LC-TPC Design Requirements

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Considerations that are going into developing a Time Projection Chamber design for future e^+e^- Linear Colliders are presented. Physics and detector design requirements are outlined, estimates of the expected LC–TPC performance and a conceptual design are given. New developments in Micropattern Gas Detectors and innovations realized in the STAR–TPC detector allow for significant improvements over previous e^+e^- TPC detectors.

1. Introduction

The international e^+e^- community hopes to get approval to build a Linear Collider in the coming years. A low-mass, highly-segmentated Time Projection Chamber (TPC) is central to the design of both the European and American detector study groups.

In an e^+e^- Linear Collider environment, a large volume Time Projection Chamber (TPC) would provide multiple precision measurements of all of charged tracks in an event, with good overall particle identification. Operating in a high magnetic field, the TPC would provide excellent track momentum and angle resolution for all tracks down to small production angles. The high precision momentum resolution and accurate pattern recognition for matching hits in inner tracking detectors would allow precise decay vertex point determination for quark tagging when used in conjunction with high precision vertex detector information. The true three-dimensional space point information would provide exceptional pattern recognition capabilities to insure high tracking efficiency, secondary vertex detection, and to allow the possibility of recognizing and isolating unwanted tracks from background processes or from secondary interactions in the detector. Combining the tracking information obtained from a low-mass TPC with high-resolution, multiple-sampling calorimetry in a Linear Collider detector would enable accurate jet energy determination through energy-flow techniques.

In this paper the physics requirements for a Linear Collider detector, and the performance requirements and design goals for a Time Projection Chamber for use in a Linear Collider environment are described. A conceptual design for the TPC is outlined, and some R&D plans are discussed. A new result arising from these studies on position measurement using induced anode pad signals is previewed.

2. Design Requirements

Investigation of the mechanism for Electro-Weak symmetry breaking, and measurement of the complete decay spectrum of the Higgs, if it exists, are the central objectives of the Linear Collider physics program. The "Higgsstrahlung" process, $e^+e^- \to Z + \text{Higgs}$, allows unbiased determinations of the Higgs mass, its production cross section and decay modes. Excellent momentum resolution is required to obtain a clean selection of leptonic Z decay events. In optimizing the design, the reconstructed Z mass resolution is required to be comparable to its natural width.

In high-energy e^+e^- annihilation, most final states involve high-mass particles, such as the W, Z, top and Higgs, decaying into quark and gluon jets. Precise measurement of individual jets demands a complete reconstruction of all the charged tracks and neutral calorimeter clusters

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Table I Expected Linear Collider TPC performance.

Number of points / track	up to 200–250 clusters
Point resolution	100–140 μm ($r-\phi$)
	~ 1 mm (z)
Double hit separation	2–3 mm ($r-\phi$)
	~ 1 cm (z)
Momentum resolution (TPC only)	$\sigma_{p_t}/p_t^2 \sim 2 \times 10^{-4}$ GeV^{-1}
dE/dx resolution	4–5%

in events, thus requiring three-dimensional points and excellent pattern recognition in both the tracking and calorimeter systems. In the search for kinks from decays of long-lived particles, e.g. $\tilde{\mu} \to \mu +$gluino, a detector with continous tracking provides excellent secondary vertex reconstruction. For Higgs mass reconstruction in multi-jet final states, excellent jet energy determination is required. A low mass construction of the tracking system improves the neutral energy determination from the calorimetry. Particle identification is important in reconstructing heavy flavour particles, or tagging heavy quark jets. It might be critical in the search for new heavy charged stable particles, and it provides another handle in reducing the effects of backgrounds.

To meet the above physics requirements, a Time Projection Chamber is being considered to provide true three-dimensional (3D) space points and continous tracking for excellent secondary vertex reconstruction. The 3D points and high redundancy of the TPC tracking system allows excellent pattern recognition efficiency to be obtained, even in the presence of high backgrounds. Fine two track separation limits the number of missed points on a track, and minimizes the number of missed and mismeasured tracks. A low mass construction of the TPC would allow good neutral energy determination in the outer calorimeters. A TPC would provide many high-precision measurements for precise momentum determination, and excellent dE/dx particle identification capability.

3. Expected LC-TPC Performance

The expected performance of a Linear Collider TPC is summarized in Table I. To minimize drift distortions, the electric and magnetic fields in the TPC are required to be highly uniform, and little or no positive ion feedback is allowed in electron amplification. Both conventional multiwire proportional chamber (MWPC) and new Micropattern Gas Detector (MPGD) endplane readout options are being considered. The use of GEM or MicroMEGAS technologies would eliminate $\vec{E} \times \vec{B}$ and track angle effects in the endplane position measurement, and are expected to improve the point resolution to 60–75 μm ($r-\phi$). The small transverse diffusion for TPC operation in a high 3–4 T magnetic field requires very narrow segmented pads and large total channel counts. New TPC readout schemes are being considered, Sec. 5, to spread the electron signal and reduce the channel count, and new high-density front end electronics are being designed. Good TPC track timing resolution is obtained, for drift velocities of 50–100 μm/nsec, by requiring individual charged tracks to point back to a reconstructed vertex in the ($r-z$) plane. The expected particle identification will allow π/K separation over the full momentum range for hadrons in multi-jet final states, and help in heavy flavour reconstruction.

4. Conceptual LC-TPC Design

In simulations and design studies to date, a large volume cylindrical TPC with an outer radius of 170–200 cm and half-length of 250–290 cm within a 3–4 T axial magnetic field is being considered. An inner TPC tracking radius of 30–50 cm is taken to allow precision small angle tracking in the combined TPC and forward Silicon disk system. Figure 1 displays a computer generated rotated view of the central section of the North American Large detector, showing the Time Projection Chamber, forward Silicon disks and the inner Vertex Detector.

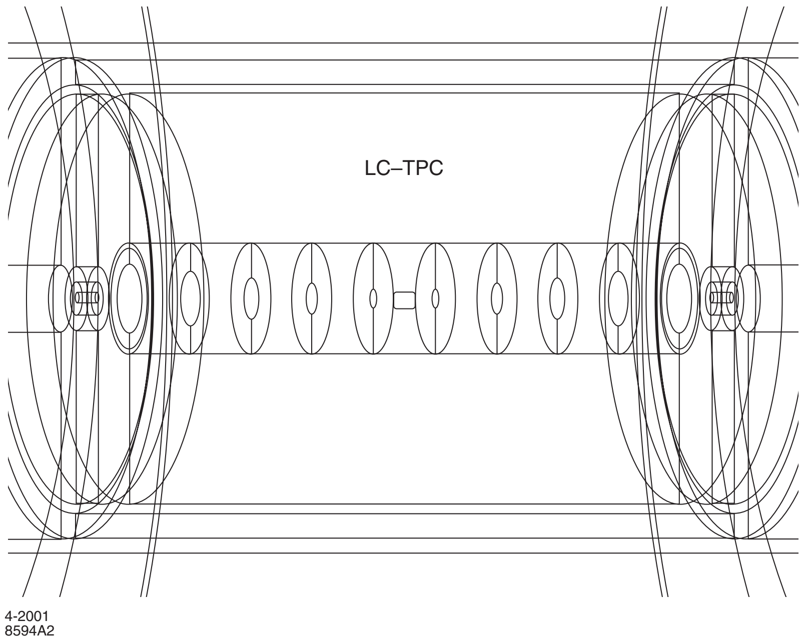

Figure 1: A WIRED 3D display of the Large LCD detector being simulated in the North American design studies.

To obtain high redundancy tracking and good dE/dx sampling, a highly-segmentated endplane readout scheme with as many as 200-250 precision point measurements per track is chosen. The endplane readout system is considered to occupy less than 20 cm in longitudinal space beyond the end of the active TPC drift space, and to be of low mass construction to optimize endcap jet energy determination.

In the barrel region, the material used to construct a TPC will be minimized (hopefully to ≤2-3% X_0) using thin inner and outer field cages and gas insulators pioneered by the STAR-TPC [1]. The use of Micropattern Gas Detectors would allow a reduction of support material in endplane construction. New low-mass high density readout electronics based on sub-micron technologies will allow a further reduction in the endcap material.

New object-oriented (OO) reconstruction software is being developed for simple and efficient tracking with the high redundancy pattern recognition provided by the TPC. The continuous tracking will be of help in identifying secondaries and decay kinks.

5. TPC R&D Plans

An international TPC R&D effort [4] is being organized to study readout options. New TPC readout possibilities offered by MPGD's, such as GEM and MicroMEGAS, are being considered. Several ideas are being pursued to reduce the channel count by spreading the electron signal after amplification.

6. Concluding Remarks

Extensive physics simulation and detector design studies performed by many different groups have been presented in international Linear Collider workshops, e.g. Ref. [2]. The European e^+e^- community has chosen the Time Projection Chamber technology for their reference design [3]. An updated Large detector design based on a TPC is being prepared for Snowmass studies in the U.S. With the advent of Micropattern Gas Detectors, the possibility of significant improvements in TPC performance is leading to interesting new gaseous detector research.

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References

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