COSMIC MUON TRACKING WITH MICROMEGAS DETECTORS AND NEUTRON SOURCE CHARACTERISATION

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DPG FRÜHJAHRSTAGUNG KARLSRUHE

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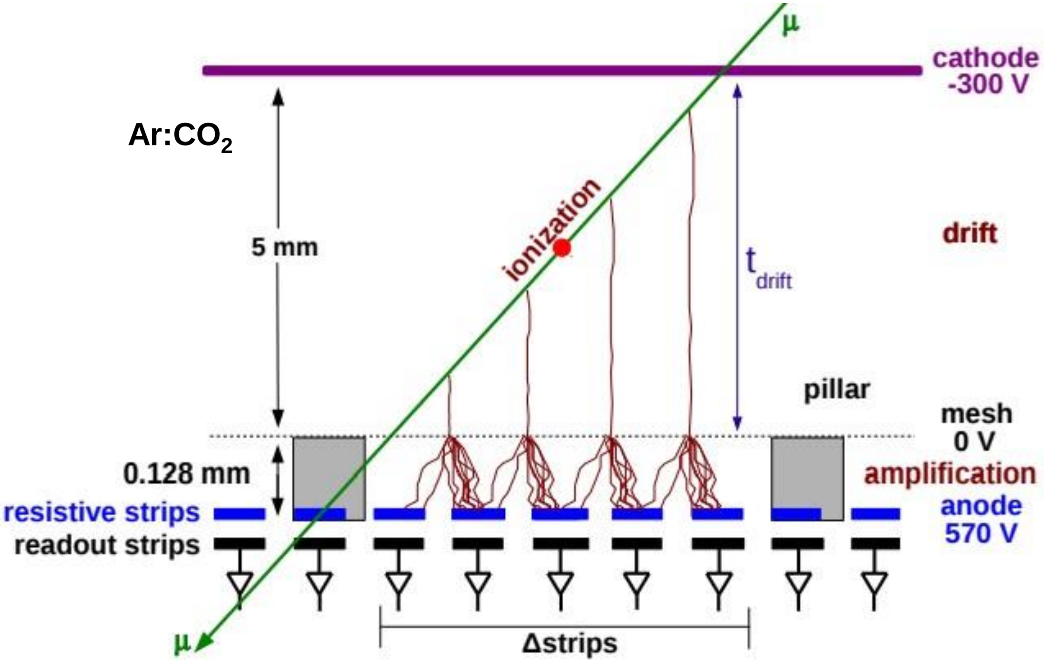
FSP ATLAS
Erforschung von Universum und Materie

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 5k-10k for $E_{Amp} \approx 50$ kV/cm
- These electrons are finally detected on the **anode**
- Fast signals makes these detectors high rate capable



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

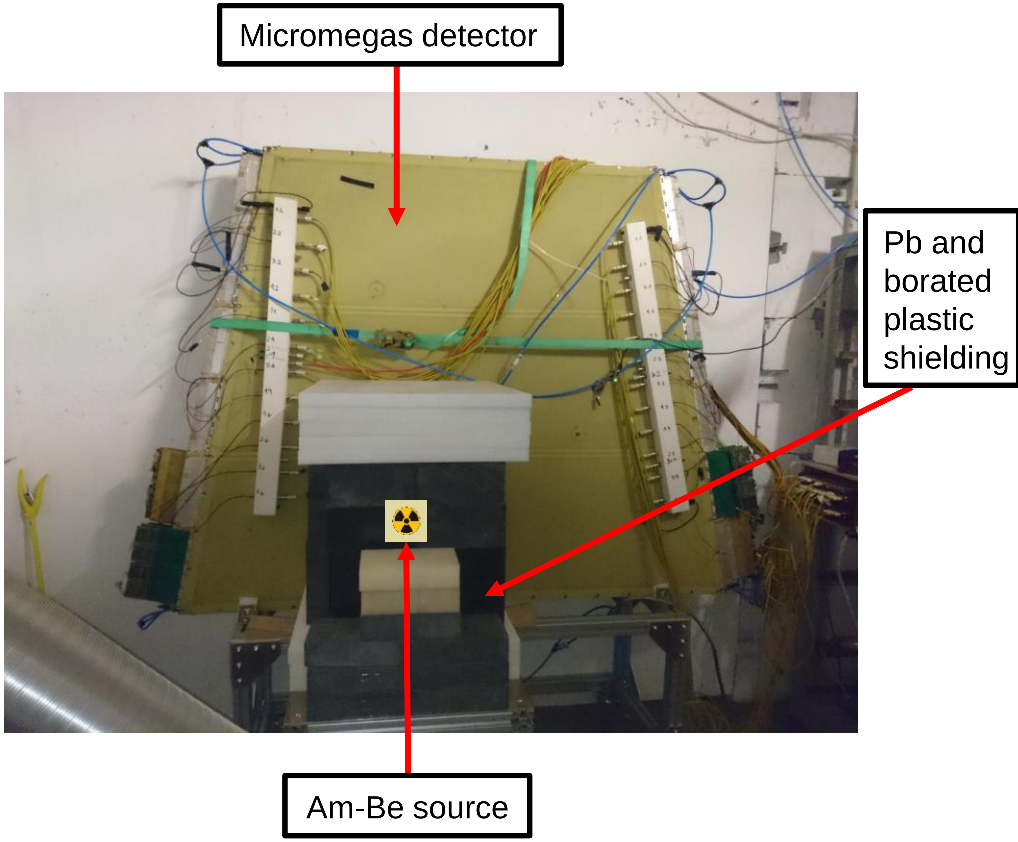
Long-term Irradiation Set-up

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

- **Motivation:**

  - **Characterisation of the neutron source** was necessary in order to understand the interactions inside the detector

  - **Testing of the detectors after the long term irradiation** to look for possible decrease in efficiency and overall performance or potential damages to the anode was required



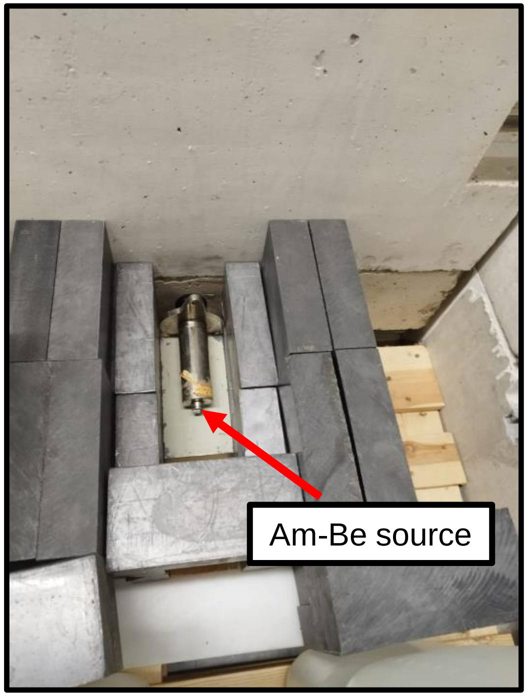
Neutron Source: Americium Beryllium

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

$$^{241}Am \rightarrow {}^{237}Np + \alpha + \gamma(59.54\,keV)$$

$$^{9}Be + \alpha \rightarrow {}^{13}C^{*}$$

$$^{13}C^{*} \rightarrow {}^{12}C + n + \gamma(4.438\,MeV)$$



Yield: $6 * 10^4$ neutrons/sec per GBq (1-10 MeV)

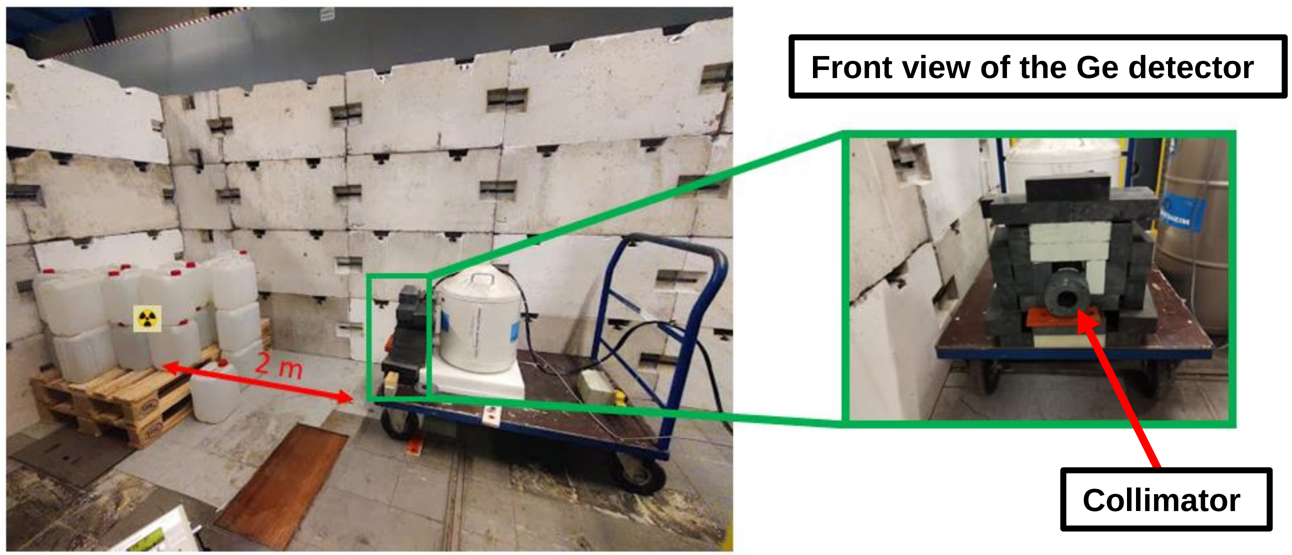
Activity: 10 GBq α → $6 * 10^5$ neutrons/sec + $6 * 10^5$ (MeV) γ
→ $10 * 10^9$ (keV) photons

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

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

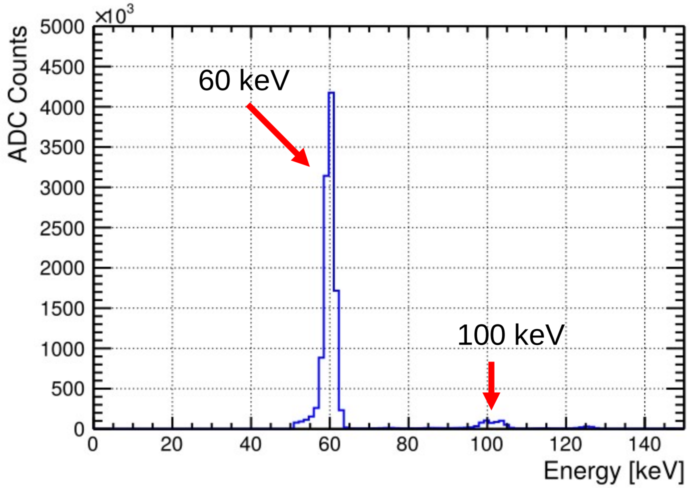
Germanium Detector

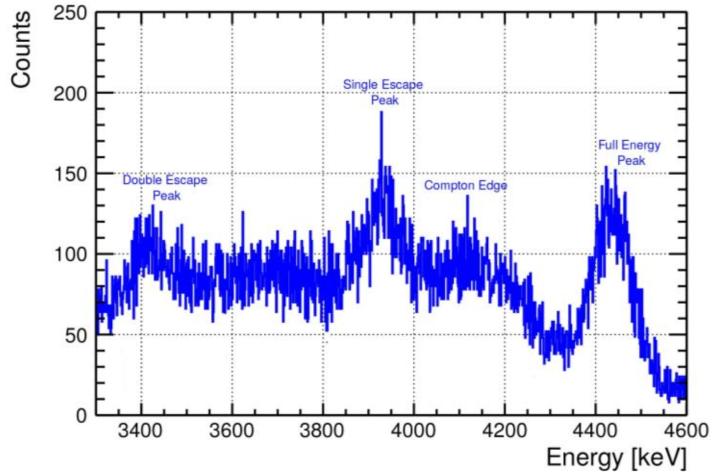
- Germanium detectors: Excellent resolution at low and high energies
- The source is kept at a distance 2 m from the detector due to its high activity rate and is shielded from all sides with water as well as lead and plastic blocks
- A collimator of r = 25 mm is used to reduce edge effects



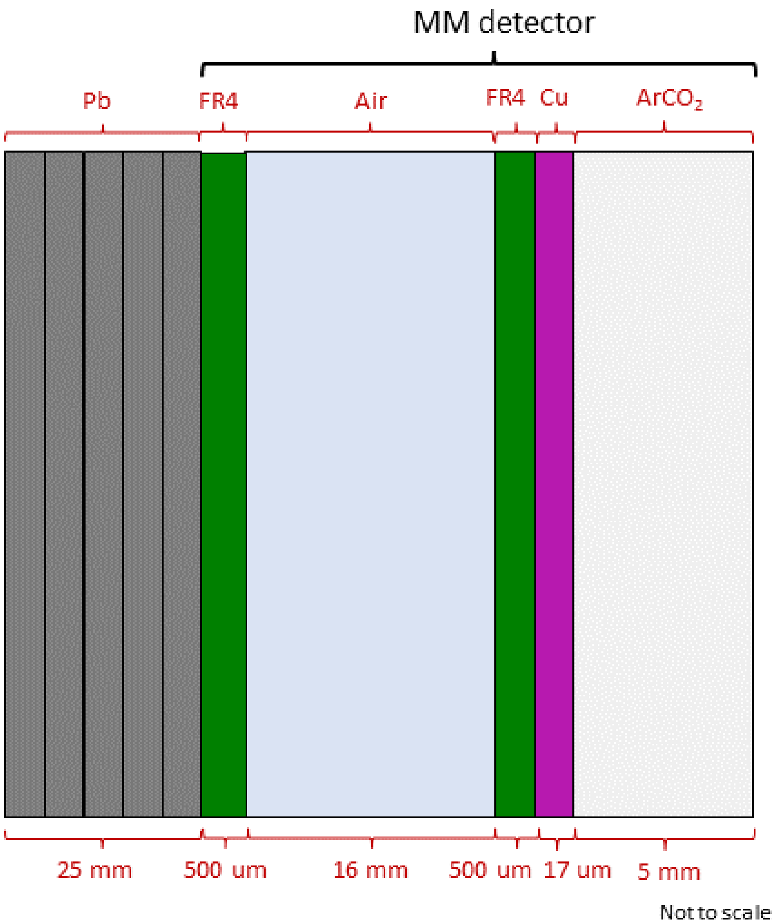
Am-Be Spectrum

- The distinct photopeak of the 60 keV photons is visible
- 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 intensity ratio between the two is calculated to be ≈ 450

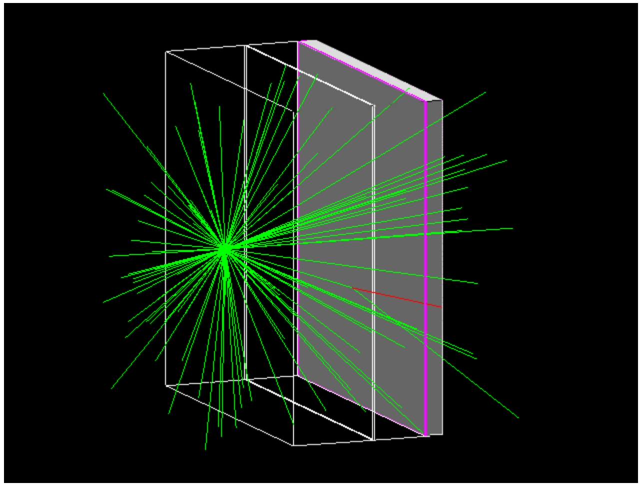




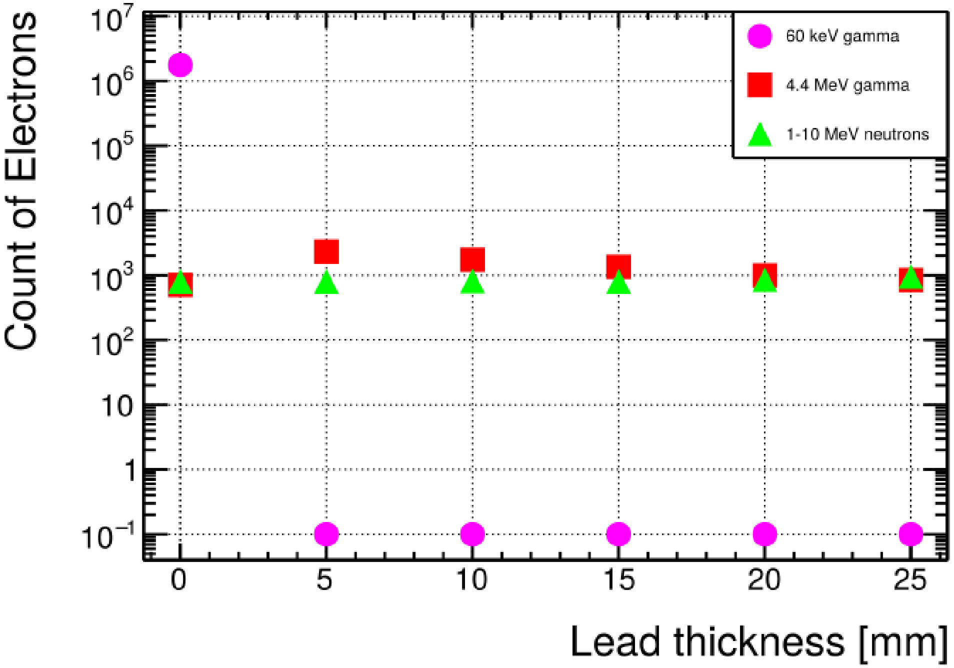
GEANT4 Simulation: Detector Set Up



- 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 450** for 60 keV γ
- Simulation for 60 keV photons for different thicknesses of Pb → as expected, complete absorption after 5 mm of Pb!

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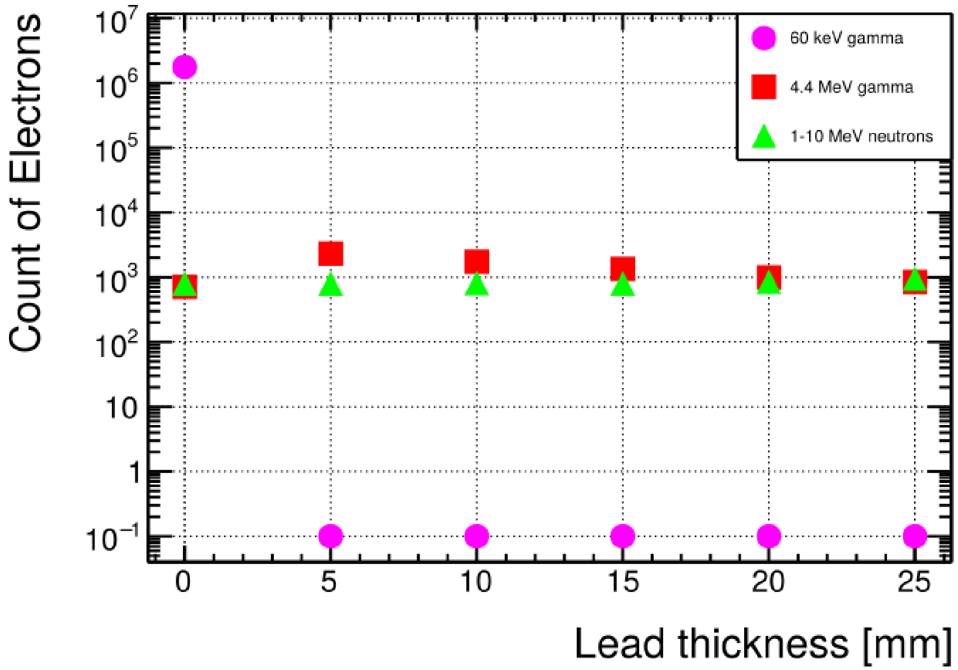

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- Total number of electrons created by 4.4 MeV γ:
  - → increases for 5 mm Pb due to Compton scattering
  - → this reduces the γ energy so more electrons are created in Cu
  - → starts attenuating for increasing Pb thickness

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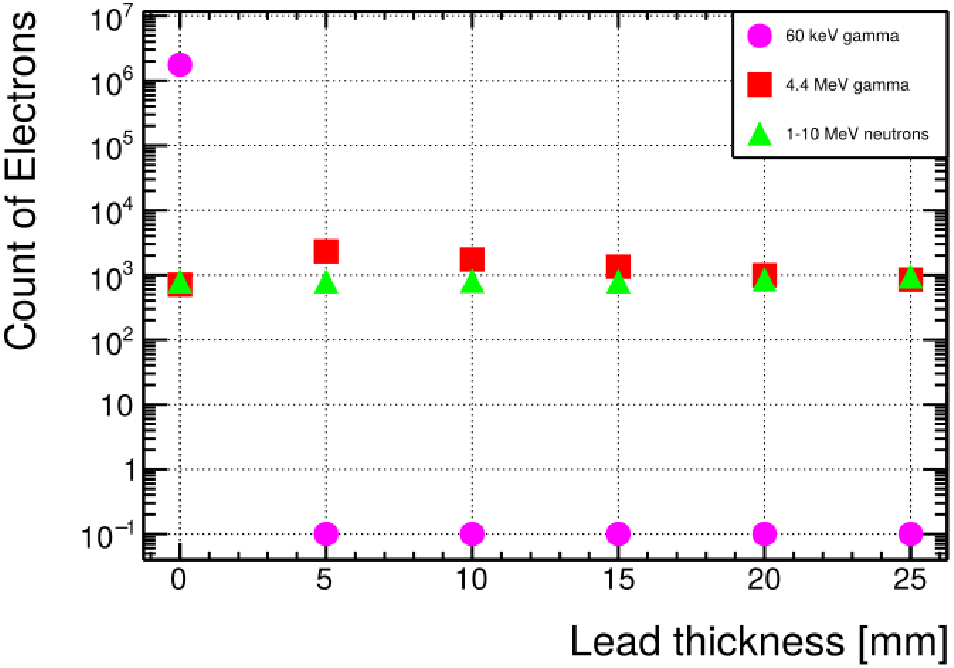

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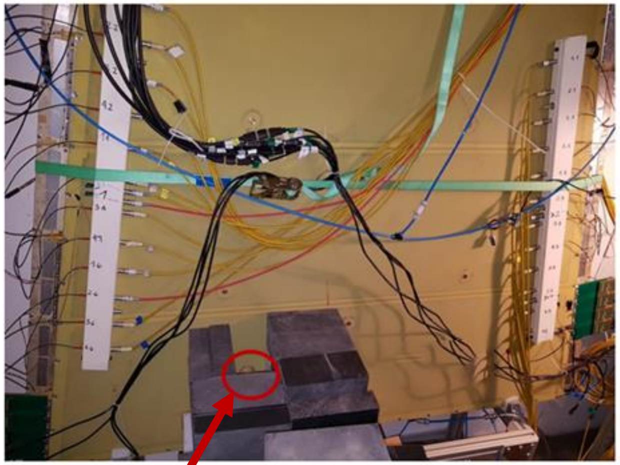
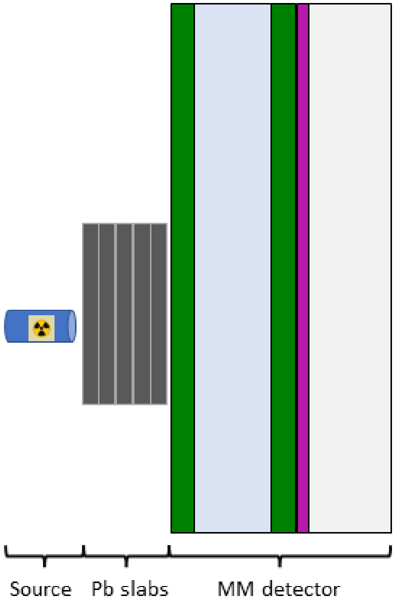
- Total number of electrons created by 4.4 MeV γ:
  → increases for 5 mm Pb due to Compton scattering
  → this reduces the γ energy so more electrons are created in Cu
  → starts attenuating for increasing Pb thickness
- Total number of electrons created by neutrons of energies ranging from 1 to 10 MeV → remains fairly constant

Behaviour of the simulation in terms of the interaction of the neutrons and photons confirms the validity of the simulation design

Long-term Irradiation Set-up



Neutron
source

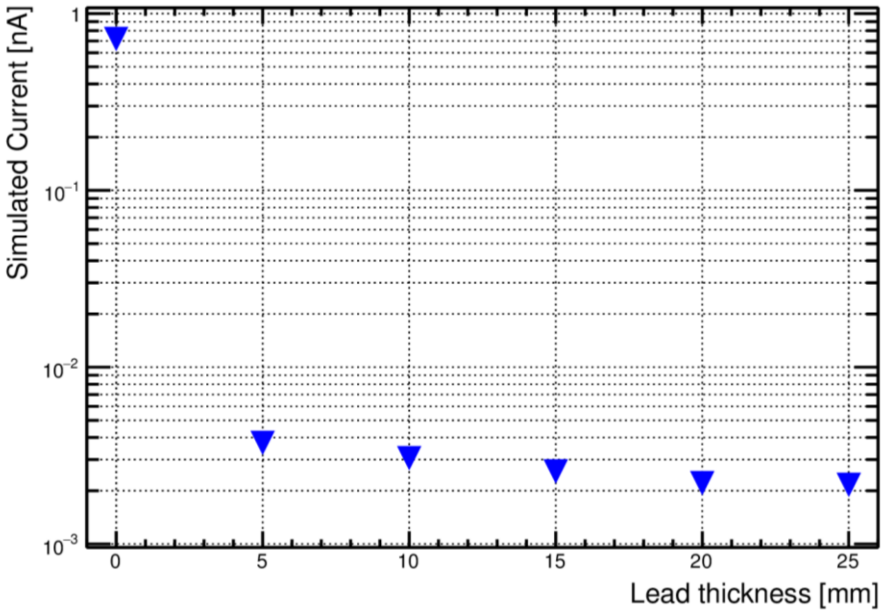


Not to scale

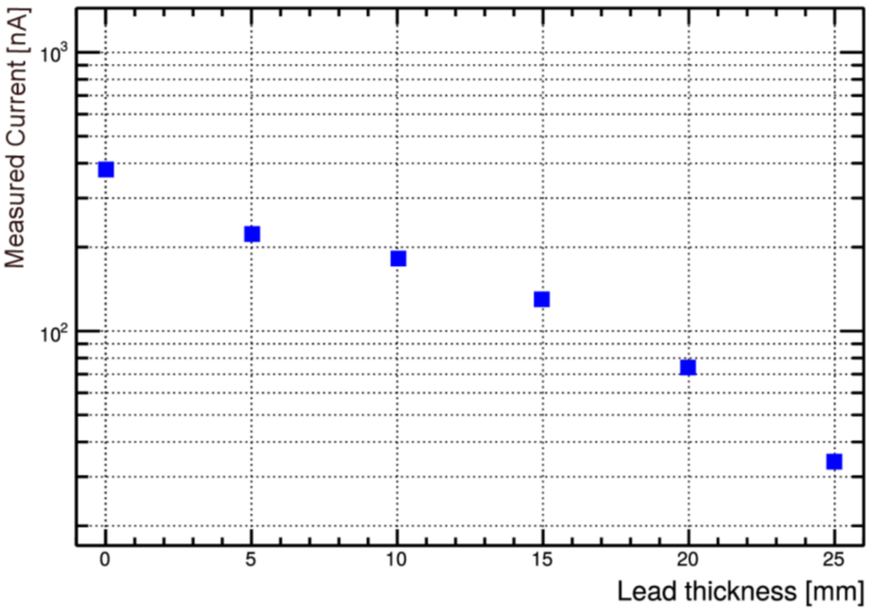
- Current is measured from the MM detector placed in front of the neutron source for varying thicknesses of Pb to attenuate the 60 keV photons in order to disentangle the MeV photons and neutrons easily

GEANT4 Simulation: Results and Comparison

Simulation



Measurement

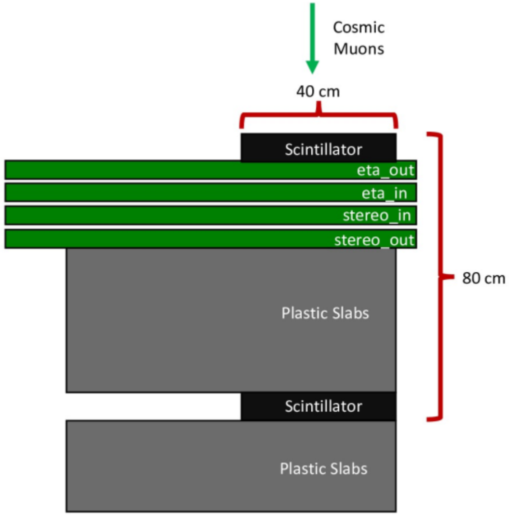


The simulated current is currently lower than expected in comparison to the measured values

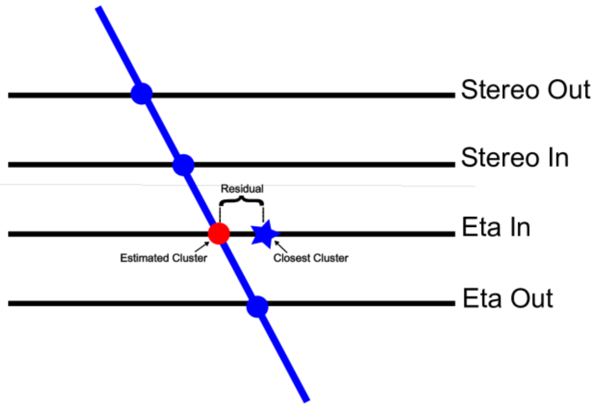
- The intensity factor R $\approx$ 450 depends on currently uncertain factors (undergoing further investigations)
- The measured current after 5 mm lead should see an exponential decrease but does not: there are some underlying mechanisms the simulation does not account for

Micromegas Detector Set-up

- 2 m^2 Micromegas detector with four detector layers; two “eta” and “stereo” layers each
- Measurements were performed with two gas mixtures: $Ar:CO_2$ and $Ar:CO_2:iC_4H_{10}$ (currently used in ATLAS)
- Three years of high background irradiation on these detectors accumulated charge equivalent to multiple years of the ATLAS working environment
- 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 hits in a layer 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
- Residual = $pos_{reconstructed} - pos_{hit}$

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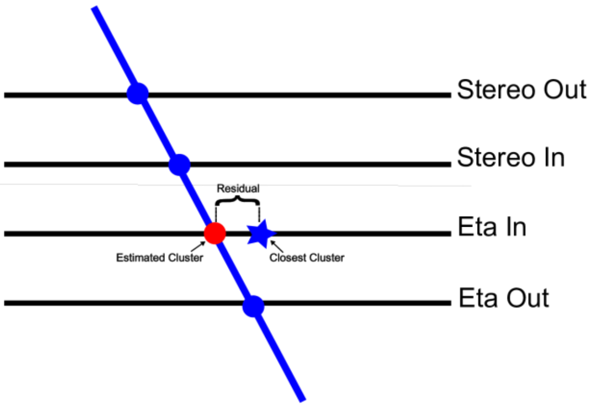

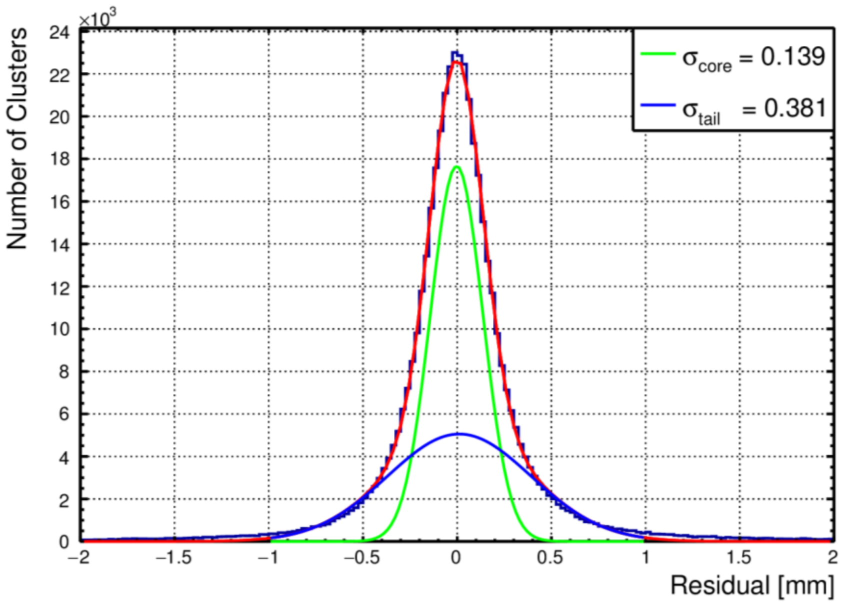

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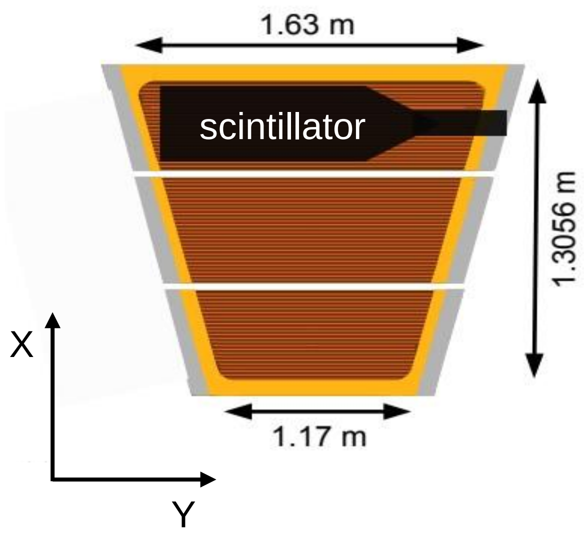
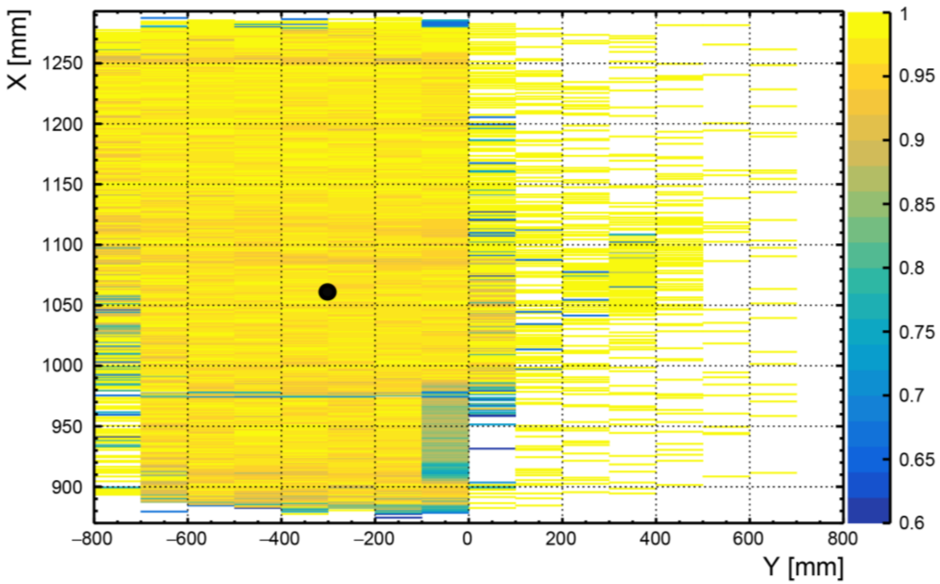
- The reconstructed hit in the layer investigated is compared to the nearest cluster found in that layer
- Residual = $pos_{reconstructed} - pos_{hit}$
- The residual of the inner eta layer is taken as the width of core Gaussian = 139 μm
- Good residuals keeping in mind the negative effects of angles 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; centre of the source is indicated with the black marker

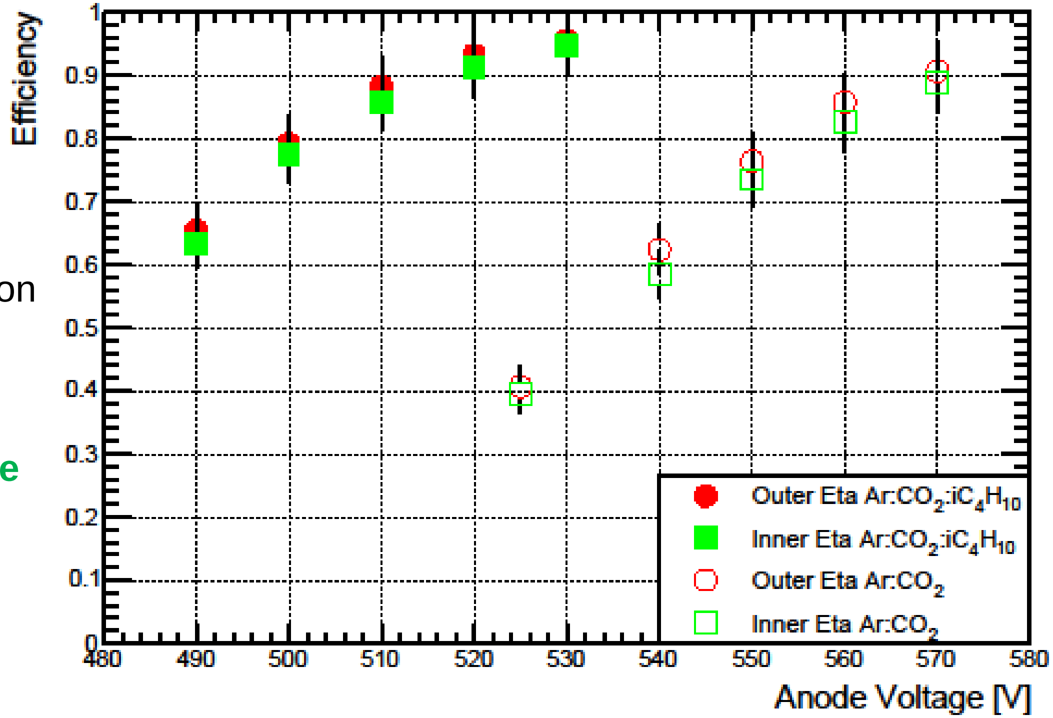




Detector Performance and Efficiency

- **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!

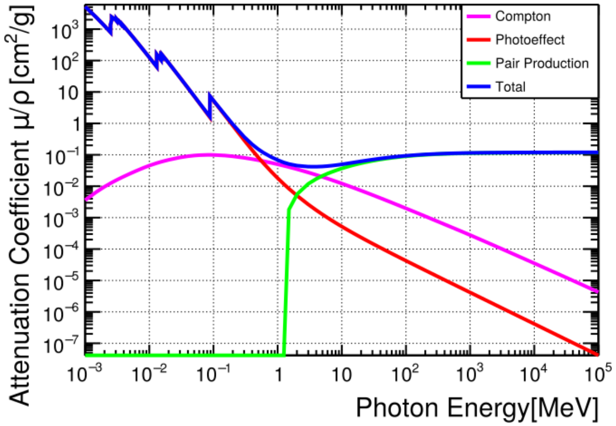


Summary and Outlook

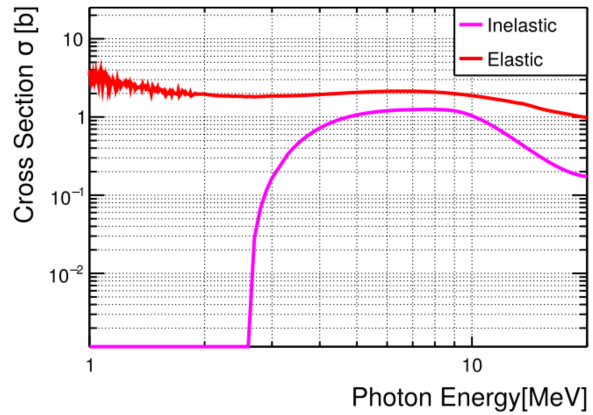
- Long term irradiation studies of Micromegas detectors in Munich were performed for 3 years under high background radiation from a neutron source which necessitated a source characterisation
- A Germanium detector was used to understand the Am-Be source intensity ratio for gammas which is estimated to be $R \approx 450$
- Geant4 simulation is used to disentangle the contributions from 4.4 MeV γ and neutrons: the simulated current is much lower compared to the measured current
- The expected behaviour of photon and neutron interaction in the detector is **seen in the simulation design** but some underlying mechanisms are unaccounted for
- 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! ☺

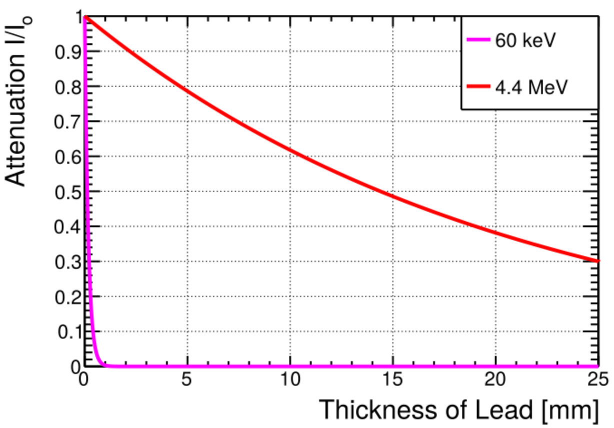
Backup

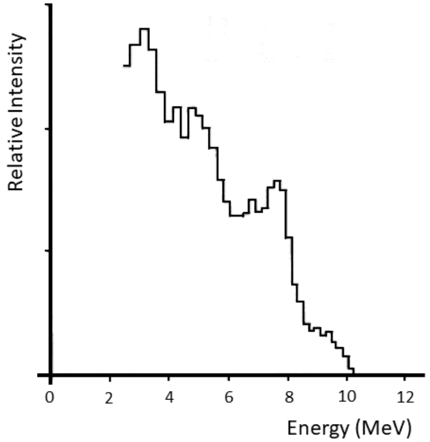


Cross Section of γ in Lead



Cross Section of neutrons in Lead





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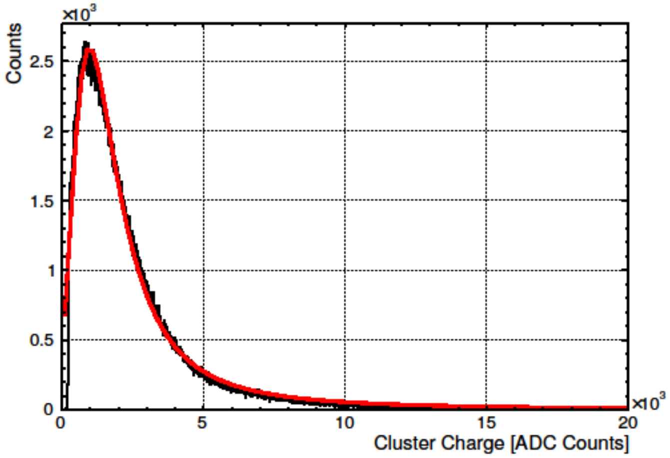
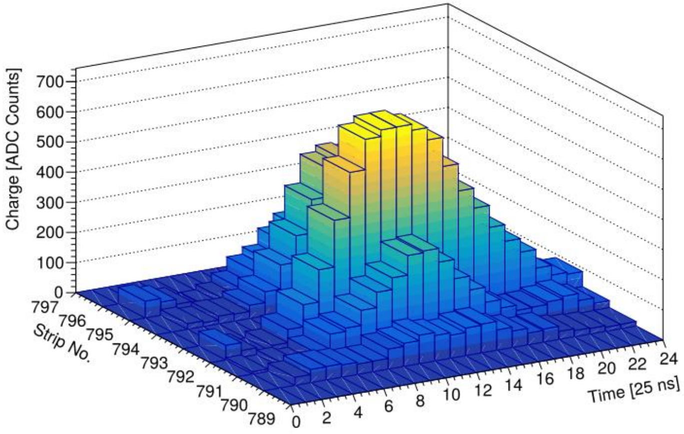
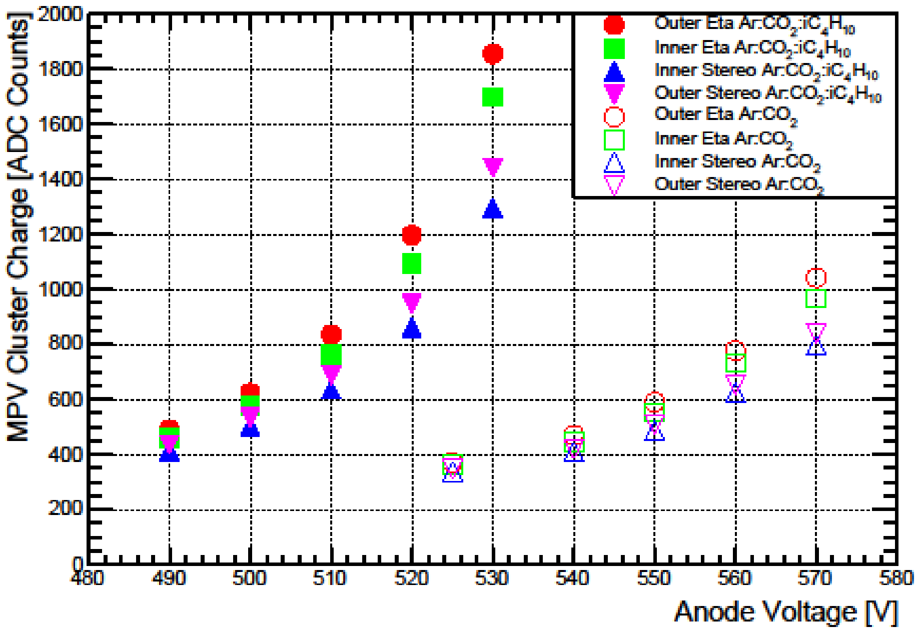


Counts
×10³
2.5
2
1.5
1
0.5
0
0
5
10
15
20
×10³
Cluster Charge [ADC Counts]



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]

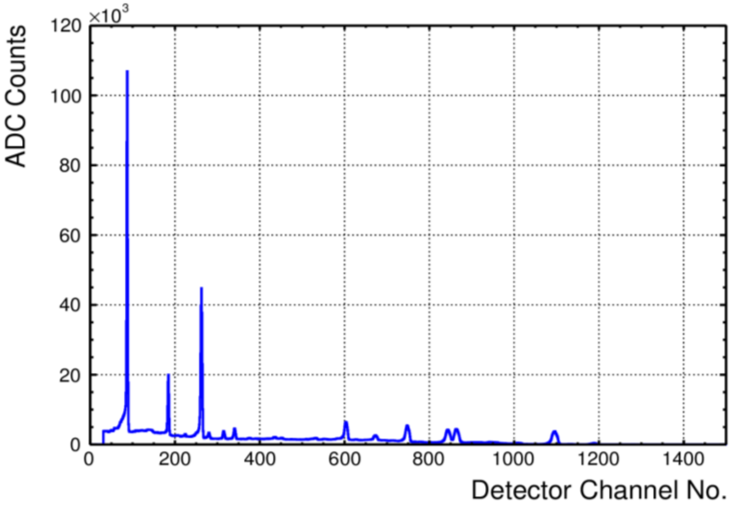


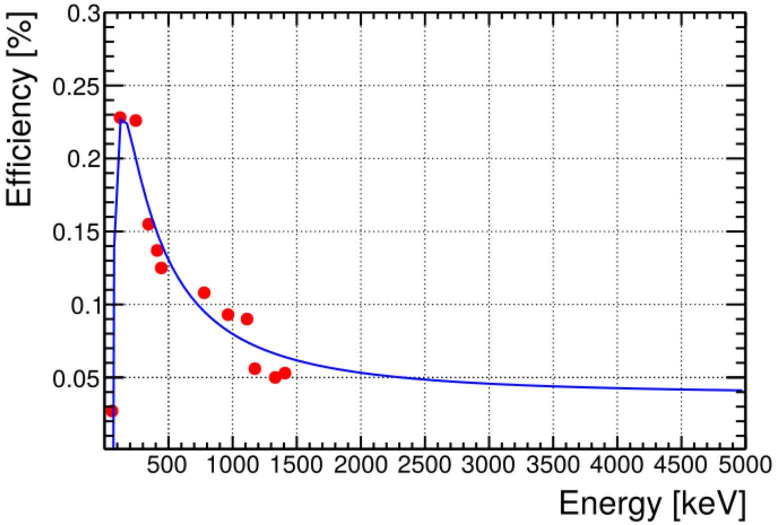
MPV Cluster Charge [ADC Counts]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
480
490
500
510
520
530
540
550
560
570
580
Anode Voltage [V]
Outer Eta Ar:CO2:iC4H10
Inner Eta Ar:CO2:iC4H10
Inner Stereo Ar:CO2:iC4H10
Outer Stereo Ar:CO2:iC4H10
Outer Eta Ar:CO2
Inner Eta Ar:CO2
Inner Stereo Ar:CO2
Outer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

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 its 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

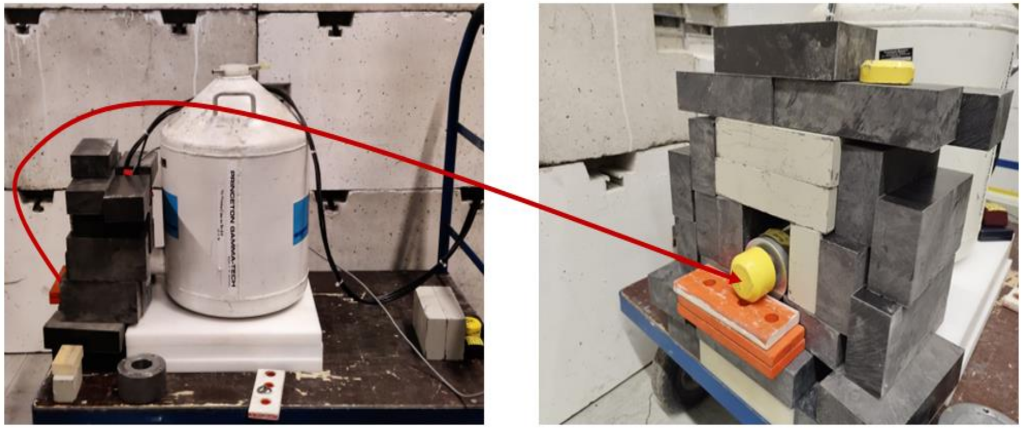
$$\varepsilon = \frac{[p0] + [p1]\cdot(\ln E) + [p2]\cdot(\ln E)^2 + [p3]\cdot(\ln E)^3 + [p4]\cdot(\ln E)^4}{E}$$

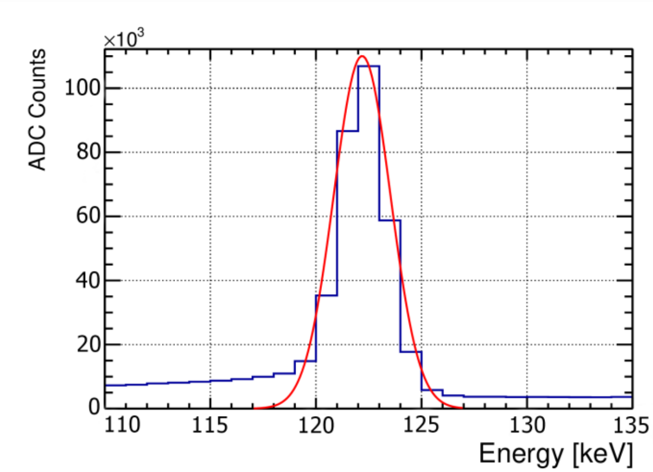




[1] Gray, P.W. and A. Ahmad (1985). “Linear classes of Ge(Li) detector efficiency functions”.

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