LC-TPC R&D*

Ron Settles†
MPI für Physik, Munich Germany
Mike Ronan‡
LBNL, University of California, Berkeley CA USA
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R&D plans are presented for developing a high performance Time Projection Chamber (TPC) central tracking detector for an e^+e^- linear collider (LC) detector. The LC-TPC must perform much better than those at PEP, Tristran or LEP because of the higher $\sqrt{s}$, more complex topologies and higher backgrounds. The goal is to increase by an order of magnitude or more the TPC granularity and accuracy, and to make it of lower mass and to be more robust against backgrounds.

1. Introduction

The detector for TESLA is described in Part III of the TDR[1]. Design issues for a Linear Collider TPC are outlined separately [2]. Some general arguments for choosing a TPC as main tracker are enumerated first: Tracks can be measured with a large number of $(r\phi,z)$ space points, so that the tracking efficiency remains close to 100% for high multiplicity jets and in presence of high backgrounds. A gaseous TPC presents a minimum of material to the $\sim 2 \times 10^3$ beamstrahlung photons per bunch crossing which traverse the detector: $\sim 3\%$ X_0 in the barrel region for the inner field cage plus chamber gas out to 1.6 m radius. The comparatively moderate σ_{point} and double-hit resolution are compensated by the large volume which can be filled with many point measurements. TPC timing is precise to about 2 ns (50 μm/ns drift speed of tracks hooked up to the Vertex Detector) so that tracks from different bunch crossings can easily be distinguished. A TPC is well suited for a large magnetic field since the electrons drift parallel to $\vec{B}$, which in turn improves the two-hit resolution by compressing the transverse diffusion of the drifting electrons ($\text{FWHM}_T \le 2$ mm for P-10 gas and 4 T field). High efficiency for non-pointing tracks, e.g. for V^0 detection, is a valuable addition to the energy-flow measurement. The TPC gives good dE/dx particle identification, also important for the energy-flow algorithm and analyses.

There are two drawbacks which can be compensated for by proper design work after our R&D programme. First, the readout endplanes and electronics present a fair amount of material to the interaction products in the forward direction: the goal is to keep this below 30% X_0. Second, its $\sim 50\mu$s memory time integrates over backgrounds from, for example, 150 TESLA bunch crossings at 500 GeV. This is being compensated by striving for the finest possible granularity: the sensitive volume will consist of at least $\sim 1.5 \times 10^6$ pads $\times$ 10^3 time buckets per pad, giving more than 10^9 3D-electronic readout pixels (voxels). Good events can then be reconstructed in the 'salt and pepper' backgrounds, which are expected to yield $< 1\%$ occupancy[4].

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†settles@mppmu.mpg.de
‡ronan@lbl.gov

Table I TPC parameters in the TESLA TDR.

Mechanical radii	320 mm inner, 1700 mm outer
Overall length	2×2730 mm
Radii of sensitive volume	386 mm inner, 1626 mm outer
Length of sensitve volume	2×2500mm
Weight	~ 4 t
Gas volume	38 m^3
TPC material goals	0.03 X_0 to outer field cage (in r)
	0.30 X_0 for readout endcaps (in z)

2. Overall design

The overall performance must be significantly better than for previous TPC's. Systematic effects in the TPC track reconstruction must be kept to $< 10\ \mu$m in order to guarantee the momentum precision $\frac{\delta p_t}{{p_t}^2} \sim 1.5 \cdot 10^{-4}$/GeV/c (TPC only) and $\frac{\delta p_t}{{p_t}^2} \sim 5 \cdot 10^{-5}$/GeV/c (overall). The amount of dead material in the TPC should also be minimized to not compromise the capabilities of the calorimeter. The system requires a new scheme of gating to be robust against space-charge buildup. The TPC for TESLA is outlined in Table I.

3. The R&D Issues and Group Interests (Table II)

3.1. Readout Technology

A.1 Gas Amplification. The advent of Gas Electron Multiplier [5] and MicroMEGAS [6] technologies gives attractive candidates for the readout planes. The electrons amplified by GEM or MicroMEGAS are detected directly by the pads, whereas in wire chamber end-planes up to now the pads see induced signals from electrons amplified at the wires. This induced signal is broader than the arriving electron cloud and thus compromises the two-hit resolution as well as the overall granularity of the TPC. However in TPC's to date wire planes have performed extremely well, and the GEM's or MicroMEGAS have to demonstrate that they can do as well or better. A wire-plane version is considered as backup for the TESLA detector.

A.2 Gating, Distortions. The new techniques cited in the preceeding section promise to have reduced ion feedback from the amplification into the drift region. The measurement of the ion feedback is thus an important part of the R&D studies. In order to guarantee robustness of operation in presence of backgrounds, this work should also include the design of a gating plane with the goal of eliminating the ion feedback altogether. If it is possible to 'cancel the gain' with regards to positive ion formation, then the only ion distortions to correct are those created by the primary ionisation, which are estimated to be small [1]. All residual distortions causing measurable systematics must be corrected (see section E on calibration).

A.3 Magnetic field. Clearly any option must work in a $\vec{B}$ field, which several labs can test.

3.2. Gas, Field Cage

The choice of gas influences strongly the design of the fieldcage, the two-hit resolution and the sensitivity to backgrounds. In the TDR gases considered were Argon with quenchers of CH_4 or a mixture of CO_2+CH_4, while in the CDR [3] also CF_4 as quencher was cited. The latter has the advantage of a factor two higher drift velocity, but the disadvantage that it is mildly electronegative and aggressive. All of these gas options must be R&D'ed using both prototypes and simulations, also in the GEM and MicroMEGAS environments.

Table II LC-TPC R&D issues and interests of the groups. In column 2, the symbols stand for G = GEM, M = MicroMEGAS, W = Wire chamber. The readout prototyping involves understanding operating voltages, performance (also in $\vec{B}$-field), ion feedback and manufacture.

	Readout	Gases	Pad Shape	Electronics	Mechanics	Calibration	Sim.& Softw.
See subsection→	A	B	C	D	E	E	
Aachen	WG		×				×
Carleton	GM		×	×			×
DESY/Hamburg	G	×	×		×	×	×
Karlsruhe	G	×					
Krakow		×					
LBNL	GMW		×	×	×	×	×
Orsay/Saclay	M	×	×	×	×	×	×
MIT	GW	×					×
NIKHEF	G/Si			×		×	×
Novosibirsk	G	×					
Rostock				×			
MPI-Munich	GMW	×	×	×	×	×	

3.3. Pad Structure

The pad shape affects the R&D issues of two-track resolution, σ_{point} accuracy and dE/dx resolution, all of which have to be optimised. As often pointed out in the case of GEM or MicroMEGAS, if all of the electrons from an arriving cloud hit a single pad, the σ_{point} is degraded compared to that where the electrons are collected by several pads and their signals averaged. Electron clouds drifting over long stretches should be spread enough by diffusion to guarantee that multiple pads are hit. However for short drift distances this may no longer be the case. Thus a good technique for "spreading the charge" must be found such that at least two pads are always hit per ionisation deposit. Ideas being proposed which later must be verified in the prototype studies are: chevron pads [1], where the charge is not really spread but the pad shape is used to divide the charge between two or more pads; induction signal on neighboring pads [1], where very fast sampling of the signal induced on neighboring pads with the Analog-Transient-Waveform-Digitizer (ATWD) chip [8] is used for the coordinate determination; conductive glass to spread the charge; thin pads and a resistive coating on the pad plane for charge division; and reading out every other finely spaced pad using capacitative coupling to the readout pads.

3.4. Electronics

$r-\phi$. Of order $1.5 \cdot 10^6$ pads are needed to allow up to ~ 200 space points and dE/dx samples to be measured per track. This corresponds to a density of electronics which is an order of magnitude larger than for STAR [7] (and 30 more than at LEP) as is thus a challenge in anybody's book. The higher density is hoped to be achieved using 0.25μm (or smaller) trace technology (STAR has 1.2μm) and new methods for integrating the electronics.

z. The ultimate two-hit resolution in the drift direction is limited by the diffusion of the drifting electrons, but for past TPCs the z-granularity due to pulse-shaping and the digitizing speed was much coarser than that of the electron diffusion. Thus from the TDR [1], sampling frequencies ranging from 20 MHz (STAR-type [7]) to more than 100 MHz (ATWD-type [8]) are being considered.

3.5. Cooling, Mechanics, Calibration, Alignment

Cooling. Cooling of the on-detector electronics is always a major design task, and to simplify the cooling of the large number of electronic channels, the TPC can profit from the LC mode of operation by ramping off the electronics between bunch trains. The electronics must be designed to include this function from the beginning. Even with this advantage the design of a 'thin' (in radiation lengths) cooling will be challenging and must be addressed from the beginning.

Mechanics. The goals of 3% X_0 in r and 30% X_0 in z are also major challenges, especially the latter in light of large pad-electronic density. Another challenge arises from the need to roll back the TPC in order to get at the inner detectors during maintainence. One should start developing solutions to these problems early in order that the final TPC can be built on a reasonable time scale.

Calibration, Alignment. The LEP experience shows that event tracks are the best tool for correcting distortions, and that inner Si layers just inside the TPC bore and a measured point outside the TPC are likewise valuable tools for mapping and monitoring the corrections. The techniques need continuing study.

References

[1] TESLA Technical Design Report, DESY 2001-011, ECFA 2001-209, March 2001.
[2] M. Ronan and R. Settles, "LC-TPC Design Requirements", in these proceedings.
[3] TESLA Conceptual Design Report, DESY 1997-048, ECFA 1997-182, May 1997.
[4] C.Hensel, Beam Induced Background at a TESLA Detector, LC-DET-2001-001.
[5] F.Sauli, GEM:A New Concept for Electron Amplification in Gas Detectors, Nucl.Instrum.Meth. A386(1997)531.
[6] Y.Giomataris et al, Micromegas: A High Granularity Position Sensitive Gaseous Detector for High Particle Flux Environments, Nucl.Instrum.Meth. A376(1996)29.
[7] STAR-Collaboration: K.H. Ackermann et al., The Star Time Projection Chamber, Nucl.Phys. A661(1999)681.
[8] `http://obsidian.lbl.gov/~ronan/talks/LCTPC/TPC_FastSampling.html`