Performance Studies of Micromegas Chambers for the ATLAS New Small Wheel Upgrade Project

2014 Test Beam results

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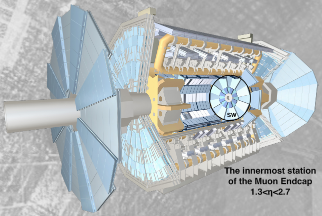
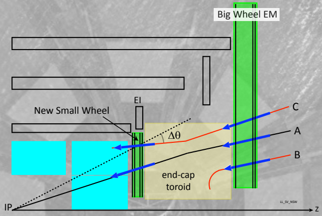
MINISTRY OF EDUCATION, LIFELONG LEARNING AND RELIGIOUS AFFAIRS
MANAGING AUTHORITY
European Union
European Social Fund
Co-financed by Greece and the European Union
NSRF 2007-2013
EUROPEAN SOCIAL FUND

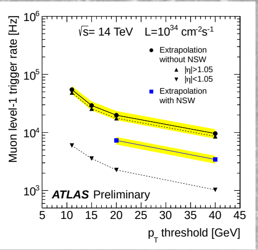
BROOKHAVEN NATIONAL LABORATORY

New Small Wheel system, with high rate capability, to be included in the muon Level-1 trigger.

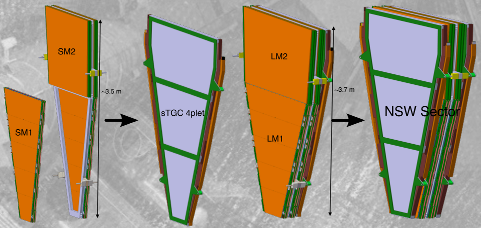
- Minimise fake triggers by reconstructing high quality ($\sigma_\theta \sim 1\,\text{mrad}$) IP pointing segments.
- Precision tracker ($100\,\mu\text{m}$) efficient for the expected high rate after the luminosity increase.

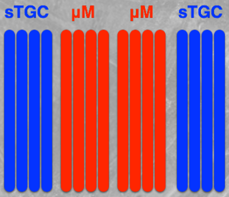






sTGC (mainly for triggering) & **Micromegas (mainly for tracking)** detectors, both providing tracking and triggering information, combined into a fully redundant NSW system!

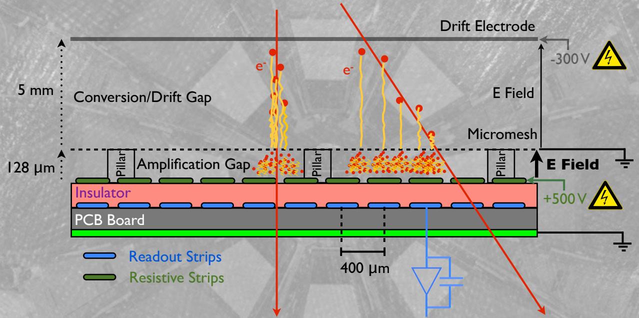




8 MM + 8 sTGC layers per NSW sector

Planar structure with two asymmetric E-field regions, separated by a metallic micromesh.

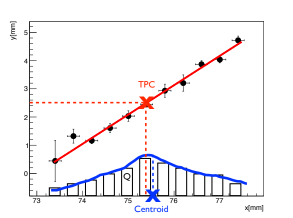
- **Drift Gap** (5 mm), $\mathbf{E_{drift}} \simeq 0.6\,\mathrm{kV/cm}$
- **Amplification Gap** (128 μm), $\mathbf{E_{amp}} \simeq 39\,\mathrm{kV/cm}$
- **Gas** mixture Ar+7% CO_2, gain $\sim 10^4$



- e^- drift towards the mesh (95 % transparent) in $\sim 100\,\mathrm{ns}$.
- Avalanche formation in the amplification region (1 ns) with fast ion evacuation ($\sim 200\,\mathrm{ns}$).
- The detector becomes **spark tolerant** by adding a layer of resistive strips ($5 - 20\,\mathrm{MOhm/cm}$).
  → **High rate capability!** (Tested up to $70\,\mathrm{kHz/cm^2}$)

Fine readout segmentation ⇒ Excellent spatial resolution BUT large # of channels (2M for NSW!).

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



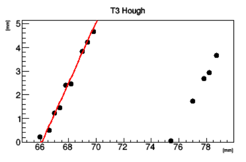
Hit & Track reconstruction

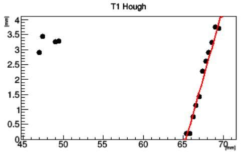
- Using charge amplitude (**Centroid** hit)
  Accuracy rapidly decreasing for larger track angles.
- Using time information (μ**TPC** segment).
  Performance improving with increasing cluster size.

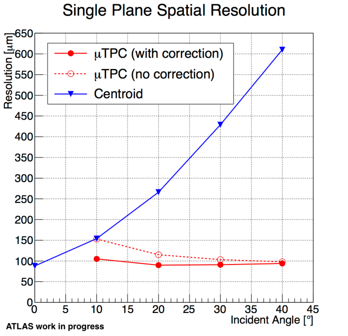
Tracks expected @ NSW $8^\circ - 30^\circ \Rightarrow$ So we are relying mostly on μTPC.

Refinement of μTPC recipe (Significant improvement)

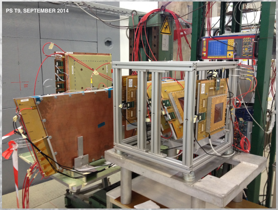
- Correct for capacitive coupling between strips.
- Fine tuning of the primary e^- position assignment along the strip width.
- Implement pattern recognition techniques for track identification (Hough transform)

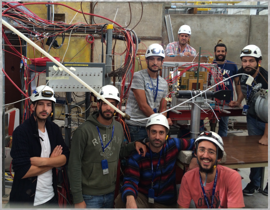


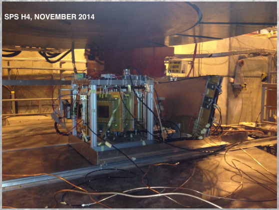




Combination of centroid & μTPC provides spatial resolution $< 100\,\mu$m independently of the track incident angle!



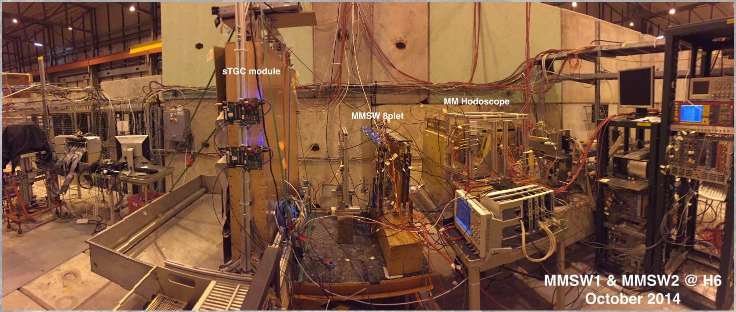


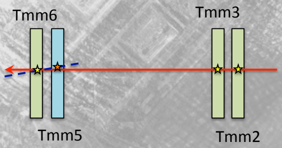


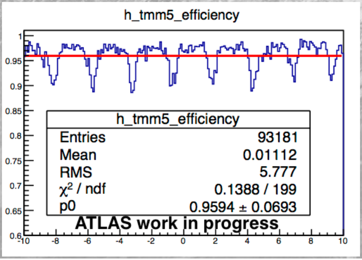
Beams back at CERN in summer 2014

Several test beam periods studying different Micromegas prototypes in various beam and magnetic field conditions.

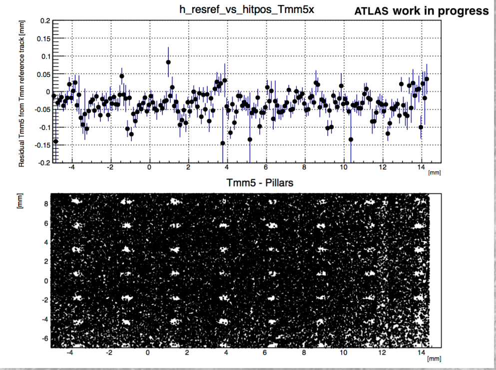
- PS T9, T10 area (π^+/p, 10 GeV/c)
- SPS H6 area (π^+ 120 GeV/c)
- SPS H4 area (π^+ 120 GeV/c, Goliath Magnet)

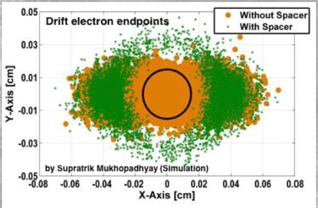


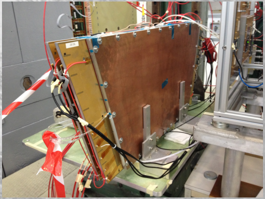


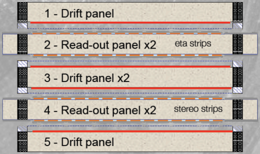


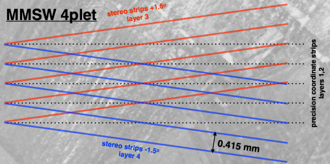
- "Inefficient" areas (pillars) are visible from simple hit reconstruction on 2-D readout chambers
- Pillars also distort the electric filed lines biassing the reconstructed hit position (max bias measured $\sim 100\,\mu\mathrm{m}$)







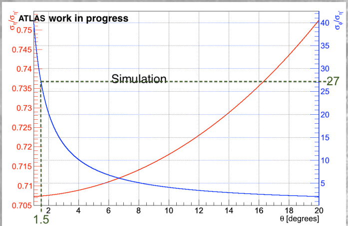




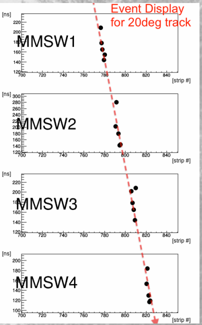
- **First MM 4plet ever built** with structure similar to the one foreseen for the NSW.
- 2 double sided readout boards, 1 double sided and 2 single sided drift panels ($1\,\mathrm{m} \times 0.5\,\mathrm{m}$).
- Comprises 4 readout layers, 1024 readout strips each, with a pitch of $415\,\mu\mathrm{m}$.

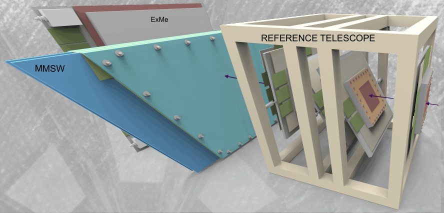
- **First test of a stereo readout strip layout with MM.**
- Strips are rotated by $\pm 1.5^{\circ}$, with respect to the precision strips, on two planes for 2^{nd} coordinate reconstruction.

Combining the 2 stereo readouts, the reconstruction accuracy for the second coordinate is expected to be $\sim 2.2\,\mathrm{mm}$ (assuming $\sim 80\,\mu\mathrm{m}$ for a single layer).

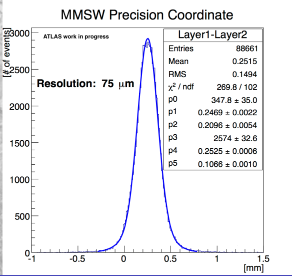


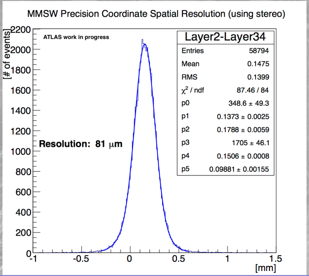
Test of the MMSW 4plet in p, π^+ beam $(6-9\,\mathrm{GeV/c})$ using a micromegas reference telescope (CERN, PS T9-10, August-October 2014).

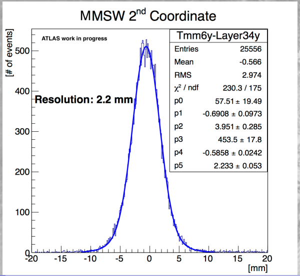


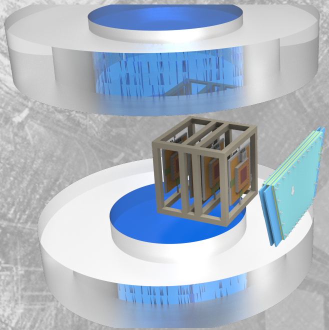


- $\sim$ **98% efficiency** for all 4 layers (2% inefficiency due to pillars).
- **Precision coordinate** hit reconstruction with $\sim$ **75** μm accuracy.
- Spatial resolution combining the the stereo layers
  Precision coordinate $\sim$ **81** μm, **2nd coordinate** $\sim$ **2.2** mm.

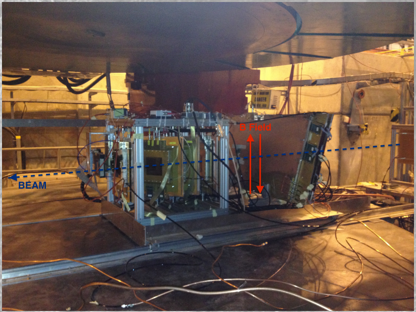


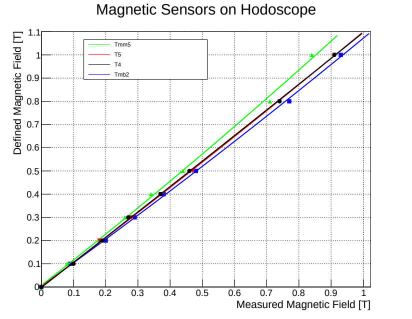


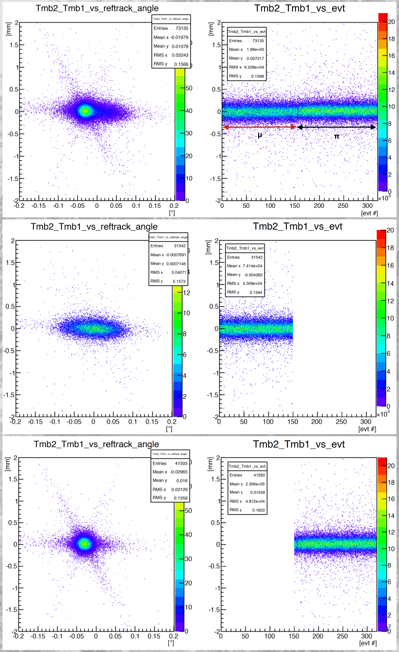


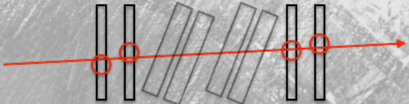


- Tests with B-Field up to 1T
- μ/π beams, with various settings (intensity, profile etc.) and B-field configurations
- 4 test chambers (1D readout, 400 μm strip pitch,5 mm drift gap)
  4 reference chambers (2D readout, 250 μm strip pitch,2.5 mm drift gap)
- Actual field was monitored using magnetic sensors along the hodoscope



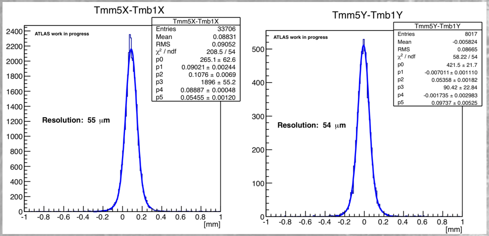






Precise MM reference track without B field ($\sim 55\,\mu\mathrm{m}$ resolution per station)

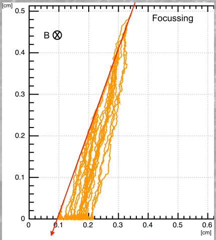
- Reference track inclination, residuals

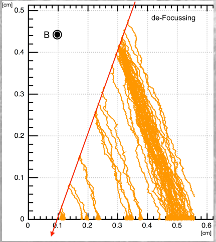


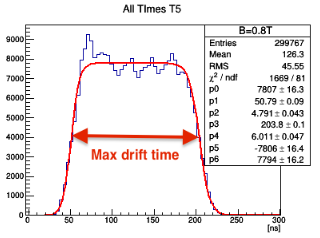
- $\mu \rightleftarrows \pi$ different angular spreads (depending on collimator/magnets settings)
- Measurable small shift ($14\mu\mathrm{m}$) observed in residual distribution

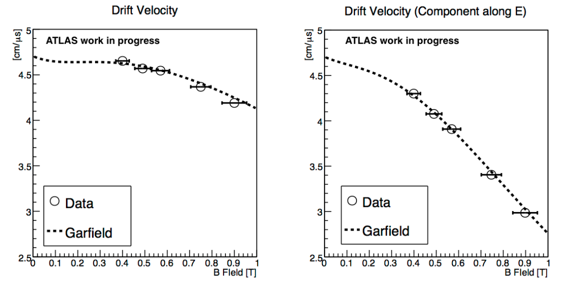
Multi-directional magnetic field in the ATLAS SW region with intensity up to **0.4**T.

- The drift path of the ionisation e^- is deviated from the electric field lines.
- The electron drift paths become longer inside magnetic field.
- **Use the measured maximum drift time to calculate the drift velocity.**

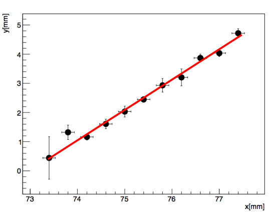




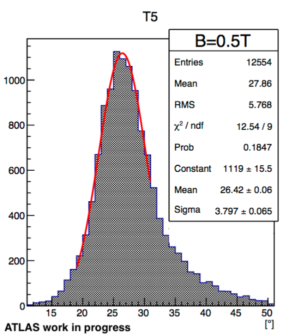


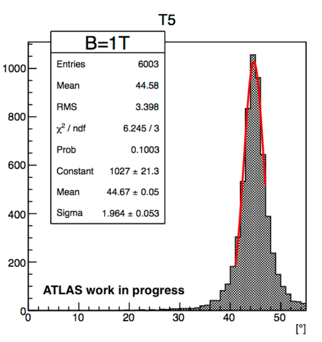


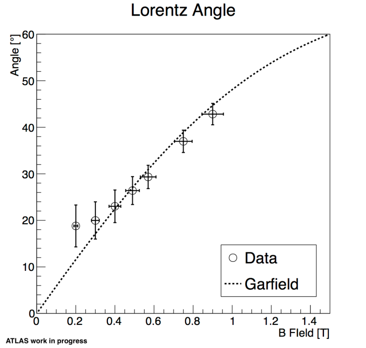
Measurements show good agreement with Garfield simulations!

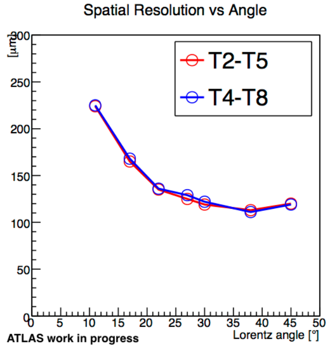


- Use runs with zero inclination for Lorentz angle measurement (example for $B = 1\mathrm{T}$)
- Using the drift velocity component along E to transform time to distance ($\theta_{reco} = \theta_{Lorentz}$)
- Reconstruct μTPC tracklet in a single gap
- **The distribution of the track slopes will give an estimate of the Lorentz angle**
- **Interpolating the tracklet in the middle of the drift gap and calculating the residuals between the x_{half} of 2 chambers we can estimate the spatial resolution**









- Measurement of the Lorentz angle is in good agreement with expectations from simulation
  - Deviation in small angles due to capacitive coupling can be corrected
- μTPC spatial resolution follows the "known trend" for increasing B field (increasing $\theta_{Lorentz}$)
- Values are slightly larger that the expected for μTPC with no B field but recipe is not optimised yet for the magnetic field data:
  - Use correct value of the v_{drift} (correct B Field)
  - B Field varies with the chamber's position (here the same v_{drift} used for all)
  - $\mathbf{E_{amp} = 500}$ V in the runs analysed was low (loss of some primary e $\rightarrow$ degraded μTPC performance)

The ATLAS NSW Upgrade will enable the Muon Spectrometer to retain its excellent performance also beyond design luminosity and for the HL-LHC phase

- Deployment of a new Micropattern Gaseous Detector (MPGD) technology, Micromegas, for the first time in a very large scale experiment ($\sim 1200\,\mathrm{m}^2$ total surface to be built)!

Extensive performance studies show that Micromegas fulfills the ATLAS requirements

- Excellent spatial resolution ($< 100\,\mu\mathrm{m}$) independent of the track incident angle.
  - Refinement μTPC technique correcting for effects due to neighbouring strips capacitive coupling.
  - Studies to understand and correct for the effect of the spacers on the hit reconstruction $\rightarrow$ **further optimisation**.
- Studies inside magnetic field do not show any sign of degraded performance.
  - Chambers perform flawlessly with magnetic field intensities up to $1\mathrm{T}$.
  - Measurements of the Lorentz angle and the drift velocity are well in agreement with Garfield simulations.
  - μTPC reconstruction was successfully applied inside magnetic field.

First test of the ATLAS-like prototype (MMSW 4plet) was very successful

- Reconstruction of the precision coordinate with an uncertainty of $\sim 75\,\mu\mathrm{m}$.
- 2^{nd} coordinate reconstruction using stereo readout strip configuration performs as expected, spatial resolution $\sim 2.2\,\mathrm{mm}$.

Thank you

ATLAS

European Union
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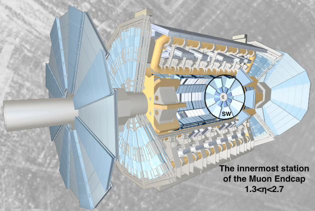
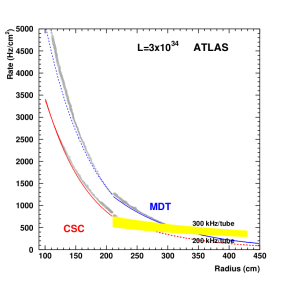
BackUp Slides

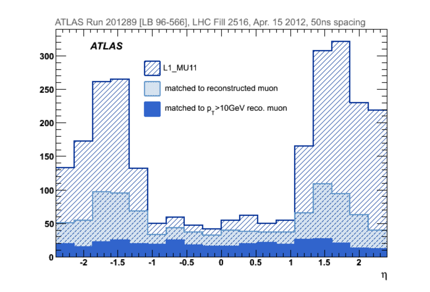
The ATLAS upgrade is motivated primarily by the high background radiation that is expected at $\mathscr{L} = 5 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, after the High Luminosity LHC (Phase II) upgrade (2025).



Muon Spectrometer upgrade will be essential already for $\mathscr{L} = 2 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, *after Phase I upgrade* (2020).

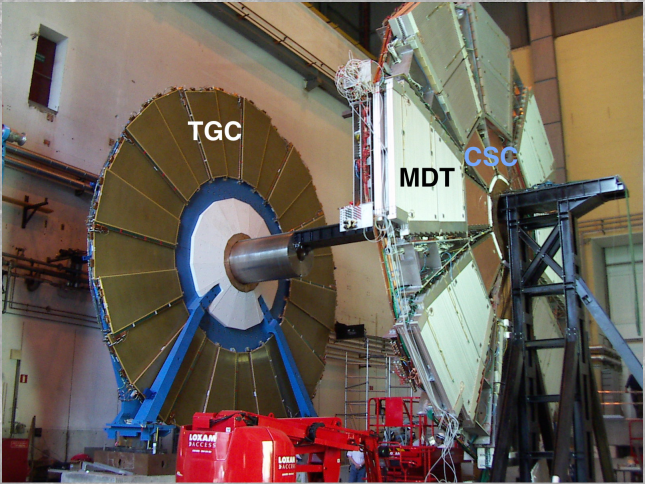
- Current SW detectors (MDT,CSC,TGC) inefficient at increased particle rate ($\sim 15\,\mathrm{kHz/cm^2}$ for HL-LHC).
- Muon trigger rate will exceed the bandwidth available to the muon system ($\sim 20\,\mathrm{kHz}$).





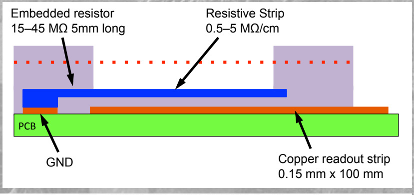
Degradation of single hit & segment efficiency, due to dead time from background hits.

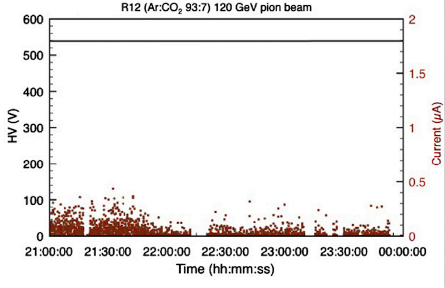
Endcap muon triggers are dominated by fakes due to background ($> 90\,\%$)*!*

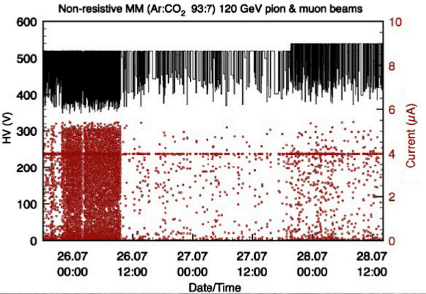


The current SW during the assembly phase. The 3 different detector technologies are visible.

- Sparks lead to a partial discharge of the amplification mesh ⇒ HV drop & inefficiency during HV ramping up
- The discharge problem has been overcome with the implementation of a layer of resistive strips.
- With a strip resistivity of $10 - 20\,\mathrm{MOhm/cm}$ spark currents are reduced by about three orders of magnitude
- Sparks are quickly quenched
- The strip pattern constrains sparks to regions of typically one or two strips.



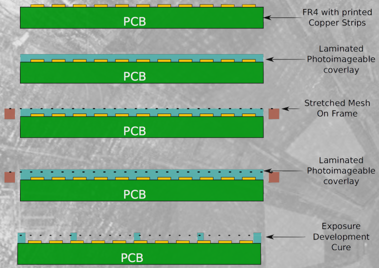




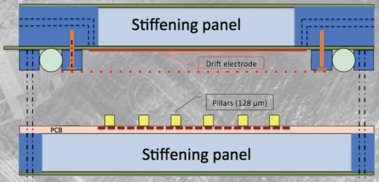
Comparison of a resistive ($5\,\mathrm{MOhm/cm}$) with a standard micromegas chamber.

Micromegas structure assembly

- Bulk (mesh glued on readout PCB).



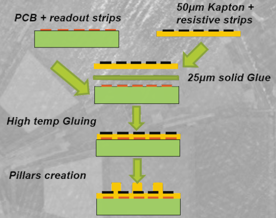
- For reliable construction of large size module the mesh is now decoupled from the readout plane.



Readout PCB production

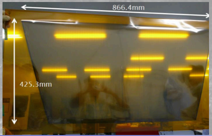
Resistive strips printed[1,2] on 50 μm kapton foil and are then glued on the readout PCB.

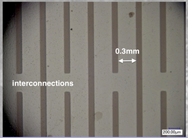
1. Screen printing 2. Sputtering



Interconnected resistive strips : **1. Homogeneous resistivity 2. Insensitivity to broken lines.**

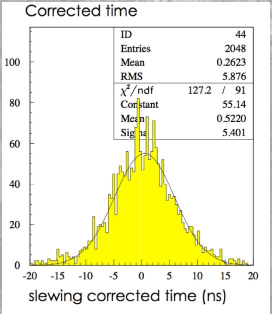
- Homogeneous resistivity
- Insensitivity to broken lines

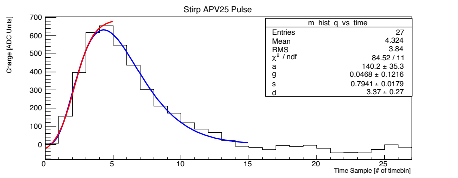


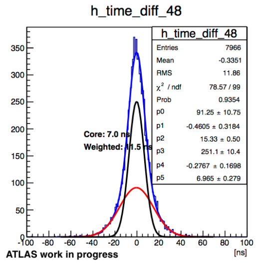


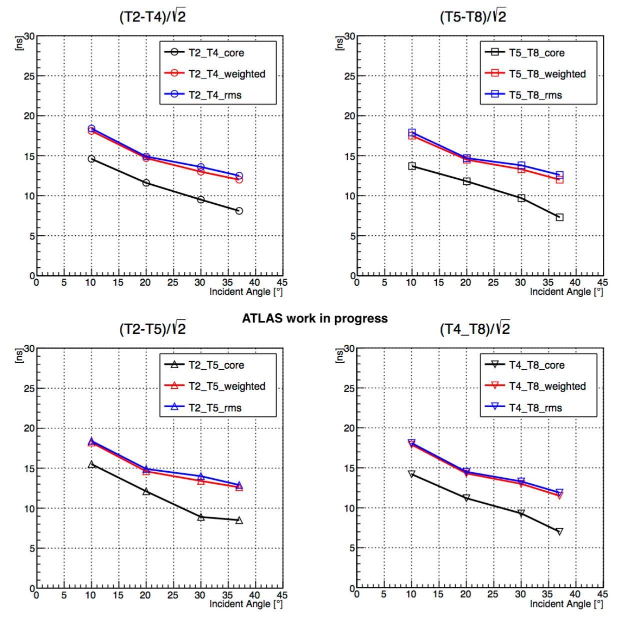
Chambers are readout using with APV25 chips, readout via the Scalable Readout System (SRS) developed by the RD51 Collaboration.

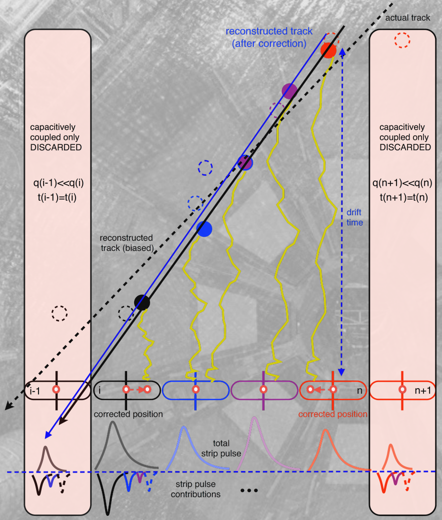
- For the μTPC mode operation a good time resolution is essential (<10 ns)
- APV 25 chip samples signal at 25 ns
- Extracting the time by fitting the signal limits our time resolution to 11-12 ns (first hit time difference between 2 chambers)
- Intrinsic Micromegas time resolution measured to be in the order of 5-6 ns

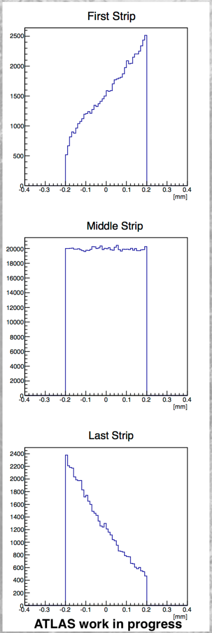






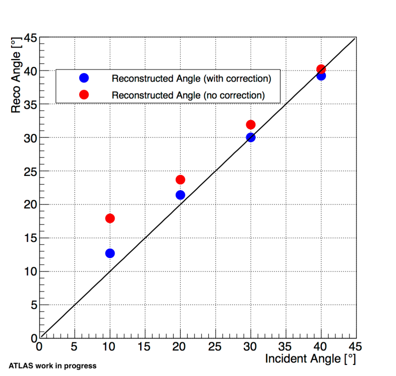

(T2-T4)/√2
[ns]
T2_T4_core
T2_T4_weighted
T2_T4_rms
Incident Angle [°]
(T5-T8)/√2
T5_T8_core
T5_T8_weighted
T5_T8_rms
ATLAS work in progress
(T2-T5)/√2
T2_T5_core
T2_T5_weighted
T2_T5_rms
(T4_T8)/√2
T4_T8_core
T4_T8_weighted
T4_T8_rms

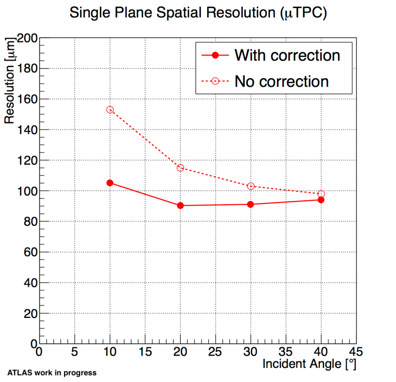


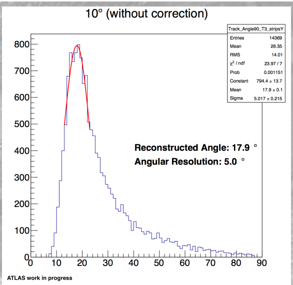


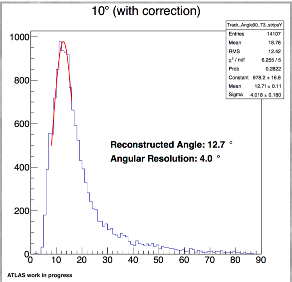
- Filter out induced-only charged strips.
- Fine tuning of the charge position along the strip pitch.

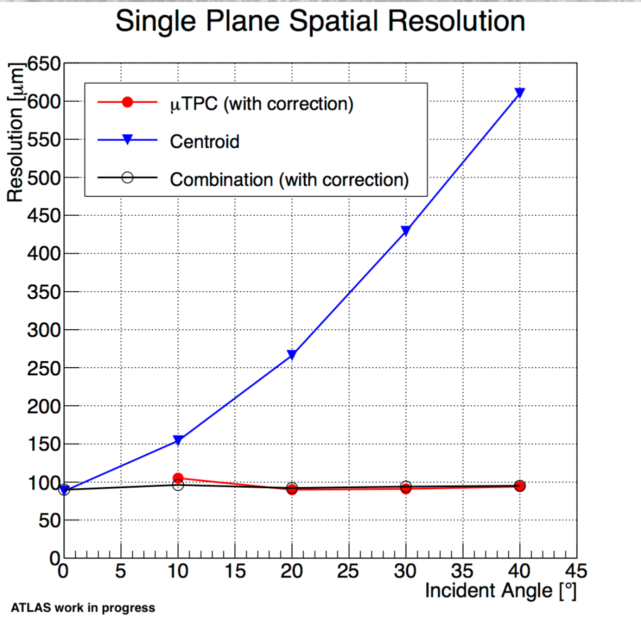
Refinement of μTPC

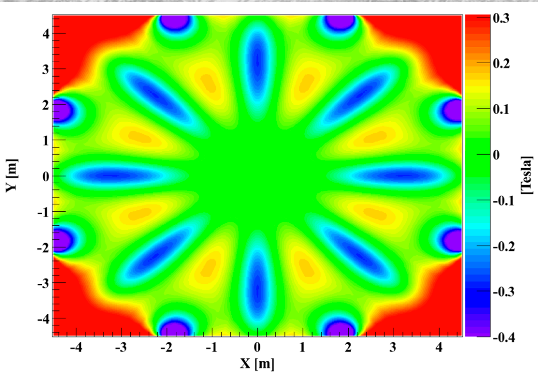









Single Plane Spatial Resolution
Resolution [µm]
650
600
550
500
450
400
350
300
250
200
150
100
50
0
µTPC (with correction)
Centroid
Combination (with correction)
0
5
10
15
20
25
30
35
40
45
Incident Angle [°]
ATLAS work in progress


Y [m]
X [m]
[Tesla]
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4