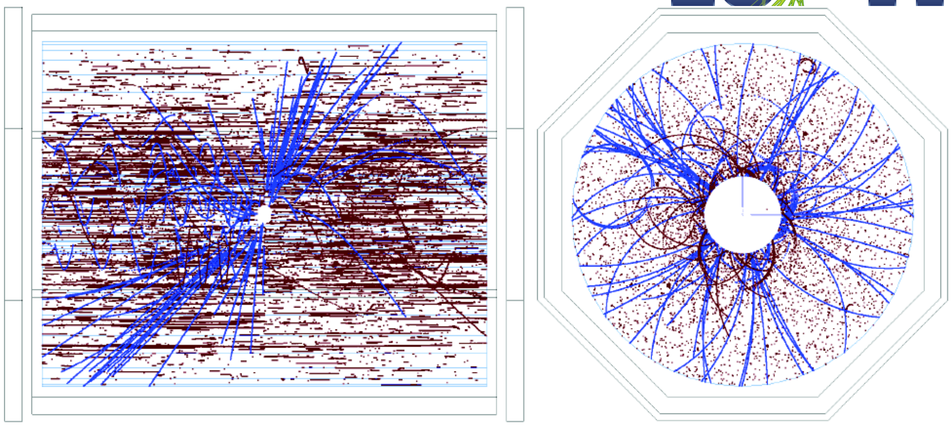
A TPC for the Linear Collider

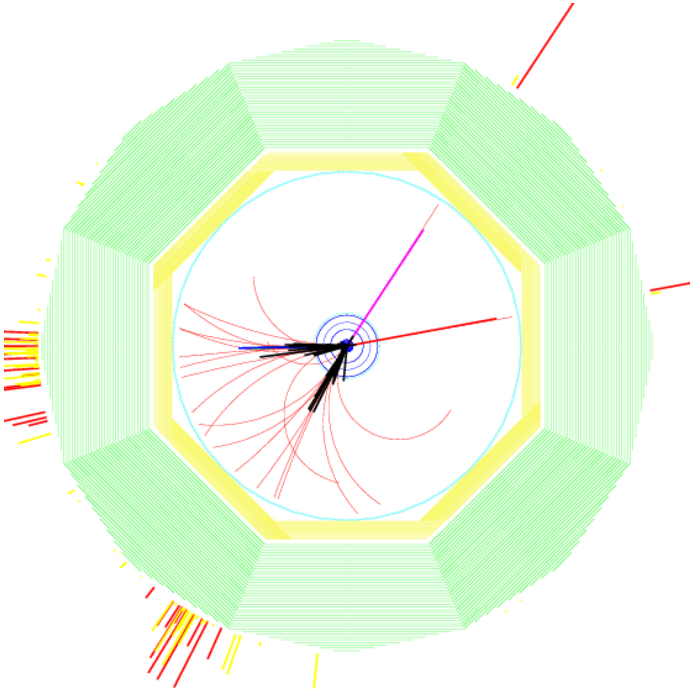
J. Kaminski
For the LCTPC-collaboration

ECFA Detector R&D Panel
DESY
2./3. May 2012

Requirements

Requirements are driven by the particle flow concept and benchmark processes. In the case of ILD – TPC the Higgs recoil is one of the stringent measurements:





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

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

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%

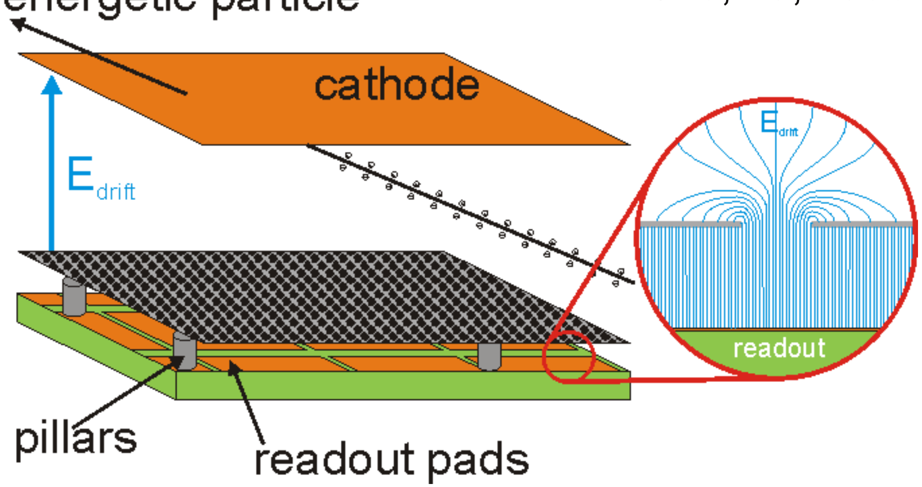
Material budget: 0.05 X_0 to outer field cage,
0.25 X_0 endcaps

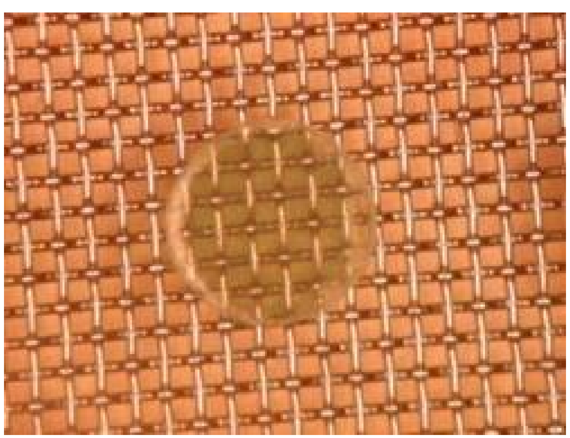
Requirements can not be met with standard MWPC readout.

Micropattern Gaseous Detectors

Micro-Mesh Gaseous Detectors

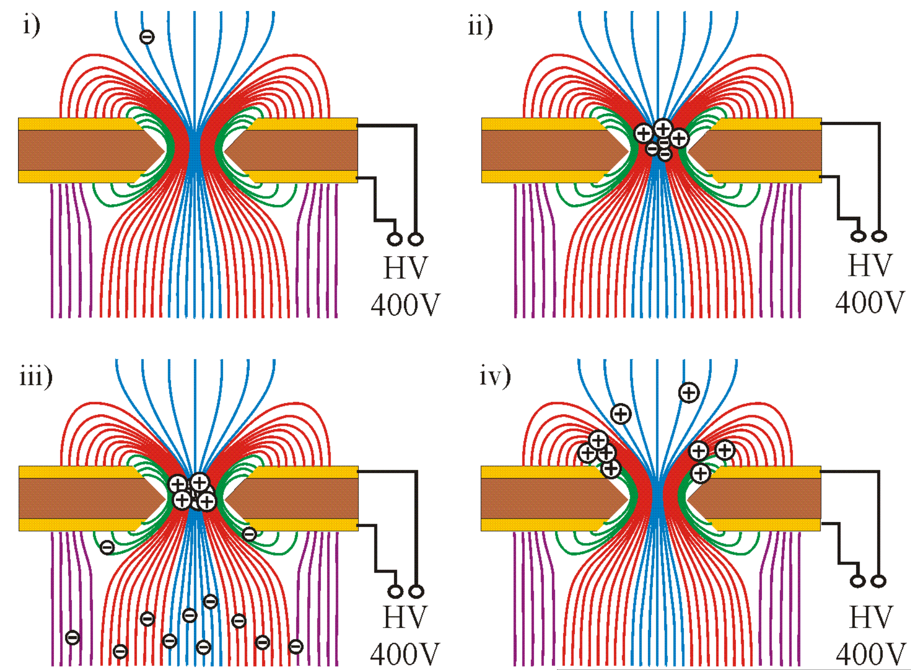
Y. Giomataris et al., NIM A376, 29, 1996.

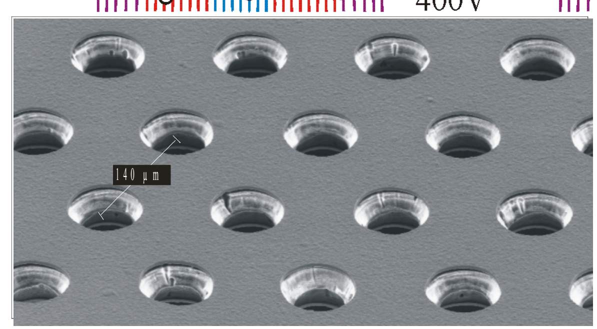


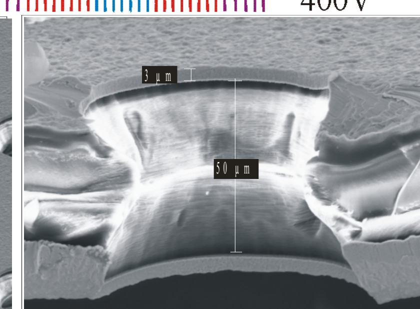


Gas Electron Multipliers

F. Sauli, NIM A386, 531, 1997.





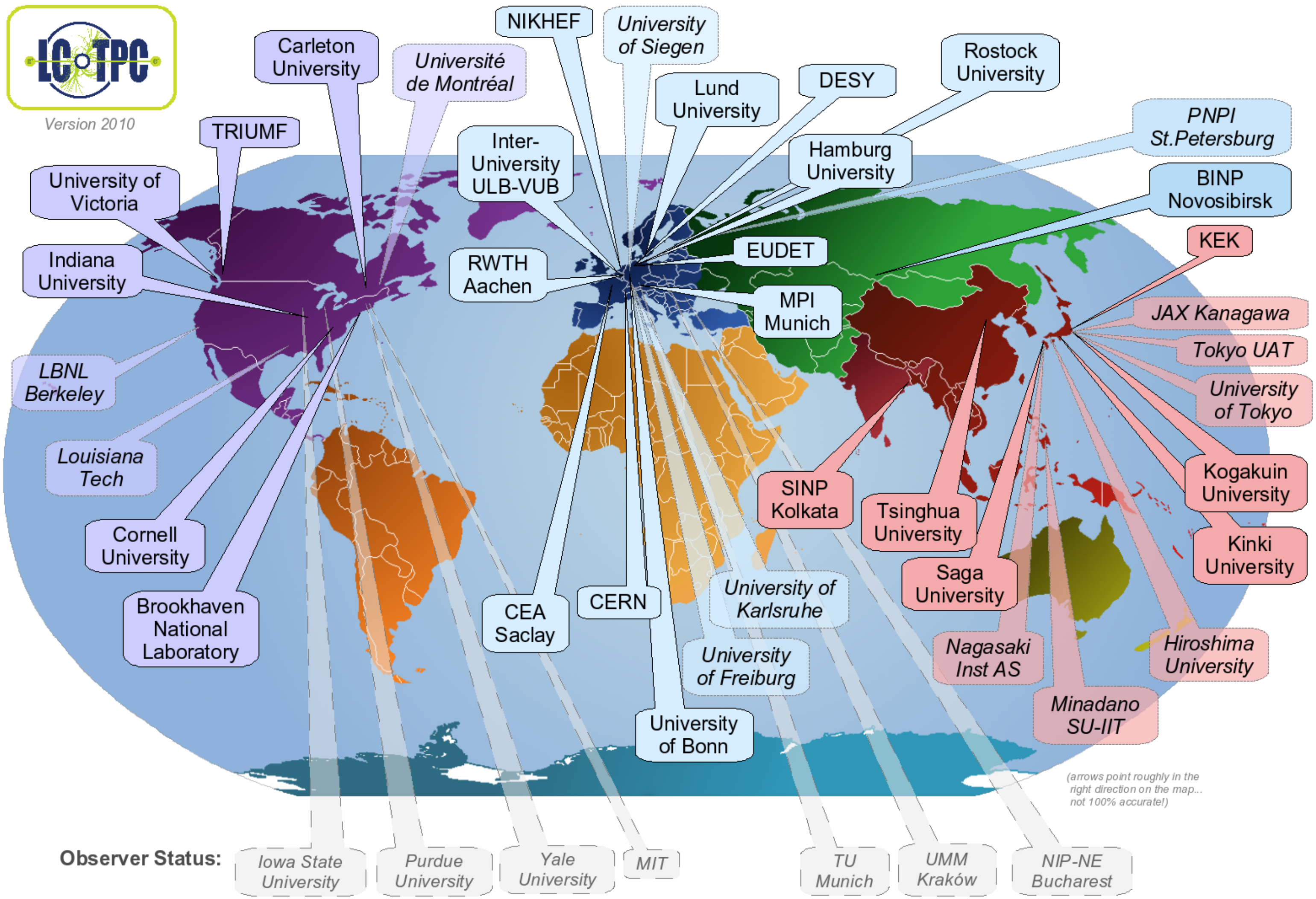


TPC with MPGDs

- Small pitch of gas amplification regions (i.e. holes)
  => improves spatial resolution, reduction of $E \times B$-effects
- No preference in direction (as with wires)
  => all 2 dim. readout geometries can be used
- No ion tail => very fast signal (O(10 ns))
  => good timing and double track resolution
- Direct e^--collection on pads
  => small transverse width
  => good double track resolution
- Ion back drift can be reduced significantly
  => continuous readout is possible
- Discharges probability can be reduced by using resistive electrodes or specific voltage setting
- Lower mechanical tension, MPGDs don't have to be stretched
  => lower material budget in end plates

Performance may be further enhanced by highly pixelized readout.

Collaboration



25 institutes signed the MoA
13 institutes are in the process
7 institutes have observer status
→ institutes from 12 countries

Close cooperation with other TPC and MPGD collaboration (T2K, RD51, …)

The Road Map

Research program consists of 3 stages:

1. Demonstration Phase

To proof feasibility with small scale detectors at individual labs
To understand reconstruction and parameter space
→ Pixel technology is still in this phase.

2. Consolidation Phase

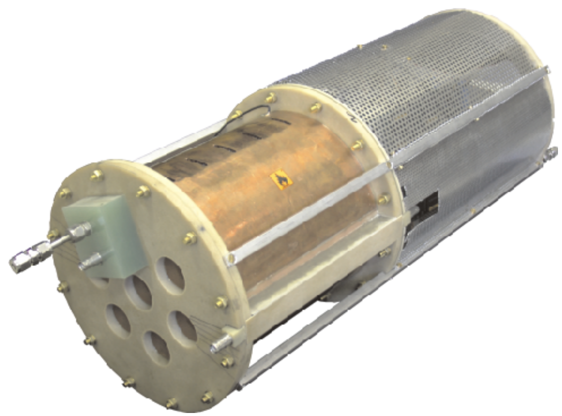
A medium size prototype is to be built to compare results and study integration issues
To test manufacturing techniques
To gain operational experience
→ Phase is ongoing, the Large Prototype is taking data with GEMs and MM.

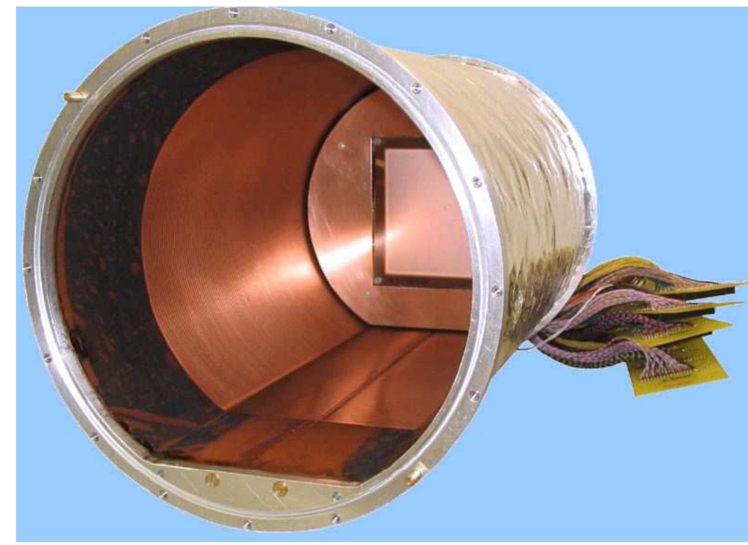
3. Design Phase

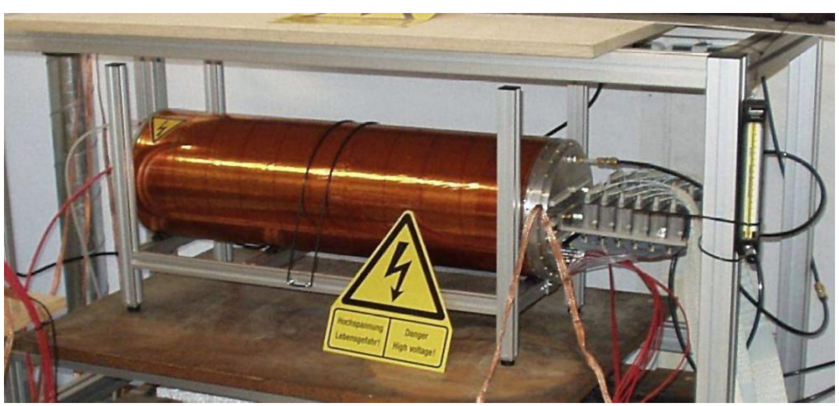
Take decision of the MPGD technology
Finish the design of final detector

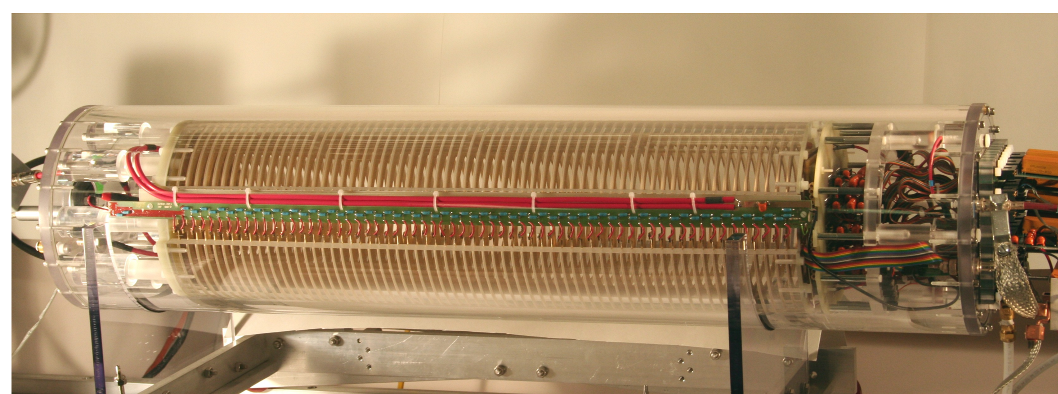
Demonstration Phase

Many small systems designed for dedicated tasks were built.
Important tool:
5 T magnet at DESY





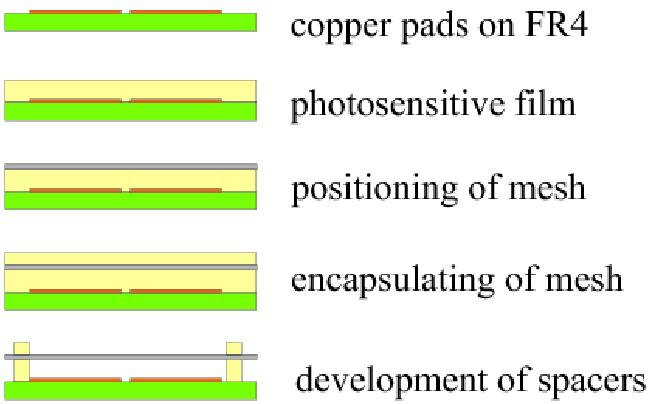


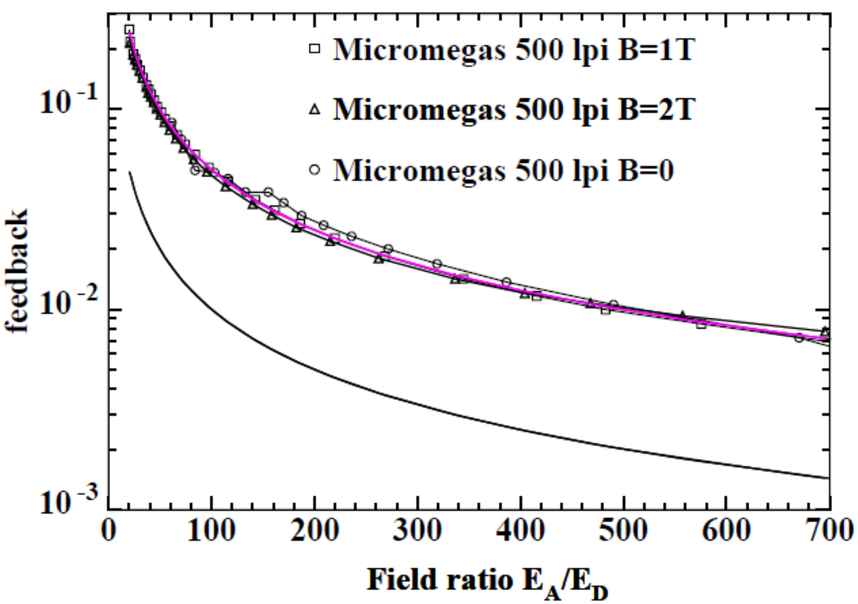


Results with Micromegas RO

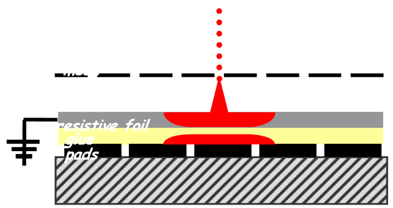
Several important developments in Micromegas R&D were achieved by the LCTPC-MM group:
- First ion back drift measurements with MM
- Development of resistive covering on pads
- First test with bulk-Micromegas

=> No discharges observed
=> Excellent space point resolution

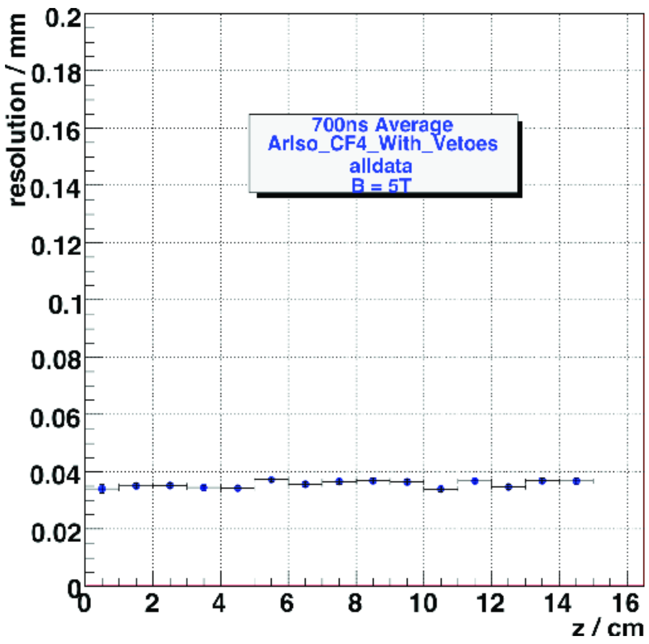




To broaden the signal shape the readout pads are covered with a resistive foil.



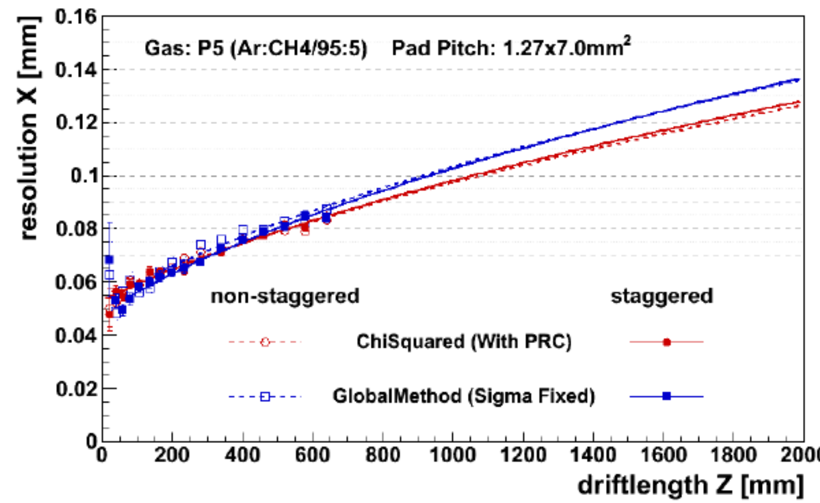
NIM A581, 254, 2007



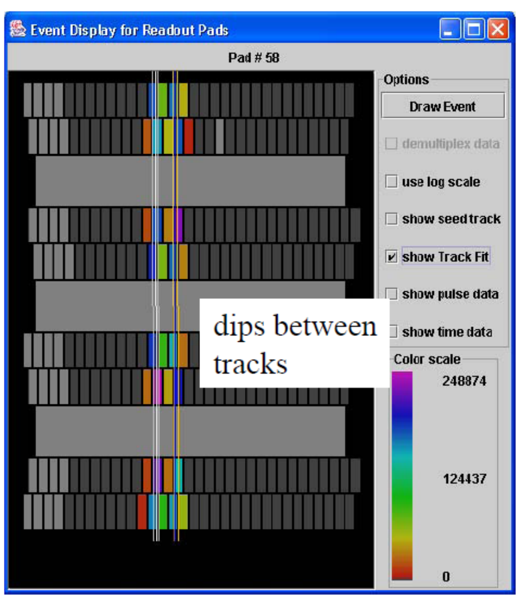
Results with GEM Readout

Measurements in high magnetic fields:

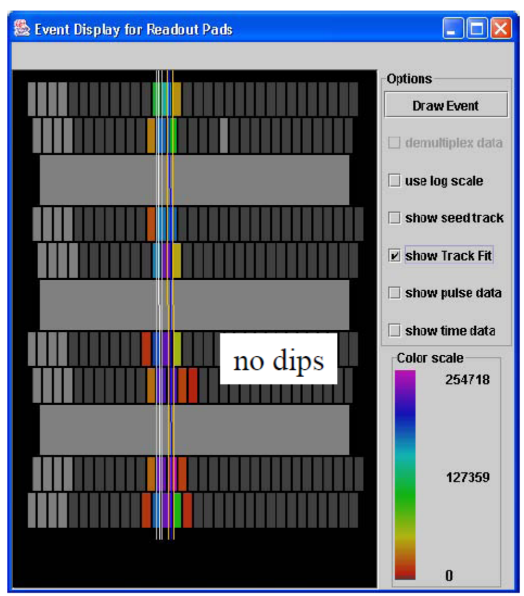
- Measurement of ion back drift
- Measurements of point resolution
- Measurements of double track resolution with laser beams
- Measurements with various pad shapes

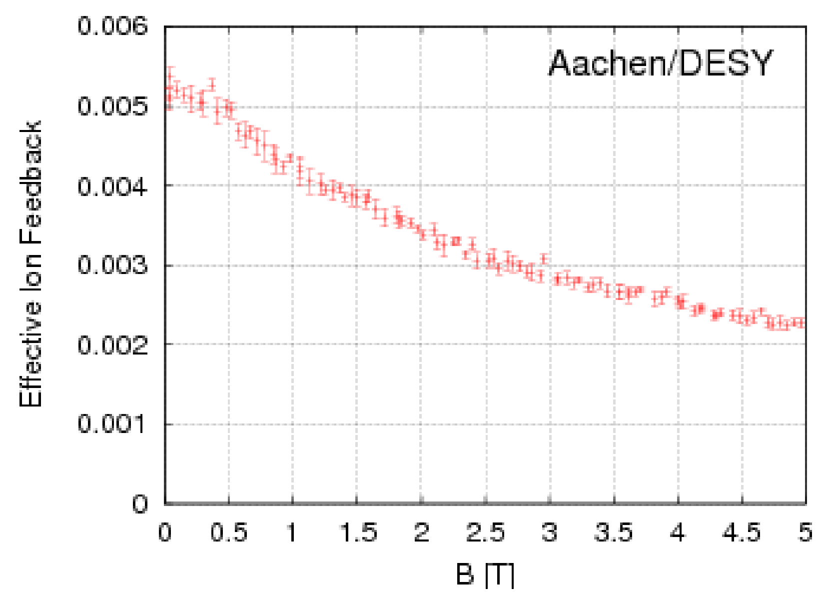


$\Delta x = 3.8$ mm



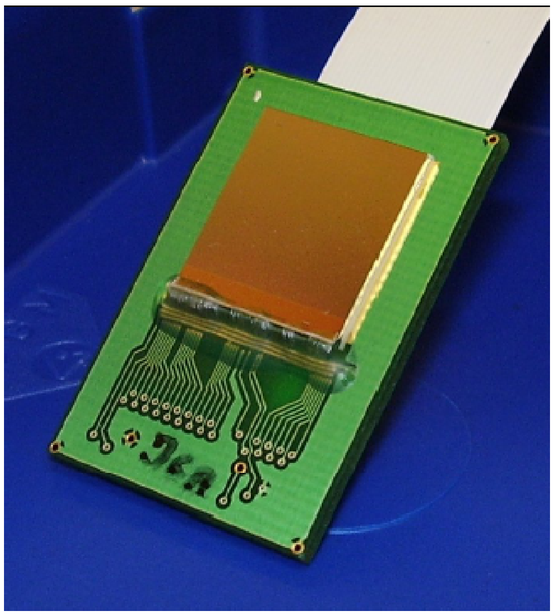
$\Delta x = 2.0$ mm

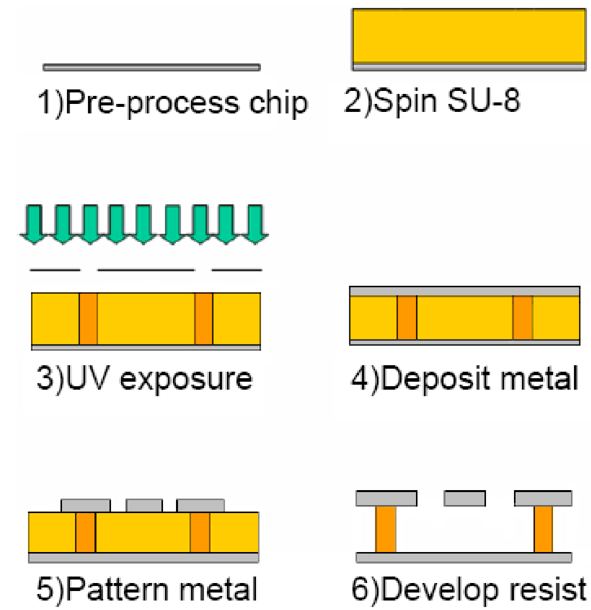


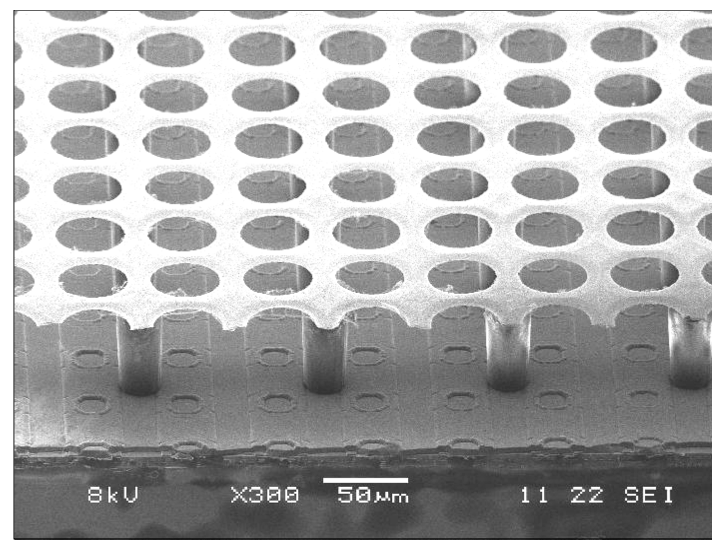


Highly Pixelized Readout

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





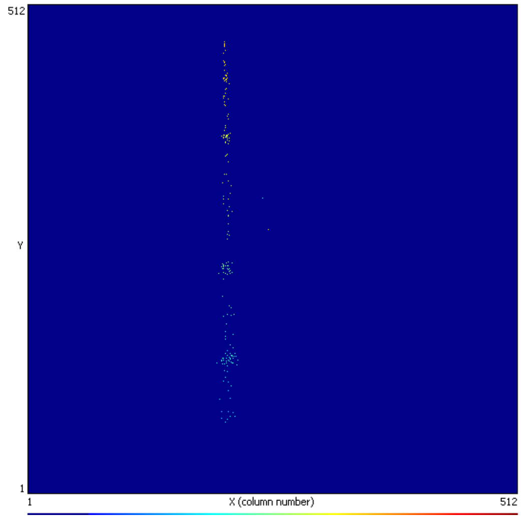


Timepix derived from Medipix-2

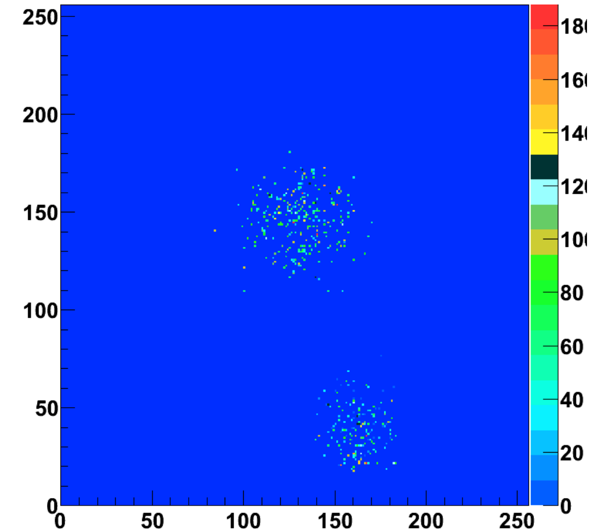
256 × 256 pixels of size 55 × 55 µm²

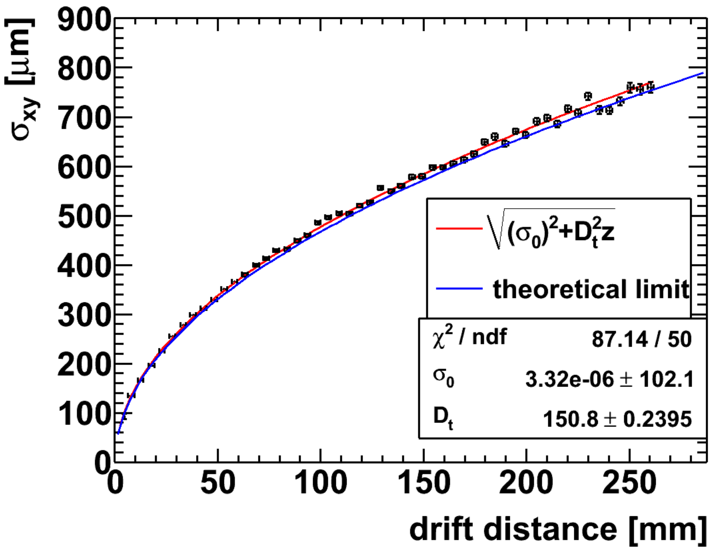
Each pixel can be set to:
- TOT ≈ integrated charge
- Time between hit and shutter end

Performance of InGrids



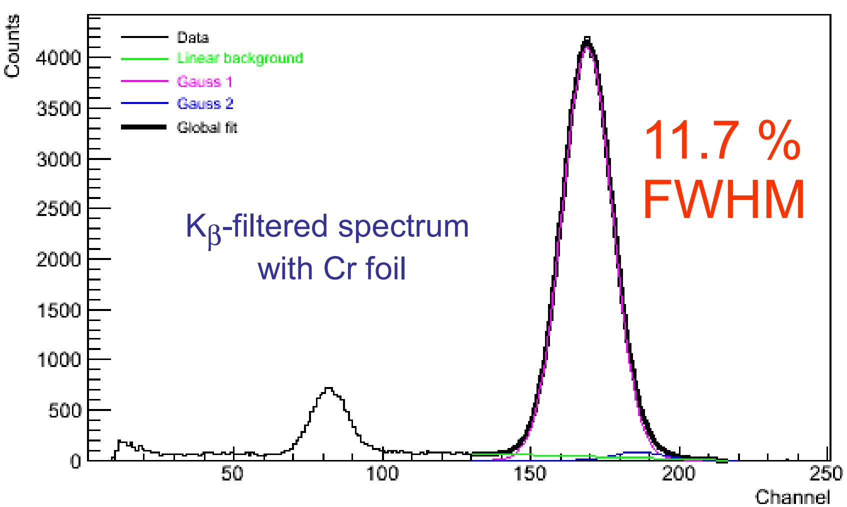
Significant progress towards large area applications:
- Si_xNi_y layer to protect against discharges
- Wafer-based production
- Development of electronics 100 chips





Spatial resolution in agreement with diffusion limit

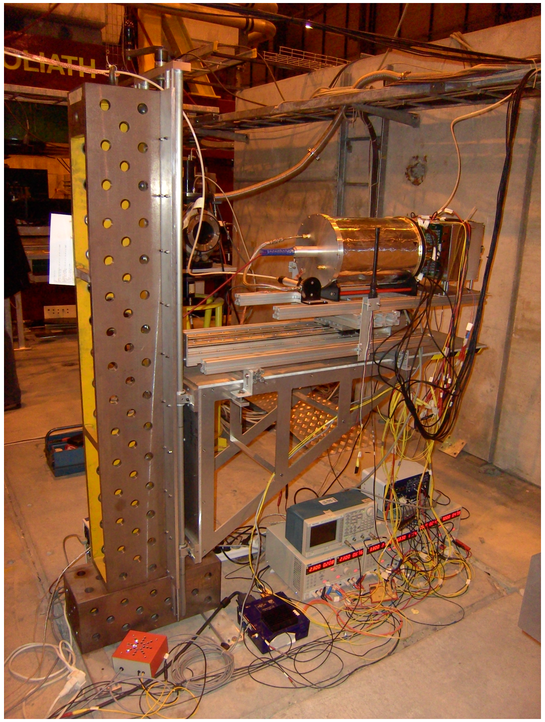
Energy resolution $\sigma_E/E \sim 5$ % (^{55}Fe) by counting primary electrons

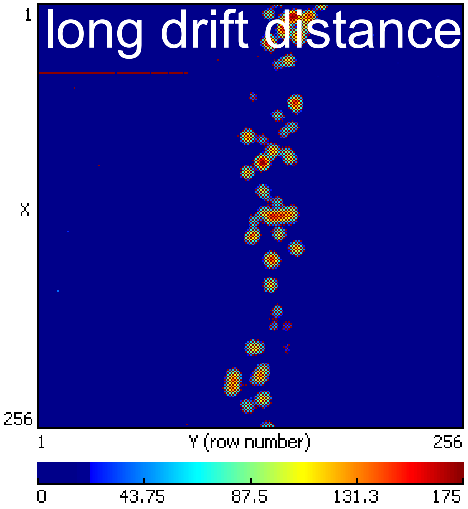


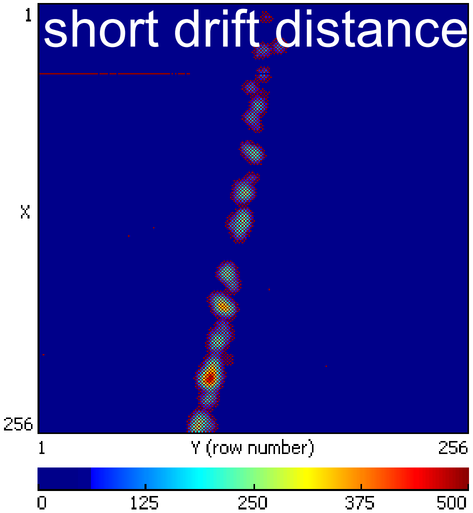
^{55}Fe spectrum in Ar:CH_4 90:10

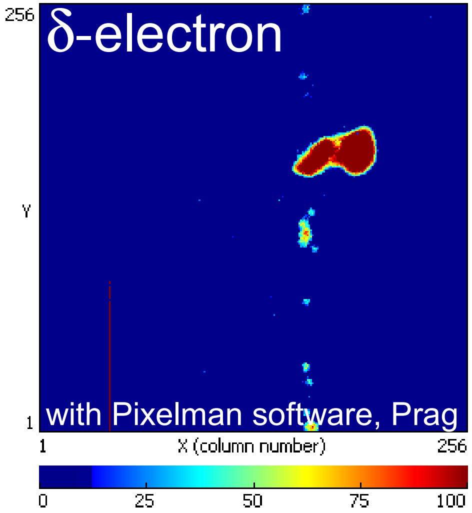
Performance of tGEMs with TP

Timepix chip below a triple GEM stack with spacings 1mm





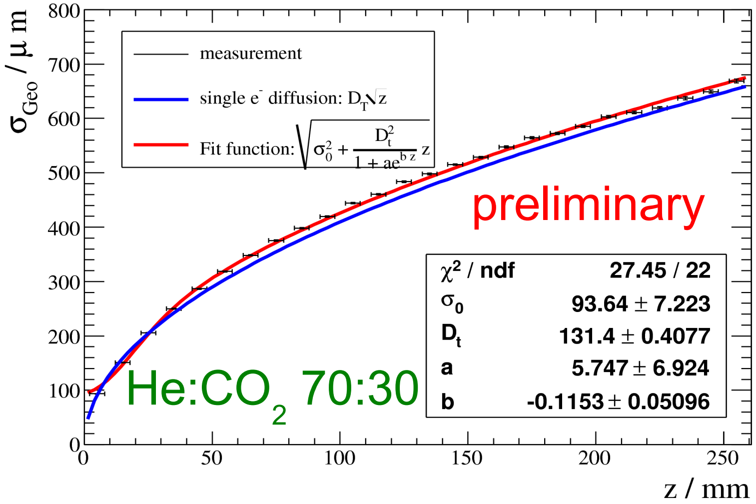


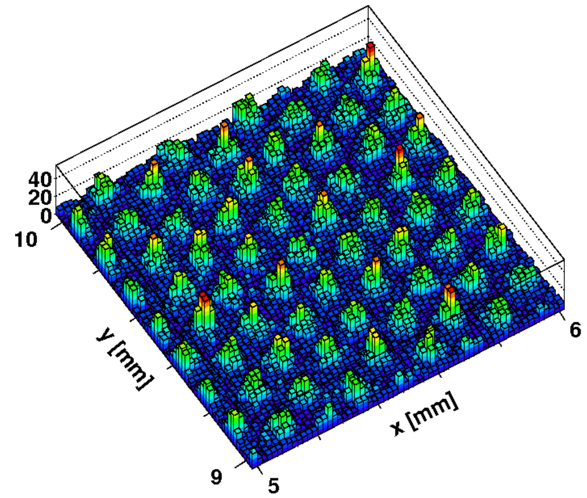


Gas: Ar/He:CO_2 70:30

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

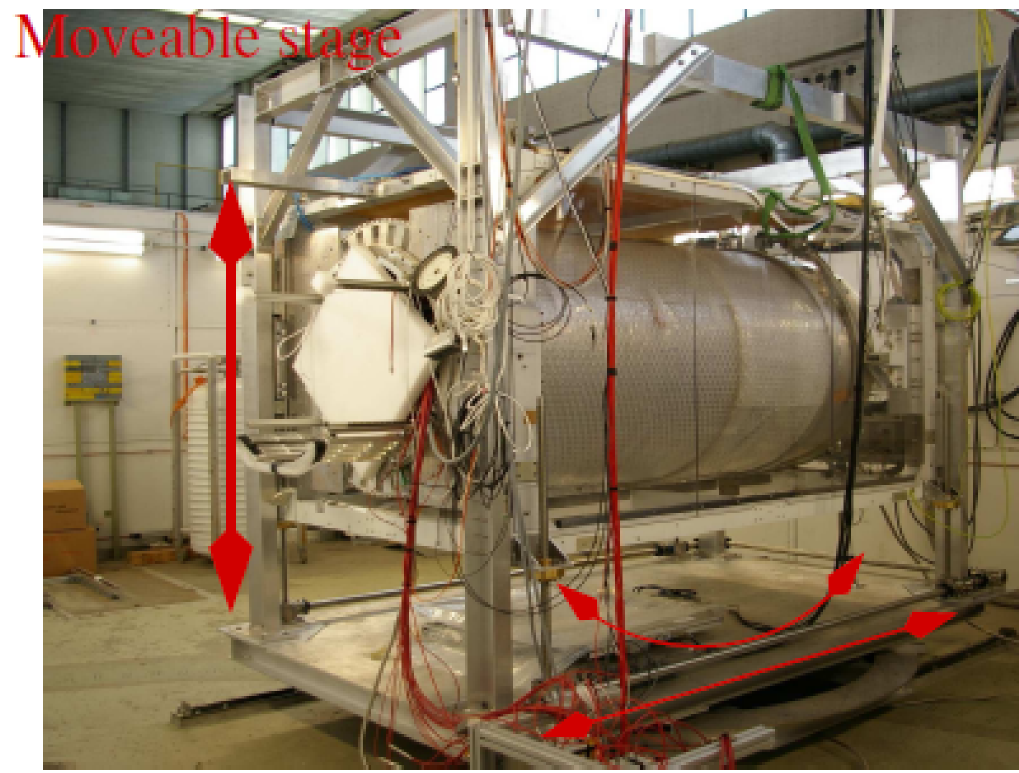
Consolidation Phase

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:

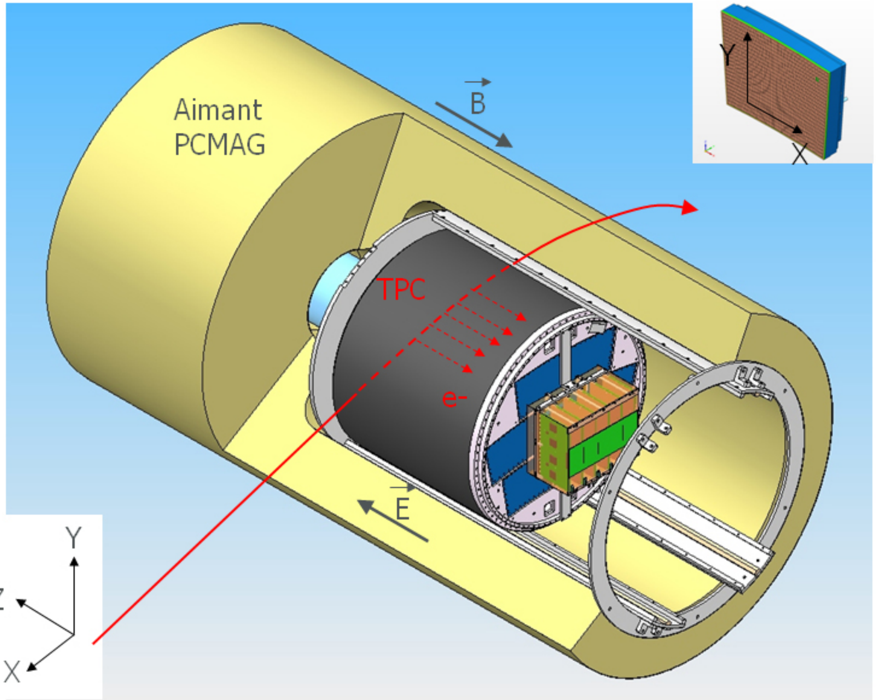
- Electron test beam
  with beam energy 1-6 GeV
- Beam trigger
- Movable support structure
- Solenoid with B < 1.25 T
- Field cage
- Cathode
- End plate with space for 7 modules
- Readout electronics
- Slow control
- External Si-trackers in discussion

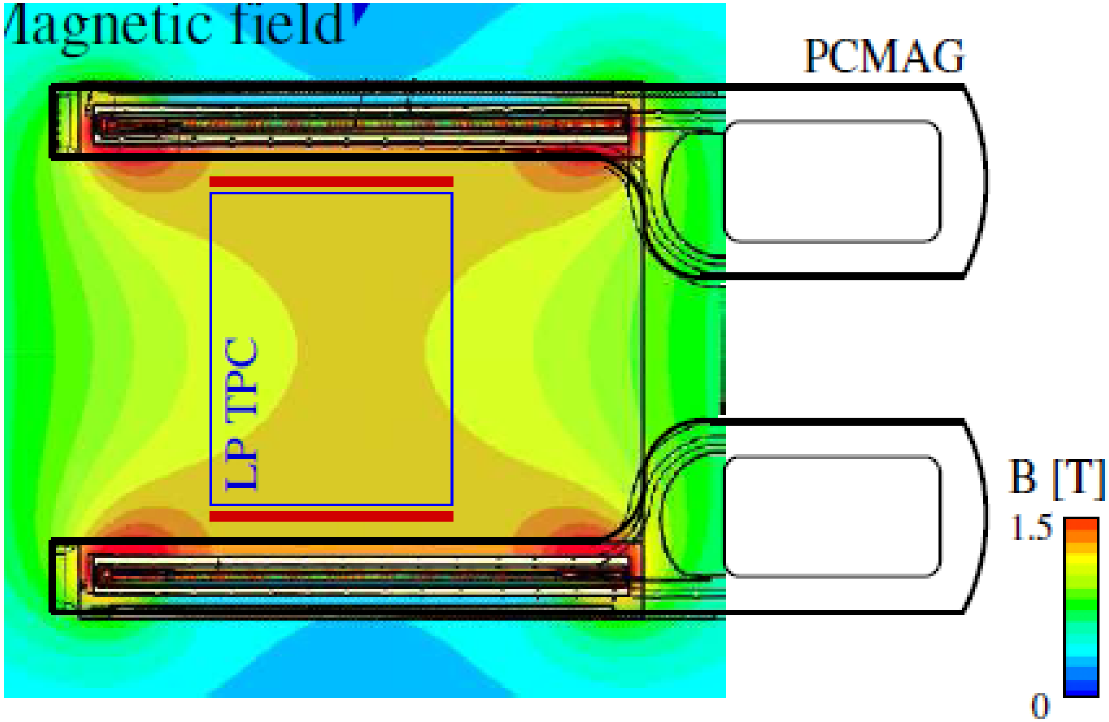
→ EUDET financed a significant fraction of setup



PCMAG

Superconducting solenoid without return yoke
→ low material budget (important for low energy e⁻-beam)
Magnetic field strength: B < 1.25 T
Bore diameter: 85 cm
Some B-field distortions → good to understand influence of distortions on measurements
On loan from KEK





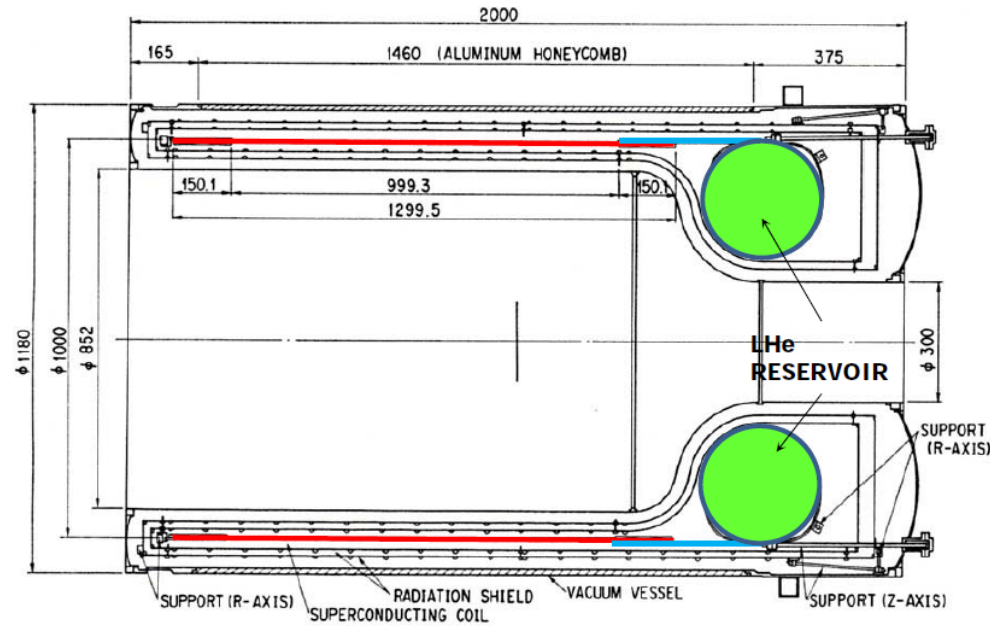
Modification PCMAG

Before the modification:

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,....



Modification at Toshiba and delivered back in 3/2012.

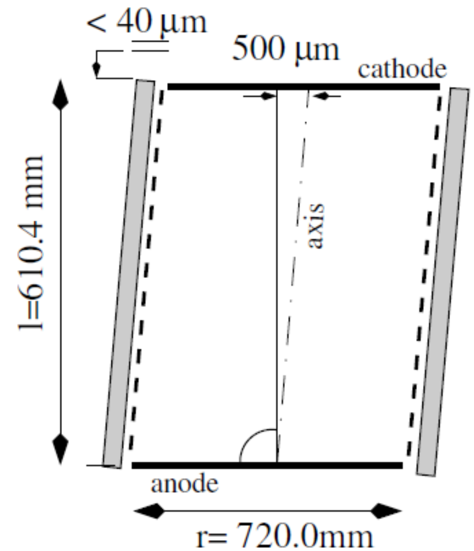
After the modification:

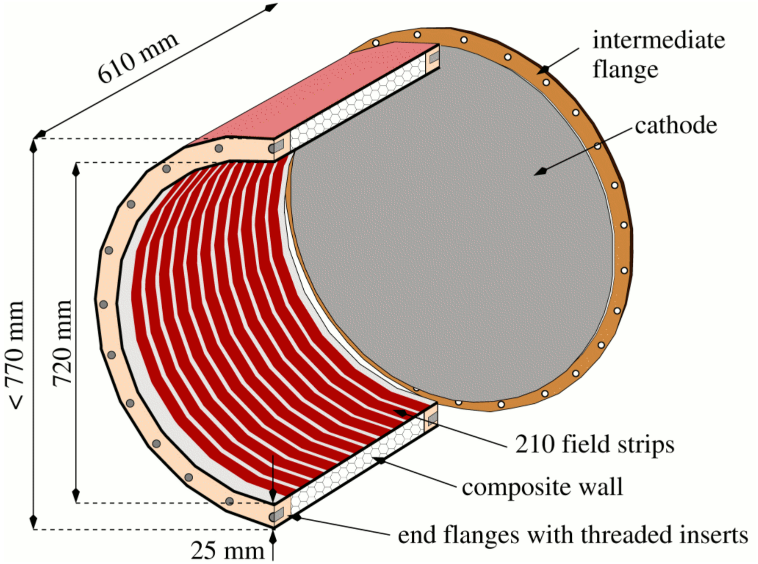
Conduction cooling by 2 cryocoolers at 4 K and 10 K.

The reservoir tank remains a heat sink.

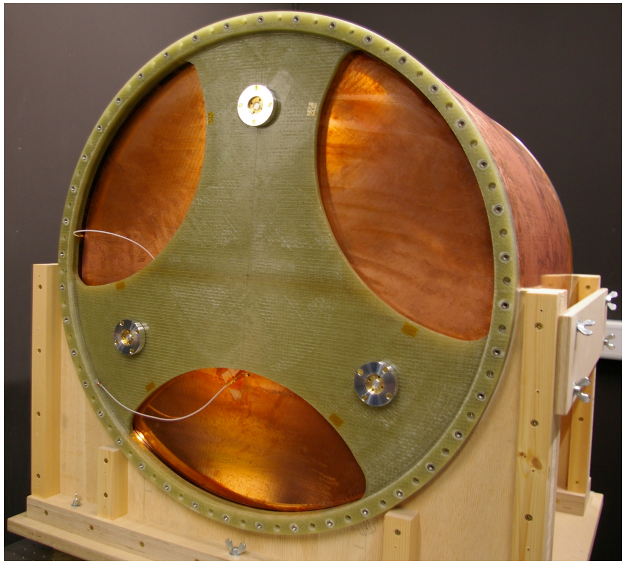
Large Prototype – Field Cage

<u>LP Field Cage Parameter:</u>
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

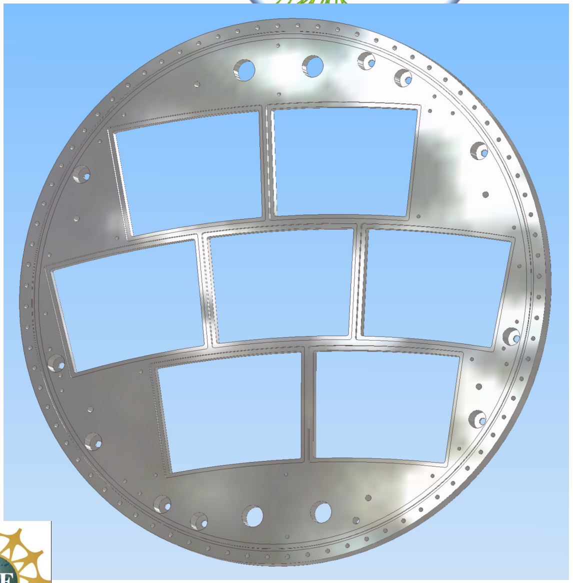




Mechanical accuracy
- Alignment of the end faces:
  δ < 40 µm
- Alignment of the field cage axis: offset at cathode ~500 µm

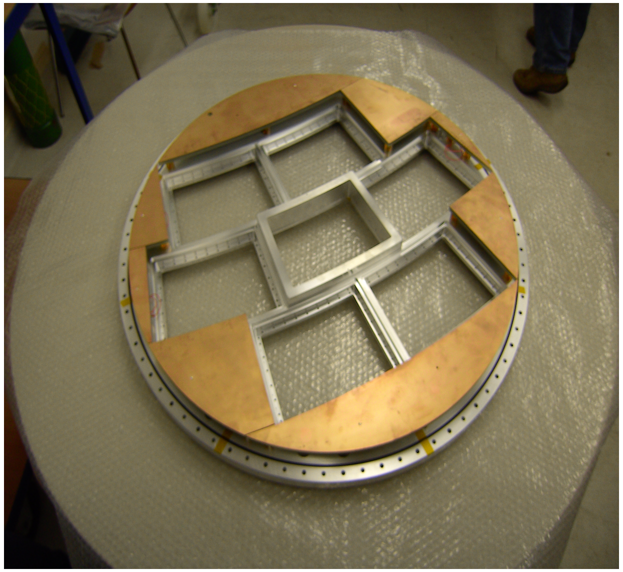


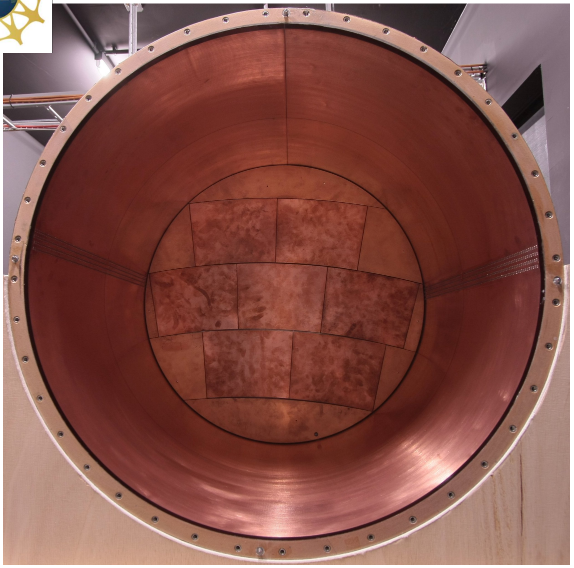
Large Prototype – End Plate



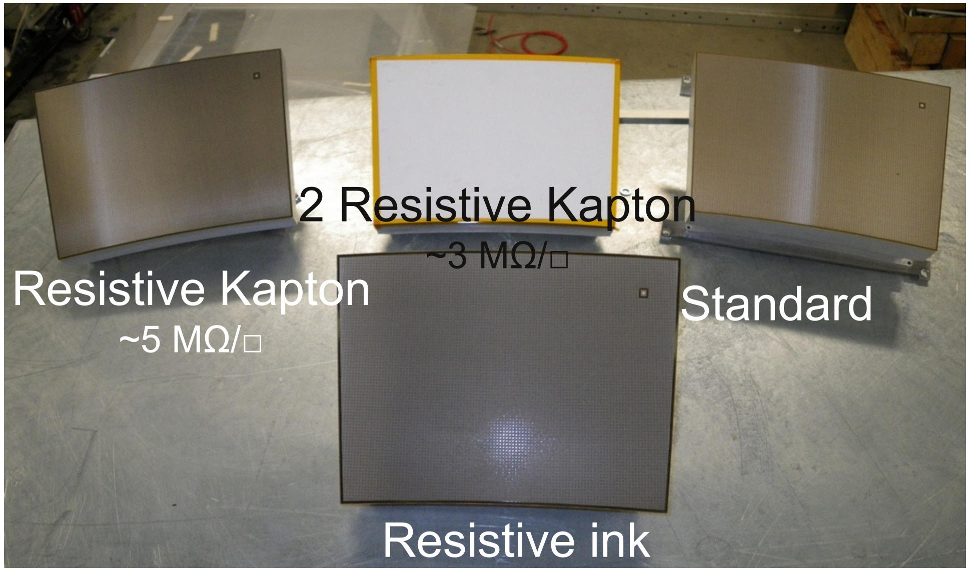
Modular End Plate

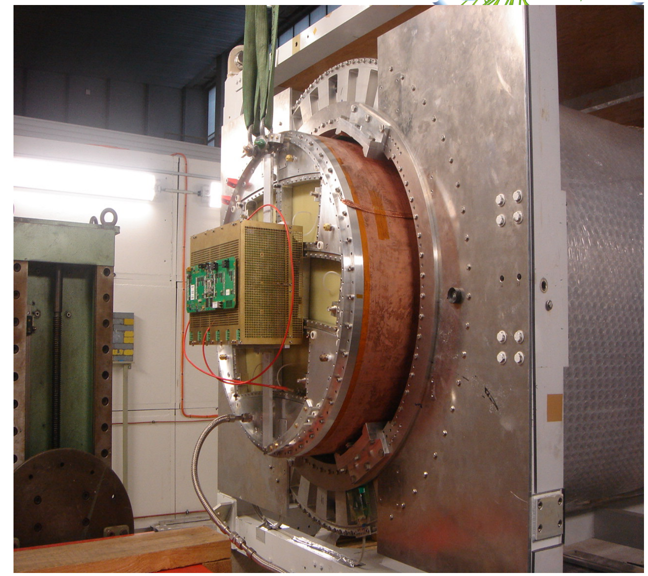
- First end plate for the LP made from solid Al
- During production the end plate was two times 'cold shocked' (cooled with liquid Nitrogen) to reduce stress.
- 7 module windows of size ≈ 22 × 17 cm^2
- Accuracy on the level of 30 μm
- Not designed to meet material budget requirements (weighs 18.87 kg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

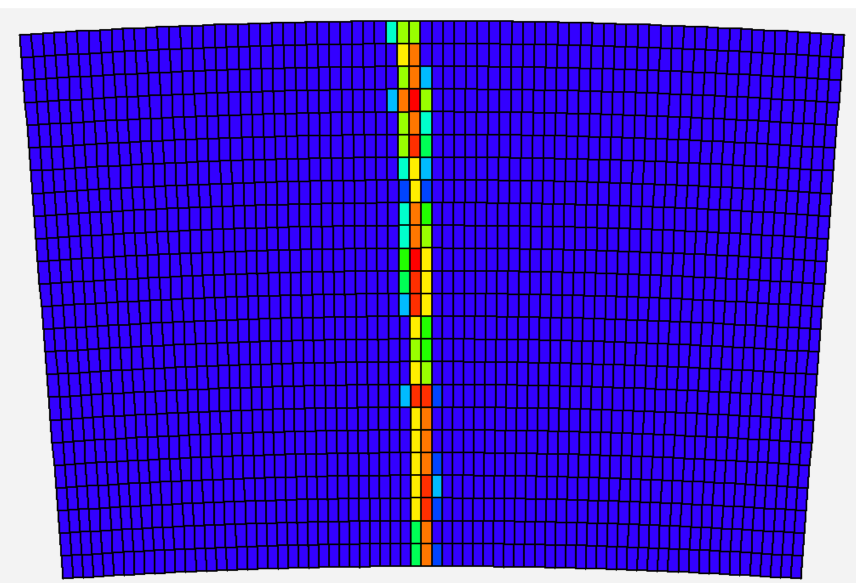




Micromegas Modules



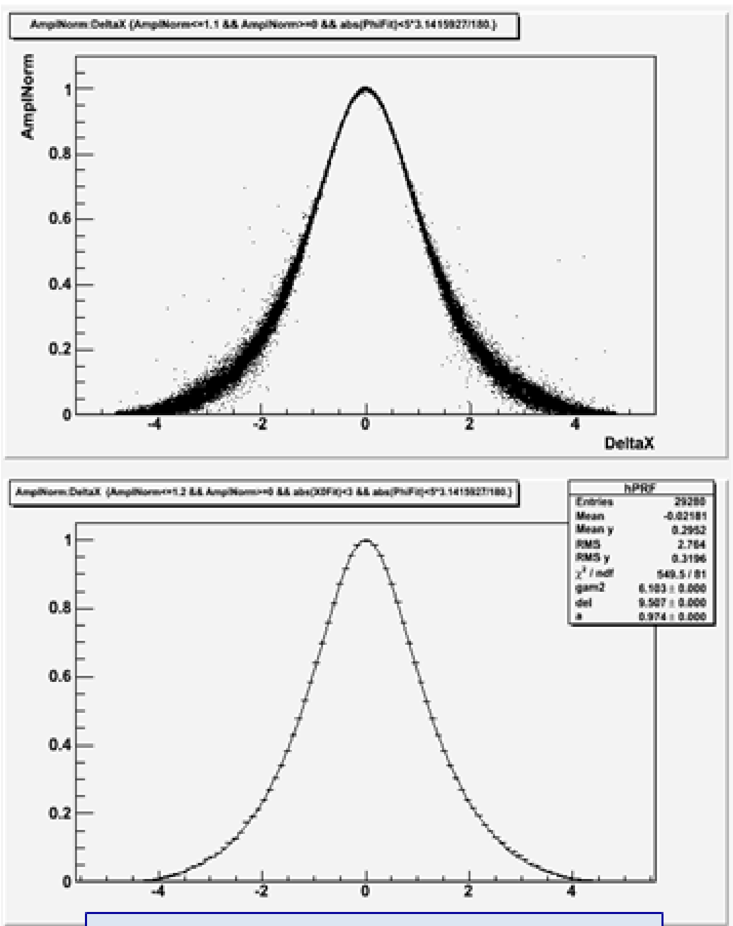




<u>Micromegas Module</u>

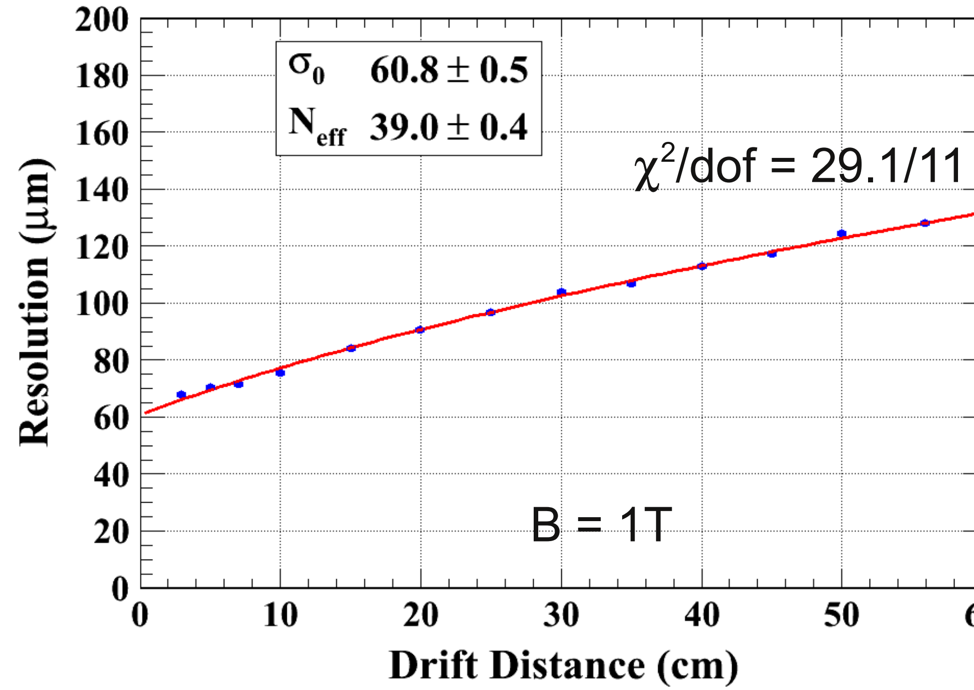
- 3×7 mm^2 large pads
- 24 row with 72 pads
  → 1728 pads per module
- Testing various resistive layers
  carbon loaded kapton, resistive ink
  O(1MΩ/□))
- AFTER electronics (T2K)

Performance of Micromegas Modules



CLK

New Modules have resistivity 3 MΩ/□.



Results (CLK Modules)

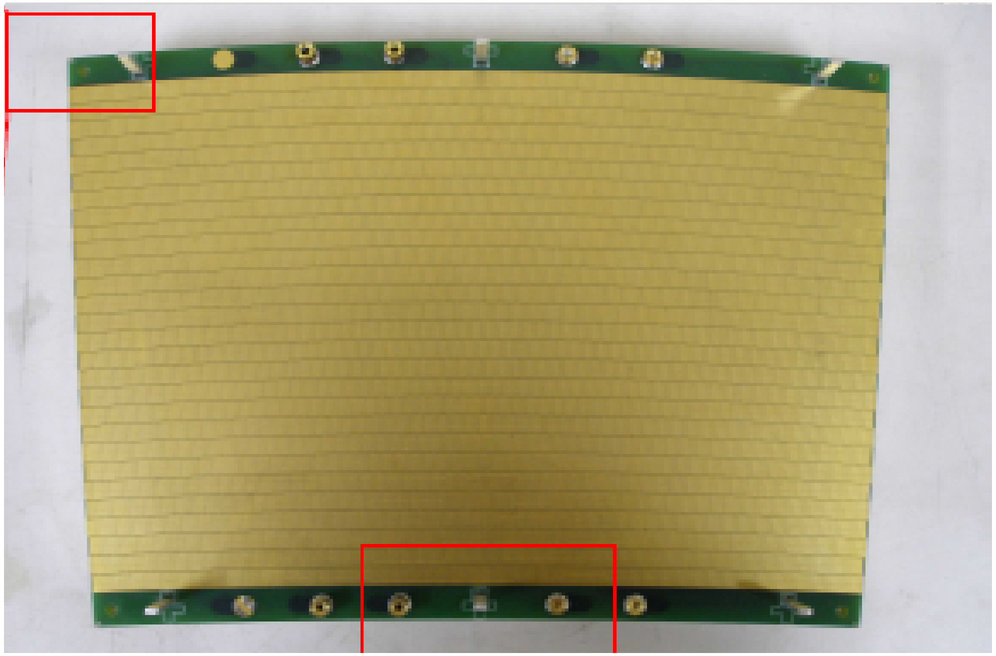
Resolution parametrized as $\sigma = \sqrt{\sigma_0^2 + D_t^2/N_{eff} \cdot z}$

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

→ σ_0 = 59 ± 2 μm

→ N_{eff} = 38 ± 0.8 per pad height

Double GEM Modules



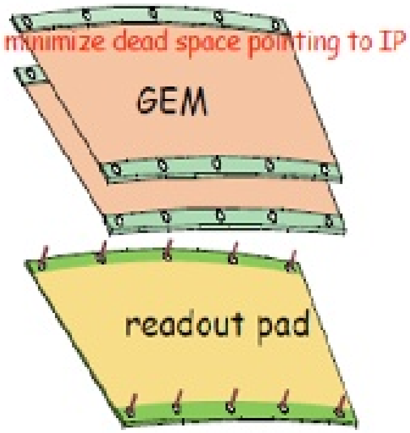
GEM Module

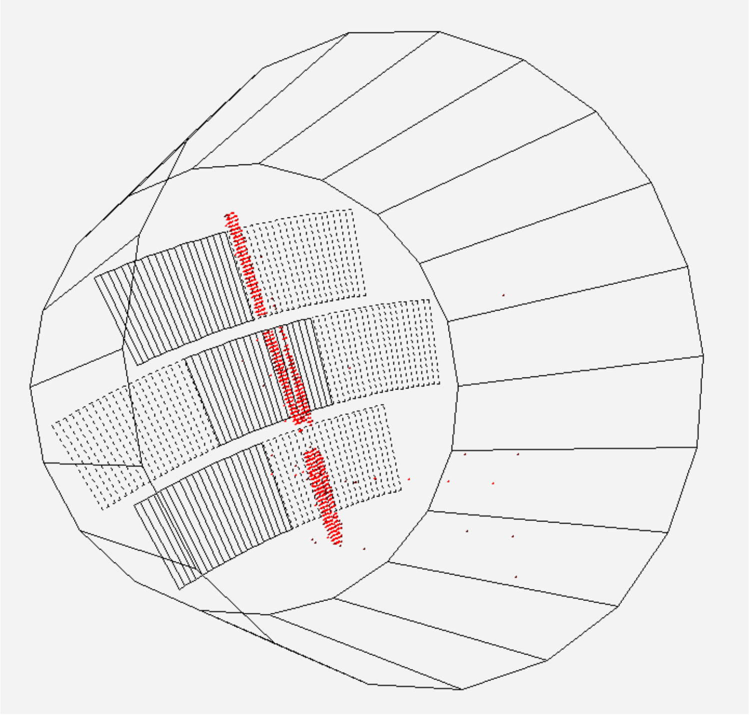
$1.2 \times 5.4\ mm^2$ pads - staggered

28 pad rows (176-192 pads/row)

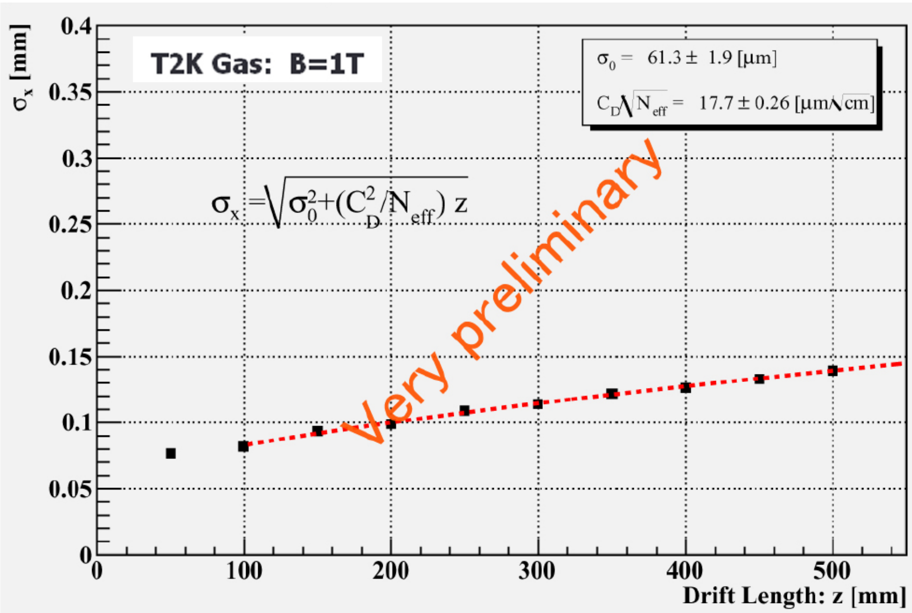
5152 pads per module

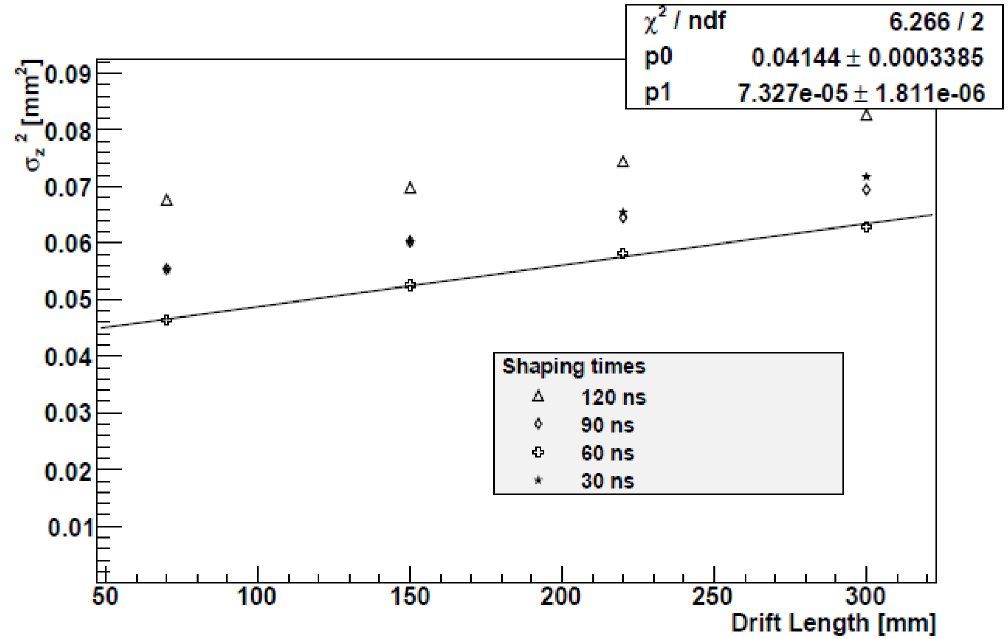
2 LCP-GEMs, 100 μm thick





Performance of Double GEMs





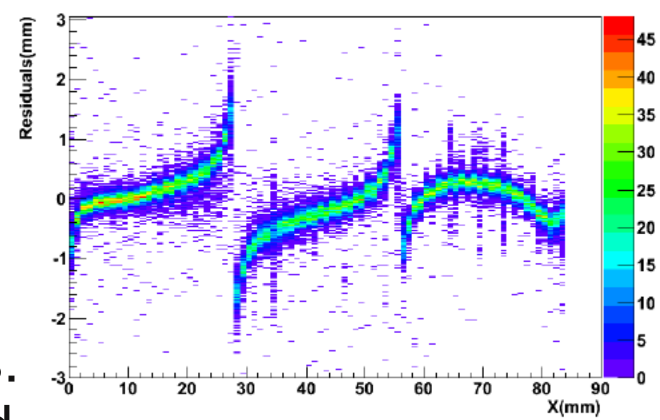
Resolution parametrized as $\sigma = \sqrt{\sigma_0^2 + D_t^2/N_{eff} \cdot z}$

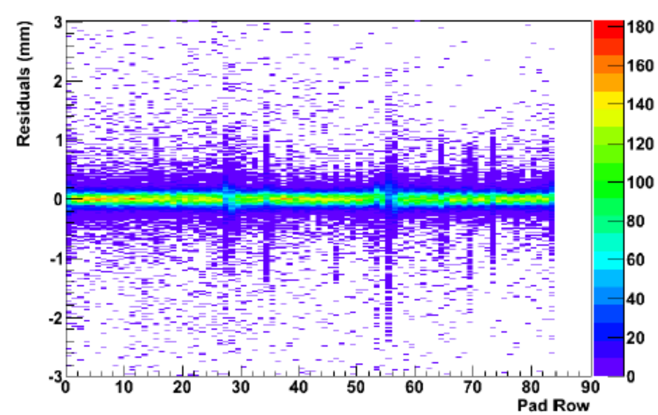
$\rightarrow \sigma_0 = 61.3 \pm 1.9$ μm

Field distortions due to frame observed.

Effect corrected in analysis.

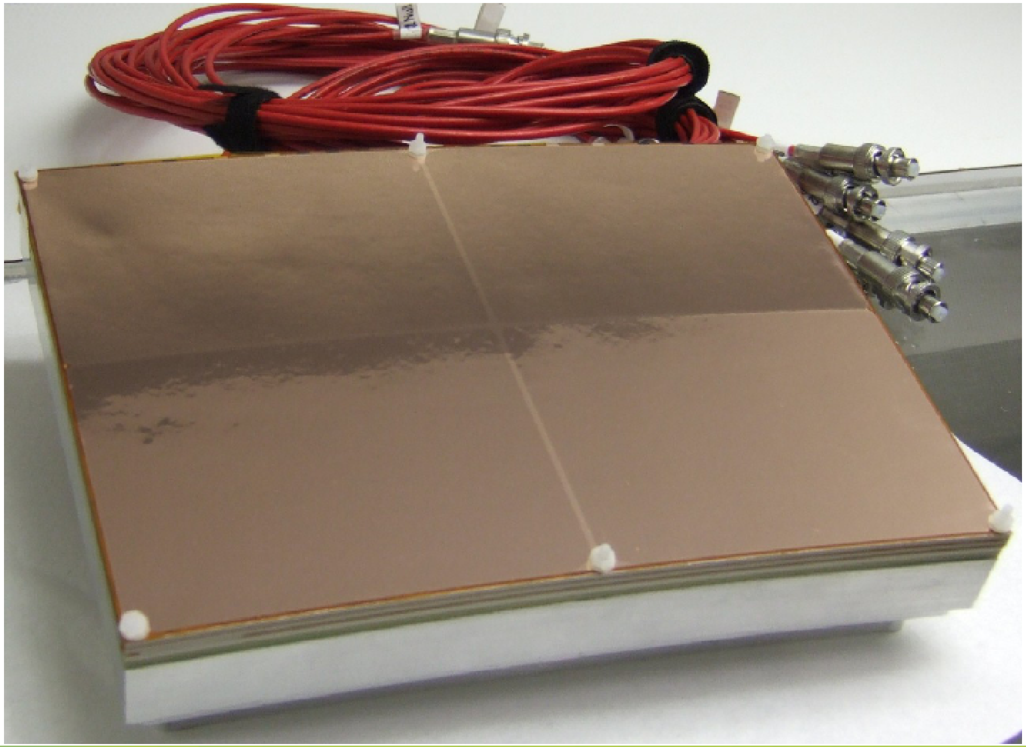
New modules are designed.

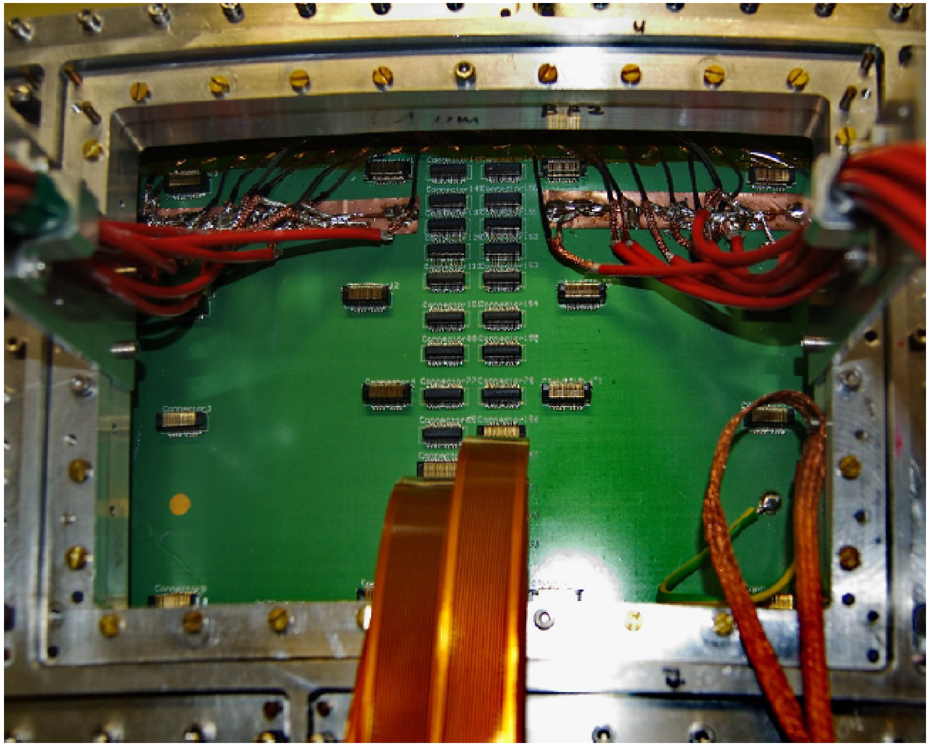




Triple GEM Module

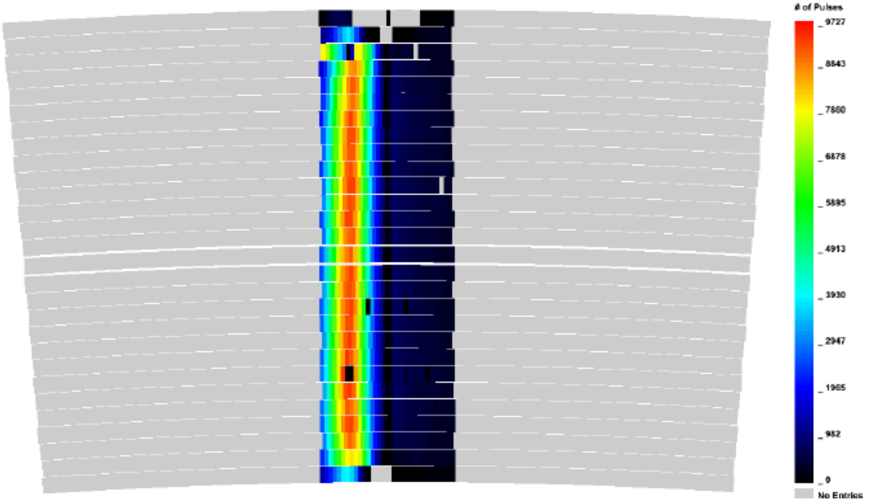
3 standard CERN GEMs mounted on thin ceramic structure (bar size ~1 mm) to reduce dead space.
GEM is segmented into 4 parts to reduce energy stored in one sector.
1000 small pads ($1.26 \times 5.85\ mm^2$)
First version tested last year: Detector could be operated in test beam, but a few shortcomings were identified.
Second version is being built with ~5000 pads.



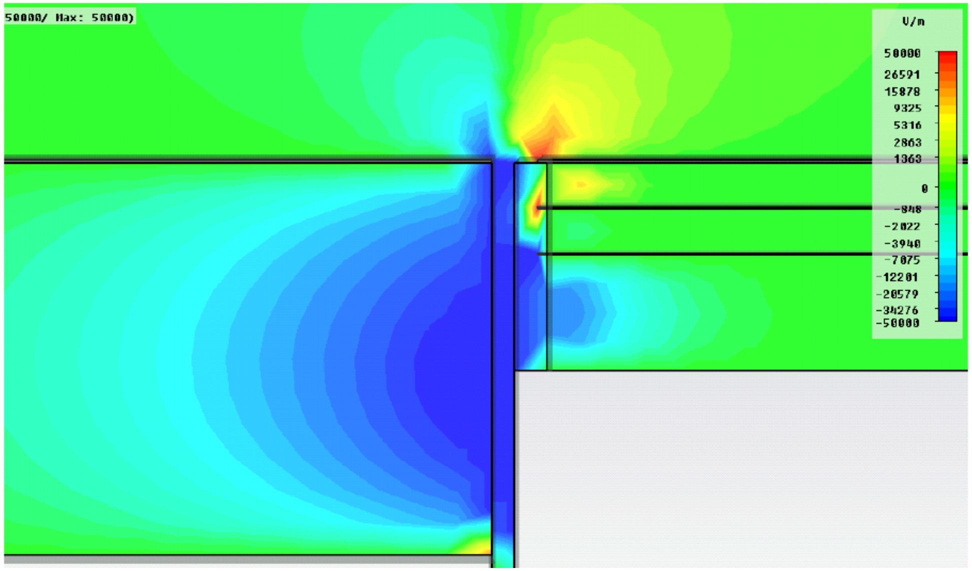


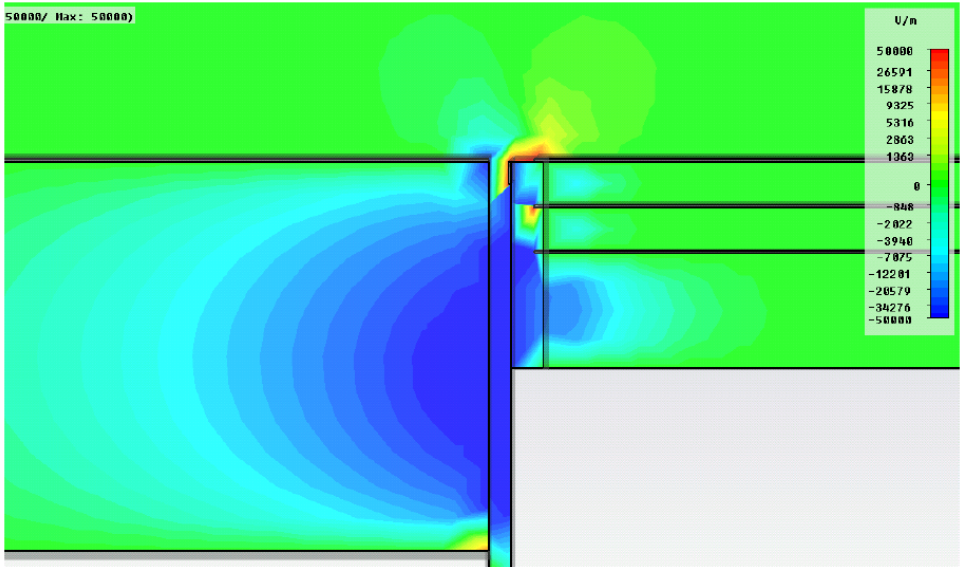
Field Distortions

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.



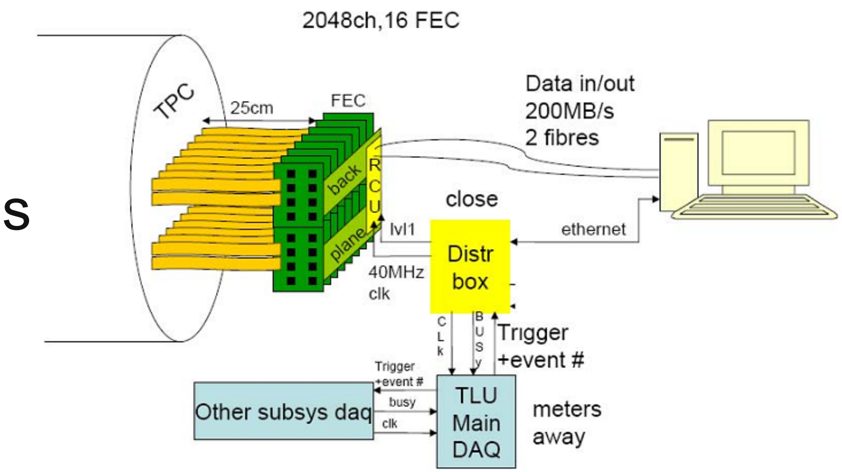
Number of reconstructed pulses



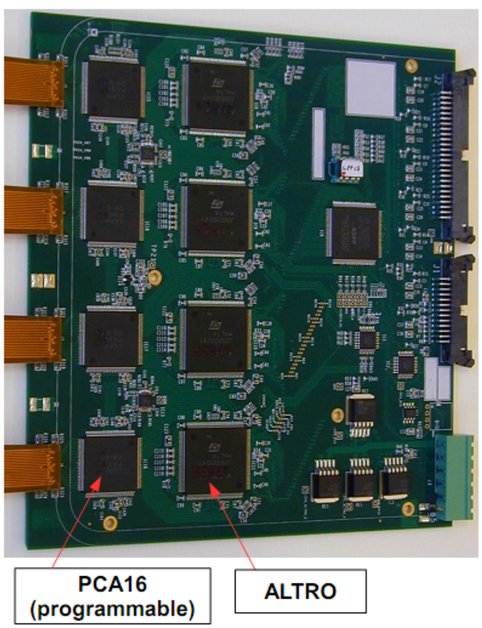


Electronics ALTRO & AFTER

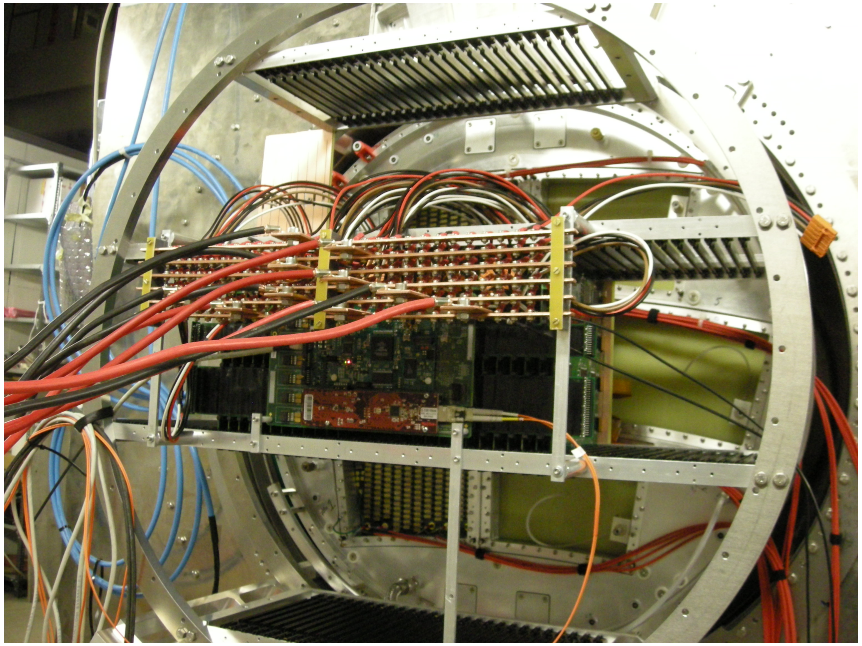
A set of 10,000 channels was built with both the AFTER chip (T2K) and the ALTRO chip (ALICE).
For the ALTRO-electronics, e.g. new FECs were designed with:
8 ALTRO ADC chips (ALICE)
8 PCA16 charge sensitive preamplifiers



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

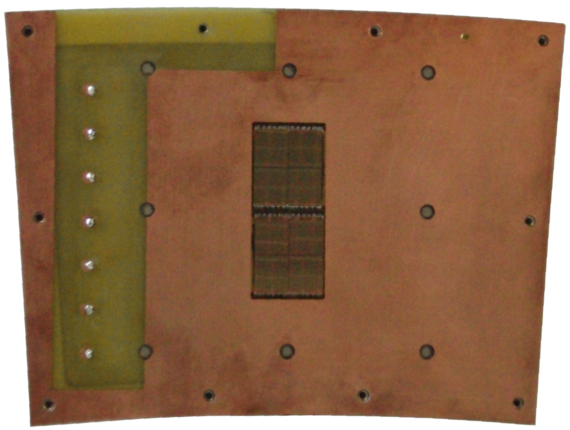


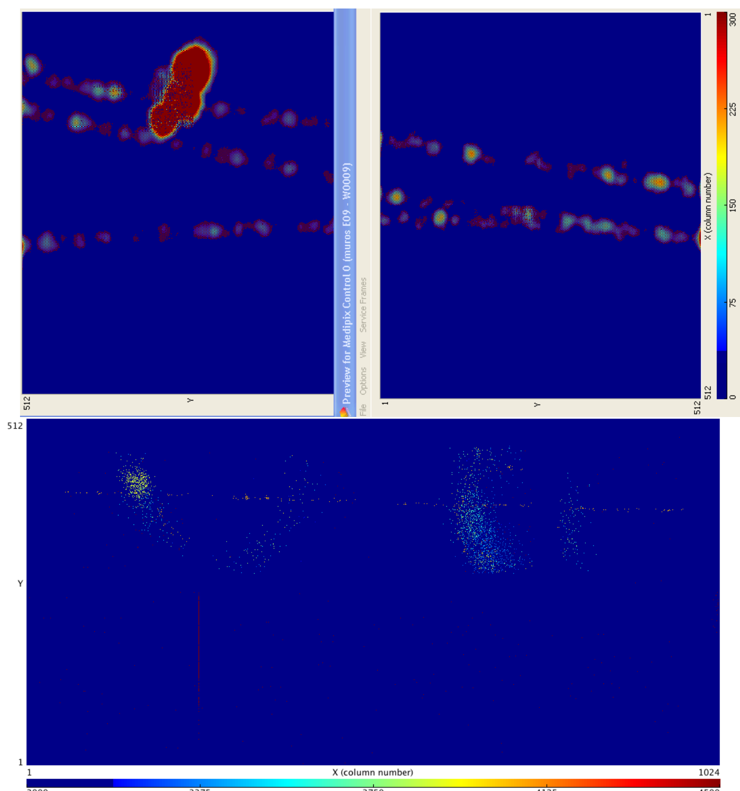
Highly pixelized Readout

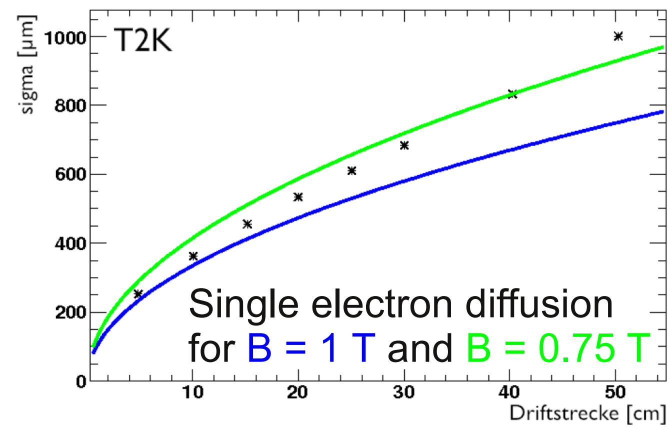
2 modules with Timepix-based readout (InGrid, triple GEM) have been built and operated in the Large Prototype.

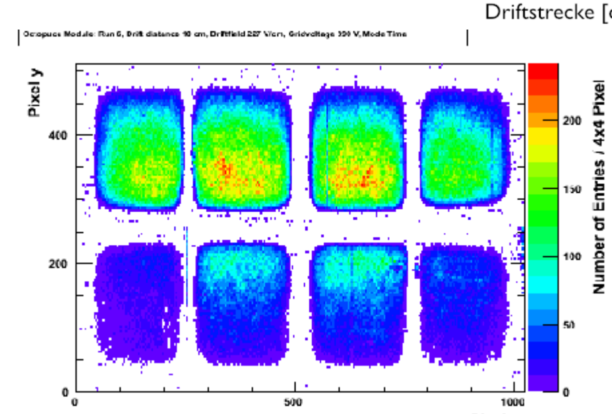
Sofar, only small areas (8 chip) have been covered.

Quantitative results were not as good as with small prototypes because of electric field distortions close to grid edges (InGrid) and of B-field distortions (triple GEMs).









MarlinTPC

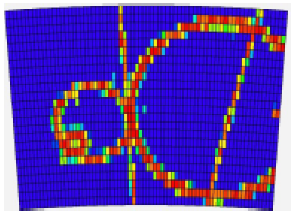
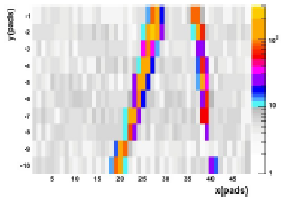
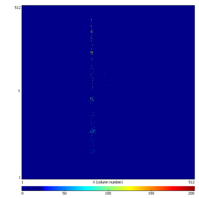
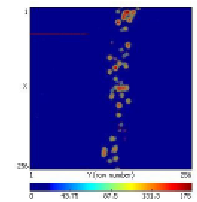
MarlinTPC is based on Marlin and ILC software.

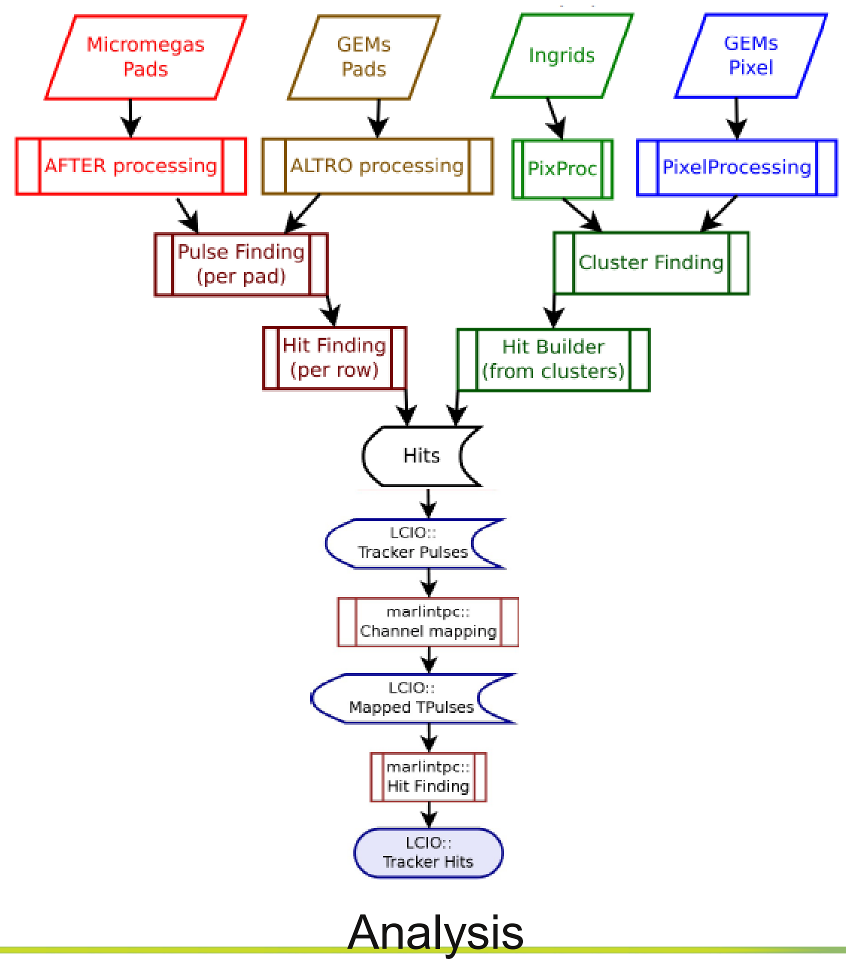
It contains a common geometry description (GEAR) and conditions data base (LCCD).

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.

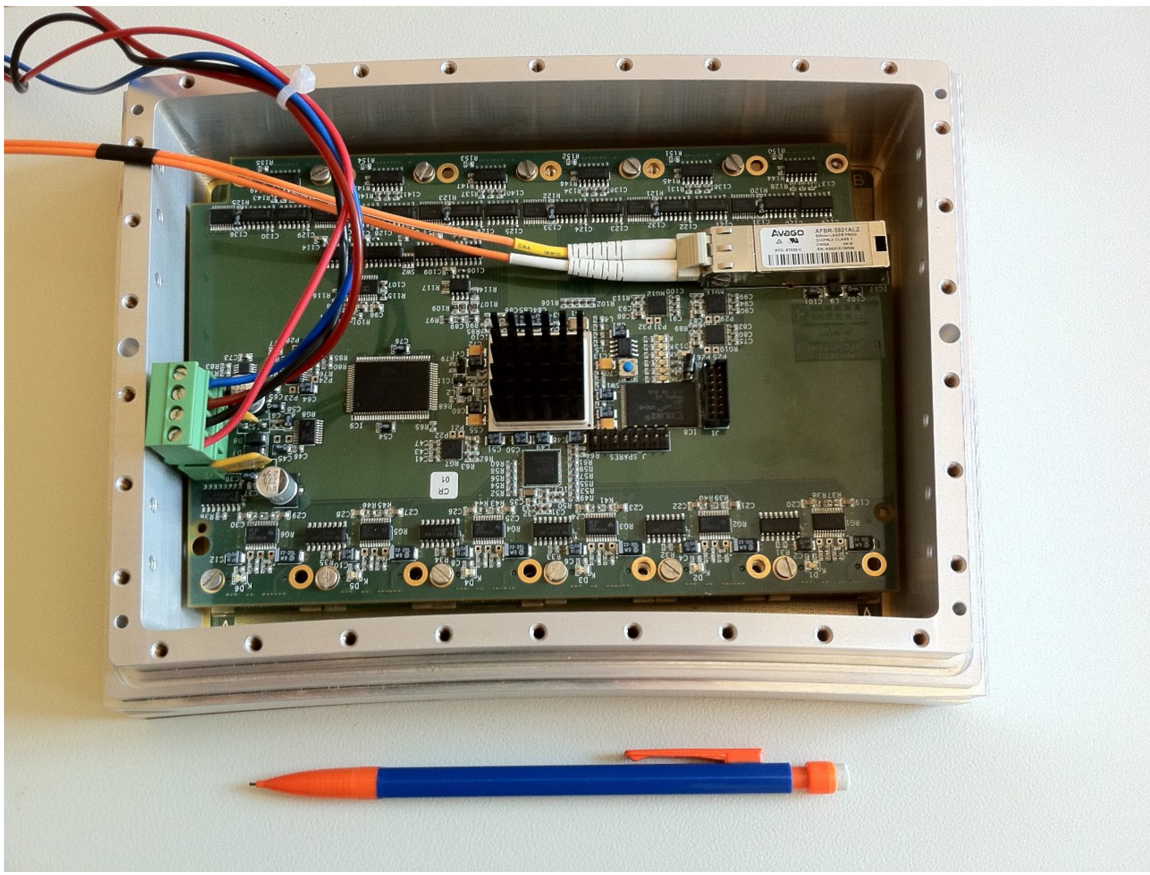







Ongoing Work -
Towards a final design

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

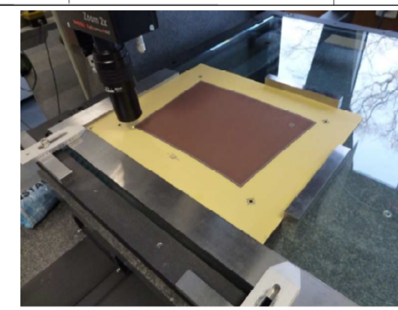
PIECE : LEITERPLATTEN

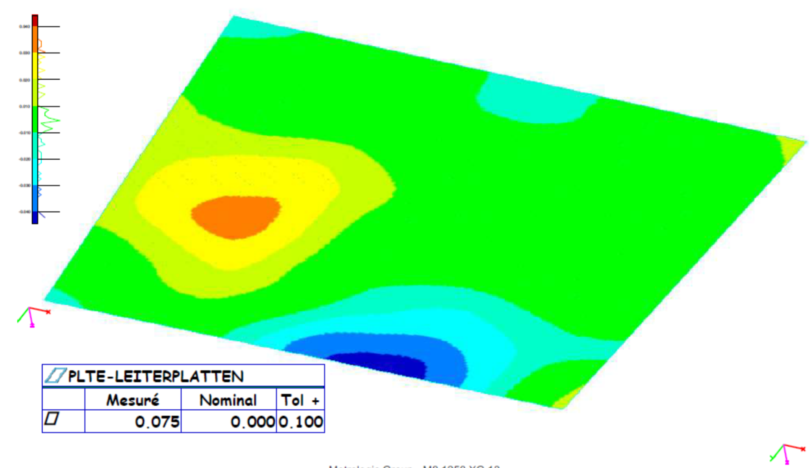
No EDMS 1203454

1/ 1

Controleur : Lilian REMANDET	Plan No : ---
Client : S. HERLANT	Fournisseur :---
Machine : Ferranti	Piece No : N°1
Temperature : 20°C ±1°C	Date : 07/03/12 16:05:13
Precision des mesures : ± 3 µm	Nom du programme :

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





New End Plate

Material budget requirement for final end plate: 8% X_0

→ Finite Element Analysis of final end plate

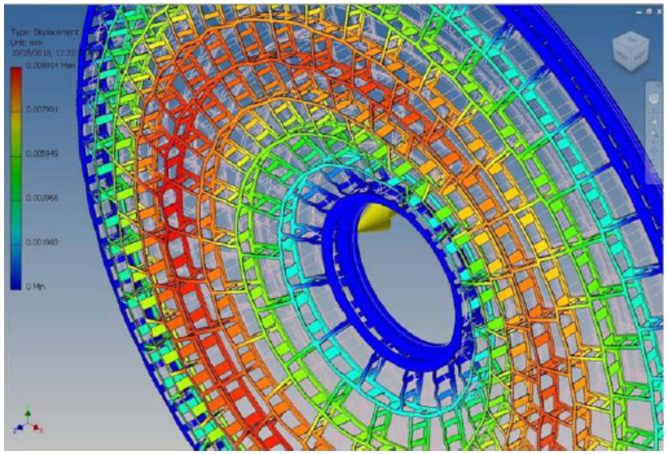
Deflection of 220 μm for overpressure of 2.1 mbar

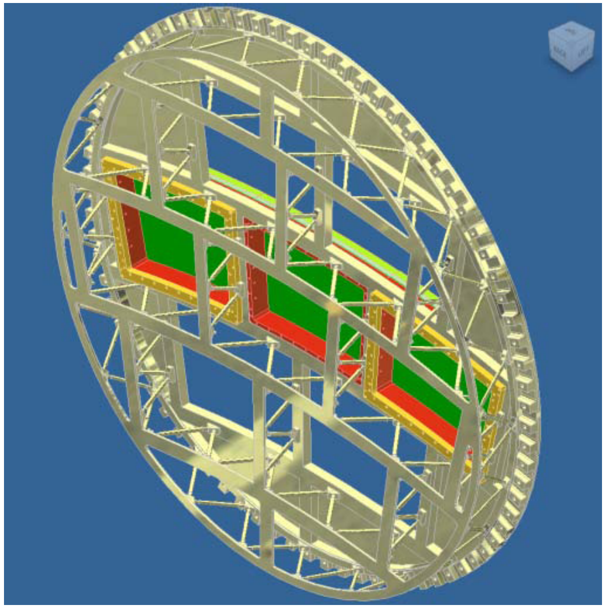
Several materials and designs have been studied

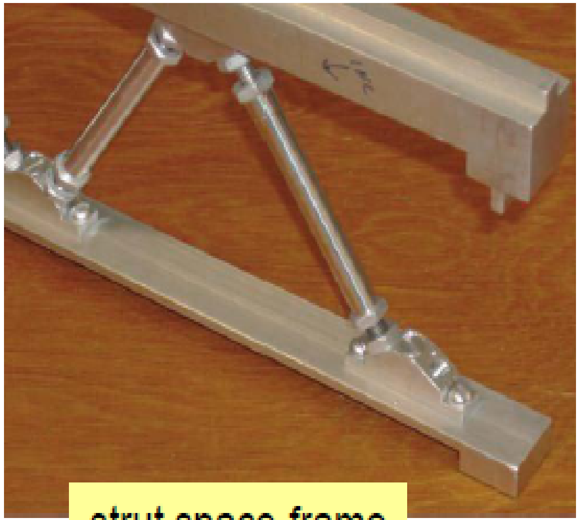
Strut space-frame design provides greatest strength-to-material.

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

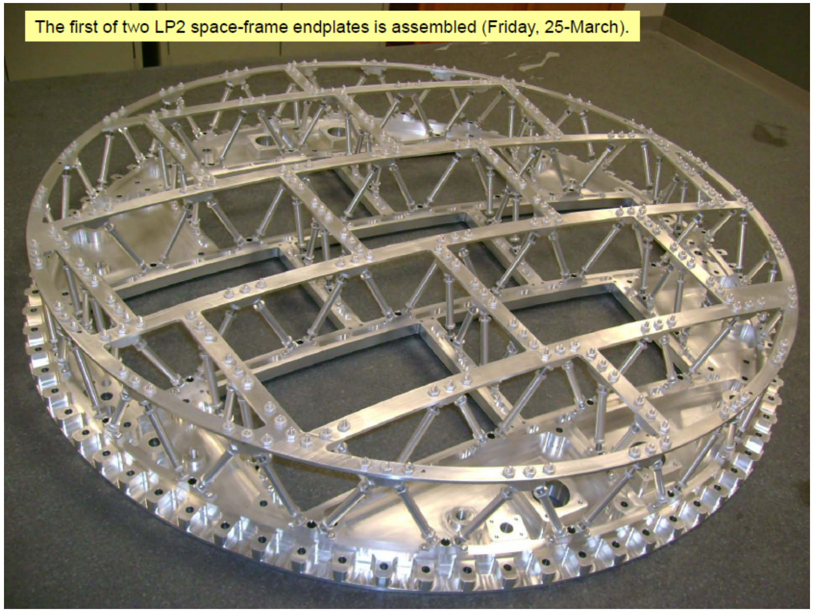
Preliminary measurements of deflection are very close to requirements







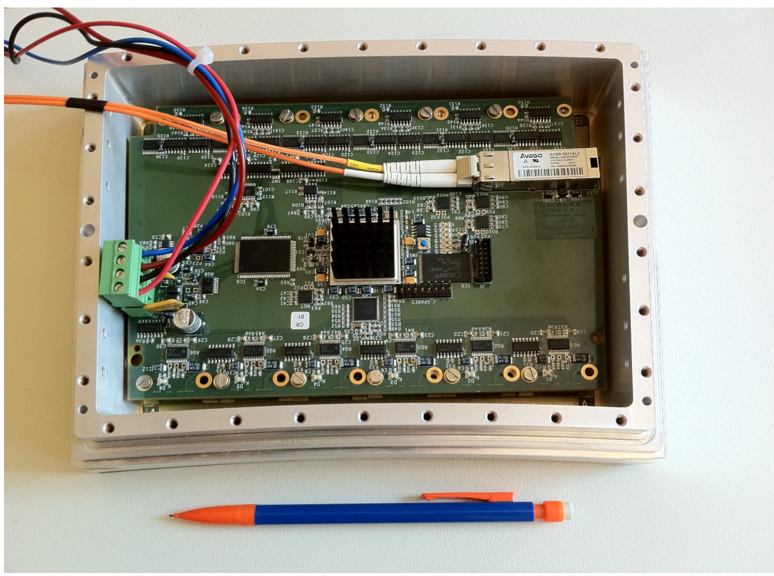
test structure

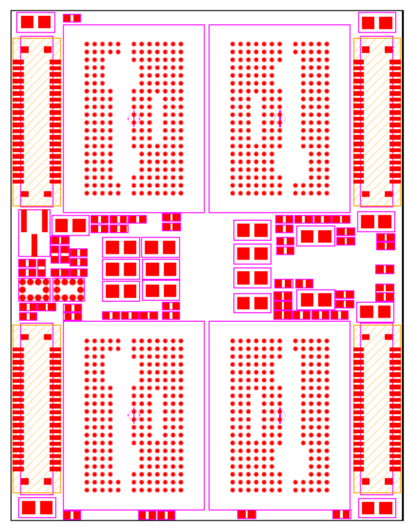


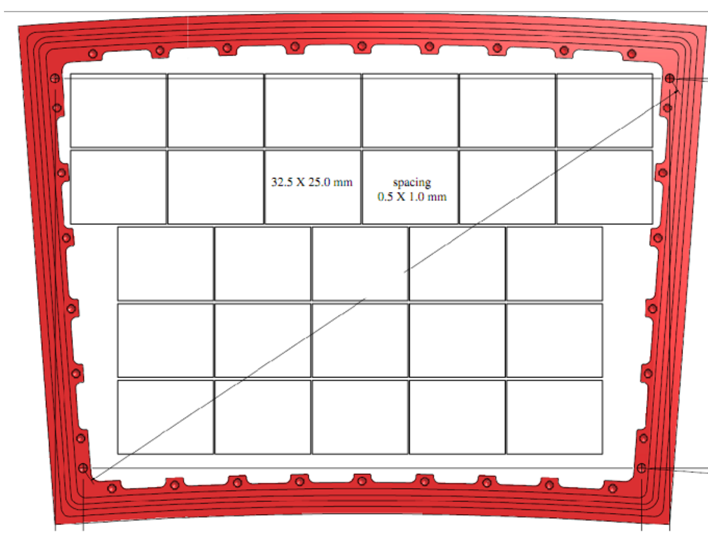
Electronics

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

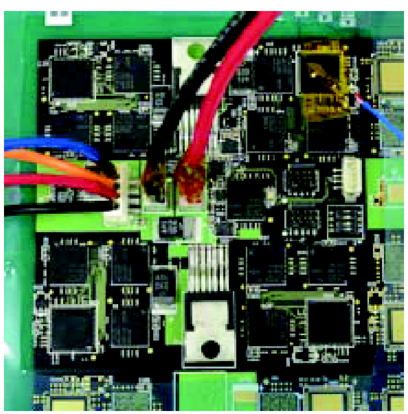
There are several methods of cooling:

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.

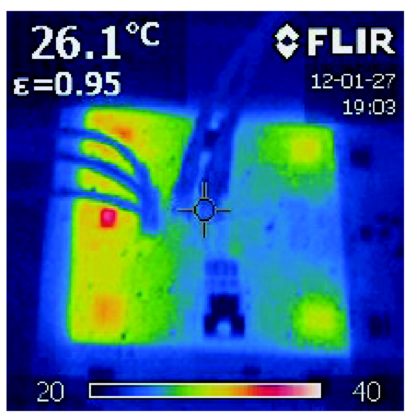
2.) Cooling with air or water

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.

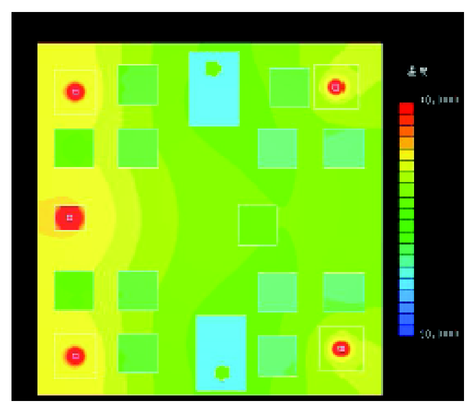
Part side



Observation



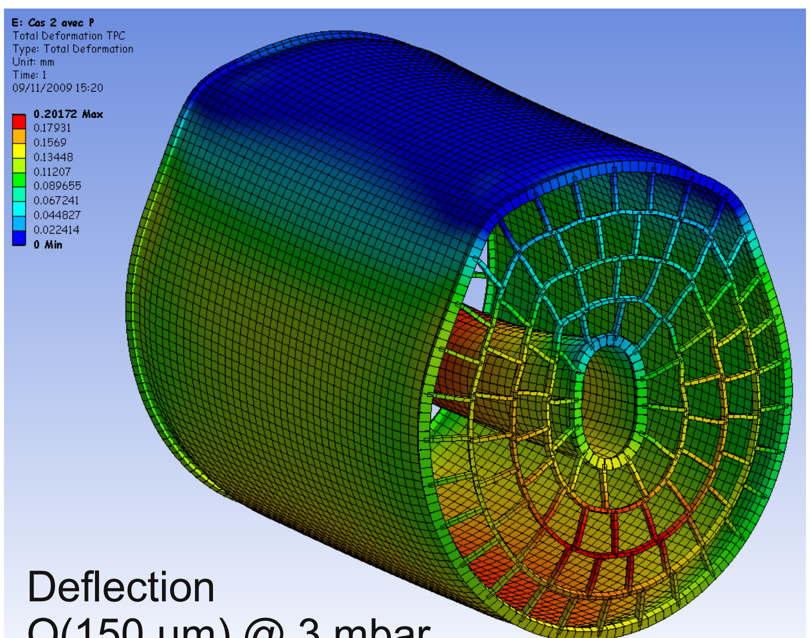
Simulation



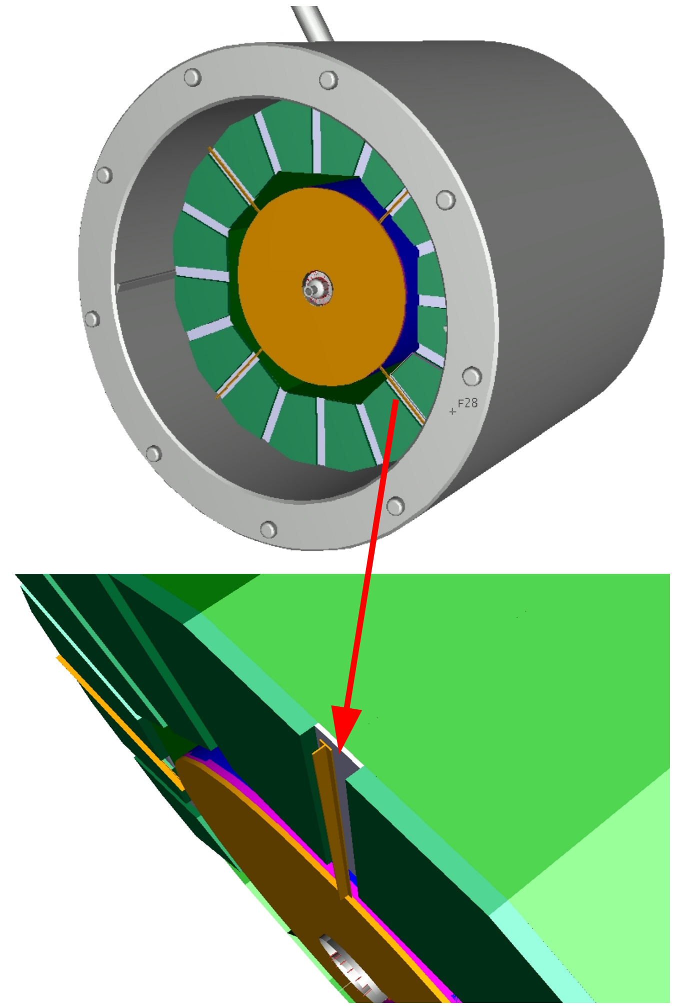
Mechanical Simulations

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.



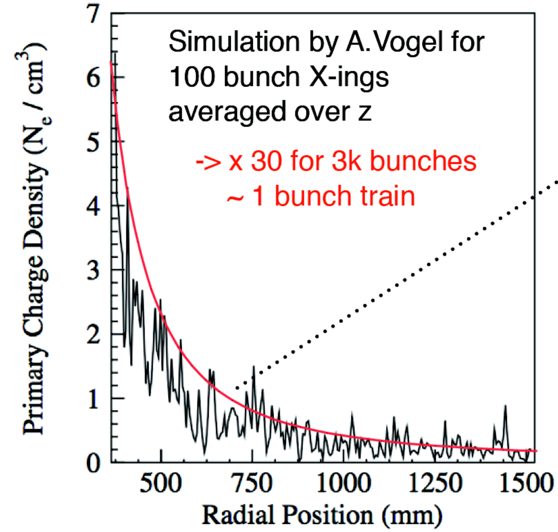
Deflection
O(150 µm) @ 3 mbar



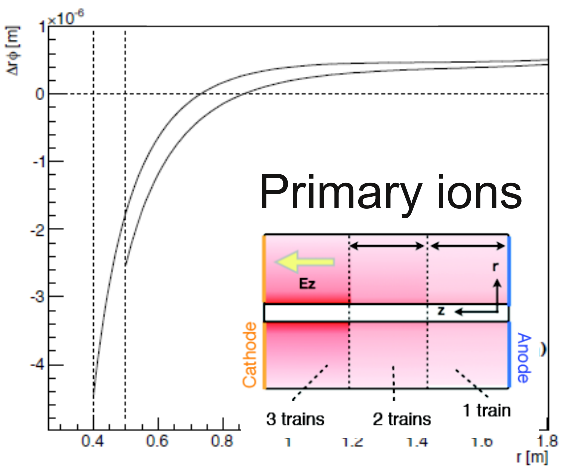
Effect of Positive Ions on e-

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

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

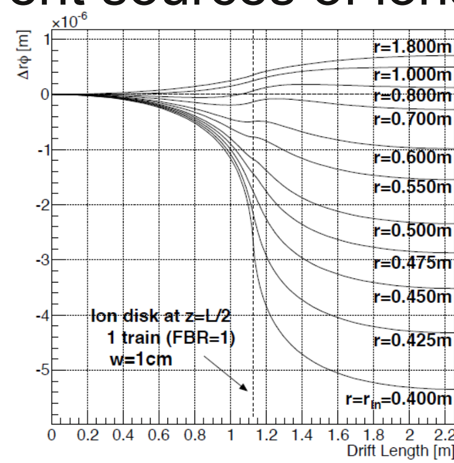


- Influence of E-field distortions on drifting electrons is evaluated for three different sources of ions:

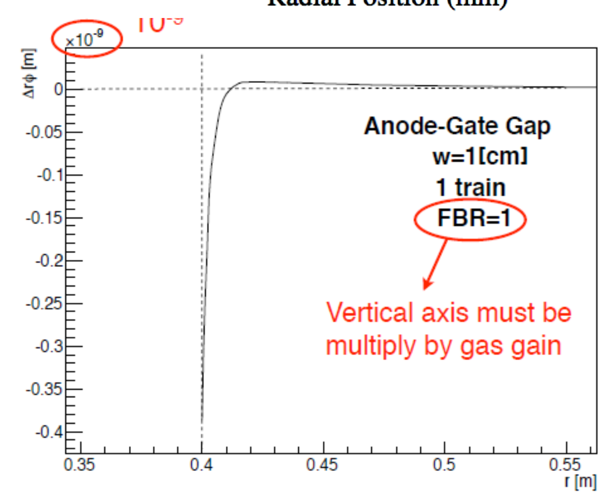


1 bunch train δ_{max} ~4.5 μm

3 bunch trains δ_{max} ~8.5 μm



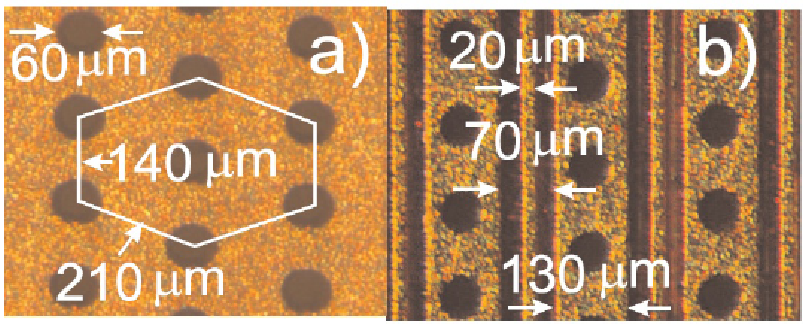
Ions from MPGD stage form 3 discs, if no gating devices is used → δ_{max} ~60 μm

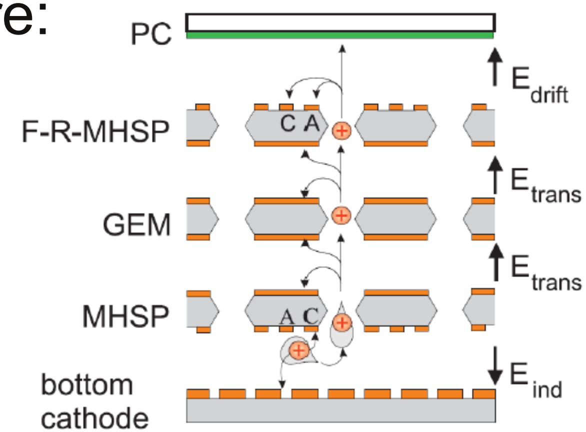


Distortions because of disk between MPGD – gating device are negligible.

Ion Back Drift Reduction

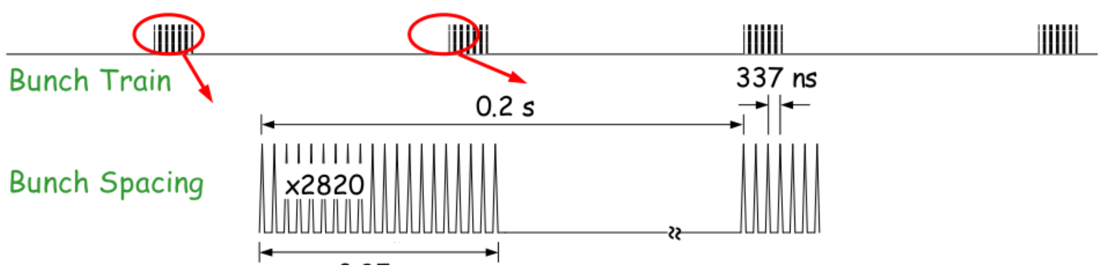
Ion back drift has to be reduced more:
1.) New devices such as MHSP





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 (ILC or CLIC) 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, but feasibility of large areas (one module) still needs to be demonstrated.

It would be very important to have the 5 T magnet (Komag) reactivated to continue high field tests.