Two-Dimensional Floating Strip Micromegas Detectors

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Outline

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2. Two-Dimensional Floating Strip Micromegas
   - First Measurements: Heidelberg Ion Therapy Center
   - Signal Simulation with ANSYS and Garfield++
   - Three Different Optimized Anode Designs
   - Measurement Results: 20 MeV Protons and 150 GeV Muons/Pions
3. Summary

Floating Strip Micromegas with 1d Readout

- MICROMEsh GASeous detectors

  drift region
  → collecting ionization charge

  amplification region
  → electron avalanche

  fast signals $\mathcal{O}(100\,\text{ns})$
  → high-rate capability

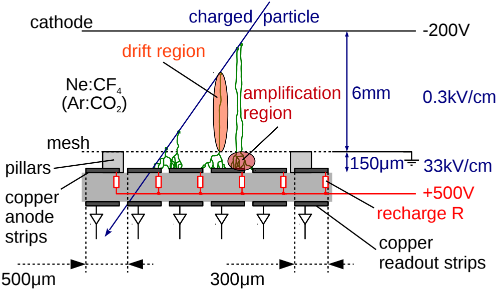
- challenge: discharges
  → non-destructive but dead time
  → efficiency drop @ high particle rates or high rate background

- solution: 'floating' copper strips

  anode strips individually connected to HV via high ohmic resistors

  signals decoupled capacitively

→ discharge confined to few strips
→ fast recovery after discharge



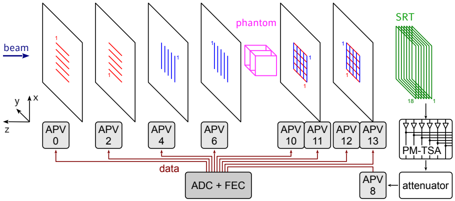
- signal decoupling: congruent readout strips
  → excellent spatial resolution (100 µm) and efficiency (>98%) at 7 MHz/cm^2

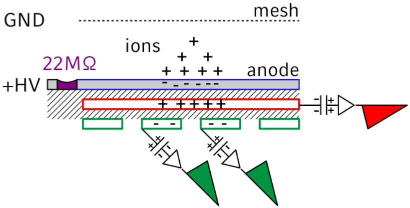
question: two-dimensional strip readout?

First Measurements with a 2d Readout @ HIT

Kapton flex PCB: 64x64 mm^2 active area

- copper anode strips, pitch 500 µm, width 300 µm, connected to HV via screen printed resistors
- parallel readout strips, width 80 µm
- perpendicular readout strips, width 400 µm





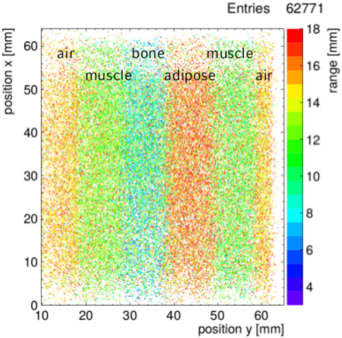
Ion Range Radiography

- ions ($E_{initial}$ known) traverse patient
  - → measure residual energy → contrast
  - → measure location → spatial info

Prototype @ HIT

- Carbon ions up to 2 MHz
- 18 layer scintillator stack

→ **it works!**
→ 2d hit position measurable
→ image reconstructable

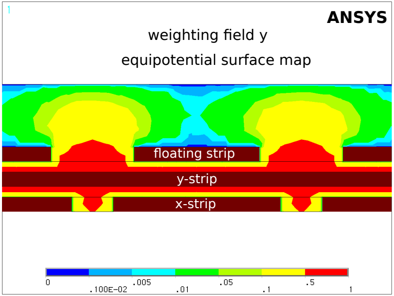


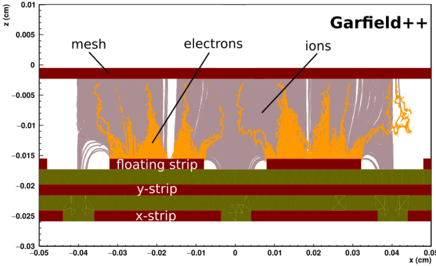
Signal Simulation: Fields, Drift & Amplification

- ANSYS: 3d model of anode
  → calculate electrical/weighting fields of all electrodes
- Garfield++: import field configuration
  → simulate charge carrier drift and amplification
- charge q at velocity $\vec{v}(t)$:
  → induces current $I^{ind}(t)$ on electrodes (Shockley-Ramo-theorem):

  $$\mathbf{I^{ind}(t) = -[q/V_w] \cdot \vec{E}[\vec{x}(t)] \bullet \vec{v}(t)}$$

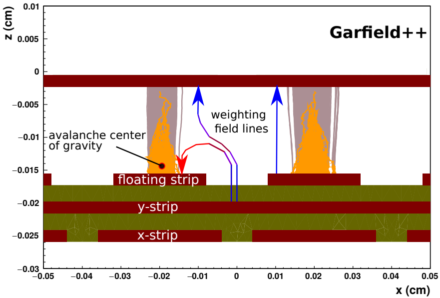
  with weighting potential V_w and weighting field $\vec{E}[\vec{x}(t)]$
- Garfield++: simulation of readout electronics response (APV25 chips)

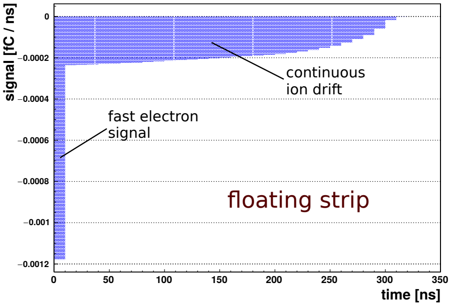


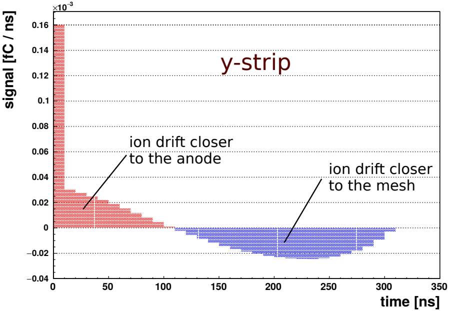


Signal Simulation: Induced Currents

- two electrons placed top of the amplification gap centered above both floating strips
- fast electron signal ($\lesssim 2$ ns): negative current on floating strips and positive current on y-strips
- ion movement towards the micro-mesh $\rightarrow$ slow component of the signal
- bipolar current (ions) on the y-strips due to weighting field line configuration



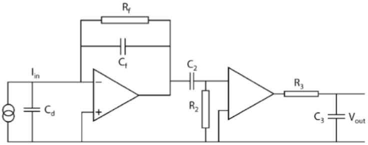




Signal Simulation: Electronics Response

- APV25 chips:
  charge integrating amplifier with CR-RC shaping (time constant $\tau = 50\,\text{ns}$)

- convolution of induced current $I_i(t)$ on electrode i with transfer function $h(t) \approx \frac{t}{\tau} e^{-t/\tau}$ yields approximation of APV25 response

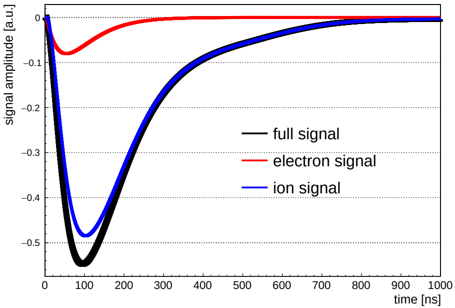


Charge-integrating amplifier with *CR–RC* shaping

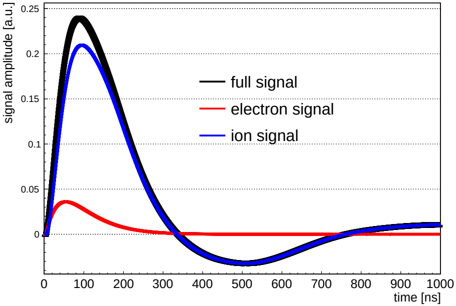
$$\begin{cases} \hat{h}(t) = -\dfrac{1}{\tau(\tau_f - \tau)^2}\left[(\tau^2 + t(\tau_f - \tau))\, e^{-t/\tau} - \tau^2 e^{-t/\tau_f}\right] & t \geq 0 \\ \hat{h}(t) = 0 & t < 0 \end{cases}$$

$$\tau = C_2R_2 = C_3R_3 \text{ and } \tau << \tau_f = C_fR_f \qquad \hat{h}(t) \approx \frac{t}{\tau\tau_f} e^{-t/\tau}$$

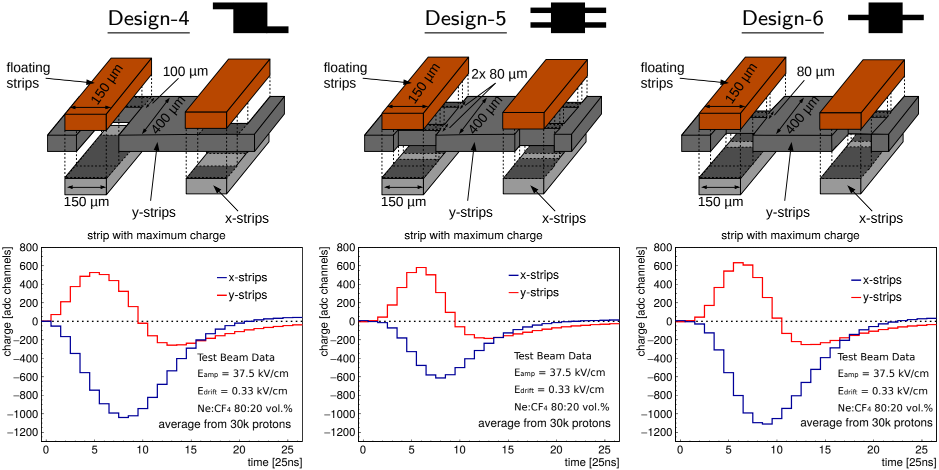
simulated APV25 response floating strip / x-strip



simulated APV25 response y-strip



Different Anode Designs: Strip Response



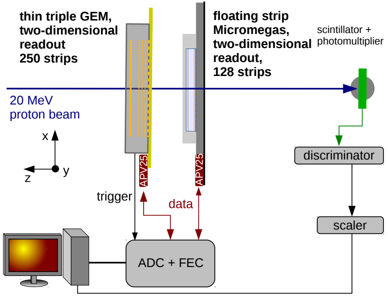
all anode designs show raw strip signals with:

- x-strips: unipolar negative strip pulse on the
- y-strips: positive, bipolar signal with negative undershoot

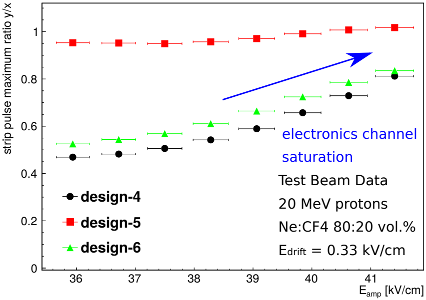
⟶ signal amplitude on x-strips depending on overlapping area with floating strips

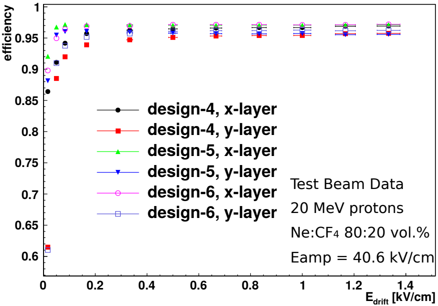
⟶ signal amplitude on y-strips independent of y-strip pattern

Measurement Results - 20 MeV Protons (1)

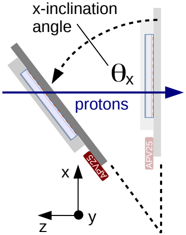


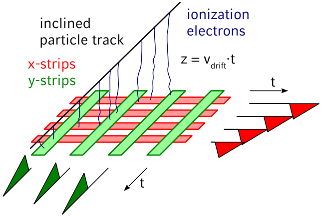
- trigger: thin triple GEM in front of Micromegas
- $\mathrm{amplitude}_y / \mathrm{amplitude}_x \sim 1$ possible
- pulse height ratio dependency driven by saturation of readout electronics on x-strips
- hit efficiency (20 mm w.r.t. GEM) around 95% for all designs and strip layers



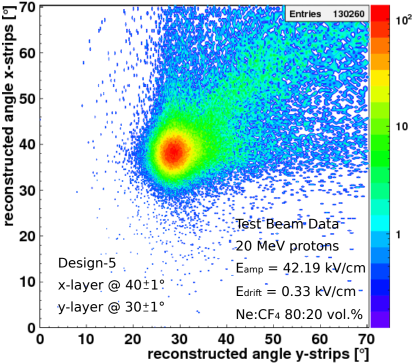


Measurement Results - 20 MeV Protons (2)



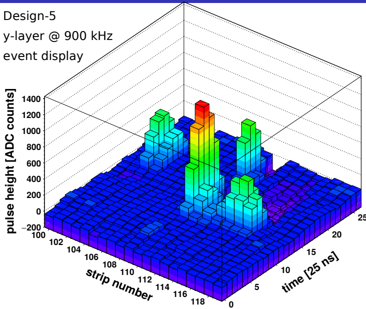


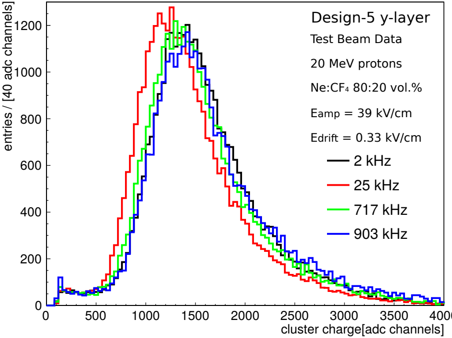
- detectors tilted w.r.t. beam axis in x- and y-direction
- μTPC angle reconstruction works independently for both strip layers
- angular resolution depending on drift- and amplification field
- angular resolution $\sim 2^\circ$ for optimized drift and amplification field for both layers

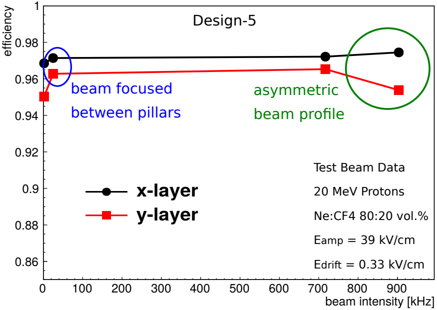


Measurement Results - 20 MeV Protons (3)

- DC beam intensities between 2 kHz and 900 kHz ($\sim$0.74 kHz/cm^2 to 325 kHz/cm^2)
- pulse height $\sim$ constant for all beam intensities for both strip layers
- particle reconstruction efficiency stays almost constant over the intensity range for both strip layers



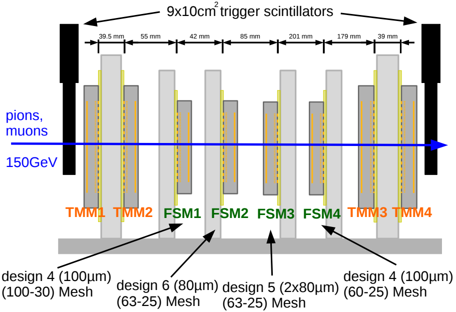


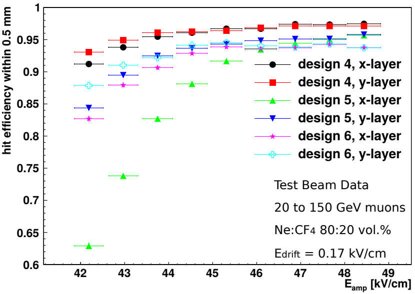


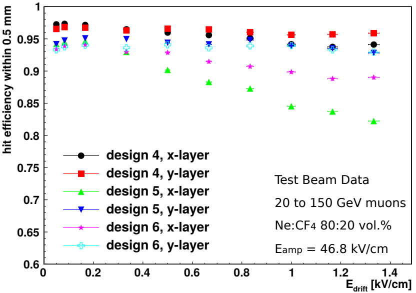
Measurement Results - 20 to 150 GeV Muons (1)

- setup at CERN SPS with 4 TMM chambers as track reference at particle rates of $\mathcal{O}$(kHz)[muons] to $\mathcal{O}$(MHz)[pions]
- extrapolate track into floating strip Micromegas and check for hit within 500 µm to track prediction

  → excellent efficiencies around 95% for all designs and both readout strip layers

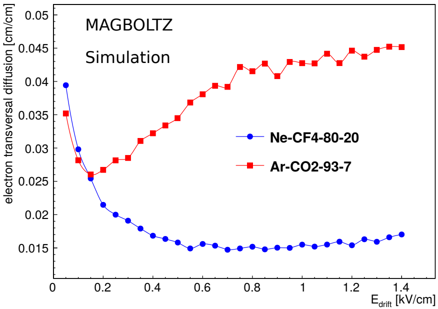


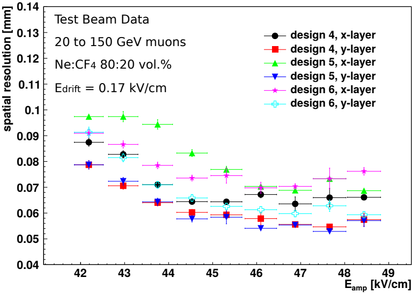


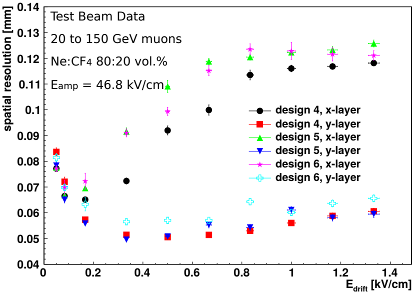


Measurement Results - 20 to 150 GeV Muons (2)

- fit residual distributions with double gaussian, take narrow sigma and correct for track uncertainty
- correct for systematic mis-reconstruction due to charge discretization on strips
- x-layer spatial resolution strongly depending on transverse diffusion of electrons in drift region
- optimum spatial resolution around 50 µm for y-layer and 65 µm for x-layer

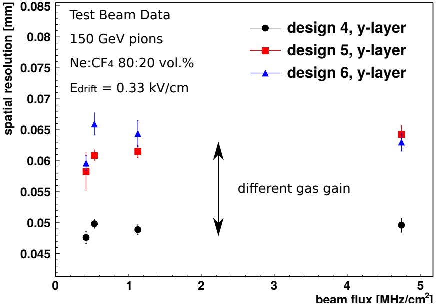


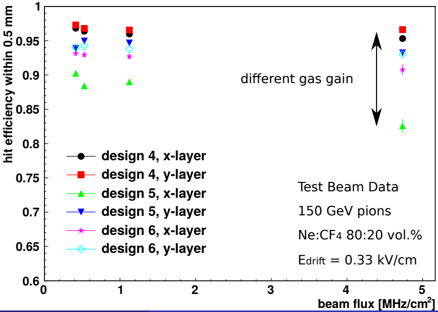




Measurement Results - 150 GeV Pions

- particle fluxes up to 5 MHz/cm^2
- smaller amplification voltages applied for designs 5 and 6 for stable operation (most probably due to cleanliness issues or anode PCB defects)
- 10% decrease of pulse height visible between lowest and highest rate
- particle reconstruction possible with over 95% efficiency at 50 μm spatial resolution at 5 MHz/cm^2





Summary

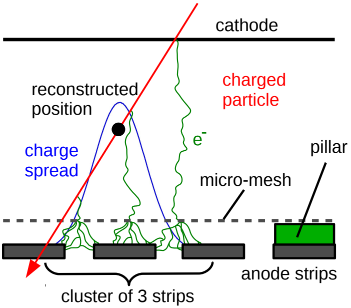
- different two-dimensional floating strip Micromegas designs have been presented
- readout strip layers: different signal polarities, duration and amplitude
- simulations explain signal formation and readout electronics response
  $\rightarrow$ detector understood
- similar pulse height on both readout strip layers can be reached
- measurements with 20 MeV protons and 150 GeV muons/pions:
  $\rightarrow$ hit efficiencies around 95% for all designs and strip layers
- µTPC angle reconstruction possible on both strip layers independently:
  $\rightarrow$ angular resolution around 2° for optimized drift- and amplification field
- excellent spatial resolution:
  $\rightarrow$ 65 µm on x-layer and 50 µm on y-layer at up to 5 MHz/cm^2 beam flux

THANK YOU

BACKUP

Signal Reconstruction - Methods

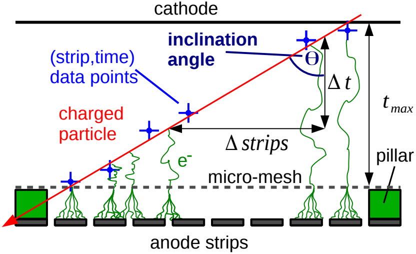
cluster reconstruction



- search for strips with a deposited charge > 3 x σ_{strip}, no further cuts
- charge spreads over strips
  ⟶ Gaussian distributed charge signal
- typically more than 2 strips hit
  ⟶ forming cluster of strips

$$\mathbf{x_{cen}} = \frac{\sum_{\text{cluster}} \mathbf{x_{strip} \cdot q_{strip}}}{\sum_{\text{cluster}} \mathbf{q_{strip}}}$$

μTPC reconstruction



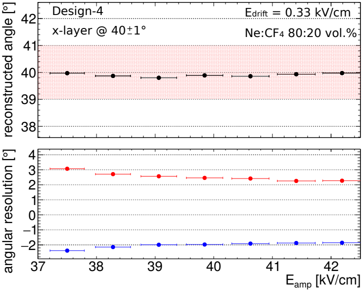
- measure arrival time of electrons:

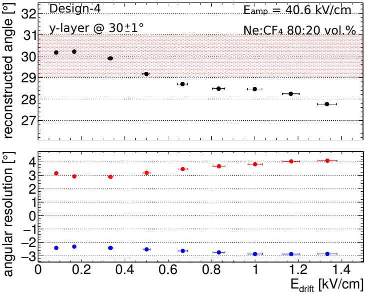
$$\longrightarrow \boldsymbol{\Theta} = \mathbf{arctan}\left(\frac{\mathbf{p_s}}{\mathbf{a \cdot v_d \cdot 25\,ns}}\right)$$

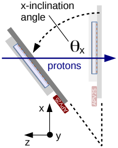
  - $\mathbf{p_s}$ = strip pitch
  - slope $\mathbf{a} = \frac{\Delta t}{\Delta \text{strips}}$
  - $\mathbf{v_d}$ = electron drift velocity
- slope from linear fit to (strip,time) data points
- v_d simulated or measured

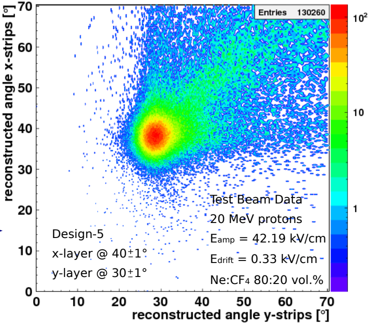
Measurement Results - 20 MeV Protons (3)

- detectors tilted w.r.t. beam axis in x- and y-direction
- μTPC angle reconstruction works independently for both strip layers
- angular resolution depending on drift- and amplification field
- angular resolution for optimized drift and amplification field around $\begin{pmatrix} +2.3^\circ \\ -1.8^\circ \end{pmatrix}$



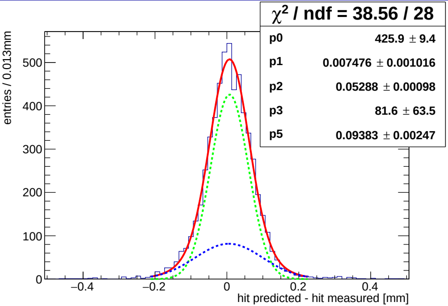


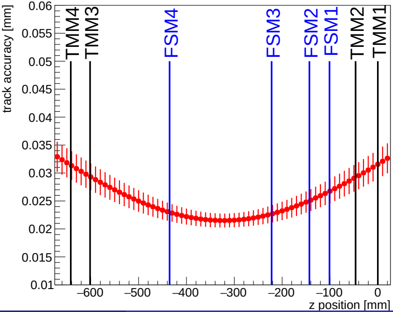




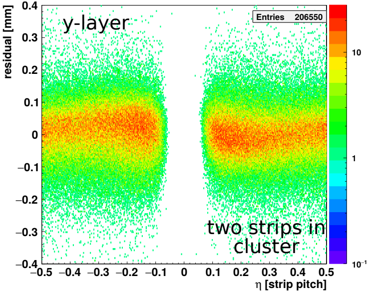
Spatial Resolution Determination

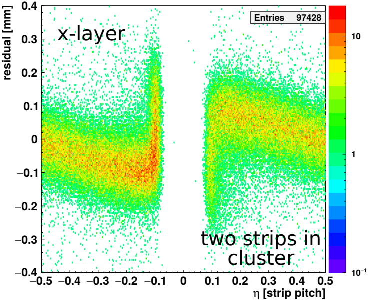
- extrapolate track into the detector under test (detector excluded in track fit)
- determine residual
  $\Delta x = x_{predicted} - x_{measured}$
- fit residual distribution with a double gaussian function within $\pm 3\sigma$
- extract sigma of core gaussian and correct it for the track accuracy at the position of the detector under test
- the spatial resolution of the detector is then given by:
  $$\sigma_{SR} = \sqrt{\sigma^2_{excluded} - \sigma^2_{track}}$$



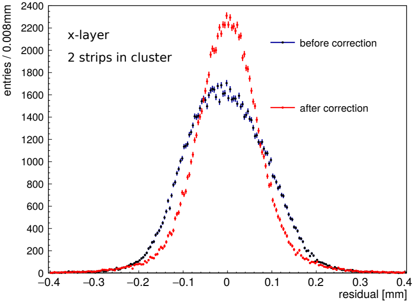


Charge Discretization Correction





- calculate difference between reconstructed hit position and the center of the nearest strip η as a function of the strips in a cluster
- residual distribution depending on η due to systematic mis-reconstruction of the hit position due to discretization of charge on the readout strips
- correcting the hit position in a second iteration yields a visible improvement of the spatial resolution



A Comparison: 2-Dimensional Resistive Strip Micromegas

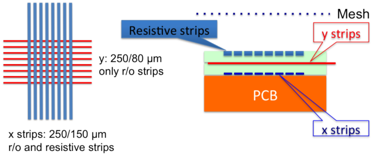


Figure 2. X-Y chamber schematics. Left. Strip layout. The bottom X readout strips are parallel to the resistive strips. The Y strips are at 90°. Right. Vertical cross-section. The X readout strips and the resistive strips are going into the figure.

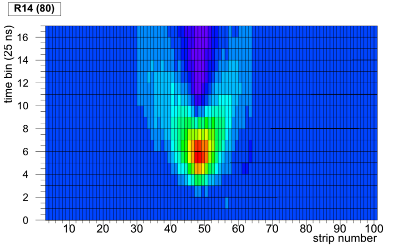
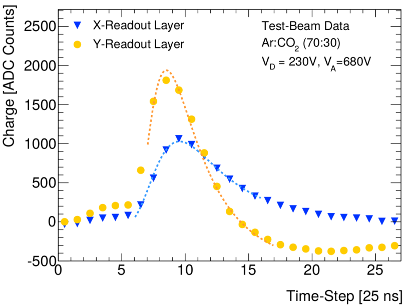


Figure 4. Intensity plot of ADC counts in the R14 chamber plotted against strip number on the horizontal axis and the time bin number (25 ns) on the vertical axis.

- 'Resistive-strips micromegas detectors with two-dimensional readout' [doi:10.1088/1748-0221/7/02/C02060]

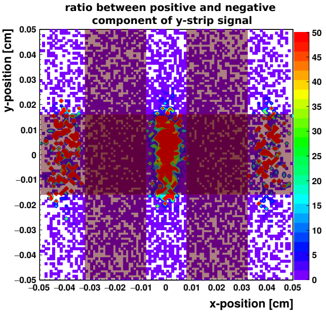


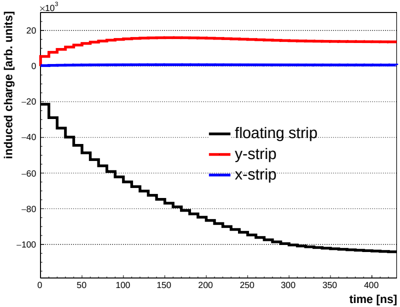
- 'Signal Characteristics of a Resistive-Strip Micromegas Detector with an Integrated Two-Dimensional Readout' [arXiv:1406.6871]
- **same (negative) signal polarity** observed on **x- and y-strips**
- signal spreads in time over adjacent y-strips

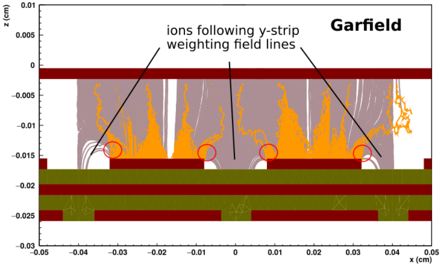
  ⟶ charge spreads along resistive strips

Signal Simulation with ANSYS and Garfield++

- 10k electrons homogeneously distributed at beginning of amplification gap
- negative contribution of y-signal negligible between floating strips
- strongest signal on y-strips if charge created between floating strips
- negative signal on x-strips due to capacitively coupled floating strip signal

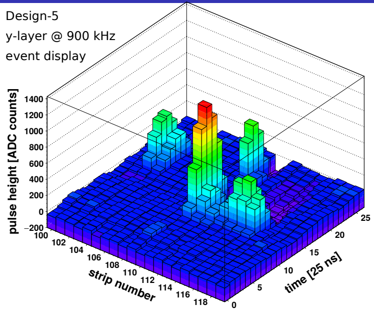


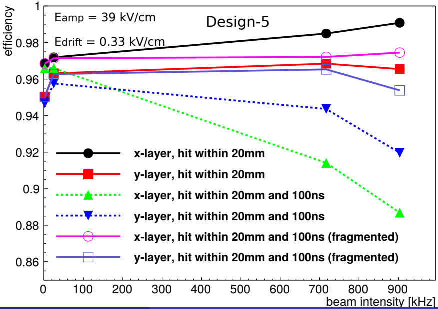




Measurement Results - 20 MeV Protons (4)

- measurements at four different beam intensities between 2 kHz and 0.9 MHz
- pulse height independent of beam intensity for both strip layers
- hit efficiency 20 mm w.r.t. GEM artificially increases due to multiple clusters in the detector in a single event
- use leading cluster of GEM and require a hit in the Micromegas within 100 ns
- if no good cluster was found: fragment clusters which have been falsely merged into a single cluster and find closest cluster (position- and timewise)
- after cluster recovery hit efficiency stays almost constant over the whole intensity range for both strip layers





Three Different Two-Dimensional Thin Anode Designs

- floating strip pitch/width: 0.5 mm/0.3mm
- **readout strips** orientation **parallel** to floating strips denoted as '**x-strips**'
- **readout strips** orientation **perpendicular** to floating strips denoted as '**y-strips**'

Design-1

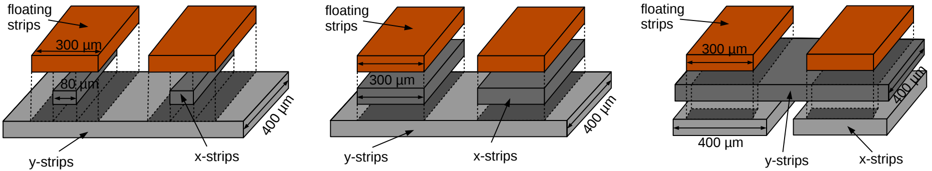
- active area: 64x64 mm^2
- 128 strips
- 80 µm x-strips (middle)
- 400 µm y-strips (bottom)

Design-2

- active area: 192x192 mm^2
- 384 strips
- 300 µm x-strips (middle)
- 400 µm y-strips (bottom)

Design-3

- active area: 192x192 mm^2
- 384 strips
- 400 µm y-strips (middle)
- 400 µm x-strips (bottom)



- 35 µm thick copper strips insulated by two 25 µm thick Kapton layers

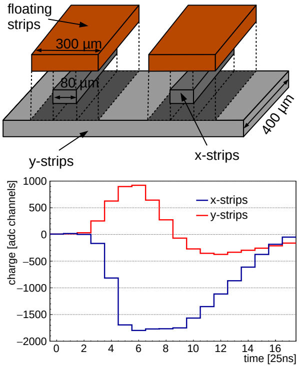
⟶ overall thickness of anode: 155 µm

Typical Signal on Strip with Maximum Charge

all anode designs show raw strip signals with:

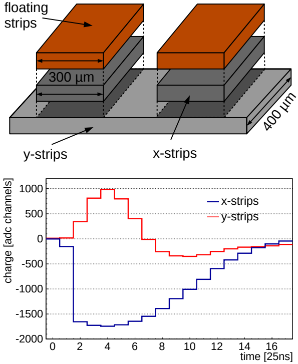
- a negative strip pulse on the x-strips (expected)
- a positive, shorter strip pulse on the y-strips with a negative undershoot (unexpected)

Design-1



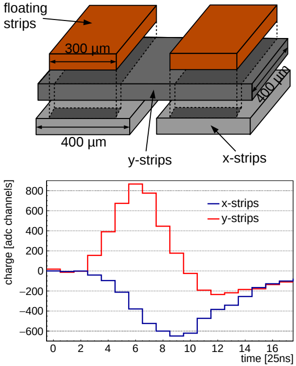
- readout saturated signal on x-strips

Design-2



- highly readout saturated signal on x-strips

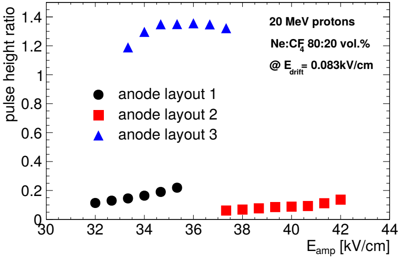
Design-3

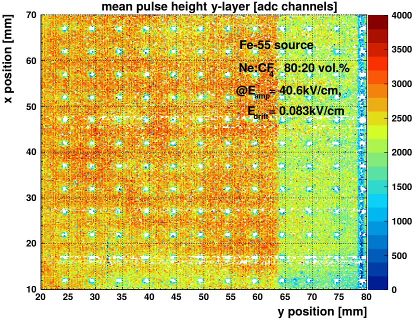


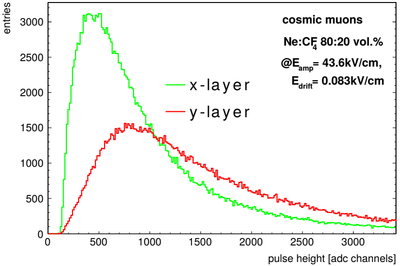
- y-strips signal higher than x-strips signal

Measurement Results - Cluster Reconstruction

pulse height ratio ph_y/ph_x







- signals with similar height observed for anode design-3, converging to a factor of $ph_y/ph_x \approx 1.4$ for $E_{amp} \gtrsim 34\,kV/cm$
- ph_x on anode design-2 shows a fully saturated signal on the APV25
- anode design-1 also shows a saturation of the signal on the x-strips

→ **best** simultaneous **signal reconstruction** observed for **anode design-3**