TPC and GEM readout

Markus Schumacher, DESY

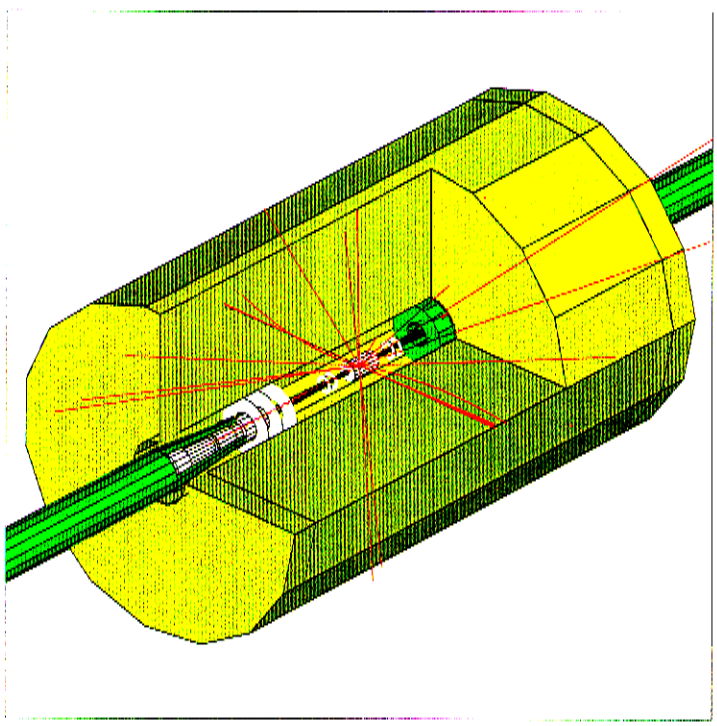
TPC as main tracker at TESLA

GEM readout

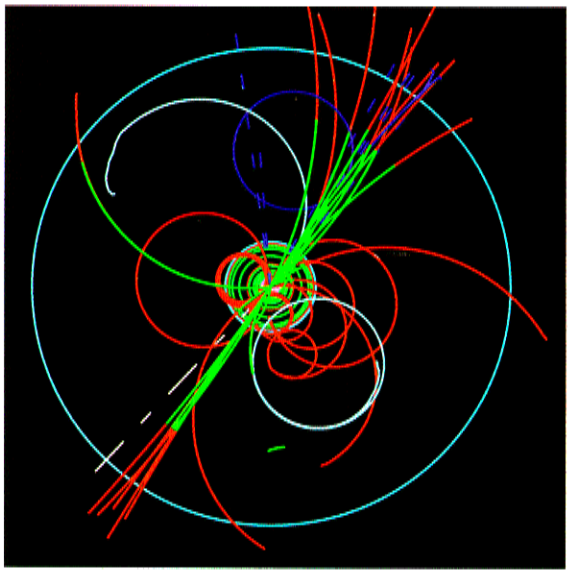
Basic design ideas

R&D at DESY

Conclusions



TPC as main tracker for TESLA detector



$l = 5\ m, R_{i/o} = 32/170cm$

- true 3-dim space points
- high redundancy, $\geq$ 118 hits per track
- low material budget, $\approx$ 3% X_0
- particle identification via dE/dx measurements

- tracking up to large radii

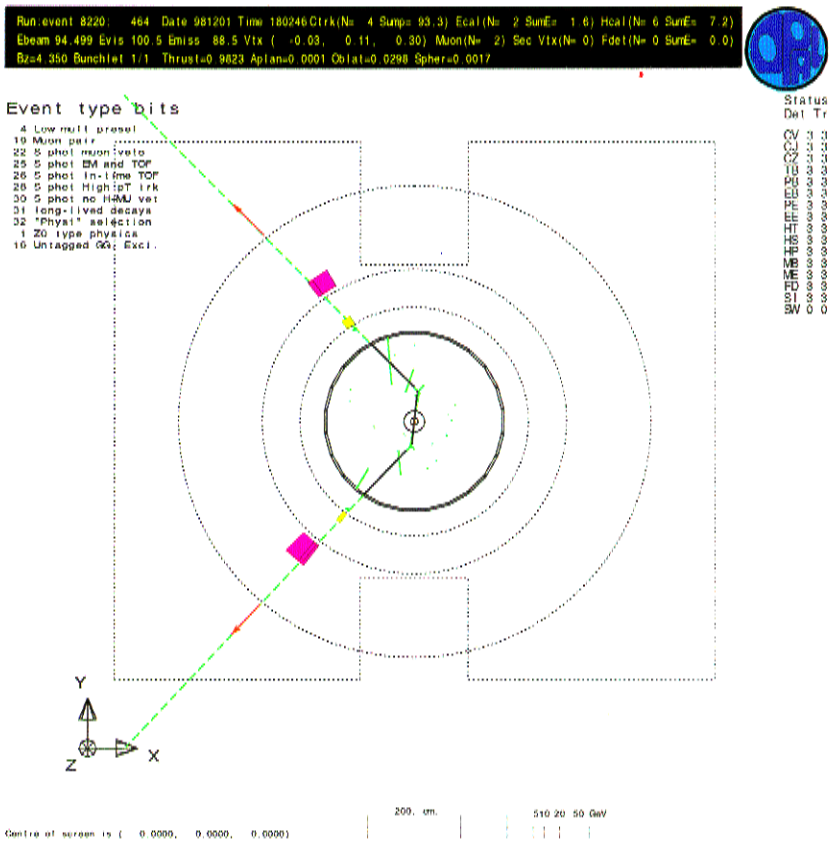
one phyics motivation:

search for longlived particles

causing kink tracks in TPC

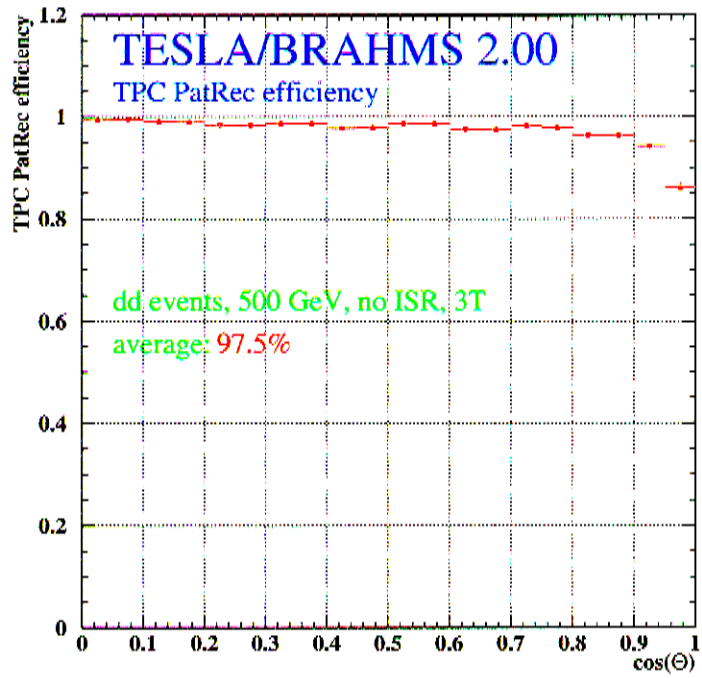
$\tilde{\mu} \rightarrow \mu \tilde{g}$

OPAL MC-Simulation



TPC performance

- highly efficient pattern recognition (→ K. Harder)
- excellent especially for high track density environment
- good multi jet capability



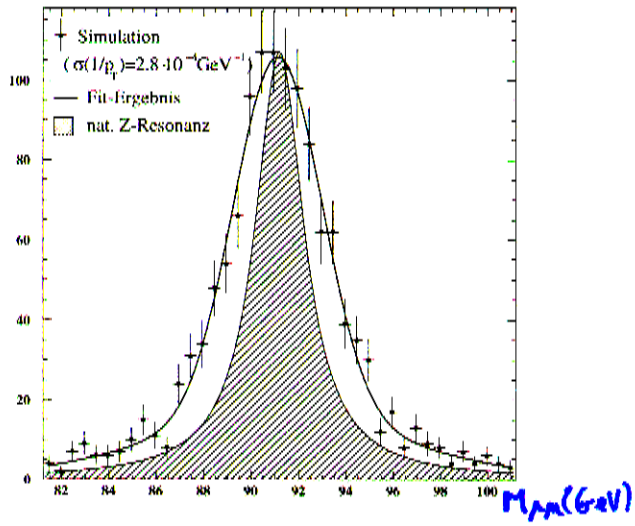
Performance goals

point res.: $\sigma_{r\phi} \leq 160\mu m \qquad \sigma_z \leq 1mm$

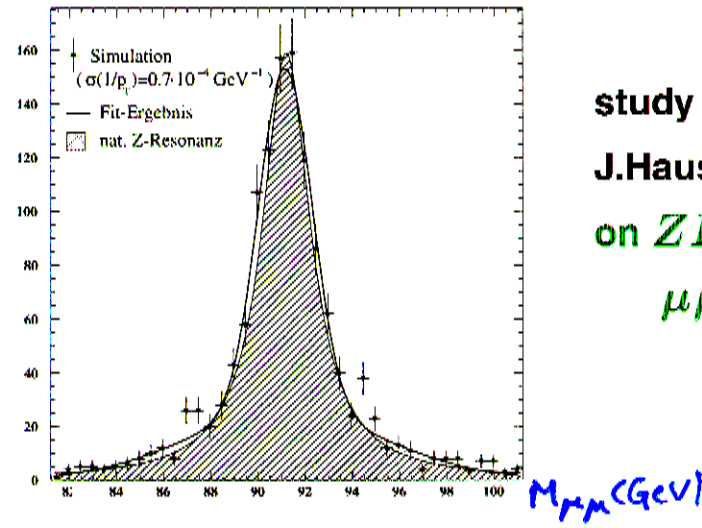
$\sigma(1/p) = 2.8 \times 10^{-4} GeV^{-1}$ (ALEPH: $12 \times 10^{-4} GeV^{-1}$)

whole tracking: $\sigma(1/p) = 0.7 \times 10^{-4} GeV^{-1}$

TPC alone



whole tracking

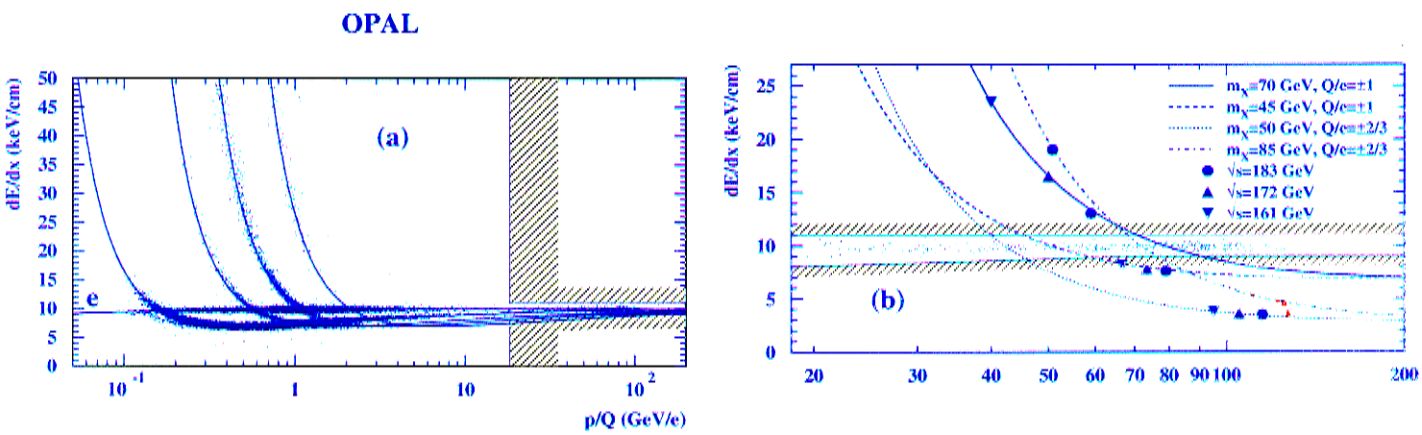


study by J.Hauschildt on $ZH \rightarrow \mu\mu X$

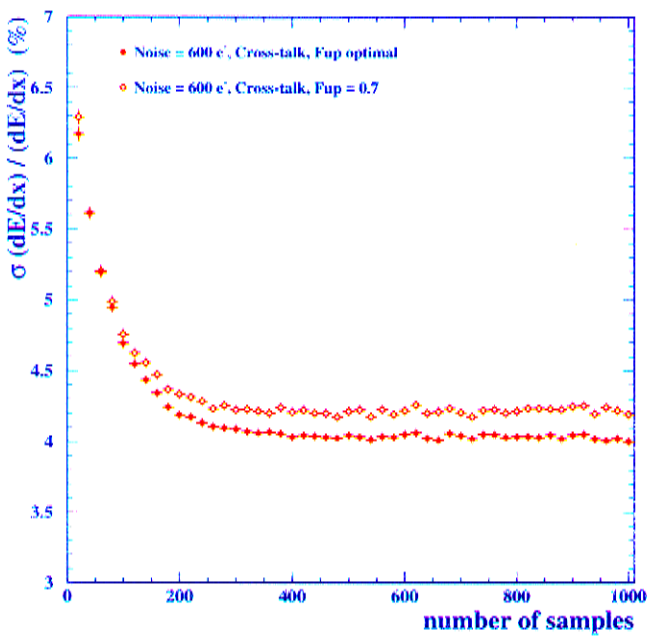
for $\sigma(1/p) = .7 \times 10^{-4}$ mass resolution = 10% of natural Z width

dE/dx measurements

- particle ID in general not as important as at present machines
- some physics uses:
  - background supression (charm/bottom tag ?)
  - Z^0 factory option: heavy flavor spectroscopy
  - searches for new charged heavy stable particles:



- simulation for dE/dx performance (by M. Gruwe, M.Hauschild)



isolated MIP

Δ_r = radial pad size

Δ_r = 1.0 cm, 118 hits

$$ideal : \sigma/(dE/dx) = 4.6\%$$

Δ_r = 0.5 cm, 236 hits

$$ideal : \sigma/(dE/dx) = 4.1\%$$

+ 0.2 % for calibration etc.

Backgrounds in TPC

- basic problem: $\Delta t_{bunch} = 337ns$ and $t_{drift} = 50\mu s$

$\Longrightarrow$ TPC sees $\approx$ 150 BX in one "picture"

backgrounds in TPC (details $\longrightarrow$ K. Buesser)

type	per BX	150 BX	hits in 150 BX
tracks in e^+e^- physics		22	3000
tracks in $\gamma\gamma$ physics	0.7	105	15000
photons	950	142500	25000
neutrons	5600	840 000	39000
total			82 000

$Ar : CO_2 : CH_4 = 90 : 5 : 5$

number of 3D readout pixels in TPC $\approx 7.9 \times 10^7$

$\Rightarrow$ occupancy $\leq 1\%$ not problematic

Gas Choice

(studies by M. Gruwe)

Mixture $Ar - CO_2 - CH_4$	σ_n $[barn]$	drift field/velocity E_{max} $[V/cm]$	v_{dmax} $[cm/\mu s]$	diffusion D_l, D_t (B=3T) $[\mu m/\sqrt{cm}]$
90-0-10	34.0	135	5.47	368, 55
90-5-5	18.0	450	4.92	217, 119
90-10-0	2.0	750	4.99	184,152

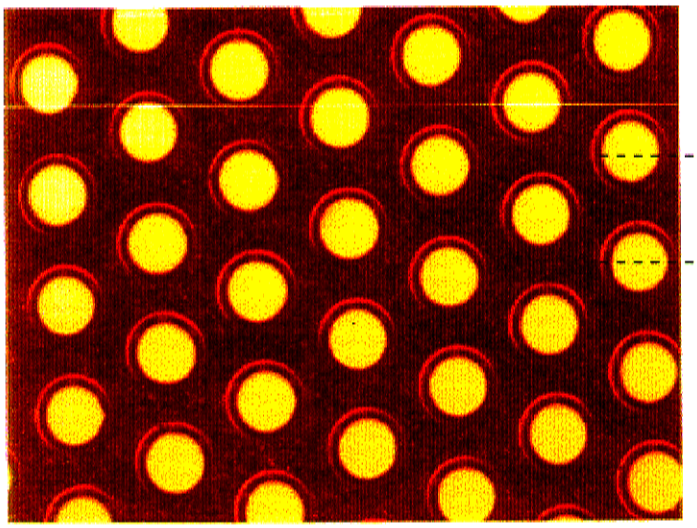
find compromise between: $\sigma_n \leftrightarrow E_{max}, v_{dmax}$

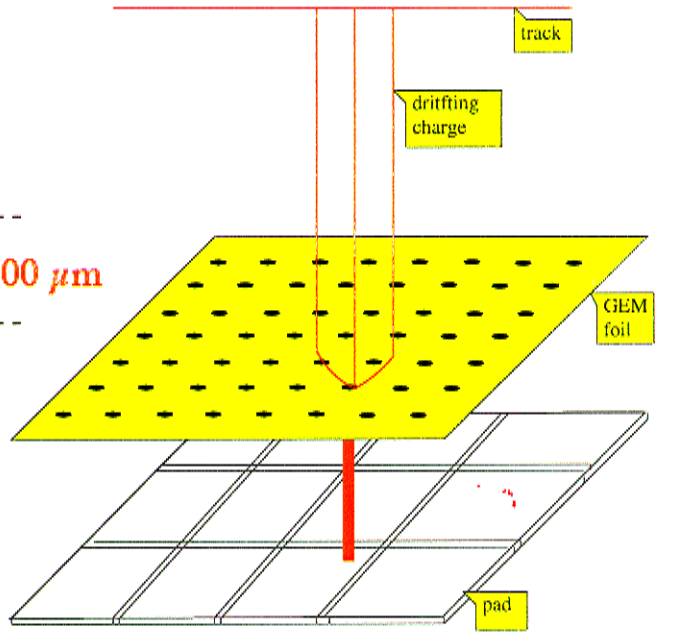
now in DESY setup: 92-5-3

GEM readout for TPC

- wire chambers need gating for supression of ion feed back
- aim: deadtime free runnnig without trigger
- no gating possible by event trigger

→ attractive alternative: readout via GEMS





second alternative under study: MICROMEGAS, P. Colas et al., Saclay

several advantages:

- true 2D-symmetry: no (small) $\vec{E} \times \vec{B} \times$ track angle effects
- only e^- signal: better intrinsic $r - \phi$ and z resolution
- possibility of mechanically simpler and thinner endcaps
- suppression of ion feedback to level of few per cent seems possible

GEM readout for TPC

open questions:

- which level of ion feedback suppression tolerable ?
- which level can be achieved by double GEM in TPC ?
- additional means for suppression

  a) third GEM with gain ≈ 1

  b) additional gating grid triggered by bunch train

  $(t_{train} = 1ms \Rightarrow L^{Ion}_{drift} \leq 1cm)$

  try to avoid wires, maybe carbon fibres

- long term stability of operation ?

  especially uniformity and stability of gain (for dE/dx)

get answers by ongoing R & D

TPC+GEM: Aachen, Karlsruhe, Hamburg, Carleton

TPC+MICROMEGAS: Saclay

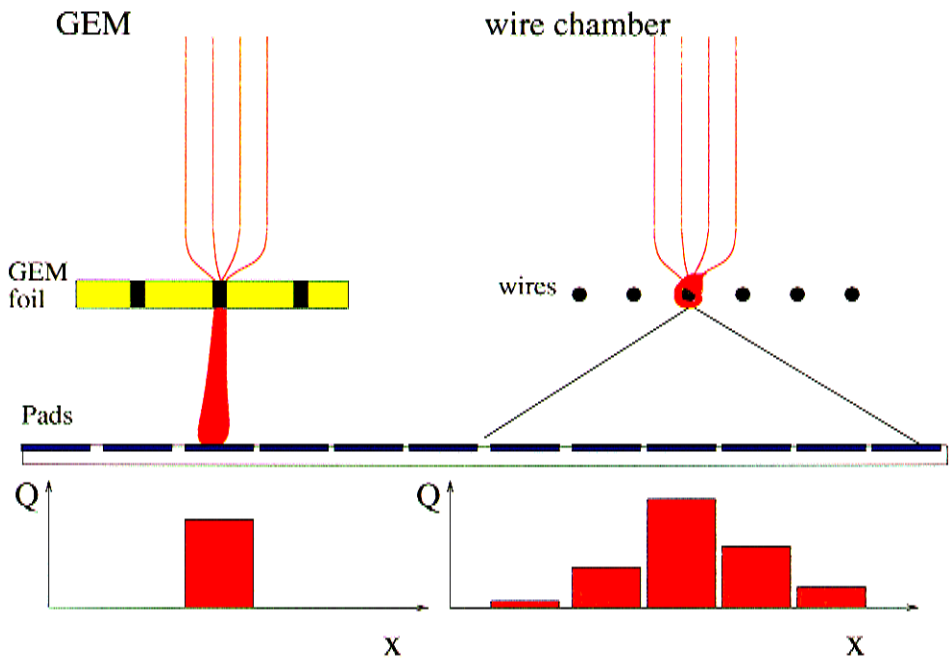
Electronics: Berkeley, Carleton, Orsay, Munich

TPC+wires: Orsay

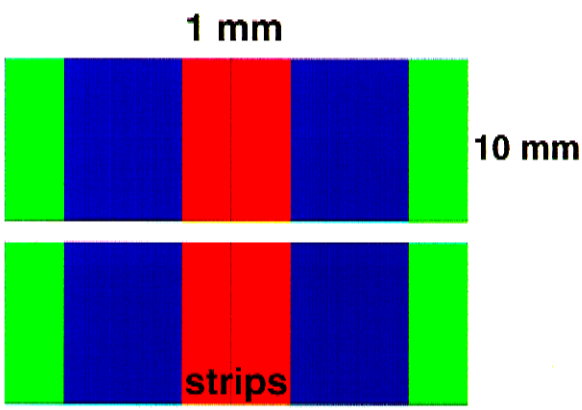
Simulation of Pad Geometries

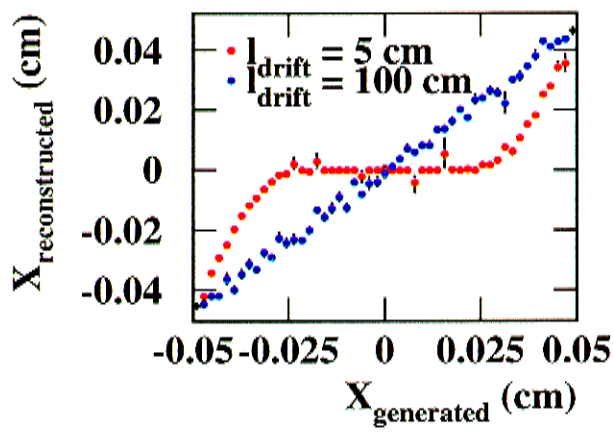
e^- signal narrower compared to wire induction signal

pad response function given by diffusion



number of channels: 1.5 million , pad area = 10 mm^2





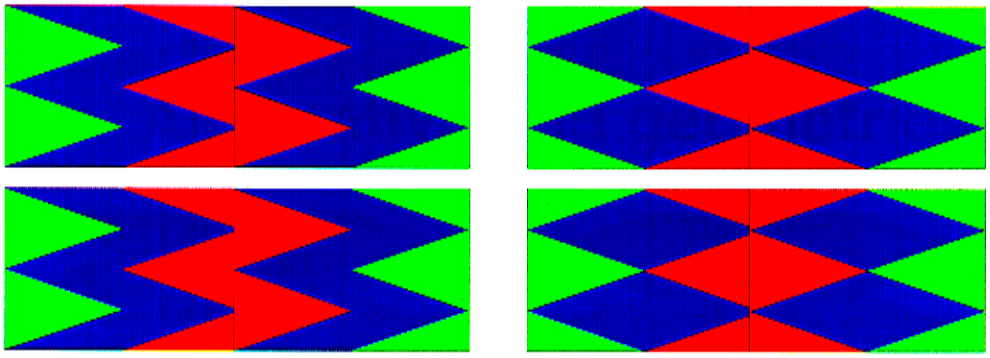
large bias 180 μm , $\sigma_{r\phi} = 250 \mu m$ (1000 $\mu m/\sqrt{12}$ = 290 μm)

$\rightarrow$ try more sophisticated pad geometries

2nd approach: use induction signals (Carleton)

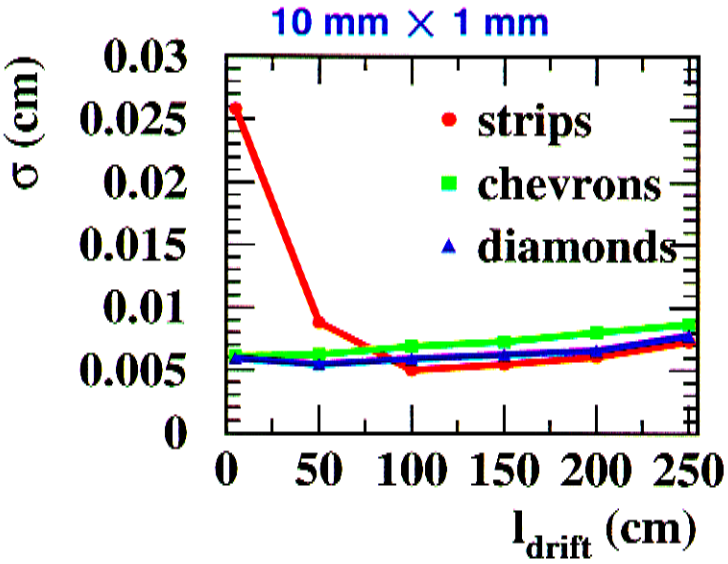
Alternative pad geometries

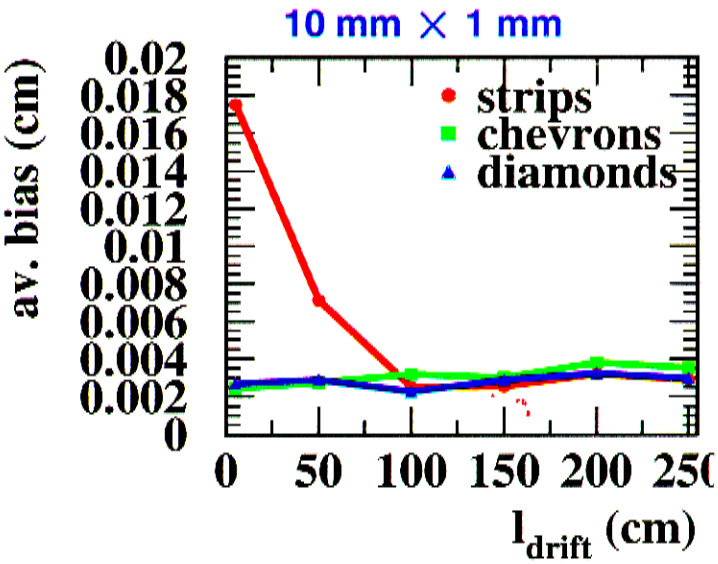
chevrons

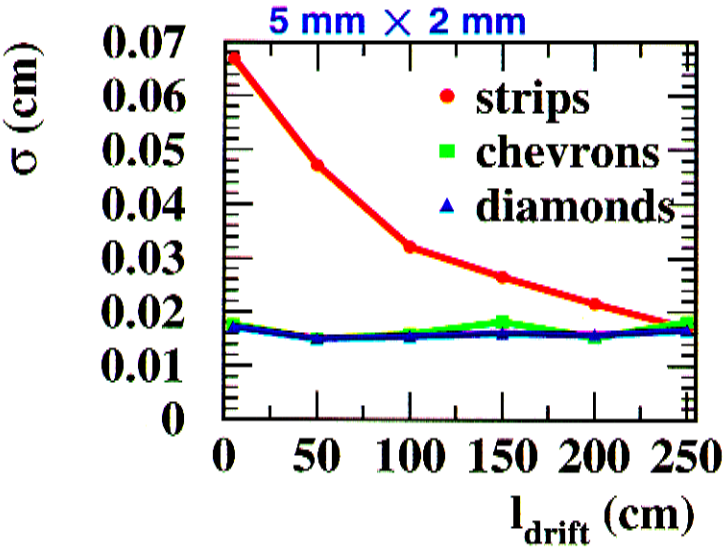


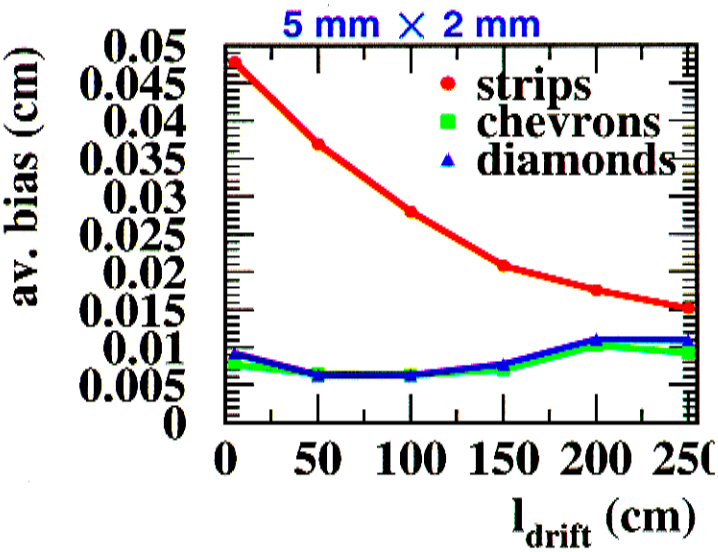
diamonds

- dependence on drift length







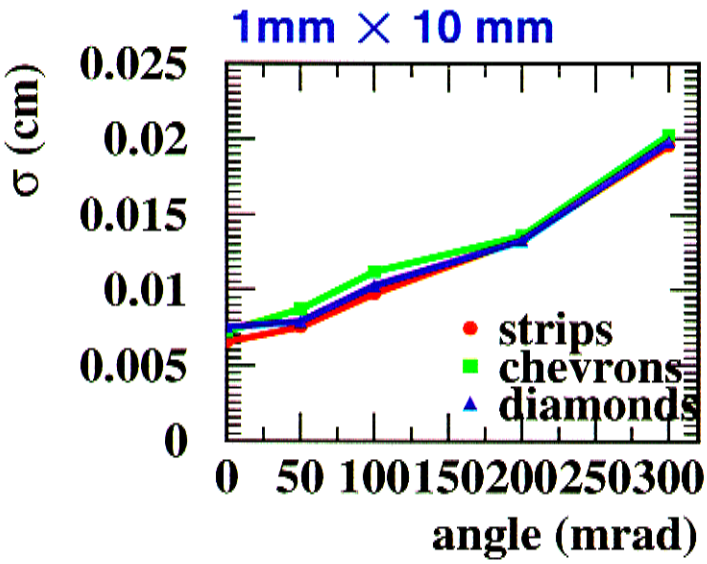


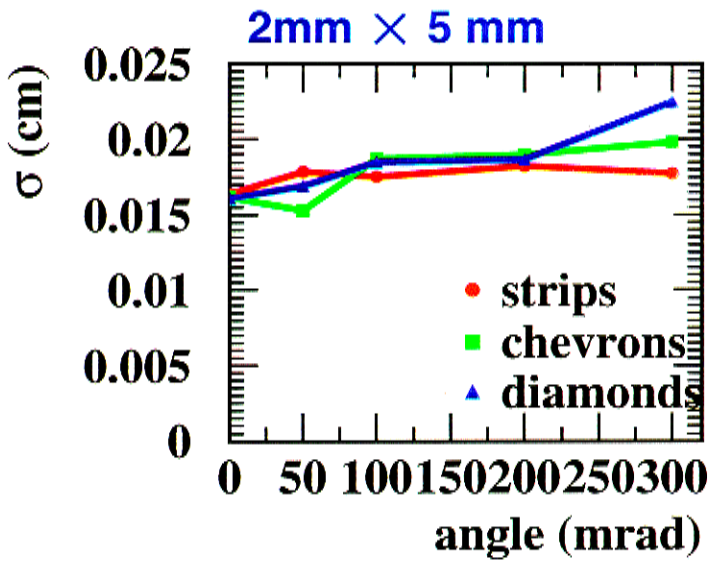
$10 \times 1mm^2$: $\sigma = 60\, to\, 90\ \mu m$, $N_{hits} = 118$

$5 \times 2mm^2$: $\sigma = 170\mu m$, $N_{hits} = 236$ $\rightarrow \sigma_{eff} = 120\mu m$

Simulation of Pad Geometries (cont'd)

- **dependence on dip angle** for l_{drift} = 250 cm





- **conclusion on pad geometry:**

— chevrons & diamonds show smaller bias and smaller dependence on drift length

— $5 \times 2\,mm^2$ and $10 \times 1\,mm^2$ meet resolution requirement
$5 \times 2\,mm^2$ worse by factor 2 to 1.3

but overall momentum resolution dominated by inner detectors

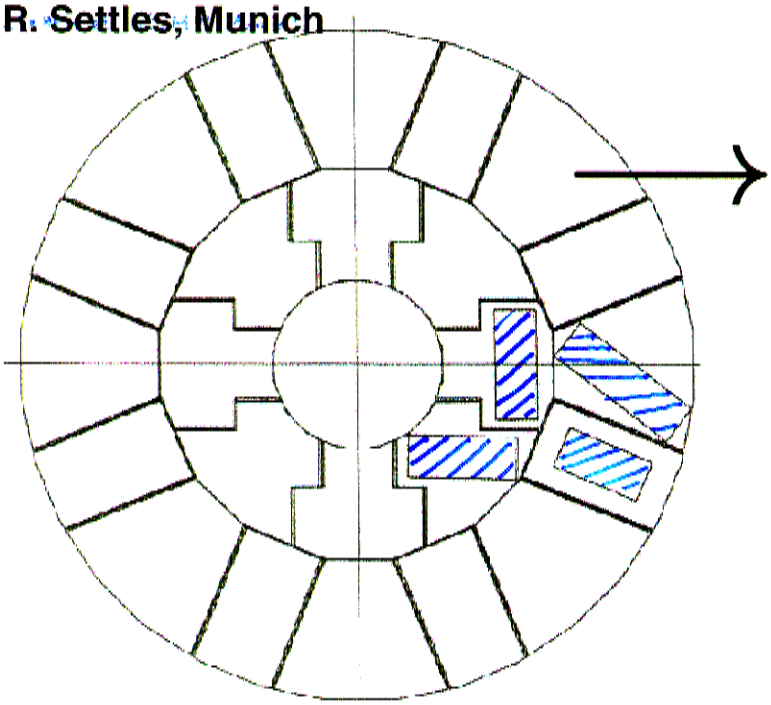
resolution depends mildly on l_{drift} and angle(track,pad)

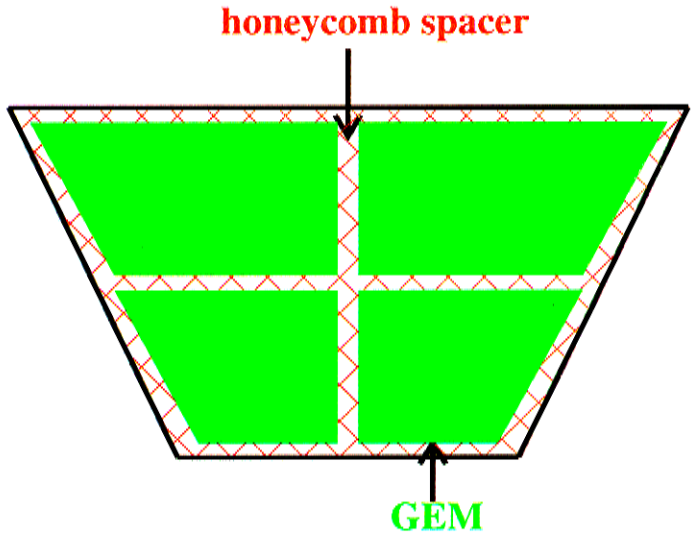
increase of number of hits per track by factor 2

$\Rightarrow$ improvement in dE/dx resolution from 4.6 to 4.1 %

Endplate design

R. Settles, Munich

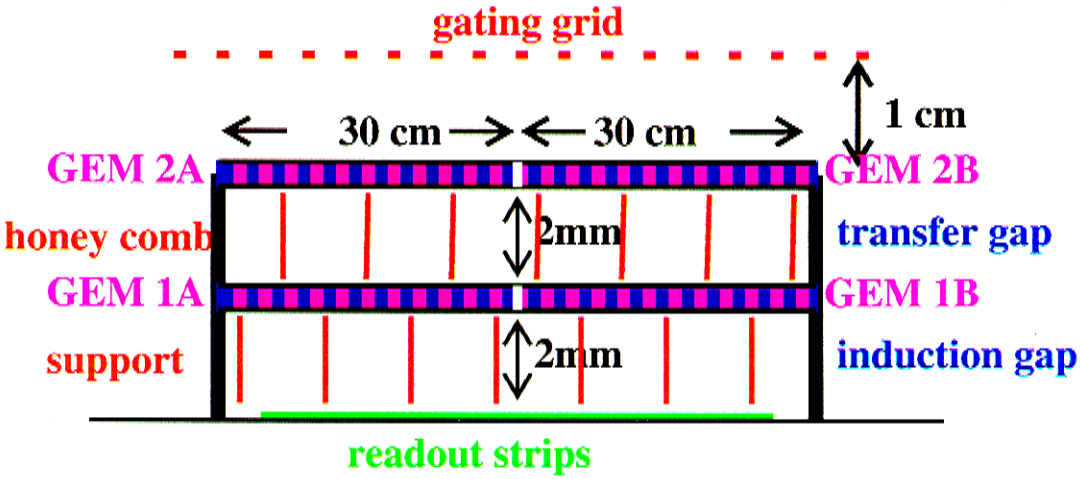




honeycomb structure for mechanical stability

non pointing sector edges

readout "tower" side view:

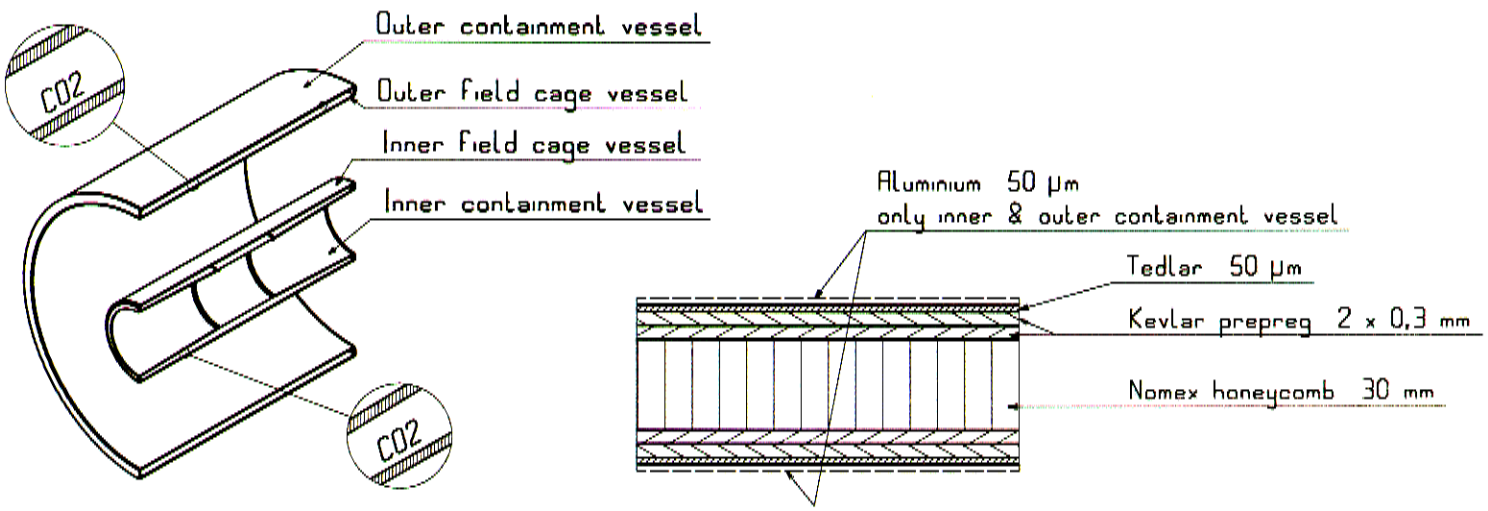


+ strong back plane (Al or G10) + compact electronics

goal: material budget $\leq 25\% X_0$

Field Cage + Electronics

Field Cage similair to ALICE (see below) and STAR field cages



- material budget: $3\% X_0$ at 90 degree (ALICE TDR)
- fine up to 100 kV (400 V/cm)
- movable for maintenance of inner detectors

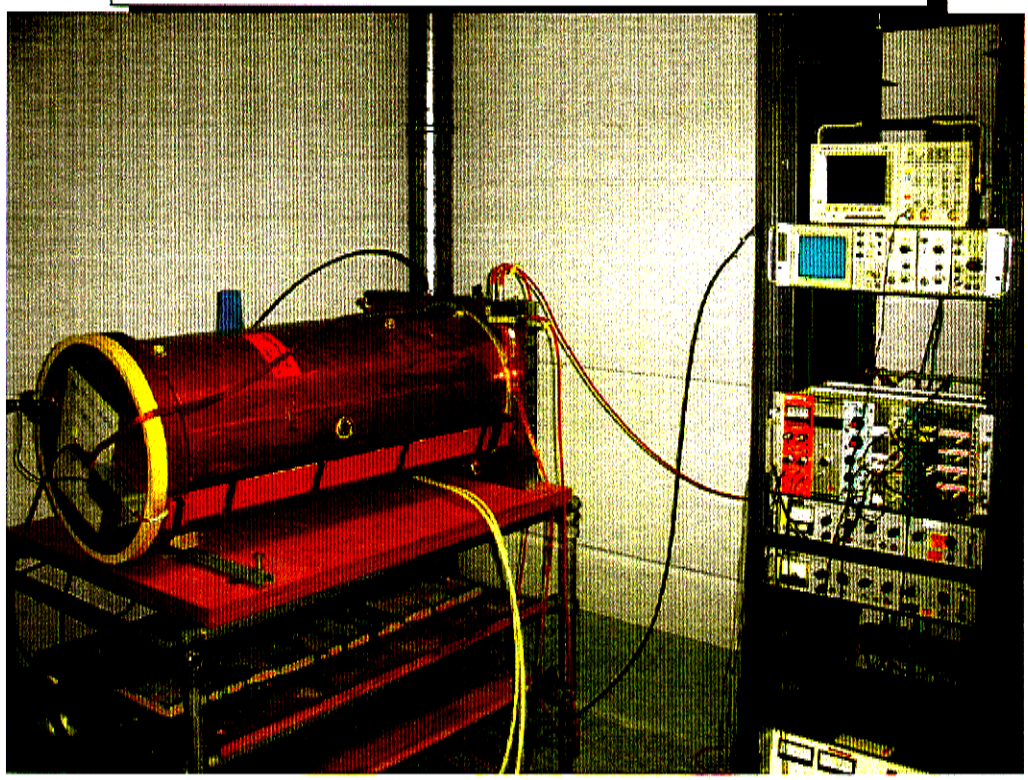
Electronics

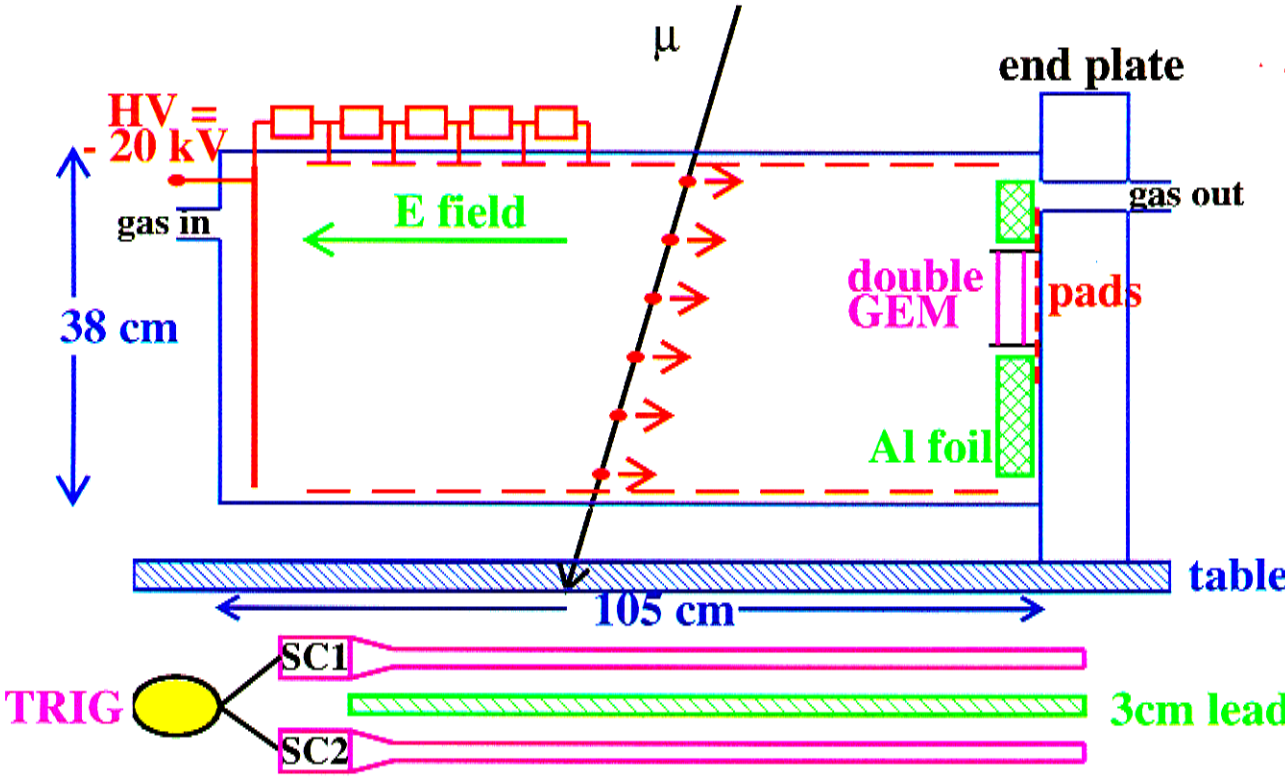
- demands: sampling and digitization on endplate

  early zero supression
- starting point: STAR type electronics (so far up to 40 MHZ)
- induction signals need sampling at $\geq$ 100 MHz

  ongoing R&D at Berkeley, Carleton and Orsay

TPC R & D setup at DESY



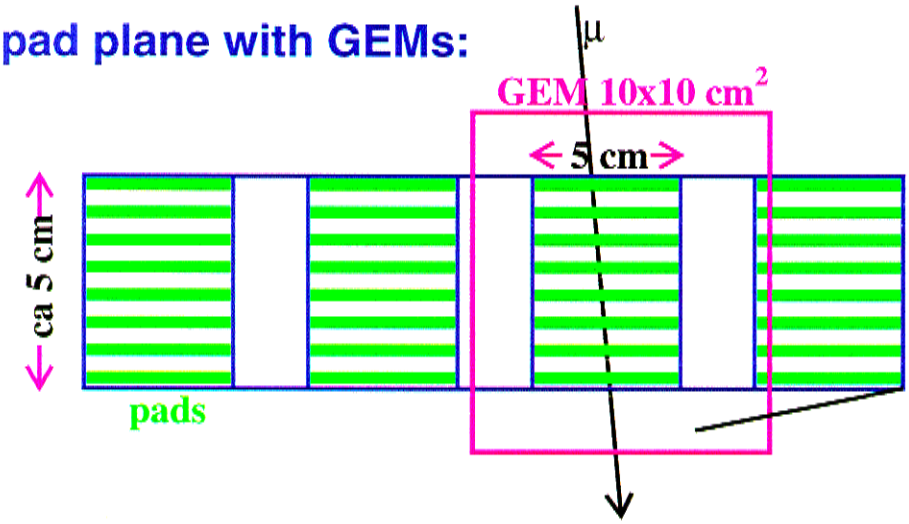


Gas mixture $Ar : CO_2 : CH_4 = 92 : 3 : 5\%$

trigger on cosmic muons, electronics from ALEPH (MPI Munich)

Endplate design

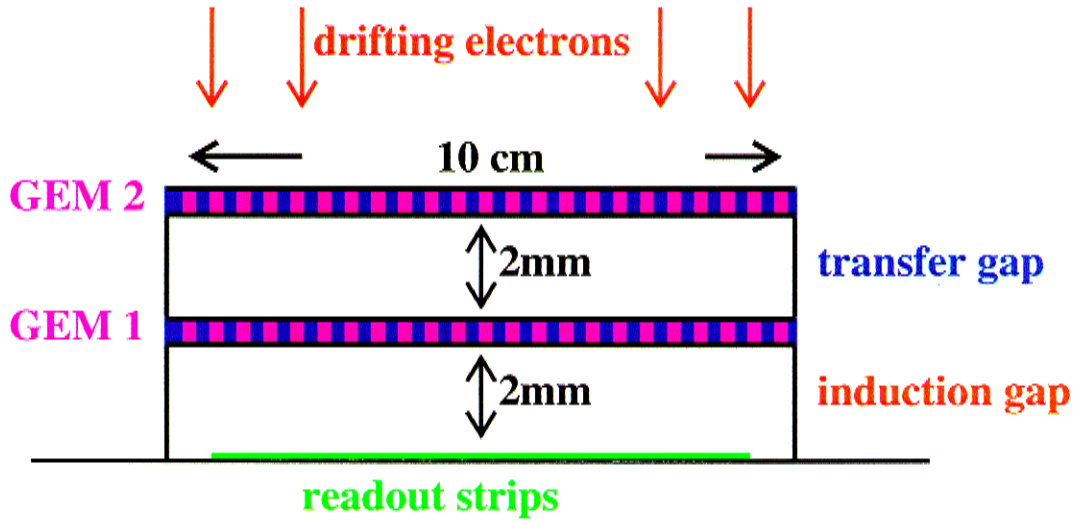
pad plane with GEMs:



one pad row covered by GEMs

→ no studies for $r - \phi$ resolution possible yet

read out "tower"

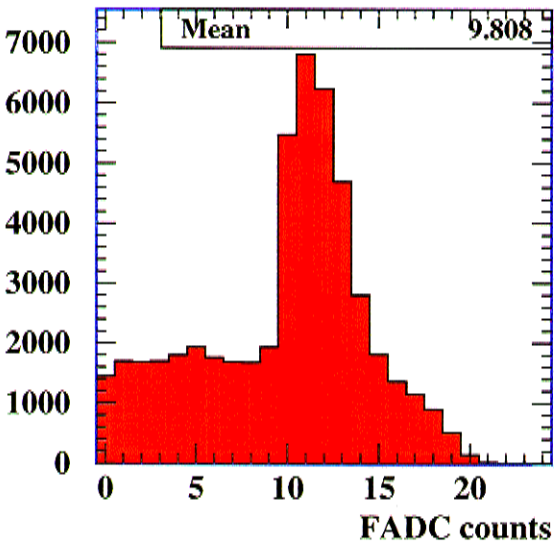


$E_{ind.}, E_{trans} \approx 1200 V/cm$ $\Delta V_{GEM1}, \Delta V_{GEM2} \approx$ 350 to 450 V

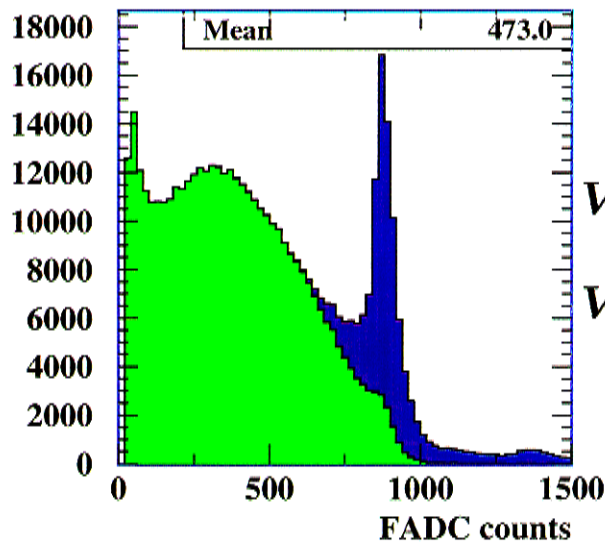
12 MHz sampling rate, 512 time buckets → 43 μs readout

Signal to Noise

noise



signal

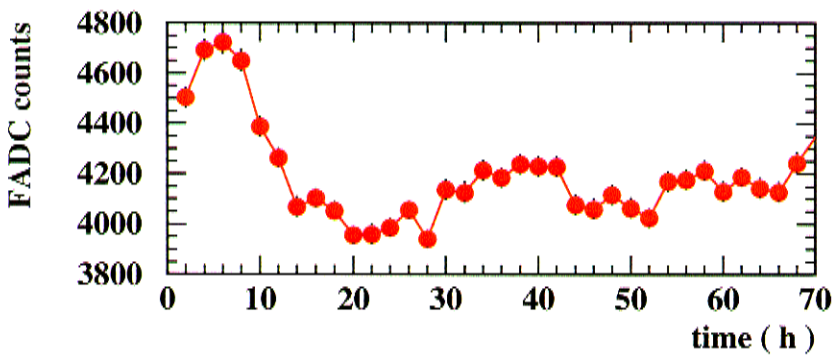


$V_{GEM1} = 430V$

$V_{GEM2} = 420V$

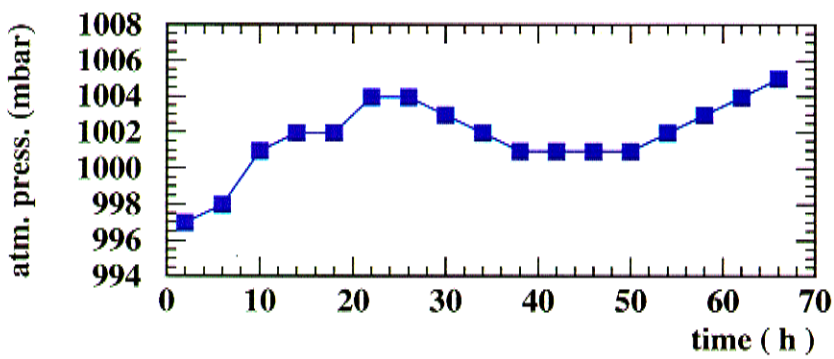
signal / noise ≥ 40

Stability of Gain



gain variation $\leq 5\%$ (last 50 hours)

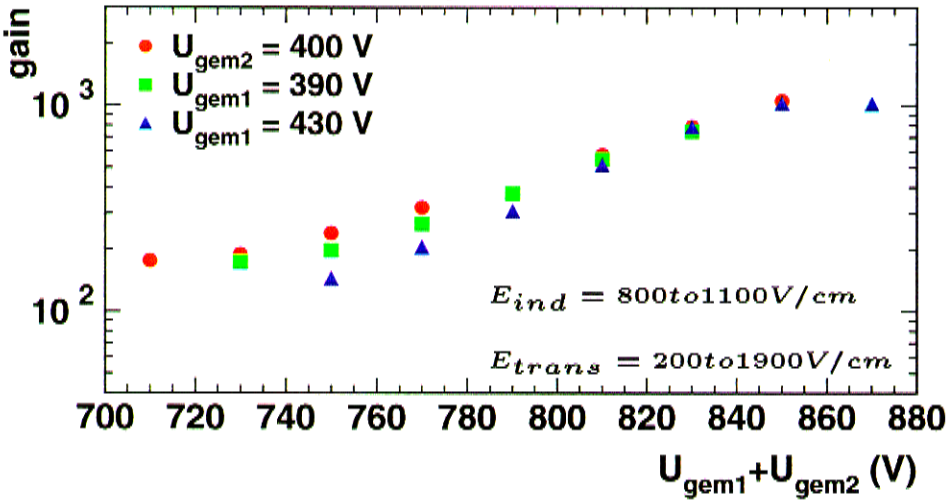
w/o correction for temp., press.



seems promising for dE/dx meas.

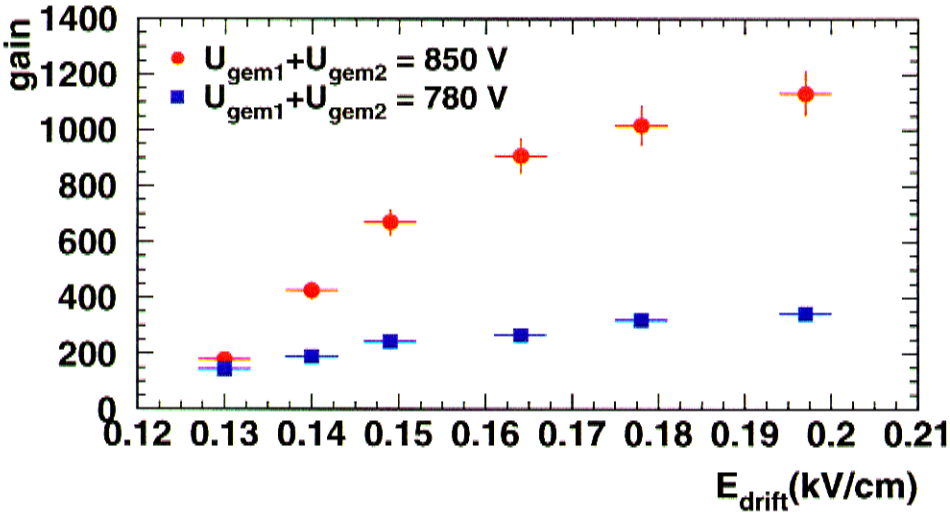
Effective Gain of Double GEM

- gain vs GEM voltages



- exponential rise with GEM voltages
- max gain ≈ 1000 (so far)

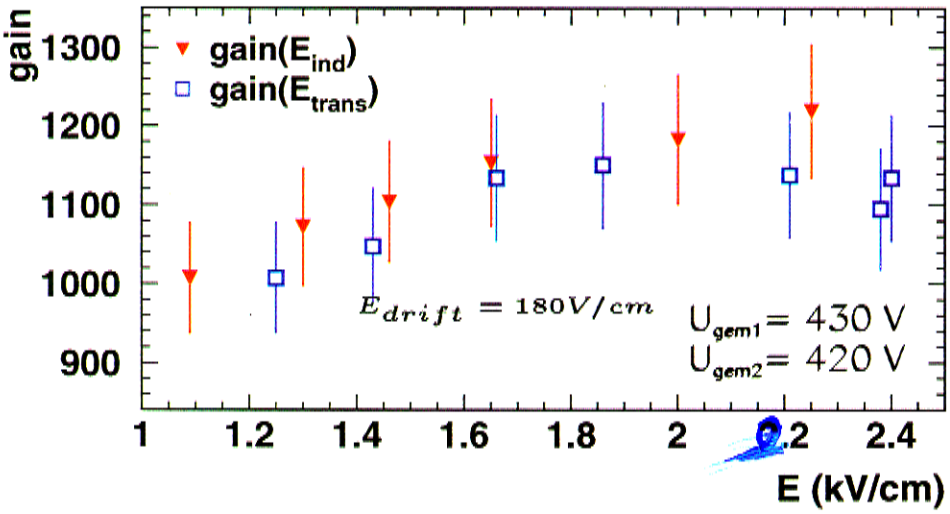
- gain vs drift field



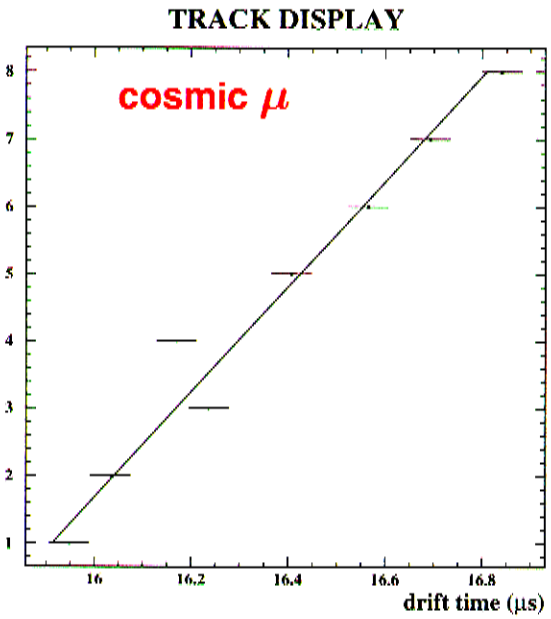
$E_{ind} = 1650 V/cm$
$E_{trans} = 1250 V/cm$

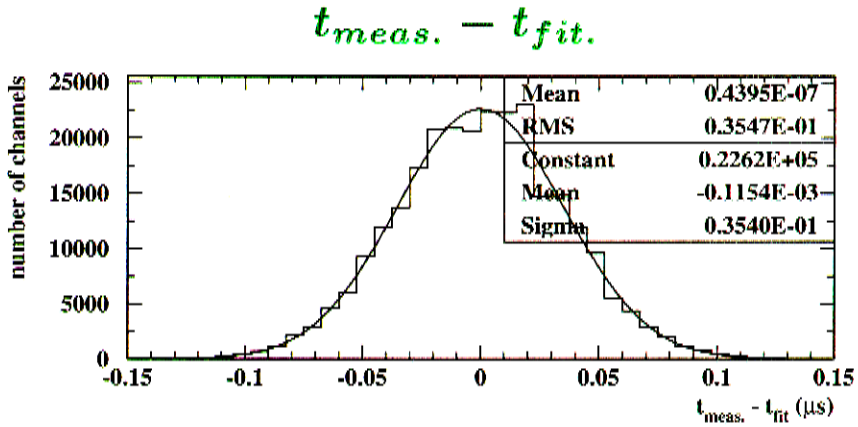
$E_{ind} = 2050 V/cm$
$E_{trans} = 1250 V/cm$

- gain vs trans. & ind. fields



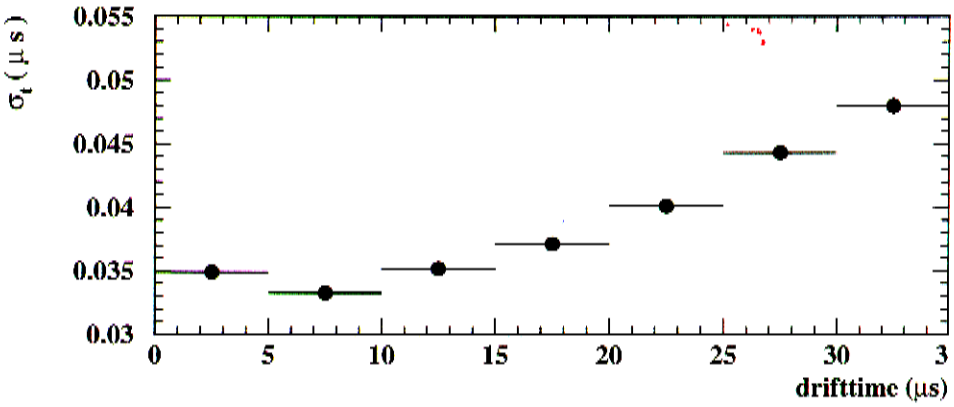
Z resolution measurement



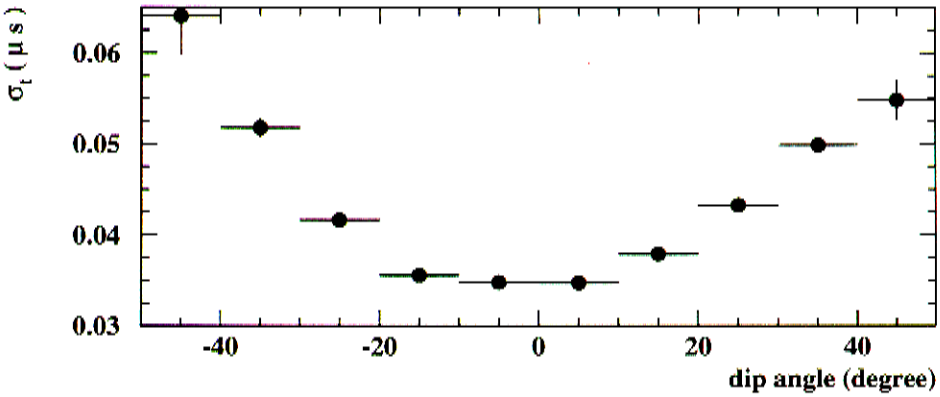


$$\sigma_z = 1.5\,mm$$

σ_z vs drift length



σ_z vs dip angle



Conclusion

- a TPC is proposed as the central track detector for TESLA offering several advantages
  (redundancy, tracking to large R, dE/dx, low material)
- operation in TESLA environment is possible
  (occupancy well below 1%)
- ungated operation for deadtime free running wanted

→ GEM readout offers several advantages
  (thinner endcaps, ion feedback supression, better resolutions ?)

- first R&D results look very promising
- open questions will be adressed by R&D in the near future
  in Aachen, Berkeley, Carleton, Hamburg, Karlsruhe
  Munich, Orsay, Saclay, ...

Acknowledgements:

thanks to my colleagues from the ECFA/DESY study for stimulating discussions and providing material for this talk, and especially to M. Hamann for his collaboration in the R&D.