TPC R&D for an ILC Detector
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Status Report from the LCTPC Collaboration [1] [2]

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Abstract

This report gives a summary of TPC studies and an update since the PRC review in May 2006. The R&D issues are related to the the LCTPC design criteria which are covered in some detail. Representative results, some of which are preliminary, for the various issues are presented and plans for the future described. The formation of an LCTPC collaboration is in progress in order to address these R&D plans coherently.

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[1] Original proposal PRC R&D-01/03 for the DESY Physics Review Committee. The present status report is compiled for the WWSOC R&D Tracking Review, Beijing, 6-7 February 2007. This report is also intended for other review bodies within the WWS.

[2] The LCTPC collaboration, https://wiki.lepp.cornell.edu/wws/bin/view/Projects/TrackLCTPCcollab, is open to all and is continually evolving; this website is updated regularly.

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1 Introduction

A detector at a the International Linear Collider (ILC) will combine a tracking system of high precision and granularity with a calorimeter system of very high granularity. This detector will measure charged tracks with an accuracy an order of magnitude better than the precision of previously built detectors at LEP, the Tevatron, HERA, RHIC or the LHC. In addition, the detector will be optimized for the reconstruction of multi-jet final states stressing the jet energy resolution and the reconstruction of individual particles in jets (particle flow). For the latter, efficiency and reliability in reconstructing charged tracks is more important than precision.

A typical design of a "large" detector is the LDC– Large Detector Concept[2] – and the GLD - Global Large Detector[3] – which have tracking systems consisting of a large TPC as the central tracker[4] combined with other detectors for vertexing, barrel and forward tracking. The current designs are similar to an earlier design proposed in the TESLA Technical Design Report[1].

Several groups world-wide have joined together to form the LCTPC collaboration to investigate the design and testing of a TPC for the ILC. The collaboration has grown of time to include groups from America, Asia and Europe: the present status can be seen in the author list of this document.

This TPC R&D has been reviewed regularly by the DESY PRC. The orginal proposal[5] was approved by the DESY PRC in 2001. Subsequent reviews were held in April 2003[6], October 2004[7] and May 2006[8]) more groups from America, Asia and Europe joined the effort; the present status is seen in the author list for this document.

In this report, the LCTPC concept is reviewed in Sec. 2, and design issues are described in Sec. 3. The related R&D efforts are summarized in Sec. 4, and examples of R&D results are presented in Sec. 5. Next R&D steps are described in Sec. 6 followed by conclusions Sec. 7. The LCTPC groups are in the process of establishing a formal collaboration in order to organize the work in a more efficient way; the LCTPC the collaboration formation is in progress, and the status is presented in the Appendix (Sec. 8).

2 The basic concept of the LCTPC

The use of a TPC as the main trackier in an ILC experiment offers several advantages. Tracks can be measured with a large number of three-dimensional $r\phi$,z space points. Thus, the comparatively moderate $\sigma_{singlepoint}$ and double-hit resolution are compensated by continuous tracking. The track-finding efficiency for continuous tracking remains close to 100%, even for tracks within high multiplicity jets and in the presence of significant backgrounds, primarily from beam-beam interactions. 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 minimize the effects due to the $\sim 10^3$ beamstrahlung photons per bunch crossing which traverse the detector. The timing is precise to 2ns (corresponding to 50 μm/ns drift speed of tracks linked to the z-strips of a Si detector with 100μm pitch), so that tracks from different bunch crossings or from cosmics can readily be distinguished via time stamping. To obtain good momentum resolution and to suppress backgrounds, the TPC has to operate in a strong magnetic field of several Tesla. It is well suited for this environment 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$_T$ $\leq$ 1.4 mm for Ar-10%CH$_4$ gas after

2 m drift in a 4T magnetic field). Non-pointing tracks, e.g. for V^0 detection, are an important addition to the particle flow measurement and help in the reconstruction of physics signatures in many standard-model-and-beyond scenarios. The TPC gives good particle identification via the specific energy loss, dE/dx, which is valuable for many physics analyses, electron-identification and particle-flow applications. The TPC will be designed to be robust and at the same time easy to maintain so that an endplate readout chamber can readily be accessed or exchanged in case of accidents such as beam loss in the detector.

Two additional properties of a TPC can and will be compensated by proper design. First, the readout endplanes and electronics present a certain amount of material in the forward direction; the goal is to keep this below $30\%X_0$. Second, the ~30–50μs memory time (depending on gas choice) integrates over background and signal events from 100–150 ILC bunch crossings at 500 GeV for the nominal accelerator configuration; this is being compensated by designing for the finest possible granularity; the sensitive volume will consist of several$\times 10^9$ 3D-electronic readout voxels (two orders of magnitude more than at LEP). It has been estimated to result in an occupancy of the TPC of less than 0.5% from beam-related backgrounds and gamma-gamma interactions[1]. (See below for further discussion.)

3 Design issues

A detector for the ILC must be designed globally to cover all possible physics channels because the roles of the subdetectors in reconstructing many of these channels are highly interconnected. For a TPC in an ILC detector, important issues are performance, size, endplate, electronics, gas, alignment and robustness in backgrounds. To ensure good performance, the LCTPC groups have been investigating all aspects from the beginning since they are well understood as a result of past experience. In the following, an overview of the issues is given; more details follow in Sec. 5 where R&D results are presented. The items are often correlated, and related ones will be indicated in parentheses.

3.1 Gas-amplification systems and performance

Some of the main goals for the TPC performance at the ILC are summarized in Table 1. Understanding the properties and achieving the best possible point resolution have been main goals of our R&D studies of Micro-Pattern Gas Detectors (MPGD)[9][10][11]; further explanations follow in Secs. 4 and 5.

The overall tracking resolution is determined by physics goals. Present understanding says that overall $\delta(1/p_t) \sim 5 \times 10^{-5}$/GeV/c will be sufficient, as defined mainly by the $e^+e^- \rightarrow HZ \rightarrow H\ell\ell$ channel used for selecting Higgs events to measure its production rate in an unbiased manner. An even better resolution is achievable with inner-silicon tracking and a TPC performance as seen in Table 1. If for physics reasons, the overall tracking accuracy should be better, a larger TPC and/or more silicon layers should be envisaged. The answer to this question is a task for the detector concept studies, LDC and GLD.

Tracking resolutions with accuracies an order of magnitude better than any of the collider detectors to date will be a challenge to achieve. The accuracy of the sagitta measurement varies between 22μm for $\delta(1/p_t) \sim 5 \times 10^{-5}$/GeV/c and 4$\mu$m for $\delta(1/p_t) \sim 1 \times 10^{-5}$/GeV/c. The systematics of alignment of tracking subdetectors must be well thought through from the beginning to guarantee the integrity of tracking over radii of one or two meters. The issues and tools for solving this problem are addressed below (Secs. 3.7 and 3.8).

Table 1: Performance goals and design parameters for a TPC with standard electronics at the ILC detector.

Size (LDC–GLD average)	$\phi = 3.6$m, L = 4.3m outside dimensions
Momentum resolution (B=4T)	$\delta(1/p_t) \sim 10 \times 10^{-5}$/GeV/c TPC only; $\times$ 0.4 incl. IP
Momentum resolution (B=4T)	$\delta(1/p_t) \sim 3 \times 10^{-5}$/GeV/c (TPC+IT+VTX+IP).
Solid angle coverage	Up to at least $\cos\theta \sim 0.98$
TPC material budget	$< 0.03\mathrm{X}_0$ to outer fieldcage in r
	$< 0.30\mathrm{X}_0$ for readout endcaps in z
Number of pads	$> 1{\times}10^6$ per endcap
Pad size/no.padrows	$\sim$ 1mm×4–6mm/$\sim$200 (standard readout)
$\sigma_{\mathrm{singlepoint}}$ in $r\phi$	$\sim 100\mu$m (average over driftlength)
$\sigma_{\mathrm{singlepoint}}$ in rz	$\sim$ 0.5 mm
2-track resolution in $r\phi$	$<$ 2 mm
2-track resolution in rz	$<$ 5 mm
dE/dx resolution	$<$ 5 %
Performance robustness	$>$ 95% tracking efficiency (TPC only), $>$ 98% all tracking
Background robustness	Full precision/efficiency in backgrounds of 1% occupancy
	(simulations estimate $<$ 0.5% for nominal backgrounds)
Background safety factor	Chamber will be prepared for 10 $\times$ worse backgrounds
	at the ILC start-up.

3.2 Endplate

The two TPC endplates have a surface of about 10 m^2 of sensitive area each. Development of the layout of the endplates, i.e. conceptual design, stiffness, division into sectors and dead space, has been started. In general, the readout pads, their size, geometry and connection to the electronics and the cooling of the electronics, are all highly correlated design tasks related to the endplates. As stated in Sec. 2, the material budget for the endcap and its effect on Ecal for the particle-flow measurement in the forward direction must be minimized (more under Sec. 3.3).

3.3 Electronics

For the readout electronics, one of the important issues is the density of pads that can be accommodated while maintaining a thin, coolable endplate. The options being studied are (a) standard readout of several million pads or (b) pixel readout of a hundred times more using CMOS techniques. Note that Table 1 assumes standard electronics; a similar table for pixel electronics will be made as soon as more understanding evolves.

(a) Standard readout:
Pad sizes under discussion. While and earlier proposed size was 2mm×6 mm[1]), smaller pads, 1mm×4–6 mm, have been found to provide improved resolution in our R&D work (Sec. 5). Studies have started to establish the realistic density of pads that can be achieved. A preliminary look at the FADC, CCD or switched-capacitor-array approach using 130 nm technology indicates that even smaller sizes might be feasible. An alternative to the FADC-

type is the TDC approach (see [5][12]) in which time of arrival and charge per pulse by charge to time conversion are measured[18]. If it turns out that the material budget requires larger pads, then the resistive-foil technique[14] is being systematically studied and is an option to maintain the good point resolution. Thus, depending on the achievable electronics density, there will be between 1 and 10 million pads per endcap to be read out.

(b) CMOS pixel readout:
A new concept is being studied by which the gas amplification is done by a "standard" MPGD, and the readout is accomplised using a matrix of Si chips with integrated readout electronics[5][19]– [22]. Implementation of a CMOS pixel readout chip with $\sim 50\mu$m pixel size would result in a very high granularity detector with $\sim 10^9$pads per endplate. If this concept turns out to be realistic, better momentum and dE/dx resolutions might be possible.

3.4 Fieldcage

The design of the fieldcage involves the geometry of the potential rings, the resistor chains, the central HV-membrane, the gas container and a laser system. These will have to be laid out for sustaining at least 100kV at the HV-membrane and with a minimum of material. For alignment purposes (Secs. 3.7 and 3.8) a laser system is foreseen and may be integrated into the fieldcage[15][16] or not[38], since this decision is pending further investigation.

3.5 Chamber gas

The choice of the gas for a TPC is crucial decision for efficient and stable operation at the ILC[13]. The $\sigma_{\mathrm{singlepoint}}$ resolution achievable in $r\phi$ is dominated by the transverse diffusion, which should be as small as possible. This means that $\omega\tau$ for the gas should be large so that the transverse diffusion is compressed by the B-field. Large $\omega\tau$ will have the added advantage of making the chamber less sensitive to space-charge effects (Sec. 3.6) and other sources of electric field non-uniformities (Sec. 3.7). Simultaneously a sufficient number of primary electrons should be created for the position and dE/dx measurements. The drift velocity at a drift field of at most a few times 100 V/cm should be 5–10 cm/μs to limit the central cathode voltage and the event overlap. The choice of operating voltage must also take into account the stability of the drift velocity due to fluctuations in temperature and atmospheric pressure. Finally while hydrocarbons have traditionally been used as quenchers in TPC gases, the concentration of hydrogen should be minimized to limit the number of background hits due to neutron-proton scattering.

The gas system will circulate and purify the chamber gas. The design of the gas system depends not only on the gas-mixture choice, but also on the required purity, overpressure and tolerable replacement rate. the system must provide temperature control consistent with a stable drift velocity as described above.

3.6 Space charge

Three sources of space charge are (a) ion build-up at the readout plane, (b) ion build-up in the drift volume and (c) ion backdrift, when ions created in the gas amplification drift back into the TPC volume.

(a) Ion Build-up at the Readout Plane.
At the surface of the gas-amplification plane during the bunch train of about 3000 bunch crossings spanning 1 ms, there will be few-mm thick layer of positive ions built up due to the

incoming charge, subsequent gas amplification and ion backdrift. An important property of MPGDs is that they suppress naturally the backdrift of ions produced in the amplification stage. Steps to minimize the backdrift are described in Sec. 5, where a backdrift of 0.25% is shown to be achievable. Thus this layer of ions will reach a density of a few tens of $\mathrm{fC/cm^3}$, depending on gas gain and the background conditions during operation. Its effect is still to be simulated, but intuitively it should affect coordinate measurement only by a small amount since the drifting electrons incoming to the anode only experience this environment during the last few mm of drift. The TPC must plan to run with the lowest possible gas gain, meaning of order 1–2 $\times$ 10^3, in order to minimize this effect.

(b) Ion build-up in the Drift Volume.
In the drift volume, an irreducible positive-ion density due to the primary ionization will be collected during about 1s (the time it takes for an ion to drift the full length of the TPC). The positive-ion density will be higher near the cathode and will be a few $\mathrm{fC/cm^3}$ at the estimated occupancy of $\sim$ 0.5%. The effect of the charge density will be established by our R&D program, but the experience of the STAR TPC[15] indicates that 200 $\mathrm{fC/cm^3}$ is tolerable (Sec. 3.7(b)) and a few $\mathrm{fC/cm^3}$ is well below this limit.

(c) Ion backdrift and gating.
The operational conditions at the linear collider – long bunch trains, high physics rate – require an open gate operation without the possibility of intra-train gating between bunch-crossings should the delivered luminosity be optimally utilized. As already mentioned, MPGDs lend themselves naturally to the intra-train un-gated operation at the ILC since they can operate with a significant suppression of the back-drifting ions. In order to minimize the impact of ion feeding back into the drift volume, a required backdrift suppression of about 1/gasgain has been used as a rule-of-thumb, since then the total charge introduced into the drift volume is about the same as the charge produced in the primary ionization.

Not only have these levels of backdrift suppression not been achieved during our R&D (Sec. 5), but also this rule-of-thumb is misleading. Lower backdrift levels will be needed since these ions would drift as few-mm thick sheets through the sensitive region during subsequent bunch trains. The charge density in the sheets would be much higher than a few $\mathrm{fC/cm^3}$ (Sec. 3.6(b)) since the volume in the sheets is $\sim$ 100 times smaller than that of the drift volume. How these sheets would affect the track reconstruction will be simulated to understand their influence, but since this backdrift into the drift volume can in principle be completely eliminated by a gating plane, a gate should be foreseen, to guarantee a stable and robust chamber operation. The added amount of material for a gating plane will be small (e.g., it was $< 0.5\%\mathrm{X}_0$ average thickness for the Aleph TPC), The gate will be closed between bunch trains and remain open throughout one full train. This will eliminate the need to make corrections to the data for such an "ion-sheets effect".

3.7 Effect of non-uniform fields

Both fields, (a) magnetic and (b) electrostatic, are involved.

(a) Magnetic field.
Non-uniformity of the magnetic field of the solenoid will be by design within the tolerance of $\int_{\ell_{\mathrm{drift}}} \frac{B_r}{B_z} dz < 2\mathrm{mm}$ as used for previous TPCs. This homogeneity is achieved by corrector windings at the ends of the solenoid. At the ILC, larger gradients will arise from the fields of the DID (Detector Integrated Dipole) or anti-DID, which are options for handling the beams inside the detector at the IRs with 14 mrad crossing-angle (as has been decided for

the ILC). This issue was studied intensively at the 2005 Snowmass workshop[39][40], where it was concluded that the TPC performance will not be degraded if the B-field is mapped to 10^{-4} relative accuracy and the calibration procedures outlined in the next point (Sec. 3.8) are followed. These procedures will lead to an overall accuracy of 2×10^{-5} which has been shown to be sufficient[40] and was already achieved by the Aleph TPC[39]. Based on past experience, the field-mapping gear and methods should be able to accomplish the goal of 10^{-4}. The B-field should also be monitored during running since the DID or other corrector windings may differ from the configurations mapped; for this purpose the option of a matrix of Hallplates and NMR probes mounted on the outer surface of the fieldcage is being studied.

(b) Electric field.

Non-unformity of the electric field can arise from the fieldcage (Sec. 3.4) and from the processes explained in Sec. 3.6: ion build-up at the gas-amplification plane and due to primary ionization in the drift volume. The other source in Sec. 3.6, ion-sheets drifting back through the chamber can be eliminated via a gating plane, as explained there.

–For the first, the field cage design, the non-uniformities can be minimized using the experience gained in past TPCs.

–The effect due to the second, ion build-up at the readout plane can be minimized by running at the lowest possible gain.

–The effect due to the third, the primary ions, is due to backgrounds and is irreducible as already mentioned. The maximum allowable electrostatic charge density remains to be specified, but studies by the STAR experiment[15] for their high-luminosity running in future, and taking into account that the LCTPC will use a gas with high $\omega\tau$ (Sec. 3.5), indicate that about 0.2 pC/cm^3 at the center of the TPC will give $\sim$10 mm distortion, which is correctable. At the nominal occupancy due to backgrounds of $\sim$ 0.5%, the space charge is estimated to be of order 1 fC/cm^3. This will be revisited by simulation within the R&D program (Sec. 6).

3.8 Calibration and alignment

The tools for solving this issue are Z-peak running, the laser system, the B-field map, a matrix of Hallplates/NMR probes outside the TPC and Si-layers inside the inner fieldcage and outside the outer fieldcage. In general[28] about 10/pb of data at the Z peak will be sufficient during commissioning for the alignment of the different subdetectors, and typically 1/pb during the year may be needed depending on the backgound and operation of the ILC machine (e.g., beam losses). A laser calibration system will is foreseen (see e.g., [38][15][16]) which can be used to understand both magnetic and electrostatic effects, while a matrix of Hallplates/NMR probes may supplement the B-field map. The z coordinates determined by the Si-layers inside the inner fieldcage of the TPC were used in Aleph[41] for drift velocity and alignment measurements, were found to be extremely effective and will thus be included in the LCTPC planning. The overall tolerance is that (Sec. 3.7) systematics have to be corrected to about 2×10^{-5} throughout the chamber volume[39][40], and this level was already achieved by the Aleph TPC[39][41].

3.9 Backgrounds and robustness

The issues here are the space-charge (Sec. 3.6) and the track-finding efficiency in the presence of backgrounds; the latter will be discussed here. There are backgrounds from the accelerator, from cosmics or other sources and from physics events. The main source is the accelerator, which gives rise to gammas, neutrons and charged particles due to 2-gamma interactions and beam-halo muons being deposited in the TPC at each bunch crossing[42]. Preliminary simulations of these under nominal conditions[1] indicate an occupancy of the TPC of less than about 0.5%.

This level will be of no consequence for the LCTPC performance, but caution is in order here. The experience at LEP was that the backgrounds were much higher at the beginning of the running (years 1989-90). However, after the simulation programs and understanding of the collider improved, the backgrounds were much reduced, even negligible at the end (year 2000).

Since such simulations have to be tuned to the collider once it is commissioned, the ILC backgrounds at the beginning could be much larger, and the LCTPC should be prepared for higher occupancy, $\sim$10% or more.

What would be the tracking efficiency in this case? For comparison, heavy-ion TPCs[15] can run with 50–5% occupancy (inside–outside radius) and still have a track recognition efficiency of $> 90\%$. Of course, the heavy-ion events are very different from e^+e^- events (they are more like the LC background), and heavy-ion physics is less sensitive to tracking efficiency. Nevertheless this statement is of technical interest: it shows how much a TPC can be loaded with hits and still function well. The TPC track finding at these occupancy levels remains good due to its continuous, high 3D-granularity tracking which is still inherently simple, robust and very efficient with the unoccupied remainder of the chamber. Results of tracking-efficiency simulation for the LCTPC in the presence of backgrounds are shown in Sec. 5.

4 R&D effort for the LCTPC

4.1 General considerations

The requirements for a TPC at the ILC and the issues are summarized in the preceding section. TPCs have been used in a number of large collider experiments in the past and have performed excellently. Those TPCs were read out by wire chambers. The thrust of this effort is to develop a TPC based on MPGDs which promise to have better point and two-track resolution than wire chambers and to be more robust in high backgrounds. Systems under study at the moment are Micromegas[9] meshes and GEM (Gas Electron Multiplier)[10] foils. Both[11] operate in a gaseous atmosphere and are based on the avalanche amplification of the primary produced electrons. The gas amplification occurs in the large electric fields in MPGD microscopic structures with sizes of order 50 μm.

The R&D program started more than four years ago is in the process of addressing the novel issues which include the following (see [5] for more details).

–Operate MPGDs in small test TPCs and compare with wire gas-amplification to prove that they can be used reliably for the TPC application.

–Study the behaviour of GEM, Micromegas and the resistive-foil technique as a function of magnetic-field strength.

–Investigate the charge transfer properties in MPGD structures and understand the related ion backflow.

–Study the achievable resolution of a MPGD-TPC for different gas mixtures.

–Study ways to reduce the area occupied per channel of the readout electronics by a factor of at least 10 compared to e.g. the Alice TPC[16] with a minimum of material budget.

–Investigate the possibility of using Si-readout techniques or other new ideas for achieving a large number of channels.
–Investigate ways of building a thin field cage which will meet the requirements at the ILC.
–Study alternatives for minimizing the endplate mechanical thickness.
–Devise strategies for robust performance.
–Pursue software and simulation developments needed for understanding prototype and the LCTPC performance. –Pursue simulation for achieving the maximum possible tracking efficiency.

4.2 R&D Phases

To meet the above goals, many of the institutes on this report assembled initially as interested groups, were joined by other institutes and all have recently formed an official the LCTPC collaboration (see Sec. 8).

The aim has been the sharing of information and experience in the process of developing a TPC for the linear collider and of providing common infrastructure and tools to facilitate these studies.

This R&D work is proceeding in three phases:
–(1)Demonstration Phase: Finish the work on-going related to many items outlined in the preceding section using "small" (ϕ ~30cm) prototypes, built and tested by several of the LCTPC groups. This work is providing a basic evaluation of the properties of an MPGD TPC and demonstrating that the requirements outlined above and in Sec. 3 can be met.
–(2)Consolidation Phase: Design, build and operate a "Large Prototype" (LP) at the EUDET facility[12] in DESY. By "Large" is meant ~1m diameter, i.e., the detector is significantly larger than the current prototypes, so that: first iterations of TPC-design details for the LCTPC can be tested, larger area readout systems can be operated and tracks with a large number of measured points are available for analyzing correction procedures.
–(3)Design Phase: Start to work on an engineering design for aspects of the final detector. This work in part will overlap with the work for the LP, but the final design can only start after the LP R&D experience allows decisions on technical options.

4.2.1 Facilities

A number of test facilities have become available over the last few years for TPC studies.

Magnets
–At DESY a high-field magnet test stand was commissioned in late 2002 which provides magnetic fields of up to 5.3T in a volume of 28 cm diameter by 60 cm length. This magnet is equipped with a cosmic ray trigger, and a UV laser was added to allow high rate and multi-track measurements. This magnet has been used by ~10 groups for tests of prototypes with MWPC, GEM or resistive-foil techniques. In addition a 1T magnet in a test beam (see below) was used.
–A 2T, 53 cm-bore magnet with homogeneous field was available at Saclay and used for studies of Micromegas TPCs with cosmics.
–At KEK two 1T coils with 85 cm-bore, one for beam tests and the other for cosmic tests, were employed. The former was "thin-walled" (20% X_0) so that the test beams could penetrate the the coil into the TPC volume with little degradation. This coil, PCMAG (earlier known as JACEE), will be used in future for the EUDET facility[12].

Test beams
–At KEK the groups have been using a test beam with momentum up to 4 GeV/c and PID capabilities for TPC measurements with electrons, pions, kaons and protons.
–One group has performed extensive prototype tests at a hadronic test beam[37] at CERN.
–DESY provides an electron test beam of up to 6 GeV electrons was used by several TPC groups. The studies employed a 1T magnet and a Si telescope. The beam will be used for the future EUDET program and equipped with the PCMAG from KEK as mentioned above.

Finally, several groups have set up and are operating small *cosmic-ray* test stands, which have been used to establish operational procedures and measurements for their prototype chambers.

4.2.2 Prototype TPC chambers

To gain experience and explore potential improvements, a number of different small prototype TPCs have been built by 12 of the groups and tested in collaboration with other groups. Several of the chambers were built to fit inside the high field test facility at DESY, the magnet at Saclay or that at KEK, to test out some first ideas about the mechanical and electrical structure of a possible future TPC. These chambers typically have diameters of ~ 30 cm and drift lengths up to 1 m.

To provide a direct comparison of MPGDs, two chambers were constructed (one at MPI/DESY/KEK and the other at Cornell/Purdue) for which endplates with all four options, MWPC, GEM, Micromegas and the resistive-foil technique, are being tested; some results are in Sec. 5. These two chambers plus the prototypes mentioned in the previous paragraph will provide valuable cross-checks on performance of the different options.

The evaluation of the performance of all above prototypes will feed into the ensuing LP R&D program at the EUDET facility, where the definitive tests for the LCTPC technology decisions will be carried out.

4.3 Executive summary of what has happened to date

Up to now during Phase(1),
–about 4 years of MPGD experience has been gathered,
–gas properties have been well measured,
–the best possible point resolution is understood,
–the resistive foil charge-spreading technique has been demonstrated,
–CMOS pixel RO technology has been demonstrated,
–the proof of principle of TDC-based electronics has been shown and
–design work is starting for the LP.

5 R&D results

A selection of R&D developments related to the LCTPC design issues in Sec. 3 are presented here.

5.1 Gas-amplification systems and performance

A central part of the R&D activities for the LCTPC is the optimization of performance of the chamber and therefore the invesigation of the performance of different types of MPGDs, as pointed out under Sec. 3.1. The GEM foils have been produced mainly at Cern[11] up to now, while foils from other manufacturers (in Germany, Japan, Russia and the USA) were tested as well. Also Micromegas have been made by the Cern workshop; a recent development was that of so-called bulk Micromegas, where the padplane, pillars and mesh are integrated into a single unit using a manufacturing procedure involving additional steps, and good results were achieved. Recently US groups have access to both GEM foils and Micromegas produced by the 3M company. In general the performance of MPGDs made by different manufacturers has been comparable but more tests will be required before any final decisions can be.

Operational experiences with MPGD TPCs
As experience has grown, reliable operating conditions have been established for both GEM and Micromegas by the TPC groups. The prototypes mentioned in Section 4.2.2 have been operated over extended periods of time. As expected cleanliness plays an important role in preparing the chambers for operation, to avoid dust and other foreign substances from compromising the HV performance of the devices.

When designing a MPGD equipped system special care has to be taken to minimize the stored energy in the end plates. The GEM or Micromegas systems form essentially large capacitors relative to the readout plane. Under some circumstances enough energy can be stored in this capacitance to destroy the MPGD in the case of a sudden discharge. This can be avoided by subdividing the MPGD into smaller areas, and properly protecting them from the power supply to avoid sudden surges in the current, as was demonstrated by the Compass experiment[27].

CB/TB members: For what follows we have to decide which plots to show. Some aspects including excerpts from subsections in the PRC2006 report are put here as place-holders. The text will have to be rewritten as soon as we decide on the plots...

Resolution studies with MPGDs
One of the central requirements for a TPC at the LC is a good single point resolution. The goal is to achieve around 100 μm, which is well below point resolutions reached in previous large TPCs. Many measurements have been performed over the last year on prototypes with MWPC, GEM and Micromegas gas-amplification endplates, and some representative results will be presented in this section. First a brief description of related software work necessary for interpreting the data will be presented.

Software work
For this work, a significant effort on simulation carried out for earlier detector studies[1], and much more has followed since data from the prototypes is being analyzed and the overall detector design is undergoing reiteration. Software/simulation/analysis work is being pursued by the groups listed under the LCTPC/LP Workpackages in Sec. 6.1. Victoria[24], DESY[26] and Carleton[14] have developed track-fitting tools for understanding the TPC resolution, and these are being utilized by all groups studying data from the prototypes. Also simulation work is on-going to understand the TPC calibration and performance in the presence of backgrounds, The calculations are being revisited with more sophisticated programs[43] and using the latest ILC machine configurations (see also Sec. 3). Further developments will be detailed in Sec. 6.2.

GEM
⟹Figure 1 shows...???

Figure 1: GEM(a)left and (b) right

Micromegas
⟹Figure 2 shows...???

Figure 2: Micromegas(a)left and (b) right

Another example: MWPC, GEM, Micromegas, resistive foil TPC tests at KEK
The runs were performed in the following order: MWPC (June 2004), GEM (April 2005), Micromegas (June 2005) and MPGD with resistive foil (October 2005) (the resistive-foil results are discussed in the next item).
⟹Figure 3 shows...???

Figure 3: Kek Beamtests(a)left and (b) right

Methods to improve the resolution
Various techniques for "spreading the charge" are under study to avoid degradation in the point resolution due to single-pad hits related to short drift distances. As reported at the previous PRC review[7], in the case of GEMs it has been shown that diffusion between the last GEM and the pad plane can defocus the charge cloud to about 0.35 mm width (depending on gas/operating parameters). Further it was shown that the pad width can be about 3 times that of the cloud and still allow enough charge sharing, but further work is needed to determine the optimal pad size using this defocussing property.

Another possibility also reported previously, the resistive-foil technique, will discussed in some detail next since more tests have been done. In this case a high surface resistivity film, used for the anode, is bonded to the readout padplane with an insulating layer of glue[35].
⟹Figure 4 shows...???

Expected resolution
⟹Figure 5 shows...???

Progress towards a TPC with CMOS pixel readout

As reported to the PRC in 2004[7], first tests were carried out in a small test chamber at Nikhef with a "MediPix" chip, developed for medical applications, and Micromegas gas amplification. The MediPix chip provided a pixel matrix with amplification and threshold discrimination, but had no time stamping capability. The Si chip for the next step was described in the PRC 2006 report[**?**]prc2006); planned is a CMOS-based pixel matrix and measure also the drift time. The chip proposed for first testa is the "TimePix" chip. Each pixel will be equipped with a preamp, a discriminator, a threshold DAC and time-stamping circuitry.

The layout at Nikhef
⟹is seen in Fig. 6...???

Since the PRC in 2004,
-there were problems with consolidation of earlier results with Micromegas[19] on Medipix presumably due to discharges which damaged the Medipix chips. This is in contrast to

Figure 4: Resistive foil(a)left and (b) right

Figure 5: Expected resolution(a)left and (b) right

Freiburg experience with triple-GEM on Medipix (see below), which did not yet damage a single chip.
-There has been qualitative understanding [36] of single electron-detection measurements (from MIPs) by the GEM and Micromegas setups at Freiburg and NIKHEF.
-First results have been achieved using an electron-multiplying grid made in wafer post-processing technology[21].
-A first series of ageing measurements of Micromegas has been carried out. The paper is in preparation, and a follow-up of systematic studies is being planned.

The setup at Freiburg[20] recently built using the MediPix chip and GEM gas amplification is
$\Longrightarrow$seen in Figure 7...???

Double-track resolution studies The resolution of close-by tracks is very important in the densely collimated jets expected at the linear collider. The specifications call for a possible double-track resolution of a few mm, which is about an order of magnitude better than in previous TPCs.

Techniques used are test beams on the one hand, UV-laser beams on the other. The approach described here is the use of a UV laser to produce close-by tracks under controlled conditions. First measurements with a laser based system were done in the 5T magnet in the summer of 2004 and reported at the previous PRC. First investigations were carried out in [24], by measuring the point resolution on close-by tracks, and further investigations of this quantity are underway[25].
$\Longrightarrow$Figure 8 shows...???

5.2 Endplate

A central part of a MPGD TPC is the structure of the readout endplate. For the prototype TPCs built so far no attempt was made to optimize the support structures for MPGD, nor has special attention been paid to minimize the material budget. Work has started for the next generation of LP prototypes as explained in Sec. 6, to develop a first realistic model of an endplate. Some ideas were shown in the LDC[2] and GLD[3] Detector Outline Documents, $\Longrightarrow$for example Fig. 9...???

A first design for the LP endplate
$\Longrightarrow$is seen in Fig. 10...???
In collaboration also with groups from the calorimeter R&D efforts within the linear collider community, studies are underway about the production and support of large area MPGDs.

Figure 6: CMOS Nikhef(a)left and (b) right

Figure 7: CMOS Freiburg/Bonn(a)left and (b) right

Figure 8: 2-track resolution(a)left and (b) right

5.3 Electronics

a) Standard Readout
An important part of the development of an LCTPC is going to be the development of high density low-power electronics that will allow a thin endplate ($< 30\%$ X_0) to be built.

Work started at the time of the PRC 2004 review[7] on a development of a dedicated electronics version for the LCTPC[17]. It took advantage of the rise time of the MPGD signals, was highly integrated, with a 10bit ADC running at 40 MHz sampling speed. An alternative development[18] started at that time will be tested within the EUDET program; this has been the investigation of a TDC based system for the readout of a TPC. The idea is based on charge-sensitive readout electronics, equipped with a charge-to-time conversion circuit and multi-hit TDC for each channel. It was demonstrated that it is feasible to operate this new type of readout electronics with a TPC detector based on GEM, and performance studies are ongoing.

The LP work planned for EUDET will adapt the ALTRO chip designed for the ALICE experiment[16] in order to have a large number of channels available for the tests.

The LCTPC readout-density requirement discussed in the Sec. 3 is an ASICs problem which appears solvable because the deep sub-micron technology available is pushing to ever-smaller features. The ALICE TPC[16] used 0.25-micron technology, and a new study for the LCTPC will address the 0.13-micron technology[29]. The power problem also appears solvable since one can take advantage of the time structure of bunch crossings at the ILC to ramp down the power between bunch trains (a train of 3000 bunch crossings followed by a 200 ms pause until the next train). Dedicated work on a electronics design for the LCTPC utilizing these aspects has is one of the LCTPC workpackages, Sec. 6. A preliminary specification is given in the following Table 2.

b)Si-based TPC-readout concepts
In this technique[5] [19][20][21][22] the MPGD is produced using wafer post-processing technology on top of a CMOS pixel readout chip with $\sim 50\mu$m pixel size. This concept offers the possibility of pad sizes small enough to observe individual single electrons formed in the gas and count the number of ionization clusters per unit track length, instead of measuring the integrated charge collected. Initial tests using Micromegas[19] and GEM foils[20] mounted on the Medipix2 chip provided two-dimensional images of minimum ionizing track clusters. A modification of the Medipix2 chip (called TimePix) to measure also the drift time is under development within the framework of EUDET[12]. Also a first working integrated grid has been produced[21]. A first set of TimePix chips has recently been produced for the LP R&D[23] being carried out at EUDET (Sec. 6).

Figure 9: IPN-Orsay endplate(a)left and (b) right

Figure 10: LP endplate(a)left and (b) right

Table 2: Electronics specification for the LCTPC.

to be written...	to be written..........
to be written...	to be written..........

5.4 Chamber gas

As already explained, the gas choice for the LCTPC is crucial. Gases being investigated are variations of standard TPC gases; some examples are: Ar(93%)CH_4(5%)CO_2(2%)–"TDR" gas, Ar(95%)CH_4(5%)–"P5" gas, Ar(90%),CH_4(10%)–"P10", Ar (90%)CO_2(10%), Ar (95%)Isobutane(5%) and Ar(97%)CF_4(3%). In general the properties measured are in good agreement with the predictions by the Magboltz simulation[31]. Thus gas simulations can be used to help design the LCTPC.

An interesting alternative to the traditional gases is a Ar-CF_4 mixture. These mixtures give drift velocities around $8-9$ cm/μs at drift field of 200 V/m, have no hydrocarbon content and have a reasonably low attachment coefficient at low electric fields. However at intermediate fields (∼5-10 kV/cm), as are present in the amplification region of a GEM or a Micromegas the attachment increases drastically, thus limiting the use of this gas to systems where the intermediate field regions are of the order of a few microns. This is the case for Micromegas, but its use has not been tested thoroughly for a GEM-based chamber. If the loss of primary electrons is significant, both the point resolution and the dE/dx measurement will be degraded. Also CF_4 can be aggressive and caution warnings must be heeded before deciding whether it should be used in a chamber the magnitude of the LCTPC. Thus, whether CF_4 is an appropriate quencher for the LCTPC is not yet known and is being tested as a part of our R&D.

5.5 Fieldcage

An important function of the field cage is to maintain as homogeneous a field as possible and be as thin as possible. Simulations have been carried out to optimize the structure of field forming strips. It is known that the most homogeneous field can be achieved if the complete area of the field cage is covered with strips. Therefore the current design foresees strips on the inside and on the outside of the insulating layer, staggered by half a width of the strips. A uniformity of better than $\delta E/E = 10^{-4}$ seems achievable. Currently work is underway to study the influence of possible field inhomogeneities on the overall resolution of the TPC.

As for the thinness, the structures for the field cage investigated are composite structures. A high tensile shell made from either carbon fibre or glass fibre and epoxy composite is glued to a shell of very light honeycomb material. On the inside a layered structure of a highly insulating material like Kapton or Mylar provides HV insulation and the surface on which the electrodes for the field cage are mounted.

Two prototype field cages were built along these principles. They differ in that one uses carbon-fibre and the other glass-fibre as structural material and in the way in which the resistive divider is mounted in the chamber. Currently experiments are under way to

commission these field cages and to understand their properties. In future these techniques can be further developed and tried at the EUDET facility, as seen in
⟹Fig. 11...???

Figure 11: Drawing of the fieldcage for the LP.

5.6 Space charge

Ion backflow and charge transfer studies in MPGD structures
Studies at Aachen were described for the PRC in 2004[7] where the optimization of GEM voltages was demonstrated. Using the parametrisation of the GEM charge transfer coefficients as a function of the electric fields, the ion backdrift is calculated as a product of charge transfer coefficients and single GEM gain factors. By scanning the whole parameter space and calculating the ion backdrift at every point, minima in ion backdrift could be found. Using this method, an ion backdrift of 2.5 per-mille has been achieved in a magnetic field of 4T. The results are seen in
⟹Fig. 12...???

Figure 12: Backflow (a)left and (b) right

Since the goal of 1/gasgain will be difficult to achieve and for other reasons discussed under Sec. 3.6(c), a gating grid will be foreseen. Gating using a GEM layer may be possible[33], but whether this will work or not is not yet completely understood. Also other options for the gating plane are also being considered.

5.7 Non-uniform fields

Other measurements was made using the Karlsruhe prototype in a CERN testbeam[37], where a positive-ion build up of about 1 pC/cm^3 was induced. The effect if this ion cloud on charged tracks is being quantified, but it seems that tracks suffer little when passing through such a region if the gradient is small.

At EUDET, the PCMAG magnetic-field gradient will amount to several percent, so that the methods in Sec. 3.8, will have to be applied, as discussed in the next section.

5.8 Calibration and alignment

This very important topic is discussed in detail in the Sec. 3.8. It will be a subject to investigate during the TPC R&D program at EUDET[12] to measure these effects and test the tools for making the corrections. In general since the problem has already been solved at LEP[38][39][41][42] to the necessary level of precision, we should make sure these tools are available and apply them to the studies at EUDET.

5.9 Backgrounds

As stated in Sec. 3.9, earlier simulations of backgrounds[1] yielded a low occupancy ($< 0.5\%$) from all sources which have been[42] and are being investigated. The calculations are being revisited with more sophisticated programs[43] and using the latest ILC machine configurations.

The tracking efficiency has been simulated for different backgrounds[44], and the results are
⟹shown in Fig. 13...???

Figure 13: Tracking efficiency (a)left and (b) right

6 Next R&D steps, the LP and SPs

The small-prototype (SP) work will continue for the next couple of years in parallel with Phase(2), the consolidation of the efforts via the construction and operation of the LP. It will be carried out at the EUDET facility[12] which is also starting and will provide the infrastructure for performing LC detector R&D. The LP work is expected to take about four years and will be followed by Phase(3), the design of the LCTPC.

6.1 The Workpackages

To summarize briefly the planning for the LCTPC and the LP, the tasks have been broken down into "LCTPC/LP Workpackages" (WP) below, and the tasks have been distributed among the LCTPC groups listed on this report. These workpackages are set up for building the EUDET facility and performing the R&D relevant to the design of the LCTPC outlined in the Sec. 3.

```
        Workpackage:                             Groups involved:
        (convener)

Workpackage (0) TPC R&D Program                  LCTPC collaboration
-------------------------------


Workpackage (1) Mechanics
-------------------------
 a) LP design, incl. endplate structure        Cornell,Desy,MPI,IPNOrsay,
    (Dan Peterson)                               +contribution from Eudet
 b) Fieldcage, laser, gas                      Aachen,Desy,St.Petersburg,
    (Ties Behnke)                                +contribution from Eudet
 c) GEM panels for endplate               Aachen,Carleton,Cornell,Desy/HH,
    (Akira Sugiyama)                               Kek/CDC,Victoria
 d) Micromegas panels for endplate              Carleton,Cornell,Kek/CDC,
    (Paul Colas)                                   Saclay/Orsay
 e) Pixel panels for endplate             Freiburg,Nikhef,Saclay,Kek/CDC,
    (Jan Timmermans)                             +contriubution from Eudet
 f) Resistive foil for endplate             Carleton,Kek/CDC,Saclay/Orsay
    (Madhu Dixit)

Workpackage (2) Electronics
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---------------------------
 a) Standard RO/DAQ sytem for LP             Aachen,Cern,Desy/HH,Lund,Rostock,
    (Leif Joensson)                                  Montreal,Tsinghua,
                                                  +contribution from Eudet
 b) CMOS RO electronics                            Freiburg,Nikhef,Saclay,
    (Harry van der Graaf)                         +contribution from Eudet
 c) Electronics/power switching/cooling for LCTPC
    (Luciano Musa)                            Aachen,Cern,Desy/HH,Lund,Rostock,

                                               Montreal,St.Petersburg,Tsinghua,
                                                  +contribution from Eudet
Workpackage (3) Software
------------------------
 a) LP software +
    simul./reconstr.framework         Desy/HH,Freiburg,Carleton,Victoria,
    (Peter Wienemann)                             +contribution from Eudet
 b) LCTPC simulation/perf., backgrounds  Aachen,Carleton,Cern,Cornell,Desy/HH,
    (Stefan Roth)                           Kek/CDC,St.Petersburg,Victoria

 c) Full detector simulation/performance           Desy/HH,Kek/CDC,LBNL
    (Keisuke Fujii)

Workpackage (4) Calibration
---------------------------
 a) Field map for the LP                       Cern+contribution from Eudet
    (Lucie Linsen)
 b) Alignment                                          Cern,Kek/CDC
    (Takeshi Matsuda)
 c) Distortion correction                                Victoria
    (Dean Karlen)
 d) Radiation hardness of materials                    St.Petersburg
    (Anatoliy Krivchitch)
 e) Gas/HV/Infrastructure for the LP                   Desy, Victoria,
    (Peter Schade)                                +contribution from Eudet
```

6.2 Software developments: status and plans.

In the course of LCTPC activities a rather large variety of simulation, analysis and reconstruction software packages has been developed. The usage of these packages ranges from studying TPC performance as part of an overall detector for different detector layouts and background conditions, optimising prototype designs, reconstructing and analysing cosmics and testbeam data from various small prototypes using different readout technologies to full detector physics analyses. Most of these individual software packages have become rather sophisticated in their particular field of application. Valuable experience was collected during usage and development of the software partly leading to novel techniques to cope with new challenges encountered in TPCs with MPGD amplification. The drawback of this specialisation is that the software often works smoothly only for particular applications or TPC setups.

Exchanging code between different packages or analysing data from different sources with the same program can be very time consuming and errorprone since the different programmes do not use commonly accepted interfaces and conventions.

In view of the converging hardware efforts (the LP), to improve the mutual understanding of our results and to avoid further double work, it is desirable to converge on the software tools. In June 2006 an initiative was started to take the first step towards this direction. Representatives of six LCTPC member institutes met at DESY to find an agreement on common software standards. It was decided to transfer the existing algorithms to a new, commonly used framework, called MarlinTPC [45], building on top of LCIO [46], the de facto standard data format for ILC related work, and the accompanying ilcsoft tools [47]. This choice is motivated by the possibility to profit from general ILC software developments and by the fact that ilcsoft tools are already used by many other subdetector, simulation and physics analysis software projects. In particular Marlin [48] was chosen as analysis and reconstruction framework. Its modularity and well defined interfaces between its modules, called processors, ensure that different developers can work on different processors in parallel without interference and to plug'n'play with processors to easily try out e. g. different algorithms. In the beginning the focus is laid on the development of reconstruction processors, to be followed by simulation and analysis ones.

Further important pillars of MarlinTPC are the Linear Collider Conditions Data (LCCD) toolkit [49] and GEAR (Geometry API for Reconstruction) [50]. LCCD allows writing and reading of conditions data describing the detector status as function of time. It allows to tag data sets for later easy reference and to request data valid at a particular point in time. GEAR allows to access geometry information needed for the reconstruction of events. Thereby it is made sure that consistent geometry information is used throughout the reconstruction.

An additional important design consideration of MarlinTPC is to make the software as grid-aware as possible in order to facilitate the usage of grid computing and storage resources as they are e. g. made available by EUDET [51].

MarlinTPC is made available through a publicly accessible software repository. It is still under development but a first release is expected in the course of the year 2007. The source code and a draft of the document describing the used conventions is available on the MarlinTPC homepage [45].

6.3 Outline of LP and LCTPC R&D tasks

Regular bi-weekly WP phone meetings started in May 2006 where details for the LP design are being worked out and the general plan of R&D steps developed. The following Table 3 gives a snapshot of present planning. The LP is under way, and the groups agree that over the next three years there will be an evolution of endplates towards a true prototype for the LCTPC. These stages are sympolized by LP1, LP1.5, LP2 in the table. Supplemental testing with the small prototypes (SP) which have been used extensively to date will continue, since there are still several issues to be explored which can be performed more efficiently with small, specialized set-ups.

7 Conclusion

The LCTPC groups after more than four years of concerted effort have accumulated a large body of data and experience with the operation of TPCs equipped with MPGDs. The basic

Table 3: LCTPC R&D Scenarios for Large Prototype and Small Prototypes.

Testbeam Options		
Lab	Beams	Availability
CERN SPS	10-400GeV e, h, μ	LHC absolute priority
DESY	1-6.5GeV e	$>$ 3 months per year
Fermilab	1-120GeV e, h, μ	Continuous (5%), except shutdown
IHEP Protvino	1-45GeV e, h, μ	One month, twice per year
KEK Fuji	0.5-3.4GeV e	From fall 2007, 240 days per year
SLAC	28.5GeV e (primary) 1-20GeV e, h (secondary)	Parasitic to PepII, non-concurrent with LCLS

Large Prototype R&D		
Device	Lab(years)	Configuration
LP1$\rightarrow$1.5	Desy/Eudet(2007-2009)	Fieldcage$\oplus$2 endplates: Gem+pixel, Micromegas+pixel
<u>*Purpose:*</u> *Test construction techniques using 10000 Alice/Eudet channels, demonstrate measurement of 6GeV beam momentum over 70cm tracklength, including development of corrections procedures*		
LP2	Fermilab/Eudet(2010-2011)	Fieldcage$\oplus$1 endplate: Gem, Micromegas, or pixel
<u>*Purpose:*</u> *Prototype for LCTPC including gating and other options, demonstrate measurement of 100GeV beam momentum over 70cm tracklength, and in jet evironment, test prototype LCTPC electronics*		

Small Prototype R&D		
Device	Lab(years)	Test
SP1	KEK(2007-2008)	Gas tests, gating configurations
SP2,SP3	Fermilab(2007-2008)	Performance in jet environment
SPn	LCTPC groups(2007-2009)	Performance, gas tests, dE/dx measurements, continuation of measurements in progress by labs with small protypes

feasibility of using MPGDs in a TPC could be demonstrated.

Currently the participating groups are in the process of finalizing first systematic investigations of the single-point and double-track resolutions. Several methods are under study to readout the large number of channels required, including a proposal to directly couple a CMOS pixel sensor to the readout plane of a TPC.

In future the work will concentrate on the design, building and operation of a series of larger prototype-endplates within the LCTPC/LP project at the EUDET facility, to test not only the basic feasibility but also detailed engineering questions. All these should be answered before a real design of a TPC for the ILC detector can be started.

The LCTPC groups expect that this second phase of the work will take around four years and will require substantial funding in addition to what will be provided by the EUDET infrastructure.

8 APPENDIX–Formation of the LCTPC Collaboration

Several meetings of the TPC groups were held between May and October 2006 where the ground rules were discussed. The following structue was decided on:

- THE COLLABORATION WILL REMAIN OPEN TO NEW GROUPS
- GENERAL STRUCTURE

  1)There will be three coordinators, one for each region, for a period of two years. These three regional coordinators (RC) will choose a chairperson who will be the LCTPC Spokesperson.

  The RCs will work with the following two boards:

  2)The technical board (TB), consisting of the existing workpackage (WP) conveners. The TB will ensure the technical integrity of their WP and compatibility with other WPs while maintaining close contact with the collaboration.

  3)The collaboration board (CB), consisting of one representative from each group or set of groups (the group leader, principle investigator or other chosen member). Each CB member looks after the resources for its group(s) (money and people).

- STATUS

  1)The RCs, after selection of candidates by search committees in each region which were voted on by the CB members of the respective region, are
  –Americas: Dean Karlen
  –Asia: Takeshi Matsuda
  –Europe: Ron Settles (who only wants to continue the job for one year) followed by Jan Timmermans.

  2)The TB members are listed in Sec. 6.1.

  3)The CB members are:

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--Americas--
Carleton:           Madhu Dixit
Montreal:           Jean-Pierre Martin
Victoria:           Dean Karlen
Cornell:            Dan Peterson
Indiana:            Rick Van Kooten
LBNL:               Dave Nygren
Louisiana Tech:     Lee Sawyer
--Asia----------
Tsinghua:           Yuanning Gao
For the CDC groups: Akira Sugiyama
Hiroshima
KEK
Kinki
Saga
Kogakuin
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Tokyo U A & T
U Tokyo
Tsukuba
Mindanao
--Europe----------
LAL Orsay/IPN Orsay: Vincent Lepeltier
CEA Sacly:           Paul Colas
Aachen:              Stefan Roth
Bonn:                Klaus Desch
Desy/UHamburg:       Ties Behnke
Eudet:               Joachim Mnich
Freiburg:            Andreas Bamberger
MPI-Munich:          Ariane Frey
Rostock:             Henning Schroeder
                        (deputy: Alexander Kaukher)
Siegen:              Ivor Fleck
Nikhef:              Jan Timmermans
Novosibirsk:         Alexei Buzulutskov
St.Peterburg:        Anatoliy Krivchitch
Lund:                Leif Jonsson
CERN:                Michael Hauschild
                        (deputy: Lucie Linsen)

--Groups with Observer status do not have CB members--
TU Munich:             Bernhard Ketzer
Purdue:                Ian Shipsey
Iowa State
MIT
Yale
Karlsruhe
Krakow
Bucharest
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- SPOKESPERSON SELECTION

  The RCs decided not to have a predetermined rotation of RCs as Chairman/Spokesperson; the Chairman will be chosen by the RCs once per year, and the reasoning for the choice will be explained to the collaboration.

  For the first year, Ron Settles was chosen to be Chairperson/Spokesperson.

- TO-DO LIST:

  –Set up important subcommittees:
  steering,
  editorial,
  speakers,
  among others.

  –Draft a collaboration document.

–Draft a loose MOA for the LP work.

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