Toward the Final Design of a TPC for the ILD Detector

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on behalf of the D_RD_9 team
Micro Pattern Gas Detector readout TPC provides pictorial 3D tracking by $\sim200$ space points with $\sigma_{r\phi}\sim100$ μm and two-hit separation of $\sim2$mm.
Why MPGD Readout?

- We need high (>3 T) B field to confine $e^+e^-$ pair BG from beam-beam interactions, then ExB is too big for conventional MWPC readout.

- 2mm 2-track separation is difficult with MWPC readout.

- Thick frames are unavoidable for MWPC readout.

ExB spreads seed electrons along the sense wires, then avalanche fluctuation limits the spatial resolution!

**Micro-Pattern Gas Detectors**

- Micromegas
- GEM
- InGrid TimePix

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Pre-LCTPC group incl. the FJ team, together, excluded MWPC option with a small prototype TPC!
After the initial stage of R&D with many small TPC prototypes, we are left with three options of MPGD TPC readout technologies for ILC, being tested at the Large prototype (LP) TPC at DESY.

I. Analog (Pad) TPC: Subject to the gas gain fluctuation in the gas amplification. Need to spread the avalanche charge for charge centroid.

1. Multi layer GEM with the standard pad (~1x5mm²) readout:
   (charge spread by diffusion)
   Asian (KEK-Saga-Tsinghua) Module, DESY module

2. Micromrgas with the resistive-anode (pad: ~3x7mm²) readout:
   Saclay-Carleton Module

II. Digital (Pixel) TPC: Free from the gas gain fluctuation. Expect 20-30% improvement of position resolution in the case of digital readout. No angular pad effect. Theoretically the best but not yet ready for full implementation of a module.

3. InGrid Micromegas mesh on Timepix chips (pixel: ~50x50μm²)
   NIKHEF-Saclay Module, Bonn-module

→ being tested in Large Prototype at DESY
Large Prototype Test Beam Facility at DESY
LC TPC Collaboration

Field cage & Mechanics, Gas system (EUDET/DESY)

Magnet: PCMAG and its upgrade (KEK, EUDET/AIDA/DESY, CERN)

Endplate (Cornell)

Field cage & Mechanics, Gas system (EUDET/DESY)

DAQ & Monitoring (EUDET/DESY)

Test beam & Facility (@DESY-T24-1 since 2008)

Cathode Laser Calib. (Victoria)

Beam Trigger (NIKEFH)

Cosmic trigger (Saclay, KEK)

MPGD Detector Modules (DESY, KEK/Tsinghua, Saclay/NIKHEF, Bonn)

Two types of Readout Electronics (EUDET/AIDA/Lund/DESY, KEK, Saclay)

Si strip detector (EUDET/SiLC/DESY)

Common Software Tools (EUDET/AIDA, DESY, KEK, etc)

2PCO2 cooling system (KEK, DESY)

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Can house up-to 7 modules

PCMAG from KEK modified by Toshiba under the framework of DESY-KEK collaboration in JFY2011 to allow Liq.He-less operation

Being used for test beam experiments since June 2012

Large Prototype test beam

5GeV electron beam

Saclay Micromegas module with 1st prototype of compact electronics

Saclay-Cadeton MM modules

Asian GEM Modules

Pad plane PCB from China

Can house up-to 7 modules
Spatial Resolution

Asian GEM Module

\[ \sigma_{r\phi} = 100 \, \mu m \]

Saclay-Carleton MM Module

Extrapolation to B=3.5T

Both options seem to satisfy the \( \sigma_{r\phi} = 100 \mu m \) requirement!
Resolution Formula

Since TPC operates on the nice and old “gas physics”; ionization, diffusion, gas amplification and fluctuation, etc., it is possible for the GEM TPC (option (1)) to formulate a fully analytic expression of its spatial resolution to understand the LP TPC results, to optimize parameters of the GEM TPC, and to extrapolate them to the ILD TPC (R. Yonamine / KF)

\[ \sigma^2_x(z; w, L \tan \phi, C_d, N_{eff}, \hat{N}_{eff}, [f]) = [A] + \frac{1}{N_{eff}} [B] + [C] + \frac{1}{\hat{N}_{eff}} [D] \]

[A]: Hodoscope effect/S-shape at the short drift distances

\[ [A] := \int_{-1/2}^{+1/2} d \left( \frac{\bar{x}}{w} \right) \left( \sum_a (aw) \langle \left( F_a(\bar{x} + y \tan \phi + \Delta x) \right) \Delta x \rangle_y - \bar{x} \right)^2 \]

[B]: Diffusion + finite pad size term

\[ [B] := \int_{-1/2}^{+1/2} d \left( \frac{\bar{x}}{w} \right) \left( \sum_a (aw) F_a(\bar{x} + \Delta x) - \sum_a (aw) \langle F_a(\bar{x} + \Delta x) \rangle \Delta x \right)^2 \Delta x \approx [A]_{z=0} + \sigma_d^2 \]

[C]: Electronics noise

\[ [C] := \left( \frac{\sigma_G}{G} \right)^2 \left( \frac{1}{N^2} \right) \sum_a (aw)^2 \]

[D]: Angular pad effect

\[ [D] := \frac{L^2 \tan^2 \phi}{12} \]

[The constant term also scales as \(1/N_{eff}\)!]

\[ \sigma_{r\phi} \ll N_{eff} \]

\[ L=6.3 \,[\text{mm}] \]

Ar

\[ \psi=60^\circ \]
\[ \psi=30^\circ \]
\[ \psi=0 \]

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Tracking Codes for LP TPC and ILD TPC

Tracking Code (MarlinTrk): now fully C++

KEK developed Kalman Filter Package (KalTest)

- The continuous tracking in TPC is very robust against the backgrounds (including the micro curlers) at ILC reaching 100% tracking efficiency (> 1GeV/c) except the forward region
- A Kalman filter based tracking code for TPC at ILC has been developed (Li Bo/ KF), and implemented in the MarlinTPC code for the beam test data analysis as well as to the new MarlinReco for the ILD physics simulation

Despite the more realism (cracks, support structures, and service materials) brought in to the simulator,

PFA performance is now better than that of LoI!
ILD Detailed Baseline Design

Letter of Intent (2009)
~700 signatories
~120 from Japan

ILD DBD now completed in March 2013!
We are now entering the phase for the Final Engineering Design!
Entering New Phase
D_RD_9

ILD Detailed Baseline Design now completed!

We are now entering the phase for the Final Engineering Design!

In addition to further R&D towards engineering design of the GEM or MM module on each side, we need to work together on the following:

- Common tracking and analysis software R&D
- Gating Device
- 2-Phase CO2 Cooling
- Readout Electronics: Analog-Digital mixed chip for (semi-)surface mounting
Common Tracking and Analysis Software

to compare different technologies on the equal footing for eventual technology choice
Kalman Filter Based Track Fitting in Non-uniform B Field

arXiv: physics.ins-det/1305.7300

Basic idea of the algorithm

To use the helical track model of KalTest in the non-uniform magnetic field, we have to:
- assume the magnetic field between two nearby layers is uniform;
- transform the frame to make the $z$ axis point to the direction of magnetic field.

![Figure 1: The updated track propagation procedure.](image)

Therefore we now have a segment-wise helical track model.

Works in B field with >40% non-uniformity!
Ion Gate
Solved the Poisson equation for the simulated ion density distribution with proper boundary conditions and then estimated the distortion of drift electron trajectory by the Langevin equation (D. Arai and KF)

For the secondary ions from the amplification, we need an ion gate device for the ion feed back ratio of $>10^{-3}$ (measured both for the triple GEM and Micromegas) at the gas gain of 1,000.

The current options of the ion gate are limited:

- The traditional wire gate is expected to work, but introduces mechanical complications to the MPGD modules. We also need to check ExB effect.

- Thin GEM gate offers the electron transmission of only 50%@ 1T $\rightarrow$ 30% loss in the point resolution (Japanese LC TPC group).

- Try a larger geometric aperture with new fabrication method?
2P CO2 Cooling
R&D on Power Pulsing and Cooling

Test with Dummy Module
Comparison with simulation

Part side
Pad side

Cooling Channel R&D

TPG: Carbon (Momentive)
Thermal conductivity ~3 x that of Cu

Open 2-Phase CO2 Cooling System for detector cooling tests at KEK

2-PCO2 Cooling Circulation System at KEK

The two phase CO2 cooling system for the LC TPC R&D (Delivered at NIKHEF)

June, 2013
S-ALTRO 16 Development
as a Pre-advanced Stage

- Received back from foundry: Q1/2011.
- Characterization done

Reference: “S-ALTRO prototype” 27.07.2010
Gas detector Signal Processor?
Our path not yet totally clear (definitely need collaboration)

S-ALTRO 16 Power Pulsing Test

Next Step

S-ALTRO
- 756mW / chip if no power pulsing
- 28mW / chip if 5Hz power pulsing

Still too high!

Natural successor of S-ALTRO chip
- Very low power ADC: 4mW/ch, complete revision of other sections, too, for low power consumption.
- S-ALTRO → GdSP 64 → 128ch / chip?
- Optimized DSP
- Fully accommodates power pulsing
- Section-by-section power management
- Applications: CMS high-η, ILD-TPC, ...?
Summary
The France-Japan collaboration on the LCTPC R&D has clarified the basic principles to determine the spatial resolution through series of test beam experiments using a Large Prototype TPC and through development of an analytic resolution formula to understand their results, and demonstrated that both the GEM and the restive anode readout Micromegas modules meet the ILC’s \( \sigma_{r\phi} \) requirement.

In addition to further R&D for solving remaining issues towards the engineering design of the GEM or MM module on each side, we need to work together on the following common issues:

- Tracking and analysis software R&D,
- Gating Device,
- 2-Phase CO2 Cooling, and
- Readout Electronics: Analog-Digital mixed chip for (semi-)surface mounting.

The France-Japan team has been the driving force of the LC-TPC collaboration. This tradition should continue towards the final design of the Linear Collider TPC.
Backup
Performance Goals

**Momentum Resolution:** $\sigma(1/p_t) = 2 \times 10^{-5}$ (GeV$^{-1}$)

>200 sampling points along a track with a spatial resolution better than $\sigma_{r\phi} \sim 100$ $\mu$m over the full drift length of >2m in B=3.5T (recoil mass, $H \rightarrow \mu^+\mu^-$).

**High Efficiency:**

2-track separation better than $\sim$2mm to assure essentially 100% tracking efficiency for PFA in jetty events. High tracking efficiency also requires minimization of dead spaces near the boundaries of readout modules.

**Minimum material:**

for PFA calorimeters behind, also to facilitate extrapolation to the inner Si tracker and the vertex detector.