Muon Tracking with Micro-Pattern Gaseous Detectors

Micromegas

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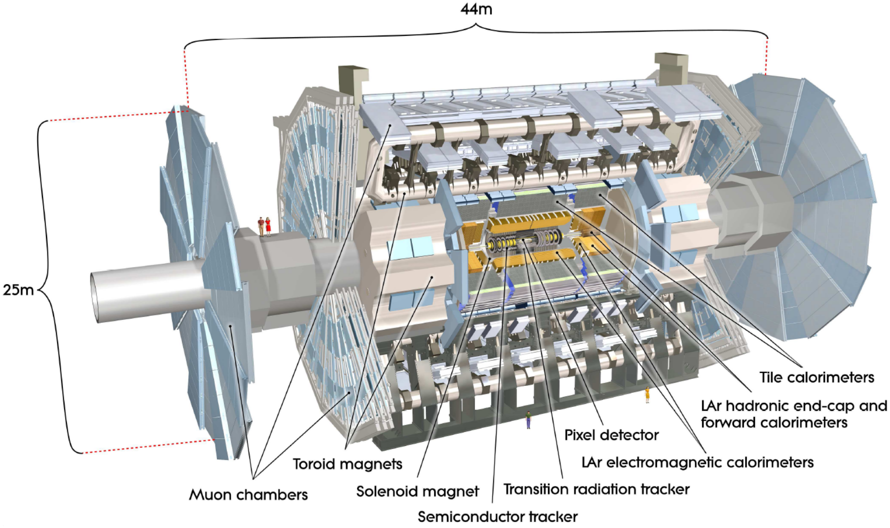
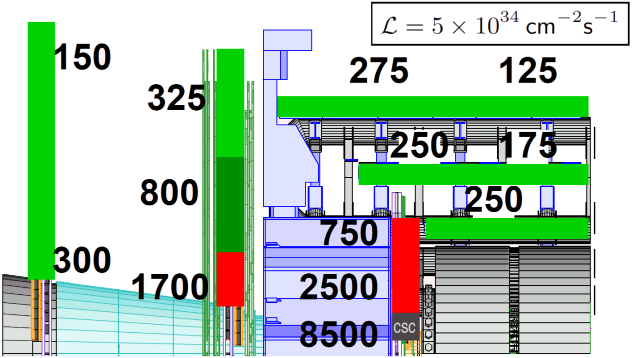
The ATLAS Experiment at LHC



sLHC: Why New Muon Detectors?



J. v. Loeben, IEEE Nucl. Sc. Symp. 2010

expected background rates [Hz/cm²], including safety factor of 5

high-rate neutron- & γ-background:

- occupancy $\leftrightarrow$ low efficiency
- degradation of spatial resolution $\leftrightarrow$ worse momentum resolution

Properties of a "good" muon detector for ATLAS

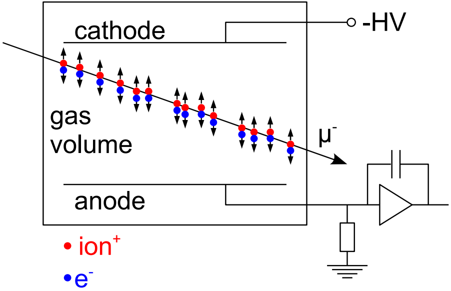
- high efficiency to muons
- good spatial resolution $\Delta r \lesssim 50\,\mu\text{m}$
- high rate capability
  - low occupancy
  - little degradation of spatial resolution in high flux γ- and neutron-background
- large area coverage
- cost effective
- reliable = no or at least little aging

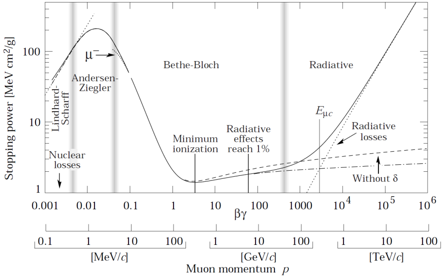
What are we doing?

- large area detector systems with good spatial resolution (ATLAS Small Wheel Upgrade, MAMMA collaboration)
- investigate behavior of Micromegas under irradiation (stability, spatial resolution, efficiency)
- muon track monitor/telescope (high-rate capable, good spatial resolution $\Delta x \lesssim 50\,\mu\text{m}$, radiation hard)
    - 140 GeV muons/pions @ H8 and H6/CERN
    - cosmic muons @ GIF/CERN
    - cosmic muons @ Tandem accelerator/MLL Garching

Outline

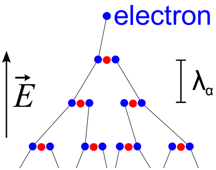
Ionization Chamber

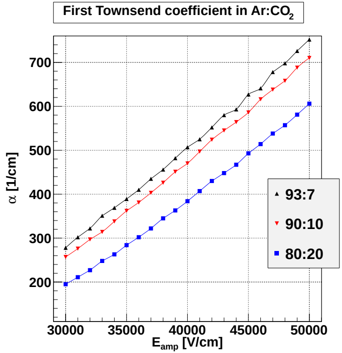




- charged particles: el.-magn. interaction dominant in gas detectors → excitation and **ionization**
- incident particle deposits energy in gas, Bethe-Bloch → $\langle dE/dx \rangle$
- $\langle dE/dx \rangle_{MIP} = 2.53\,\text{keV/cm}$ in Ar @ NTP
- $\#_{e-\text{ion pairs}} = \frac{\langle dE/dx \rangle}{W_I}$
- $W_I \sim 25\,\text{eV}$ in Ar (also accounts for excitation) →∼**100 e-ion-pairs/cm**
- measureable but really difficult!

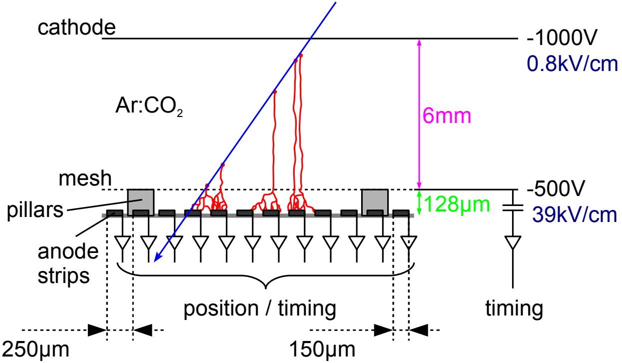
Gas Amplification

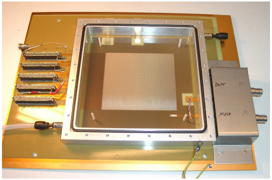




- in **strong electric fields**, e^- gain enough energy to further ionize the gas
- mean free path $\lambda_\alpha = 1/\alpha$
- first Townsend coefficient $\alpha = \#_{e-\text{ion pairs}}/\text{cm}$
- $N(x) = N_0 \exp(\alpha x)$
- **gain factors of 3000 - 20000** sufficient

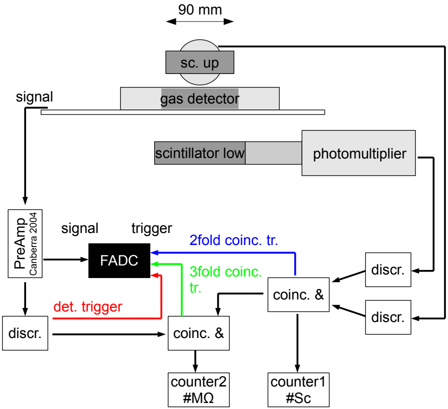
Setup & Functional Principle





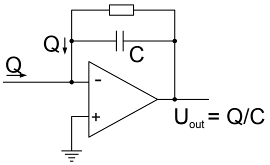
- ionization in 5-7 mm drift region
- gas amplification in 128 μm amplification region
- $90 \times 100\,\text{mm}^2$, 360 strips (150 μm width and 250 μm pitch)
- gas: **Ar:CO_2 93:7**, 90:10, **85:15** and 80:20 @ NTP

Flash ADC: Setup

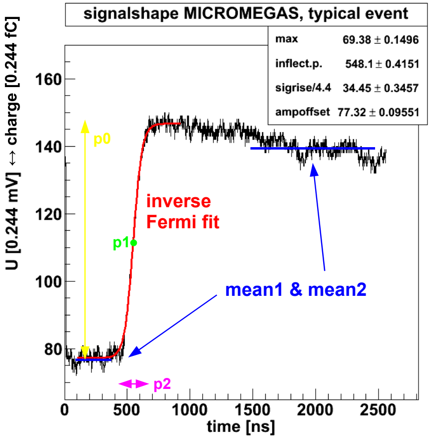


- 1 GHz FADC → **temporal structure of charge signals**
- all strips or subgroups of strips interconnected
- internal trigger: det. trigger, ^{55}Fe source
- external trigger:
  - 2 fold coinc.
  - 3 fold coinc., cosmics
- **efficiency** $\varepsilon = \frac{\# M\Omega}{\# Sc \times f_{\text{geom}}}$
- MC simulation of cosmic tracks → correction factor f_{geom}
- $\varepsilon_{\text{mip}} \gtrsim 98\%$

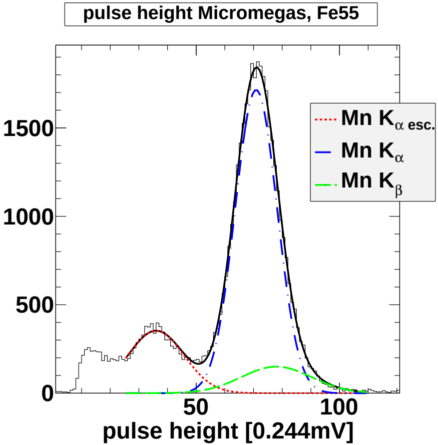
Flash ADC: Signal Analysis



- $f(t) = \frac{p0}{\exp((p1-t)/p2)+1} + p3$
- **p0** → amplitude: 3 - 250mV
- **p1** → timing
- **p2** → rise time: 45 - 200 ns
- **p3** → offset, only small variation
- possible condition: mean1 - mean2 $> 3\sigma$



Energy Resolution @ 5.9 keV X-rays

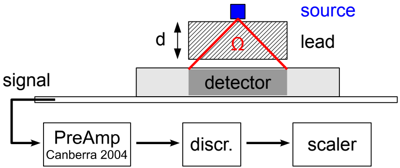


^{55}Fe decays via electron capture.
Photoeffect dominant interaction $\rightarrow$ mono-energetic lines:

- 5.9 keV ($\mathrm{Mn}_{K\alpha}$)
- 6.5 keV ($\mathrm{Mn}_{K\beta}$)
- 2.94 keV ($\mathrm{Mn}_{K\alpha,\mathrm{esc}}$)

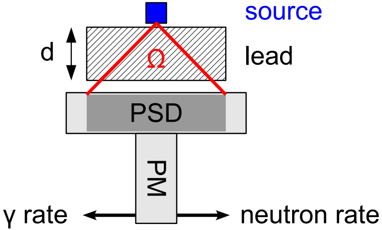
$\frac{\Delta E}{E}_{\mathrm{FWHM}} = 24\%$

Efficiency for Gammas (^{137}Cs)

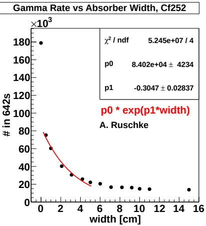


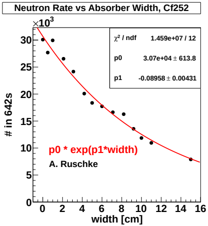
- **calibrated sources** with known activity $\dot{N}_{\text{tot}}$
- **count signals** within 300 s $\rightarrow \dot{N}_{\text{meas}}$
- determine solid angle Ω and correct for absorption (Al-lid with width d_{eff}) $\rightarrow$ $\dot{N}_{\text{true}} = \dot{N}_{\text{tot}} \cdot \frac{\Omega}{4\pi} \cdot \exp(-\lambda \cdot d_{\text{eff}})$
- $\varepsilon = \dot{N}_{\text{meas}} / \dot{N}_{\text{true}}$
- ^{137}Cs ($E_\gamma = 662\,\text{keV}$): $\dot{N}_{\text{true},\gamma} = (1.59 \pm 0.04)\,\text{MHz}$ $\varepsilon_\gamma = (2.6 \pm 0.2) \times 10^{-3}$

Efficiency for Neutrons (^{252}Cf)

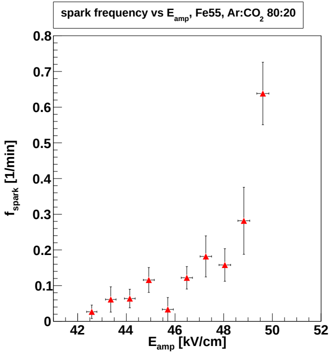


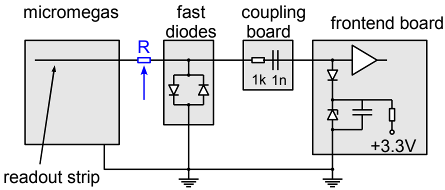
- E_n up to 8 MeV, $E_\gamma \approx$ keV…4 MeV
- issue: only total rate measurable $\rightarrow \dot{N}_{\text{meas}}(\text{neutron}) = ?$
- add Pb-absorber and measure total rates $R_{d=1\text{cm}}$ & $R_{d=5\text{cm}}$
- $R_{1\text{cm}} = f_{1\text{cm},n}\dot{N}_{\text{meas},n} + f_{1\text{cm},\gamma}\dot{N}_{\text{meas},\gamma}$
  $R_{5\text{cm}} = f_{5\text{cm},n}\dot{N}_{\text{meas},n} + f_{5\text{cm},\gamma}\dot{N}_{\text{meas},\gamma}$
- use PSD to determine the fs
- ^{252}Cf:
  $\dot{N}_{\text{tot},n} \cdot \frac{\Omega}{4\pi} = (9.1 \pm 0.3)$ kHz
  $\dot{N}_{\text{tot,fiss}\gamma} \cdot \frac{\Omega}{4\pi} = (16.4 \pm 1.3)$ kHz
  $\varepsilon_n < 6.8 \times 10^{-4}$ @ 95% CL
  $\varepsilon_\gamma = (1.5 \pm 0.4) \times 10^{-3}$





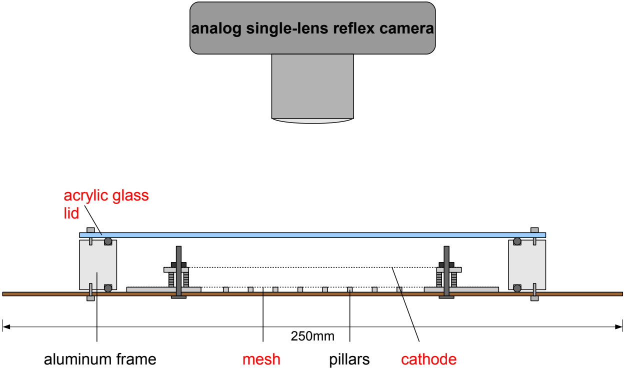
Sparking in Micromegas





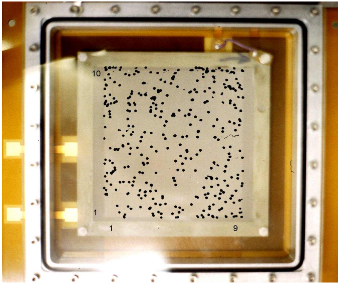
- discharges from mesh onto anode, **non-desctructive**
- possibly triggered by highly-ionizing particles ($\Delta E \gg 400\,\text{keV}$)
- $r_{\pi^-} = (1.0 \pm 0.2) \times 10^{-5}$/pion @ flux $5 \times 10^4 \text{s}^{-1}\text{cm}^{-2}$
- dead time after spark $< 20\,\text{ms}$
- protection of readout electronics absolutely necessary
- additional resistor to avoid mesh discharge

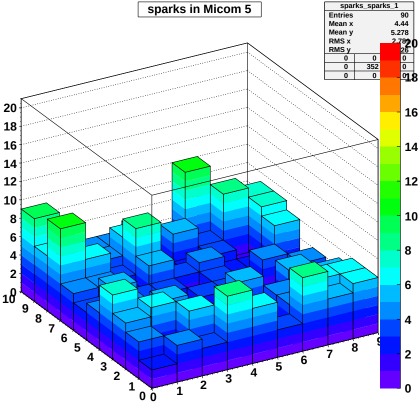
Spark Photographs Cosmics – Setup



- ground readout strips via $10\,\text{k}\Omega$ resistor, switch on high voltage
- use analog single-lens reflex camera (with film!) for long-time exposure $\sim 16\,\text{h}$
- sparks visible as small white dots due to excitation of gas

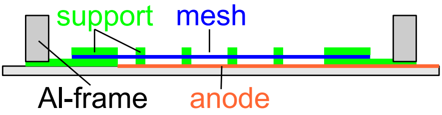
Spark Photos – No Irradiation



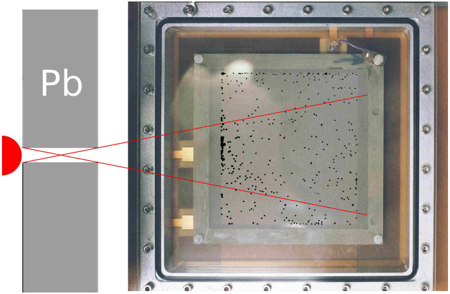


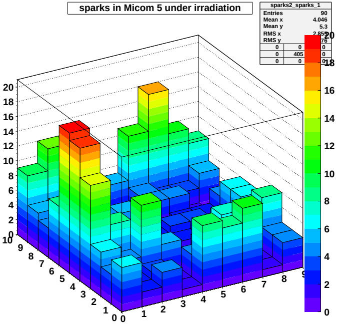
- discharges not localized, but ∼ homogeneously distributed over active area
- more discharges at the edges of the active area

→ highly-ionizing particles + charge-up effects?



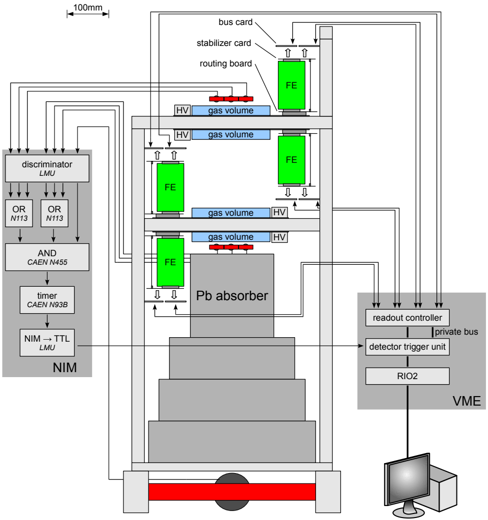
Spark Photos – γ Irradiation





- ^{137}Cs ($E_\gamma = 662\,\text{keV}$)
- increased spark rate due to irradiation
- reaction of γs in Al-frame or cathode-frame?
- further investigation needed

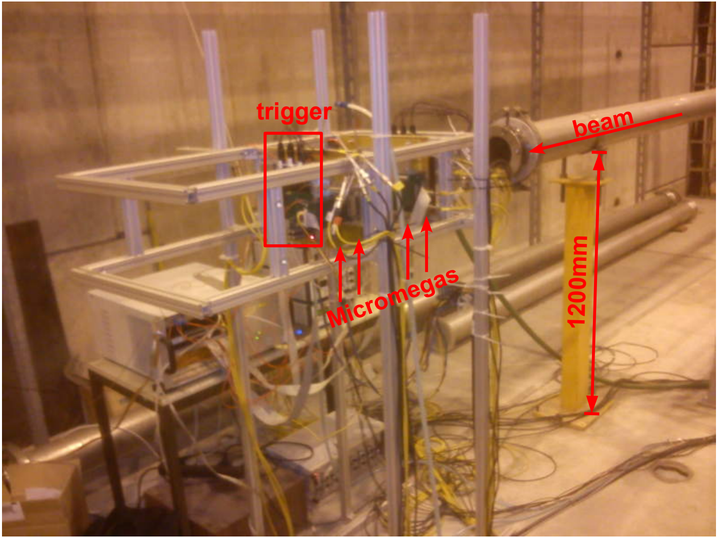
Tracking System: Cosmics Setup



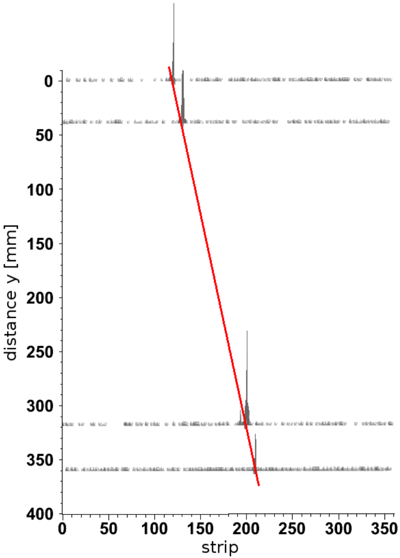
- 4 Micromegas
- strips parallel → 2-dim. track reconstruction
- modified Gassiplex based strip readout, formerly used in HADES
- 16 ch per Gassiplex; 4 Gassiplex per frontend; 6 FEs per detector → 1500 channels
- trigger: 6 strip scintillators (3rd track coordinate) + 1 scintillator panel (600 MeV energy cut)

Tracking System: Testbeam Setup

H6 beamline/CERN: π^- with $p = 120 - 300\,\text{GeV}$

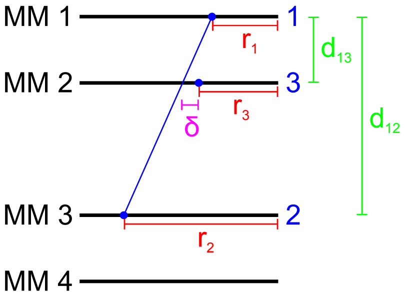


Tracking System: Data Analysis



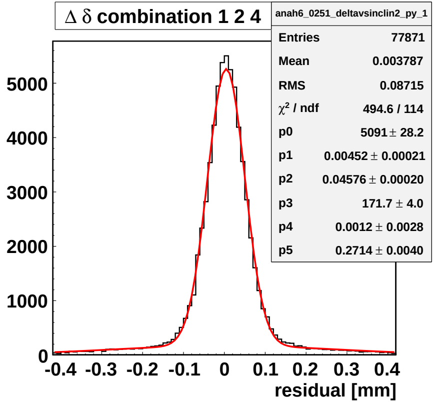
- hits: center-of-gravity method, regarding only those strips with amplitude$>3\sigma$ around the one with maximum amplitude
- hit ambiguities: look for significant hits on a 5.25 mm wide road, defined by other detectors
- track reconstruction: linear fit through all detectors → alignment

Determination of Spatial Resolution



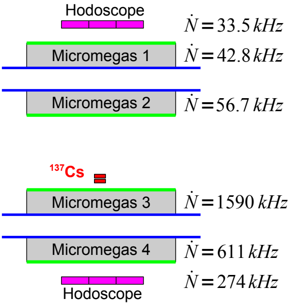
- **interpolate track prediction** by two detectors **into 3rd and compare with measured hit** in that detector
- $\delta = r_3 - r_2 \frac{d_{13}}{d_{12}} - r_1 \left(1 - \frac{d_{13}}{d_{12}}\right) \rightarrow$
  $(\Delta\delta)^2 =$
  $(\Delta r_3)^2 + \left(\frac{d_{13}}{d_{12}} \Delta r_2\right)^2 + \left[\left(1 - \frac{d_{13}}{d_{12}}\right) \Delta r_1\right]^2$
- 4 different triplett-equations & 4 $\Delta r_i \rightarrow$ solvable system

Spatial Resolution for 120 GeV Pions – Preliminary



- 120 GeV pions, angle 90°
- simplified assumption: spatial resolution the same for all detectors → only one equation
- $\Delta r = \Delta\delta/\sqrt{1.79} \sim 34\,\mu\mathrm{m}$

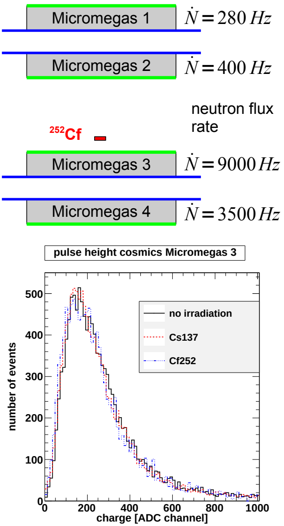
Spatial Resolution: Irradiation with ^{137}Cs



tripl.	$\Delta\delta$ [µm]	$\Delta\delta_{irr}$ [µm]
123	(105 ± 5)	(108 ± 5)
124	(108 ± 5)	(108 ± 6)
134	(118 ± 7)	(117 ± 5)
234	(122 ± 7)	(119 ± 5)

- $E_\gamma = 662\,\text{keV}$
- 2 sources with $A_{tot} \sim 5.8\,\text{MBq}$
- $1.6\,\text{MHz} \times (2.6 \times 10^{-3}) = 4.1\,\text{kHz}$
- efficiency $\varepsilon_\gamma = (2.6 \pm 0.2) \times 10^{-3}$
- slight increase of spark rates $f_{\text{sp, Cs137}}/f_{\text{sp,no irrad.}} = 1.26 \pm 0.07$
- no significant degradation of spatial resolution visible → Micromegas expected to be suitable for providing track reference/trigger in GIF measurements ($\sim 20\,\text{MHz}$ @lab → $\sim 50\,\text{MHz}$ @GIF)

Spatial Resolution: Irradiation with ^{252}Cf



- α-source, in 3% spontaneous fission $\rightarrow E_\gamma = \text{keV} \cdots 4\,\text{MeV}$ & $E_n \leq 8\,\text{MeV}$
- $\dot{N}_{3,n} = (9.1 \pm 0.3)\,\text{kHz}$
- $\varepsilon_n < 6.8 \times 10^{-4}$ @ 95% CL
- increase of spark rates $f_{\text{sp, Cf252}} / f_{\text{sp,no irrad.}} = 0.5\,\text{min}^{-1} / 0.19\,\text{min}^{-1} = 2.6 \pm 0.2$
- spatial resolution: statistic not sufficient for usual method, but no degradation expected since pulse height unchanged

Summary

- stable operation with single plane readout and fast strip readout @ $\varepsilon \sim 98\%$
- energy resolution for 5.9 keV X-rays: $\Delta E/E \sim 24\%$
- tracking system with 4 Micromegas running, readout stable in lab and in hadron beam for $\sim O(\text{week})$
- single detector spatial resolution of $\overline{\sigma} = 34\,\mu\text{m}$ for 120 GeV Pions
- no degradation of spatial resolution under irradidation with ^{137}Cs, no degradation for ^{252}Cf expected

Thank you!