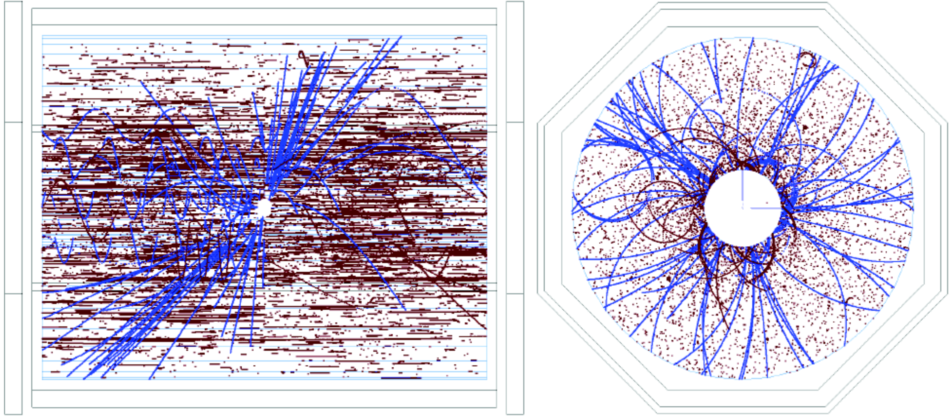
Overview of TPC activities for a Linear Collider

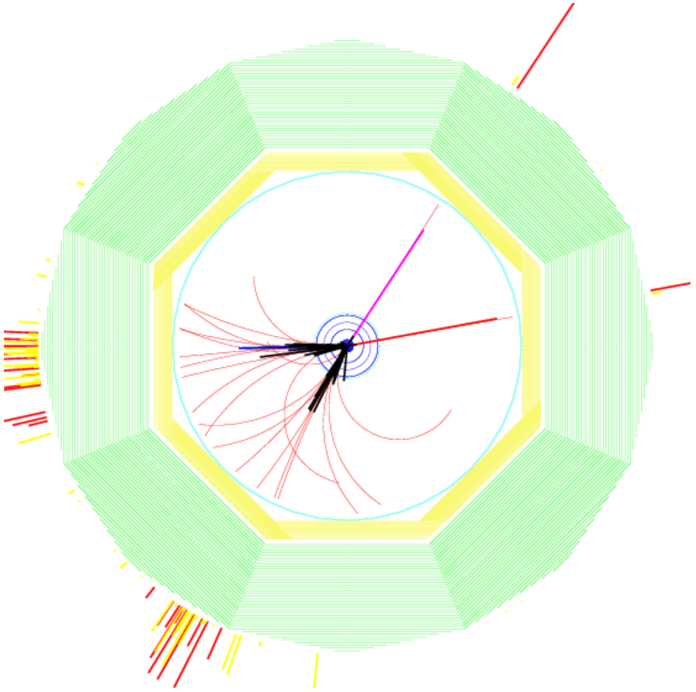
J. Kaminski
University of Bonn

ILC Tokusui Workshop 2012
KEK
20./21. December 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: $\sigma(r\varphi) < 100\ \mu m$
$\sigma(z) < 500\ \mu m$

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%

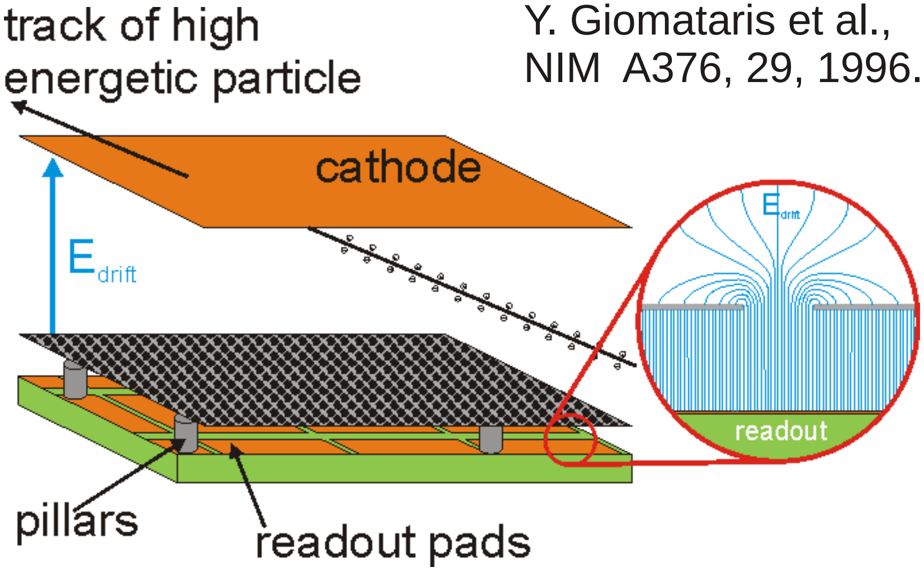
Material budget: 0.05 X_0 to outer field cage,
0.25 X_0 endcaps

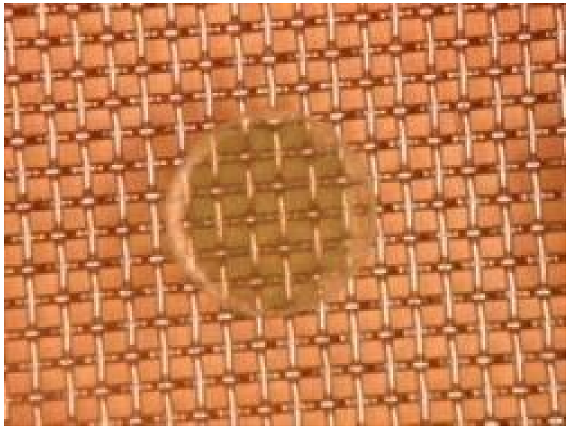
Requirements can not be met with standard MWPC readout.

Micropattern Gaseous Detectors

Micro-Mesh Gaseous Detectors

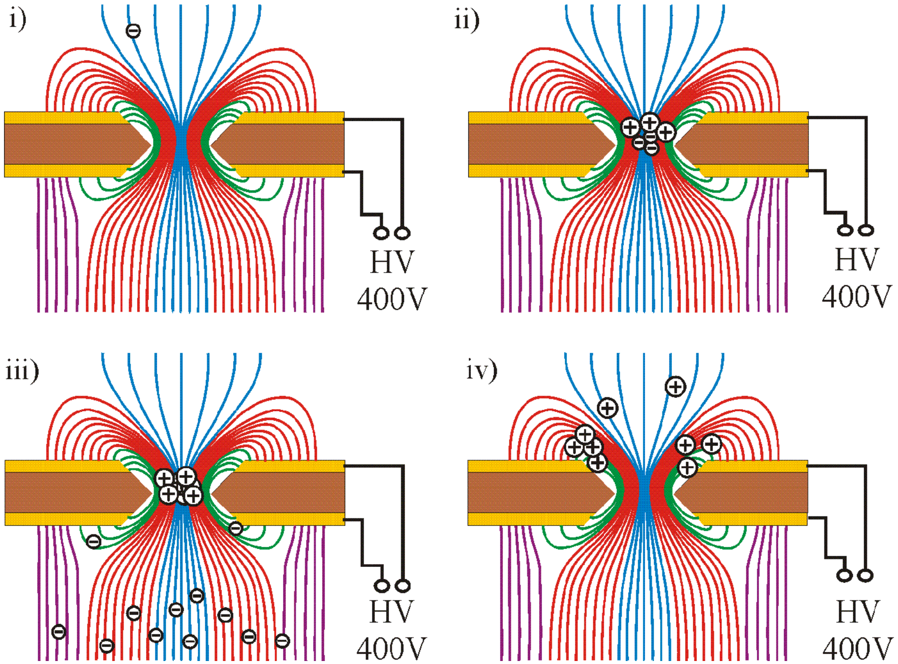
Y. Giomataris et al.,
NIM A376, 29, 1996.

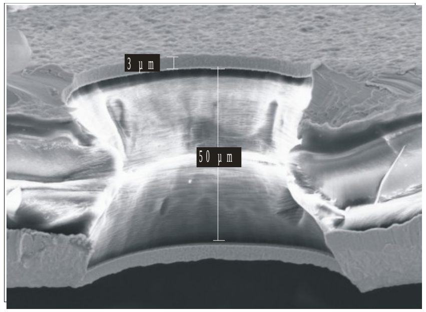




Gas Electron Multipliers

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 long 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.

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.

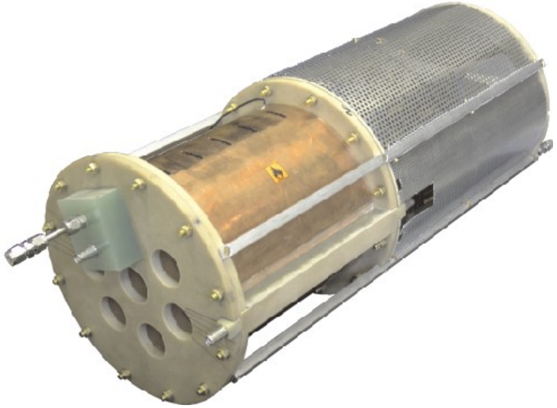
3. Design Phase

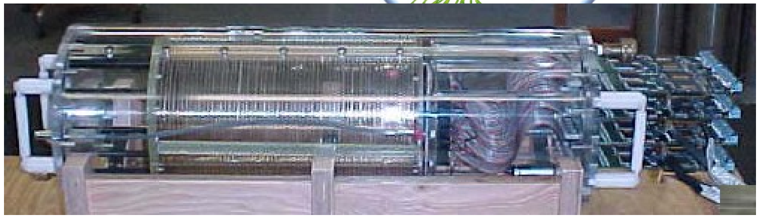
Take decision of the MPGD technology

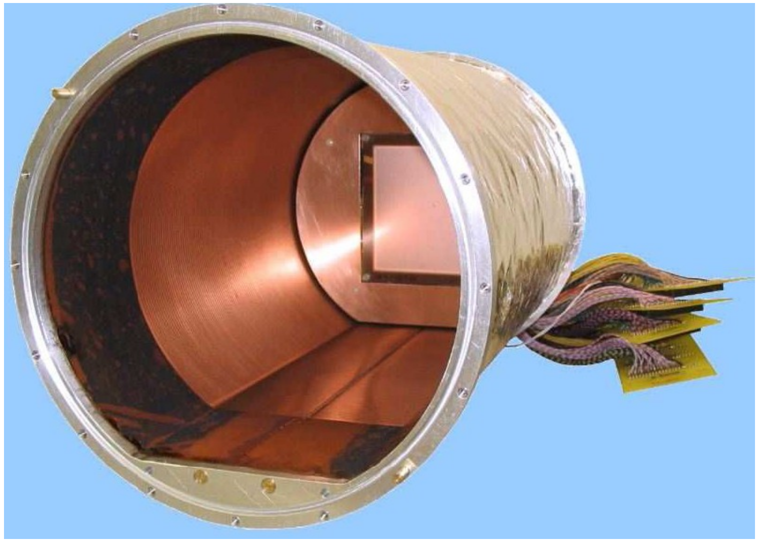
Finish the design of final detector

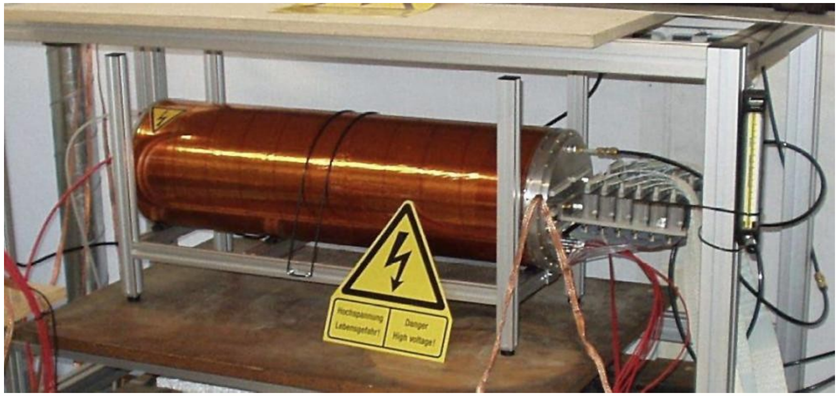
Demonstration Phase

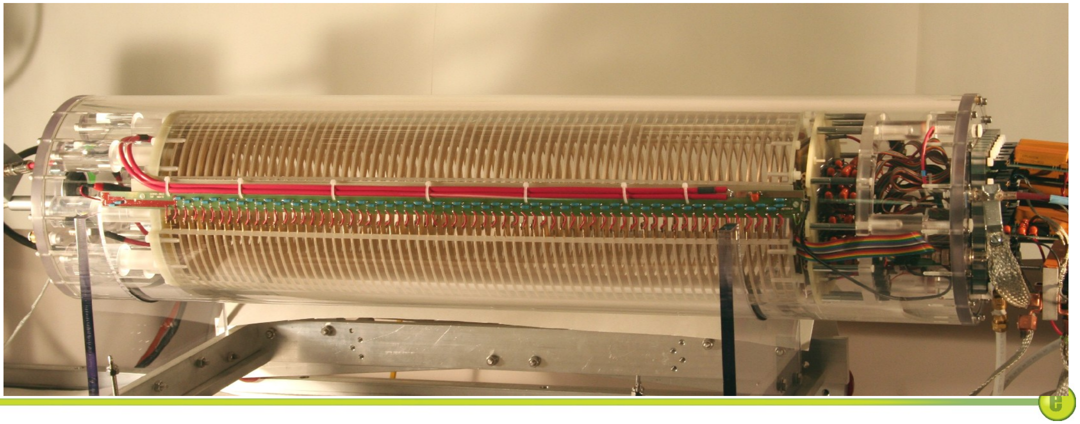
Many small systems designed for dedicated tasks were built.
Important tool:
5 T magnet at DESY







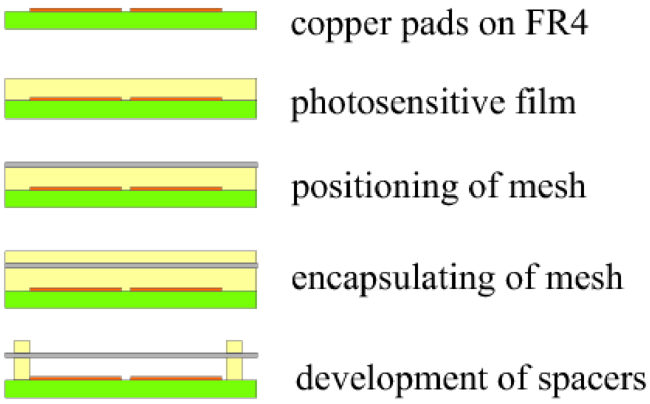


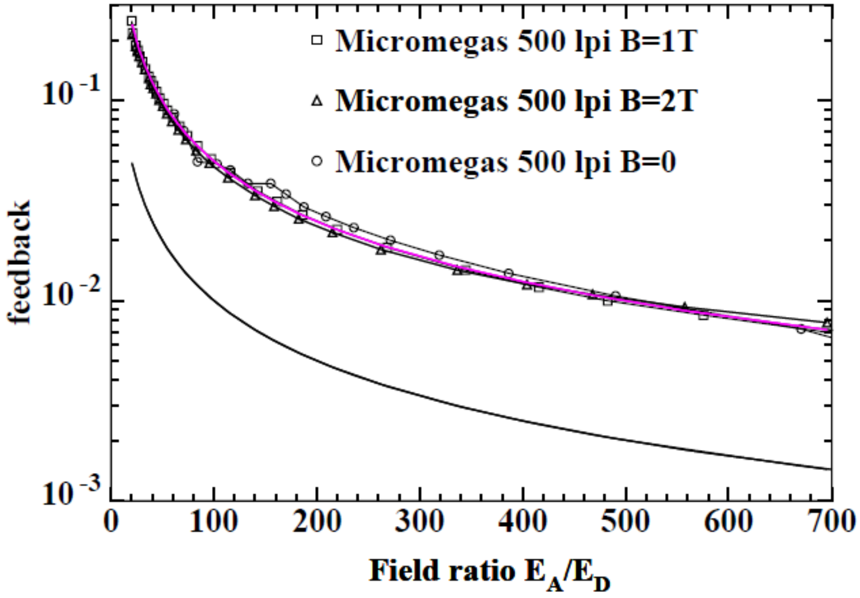


Results with Micromegas RO

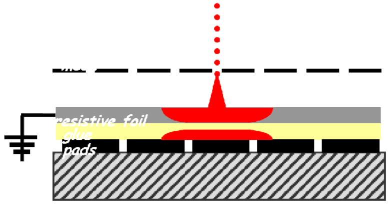
Several important developments in Micromegas R&D were achieved by the LCTPC-MM group:
- First ion back drift measurements with MM
- Development of resistive covering on pads
- First test with bulk-Micromegas

=> No discharges observed
=> Excellent space point resolution

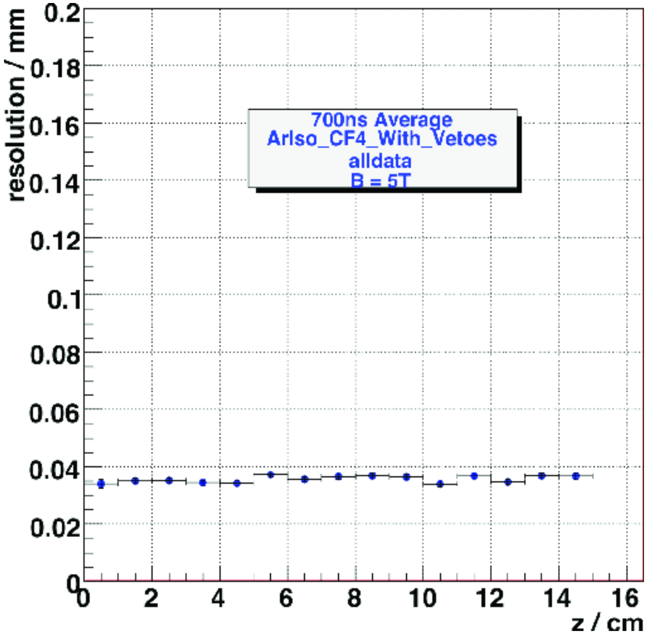




To broaden the signal shape the readout pads are covered with a resistive foil.

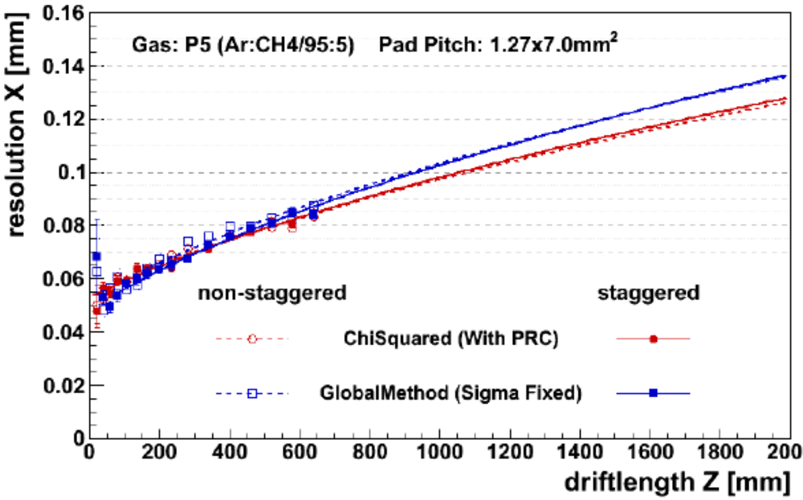


NIM A581, 254, 2007

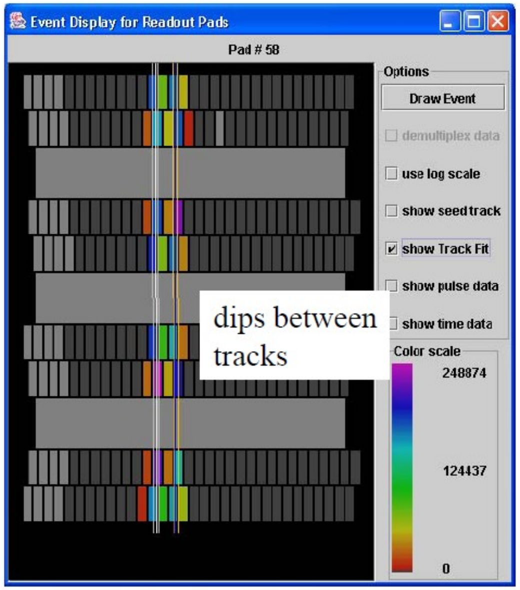


Results with GEM Readout

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



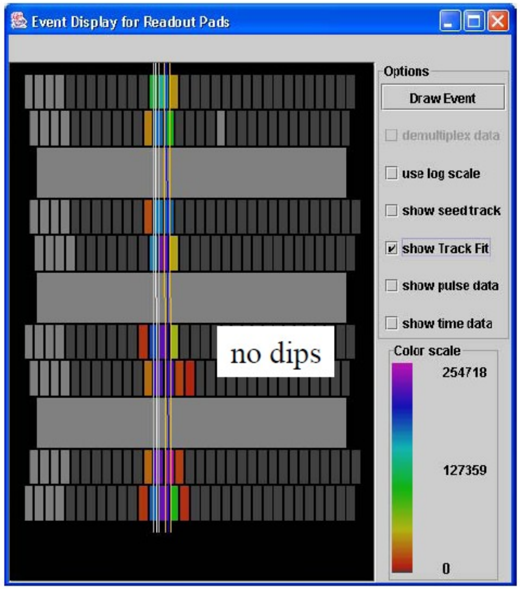
Δx = 3.8 mm



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

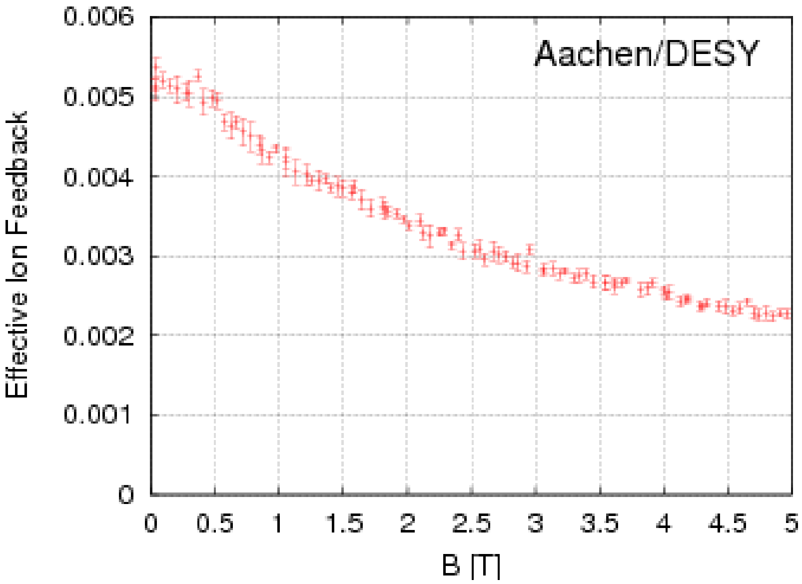
dips between tracks

Δx = 2.0 mm



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

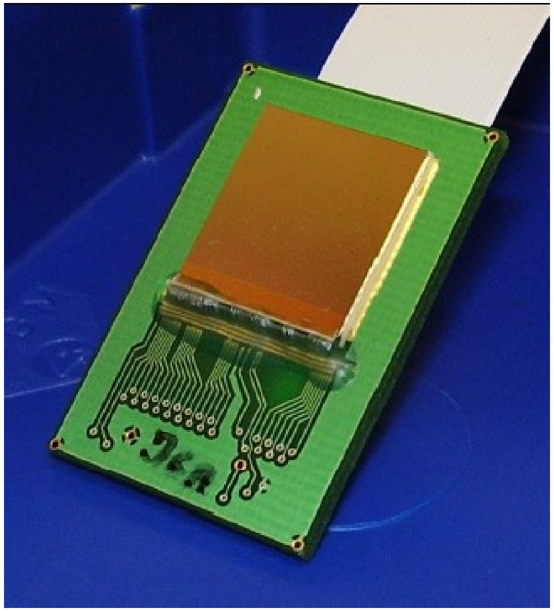
no dips



J. Kaminski
ILC Tokusui Workshop 2012

Highly Pixelized Readout

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

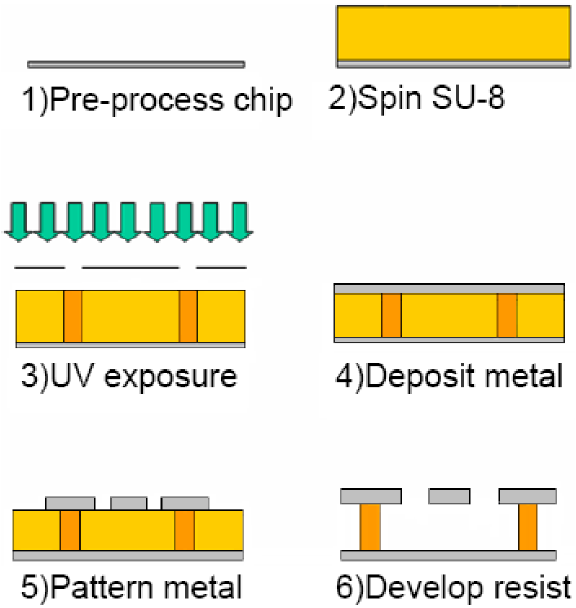


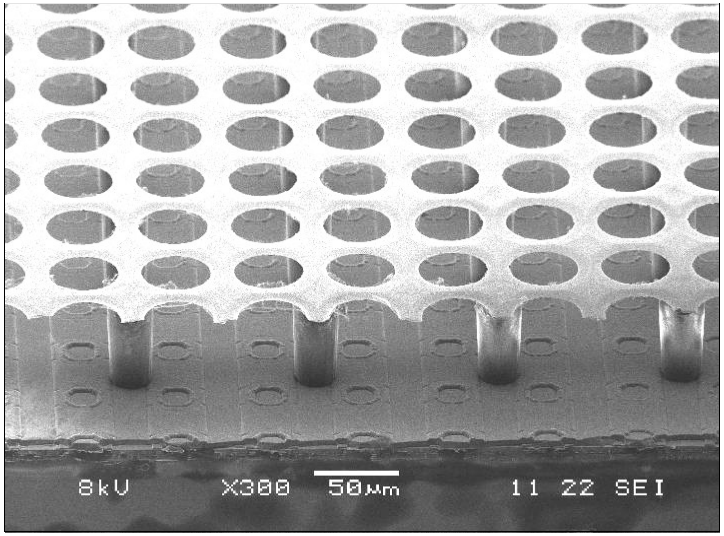
Timepix derived from Medipix-2

256 × 256 pixels of size 55 × 55 µm²

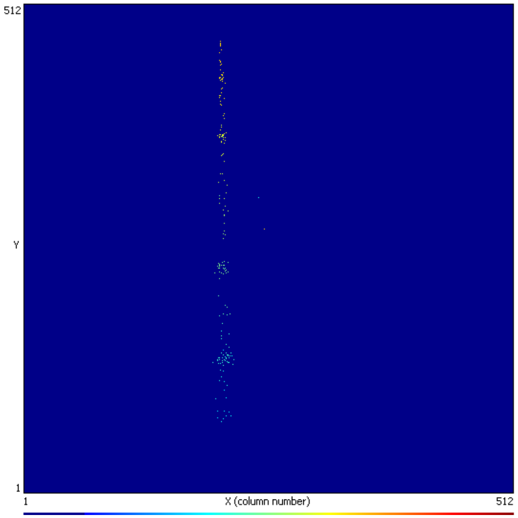
Each pixel can be set to:

- TOT ≈ integrated charge
- Time between hit and shutter end



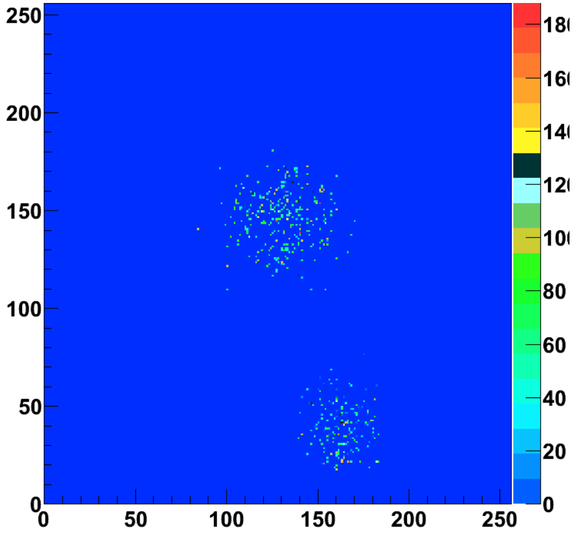


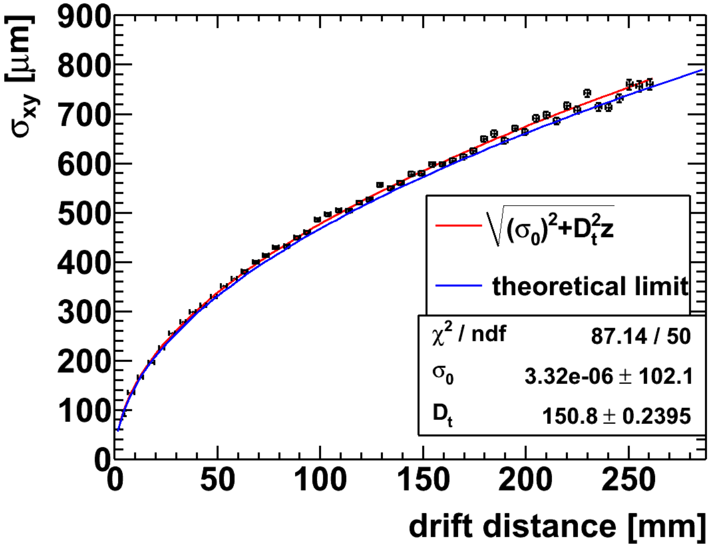
Performance of InGrids



Significant progress towards large area applications:

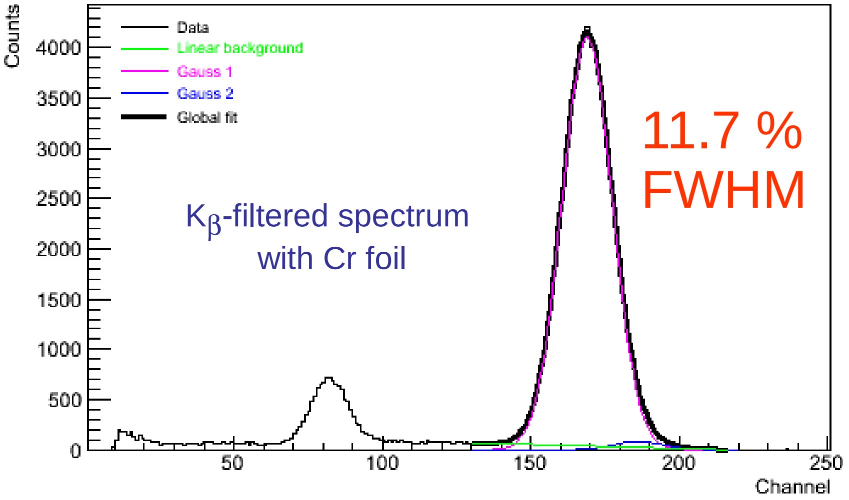
- Si_xNi_y layer to protect against discharges





Spatial resolution in agreement with diffusion limit

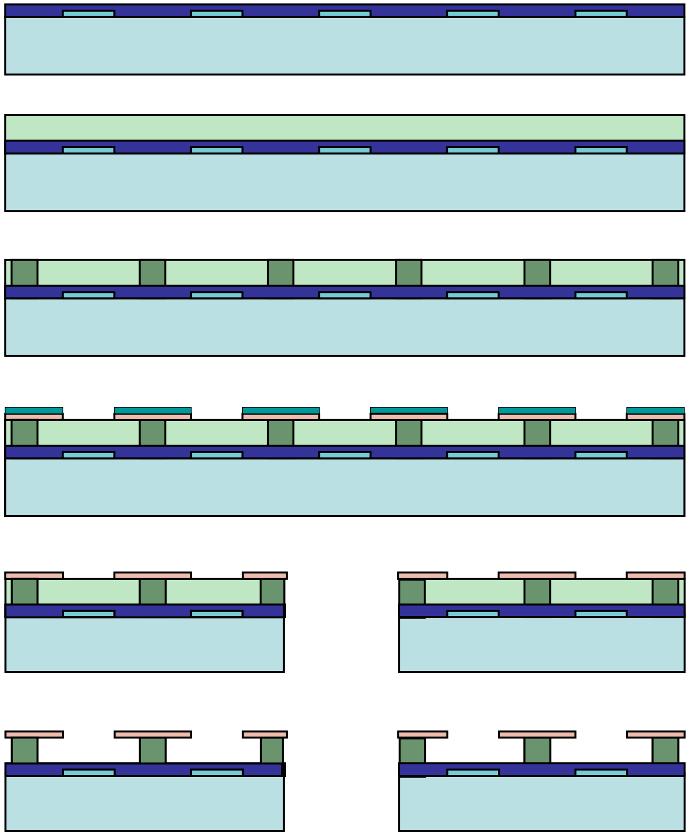
Energy resolution $\sigma_E/E \sim 5\ \%$ (^{55}Fe) by counting primary electrons



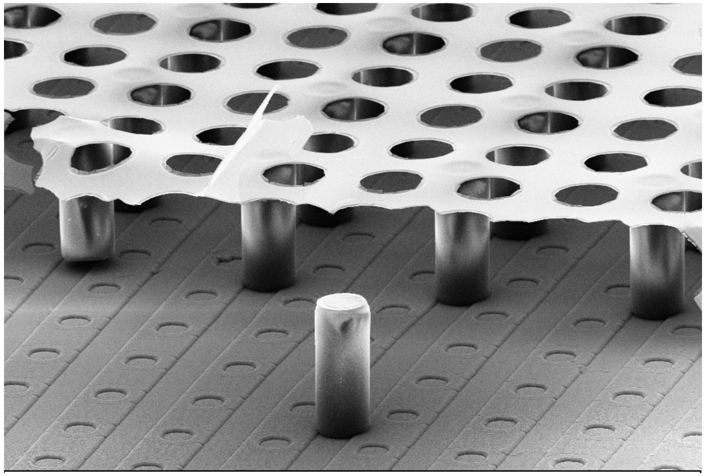
^{55}Fe spectrum in Ar:CH_4 90:10

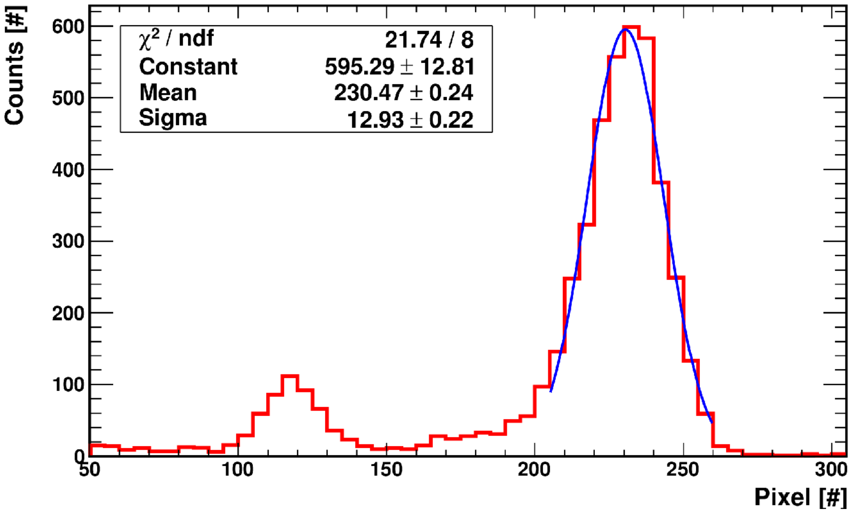
Wafer-based Production

Production at Twente was based on 1 - 9 chips process.
This could not satisfy the increasing demands of R&D projects.
New production set up at the Fraunhofer Institut IZM at Berlin.
This process is wafer-based → 1 wafer (107 chips) is processed at a time.



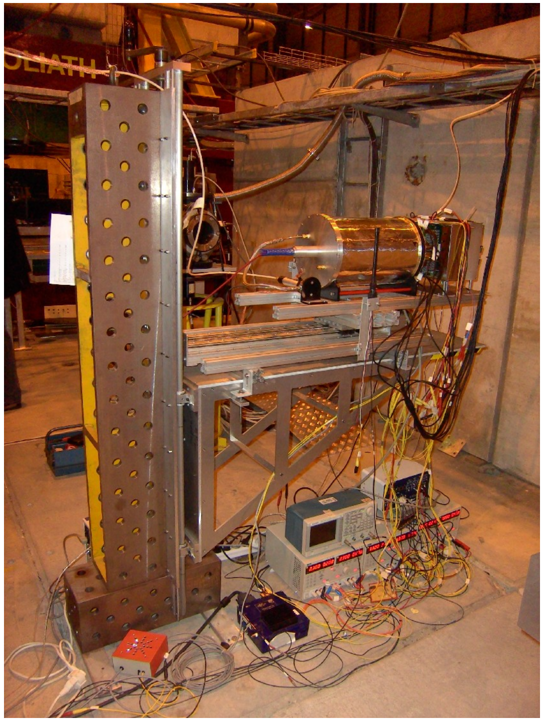
1. Formation of Si_xN_y protection layer
2. Deposition of SU-8
3. Pillar structure formation
4. Formation of Al grid
5. Dicing of Wafer
6. Development of SU-8

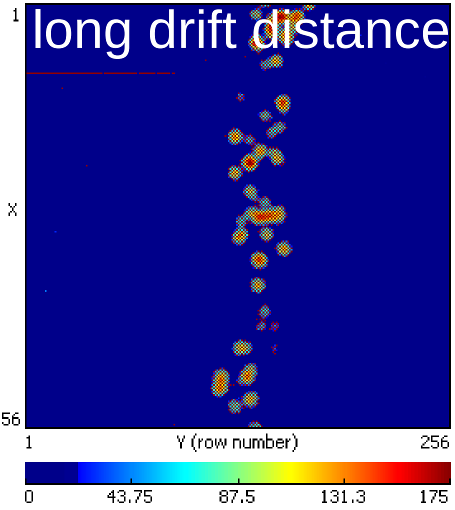


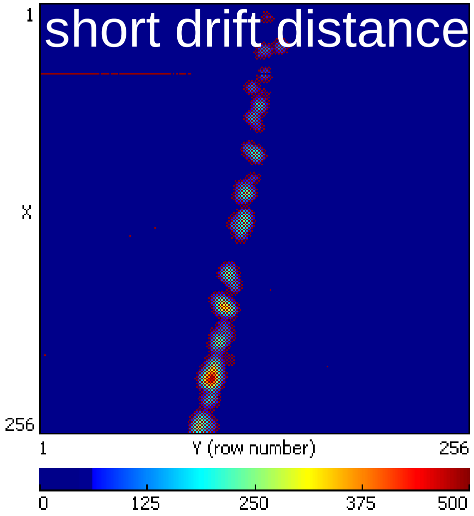


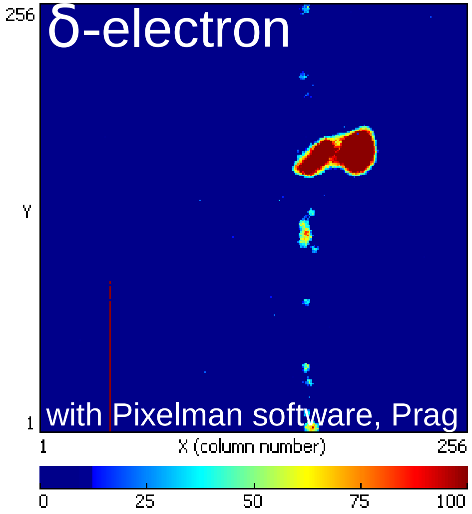
Performance of tGEMs with TP

Timepix chip below a triple GEM stack with spacings 1mm




long drift distance


short drift distance

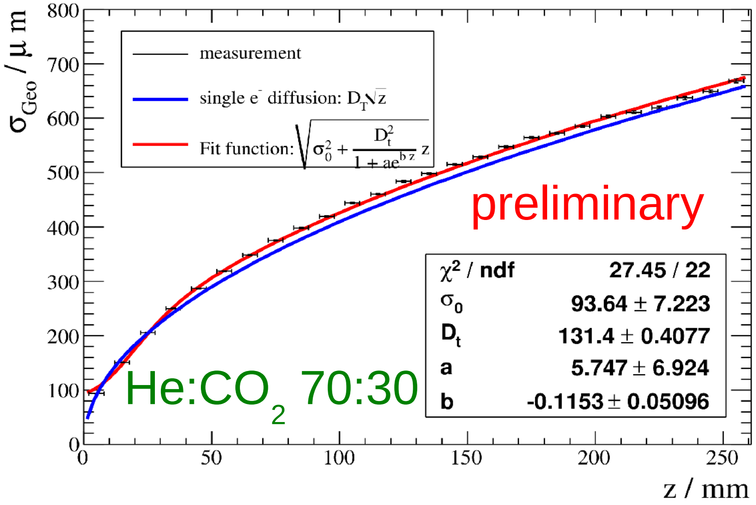

δ-electron

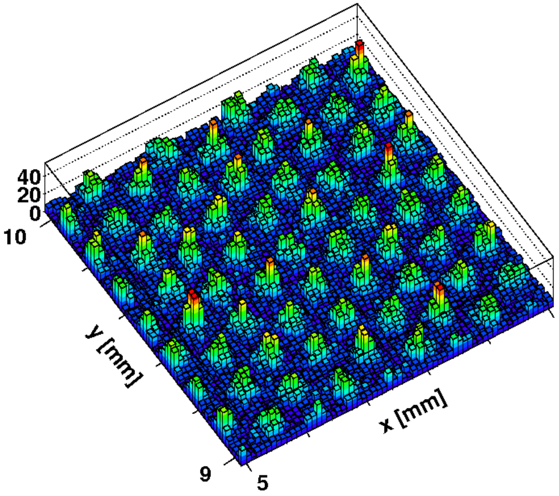
with Pixelman software, Prag

<u>Gas:</u> 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





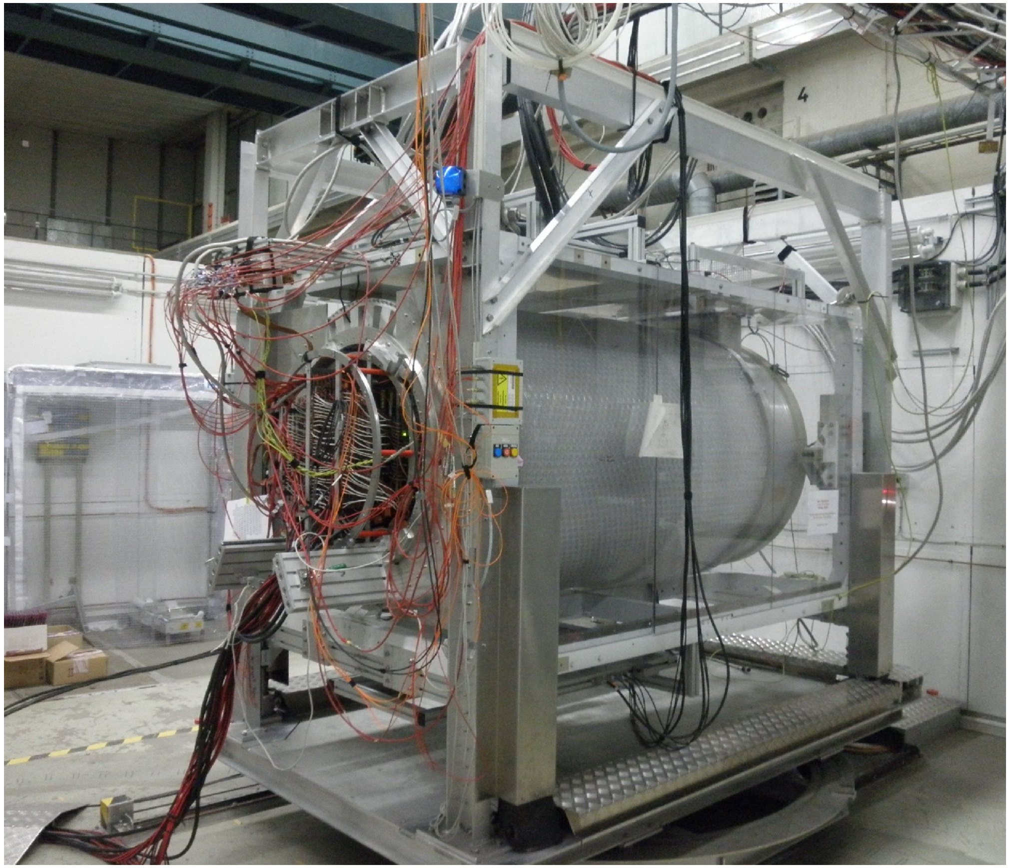
'Electron-tomography' of a GEM

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

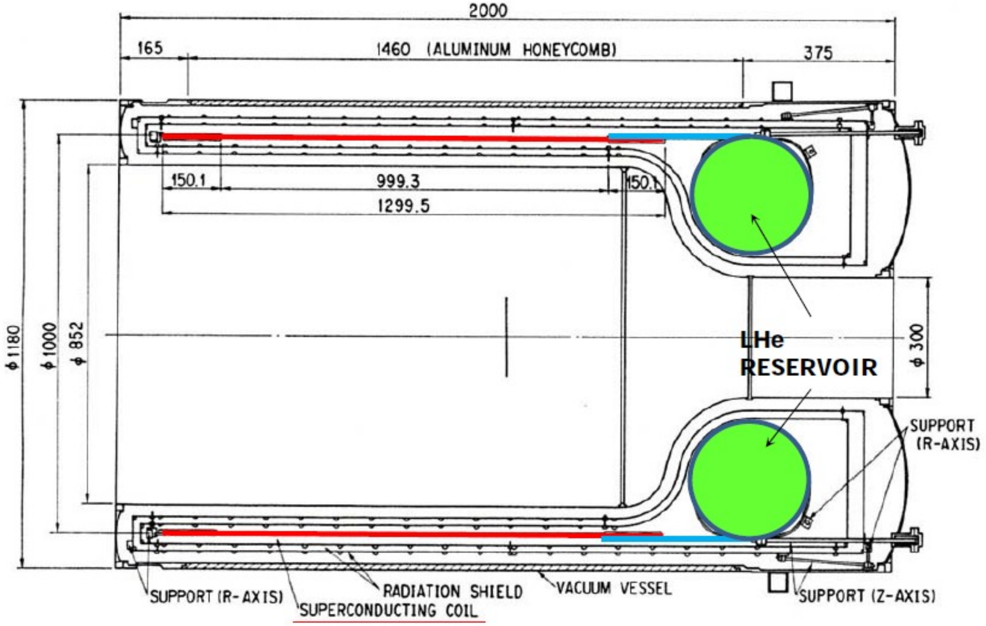


PCMAG

Superconducting solenoid without return yoke
→ low material budget (important for e^--beam)
On loan from KEK

Modification from conduction cooling by LHe to conduction cooling by 2 cryocoolers at 4 K and 10 K.

<u>Before the modification:</u>
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,....

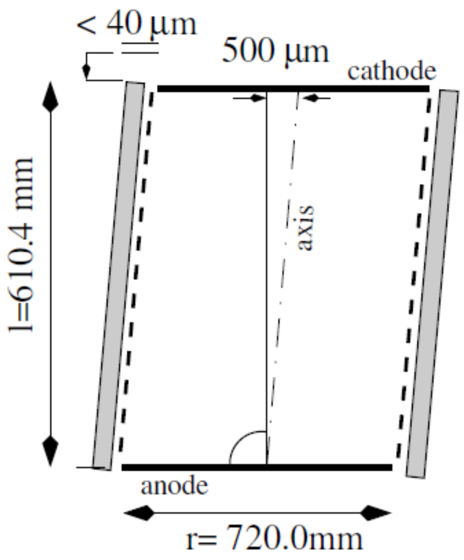


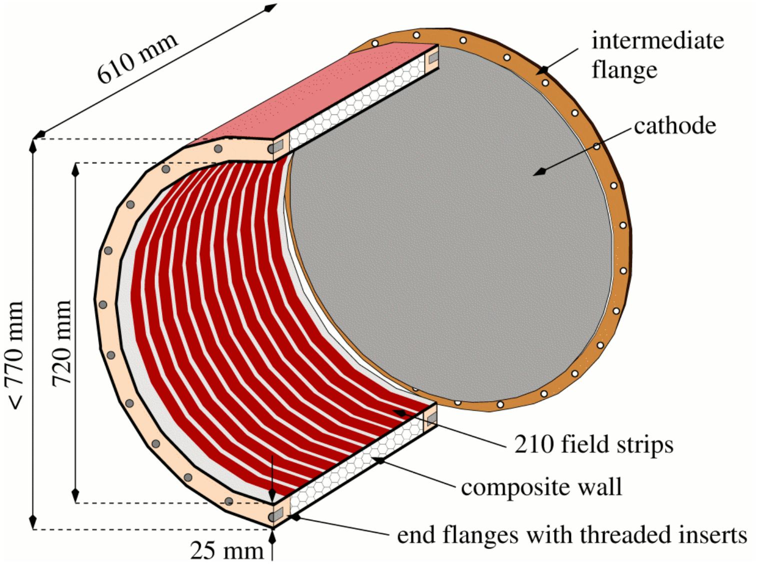
Modification at Toshiba and delivered back in 3/2012.

Much simpler operation now.

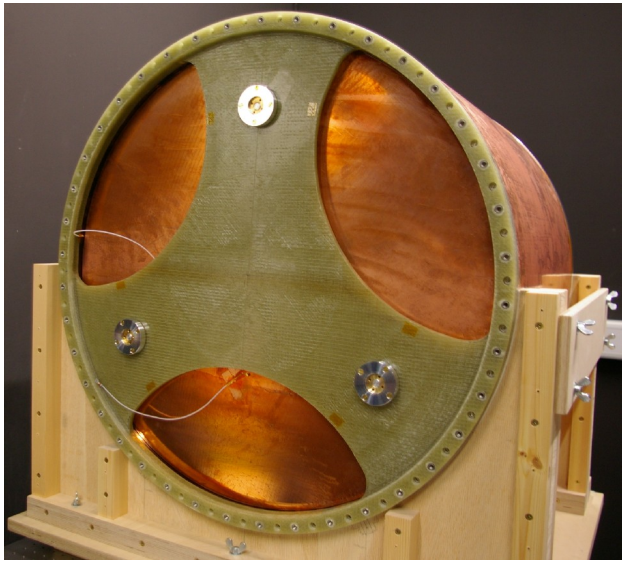
Large Prototype – Field Cage

<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

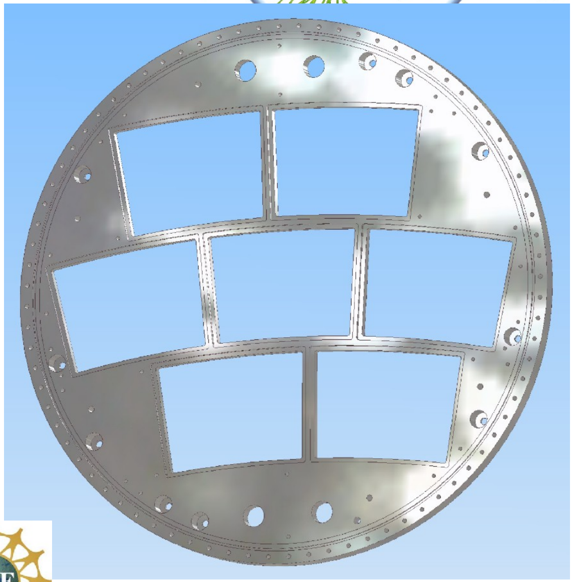




Mechanical accuracy
- Alignment of the end faces: δ < 40 µm
- Alignment of the field cage axis: offset at cathode ~500 µm

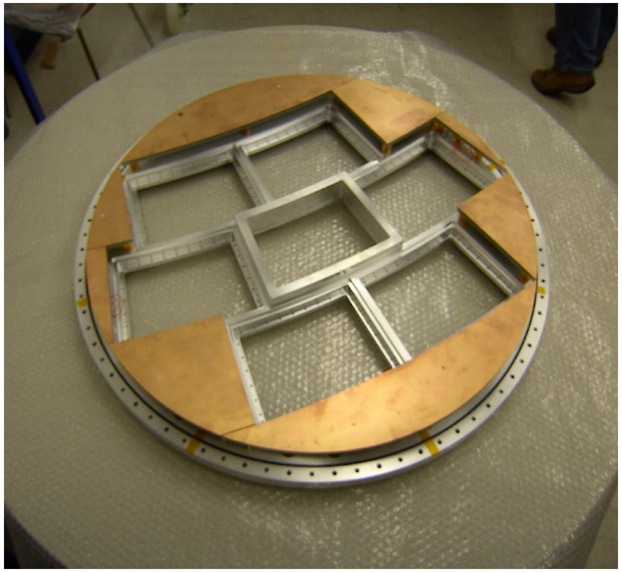


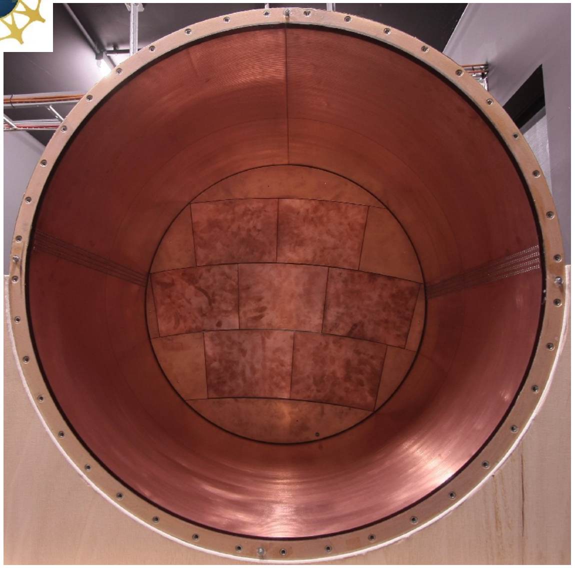
Large Prototype – End Plate



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)





New End Plate

Material budget requirement for final end plate: 8% X_0

→ Finite Element Analysis of final end plate

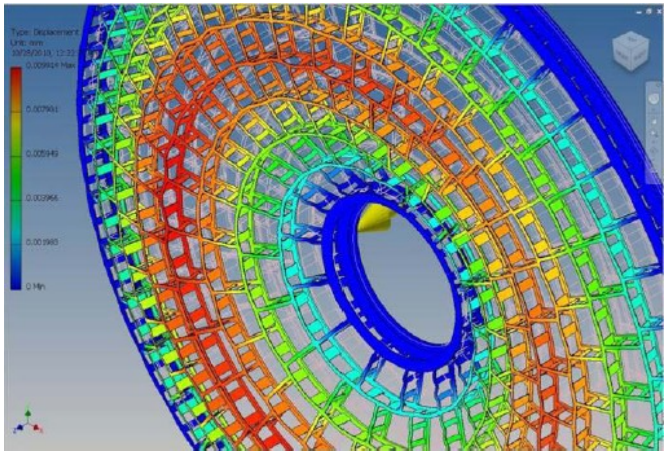
Deflection of 220 µm for overpressure of 2.1 mbar

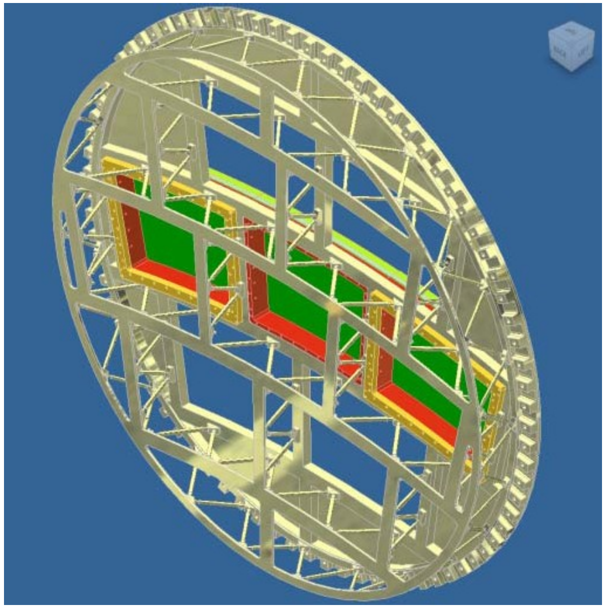
Several materials and designs have been studied

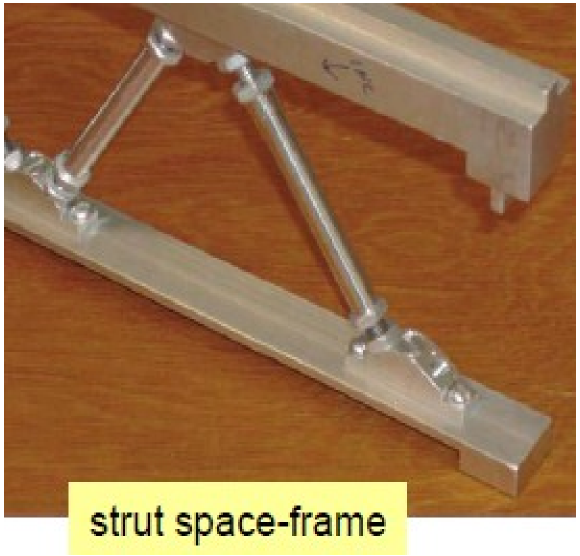
Strut space-frame design provides greatest strength-to-material.

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

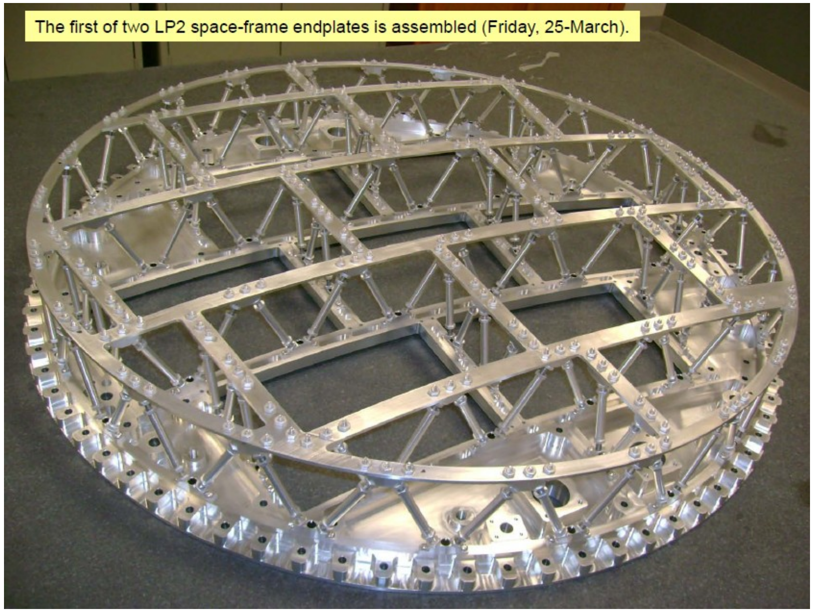
Preliminary measurements of deflection are very close to requirements





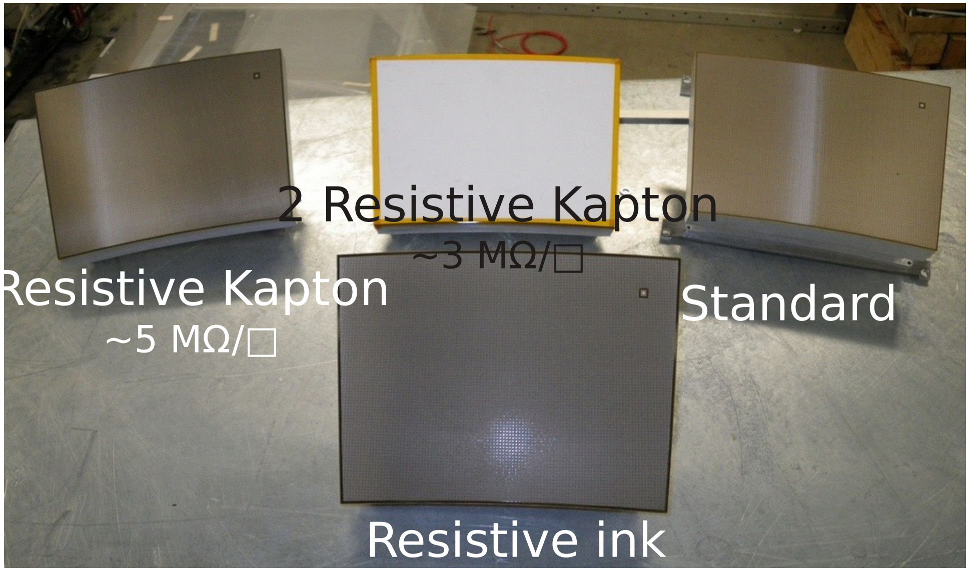


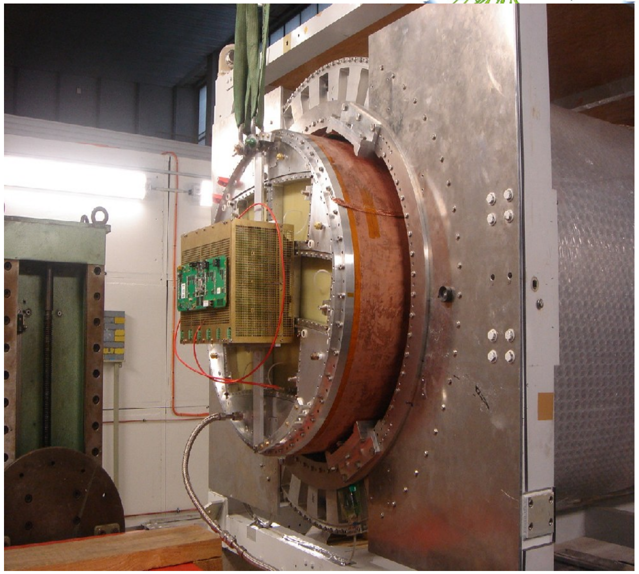
test structure

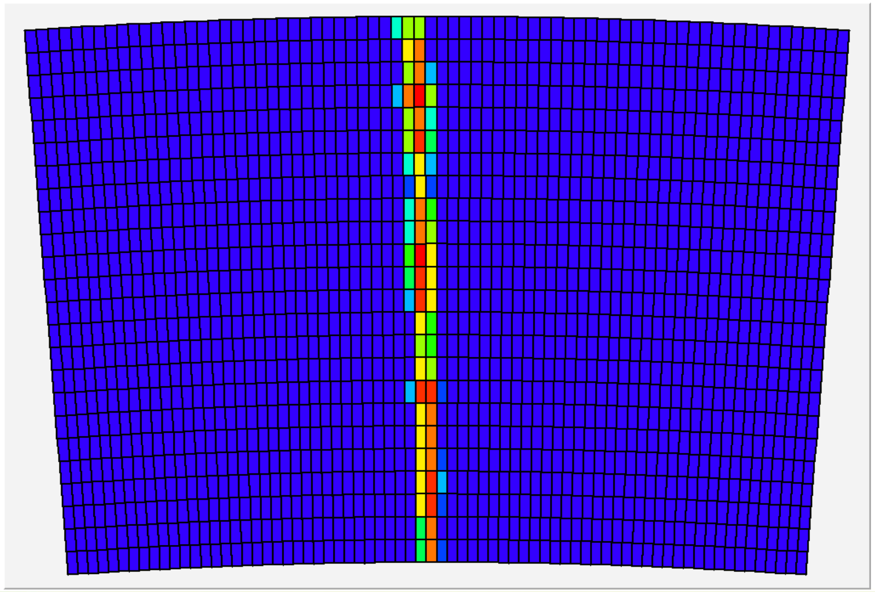


The first of two LP2 space-frame endplates is assembled (Friday, 25-March).

Micromegas Modules



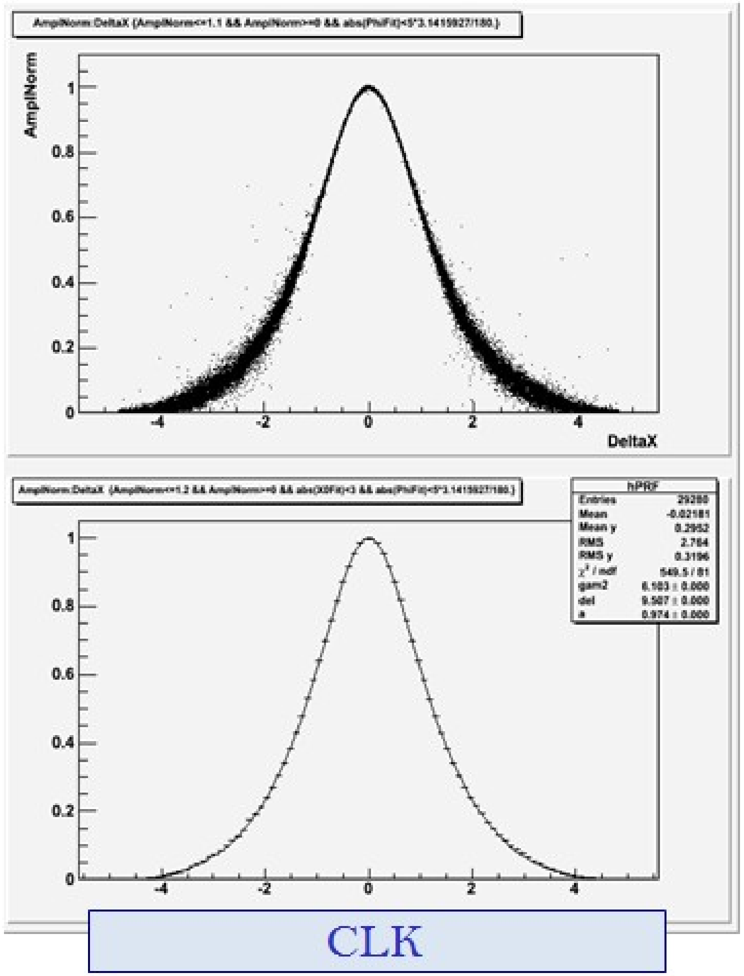




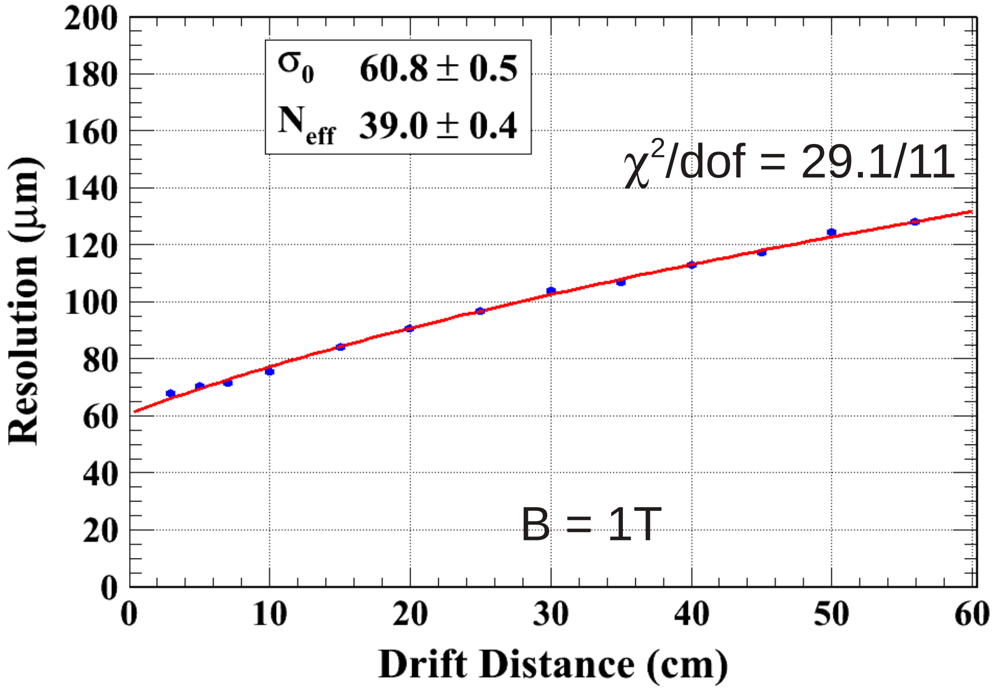
Micromegas Module

- 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



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):

→ $\sigma_0 = 59 \pm 2$ µm

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

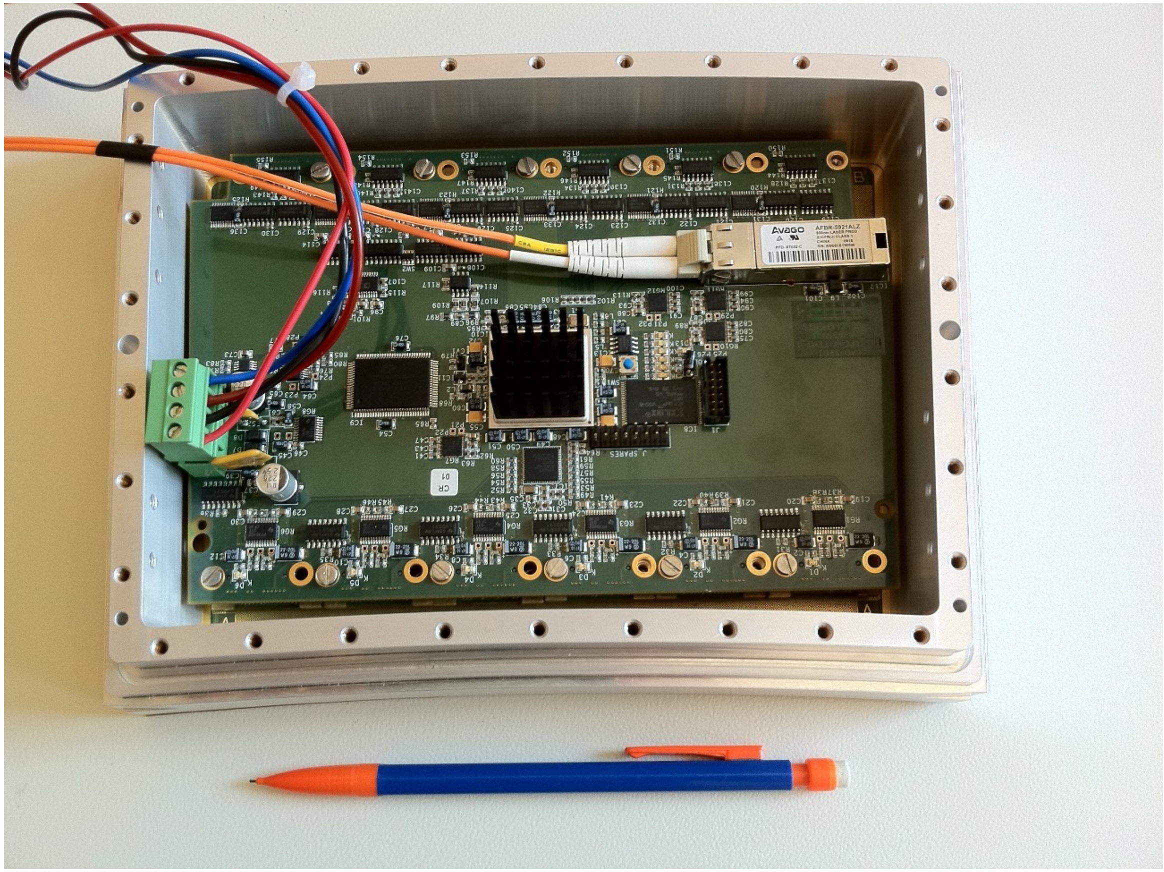
9 Micromegas Modules

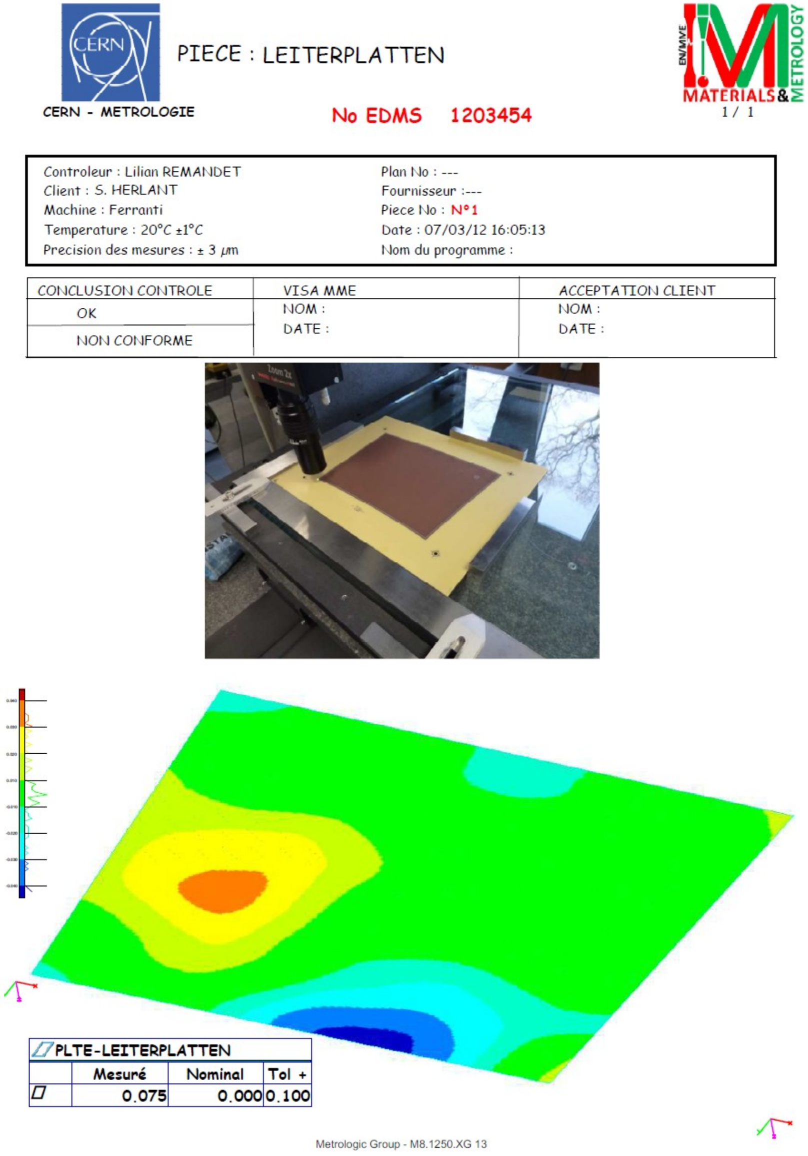
9 modules are built in collaboration with industry to study quality aspects in 'mass'-production:

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

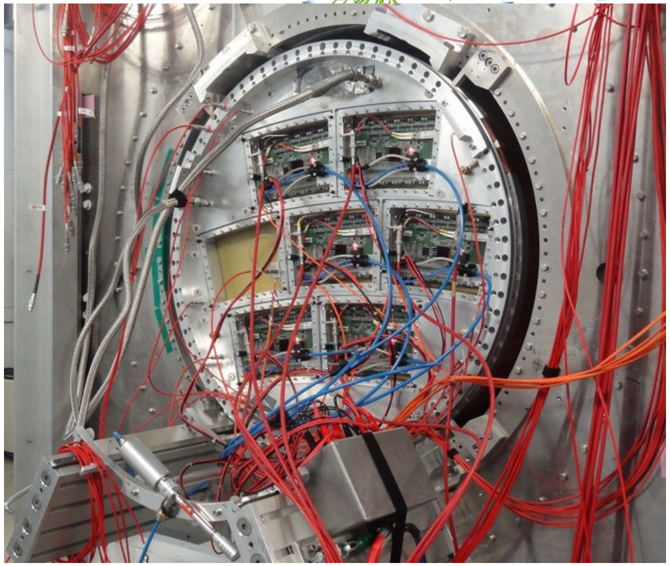
	Mesuré	Nominal	Tol +
▱	0.075	0.000	0.100

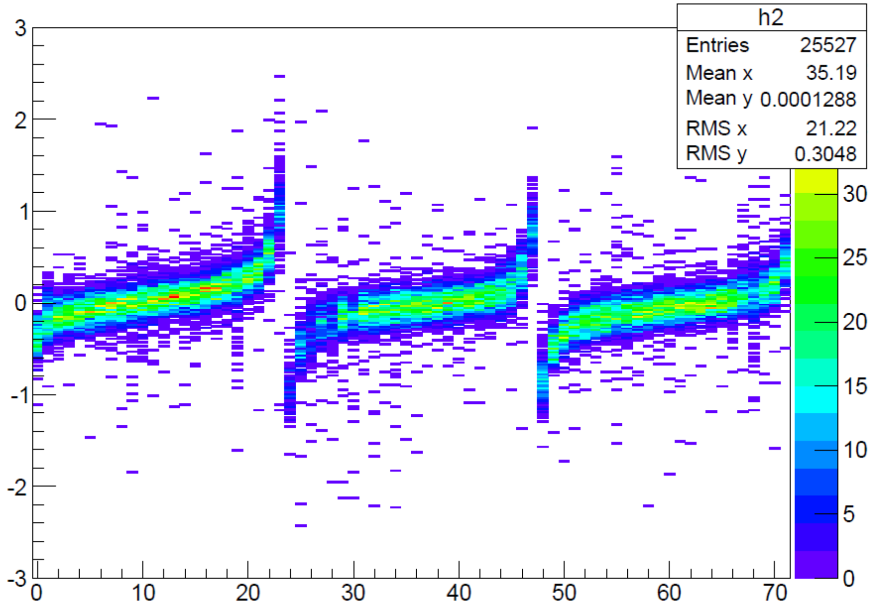
Metrologic Group - M8.1250.XG 13

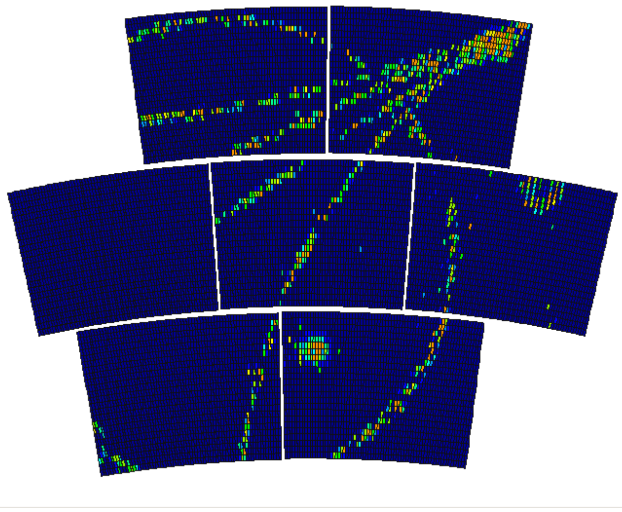
Multi-module test beam

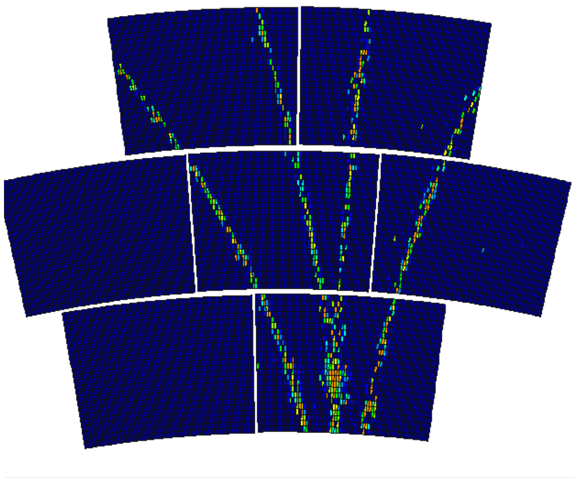
French/Canadian test beam campaign with
6 Micromegas modules with integrated electronics

- Very fast commissioning and installation
- Multi-track events were observed
  → possibility to study 2-track resolution
- Successful test beam effort which will be continued next year
- Analysis showed distortions close to the border of the modules (like GEM modules)









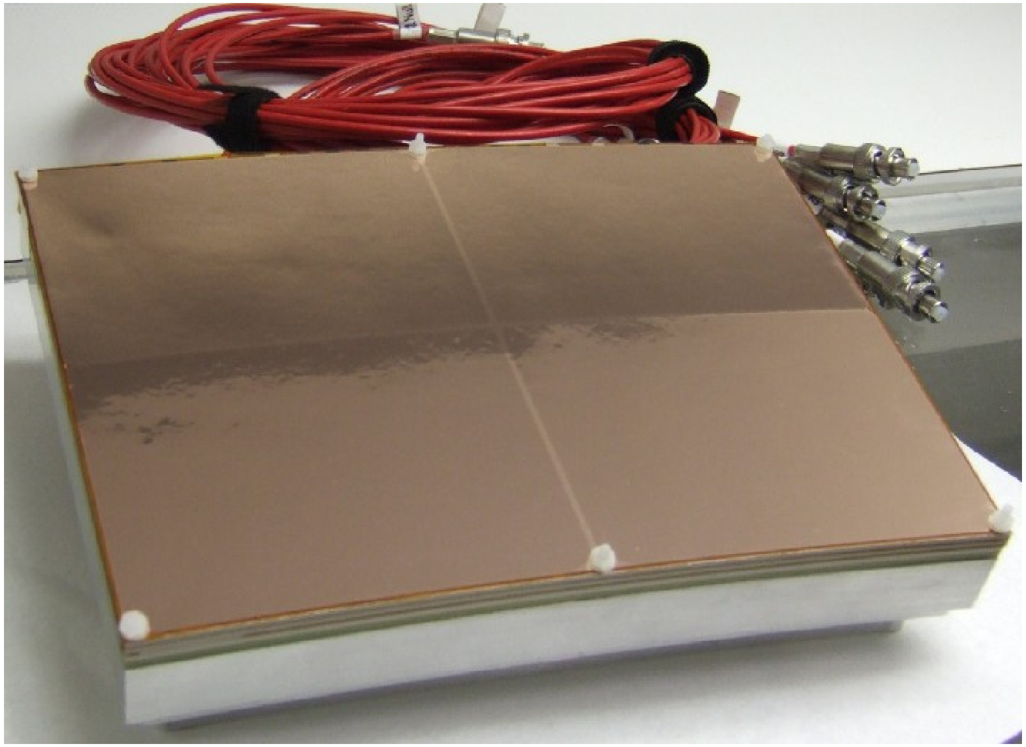
Triple GEM Module

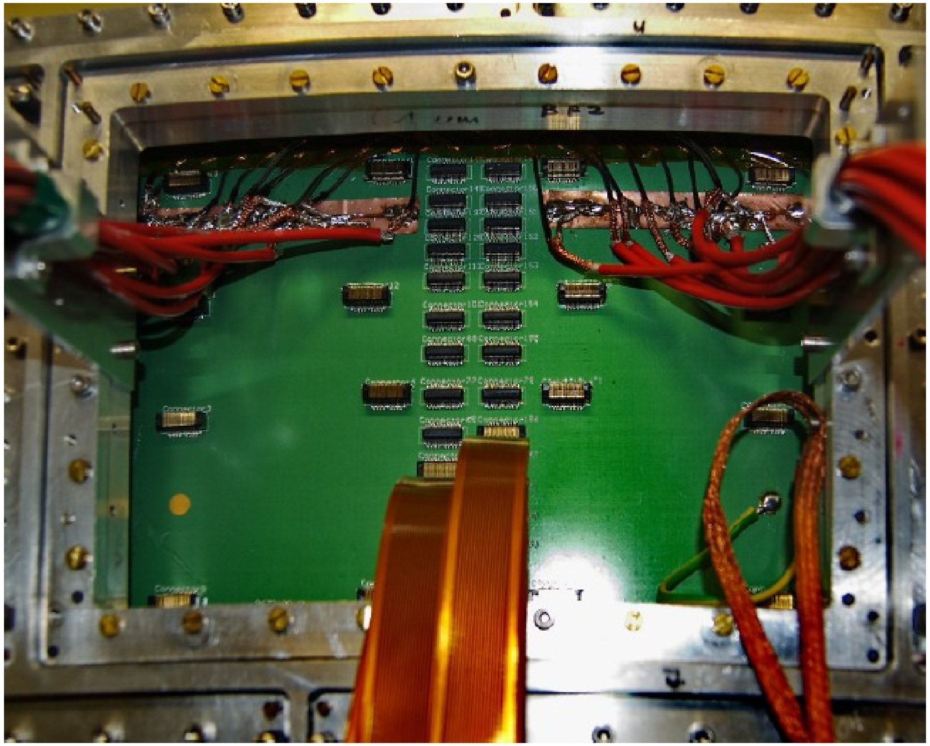
3 standard CERN GEMs mounted on thin ceramic structure (bar size ~1 mm) to reduce dead space.

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.



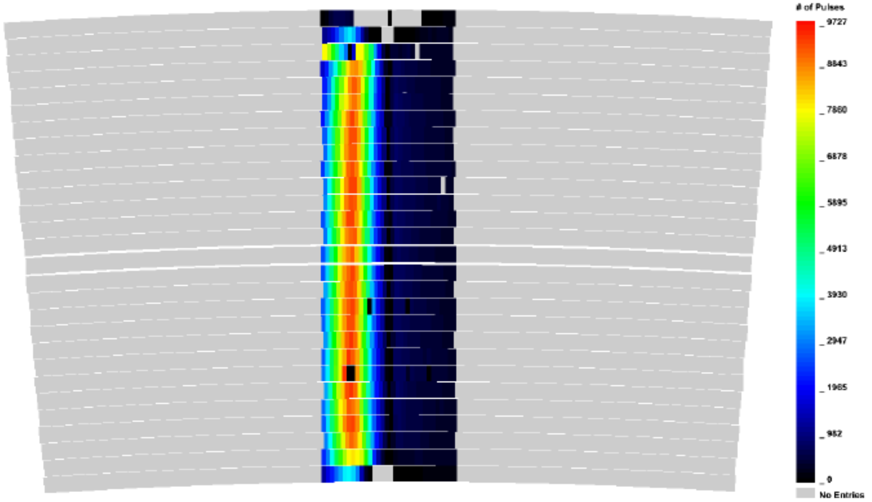


Field Distortions

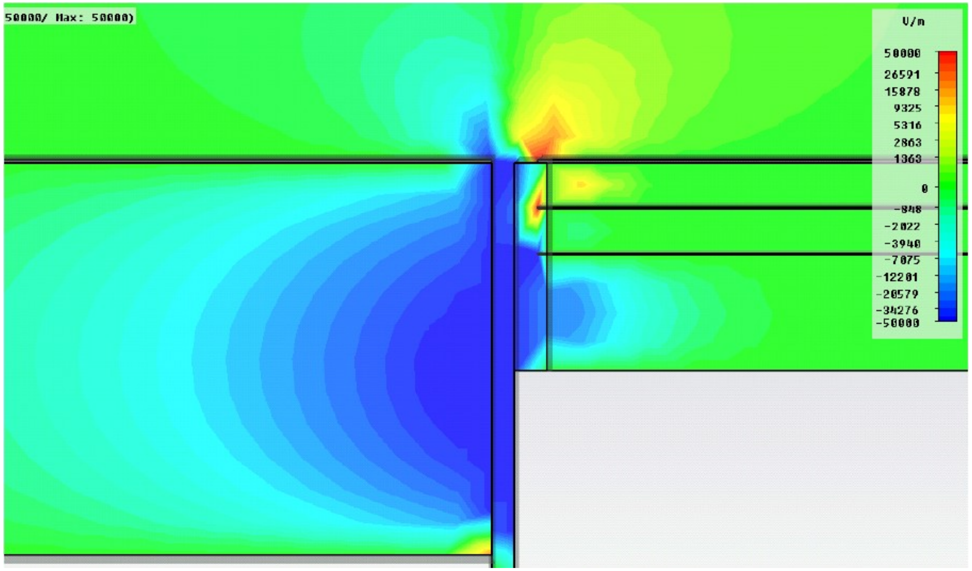
Field distortions at borders of modules were observed.

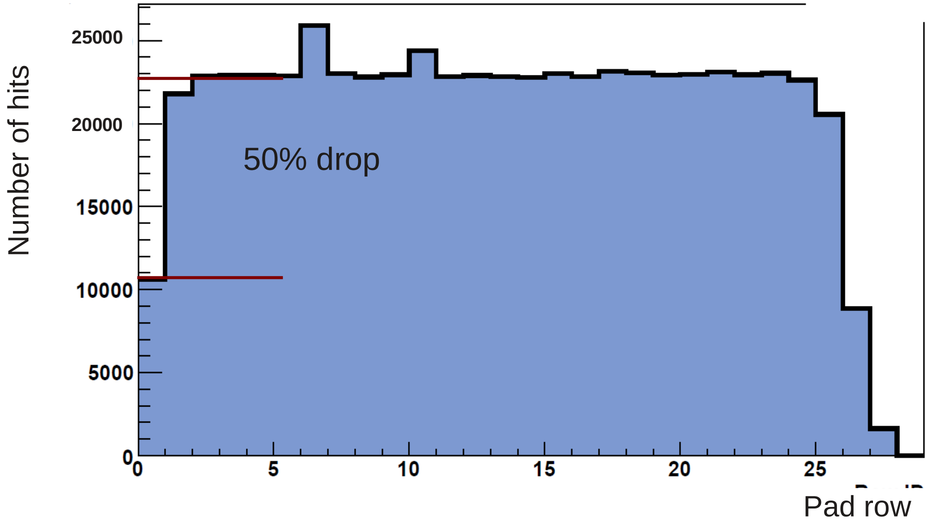
Maybe largely due to field configuration of dummy modules.

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



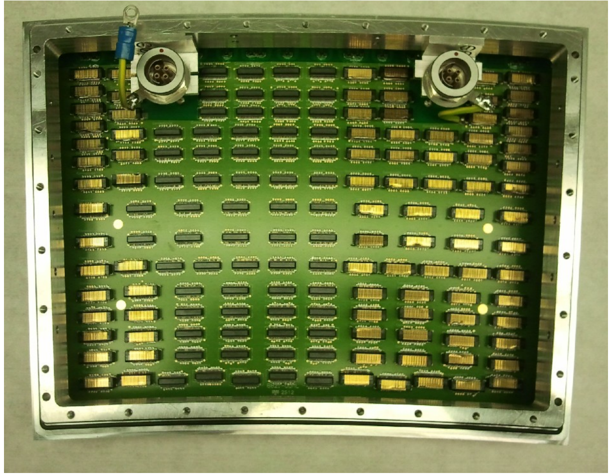
Number of reconstructed pulses

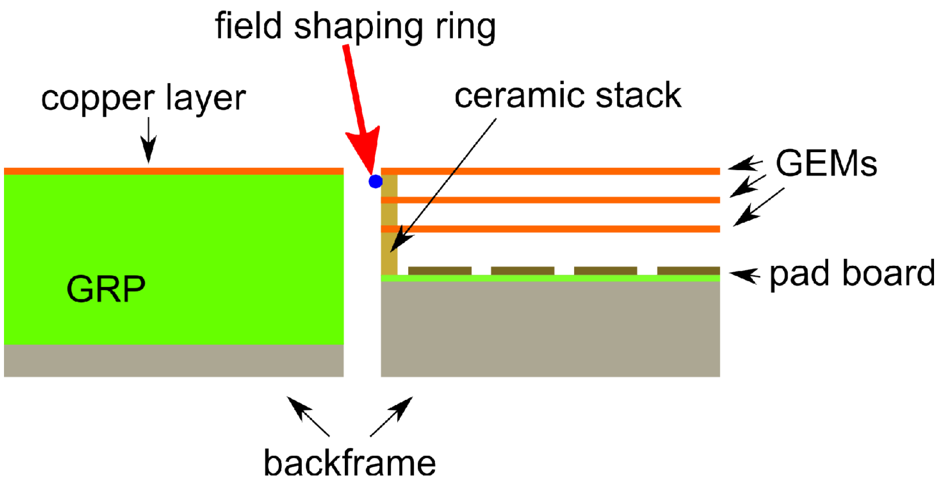




Revised triple GEM Modules

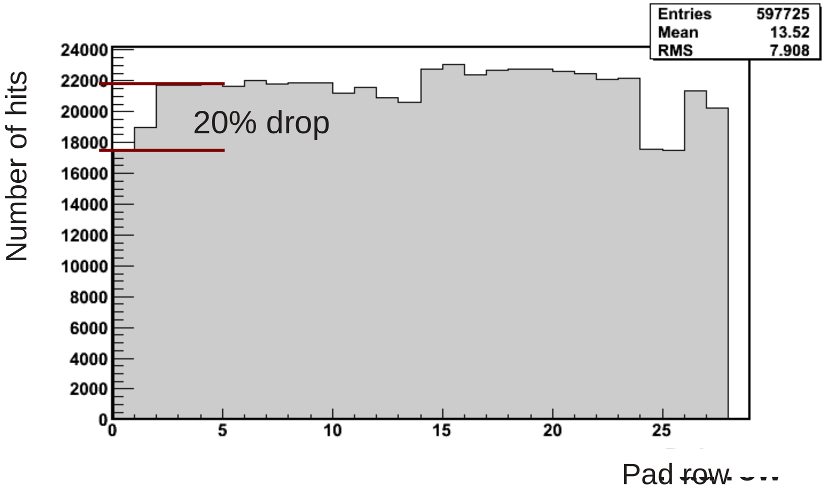
- Pad plane now full area covered by 4839 pads
- Improved HV distribution and guard ring to minimize field distortions





Sept. 2012: new measurements with three modules in DESY test beam

- Problem with gas tightness due to new cable holding structure
- Problems with HV-stability of field cage
- Next test beam planned early 2013



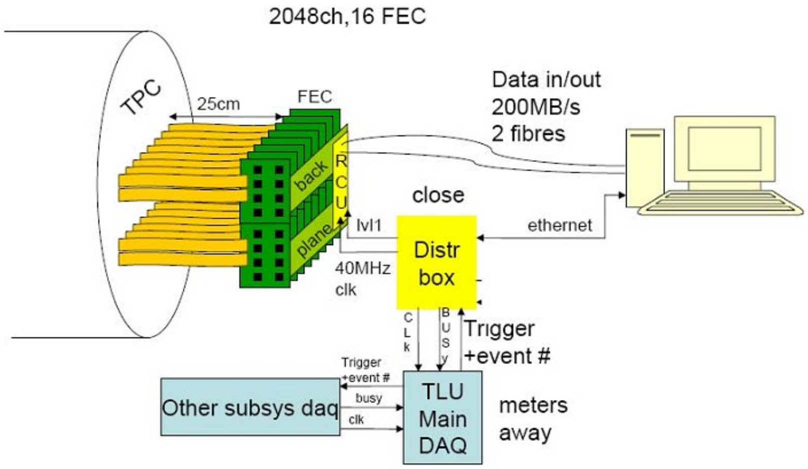
Electronics ALTRO & AFTER

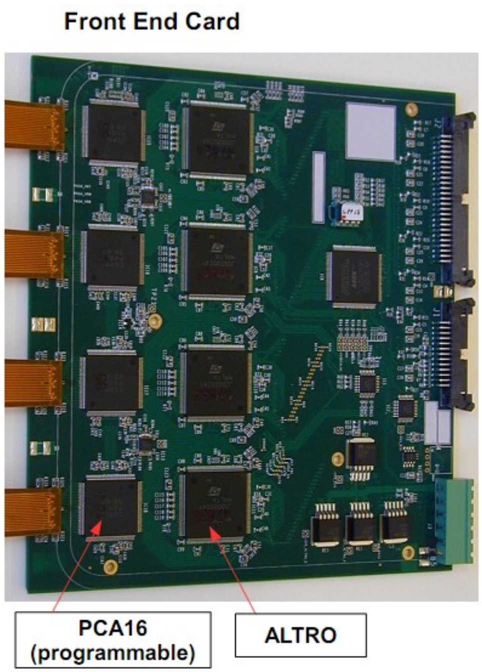
A set of 10,000 channels was built with both the AFTER chip (T2K) and the ALTRO chip (ALICE).

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

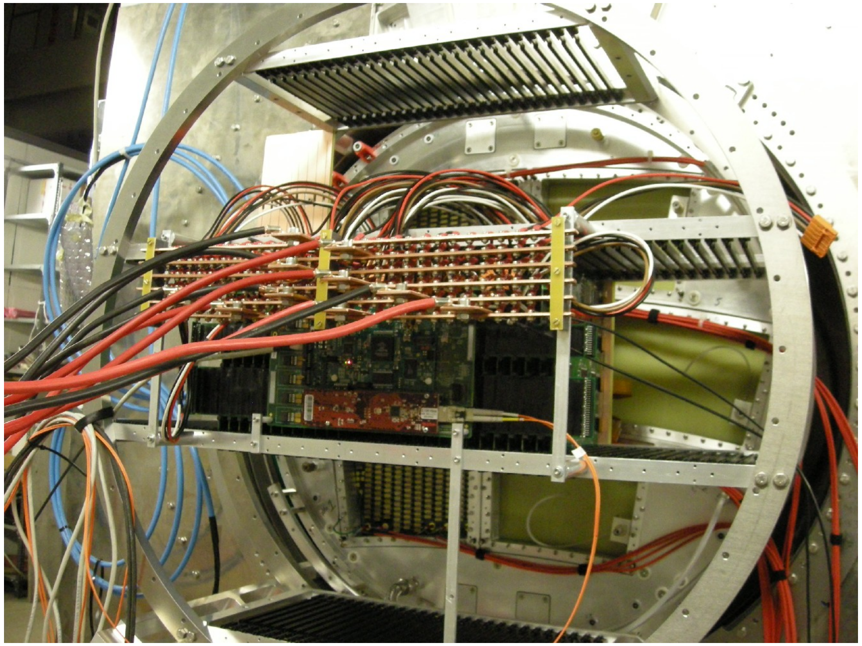
8 ALTRO ADC chips (ALICE)

8 PCA16 charge sensitive preamplifiers





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

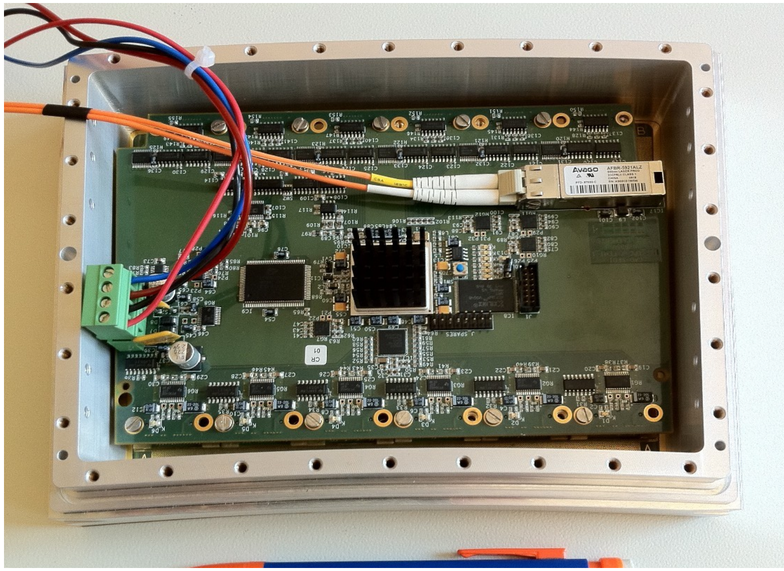


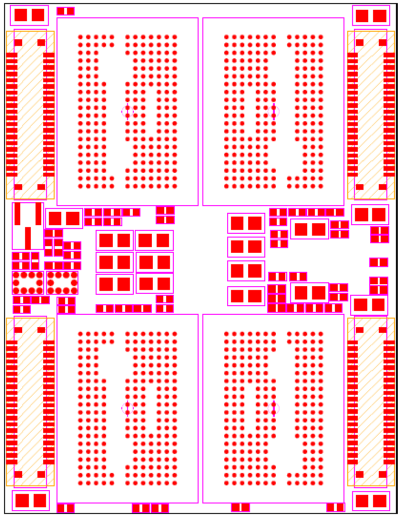
Electronics

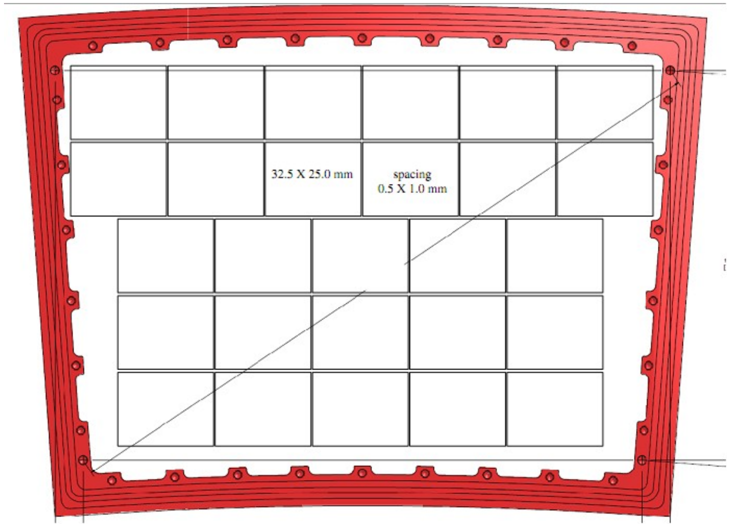
Production of a 2nd version for AFTER and ALTRO electronics is ongoing:

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







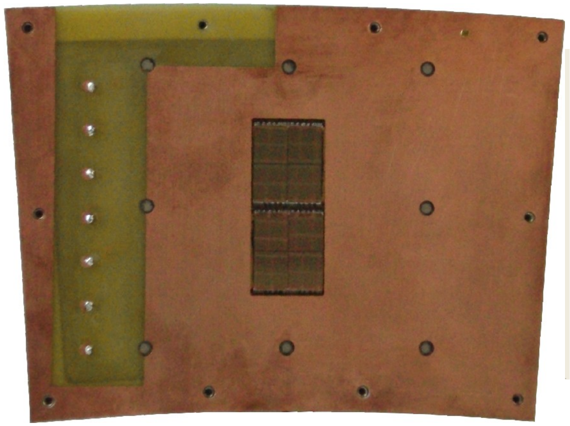
3.) Design of new 128-channel chip (GdSP) together with CMS (~2 years)

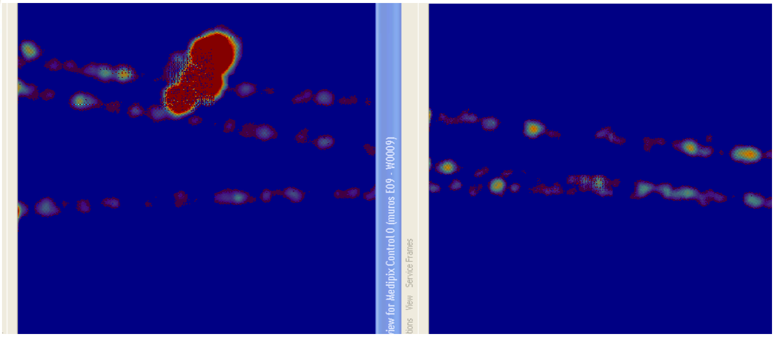
Highly pixelized Readout

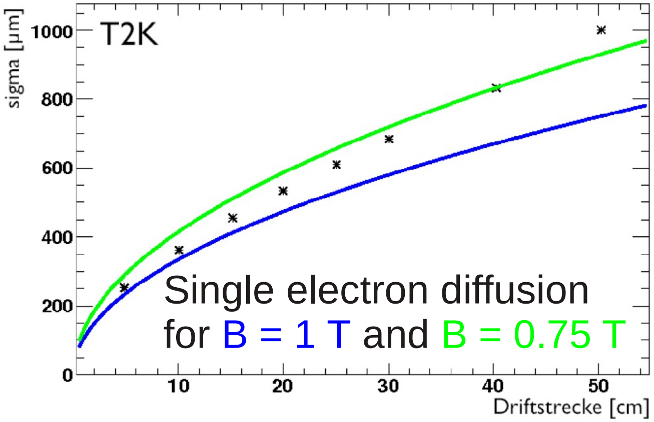
2 modules with Timepix-based readout (InGrid, triple GEM) have been built and operated in the Large Prototype.

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

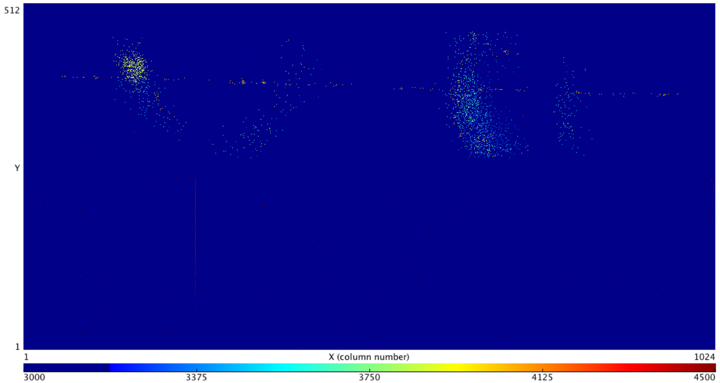
Quantitative results were not as good as with small prototypes because of electric field distortions close to grid edges (InGrid) and of B-field distortions (triple GEMs).

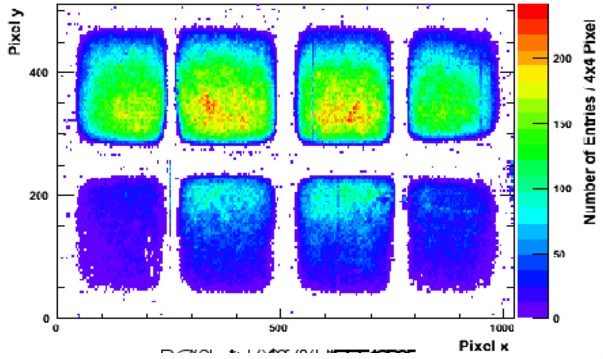






Single electron diffusion for B = 1 T and B = 0.75 T





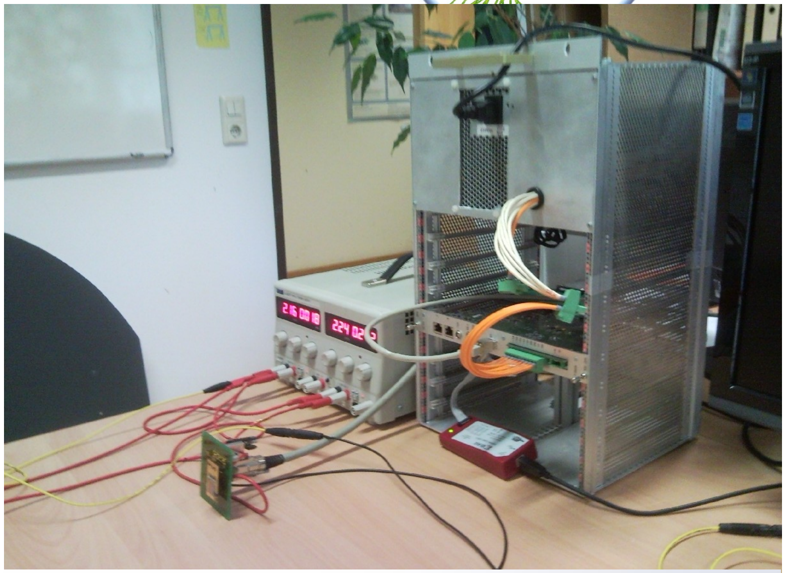
Towards many Chips Modules

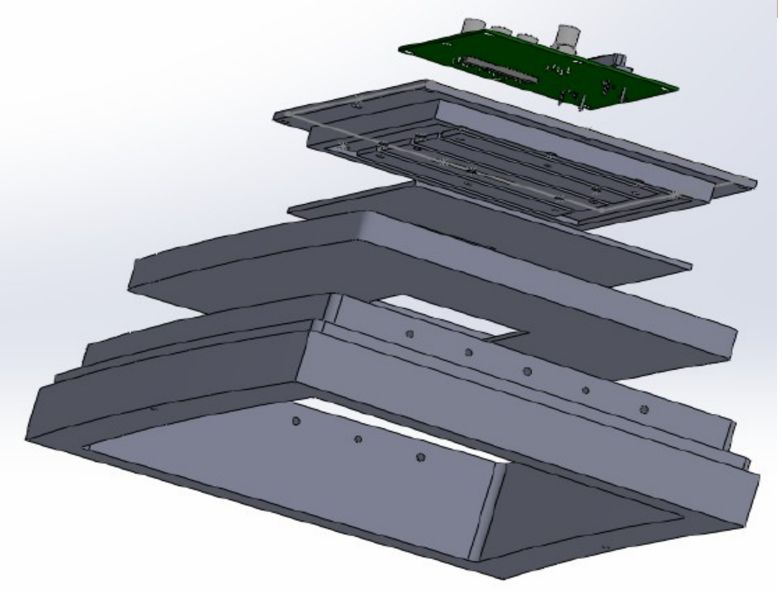
For large scale application many chips are necessary (O(100) per module)

→ scalability of readout has to be ensured

→ SRS: Scalable Readout System (RD51)

- Adapted to Timepix chip, readout of one chip in operation
- Octoboard (8 chips) in preparation: Test in Large TPC Prototype at DESY in March/April 2013 with GEM gas amplification, possibly also with InGrids
- Second module from Saclay/NIKHEF
- Long scale: 96 chip module (50% active surface, 6 mio. channels)





DAQ software / SRS FPGA firmware

- Ready to handle octoboard
- Calibration algorithm test ongoing, current results promising

MarlinTPC

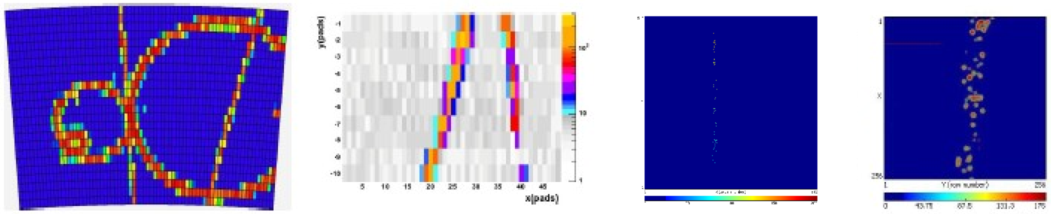
MarlinTPC is based on Marlin and ILC software.

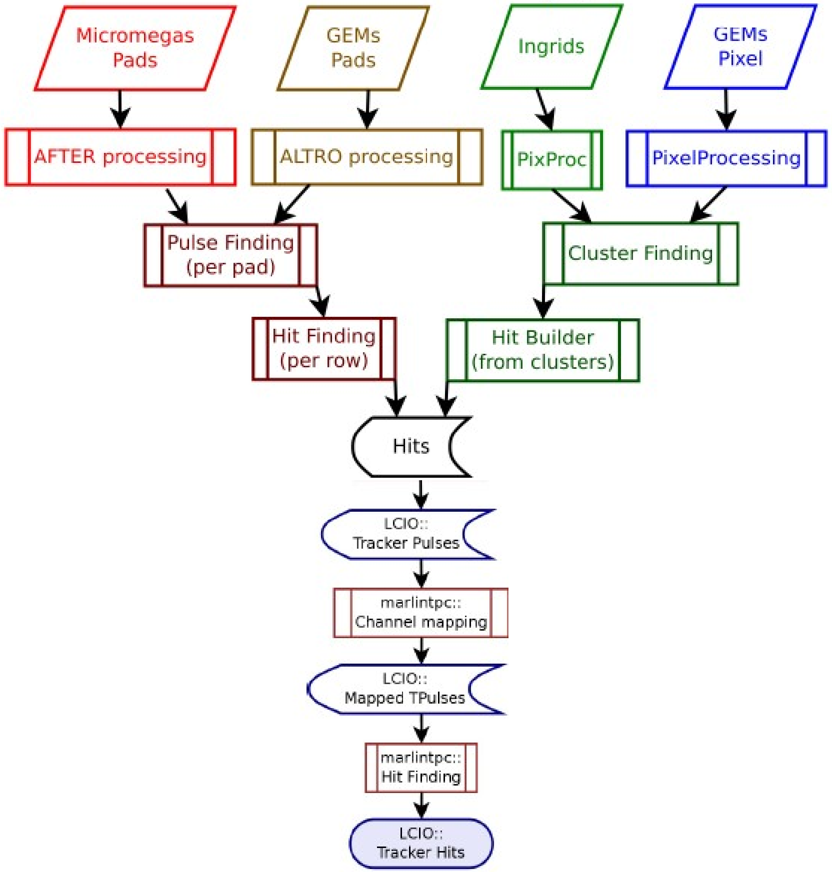
It contains a common geometry description (GEAR) and conditions data base (LCCD).

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

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.

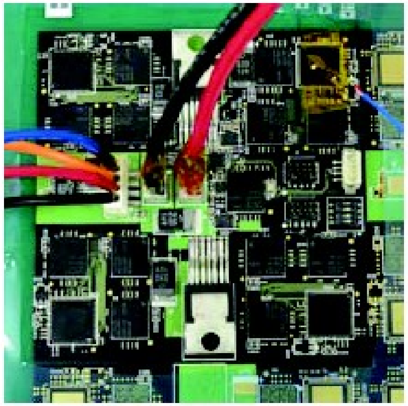
2.) Cooling with air or water

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

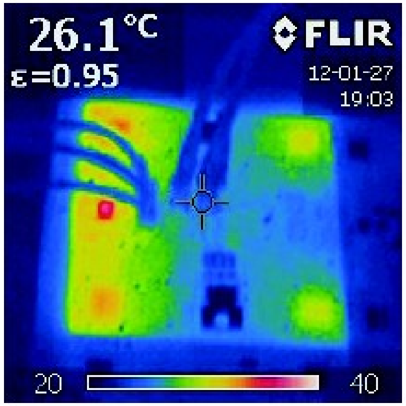
Simulations of electronics and heat distributions are made to understand heat flow and cooling needs.

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

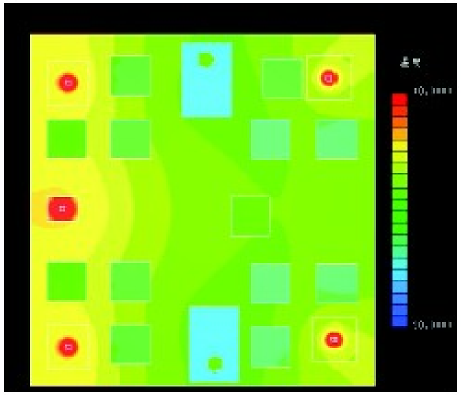
Part side



Observation

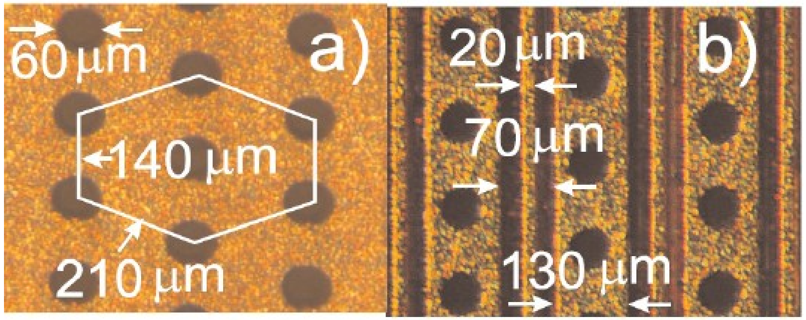


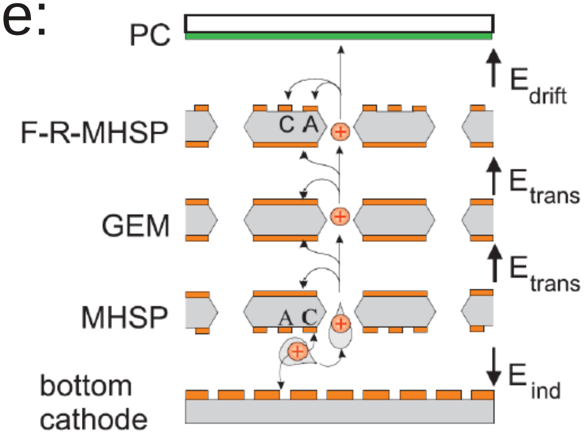
Simulation



Ion Back Drift Reduction

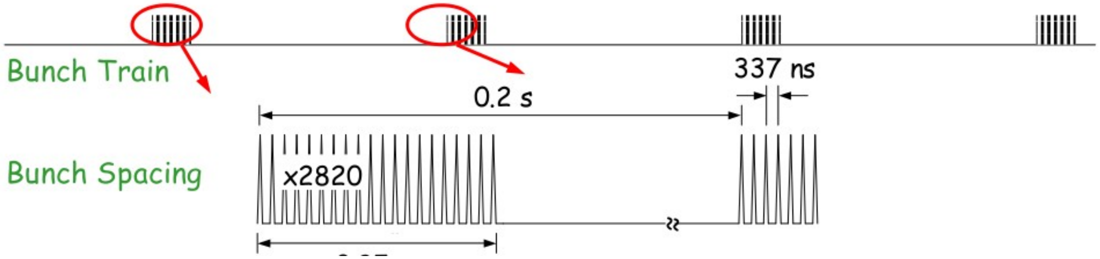
Ion back drift has to be reduced more:
1.) New devices such as MHSP





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.

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

We are all very happy about the contributions from Japan, which were left out from this talk and will be discussed in this session. In particular I want to thank Matsuda-san, Fujii-san and Sugiyama-san for there important contributions to this project.

Outlook

Some open issues have to be addressed (not a complete list):

Ion gate

Field distortions at module borders

Track finding and fitting in inhomogeneous E and B-fields

Discharge probability and effects on efficiency

External tracking device for the test facility