Study of a Large Prototype TPC for the ILC using Micro-Pattern Gas Detectors

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37th International Conference on High Energy Physics,
Valencia, Spain, 4th of July 2014

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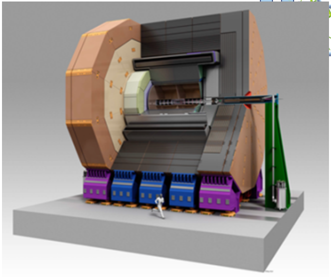
A TPC for ILD

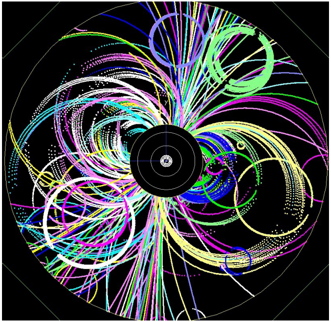
Requirements:

- **Tracking efficiency**
  close to 100% down to low momentum to fulfill Particle Flow Algorithm (PFA) requirements.
- **Minimum material**
  in front of the highly segmented calorimeter
- **Momentum resolution**
  $\sigma(1/p_t) = 2 \times 10^{-5}$ /GeV for Higgs mass measurement
  (TPC alone 10^{-4} /GeV)

Solution: TPC

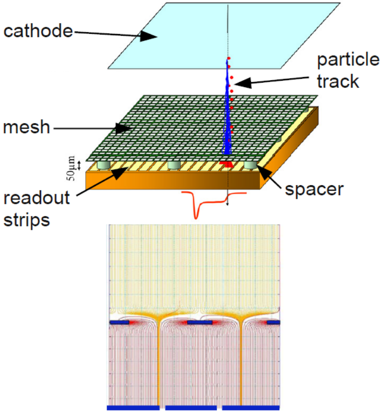
- $\approx$ 200 continuous position measurements along each track
- Single point resolution of $\sigma_{r\phi} <$ 100 µm
- Lever arm of around 1.2 m in the magnetic field of 3.5–4 T





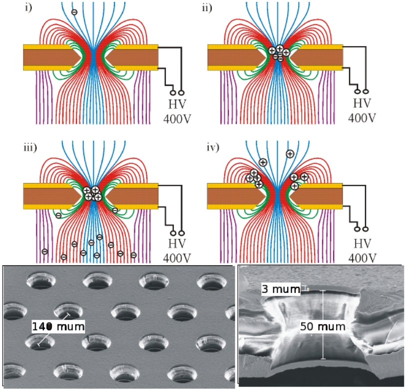
Micro-Pattern Gas Detectors

Micro-Mesh Gaseous Detectors



Y., Giomataris et al.,
Nucl. Instrum. Meth. A376:29-35,1996.

Gas Electron Multipliers



F. Sauli, Nucl. Instrum. Meth. A386:531-534,1997.

Options for a MPGD TPC

After the initial stage of R&D with many small TPC prototypes,
we have four options of MPGD being tested at the Large Prototype TPC (LP)

1. Multilayer **GEM** with the **pads** to readout the signal charges spread on the pad plane by the diffusion.
2. **Micromegas** with **pads** and resistive-anode to spread the very narrow charge on the pad plane.
3. Multilayer **GEM** with **pixel** readout. The pixel readout can help to cope with high occupancy.
4. **Micromegas** mesh with **pixel** readout detecting individual primary electrons with close to 100% efficiency.
   (There are a lot of applications of different purposes for this microscopic imaging capability.)

The Large Prototype

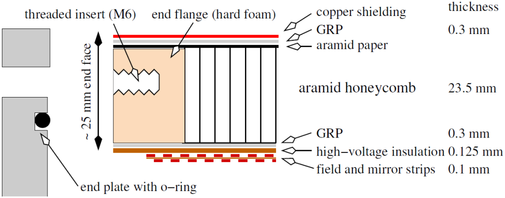
The Large Prototype has been built to compare different detector readouts under identical conditions and to address integration issues

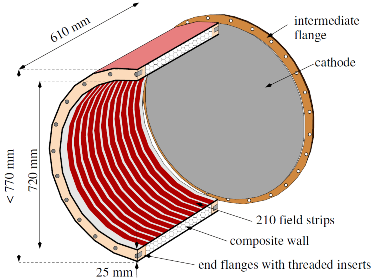
LP field cage parameters:

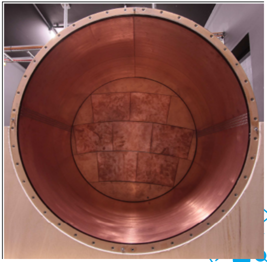
- L = 57 cm
- D = 72 cm
- up to 25 kV
  $\Rightarrow$ E $\approx$ 350 V/cm
- made of composite materials
  $\Rightarrow$ 1.21 % X_0

Modular endplate

- 7 module windows
- each module size $\approx 22 \times 17$ cm^2







Infrastructure @ DESY Testbeam Facility

Field cage & Mechanics
(EUDET: DESY)

Magnet: PCMAG
(EUDET/AIDA, LC TPC KEK,CERN, DESY)

Test beam & Facility (DESY)

Gas system
(Rostock, DESY)

MPGD Detector Modules
(LCTPC)

Cathode Laser Calibration
(LCTPC/Victoria)

DAQ & Monitoring
(EUDET)

Beam Trigger
(LCTPC/Nikhef)

Endplate
(LCTPC/Cornell)

Cosmic trigger
(LCTPC/KEK, Saclay)

Two types of Readout electronics
(EUDET/AIDA ; LCTPC/Lund, DESY, KEK, Saclay)

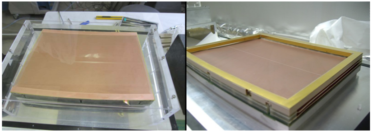
Software development
(EUDET/AIDA & LC TPCs)

Traci: Two phase CO2 cooling system
(KEK, Nikhef)

GEMs with Pads

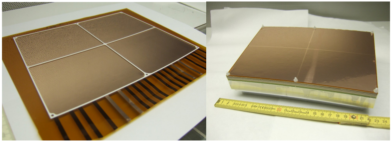
Asian GEM module:

- 2 GEMs, 100 µm thick, without side support
- $1.2 \times 5.4\ \text{mm}^2$ pads, 28 pad rows



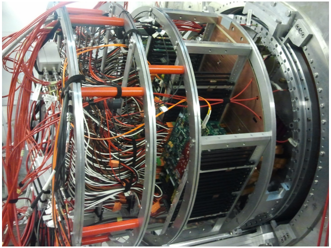
DESY GEM module:

- Triple CERN GEM, 50 µm thick, with thin ceramics frame
- $1.26 \times 5.85\ \text{mm}^2$ pads, 28 rows



About 5000 pads per module for both module types

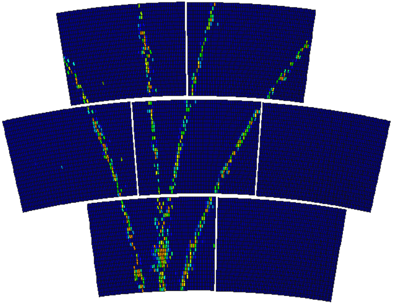
ALTRO readout electronics $\approx$ 10000 channels

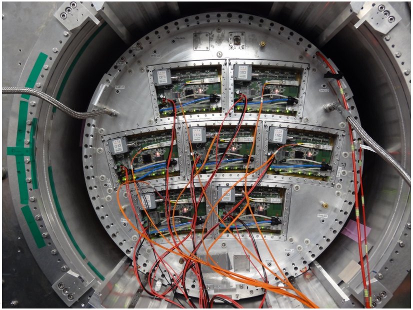


Next step: SALTRO (improved integration)

Micromegas with Pads

Compact T2K electronics mounted directly
on the back side of each Micromegas module





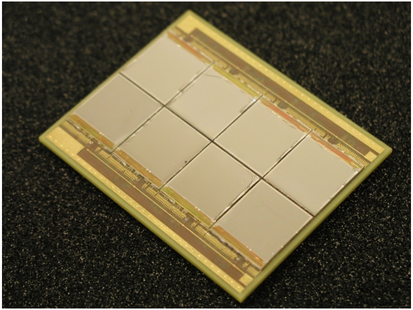
- 3×7 mm^2 large pads
- 24 rows with 72 pads
- 1728 pads per module
- Resistive foil to spread charge

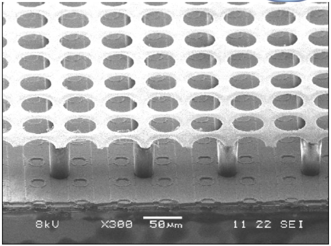
Fully equipped endplate with 7 modules
with 12000 channels

Pixel Readout

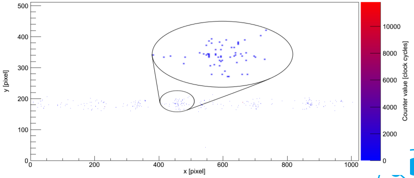
Bump bond pads for Si-pixel detectors serve as charge collection pads

Octopuce:





InGrid: Pixel + Micromegas



256 $\times$ 256 pixel of size 55 $\times$ 55 μm^2

Each pixel can be set to:

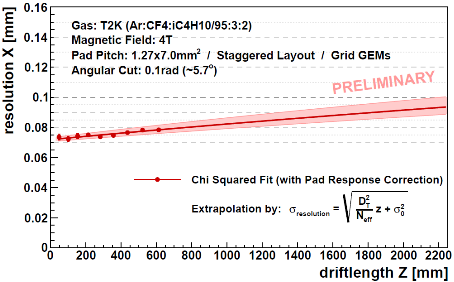
- Hit counting
- Charge measurement
- Time measurement

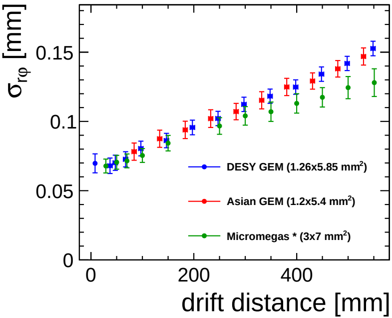
Results: Point Resolution

Different modules in the LP

- B=1 T
- T2K Gas: $Ar(95\%)CF_4(3\%)iC_4H_{10}(2\%)$

All modules show comparable resolution.
(* different analysis and cuts for Micromegas)





Extrapolation from small GEM prototype data at 4T meets requirements for single point resolution.

Status and Challenges

Status:

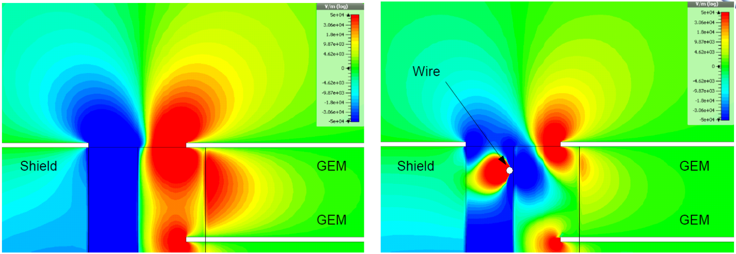
- MPGD technologies established
- First integration tests of modules in the LP successful
- Single point resolution obtained

Things we still need to do:

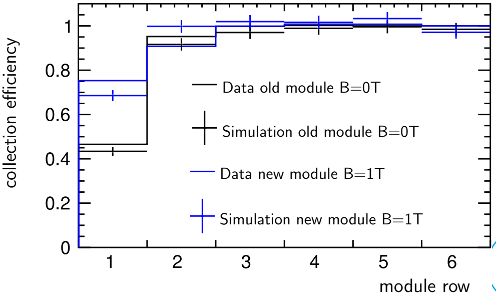
- Long term stability and production of MPGD technologies
- Understand, minimize and correct field distortions
- Demonstrate momentum resolution → external reference needed
- Limit ion back flow → design a gating scheme
- Design and build a new field cage (started), endplate (done) and cathode
- Design and build next generation of electronics
- Environmental control, calibration etc.
- Detector integration

Field Distortions I

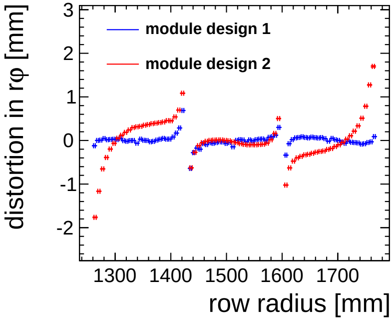
All modules observe field distortions at the borders:

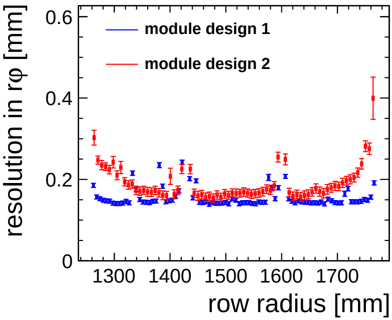


Charge collection efficiency can be improved with field shaping (e.g. a wire).



Field Distortions II





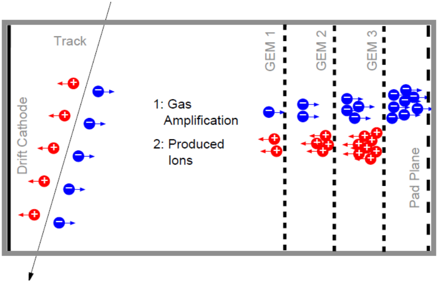
Distortion of electron path at the border due to ExB effects.

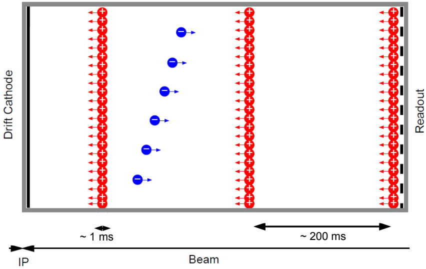
Influences track angle and therefore also the single point resolution.

Ion Back Flow: Principle

@ ILC TPC:

- After each bunch train, a disk of positively charged ions from the amplification stage drifts back into the TPC volume
- Due to the very slow drift of ions up to three disks simultaneously in the gas volume of the ILD TPC → field distortions
- With adjusted GEM settings, the ion back flow can be minimized, but not to zero

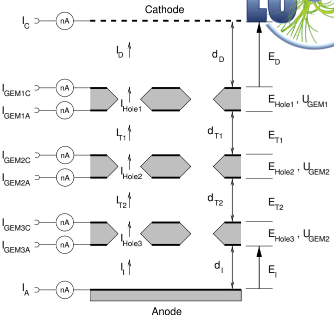




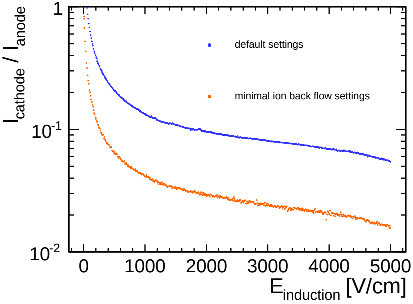
Ion Back Flow: Measurements and Optimization

Setup to measure currents:

- Optimize the GEM setting for minimal ion back flow
- Compare results with Garfield simulation (ongoing)



Ion Back Flow:



Value	Standard	Ion back flow
E_D [V/cm]	250	250
U_{GEM1} [V]	250	230
E_{T1} [V/cm]	1500	2500
U_{GEM2} [V]	250	260
E_{T2} [V/cm]	1500	290
U_{GEM3} [V]	250	290
E_I [V/cm]	3000	4500

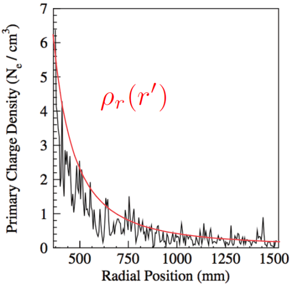
Both settings have the same gain ($\sim$ 5000).
Triple GEM stack at 4T can reach ion back flow of 2.5 ‰

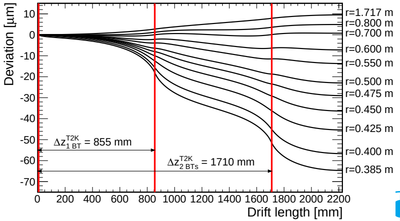
Ion Back Flow: Calculation

- The radial profile of the disk is dominated by machine-induced background during a bunch train
- Assumption: ion back flow factor from the amplification of 1 with respect to the primary ion charge
- Calculation of the expected distortion when electron passes through ion disk
  $\Rightarrow$ Maximum of $\approx$ 20 µm per disk
- Results in up to 60 µm distortion

$\Rightarrow$ **Gating needed**

- Decide if wire, mesh or GEM gate
- Modules will be equipped with gates





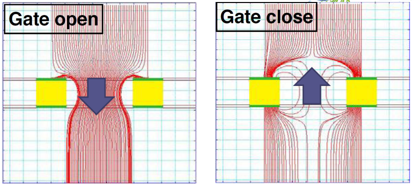
Ion Gate Options

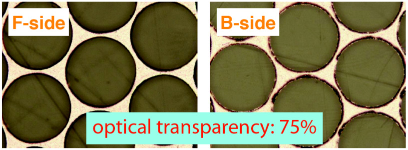
Preferred solution:

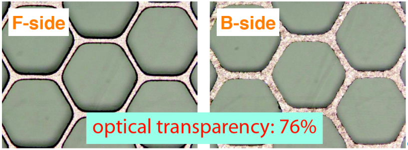
- Gate should be MPGD device
- Gate should be mounted on modules

GEMs as ion gate:

- High optical transparency required: 85-90%
  → Large Aperture GEM
- R&D by Dr. Arai (Fujikura Ltd.)
- 2 prototypes:
  1. Round, rim width 15/30 μm (F/B side), UV laser
  2. Hexagonal, rim width 30/40 μm (F/B), NI plating
- Tests ongoing







Outlook: Plans of LCTPC

The next few years:

Before entering the engineering design of an ILD TPC, the following issues need to be studied further:

1. Ion gate: the most urgent issue
2. Smaller technical and long term stability issues with MPGD technologies and MPGD modules
3. Local distortions of MPGD modules
4. Demonstration of power pulsing
5. Cooling of readout electronics and temperature control of TPC
6. Performance of MPGD TPC in 3.5 T magnetic field
7. Studies of mechanics for ILD sized TPC