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

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On behalf of the LC TPC groups:

Aachen, Berkeley, Carleton, Cracow, DESY, Hamburg, Karlsruhe, MIT, Montreal, MPI Munich, NIKHEF, Novosibirsk, Orsay, St. Petersburg, Rostock, Saclay, Victoria

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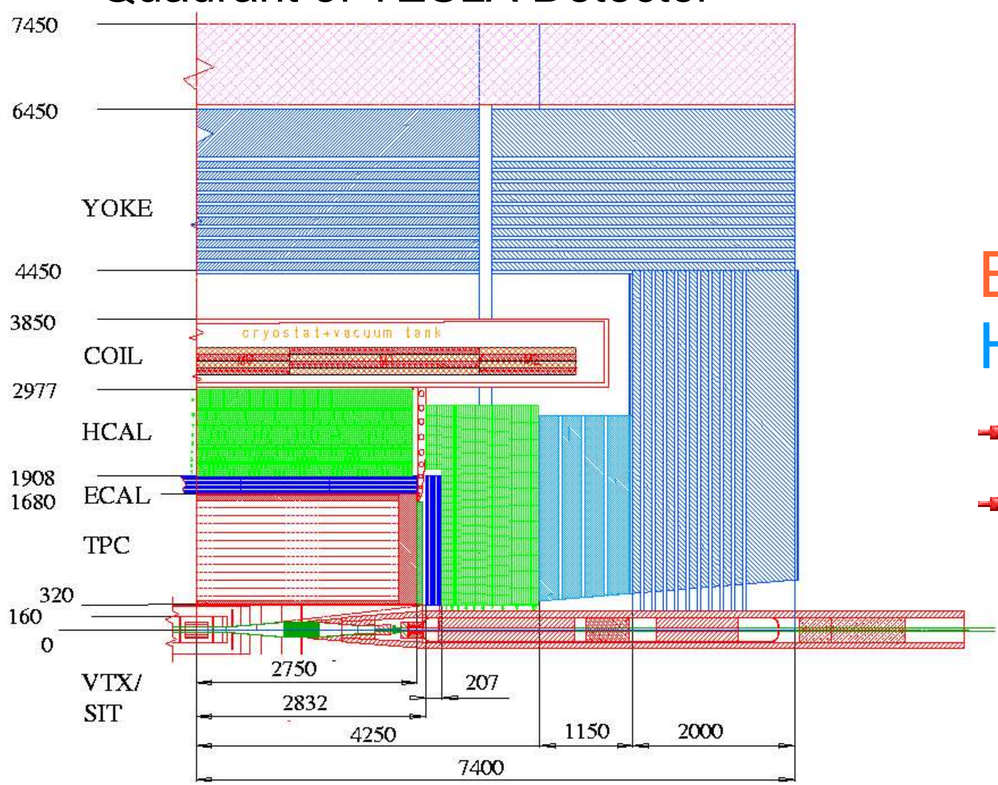
A Detector for a Linear Collider

LC: e^+e^- collider, $m_Z \leq \sqrt{s} \leq 1$ TeV,

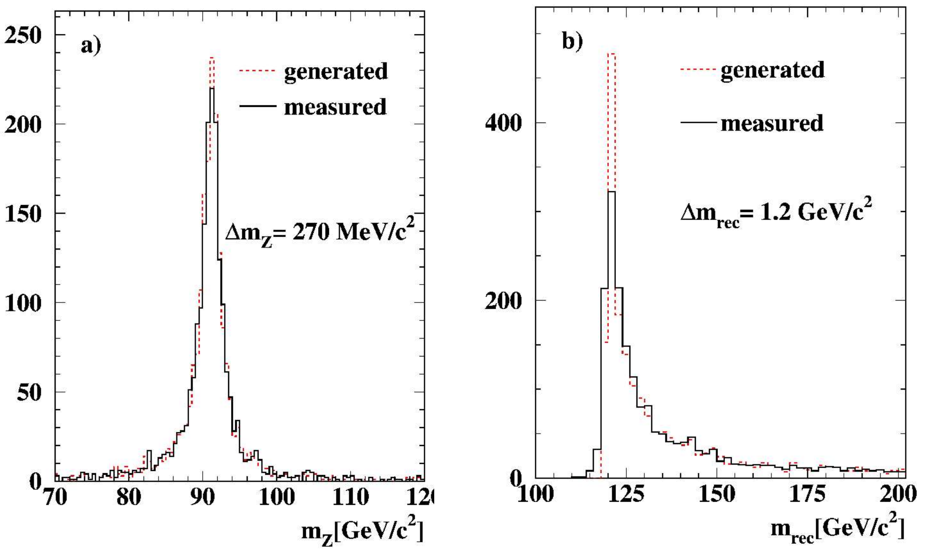
$L \leq 5\times10^{34}$ cm^{-2}s^{-1}

LC detector concept focuses on precision

Quadrant of TESLA Detector



Higgs-strahlung $e^+e^- \to HZ \to Hl^+l^-$



Example: Reconstruction of Higgs properties requires:

- excellent momentum resolution
- good particle identification

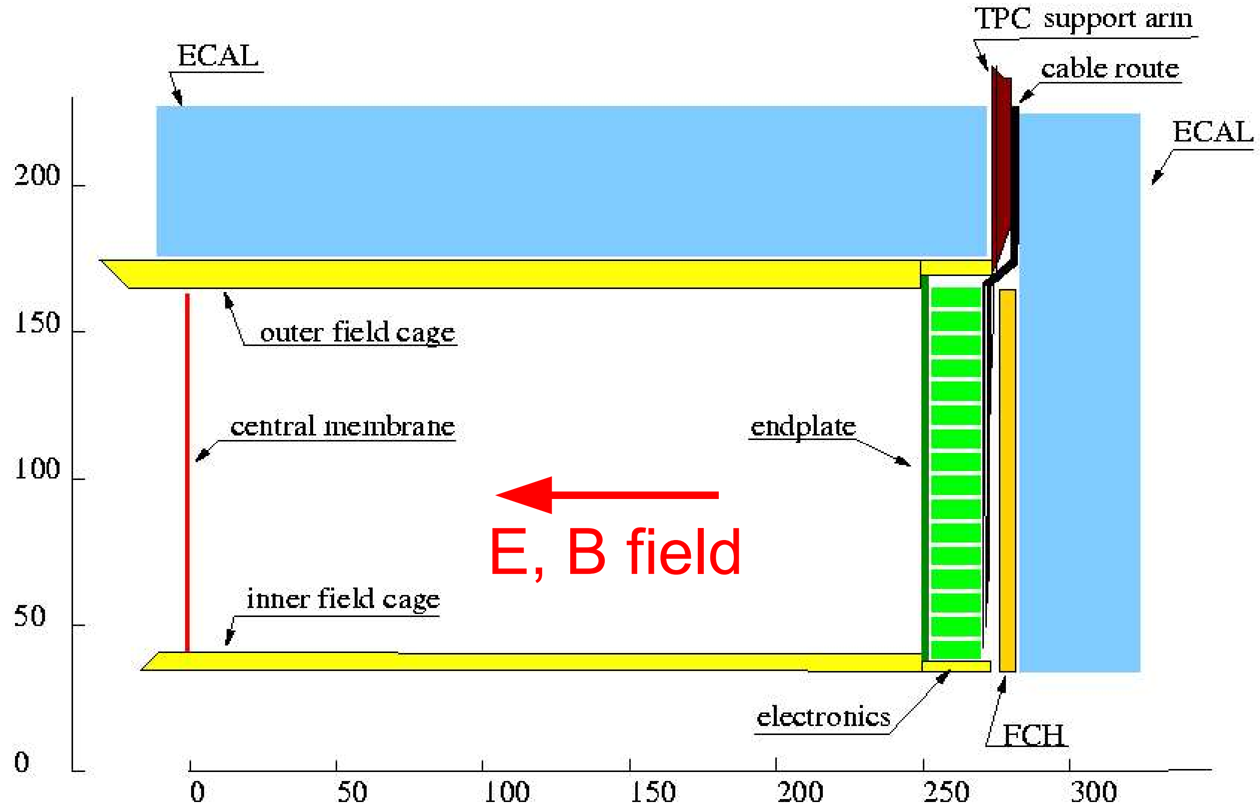
High resolution tracker (+ vertex detector) essential to achieve this goal

Time Projection Chamber (TPC)

Instrument a large volume with many voxels and a minimum amount of material, 3D reconstruction, good particle identification via dE/dx

Example: TESLA TPC

- Length 5.46 m, ∅ 3.4 m
- Magnetic field 4 T
- Field cage 0.03 X_0
- 1.2×10^6 channels
- 200 points per track

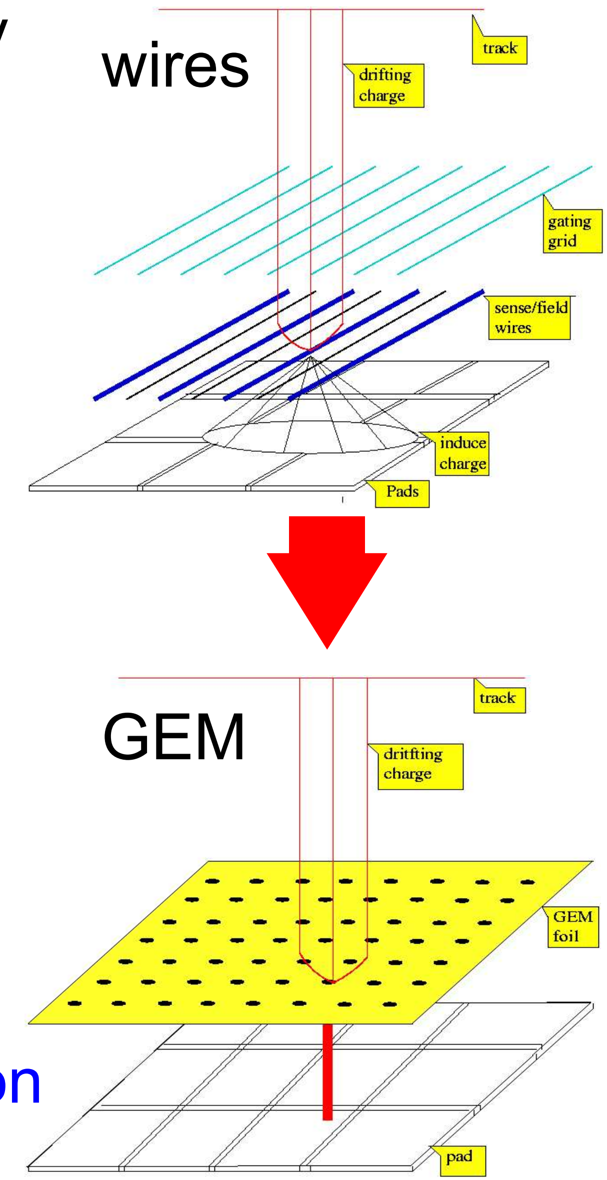


Envisaged precision:

- Momentum resolution: $\Delta p_t/p_t^2 = 1.5\times10^{-4}$ GeV^{-1} (1/10 x LEP)
- Single point resolution: 100 μm
- dE/dx accuracy: 5 %

New Gas Amplification Devices

Replace conventional MWPC system (wires) by Micro Pattern Gas Detectors (MPGD):



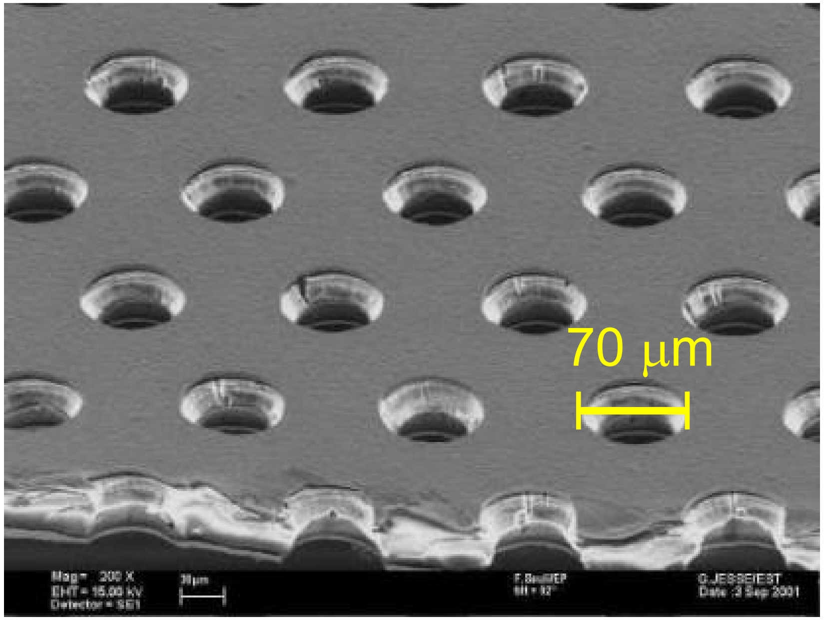
Most promising examples:

- Gas Electron Multiplier (GEM) (F. Sauli, 1996)
  $\rightarrow$ this talk
- Micromegas (Y. Giomataris *et. al.*, 1996)
  $\rightarrow$ talk by P. Colas

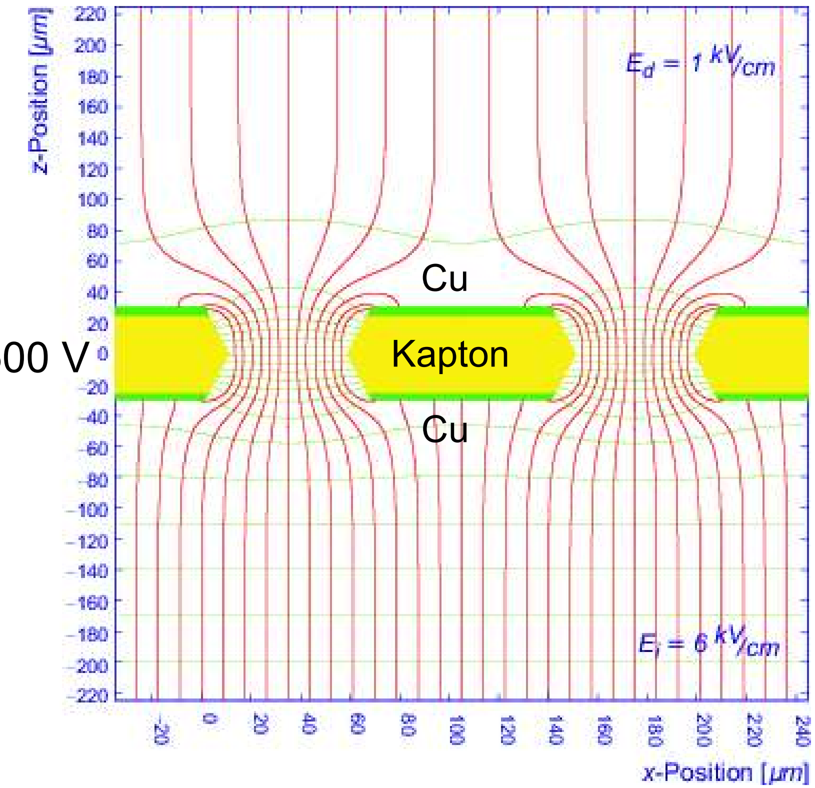
Advantages:
- Two-dimensional symmetry
- Amplification structure of order 100 μm
- Fast electron signal
- Intrinsic ion feedback suppression
- Allow simpler mechanics

The Gas Electron Multiplier (GEM)

- 50 μm thick Kapton foil
- 5 μm copper coating on both sides
- hexagonally aligned holes
  ∅ 70 μm, 140 μm pitch



300-500 V



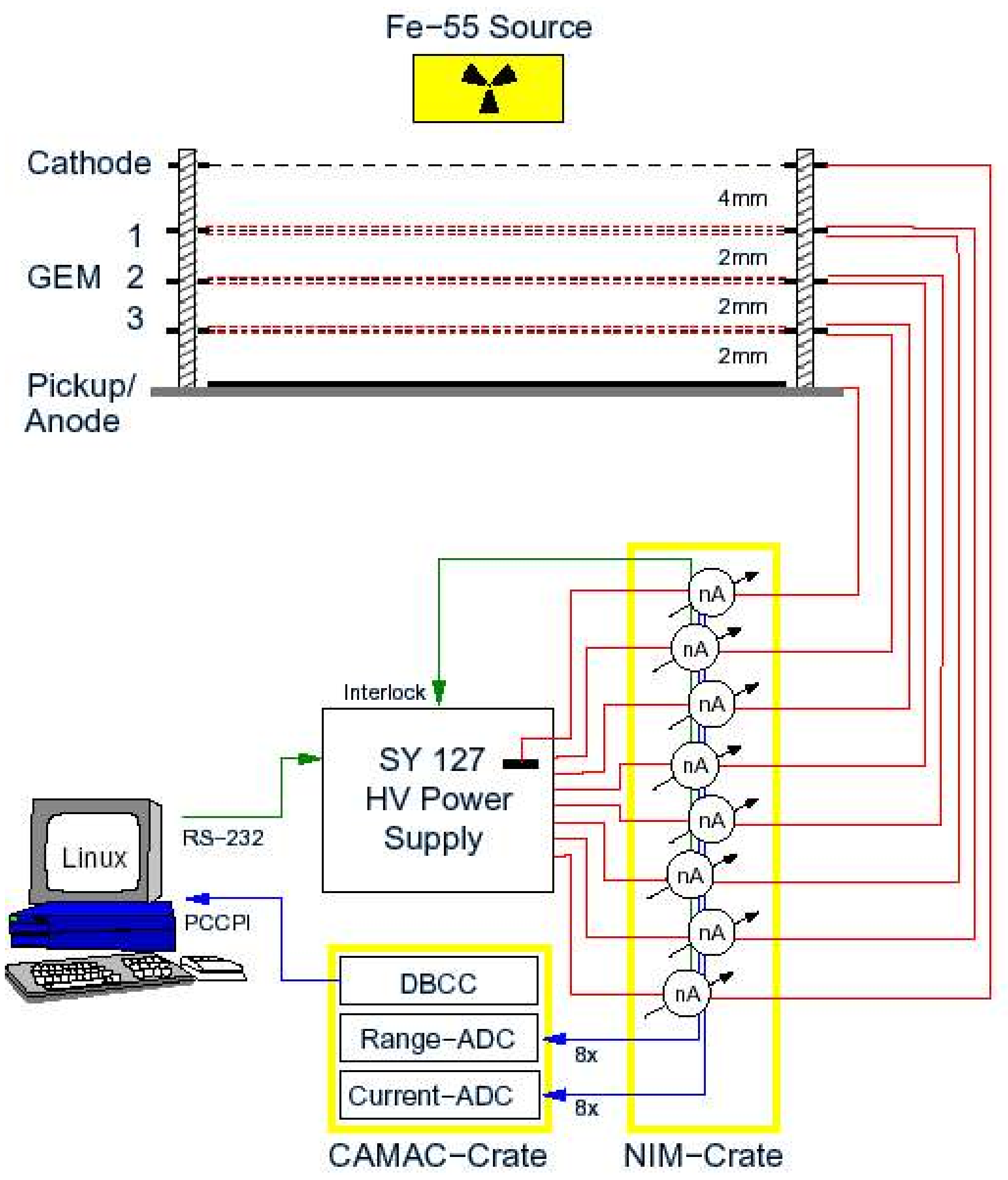
Multiple GEM structures:

- Safer operation
- More flexibility to optimize charge transfer

R&D Overview

- Study charge transfer through GEMs in high B fields
- Optimize GEM voltage settings:
  - Maximal transparency for electrons
  - Minimal transparency for ions ($\rightarrow$ distort drift field)
- Optimize field cage design
- Determine achievable spatial resolution in high B fields
- Prove reliable operation of TPCs with GEM amplification

Setup for Charge Transfer Measurements

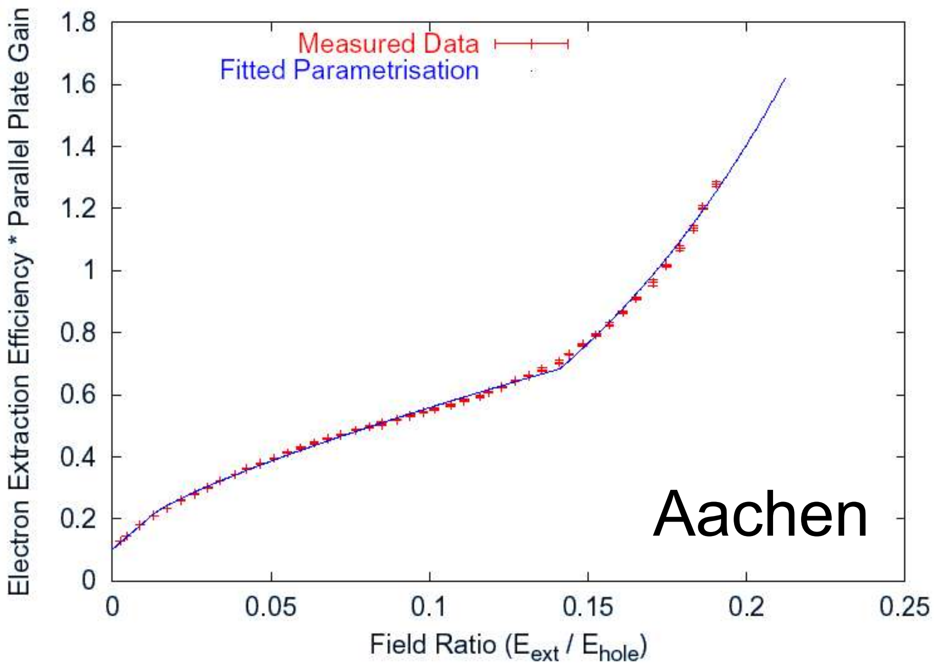


- Triple GEM structure with current readout
- Measurements in super-conducting 5 T magnet at DESY

Parametrization of Transfer Coefficients

Measured and parametrized for Ar-CH_4-CO_2 (93-5-2) at 4 T

Example: e^- extraction efficiency



Corresponding parametrizations for:

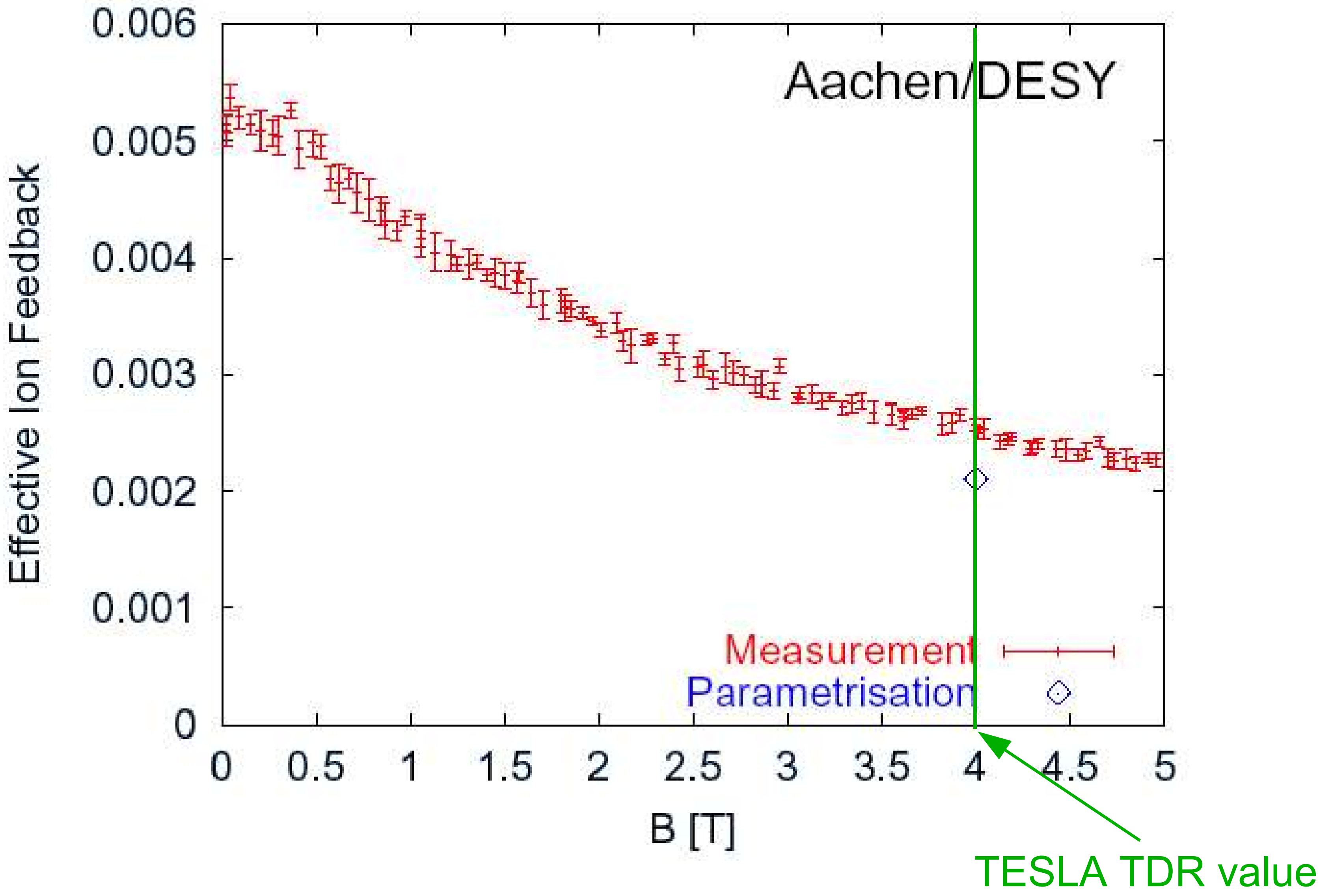
e^- collection efficiency, gain,
ion collection/extraction efficiency

Parametrizations used to find HV setting with minimal ion feedback:

$$IF = I_{Cathode} / I_{Anode}$$

Ion Feedback

Optimal: IF x gain < 1

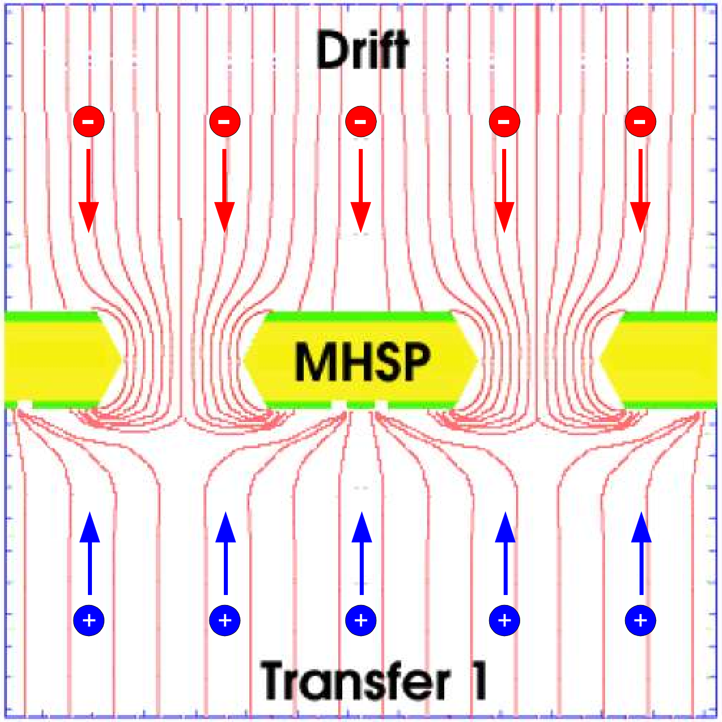


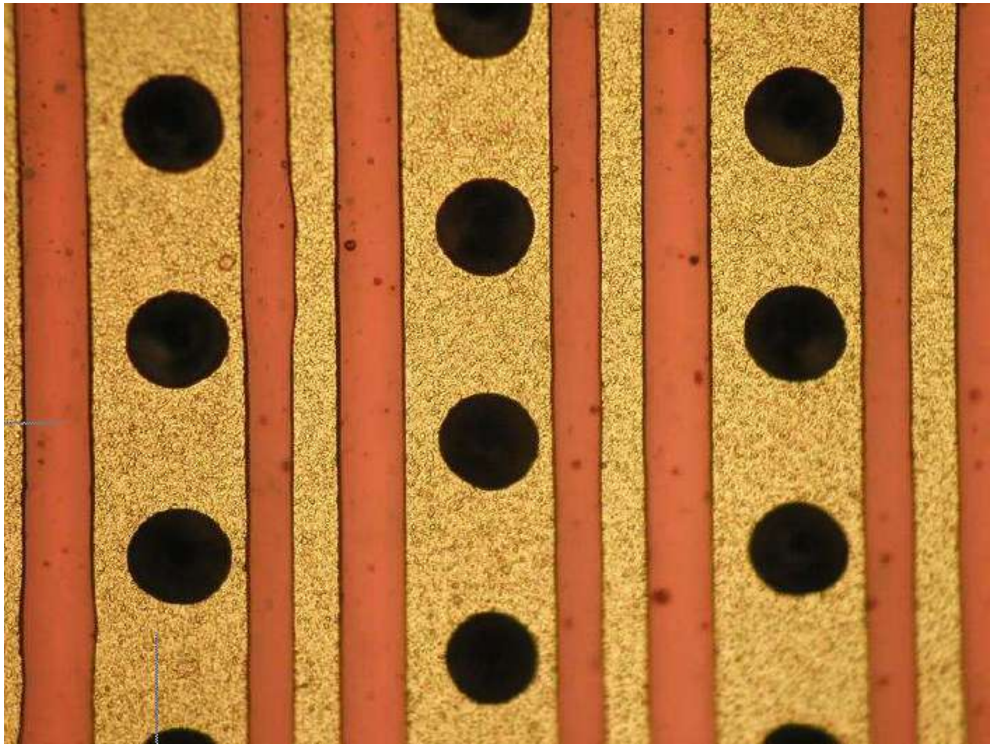
Micro Hole Strip Plate (MHSP)

Idea to reduce ion feedback:

Replace first GEM of triple GEM stack with MHSP

Electric field line simulation:



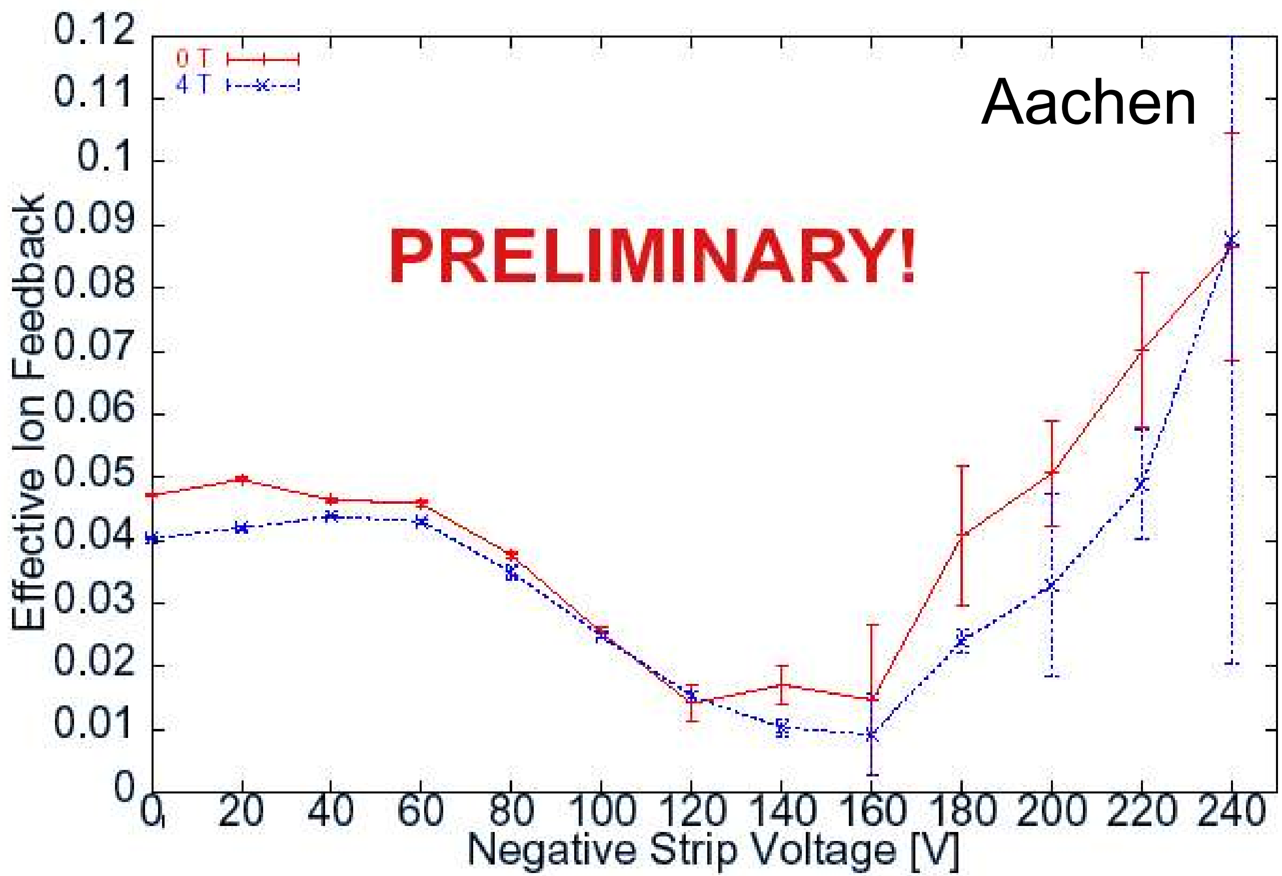


Principle:

Apply negative strip voltage

→ Ions collected on strips, electrons extracted from holes due to diffusion

First Measurements with MHSPs



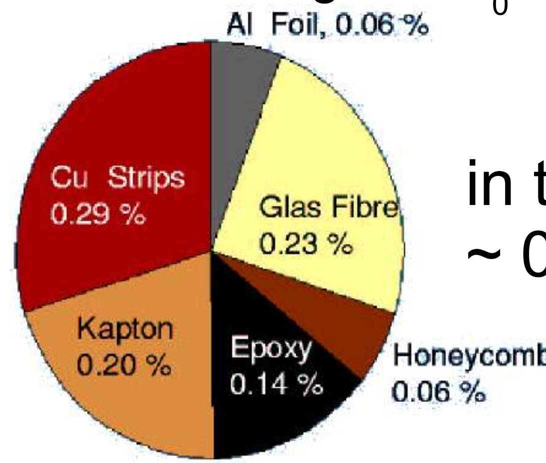
- Neg. strip voltage reduces IF by a factor of 4
- Principle proven
- Optimization to be done

Field Cage Design

Requirements:

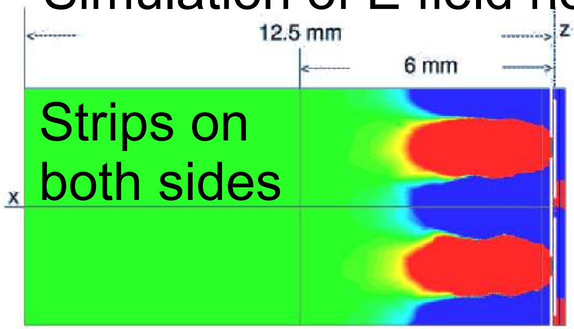
- Low material budget
- Good electric field homogeneity
- Low heat emission of resistor chain
- High voltage resistance

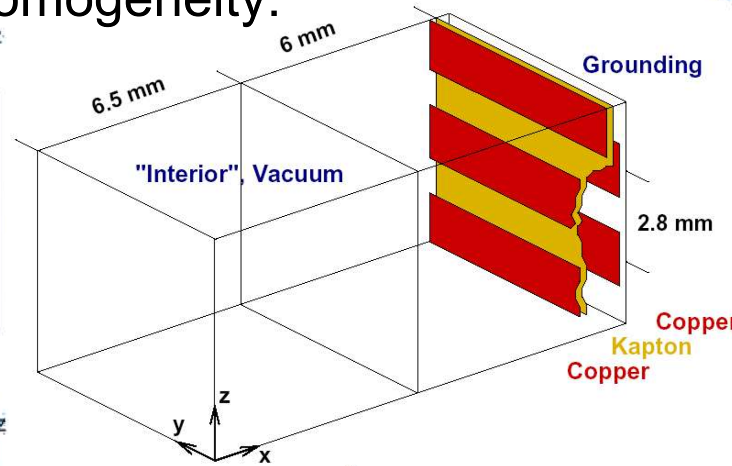
Material budget in X_0:

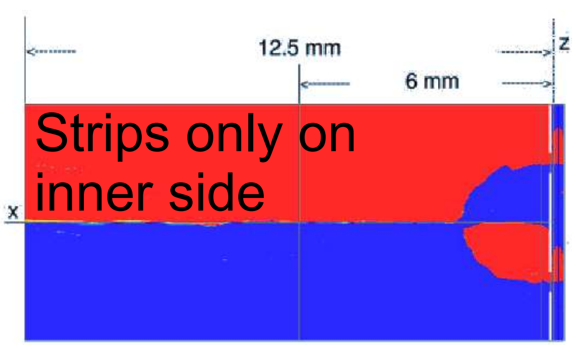


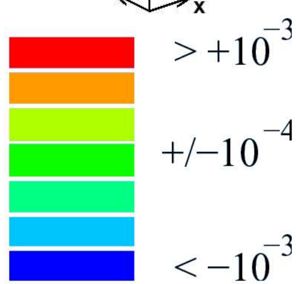
in total $\sim 0.01\ X_0$

Simulation of E field homogeneity:









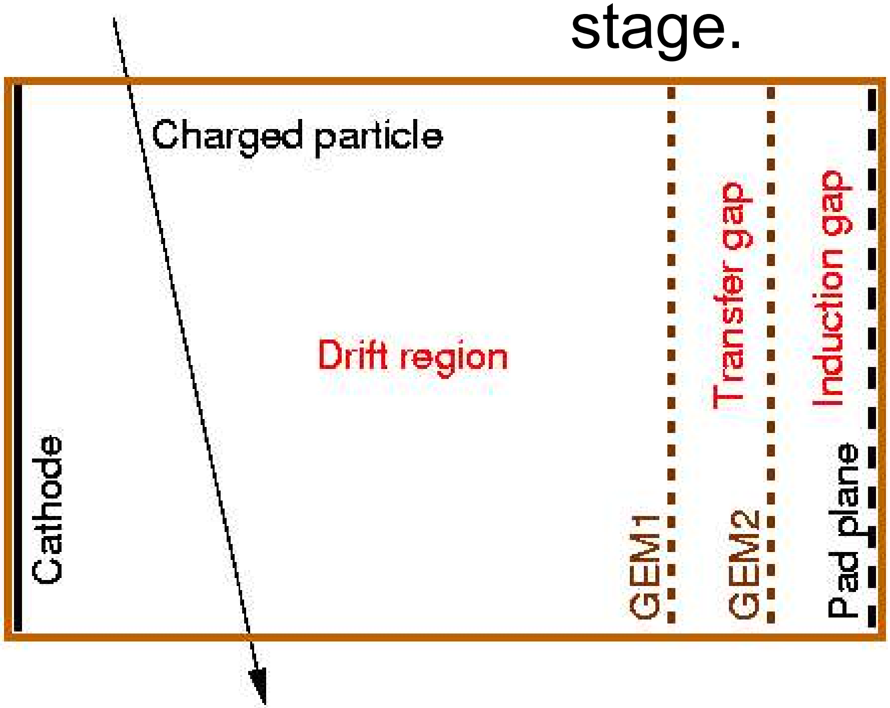
$\Delta E/E$

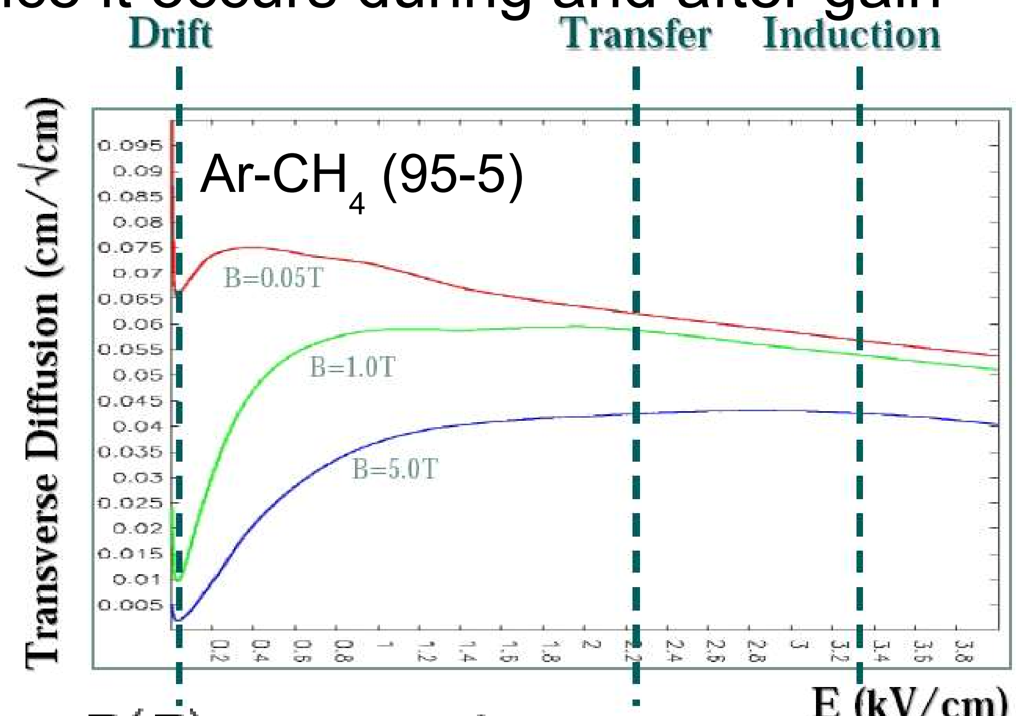
Finished prototype:

Defocussing

Narrow electron signal → Challenge to accurately reconstruct track position with reasonable number of channels

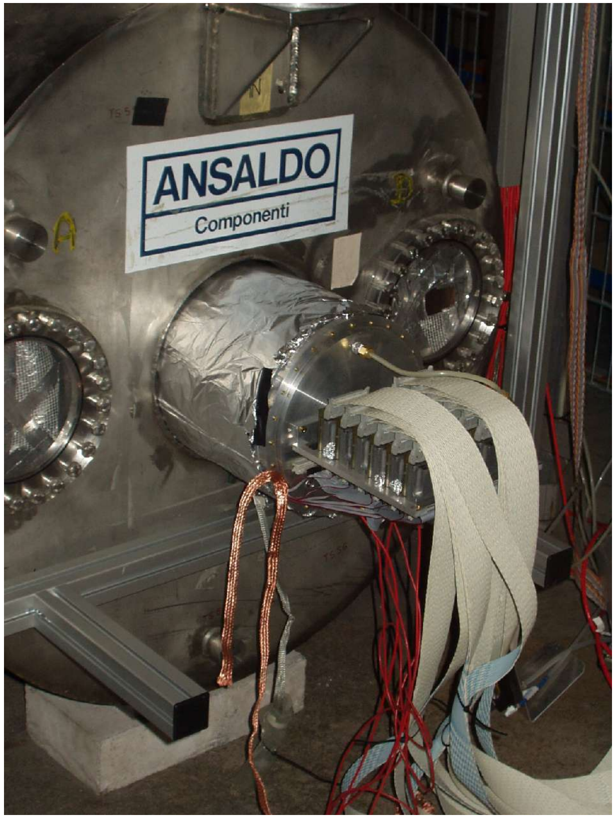
GEM advantage: Diffusion between GEMs spreads charge over larger area. Defocussing does not degrade track resolution since it occurs during and after gain stage.

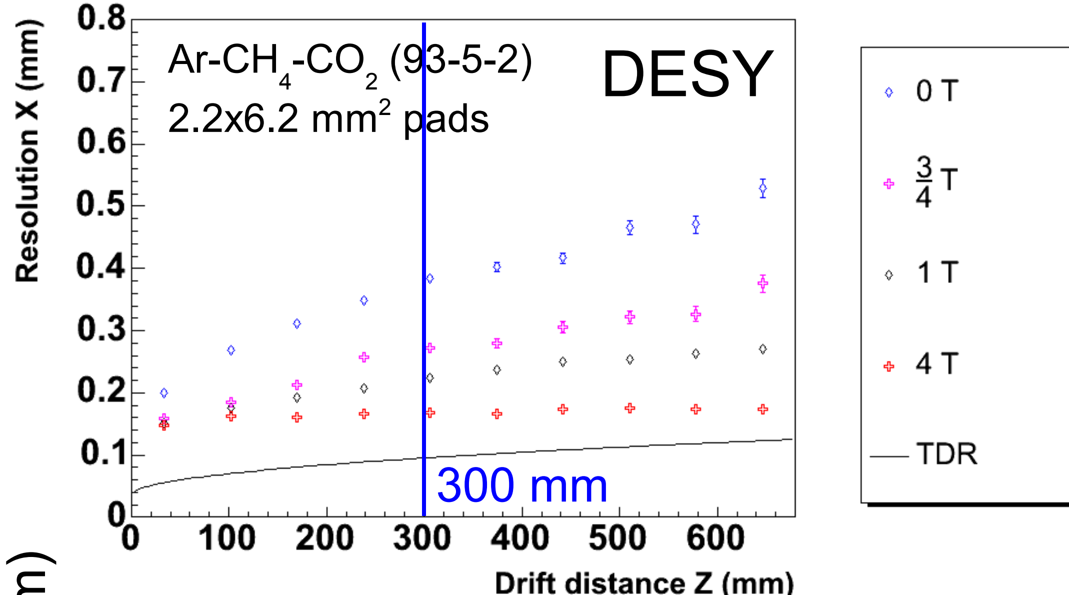


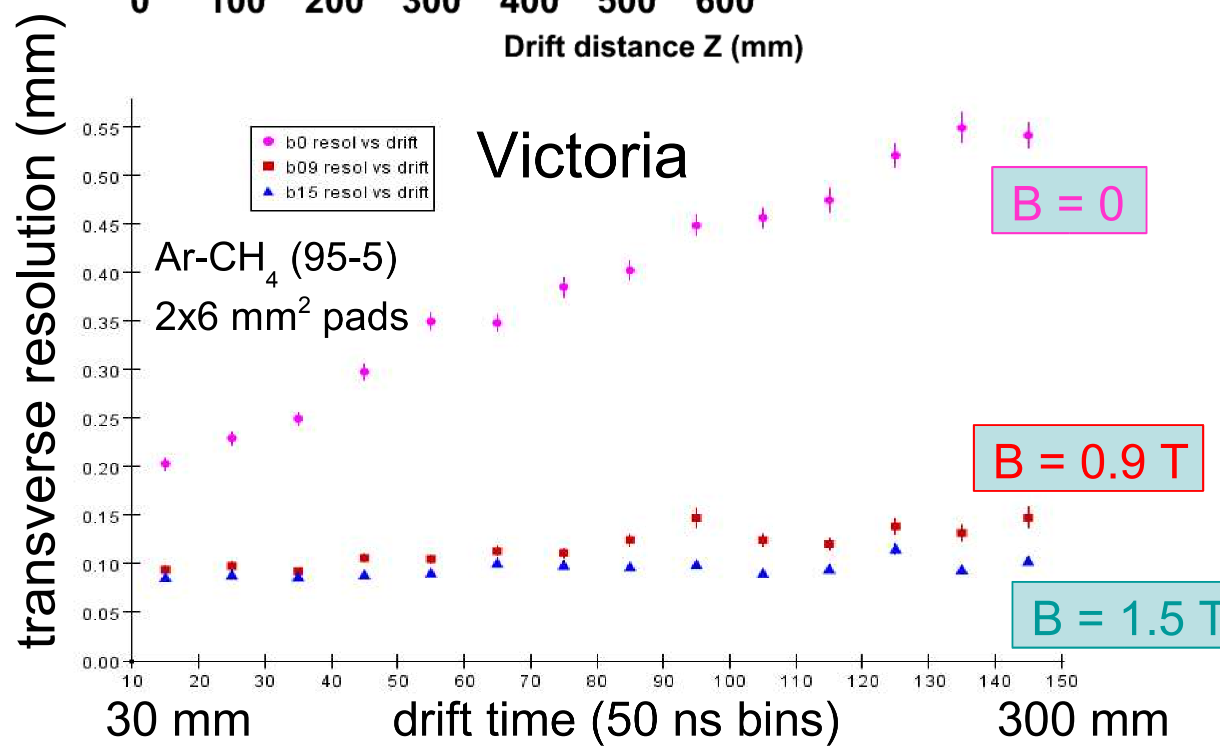


B dependence of diffusion: $\frac{D(B)}{D(0)} = \frac{1}{1+\omega^2(B)\tau^2(E)}$

Transverse Resolution







Measurements with small TPC prototypes in 5 T magnet at DESY

Summary

- Gained good understanding of charge transfer through GEMs.
- Ion feedback of 2.5 ‰ has been achieved with triple GEM setup at 4 T. Is this enough?
- First attempts to suppress IF using MHSPs. Optimization of settings to be done.
- Several TPC prototypes with GEM amplification have been built. Quality increases with time.
- Measurements with small prototypes:
  Resolution ~ 100 μm feasible (2x6 mm^2 pads, P5 gas)
- Promising achievements with small TPCs.
  Experience with large-scale prototypes has to be gained.