NEUTRON SOURCE CHARACTERISATION AND COSMIC MUON DETECTION WITH MICROMEGAS DETECTORS

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IMPRS WORKSHOP

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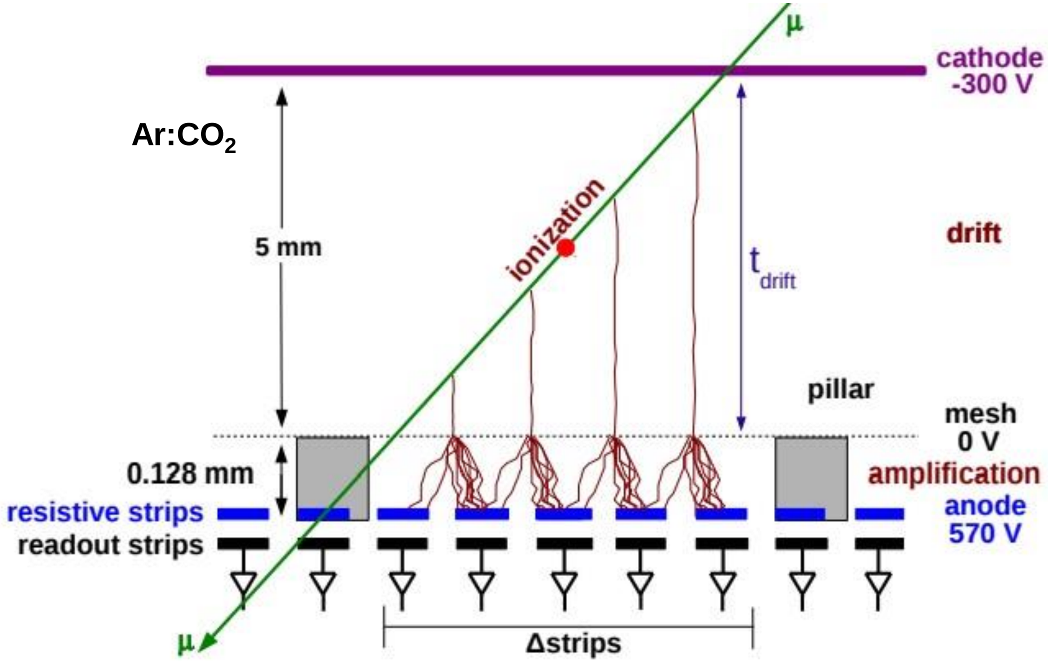
Working Principle of Micromegas Detectors

- Micromegas (Micro-Mesh Gaseous Structure) → gaseous detector with 3 planar structures
- A particle ionises the gas in the drift region → electrons drift down due to an electric field $E_{Drift} < 1$ kV/cm
- Electrons reach the amplification region with a gain of 5000-10000 for $E_{Amp} \approx 50$ kV/cm
- These electrons are finally detected at the readout strips on the anode
- Fast signals resulting in short dead time makes these detectors high rate capable

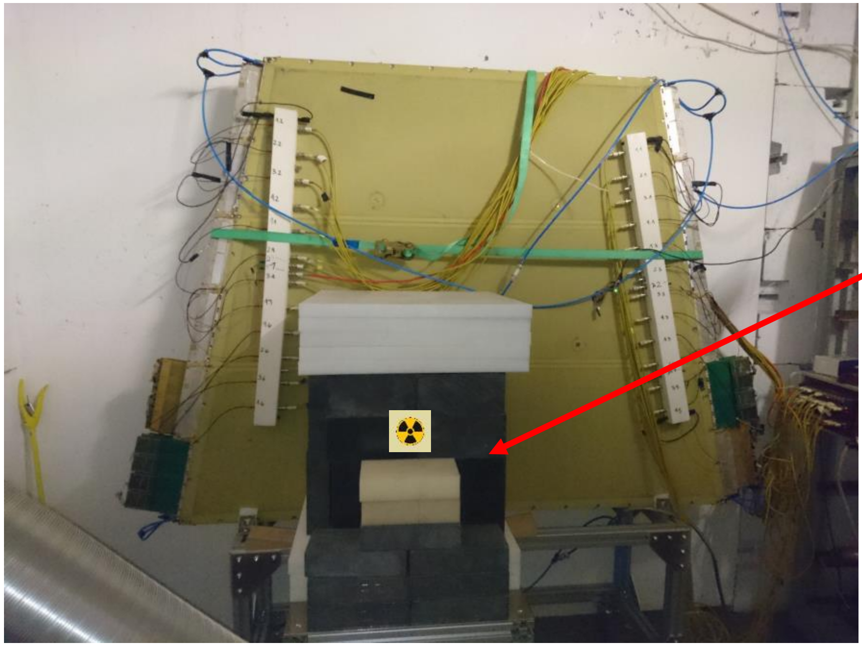


Due to their high rate capability, Micromegas are used in high background environments of several experiments like ATLAS, COMPASS, etc.

Long-term Irradiation Set-up

- **Project**: Long term irradiation studies of Micromegas detectors in Munich were performed for 3 years under high background radiation from a neutron source

- **My Role:**
  - Characterisation of the neutron source and obtain the gamma spectrum using a Germanium detector
  - Disentanglement of the contributions from the source in the Micromegas detector using a Geant4 simulation
  - To look for possible decrease in efficiency and overall performance or potential damages to the anode



Pb and borated plastic shielding

Neutron Source: Americium Beryllium

We need to first understand the source: Am-Be (10 GBq)

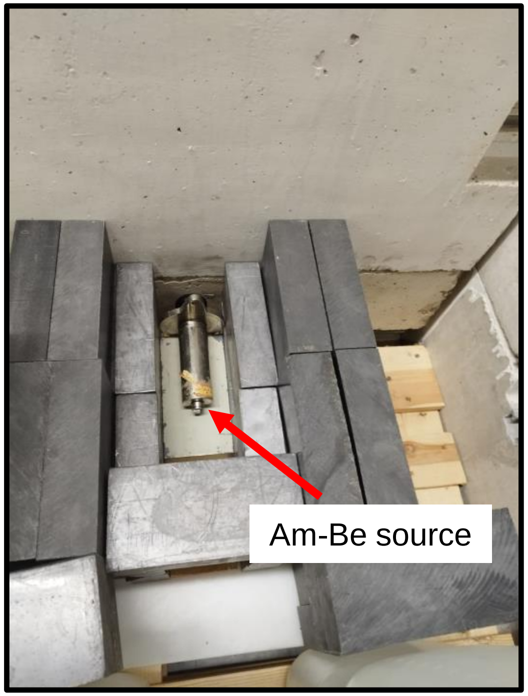
$$^{241}Am \rightarrow 237Np + (60\ keV)\,\gamma + \alpha$$
$$^{9}Be\ +\ \alpha \rightarrow {}^{12}C\ +\ n\ + (4.4\ MeV)\,\gamma$$

Yield: $6 * 10^4$ neutrons/sec per GBq

Activity: 10 GBq α → $6 * 10^5$ neutrons/sec + $6 * 10^5$ γ (4.44 MeV)
→ $10 * 10^9$ (60 keV) photons

Actual intensity of the gammas externally seen after attenuation from casing, absorption in ^{9}Be (for 60 keV) and other external factors is unclear

$$R = \frac{A_{60keV} \cdot I_{60keV} \cdot I_{Be} \cdot I_{StainlessSteel}}{A_{4.4MeV}}$$



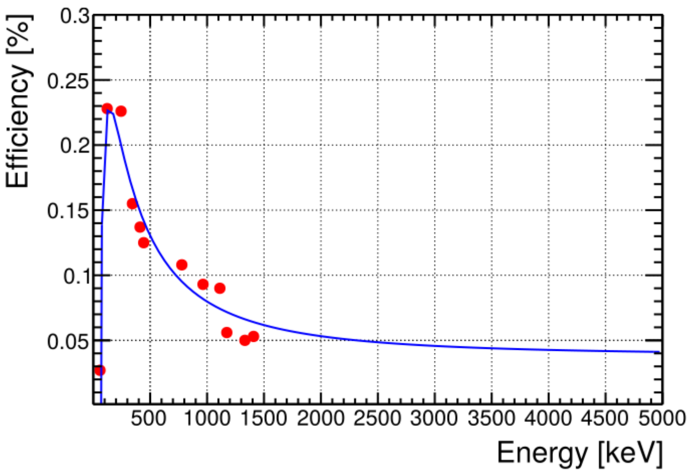
Germanium Detector

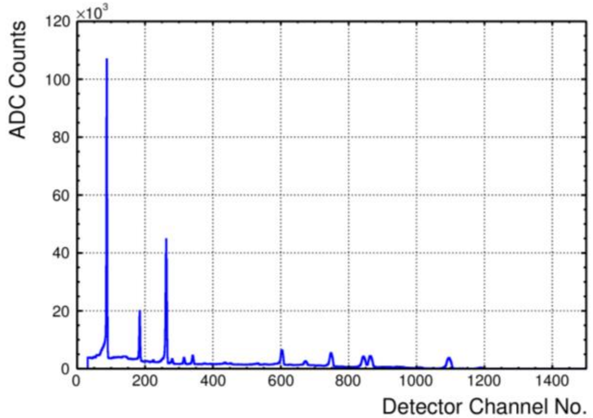
- Germanium detectors: Excellent resolution at low energies (due to low average energy required to make an electron hole pair) and high energies (due to high atomic number)

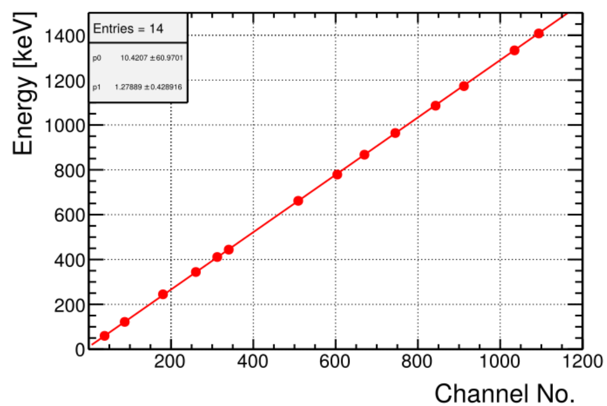
- Energy calibration of detector performed with sources of known energy and intensity: ^{152}Eu, ^{241}Am and ^{60}Co

- Efficiency of detector was also estimated using a polynomial of the fourth order[1] given by

$$\epsilon = \frac{[p0] + [p1] \cdot (\ln E) + [p2] \cdot (\ln E)^2 + [p3] \cdot (\ln E)^3 + [p4] \cdot (\ln E)^4}{E}$$

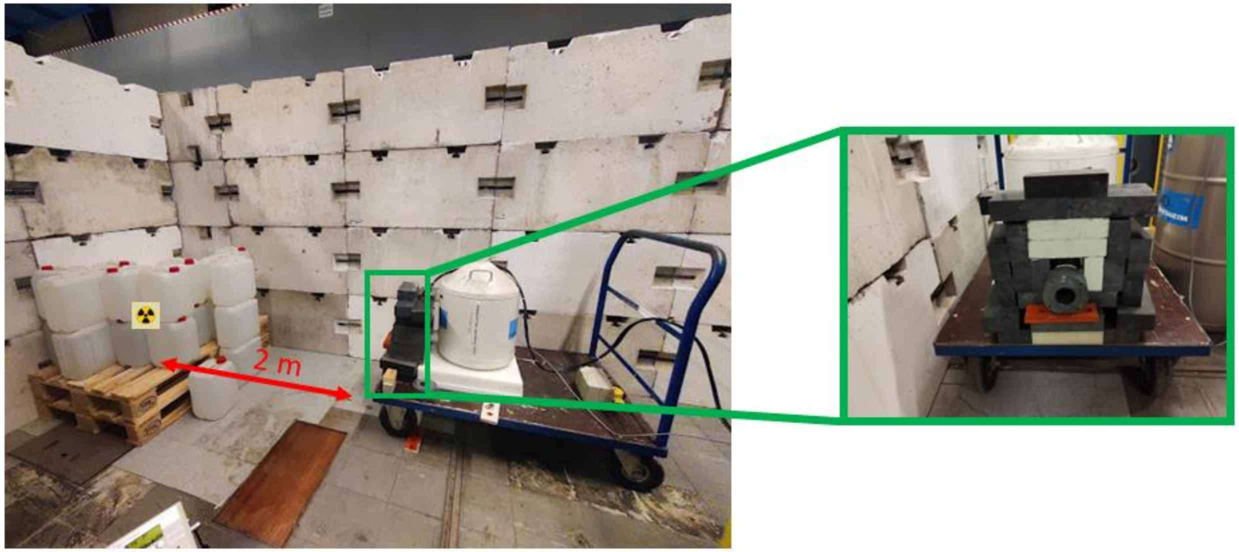






[1]Gray, P.W. and A. Ahmad (1985). “Linear classes of Ge(Li) detector efficiency functions”.

Germanium Detector Set-up for Am-Be Source

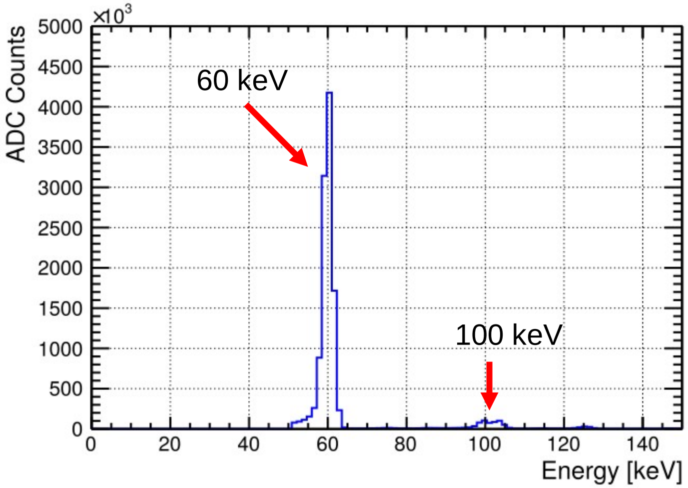


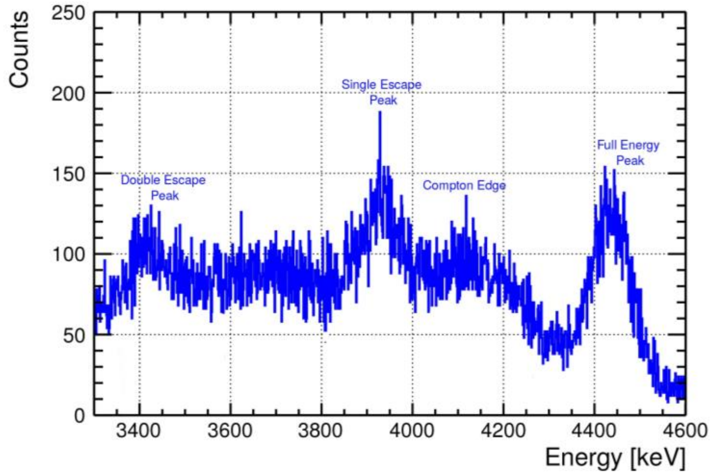
- The source is kept at a distance 2 m from the detector due to its high activity rate and is shielded from all sides with water as well as lead and plastic blocks
- A collimator of r = 25 mm is used to reduce edge effects with a solid angle of 6.06×10^{-4} std

Am-Be Spectrum

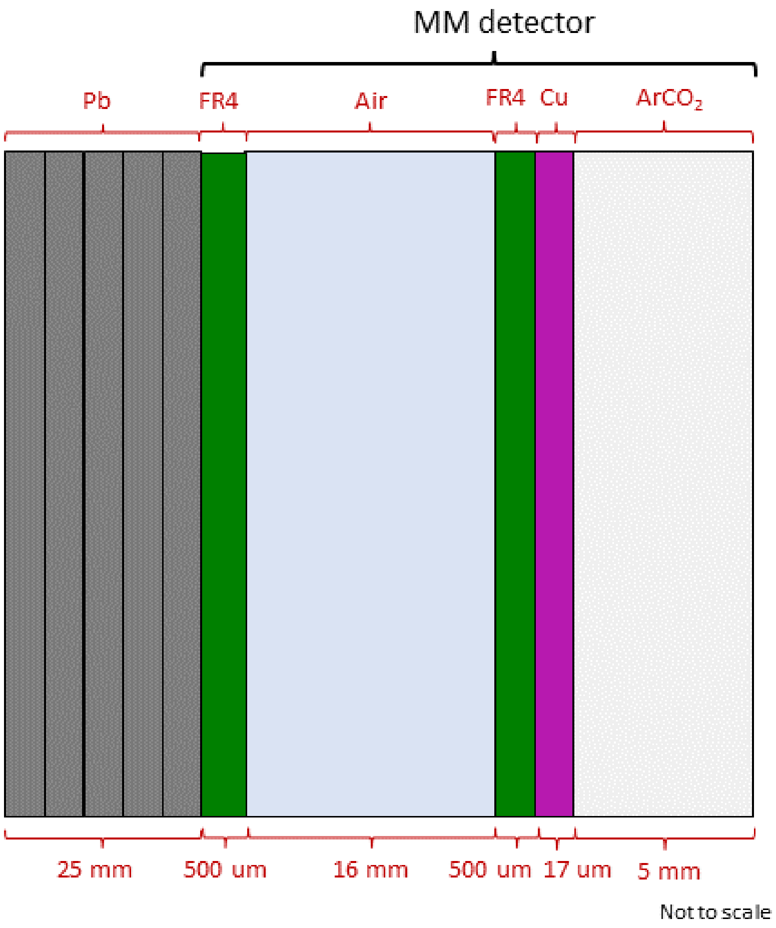
- The distinct photopeak of the 60 keV is visible, along with the 100 keV peak, which has a small branching ratio in comparison
- For the 4.4 MeV gammas, there are three main contributing interactions: photoeffect, Compton effect and pair production and their respective peaks can be seen
- The relative efficiency of the two energies can be estimated from the previous efficiency fit to get the intensity ratio between the two is calculated to be ≈ 150 using

$$R = \frac{N_{60keV}}{I_{60keV}} \cdot \frac{I_{4.4MeV}}{N_{4.4MeV}} \cdot \epsilon_{rel}$$

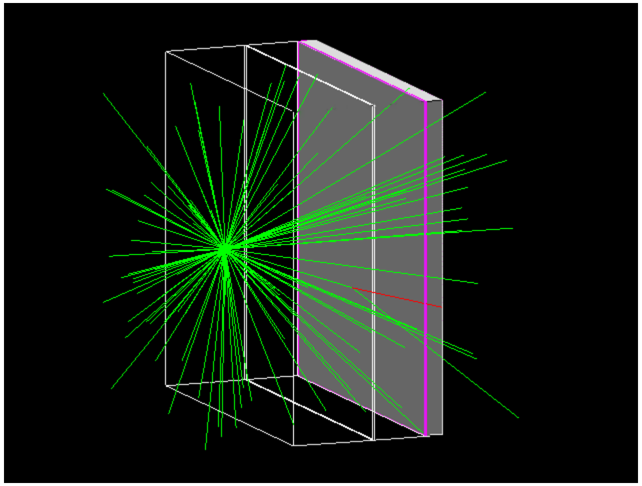




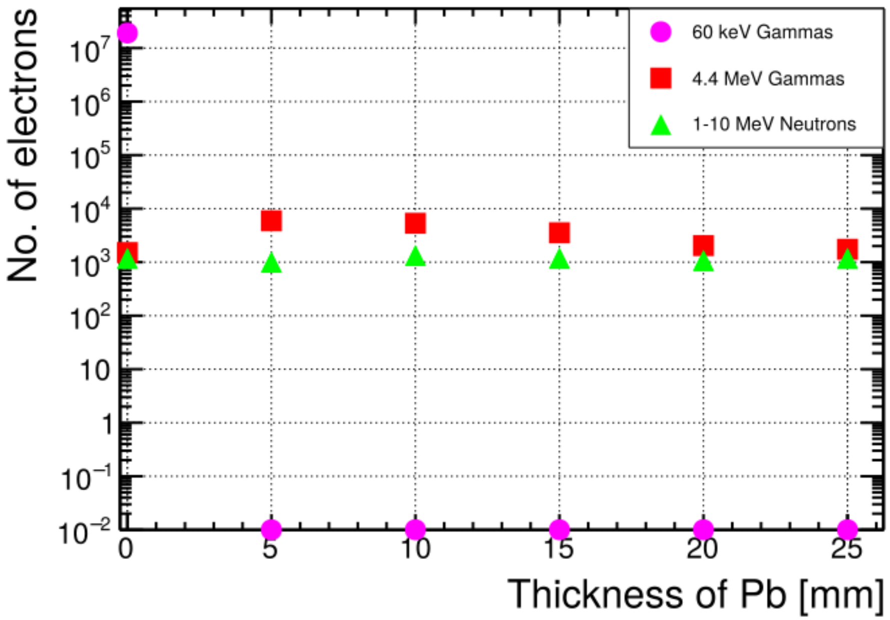
GEANT4 Simulation: Detector Set Up



- Physics list used: QGSP_BERT_HP
- Point source of photons and neutrons emitted in 2π
- All the primary and secondary electrons created that reach the gas or created in the gas are counted!

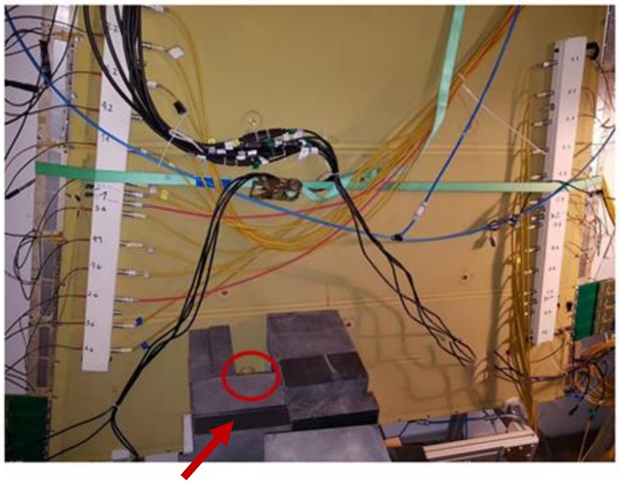


GEANT4 Simulation: Results

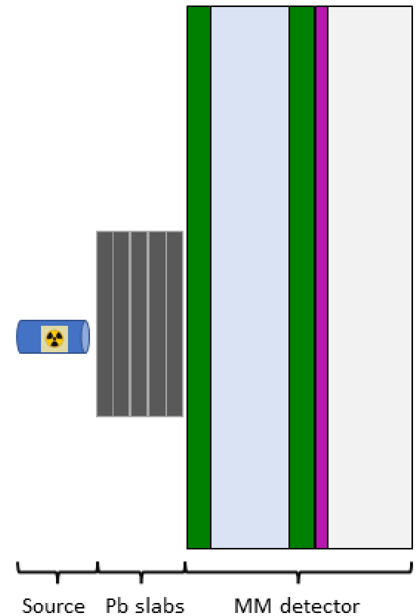


- Accounting for the normalisation factor 150 for 60 keV γ
- Simulation for 60 keV photons for different thicknesses of Pb → as expected, complete absorption after 5 mm of Pb!
- Total number of electrons created by 4.4 MeV γ:
  - → increases for 5 mm Pb due to Compton scattering
  - → this reduces the γ energy so more electrons are created in Cu
  - → starts attenuating for increasing Pb thickness
- Total number of electrons created by neutrons of energies ranging from 1 to 10 MeV → remains fairly constant

Long-term Irradiation Set-up



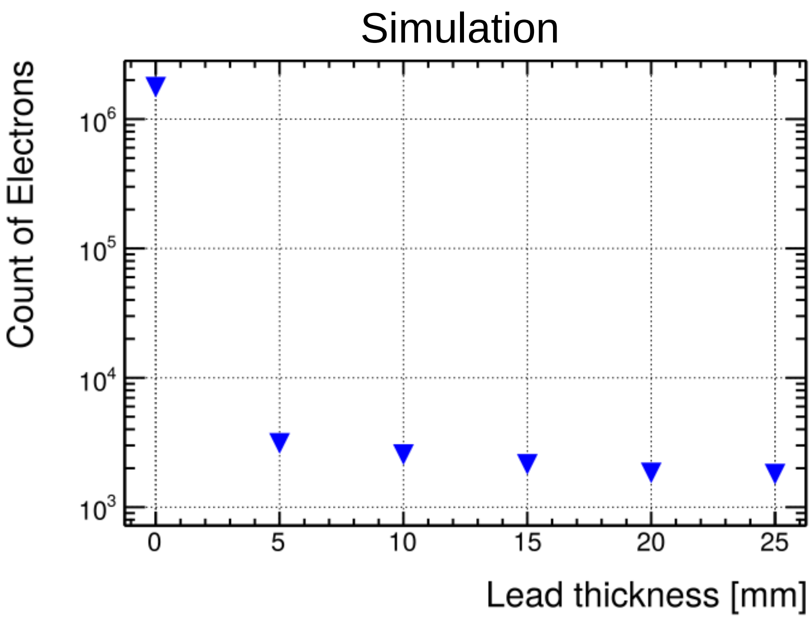
Neutron source

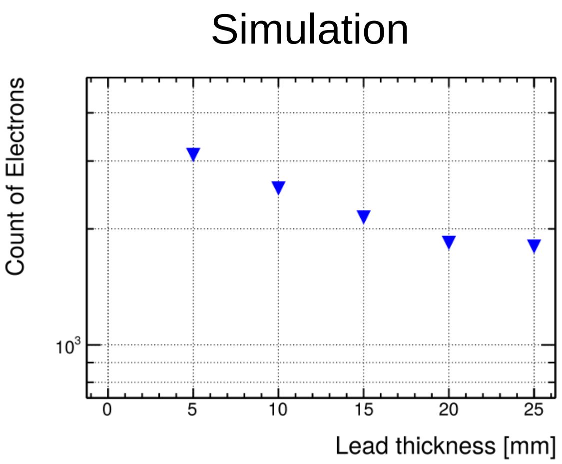


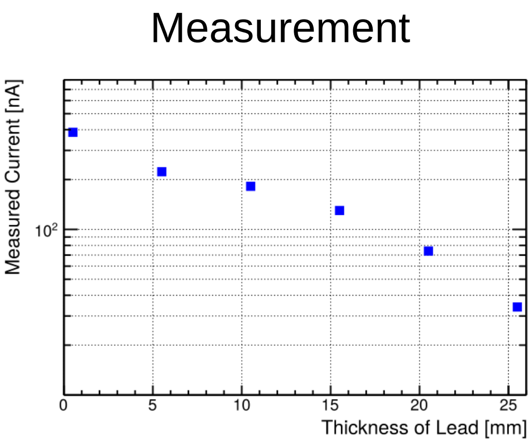
Not to scale

- Current is measured from the MM detector placed in front of the neutron source for varying thicknesses of Pb to attenuate the 60 keV photons in order to disentangle the MeV photons and neutrons easily
- Current measured is proportional to the number of electrons produced by the radiation
- The total number of electrons produced in the simulation must then follow a similar trend to the current

GEANT4 Simulation: Results







- Simulation is in good agreement with the measured current for increasing thickness of lead after 5 mm
- At 0 mm lead, simulation values are higher than expected
- The intensity factor R ≈150 depends on currently uncertain factors like geometry of the detector and its crystal dimensions but is undergoing further investigations

Micromegas Detector Set-up

- Three years of high background irradiation on these detectors accumulated charge equivalent to multiple years of the ATLAS working environment

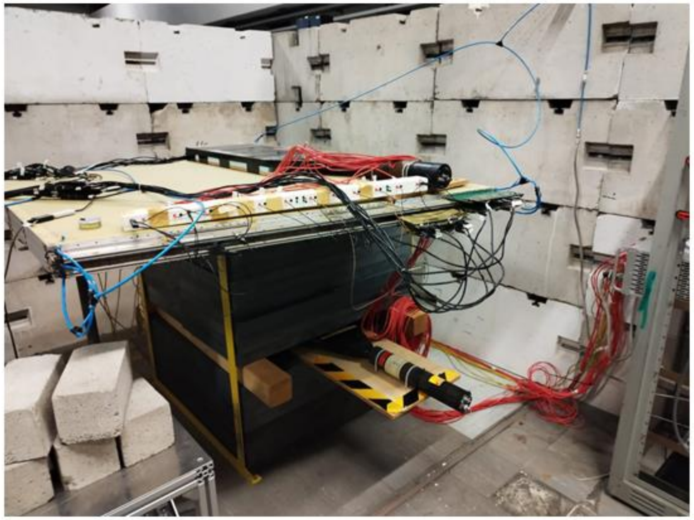
- To check for possible deterioration in the performance of the detector, measurements were performed with two gas mixtures: $Ar:CO_2$ and $Ar:CO_2:iC_4H_{10}$ (currently used in ATLAS)

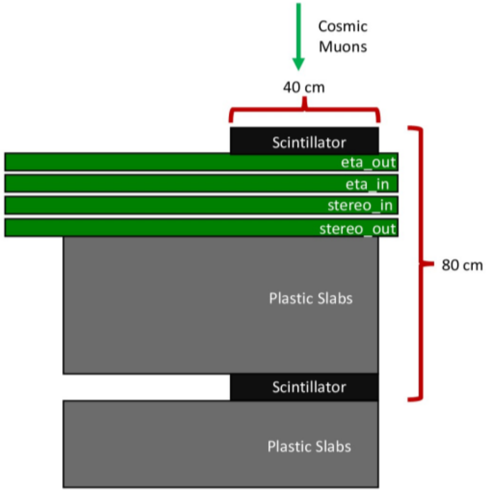
- 2 m^2 Micromegas detector with four detector layers; two eta layers and stereo layers each

- Two scintillators used for coincidence triggering with an acceptance angle is used to determine an event

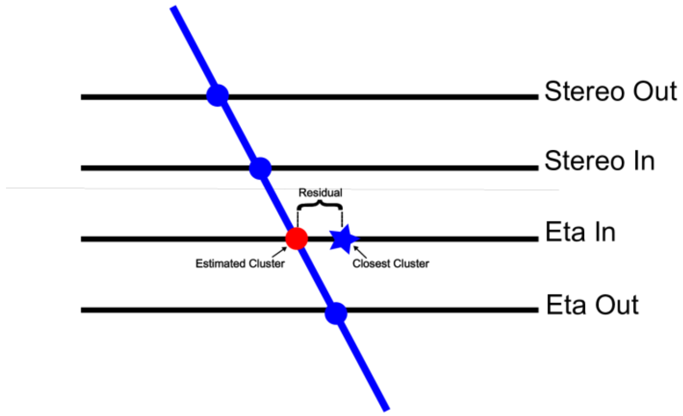
- Measurements performed for cosmic muons: muon spectrum of different energies and angles accepted

- Muon signal: 2 or more strips hit form a "cluster"



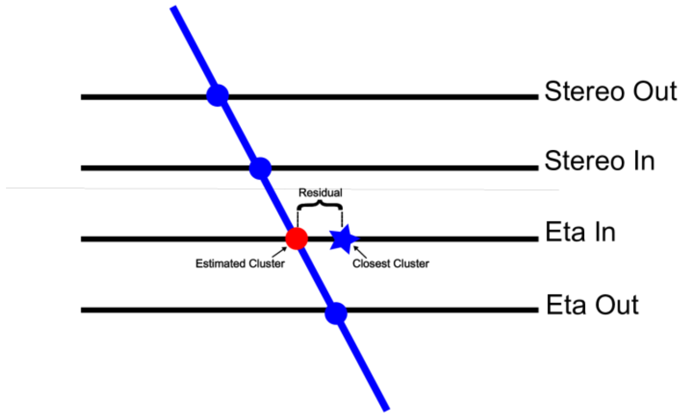


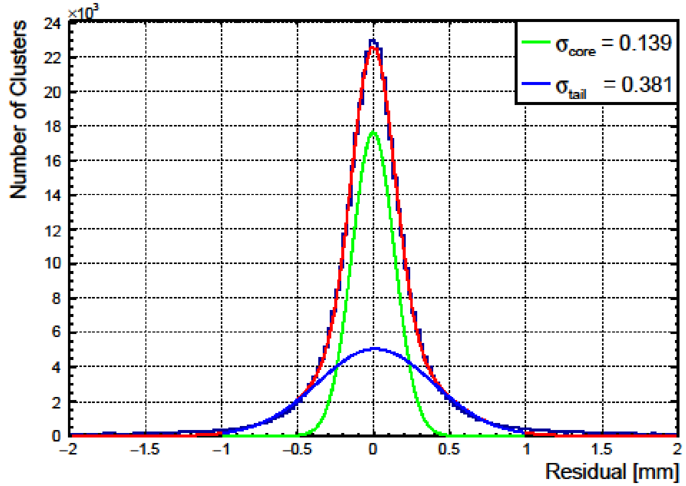
Track Reconstruction



- Track reconstruction using clusters from reference layers is iterated for the investigation of each layer
- The reconstructed hit in the layer investigated is compared to the nearest cluster found in that layer

Track Reconstruction

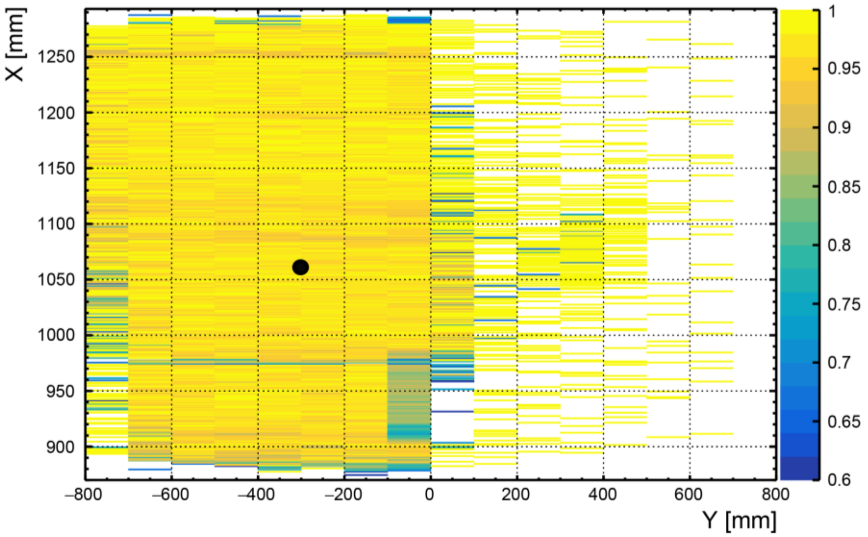


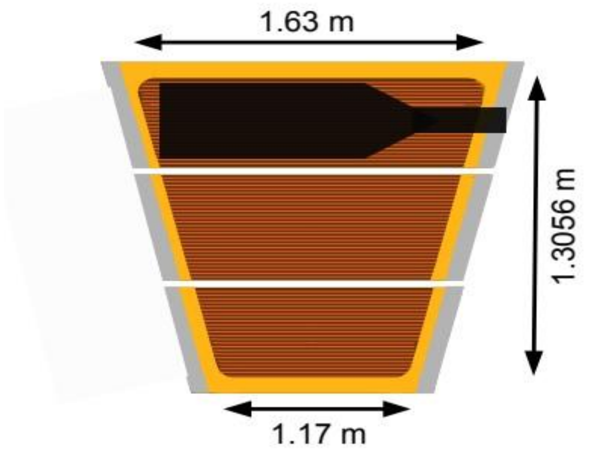


- Track reconstruction using clusters from reference layers is iterated for the investigation of each layer
- The reconstructed hit in the layer investigated is compared to the nearest cluster found in that layer
- The residuals are plotted for each event in the layer and fit to a double Gaussian
- The residual of the inner eta layer is taken as the width of core Gaussian = 139 μm
- Good residuals keeping in mind the negative effects of angles of cosmic muons and their energy spectrum leading to multiple scattering!

Detector Performance and Efficiency

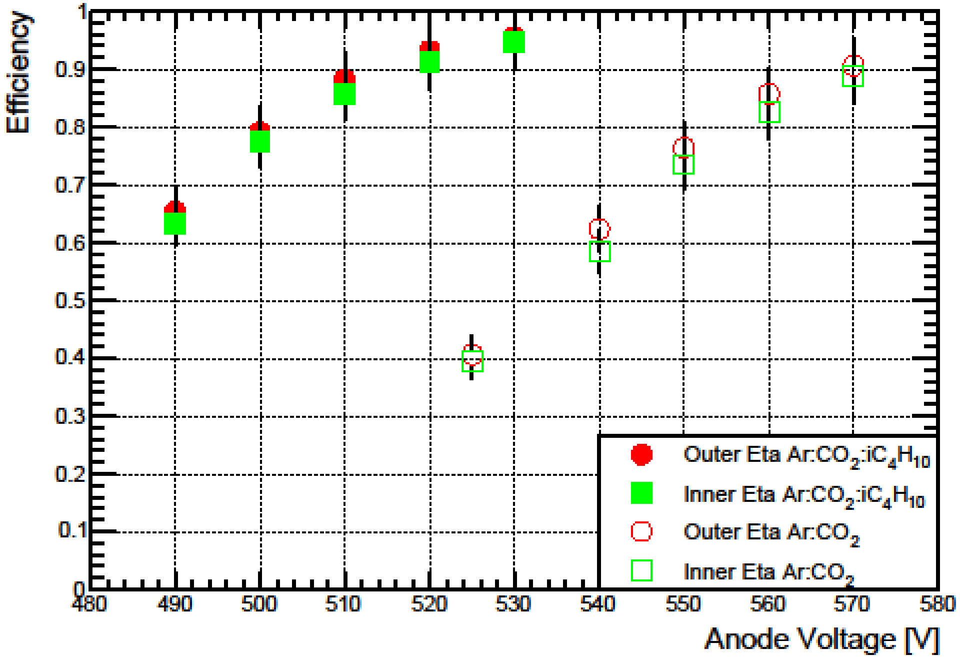
- Efficiency of detector layer estimated using total clusters found in the investigated layer having a residual window of $\pm$ 5 mm
- Efficiency plot for outer eta layer, which was the layer closest to the source, is shown
- No decrease in efficiency seen in the immediate vicinity of the irradiated area; center of the source is indicated with the black marker





Detector Performance and Efficiency

- Efficiencies above 90% for the eta layers is the standard requirement for high rate capable detectors which is successfully met for higher amplification voltages for both the gas mixtures
- Three years of high background irradiation shows no degradation in the efficiency of the detector!



Conclusion

- Long term irradiation studies of Micromegas detectors in Munich were performed for 3 years under high background radiation from a neutron source which necessitated a source characterisation

- A Germanium detector was used to understand the Am-Be source intensity ratio for gammas. Calibration and efficiency of the detector was performed to obtain the Am-Be gamma spectrum and the intensity ratio is estimated to be $R \approx 150$

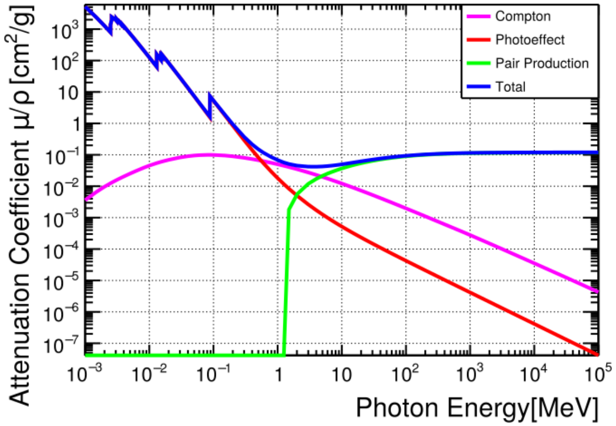
- Geant4 simulation is used to disentangle the contributions from 4.4 MeV γ and neutrons: the number of electrons produced by the ionizing radiation in the simulation is compared to the measured current

- The correlation between simulated results and the measured data confirms the validity of the simulation design and shows good agreement for attenuated 60 keV photons

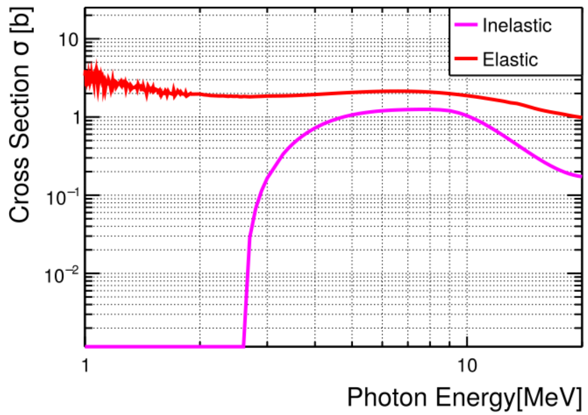
- Efficiency of Micromegas detectors in Munich after irradiation with background from Am-Be neutron source for three years showed no decrease or degradation in performance of the detector. Efficiencies above 90% were achieved for both the gas mixtures.

THANK YOU FOR LISTENING! ☺

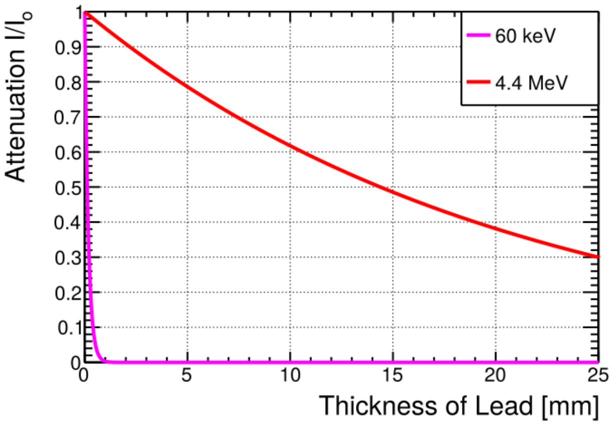
Backup

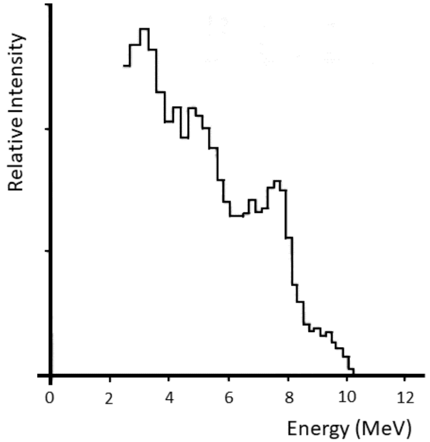


Cross Section of γ in Lead



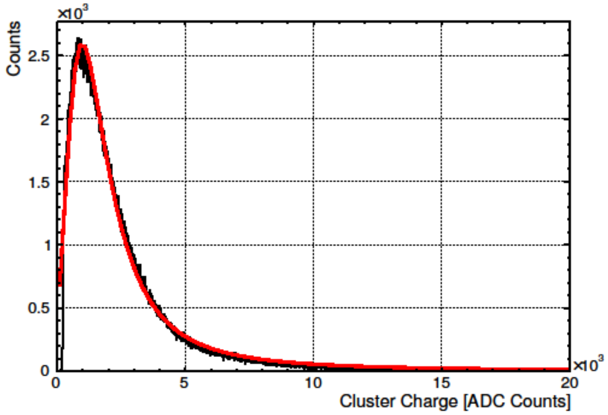
Cross Section of neutrons in Lead



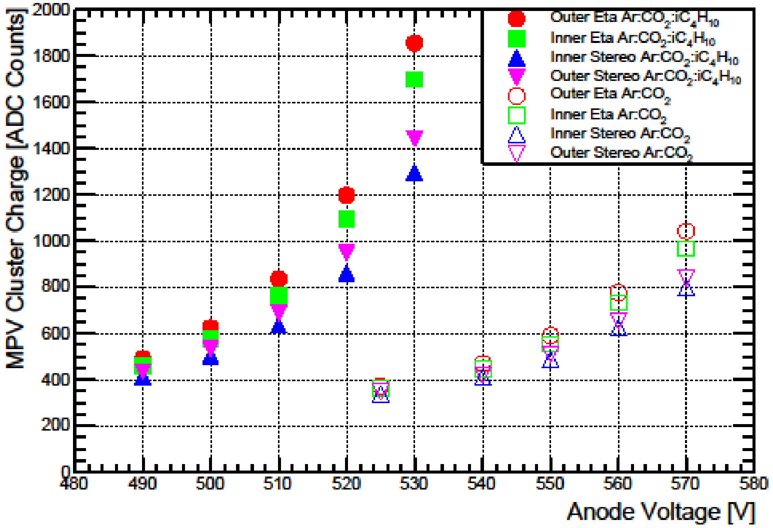


Intensity of neutrons in Am-Be source

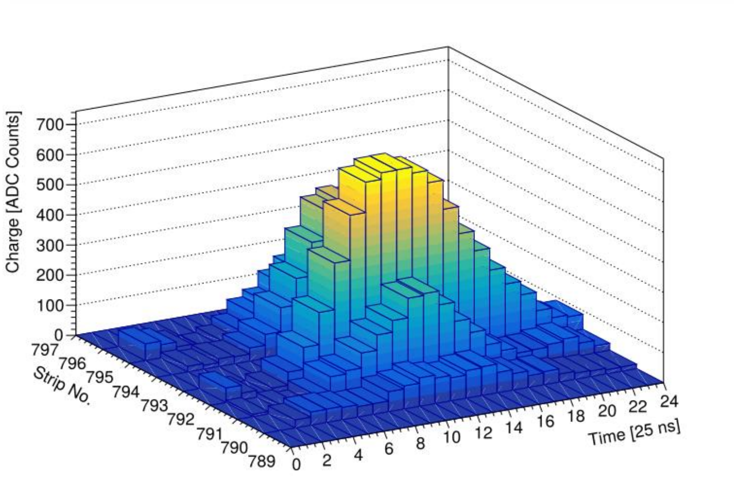
Backup



×10^3
Counts
2.5
2
1.5
1
0.5
0
0
5
10
15
20
×10^3
Cluster Charge [ADC Counts]

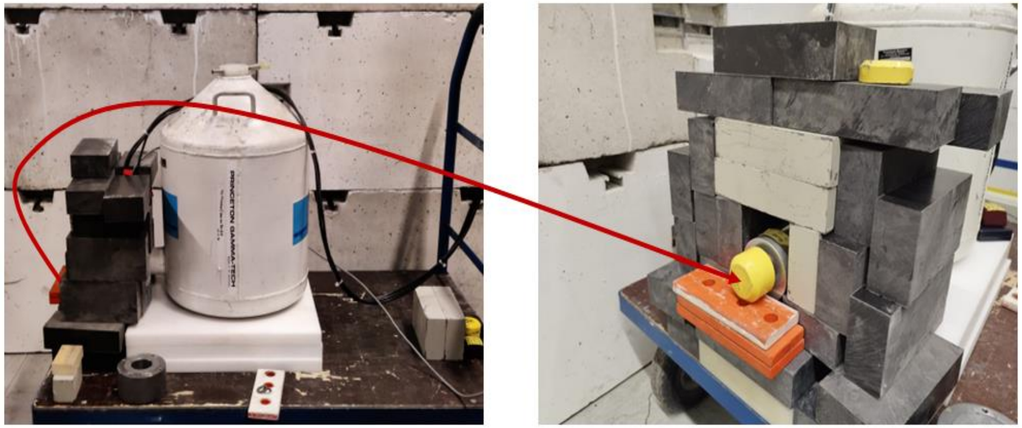


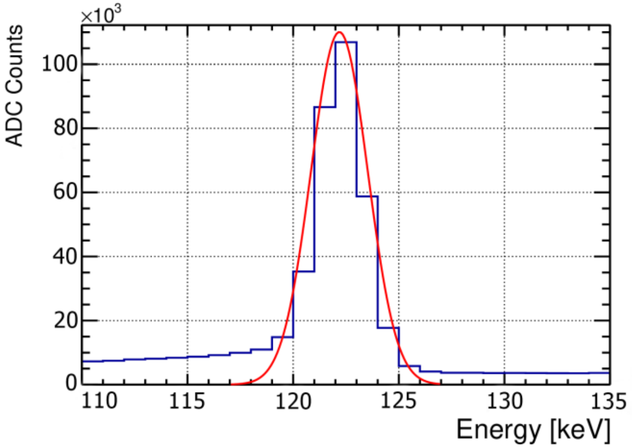
2000
1800
1600
1400
1200
1000
800
600
400
200
0
480
490
500
510
520
530
540
550
560
570
580
MPV Cluster Charge [ADC Counts]
Anode Voltage [V]
Outer Eta Ar:CO2:iC4H10
Inner Eta Ar:CO2:iC4H10
Inner Stereo Ar:CO2:iC4H10
Outer Stereo Ar:CO2:iC4H10
Outer Eta Ar:CO2
Inner Eta Ar:CO2
Inner Stereo Ar:CO2
Outer Stereo Ar:CO2



Charge [ADC Counts]
700
600
500
400
300
200
100
0
797
796
795
794
793
792
791
790
789
Strip No.
0
2
4
6
8
10
12
14
16
18
20
22
24
Time [25 ns]

Efficiency Estimation





$$\epsilon = \frac{N}{A_s I_\gamma t}$$

ATLAS Upgrade: New Small Wheels

- High Luminosity Upgrade of the LHC: the muon spectrometer of the ATLAS will face much harsher background rate at $L = 7.5\times10^{34}\ cm^{-2}\ s^{-1}$
- To handle the high background radiation, the Micromegas were chosen to replace the MDTs (Monitored Drift Tubes) and the CSCs
- The gas used in the Micromegas detectors was changed from $Ar:CO_2$ (93:7%) to $Ar:CO_2:iC_4H_{10}$ (93:5:2%) due to high voltage instabilities