Ion backdrift studies

Klaus Zenker

RD51 Mini Week

23.11.2011

Time Projection Chamber

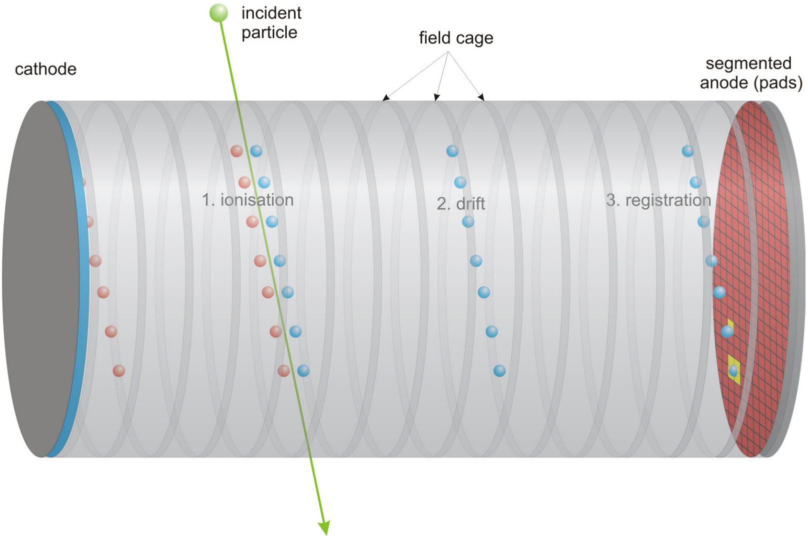

Figure: Principle of a TPC by Oliver Schäfer

Drift of particles

$$m\frac{d\overrightarrow{v}}{dt} = e\,\overrightarrow{E} + e\left(\overrightarrow{v} \times \overrightarrow{B}\right) + \overrightarrow{Q}(t)$$

- $\overrightarrow{Q}(t)$ denotes a noise term connected to stochastic scattering with gas molecules
- stationary solution ($\overrightarrow{v_\mathrm{D}} = \langle \overrightarrow{v} \rangle$; $t \gg \tau$):

$$0 = \left\langle m\frac{d\overrightarrow{v}}{dt} \right\rangle = e\,\overrightarrow{E} + e\left(\overrightarrow{v_\mathrm{D}} \times \overrightarrow{B}\right) - \frac{m}{\tau}\overrightarrow{v_\mathrm{D}}$$

Drift of particles

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- using $\omega = Be/m$ and $\mu = \tau e/m$:

drift velocity

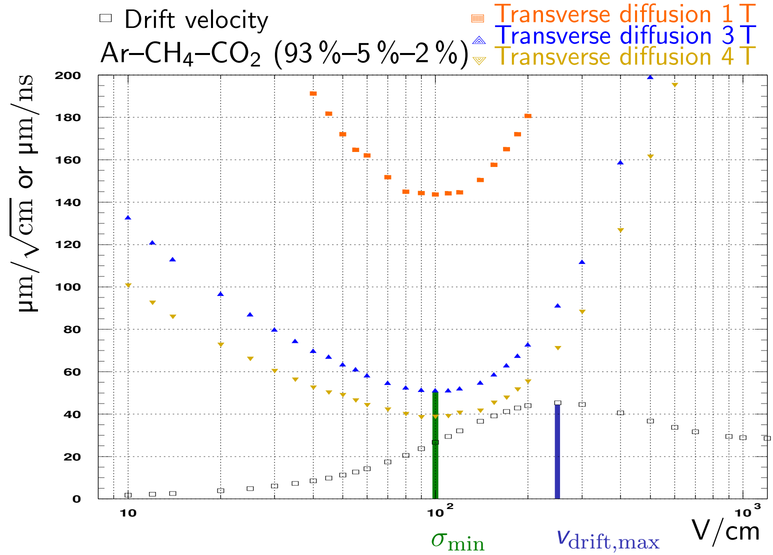
$$\overrightarrow{v_{\mathrm{D}}} = \frac{\mu E}{1+\omega^2\tau^2}(\underbrace{\overrightarrow{e_E}}_{\text{ion}} + \omega\tau\overrightarrow{e_E} \times \overrightarrow{e_B} + \underbrace{\omega^2\tau^2\left(\overrightarrow{e_E} \cdot \overrightarrow{e_B}\right)\overrightarrow{e_B}}_{e^- \text{ (if } B\neq 0)})$$

Ions vs. electrons I

Typical values:

	ion	electron	
μ	$\approx 1.5\,\mathrm{cm^2/Vs}$	$\approx 10^4\,\mathrm{cm^2/Vs}$	
$\overrightarrow{v_\mathrm{D}}$	$\approx 3.75\,\mathrm{m/s}$	$\approx 2.5\,\mathrm{cm/\mu s}$	@$\lvert\overrightarrow{E}\rvert = 250\,\mathrm{V/cm}$

Gas Properties of TDR gas



[http://www-hep.phys.saga-u.ac.jp/ILC-TPC/gas/]

ILC

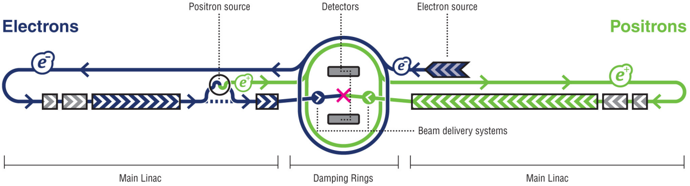
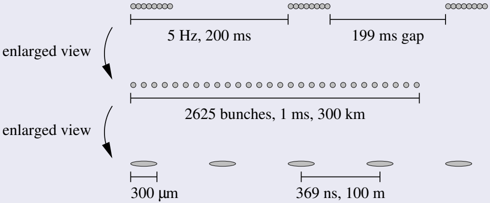


Figure: ILC baseline design [ILC-REPORT-2007-001]

Bunch Structure



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

Ions vs. electrons II

Typical values:

	ion	electron	
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$\overrightarrow{v_\mathrm{D}}$	$\approx 3.75\,\mathrm{m/s}$	$\approx 2.5\,\mathrm{cm/\mu s}$	$@|\overrightarrow{E}| = 250\,\mathrm{V/cm}$

Ion discs

Distance passed by the ion disc per bunch crossing:

$$x_\mathrm{disc} = 0.199\,\mathrm{s} \cdot 3.75\,\mathrm{m/s} = 74.6\,\mathrm{cm}$$

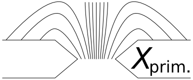
ILD TPC drift region: 2.25 m

- there will be three discs in the ILD TPC
- they are produced in the amplification stage of the TPC
- in addition there are also the ions produced in the TPC drift volume

Ion production in detail

Primary ions:

- primary ions are spread over the entire GEM hole diameter
- ionization takes place in the complete hole cross section
- ions $\left([\omega\tau]^{\mathrm{e}^-} \gg [\omega\tau]^{\mathrm{ion}}\right)$ follow the electric field lines
- $\Rightarrow$ intrinsic ion suppression (extraction efficiency $X_{\mathrm{prim.}}$)



Ion production in detail

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- ionization takes place in the complete hole cross section
- ions $\left([\omega\tau]^{\mathrm{e}^-} \gg [\omega\tau]^{\mathrm{ion}}\right)$ follow the electric field lines
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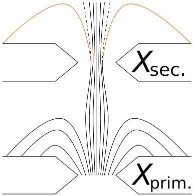
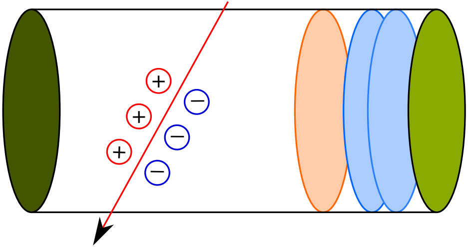
Secondary ions:

- $\Rightarrow$ primary ions reaching a second GEM are in that case secondary ions
- following the electric field lines they go through the center of the GEM hole
- diffusion is negligible
- extraction efficiency:

$$X^{\mathrm{top}}_{\mathrm{sec.}} = \begin{cases} \frac{X^{\mathrm{top}}_{\mathrm{prim.}}}{X^{\mathrm{bottom}}_{\mathrm{prim.}}} & \text{for } X^{\mathrm{top}}_{\mathrm{prim}} < X^{\mathrm{bottom}}_{\mathrm{prim}} \\ 1 & \text{for } X^{\mathrm{top}}_{\mathrm{prim}} > X^{\mathrm{bottom}}_{\mathrm{prim}} \end{cases}$$



How to suppress ions?



- anode
- cathode
- amplification GEMs
- gating GEM
- ionizing particle

1. clean ions between 2 trains
   $\Rightarrow$ requires a high ion velocity ($\overrightarrow{v_\mathrm{D}}^\mathrm{ion} > 12\,\mathrm{m/s}$)
   - since a high drift field is not wanted: $\mu^\mathrm{ion} > 4\,\mathrm{cm^2/Vs}$
   - to achieve this one could use a different gas mixture
2. gate ions in front of amplification volume
   - 2.1. wire gate
     - gate after each bunch train
     - possibly leads to field distortions
   - 2.2. GEM gate
     - coninuous ion supression

$\Big\}$ Ions produced in the drift area can not be reduced

GEM properties

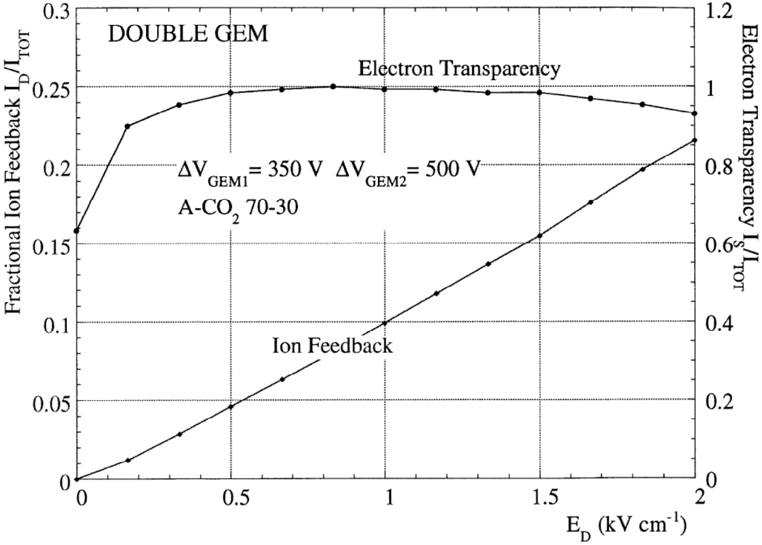


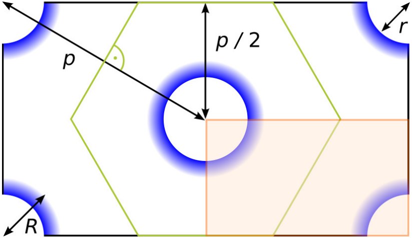
Figure: Ion feedback and electron transparency [Nucl. Instrum. Meth. **A438**, 376-408 (1999)]

Motivation
- Particles in fields
- ILC

Ion suppression
- How-to
- Simulation
- Experiment

Conclusion

GEM geometry



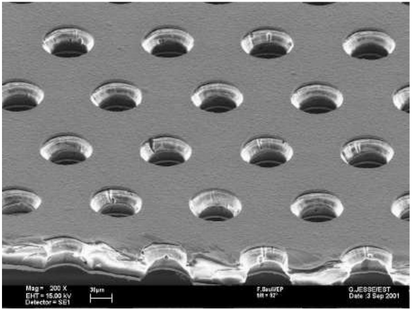


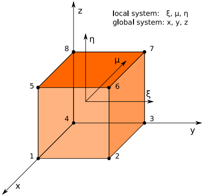
Figure: GEM foil [`http://gdd.web.cern.ch/GDD/`]

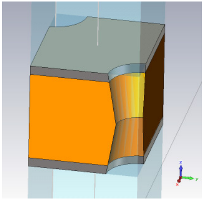
CERN GEM:

- double conical holes
- kapton (50 µm) enclosed by copper surface (5 µm)
- $r = 25\,\mathrm{\mu m}$, $R = 35\,\mathrm{\mu m}$
- pitch $p = 140\,\mathrm{\mu m}$
- optical transparency $\tau_{\mathrm{opt.}} = \frac{A_{\mathrm{hex.}}}{A_{\mathrm{circ.}}} = \frac{2\pi R^2}{\sqrt{3}p^2} = 22.6\,\%$

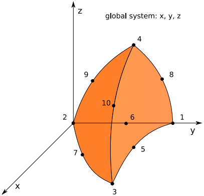
1. Field simulation:

- 3D model of the GEM stack
- software using finite element methods are used to calculate potential
- CST Studio Suite™
  - eight-node cubic basic elements
  - material is merged with the PBA® algorithm





- ANSYS®
  - ten-node tetrahedral basic elements
  - each element is filled with one material

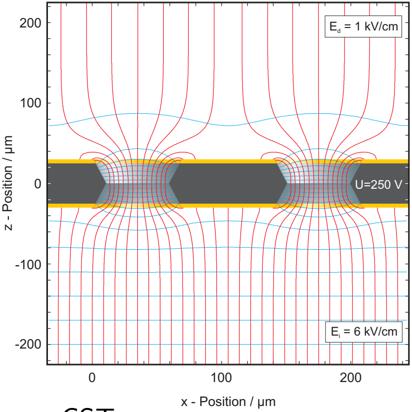


2. Electron/Ion drift:

- Garfield++
  - treats ionization processes and the ion/electron transport
  - electron transparency and ion back drift can be calculated

Initial Problems:

- Ansys
  - no FLC license for ANSYS
  - I have no rights to work on lxplus (CERN)



Firgure: GEM field lines by Blanka Sobloher

- CST
  - there is no interface for CST in Garfield++

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- Garfield++
  - treats ionization processes and the ion/electron transport
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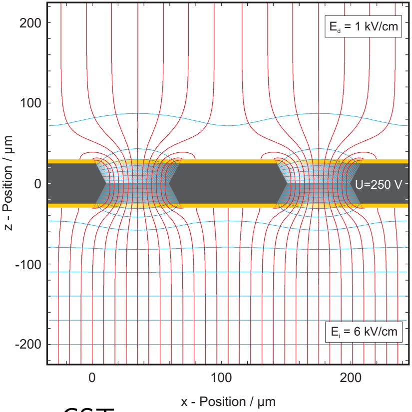
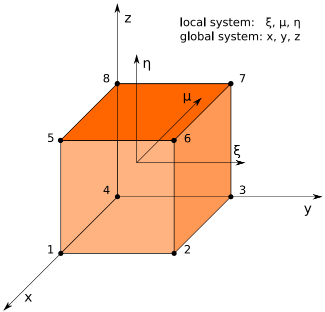


Firgure: GEM field lines by Blanka Sobloher

✓Initial Problems:

- Ansys
  - I found a group with an ANSYS license
  - I should get access to lxplus soon
- CST
  - interface was written and works

CST interface to Garfield++



node k	1	2	3	4	5	6	7	8
ξ_k	-1	1	1	-1	-1	1	1	-1
μ_k	-1	-1	1	1	-1	-1	1	1
η_k	-1	-1	-1	-1	1	1	1	1

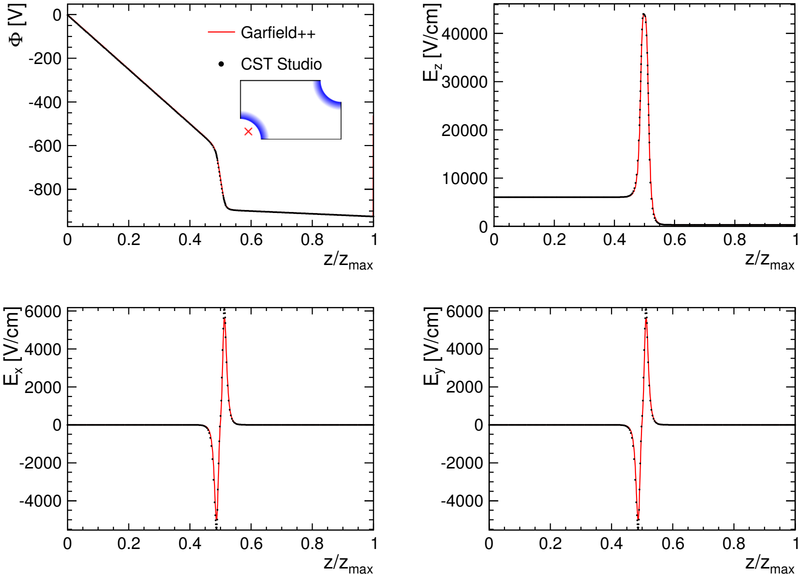
$$\xi = 2 \cdot \frac{x - x_4}{\Delta x} - 1; \quad \mu = 2 \cdot \frac{y - y_4}{\Delta y} - 1$$

$$\eta = 2 \cdot \frac{z - z_4}{\Delta z} - 1$$

$$\Phi(\xi,\mu,\eta) = \sum_{k=1}^{8} \Phi_k \overbrace{\frac{1}{8}\left(1+\xi_k\xi\right)\left(1+\mu_k\mu\right)\left(1+\eta_k\eta\right)}^{\text{shaping function } N_k}$$

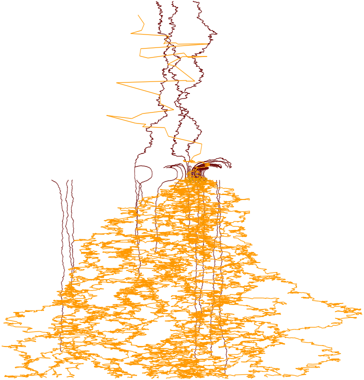
$$E_x = -\frac{\partial \Phi}{\partial x} = -\frac{\partial\left(\sum_k N_k\Phi_k\right)}{\partial(\xi,\mu,\eta)}\frac{\partial(\xi,\mu,\eta)}{\partial x}; \quad J^{-1} = \frac{\partial(\xi,\mu,\eta)}{\partial(x,y,z)}$$

Garfield++ interface at work



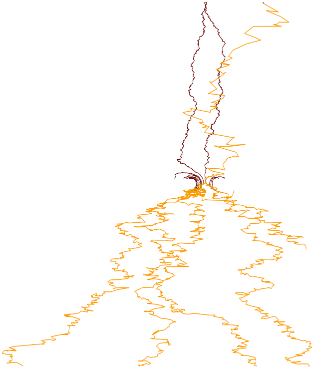
Garfield++: e^- crossing a single GEM (TDR gas)

CST:



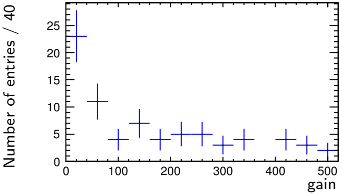
- $E_{\mathrm{drift}} = 250\,\mathrm{V/cm}$
- $E_{\mathrm{induction}} = 6000\,\mathrm{V/cm}$
- $U_{\mathrm{GEM}} = 300\,\mathrm{V}$

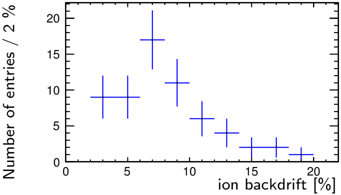
ANSYS:

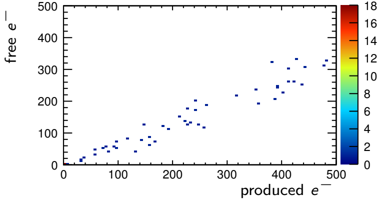


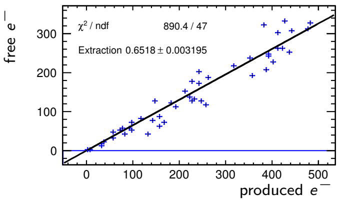
- $E_{\mathrm{drift}} = 600\,\mathrm{V/cm}$
- $E_{\mathrm{induction}} = 2000\,\mathrm{V/cm}$
- $U_{\mathrm{GEM}} = 300\,\mathrm{V}$

First look (CST)









Experiment

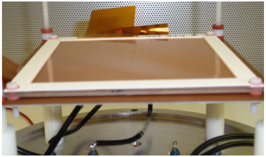


Figure: Small TPC [DESY-THESIS-10-015]

The DESY Small Prototype is being used.

- diameter of 25 cm
- drift length of 20 mm
- ^{55}Fe source on top of the cathode

Two type of GEMs will be considered in the beginning:

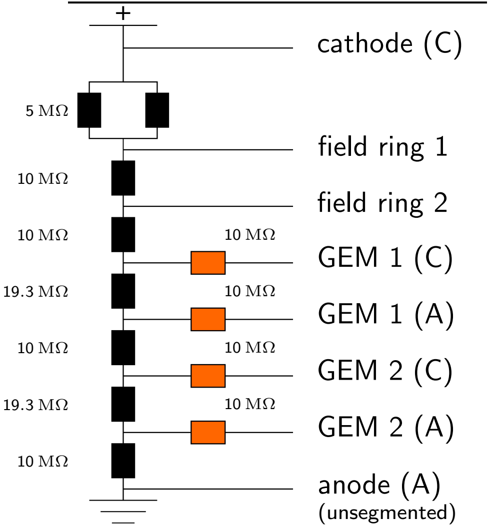
- standard CERN GEMs ($R = 35\,\mu\mathrm{m}$, $\tau_{\mathrm{opt.}} = 0.23$)
- modified CERN GEMs ($R = 50\,\mu\mathrm{m}$, $\tau_{\mathrm{opt.}} = 0.46$)

After commissioning stacks of two same type GEMs, a stack of three GEMs will be used.

In addition, we contemplate to measure the currents in the system to prove the ion suppression.

Experimental setup

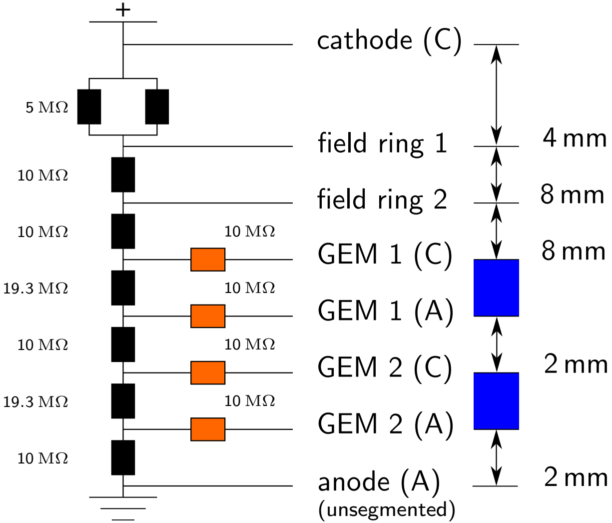
voltage divider
as power source



Experimental setup

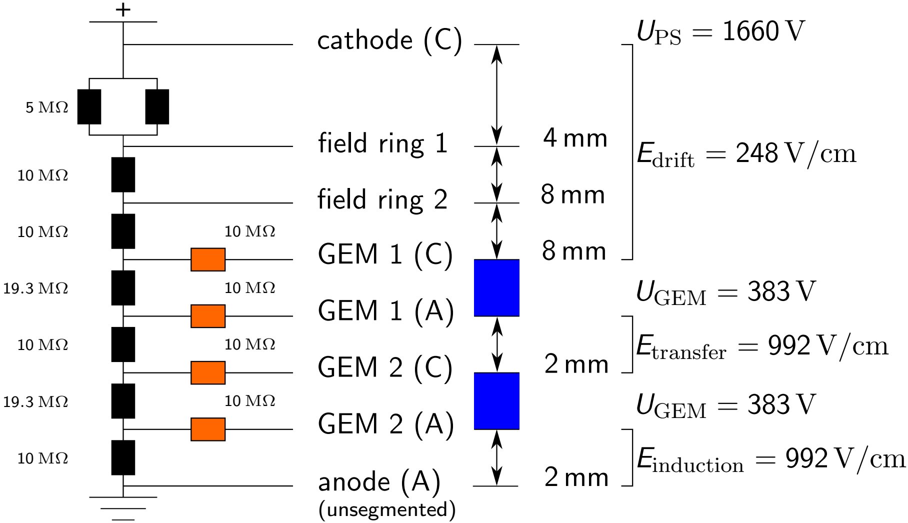
voltage divider as power source

geometric specifications



Experimental setup

voltage divider as power source | geometric specifications | electrostatic specifications



$U_{\mathrm{PS}} = 1660\,\mathrm{V}$

$E_{\mathrm{drift}} = 248\,\mathrm{V/cm}$

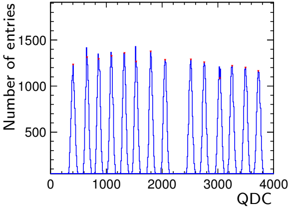
$U_{\mathrm{GEM}} = 383\,\mathrm{V}$

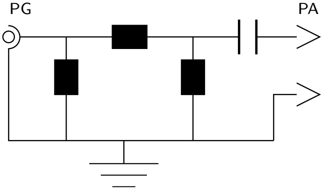
$E_{\mathrm{transfer}} = 992\,\mathrm{V/cm}$

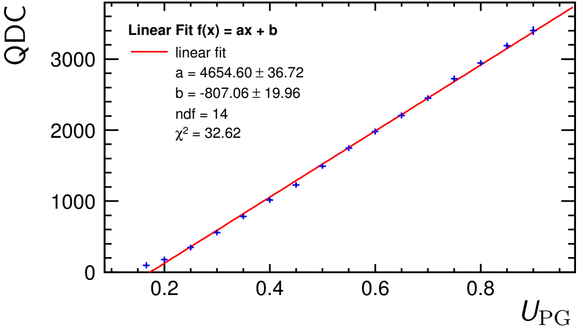
$U_{\mathrm{GEM}} = 383\,\mathrm{V}$

$E_{\mathrm{induction}} = 992\,\mathrm{V/cm}$

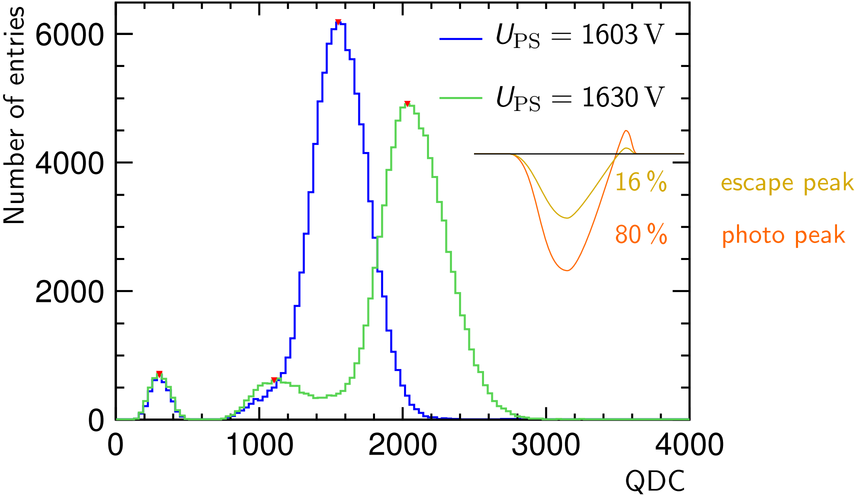
Calibration of the preamplifier (PA) with a charge injector



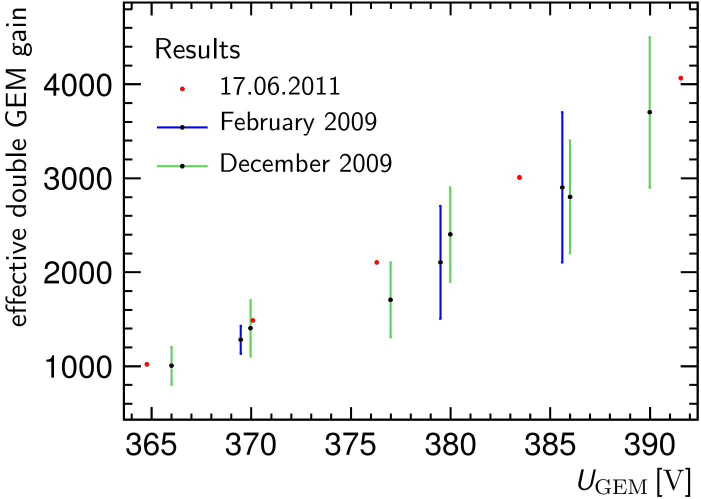




Results: Measurement of a Fe^{55} source spectrum



Comparison of the effective double GEM gain



Conclusion

Simulation:

- simulation with two different FEM software was prepared
- Garfield++ interface can be improved
- detailed study of ion back drift has started
    - minimize the ion back drift
    - keep electron transparency high

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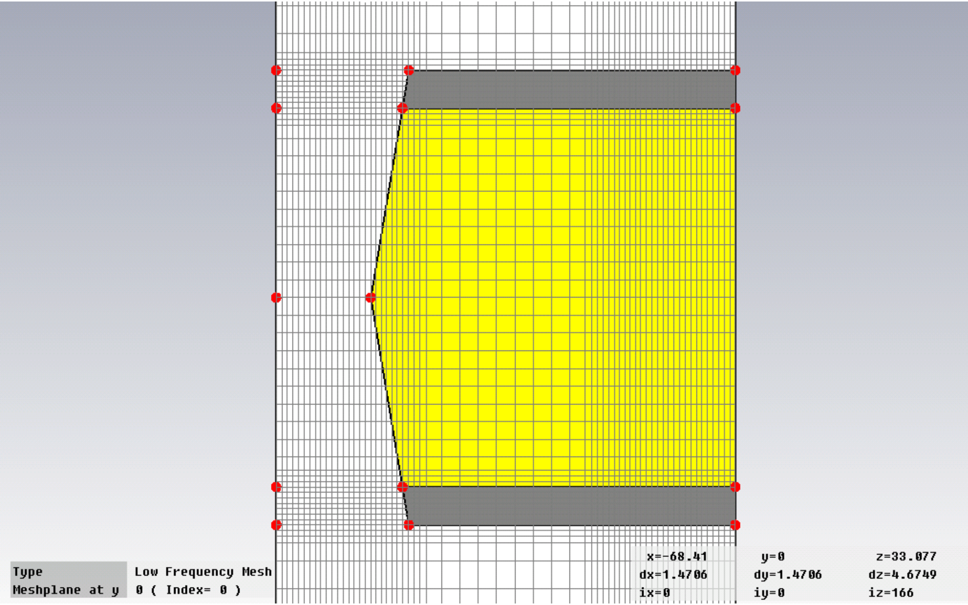
  - minimize the ion back drift
  - keep electron transparency high

Experiment:

- commissioning of the small prototype not yet complete
- first results look promising
- after commissioning is finished:
  - compare effective double GEM gain of standard CERN GEMs with other GEMs (smaller hole radius 50 µm)
  - compare these results with simulation
  - build triple GEM stack in the small prototype with minimized ion back drift
  - measure the ion back drift

Backup

Mesh view for single GEM in CST



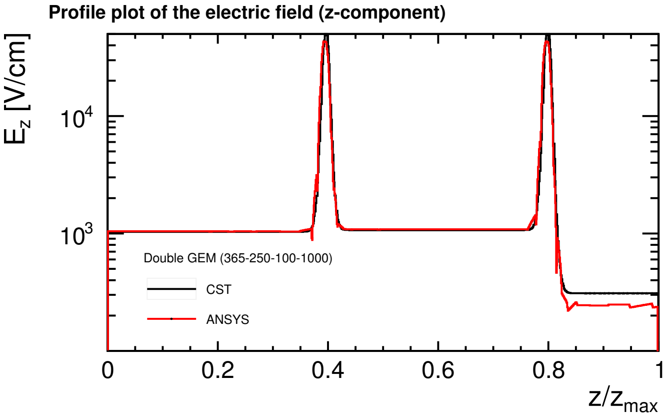
Type	Low Frequency Mesh
Meshplane at y	0 (Index= 0)

x=-68.41 y=0 z=33.077

dx=1.4706 dy=1.4706 dz=4.6749

ix=0 iy=0 iz=166

ANSYS vs. CST (preliminary)



Frist look (ANSYS, different backdrift definition)