ILC Minimum Machine Study Proposal

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Prepared by the Technical Design Phase Project Management

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The ILC Minimum Machine Definition

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Table of Contents

1 Introduction

1.1 The Minimum Machine Philosophy

The concept of the “minimum machine” has evolved over the last twelve-months and has now become the corner-stone of the project management’s cost-reduction strategy for Phase 1 of the Technical Design Phase, as described in the published R&D Plan. The “minimum machine” studies will proceed in three stages:

- The basic parameters and layouts for a limited set of “minimum machine configurations” will be defined. These parameters and layouts will provide a basis for understand cost-increments and cost-performance trade-offs (beginning 2009). This is essentially the purpose of this document.
- The GDE will perform cost-reduction and performance studies of the minimum machine, leading to possible options for a new baseline. For each of the options, the GDE will provide an estimate of the cost saving, and evaluate any increased risk to the performance (end 2009).
- Towards the end of 2009, the Project Managers and Technical Area Group Leaders will examine the results of the cost-reduction and performance risk studies and consider the status of critical R&D, leading to a proposal for a new machine baseline early in 2010.

It is important to emphasise that adopting a new baseline in 2010 is for the purposes of producing a new defendable updated VALUE estimate for the TDR in 2012 – a primary GDE deliverable.

The term “minimum machine” does not refer to any definable true minimum, but instead is a euphemism for high-level alternative design concepts which promise significant cost-reduction while maintaining the physics scope: the machine is “minimum” in the sense that many of the cost-reduction concepts come at the expense of perceived risk to the machine performance (accessibility, operations, commissioning *etc*.).

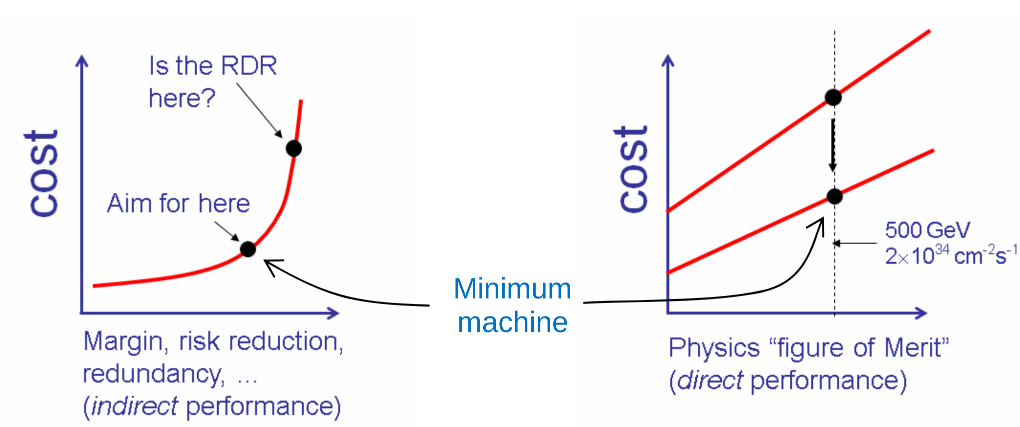


Figure 1: Understanding cost drivers: the Minimum Machine study concept

The RDR baseline design is considered sound but assumed in many aspects to represent a conservative approach, primarily to mitigate potential performance risk. Figure 1 depicts the rationale behind the minimum machine cost-reduction strategy by introducing two concepts:

- *Direct* performance (right-hand diagram), which can be considered a physics 'figure of merit' such as centre-of-mass energy or peak luminosity. Understanding the derivatives of the direct cost of these physics performance parameters is an important part of the minimum machine studies.
- *Indirect* performance (left-had diagram), into which we place margin, redundancy, *etc*. i.e. those design elements which do not directly affect (for example) peak luminosity, but tend to impact operational aspects of the machine or performance risk (potentially affecting integrated luminosity within a given time frame)

The minimum machine study is primarily focused on understanding the indirect performance related costs, by attempting to quantify the cost-performance gain.

With the expected resource situation in calendar year 2009, it is not practical to attempt to make a comprehensive study of all design elements of the RDR baseline to establish such cost-performance ratios. Instead a more pragmatic approach is proposed which concentrates on the identified critical RDR cost-drivers – specifically CFS.

A reduction in the total required underground tunnel length is essentially proposed by a re-design of the machine layout and (in some cases) alternative approaches to critical technical sub-systems. The project management, after review, has decided to focus on seven key areas (minimum machine elements) which are believed to offer substantial cost reduction, while acceptably increasing the performance risk. Figure 2 introduces the primary machine elements, which are described in detail in section 2.

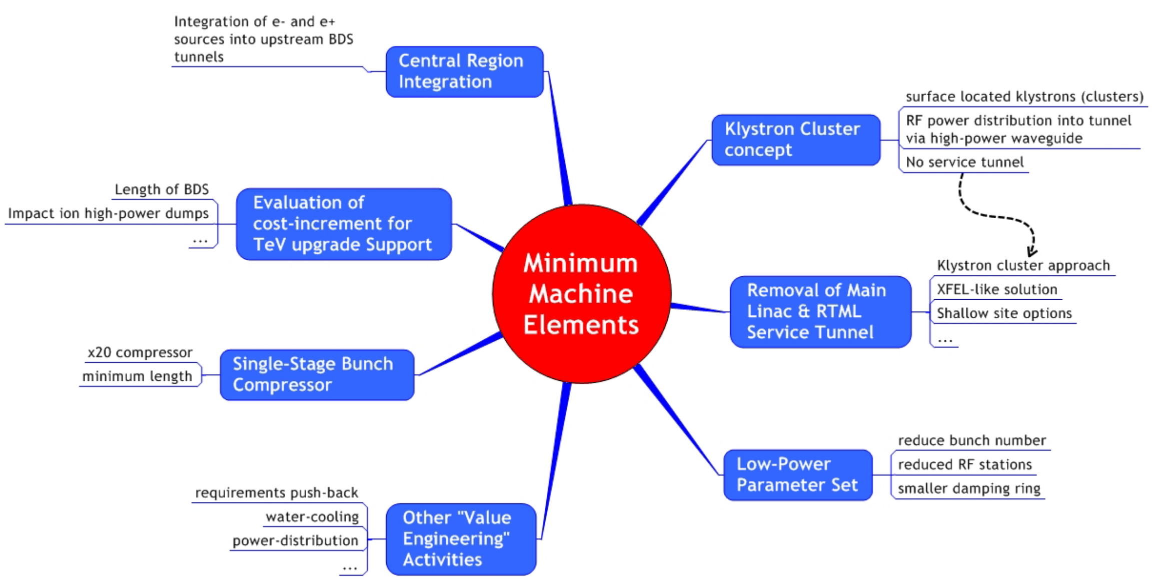


Figure 2: The Minimum Machine study elements.

1.2 Relationship to the Current RDR Baseline

The RDR baseline is the basis for the published VALUE estimate, and represents a relatively detailed design in support of that estimate. The RDR baseline is also the result of a consensus driven international process.

By contrast, the minimum machine studies in 2009 cannot be an equivalent design effort, and the specific design elements have been selected by the project management. In addition, it is not foreseen to make any new or updated cost estimates during this period (TD Phase 1). It will therefore be necessary to base all the incremental cost estimates associated with these alternative designs on the existing RDR cost data (as far as possible). The RDR baseline will remain effective for all reference, until the top-down driven studies are concluded (end of 2009), at which point the results can be reviewed by the community, and a final consensus-driven decision on a new baseline can be made (see section 1.3).

1.3 The Process towards Formal Re-Baseline

The results of the studies outlined in this document – together with a review of the on-going risk mitigating R&D programmes – will allow the community to re-define the baseline in early 2010. The time scale for this process is shown in Figure 3, and is consistent with the goals and milestones outlined in the R&D Plan.

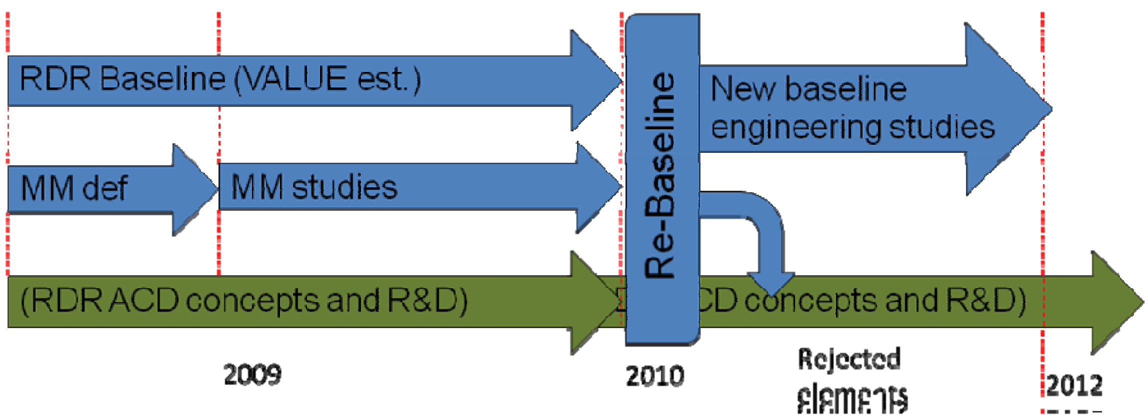


Figure 3: Time-line for minimum machine studies

Figure 3 indicates several key-points of the proposed process:

- The Minimum Machine definition (“MM def” in Figure 3) is essentially this document, which outlines the scope of the elements and plans for the identified studies during calendar year 2009 (“MM studies”, see section 2.8).
- The formal support for the RDR baseline as the primary cost-basis for the studies (as described in section 1.2). The RDR baseline will be superseded in 2010 after due process and subsequent consensus-driven agreement by the community.

- The continued formal support for the so-called ACD R&D activities, some of which may be considered mature enough by the end of 2009 to be considered for baseline adoption in 2010.

During the process of re-baselining in 2010, it is important to note that all options considered viable and suitably mature enough to support an updated cost-estimate in 2012 can be considered. The specific minimum machine elements outlined in this document will be evaluated in terms of estimated cost saving and their potential impact on the risk. If the increased risk is deemed not acceptable in light of the cost benefit, then the proposed design modification will not be adopted as baseline (as depicted by the "elements rejected" arrow in Figure 3).

The exact formal process of baseline adoption remains to be defined, and will be developed in parallel to the studies during 2009 by the Project Management[1].

2 Minimum Machine Study Elements

In the following sections, the main elements of the minimum machine studies will be briefly described.

2.1 Main Linac

As the single-largest cost, the main linac remains the primary focus of the TD Phase activities. Specifically, the world-wide investment in SCRF technology – and particularly the high-gradient programme – represents the largest cost-leverage per R&D investment.

Beyond the SCRF linac technology itself, three possible cost-reduction design modifications have been identified which will form part of the minimum machine studies:

- removal of the underground service tunnel (single underground tunnel housing the accelerator);
- klystron cluster concept (RF power distribution alternative);
- processed water cooling specifications (higher ΔT solutions).

These three concepts are not independent from each other: the specific engineering solutions for each case are necessarily integrated with choices made for the other two. Therefore it will certainly be necessary to look for self-consistent cost-optimum solutions for several scenarios. For the purposes of this document, however, we will deal with each of these concepts separately in the following sections.

[1] The process itself will require community consensus.

2.1.1 Removal of the service tunnel

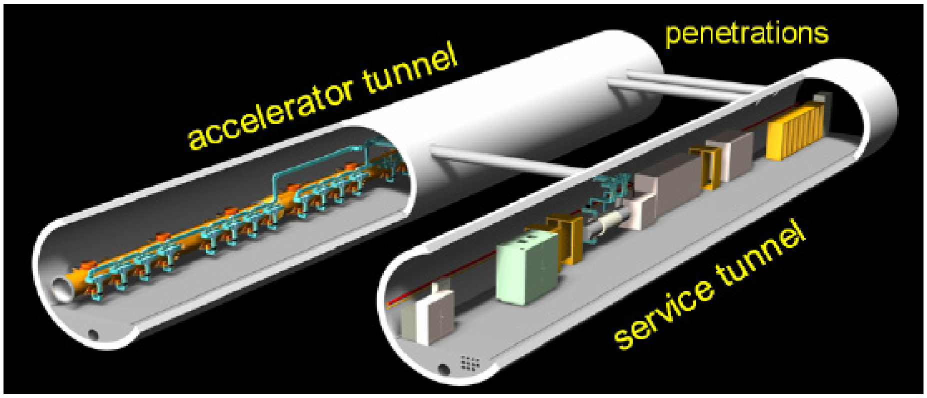


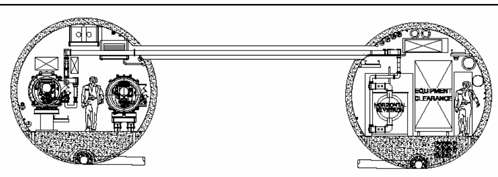
Figure 4: RDR two-tunnel solution

Figure 4 shows the RDR solution for the Main Linac twin-tunnel housing. The choice of a separate tunnel (service tunnel) to house the RF power sources, power supplies and electronics was primarily driven by:

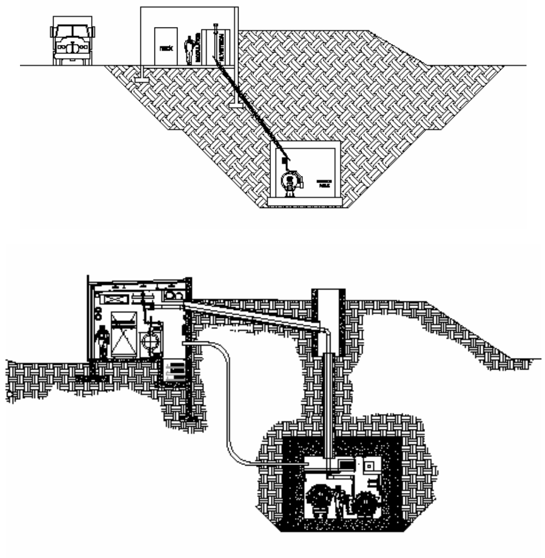
- concerns over reliability and in particular access to klystrons and other hardware during beam operation to achieve high availabilities (and in particular required access to during beam commissioning);
- use of the twin-tunnel solution as the corner-stone for the adopted emergency egress philosophy.

However, there is a general agreement that there is a significant cost incursion for the second tunnel. At the time for the RDR, it was accepted that the incremental cost of service tunnel solution justified the gains in performance and safety. It should also be noted that such a twin-tunnel scheme was consider in the light of the deep-tunnel solutions studied for all three RDR sample sites.

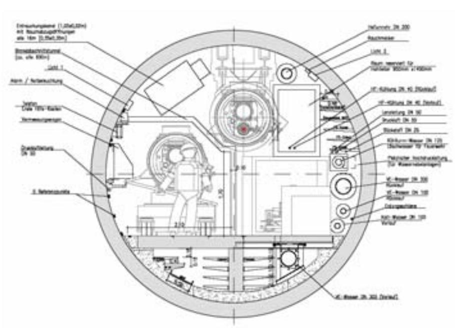
Given the level of maturity of the RDR twin-tunnel baseline design, it would seem prudent to attempt to quantify the above statements as part of the minimum machine studies. To that end, it is proposed to study options towards a single underground tunnel solution. As with all the minimum machine studies, the primary goal will be to evaluate the potential cost saving while attempting to quantify the increased risk.



RDR twin-tunnel solution (deep rock site). Klystrons, modulators, power supplies and electronics are located in service tunnel, allowing access during beam operation.



Possible cut and cover solutions for a suitable shallow site. Use of surface gallery still maintains access to klystrons, modulators, power supplies *etc.* during operations.



European XFEL tunnel solution:

- Single underground tunnel
- Cryomodules suspended from tunnel ceiling
- Pulse transformers, klystrons, power supplied and electronics in tunnel (no access during operation)
- Modulators in localised surface buildings; many long pulsed cables (~2km) connect modulators to klystrons.

Figure 5: single underground tunnel options (RDR solution included for comparison)

Figure 5 shows the possible scenarios for single underground tunnel solutions. They fall into two generic types:

1. Shallow site-like solutions – basically a near-surface underground structure (tunnel or cut-and-cover construction) with surface support building for housing klystrons, modulators and cryogenic plants. Such a solution maintains access to critical components during beam operation. The primary cost savings are via replacement of an underground tunnel with a suitable surface building, and the arrangement (and depth) of shafts. Such a solution does not negatively impact availability over the existing two-tunnel solution, and would ease the water cooling requirements for the RF power sources (a further cost saving). However, the solution is geographically constrained to potential sites which are relatively flat with no or limited existing surface construction (unpopulated areas).

2. European XFEL solution (or similar variant): A single underground tunnel which houses the accelerator (cryomodules), klystrons, pulse transformers, power supplies and electronics. Modulators (considered a reliability risk) are located in surface buildings and connected to the in-tunnel RF stations via long pulsed cables. The primary cost saving is the removal of the service tunnel and the associated transverse penetrations; this saving must be offset by: (i) the cost of the many long pulsed cables; (ii) the additional surface building area to house the modulators; (iii) any increase in tunnel diameter required to accommodate the higher volume of components in the single-tunnel[2]. A critique of the XFEL single-tunnel solution is the lack of access to klystrons *etc.* during beam operations, mandating down-time to replace or repair components. An additional investment will be warranted to offset this (to some degree) using redundancy or high(er)-availability specified components. Since the European XFEL is an approved construction project, all of these challenges will need to be addressed. The GDE needs to maintain close contacts with the XFEL project during the engineering design, construction and ultimately commissioning and operations phase to evaluate the suitability (and cost saving) of the solution extrapolated to the ILC. The XFEL will be constructed in a relatively shallow site (≤25 m deep); however there is no fundamental reason why the solution cannot be extended to deep-rock sites similar to the RDR sample sites.

A third single-tunnel variant is associated with the klystron cluster concept, where the klystrons are located together with the modulators in localised surface buildings separated by approximately 2 km. Compared to the XFEL solution, the klystron cluster concept removes the need for the long pulsed cables, and by placing the complete RF power source on the surface, addresses several of the concerns over availability. A more detailed discussion is given in the next section (section 2.1.2).

2.1.2 Klystron cluster concept

A linac configuration that would make use of a single tunnel and reduce electrical/cooling costs significantly is to have the RF power generated in modulator/klystron clusters on the surface and then transported down and along the beam tunnel; this solution is in many ways analogous to the XFEL solution (section 2.1.1), except that the power is transported into the tunnel as microwaves in a high-power, low-loss, over-moded waveguide, instead of via 10 kV HV pulsed cables. The tunnel power and cooling systems are much simpler (no underground klystron collector heat loads). Also, with the RF sources in ~350 MW clusters, it may be easier to recover power from the dissipated heat. Having both klystrons and modulators now on the surface – and therefore accessible during beam operation – will help alleviate many of the concerns of availability associated with the

[2] The XFEL design currently has a 5.2 m diameter tunnel, compared to the 4.5 m diameter tunnel for the RDR baseline.

XFEL solution, although some electronics (LLRF, BPM etc.) and possibly magnet power supplies would still be located in the accelerator tunnel.

The current proposal is to have 35 klystrons in a cluster, requiring ~350 MW peak power in the RF transport (over-moded waveguide), feeding 32 standard RDR RF units (96 cryomodules, or 2,496 cavities). Two such clusters would be located together on the surface, supplying ±1.2 km of linac, with the surface buildings and shafts being ~2.4 km apart (see Figure 6).

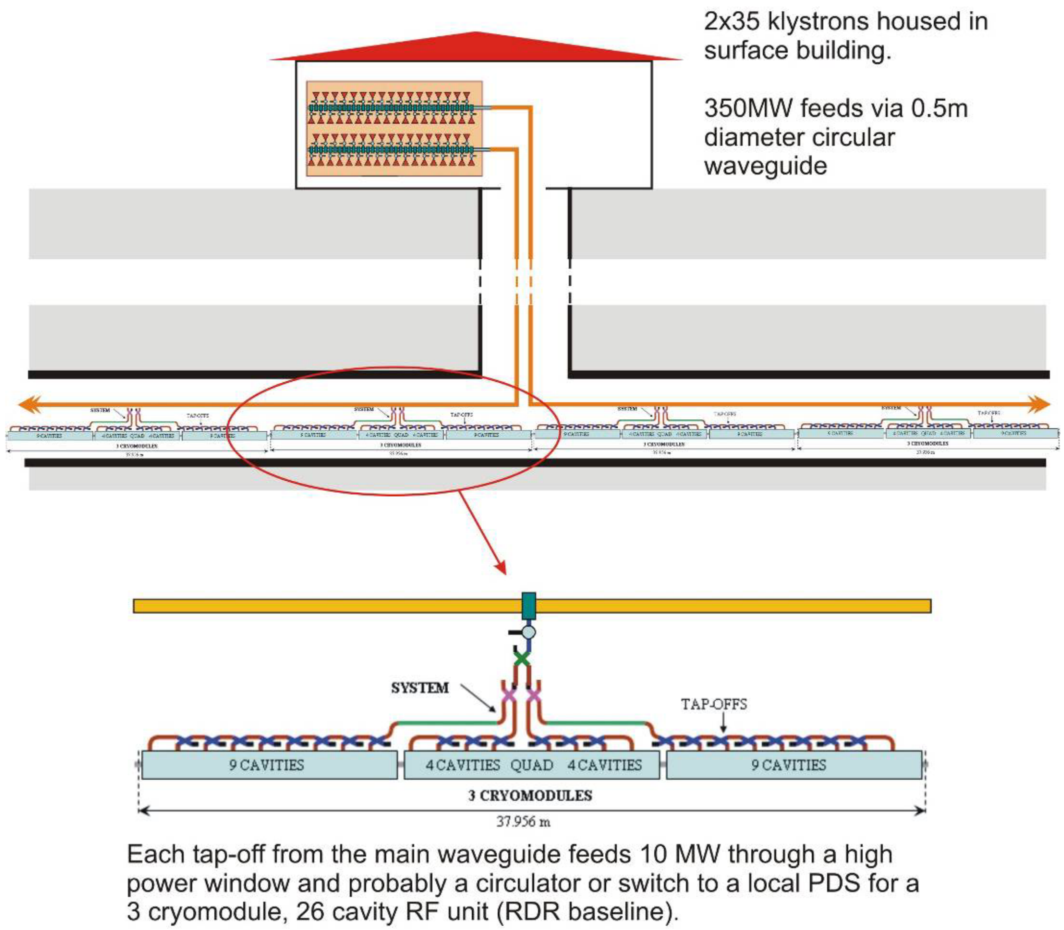


Figure 6: klystron cluster concept.

Power from the 35 klystrons in a cluster is combined by coupling each sequentially into the main waveguide through a reversed tap-off, or tap-in. With decreasing tap-in coupling ratios and proper phasing, the power can be made to flow in one direction at each junction. Isolators protect the klystrons from any mismatched or reflected power. The tap-offs in the accelerator tunnel, at ~38m RF unit intervals, are implemented via the time reversal of the combining process in identical components, with increasing couplings. Once the ~10 MW is extracted for each RF unit, a variable tap-off (VTO) or an isolator followed by a variable reflector could be used to adjust the RF power to that unit (if needed). Inter-pulse shutoff should also be possible to individual RF units, although not intra-pulse without turning off the whole cluster. As in the current RDR design, the individual cavity phase shifters would be used to adjust the RF phase, although one high-power phase shifter per RF unit would be preferable.

The main feasibility questions are

- Reliably sustaining ~350 MW 1.6 ms RF pulses: the waveguide pipe itself should not be a problem as there are no electric fields terminating on the surfaces[3]. The tap-in, tap-off devices and bends will require R&D. Based on X-band results and recent long pulse (1 ms) L-band cavity results from SLAC, it is estimated the system would be robust if the surface fields were kept below 10 MV/m, which should be feasible with such a large diameter pipe around which the tap-ins and tap-offs would be wrapped (this field level is less than half of that sustainable in low power, long pulse L-band systems).
- The intra-pulse LLRF control could only be done over lengths of ~1.2 km unless fast I/Q controllers like those being developed for low-beta machines are used. Thus we would need to assess whether this coarse granularity would provide adequate energy control along the bunch trains. The cavity piezo controllers could be used to provide more than Lorentz detuning compensation (at least on average in an RF unit).

The primary expected cost reduction (compared to the RDR) comes from:

- having only one tunnel of the smaller diameter (independent of tunnel depth);
- not having to distribute extensive AC power and water cooling in the tunnel (would only have necessary LLRF and beam instrumentation electronics as well as magnet power supplies);
- not having to deal with air heat removal and the safety issues of operating the beam with people in the service tunnel;
- decoupling the RF system heat removal issue from the tunnel air temperature issue, potentially allowing the energy to be recovered from the heat losses (e.g. running the collectors at very high temperatures);
- simplifying the installation process.

Finally, adoption of the Marx modulator (an existing ACD item currently being prototyped at SLAC) is included, which will hopefully lead to further cost reduction, as well as a potential increase in reliability over the existing bouncer modulator baseline.

[3] At X-band, SLAC has transported 500 MW in much smaller pipe, albeit with pulses of only 400 ns, and 300 MW in 2.3 cm rectangular waveguide, where the E-fields do terminate on the walls.

2.2 Low power option

2.2.1 A brief review of the RDR parameter plane

All sub-systems of the RDR baseline are designed to accommodate the so-called *parameter plane* in an attempt to mitigate risk in achieving the desired luminosity performance. The parameter plane is defined in terms of four self-consistent parameter sets – one nominal parameter set, and three parameter sets which are scaled from the nominal set. Each of these latter three sets assumes that a critical parameter in the nominal set (single-bunch charge, vertical emittance, number of bunches) is not achieved, and that the subsequent reduction in luminosity performance can be mitigated by adjustment of other (sub-system) parameters. Taken together, the parameter plane represents a low-risk conservative design, but one which may not represent a low-cost design. Therefore, within the context of the minimum machine studies, it is considered prudent to re-evaluate the parameter plane from the context of lowest cost, although at the same time accepting that this would inevitably increase the performance risk.

In terms of cost reduction, peak RF power has the greatest leverage since it allows reduction of the number of RF stations (klystrons and modulators and associated CF&S costs). In general the luminosity is restored by pushing the beam-beam parameters, which – although an increase in performance risk – are not considered a major cost driver. The peak power can be reduced by either (i) reducing the single-bunch charge *N*, or (ii) by reducing the number of bunches n_b within the same beam pulse; both result in a lower beam current. However, as the luminosity scales as $L \propto N^2 n_b$, it is more advantageous to reduce the number of bunches, clearly favouring a "Low-P" like parameter set.

The lower number of bunches has the additional attractive feature of being able to reduce the circumference of the damping ring, while maintaining the same inter-bunch distance (critical for the fast injection and extraction kicker – see section 2.2.3).

The RDR Low-P parameter set represents a factor-of-two reduction in the number of bunches. The luminosity is achieved by pushing on the beam-beam – effectively increasing the beamstrahlung from 2.4% (nominal) to 4.5%. It is important to note that this parameter set assumes a reduction in bunch length at the IP from 300 µm (nominal) to 200 µm; this will not be possible if a single-stage bunch compressor is adopted (section 2.4). A proposed work-around is to make use of the so-called *travelling focus* concept, which could allow for the longer bunch length while maintaining the luminosity, at the same time as reducing the beamstrahlung (see

Table 1).

Table 1: Possible low-power parameter set using travelling focus concept (new Low P). RDR nominal and Low-P parameter plane sets are shown for reference.

	Nom. RDR	Low P RDR	new Low P
E_{CM} (GeV)	500	500	500
Particles per bunch, N ($\times 10^{10}$)	2.0	2.0	2.0
Bunches per pulse, n_b	2625	1320	1320
Pulse repetition rate (Hz)	5	5	5
Peak beam power, P_b (MW)	10.5	5.3	5.3
$\gamma\varepsilon_x$ (µm)	10	10	10
$\gamma\varepsilon_y$ (nm)	40	36	36
β_x (cm)	2.0	1.1	1.1
β_y (mm)	0.4	0.2	0.2
Traveling focus	No	No	Yes
σ_x (nm)	640	474	474
σ_y (nm)	5.7	3.8	3.8
σ_z (µm)	300	200	300
Beamstrahlung* $\delta E/E$	0.023	0.045	0.036
Luminosity* ($\times 10^{34}$ cm^{-2}s^{-1})	2.0	1.7	1.9

*) simulated using GUINEA-PIG

2.2.2 Implications for the Main Linac

The primary cost saving associated with a reduction in beam power is via the reduction in the number of RF stations; *i.e.* a single 10MW klystron is used to drive a higher number of cavities, resulting in a longer RF unit. In addition to the direct reduction in the number of klystrons, modulators, power-supplies *etc.*, there are also potential cost savings via the associated conventional facilities (processed water cooling and AC power distribution).

Table 2: Examples RF parameters for a low beam-power option. The numbers assume an accelerating gradient of 31.5 MV/m and TESLA-shaped cavities (R/Q = 1.036 kΩ). The bunch charge is 3.2 nC. A maximum usable klystron power of 8 MW is assumed (20% overhead for control and losses).

Reduction in RF stations		RDR	RDR*	33%	50%
# cavities / RF unit		26	26	39	52
RF unit voltage	MV	846.8	846.8	1270.3	1693.7
# bunches		2625	2625	1312	1312
bunch spacing	ns	369	339	509	679
beam current	mA	8.7	9.4	6.3	4.7
beam pulse	μs	969	891	668	890
Q_{ext}		3.63	3.34	5.00	6.67
cavity time constant	μs	888	817	1225	1633
fill time	μs	616	566	849	1132
RF pulse	ms	1.6	1.5	1.5	2.0
Klystron P_{for} (fill)	MW	7.3	8.0	8.0	8.0
Klystron P_{for} (beam)	MW	7.3	8.0	8.0	8.0
Efficiency		61%	61%	44%	44%

Table 2 indicates possible RF parameter settings for 33% and 50% reduction of RF stations, as well as the RDR parameter set for reference. (A second reference full-power RDR* parameter set utilises the assumed maximum 8 MW klystron power.)

In general, the lower beam-power option has the following implications:

- An increase in Q_{ext}, resulting in a longer fill-time and a smaller cavity bandwidth; the latter will have implications for de-tuning errors and possible impact on control overhead (although this may well be more than offset by the reduced beam-loading).
- A reduction in RF power to beam power efficiency: thus a reduction in beam power by a factor of 2 results in a decrease in average RF power by a factor of ~1.4.
- In some cases (50% reduction example in

Table 2), an increase in RF pulse length will be required (2 ms in this example).

- Increased RF losses in the longer waveguide distribution system.
- The lower power at the cavity tap-offs and couplers is advantageous. We should also note that this has positive implications for the klystron cluster distribution concept outlined in section 2.1.2.

2.2.3 Implications for the Damping Rings

A reduction in the number of bunches by a factor of two allows a reduction by the same factor in the circumference of the damping rings, while keeping the current (bunch spacing) in the rings constant. To first order, this could result in a reduction of the damping rings cost by almost a factor of two. However, this naïve cost scaling will be offset to some extent by the exact design of the smaller rings; for example the required RF power remains the same (fixed damping time, energy and current), as may the number of shafts. Other points for consideration include the following:

- smaller bending radius in the arcs may result in more than a factor-of-two reduction in damping wiggler length;
- actual cost savings will depend on the lattice design needed to achieve the desired emittance (a simple scaling of the existing lattice with FODO arc cells may not be sufficient);
- the straight sections must allow enough space for the RF, wiggler, and injection and extraction systems; this may affect the ratio of straight-section length to arc length, with consequences for the proposed central integration layout described in section 2.3.

In addition, certain collective effects – notably space charge – scale with the circumference. Reducing the circumference by a factor of two therefore raises the possibility of reducing the energy, with potentially significant benefits. Within the damping rings themselves, for example, the electrical power requirements for rf and magnet systems will be reduced. Benefits for downstream systems could include simplification of the bunch compressors resulting from reduced longitudinal emittance in the beam extracted from the damping rings. However, benefits such as these must be carefully balanced against increased risks in the damping rings: reducing the beam energy will make the beam more susceptible to collective effects (including electron cloud); and the size of the injected beams will be increased, because of the loss of some adiabatic damping in the acceleration from the sources.

2.2.4 Implications for beam dynamics

As already described in the section 2.2.1, the reduced beam power is compensated by pushing on the beam-beam at the interaction point to maintain the design peak luminosity. A review of

Table 1 indicates that this is achieved by a small reduction in the vertical emittance (reduced emittance growth budget), and stronger focusing at the IP in both planes. The higher disruption parameter results in a narrower region of stability which in general leads to tighter alignment tolerances (both static and dynamic), and a greater sensitivity to wakefields. The proposed travelling focus will also have potential repercussions on luminosity stability and tuning. Beyond the accelerator, the impact on the detector design and physics must also be assessed. While none of these are seen as potential show-stoppers or cost-drivers, they are considered as increased risk to the luminosity performance.

2.2.5 Other implications

Reduction of the beam power has implications for all systems beyond those described in some detail in the previous sections. Although they are not large cost drivers, they do impact on performance at some level. We list them here for completeness:

- For the electron source, the reduce bunch number opens up two possible scenarios:
    - Keeping the average current fixed at ~9 mA but reducing the length of the pulse; this would reduce pulse length for both the laser, DC gun and the warm RF capture sections, but would require the SCRF 5GeV injector linacs to accelerate the full current (i.e. no reduction in RF stations as in the Main Linacs).
    - Keep the pulse length, but reduce the current (as in the Main Linac); this would afford similar cost savings in the 5GeV injector linacs as for the Main Linac, and the longer bunch spacing may help against the cathode charge limit in the photo-injector.
- Positron source: the average power on the target is reduced by a factor-of-two as is the general activation of the area (per unit time).
- All beam dumps in general, and specifically the main high-power dumps in the BDS must only deal with half the power. Reducing the engineering scope of the main dumps could afford some cost savings, but this has implications for future upgrades.
- In principle, the BDS has been designed to accommodate the original RDR low-P parameter set (

Table 1). The reduced beamstrahlung afforded by the longer bunch length and the travelling focus could lead to a further cost optimisation of the extraction line energy aperture, although this is not likely to be a major cost saving.

2.3 Source and BDS Integration (Central Region)

2.3.1 The Central Region in the RDR

The "Central Region" in the RDR is the region between the ends of the linacs and contains the injectors, the damping rings, the beam delivery system (BDS) and the interaction region. Figure 7 shows the tunnel complex on the electron linac side where the injectors and damping rings are vertically separated by ~10 m from the beam delivery tunnel system. There is also a single service tunnel (green) which contains power supplies, klystrons etc. and is shared between the injectors and the BDS. The electron side also houses the "keep-alive" positron source – a low-power conventional thick-target source capable of producing ~10% of the required positron current.

This geometry allows commissioning and or tuning operations of the injectors with personnel in the IR, the BDS and the linacs.

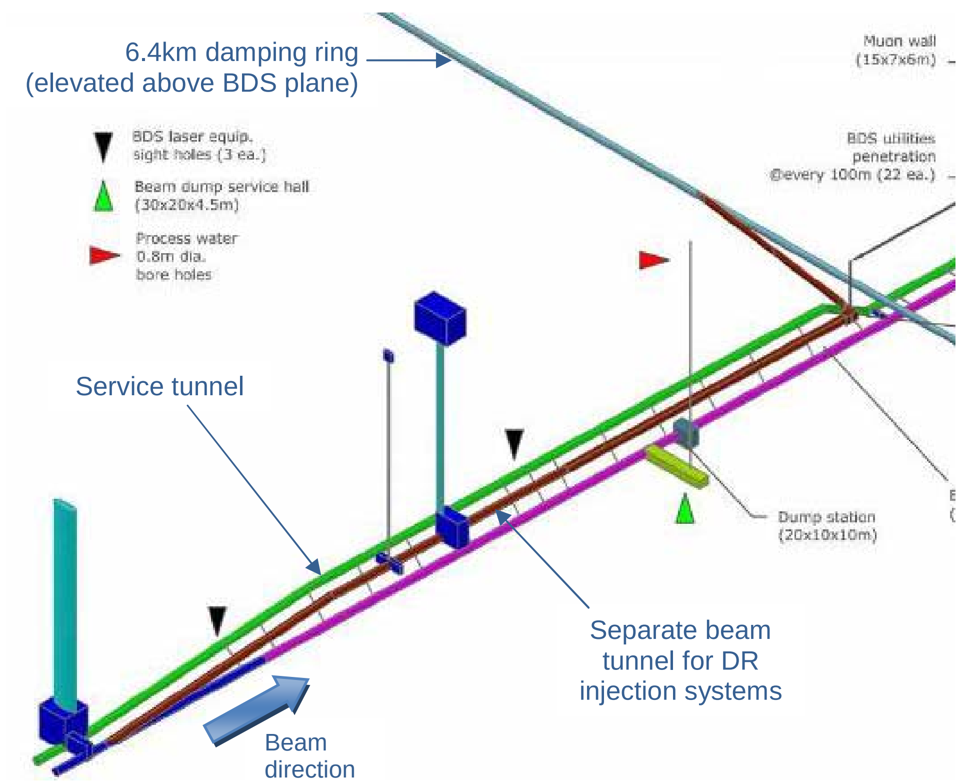


Figure 7: RDR BDS layout (final focus and IR not shown)

If one reconsiders the desirability of this latter statement and accepts a compromise that allows operation with personnel excluded from the first part of the BDS, then one can reconsider having the equipment and tunnels in the same plane and have the injectors share the same tunnel as the BDS. The three tunnels in Figure 7 would then be reduced to two over ±1.5 km. The layout of the DR tunnel could be either in the crossing geometry as shown or off to the side of the main beam line but now in the same plane as the other tunnels. The continuing need for the service tunnel or equivalent buildings will be coupled with the discussions in section 2.1.1.

2.3.2 Consolidation of Main and Keep-Alive Positron Sources

In the RDR the main undulator driven polarized positron source is in the middle of the linac occupying a special 1.2 km insert and the lower power keep-alive source is in the central region. With the in-plane geometry of the central region one can also consider consolidating these two into one system at the location of the keep-alive source, sharing the tunnel with the first part of the BDS. This combined system would have a shared e+ target, capture section and 5 GeV booster linac, and the 1.2 km insert in the Main Linac would be eliminated.

The location of the primary (undulator) positron source at the 150 GeV point in the electron linac was considered to be the best choice when considering overall operation over a wide range of energies. The impact and alternative operating scenarios will have to be revisited as this positron source undulator is now at the end of the linac and at full operating energy.

Figure 8 shows a schematic diagram of how such an positron source system could be combined with the BDS in a single tunnel. It also shows the possibilities of sharing beam dumps for different operating modes and indicates the location of a single major shaft or access point which would be for target replacement and end of linac functions.

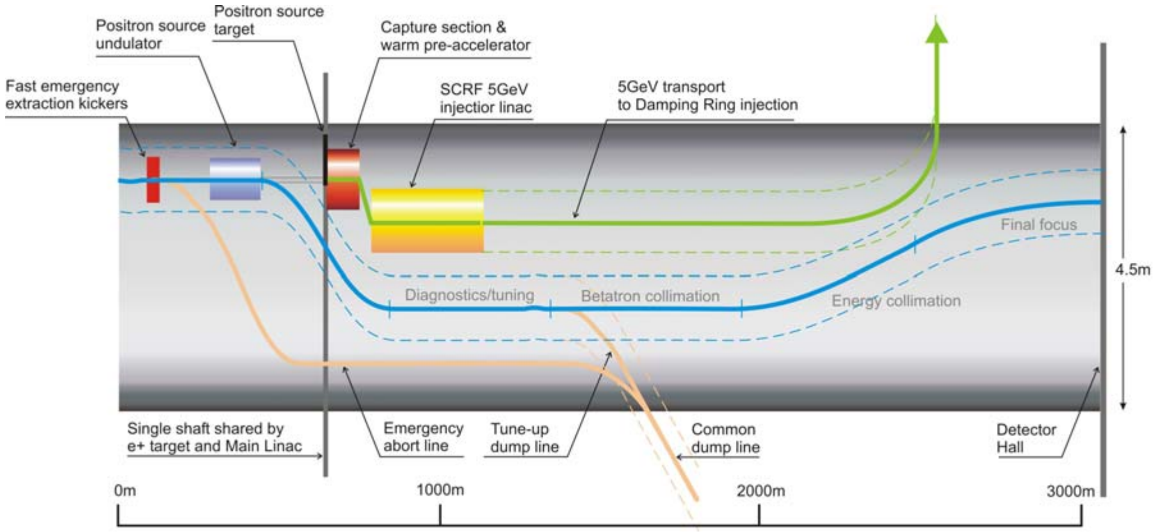


Figure 8: A possible example of positron source integration into the RDR BDS geometry. (Note very different vertical and horizontal scales.)

2.3.3 A Consolidated Central Region

Combining all of the above elements, it is possible to locate both injector complexes and the BDS in a single 5 km region. Figure 9 is a diagram and list of the systems in this region.

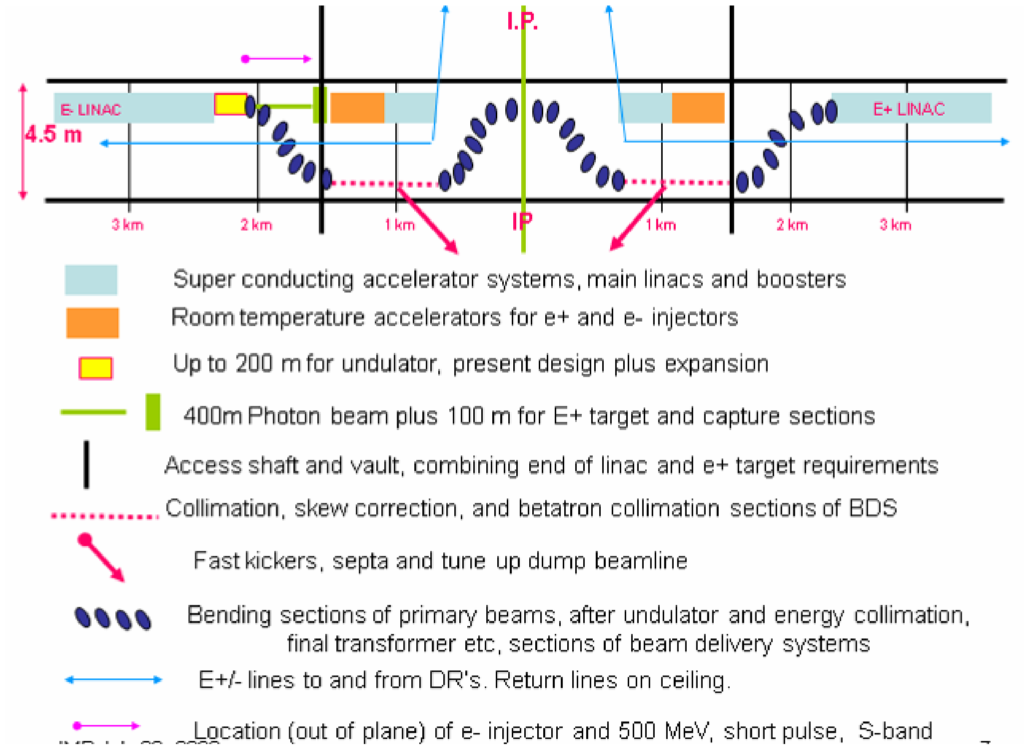


Figure 9: Elements in Consolidated Central Region
(14mr crossing angle is not indicated for simplicity)

There are many questions of detail and practicality that require study including the location and orientation of the DR's and injection tunnels. These questions are both with technical systems and CF&S systems and are strongly coupled.

Early choices will need to be made in the 2009 Minimum Machine study program to limit the number of combinations of these ideas that will reward further work and allow the necessary evaluation of potential cost reductions and impact on risk and operability. One interesting question is whether the studies of single tunnels, klystron clusters, *etc*. is cost effective and practical to the central complex, where considerations of the impact of surface structures will be different from that in the extended Main Linacs.

2.4 Single-stage bunch compressor

The baseline (RDR) design includes a two-stage compressor, facilitating an overall maximum bunch compression ratio of a factor of ~45. The main arguments in support of a two-stage compressor are

- Support of the parameter plane (flexibility): Assuming the RDR 9 mm damping bunch length, the two-stage compressor system can achieve bunch lengths of 200 µm (low-P parameter set).
- Reduced RMS energy-spread at the entrance to the Main Linac (at 15 GeV) significantly reducing the emittance growth in the Main Linacs due to chromatic

aberrations. (This must be offset by the problems arising from cavity tilts and long bunches in the extended bunch compressor itself.)

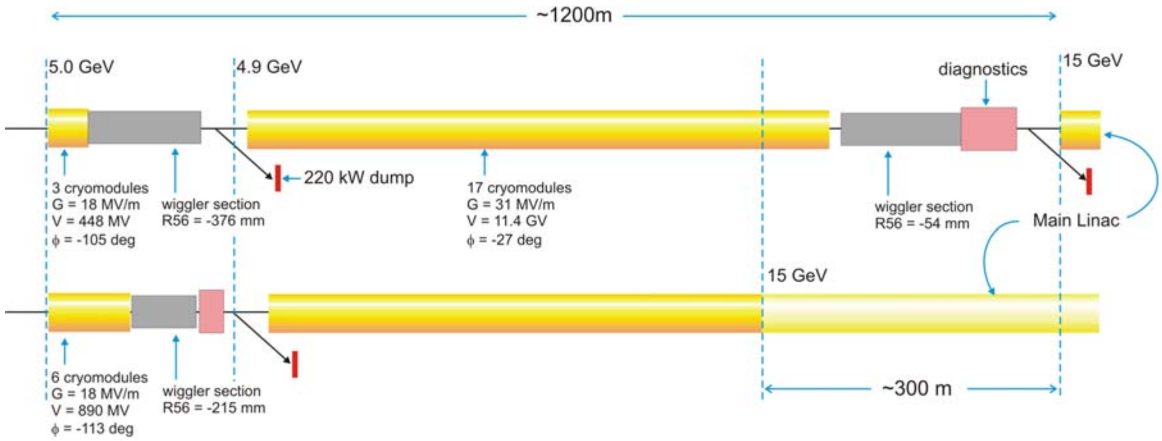


Figure 10: The RTML two-stage compressor (top) and a possible short single-stage compressor (bottom). Not that it is important to compare the total lengths to the same reference energy (15 GeV)

With the adoption of a damping ring lattice capable of achieving a 6 mm bunch length, it is now possible to reconsider the possibility of a single-stage compressor with an overall reduction in compression ratio. Figure 10 compares the geometry of the RDR two-stage system with a possible single-stage system capable of a factor of 20 compression, which is sufficient to achieve the nominal bunch length at the interaction point of 300 μm. The cost advantages of the single-stage system are

- Reduction in beamline and associated tunnel length by ~300 m (including ~60 m of SCRF linac)
- Removal of the second 220 kW dump and dump line components
- Possible shortening of the diagnostics sections (lower energy)

The loss of flexibility and achievable bunch-length range has implications for the low-power option discussed in section 2.2, as well as an increased risk with respect of achieving the design damping ring length. The impact of the increased RMS energy spread on the Main Linac emittance growth has been extensively studied in the past, and must be balanced against the observed problems (in simulation) of the control of the emittance in the two-stage system, which may prove more tractable in the simpler one-stage system.

2.5 Estimation of incremental cost for TeV upgrade support

To help facilitate the desired but optional upgrade to 1 TeV centre-of-mass energy, the geometry of the Beam Delivery System is extensively laid out for 500 GeV beam operation, but with a reduce number of dipole magnets (“missing” magnets). The upgrade scenario is then relatively straightforward, only requiring the installation of the additional dipoles and power supplies. The main high-powered dumps have also been specified for the higher expected beam power.

As part of the minimum machine study, it is intended to evaluate and quantify the cost of this support, by designing a 'minimum length' system capable of maximum beam energy of 250 GeV. This study would include estimates of the reduced power main dumps.

It is important to note that this study is not independent from the central region integration described in section 2.3, since the required (minimum) tunnel lengths may be constrained by other requirements.

2.6 Other "Value Engineering"

For completeness, it is important not to overlook possible cost savings across the technical solutions proposed in the RDR design, again specifically in the area of Conventional Facilities (water cooling, power distribution). Other clearly identified areas are the consolidation are the number magnet families (via standardisation); reduced-cost solutions for the power supplies and cables; vacuum requirements and solutions (again potentially via standardisation).

2.7 Scope of Studies and Required Expertise (Resources)

A cursory evaluation has been made of the type and scope of the studies in 2009, as well as the type of expertise that is expected to be required to address them. Essentially four categories of studies have been identified, briefly summarised in Table 3.

Table 3: Identified (top-level) study categories for the Minimum Machines elements.

Category	Scope	Expertise / Comments
Interference / Integration (***design work***)	• Lattice layouts • Tunnel cross-section models (3D CAD) • (Installation related) • Component placement *etc*	CAD (CFS) engineer(s), optics (accelerator physics) expert(s). Look for (conceptual) engineering solutions.
Operations, Commissioning, Availability (***concepts, philosophy, risk assessment***)	• Less independent machine operation • Reliability issues (accessibility) • Commissioning	Much more difficult to quantify. Looks for experienced experts Brainstorm qualitative

	strategies *etc*.	concepts (solutions)
Hardware R&D **(*hardware development programmes, demonstrations etc.*)**	• High-power RF distribution concept • Marx modulator (on-going) • Increased RF pulse length (low-P)	Engineering / technical as appropriate. FTE and MS required. Well defined goals for R&D programme. Acceptance criteria of proposed solution.
Beam Dynamics **(*simulations*)**	• Emittance preservation • BDS tuning • Travelling focus 'stability' • …	Beam dynamics and simulation specialists (LC experts). (good coordination, well defined questions)

2.8 Special considerations of the impact on the TeV energy upgrade

Although the focus of the minimum machine study is on the 500 GeV baseline machine, one important aspect of evaluating the design elements described above is the potential impact on the energy upgrade to 1 TeV centre-of-mass. It is expected that the central region integration and 'minimum' 500 GeV BDS are most likely to have the greatest impact. It is important to propose – at least conceptually – scenarios to successfully upgrade the machine to 1 TeV, and in particularly to estimate their potential impact on cost and schedule of that upgrade.

3 Detailed Scope and Plans for Minimum Machine Studies

The following sections will detail the plans for the 2009 studies related to the minimum proposed machine elements. The sections are organised via the relevant Technical Area Groups.

3.1 Main Linac

3.1.1 Identified critical issues

In general, elimination of the service tunnel requires a redesign of the accelerator tunnel layout to accommodate the parts of the RF and control systems that would not be moved to the surface. XFEL development should be followed closely, and aspects such as suspending the cryomodules from the ceiling considered. For a shallow site, the RF power transmission efficiency will not be significantly lower than in the two-tunnel case. Safety and emergency egress for personnel in the tunnel will have to be rethought.

For the klystron cluster concept, major concerns include the power handling capacity of the waveguides, tap-in/off's and especially bends, the efficiency with which so many sources (~35) can be combined (coupling tolerances, power levels, phasing), and whether LLRF control can achieve the required tolerances for flat bunch train acceleration with effectively one source per 1.25 km of linac. Also, the large main waveguide (0.5 m diameter) with vacuum pumping and larger tap-offs with multi-megawatt circulators must be fit into the tunnel cross-section layout.

As mentioned in section 2.2.2, there are several main linac issues related to the low power option, which entails feeding more cavities per klystron. The corresponding expansion of the unit RF power distribution system will cause a decrease in transmission efficiency. This might mean, for example, that for the half beam power case the number of cavities that can be fed goes only to 50, rather than 52. Also, the fill time of the cavities increases with reduced beam current, requiring an RF pulse duration increase of up to 33%. This impacts klystron and modulator design and reliability. For other components, such as circulators, phase shifters, and loads, the longer pulse will likely be more than balanced by the lower peak power. Effects on low-level RF also need to be considered. Increased cavity Q means more sensitive coupler tuning and greater piezo burden, and more cavities per unit means coarser phasor sum control. The effect on the cryogenic heat load also needs to be evaluated. Lower power through the coupler will help, but longer rise and fall times in the cavity will hurt. Also, the reduced bunch frequency makes it more likely that energy will be resonantly deposited in higher-order modes.

3.1.2 Proposed relevant studies

- For klystron cluster scheme, design tap-ins/offs and bends and work with industry to inexpensively produce 0.5 m diameter, copper-lined, vacuum pipe.
- High power test klystron cluster scheme components in progressively larger systems: 1) operate a back-to-back tap-in and tap-off non-resonantly at 10 MW to test wrap-around mode converters, 2) repeat (1) with different waveguide terminations to resonantly build up 350 MW to test robustness of inner-to-outer coaxial waveguide transitions, 3) use back-shorted tap-in to resonantly power a 100 m waveguide section to 350 MW to assess the effect of a longer discharge time if breakdown occurs and 4) use a tap-in and tap-off pair as a directional coupler to resonantly charge a 200 m waveguide racetrack to test the robustness of the bends. Also include a 10 MW tap-off and tap-in "bypass" to more realistically

simulate the power flow as would be seen at ILC. If during these tests, no breakdowns occur in the high power (350 MW) components, or if such breakdowns appear benign even if extrapolated to the five-times longer effective shut-off times at ILC, then the cluster scheme could be adopted for ILC with reasonable confidence that it would work reliably.

- Study beam-off LLRF data from FLASH to develop a model of cavity frequency perturbations that would then be applied to assess the impact of the longer delay times and coarser energy control in the klystron cluster scheme. Also use this model to study how the higher cavity Q's associated with the lower current options would affect the LLRF system performance.
- Study impact of the low current (50%) option on linac cost and reliability. In particular, assess how the increased pulse length would affect the modulator and klystron design and performance.

3.1.3 Summary of resource requirements

- At least one FTE per year for two years to do design and impact studies.
- For the klystron cluster proof-of-principle tests, need about 1 M$ per year (labour, materials and overheads) for two years.

3.2 CFS

3.2.1 Identified Critical Issues

The most important issue for the CFS design with respect to the proposed Minimum Machine Design elements is the fact that these new configurations affects the CFS design in virtually all aspects with the possible exception of 3.7 Simulation. We have completed a good deal of work regarding the Klystron Cluster alternative and have concluded that the elimination of the service tunnel for the Main Linac area results in a substantial CFS cost savings. The impact of the elimination of the Main Linac service tunnel for any other machine area has not yet been investigated and will necessarily be a fundamental issue in the analysis of the new central configuration.

A second issue that is a bit more practical, but no less important, is the time needed for the various area systems to develop a new beamline layout and configuration (lattice) as a result of these proposed machine alternatives. The various beamline layouts and connection points, as well as verification of support equipment requirements and locations are the first items needed for the CFS Group to begin its analysis and develop the 3D drawings to facilitate the analysis. Certainly as portions of this information can be made available work can begin, but completion of the analysis for the CFS group must necessarily be based on a complete enclosure layout from the sources to the IR and dump regions. It will be essential to utilize the established points-of-contact between CFS and each area system to facilitate this transfer of information.

3.2.2 Proposed Relevant Studies

- Verify criteria and layout for the Main Linac Klystron Cluster alternative and develop 3D drawings
- Gather criteria for e- and e+ Sources, begin enclosure layout and develop 3D drawings
- Gather criteria for Damping Ring, begin enclosure layout and develop 3D drawings
- Gather criteria for RTML, begin enclosure layout and develop 3D drawings
- Gather criteria for BDS, begin enclosure layout and develop 3D drawings
- Develop comprehensive layout and 3D drawings of entire central region including all accelerator and service tunnel and enclosure requirements
- Review implications of new layout with respect to Process Water and HVAC systems
- Review implications of new layout with respect to Electrical Distribution system
- Review implications of new layout with respect to Life Safety and Egress Requirements
- Develop a new central area cost estimate incorporating all changes with respect to the new Minimum Machine design

3.2.3 Summary of Resource Requirements

The resource requirements listed below represent only a high level analysis of the Minimum Machine design. The CFS effort indicated will provide a reasonable understanding of the overall layout and indicate a general indication of cost impact. A full design and detailed cost estimate are not within the scope of this resource profile.

- Gather criteria, begin layout and 3D drawings for all areas 0.5 FTE
- Develop comprehensive layout and 3D drawings 0.25 FTE
- Review Process Water, HVAC and Electrical Distribution 0.5 FTE
- Review Life Safety and Egress requirements 0.25 FTE
- Develop cost estimate 0.25 FTE

3.3 Sources

3.3.1 Identified critical issues

In the RDR the main undulator driven polarized positron source is in the middle of the linac occupying a special 1.2 km insert and the lower power keep-alive source is in the central region. With the in-plane geometry of the central region one can also consider consolidating these two into one system at the location of the keep-alive source, sharing the tunnel with the first part of the BDS. This combined system would have a shared e+ target, capture section and 5 GeV booster linac, and the 1.2 km insert in the Main Linac would be eliminated.

The location of the primary (undulator) positron source at the 150 GeV point in the electron linac was considered to be the best choice when considering overall operation over a wide range of energies. The impact and alternative operating scenarios will have to be revisited as this positron source undulator is now at the end of the linac and at full operating energy.

Critical issues include:

- Undulator now at end of linac so has to operate over wide electron energy range
- Variable energy operation implies variable positron yield and so variable luminosity unless properly managed
- Auxiliary source to share maximum amount of infrastructure with baseline source
- Close interaction between BDS and positron source
- Up to five beams in the tunnel in some parts of the central region and also BDS potentially interfering with the target remote handling area

3.3.2 Proposed relevant studies

- Re-optimisation of the undulator based source at the end of the linac rather than at the 150GeV fixed energy (undulator parameters, target parameters, etc). Will require 0.3 FTEs total from ANL, DESY, STFC, and CI.
- Assessment of the impact of the undulator operating over a wide range of electron energies on the positron yield and so the final luminosity. A number of options for how to cope with reduced yield at low energy need to be assessed. Will require 0.3 FTEs total from ANL, DESY, STFC, and CI.
- Optimisation of the auxiliary source so as to share as much infrastructure with the undulator based source as possible (target, matching device, etc). Will require 0.3 FTEs total from Hiroshima, ANL, DESY, and CI.
- Coordination with the BDS design which now interacts very closely with the positron source. Will require 0.2 FTEs total from STFC.

- 3D CAD modelling of tunnel in key areas (5 beam region, target region) to assess space requirements in close liaison with CFS group. Will require 0.2 FTEs total from STFC.

3.3.3 Summary of resource requirements

It is anticipated that for the minimum machine studies effort will be required at the level of 1.35 FTEs broken down as follows:

- 0.5 FTEs at STFC
- 0.25 FTEs at ANL
- 0.25 FTEs at DESY
- 0.15 FTEs at CI
- 0.2 FTEs at Hiroshima

3.4 Damping Ring

3.4.1 Identified critical issues

Minimum machine studies for the damping rings will focus on the low-power parameter set (

Table 1). The low-power parameter set has half the number of bunches compared to the RDR baseline, and allows the possibility of reducing the circumference of the rings by half, while maintaining the same bunch spacing and beam current. To first order, halving the circumference of the rings would be expected to halve the costs of the system. However, assuming the same beam energy and damping time, the rf power requirements will be the same; and modifications to the lattice (e.g. to achieve the same emittance with fewer arc cells) may mean that the number of magnets is reduced by a factor less than two. A proper evaluation of cost savings will need to be based on a specific lattice design.

Maintaining the same bunch spacing would mean that the technical difficulty of the injection/extraction systems (which are critical R&D items) would not be increased; while maintaining the same bunch spacing and beam current would mean that certain collective effects – in particular, electron cloud – should not be made more severe.

The impact of some collective effects, such as space charge, should be reduced in rings with reduced circumference. This raises the possibility of reducing the beam energy, which would have benefits for the damping rings (in reducing the rf and magnet power requirements) and for downstream systems, notably the bunch compressors (because of the reduced longitudinal emittance of the beam extracted from the damping rings). However, reducing the beam energy also increases the impact of a range of collective effects, including intrabeam scattering, electron cloud, and impedance effects; and increases the injected beam size, because of the loss of some adiabatic damping during acceleration from the sources. The potential impact of these effects needs to be evaluated.

3.4.2 Proposed relevant studies

To provide a self-consistent evaluation of the benefits of a reduced circumference (and possibly, a reduction in energy) it is desirable to base studies on a specific lattice design. Two lattice designs with roughly 3 km circumference (half that of the present baseline) are already available: one from the Configuration Studies of 2005; and another based on the present baseline lattice with modified arc cells (taken from a lattice design for SuperB). The latter has the benefit of having straight sections almost identical to the present baseline; all necessary systems are included, and comparisons between the lattices with different circumferences can be made more simply and directly.

Some modifications to both the available 3 km lattices are still needed; these will be performed by Cockcroft Insitute, and INFN-LNF. Following the necessary modifications, a selection will be made of the lattice that will provide the basis for the minimum machine studies in the damping rings area system. The following tasks will then be performed through 2009 (note that some of these tasks are closely connected with on-going technical design work that is required to develop the baseline configuration through the TDP):

- Evaluate selected beam dynamics effects in the 3 km damping ring, including the impact of reduced energy (Cockcroft/INFN-LNF).
- Lattice designs for the injection/extraction lines for both options (6 km baseline, and 3 km minimum machine) will be developed (INFN-LNF).

- Work will continue on developing an impedance model. This will be based on technical designs for individual components, so that models can be developed for both the 6 km and 3 km configurations. (Cockcroft/INFN-LNF).
- Work will continue on developing and maintaining CAD models and cost estimates for both the 6 km and 3 km configurations (Cockcroft).

By the end of 2009, a technical and cost comparison of the 6 km and 3 km configurations will be produced. The technical evaluation will address important beam dynamics issues, including the impacts of reductions in circumference and energy.

3.4.3 Summary of resource requirements

It is anticipated that throughout 2009, effort will be required at the level of:

- 2 FTE at Cockcroft Institute (1 FTE design and cost engineer; 1 FTE beam dynamics/accelerator physics); and,
- 1 FTE (beam dynamics/accelerator physics) at INFN-LNF.

3.5 RTML

As described in section 2.4 replacing two-stage bunch compressor with a single-stage is big potential cost saving option for RTML area. Single stage BC is less flexible solution and will support sets of beam parameters from Table 1 with 300 micron bunch length only. Currently there are two possible single-stage compressor designs under consideration: compression in multi-periodic wiggler system and ultra-short design with compression in simple chicane system. Single-stage BC is expecting to be more sensitive to alignment of cavities and magnets, and phase-amplitude stability of the SC cavities. Critical issues are emittance preservation in bunch compressor due-to errors, chromatic effects and coupler RF kick and wakes. (priority #1)

Another big cost saving is removal one (per side) of the 220 kW dump and dump line components (which was located after 2nd compressor in baseline design). Remaining extraction line and 220kW dump, located after single stage compressor has to be redesigned since beam increased from ~2.5% to ~4%. This is an issue (priority #2)

Cost saving is possible by shortening of the diagnostics and matching sections (5 GeV instead of 15 GeV in baseline design). New lattice design and performance studies are also issues (priority #2)

Post-acceleration section from 5 GeV to 15 GeV is identical to regular Main Linac lattice and has to part of them. Emittance preservation studies in Main Linac with the beam parameters (energy spread) provided by RTML is an issue and have to be coordinated by both areas (priority #2).

Changes in Damping Ring and e+/e- sources discussed above in Minimum Machine configuration will affect design and length of the RTML line from DR tunnel to main tunnel. This is possible big changes will require and it is an issue (priority #3).

3.5.1 Proposed relevant studies

Studies of single-stage bunch compressor will include the following packages:

- Lattice design of a single-stage bunch compressor, diagnostics section and matching section. Will require ~0.4 FTE's for both designs (wiggler and chicane). (FNAL/BNL/KNU-Korea)
- Beam physics simulation to study effect of coupler rf kick, alignment and phase-amplitude stability of the RF system and provide requirements. The goal to demonstrate that RTML emittance budget can be achieved and beam parameters at the exit of RTML system provide acceptable emittance budget in Main Linac. It will require ~0.7 FTE's (FNAL/KNU-Korea)
- Re-design extraction line and 220kW dump with higher energy spread beams after compressor. It will take ~0.3 FTE's (BNL)
- Developing CAD models and cost estimations for both types of single-stage bunch compressors: wiggler type design and ultra-short chicane type design. It will require ~0.4 FTE's (FNAL)
- Re-design RTML section from DR tunnel to Main Linac Tunnel. It will require ~0.7 FTE's. This task has low priority and can be completed after more detailed configuration of other area systems: DR and sources (???/FNAL).

3.5.2 Summary of resource requirements

It is anticipated that throughout 2009 effort will be required at the level of:

- 1 FTE at KNU-Korea – lattice design and beam dynamics/accelerator physics
- 1.4 FTE at Fermilab – (1 FTE- beam dynamics/accelerator physics and 0.4 FTE – design and cost engineer)
- 0.3 FTE at BNL – compressor and dump lattice design.

3.6 BDS

3.6.1 Identified critical issues

Minimum machine studies for the Beam Delivery System will focus on further evaluation of the low-power parameter sets (

Table 1). The low power parameter sets allow maintaining the same luminosity with half the number of bunches. This is achieved by means of tighter focusing at the IP, with reduced IP beam size and beta function. This would lead to the need to perform tighter collimation and may result in tighter requirement on the incoming to BDS beam jitter, as it can lead to beam emittance growth via the collimator wake-field effects. The latter in turn could be ameliorated by tail-folding octupoles, which for the moment are considered as an additional safety factor, but could in principle be considered as a part of baseline design. Smaller beta-function at the IP may also increase effects of the aberrations and increase requirements to the field quality, etc., which would need to be evaluated.

The new low power parameter set, which will be the focus of studies, allow using the nominal 300 micron bunch length, which is supposedly simplifies requirements to the bunch compressor. However, the IP beta-function is focused to 200 microns, and the luminosity reduction which is nominally is expected in such case due to hour-glass effect, is mitigated by use of the travelling focus (the method was suggested in 1991 by V.Balakin). In the travelling focus mode, the focal point of the bunch moves during collision in such a way that it coincides with location of the opposite bunch. The beam-beam forces then keep bunches well focused on each other, overcoming the hour-glass effect. The limit, how deep one could focus the beam in travelling focus mode, is then defined by the beam-beam instability, and thus by the tolerances on the beam-beam offset at the IP. The new low power parameter set described in the Table 1 is believed to be close to the optimum, when the increase of these tolerances may be achievable.

Long (nominal) length of the bunch in new low power parameter set is also beneficial for reduction of beamstrahlung energy spread and also for reduction of the kick to low energy incoherent pairs, whose trajectory define shape of the vertex detector and thus may affect vertex detector resolution. These effects need to be evaluated in details, by and in close communication with detector groups. The new low P set also need to be evaluated from the extraction line point of view.

Generation of travelling focus condition can be achieved by two methods. The first involves creation of small coherent z-correlated energy shift within the bunch, combined with small uncompensated chromaticity, and the second method uses transverse deflecting cavities, which give x-z correlated kick and thus x-z correlated offset in final focus sextupoles that give z-correlated additional focusing within the bunch. These methods need to be evaluated in details.

In addition, BDS group will also be looking in some shortening of the beam delivery system allowing larger, several to ten percents beam size growth at the maximal energy of 1TeV CM.

The issues with central region integration, which are relevant for BDS design, include, but not limited to evaluation of necessary transverse separation and allowed emittance growth in the dogleg that offsets BDS beamline and the undulator (this is expected to be done by e+ group); re-evaluation of the upstream polarimeter location (before or after the undulator); considerations of use of common beam dump for several beamlines; implications for layout and IP positions in cases of upgrades or modifications, as well as for location of fast extraction, beam diagnostics and polarimeter caused, by beamline asymmetry if the positron source undulator chicane is placed on one side only;

implications to installation, commissioning and running due to complexity of the central integration region; etc.

3.6.2 Proposed relevant studies

Studies relevant for the issues identified above include:

- Evaluate new low power parameter set from IP beam-beam dynamics and beam offset sensitivity point, and collimation and optics points of view (SLAC, Cockcroft Institute).
- Evaluate methods to create travelling focus together with Beam dynamics group (CERN-KEK).
- Evaluate effects of new low power set on detector background (SLAC, KEK, DESY).
- Evaluate beam delivery system allowing for larger beam size growth due to synchrotron radiation. (Cockcroft Institute, SLAC).
- Evaluate central integration issues relevant for beam delivery.

By the end of 2009, a technical evaluation will be produced.

3.6.3 Summary of resource requirements

It is anticipated that throughout 2009, effort will be required at the level of:

- 1.5 FTE at Cockcroft Institute (0.25 FTE design engineer; 1.25 FTE beam dynamics/accelerator physics); and,
- 1.5 FTE at SLAC (0.25 FTE design engineer; 1.25 FTE beam dynamics/accelerator physics); and,
- 0.5 FTE at KEK (beam dynamics/accelerator physics and detector physicist); and,
- 0.25 FTE at CERN (beam dynamics/accelerator physics); and,
- 0.25 FTE at DESY (detector physics).

3.7 Simulation

3.7.1 Identified critical issues

Critical beam dynamics issues in the single-stage bunch compressor are bunch timing stability and preservation of low emittance. Bunch fluctuations affect collision timing of two beams at the interaction point. Since the single-stage scheme increase the momentum spread, emittance dilution due to dispersive effects can be significant both in the bunch compressor itself and in the main linac. These issues depend on design of the bunch compressor (RTML).

Critical beam dynamics issues related to the new Low P parameter are luminosity performance of the final focus system and performance of the main linac inducing necessary z-E (longitudinal position and energy) correlation. The issues are from the low beta-function optics and traveling focusing scheme. These depend on design of the final focus (BDS).

3.7.2 Proposed relevant studies

For bunch timing stability of single-stage bunch compressor, the goal is to estimate required RF stability by simulations. Simulations should be performed including various errors related to RF system in the bunch compressor. In addition, effect to luminosity may have to be evaluated by simulations of collisions.

For low emittance preservation of single-stage bunch compressor, the goal is to estimate tolerance of misalignment and specification of diagnostics system. It will include finding appropriate beam tuning (correction) methods. Simulations of the bunch compressor and main linac will be necessary.

About four weeks full time work of an expert will be necessary for the studies for single-stage bunch compressor. Two independent studies are desirable for cross checking.

For evaluation of luminosity performance of the final focus system with the low beta-function optics and traveling focusing scheme, simulation of the final focus beam line should be performed. The goal is to estimate tolerances of various errors. Simulation of the main linac including creation of z-E correlation for the traveling focusing should be also performed to check the performance of this scheme. About six weeks full time work of an expert will be necessary for this study. Two independent studies are desirable for cross checking.

3.7.3 Summary of resource requirements

Required man power will be; (a) about four weeks full time work of an expert for single-stage bunch compressor and (b) about six weeks full time work of an expert for the low beta-function optics and traveling focusing scheme. Each of them should be doubled for two independent cross checking studies.