Study of a multi-module Micromegas TPC prototype for tracking at the International Linear Collider

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At the ILC, $e^-$ $e^+$ will collide initially in the range $\sqrt{s} = 240 - 500$ GeV. It is a precision measurement and discovery machine.

Different production processes and decay modes of Higgs boson will be studied at different energy ranges.

A major Higgs production process at $\sqrt{s} = 250$ GeV is Higgs-strahlung: $e^- e^+ \rightarrow Z H$, followed by $Z \rightarrow \mu^+ \mu^-$. The advantages of Higgs-strahlung are:

- Identification of Z boson with a well defined energy corresponding to the kinematics of recoil against 125 GeV Higgs helps to identify a Higgs event even without studying the Higgs decay.
- Total decay width of the Higgs boson can be determined and the Higgs couplings can be studied with precision.
- Invisible decay modes can be studied.
- From the decay of Z boson, Higgs mass can be measured precisely.

Cross sections of three major Higgs production processes as a function of centre of mass energy.

**International Large Detector**

**ILD-TPC dimension**
- Length of the TPC ~ 4.6 m
- Diameter of the TPC ~ 3.6 m
- Magnetic field ~ 3.5 T

**A TPC as main tracker has the benefits of:**
- Continuous, truly 3-D tracking.
- Robust pattern recognition.
- High efficiency tracking over large momentum range.
- Low material budget.

**Resolution requirement**
Physics goal sets the limit of r-phi resolution to be better than 100 µm over full drift length for 3.5 T magnetic field.
ILD-TPC schematic
(Principle of a TPC and Micromegas)

Drift plane

Mesh

Spacers

Anode Plane

A module with its readout electronics

7-module demonstrator
The Large prototype TPC for ILC at DESY

The movable stage and the 1T magnet.

1-6 GeV e- beam

The field cage
• Drift length = 56.80 cm
• Inner diameter = 72 cm
Micromegas module

- Module size: 22 cm × 17 cm
- Readout: 1726 Pads
- 24 rows
- Pad size: ~3 mm × 7 mm

End plate of the LPTPC

- Pad size: ~3 mm × 7 mm
- 24 rows
- Mesh size: 22 cm × 17 cm
- Readout: 1726 Pads
In standard Micromegas resolution is given by,
\[ \text{Resol} = \frac{w}{\sqrt{12}} \]

At LP-TPC, Resistive Micromegas are used, where charge is dispersed on the resistive foil. It is glued on top of the pads.

\( \sigma \) of the charge distribution
\[ = \sqrt{\frac{2t}{RC}} \]

\( R \) -> the surface resistivity of the layer.
\( C \) -> capacitance per unit area and \( t \) is the shaping time of the electronics.

• Commonly used Carbon Loaded Kapton (CLK) is unavailable now.
• A new resistive material, Diamond Like Carbon (DLC) is available from Japan.
• We used both in the recent beam test during March 2015.
**Study of different parameters**

**Track Micromegas modules**

<table>
<thead>
<tr>
<th>Studies</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>At different drift distances</td>
<td>full available drift length of 60 cm</td>
</tr>
<tr>
<td>At different phi (degree)</td>
<td>0, 2, 4</td>
</tr>
<tr>
<td>At different theta (degree)</td>
<td>10 to 30 in steps of 5</td>
</tr>
<tr>
<td>At different X positions</td>
<td>‘-40’ mm to ‘30’ mm</td>
</tr>
<tr>
<td>At different peaking time of the electronics.</td>
<td>100 ns to 1000 ns</td>
</tr>
<tr>
<td>At two different fields</td>
<td>140 V/cm, 230 V/cm</td>
</tr>
<tr>
<td>At different noise thresholds</td>
<td>3 sigma and 4.5 sigma</td>
</tr>
<tr>
<td>At two different magnetic fields</td>
<td>0 T and 1 T</td>
</tr>
<tr>
<td>At different momenta</td>
<td>1 GeV to 5 GeV</td>
</tr>
<tr>
<td>Cosmic rays</td>
<td>B = 1 T and B = 0 T</td>
</tr>
</tbody>
</table>

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Pre-thesis seminar, Deb Sankar Bhattacharya, 10 Dec 2015
The beam position on the TPC is plotted against reconstructed time.
Slope gives the drift velocity.
Intersection of two such curves for two different fields gives the time of starting-drift ($T_0$).
The drift time (or length) is calibrated from $T_0$.

Measured drift velocity is in very good agreement with simulation*.

<table>
<thead>
<tr>
<th></th>
<th>$E=140\text{ V/cm}$</th>
<th>$E=230\text{ V/cm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{V}_d\text{ Data}$</td>
<td>$56.7 \pm 0.1\mu m/\text{ns}$</td>
<td>$74.1 \pm 0.2\mu m/\text{ns}$</td>
</tr>
<tr>
<td>$\bar{V}_d\text{ Magboltz}$</td>
<td>$57.9 \pm 1.0\mu m/\text{ns}$</td>
<td>$75.5 \pm 1.0\mu m/\text{ns}$</td>
</tr>
<tr>
<td>$D_\bot\text{ Magboltz}$</td>
<td>$74.5 \pm 2.5\mu m/\sqrt{\text{cm}}$</td>
<td>$94.8 \pm 3.1\mu m/\sqrt{\text{cm}}$</td>
</tr>
</tbody>
</table>

*Magboltz is a simulation tool to compute different gas transport parameters in gaseous detectors
There could be misalignment between the modules during installation.
The grounded peripheral frame of the module creates localized electric field distortion.

Alignment correction and Distortion correction are done during analysis.

Before and after Alignment correction

Before and after Distortion correction

Analysis is done in MarlinTPC framework.
Investigation of Track distortion by Numerical Methods

Simulation tool combines
Garfield + neBEM + Heed + Magboltz

Micromegas modules on the LPTPC endplate.

Module size: 17 cm × 22 cm. reference frame is in r-phi system.

The simulated Micromegas modules

Module size: 3.4 cm × 3.4 cm. reference frame is Cartesian.

Distribution of the residuals as obtained in Experiment without alignment correction.

Distribution of the residuals as obtained in Simulation

Pre-thesis seminar, Deb Sankar Bhattacharyya, 10 Dec 2015
B=1T, peaking time = 100 ns, E=230 V/cm, phi = 0

at 60 cm drift, r-phi resolution is below 150 µm for B = 1 T

at 60 cm drift, Z resolution is below 0.4 mm for B = 1 T

Fit formula: \[ \sigma = \sqrt{\sigma_0^2 + \frac{C_d^2 \cdot Z}{N_{eff}}} \]

\( \sigma_0 \) : the resolution at Z=0

\( N_{eff} \) : the effective number of electrons

In 1 Tesla magnetic field, for ~ 60 cm drift length, the space and time resolutions of Micromegas corresponds to ILC requirements over full drift length, for 3.5 T magnetic field
The positive ions created in the avalanche can flow back to the drift space, building up a charge density which affects the electron drift.

- Ion Backflow can affect the performance of a gaseous detector.
- In Micromegas, the backflow is intrinsically suppressed.

- The backflow fraction (IBF) is defined by: \( N_b/N_t \)
  where \( N_b \) is number of back flowing ions and \( N_t \) is the total ions produced.
- In experiment IBF is measured as: \( I_C/(I_M+I_C) \)
  where \( I_C \) is current on the drift cathode and \( I_M \) is the current on the micromesh.
- In simulation IBF is calculated as : \( N_b/N_t \).

Experimental setup for IBF measurement

Experimental and Simulation results
Heating of the electronics

- Each (Micromegas) electronic takes nearly 30 W of power.
- This increases the temperature of the detector up to 70 deg C
- Electronics can be damaged if it runs for hours without cooling
- Temperature gradient in TPC would occur if heat is not removed

Temperature gradient in ILD-TPC
Simulation with COMSOL

Drift velocity Vs Temperature
Simulation with Magboltz
Two-phase CO2 cooling during 2015 beam test

During cooling, temperature is below 28 deg C and stable within 0.2 deg C.

Micromegas electronics and cooling setup

Stable temperature during cooling
List of publications

- **Test of Micro-pattern Gaseous Detector modules with a large prototype Time Projection Chambers.**
  *Deb Sankar Bhattachary*,
  On behalf of LCTPC collaboration.

- **Investigation of ion backflow in bulk micromegas detectors.**
  P. Bhattacharya*,  *D. Sankar Bhattacharya*, S. Mukhopadhyay, S. Bhattacharya, and N. Majumdar.
  [2015 JINST 10 P09017]

- **Measurement and simulation of two-phase CO2 cooling in Micromegas modules for a Large Prototype of Time Projection Chamber.**
  *Deb Sankar Bhattachary*, David Attié, Paul Colas, Supratik Mukhopadhyay, Nayana Majumdar, Sudeb Bhattacharya, Sandip Sarkar, Aparajita Bhattacharya and Serguei Ganjour.
  [2015 JINST 10 P08001].

- **Test of a two-phase CO2 cooling system with a Micromegas modules.**
  *Deb Sankar Bhattachary*, Paul Colas, David Attié.
  [LC-DET-2014-005].

- In progress

- **Track Distortion in the Large Prototype of a Time Projection Chamber for the International Linear Collider.**
  *Deb Sankar Bhattachary*, Purba Bhattacharya, Supratik Mukhopadhyay, Nayana Majumdar, Sudeb Bhattacharya, Sandip Sarkar, Paul Colas, David Attie, Serguei Ganjour and Aparajita Bhattacharya.
  [Proceeding of ‘XXVII IUPAP Conference on Computational Physics 2015’, IIT Guwahati, Assam, India.]

- **Numerical Study of Electrostatic Field Distortion on LPTPC End-Plates based on Bulk Micromegas Modules.**
  Purba Bhattacharya*, *Deb Sankar Bhattachary*, Supratik Mukhopadhyay, Nayana Majumdar, Sudeb Bhattacharya, Paul Colas and David Attie.
  [Proceeding of ‘MPGD 2015, 12-17 October 2015’, Trieste – Italy]

- **Beam tests of single Micromegas TPC modules for the linear collider.**
I express my sincere gratitude to my supervisors, Dr. Paul Colas, Prof. Supratik Mukhopadhyay and Prof. Aparajita Bhattacharya.

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THANK YOU
Backup Slides
Normalised main pulse for BD and CLK

Charge per Cluster for CLK and BD modules at 200 ns peaking time of the electronics

Charge per Cluster in BD is slightly more than CLK. This is because, BD has slightly larger capacitance than CLK.

The pulse shape of both detectors are nearly same. DLC modules are good substitute for CLK.
Investigation on Track distortion by Numerical Methods

Simulated Micromegas modules

$E_x$, $E_y$ and $E_z$ components are plotted. Large values of $E_x$ and $E_y$ at the module edge explains electric field distortion.

Electrons are drifting at $B=0T$

Electrons are drifting at $B=1T$
Two-phase CO2 cooling

Experimental and simulation result for one MM module shows heating and cooling

Experimental result with one module
Shows the heating and cooling

Simulated result for one module
Shows heating and cooling
Two-phase CO2 cooling

simulated model (COMSOL) shows how cooling works