Development of Micromegas detectors for the ATLAS Muon System upgrade

Paolo Iengo (INFN - Napoli)

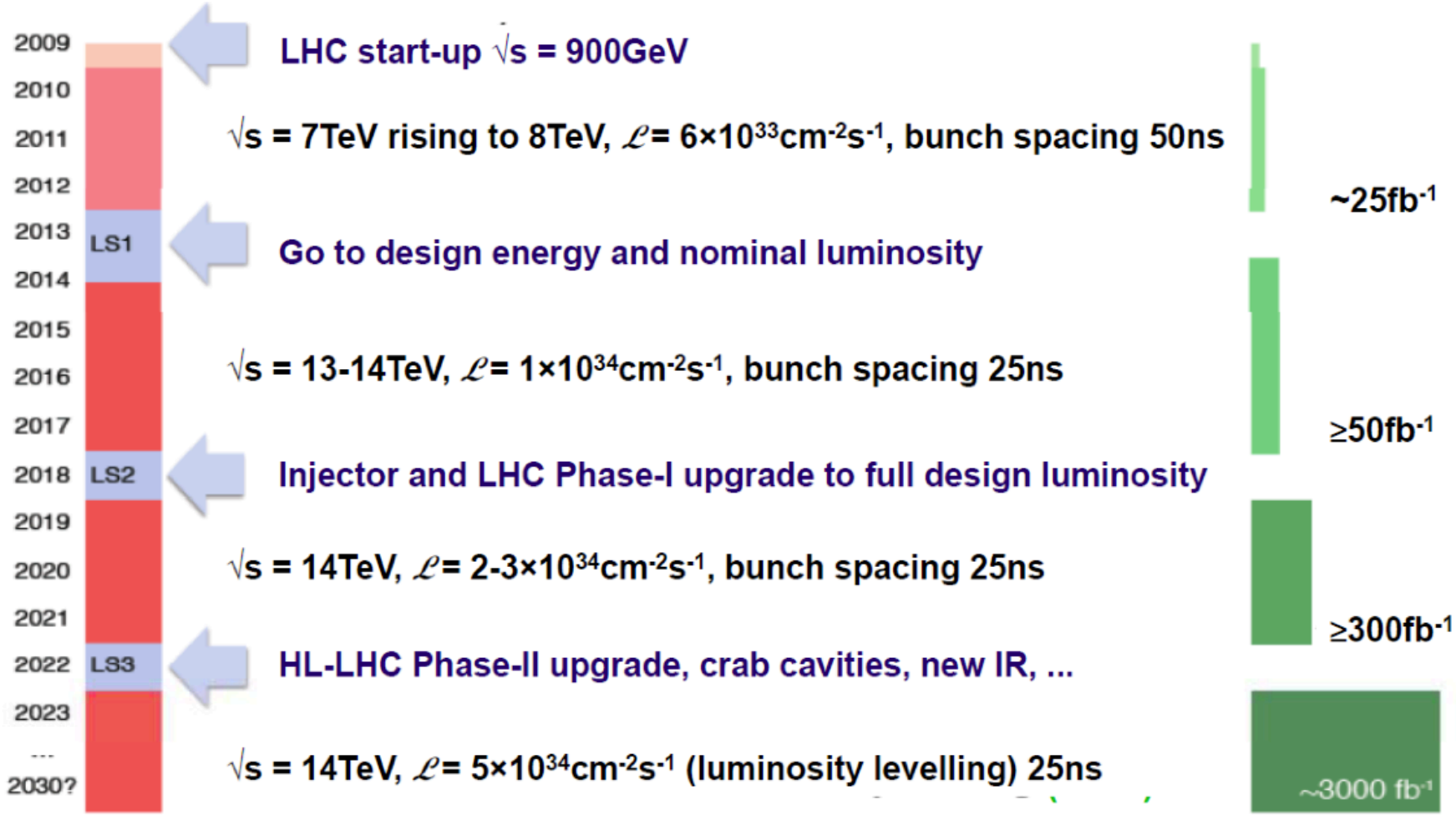
On behalf of the MAMMA* Collaboration

*Muon ATLAS MicroMegas Activity

Arizona, Athens (U, NTU, Demokritos), Brandeis, Brookhaven, CERN, Carleton, Frascati, Istanbul (Bogaziçi, Doğuş), JINR Dubna, MEPHI Moscow, LMU Munich, Naples, CEA Saclay, USTC Hefei, South Carolina, Thessaloniki

Introduction

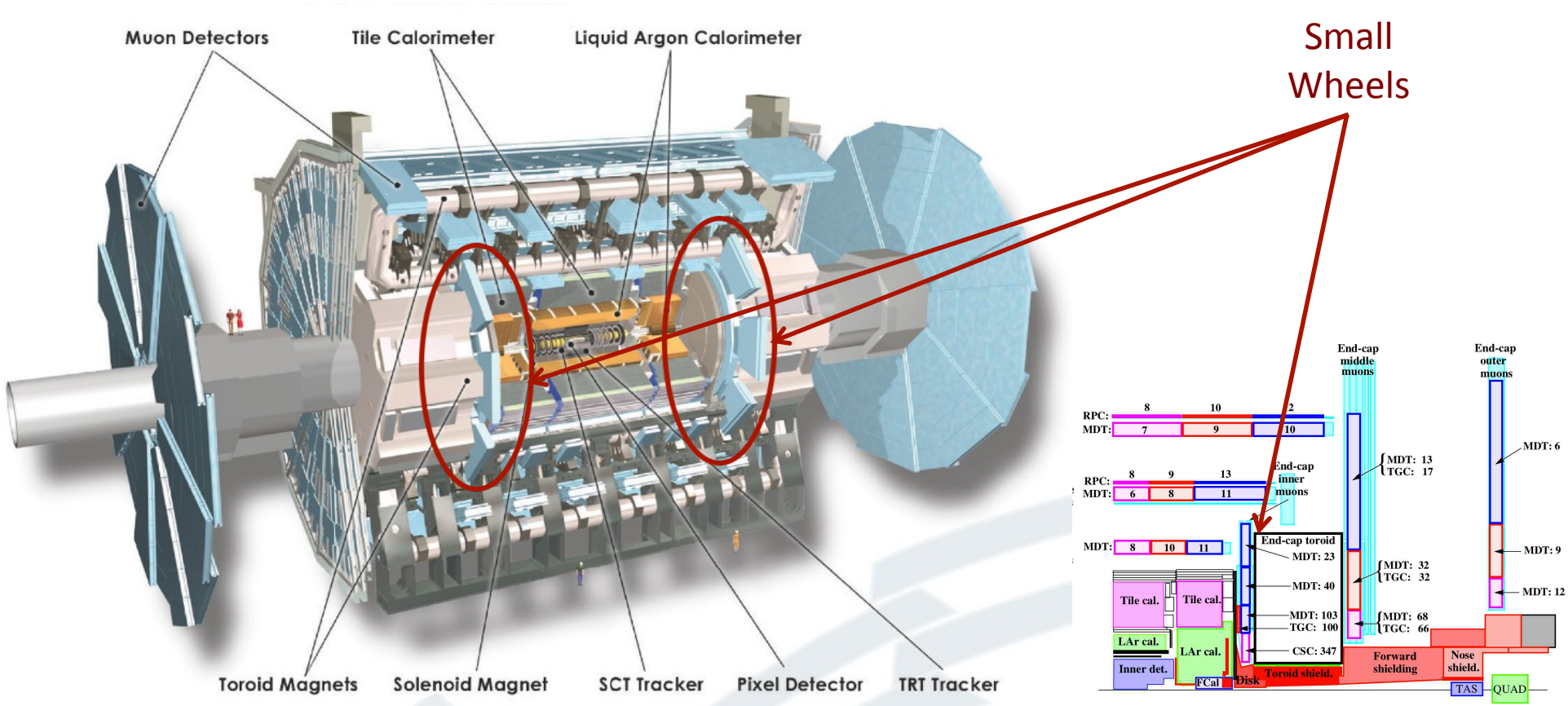
- LHC schedule: towards 3000 fb^{-1}



https://indico.cern.ch/getFile.py/access?contribId=31&sessionId=5&resId=1&materialId=slides&confId=164089

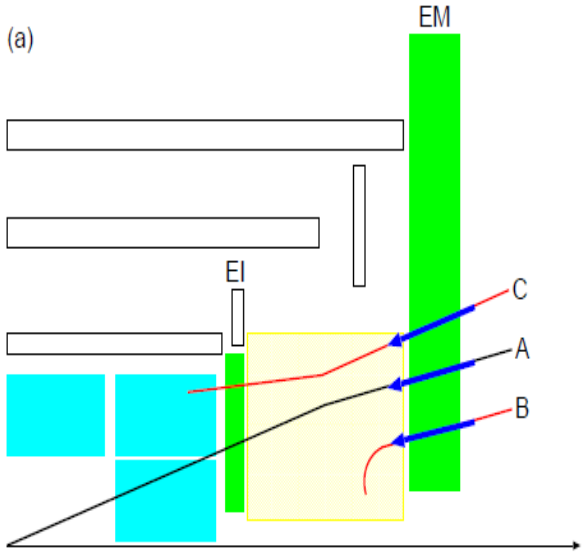
Upgrade of ATLAS Muon Spectrometer

- Small Wheel muon chambers need to be upgraded in phase I
  - Present detectors will reach their rate limit at ~$5x10^{34}$ $cm^{-2}s^{-1}$
  - Reduce the fake rate at p_T>20GeV (at present small wheel not used in LVL1 trigger)
  - Improve p_T resolution to sharpen thresholds

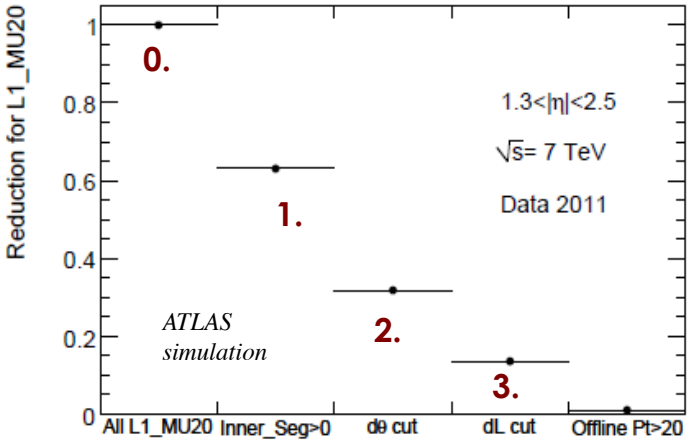


The New Small Wheel

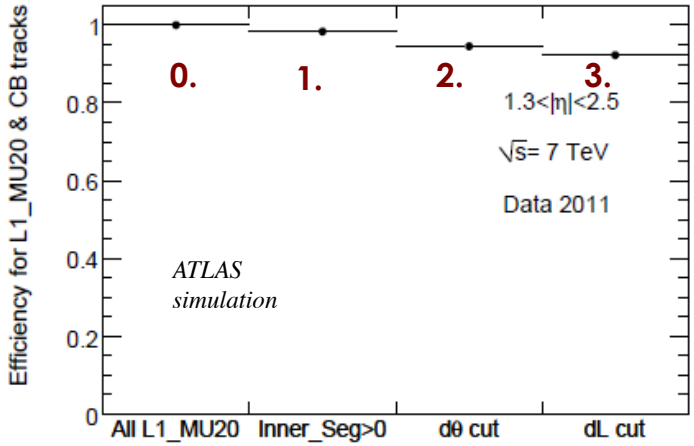
- Reduction of fake rates with NSW:
  - 0. w/o NSW
  - 1. requiring the presence of a segment in NSW
  - 2. requiring NSW segment pointing to IP (ϑ<1mrad)
  - 3. requiring NSW segment matching in (η,ϕ) the EM muon chamber trigger segment



Reduction of L1_MU20 trigger rate



Efficiency of L1_MU20 trigger



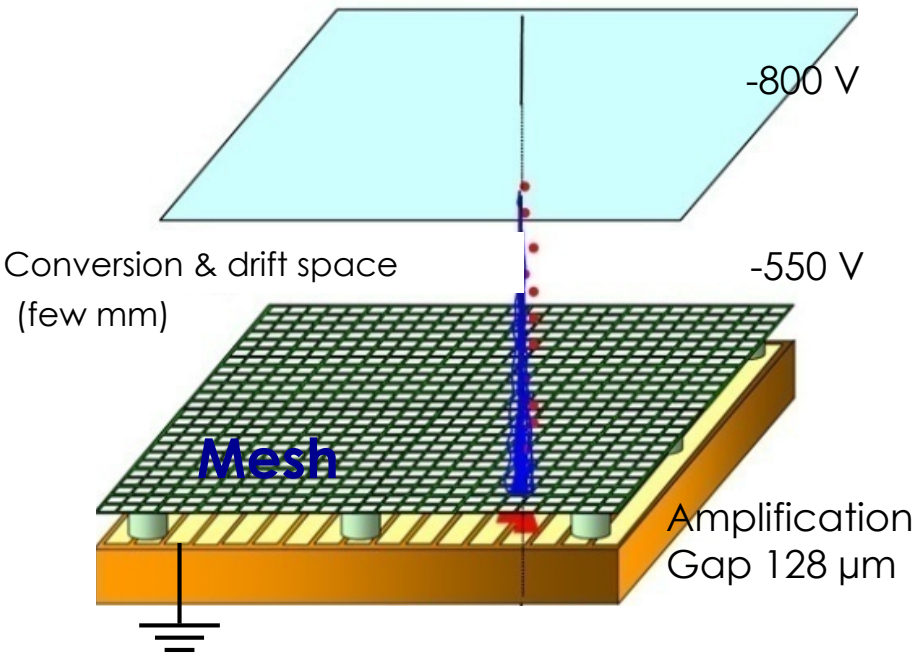
- Three options proposed for NSW:
  - sMDT+sTGC
  - sMDT+mRPC
  - Micromegas

The MAMMA Project

Replace the muon chambers of the Small Wheels with 128 micromegas chambers (0.5–2.5 m^2)

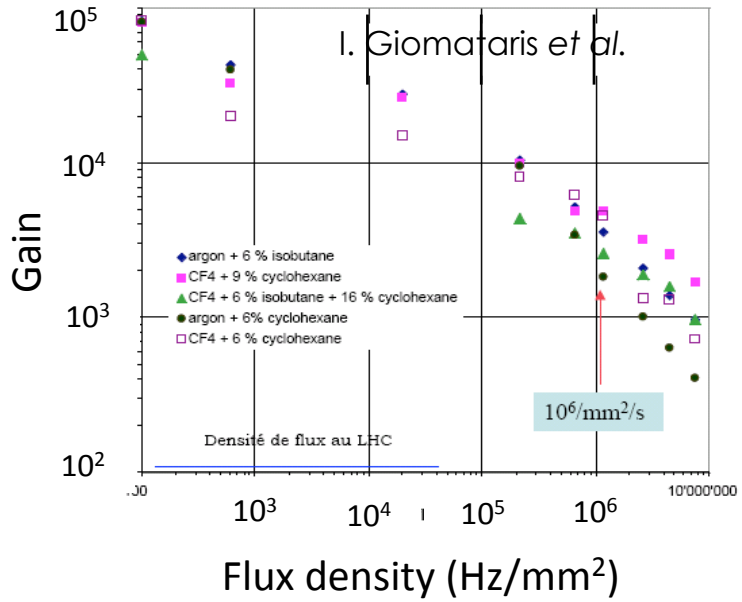
- Combine precision and 2nd coord. measurement as well as trigger functionality in a single device
- Each chamber comprises eight active layers, arranged in two multilayers
  - ⇒ a total of about 1200 m^2 of detection layers
  - ⇒ 2M readout channels
- Project started in 2007
  - Proto-Collaboration MAMMA (Muon Atlas MicroMegas Activity) formed with 15 groups involved
  - Napoli involved since the beginning, Frascati recently joined, others interested

Micromegas operating principle



No space charge effect
Intrinsic rate limit ~200 MHz/cm^2

- Micromegas (I. Giomataris, G. Charpak 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



Performance & µTPC mode

Performace requirements for the Small Wheel chambers

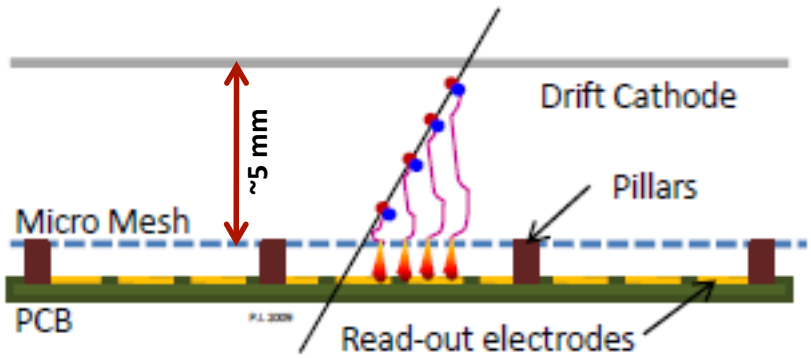
- Rate capability 15 kHz/cm^2 (L ≈ 5 x 10^{34} cm^{-2}s^{-1})
- Efficiency > 98%
- Spatial resolution ≈100 µm (Θ_{track}< 30°)
- Good double track resolution
- Trigger capability (BCID, time resolution ≤ 5–10 ns)
- Radiation resistance
- Good ageing properties

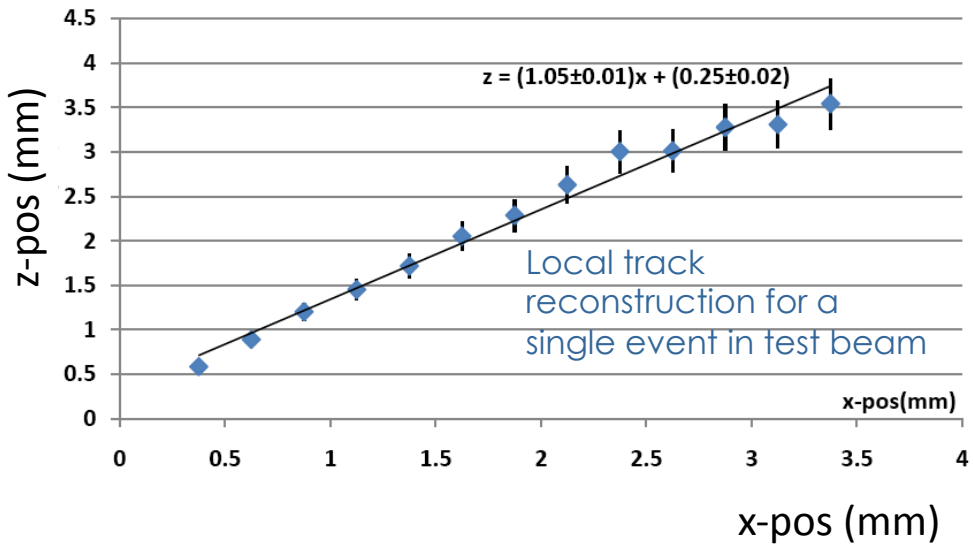
Micromegas can satisfy all of them

Addressed problems:

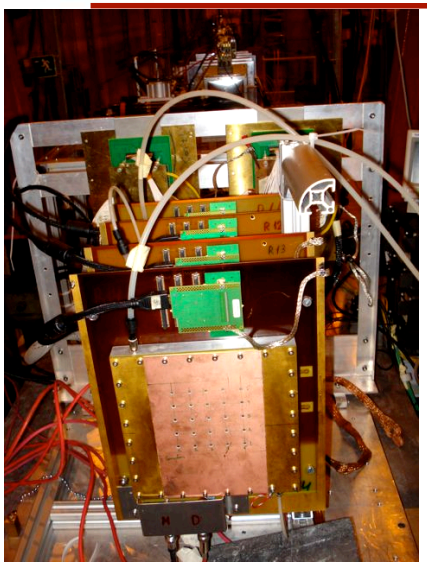
1. Tracking for inclined tracks
2. Large-size detectors
3. Sparks

- Micromegas as µTPC
  - Can deliver track vector in single plane for track reconstruction at LVL1 trigger

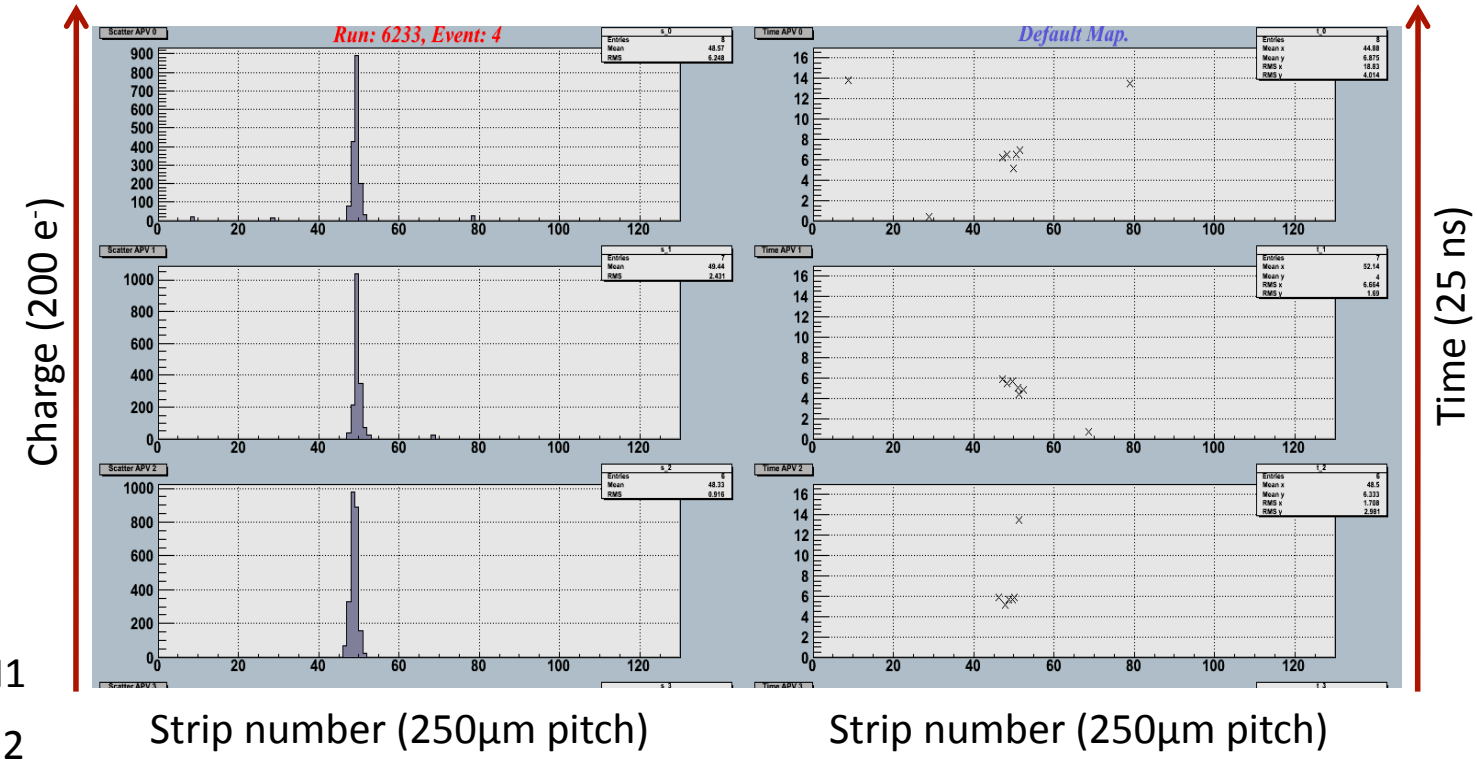




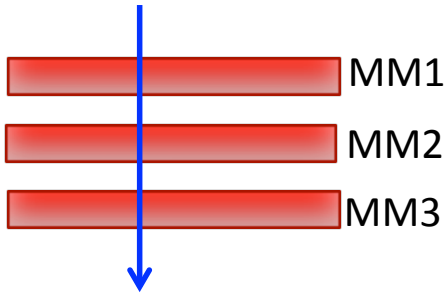
Event display from TB



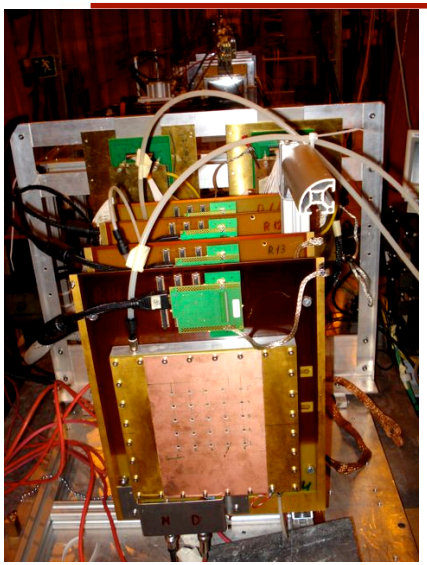
- ~ Vertical track



Three chambers in stack

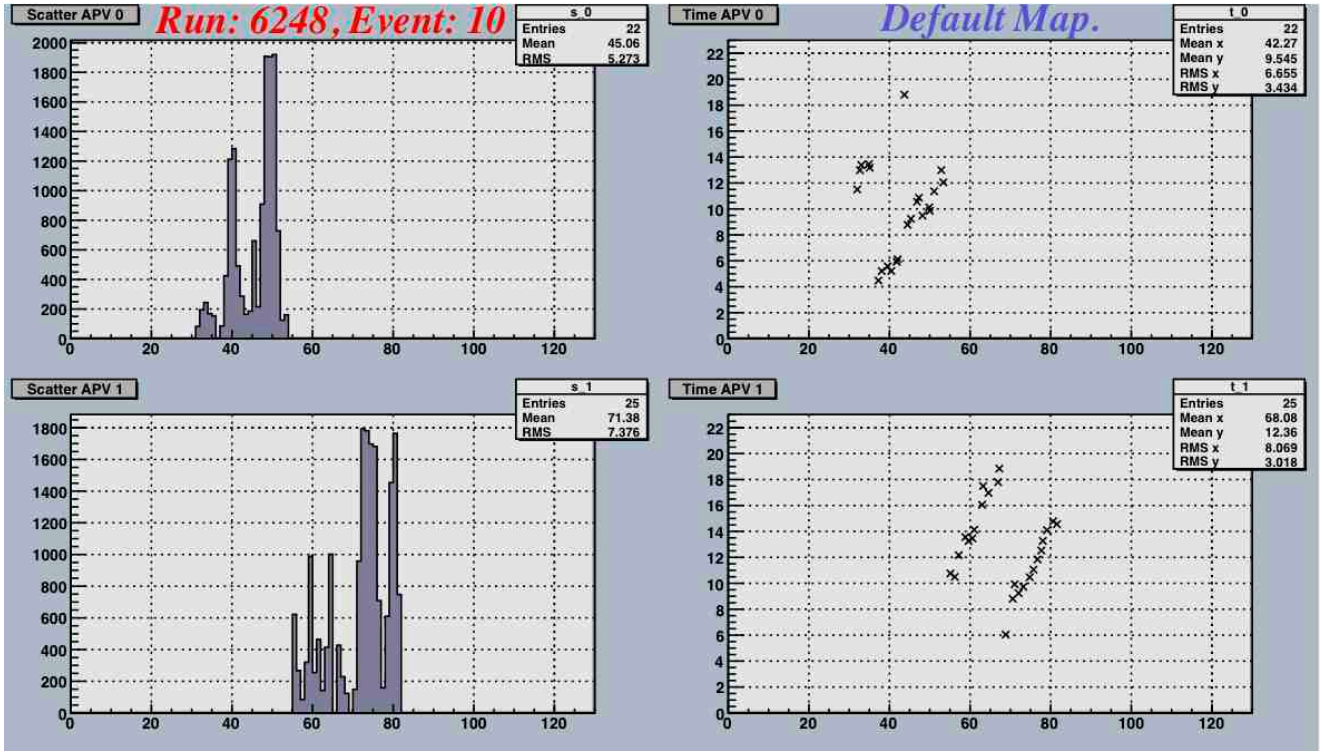


Event display from TB



- Two Inclined tracks (~40°)

Charge (200 e⁻)

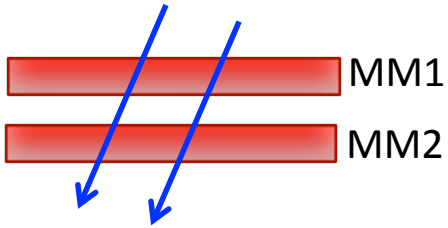


Time (25 ns)

Strip number (250µm pitch)

Strip number (250µm pitch)

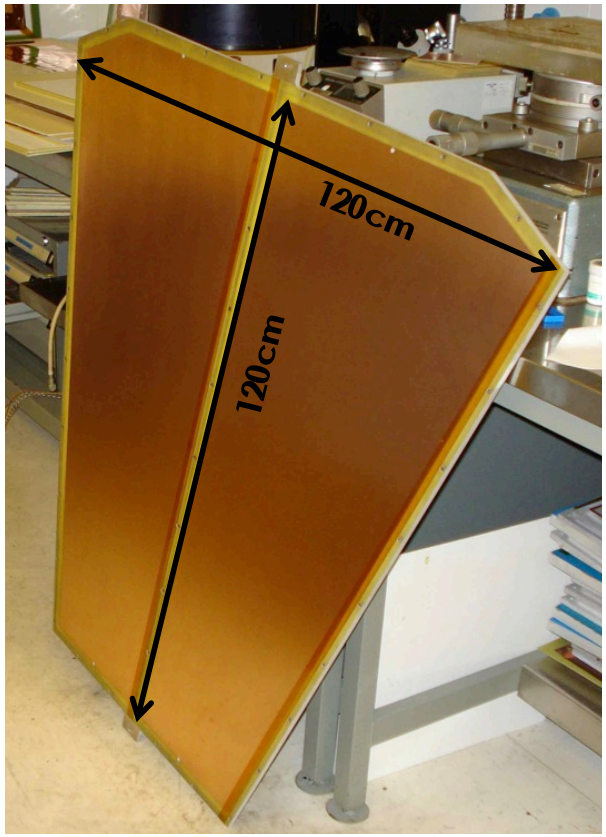
Two chambers in stack



Tracks separated by 5mm

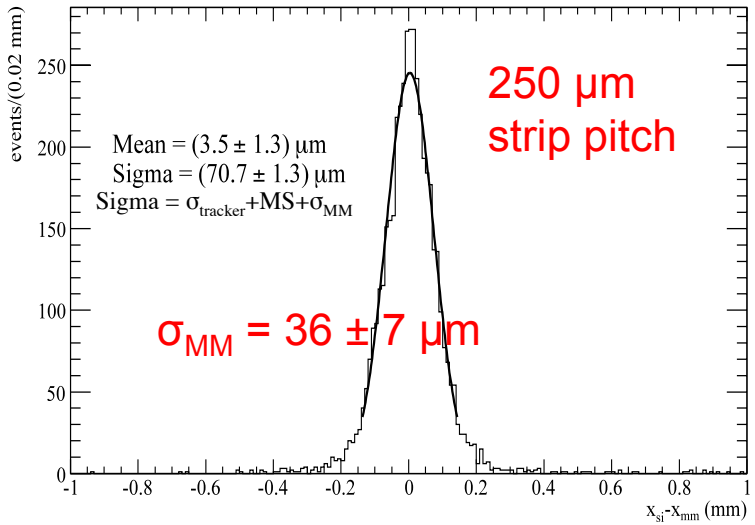
Large-size Micromegas

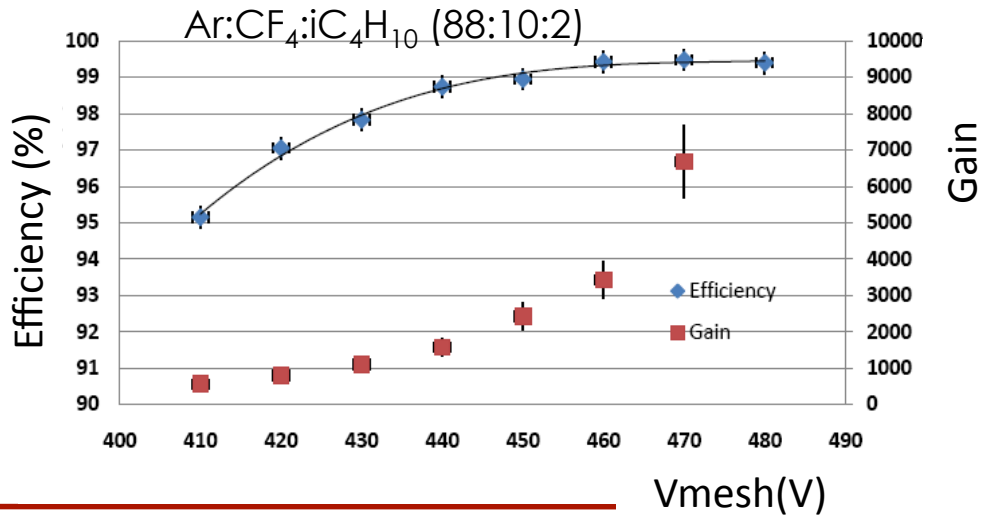
- A production technique developed in 2006 (bulk-micromegas) opened the door to industrial fabrication
- Reliable production of large size Micromegas is possible!



The largest MM ever built

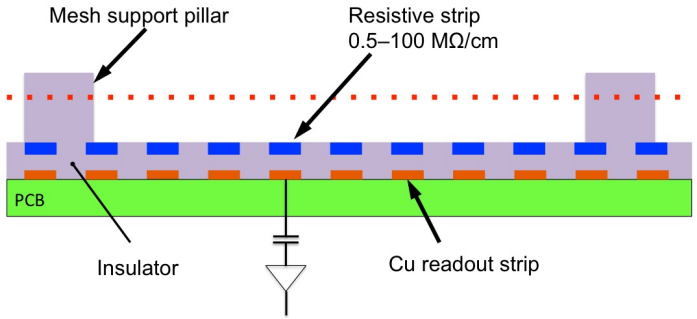
Spatial resolution (mm)

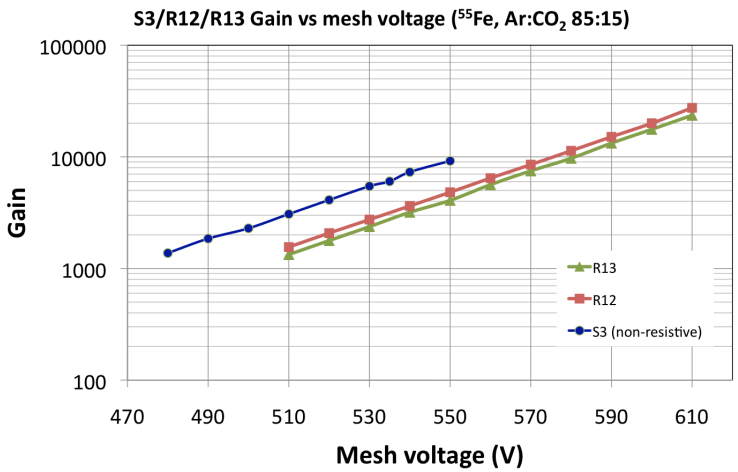




Sparks: problem and solution

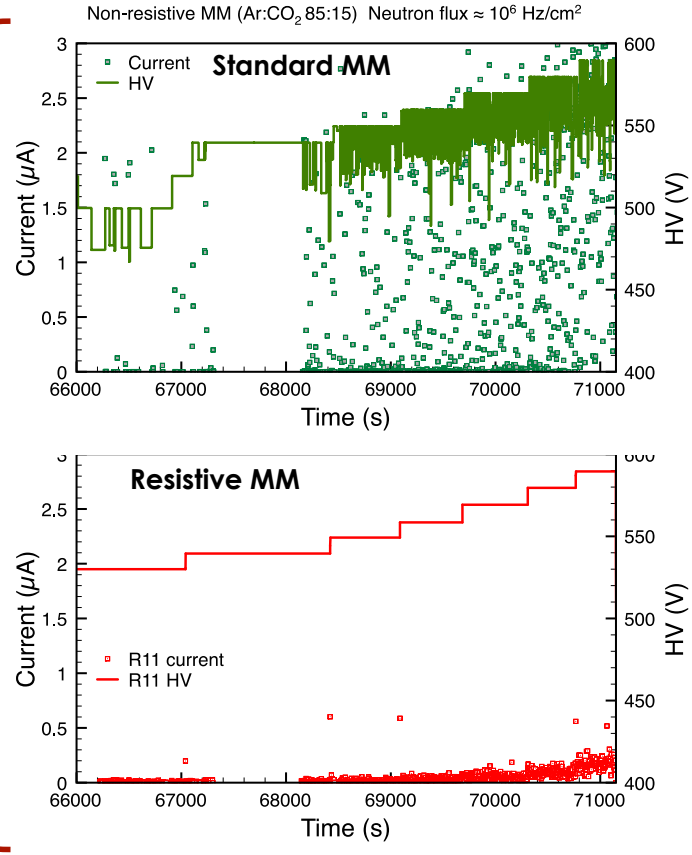
- Small defects or impurities on the detector surfaces trigger discharges (breakdowns). Even in device of good quality, when the avalanche reaches Raether limit (10^6-10^7 e-) a breakdown appears in the gas, often referred as 'spark'
- Sparks lead to a partial discharge of the amplification mesh → HV drop & inefficiency during charge-up; not acceptable at LHC. Risk of damaging for chamber and FE-elx





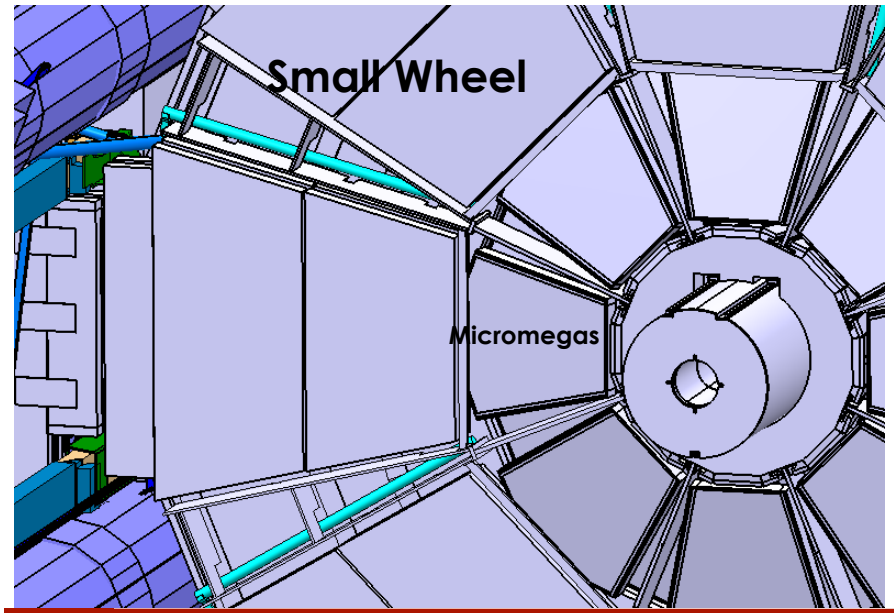
- Sparks can be drastically reduced by adding a resistive layer on the r/o strips
- Specific R&D to optimize the resistive protection
- Excellent results

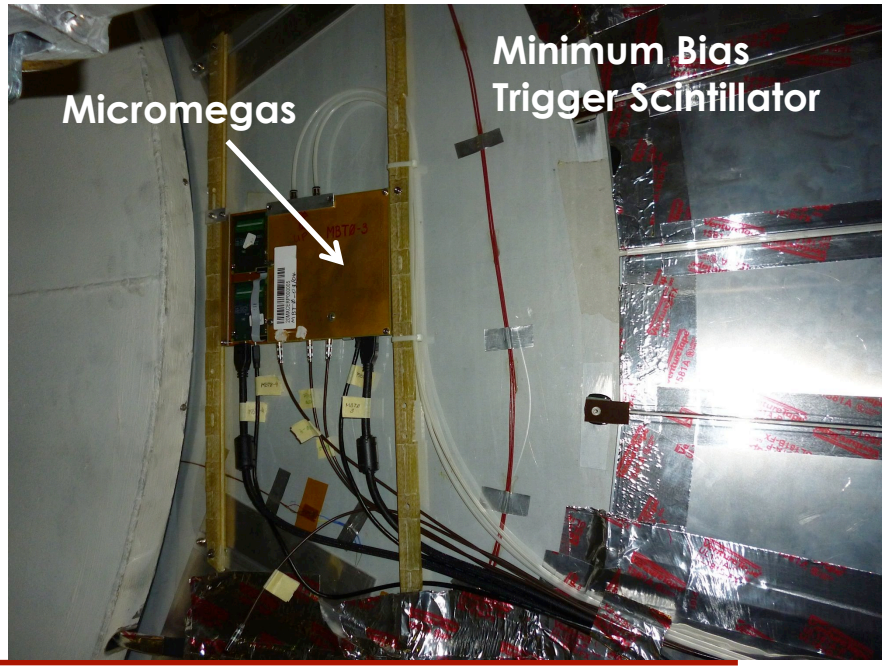
Test in neutron beam (10^6 Hz/cm^2)



Micromegas in ATLAS

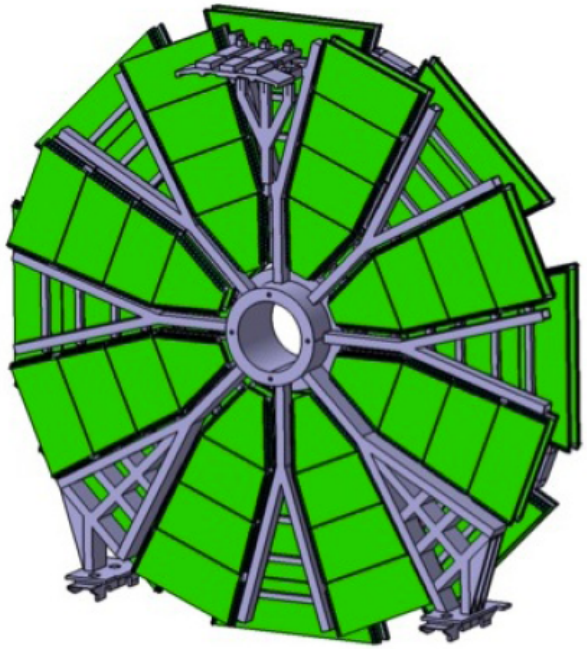
- Four small MM chambers were installed in ATLAS behind the last muon station in April 2011 and smoothly operated all along the 2011 (background measured to be ~3 Hz/cm^2 at L=10^{34} cm^{-2}s^{-1} ; ~3 times lower than nearby EOL MDT)
- First large size resistive MM assembled and tested in muon beam in 2011 to be installed in the ATLAS cavern on the small wheel for test
- A small prototype has been installed to evaluate the possibility to replace the Minimum Bias Trigger Scintillator of ATLAS with Micromegas
- Integration in the ATLAS acquisition system





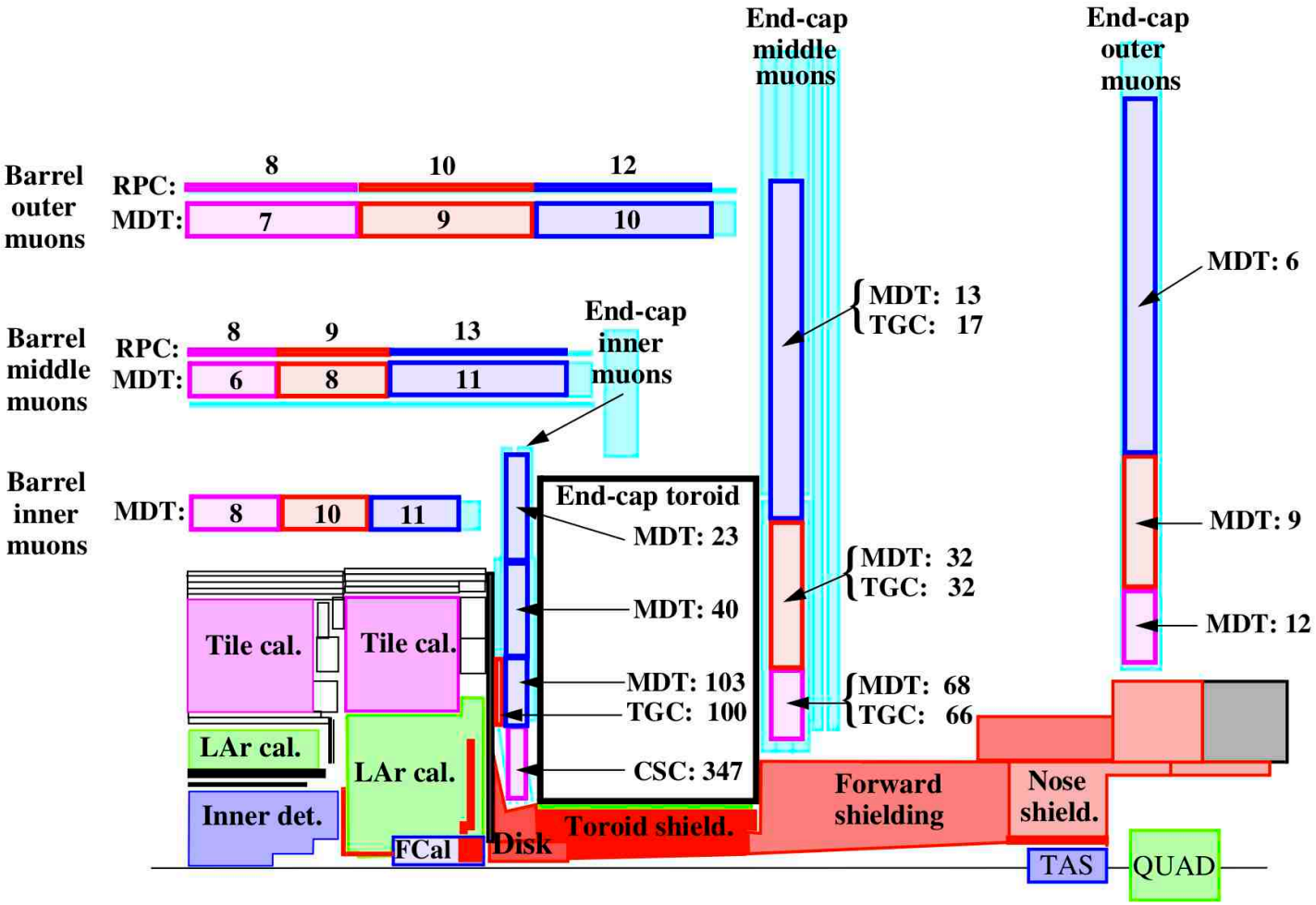
Summary & Plans

- The Small Wheels of the ATLAS Muon Spectrometer need a major upgrade to cope with the LHC phase-1 luminosity
- Micromegas fulfil all of the Small Wheel requirements
- We found an efficient spark-protection system that is easy to implement; sparks are no longer a show-stopper
- MMs are very robust and (relatively) easy to construct; large-area resistive-strip chambers can be built and they work very well
- Good single-plane tracking performance can be obtained by exploiting the µTPC mode
- From the three original proposals for the NSW a 'mixed' option is now under discussion in the collaboration:
  - TGC+Micromegas
- Decision to be made this year, installation of NSW in 2018.

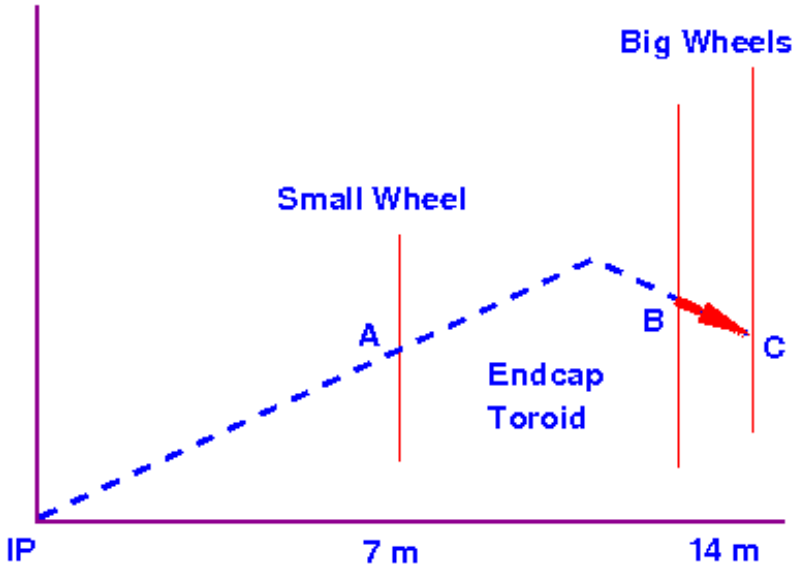


Backup Slides

Introduction

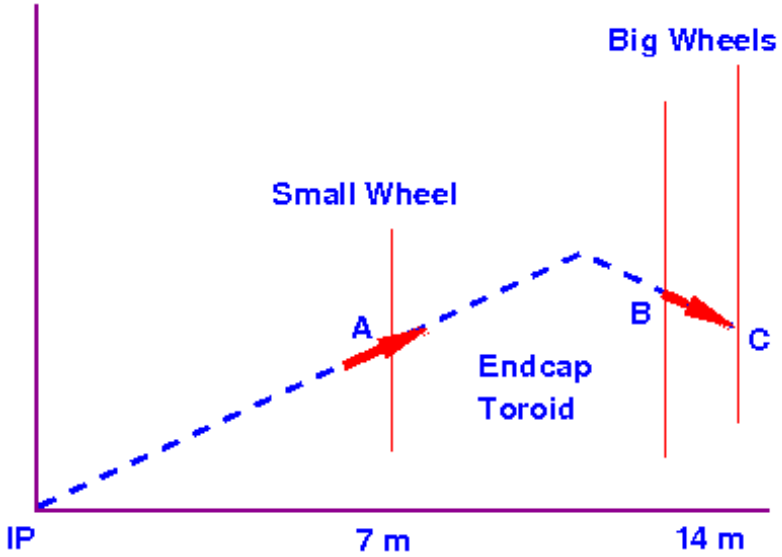


The problem of the fake rate



Current LVL1 end-cap trigger

- Only the vector BC at the Big Wheels is measured
- Momentum defined by assumption that track originated at IP
- Random background tracks can easily fake this
- Currently 96% of forward high-p_T triggers (at LVL1) have no track associated with them

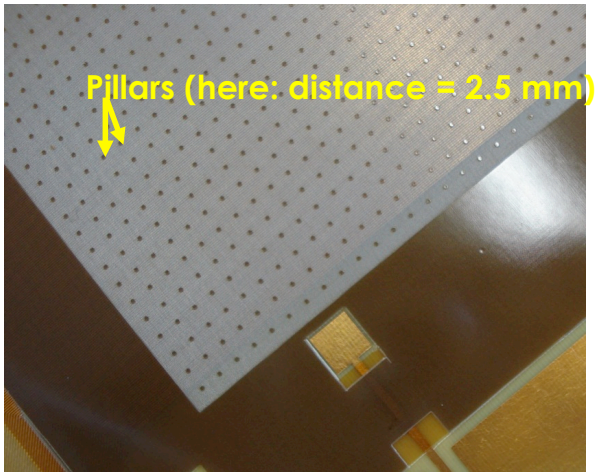


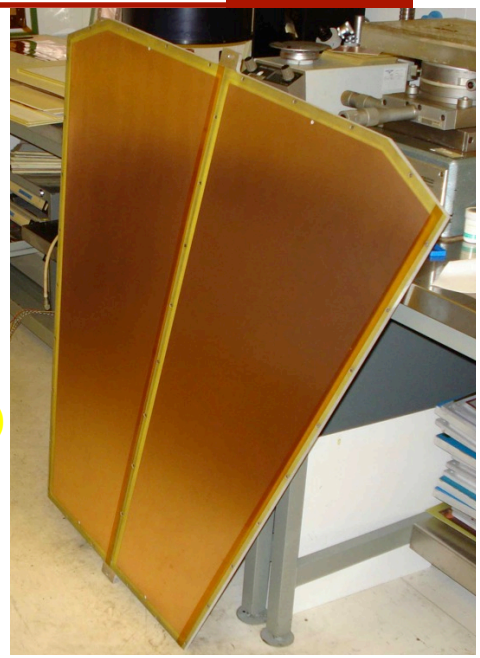
Proposed LVL1 trigger

- Add vector A at Small Wheel
- Powerful constraint for real tracks
- A pointing resolution of 1 mrad will also improve p_T resolution

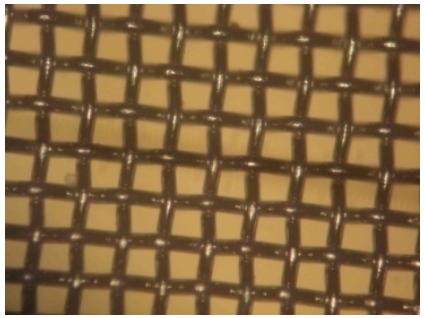
The bulk-Micromegas

- A production technique developed in 2006 (bulk-micromegas) opened the door to industrial fabrication
- Big effort for going to large dimensions
- In 2007 production of the first large MM prototype for ATLAS (50x60 cm2, the largest MM at the time)
- In 2010 production of a CSC-size Micromegas
- Reliable production of large size Micromegas is possible!



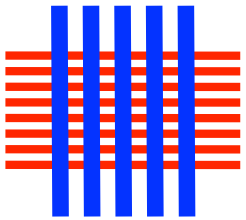


The mesh

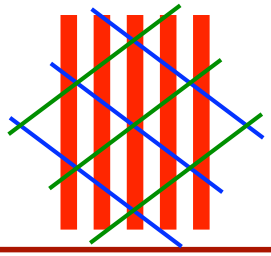


- Other improvements in the segmentation of the r/o electrodes
- 2D (xy) and 3D (xuv) r/o strips showed encouraging results

2D readout

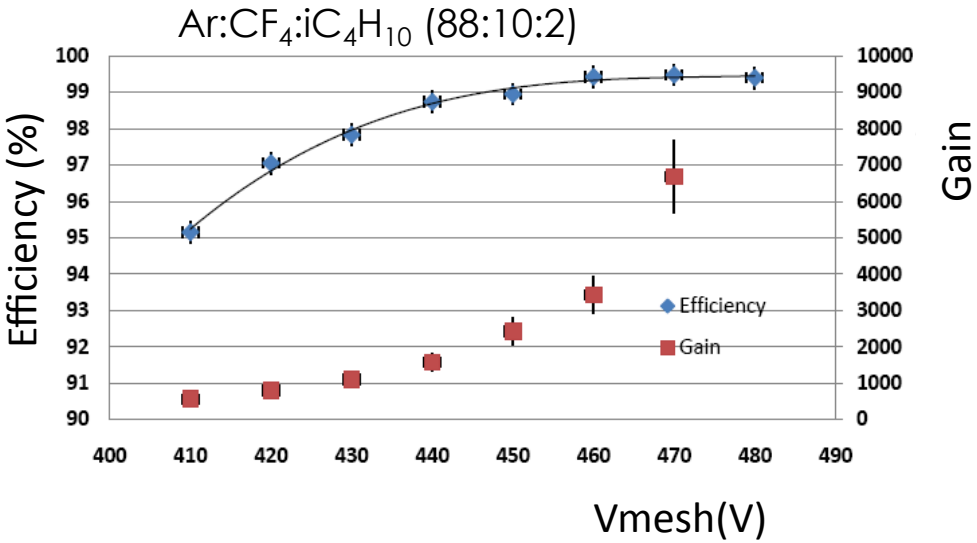


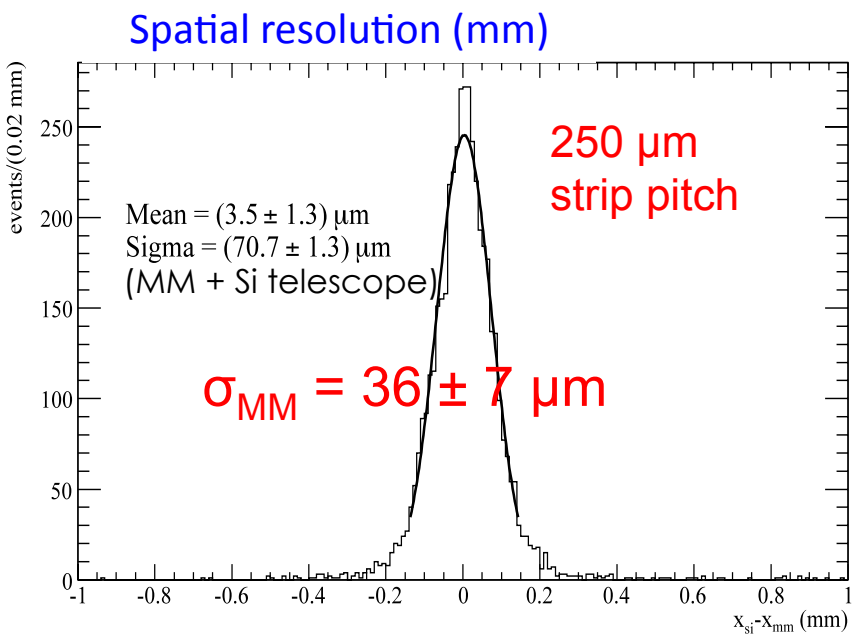
3D readout

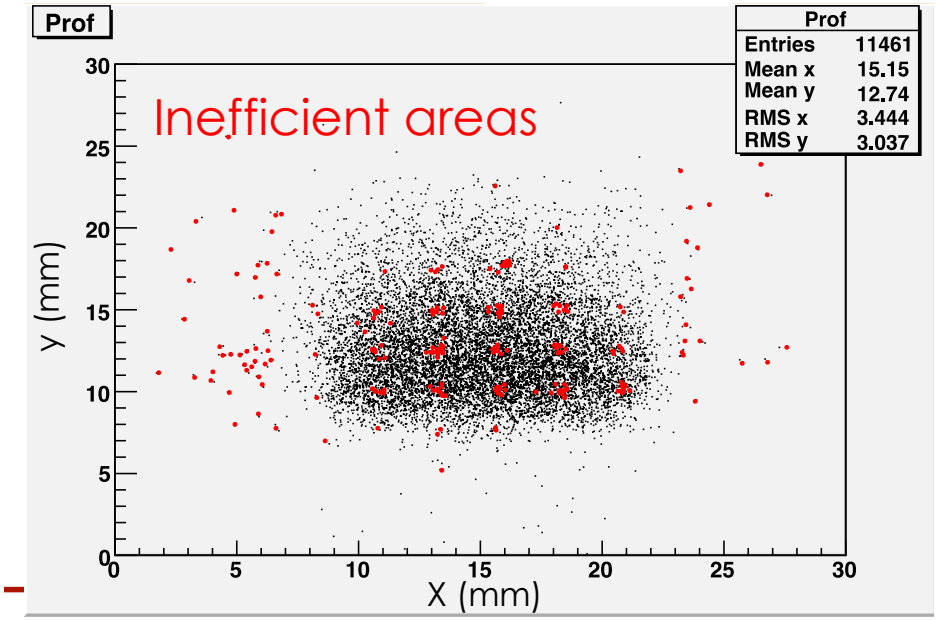


Demonstrated performance

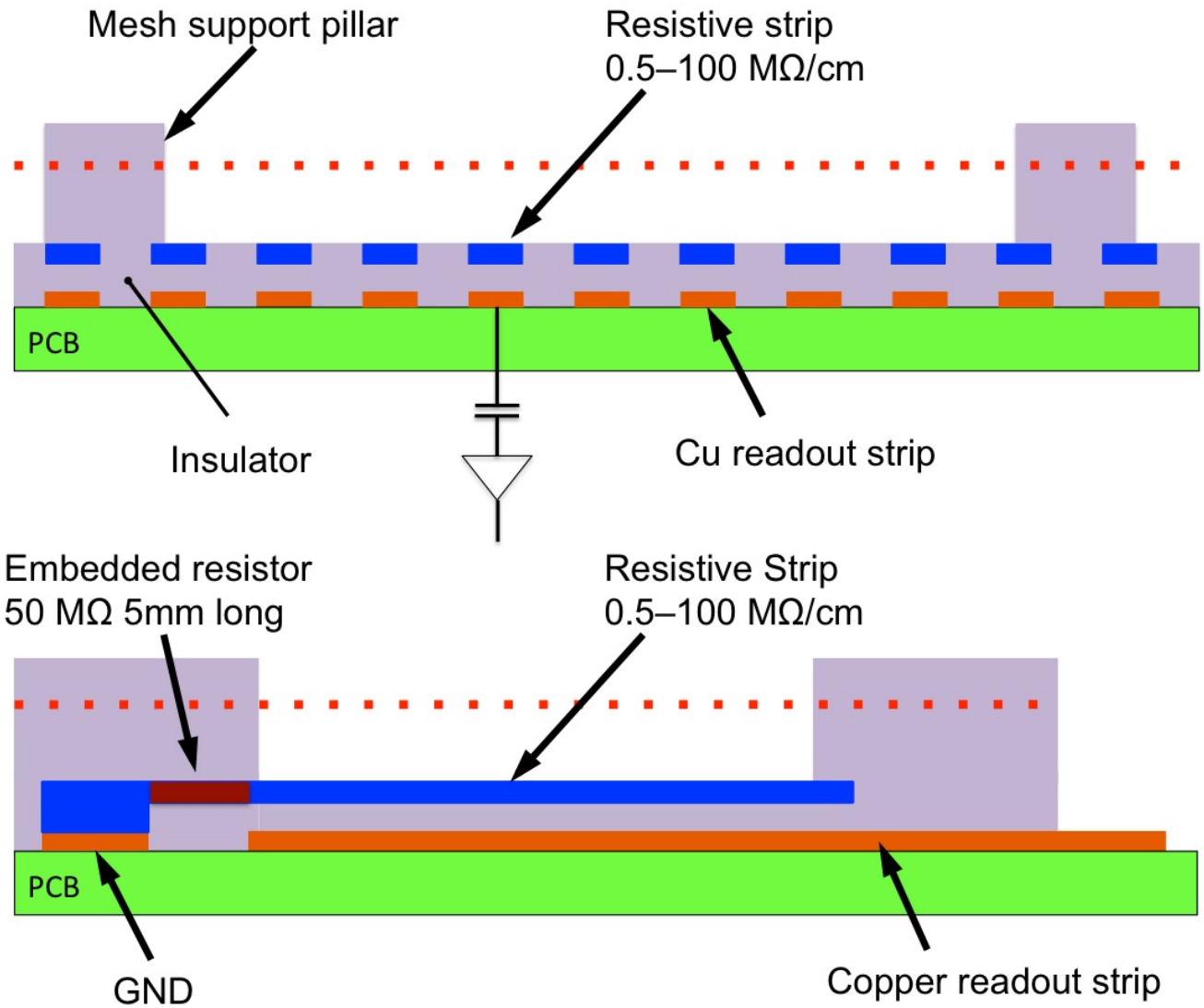
- Standard micromegas
- Safe operating point with efficiency ≥99%
- Gas gain: 3–5 x 10^3
- Very good spatial resolution



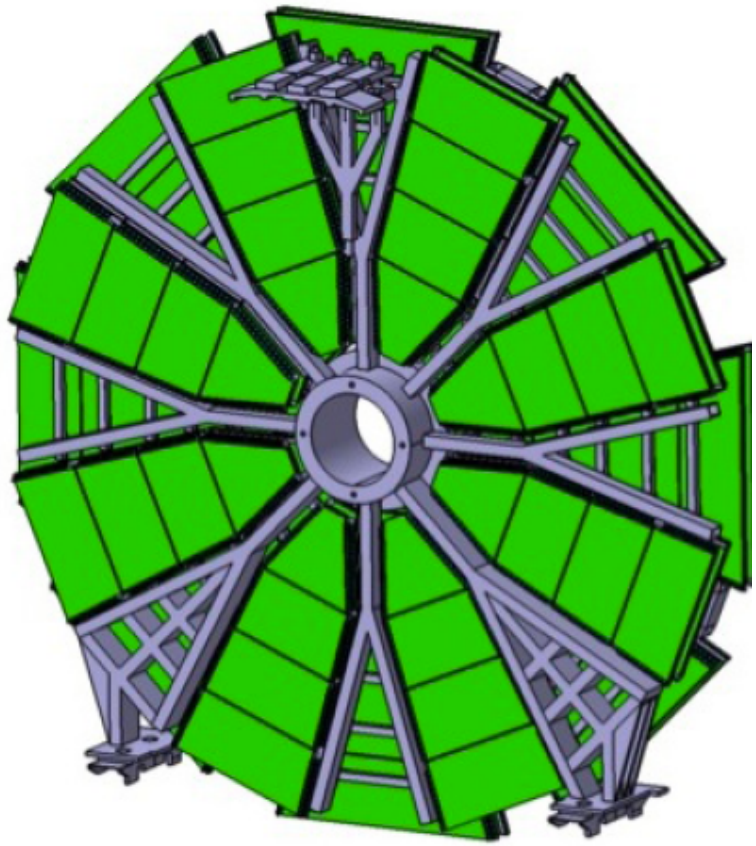




Resistive-strip protection concept



NSW layout



A tentative Layout of the New Small Wheels and a sketch of an 8-layer chamber built of two multilayers, of four active layers each, separated by an instrumented Al spacer for monitoring the internal chamber deformations