R&D for the International Linear Collider

GDE R&D Board*

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1 Introduction

This document attempts to give an overview of the R&D for the ILC. The document reflects the status of understanding of ILC R&D in April 2007 when the information was gathered for the meeting of the Machine Advisory Committee for the ILC. The selection of topics is highly selective, emphasizing items that are critical for the progress of the ILC towards the engineering phase. These cases have been sufficiently developed to be included in a global coordinated R&D plan.

The items included are considered to have a major impact on the performance or the cost of the ILC and are thus deemed high-priority. The implementation of emerging new solutions may affect the layout of the ILC. Such changes may be absorbed in the engineering plans for the ILC if they are adopted sufficiently early. We have made definitive assumptions on the timelines for the EDR phase. When the required research extends beyond the EDR phase, ways of risk mitigation are outlined. In some cases the estimated cost of not carrying out the R&D or not achieving the expected R&D results are quantified.

This approach impacts the role of so-called alternate solutions. Evidently if the alternates do not lead to a more attractive solution over the time span of the EDR they are not considered in earnest for the EDR. It is, however, recognized that such research may still be valuable and if successful would come into play if the overall time lines have to be adjusted.

The transition to the engineering phase is outlined when necessary although it is noted that the distinction between R&D and engineering in many cases is artificial.

The document makes no attempt to give a complete list of the many research activities that are under way worldwide. The R&D board has collected this information and often has suggested changes to the specific implementation in national or other programmatic approaches. In several cases this has led to a better load sharing and resource usage in the various regions. This report does not touch on that aspect of the activities in the R&D board: it describes a snap-short of a R&D plan which already reflects a large degree of consensus.

It should hence be emphasized that the failure to mention a particular R&D activity in this report does not imply a classification as low-priority. The significance may be that the R&D does not impact the engineering of the ILC, that the fruits of the R&D come to bear at a later stage or that the alternate approach is still too risky despite of huge potential cost savings.

2 Global R&D strategy

R&D for the ILC is funded through national programmes (via the national laboratories) or through programmatic approaches (such as, e.g. for the European Commission). In the absence of a central R&D budget the R&D board has given advice and guidance aimed at shaping these programs in order to avoid duplication of activities where this is not felt necessary or to provide additional.

In some areas the required resources exceed those available and a more coordinated approach was required to cope with the highest-priority R&D issues. The R&D board has thus established topical task forces that address the R&D for a particular area in an international context. The pre-eminent example is the work on the cavity gradient in which all regions participate. The regions have agreed on a common plan, which they are trying to execute in an optimised fashion. The task forces to date are:

S0: Cavity gradient

S1: Module gradient

S2: Module string test

S3: Damping rings

S4: Beam delivery system

S5: Positron source

The list will be expanded as the need arises. It should be emphasised that prior to the task forces working groups have been formed that study the issues in a more complete manner which is not limited to the narrow time constraints given by the time lines of the EDR. The task forces make use of the human resources in the working groups to tackle their research challenges. Naturally there are more working groups than task forces and their progress is implicitly assumed in this document. As only one example the controls group is not mentioned here since it is assumed that eventually the most advanced monitoring and control system will be implemented for the ILC with its unprecedented requirements on controls and feedbacks.

The assumptions for this report are outlined below.

2.1 Assumptions on time lines

The baseline assumption for completion of the EDR phase is end 2009. By the end of the EDR phase the R&D is complete to allow for a decision on the layout of the machine and for a proper assessment of the cost of the machine. This overall assessment will be the basis for the decision process for the approval process, which is subsequently foreseen to start.

2007 – 2009	EDR phase
2010 – 2011	Approval
2012 – 2018	Construction
2019 – 2020	Commissioning

It is assumed that after a seven years construction period the commissioning phase of the ILC will commence and that the ILC will be available for experimentation before the end of the next decade.

2.2 Risk mitigation

The purpose of the R&D for the ILC is a) to establish that the chosen technologies are viable to achieve the required performance for the machine, b) that the cost of the technology has been minimised and c) that the chosen path provides sufficient flexibility for the operation of the ILC such as to guarantee successful operation even when unforeseen constraints arise that affect the working point of the machine.

All these R&D goals can eventually be expressed in equivalent cost. In simple terms, a cost of a severe R&D oversight that inhibits operation of the ILC may approach the total cost of the machine. In other cases, R&D that improves the luminosity of the machine by a certain factor can be compared to the corresponding savings in running time. Similarly other delays can be compared to the additional cost incurred at the various stages.

The purpose of R&D for the ILC hence is to reduce risk, i.e. extra cost, delays or compromised performance. The concept of risk mitigation is one that drives both engineering and R&D. This approach – implemented in a systematic manner – is currently being pursued both for R&D and engineering for the ILC. It is expected to yield quantitative assessments of the benefit of R&D in the near future. We are following this approach in the cost intensive R&D for the S0S1 task force.

2.3 Treatment of alternative solutions

The baseline program lays out specific technical solutions. Potential cost savings from alternate approaches have not been evaluated in the RDR, which states the cost of the baseline program. Nonetheless, such alternate solutions may soon become sufficiently mature to be considered replacements for the baseline solutions. Eventually an alternate may be sufficiently advanced to actually reduce the risk for the ILC and consequently would be selected as the new baseline.

Such changes are only reasonable in a certain window of opportunity. If the progress on an alternate is too late and the additional cost incurred with the design changes surpasses the benefits it will have to be discarded or considered for upgrades.

The emphasis in pursuing alternate solutions hence depends on their “near-term” potential, the additional strain on resources and the “risk” of the baseline option. The approach consequently outlines the alternatives of interest and also discusses the level of effort with which the alternates are being explored.

3 Report from the task forces

3.1 S0/S1

The ILC baseline has assumed an operational gradient of 31.5 MV/m as the average accelerating gradient. Such a gradient has been demonstrated in individual cavities but is not routinely achieved in cavity production. Given its impact on the cost and performance of the ILC the EC has requested the ILC R&D Board to set-up the S0/S1 Task force with the following charge:

- to carry out a closely coordinated global execution of the work leading to the achievement of the accelerating gradient specified in the ILC Baseline.
- A definition of the goals for the cavity performance in terms of gradient and yield and a plan for achieving them should be proposed by this group, which should take account of the global resources available and how they may be used most rapidly and efficiently.
- The accelerating gradient performance and yield should be specified both for an individual 9-cell cavity and for an individual cryomodule, and the plan should cover the demonstration of this performance in both cases.
- The GDE will facilitate the coordination at the global level to achieve this vital goal as soon as possible.

The main assumption of the task force is that the basic recipe for the cavity treatment to achieve highest gradients is known: Electropolishing (EP), High Pressure Water Rinse (HPR) and In-situ Bake-out.

Despite of a number of successes the results on the cavity gradients are not yet easily reproducible. Field emission is a major problem limiting the cavity performance. Some surface contaminants have been identified e.g. sulphurous which are evidently produced in long EP processes. A fine-tuning of the surface preparation parameters is needed to specifically remove those contaminants (for a study see single-cell program).

Two other aspects need to be considered when defining a comprehensive R&D plan: First, new cavity vendors are being sought. Performance impacts due to their learning curve have to be avoided. It is thus necessary to protect the understanding of surface preparation process from the potential fabrication errors by new vendors. Second, a statistically meaningful sample of cavities and RF tests is needed to assess overall cavity fabrication and preparation. Therefore, a reasonably large number of cavities from several regions must be available from a production-like mode, eventually.

The task force has defined the R&D goals:

S0 Ultimate Goal

- The cavity performance is influenced by the fabrication process and surface preparation. An effort in all the regions is thus required to qualify further vendors for cavities.
- The preparation process and vertical test yield for 35 MV/m at $Q_0 = 10^{10}$ should be greater than 90% for a sufficiently large number (greater than 100) of preparation and test cycles. To this end there should be a complete description of the preparation and testing processes (reproducibility in other places). The time scale should be commensurate with the completion of the EDR (middle of 2009).
- Once a viable cavity process has been established through a series of preparations and vertical tests on a significant number of cavities a gradient of 35 MV/m at $Q_0 = 10^{10}$ should be achieved in a sufficiently large final sample (greater than 30) of nine-cell cavities. The tests are done in the low-power vertical dewar in a production-like operation such that all cavities

get the same treatment. The yield for successful cavities of the final production batch should be larger than 80% in the first test and should go up to 95% after reprocessing. This is consistent with the assumption in the RDR costing exercise. For the ultimate experiment only qualified vendors and qualified preparation infrastructure would be employed. The experiment should include further results from parallel R&D efforts (single-cell and tight-loop – see below). The ultimate experiment will start end 2009 and results would probably be available in the post-EDR era. The number of cavities should be a multiple of 30 with 30 being the minimum.

S1 Ultimate goal

- Achieve 31.5 MV/m at a $Q_0=10^{10}$ as operational gradient as specified in the BCD in more than one module of 8 cavities including e.g. fast tuner operation and other features that could affect gradient performance.
- All cavities built into modules perform at 31.5 MV/m including enough overhead as described in the BCD. The cavities accepted in the low-power test should achieve 35 MV/m at $Q_0=10^{10}$ with a yield as described in the S0 definition (80% after first test, 95% after re-preparation).
- At least three modules should achieve this performance. This could include re-assemblies of cryostats (e.g. exchange of cavities). Note that the module design does not have to be final at this stage. The modules should be operated for a few weeks.

S1 Intermediate goal

- Achieve 31.5 MV/m average operational accelerating gradient in a single cryomodule as a proof-of- existence. If some cavities perform below the average, this could be achieved by tweaking the RF distribution accordingly.

3.1.1 Ideal plan

S0 – Cavity Performance in vertical test

Several main activities have been identified which are closely coupled and partially progress in parallel. The subdivision of tasks will allow tracking of the progress of the task force plan.

- Research on single-cell to establish more reliable final preparation parameters. The efforts concentrate on the final rinse after EP before HPR. The candidate processes are Ultrasound, Short EP (or HF rinse), H_2O_2 –rinse. The step is seen as the most efficient way for comparing preparation recipes. The program is well under way (major effort at KEK) with very promising results.
- The Tight-loop program rests on an international multi-cell cavity exchange program. In its first round it attempts to identify the regional differences in preparation and testing. Its second round applies the single-cell results to multi-cells and tries to achieve the same performance. This goal has to be achieved under production like conditions.
- Independently ongoing productions are to be monitored, such as the XFEL-preparation, the involvement of new vendors and the use of the improved preparation process for an ultimate batch of cavities.

S1 – Module performance

For the demonstration of the module performance the ongoing effort on module production will be monitored. A clear improvement of the average gradient has been demonstrated recently. The best operational gradient so far is 28.5 MV/m.

The evaluation of a cavity production model and the module production are consistent with both having enough cavities and cryostats available. For the S1 effort "re-population" of cryostats with improved cavities is an option so as to reduce cost significantly. Generally, the cost for cryostats is included within the S2 program. Nonetheless, there is an issue with conflicting interests of module gradient test (S1) and full beam tests (S2) as modules in accelerator installations cannot be frequently exchanged to install improved cavities.

The lead-time for module demonstration is long especially because a higher yield will be demonstrated only in 2008/2009. To reduce the waiting time and as a demonstration of the proof-of-principle for the intermediate goal a fast-track module with cavities from several regions is being discussed. A new effort in collaboration would be needed to enable this goal.

Major Milestones until 2009

S0

- Tight-loop tests: first cavities have been identified for this ongoing exchange program. A third of first loop tests will be finished by end of 2007. The first loop of tests will be completed by mid 2008 and the second loop by beginning/mid 2009.
- As part of the production-like effort 14 ACCEL cavities in the US and the 6th production at DESY will have been tested. Among the new vendors the data from the AES cavities in the US and 6 (10) cavities in Japan will be available. Until mid 2009 at least another 15 ACCEL TESLA-short cavities will be tested in the US[1].

S1

- Tests of modules M7, M8, M9 (FNAL), STF Phase 1.
- Acquisition of further modules: 2 in 2008 (1st US module, 1st type 4 cryomodule) and 2 in 2009 (2nd and 3rd type 4 cryomodule). Module M10 (or one US module) should become the dream module.

3.1.2 Resources and Benefits

In order to assess the impact of the research on the project cost an estimate of the impact on the whole ILC project could be made. A simple question is: what is the cost penalty for taking a cavity performance distribution of today?

The main effect on the total project cost would be a lower average gradient – as long as a variety of gradients can be accommodated in the machine (following C. Adolphsen). An average gradient of 28 MV/m and a flat distribution between 22 and 34 MV/m such as achieved in DESY's 4th production requires to optimise the power distribution and to compromise somewhat on the energy overhead due to reduced efficiency of the RF unit. As a result the linac has to be enlarged by 12.5% and the cost increases by 7% or ~500 MILCU.

A second impact on the total project cost is related to width of the cavity gradient distribution. If one estimates the precision on the fraction delta e of "faulty" cavities, one arrives with N=100 cavities from one manufacturer processed once or twice, at delta e=$(e*(1\text{-}e)/N)^{0.5}$, or delta e=4% for e=20%. The worst case need is 4% corresponding to 30 MILCU. The corresponding numbers for N=60 (30) cavities are 5.1% (7.3%) or 38 (54) MILCU. The time-line for a final batch of N cavities could be post EDR.

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[1] The number of cavities is likely to increase; the details depend on when the 2009 cavities will be available for testing. The number given follows a conservative approach.

Estimation of R&D cost

It is acknowledged that the cavity production is an expensive R&D item with significant lead times. Nonetheless, it is mandatory to have a continuing flow of smaller production batches of cavities so as to improve processes and quality control measures. In addition, these will be used for estimation of final batch size of the ultimate cavity batch.

For an estimation of the R&D cost the task force developed three scenarios for cavity productions which takes into account existing plans in the regions and makes certain assumptions about the planning based on available resources (funding levels).

Scenarios for Cavity Production

- Pessimistic case
    - EU: solely XFEL project preparation and limited (re-) processing to XFEL gradient (~28 MV/m)[2]
    - Flat budgets in US and Japan
- Realistic scenario
    - EU: XFEL as above: 30 additional cavities from EU FP7 PP with ILC-type processing
    - Japan: flat budget
    - US: Minor increase in cavity numbers
- Optimistic scenario
    - EU: as above (XFEL + EU). Additional high-gradient program at DESY
    - Japan: flat (+20% increase in cavities)
    - US: roughly double number of cavities in 2009 to 60

For the estimation of the cost of these scenarios the task force calculated the fabrication cost and one process cycle for the production batches. For each processing 30 k$ including labor are taken[3]. A number of re-preparation cycles are included (20%) for the full cost estimate. This assumes the existence of cavity preparation infrastructure. Infrastructure development is not considered as part of S0.

The process cost for the tight-loop is added to the production-like effort calculated in Table 1. For the roughly 100 processes (81 first loop, 27+ second loop) this amounts to about 3.5 M$. The final major cost item is the batch for the ultimate goal demonstration. Currently 30 cavities with processing are assumed which corresponds to roughly 3 M$.

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[2] Depending on the outcome of the ILC program within the next year XFEL might still change the procedures for preparation. So the distinction XFEL-ILC is somewhat artificial. Impact on schedule and investment need to be considered.

[3] These estimates are made with very limited experience available at this time. The value should be considered as a conservative estimate.

Table 1: Cost associated with the production efforts in the funding scenarios described in the text.

		KEK			US				EU						
		2007	2008	2009	2006	2007	2008	2009	2007	2008	2009	Sum over 2007-2009	Cost Fabrication	Cost Processing	Cost Sum
	pessimistic	6		24	8	8	12	20	30	20	30	158	11850000	6636000	**$ 18.486.000,00**
	realistic	6		24	8	20	20	30	30	30	60	228	17100000	9576000	**$ 26.676.000,00**
S0	optimistic	10		24	8	22	24	60	30	30	60	268	20100000	11256000	**$ 31.356.000,00**

Value Added from these Scenarios

The data which will be available from these scenarios will allow a detailed estimate on average gradient and spread to be compared with DESY's 4th production.

Even in the pessimistic scenario this will improve the estimate on the gradient significantly which is then based on roughly 160 cavities will be tested up to 2009 (include 2006 cavities). About 80 will be put through a mature infrastructure for the final preparation step with tight quality control at the vendors. Although this data set might still slightly differ from the final ILC preparation process and the cavities will be partially used for final treatment setup at companies, it is the backbone of the dataset. Certainly, the fabrication yield can be estimated from this data set at least to exclude major fabrication problems. The other 80 will be partially from qualified vendors and new vendors and be prepared in new infrastructure tailored to the final ILC preparation process. Thus, this approach will provide a lower bound on the average gradient. The minimum expectation is a gradient at the level of the 4th production at DESY ~27 MV/m with a spread of 4 MV/m.

In the other scenarios more cavities are put through the optimized ILC process assumed to be available by mid 2008. The advantage is a demonstration of a higher average gradient with significantly improved data (although a certain fraction of the cavities will be tested only in 2010): The number of cavities for the various scenarios are 80 cavities (pessimistic), 120 cavities (realistic) and 150 cavities (optimistic). All scenarios assume roughly 30 cavities from new vendors. In the optimistic scenario a cavity batch comparable to the current TTF/FLASH production would be available for an evaluation of the ILC accelerating gradient.

S0/S1 Plan Cost Estimation

Taking the optimistic scenario which provides highest confidence about the gradient distribution with a final batch of 30 cavities for the ultimate goal and the tight-loop experiments the cost for the S0S1 plan are roughly 38 M$. As said above S1 cost is contained within S2 cost estimates.

This needs to be compared to a reduction of the average gradient for the ILC by 12.5% (~ 500 MILCU). In comparison the cost associated with the risk due to the width of the gradient spread is smaller but still almost twice the cost of the S0 program.

3.2 S2 – String test

The S2 task force was created by the Global R&D board in June 2006 to determine the nature and size of a system test needed to properly test the ILC acceleration technology. Our charge was to set the goals, specifications and a timeline for the system test(s). This section contains our conclusions. There is more detailed information about our deliberations on the S2 Wiki page and the full report is available online .

Our major conclusions are summarized in the following bullets.

- The TTF facility at DESY has provided valuable system tests of many elements of the ILC technology. More tests can and should be performed there. Further testing activities for the XFEL, as well as the complete XFEL, will continue to provide valuable experience.
- However several important changes to the TTF design are being planned for the ILC. These include a higher gradient, relocation of the quad to the center of the cryomodule, shortening of the cavity end-group, and a new tuner design. Also under discussion are different modulators, klystrons, and cavity shapes among other developments. These design changes are numerous and major enough that a further system test is warranted.
- The basic building block of the ILC linac is one RF unit containing three cryomodules with full RF power controlled as in the final linac. The minimum size system test needed to confirm the performance of a new design is a single RF unit with ILC like beam. As many tests are statistical in nature, a longer string test with several RF units or multiple tests with one RF unit would be better. The primary reason beam is needed is to check that higher order modes (HOMs) are coupled out and absorbed so they do not cause a significant heat load at liquid helium temperature.
- All three regions have expressed a desire for command of basic ILC SCRF technology and are preparing to manufacture cryomodules locally. Local test facilities at the scale of 1 RF unit are under construction in Asia and the Americas. Europe is trying to increase its ILC related efforts with a forthcoming proposal to the European Commission (FP7). The proposal will be based on expanding the usage of existing infrastructures.
- As construction of the project starts, a test facility (or facilities) will be needed to qualify manufactured RF unit components of the final consolidated ILC linac system design. These components may be built at industries in different regions. One of the possible scenarios is to build a test string with contributions of a total of several RF units from the three regional teams. There are many factors that will influence the choice of the size of the string and whether the goals can be accomplished instead through several smaller tests or one long string. These factors will be coupled to the future industrialization strategy adopted for ILC main linac components. Therefore we cannot at this stage determine the ideal scale of this second phase of system tests.
- Sections 5 and 6 of the full report list reasons for doing tests and give a rough schedule for doing them in a phased approach. Some of the reasons for tests evolved from the R1 – R4 ranked lists of technology demonstrations called for by the Greg Loew TRC report. Our plan is based on a natural schedule for components to be ready. Therefore some low risk items are tested earlier than some high risk items. The phasing of the plan recognizes development times necessary for the final design of components, as well as the need for a few iterations that may be necessary to reach ILC specifications for the full RF unit, especially if these have to be implemented outside the TTF. There are number of phases to the system tests we propose (starting with 1 cryomodule and ending with several RF units). Phase 1.3 (at least 1 RF unit of near final ILC design) should be successfully tested before more than 1% of the final industrially produced ILC cryomodules are manufactured. This keeps the risk of having to rebuild a large number of cryomodules low while accepting a moderate risk of a schedule delay and having to rebuild 1% of the cryomodules. This risk is moderate because the successful phase 0 and 0.5 tests were done with cryomodules only slightly different than the final design.

Table 2 describes the phases of the system tests and gives rough completion dates.

Figure 1 gives the schedule in graphical form showing its relation to other parts of the project.

Costs are a bit difficult to define as these system tests are done in stages some of which are already completed.

We estimated that at a lab which had a cryoplant and an empty building but virtually nothing else it would cost $86M not including lab labor to build phase 1.3. This included: infrastructure to process and test cavities and assemble cryomodules; purchasing the parts for non-final versions of cavities and cryomodules along with those for the final versions; beam source, buncher, diagnostics, spectrometer, dump; shielding and PPS system; cryogenic lines; klystrons, modulators, LLRF, and RF distribution.

Fermilab has estimated a cost of $32M not including lab labor to build phase 1.3. This does not include the infrastructure or parts costs for building the cryomodules as this is partly done and is accounted in a different part of their budget proposal. They have an injector which they will be moving hence its cost is reduced.

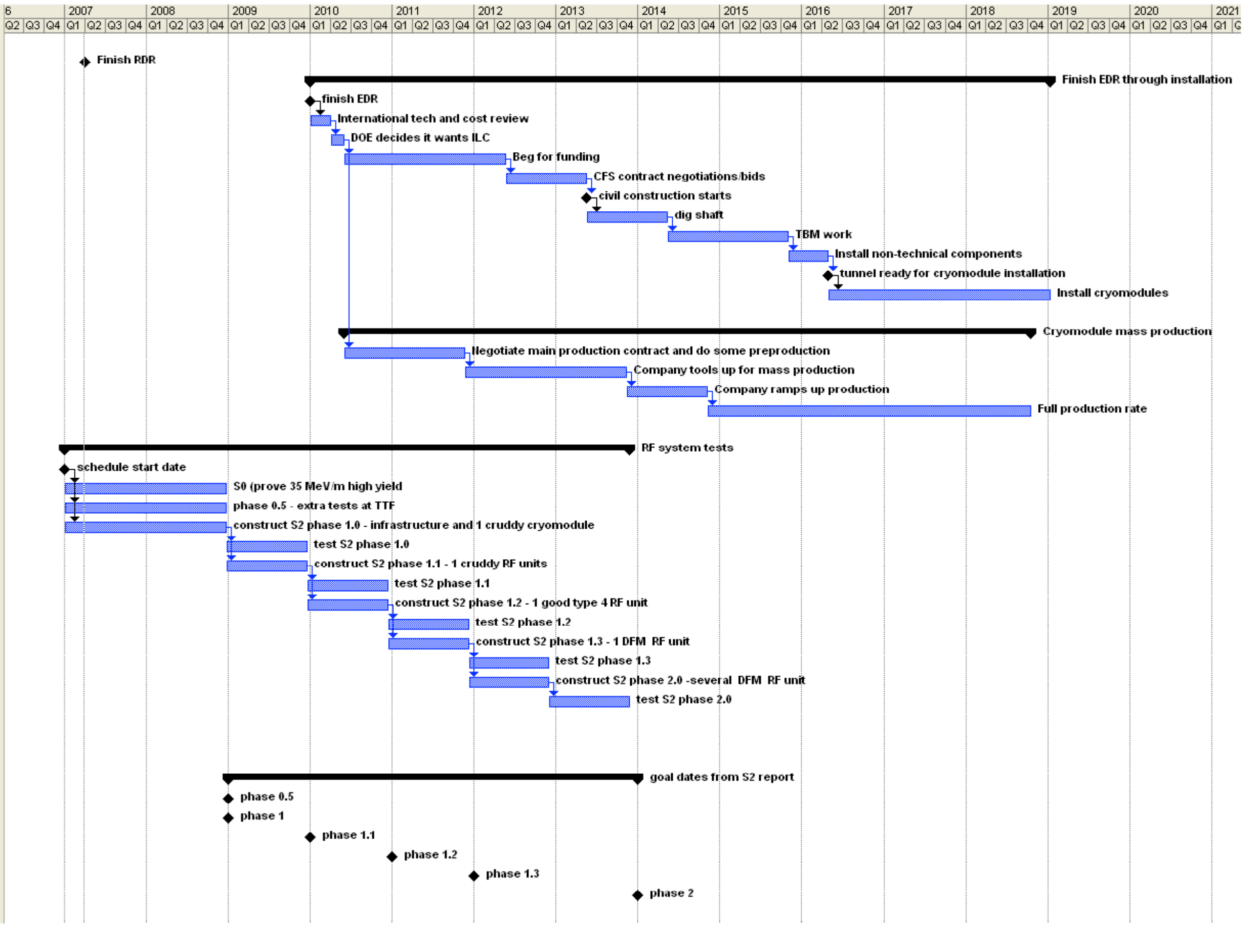
KEK has estimated a cost of 1,579,220 k-yen or about $13M not including lab labor to build phase 1.3. This assumes they have finished an earlier phase which puts beam through a single cryomodule.

Each group has estimated what is appropriate for it given what they already have (or have planned for the near future). As they are estimating different things, it is no surprise the answers are quite different.

Table 2 Rough technically limited schedule for completing the string tests.

Phase	Completion date	Description
0	2005	TTF/FLASH, not final cavity design, type 3 cryomodule, not full gradient, has beam but work is needed to have regular ILC bunch structure, roughly 2 RF units.
0.5	2008	Extra tests at TTF/FLASH with same type cryomodules as phase 0
1	2008	1 cryomodule, not final cavity design, type 3 cryomodule (and/or) STF type cryomodule, not full gradient, no beam
1.1	2009	1 RF unit, not all final cavity design, not all type 4 cryomodules, not full gradient, beam not needed for tests, but should be built so it and the LLRF are debugged for the next step
1.2	2010	1 RF unit (replacing cryomodules of phase 1.1), final cavity design, full gradient, type 4 cryomodules, with beam
1.3	2011	1 RF unit (replacing cryomodules of phase 1.2), final cavity design, full gradient, type DFM cryomodules, with beam
1.4	2011	Tunnel mockup above or below ground. 1 RF unit perhaps built with parts taken from earlier tests. Includes RTML and e+ transport, no beam
2	2013	Several RF units at one site (of the final ILC?) as a system test of final designs from multiple manufacturers. Need for beam depends on design changes made after phase 1.4.
3	2013	XFEL
4	2018	First 2.5 km of ILC

Figure 1: System test schedule in relation to other major project milestones



3.3 *S3 – Damping rings*

Six issues for the damping rings have been identified as requiring very high priority R&D in the next few years. These issues are:

- electron cloud;
- fast injection and extraction kickers;
- lattice design;
- low-emittance tuning;
- impedance-driven single-bunch instabilities;
- ion effects.

In each case, R&D is required either to validate the baseline configuration laid out in the RDR, or to provide information that will allow further parameter specifications and detailed design work to proceed. In addition to those R&D items identified as “very high priority”, there are many items that are considered “high priority”: these include specification of magnet field quality to ensure good acceptance; specification of requirements for alignment and survey; characterization of multi-bunch instabilities, and specification of the feedback system; development of technical designs for the damping wiggler, vacuum and RF systems; and development of a range of advance instrumentation and diagnostics devices. Attention will first be given to the very high priority R&D items, with work continuing on the high priority items as resources permit. Below, we briefly describe the status and objectives of R&D for the very high priority items.

3.3.1 e-cloud

Significant effort has been devoted over recent years to understanding the electron cloud effect, and to developing predictive models. However, given the range of phenomena related to electron cloud, and the sensitive dependence of its effects on details of the accelerator environment, there is still significant uncertainty in the impact that electron cloud could have on the performance of the positron damping ring. The best estimates, based on simulations that make significant extrapolations from existing data, suggest that without major improvements in techniques used to suppress build-up of electron cloud, it is likely that electron cloud will prevent the specified beam quality and stability being achieved. It may then be necessary to operate with significantly reduced beam current, or to perform further R&D before implementing (potentially expensive) remediation.

The best data on electron cloud in positron storage rings comes from the B factories, where early problems caused by electron cloud were eventually solved by the use of solenoid windings in the straight sections of the rings. The ILC positron damping rings will operate in a regime different in several respects from the B factories. Although the beam current will be lower, the emittances will be smaller by more than an order of magnitude, making the beam potentially much more sensitive to destabilizing effects. Also, the positron damping ring will include 200 m of wiggler, where solenoid windings will be ineffective at suppressing the cloud.

R&D on electron cloud will focus on two areas: understanding the build-up of electron cloud, and the development of techniques for its suppression; and understanding the interaction between the cloud and the beam, leading to a specification on the maximum tolerable cloud density in the positron damping ring. Both areas will involve experimental and simulation studies. There are several suppression techniques that appear promising, including the use of vacuum chamber coatings having low secondary electron yield, use of grooved chamber surfaces, and use of clearing electrodes. These techniques need to be studied to determine the most effective prescription for the positron damping rings, with the least severe side effects.

The electron cloud effects is of significant importance for many storage rings (for protons and heavier ions as well as electrons); and, as a result, there are many groups around the world interested in pursuing electron cloud studies that would be of direct benefit for ILC. Potential test facilities include PEP-II, CesrTA, KEKB and DAΦNE.

3.3.2 Fast injection and extraction kickers

The injection and extraction kickers for the damping rings must have rise/fall times less than the bunch separation in the rings; this could be as short as 3 ns in the baseline configuration. To achieve the necessary deflection angles, pulses of many kV are required; furthermore, the kickers must operate reliably at repetition rates of 6 MHz (for bursts of 1 ms), and with pulse-to-pulse stability of better than 0.1%. These parameters are beyond the state-of-the-art in kicker technology.

Possibly the most demanding component of the injection/extraction kickers is the fast, high-power pulser. While there are several possible technologies that approach the parameter specifications for the damping rings – including fast ionization dynistors, drift step recovery diodes, and inductive adders based on mosfet devices – none has yet demonstrated the full parameter specifications for the damping rings. It is possible that further development of any one of these devices may provide an acceptable solution; or some hybrid technology may be needed; or some additional component capable of enhancing the output from a basic pulser (for example, ferrite pulse sharpeners).

As well as the pulser, the stripline electrodes that generate a deflecting field from a high-voltage pulse require careful study. Here, the issues include achieving a sufficiently good impedance match to the pulser and the load, producing a design with sufficient aperture and field quality for the injected beam, and minimizing the beam impedance to avoid instabilities and higher-order mode heating.

The pulser R&D will be primarily experimental, and there are several groups already working on the different candidate technologies. Although much can be achieved using bench tests of prototypes, tests of kickers with beam will be necessary to demonstrate reliable operation meeting all specifications. Possible test facilities include the KEK-ATF and the A0 beamline at FNAL, both of which have already been used for early tests of some devices. The stripline electrodes, though still requiring R&D are relatively conventional; thus, computer modelling and design studies will be appropriate in the near term, but ultimately prototypes will need to be built and tested.

3.3.3 Lattice design

The lattice design provides the basic parameters for many technical subsystems (including the magnets, vacuum system and RF), as well as providing the basis for a wide range of beam dynamics studies. Thus, in order for engineering design work to proceed efficiently, a stable lattice design is required at an early stage. Many of the lattice parameters – such as the damping times and equilibrium emittances – are fairly easily achieved in a lattice conforming to the baseline configuration; but issues such as the acceptance and the sensitivity to errors are very challenging. An acceptance that is insufficient can lead to significant loss of particles from the injected beam, with potentially very serious damage to damping ring components. A lattice that is sensitive to alignment and focusing errors may make it extremely difficult or impossible to meet the specifications on beam quality and stability.

The lattice used as a basis for the RDR meets the principle parameter specifications and shows a promising acceptance. However, as our understanding of the machine requirements and engineering issues evolves, and the potential impact from such effects as electron cloud, impedance and ground motion become better known, it will be possible to optimise the lattice design for performance and cost. Lattice design work requires essentially no experimental studies. There are several groups (including those at ANL and IHEP) intending to explore a range of design options that may be expected to produce alternatives as well as an effective baseline design. While lattice design work generally proceeds iteratively (with modifications made in response to issues raised by development of technical designs of the major components), it is important that process of making design changes is controlled, so that there is a stable basis for studies depending on the lattice design, while allowing flexibility to enable improvements to be made.

3.3.4 Low-emittance tuning

The beam extracted from the damping rings is specified to have a vertical emittance of 2 pm; however, the lowest vertical emittance achieved in any storage ring to date is 4.5 pm (in the KEK-ATF). There is a need for development of more effective procedures for beam-based magnet alignment, orbit and dispersion correction, and compensation of coupling. While simulation studies have an important role in this R&D, experimental work and eventual demonstration of 2 pm vertical emittance will be essential to validate the ILC parameters. Closely connected with these studies will be the development of advanced instrumentation and diagnostics, including tests of high-precision BPM systems, and devices capable of fast beam-size measurements with micron resolution.

It is expected that the KEK-ATF will continue to be an important facility for experimental studies of low-emittance tuning through 2008. However, as the focus of studies shifts to ATF2 and issues relating the beam delivery system, there will be less availability of the damping ring for tuning studies. There is interest at some light sources, including the ALS at LBNL, and the APS at ANL, in developing low-emittance tuning techniques, with the potential of achieving emittances in the range of a few pm. CesrTA could also provide an important facility for such studies.

3.3.5 Impedance-driven single-bunch instabilities

Beam instabilities driven by short-range wake fields were a major operational issue for the SLC damping rings: even small variations in the charge distribution in the beam extracted from the rings had a significant impact in the tuning and operation of downstream systems. This experience makes single-bunch instabilities a concern for the ILC damping rings, particularly since preliminary estimates indicate little margin between the nominal operating parameters and single bunch instability thresholds. However, the present estimates must be based on broad assumptions regarding the impedance of the vacuum chamber. While the assumptions made are thought to be realistic, it is known that the onset and behaviour of single-bunch instabilities can be sensitive to details in the character of the impedance. In order properly to assess the baseline configuration and the developing design, it is therefore necessary to construct an accurate impedance model and study the effect of this impedance on the beam under a range of operational conditions (including variations in bunch charge, bunch length, and momentum compaction factor).

The following is an appropriate outline for the studies into single-bunch impedance-driven instabilities:

- Specify the vacuum system, including quantities and outline parameters of principal components expected to contribute to the chamber impedance.
- Develop technical designs for principal vacuum chamber components.
- Construct an impedance model based on the component designs.
- Assess the impact of the impedance on the beam, under a range of operational conditions.
- Review and improve the designs of the principal components, to mitigate impedance effects as necessary, optimise performance and minimize cost.

The R&D program will require close collaboration and effective coordination between the vacuum technical experts who will specify and provide outline designs for the vacuum system, the engineers who will develop technical designs for the chamber components, and the beam dynamics specialists who will construct the impedance model and determine the effects on the beam.

Initial estimates indicate that the impedance specifications will be demanding, but can be met by careful design work. Experience with existing machines suggests that construction of an accurate and reliable impedance model will be challenging; however, improvements in software tools and computing power in recent years have increased our abilities in this area. There is particular expertise with impedance modelling at SLAC, where there is interest and intent to contribute to this work. The Cockcroft Institute and LBNL can provide technical expertise with vacuum systems and engineering effort for design work. KEK and IHEP have considerable relevant experience, and have expressed interest in being involved in the work. The goal should be to complete at least the first iteration of the program outlined above in time for the EDR.

3.3.6 Ion effects

Ion trapping is a familiar cause of instability in electron storage rings. In existing machines, leaving gaps in the fill pattern is an effective way to clear ions and prevent ion-induced instabilities; however, in machines with very low emittance and moderately high current, there is some evidence that sufficient ions can be accumulated in the course of a few bunches to significantly affect the stability of the beam. Qualitative observations of such a “fast ion instability” have been made at ALS, PLS and ATF. The baseline configuration of the electron damping ring is consistent with the inclusion of frequent gaps that should prevent ions affecting the quality of the beam; however, there remains significant uncertainty in the models, which makes it difficult to predict with any confidence the impact that ions could have on the damping ring. Fast feedback systems may help to counteract ion-induced instabilities, but ultimately a very low residual gas pressure is likely to provide the most effective means of suppression. Development and confirmation of reliable models in the appropriate parameter regime are needed, in order to provide specifications and designs for the vacuum and feedback systems that are optimised for performance and cost.

The need for ultra-low beam emittance to make quantitative measurements presents a challenge for studies of fast ion instability; both because of the difficulty of achieving the required emittance, and the difficulty of making measurements with sufficient precision. However, such studies may be possible at the ATF, CesrTA, and the ALS. A systematic program will require the ability to tune reliably for vertical emittance of a few picometres, and to measure beam size and coherent motion along a train of some number of bunches, under varying conditions of bunch charge and residual gas pressure. The ability to determine the effects of fast feedback systems is also strongly desirable.

If the required facilities are available, the necessary measurements could be completed within two to three years. This will allow development and validation of reliable models, that can be used to predict the impact of fast ion effects on the electron damping ring. It will then be possible to optimise the design of the ring, particularly in regard to the vacuum and feedback systems, and the possible fill patterns during operation.

3.4 S4 Beam Delivery System

3.4.1 Preamble

Starting from the second half of 2006, the BDS area leaders were focusing on developing the internationally coordinated plans for EDR phase and beyond. Since November 2006, the GDE S4 task force was coordinating these planning efforts[1]. The S4 developed the overall assumption about EDR goals, in application to Beam Delivery System, and, via series of expanded meetings with leaders of particular work packages or collaboration leaders, the list of R&D to be focused on during EDR phase as well as the detailed schedules and milestones for critical areas. The results of such deliberations are summarized below. The projected budget situation was taken into account and in certain cases, when limited resources were identified to have caused delays with respect to the desired pace of progress, the GDE and regional leaders were notified[2] (the budget issues are not discussed below, as this is understood to be beyond the scope of the R&D section of the RDR document). The ongoing BDS cost risk analysis was also taken into account inasmuch as it was relevant for EDR planning.

3.4.2 BDS plans for BDR

In planning the EDR efforts, the S4 assumed that the EDR, till the end of 2009, will follow by two years of approval period, till the end of 2011, after that construction would start, in the beginning of 2012. Although a longer schedule was mentioned, the optimistic schedule was chosen for planning, which may be possible provided that the LHC would give exciting results, the yield of SRF cavities production will be steadily and predictably improving, the process of site selection and approval will be expedited, the commitment to invest in ILC will form in all three regions, and the cost uncertainty will be reduced.

Taking into account the above described schedule and that one of the overall goals should be striving for the early start of the ILC construction, the following defining principles of BDS planning for EDR were adopted:

- the efforts should focus on reduction of cost uncertainty, which means designing systems to appropriate level; and verification of performance via developments and tests of critical prototypes;
- one should not plan to complete all the BDS work at the end of EDR, instead, need to plan to continue optimization and final design after EDR and during earlier years of construction;
- if some development could have high political visibility, in addition to scientific impact, and could tip the balance for early start of ILC construction, this should be taken into account in planning

Several high priority areas of development were identified, in BDS area, where the novelty of design and technical challenges are such that focused efforts are needed in the EDR phase, to verify the performance, reduce risk and cost uncertainty, and develop optimized technical solutions. These areas, which will become the basis or form part of corresponding work package, are (*italic font indicate hardware to be built in EDR*):

- Integrated design of IR, development of IR superconducting magnets, *build engineering prototype of FD magnets*, design study to ensure IR mechanical stability, design of push-pull arrangements
- development of crab cavity systems, *test phase control system with two single cell cavities, build single multi-cell cavity*
- design, *construction, commissioning and operation of ATF2 test facility*
- development of laser wires for beam diagnostics, *prototype laser wires at ATF2*
- development of intra-train feedback, *prototype at ATF2*
- development of beam dump design and *study of beam dump window survivability*
- development of collimator design, *verification of collimation wake-fields with measurements and verification of collimation beam damage*
- development and *tests of MDI type hardware such as energy spectrometers, IP feedback BPMs, BeamCals, etc.*
- and the design work, which does not involve hardware development but use results of the above listed work.

Following the guiding principles, and having identified the areas of focused efforts in EDR phase, the overall schedule for BDS in EDR and beyond was developed, which is shown at the end of the document. Examples of detailed schedules for several systems are also shown below, however, in some cases these schedules were limited by presently known level of funding, and their adjustment and mitigation is under discussion and therefore not shown here.

For several critical systems the design features, challenges and the corresponding EDR goals are described below in some details.

The integrated design of the Interaction Region is centered around the superconducting Final Doublet, which design and developed is led by BNL. In EDR, an engineering prototype of the QD0 cryostat, containing self-shielding QD0 quad with corrector coils, the sextupole-octupole SD0/OC0 magnet, the anti-solenoid, and a dummy first extraction quad, will be built. This engineering prototype is to verify the design, which relies on compact direct wound magnets to provide the independent incoming and outgoing apertures separated by mere 49mm defined by 14mrad crossing angle over the L* distance of 3.5m.

The prototype is also aimed for studies of mechanical stability of the magnets, when integrated into cryostats, and connected to cryogenic system. The FD stability requirements are in the 100-200nm range (the luminosity reduction is 1-2%, 5%, 15-20% for rms FD vibration of 100nm, 200nm and 500nm, correspondingly). Very rough estimation, comparing with existing cryo magnets of completely different design which show 0.3-1micron level vibration, tell that the needed improvement is about a factor of three to five. Vibration studies will be performed after the prototype is built, and in meantime the methods to measure mechanical stability of the cold mass and of the magnetic center, will be developed.

The integrated design of IR, in a wider sense, includes all the systems such as cryogenics, supports of the FD, shielding of beamlines, the interface parts of the detector, lifting equipment in the IR hall and alignment systems, and so on. The single IR push-pull scheme sets specific new challenges for the design. For example, one of design constraints of the cryogenic system is that disconnection of cryo-line are not allowed during push-pull operation, and that the cryo-lines should be placed so that they would not interfere with detector door opening on the beamline. Engineering integrated design of IR will be a major focus of EDR work.

Development of the crab cavity system is led by UK-US (Cockcroft Institute, FNAL and SLAC) collaboration. Crab cavity design challenges include phase stability of about 67fs (or 0.094deg of 3.9GHz), which corresponds to <2% luminosity loss (quadratic dependence of dL on dt); couplers that should provide adequate level of damping of unwanted modes; a cryostat with appropriate level of microphonic rejection, etc.

The EDR plans take into account the synergy with developments of other ILC cavities (e.g. 3rd harmonic XFEL cavity) and with developments at non-ILC projects (e.g. LLRF for Energy Recovery Linac or XFEL). The EDR plans would include design of cavity and couplers, fabrication of one cavity and its low power tests, in an adjusted CKM cryostat, developments of RF system and tests of phase stability with two single cell cavities, conceptual design of the integrated system and of the cryostat. This EDR work will follow by tests of single cavity with beam at ILCTA around 2010, and later by design and construction of an optimized cryostat and of the second cavity, their integration and beam tests of two cavities.

The ATF2 facility is being constructed in ILC-like manner, when hardware is provided by in-kind contributions from all three regions, while Japan, as the host country, contributes also the civil construction and most of operation expenses. The ATF2 will prototype the ILC Final Focus system, help in development of tuning methods and instrumentation (laser wires, fast feedback, submicron resolution BPMs), help to learn achieving reliably the nanometer level beam size and beam stability, and potentially able to test stability of FD magnetic center. ATF2 is one of central elements of BDS EDR work, as it will address a large fraction of BDS technical cost risk.

The beam operation of ATF2 is scheduled to start in October 2008 and commissioning may take up to about a year. Studies will first focus on investigation of the small beam size while studies of nanometer beam stability rely on further development of hardware and will take place at the next stage. In addition to the technical challenges of ATF2, the collaboration will need to address the organizational challenges to perform coordinated integration and commissioning of ATF2, providing relevant experience for ILC.

The work on beam dumps during EDR would focus on engineering design of the water dump and the radiation water system, including considerations of tritium containment, window replacement, removal of dump and access for service. The accompanying prototype and beam test work would include studies of window irradiation (the place is to be defined, the BLIP facility is a candidate) and possibly prototyping the front-end of the mechanism of remote window replacement. These EDR activities would produce a design of the beam dump that could be submitted for pre-approval to environmental agencies.

During EDR, development of MDI type hardware would continue to be developed and tested with beam at ESA. This will include BPM based and synchrotron radiation stripe based energy spectrometers and the IP feedback hardware and tests of its resistance to background. Measurements of collimation wake-fields will also be continued at ESA, while the place for the beam damage tests of the collimator spoilers is still to be determined. The ESA facility will be available for BDS tests throughout 2008, while after that it may be unavailable. If additional beam tests, with beams of ESA characteristics, would be needed after 2008, the SABER facility may be used although its starting date is not yet known.

The design work, both accelerator and detector physics design and engineering design, will be a focus of EDR work. This would include design and integration of beamlines, conventional facilities, vacuum system, magnets, instrumentation, collimators, etc. The design work will also include considerations of new ideas, which may improve performance of Beam Delivery subsystems.

The design work will also include the optics, background and similar studies for small and zero crossing angle alternative schemes. Recent work on head-on scheme concentrated on optics design, evaluation of performance of existing electrostatic separators and laying out their placement in the tunnel, analysis of beam losses in the intermediate dump & beamline. For 2mrad scheme the recent work was focused on design of minimal most economical and shortest system, potentially without downstream diagnostics while alternative ideas of beam diagnostics directly at IP are being investigated. One of the goals of redesign was to ease magnet challenges posed by Vancouver scheme. Hardware developments are not planned for IR alternatives during EDR (there is synergy with LARP & European programs on large aperture SC Nb3Sn magnets). The timeline for IR design would include evaluation of the state of the design of alternatives and of baseline developments, near the end of EDR, at which point one would evaluate if any new technical facts or the physics results from LHC would favour pursuing an alternative configuration beyond the EDR, and if the detailed engineering design and hardware development may need to be refocused to finalize the design.

Table 3: Activities in the Beam Delivery System

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	EDR			Approval		Construction							Comm iss.
Constr aints				LHC physics	total length frozen		tunnel & optics layout frozen		optics details frozen		tunnel ready for installn		
Beam dumps	beam dump conceptual design and critical tests			pre approv al		beam dump final engineering			b.dump design frozen	beam dump construction		beam dump installe d	
crab cavity	design, build & test of conceptual phase control system; cavity fabrication; conceptual cryostat design; LLRF develop and test with single cells			design of cryostat; cavity integration; beam test of one cavity		beam tests of two cavities		final engineering		production		installe d	

ATF2	ATF2 construction and installation. Start of commissioning	Commissioning	Beam size and optics study	Beam stability study	2nd phase, e.g. SC FD; smaller emittance & beam size	Instrumentation developments and tests at beamline				
Final Doublet	Engineering design; full length prototype; stability design study and initial stability tests		Stability tests & design optimization		final design	production	lab tests	installation and pre-commissioning		
Detectors	Conceptual design; selection of two concepts; continue design		Design optimization		final design and start of production	Construct, assemble and pre-commission on surface			Lower down & commiss	
IR integrated	Conceptual eng. design of IR vaccum chambers; supports; pacman and moving shielding; cryogenic; service platform; detector moving system; cranes; etc.		Detailed eng. design of integrated IR with finalized choice of two detectors for final design		final design and start of production	production		installation and pre-commissioning		
Magnets	Optimization of number of styles; conceptual design of most magnets; definition of interfaces; Detailed design of low field and other special magnets; Vibration -wise design		Design and cost optimization; layouts with real space allocation, and detailed interfaces.		final design & needed prototypes	production		installation and pre-commissioning		
Collimation	Tests of collimation wakefields and beam damage tests; conceptual eng. design		Detailed eng. design; optimization & integration into beamline		final design & pre-production prototypes	production		installation and pre-commissioning		
Instrumentation	Develop laser wires; test feedback BPMs with secondary beam; conceptual eng. design		Detailed eng. design; optimization & integration into beamline		final design & pre-production prototypes	production		installation and pre-commissioning		
Vacuum system	Physics and conceptual eng. design. Detailed design of IR vacuum chamber.		Detailed eng. design; optimization & integration of beamlines		final design	production		installation		

3.5 *S5 – Positron Source*

The positron source consists of an undulator, a relatively thin gamma conversion target, a positron capture section (OMD) and a pre-accelerator injecting into the damping ring. Short reference is made to describe the current status of R&D on individual components and the system. Emphasis is placed on the aspects that are critical for the layout of the machine, among which the required positron yield is the biggest challenge.

3.5.1 Undulator

Short superconducting undulators have been built by both CCLRC and Cornell. These have confirmed that the undulator is feasible in general. A 4m long prototype (active length of 3.5m) is now being constructed by CCLRC, and Cornell have also proposed building a long prototype. This is essential to prove that the present design can be scaled up to the level needed by ILC. There is still scope to improve the undulator parameters (period, field, k-factor, bore) to increase the positron yield per metre and efforts in this direction should continue. The complete undulator section (undulator modules, the cryogenic strings, and the room temperature sections with quads, BPMs, photon collimators, pumps, etc) has not been designed yet and this requires further optimisation to achieve the most efficient solution. This optimisation will involve additional wakefield studies, tolerance modelling, vacuum calculations, electron optics, and significant engineering. Furthermore, the undulator itself should move into an industrialisation phase and a fully instrumented, robust, reliable, value engineered design developed.

3.5.2 Target

The baseline target is a 1m diameter, rotating, 5 spoked wheel made of titanium alloy. The wheel rotates at high speed (100m/s at the rim) in a vacuum and has integral water-cooling. It will become highly activated and will need to be in a remote handling area. A concept has been developed by LLNL/SLAC and this has been passed to Liverpool/CCLRC who are further refining the design and are generating machine shop drawings. This work continues to be supplemented by LLNL vibrational and thermal studies. The plan (subject to UK funding) is to prototype the target in 3 stages at Daresbury. The first stage will be to build a wheel of the correct material and to spin it at full speed out of vacuum but in a magnetic field. This will confirm mechanical issues such as balancing, performance of the motors and drive shafts etc and also eddy current effects such as magnetic braking, heating and induced vibration. These eddy current effects are being simulated independently by ANL/CCLRC/Cornell. The second stage is to operate the system in a vacuum to prove the vacuum levels required can be achieved and maintained for long periods. This second stage will pass water through the wheel at the required pressure as well. The third prototype stage will be to operate the full system (rotating wheel in a vacuum with the OMD magnetic field) with an external heat source to try to replicate possible thermal problems associated with the target. Target activation studies are being led by DESY with Liverpool/CCLRC also contributing in this area.

In addition to this baseline work alternative materials are being studied for the target wheel (CCLRC) which could operate with radiative cooling only or might have much lower conductivity and so be able to operate more effectively in a magnetic field or utilize the liquid metal targets being advocated by groups at Cornell and BINP.

3.5.3 Optical Matching Device

The optical matching device serves to capture a larger fraction of the produced positrons of the target. Using a magnetic field decreasing from 4 T immediately behind the target, the positron yield can be increased by typically a factor 2. There are two options under discussion: a superconducting coil and a pulsed normal conducting coil. Engineering design have to be produced to show that e.g. the operation of a superconducting coil is viable in the high radiation environment of the target and that the flux concentration required can be achieved.

The interaction of the magnetic field with the spinning target needs to be studied both from the mechanical point of view and with respect to its effect on the polarisation transfer in the target.

3.5.4 Remote Handling

The target and OMD will need to be installed in a remote handling area since they will become highly activated. CCLRC have developed some initial schemes for the area and these include the ability to vertically remove the target system and to replace it with a spare system. Although such changes would naturally be scheduled during shutdowns they would also be required if the target failed during operational time. In that case the changeover time (presently estimated at 53 hours) for the target systems becomes critical. This time should be reduced during the design phase to increase the ILC positron source availability.

3.5.5 Positron Source System

Multivariate optimization studies are needed to refine system and component functional requirements and performance specifications and tolerances. This effort integrates the subsystem R&D into the overall design. The optimization is aimed at developing a robust and reliable positron source given a range of possible undulator parameters, target requirements, and capture expectations. These efforts include the development of a realistic start-to-end simulation of the full ILC positron production, beginning with the high energy photon production and continuing through polarized pair-production, positron capture, collimation, acceleration, and transport to the entrance of the ILC damping ring. The simulation permits optimization and trade-off studies within the large parameter space that includes undulator parameters, target damage issues, field configuration of the capture optics, acceleration gradients, collimation, and spin preservation. This work is conducted in collaboration with the Americas and European regional partners, with SLAC taking the lead in coordinating the activities and ANL playing a major role in the developing the overall systems modelling. This work will continue through to commissioning.

3.5.6 Upgrade to Higher Positron Polarization

The baselined configuration produces positrons with an overall polarization of about 30%. Positron polarization in the range of 60% is possible with the addition of more undulator sections and angular collimation of the incident photon flux. The EDR design is required to be fully compatible with the upgraded scenario for higher polarization. A more detailed design is required. These efforts are just being started in earnest amongst the European and Americas regional partners

3.5.7 Alternative Positron Source – The Compton Source

The ILC positron source based on the Compton back-scattering is an interesting alternative because it requires only a few GeV electron beam to produce high energy gamma for the positron generation. The Compton Source does not make any inter-system dependency between the electron and positron arms in ILC and a priori improves the total system availability. The system could be demonstrated independently of the real ILC with appropriate conditions in beam energy, positron intensity, etc.

The biggest challenge for the Compton source is to achieve the required yield of high-energy photons. The success hinges on the initial photon intensity and the focusing of electron and photon beams for the scattering process. Fortunately, the technology of the Compton back-scattering is a candidate of a future X-ray source with a compact system and R&D is actively pursued around the world. Thanks to the recent development of the laser technology, several kW class high power lasers are now commercially available and can be used for the Compton Source. Important mile-stones are summarized as follows:

1. Develop a conceptual design, which is fully compatible to the ILC requirements and includes expected technological developments.
2. Develop key technologies, e.g. laser, optical cavity and its precise control, target, capture optics, etc. The emphasis here is placed on system integration of the advanced technologies.
3. Demonstrate the positron generation at a level scalable to the real ILC positron source.

The first stage is currently being explored. Three different concepts have been proposed: Linac based, Storage-ring based, and ERL based. They have different pros and cons and the viability depends on the respective key components and technologies. A first conceptual design will be established within a few months from now following the PosiPol workshop in Paris in May.

Initial experimental studies have already started. As a collaboration among many labs and universities, gamma-ray and positron generation with a pulse-stacking optical cavity in an electron storage ring is carried out at KEK-ATF. This experiment is generating positrons with a concept similar to that proposed for the ILC positron source. This experiment contains many aspects listed in the second mile-stone. Another advanced concept for the optical stacking cavity is under development at LAL in France. This optical cavity has 4 mirrors with a 104 – 105 enhancement factor (103 in KEK-ATF). In

BNL-ATF, an experiment of the gamma ray generation for the linac based Compton source has been carried out. In their scheme, an extremely high power and high repetition CO_2 laser is a key component.

It is expected that the technical feasibility of the Compton Source will become clearer over the next two years.

4 Conclusions

This report summarises the status of "critical" R&D for the ILC as of April 2007. The critical R&D has been addressed in "task forces", which help to organise the R&D across institutes and regions. The task forces provide the necessary focus in R&D in the absence of a more formal central project management. The outcome of these R&D plans is discussed with the various national research funding bodies. The research goals have been confirmed by the Machine Advisory Committee of the ILC. These plans also provide the guidance for R&D as the ILC moves into the engineering phase.

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[1] Material from S4 meetings is available at http://ilcagenda.linearcollider.org/categoryDisplay.py?categId=80, Access code "s4meeting"

[2] Report of S4 task force to ILC MAC, April 27, 2007, http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=1388