Discharge Studies in Floating Strip Micromegas Detectors

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Studies done while at Ludwig-Maximilians-Universität Munich

RD51 Collaboration Meeting March 2016

March 11th 2016

Motivation: Floating Strip Micromegas R&D

High Energy Physics

- muon tracking $\mathcal{O}\,(100\mu\mathrm{m})$
- high-rate background $\mathcal{O}\,(20\,\mathrm{kHz/cm^2})$
- large-area detectors $\mathcal{O}\,(\mathrm{m}^2)$

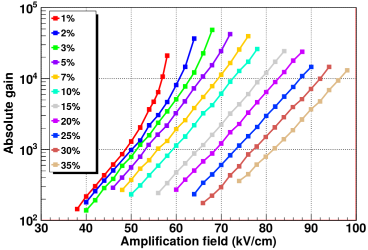
Medical Physics

- ion tracking $\mathcal{O}\,(100\,\mathrm{MeV})$
- particle rate $\mathcal{O}\,(\mathrm{MHz})$
- ion transmission imaging

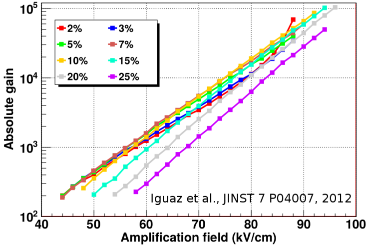
Detector Physics

- discharge formation & propagation
- discharge limits & rates in various gas mixtures
  → identify (light?) gas mixtures with high gain at low discharge probability
  → understand why they behave in this way

Argon:Isobutane



Neon:Isobutane



→ discharge tolerant floating strip Micromegas for high rate applications

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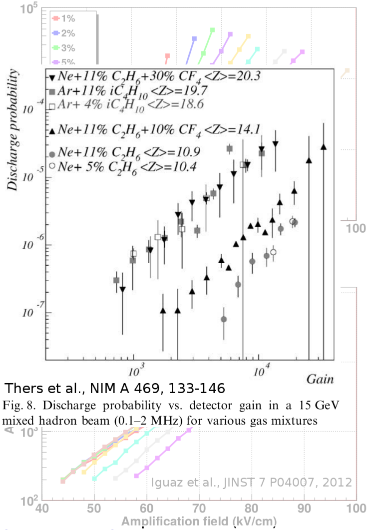
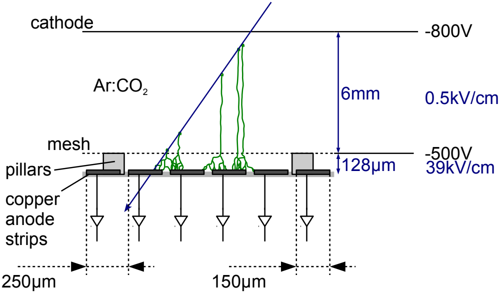


Thers et al., NIM A 469, 133-146

Fig. 8. Discharge probability vs. detector gain in a 15 GeV mixed hadron beam (0.1–2 MHz) for various gas mixtures

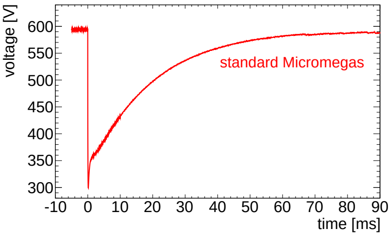
→ discharge tolerant floating strip Micromegas for high rate applications

Floating Strip Micromegas

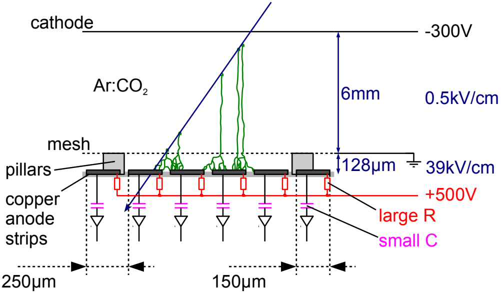


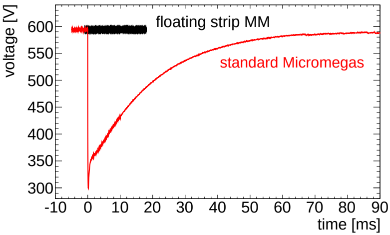
challenge: discharges

- charge density $\geq 2 \times 10^6$ e/0.01 mm^2 (Raether limit)
- conductive channel
  $\rightarrow$ potentials equalize
- non-destructive,
  but dead time
  $\rightarrow$ efficiency drop



Floating Strip Micromegas





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  → potentials equalize
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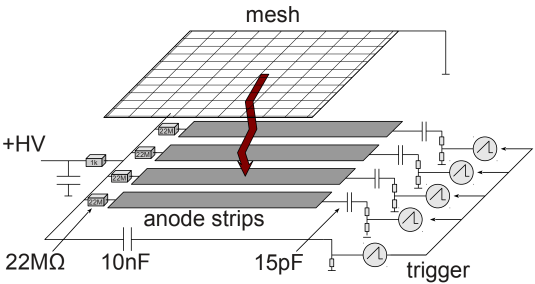
  but dead time
  → efficiency drop

idea: minimize the affected region

- "floating" copper strips:
  - strip can "float" in a discharge
  - individually connected to HV via 22MΩ
  - capacitively coupled to readout electronics via pF HV capacitor
  - only two or three strips need to be recharged

→ dedicated measurements & detailed simulation

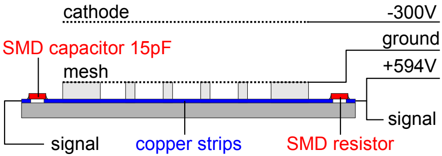
Discharge Study with Floating Strip Micromegas



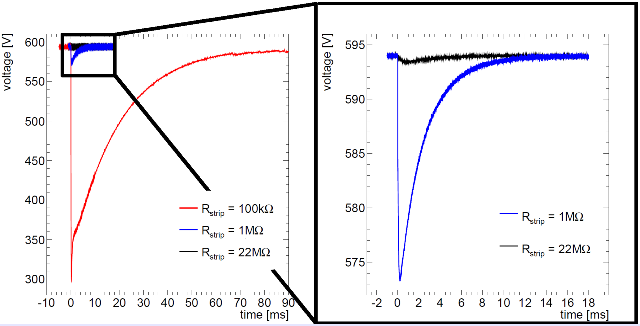
- alpha source
  → induces discharges
- voltage drop on one to three strips
  → recharge current
- global high voltage drop
  → affects all strips
- voltage signal on seven neighboring strips
  → discharge topology

Optimization of the Floating Strip Principle

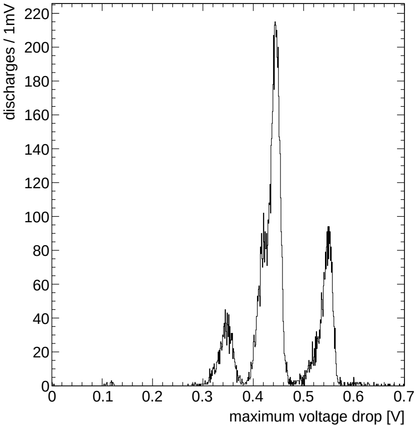
- standard Micromegas (approximative):
  100 kΩ
  300 V drop, dead time ∼80 ms
- intermediate: 1 MΩ
  20 V drop, dead time ∼10 ms
- floating strip: 22 MΩ
  0.5 V drop → negligible



measured average voltage pulse

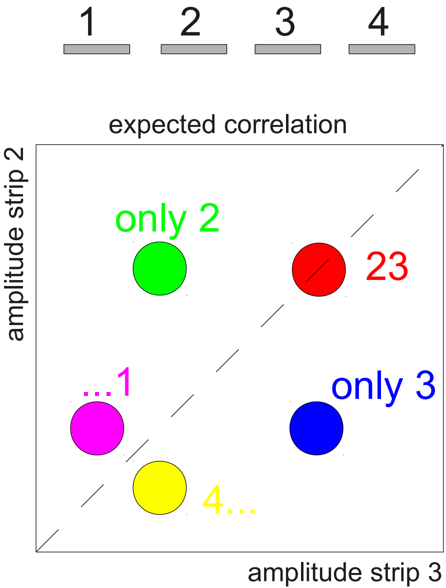


Detailed Investigation of the Global Voltage Drop



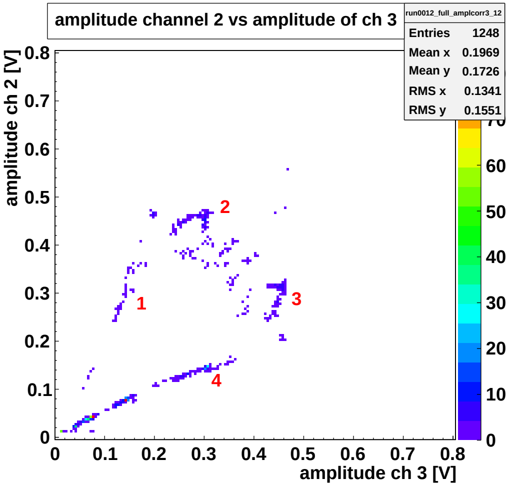
measured voltage drop of common HV potential
→ discrete structure
→ probably corresponds to discharge on one, two or three strips.
How can we show this?
→ investigate discharge topology

Discharge Topology - Expected Amplitude Correlation



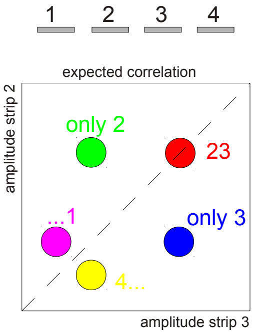
- measure voltage signal on neighboring strips
- two reasons for signals on strips:
  - discharge onto strip
  - capacitive coupling from neighboring strips

Discharge Topology - One Strip

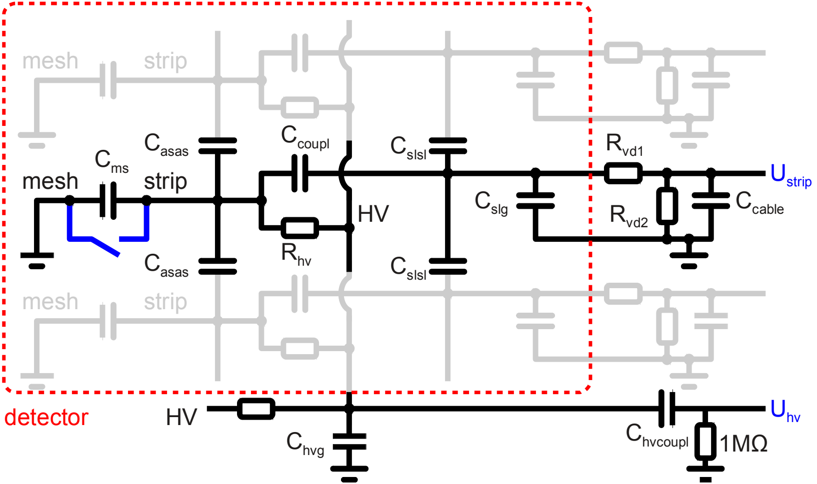


discharges on separate strips distinguishable
BUT
substructure?

→ analyze the topology in depth with the circuit simulation program LTSpice

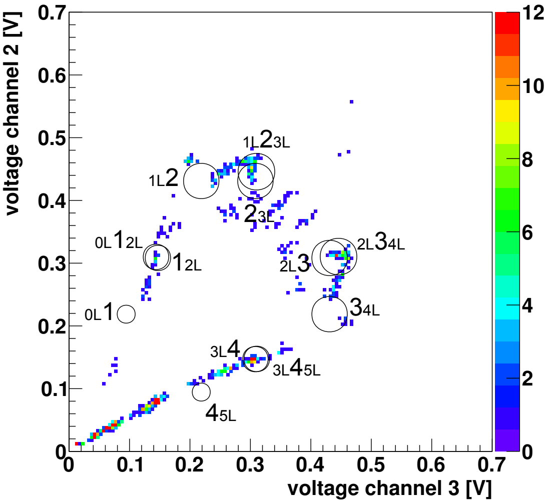


LTSpice Detector Simulation



- consider the involved capacitances e.g. between neighboring strips, coupling capacitors, cable capacitance ...
- simulate discharges (blue switch)

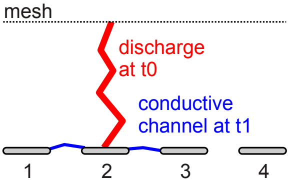
Discharge Topology - One Strip



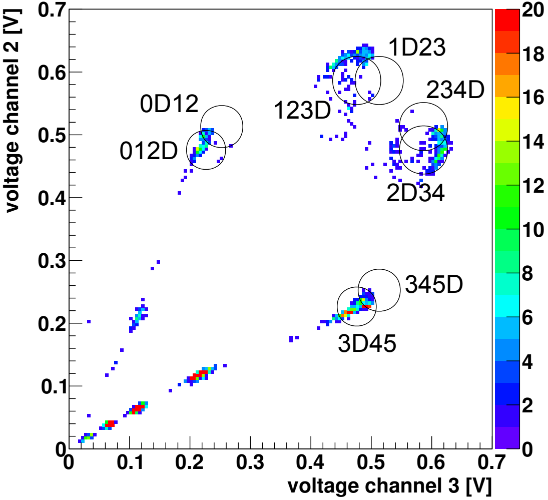
two processes:

- discharge on one strip

1. after discharge has ceased, charge leaks onto both neighboring strips
2. sometimes only one of the neighboring strips is affected

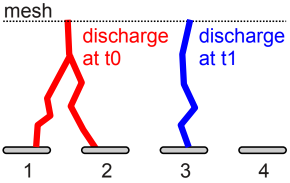


Discharge Topology - Three Strips



one process:

- discharge on two strips
- after discharge has ceased, second discharge on the third strips



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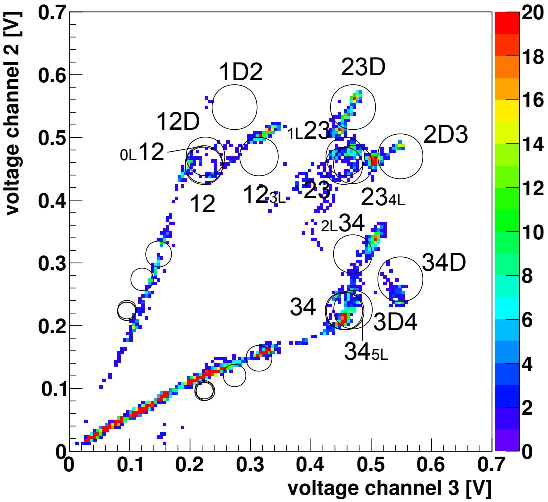
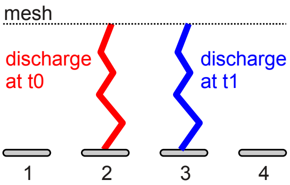
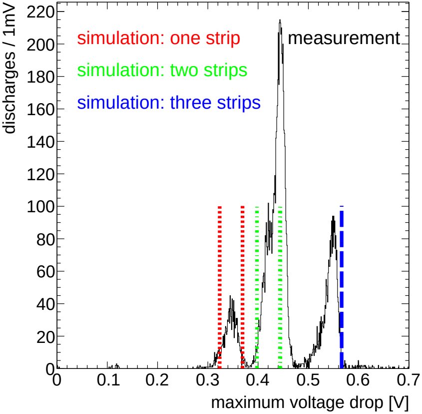


three processes:

1. discharge on two strips
2. discharge on two strips, after discharge has ceased, charge leaks onto a neighboring strip
3. discharge one one strip, after discharge has ceased, second discharge on the second strip



Optimum Configuration: Global Voltage Drop



- good agreement between simulation and measurement
- only two free parameters
  - response time of HV supply: 500 ms
  - voltage difference between strips at which leakage stops: 220 V
- peaks correspond indeed to discharge of one, two or three strip

Summary

floating strip principle works

- discharges: negligible effect on common high-voltage
- discharges are localized
- no damage/aging due to discharges

→ ideal device to measure discharge rates with different gases at amplification fields suitable for MIP detection

measurements

- muon tracking in high-rate background (Bortfeldt, The Floating Strip Micromegas Detector, Springer 2015)
- tracking of high-energy pions
- tracking of ions at highest rates
- ion radiography (Bortfeldt et al., Low-Material-Budget FSM for Ion Transmission Radiography, VCI 2016)

detector	beam	gas Ar:CO_2 [vol. %]	E_{amp} [kV/cm]	P_p
$6.4 \times 6.4\,\mathrm{cm}^2$ floating strip	5.5 MeV alphas	93:7	37	10^{-1}
$9 \times 10\,\mathrm{cm}^2$ standard	120 GeV pions	85:15	41	10^{-5}
$48 \times 50\,\mathrm{cm}^2$ floating strip	120 GeV pions	93:7	38	10^{-4}
$6.4 \times 6.4\,\mathrm{cm}^2$ floating strip	cosmic muons + 20 MeV protons	93:7	36	3×10^{-7}
$6.4 \times 6.4\,\mathrm{cm}^2$ floating strip	20 MeV protons	93:7	33	2×10^{-7}
$6.4 \times 6.4\,\mathrm{cm}^2$ floating strip	88.83 MeV/u ^{12}C	93:7	30	5×10^{-7}
$6.4 \times 6.4\,\mathrm{cm}^2$ floating strip	221.06 MeV/u protons	93:7	30	5×10^{-8}

Summary

Thank you!

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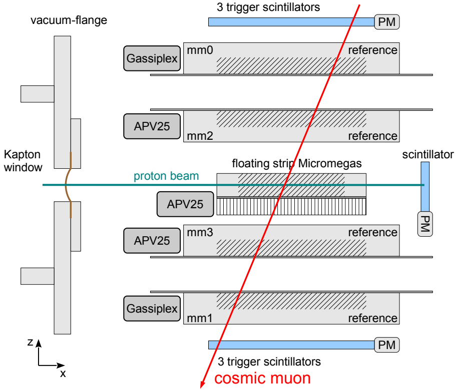
backup – Cosmic Muon Tracking under High-Rate Background Irradiation



floating strip Micromegas

- active area: $6.4 \times 6.4\,\text{cm}^2$
- 128 strips, 300 μm width, 500 μm pitch
- 10 mm drift gap

reference tracking system

- two non resistive Micromegas
- two resistive Micromegas
- 2×3 trigger scintillators

questions:

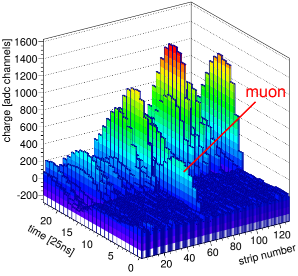
- muon identification
- efficiency
- spatial resolution
- stability

proton background irradiation

- 20 MeV protons, 550 kHz
- lateral beam spot: $6 \times 0.5\,\text{cm}^2$
- traverse detector $\rightarrow$ signal on all strips

backup – Distinguishing Cosmic Muon and Proton Background Signals

Cosmic Muon + Proton Event

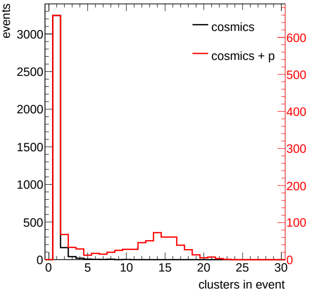


two event classes:

- only muon
- coincident muon and proton:
  → direct influence on signal

- proton produces coincident signals on many strips
- muon signal similar to background
- use reference track for cluster selection

of Clusters per Event

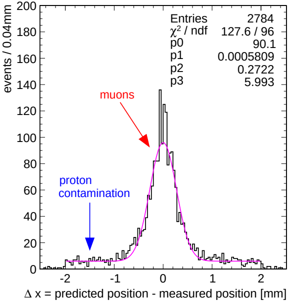


- event with muon only: ≤ 6 clusters
- events with muon + proton: > 6 clusters

→ distinguishable

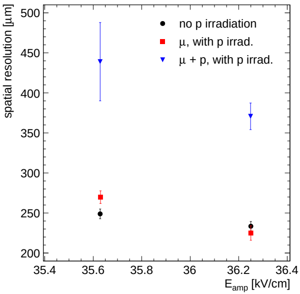
backup – Cosmic Muon Tracking in High-Rate Background

residual distribution



- muon detection in background possible
- occasionally background misinterpreted as muon

spatial resolution



- no indirect effects as e.g. space charge
- only deterioration if muon and proton are coincident

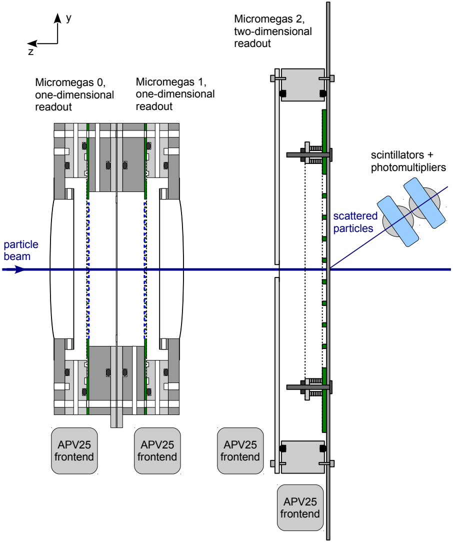
efficiency

- expectation for complete blinding: $\varepsilon_{\text{irrad}}/\varepsilon_{\text{no irrad}} = 0.617$
- $\varepsilon_{\text{irrad}}/\varepsilon_{\text{no irrad}} = 0.709$

stability

- discharge rate 0.17 Hz
- inefficiency: 4.1×10^{-6}

backup – Ion Tracking with Thin Micromegas at Highest Rates



beams

- ^{12}C @ 88 MeV/u to 430 MeV/u
  2 MHz to 80 MHz
- p @ 48 MeV to 221 MeV
  80 MHz to 2 GHz
- thanks to S. Brons and the HIT accelerator team for the support

floating strip Micromegas

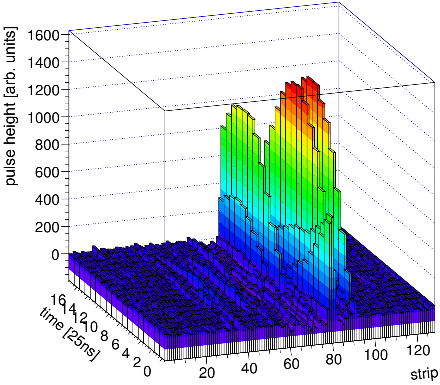
- $6.4 \times 6.4\,\mathrm{cm}^2$ doublet
- low material budget
  (FR4 + Cu $\leq$ 200 μm)

additional detectors

- $9 \times 9\,\mathrm{cm}^2$ monitoring Micromegas with x-y-readout
- trigger on secondary charged particles

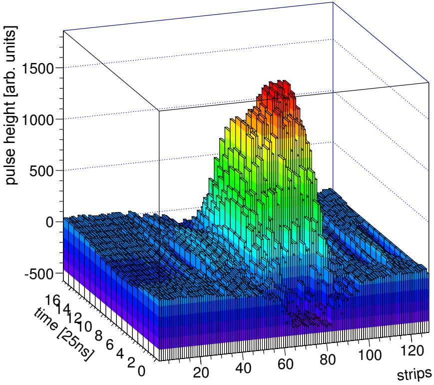
backup – Signals at Lowest and Highest Rate

^{12}C, E = 430 MeV/u, 5 MHz



3 particles clearly distinguishable
→ single particle tracking possible

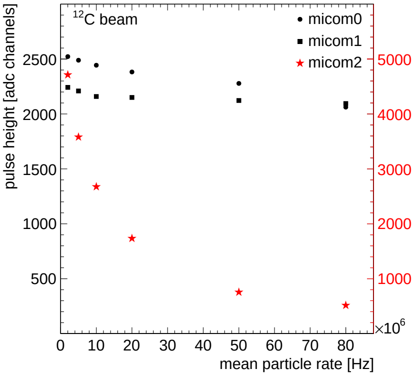
p, E = 221 MeV, 2 GHz



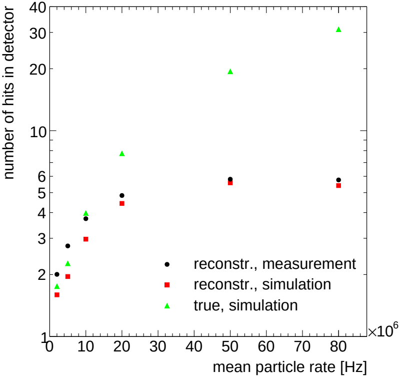
integration over ∼ 800 coincident particles
→ envelope of beam profile

backup – Rate Capability – Carbon Ions

pulse height



reconstructed hits per event

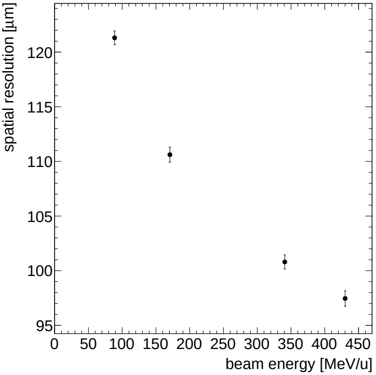


- up to 80 MHz single particle tracks visible
  but not all of them separable
- only 20% reduction @ 80 MHz

- reconstruction of all particle hits up to $10\,\mathrm{MHz} = 7\,\mathrm{MHz/cm^2}$

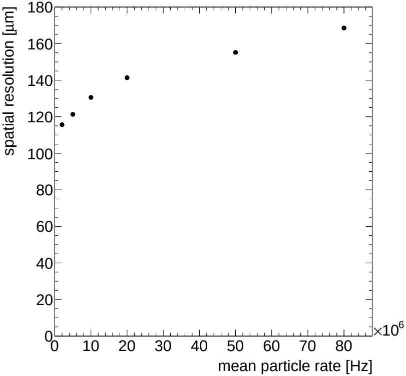
backup – Spatial Resolution – Carbon Ions

spatial resolution vs energy
5×10^6 Hz



25% improvement: reduction of ionization tails & decreasing multiple scattering

spatial resolution vs rate
88 MeV/u



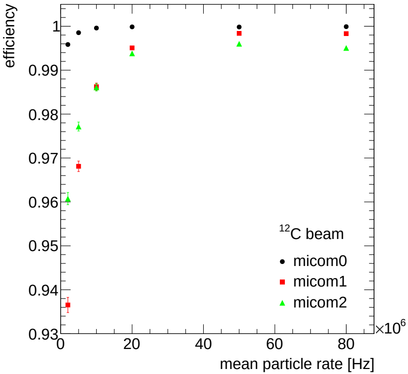
only 35% degrading: slight distortion of hit position by hits on adjacent strips

→ resolution well below 0.2 mm

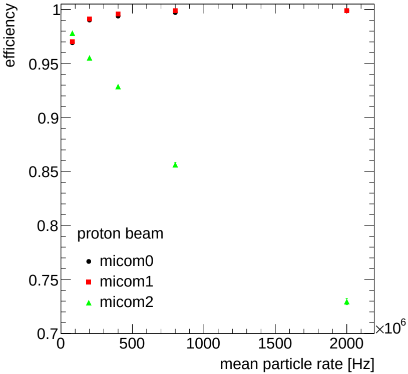
→ completely sufficient for ion transmission imaging

backup – Detection Efficiency vs Particle Rate

^{12}C, 88 MeV/u



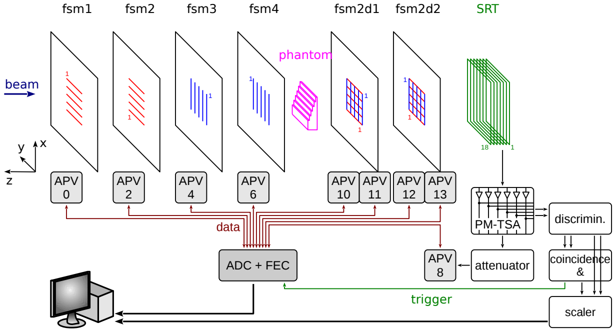
p, 221 MeV



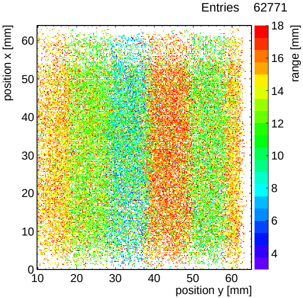
- low rates: single particle detection efficiency
- high rates: detector up-time

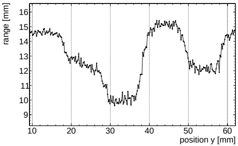
→ no efficiency & up-time reduction in floating strip Micromegas

backup – Ion Radiography at HIT



tissue-equivalent slab phantom

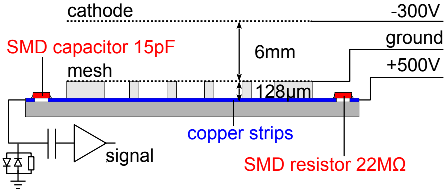




- first test of imaging system
- commissioning of scintillator range telescope (18 layers)
- commissioning of 2d floating strip Micromegas
- commissioning of range telescope electronics

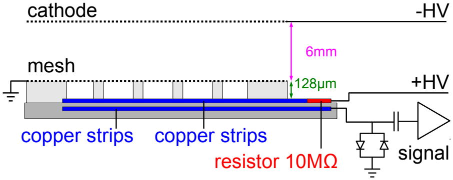
backup – Discrete & Integrated Floating Strip Micromegas

discrete



- exchangable Rs and Cs
  → optimization possible
- more complicated assembly
  → soldering ×2 for each strip
- space requirements due to HV sustaining components
  → strip pitch limited to 0.5 mm

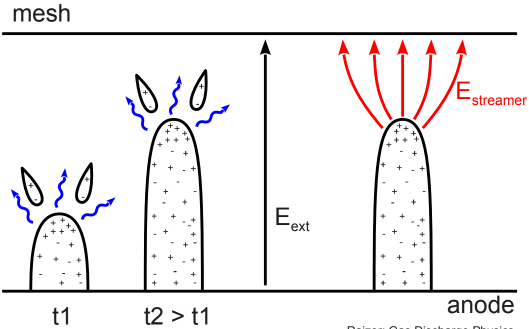
integrated



- anode strips: connected to HV via printable paste resistors
- readout strips: second layer of copper strips
  capacitive coupling through the board, intrinsically HV sustaining

backup – Possibility for Discharge Development

- if charge density exceeds $1.77 \times 10^8\ e/\text{mm}^2$
  $\rightarrow$ streamer development
  $\rightarrow$ well conducting plasma channel between mesh and strip(s)
- seem to be unavoidable
- localized
- limit the affected region!



Raizer: Gas Discharge Physics