TPC R&D by LCTPC
Organisation, results, plans

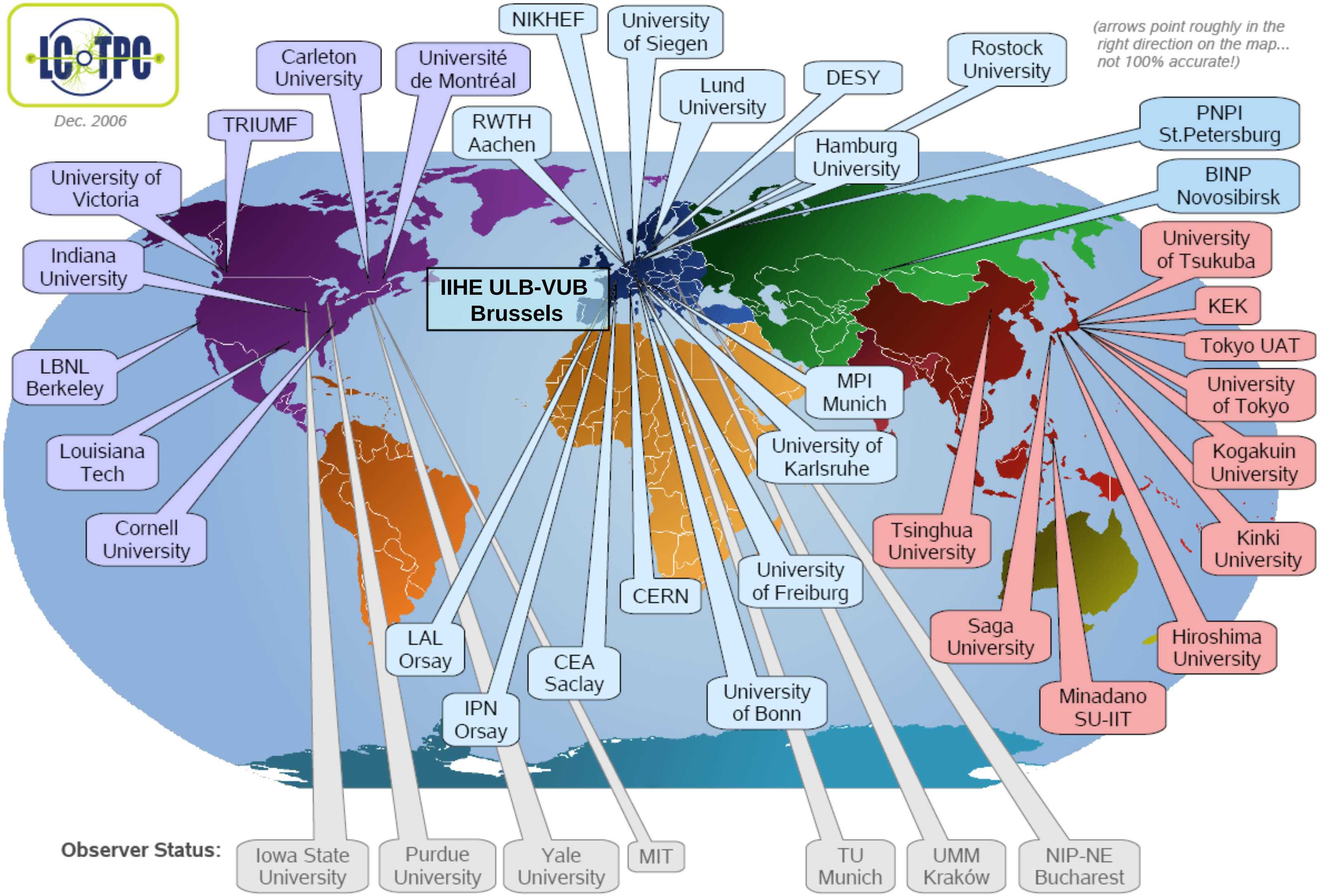
Jan Timmermans
NIKHEF & DESY(2009)

On behalf of the LCTPC Collaboration

TILC09, Tsukuba

20 April, 2009

LCTPC Collaboration



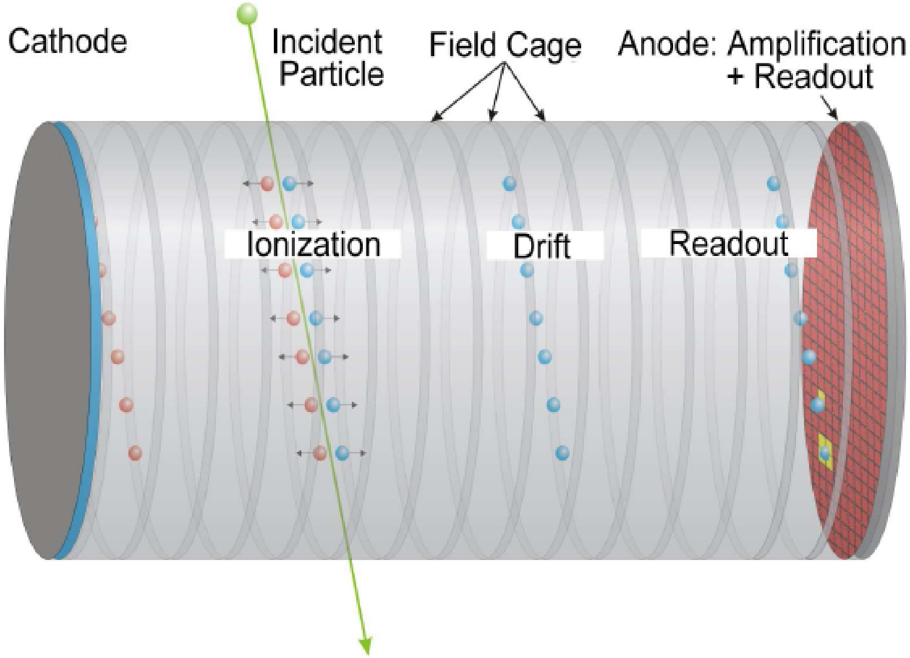
LCTPC Collaboration

➢ Performance goals and design parameters for a TPC with standard electronics at the ILC detector

Size	$\phi = 3.6$m, L = 4.3m outside dimensions
Momentum resolution (3.5T)	$\delta(1/p_t) \sim 9 \times 10^{-5}$/GeV/c TPC only ($\times$ 0.4 if IP incl.)
Momentum resolution (3.5T)	$\delta(1/p_t) \sim 2 \times 10^{-5}$/GeV/c (SET+TPC+SIT+VTX)
Solid angle coverage	Up to $\cos\theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\sim 0.04X_0$ to outer fieldcage in r
	$\sim 0.15X_0$ for readout endcaps in z
Number of pads/timebuckets	$\sim 1\times10^6$/1000 per endcap
Pad size/no.padrows	$\sim$ 1mm$\times$4–6mm/$\sim$200 (standard readout)
σ_{point} in $r\phi$	$< 100\mu m$ (average over $L_{sensitive}$, modulo track ϕ angle)
σ_{point} in rz	$\sim$ 0.5 mm (modulo track θ angle)
2-hit resolution in $r\phi$	$\sim$ 2 mm (modulo track angles)
2-hit resolution in rz	$\sim$ 6 mm (modulo track angles)
dE/dx resolution	$\sim$ 5 %
Performance	> 97% efficiency for TPC only (p_t > 1GeV/c), and
	> 99% all tracking (p_t > 1GeV/c) [82]
Background robustness	Full efficiency with 1% occupancy,
	simulated for example in Fig. 4.3-4(right)
Background safety factor	Chamber will be prepared for 10 $\times$ worse backgrounds
	at the linear collider start-up

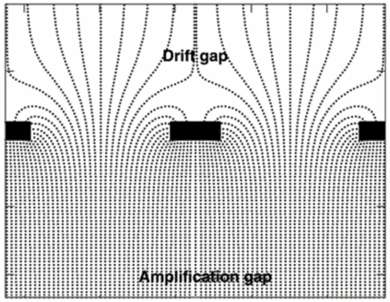
with MPGD

TPC with MPGD

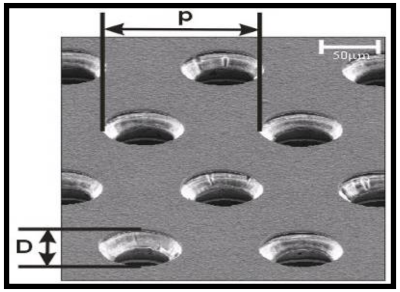


MicroPatternGasDetector
MPGD
not limited by **E** x **B** effects

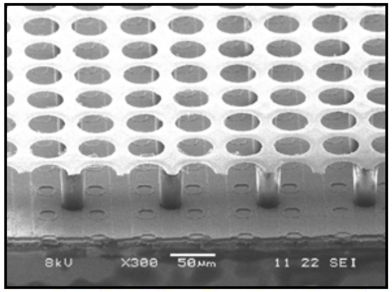
MicroMegas

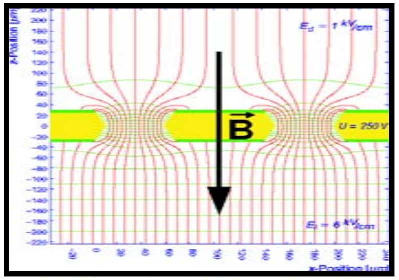


GEM



- **Two gas amplifications**:
- **Analog TPC**
  with standard pad readout
  (need signal broadening)
  Digital TPC
  with CMOS pixel readout





R&D strategy

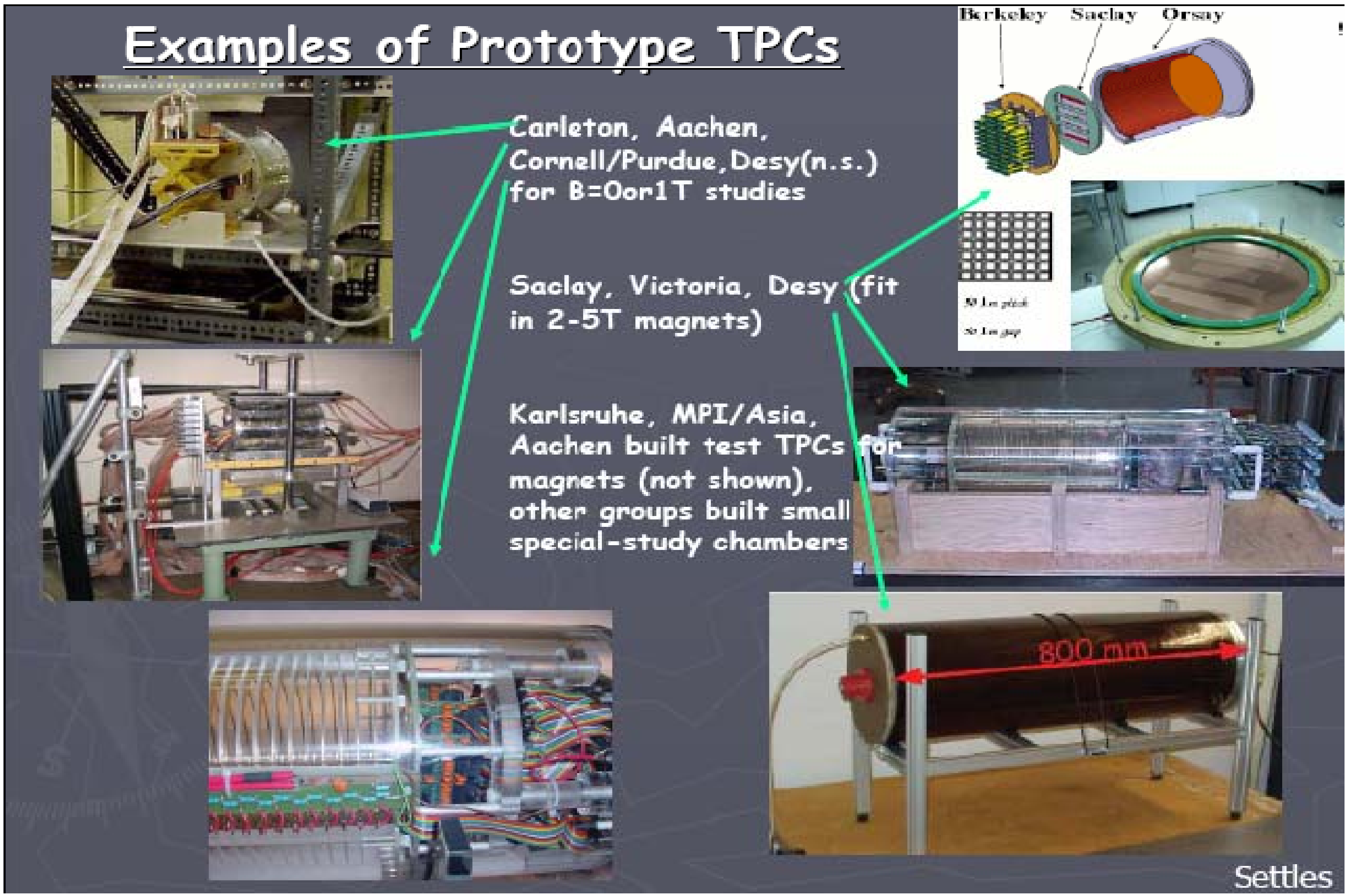
Three phases:

- Demonstration phase: using small prototypes (SP) Φ~30 cm; basic evaluation of TPC with Micropattern Gas Detectors (MPGD) gas amplification
- Consolidation phase: design, build and operate Large Prototype (LP) at EUDET facility @ DESY Φ~1 m
- Design phase: start work on engineering design for final detector

- **What has been learned sofar during phase (1)**
  - 6 years of of MPGD experience
  - Gas properties measured
  - Point resolution understood
  - Resistive anode charge dispersion demonstrated
  - CMOS pixel technology demonstrated (small scale)
  - Proof-of-principle of TDC-based electronics
  - LP operations have started
- **Current and next steps during phase(2)**
  - 2009-12: continue R&D on technologies at LP, SP, simulations, verify performance goals
  - 2009-11: R&D on advanced endcap; power pulsing, electronics and mechanics critical issues
  - 2011-12: test advanced endcap prototype at high energy and power-pulsing in high-B field
  - 2012-18: design, build LCTPC

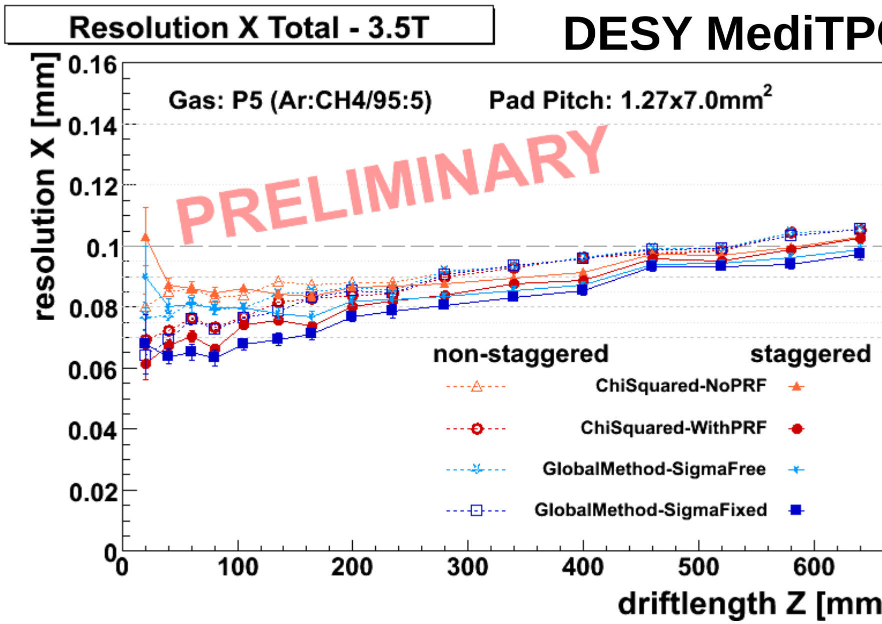
Point resolution of MPGD TPC

Special resolution and configuration/operation of MPGD TPC has been studied using various small TPC prototypes since 2000 in the LC TPC collaboration

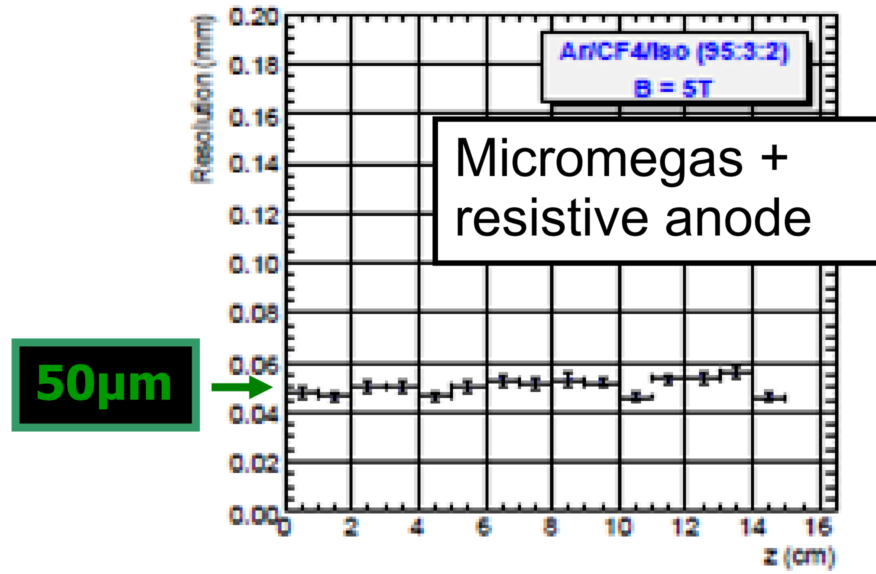


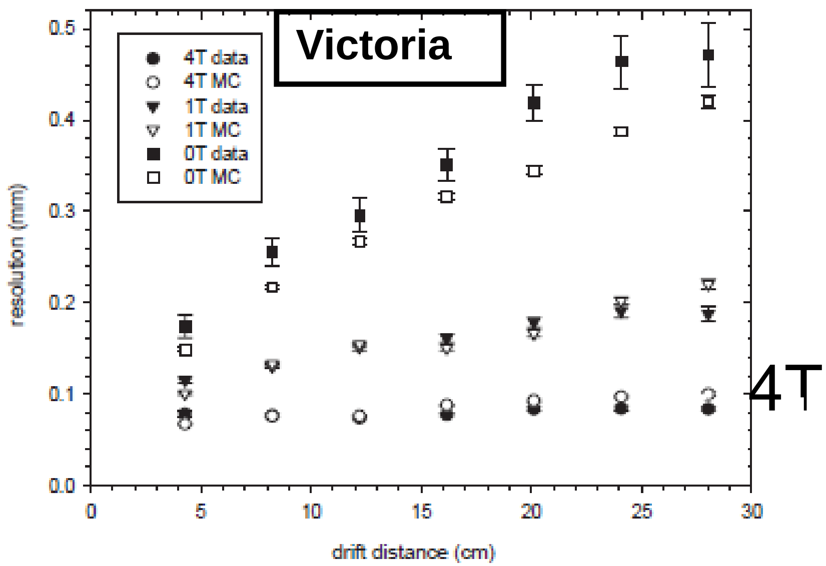
Some 'SP' resolution plots

DESY MediTPC

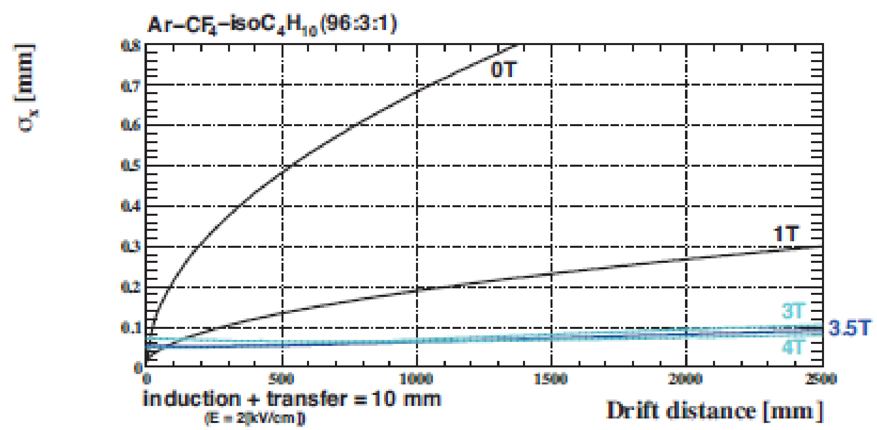


In DESY 5T solenoid





GEMs



Pixel readout

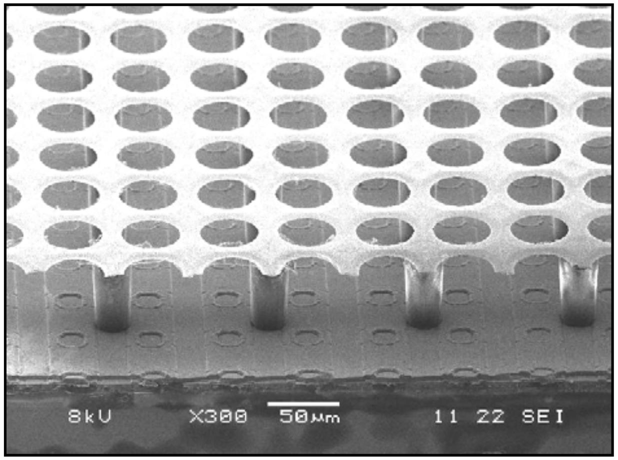
· Timepix chip + SiProt + Ingrid:

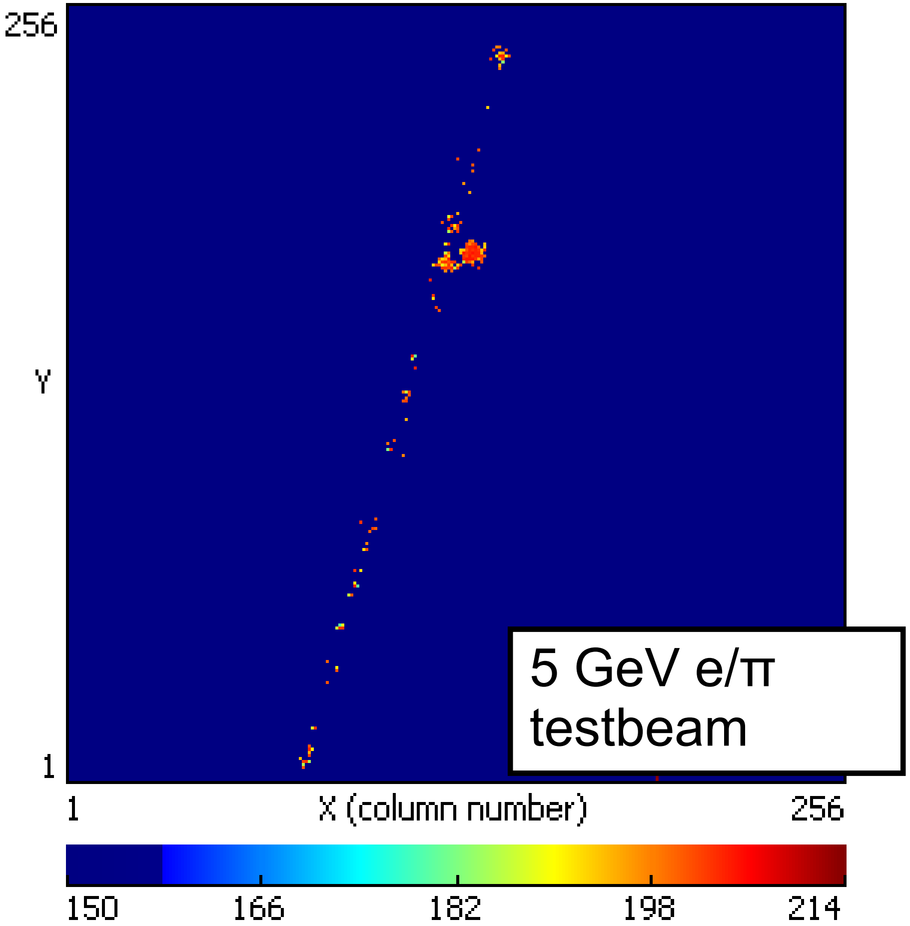
Timepix chip:

•256x256 pixels

•pixel: 55x55 μm^2

•active surface: 14x14 mm^2

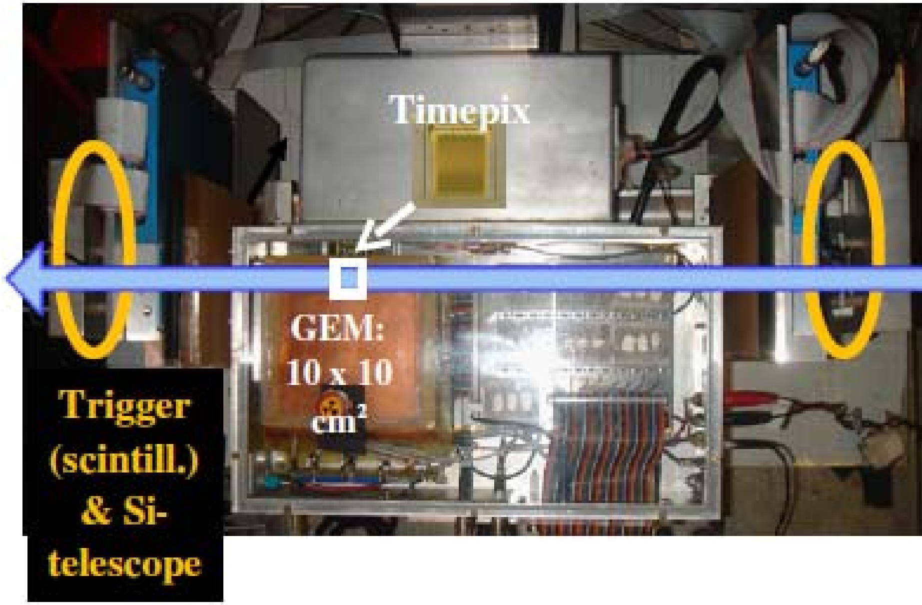




• zero-drift resolution should be below 55 μm

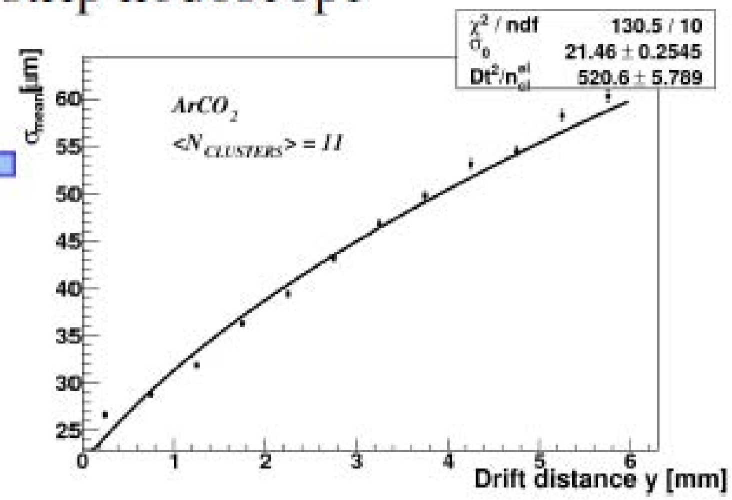
• allows cluster counting

Freiburg: Timepix readout + GEMs

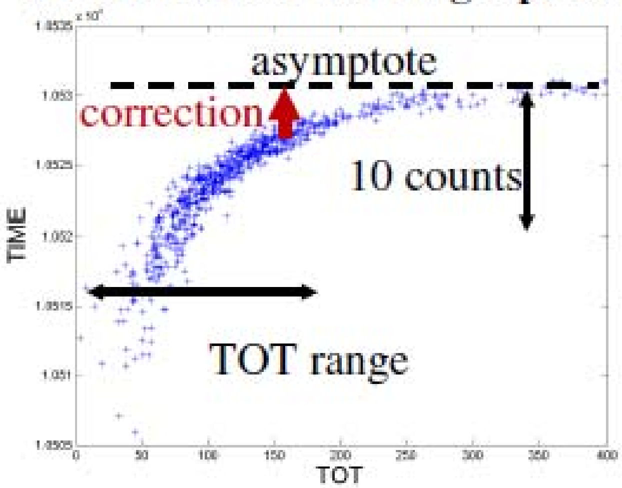


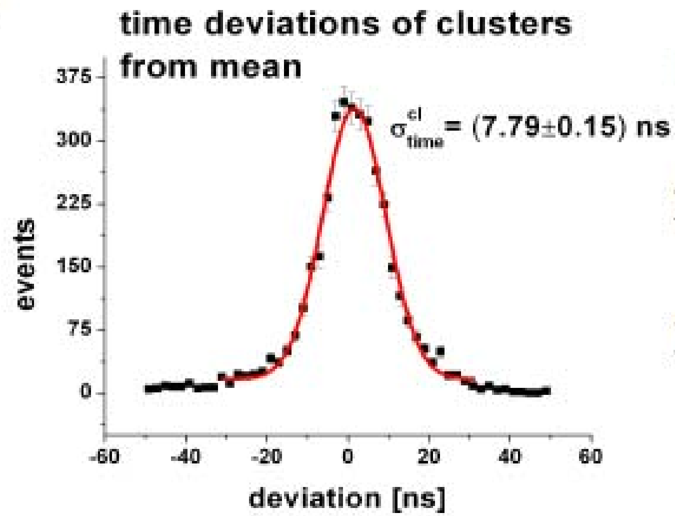
5 GeV e-beam

Si-strip hodoscope



TIME vs. TOT for single pixels





1. Take TIME at cluster centroid
2. Correct with TOT at same position
3. Determine mean of corrected TIME values in an event

Consolidation Phase

- Design, build and operate a “Large Prototype” (LP)
- First iterations of LCTPC design details can be tested
- Larger area readout can be operated
- Tracks with a large number of measured points are available $\rightarrow$ analysis and correction procedures

LP test facility @ DESY

Pixel beam telescope
(EUDET)

Si strip detector
(EUDET/SiLC)

Magnet: PCMAG
(LC TPC/KEK,CERN)

Field cage &
All Mechanics
(EUDET: DESY)

Endplate
(LC TPC/Cornell)

Test beam (DESY)

Different MPGD Detector Modules
GEM, MicroMegas, Pixel
LC-TPC, Saclay, KEK, Bonn, NIKHEF, ...

Gas system
(EUDET:DESY)

DAQ & Monitoring
(EUDET)

Cosmic trigger
(LC TPC: KEK, Saclay)

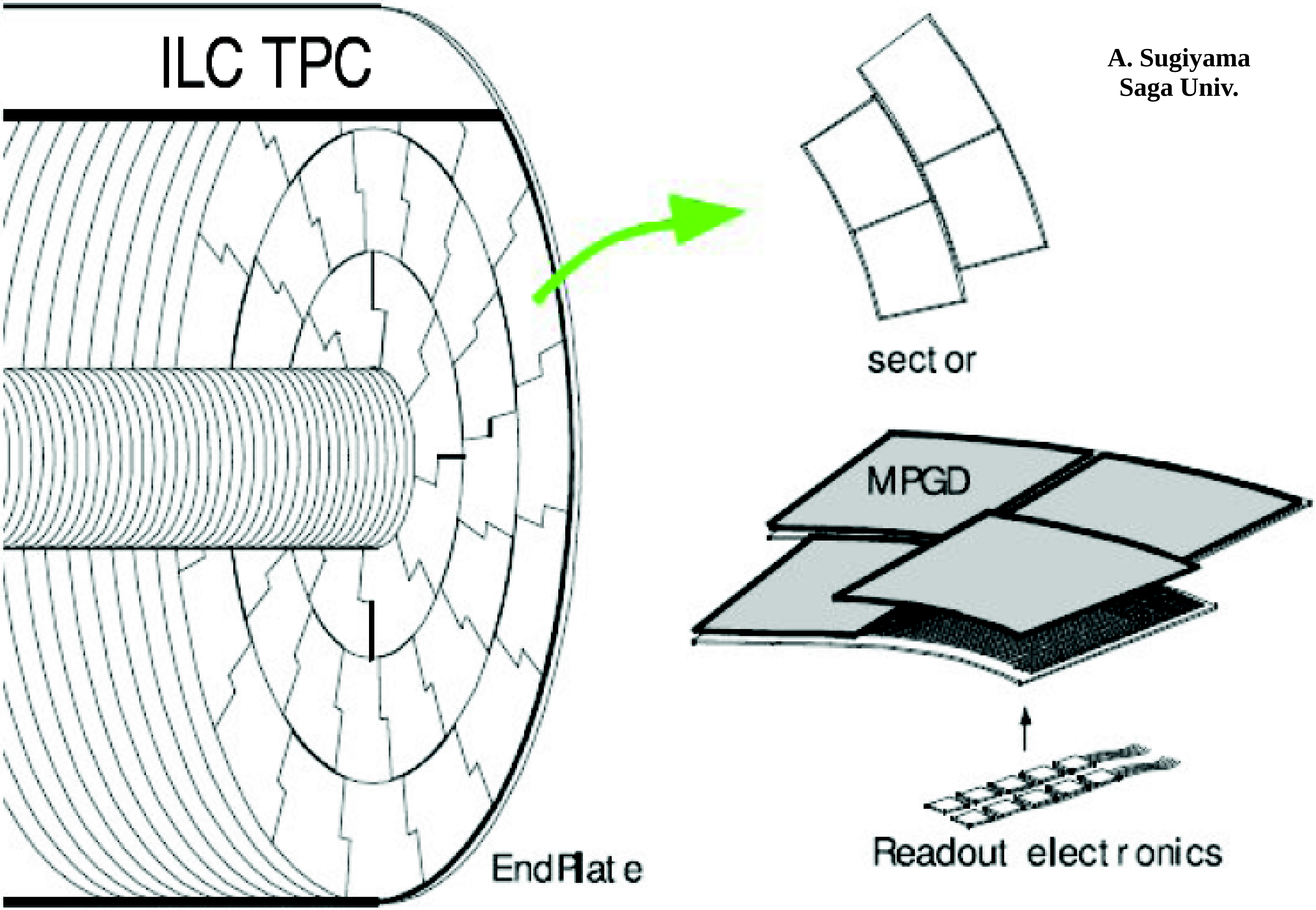
Three types of Readout electronics
(EUDET:CERN, Lund & LC TPC (Altro), Saclay (T2K), Rostock (TDC, HERA-B),

Software development
(EUDET & LC TPC)

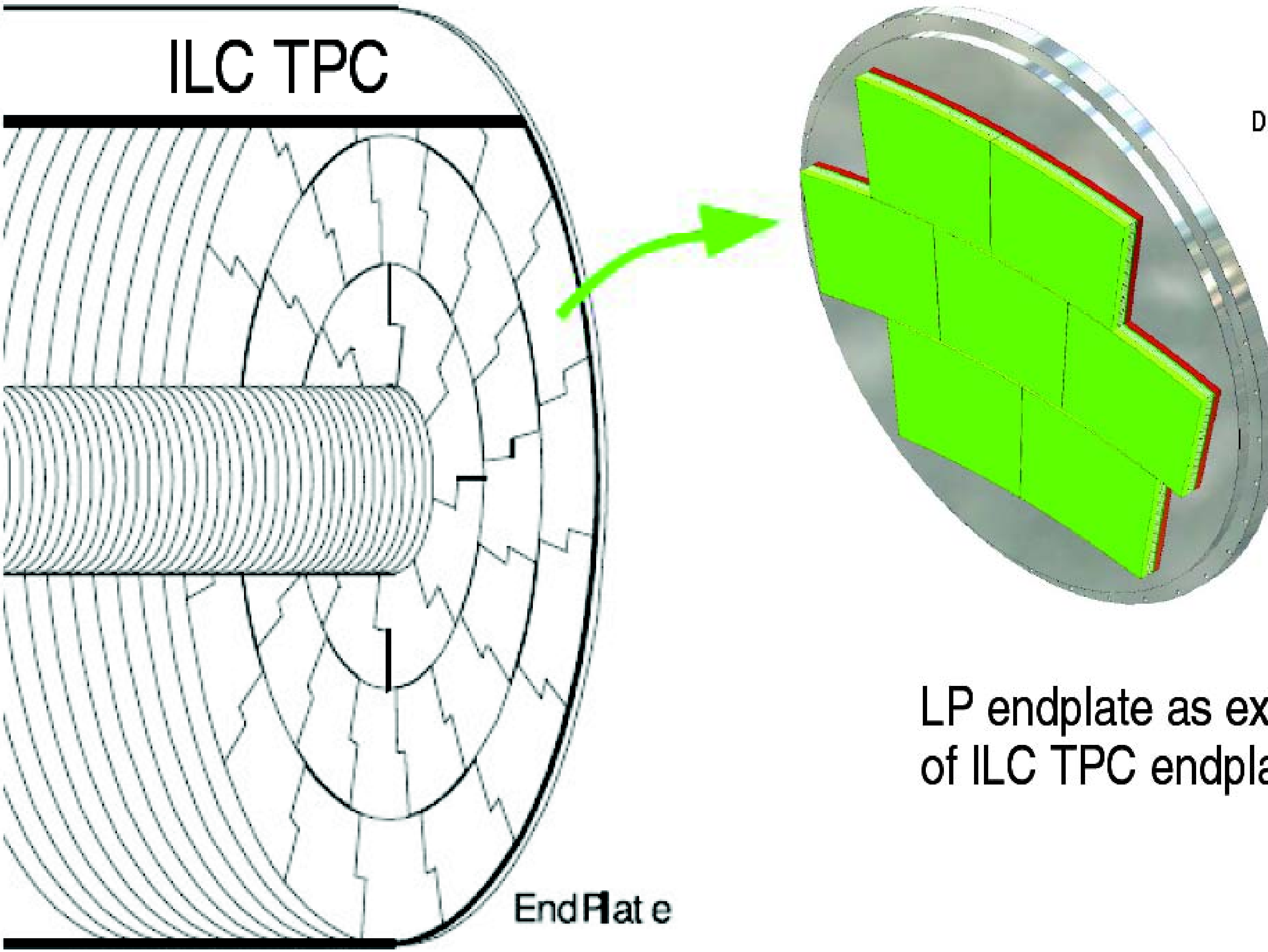
T. Behnke

TPC with MPGD

A. Sugiyama
Saga Univ.



TPC with MPGD

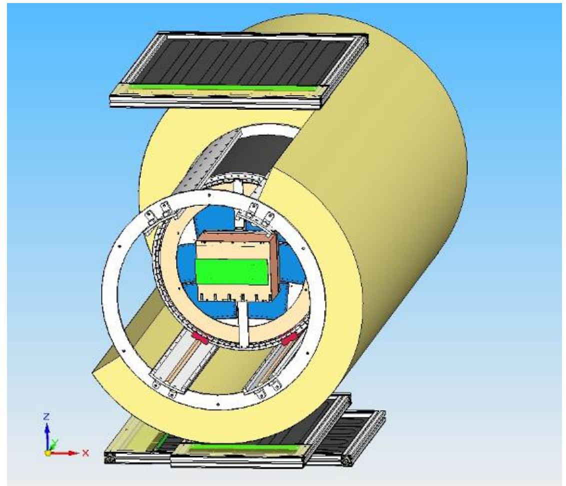


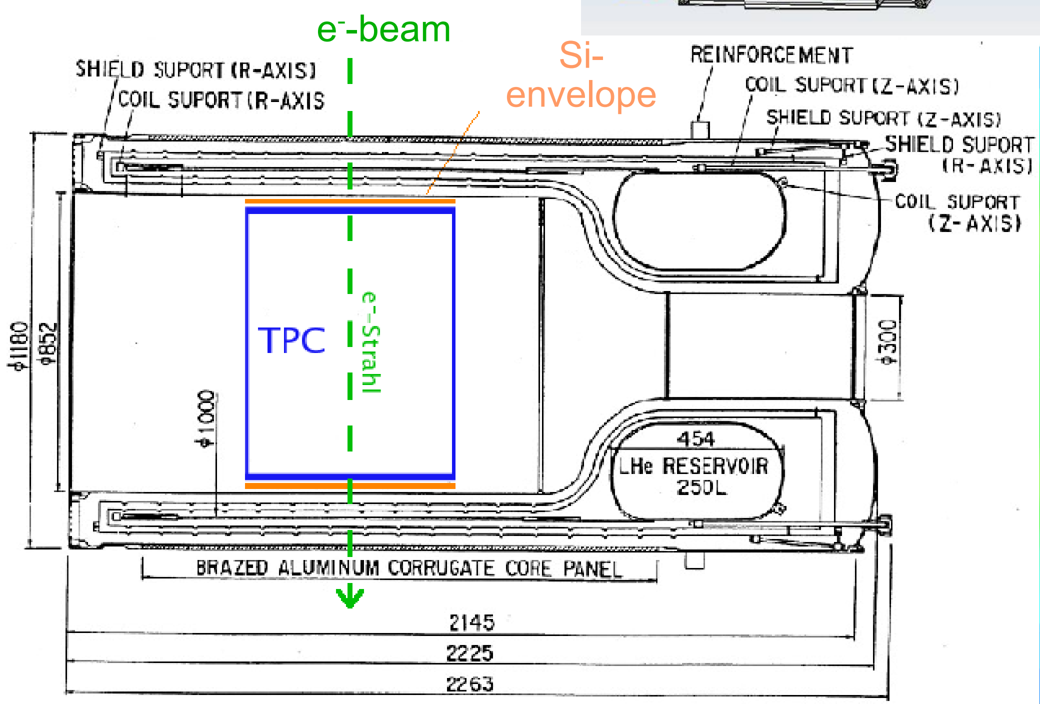
D. Peterson, Cornell

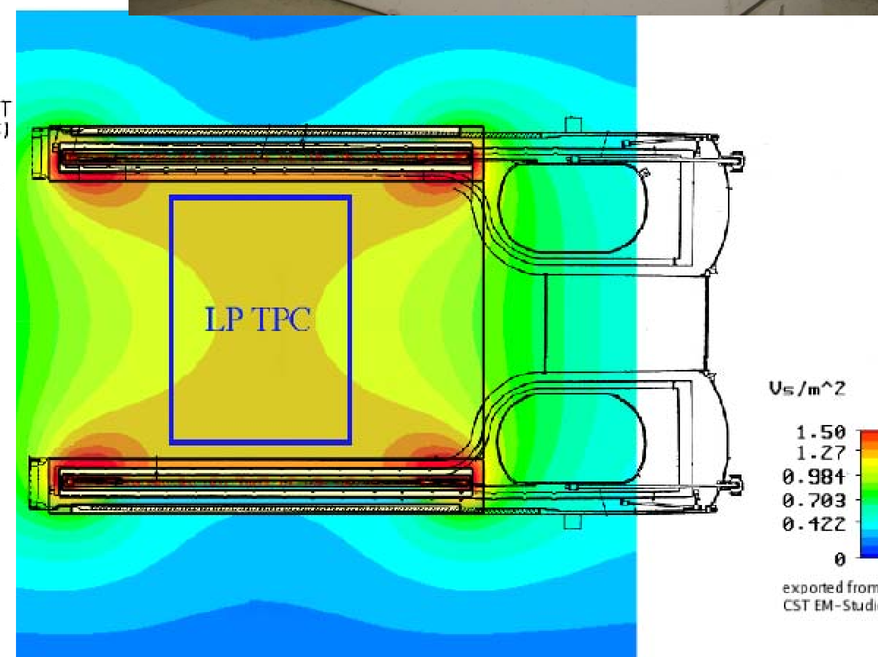
LP endplate as excerpt of ILC TPC endplate

DESY Setup

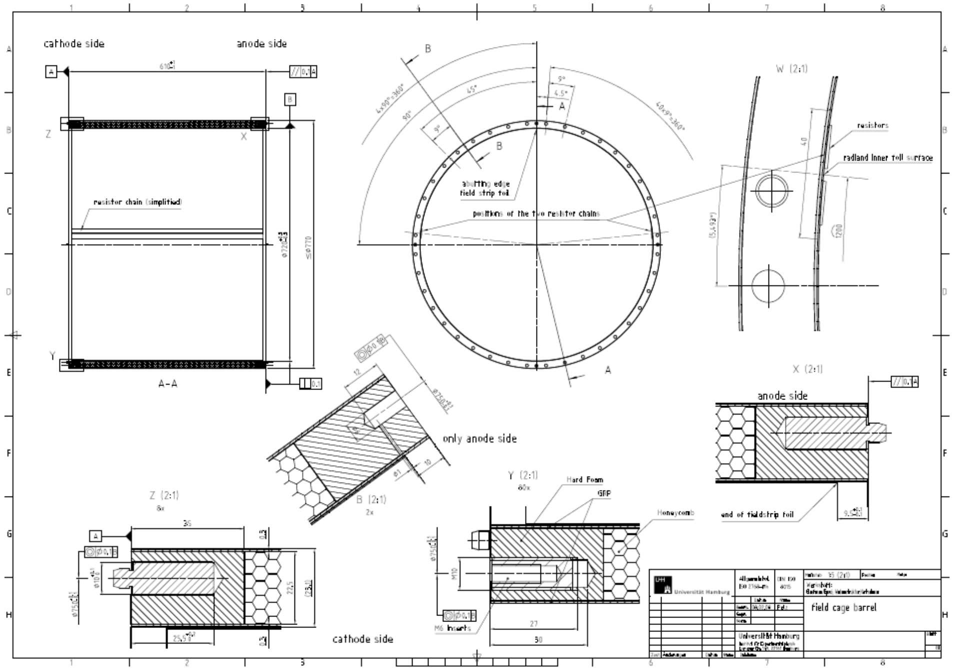
- *e*⁻ test beam @DESY
- PCMAG

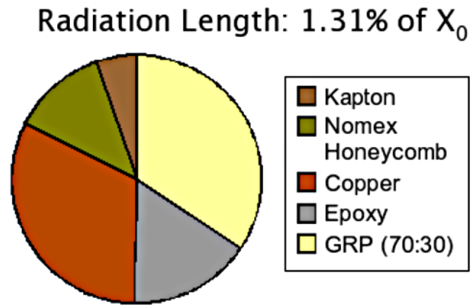


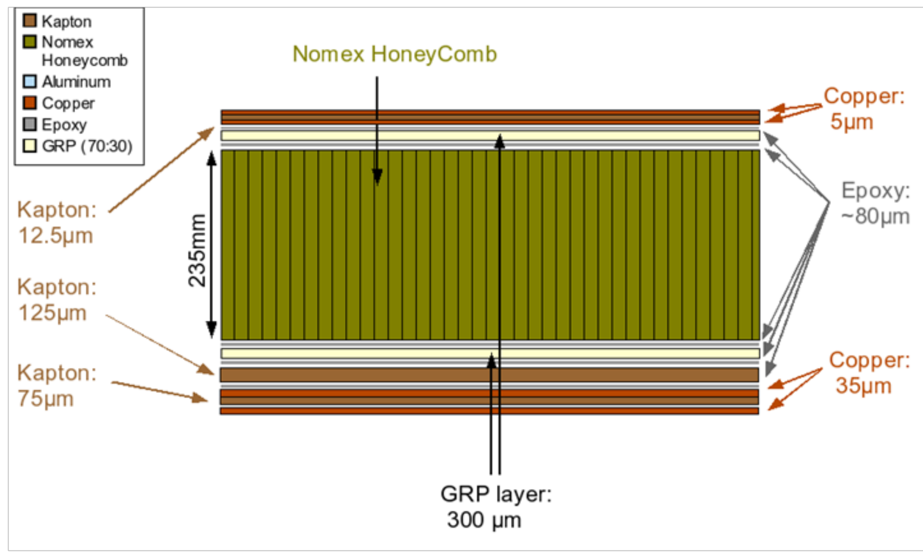




LP-TPC Field Cage (FC)

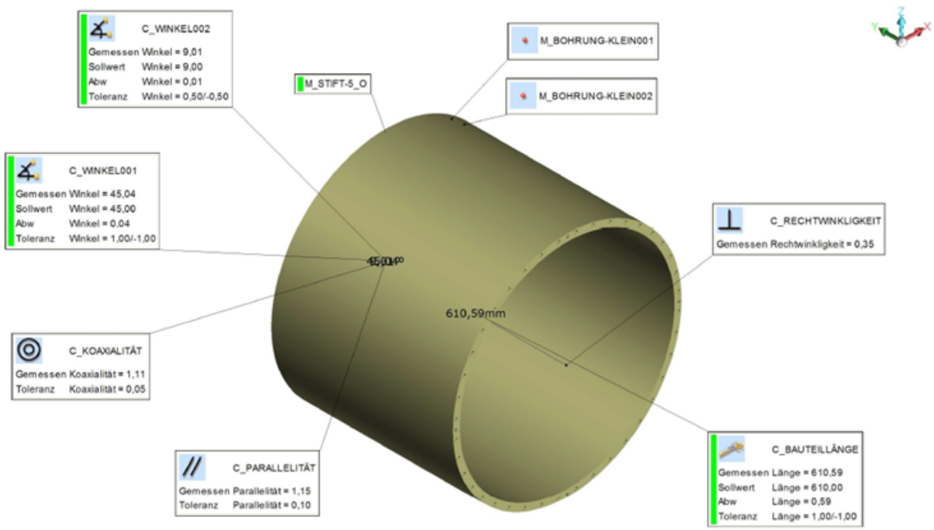


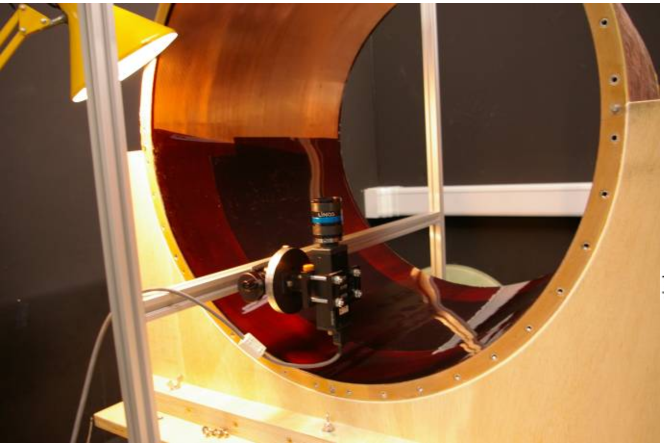


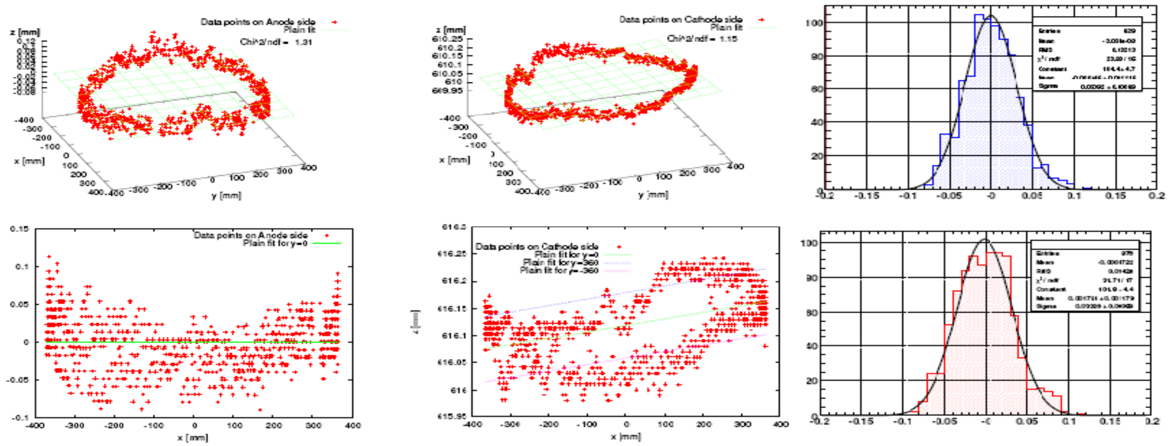


Diameter: Inner 720 mm, Outer 770 mm
Wall thickness 25 mm
Length 610 mm

LP-TPC Field Cage (FC)





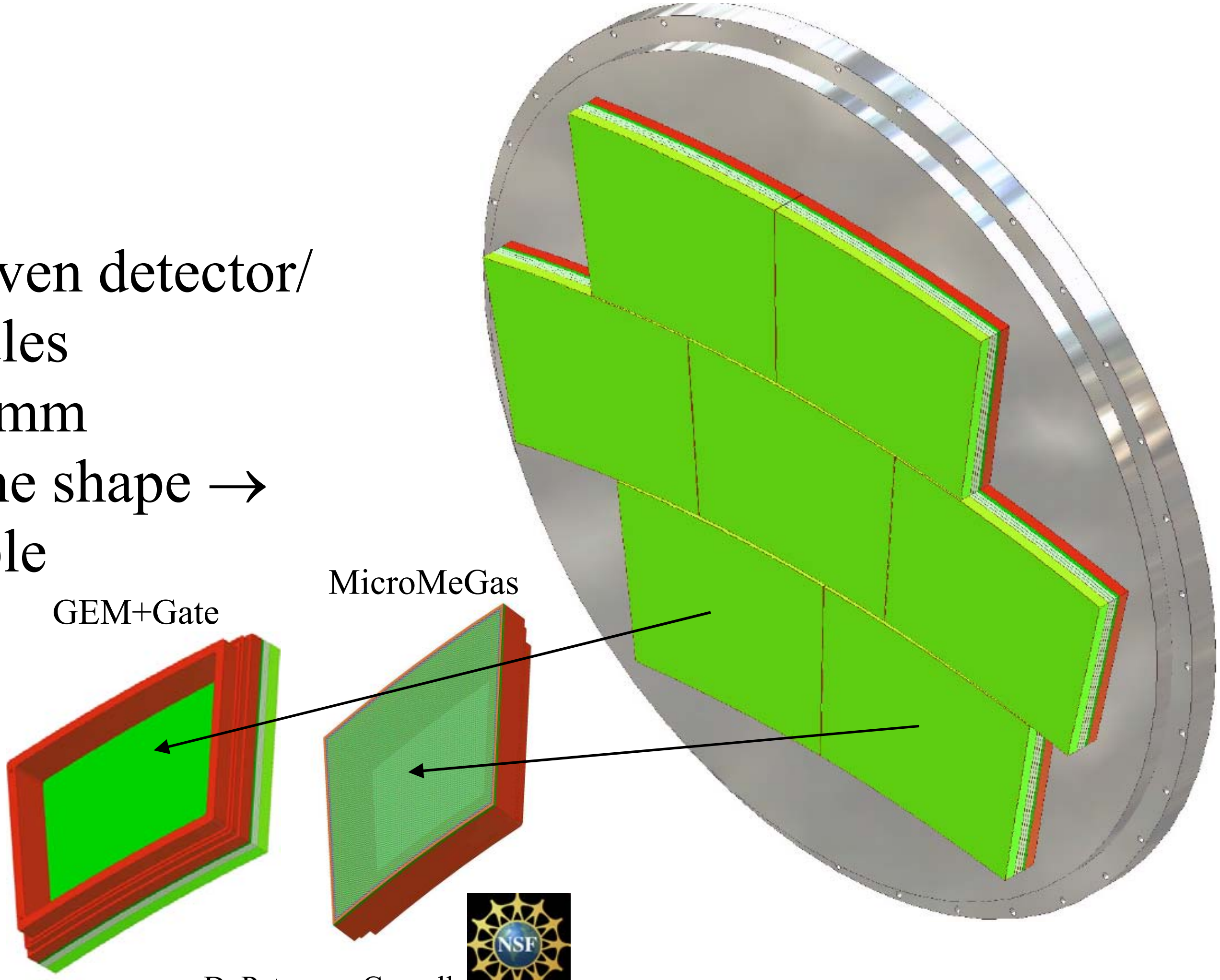


Parallelism Cathode/Anode $\delta = 0.110 \pm 0.003\,\mathrm{mm}$

LP-TPC Endplate

Endplate:

- Aluminum
- Accommodates seven detector/ dummy modules
- $d = d_{outer,FC} = 770$ mm
- Modules have same shape → interchangeable



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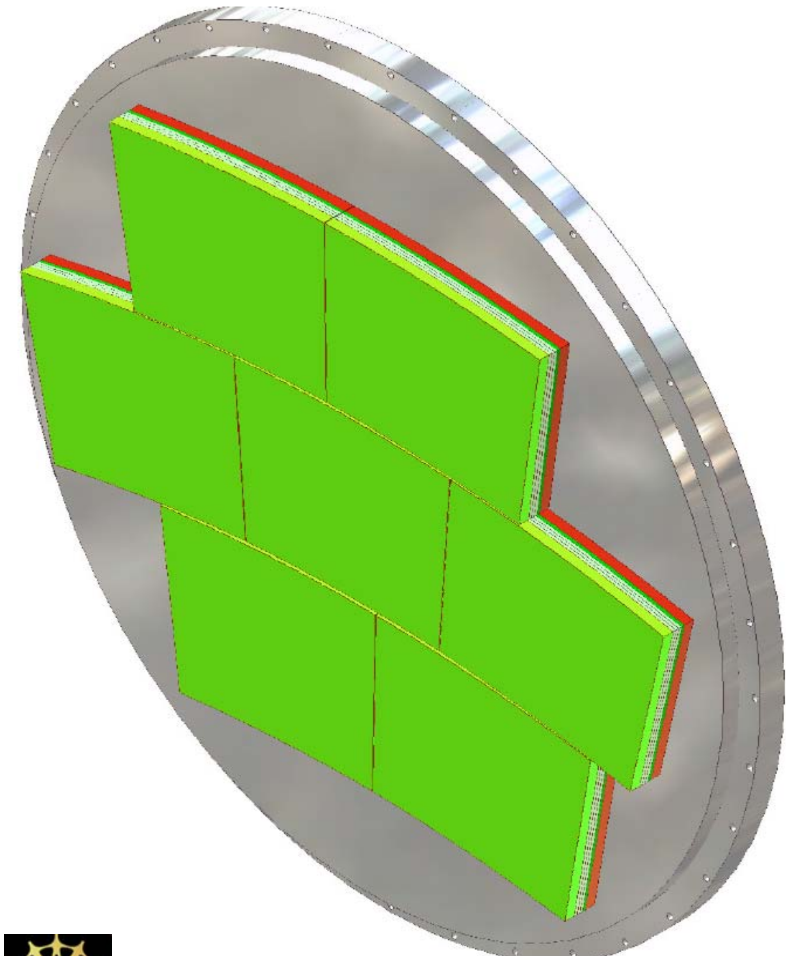
LP-TPC Endplate

Endplate:

- Aluminum
- Accommodates seven detector/ dummy modules
- $d = d_{outer,FC} = 770$ mm
- Modules have same shape → interchangeable
- Modules curvature according to ILC TPC (R = 1430/1600 mm)



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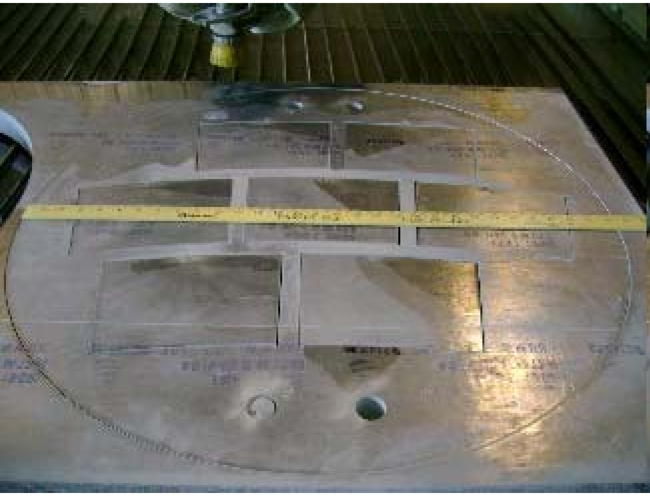
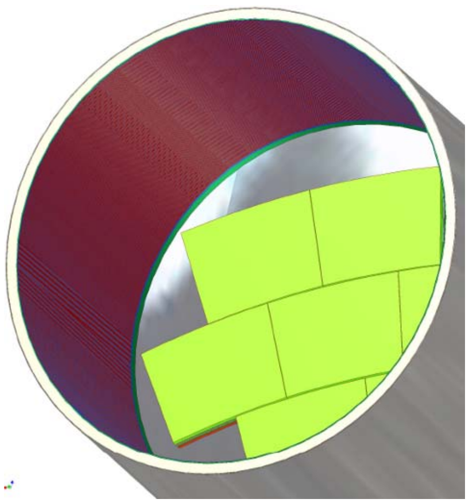
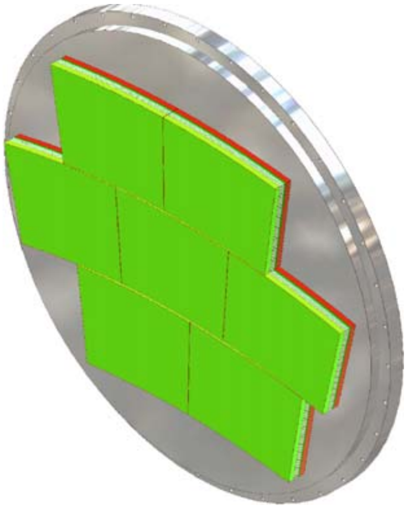
LP-TPC Endplate



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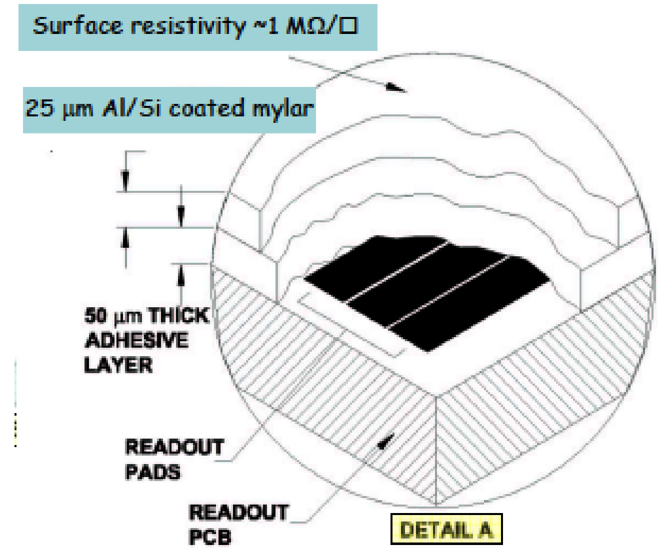
MicroMegas

A first ‘bulk Micromegas’ panel (without resistive foil) and a second, with a resistive carbon-loaded kapton, have been produced at CERN

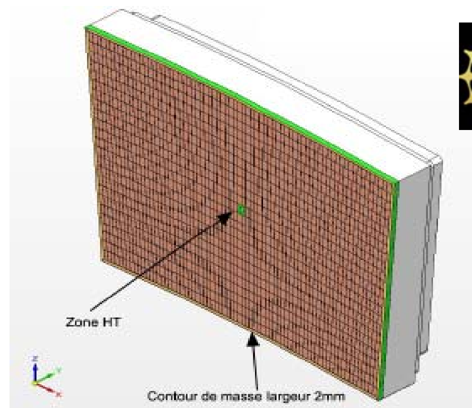
(Rui de Oliveira)



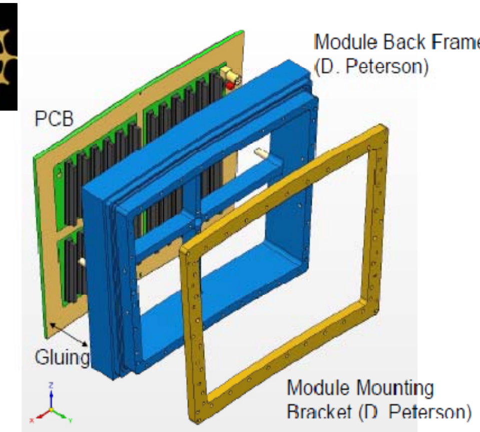
MicroMegas for LP:

24 rows x 72 pads

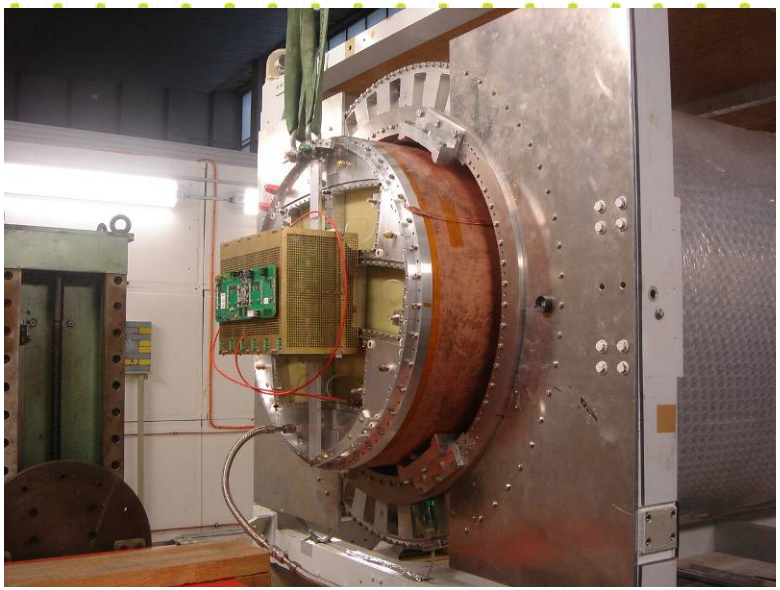
Av. Pad size: 3.2 x 7mm²

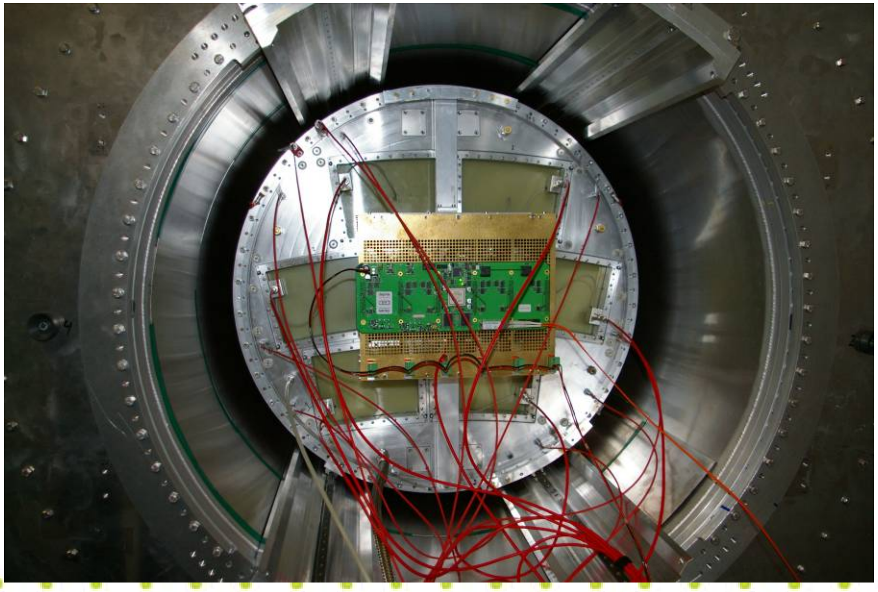


Detector side

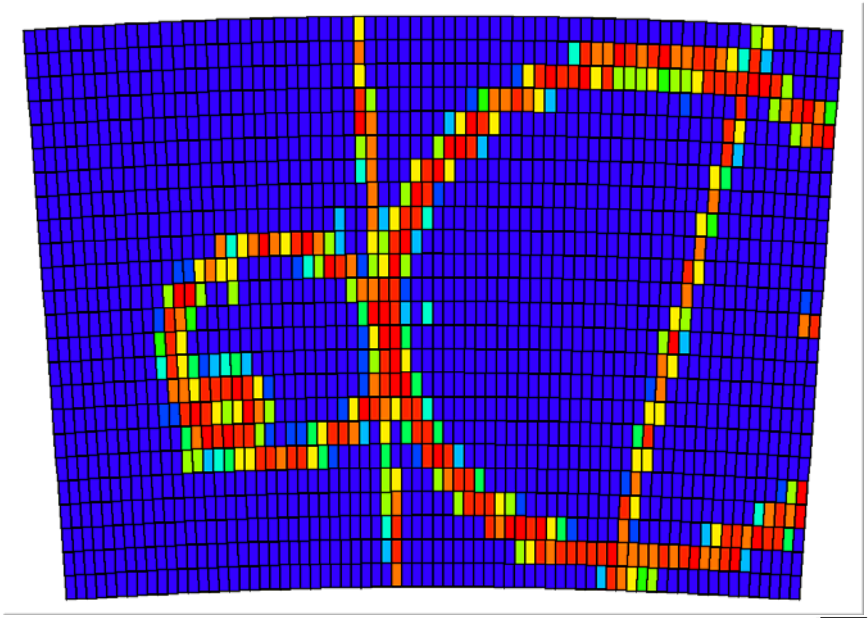


LP - MicroMeGaS

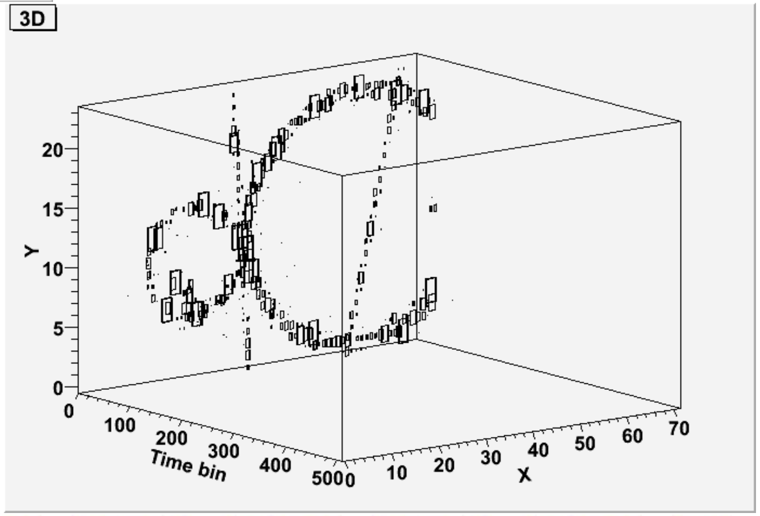




LP - MicroMeGaS

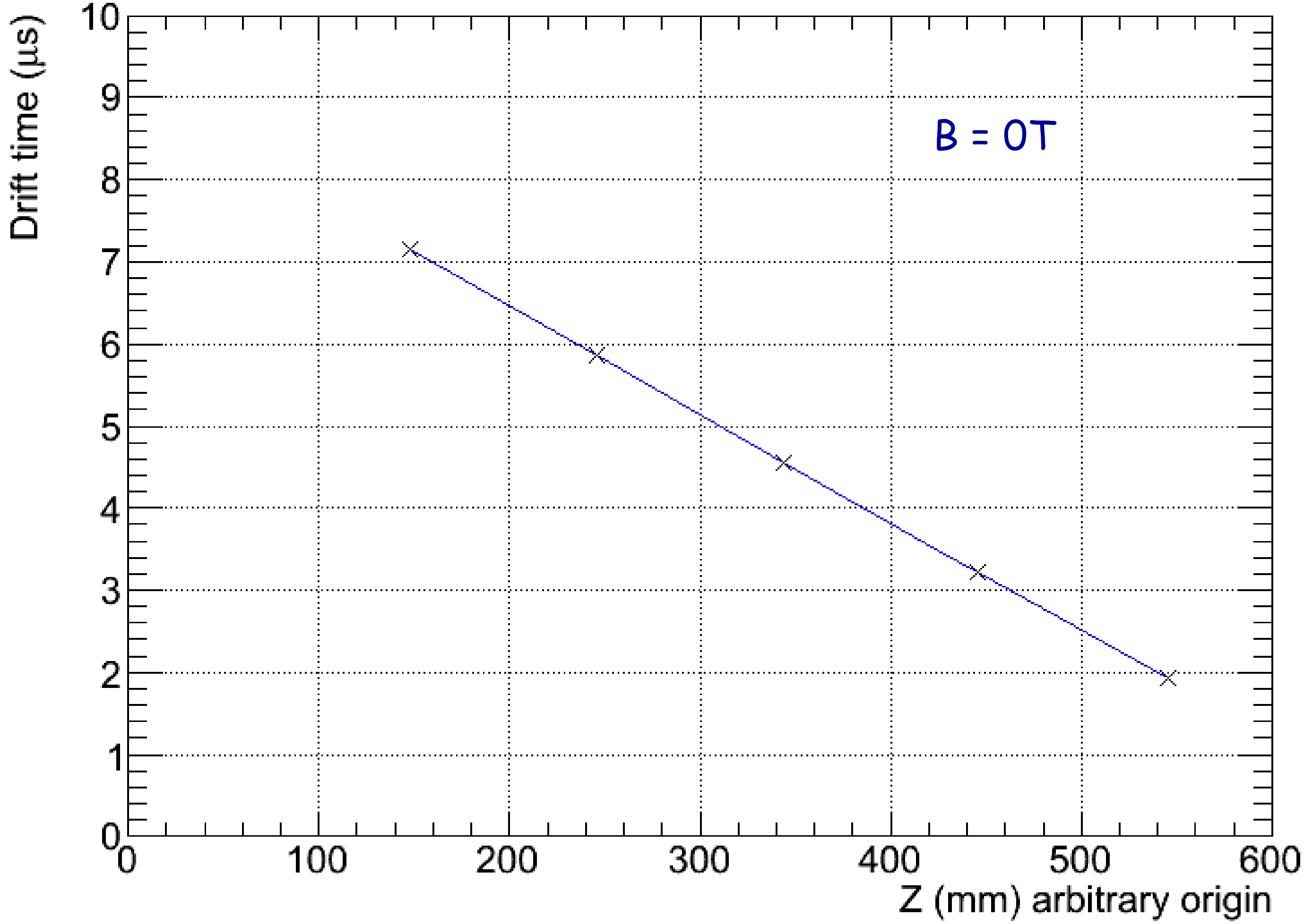


MicroMegas: electron event with B = 1 T

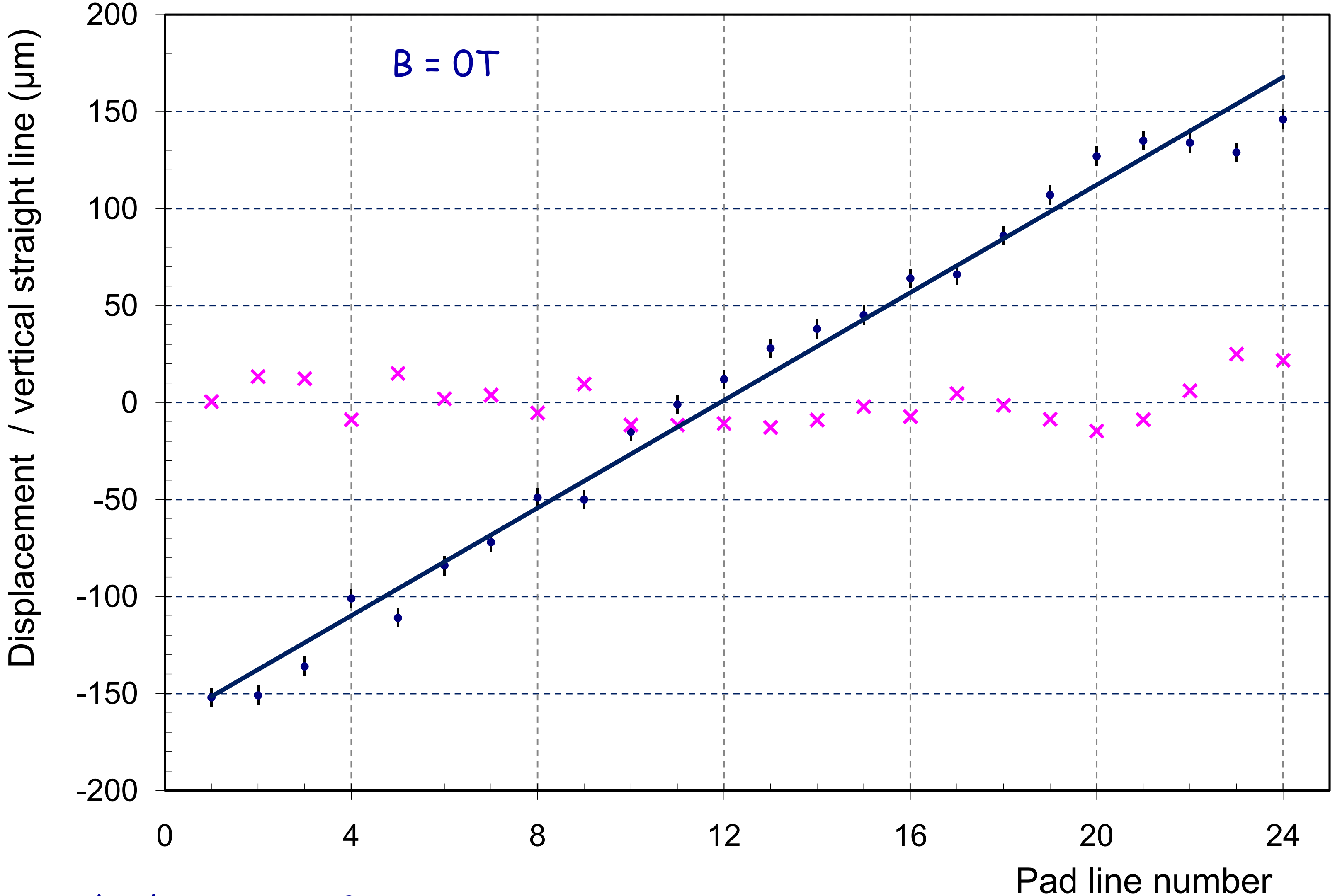


Drift velocity measurement

- Measured drift velocity (E_{drift} = 230 V/cm, 1002 mbar): 7.56 ± 0.02 cm/μs
- Magboltz: 7.548 ± 0.003 for $Ar/CF_4/iso\text{-}C_4H_{10}/H_2O$ (95:3:2:100ppm)



Systematics

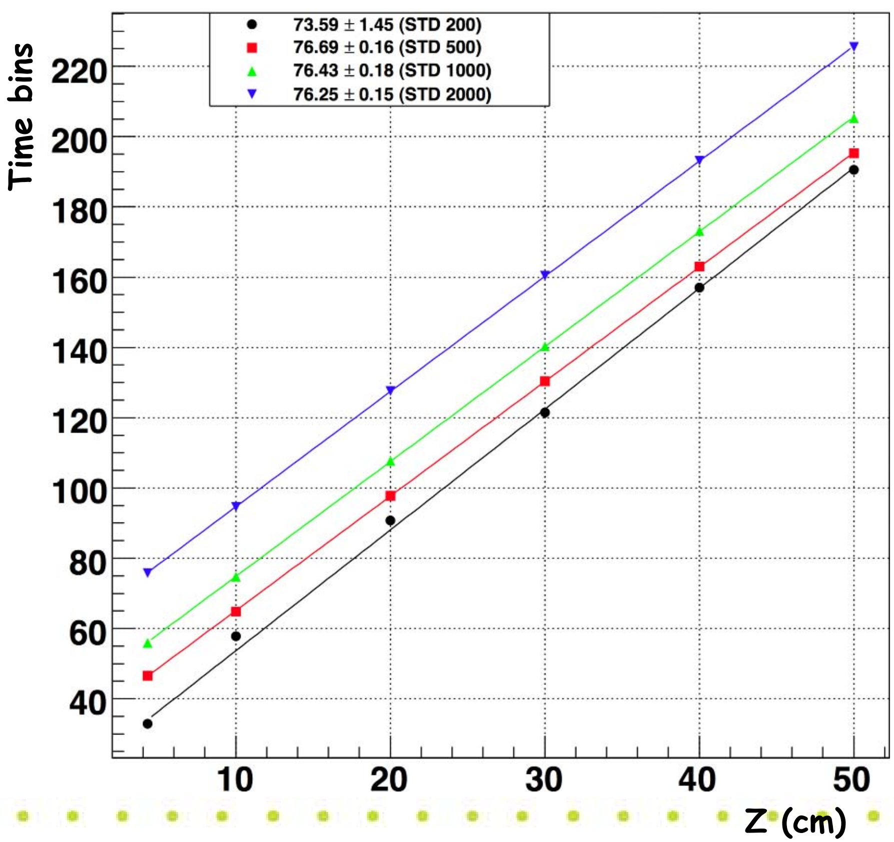


→ rms displacement: ~9 microns

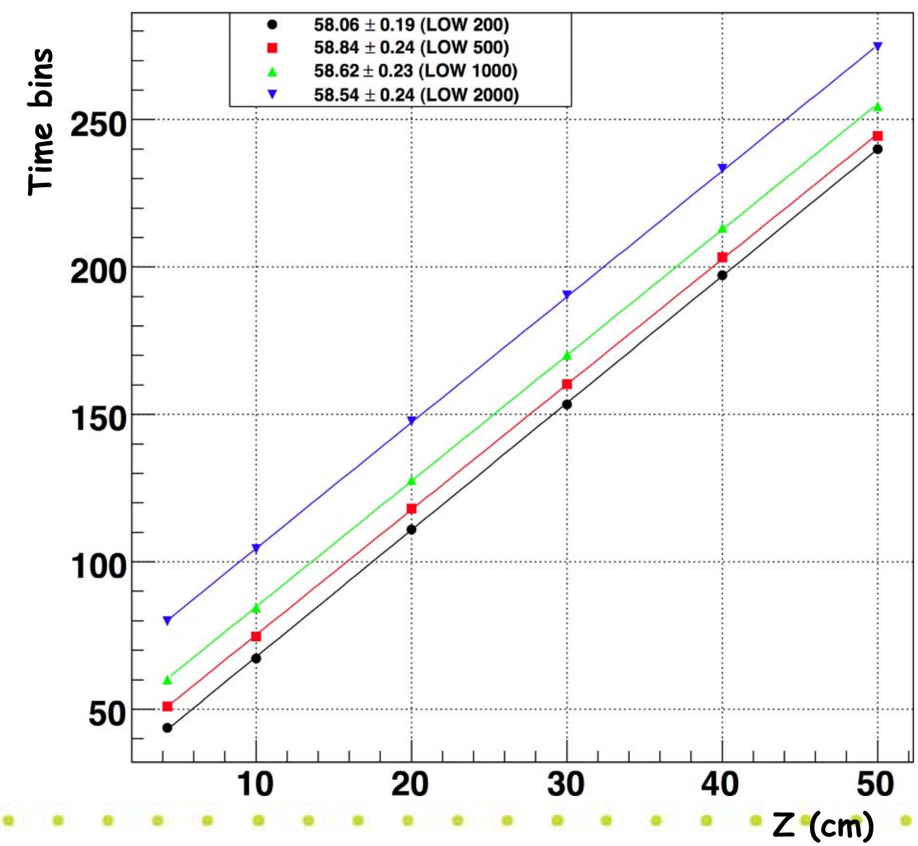
Drift Velocity vs. Peaking Time

- B=1T data
- For several peaking time settings: 200 ns, 500 ns, 1 μs, 2μs

- E_{drift} = 220 V/cm
- $V_d^{Magboltz}$ = 76 μm/ns



- E_{drift} = 140 V/cm
- $V_d^{Magboltz}$ = 59 μm/ns

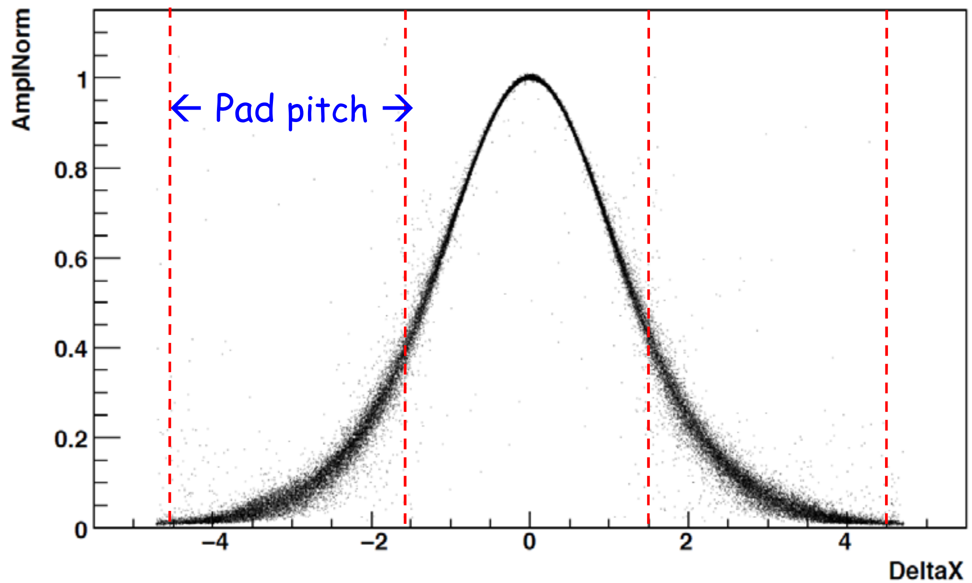


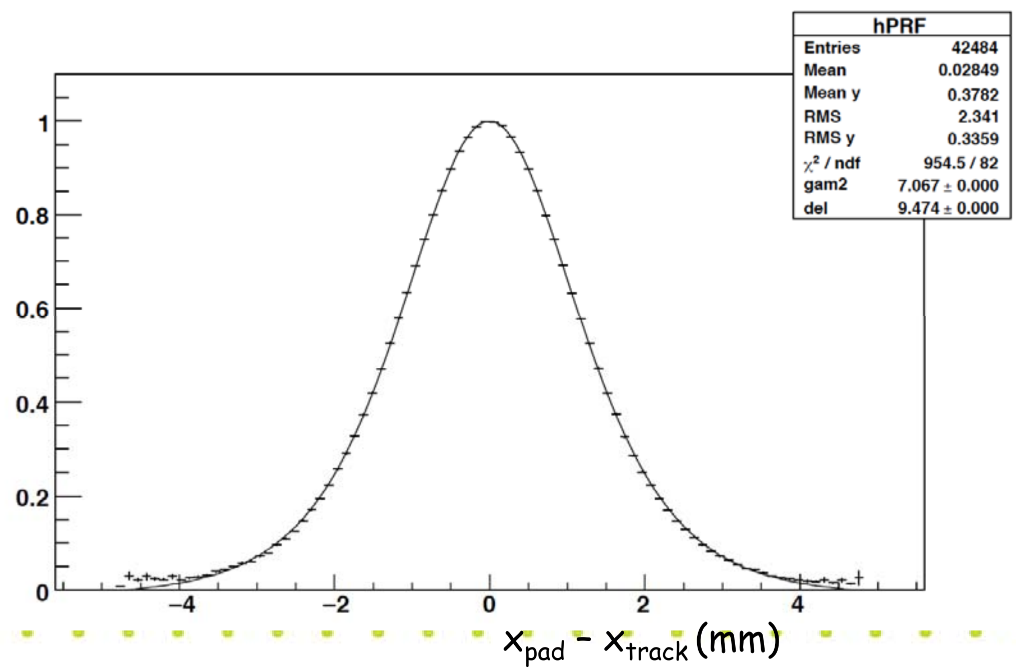
Determination of the Pad Response Function

- Fraction of the row charge on a pad vs $x_{pad} - x_{track}$ (normalized to central pad charge)

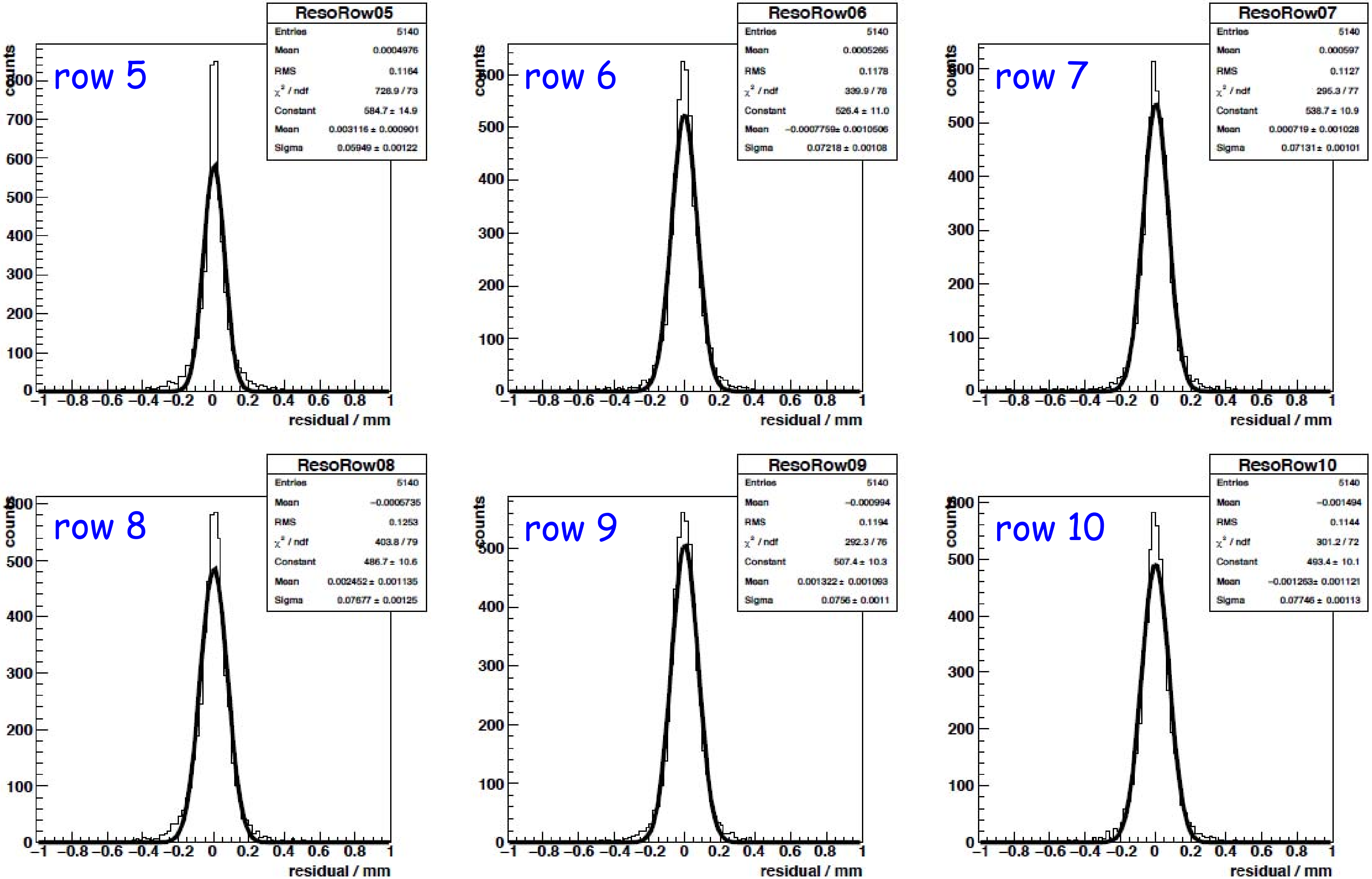
→Clearly shows charge spreading over 2-3 pads (use data with 500 ns shaping)

- Then fit x(cluster) using this shape with a χ^2 fit, and fit simultaneously all lines to a circle in the xy plane





Residuals (z=10 cm)

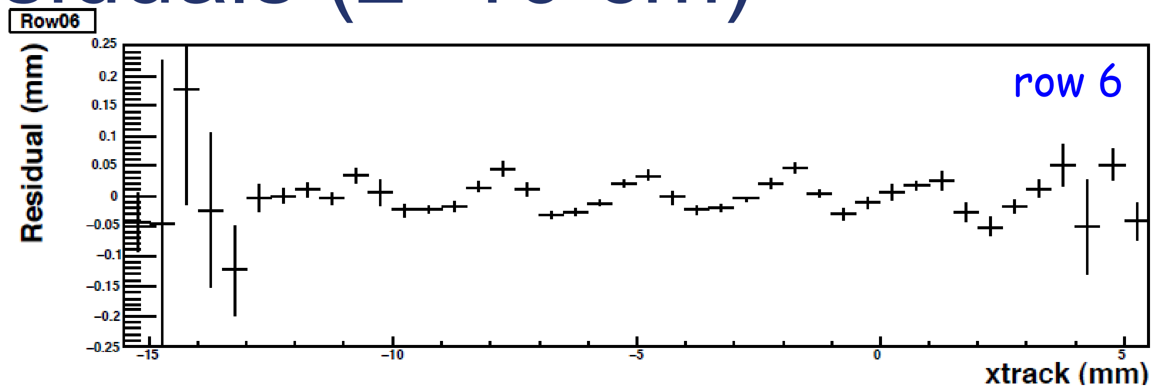


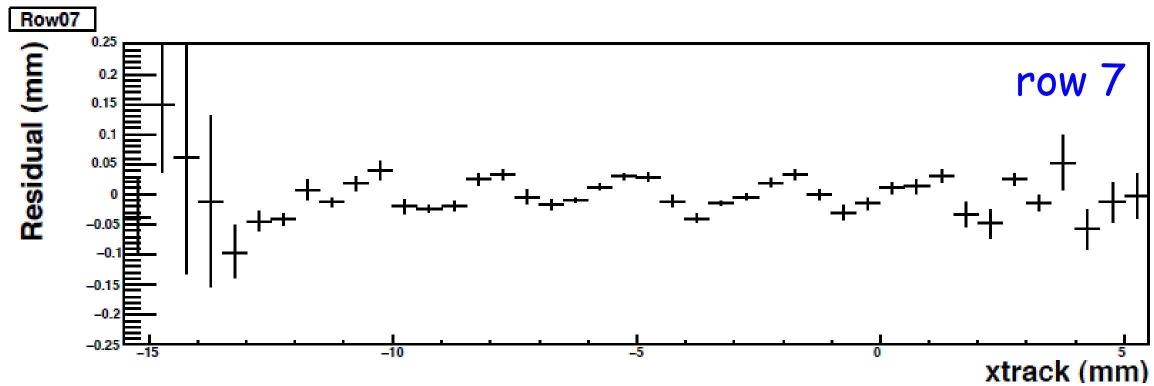
- *Lines 0-4 and 19-23 removed for the time being (non gaussian residuals, magnetic field inhomogeneous for some z positions?)*

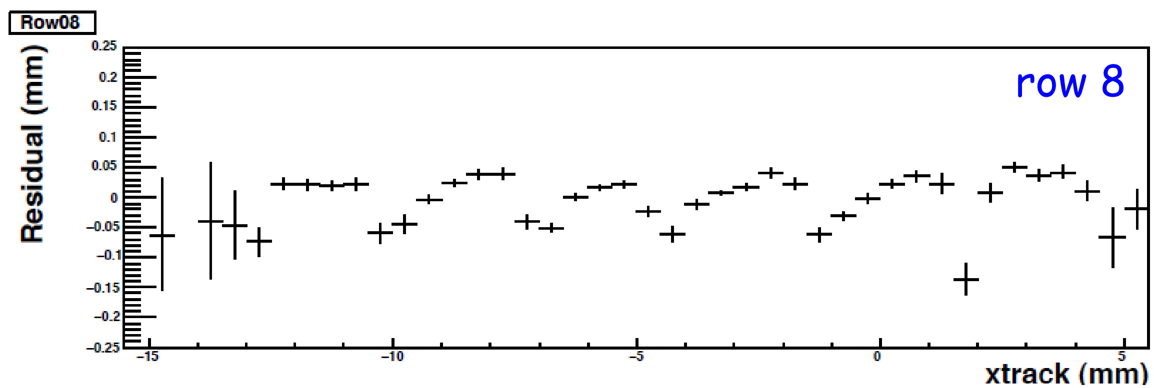
Residuals (z=10 cm)

- There is a residual bias of up to 50 micron, with a periodicity of about 3mm.

- Unknown origin:
  - Effect of the analysis?
  - Or detector effect:
    - pillars?
    - Inhomogeneity of RC?

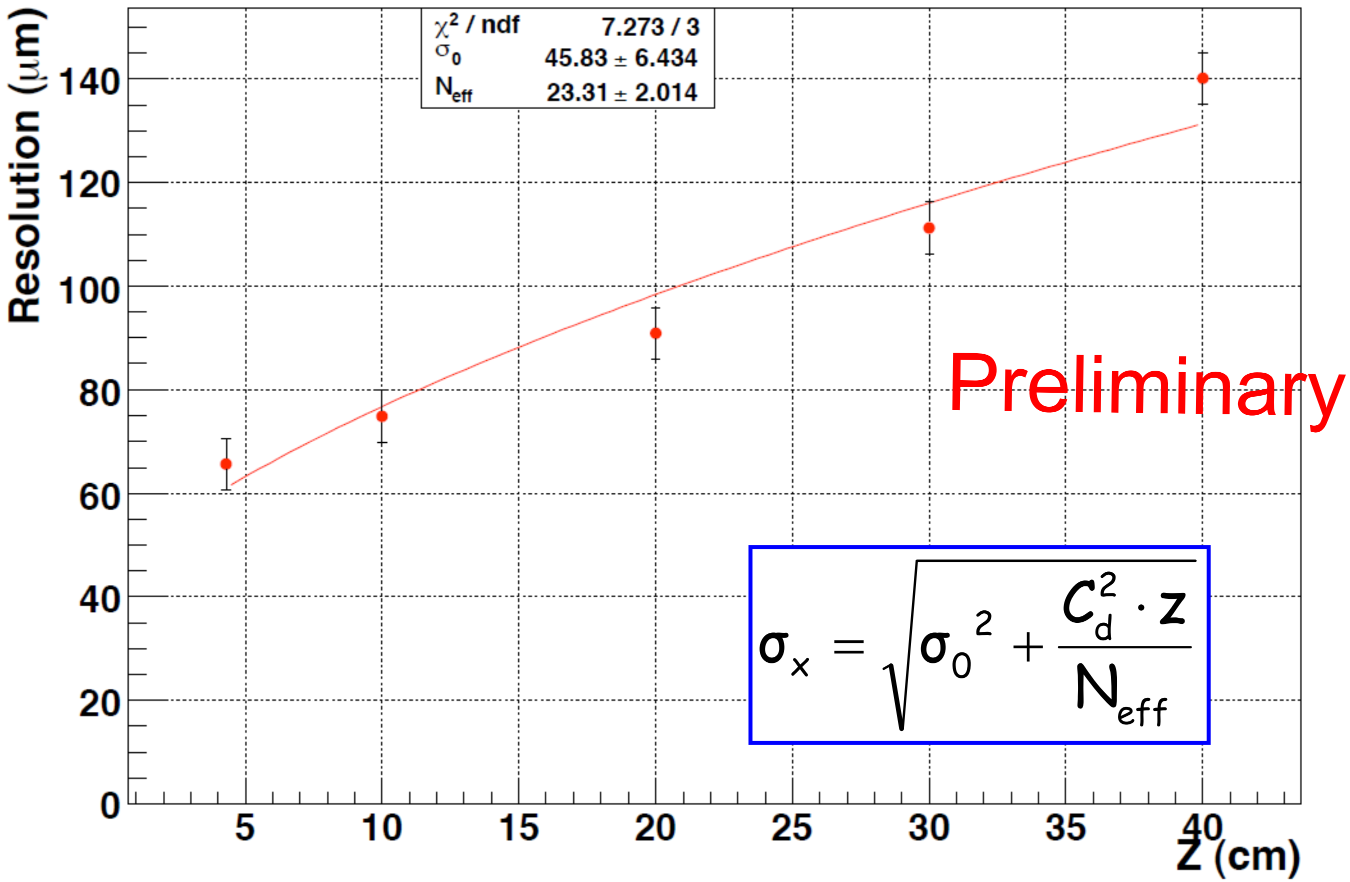






Spatial resolution at 1T

Shaping 500 ns



- Resolution (z=0): σ_0 = 46±6 microns with 2.7-3.2 mm pads
- Effective number of electrons: N_{eff} = 23.3±3.0 consistent with expectations

Readout Electronics

Three-fold readout electronics:

- ALICE based:
  new PCA16 amplifier chip + ALTRO chip (EUDET & LCTPC)

- T2K based:
  AFTER electronics for T2K TPC (CEA Saclay)

- TDC based (University of Rostock)

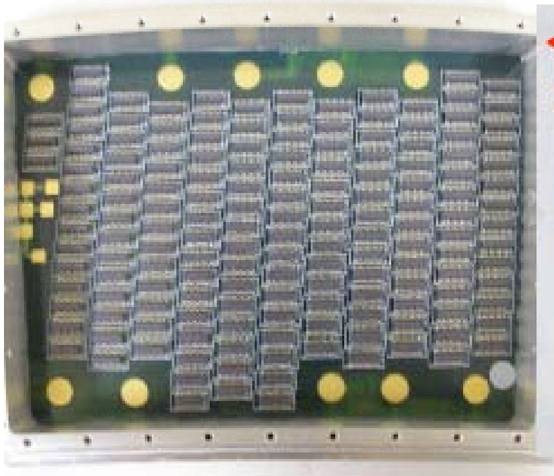
AFTER electronics for MicroMeGAS (resistive anode readout
ALTRO and TDC based electronics will be hooked to the GEM detector modules (connector compatibility)

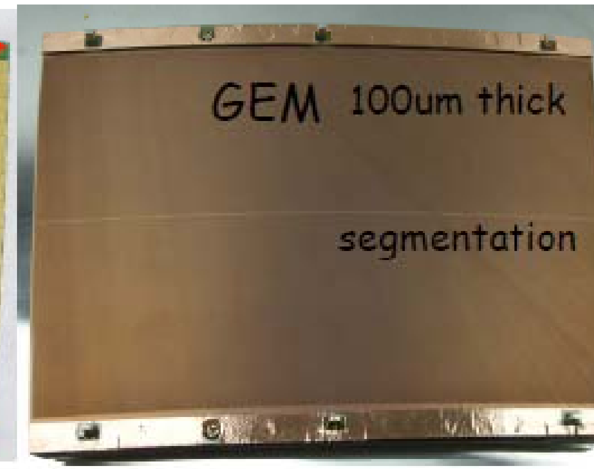
Double GEM modules

GEM module

conceptual design

minimize insensitive area pointing IP between modules (limited frame)





Bunch of tiny connectors
(40 pins) 161 connectors

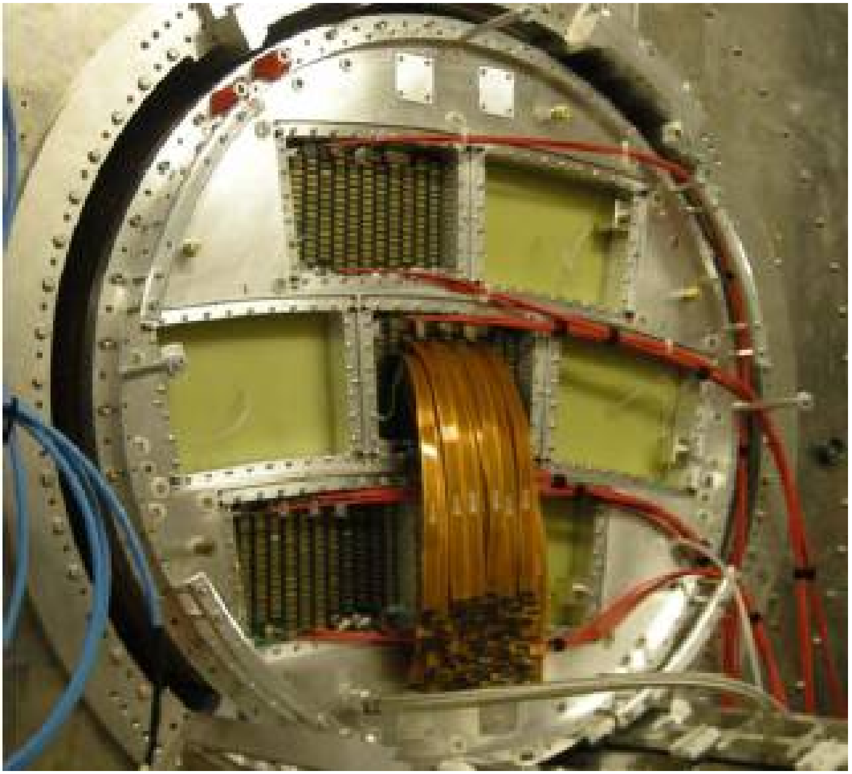
all other space for HV supply
+ Back Frame

28 pad raws (176/192 pads/raw)
~1.2(w) x 5.4(h) mm^2
staggered every each layer

Total 5,152 ch/module

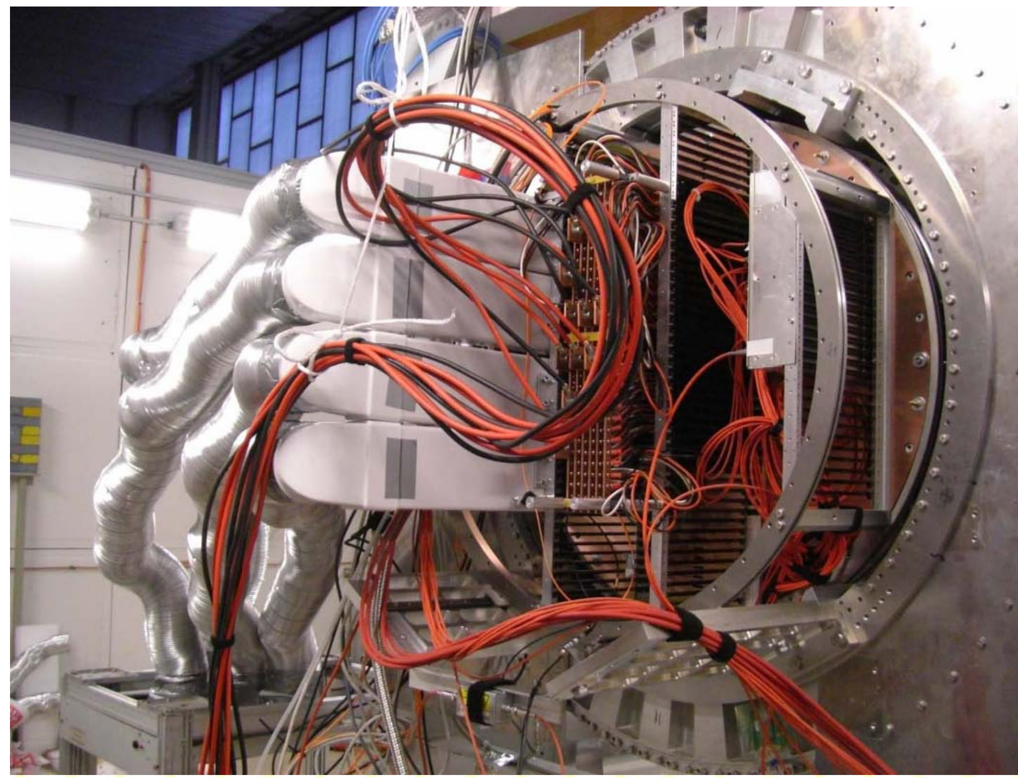
Gate GEM (14um thick) will be on top of the module → later in 2009

Double GEM



About 3200 channels readout electronics (Altro/Alice) CERN&Lund

(10000 channels later in 2009)



Double GEM modules

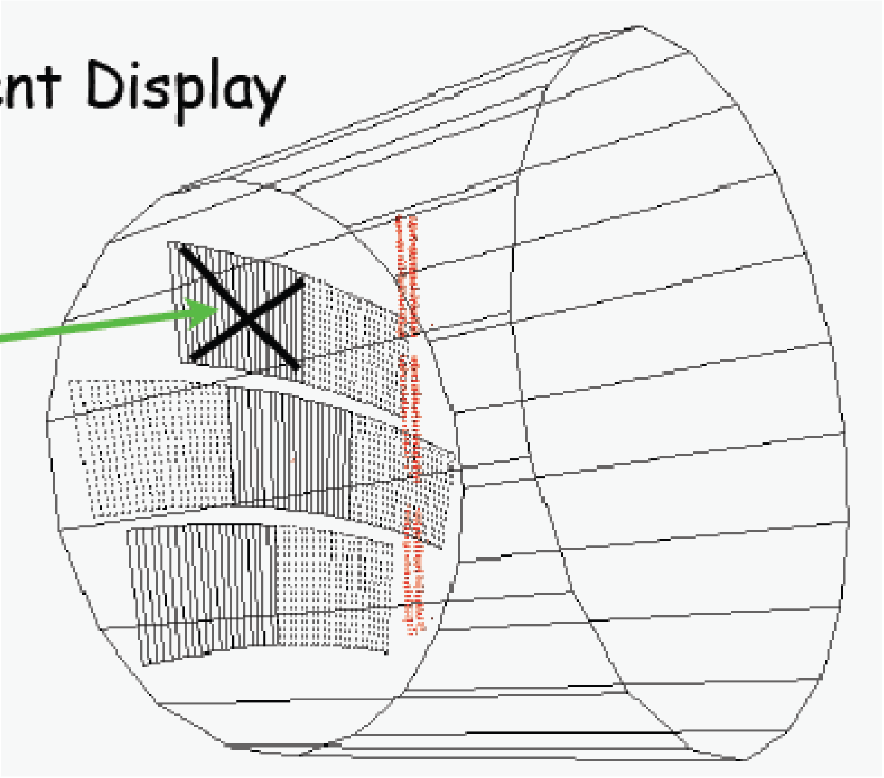
2 data taking periods: Feb. 1^{st} – Mar. 6^{th} 2009
Mar. 23^{rd} – Apr. 8^{th} 2009

Event Display

At the beginning of 2nd period of beamtest
we could see hits over 3 modules

We have to give up module 6
after problem of drawing current

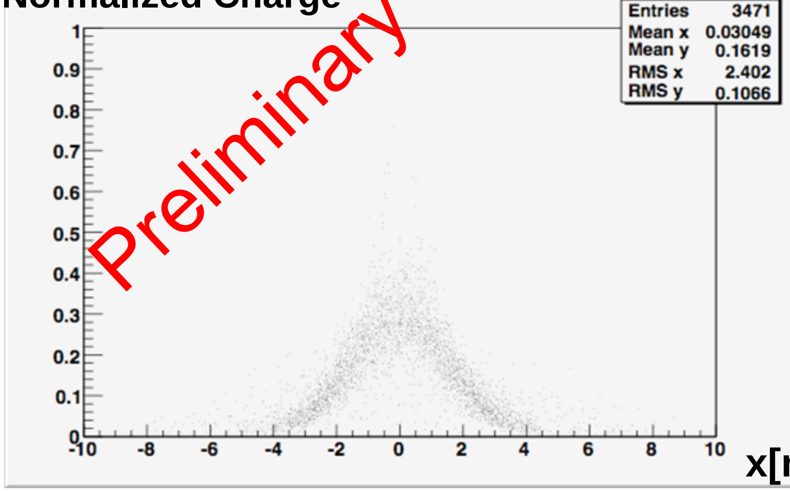
Data taken at 2nd. 2 modules alive

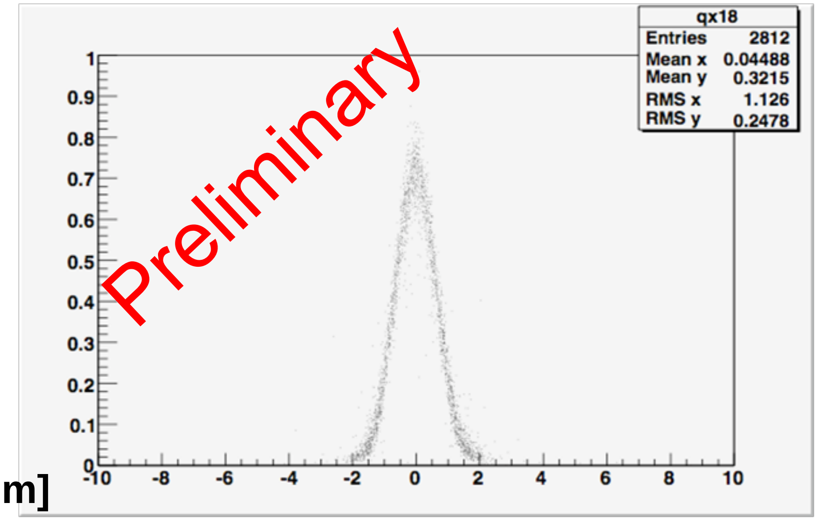


Pad response function

Z=250mm, Row 18

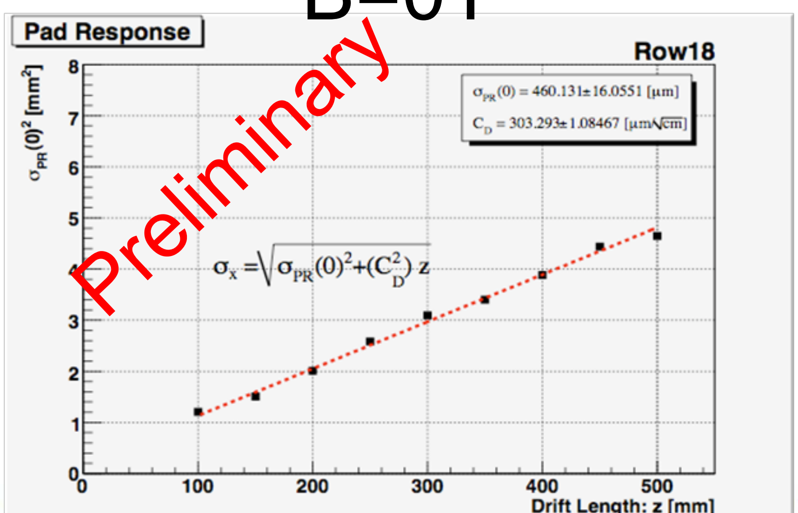
Normalized Charge



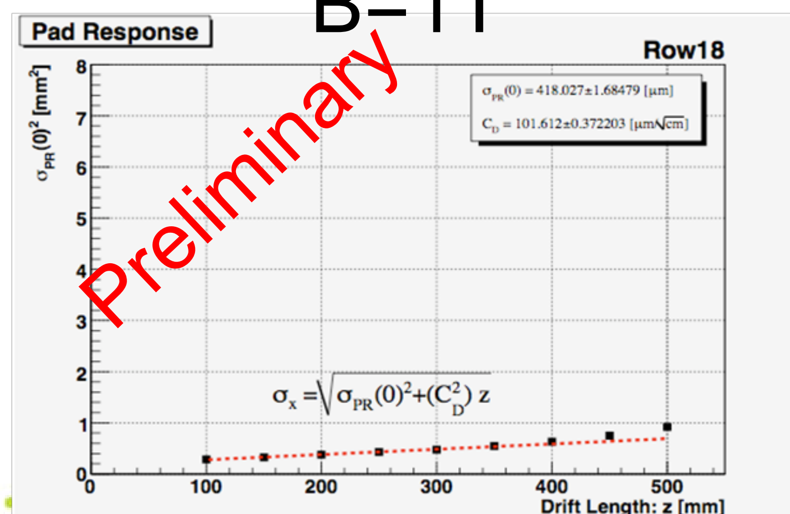


x[mm]

B=0T



B=1T



$\sigma^2 = \sigma_0^2 + C_D^2 z$

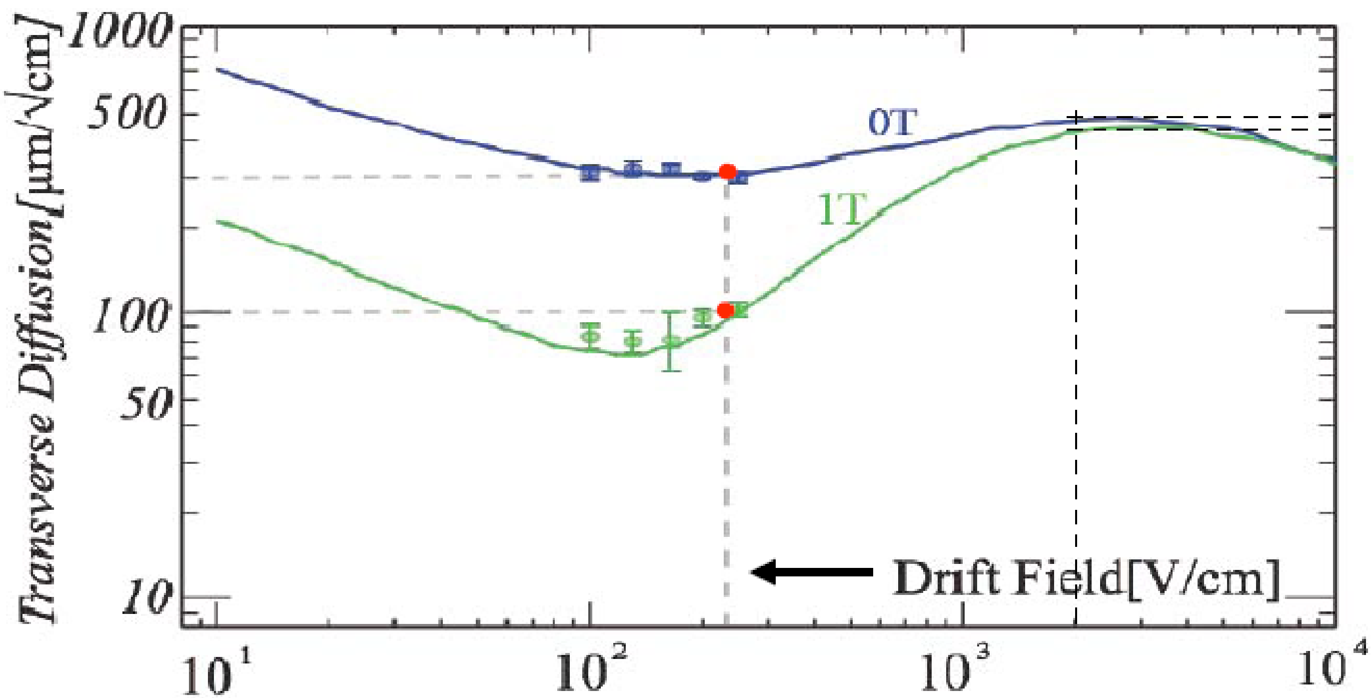
Diffusion constant

from Data

	B = 0 T	B = 1 T
C_D [um/√cm]	303	102
error	1	1

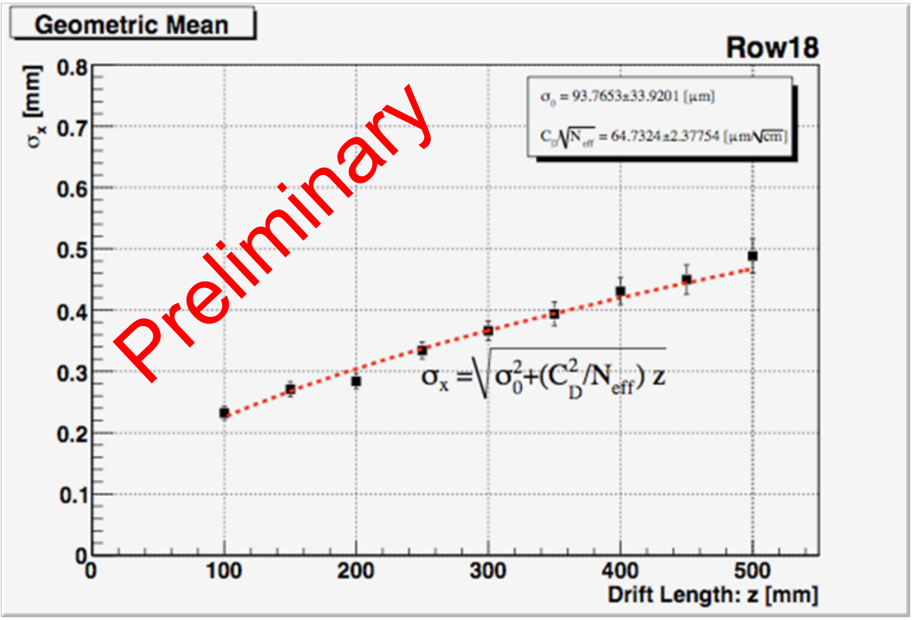
Comparison to MagBoltz and result of Small Prototype

Points means MP-TPC results.



Resolution vs. drift length

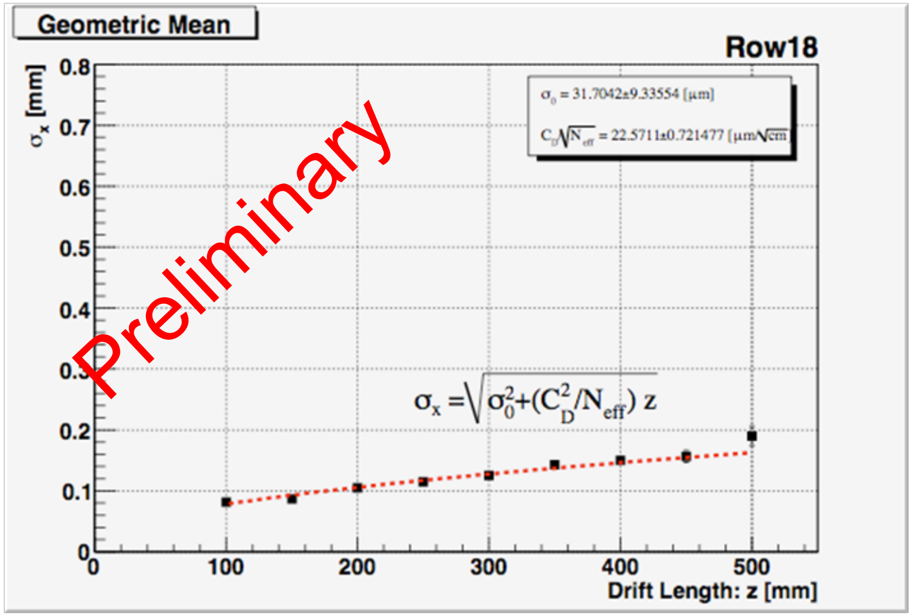
Residual: $\sigma^2 = \sigma_0^2 + C_D^2\, z/N_{eff}$



B=0T

$$\frac{C_D}{\sqrt{N_{eff}}} = 65 \pm 2[\mu m/\sqrt{cm}]$$

$$N_{eff} \sim 22$$



B=1T

$$\frac{C_D}{\sqrt{N_{eff}}} = 22.6 \pm 0.7[\mu m/\sqrt{cm}]$$

$$N_{eff} \sim 20$$

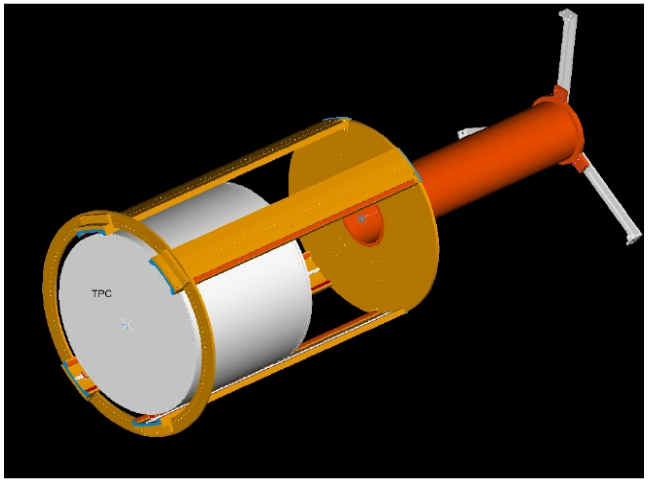
Consistent with SP measurements, taking into account different pad height and electron vs. ‘mip’

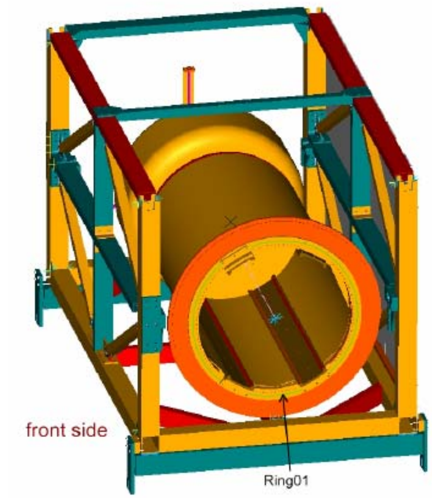
These first results are quite encouraging; now the real LP1 study starts:

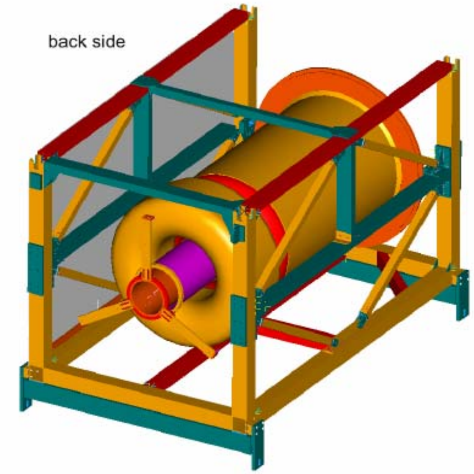
- **Systematic study of resolution**
  - o In (x,y) and z
  - o Dependence on position, pulse height, drift distance, angle
- **Gain uniformity**
- **Cross talk**
- **Momentum resolution**
- **2-track separation**
- **Tracking under non-uniform field**

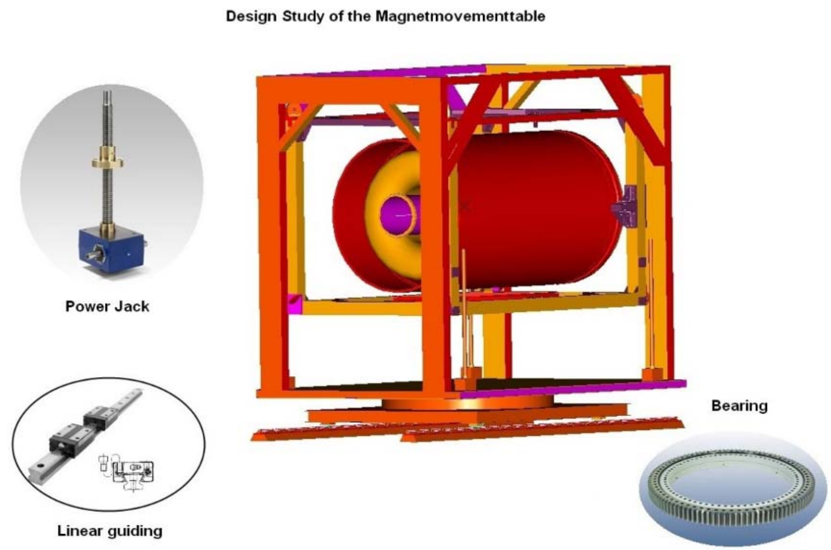
- **Tracking and analysis over all modules**
  - o Effects of module boundaries
  - o Momentum resolution

LP Mechanics







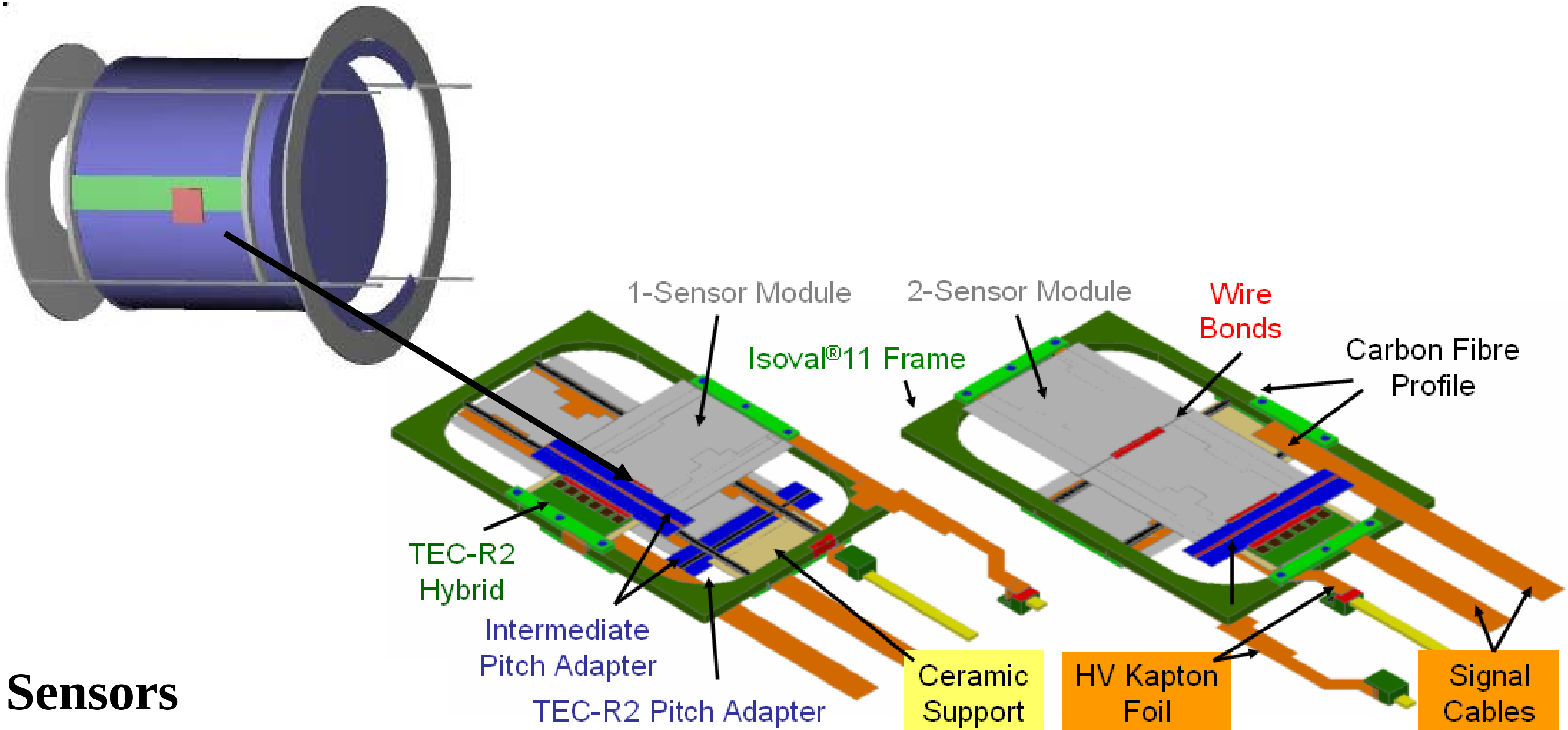


Support structures:

- TPC
- PCMAG

F. Hegner, V. Prahl, R. Volkenborn, DESY

Si Envelope

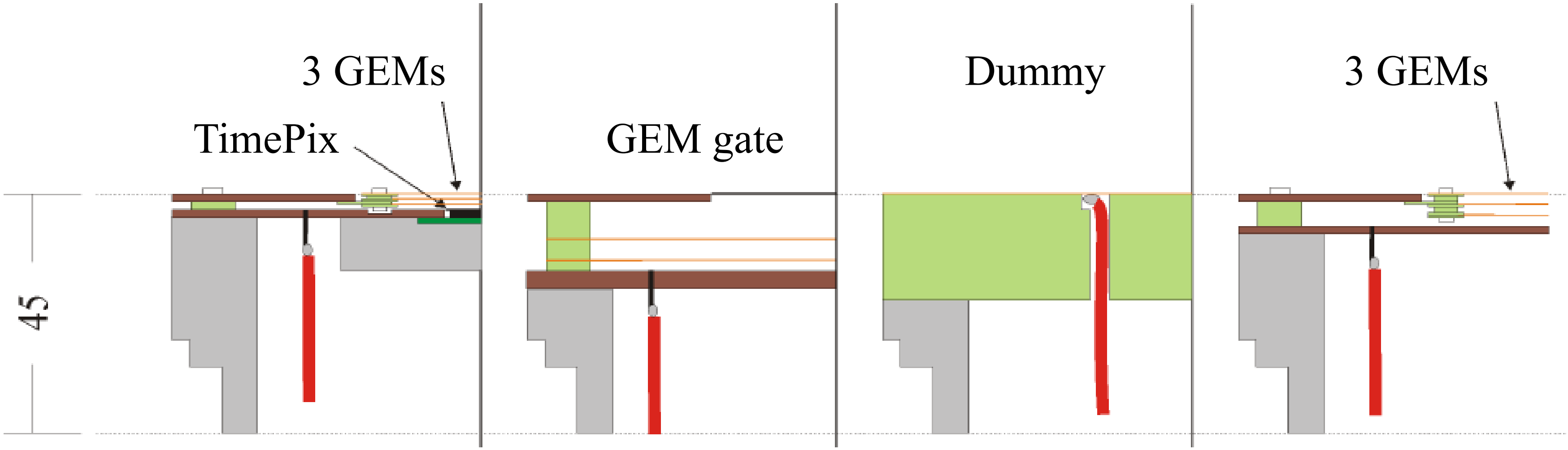


Sensors

- first setup: only 768 channels can be read out
  - ➢ the readout sensitive area is reduced to 38.4 x 38.4 mm²

(only the intersecting readout area of the two modules on top of each other is interesting)

Further Tests: CERN GEM

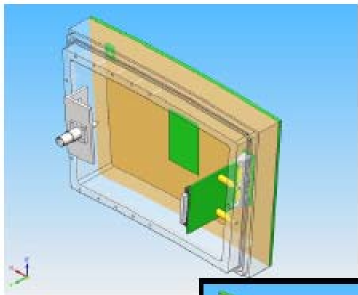


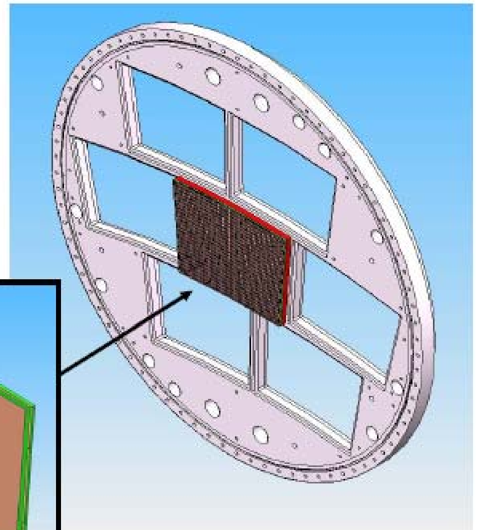
3 GEMs + pads

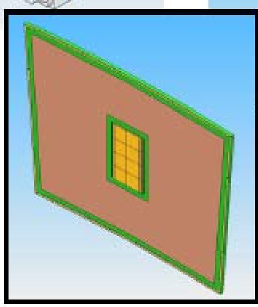
Current idea:
3 standard GEMs
140/70/60
100 cm^2
2 mm spacing between GEMs
pads: 1 x 4 mm^2

Further Tests: TimePix

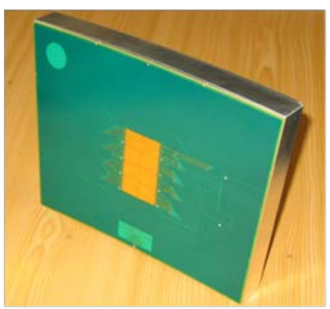
With MicroMEGAS (Saclay-NIKHEF)







To be inserted in place of a standard panel in the LC-TPC Large Prototype



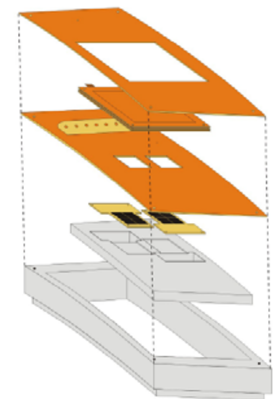
P. Colas, CEA Saclay

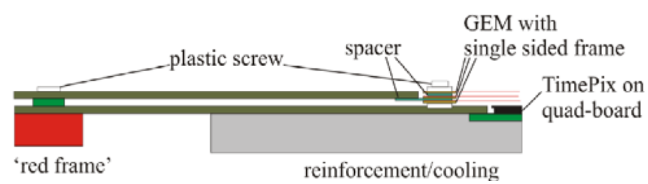
Plans of module for LPTPC with GEM/TimePix readout

gas amplification:
  3 standard GEMs
  (60/70/140)

transfer and induction gap:
  1mm

readout: 2 Quad-boards
  (4 TimePix chips each)



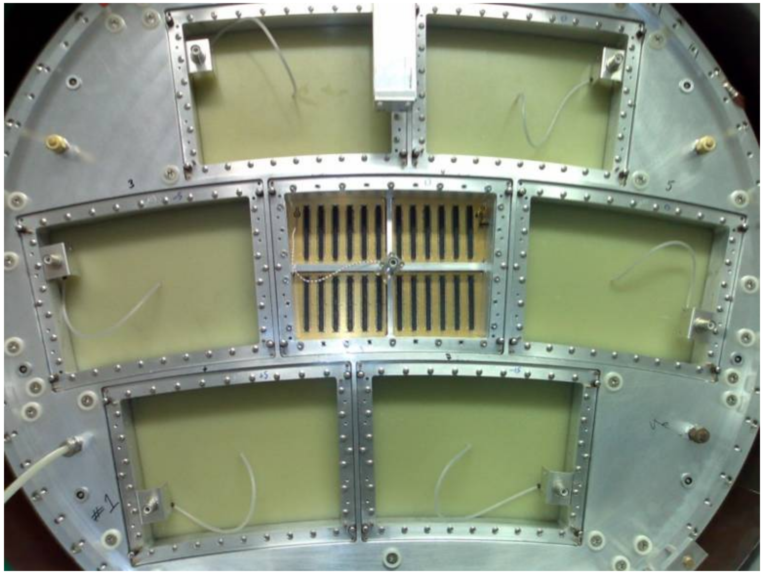


universitätbonn

2

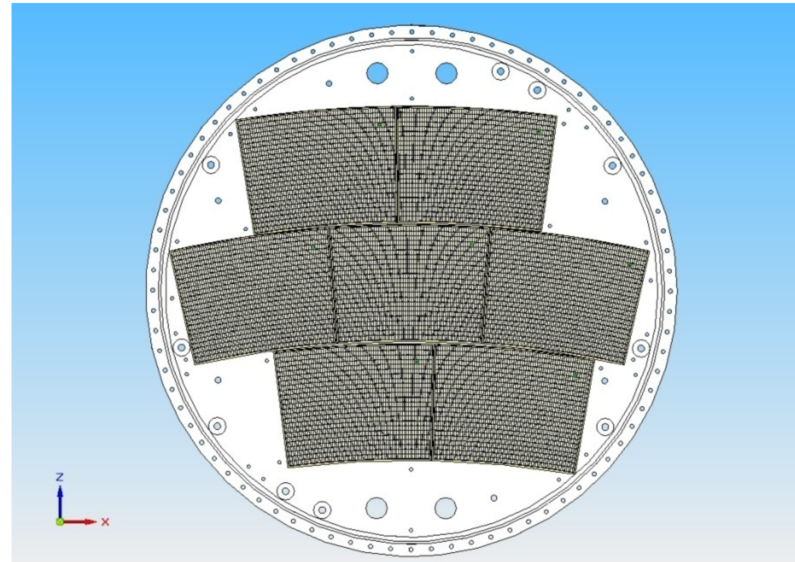
J. Kaminski, Univ. of Bonn

Further tests for Micromegas

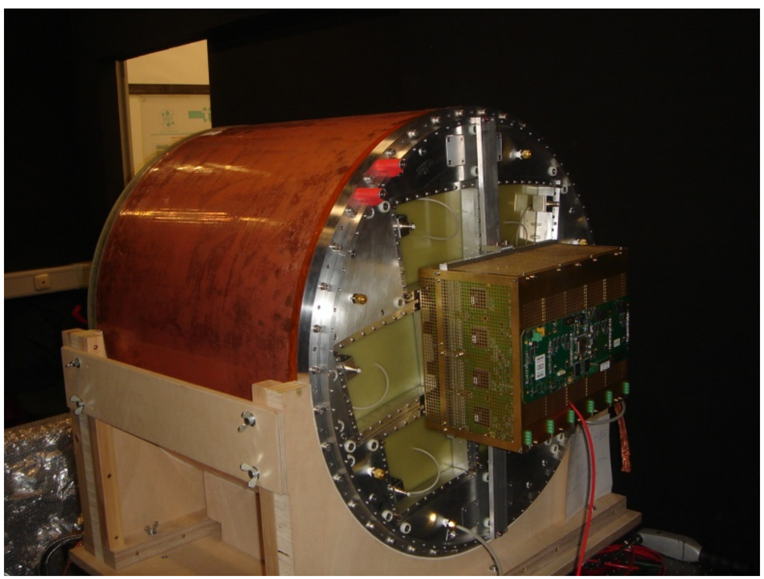


In 2008 with one detector module

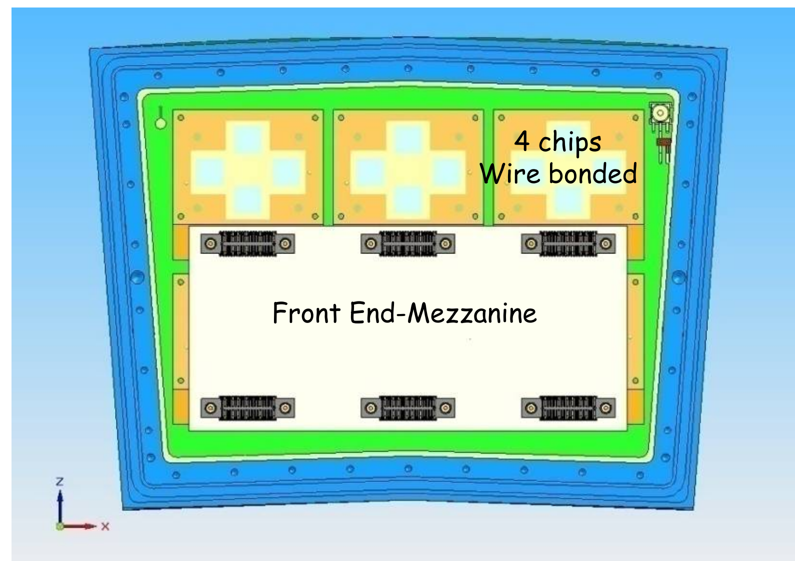
Resitive technology choice



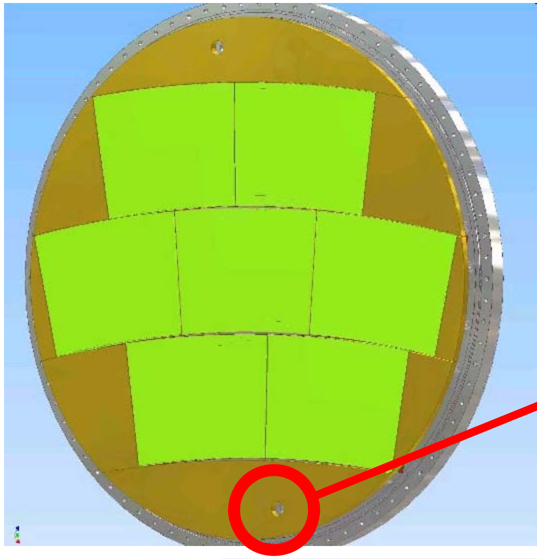
In 2009/10 with 7 detector modules.

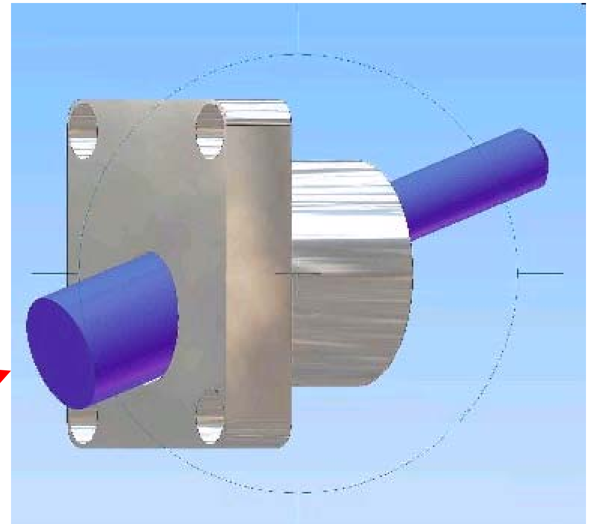


Compact the electronics with possibility to bypass shaping

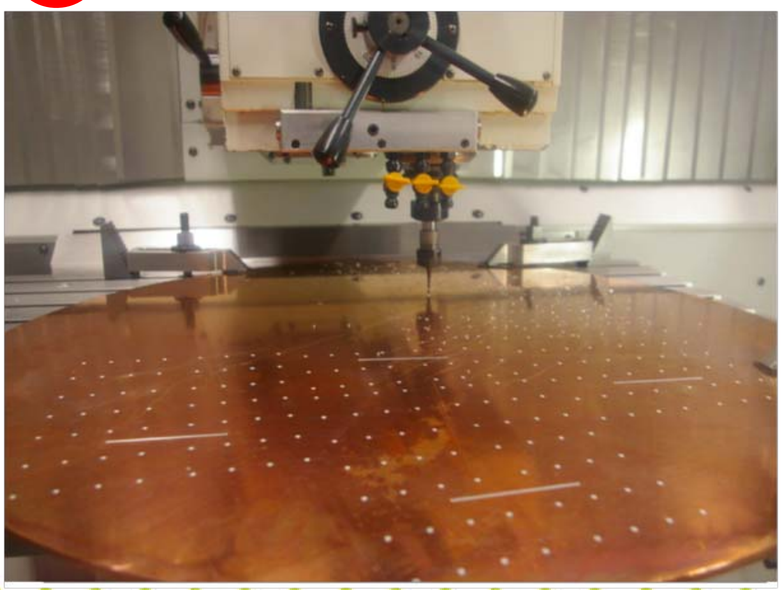


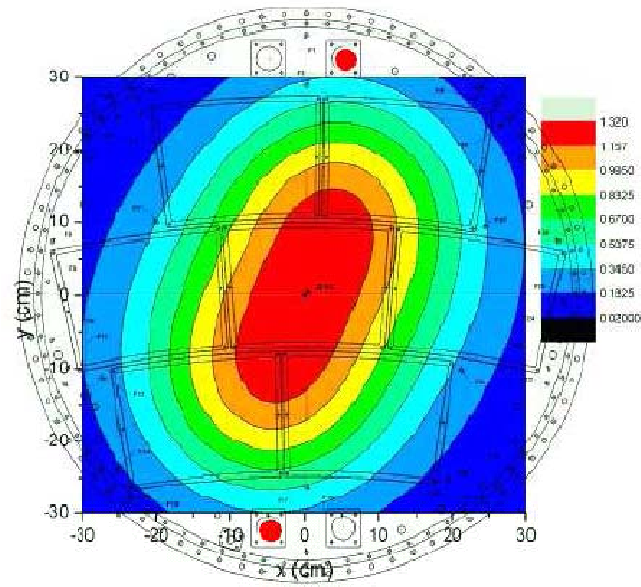
Laser Calibration Setup





DESY UV Laser





Summary & Outlook

- ✓ A Large Prototype of a TPC has been built and is being assembled/tested/commissioned by the LCTPC collaboration

- ✓ Two MPGD technologies are being tested:
  - Micromegas
  - GEM

  First (preliminary) results presented

- ✓ Infrastructure for Large Prototype has been constructed

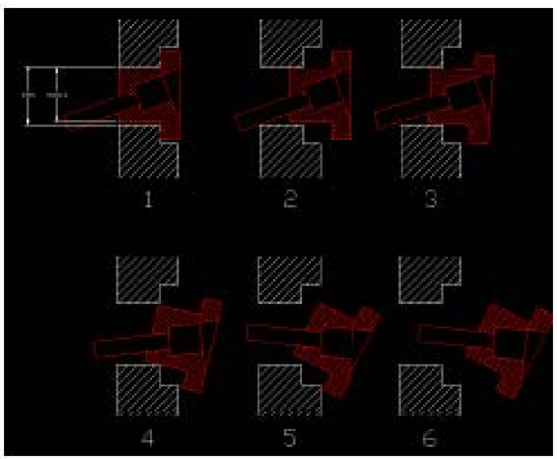
- ✓ e^- test beam (DESY) in conjunction with PCMAG (*1T* magnet)

- ✓ Continuation with different configurations

- ✓ Advanced endplate discussions (both on mechanics, electronics, cooling) have started backup slides

Photo-electron calibration system tests

- The laser light delivery system for the photo-electron calibration system will be shipped to DESY this month



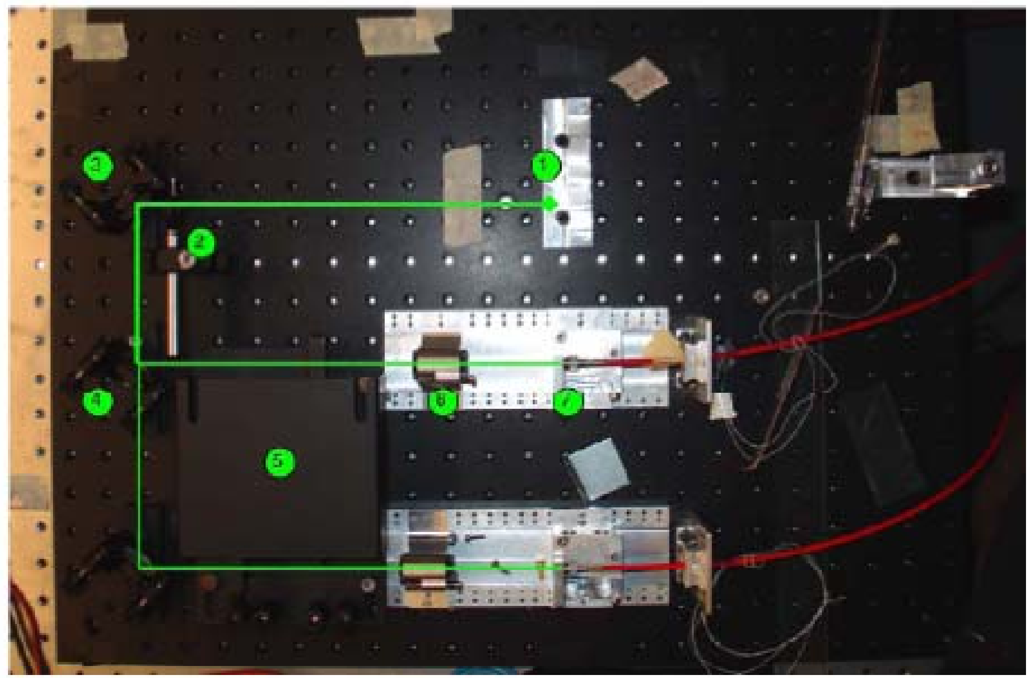


Figure 4: Components of the calibration system which will be placed on the laser table. Light exits the laser at (1) (the laser is not present in the photo), passes through a collimator that eliminates excess light from the laser (2), reflects off the first mirror (3), and passes a beamsplitter (4) that divides the light into branches that pass through a beam blocker system (5) enter a lens (6) that focuses the light onto the face of the red fibre-optic cables (7), which it follows to the TPC.

Carlton

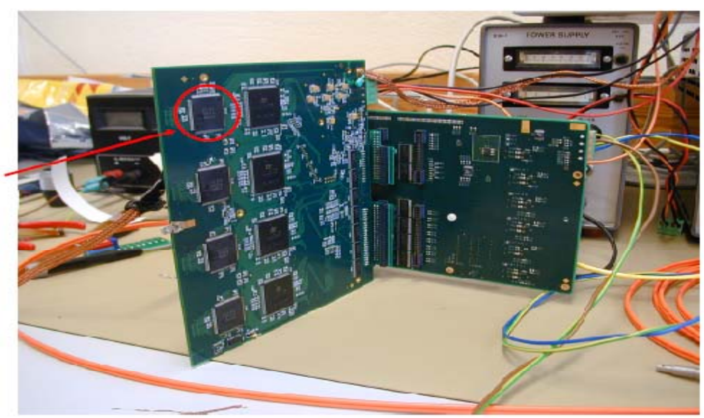
Readout Electronics: ALTRO

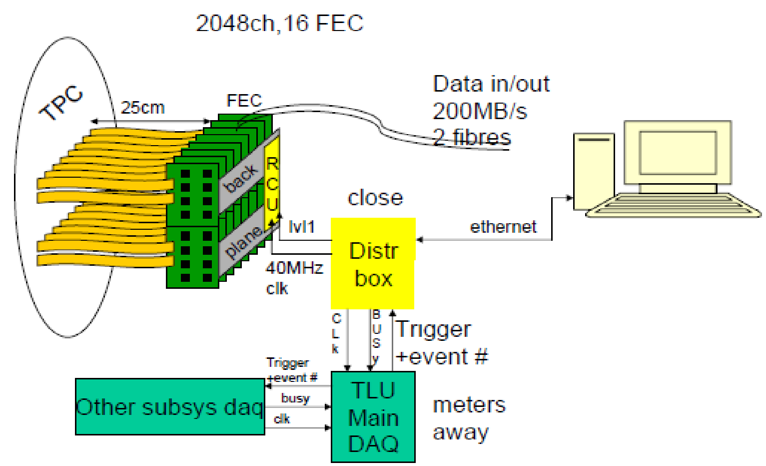
PCA16:

1.5 V supply; power consumption <8 mW/channel
16 channel charge amplifier + anti-aliasing filter
Fully differential output amplifier
Programmable features
signal polarity
Power down mode (wake-up time = 1 ms)
Peaking time (30 – 120 ns)
Gain in 4 steps (12 – 27 mV/fC)
Preamp out mode (bypass shaper or not)
Tunable time constant of the preamplifier
Basically pin-compatible with PASA

The test set up with a fully equipped front end board

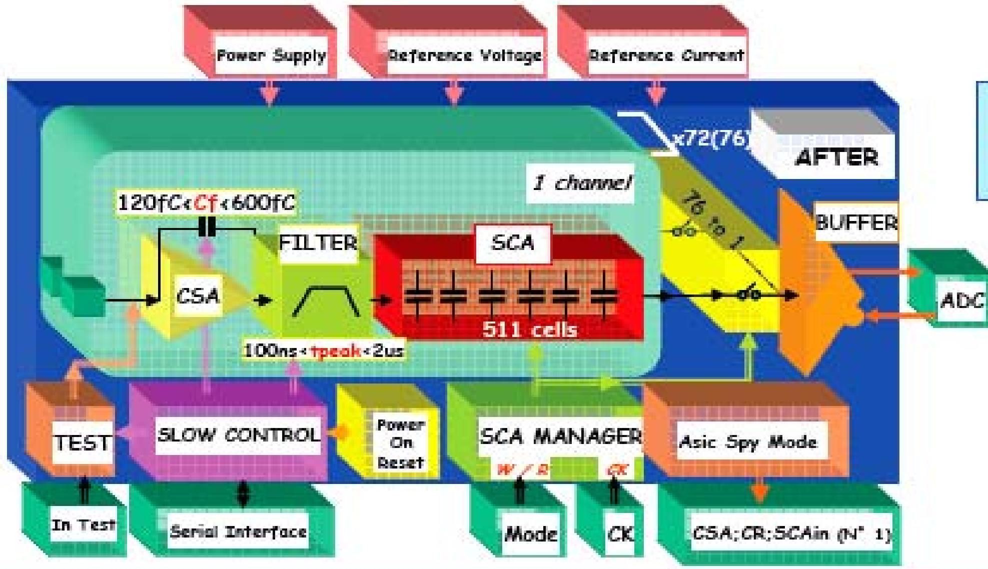
PCA16





Readout Electronics: AFTER

AFTER Main Features



- No zero suppress.
- No auto triggering.
- No selective readout.

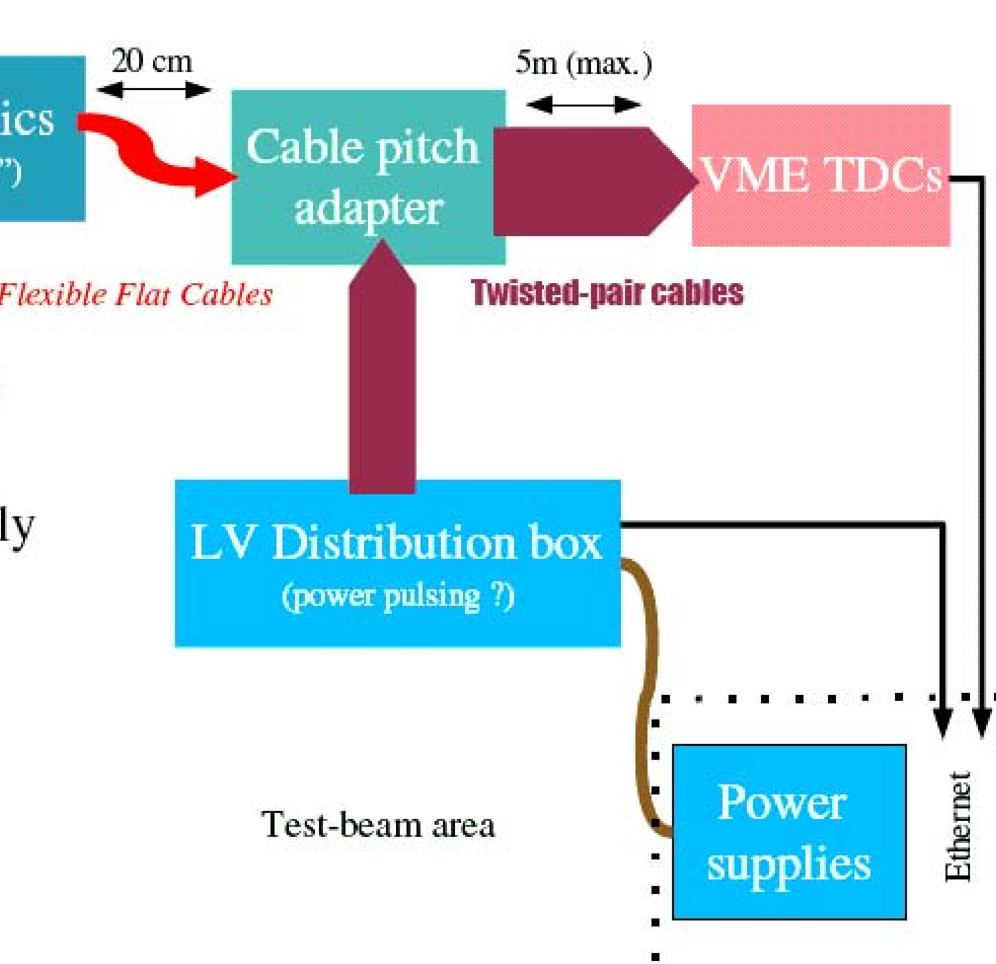
Main features:

- **Input Current Polarity:** positive **or** negative
- **72** Analog Channels
- **4** Gains: 120fC, 240fC, 360fC & 600fC
- **16** Peaking Time values: (100ns to 2µs)
- **511 analog memory cells / Channel:** Fwrite: 1MHz-50MHz; Fread: 20MHz

- **Slow Control**
- **Power on reset**
- **Test mode:** calibration or test **[channel/channel]** functional **[72 channels in one step]**
- **Spy mode on channel 1:** CSA, CR or filter out

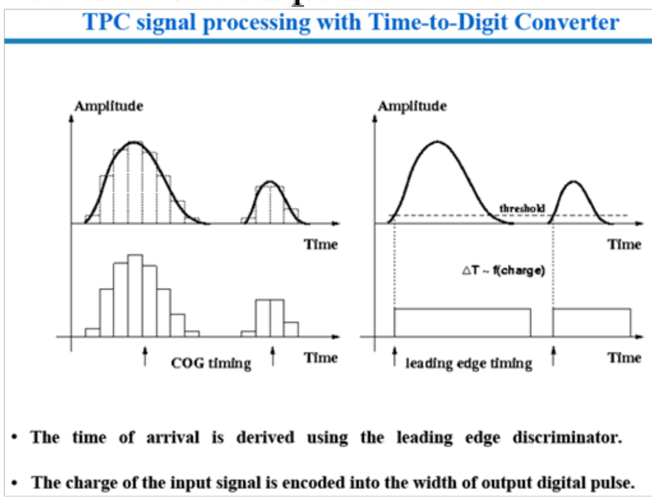
LCTPC meeting Oct. 10, 2007 *E. DELAGNES* 4

Readout Electronics: TDC



32 channels
Board size: 30 mm x 100mm*

Boards will be installed directly onto the endplate.

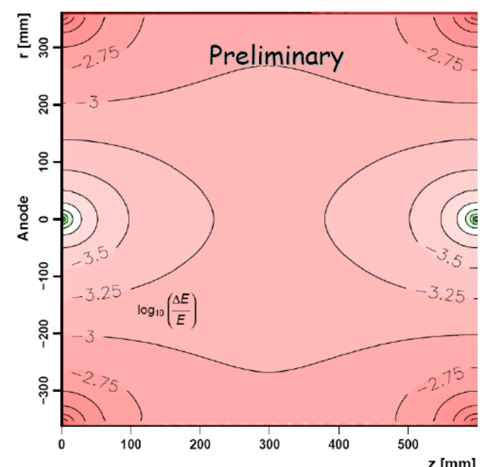


A. Kaukher, Univ. Rostock

LP-TPC Field Cage (FC)

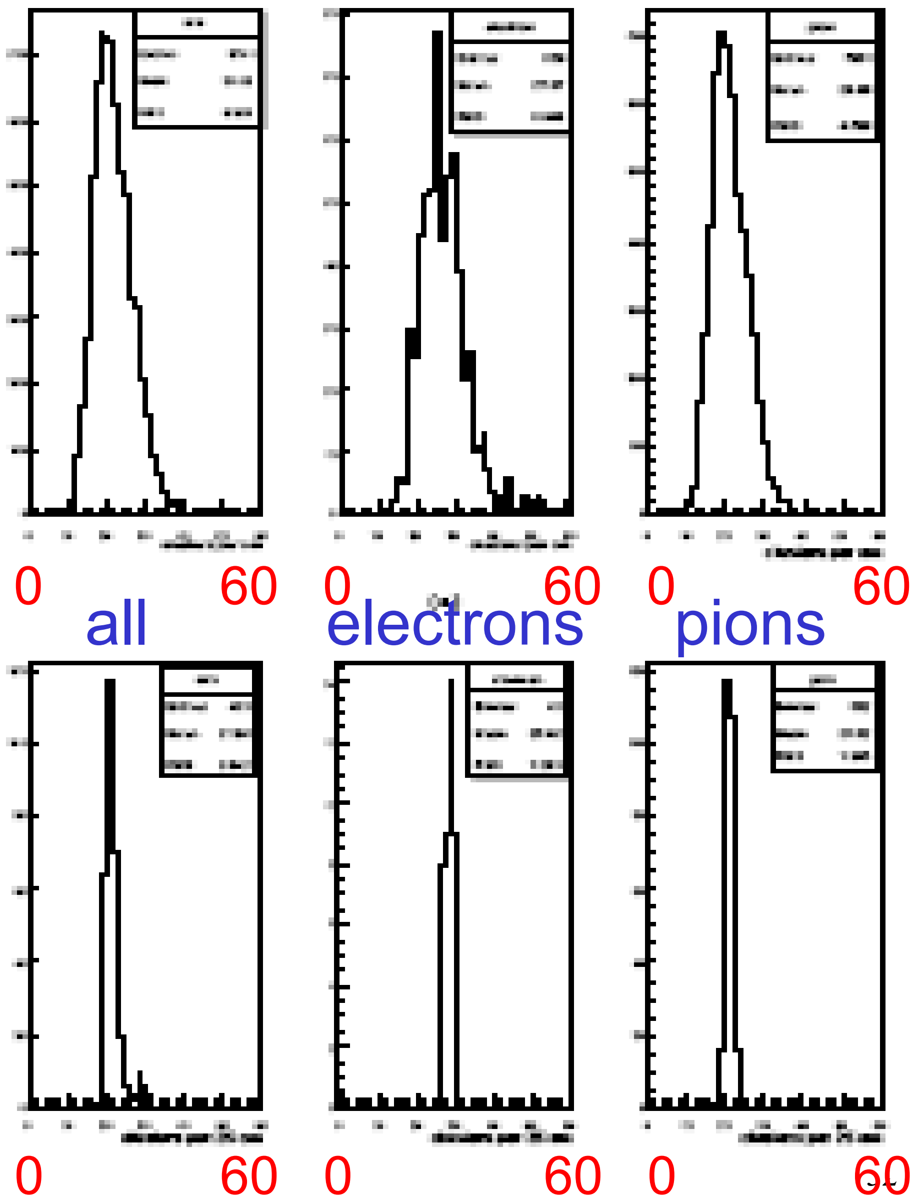
Summary:

- Parallelism $\delta = 0.110 \pm 0.003\,\mathrm{mm}$
- Skew angle of field cage
  1 mrad (20% error)
  Offset anode – cathode: (540±40)µm
- Flatness of anode / cathode surface **~ 35 µm**



P.Schade, DESY

Cluster counting distribution in He/iC_4H_{10}



- Using 1 cm tracklength

Electrons:

Avg=27.1/cm rms=6.3

Pions: 21.0/cm 4.8

Electrons:

Avg=28.4/cm rms=1.2

Pions: 21.0/cm 1.2

- Using 25 cm tracklength

4.4 σ difference