LC-TPC R&D
(Goals, Status, Plans)

DESY PRC 28.10.04
(and WWSOC review panel)

Ron Settles
MPI-Munich/DESY
for the LC TPC Groups
## LC TPC Groups

### Europe
- RWTH Aachen
- DESY
- U Hamburg
- U Karlsruhe
- UMM Krakow
- MPI-Munich
- NIKHEF
- BINP Novosibirsk
- LAL Orsay
- IPN Orsay
- U Rostock
- CEA Saclay
- PNPI StPetersburg

### America
- Carleton U
- LBNL
- MIT
- U Montreal
- U Victoria
Other active LC TPC Groups

Asian ILC gaseous-tracking groups
- Chiba U
- Hiroshima U
- Minadamo SU-IIT
- Kinki U
- U Osaka
- Saga U
- Tokyo UAT
- U Tokyo
- NRICP Tokyo
- Kogakuin U Tokyo
- KEK Tsukuba
- U Tsukuba

USA
- Chicago/Purdue
- Cornell (UCLC)
- MIT (LCRD)
- Temple/Wayne State (UCLC)
- Yale
HISTORY

A DECADE OF TRACKING STUDIES

1992: First discussions on detectors in Garmisch-Partenkirschen (LC92). Silicon? Gas?
5/2001: Kick-off of Detector R&D
11/2001: DESY PRC prop. for TPC (European & North American teams)

- Recommendations of 52nd Meeting of the DESY PRC 25-26 October 2001
  PRC R&D-01/03: LC TPC R&D
  The PRC recommends the approval of the proposed R&D programme. It encourages the collaboration to perform high magnetic-field tests of the different end-plate technologies (GEM, MICROMEGAS and standard wire chambers).

- Status Report given at DESY PRC meeting 07 May 2003
  The PRC congratulates the collaboration for the progress achieved in many areas of the project and looks forward to tests of large area prototypes of the three readout technologies in high magnetic field. The PRC recommends the continuation of the program and looks forward to a status report in Autumn 2004.
Goal

To design and build an ultra-high performance

Time Projection Chamber

...as central tracker for the ILC detector, where excellent vertex, momentum and jet-energy precision are required...
"Large" Detector example

- **Flavor tag** \( \delta(\text{IP}) \approx 5\mu m \oplus \frac{10 \mu m \text{ GeV/c}}{\rho \sin^{3/2} \theta} \)
- **Track momentum** \( \delta(1/p_t) \approx 6 \times 10^{-5} \text{ GeV/c}^{-1} \)
- **Particle Flow** \( \delta E/E \approx 0.30 / \sqrt{E} \)

Energy flow
- granularity
- hermeticity
- min. material inside calos
- calos inside 4 T coil
Physics determines detector design

★ momentum: \( d(1/p) \sim 10^{-4}/\text{GeV (TPC only)} \)
\( \sim 0.6 \times 10^{-4}/\text{GeV (w/vertex)} \)
\( (1/10 \times \text{LEP}) \)

\( e^{+}e^{-} \rightarrow \text{ZH} \rightarrow \mu\mu X \)
goal: \( \delta M_{\mu\mu} < 0.1 \times \Gamma_{Z} \)
\( \rightarrow \delta M_{HH} \) dominated by beamstrahlung

★ tracking efficiency: 98% (overall)

excellent and robust tracking efficiency by combining vertex detector and TPC, each with excellent tracking efficiency
Motivation/Goals

- Continuous tracking throughout large volume
- ~98% tracking efficiency in presence of backgrounds
- Minimum of $X_0$ inside Ecal (<3% barrel, <30% endcaps)
- $\sigma_{pt} \sim 100\mu m$ ($r_\phi$) and $\sim 500\mu m$ ($rz$) @ 4T for right gas if diffusion limited
- 2-track resolution <2mm ($r_\phi$) and <5mm ($rz$)
- $dE/dx$ resolution <5%
- Full precision/efficiency at 30 x estimated backgrounds
R&D program

• gain experience with MPGD-TPCs, compare with wires
• study charge transfer properties, minimize ion feedback
• measure performance with different B fields and gases
• find ways to achieve the desired precision
• investigate Si-readout techniques
• start electronics design for 1-2 million pads
• study design of thin field cage
• study design thin endplate: mechanics, electronics, cooling
• devise methods for robust performance in high backgrounds
• pursue software and simulation developments
OUTLINE

First, briefly,

- Gas-amplification systems
- Prototypes
- Facilities
- Overview a few activities which are still in early stages
  - Field cage
  - Electronics
  - Mechanics
  - Simulation

Then, PROTOTYPE RESULTS and PLANS...
**Gas-Amplification Systems:**

**GEM:** Two copper foils separated by kapton, multiplication takes place in holes, uses 2 or 3 stages

**Micromegas:** Micromesh sustained by 50µm pillars, multiplication between anode and mesh, one stage

- **GEM** - Two copper foils separated by kapton, multiplication takes place in holes, uses 2 or 3 stages.
- **Micromegas** - Micromesh sustained by 50µm pillars, multiplication between anode and mesh, one stage.

\[ S1/S2 \sim \frac{E_{\text{amplif}}}{E_{\text{drift}}} \]

\[ P \sim 140 \text{ µm} \]

\[ D \sim 60 \text{ µm} \]
Gas-Amplification Systems:
Possible manufacturers

GEM: --CERN
--Novogorod (Russia)
--Purdue + 3M (USA)
--other companies interested in Europe, Japan and USA

Micromegas: --CERN together with Saclay/Orsay on techniques for common manuf. of anode + pillars

![Graph](image)
Examples of Prototype TPCs

Carleton, Aachen, Desy (not shown) for B=0 studies

Desy, Victoria, Saclay (fit in 2-5T magnets)

Karlsruhe, MPI/Asia, Aachen built test TPCs for magnets (not shown). Other groups built small special-study chambers.
Facilities

- DESY 5T magnet, cosmics, laser
- Kek 1.2 T, 4 GeV test-beam
- DESY 1T, 6 GeV electron test-beam
- Saclay 2T magnet, cosmics
- CERN test-beam (not shown)
Field Cage Activities

- FC ideas tried in Desy test TPC
- Software calculations at Aachen demonstrate need for double-sided strips, test chamber built.
- St.Petersburg calculations of several FC configurations.
- Need to study Alice FC ideas.

• finally building and mounting finished
• fits in the 5 T magnet
• first tests ongoing

Copper strips:
width 2.3 mm
distance 0.5 mm
⇒ field with double-sided strips much better than with one-sided strips
Work on Electronics

Aleph and Star setups (3 of each) used for prototype work don’t take advantage of fast Gem/Mm signals from direct e-.

- Rostock working on TDC idea.

- Aachen studying highly integrated conventional approach.

- Nikhef developing “Si RO” concepts (next slide)
Electronics Development

Nikhef on CMOS readout techniques, joined by Saclay

~ 50 x 50 µm^2 CMOS pixel matrix + Micromegas or Gem
~ preamp, descr, thr.daq, 14-bit ctr, time-stamp logic / pixel
~ huge granularity(digital TPC), diffusion limited, sensitive to indiv. clusters for right gas
~ 1st tests with Micromegas + MediPix2 chip
→ more later…
Arrangements of detectors on the active area of the end cap (2/2)
Trapezoidal shapes assembled in Iris shape

Annotations: Pn is the type number of PADS boards or frames

12 sectors (30° each) as super modules are defined

- On each, 7 modules are fixed
- The sizes of detectors are varying from 180 to 420 mm

These arrangement seems to be the best as only 4 different PADS are necessary

Principle for a Super Module equipped with detector 1

- Detector 1 made of 8 mm of epoxy or sandwich
- Frame of the super module made of 10 mm epoxy reinforced with 15x40 mm carbon bar
- Carbon wheel with frames 28x100 mm

Deformation limit acceptability to define
Here is 20 μm / mbar of pressure

Complete wheel with 12 super modules
Much activity
Simulations to understand prototype results
Must recheck some issues now, like
- robustness against backgrounds and
- TPC design, overall performance
Work started in Aachen, Desy, Asia...
PROTOTYPE RESULTS

Presently mapping out parameter space: demonstration phase

Gas studies
- Drift velocity measurements
- Ion backdrift
- Track distortion studies

Point resolution
- Two-track resolution

Methods for improving resolution

Results from CMOS Pixel readout
Prototype Results

Gas studies

Choice of gas crucial
- Correlated to diffusion-limited resolution
- Drift field should not be too high
- Drift velocity should not be too low
- Hydrogen in quencher sensitive to neutron background

Studied, e.g. (many done, more underway):
- "TDR" Ar-CH4(5%)CO2(2%)
- P5,P10 Ar-CH4(5%,10%)
- Isobutane Ar-iC4H10(5%)
- CF4 Ar-CF4(2-10%)
- Helium-based

Simulations will be useful since they have been checked (next slide)
Prototype Results

Gas studies

Encouraging cross-checks to Magboltz simulation
Karlsruhe group (earlier by Saclay and others also):

- TDR gas
- Magboltz simulation
- Experimental data

- P10
- Magboltz simulation Ar-CH$_4$ 90-10
- Measurement Ar-CH$_4$ 90-10
Prototype Results

Gas studies: ion backdrift

Should be as small as possible to reduce ion buildup in gas-amplification region and possible ion leaking into drift volume.

Micromegas

X-ray source

Gas studies: ion backdrift

Micromegas 1500 lpi, gap 100μm

3GEM+PCB

ΔV_D=ΔV_GEM

He 1 atm

He 5 atm

He 10 atm

Ar/CF_4(90/10) 1 atm

E_D=0.5 kV/cm

Ar/CF_4(90/10) 1 atm

Gain

Ion feedback: I_C/I_A
Prototype Results

Ion backdrift optimization

Aachen study for GEMs

Minimal ion backdrift can be achieved with:

- $E_{\text{Drift}}$ fixed at 240 V/cm
- $U_{\text{GEM1}}$ small influence
- $E_{T1}$ maximal
- $U_{\text{GEM2}}$ small influence
- $E_{T2}$ minimal
- $U_{\text{GEM3}}$ maximal
- $E_{\text{Ind}}$ maximal

$U_{\text{GEM1}}$ and $U_{\text{GEM2}}$ allow variation of effective gain without changing ID.

- With optimization, rel. ion backdrift $\sim 2.5\%$ indep. of gain
- Even with $10^5$ more charge-density than expected, optimization dramatic

Prediction from parametrisation:
IB independent of $G_{\text{eff}}$

- Lower $G_{\text{eff}}$ yields lower backdrifting charge $Q_{\text{IB}}$
- For $G_{\text{eff}} = 1000$: $Q_{\text{IB}} \approx 2.5 Q_{\text{primary}}$
- Still an open question: How much ion backdrift can be tolerated?

$B = 4 \, T$, measured at DESY

28/10/2004
Prototype Results

Point resolution, Wires

-- Measured by Asia/MPI/Desy teams in MPI wire chamber and KEK magnet at KEK test beam (1-4 GeV hadrons with PID), B=0&1T, TDR gas

-- 2x6mm^2 pads, 1mm wire-to-pad gap

-- PRF width measured to be = 1.43mm

-- Point resolution measured by fitting track to outer 6 rows and comparing track to hit on innermost 7th row. This method is known to overestimate the resolution (better method being implemented—see next slides)
Prototype Results

Point resolution, Micromegas

--- Ageing negligible
--- Diffusion measurements $\Rightarrow$ $\sigma_{pt} < 100\mu$m possible
--- At moment only achieved for short drift (intrinsic $\sigma$) for gain~5000 (350V mesh), noise~1000e
--- Analysis continuing...
Prototype Results

Point resolution, Gem

--Two examples of $\sigma_{pt}$ measured for Gems and 2x6mm^2 pads.

--In Desy chamber (triple Gem), method of fitting track without one padrow whose hit is compared with track (overestimate of $\sigma_{pt}$).

--In Victoria chamber (double Gem), unbiased method used: track fit twice, with and without padrow in question, $\sigma$ determined for each case; geometric mean of the two $\sigma$'s gives the correct result.

--In general (also for Micromegas) the resolution is not as good as simulations expect; we are searching for why (electronics, noise, method).
Prototype Results

**Improving point resolution with resistive foil**

Carleton work. Charge dispersion via resistive foil improves resolution: for $B=0$
Medipix2+Micromegas: results

--Single-electron sensitivity demonstrated: Fe55 source, open30s/close, He/20%Isobut., threshold=3000e, gain=19K (-470V Mmegas), -1kV drift

--Measure diffusion const.~ 220µm/√cm, N_cluster~0.52/mm, in reasonable agreement with simulation

--Future: develop "TimePixGrid" prototype by Nikhef/Saclay/et.al. for TPC application
Prototype Results

Two-track resolution studies

Laser optics

Studies just starting.
Victoria steering mechanics, Desy laser and 5T magnet.

σ_point for cosmics ~ laser ~ 80µm
2-track resol. for lasers ~ 1-2mm:
how the resolution on one track is affected by presence of a nearby parallel track at same drift dist.
Prototype Results

Operational experience

- No systematic statistics yet
- Several groups have had problems with sparking (with both Gems and Micromegas)
- But it is too early to take this seriously (I had similar problems with Aleph)
- Needs systematic study (to avoid an msgc-type problem)
**Other activities:**

<table>
<thead>
<tr>
<th>Institution</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIT</td>
<td>Lorentz-angle meas., Gas studies, Gem resolution/manufacturing</td>
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<tr>
<td>Cornell</td>
<td>Simulation of pad size, resolution needed</td>
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<tr>
<td>Purdue</td>
<td>Gem manufacture together with 3M company</td>
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<tr>
<td>Cornell/Purdue</td>
<td>Manufacture of prototype for studies</td>
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General Happenings...

Steering group takes care of workshop/conference talks, phone/video meetings, contact with other labs, etc.

Video, VRVS/phone TPC R&D meetings every few months

Task-sharing among groups is very fruitful and productive, e.g.

--LBNL providing Star electronics for Canadian, French, German labs
--MPI providing Aleph electronics for Asian, Canadian, German labs
--DESY 5T magnet to be used by Canadian and German groups
--Saclay 2T magnet to be used by North American and French groups
--Test beams in DESY and KEK being used by Asian, Canadian, German labs
--MicroMEGAS work by Canadian, French and US groups
--GEM projects by Canadian, German, Russian and US groups
--Fieldcage studies started in Russia and Germany
--Electronics work in Canada, Germany, Holland, France
--Endplate mechanics/cooling studied by German, French groups
Plans

1) Demonstration phase
   - Continue work for ~1 year with small prototypes on mapping out parameter space, understanding resolution, etc, to prove feasibility of an MPGD TPC. For Si-based ideas this will include a basic proof-of-principle.

2) Consolidation phase
   - Build and operate “large” prototype (Ø ≥ 70cm, drift ≥ 50cm) which allows any MPGD technology, to test manufacturing techniques for MPGD endplates, fieldcage and electronics. Design work would start in ~1/2 year, building and testing another ~ 2 years.

3) Design phase
   - After phase 2, the decision as to which endplate technology to use for the LC TPC would be taken and final design started.
Summary

• Experience with MSGCs being gathered rapidly
• Gas properties rather well understood
• Diffusion-limited resolution seems feasible
• Resistive foil charge-spreading demonstrated
• CMOS RO demonstrated
• Design work starting

Requests

• Continued support of PRC
• Positive recommendations to funding agencies
• PRC support for globalization of R&D
• Test beam facilities for next 3 years
TPC milestones

2005  Continue testing, design large prototype
2006-2007  Test large prototype, decide technology
2008  Proposal of/final design of LC TPC
2012  Four years for construction
2013  Commission TPC alone
2014  Install/integrate in detector