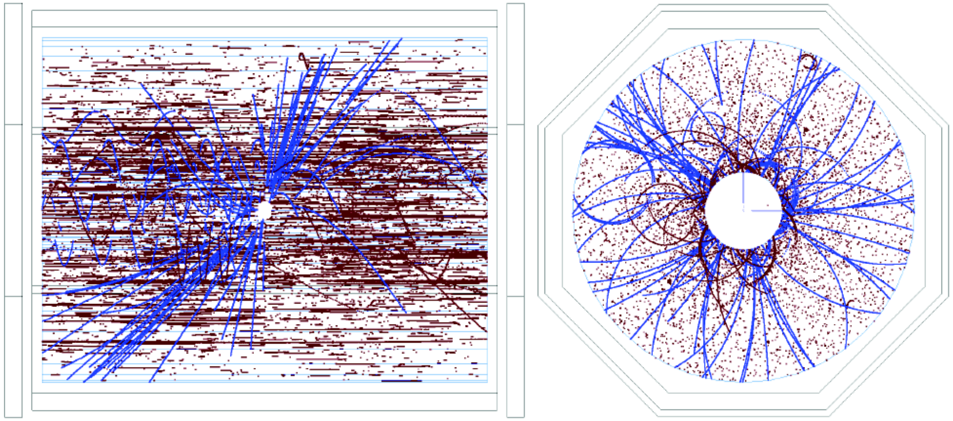
A TPC for the Linear Collider

J. Kaminski
For the LCTPC-collaboration

ILD workshop
Fukuoka, Japan
23.-25. May 2012

Requirements



Momentum resolution: $\delta(1/p_t) < 9\times10^{-5}$ GeV/c

→ Spatial resolution: $\sigma(r\varphi) < 100\ \mu m$
$\sigma(z) < 500\ \mu m$

97 % tracking efficiency for TPC only (with background) for $p_t > 1$ GeV/c

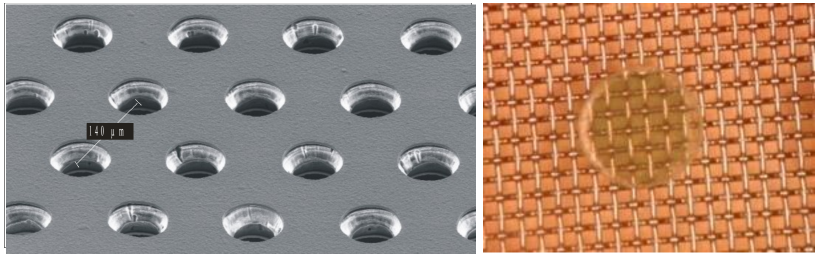
2-hit resolution: < 2 mm($r\varphi$) and < 6 mm(z)

dE/dx resolution: ~ 5%

Material budget: 0.05 X_0 to outer field cage,
0.25 X_0 endcaps

Different Gas amplification and readout concepts are being studied for TPC applications:

1.) Micromegas with resistive layer on pads
2.) GEMs with pad readout
3.) InGrids: Micromegas on top of highly pixelized CMOS chips
4.) GEMs with highly pixelized CMOS chips



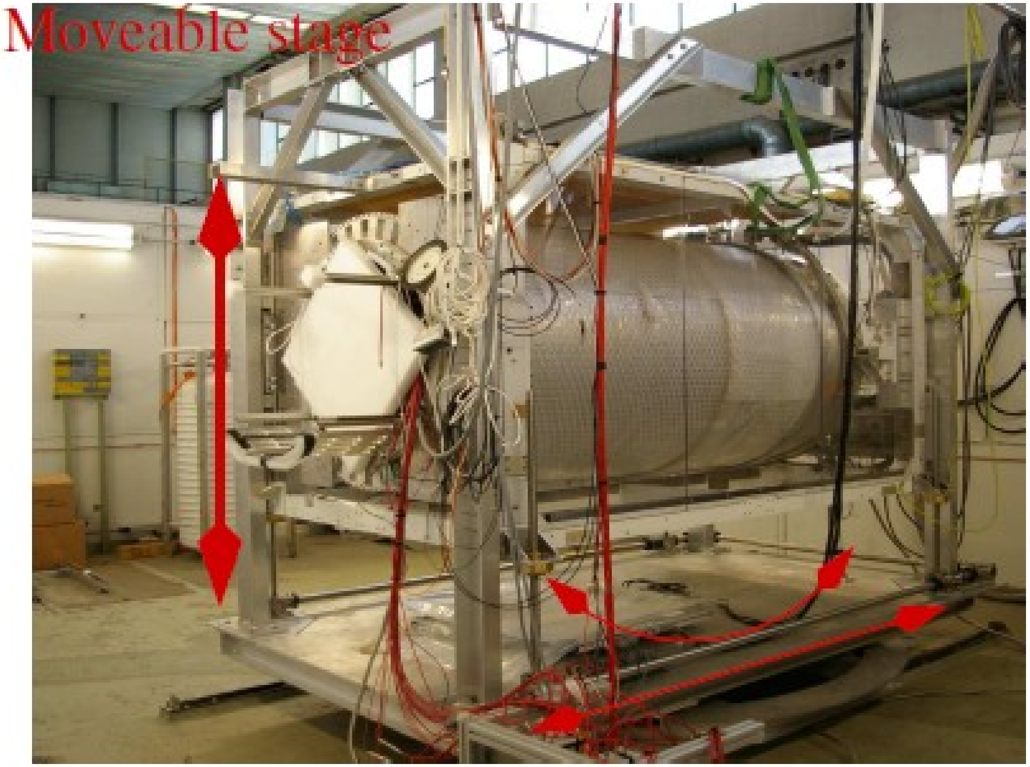
EUDET Test Facility

Medium size prototype to compare different detector readouts under identical conditions and to address integration issues.

Test facility for TPC-R&D was set up at DESY test beam area T24a:

- Electron test beam
  with beam energy 1-6 GeV
- Beam trigger
- Movable support structure
- PCMAG: Solenoid with B < 1.25 T
- Field cage
- Cathode
- End plate with space for 7 modules
- Readout electronics
- Slow control
- External Si-trackers in discussion

→ EUDET financed a significant fraction of setup



Modification PCMAG

Superconducting solenoid without return yoke → low material budget

Some B-field distortions

→ good to understand influence of distortions on measurements

<u>Before the modification:</u>

Conduction cooling by LHe in reservoir tank (in green)

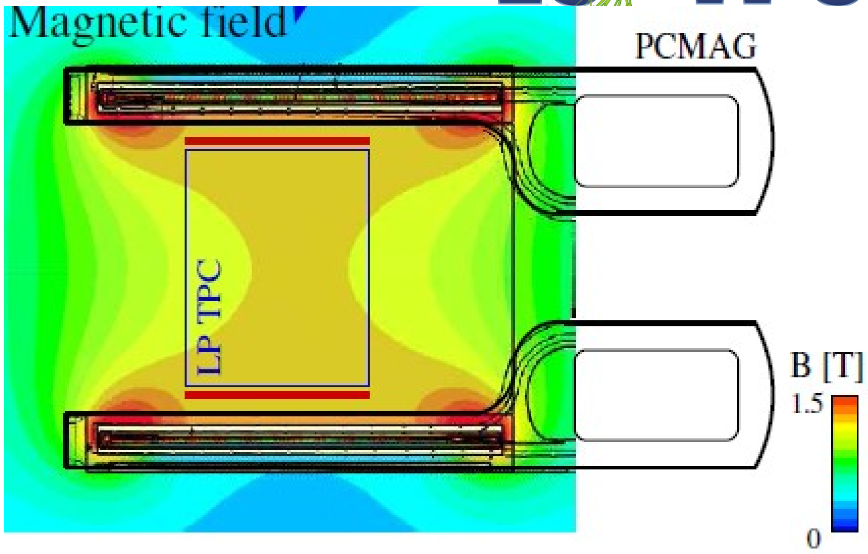
Magnet had to be refilled with LHe every ~2 weeks by hand

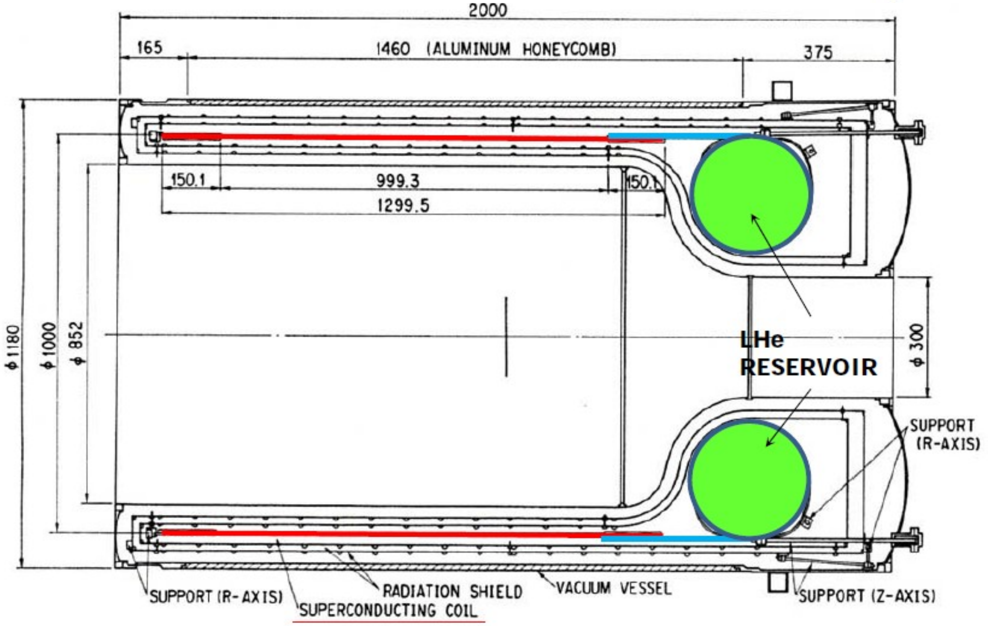
Over time also air got into the tanks → pipes were clocked with frozen N_2, O_2, H_2O,....

<u>After the modification:</u>

Conduction cooling by 2 cryocoolers at 4 K and 10 K.

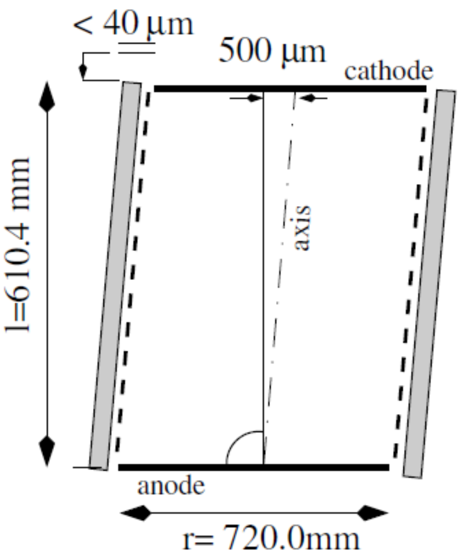
The reservoir tank remains a heat sink.

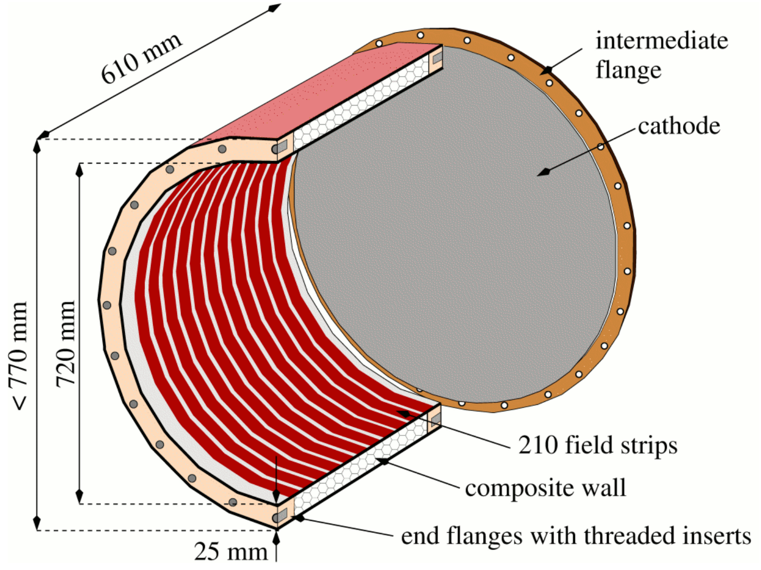




Large Prototype – Field Cage

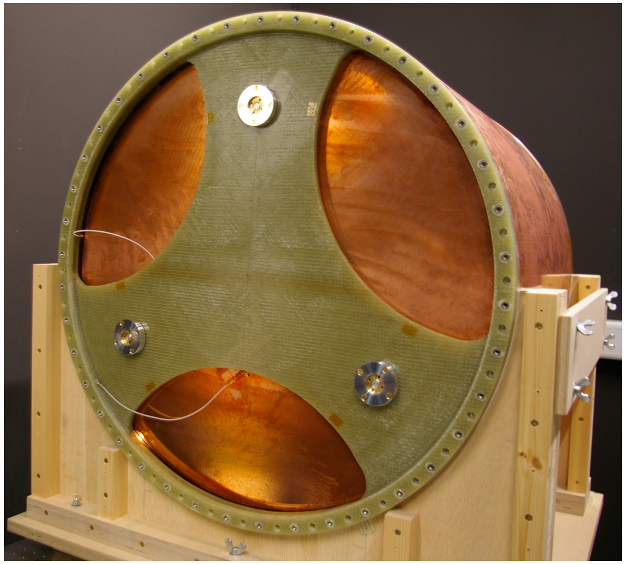
LP Field Cage Parameter:
Length = 61 cm
Inner diameter = 72 cm
Up to 25 kV at the cathode
=> Drift field: E ≈ 350 V/cm
Made of composite materials
=> Material budget: 1.24 % X_0



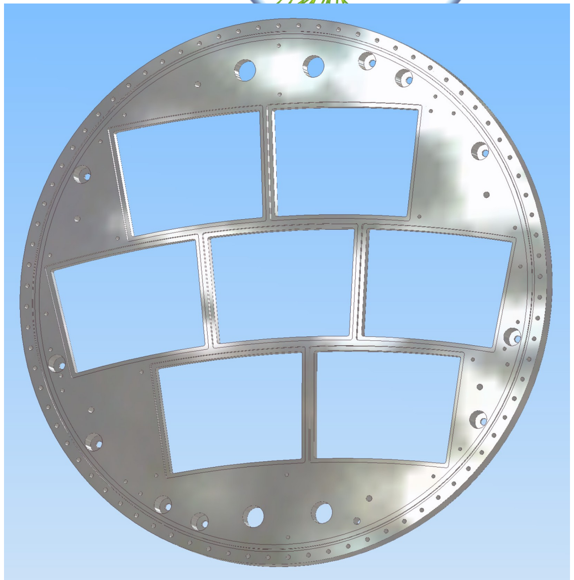


Mechanical accuracy

- Alignment of the end faces: δ < 40 µm
- Alignment of the field cage axis: offset at cathode ~500 µm

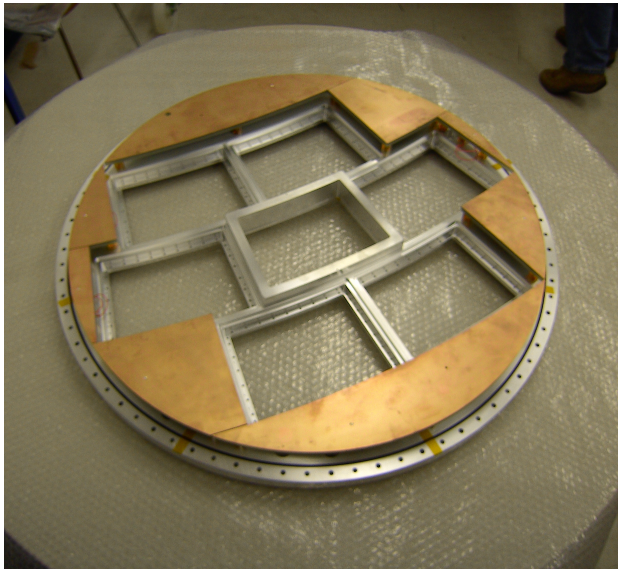


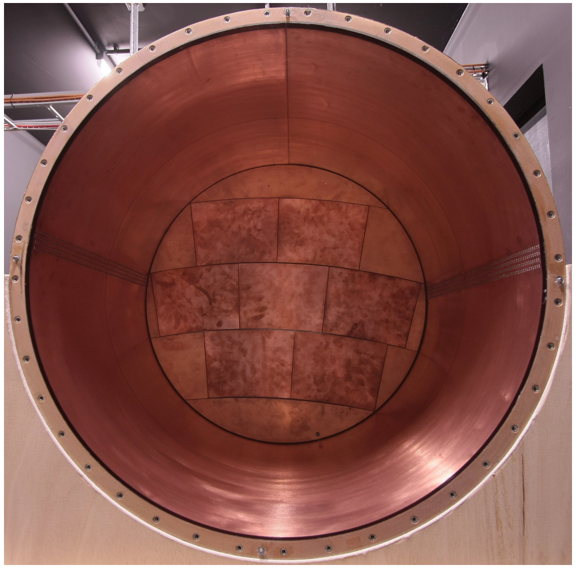
Large Prototype – End Plate



Modular End Plate

- First end plate for the LP made from solid Al
- During production the end plate was two times 'cold shocked' (cooled with liquid Nitrogen) to reduce stress.
- 7 module windows of size ≈ 22 × 17 cm^2
- Accuracy on the level of 30 µm
- Not designed to meet material budget requirements (weighs 18.87 kg → 16.9 % X_0)





J. Kaminski
ILD workshop
Fukuoka, May 2012

New End Plate

Material budget requirement for final end plate: 8% X_0

→ Finite Element Analysis of final end plate

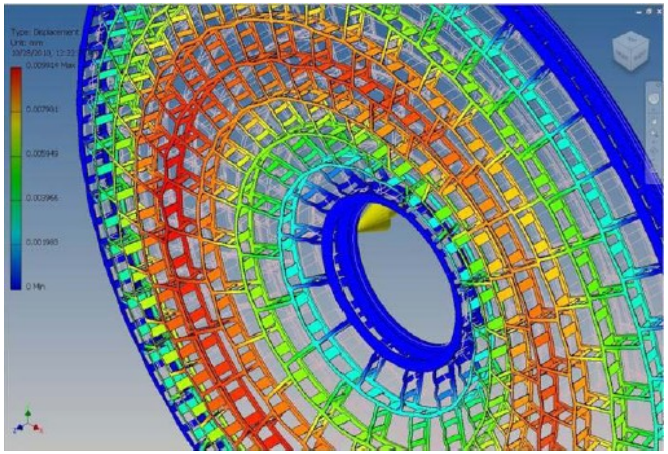
Deflection of 220 μm for overpressure of 2.1 mbar

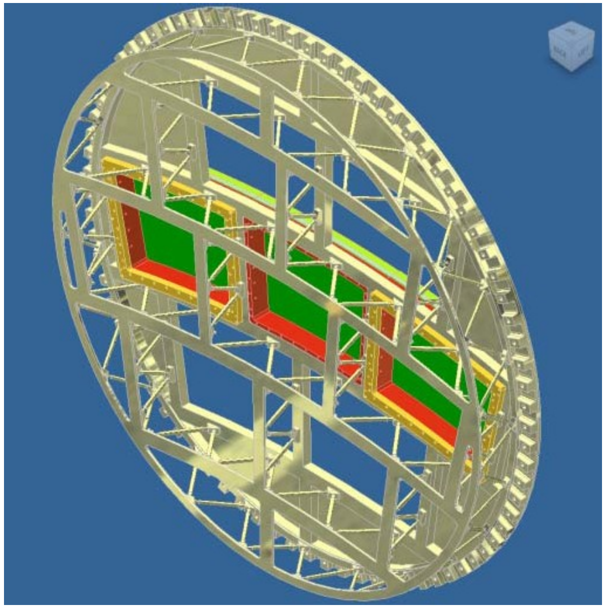
Several materials and designs have been studied

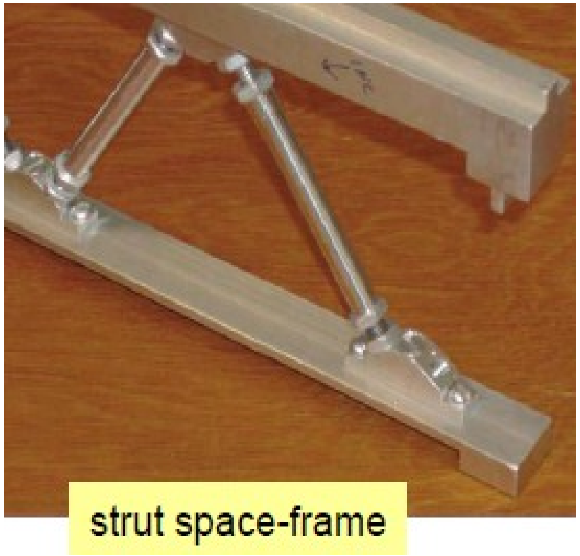
Strut space-frame design provides greatest strength-to-material.

Second end plate for LP designed and built (8.8 kg)

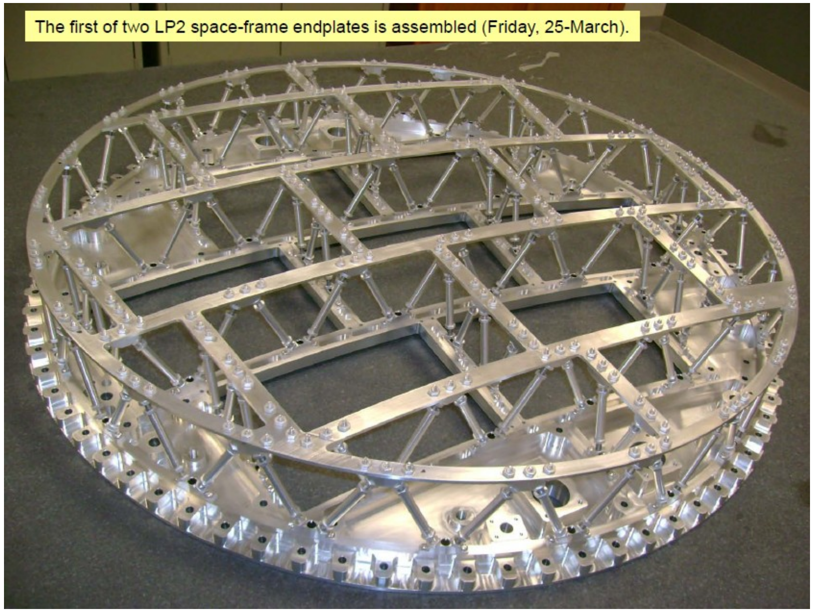
Preliminary measurements of deflection are very close to requirements



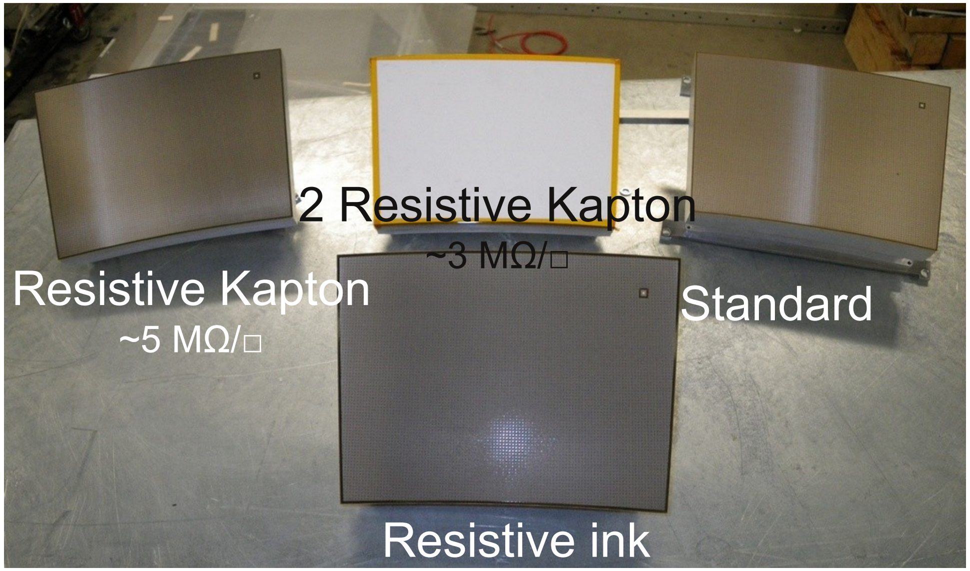


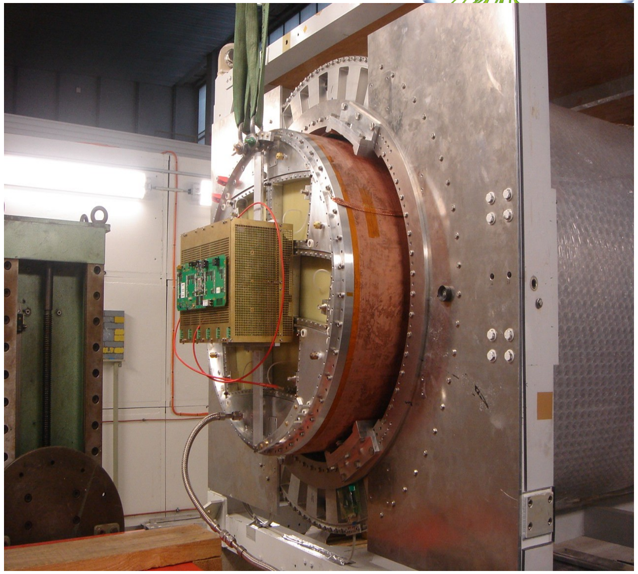


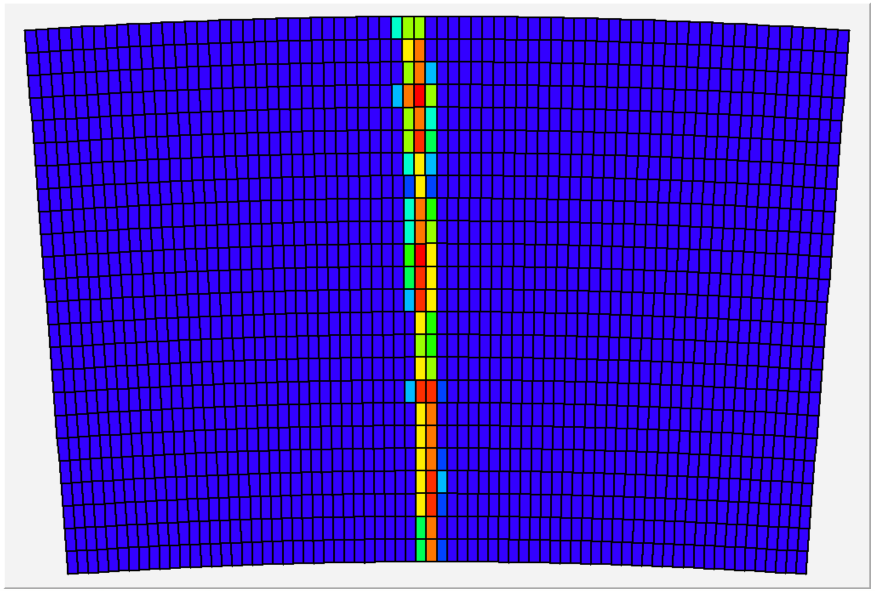
test structure


The first of two LP2 space-frame endplates is assembled (Friday, 25-March).

Micromegas Modules



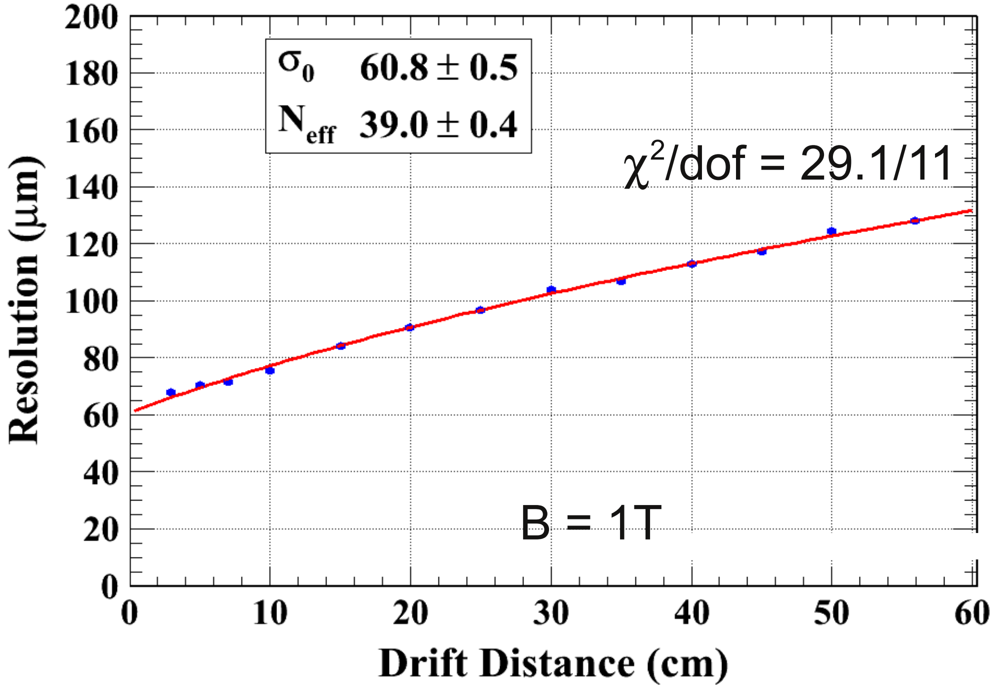


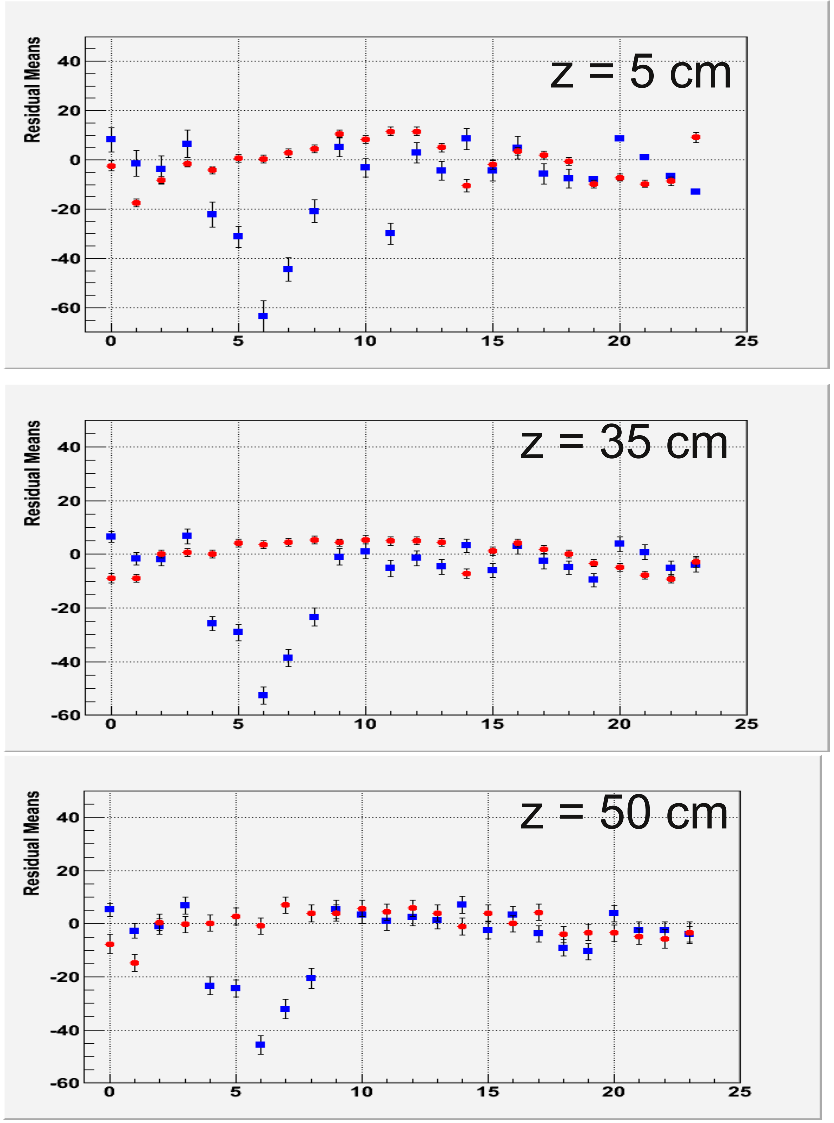


<u>Micromegas Module</u>

- 3×7 mm^2 large pads
- 24 row with 72 pads
  → 1728 pads per module
- Testing various resistive layers
  carbon loaded kapton, resistive ink
  O(1MΩ/□))
- AFTER electronics (T2K)

Performance of Micromegas Modules





Mean of residuals vs row number for resistive ink and CLK

Results (CLK Modules)

Resolution $\sigma = \sqrt{\sigma_0^2 + D_t^2/N_{eff} \cdot z}$

Combining results (e.g. B = 0T, B = 1T):

→ $\sigma_0 = 59 \pm 2\ \mu m$

→ $N_{eff} = 38 \pm 0.8$ per pad height

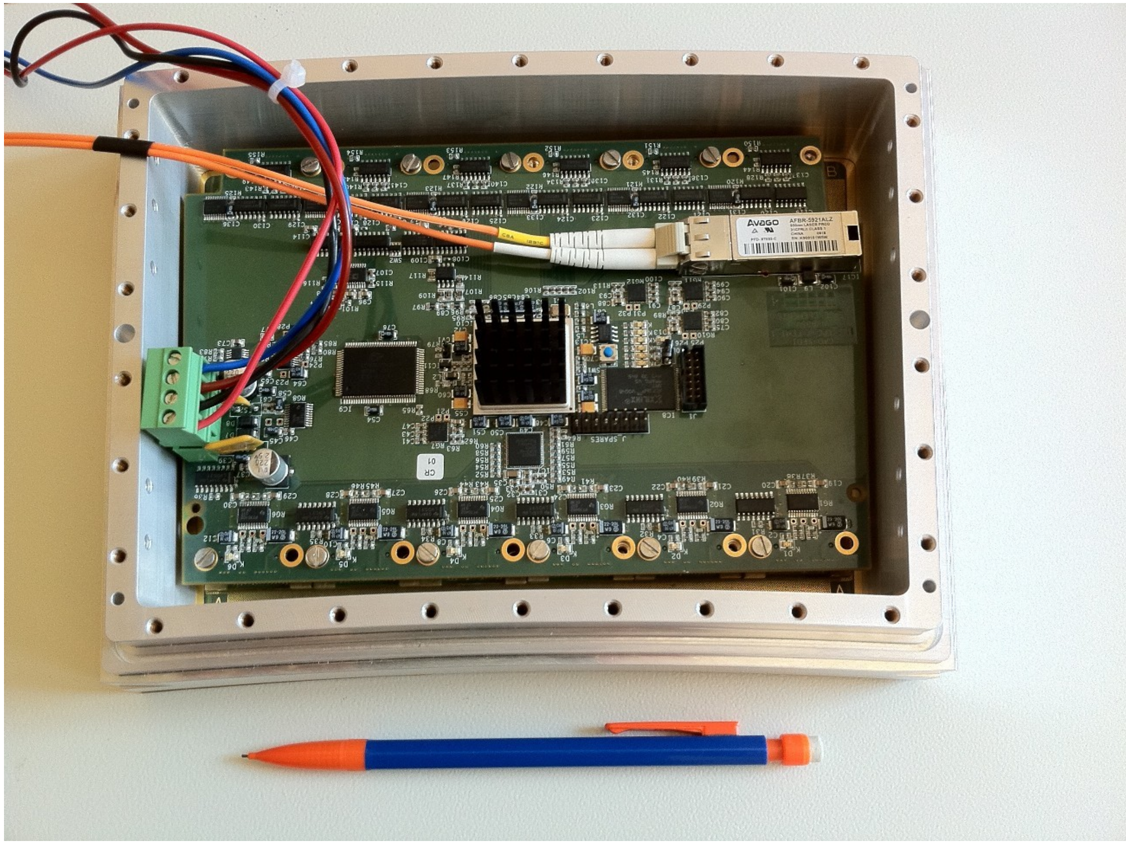
9 Micromegas Modules

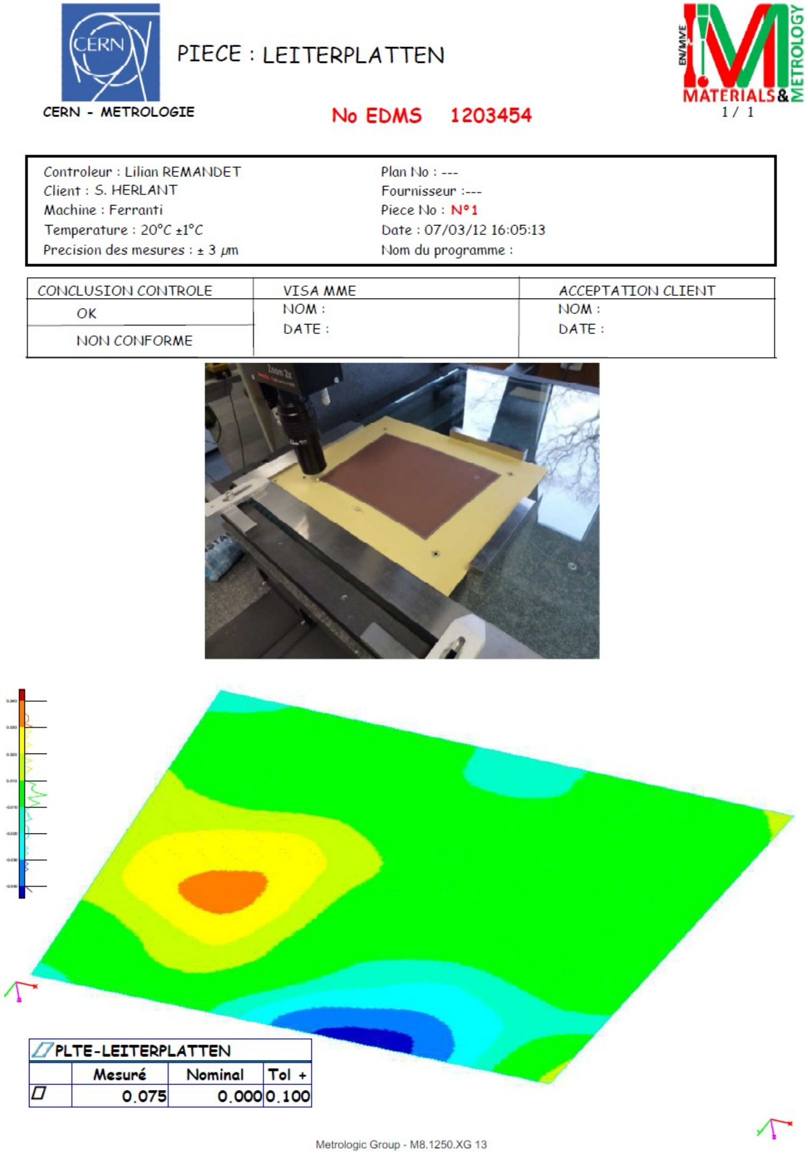
9 modules are built in collaboration with industry to study quality aspects in 'mass'-production:

High quality PCB study (by ELTOS with RD51).

First 4 new PCBs returned from fabrication.

Flatness better than 70 µm!





CERN - METROLOGIE

PIECE : LEITERPLATTEN

No EDMS 1203454

1 / 1

Controleur : Lilian REMANDET
Client : S. HERLANT
Machine : Ferranti
Temperature : 20°C ±1°C
Precision des mesures : ± 3 µm

Plan No : ---
Fournisseur :---
Piece No : N°1
Date : 07/03/12 16:05:13
Nom du programme :

CONCLUSION CONTROLE	VISA MME	ACCEPTATION CLIENT
OK	NOM : DATE :	NOM : DATE :
NON CONFORME		

PLTE-LEITERPLATTEN

	Mesuré	Nominal	Tol +
⏥	0.075	0.000	0.100

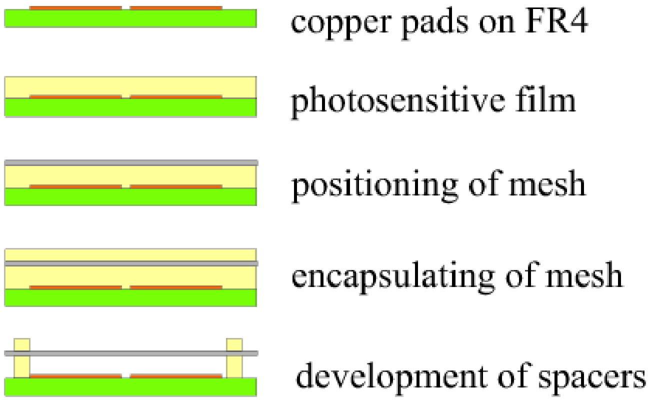
Metrologic Group - M8.1250.XG 13

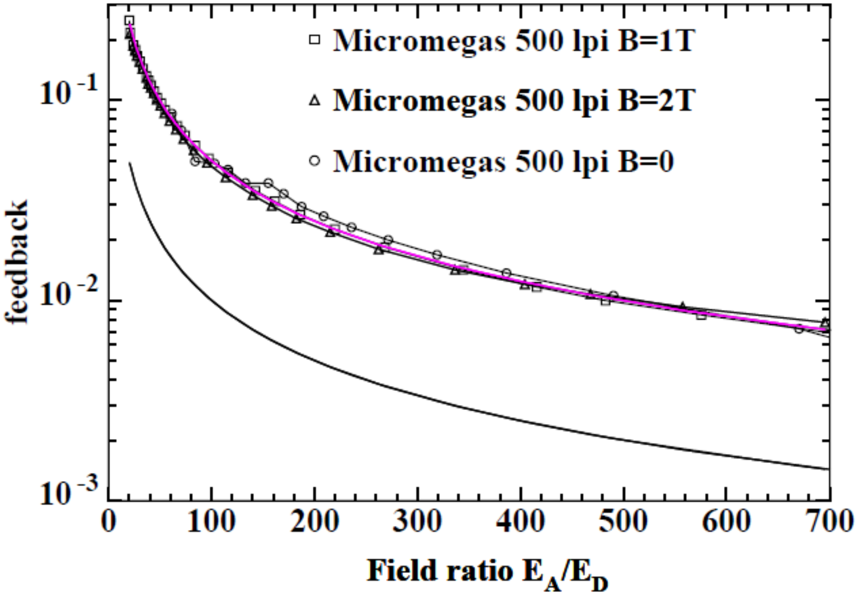
New Modules have resistivity 3 MΩ/□ (CLK).

Small Prototypes with MM

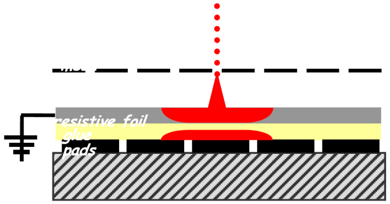
Several important developments in Micromegas R&D were achieved by the LCTPC-MM group:
- First ion back drift measurements with MM
- Development of resistive covering on pads
- First test with bulk-Micromegas

=> No discharges observed
=> Excellent space point resolution

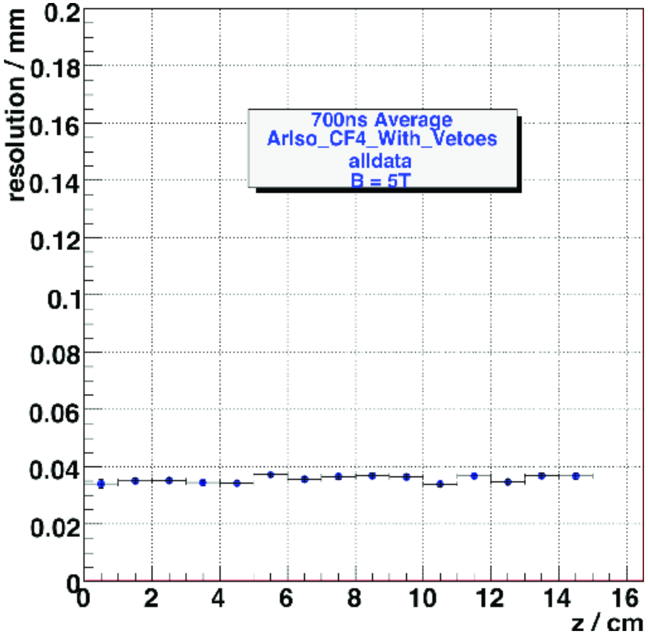




To broaden the signal shape the readout pads are covered with a resistive foil.

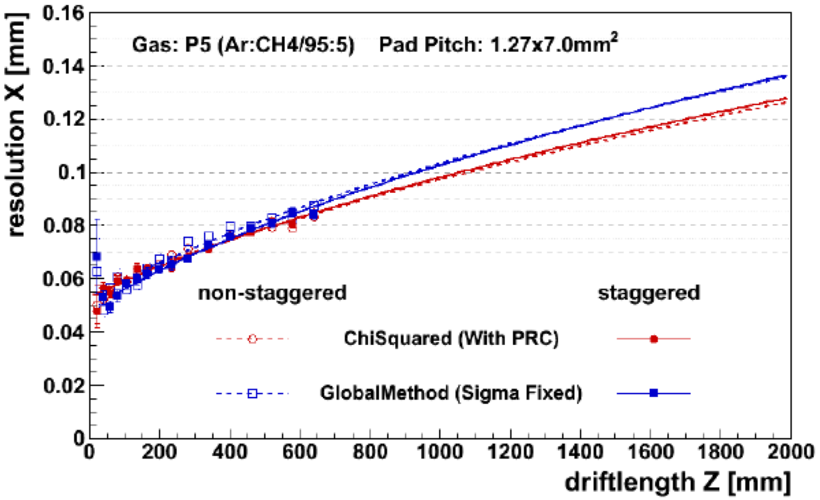


NIM A581, 254, 2007

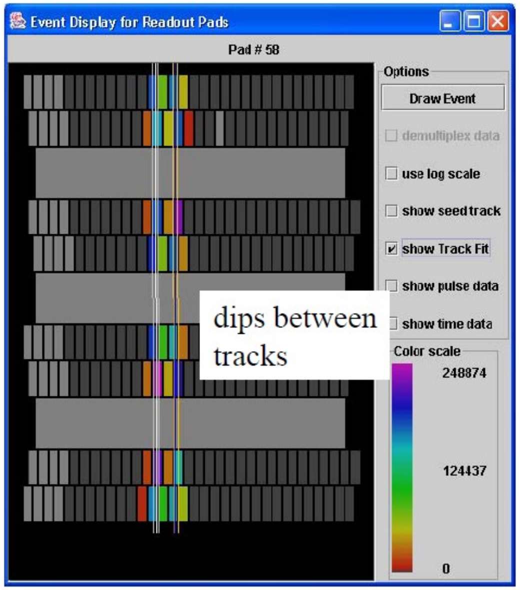


Small Prototypes with GEMs

Measurements in high magnetic fields:
- Measurement of ion back drift
- Measurements of point resolution
- Measurements of double track resolution with laser beams
- Measurements with various pad shapes



Δx = 3.8 mm

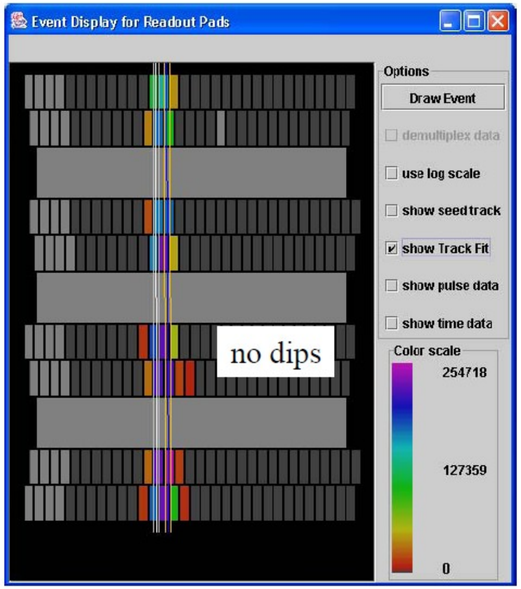


☐ demultiplex data
☐ use log scale
☐ show seed track
☑ show Track Fit
☐ show pulse data
☐ show time data

Color scale: 248874, 124437, 0

dips between tracks

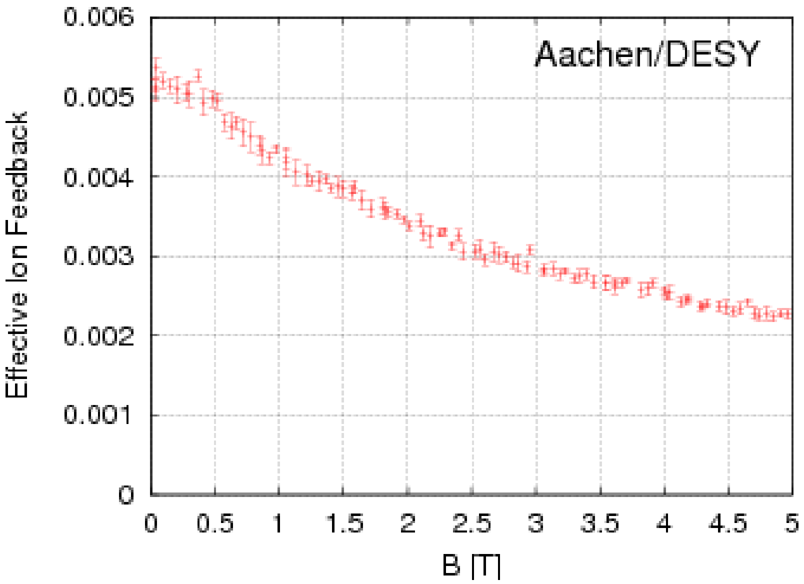
Δx = 2.0 mm



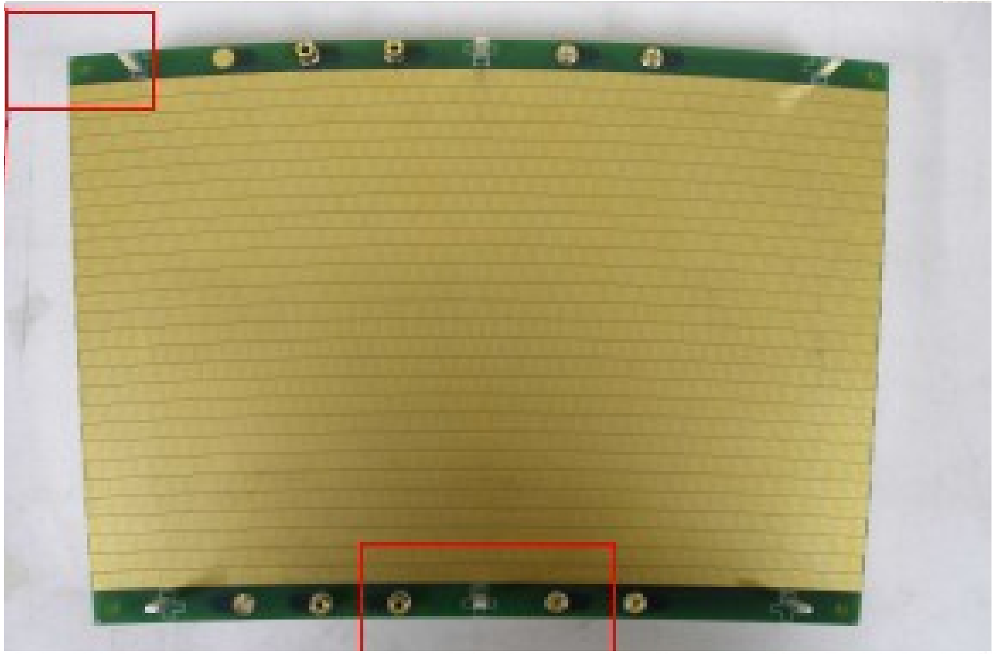
☐ demultiplex data
☐ use log scale
☐ show seed track
☑ show Track Fit
☐ show pulse data
☐ show time data

Color scale: 254718, 127359, 0

no dips



Double GEM Modules



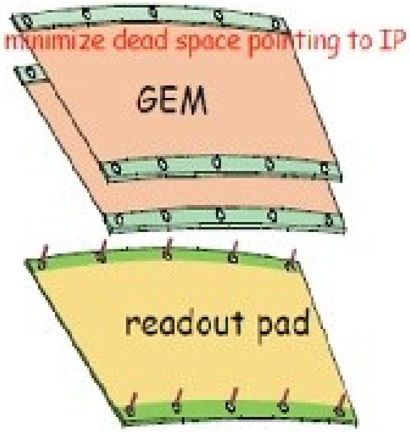
GEM Module

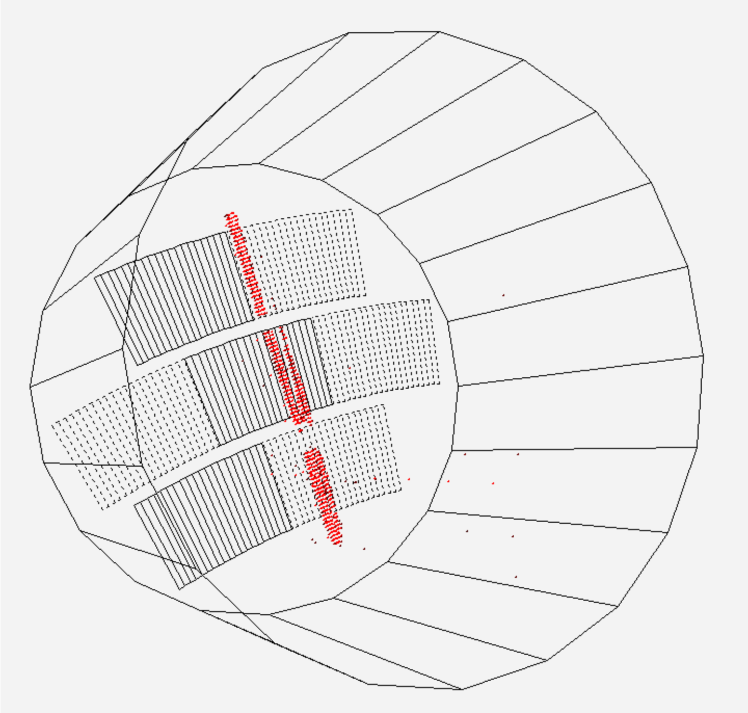
1.2×5.4 mm^2 pads - staggered

28 pad rows (176-192 pads/row)

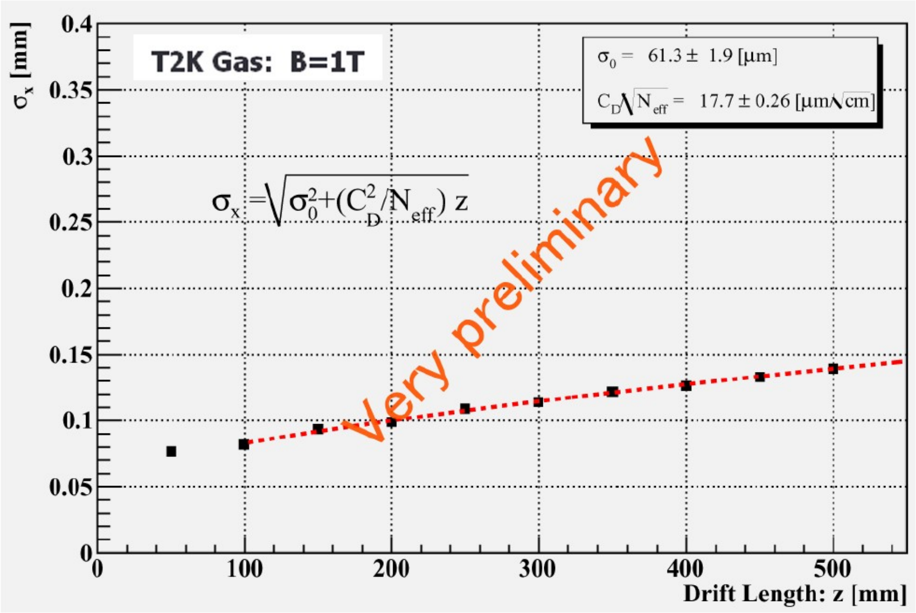
5152 pads per module

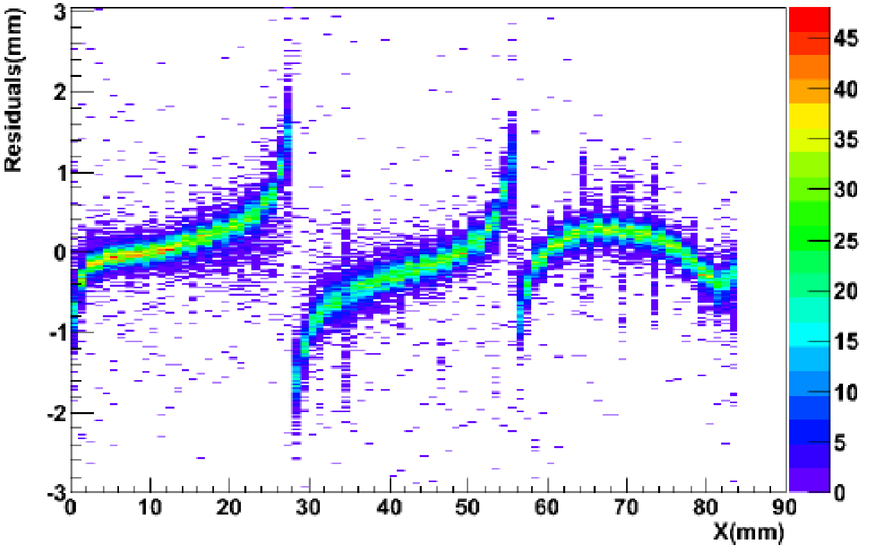
2 LCP-GEMs, 100 µm thick

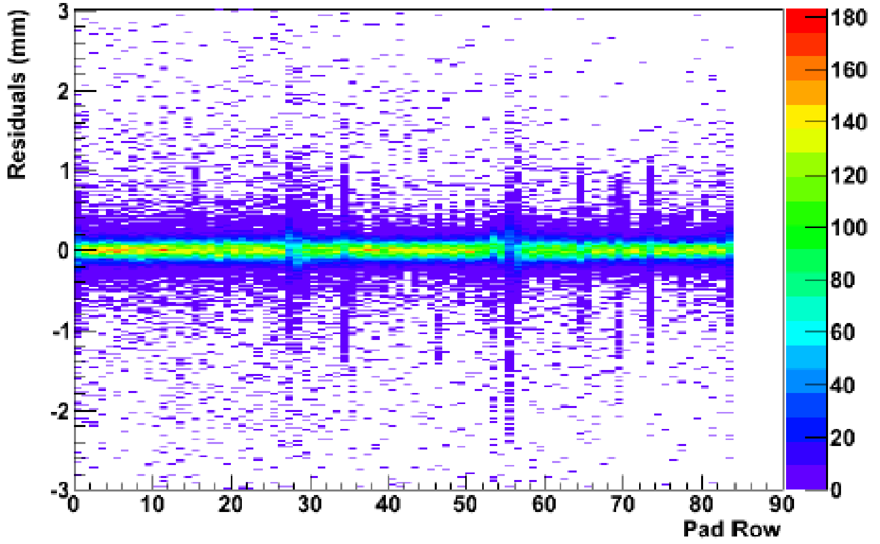




Performance of Double GEMs







Resolution parametrized as $\sigma = \sqrt{\sigma_0^2 + D_t^2/N_{eff} \cdot z}$
→ $\sigma_0 = 61.3 \pm 1.9$ μm

Field distortions due to frame observed.

Effect corrected in analysis.

New modules are designed.

Triple GEM Module

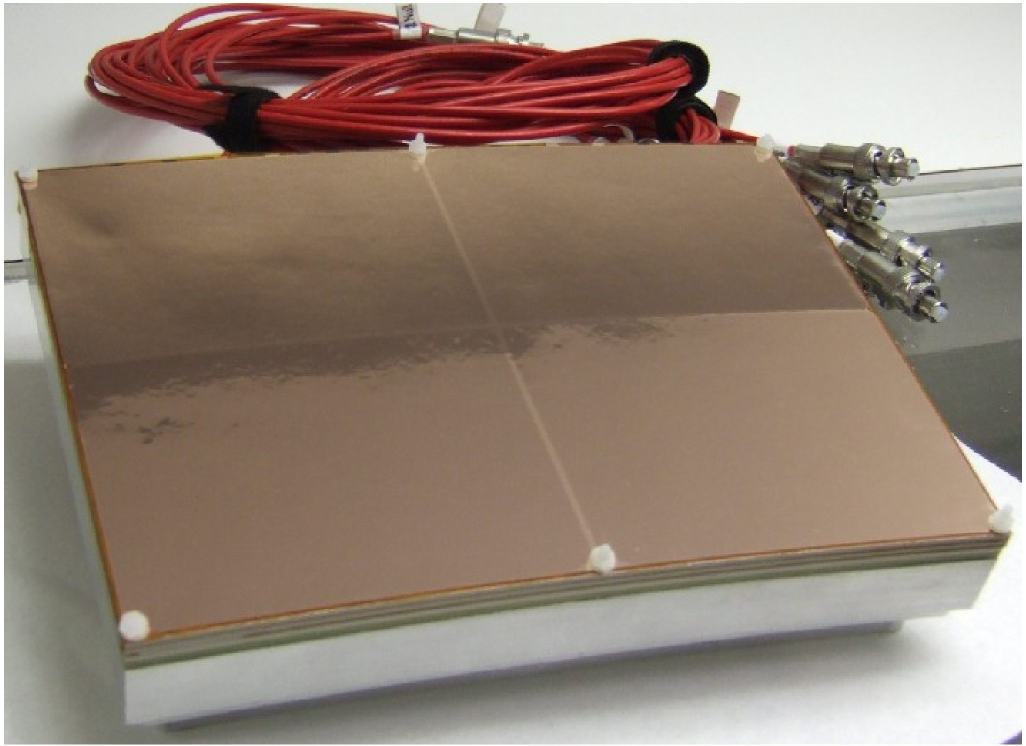
3 standard CERN GEMs mounted on thin ceramic structure (bar size ~1 mm) to reduce dead space.

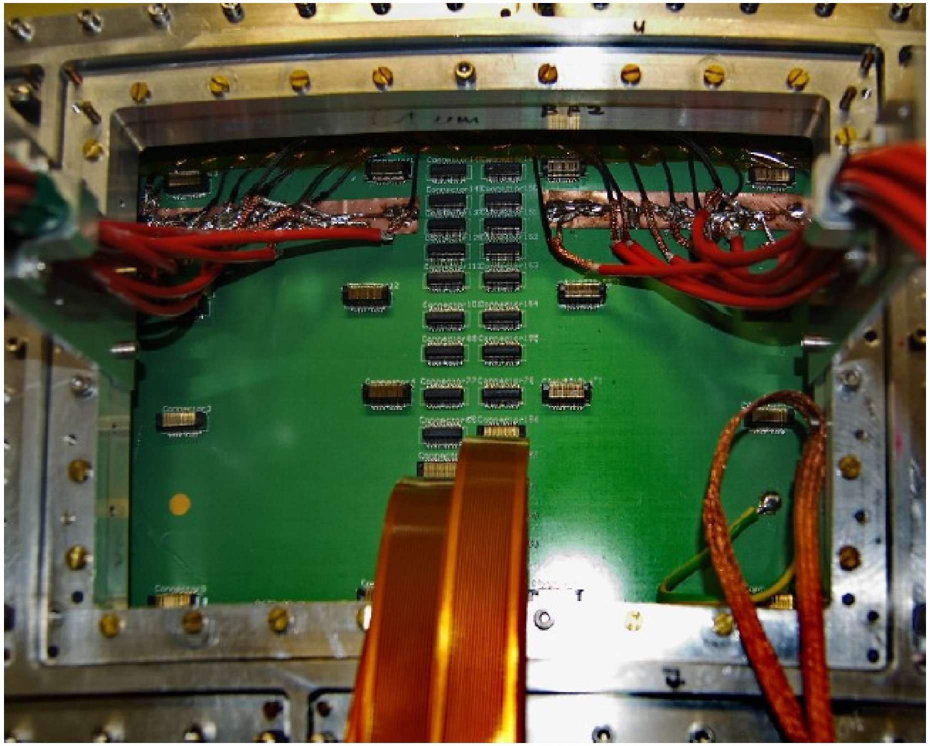
GEM is segmented into 4 parts to reduce energy stored in one sector.

1000 small pads (1.26 × 5.85 mm^2)

First version tested last year: Detector could be operated in test beam, but a few shortcomings were identified.

Second version is being built with ~5000 pads.



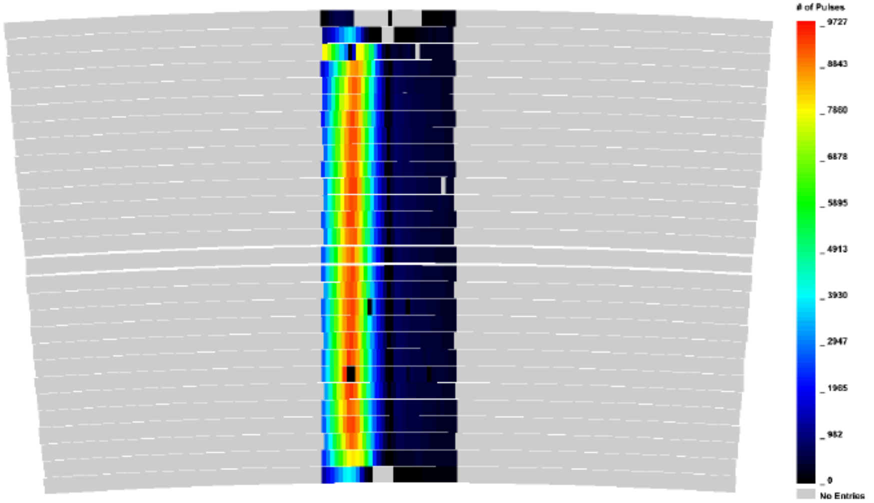


Field Distortions

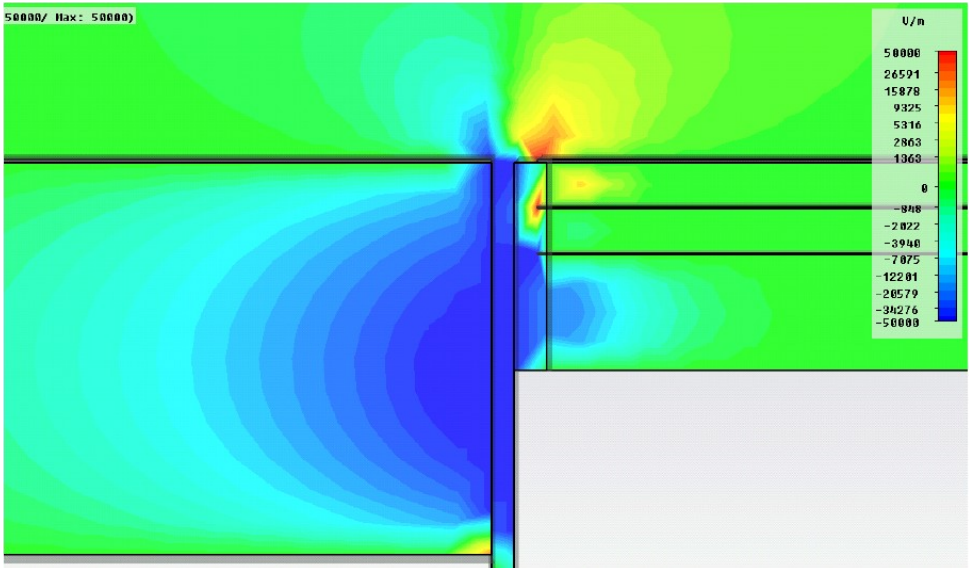
Field distortions at borders of modules were observed.

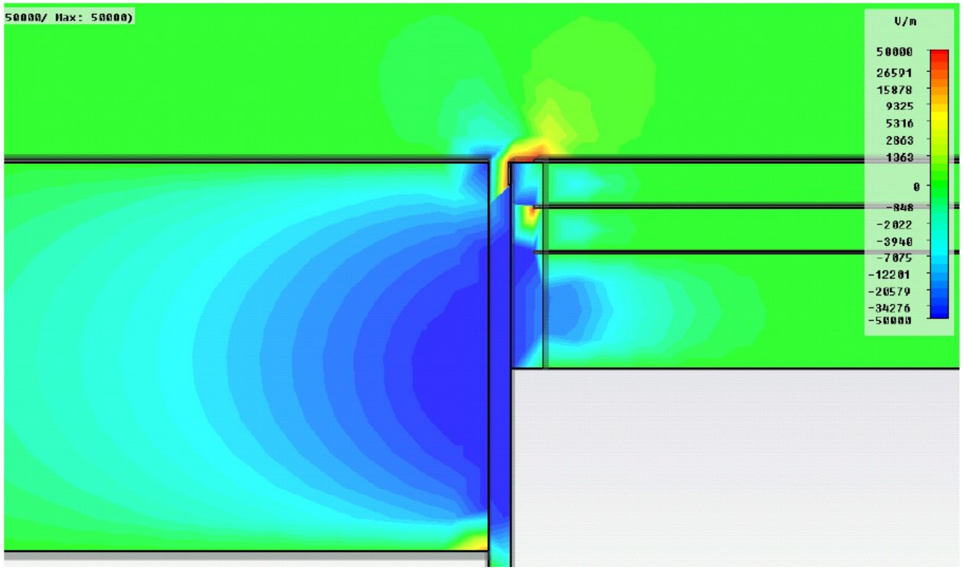
Maybe largely due to field configuration of dummy modules.

Solution: additional field strips on ceramic frame reduces the distortion a lot.



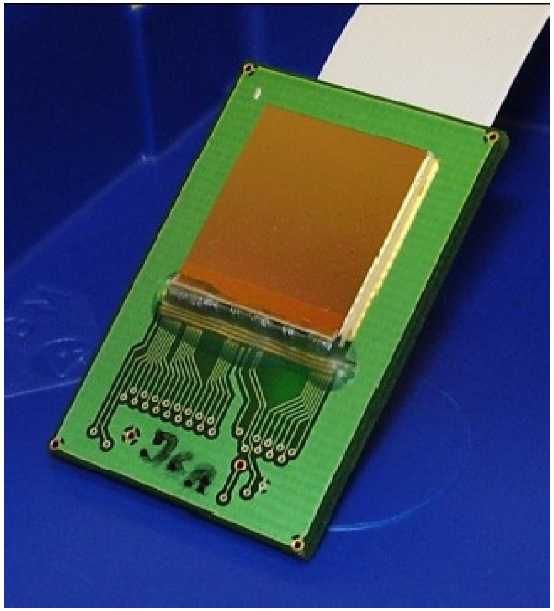
Number of reconstructed pulses





Highly Pixelized Readout

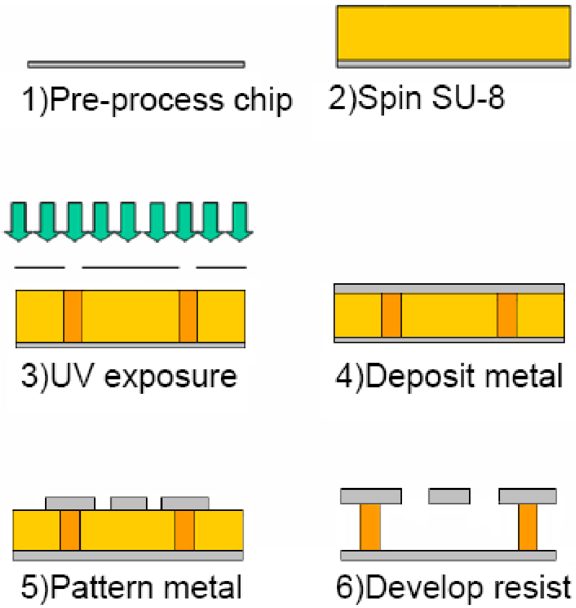
Bump bond pads for Si-pixel detectors serve as charge collection pads.

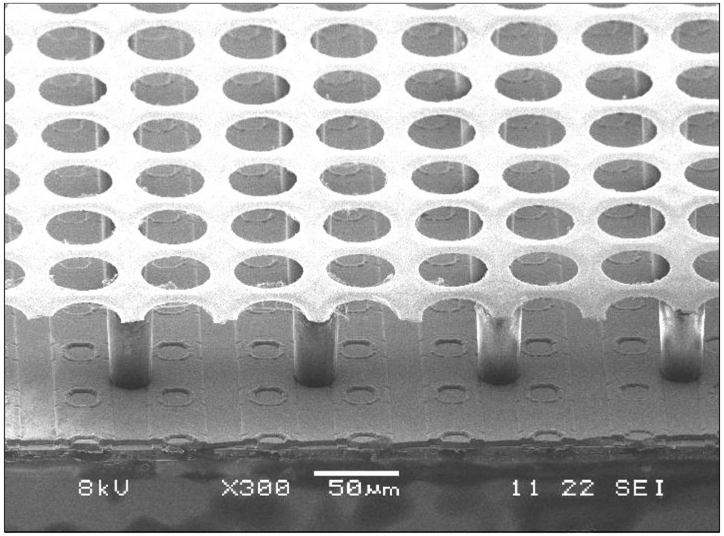


Timepix derived from Medipix-2

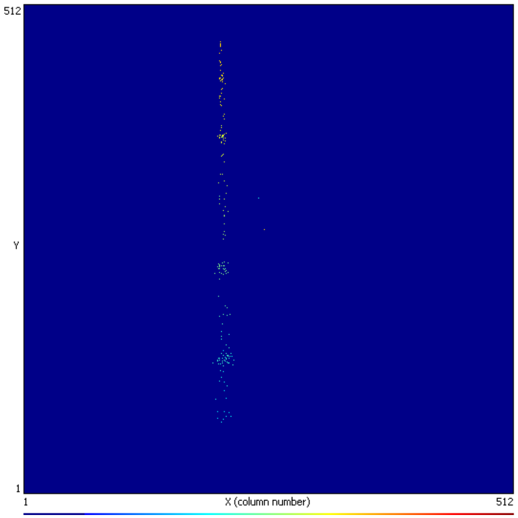
256 × 256 pixels of size 55 × 55 µm²

Each pixel can be set to:
- TOT ≈ integrated charge
- Time between hit and shutter end



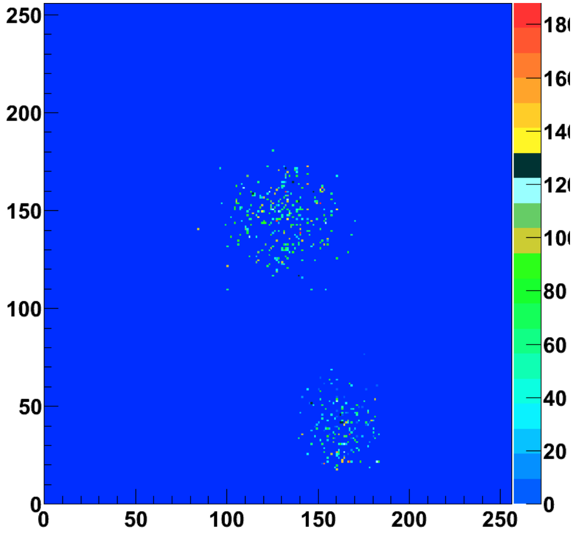


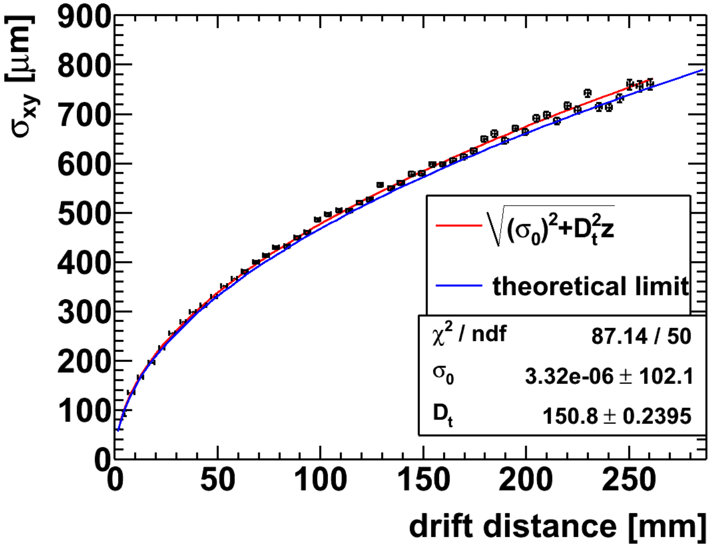
Performance of InGrids



Significant progress towards large area applications:

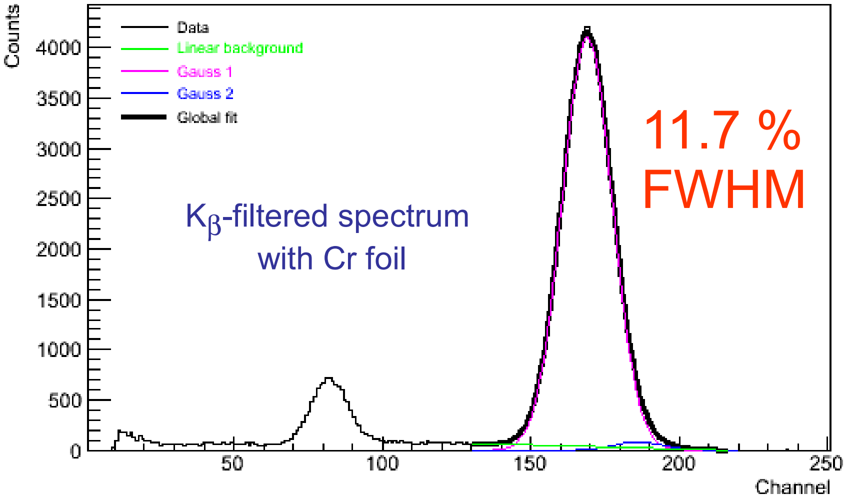
- Si_xNi_y layer to protect against discharges
- Wafer-based production
- Development of electronics 100 chips





Spatial resolution in agreement with diffusion limit

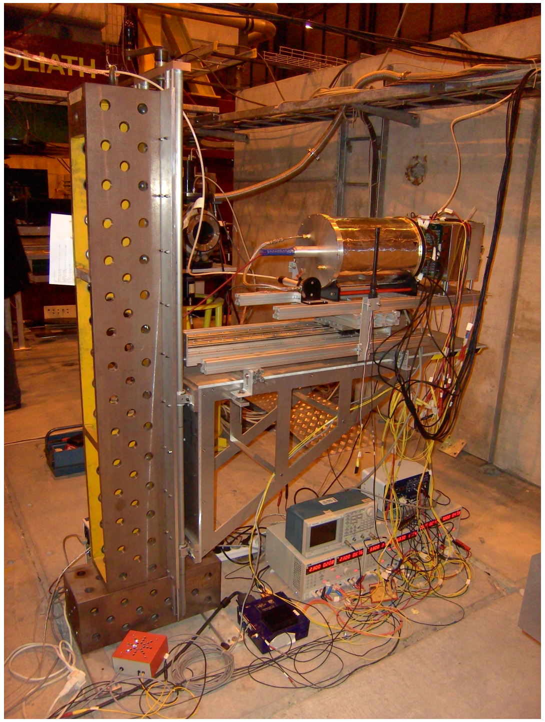
Energy resolution $\sigma_E/E \sim 5\ \%\ (^{55}Fe)$ by counting primary electrons

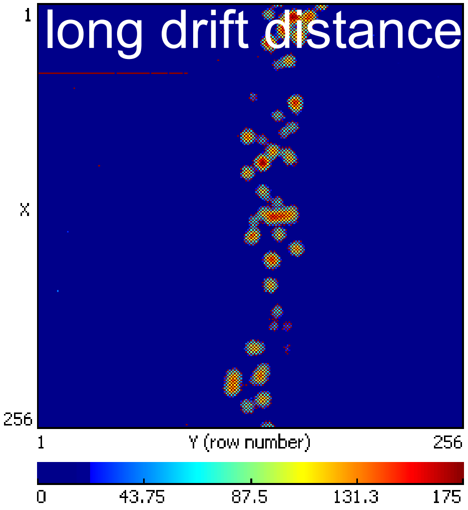


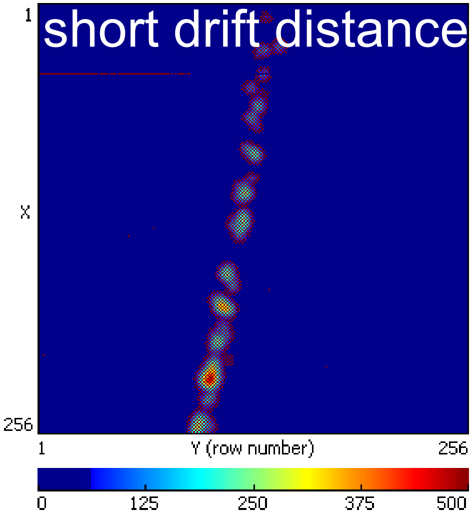
^{55}Fe spectrum in $Ar:CH_4$ 90:10

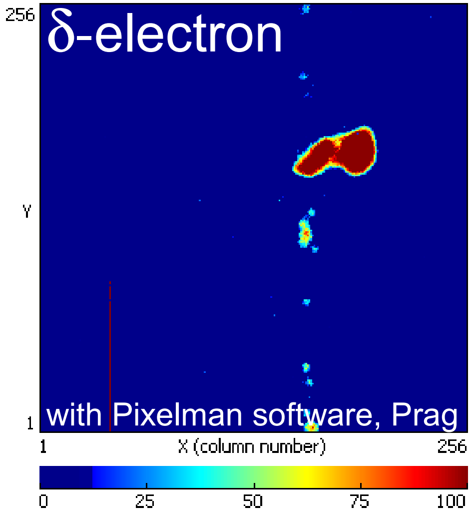
Performance of tGEMs with TP

Timepix chip below a triple GEM stack with spacings 1mm





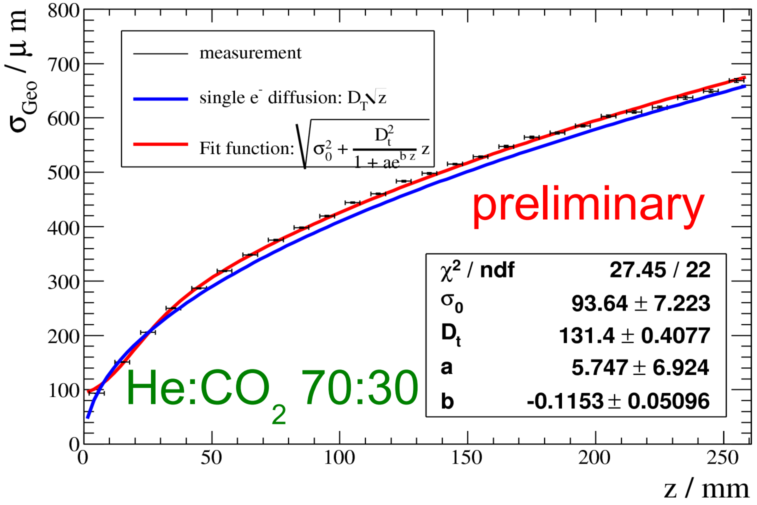


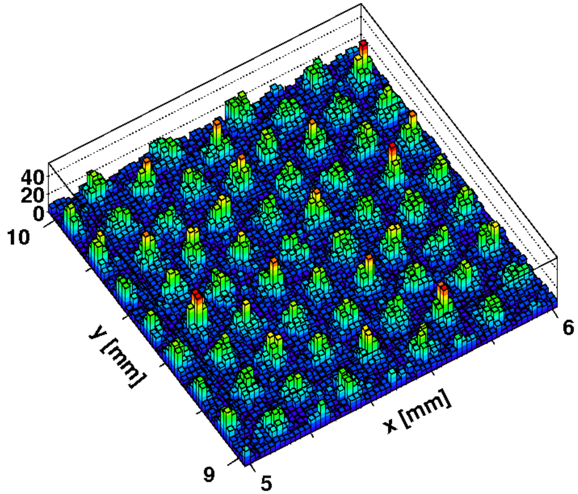


Gas: Ar/He:CO_2 70:30

Good performance with cosmic rays, electron and hadron test beams and in high magnetic fields

Spatial resolution of single electrons





'Electron-tomography' of a GEM

MarlinTPC

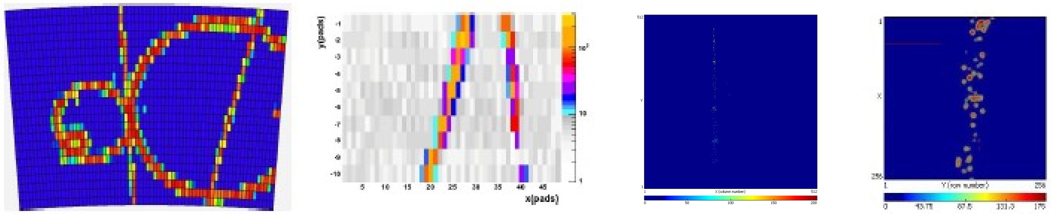
MarlinTPC is based on Marlin and ILC software.

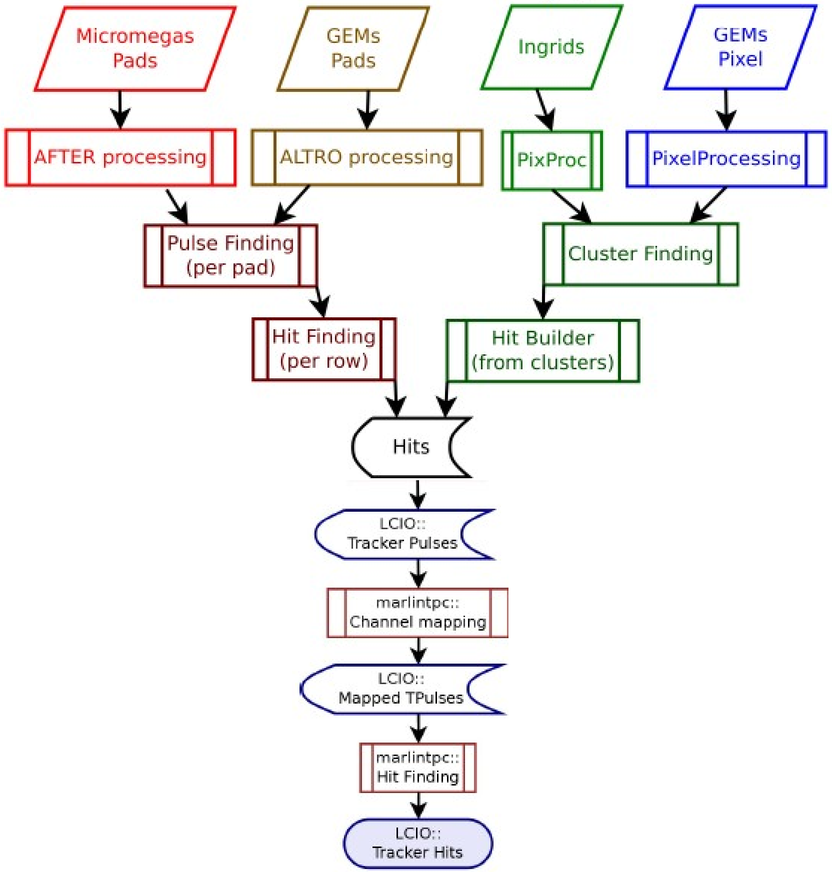
It contains a common geometry description (GEAR) and conditions data base (LCCD).

Reconstruction on hit-level is done differently for the various technologies.

Tracking is interchangeable, several different track finders and fitters are available.

Most analyses are done in MarlinTPC → better comparable.





Micromegas Pads
GEMs Pads
Ingrids
GEMs Pixel
AFTER processing
ALTRO processing
PixProc
PixelProcessing
Pulse Finding (per pad)
Cluster Finding
Hit Finding (per row)
Hit Builder (from clusters)
Hits
LCIO:: Tracker Pulses
marlintpc:: Channel mapping
LCIO:: Mapped TPulses
marlintpc:: Hit Finding
LCIO:: Tracker Hits

Analysis

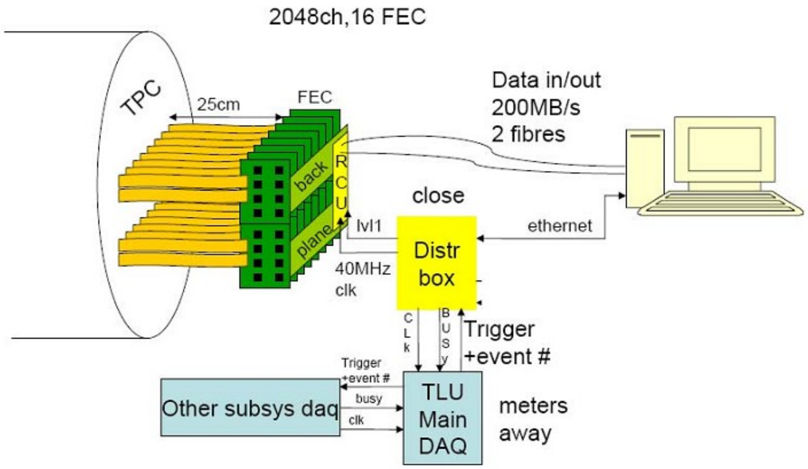
Electronics ALTRO & AFTER

A set of 10,000 channels was built with both the AFTER chip (T2K) and the ALTRO chip (ALICE).

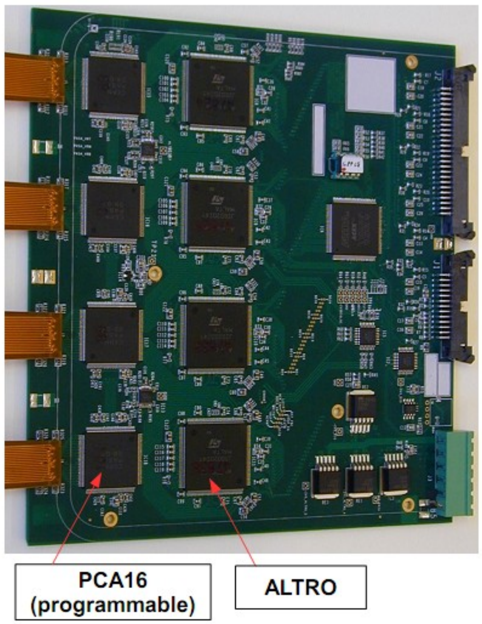
For the ALTRO-electronics, e.g. new FECs were designed with:

8 ALTRO ADC chips (ALICE)

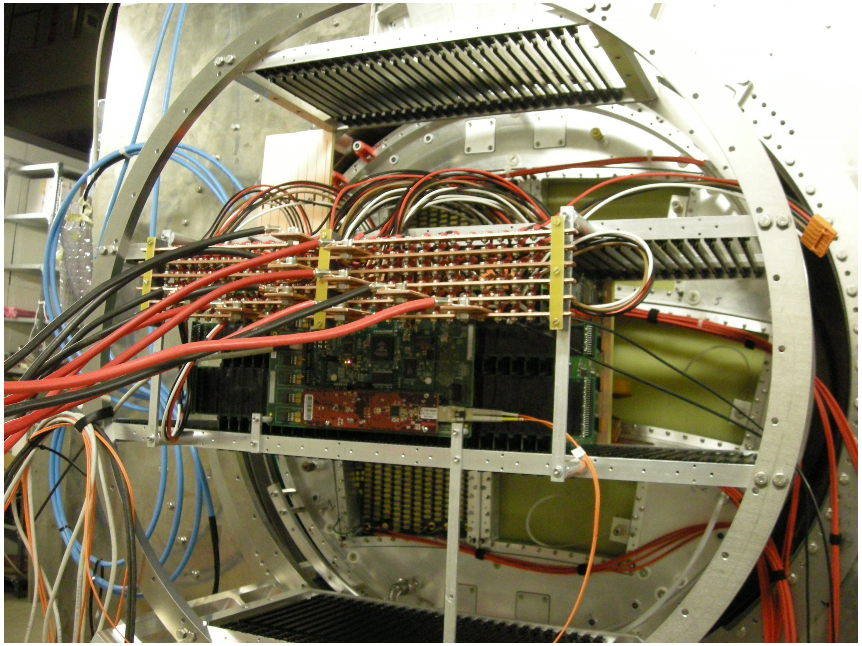
8 PCA16 charge sensitive preamplifiers



Front End Card



Electronics is programmable w.r.t.
shaping time
(30, 60, 90, 120 ns)
gain
(12, 15, 19, 24 mV/fC)
decay (continuous)
polarity

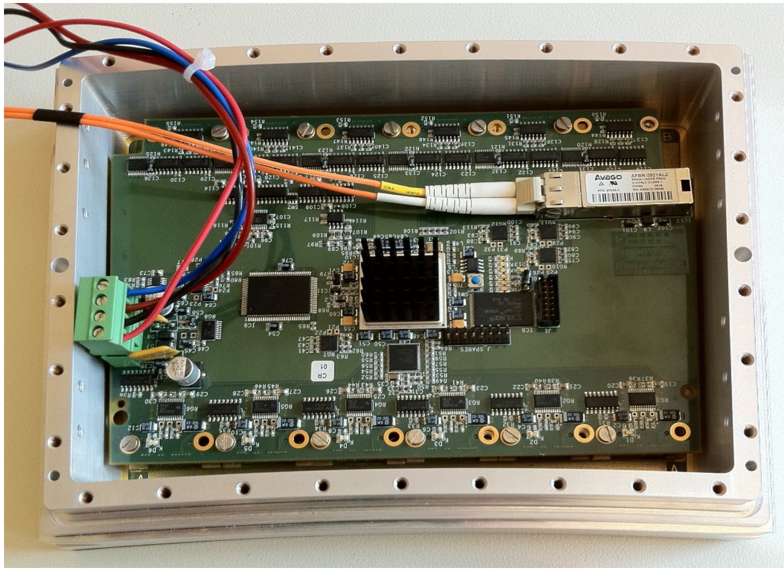


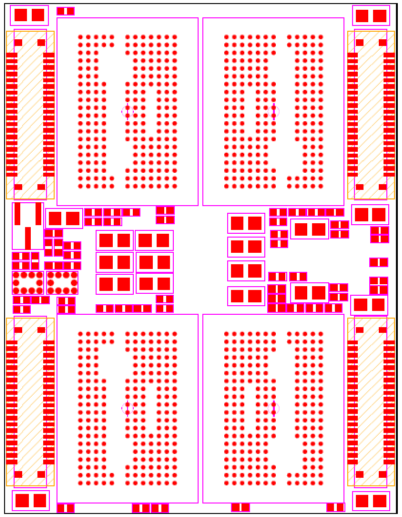
Electronics

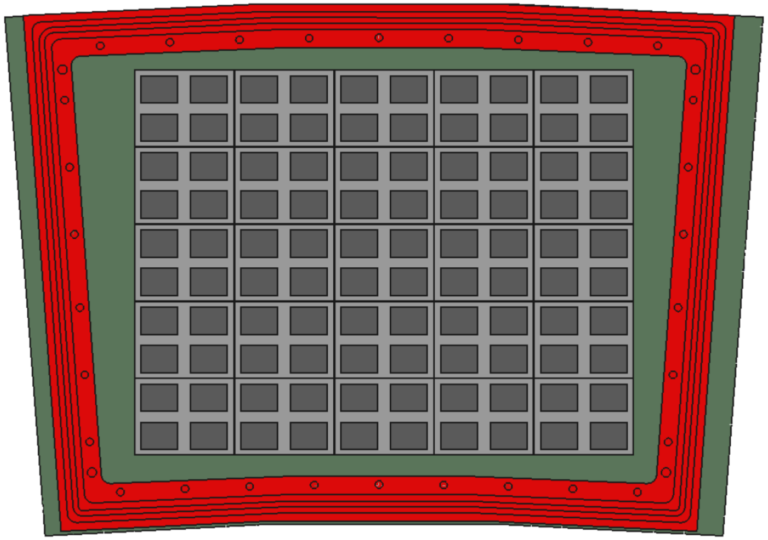
Production of a 2nd version for AFTER and ALTRO electronics is ongoing:

1.) AFTER: redesign of the PCB to use less space/channel and mount the readout electronics directly on padplane (+ cooling, ….)

2.) SALTRO-16: New chips are produced, fully tested and available. The chips include preamplifier, shaper and digitization unit.
Multi Chip Carrier (carrier boards) will also be placed directly on padplane







3.) Design of new 128-channel chip (GdSP) together with CMS (~2 years)

Cooling

There are several methods of cooling:

1.) Power pulsing: shut down electronics, when there are no collisions (bunch train structure of ILC/CLIC-beam)

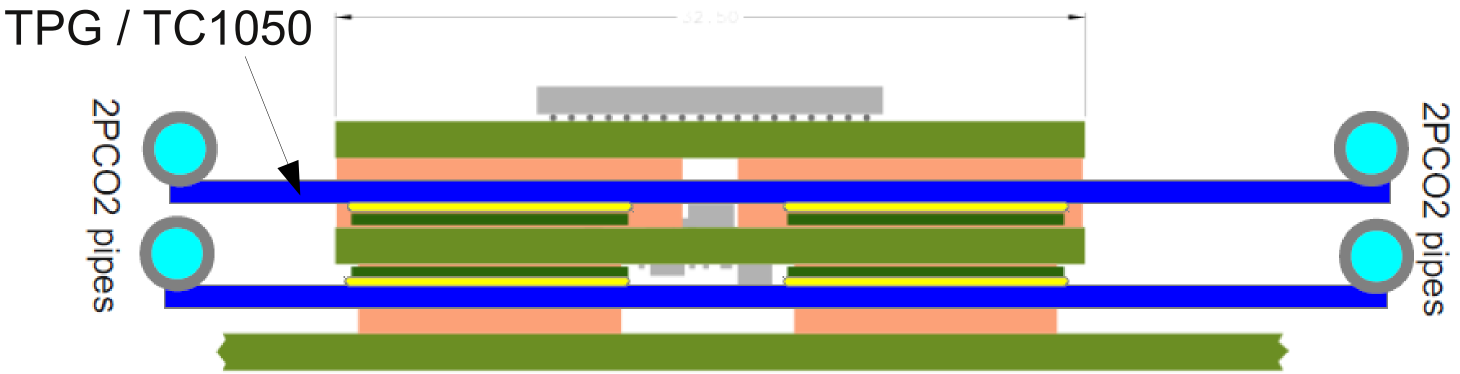
Tests with new SALTRO-16 show a power reduction of 18 for CLIC beam (42 mW instead of 757 mW per chip), about 60 for ILC beam.

2.) Cooling with air or water

3.) 2-phase CO_2 cooling → cooling pipes can be made smaller → lower material budget

Simulations of electronics and heat distributions are made to understand heat flow and cooling needs.

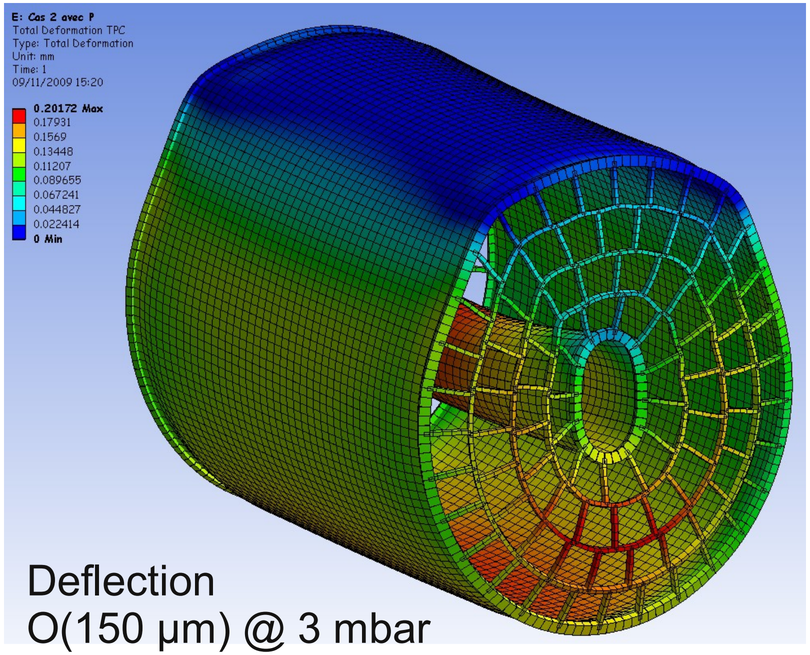
A cooling plant will be installed in 2013 for tests at LP.



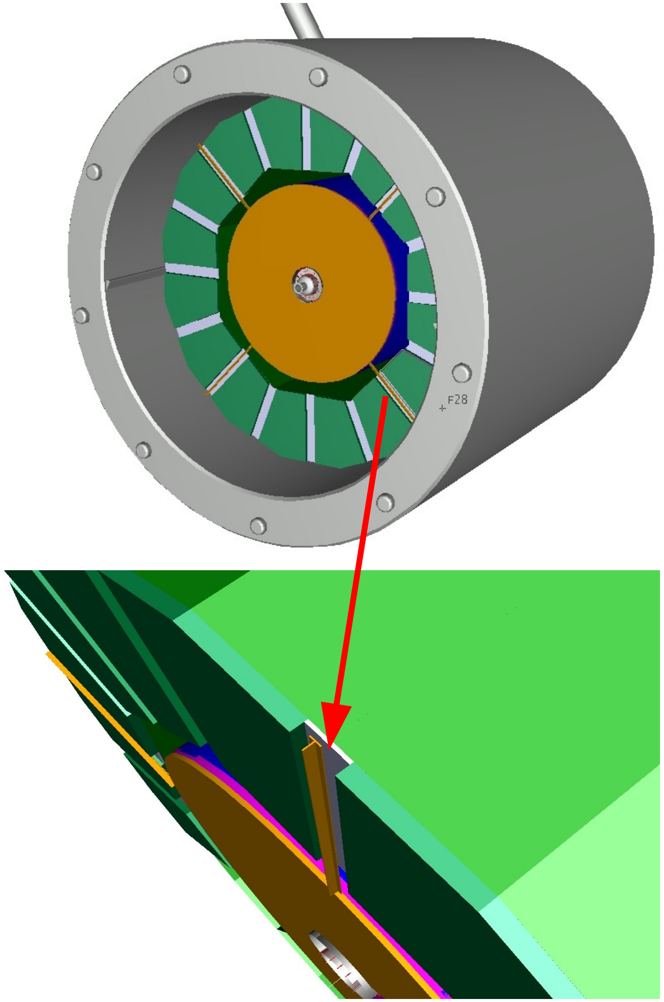
Mechanical Simulations

Simulations regarding several mechanical aspects such as deformation and fixation of TPC to other subdetectors are ongoing.

Two points of fixation (HCAL or cryostat) are being simulated and forces (also due to earthquakes) are considered up to an acceleration of 1.5 m/s².



Deflection
O(150 μm) @ 3 mbar

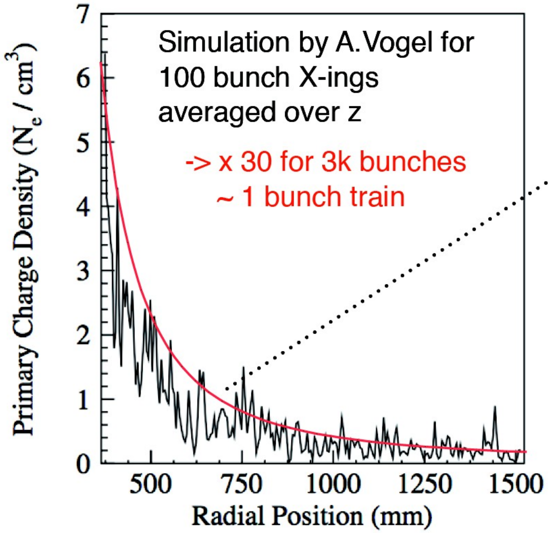


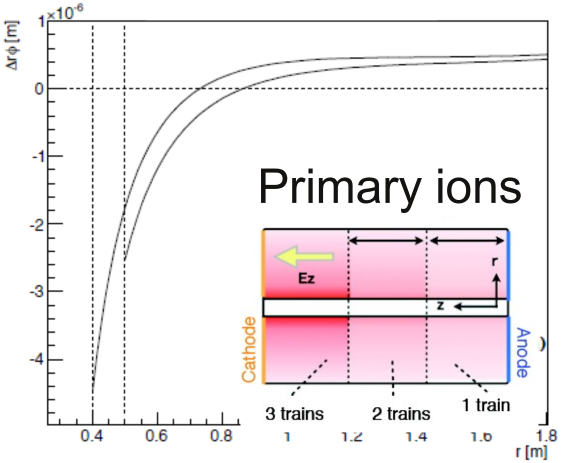
Effect of Positive Ions on e$^-$

- Charge density due to beam background was approximated based on simulations.
- Complicated equations were solved to get E-field:

$$E_r(r,z) = -8\pi \sum_{n=1}^{\infty} \frac{\sin(\beta_n z)}{I_0(\beta_n a)K_0(\beta_n b) - I_0(\beta_n b)K_0(\beta_n a)} \int_0^L \frac{dz'}{L}\, \sin(\beta_n z')\hat{\rho}_z(z')$$
$$\Big[[K_0(\beta_n b)I_1(\beta r) + I_0(\beta_n b)K_1(\beta_n r)] \int_a^r dr' \, \frac{K_0(\beta_n a)I_0(\beta r') - I_0(\beta_n a)K_0(\beta_n r')}{K_0(\beta_n r')I_1(\beta_n r') + K_1(\beta_n r')I_0(\beta_n r')} \,\bar{\rho}_r(r')$$
$$+ [K_0(\beta_n a)I_1(\beta r) + I_0(\beta_n a)K_1(\beta_n r)] \int_r^b dr' \, \frac{K_0(\beta_n b)I_0(\beta r') - I_0(\beta_n b)K_0(\beta_n r')}{K_0(\beta_n r')I_1(\beta_n r') + K_1(\beta_n r')I_0(\beta_n r')} \,\bar{\rho}_r(r') \Big]$$

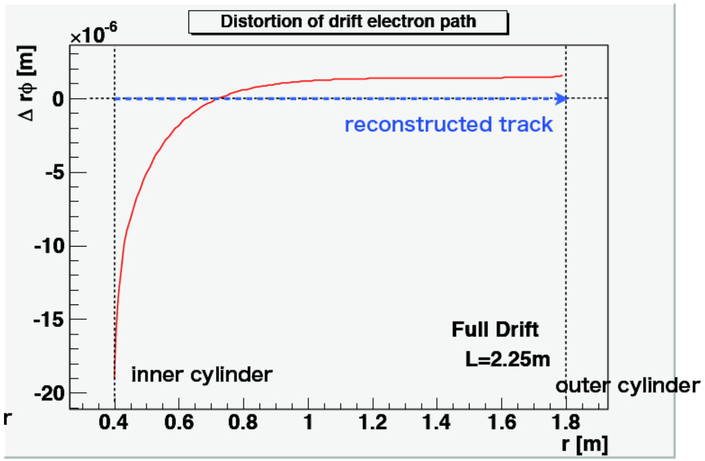
- Influence of E-field distortions on drifting electrons is evaluated for three different sources of ions:



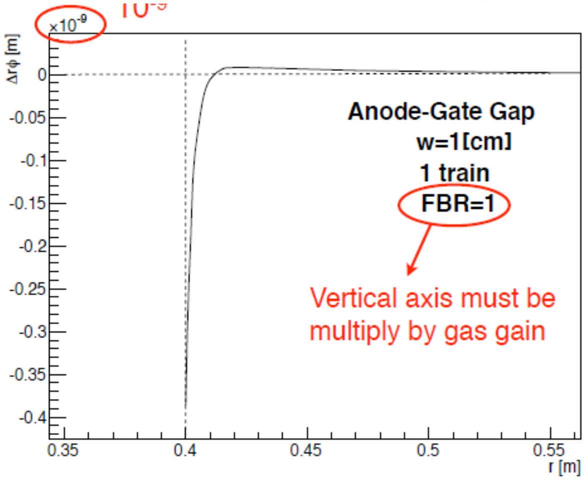


1 bunch train δ_{max} ~4.5 µm

3 bunch trains δ_{max} ~8.5 µm



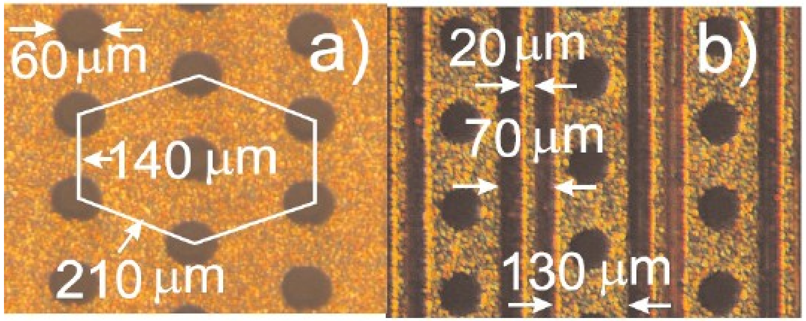
Ions from MPGD stage form 3 discs, if no gating devices is used → δ_{max} ~60 µm

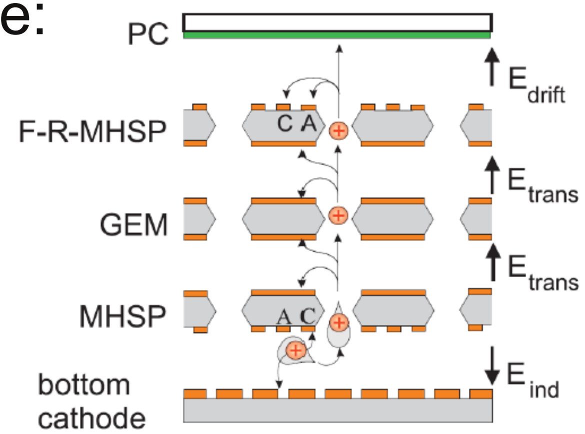


Distortions because of disk between MPGD – gating device are negligible.

Ion Back Drift Reduction

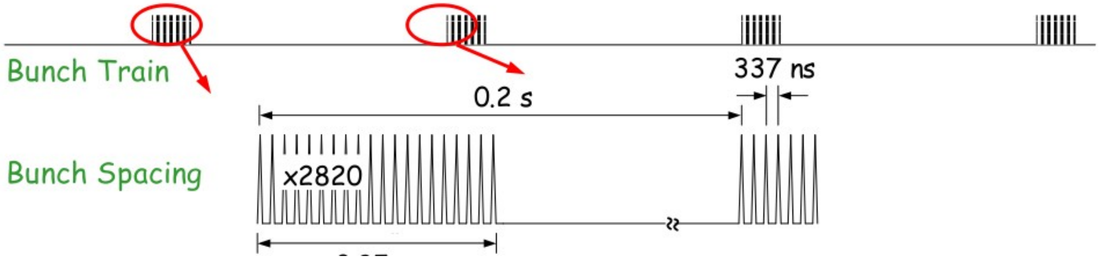
Ion back drift has to be reduced more:
1.) New devices such as MHSP





IFB of ~10^{-4} has been shown for gains of 10^4 and full transparency

2.) Gating devices to remove ions in period between bunch trains



Discussion has started and first measurements are planned for gating devices made of wires, meshes or GEM-like structure.
It is important to maintain a ~100% transparency for primary electrons.

Summary

The TPC for a future Linear Collider has stringent requirements.

Requirements can be met with MPGDs (Micromegas and GEMs).

Proof of principle has been shown for a wide variety of environments (high magnetic fields, various gases, different pad geometries, ….).

The Large Prototype in the DESY test beam facility is an ideal place to study integration issues. Several issues have been found (mostly field distortions at the edge of readout modules) and are being worked upon.

Mechanical and cooling issues are under study.

Highly pixelized readout has shown very promising first results, feasibility of large areas (one module) still needs to be demonstrated.