Studies of a GEM based readout for the ILD TPC

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Introduction

- The International Linear Collider (ILC) and the International Large Detector (ILD)
- A Time Projection Chamber as central tracking device for the ILD
- Challenges for the ILD TPC

Experiment

Simulation

ILC and ILD

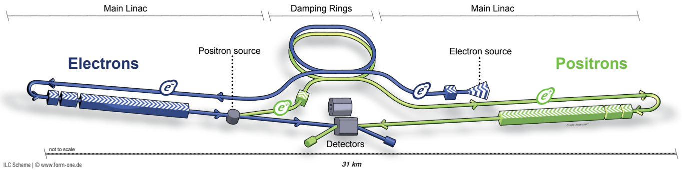


Fig.: ILC Design [www.linearcollider.org/]

- e^+e^- linear collider
  - Collision energy: 500 GeV
  - Length: 31 km @ 31,5 MV/m
- Precision measurements with the ILD
  - Time Projection Chamber
  - → Drift length: 2,25 m
  - → $\delta(1/p_t)^{\text{TPC}} \sim 9 \times 10^{-5}\,/\text{GeV}/c$

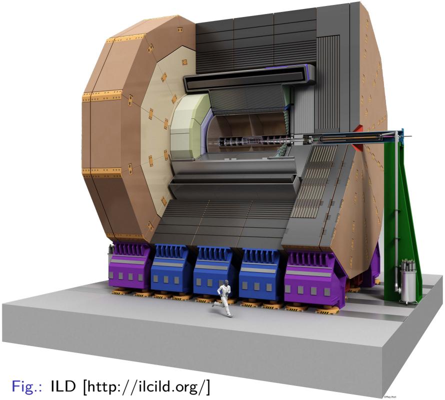


Fig.: ILD [http://ilcild.org/]

Time Projection Chamber

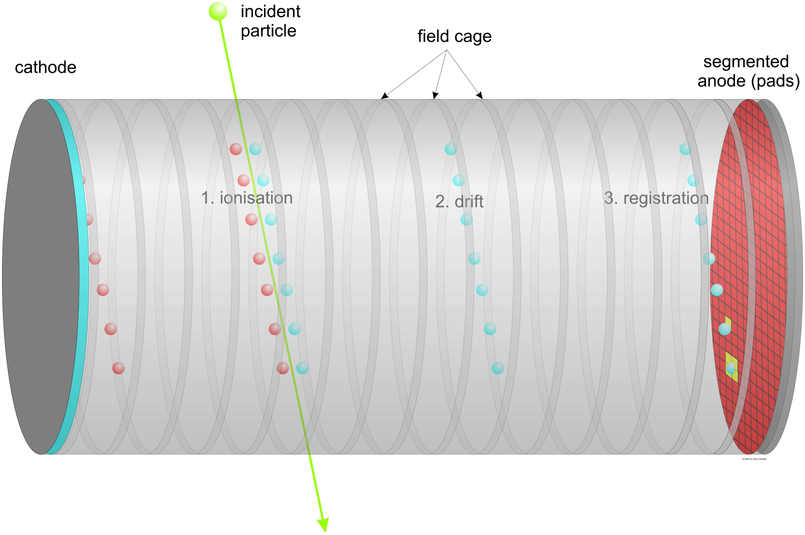
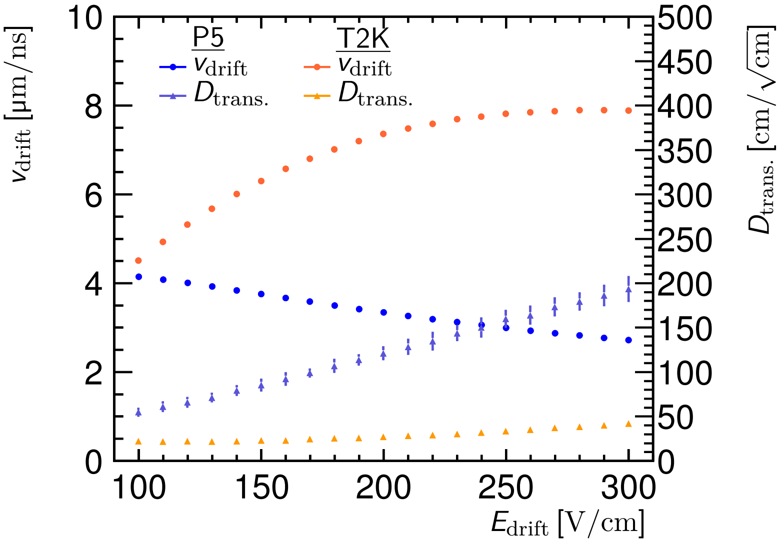


Fig.: Sketch of the working principle of a TPC (by Oliver Schäfer)

Gas properties ($B = 3.5\,\mathrm{T}$)



Details on the ILD TPC

	Ion	Electron
μ	$\approx 2\,\mathrm{cm^2/Vs}$	$\approx 1.5 \times 10^4\,\mathrm{cm^2/Vs}$
$\overrightarrow{v_D}$	$\approx 5 \times 10^{-4}\,\mathrm{cm/\mu s}$	$\approx 3.5\,\mathrm{cm/\mu s}$

} 95 % Ar – 5 % CH_4, B=3.5 T, E=250 V/cm

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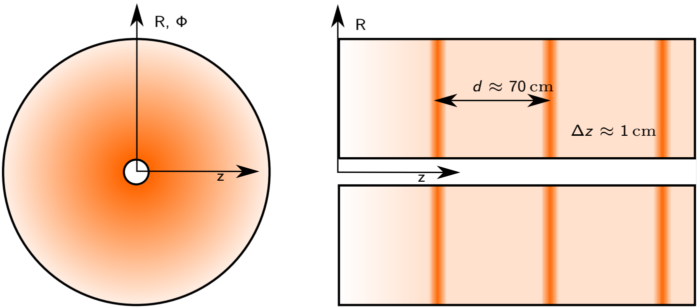


Fig.: Ion discs in the ILD TPC.

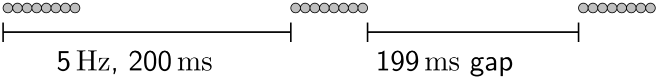
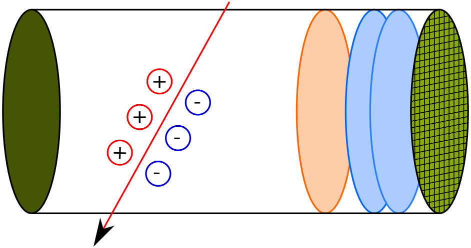


Fig.: ILC bunch spacing.

How to suppress ions?

1. Clean ions between 2 trains
   - ⇒ Requires a high ion velocity ($\vec{v}_{\mathrm{D}}^{\,\mathrm{ion}} > 12\,\mathrm{m/s}$)
     - Since a high drift field is not wanted $\mu^{\mathrm{ion}} > 4\,\mathrm{cm}^2/\mathrm{Vs}$
     - To achieve this one could use a different gas mixture
2. Gate ions at the amplification stage
   - 2.1. Gate after each bunch train
     - Wire gate
     - Possibly leads to field distortions
   - 2.2. Introduce gate GEM which suppresses ion back drift constantly

⇒ Ions produced in the TPC can not be reduced



- Cathode
- Ionizing particle
- Gating GEM
- Amplifying GEMs
- Anode

Studies

Experiment:

- Triple GEM setup with three standard CERN GEMs
- Measurement of the currents on all electrodes
- Replaced GEM I with one that has larger holes (100 μm instead of 70 μm)

⇒ Measurements were done with T2K gas – 95 % Ar, 3 % CF_4, 2 % C_4H_{10}

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Simulation:

- Triple GEM setup with different voltages on GEM I
- Considered a GEM with 70 μm and 100 μm holes as GEM I

⇒ Simulations were done with P5 gas – 95 % Ar, 5 % CH_4

Setting used for measurements

Variation of basic settings:

- Considered different amplifications

⇒ $U_{\mathrm{GEM}} = 250, 280,$ 260, 270 V

Variation of minimal ion back drift settings:

- Investigate the influence of the second transfer field

⇒ $E_{\mathrm{transfer,II}} = 290,$ 1500, 2500 V/cm

distance	fieldstrength/voltage	
4 mm	250 V/cm	250 V/cm
GEM I	250 V	230 V
2 mm	1500 V/cm	2500 V/cm
GEM II	250 V	260 V
2 mm	1500 V/cm	290 V/cm
GEM III	250 V	290 V
2 mm	3000 V/cm	4500 V/cm

Considered in the following: large gain, small gain, IBF settings.

Measurements in detail

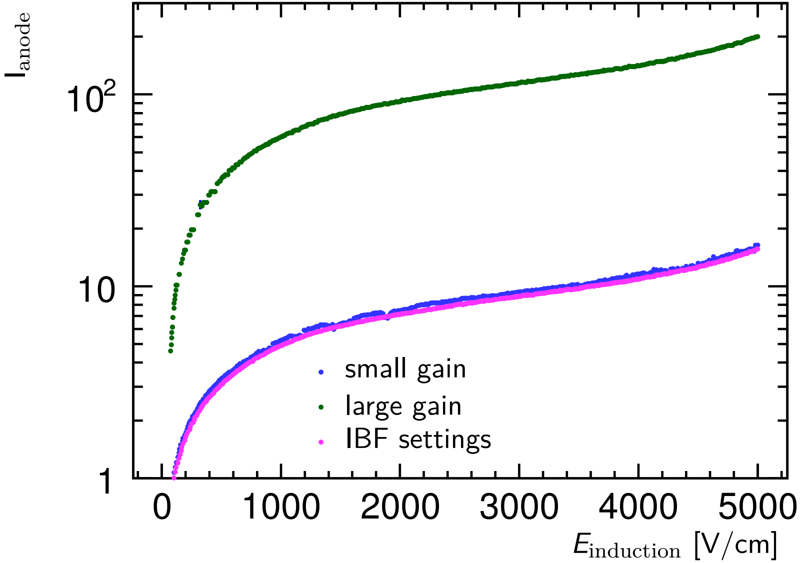
Example:

$$G(U_{\mathrm{GEM3}}) = \frac{I_{\mathrm{anode}} + I_{\mathrm{GEM3,anode}}}{I_{\mathrm{GEM3,cathode}}}$$

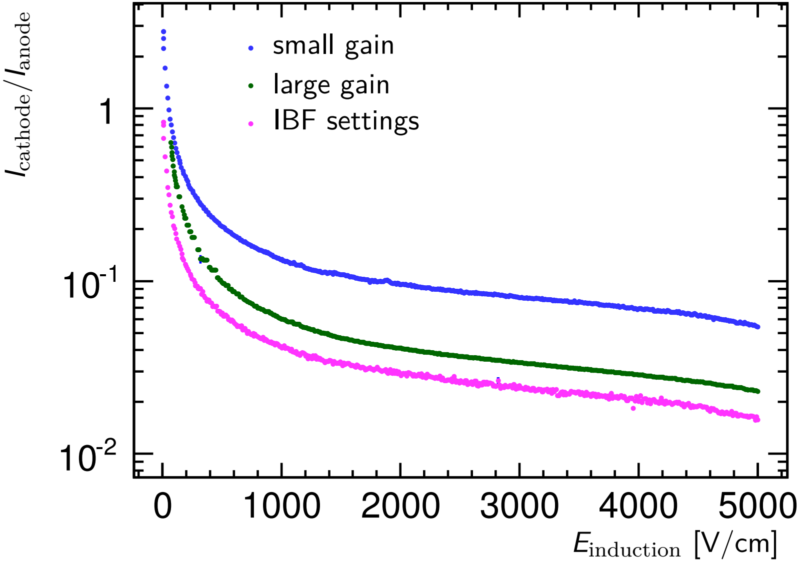
Measurements:

What?		Where?	Depending on?
single GEM gain		GEM III	U_{GEM3}
collection eff. e^-	C^-	GEM I	E_{drift}
extraction eff. e^-	X^-	GEM III	$E_{\mathrm{induction}}$
collection eff. ions	C^+	GEM II	$E_{\mathrm{transfer,II}}$
prim. extraction eff. ions	$X^+_{\mathrm{prim.}}$	GEM III	$E_{\mathrm{transfer,II}}$
sec. extraction eff. ions	$X^+_{\mathrm{sec.}}$	GEM I	E_{drift}

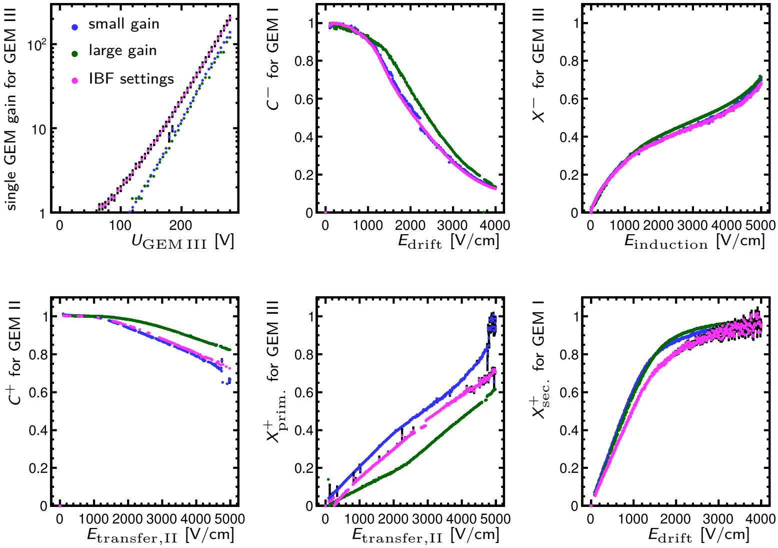
Gain for 70 μm holes



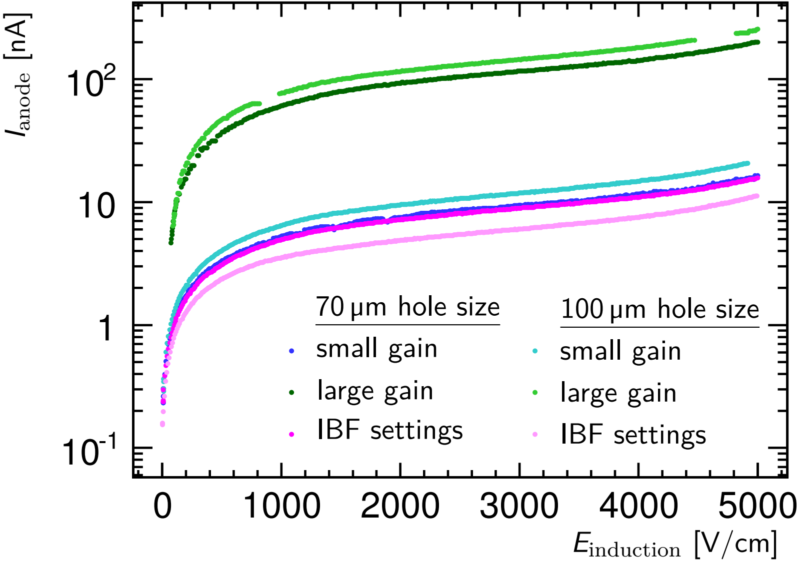
Ion back drift for 70 μm holes



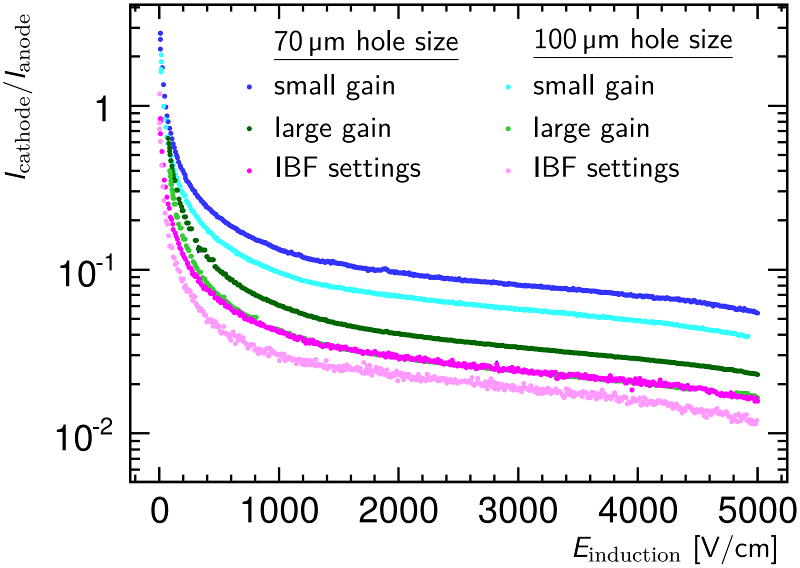
Coefficients with standard GEM on top of the stack



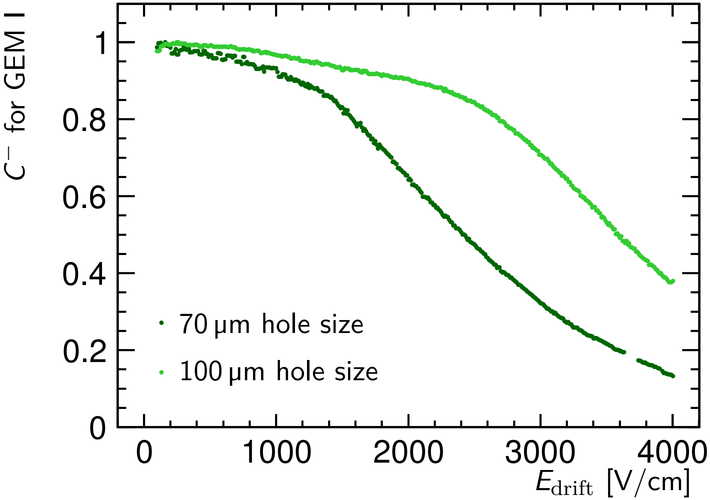
Gain for 70 μm and 100 μm holes



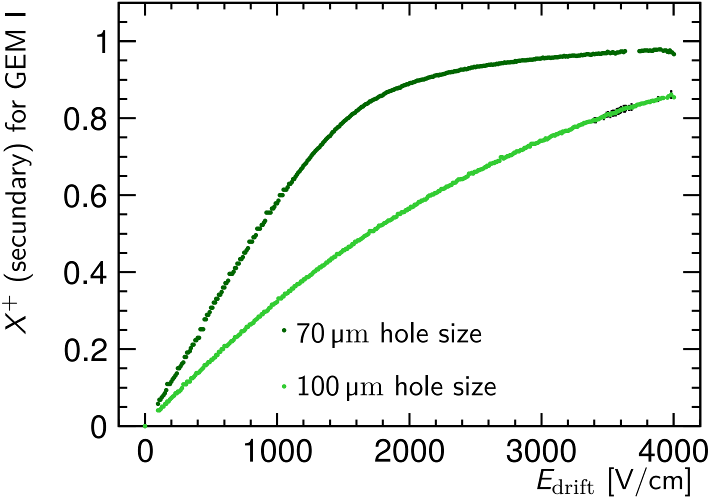
Ion back drift for 70 μm and 100 μm holes



Collection efficiency for electrons on GEM I

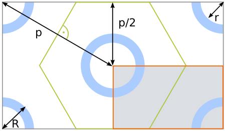


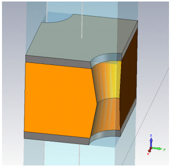
Extraction efficiency for ions on GEM I

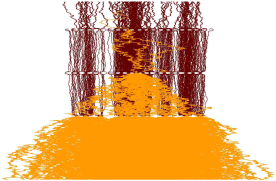


Details on the simulation

1. Simulation of the fields with a finite element based software (CST™)
   - Only a single GEM is simulated with ≈ 300 μm space on top/below
   - The fields and voltages are set according to the GEM position in the stack
   - Field data is exported
2. Simulation of the particle drift and amplification with GARFIELD++
   - The single GEMs from the field simulation are stacked
   - Space between them is filled with a constant electric field
   - Constant B field can be added
   - End points of the electrons/ions are analyzed







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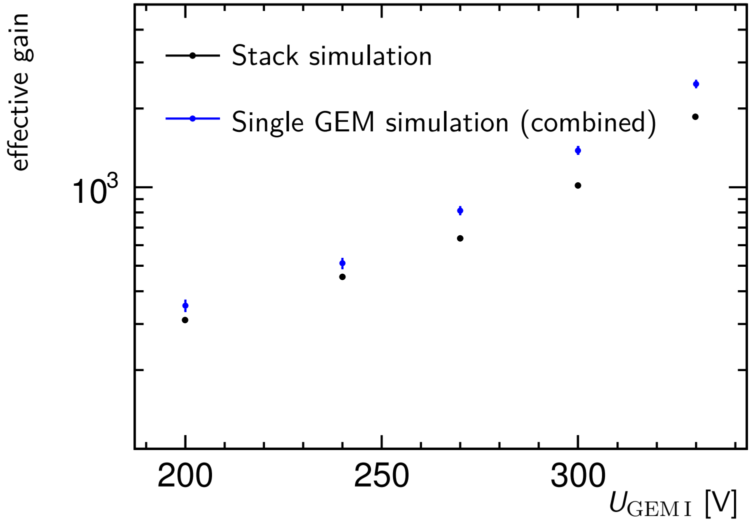
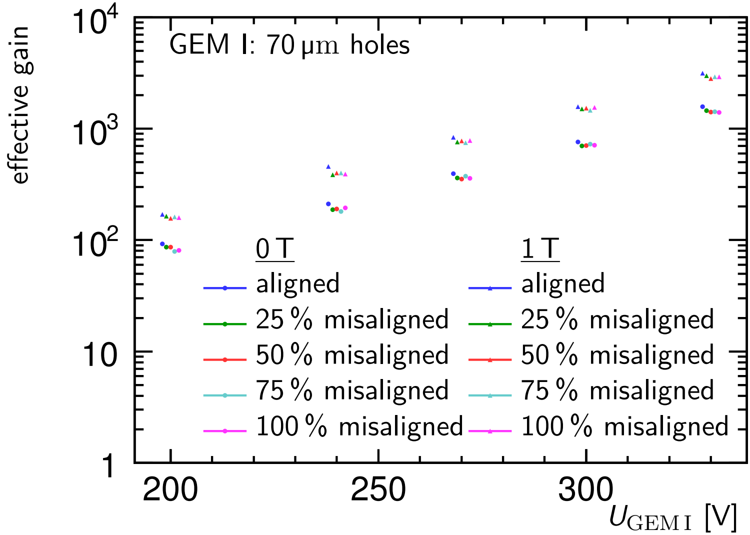
distance	field/voltage
1.5 mm	250 V/cm
GEM I	200 – 330 V
2 mm	1500 V/cm
GEM II	350 V
2 mm	1500 V/cm
GEM III	350 V
3 mm	3000 V/cm

*Changed compared to the experiment

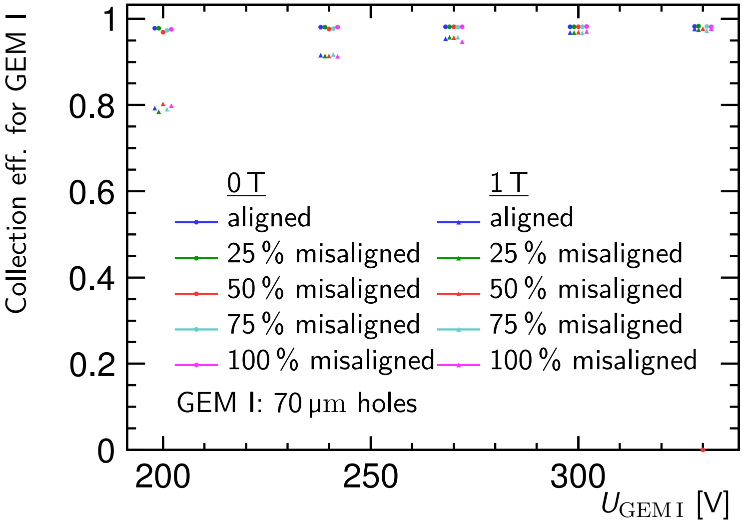
Single GEM simulation vs. stack simulation



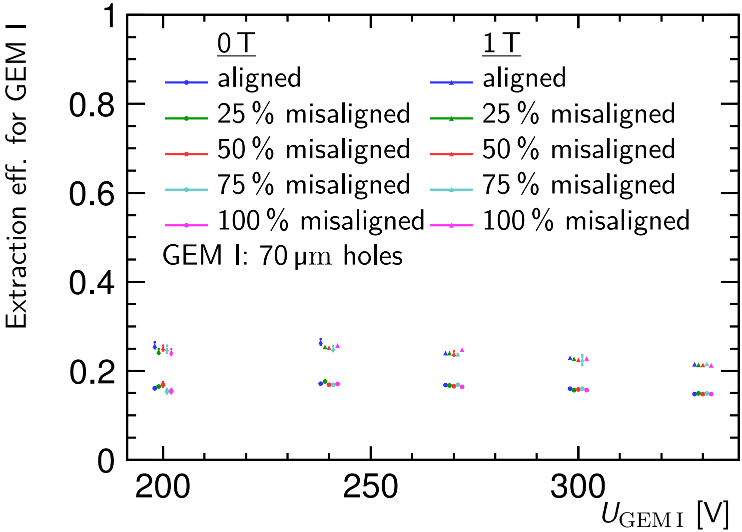
Misalignment of the GEMs



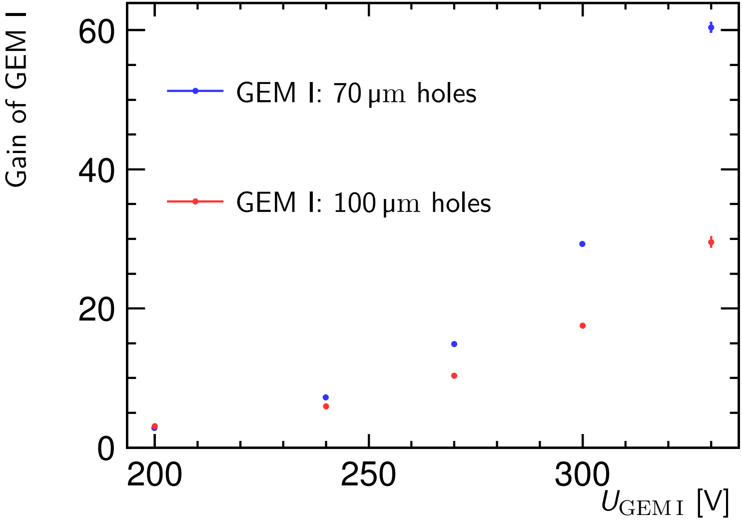
Collection Eff. with and without magnetic field



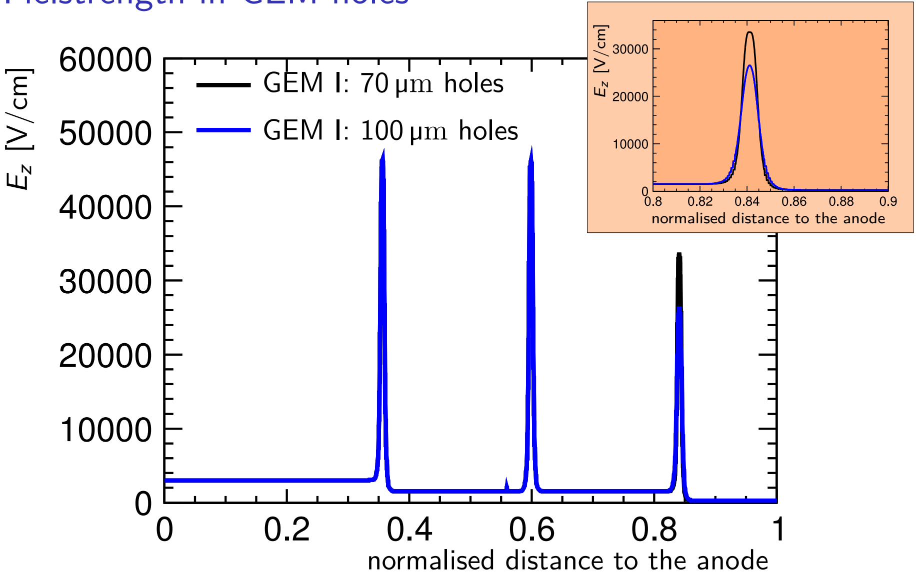
Extraction Eff. with and without magnetic field



Gain for 70 μm and 100 μm holes



Fielstrength in GEM holes



Conclusions

Experiment:

- Successfully measured various parameters of a triple GEM stack for T2K gas
- Comparison of two different GEMs on top of the stack shows:
  - IFB can be reduced with larger holes in GEM I
  - But: this GEM is not as stable (more discharges are observed)

Simulation:

- Successfully simulated a stack of three GEMs
- Simulation shows it is not sufficient to simulate only one GEM and deduce results for a stack
- Simulation can be used to study the influence of a magnetic field
- Results are preliminary and will be investigated further
- Still to do: realize experimental conditions in the simulation (e.g gas type)

Backup

Summary of the measurements

$$G(U_{\mathrm{GEM3}}) = \frac{I_{\mathrm{anode}} + I_{\mathrm{GEM3,anode}}}{I_{\mathrm{GEM3,cathode}}} = \beta e^{\alpha E_{\mathrm{hole}}}$$

$$E_{\mathrm{hole}} = aU_{\mathrm{GEM}} + b\left(E_{\mathrm{top}} - E_{\mathrm{bottom}}\right), \, b = 0.0623^{1}$$

$$C^{-}_{\mathrm{GEM1}}(E_{\mathrm{drift}}) = \frac{I_{\mathrm{anode}}}{I_{\mathrm{anode,max}}} e^{\alpha b\left(E_{\mathrm{drift,max}} - E_{\mathrm{drift}}\right)}$$

$$X^{-}_{\mathrm{GEM3}}(E_{\mathrm{induction}}) = \frac{I_{\mathrm{anode}}}{I_{\mathrm{anode}} + I_{\mathrm{GEM3,anode}}}$$

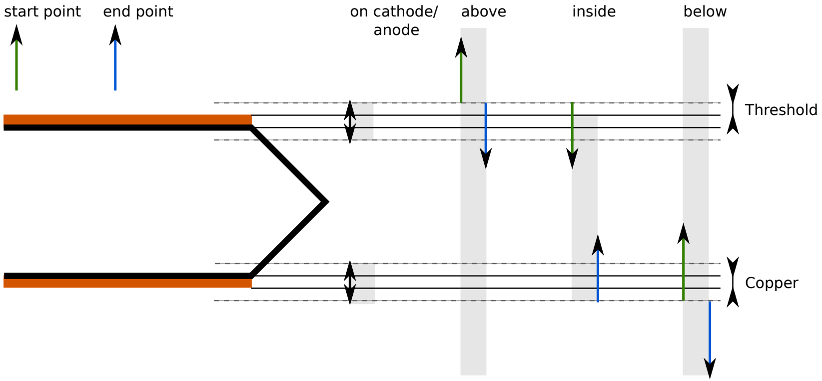
$$C^{+}_{\mathrm{GEM2}}(E_{\mathrm{TF2}}) = 1 - \frac{I_{\mathrm{GEM2,anode}} - I^{0}_{\mathrm{GEM2,anode}}}{-(I_{\mathrm{GEM3,anode}} + I_{\mathrm{anode}}) + I_{\mathrm{GEM3,cathode}}}$$

$$X^{+}_{\mathrm{prim.,GEM3}}(E_{\mathrm{TF2}}) = \frac{I_{\mathrm{GEM3,anode}} + I_{\mathrm{anode}} + I_{\mathrm{GEM3,cathode}}}{I_{\mathrm{GEM3,anode}} + I_{\mathrm{anode}}}$$

$$X^{+}_{\mathrm{sec.,GEM3}}(E_{\mathrm{drift}}) = \frac{I_{\mathrm{cathode}}}{I_{\mathrm{cathode}} + I_{\mathrm{GEM1,cathode}}}$$

[1] See e.g master thesis by Blanka Sobloher

Definition of coefficients in the simulation

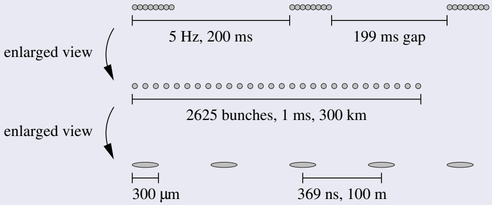


e(InFront) = N(above)
e(InHole) = N(above || inside || below)
e(Extracted) = N(below)

coll. Eff. = [e(InFront) - e(on_gem_cathode)] / e(InFront)
gain = e(InHole) / [e(InFront) - e(on_gem_cathode)]
extrac. Eff. = e(Extracted) / e(InHole)

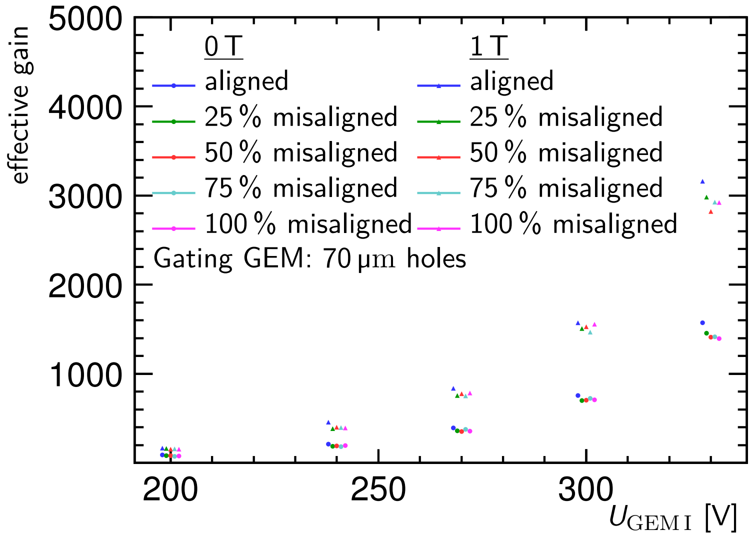
ILC details

Bunch Structure

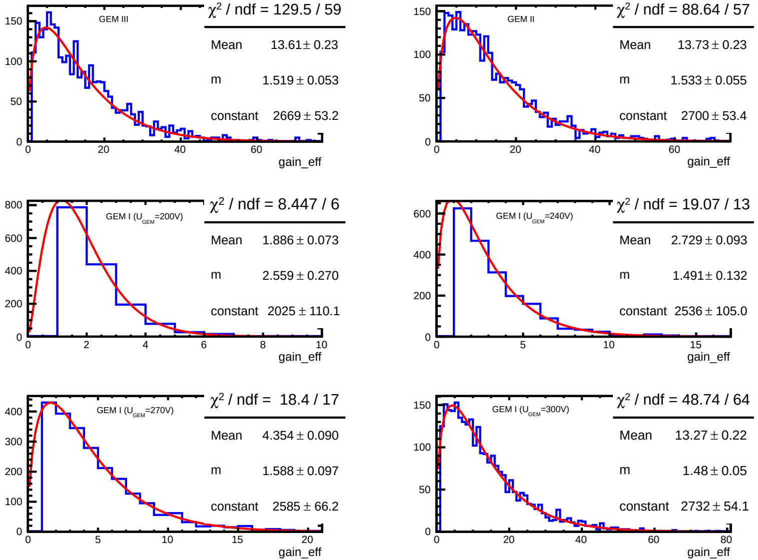


Firgure: ILC bunch structure [DESY-THESIS-2008-036]

Misalignment of the GEMs



Single GEM gain in simulation



Gain of a GEM stack in simulation