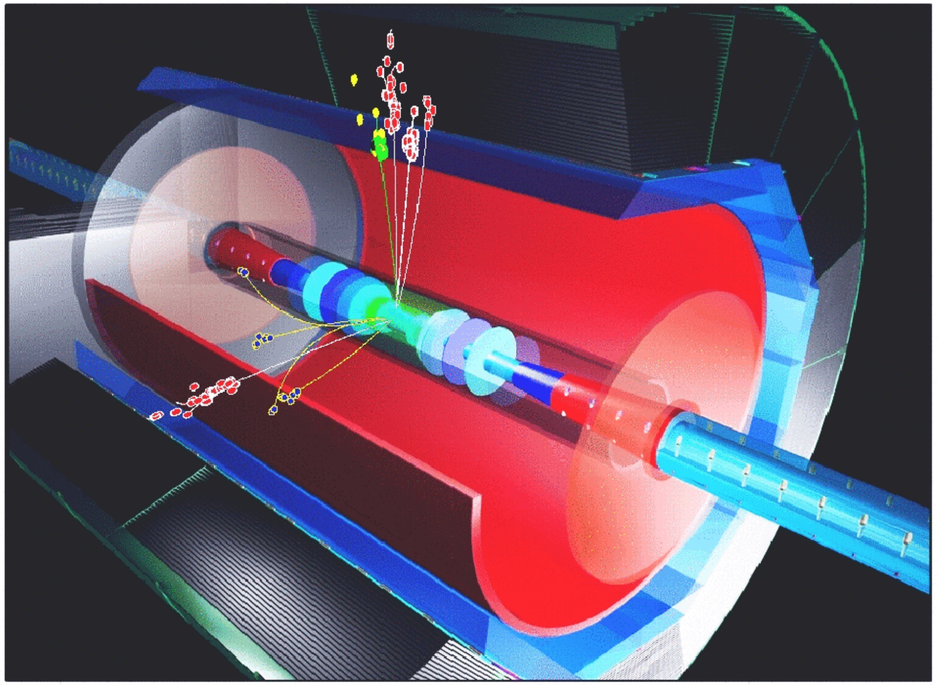
TPC R&D for a Linear Collider

Nabil Ghodbane

CERN-EP



- Introduction:
  - Why a Linear Collider ?
  - The detector concept
  - TPC as a central tracker
- TPC R&D issues:
  - Gas amplification systems
  - Ion feedback suppression
  - Tracking resolution studies
  - Front End Electronics
- Conclusions

CERN, March 8th 2004

Why a Linear Collider ?

Clearly, today the Standard Model gives a coherent and well tested picture of elementary particles and their interactions

BUT many questions remain unanswered, like:

→ **Higgs Mechanism for masses**
→ **Origin of masses**
→ **Unification of the three+one forces**

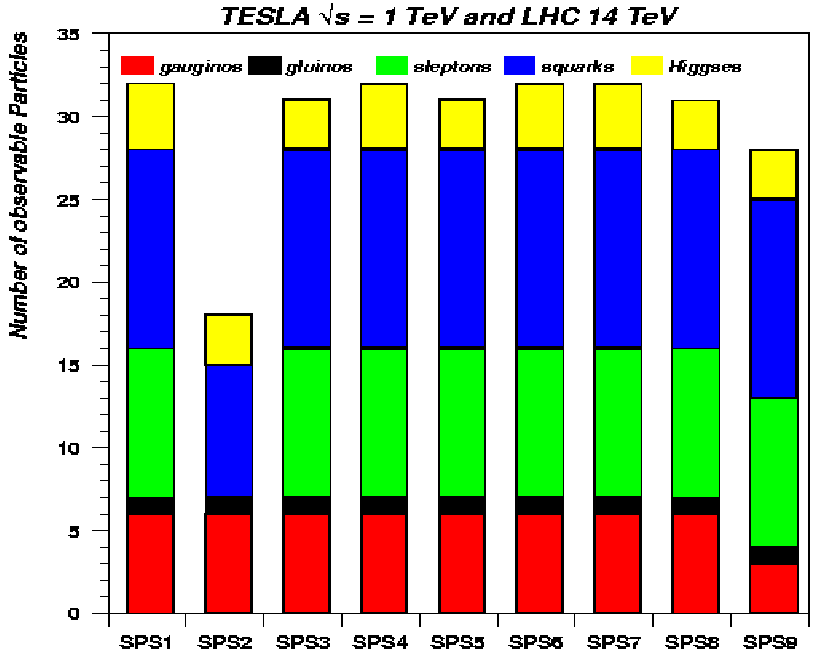
- If new particles or new physics exist, first indications should be discovered at the **Tevatron** (2 TeV pp at Fermilab) or the **LHC** (14 TeV pp at CERN).
- A Linear Collider should then complete the picture by doing precise studies.
  - **clean** (well defined initial state)
  - **flexible** (tunable beam energy)
  - **precise** (high luminosity)

One example of the **synergy** between an e+e- and a pp machine:

1983: discovery of W and Z by UA1 and UA2 at CERN using a p p Collider (270 GeV)
1989-2000: Precision measurement at LEP (e+e-) (90 – 208 GeV)

Why a Linear Collider ?

Ongoing LC/LHC studies show the synergy of the two machines e.g.
- **Higgs searches**
- **supersymmetric particle searches**



Turning Silver into Gold

edges only:

	LHC	LHC+LC (0.2%)	LHC+LC (1.0%)
$\Delta m_{\tilde{\chi}^0_1}$	4.8	0.19	1.0
$\Delta m_{\tilde{l}_R}$	4.8	0.34	1.0
$\Delta m_{\tilde{\chi}^0_2}$	4.7	0.24	1.0
$\Delta m_{\tilde{q}_L}$	8.7	4.9	5.1
$\Delta m_{\tilde{b}_1}$	13.2	10.5	10.6

for 300 fb^{-1} @LHC and LC χ^0_1 mass with 0.2%/1% precision

combined with invariant masses:

	LHC	LHC+LC (0.2%)	LHC+LC (1.0%)
$\Delta m_{\tilde{g}}$	8.0	6.4	6.5
$\Delta m_{\tilde{q}_R}$	11.8	10.9	10.9
$\Delta m_{\tilde{b}_1}$	7.5	5.7	5.7
$\Delta m_{\tilde{b}_2}$	7.9	6.3	10.6
$\Delta m_{\tilde{\ell}_L}$	5.0	1.6	1.9
$\Delta m_{\tilde{\chi}^0_4}$	5.1	2.25	2.4

often dominated by LHC energy scale systematics

numbers are preliminary

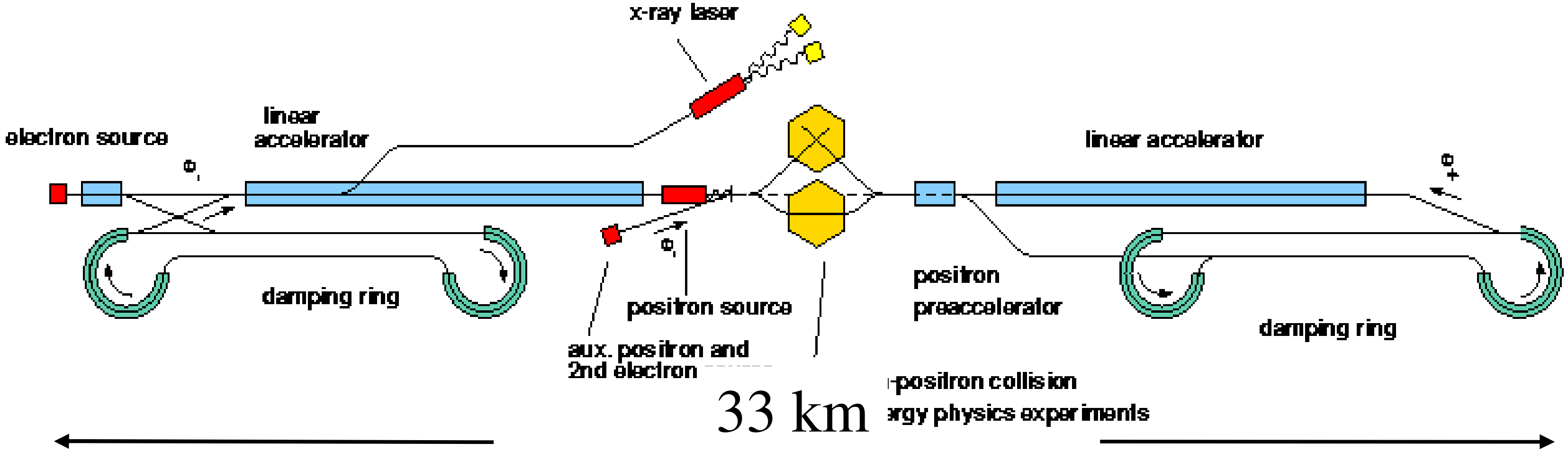
Klaus Desch, LHC+LC Synergy: SUSY as a case study, 07/01/04

K.Desch, ALPCG ´04

Linear Collider concepts

Three ongoing projects…

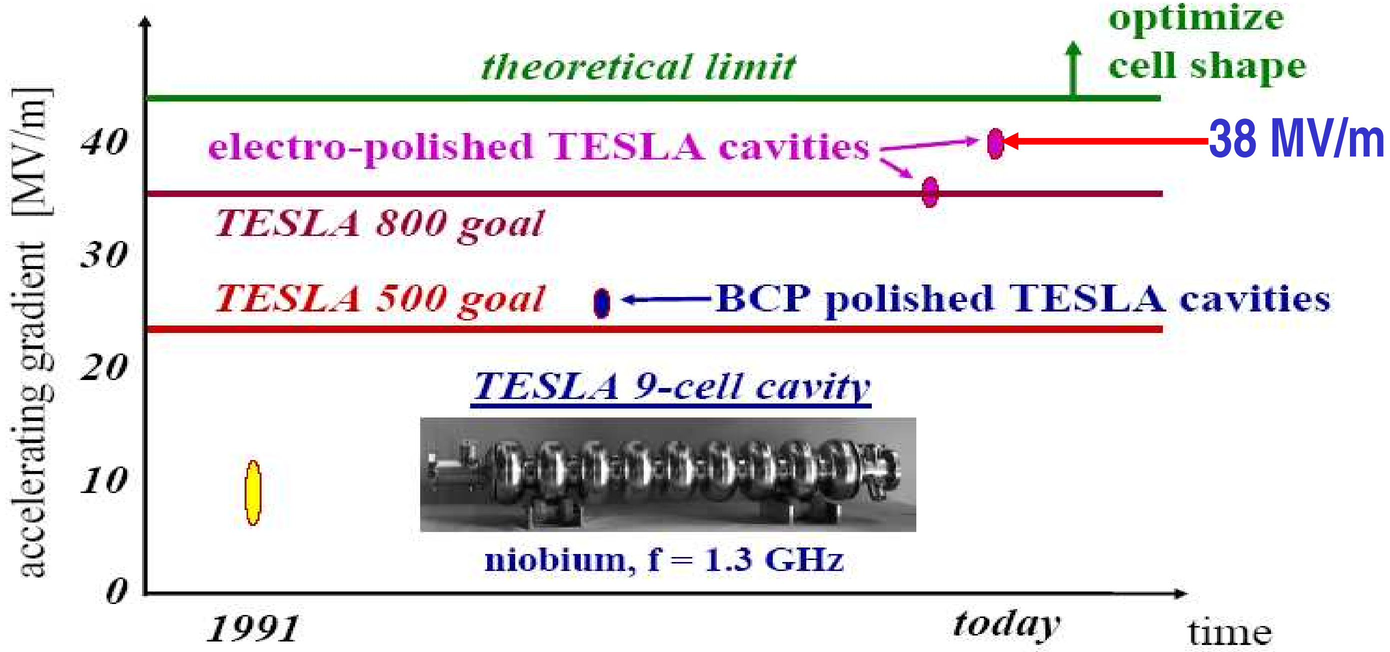
	TESLA	NLC /GLC-(X)	CLIC	SLC (2000)
L (10^{34} $cm^{-2}s^{-1}$)	3.4 5.8	2.0 3.4	2.0 8.0	9.3 x 10^{-4}
√s (GeV)	500 800	500 1000	500 3000	92
RF Frequency (GHz)	1.3	11.4 (X-Band)	30	2.6
Beamstrahlung (%)	3.2 4.3	4.6 10.2	31	0.03
Gradient (MV/m)	23.4 35	70	172 150	20
bunches/train	2820 4886	196	154	1
Δt bunch (ns)	337 176	1.4	0.67	8 360 000
Repet. Rate (Hz)	5	120	200 100	120
Charges / Bunch (1E10)	2	0.75	0.4	4
σx / σy (nm)	553 / 5	245 / 2.7	43 / 1	1000 / 400



TESLA-Project (DESY):

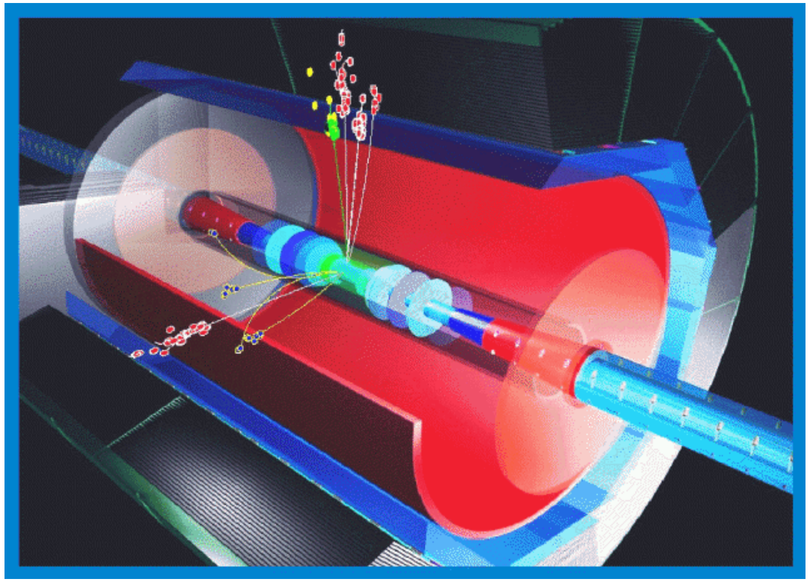
- Acceleration based on superconductive cavities
- Technical Design Report March 2001
- BMBF approved the xFEL project
- TTF (Tesla Test Facility) phase 2 (2004):
  - 6 cryomodules of 8 x 9-cells each
  - 1 GeV e- beam (= 6.4 nm)
- xFEL construction 2005 (Hamburg, DESY)

35 MV/m reached with <u>9-cell cavities</u> -> 800 GeV!



M.Liepe, ALPCG ´04

Which detector for the LC?
a detector like ALEPH or SLD ?


Artistic view of the TESLA detector

- Higher energies

- More complex final states:

  up to 8 partons in the final state

  $e^+e^- \to H^+ H^- \to t\, b\, t\, b$

- Large Lorentz Boost ⟹ Higher particle densities in jets:

  e.g. 1/mm^2 in vertex detector

- Background processes for new physics searches will be different:

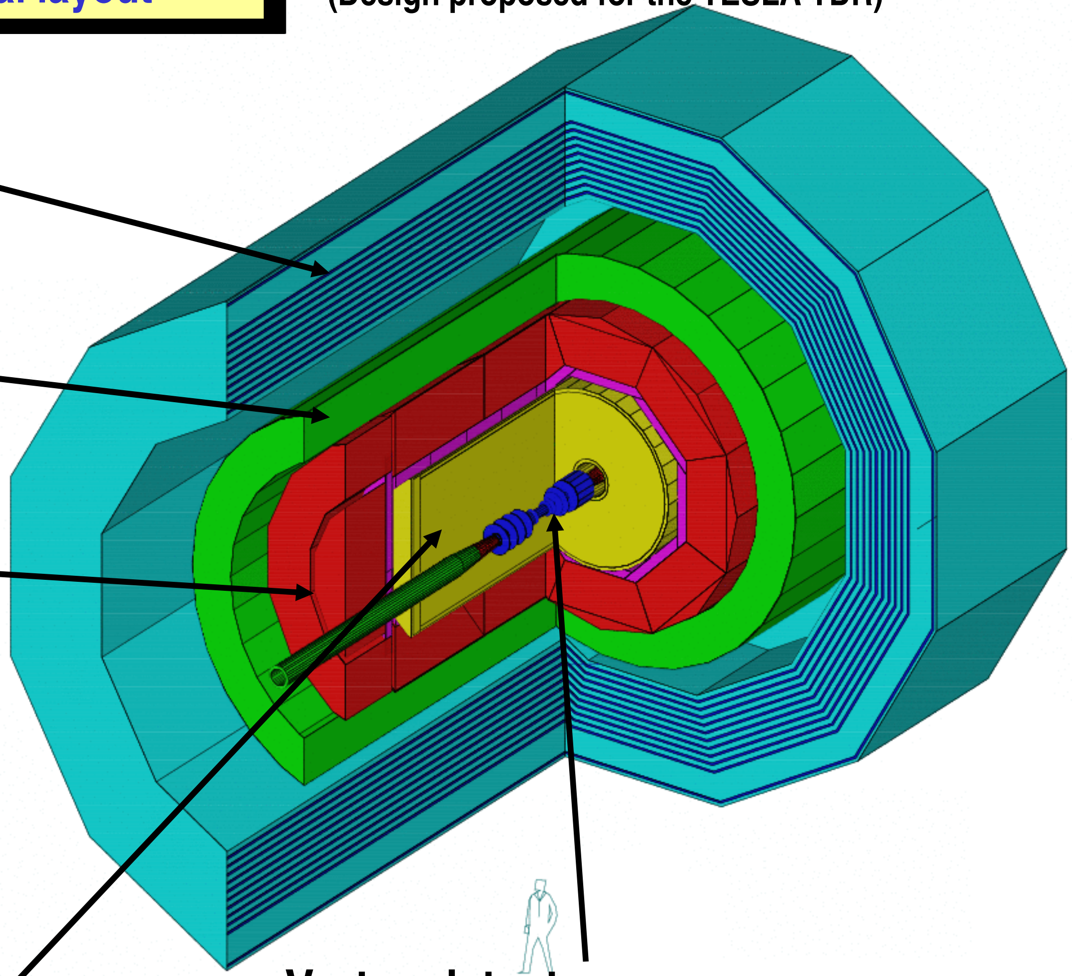
$e^+e^- \to qq$	330/h
$e^+e^- \to WW$	930/h
$e^+e^- \to tt$	70/h

- Bunch and time structure is different

Clearly an R&D effort for detector is needed!

The Linear Collider detector: general layout

(Design proposed for the TESLA TDR)



Muon detector

Coil
B = 4 Tesla

Calorimeter
- fine 3D granularity
- very good energy flow

HCAL: $\sigma_E = 3 \oplus 35/E^{1/2}$ %
Tile / Digital HCAL

ECAL: (H $\rightarrow \gamma\gamma$, $\chi_0 \chi_0 \rightarrow$ G G $\gamma\ \gamma$)
- TESLA : $\sigma_E = 1 \oplus 13/E^{1/2}$ %
- LEP : $\sigma_E = 1 \oplus 18/E^{1/2}$ %

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

Vertex detector
- reconstruction of secondary vertices of b and c quark decays
(technology: CCD or MAPS or DEPFET)

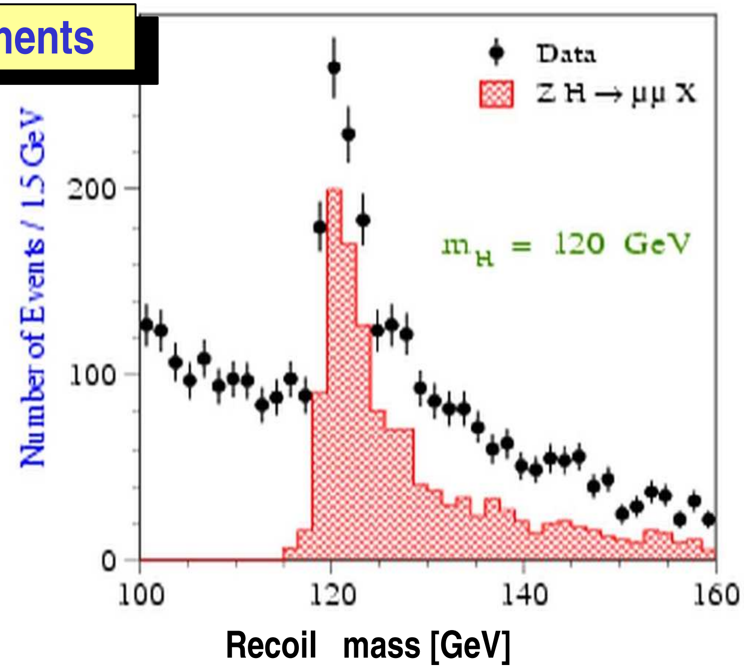
- TESLA: $\delta(IP) < 5 \oplus 10/(p \sin^{3/2}\theta)$ μm
- LEP : $\delta(IP) < 30 \oplus 75/(p \sin^{3/2}\theta)$ μm (Si strip)
- SLD : $\delta(IP) < 8 \oplus 33/(p \sin^{3/2}\theta)$ μm (CCD)

TPC as the central tracker at LC: physics requirements

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

  goal: $\delta M_{\mu\mu} < 0.1 \times \Gamma_Z$

- 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

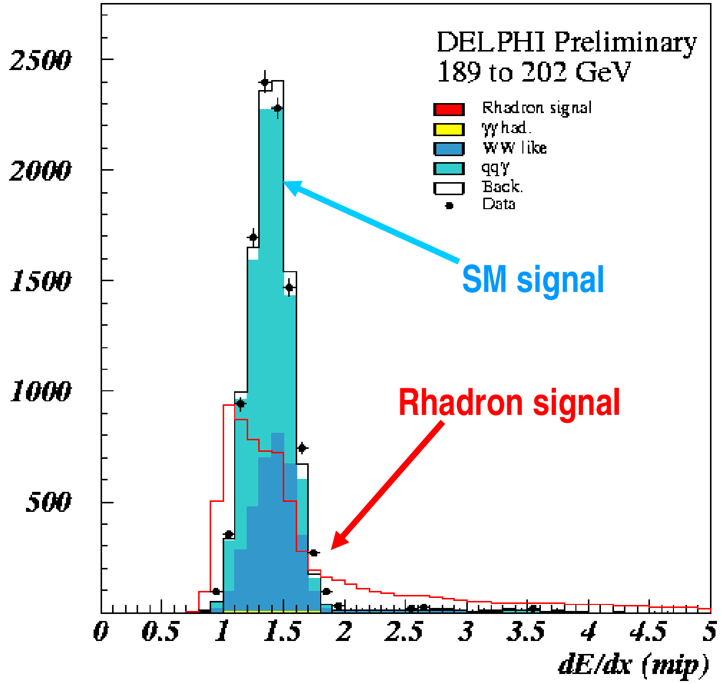
  $\delta(1/p_T) = 6 \times 10^{-4}$ / GeV [ALEPH @ LEP]

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

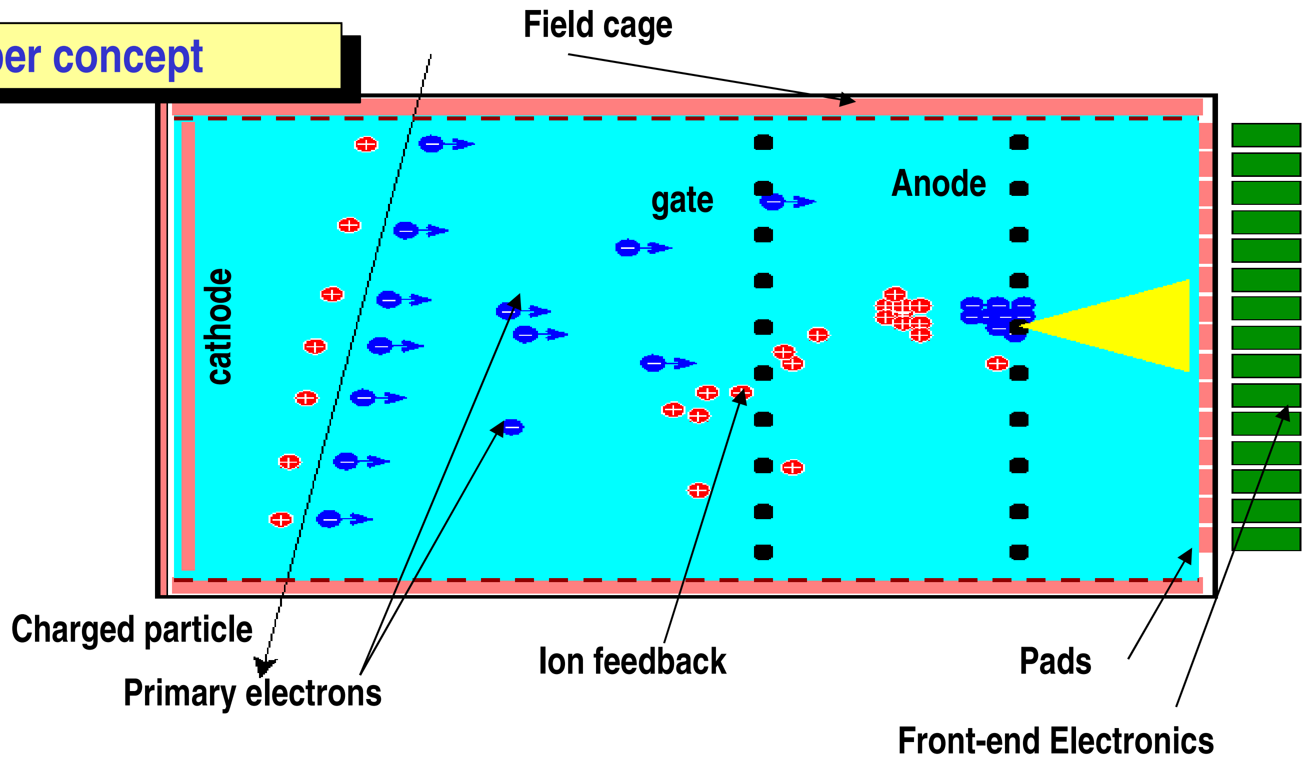
  $\varepsilon > 97.5$ % [p > 1 GeV]

- 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 interval small

TPC as the central tracker at a Linear Collider: the TESLA TDR choice

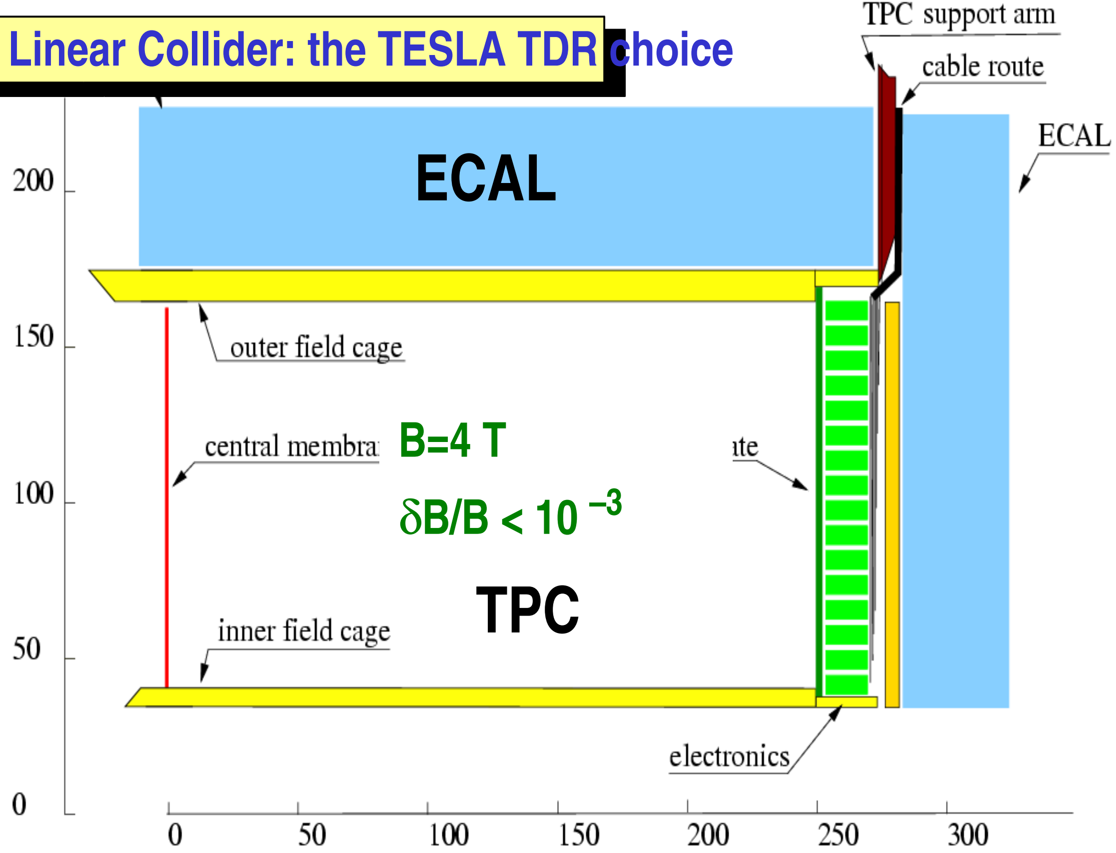
- Large TPC sensitive volume

  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 / $L^{1/2}$



- Total Drift time 50 μs = 160 BX ⇒80000 hits in TPC (physics+BG)
  (BG mainly neutrons ~5600 n/BX)

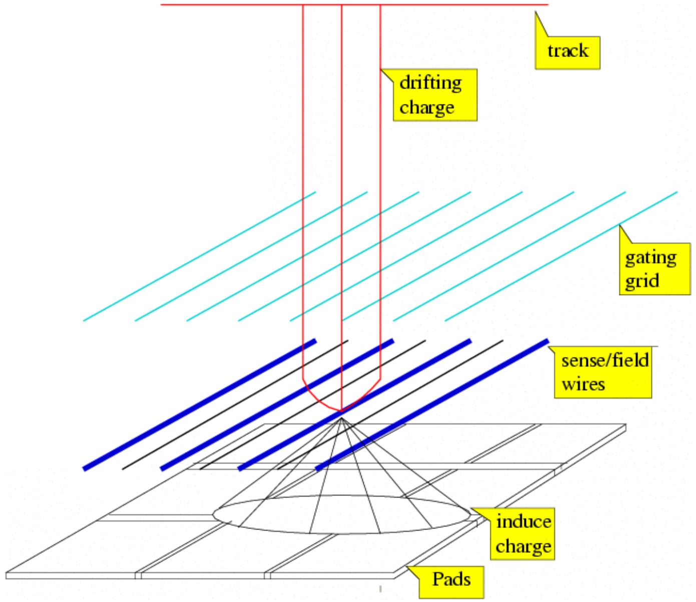
- 1.2MPads+20MHz ⇒0.1% occupancy

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

TPC as the central tracker: 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...)

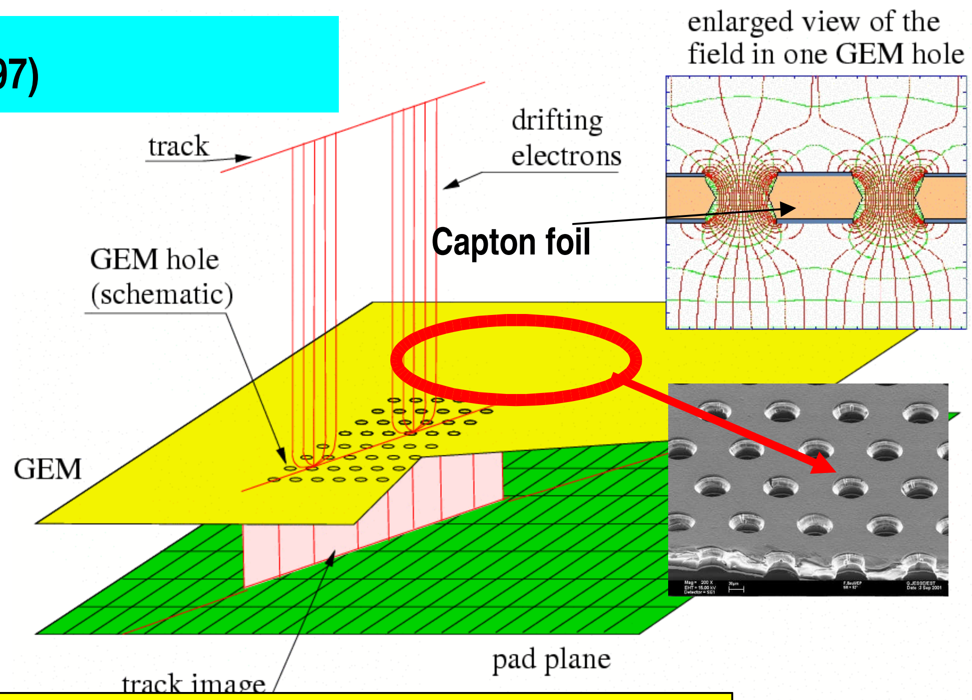
But

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

TPC as the central tracker: 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, 140 μm pitch
  - density of holes (50-100/mm²)
- Strong field (~ 80 kV/cm) between the two conductive sides.



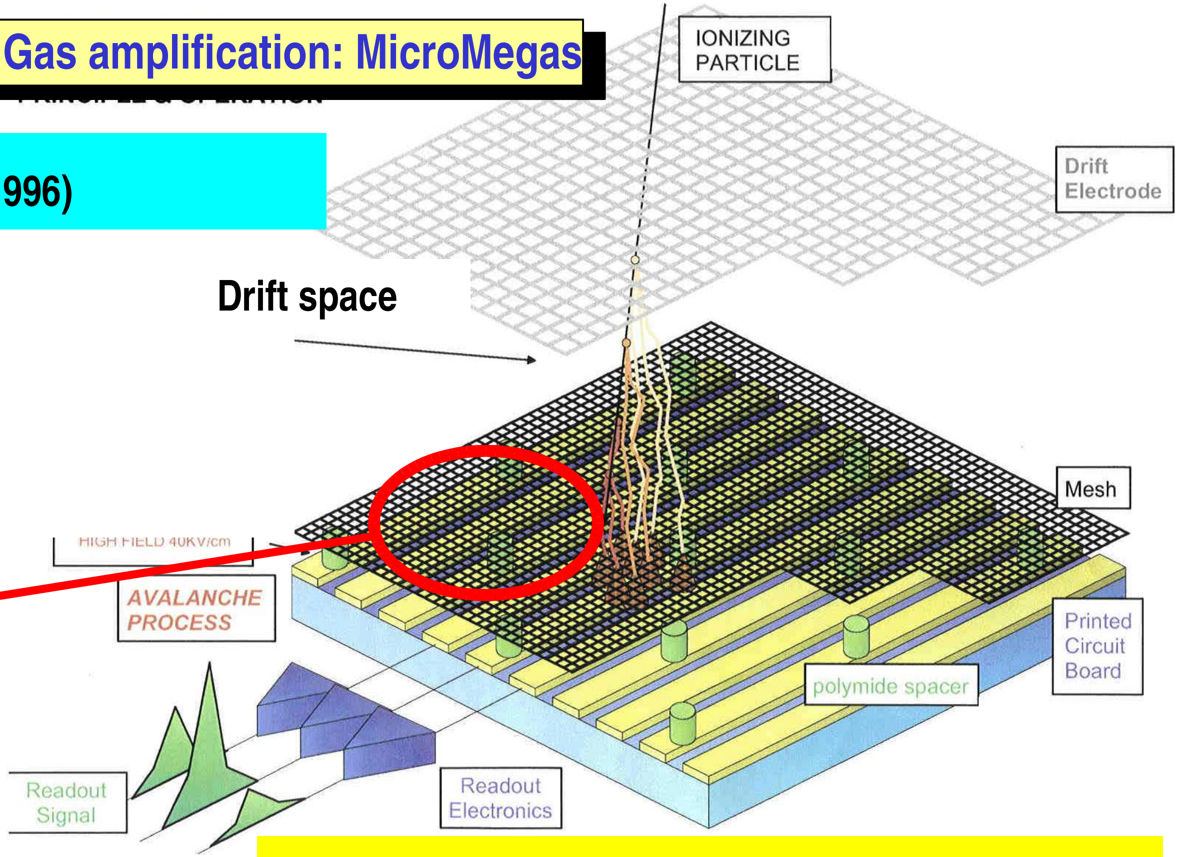
Advantages of GEM:

- 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)

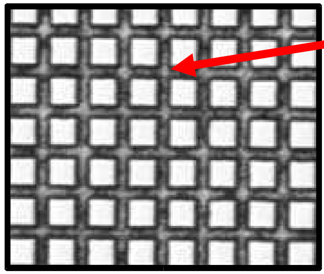
TPC as the central tracker: Gas amplification: MicroMegas

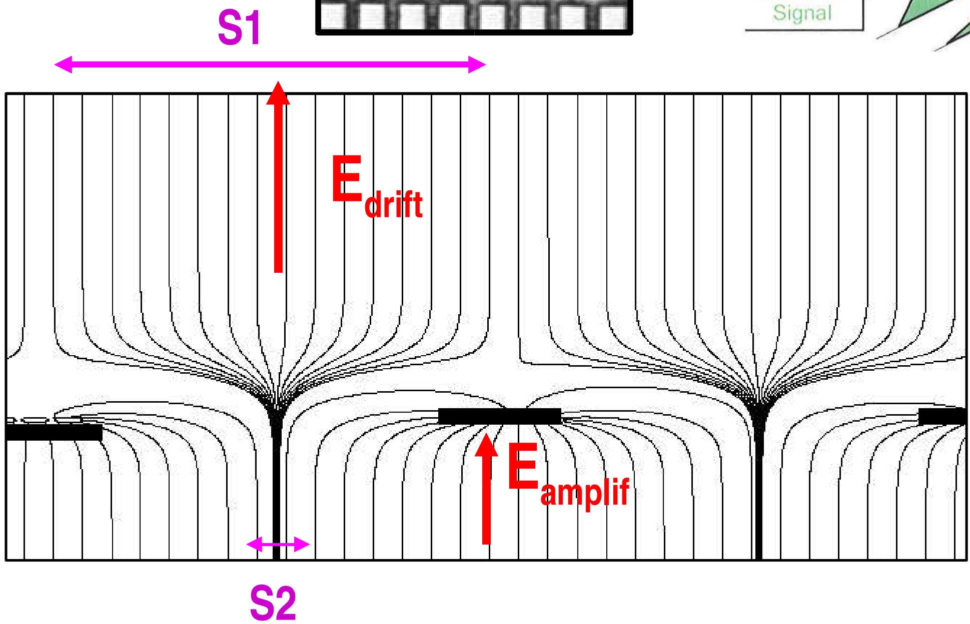
MicroMegas (Y. Giomataris et al., 1996)

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



2 x 25 µm





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 as the central tracker : ongoing R&D activities

- to meet the Physics goals

- to design a TPC as a central tracker at a Linear Collider

  Several R&D groups...

R.Settles, Asian LC workshop ´03

TPC as the central tracker : ongoing R&D activities

Several issues are addressed by the TPC study group
(For more details see note LC-DET-2002-008: http://www-flc.desy.de/lcnotes)

- **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 high 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)
(7.8 for ALEPH @1.5 Tesla)

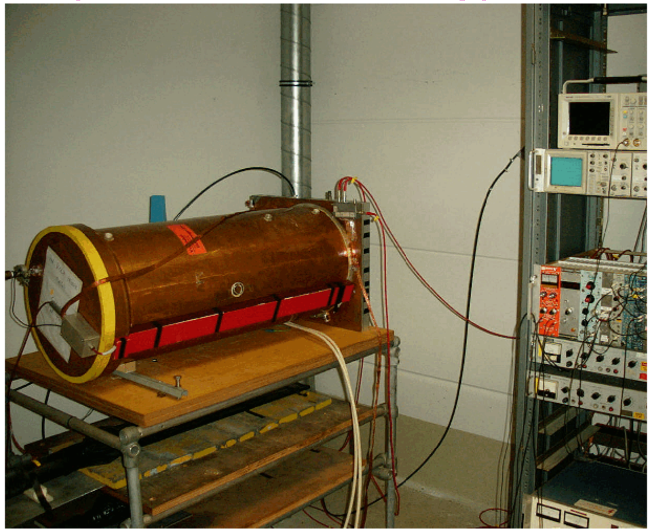
- **Electronics:**
  - sampling and digitization on endplates, etc..
- **behavior in Test Beams**
- **Simulation and software development**

TPC : ongoing R&D activities: gain stability

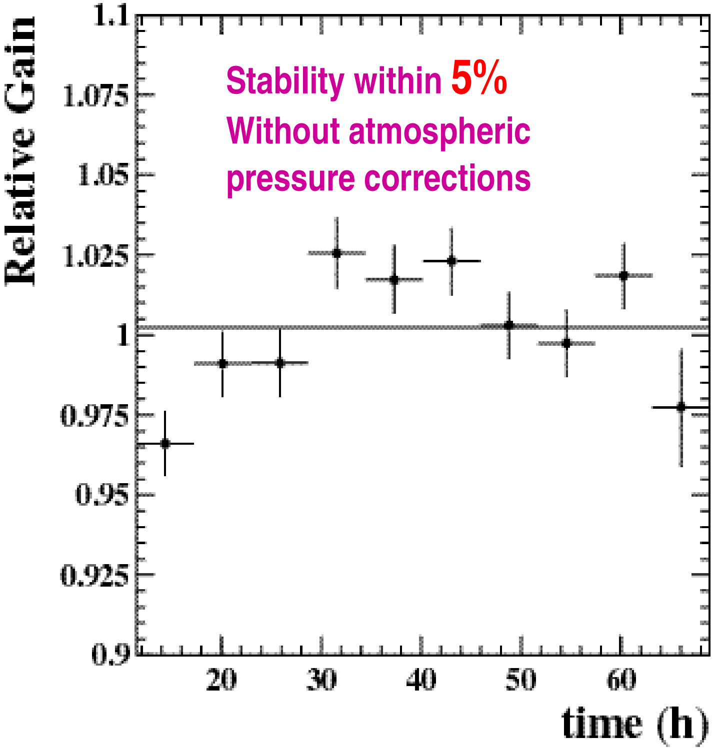
A typical TPC setup e.g. DESY:

- 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 11 MHz.
- 64 readout channels
- signal / noise > 40

(One DESY TPC setup)



Gain stability



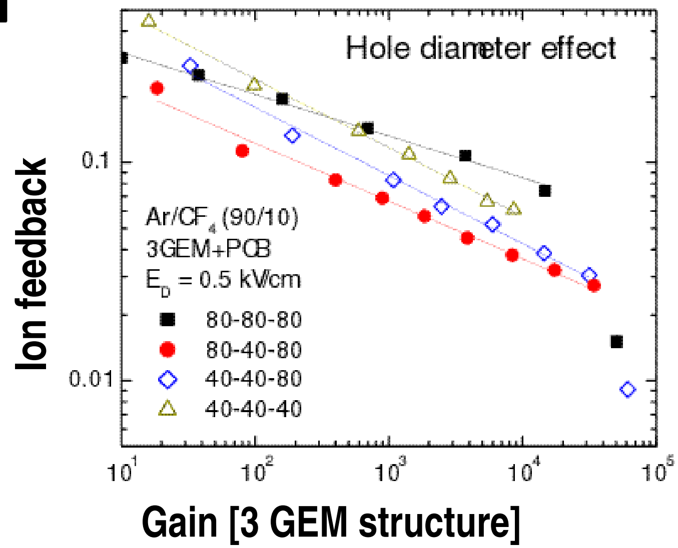
Goal: to reach a dE/dx measurement with 5% precision a gain stability homogeneity at 1% level

TPC : ongoing R&D activities: ion feedback studies

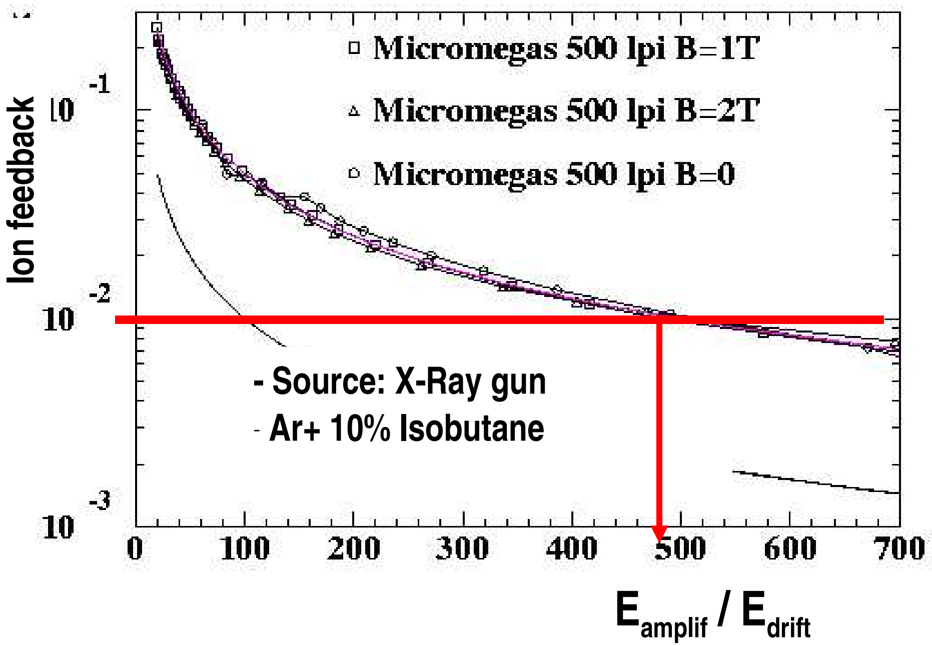
Two sources of ions in a TPC:
- ions created in the TPC drift volume by primary ionization
- ions created during the avalanche

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)



Ion Feedback does not depend on the magnetic field for MicroMegas

TPC : ongoing R&D activities: ion feedback studies

A Magnet Test Facility is provided by DESY to the TPC study groups.

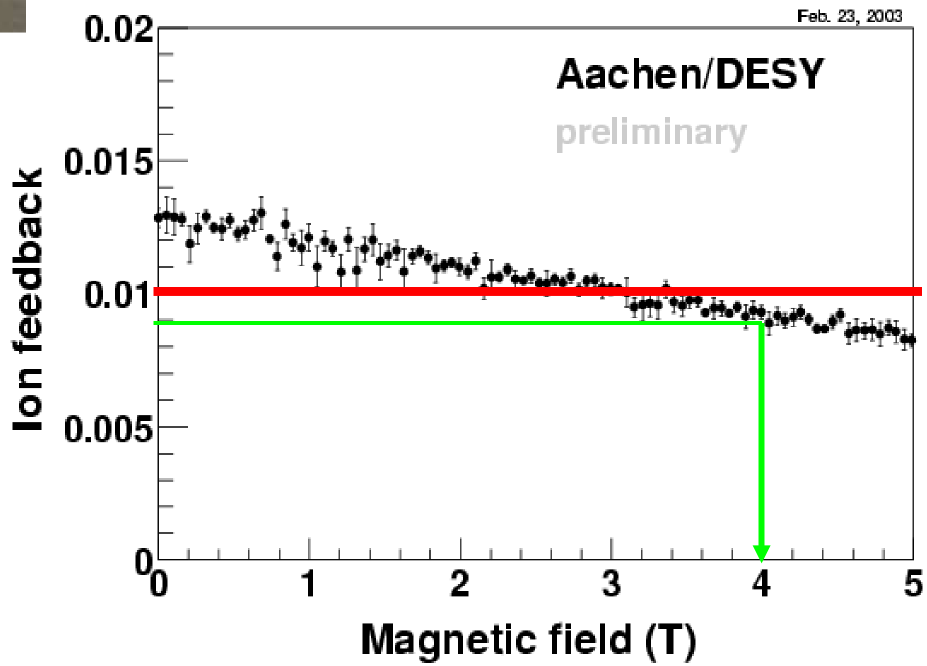
Parameters:

- up to 5 Tesla
- diameter: 28 cm
- length: 187 cm

Setup: three GEM structure:
Fe source

Ion feedback decreases with B

(at TESLA, <1% for 4 T)

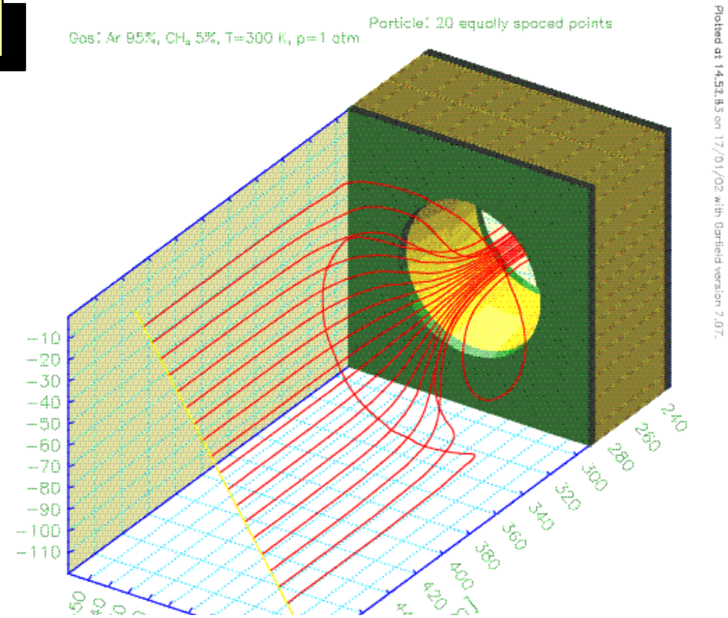


TPC : ongoing R&D activities: simulations

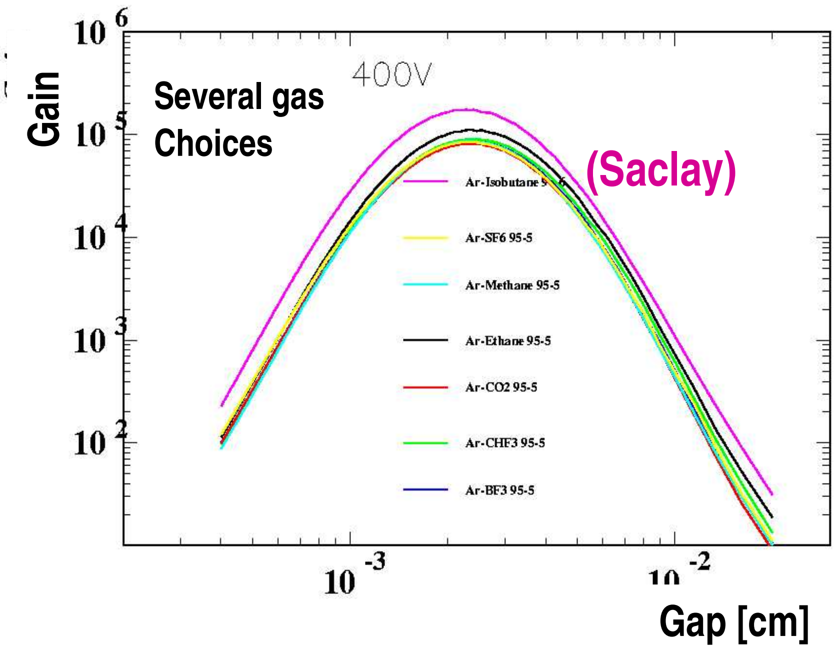
- A need to better understand several aspects of MPGD

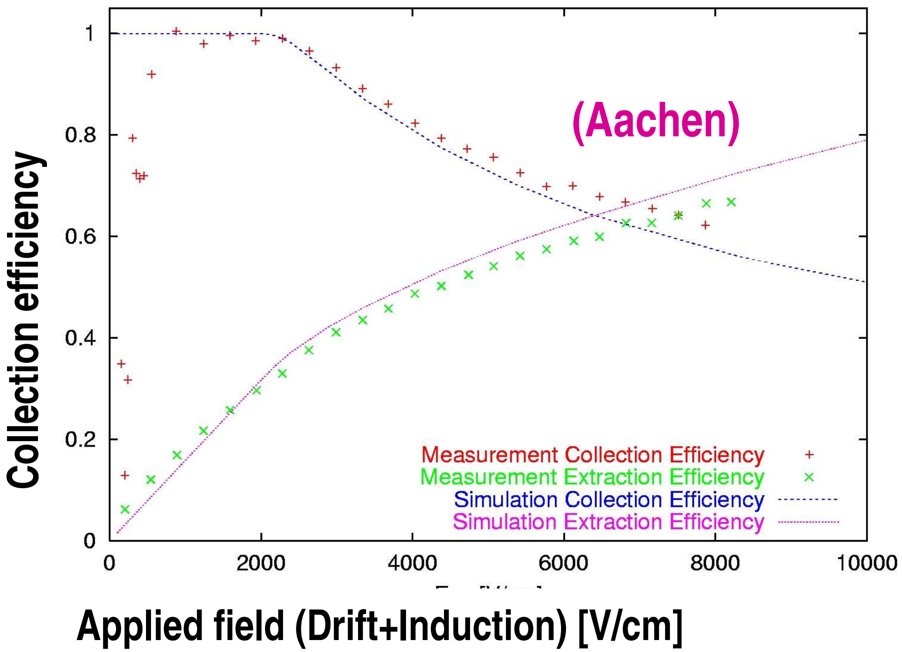
- Simulation of a GEM with and without magnetic field:
  Systematic studies like e.g. e- collection efficiency

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

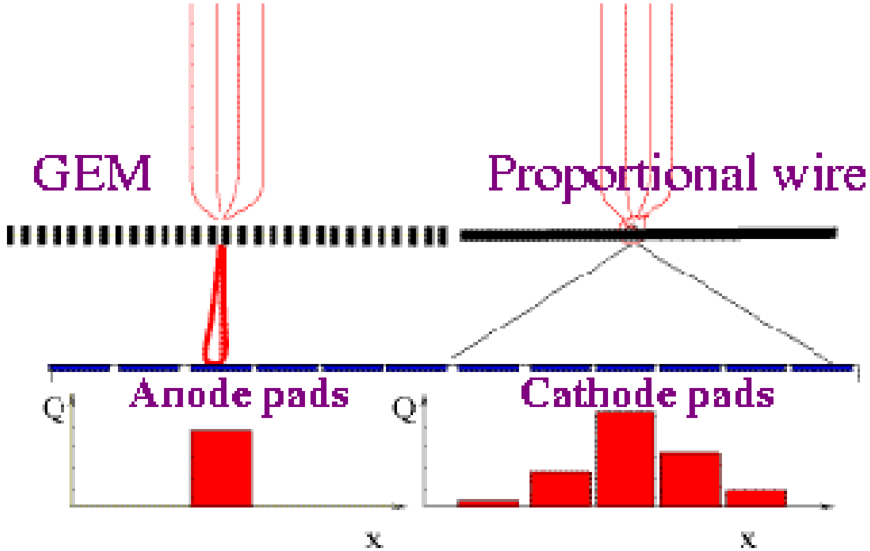


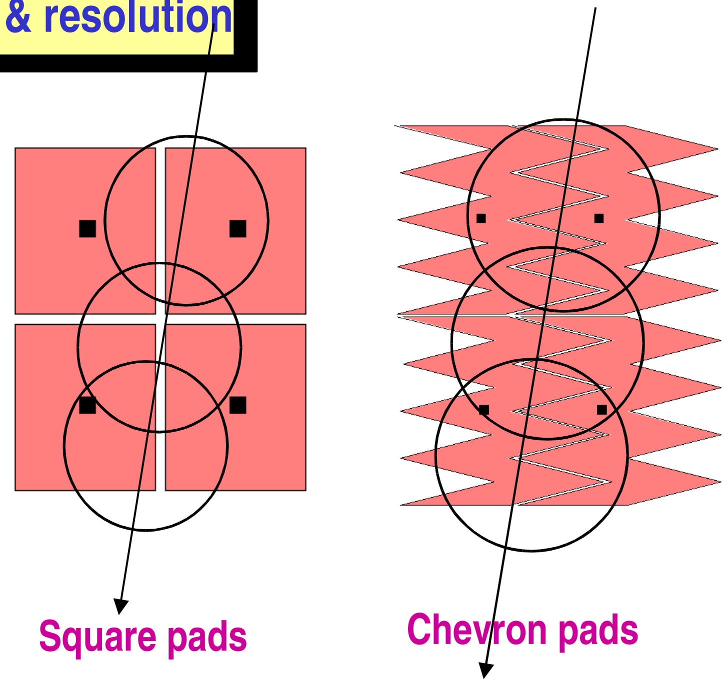
(Aachen: Garfield simulation of a GEM hole)





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

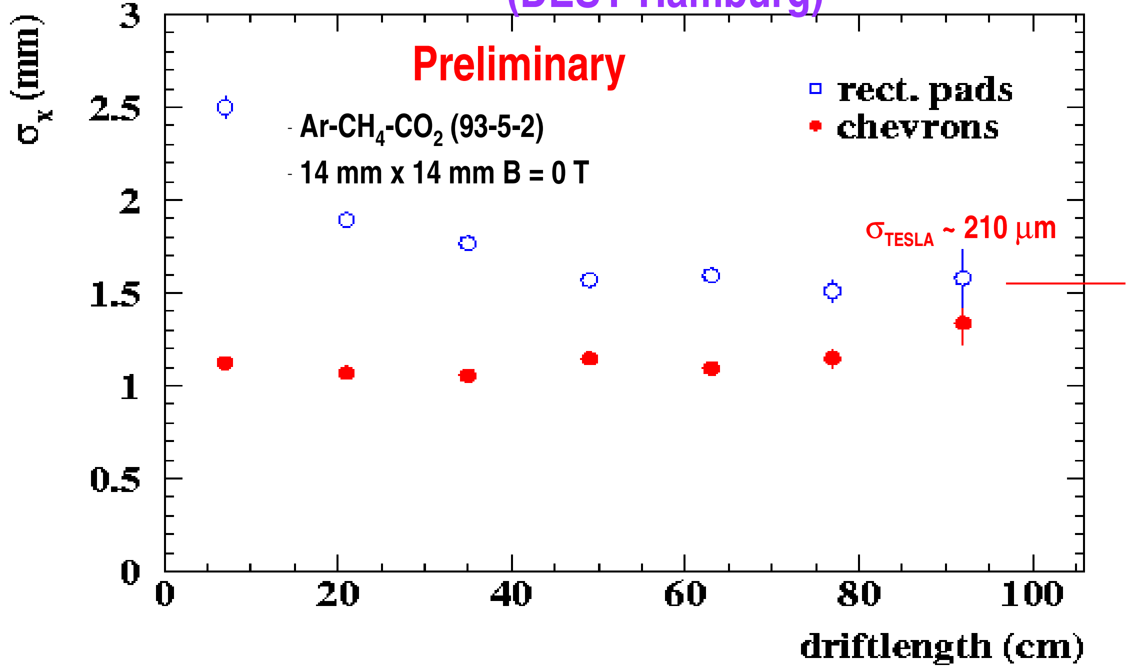
Solution: better charge sharing

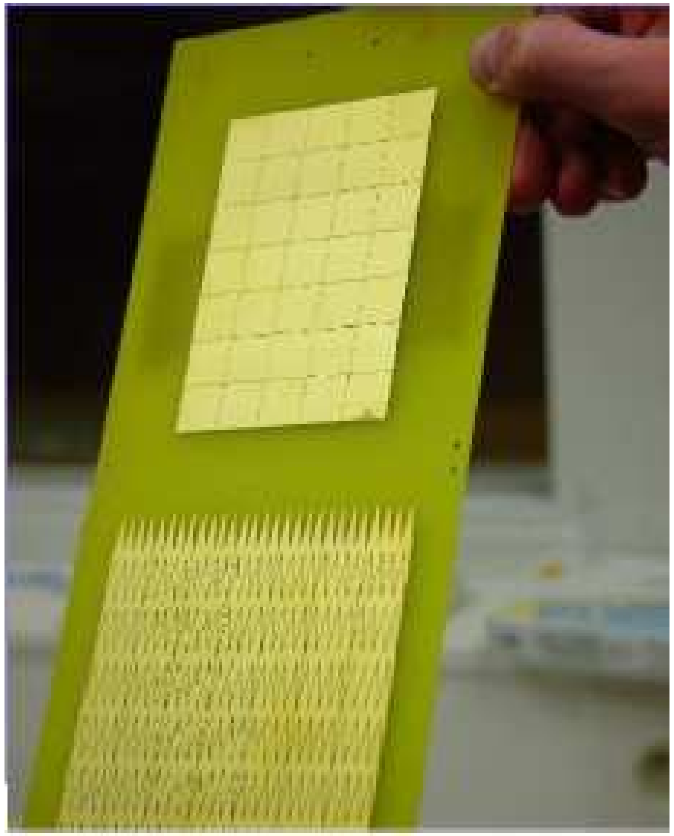
- smaller pad size.
- use specially shaped pads i.e. other geometries like chevrons for a better charge sharing between neighbor pads.
- increase size of charge cloud using resistive foils before the pads.

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

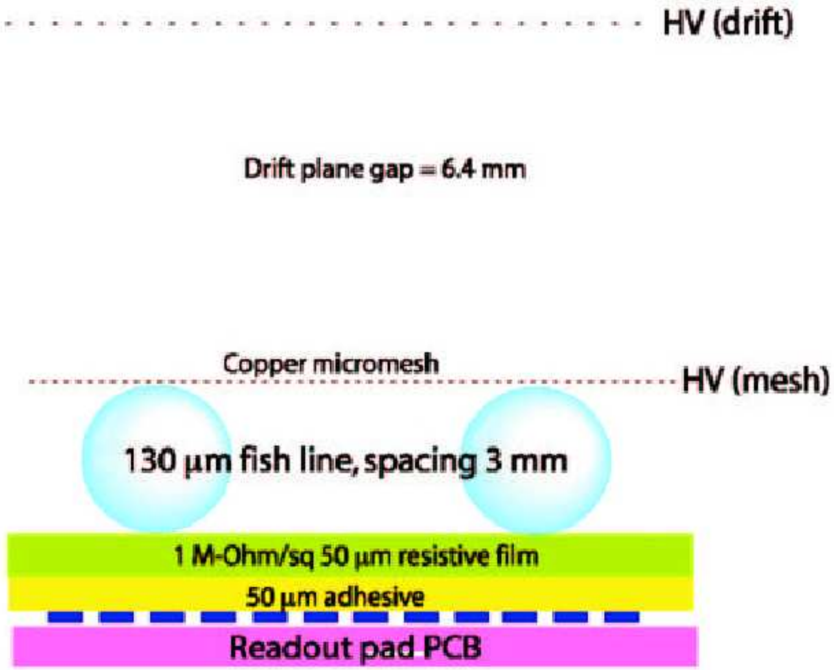
- **Resolution vs drift length:**
  - better charge sharing for chevrons
  - at small drift distances, chevrons give a better resolution than square pads.
  - needs a better understanding (work in progress)

(DESY Hamburg)



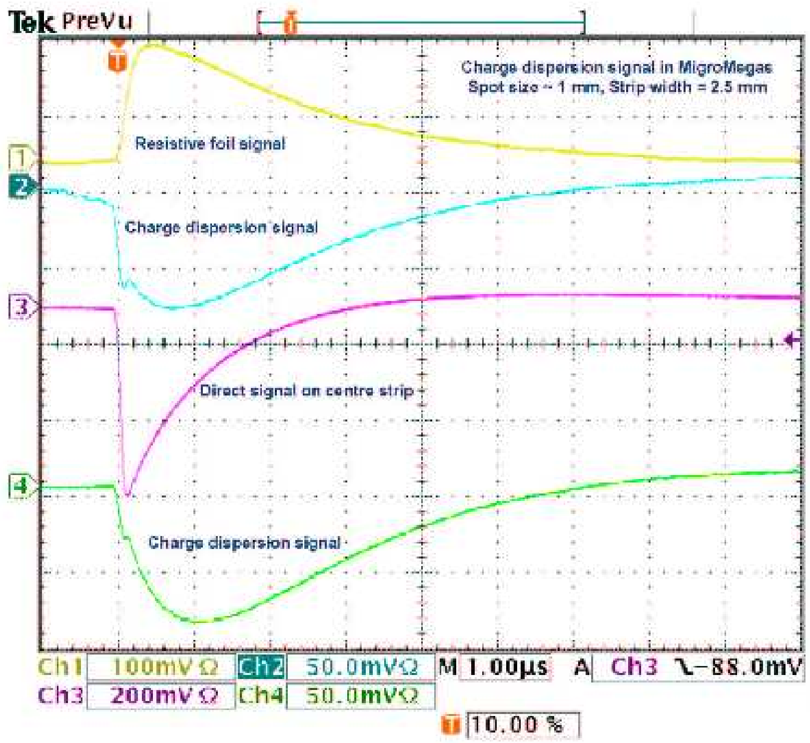


TPC : ongoing R&D activities: charge sharing



Charge sharing enhancement:

signal spread studies using resistive foils



Source: M.Dixit (Victoria U.)

TPC : ongoing R&D activities: use MEDIPIX chip as anode

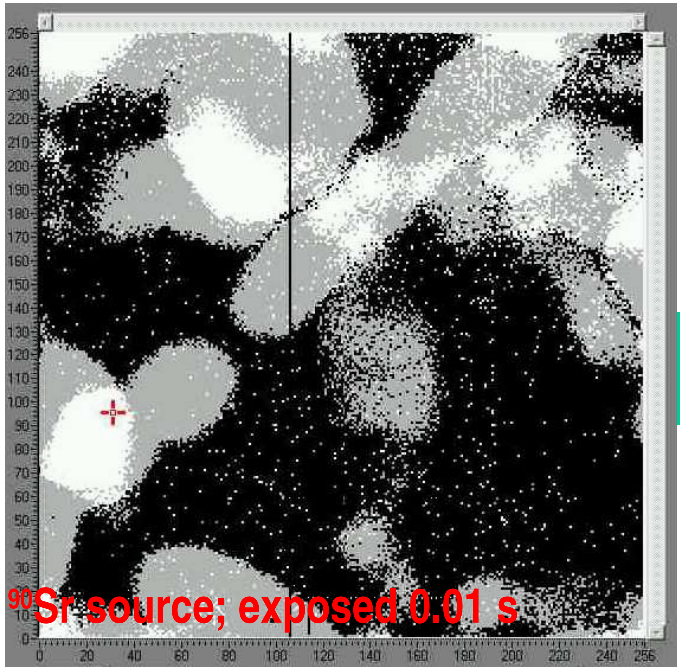
Problem:

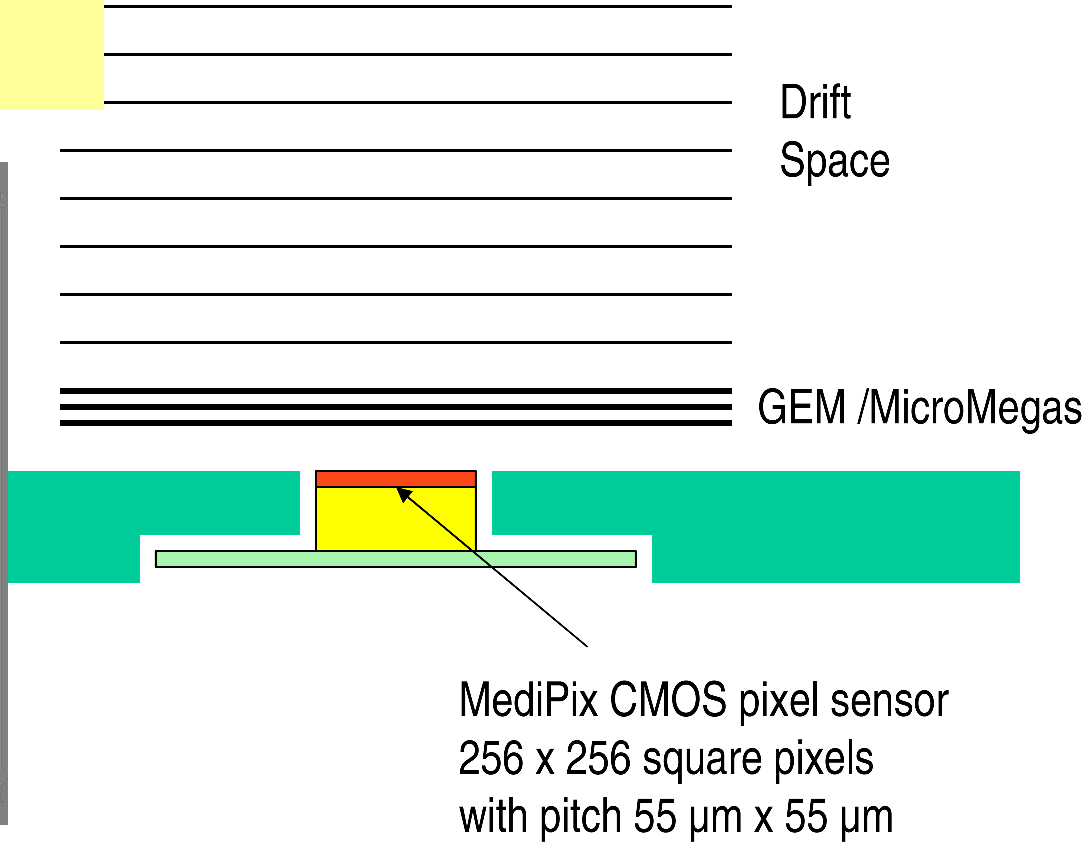
Performance of drift chambers equipped with GEM or Micromegas foils is limited by the size of the anode readout pads.

Idea:

Ideally, each GEM or Micromegas hole is associated with a single channel including a low-noise preamp, one or more discriminators and time stamp circuitry.

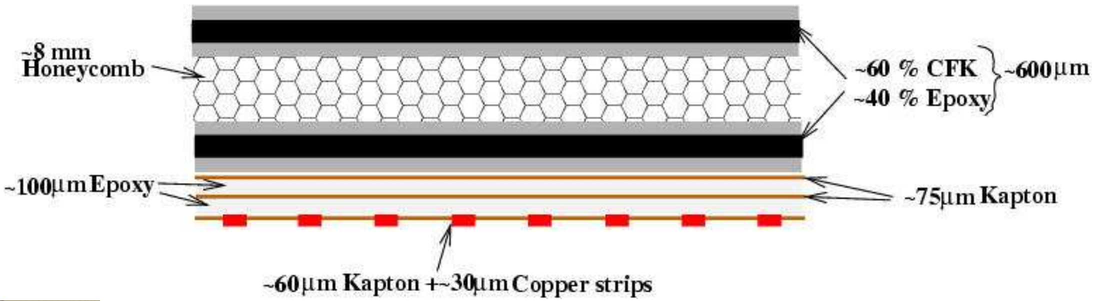
H.Van der Graaf, TPC meeting feb. 04 (NIKHEF)

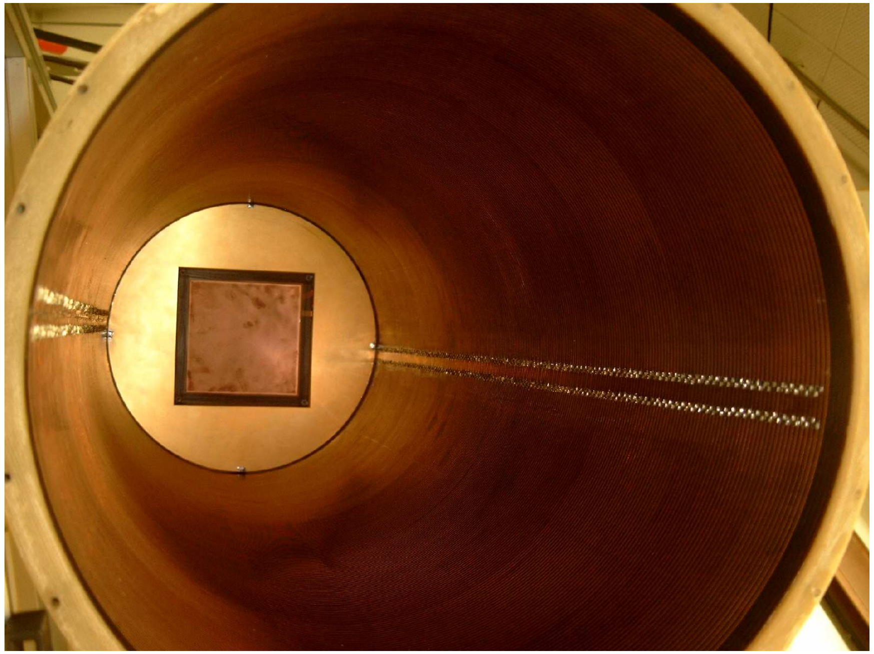




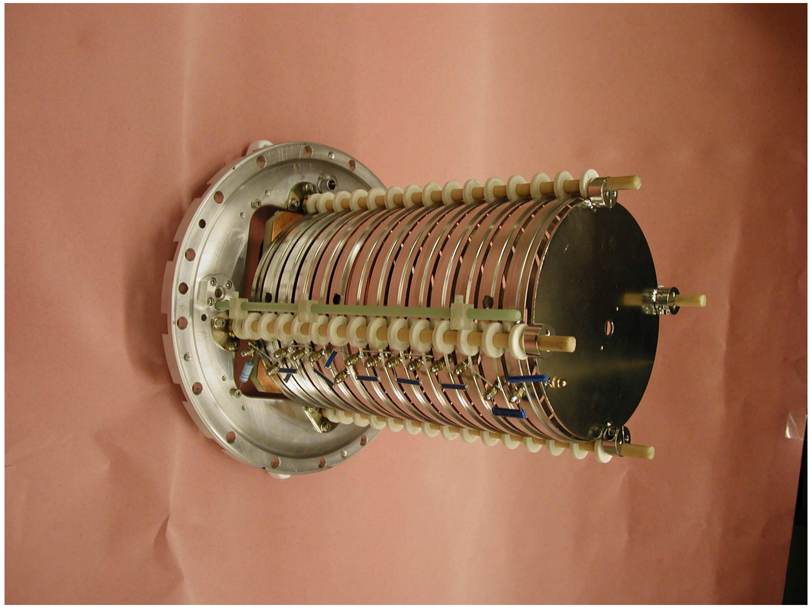
TPC : ongoing R&D activities: Field Cage Studies

To get an expertise, several TPCs are designed:
The field cage structure is a major issue:
keep the material budget LOW (3% X_0)



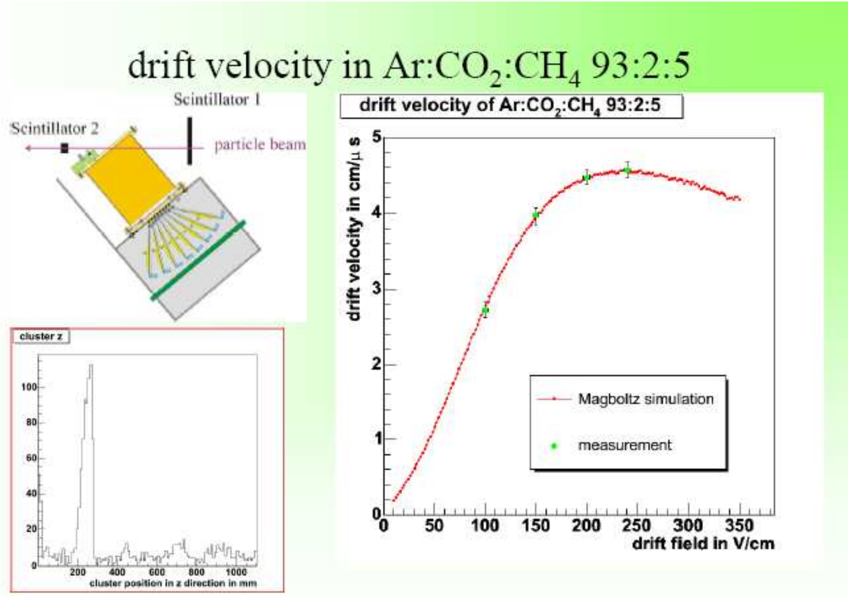


Field cage structure of the TPC built at DESY (192 channels)



MPI/DESY/KEK TPC (wires, GEMs, MicroMegas)

TPC : ongoing R&D activities: test beam studies



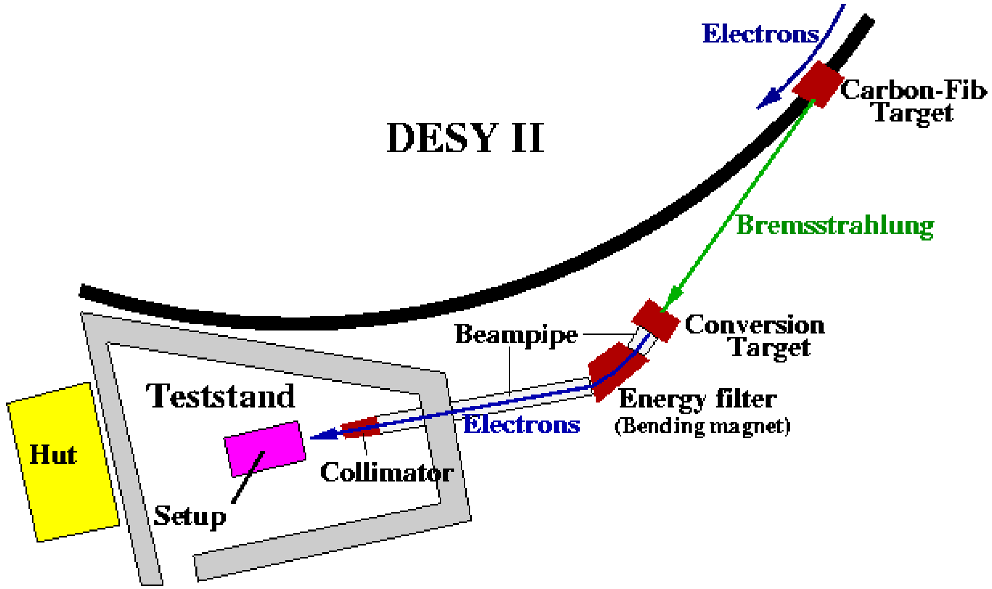
Behavior of TPC prototypes using GEMs and MicroMegas have already started:

Karlruhe: test beam with a 9GeV hadron beam at CERN:

- drift velocity
- spatial resolutions
- track distortions

J.Kaminski, ECFA workshop, Montpellier ´03

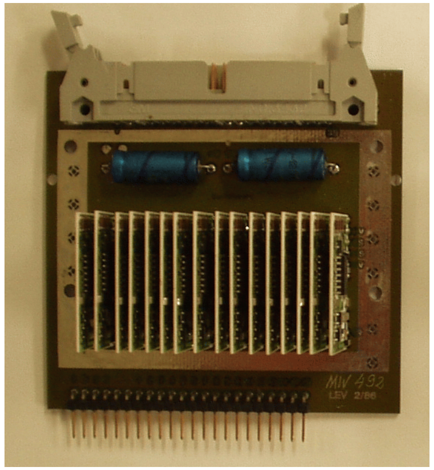
Behavior with an e- beam (6GeV)
Soon...



TPC : ongoing R&D activities: Front End Electronics

Up to now, very little effort has been made for the Front End Electronics

To readout the TPC, several institutes make use of the ALEPH electronics



ALEPH preamplifier
(16 channels)

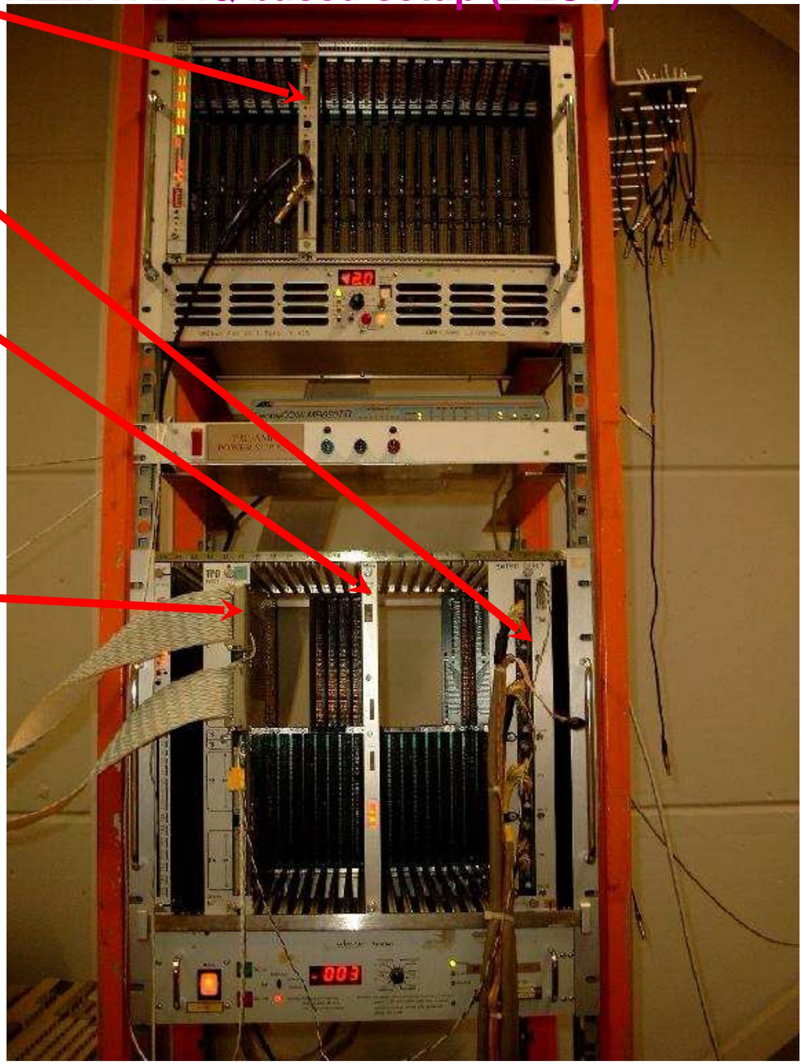
ALEPH DAQ based setup (DESY)

CPU (FIC)

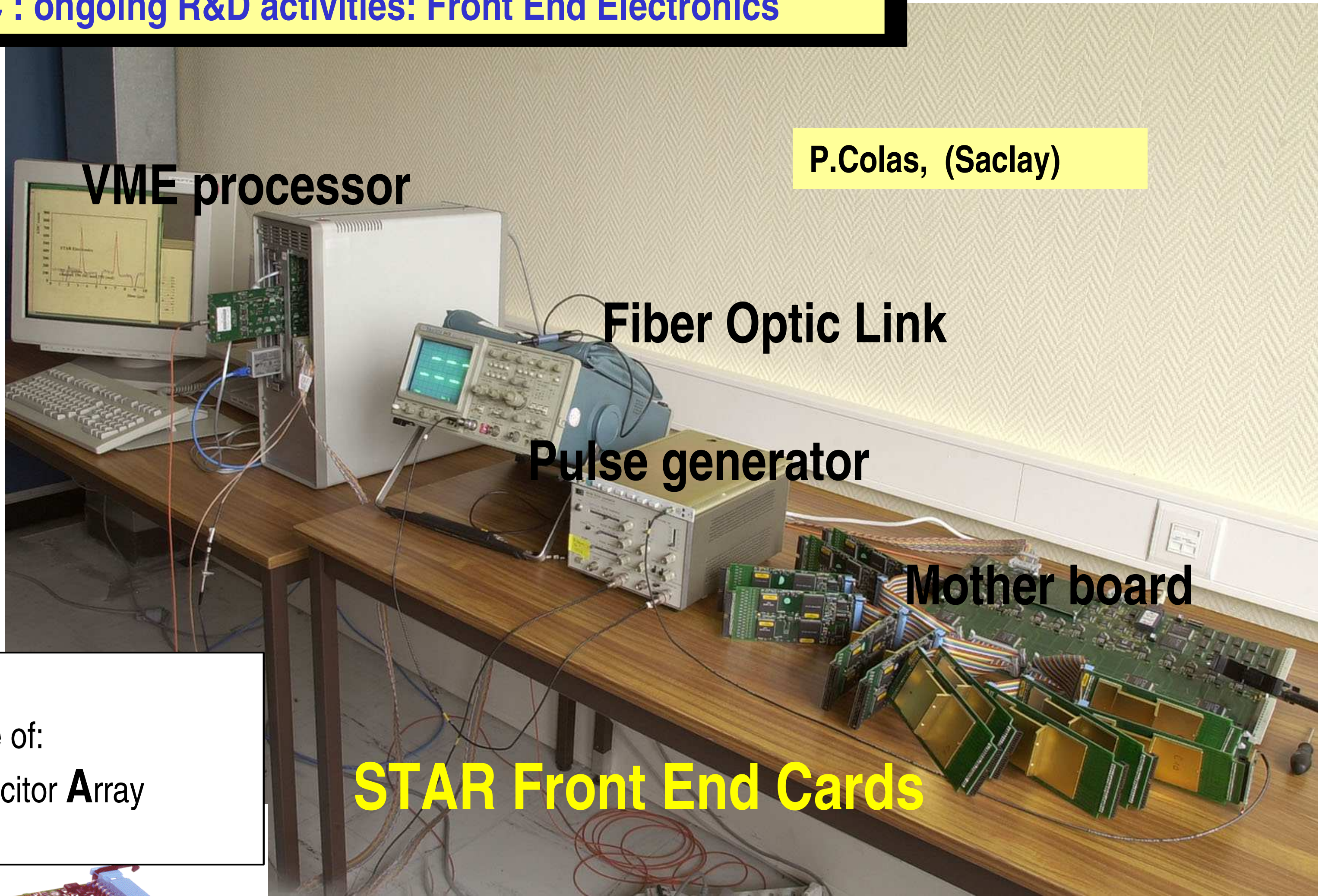
Clock @ 12MHz

FB to VSB Interface (FVSBI)

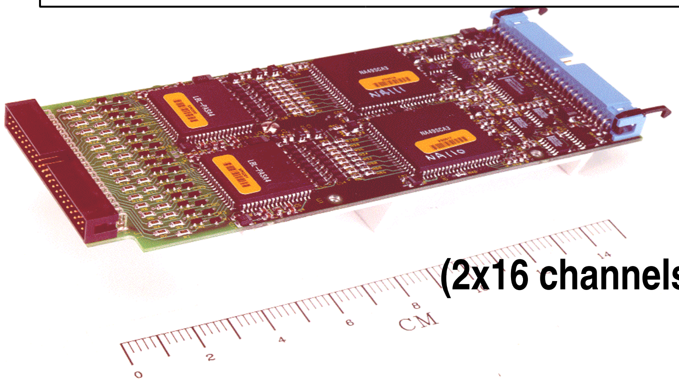
TPD FADC (64 channels)



TPC : ongoing R&D activities: Front End Electronics



2 x 16 **SCA/ADC**
One channel is made of:
- 512-**S**witch **C**apacitor **A**rray
- 12 bit ADC



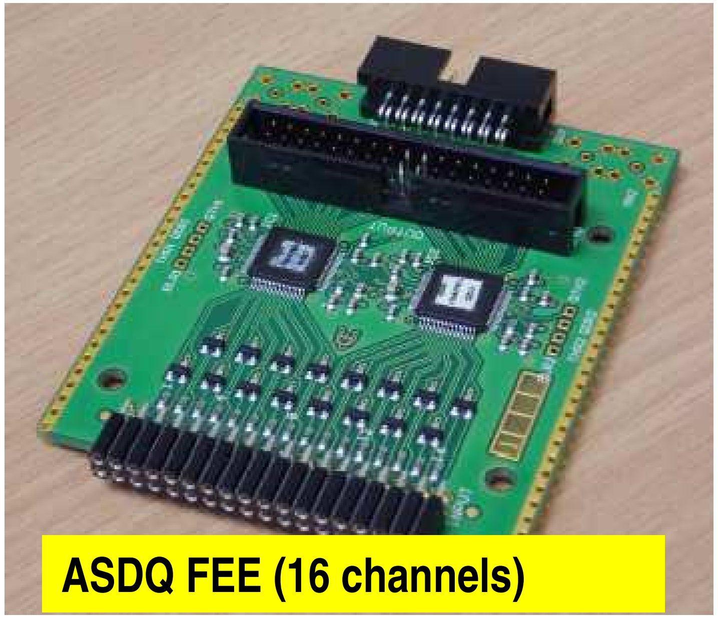
(2x16 channels)

Or use the STAR TPC electronics

TPC : ongoing R&D activities: Front End Electronics

Another approach for the FEE is being investigated:

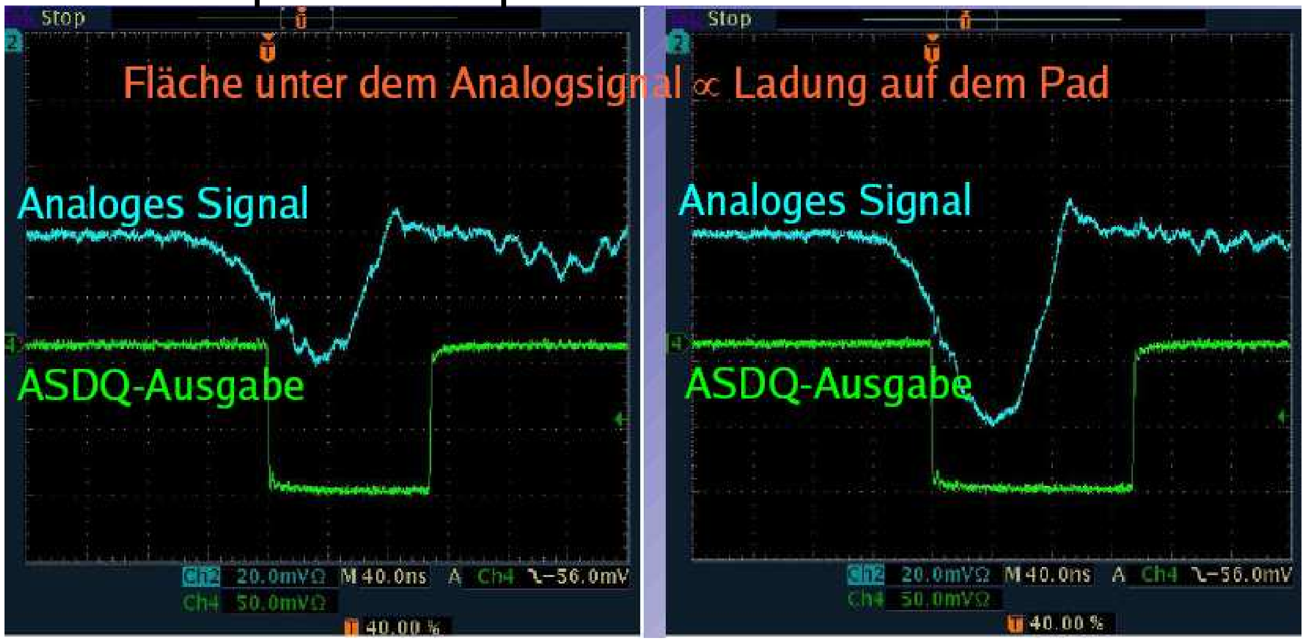
- for each PAD, the information to be read is:
  - charge (for dE/dx) and arrival time of the charge cloud.
  - -> instead of FADCs, use of TDCs combined with a Charge to Time Converter: ASDQ chip.



ASDQ FEE (16 channels)

Arguments:

- cheaper (1.2x 10^{+6} channels)
- reduced Data flow (t, Δt)
- power consumption reduced



t = arrival time

Δt ~ collected charge

A.Kaukher, (Rostock U.)

Summary

A Linear Collider is clearly the next biggest project in HEP 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).**

To know more about:

the different Linear Collider projects:

http://www.linearcollider.org

the ongoing R&D for the detector:

http://www.desy.de/flc

the ECFA-DESY TPC study:

http://alephwww.mppmu.mpg.de/~settles/tpc/welcome3.html

Big THANK to the DESY TPC group for providing some material for this talk!

Slides available on **http://www.cern.ch/ghodbane**