Detector R&D towards the International Linear Collider

Large TPC Prototype of LCTPC

Klaus Dehmelt

DESY

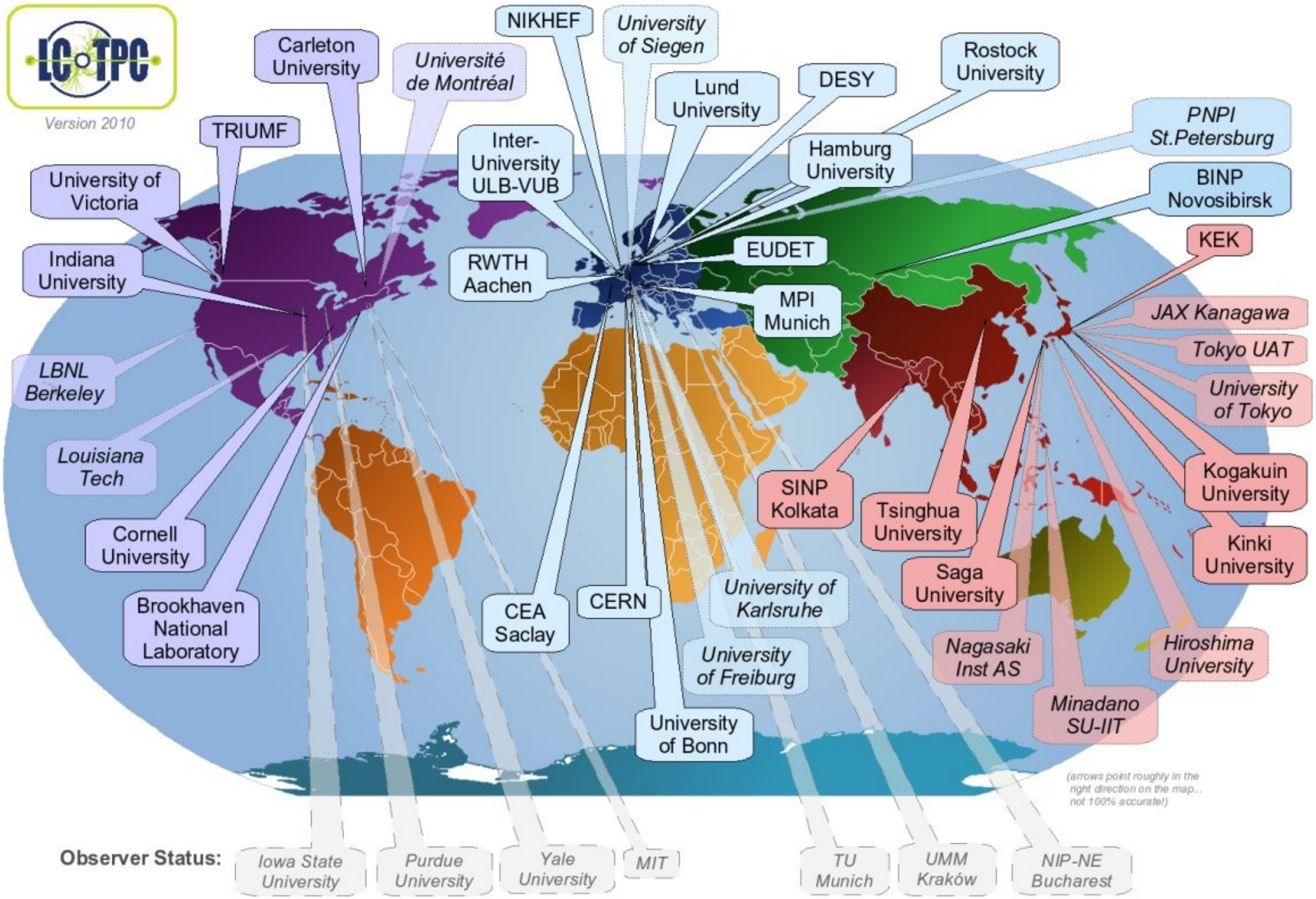
On behalf of the LCTPC Collaboration

LCWS2010

Beijing, China

March 27, 2010

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)
Background robustness	Full efficiency with 1% occupancy
Background safety factor	Chamber will be prepared for 10 $\times$ worse backgrounds at the linear collider start-up

with MPGD

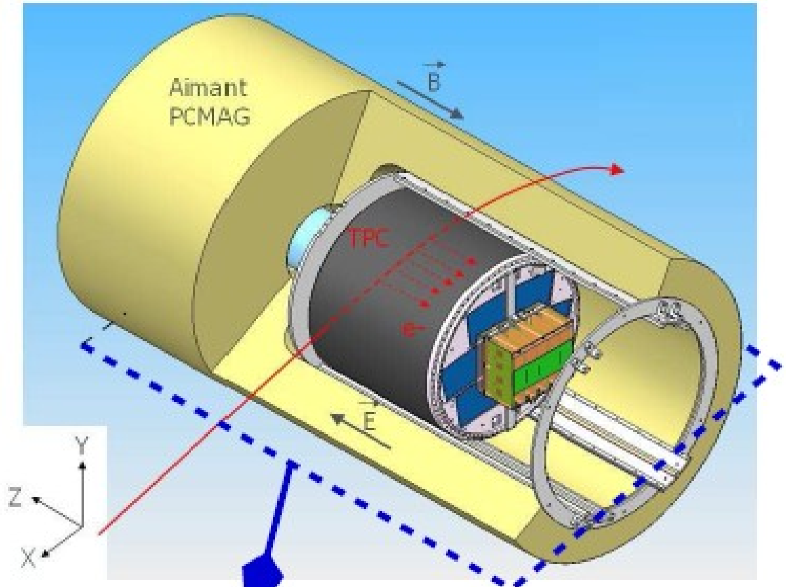
Consolidation Phase

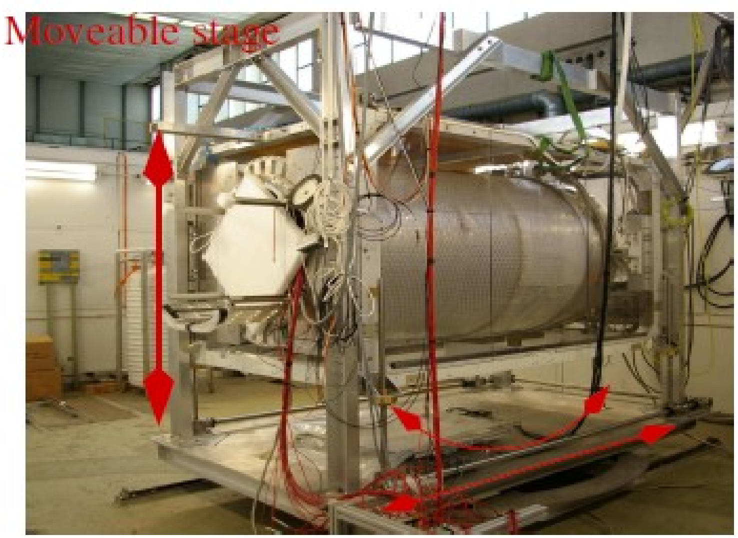
- Design, build and operate a “Large Prototype” (LP)
- First iterations of LCTPC design details can be tested
- Larger area readout can be operated
- Tracks with a large number of measured points are available $\rightarrow$ analysis and correction procedures

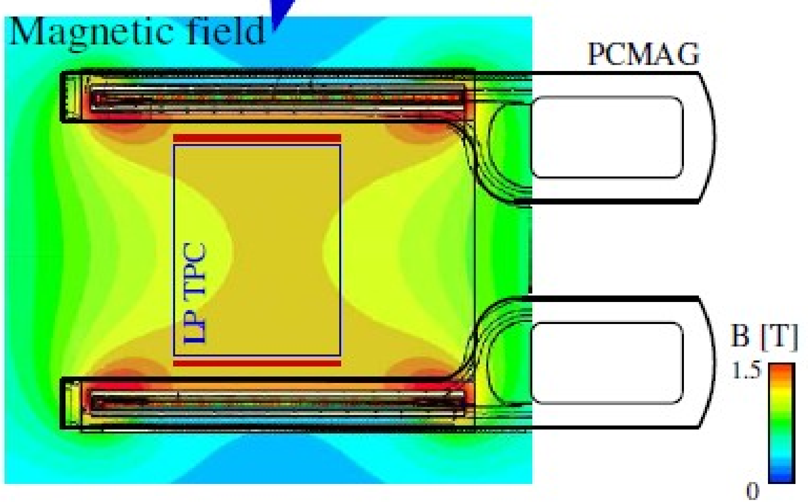
DESY Test Beam Setup

EUDET setup for TPC R&D

- PCMAG with $B \leq 1.25\,\mathrm{T}$
- bore diameter: $85\,\mathrm{cm}$
- LP support structure
- Test Beam e^- with $1\,\mathrm{GeV} \leq E_{\mathrm{beam}} \leq 6\,\mathrm{GeV}$

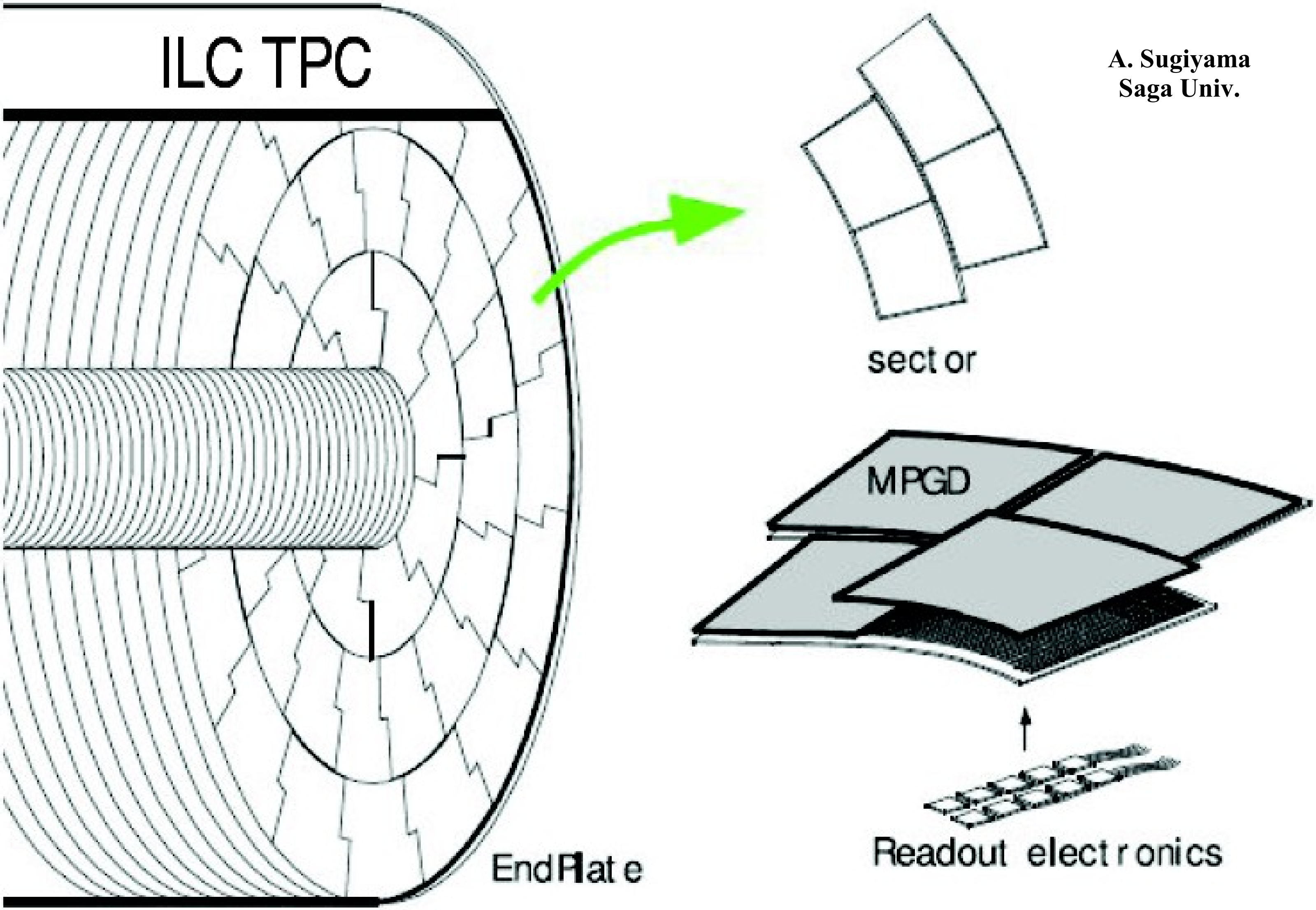


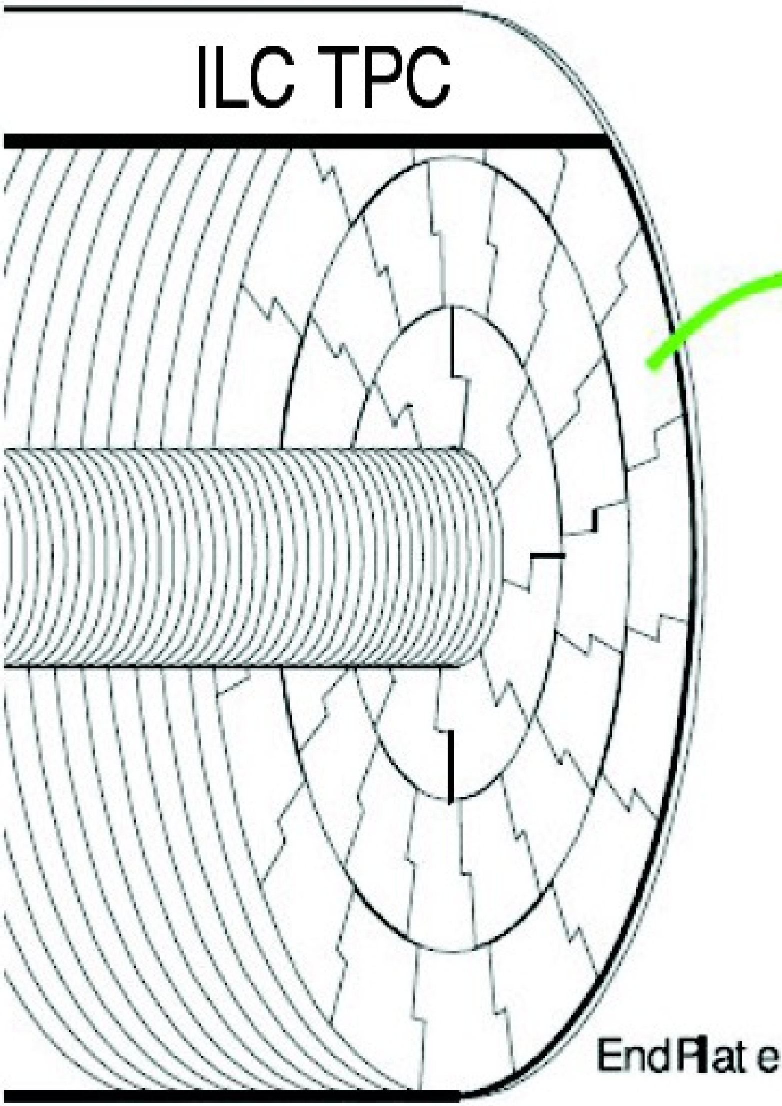


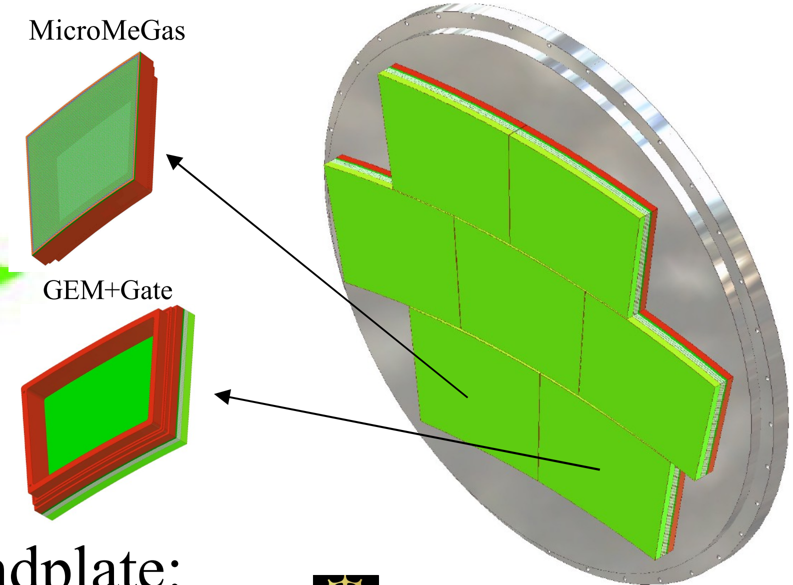


TPC with MPGD

A. Sugiyama
Saga Univ.





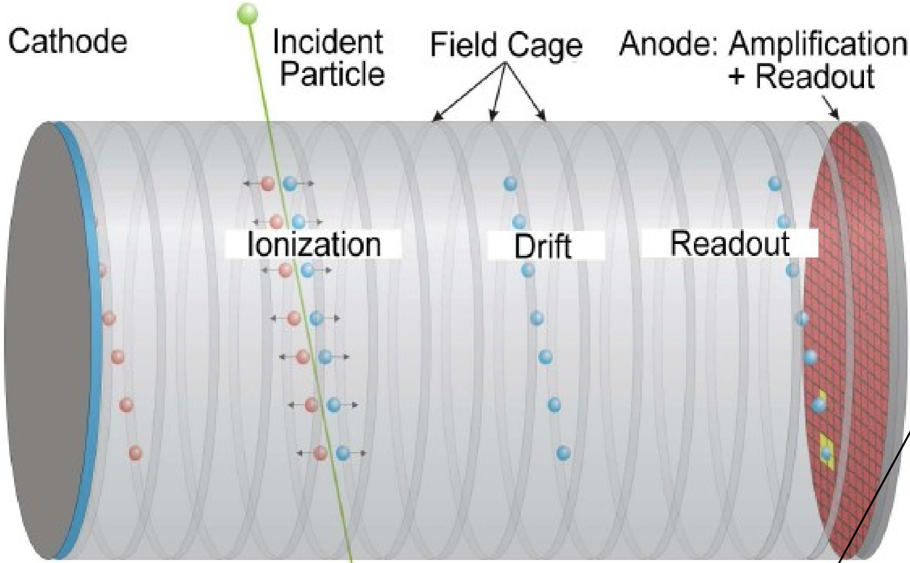


D. Peterson, Cornell

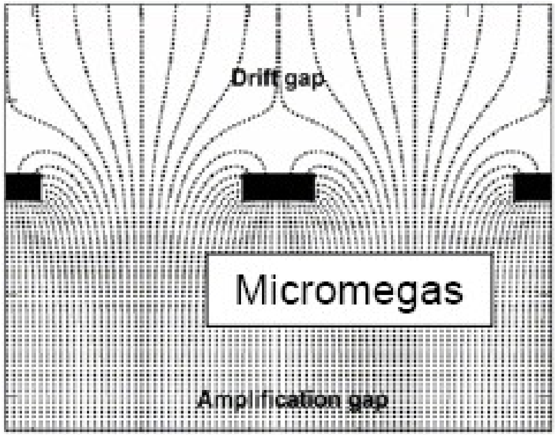
Endplate:

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

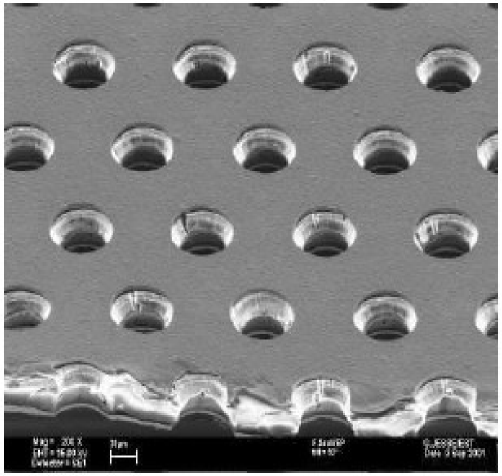
TPC with MPGD

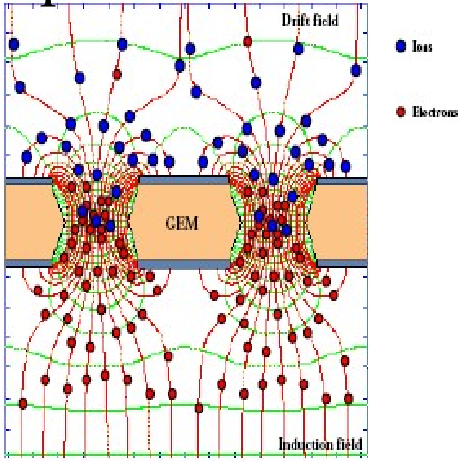


MicroPatternGasDetector
MPGD
not limited by **E** x **B** effects



Gas Electron Multiplier GEM

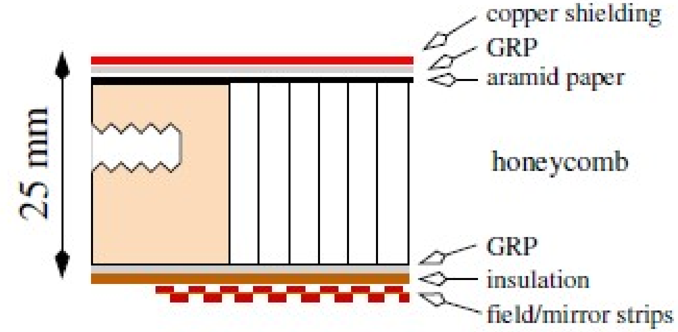




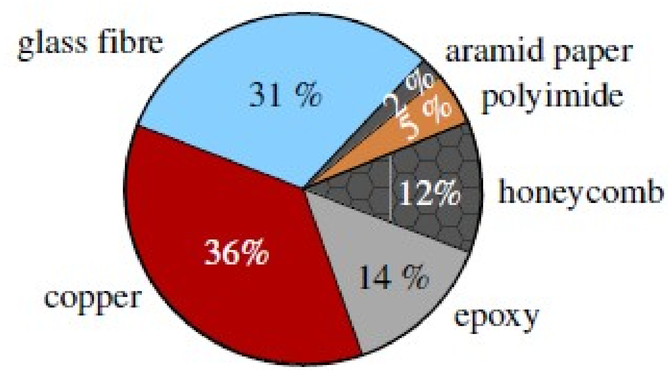
LP-TPC Field Cage (FC)

Diameter: Inner 720 mm,
Outer 770 mm
→ wall thickness 25 mm
Length 610 mm
HV to be applied: up to 20 kV

→ structure made from composite materials

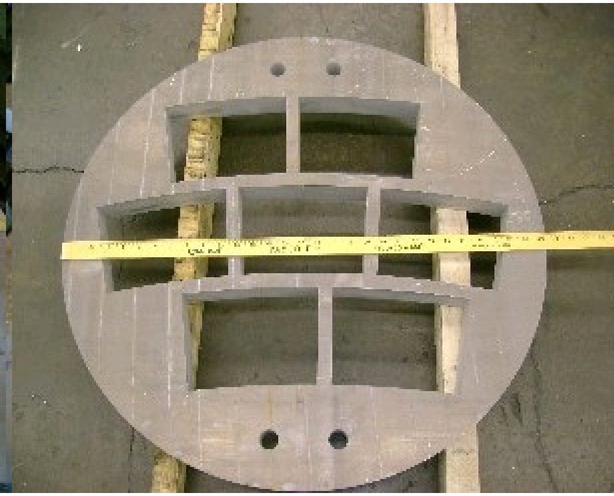


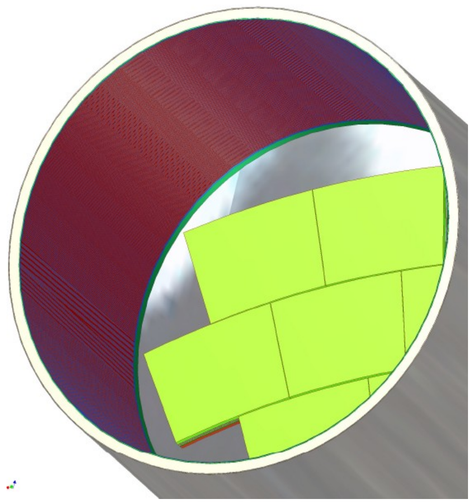
→ material budget: 1.24 % X_0

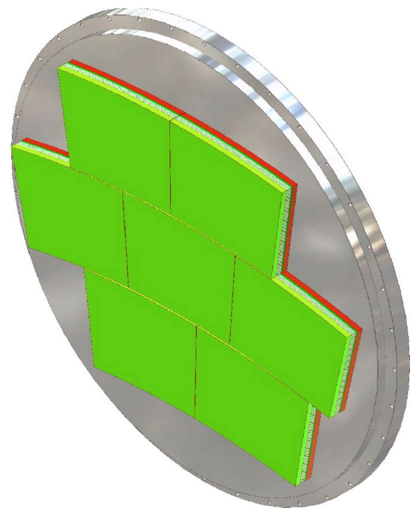


⇒ 1 % X_0 per wall within reach

LP-TPC Endplate



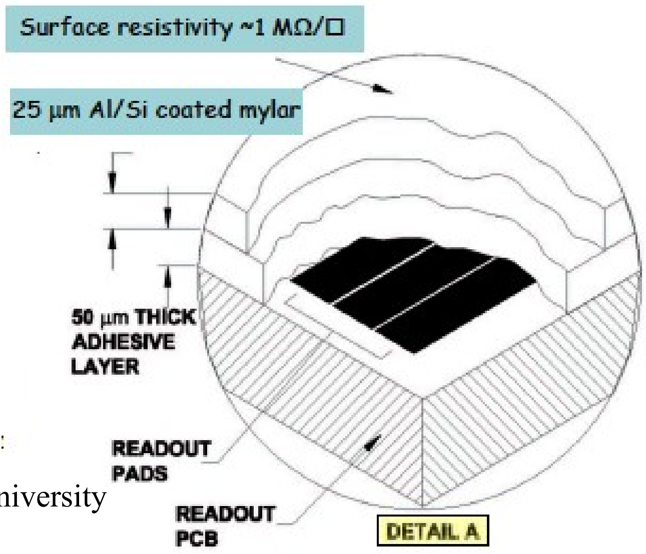




D. Peterson, Cornell

MicroMeGaS Structure

‘Bulk Micromegas’ panels, without resistive foil and with resistive carbon-loaded kapton, have been produced at CERN (Rui de Oliveira)

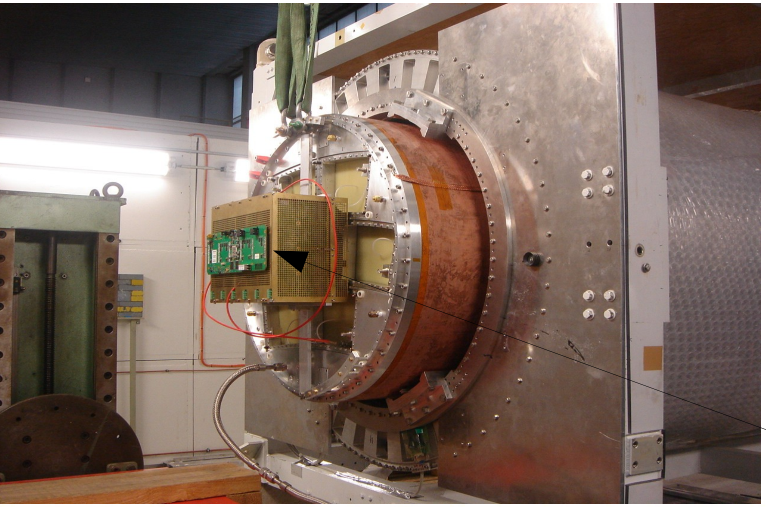


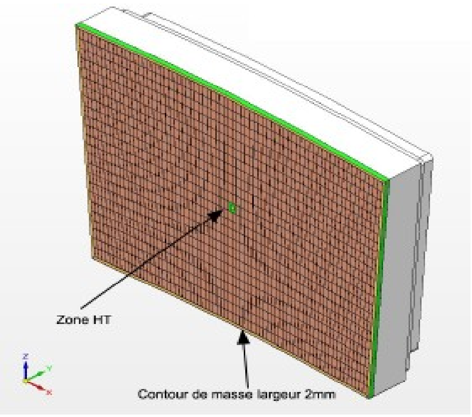
MicroMeGas for LP:

24 rows x 72 pads

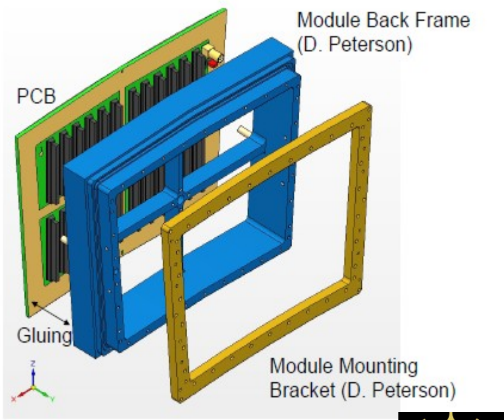
Av. Pad size: 3.2 x 7mm²

P. Colas, CEA Saclay
M.S.Dixit, Carleton University





Detector side

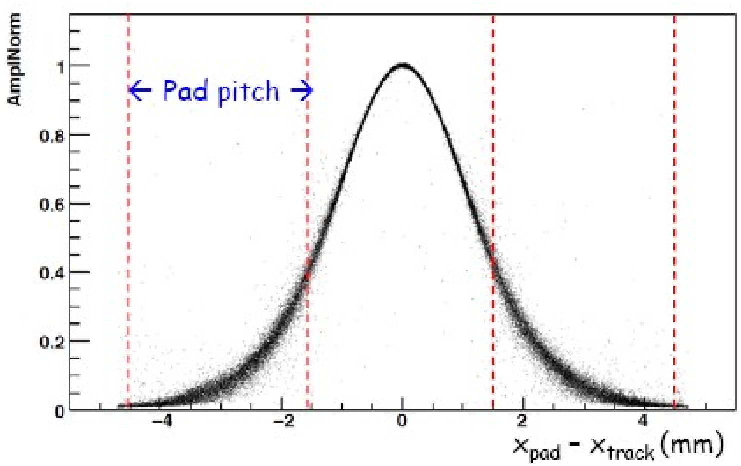


Readout electronics: AFTER (T2K TPC)

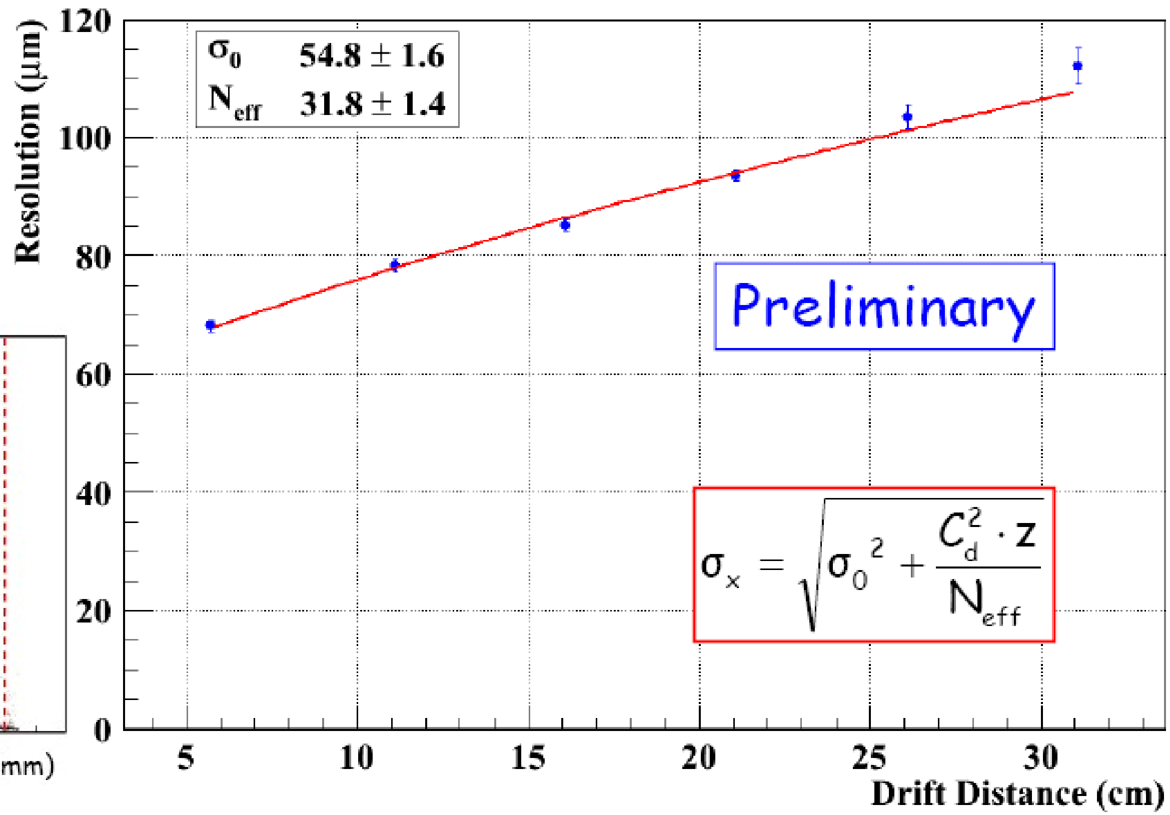
Electrons (5 GeV), Magnetic field (B=1T)

- 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 (data with 500 ns shaping)



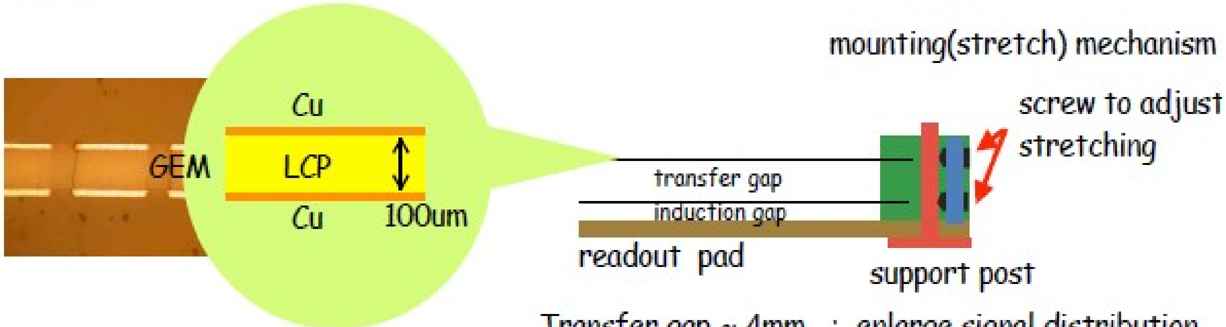
- Resolution at z=0: σ_0 = 54.8±1.6 µm with 2.7-3.2 mm pads (w_{pad}/55)
- Effective number of electrons: N_{eff} = 31.8±1.4 consistent with expectations



P. Colas, CEA Saclay

Double GEM Structure

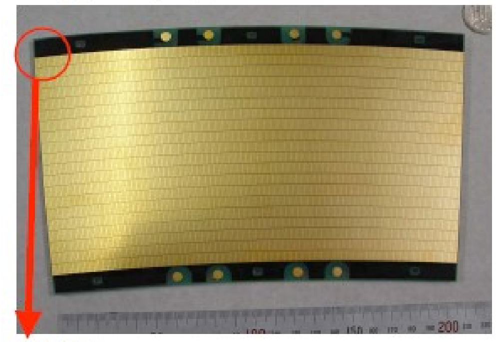
GEMs

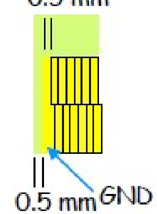


Transfer gap ~ 4mm : enlarge signal distribution
(+2mm) width > 0.3* pad pitch

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

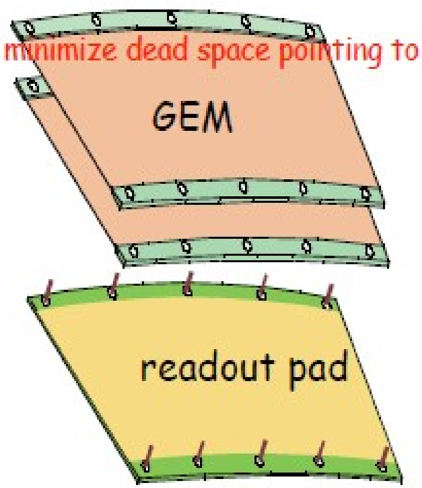
Total 5,152 ch/module

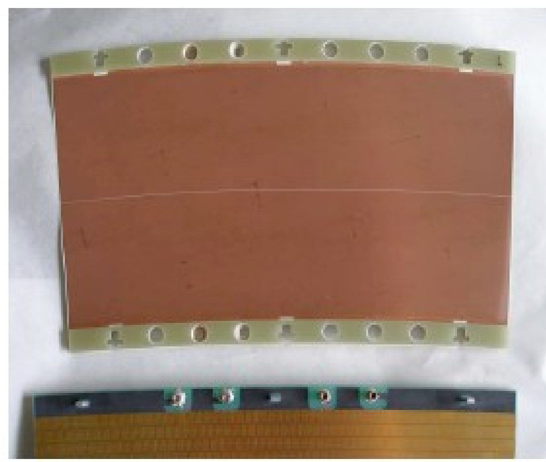


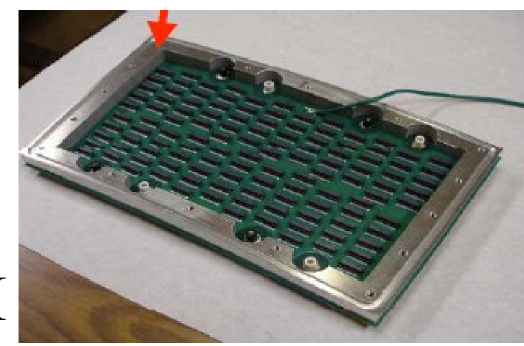


6 layers PCB
one GND layer

frame : top & bottom frame.
no side frame



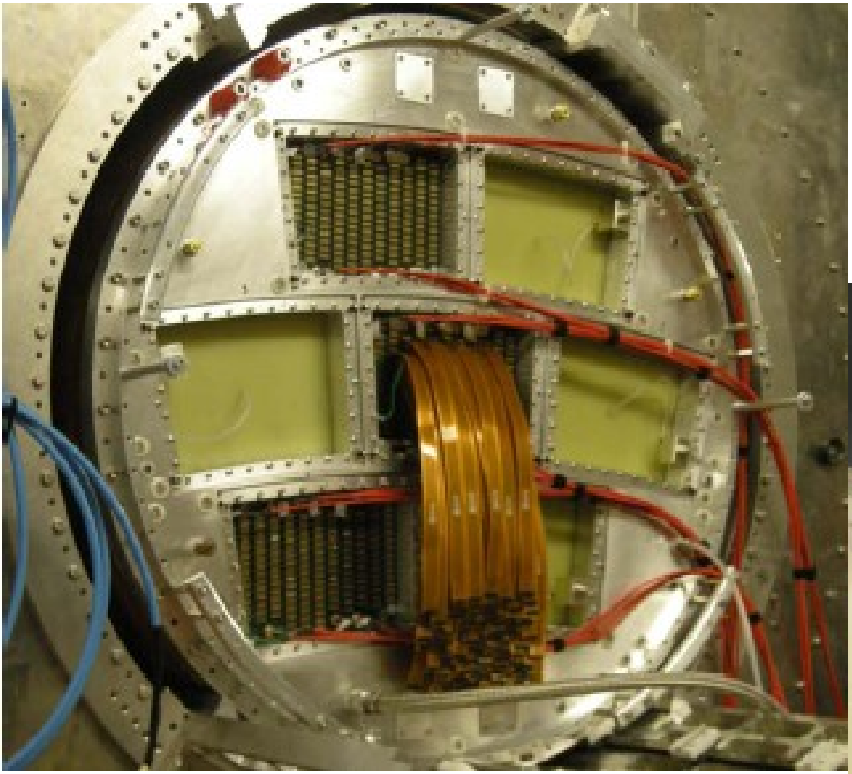




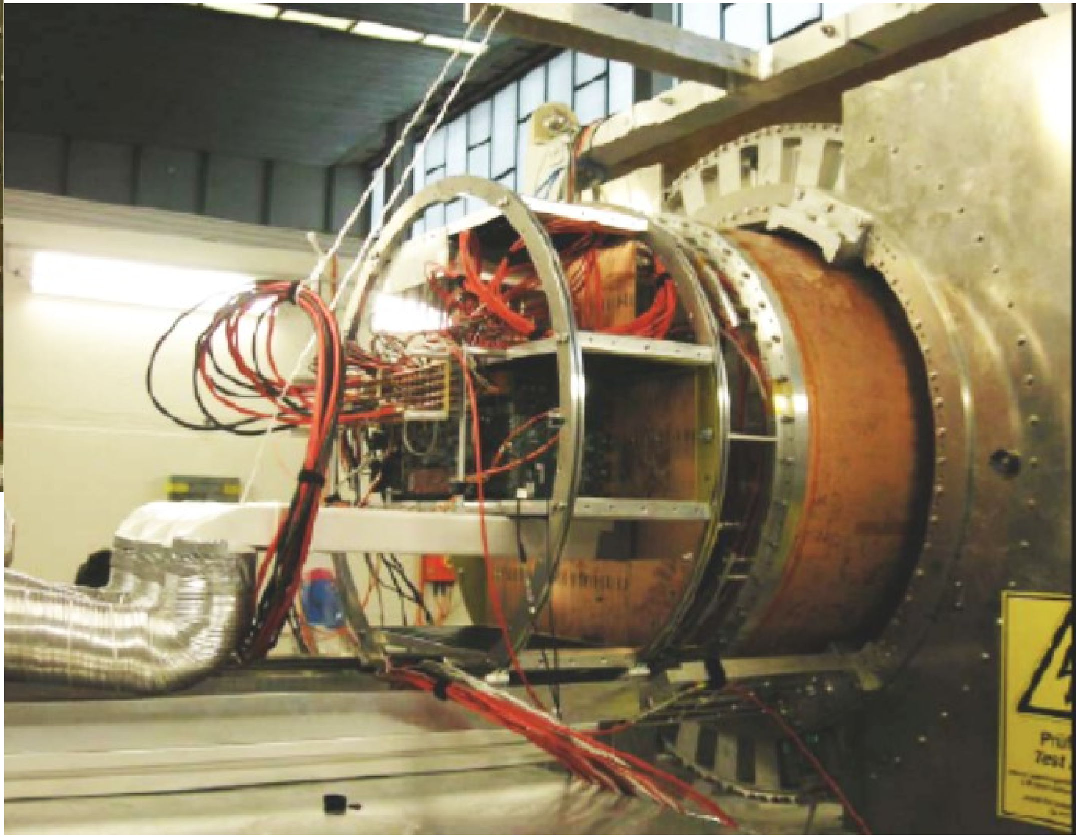
Setup planned w/ gating GEM

A. Sugiyama, Saga Univ.

Double GEM Structure



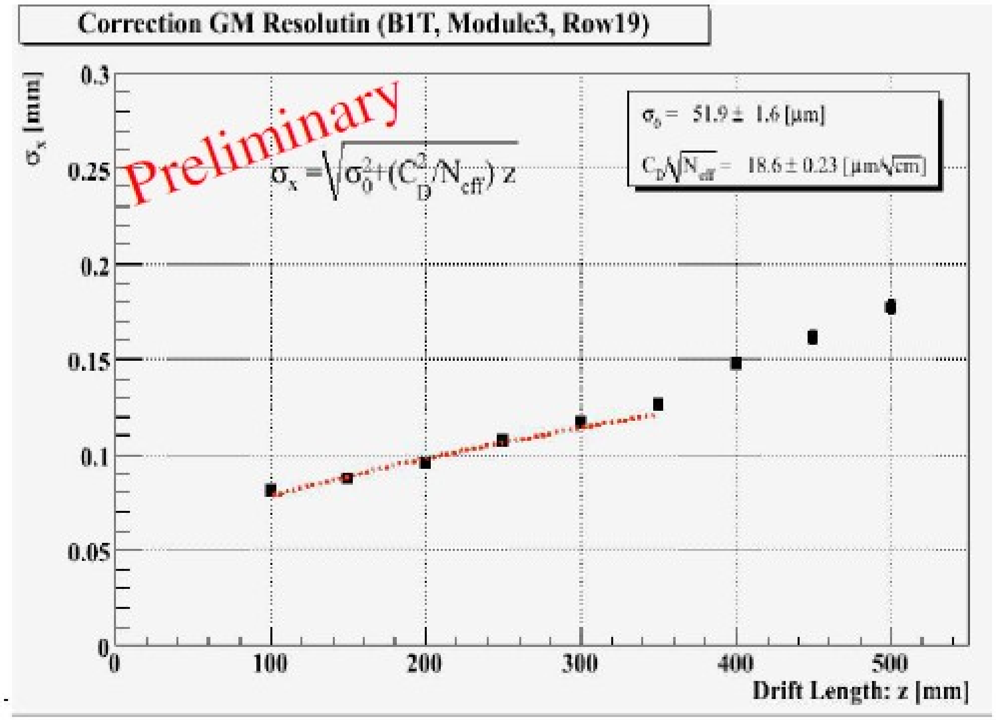
About 3200 channels readout electronics



Readout electronics:
Based on ALTRO (ALICE TPC)
L. Joensson, LUND University

Double GEM Structure

P. Schade. DESY

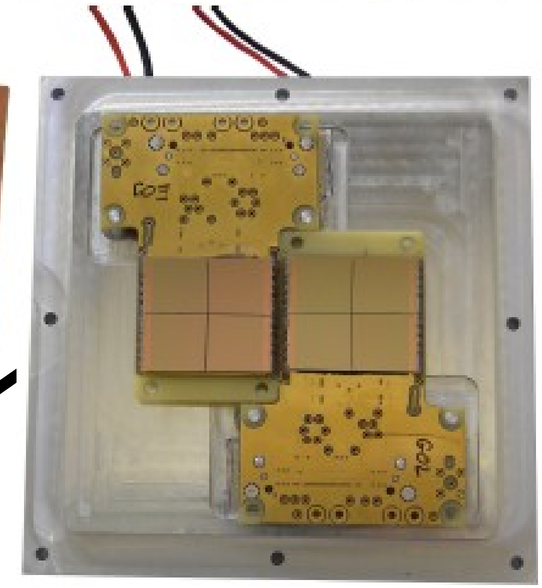


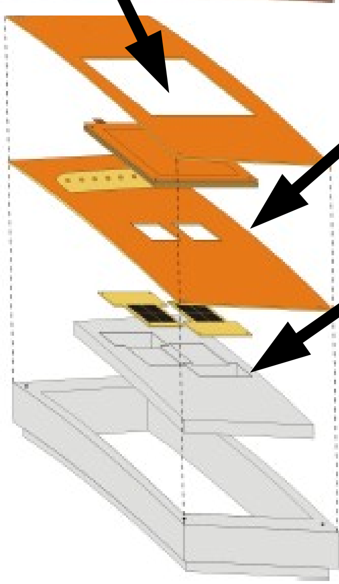
First Results (GEM modules)

- res. parametrized as $\sigma_\perp = \sqrt{\sigma_0^2 + D^2/N_{\text{eff}} \cdot z}$
  $\rightarrow D/\sqrt{N_{\text{eff}}} = 18.5 \pm 0.2\,\mu\text{m}/\sqrt{\text{cm}} - \sigma_0 = 51.9 \pm 1.6\,\mu\text{m}$

3-GEM Structure & TimePix

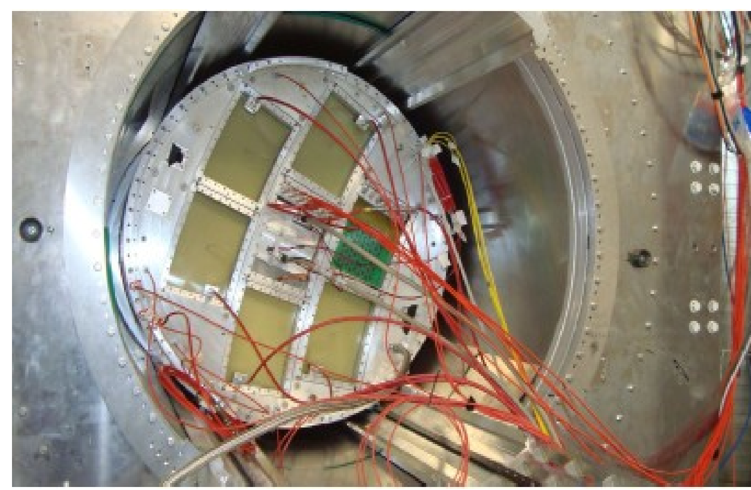






Readout:
2 quadboards
(4 TimePix
chips,
1.4 x 1.4 cm^2 each)

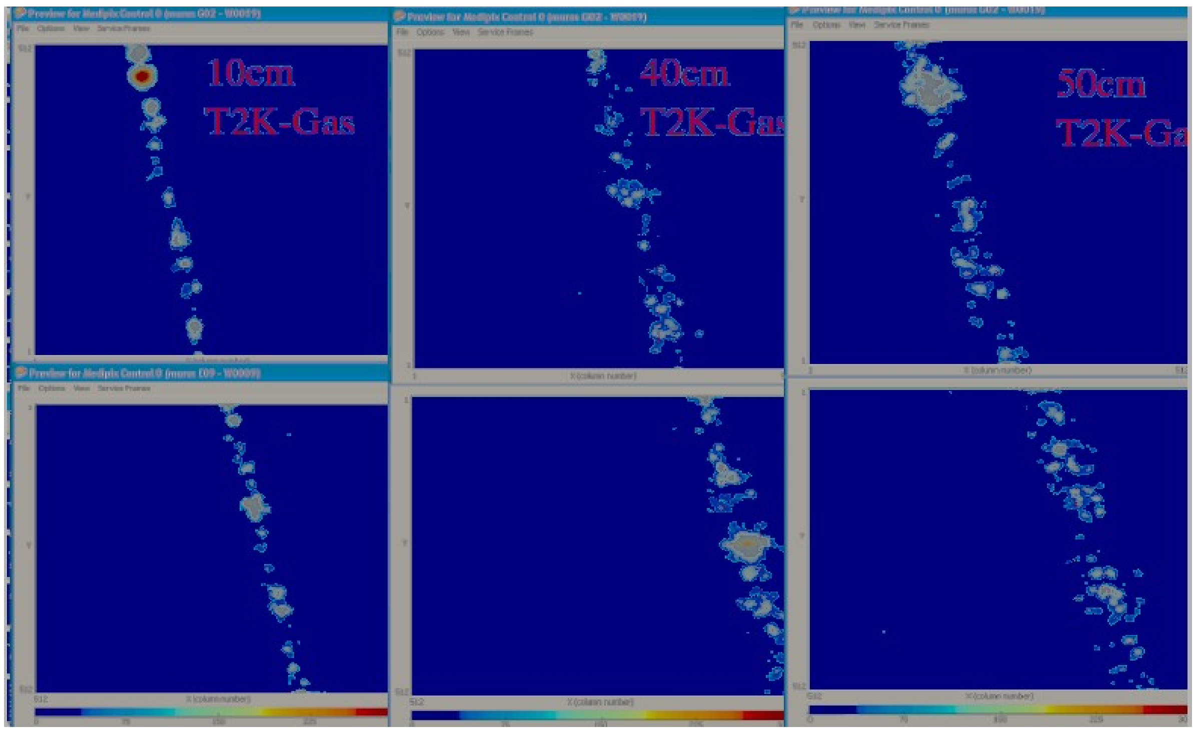
J. Kaminski, Univ. of Bonn

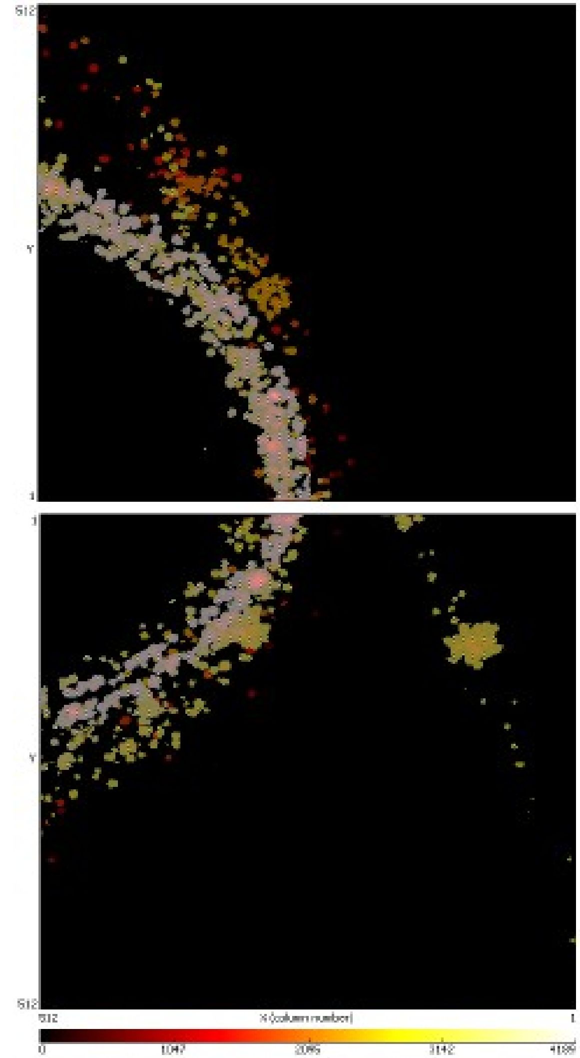


3-GEM Structure & TimePix

Largest amount of readout channels
on one TPC anode so far: # ch ≅ 500 k

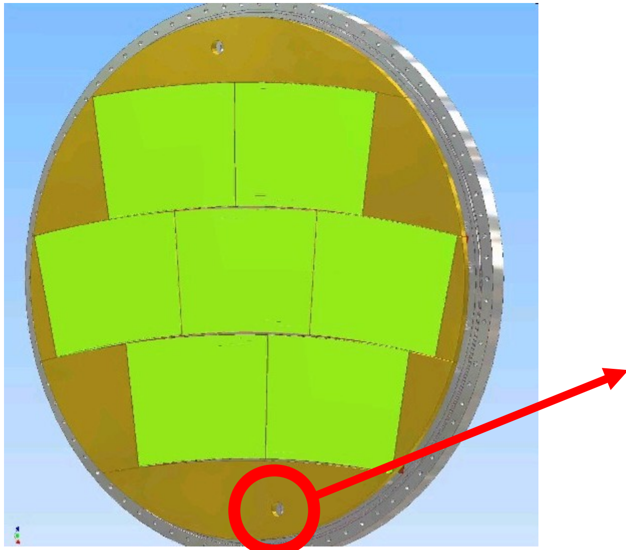
- Single cluster detection
- Clear identification of δ-electrons
- Cluster counting → improve dE/dx measurement
- Analysis ongoing

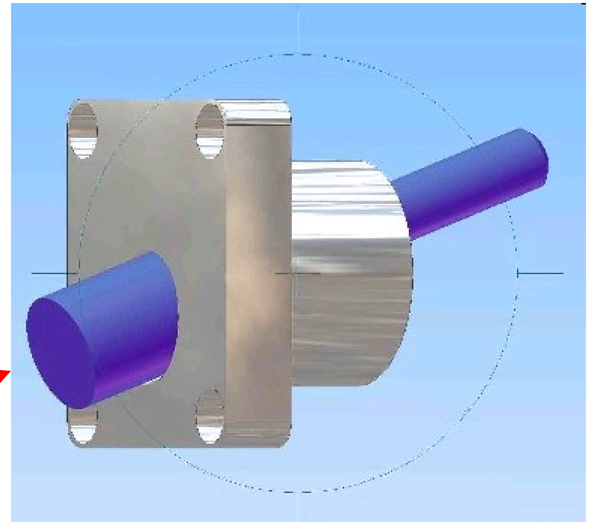


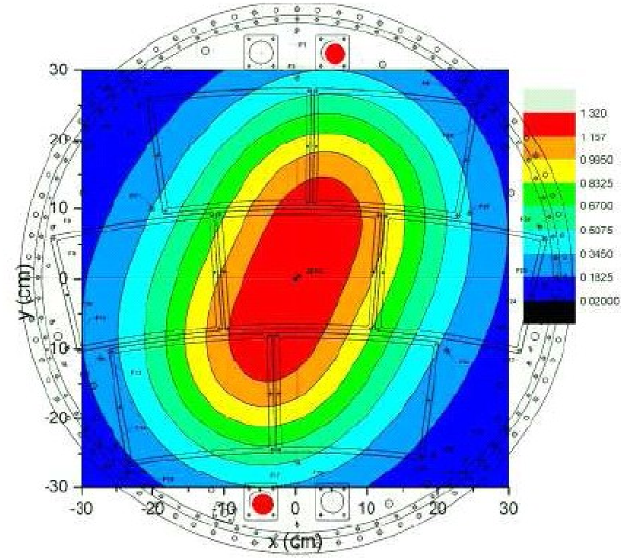


J. Kaminiski, Univ. of Bonn

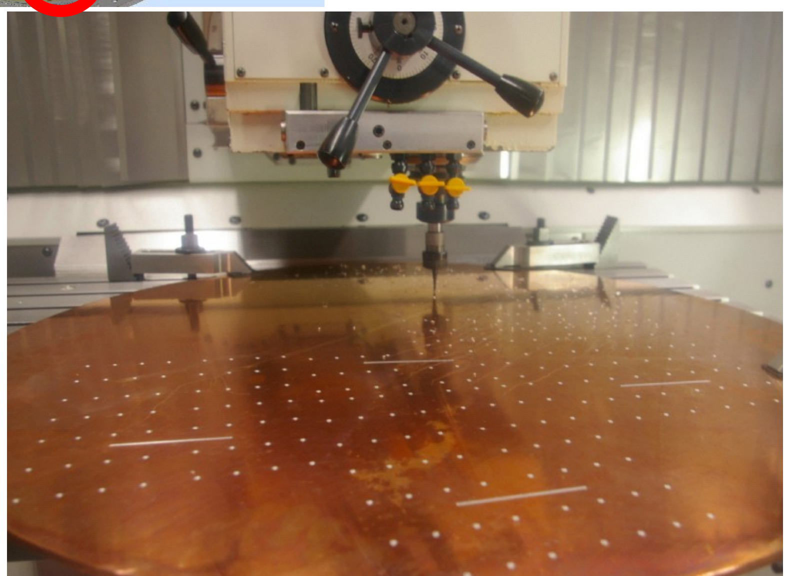
Laser Calibration Setup



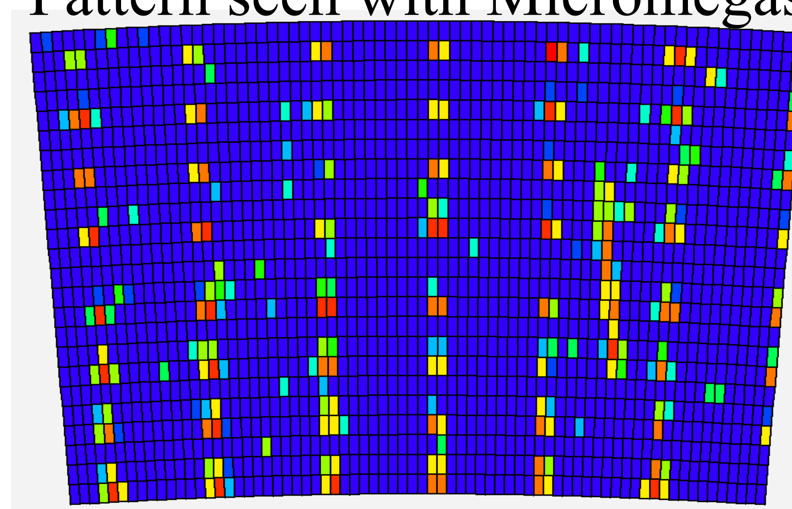




P. Conley
Victoria Univ.



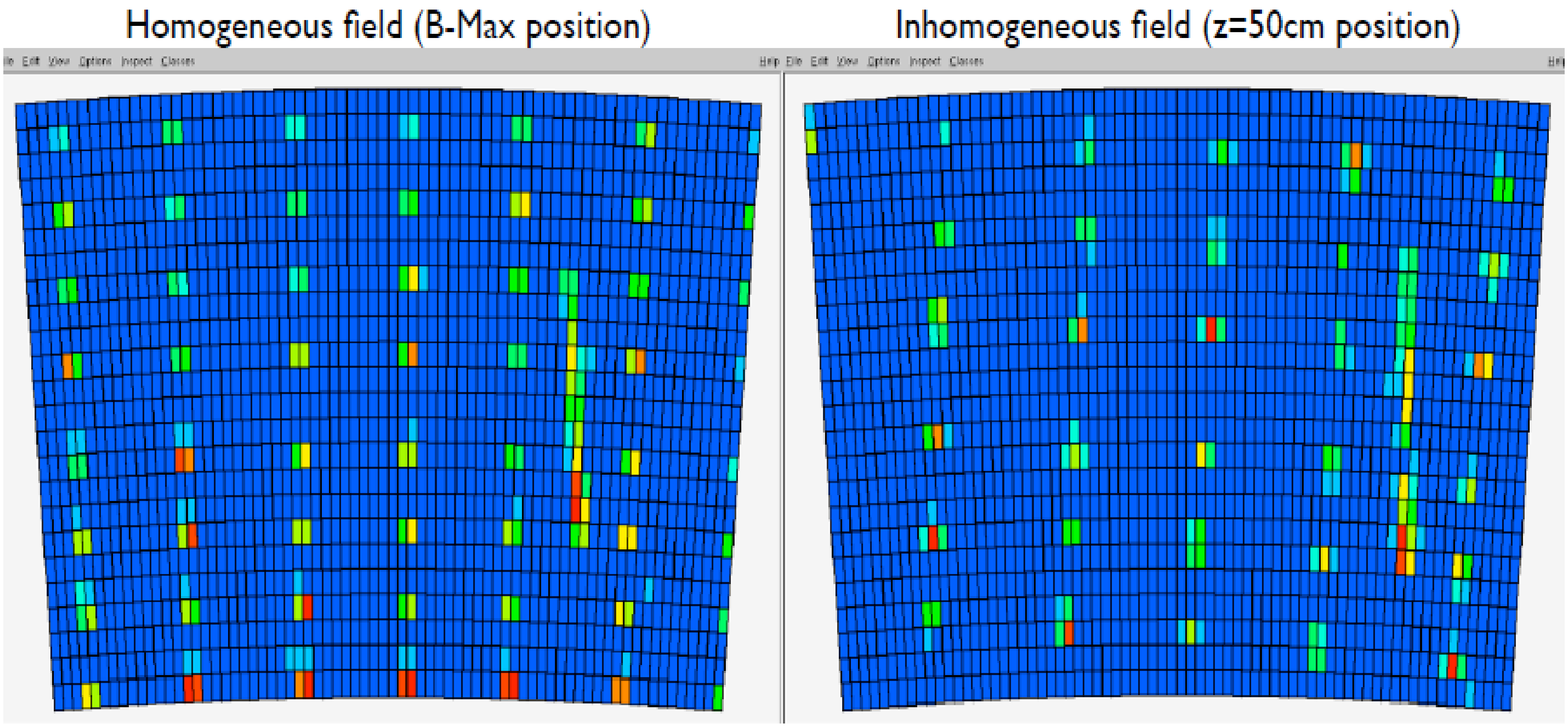
Pattern seen with Micromegas



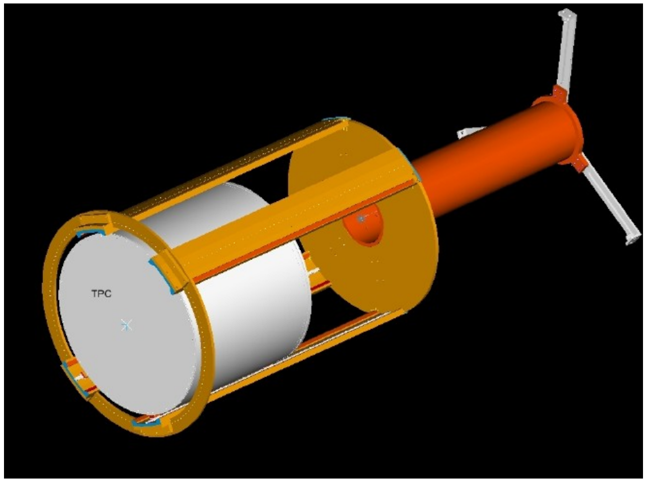
Laser Calibration Setup

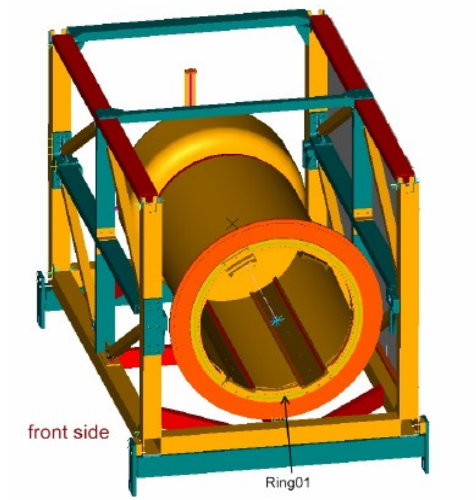
P. Conley
Victoria Univ.

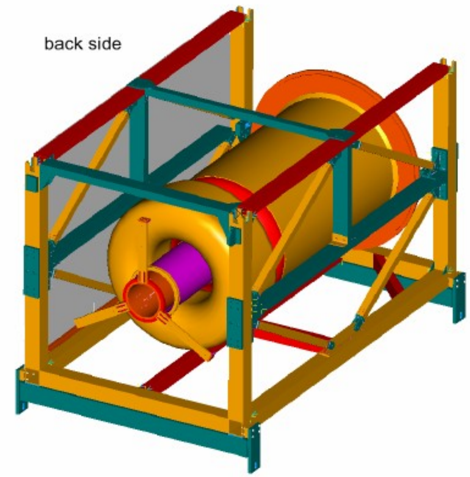
Distortions seen with MicroMegas module

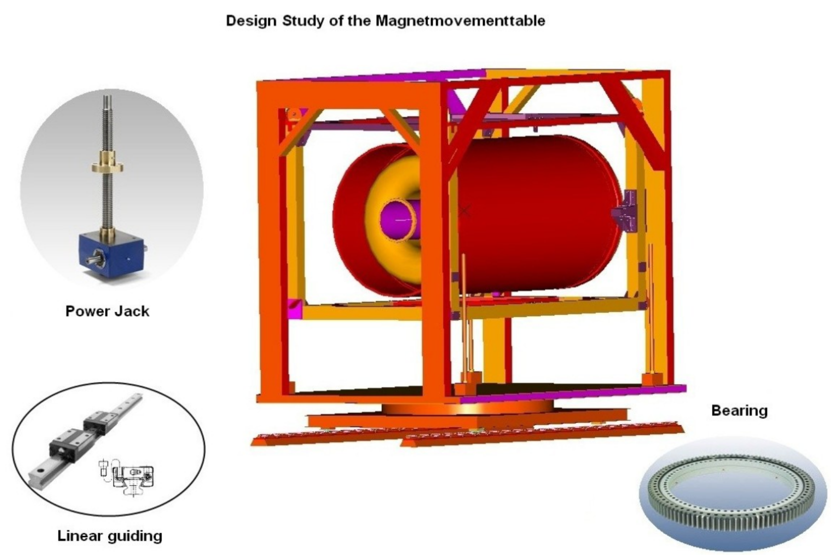


LP Mechanics





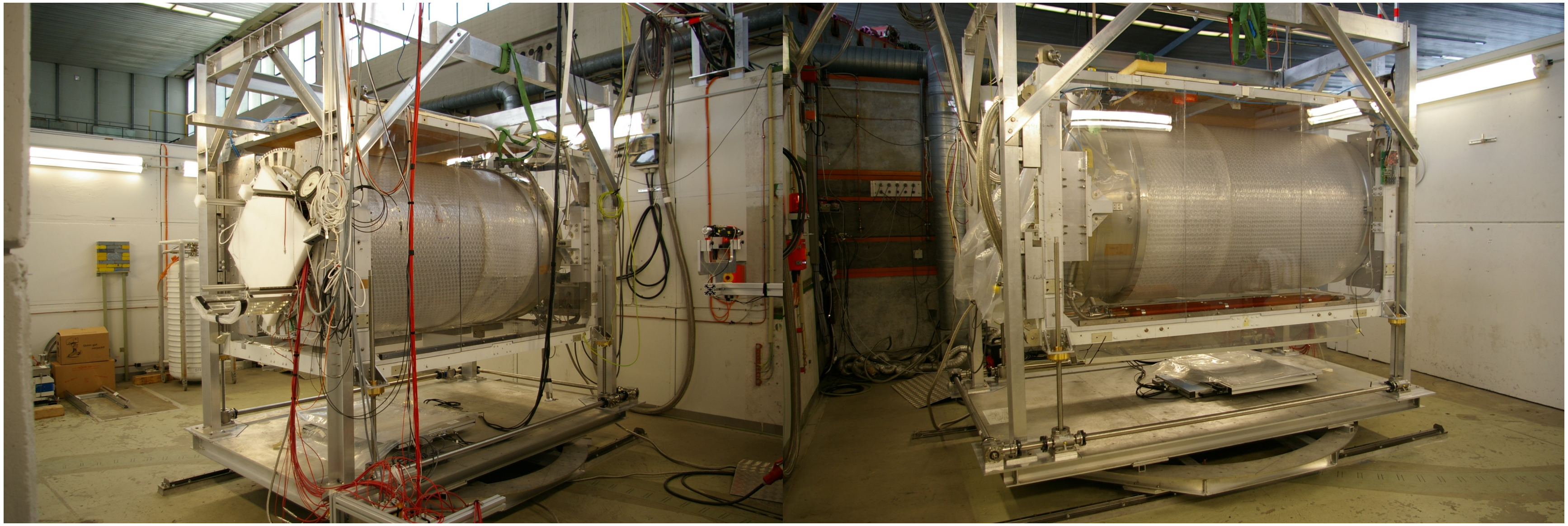




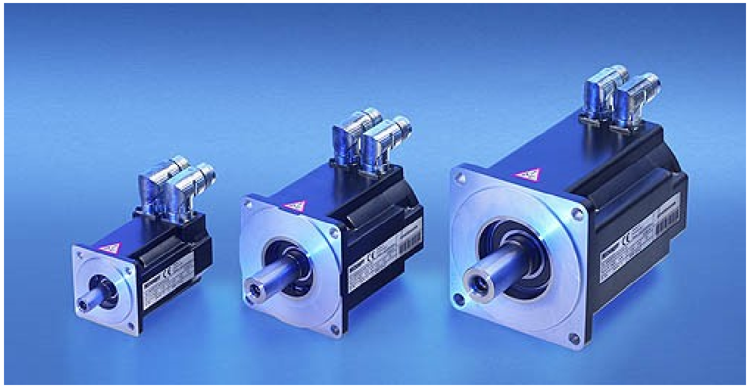
Support structures:

- TPC
- PCMAG

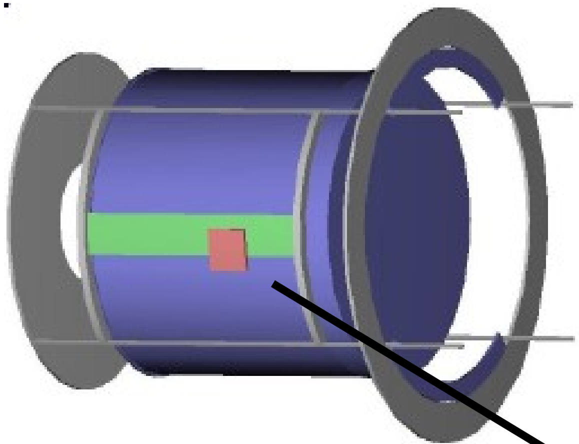
F. Hegner, V. Prahl, R. Volkenborn, DESY

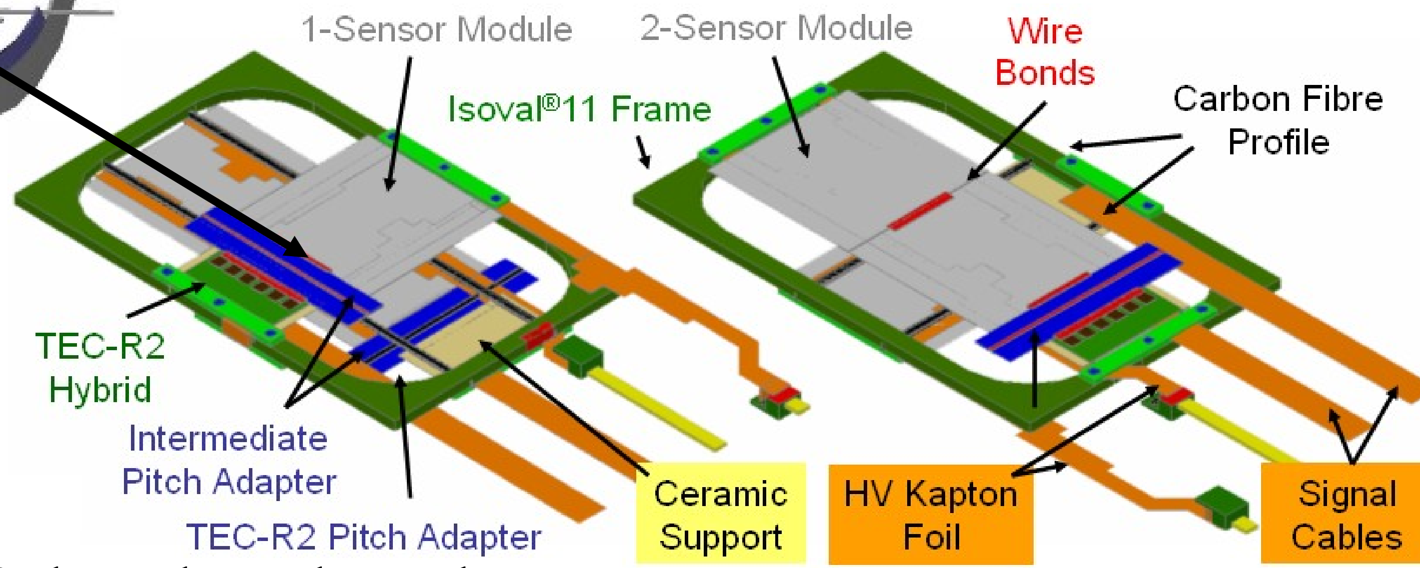


Actuation and Control



Si Envelope



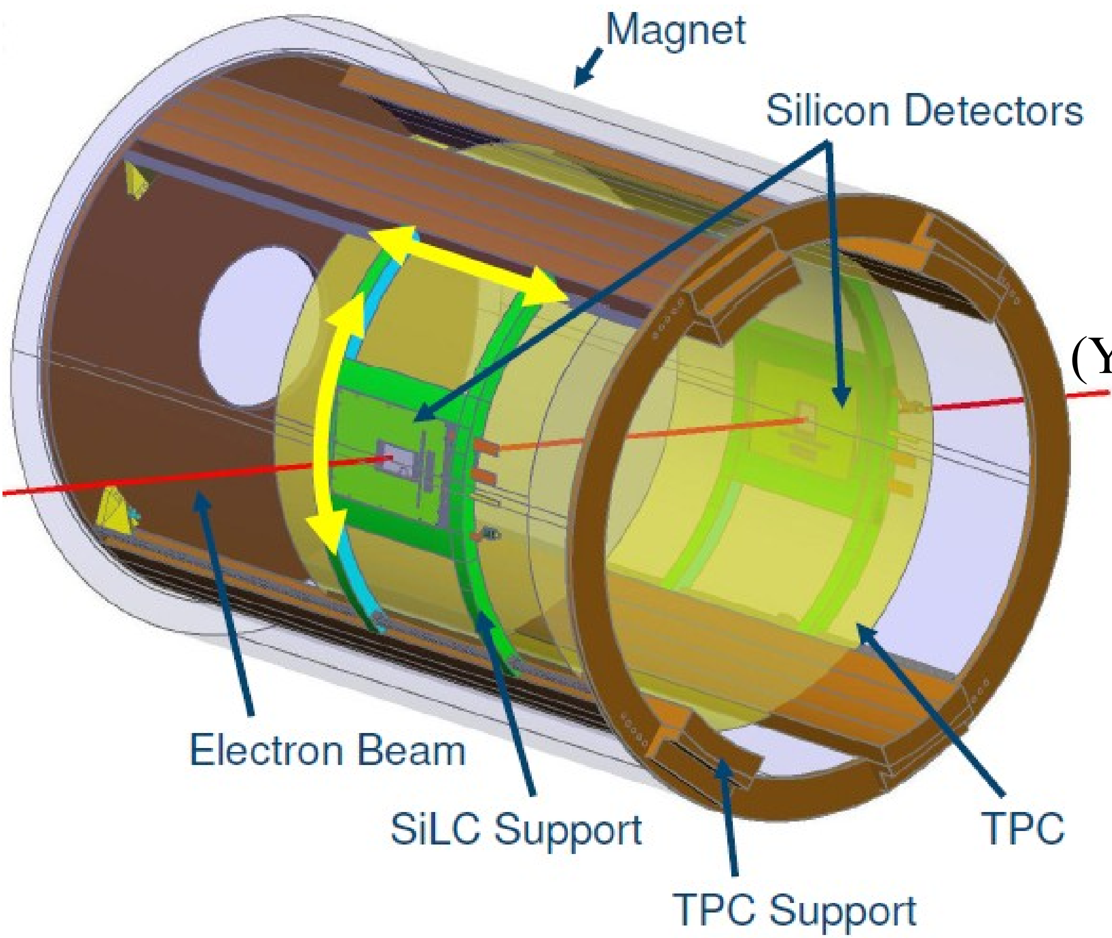


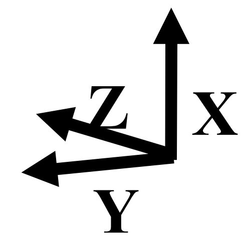
S. Haensel, HEPHY Vienna

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)

Si Envelope



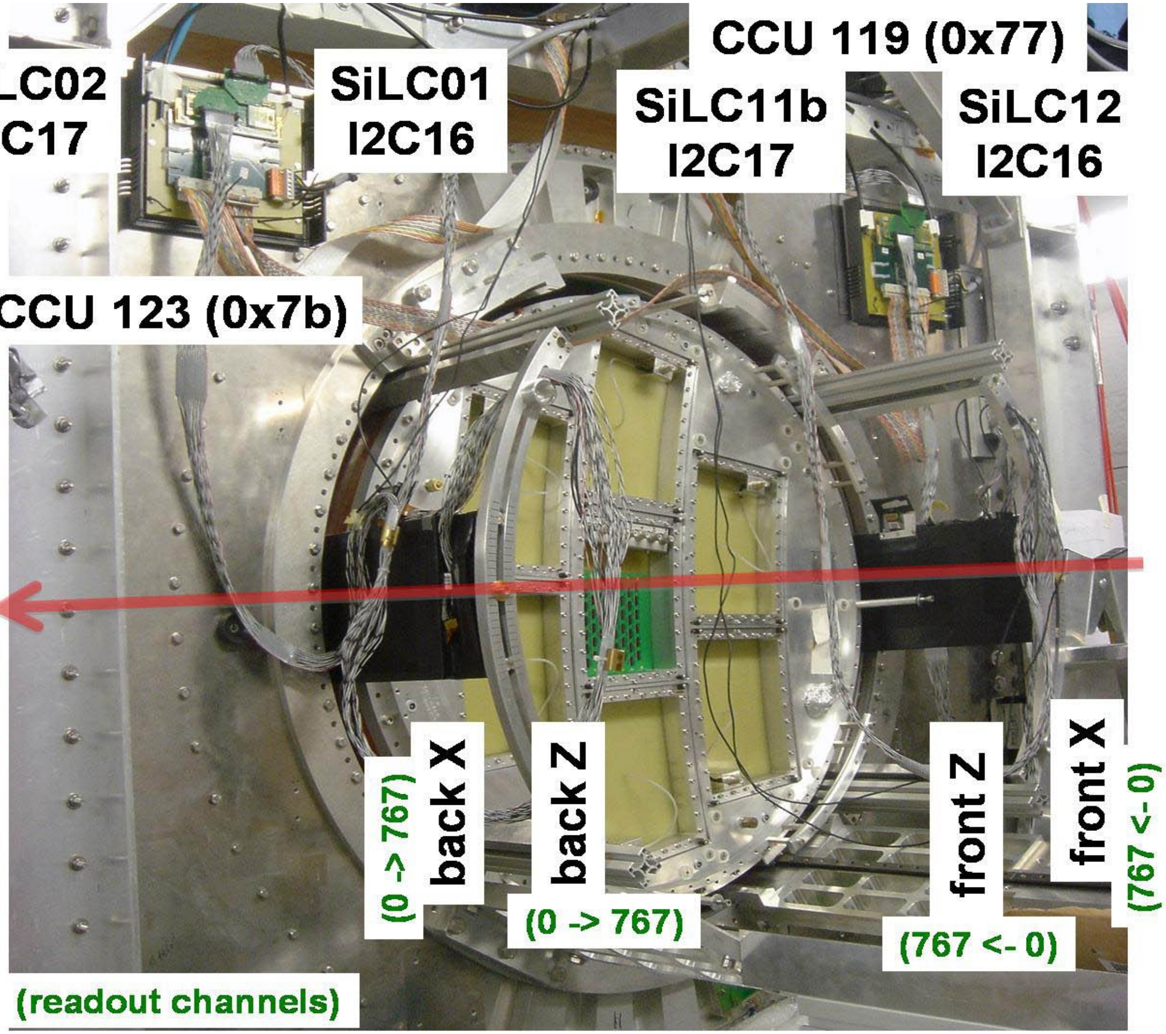


(Y = beam direction, Z = drift distance)

S. Haensel,
HEPHY
Vienna

Si Envelope

Geometry of the Silicon Sensors

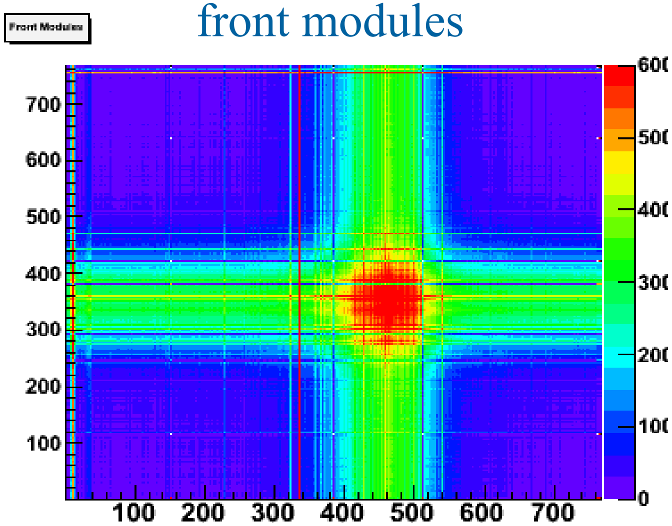


S. Haensel,
HEPHY
Vienna

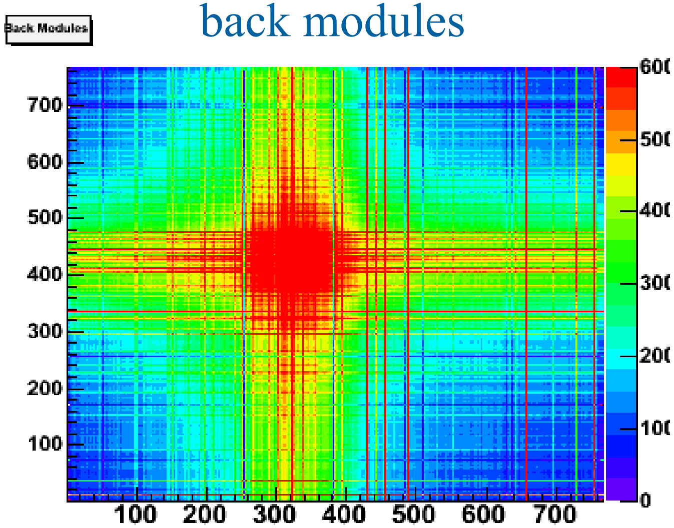
Si Envelope

first look at the data

front modules



back modules



Hit Profile of the 768 strips (50 µm pitch) of the silicon strip sensors - Run 20075 (42434 events)

x-axis = sensor which measures z

y-axis = sensor which measures x

-> for each cluster in the silicon sensors, the strip with the highest signal was counted

-> from the top plot the diameter of the beam can be determined to be about 5 mm

-> the bottom plot shows that we get quite a lot of (charged) secondary particles

Verified by looking at the mean number of clusters per event of the four silicon sensors:

front sensors ~ 1.4 clusters/events

back sensors ~ 2.8 clusters/events

S. Haensel, HEPHY Vienna

Standard CERN-GEM

10 x 10 cm^2 CERN GEM:

Flatness study

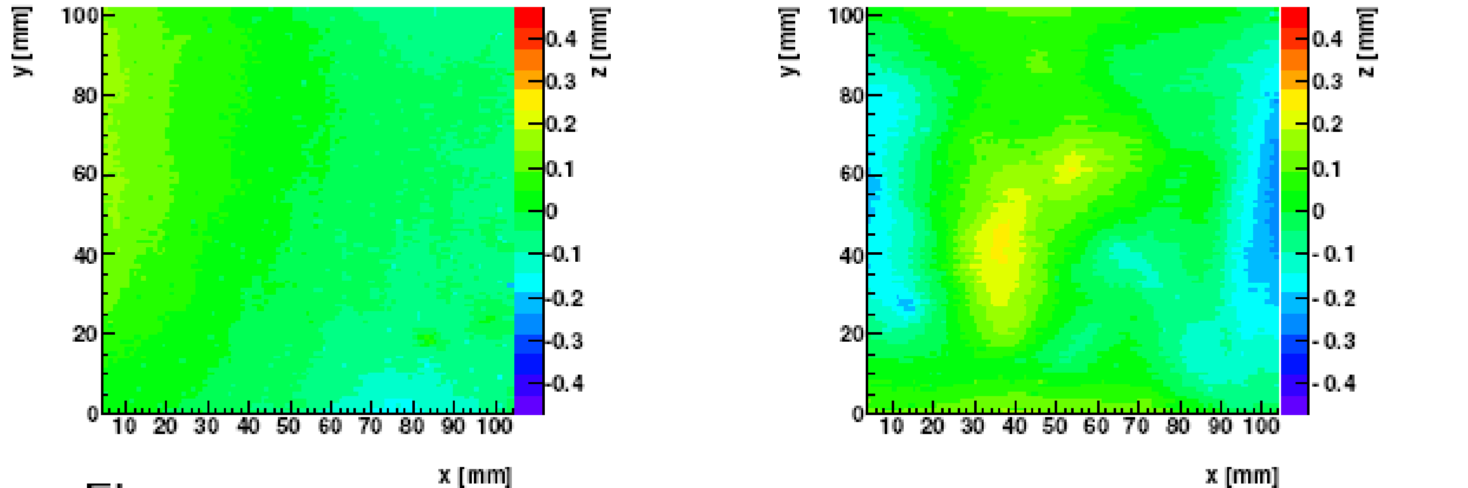


Figure: GEM 7 (Δz: 355 μm) - GEM 17 (Δz: 509 μm) - GRP frames

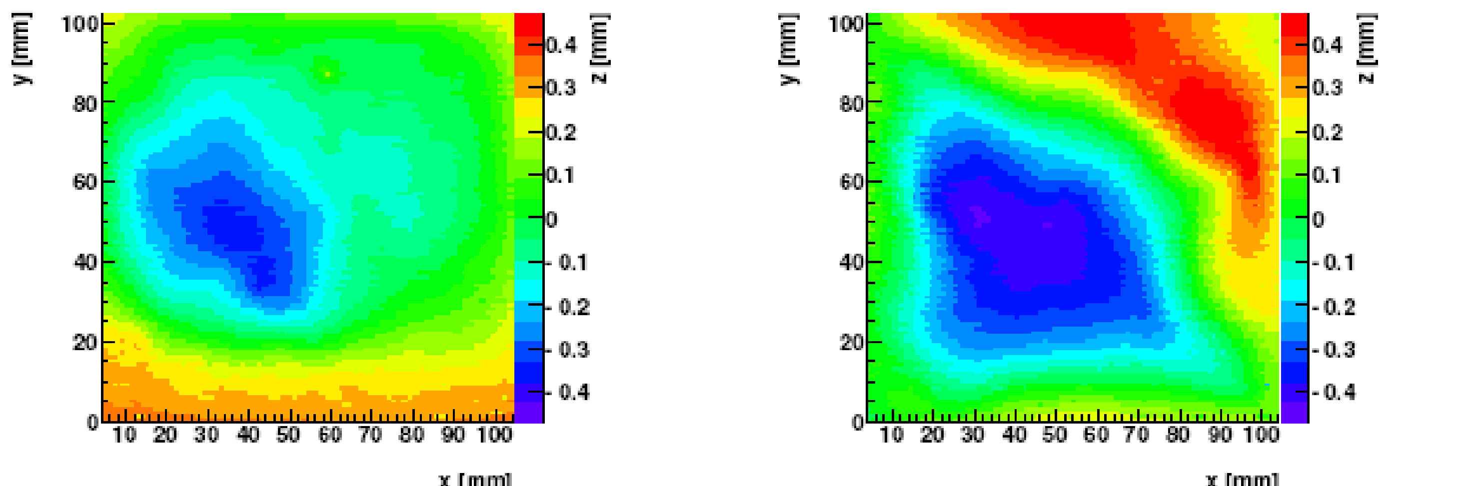


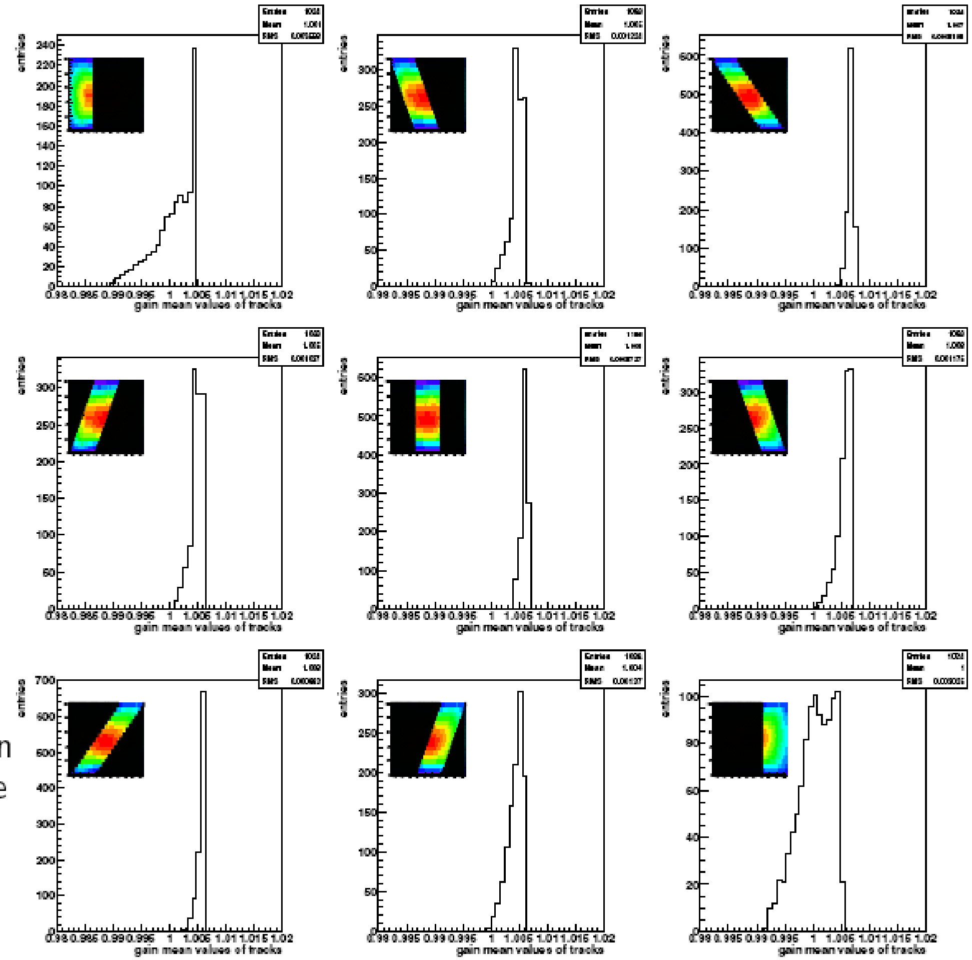
Figure: GEM 18 (Δz: 733 μm) - GEM 26 (Δz: 922 μm) - GRP frames

L. Hallermann, DESY

Standard CERN-GEM

region	mean value	RMS
left-left	1.001	0.36 %
left-mid	1.005	0.12 %
left-right	1.007	0.05 %
mid-left	1.005	0.10 %
mid-mid	1.006	0.06 %
mid-right	1.006	0.12 %
right-left	1.006	0.07 %
right-mid	1.004	0.14 %
right-right	1.000	0.30 %

Table: Mean values and root mean squares of averaged track gains in different regions. The RMS represents the fluctuation of the effective gain corresponding to tracks within one region.



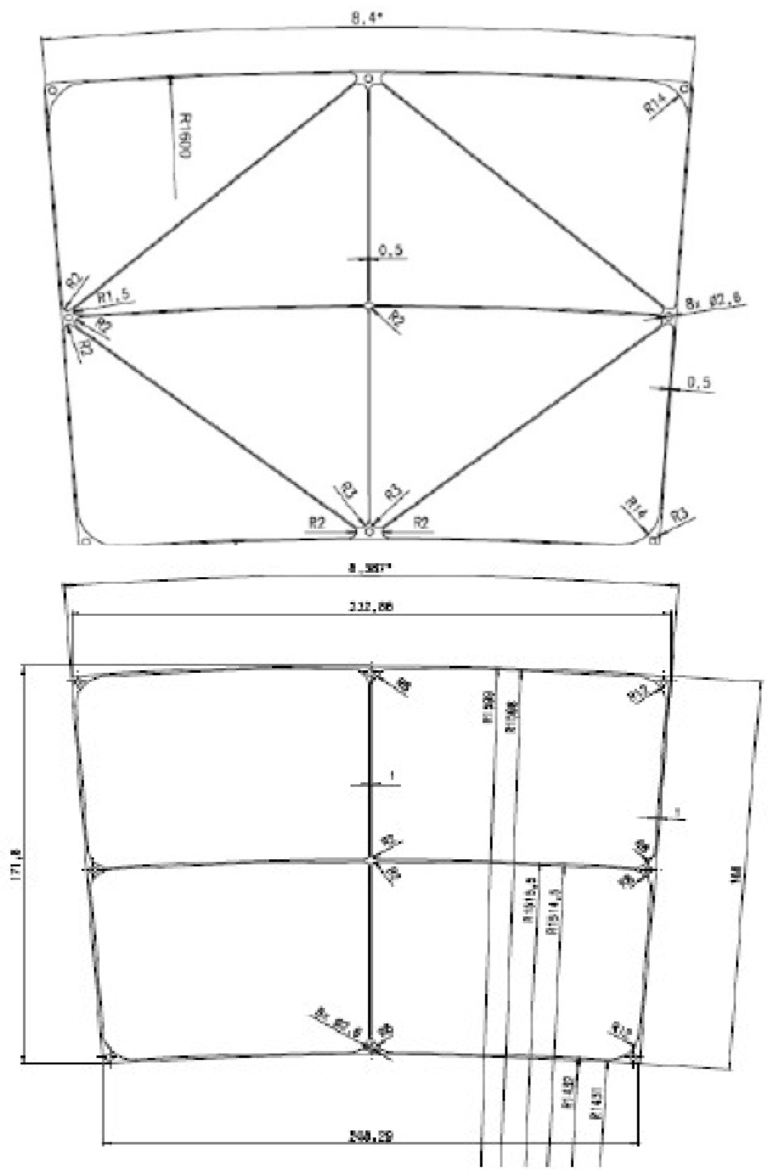
L. Hallermann, DESY

LP DESY-GEM Module

Design studies started

- Complete area coverage for LP module
- Standard CERN GEM:
  d = 70 µm
  p = 140 µm
  50 µm thick Kapton, each side covered with 5 µm Cu
- Ceramic frame
- Readout pads:
  (1.1 / 1.25) x (5.6 / 5.8) mm^2
  28 rows
- Gating GEM / wires optional

S. Caiazzo, DESY



Summary & Outlook

- A Large Prototype of a TPC has been built and is being assembled/tested/commissioned by the LCTPC collaboration
- Two MPGD technologies (with three electronics techniques) are being tested
- Infrastructure for Large Prototype has been constructed
- e^- test beam (DESY) in conjunction with PCMAG (*1T* magnet)
- Preliminary results are looking very promising
- Further test beam campaigns during this year:
  - Backplane integrated 10,000 channel readout system, based on ALTRO electronics → presently ongoing
  - Seven Micromegas modules with AFTER electronics attached to the modules
  - DESY GEM w/ ceramic grid

Summary & Outlook

Large Prototype R&D

Device	Lab(years)	Configuration
LP1	Desy(2007-2011)	Fieldcage⊕2 endplates: GEM+pixel, Micromegas+pixel
Purpose: Test construction techniques using ~10000 Altro or T2K channels to demonstrate measurement of 6 GeV/c beam momentum over 70cm tracklength, including development of correction procedures.		
LP1.5	Desy(2012)	Fieldcage⊕thinned endplate: GEM+pixel, Micromegas+pixel
Purpose: Continue tests using 10000 Altro or T2K channels to demonstrate measurement beam momentum over 70cm tracklength using LP1 thinned endplate. If possible, test a jet-like environment.		
LP2	FL*C*D*O/AidaTBC (after 2012)	Fieldcage⊕advanced-endcap prototype: GEM, Micromegas, or pixel
Purpose: Prototype for LCTPC endcap module design: mechanics, electronics, cooling, power pulsing, gating. Demonstrate measurement of high momentum.		

Study (in approximate order of priority)
•Continue tests in electron beam to perfect correction procedures
•Advanced endplate studies with max. 15% X0 including cooling
•Powerpulsing/cooling tests using both LP and SP
•Future tests in hadron beam (if possible) for momentum resolution and for performance in a jet environment
•Ion backflow simulations of ion sheets for Gem, Micromegas and design/test gating device

Summary & Outlook

Large Prototype R&D

Device	Lab(years)	Configuration
LP1	Desy(2007-2011)	Fieldcage⊕2 endplates: GEM+pixel, Micromegas+pixel
Purpose: Test construction techniques using ~10000 Altro or T2K channels to demonstrate measurement of 6 GeV/c beam momentum over 70cm tracklength, including development of correction procedures.		
LP1.5	Desy(2012)	Fieldcage⊕thinned endplate: GEM+pixel, Micromegas+pixel
Purpose: Continue tests using 10000 Altro or T2K channels to demonstrate measurement beam momentum over 70cm tracklength using LP1 thinned endplate. If possible, test a jet-like environment.		
LP2	FL*C*D*O/AidaTBC (after 2012)	Fieldcage⊕advanced-endcap prototype: GEM, Micromegas, or pixel
Purpose: Prototype for LCTPC endcap module design: mechanics, electronics, cooling, power pulsing, gating. Demonstrate measurement of high momentum.		

Study (in approximate order of priority)
•Continue tests in electron beam to perfect correction procedures
•Advanced endplate studies with max. 15% X0 including cooling
•Powerpulsing/cooling tests using both LP and SP
•Future tests in hadron beam (if possible) for momentum resolution and for performance in a jet environment
•Ion backflow simulations of ion sheets for Gem, Micromegas and design/test gating device

Summary & Outlook

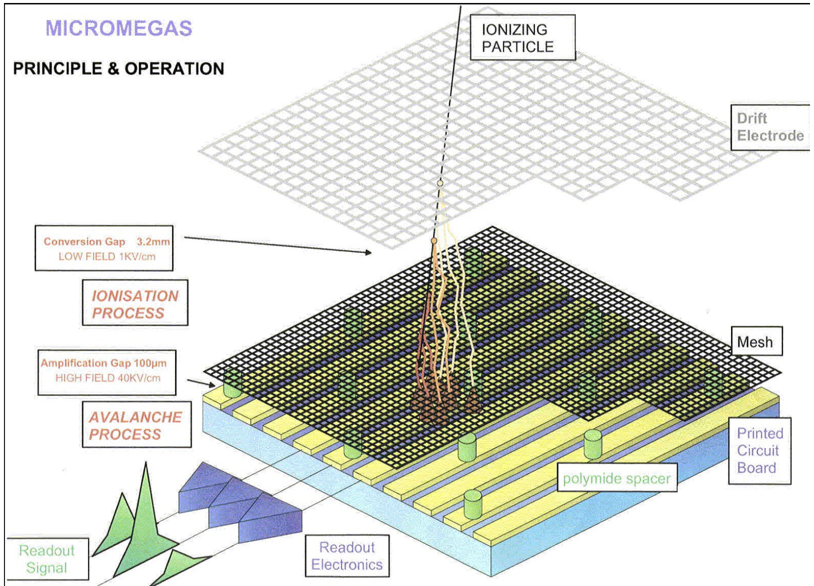
Large Prototype R&D

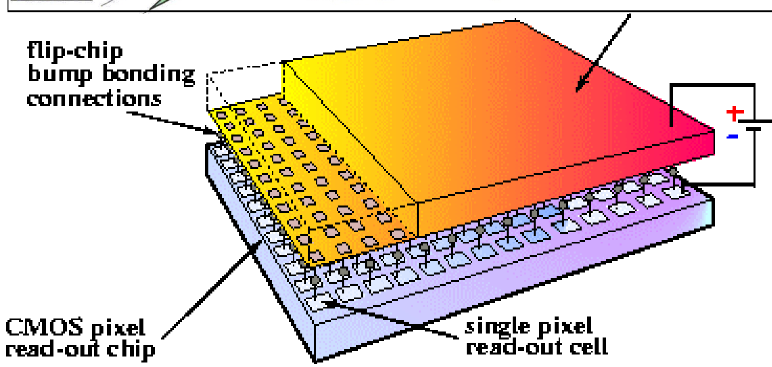
Device	Lab(years)	Configuration
LP1	Desy(2007-2011)	Fieldcage⊕2 endplates: GEM+pixel, Micromegas+pixel
Purpose: Test construction techniques using ~10000 Altro or T2K channels to demonstrate measurement of 6 GeV/c beam momentum over 70cm tracklength, including development of correction procedures.		
LP1.5	Desy(2012)	Fieldcage⊕thinned endplate: GEM+pixel, Micromegas+pixel
Purpose: Continue tests using 10000 Altro or T2K channels to demonstrate measurement beam momentum over 70cm tracklength using LP1 thinned endplate. If possible, test a jet-like environment.		
LP2	FL*C*D*O/AidaTBC (after 2012)	Fieldcage⊕advanced-endcap prototype: GEM, Micromegas, or pixel
Purpose: Prototype for LCTPC endcap module design: mechanics, electronics, cooling, power pulsing, gating. Demonstrate measurement of high momentum.		

Study (in approximate order of priority)
•Continue tests in electron beam to perfect correction procedures
•Advanced endplate studies with max. 15% X0 including cooling
•Powerpulsing/cooling tests using both LP and SP
•Future tests in hadron beam (if possible) for momentum resolution and for performance in a jet environment
•Ion backflow simulations of ion sheets for Gem, Micromegas and design/test gating device

Backup Slides

TimePix





- High field created by Gas Gain Grids
- Most popular: GEM and Micromegas

Use 'naked' CMOS pixel readout chip as anode

J. Timmermans
NIKHEF

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:
  ASDQ chip + TDC (EUDET & Uni Rostock)

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

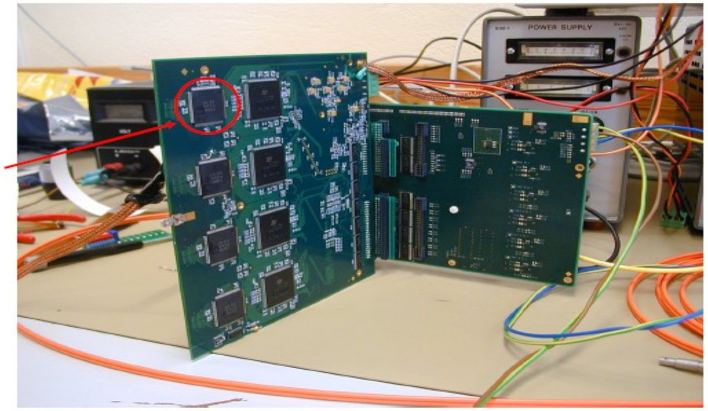
Readout Electronics: ALTRO

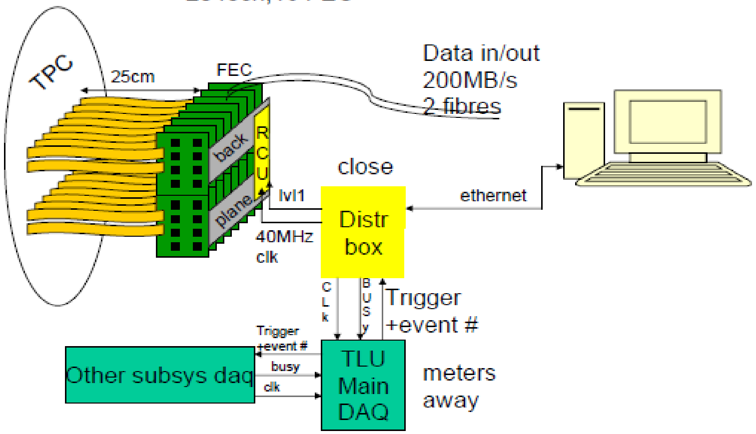
PCA16:

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

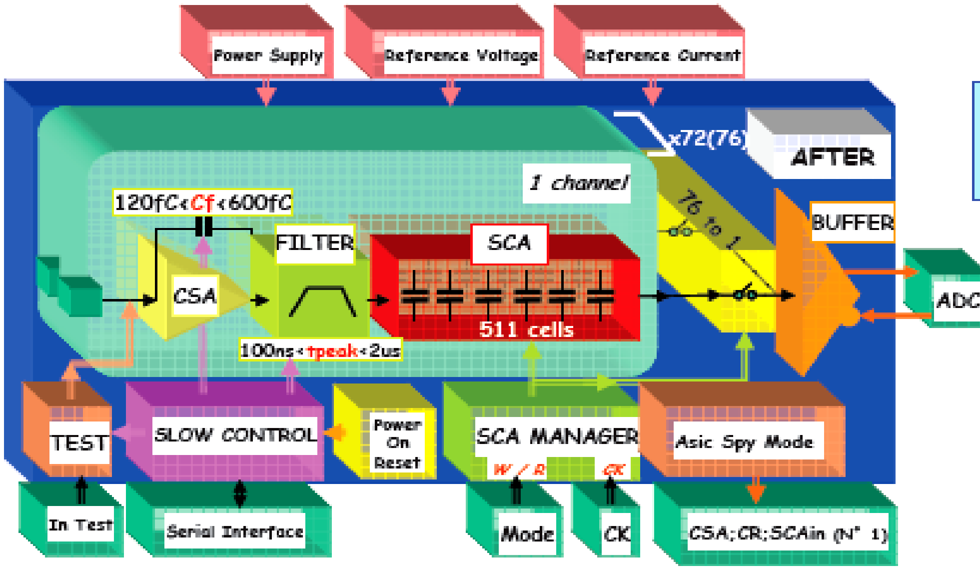




Readout Electronics: AFTER

AFTER Main Features

dapnia
cea
saclay

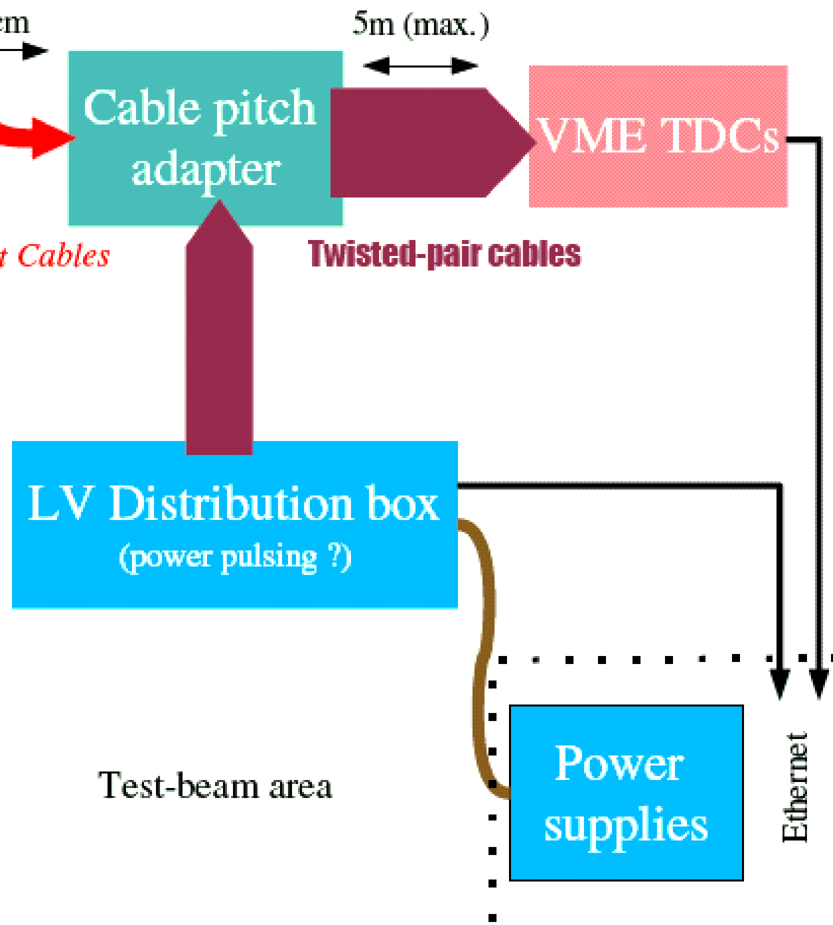


- No zero suppress.
- No auto triggering.
- No selective readout.

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

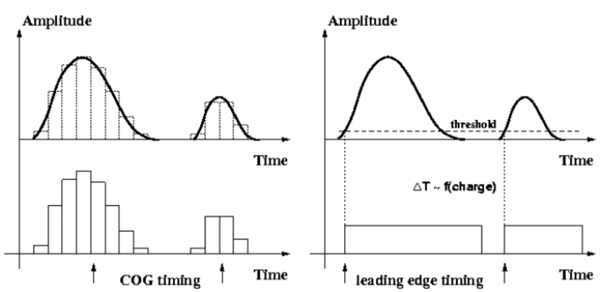
LCTPC meeting Oct. 10, 2007 *E. DELAGNES* 4



32 channels
Board size: 30 mm x 100mm*

Boards will be installed directly onto the endplate.

TPC signal processing with Time-to-Digit Converter

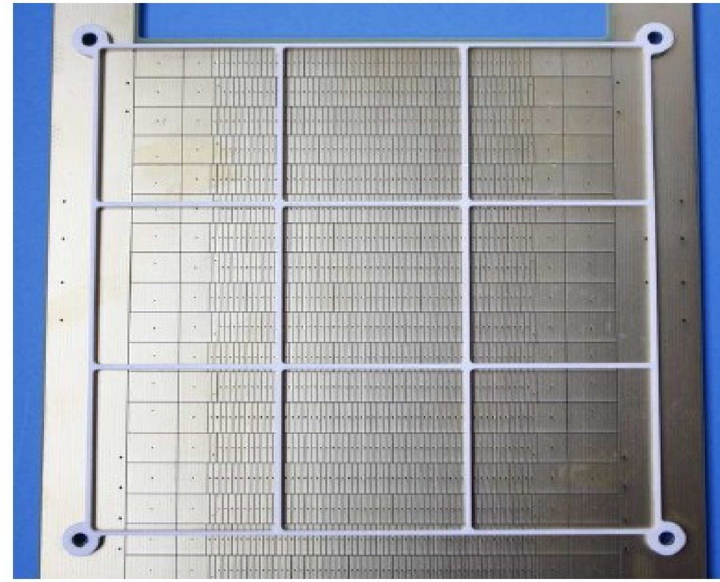


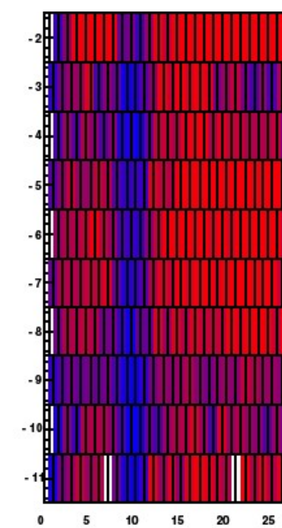
- **The time of arrival is derived using the leading edge discriminator.**
- **The charge of the input signal is encoded into the width of output digital pulse.**

A. Kaukher, Univ. Rostock

Standard CERN-GEM

- triple grid GEM
- sensitive volume
  $10 \times 10 \times 66\,\text{cm}^3$
- pad size: $1,27 \times 7\,\text{mm}^2$
- 12 rows, 48 pads
- cosmics
- 95% Argon, 5% CH_4
- magnetic field up to 4 T

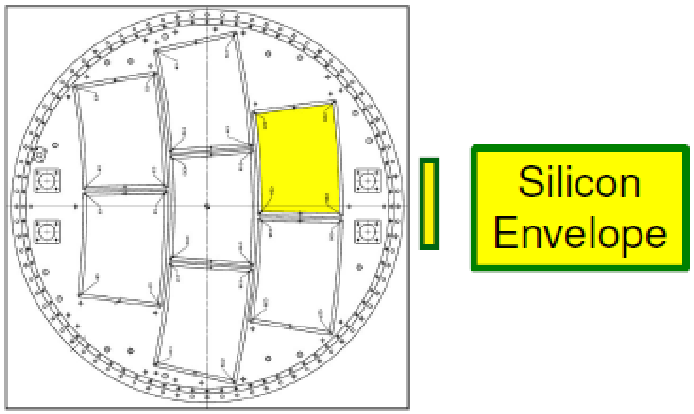


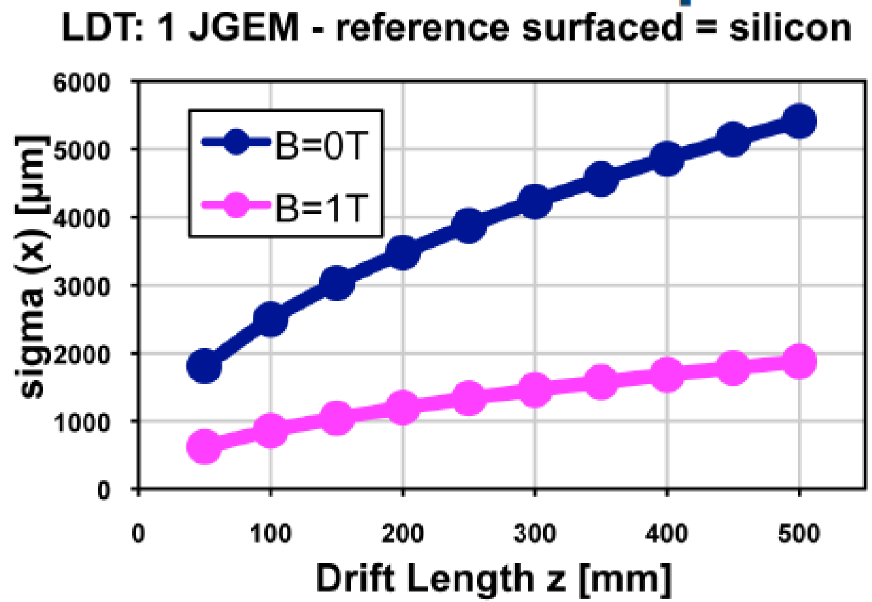


L. Hallermann, DESY

Alignment of TPC and Silicon Envelope

One JGEM – reference surface = silicon envelope





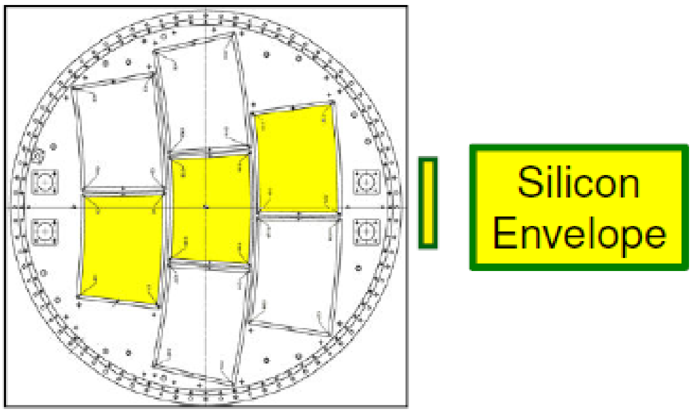
	sigma (x) [µm]	
z [mm]	B=0T	B=1T
50	1813.286	622.096
100	2499.653	859.056
150	3031.417	1043.438

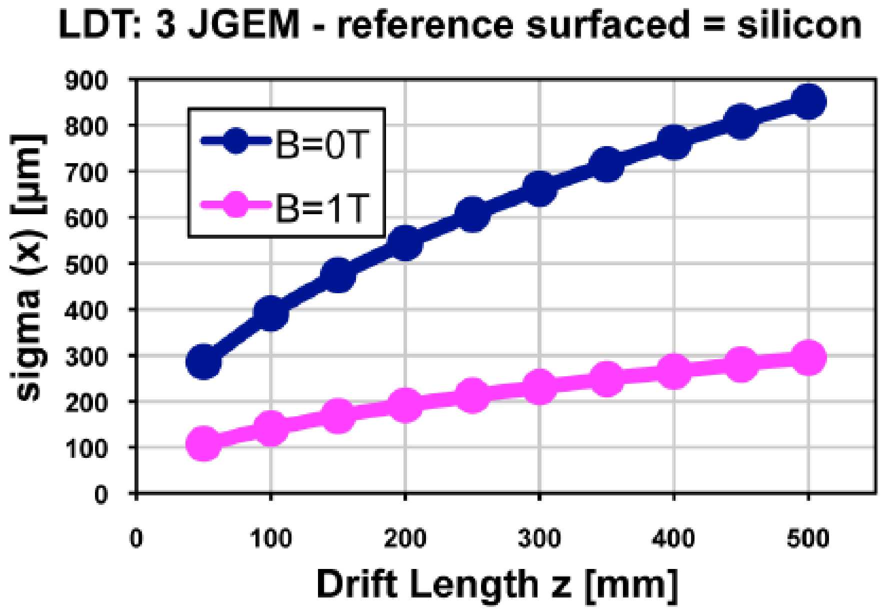
At z=50mm (B=1T): to achieve a resolution on the silicon plane of 2µm ~ 100000 and of 1µm ~ 400000 tracks are needed,

You must consider that only statistical errors are regarded!!!

Alignment of TPC and Silicon Envelope

Three JGEM – reference surface = silicon envelope





	sigma (x) [µm]	
z [mm]	B=0T	B=1T
50	285.915	106.845
100	391.359	140.795
150	473.88	168.007
500	851.011	294.98

At z=50mm (B=1T): to achieve a resolution on the silicon plane of 2µm ~ 3000 and of 1µm ~ 12000 tracks are needed,

In this configuration systematic errors will dominate!