Study of Charge-Up Processes in Gas Electron Multipliers

RD51 Meeting

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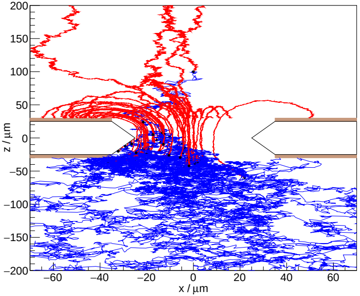
05 December 2018

What is Charge-Up?

- Charged particles end up on polyimide
- High resistance of polyimide
- Charge remains there
- Configuration of electrical fields changes

⇒ Charge-Up

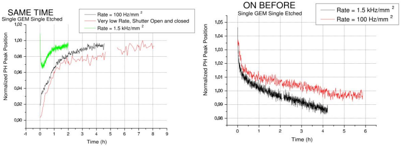


Simulation of one avalanche

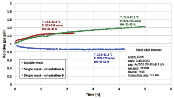
Lowest common denominator:
Effective Gain changes

- Increase or decrease?
- Time constant?
- Percentual change?

$\Rightarrow$ Quantitative study



[1]



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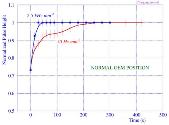


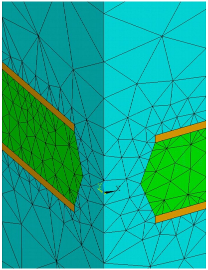
[3]

[1] G. Croci, Study of relevant parameters of GEM-based detectors, Master Thesis (2007)

[2] J.A. Merlin, Study of long-term sustained operation of gaseous detectors for the high rate environment in CMS, PhD Thesis (2016)

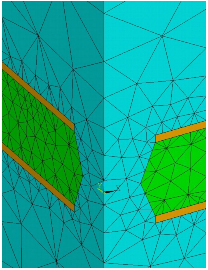
[3] C. Altunbas et al., Construction, test and commissioning of the triple-GEM tracking detector for COMPASS, Nucl. Instr. and Methods in Phys. Research (2002)

Simulation Workflow



ANSYS

Calculate configuration of electrical field



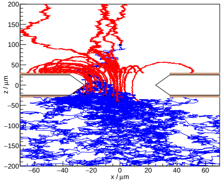
ANSYS

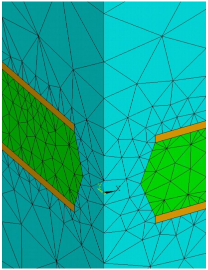
Calculate configuration of electrical field

↓

Garfield++

Simulate the movement of electrons and ions





ANSYS

Calculate configuration of electrical field

↓

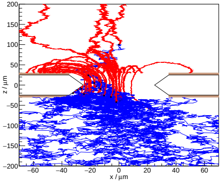
Garfield++

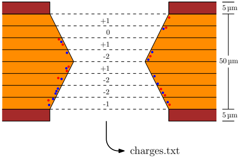
Simulate the movement of electrons and ions

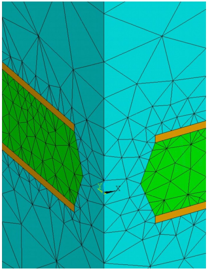
→

Analysis programs

Analyse where the trajectories of charges end







Framework created by Steffen Urban

ANSYS
Calculate configuration of electrical field

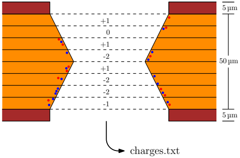
↓

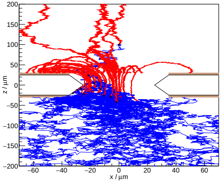
Garfield++
Simulate the movement of electrons and ions

→

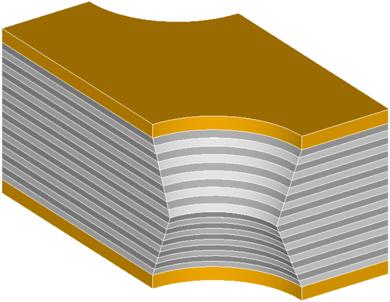
Analysis programs
Analyse where the trajectories of charges end

→ (back to ANSYS)





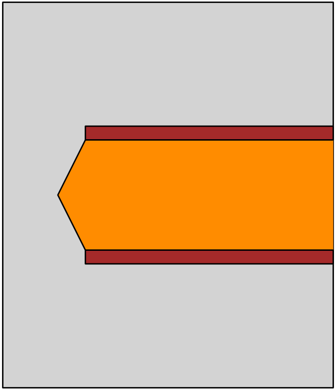
Repeat this a few hundred times



- Unit cell
  - With surface charge
- Calculate field maps

ANSYS

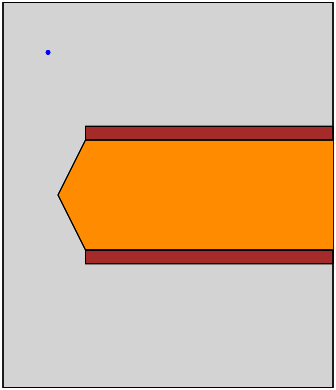
Illustration:



- Unit cell
  - With surface charge
- Calculate field maps
- Load field maps and define geometry

ANSYS

Illustration:



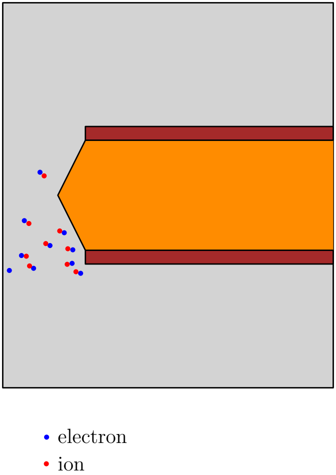
- electron
- ion

- Unit cell
  - With surface charge
- Calculate field maps

} ANSYS

- Load field maps and define geometry
- Place electron (randomly)

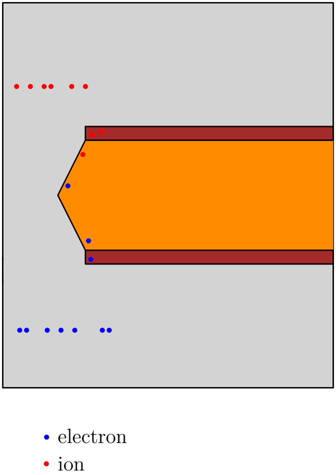
Illustration:



- Unit cell
  - With surface charge
- Calculate field maps
- Load field maps and define geometry
- Place electron (randomly)
- Create avalanche

ANSYS

Illustration:



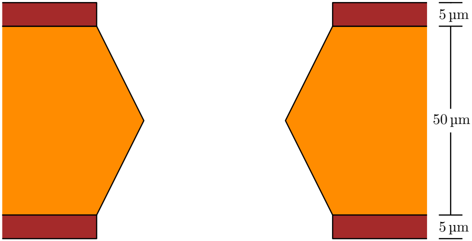
- Unit cell
  - With surface charge
- Calculate field maps

ANSYS

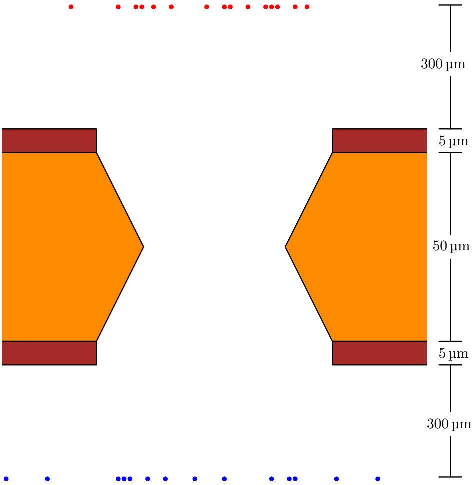
- Load field maps and define geometry
- Place electron (randomly)
- Create avalanche
- Let all particles drift

Garfield++

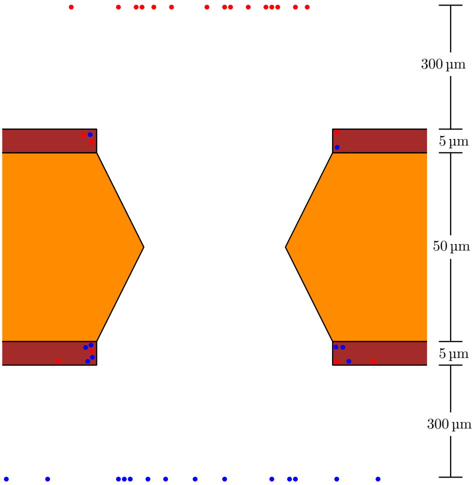
- Where do the charges end up?



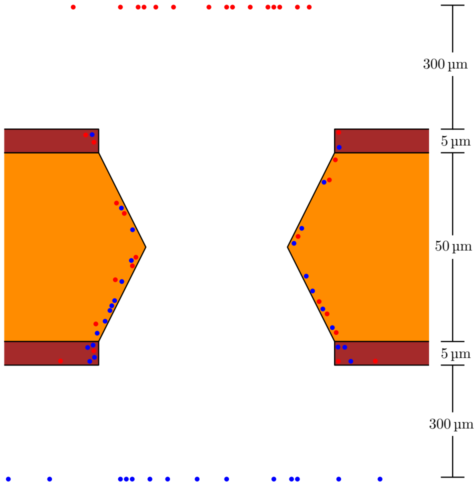
- Where do the charges end up?
  - End of simulated volume



- Where do the charges end up?
  - End of simulated volume
  - Copper

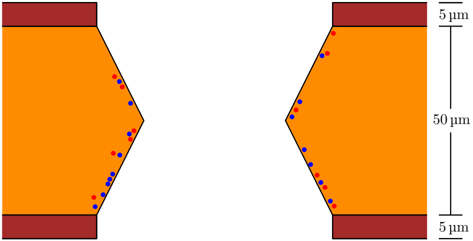


- Where do the charges end up?
  - End of simulated volume
  - Copper
  - Polyimide

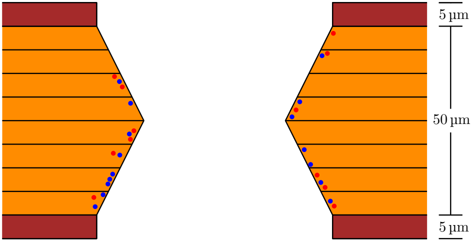


- Where do the charges end up?
  - End of simulated volume
  - Copper
  - Polyimide

- Charges on polyimide interesting



- Where do the charges end up?
  - End of simulated volume
  - Copper
  - Polyimide
- Charges on polyimide interesting
- Divide polyimide in slices

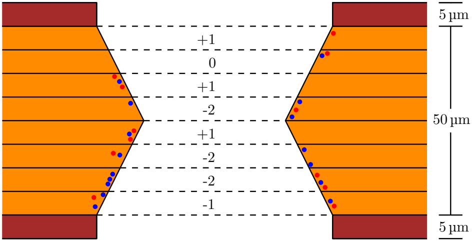


- Where do the charges end up?
  - End of simulated volume
  - Copper
  - Polyimide

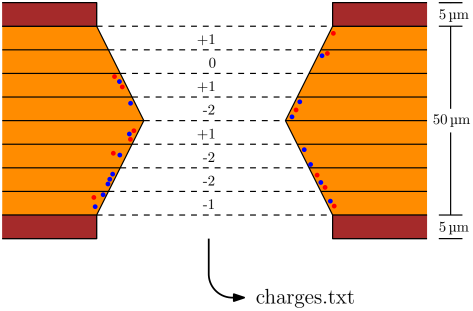
- Charges on polyimide interesting

- Divide polyimide in slices

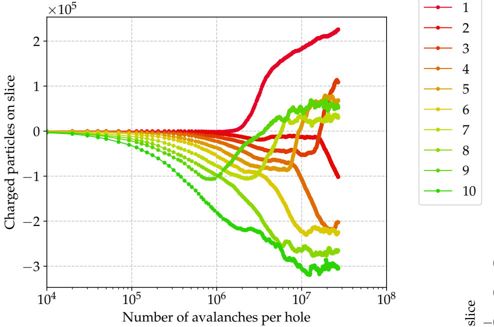
- Count net charge on each slice

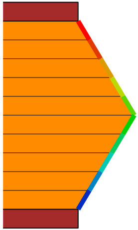


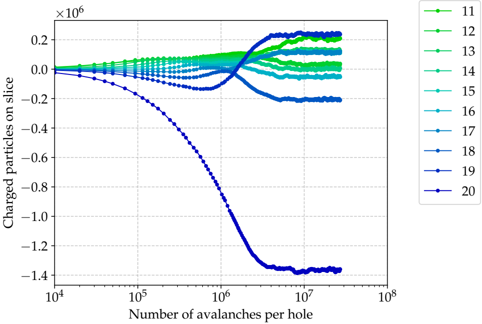
- Where do the charges end up?
  - End of simulated volume
  - Copper
  - Polyimide
- Charges on polyimide interesting
- Divide polyimide in slices
- Count net charge on each slice
- Apply surface charge in ANSYS



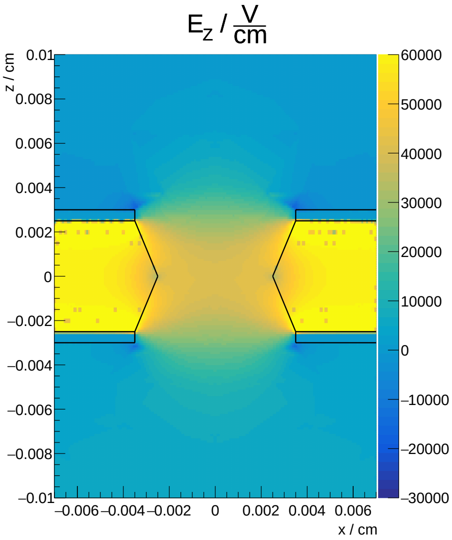
Results with 20 Slices



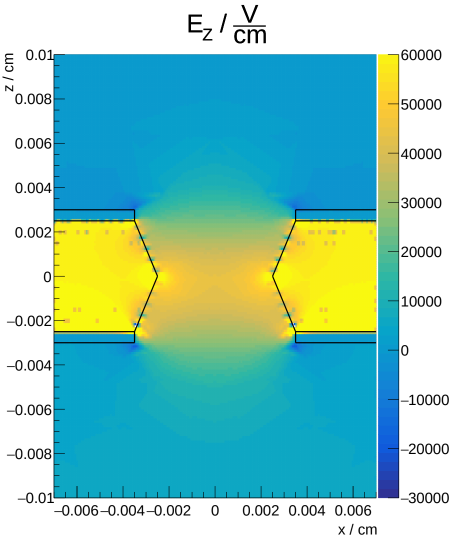




- Dipole-like configuration (e.g. slice 19 & 20)
- Due to discretization of problem

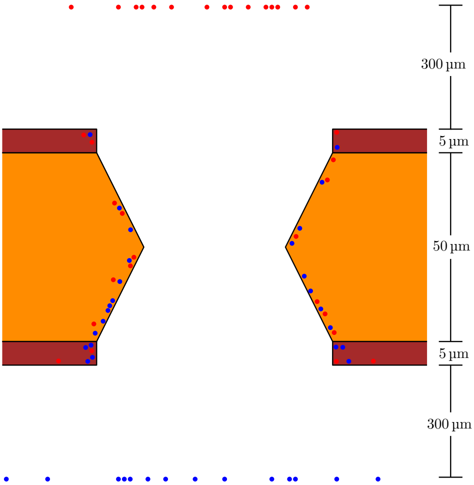


Initial configuration

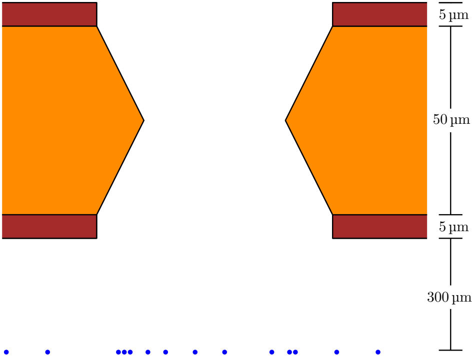


After charge-up

- Where do the charges end up?
  - End of simulated volume
  - Copper
  - Polyimide



- Where do the charges end up?
  - End of simulated volume
  - Copper
  - Polyimide
- Electrons at the end of simulated volume

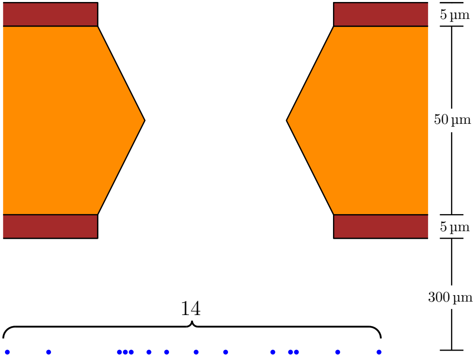


Development of Effective Gain

- Where do the charges end up?
  - End of simulated volume
  - Copper
  - Polyimide

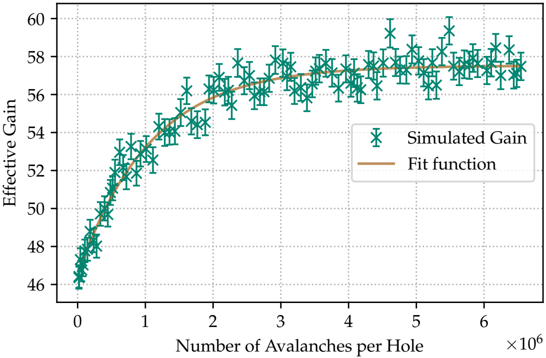
- Electrons at the end of simulated volume

- Count number of electrons
  - Effective Gain

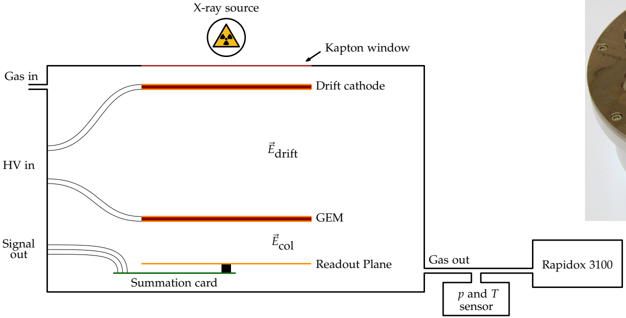


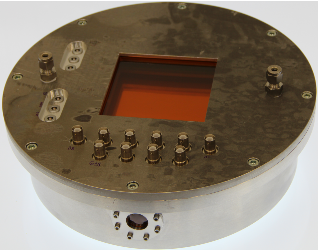
Simulation of a GEM with $U_{\mathrm{GEM}} = 350\,\mathrm{V}$

- Eff. gain increases by $\approx 25\,\%$
- „Time constant“ $\approx 1 \times 10^6$ aval./hole
- Does that fit to measurements?



Master's Thesis P. Hauer



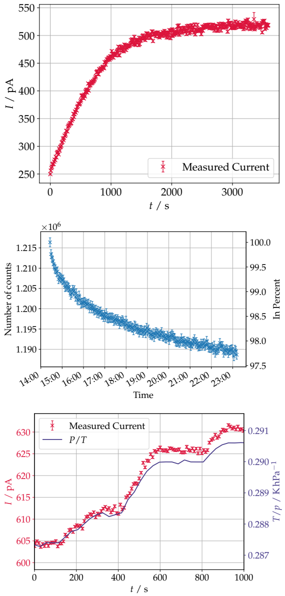


- Adjustable and measurable conditions
  - Behaviour of X-ray source, voltage settings etc.
  - Humidity, pressure and temperature etc.
- $G_{\text{eff}} = \frac{I_{\text{Readout}}}{I_{\text{Primary}}}$

Many effects that change the „effective gain“

- HV connection
- Unstable X-Ray source
- Pressure and temperature changed

$\Rightarrow$ Be careful!



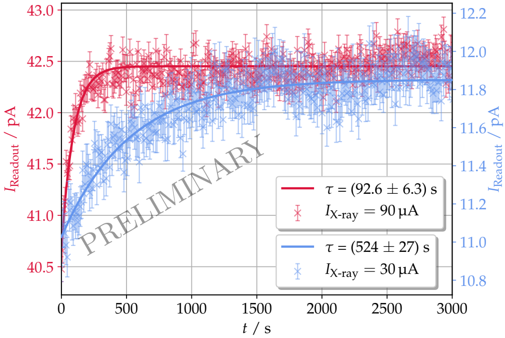
What is expected and how can we investigate this?

- Local effect
- Gain should be constant after spot is „charged-up“
- Time constant depends on I_{Primary}

What is expected and how can we investigate this?

- Local effect
  - Change position of irradiation
- Gain should be constant after spot is „charged-up“
  - Measure after spot was irradiated before
- Time constant depends on I_{Primary}
  - Change $I_{\text{X-ray}}$

- Different I_{Primary}
  - Leads to different time constants
- In each measurement:
  - $I_{\text{Primary}} = \text{const.}$
  - $I_{\text{Readout}} \propto G_{\text{eff}}$
- Increase $\approx 5\,\%$ to $10\,\%$
- Time constant 0.85×10^6 to 1.35×10^6 aval./hole



$U_{\text{GEM}} = 350\,\text{V}$

- Simulations predict:
  - Rate-dependent effect
  - Gain increase ≈ 25 %
  - „Time constant“ ≈ 1×10^6 avalanches/hole

- Measurements show:
  - Rate-dependent effect
  - Gain increase ≈ 5 % to 10 %
  - „Time constant“ ≈ 0.85×10^6 to 1.35×10^6 aval./hole

- What's next?
  - Different voltage settings
  - Single conical GEMs
  - Influence of humidity

Thank you for your attention.

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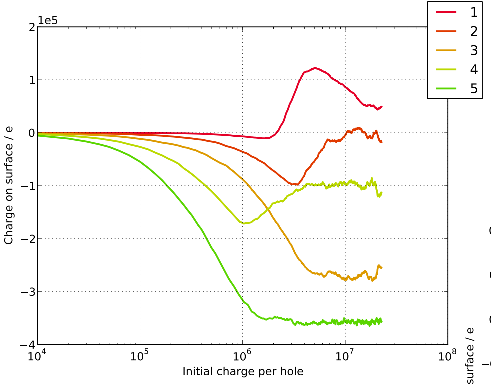
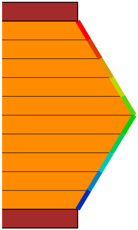
Steffen Urban
Karl Flöthner
Markus Ball
Bernhard Ketzer

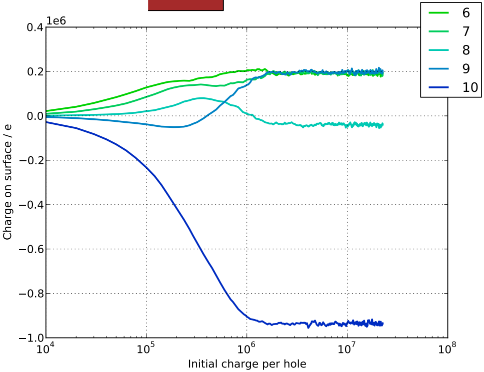
HISKP – Universität Bonn

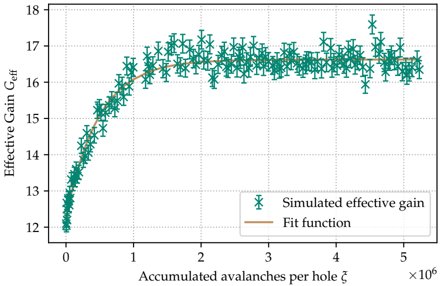
Backup

Results with 10 Slices

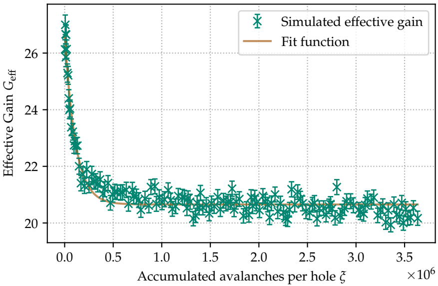








Effective Gain G_{eff}
Accumulated avalanches per hole ξ
$\times 10^6$
Simulated effective gain
Fit function



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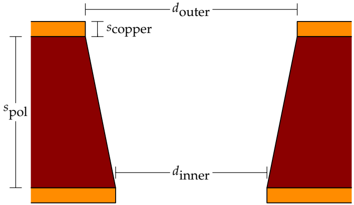
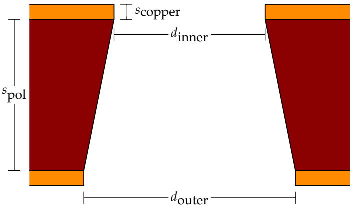
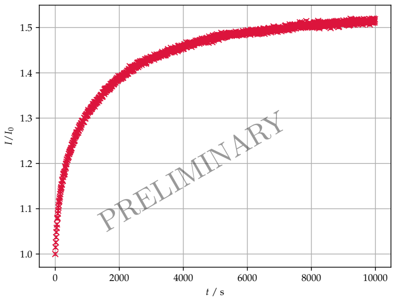


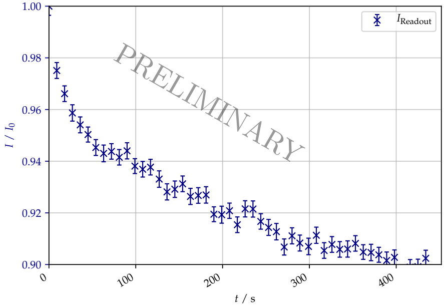
d_{outer}
s_{copper}
s_{pol}
d_{inner}

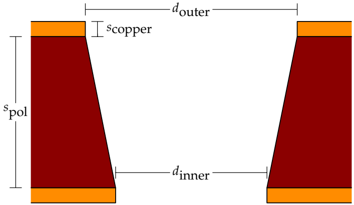


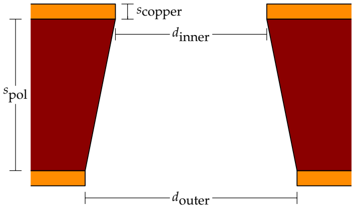
s_{copper}
d_{inner}
s_{pol}
d_{outer}

Measurement Results for Single Conical GEMs

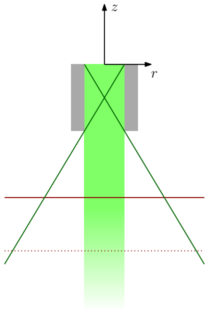


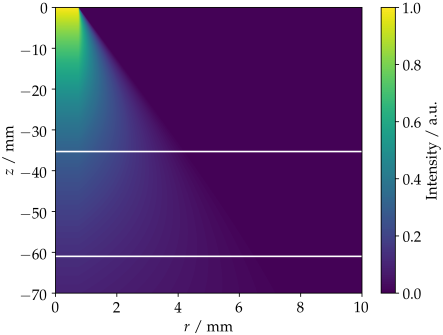


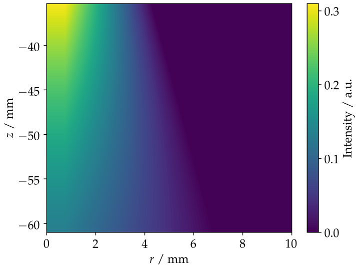


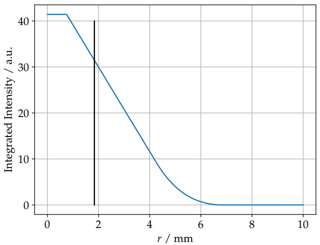


Profile of the Mini-X

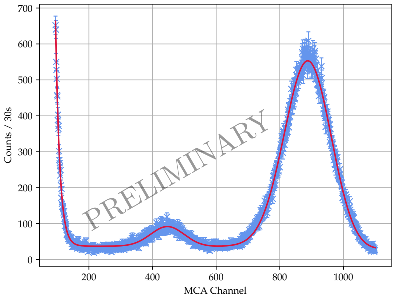


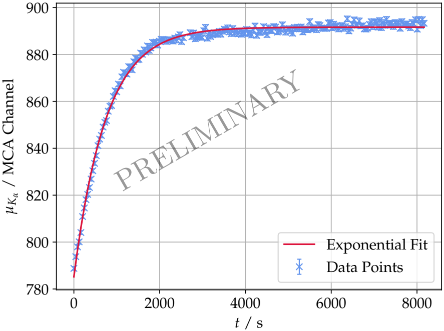


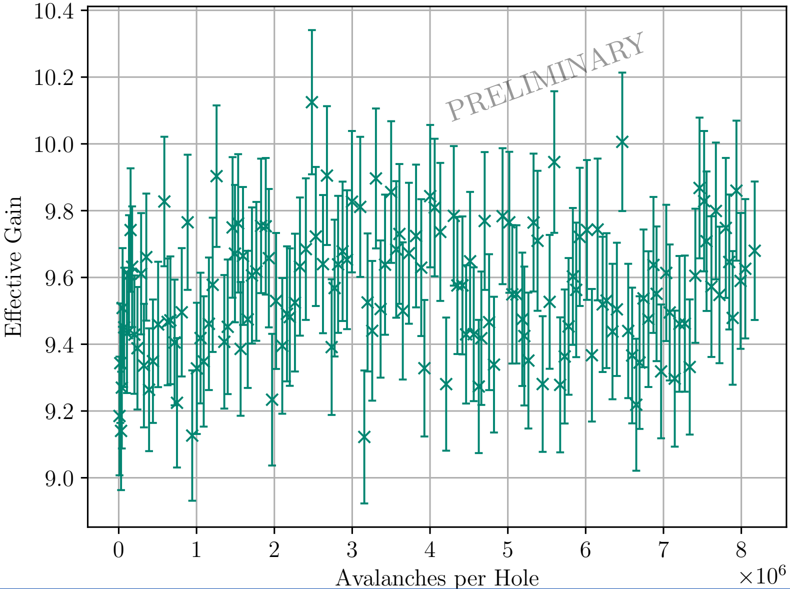




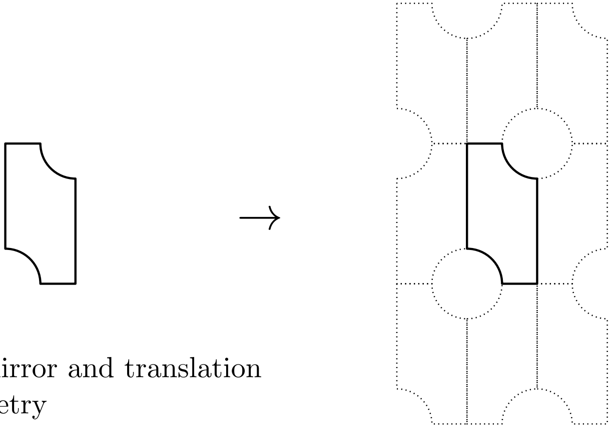
Measuring the Spectrum of an FE55 source







PRELIMINARY
Effective Gain
Avalanches per Hole
$\times10^6$
10.4
10.2
10.0
9.8
9.6
9.4
9.2
9.0
0
1
2
3
4
5
6
7
8



- Use mirror and translation symmetry