DESY-PRC R&D 01/03
October 4, 2001

LC TPC R&D
A Proposal to the DESY PRC

The LC TPC group

Aachen, LBNL, Carleton/Montreal, DESY/Hamburg, Karlsruhe, Kraków, MIT, MPI-Munich, NIKHEF, Novosibirsk, Orsay/Saclay, Rostock

Abstract

A Time Projection Chamber is foreseen as central tracker for a detector at the linear collider TESLA, and is being studied also for other proposals of linear electron-positron colliders. The LC TPC has to face significantly more complicated topologies and higher backgrounds than at previous e^+e^- machines, which puts stringent requirements on the overall system design. In the present document the design issues and R&D plans are presented for developing such a high-performance TPC. Particular emphasis is put on the R&D for a new type of gas-amplification system, based on micro-pattern gas chambers.

Authors

M. Killenberg, S. Lotze, J. Mnich, S. Roth, R. Schulte, B Sobloher, W. Struczinski and M. Tonutti
RWTH Aachen Germany

F. Bieser, W. Edwards, D. Nygren, M. Ronan and H. Wieman
LBNL, University of California, Berkeley CA USA

R.C. Carnegie, M. Dixit, J. Dubeau, D. Karlen and H. Mes
Carleton University, Ottawa Canada

J.-P. Martin
University of Montreal, Montreal Canada

T. Behnke, M. Hamann, K. Harder, T. Kuhl and M. Schumacher
DESY, Hamburg Germany

R.-D. Heuer and T. Lux
Universität Hamburg Germany

J. Kaminski, S. Kappler and T. Müller
Universität Karlsruhe Germany

E. Rulikowska
University of Mining and Metallurgy, Kraków Poland

U. Becker, P. Fisher, S. Mtingwa, C. Paus, F. Taylor and R. Yammamoto
MIT, Cambridge MA USA

V. Eckardt and R. Settles
MPI für Physik, Munich Germany

H. van der Graaf and J. Timmermans
NIKHEF, Amsterdam Netherlands

A. Bondar, A. Buzulutskov, L. Shekhtman, A. Sokolov and A. Vasiljev
Budker Institute of Nuclear Physics, Novosibirsk Russia

R. Cizeron, J. Jeanjean and V. Lepeltier
LAL, IN2P3 and Université de Paris-Sud, Orsay France

B. Genolini, J. Peyré and J. Pouthas
IPN, IN2P3 and Université de Paris-Sud, Orsay France

P. Colas, A. Delbart, Y. Giomataris and P. Rebourgeard
DAPNIA-CEA, Saclay France

A. Kaoukher, H. Schröder, R. Zimmermann
Physikalisches Institut der Universität Rostock, Rostock, Germany

1 Introduction

The detector for TESLA is described in Part III of the TDR [1]. A central part of the tracking system is a large volume time projection chamber (TPC). In this proposal the steps for developing this TPC are discussed, and a program of research is outlined to solve the open questions. The goal of the proposal is to demonstrate within approximately three years the feasibility of a TPC for TESLA via a realistic prototype module, and to be ready to start the final engineering design, should a TPC be chosen as the central tracker for a linear collider of the next generation.

Some general arguments for a TPC as main tracker are repeated here to set the stage for the R&D issues.

- The tracks can be measured with a large number of ($r\phi$,z) space points, so that the tracking is continuous and the efficiency remains close to 100% for high multiplicity jets and in presence of high backgrounds.
- It presents a minimum of material to particles crossing it. This is important for getting the best possible performance from the electromagnetic calorimeter, and to minimise the number of spurious hits in the TPC from photon conversions.
- The comparatively moderate σ_{point} and double-hit resolution are compensated by the large volume which can be filled with fine granularity. The timing is precise to a few ns, good enough to separate events and tracks from different bunch crossings.
- It 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 (FWHM$_T \leq 2$ mm for Ar-CH_4 gas and a 4 T magnetic field).
- The large volume and large number of points helps to obtain an excellent efficiency in reconstructing long lived stable particles (V^0 detection).
- The TPC gives good particle identification via the specific energy loss, dE/dx, which is also important for the energy-flow algorithm and many physics analyses.
- A TPC is easy to maintain since, when designed properly, an endplate readout chamber can be simply exchanged if it is having problems.

To obtain good momentum resolution and to surpress backgrounds near the vertex, the TPC has to operate in a strong magnetic field. For the TESLA detector a 4 T solenoidal field is foreseen. The magnetic field has to be mapped to better than 10^{-3} in order to minimise corrections for the distortion of drifting electrons.

There are two drawbacks inherent to a TPC which can be minimised by proper design work following the ensuing 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 ~ 50 μs memory time integrates over background and signal events from 160 TESLA bunch crossings at 500 GeV and twice as many at 800 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). Assuming roughly 10 electronic voxels are hit per ionisation deposit, then the chamber will have an effective granularity of 10^8 voxels (two orders of magnitude more than at LEP). This would then result in an occupancy of the TPC of less than 1% from beam backgrounds and gamma-gamma interactions[3]. Simulations have shown that the physics events can be extracted from this even if the machine background calculations are wrong by a large factor.

2 Overall Design

The design is presented in the TESLA TDR [1] and is an improved version of that in the CDR [2]. The main requirements were to develop a system which can achieve an overall performance which is significantly better than at LEP and in other current experiments – both in resolution and in granularity, which represents as little dead material as possible, and which is capable of operating continuously throughout one TESLA bunch train of $\sim 1\,\mathrm{ms}$ length. To achieve the performance systematic effects in the TPC track reconstruction must be kept to less than 10 μm to guarantee the momentum precision $\delta p_t/{p_t}^2 \sim 1.5 \cdot 10^{-4}/\mathrm{GeV/c}$, (TPC only) and $\delta p_t/{p_t}^2 \sim 5 \cdot 10^{-5}/\mathrm{GeV/c}$ (overall).

To ensure good solid angle coverage, good track resolution and simultaneously good determination of the specific energy loss, $\delta(\mathrm{dE/dx})/(\mathrm{dE/dx}) \leq 5\%$, a large number of points should be measured along each track. This dictates that the chamber should be rather large, both radially and longitudinally. At TESLA the main parameters for the TPC are listed in Table 1. The inner radius of the TPC is given by the size of the mask system, which extends to inside the TPC bore and which in turn is given by the dimensions of the final focus quadrupoles. The outer radius is determined by the dimensions of the calorimetry and the size needed to achieve both the desired momentum resolution and the measurement of around 200 space points along a track for the dE/dx resolution.

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 sensitive 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)

Table 1: TPC parameters in the TESLA TDR.

3 The R&D Issues

The main challenge of this TPC is to design and build a system with the finest possible granularity, which is robust in operation and performance in high backgrounds, has a minimum of material in front of the calorimeters and is constructed in such a way that systematic distortions can be controlled to better than $10\,\mu$m over the whole volume. Development work is needed on all aspects of the TPC, in particular on the amplification and ion-suppression schemes and on the integration of frontend electronics.

3.1 Readout System

TPC gas-amplification readout systems up to now have been realised using proportional wire chambers. These systems worked extremely well and provided robust and reliable solutions. However they have a number of drawbacks: wire chambers are intrinsically one-dimensional and systematics due to $\vec{E} \times \vec{B}$ wire effects in strong magnetic fields are significant. The signal produced in the wire chamber is read out via pads which detect the induced signals from 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. In addition the fact that many wires need to be supported means that more material has to be present in the endplates.

With the advent of micropattern gas detectors such as the Gas Electron Multiplier [4] or MicroMEGAS [5] attractive candidates exist for the readout planes which solve some of the drawbacks of the wire technology. These devices are intrinsically two-dimensional, they have hole or grid spacing similar to the point resolution of around $100\,\mu$m, and they can be built with less material present in the end plates.

Before a TPC based on one of these new technologies can be safely proposed, several questions need to be addressed.

3.1.1 Chamber Development

The properties of the micropattern gas detector (MPGD) such as gain, stability, granularity, etc are related in part to mechanical properties of the MPGD. For GEMs most studies so far used foils supplied by CERN with similar hole shape and hole spacing. A systematic optimisation of the shape of the GEM holes, of their arrangements and of the density of holes is needed. This should go hand-in-hand with a comparison of GEMs supplied from different sources. Particular emphasis should go into the development of GEM structures which are more stable and uniform than currently available. Similar studies are needed for the MicroMegas. Special emphasis is put on the further development of the grid, where an optimisation of the grid parameters is necessary.

MPGD operation

MPGDs are still comparatively new devices, with little experience in operation and long term behaviour. Valuable information is expected to be available soon from experiments like HERA-B and Compass where GEMs will be used for the first time on a large scale. Nevertheless it is desirable to complement this by dedicated exploration of the parameter space available for stable MPGD operation via small-scale laboratory tests. Important for the application in the TPC are the long term stability of the MPGD and the homogeneity of the device. This has consequences for the capability of the final TPC to contribute to the identification of particle types via the measurement of the specific energy loss dE/dx. This work also includes a comprehensive study of systematic effects which might affect the behaviour of a MPGD TPC.

Signal pickup

The ionisation originating in the drift volume of the TPC is amplified in the MPGD and transferred onto a set of pads which are read out via charge sensitive preamplifiers. The charge is measured directly, as opposed to wire chambers where the signal generated at the wires is induced on the pads. This direct charge provides for large signals, but has the drawback that no or only very small induced signals are usable on neighbouring pads. Thus if the charge is picked up by a single pad only, that point will be measured with worse resolution than for the case where several pads are hit. The former can happen for drift distances that are too short to allow sufficient charge-spreading by diffusion. One solution for example to fully use the resolution given by the size of the electron cloud would be to have pad sizes similar to spacing between GEM holes, but this would result in a number of pads which is much too large.

A number of ideas are being discussed how the resolution can be improved:

- Specially shaped pads can be used which maximise the charge sharing between neighouring pads, without actually spreading the charge. Results from simulations are promising, but need to be confirmed experimentally [7].
- During the gas amplification in a GEM a small signal is induced on the pads, before the full electron signal arrives. It has been shown that these signals can be used to improve the resolution via very fast sampling with the ATWD chip[8], albeit at the cost of a significantly more complicated electronics and hit reconstruction.
- Different techniques are being discussed to physically spread the charge on the pads. This can be done by inserting a resistive layer on top of the pads. Significant R&D is needed to demonstrate this technique.
- Similar to the technique used in Si detectors the density of pads can be increased, with only every second, third or similar pad being read out. Capacitive coupling between the pads can be used to improve the resolution. Such an approach has never been used in a TPC.

This question has many consequences for the design of the endplate, the number of channels, and therefore ultimately also the cost. It is one of the central questions to be addressed in this R&D.

MPGD aging

Although radiation damage to detectors is not expected to be a major concern at a linear collider, nevertheless care has to be taken to ensure that all components survive for the estimated lifetime of the experiments. In particular a significant neutron flux is expected at the location of the MPGDs. Therefore dedicated neutron irradiations and ageing studies should be carried out to measure the dose up to which a MPGD TPC can operate reliably. Apart from influencing the materials used in the construction of the chamber this can also dictate the choice of gas and have consequences on the type and operation of the MPGD.

MPGD towers

Currently typical MPGD sizes are $\leq 40\times40$ cm^2, though larger detectors might become available in the future. Since the TPC endplate is much larger, ways have to be found to combine individual MPGDs into larger active areas, with as small as possible dead zones and distortions between neighbouring MPGDs. In the TDR the concept of a MPGD tower was introduced. The MPGD, together with the readout pads, possibly a gating plane, and the readout electronics for the pads form one self-contained unit. The idea is that spacers maintain the MPGDs at the proper distance without external frames, thus minimising dead zones between the MPGDs. Significant work is needed to further develope this idea and to understand how to build these MPGD towers and the interface between neighbouring MPGD towers.

For GEMs to obtain large enough gains (gains up to a few 1000 are thought to be sufficient) it might be necessary to cascade at least two GEMs. Further studies should clarify whether two or even more GEM planes are needed, what the implications of such multi-GEM detectors are and how robust is the operational experience with them.

Ion feedback

To achieve the best possible spatial resolution with a TPC the drift volume should be kept as clear as possible of positive ions. In conventional wire TPCs to now, a gating plane was installed which effectively blocked positive ions from drifting back into the TPC volume for all times except after a trigger. At a linear collider like TESLA no explicit fast trigger is foreseen, thus excluding the possibility of gating the TPC as before. The use of MPGDs promises to reduce the ion feedback from the amplification into the drift region significantly. The degree of ion feedback depends strongly on the exact choice of operational parameters and the MPGD used. At the moment a suppression to the level of 10^{-2} has been demonstrated, however, it is assumed that a level of up to 10^{-4} (at least 1/gain) is needed to ensure that the positive-ion effects are at an acceptable level. The measurement of the ion feedback is thus an important part of the R&D studies.

In case this goal of 10^{-4} cannot be reached and to guarantee a stable and robust chamber operation, the insertion of a gating plane might be needed. This plane might be gated in between bunch trains, but remain open throughout one full TESLA train. This could eliminate ion feedback into the drift volume completely in principle, but the drift velocity of the ion components of the gas must be measured. These v_{ion} measurements constitute important R&D and will illuminate the feasibility of such a solution.

Magnetic field behaviour

MPGDs have been shown to operate reliably in strong magnetic fields, as they are planned for the TESLA detector. One of the advantages of the MPGD in fact is that when operating in a magnetic field a significant reduction of systematic effects close to the MPGD due to $\vec{E} \times \vec{B}$ distortions is expected, when compared to a TPC equipped with wire chambers. Dedicated studies are needed to prove and quantify this effect, and to understand the level of remaining systematic effects, as a function of the type of the MPGD used. For this study the operation of a MPGD TPC in a strong magnetic field under realistic conditions is essential.

Double track resolution

While first results on the spatial resolution obtainable with a MPGD TPC look very promising and were documented in the TDR, no experimental results exist yet on the achievable double track resolution. It is expected that significant improvements can be made compared to a wire TPC, but experimental proof is lacking. This measurement requires extensive test beam studies.

3.1.2 Gas Studies

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 based with quenchers of CH_4 or a mixture of CO_2+CH_4. The admixture of quenchers influences strongly the drigt velocity, the voltage at which the drift velocity reaches a plateau, and other parameters. In addition other quenchers like CF_4 are being considered and require understanding of their properties. Although it is not foreseen to operate the TPC at any significant overpressure, small degree of presurisation might help in stabilising the chamber against influences of the exterior. This of course will strongly impact on the design of the field cage and the end plates.

3.1.3 Electronics

A TPC equipped with MPGDs will pose new challenges on the design of the readout electronics. In the TDR the number of channels considered was around 0.6×10^6 per side. Due to this large number, very compact and cheap electronics are needed which simultaneously fully utilise the potential of the TPC. Development work is expected to happen in the area of the preamplifier and the digitisation technique used. Highly integrated solutions must be found, where e.g. the pre-amplifier and the digitisation electronics are combined into one chip.

Several options are under investigation for the digitisation. In the past modules based on CCD/ADCs or FADCs have been used to read out the timing and charge information from the pads. Alternatively the use of advanced multi-hit-TDC/ADC boards will be investigated. In addition to more integration, higher sampling speed is also wanted, as already mentioned.

The most modern system for the readout of a TPC is that developed for the Star experiment at Brookhaven[6] based on the switched-capacitor-array/ADC technique. The packing density however is still an order of magnitude smaller than that for the

TESLA TPC. For the next generation of prototype chambers a solution similar to that of the Star experiment will probably be used.

3.2 Endplate Design

For the conceptual layout as given in the TDR, the endplate is subdivided into 8 individual modules. Each can be removed without disturbing the neighouring ones, so that a maintainance and repair of modules is possible. Further development work is required to translate the conceptual design into a real one. Many technical questions have to be solved, both mechanically and electrically.

3.2.1 Cooling

Cooling of the on-detector electronics is always a major design task. At the TESLA collider the design can profit from the long idle times between bunch trains. It is expected that a properly designed electronics can be switched off between trains, thus significantly reducing the average power and therefore the cooling power needed.

3.2.2 Mechanics

The goal as spelled out in the TDR are that the fieldcages together should not present more that 3% of a radiation length of material, and that the endplate should not be thicker than 30% of a radiation length. It will be particularly challenging to fit the large number of electronic channels onto the endplates without introducing too much material. Another issue is the plan to roll out the TPC in order to service the inner detectors. These aspects will be demanding on the engineering and must be studied on a timely basis.

3.3 Fieldcage Design

Of central importance for the reliable and stable operation of the TPC is a proper design of the fieldcage. The system proposed in the TDR is based on HV-experience gained with the Aleph, Star and D0 experiments. Further work is needed to detail the design and to test it comprehensively. It is planned that the next generation of prototypes should be equipped with a development version of the proposed fieldcage. The main questions to be addressed are:

- high voltage stability of the structure
- mechanical stability of the structure
- optimization of the field strip pattern
- development of compact voltage dividers
- integration of the cathode into the field cage.

3.4 Calibration, Alignment

The LEP experience shows that tracks from e^+e^- events and in particular Z-peak running are the best source for correcting distortions, that Si layers inside the TPC inner field cage and that a measured point outside the TPC are likewise valuable tools for mapping and monitoring the corrections. The inner Si layers are already the TDR design, while an outer point (along the lines of the Opal z-chamber but two-dimensional) is not yet. Aleph could correct the effects to the 30 μm level but did not have a measured point outside the TPC, and it should be studied to see if an outside point would improve the reduction of distortions to below 10 μm. Recently a group from the University of Paris[9] has investigated the track-momentum performance using the first Si layers of the ECAL which would give just such an outside track point. They have shown that the momentum measurement can improve by $\mathcal{O}(10\%)$, but alignment and distortion corrections have not yet been studied.

A laser system was included in the TDR design as a tool to help monitor the distortions. The implications and the usefulness of such a system have to be studied. If calibration with laser turns out be inadequate, it should be dropped, since it also introduces significant mechanical complications into the design.

3.5 Software Developments

The software effort needed to accompany the research and development work for the TPC has two components.

First some development work is necessary to provide software tools which can simulate the behaviour and properties of MPGDs in more detail in order to understand better the results from prototype work on a MPGD TPC. In particular the detailed modeling of the charge collection properties of a MPGD, of the ion feedback and the signal generation is still unsatisfactory.

Second the MPGD TPC needs to be fully modeled and included in the GEANT based detector simulation for the TESLA detector. Although significant studies were done in the preparation for the TDR, more work on the detailed simulation of the different TPC parts and on their interaction with the pulse and track reconstruction should be done.

Both efforts are needed for the development, and in particular for the analysis of the planned test beam experiments, but will also be incorporated into the overall TESLA simulation software.

4 Participating Institutes

In this section a brief description of the work ongoing and planned in the different institutes participating in this proposal is given.

Aachen	RWTH Aachen has experience in design and test of gas detectors, specifically the MSGC+GEM detectors for CMS. They are studying operating parameters and ion feedback for GEM technology using small test chambers. A 1.4 m^3 TPC has been installed for the test of prototype readout modules. Also foreseen is to understand the implications of the different manufacture processes of GEM foils. The measurements will be accompanied by numerical simulations of the structures allowing optimization of the geometry of the GEM foils, the operating voltages and the readout pads. Aachen is also equipped with clean-room facilities and gas systems.
Berkeley	LBNL in Berkeley has acquired valuable experience in building the PEP4 and Star TPCs. They are interested in all aspects of this R&D. Techniques for spreading the charge are being thought about, and further miniaturization and packaging of the readout electronics will be pursued.
Carleton/Montreal	Carleton U. in Ottawa and U. Montreal are running tests on GEM prototypes, fast-sampling electronics (ATWD) and pad shapes. Simulations to better understand how a TPC would work with GEM or MicroMEGAS technology are in progress, and gating using GEM technology is under development.
DESY/Hamburg	DESY and the University of Hamburg are working closely together on the GEM readout for the TPC. The R&D projects include a TPC prototype (drift length$\sim$1 m) to study the effects of different field configurations and the track resolution using different pad sizes and shapes. An endplate has been built which allows installation of pad arrays in a modular way. A 1 T solenoid has been recommissioned for performance tests in a magnetic field using the DESY electron beam. Apart from the TDR gas mixture, properties of other mixtures will also be investigated. The operation studies are accompanied by extensive simulations of pad size and shape and of different drift gases. In a separate small setup important parameters such as ion-feedback and the performance of a GEM for gating are to be measured. The mechanics of GEM supporting structures will be developed.
Karlsruhe	Karlsruhe University has developed GEM detectors for LHC applications and for medical imaging. The institute is equipped for studies of radiation hardness and of TPC/GEM performance with different gas mixtures in high magnetic fields. A small TPC has been measuring ion feedback, drift

velocity and electron diffusion, and a larger TPC/GEM detector is under construction to allow more accurate studies to find an optimal operating point. A small test chamber is also being designed for measurements in a 4T magnetic field. Karlsruhe is prepared to set up a readout system for general R&D use by the TPC community.

Krakow — UMM Krakow will study gas-mixture parameter space to find the optimum for a TPC with MPDG readout. Mixtures will be tested with and without small amounts of CF_4, which permits potentially high drift velocities and small sensitivity to the neutron background, but is also mildly electronegative for certain drift fields. The ion drift velocity will also be measured for all the different mixtures. Krakow will also do design work on the general gas supply system.

MIT — MIT in Cambridge MA plans to measure drift velocity and Lorentz angle for 10 different gas mixtures using a small prototype chamber in magnetic field which has recently been commissioned. They can study 1, 2 and 3-fold GEMs using laser tracks or cosmics. Simulation work is starting on new GEM designs which can then be fabricated locally.

MPI-Munich — MPI-Munich constructed major TPC components for the Aleph, NA35, NA49 and Star experiments and thus have built up facilities for doing prototype work on any aspect for the LC TPC. In the near future studies are planned on quenching gases, calibration methods (Krypton), long drift distances, ion drift velocity and fabrication methods.

NIKHEF — NIKHEF in Amsterdam is studying the possibility of combining GEM foils with a Si pixel sensor. A test chamber with 10cm$\times$10cm double GEM and 10cm drift length is being built which can be read out with an a Si pixel detector (MediPix 1) having 64$\times$64 square pixels of size 170μm$\times$170μm. The Si readout can be replaced by an MWPC for comparison. Studies using Fe^{55} quanta and cosmics are foreseen, and they will be checked with simulations. Also electronics and alignment will be studied.

Novosibirsk — BINP Novosibirsk will study GEMs using different gas mixtures. They have working triple-GEM detectors (10cm$\times$10cm) using Premux electronics and are doing measurements on ion-feedback with this set-up. Others will follow, e.g. on gating using a GEM plane or a special electrode. Possibilities are being discussed with two companies for producing GEM prototypes in Russia with the aim of optimising the endcap detector geometry, such as hole size, pitch, etc.

Orsay/Saclay	Orsay (IPN and LAL) and Saclay (DAPNIA-CEA) are working together and test prototypes using the MicroMEGAS technology and Star electronics, in collaboration with LBL. Measurements of drift velocity, gain, energy resolution, ion feedback MicroMEGAS operating parameters are going on. Further plans are to study aging and the problem of electron attachement with CF4, and to measure ion drift velocities. Also 2T and 3T magnets might become available for prototype testing.
Rostock	Rostock University has extensive experience designing and building readout electronics for HEP experiments. They are interested to contribute to the development and design of dedicated readout electronics for a MPGD TPC.

5 Priorities, Road Map, Milestones

The goals of the R&D work detailed above can be structured into three parts: short term, medium term and long term goals.

The most important development work to be done is on the gas amplification system. The main question to be solved is which amplification scheme is best suited for a TPC at a linear collider.

With slightly lower priority and on a somewhat longer time scale, progress has to be made on a more detailed technical design of the different parts of the TPC, in particular of the electronics and of the fieldcage. Significant engineering is necessary in these areas.

For the long term solutions for the integration of the TPC into the overall mechanical detector concept have to be found. The currently proposed solutions as presented in the TDR will have to evolve further as the concept is refined.

The work on the first two issues will include a combination of tests at the different labs and small scale beam tests. It is expected to lead up to the construction of a prototype for the LC TPC and start of significant beam testing in approximately three years (see below).

5.1 Milestones

As pointed out the investigation of the amplification system is the most pressing question to be answered by the proposed R&D program. While it is most likely that a final decision on the technology to be used can only be taken once a real detector collaboration for TESLA has formed, important information should be available earlier. It is expected that many of the questions outlined above can be answered within approximately two years.

The major goal of this proposal is the construction of a TPC prototype module optimised for the TESLA environment. This TPC module should reflect the main results from the R&D work on gas-amplification system, endplate and fieldcage, and use the best prototype electronic scheme available at that time. Such a prototype can be designed and built within approximately one year after the two-year development phase mentioned above, assuming that no major difficulties are found during that phase. This sums up to the three years mentioned above. The prototype TPC module will then be tested at DESY in an electron test beam to determine its basic operation characteristics. Tests in hadron test beams at other labs, might be necessary at a later date.

It should be pointed out that basic development work on the gas-amplification scheme will likely continue also beyond the two-to-three years, since it will include the construction and operation of a number of small test systems, each with of order a few hundred channels, which will be undergoing extensive testing.

5.1.1 Distribution of Responsibilities

Table 2 gives a list of the main tasks and the groups which will work on them. This overview was compiled to make sure all areas are covered adequately.

5.1.2 Test Schedule

To carry out the proposed program a series of tests is needed. An important ingredient will be the availability of sufficient test beam time at DESY. The existing test beams with electron energies up to 6 GeV will be sufficient for many of the tests, if a proper infrastructure can be maintained. Two aspects are of particular importance:

- The availability of a Si telescope to do measurements of the resolution of the TPC. Such a telescope is currently installed in the beam T22 at DESY. We request that for the duration of this project DESY undertakes the maintenance of this device, and ensures that it remains available.
- The availability of a sufficiently strong and large magnet, to study the magnetic field behaviour. At least initially two existing magnets (the old TASSO compensation coils) can be used, which will allows solenoidal fields up to 1 T. However the continued use of these fairly old devices will require some investments. As stated above, Karlsruhe, MIT and Saclay also have magnets for prototype work.

We like to stress that the provision of adequate test beam facilities is an essential part of this proposal to DESY.

5.2 Funding

Most of the groups signing this proposal have funding or have applied for funding at their own home institutions. The request to DESY entails:

- provision of a test beam with infrastructure as outlined above
- access to the DESY workshops and facilities for prototype construction
- the DESY group signing this proposal asks for proper funding of its R&D activities as detailed in Table 2 and Section 4.

6 Summary

The present proposal by a global group of institutes has goal of coordinating important R&D work needed to make the Time Projection Chamber a viable technology for the central tracker of the TESLA detector. The main challenge is to design a continuous-tracking, high-performance TPC with the finest possible granularity, which is robust in high backgrounds, has a minimum of material and can keep residual distortions below $10\,\mu$m. Development work is required on all aspects of the TPC, in particular on the amplification, the ion-suppression scheme and the large-scale integration of electronics. The aim is to make technical decisions based on the present R&D within two years, to design and build a realistic prototype within the following year and to then start extensive testing about three years from now.

References

[1] TESLA Technical Design Report, DESY 2001-011, ECFA 2001-209, March 2001.

[2] TESLA Conceptual Design Report, DESY 1997-048, ECFA 1997-182, May 1997.

[3] C.Hensel, Beam Induced Background at a TESLA Detector, LC-DET-2001-001.

[4] F.Sauli, GEM: A New Concept for Electron Amplification in Gas Detectors, Nucl.Instrum.Meth. A386(1997)531.

[5] Y.Giomataris et al, Micromegas: A High Granularity Position Sensitive Gaseous Detector for High Particle Flux Environments, Nucl.Instrum.Meth. A376(1996)29.

[6] STAR-Collaboration: K.H. Ackermann et al., The Star Time Projection Chamber, Nucl.Phys. A661(1999)681.

[7] M.Schumacher, Pad readout geometries for a TPC with GEM readout for the TESLA linear collider, LC-DET-2001-014.

[8] `http://obsidian.lbl.gov/~ronan/talks/LCTPC/TPC_FastSampling.html`

[9] `LC Note: http://www.desy.de/~lcnotes/notes.html`

J.E. Augustin, M. Berggren and A. Savoy-Navarro, Study of a Silicon External Tracker: SET, LC-DET-2001-075.

Topic	Aachen	Berkeley	Carleton/Montreal	DESY/Hamburg	Karlsruhe	Krakow	MIT	MPI-Munich	NIKHEF	Novosibirsk	Orsay /Saclay	Rostock
MPGD development	G				G					G	M	
MPGD operation	G	B	B	G	G					G	M	
MPGD signal pickup	G	B	B	G							M	
Si readout									G			
MPGD ageing					G		G				M	
MPGD tower				G							M	
MPGD ion feedback	G		B	G	G					G	M	
MPGD B-field behaviour				G	G						M	
MPGD 2-track resolution				G							M	
Gas studies						B	B	B			B	
Gas system						B						
Electronics		B						B			B	B
Endplate Design		B		G				B				
Cooling		B						B				
Mechanics				G				B				
Fieldcage Design				B				B			B	
Calibration												
- MPGD Simulation	G		B								M	
- Pad simulation			B	B							B	
- Alignment				B				B	B		B	
- Laser		B						B				
Software				G							B	

Table 2: Preliminary task list and work planned by the institutes on the tasks. G stands for research mostly directed towards GEMs, M for mostly MicroMegas research and B for development work usable for both technologies.