

# High-Rate Capable Floating Strip Micromegas Detectors

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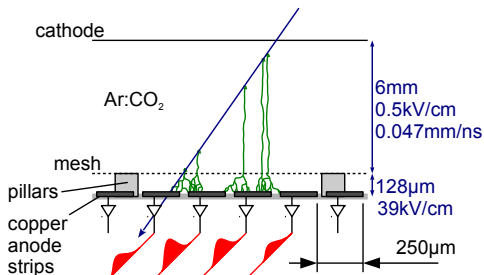
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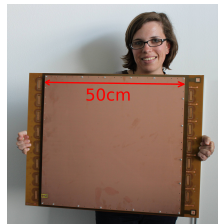
# The Micromegas Detector



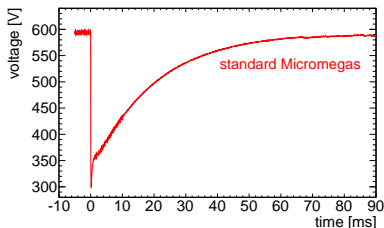
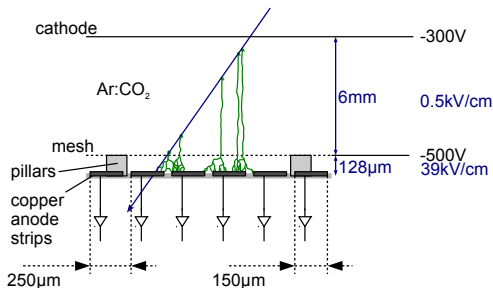
- gas amplification  $10^3$  to  $10^4$
- charge signal on strips  
→ single strip readout  
→ spatial resolution  $\mathcal{O}(50\mu\text{m})$  & timing  $\mathcal{O}(\text{ns})$
- fine segmentation and fast drain of positive ions  
→ high-rate capable

- promising detector technology for e.g. muon spectrometers, medical application, nuclear physics ...
- use in highest particle rates
- stable operation in high-rate background environments
- high efficiency  $\leftrightarrow$  discharges should have negligible influence on performance

→ novel concept: Floating Strip Micromegas for high rate applications



# Floating Strip Micromegas



## challenge: discharges

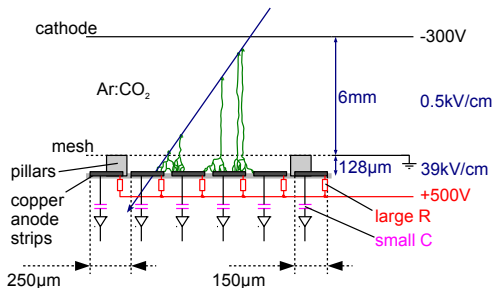
- charge density  $\geq 2 \times 10^6 \text{ e}/0.01 \text{ mm}^2$
- conductive connection  $\rightarrow$  potentials equalize
- non-destructive, but dead time  $\rightarrow$  efficiency drop

## idea: minimize the affected region

- “floating” copper strips:
  - strip can “float” in a discharge
  - individually connected to HV via  $22\text{M}\Omega$
  - capacitively coupled to readout electronics via  $\text{pF}$  HV capacitor
  - only two or three strips need to be recharged

$\rightarrow$  dedicated measurements & detailed simulation

# Floating Strip Micromegas

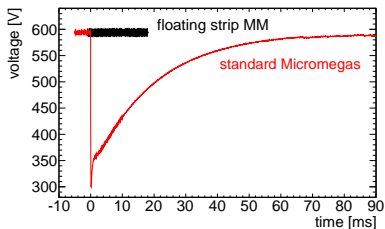


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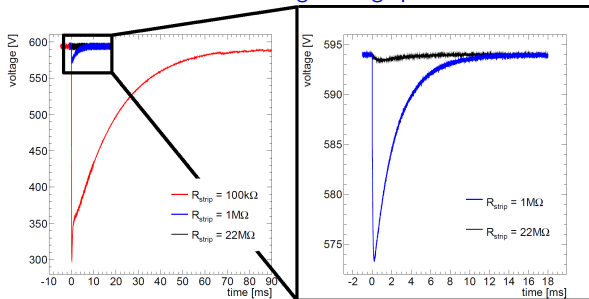
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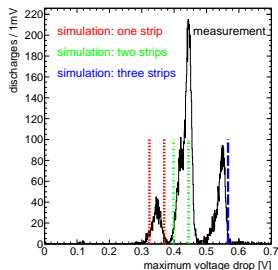
# Discharge Study: Measurement & Simulation

measured average voltage pulse



- 100 k $\Omega$  ( $\approx$ standard MM):  
300 V drop, dead time  $\sim$ 80 ms
- 1 M $\Omega$ : 20 V drop, dead time  $\sim$ 10 ms
- 22 M $\Omega$  (= floating strip Micromegas):  
0.5 V drop  $\rightarrow$  negligible

detailed voltage drop



- 1, 2 or 3 strips involved  
 $\rightarrow$  discharges are localized
- topology:
  - direct, btw mesh and strips
  - delayed, btw mesh and strips
  - delayed, btw adjacent strips

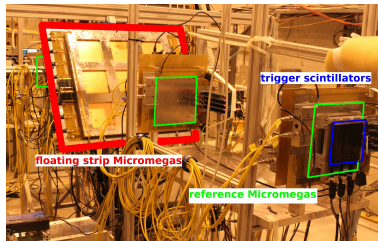
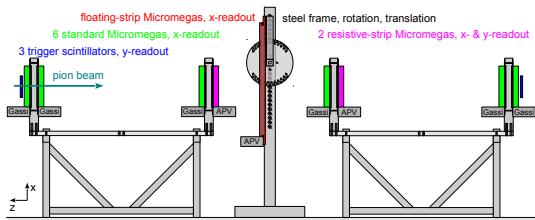
## floating strip principle works

- discharges: negligible effect on common high-voltage
- discharges are localized

## measurements

- tracking of high-energy pions
- muon tracking in high-rate background
- tracking of ions at highest rates

# 50 × 48 cm<sup>2</sup> Micromegas in 120 GeV Pion Beam @ H6 SPS



## floating strip Micromegas

- 1920 strips, 150  $\mu\text{m}$  width, 250  $\mu\text{m}$  pitch
- 8 mm drift gap
- x-y- and angular scans

## tracking system:

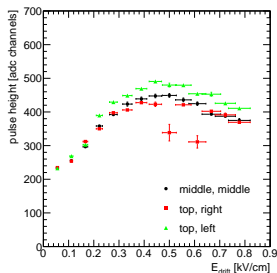
- six non resistive Micromegas
- two resistive Micromegas
- 2 × 3 trigger scintillators

## questions:

- efficiency
- spatial resolution
- homogeneity
- inclined track reconstruction

# Pulse Height, Efficiency & Spatial Resolution

## pulse height vs $E_{\text{drift}}$



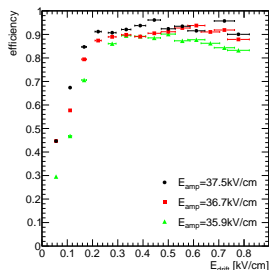
small  $E_{\text{drift}} < 0.4$  kV/cm:

- low charge separation
- long signal duration

large  $E_{\text{drift}} > 1.0$  kV/cm:

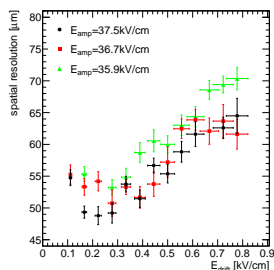
- low electron mesh transparency

## efficiency vs $E_{\text{drift}}$



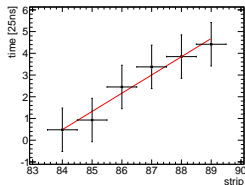
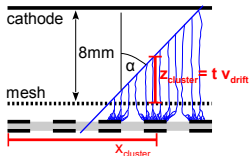
- limited by detectable ionization charge
- limited by mesh-supporting pillars
- only weak dependence on absolute pulse height

## spatial resolution vs $E_{\text{drift}}$



- optimum resolution  $(49 \pm 2) \mu\text{m}$   
 $\leftrightarrow$  minimum transverse electron diffusion

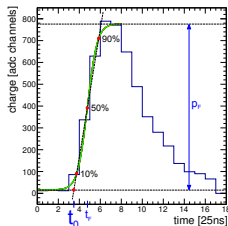
# Track Inclination Reconstruction



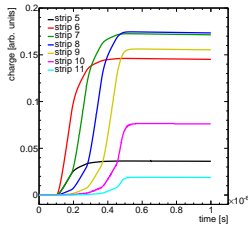
method:

- arrival time  $\leftrightarrow$  drift distance
- measure arrival time of charge cluster on strip  
→ signal timing  $t_0$
- fit time-strip-data points with line  
→ track inclination

signal fit



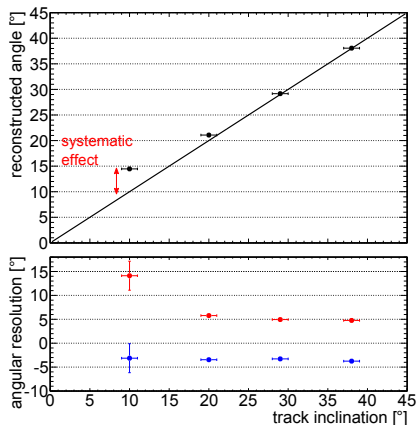
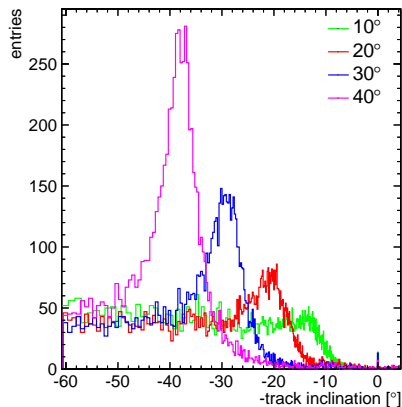
simulated signals



systematics:

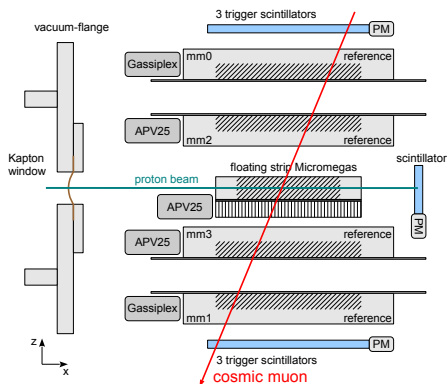
- capacitive coupling of signals onto neighboring strips
- simulation with parameter-free LTSpice detector model

# Track Inclination Measurement



- track inclination reconstruction possible for angles  $20^\circ \leq \alpha \leq 40^\circ$  with angular resolution  $\left(\begin{smallmatrix} +6 \\ -4 \end{smallmatrix}\right)^\circ$
- distribution with tails towards larger angles due to mis-identified signals
- systematic behavior understood  $\rightarrow$  calibration possible

# Cosmic Muon Tracking under High-Rate Background Irradiation



## floating strip Micromegas

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

## reference tracking system

- two non resistive Micromegas
- two resistive Micromegas
- $2 \times 3$  trigger scintillators

## questions:

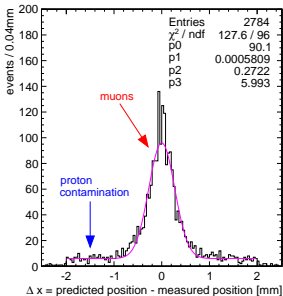
- muon identification
- efficiency
- spatial resolution
- stability

## proton background irradiation

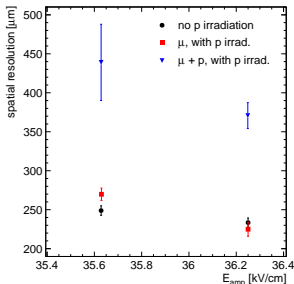
- 20 MeV protons, 550 kHz
- lateral beam spot:  $6 \times 0.5 \text{ cm}^2$
- traverse detector  $\rightarrow$  signal on all strips

## Cosmic Muon Tracking in High-Rate Background

## residual distribution



## spatial resolution



two event classes:

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

## efficiency

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

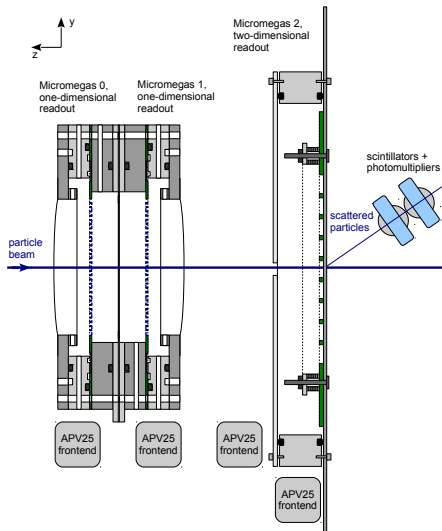
## stability

- discharge rate  
0.17 Hz
- inefficiency:  
 $4.1 \times 10^{-6}$

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

- only influence for coincident muon and proton!
- no indirect effects

# Ion Tracking with Thin Micromegas at Highest Rates



## beams

- $^{12}\text{C}$  @ 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

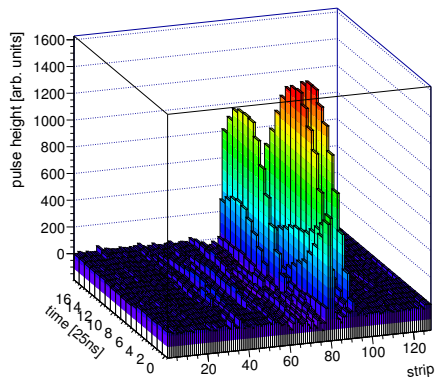
- $6.4 \times 6.4 \text{ cm}^2$  doublet
- low material budget (FR4 + Cu  $\leq 200 \mu\text{m}$ )

## tracking system

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

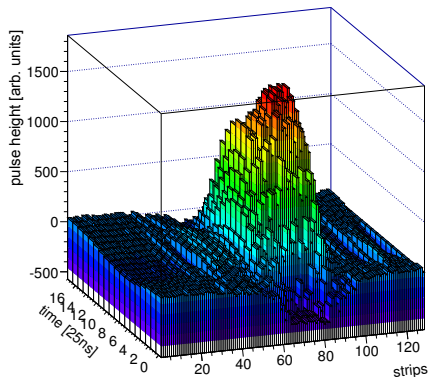
## Signals at Lowest and Highest Rate

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



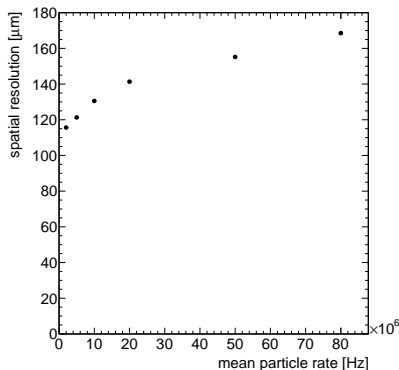
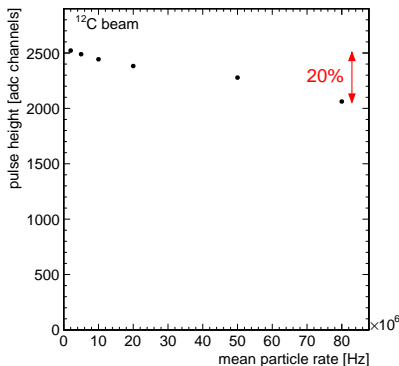
3 particles clearly distinguishable  
 → single particle tracking possible

$\text{p}$ ,  $E = 221 \text{ MeV}$ , 2 GHz



integration over  $\sim 800$  coincident particles  
 → envelope of beam profile

# Pulse Height & Spatial Resolution for 88 MeV/u Carbon Ions



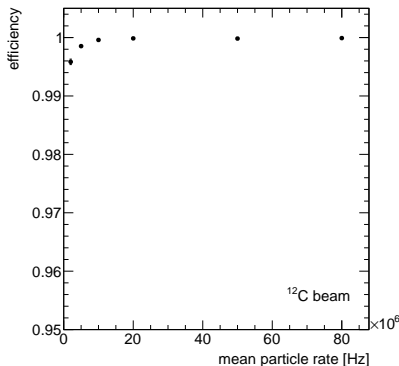
- up to 80 MHz single particle tracks visible but not all of them separable
- only 20% reduction @ 80 MHz

- highest rates: slight distortion of hit position by hits on adjacent strips
- limited by multiple scattering
- sufficient for medical application

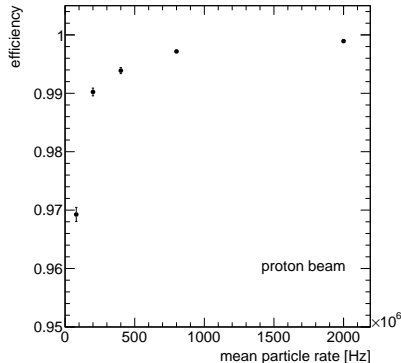
→ tracking of carbon ions at highest rates possible

# Detection Efficiency vs Particle Rate

$^{12}\text{C}$ , 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

## Summary

- novel floating strip Micromegas
- discharges:
  - behavior and topology understood
  - negligible influence on efficiency
- high-energy pion tracking with  $48 \times 50 \text{ cm}^2$  floating strip Micromegas
  - efficiency  $> 0.95$
  - spatial resolution  $< 50 \mu\text{m}$
  - homogeneous
- cosmic muon tracking in intense proton background possible
- medium-energy carbon ion and proton tracking at highest rates
  - separation of all particles at rates  $\leq 10 \text{ MHz}$
  - only 20% pulse height reduction at 80 MHz
  - spatial resolution better  $180 \mu\text{m}$  at all rates  $\leq 80 \text{ MHz}$
  - stable operation up to highest rates of 2 GHz

floating strip Micromegas: versatile, discharge tolerant, high-rate capable tracking detectors with good spatial resolution

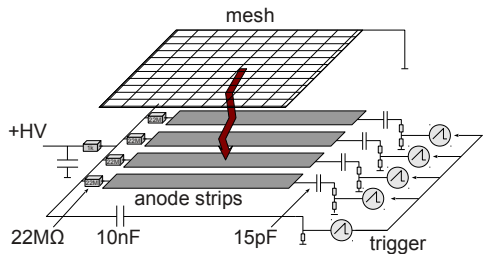
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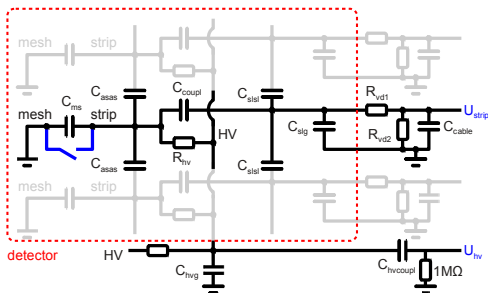
**Thank you!**

# backup – Discharge Study: Measurements & Simulation



## measurement

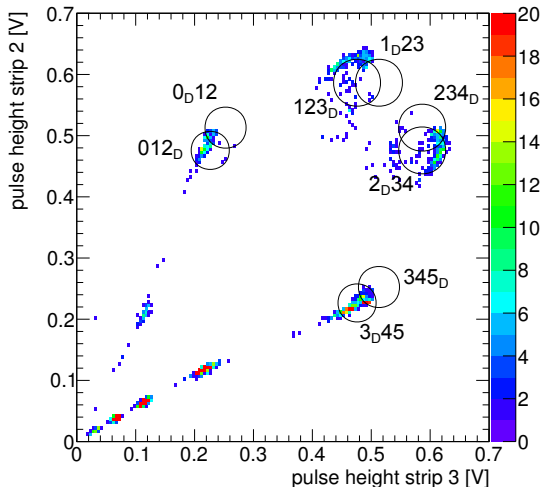
- induce discharges with alpha source @  $\sim 1$  Hz
- directly measure the global high voltage drop  
→ affects all strips
- directly measure the voltage on seven adjacent strips  
→ discharge topology



## simulation

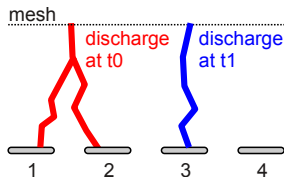
- LTspice detector simulation
- consider involved capacitances and resistances
- simulate discharges (blue switch)

## backup – Discharge Topology - Three Strips

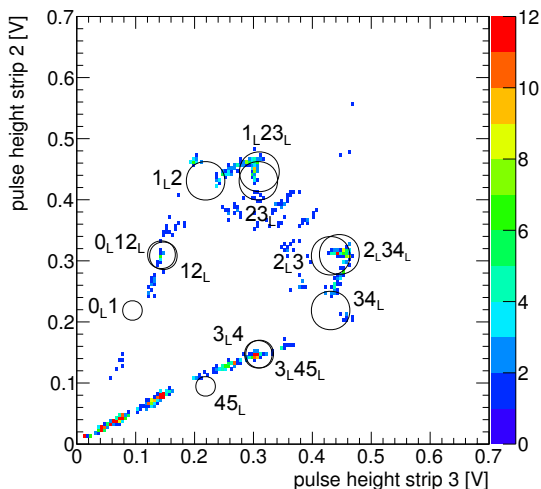


one process:

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

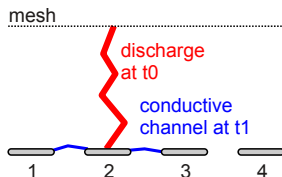


## backup – Discharge Topology - One Strip

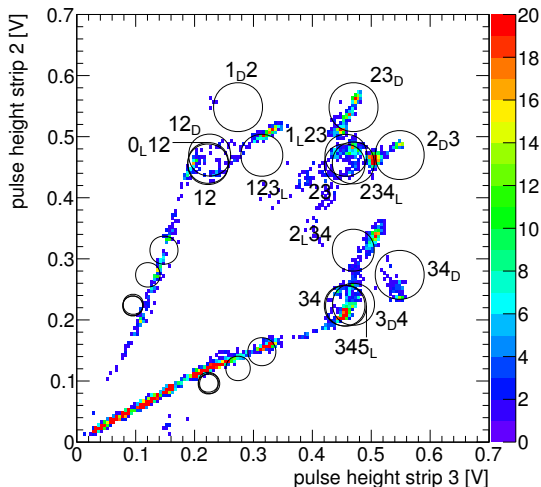


two processes:

- 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

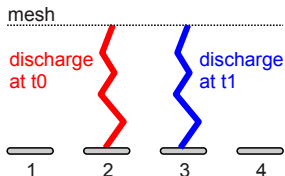


## backup – Discharge Topology - Two Strips

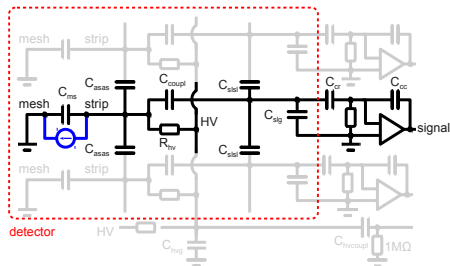


three processes:

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



# backup – Track Inclination Reconstruction Systematics: LTSpice-Simulation



- use LTSpice to simulate 16 neighboring strips, read out via charge-sens.-preamps
- consider mesh-anode strip, anode strip-ground, anode strip-anode strip, coupling, stripline-stripline and stripline-ground capacitance, no free parameter
- inject time dependent current on anode strips → study signals on all other strips

