The TESLA Time Projection Chamber

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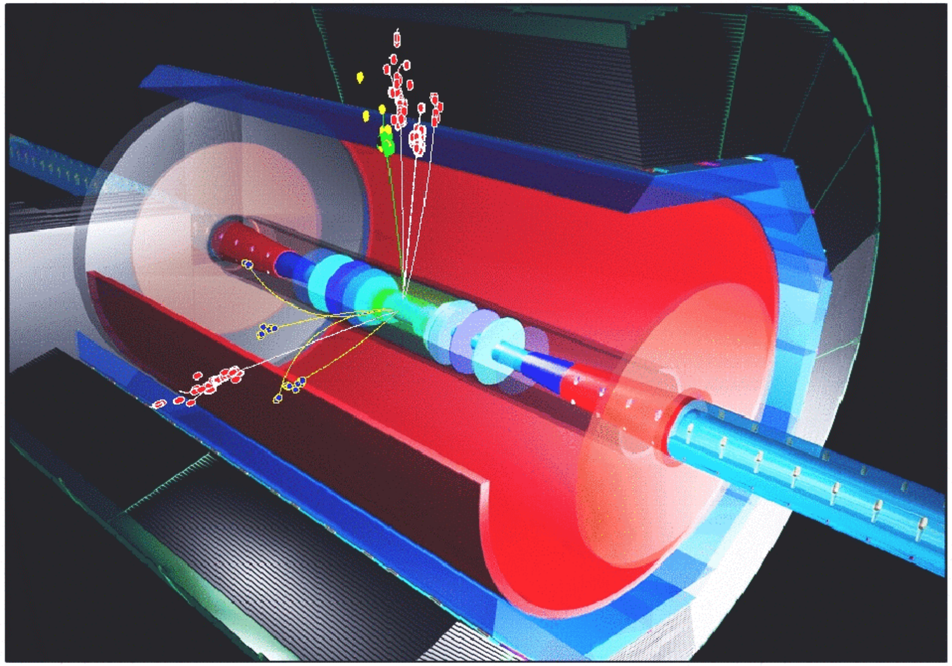
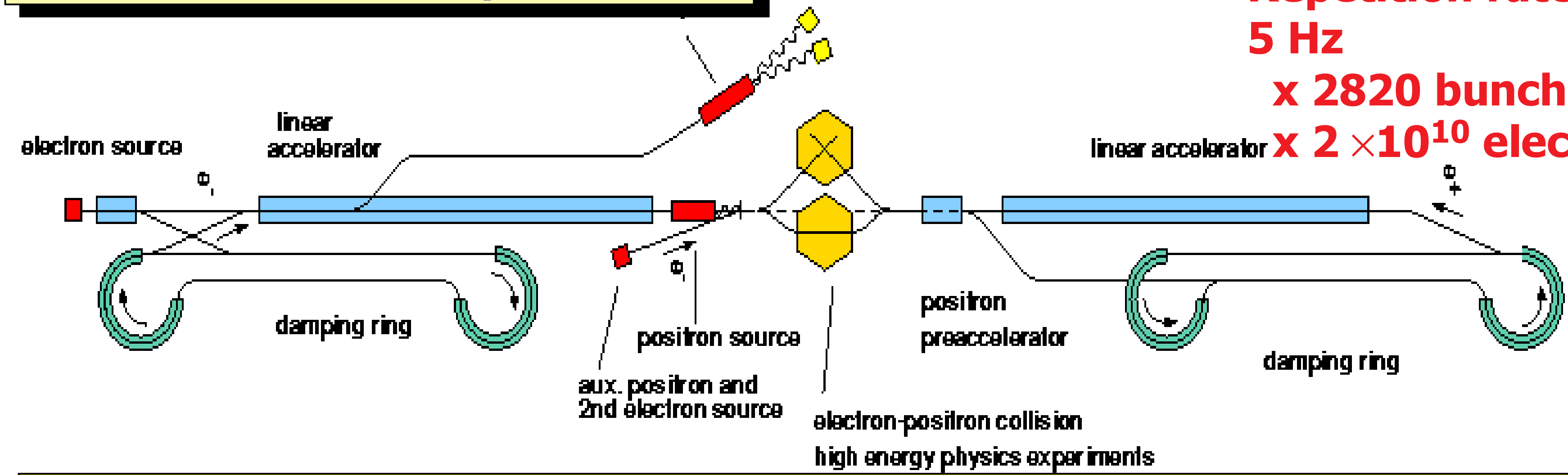
(for the ECFA-DESY Linear Collider TPC working group)



- Introduction:
  - TESLA detector concept
  - TPC as a central tracker
- TPC R&D issues:
  - Gas amplification systems
  - Ion feedback suppression
  - Tracking resolution studies
- Future plans
- Conclusions

TESLA : TeV Energy Superconducting Linear Accelerator

The TESLA machine: parameters

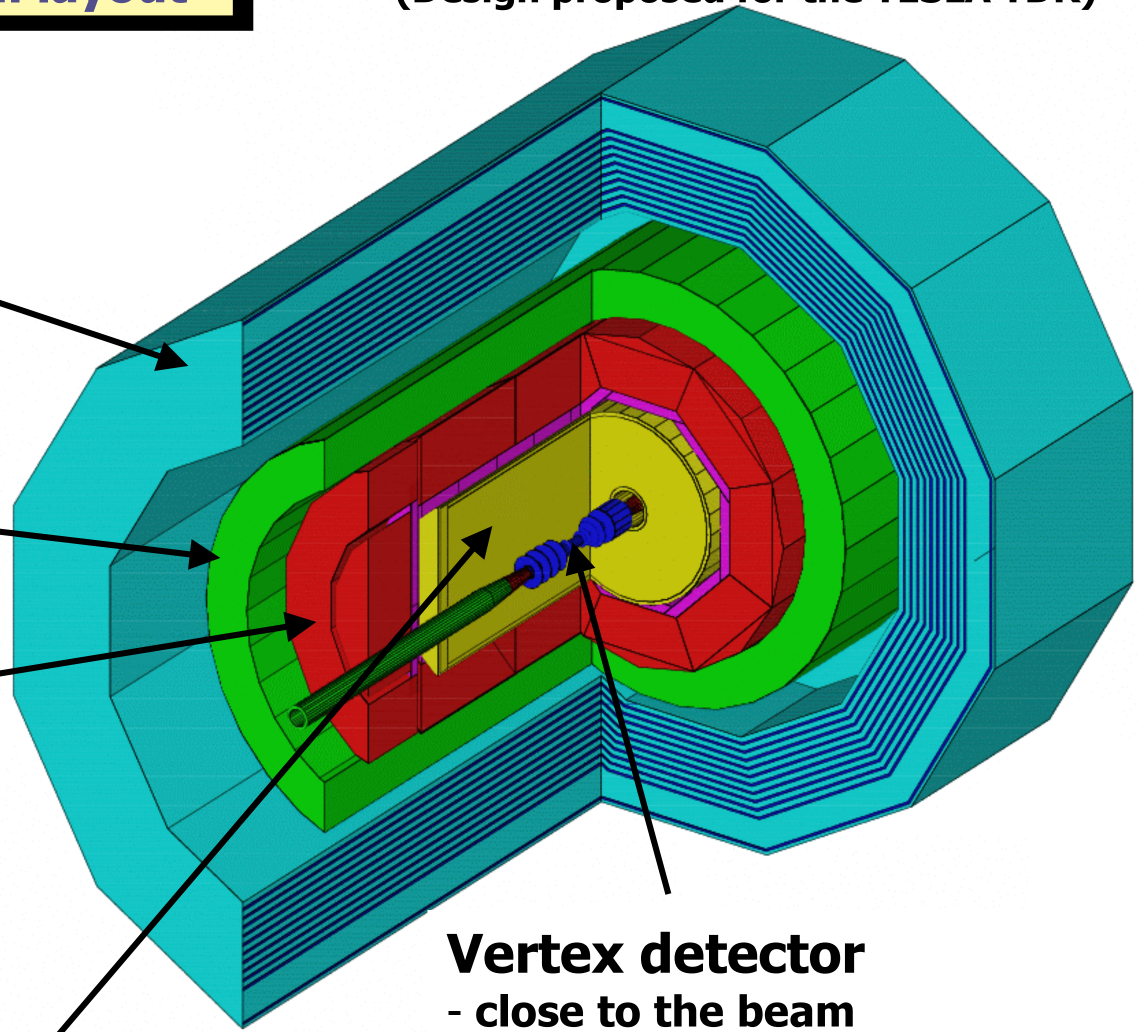


Repetition rate : 5 Hz x 2820 bunches x 2 $\times 10^{10}$ electrons

Parameter	TESLA	LEP200	SLC
• C.M. Energy [GeV]	500	209	92
• Luminosity [cm^{-2}/s]	3.4 x 10^{+34}	6.0 x 10^{+31}	3.0 x 10^{+30}
• Beam size σx [nm]	**553**	300 000	1 500
• Beam size σy [nm]	**5**	8 000	650
• Bunch length [mm]	**0.3**	10	1
• Particles per bunch	2 x 10^{+10}	4.5 x 10^{+10}	4 x 10^{+10}
• Bunches / train	2820	4	1
• Bunch interspacing [ns]	337	22 000	8 360 000
• Repetition rate [Hz]	5	45 500	120
• Beamstrahlung [%]	4		0.03

The TESLA detector: general layout

(Design proposed for the TESLA TDR)



Muon detector

Coil
B = 4 Tesla

Calorimeter
- fine 3D granularity
- very good energy flow

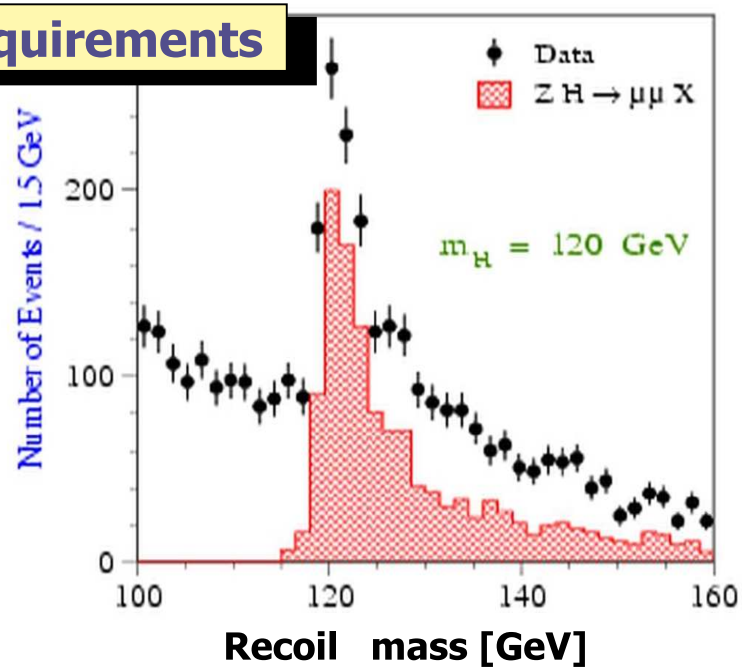
Vertex detector
- close to the beam
- reconstruction of secondary vertices of b and c quark decays

Time Projection Chamber
- Low amount of material [gas]
- Large number of 3D points
  - → precise tracking
  - → excellent momentum resolution

TPC as the central tracker at TESLA: physics requirements

- **Higgs(es) searches**
  - **dilepton recoil mass for Z H events**

- **Searches for new particles:**
  - **kink tracks**
  - **long lived charged particles**
  - **end point measurements for SUSY decay chains**



Impose several requirements:

- **high momentum resolution:**

  $\delta(1/p_t) < 5 \times 10^{-5}$ / GeV

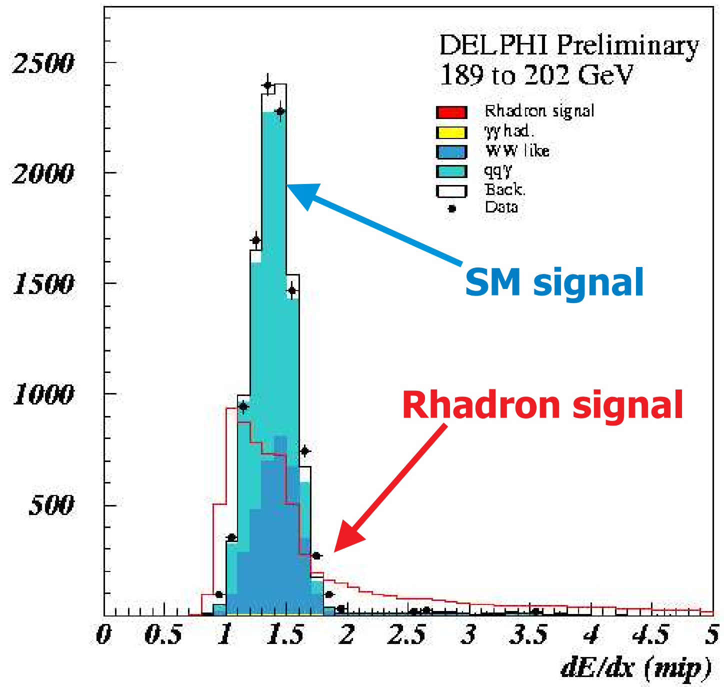
  $\delta(1/p_T) = 6 \times 10^{-4}$ / GeV [ALEPH @ LEP]

- **high tracking efficiency with efficient pattern recognition despite the high track /jets density environment:**

  $\varepsilon > 97.5\ \%$ [p > 1 GeV]

- **a large TPC sensitive volume**
- **a good dE/dx resolution**

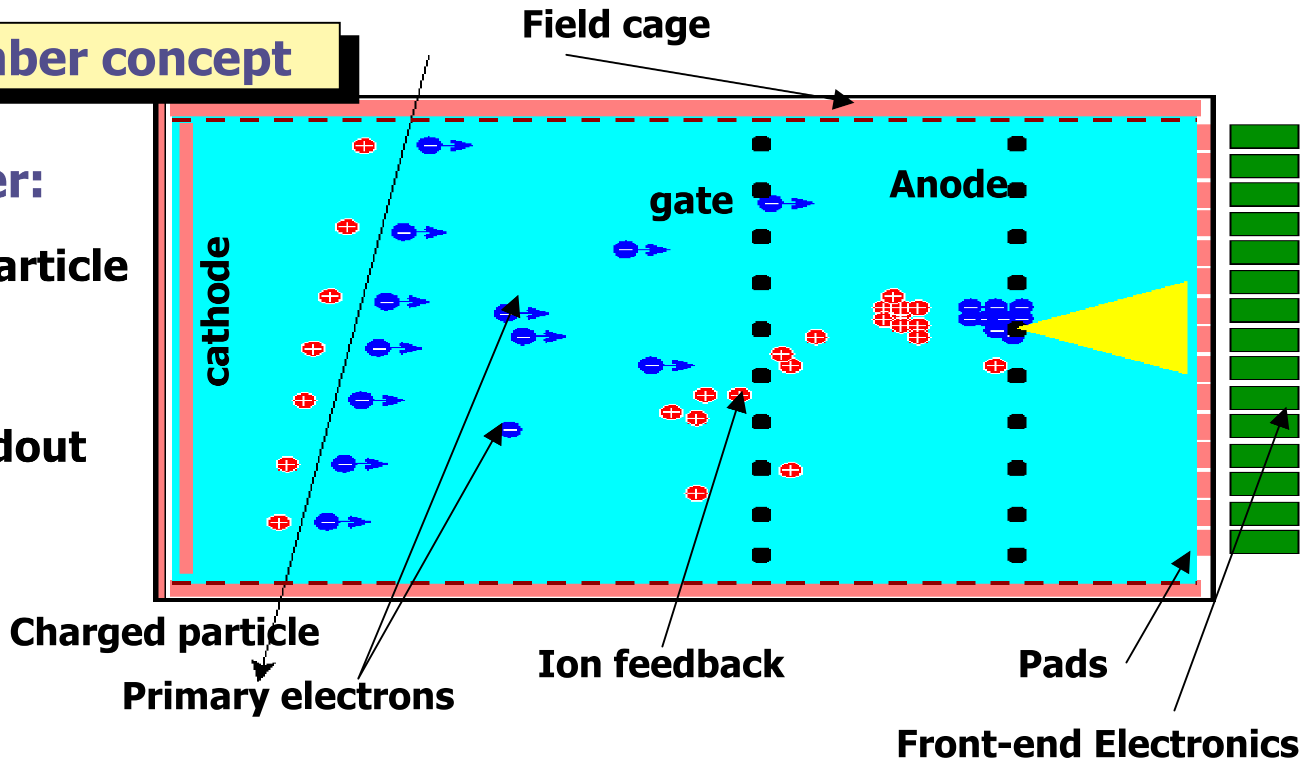
  $\delta(\log[dE/dx]) < 4.5\ \%$



Time Projection Chamber concept

Time Projection Chamber:

- ionization by a charged particle
- electrons avalanche
- signal induced on the readout pads

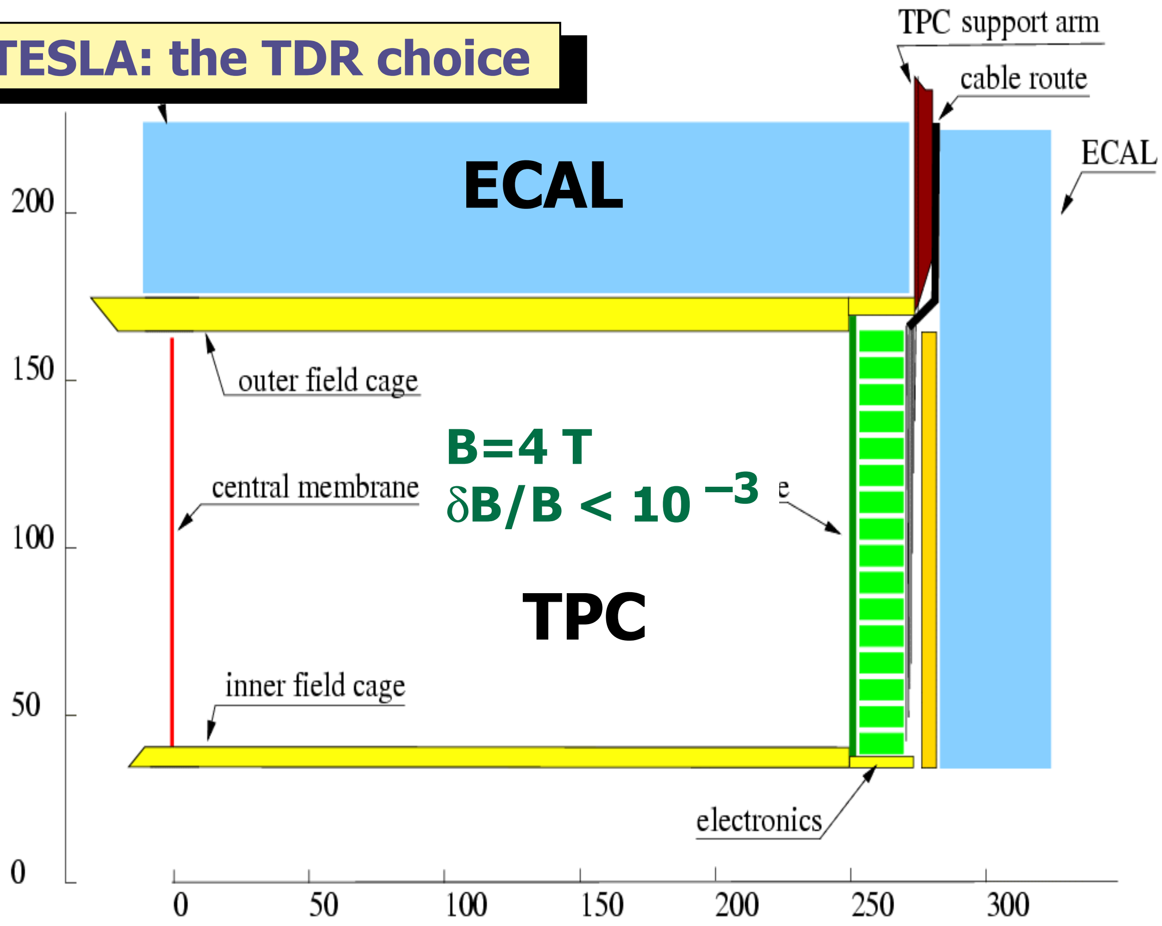


Problems addressed by the Time Projection Chamber

- minimization of material budget (X_0) for field cage and end caps
- ions return in the drift volume and cause field distortions
- E X B effects have to be minimized
- gas choice is a crucial issue :

  compromise between aging properties, σ_n, E_{max}, v_{drift} and $D_{L,T}$
- at TESLA, continuous readout and bunch time intervalle small

TPC as the central tracker at TESLA: the TDR choice



- **Large TPC sensitive volume**

  Length: 2 x 250 cm

  Inner radius: 38 cm

  Outer radius: 163 cm

- **Gas mixture:**
  - **$Ar - CH_4 - CO_2$: 93 – 5 – 2**
  - **σ_n = 17 barn**
  - **v_{drift} = 4.55 cm/μs**
  - **E_{max} = 230 V/cm**
  - **$D_{L,T}$ = 310,70 μm / $L^{1/2}$**

- **Background in TPC: 82 000 hits**
  (mainly neutrons ~5600 n/BX) but occupancy < 1 %

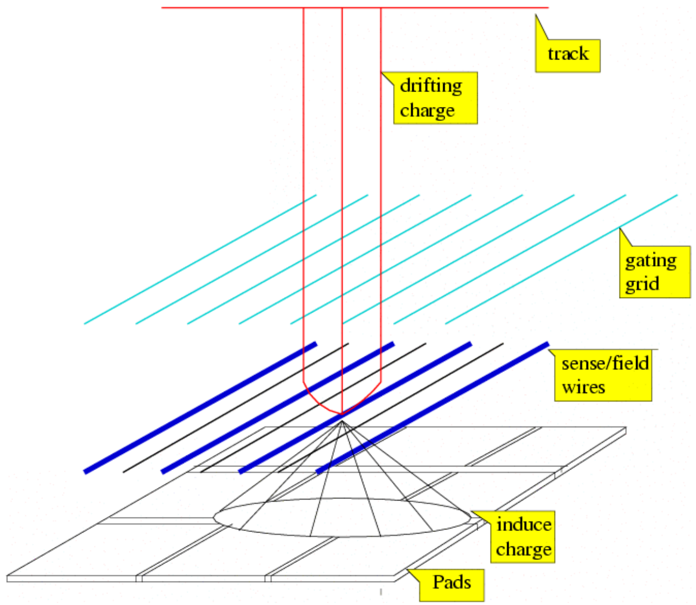
- **large number of spatial points:**
  200 (z, r, φ) per track (dE/dx, p_t)

- **very fine granularity:**
  ~ 1.2 millions pads 2 x 6 mm^2

TPC as the central tracker at TESLA: Gas amplification: wires

For the drifting electron amplification several solutions are considered:

Wires



Principle

- primary electrons
- amplification
- signal, induced on the pads
- gating plane for ion feedback reduction

Advantages

- known technology (e.g. TOPAZ, ALEPH, DELPHI, etc...)

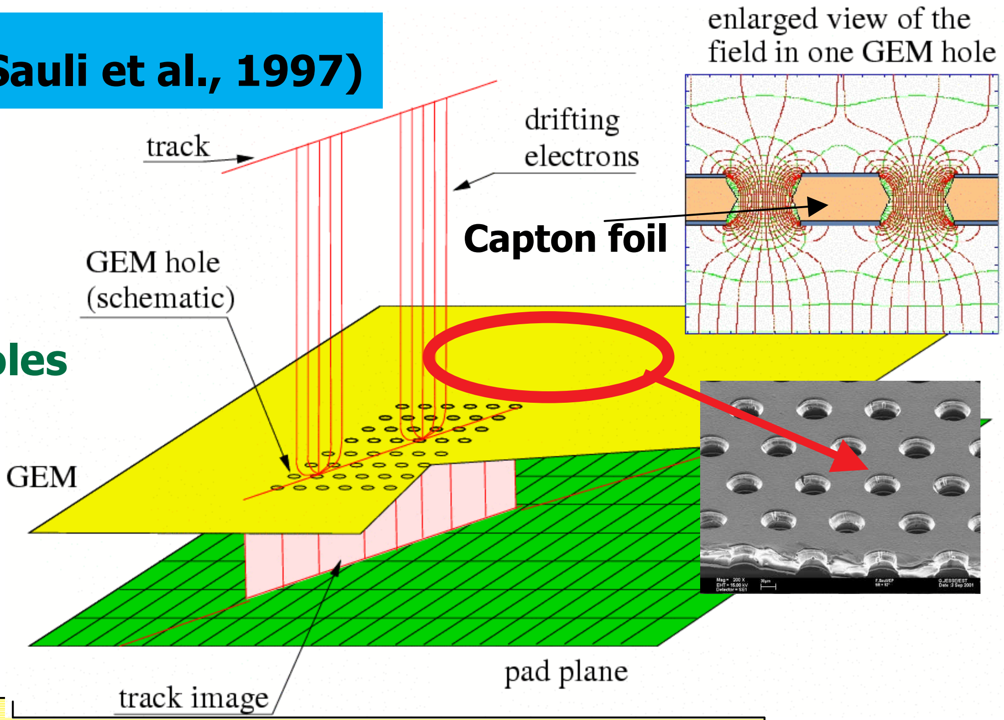
But

- high magnetic field
- ion feedback needs gating after every bunch crossing?
- E x B effects

TPC as the central tracker at TESLA: Gas amplification: GEM

Gas Electron Multiplier (F. Sauli et al., 1997)

- thin polymer base (~50 μm)
- coated on each side by ~ 5 μm copper.
- perforated by a high density of small holes
  - 70 μm holes, 100 μm pitch
- Strong field (~ 80 kV/cm) between the two conductive sides.



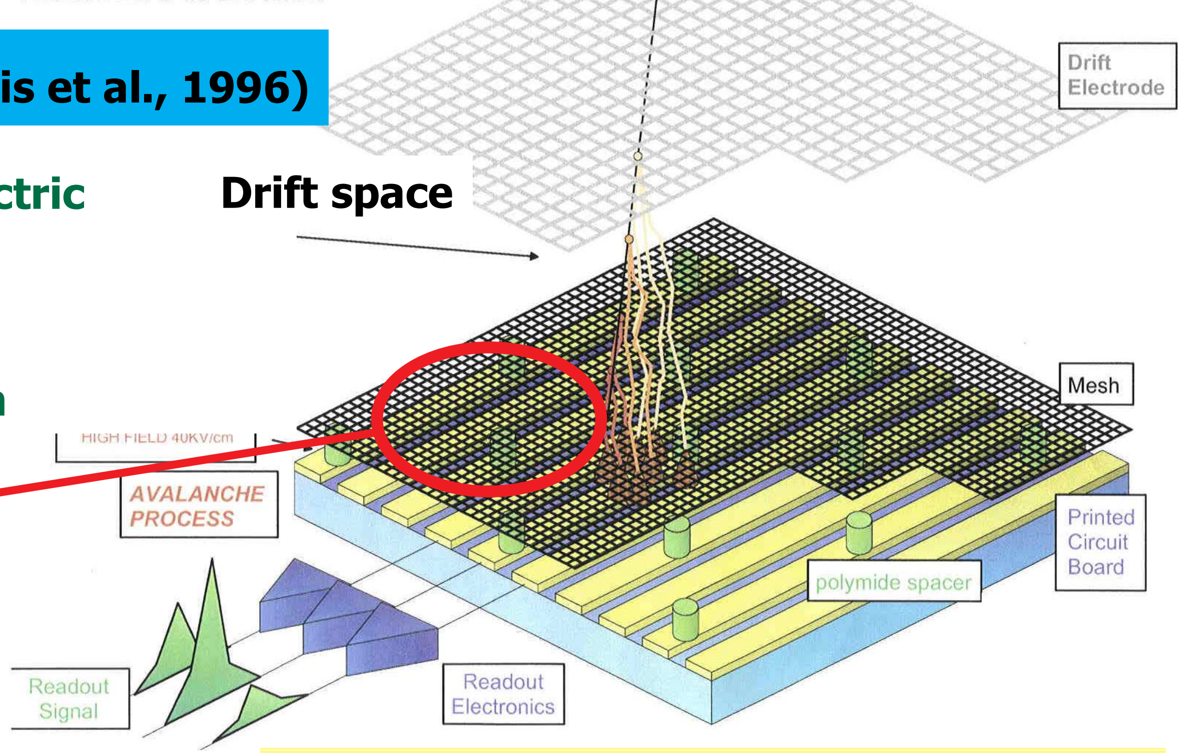
Advantages of GEM:

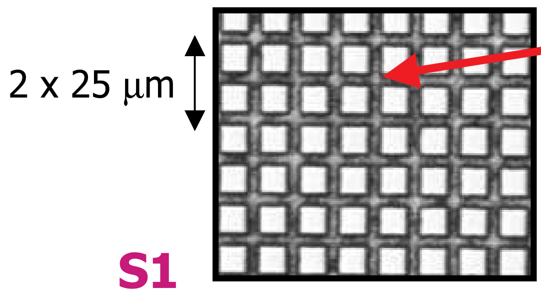
- almost no E x B effects (~ 50 μm)
- natural suppression of ion feedback
- low material budget
- 2-D symmetry
- high gain and possibility to use multi GEM structure
- fast signal collection
- simple design (no mechanical tension)

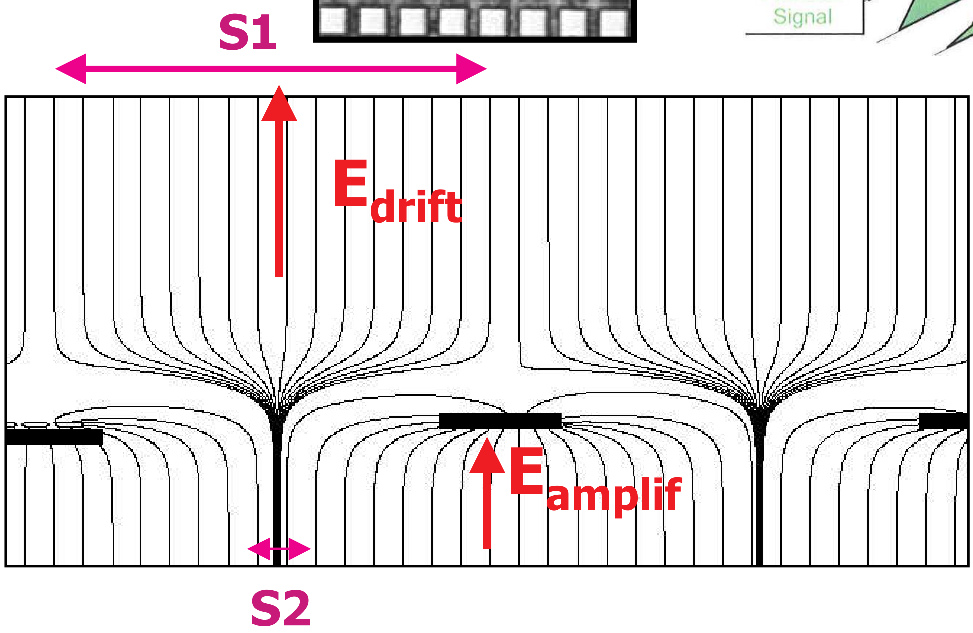
TPC as the central tracker at TESLA: Gas amplification: MicroMegas

MicroMegas (Y. Giomataris et al., 1996)

- thin metallic mesh held by dielectric support
- amplification gap~ 100 μm
- high field in the gap ~ 40 kV/cm







Same advantages as GEM

- large gains (10^3-10^4)
- Funnel effect → efficient ion collection

$$S1/S2 \sim E_{amplif} / E_{drift}$$

Ions are unlikely to follow the field lines and return to the drift volume.

Ions return to the grid

TPC : ongoing R&D activities

(For more details see note LC-DET-2002-008: http://www.desy.de/~lcnotes)

Participating institutes to the LC TPC R&D program:

Aachen, Carleton, DESY, Karlsruhe, Krakow, LBNL, MIT, MPI Munich, NIKHEF, Novosibirsk, Orsay (LAL+ IPN), Rostock, Saclay, Victoria.

- **Gas amplification system:**
  - GEM or (and) MicroMegas or wires
  - Ion feedback

- **Readout pad shape:**
  - Pad geometry studies (chevrons, squares, etc...)
  - Spatial, two track and dE/dx resolution

- **Gas mixture:**
  - Drift velocity
  - Aging and effects on the field cage design

- **Behavior in magnetic field:** (effect on electron transparency, etc...)

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

$\omega\tau \approx 20$ **(4 Tesla)**

- **Electronics:**
  - sampling and digitization on endplates, etc...

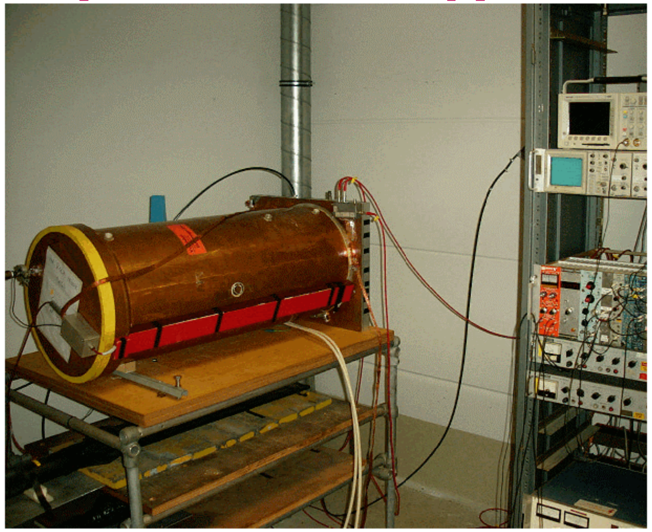
- **Simulation and software development**

TPC : ongoing R&D activities: gain stability

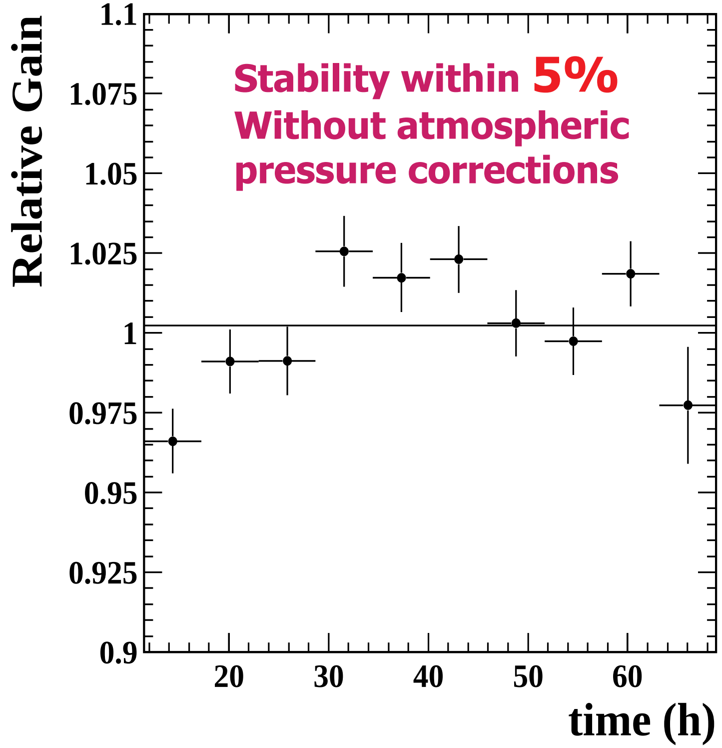
A typical TPC setup e.g. DESY:

- Use of cosmic muons
- two scintillators as triggering signal
- maximal drift length (1m)
- double GEM structure
- gas mixture: $Ar:CH_4:CO_2 = 93:5:2$
- electronics à la ALEPH:
  (Fastbus technology TPD+FVSBI)
- readout sampling at 12 MHz.
- 64 readout channels
- signal / noise > 40

(DESY TPC setup)



Gain stability



Goal: to reach a dE/dx measurement with 5% precision a gain stability homogeneity at 1% level

TPC : ongoing R&D activities: ion feedback studies

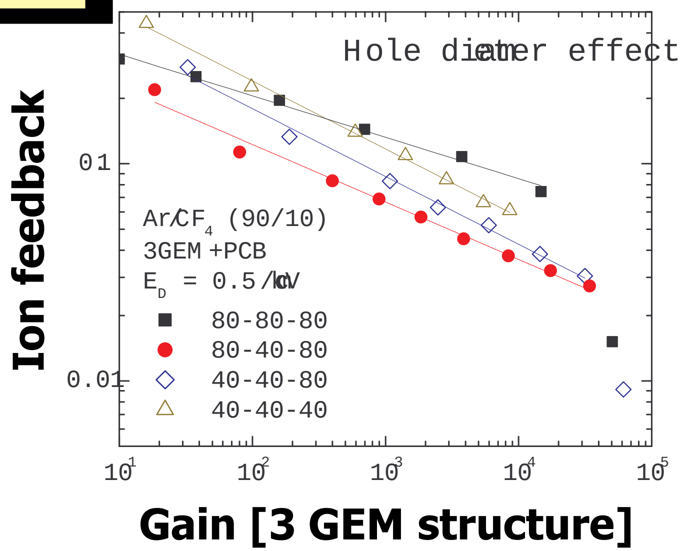
Two sources of ions in a TPC:

- ions created in the TPC drift volume by primary ionization
- ions created during the avalanche

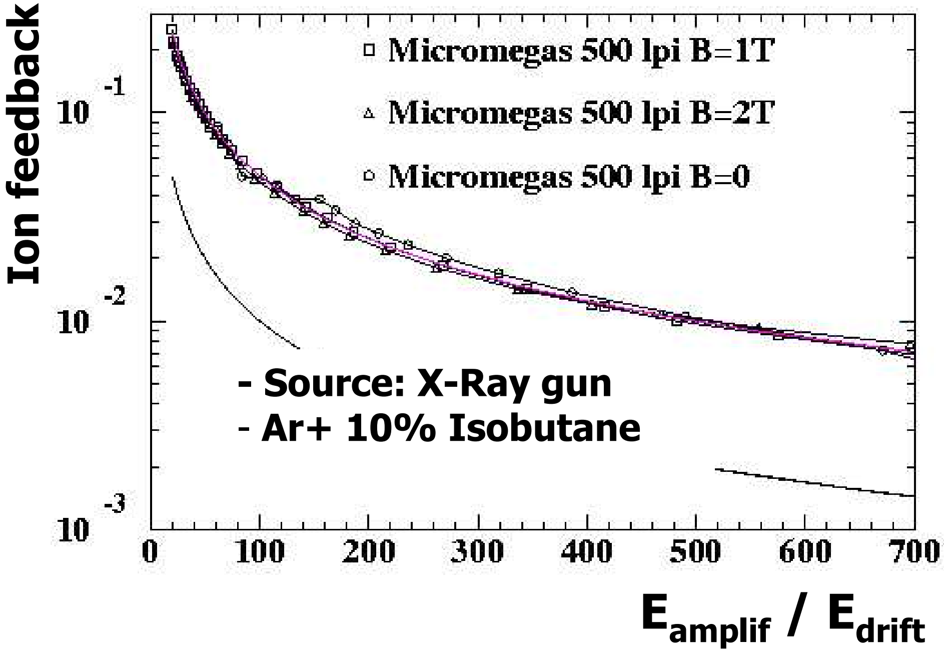
Ion feedback is a crucial issue at TESLA:

- to which level can it be suppressed ?
- How does the ion feedback evolve with high magnetic field ?

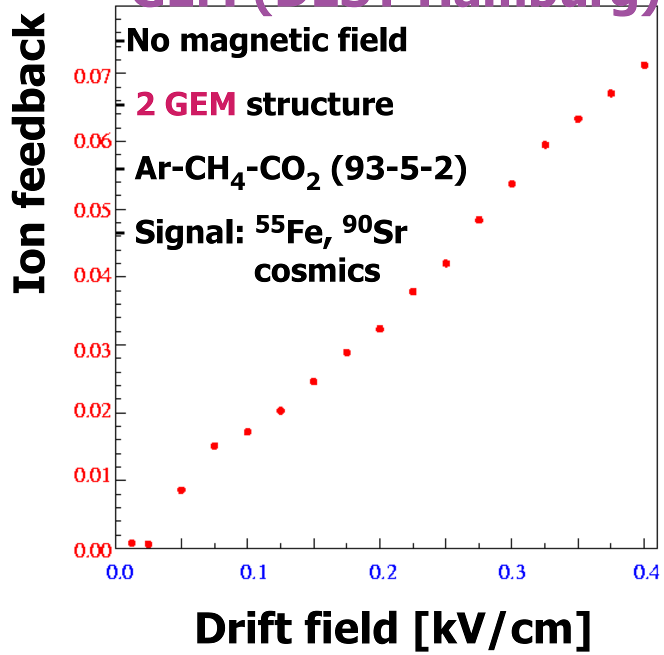
GEM (Novosibirsk)



MicroMegas (Saclay/Orsay) with B



GEM (DESY Hamburg)

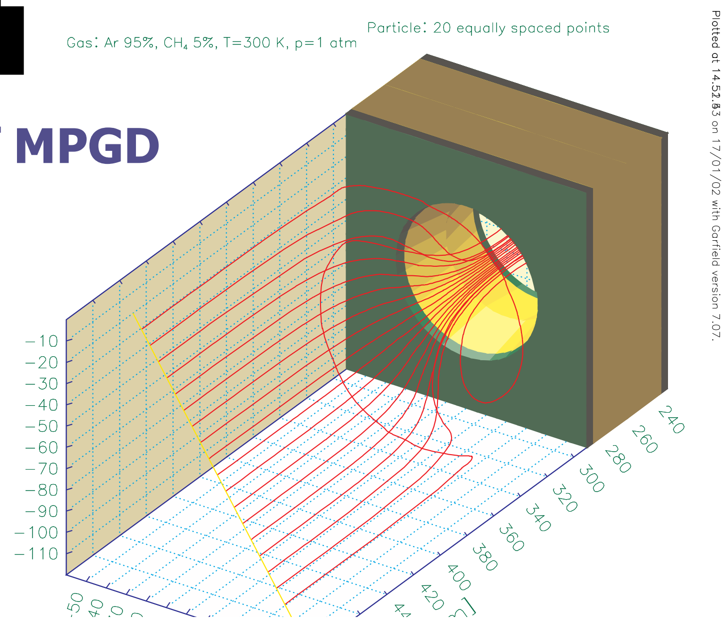


TPC : ongoing R&D activities: simulations

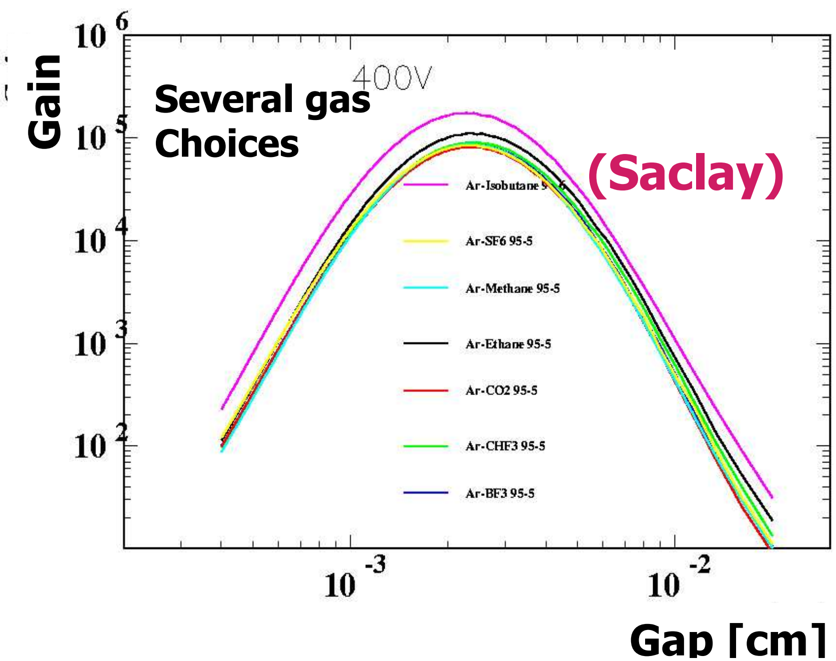
- A need to better understand several aspects of MPGD

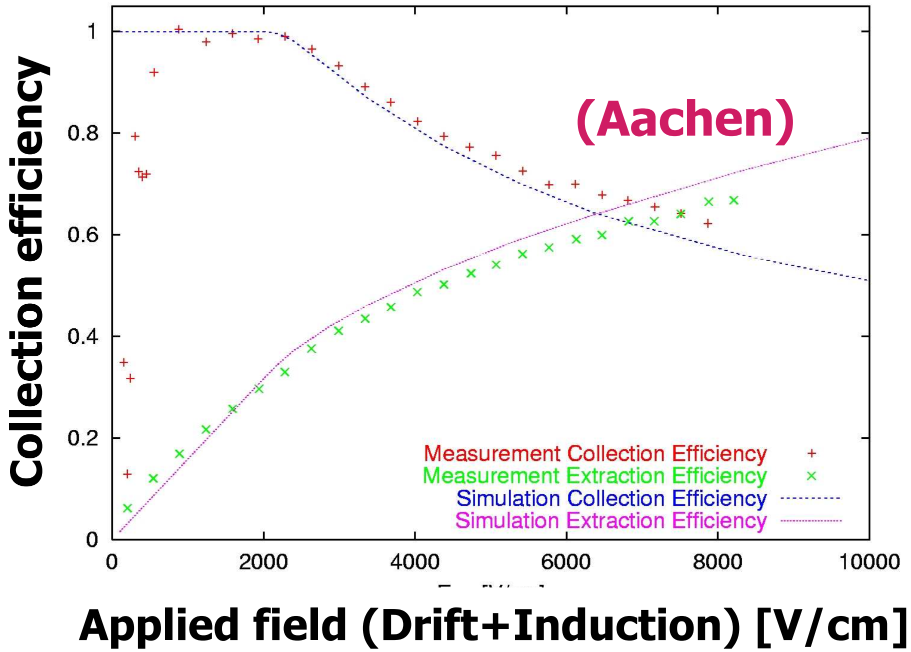
- Simulation of a GEM with and without magnetic field:
  Systematic studies like e.g. e- collection efficiency

- Amplification properties simulation:
  - gas choice (carrier, effect of quencher)
  - optimal gap

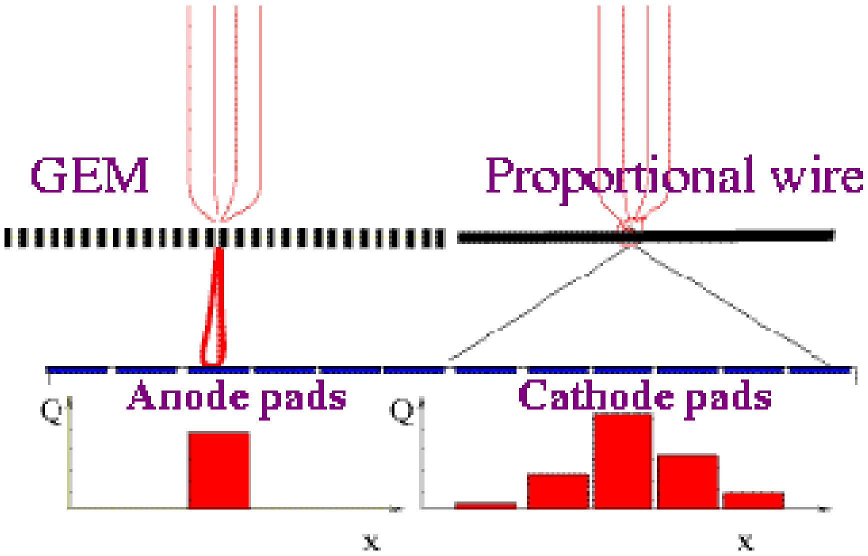


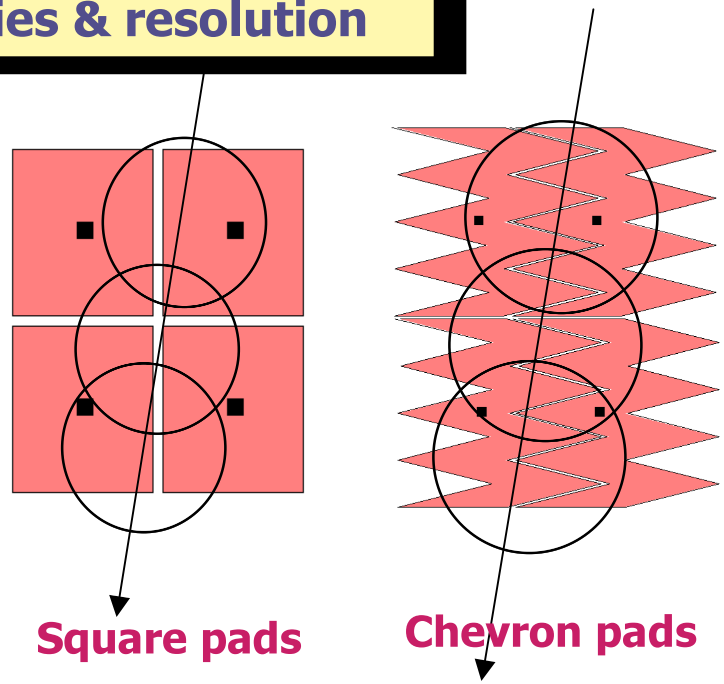
(Aachen: Garfield simulation of a GEM hole)





TPC : ongoing R&D activities: pad geometries & resolution





Several drawbacks for electron collection using MPGD (GEM or MicroMegas):

- **for small drift distances, charge cloud may be collected on a single pad since reduction of transverse diffusion due to high magnetic field**
- **center of gravity method not efficient**

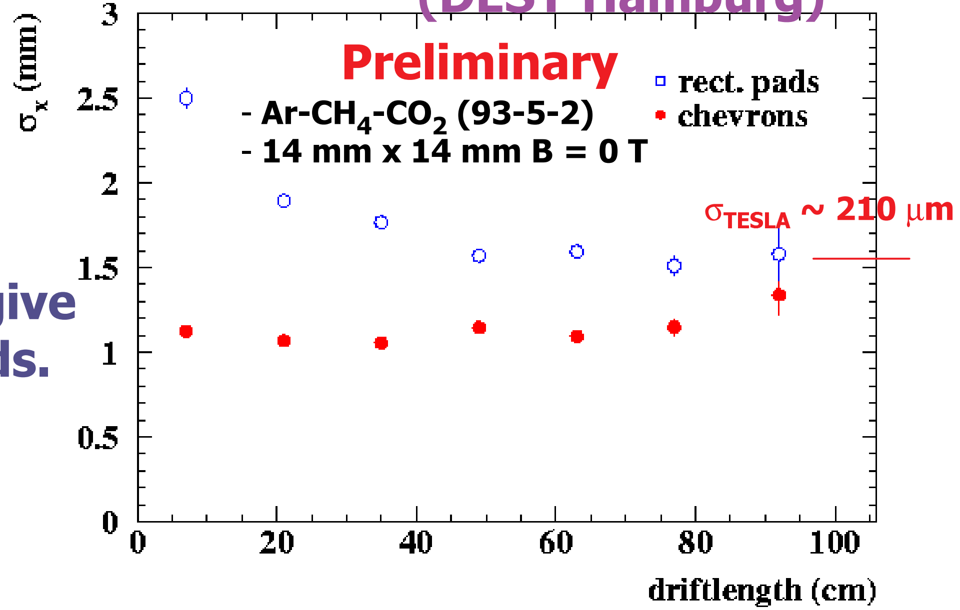
Solution: better charge sharing

- **smaller pad size.**
- **use specially shaped pads i.e. other geometries like chevrons for a better charge sharing between neighbor pads.**
- **increase size of charge cloud using resistive foils before the pads.**

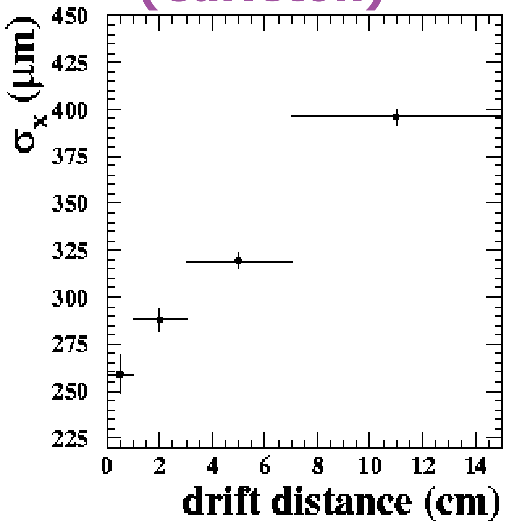
TPC : ongoing R&D activities: pad geometries and resolution

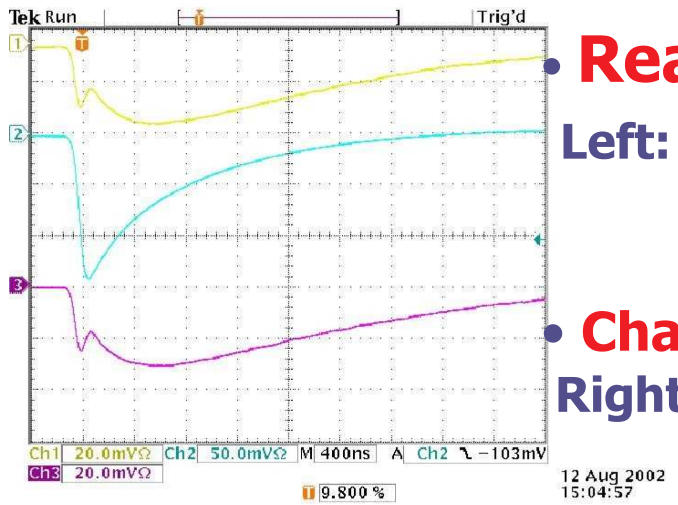
(DESY Hamburg)

- **Resolution vs drift length:**
  - better charge sharing for chevrons
  - at small drift distances, chevrons give a better resolution than square pads.
  - needs a better understanding (work in progress)



(Carleton)





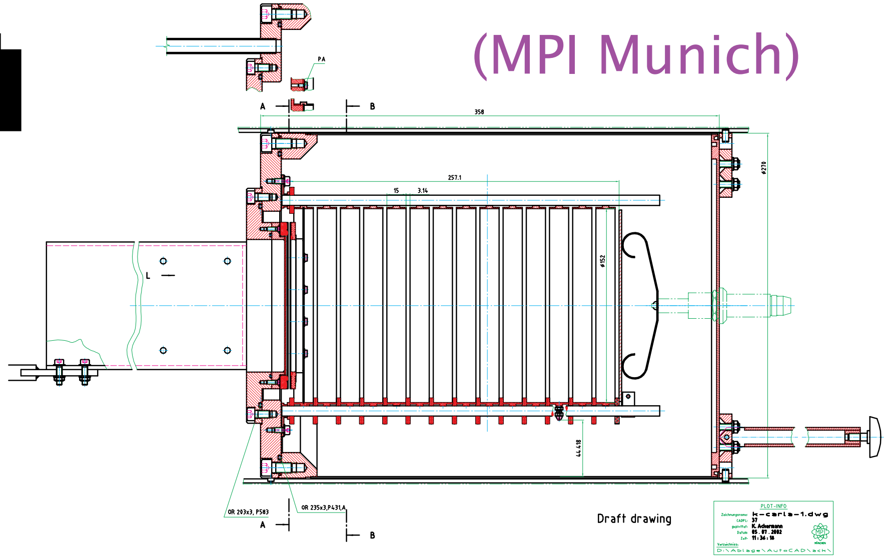
- **Readout pad:**

Left: Measured spatial resolution using $ArCO_2$ gas (pads 2.5 mm x 5 mm)

- **Charge sharing enhancement:**

Right: signal spread studies using resistive foils

TPC R&D working group: future plans



(MPI Munich)

- Ongoing R&D studies for:
  - MPGD studies (GEM, MicroMegas)
  - test GEM from different vendors
  - gas property studies
  - charge sharing, gain, etc...
  - simulation
- Test beam with an electron beam facility at DESY
- Several new TPC prototypes are being built:
  - Carleton
  - DESY Hamburg
  - MPI Munich
  - Victoria

Study magnetic field effects using:

- a DESY superconducting magnet (5 Tesla)
- a Saclay magnet (2 Tesla)

Conclusions

A linear collider is clearly the next biggest project after LHC

Strong R&D activities to develop a Time Projection Chamber as the main Tracker at the future linear collider:

- **Several institutes are joining their efforts to achieve the different milestones (see e.g. LC-DET-2002-008).**

Participating institutes to the LC TPC R&D program:

Aachen, Carleton, DESY, Karlsruhe, Krakow, LBNL, MIT, MPI Munich, NIKHEF, Novosibirsk, Orsay (LAL+ IPN), Rostock, Saclay, Victoria.

More informations about:

- **TESLA:**
  http://tesla.desy.de/tdr
- **TPC R&D working group:**
  http://www.desy.de/conferences/ecfa-desy-lcext.html

Slides available on http://www.desy.de/~ghodbane