LCTPC: Towards a TPC for ILC

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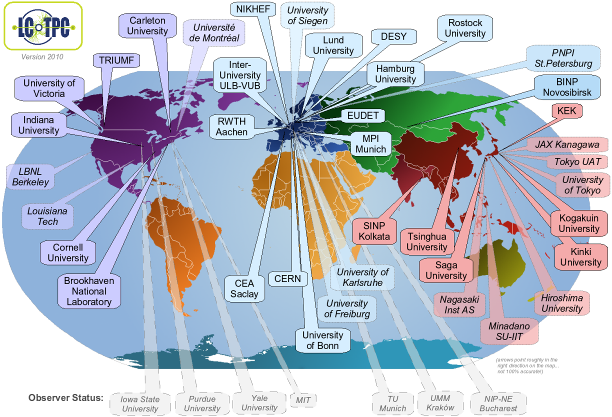
Overview

- The Collaboration
- The Large Prototype
  - New Endplate
  - New Field Cage
- MPGD Readout Modules
- Ion Back Flow
- Momentum Resolution
- Open Topics
- The case for a TPC at ILD

LCTPC - Collaboration

31 Institutes from 12 countries have signed MoA
13 institutes have an observer status R&D in 3 phases:

1. **Demonstration Phase**
   Test feasibility with small scale detectors at individual labs
2. **Consolidation Phase**
   A medium size prototype was built to compare results and study integration issues
3. **Design Phase**
   Design of final detector



The Large Prototype

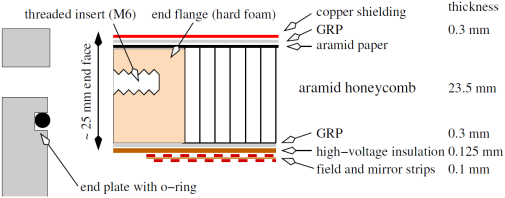
Large Prototype has been built to compare different detector readouts under identical conditions and to address integration issues

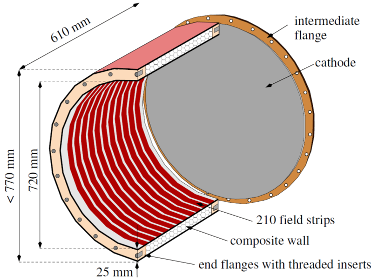
LP field cage parameters:

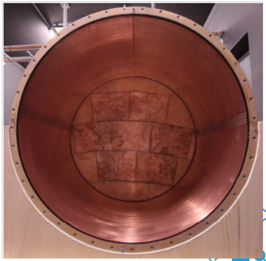
- L = 57 cm
- D = 72 cm
- up to 25 kV
  $\Rightarrow$ E $\approx$ 350 V/cm
- made of composite materials
  $\Rightarrow$ 1.21 % X_0

Modular endplate

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





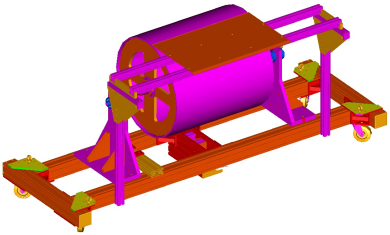


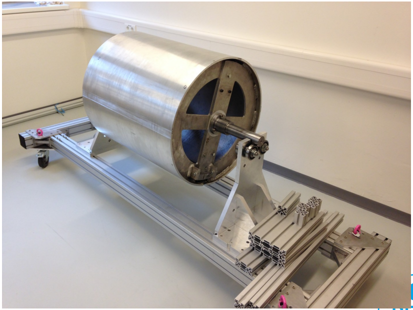
New Field Cage

Production at DESY, gain experience in handling materials and building large mechanical structure with high precision

Main Goals:

- New fieldcage with better precision
- Investigate better materials
- Improve other details, e.g. HV distribution

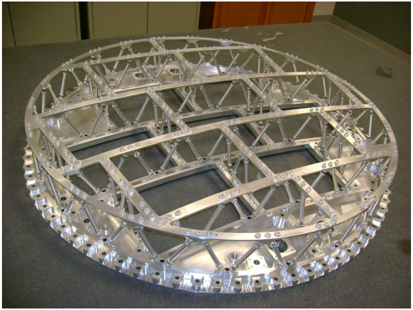


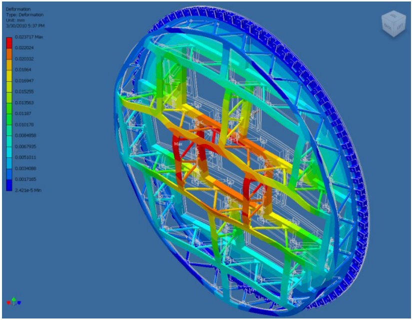


New Endplate

Goal: Total material budget for endplate less than 25% X_0, including modules and electronics

Solution: Only the "strut" space-frame design can fulfill material budget and rigidity requirements at the same time





Deflection studies:
measured: 27 μm/100 N, calculated with FEA: 23 μm/100 N

Options for a MPGD TPC

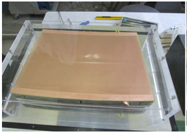
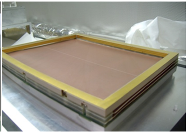
After the initial stage of R&D with many small TPC prototypes,
we have four options of MPGD being tested at the Large Prototype TPC (LP)

1. Multilayer **GEM** with the standard **pads** to readout the signal charges spread on the pad plane by the diffusion.
2. **MicroMegas** with resistive-anode **pads** 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.)

GEMs with Pads

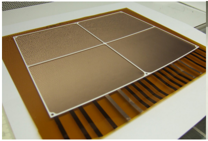
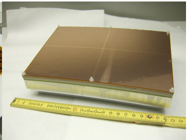
Asian GEM module:

- 2 GEMs, 100 µm thick, without side support
- 1.2×5.4 mm^2 pads, 28 pad rows

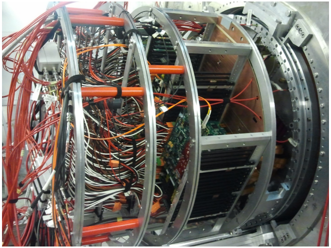
DESY GEM module:

- Triple CERN GEM with thin ceramic frame
- 1.26×5.85 mm^2 pads, 28 rows

About 5000 pads per module for both module types

ALTRO readout electronics
$\approx$ 10000 channels



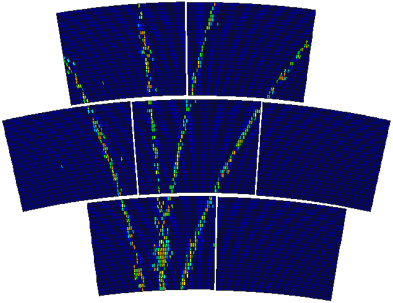
Next step: SALTRO (improved integration)

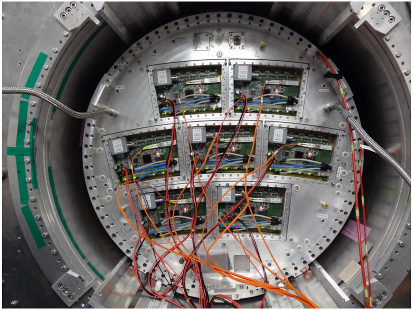
More details by Yukihiro Kato "Activity report of ILD-TPC Asia group"

and Astrid Münnich "Performance of DESY GEM Module in Testbeam Measurements"

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

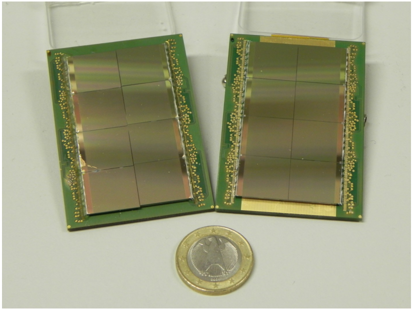
Fully equipped endplate with 7 modules with 12k channels

More details by Paul Colas "Recent results from test bench and beam tests of Micromegas TPC modules"

Pixel Readout

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

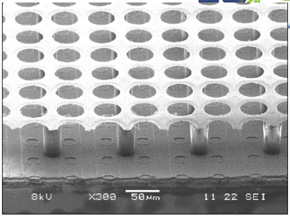
2 Octoboards with bare Timepix chips:



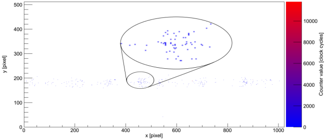
256×256 pixel of size $55 \times 55\ \mu m^2$

Each pixel can be set to:

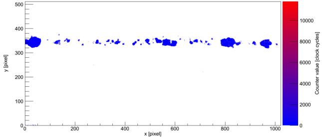
- Hit counting
- Charge measurement
- Time measurement



InGrid: Pixel + Micromega



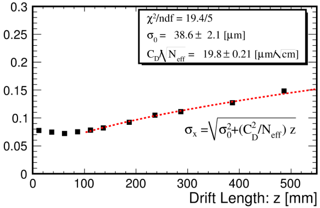
Pixel + GEMs



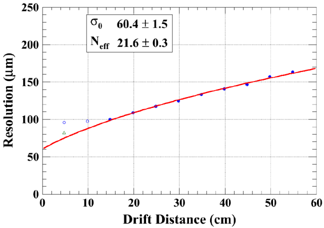
Module Performance

All modules show similar spatial resolution:

GEMs (Asian)

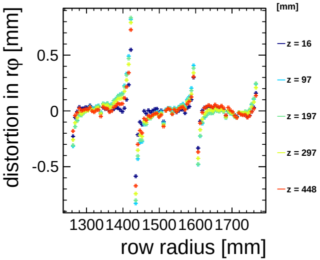


MicroMegas

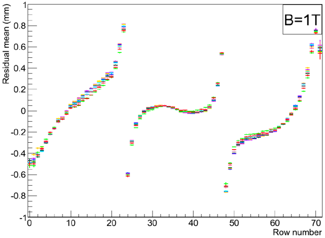


All modules observe field distortions at the borders:

GEMs (DESY)



MicroMegas

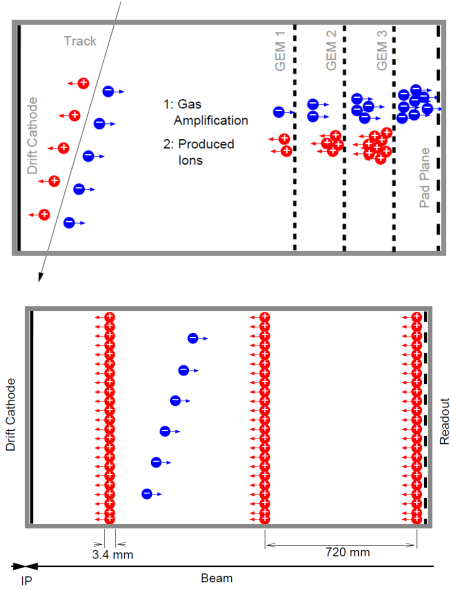


Current Topics

- Field distortions:
  - Improve module designs to limit distortion at the borders
  - Apply corrections for electric and magnetic field distortions
  - Needs field maps and dedicated software
- Ion back flow:
  - Study intrinsic suppression of ion back flow inside amplification structure
  - Design and test gating schemes
  - Evaluate effect of remaining ions on field homogeneity
- External reference for momentum resolution
  - Several layers of silicon detectors between the magnet and the TPC
  - Alignment of the two systems
- Electronics development
- Cooling system (CO_2 system close to being installed)
- Endplate integration
- Calibration: drift velocity, temperature, gain
- Software development

Ion Back Flow: Principle

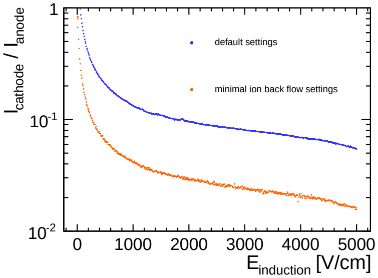
- After each bunch train, a disk of positively charged ions from the amplification stage drifts back into the TPC volume
- Due to the very slow drift of ions up to three disks simultaneously in the gas volume of the ILD TPC $\rightarrow$ field distortions
- With adjusted GEM settings, the ion back flow can be minimized, but not to zero
- Gating possibilities: wires, mesh, GEMs, ...?



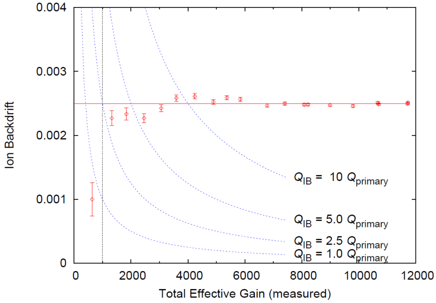
Ion Back Flow: Measurements and Optimization

Setup to measure currents:

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



Both settings have the same gain.



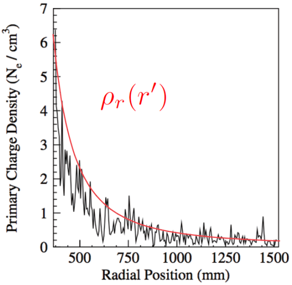
Value	Standard	ion back flow
E_D [V/cm]	250	250
U_{GEM1} [V]	250	230
E_{T1} [V/cm]	1500	2500
U_{GEM2} [V]	250	260
E_{T2} [V/cm]	1500	290
U_{GEM3} [V]	250	290
E_I [V/cm]	3000	4500

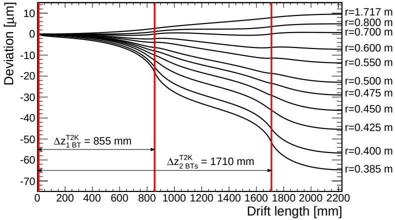
Ion Back Flow: Calculation

- The radial profile of the disk is dominated by machine-induced background during a bunch train
- Assumption: ion feed back 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 $\approx 20\ \mu$m per disk
- Results in up to 60 μm distortion

$\Rightarrow$ **Gating needed**

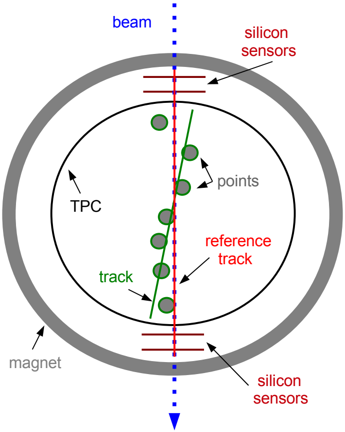
- Decide if wire, mesh or GEM gate
- Modules will be equipped with gates





Details on gates Yukihiro Kato "Activity report of ILD-TPC Asia group"

External Reference for Testbeam Setup



Motivation:

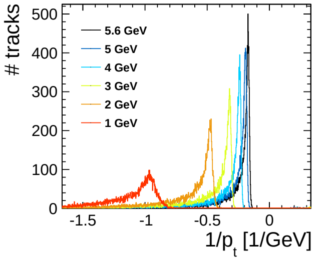
- Necessary for momentum resolution to unfold beam spread and multiple scattering in magnet from measured distribution
- Helpful for unbiased resolution and distortion evaluation

Specification:

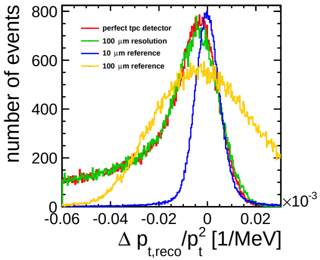
- Required spatial resolution per point $< 10\ \mu\text{m}$
- Sensitive area $\sim 5 \times 10\ \text{cm}^2$
- Readout needs to be synchronized with TPC DAQ
- Tight spatial constraints: ~ 4 cm between TPC and magnet

Momentum Resolution with Testbeam Setup

- Measure the curvature of the track
- Distribution is dominated by beam spread and multiple scattering in magnet
- We need a value to compare it with to evaluate momentum resolution



Without an external reference a reference track has to be created from the data itself.
→ Prone to bias, reduces the number of points that can be used for the measurement by at least a factor of 2.
→ Resolution of TPC not sufficient to prove momentum resolution with the required precision (10^{-4} /GeV).



Plans of LCTPC

The next few years:

Before entering the engineering design of ILD TPC, we still need to study the following issues:

1. Ion gate: the most urgent issue
2. Some issues with MPGD technologies and MPGD modules
3. Local distortions of MPGD modules
4. Demonstration of power pulsing (with the SALTRO16 and future electronics)
5. Cooling of readout electronics and temperature control of TPC
6. Performance of MPGD TPC in 3.5T magnetic field

The case for a TPC at ILD

Advantages of the TPC

The standard arguments:

- Material budget
- Very good pattern recognition → perfect for Particle Flow
  - Large number of 3D points
  - Reconstruction of kinks, non-pointing tracks
  - High tracking efficiency
  - Background suppression
- dE/dx

What about the SET? Does the TPC need it?

- Correction of distortion
- Alignment, calibration
- Time stamping

→ A task for the detector optimization group

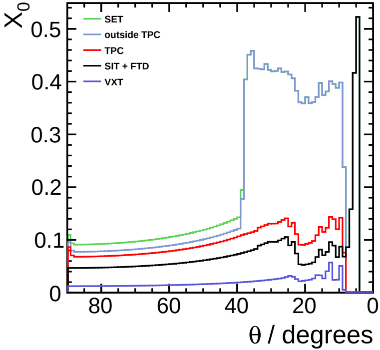
Which physics analysis really uses specific advantages of the TPC?

→ Current benchmarks do not challenge the TPC!

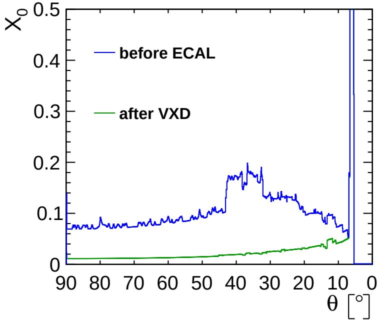
A Word on Material Budget

Not only the amount of material is important, but also its distance from the calorimeter!
$\rightarrow$ The closer to the calorimeter the better for jet energy resolution

ILD



SID (CLIC version)



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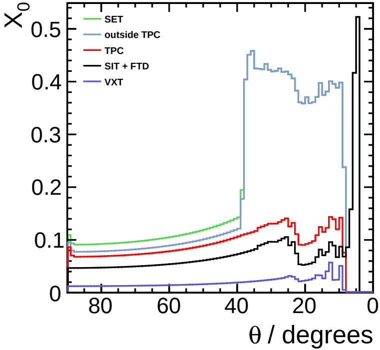
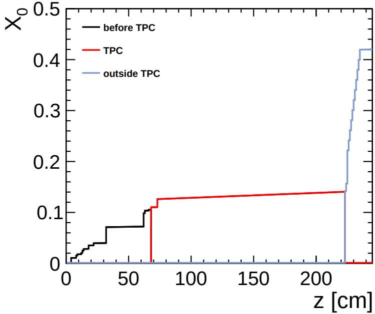


ILD, $\theta = 26^\circ$



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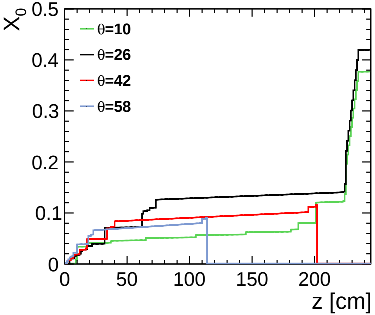

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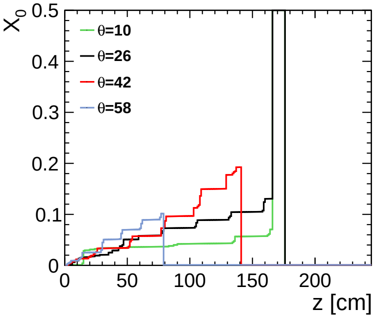
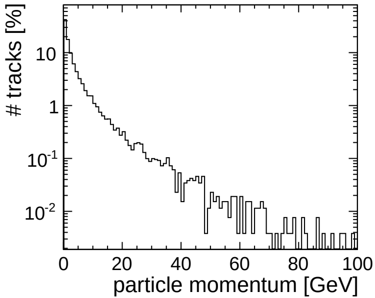
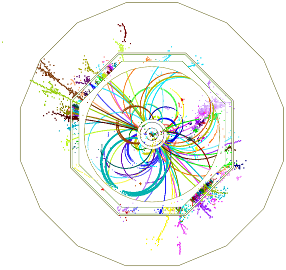


Low Momentum Tracks and Kinks

Zqqqq @ 500 GeV → 42% off tracks <1 GeV



$t\bar{t} \rightarrow 6q$ @ 500 GeV

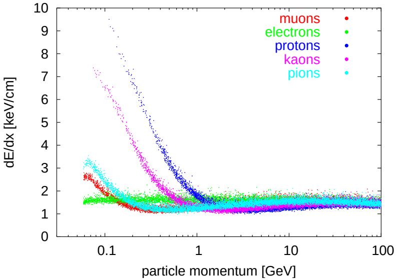


Reconstruction of kinks and non-pointing tracks:

- Improves vertex information
- Allows to study decay of resonances, e.g. Λ_b
- GMSB → up to 1m decay length

- BSM after LHC: small mass differences
  → soft tracks, exclusive decays
- SM: multi-jet final states: 6,8 or 10 jets
  → PFA performance limited by jet-finding
  → exclusive decay chain reconstruction

Particle ID with dE/dx



- dE/dx not implemented in simulation and therefore not exploited in physics studies
- Mass information for track fit is important especially for low momenta where dE/dx is powerful

→ requires input from LCTPC to incorporate dE/dx information in the full detector simulation as we have it in our detailed simulations in MarlinTPC
→ requires collaboration with analysis groups to find right benchmarks

Examples from ALEPH:

- Identification of low momentum electrons, separation form other charged particles e.g. pions
- Separate protons from anti-protons
- Identification of heavy charged particles

Summary & Outlook

Status:

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

Things we still need to do:

- Demonstrate momentum resolution $\rightarrow$ external reference needed
- Understand, minimize and correct field distortions
- Limit ion back flow $\rightarrow$ design a gating scheme
- Study dE/dx
- Design and build next iteration of field cage, endplate and cathode
- Design and build next generation of electronics

Prove the advantages of the TPC all the way to the physics analysis!

BACKUP

Backup: Ion Back Flow