13° Topical Seminar on Innovative Particle and Radiation Detectors
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Study of the performance of the MicroMegas chambers for the ATLAS muon spectrometer upgrade

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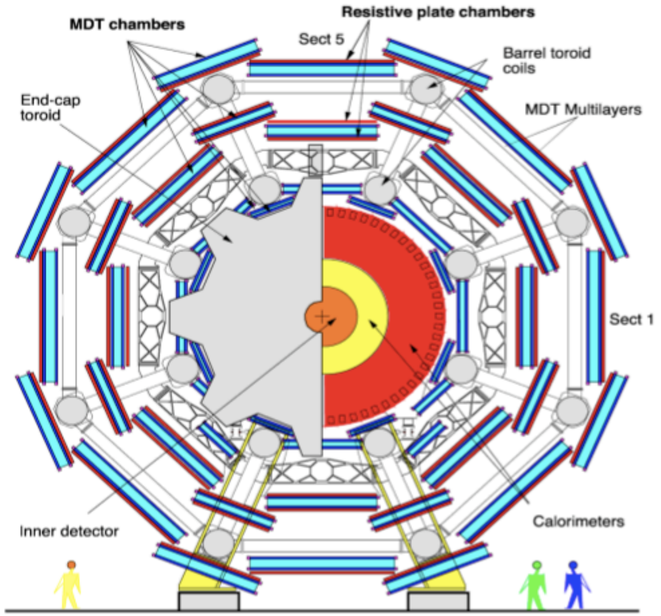
On behalf of the **Muon ATLAS** collaboration

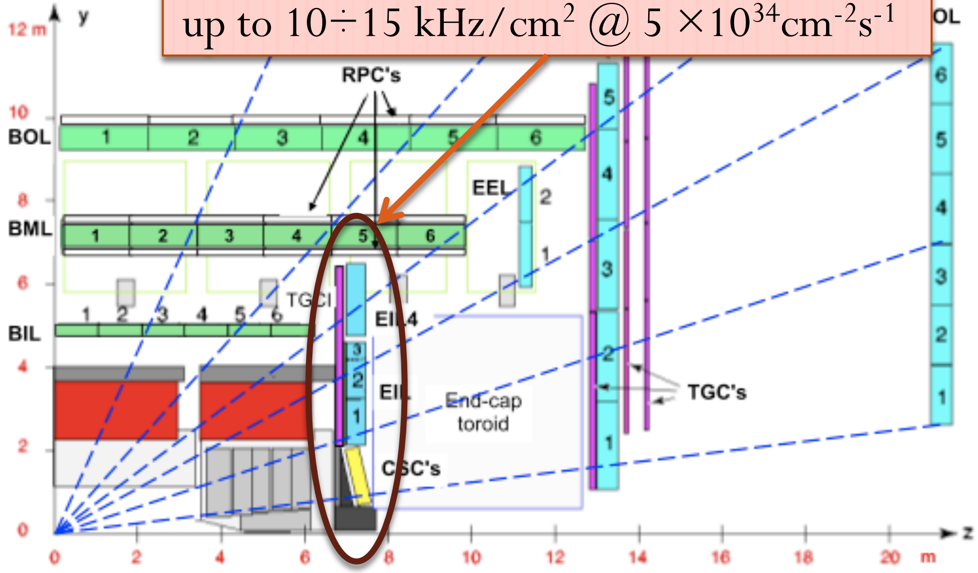
and of the **MAMMA**(*) collaboration

(*) Muon Atlas MicroMegas Activity

The ATLAS Muon Spectrometer



“Small” wheel: region with highest rate up to 10÷15 kHz/cm^2 @ 5 $\times 10^{34}$cm^{-2}s^{-1}

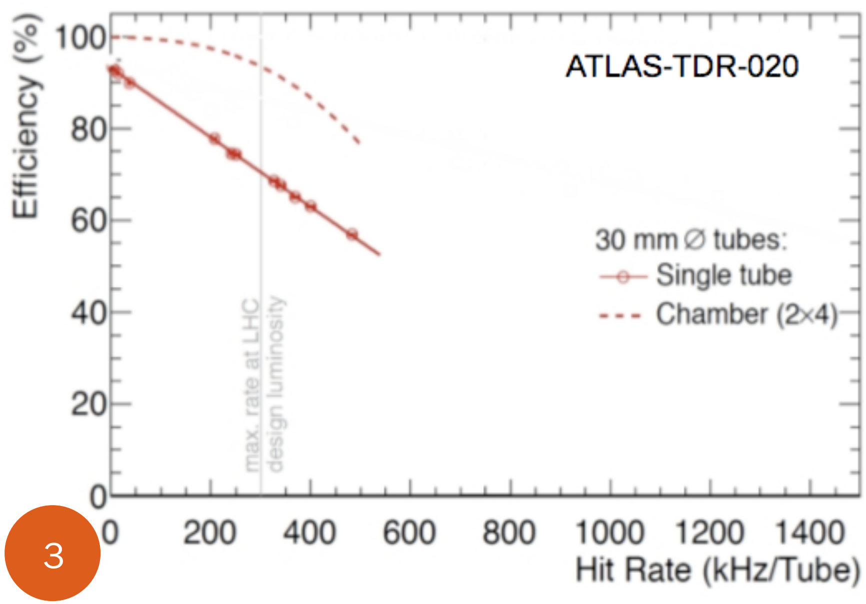


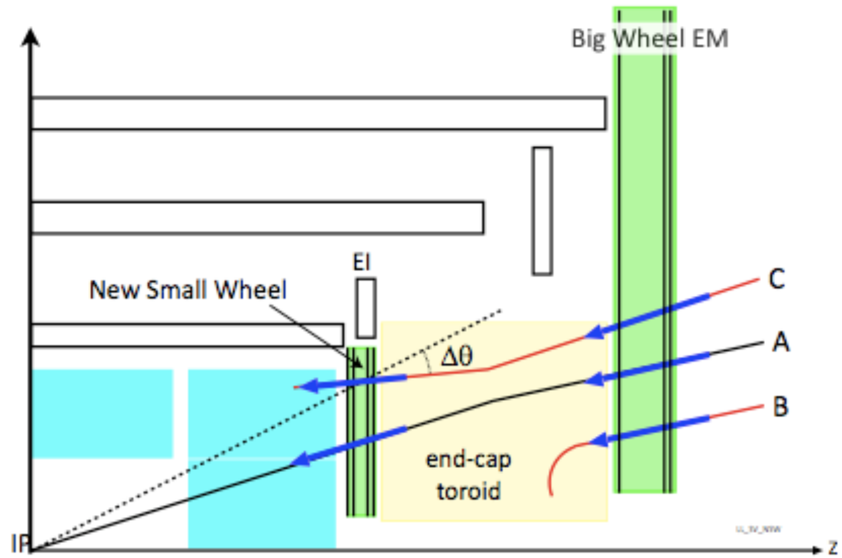
		Chamber resolution (RMS) in			Measurements/track		Number of	
Type	Function	z/R	ϕ	time	barrel	end-cap	chambers	channels
MDT	tracking	35 μm (z)	—	—	20	20	1088 (1150)	339k (354k)
CSC	tracking	40 μm (R)	5 mm	7 ns	—	4	32	30.7k
RPC	trigger	10 mm (z)	10 mm	1.5 ns	6	—	544 (606)	359k (373k)
TGC	trigger	2–6 mm (R)	3–7 mm	4 ns	—	9	3588	318k

Upgrade New Small Wheel: motivations

Sizeable decrease of MDT efficiency and resolution above the design luminosity
→"Tube size" ≈ 3 cm × 1 m × 750 ns;
→ Large ion evacuation time
For L≈ 5×10^{34} $cm^{-2}s^{-1}$ >1 MHz/Tube
> 50% drop in chamber efficiency

High ***fake rate*** with present endcap trigger
→ $R(p_T>20\ GeV)=51\ kHz$ (@ 3×10^{34}, 14 TeV)
A factor 3 reduction of trigger rate with NSW (95% fake → 10% fake)
→ $R(p_T>20\ GeV)=17\ kHz$ (@ 3×10^{34}, 14 TeV) compatible with bandwidth requirement.

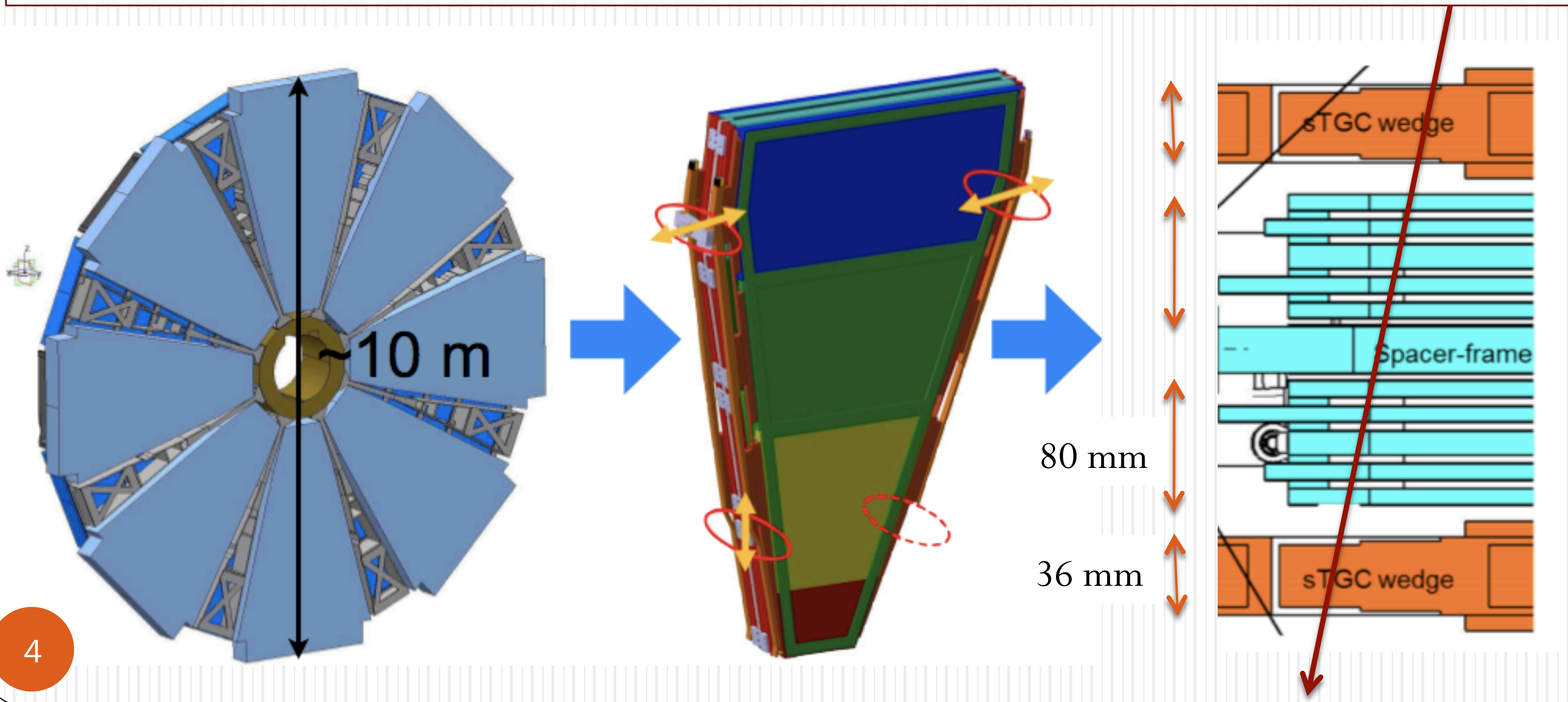




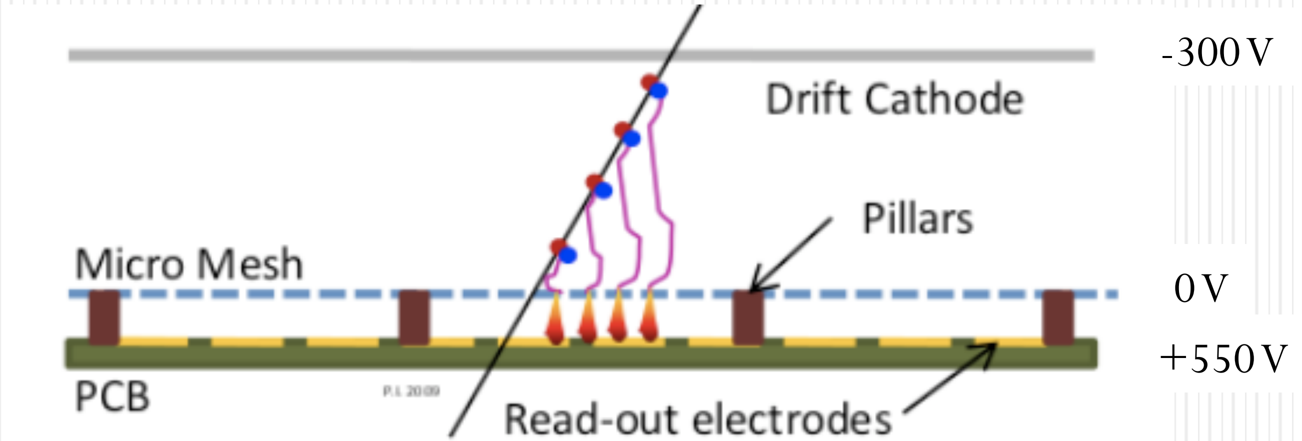
→Accept **topologies A** and reject **B / C**

Upgrade New Small Wheel: layout

- 16 sectors per wheel (8 large and 8 small): total detector diameter ≈ 10 m;
- 2 technologies: **sTGC** (small Thin Gap Chambers) and **MM** (MicroMegas)
- 8 MM and 8 sTGC layers: trigger and tracking provided by both detectors
- MM quadruplet configuration with two back-to-back doublets.



MicroMegas: working principle



Detector components (numbers are referred to ATLAS MM):

1) 5 mm thick gas gap with low electric field (≈ 0.6 kV/cm) for conversion and drift;
2) Thin metallic mesh 128 μm above readout strips (on special pillars);
3) Large electric field between the mesh and the strips (40÷45 kV/cm) for avalanche;
4) Read-out strips with 250 ÷ 500 μm pitch on a PCB plane.

➔ The mesh is practically transparent to electrons (due to high electric field ratio);

➔ Ions from the avalanche are evacuated by the mesh.

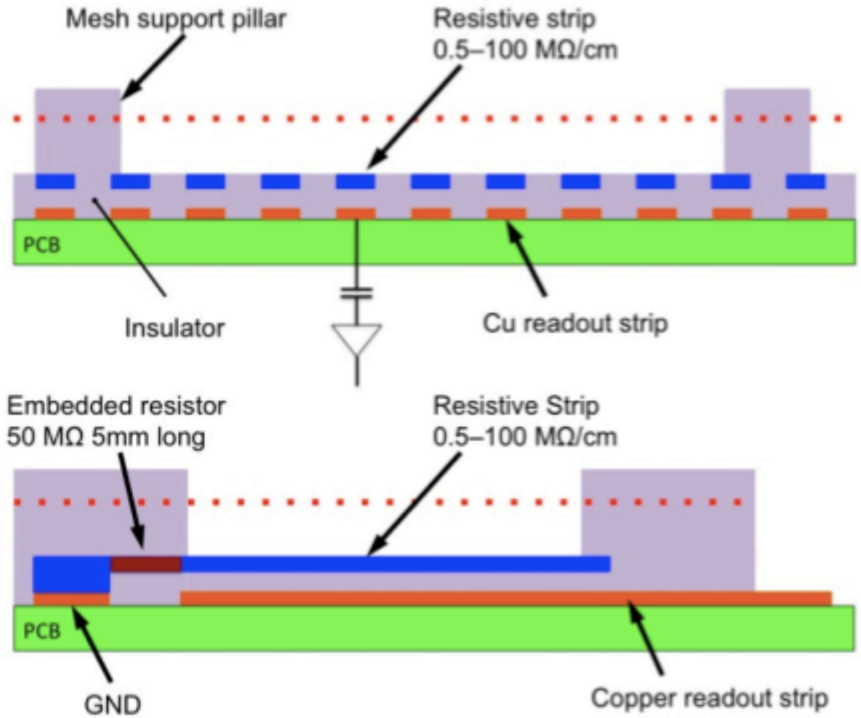
MicroMegas for NSW - I

1. Tracks are expected to be at angles in the range $8 \div 35$ deg. → μTPC reconstruction mode has to be used (see below).
2. High flux of heavily ionizing particles ($>10^3$ e^-) at LHC: effect of sparks (due to the required high amplification gain $\approx 10^4$) to be reduced → resistive anode strips above read-out strips.
3. A magnetic field of up to 0.3 T is present in the NSW region with different orientations → methods are studied to take into account Lorentz angle effects.
4. Strip positions have to be known with precisions of O(50 μm) → construction procedure should guarantee such a precision and alignment tools should be foreseen.

Specific tests for each point are described in the following.

MicroMegas for NSW - II

- Gas Mixture: Ar(93%) – CO_2(7%)
- Drift velocity ≈ 5 cm/μs ➔ Maximum Drift Time = 100 ns
- Strip pitch = 400 μm, strip width = 300 μm
- HV configuration: mesh at ground, cathode -300 V, strips +550 V
- Resistive strips to make "inoffensive" the sparks
- 2 nd coordinate through stereo strips: in half planes the strips are tilted by 3° providing 2 nd coordinate at O(cm) level.

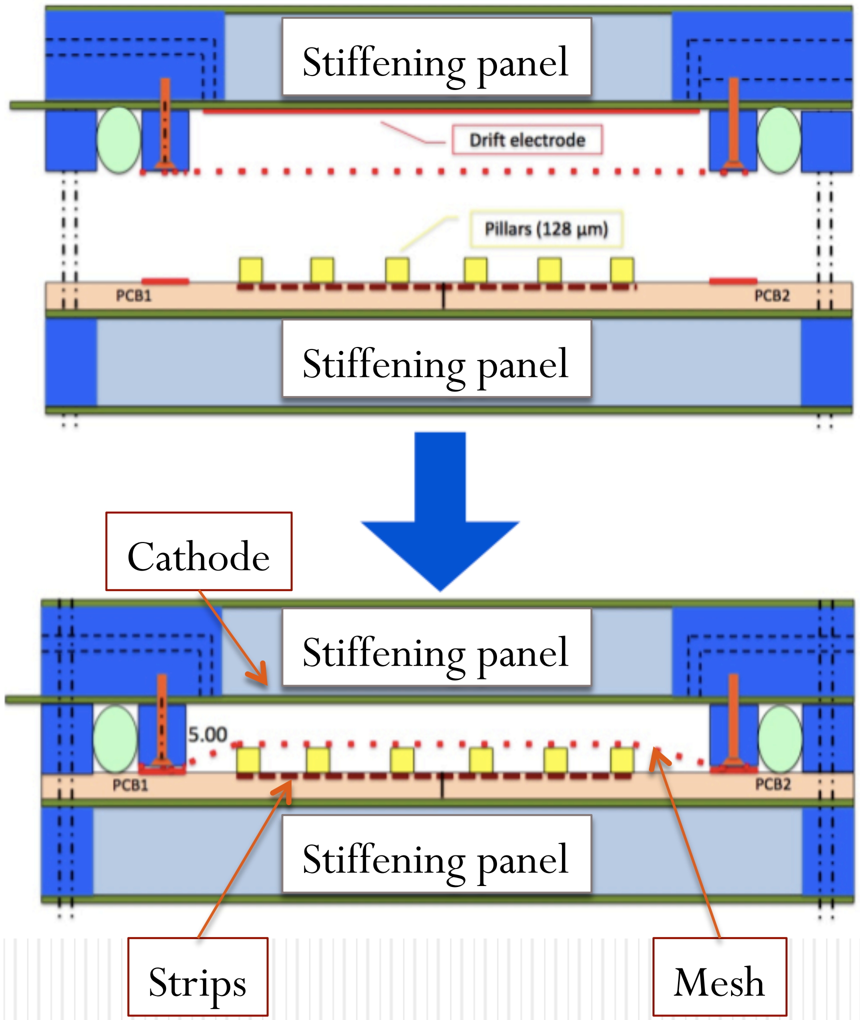


MicroMegas for NSW - III

-- Construction procedure under study.
A new construction method will be adopted (not "bulk-micromegas"):

the mesh is glued on the drift panel;
then is glued on the strip panel.

-- Read-out through VMM electronics (validation in progress of first prototypes) a 64-channel front-end chip developed for sTGC and MM for tracking and triggering.

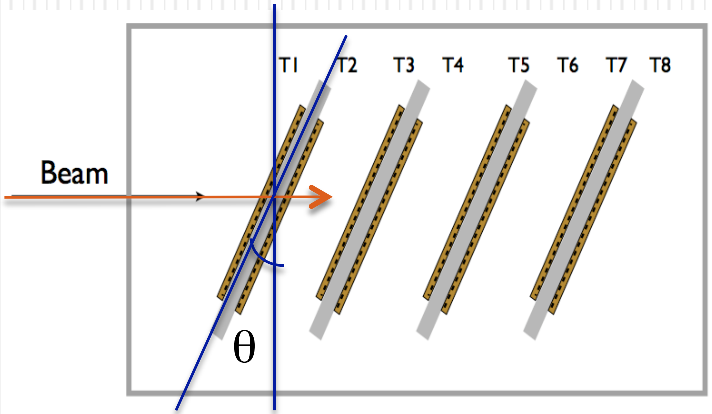


Summary of tests done on prototypes

- Test-beam at CERN-H6 (120 GeV pions/muons)
  - measurement of efficiency
  - measurement of space resolution in the full angular range (validation of the μTPC operation mode)
- Test-beam with chambers in magnetic field at CERN-H2 (120 GeV pions/muons) and at DESY (1÷5 GeV electrons)
  - measurement of the Lorentz angle and validation of simulation results;
  - measurement of the space resolution in magnetic fields up to 1 T;
- Irradiation tests with *neutrons*, γs, αs at Saclay
  - equivalent of 10 years of HL-LHC simulated
  - prototypes tested on beam at CERN-H6 after irradiation

All tests done using APV25 electronics read-out through SRS

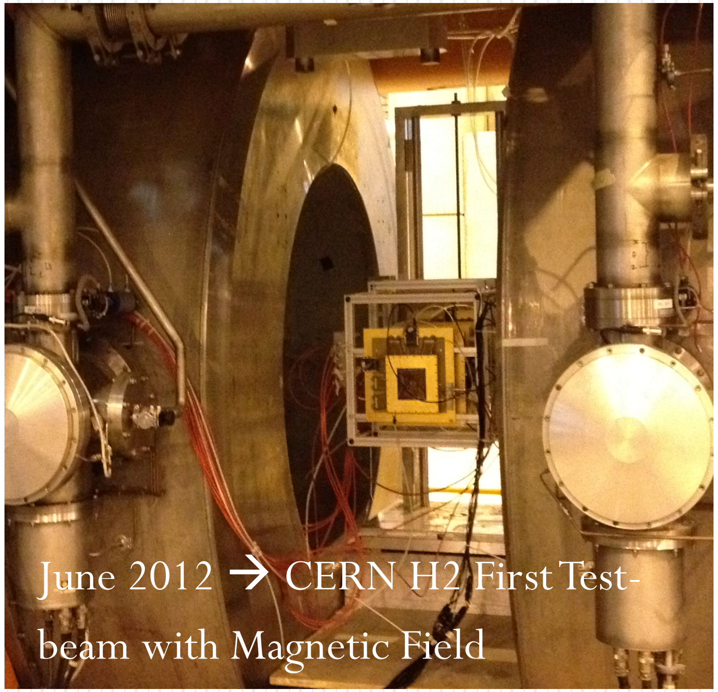
Test-Beam set-up 2012-2013



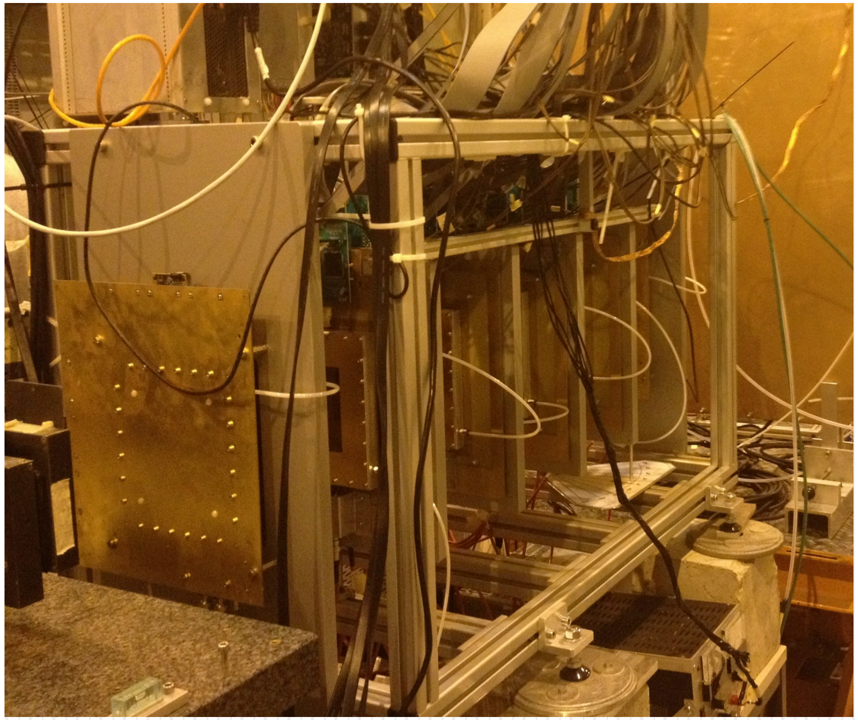
8 chambers 10x10 cm^2 x-y view 400 μm pitch operated with Ar-CO_2 gas mixture

July-September 2012 → CERN H6 (120 GeV pions)

-- Tests and validation of μTPC mode with APV25
-- First test of VMM1 chip.
-- First tests on large size MM 1x1m^2

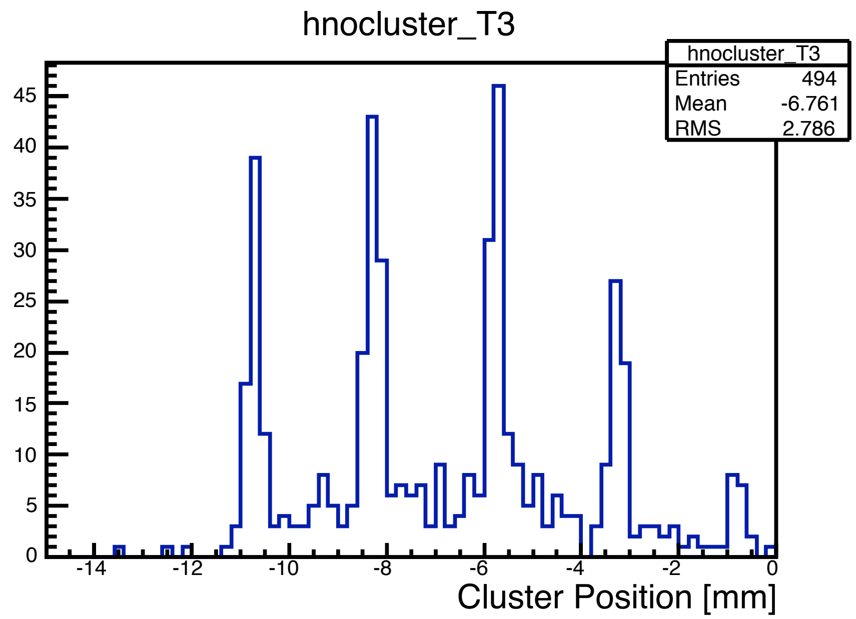


June 2012 → CERN H2 First Test-beam with Magnetic Field



Results: chamber efficiency

- Efficiency is determined by tracking on all chambers apart from one and looking for hits in the remaining chamber.
- Global 1-2% inefficiencies mostly due to the "pillars" (towers with 2.5 mm pitch and 300 μm diameter where the mesh is held). Dead Area = $\pi\ (0.3/2)^2/2.5^2 = 1.1\%$



Results: space resolution - I

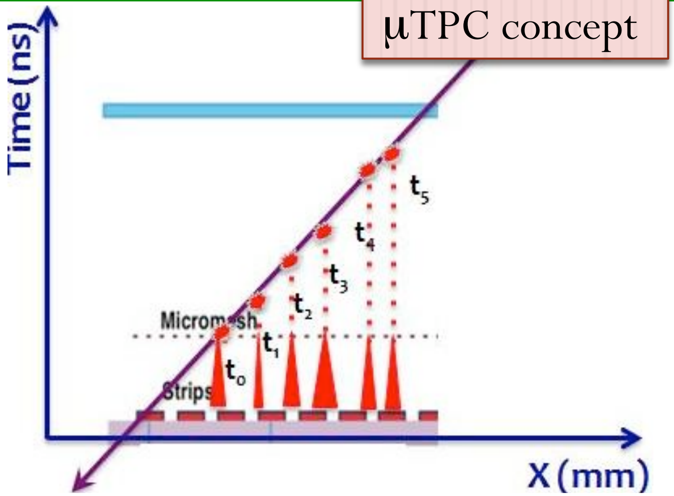
- X coordinate obtained:
  - charge centroid
  - μTPC (position at half gap after tracklet fit $Z=mX+c$)

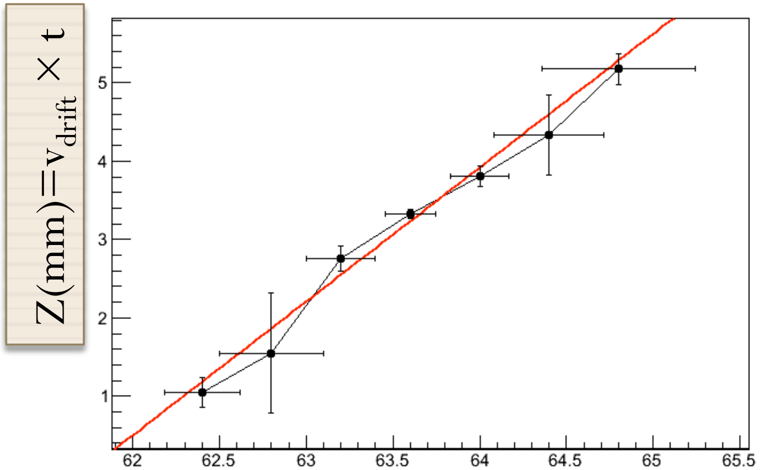
$$X_{cent} = \frac{\sum_{k=1}^{N} q_k x_k}{\sum_{k=1}^{N} q_k}$$

$$X_{half} = \frac{Z_{half} - c}{m}$$

- The two values of X are combined to improve the resolution especially in the 10° region (where the two methods provide comparable resolutions)
- Resolution extracted from the difference between two chambers (due to the negligible effect of the beam divergence)

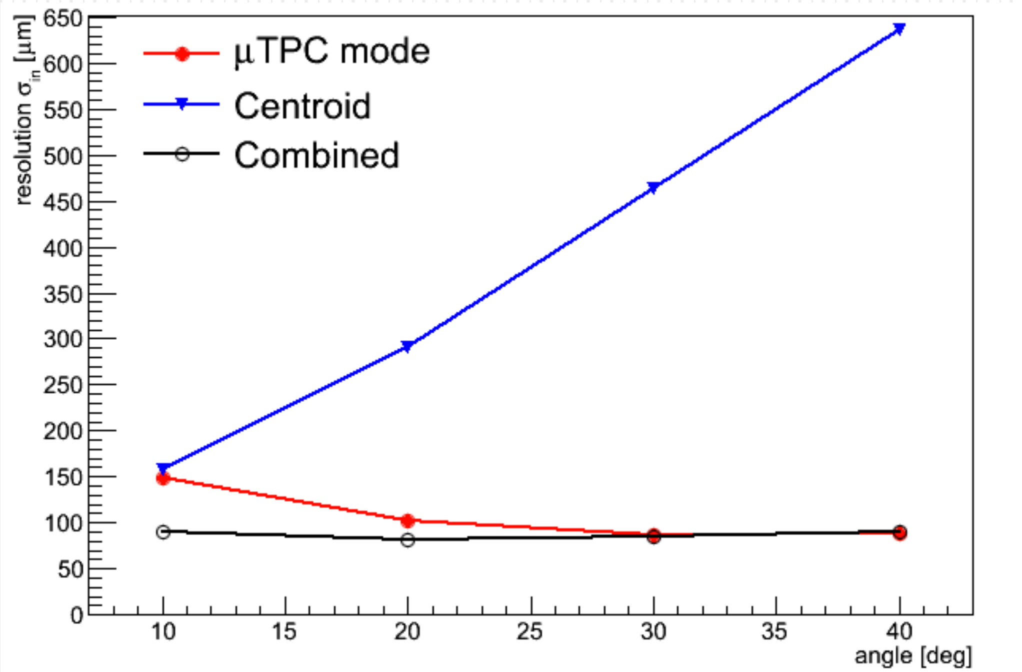
μTPC concept





Results: space resolution - II

- μTPC mode gives the best resolution above 10°
- Resolution below 100 μm in the full angular range of NSW
- Combination improves resolution at small angles due to an observed anti-correlation between X_{cent} and X_{half}



Results: Magnetic Field - I

B component orthogonal to ***E*** directly affects the charges drift

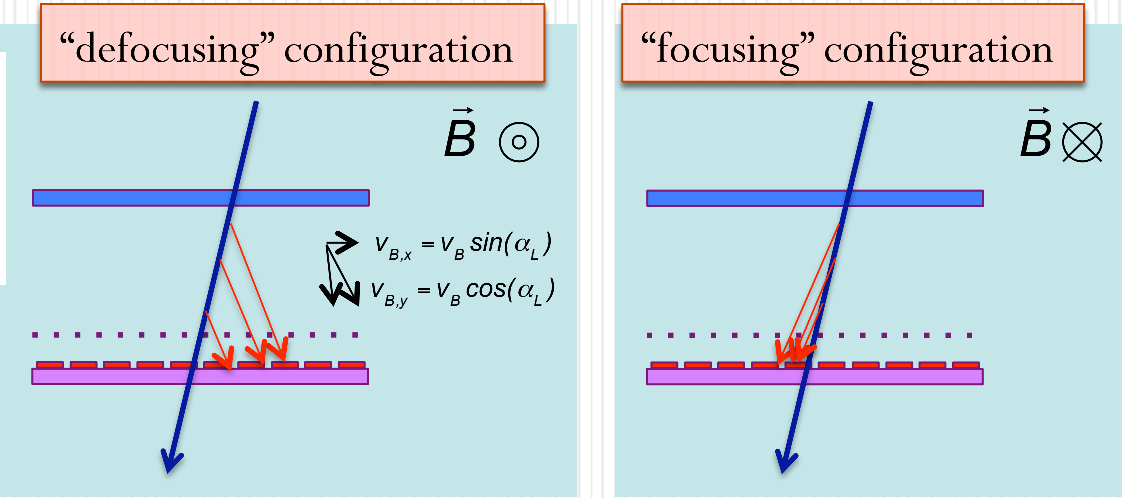
➔ systematic δx on position

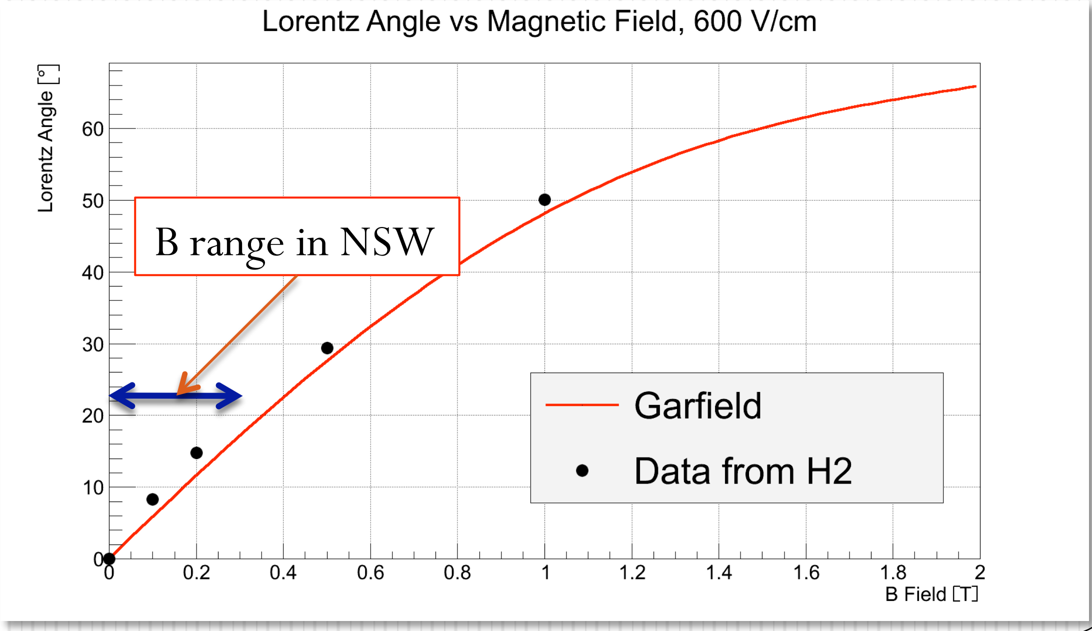
$$\delta x = \frac{d}{2}\tan\alpha_L \approx B(T) \times 2.8mm$$

The Lorentz angle α_L measured vs ***B*** is in agreement with simulations (based on Garfield)

Typical values of the Lorentz angles expected are <20°

➔ systematics at O(100 μm)

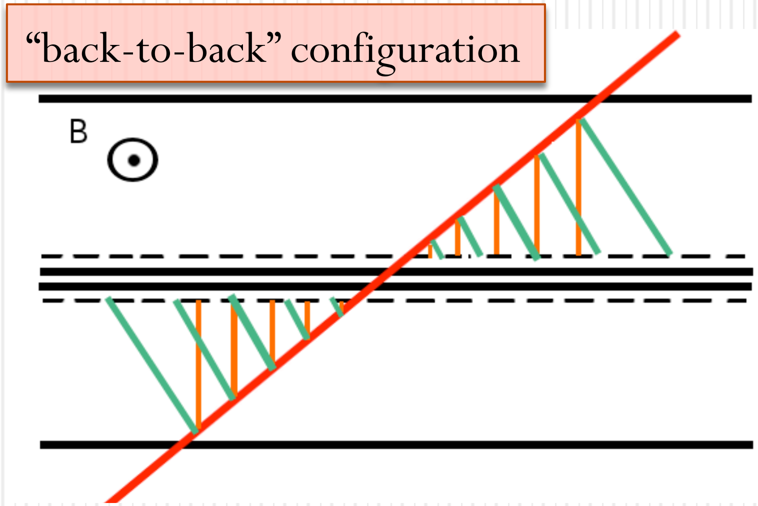




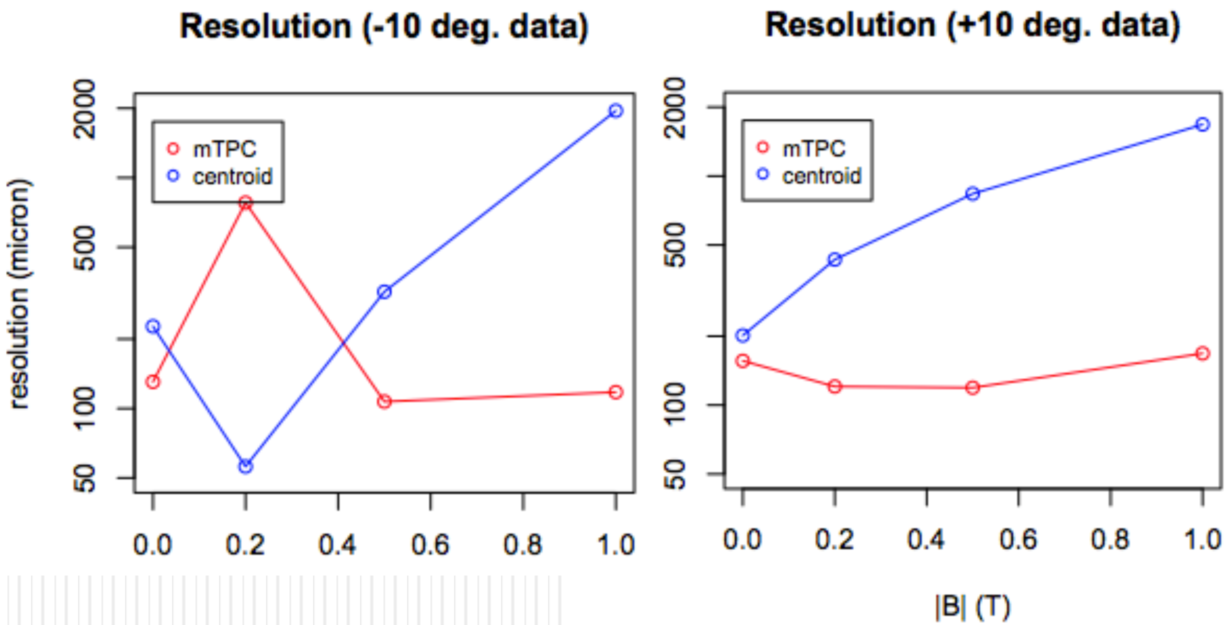
Results: Magnetic field - II

MM back-to-back configuration:
- the average point measured in the doublet is "systematic-free" due to the symmetry.

(provided ***B*** is uniform in the doublet)
Angle corrections based on the knowledge of ***B*** are also possible.



Resolution at 100 μm in a wide $B - \theta$ range (by combining X_{cent} and X_{half})
- "singular configurations" can be easily managed



Results: irradiation tests - I

Extensive program of irradiation of small prototype (10×10 cm^2) at Saclay in 2012
General strategy:

→ 5÷10 years HL-LHC equivalent simulated
→ high spark rate simulated with α particles
→ two identical chambers: one irradiated and one not irradiated; both tested after irradiation at H6 beam @ CERN

Irradiation with	Charge Deposit (mC/cm^2)	HL-LHC Equivalent	Results
X-Ray	225	5 HL-LHC years equivalent	No evidence of ageing
Neutron	0.5	10 years HL-LHC years equivalent	No evidence of ageing
Gamma	14.84	10 years HL-LHC years equivalent	No evidence of ageing
Alpha	2.4	5×10^8 sparks equivalent	No evidence of ageing

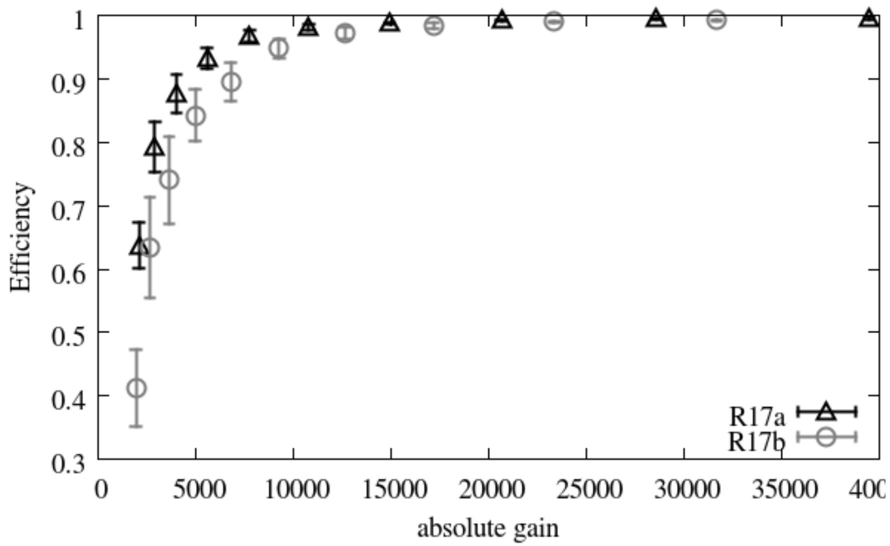
Results: irradiation tests - II

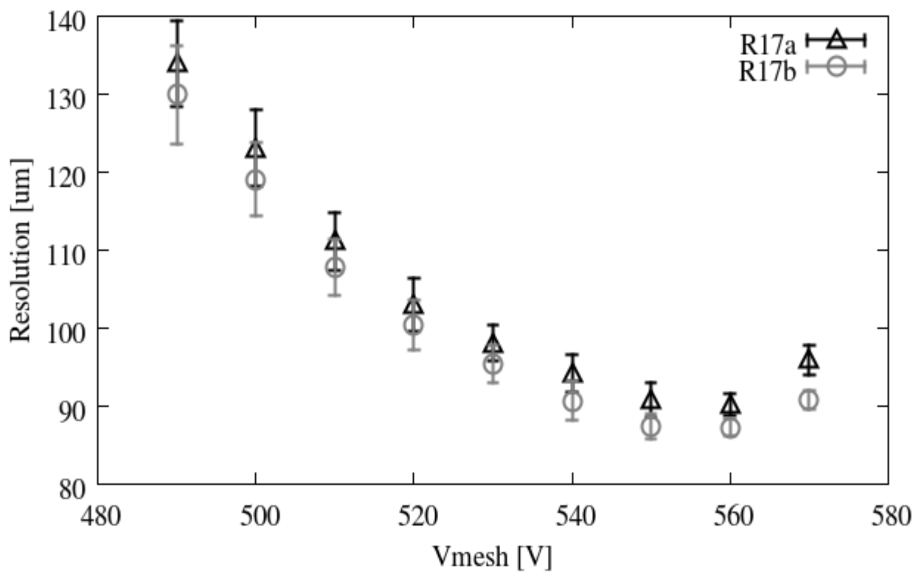
Comparison of efficiency and resolutions for the two identical chambers:

→ R17a irradiated

→ R17b not irradiated

No evidence of efficiency and resolution degradation after exposure.

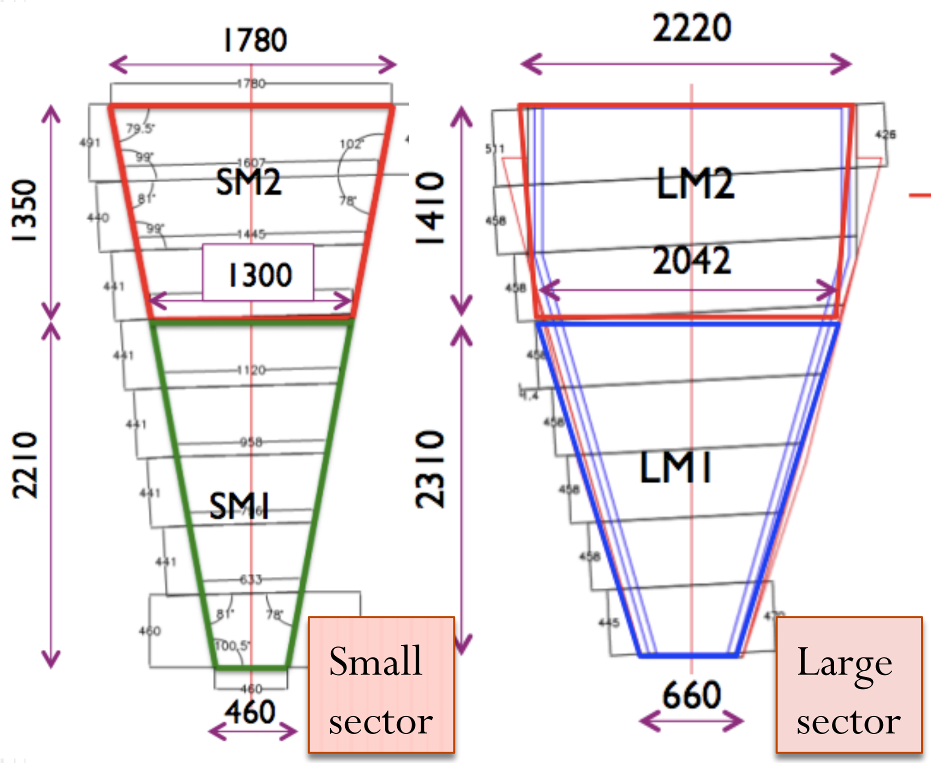




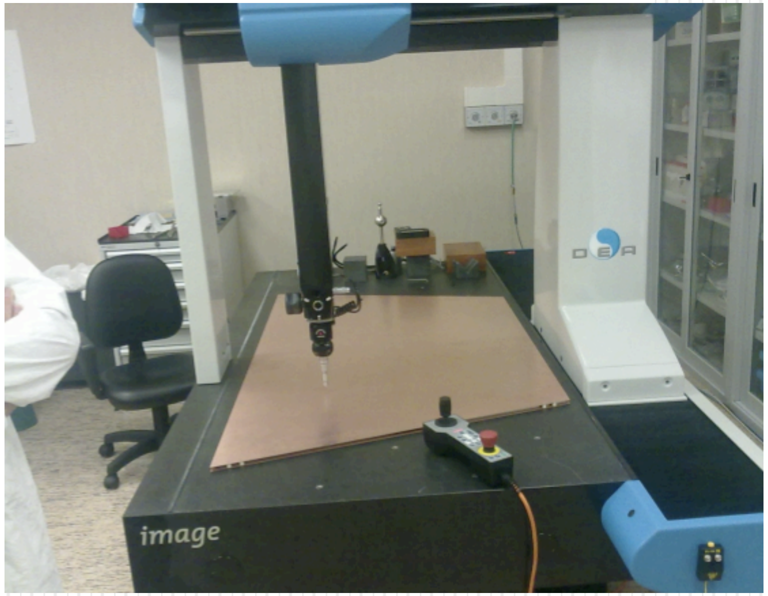
HV = 550 V (best resolution) corresponds to a gain of ≈ 20000 (safe working point)

Mechanical tests

- The dimensions of the chambers have been defined.



Mechanical tests are ongoing to define a construction procedure providing a planarity at O(50 μm)



RMS below 20÷30 μm obtained in prototype panels of 1÷2 m^2 size

Planarity measurements with CMM-Machine on prototype panels.

Summary and Outlook

- The MicroMegas chambers have been chosen for the upgrade of the ATLAS muon spectrometer in the forward region.
- Tests done on prototypes show that these detectors provide the required performance in the expected high rate environment.
- Now the mainstream of this work is:
  - to go to very large surface detectors
  - to prove that on such surfaces the mechanical properties are mantained
  - to define and start a serial production for installation in 2018.

BACKUP

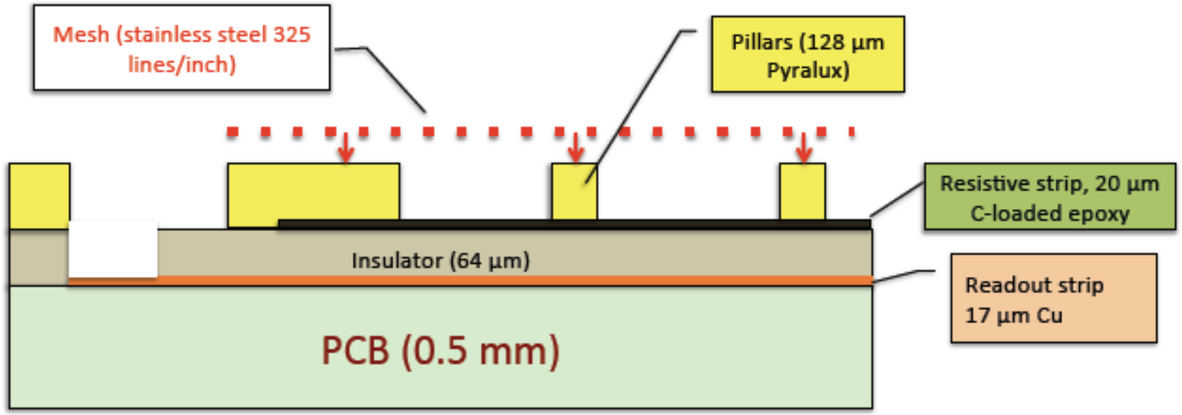
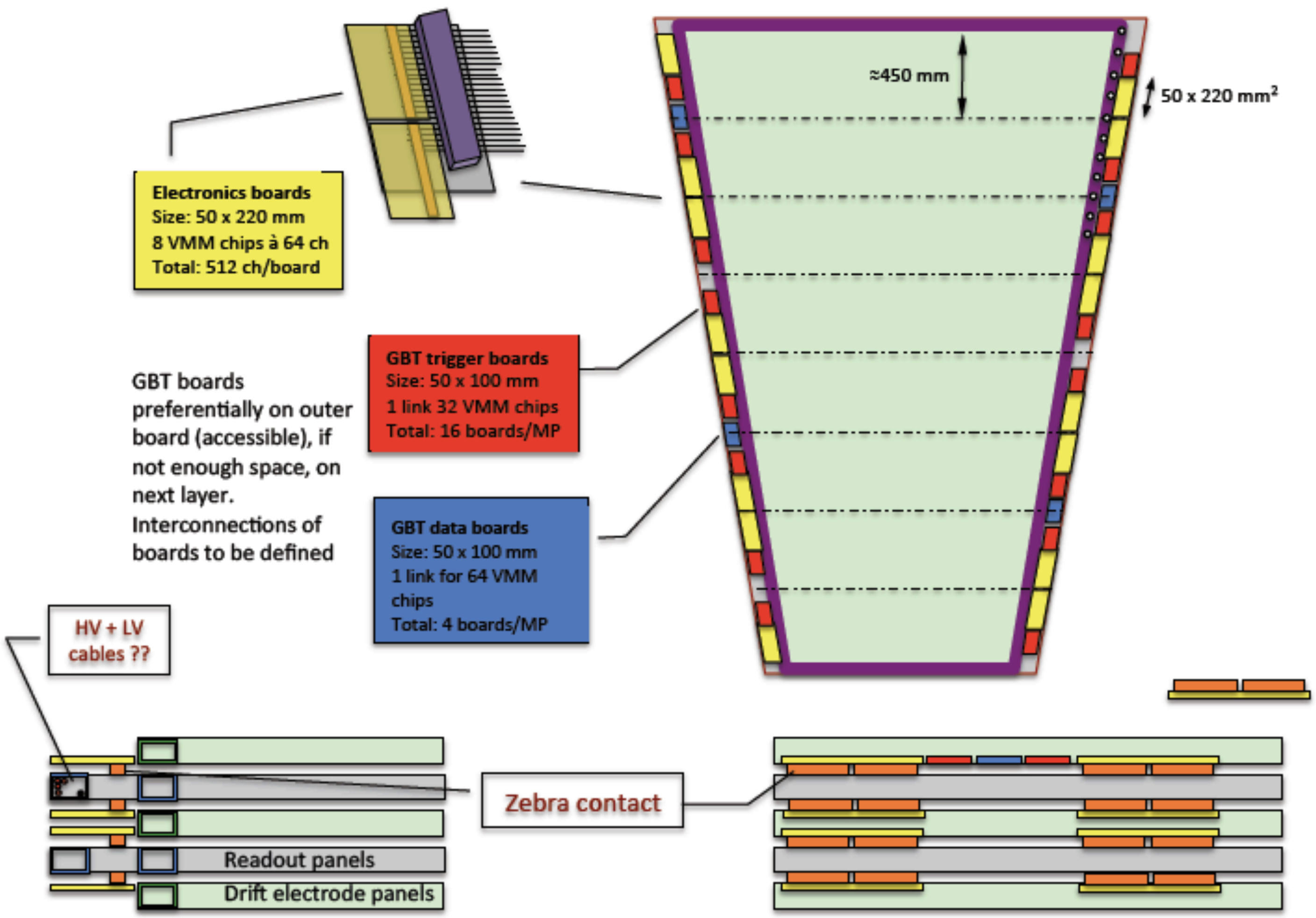


Table 5.1: Main MM detector and operating parameters.

Item/Parameter	Characteristics	Value
Mesh	Stainless steel separate from readout board	325 lines/inch
Amplification gap		128 µm
Drift/conversion gap		5 mm
Resistive strips	Interconnected	R = 10–20 MΩhm/cm
Readout strip pitch		0.425–0.445 mm
Stereo angle	4/8 layers	±1.5°
Total number of strips		2.1 M
Gas	Ar:CO_2	93:7
HV on resistive strips	positive polarity	550 V
Amplification field		40 kV/cm
Drift field		600 V/cm

Arrangement of electronics on MM readout panels



VMM electronics

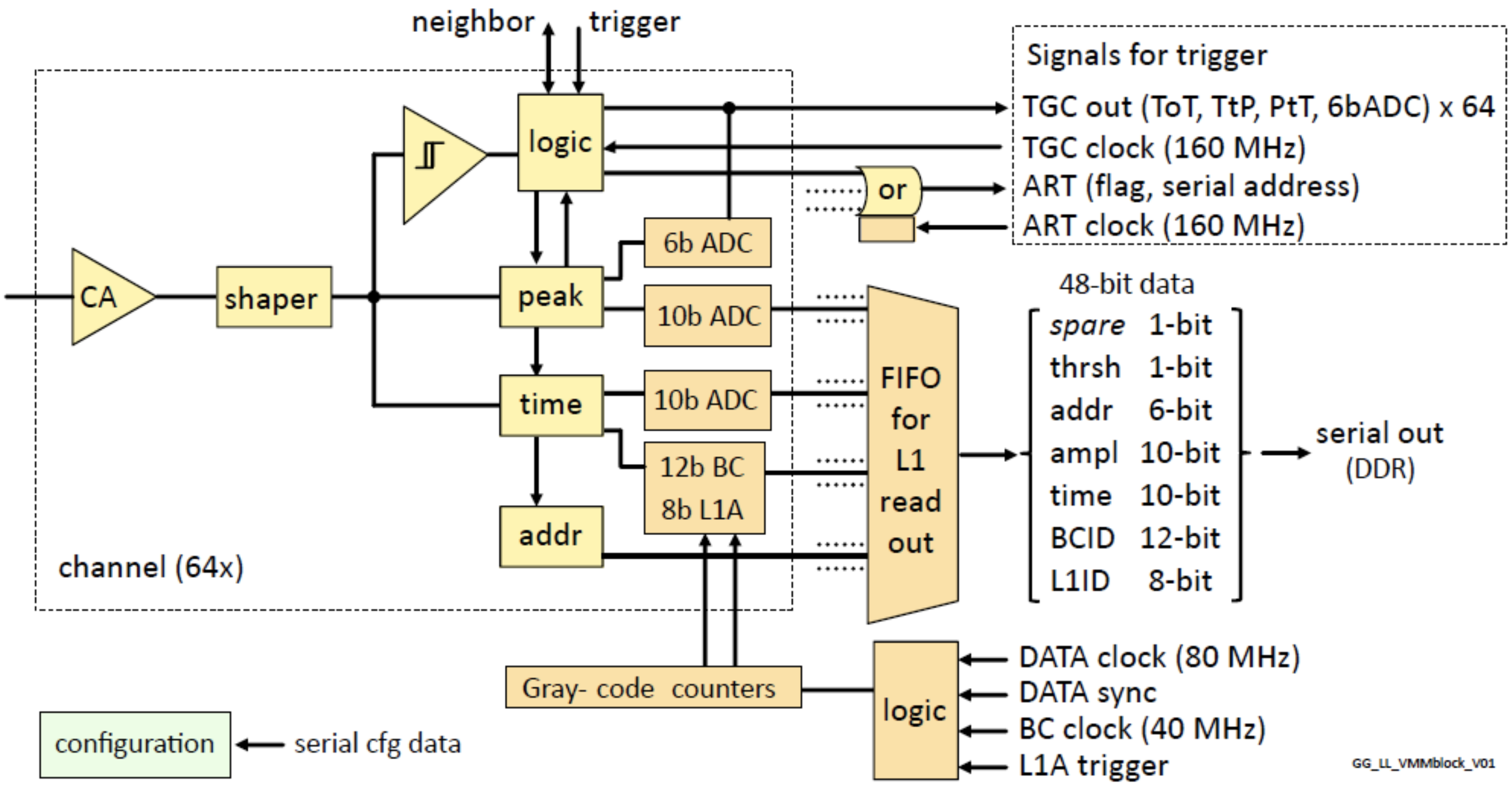


Figure 12.3: Block diagram of the VMM ASIC

MM trigger

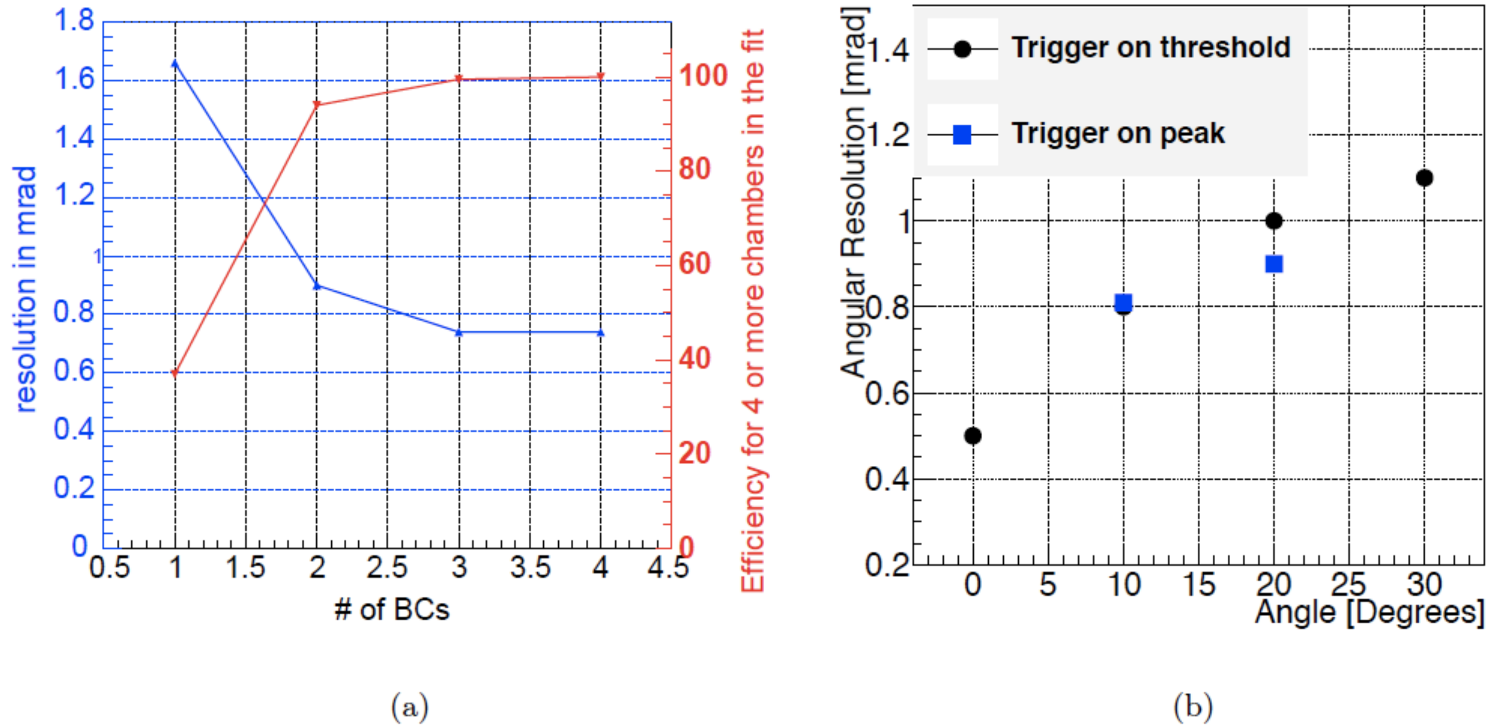
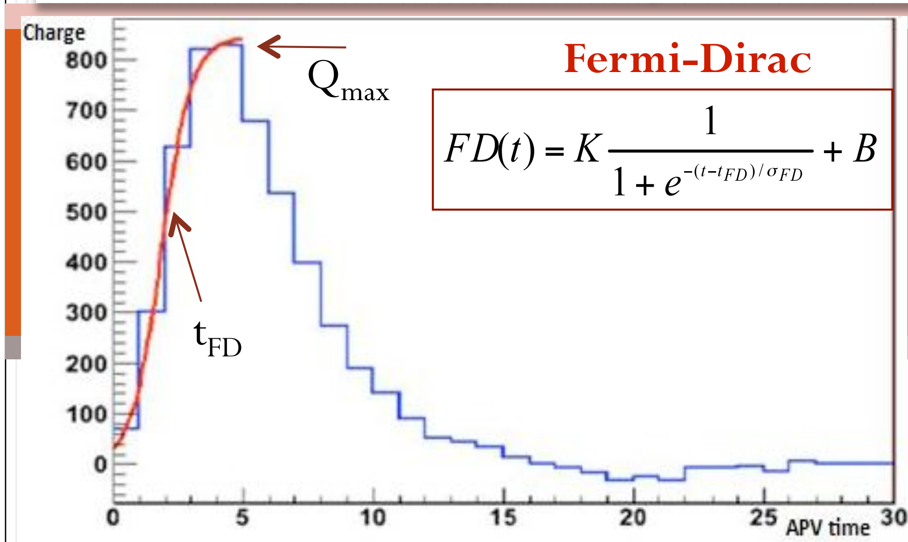
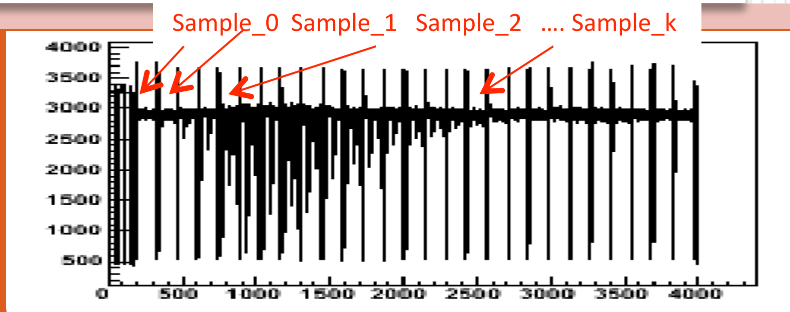


Figure 12.14: (a) Simulation results; efficiency (right scale), and angular resolution as a function of the size of the rolling BC window requiring five or more planes.
(b) Angular resolution measured in a test beam as a function of incident angle. The dots use the Address in Real time at threshold crossing while the square use the ART at amplitude peak. The lever arm was 50 cm.

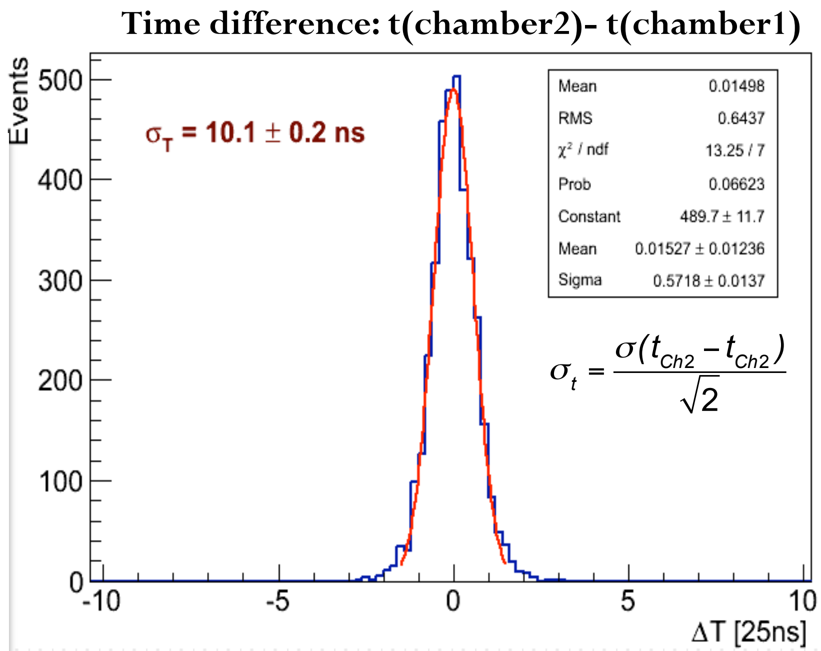
APV25 Read-Out – Time and Charge – Time Resolution

Timings and Amplitudes measured for each hit-strip applying a fit function to the sampled shaper output values





Strip waveform as a function of time (1 sample = 25 ns)



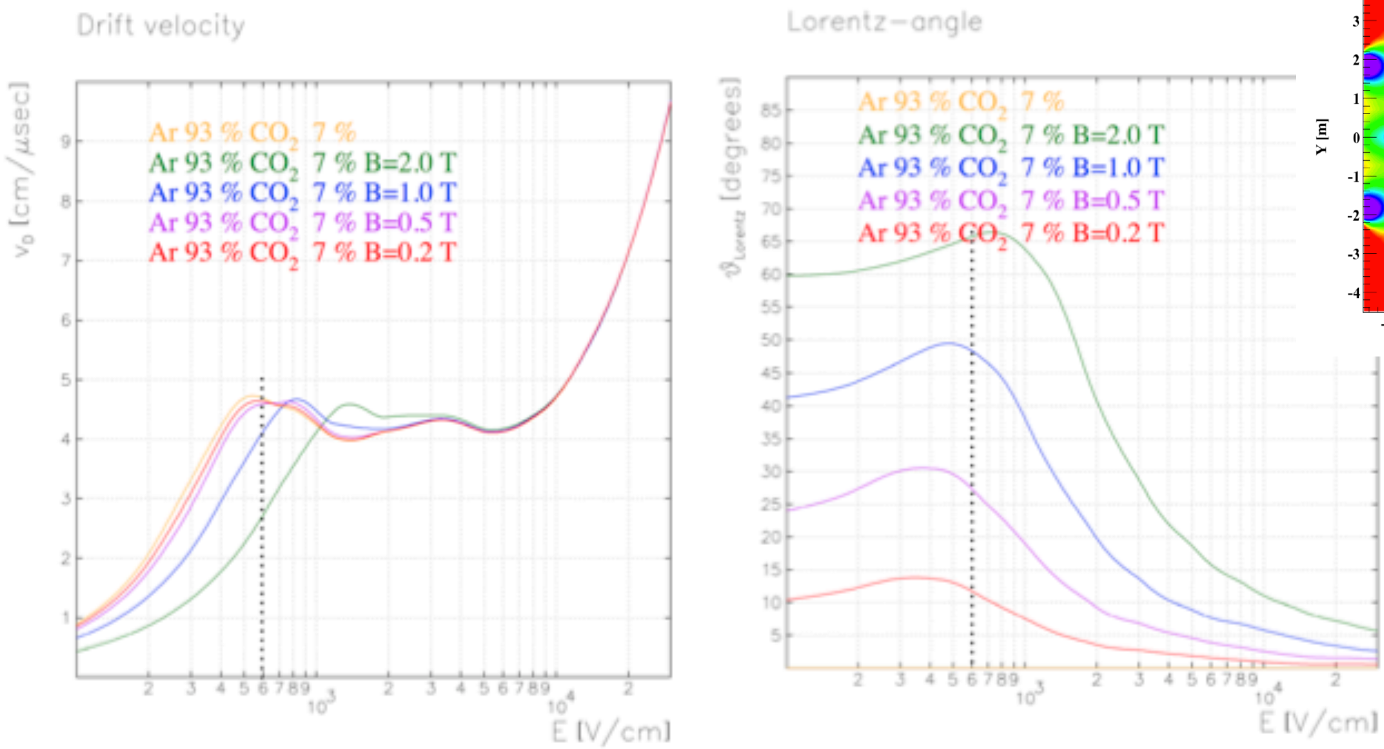
- Intrinsic Time Resolution ~ 5ns (primary ionization spread)
- Temporal resolution estimated from earliest strip differences between two MM back-to-back for inclined tracks (30°)
- Measured σ_T~10 ns. Dominated by APV25 response and precision of the fit

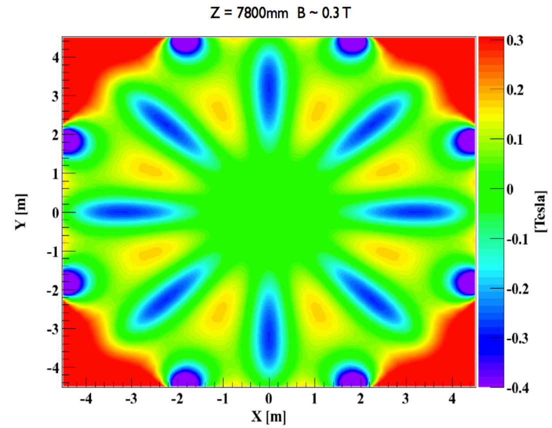
MAGNETIC FIELD IN THE NEW SMALL WHEEL

- The MM chambers of the NSW will operate in a magnetic field with large variations and values up to about 0.3 T, with different orientations with respect to the chamber planes but a sizable component orthogonal to the MM electric field.

- The effect of the magnetic field on the detector operation has been studied with test beam data and simulations.

Gas Properties - Drift Velocity & Lorentz Angle vs Electric Field

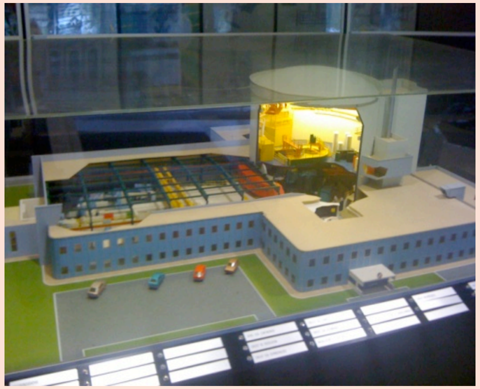




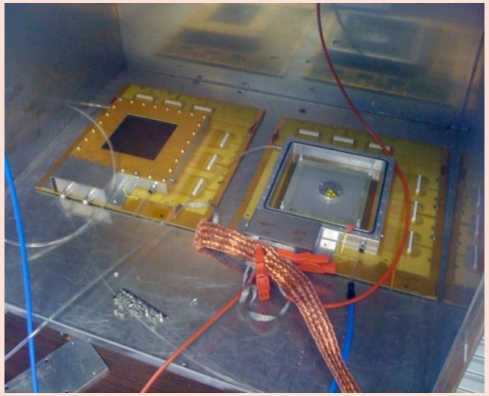
OVERVIEW OF AGEING TESTS

X-ray beam

Cold neutron beam

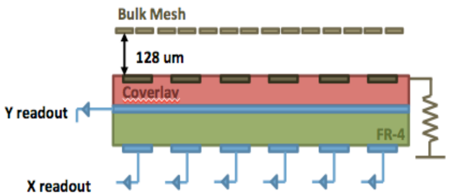


Alpha source



Gamma source

Extensive Program of irradiations done last year at Saclay



R17a detector is exposed to different radiation sources

R17b detector is kept unexposed.

Gain control measurements are performed before and after each exposure.

After the ageing both detectors are taken to the H6 CERN-SPS pion beam line.

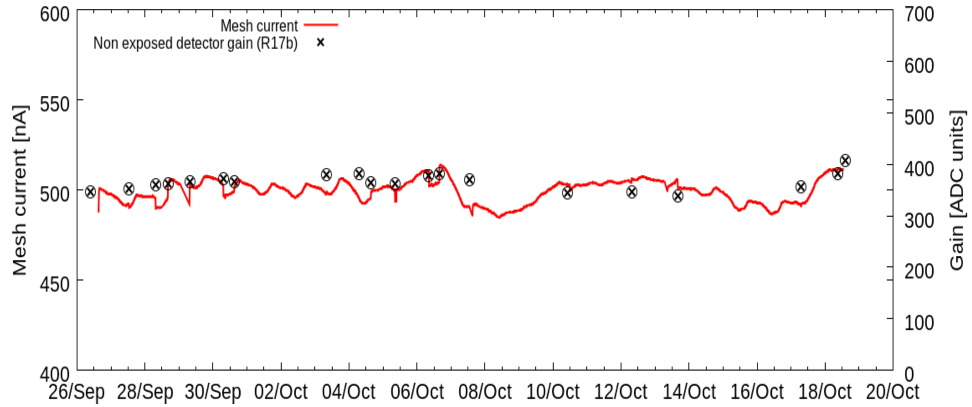
The goal to accumulate an integrated operation charge equivalent to the one would be obtained at the HL-LHC for 10 years for each type of radiation.

Overview of Ageing Tests

- X-Ray Accumulated charge:

Exposure: 918 mC for 4 cm^2 in 21.3 effective days
225 mC/cm^2 Vs 32 mC/cm^2 estimated for 5 years of HL-LHC

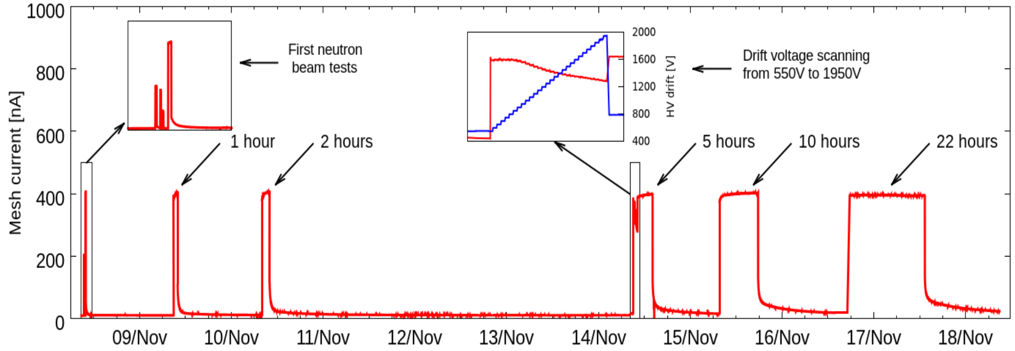
Mesh current evolution and gain control measurements of non-exposed detector (connected in the same gas line in parallel)



- Neutron Irradiation:

flux ~8x10^8 n/cm^2/sec ; Energy : 5 to 10 meV
At Orphee ~ 3x10^{12} n/cm^2/hour which is about 2 HL-LHC years

Mesh current during the different neutron irradiation periods



- Gamma Irradiation:

^{60}Co exposure between March 22nd and April 11th 2012.
Total exposure time : 480 hours
Total integrated charge : 1484 mC
Mean mesh current : 858.4 nA
More than 5 years of HL-LHC

Mesh current evolution with a zoomed plot of humidity measurements taken at the COCASE facility