R&D on Small-pad Micromegas for the Phase II upgrade of the ATLAS Muon Spectrometer

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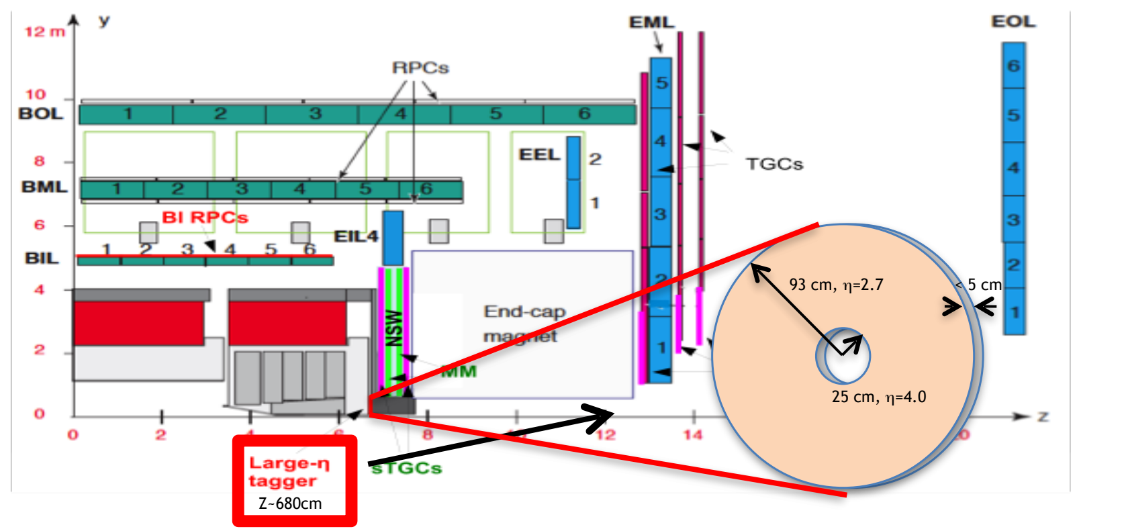
Introduction

In view of the ATLAS Phase II Upgrade, a proposal to extend the detector acceptance of the muon system to large η (up to |η|~4) is being considered. The extension of the muon detection, together with the extension of the inner detector to the same range in η, has been demonstrated to enhance "physics" performance [1]. The aim of the new detector is to tag muons, relying on the combination with the inner detector track for the momentum measurement. The new Large-η Muon Tagger should cope with extremely high particle rate, dominated by background hits up to about 10 MHz/cm^2 in the most forward region.
In order to minimize the occupancy, pixel or small pad readout are needed. Micro-Pattern-Gaseous-Detectors is a suitable technology for this purpose.
We present the development of resistive Micromegas with O(mm^2) pad readout aiming at precision tracking in high rate environment without efficiency loss up to several MHz/cm^2.
A first prototype has been designed, constructed and tested. It consists of a matrix of 48x16 pads. Each pad with rectangular shape with a pitch of 1 and 3 mm in the two coordinates.
The active surface of this prototype is 4.8x4.8 cm^2 with a total number of 768 channels.
Characterization and performance studies of the detector have been carried out by means of radioactive sources, X-Rays, cosmic rays and test beam.

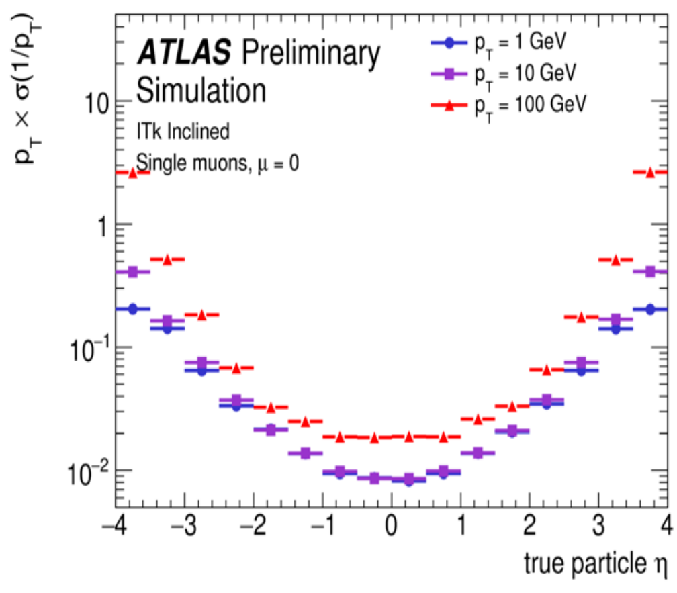


Physics Implications

The extended coverage associated with this upgrade can be valuable for reconstructing low-mass final states whose decay products are produced with a very broad η distribution.
It also extends the η-coverage for vetoing additional leptons from backgrounds.
Examples of physics processes that would profit from large η are [1]:

- Increased acceptance for $H \rightarrow ZZ \rightarrow \mu\mu\mu\mu$ **~15%**
- Additional lepton veto for $ZW^+ \rightarrow \mu\mu l\nu$ background to $W^+W^+ \rightarrow \mu l$ $\ell^+\ell^-\ell^+$ vs $\ell^+\ell^+$ **$\Delta\mu/\mu$ -13%**
- Increased acceptance for $ZV \rightarrow$ multi leptons
- Measurement of the forward-backward asymmetry of Z boson decay.

At |η| = 4.0 the curvature resolution - or equivalently the transverse momentum resolution - degrades due to the shorter lever arm with respect to the magnetic field. However forward particles of a given energy have a much softer p_T spectrum due to the small transverse component with respect to the beam axis.



A relative curvature resolution of 13% (40%) is retained for muons with p_T = 1 GeV (10 GeV) in the forward region [2].

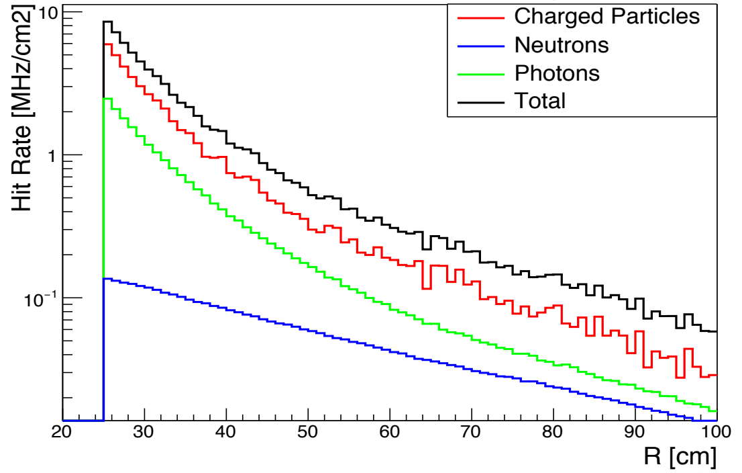
Requirements for the Large-η Muon Tagger

The main requirements necessary to achieve the "physics" performance are:

- ✓ Reconstruct a muon segment after the calorimeter;
- ✓ Match with an ITK track (position, angle): determination of the muon p_T;
- ✓ Operation at ~1-10 MHz/cm^2 at R=25 cm;
- ✓ Position resolution: few 100 μm;
- ✓ Angular resolution ~ 10 mrad;
- ✓ Requirements (greatly) relaxed at large R.

Hit Rate

Hit rate per cm^2
Simulation work in progress



Approximate sensitivities based on GEANT ongoing studies on NSW Micromegas:

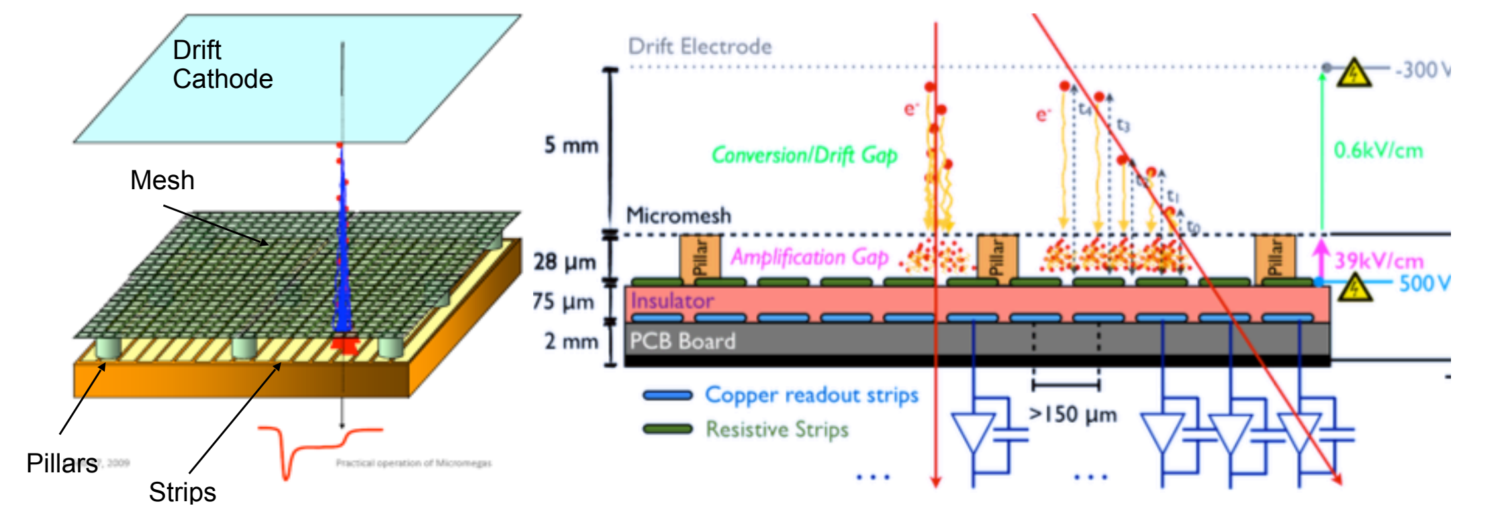
- neutrons= 0.1%
- gamma= 1%
- charged= 1 with a threshold on electron energy of 1 MeV

At HL-LHC, for μ=180 (number of pp collisions per bunch crossing) and L=10^{35} cm^{-2}s^{-1}, the hit rate is about 10 MHz/cm^2 at η = 4.0 (R~25 cm).

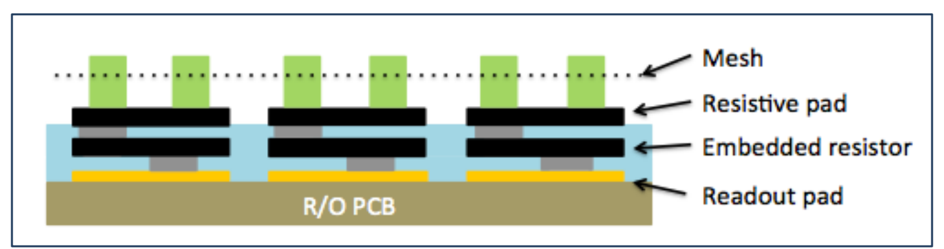
Development of Small Pad Resistive Micromegas

The main problem of first generation Micromegas, the discharges with high flux of highly ionizing particles, has been overcome in recent years during the development phase for the Micromegas for the ATLAS upgrade with the implementation of a layer of resistive strips facing the amplification gap [3].

Principle of operation of a resistive strip Micromegas

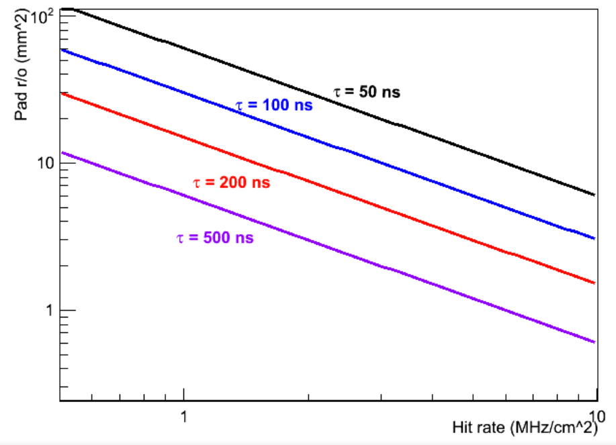


In order to minimize the occupancy, the proposed detector, **Small Pads Resistive Micromegas** [4], is based on a pad readout.
The anode copper pads are overlaid by an insulating layer carrying a pattern of resistive pads of the same size of the anode ones. The readout and resistive pads are connected by intermediate resistors embedded in the insulating layer (technical solution inspired by a similar R&D by COMPASS [5,6]).

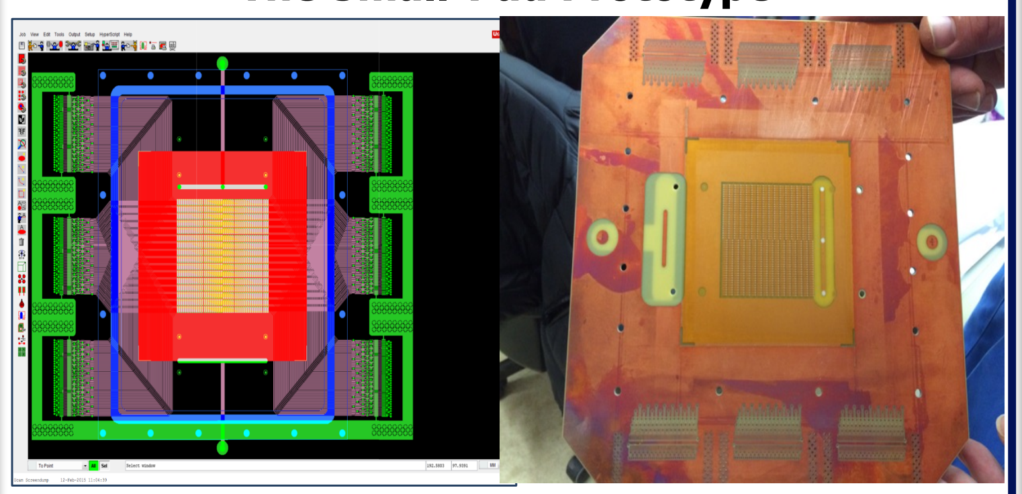


Dimension of the pad readout (either strips or pads) as a function of the hit rate for an occupancy level of 3% and different pulse width (or charge collection time).

Work in progress



The Small-Pad Prototype

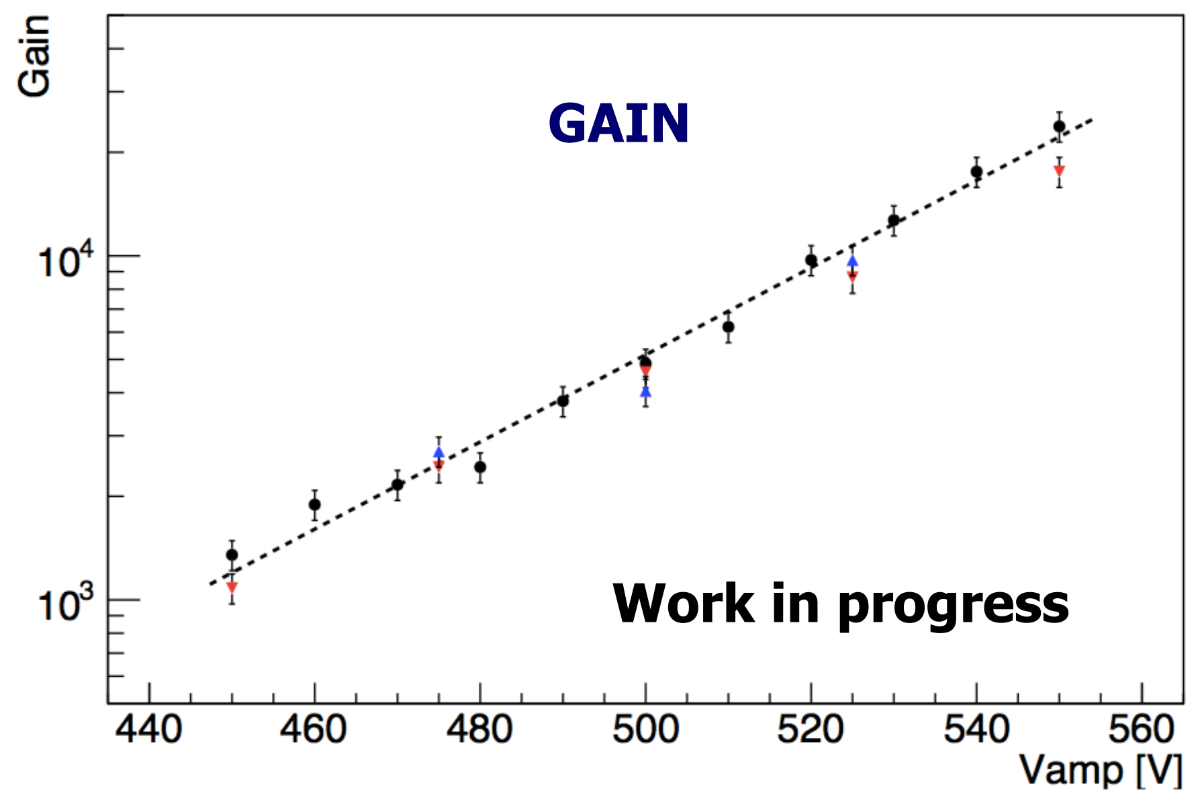


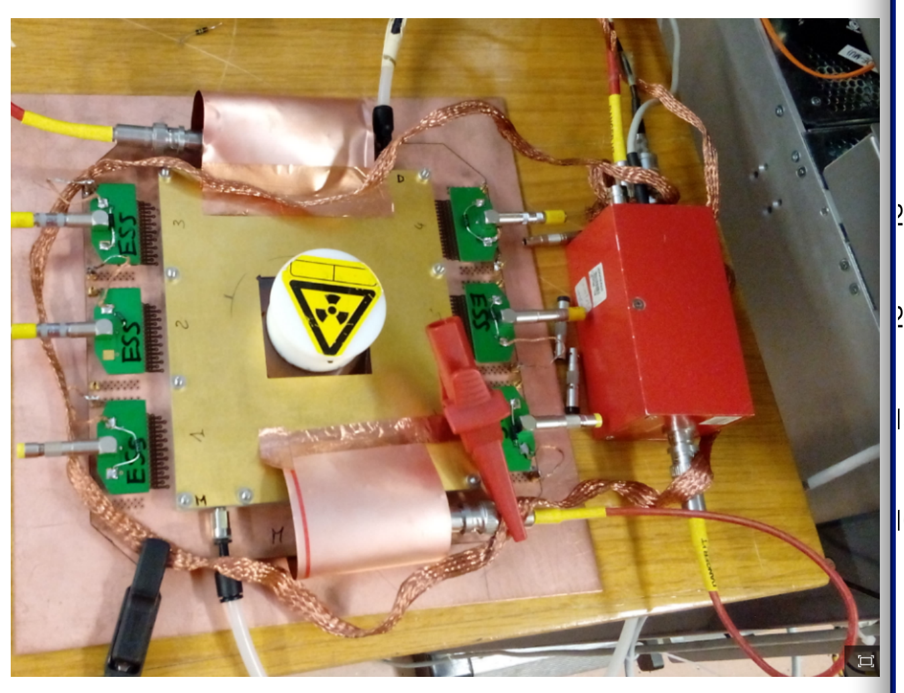
Left-Top: sketch of the small-pad micromegas detector with embedded-resistor structure;
Left-Bottom: layout for the first prototype;
Right: the readout PCB of the constructed prototype.

Detector Characterization

Characterization and performance studies of the detector have been carried out by means of radioactive sources, high irradiation X-Rays, cosmic rays and test beam.

Characterization has been carried out with **55Fe source** and Ar/CO2 (93:7) as gas mixture.
The amplification factor has been measured to be ~10^4, with the chamber operated at Vamp= 530 V and Vdrift= 300 V compatible with standard Micromegas chambers.

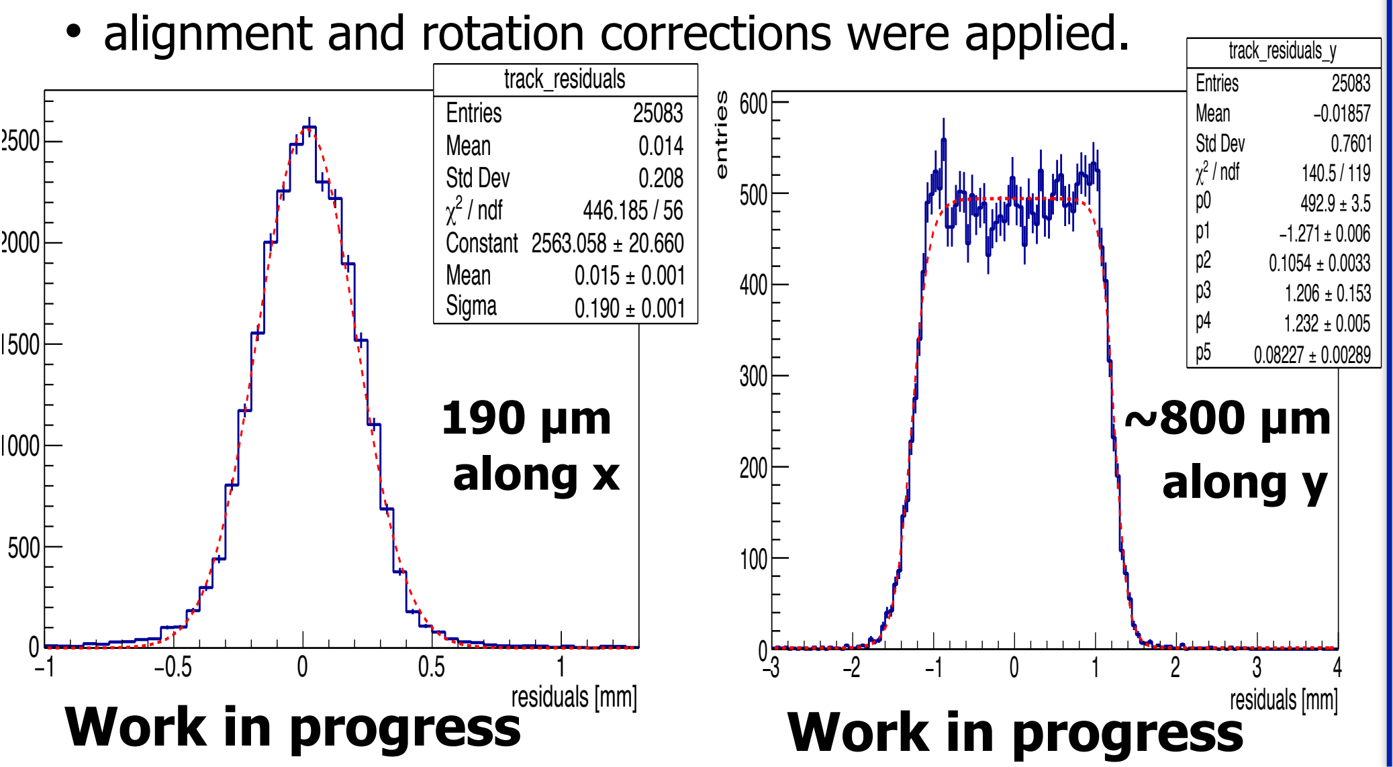




Performance studies of the prototype have been carried out at **SPS H4 beam line at CERN,** with muon beam. Tracking has been performed with 2 bulk double readout Micromegas chambers (X,Y) readout via APV25 and SRS [7].
The gas mixture used was Ar /CO2 93:7.

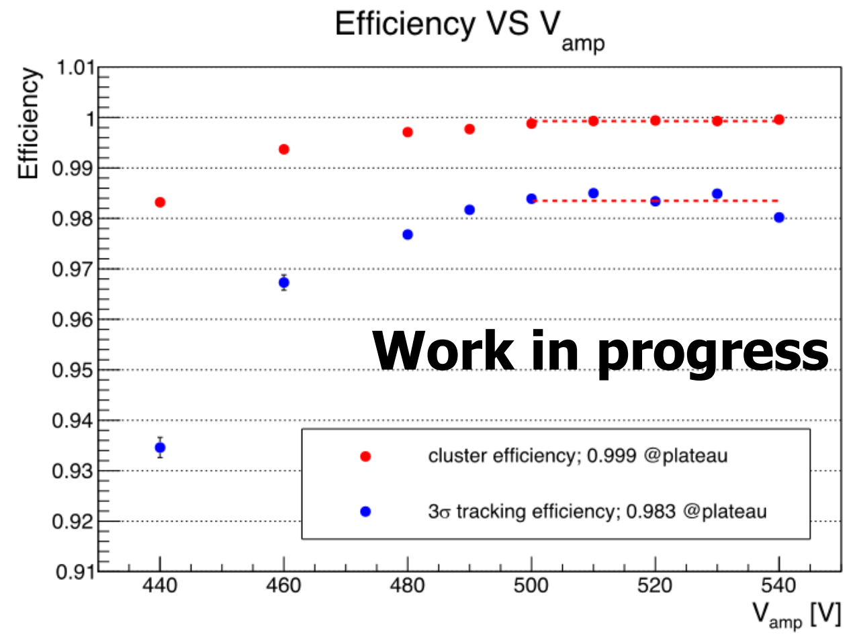
Position resolution is obtained by the difference between the position measured from the prototype and that extrapolated by tracking chambers.

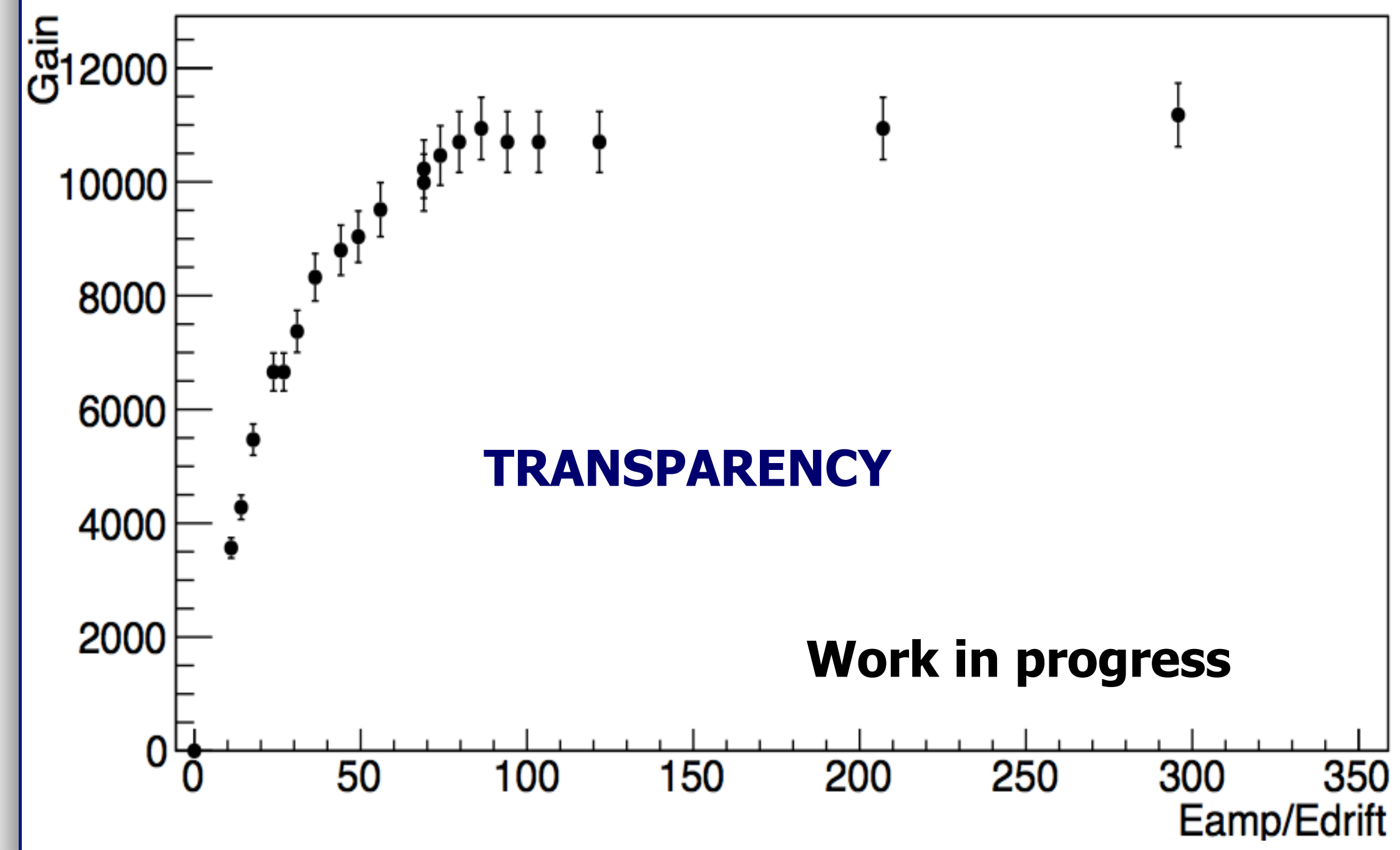
- alignment and rotation corrections were applied.



The **"turn-on" efficiency** curve is obtained:

1) By finding a cluster anywhere in the detector for any reference track **~100%**
2) By finding a cluster within 3sigma from the extrapolated impact point of the reference track **> 98%**





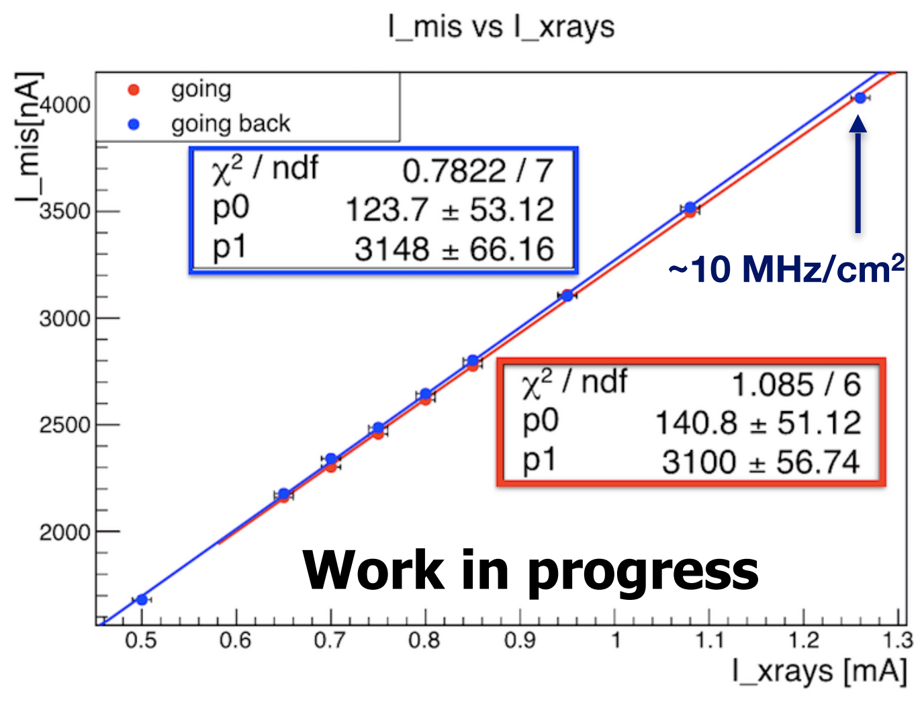
Detector gain measured with **55Fe source** as a function of the ratio between the amplification and drift electrical fields. For all measurements the amplification voltage was constant at a value of Vamp= 530 V.

For values Eamp/Edrift >80 the gain reaches its maximum, corresponding to the maximum value of the mesh transparency (very close to 100%).

PRELIMINARY analysis of the data taken with X-Ray Source few weeks ago:

- Detector current in the amplification gap VS current of the (Cu) X-Ray gun
- Many checks still ongoing (i.e. Linearity of the X-ray gun Vs Rates, X-ray spot-size, etc...)

Measurements of Linearity vs High Rate



Preliminary results are very promising showing no drop in current (i.e. Gain) at rates

>10 MHz/cm^2

Data taken with a Gain ~ 10^4

For a X-Ray conversion, the collected charge is a factor of 5-6 larger with respect to MIP.

References

[1] **ATLAS Collaboration**, ATLAS Phase-II Upgrade Scoping Document;
[2] **ATLAS Collaboration**, Expected Performance of the ATLAS Inner Tracker at the High-Luminosity LHC, ATL-PHYS-PUB-2016-025,06 Oct 2016;
[3] **T. Alexopoulos et al.**, A spark-resistant bulk-MicrOMEGAs chamber for high-rate applications, Nucl. Instrum. Meth. **A 640** (2011) 110;
[4] **M. Alviggi et al.**, Small-pads resistive micromegas, 2017_JINST_12_C03077;
[5] **F. Thibaud et al.**, Performance of large pixelised MicrOMEGAs detectors in the COMPASS environment, 2014 JINST 9 C02005;
[6] **C. Adloff et al.**, Construction and test of a 1x1 m2 Micromegas chamber for sampling hadron calorimetry at future lepton colliders,Nucl. Meth. A 729 (2013) 90–101;
[7] **M. Raymond, et al.**, Nuclear Science Symposium Conference Record 2 (2000) 9.

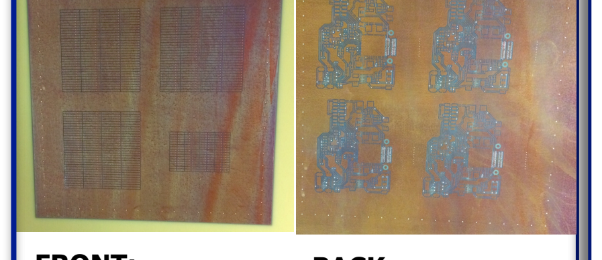
Open Issues and Outlook

Next steps for detector R&D.
The key aspect of future developments is the possibility to scale the detector to larger size
⟶ back-wire-bonded front-end chip;

- Multi-channels, low power, rad hard chips;
- cooling: embedded tubes in the PCB with CO2 cooling.

Further studies: different readout and resistive planes layout.

New Prototype: Back-wire-bonded front-end chip



FRONT: 3 minipad regions with pitch 8x1 mm; 1 minipad regions with pitch 3x1 mm

BACK: Layout of the 4 regions with APV25

Simulation

Background particle fluences are being revised for the large-η Muon Tagger.

- Implement a more realistic description of the detector response to background particles;
- Generate true muon trajectories (on top of background) ⟶ efficiency to muons;
- Add other sources of background (on top of TRUE muons) and punch through particles;
- Evaluate fake-segment survival fraction after matching with ID tracks.

We want to acknowledge for the valuable support:
- the RD51 Collaboration;
- the CERN MPT Workshop.