MicroMeshGas Detector (MM)

Outline

- Brief History
  - The Start of the MM Detector (1996)
  - The MM Evolution
    - Resistive (principal of operation)
    - Bulk (technical for easier and effective industrial production)

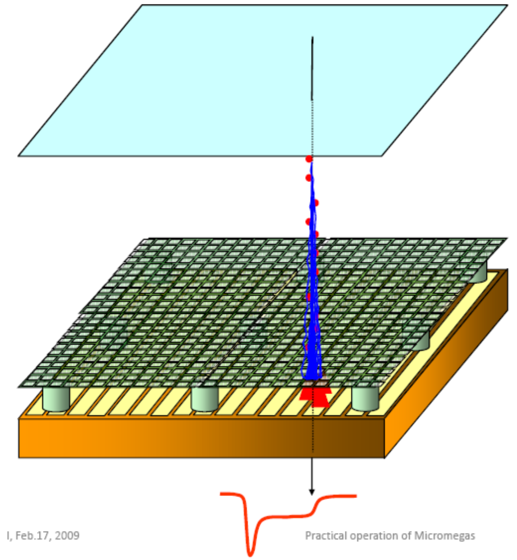
- Performances of Resistive/Bulk MM small prototypes
  - Spatial Resolution
    - Normal Tracks
    - Inclined Track (μTPC mode)
  - Operation in high magnetic field

- A new MM application: The ATLAS New Small Wheel
  - The Actual Small Wheel
  - The New Small Wheel

- Construction of the Large Area resistive MM for the NSW in ATLAS

- Test of the Final detectors Mod0 , Mod0.5, SM1 Doublet. (Where we are now!)

The Start of MM Detectors



Micromegas (MM): MICRO-MEsh GASeous

Belongs to the family of Micro-Pattern Gas Detector, the detector family born in the 1988 with the Micro-Strip Gas Chamber (A. Oed).

MM are parallel-plate chambers (about 5mm wide) where the amplification (up to 10^5) occur in a thin gap, separated from the conversion region by a fine metallic micro-mesh, supported by ~100 µm high insulating pillars.

Charge is collected on the anode readout board, generally realized with suitable segmented standard PCB.

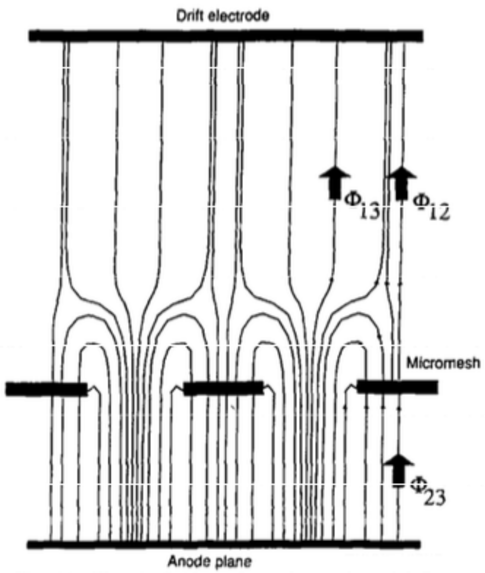


Fig. 11. Electric field configuration and partial flows.

Funnel field lines

↓

Electron transparency very close to 1

Small gap

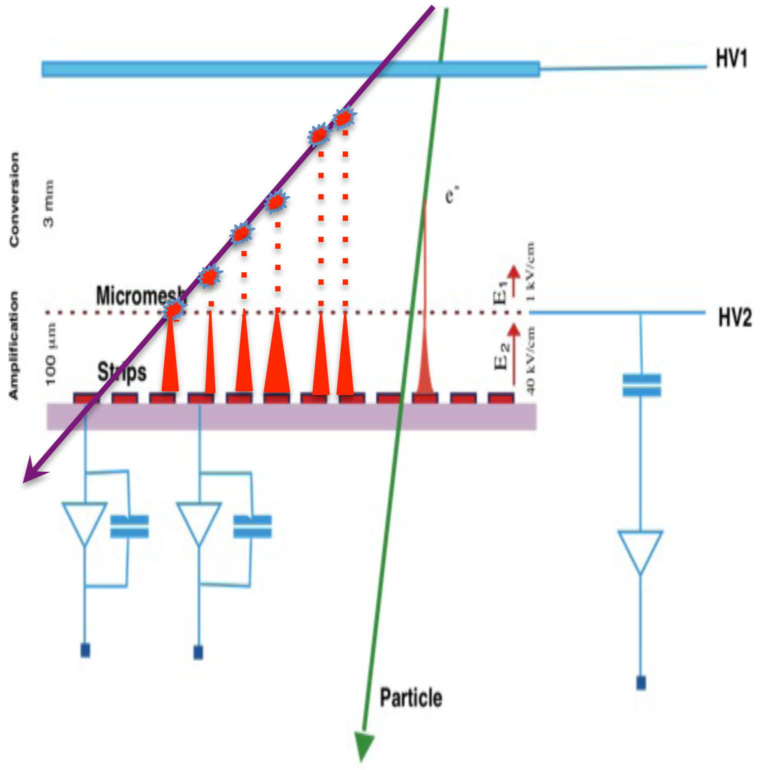
↓

Fast evacuation of the positive ions (~100 ns)

Y.Giomataris et al. NIM A 376 (1996) 29-35

"….our detector combines most of the qualities required for a high-rate position-sensitive particle detector: excellent resolution can be obtained with fine strips printed on a thin G10 substrate or a thin kapton foil."

The Start of MM Detectors



Two Different Operation Modes

- By measuring the average of Charge collected in few strips for Normal Tracks
- By measuring the signal arrival Time in more strips for Inclined Tracks (μ-TPC)

MM Typical Values

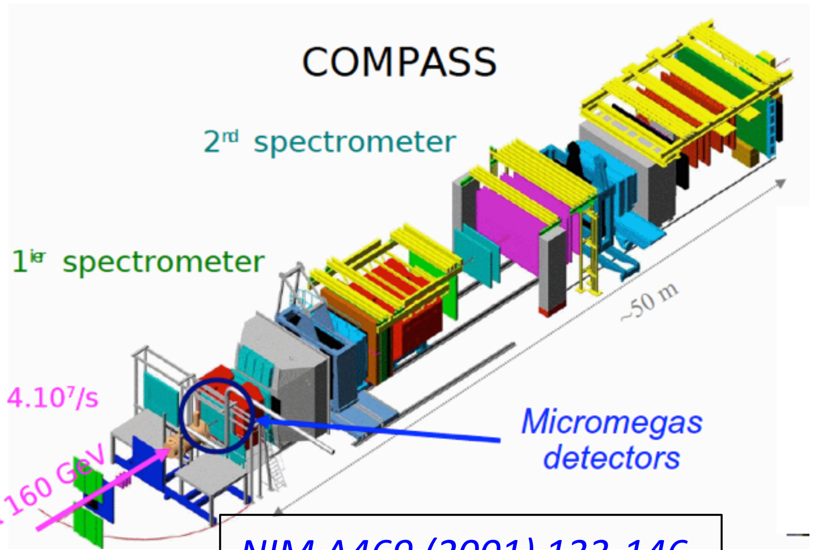
- Wide drift region (typically a few mm) with moderate electric field of about 500 V/cm
- Narrow (100 μm) amplification gap with high electrical field (40–50 kV/cm)
- A factor $E_A/E_D \approx 70$–100 is required for full mesh transparency for electrons
- With typical drift velocities of 50 μm/ns (better if saturated) electrons need 100 ns for a 5 mm gap and Spatial Resolution of about 100 μm or better can be achieved.

At this first stage the greatest "enemy" of MMs was the discharges, sparks between mesh and strips, in particular with high flux of ionizing particles.

The main limitation for very large diffusion of MM in the very beginning

The MM Evolution: Resistive Strips

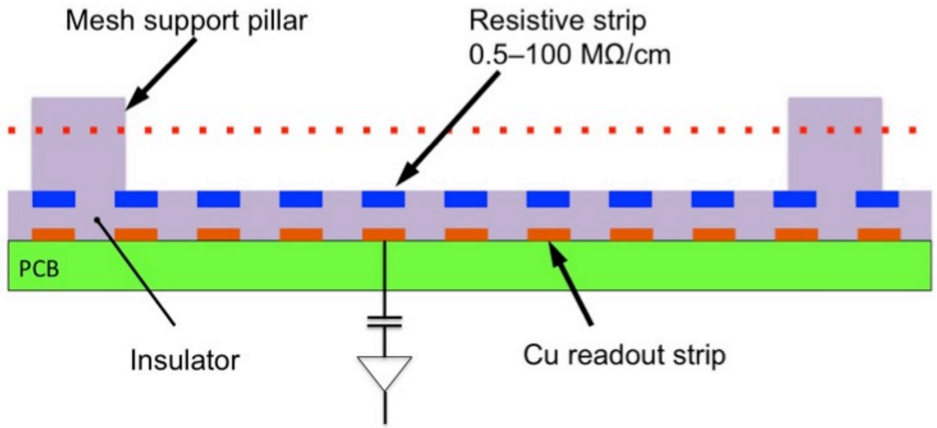
Compass Experience with Standard MM



NIM A469 (2001) 133-146

"…The detector is subject to discharges of current which occur at a rate growing as a power function of the gain and proportional to the incident flux of hadrons....for the Ne-C_2H_6-CF_4 mixture (79-11-10), at fully efficiency, the spark probability (per incident particle) is smaller than 10^{-6}…"

Resistive Strips

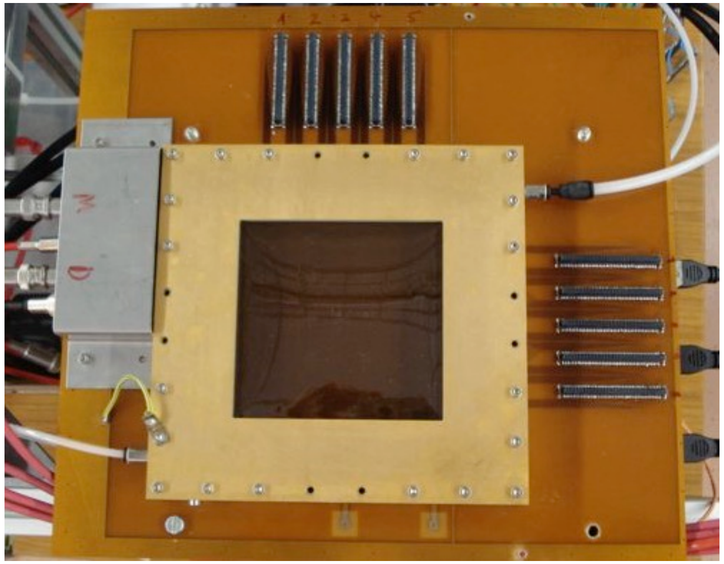


MAMMA Collaboration, NIM A640 (2011) 110

- Sparks dumped by the strips high resistivity, typical value is 1MΩ / Sq.
- Resistive strips at high voltage and mesh at ground is a more safe and easy configuration.
- RO strips are strongly coupled to resistive one and keep all the signal

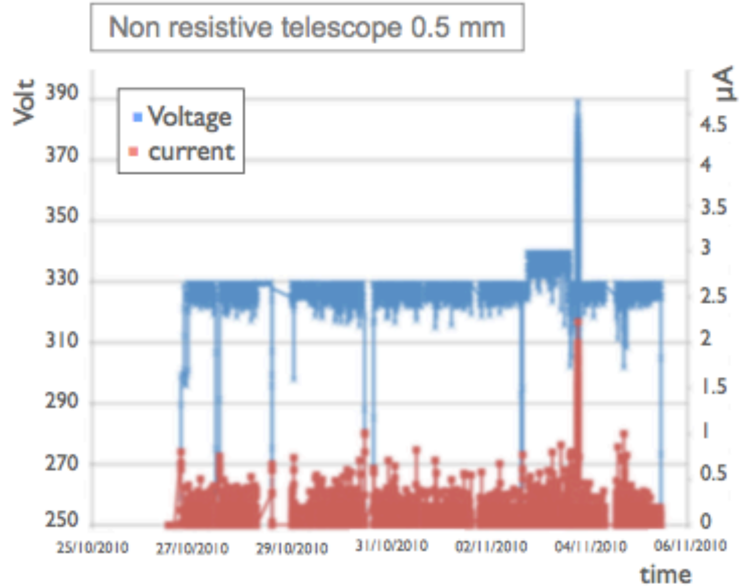
Mamma:
Muon Atlas MicroMegas Activity

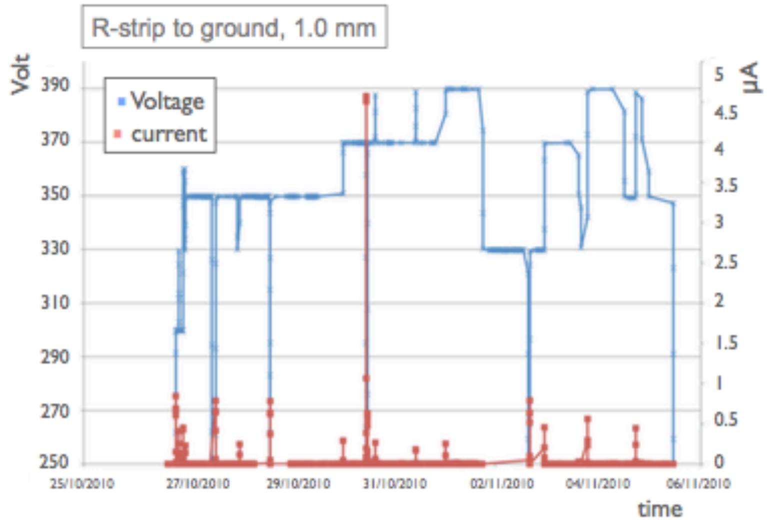
A synergy of the Atlas Collaboration +
the RD51 Collaboration (MPGD) +
the Cern PCB Laboratory (Rui de Olivera)



With this new scheme many small MM prototypes have been produced at Cern and tested in various test beam for different geometry, gain, gas mixture, magnetic field effect…

Strong reduction of sparks on Resistive MM

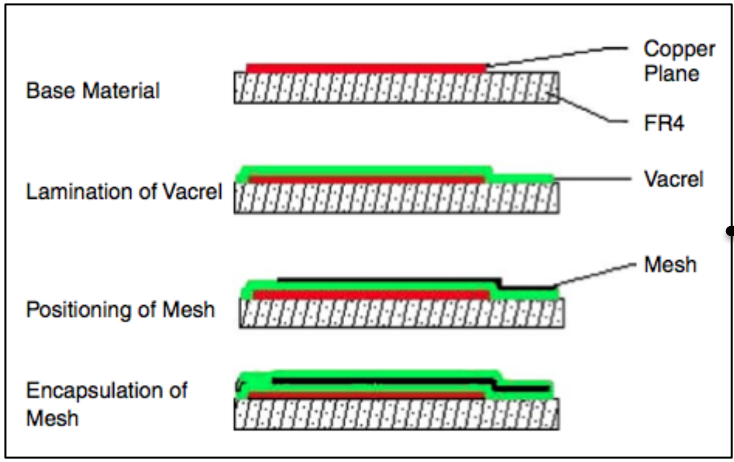




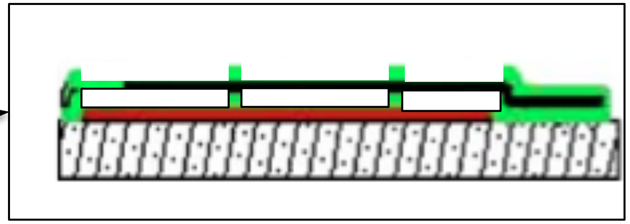
The MM Evolution: Bulk Technology

The Bulk MM

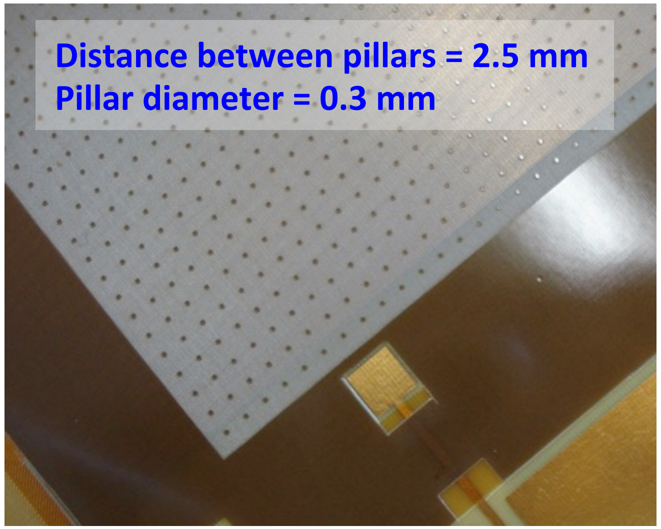
Making a step backward…in 2006 the first Bulk MM was produced at Cern.
In the bulk MM the mesh is embedded in the PCB

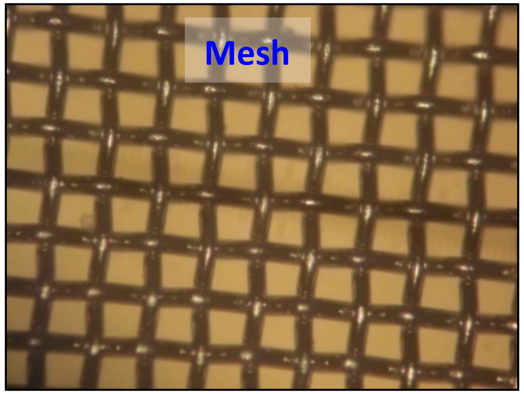


NIM A560 (2006) 405



The Insulator (Vacrel 8100 in this case) is photosensitive and can be removed by etching, creating the pillars.





- New mesh used for bulk MM.
- Woven wire mesh, wire diameter about 20-30 μm and about 80% transparency.
- Largely produced for serigraphic application.
- Electroformed micromesh was normally used before.

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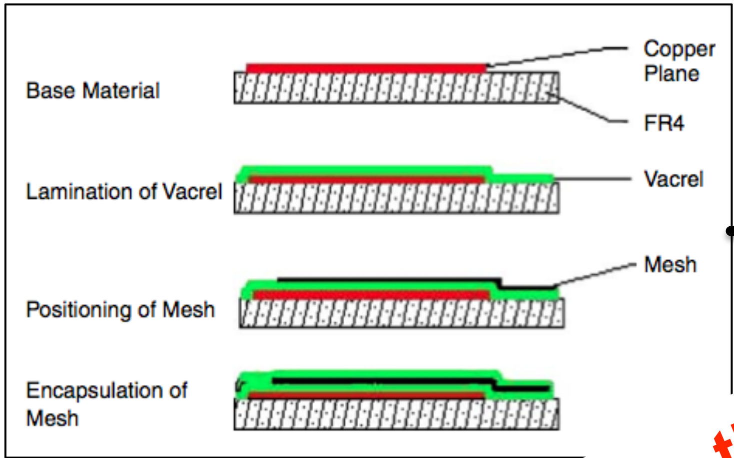

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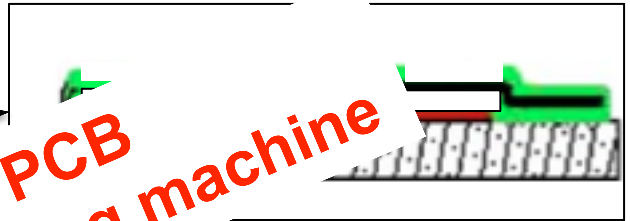

Th… … in this case) is photosensitive
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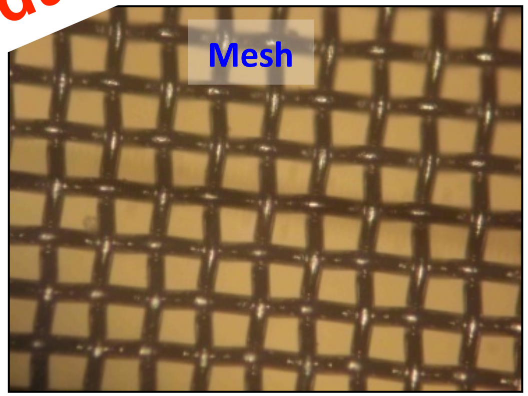
Limited to less than 60 cm wide PCB for typical industrial manufacturing machine



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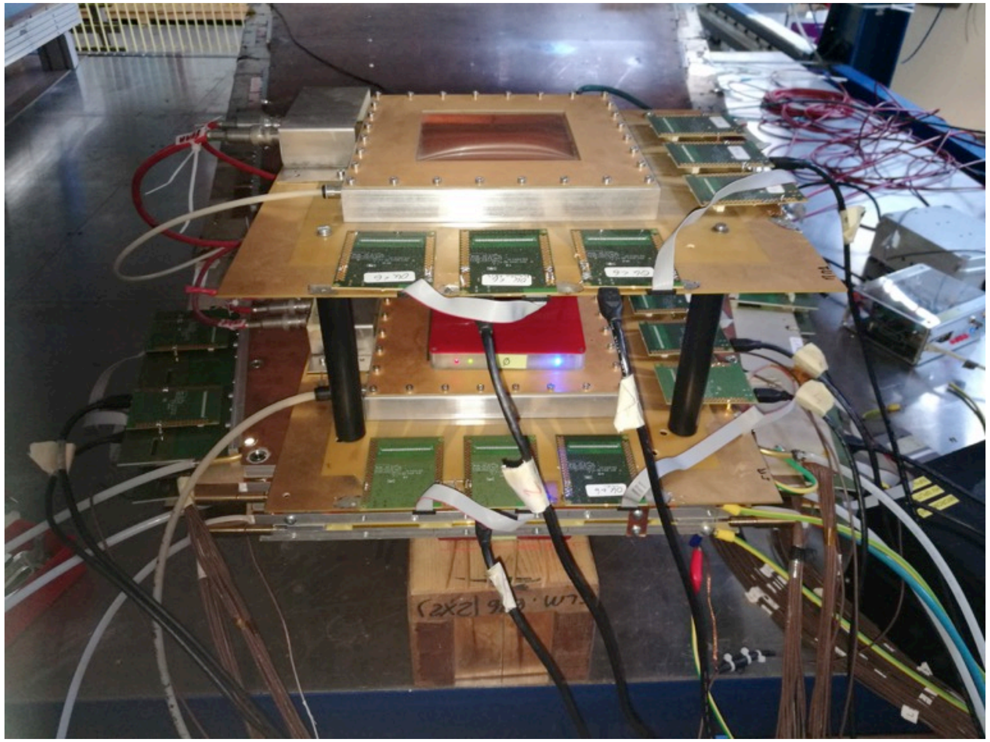
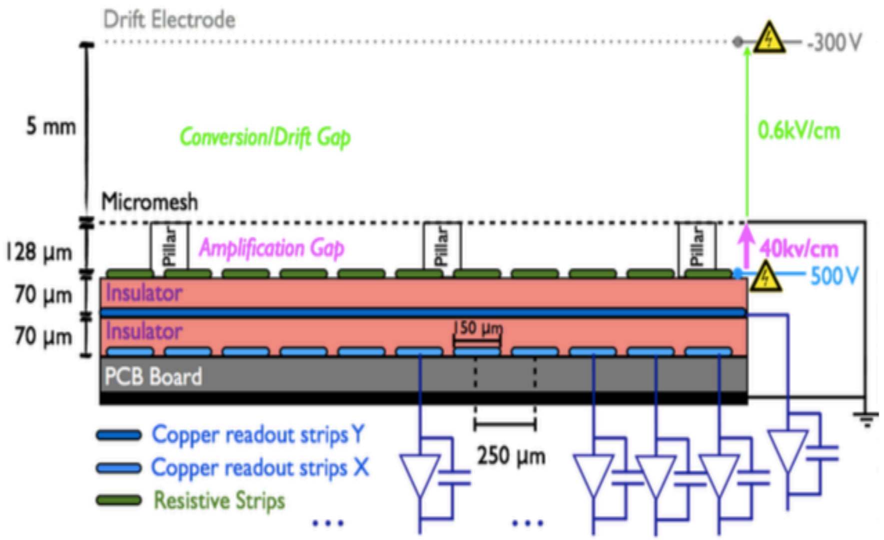
Performances of Resistive/Bulk MM prototypes

First Test Beam campaign has been performed using the APV25 as FE Electronics.

APV25 is an ASIC chip with 128 channels with single Pre-Amp and Shaper and a Pipeline clocked at 40 MHz, designed for CMS silicon tracker detector.

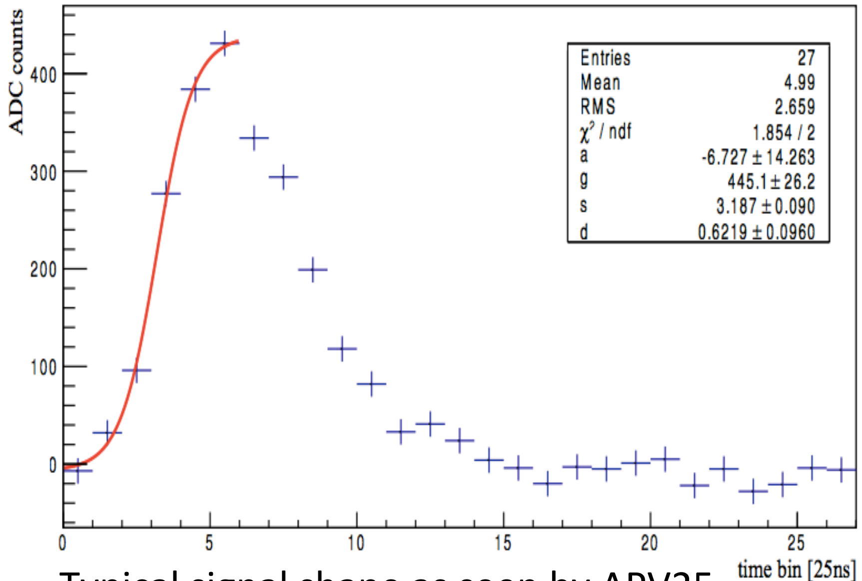
APV25 is used on MM making a signal sampling recording the integrated charge of the signal every 25 ns. RO is done using a system (called SRS) developed for this purpose by RD51 group.





Small MM prototype with two orthogonal view:
X - parallel to resistive strips
Y - orthogonal to resistive strips

Performances of Resistive/Bulk MM prototypes

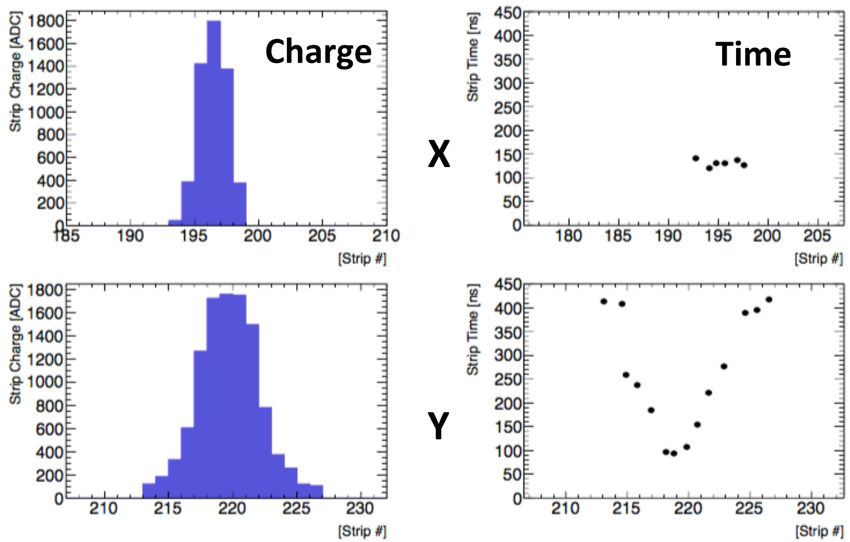


Typical signal shape as seen by APV25

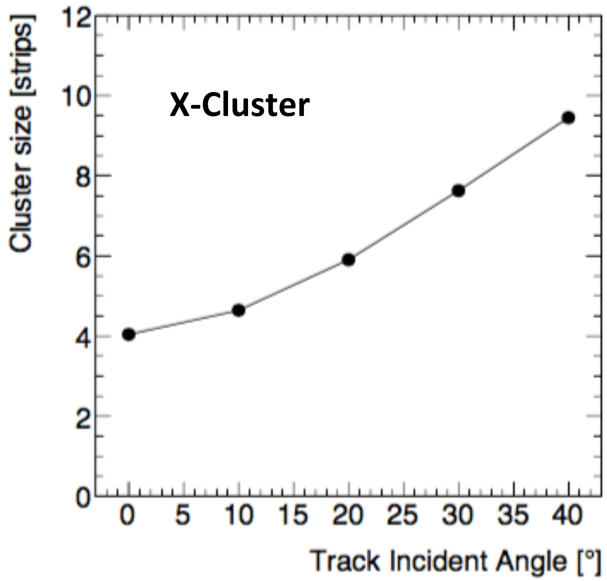
APV25 directly provides signal Charge needed to reconstruct perpendicular tracks (angle wrt the normal to the strips plane < 10°)

Time information, needed for μTCP reconstruction must be evaluated by the signal shape.

In the pic the fit to the rise-time of the signal is done using a Fermi-Dirac function, the time corresponding to the inflection point is used as faster arrival time.

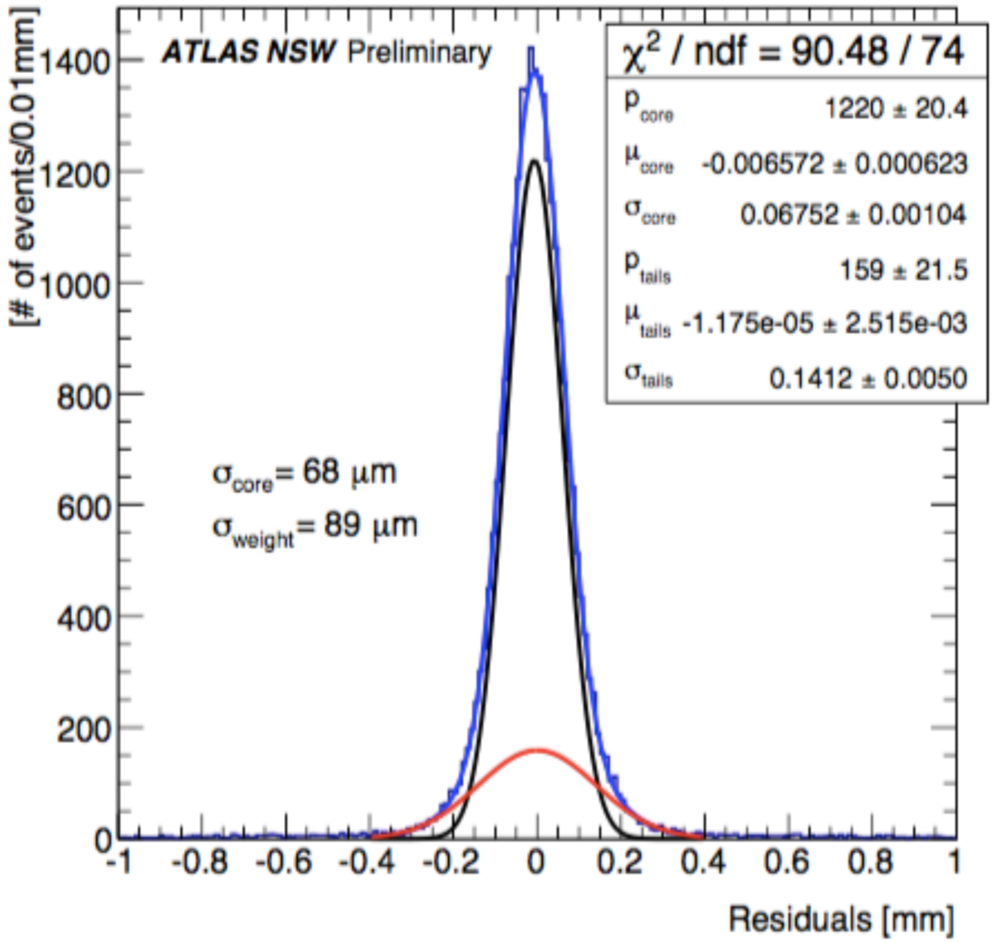


Adjacent firing strips are grouped in a cluster, and the average number of strips in a cluster depends on the angle of the incident track.



Performances: Space Resolution Normal Tracks

Spatial resolution for normal tracks, only charge information is used



This plot is obtained using the information of two MM in a test beam with particles at 0°

The difference of the two X cluster centroid are plotted (all constant related to relative alignment are removed)

Assuming the two MM be similar we divided by SQRT(2) to get the evaluation for a single MM.

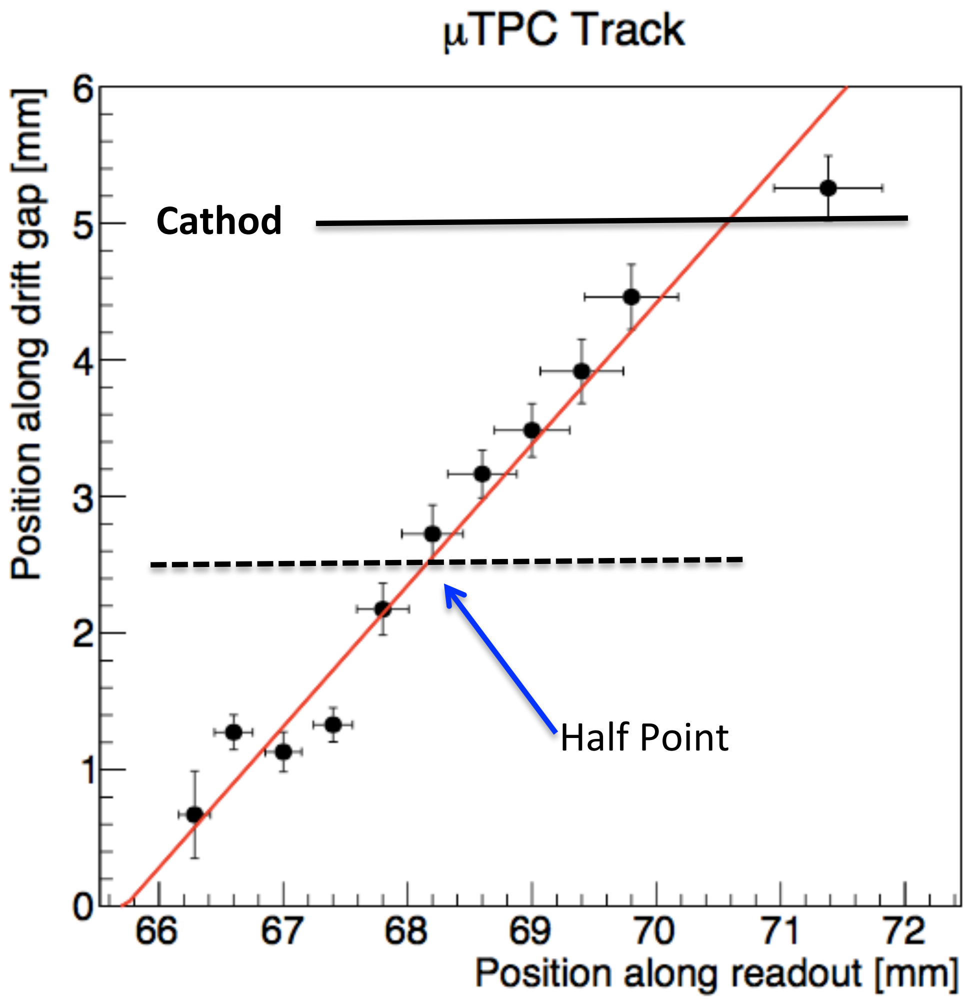
Fit is done with two Gaussian to take into account the tails, the final Gaussian is obtained weighting the two by the relative population.

Almost the same can be obtained with the Y coordinate

This is a very fast evaluation better can be done with more accurate analysis

Performances: Space Resolution Inclined Tracks

Spatial resolution for inclined tracks, only time information is used



This plot shows for an inclined track the fast arrival time measured for each strip.

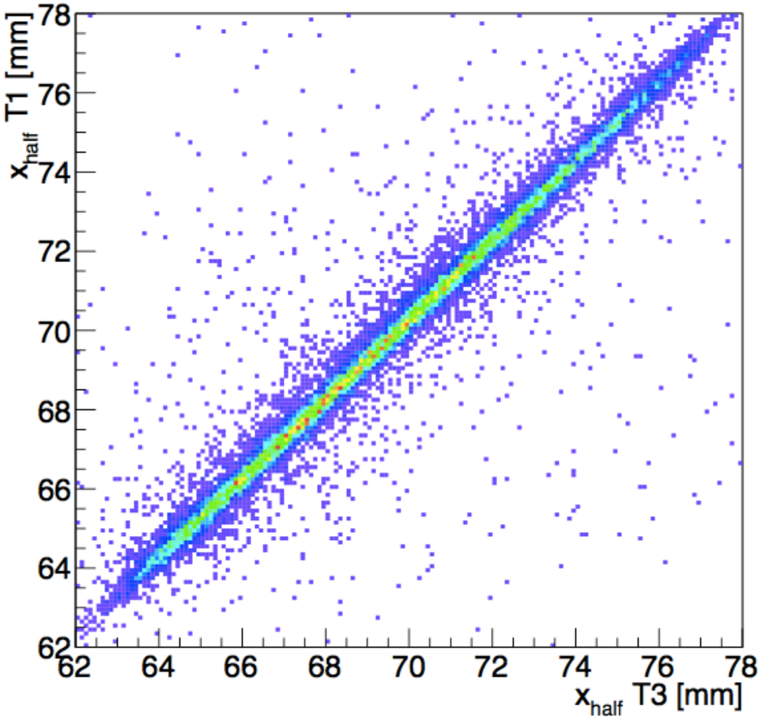
The linear fit reproduce the track trajectory in the detector.

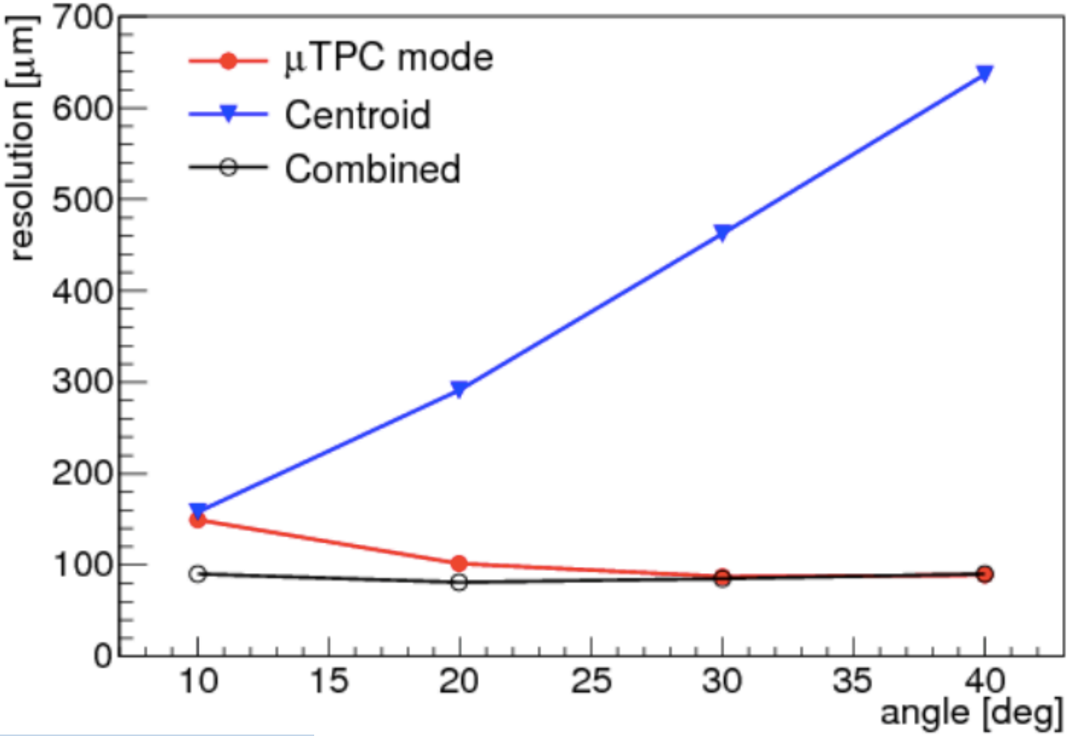
It is important to have a patter recognition to find good candidate for an inclined track, many algorithms have been studied for this purpose.

It is important to find good software cluster even when you have holes in the real cluster, because only few primary electrons arrive to a single strip.

The reconstruction procedure determine with a minimum error the point in the middle of the drift gap, the error on the extrapolation to the strips plane is bigger.

Spatial resolution for inclined tracks, only time information is used



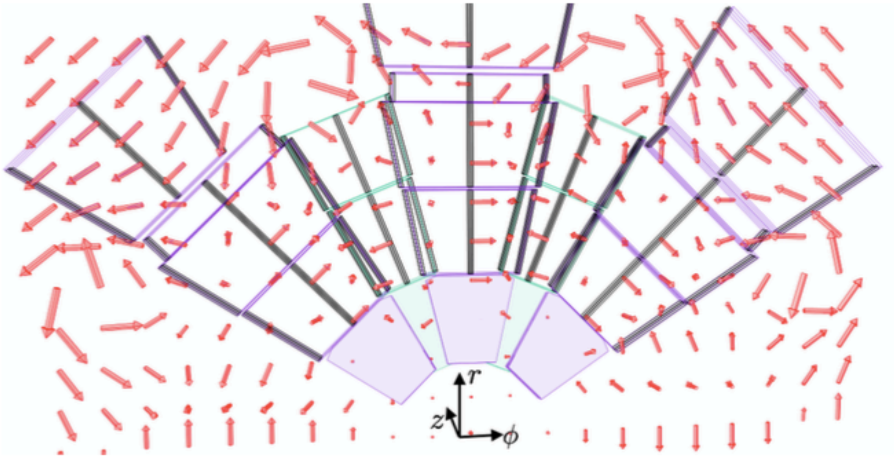


This plot is obtained using the information of two MM in a test beam with particles at 30°

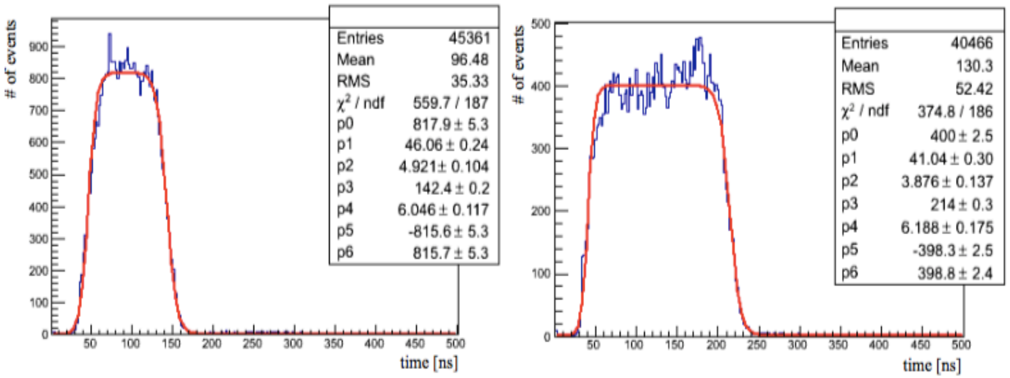
The correlation between the two X_{half} point is shown, repeating the same procedure described in the normal track case, we obtain the spatial resolution in this condition.

Ten Degrees is a sort of "*Middle Earth*" between the two different methods. Centroids dominates at smaller angles, and μTPC at larger

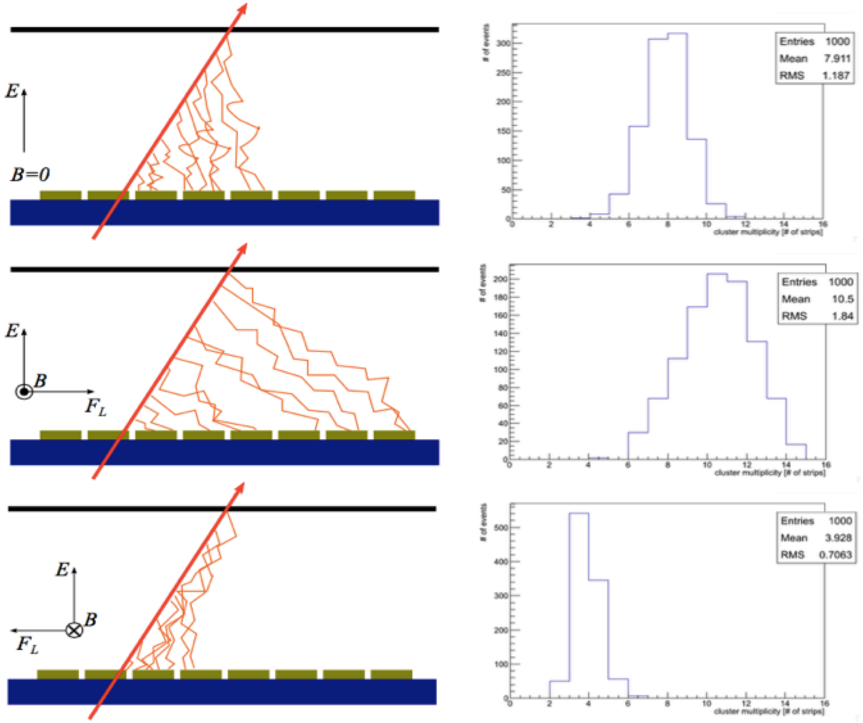
Performances: Operation in High Magnetic Field



Atlas Magnetic field in the region of the Small Wheel



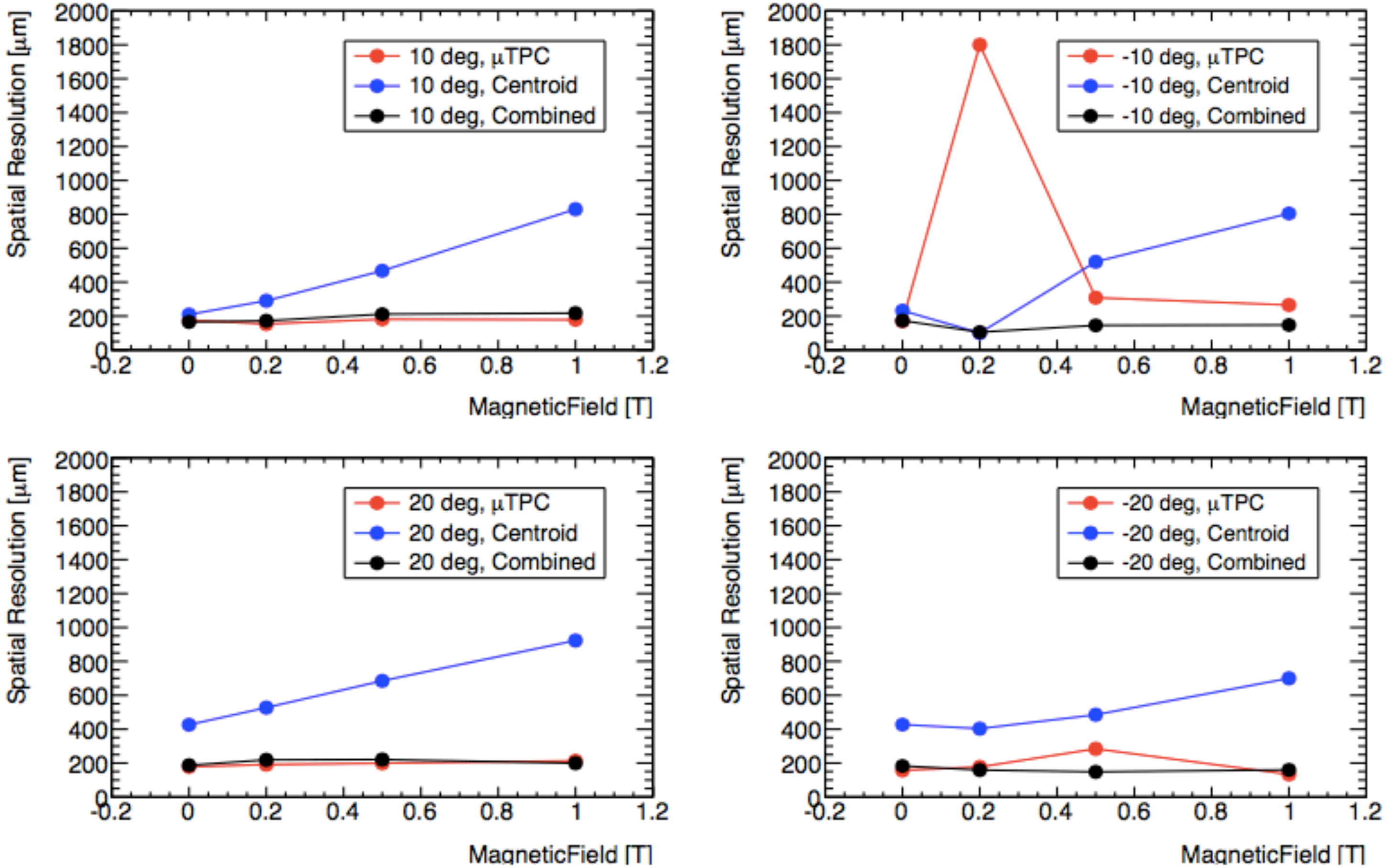
Plot of the First Arrival Time for firing strips
Track are 30° inclined.
On left B=0, on right B=1T (defocusing)



Qualitative effect of the magnetic field on the electron drift.
Depending on the field direction we get electrons focusing or defocusing, and this affect the cluster size.

Performances: Operation in High Magnetic Field

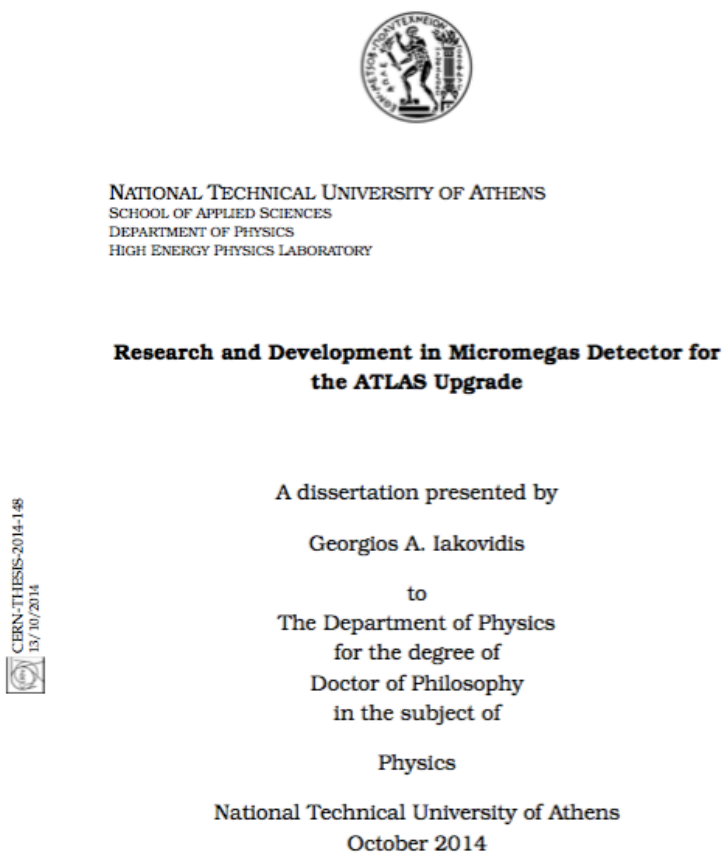
Spatial Resolution as function of the Magnetic



Defocusing for positive angles

For positive angles (defocusing) the μTPC mode is more effective even at angles close to zero.
For negative angles (focusing) the centroid mode is more competitive and for small angle and small magnet field is necessary.

Performances: Reference



CERN-THESIS-2014-148
13/10/2014

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HIGH ENERGY PHYSICS LABORATORY

Research and Development in Micromegas Detector for the ATLAS Upgrade

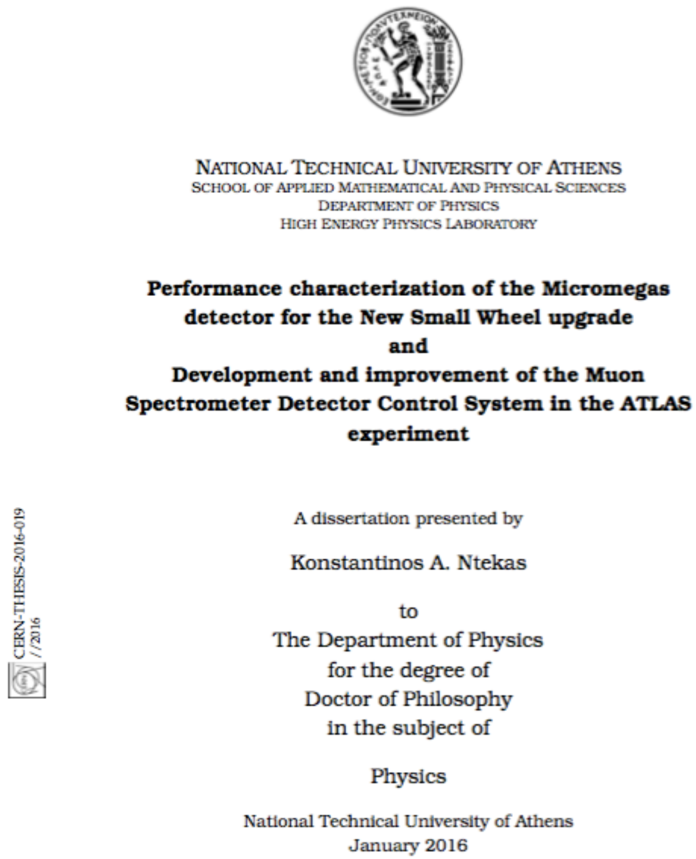
A dissertation presented by

Georgios A. Iakovidis

to
The Department of Physics
for the degree of
Doctor of Philosophy
in the subject of

Physics

National Technical University of Athens
October 2014



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/ /2016

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Performance characterization of the Micromegas detector for the New Small Wheel upgrade and Development and improvement of the Muon Spectrometer Detector Control System in the ATLAS experiment

A dissertation presented by

Konstantinos A. Ntekas

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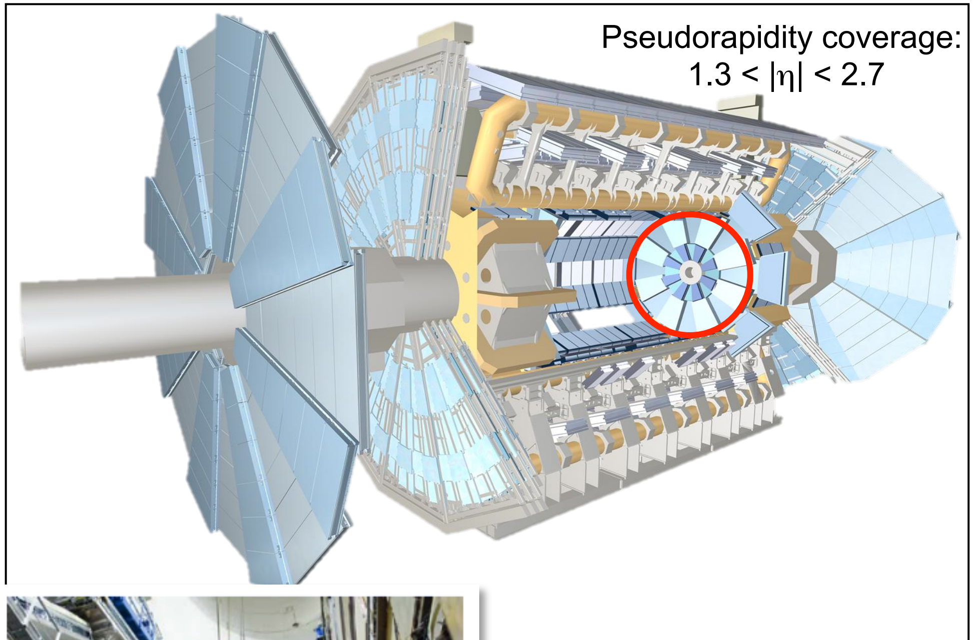
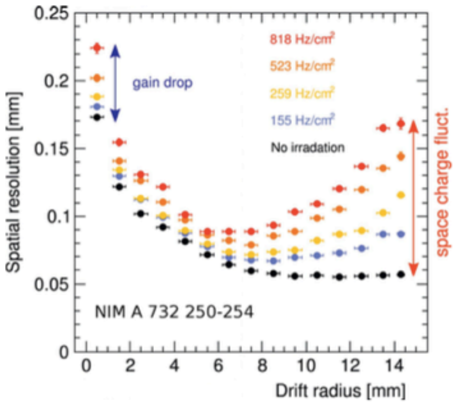
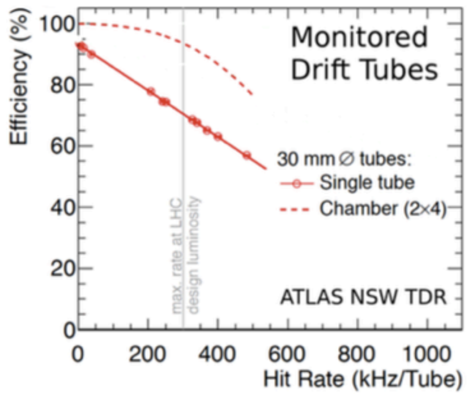
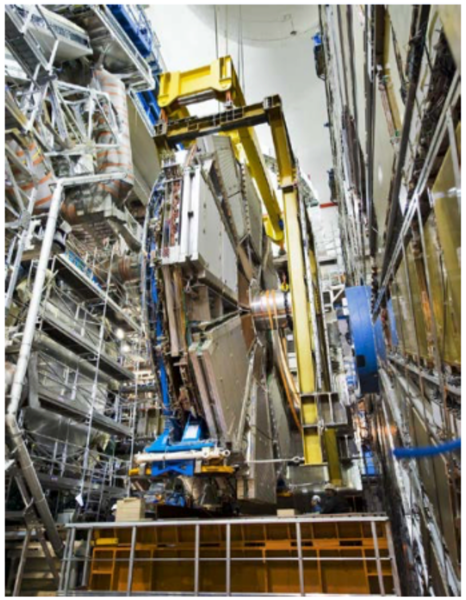
The NSW: The Actual Small Wheel



Small Wheel designed for Luminosity up to 10^{34} $cm^{-2}s^{-1}$

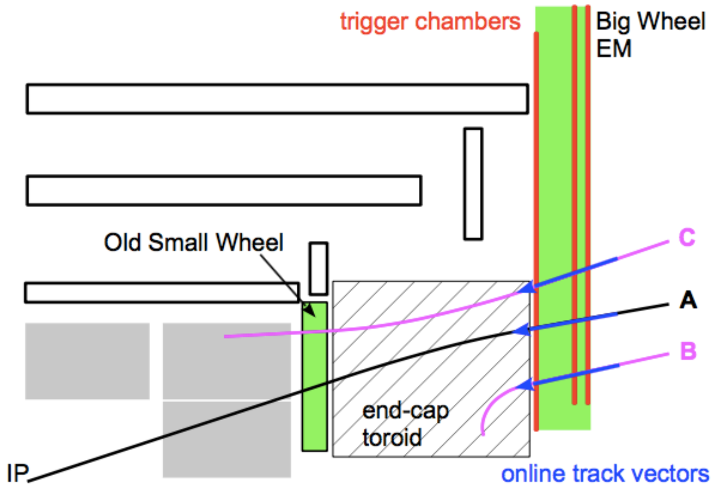






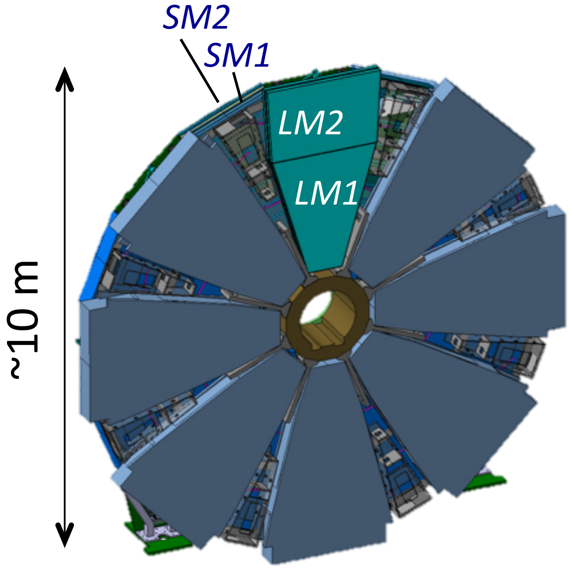
Small Wheel Detectors:

- Atlas Tubes (MDT) 30mm dia.
- Cathode Strip Chamber (CSC) in the inner part
- TGC for 2^{nd} coordinate

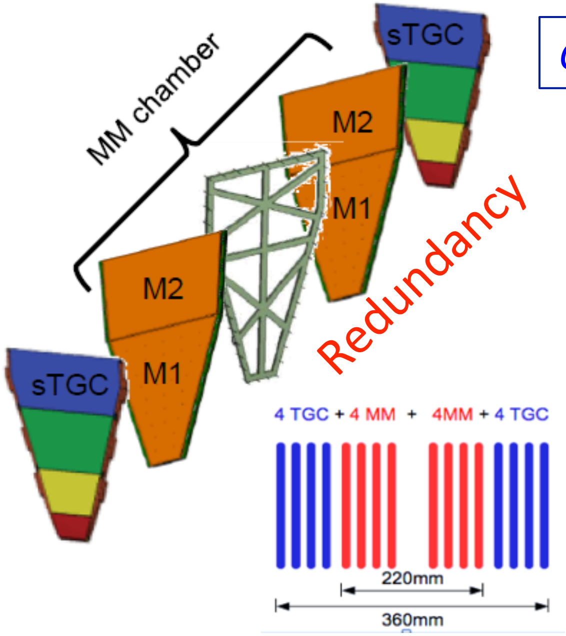


- currently: tracks A, B, C create Level 1 trigger

Main ATLAS upgrade during the Long Shutdown 2 (2019/20) (Phase-1)



Each NSW has 16 sectors
8 Large + 8 Small



CERN-LHCC-2013-006 ATLAS-TDR-020

Two different technology:
- MM (main role tracking)
- sTGC (main role trigger)

NSW Requirements

- 15% P_T resolution at 1 TeV

→ ~100 μm resolution per plane

- Keep single muon trigger under control

→ 1 mrad online angular resolution

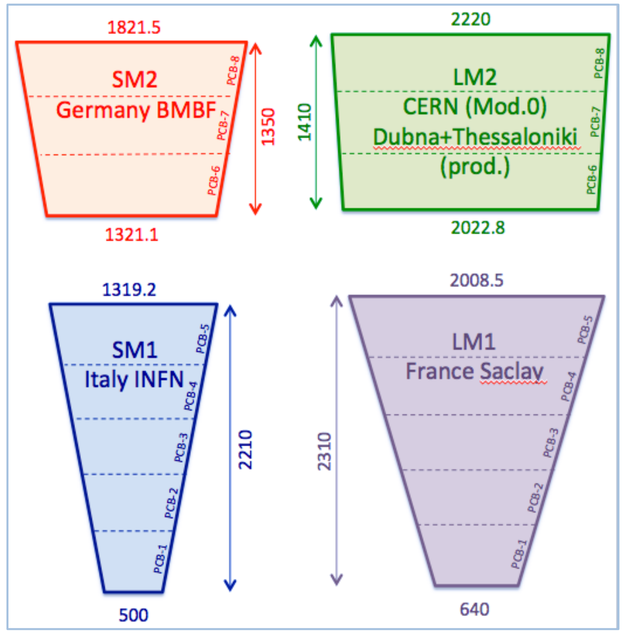
About 15kHz / cm² at L ≈ 5 x 10^{34} $cm^{-2}s^{-1}$

S/L M1 : 5PCB
S/L M2 : 3PCB

PCB:
~ 420mm wide
1024 Strips

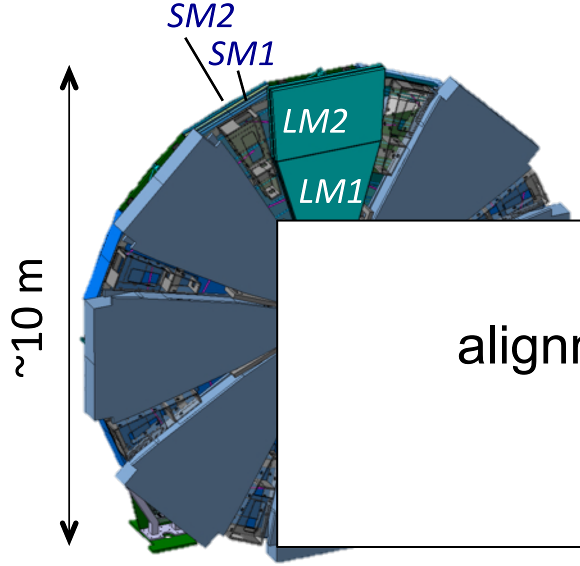
MM Sharing

32 Quadruplet / Site



The NSW

Main ATLAS upgrade during the Long Shutdown 2 (2019/20) (Phase-1)



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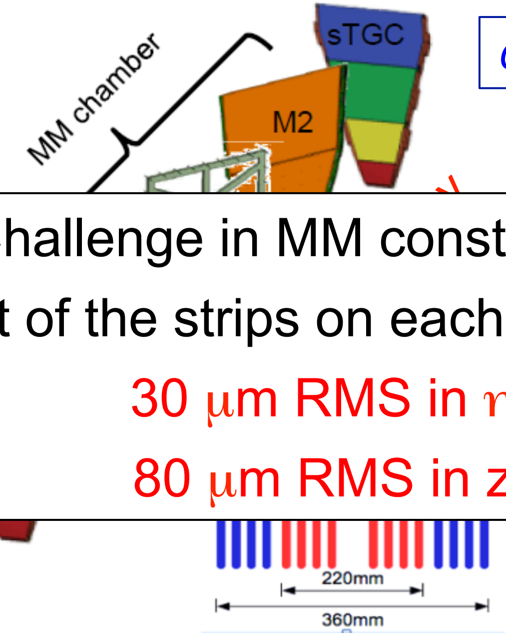


CERN-LHCC-2013-006 ATLAS-TDR-020

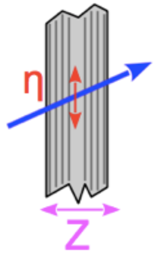
Two different technology:

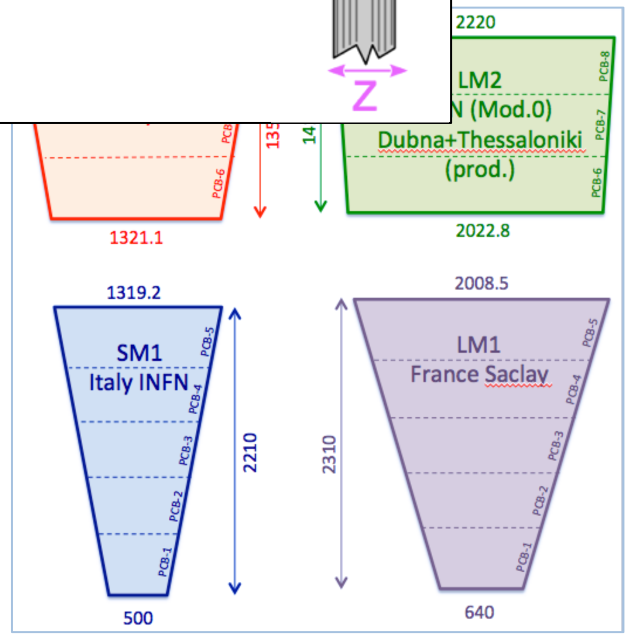
Challenge in MM construction:

alignment of the strips on each detection layer

30 μm RMS in η

80 μm RMS in z





32 Quadruplet / Site

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- → ~100 μm resolution per plane
- Keep single muon trigger under control
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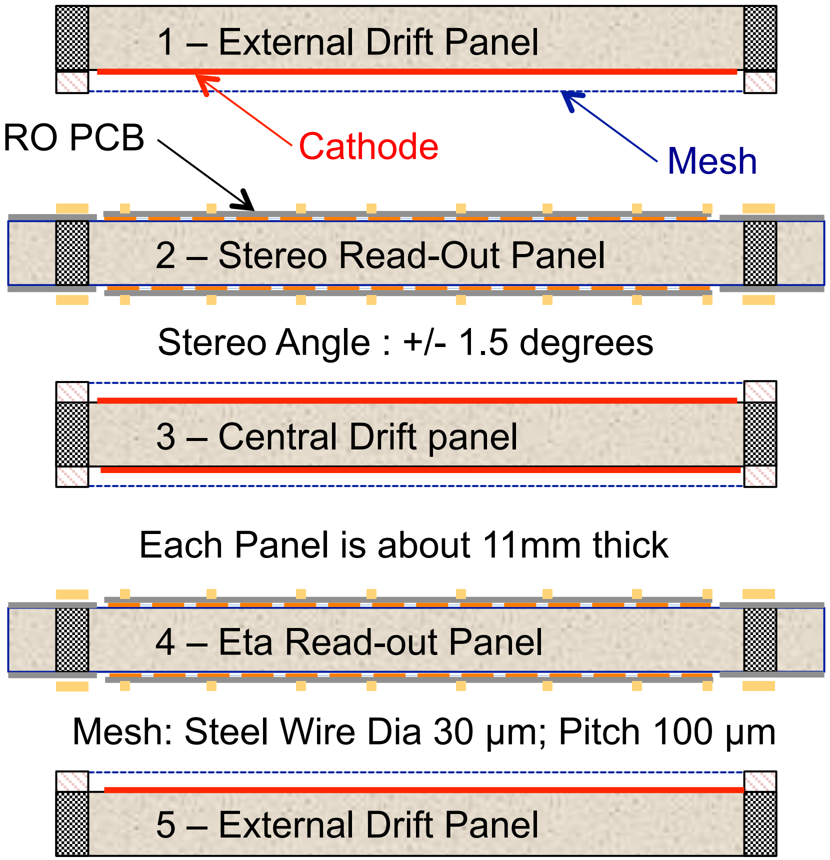
S/L M1 : 5PCB
S/L M2 : 3PCB

PCB:
~ 420mm wide
1024 Strips

ATLAS MM : Structure

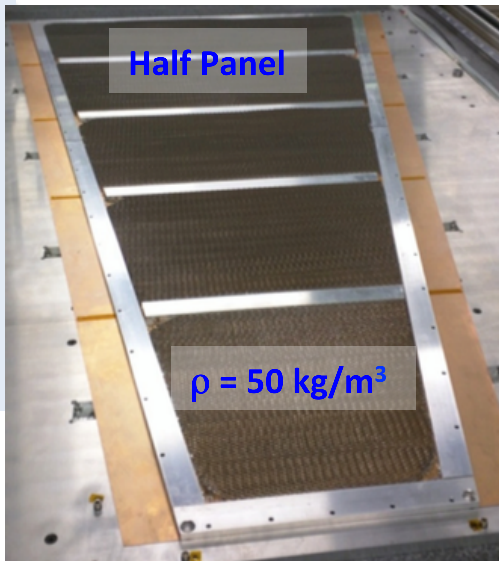
MM Quadruplet Exploded View



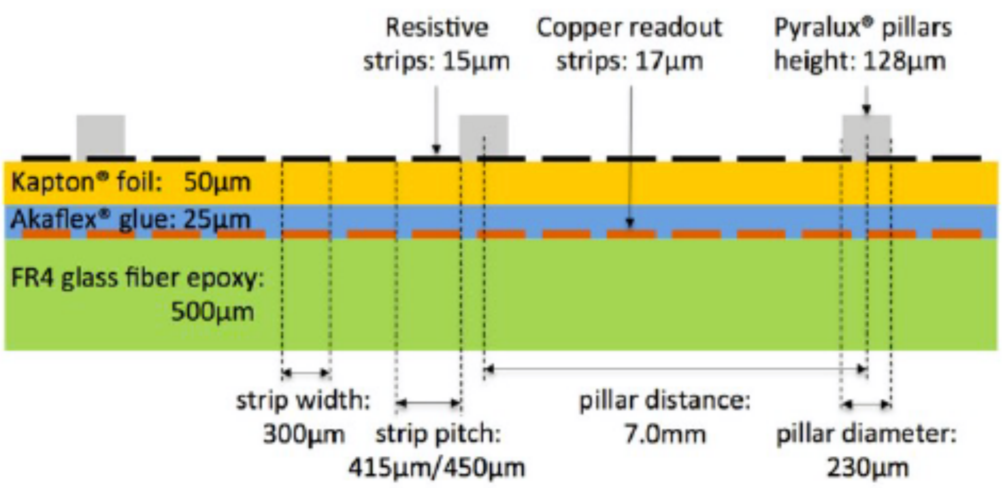
Five panels joined to make a detector unit (Quadruplet) with 4 gas layers.

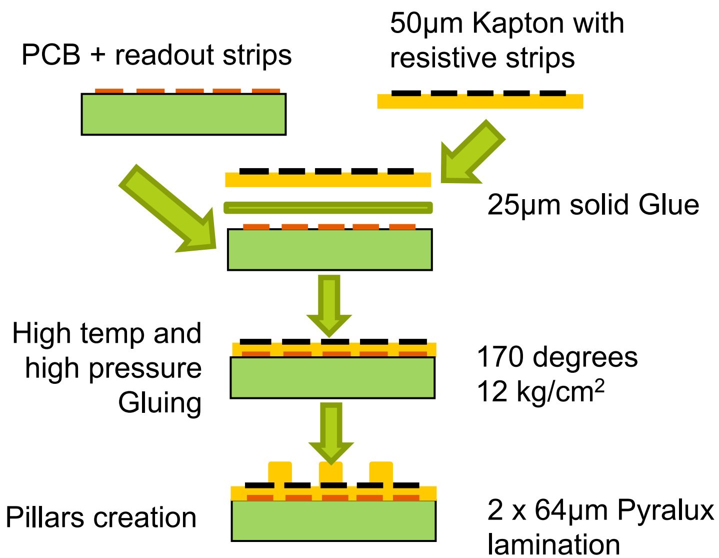
Building Large Area MM

- Panel is a sandwich of 0.5 mm PCB skin with honeycomb in the middle and frames in the perimeter and in the joint of two adjacent PCB. Honeycomb and frames are in Al.
- Different Panels are needed for a Quadruplet
  - RO Panels (Eta and Stereo)
  - N.2 External Drift Panels
  - One Central Drift Panel
- For each gas layer a unique Mesh is glued on the drift panel, using a custom frame that define the 5 mm height.
- Slow bi-component epoxy is used as glue.

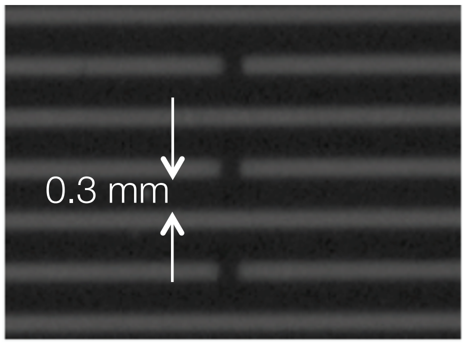


ATLAS MM : RO PCB

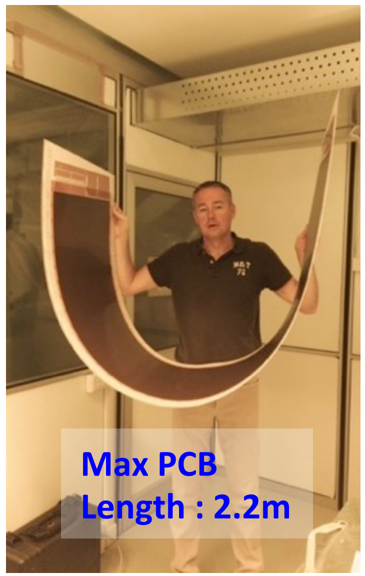




- All production steps of the PCB construction procedure are industrially well known.
- The collaboration is directly taking care of the production of the Resistive Strips on Kapton. Screen Printing technology is used.
- "Ladder pattern" (join every 10mm) used for homogeneous resistivity and insensitivity to broken lines.

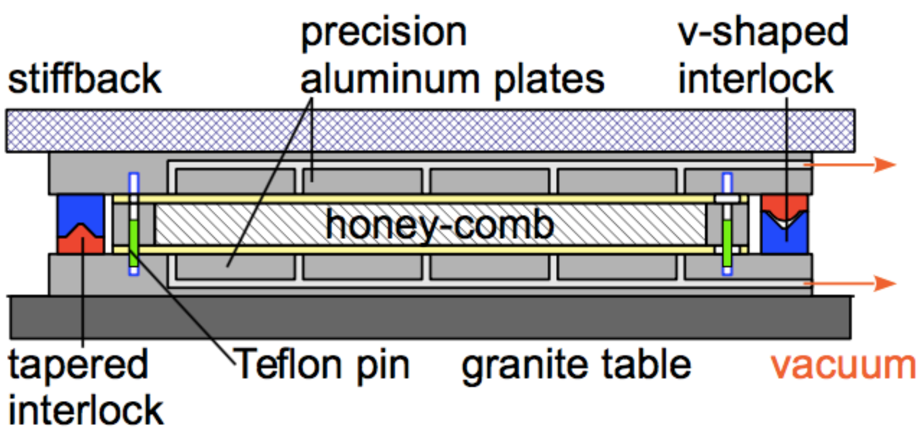


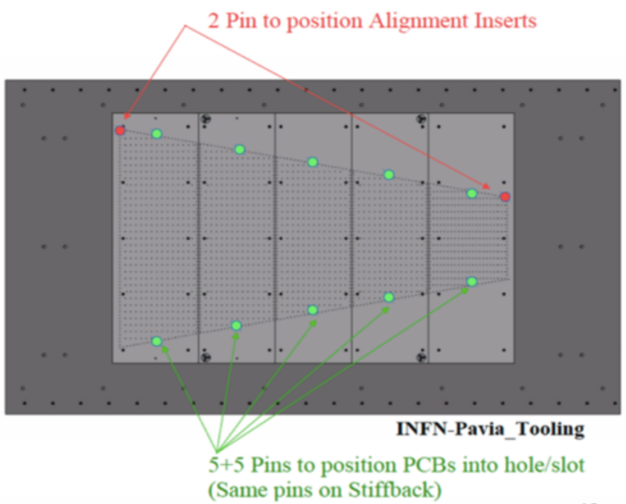
Typical Resistivity
~800 kΩ/□

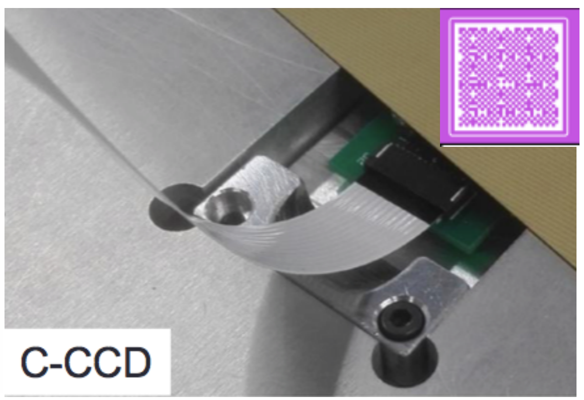


- Challenge in MM construction: strips alignment
  - 30 μm RMS in η
  - 80 μm RMS in z
- Precision Panel construction is guaranteed by high precision hole/slot on PCB and by the external tooling.
- Position check is done reading masks etched on the PCB, using optical sensors. (Not present for Mod0 and Mod0.5)
- Glue compensate for non-precise components.

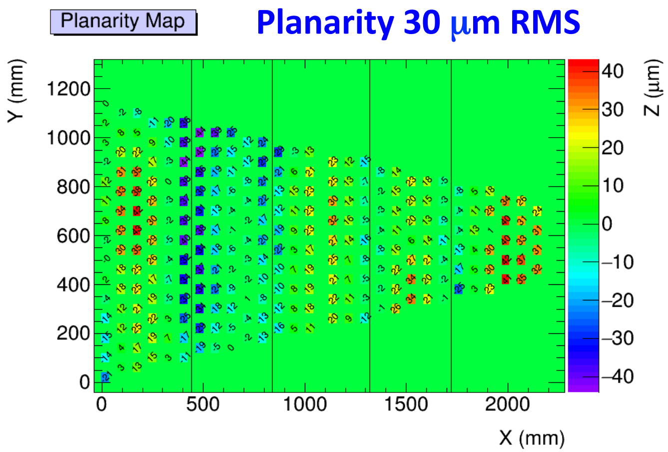
Stiffback Construction Method







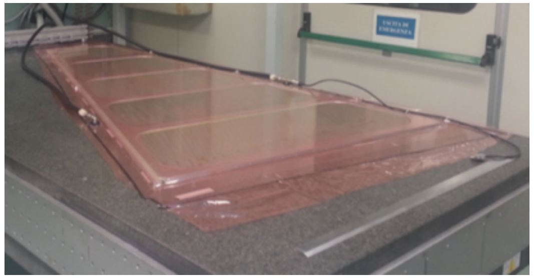
Planarity 30 μm RMS



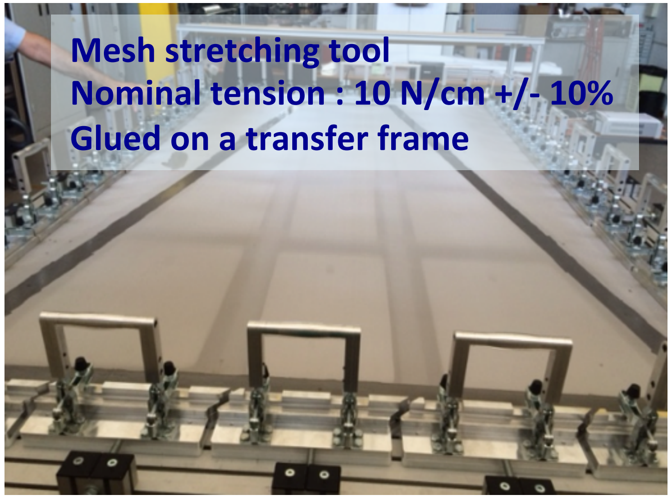
ATLAS MM : Drift Panels

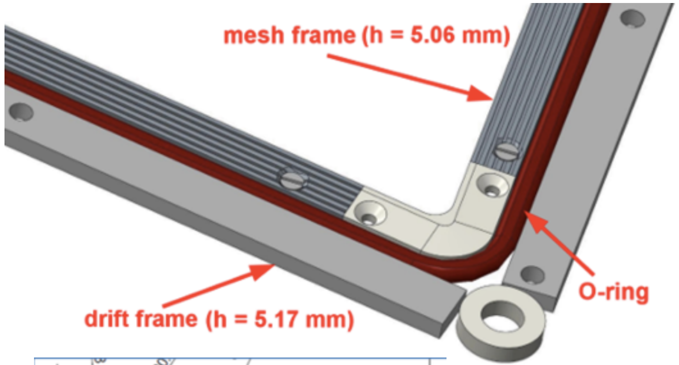
Drift Panels are build using different techniques in different sites.

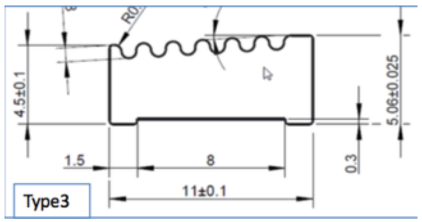
Stiffback, like RO Panels, or Vacuum bag. Results are similar.

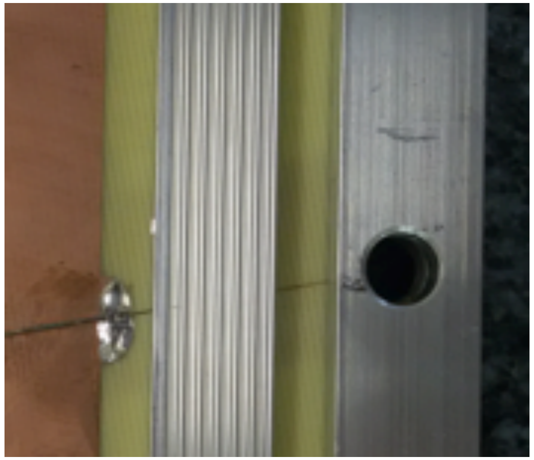


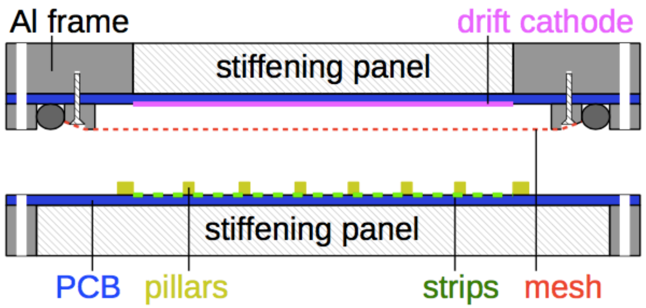
The floating mesh is attached to the drift panels

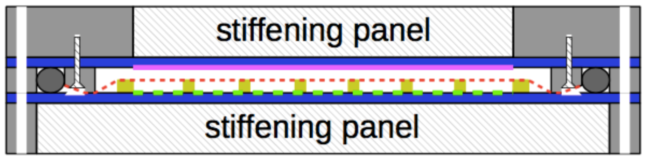








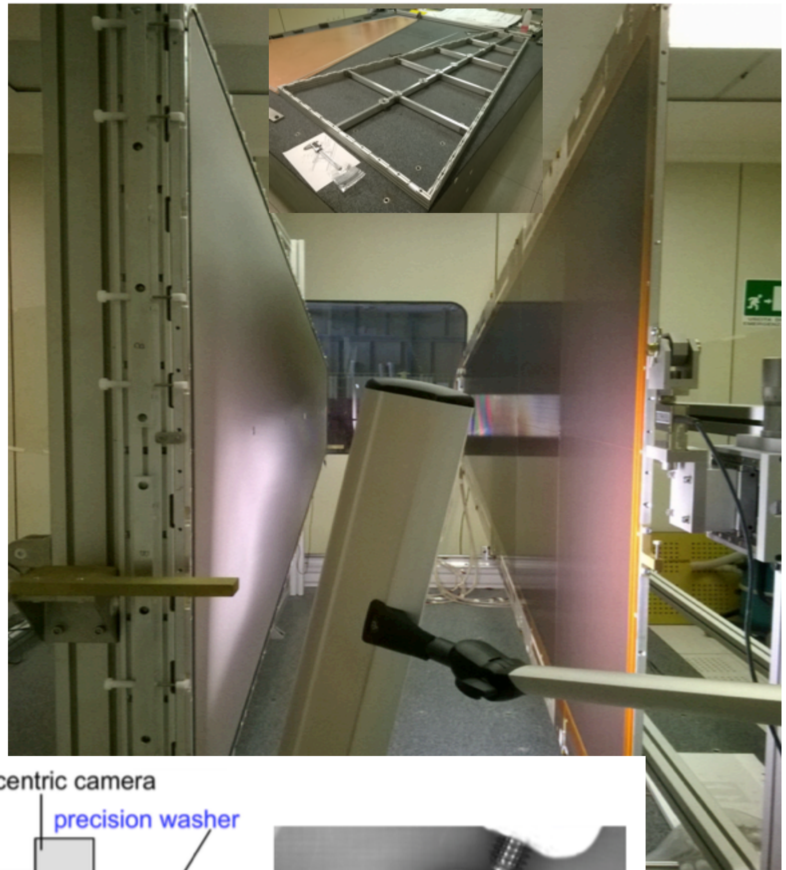


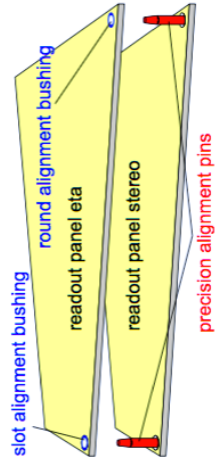


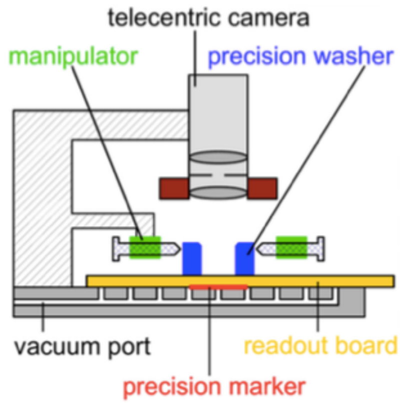
Vertical Panel Assembly

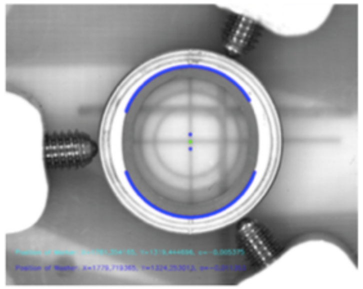
- Cleanliness
- No panel deformation under its own weight
- Panel deformation because of the mesh

External drift panel, because of the mesh tension, is deformed, with a sagitta of about few mm, when put in vertical.
During the assembly a support structure called stiff-frame is used and visible on the left part of the picture (fixed part);
RO (stereo) panel on the right (movable part)
Precise pins/slot are glued on the RO panels for relative alignment





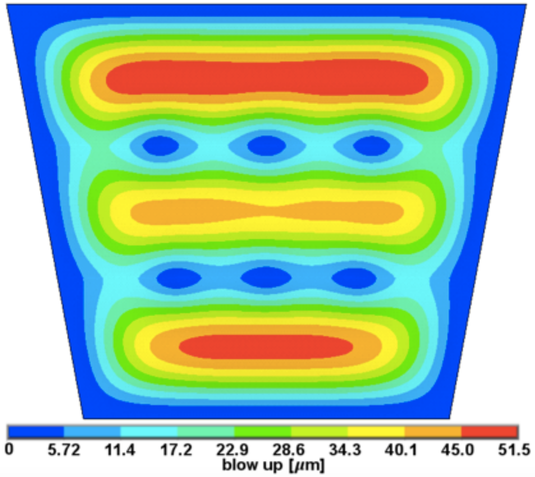




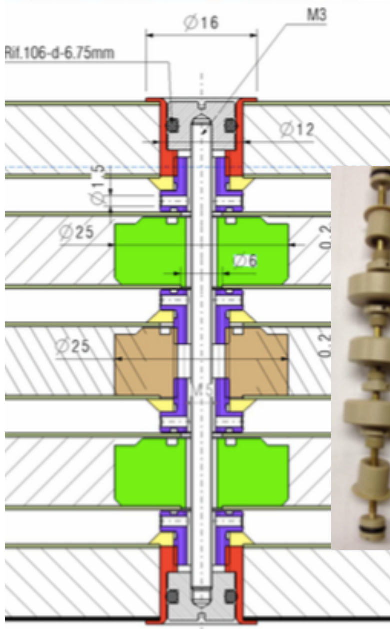
ATLAS MM : Quadruplet (SM1 Mod0)

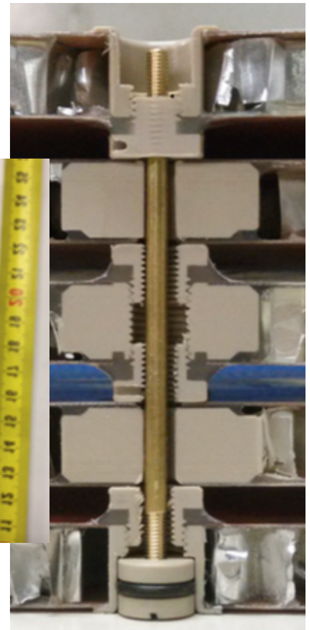
The two external surfaces are deformed by the overpressure due to gas flowing in the detector.

Simulations show many hundreds of microns largest deviation.

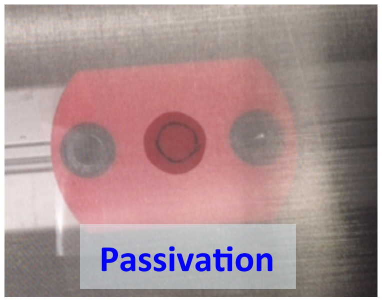


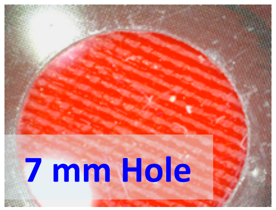
Simulation with 6 interconnections for 2 mbar overpressure, the largest deformation is now 50 μm.
The final number of interconnections range from 4 to 7.



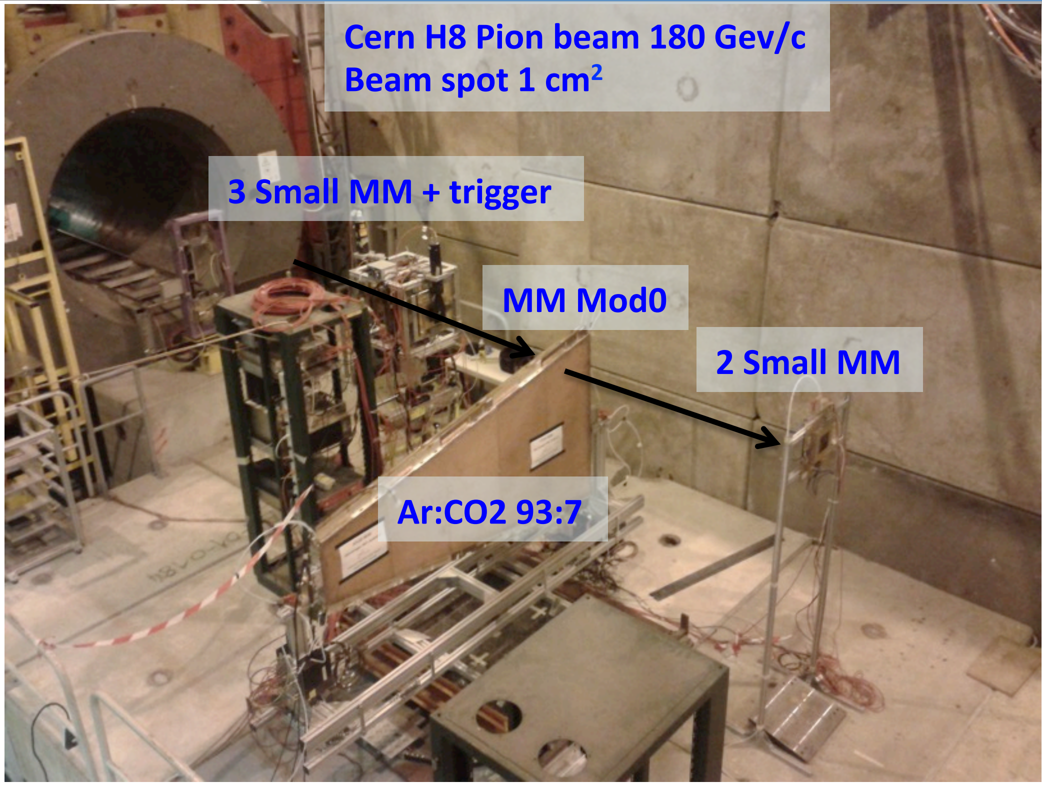


Need to make holes in the mesh !

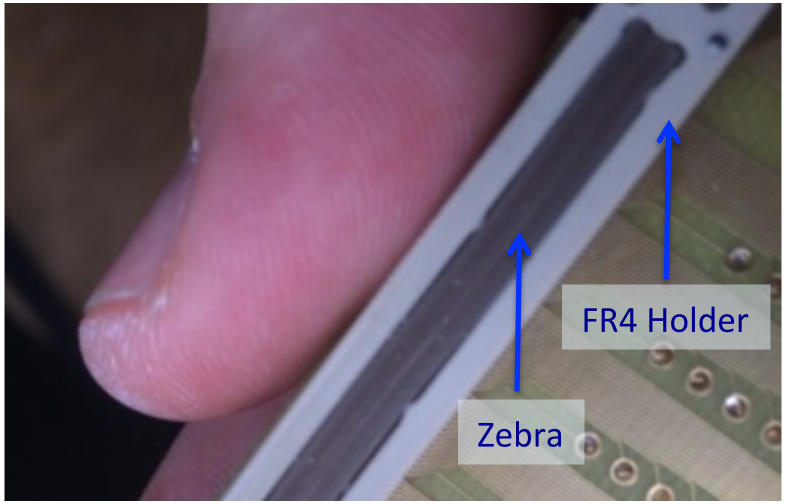




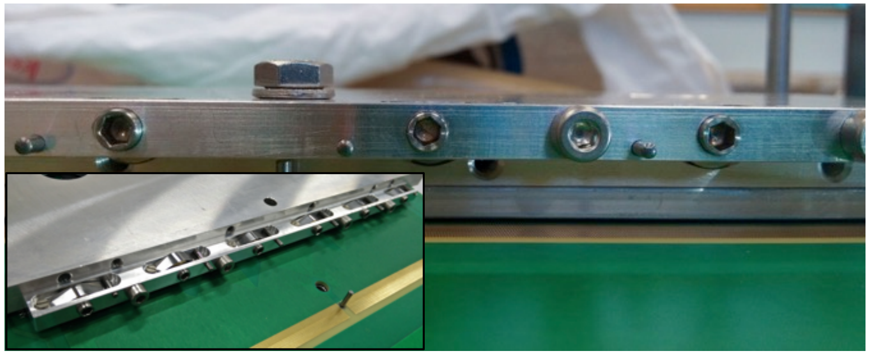
MM SM1 Mod0 Test Beam at Cern H8



Used final Zebra connectors to Read-Out the strips with some adapter boards to use the APV25 being the final electronic not jet available.

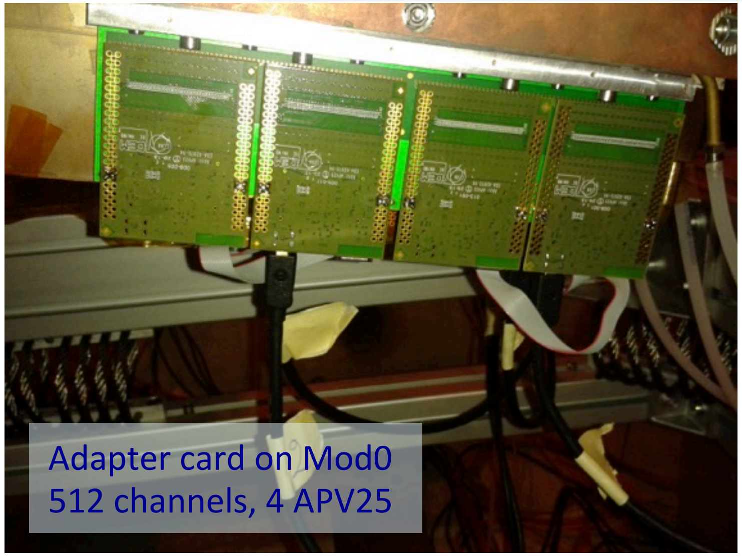


Zebra connector is a rubber strips with high contacts density inside (typical pitch 50-100 μm).
The Read-Out card has the identical footprint of the PCB and the zebra get connection.
Zebra needs to be pressed in order to get contact, this is done via a compression bar.



MM SM1 Mod0 Test Beam at Cern H8

2

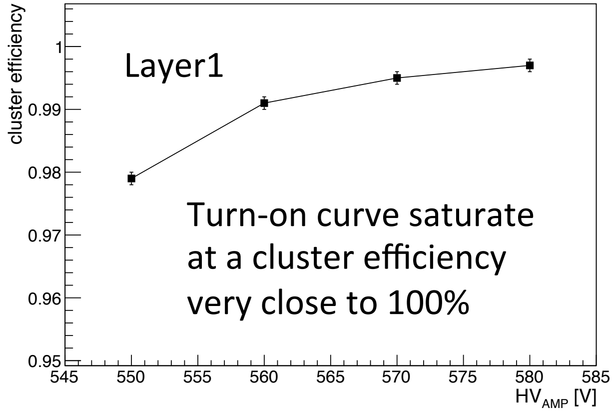


Track-based efficiency

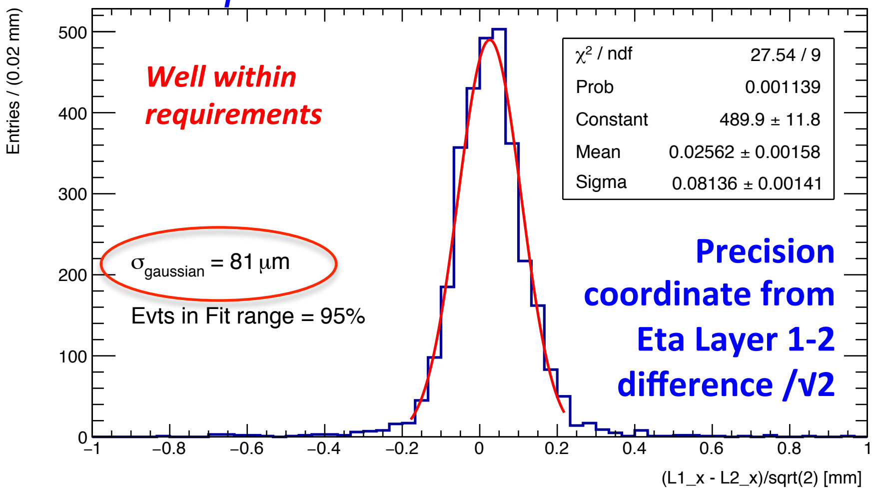
One cluster within given distance from the reference track impact.

Normal Incidence

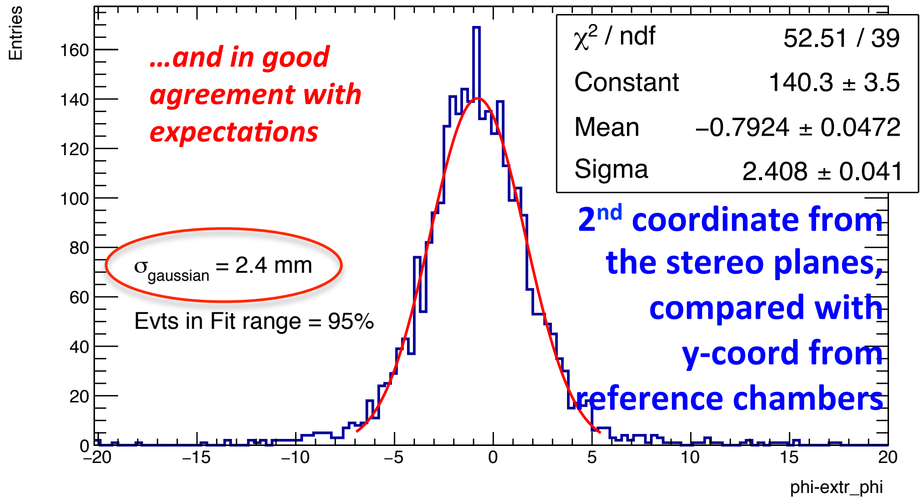
Cluster efficiency Vs Amplification HV



Preliminary result: Spatial Resolution of the precision coordinate



Preliminary result: Spatial Resolution of the second coordinate.

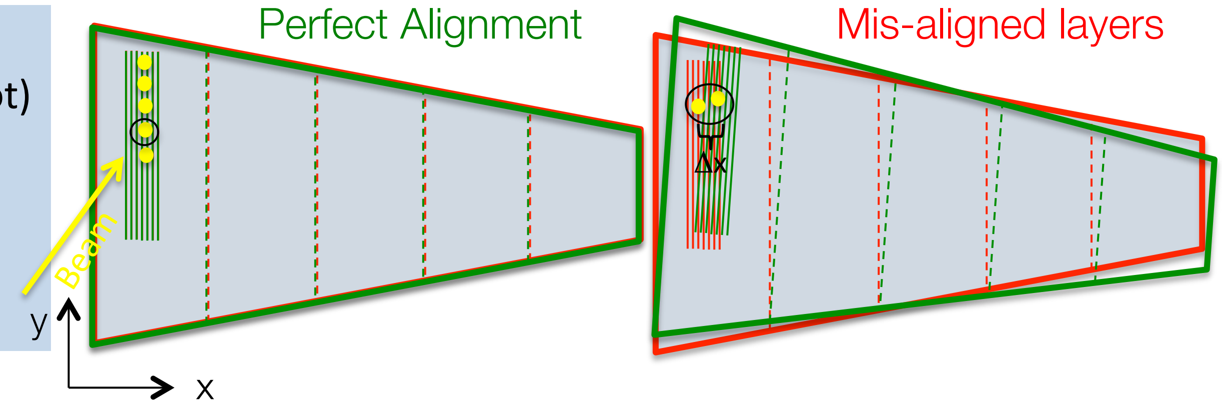


MM SM1 Mod0 Test Beam at Cern H8

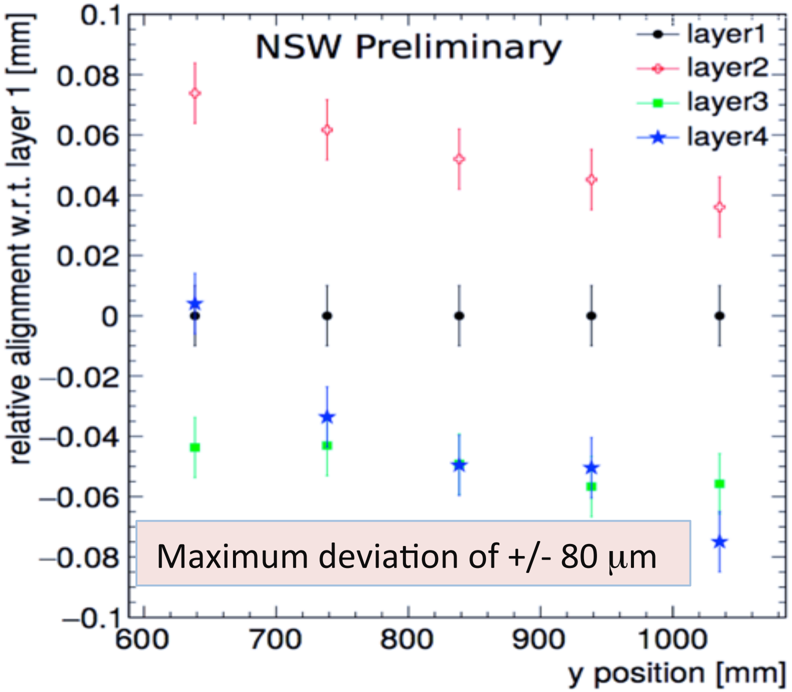
Evaluation of Layers Relative Alignment wrt Layer_1 :

Measurements at different vertical positions, along the strips. (yellow spot)

For each y-position measure Δx between *layer_i* and *layer-1* using reference tracks defined by the small bulk MM in the beam setup



$\Delta x = x_{layer\_i} - x_{layer\_1} = 0$ $\Delta x = x_{layer\_i} - x_{layer\_1} \neq 0$



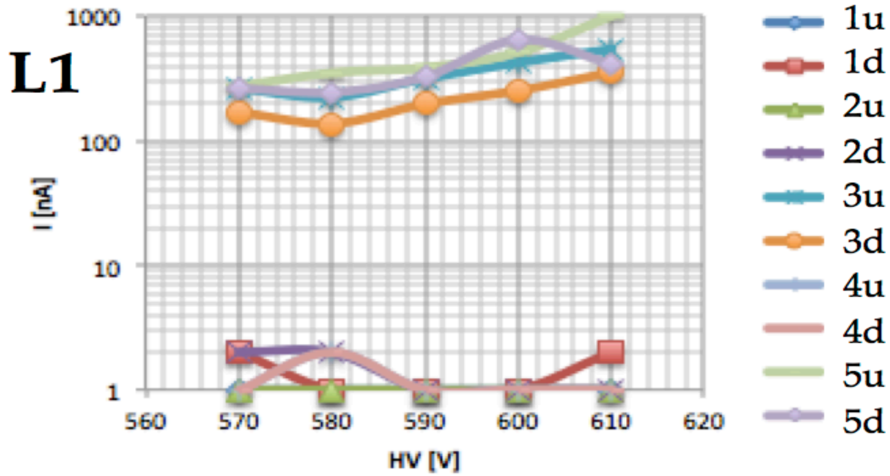
Problem of HV Instability

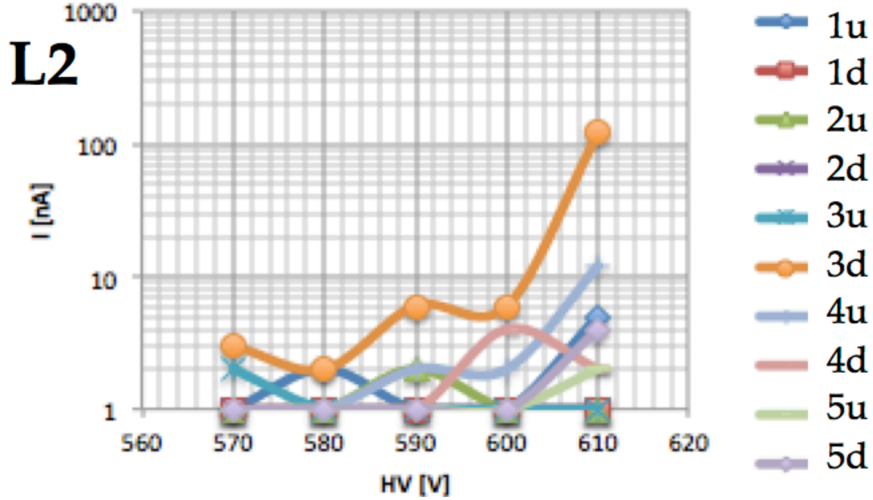
The SM1 Mod 0 has 20 RO PCB (10 Stereo and 10 Eta), each PCB is “divided” in two for HV supply (to increase segmentation) therefore we have 40 different zones that we call Sectors.

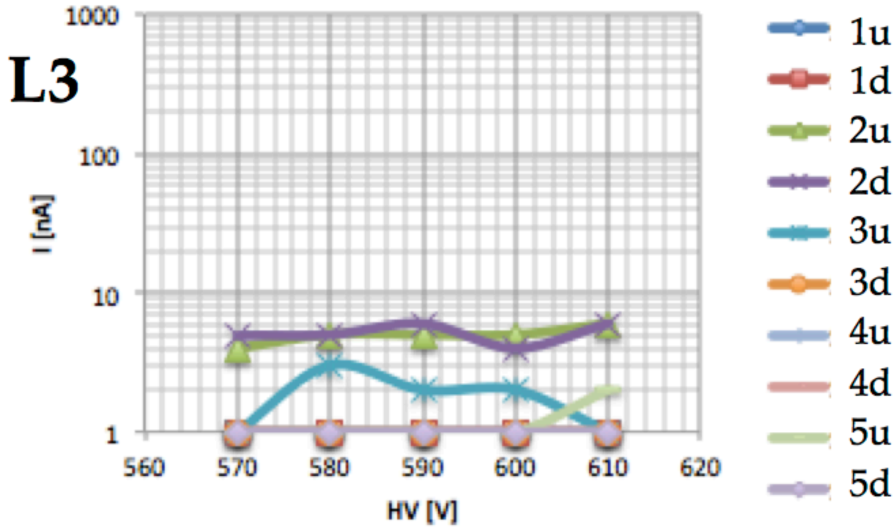
About 20 sectors were stable and with a small (order of 10 nA) dark current at the working point (580-590V on the resistive strips).

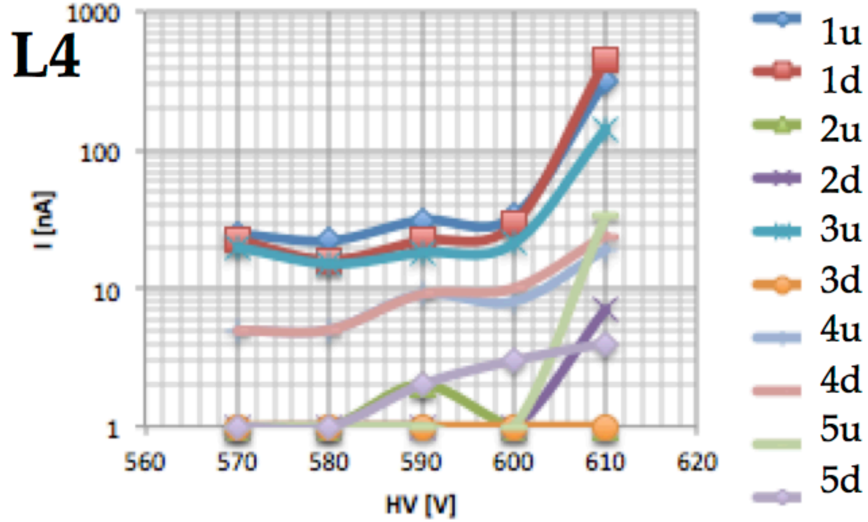
MM SM1 Mod0.5 Test at Cosmic Stand@LNF

After the construction (summer 2017) we put Mod0.5 in the Cosmic Test Stand and we start a slow conditioning using the standard mixture. Most update working condition are plotted

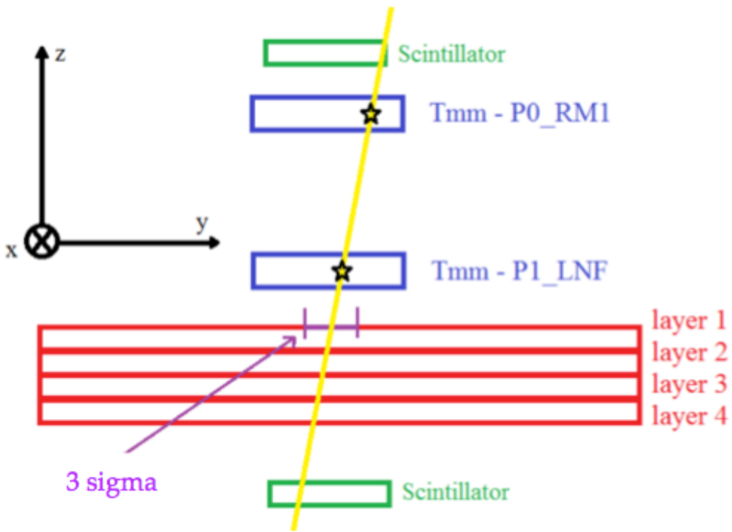


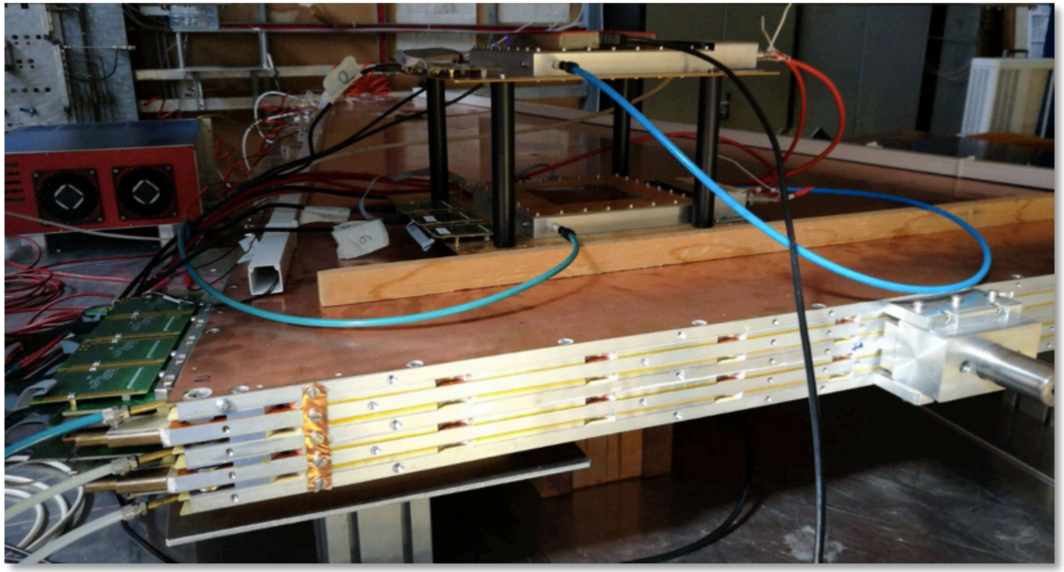


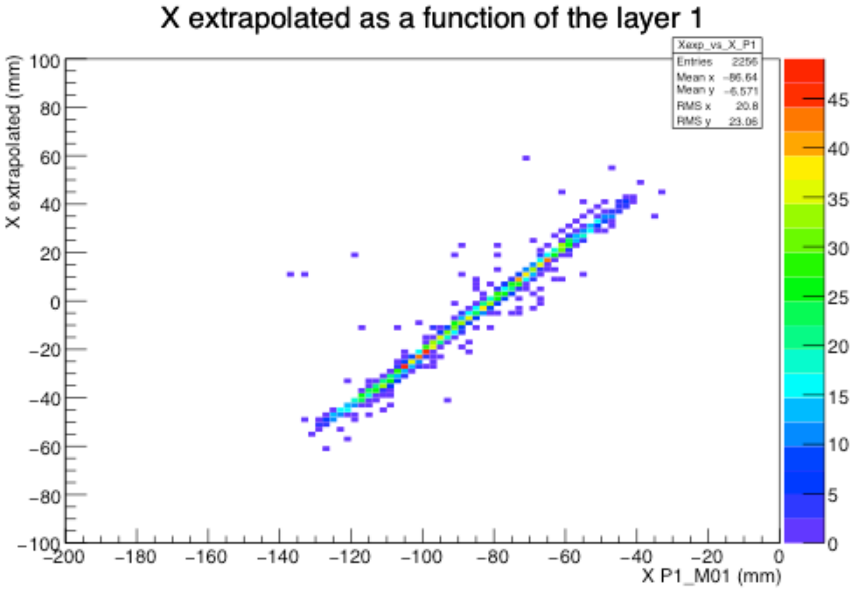


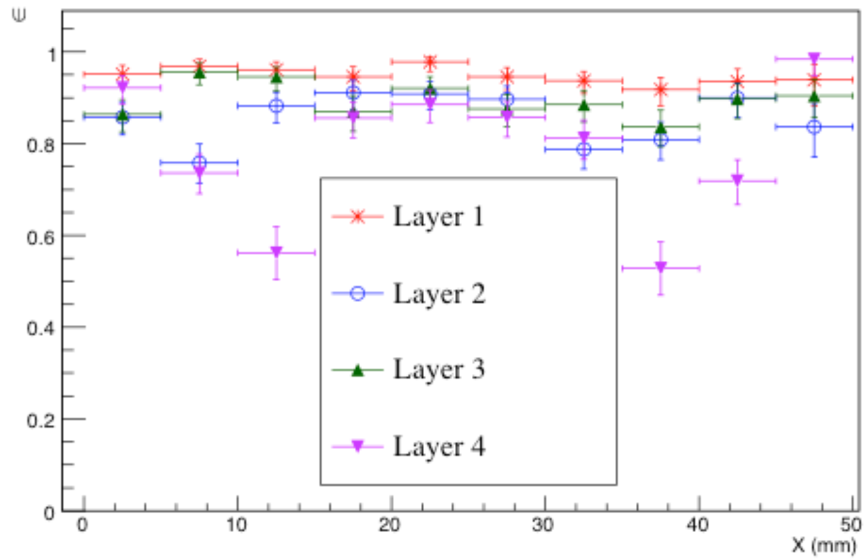


MM SM1 Mod0.5 Test at Cosmic Stand@LNF









MM SM1 Doublet (Here we are!)

As soon as we had the availability of the first RO panel (Eta) built using PCB from the final production , we decided to assembly a “Doublet” mounting it with two external Drift panels.

The purpose was to check HV stability with the new PCB.

Results was not satisfactory not only for the Italian group but for all the construction sites.

The Collaboration decided to involve in the story the Cern PCB group lead by Rui de Oliveira.

SM1 and SM2 (German group) Doublets were sent to Cern to be polished using the tools available in Rui’s Laboratory

Results are good, the Collaboration is now evaluating the impact of this new procedure in the overall construction scheme.

After more than 20 Years, MM can be considered a mature technology to be used in a very challenging environment like the Large Eta zone in the LHC experiments.