Design and Construction of a TPC using GEM Foils for Gas Amplification

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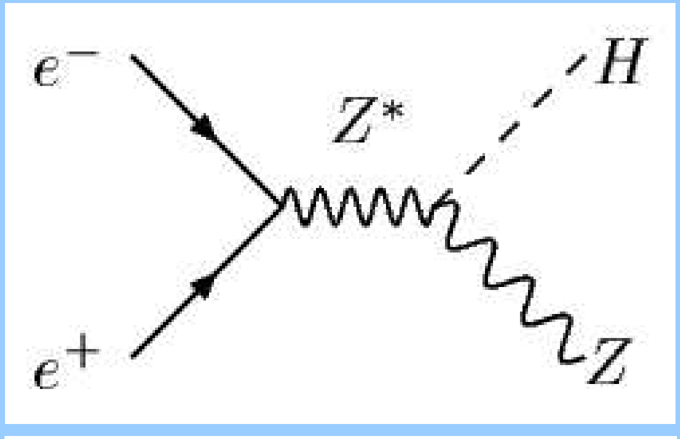
bmb+f Großgeräte der physikalischen Grundlagenforschung

Overview

- introduction
- ion backdrift
- charge width
- construction of a TPC prototype
- summary and outlook

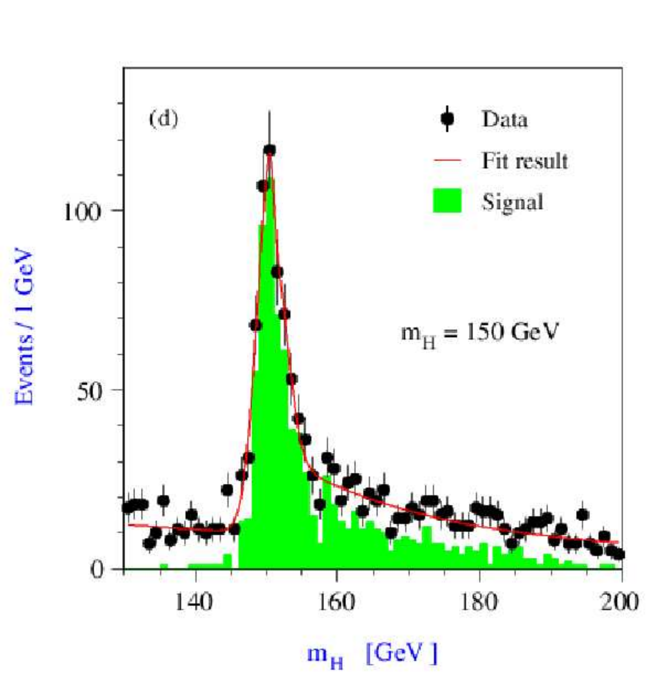
Introduction: Requirements for LC Tracking

Precision measurements to complement discovery machine LHC



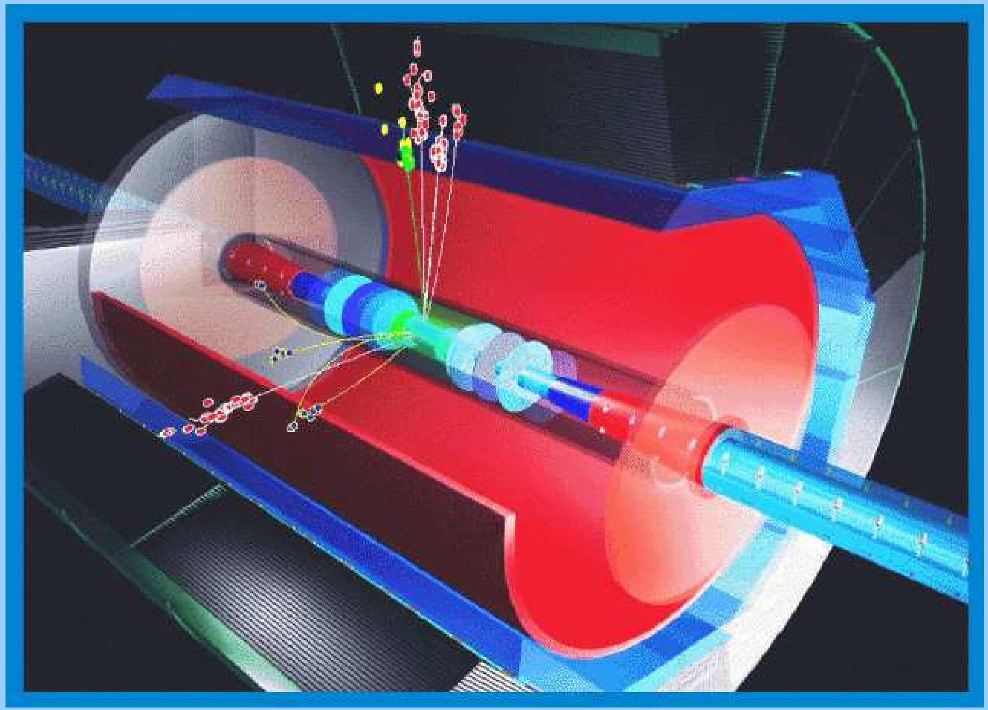
Example:

- Study of higgs properties in $e^+e^- \rightarrow HZ \rightarrow He^+e^- \ (\mu^+\mu^-)$
- Tag higgs through leptonic Z decay (recoil mass)
- Ideal: Recoil mass resolution only limited by Z width $\Rightarrow$ Momentum resolution small vsersus Z width: $\sigma(\frac{1}{p_t} < 5 \cdot 10^{-5} GeV^{-1})$ (full tracker)



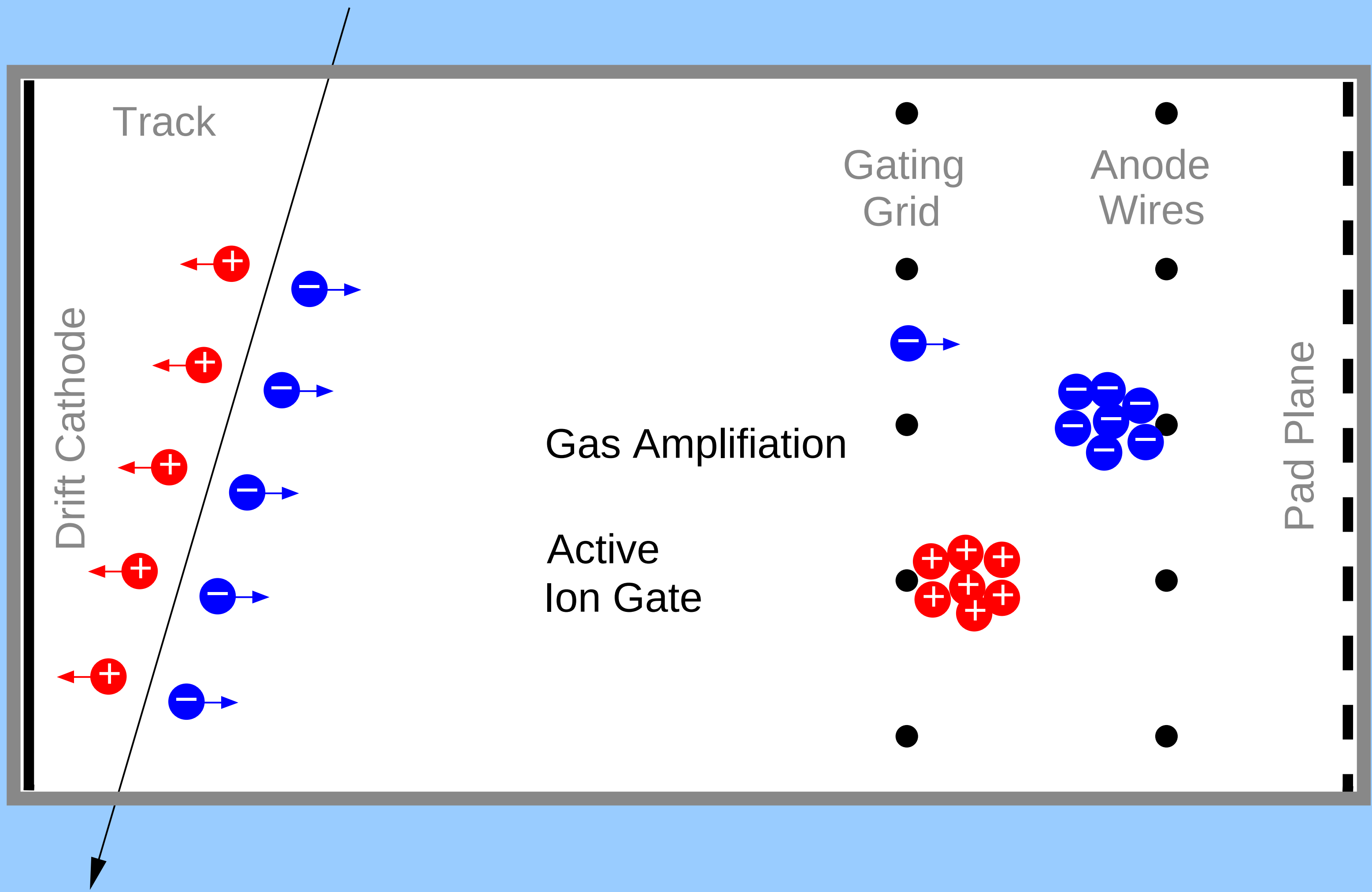
Introduction: TPC as Central Tracker

- Large volume (R=1.7m)
- Simple 3-d track reconstruction (Goal: 200 points per track)
- Very low material budget: 3% X_0 in barrel, 30% X_0 in readout
- Good measurement of specific ionisation $\left(\frac{dE}{dx}\right)$ along the track (Goal: 5% resolution)

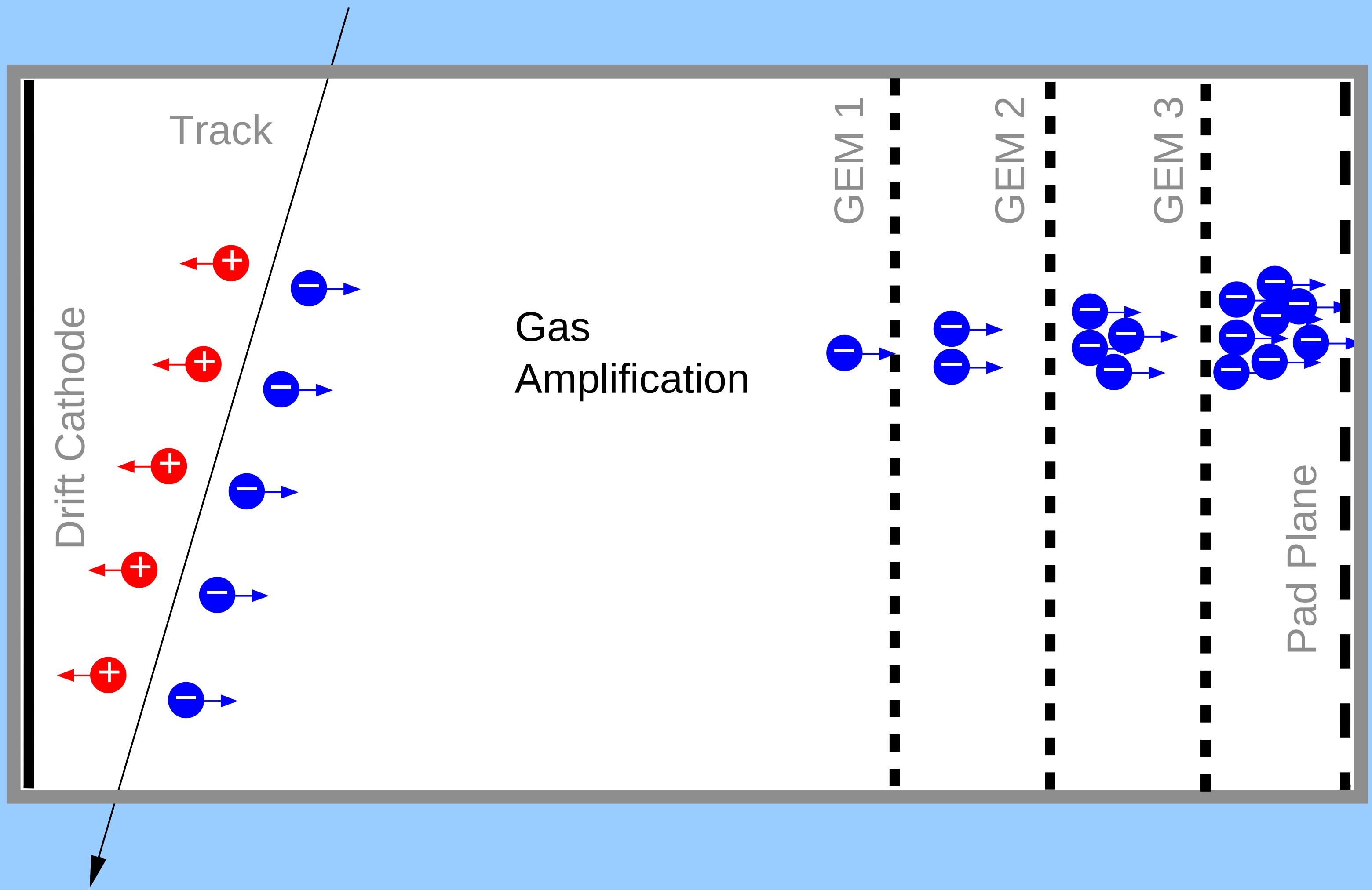


4T magnetic field

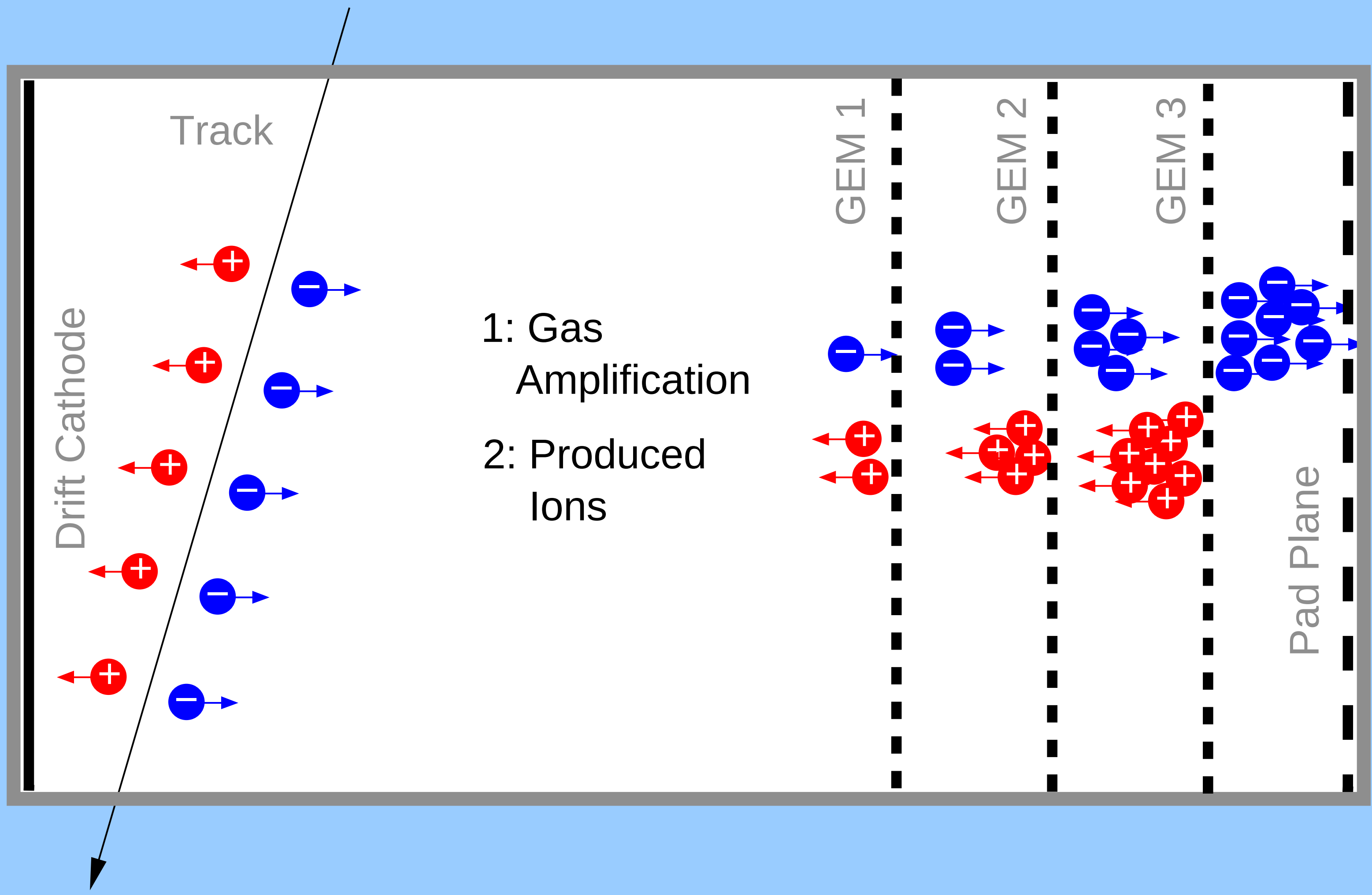
A TPC with conventional wire readout



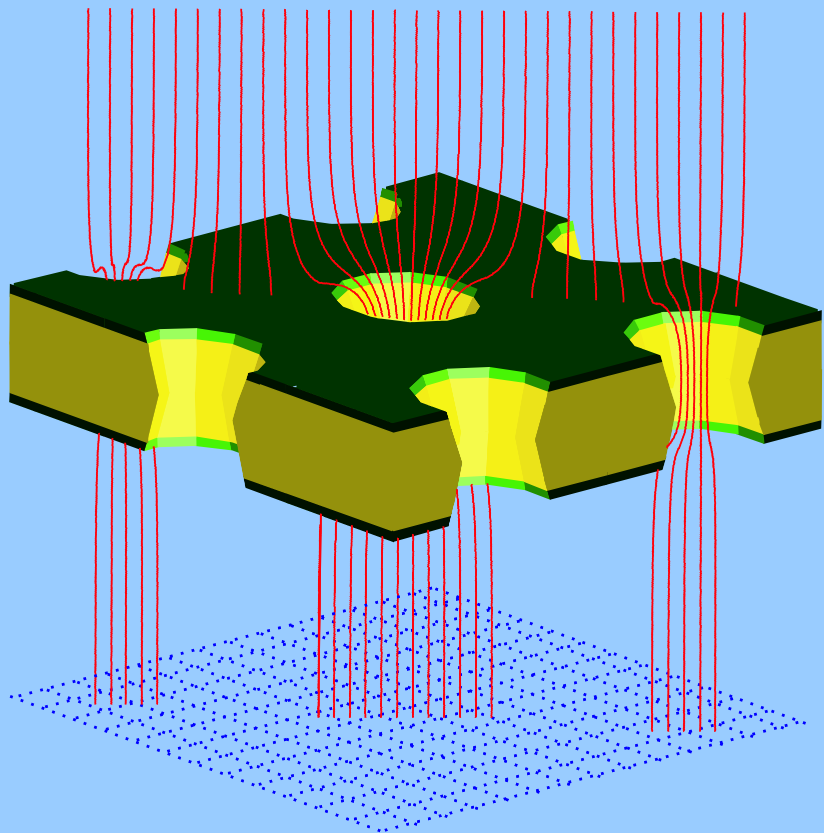
A TPC with GEM Readout



A TPC with GEM Readout

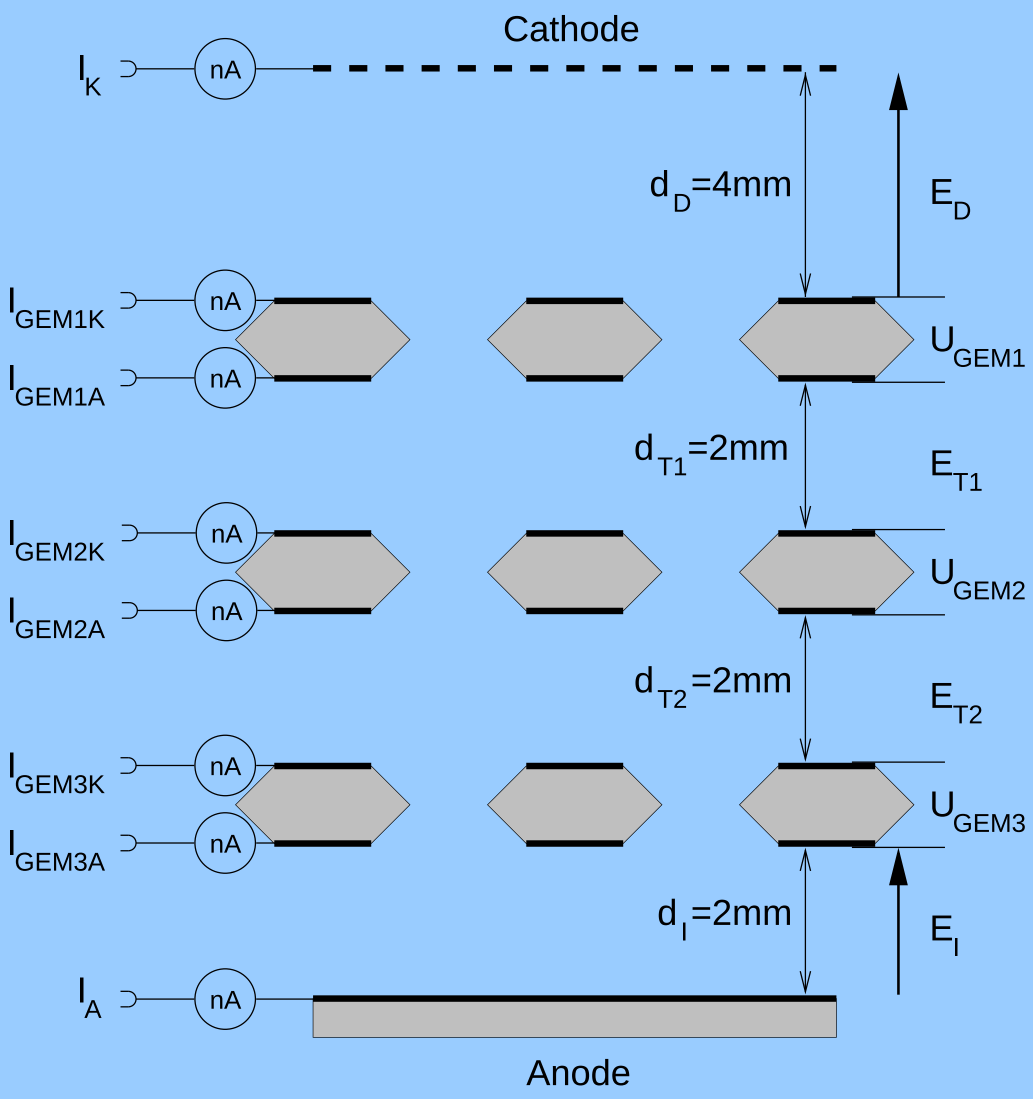


- Smaller structures (140 μm pitch): Potential for improved spatial resolution (Goal: $100 \mu m$ single point resolution)
- 2-d symmetry $\rightarrow \vec{E} \times \vec{B}$ effects smaller than with wires
- Fast e^- signal on pads
- Intrinsic suppression of Ion Backdrift $\rightarrow$ No active gating needed?

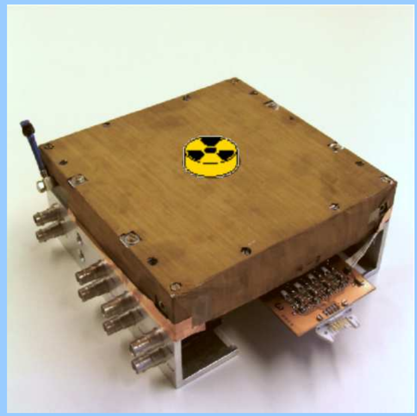


GEM: Gas Electron Multiplier (Sauli, 1996)

Ion Backdrift: Setup and Parameters



^{55}Fe source



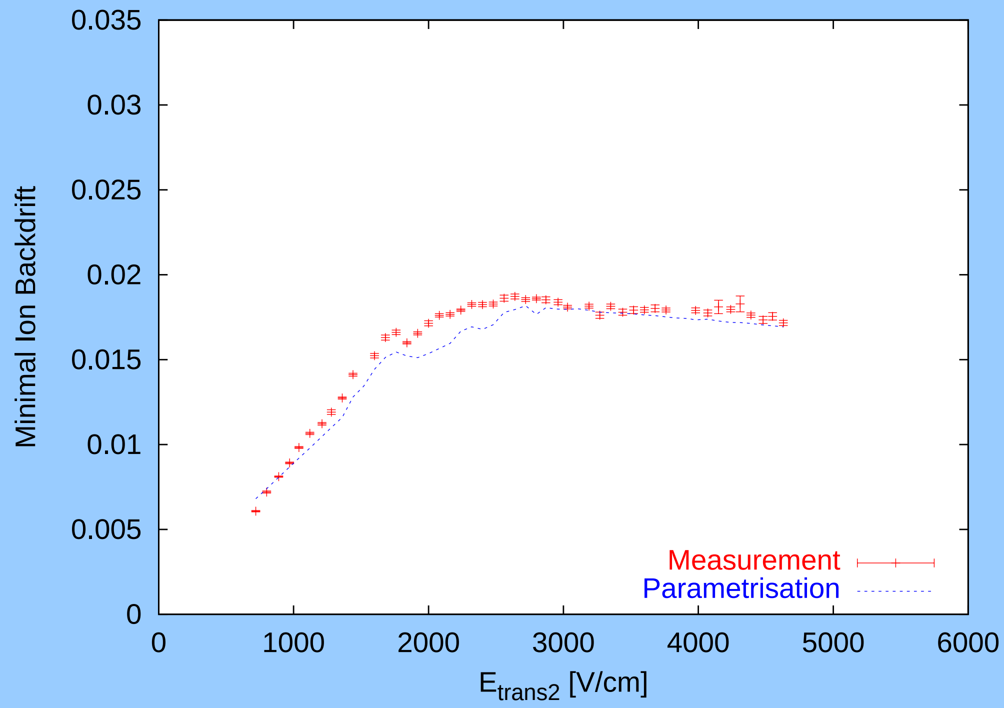
3 GEM voltages and 4 electric fields (7 chamber parameters) determine charge transfer

Ion backdrift (IB) and eff. gain (G_{eff}) are parametrised with respect to these 7 parameters

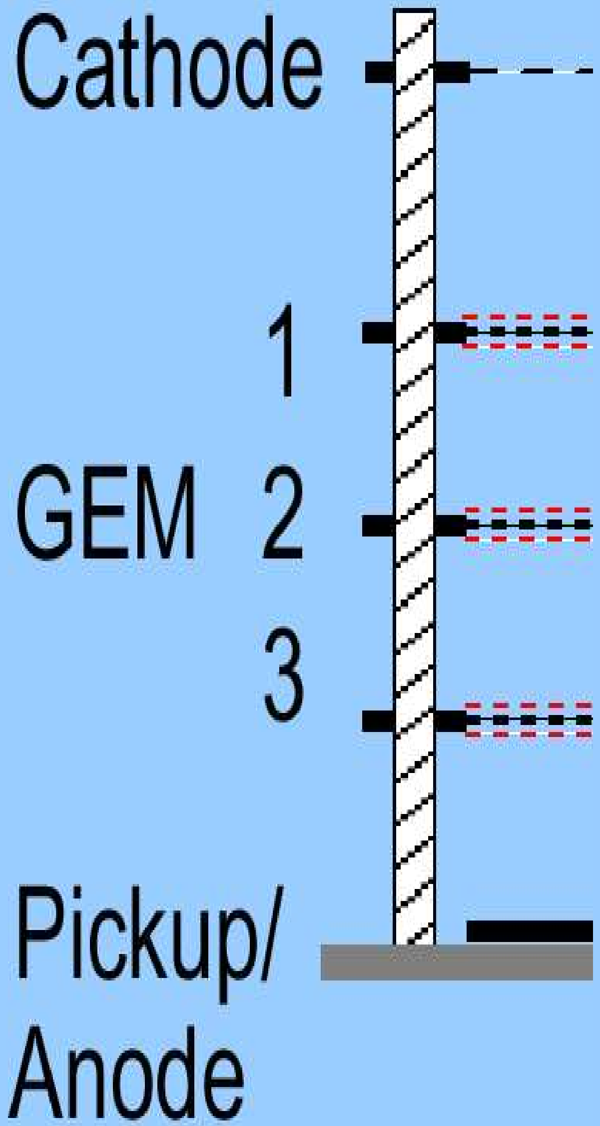
Ion Backdrift: Finding Minimum

- Parameter space is scanned stepwise with a C program.
- At every point the calculated ion feedback, effective gain and corresponding parameters are written to hard disk.
- The obtained data set can be searched for minima.
- Optimized settings can then be measured automatically.

Example for one parameter:



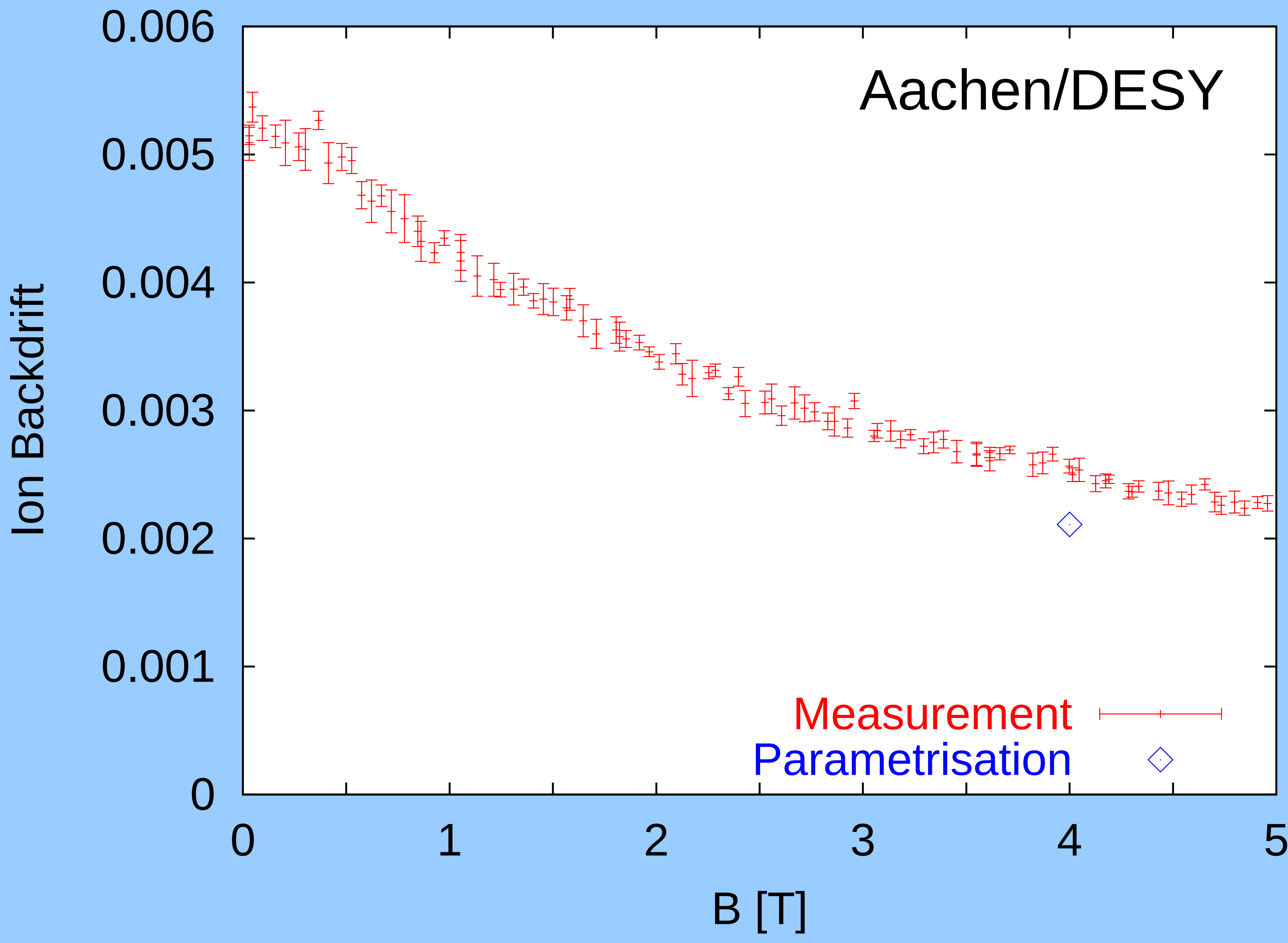
Parameter settings for minimal ion backdrift



- E_{Drift}: fixed at 200 V/cm
- U_{GEM1}: small influence
- E_{Trans1}: maximal
- U_{GEM2}: small influence
- E_{Trans2}: minimal
- U_{GEM3}: maximal
- $E_{Induction}$: maximal

U_{GEM1} and U_{GEM2} allow variation of eff. Gain, without changing the IB.

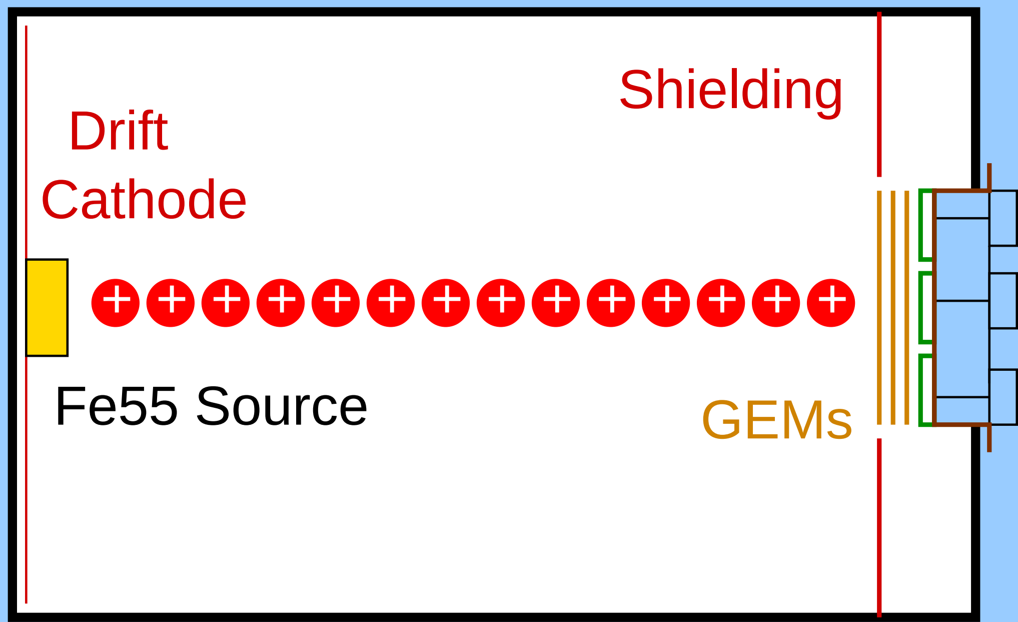
Ion Backdrift in a Magnetic Field



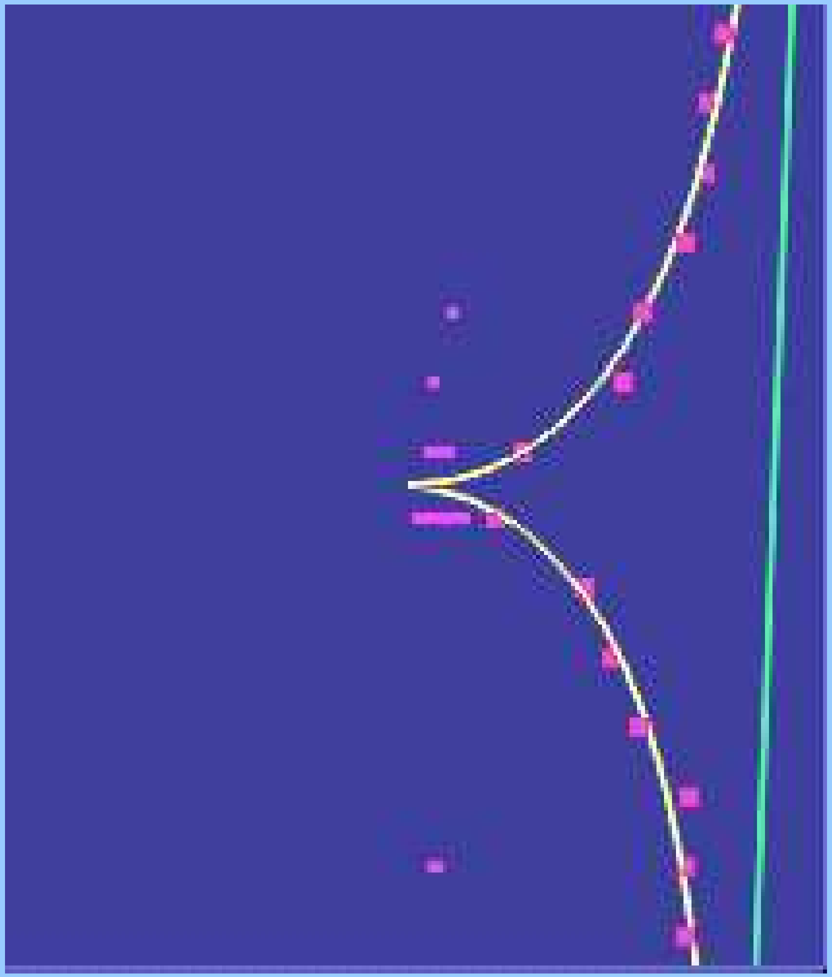
Ion Backdrift: Track Measurements

Application of a radioactive ^{55}Fe source at the cathode exactly opposite of the readout

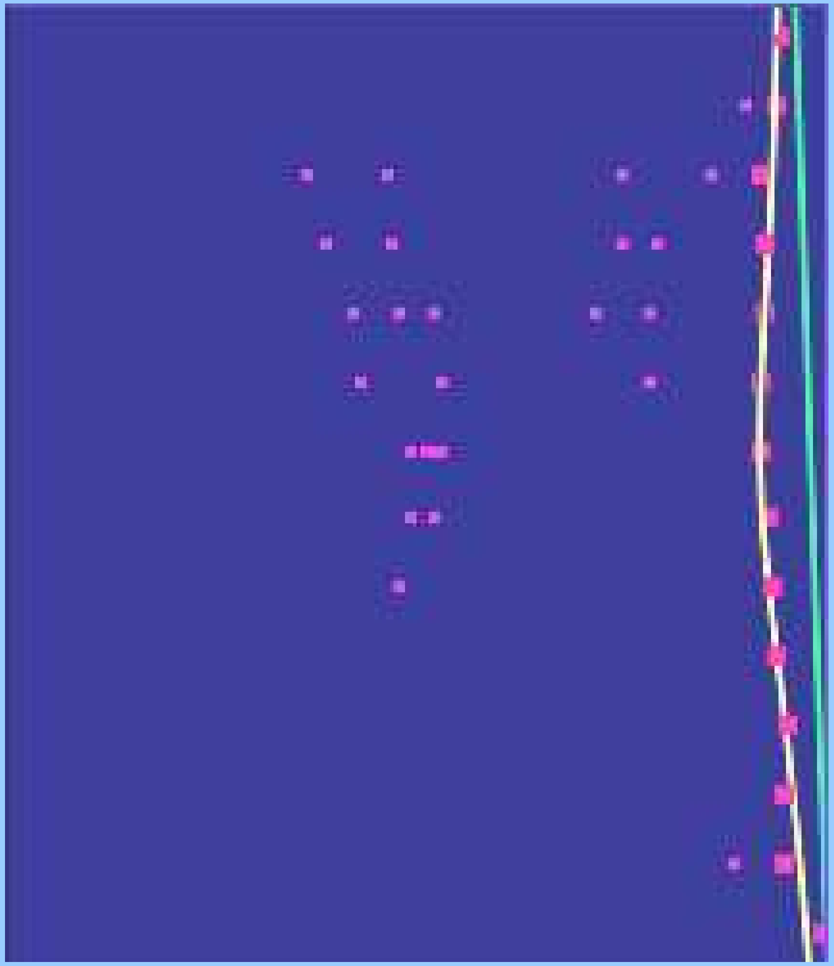
- Continuous creation of a large amount of electrons
- Forming of an ion tube between source and readout



Ion Backdrift: Track Distortions

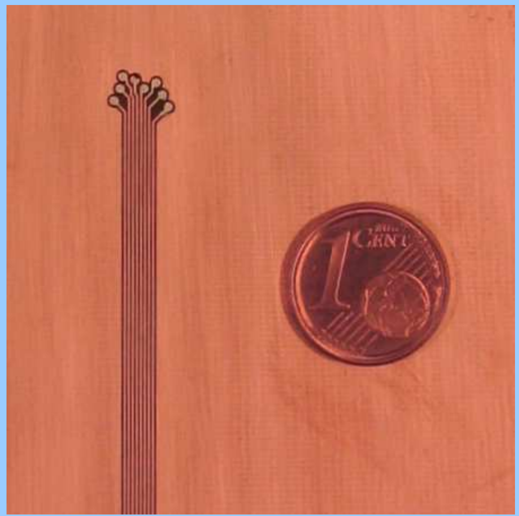


large ion backdrift

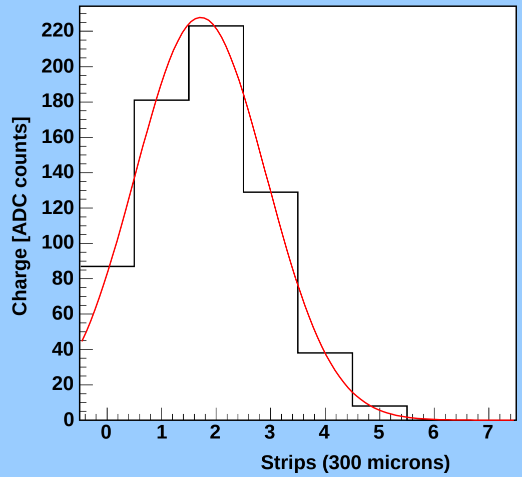


small ion backdrift

Pulse Width Studies



300 μm pitch

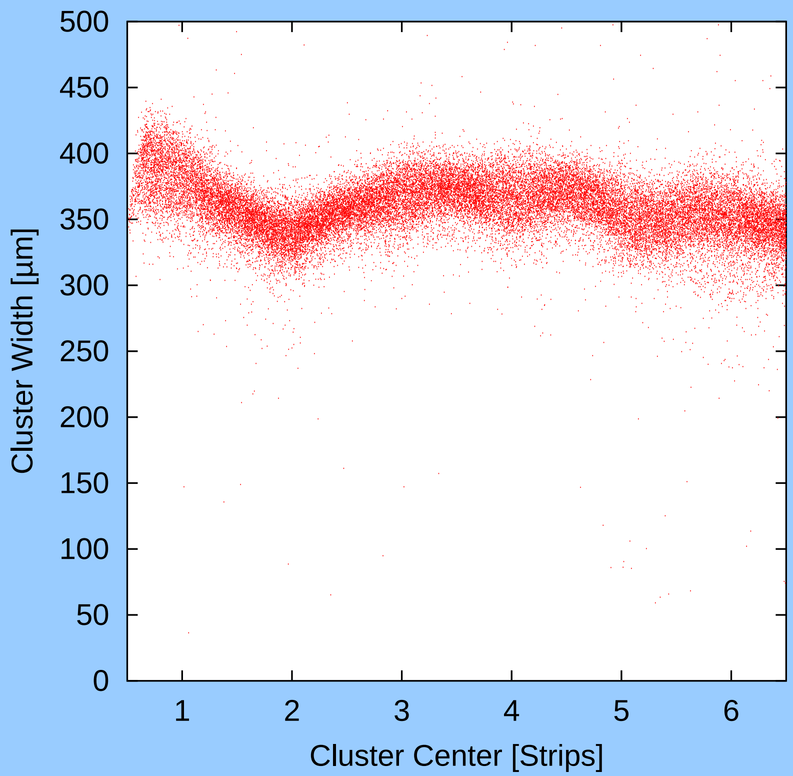


spatial distribution for one event

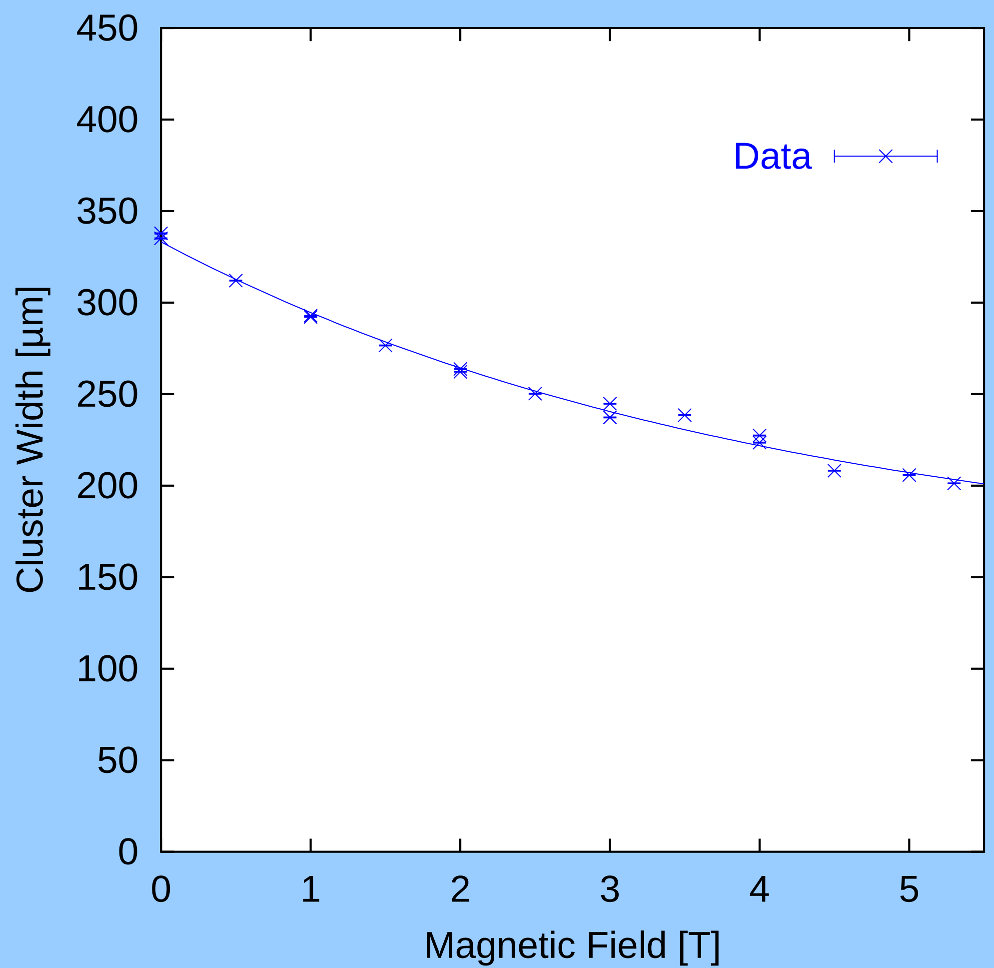
fit data with

gaussian using $\bar{x}$ and σ

data points for 30 000 events



Pulse Width in Magnetic Field



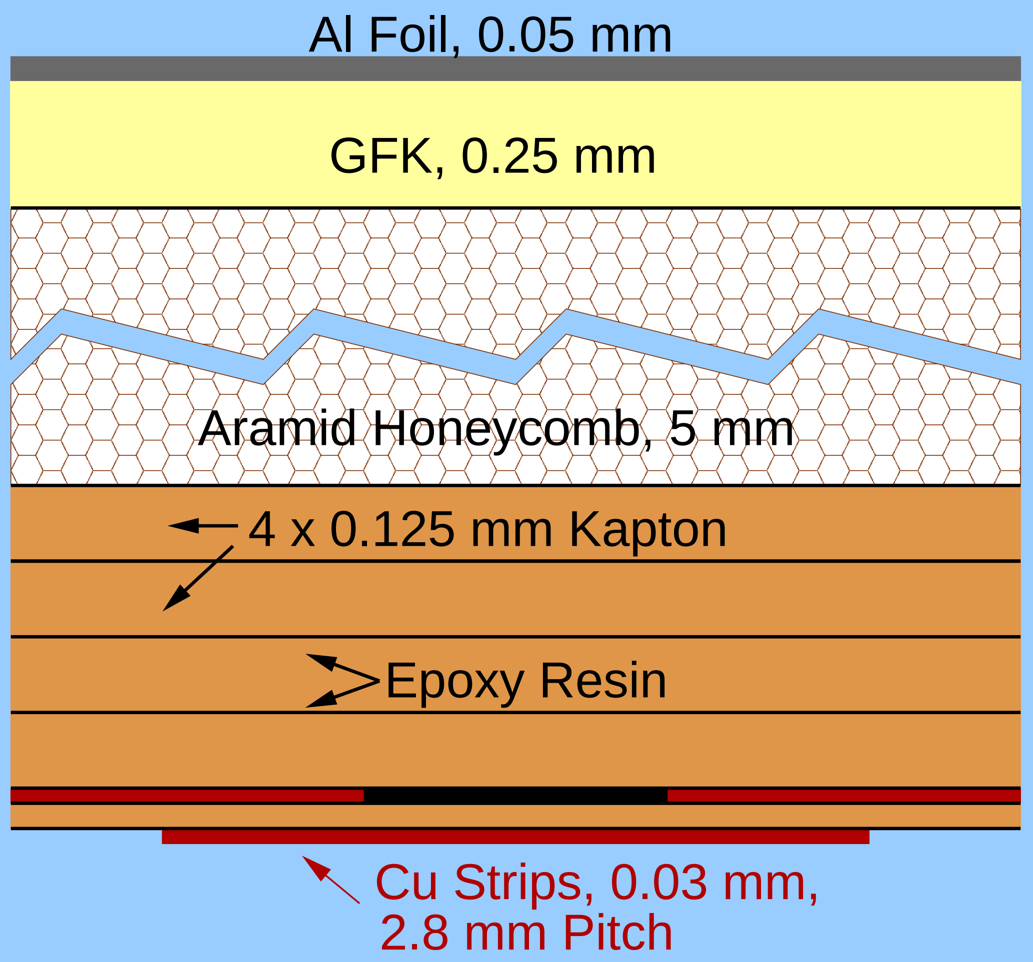
E / B field dependence (diffusion):

$$\sigma_{\mathrm{diff}} \propto \frac{1}{\sqrt{1+\omega^2(B)\tau^2(E)}}$$

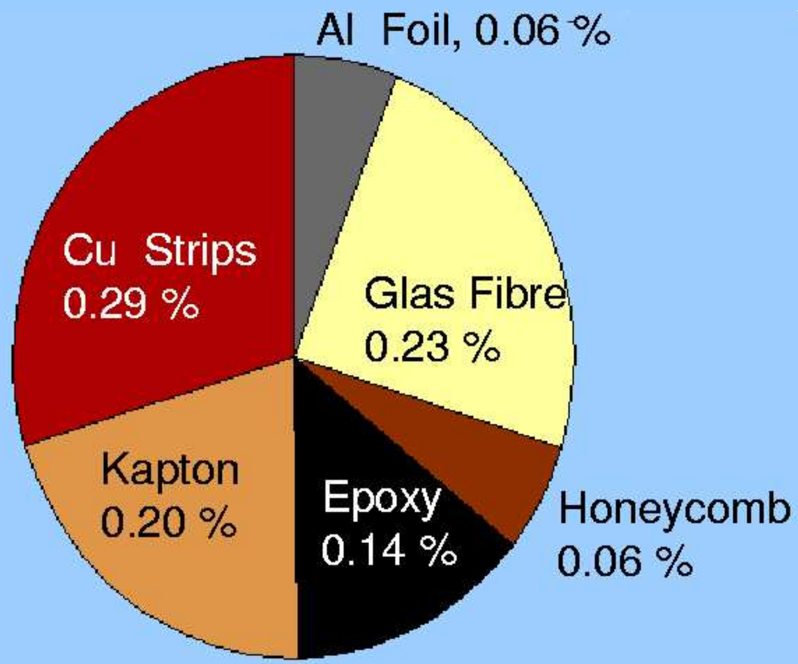
TPC Prototype: Construction

- 5T Magnet at DESY
  $\Rightarrow$ 260 mm diameter
- SMD resistors as voltage divider $\Rightarrow$ pitch = 2.8 mm
- GEM readout from test TPC is used
- drift distance = 26 cm
- maximum drift field = 1000 $\frac{V}{cm}$
- materials with low density

TPC Prototype: Radiation Length



fraction of radiation length

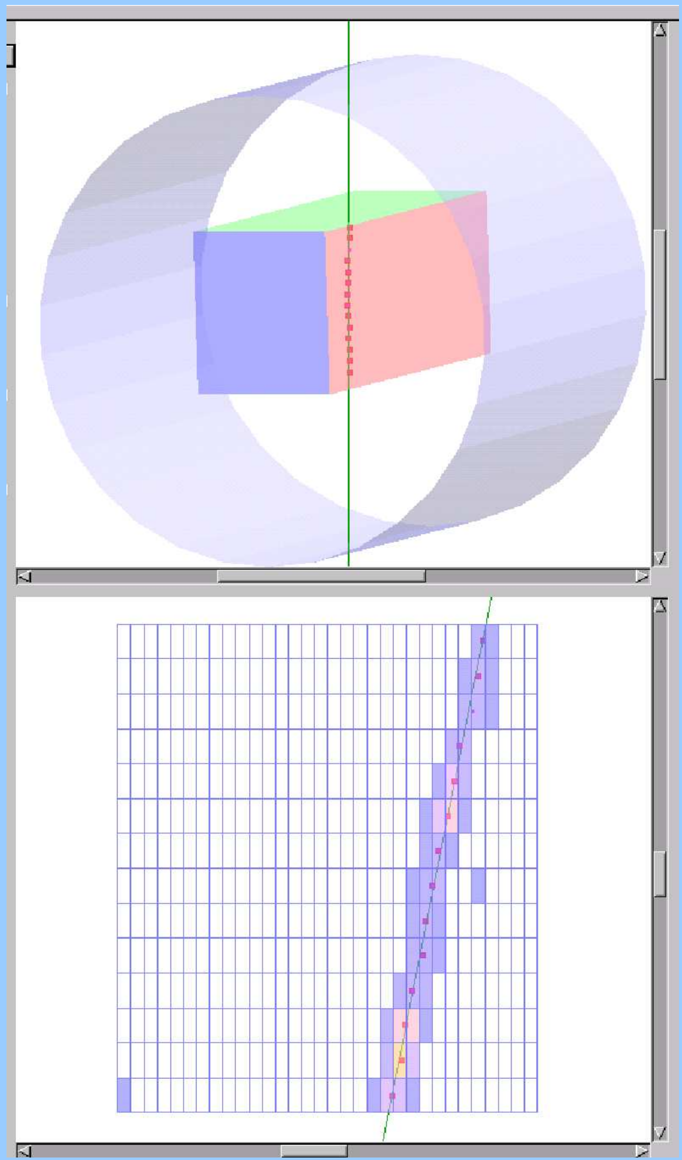


altogether 1% radiation length

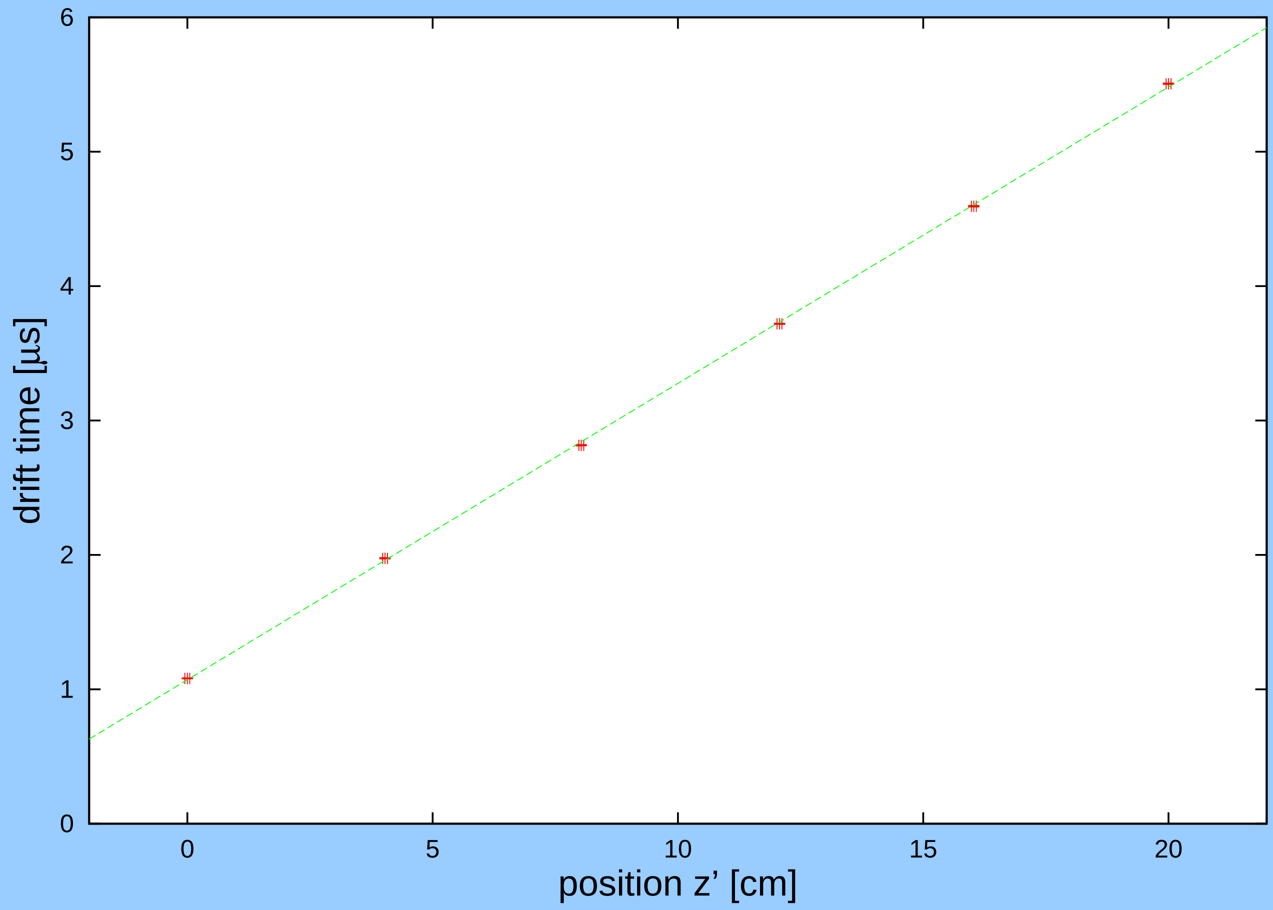
$\Rightarrow$ 3 % radiation length possible for TESLA-TPC

TPC Prototype: First Results

first cosmic muon



homogeneous drift velocity



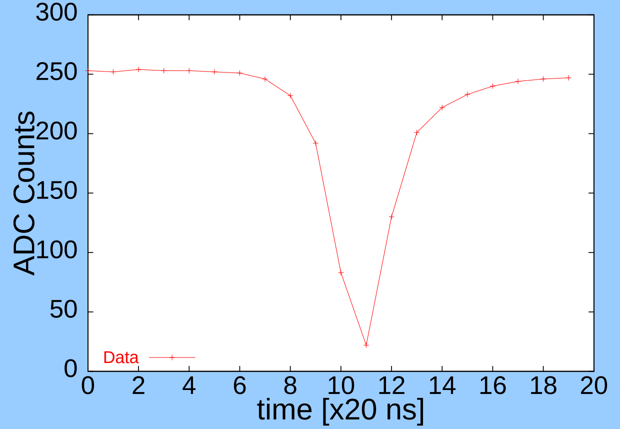
TPC Prototype: Electronics

Goal: Develop a test readout with 512 channels for our TPC.

Requirements

- Fast preamplifiers to take advantage of the fast GEMs
- Fast data aquisition to allow reasonable operation in test beam runs
- Fast ADCs to match the preamplifier speed
- Small preamplifiers to allow compact readout design with small pads

Preamplifier



^{55}Fe Pulse

Status

- First, fast signals with preamplifiers
- No ADCs yet

Summary

- Ion backdrift is well understood
- A magnetic field of 4 T decreases ion backdrift by a factor of ≈ 2, a value of $\leq$ 2.5$\times$10^{-3} was achieved
- The magnetic field also reduces the cluster width. Values as small as $\sim$ 200 μm in 4 T magnetic field are observed
- Prototype TPC with 28 cm diameter and 26 cm drift length constructed
- First results with new electronics

GEMs work well as amplification structure for a TPC!

Outlook

- Simulations of the linear collider TPC
- Investigate the maximum permitted ion backdrift
- Build a hodoscope with silicon modules to analyse the spatial resolution
- Finish development of new electronics for use with the prototype

Test beam runs with our prototype!

Backup: Charge Transfer Coefficients

- Collection Efficiency

$$C^{\pm} = \frac{N_{\mathrm{e}^-,\mathrm{I}^+} \text{ collected into hole}}{N_{\mathrm{e}^-,\mathrm{I}^+} \text{ before GEM}}$$

- Extraction Efficiency

$$X^{\pm} = \frac{N_{\mathrm{e}^-,\mathrm{I}^+} \text{ extracted from GEM}}{N_{\mathrm{e}^-,\mathrm{I}^+} \text{ in GEM-hole}}$$

- Gain (single GEM)

$$G = \frac{N_{\mathrm{e}^-} \text{ in GEM-hole}}{N_{\mathrm{e}^-} \text{ collected into hole}}$$

Backup: Charge Transfer Coefficients 2

- Effective Gain (multiple GEMs)

$$G_{eff} = \frac{I_{\text{Anode}}}{I_{\text{primary}}} = \prod_{i=1}^{N_{\text{GEMs}}} C_i G_i X_i$$

- Relative Ion Backdrift

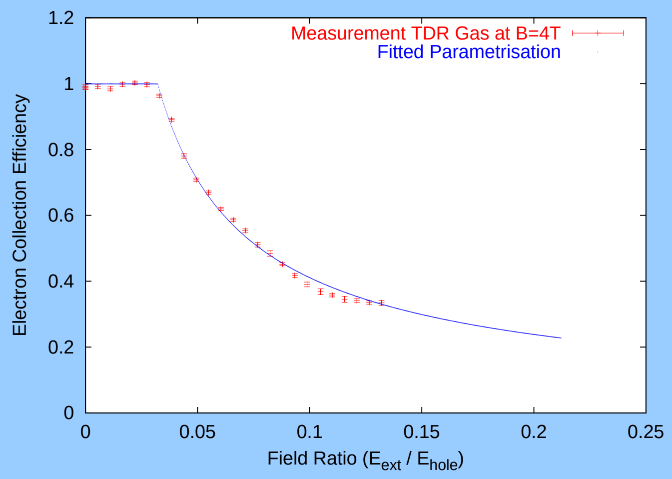
$$IB := \frac{I_{\text{Cathode}}}{I_{\text{Anode}}}$$

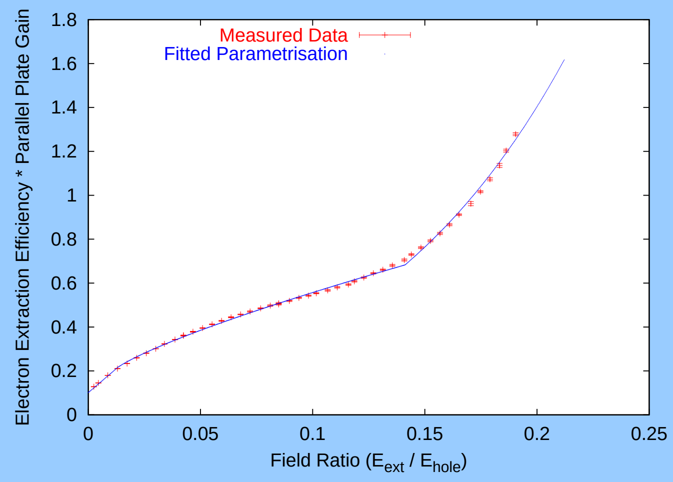
$$\Rightarrow G_{\text{eff}} \cdot IB = \frac{I_{\text{Cathode}}}{I_{\text{primary}}}$$

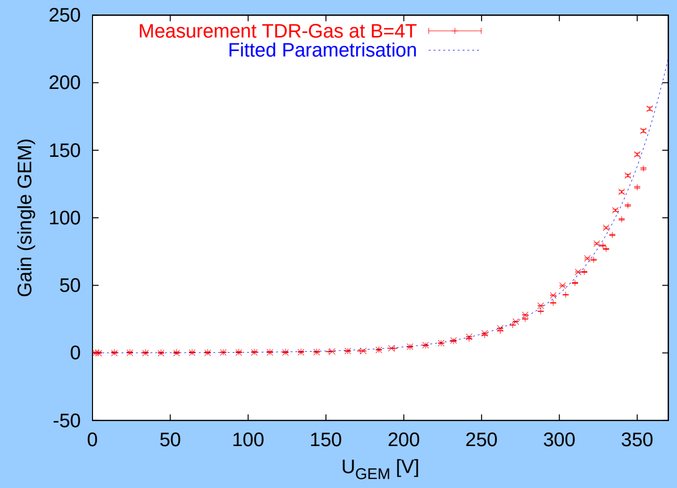
$$\boxed{\Rightarrow I_{\text{Cathode}} \approx I_{\text{primary}} \Leftrightarrow IB = \frac{1}{G_{\text{eff}}}}$$

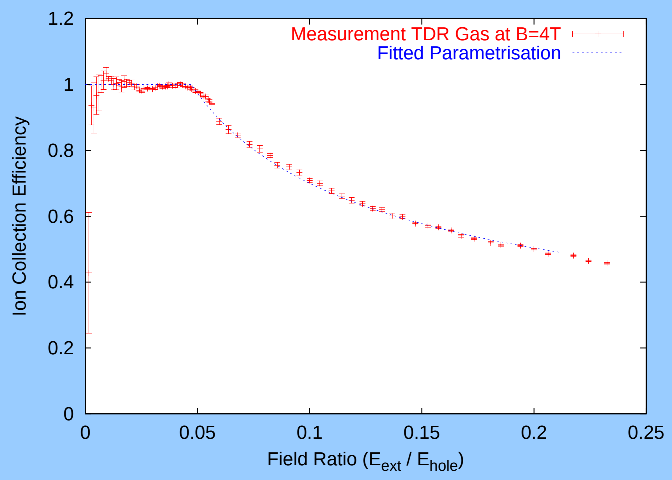
For this Analysis: $G_{eff} = 10^4 \Rightarrow$ Goal: $IB = 10^{-4}$

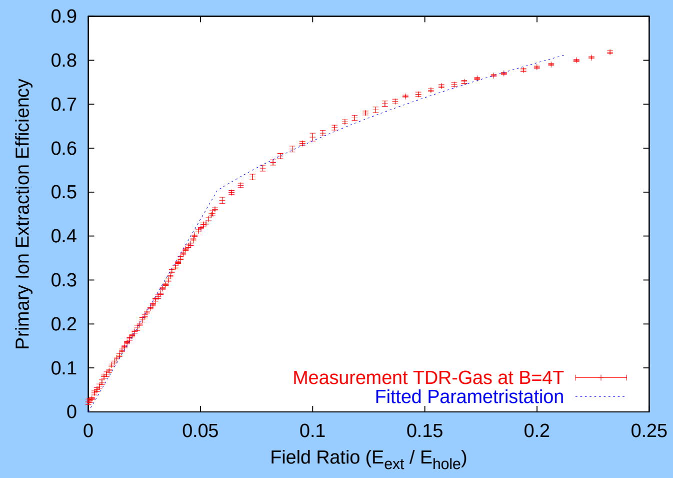
Backup: Parametrisation of Transfer Coefficients

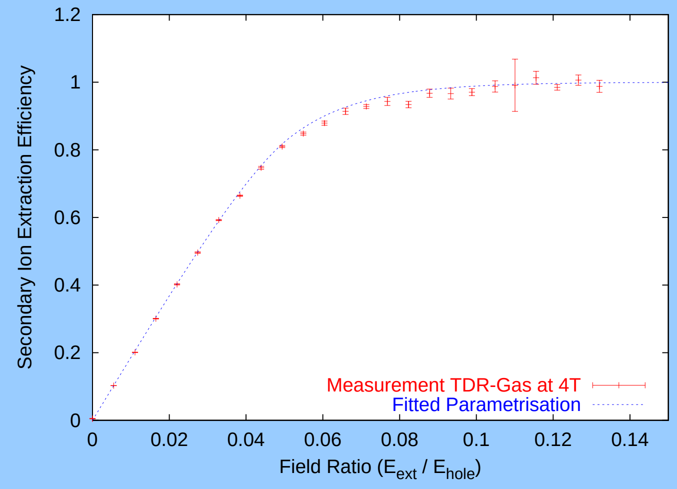






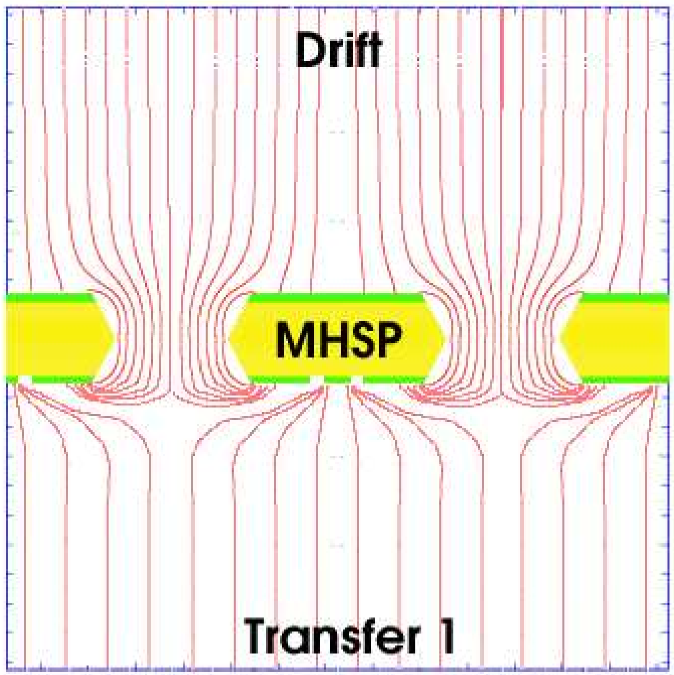




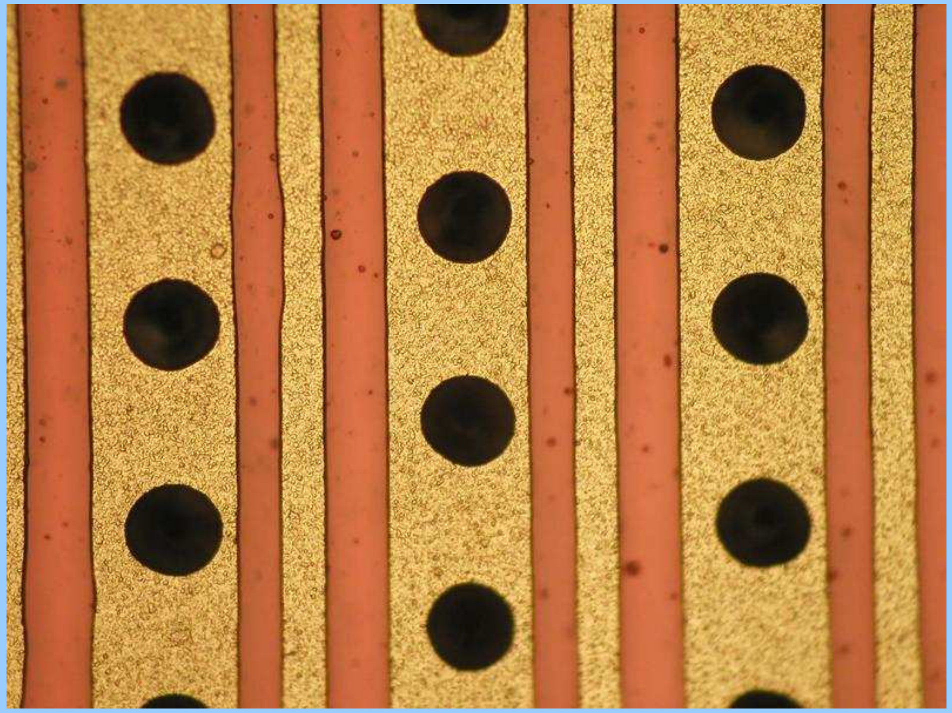


All Parametrisations for TDR Gas at B=4T!

Replace the first GEM with a MHSP:

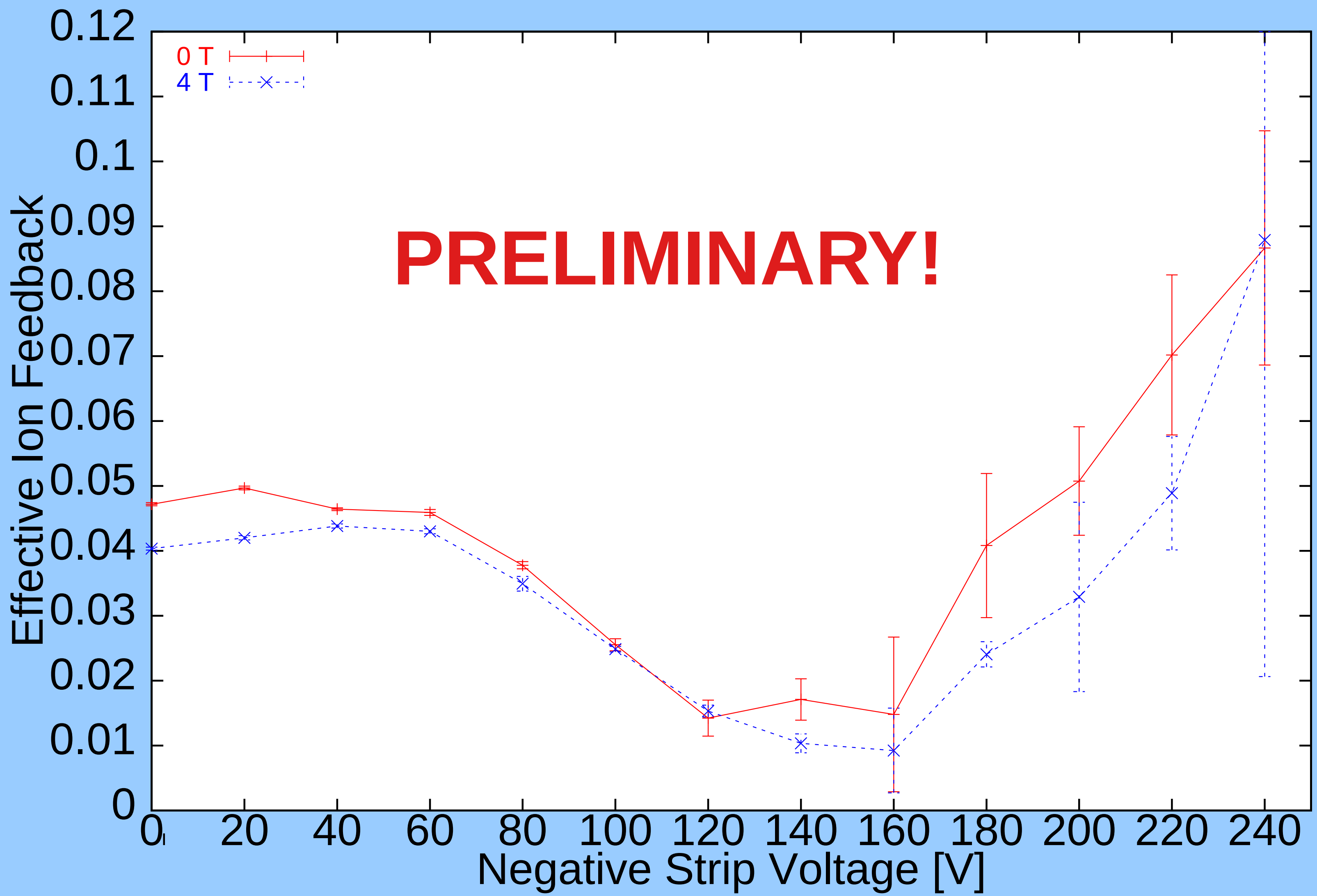


sketch



Idea: Negative strip voltage $\Rightarrow$ Ions are collected on the strips, while electrons, due to diffusion, pass.

Backup: First Measurements with MHSPs



Not yet optimised setting!

Backup: Fit 1

- line of backdrifting ions of infinitesimal thickness and infinite length $\Rightarrow \vec{E} = \frac{\alpha'}{r}\frac{\vec{r}}{r}$
- $v_{drift} \propto \vec{E}$ for small fields

Equation of motion for point:

$\frac{d\vec{r}}{dt} = -M\vec{E}$ M is electron mobility

In polar coordinates: $\frac{dr}{dt} = -M\frac{\alpha'}{r}$

$$\Rightarrow r(t) = \sqrt{r_0^2 - \alpha t}$$

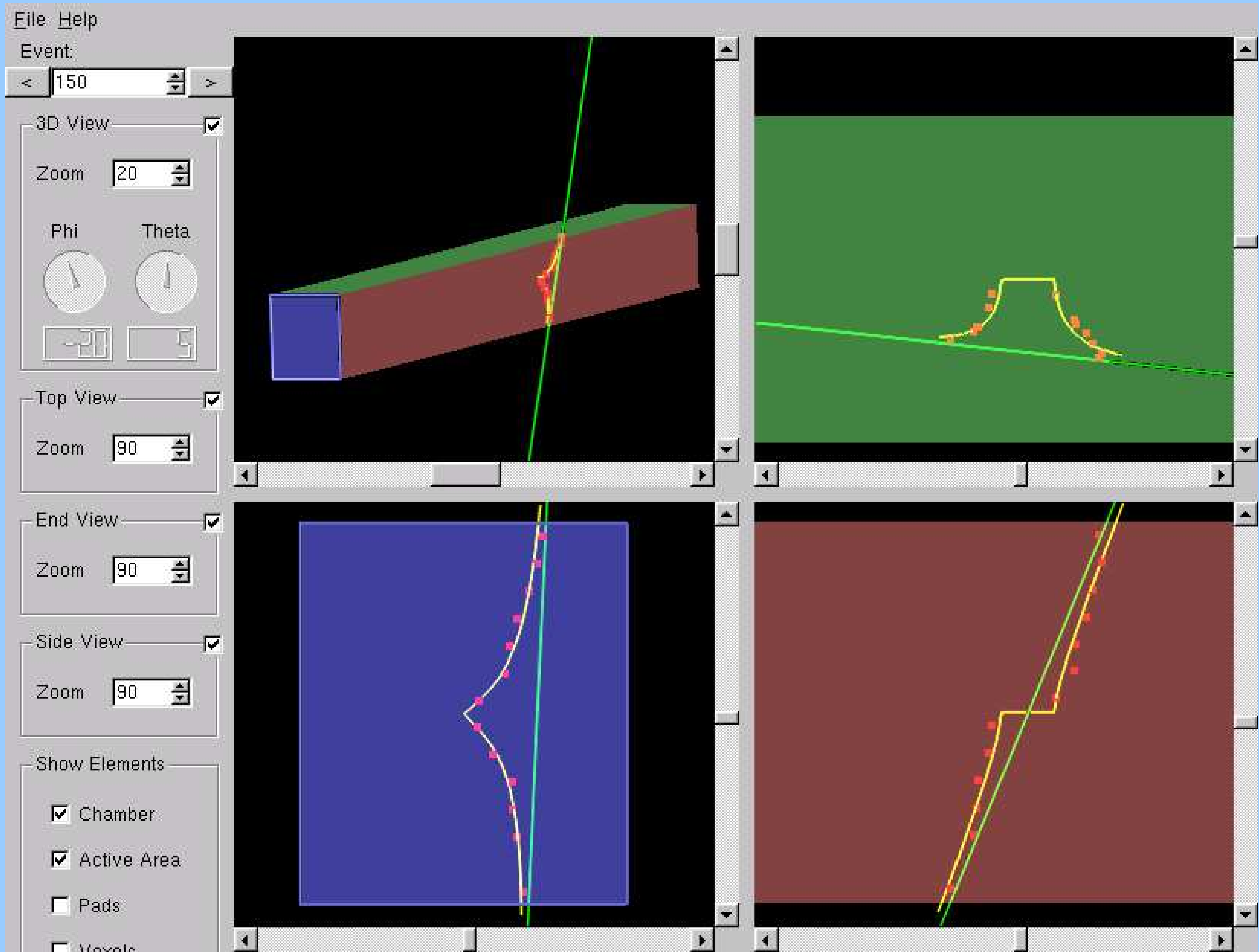
Start with straight line $x = ay + b$
in polar coordinates: $x = r\cos(\varphi) \quad y = r\sin(\varphi)$

$$r_0 = \frac{b}{\cos(\varphi_0) - a\sin(\varphi_0)}$$

φ does not change with time

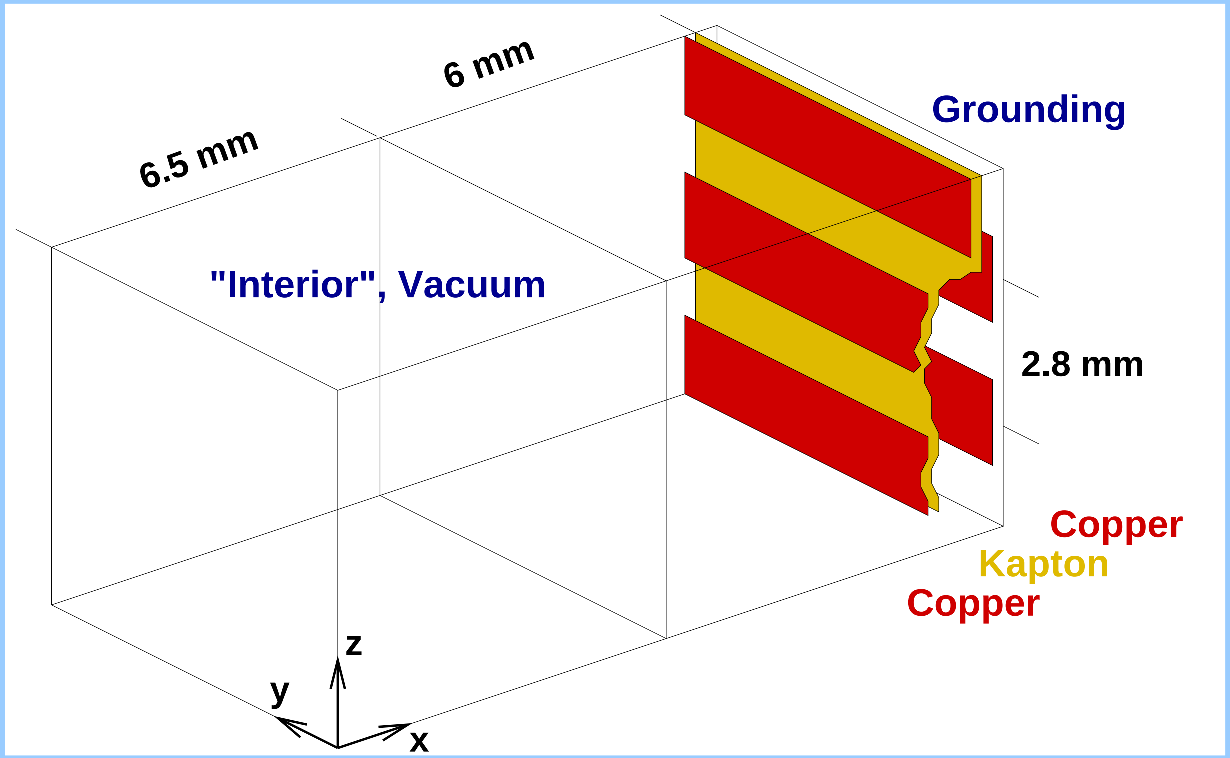
$$\Rightarrow r(\varphi, t) = \sqrt{\frac{b^2}{\left(\cos(\varphi) - a\sin(\varphi)\right)^2} - \alpha t}$$

Backup: Example for Fit

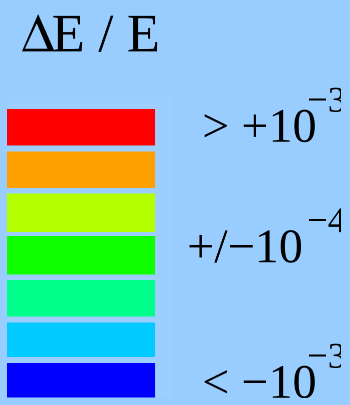


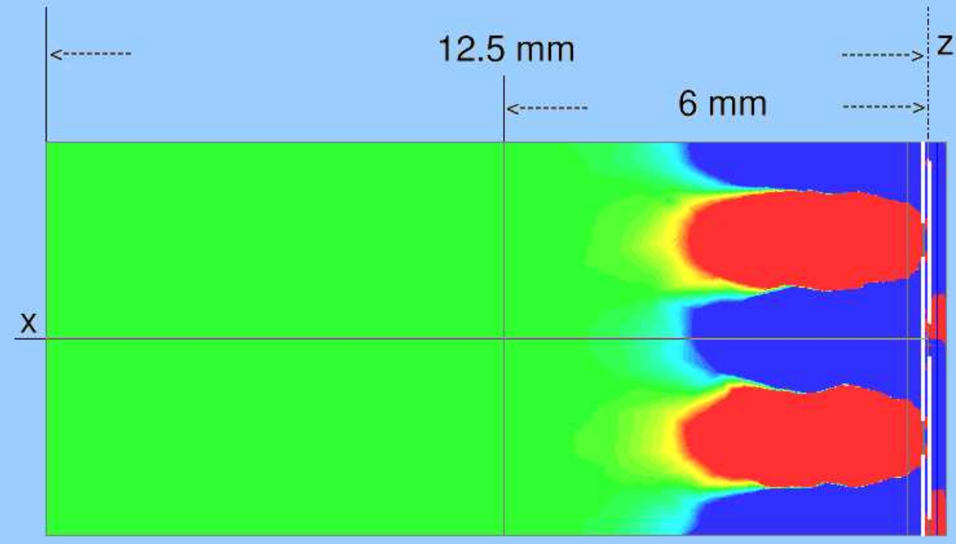
TPC Prototype: Simulation

- optimisation of the field cage
- simulations of strip geometry with Maxwell 3D:
  copper strips on one or both sides,
  different ratios of strip width and distance with fixed pitch (2.8 mm)



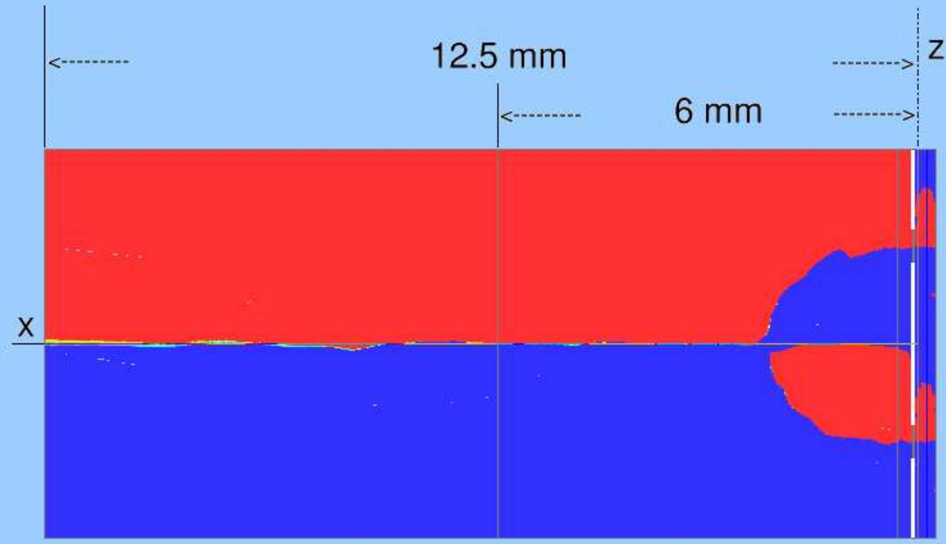
Simulation: Results





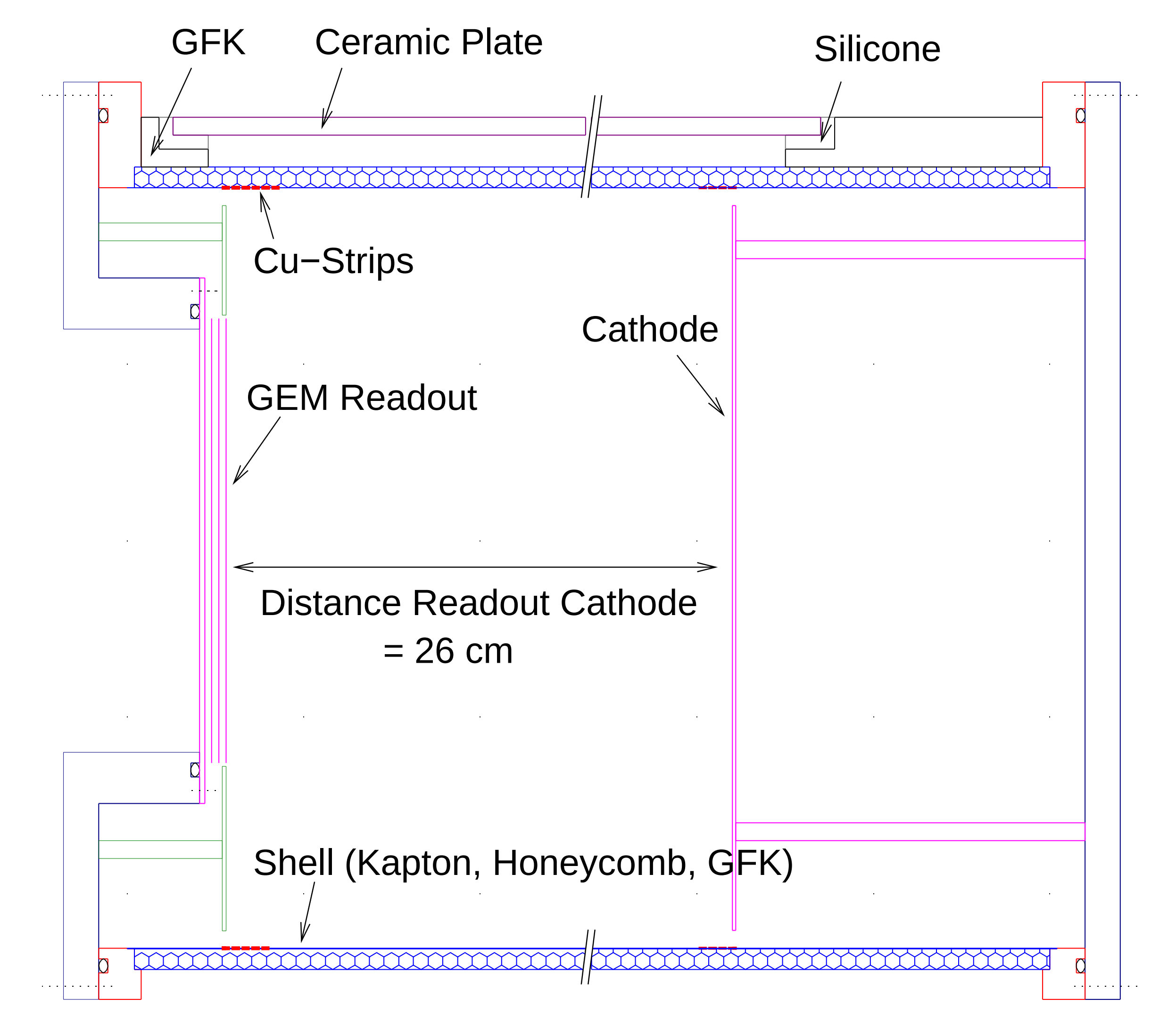
$E_{parallel}$, strips on both sides

Cu strips:
width 2.3 mm
distance 0.5 mm



$E_{parallel}$, strips on one side

Backup TPC Construction



xz profile of the TPC prototype

Ø= 260 mm

pitch = 2.8 mm

R = 4.7 MΩ (SMD)

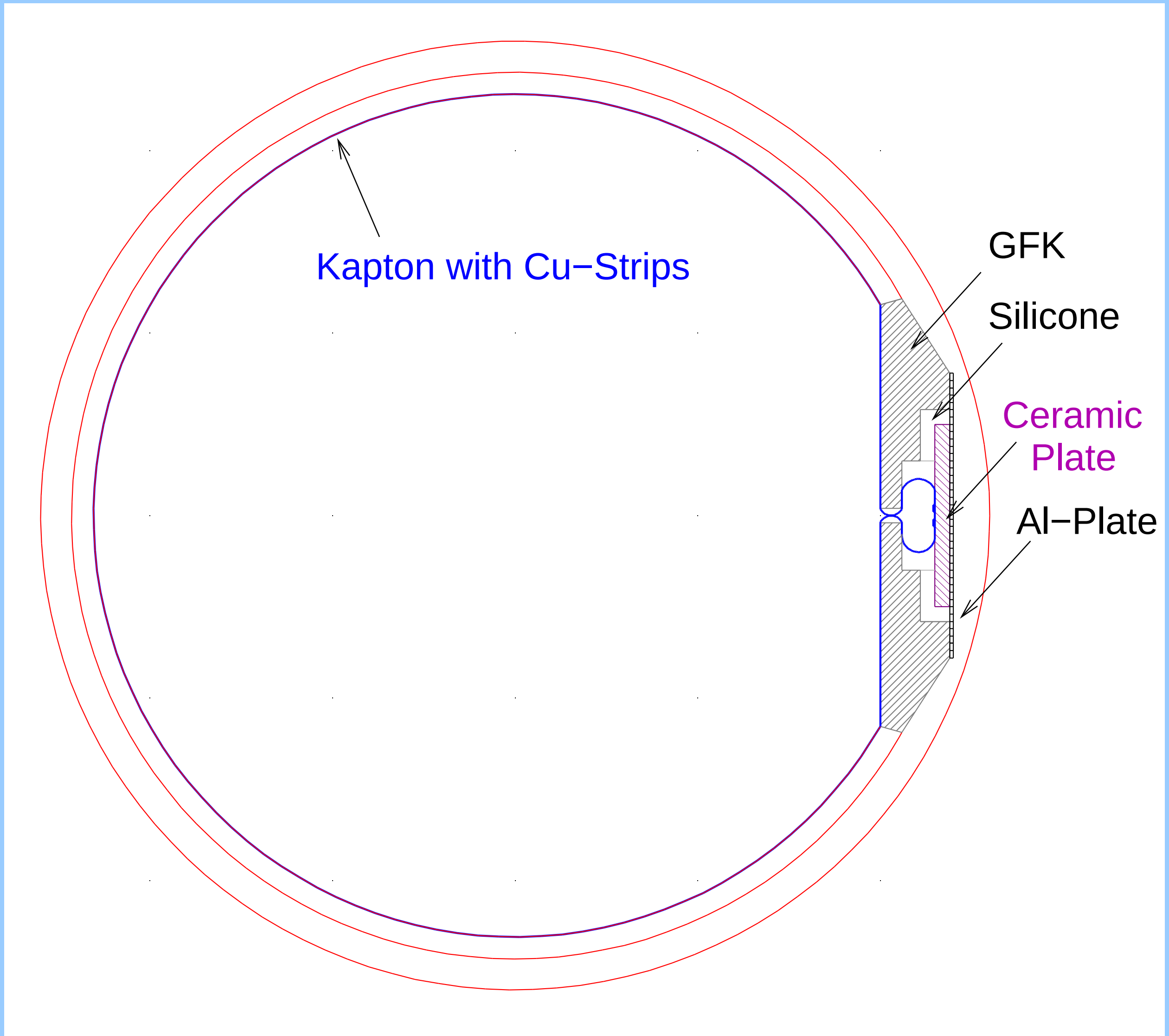
ΔU_{max} = 26 kV

ℓ_{drift} = 26 cm

E_{max} = 1000 V/cm

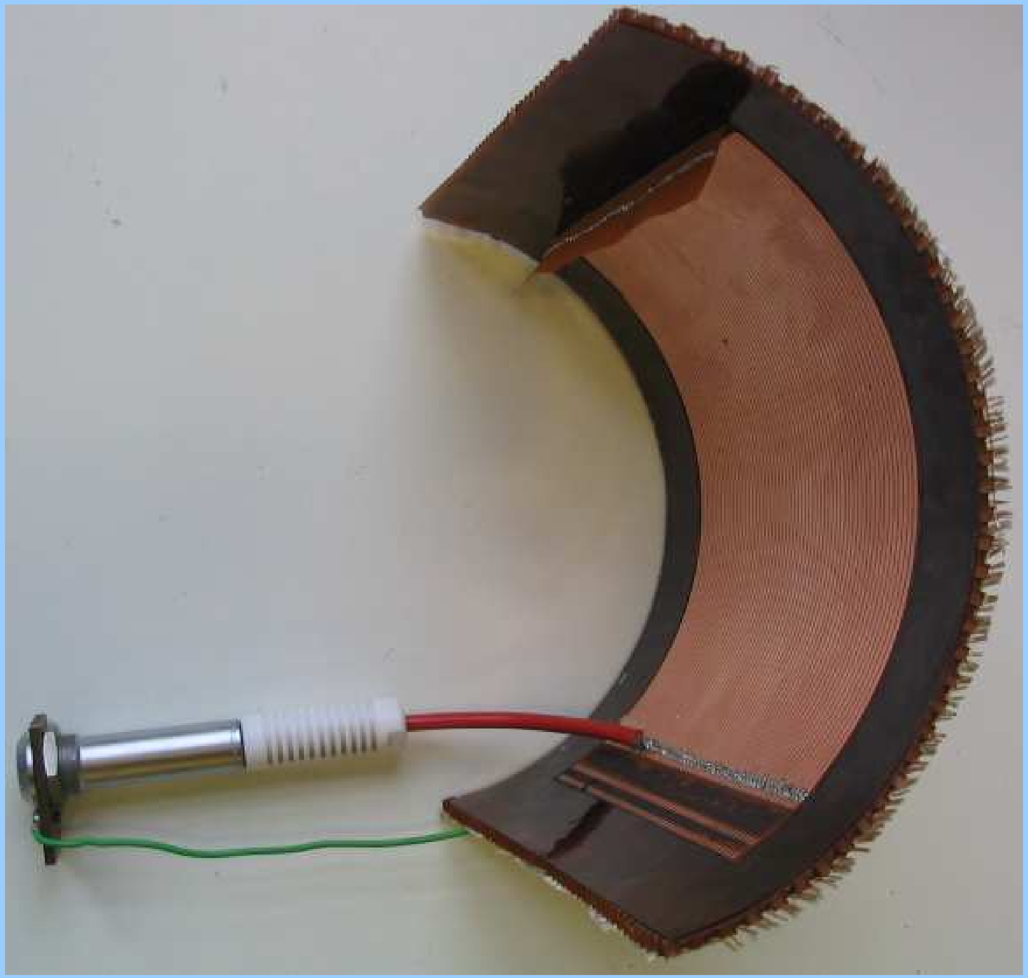
δU_{max} = 277 V/strip

Backup: TPC Fieldcage



xy profile of the field cage

Backup: HV Tests for the TPC Prototype



test of dielectric strength of the sandwich structure:

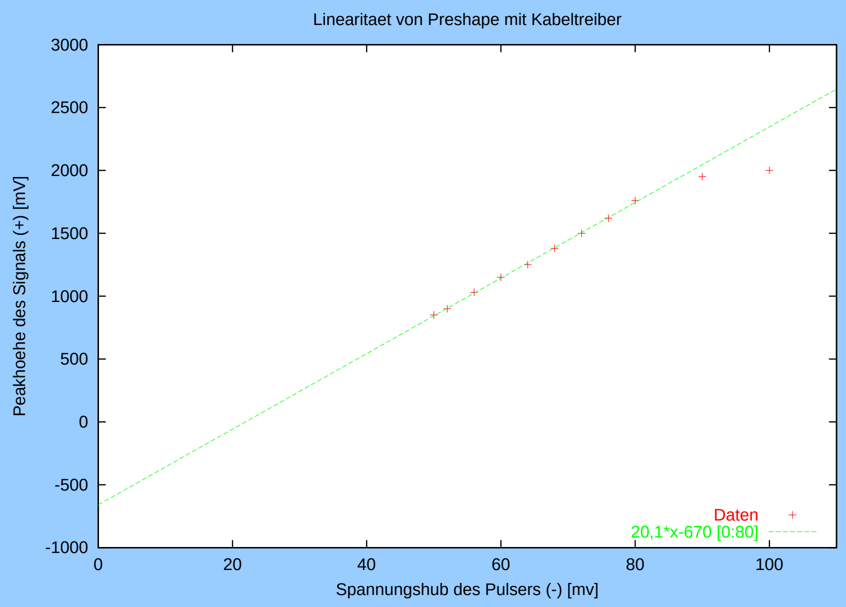
$U = 30\ \mathrm{kV}$ one week without trip

final strip design: inside: width 2.0 mm, distance 0.8 mm
outside: width 1.8 mm, distance 1.0 mm

Backup: Cable Driver

- discrete 8 channel amplifier cards
- connected to preshape via $\sim$25 cm cable
- 50Ω output $\longrightarrow$ LEMO

Problem: hot and rather large $\Rightarrow$ new design desirable



First test of linearity of preshape with cable driver looks promising!

Backup: ADCs

criteria	requirements	status
bus type	VME	VME
resolution	$\geq$ 10 bit	8 bit
sampling rate	$\geq$ 40 MHz	50 MHz
channels per module	$\geq$ 16	4
channels total	512	20

$\Rightarrow$ no solution yet!

But 32 channel ADC from TU Munich (Igor Konorov) are being tested!