Studies of Micro Pattern Gas Detector modules of a Large Prototype TPC for the ILD at ILC

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on behalf of the LCTPC Collaboration
ILD:
$E_{cm} = 0.5 \& 1 \text{ TeV}$

Components:
- Vertex
- Silicon tracking (SIT/SET/ETD/FTD)
- Gaseous TPC
- ECAL/HCAL/FCAL
- SC coil (3.5 or 4 Tesla)
- Muon in Iron Yoke

ILD Requirements:
- Momentum resolution: $\delta(1/p_T) < 2 \times 10^{-5} \text{ GeV}^{-1}$
- Impact parameters: $\sigma(r\phi) < 5 \mu m$
- Jet energy resolution: $\sigma_E/E \sim 3-4\%$
Total of 12 countries from 25 institutions members + several observer institutes
TPC is the central tracker for ILD

- Large number of 3D hits → continuous tracking
- Up to 200 positions measurements along each track
- Good track separation and pattern recognition
- Single hit $\sigma(r\phi)$ at $z=0 \approx 60 \mu m$ and $\sigma(r\phi) < 100 \mu m$
- $\sigma(z)$ at $z=0 \approx 400 \mu m$ and $\sigma(z) < 1400 \mu m$

Low material budget inside the calorimeters (PFA)
- Barrel: ~5% $X_0$ and Endplates: ~25% $X_0$

**TPC Requirements:**

- **Momentum resolution:**
  $\delta(1/p_T) < 9 \times 10^{-5} \text{ GeV}^{-1}$
- **Single hit resolution 3.5T:**
  $\sigma(r\phi) < 100 \mu m$
  $\sigma(z) \approx 500 \mu m$
- **Tracking eff. for $p_T > 1$ GeV:**
  $> 97%$
- **dE/dx resolution** ~5%
Large Prototype at DESY

- Two options for endplate readout with pads:
  - **GEM**: 1.2×5.8 mm² pads (smaller pad – more electronics)
  - **Resistive Micromegas**: 3×7 mm² pads (larger pads – less electronics)
- Alternative: **pixel** readout with pixel size ~55×55 μm² (newest)
Micro Pattern Gas Detector (MPGD)

Technology choice for TPC readout: Micro Pattern Gas Detector

- no preference in track direction
- fast signal & high gain
- better ageing properties
- no E×B effect
- low ion backdrift
- easier to manufacture

Resistive Micromegas (MM)

- MICROMEsh GAseous Structure
- metallic micromesh (typical pitch 50µm)
- supported by 50 µm pillars, multiplication between anode and mesh, high gain

GEM

- Gas Electron Multiplier
- doublesided copper clad Kapton
- multiplication takes place in holes, with 2-3 layers needed

Avalanche

- ~100 µm
- 40 kV/cm
- 50-100 µm
- 40 kV/cm
- ~2000 µm
- 3 to 4 kV/cm

Discharge probability and consequences can be mastered (use of resistive coatings, several step amplification, segmentation) – MPGD more robust mechanically than wires
LCTPC Scientific Program

- Development of MPGD assembly procedure with integrated readout
- Measurement of transverse and longitudinal resolution
- Optimization (i.e. reduction) of field distortion in amplification gap
- Further R&D in progress at the hardware/design/construction level

GEM (simulation)

No field shaping ring

Wire field shaping ring

GEM (measurement)

50% drop

20% drop
Field Distortions (E x B effect)

Micromegas modules

B=1T

B=0T

After alignment

software off-line correction for module alignment and field distortion
Triple GEM Modules (European GEM)

- Three standard CERN GEMs mounted on a light ceramic frame (1 mm)
- Partially equipped (1000 pads, 1.26 x 5.85 mm²)
- Bottom GEMs segmented into 4 sectors to reduce stored energy
- Top GEM electrode not segmented
- Read out by ALTRO electronics
- HV line for each GEM side
- Protection resistors very close to GEM
- 5000 pad version being built
Double GEM Modules (Asian GEM)

- Laser-etched Liquid Crystal Polymer by SciEnergy, Japan
- 100 µm thick
- 28 staggered rows of 176-192 pads
- Pad 1.2 x 5.4 mm²
Micromegas: Module Design

- pad-plane (front)
- pad-plane connector
- radiators
- FEC
- frame cooling pipe
- HV supply
- FEM
Micromegas Resolution

- R&D: Saclay & Carleton
- Endplate fully equipped (all modules populated)
- Read out by AFTER electronics
- Optimized shaping time and mesh voltage
- Resistive layer to spread charge for better clustering and centroid determination
- Two type of resistive layers: Carbon-Loaded Kapton (CLK) and Black Diamond (BD)
- Full CO₂ cooling system (with NIKHEF & KEK) in 2015 testbeam
Transverse (r-Φ) Resolution

Micromegas $3 \times 7 \text{ mm}^2$ pads and GEM $1.2 \times 5.8 \text{ mm}^2$ pads

Extrapolate to B=3.5T

![Graph showing resolution vs drift distance with lines for B=1T and B=3.5T, and a 100 μm arrow]
Highly Pixelated Readout (GridPix)

- Micromegas on a pixelchip
- Resistive protection layer (4-8 µm) on top of chip
- Insulating pillars between grid & pixelchip
- One hole above each pixel
- Amplification directly above the pixelchip
- Very high single point resolution

Timepix: 256 x 256 pixels of size 55 x 55 µm²

- low threshold level ~500 e- (90 e- ENC)
Mounting of the central module with 96 InGrids

Total 160 InGrids active area

Installation of the cooling circuit

GridPix
Large scale application / Large active area
GridPix Resolution

Spatial resolution (preliminary):

In x-y plane, from residuals, with and without B-field

Transverse spatial resolution follows diffusion of single electrons

The single hit resolution does not depend on the track angle

Expected resolution as good, or better, than MPGD pad readout

Reconstructed diffusion constants in agreement with simulations
Ion Gate for the TPC

- Ion Gating: suppress ion backflow into the main TPC drift volume
- Radial profile of the ion disk produced during the avalanche is dominated by machine-induced background during a bunch train
- Expect 60 μm distortion when drift electrons pass through ion disk
- GEM gating system testbeam in preparation by Japanese group
Summary – Outlook

A lot of experience has been gained in building and operating MPGD TPC panels within the LCTPC collaboration.

The characteristics of the MPGD, such as the uniformity, spatial resolution, stability studied in detail. Steady progress. R&D mature.

Results of LCTPC indicate that it meets resolution goal at ILC:
\[ \sigma(r\phi) \text{ at } z=0 \approx 60 \mu m \text{ and } \sigma(r\phi) < 100 \mu m \]
\[ \sigma(z) \text{ at } z=0 \approx 400 \mu m \text{ and } \sigma(z) < 1400 \mu m \]

On-going progress on ion grid (gating), power pulsing electronics, multi-track pattern recognition as well as detailed simulation

- Precise & reproducible MPGD assembly within mechanical tolerance
- Large area module with minimal field distortion in amplification gap

There is renewed optimism for the ILC going forward.
LCTPC is in a good position and ready for a call for the ILD experiment.

A. Bellerive – ICHEP August 16, 2016
- Time Projection Chamber (TPC)
- Vertex (VTX) detector is realized with multi-layer of pixels
- Silicon strip (SIT) detectors are arranged to bridge the gap VTX and the TPC

TPC $\lesssim 200$ continuous position measurements along each track in a gas with the point resolution of $\sigma_{r\phi} < 100\mu m$, and a lever arm of around 2m in the magnetic field of 3.5-4T. 2-track separation: 2 mm in $R\phi$ and 6 mm in $z$ in a high density background environment.
ILD ECAL and HCAL

large radius and length ➔ to separate the particles
Hermitic, but compact (inside the coil of the solenoid)

large magnetic field ➔ to sweep out charged tracks

“no” material in front of calorimeters ➔ stay inside coil

small Molière radius of calorimeters ➔ to minimize shower overlap

high granularity of calorimeters ➔ to separate overlapping showers
A 3D camera, which captures the passage of charged particles.

(1) **Ionization**: along path of charged particle

(2) **Drift & Diffusion**: spread as Gaussians in Transverse and Longitudinal planes (statistical)

\[ \sigma^2 = \sigma_0^2 + D^2 \cdot z \]

\[ D = \text{diffusion} \left( \frac{\mu m}{\sqrt{cm}} \right) \]

Transverse diffusion is suppressed by the Magnetic field (Lorentz Force)

(3) **Amplification**: boost number of electrons

(4) **Readout Pads**: pads convert to digital record
Multi-module LCTPC

Period
2012-2015

2013 data
6-module

2014 data
7-module with cooling

2015 data
7-module with cooling
2 new modules
Micromegas (MM)
Charge Dispersion

Resistive Anode