# Micromegas Detectors for the Muon Spectrometer Upgrade of the ATLAS Experiment

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# Outline

*Introduction*

- LHC and the ATLAS Experiment
- The upgrade program
- The ATLAS Muon Spectrometer and the New Small Wheel

*Micromegas construction*

- The Micromegas technology
- Micromegas for the NSW
- Detector construction and Module 0

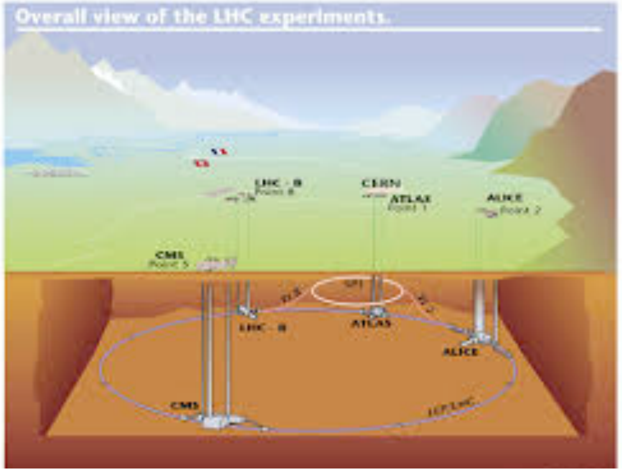
*Test and Results*

- Micromegas small prototype performance
- The medium size prototype (MMSW)

*Conclusion and outlook*

# LHC AND ATLAS EXPERIMENT

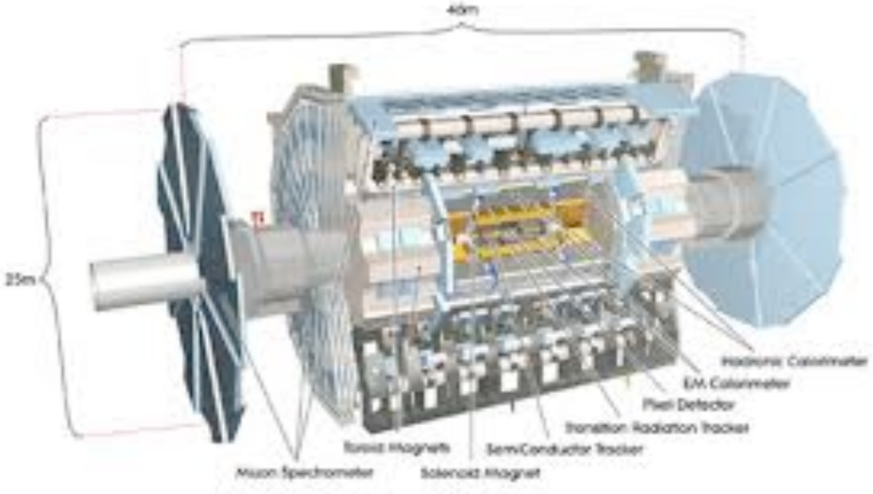
**Large Hadron Collider**
**Proton-proton & heavy ion collider @CERN**
27 km, 1232 dipole magnets
+ 400 quadrupole magnets
+ Various other types of magnets



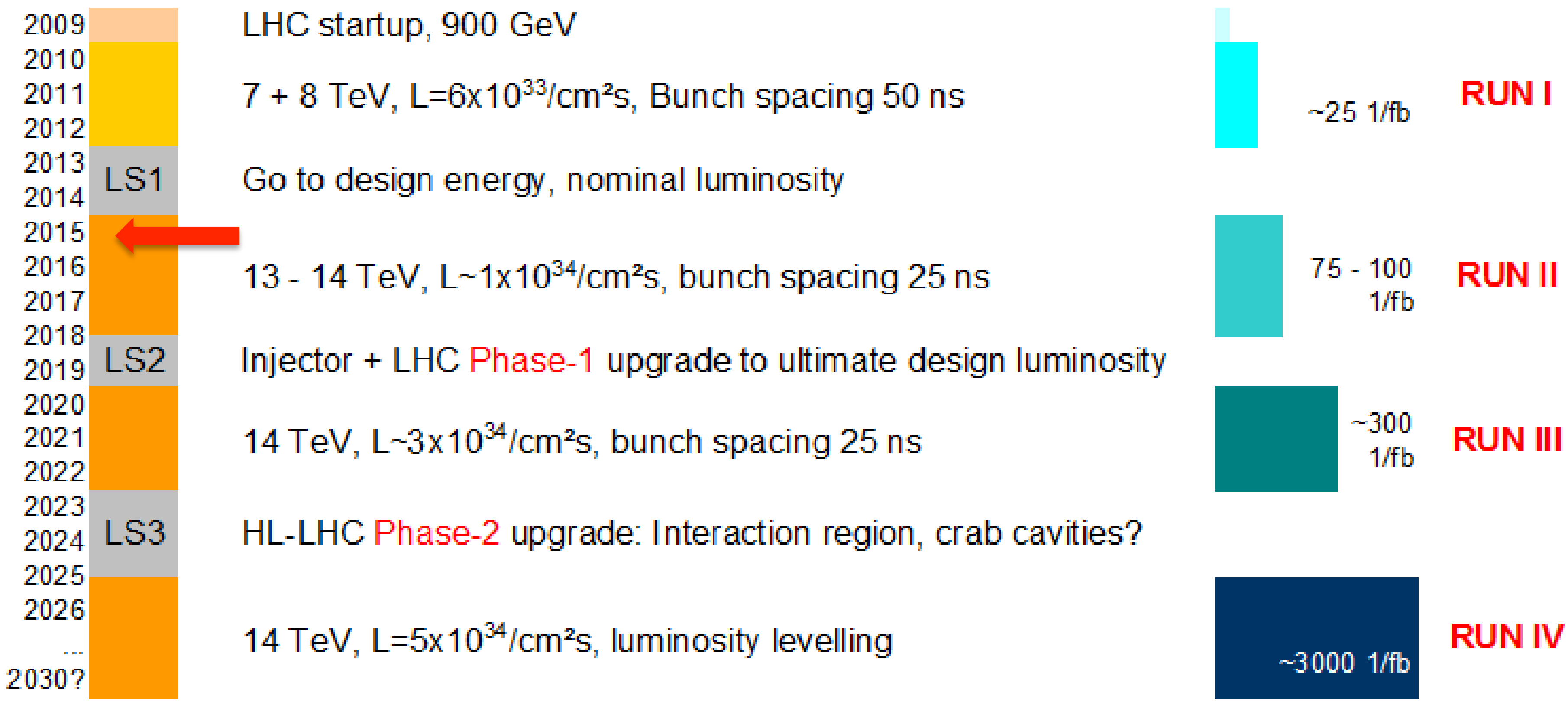

**LHC design parameters**
$E_{CM}$ = 14 TeV
L = 1 x 10^34 cm$^2$s

ATLAS: General purpose detector

- Search of new particles: Higgs boson, others...
- High precision measurements of the particle physics Standard Model
- Studying the strong interactions in heavy-ion collisions



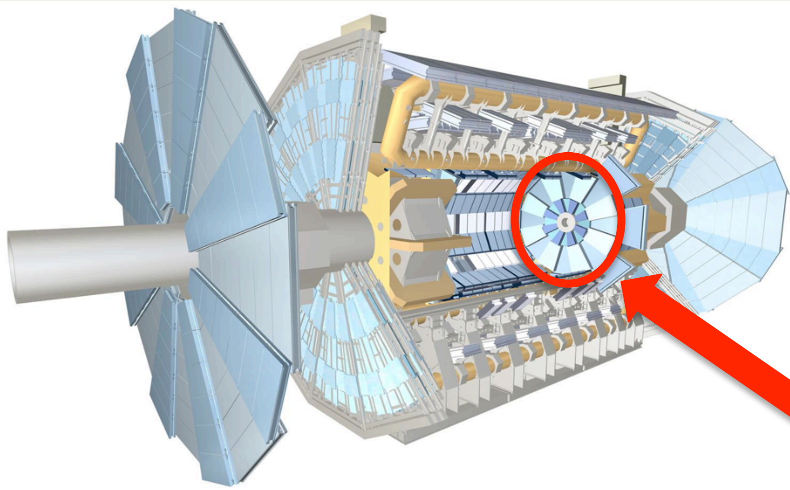
# LHC AND THE UPGRADE PROGRAM

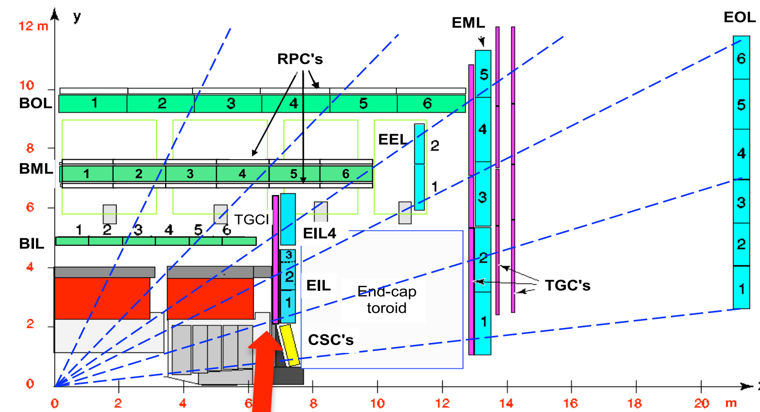



**ATLAS (main upgrade activity):**

- Phase-0 Upgrade: *Consolidation + Insertable B-Layer (IBL) in LS1*
- Phase-1 Upgrade: ***New Small Wheels***, *Calorimeter trigger upgrade, FTK.*
- Phase-2 Upgrade: *Inner Tracker, Muon Spectrometer, Calorimeter,... under evaluation*

# The ATLAS Muon Spectrometer and the Small Wheel






- In the Barrel Region the ATLAS Muon Spectrometer is realized by RPC and MDT detectors, while in the End Cap Regions CSC, MDT and TGC detectors are used
- The Small Wheel (Innermost Endcap Muon Station) is the region with highest background rates in the present ATLAS Muon Spectrometer
- The present system is based on Cathode Strip Chambers (CSCs), Monitored Drift Tubes (MDTs) and TGC for particle tracking
- Located between endcap calorimeter and endcap toroid

# New Small Wheel Motivations

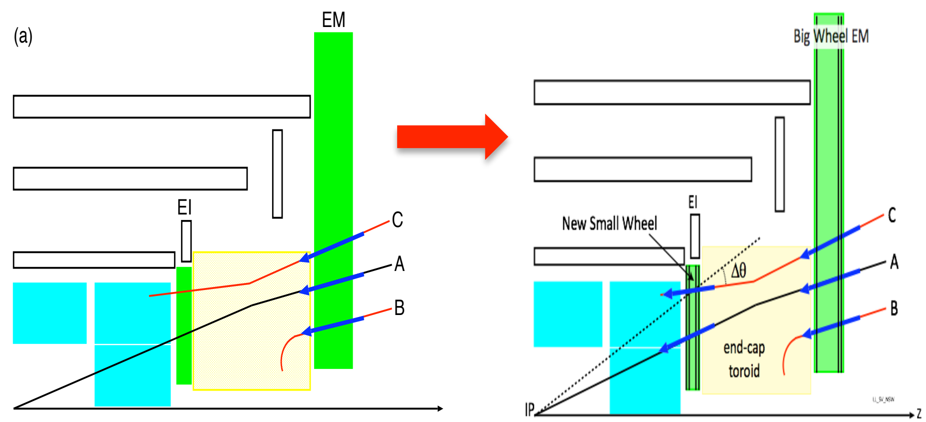
***Consequences of luminosity rising beyond design values for forward muon wheels***

***TRIGGER:***

- Present Muon L1 trigger in the EndCap relies on the Big Wheel station only: Calculating a track angle/ vector and extrapolating to IP
- The Level1 Trigger rate in the EC is dominated by fake triggers
- At a 3 x $10^{34}$ $cm^{-2}s^{-1}$ L1MU20 ($p_T$>20 GeV) rate is estimated ~60 kHz, exceeding the available bandwidth (~20kHz for muons)

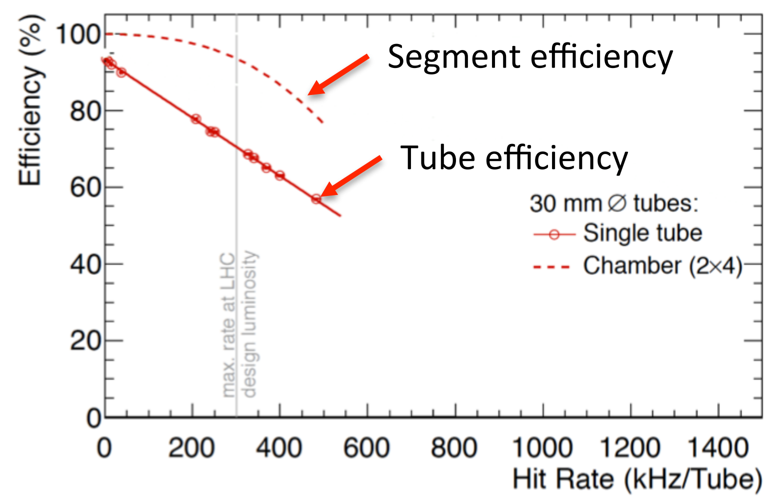
Present Level1 muon trigger

Upgrade L1 muon trigger with NSW

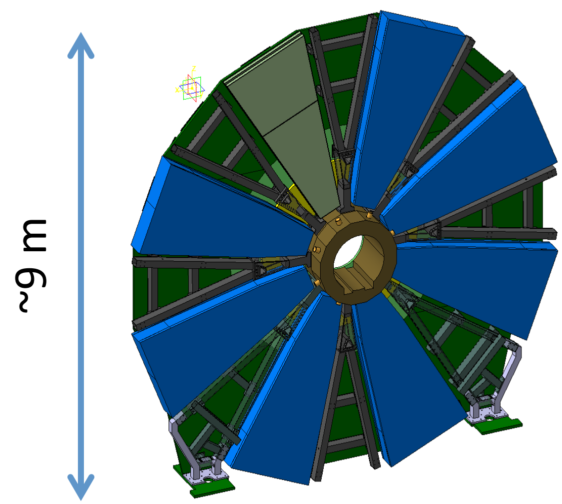



***TRACKING:***

- At $5\times10^{34}$ $cm^{-2}$ $s^{-1}$ (luminosity of HL-LHC) the maximum expected rate in the NSW is about 15 kHz/ $cm^2$ (>5 MHz/MDT/tube)
- Above 300 kHz/tube the MDT efficiency drops significantly due to dead time from background hits, and the resolution decrease due to gain loss caused by space charge
- Limit for CSCs is reached even earlier, due to only 4 detection layers (instead of 6 for MDT)

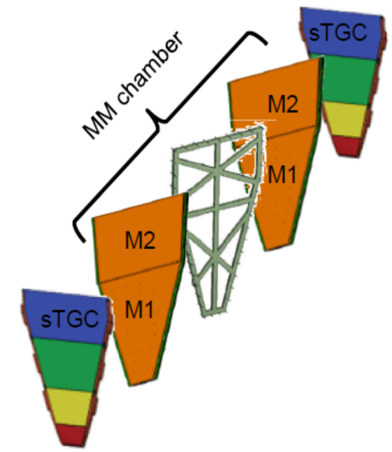


# New Small Wheel layout




**Each wheel is segmented into 16 sectors (8 small + 8 large alternating), consists of:**

- 2x2 Micromegas modules forming 2xWedges on either side of a rigid spacer frame (50mm)
- 2x3 sTGC modules forming 2xWedges on both outer sides of Micromegas




## New Small Wheels will be equipped with sTGC and MicroMegas (MM) detectors:

**sTGC primary trigger detector**

**Bunch ID with good timing resolution**
**– additional suppression of fakes**

**Based on proven TGC technology;**
**Pads & strips, instead of only strips as in current detector**

**Good space resolution providing track vectors with < 1 mrad angular resolution , redundant tracking**

**MM primary precision tracker**

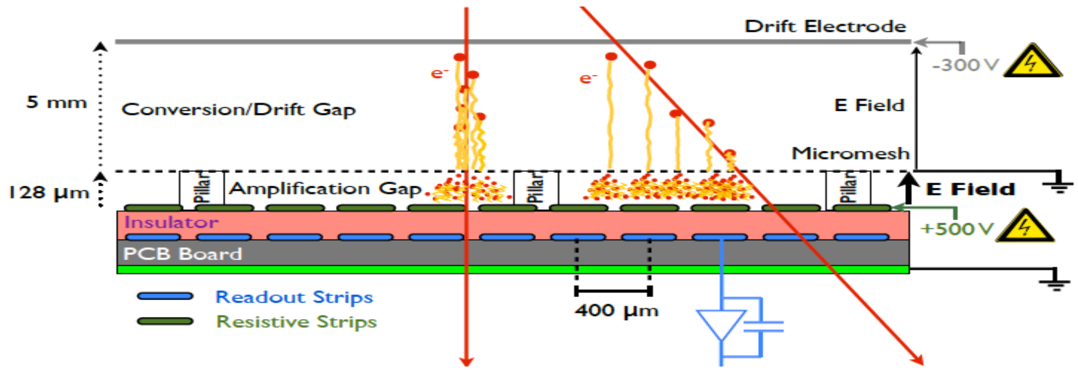
**Space resolution < 100 μm independent of track incidence angle**

**Good track separation due to small 0.5 mm readout granularity (strips)**

**MM 2nd coord will be achieved by using ± 1.5° stereo strips in half of the planes**

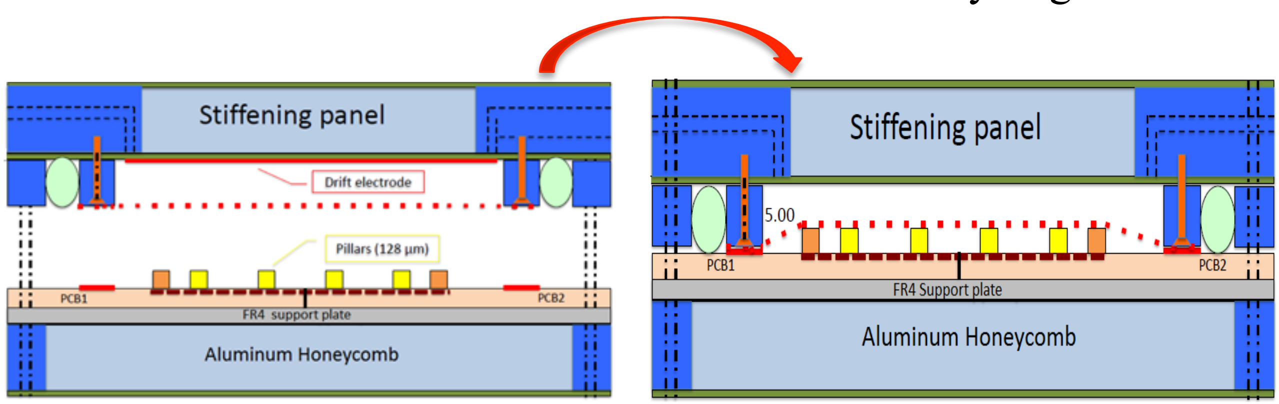
**Provide independent track vector – redundant triggering**

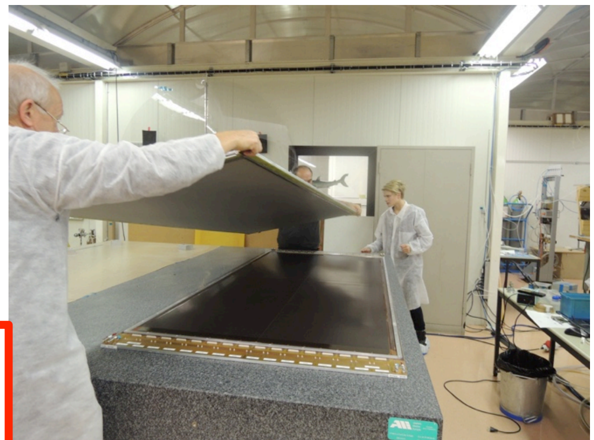
# MicroMegas Technology for the ATLAS NSW Upgrade




- **Micromegas (I. Giomataris et al., NIM A 376 (1996) 29)** are parallel-plate chambers where the amplification takes place in a thin gap, separated from the conversion region by a fine metallic mesh.

We opted for a non-bulk technique (**floating mesh**) that uses also pillars to keep the mesh at a defined distance from the board, the mesh is integrated with the drift-electrode panel and placed on the pillars when the chamber is closed. This allows to build very large chambers using standard PCB .



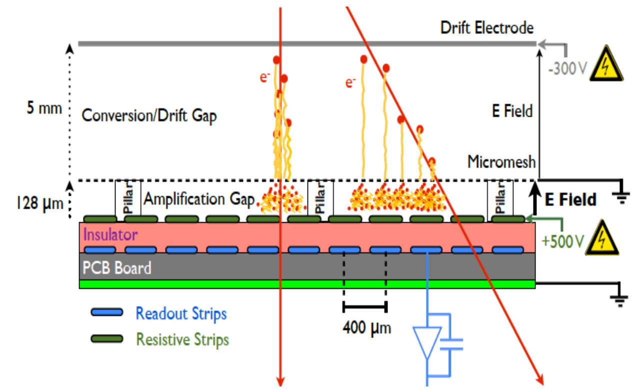



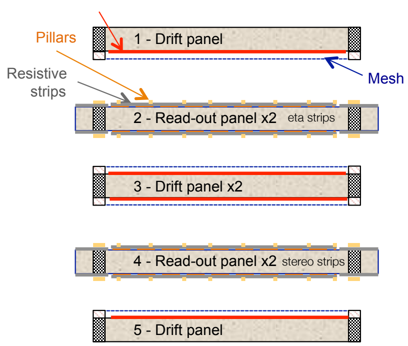
**Requirements for a µ momentum resolution of 15% @ 1TeV in Atlas**

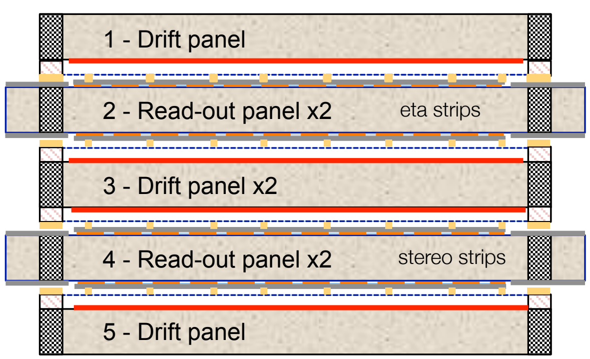
| | |
|---|---|
| Precision of strip position in Eta (precision coordinate) | 30 µm r.m.s. |
| Precision of strip position in Z (perpendicular to the detection plane) | 80 µm r.m.s. |

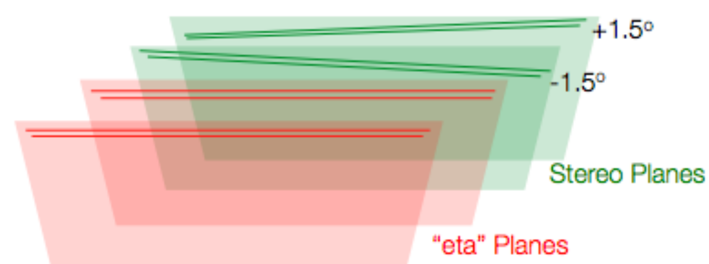
# MicroMegas Technology for the ATLAS NSW Upgrade

- Drift region: 5 mm
- Grounded mesh (stainless steel, 325 lines/inch)
- Amplification region: thin gap (128 μm)
- Amplification E field ~ $4 \times 10^4$ V/cm , Drift E field 600 V/cm
- Resistive anode strips for spark-protection
- Capacitive coupling of the resistive strips with readout strips.
- Two possible techniques to realize the resistive strips: sputtering or screen-printing
- The NSW will employ 4 MM-planes chambers
- operated with an Ar/CO2 93/7 mixture



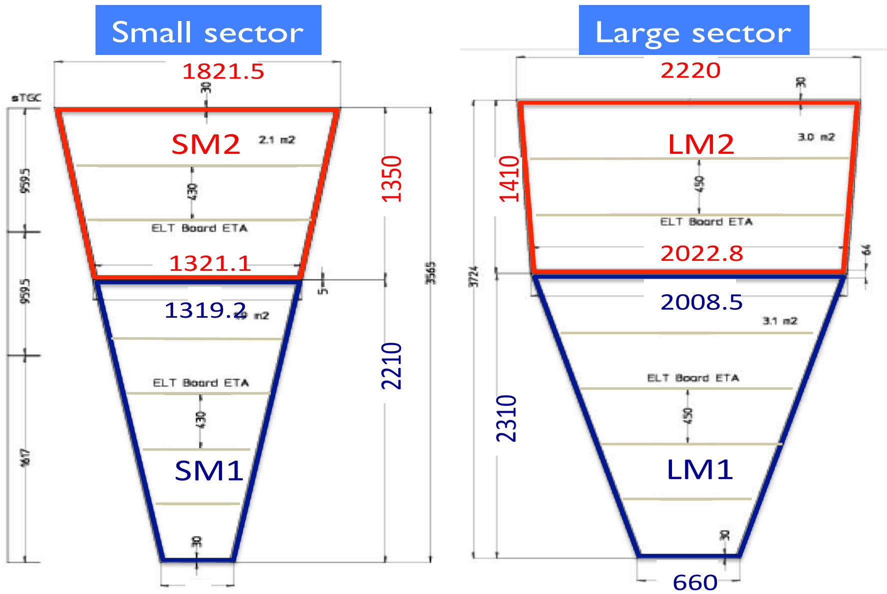



# MMs production site toward M0 construction

NSW Micromegas has 4 different chamber types, production is distributes over several groups, labs and institutes, in several countries, quadruplets are built at institutes, with certain components done in industry

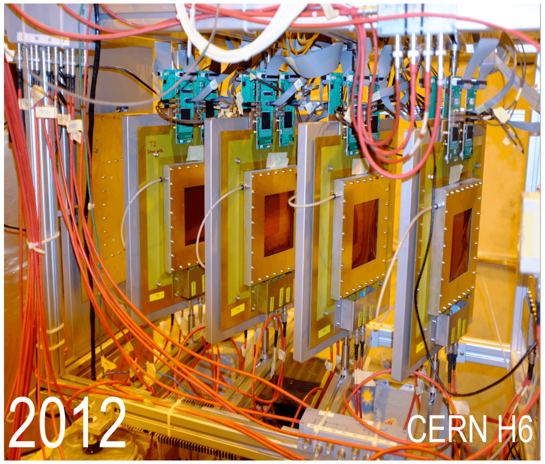


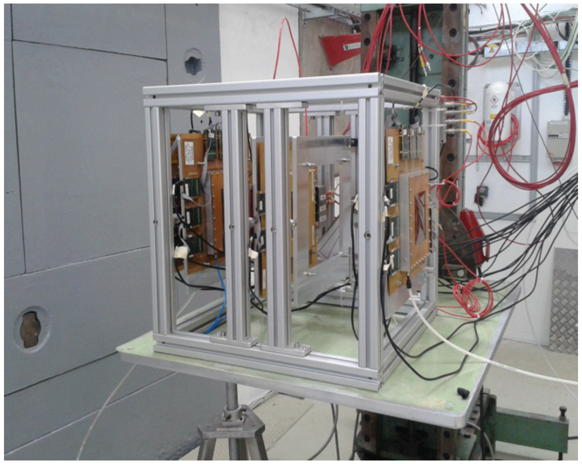

Construction sites:
- SM1 -> Italy
- SM2 -> Germany
- LM1 -> France
- LM2 -> Russia/Greece (+ Cern)

**Inner module: 5 PCB boards**
**Outer module: 3 PCB boards**

- All production sites are either ready with the basic equipment, or will be ready soon.
- The tooling and quality control for the chamber construction is under preparation.
- Materials for Module 0 construction already delivered, PCB for readout panels in preparation.
- Modules 0 foreseen for end of Summer .

# Performance of MMs prototype



Extremely wide performance analysis program ongoing since 2008 in order to fully characterize the Micromegas chambers.

The analysis program has made use of:

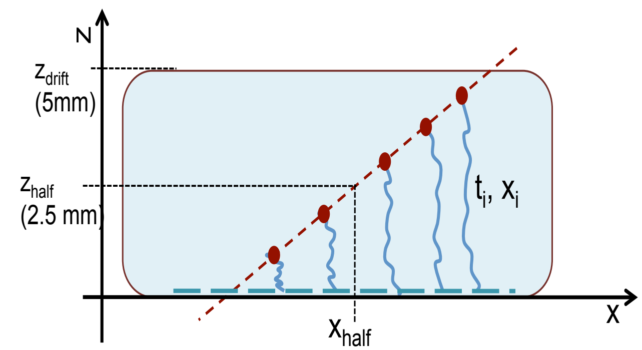
- Several test beam campaigns
- Test with cosmic ray
- X-ray guns for gain and mesh transparency measurements
- Irradiation tests ( $\gamma$, $\alpha$, neutron ) for ageing and radiation hardness studies

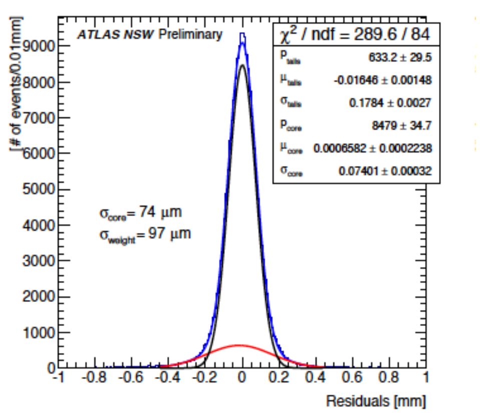
# Resolution studies

**Micromegas will be the main precision tracker of the NSW (required spatial resolution 100μm).**

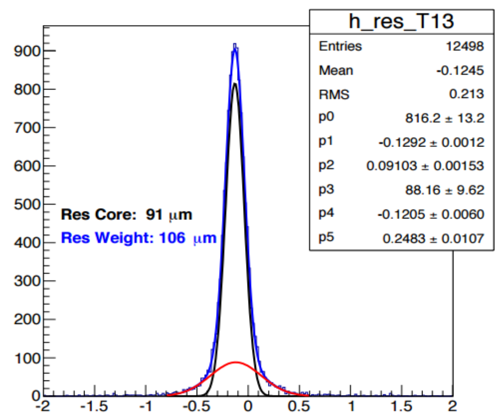
Two different methods are used in order to extract the correct spatial information:

- Using charge amplitude (Centroid hit)
    - Accuracy rapidly decreasing for larger track angles.
- Using time information (μTPC segment).
    - Performance improving with increasing cluster size.

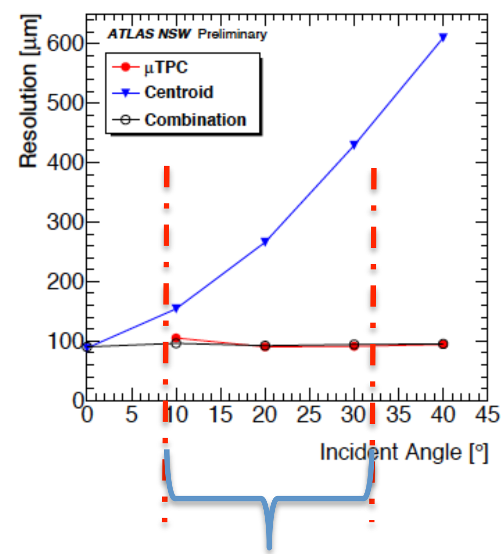



Resolution achieved with centroid method for perpendicular track using chamber with 400 μm strip pitch




Resolution achieved with μTPC method for 30 $^0$ inclined track using chamber with 400 μm strip pitch

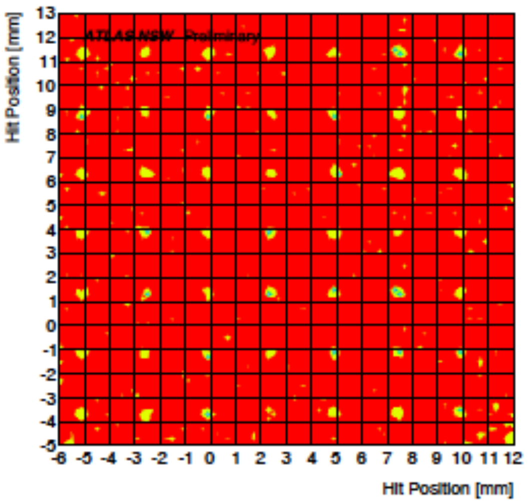


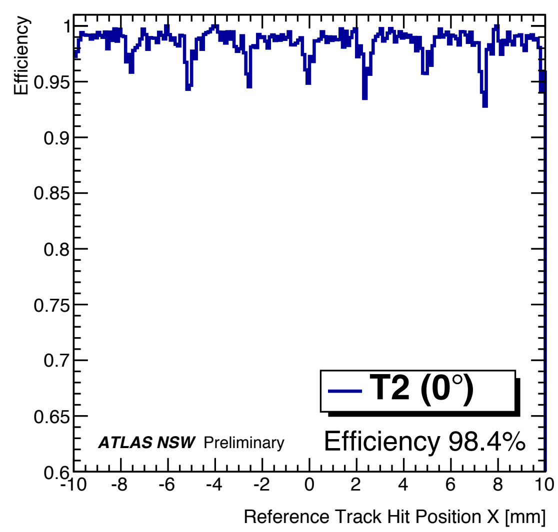

NSW expected track angles

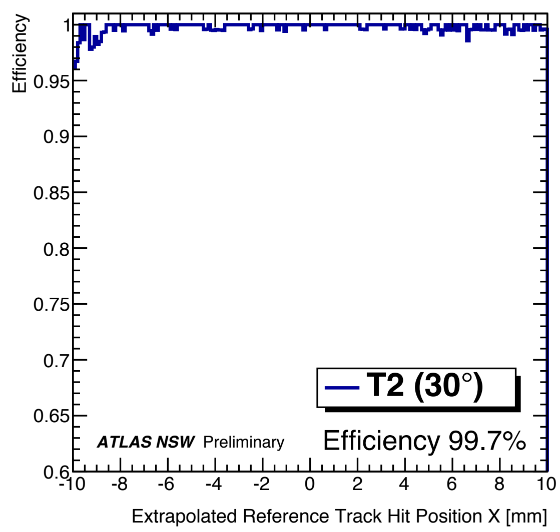
# Efficiency studies

Hit reconstruction efficiency as a function of the extrapolated reference track hit for a single readout chamber of T type (10 x 10 cm2).

On the left side a 2D efficiency plots for a T chamber, the pillar grid is structure is clearly evident
The plot in the center corresponds to the reconstruction efficiency obtained by using perpendicular track, while the left plot reports efficiency obtained with $30^0$ inclined track.
The efficiency drops ( about 5%) appearing every 2,5 mm correspond to the pillar structure supporting the mesh, the effect of the pillars became less evident with the inclined track which produce larger clusters.



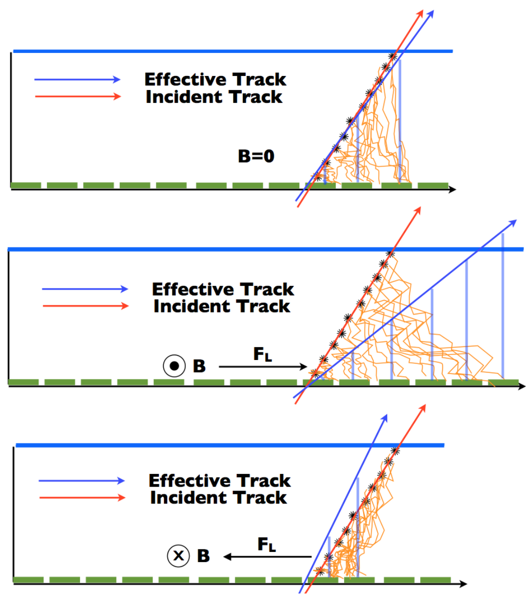



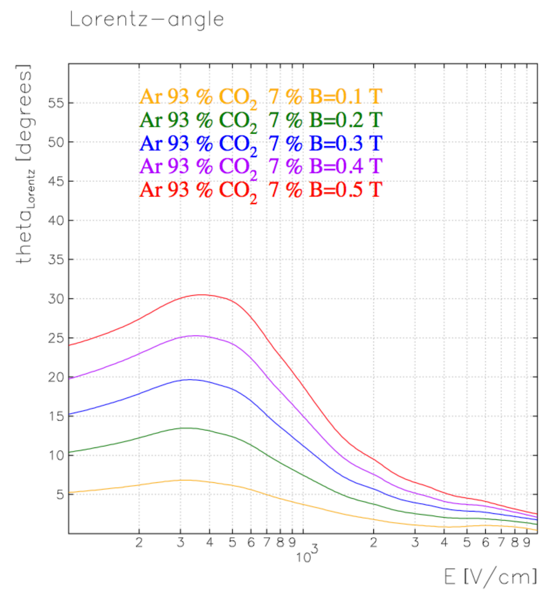



# MM performance in magnetic field

The MM chambers of the NSW will operate in a magnetic field of a magnitude 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.

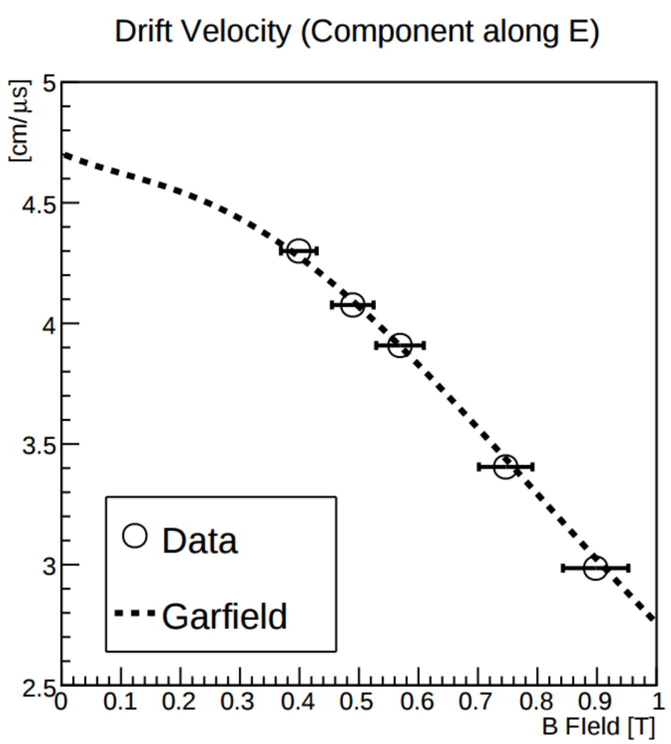
The drift direction of the ionization electrons is tilted with respect to the electric field direction by the Lorentz angle $\theta L$ .
The tilt of the drift direction gives a sizable shift ($\delta x$) of the reconstructed hit position.
At the singular configuration, the bad performance of the $\mu$TPC method is compensated by the good performance of the cluster centroid method, due to the very small cluster size. A combination algorithm can be applied to have a constant resolution through all configurations

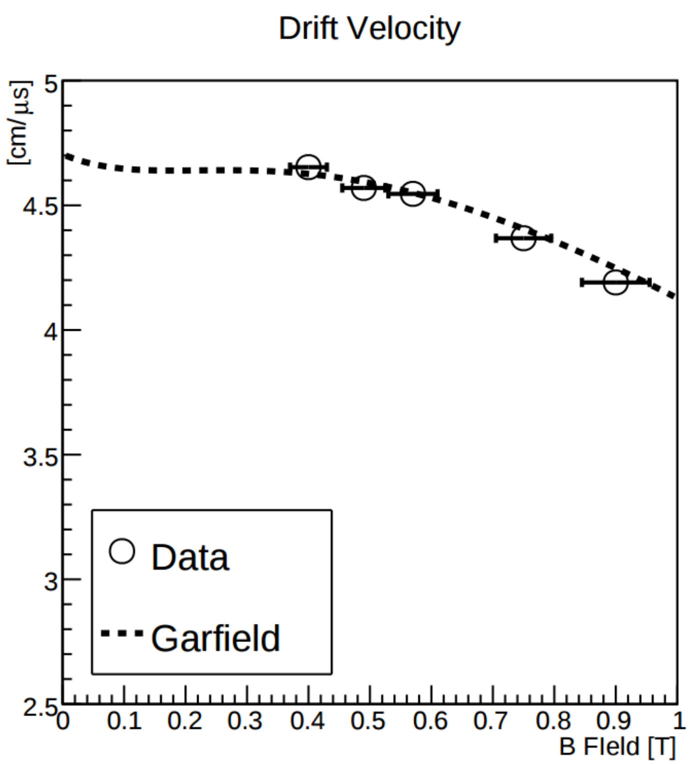


# MM performance in magnetic field

- The component of the Drift Velocity along E field can be measured, from the distribution of the arrival times of the single clusters knowing the gap size and the applied B field.
- Knowing the the Lorentz angle the Drift Velocity can be calculated

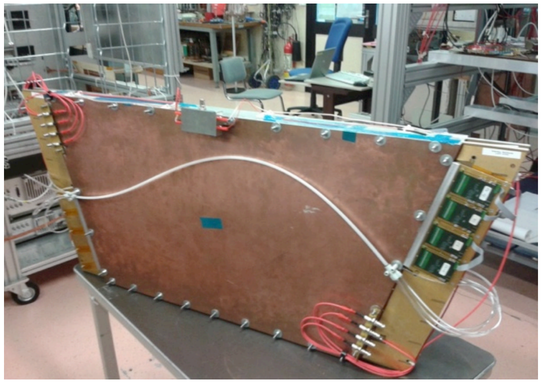


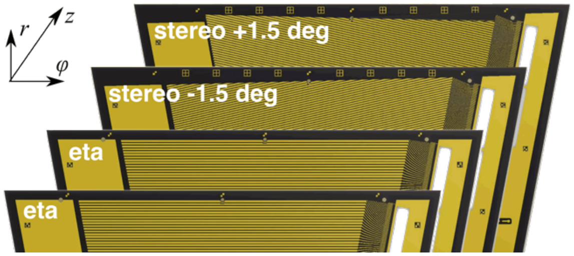



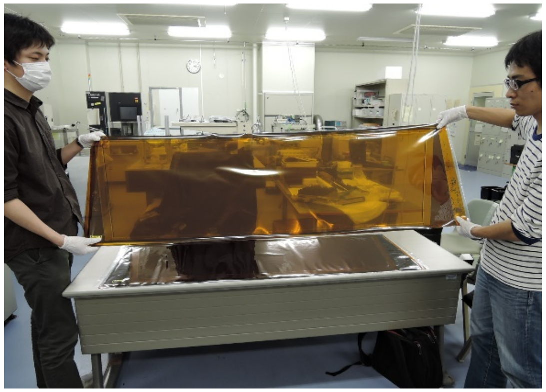
# The medium size prototype (MMSW)

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

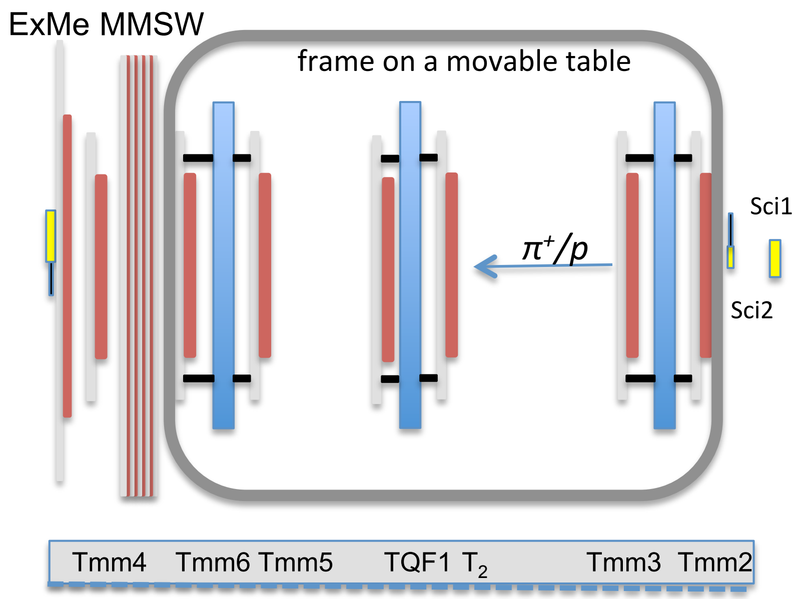
- A quadruplet structure with two double sided readout boards, one double sided and two single sided support (drift) panels equipped with the drift electrode and the micromesh.
- Readout comprises **1024 strips per plane** with a pitch of **415µm**. The strips are **rotated by ±1,5º** on two planes to measure the second coordinate. Position **resolution** are expected to be better than **100 microns** in the precision coordinate (along the direction of the track bending) , and better than **2.5 mm** in the second coordinate orthogonal to the precision one.
- 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.

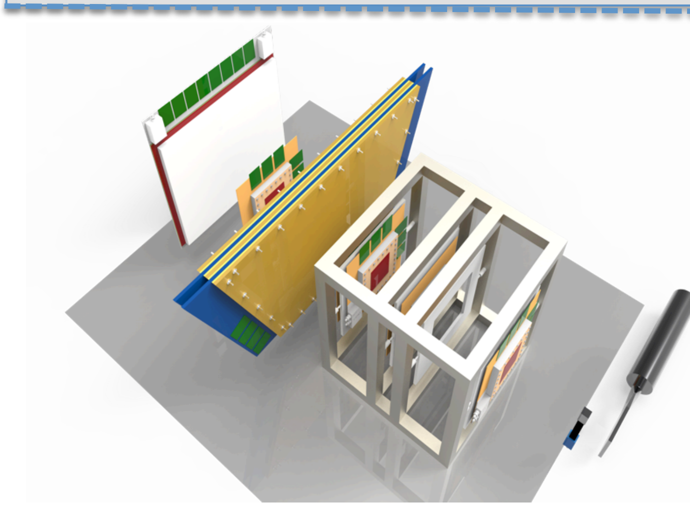




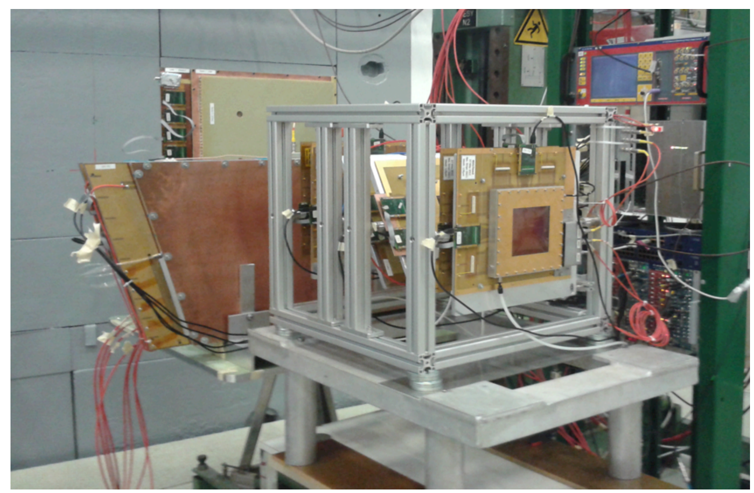
# MMSW Test beam results



MMSW chamber has been extensively studied during the MMs test beam campaign.

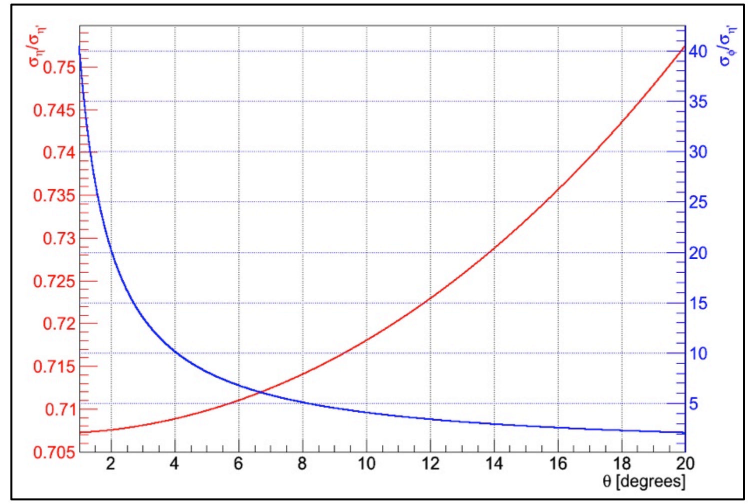
The chamber has been placed between an hodoscope, hosting several MMs small chambers including 4 double view chambers (Tmm) and a similar chamber (Tmm) placed behind the MMSW chamber to reconstruct the incoming particles (*pions & protons*).

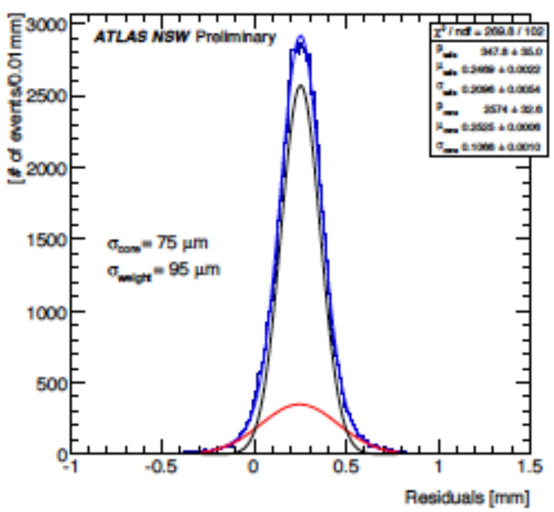


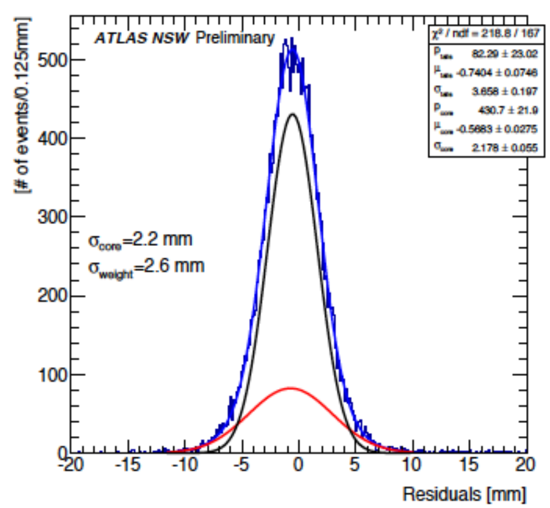
# MMSW  Test beam results

Due to the 1.5° rotation used to built the stereo strip, a resolution on the second coordinate is expected to be: $\sigma_y$=27 * $\sigma_x$ (*right upper plot*).

Resolutions for the precision and second coordinate, extracted by the test beam data ( *lower plots*)




Measured resolution for first and second coordinate are well within specifications

Efficiency ≈98% for all the layers (2% inefficiency caused by the pillars)

# Conclusion and outlook

- *The ATLAS NSW Upgrade will enable the Muon Spectrometer to retain its excellent performance*
- *First time Micromegas detectors will be used on a very large scale to built large area chambers in a particle physics experiment*
- *Design and construction methods have been refined and tested to achieve the Atlas requirements*
- *Extensive performance studies show that Micromegas fulfill the ATLAS requirements*
- *Excellent spatial resolution (< 100 μm) independent of the track incident angle*
- *Studies inside magnetic field do not show any sign of degraded performance.*
- *Working quadruplet prototypes (MMSW) have been built following the ATLAS chambers layout, its performance are within the ATLAS specification*
- *MMSW chamber will be installed into the ATLAS experiment during 2015/16 run*
- *Module-0 construction at the different construction sites will start soon and will be ready at the end of summer*
- *Transition to series production beg 2016*
- *End of production mid 2017 (2 modules/month/sites)*