Recent Developments in Gaseous Tracking Detectors

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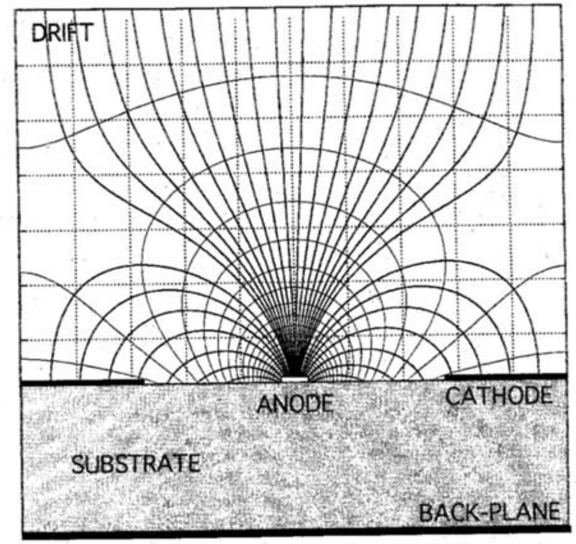
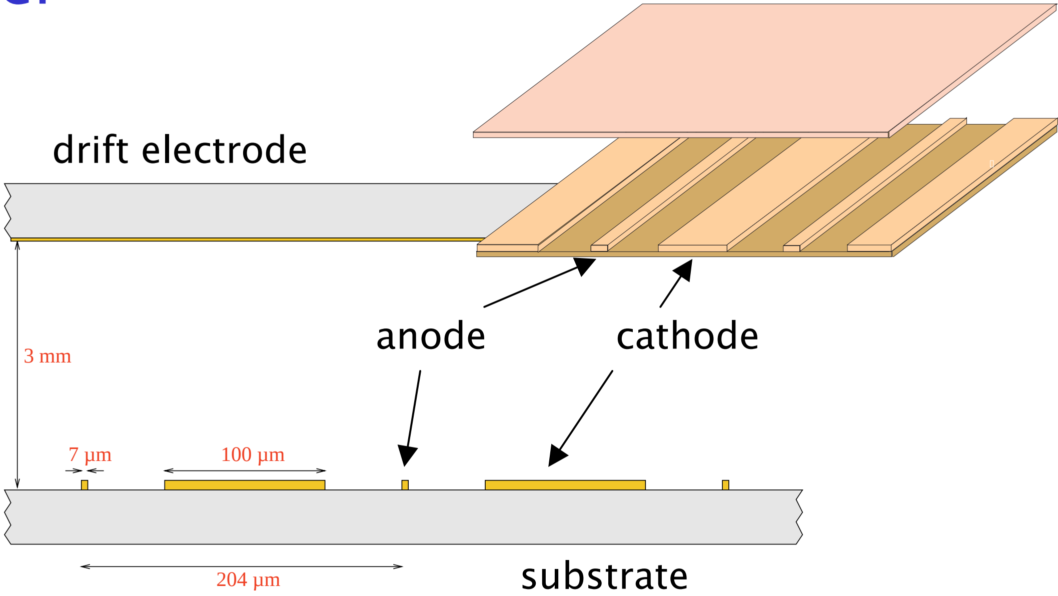
RWTH Aachen

Outline:

1. Micro pattern gas detectors (MPGD)
2. Triple GEM detector for LHC-B
3. A TPC for TESLA

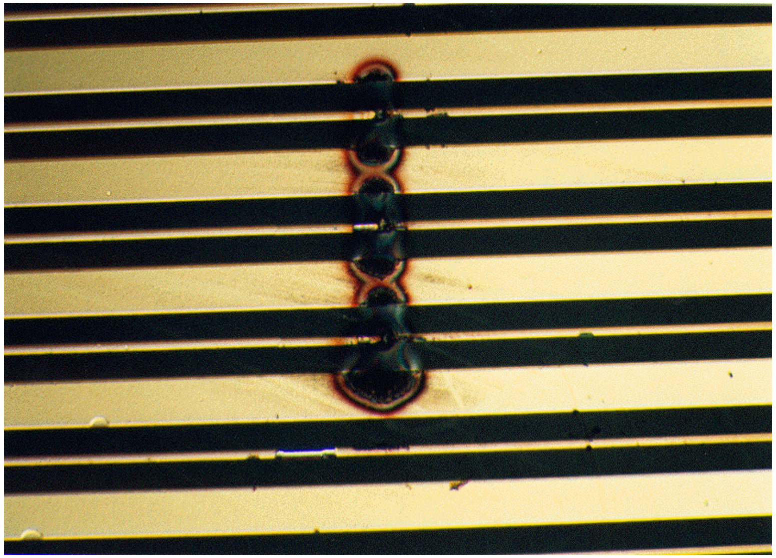
Micro Strip Gas Chamber



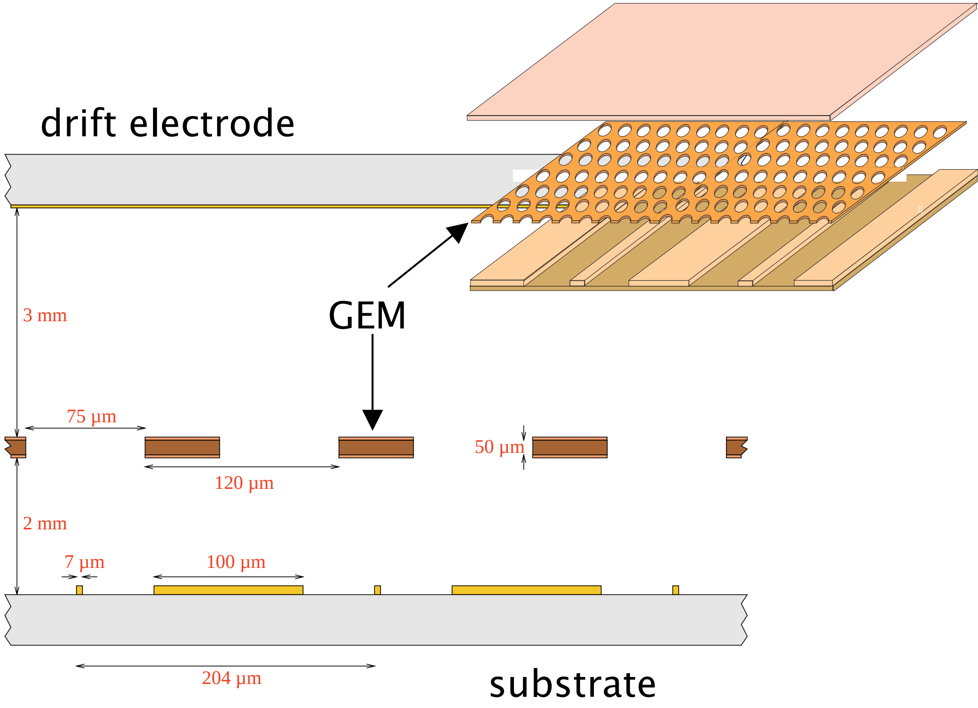


A. Oed (1988)

- pattern of thin anodes and cathode strips
- high spatial resolution and rate capability
- BUT: exposure to highly ionizing particles leads to damaging discharges



Micro Strip Gas Chamber + Gas Electron Multiplier



Solution to discharge problem:

- operation of MSGC with additional pre-amplification

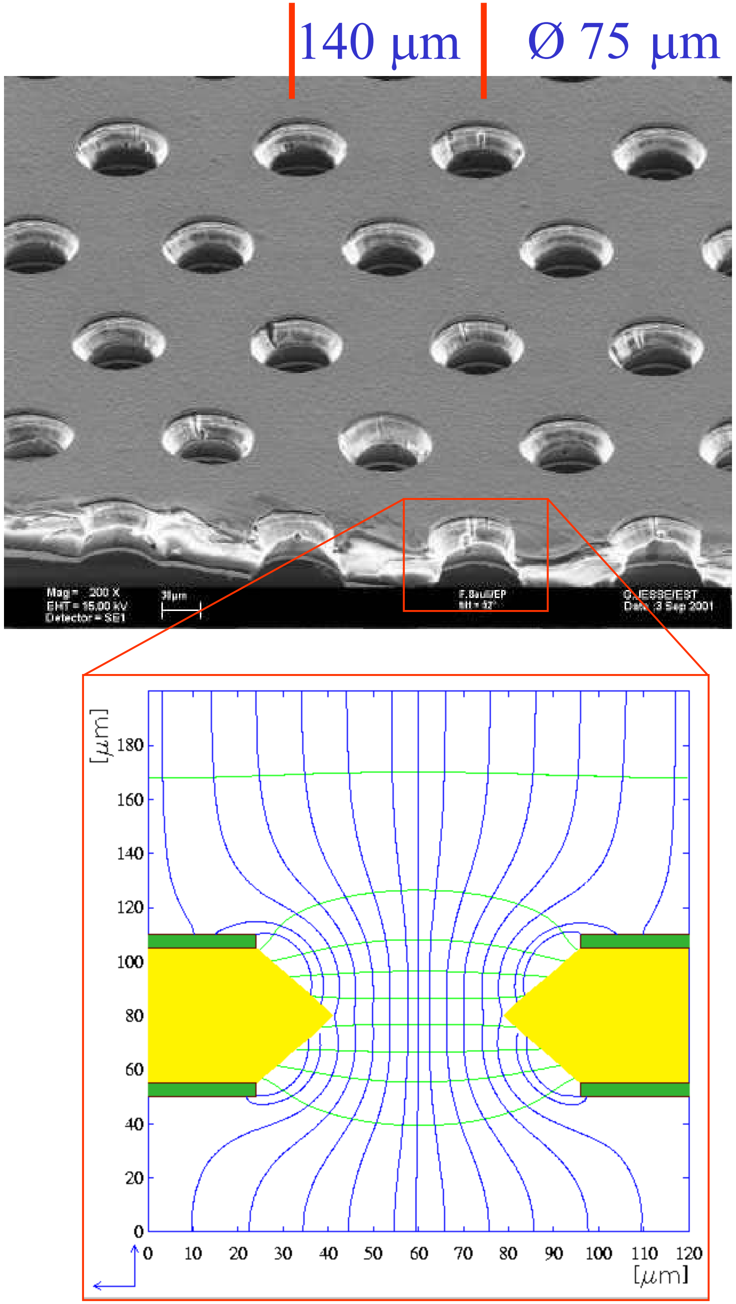
- gas electron multiplier (GEM) foils with typical gain of 10

- ca. 200 such detectors currently in operation at HERA-B

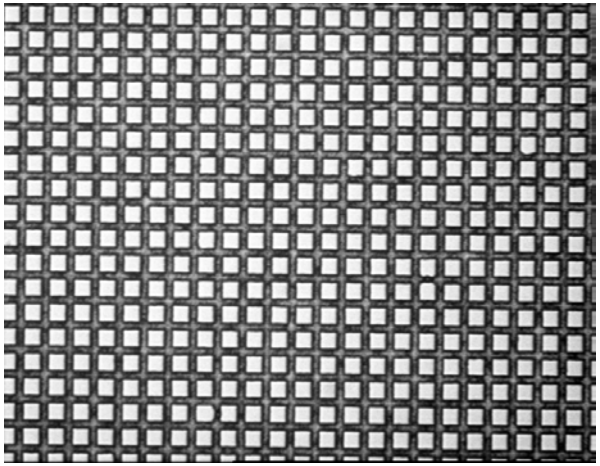
Gas Electron Multiplier (GEM)

F. Sauli (1996)

- 50 µm Kapton foil, double-sided clad with copper
- holes are perforated through using wet etching techniques
- GEM voltages up to 500 V produce gains up to 10^4
- little dependence on external fields (loose mechanical tolerances)
- decoupling of amplification and detection region
- signal only from electron collection (no slow ion tail)

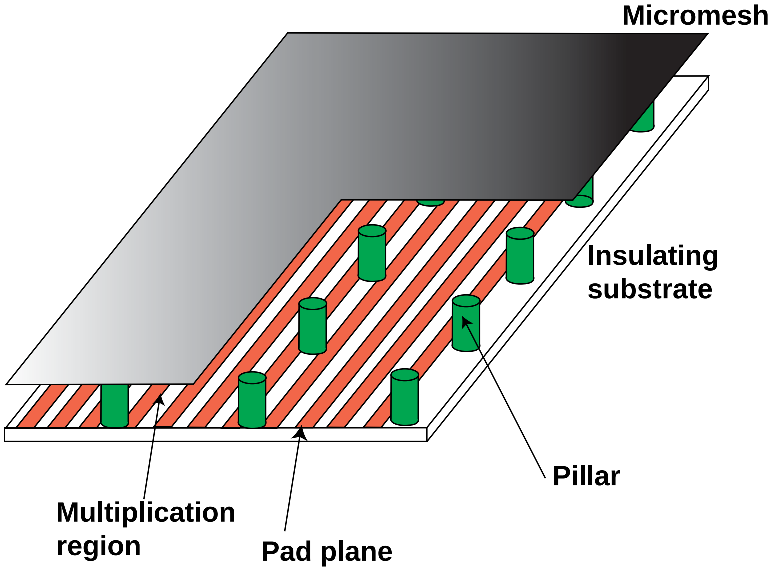


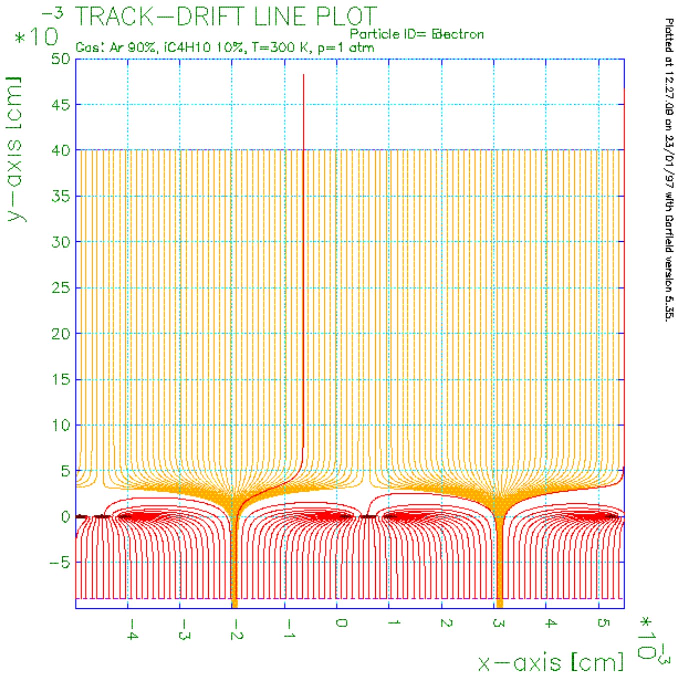
Micromegas



Y. Giomataris (1996)

- very asymmetric parallel plate chamber using a micro mesh (thin metal grid)
- saturation of Townsend coefficient: reduced dependence of gain on gap variations
- ion feedback suppression (funneling of drift lines)





Breed of Micro Pattern Gas Detectors

Micro Strip Gas Chamber

Micro Gap Chamber

Micro Dot Chamber

Micro Pin Structure

Micromegas

Compteur a Trouve

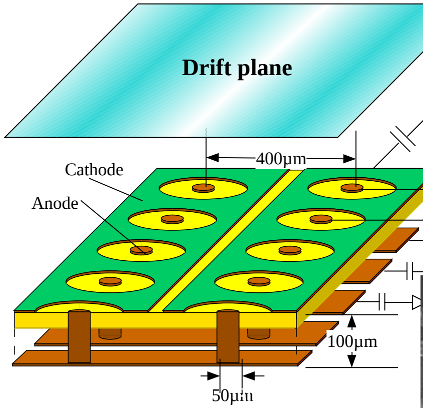
Micro Groove Detector

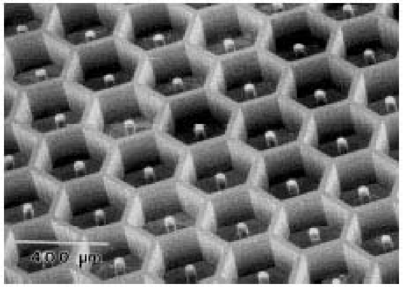
Well Detector

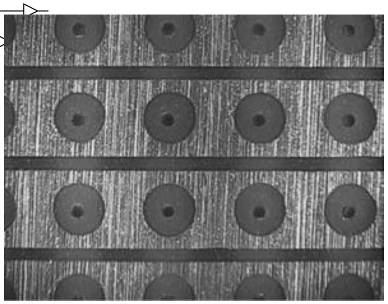
Micro Wire Detector

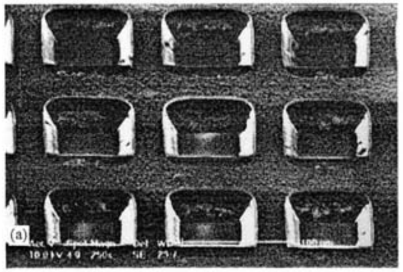
Gas Electron Multiplier

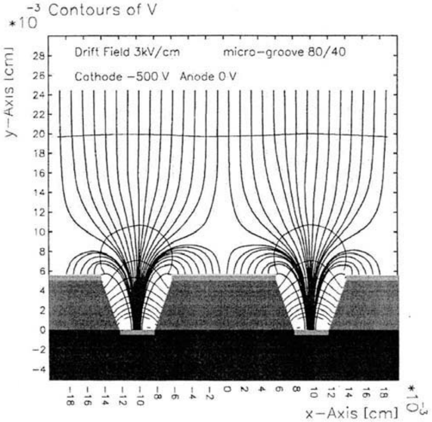
Sandglass Detector

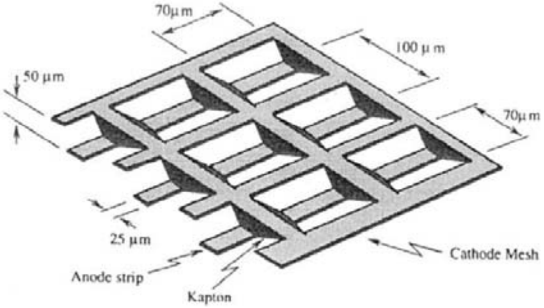








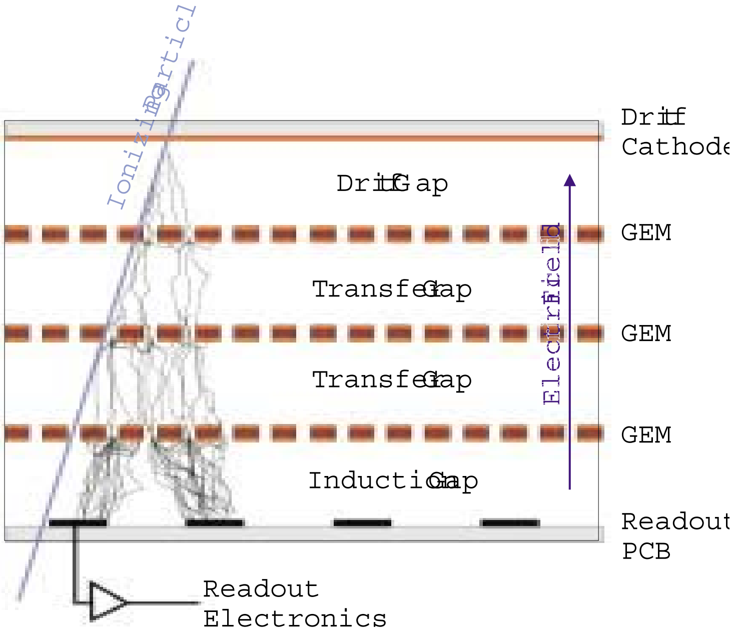




Triple GEM detectors

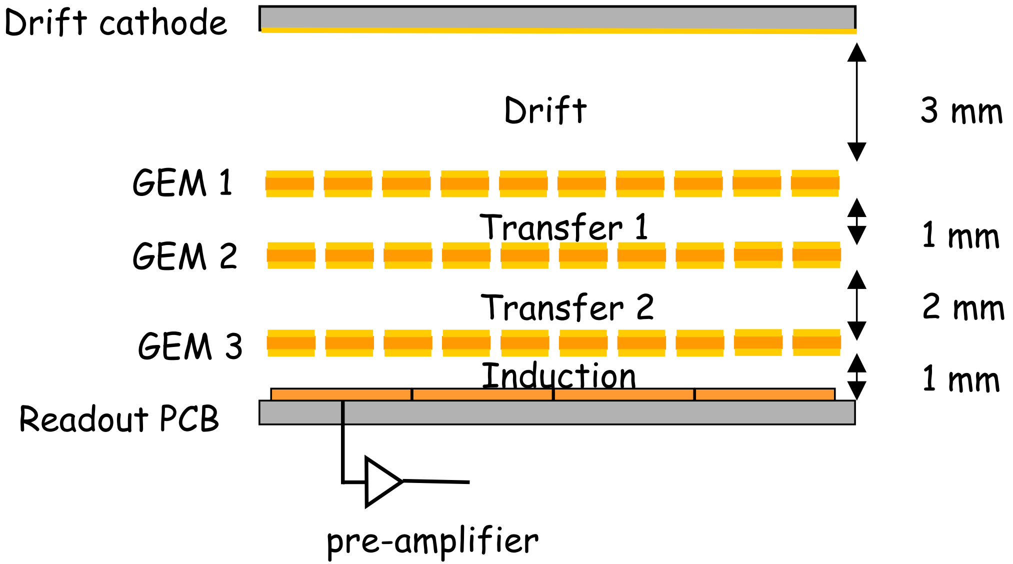
Compass tracker

- running fixed target experiment
- small area tracking near beam
- high rates 100 kHz/strip



LHC-B muon chamber

- LHC experiment in preparation
- central region of first muon station
- high rates 500 kHz/cm^2

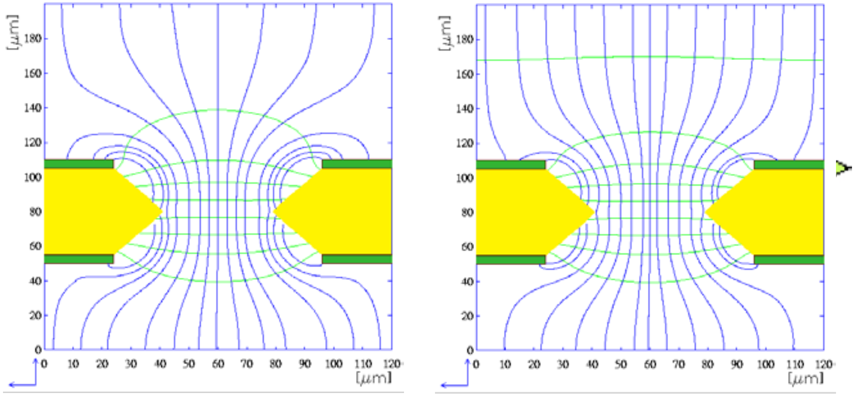


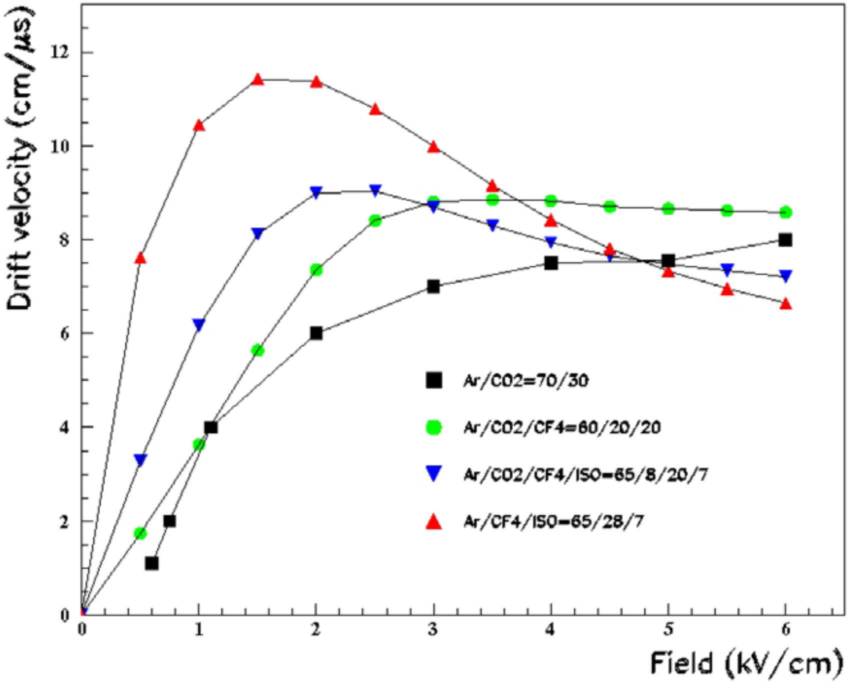
Time Performance: Drift velocity vs. Transparency

LHC-B muon trigger

Bencivenni et al.

- bunch tagging (99% in 25 ns time window)
- time spread $\sigma(x) \propto 1/(n\, v_{drift})$
- high transparency (n) and fast gas (v_{drift})
- collection efficiency for primary electrons decreases with increasing drift field!
- find gas with high drift velocity at low fields

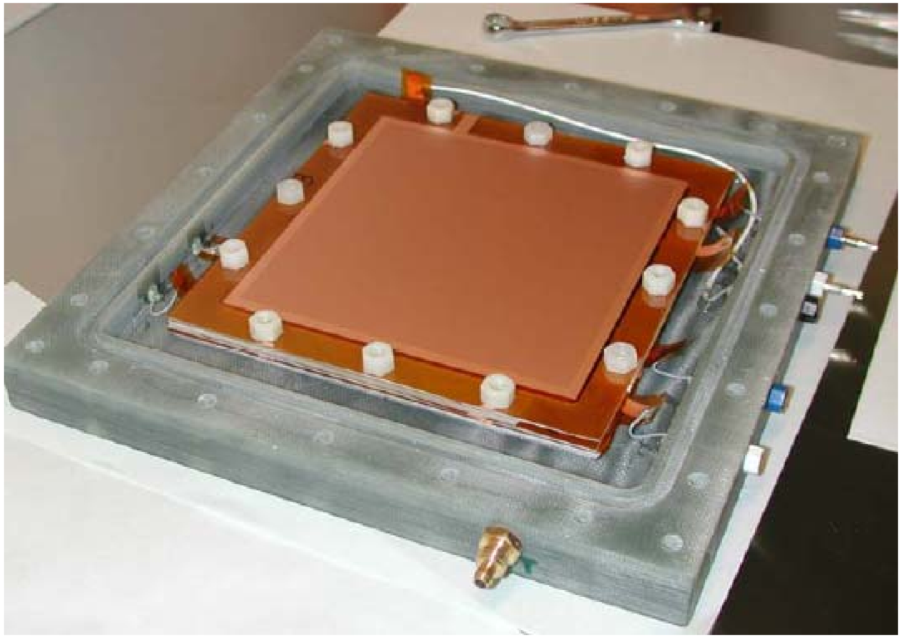


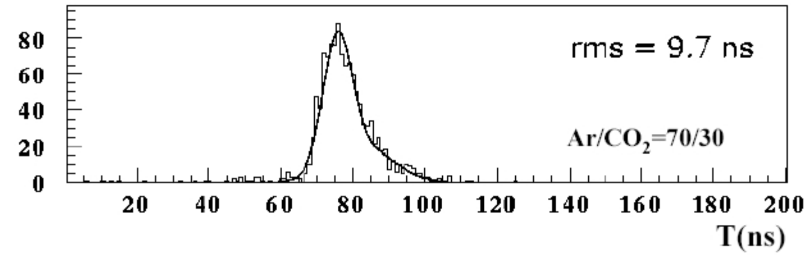


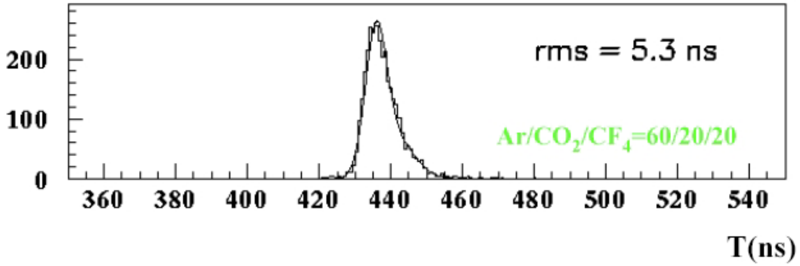
Time resolution

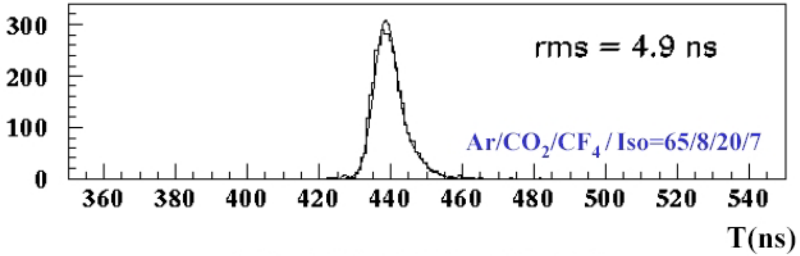
Test chamber in PSI test beam

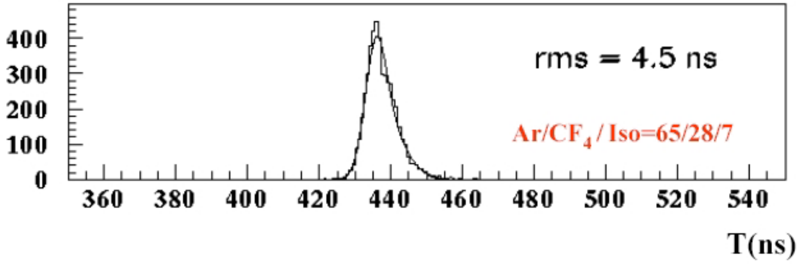
- high intensity pion beam
- 1 ns spills every 20 ns
- 30 kHz on detector active area











Trigger efficiency

Efficiency loss due to

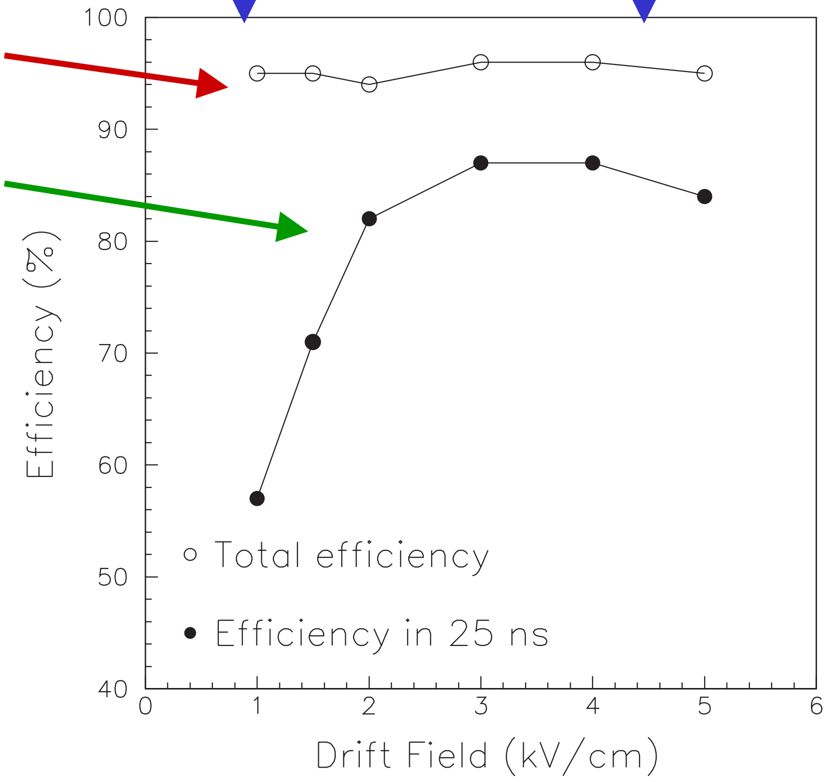
low drift velocity

reduced transparency

Efficiency in

300 ns

25 ns



A TPC for TESLA

Pro: + large sensitive volume with low material budget (3% X_0)

+ for each track 200 true 3-dimensional space points

+ high tracking efficiency due to efficient pattern recognition

+ dE/dx measurement

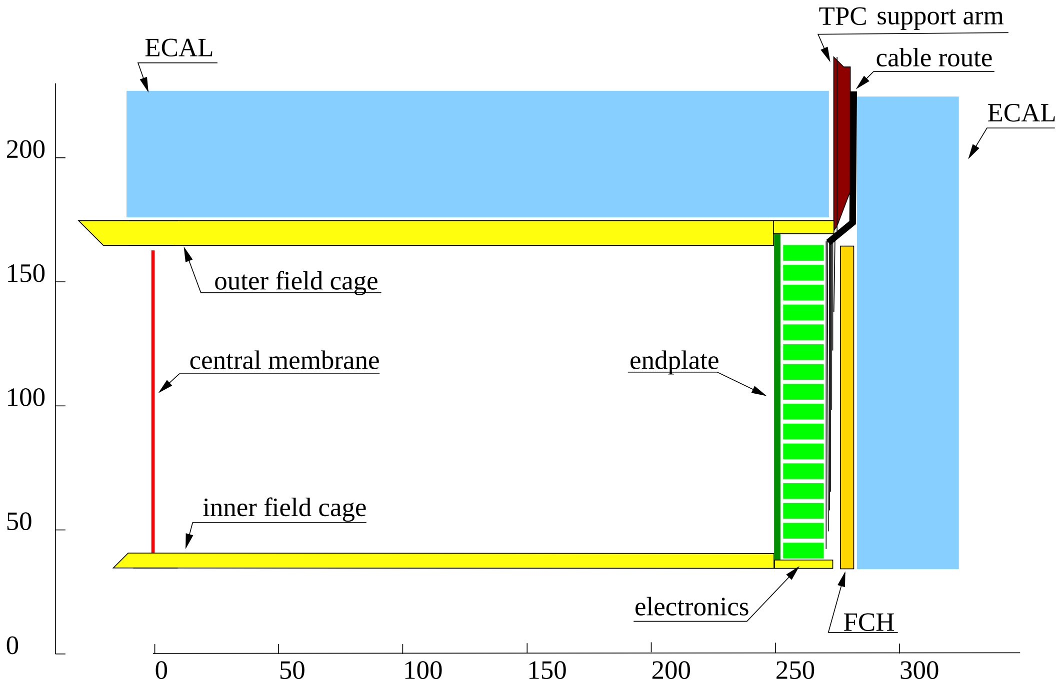
Contra: – moderate point resolution

– slow readout
(55μs → 150 BX)

Goals: – 10 x better than LEP TPC

– momentum resolution
$\Delta(1/p_t) < 2 \cdot 10^{-4}$ (GeV/c $)^{-1}$

– 5% precision for dE/dx



TPC gas amplification schemes

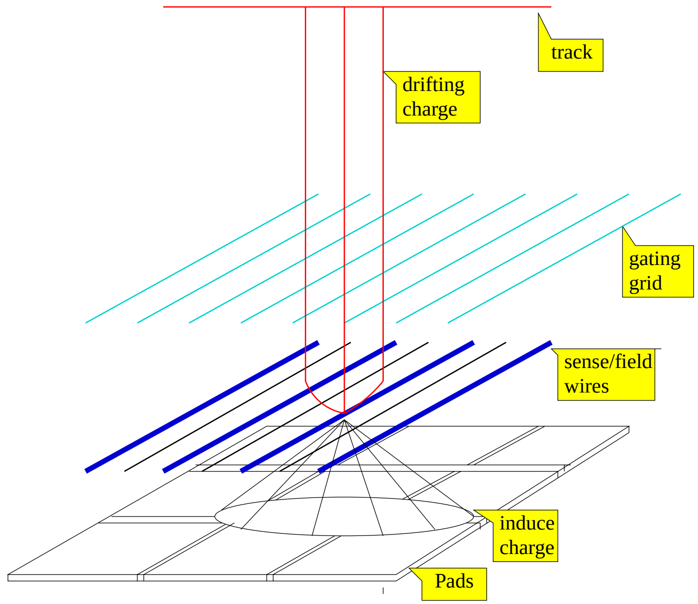
MWPC:

worked well in the past (backup solution)

induction signal of wires on pads

gating plane to suppress ion feedback into drift volume

E x B effects in pad response



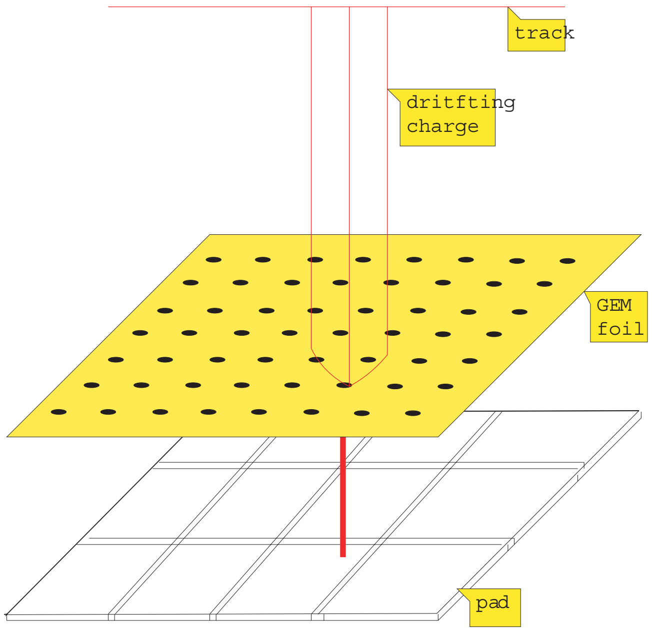
MPGD:

GEM or Micromegas

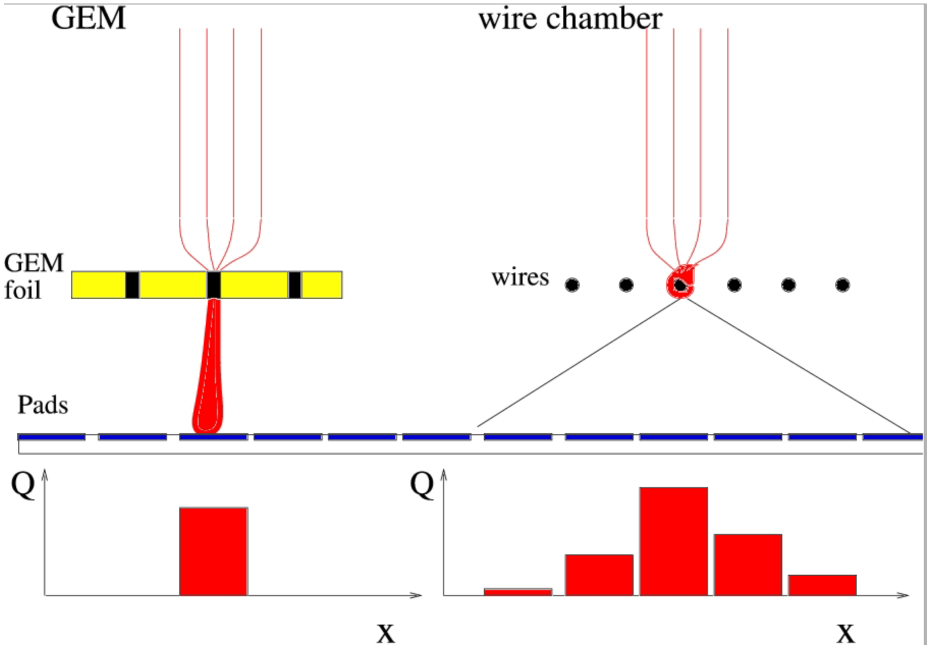
collection of electron signal

intrinsic ion feedback suppression

2-dim symmetry: no E x B effects



Readout pads



Drawback of electron collection:

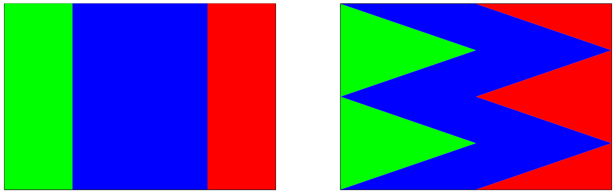
no broadening due to induction, single pad collects all charge for small distance

Solutions:

use smaller pads, replace pads by silicon readout chip

capacitive or resistive coupling of neighbouring pads

use more fancy geometry (chevrons)



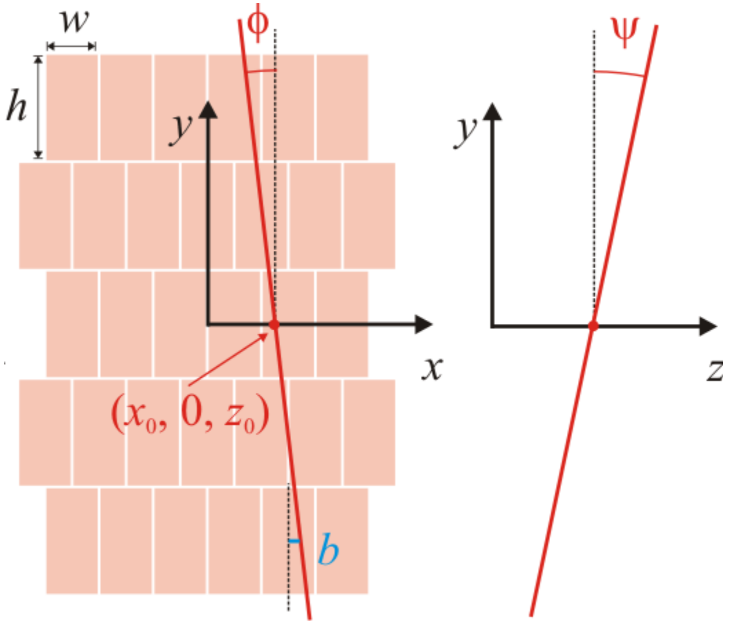
Readout pads – spatial resolution

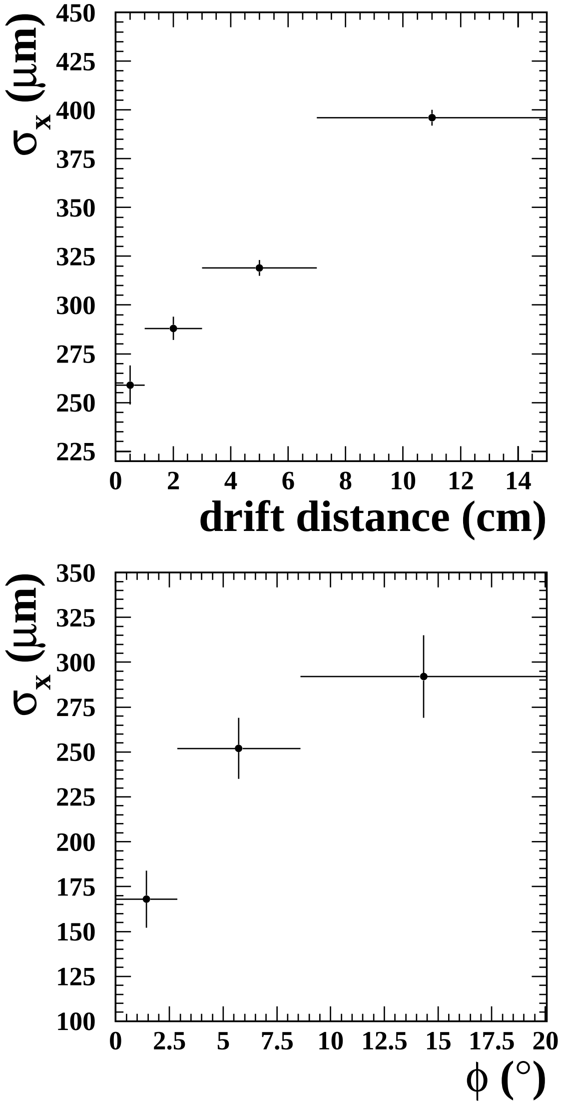
(Carleton)

expected spatial resolution: 100 µm –150 µm

first results for spatial resolution of a GEM TPC with

- 15 cm drift length
- no magnetic field
- slow gas Ar–CO_2: 70–30
- 32 readout pads 2.5mm x 5mm



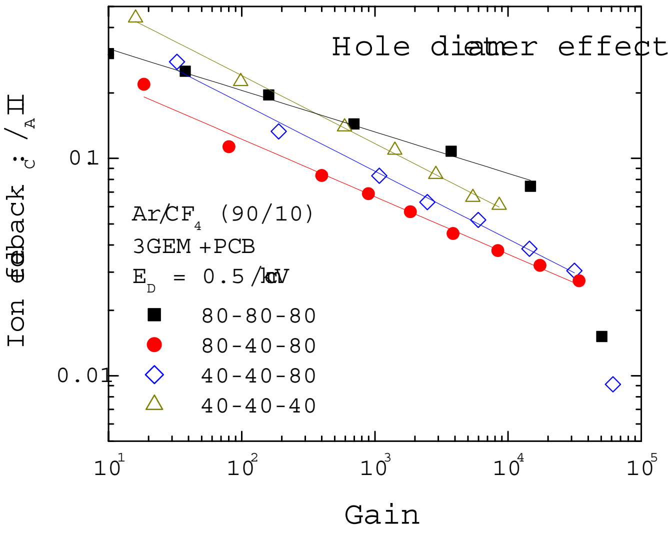


Ion feedback results

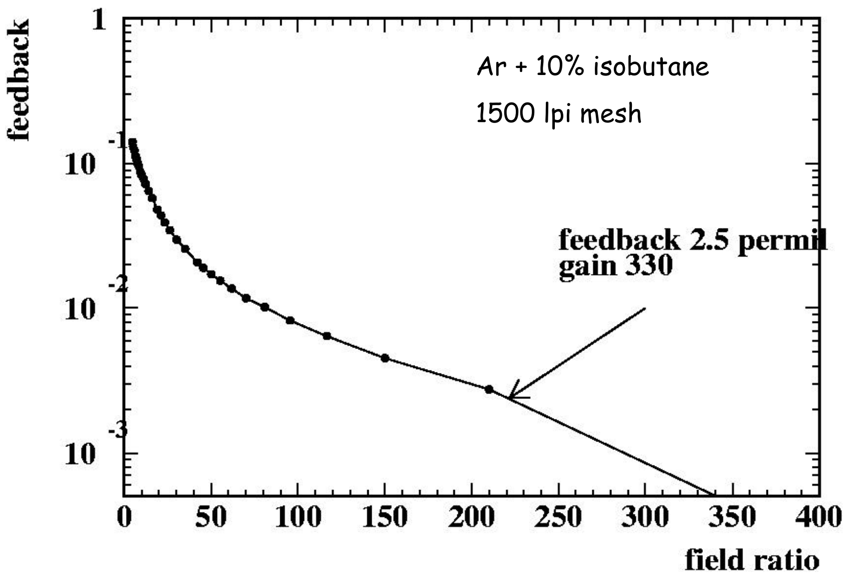
Several measurements with respect to different parameters

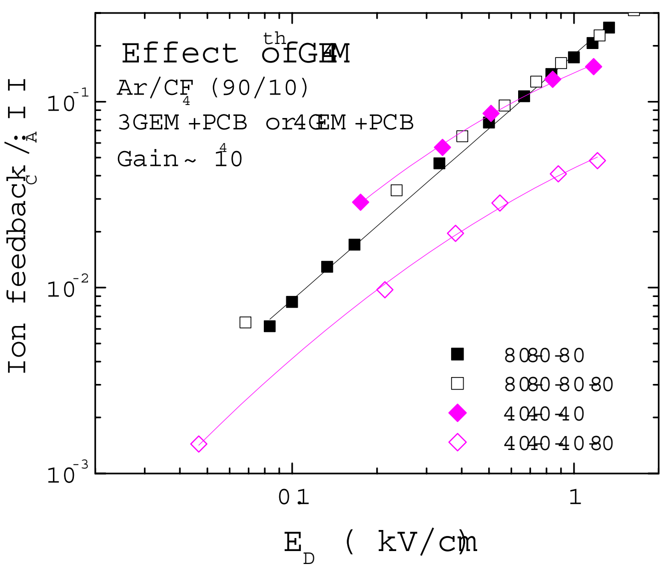
Goal: minimization of ion feedback

GEM (Novosibirsk)



Micromegas (Saclay/Orsay)





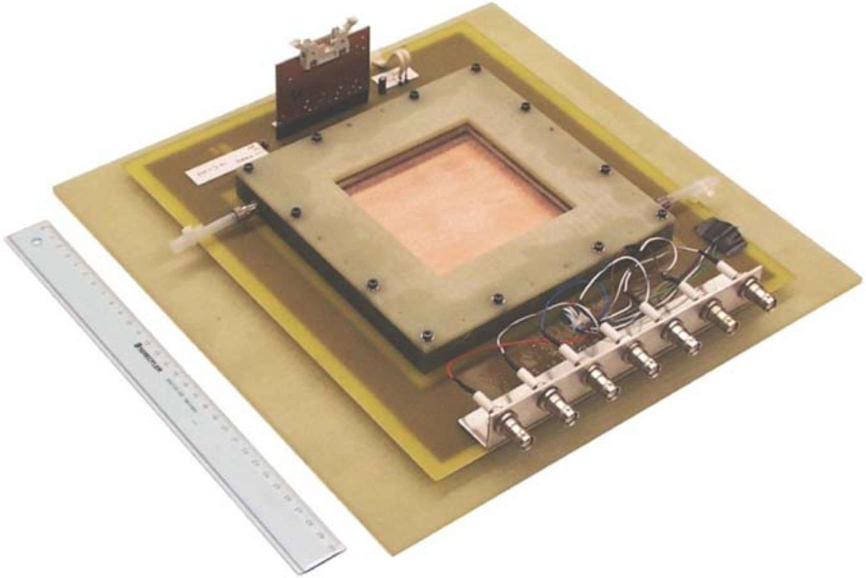
Charge Transfer in GEM structures

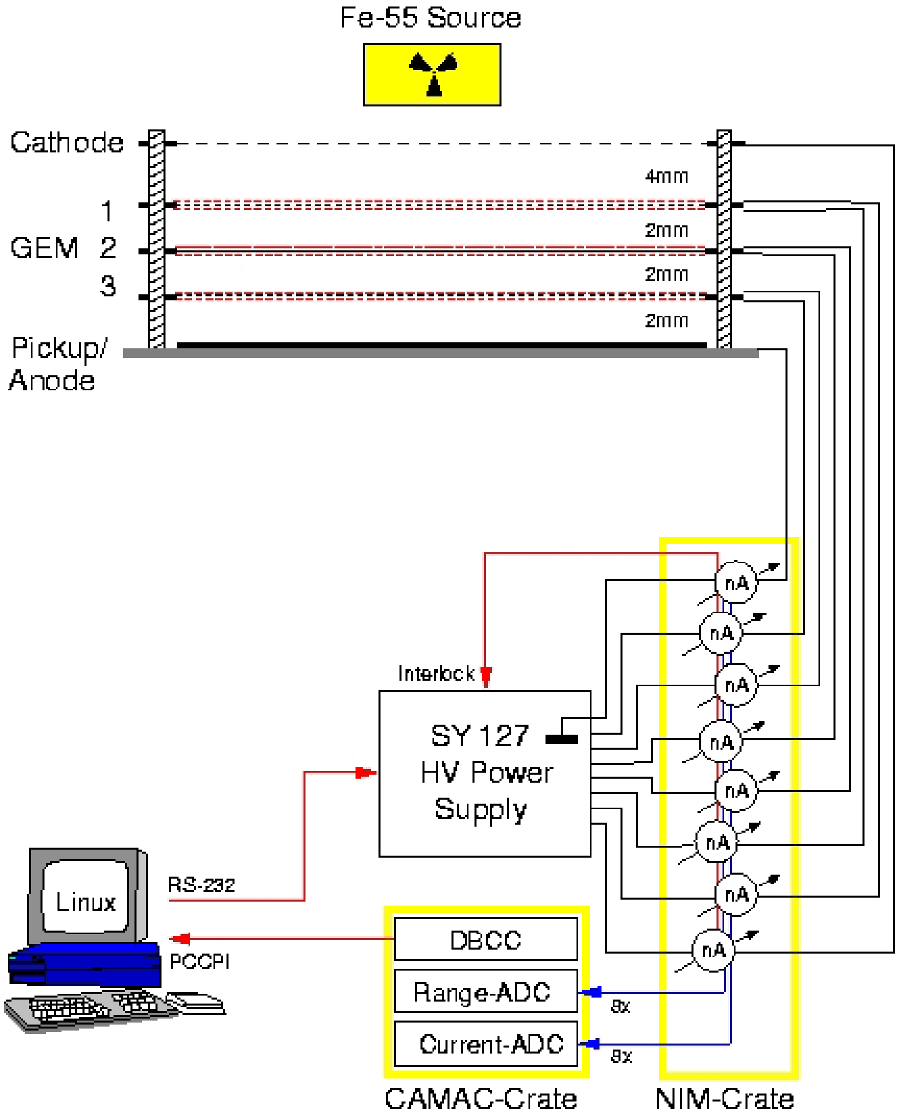
Definition of charge transfer coefficients

- Collection efficiency C
  charge fraction collected into GEM hole

- Extraction efficiency X
  charge fraction extracted out of GEM

Measurement of all electrode currents



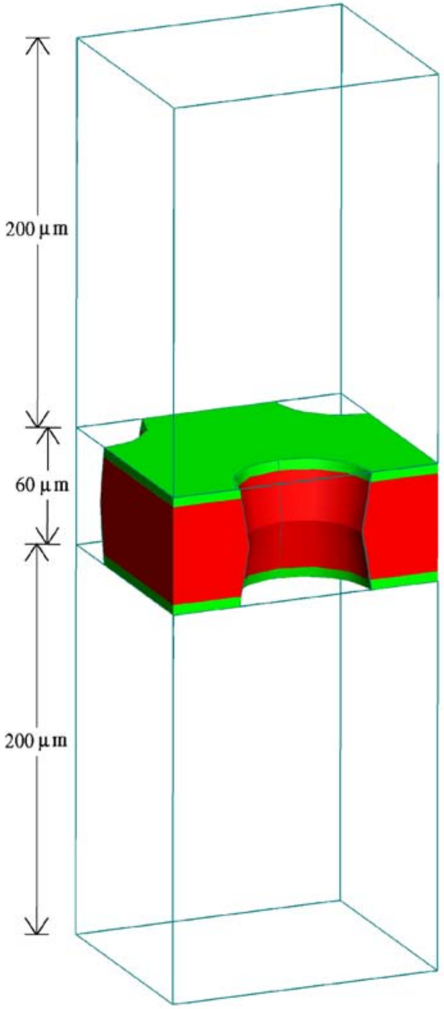


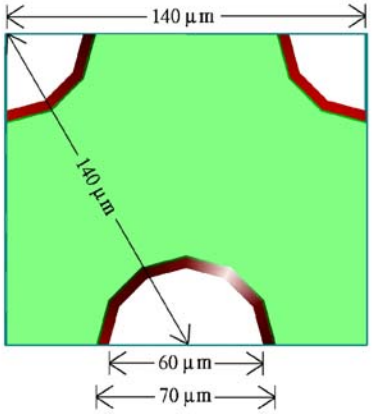
Simulations – Maxwell 3D

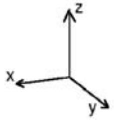
Numerical simulation performed with finite elements calculation using the program Maxwell 3D

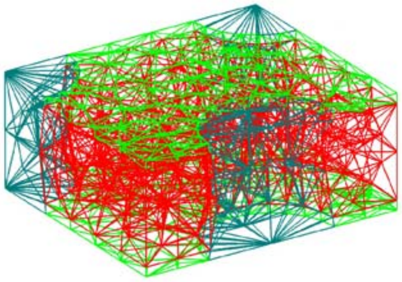
Define unit cell of GEM foil

Program provides map of electrical field in GEM structure









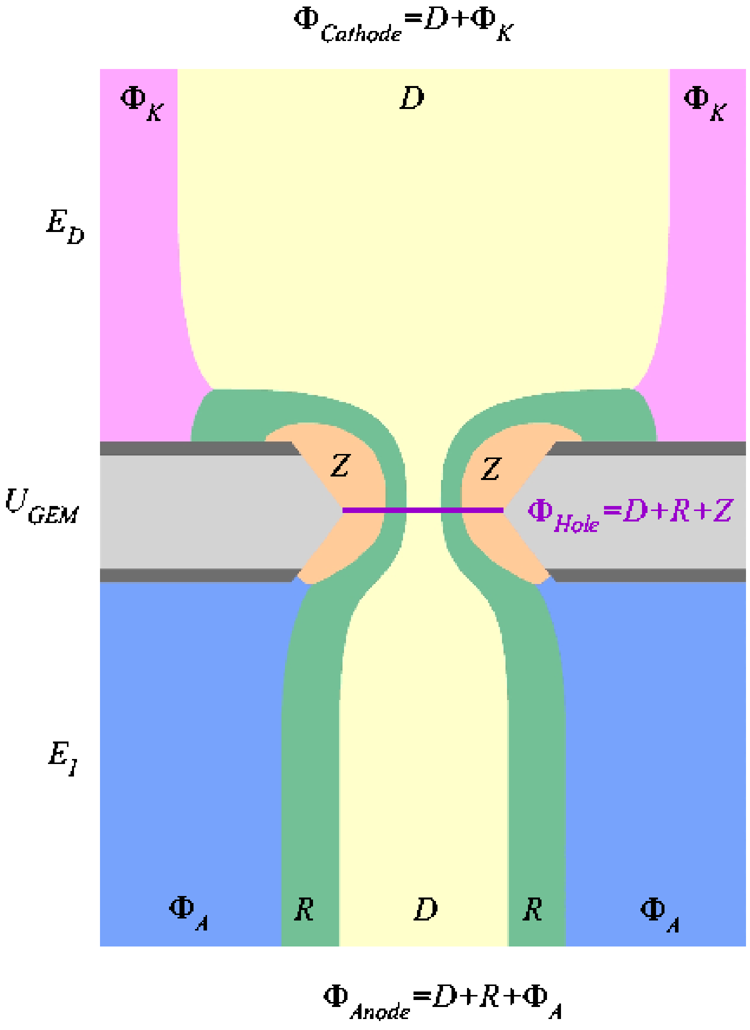
Flux of electrical field

Electric Flux: $\Phi = \int_F \vec{E}(\vec{r})\, d\vec{f}(\vec{r})$

Assumption:
Charges follow electrical field lines

Define different electric fluxes

Calculate the transfer coefficients
C and X from these fluxes

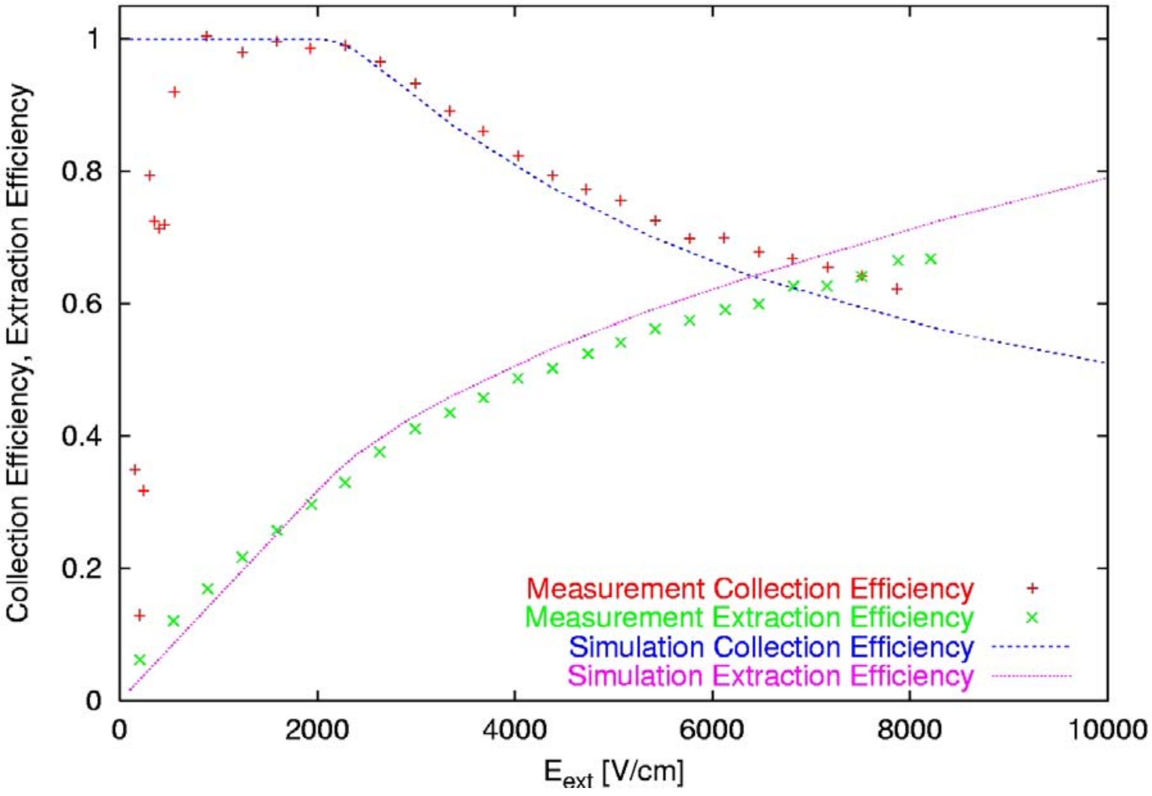


$$C_{up} = \frac{D}{D + \Phi_K} = 1 - \frac{\Phi_K}{\Phi_{Cathode}}$$

$$X_{down} = \frac{D + R}{D + R + Z} = \frac{\Phi_{Anode} - \Phi_A}{\Phi_{Hole}}$$

Comparison: Measurement and Simulation

(Aachen)



Magnetic field

Langevin equation:

$$\vec{v}_{Drift} = \frac{e}{m_e}\frac{\tau E}{1+\omega^2\tau^2}\left\{\hat{E} + \omega\tau(\hat{E}\times\hat{B}) + \omega^2\tau^2(\hat{E}\cdot\hat{B})\hat{B}\right\}$$

ω = cyclotron frequency
τ = mean free time

Aleph: B = 1.5 T → $\omega\tau = 9$

Tesla: B = 4 T → $\omega\tau = 24$

Impact on electron collection efficiency ?

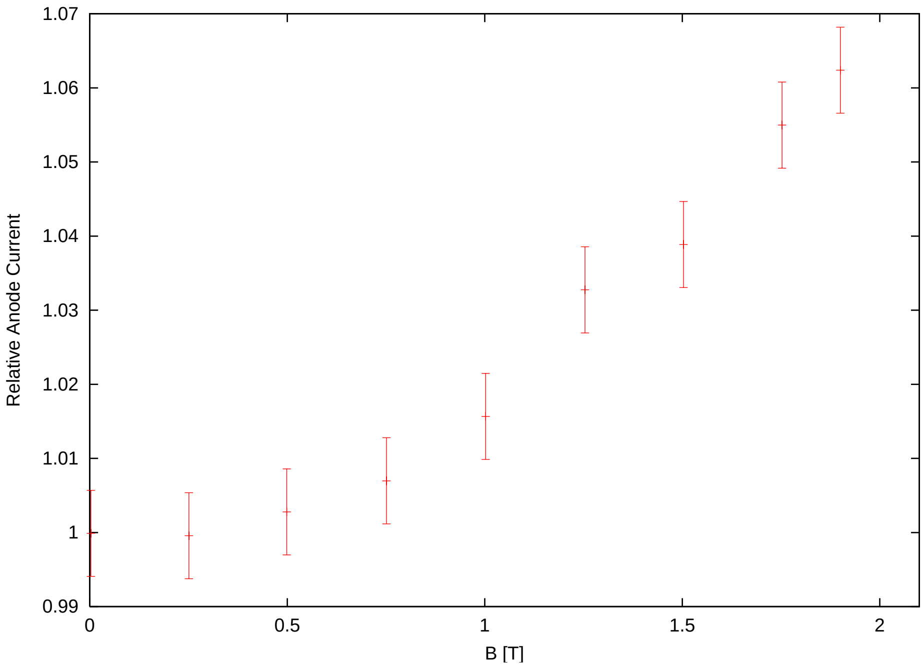
Magnetic field

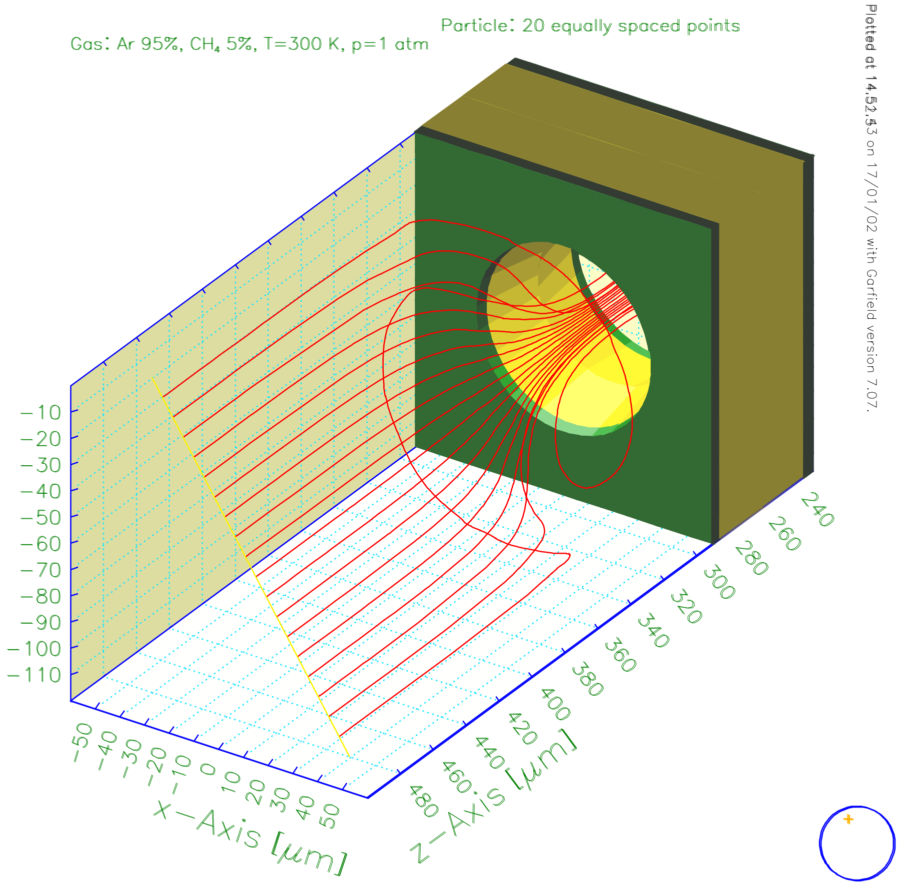
Garfield simulation of drift lines at 4T

Current measurements with triple GEM structure up to 2T

No indication for efficiency drop !

(Aachen)





Gain Stability: dE/dx capability

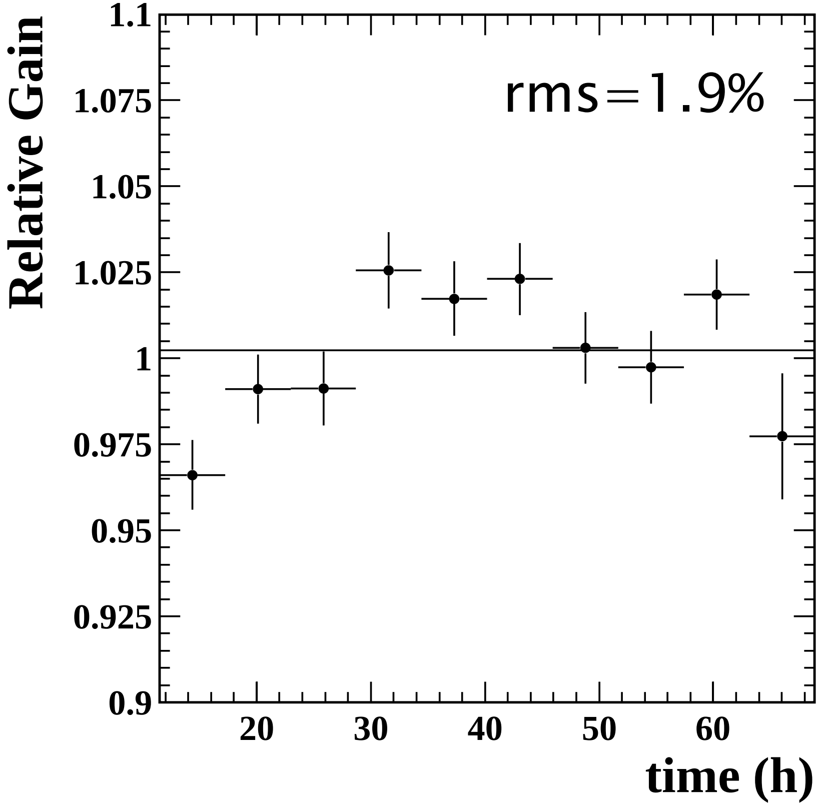
Goal: dE/dx measurement with 5% precision

requires gain stability and homogeneity at 1% level

(Hamburg)

Measurement:

- drift length max 1 m
- double GEM structure
- TESLA TDR Gas
  $Ar:CH_4:CO_2 = 93:5:2$

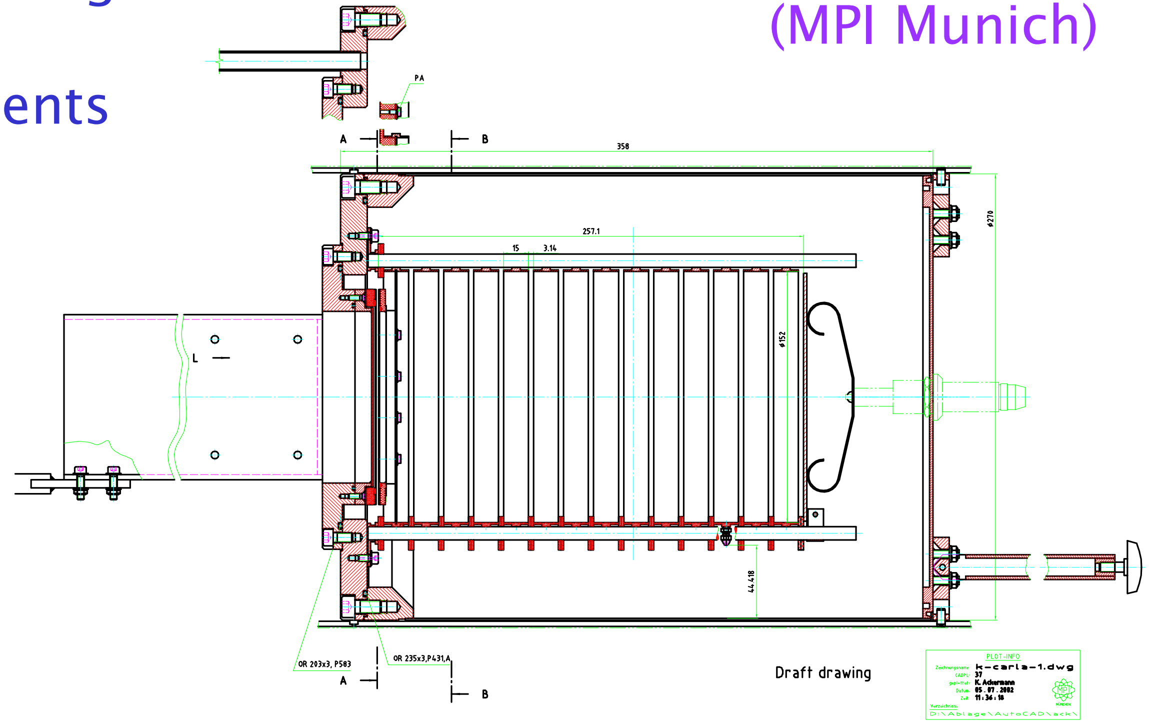


Outlook: TPC prototype

Design of field cage for TPC prototype

- Test of all amplification schemes
- Measurements in 5 T magnet
- Test beam measurements

(MPI Munich)



Draft drawing