Sketch for a Large Detector Concept

LDC

The LDC concept group[1]

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Purpose

The main goal of this, still very preliminary, document is to provide a starting point for a detailed optimization of the concept of a Large Detector for ILC (LDC). After defining the basic detector ideas, and the physics reactions driving the design, we discuss a series of questions relating to the overall detector layout and[1] to individual sub-detector systems. At some point, to have a realistic concept, they have to be completed and answered.

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1 The LDC concept

The Large Detector Concept promotes the conceptual design, parameter optimization and physics benchmarking of a detector based on a large volume continuous gaseous tracker, able to reconstruct the trajectory of charged particles with a large number of three-dimensional points, followed by a highly granular calorimeter.
The LDC envisages to adopt a Time Projection Chamber and to have both the electromagnetic and the hadronic calorimeters contained inside the coil, providing a field of the order of 4 T, to ensure precision in the particle momentum measurements and containment of accelerator-induced backgrounds. The outstanding particle reconstruction capabilities offered by the combination of a TPC and a calorimeter of high granularity, will be matched by excellent vertexing performances and will be extended down to small polar angle by a careful design of the forward detectors.

This detector appears best suited for dealing with the large dynamic range in particle energy, complexity of final states and signal-to-background ratio dictated by the ILC physics program. One of the central activities envisaged for this study is to perform an overall design optimization from higher level parameters such as the overall detector aspect ratio to the details of performance optimization at the detector interfaces. The two main drivers of this optimization process are the tracking performance and the energy flow performance, which are regarded as central to the success of experimentation at the ILC.

2 Physics and the LDC

The optimization of the LDC will be guided by the study of sets of benchmarks. We envisage two distinct sets. The first consists of single particles, generated over the full polar angle range and the full momentum range. These will determine the single particle response, address the issues of geometrical coverage and detector boundaries and define a basis for performances to be used in fast simulation. The second set is represented by full physics reactions. The program of detector optimization can be carried out by investigating physics processes in three main classes: physics of the Higgs boson and strong symmetry breaking, Supersymmetry in relation to determining the nature of Dark Matter and the mechanism of symmetry breaking, precision measurements of Standard Model processes and their sensitivity to New Physics at high energy scales. The definition of an economical set of benchmark physics reactions is presently being reviewed by a panel consisting of one representative per region and one per detector concept.

3 The Baseline Detector

The starting point of the LDC optimization is very close to the TESLA detector as proposed in the TESLA TDR. This detector is very similar to the American large detector concept, LD. The main parameters of the baseline detector are summarized in Figures 1 and 2.

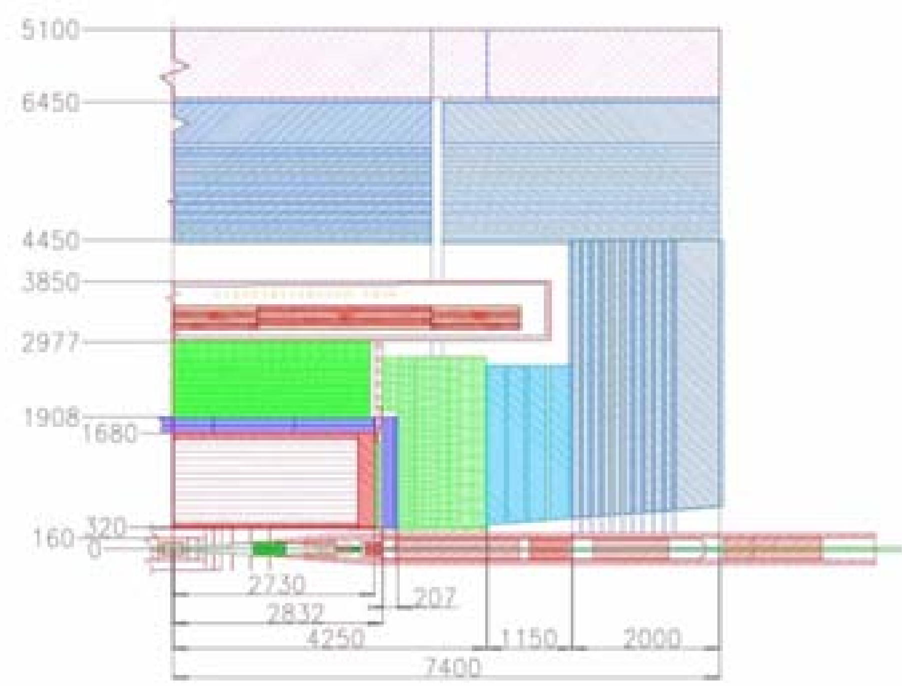

Figure 1: Cross sectional view of the TESLA detector used as a baseline for the LDC detector.

More details on the baseline detector may be found in the TESLA TDR, part IV. The main components of the detector are (from the inside to the outside):

- 5 layers of vertex pixel detectors (VTX)
- system of 7 Si disks (Pixel and strips) in the forward direction (FTD)
- Very forward region instrumented with a luminosity calorimeter (LCAL) and a precision calorimeter for diagnostics and physics, (BEAMCAL)
- 2 layers of Si strip detectors outside the VTX detector (SIT)
- large volume TPC as central tracking detector (TPC)
- several layers of drift tubes behind the TPC endplate (FCH)
- SI-W ECAL in barrel and end cap (ECAL)
- Steel – Scintillator or Steel RPC hadronic calorimeter (HCAL), barrel and end cap
- 4T superconducting coil including compensation windings for better field homogeneity

- Instrumented Iron return yoke equipped with several layers of RPC chambers for muon detection (MUON), supplemented by an instrumented Steel Plug to fill the gap between the Yoke end cap and the HCAL end cap inside the magnet

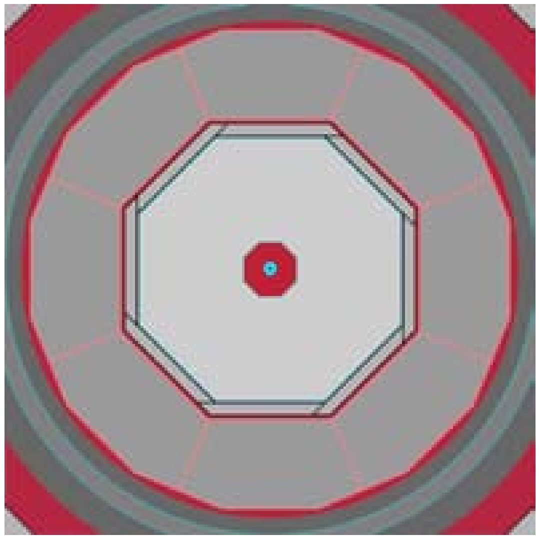

Figure 2:The transverse structure of the detector.

Compared to the TESLA detector the very forward direction has been re-designed to confirm to new beam delivery systems designed for the ILC, which have a larger L*. A drawing of this layout is shown in Figure 3.

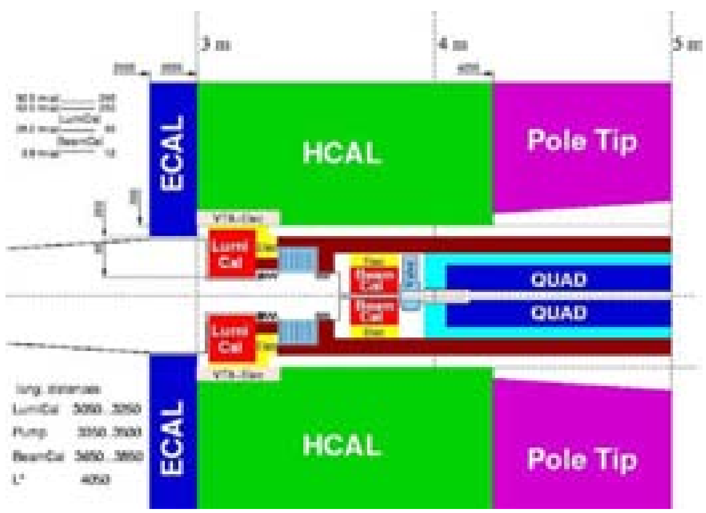

Figure 3: Layout of the very forward region in the LDC baseline detector.

The technologies of the different subdetectors are listed in Table 1. In Table 2 the main performance parameters are listed together with the targeted performance.

Subdetector	**Acronym**	**Possible technologies**	**Comment**
Vertex Detector	VTX	Si pixel	Technology not decided
Forward Tracker	FTD	Si pixel and strips	Standard LHC type Si?
Luminosity calorimeter	LCAL	Si-W Crystal option under study	
Beam Calorimeter	BCAL	Diamond-W	Was LAT in TDR
Intermediate Tracker	SIT	Si-strips	LHC technology
Silicon Envelope	SET	Long Si strip	Exact extend of this option is being studied
Time projection chamber	TPC	GEM/ Micromegas readout Si read out under study	
Forward Chambers	FCH	Straw Tubes Si under investigation GEM's under investigation	
Electromagnetic calorimeter	ECAL	Si-W Hybrid options under study	
Hadronic calorimeter	HCAL	Fe-Scintillator analogue Fe-RPC digital Fe-GEM digital	
Muon chambers	MUON	RPC	
Magnet	MAG	4T superconducting	Based on CMS design

Table 1: Summary of the main parts of the LDC baseline detector and the current technology choices.

Parameter	Target Performance
Impact Parameter Resolution	$\sigma_{IP} < 5\ \mu m + 10\ \mu m/p_t$
TPC momentum resolution	$\delta(1/p_t) < 2 \times 10^{-4}\ (GeV)^{-1}$
TPC dEdx resolution	< 5%
Combined Tracking Performance for $\cos\theta$ close to $\pi/2$	$\delta(1/p_t) < 5 \times 10^{-5}\ (GeV)^{-1}$ systematics < 10 μm ε>99% for p > ?? GeV fake rate < ?? %
Forward Tracking Coverage	$\theta > 100$ mrad
Forward Tracking Performance	
ECAL energy resolution	$\Delta E/E < 0.1/\sqrt{E\ (GeV)} + 0.01$

HCAL energy resolution	$\Delta E/E < 0.5/\sqrt{E\,(\mathrm{GeV})} + 0.04$
BCAL coverage	Approx. 30 mrad to appr. 5 mrad
LCAL coverage	Approx 50 mrad to appr. 30 mrad
BCAL resolution	
LCAL resolution	
Jet energy resolution (particle flow)	$\Delta E_{Jet}/E_{Jet} < 0.3/\sqrt{E\,(\mathrm{GeV})}$
Muon detector	$\varepsilon > 99\%$ for $p > 6$ GeV

Table 2: List of main detector parameters and target performance

4 Detector Optimization

The LDC detector concept has undergone a first round of optimization in 2000/2001, in preparation of the TESLA TDR and the Snowmass book. In the mean time particle flow as a base paradigm for a detector at the ILC has been widely accepted, and its implications are much better understood. In many respects particle flow is the main driving force behind many of the components of the detector.

One of the most challenging requirements for the LDC detector is the reconstruction of the hadronic decay modes of the W and the Z or H. The best way to optimally reconstruct these decays is the individual reconstruction of each of the particles in the event, in the part of the detector best suited for charged particles, photons, and neutral hadrons. Particle flow thus is the attempt to reconstruct charged particles in the tracker, photons in the electromagnetic part of the calorimeter, and neutral hadrons in the hadronic part of the calorimeter. In such a scheme, the individual resolution requirements of these devices are of less importance, but the capability to separate the different particles dominates. Thus a detector optimized for particle flow needs to be optimized in the direction of a large highly efficient tracker, a very granular electromagnetic calorimeter, and a granular and efficient hadronic calorimeter. Material between the tracker and the calorimeter should be minimized to optimize the chances of correctly associating particles in the tracker and in the calorimeters. In addition the detector needs to be able to find and measure decaying particles efficiently (V0's), find tracks backscattering from other parts of the detector into the tracker, identify prompt electrons over a wide momentum range, and identify and sign tau's.

These requirements naturally seem to favor a solution where the tracker and the calorimeters are contained inside the magnet, and a large magnet to be able to maximize the thickness of the calorimeters and the shower separability.

5 Questions

5.1 Particle Flow

5.1.1 General particle flow

- The current design has calorimetry with four components: electromagnetic, hadronic and forward calorimeters and tail catcher/ muon identifier. Is this separation optimal?
- The current shape of the calorimeter is octagonal. Is this optimal, also in view of the other detectors like TPC etc.
- Calorimetric coverage extends in the current design to close to 5 mrad. Are the boundaries optimal? How far do we need to go?
- How important are gaps between the calorimeter components? How important are gaps between the calorimeters and other components as e.g. the tracker?

5.1.2 Photon reconstruction

- How little material is acceptable in front of the calorimeters, and where?
- How important is efficient separation between two close-by photons? Or is it enough to separate photons and hadrons in more general terms?
- What is the optimal transverse and longitudinal separation?
- How much is the capability to separate close-by particles influenced by the calorimeter material, how much by the magnetic field?

5.1.3 The calorimeter system

- What is the optimal material for the ECAL? Tungsten? Lead? Uranium? What is the optimum relation between the Moliere radius and the sampling fraction?
- What is the optimal shape of the calorimeter? Round, octagonal, other shapes?
- What is the optimal transition barrel – end cap done? Is the current scheme of a long barrel in front of the end cap optimal? Are there alternatives?
- How close should the end cap be to the endplate of the TPC? How much material in font of the end cap is acceptable?
- How important are cables, support structures etc for the performance of the ECAL?
- What are the main factors to separate photons from hadrons? The separation from hadrons can be done based both on longitudinal and transverse information. On the longitudinal side we have to optimize the interaction over radiation length. Uranium and lead are slightly better than tungsten, is this an argument? On the transverse side there are four points: the magnetic field, the distance from the collision point, the lateral extension of electromagnetic showers (Moliere radius) and the read-out granularity.
    - The choice of magnetic field may be driven more by background considerations and momentum precision than by shower separation

considerations. A high magnetic field does not help for neutral hadrons, and has hardly any effect in the end cap.

- There is a direct interplay between distance between the calorimeter and the interaction point, and Moliere radius. For a given separation they scale proportionally except that the Moliere radius has a lower bound. Scaling with the square root of the density it is best for tungsten at 0.9 cm. A 1.4 cm radius at 170 cm is equivalent to 1.1 at 130 cm. How large can we afford a calorimeter?
- Once the Moliere radius is chosen the optimal read out cell size has to be defined. It has to be noted though that in the first few radiation lengths the shower is much narrower and a smaller cell size in this region can help dramatically in the separation. Does it make sense to align and to calibrate the TPC using the ECAL, particularly if the first layer is very fine-grained?
- The photon energy has to be properly measured, up to what accuracy? The same question holds for their position and angle. Once the read our granularity has been chosen (and small enough), position and angle accuracy are depending only on the energy resolution except if we can know well the starting point of the shower (see point above).
- Interplay between the Moliere radius and the sampling. To improve the resolution means a larger number of samplings hence a worse Moliere radius. What is the optimum, knowing that for cell sizes clearly below this radius there is no more improvement?
- Another question is the depth of the "electromagnetic" part of the calorimeter. Where should we put the boundary between electromagnetic and hadronic calorimeter, or could the coarser read out of an HCAL be used for reading the tail of electromagnetic showers without these clouds hampering the functioning of the HCAL itself?

- The next important issue is the detection of neutral hadrons. A shower for a neutral hadron occupies more space than an electromagnetic shower, and thus is less sensitive to dead zones. The resolution is a key factor because it will dominate the jet energy/mass resolution. However the separation between showers is a major consideration because of the large extend of showers with the resulting large probability for overlaps. The muon identification is, apart from the neutral hadron measurement, an important part of the hadronic calorimeter, as the muon system, outside the coil, has a rather high cut off in energy.

    - Calorimeter depth: A typical ECAL presents about 1 interaction length to a particle. The current design for the HCAL corresponds to adding 4 more interaction lengths. The level of pions sailing through the calorimeters is at the percent level. This has two consequences: they constitute a background to muons, and the showers are not well contained. Is the tail catcher a part of the solution? Is the detailed knowledge of the development of the shower a solution? Should we increase the depth of the calorimeter or go from iron to tungsten or part of tungsten? A special case is the end caps. Shouldn't we consider going to 7 interaction lengths and forget about the muon chambers in that part of the detector to improve the quality of the magnetic field, or conversely reduce the coil length suppressing the return yoke plug?

- Resolution: The intrinsic resolution to hadrons is driven by the ratio of response to electromagnetic and hadronic components. How can we optimise this by playing with the amount of tungsten in the radiator or the nature of the detecting medium? How can we optimize it by using a fine granularity identifying the two components and weighting them adequately? Can we play with the saturation of the response to equalize the response to the two components?

- Separation between charged and neutral showers: This question is at the core of the particle flow. Is it possible to achieve an adequate topological separation between showers? What is the optimum granularity for that purpose? Can we identify neutrals coming from charged interactions in the calorimeter and separate them from the prompt ones? We need to confine the showers as much as possible, use tungsten? Do we need to be able to identify the direction of neutral clusters?

- Muon detection: Using a muon system outside the coil in the current design sets a momentum threshold at around 5 GeV. We need to identify muons at lower energies. What can be the efficiency and the contamination of finding muons in the HCAL? Do we need then to improve the contamination at high energies with an external muon identifier?

5.2 Tracking

The proposed tracking system has three components:

- A large volume TPC
- A high precision vertex pixel detector
- A Si tracking system, surrounding the TPC on the inside and possibly the outside.
- A SI pixel and strip tracking system in the forward direction

5.2.1 Interface to the machine

- Inner radius of the vertex detector: The inner radius is driven by machine requirements (aperture of the machine) and background. The length of the first layer is driven by the magnetic field. Is 4T optimal for this?
- Outer radius: The outer radius at the moment is somewhat arbitrary. How can we define the interface to the SIT? What are the constraints?
- Length of the vertex detector: The length of the first layer is driven by the backgrounds, the other one by the requirement to have good solid angle coverage. Is the current layout optimal?
- Layout of the vertex detector: only barrel, integrated end caps? Does it make sense to revisit the question of end caps in the VTX detector? They introduce complexity, and possibly more material. How does one extract the cables from the barrel in the presence of end caps? Are they needed?

- Alignment issues: How can we align the VTX relative to the rest of the detector?
- Material: realistic ladder and support structure estimate, electronics, cables, etc. Where are the cables routed? Where does the electronics sit? Is the TDR place on the mask still an alternative, given that the distance between detector and mask has changed significantly?

5.2.2 Interface between VTX and TPC

- The SIT was introduced for track merging and for V0 efficiency reasons. These studies should be redone.
- Is the current SIT layout optimal? Which role does its material play in the overall track reconstruction?
- In the forward direction, the FTD is currently a system of pixels and disks. How important is its material. How stable is forward tracking.
- The CTD layout needs to be re-optimized for the new L*.
- Is there an advantage to having a continuous VTX tracker, such as a mini-TPC?

5.2.3 Central Tracking

- The inner radius of the TPC was set by the outer radius of the mask, and considerations on opening the detector and accessing the inner components. How relevant are these considerations. Are there other arguments for a different inner radius?
- What should be the outer radius of the TPC? This is closely related to the ECAL, and the question of particle flow.
- What is the “minimum” TPC to achieve the desired level of stable and robust tracking?
- How important is the role of the endplates and the material in the endplates? How much is particle flow deteriorating for different amounts of material in the endplate.
- What is the optimal length of the TPC? This is probably driven mostly by particle flow considerations.
- How important is the FCH behind the TPC? Do we need stand-alone tracking capability in there, or is a simple device which adds one or two hits sufficient?
- Which technology is optimal for the FCH?
- Alignment and calibration: How do we align the TPC? Do we need external references like the SET or a granular first part of the ECAL?
- Alignment: How do we align the TPC relative to the inner tracking detectors?
- Shape of the TPC: What is the penalty for a round TPC inside an octagonal ECAL, if any?
- How efficient is the TPC for detecting backscattered particles. How important are these?
- What quality of the field do we need in the TPC, SIT, and other detectors?
- How can we measure and monitor the field distortions at the required level of accuracy?

5.3 Forward Detectors

- How can we integrate the forward calorimeters, in particular the BCAL, into the overall calorimeter scheme.
- Backgrounds in the current version are approx. a factor of 2 larger than in the original TESLA design. Is this a problem?
- What is the influence of a crossing angle (2 mrad, 20 mrad) on the performance and design of the forward detectors?

5.4 Muon Detector

- Do we need one? muon identification, tail catcher, cosmic veto?
- Is the separation between barrel and endcap optimal?
- How many layers of sensitive detector do we need?
- Which role plays the plug? Does it make sense to eliminate the plug, at the cost of a shorter magnet and thus a less homogeneous field?
- How thick should the muon system be?
- Can the muon system play its role as a tail catcher even behind 1 interaction length of magnet?