# Towards a TPC at the ILC

Peter Wienemann
University of Freiburg
for the ILC TPC groups

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# ILC TPC groups

**Europe:**
RWTH Aachen
DESY
U Hamburg
U Karlsruhe
U Freiburg
UMM Krakow
MPI-Munich
NIKHEF
U Lund
BINP Novosibirsk
LAL Orsay
IPN Orsay
U Rostock
CEA Saclay
PNPI St. Petersburg

**Asia:**
Chiba U
Hiroshima U
Minadamo SU-IIT
Kinki U
U Osaka
Saga U
Tokyo UAT
U Tokyo
NRICP Tokyo
Kogakuin U Tokyo
KEK Tsukuba
U Tsukuba
Tsinghua U

**America:**
Carleton U
LBNL
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TRIUMF
Indiana U
U Montreal
U Victoria
Purdue
Cornell
Yale

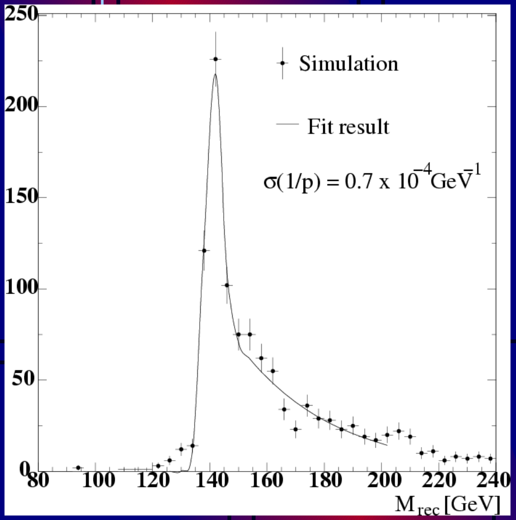
# Tracking at the ILC

## Tracking requirements of ILC physics program:

- excellent momentum resolution
- high reconstruction efficiency and robustness
- good particle identification capabilities
- minimum interference with calorimetry

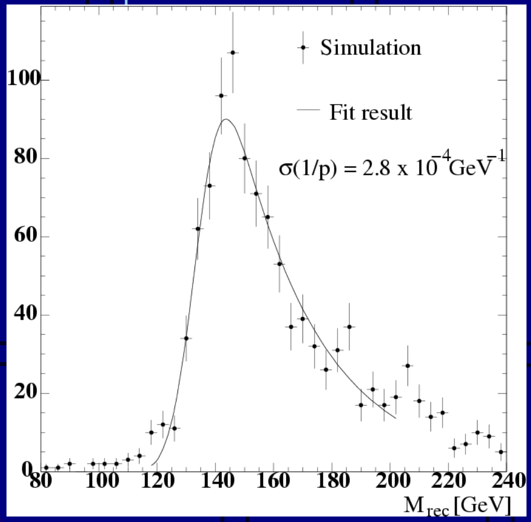
Higgs-strahlung $e^+e^- \to HZ \to Hl^+l^-$

$\sigma(1/p_T) = 0.7 \times 10^{-4}$ GeV$^{-1}$




recoil mass (GeV)

$\sigma(1/p_T) = 2.8 \times 10^{-4}$ GeV$^{-1}$



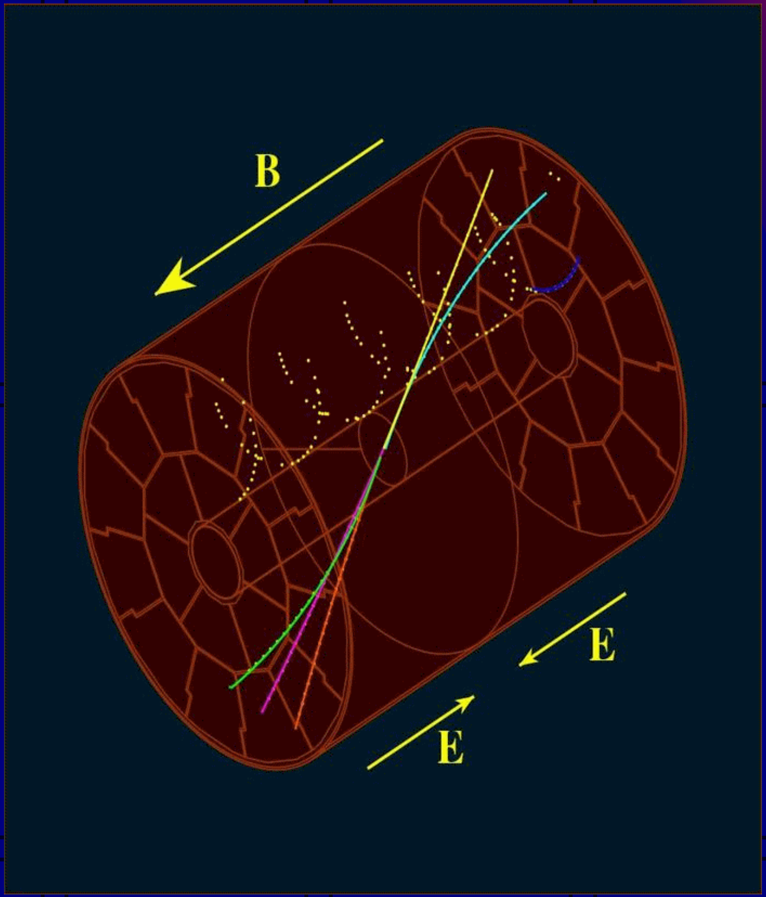

recoil mass (GeV)

## Discussed options:

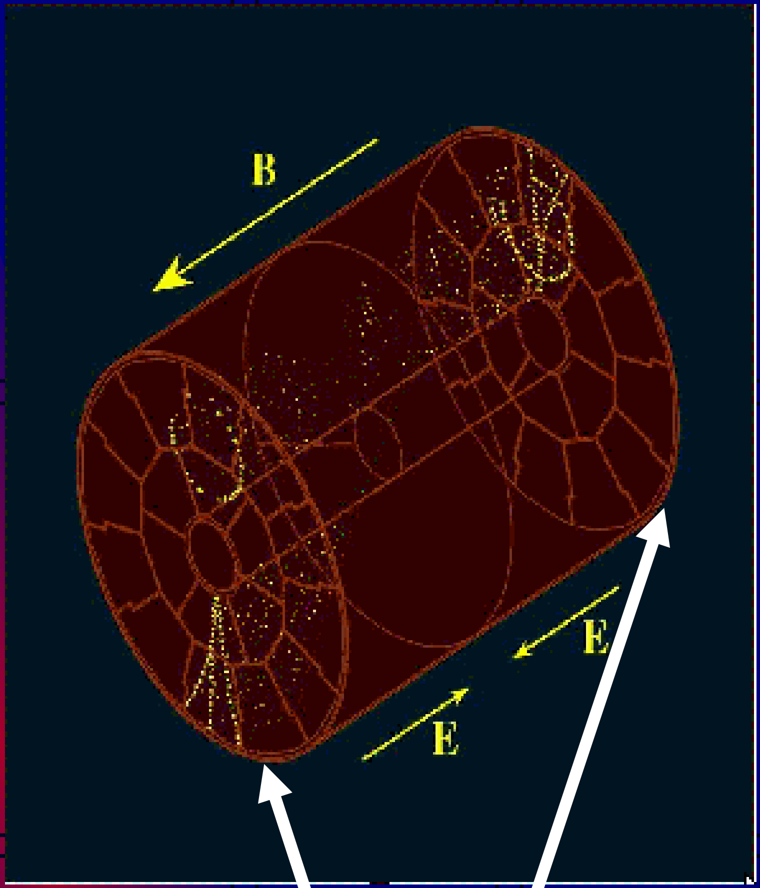
- Si tracker (SiD)
- TPC (LDC, GLD)

# Working principle of a TPC

A good candidate for the main tracker is a time projection chamber:




55μs




moment of interaction

readout planes

# Advantages of a TPC

- Relatively cheap instrumentation of large volume with many voxels (robustness)
- Minimum amount of material
- genuine 3D track reconstruction without ambiguities
- good particle identification through dE/dx measurement

# New gas amplification devices

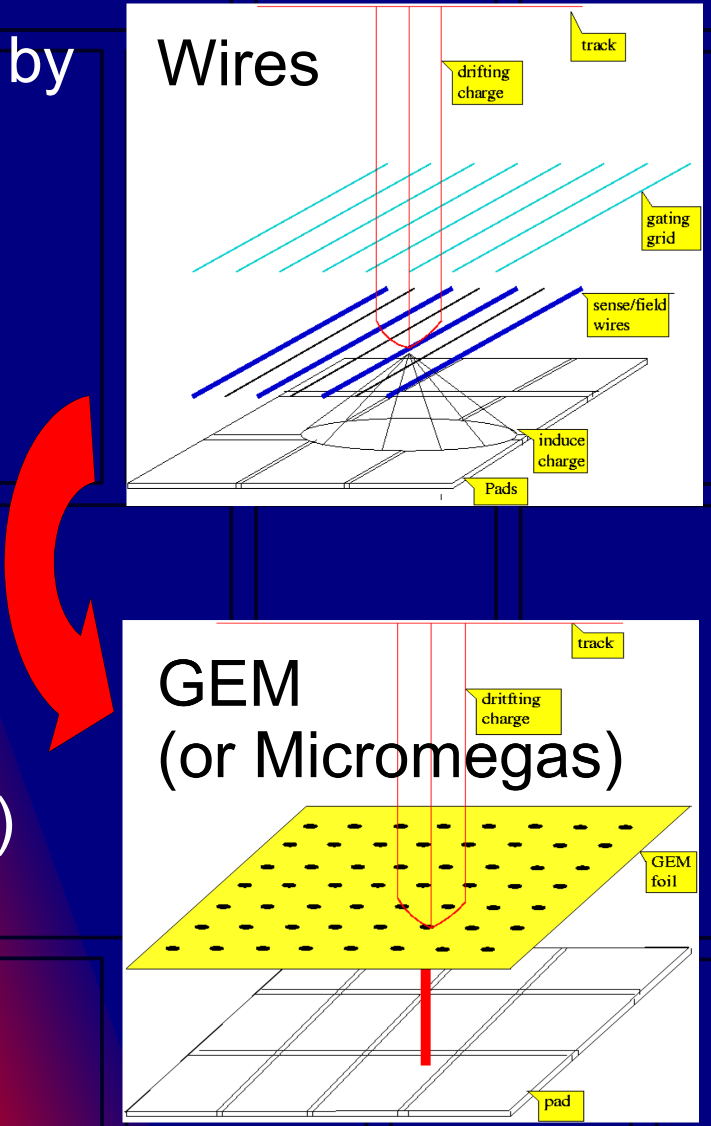
Replace conventional MWPC system (wires) by micropattern gas detectors (MPGD)

Most promising:

- Gas electron multiplier (GEM) (F. Sauli, 1997)
- Micromegas (Y. Giomataris *et al.*, 1996)

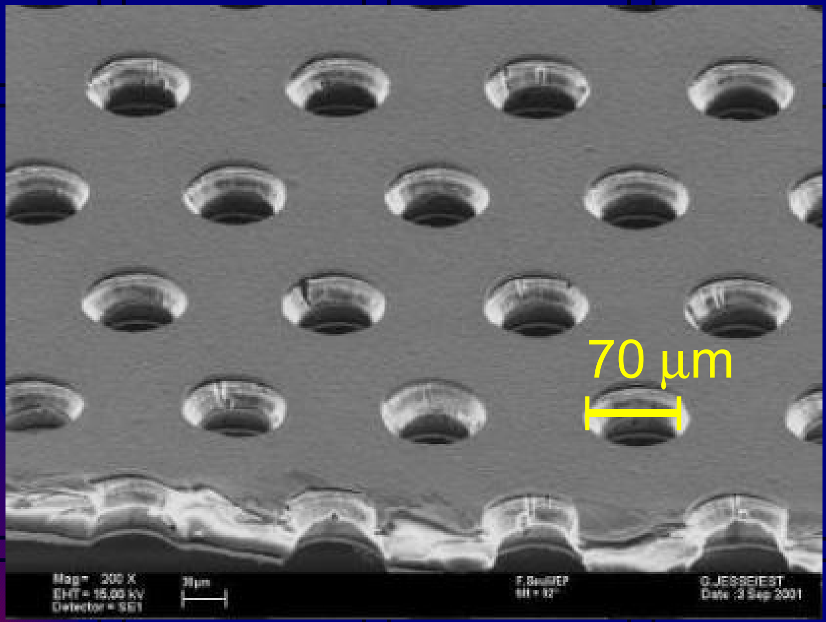
Advantages:

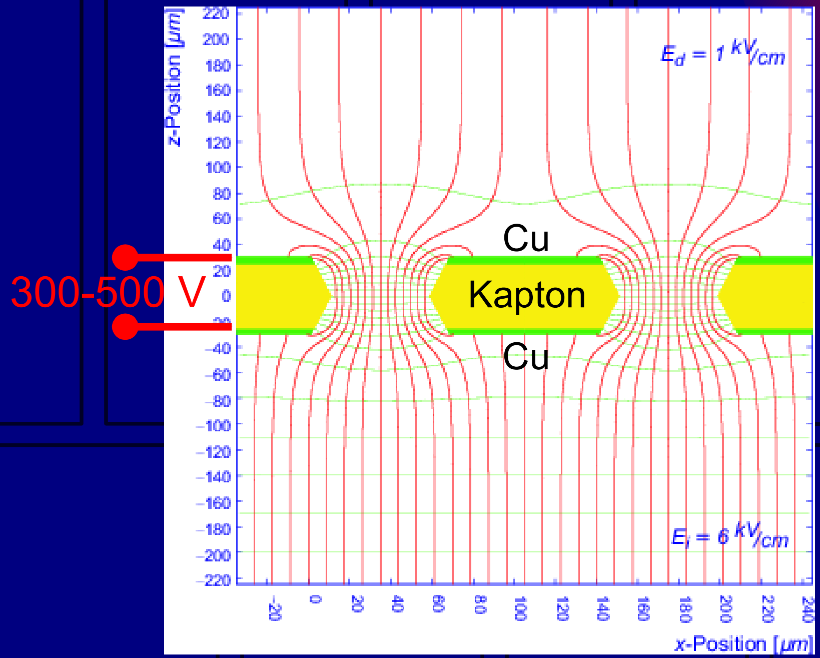
- Amplification structures of order O(100 μm)
- Intrinsic ion feedback suppression
- Fast and narrow electron signal



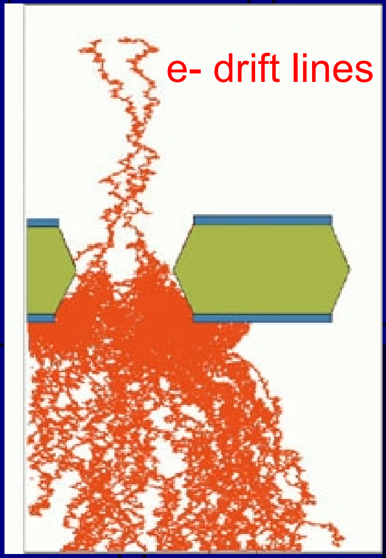
# Gas electron multiplier (GEM)

- 50 μm thick Kapton foil
- 5 μm copper coating on both sides
- hexagonally aligned holes
  ∅ 70 μm, 140 μm pitch
- multiple GEM stacks possible
  (flexibility to optimize operation)



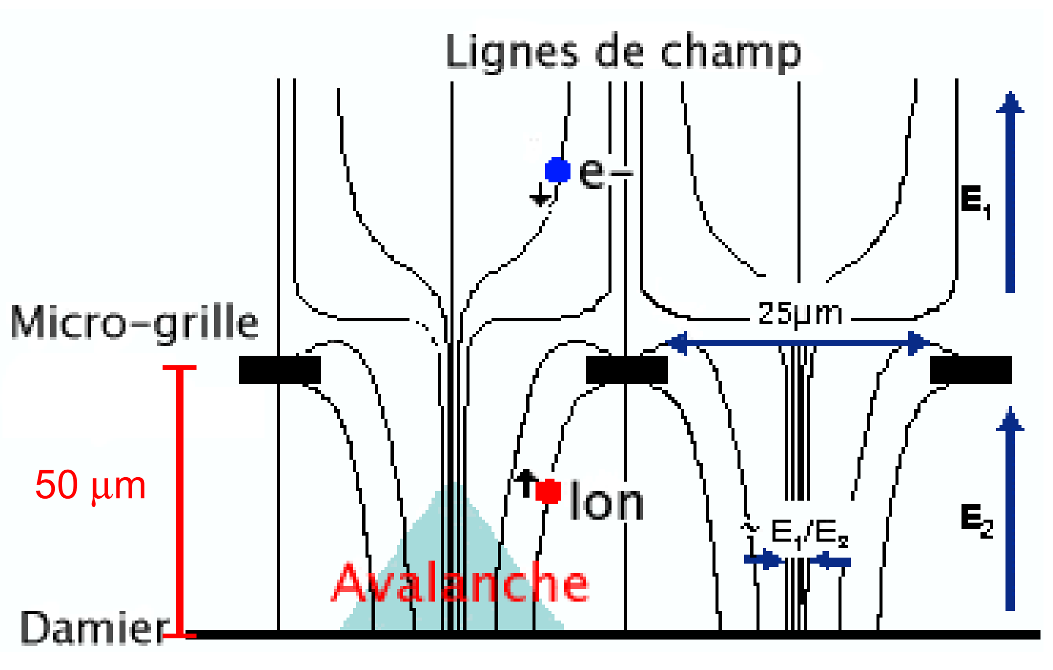



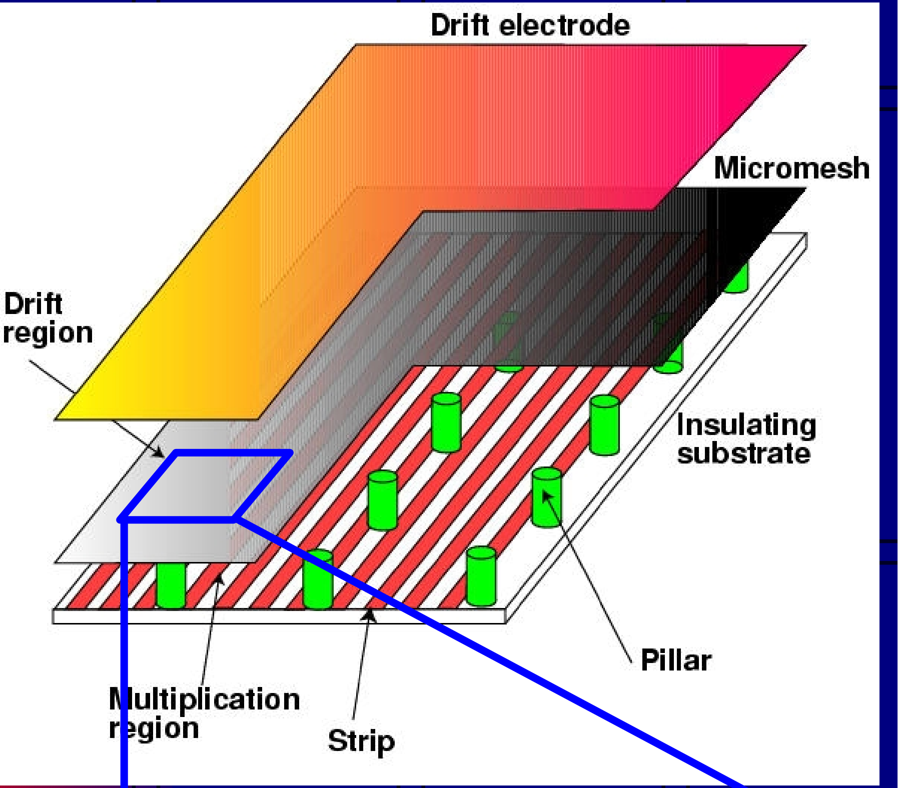

Electron avalanche inside holes:

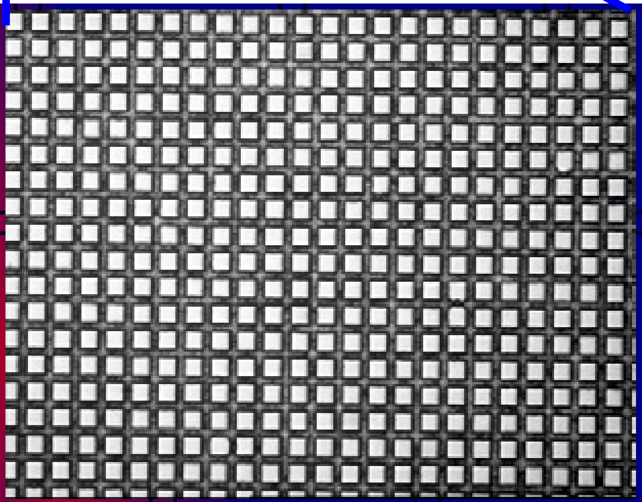


# Micromegas

- Mesh with typically 50 µm pitch
- Typically 50 µm between mesh and pads
- Very small diffusion in amplification gap



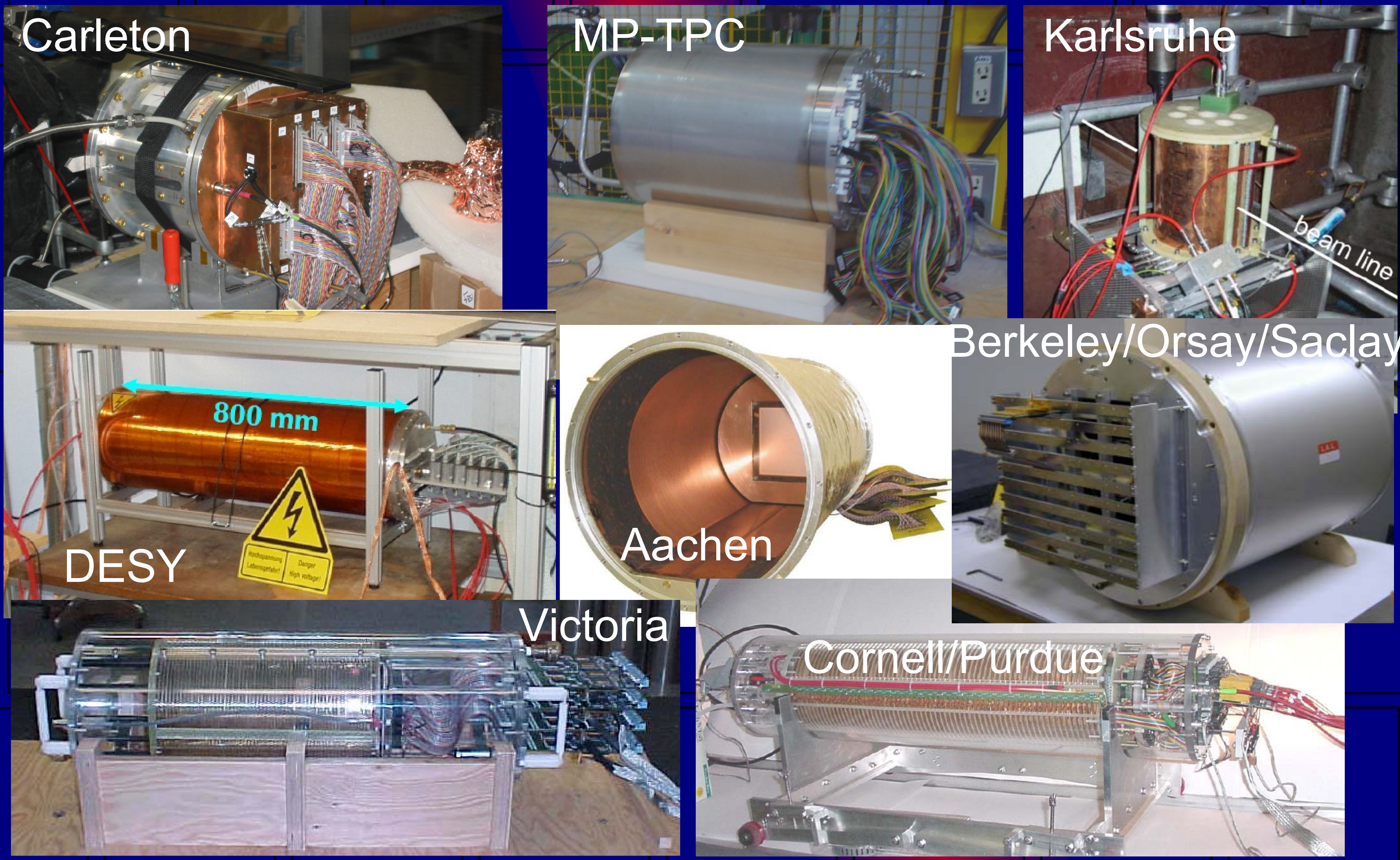



# Overview of R&D activities

- TPC prototypes
- Spatial resolution
- Ion backdrift
- TPC with pixel readout
- Large prototype
- Organization
- Time scale of next steps

# TPC prototypes



# Spatial resolution

Momentum resolution is closely connected to spatial resolution

Gluckstern formula:

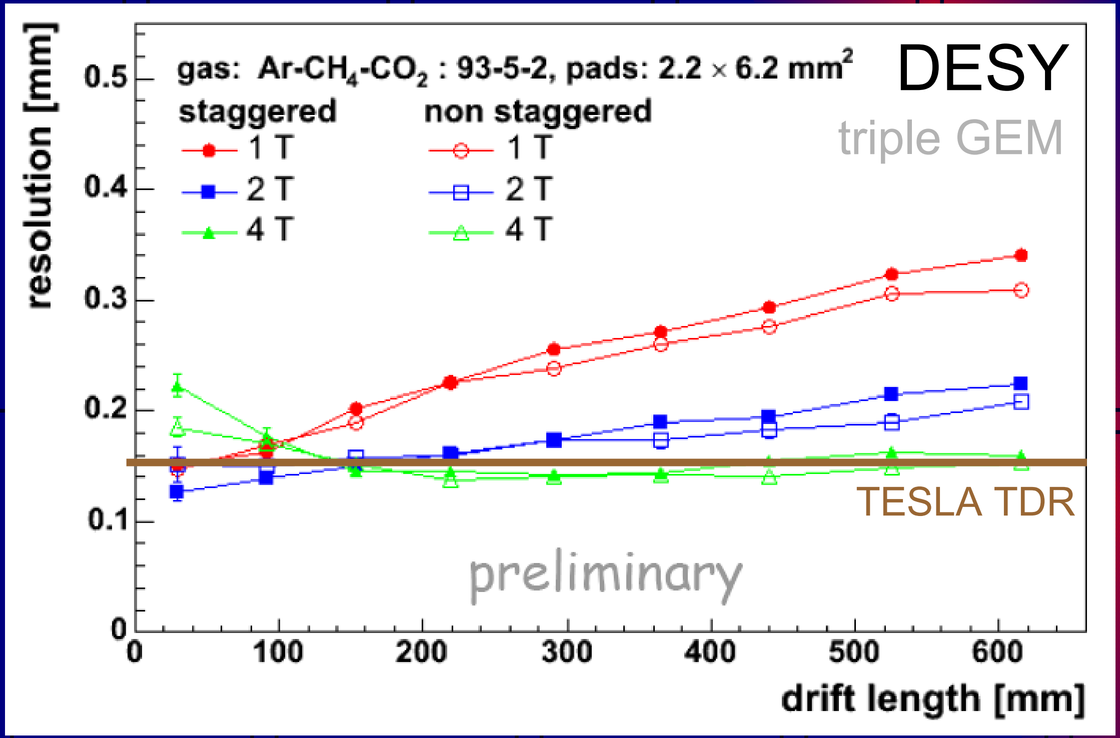
$$\frac{\sigma_{p_T}}{p_T} = \left[ \frac{\sigma_{r\varphi}}{0.3\ L^2\ B} \, p_T \sqrt{\frac{720}{N+4}} \right]$$

$p_T$: tr. momentum
$\sigma_{r\phi}$: point resolution
$L$: track length
$B$: magnetic field
$N$: # track points

Goal in TESLA TDR (TPC alone): $\Delta p_T/p_T^2 = 1.5\times10^{-4}\ \mathrm{GeV}^{-1}$

Corresponds to 150 µm (100 µm) average point resolution transverse to drift direction for an outer TPC radius of 162 cm (139 cm)

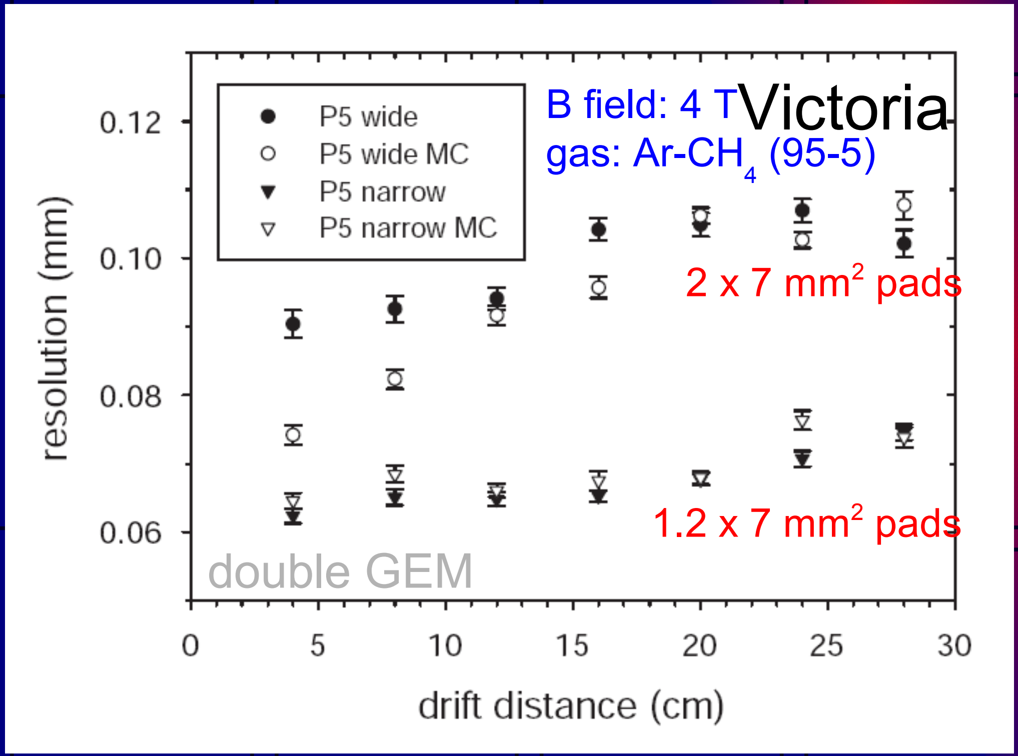
# Spatial transverse resolution




- Different pad arrangements have different fit systematics
- Good agreement
  ⇒ systematics under control
- Not enough charge sharing for 2.2 mm wide pads at 4 T in $Ar\text{-}CH_4\text{-}CO_2$ (93-5-2) for optimal performance
- TESLA TDR requirements ≈ fulfilled

Good progress in understanding fit systematics during last two years

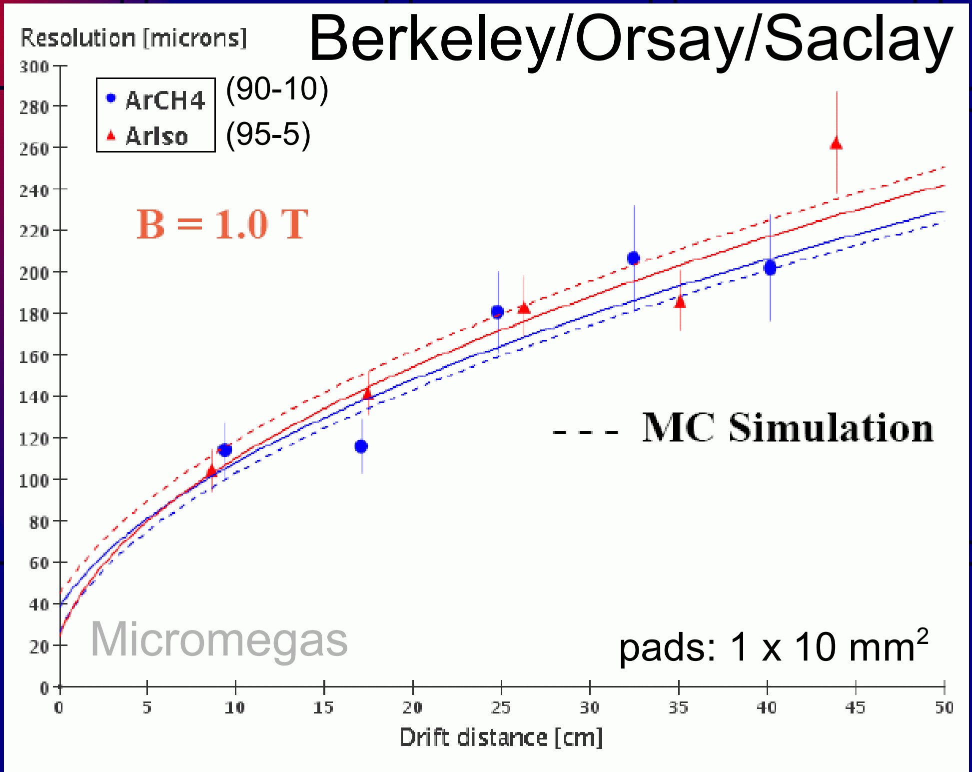
# Spatial transverse resolution




With different gas and different pad size:

≈ 70 µm achieved at 4 T

Measurements at 4 T only possible in DESY magnet so far

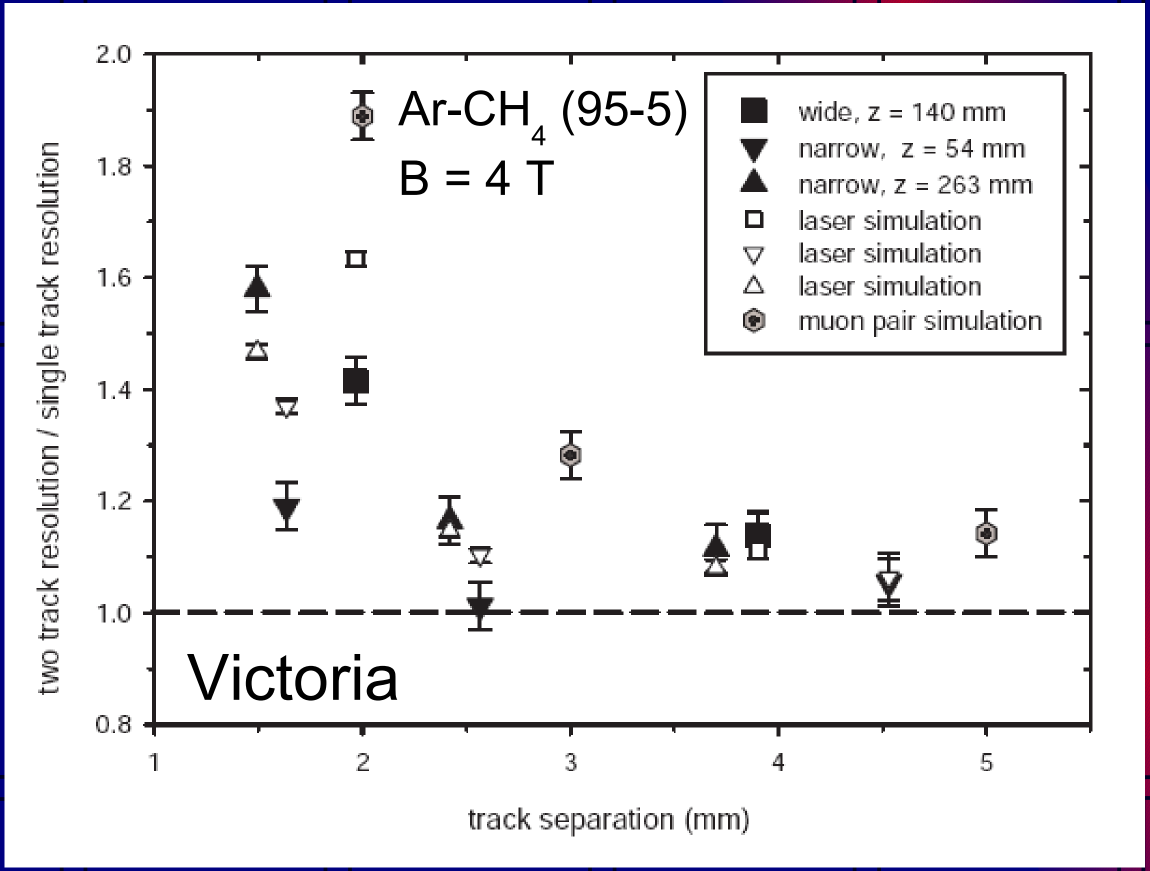



Similar performance for Micromegas

Simulations in good agreement for GEMs and Micromegas

# Two track resolution

Transverse two track resolution studied using laser beams:



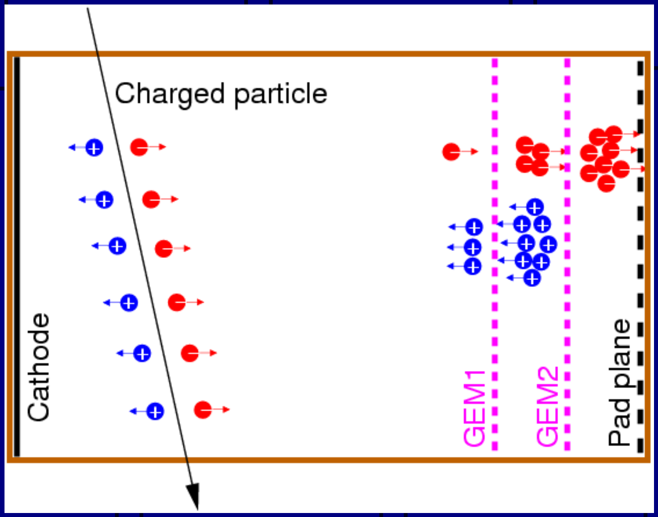

Good resolution for tracks whose separation is more than ~1.5 times the pad width

# Open questions

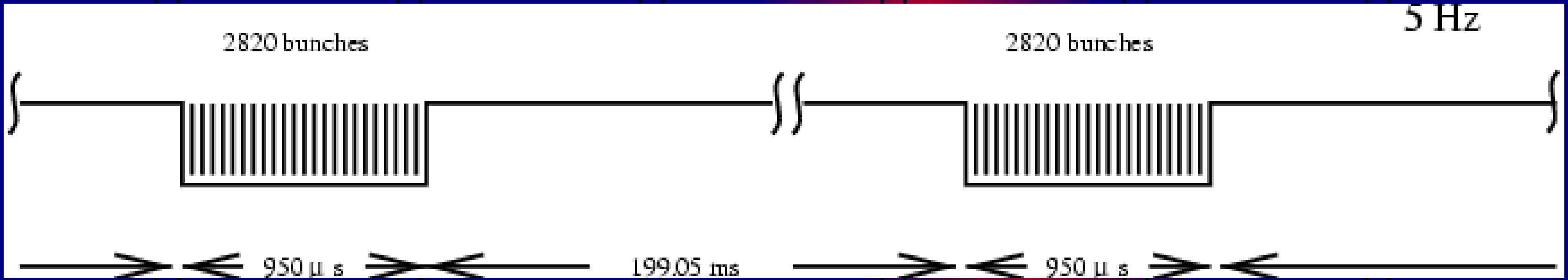
- Does the performance achieved with small prototypes scale to larger chambers?
  $\rightarrow$ Large prototype
- Can the performance of the developed algorithms be re-produced in more realistic environments? In particular:
- How much dilute ions the spatial resolution?

# Ion backdrift

$$\text{Ion backdrift} = \frac{\text{\# ions on cathode}}{\text{\# electrons on pads}}$$




Important issue due to ILC bunch structure:




- 337 ns between BX ≈ 1/160 maximal e- drift time
  ⇒ ungated operation needed for a whole bunch train (1 ms)
- Intrinsic ion feedback suppression of amplification system necessary

# Ion backdrift

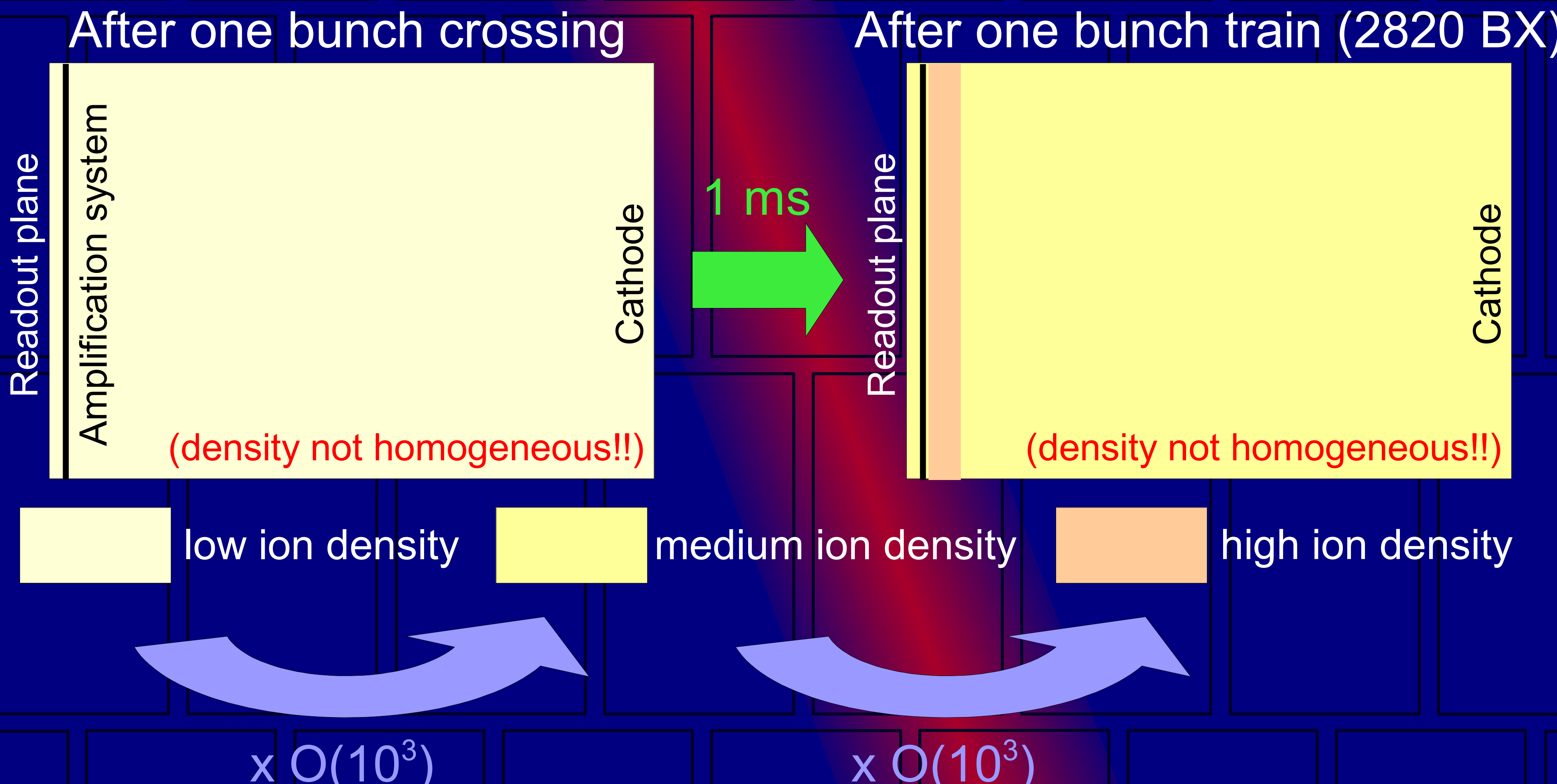
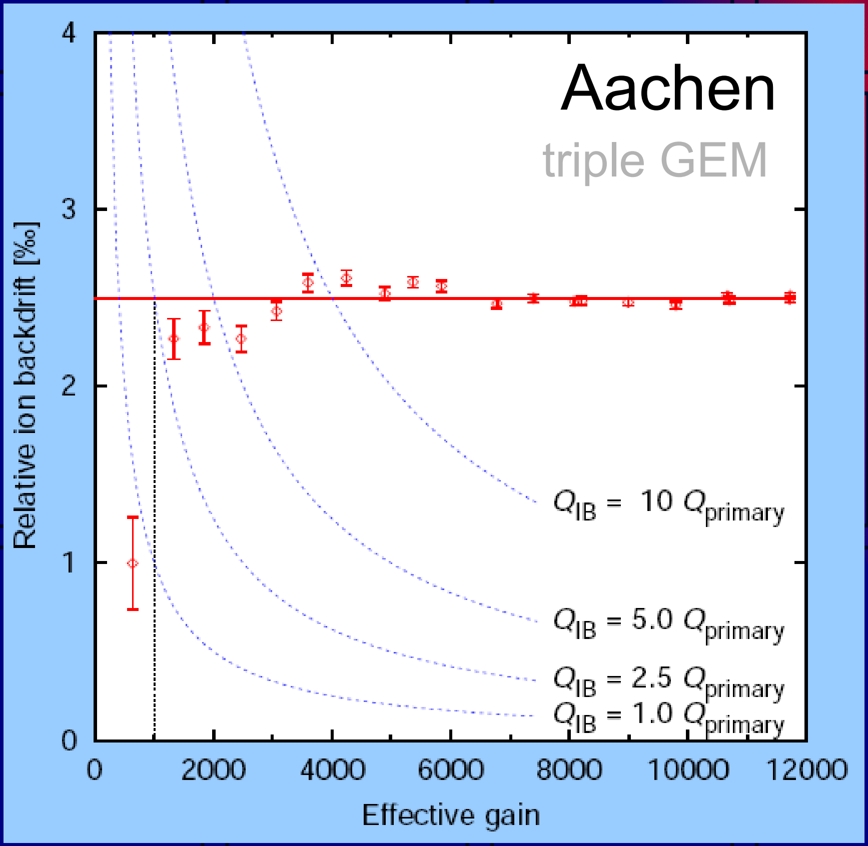
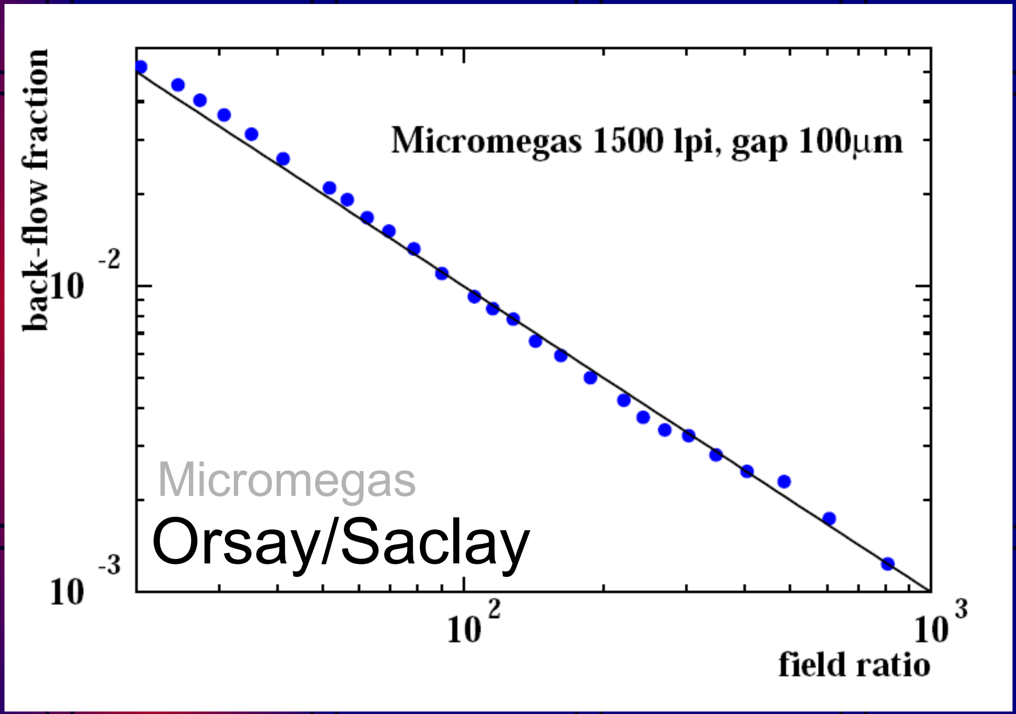



**Figure of merit: ion backdrift × gain**

# Ion backdrift




Ion backdrift independent from gain at 0.25 % at 4 T

Ion backdrift ∝ 1 / log(gain)
Per mille level achieved

Ion backdrift × gain < 5 seems achievable

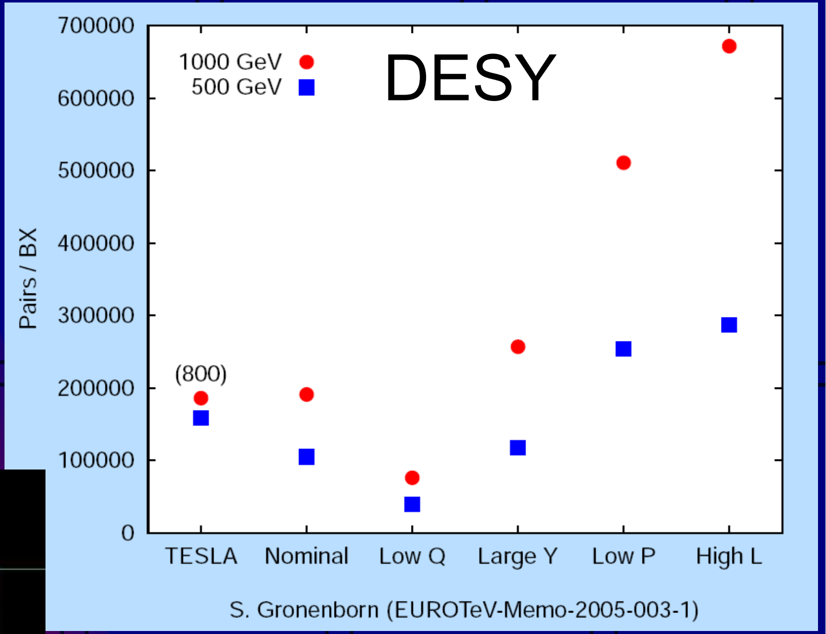
How large is expected primary charge?

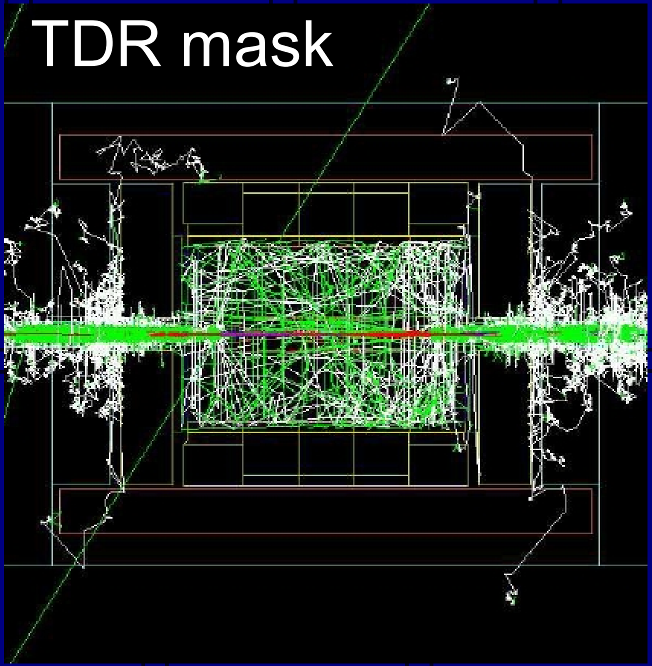
# Primary charge in TPC

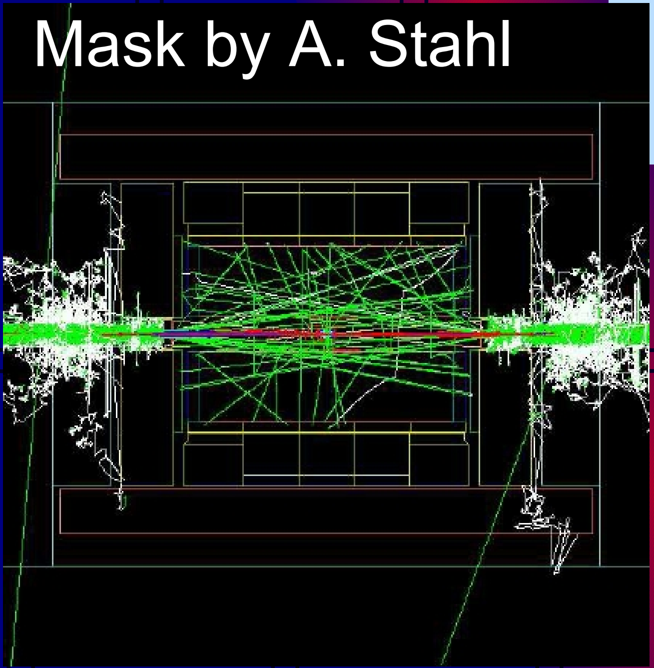
Main primary charge source is e+e- pairs from fusion of beamstrahlung photons (not “physics” processes)

Expected charge production in TPC subject to large uncertainties:

- beam parameters
- mask design
- Geant4 simulation

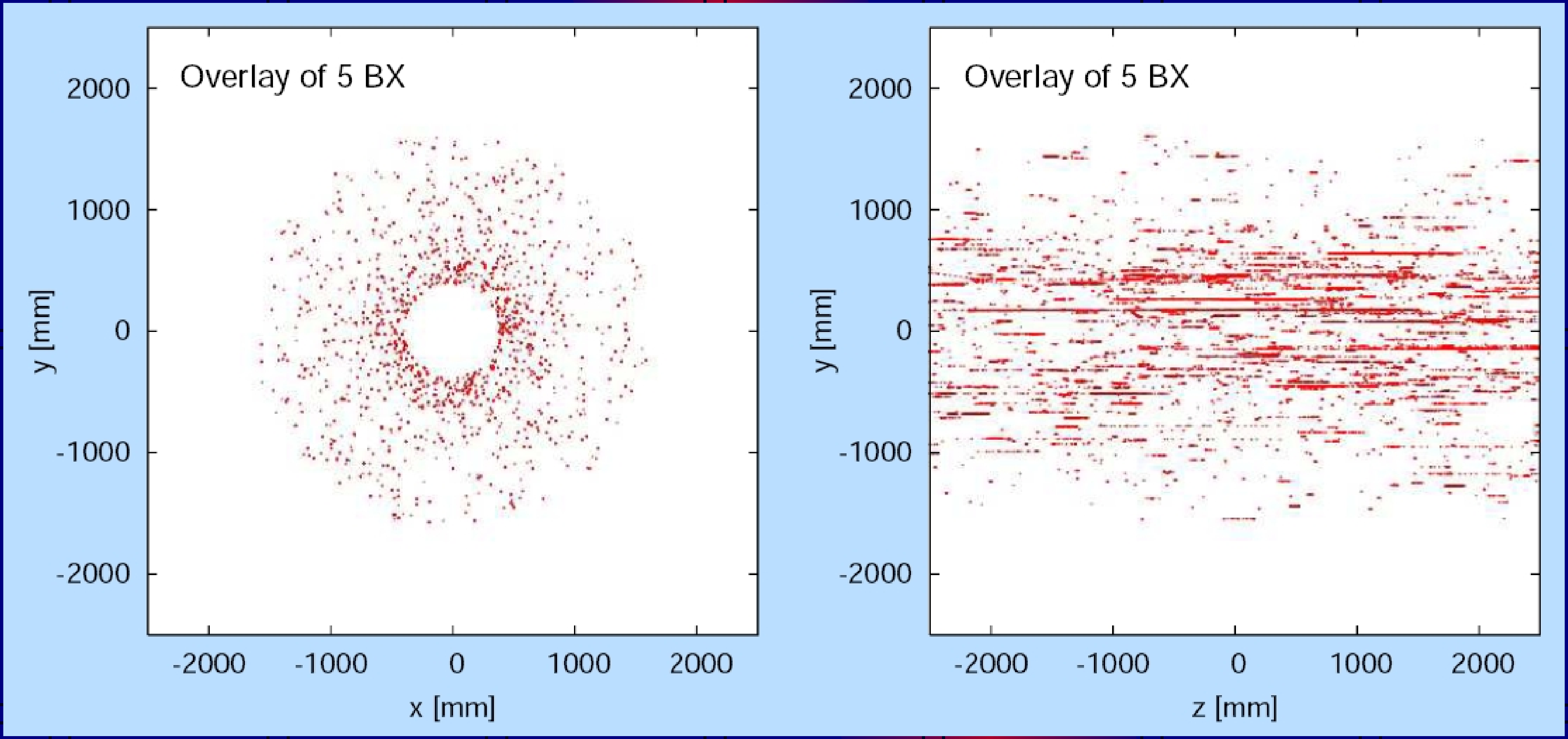


# Primary charge in TPC

Charge deposits from e+e- pairs in TPC after 5 BX:




Open question: How much do ions resulting from these charge deposits affect the spatial resolution?

# TPC with pixel readout

Read out TPC using CMOS readout chip with pixel size O(100 μm) instead of conventional pads

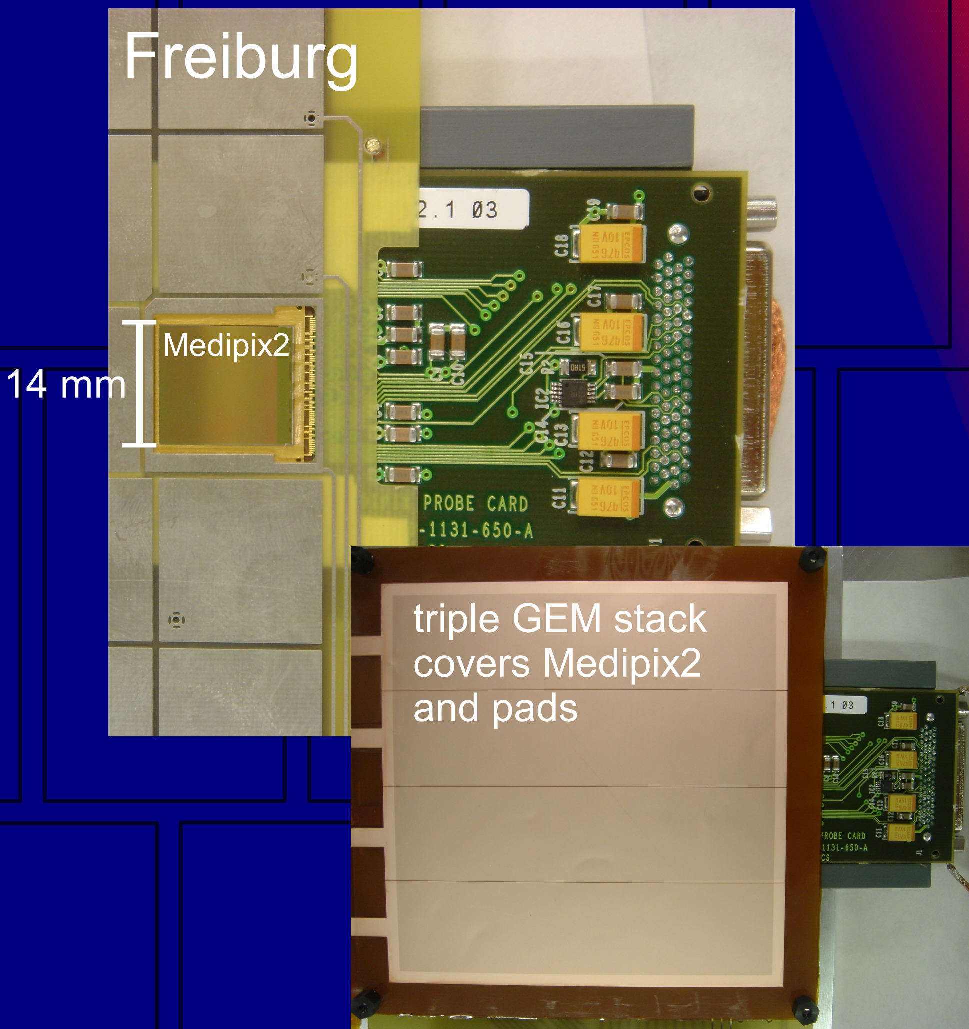
Pixels only provide binary information → Digital TPC

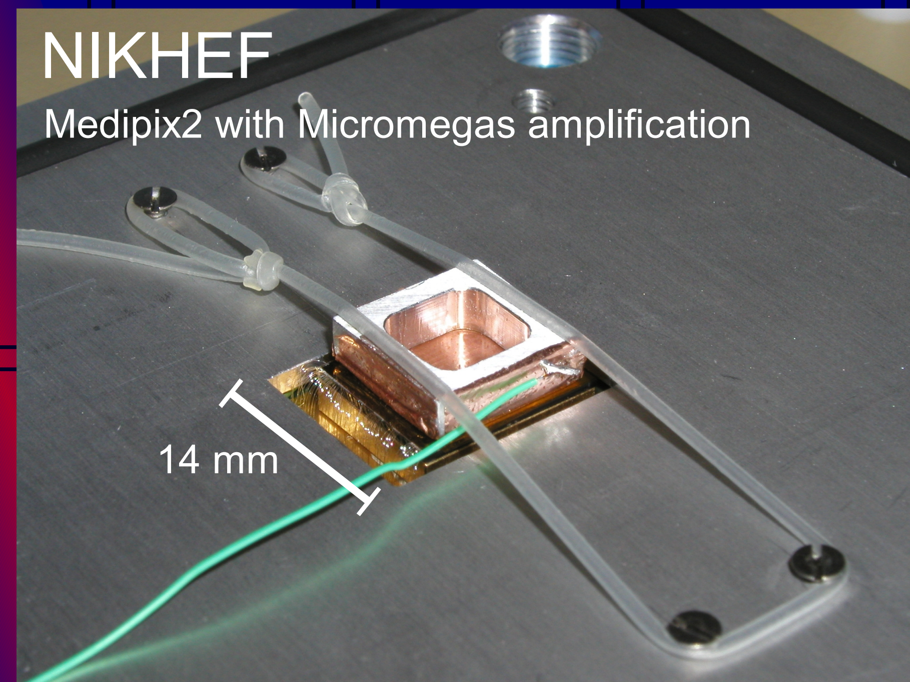
Features:

- Allows to see individual ionization clusters = basic track building blocks (potential to achieve ultimate resolution)
- "Typical" track would be sampled by
  30 clusters/cm × 120 cm = 3600 clusters
- Potential to improve dE/dx measurement by a factor of ≈ 2 using cluster counting (Poissonian vs. Landau distribution)
- Insensitive to gain fluctuations/variations
- Very compact, simple (binary) electronics

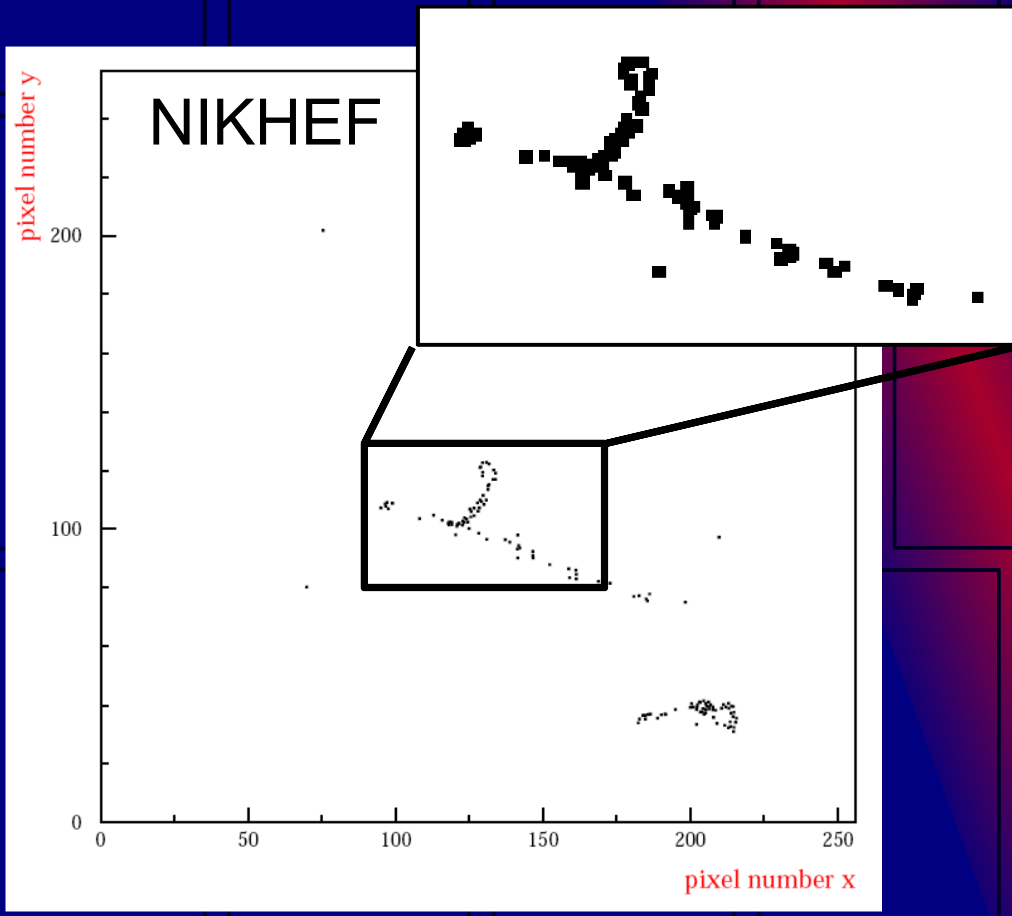
# Medipix2 setups

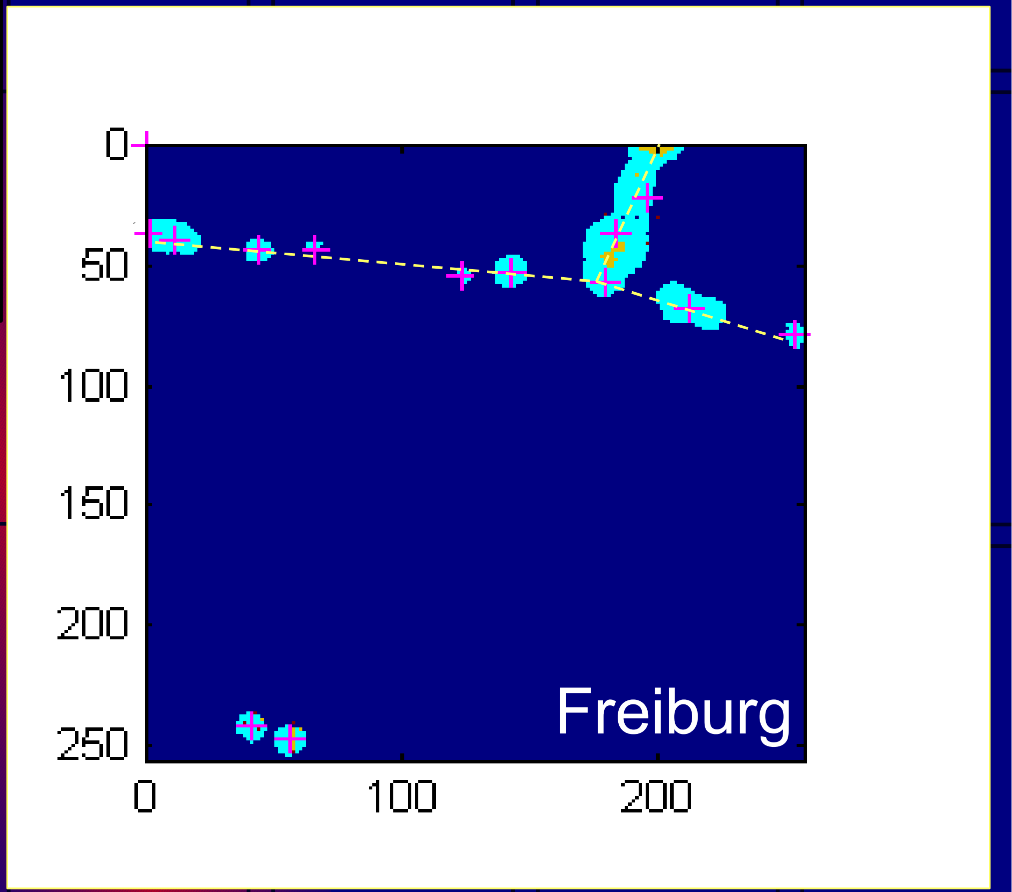
First experience collected with Medipix2 chip developed for x-ray imaging (provides no time information)



# δ electron events




Micromegas:

One primary e- → one pixel (small diff.)

Estimated single e- detection efficiency for present setup: O(90 %)

GEMs:

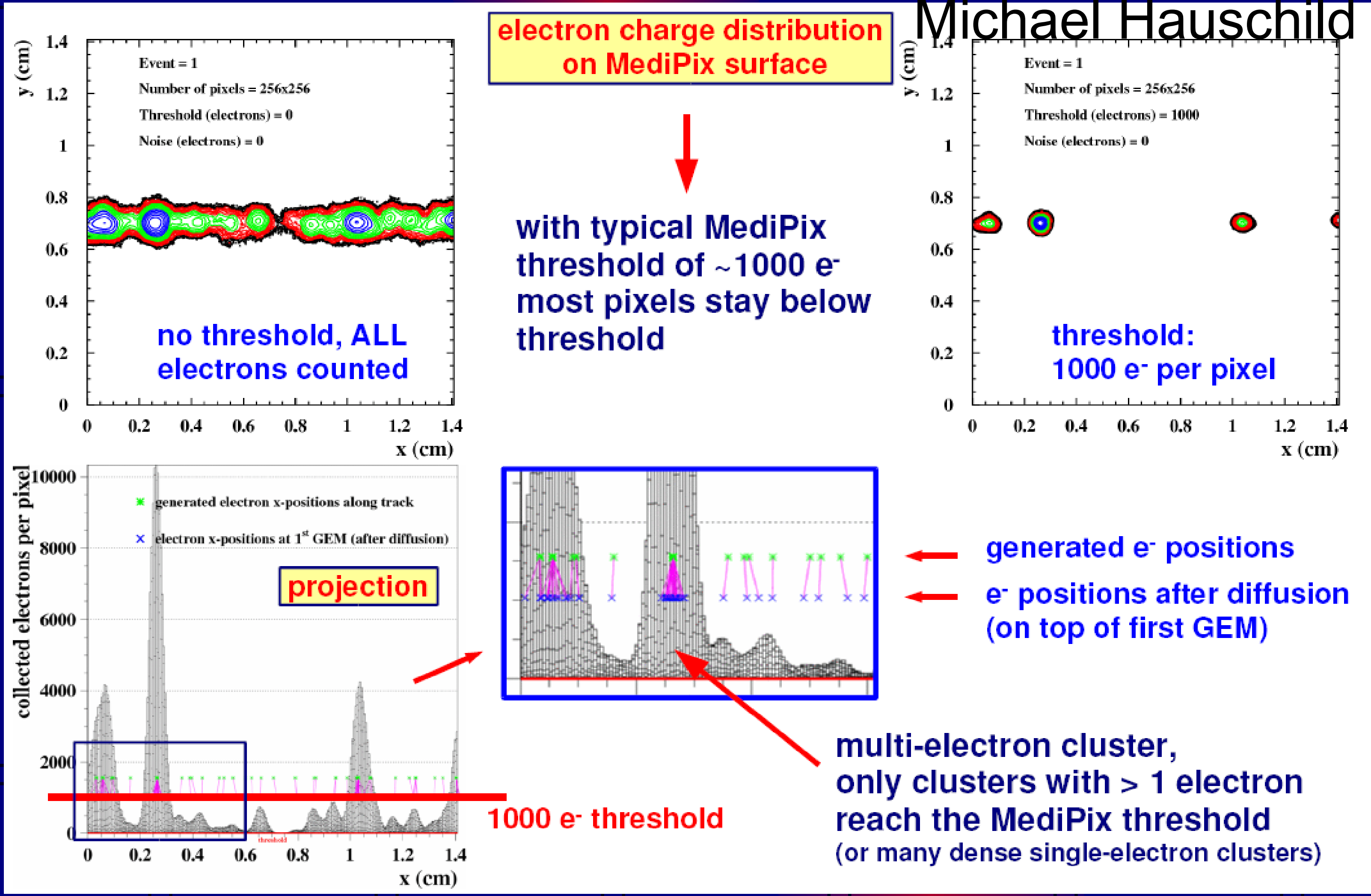
One prim. e- → several pixels (larger diff.)

Estimated single e- detection efficiency for present setup: O(50 %) in $HeCO_2$

# Medipix2 simulation

Simulation of Freiburg GEM setup:

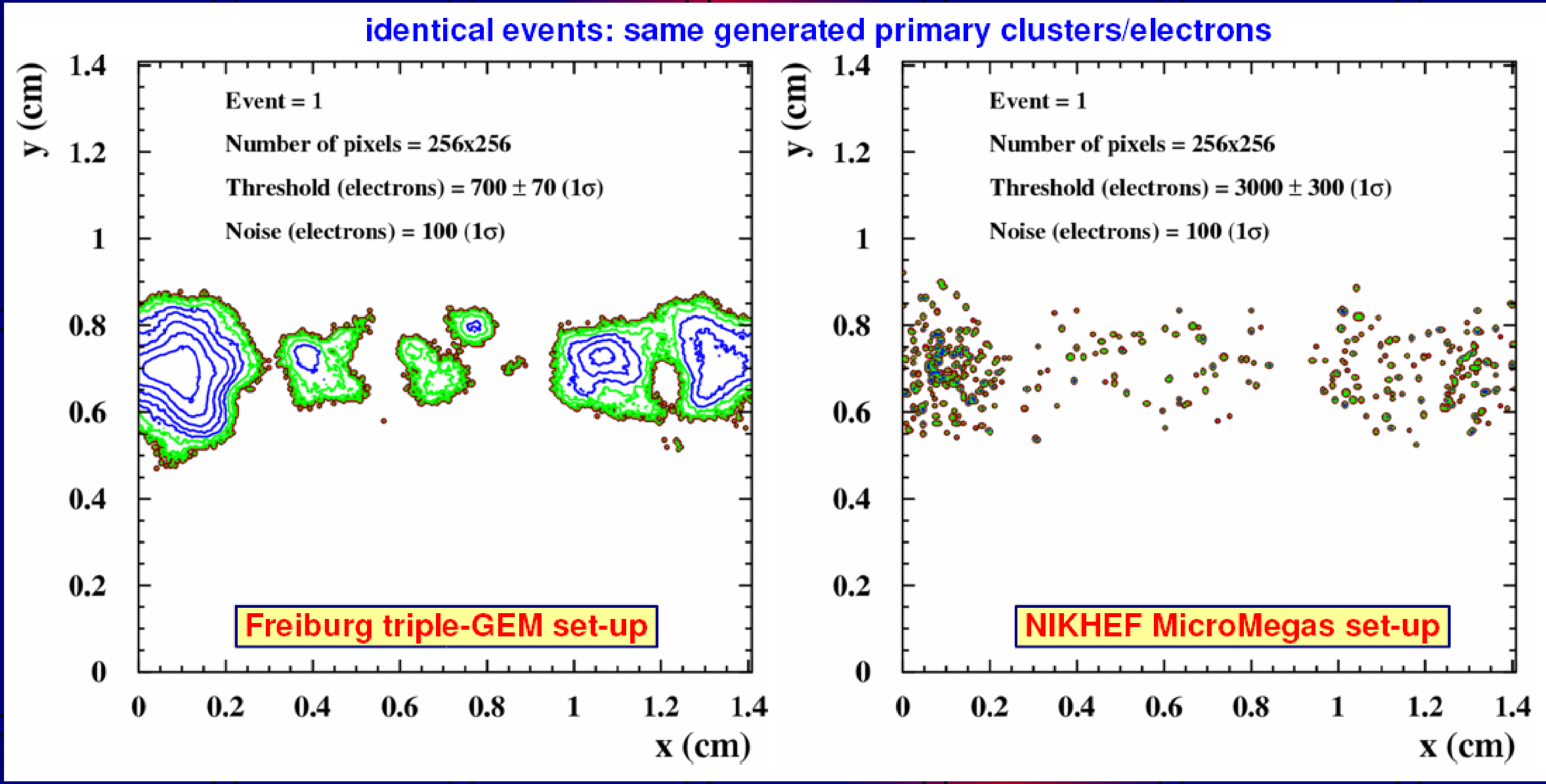
Michael Hauschild




⇒ Keep threshold low and diffusion small

# Pixel TPC at the ILC

Present status extrapolated to “typical” ILC conditions:
100 GeV muon, B = 4 T, Ar-$CO_2$-$CH_4$ (93-2-5), 100 cm drift

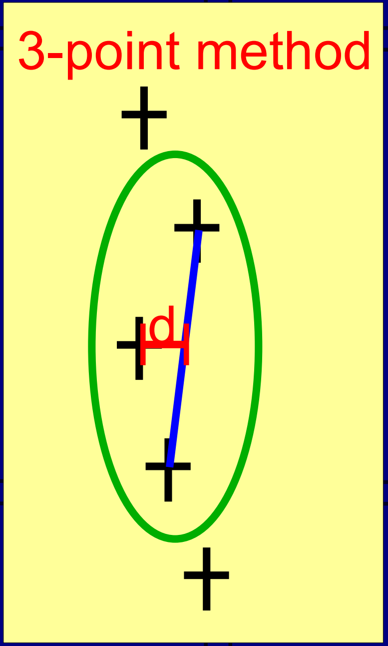


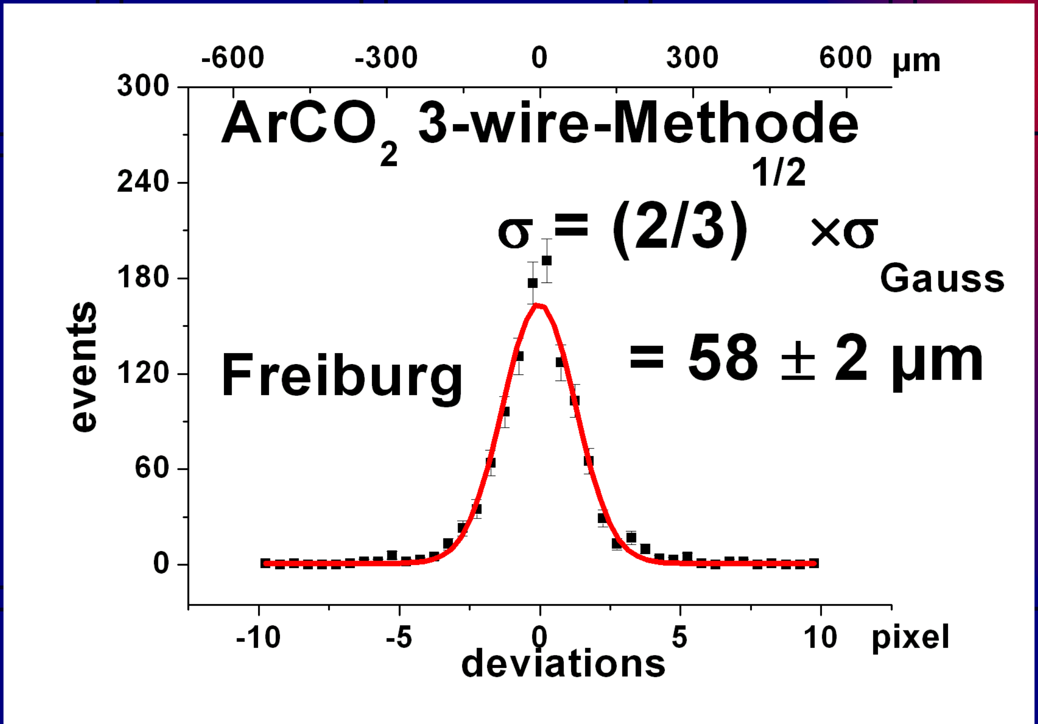

GEMs good to detect whole clusters
Micromegas good to detect single electrons

# Spatial resolution with Medipix2

Determination of resolution with radioactive β source hampered by multiple scattering

⇒ use of 3-point method (less sensitive to mult. scatt.)



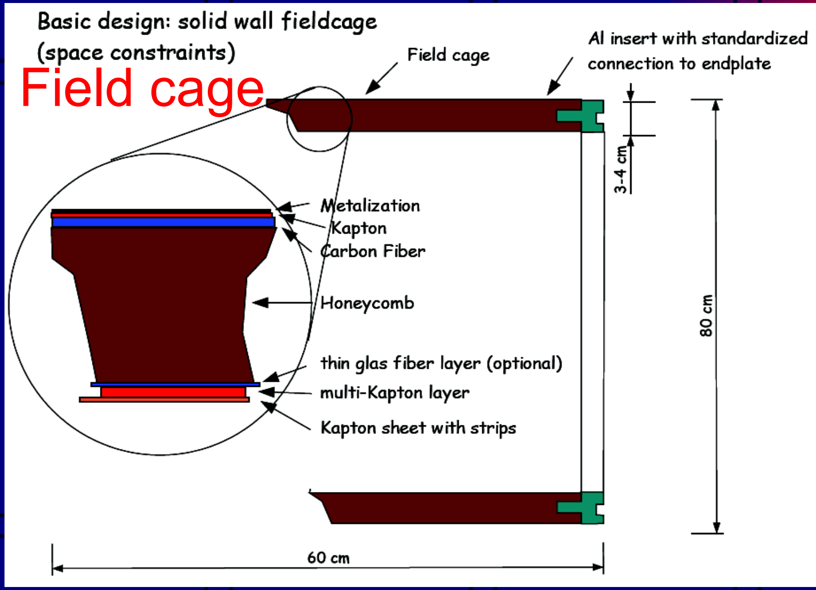

Cluster resolution:

| no B field | Ar/CO2 | He/CO2 |
|---|---|---|
| 3-point method | 58 ± 2 µm | 53 ± 3 µm |

# Timepix

- Add time information to Medipix → Timepix (part of EUDET)
- Up to 100 MHz clock distributed to all pixels
- Dynamic range $2^{14}$ x 10 ns = 160 µs
- Discharge protection
- No zero-suppression (for time being), keep chip size, pixel size and readout protocol for Medipix2 compatibility
- Submits in 0.25 µm via CERN to IBM:
engineering run (~8 wafers) in 2006, production run (~48 wafers) in 2007

# Large Prototype

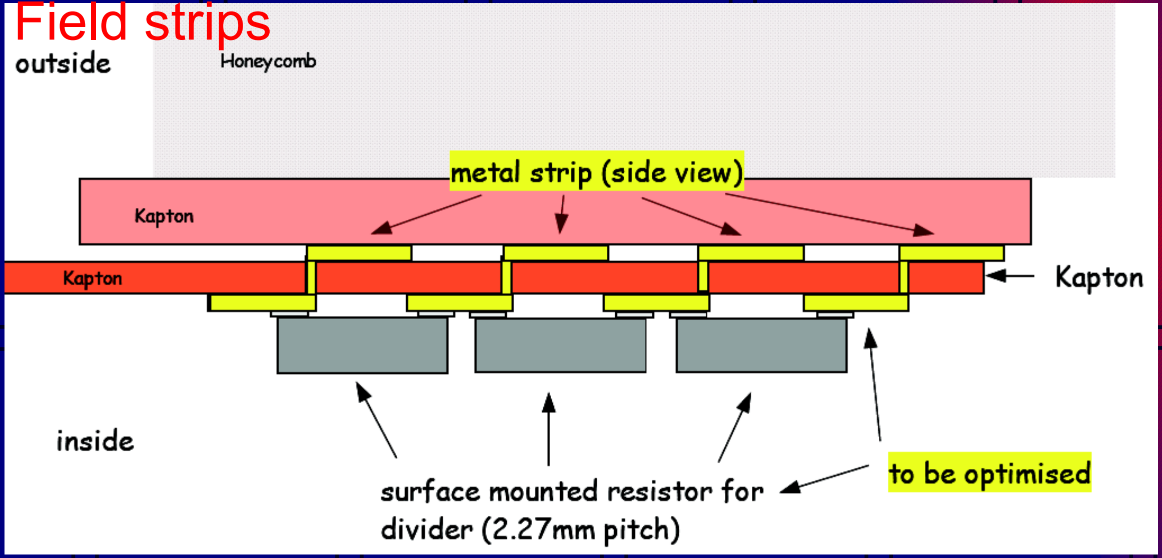



## Field cage:

Generic for different end plates technologies (part of EUDET)

Based on experience from DESY MediTPC prototype and Aachen simulations

Will be built by DESY, ready by Summer 2007




## End plates:

Different plates for different technologies. Built by groups (not part of EUDET)

# Other LP activities

Test beam area at DESY:

- electron beam
- large aperture 1.2 T magnet from KEK
- part of EUDET (DESY)

Electronics (FADC based):

- pre-amp shaper chips: progr.'able ASIC developed at CERN
- modified ALTRO chip (40 MHz)
- part of EUDET (Lund/CERN)

Electronics (TDC based):

- Q-to-t chip (ASDQ) + TDC
- part of EUDET (Rostock)

Software:

- harmonized analysis, simulation and reconstruction framework based on ILC soft tools
- part of EUDET

All EUDET activities in close collaboration with ILC TPC

# Organization

Tasks broken down to work packages with different coordinators:

- Mechanics: field cage design, end plates for GEMs, Micromegas and pixel readout
- Electronics: FADC-based, TDC-based, CMOS readout, cooling, power switching
- Software: analysis, simulation, reconstruction software, background studies, full detector simulation and performance studies
- Calibration: field map, field distortions, alignment

# Time scale

- Summer 2006: first Timepix chips
- Winter 2006/2007: pre-amplifier, DESY test beam area
- Summer 2007: LP field cage ready to be used
- Winter 2007/2008: DAQ prototype available
- Winter 2009/2010: compact readout system prototype

# Summary

- TPCs with MPGD gas amplification are routinely operated by many groups.
- Achieved point resolution with small prototypes sufficient to meet momentum resolution requirements.
- Per mille level ion backdrift values can be achieved at low gain.
- Pixel TPC proof-of-principle accomplished. Timepix is next step.
- First LP results expected by end of next year.