A Novel Two-Dimensional Readout Design for Floating Strip Micromegas Detectors

Felix Klitzner

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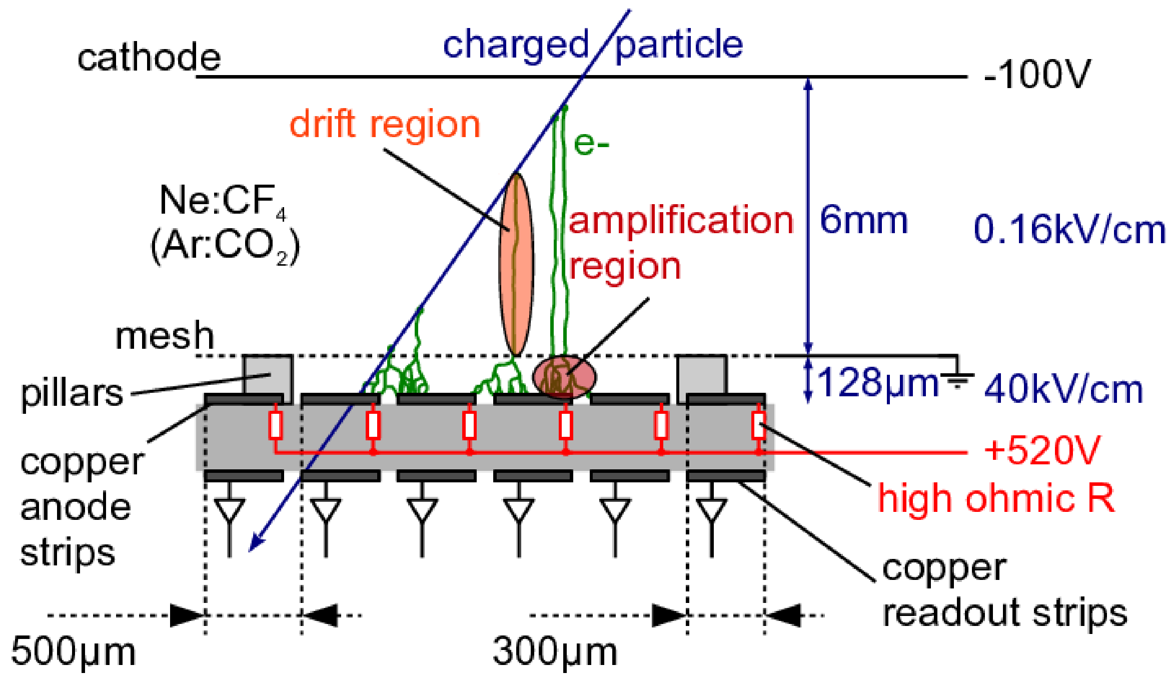
• Principle - **MICROME**sh **GAS**eous detectors

One-dimensional Floating Strip Micromegas

- **Drift** region
  - Collecting **ionization** charge
- **Amplification** region
- **Anode: copper strips (floating)**: individually connected to HV via high ohmic resistors (~20MΩ)
- **Copper readout strips** (~10pF)
- **Fast recovery** after local discharge (1-3 strips) → **high rate capable**

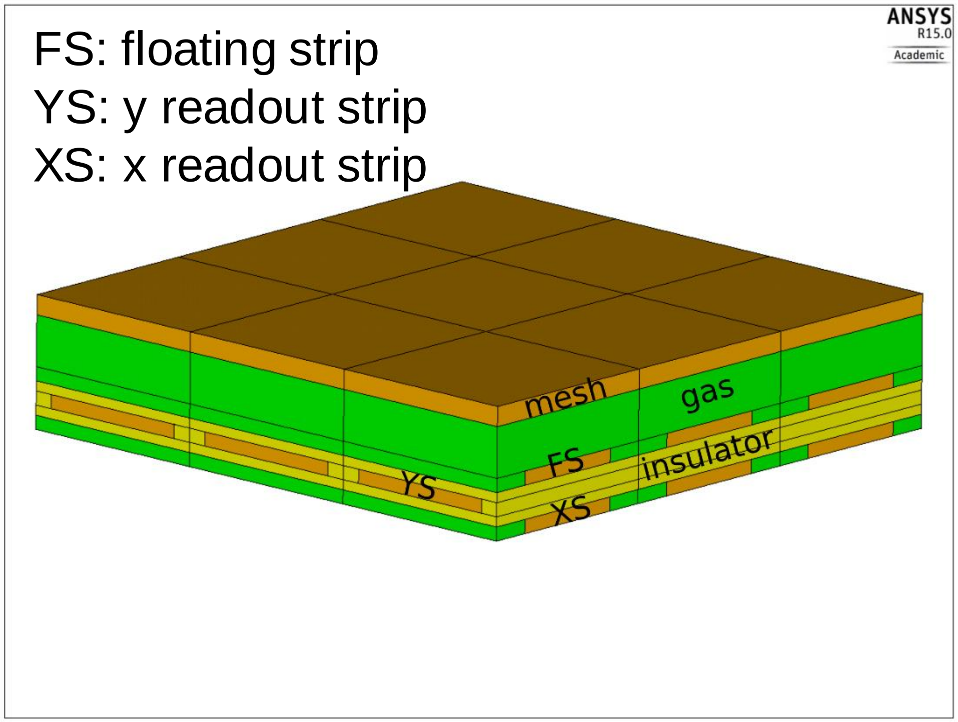


Is a two-dimensional readout possible?

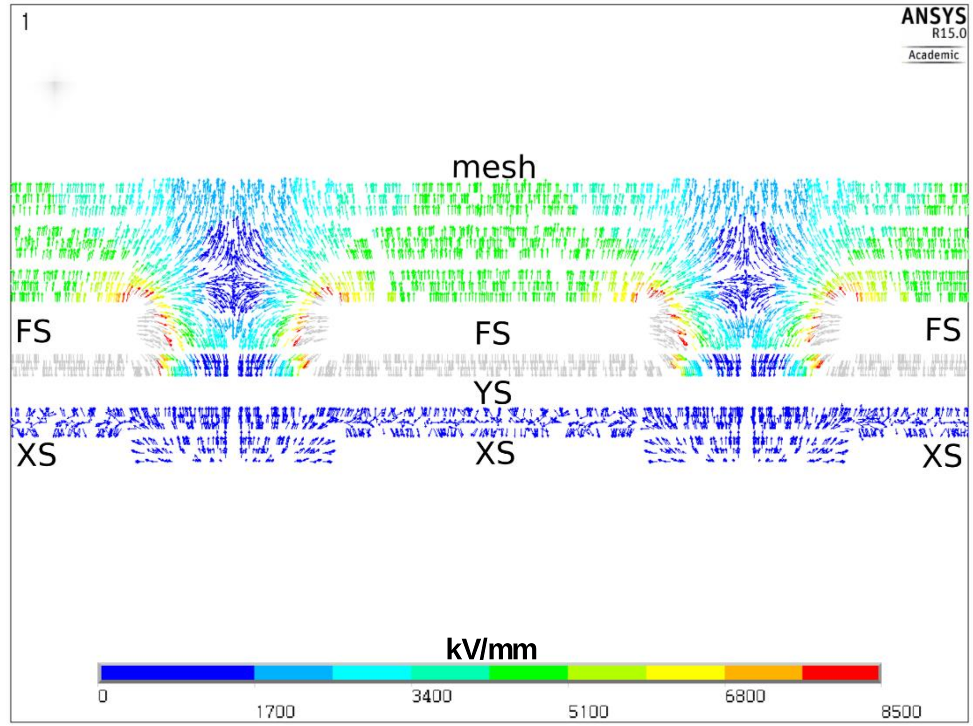
Signal Formation – Electric Field Configuration

2d FSM detector model designed in **ANSYS** (three copper strip layer anode)

geometry, amplification region



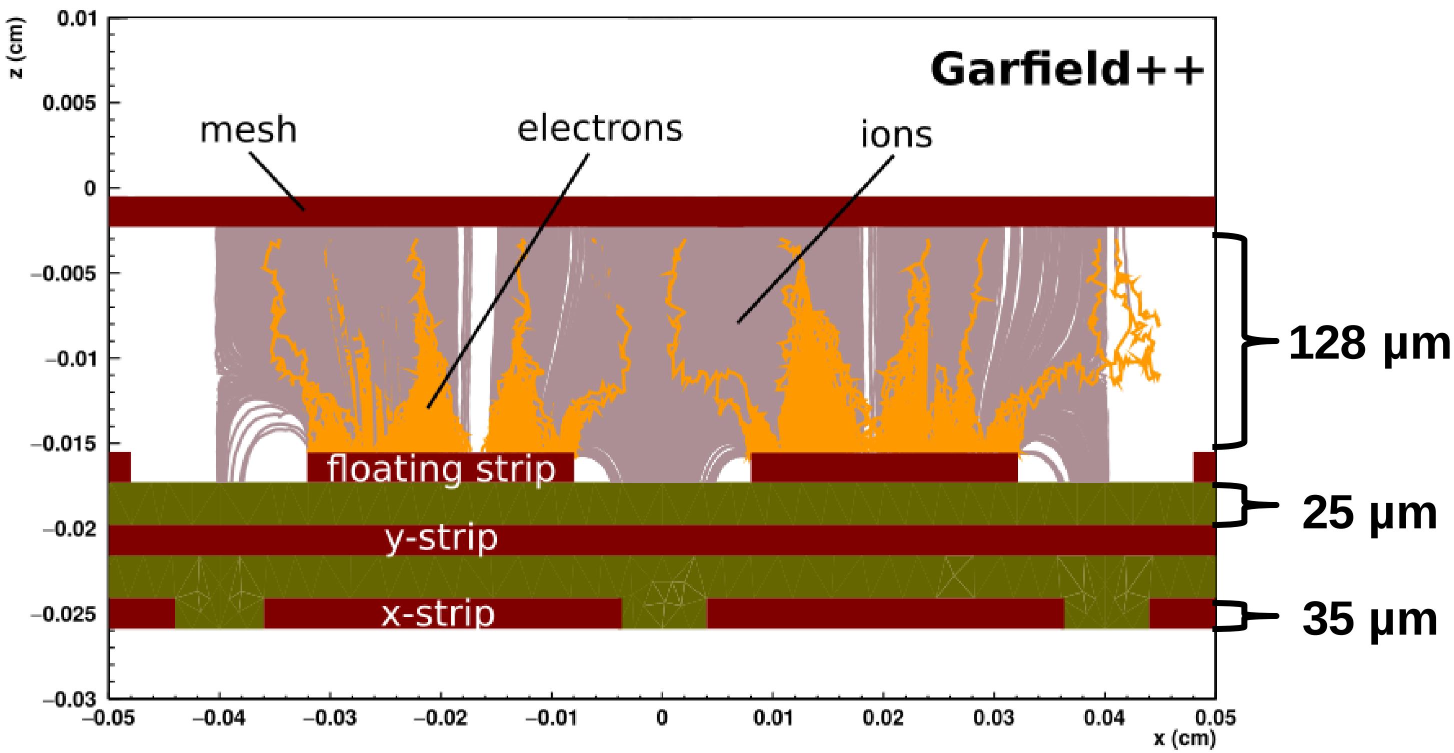
E-field solution for FS @ 580V



Strip Pitch: 0.5mm; Strip Width: 0.3mm (FS), 0.4mm (YS), 0.3mm (XS)

Signal Formation – Charge Carrier Movement

charge carrier drift and amplification simulated with **GARFIELD++**



what kind of **signals** to be expected on the **readout strips?**

→ **combination** of **directly induced** (by charge movement)
and **capacitively coupled signals**

Signal Formation – Induced Signals

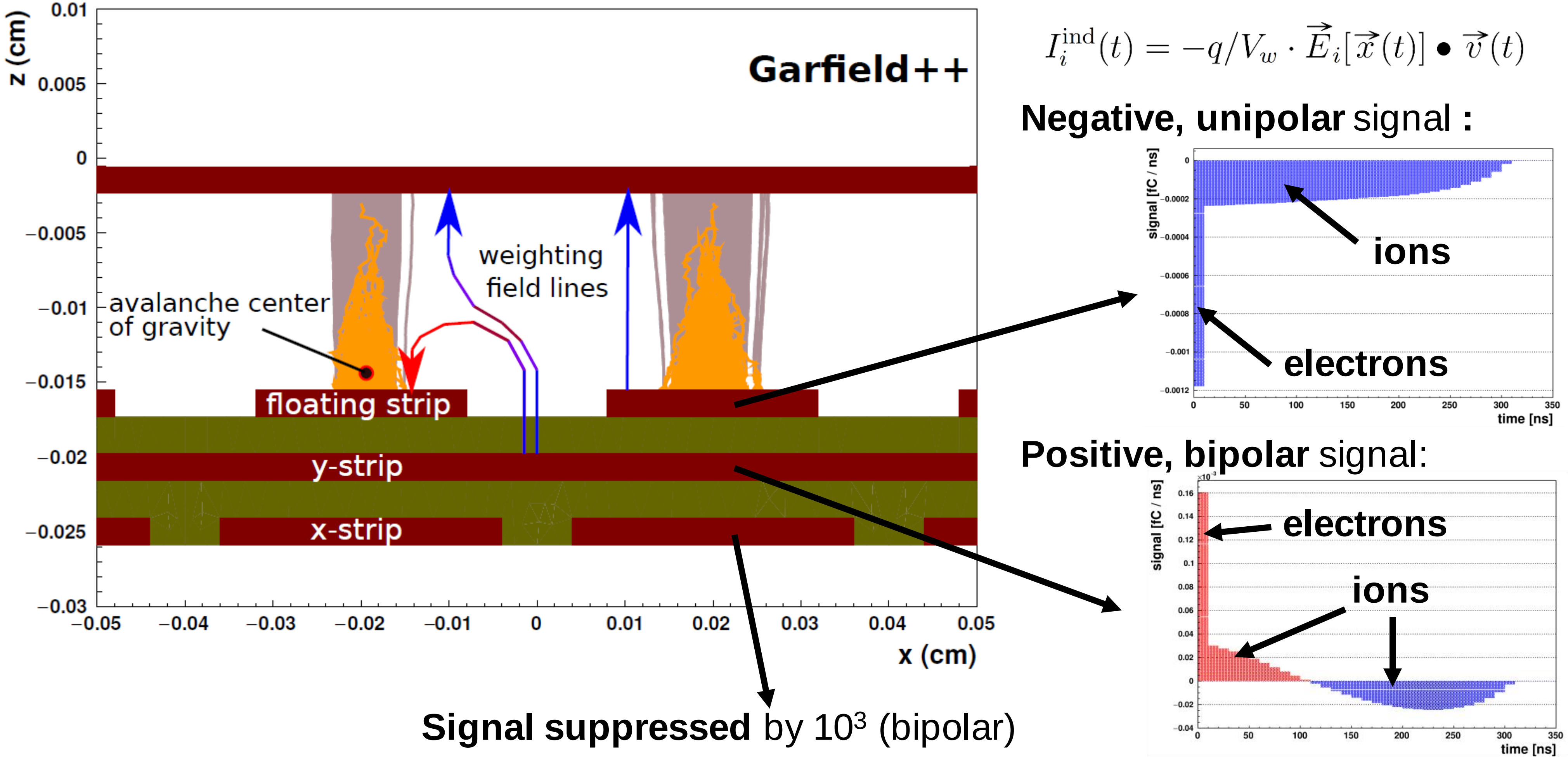
signals induced on electrodes by movement of charges **through weighting fields**

Shockley–Ramo theorem

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

Negative, unipolar signal **:**

Positive, bipolar signal:

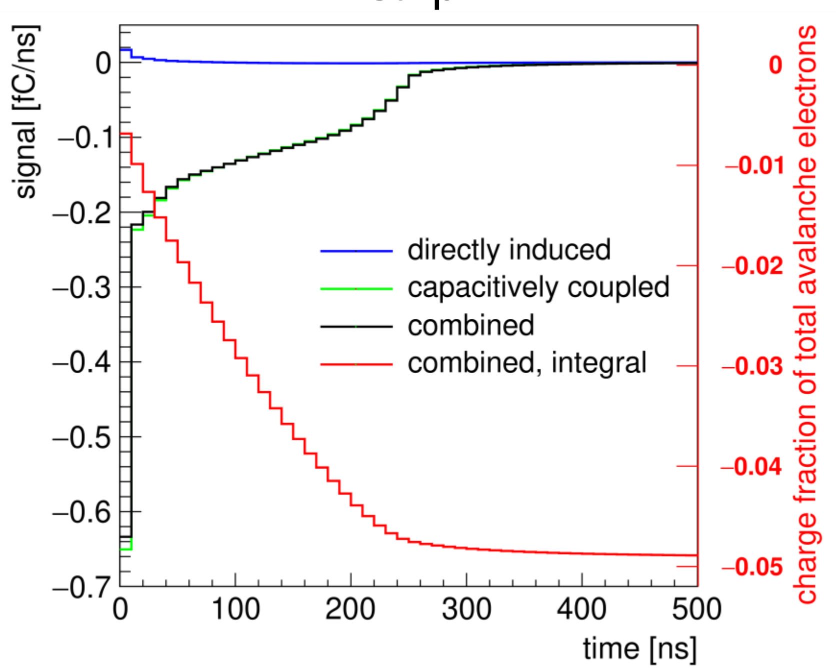


Signal suppressed by 10^3 (bipolar)

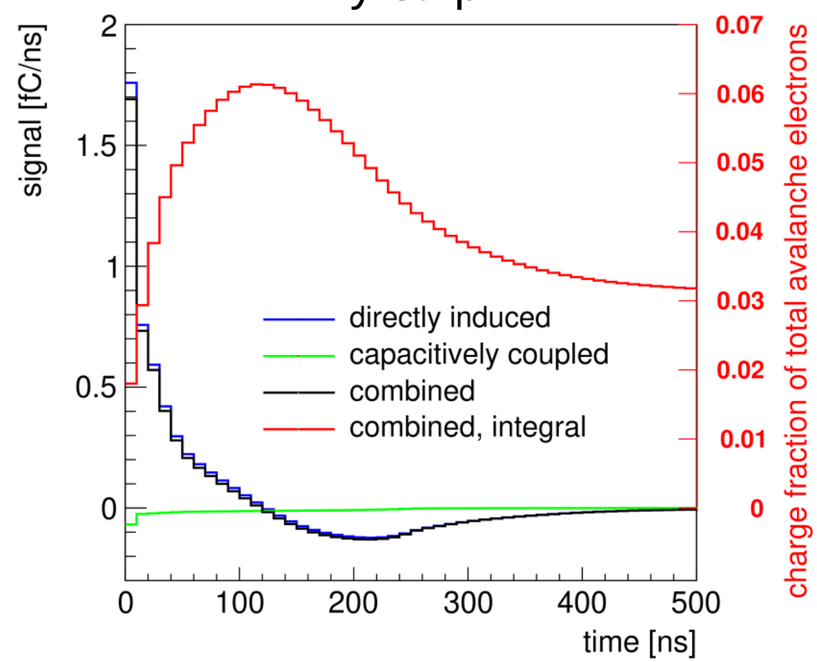
Signal Formation – Induced + Capacitively Coupled Signals

Capacitances simulated with ANSYS
→ **Charge sharing** between floating- and readout-strips **calculated**

x-strip



y-strip



dominant signal:
capacitively coupled floating strip signal

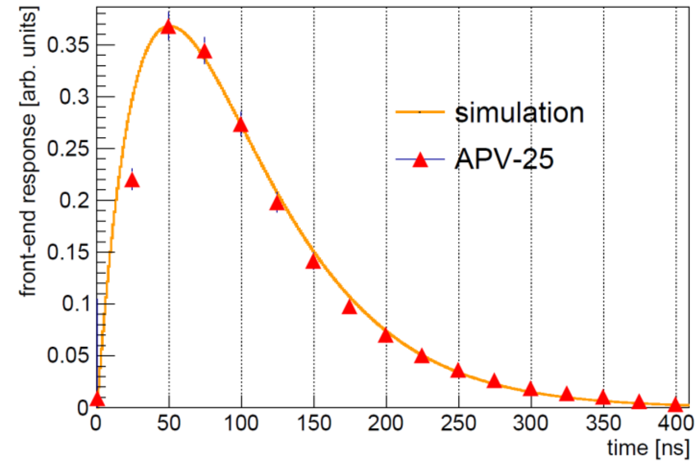
dominant signal:
directly induced signal from avalanche

Here: **only ~5%** of avalanche charge **transferred to** the **readout strips**
→ needs **optimization of strip geometry**

Signal Formation – Front-End Response

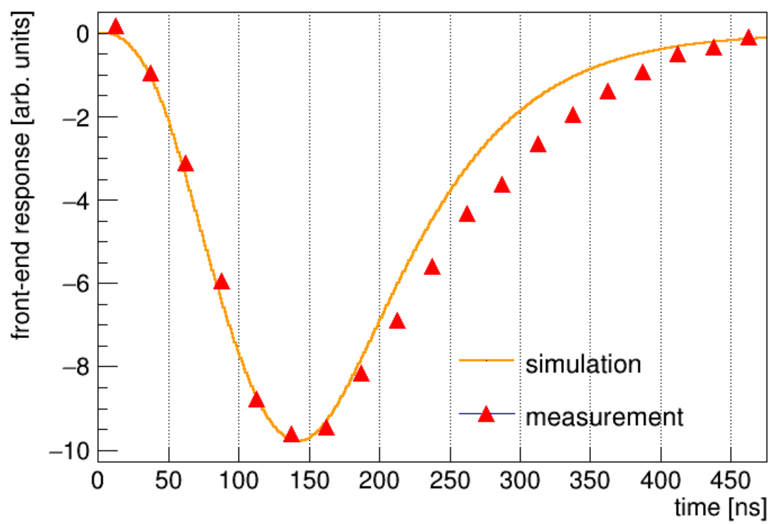
- simulate frontend electronics (**APV-25** hybrid board) response to delta-pulse (**transfer-function**)
- take into account finite **input impedance** of electronics channel and **detector strip capacitance**
- convolute current signal with the transfer function
  → chip response for both readout strips

delta-pulse response

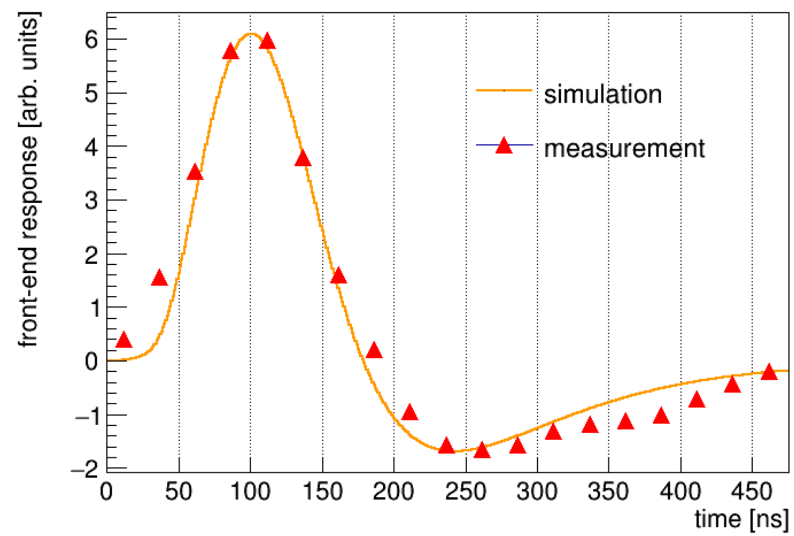


Simulated & measured electronics response to a MIP:

x-strip response



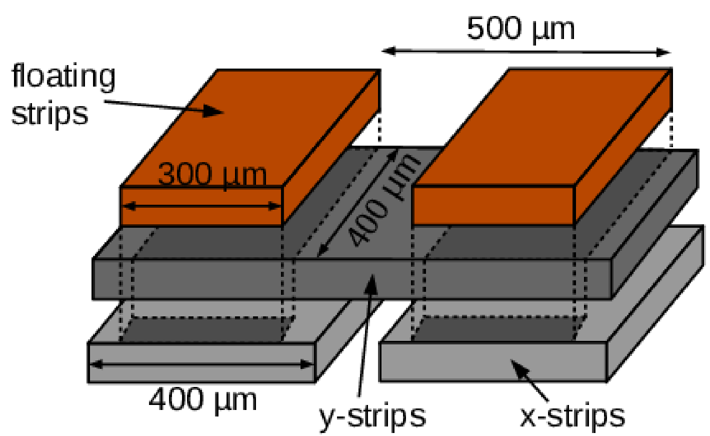
y-strip response

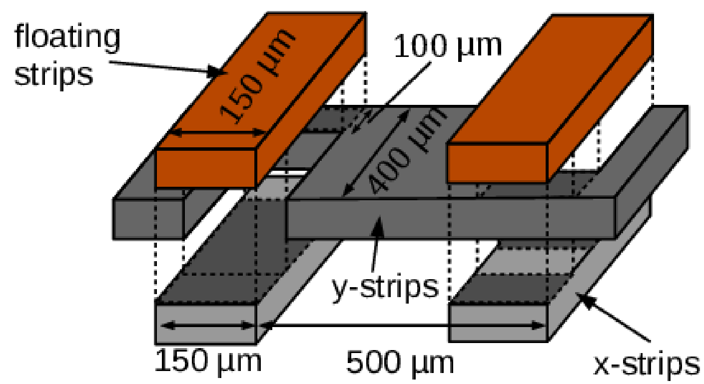


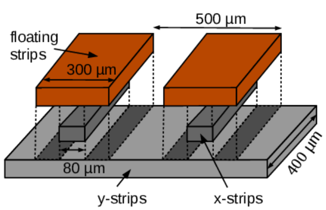
Anode PCB Designs

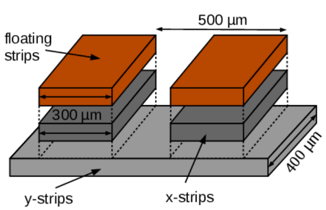
different anode pcb concepts have been developed and tested, mainly distinguishable by:
classical straight readout strips (left) and **novel pattern-based** (right) readout strips

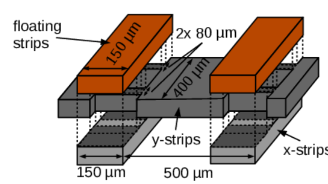
classical design	**novel** design

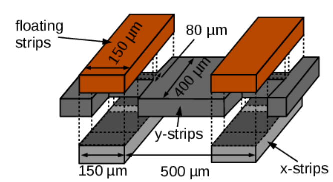


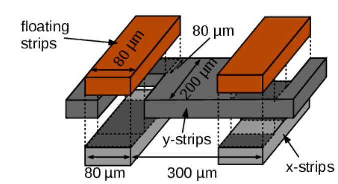






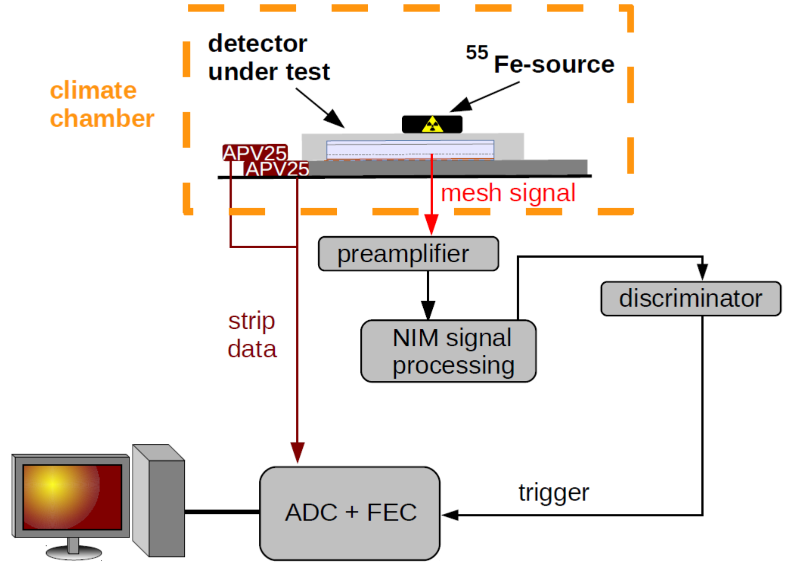




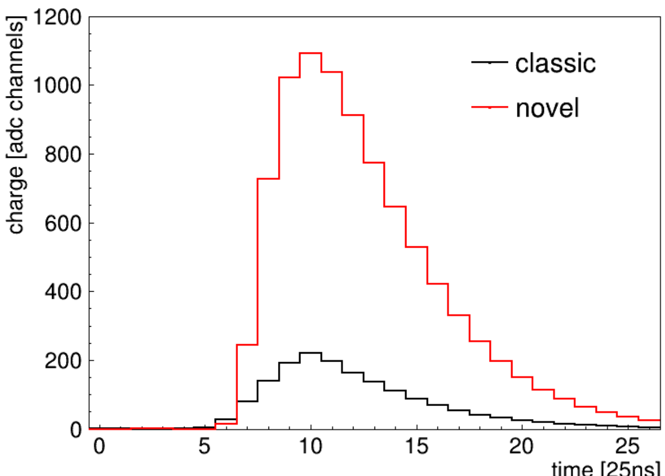


Comparison of Classical and Novel Anode Signals

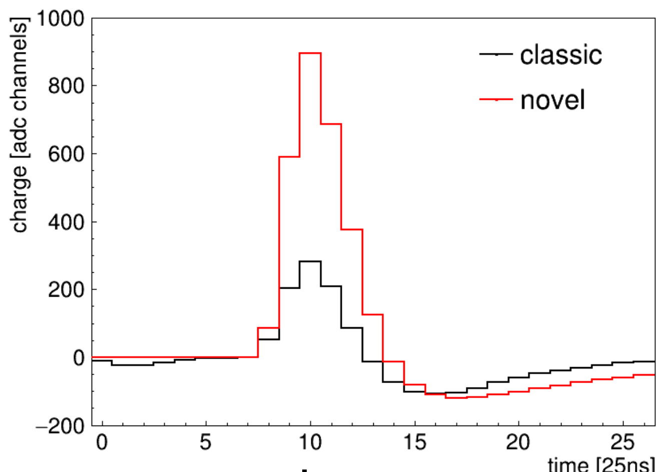
- ^{55}Fe source **comparison measurement** in a temperature/humidity **controlled environment** (climate chamber)
- Detector gas: $NeCF_4$ 80:20 vol.%



average signal on strip with highest charge:

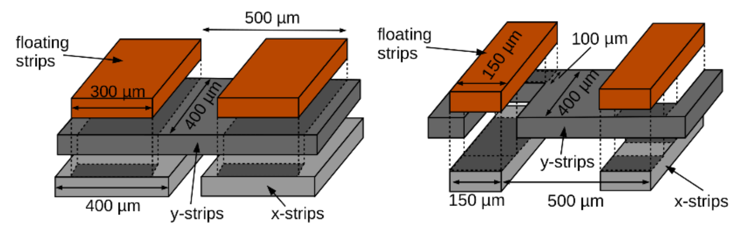


x-layer



y-layer

classical → novel



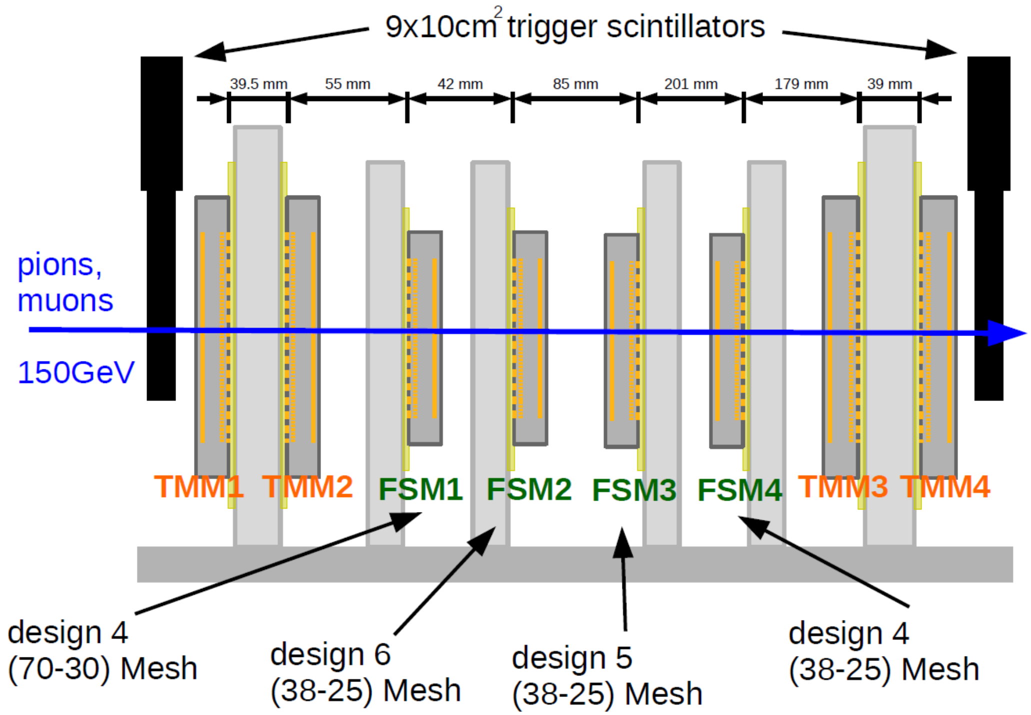
→ **increase of pulse height** on **both** readout strip **layers**

Performance in High Energy Beams at CERN

Setup at the SPS H8 beamline

- 10-150 GeV muons at kHz intensity
- 150 GeV pions up to MHz intensity

used detector gas:
Ne:CF_4 80:20 vol.%



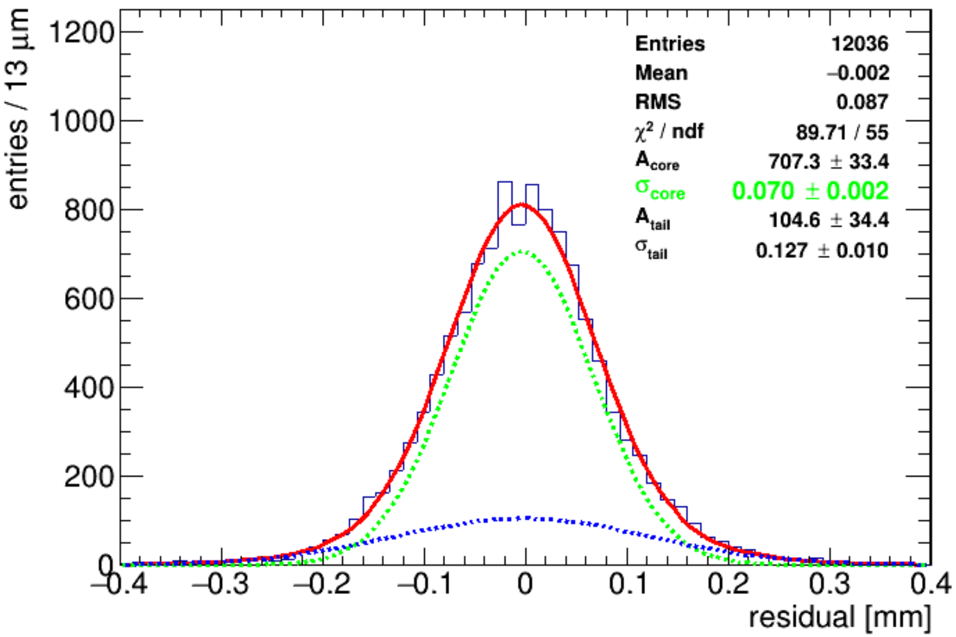
Investigation of spatial resolution and **efficiency** at:

- **perpendicular** tracks
- **inclined** tracks
- perpendicular tracks at **high rate**

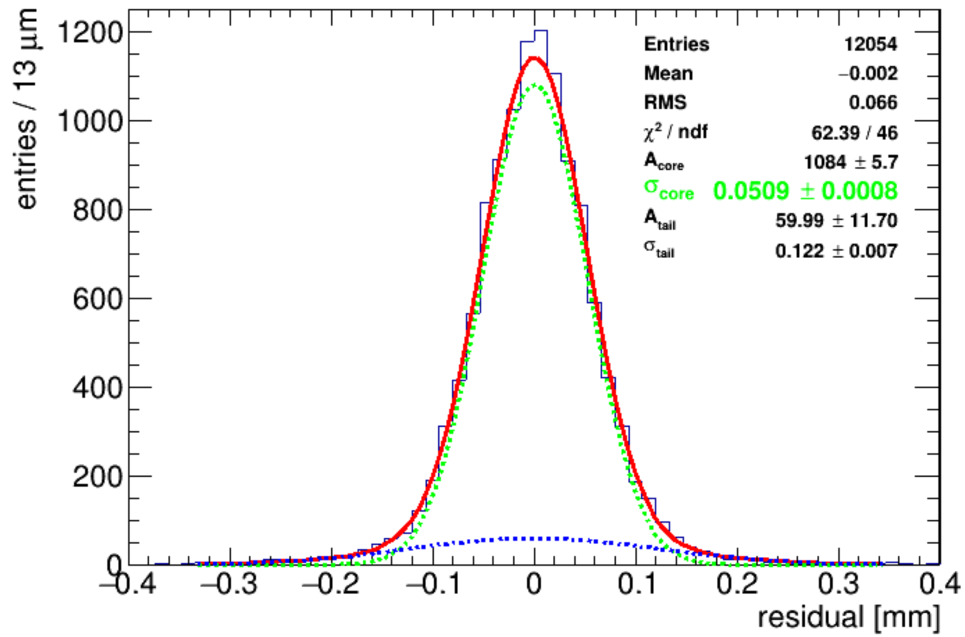
external track reference: accuracy better than 30µm

Resolution/Efficiency: Perpendicular Tracks

- extrapolate track from TMMs into the floating strip Micromegas
- **residual** = **predicted hit – measured hit** → fit distribution with double Gaussian



x-layer

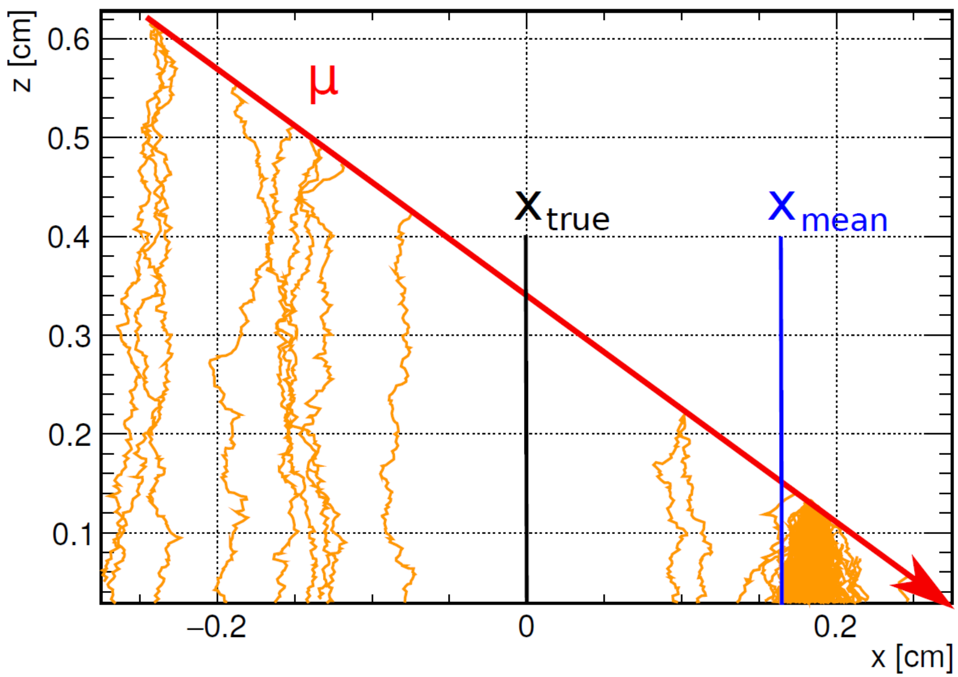


y-layer

- very good **spatial resolution**: **x-layer: 79µm** and **y-layer: 54µm** (core + tail weighted)
- charge discretization on floating strips → degradation of spatial resolution on x-layer
- **efficiency** in a 5σ window: **98%** (at an intensity of 420kHz/cm^2)

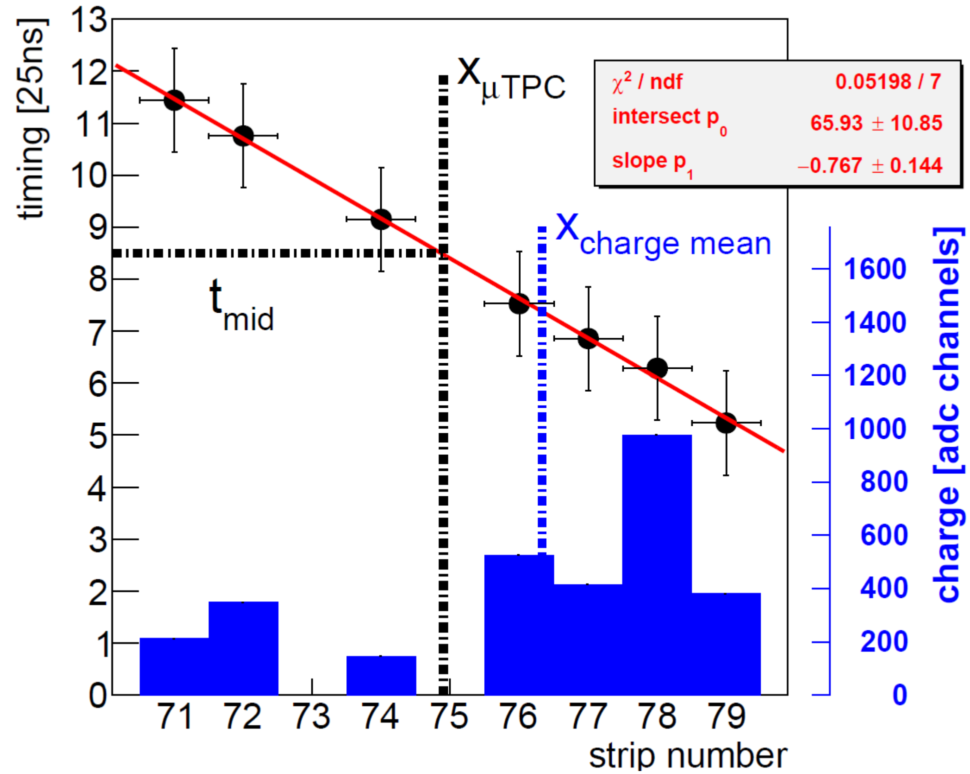
Signal Reconstruction – Inclined Tracks

simulation: muon at 40 degrees



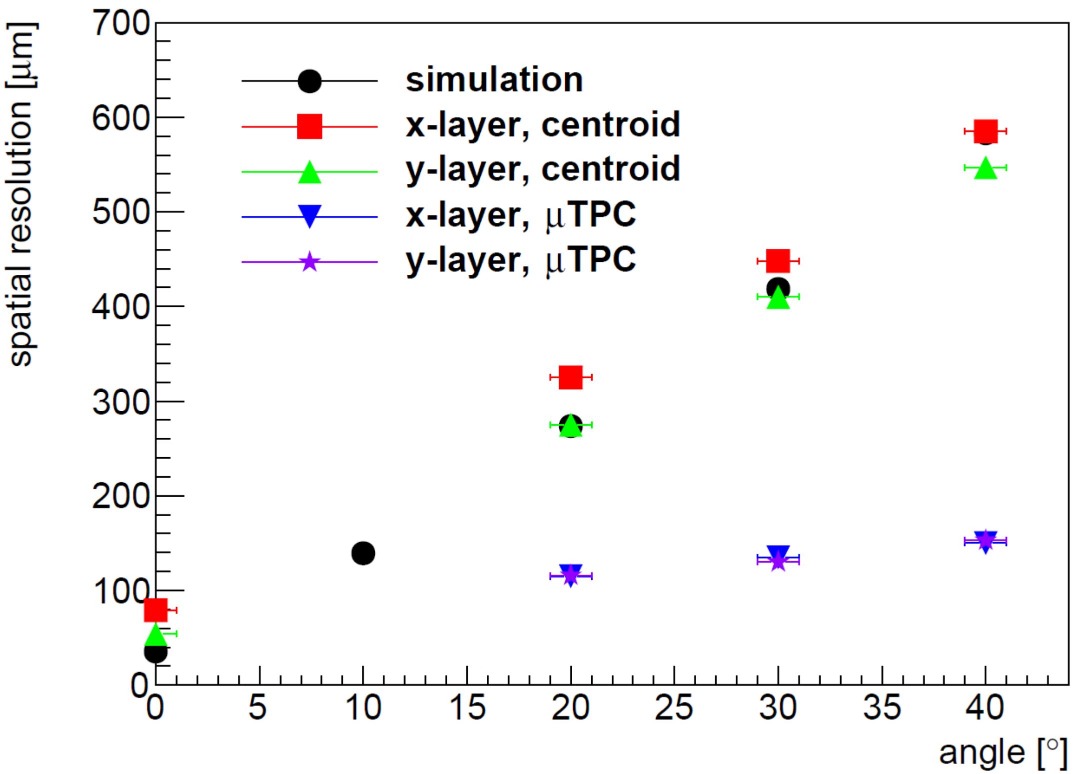
→ **centroid** position **distorted** by charge clustering along track

measurement: muon at 40 degrees

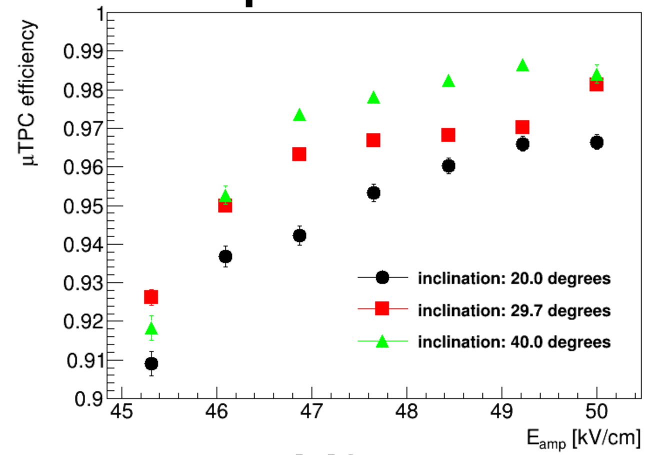


better approach: **μTPC method**

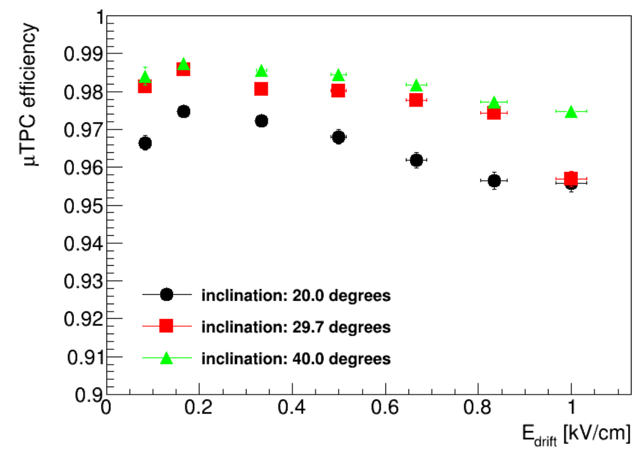
Spatial Resolution / Efficiency – Summary



amplification scan



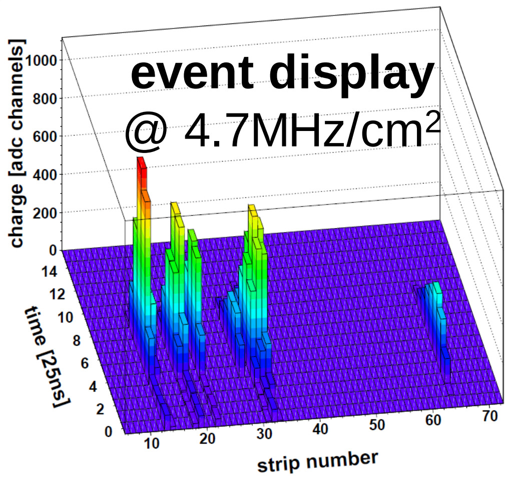
drift scan



→ **Spatial resolution below 150µm** on **both layers** for **all angles**

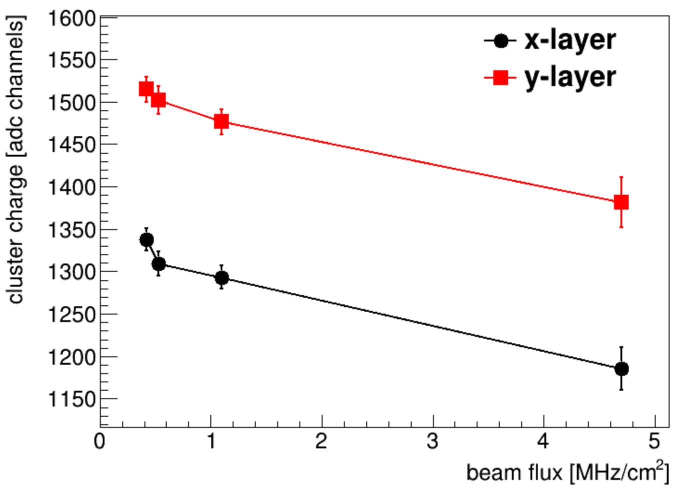
→ **Efficiency above 97%** for dedicated choice of drift and amplification field **for all angles**

High Rate Performance – Pion Beams

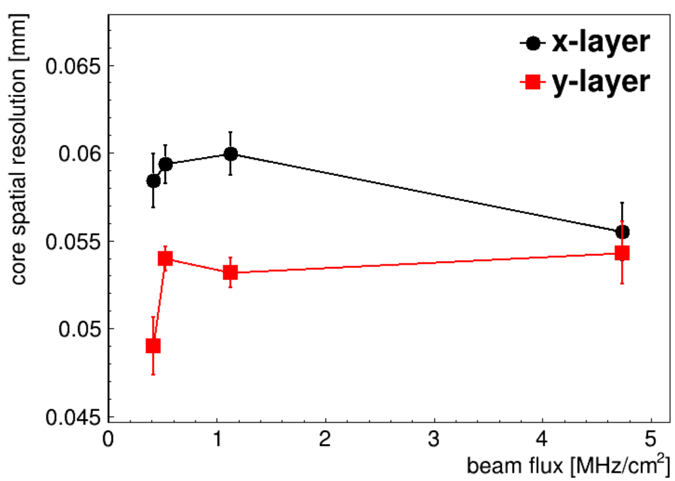


multiple particles in the detector at nearly the same time
→ resolvable in both dimensions

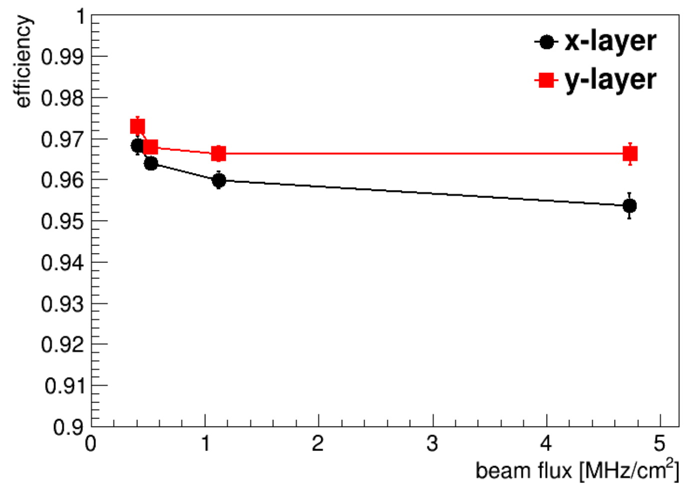
pulse height



spatial resolution (core)



efficiency

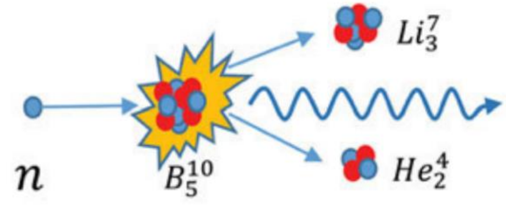


→ ~ constant up to 5MHz/cm²

Measurements with Neutrons and ^{10}B Cathode

Stable operation at a Neuton fluxes of ~ kHz/cm^2 and MIP gain values: anode current constant at ~7µA at 570V

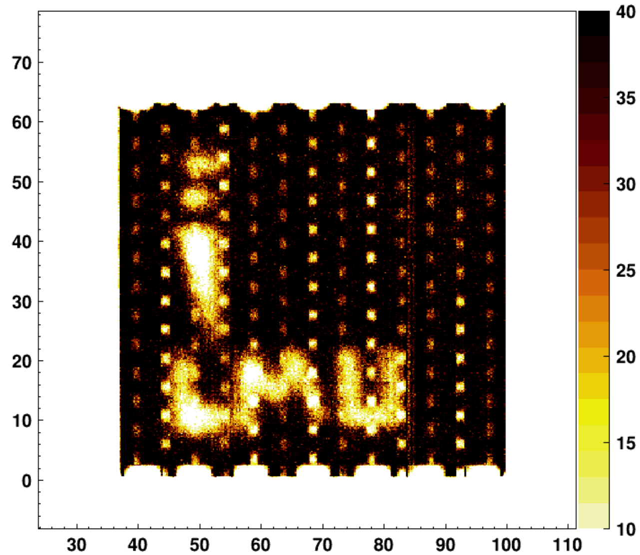
Neutron capture process produces densely ionizing nuclei **at the cathode**:



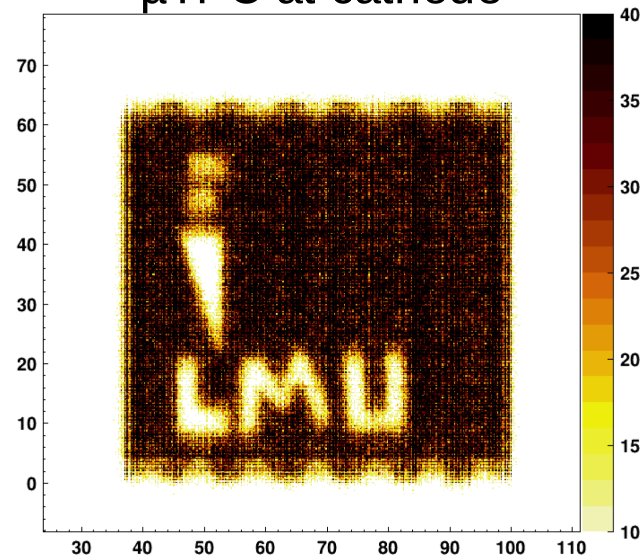
→ **Low gain required**: U_{amp} = 450V

^{10}Boron coated cathode with copper tape

centroid



µTPC at cathode



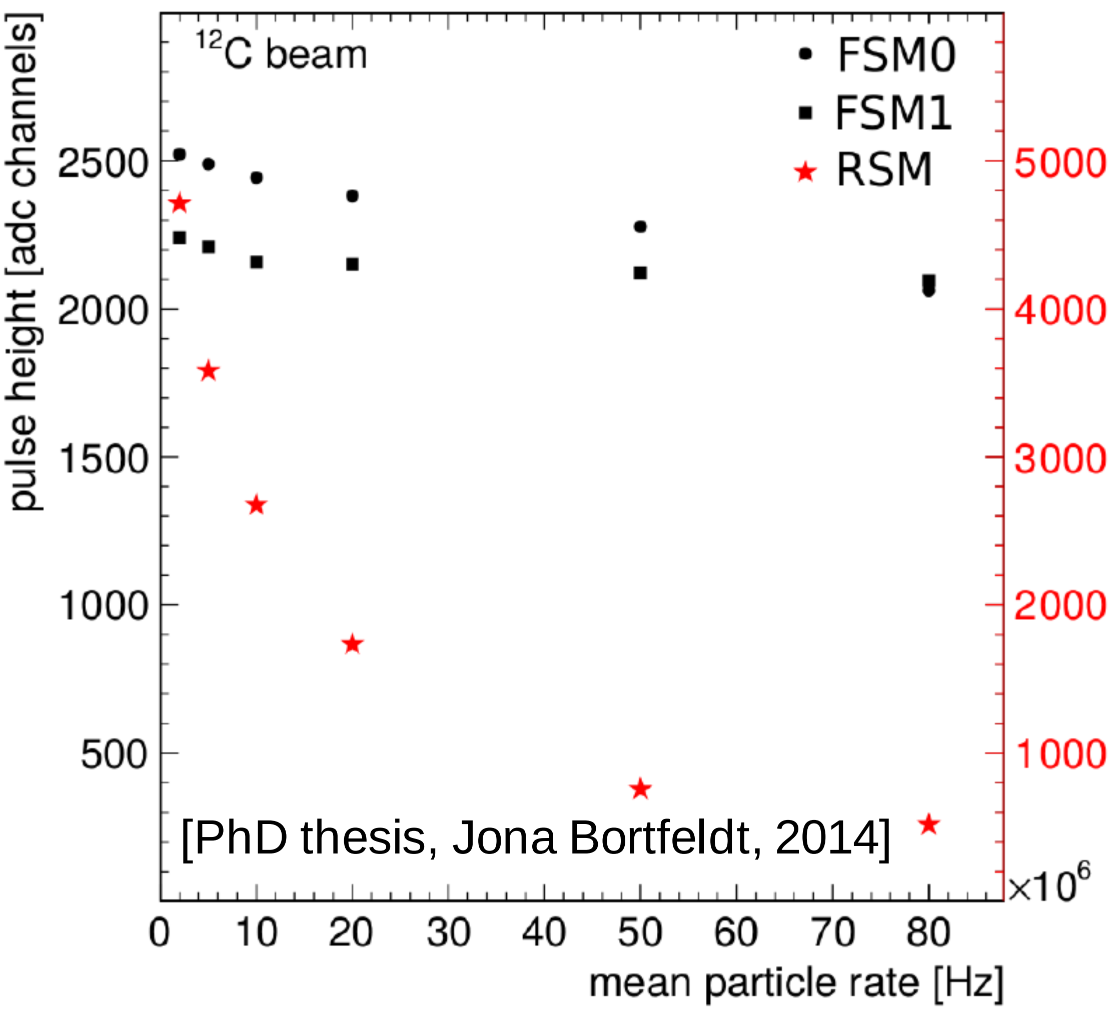
Summary

- Novel Two-Dimensional Floating Strip Micromegas have been developed and operated successfully
- Detailed simulations explain the signal formation:
  - optimized anode PCB strip geometry to increase directly induced signals
  - optimized capacitances between the strip layers
- Perpendicular readout strips with alternating width:
  - increase of pulse height on both layers
  - similar amplitudes on both layers
- Spatial resolution
  - between 50 to 80 µm for both layers at perpendicular incidence
  - below 150 µm for incidence angles smaller than 40 degrees
- High rate capable: ~constant efficiencies above 95% up to particle fluxes up to $5MHz/cm^2$
- Stable under Neutron irradiation

THANK YOU

BACKUP

Performance of 1d Floating Strip Micromegas



- **pulse height** almost **constant** up to several **MHz** beam intensity
- possible to assemble with very **low material budget**

→ attractive to medical imaging applications [doi.org/10.1016/j.nima.2016.05.003]

→ **two-dimensional readout possible** but **different signals** on the two readout strip layers **observed**

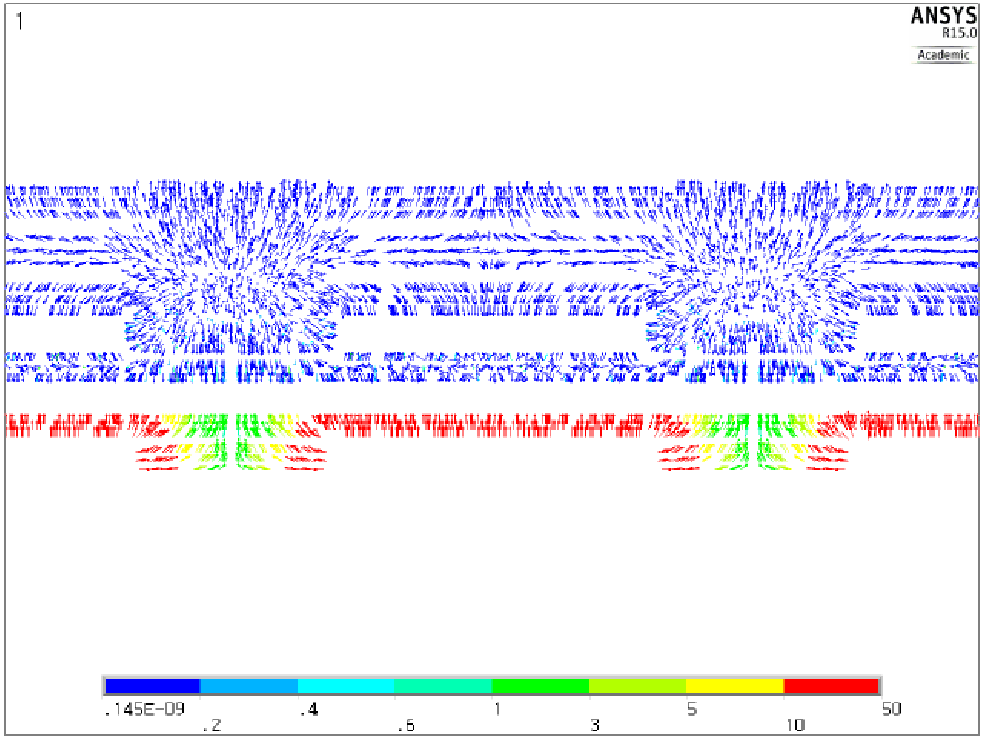
→ detailed **understanding of signal** formation **necessary**

Signal Formation in 2d FSM (3)

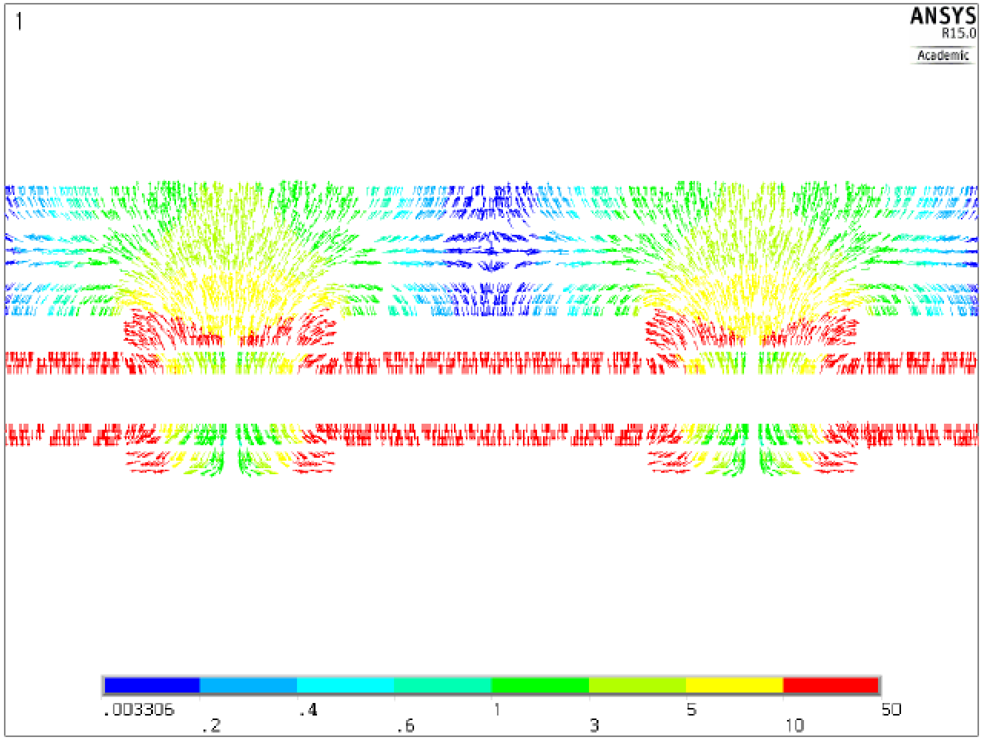
induced signals based on **weighting field theory:**

The current induced on a grounded electrode by a point charge q moving along a trajectory $\boldsymbol{x}(t)$ is $I_n^{ind}(t) = -q/V_w \boldsymbol{E}_n[\boldsymbol{x}(t)]\, v(t)$, where $\boldsymbol{E}_n(\boldsymbol{x})$ is the electric field in the case where the charge q is removed, electrode n is set to voltage V_w, and all other electrodes are grounded.

(Shockley Ramo Theorem)

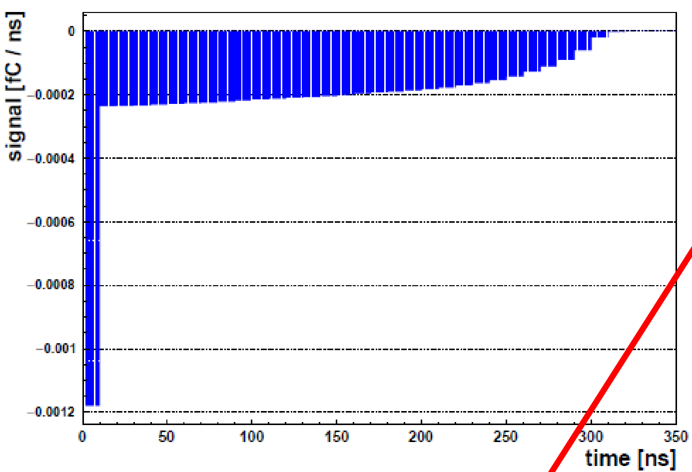


- weighting field of x-strips

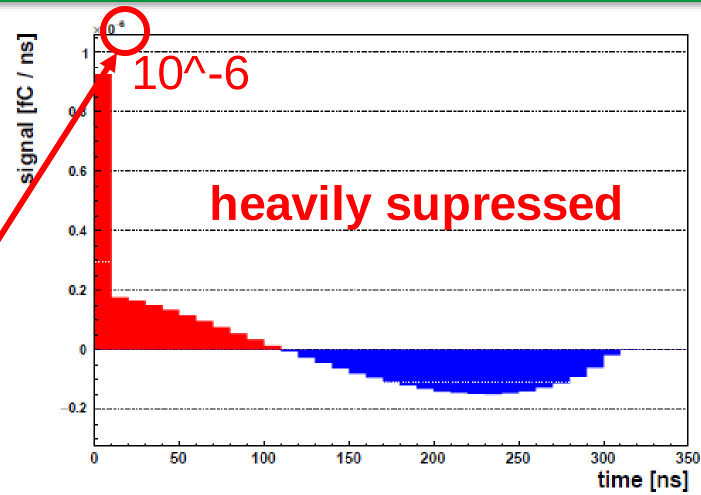


- weighting field of y-strips

Signal Formation in 2d FSM (5)

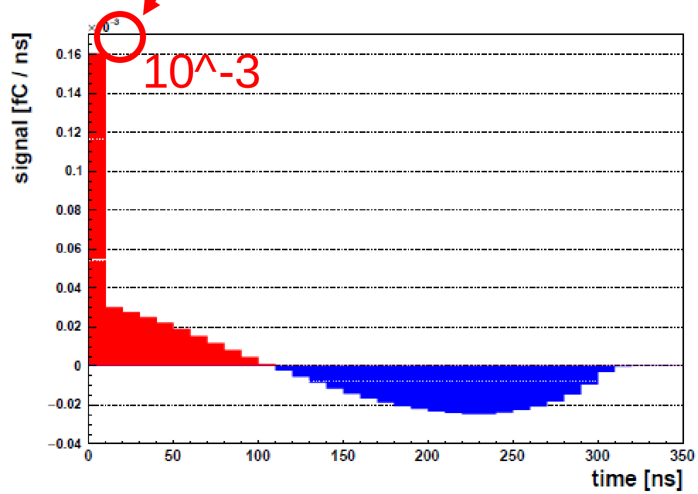


(a) floating strip



(b) parallel readout strip

induced currents on all electrodes as a function of time



(c) perpendicular readout strip

- also bipolar signal induced on parallel readout strips
- **but: three orders of magnitude supressed**
- **capacitive coupling not considered!**

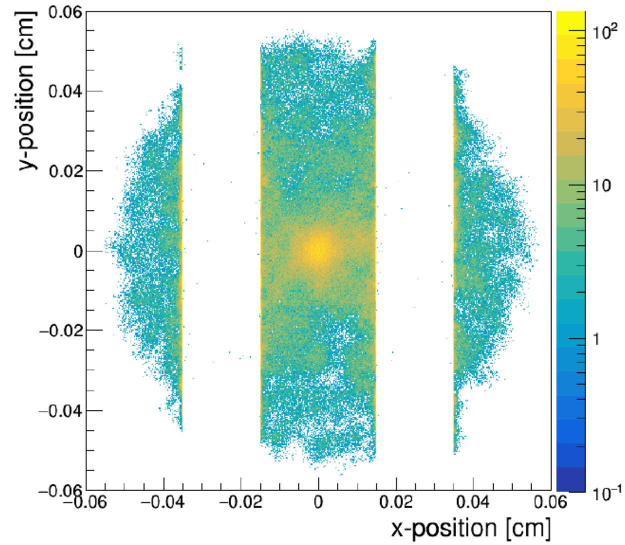
Signal Formation in 2d FSM (7)

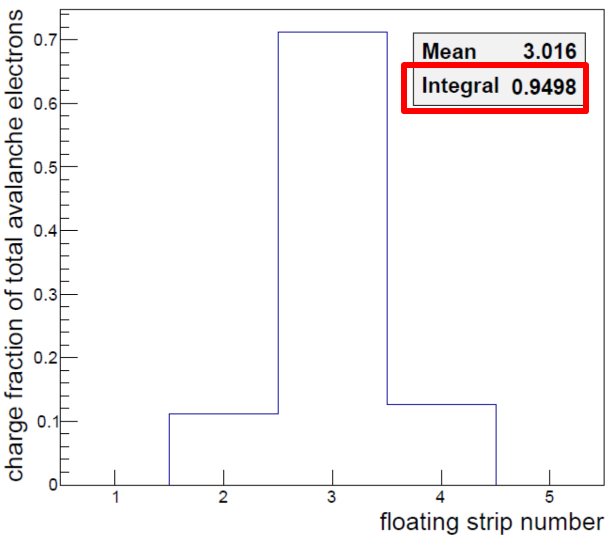
- combine induced currents and capacitive coupling

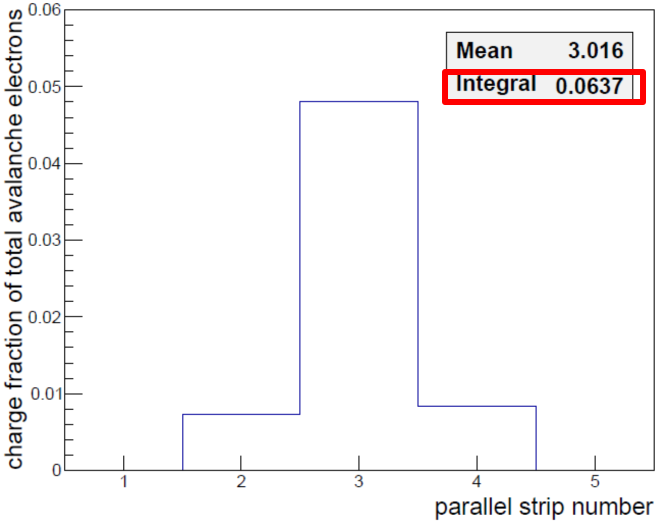
→ simulate fraction of signal coupled to all electrodes in the amplification process:

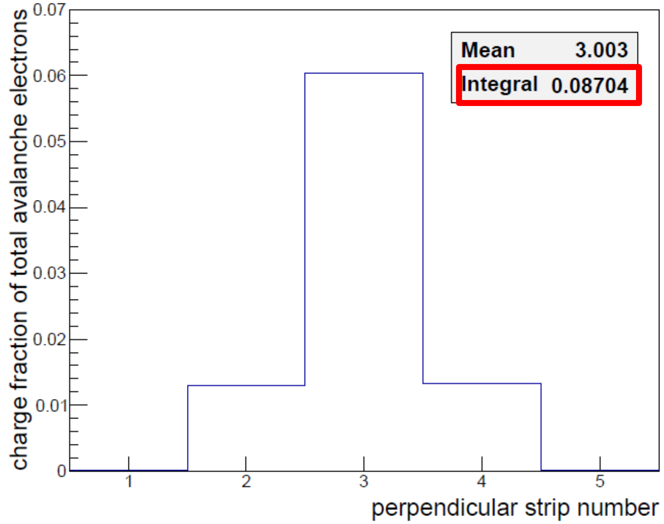
→ small coupling to both readout strips observed

→ needs optimization!





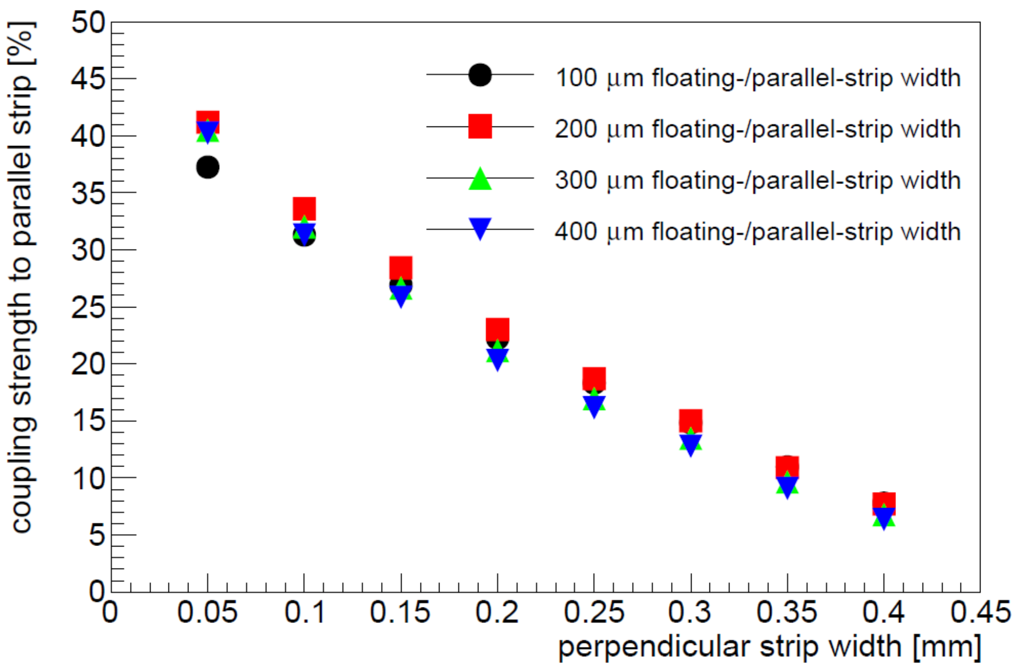




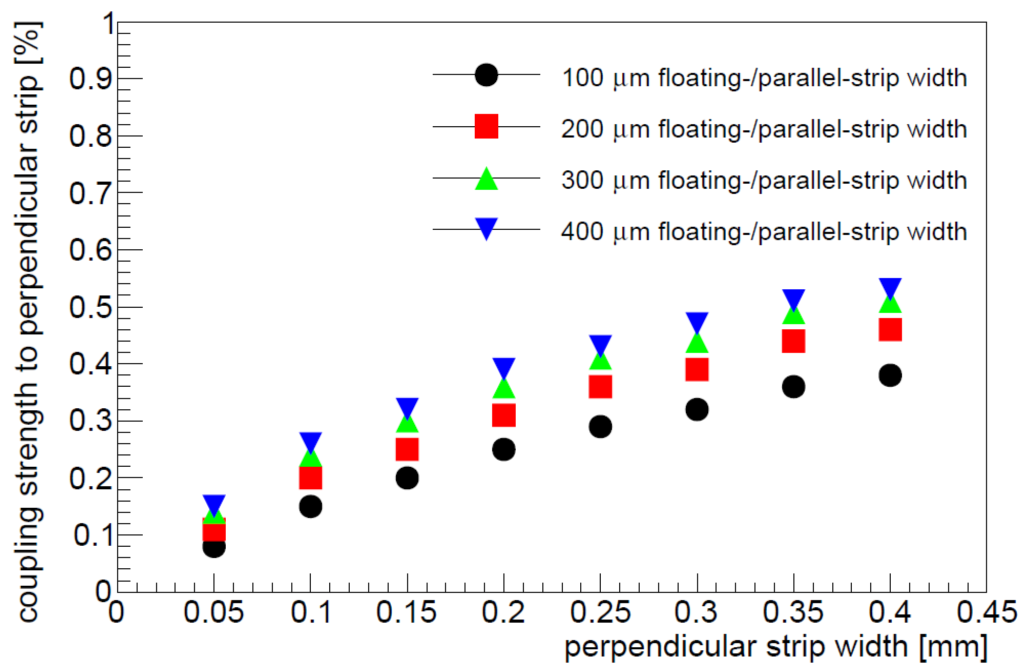
Signal Formation in 2d FSM (6)

- capacitance network of anode simulated with ANSYS
- **capacitive coupling from floating strip to both readout strips:**

x-strips



y-strips



→ coupling to both strip layers strongly depending on perpendicular strip width

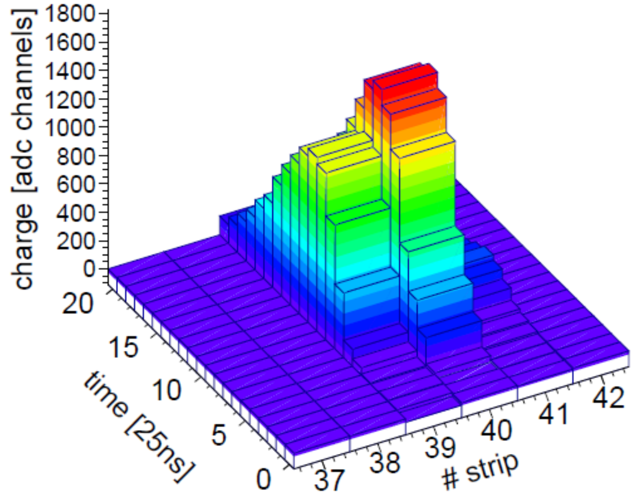
→ parallel signal fraction up to 40%, perpendicular signal fraction below 1%

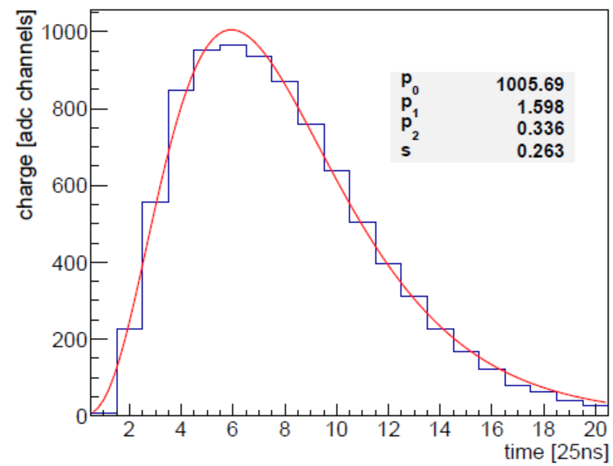
Measurement: MIP Signal Front-End Response

Typical signal from a **cosmic muon** measured with APV25 frontend boards connected to both readout strip layers:

APV configured to **expect negative currents**:

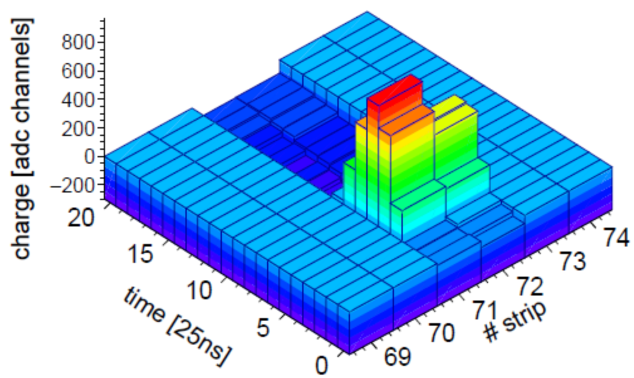
x-strips response positive:
→ **negative, unipolar signal**

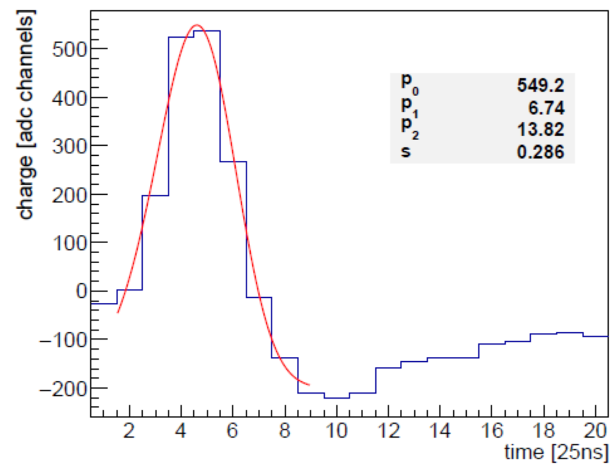




APV configured to **expect positive currents**:

y-strips response positive:
→ **positive, bipolar signal**

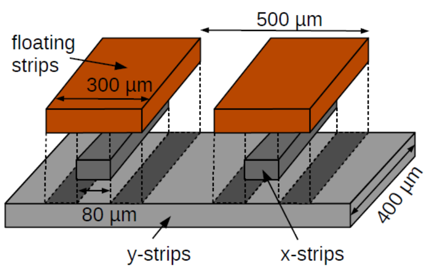




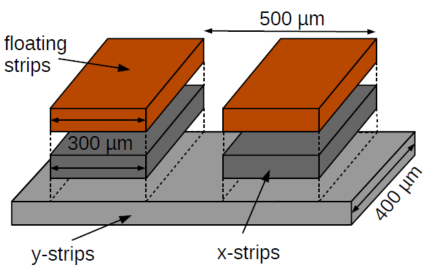
Anode PCB Designs and Detector Geometries

different anode pcb concepts have been developed and tested, mainly seperable by:
classical straight readout strips (left) and **novel pattern-based** (right) readout strips

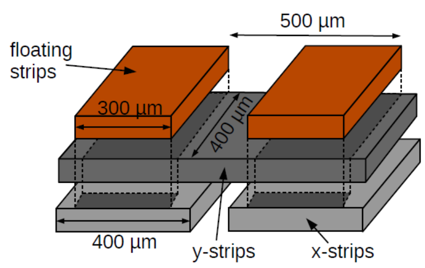
classical designs



(a) design 1

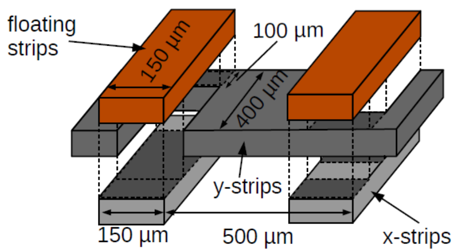


(b) design 2

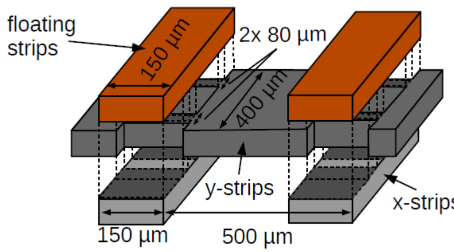


(c) design 3

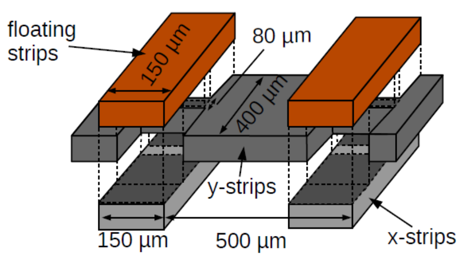
novel designs



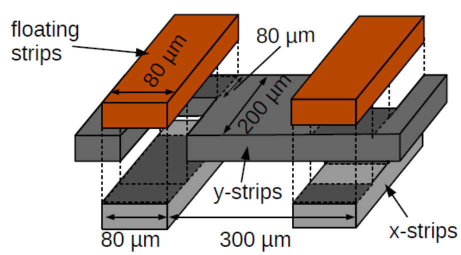
(a) design 4



(b) design 5



(c) design 6

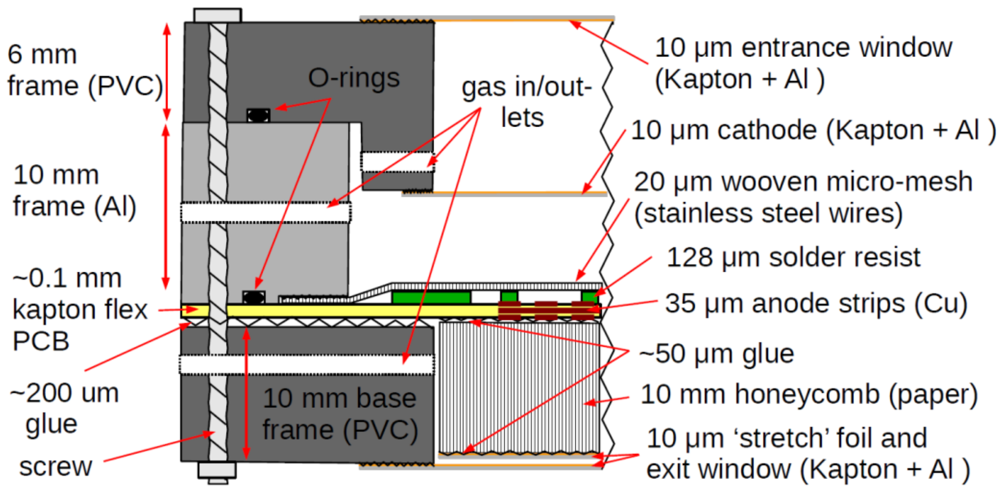


(d) design 7

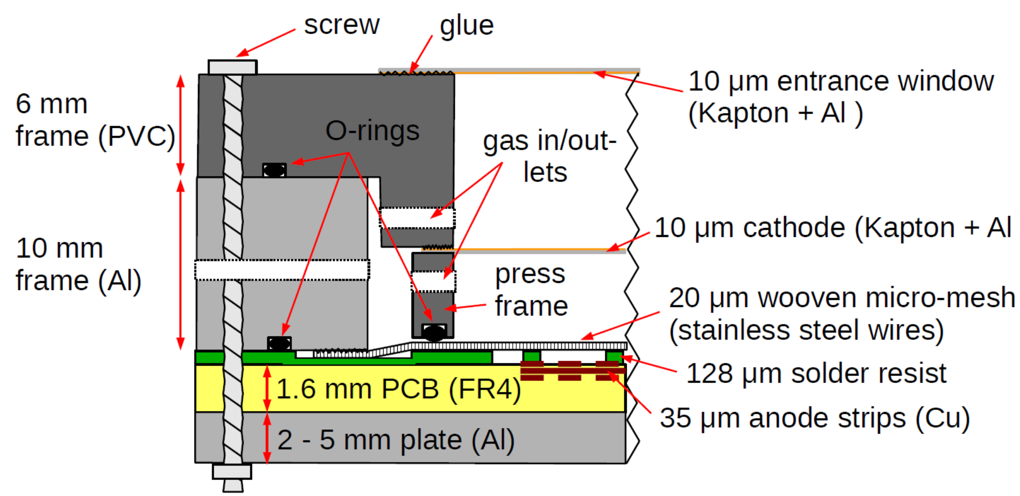
Anode PCB Designs and Detector Geometries

Two different detector geometries: low material budget on a 20cm x 20cm active area (left) and 6.4 cm x 6.4 cm active area with a stiff base plate for R&D studies (right)

classical designs (except design 1)	novel designs



384 strips



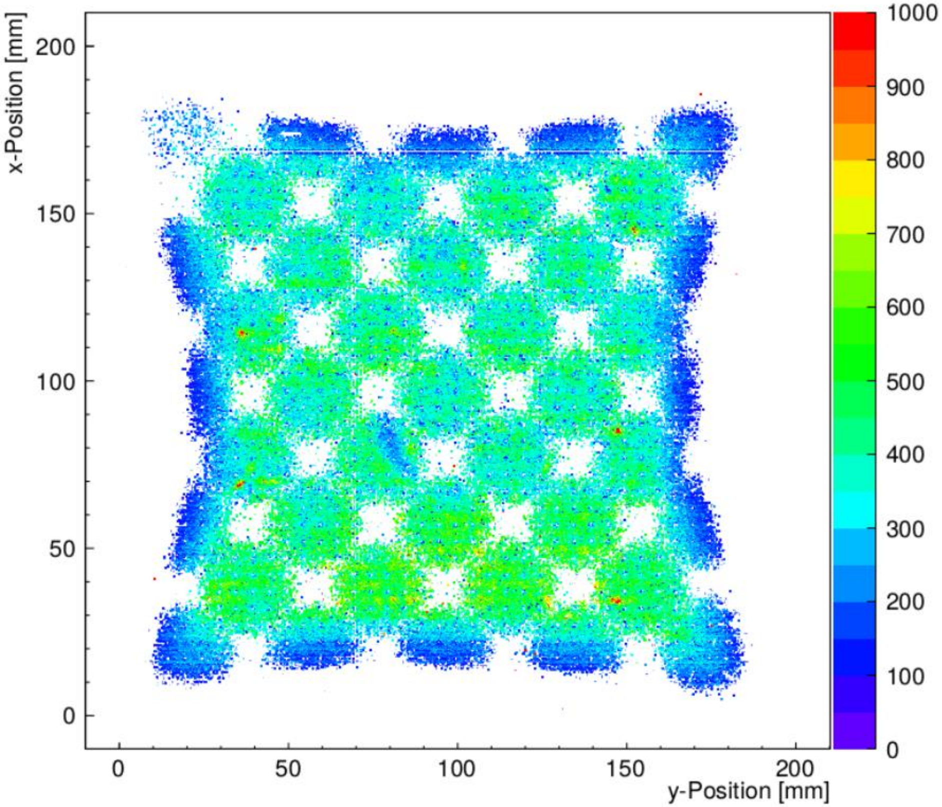
128 strips

Quick Summary on low material budget FSM

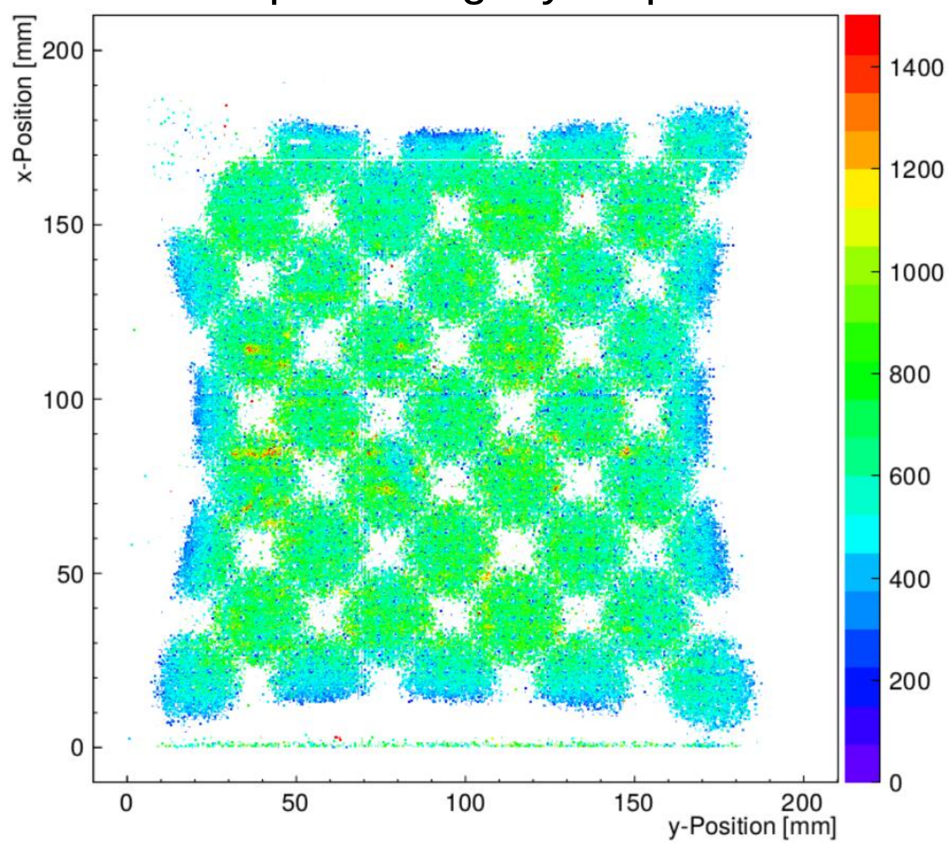
Fe-55 pulse height on both readout layers:

- large fraction of active area working, pillars visible
- homogeneous and similar pulse height on both layers
- ‚pillow'-like structure at borders due to not properly attached mesh to the pillars

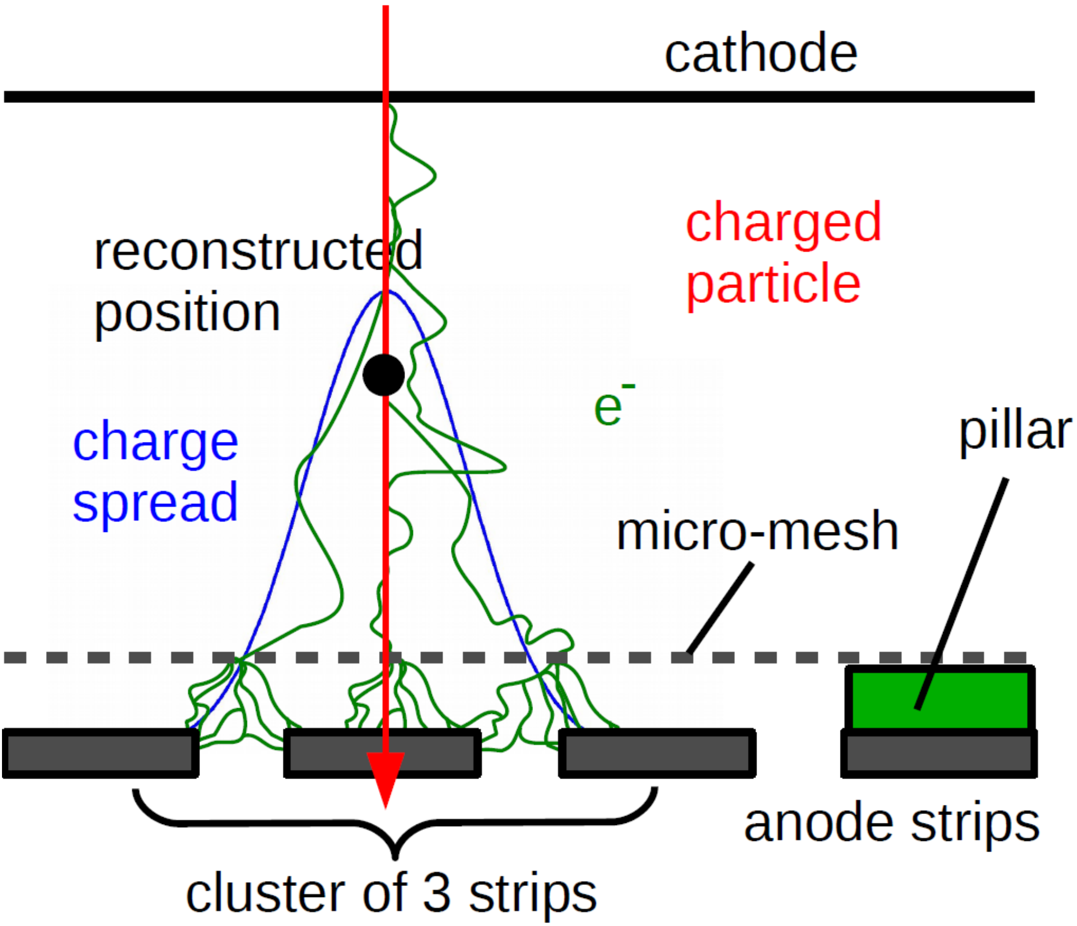
pulse height x-strips



pulse height y-strips



Signal Reconstruction – Perpendicular Tracks



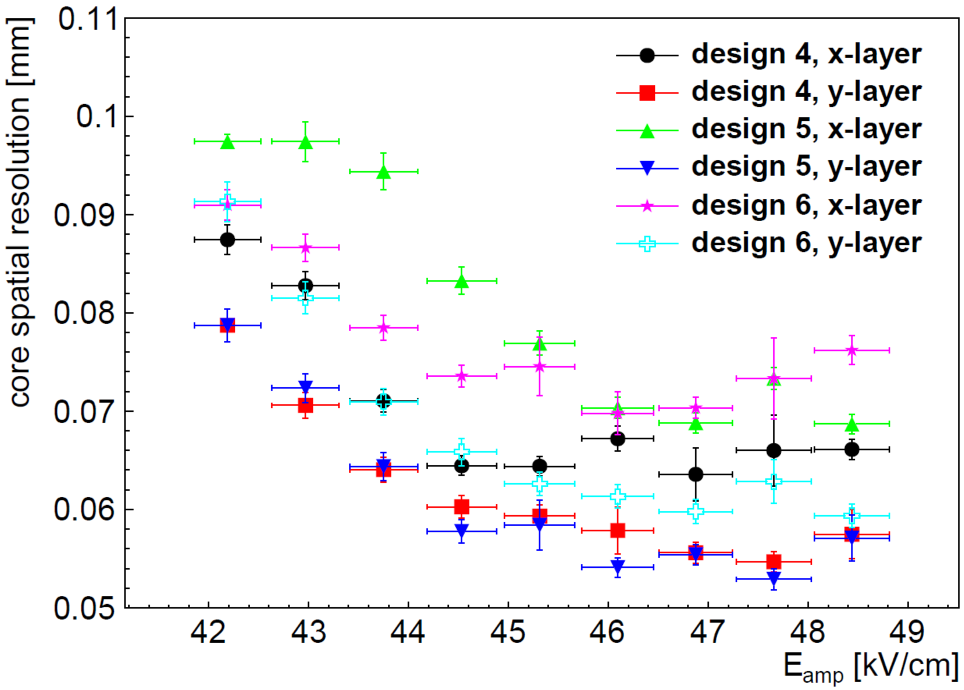
Centroid Method

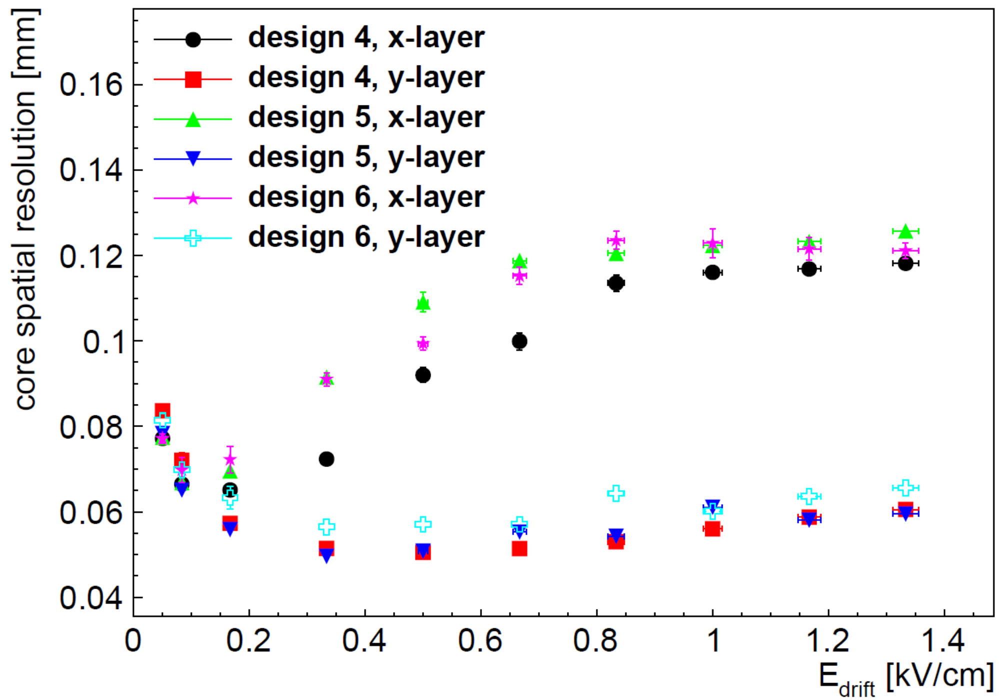
- search for strips with a deposited charge $> 3 \times \sigma_{strip}$, no further cuts
- charge spreads over strips $\longrightarrow$ gaussian distributed charge signal
- typically more than 2 strips hit $\longrightarrow$ forming cluster of strips

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

Resolution Scans: Perpendicular Tracks (muons)

- resolution as a function of amplification field (left) and drift field (right)

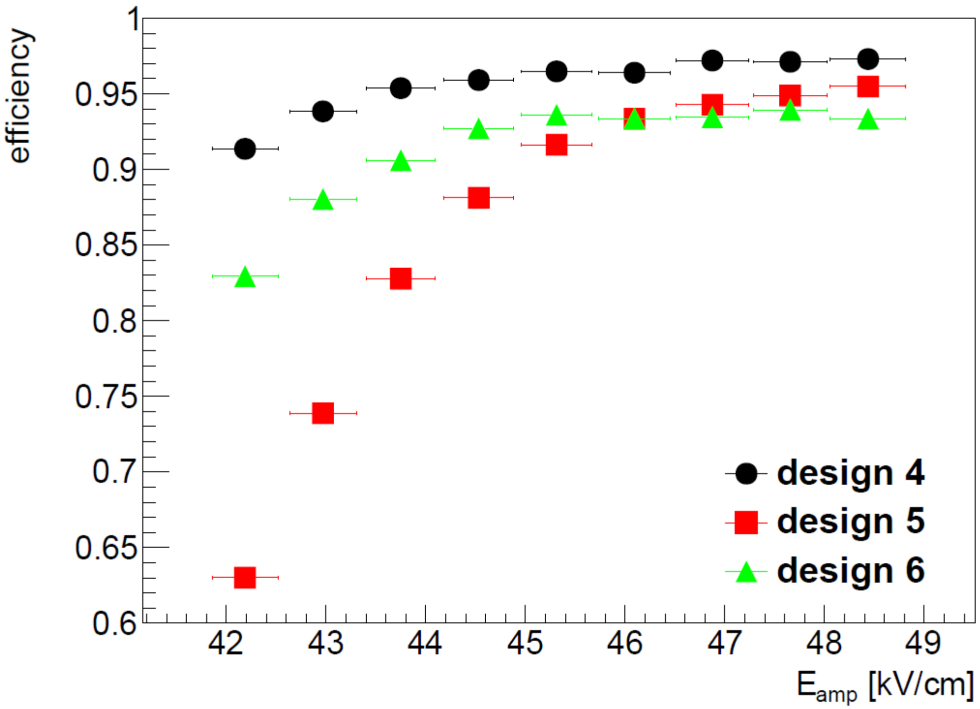




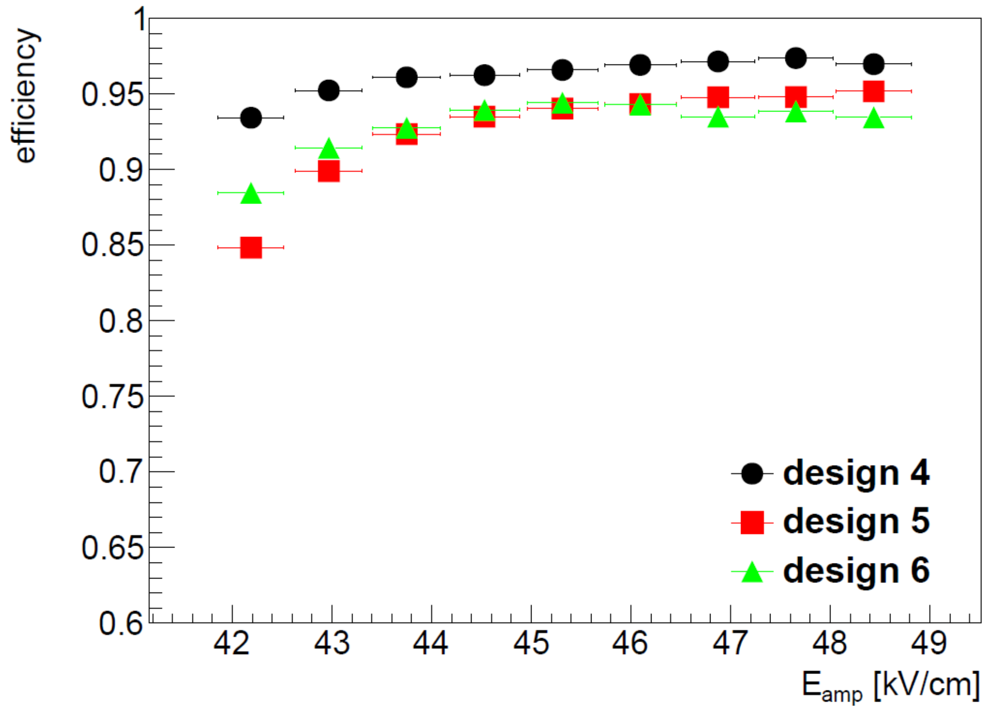
- **amplification scan**: **plateau** reached at around **46kV/cm** (= ~590V over 128um gap)
- **drift scan**: resolution depending on **transversal diffusion** of electrons in the drift region

Efficiency Turn On: Perpendicular Tracks (muons)

- Efficiency as a function of amplification field



(a) x-layer

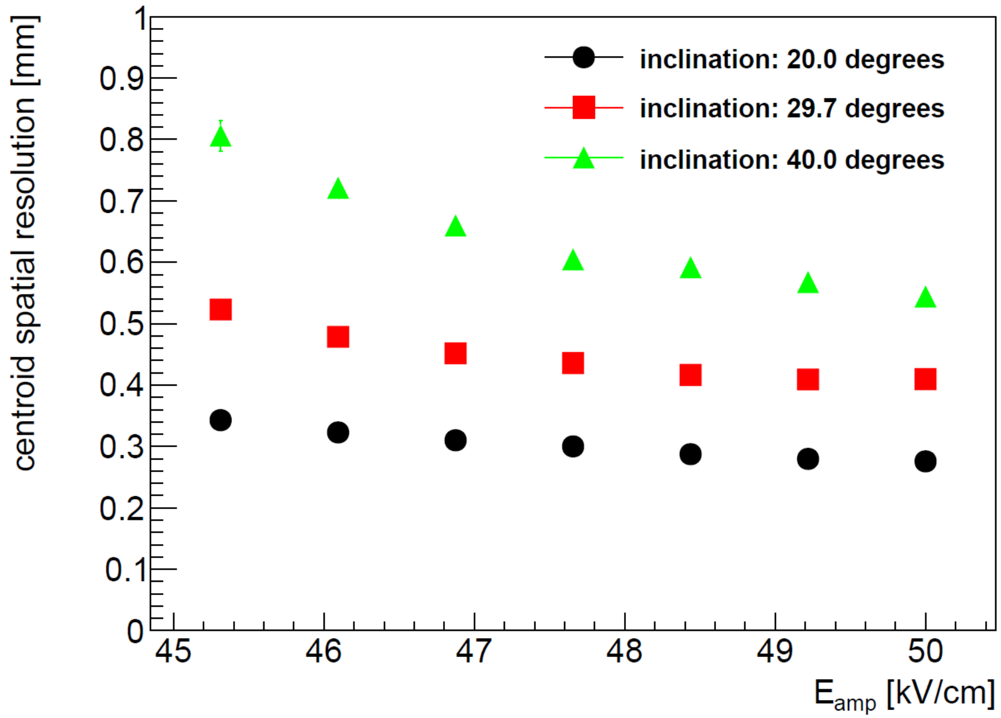


(b) y-layer

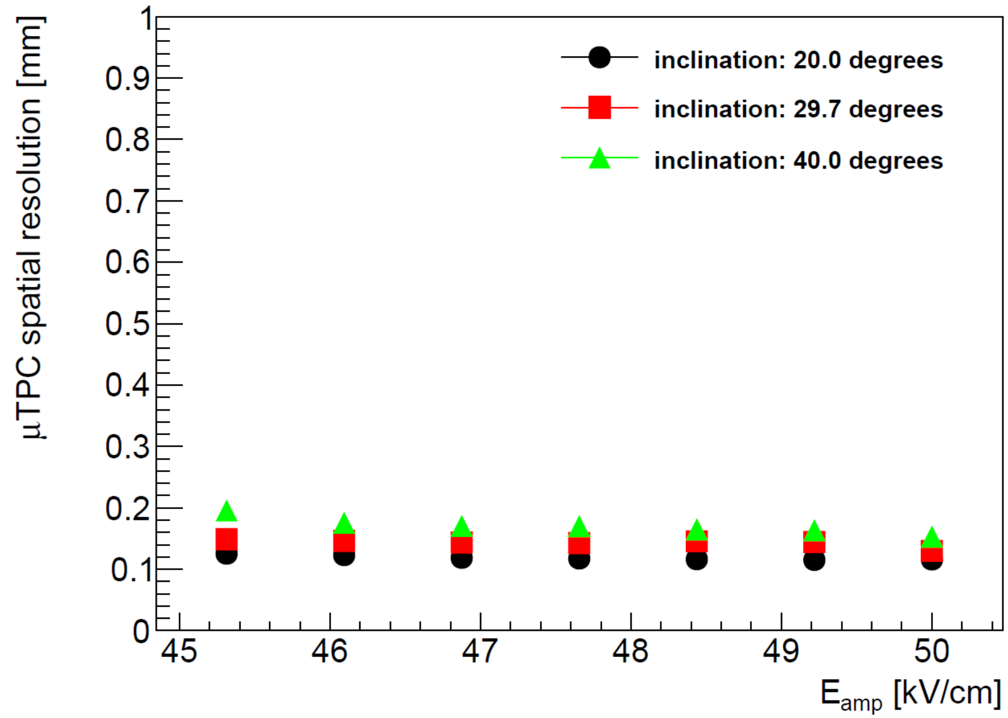
- **x-layer efficiency depending** on design i.e. **capacitive coupling** strength to floating strips
- **design 4 best performance**, plateau around 95%
- around **3% efficiency loss** caused by **pillars** (0.4mm x 2 mm size)

Spatial Resolution – Inclined Tracks – Amp. Scan

centroid method



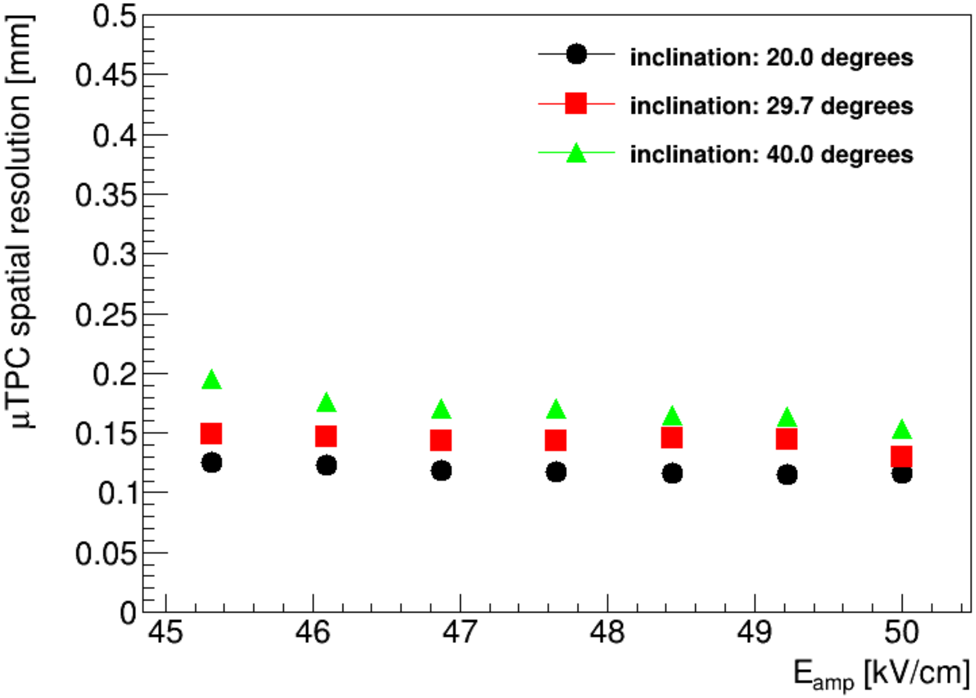
µ-TPC method



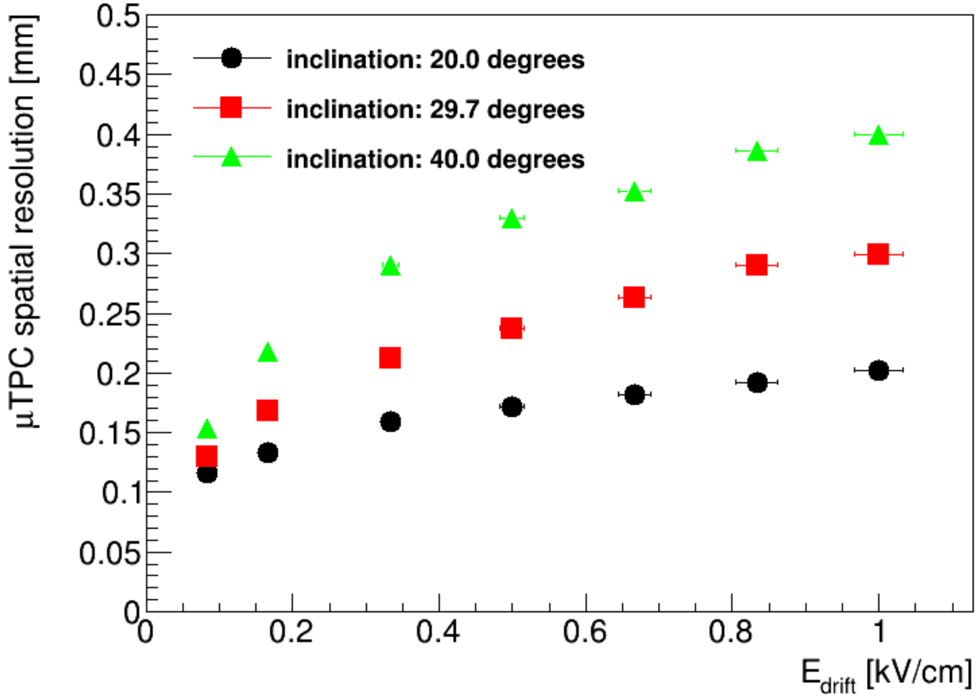
→ spatial resolution **below 150um up to 40 degree incidence** with the µ-TPC method

Spatial Resolution – Inclined Tracks - uTPC Method

variation of **amplification** field



variation of **drift** field

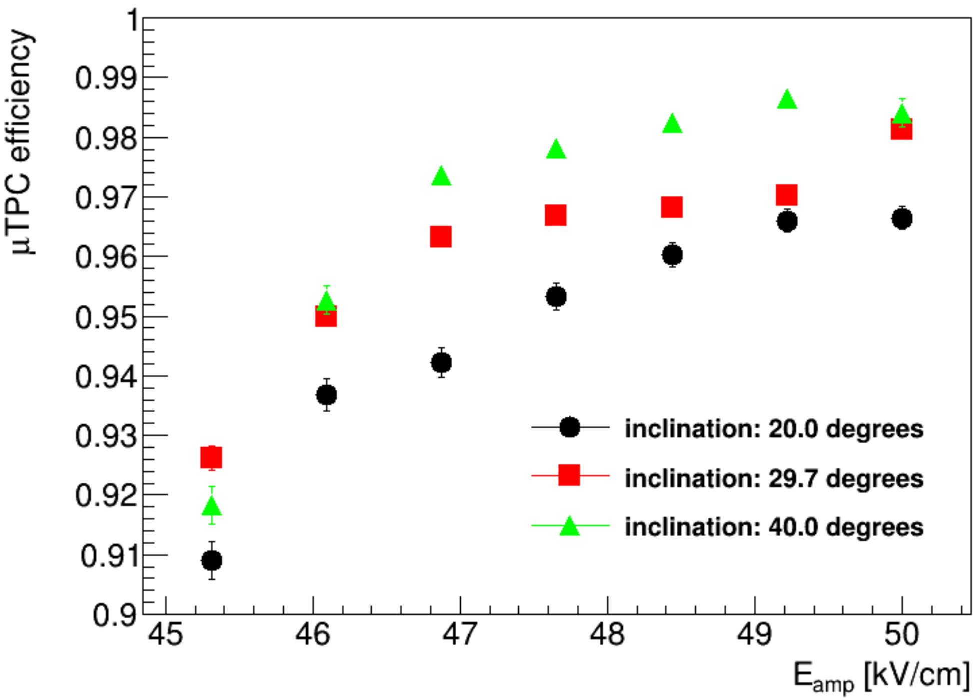


→ spatial resolution depending on **electron drift velocity**

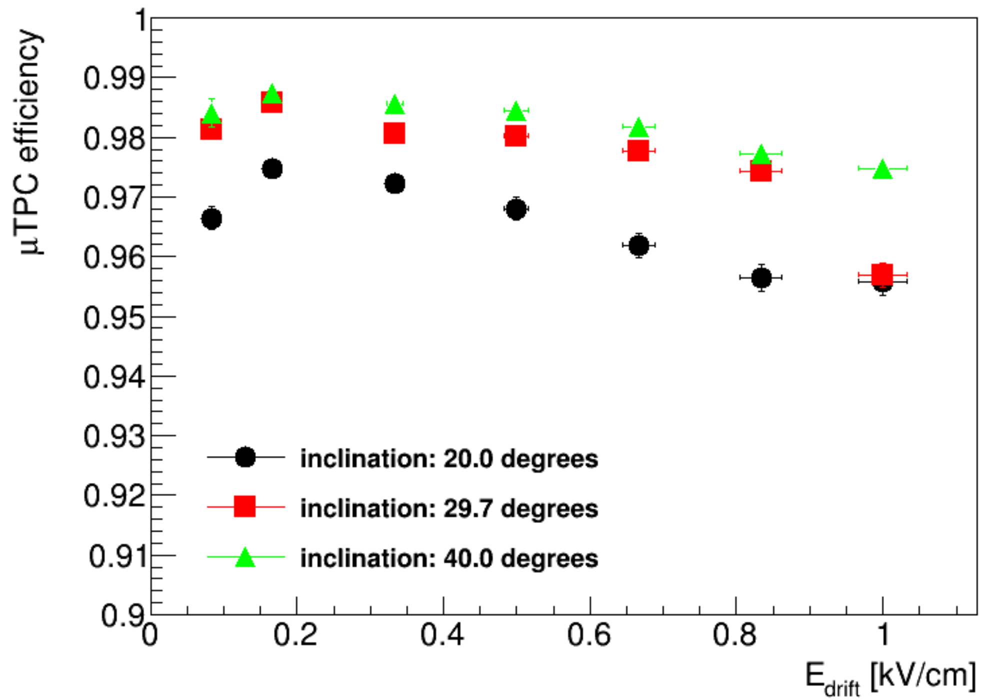
→ below **150um** up to **40 degree** incidence for **small drift fields**

Efficiency– Inclined Tracks - uTPC Method

variation of **amplification** field



variation of **drift** field

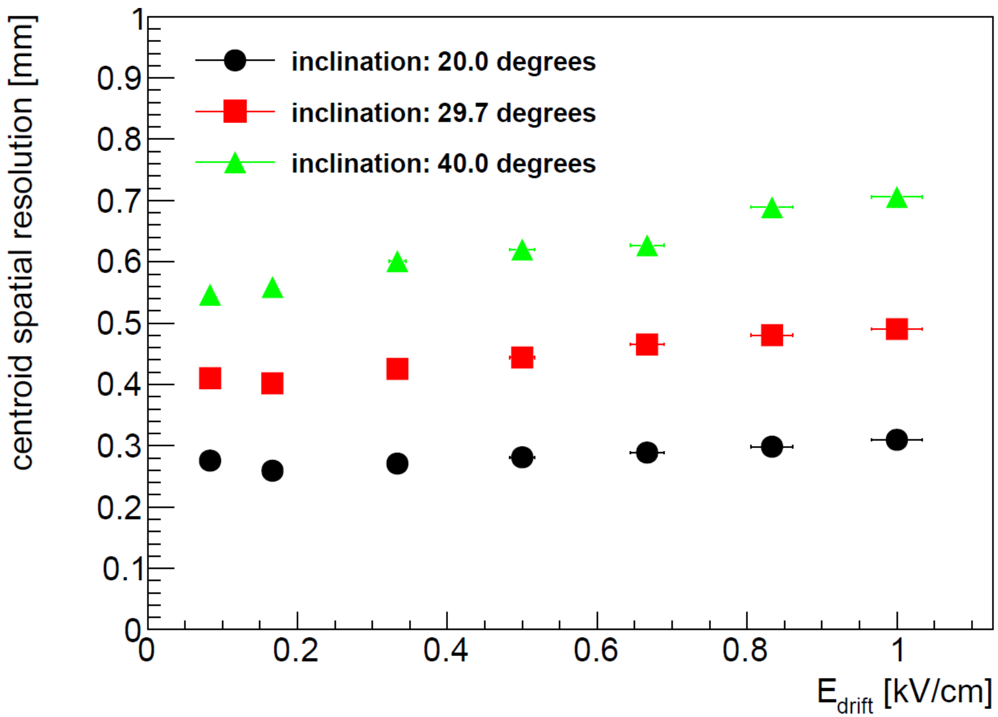


→ Efficiency follows gain and mesh transparency behavior

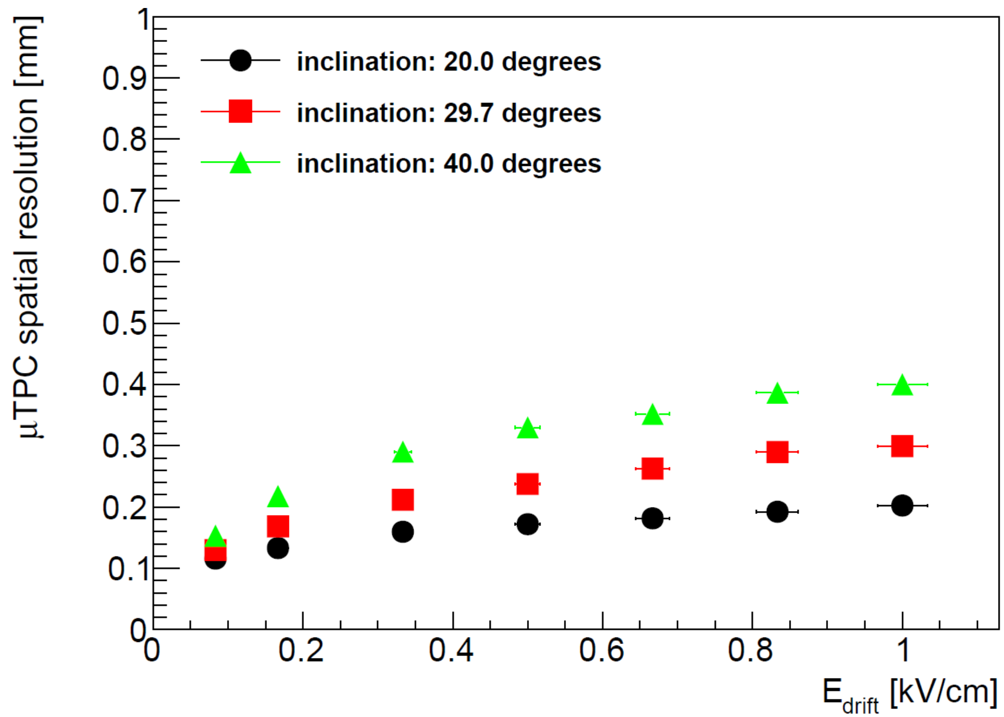
→ Efficiency **above 97%** for dedicated choice of drift and amplification fields

Spatial Resolution – Inclined Tracks – Drift Scan

centroid method



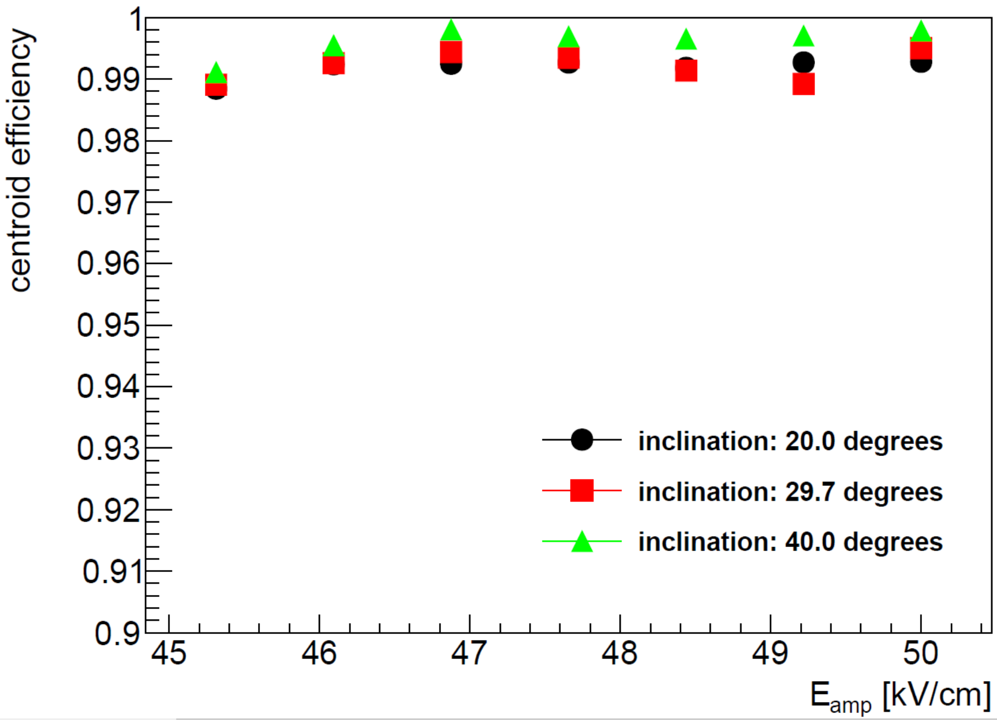
µ-TPC method



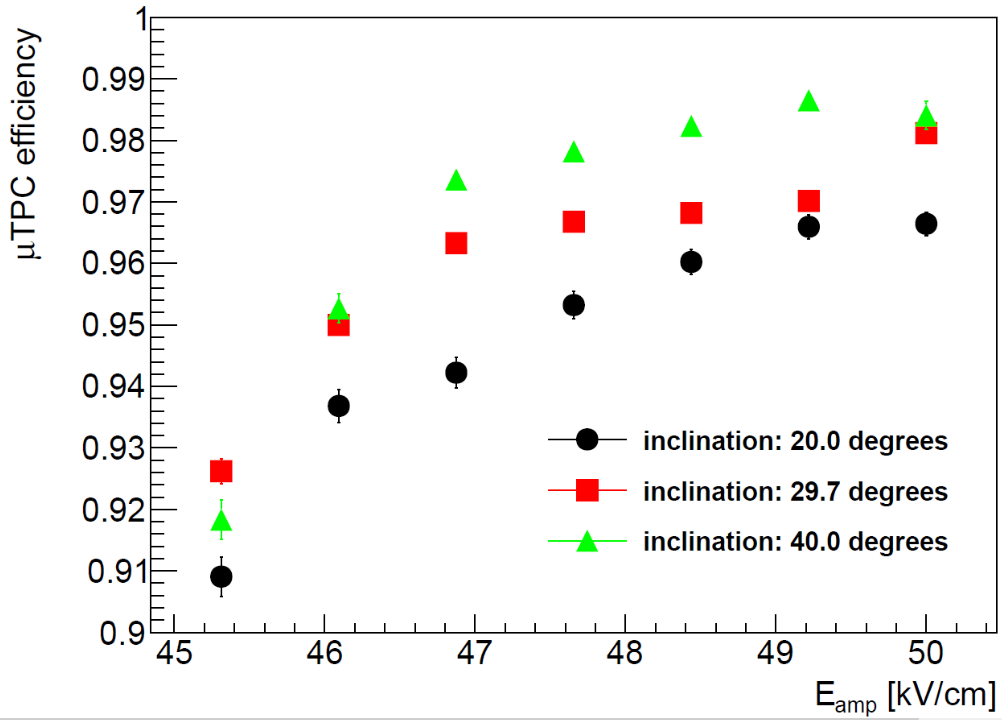
→ µ-TPC spatial resolution depending on electron drift velocity

Efficiency– Inclined Tracks

centroid method



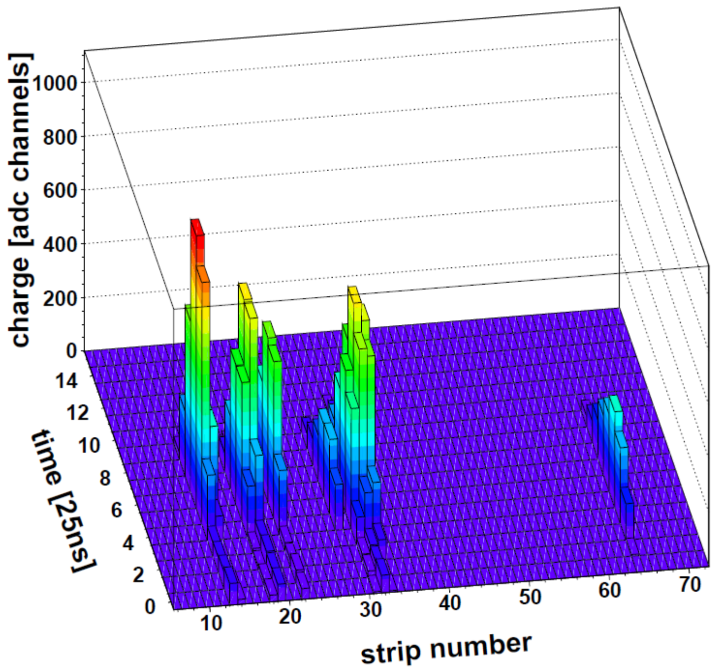
μ-TPC method



→ **Centroid efficiency close to 100%** (independent of pillar size)
→ **μ-TPC efficiency above 96%** reached for all angles (at small drift fields)

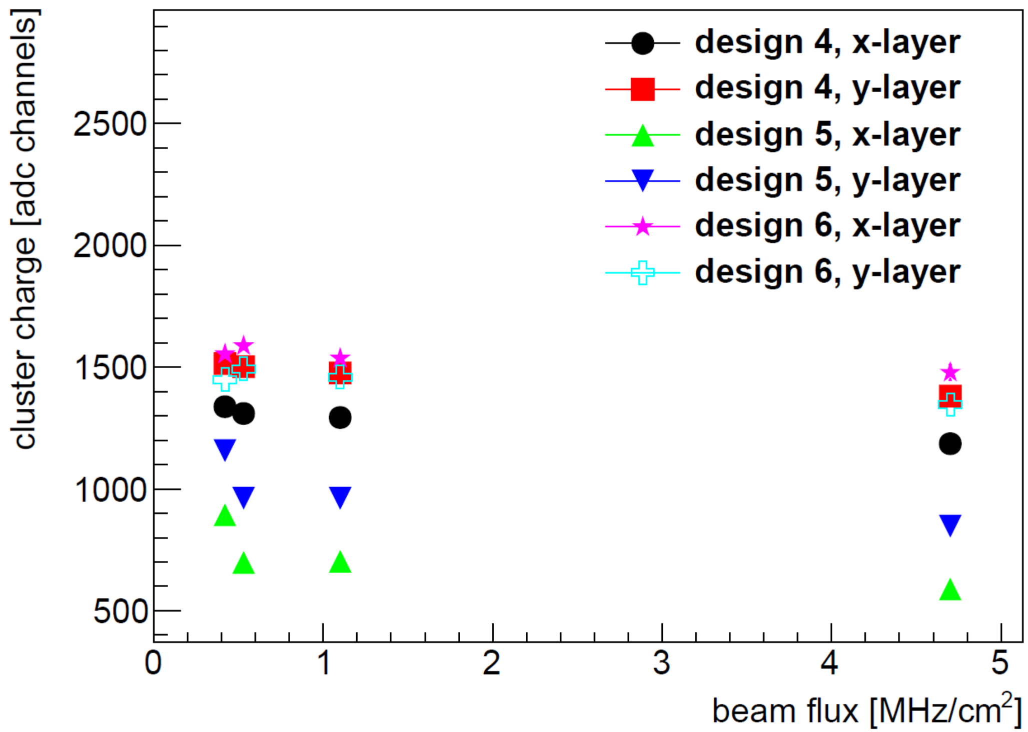
High Rate Measurements - Pions

event display
@ 4.7MHz/cm^2



Sometimes more than **4 particles simultaneously** within **20 strips**

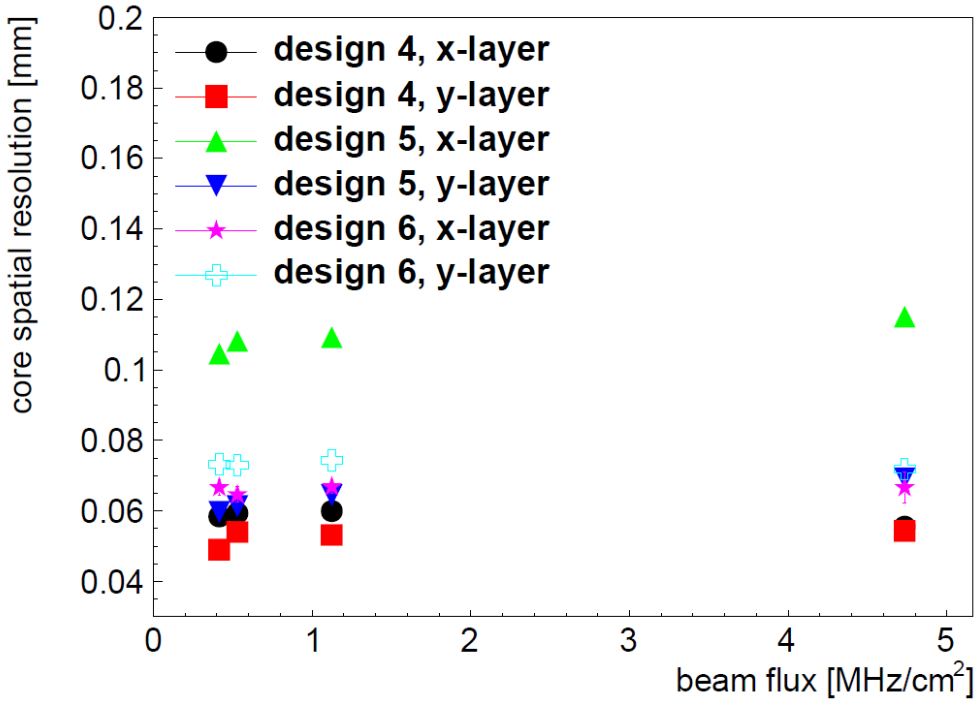
pulse height for different rates



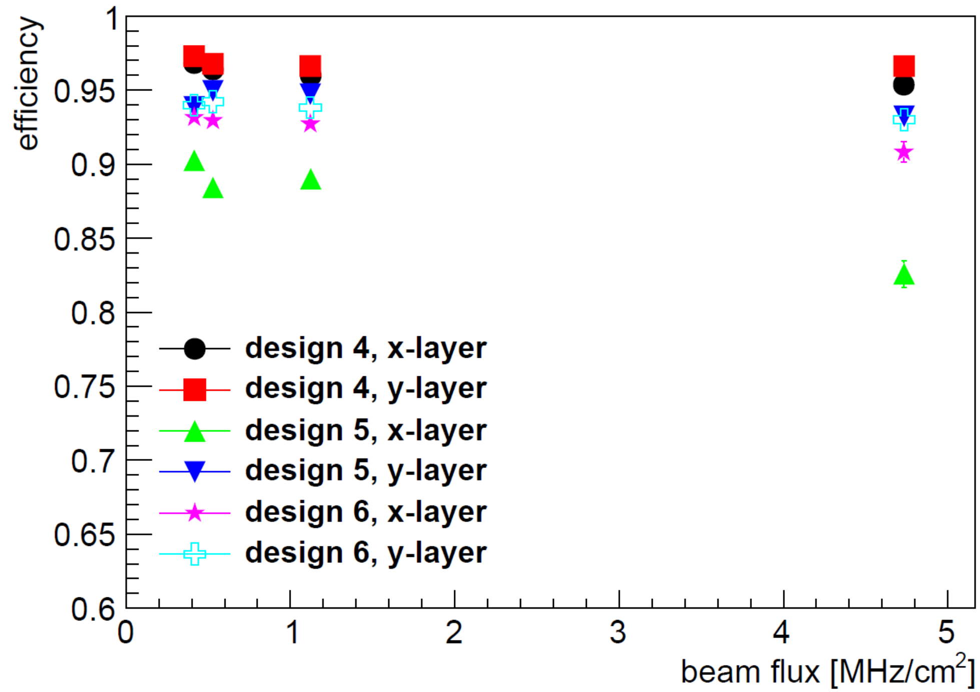
→ Almost constant up to 5MHz/cm^2

High Rate Measurements - Pions

spatial resolution (core)



efficiency



→ ~ constant up to 5MHz/cm^2