TPC for $e^+e^-$ Linear Collider and Limitations at High Luminosity
Outline

• Motivation and adaptation to the ILC machine
• R&D : integration and 2P CO2 cooling
• New scheme for Micromegas : encapsulation
• Recent results
• To gate or not to gate : ion space charge issue
• Ion backflow
Motivation

- Need to reconstruct complex multi-track events (jets) in a noisy environment: calls for high segmentation
- Also need to reconstruct very accurately high energy tracks from Z recoil to Higgs. This translates into $O(10 \, \mu m)$ control of the systematics on sagitta

- Silicon detectors give point measurement accuracy, but also introduce multiple scattering, while a TPC provides a continuous 3D track reconstruction with minimal matter: useful for V0, kinks, connecting to vertex tracker, other silicon trackers, and to calorimeter.
- Also a TPC has dE/dx capability, for K/π separation

$e^+e^- \rightarrow HZ, \ Z \rightarrow \mu\mu$
The LCTPC collaboration and the DESY test setup

All the TPC R&D is gathered. www.lctpc.org

The collaboration shares a test facility at the DESY T24 test beam (Field cage, magnet, endplate, cosmic-ray trigger, ancillaries)

Allows testing/comparing several technologies/ideas with cost-awareness
Technologies

Micromegas: Micromesh gaseous chamber

GEM: Gas Electron Multiplier
The DESY GridGEM Module

Design Goals

- Maximum sensitive area
- Minimal gaps
- Minimal material

Design Choices

- Integrated, self supporting GEM amplification structure
  - 3 GEM stack supported by thin ceramic grids
- Segmented readout anode:
  - ~5000 pads (1.26 × 5.85 mm²) in 28 rows
  - ~95% sensitive area
- Size and shape as planned for ILD TPC (~17 × 23 cm²)
- Custom ALTRO system as readout electronics
The Saclay Micromegas Module

Fully integrated electronics and cooling

PCB equipped with a RC continuous circuit covering the pads (insulator + resistive foil), to spread the charge, so that several pads are hit and a barycenter can be used to improve the resolution
Gridpix: ‘digital TPC’

Reconstruct every ionization electron with a high efficiency. Measure dE/dx by cluster counting.

Now uses Timepix 3 and chip protection against sparks has been improved.

18/01/2019
TPC for ILC and Limitations at High Lumi
QUAD design and realization

- Four-TimePix3 chips
- All services (signal IO, LV power) are located under the detection surface
- The area for connections was squeezed to the minimum
- Very high precision 10 μm mounting of the chips and guard
- QUAD has an sensitive area of 68.9%
- DAQ by SPIDR
- Tested in a beam in Bonn
CO2 has a large latent heat in vaporisation (1/4 H2O), a large specific heat, and a low viscosity.

At 50 bar the two-phase fluid is at almost 10°C, avoiding condensation. At 65 bar it can take out heat at room temperature.
2-phase CO2 cooling

• Pioneered at Nikhef and CERN, studied at KEK.
• KEK bought a compressor (« TRACI ») for ILC and Belle II, installed at DESY Test Beam T24.
• Tested in 2014 and 2015 with 7 independent modules with a distribution by a manifold (« clarinette »). 0.8 mm inner diameter pipe.
• This time (2018) tested with 4 modules in one loop. Very stable operation at 50 bar. 28-31°C on the FECS: continuous operation during 11 days without any incident.
Tests in 2014 and 2015 at DESY Test beam with 7 Micromegas modules

And tests were carried out in November 2018 with 1 loop 4-module circuit.
Monolithic cooling plate in 3D printing

Very easy way to manufacture complicated structures, including shapes like an integrated serpentine where no drilling tool can be used

However every layer must be almost totally supported

Material availability still reduced, but evolving

Being realized at Saclay within a R&D project on metallic additive manufacturing (COSTARD)
Could be tested in a future beam test

M. Riallot, Y. Jan
4 new Micromegas modules tested in November 2018 at DESY, with
- New ‘spaceframe’ endplate
- 1-loop 2-Phase CO2 cooling
- Improved mechanics : 99.9% good connections
- New scheme : encapsulated resistive anode
Encapsulated Resistive Anode Micromegas

New scheme, to **reduce distortions** at the edges of the modules: mesh at ground (same potential as the frame), and resistive anode at the +ve HV. Also encapsulation **reduces the EMI**. Another advantage: the amplification field can be tuned independently of the drift field, providing **flexibility**. The gains can be equalized while keeping the drift field very uniform.
Track distortions B= 1 T

- Including ExB

\[ \text{Ed} = 230 \text{V/cm} \]

Data selection:
- \# of tracks = 1,
- No saturated pulse

\[ \Delta = \text{Hit} - \text{track} \]

In 2015, \( z = 100 \text{ mm} \) has already big distortions.

Huge improvement (10 times) between the module boundary

ExB effect between modules is fully suppressed in the new scheme.
dE/dx resolution

Test beam results extrapolated to ILD
GEM data: 4.1% with 220 points (1.35 m track)
Micromegas data: 4.5 to 4.8% with 170 samples
(1.2 m track). MC expectation 4.3%.
- slight correlation between rows.

With pixel, resolution reaches 2.7% (MC 2.5%)
with a new algorithm
(distance between pixels)
Other highlights of 2018

• Resumed analysis meetings: dE/dx studies in 4 technologies, z resolution and 2-track separation, distortion studies.
• Re-started work on TPC Mechanics: static deformations under weight and pressure, new solution for TPC fastening
• Continued ILD integration studies, scheme to assemble and test the detector in Kitakami. Revision of the costing.
• Evaluation of the resources necessary in Kitakami: space and power.

HOPE FOR A GREEN LIGHT VERY SOON!
Space charge leads to an E-field in a the limited region of the drift space, thus with a transverse component. ExB is non-zero, causing distortion of the drift trajectory of the ionization electrons.

Quantitatively studied by Daisuke Arai and Keisuke Fujii (2012)
Result
Primary Ion

point resolution $100\mu m >$ Maximum distortion is $8.5\mu m$. Small!!
Secondary ions : Need for gating

In TPCs, ions are produced and migrate very slowly (1 m/s). They produce a charge density which can be one or two orders of magnitude above the primary ionization (IBF*Gain). The resulting electric field can be the origin of distortions.

At the ILC, the bunch trains last about 1ms every 200 ms, giving rise to ion disks slowly drifting to the cathode.
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After 2 disks, the electrons receive a kick of up to 60 µm, too much wrt the systematics.
primary ionisation

nothing to do except to collect ions « quickly » in order to decrease its density in the TPC
need to do more simulations (calculations) on the distortions induced by these ions

secondary ionisation

• probably impossible to collect secondary ions on the cathode before 200 ms
• do we need a gating device?
   if \( N_s \approx N_i \), may be not, except if the high density secondary ions slice is a problem,
   if \( N_s \) large, probably yes we have to gate secondary ions,
• simulations (and/or calculations/experiments) of the distortions induced on electron
  drift (with \( B \)) are needed,
• ion mobility measurements (or calculations) are probably needed for gate optimization
• more work and thinking on gating devices:
  a gate should be transparent to electrons,
  should not induce distortions and ExB effects
  should be optimized for a given gas mixture
Work on ion mobility measurement (André Cortez et al.)

Study of ions in ArCF4, ArC2H6, ArIsobutane, ArCF4Isobutane mixtures (and others), to predict the ion disk structure and time evolution.

This allows dimensioning the gap of the gating device: ~5 mm. (luminosity upgrade case included).

There are a few caveats: the measurements are at low pressure and there can be very slow ion clusters not seen in the measurement.
Feasibility of the Z pole running at ILC (GigaZ)

• The Lumi at 250 GeV ILC is $1.3 \times 10^{34} \text{ /cm}^2/\text{s}$
• At the Z it is $10^{33} \text{ /cm}^2/\text{s}$, i.e $10^{-} \text{ /fb/year}$
  • Z cross-section $\sim 30 \text{ nb} \rightarrow 3 \times 10^8 \text{ Z per year} \rightarrow \text{GigaZ}$
  • $30 \text{ Z/s} = 6 \text{ per train crossing. x30 tracks}$
• Gain x IBF $\sim 3$ (Gain 1000-1500, IBF 3permil-2permil)
• A TPC at GigaZ at ILC is basically feasible
• However at 100 or 1000 times the luminosity, ion feed back, and event primary ionisation, is a problem.
Feasibility of TPC at Z pole

- 600 Ion Disks induced from Z->qq events at 2E34cm$^{-2}$s$^{-1}$
- Voxel occupancy & Charge distortion from Ion Back Flow (IBF)
- Cooperation with CEA & LCTPC

Trajectory of Track & Primary Ion

Trajectory of the Back Flow Ions = Track Image formed by Back Flow Ion
Feasability of the Z pole running at CEPC (TeraZ)

At $2 \times 10^{34} \text{cm}^2\text{s}^{-1}$ (20 times ILC) it is still OK, but at 1000 times the lumi a TPC does not work anymore.

Conclusions from Manqi:

- Voxel occupancy $\sim (10^{-4} - 10^{-6})$ level, safe
- Safe for CEPC if the ion back flow be controlled to per mille level
- The charge distortion at ILD TPC would be one order of magnitude then the intrinsic resolution ($L = 2E34 \text{cm}^2\text{s}^{-1}$)
Ion backflow measurements

• This work was started in 2002

• Since then many applications:
  • ILC, CEPC
  • PANDA TPC (C. Höppner et al. TU Munich),
  • ALICE (see P. Gasik’s talk),
  • sPHENIX (S. Aune, H. Pereira et al.),

• and attempts to suppress ion backflow :
  • double meshes,
  • 4 GEMs,
  • 3GEMs with Micromegas...
PRINCIPLE OF THE MEASUREMENT OF Ion Back Flow

- The ion backflow fraction is given by:

\[ \text{IBF} = \frac{I_{\text{drift}}}{I_{\text{mesh}}} = \frac{I_1}{I_2} \]

- Determination of the primary ionisation from the drift current at low \( V_{\text{mesh}} \)

- Using equation (1) & (2) \( G \) is eliminated \( \rightarrow \) IBF

Caveats : if too much intensity of the gun is used, space charge affects the electric field and gives rise to underestimate of the backflow! See M. Ball et al, JINST 2013 (MPGD2013, Zaragoza)

Ion backflow studies for the ALICE TPC upgrade with GEMs

P. Colas et al., NIMA585(2004)226
• **IBF calculation:**

![Periodical structure](image1)

![Sum of gaussian diffusions](image2)

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Very difficult to go beyond field ratio limit
Calculation for a field ratio of 1000
Reach optimal IBF for
avalanche size/ pitch > 0.5

Measurements with Ingrids (integrated grids, same as for pixel detectors)

Measurements in progress at Saclay (sPHENIX)

S. Aune, H. Pereira et al., preliminary
CONCLUSIONS

• A lot of progress in R&D and integration for a TPC at ILC

• Space charge effects might introduce unacceptable distortions at the highest luminosities envisaged in future e+e- colliders
  • From primary ions at the highest lumi
  • From secondary ions if no gating is possible and if IBF cannot be further suppressed

• It is a challenge to go beyond the field ratio limit in IBF

LET US FACE IT!