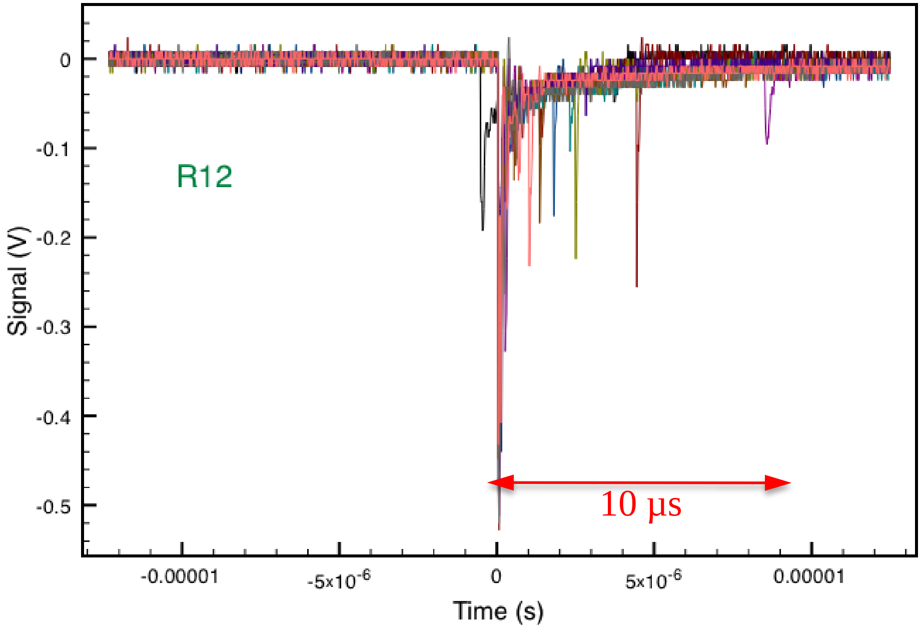
R11:
Low currents
Despite discharges, but no HV drop
Chamber operated stably up to max HV

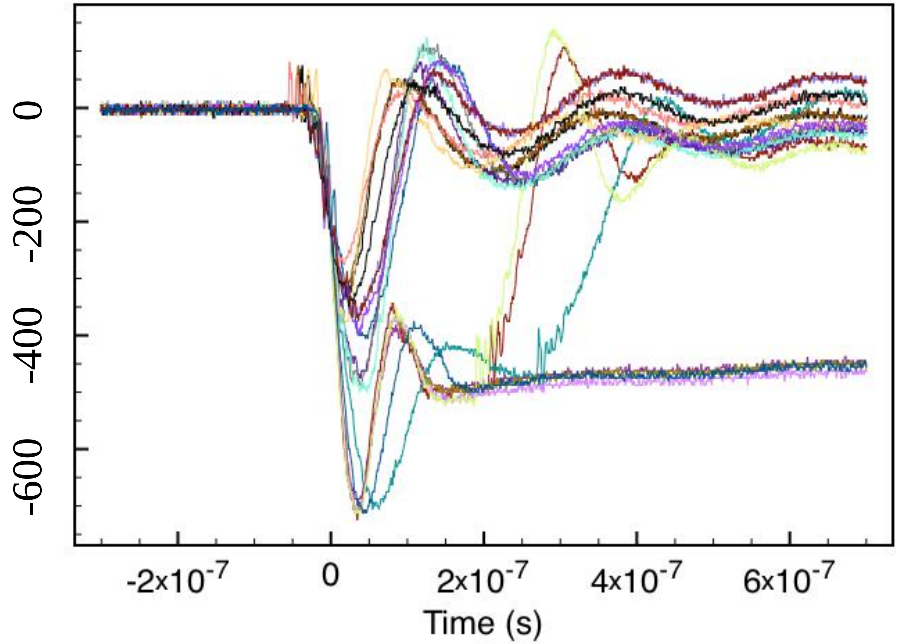


Making MMs spark resistant

Sparks measured directly on readout strips through 50 Ohm
Several spark signals plotted on top of each other to enhance the overall characteristics

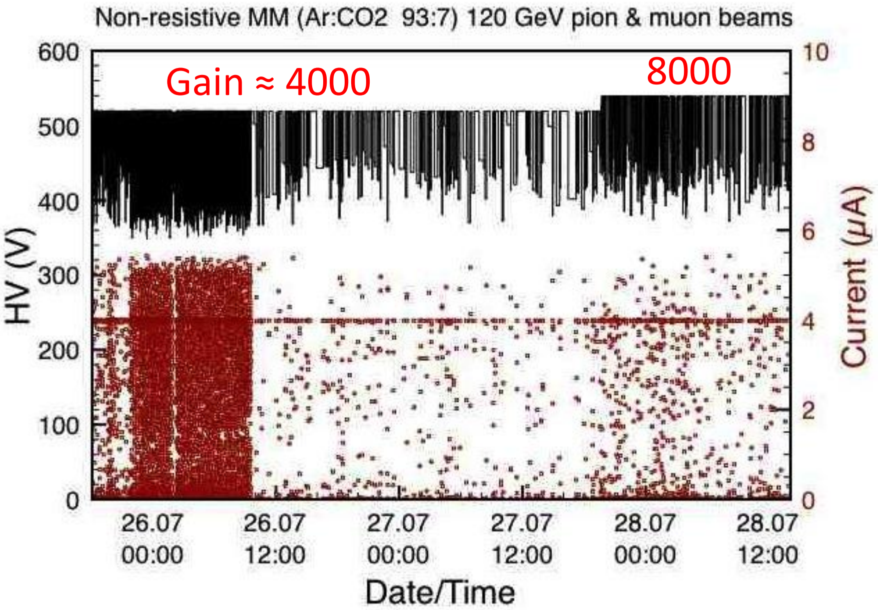
R12 shows 2-3 order of magnitude less signal and shorter recovery time than standard MM

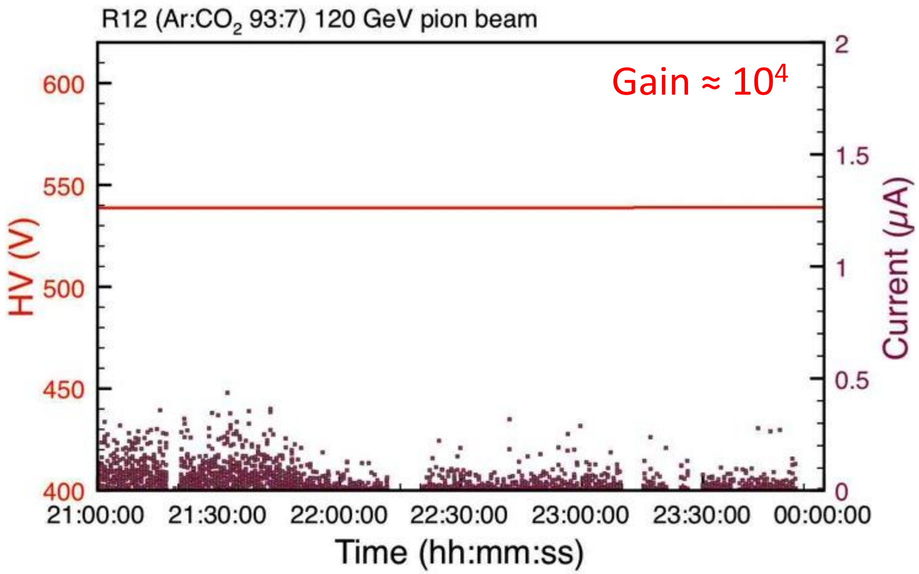




Making MMs spark resistant

Sparks in 120 GeV pion & muon beams



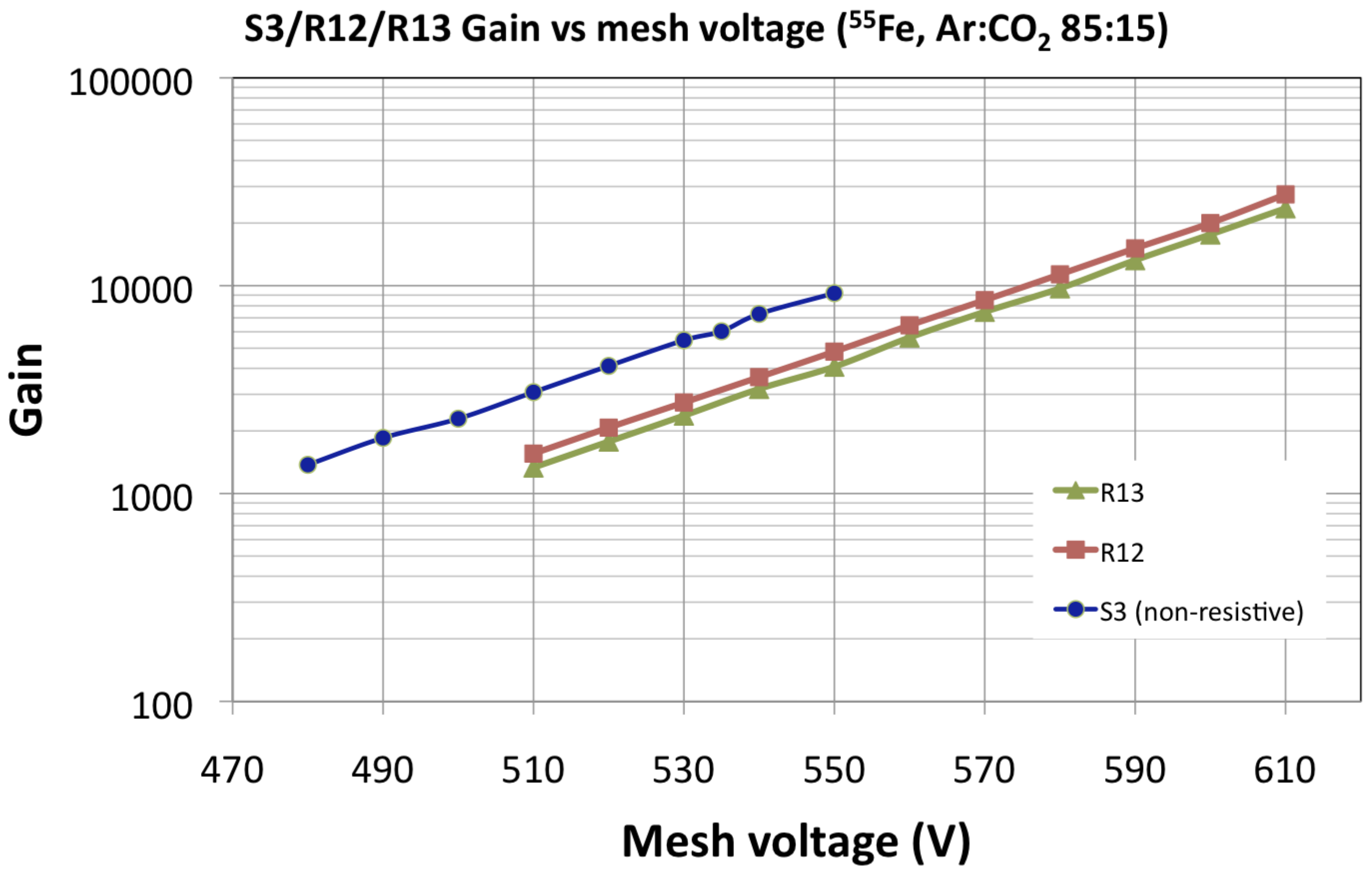


- Pions, no beam, muons
- Chamber inefficient for O(1s) when sparks occur

- Stable, no HV drops, low currents for resistive MM
- Same behavior up to gas gains of > 10^4

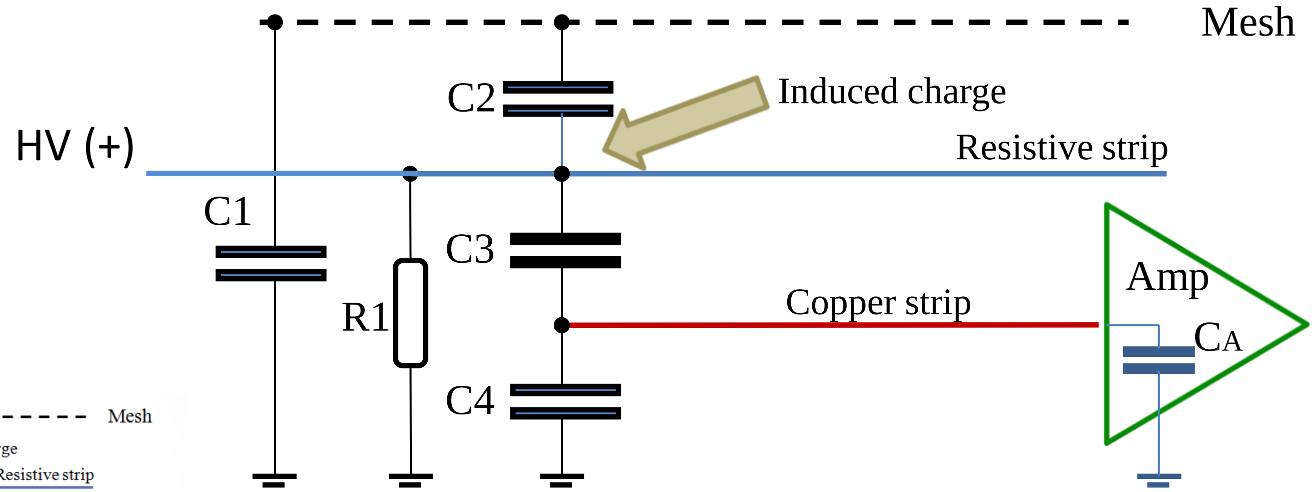
Making MMs spark resistant

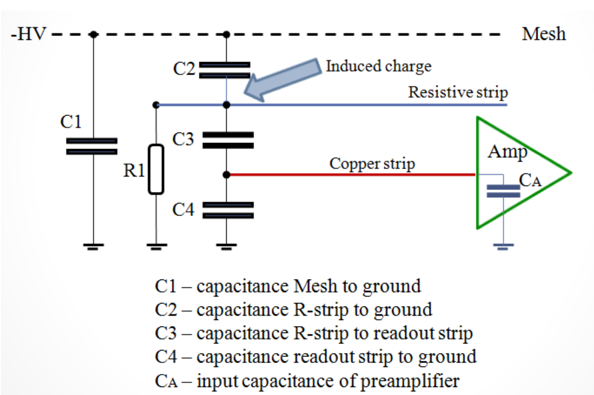
Gain as a function of HV for standard and resistive MMs



Making MMs spark resistant

Equivalent scheme of resistive Micromegas chambers *(Reversed HV schema, more stable during the operation)*

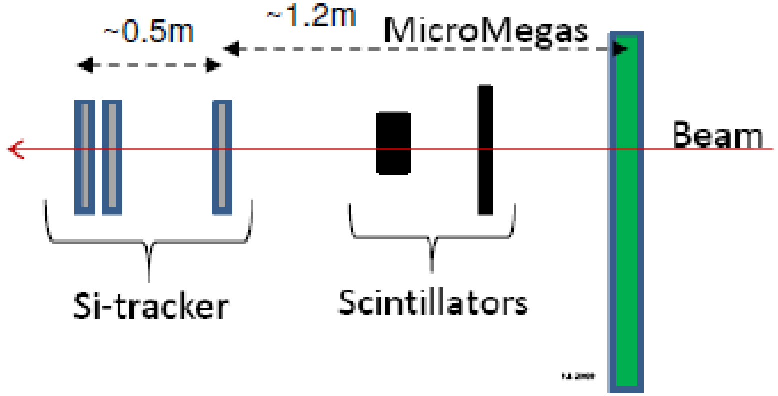




C1 – capacitance Mesh to ground
C2 – capacitance R-strip to ground
C3 – capacitance R-strip to readout strip
C4 – capacitance readout strip to ground
C_A – input capacitance of preamplifier

Performance & ageing studies

Micromegas performance

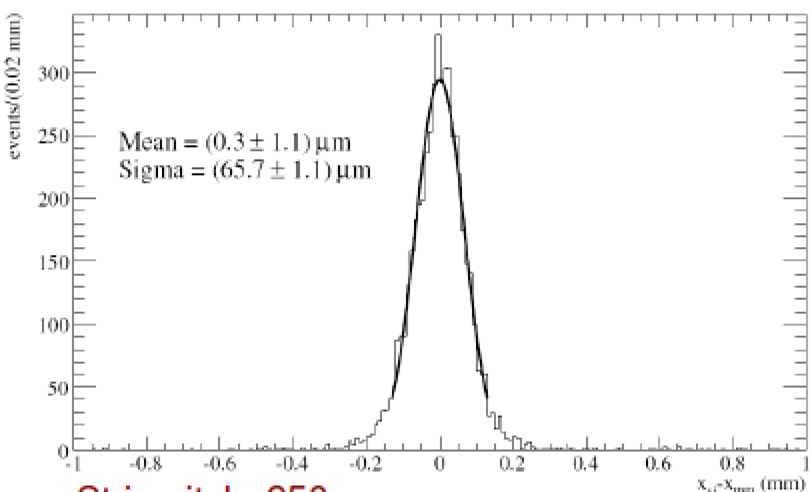


Residuals of MM cluster position and extrapolated track from Si.
Three contributions to width of distribution :

- –*Si Telescope extrapolation @ MM ~30 µm*
- –*Multiple scattering ~53 µm*
- –*Intrinsic MM resolution*

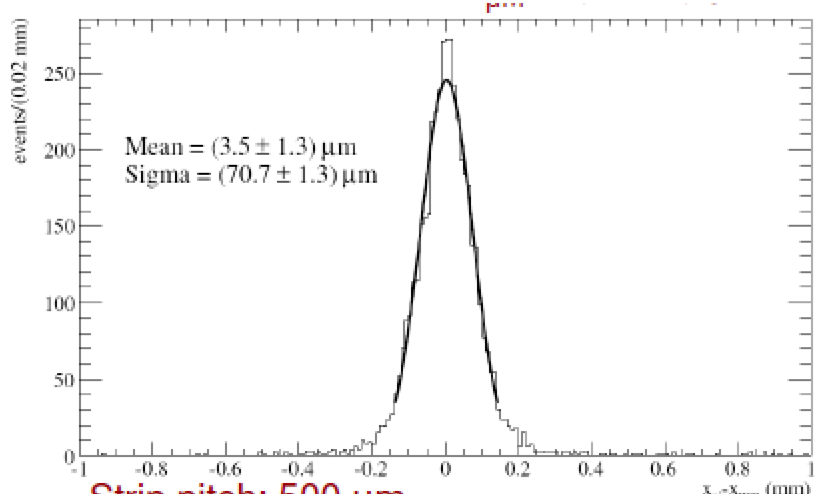
~61 µm

σ_{MM} = 24 ± 7 µm



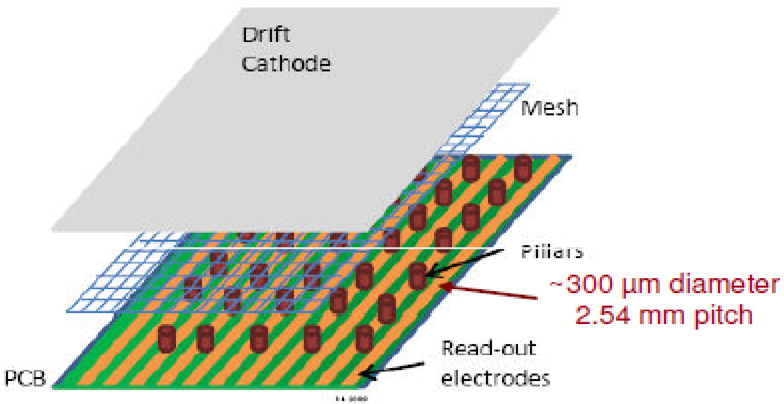
Strip pitch: 250 µm

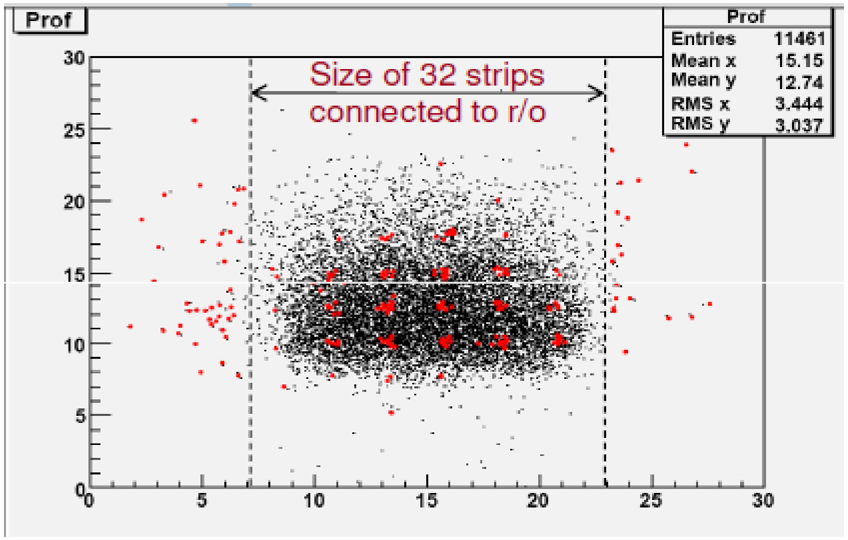
σ_{MM} = 36 ± 5 µm

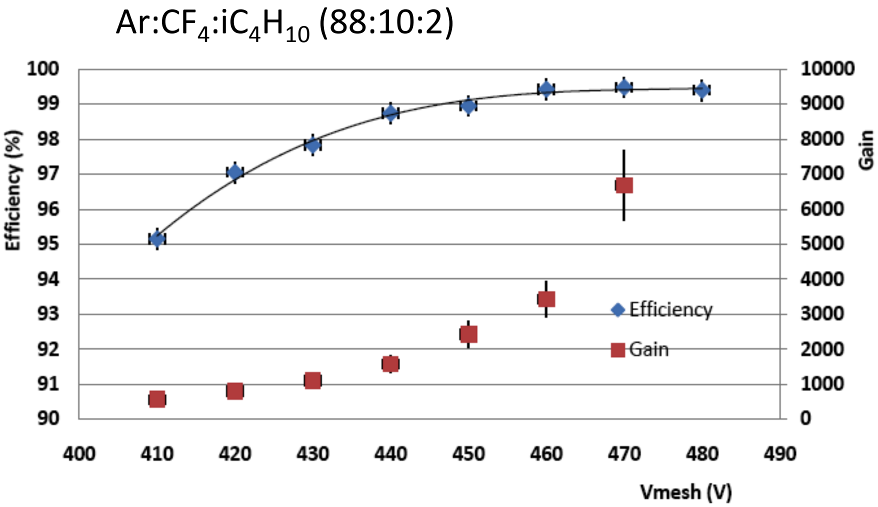


Strip pitch: 500 µm

Micromegas performance

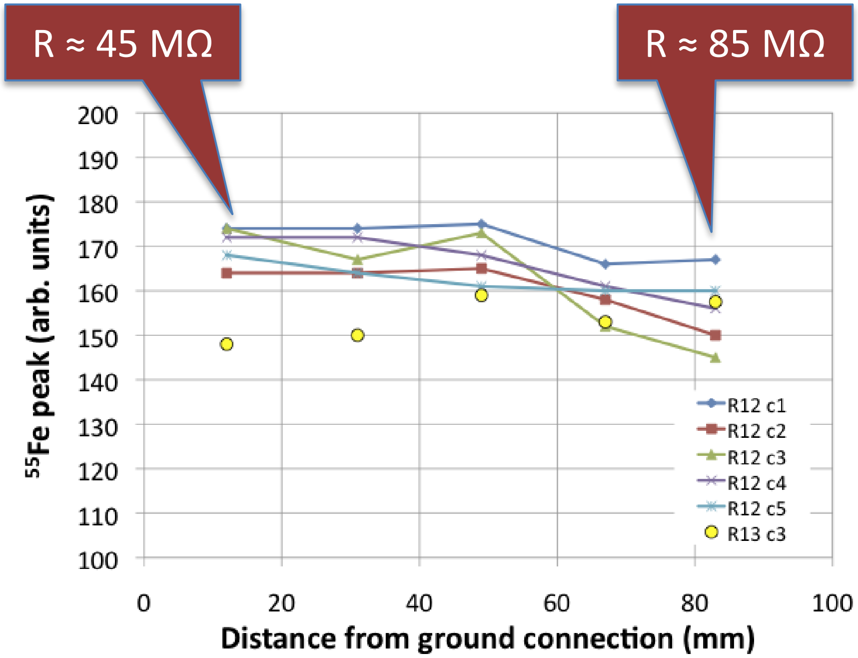


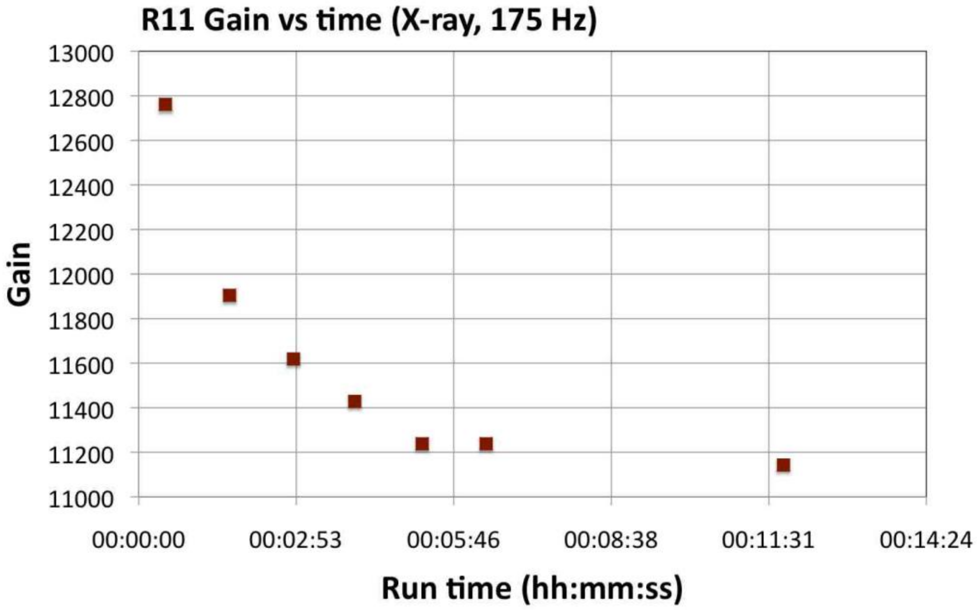




- Standard Micromegas
- Safe operating point with excellent efficiency
- Gas gain: 3–5 x 10^3
- Superb spatial resolution

Homogeneity and Charge-up

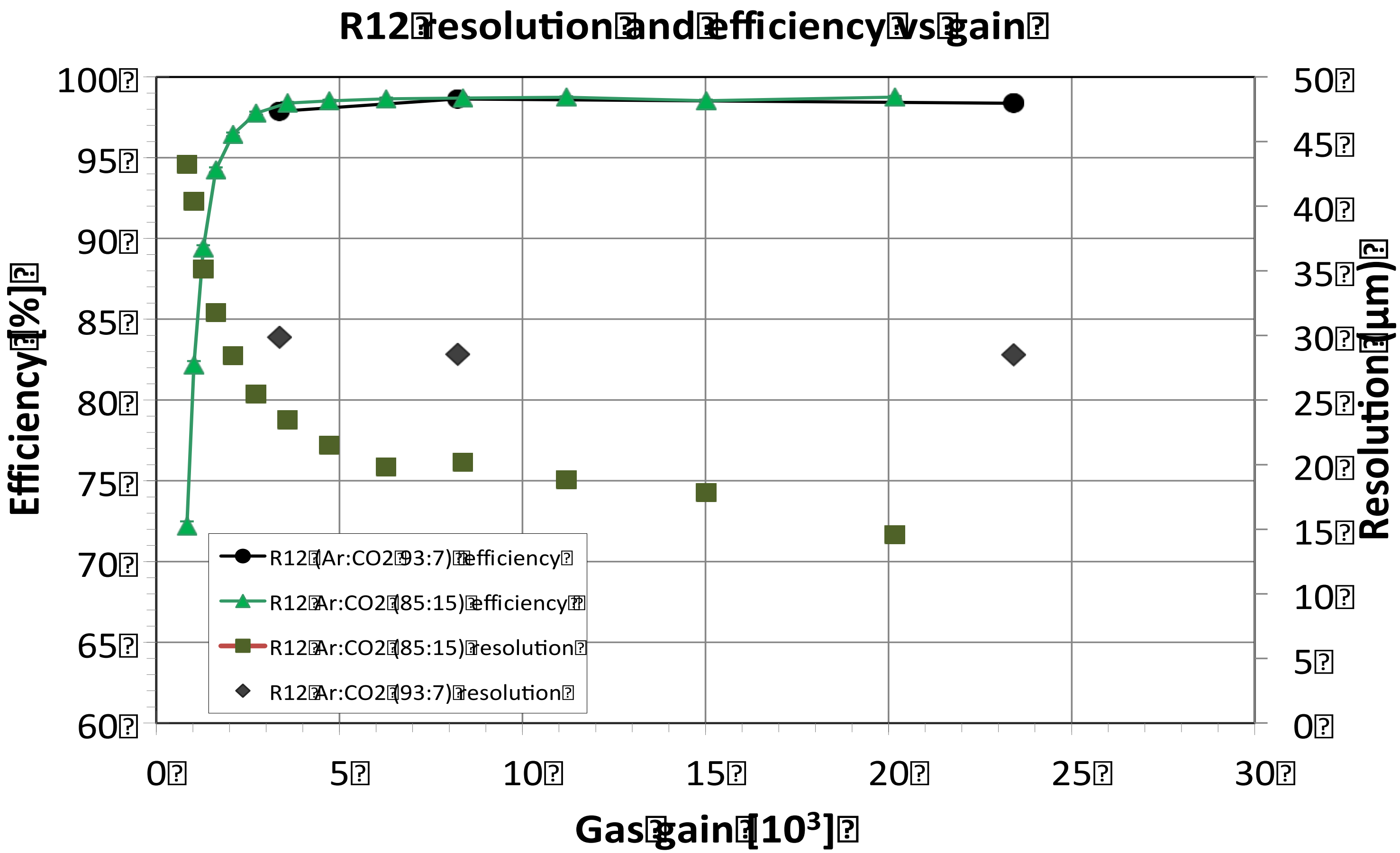




- No strong dependence of effective gain on resistance values (within measured range)

- Systematical gain drop of 10–15% for resistive & standard chambers; stabilizes after a few minutes
- Charge-up of insulator b/w strips ?

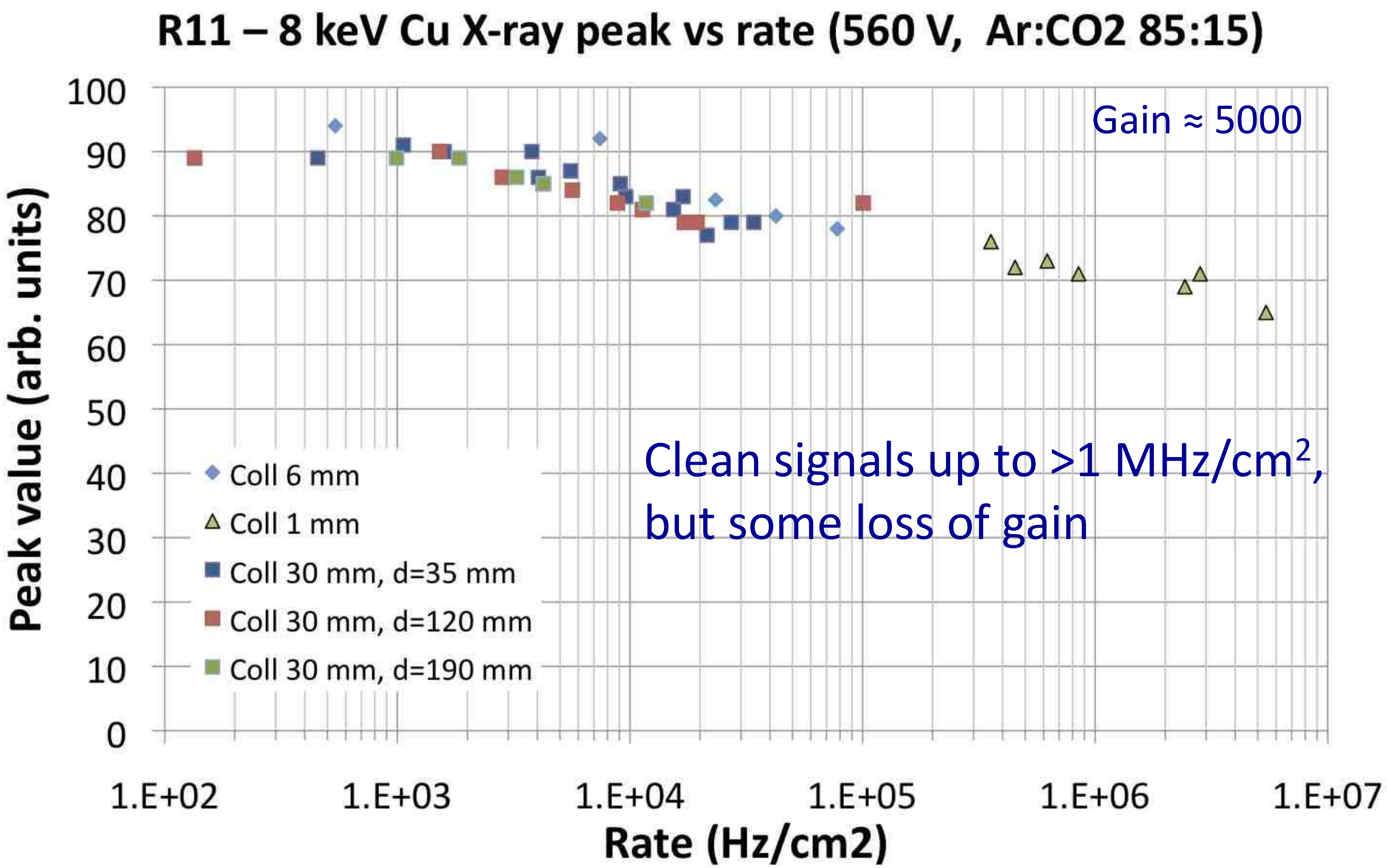
Spatial resolution & efficiency for R12 (250 µm strips)



Resistive strip chambers are fully efficient (≈98%)over a wide range of gains

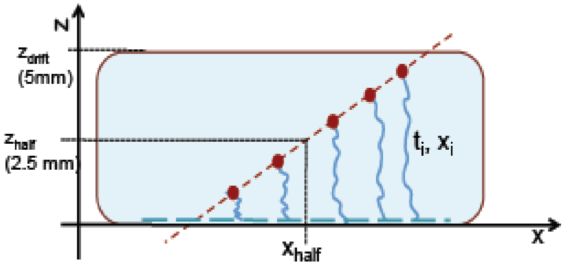
Spatial resolution with 250 µm strip: ≈30 µm with Ar:CO_2 (93:7), even better with 85:15

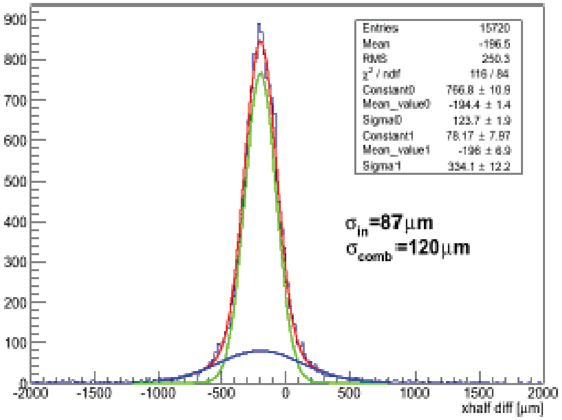
R11 rate studies



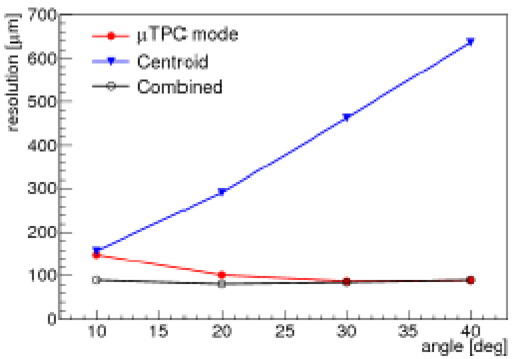
MicroMegas as µTPC

- *For non-perpendicular incidence, position resolution degraded due to fluctuation of charge deposition along the track*
- *Use the Micromegas as a µ-TPC measure arrival time of signals on strips and reconstruct space points in the drift gap*

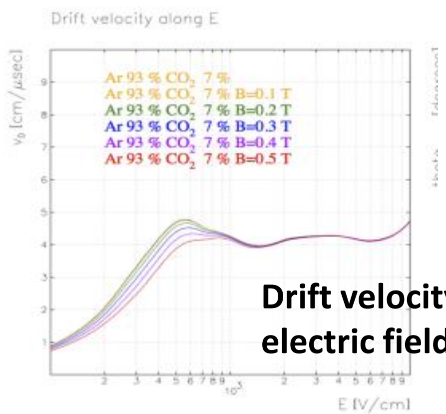




Left: principle of the MM TPC operating mode.
Right: distributions of Δx_{half} for particle impact angle of 30.
The distribution is fitted with a double Gaussian (red line) accounting for a core distribution (green line) plus tails (blue line). The widths of the two Gaussians are reported in the plot.



MM spatial resolution with charge centroid method (blue triangles), TPC method (full red circles) and the combination of the two (black open circles) as a function of the particle impact angle.

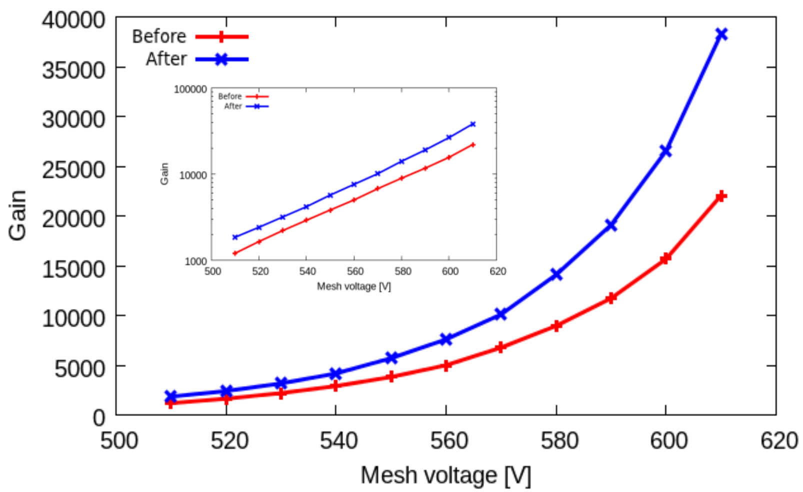


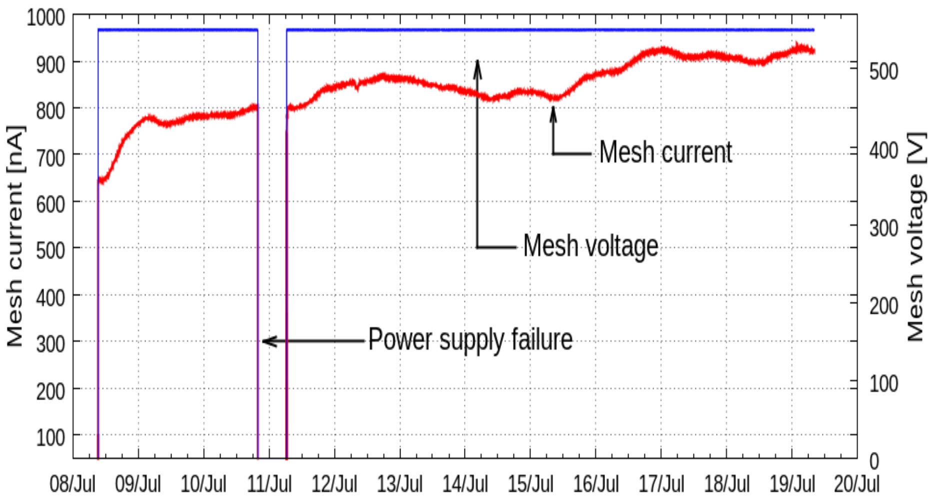
Drift velocity along the electric field

Aging: Long-time X-ray exposure

- A resistive-strip MM has been exposed at CEA Saclay to 5.28 keV X-rays for ≈12 days

  Accumulated charge: 765 mC/4 cm^2
- No degradation of detector response in irradiated area (nor elsewhere) observed; rather the contrary (to be understood)
- Expected accumulated charge at the smallest radius in the ATLAS Small Wheel: 30 mC/cm^2 over 5 years at sLHC





Aging: Long-time X-ray exposure

- A resistive-strip MM (R17a) has been exposed at CEA Saclay to 5.28 keV X-rays for 12 and 21 days. In parallel, an 'identical' chamber (R17b) was measured without being irradiated continuously, in the 2nd period.
- Accumulated charge: 765 + 918 mC/4 cm^2 (>20 years of sLHC)

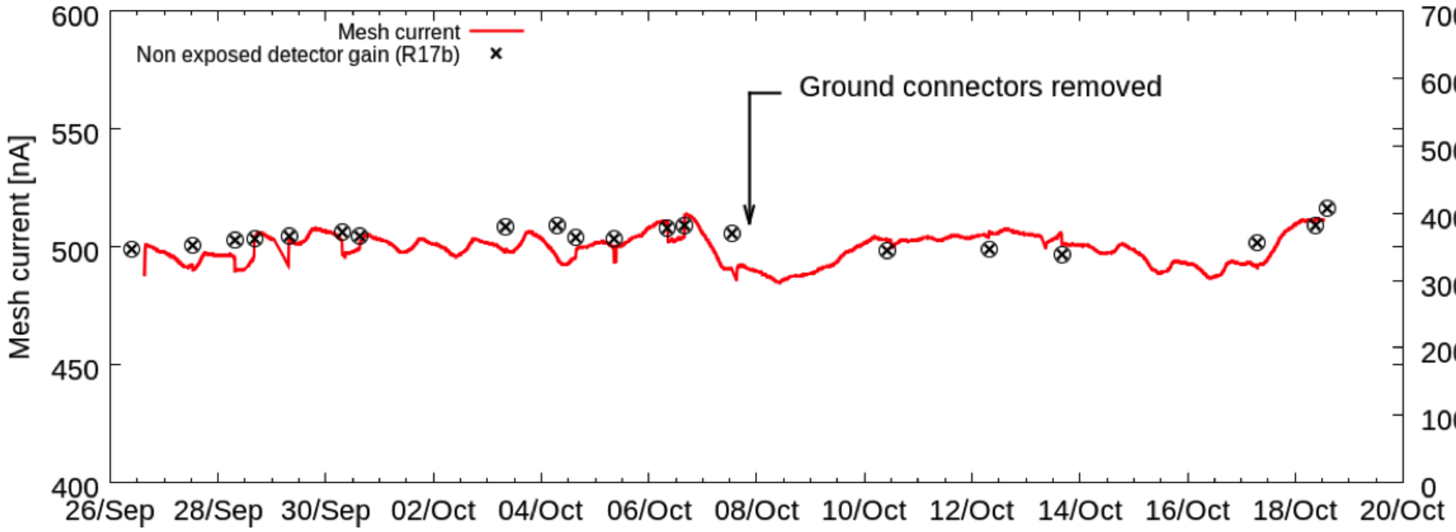
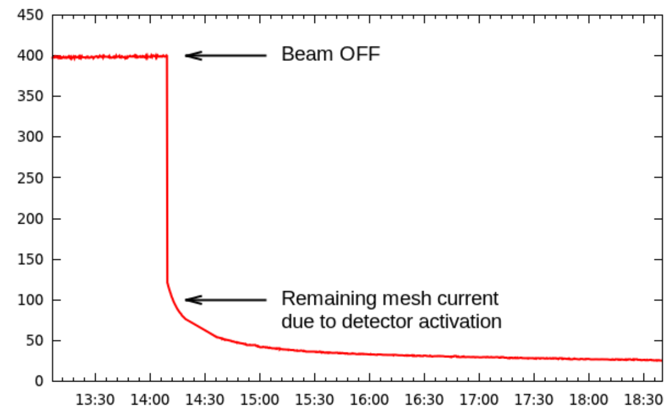
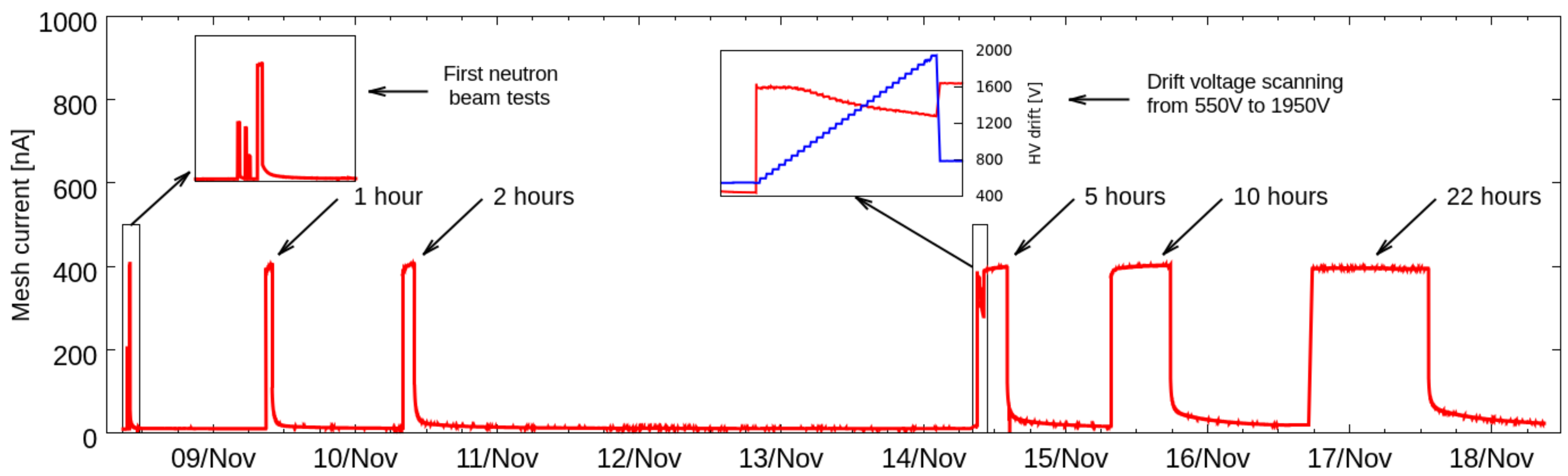


Figure 9. Mesh current evolution provided by the high voltage power supply (red line) and the R17b gain control measurements with R17b detector (black circles).

Aging : Exposure to thermal neutrons

- R17a was then moved to the Orphee reactor at Saclay and has been under radiation from 7 – 17 Nov 2011
- Neutron flux is ≈0.8 x 10^9 n/cm^2/s with energies of 5–10 x 10^{-3} eV
- Total exposure on-time: 40 hrs equivalent to ≈20 years LHC at 5 x 10^{34} cm^{-2}s^{-1} (including a safety factor of 3)
- Detector response perfectly stable over full duration of irradiation

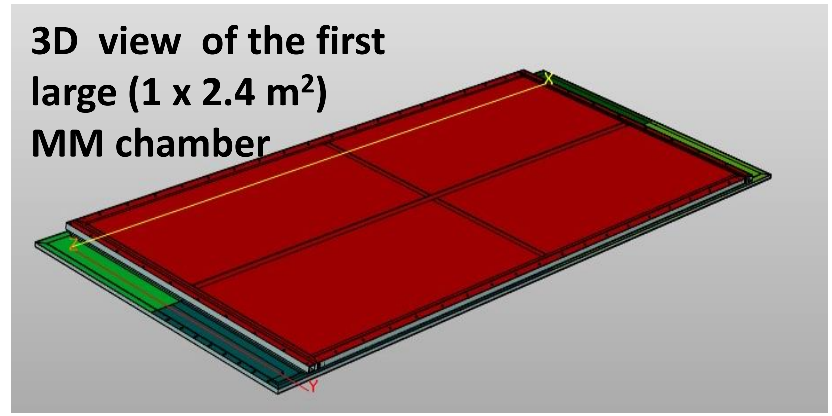




Large-area micromegas chambers

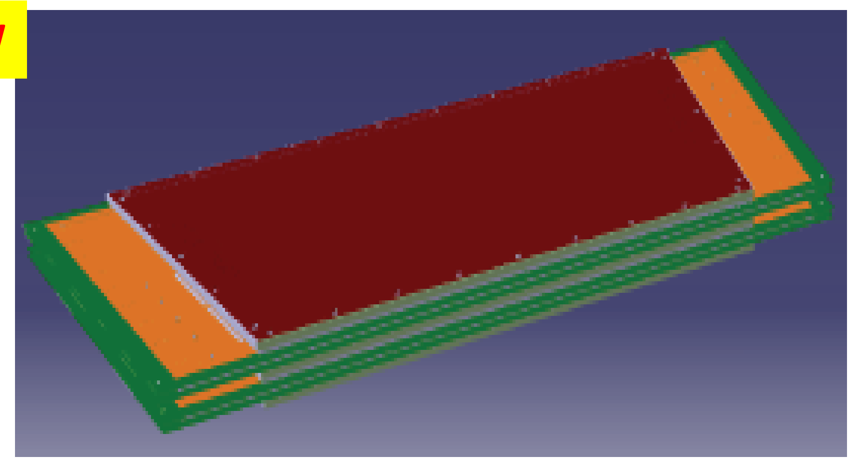
L1

L2



L3

MSW



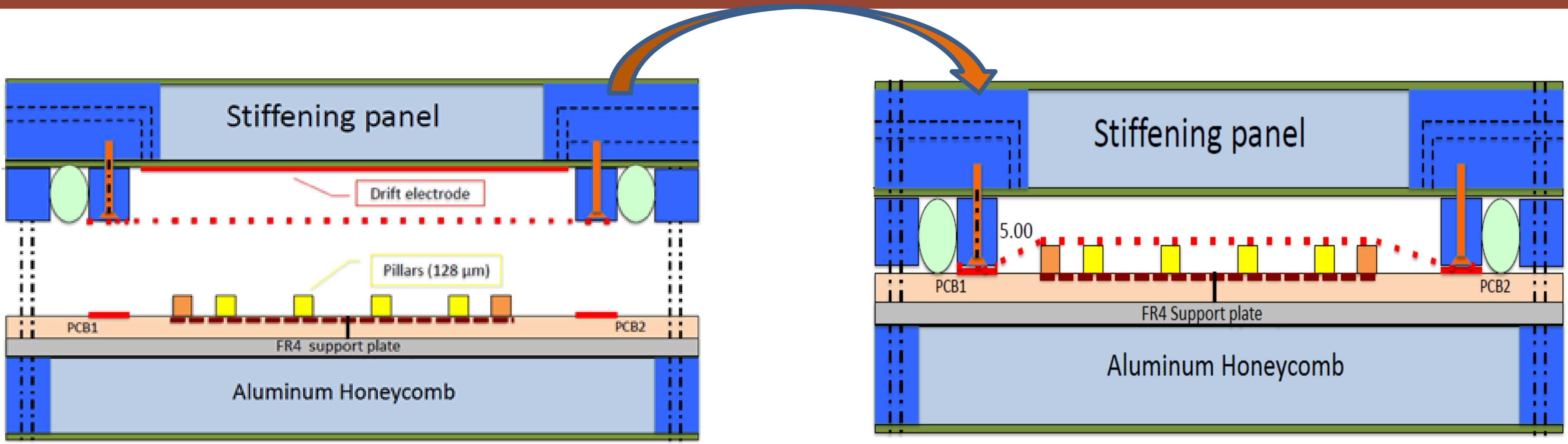
Large-area micromegas chambers

The goal was to establish a construction concept that could be used for the larger chambers
Given that the machines to go to larger dimensions chamber are not easy available we were "obliged" to go with standard-size PCBs.

Bulk or no Bulk this is the question ?

- *We had experienced problems in large chambers with currents; any dust caught under the mesh is hard to remove*
- *We opted for a non-bulk technique that uses also pillars to keep the mesh at a defined distance from the board, however, the mesh is not fixed but integrated with the drift-electrode panel and placed on the pillars when the chamber is closed.*

Large-area micromegas chambers



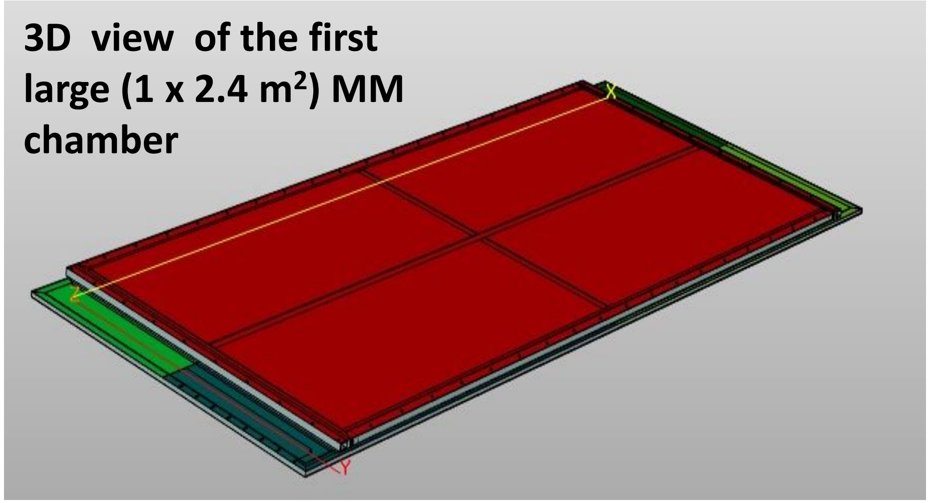
First MM Large chamber（L1） assembled with “floating mesh” technique

1 x 1 m2 readout board composed of 2 boards of 0.5 x 1 m2

2048 strips of 1.06 m length with a pitch of 0.45 mm

The 1 x 2.4 m^2 chamber (L2)

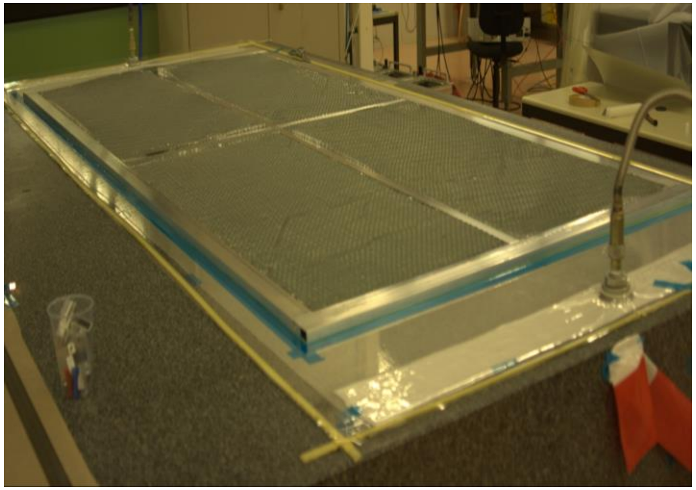
- **Parameters:**
  - Chamber dimensions: 1 x 2.4 m^2
  - 2 x 2048 strips separated in the middle
  - Four PCBs (0.5 x 1.2 m^2, thickness 0.5 mm) glued to a 10 mm thick stiffening panel
  - Floating mesh, integrated into drift-electrode panel (15 mm thick)
  - PCBs made at CERN, resistive strips have been printed in industry using screen printing technique

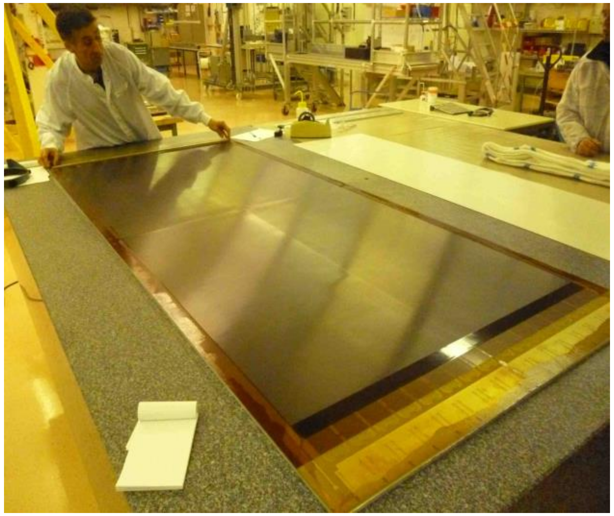


Construction procedure

- **On the granite table a vacuum sucking system was installed using a thin plastic mesh covered by a thin perforated plastic foil**
- **The FR4 sheets and the MM PCBs were then placed on the table, aligned, and sucked to the table to create a flat surface.**

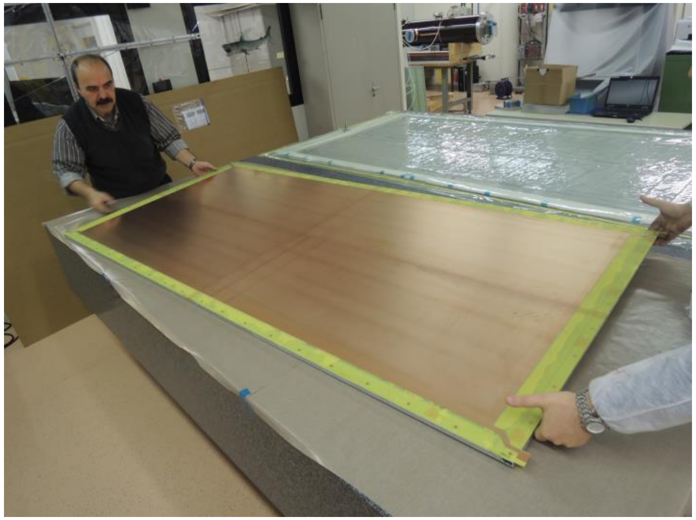
1) Honeycomb and aluminium frame gluing on the FR4 sheets, on the second face the PCB (drift or r/o) will be glued



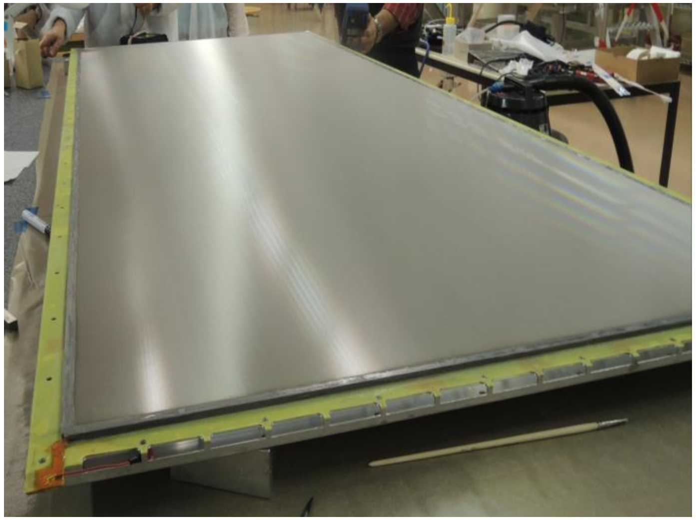


2) Read out panel completed

3) Drift electrode panel completed

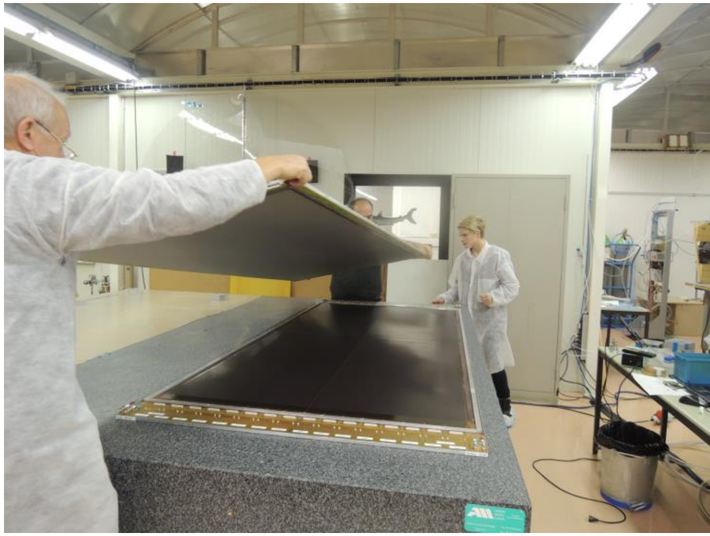


Construction procedure



4) Drift electrode panel with mesh glued to it

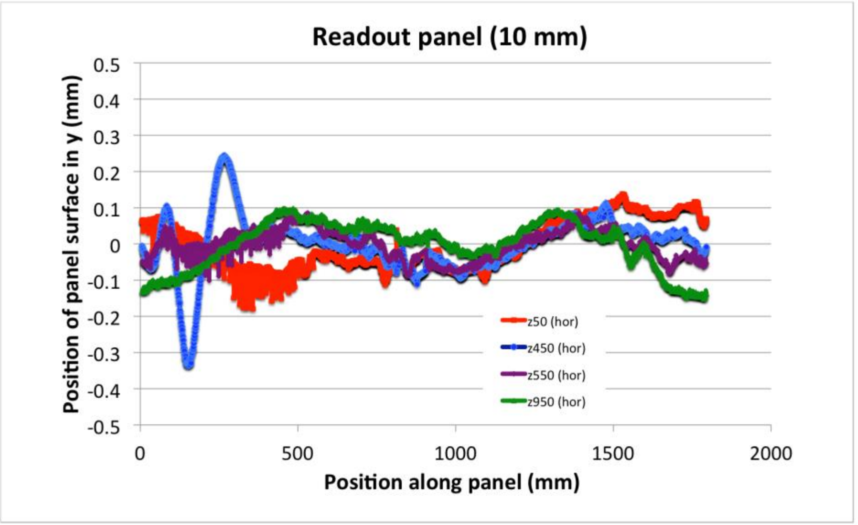
5) Chamber assembly



Problems with L2 chamber

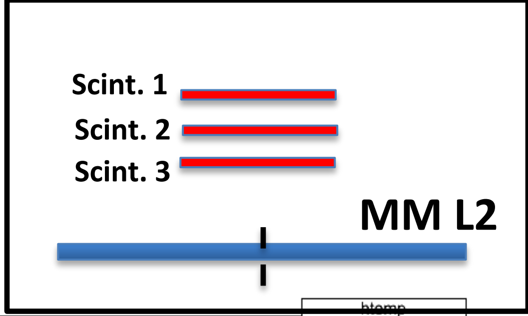
- Non planarity of readout board

Planarity measurements of the readout board after the gluing on the readout support panel shown that same area are not perfectly flat



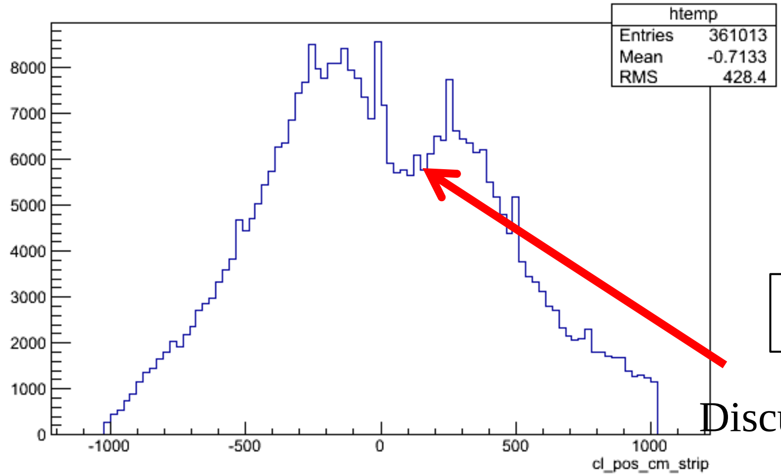
- Panel deformation for gas pressure
  - Due to the large area, under the gas pressure the chamber was deformed, as a consequence low efficiency was observed (mesh not touching pillars)
  - To operate correctly the L2 bars were tightened to the chamber surface to maintain planarity
  - For L3 Chamber new mechanical constrain in the meddle of the chamber have been added

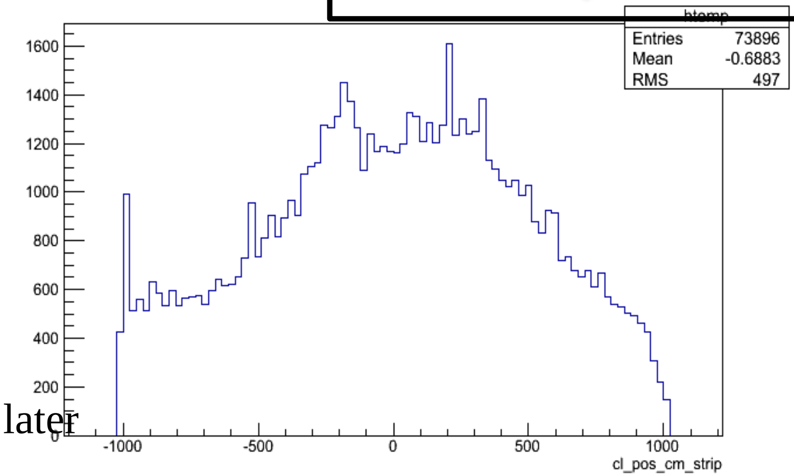
L2 Cluster profile with cosmics



SIDE A

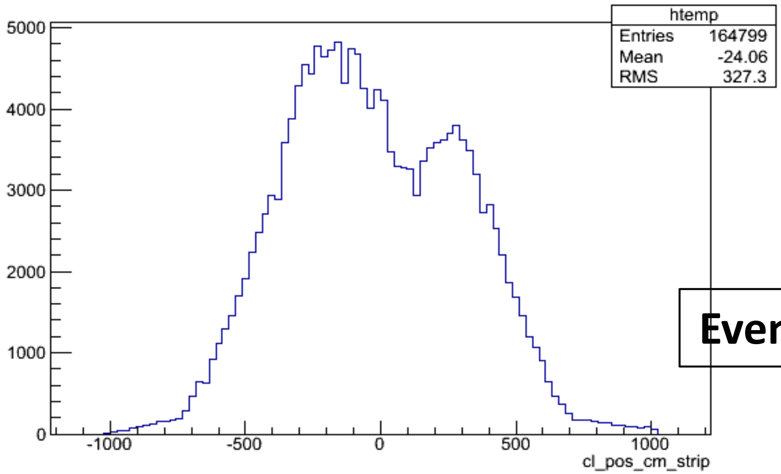
SIDE B

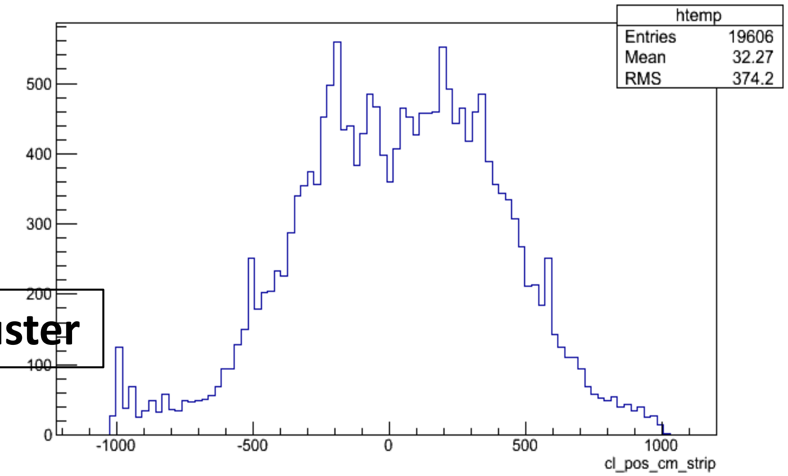




All events

Discussed in detail later

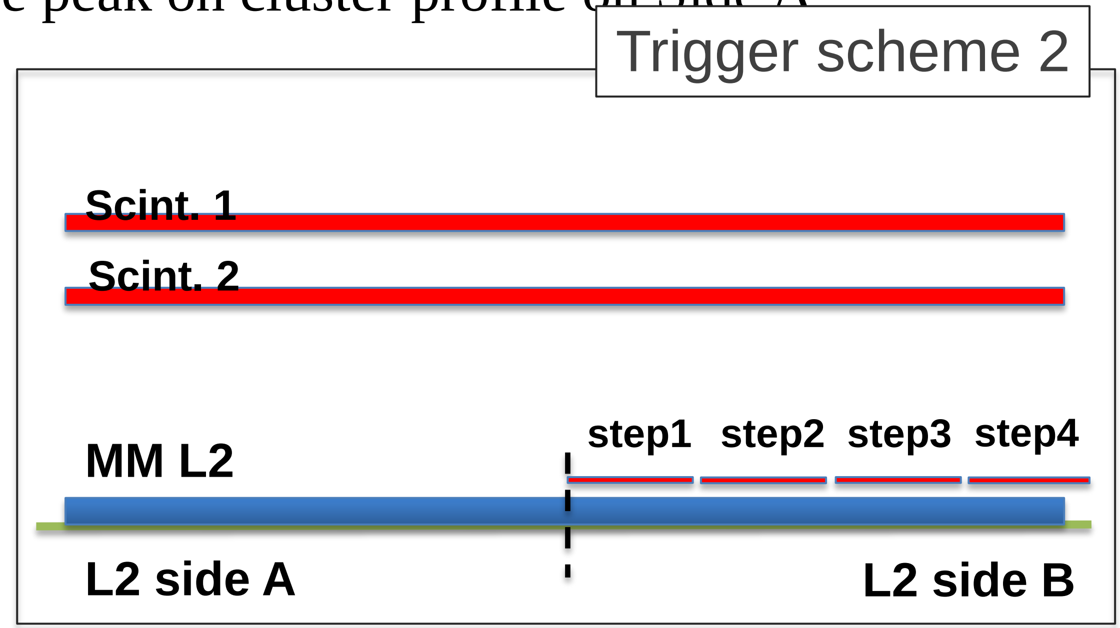




Event with one cluster

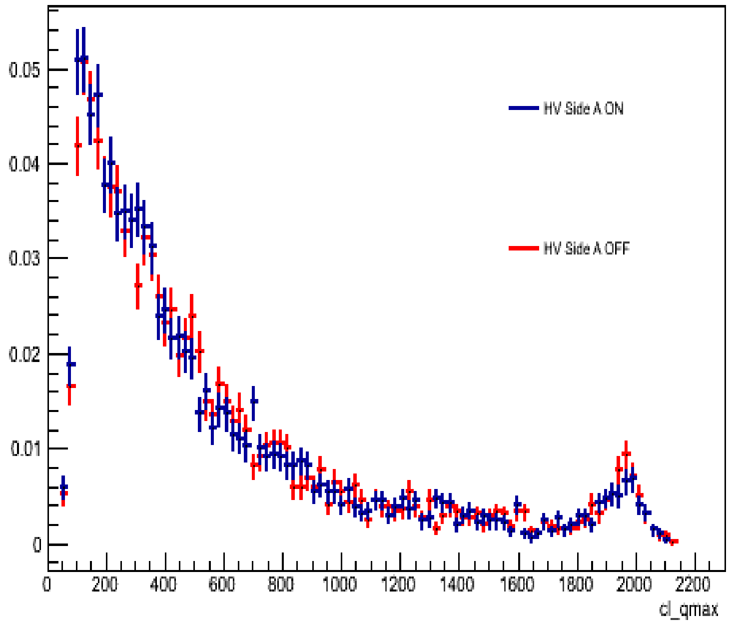
L2 Surface Scan

- Used to:
  - Investigate the effect from switching the HV on resistive strips on side A on/off
  - Investigate the double peak on cluster profile on Side A

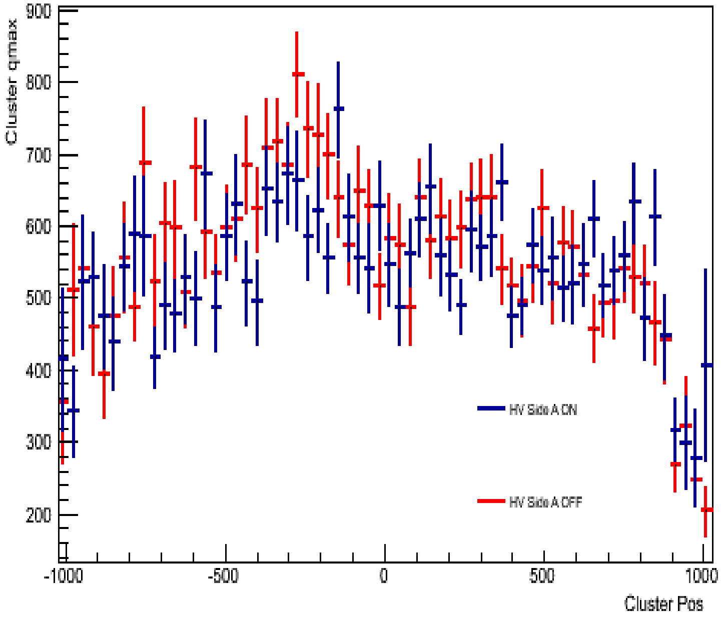


L2 Surface Scan

Switching off half of the detector (side A) does not imply any effect on the Side B



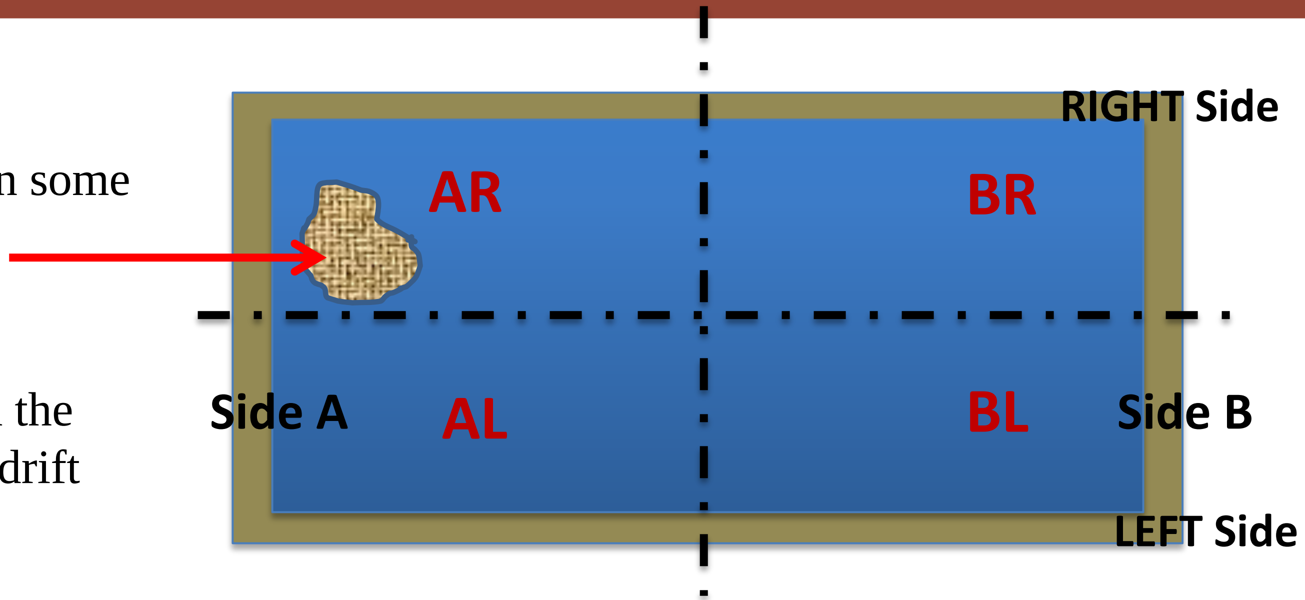
- Cluster charge distribution

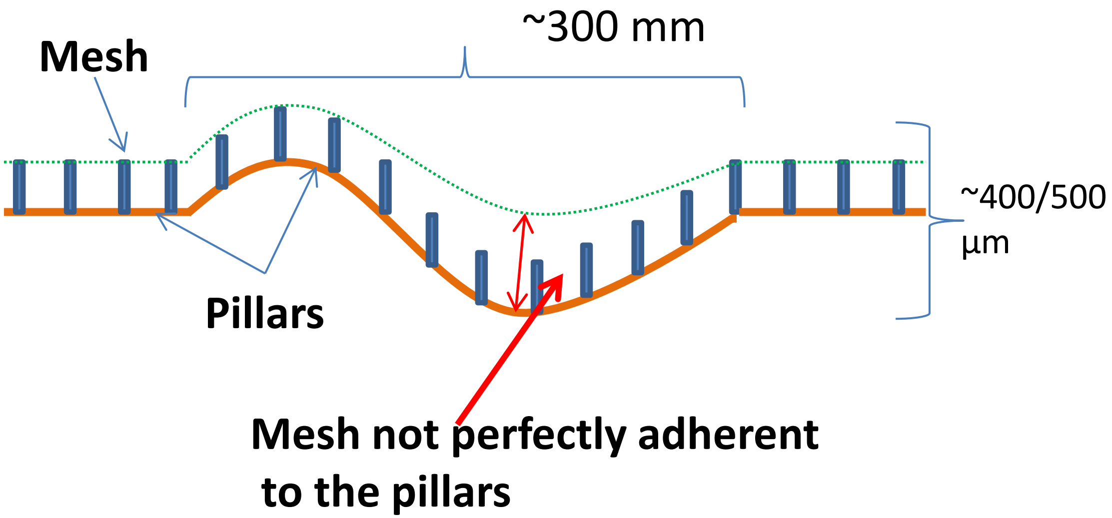


- Cluster charge as a function of cluster position

L2 Surface Scan

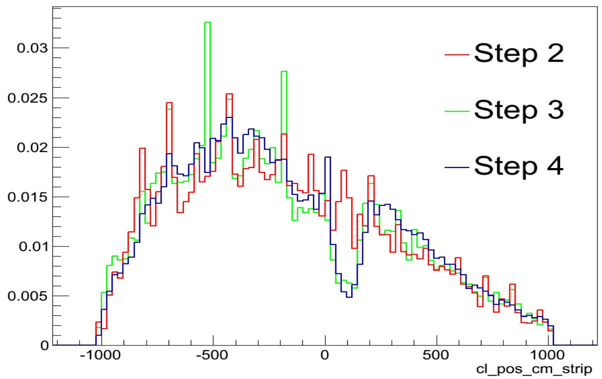
- Read out board not flat in some area (AL/AR)
- The mesh is stretched on the frame mounted over the drift plane
- The non-flatness over short distances of the readout boards prevents the mesh to following the shape of the board; leading to a smaller amplification field in some regions.





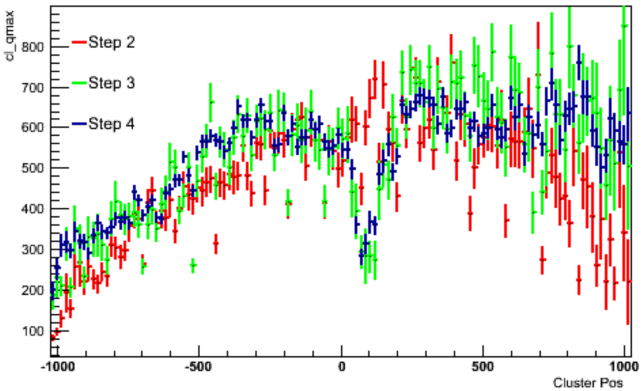
L2 Surface Scan

Moving the orthogonal scintillator from step 1 to step 4, a clear dip appear in the cluster profile, similarly the same effect appear in the charge profile.

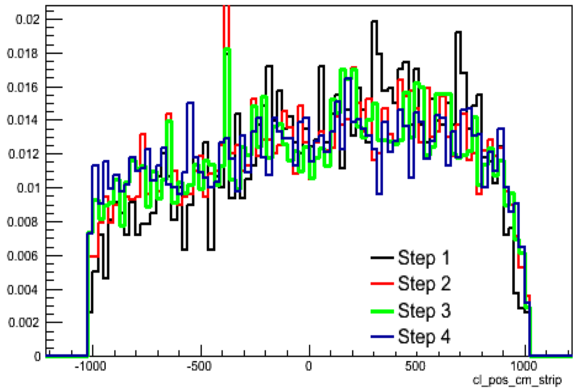


(SideA)

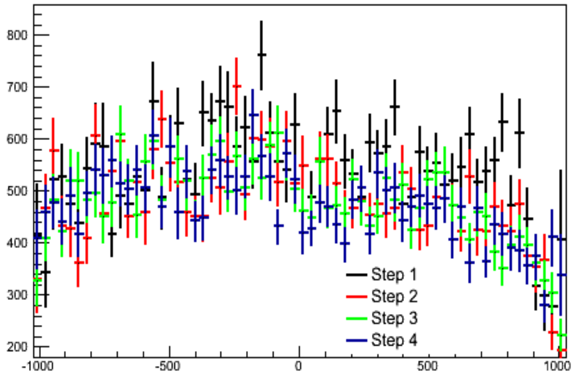
Step 1 is not added to make the plots more clear



On side B, moving the orthogonal scintillator from step 1 to step 4 the cluster profile and "cluster charge" profile appears regular and uniform.

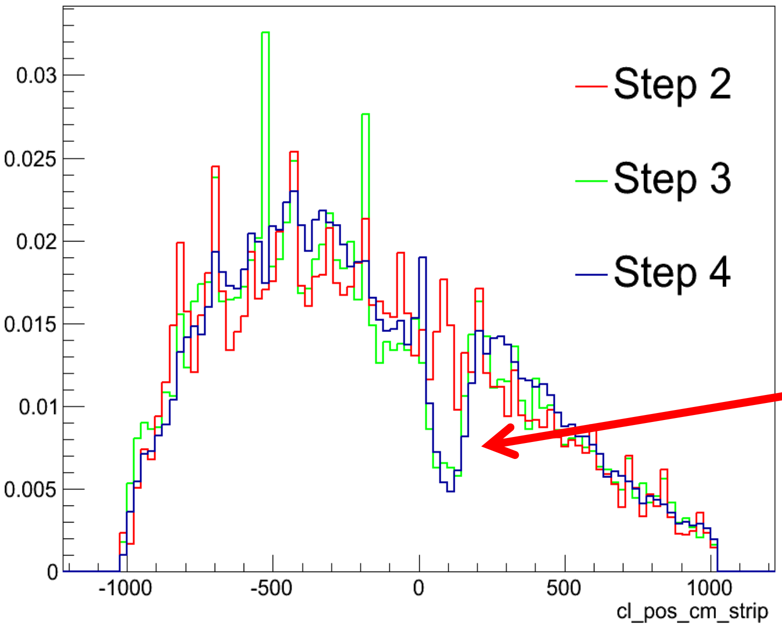


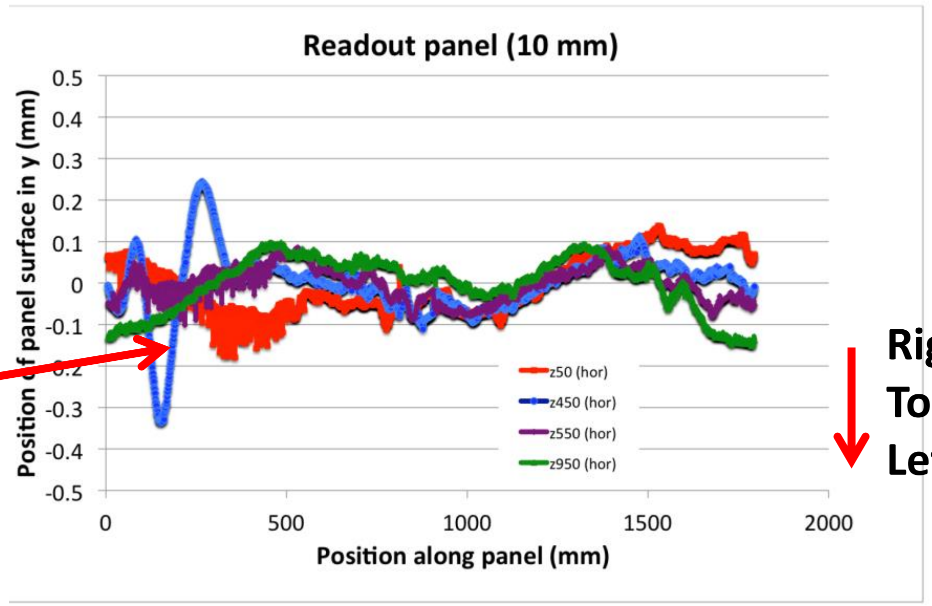
(SideB)



L2 Surface Scan

The position of the dip on cluster profile seem to be in agreement with what measured by the laser





Right To Left

LEFT Side **RIGHT Side**

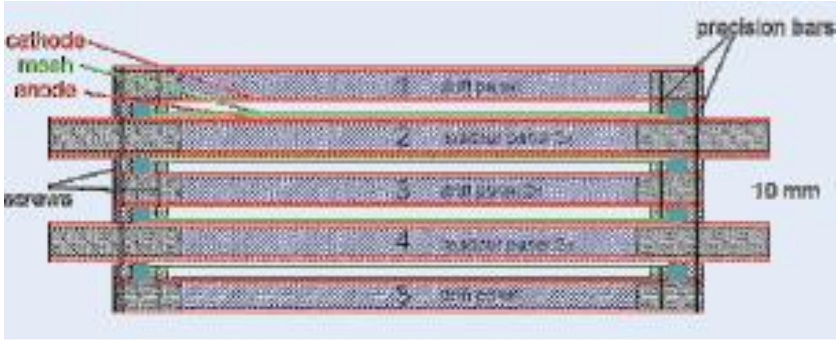
Side A → **Side B**

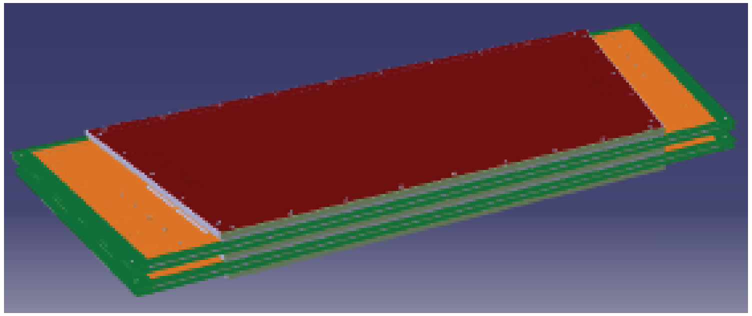
Side A cluster profile

The Micromegas Small Wheel prototype (MMSW)

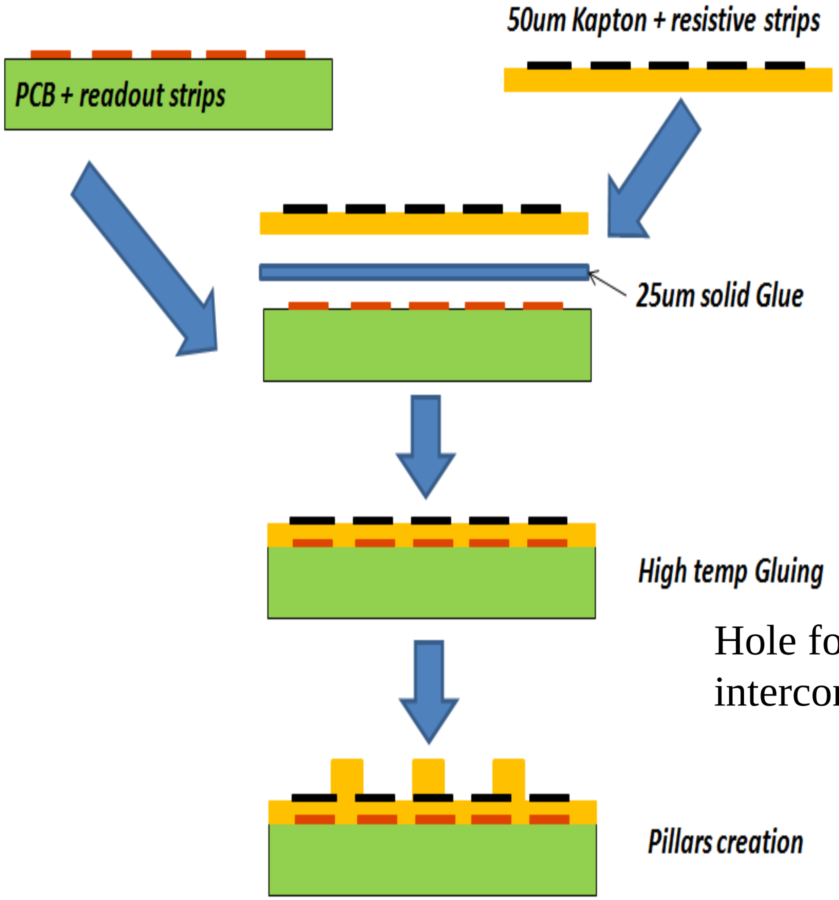
The 0,5m2 prototype adopts the general design foreseen for the Micromegas detectors in the NSW:

- A quadruplet structure with two double sided readout boards, one double sided and two single sided support (drift) panels equipped with the drift electrode and a frame holding the micromesh.
- Readout comprises 1024 strips per plane with a pitch of 415µm. The strips are rotated by 1,5° on two planes to measure the second coordinate.
  A spatial resolution of <100 µm / <1mm in the precision/ second coordinate is expected.
- The readout strips are covered by Kapton® foil with sputtered resistive strips to improve spark tolerance and a pattern of 128µm high support pillars to define the position of the floating mesh.





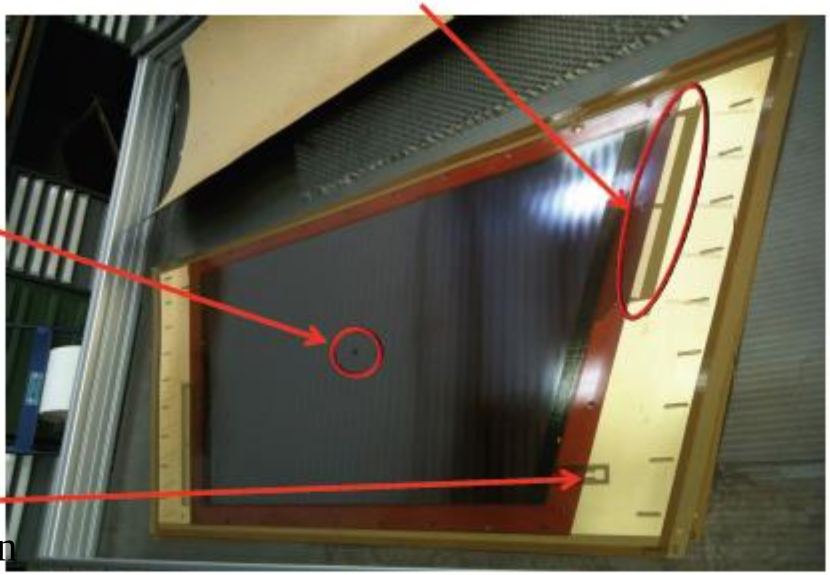
MSW PCB Readout: construction process



- Resistive strips on 50 μm kapton foil are glued on the PCB with readout strip pattern
- Novel technique for resistive strips: sputtering (A. Ochi, details after)

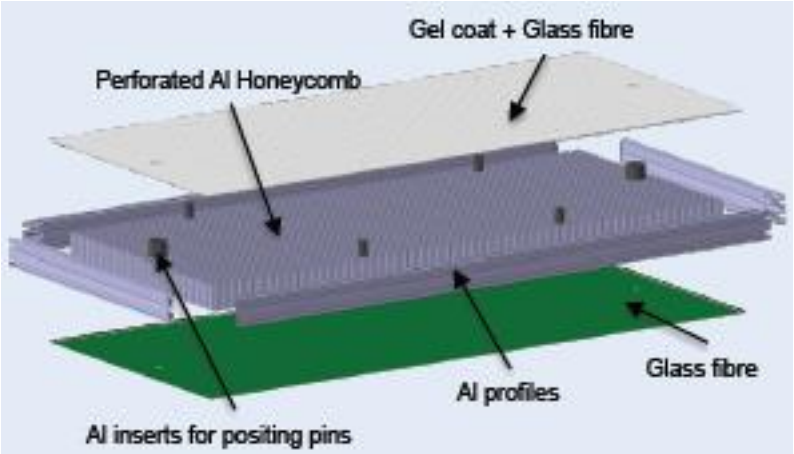
Readout strips (512 channels per side) for Zebra interconnection (no connector mounted on the boars)

Hole for central interconnection



Pad for HV distribution on resistive strips

MSW: Tools & procedures for construction

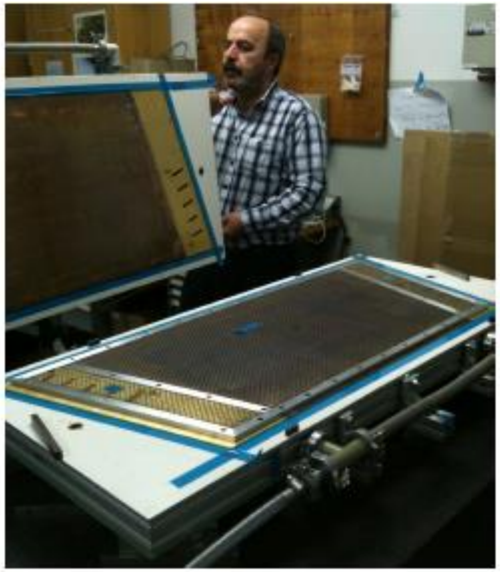


Two vacuum stiff-backs are used to accurately position and fixate the readout / drift boards during the gluing process.
A Gel coat + glass fibre surface is meant to inherit the flatness of the marble table. The honeycomb structure ensures stiffness and low weight.

Panel positioning e gluing →

Alignment of the two PCB is obtained with reference pins

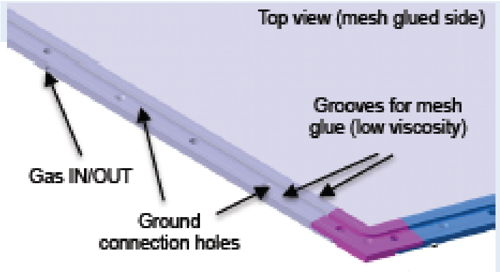
Precise thickness of the panel is obtained with precision shims, allowing the glue layers to compensate for honeycomb thickness inhomogeneity



Spacer frame and mesh gluing procedure

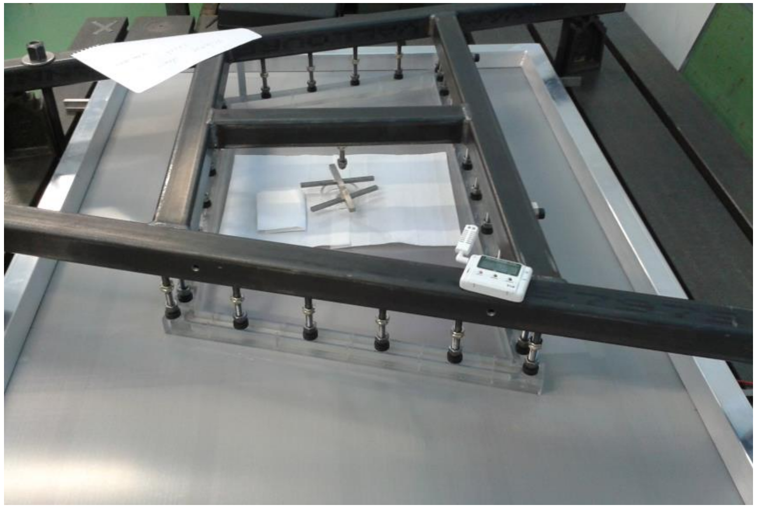
The spacer frame, mounted on the drift panel serves several purposes:

- Holding the stretched micromesh in a precise distance of 5mm from the drift cathode, forming the drift gap.
- Serving as gas manifold (distribution channel & holes).
- Ensuring ground connection of the mesh.
- Enable precise mesh gluing procedure (glue grooves).

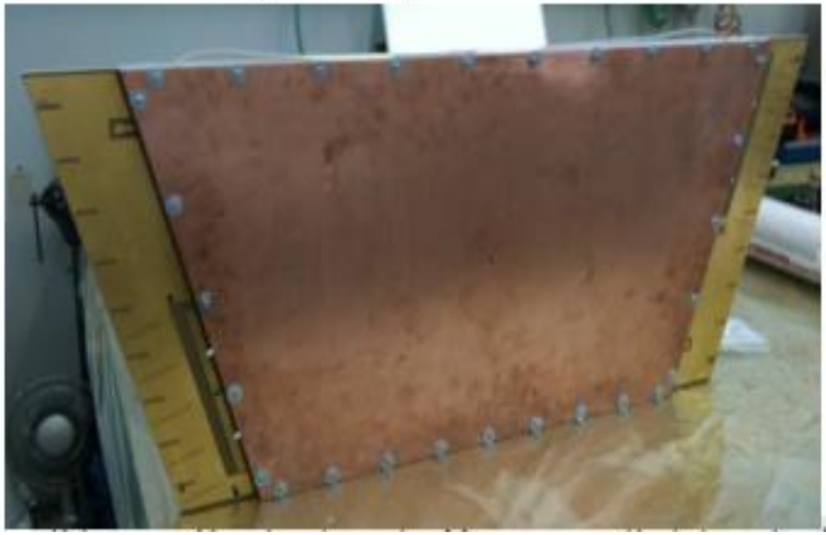


Drift panel with mesh support prepared for the mesh gluing

Mesh gluing system



MSW chamber



First Micromegas multiplet assembled

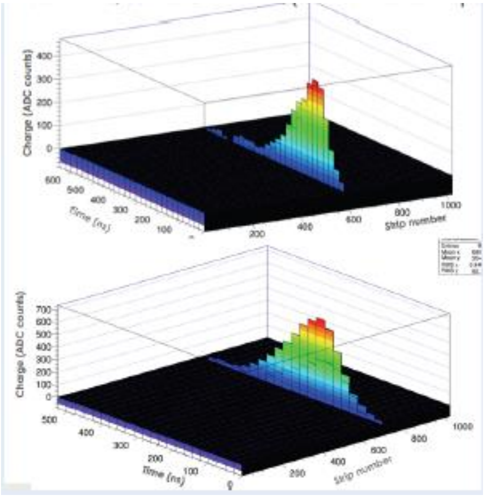
Micromegas equipped with HV connectors and front-end boards

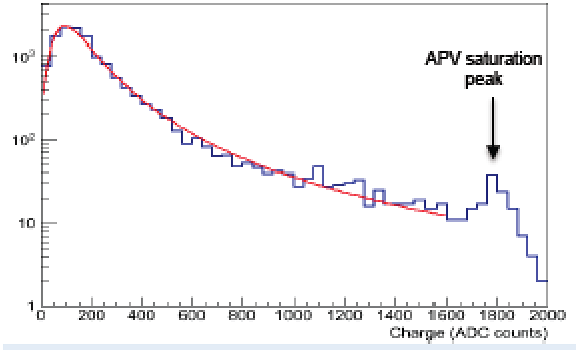
Insertion of the mezzanine board (conversion from zebra to Panasonic connectors)

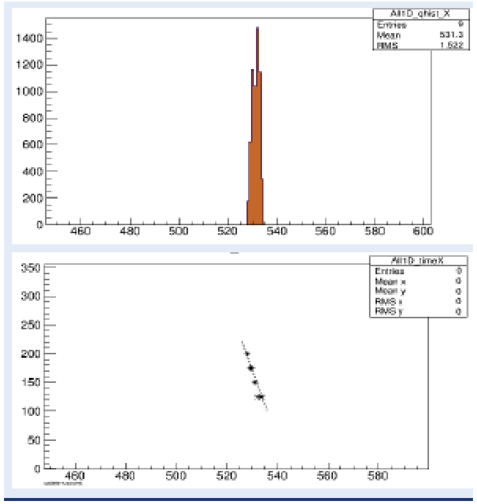
First MSW chamber tests

One Micromegas doublet (1 double sided readout panel + 2 external (single sided) drift panels has been pre-assembled to perform first tests in the ATLAS cosmic ray stand in the RD51 laboratory at CERN.

Using APV25 front-end ASIC, an SRS based readout system and the dedicated DAQ software MMDAQ cosmic rays could be detected in both detector layers



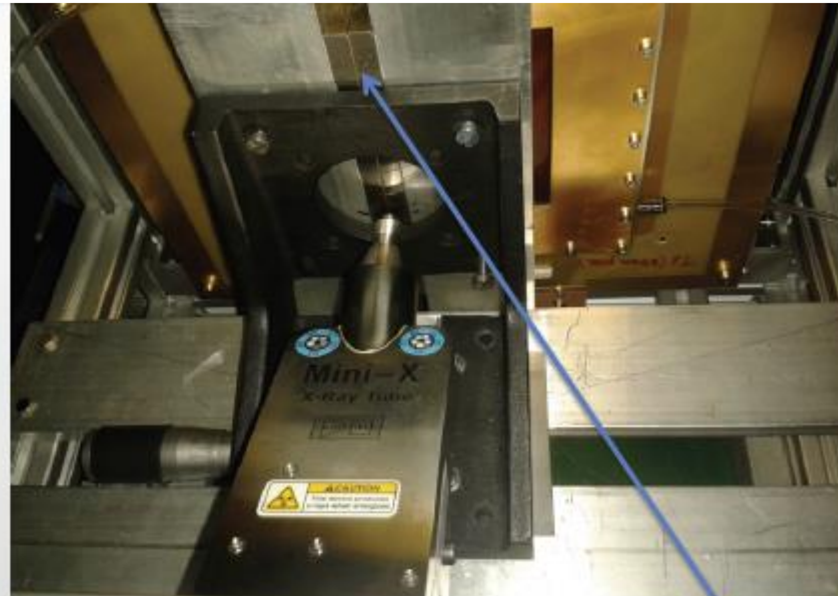




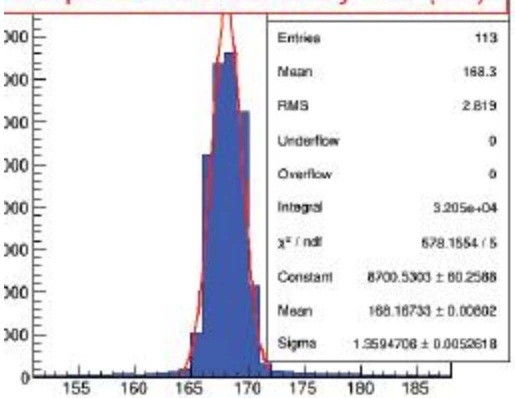
QA/QC with X-Ray scanner

Possible Tasks:

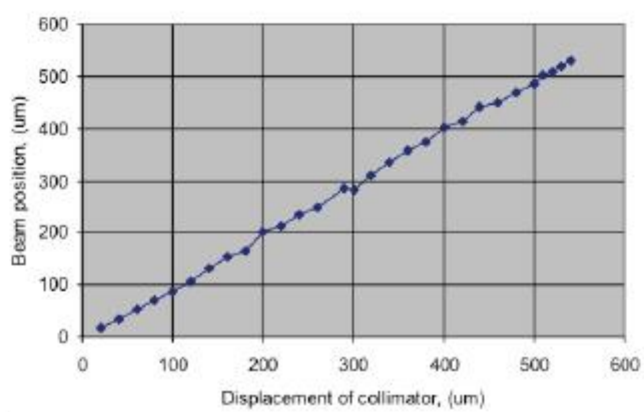
- Gas gain uniformity
- Hot spots detection
- HV instability regions
- Leakage current
- Position accuracy and quadruplet alignment verification
- Other…



Strip Position Accuracy <10 μm)



Difference between Nominal and reconstructed beam position

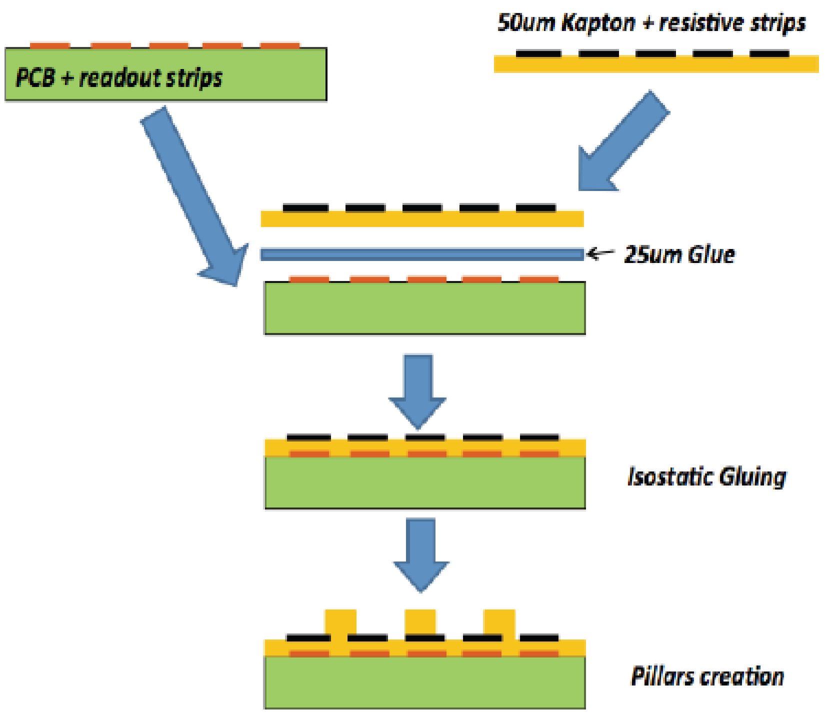


- 1mm Xray Collimator + 0.2 mm collimator in front of the chamber
- AVP25 DAQ used
- HV=520->470 to reduce saturation
- Xray at U=10 kV I=100 uA

THE PCB READ-OUT BOARDS

Readout PCB production in industry:

- Evaluating several companies
- 2m X 0.5m boards have been already produced
- Defining QA/QC procedures and development of methods has started, QA/QC to be done at the company

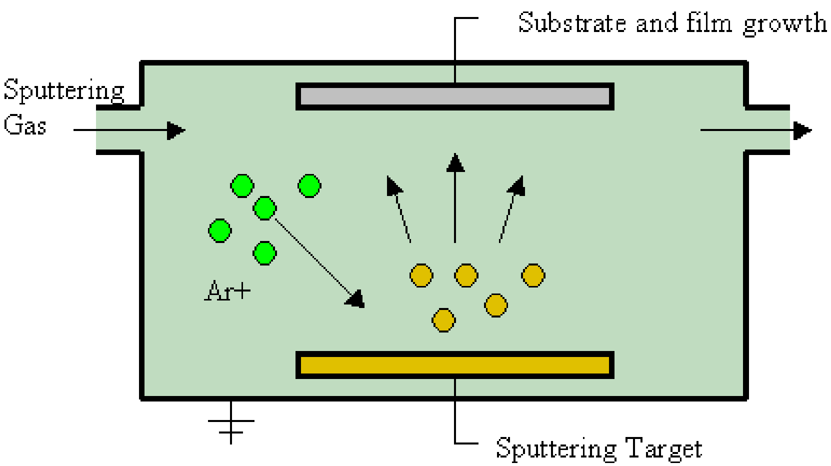


Resistive Foils 2 options:

- Screen Printing
- **Sputtering**
  (Promising results from Japan)

Liftoff process using sputtering

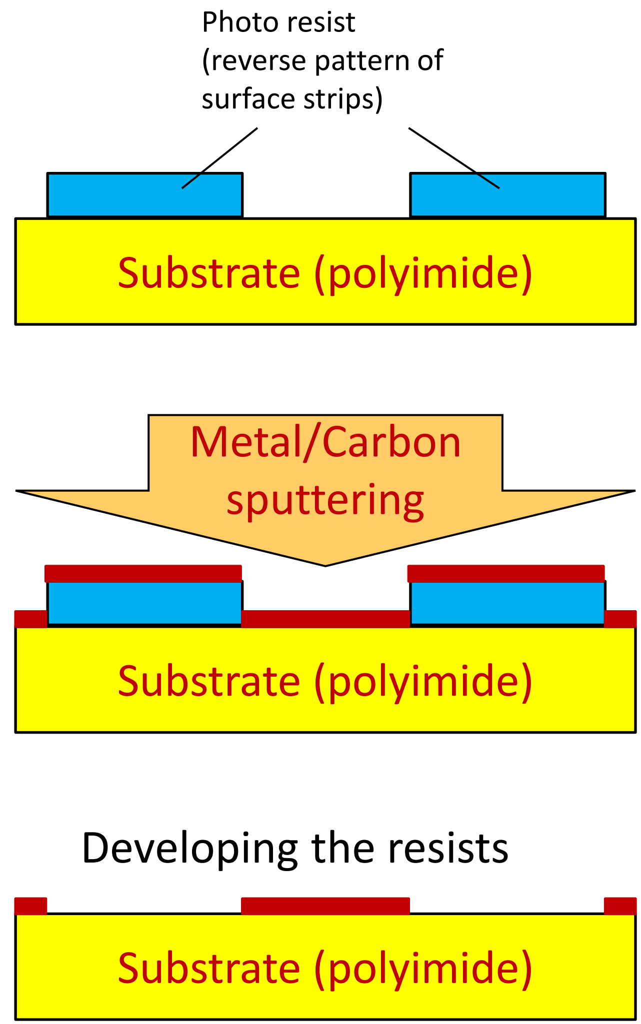
- Very fine structure (a few tens micro meter) can be formed using photo resist. (same as PCB)
- Surface resistivity can be controlled by sputtering material and their thickness



@PCB company (Laytech inc.)

@Sputtering company (Be-Sputter inc.)

@PCB company (Laytech inc.)

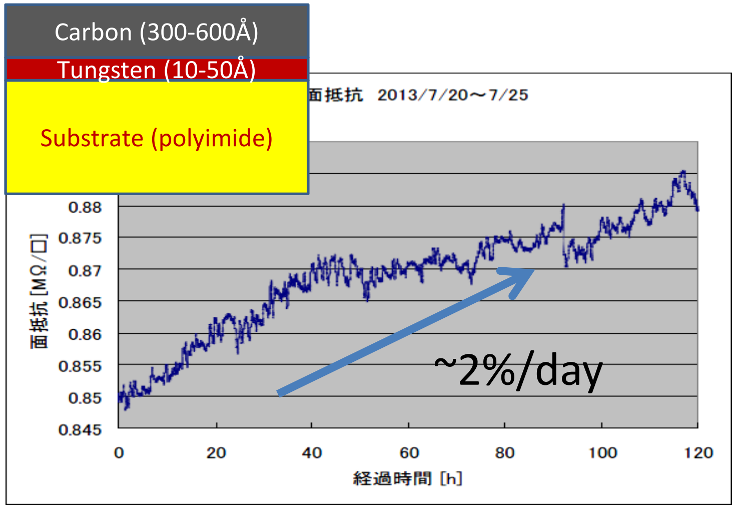


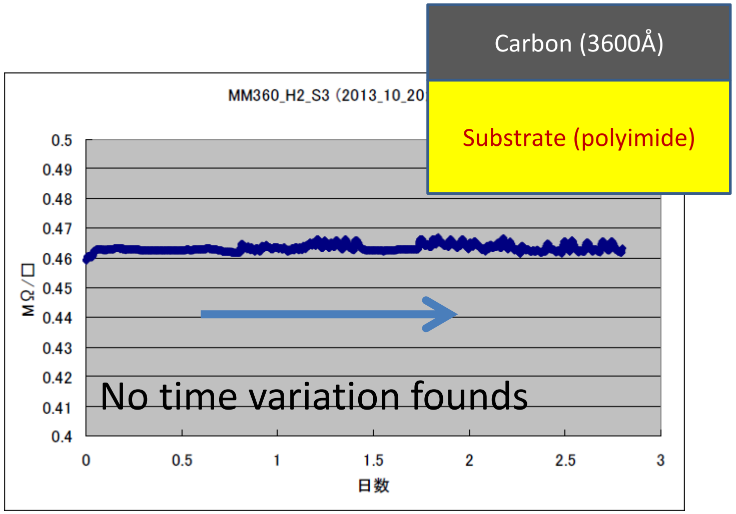
Thick carbon (only) sputtering

Different techniques tested , many tests done : Resistivity, Adhesion, Bending, Chemicalr obustness (Appropriate resistivity ~500 kΩ/sq, good mechanical/chemical properties)

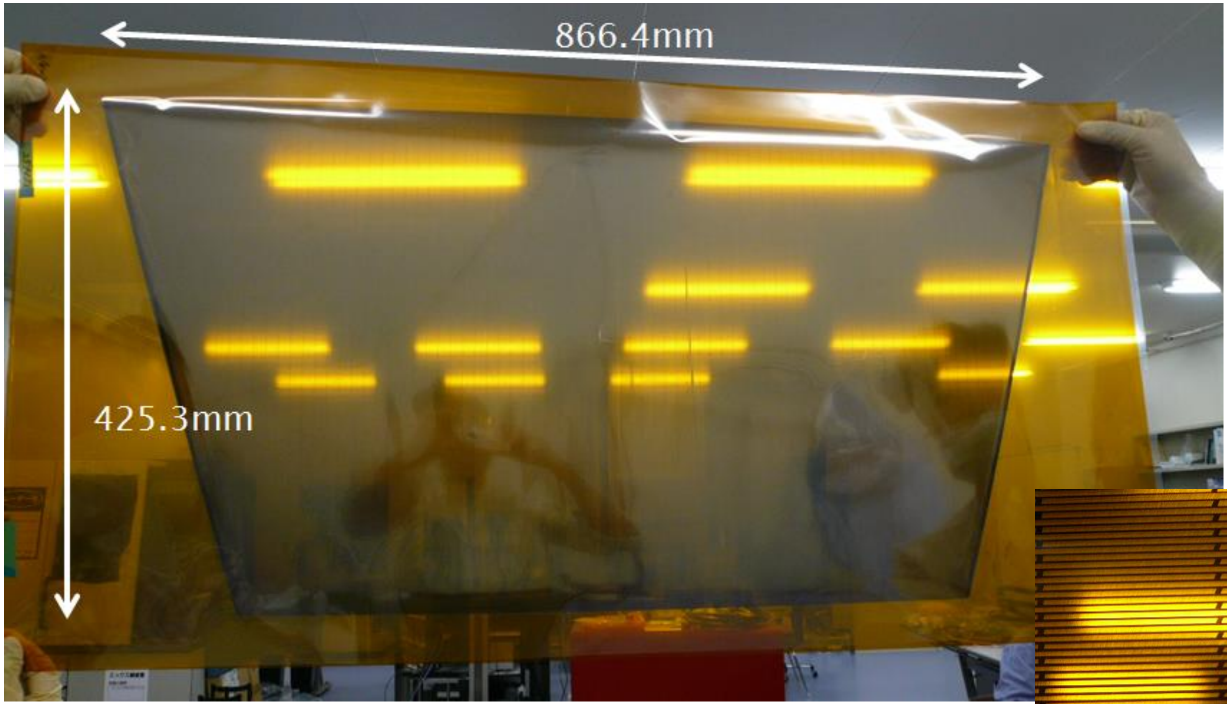
- **Early prototype:**
  - Tungsten (10-50Å) +Carbon (300-600Å)
  - Lower resistivity (<1MΩ/sq.) was available using thickness control of the metal.
  - Time variation founds (~2%/day) after several weeks from sputtering

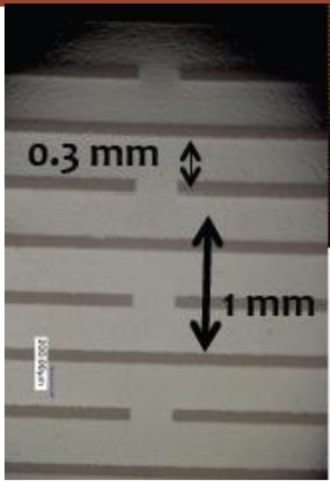
- **New prototype**:
  (September 2013)
  - Carbon only, 3600Å
  - Surface resistivity ~ 500kΩ/sq.
  - No time variation founds after several days from sputtering

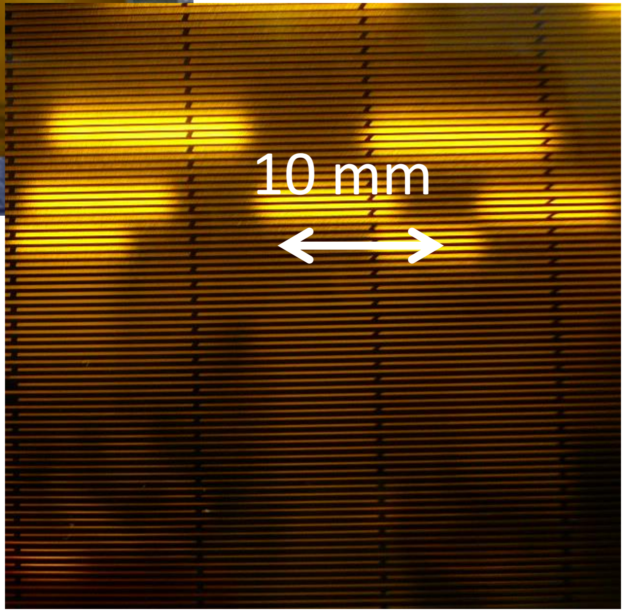




Resistive strip foil







Summary

- Micromegas fulfill all (of our) requirements
- Excellent rate capability, spatial resolution, and efficiency
- We found an efficient spark-protection system that is easy to implement; sparks are no longer a show-stopper
- A well defined method, to built large MMs, has been developed
- Large-area resistive-strip chambers have be built and tested
- Large MMs are robust and (relatively) easy to construct (once one knows how to do it)

Thank you !

for your invitation to speak here
and
your attention

Backup

Why a New Small Wheel

- **Small Wheel muon chambers were designed for a luminosity of L = 1 x 10^{34} cm^{-2} s^{-1}**

  The rates measured today are 2–3 x higher than estimated;
  all detectors in the SW will be at their rate limit at 5 x 10^{34} cm^{-2} s^{-1}

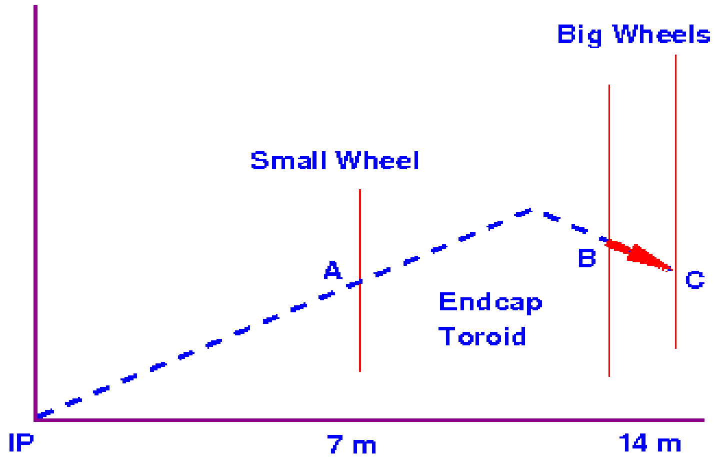
- **Eliminate fakes in high-p_T (> 20 GeV) triggers**

  At higher luminosity p_T thresholds of 20-25 GeV are a MUST
  Currently over 95 % of forward high p_T triggers are fake

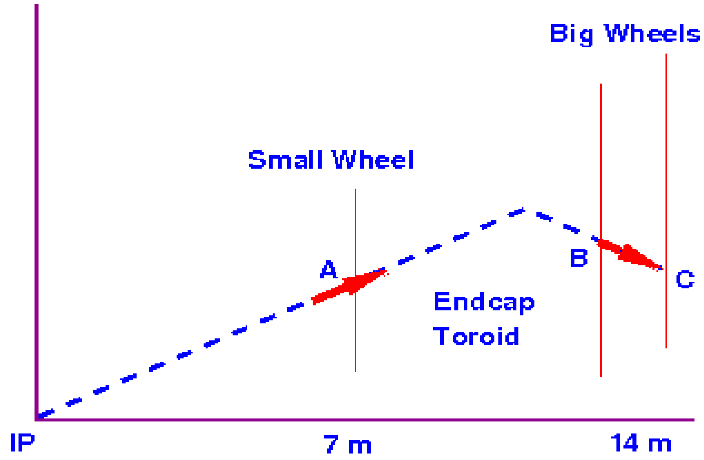
- **Improve p_T resolution to sharpen thresholds**

  Needs ≤1 mrad pointing resolution

Fake Tracks problem in the ATLAS EndCap



Current LVL1 end-cap trigger



LVL1 end-cap trigger after the upgrade

- *Only the vector **BC** at the Big Wheels is measured*
- *Momentum defined by assumption that track originated at IP*
- *Random background tracks can easily fake this*
- *Currently **96%** of forward high-p_T triggers (at LVL1) have no track associated with them*

- *Add vector **A** at Small Wheel*
- *Powerful constraint for real tracks*
- *A pointing resolution of 1 mrad will also improve pT resolution*

Large-area micromegas chambers (L1)

1 x 1 m2 MM being closed in Rui's 'clean room

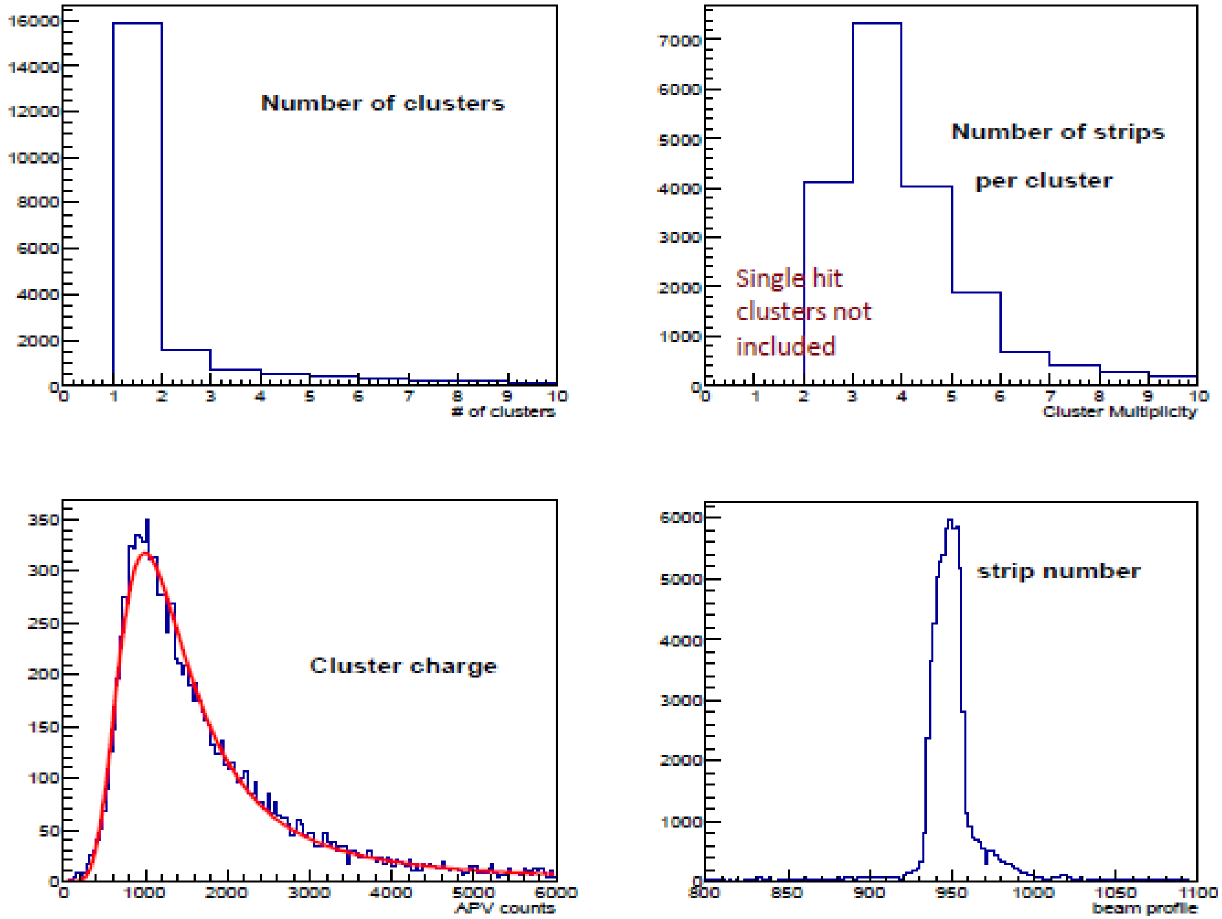
Drift electrode and mesh panel (top) and detail showing the O-ring as gas seal

First experience with 1 x 1 m2 chamber

- Chamber construction and assembly was straightforward
  - Separation of readout panel and drift/mesh panel is feasible
  - Chamber can be opened and cleaned, if required; easy assembly
- Cosmics showed nice signals and good homogeneity over full chamber area;
- Low noise despite 1.06 m long strips
- Good performance confirmed by test beam results
- The chamber needs an about 10% higher HV compared to a bulk chamber, suggesting that the amplification gap is about 10–15 µm larger

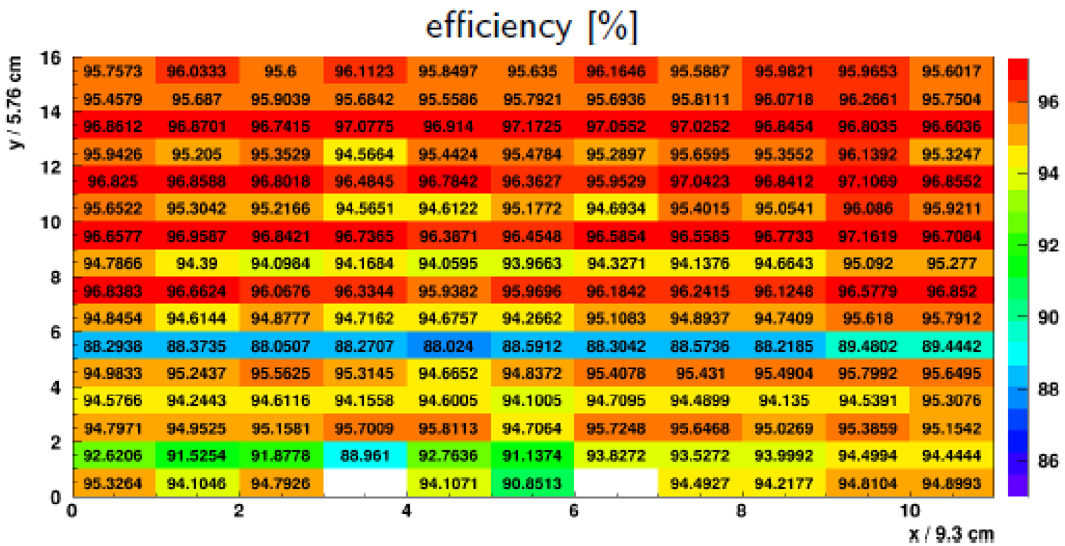
First experience with 1 x 1 m2 chamber

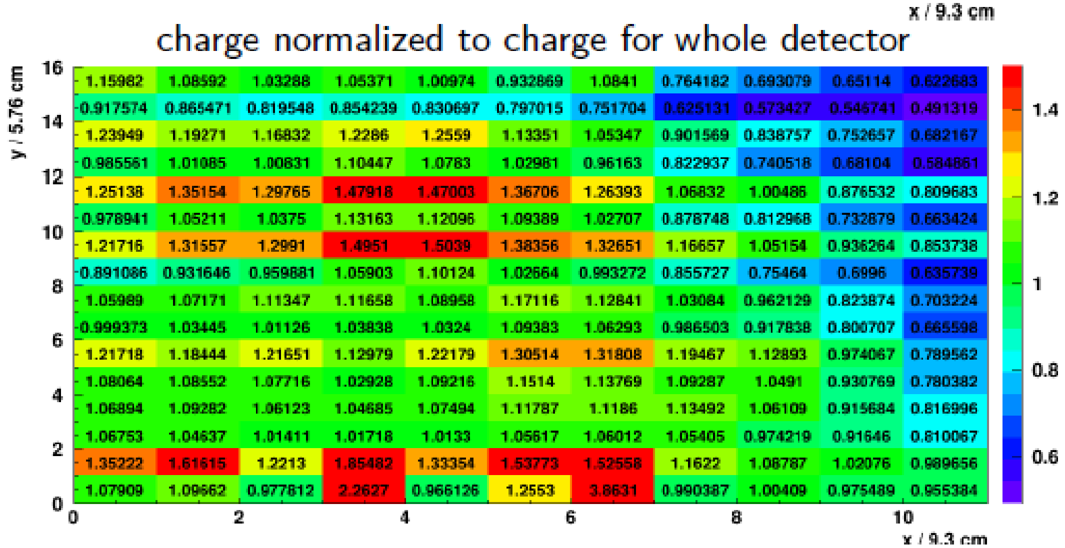
Test beam results (120 GeV pions)



L1, Efficiency and Charge Distribution

- ➢Efficiency homogeneous over active area 95%
- ➢Regions with lower efficiency because of:
  - ➢dead strips
  - ➢muon acceptance
- ➢Pulse height variation < 20%

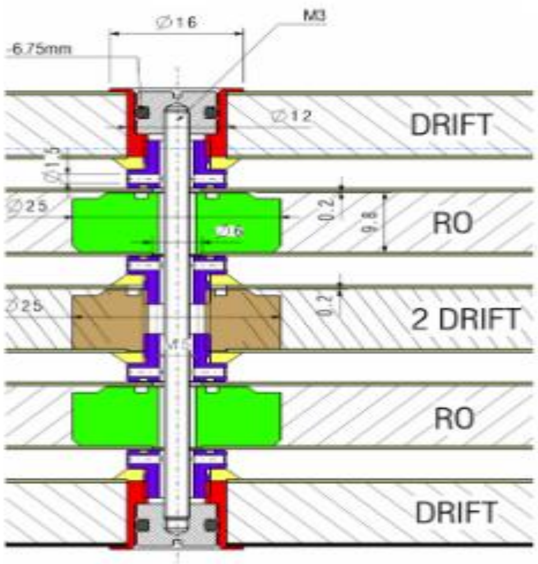


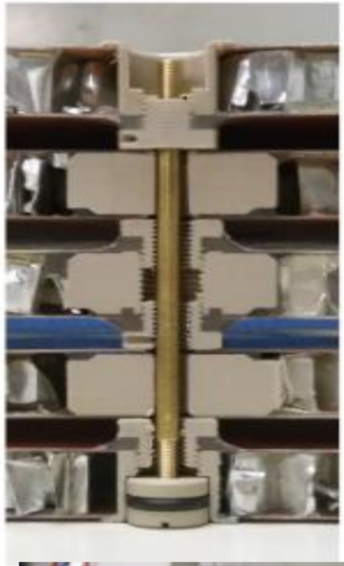


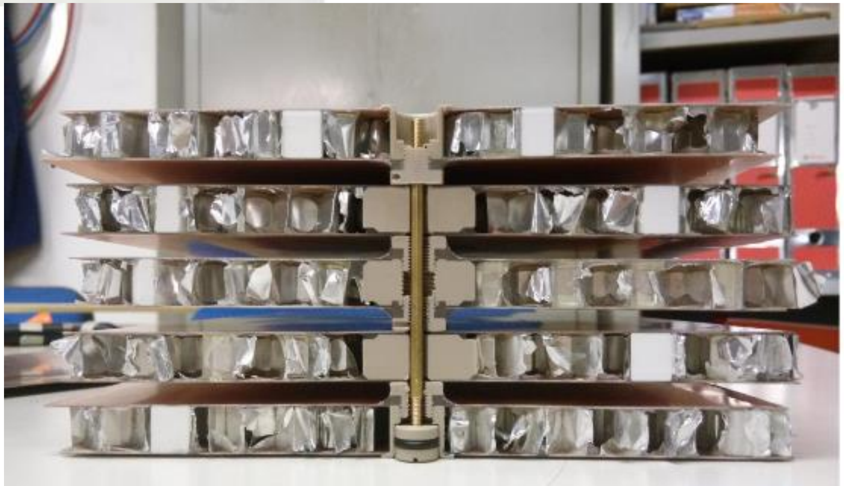
Summary for the experience with L2 chamber

- A 2 x 1 m^2 Micromegas chamber has been successfully built and is working smoothly.
- The chamber response is quite uniform.
- HV of up to +580 V in Ar:CO_2 (93:7) has been applied to the readout strips without sparks, aiming to increase the HV during next round of test.
- A dip in the detector response has been identified in correspondence of not perfect planarity of the readout board

Mechanical solution for interconnections (example)







Test the feasibility of mechanical machining of the interconnections

- PEEK chosen as material
- Two sets of interconnections produced and mounted in test panels
- One has been cut to check glue disposal

Possible position for interconnections