The ATLAS New Small Wheel Upgrade Project

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On behalf of the ATLAS Muon Collaboration

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Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ ΚΑΙ ΘΡΗΣΚΕΥΜΑΤΩΝ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

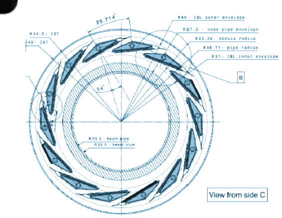
Outline

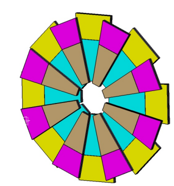
- ✓ Motivation for the New Small Wheel Upgrade
- ✓ New Small Wheel Upgrade - What is Involved?
- ✓ Micromegas & STGC Technology
- ✓ Performance
- ✓ Summary

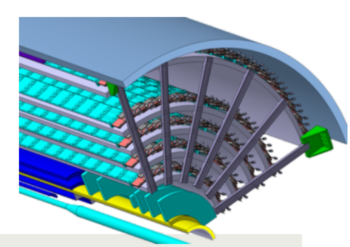
ATLAS Future Upgrades

LHC Upgrade Schedule

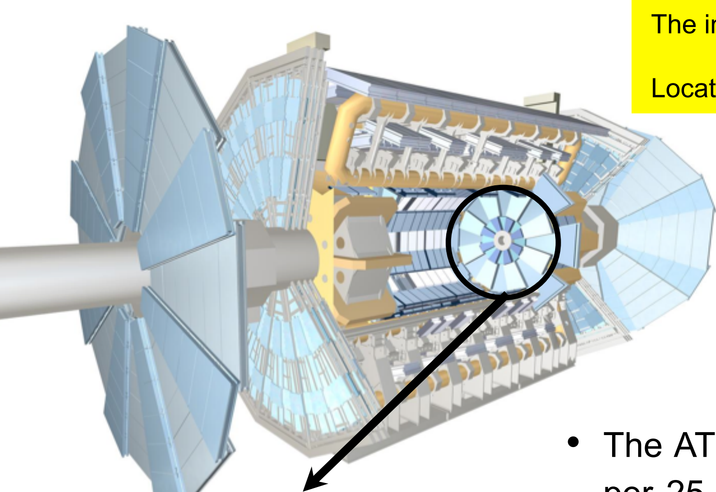
- **Phase 0 (installed):**
  - **new Pixel Inner B-Layer**
- **Phase I (approved):**
  - **Fast Track Trigger (electronics)**
  - **LAr (trigger electronics)**
  - **TDAQ**
  - **<u>NSW (New Small Wheel)</u>**
- **Phase II (planning): Replace complete inner detector**







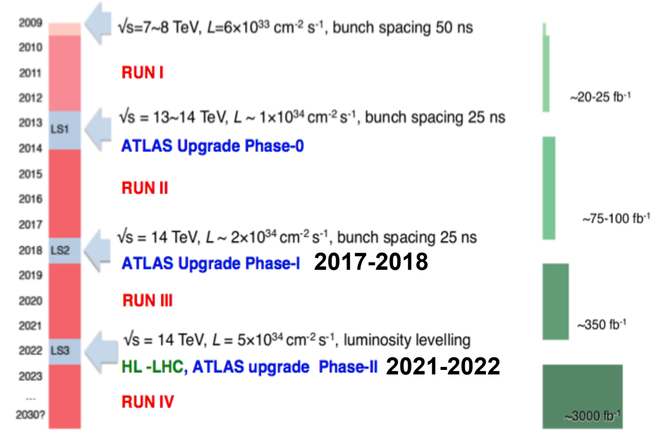
Motivation ATLAS Small Wheel Upgrade 2017-18 (Phase I)

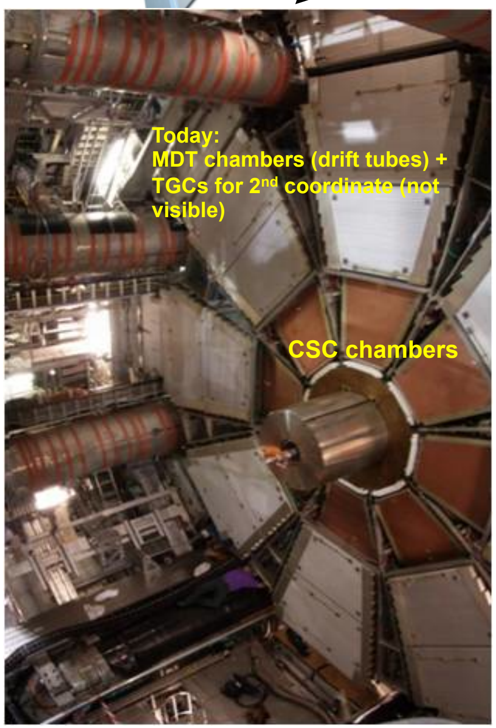


The innermost station of the muon endcap

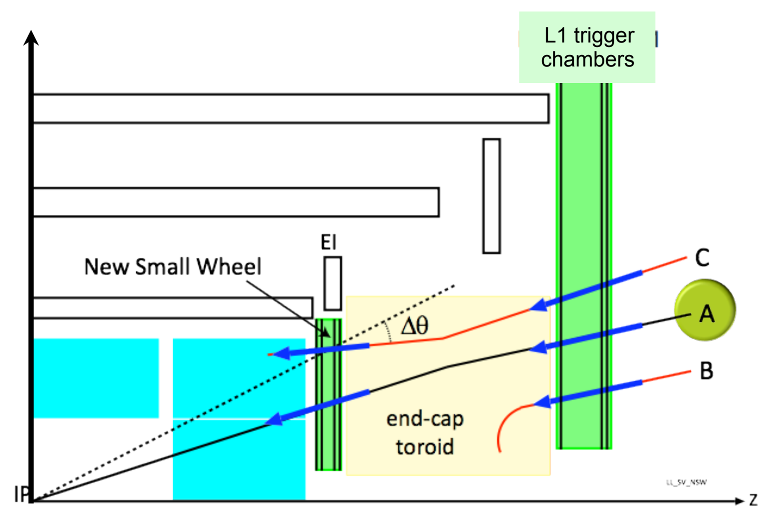
Located between endcap calo and toroid

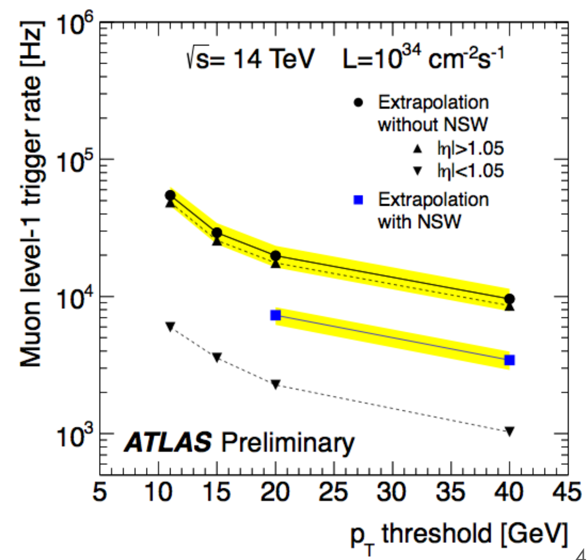
Pseudorapidity coverage:
$1.3 < |\eta| < 2.7$





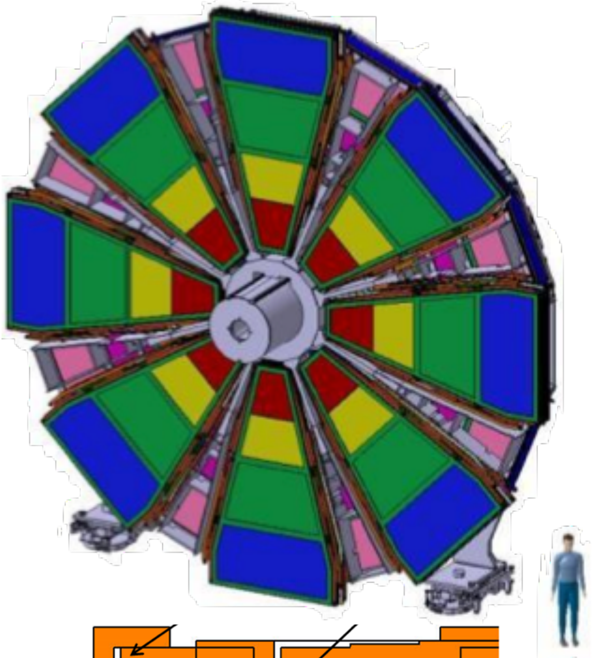
- The ATLAS upgrade is motivated primarily by the pile-up rate ($\langle n \rangle$=55 interactions per 25 ns bunch crossing) that are expected at $L=2\times10^{34}$ cm^{-2}s^{-1}. This will lead to an increased particle flux (rate) which the present detectors (MDT + CSC) cannot handle efficiently. Also, added trigger capability.
- Replacing the Small Wheels with a detector that can provide precise tracking and trigger segments will eliminate fake triggers without loss on physics acceptance.



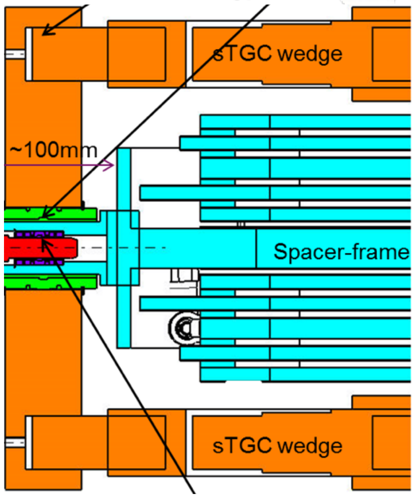


New Small Wheel – Layout 1/2

- <u>*Increased Phase I backgrounds (up to 15kHz/cm^2), the NSW must maintain existing trigger rate (total Level-1 rate is 100 kHz) - Trigger decision in 1μs latency*</u>

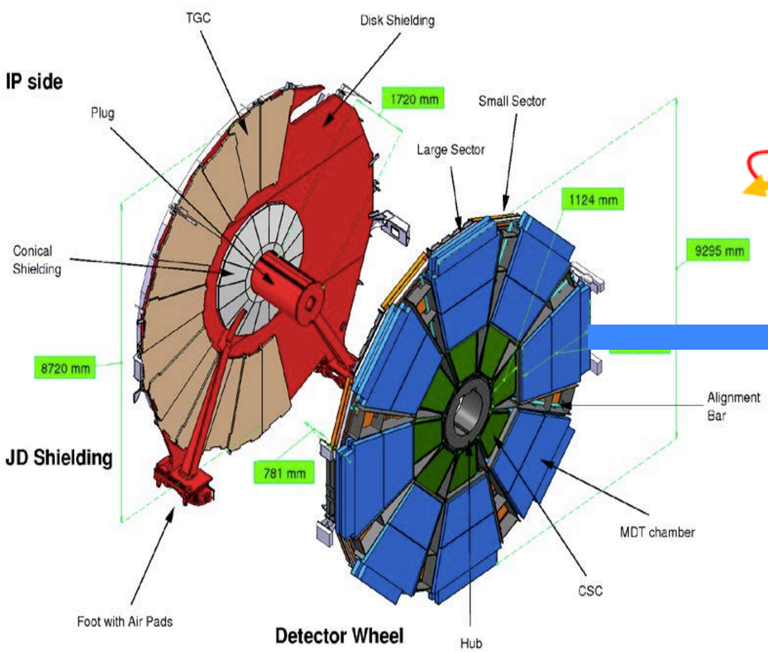


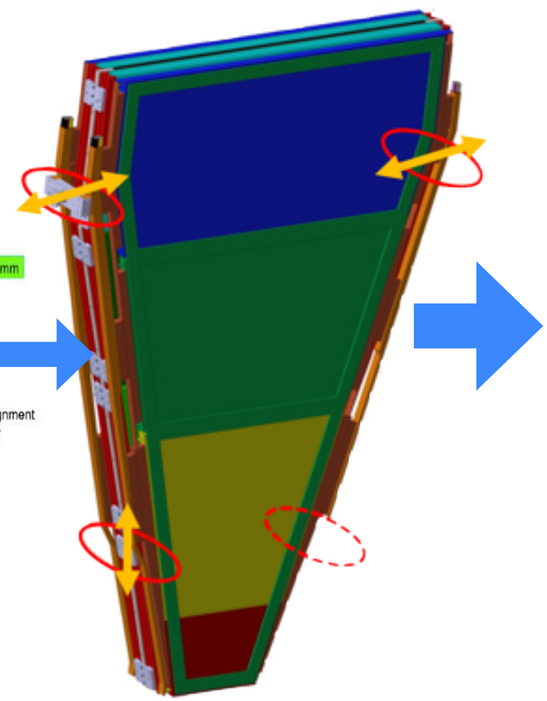
- Micro-Mesh Gaseous detectors (Micromegas): primary precision tracker
  - Space resolution ~ 100 μm independent of track incidence angle.
  - Good track separation due to small ~0.45 mm readout granularity (strips) and second coordinate measurement with stereo angle layout.
  - Excellent high rate capability due to small gas amplification region and small space charge effects.
  - 2.1M channels.
- "small-strip" Thin Gap Chambers (sTGC): primary trigger detector
  - Bunch ID with good timing resolution – additional suppression of fakes
  - Good space resolution providing track vectors with ~ 1 mrad angular resolution.
  - Based on proven TGC technology Pads & strips, instead of only strips as in current detector
  - 332K channels (incl. strips, wires, pads)

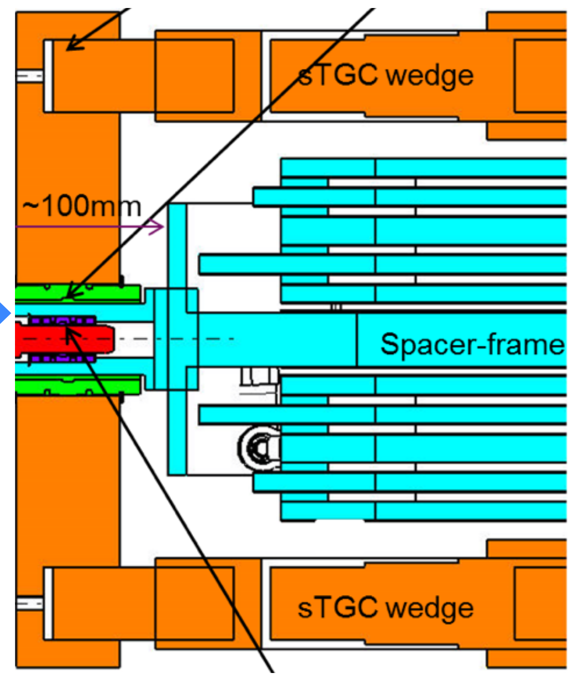


New Small Wheel (NSW) Layout 2/2

- Two technologies: Both Micromegas & sTGC detectors will provide tracking and trigger data
- 16 Sectors per Wheel (8 large, 8 small)
- 2 Multilayers per Sector for Micromegas & 3 Multilayers per Sector for sTGC
- 8 Micromegas Layers & 8 sTGC Layers per Multilayer

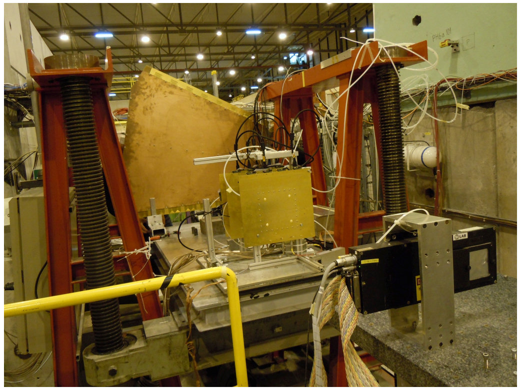




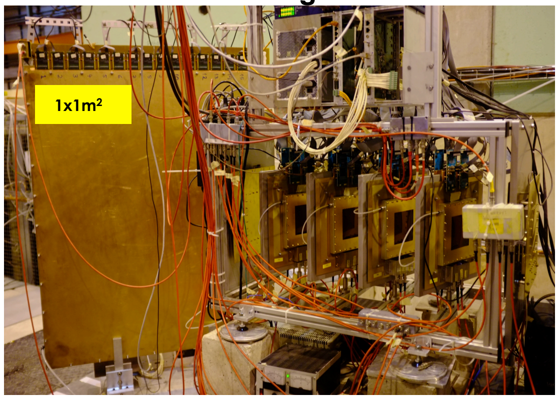


Full Development Time-Plan

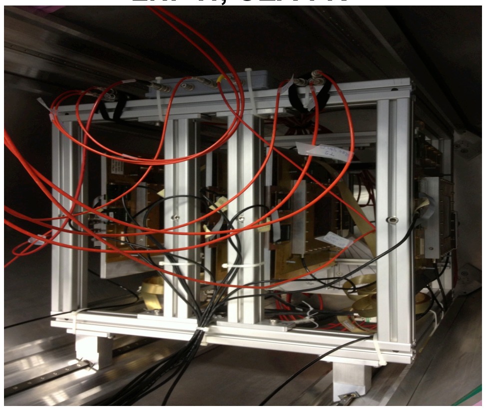
non-resistive MM, SPS/CERN, Demokritos-GR



resistive MM, SPS/CERN, Demokritos-GR, Garching-GE

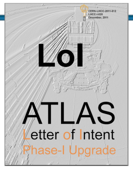


resistive MM, DESY II/DESY, LNF-IT, CEA-FR

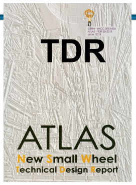


2008 2009 2010 2011 2012 2013

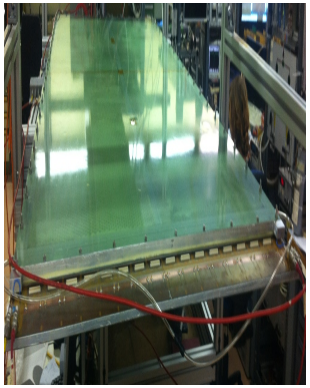
developed new MM technology



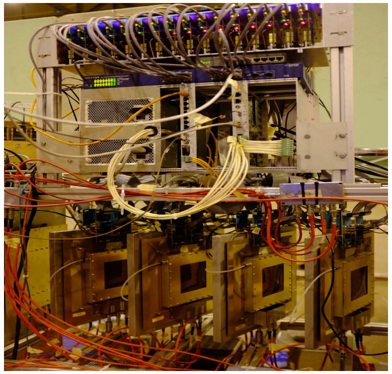
approved by ATLAS



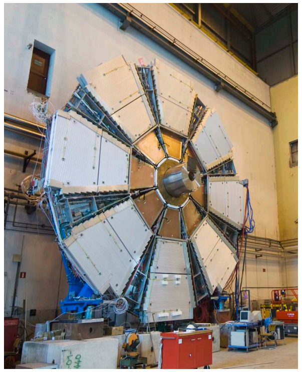
module-0 production & qualification



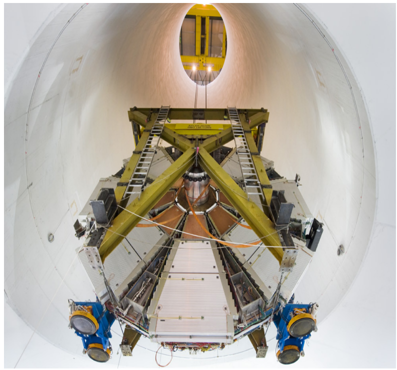
Full-production of chambers and electronics



Full commissioning on surface



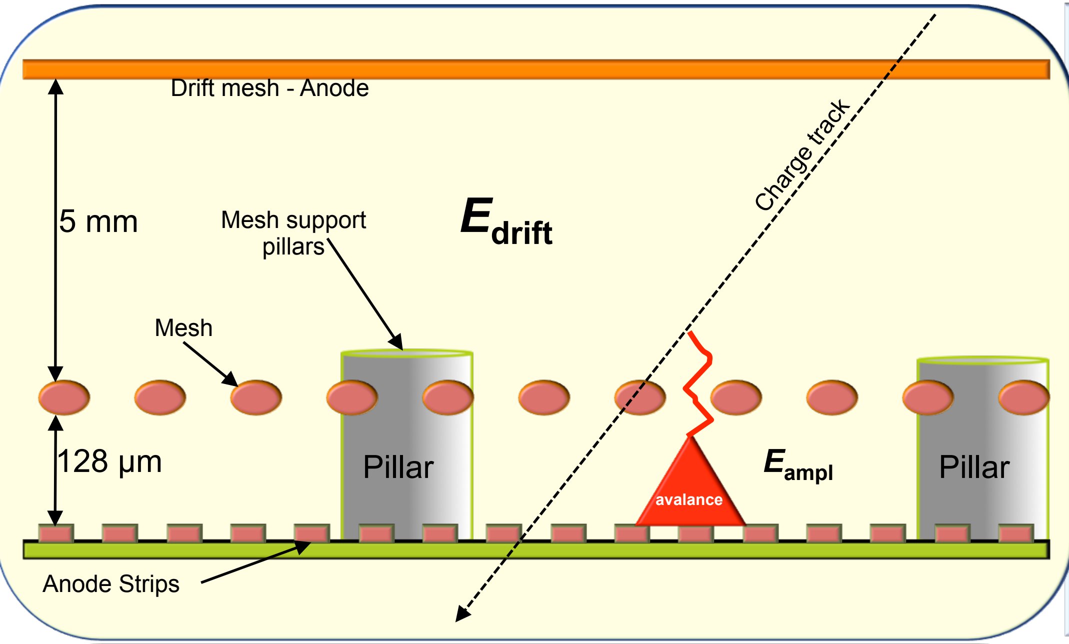
Full installation in cavern

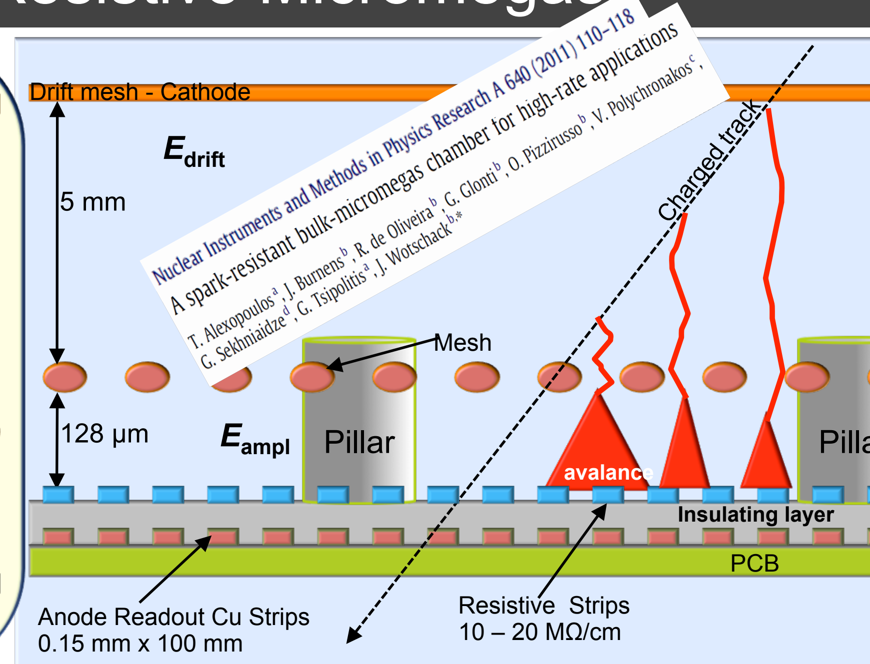


Running...

2014 2015 2016 2017 2018 2019

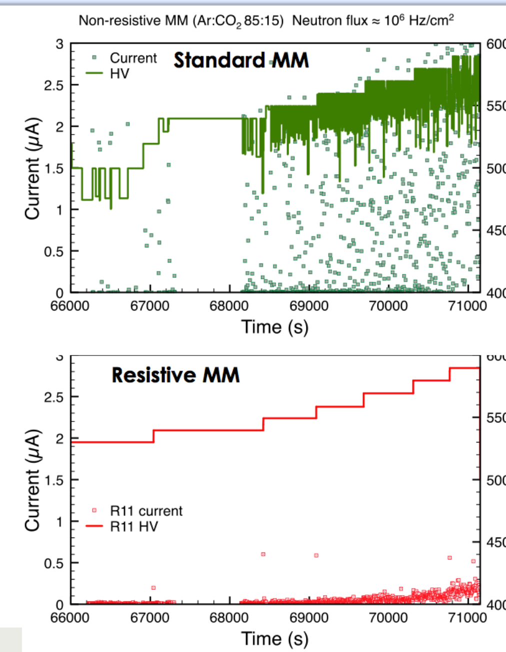
Micromegas technology - Resistive Micromegas





- 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
- The thin amplification gap (short drift times and fast absorption of the positive ions) makes it particularly suited for high-rate applications

Test in neutron beam (10^6 Hz/cm^2)



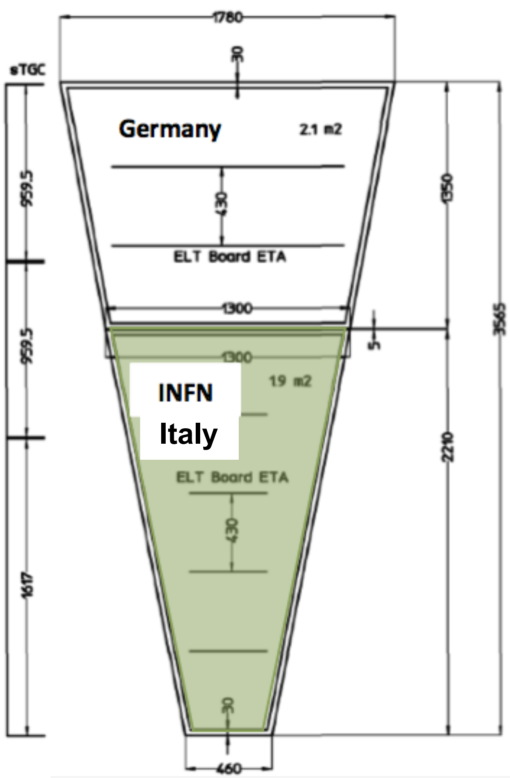
Micromegas Construction

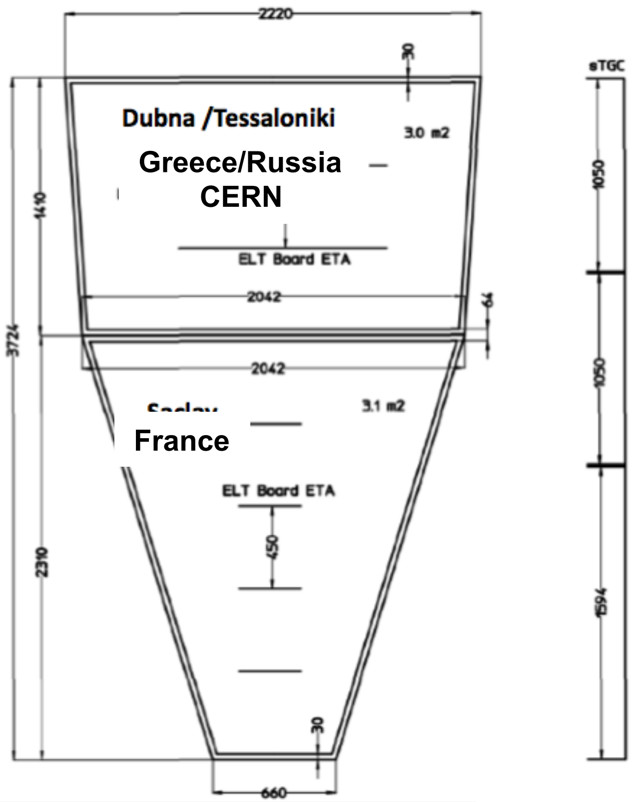
- Mechanics & Electronics is a multi-national operation; Mechanics: institutes from 6 countries, Electronics: Institutes from 10 countries (USA, Italy, Romania, Netherlands, Italy, Israel, Greece, France, Chile, Taiwan) -- Total: 30 Institutions are involved

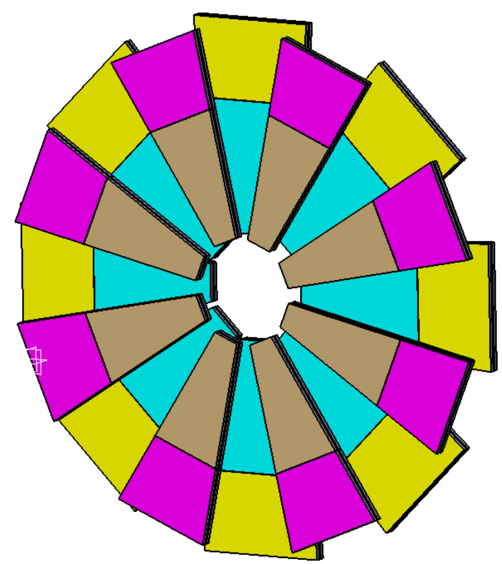
See talk by George Iakovidis on Electronics

- 8 layers of Micromegas detectors will equip each large & small NSW sectors; for half of the layers, the strips will be under a stereo angle to measure the second coordinate.

Total Surface	1200 m^2
Total number of MM Channels	2.1 M
Micromegas Strip Pitch	0.445 mm
Gas	$Ar:CO_2$ 93:7 atm pressure
Drift Gap	5 mm
Amplification Gap	128 μm
HV on Resistive Strips	550 V
Drift Field	600 V/cm
Resistive Strips	10-20 MΩhm/cm
Stereo Strips on 4/8 Layers	1.5°



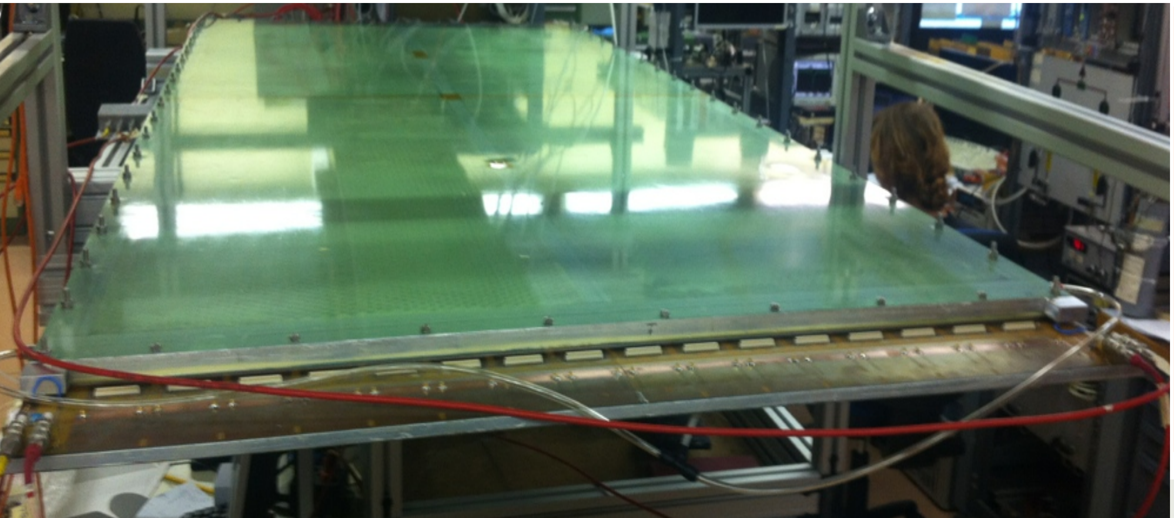




See talk by Dimos Sampsonidis on Micromegas contruction

Muon ATLAS MicroMegas Activity (MAMMA R&D)

- Last years mainly focused on R&D of resistive Micromegas to fulfill ATLAS milestones for the muon forward region upgrade.
- Had an extensive and intense test beam program. More than 22 weeks in the last 4 years.
- Construction & test of big prototypes 1.2 x 0.6 m^2, 1.0 x 1.0 m^2, 1.0 x 2.4 m^2.
- Test of Micromegas under the influence of a magnetic field.
- Validate performance and functionality of new front-end VMM ASIC.
- Several irradiation tests; neutrons, X-rays, alphas, gammas.
- Installation of Micromegas prototypes in the ATLAS cavern.



Main objectives of the tests were to demonstrate the achievement of the performance requirements needed for the upgrade of ATLAS. Among them:

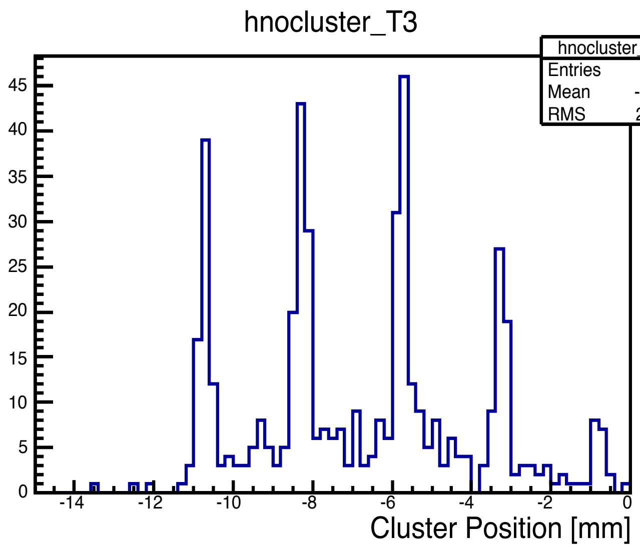
- Spatial resolutions for inclined tracks

→ demonstration of operation in micro-TPC mode

- Tracking performance under magnetic field
- Ageing with high irradiation tests
- Build large scale Micromegas
- Trigger capability

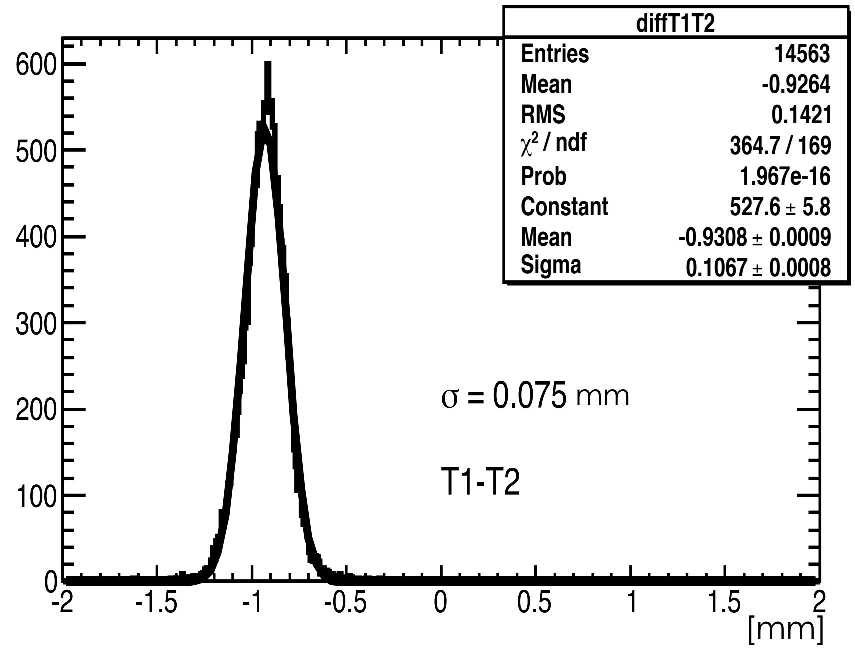
Micromegas Efficiency & Spatial Resolution for Normal Tracks

Distribution of local inefficiencies as measured from the missing hits on one chamber corresponding to a reconstructed track from the other chambers.



Global inefficiencies of <2% consistent with the partially dead area due to the presence of 300 μm diameter pillars separated by 2.5 mm.

Spatial resolution for perpendicular tracks estimated by difference of cluster charge centroid measurements of pairs of MM chambers.

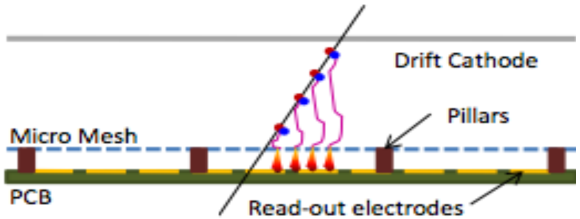


About 75 μm with an average cluster size of 3.2 strips (400 μm pitch).
Similar results obtained with a full track reconstruction method.

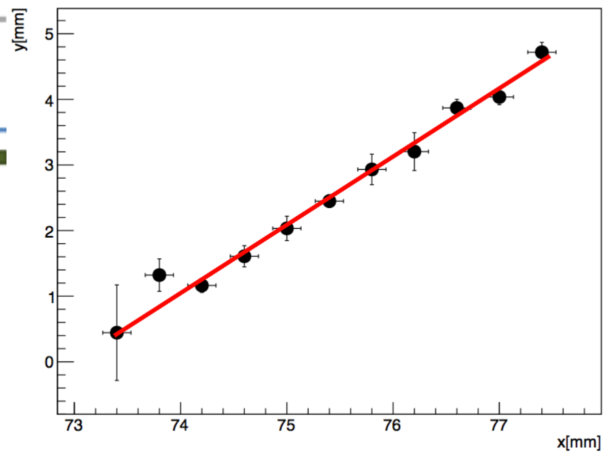
See talk by Kostas Ntekas on Micromegas performance

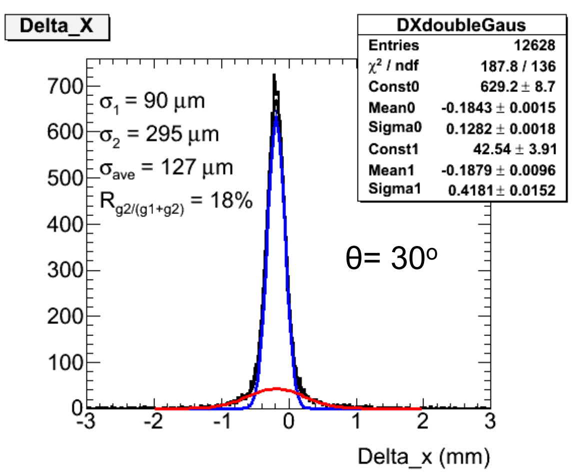
μTPC Mode for Incline Tracks

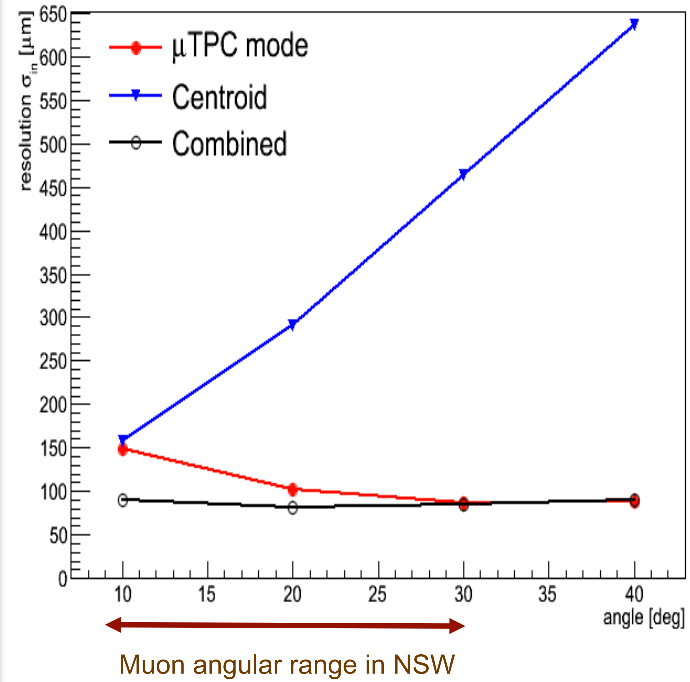
- Sub 100 μm spatial resolution easy to achieve for perpendicular tracks
- For inclined tracks need to exploit time information to operate in micro-TPC mode



Single Segment Reconstruction in a Micromegas



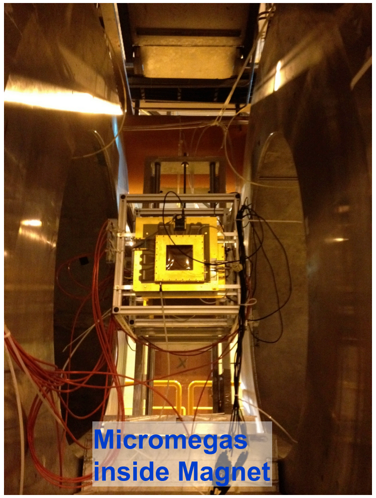


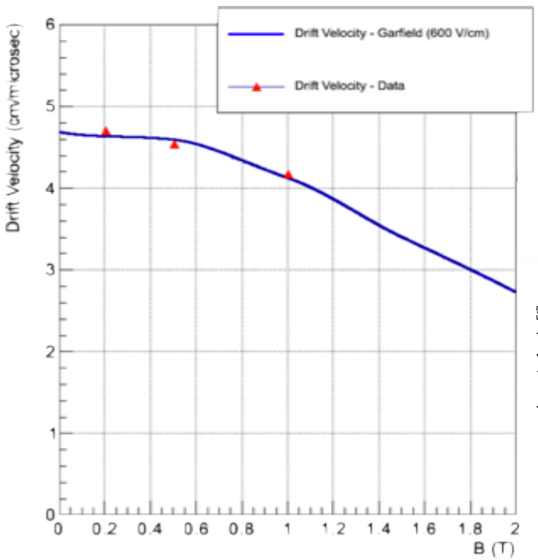


See talk by Kostas Ntekas on Micromegas performance

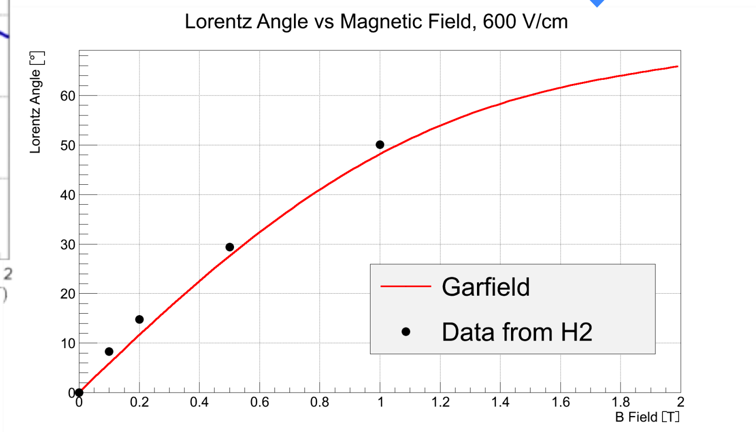
Micromegas Performance in *B*

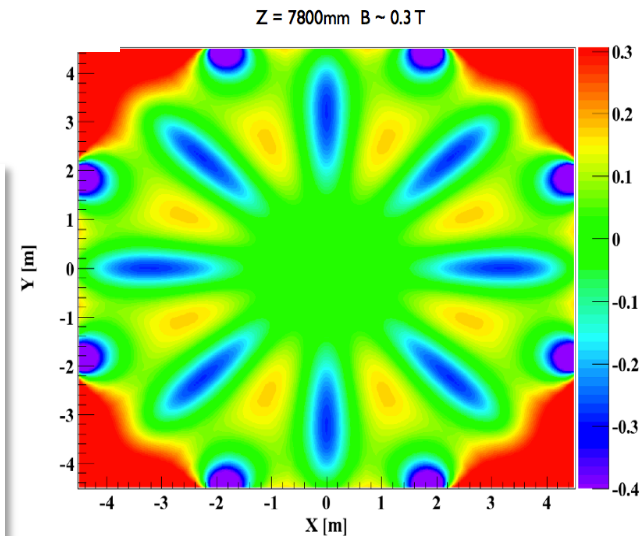
- ATLAS New Small Wheels will be operated in a mixed directional ***B*** field up to 0.4 T.
- Micromegas chambers tested successfully in a magnetic field up to 1 T showing no performance degradation.
- Lorentz angle & drift velocity measurements are in agreement with simulation.





Lorentz angle from perpendicular tracks; E_{drift} = 600V/cm

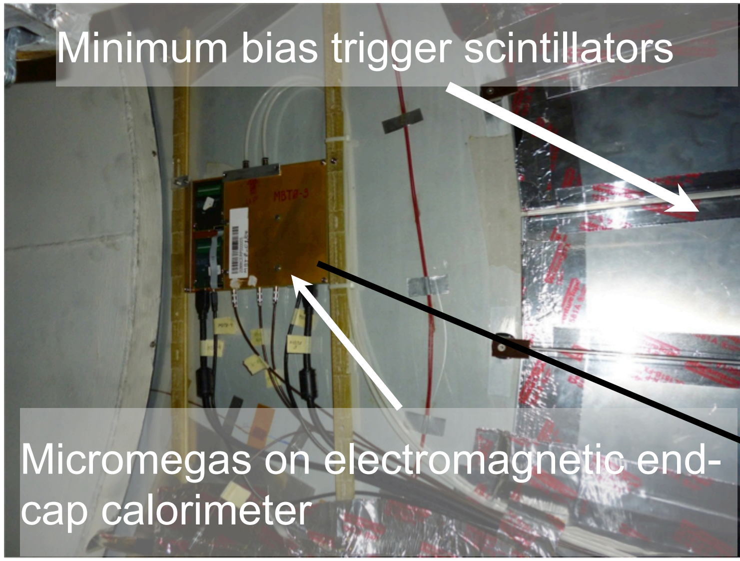


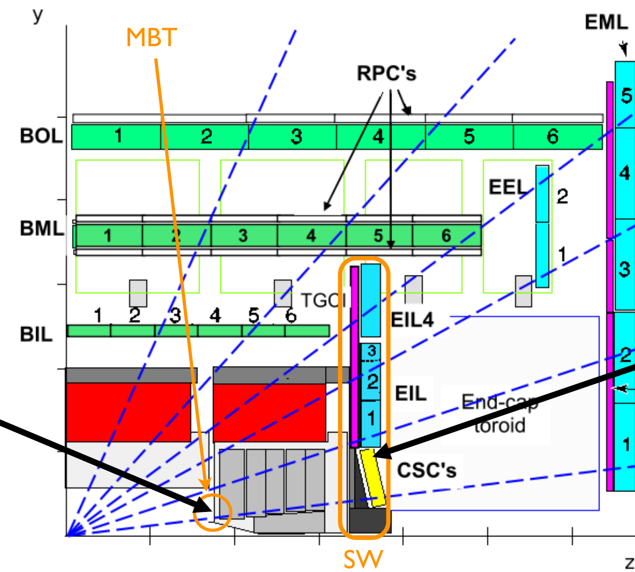


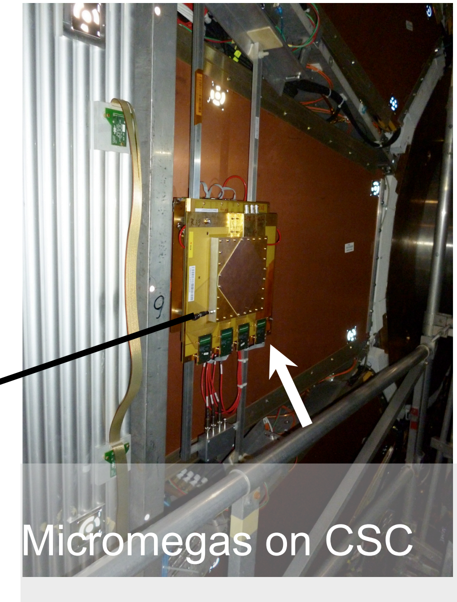
ATLAS End-Cap Toroid field

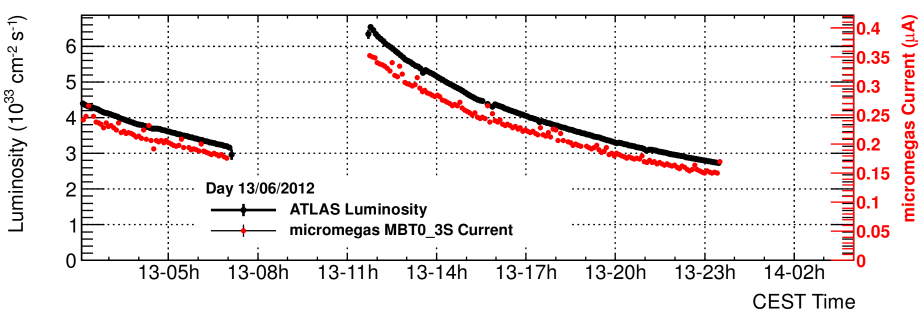
See talk by Kostas Ntekas on Micromegas performance

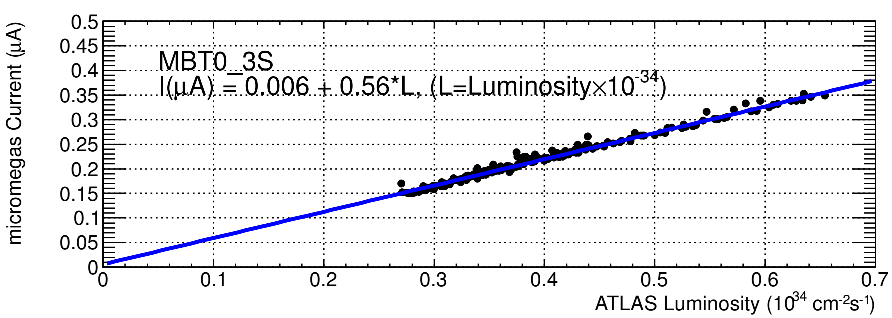
Micromegas Performance in ATLAS



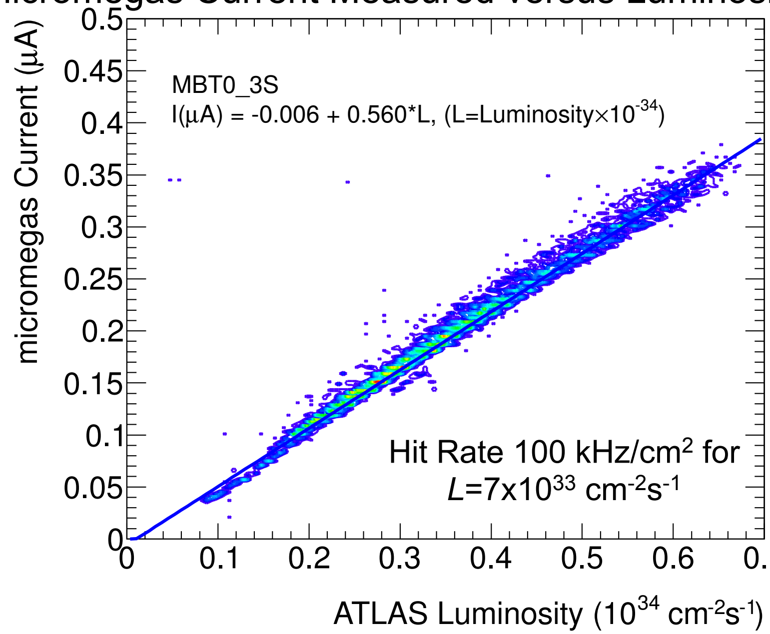




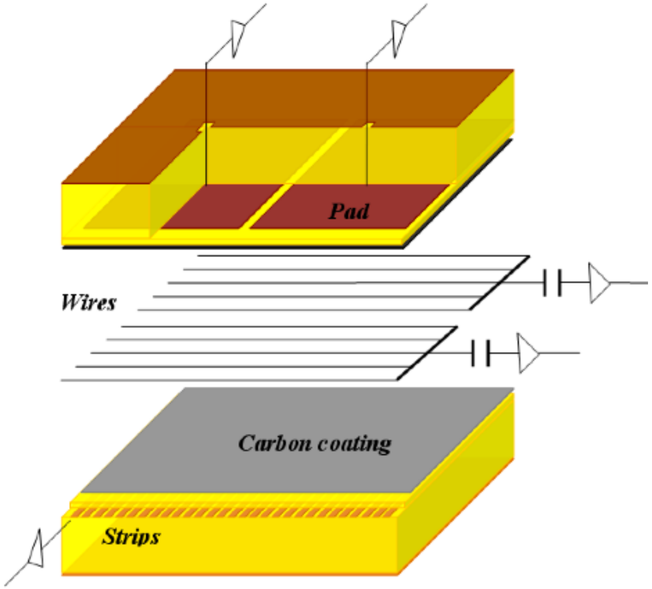




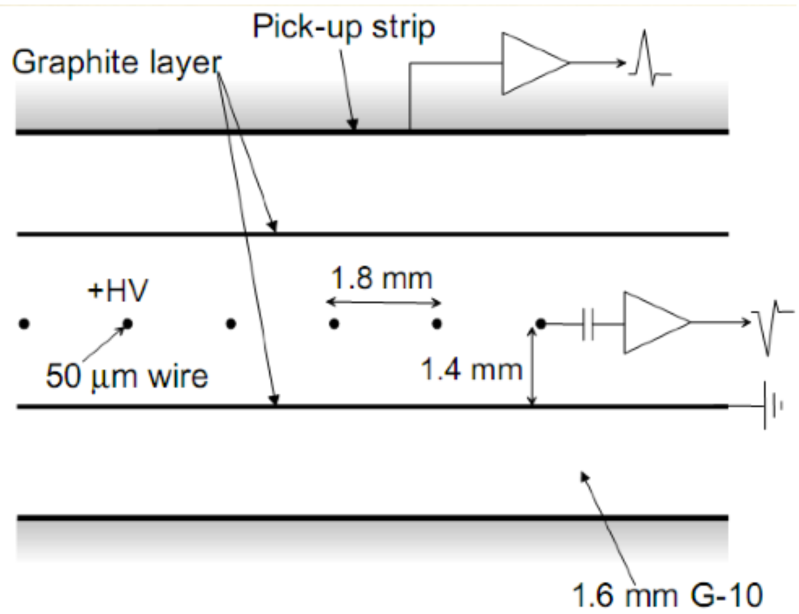
Micromegas Current Measured versus Luminosity



sTGC Technology



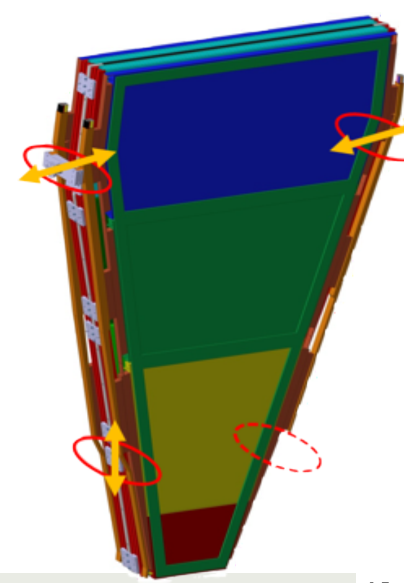
sTGC Geometry	
Wire-carbon gap	1.4 mm
Wire-wire gap	1.8 mm
Strip pitch	3.2 mm
Gas mixture	CO_2:n-pentane (55:45)
Wire potential	2.9 kV



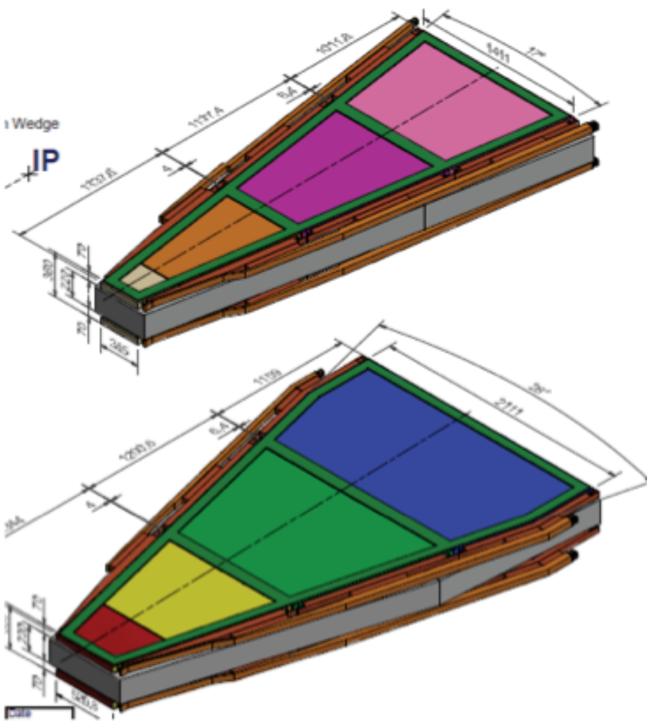
Quadruplet:

- 4 wire planes
- 4 strip planes
- 4 pad planes

2 Quadruplets/plane



sTGC Construction

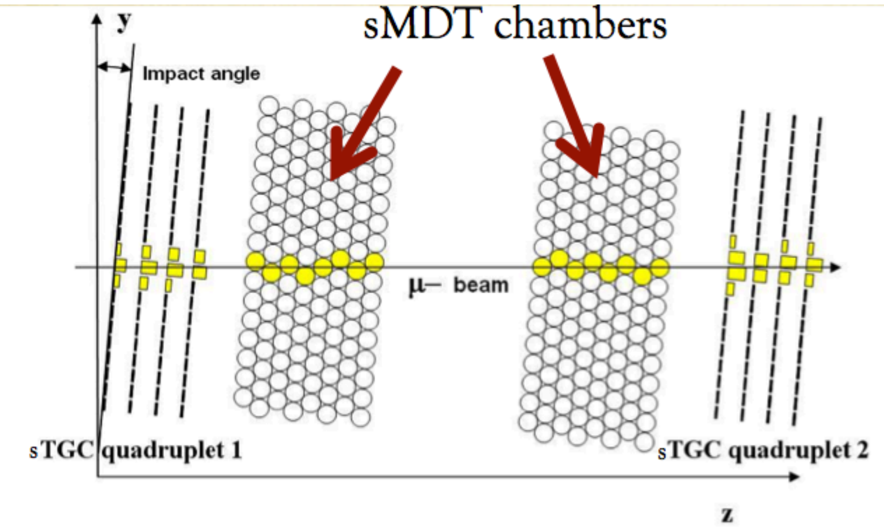


- Six different module types
- Production sites: Canada, Chile, China, Israel & St. Petersburg

Graphite spraying machine @ Weizmann: In place and ready

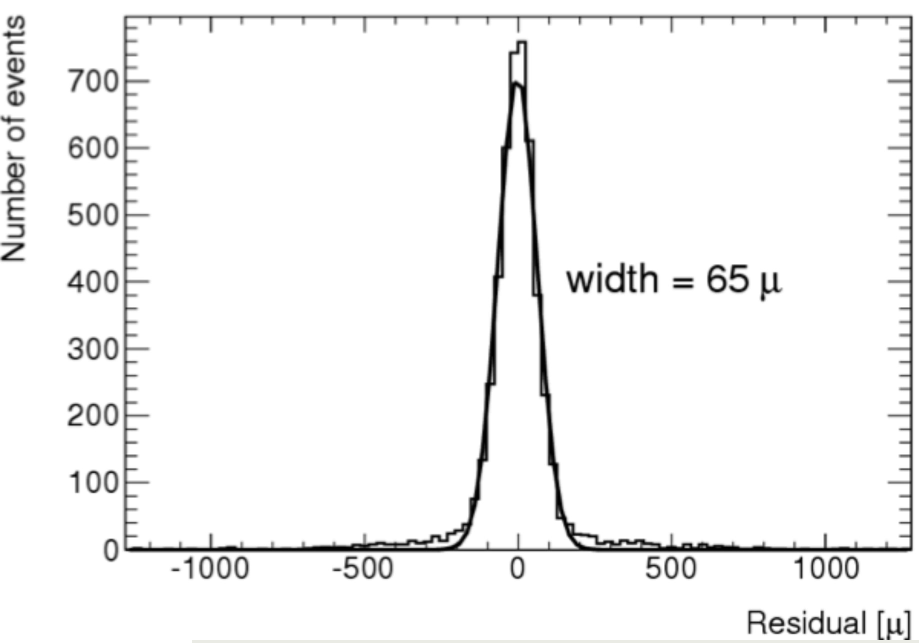
Wire winding machine @ Weizmann installed end 2013, same controls purchased by Chile and Canadian groups

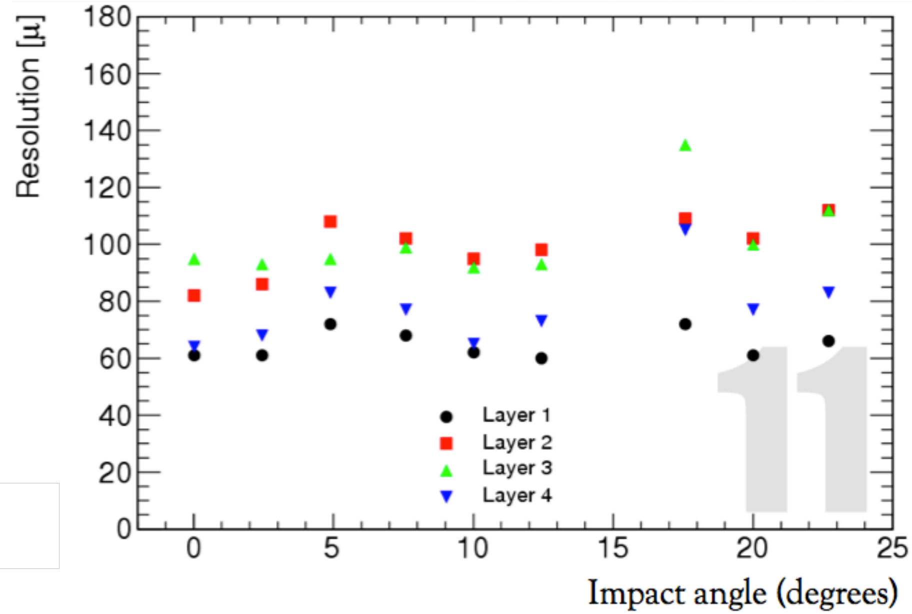
sTGC Performance – Position Resolution



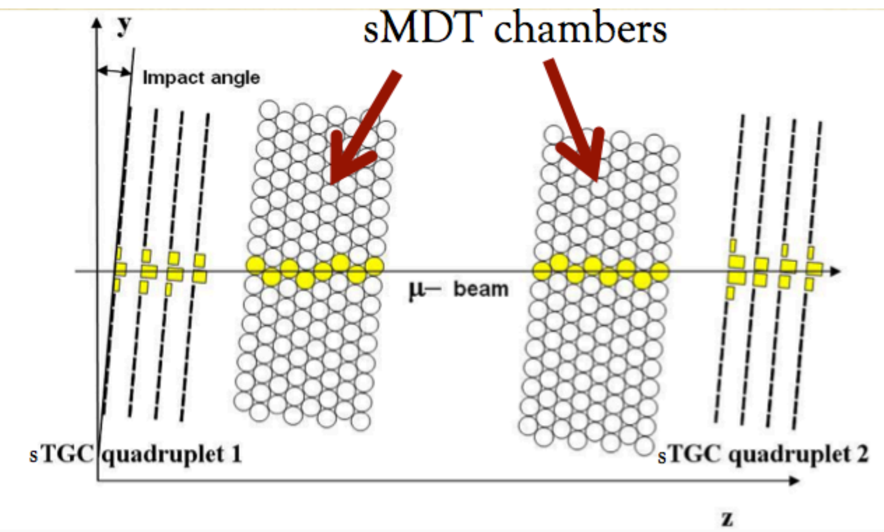
Using muons 180GeV/c in a testbeam @ SPS

- **Test two sTGC quadruplets**
- **Position resolution**
- **Position resolutions vs Impact angle**



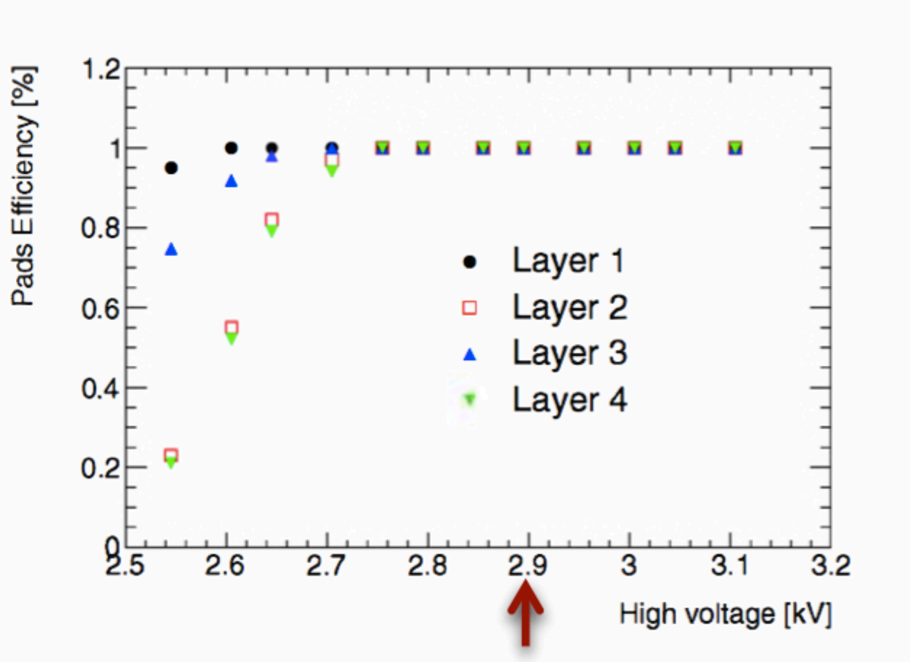


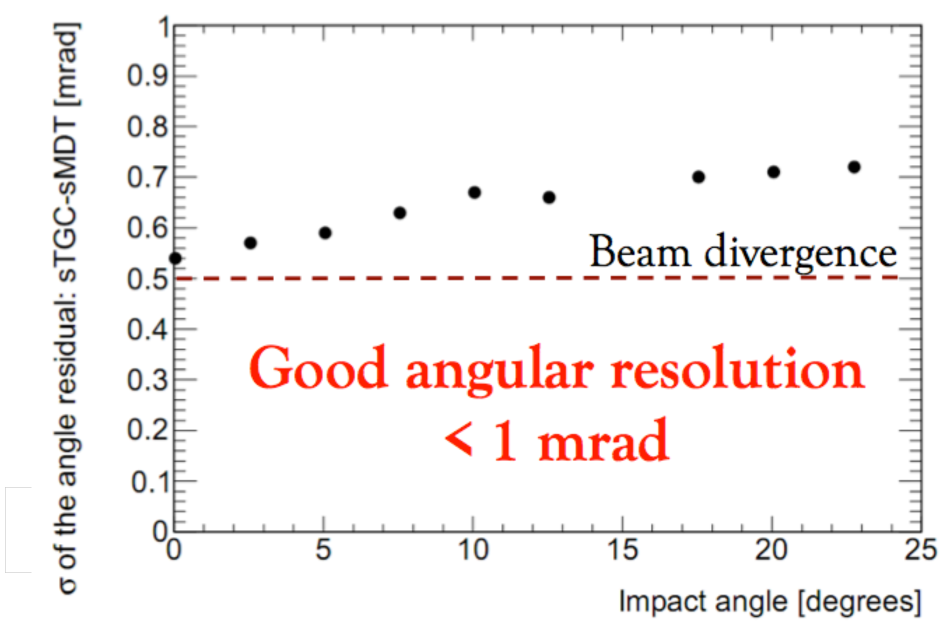
sTGC Performance – Angular Resolution



Using muons 180GeV/c in a testbeam @ SPS

- **Test two sTGC quadruplets**
- **Efficiency vs applied HV; efficiency above 99% for all layers above 2.75 kV!**
- **Angular resolution vs Impact angle; good angular resolution less than 1 mrad!**

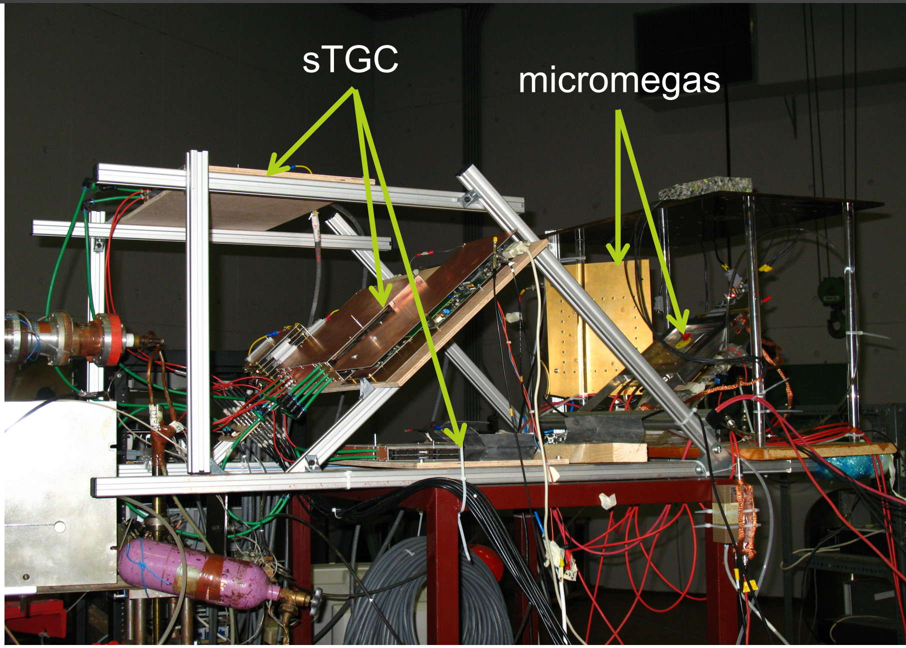


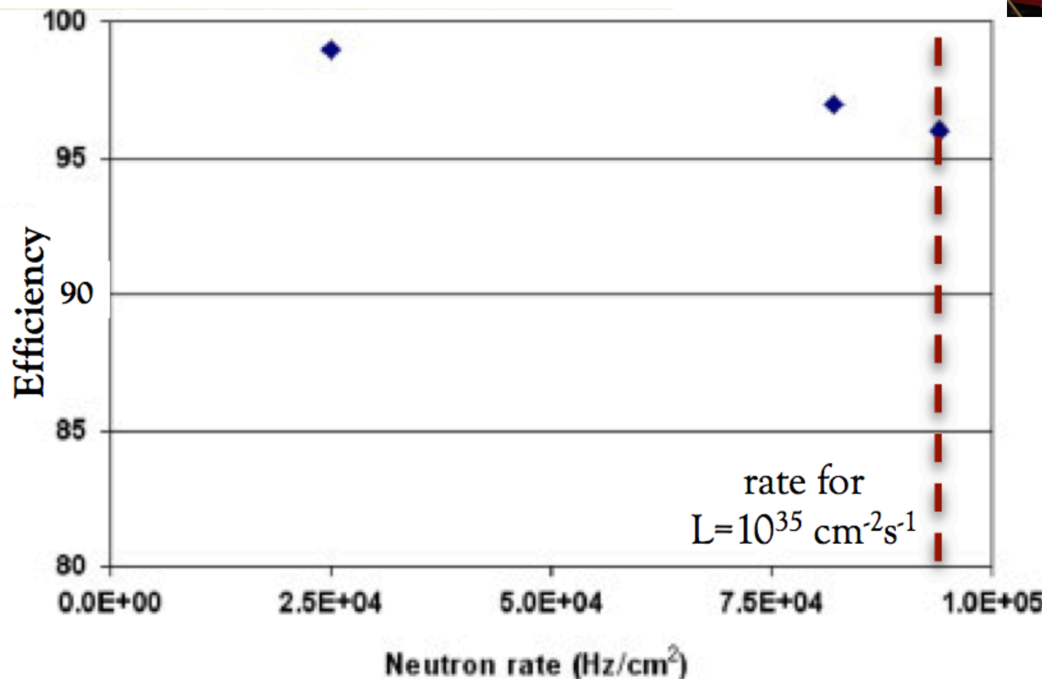


sTGC Performance – Irradiation w/ Neutrons

Using neutrons in Demokritos, Greece:
Cosmic tracking under neutron irradiation
5.5-6.5 MeV neutrons produced in $^2H(d,n)^3He$

- **No drastic degradation of the efficiency: less than 4% at the highest dose rate**
- **No sparks observed**





Summary

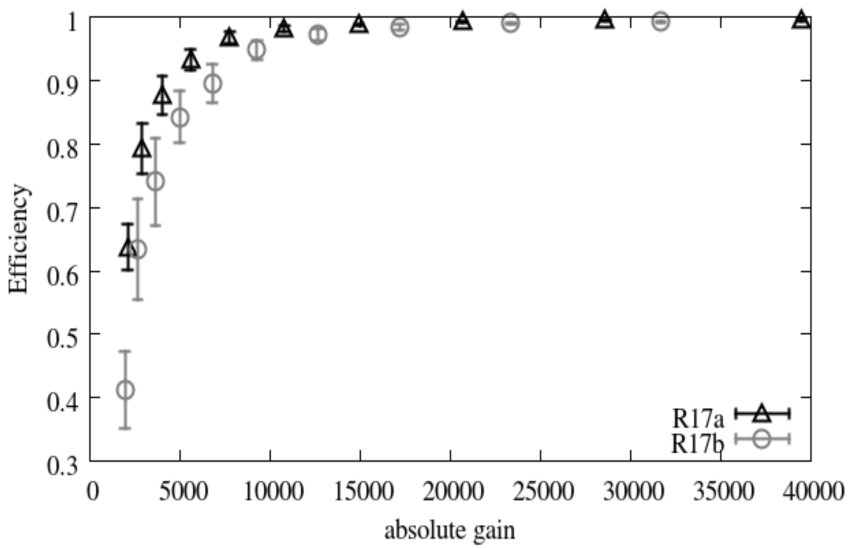
- ✓ A Heavy & Intense NSW Upgrade Program Ahead of Us
- ✓ NSW activities in Full Swing
- ✓ In the Process of Developing Micromegas for the Upgrade of the ATLAS NSW a Series of Tests Have Been Conducted
- ✓ Micromegas is a Matured Technology along with the Robust sTGC Technology
- ✓ All Performance Requirements are Fulfilled!

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ ΚΑΙ ΘΡΗΣΚΕΥΜΑΤΩΝ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

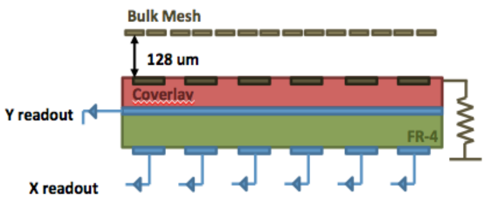
Ageing Performance Studies

Extensive program of irradiations on small prototype (10x10 cm^2) performed at C.E.A. Saclay, Orphee reactor,

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 x 10^8 sparks equivalent	No evidence of ageing



Both detectors reach efficiencies of about 99.5% for the highest values of the gain, proving that there is no visible degradation effect in these measurements



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 SPS/ CERN.
- 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.

Performance evaluated in terms of efficiency and spatial resolution