Studies for the Linear Collider TPC at DESY/Hamburg University

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Outline

• The Linear Collider TPC

• TPC R&D in Hamburg: GEM readout

• GEM TPC Activities at KEK
Short Motivation for a LC

• Complementarity to the LHC
  • well defined initial state
  • precisely adjustable centre-of-mass energy
  • low background;
→ suitable for
  • precision measurements, e.g. mechanism of EW symmetry breaking, SUSY spectroscopy, and
  • the discovery of new phenomena, e.g. SUSY;

requirement: high luminosity (≈ 1000 x LEP)
→ high precision detector
DESY LC Proposal: TESLA

- based on superconducting technology
- energy range: 90 - 500 (800) GeV
- luminosity: $3.4 \cdot 10^{34}$ cm$^{-2}$ s$^{-1}$
- polarised beams
- several other running options: $\gamma \gamma$, $\gamma e$, $e^- e^-$, $(ep)$
The Detector Concept

- precise vertex detectors
- large tracking detectors
- high granularity calorimeter
- B = 4 T
- yoke
Physics Requirements

- Higgs searches
dilepton recoil mass for
$Z H$ events,
goal: $\delta M(\mu,\mu) < 0.1 \times \sigma(Z)$.

- high momentum res.
$\frac{\delta p_t}{p_t^2} = 5 \times 10^{-5} \text{ GeV}^{-1}$ (1/10 LEP)
Physics Requirements

• Searches for new particles
e.g. charged particles with different lifetimes in GMSB models:
  • highly ionising tr. \((t > 10 \times 10^{-6} \text{ s})\)
  • kinked tracks \((t > 10 \times 10^{-9} \text{ s})\)

impose

• large sensitive volume
• good dE/dx resolution \((\leq 5 \%)\)
• efficient pattern recognition
The TESLA TPC

General TPC properties

- 3 dim., unambiguous space points
- E and B parallel, no E x B effects

Specifications

- Gas: 93% Ar, 5% CH₄, 2% CO₂
- large volume:
  - L = 5.46 m,
  - d = 3.4 m.
- Field cage: 3% $X_0 \rightarrow$ calorimetry.
- $1.2 \times 10^6$ channels,
- 200 points per track $\rightarrow$ robust track finding, efficient pat.rec.

Envisaged precision:

- momentum resolution: $\delta p_t / p_t^2 = 1.5 \times 10^{-4}$ GeV$^{-1}$ (1/10 x LEP),
- single point resolution in r-$\phi \approx 100$ $\mu$m (ALEPH TPC: 200 - 400 $\mu$m),
- dE/dx resolution = 5 %.

R&D needed
**R&D Issue: Gas Amplification**

Conventional readout: WIRE CHAMBER

- Broad induction signal on pads
- Resolution limited due to $E \times B$ effects
- Large ion feedback without gating

New approach: MICRO PATTERN GAS DETECTORS

- Sharp electron signal on pads
- 2-D symmetry
- Intrinsically better resolution
- Natural suppression of ion feedback
Gas Electron Multiplier (GEM)

- 50 µm thick kapton
- coated with 5 µm layers of copper
- perforated (140 µm pitch, 70 µm hole diameter)
- voltage of several hundred volts applied between copper layers
- amplification within the holes
- gain up to $10^4$ for a single GEM feasible
- higher stability (at high gain) with multi-GEM-structure
Double GEM Module

Parameters
- gap sizes
- transfer field
- induction field
- GEM voltages

Voltage supply:
- a) one voltage divider for both GEMs
- b) preferable: decoupled voltage dividers
Tracking with GEMs

Drawbacks:

- Narrow electron signal is only collected on few pads.
- Calculation of the charge centre-of-gravity unprecise.

Possible Solutions:

- Smaller pads ... but: total number of readout channels increases
- Pixel readout
- Capacitive or resistive coupling of adjacent pads
- Alternative pad geometries
Increase charge sharing without increasing the total number of pads (TESLA TPC: 1 200 000)
TPC R&D Activities at DESY/Hamburg U

Determination of TPC properties with GEM readout using software simulation and measurements:

1) point resolution in magnetic fields up to 5 T
2) gain homogeneity
3) double track resolution
4) ion feedback
5) ...
Software Simulation Tool

Stand-alone Fortran program which includes

- simulation of the gas properties using MAGBOLTZ,
- simulation of the primary ionisation using HEED,
- Polya distribution for the description of the gas gain inside GEM holes.

Parameters in the presented study:

$E_{\text{ind}} = E_{\text{trans}} = 2 \text{ kV/cm}, E_{\text{drift}} = 230 \text{ V/cm}, \text{gain/GEM} = \sqrt{1000}, B = 4\text{T},$

pad size = 2mm x 6mm, chevrons: 4 'zig zags', number of pad rows = 21
Determination of the Point Resol.

- calculation of the center-of-gravity of charge clusters
- (linear) $\chi^2$-track fit

→ calculation of residuals:
Point Resolution

Simulation parameters:

- $B = 4$ T
- pad size = 2 mm x 6 mm
- gas: 93% Ar, 5% CH$_4$, 2% CO$_2$
Measurement: TPC Setup

Completed a new GEM-TPC prototype for resolution measurements in high magnetic fields last autumn.
Improved DAQ System

- based on ALEPH technology
- Switched from Mac to VME CPU
- full exploitation of TPD features (e.g. hardware based pedestal subtraction)
- some software optimisation still has to be done (e.g. zero suppression)
Measurements in 5 T Magnet

The Magnet:
- Superconducting magnet
- 5.3 T maximal field
- 28 cm aperture
- 187 cm cryostat length

The Chamber:
- 192 readout channels
- 6 x 2 mm readout pads
- Active area 5.28 x 4.96 cm$^2$
- Gas Ar-CH$_4$-CO$_2$ (93-5-2)
- cosmic muons
Two Events

0 Tesla ($\sigma_{\text{Diff}} = 3.9 \text{ mm} \approx 2 \text{ pads for 50 cm drift}$):

4 Tesla ($\sigma_{\text{Diff}} = 0.5 \text{ mm} = 0.25 \text{ pads for 50 cm drift}$):
Point Resolution in r-\(\phi\)

Large drift volume of prototype allows resolution measurements up to 70 cm drift distance

- resolution rises with drift length due to diffusion for 0 T and 1 T.
- at 4 T, even at 70 cm drift distance no rise in the resolution seen

Resolution achieved with first preliminary analysis:

\[ \approx 130 \, \mu m \] at 4 T

- more investigations needed to determine systematic effects
- more statistics for short drift lengths
Gain Homogeneity

→ Importance for dE/dx resolution (TDR goal: 5 %).

→ Measurement of gain homogeneity requires good calibration of each readout channel.

Calibration method

Split data sample into two sets:
• calibration set
• analysis set

Take calibration set and re-weight mean charge in each channel to be equal to the channel averaged charge
Gain Homogeneity

Before calibration:

Analysis set:

After calibration:

7% spread still contains statistical, thermal, ..., fluctuations
→ more work and data needed
**DESY Electron Test Beam**

**Motivation:**
- High statistics in short time
- Study field distortions systematically
- double track resolution (target)

- up to 6 GeV e⁻/e⁺ beam
- 0.75 T magnet
- trigger: 2 finger scintillators
  - silicon beam telescope
First Events

Status

• first data taking period finished
• data analysis just started
UV Laser System

The laser tests are carried out with our old large chamber.

Setup used to produce laser tracks in the TPC
Laser Tracks

30 cm drift length:

90 cm drift length:
Setup f. Laser Double Track Studies

- Mirror
- UV-filter plate
- Optical wedge
- Gallilean Telescope
- TPC, length 100 cm, diameter 38 cm
- CCD array
- UV-Laser
- Beam dump
- Trigger from Laser and coincidence with CCD array.

- d(1) = 5.5 cm distance from endplate
- d(2) = 30.5 cm
- d(3) = 95.5 cm

Markus Hamann
29 June 04, KEK, Tsukuba, Japan
A Laser Double Track Event

dead channel
Summary and Outlook

- Successful data taking with different TPC prototypes
  - cosmic muons in magnetic fields up to 5 T
  - electron test beam in fields up to 0.75 T
  - laser beam → two track resolution
  - measurement of ion feedback (not mentioned)

→ GEM (MPGD) readout promising for the linear collider TPC.

- Analysis of huge amount of data to be done, e.g. implementation of PRF into track fit, determination of double track resolution.

- More measurements planned, e.g. with different pad arrangements and geometries aiming $\sigma_{r\phi} = 100\mu$m.
GEM TPC Studies at KEK

Purpose

- compare basic chamber performances of MWPC and MPGD readout
  - spacial resolution
  - 2-track separation
  - dE/dx capability
- use the readout plane of the same TPC for MWPC and MPGD (GEM)
- comparison of data with simulation
- establish design procedure for a full scale MPGD TPC
GEM TPC Studies at KEK

International Collaboration

- GLC CDC Group
  Hiroshima, KEK, Kogakuin, Kinki, MSU, Saga, Tokyo, Tsukuba, TUAT

- MPI/DESY Group, Germany

- IPN Orsay Group, France
GEM TPC Studies at KEK

- Hadron beam measurements with MWPC readout from 16/June/04 until 01/July/04,
- O(100 000) evts. already recorded; data analysis started.

Event recorded at $p = 4$ GeV, $\pi^-$ trigger, $B=1T$. 

pads not being read out
GEM test for gLC/TPC @KEK
Sugiyama et al.

triple GEM
10 x 10 cm²
2 types
Japanese (CNS/Fuchigami)
CERN

Readout
MPI TPC pads (2 mm x 6 mm)
Belle CDC’s Pre/Post amplifier
ADC only (24 ch)

Signal from Fe 5.9 keV X-ray

Gain vs. HV

saturation due to amp.

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29 June 04, KEK, Tsukuba, Japan
Beam data

readout 6 pad-raws: 4 pads/raw

Charge distribution on pads @ raw 8

Xtrk → COG(9)

signal response fcn.

position ← COG of 4 pads
residual = COG(6) - 0.5*(COG(1) + COG(11))

σ = 0.344 mm

Very Preliminary
GEM TPC Studies at KEK

- Next: Careful and systematic data analysis and
- GEM installation in the TPC readout plane,
  - measurements with cosmic muons in magnet,
  - GEM measurements in hadron beam planned for spring 2005.