TPC R&D for an ILC Detector

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.

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

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].

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 tracker 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 $\sim$2ns (e.g., 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$_T \sim 1.4$ mm for Ar-10%CH_4 gas after 2 m drift in a 4T magnetic field[9]). 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) or even several 10^{12} voxels in case of a CMOS pixel readout. 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[4]. (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 upfront from the start 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)[10][11][12]; further explanations follow in Secs. 4 and 5.

The following issue is a good example where the overall detector design must take into account all subdetectors. Namely, the tracking efficiency quoted for the TPC only is for all tracks, the inefficiency arising mainly from tracks that miss the TPC. For tracks that enter or originate in the TPC, the tracking efficiency is $\sim 99\%$. For comparison, the value for the VTX is listed, for which a similar situation exists. The forward-tracking discs [1][2] catch most of the missed tracks so that the overall tracking efficiency is $> 99\%$ for all tracks, with excellent redundancy for the complex topologies and backgrounds which will be delivered by the ILC machine.

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[4], as defined mainly by the $e^+e^- \to HZ \to H\ell\ell$ 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

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 (for radial tracks, averaged over driftlength)
$\sigma_{\mathrm{singlepoint}}$ in rz	$\sim$ 0.5 mm
2-hit resolution in $r\phi$	$<$ 2 mm
2-hit resolution in rz	$<$ 5 mm
dE/dx resolution	$<$ 5 %
Performance robustness	$>$ 95% tracking efficiency for all tracks–TPC only)
(for comparison)	($>$ 95% tracking efficiency for all tracks–VTX only)
	$>$ 99% all tracking[13]
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.

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[1] and GLD[2].

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).

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 stiff, 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 in due time, as soon as more understanding evolves.

(a) Standard readout:
While an earlier proposed size was 2mm×6 mm[4]), 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 approach (à la Alice[14]) using 130 nm technology (Sec. 5.3) indicates that even smaller sizes might be feasible. An alternative to the FADC-type is the TDC approach (see [5][15]) in which time of arrival and charge per pulse by charge to time conversion are measured[16]. If it turns out that the material budget requires larger pads, then the charge-dispersion readout technique[17] 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 for the combined gas amplification and readout is under development [5]. In this concept the "standard" MPGD is produced in wafer post-processing technology[18] on top of a CMOS pixel readout chip[39], thus forming a thin integrated device of an amplifying grid and a very high granularity endplate with all necessary readout electronics incorporated. For a readout chip with $\sim 50\mu$m pixel size, this would result in $\sim 2 \cdot 10^9$ pads ($\sim 4 \cdot 10^4$ chips) per endcap. This concept offers the possibility of pad sizes small enough to observe the individual primary electrons formed in the gas and count the number of ionisation clusters per unit track length, instead of measuring the integrated charge collected. If this concept turns out to be realistic, better momentum resolution, dE/dx resolution (through primary ionisation cluster counting) and 2-track separation seem 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[20][14] or not[21] (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[9]. The $\sigma_{\text{singlepoint}}$ 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 chosen 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.

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 backflow. An important property of MPGDs is that they suppress naturally the backflow of ions produced in the amplification stage. Steps to minimize this backflow are described in Sec. 5.6, where a suppression to 0.25% is shown to be achievable. Thus this layer of ions will reach a density of $\mathcal{O}(100)$ fC/cm^3, depending on gas gain and the background conditions during operation. Its effect will be simulated, but intuitively it should affect coordinate measurement only by a small amount since the drifting electrons incoming to the anode experience this environment during only the last few mm of drift. The TPC must plan to run with the lowest possible gas gain, meaning $\sim$ 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 $\sim$1 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[20] indicates that 200 fC/cm^3 is tolerable (Sec. 3.7(b)) and $\sim$1 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 drifting 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. 5.6), 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 the ~1 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 $< 0.5\%X_0$ 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 $\int_{\ell_{\rm drift}} \frac{B_r}{B_z} dz < 2$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[22][23], 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[23] and was already achieved by the Aleph TPC[22]. Based on past experience, the field-mapping gear and methods should be able to accomplish the goal of 10^{-4} for the B-field. 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[20] 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 a ~10 mm displacement, which is of the same order as due to that of the anti-DID and 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[24] 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 loss). A laser calibration system will is foreseen (see e.g., [21][20][14]) 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[25] 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[22][23], and this level was already achieved by the Aleph TPC[22][25].

3.9 Backgrounds and robustness

The issues 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 collider, from cosmics or other sources and from physics events. The main source is the collider, 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[26]. Preliminary simulations of these under nominal conditions[4][27] indicate an occupancy of the TPC of less than about 0.5%.

This level will be of no consequence for the LCTPC performance. 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). Then, 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[20] can run with 50–5% occupancy (inside–outside radius) and still have a track recognition efficiency of $\sim$ 90% at the outside. Of course, the heavy-ion event topologies 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. 5.9.

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[10] meshes and GEM (Gas Electron Multiplier)[11] foils. Both[12] 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 charge-dispersion readout 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[14] 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[15] 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 charge-dispersion readout 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[15].

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[28] at CERN.
–DESY provides an electron test beam of up to 6 GeV electrons that 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. –Other future test-beam possibilities will be described in Sec. 6.

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 charge-dispersion readout 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-anode charge-dispersion 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 has started for the LP.

5 R&D results

A selection of recent R&D developments related to the LCTPC design issues in Sec. 3 is 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[12] 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 conclusions can be made. 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.

5.1.1 *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[29].

5.1.2 *Resolution studies with MWPC, GEM and Micromegas*

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 for stiff tracks, which is well below point resolutions reached in previous large TPCs. Many measurements have been performed over the last years on prototypes with MWPC, GEM and Micromegas gas-amplification endplates, and a few representative results will be presented in what follows.

First, a brief description of related software work for interpreting the data is given. A significant effort on simulation carried out for earlier detector studies[4], 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[30], DESY[31][32] and Carleton have developed track-fitting tools for understanding the TPC resolution, and these are being utilized by all groups studying data from the prototypes. The first[30] method is referred to as the "Global-Fit or Global-Likelihood Method", the second[32] is called the "χ^2 Method" and the third[17] was developed for the charge-dispersion technique (Sec. 5.1.4). The status of and plans for further software developments will be detailed in Sec. 6.2.

For some of the following results, the point resolution is parametrized by $\sigma_{r\phi} = \sqrt{\sigma_0^2 + C_D^2/N_{eff} \times z}$, where, σ_0 depends on diffusion during gas amplification (sometimes called "diffusion spreading") and the ratio between signal-charge spread and geometrical pad size, C_D is the diffusion constant, N_{eff} is the effective number of electrons contributing to the resolution as determined by effects of statistics, gain fluctuations and efficiency in amplification, and z is the drift distance.

MWPC

Different techniques of gas amplification were tested with a combination of gas mixtures and read-out pad planes mounted in a prototype chamber built at MPI-Munich[33] and tested with cosmics at in the 5T magnet at DESY and in a test beam at KEK using a 1T magnet (see Sec. 4.2.1). Measurements at DESY were performed in early 2004, and the test-beam runs at KEK were performed in the following order: MWPC (June 2004), GEM (April 2005), Micromegas (June 2005) and MPGD with charge-dispersion resistive foil (October 2005).

Results using MWPC gas-amplification are found in Fig. 1 which displays the resolution for different B-fields, left for DESY using cosmics and right at the KEK test beam. The measurements agree to within a few percent, which is reasonable since the composition of angles in cosmic and in beam track samples is somewhat different. They show that at B = 4T, the E$\times$B effects degrade the resolution significantly.

This was expected at high fields, and due to the confirmation by these measurements, the option of MWPC gas-amplification for the LCTPC has been dropped.

Micromegas

As said above, in June 2005, test beam data were taken at KEK in the magnet (PCMAG) at B-fields of 0, 0.5 and 1T. The pad size was $2.3 \times 6.3\text{mm}^2$.

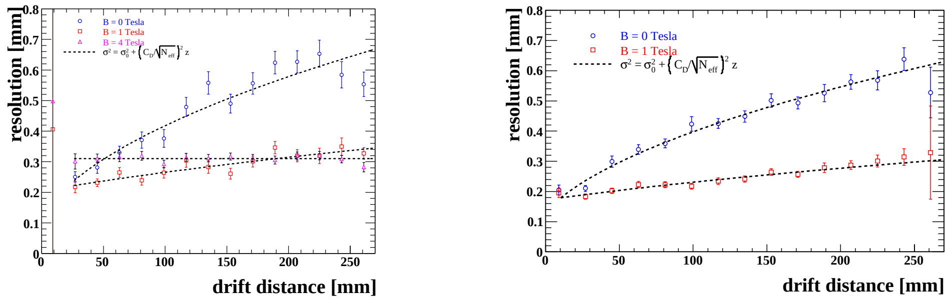

Figure 1: *Measurement of the point resolution using MWPC amplification for different magnetic fields. Left: Using cosmics in the 5T magnet at DESY. Right: Using the test beam at KEK in a 1T magnet.*

Figure 2-upperleft shows an example of the measurement of the diffusion coefficient, a key parameter for the choice of the LCTPC gas. In the course of these tests, the expected MPGD resolution became rather well understood analytically[34] (see Sec. 5.1.3), as the comparison with data shows in Fig. 2-upperright and Fig. 2-lowerleft, using both fit methods described in the introduction to this section. Also the Monte Carlo agrees well as seen in Fig. 2-lowerright, so that these tools can be used in studying the expected resolution of the LCTPC (Sec. 5.1.3)

These curves show that at low drift distance (below 5 cm) the charge from ionization is concentrated on a single pad per row, which prevents a barycenter from being calculated and hits are reconstructed in the middle of the pad with an uncertainty related to the pad width. Moreover tracks reconstructed under these conditions are biased towards the middle of a pad line, faking an better resolution (Fig. 2-upperright and Fig. 2-lowerleft). The expected degradation at low distance, due to the so-called hodoscope effect, is thus underestimated due to this track bias.

GEM

Figure 3-upperleft and -upperright show Monte Carlo studies and measurements of the influence of the number of pad rows on the single point resolution and the dependence on the reconstruction method. Here, the simulation was primarily adjusted to study the systematics of the fit methods, and not to agree perfectly with the measurements. The results show that, while the Chi-Squared and the Global-Fit methods become comparable given enough measurement points, both fit methods differ significantly using only 6 pad rows. While the Global-Fit method[30] tends to more conservative results if only 6 measurement points are available, the Chi-Squared[32] fit tends to result in a more-optimistic single point resolution. This can also be seen in Fig. 3-upperright, where resolution results from measurements with the MediTPC prototype[35] in the 5T magnet at DESY using two different pad layouts are presented. Depending on the pad layout and the reconstruction method the results show quite a large spread. Further the results indicate that a pad pitch of 2.2 mm is too large to reach the resolution goal of $\sim$100 μm.

Figure 3-middleleft demonstrates that the precision improves for narrower pads in the case of GEM[28]. In Fig. 3-middleright the measurement of the spatial resolution for pads with 7 mm height and 1.2 mm pitch for the TDR gas(Sec. 5.5) and different B-field strengths[30] gave encouraging results. Similarly for Fig. 3-lowerleft showing the resolution measured using the MP-TPC with GEM gas-amplication at the KEK test beam for the P5 and the TDR gases,

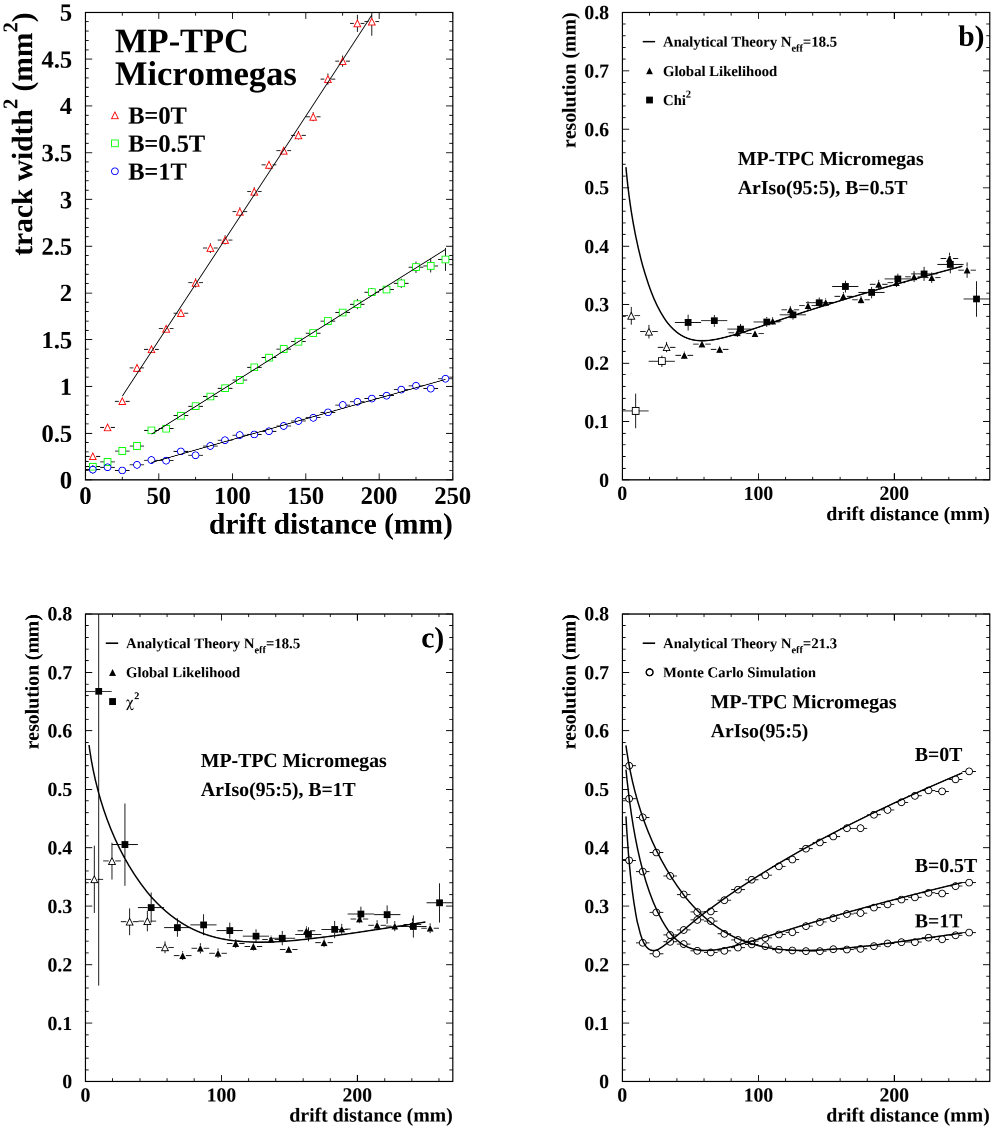

Figure 2: *Examples based on measurements using Micromegas at the beam tests at KEK. Upperleft: Gas properties, in this case the diffusion coefficient. Upperright: Resolution at 0.5T comparing 2 fit methods and the analytical theory (see text). Lowerleft: Similar to Upperleft for 1.0T. Lowerright: Comparison with Monte Carlo and the analytic formulation.*

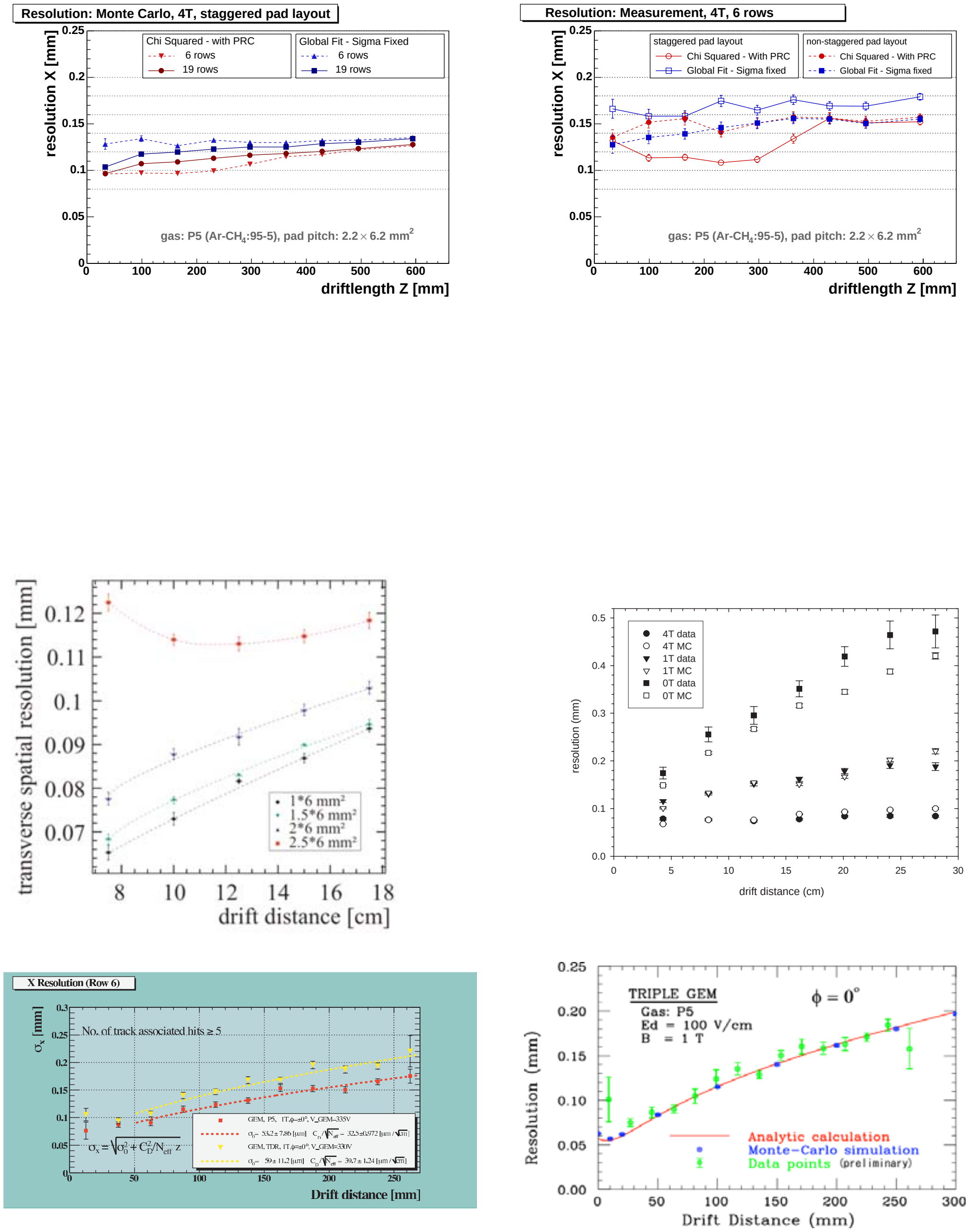

Figure 3: *Upperleft: Simulation of– and Upperright: Measurement of– the single point resolution for P5 gas, 4 T magnetic field,* $2.2 \times 6.2\,mm^2$ *pad pitch and drift distances up to 660 mm from reconstruction with MultiFit[32][36] using the Chi-Squared and the Global-Fit methods. Middleleft: Precision as a function of pad width.[28] Middleright: Measurement of the spatial resolution for 7 mm × 1.2 mm pads for different B-fields and the TDR gas. Lowerleft: Resolution with GEM gas-amplication in the MP-TPC at the KEK test beam for the P5 and the TDR gases. Lowerright: Similar to Lowerleft showing comparison with simulation and the analytic formula[34].*

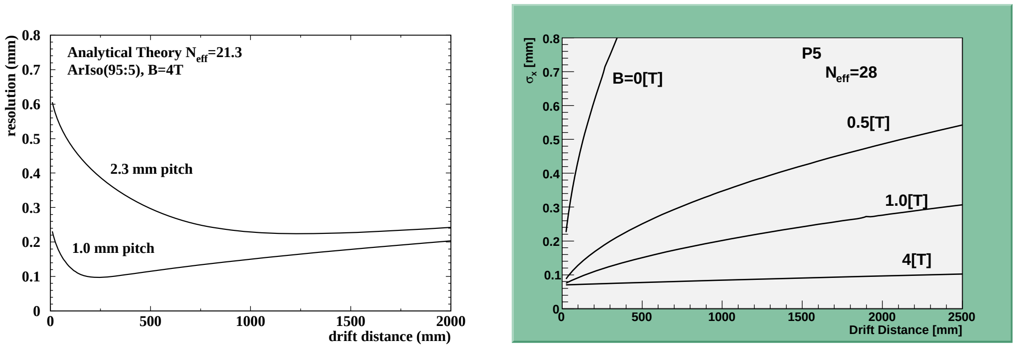

Figure 4: *Left: expected resolution without diffusion spreading as for Micromegas. Right: resolution expected with diffusion spreading as expected for GEM.*

and Fig. 3-lowerright includes of data from simulation and from the analytic formula[34].

5.1.3 *Expected momentum resolution*

For MPGDs in general, the expected resolution has been analytically derived[34]. The results depend on MPGD parameters of course; an example is presented in Fig. 4. This analytical formula, which has been confirmed by test-beam measurements as shown by several results above, can be used to help design the LCTPC. Figure 4 shows the expected resolution for two cases, left without diffusion spreading as in the case of Micromegas, and right with diffusion spreading as produced in the induction gap of a triple GEM.

Figure 4-left shows that, at the ILC in a 3-4 T magnetic field, the diffusion is so small for Micromegas that the situation is unfavorable and the hodoscope effect worsens the resolution at short drift distances, even for 1mm-pitch pads. Thus a method to spread the charge (see Sec. 5.1.4 below) would be necessary to reach the target performance in the case of Micromegas, whereas for GEM it is not needed.

5.1.4 *Methods to improve the resolution*

Various techniques for "dispersing 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 three 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 charge-dispersion readout technique, will be 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[37], as seen in Fig. 5-upperleft. The resistive anode film forms a distributed two-dimensional RC network with respect to the readout plane. A localized charge arriving at the anode will disperse with a time constant determined by the anode surface resistivity and the capacitance per unit area. With the initial charge covering a larger area as time passes,

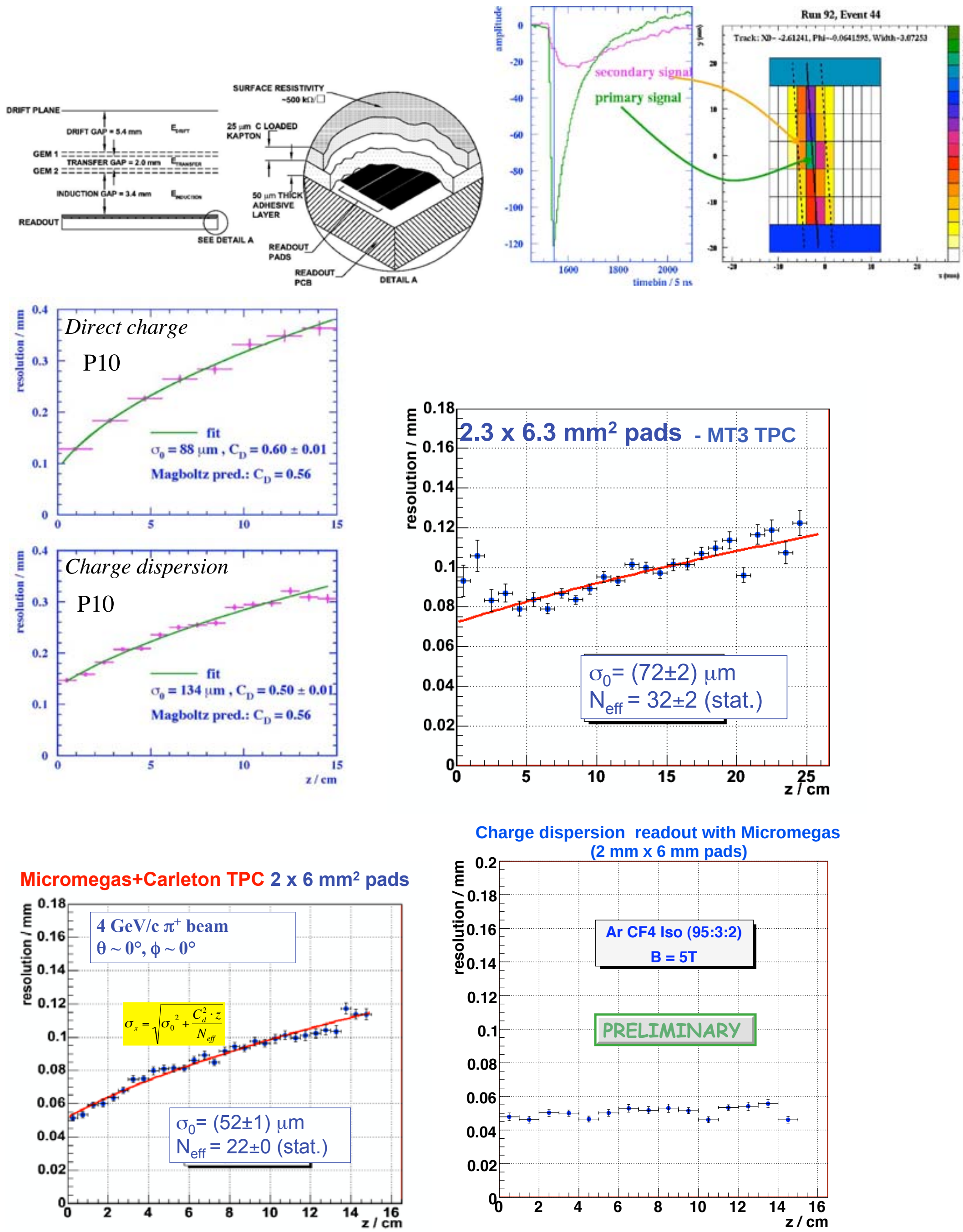

Figure 5: *Charge-dispersion readout; all measurements with resistive anode. Upperleft: Sketch of an anode with resistive foil. Upperright: Illustration of the signal evolution. Middleleft: Measurements at Carleton without magnetic field. Middleright: Measurements in the KEK testbeam using the MP-TPC (MT3 in the figure) with GEM. Lowerleft: Measurements in the KEK testbeam using the Carleton TPC with Micromegas. Lowerright: Preliminary results with cosmics at high B-field in the DESY 5T magnet using the Carleton TPC with Micromegas.*

wider pads can be used for position determination. First proof-of-principle experiments with a resistive readout plane were performed using a collimated soft X-ray source [17]. To study this method in a real TPC, a test TPC was modified as described above. The gas amplification was via a double GEM system. Figure 5-upperright illustrates a TPC charge dispersion pulse for two pads. Both the pulse rise time and the decay time depend on the position of the charge with respect to the pad. The charge collecting pad shows a fast signal. The signals on the adjacent pads have a slower rise and decay time.

A detailed simulation has been done to understand the characteristics of charge dispersion signals. Initial ionization clustering, electron drift, diffusion effects, the MPGD gain, the intrinsic detector pulse-shape and electronics effects were included. Two points are important to note:
-To extract the optimal resolution a detailed knowledge of the pad-response function (PRF) is needed. The pad-response function is measured using cosmic muons in seperate runs.
-The charge dispersion signals are affected by non-uniformities in the anode resistivity and the capacitance per unit area. Position measured from PRF need to be corrected for local RC distortions. The bias corrections were also determined from the internal consistency of the calibration data set.

This technique was tested earlier with cosmics at Carleton without magnetic field; results are seen in Fig. 5-middleleft. Further measurements were made recently in the 4 GeV/c pion beam at KEK with magnetic field as described above. Several gases were used, Argon with different quenchers: CO_2, CH_4, C_4H_{10} and CF_4.

Figure 5-middleright presents results obtained with the MP-TPC, P5 gas and 1T B-field measured, and Fig. 5-lowerleft obtained with the Carleton TPC prototype and Micromegas endplate using Argon-Isobutane gas and B=1T. All results are still preliminary and in preparation for publication. Finally measurements on cosmics in the DESY 5T magnet were performed to test the technique at high magnetics fields, and preliminary results are plotted in Fig. 5-lowerright. Clearly these results are intriguing, and next measurements (Sec. 6.3) are being planned to test the technique in a jet environment.

5.1.5 *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 was the use of a UV laser to produce close-by tracks under controlled conditions. First measurements with a laser-based system performed in the 5T magnet in the summer of 2004 were reported at the previous PRC[8]. These investigations[30] were carried out by measuring the point resolution on close-by tracks. Figure 6 shows the result of these first measurements. The results indicate that for short drift distance, the two-track resolution is acceptable above around 1.6mm. The simulation result for muons with 2 mm wide pads, indicate good resolving power for separations above around 3 mm. Further studies using a laser-based system are underway[38].

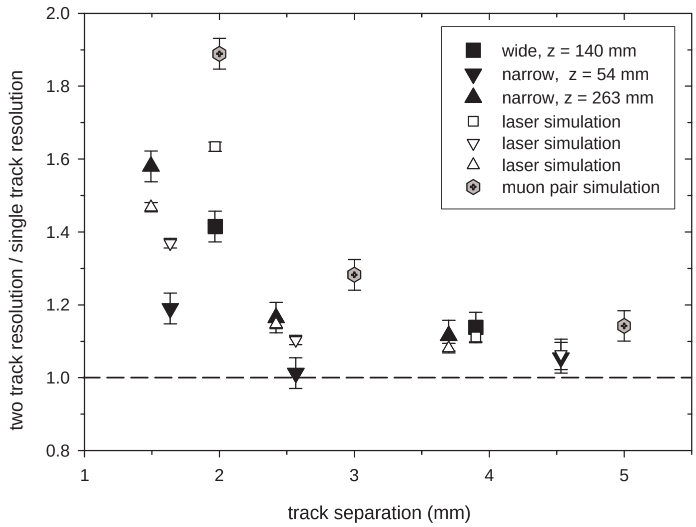

Figure 6: *The degradation in transverse resolution is shown as a function of the transverse separation between two parallel tracks, for P5 gas at 4T. The z values shown are the drift distances of the tracks. The wide pads have 2 mm pitch, the narrow ones have 1.2 mm. The laser data and simulations (open symbols with the same shape) show rough agreement.*

5.1.6 *Progress towards a TPC with CMOS pixel readout*

Initial "proof-of-principle" tests using Micromegas and GEM foils provided 2-dimensional images of minimum ionising track clusters[39][40] using the Medipix2 chip, developed for medical X-ray imaging. Within the EUDET programme a modification of the Medipix chip was developed (the TimePix chip), which also measures the arrival time of the signals on each pixel of the matrix, thus providing a full 3D image of tracks. Every pixel in the chip matrix can be selected to record either arrival time w.r.t. a common stop or to record the time-over-threshold, thus providing a (crude) pulse height measurement. A first full-reticle submit during summer 2006 was successful and the chip is being tested in small drift chambers both with Micromegas and GEM gas multiplication systems (Sec. 6.3).

The layout at Nikhef is seen in Fig. 7.

Since the PRC in 2004,

–First results used an electron-multiplying grid made in wafer post-processing technology (Ingrid)[18]. Since then much better control of the production process has been achieved and various geometries of grid holes shape and pitch and of the height of the multiplication gap were produced and tested with various gas mixtures.

–There were problems with consolidation of earlier results with Micromegas[39] on Medipix presumably due to discharges which damaged the Medipix chips. This is in contrast to Freiburg experience with triple-GEM on Medipix (see below), which did not yet damage a single Medipix chip. To prevent discharges two possibilities are being pursued:(a) The application of a highly resistive amorphous Silicon layer on the chip (the first TimePix chip tested with Micromegas was 'protected' this way). (b) The production of a double integrated (Micromegas) grid in post-processing, such that the gas multiplication gap will no longer be immediately above the chip. A successful fabrication attempt was made (Fig. 8(right)).

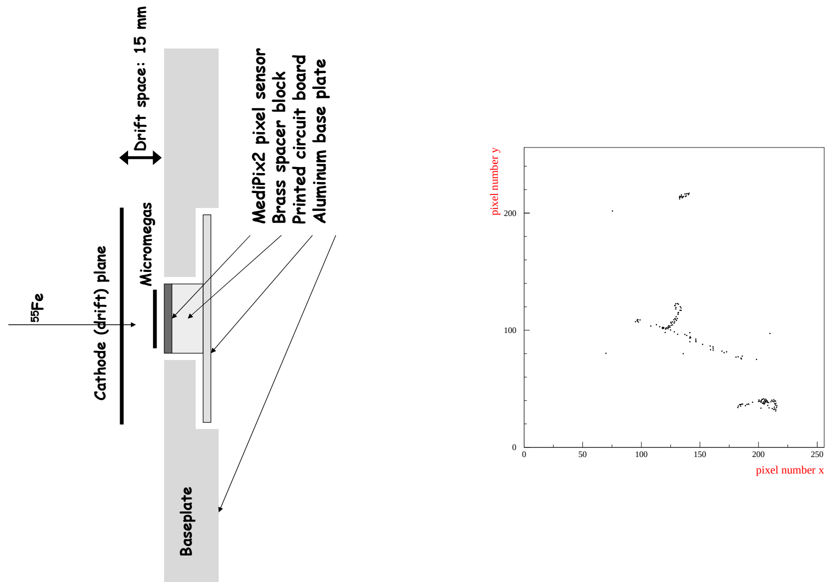

Figure 7: *Left: The layout of the chamber with the MediPix2, the Micromegas and the drift gap. Right: Image recorded in 2004 from the MediPix2/Micromegas prototype TPC showing a cosmic charged particle track together with a δ-electron. The total size of the image is 14.1 $\times$ 14.1 mm^2.*

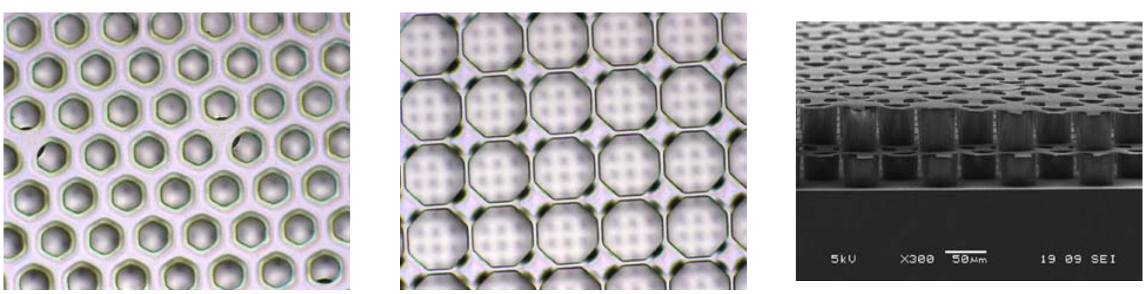

Figure 8: *Left/Middle: Two of the various Ingrid structures used. Note that the insulating pillars do not create local losses. Right: first attempt for making a double integrated grid (see text).*

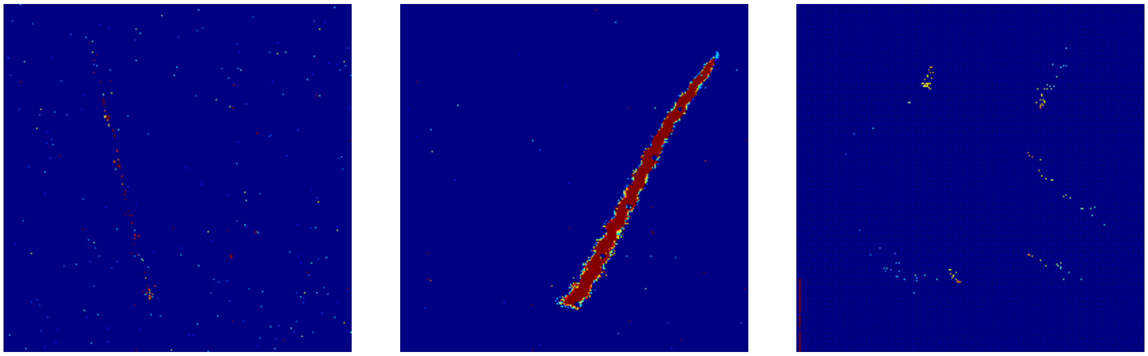

Figure 9: *Track images with TimePix in NIKHEF setup. Left: Random cosmic track and Middle: Alpha particle, both in 'time-over-threshold' mode. Right: tracks from cosmics in triggered 'arrival-time' mode.*

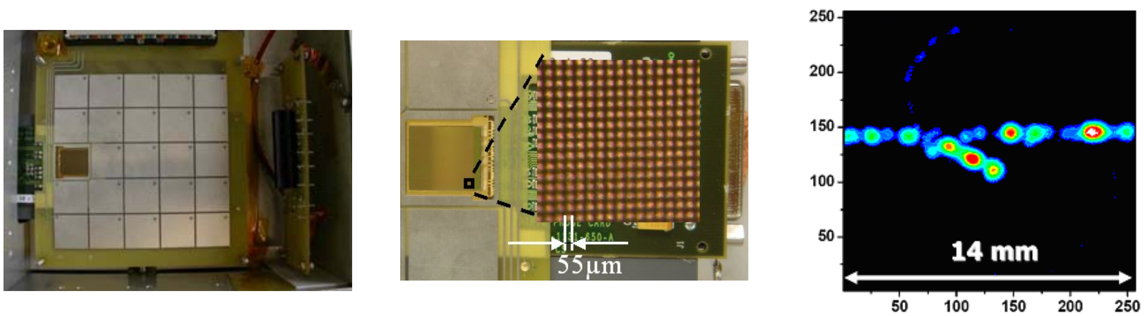

Figure 10: *Left, Middle: Layout of the Freiburg/Bonn test chamber with Medipix2/Timepix and GEMs. Right: track image with the Timepix of a 5 GeV electron + delta ray.*

–There has been qualitative understanding [42] of single electron-detection measurements (from MIPs) by the GEM and Micromegas setups at Freiburg and NIKHEF.
–A first series of ageing measurements of Micromegas has been carried out. A preliminary conclusion is that within a Micromegas amplification gap the ageing rate is a factor ~ 400 smaller compared to a wire chamber.
–In the last few weeks first tracks from radioactive source and cosmics were observed in the NIKHEF test chamber equipped with the new TimePix chip with a Micromegas grid as gas multiplier. This TimePix chip was 'discharge protected' with an amorphous Si layer and survived already for more than 4 weeks. Examples of observed tracks, both in 'time-over-threshold' and in 'arrival time' mode are shown in Figure 9.
–In 2006 a triple-GEM detector equipped with a Medipix2 chip (see Fig. 10) was extensively tested at Freiburg university [41] and in the DESY electron test beam. Stable operation of the system at gas gains of up to several 10^5 was possible. From the test-beam data which were taken with a Silicon strip telescope for beam definition, the dependence of the single-point resolution on the drift length could be shown. A single-point resolution of $\sigma_0 \approx 30\mu$m at zero drift length was measured. Later, the same chamber was equipped with the first Timepix chip and operated successfully in the testbeam; data analysis is underway. Both the time-over-threshold (TOT) mode and the time mode of the chip were exploited (Fig. 10(right)).

After these successful proof-of-principle tests carried out in 2004-2006, the next steps aim towards optimization of specific issues and towards the development of realistic multi-chip modules to be incorporated into the LP.

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 MPGDs, 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 also shown in the LDC[1] and GLD[2] Detector Outline Documents.

Preliminary thinking about the design for the LP endplate is seen in Fig. 11-upper (see also Sec. 6.3).

5.3 Electronics

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

A development[16] started in 2004 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[14] in order to have a large number of channels (up to 10000) available for the tests.

Studies for the LCTPC standard electronics are also a further development of the ALICE system; the status is reviewed next.

5.3.1 Standard-electronics system overview

A single readout channel is comprised of three basic functional units: a charge sensitive amplifier (CSA); a 10-bit 40-MHz low power ADC; a digital circuit that contains a filter for signal interpolation and noise reduction, the baseline correction and zero suppression, and a multiple-event acquisition memory.

Current state-of-the-art developments mix sensitive analogue ADC circuits with high-speed digital processing, whereas the low-noise amplifiers are still kept separate. An example is the readout electronics for the ALICE TPC[14][43]. The analogue functions are realized by a custom integrated circuit, the PASA chip[44] implemented in the AMS CMOS 0.35μm technology, which contains 16 channels with a power consumption of 11 mW per channel. Whereas the ADC, the digital signal processor and the acquisition memory are integrated in a separate custom integrated circuit, the ALTRO chip[45], implemented in the STMicroelectronics CMOS 0.25 μm technology, which also contains 16 channels with a power consumption of 16mW per channel.

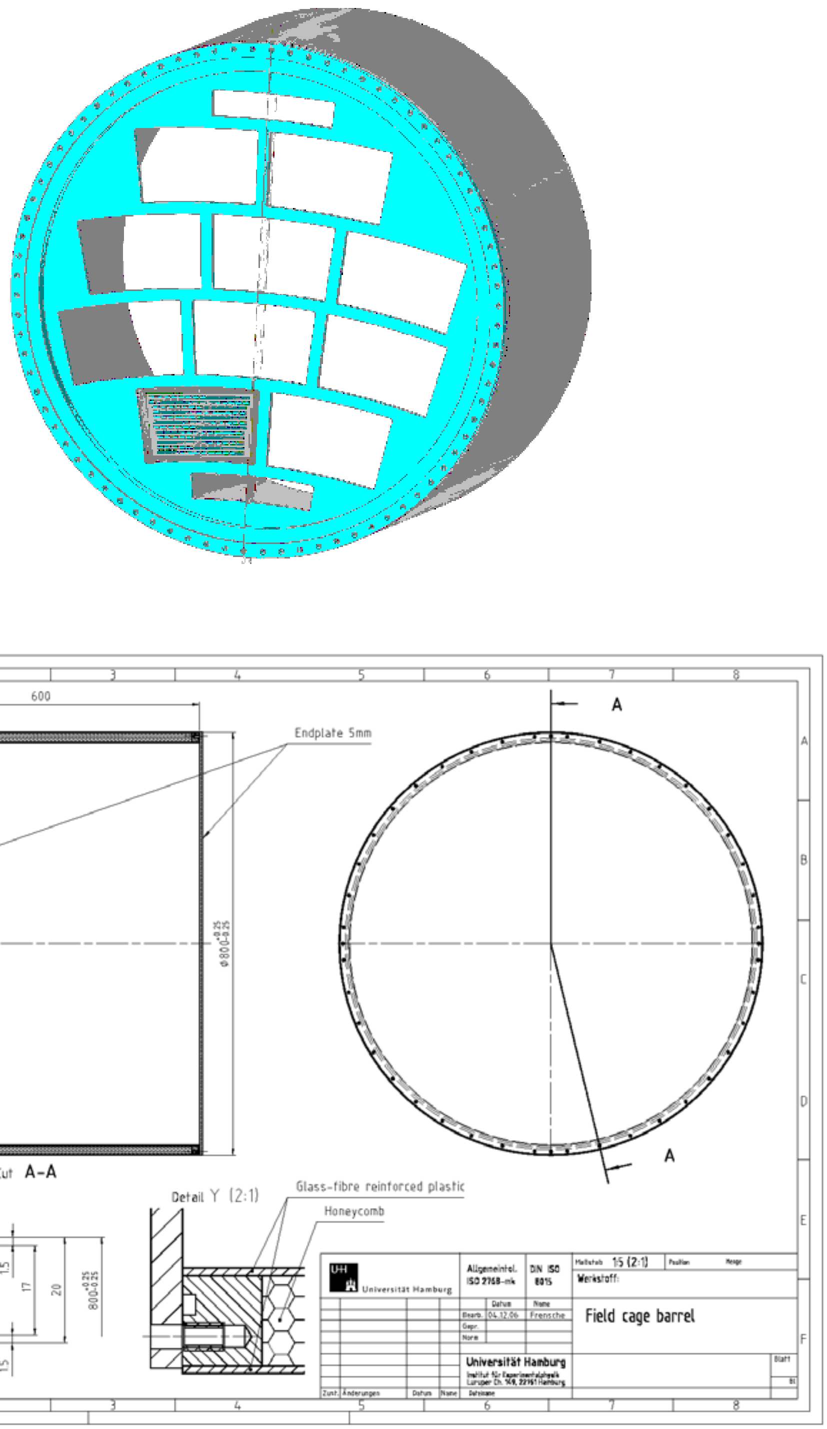

Figure 11: *Design studies for the LP. Upper: LP endplate. Lower: LP fieldcage.*

The readout planes, which currently are being studied for the ILC TPC, have pads that can be as small as $1 \times 4\text{mm}^2$ (6 times smaller than the ALICE TPC pads). The close integration of both analogue and digital circuits in a single chip, constitutes the essence when trying to optimize high density, low-power and low-cost requirements. Therefore, the development of the readout electronics for the ILC TPC calls for an R&D program that aims at studying, designing and testing circuits for the implementation of
1) programmable low-noise charge amplifiers,
2) analogue pre-filters for optimum digital processing,
3) high-speed high-resolution ADCs,
4) programmable digital filters for noise reduction and signal interpolation,
5) signal processors for the extraction and compression of the signal information (charge and time of occurrence) and
6) multiple-event acquisition memory.

These circuits are the core of an ASIC, which has to support several channels (e.g., 32 or 64 channels/chip), to be implemented in a 130nm CMOS technology. As will be shown in the following, preliminary studies indicate that such a circuit could be integrated in an area of about 1mm^2 per channel, without considering the IO pads that are anyway common to a large number of channels, and has a power consumption of about 25mW/channel. The total power for a large number of pads can be reduced due to the time structure of the ILC bunch crossings(BX) (1ms BX-train, followed by 200ms between trains); thus the circuit is being conceived to support a standby mode, with a power consumption below 1mW. Moreover, given the very large spacing between bunch trains, a scheme is well conceivable in which the electronics is completely powered down between bunch trains and resumed 1ms before the next train. This chip could be directly mounted on the surface of the readout pad plane.

5.3.2 Programmable charge amplifier

Table 2 gives a summary of the specifications of the programmable charge amplifier. The programmability is illustrated in Fig. 12-left and Fig. 12-right, corresponding to rows 1 and 3 of Table 2, respectively. This circuit is currently under study and the specifications have

Table 2: Specification for the Programmable Charge Amplifier (PCA)

Conversion Gain	Programmable in the range 10-30 mV/fC
Dynamics (max Signal/noise)	~ 2000
Peaking Time	Programmable in the range 30-100ns
Signal Polarity	Programmable for positive or negative pulses
Power consumption	<8mW/channel (<1mW in standby mode)
Nr. Channels	32
Area	0.2 mm^2/channel
Technology	CMOS 130nm

to be considered as very preliminary.

The circuit consists of a single-ended Charge Sensitive Amplifier (CSA), followed by a pole-zero cancellation network and two low-pass filtering stages (see Fig. 12). The low-pass

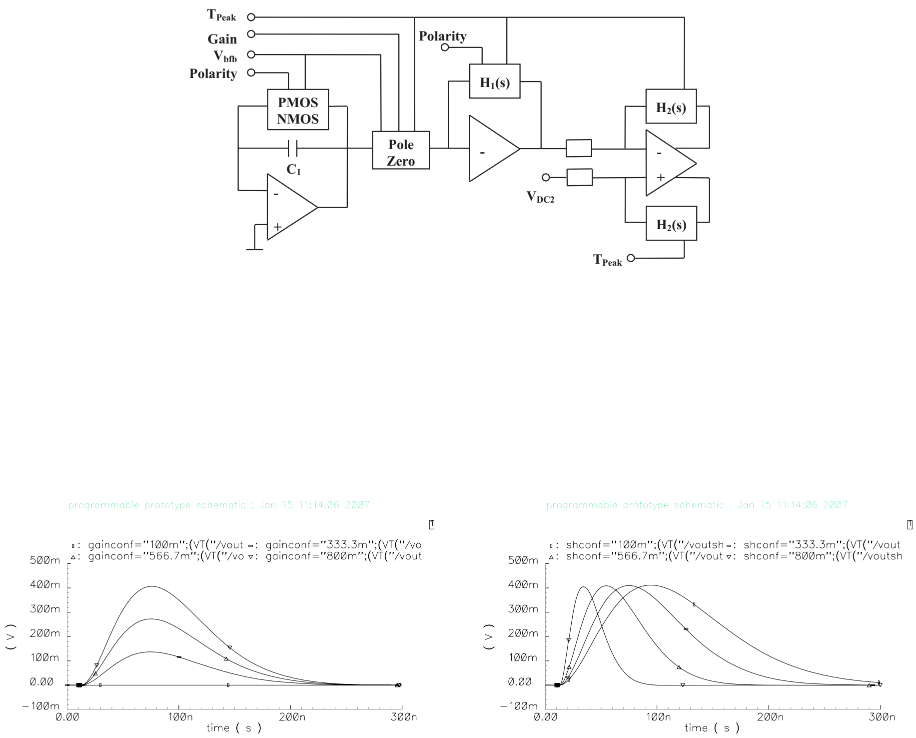

Figure 12: *Upper: Block diagram of the programmable Charge Sensitive Amplifier. Lowerleft: Programmable conversion gain in the range 10 to 30mV/fC; this plot shows the circuit implse response function to a delta-like 13.3fC charge-input signal. Lowerrightight: CSA peaking time which is probrammable from 30 to 100ns.*

filter has the function of limiting the bandwidth of the output signal before the analogue to digital conversion. The feedback capacitance of the CSA is continuously discharged by a MOS transistor biased in the MΩ-region in order to minimize current noise. The implemented non-linear pole-zero network allows high rate operation while maintaining good cancellation of the pole introduced by the preamplifier. The first shaping filter is built by a scaled replica of the CSA in order to save power but still maintaining the same DC operational point which is essential for the implementation of the pole-zero network. The second low-pass filtering stage further limits the signal bandwidth and, in addition, converts the single-ended input into a differential output.

Charge Sensitive Amplifier prototype circuit A first prototype of a CSA circuit was developed during the year 2006. The main characteristics of the prototype, which were measured on about 20 samples, are listed in Table 3.

This circuit was developed aiming at the following objectives, a) to verify the suitability of the IBM CMOS 130nm process for low-noise analogue applications and b) to study the performance of a circuit that represents a first step, in terms of building blocks and architec-

Table 3: Characteristics of the prototype Charge Sensitive Amplifier (CSA)

Process	IBM CMOS 130nm
Nr. channels	12
Conversion gain	9.5 mV/fC
Impulse response peaking time	100 ns
Equivalent noise charge	$270e(\mathrm{C}_{in} = 10\mathrm{pF})$
Dynamic range (max signal/noise)	4600
Power consumption	10 mW
Package	CQFP 144

ture, towards a programmable circuit for the LPTPC.
The results above indicate that both goals have been met and are very encouraging for the development of the final version. However, it should be noticed that, with respect to the final circuit, this prototype did not have any programmability. A new circuit, which includes the programmability of the conversion gain and of the peaking time as defined in Table 2, is planned for submission in the 2nd quarter of 2007. This is the circuit will be employed for the readout of the LP in the year 2008.

5.3.3 Analogue to digital converter

The analogue to digital conversion will be performed by a low-power 10-bit 40MHz ADC. It has a pipelined architecture, consisting of 9 internal conversion stages, in which the analog signal is fed and sequentially converted into a digital code. In this range of resolution and sampling frequency, the pipelined architecture is the optimal one for low-power consumption applications. The superior performance of this architecture comes from the break-up of the digital conversion process into multiple steps and the use of redundancy. The input analogue signal is sampled on the clock rising edge while the output digital code is issued on the clock's falling edge. The delay between the initial sample of the input signal and the corresponding output code (data latency) is 5.5 clock cycles. A first prototype of this circuit will be constructed by the end of 2007. The estimated values for the power consumption and area are respectively 14mW and 0.2 mm^2 per channel.

5.3.4 Signal processing and acquisition memory

This circuit has to process a train of pulses sitting on a common baseline. When a Level-0 (L0) trigger is received, a predefined number of samples is processed and temporarily stored in a data memory (*acquisition*). This acquisition is frozen if a Level-1 (L1) trigger is received; otherwise, it is overwritten by the next acquisition.

The Data Processor implements algorithms in several stages of circuitry to condition the signal. The first stage is the Baseline Correction I. Its main task is to prepare the signal for further signal processing, by removing low frequency perturbations and systematic effects. The next processing block is a general purpose 4th order IIR filter. The filter is able to shape the signal for optimum extraction of the pulse features. Since the filter coefficients for each channel are fully programmable and re-configurable, the circuit is able to deal a wide range of signal shapes. This also allows maintaining a constant quality of the output signal regardless of ageing effects on the detector and/or channel-to-channel fluctuations. The subsequent processing block, the Baseline Correction II, applies a baseline correction scheme based on a moving average filter. This scheme removes non-systematic perturbations of the baseline that are superimposed to the signal. At the output of this block, the signal baseline is constant with an accuracy of 1 LSB. Such accuracy allows an efficient data compression using a Zero-Suppression procedure, which discards all data below a programmable threshold. In the Data Format, each data packet is formatted with its time stamp and size information in a way that reconstruction is possible afterwards.

The output of the Data Processor is sent to a 8K-word (10-bit word) data memory able to store the history of the detector over a period of 1ms, assuming a maximum signal occupancy of 20%. Data can be read out from the chip at a maximum speed of 160MHz through a 4-bit wide bus, yielding a total bandwidth of 80Mbyte/s. The estimated values for the power consumption and area are 2mW and 0.6mm^2 per channel.

5.4 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. Preliminary ideas have been developed as seen in Fig. 11-lower of Sec. 5.2.

5.5 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[46]. Thus gas simulations can be used to help design the LCTPC.

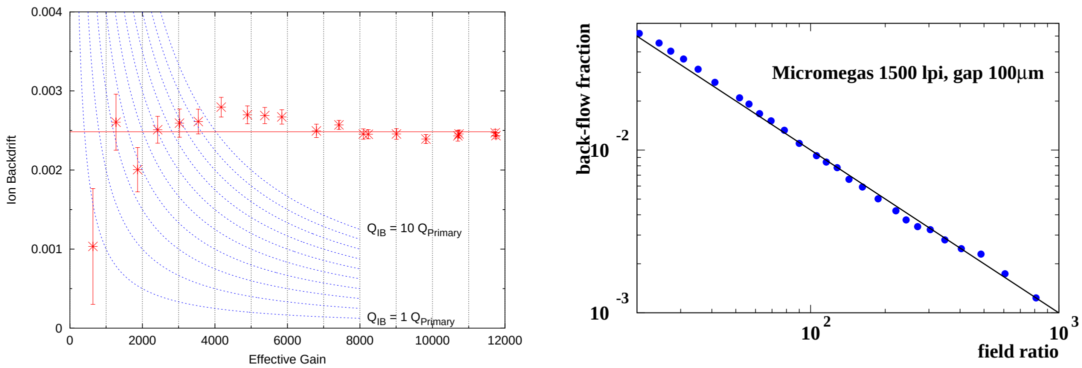

Figure 13: Left: Relative ion backdrift versus effective gain for optimized triple-GEM voltages. Right: Ion backflow fraction as measured with Ar-10%CH_4 for Micromegas (the line is the expectation from the inverse-field-ratio law).

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[47] 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.

5.6 Space charge

Ion backflow and charge transfer studies in MPGD structures have been going on for several years at Aachen. Some 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 was 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 was achieved in a magnetic field of 4T. The results are seen in Fig. 13-left[48], which shows the dependence of the minimum ion backdrift on the effective gain of the triple-GEM structure. For each data point, all GEM voltages and fields were optimized and the resulting ion backdrift was measured. The relative ion backdrift is almost independent of the gain. Therefore, the choice of low gasgain (if the signal to noise ratio is acceptable) will lead to a low absolute ion charge drifting back into the drift volume. However the desired 1/gasgain supression would only work for gasgains of 400 or below, and since the LCTPC electronics design has just started (Sec. 5.3) for a gasgain of 2000, it is not clear whether the signal/noise ration will be sufficient in the case of 400.

For Micromegas[49], the TPC drift and the multiplication region see very different electric fields, with a ratio of typically 300 between them. Charge which arrives from the drift region within one mesh gap is compressed to a funnel of a size of typically only a few microns. The electrons then diffuse on their way towards the readout plane. The typical diffusion for electrons in the high field region between the mesh and the readout plane is around 15 μm (depending on field and gas), which is large compared to the size of the funnel. The ions are mostly produced towards the end of the electron drift, i.e., when the electrons are well diffused. The ions drift back following the electric field lines. Only those few which have been produced within the funnel will go back into the drift region, the rest will be absorbed by the mesh. It has been shown that the expected ion backflow can be described simply by the inverse ratio of the two fields. This simple model has been tested successfully in a number of experiments. The results, Fig. 13-right[7], show that measurements and theory agree very well. From the plot it can be seen that a total ion backflow of a few times 10^{-3} seems possible. For this case field ratios of around 300 implies a backflow suppression factor down to 0.3% which may not be small enough, similar to the case for GEMs above. As described in Sec. 3.6

Since the goal of 1/gasgain will be difficult to achieve and for other reasons discussed under Sec. 3.6(c), a gating grid should be foreseen. Gating using a GEM layer may be possible[50], but whether this will work with our tolerance of allowing at most 10% loss of the primary charge is not yet completely understood. Other options for the gating plane are also being considered.

5.7 Non-uniform fields

Other measurements were made using the Karlsruhe prototype in a CERN testbeam[28], 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[15] to measure these effects and test the tools for making the corrections. In general since the problem has already been solved at LEP[21][22][25][26] 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[4] yielded a low occupancy ($< 0.5\%$) from all sources which have been[26] and are being investigated. The calculations are being revisited with more sophisticated programs[51] and using the latest ILC machine configurations.

The tracking efficiency has been simulated for different backgrounds[52], and the results are shown in Fig. 14 where it can be seen that efficiency will be excellent at 1% occupancy for the voxel sizes being considered for the LCTPC.

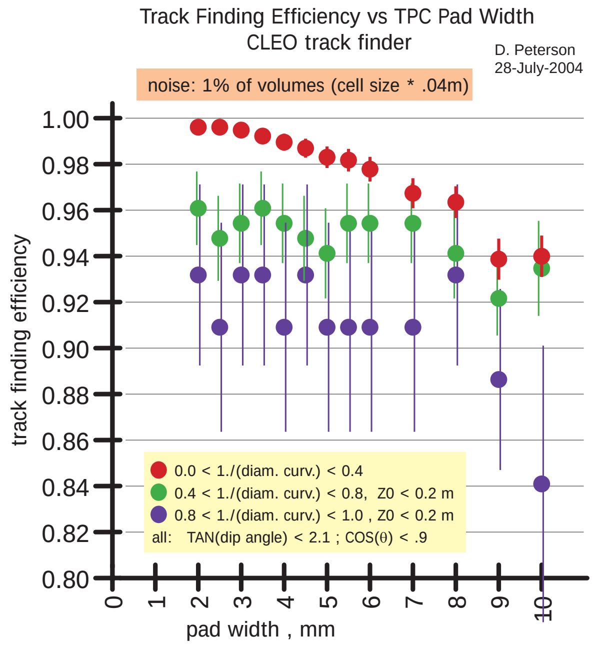

Figure 14: *Tracking efficiency study*

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[15] 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. The groups have chosen to participate in the various workpackages based on R&D plans to be covered by their national resources which are being requested.

```
        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) Charge-dispersion-foil for endplate     Carleton,Kek/CDC,Saclay/Orsay
    (Madhu Dixit)

Workpackage (2) Electronics
---------------------------
 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. As pointed out in Sec. 5.9 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[51] and using the latest ILC machine configurations.

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 programs 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[53], building on top of LCIO[54], the de-facto standard data format for ILC related work, and the accompanying ilcsoft tools[55]. 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[56] 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[57] and GEAR (Geometry API for Reconstruction)[58]. 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 will e.g. made available by EUDET[59].

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[53].

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. Table 4 gives the general foverall for the 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 using small, specialized set-ups.

Table 4: 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→1.5	Desy/Eudet(2007-2009)	Fieldcage⊕2 endplates: GEM+pixel, Micromegas+pixel
Purpose: 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⊕endplate: GEM, Micromegas, or pixel
Purpose: 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 groups with small prototypes

The small-prototype work is driven to a large extent by the needs of the individual labs, whereby certain issues are and will be looked at on request of the collaboration (the examples in Table 4).

The general R&D plans driven by LCTPC/LP issues were given in our report to the

WWS R&D panel one year ago (see Sec. 8 for more details) and have not changed:
· Build the LP facility.
· Test methods for tiling the endplate with GEM panels.
· Test methods for tiling the endplate with Micromegas panels.
· Test methods for tiling an endplate with pixel(CMOS) panels.
· Develop high-density, low-power front-end standard electronics.
· Investigate feasibility of high-density, low-power front-end CMOS electronics.
· Translate endplate alignment and field mapping into corrections.
· Demonstrate the ability to align a large tiled system and measure beam tracks correctly over a large area.

Since the CMOS pixel technique is new and has the longest R&D road ahead, next plans are listed here:
- tests of first integrated Ingrid/TimePix detectors with protection layer,
- tests of first double-Ingrid ("Twingrid") structures,
- development and test of through-wafer vias to replace the wirebonding from chip to supporting pcb,
- construction of a small TPC to reconstruct 3-dimensional tracks fully exploiting the Time mode of Timepix, with 30 cm of drift length (Bonn),
- tests with magnetic field (using e.g. the PCMAG magnet at DESY),
- construction of endplate modules with Micromegas/Ingrids and GEMs for the LP,
- (GEM-specific): reduction of the transverse diffusion in the gas amplification,
region (reduction of 'blob size' (magnetic field, smaller transfer and induction gaps, tests with 2-GEM setup) (Freiburg/Bonn),
- optimization of pixel size (tests with post-processed chips, simulation),
- engineering aspects of a large system (mechanics, cooling, power distribution, data reduction, fast readout),
- improved data analysis (cluster and track reconstruction algorithms, double track resolution study, dE/dx study),
- simulation (performance of a large system).

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 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 (Sec. 6.1). 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 at most one year) followed by Jan Timmermans.

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

  3)The CB members are:

```
--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
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```
Kinki
Saga
Kogakuin
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 an MOA for the LP work.

- FINANCES AND MANPOWER

Our collaboration is still forming and the funding situtation for many labs is in an embryonic state. Therefore our labs decided unanimously to put no new funding information in this document which will most likely diffuse into the public domain. The report to the WWS R&D panel one year ago has been published and is presented here to show where our deliberations commenced when the collaboration formalities were completed three months ago. The present financial/manpower situation will be discussed at the closed session of the Beijing tracking review.

```
                        ILC Detector R&D Project

                Topic priorities and estimated support needed

* Project name: LCTPC R&D
* Contact person: Ron Settles
* WWS R&D Panel affiliate: Formerly Dan Peteson, now Dean Karlen
* Funding countries (regions): Canada/USA (Americas), China/Japan (Asia),
                             EU/France/Germany/Netherlands/Poland/Russia
                             /Sweden/CERN (Europe).
For details of regions, countries, institutes and collaborators, see
https://wiki.lepp.cornell.edu/wws/bin/view/Projects/TrackLCTPCcollab

      => This is a one-form overview to give a coherent reply on
priorities and overall financial framework.  The relevant LC-TPC groups
(i.e., those able to estimate their finances at the moment) will supply
the information for their respective funding needs.

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                             Priority 1 topics

* Proof-of-principle completion date, end 2008 or end 2010?  End 2008

* Topic-description overview (~1 line description per topic)
      => The TPC groups have divided the R&D work into three Phases:
* [1] Demonstration Phase: finish the work on small TPC prototypes.
* [2] Consolidation Phase: design, build and test a Large Prototype (LP).
* [3] Design Phase for the LC-TPC . (Priority 2  see below.)

 Topic descriptions for Phase [1], the Small Chamber Program
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* Demonstrate the reliability of MPGDs and compare with MWPC technology.
* Demonstrate the goal resolution for each candidate MPGD with and without resistive-anode foil, in magnetic fields.
* Optimize the resolution for MPGDs, for different gas mixtures in magnetic fields.
* Measure charge-transfer properties and ion backflow for MPGDs in TPCs.

Topic descriptions for Phase [2], LP hardware

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* Build the LP facility (magnet, fieldcage, endplates, electronics, readout, infrastructure), including development of TPC-endplate designs which approach the size needed for the final LC-TPC. (In this large cooperative program, construction of the LP components will be distributed amongst the groups.)
* Demonstrate and test methods for tiling the endplate with GEM panels, without or with resistive-anode foil.
* Demonstrate and test methods for tiling the endplate with Micromegas panels, with or without resistive-anode foils.
* Demonstrate and test methods for tiling an endplate with pixel (CMOS) panels.
* Develop high-density, low-power front-end electronics capable of preserving the coordinate resolution for standard electronics.
* Investigate feasibility of high-density, low-power front-end electronics capable of preserving the coordinate resolution for CMOS electronics.

Topic descriptions for Phase [2], software/simulation issues for the LP/LCTPC.

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* Establish LP software and simulation/reconstruction framework.
* Calculate track reconstruction efficiency w.r.t. momentum, direction, and jet density in an environment with backgrounds.
* Determine acceptable limits for noise.
* Simulate design/performance of the LC-TPC for GEM, Micromegas, and Pixel.

Topic descriptions for Phase [2], calibration/reliability issues for the LP/LCTPC.

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* Translate endplate alignment and field mapping into track distortion corrections.
* Demonstrate the ability to align a large tiled system and measure beam tracks correctly over a large area.

* Urgent financial requirements for Priority 1 topics:

Established support for LP (EUDET)	2006-09	2006	2007	2008	2009
Equipment (k$)	1659	25%	25%	25%	25%
FTEs (# persons)	11	11	11	11	11

Additional support needed for LP/LCTPC					
Equipment (k$)	~1700	25%	25%	25%	25%
FTEs (#persons)	>10	>10	>10	>10	>10

Equipment include all non-staff costs - consumables, travel, overhead. FTEs includes academics, students and support which are combined for this overview.

Comments: The TPC groups within the EUDET consortium have approved funding as indicated above; this will cover ~50% of the costs for the LP and LCTPC programs. The extra-EUDET TPC groups are of about equal strength (manpower and resources) to those in EUDET, as estimated from the report to the DESY PRC in October 2004. The extra-EUDET TPC groups will thus be requested to generate a matching amount to that already approved for EUDET, as indicated under additional support needed. The extra-EUDET TPC groups will be applying individually for support to carry out their parts of the programs. The funding profile will not be exactly flat, but until it is known better for the extra-EUDET groups, the above can serve as a working hypothesis.

Priority 2 topics

* Topic-description overview (~1 line description per topic)
  => Priority 2 topics are evolving for the 3rd phase:
* [3] Design Phase for the LCTPC.

Topic descriptions in preparation for Phase [3], reliability issues for the LCTPC.

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* Measure radiation hardness of equipment considered for the final LCTPC.
* Measure compatibility of materials/equipment in contact with the gas volume.
* Topic descriptions for Phase [3], other issues relating to the LCTPC design and manufacture.
* These will be made available at the appropriate time in future.

No funding information is requested for Priority 2 topics at this time.

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