To: Distribution

From: GDE Change Control Board

Subject: Response to the Change Request (October 25, 2006) for the BCD RTML

Section - CCR#19

Preamble

This is the CCB response to the proposed changes to apply to the RTML (ring-to-main-linac) section of the November 5, 2006 version of GDE ILC Baseline Configuration Document [1]. CCB received the change configuration request (CCR#19) from P.Tenenbaum on October 24, 2006 [2], and CCB forwarded it to GDE the same day. However, CCB put the CCR in "on-hold" status first, since part of the discussion of CCR#19 relied on CCR#18 [3] which was still under CCB review at that time. The formal CCB review of CCR#19 began on October 28. While this CCR#19 was initially treated as Class-1, it was reclassified as Class-2 based on the magnitude of its cost impact found on November 8. K.Kubo, D.Schulte and S.Mishra were assigned as the CCB reviewers. The CCB hearing on CCR#19 was held on November 8 during the Valencia GDE meeting [4].

Summary

Requester proposed:

To apply two types of changes in the RTML design baseline:

- a. Changes of beamline definitions and functionality descriptions of RTML so that they match the so-called "centralized damping ring layout" as proposed with CCR#18 [3] and as approved by EC on November 5, 2006.
- b. Changes of numerous aspects of technical implementation of RTML beamline in an attempt to reduce the construction cost of this subsystem.

CCB response:

- CCB acknowledges, as claimed by the requesters, that part of this CCR #19
 relates to revision of beamline definitions and functionality descriptions of RTML
 that is introduced to match the centralized damping ring layout of CCR#18. CCB
 found that these portions of proposed revisions are consistent with CCR#18, and
 that they should be approved as they are. CCB notes that the cost impact (in this
 case increase) associated with these changes have been already accounted for
 and have been approved with CCR#18.
- CCB found that additional revisions related to the cost reduction measures
 amount to a cost impact that they qualify as Class-2. Consequently, CCB
 assumes that the CCB role concerning this part of change request is to assess its
 merits and make a recommendation to EC, rather than to make a final
 configuration change decision.

3. CCB recommends EC to adopt this change request CCR#19, with small refinements on illustration (Appendix A), for reasons detailed below in the Discussion section.

Discussion:

The following discussion is laid out in accordance with the proposed list of changes with CCR #19, which have been provided by the requester at:

 $\frac{\text{http://www.linearcollider.org/wiki/lib/exe/fetch.php?cache=cache\&media=bcd:ccr19hearingrtml200}{61108.pdf} \text{ . CCB thanks the requester for his very thorough and well organized job, which greatly helped the CCB review process..}$

CF - Conventional Facilities Changes

A. The following changes to the RTML's conventional facilities have been requested as part of cost reduction measures:

- 1. The 9 meter shafts at Points 8 and 9 are deleted. The shaft at Point 9 has been moved to the electron source CFS (so the e- source group can decide whether to keep it or not), while the shaft at Point 8 is removed in its entirety.
- 2. The 14 meter shafts at Points 10 and 11 are moved as far upstream as possible, basically to the start of the turnaround, and the "two-way tunnel" from the turnaround to the Points 10/11 shafts are converted from drill and blast (D&B) to tunnel boring machine (TBM), with tunnel diameters identical to that in the main linac.
- 3. The office buildings and workshops at Points 10 and 11 are removed.
- 4. The ID of the turnaround tunnel is reduced. The final diameter is to be determined, but is whatever diameter is the least expensive to construct (the requesters believe that a 3 meter diameter would suffice, as the turnaround contains only room-temperature magnets and BPMs).
- 5. The "two way beamline" section is switched from side-by-side beamlines to vertically-stacked beamlines. This implies that there will have to be a change in beamline elevation in the turnaround, which will probably require an additional 20 meters of turnaround tunnel per side. According to the requesters the intention is to allocate space for an aisle for personnel.
- 6. The RTML tunnel and its service tunnel are reduced by about 108 meters per side due to the removal of 3 RF units from BC2 (see Cavities and Cryomodules, below).
- 7. Electrical handling, process water, piped utilities, air treatment, and installation are all reduced. The exact reduction in each has not been determined, but we have assumed that it is around 20%, which is the mean reduction in cost of all other changes documented here.
- B. The following changes have been made in support of the central DR:
 - 8. Most obviously, some length of beam tunnel and service tunnel are needed to connect the linac tunnel to the central DR tunnel. Since these tunnels support the electron source,

- positron booster, and keep-alive source, we do not further describe them here other than to note that these additional tunnels are needed.
- 9. The new tunnel will need dump enclosures on each side for 220 kW dumps (i.e, 5 GeV, full power dumps), so that beam from the DR can be dumped before entering the main linac tunnel.
- 10. The new beamline will require additional electrical and cooling capacity. The main length of beamline (about 15 km per side) presents a heat load of about 1 W/m. In addition, there is about 100 meters per side which has a heat load of about 100 W/m.

C. Discussion and CCB assessment

- CF-1: CCB agrees with the following observation: Since the shaft Point 9 was near the e-source / e-DR, part of its functionality has to move to neighborhood of e-source which is now relocated to the new position. The shaft at Point 8 is on the e+DR side, thus, can be removed.
- CF-2: The requester noted in response to a CCB inquiry that the cost of TBM is approximately 1/3 of D&B, according to the model used by CF/S Group. CF-2 is an attempt to maximize TBM and to minimize D&B in the CF/S work related to RTML.
- CF-3: The requester responded to a CCB inquiry with a contextual clarification that this information is provided primarily for use of the CF/S group.
- CF-6: A question was raised if it would be too aggressive to eliminate 3 RF units in BC2, together with the tunnels to accommodate them, which means an irreversible move. A discussion in support of this change was provided by the requester during the CCB hearing [4]. The requester claimed that the risk of luminosity loss is minimal, since cryomodules with good performance can be specially selected for use with BCs during construction. At some future time, if more voltage is found necessary, new, higher-performing modules could be used for substitution.
- CF-7: The requester responded to a CCB inquiry with a clarification that the reduction in the cost here is assumed to be proportional to the reduction of the beamline elements considered. CCB concurs that this is a reasonable first order assumption to make at this point of design development.
- CF-10: The requester responded to a CCB inquiry with a clarification that the 100 m line with the heat load of 100W/m in question is the so-called "escalator", where strong focusing is needed to prevent emittance growth due to the SR and the high-order dispersion functions.
- CCB Assessment: CCB agrees with the requester that the changes from CF-1 through 7 are reasonable and acceptable as cost reduction measures; the changes from CF-8 through 10 are adequate and acceptable in making the RTML CF/S consistent with CCR#18, which have been approved as of Nov. 5, 2006.
- CCB Comment 1: CCB recommends the requester to include a simple topology chart within BCD which illustrates the defined areas of sub-beamlines that are quoted in the main text of the RTML section.
- CCB Comment 2: CCB appreciates the detailed descriptions of changes related to CF/S aspects of RTML system, as offered by the requester. These CF/S descriptions, in principle, ought to be documented in the CF/S section of BCD. The CF/S section of BCD, however,

at this moment does not offer meaningful materials to serve as basis for adequate CF/S configuration control. CCB wishes to point out that this situation needs to be addressed without excessive delays.

VAC - Vacuum System Changes

A. The following changes to the RTML's vacuum systems have been requested as part of the cost reduction:

- 1. The vacuum specification in the main RTML section has been changed from 10 nTorr to 100 nTorr.
- 2. Heaters for *in situ* baking of the vacuum system have been eliminated.
- 3. The vacuum system which supports the RTML cryomodules has been reduced in scope due to the elimination of 3 cryomodules per side (out of an original design which called for 20 per side).
- B. The following changes have been requested in support of the Central DR, CCR#18:
 - 4. Addition of 15 km per side of 2 cm OD vacuum chamber for the long transfer line. The long transfer line vacuum specification is 20 nTorr, and this system will use *in situ* baking to achieve this performance at tolerable cost.

C. Discussion and CCB assessment

- VAC-2: The requester responded to a CCB inquiry with a clarification that the intention is to remove the entire beamline for space that has been previously allocated for the 3 cryomodules that are to be removed (change CAV-1); the cryomodules are not replaced by beam pipe "spool pieces".
- More discussion related to the change VAC-1 appears under ACCPHY-3.
- CCB Assessment: CCB agrees with the requester that the changes VAC-1 and 2 are reasonable for the required cost reduction. The change VAC-3 is a derivative of CAV-1. The change VAC-4 has been accepted as part of CCR#18.

MAG - Magnet System Changes

A. The following changes to the RTML's magnet systems have been requested as part of the cost reduction:

- 1. Elimination of the horizontal corrector magnets at the vertically-focusing quadrupoles. This constitutes 25% of the total number of correctors, or about 137 dipole correctors per side.
- 2. Elimination of about 4 SC quads and 6 SC dipole corrector per side, due to removal of 3 RF units per side in an area with 1 quad per 2 CMs.
- 3. Elimination of about 58 quads per side in each turnaround, plus 87 dipole correctors per side (58 y correctors and 29 x correctors). The length of the turnaround FODO cell is doubled. The strength of the remaining quads is reduced by about half (not quite half, as the phase advance per cell has to be increased to limit the SR emittance growth to something tolerable).

- 4. In the Vancouver cost and parts count roll-up, the HKEXT_BC1 and HKEXT_BC2 kickers were double-counted as kickers (K20L1000) and as DC correctors (DCRTML3). The DC corrector entry for each of these fast kickers is deleted.
- B. The following changes have been made in support of CCR#18.
 - 5. Addition of approximately 400 weak quadrupoles per side for the long transfer lines. The quads are approximately based on the QFCOLL / QDCOLL design (QRTML1). However, in this incarnation, these quads have to fit into a 50 cm x 50 cm envelope, which the current QRTML1 quad may not be able to do because it is air cooled. Each quad has an independent power supply.
 - 6. Addition of approximately 16 strong quadrupoles per side (comparable to the current QDA / QFA quad in RTML), in the so-called "escalator" section.
 - 7. Addition of approximately 600 dipole correctors (400 vertical, 200 horizontal) in the long transfer line.
 - 8. Addition of approximately 16 rectangular bend magnets, with effective length 0.4 m and bend angle 2.75 mrad at 5 GeV beam energy, in the so-called "escalator" section.
 - 9. Addition of one pulsed dumpline per side, with approximately 8 pulsed kickers of HKEXT_BC1 design per side, approximately 4 septa of BC1SEPT design per side, and a handful of miscellaneous extraction quads and bends per side.

C. Discussion and CCB assessment

- MAG-1: The presenter pointed out that typical beta functions in the turnaround, the emittance sections, the BC wigglers, etc are quite different, and that all of the vertical steering magnets will be maintained.
- Discussion related to the change MAG-1 is from an accelerator physics point of view is found under ACCPHY-7.
- MAG-5 through MAG-9: There was a question concerning their accounting, and it was confirmed at the CCB hearing [4] that these costs were captured in CCR#18.
- CCB Assessment: CCB agrees with the requester that the changes from MAG1 to 4 are reasonable for the required cost reduction, and the changes MAG-5 to 9 are associated with and accounted for in CCR#18, which have been approved.

CAV - Cryomodule and Cavity Changes

A. The following changes to the RTML's cryomodules and cavities have been made as part of the cost reduction:

- 1. Elimination, on each side, of 3 RF units containing 9 cryomodules and 72 cavities from the second-stage bunch compressor. The remaining units must be capable of operating at 31.1 MV/m to attain the desired final energy and bunch length.
- 2. Elimination, on each side, of 3 room-temperature dipole-mode structures (crab cavities).

C. Discussion and CCB assessment

- CCB notes that there are no changes requested in the configuration of BC1. BC1 assumes 24 cavities fed by one klystron, as of CCR#9 that was approved in April, 2006. While no spare cryomodules are implemented, a set of klystron and modulator are reserved as spare RF unit for BC1.
- On BC2, the requester gave a clarification in response to a CCB inquiry as follows: The maximum total voltage in BC2 will be reduced and, as described in the change ASSPHYS 1, the configuration which used 54 cryomodules at 27.9 MVm (150A) is no longer achievable if this change is accepted. It was noted that 3 spare cryomodules are still maintained.
- Discussion related to the change CAV-2 is found under ACCPHY-5.
- CCB Assessment: With the discussion noted under ACCPHY-5, CCB finds that these changes are reasonable as cost reduction measures.

RF - RF Power Changes

A. The following changes to the RTML's RF power systems have been made as part of the cost reduction:

- 1. Elimination of 3 1.3 GHz RF units per side, each unit constituting a modulator, klystron, and all the trimmings.
- 2. Elimination of 3 S-band RF units per side, including all units with SLED cavities.

B. CCB assessment:

- These changes are derivatives of changes to apply for Cryomodules and Cavities.

INSTR - Instrumentation Changes

A. The following changes to the RTML's suite of instrumentation have been made as part of the cost reduction:

- 1. Elimination of about 60 cavity BPMs per side. Each BPM was associated with a quadrupole magnet which has been eliminated.
- 2. Elimination of 2 wire scanners per side from the EMIT section, leaving 4 wires per EMIT station.
- B. The following changes have been made in support of CCR#18:
 - 3. Addition of about 400 room-temperature cavity BPMs per side, as part of the long transfer line
 - 4. Addition of a laser wire emittance station on each side, with a laser and 4 laser wire scanners per side, near the extraction point from the DR. In addition, the OTR and metal wire used for this purpose in the BCD RTML are removed.
 - 5. Some additional feedbacks, type and location TBD, will most likely be needed as part of this expansion of the ILC's total length of beamline.

C. Discussion and CCB assessment

- Discussion related to the changes INSTR-2 and 4 are given under ACCPHY-4.

- CCB Assessment: CCB agrees with the requester that the changes INSTR-1 and 2 are reasonable as cost reduction measures and the changes INSTR-3 to 5 are required to support CCR#18, which has been approved.

COLL - Collimators and Dumps Changes

A. The following changes to the RTML's collimators and dumps have been made as part of the cost reduction:

- 1. Elimination of the 22 kW pulsed dump after BC1 and the 660 kW pulsed dump after BC2, and replacement of both of these dumps with 220 kW dumps.
- B. The following changes have been made in support of the Central DR:
 - 2. Addition of one 220 kW dump per side after DR extraction.
 - 3. Addition of one collimation section per side (i.e. each side now has double the original number of spoilers and absorbers).
 - 4. The insertable 1 kW stopper downstream of DR extraction is now obsolete and will be removed.

C. Discussion and CCB Assessment

- While the dumps after BC1 can accept a full beam power, the dumps after BC2 can only accept 1/3 of full beam power. Therefore, there are potential availability/operational issues and they are discussed under ACCPHY-2.
- COLL-1 and COLL-2: The requester noted in response to a CCB inquiry that they should be separately considered.
- Upon consultation with the requester CCB understands that maintenance personnel can access the ML tunnels when the full power beam is parked at the DRX dump.
- CCB Assessment: CCB agrees with the requester that the change COLL-1 is reasonable for the required cost reduction and the changes COLL-2 to 4 are consistent with CCR#18, which has been approved.

CRYOGEN - Cryogenics Changes

A. The following changes to the RTML's cryogenic systems have been made as part of the cost reduction:

- 1. Reduction in cryo system capacity due to elimination of 3 RF stations (9 CMs) per side.
- B. CCB assessment: This is consistent with changes to apply to Cryomodule and Cavity.

CTRL - Controls Changes

A. The requester noted: There are no direct changes to the control system. However, as illustrated above, there will be a number of changes due to the changing number and placement of elements. It was pointed out that the reduction in the control system cost should be proportional to the change in the number of components and subsystems to be controlled.

B. CCB assessment: CCB agrees with requester's statement.

INSTALL - Installation Changes

A. The requester noted: There are no direct changes to the installation. However, as illustrated above, there will be a number of changes due to the changing number and placement of elements. It is expected that the reduction in the installation cost should be proportional to the change in the number of components and subsystems to be installed.

B. CCB assessment: CCB agrees with requester's statement.

ACCPHY - Accelerator Physics and Operations Changes

- A. The requester noted that all of the changes listed so far will imply a large number of changes to the beam dynamics and operations of the RTML.
- B. First, the requester listed the changes related to cost reduction as follows:
 - The flexibility of the bunch compressor is reduced. In particular, the 150A configuration is now unachievable, although the other configurations (300B, 150B, 300A) remain attainable. (Here, "150" or "300" means the final bunch length in microns. The suffix "A" or "B" indicates the setting of the total rotation in longitudinal phase space: "A" = 180 deg, and "B" = 90 deg. "B" has tighter DR phase stability tolerance and looser transverse tolerance http://www.linearcollider.org/wiki/doku.php?id=rdr:rdr_as:rtml_accelerator)
 - 2. It is no longer possible to park full-power beam immediately upstream of the linac injection point (i.e., at 15 GeV and full compression). The dump at the end of BC2 can now take only about 1/3 of the total power. However, the dump at the end of BC1 can now take full power. Since all the dumps have intra-train and train-by-train capability, one can imagine running 1 Hz to the BC2 dump and 4 Hz to the BC1 dump and still doing some amount of accelerator studies on the RTML (although more slowly than before).
 - 3. The beam-gas scattering in the RTML is increased by a factor of 10, by the reduction in vacuum quality. However, previous studies indicated that this was originally at the level of 9×10^{-8} of the beam power (http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-tn-06-007.pdf). Increasing this to 9×10^{-7} is still well below the IP's goal of $(1\sim2)\times10^{-5}$ from the RTML, ML, and BDS, combined.
 - 4. It is no longer possible to directly measure normal-mode emittances and coupling parameters at the EMIT sections, although it is still possible to measure projected emittances, which are adequate for tuning purposes.
 - 5. Some of the modes of operation planned for the crab cavities are no longer viable. In particular, the YZ and P_yZ correlations can no longer be measured, and the cavities can no longer be run non-invasively (which was achieved by using 2 cavities with a -I between them). However, the bunch length and P_Z (total momentum) correlation can still be measured at each bunch compressor.

- 6. The growth of the horizontal emittance from misalignments may increase due to reduction in the number of correctors (in practice we think that this will be negligible).
- 7. The turnaround will have additional emittance growth from both synchrotron radiation and from misalignments (since the phase advance per cell is increased to partially compensate the SR effects). In addition the R_{56} of the turnaround is increased, which will stretch the bunch out upstream of the bunch compressor and may have some effects (not yet studied).

B. Then the requester listed up changes related to the new systems needed for CCR#18:

- 8. There is an additional emittance measurement station immediately downstream of the DR exit, which includes laser wires. Thus it is now possible to do full-train emittance measurements of beam right after extraction.
- 9. There is a pulsed dump which can be used for tuneup purposes near the DR exit.
- 10. The Personnel Protection System (PPS) segmentation of the ILC has been reduced. In particular, when there is beam downstream of the new tuneup dump (ie, into the RTML's long transfer line), it is not possible to let people into the RTML or the linac (although it may be OK to enter the BDS under these circumstances).
- 11. The collimators immediately upstream of the turnaround can no longer be protected by switching off the DR extraction system (although the ones immediately downstream of the DR extraction still can be).
- 12. In principle there are a wide variety of accelerator physics issues in the long transfer lines. In practice we think that most of these will not be interesting emittance growths will be small, jitter amplifications from ions will be small, etc. However, there will be additional operational issues related to the sheer number of additional devices in the transfer lines.

D. Discussion and CCB assessment

- ACCPHY-1: CCB notes that this change still maintains the RTML capability of longitudinally compressing the bunches from 6 mm to 150 μ m, and from 9 mm to 300 μ m. CCB finds this acceptable.
- ACCPHY-3: In response to a CCB question, the requester explained that BDS/MDI design has set the limit of beam halo as (1~2) × 10⁻⁵, consistent with the discussion given for CCR#16 (BDS muon spoiler reduction from 27m to 5m).
- ACCPHY-4: The requester remarked that measurements of projected emittance are non-invasive.
- ACCPHY-4 and 8: The requester noted and CCB agrees that if the horizontal and vertical phase advances in the laser wire regions were made different (they are kept the same in the present design), measurement of normal-mode emittances and coupling parameters will be possible. This presents an area of possible design improvement in the future.
- ACCPHY-4 and 8: The requester confirmed that two slots for installing additional laser wires will be reserved, and CCB notes that this is a good provision to assume.
- ACCPHY-5: It was noted that one crab cavity is maintained at each stage of bunch compressor (a total of four cavities in two RTMLs), and CCB finds that it is adequate.
- ACCPHY-5: The requester noted and CCB agrees that while measurement of PZ correlation is essential, YZ and P_yZ etc will not be critical and thus can be foregone.

- ACCPHY-6: Common experiences tell, and both the requester and CCB agree that not all quadrupole magnets have to have both the horizontal and vertical beam steering dipole magnets, and that this will be true for RTML, too.
- ACCPHY-7: The requester pointed out and CCB agrees that reduction of the quad population and their focusing strength makes the alignment tolerance looser. So this is not a concern from the alignment standpoint by itself. However, the requester noted that emittance increase due to SR will be larger by factor 8, when this change is applied with the phase advance per cell unchanged. Since the increase of the horizontal emittance due to SR in the turnaround of the present baseline has been about 2%, the emittance growth will become 16%. A new lattice design, with stronger focusing (larger phase advance per cell), is necessary to mitigate this emittance growth. This design work will require more detailed study but is expected to be possible. CCB notes that a fully satisfying alignment and tuning procedure for the RTML remains to be demonstrated
- Related to the changes ACCPHY-9 and 10, there were several CCB inquiries which were responded as follows: Each pulsed dump has both fast kickers for MPS action between bunches of a train, and pulsed bends similar to the SLC pulsed beam dump which can remove entire trains on a train-by-train basis, or be operated DC (it has both pulsed and DC power supplies). In addition, a new tuneup dump is placed upstream of the escalator, so when access is set to the ML the beam is parked on this new tuneup dump via the DC supply, turn off the escalator bends DC supply, and PPS stoppers inserted, so that beam cannot enter the ML.
- There was a question about the detailed power specification of the dump, related to the changes ACCPHY-2, 9 and 10, beyond what has been discussed in COLL-2~4. It was explained that the ongoing debate over dump power ratings is not yet resolved enough to incorporate these specifications into the baseline.
- Related to the change ACCPHY-11, it was noted that the collimators can be damaged if there is a fault in the return line: At the moment a serious fault in the return line will lead to a collimator is hit by the beam, in the same way that a serious fault in the linac will lead to some sort of damages in the linac. The requester remarked that same or similar systems are needed to protect both areas, and its description and design are beyond the scope of the RTML BCD.
- CCB Assessment: CCB agrees with the requester that while certain beamline design and engineering issues remain to be resolved, no prohibitively difficult issues are foreseen to arise, as the result of proposed changes, in the area of beam dynamics.

COST – Costing Issues

- Below is an excerpt from the minutes of the CCB hearing on CCR#19 [4].
- The requester explained the breakup of the cost changes associated with this CCR.
 - a) Changes to maintain consistency with CCR#18 incur a cost increase, dominated by the expenses needed to introduce new beamlines, including the 5GeV transport.
 - b) Changes to reduce the RTML cost, naturally, brings a cost reduction.
 - The absolute magnitude of the latter is approximately $\times 1.5$ of the former.
- CCB noted that the point a) above has been already accounted for in review of CCR#18.

- CCB, therefore, determined that only the portion corresponding to b) is to be considered as the cost impact associated with CCR#19.
- GDE Cost Engineers reported that the relative magnitude of the cost impact of CCR#19 b) is approximately 18% of the RTML construction cost (Appendix B). The largest cost reduction is brought by reduction of part of conventional facilities, followed by reduction of cavities in BC2.
- Based on the magnitude of the cost impacts, CCB determined that this CCR should be classified as Class-2.

Overall CCB Assessment:

- 1. CCB finds that this CCR brings in a substantial cost reduction while maintaining a good likelihood of achieving a workable ILC design.
- 2. In the spirit of present definition of BCD, which reads "A forward looking configuration which we are reasonably confident can achieve the required performance *and* can be used to give a reasonably accurate cost estimate by late-2006/early-2007 in a 'Reference Design Report.'", CCB finds that this CCR to be acceptable.
- 3. CCB, therefore, recommends EC to adopt this CCR with minor revisions as noted in item 6 below.
- 4. CCB, however, notes that following issues call for further studies either by the RTML Area Group or other responsible parties:
 - Refinement and optimization of the beam optics design of the diagnostic sections with laser wire scanners.
 - Evaluation of the quality of the emittance preservation to ensure that the design is fully satisfactory.
 - Clear definitions of power rating specifications for the beam dumps and their implementation.
 - Design of machine protection measures which prevent major damages from accidental dumping of the beams at wrong locations.
- 5. CCB also wishes to draw attention of responsible parties that CF/S section of BCD should be filled in, including the descriptions of RTML conventional facilities discussed in this CCR, together with CF descriptions of other area systems. This is to allow suitable configuration control of related subjects before the job becomes too difficult to keep track of.
- CCB recommends a small touch-up's to the proposed new text for RTML section of BCD.in
 which to introduce an easy-to-see topology diagram of the RTML beamline. A suggested new
 replacement text for the RTML section is attached in Appendix A.

Additional Notes:

Handling of Cost-Related Information:

The "Hearing" on the cost impacts was held as a face-to-face meeting on November 8, 2006 during the GDE meeting at Valencia. The minutes of the hearing are available at [4]. However, as announced by GDE EC and reported at the Vancouver GDE meeting all public communication from CCB will have all "raw" cost numbers withheld (replaced by fractional numbers wherever possible and adequate).

END

References

- [1] http://www.linearcollider.org/wiki/doku.php?id=bcd:bcd_home .
- [2] http://lcdev.kek.jp/ML/PubCCB/msg00093.html http://www.linearcollider.org/wiki/doku.php?id=rdr:rdr_as:rtml_changes_for_valencia
- [3] http://lcdev.kek.jp/ML/PubCCB/msg00092.html
 http://lcdev.kek.jp/ML/PubCCB/msg00102.html
 http://lcdev.kek.jp/ML/PubCCB/msg00108.html
 http://lcdev.kek.jp/ML/PubCCB/msg00108.html
- [4] Minutes of CCB Hearing, Nov.8, 2006.

 $\underline{http://www.linearcollider.org/wiki/lib/exe/fetch.php?cache=cache\&media=bcd:ccr19hearingrtml200}\\ \underline{61108.pdf}\;.$

Appendix A

Suggested replacement text for the new Parameter and Layout section of BCD is attached in the following four pages.

5. Ring to Main Linac

Overview

The ILC Ring to Main Linac (RTML) is the collection of beamlines which transfer the beam from the damping ring to the main linac on each side of the collider. In addition to transporting the beam between these two regions, the RTML beamlines perform all the manipulations in the beam conditions which are required to match the parameters of the beam extracted from the damping ring to the parameters required of the beam injected into the main linac. The parameter matching includes:

- Collimation of beam halo generated in the damping ring
- Transformation of the beam polarization direction from the direction required in the damping ring (nominally vertical) to the direction required by experimenters at the IP
- compensation of the beam jitter introduced in the damping ring, during extraction from the damping ring, or during transport to the ends of the ILC site
- Compression of the bunch length from the equilibrium length of the damping ring to the shorter length required in the linac and at the IP.

In addition, the RTML must provide instrumentation and diagnostics sufficient to measure and control emittance growth, beam jitter amplification, spin dilution, and other beam quality reductions which would otherwise be introduced by the beamlines of the RTML; and the RTML must provide a set of dumps and stoppers which can stop the beam from entering downstream systems during beam tuning at upstream locations or during maintenance accesses at downstream locations. Last but not least, the RTML must be made as cost effective as possible within the constraints of achieving its technical goals.

Baseline

A baseline configuration for the RTML has been selected.

Description

Below is a description of the RTML, divided according to sub-beamlines in longitudinal ("S-position") order. Figure 1 shows an approximate topology of the layout of RTML and its beamline composision.

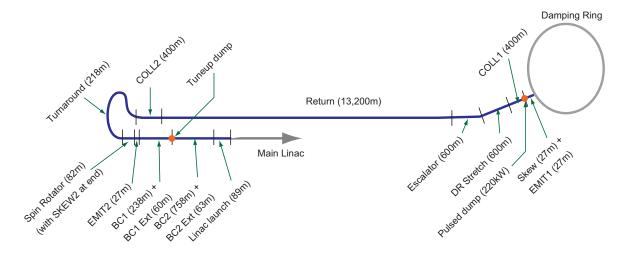


Figure 1: Approximate topology of the RTML layout and its beamline composision.

Skew Correction and Emittance Measurement

This beamline uses a set of four orthonormal skew quadrupole magnets to couple all four xy coupling terms in the beam matrix; this allows coupling introduced by the process of beam extraction from the damping ring to be corrected globally. The coupling correction section is followed by an emittance measurement station, which checks to make sure that the emittance correction is properly performed. The current baseline calls for a system which can measure only the projected horizontal and vertical emittances, and not the full beam matrix and the normal mode emittances and the coupling terms. The system for emittance measurement uses four laser wires driven by a common laser, with 45 degree phase advance between the wires in each plane. There is also a small chicane which separates the full-energy beam from the low-energy particles and photons produced by Compton scattering in the laser wire. At the end of this beamline there is a pulsed extraction system and a full-power (220 kW) dump which can be used to stop the beam from passing into the <u>collimation section</u> and other downstream areas. This stopper can be used when the beam extracted from the damping ring is being tuned up, when downstream systems are unprepared to receive beam, or duing Machine Protection System interrupts which occur within a single bunch train.

Transverse Collimation

This beamline uses a spoiler/absorber scheme to collimate halo particles which are generated in the damping ring. Collimation is 2 phases x 2 planes x 1 iteration, and both planes are nominally collimated at the same depth. The spoiler positions and apertures are adjustable; the absorbers may also need to be adjustable. The beam is sufficiently enlarged at the spoiler locations to prevent damage to the spoilers in the event of a direct hit from the beam core by a small number of bunches (requiring either that damping ring extraction

is halted after that number of bunches); the spoilers, in turn, enlarge the beam core to prevent damage to the absorbers from a direct hit from several bunches of the beam.

Damping Ring Stretch

This is a simple coasting beamline, the purpose of which is to make up the distance between the damping ring extraction and the Escalator Beamline (see below); the damping rings are fixed to be at or near the center of the ILC site, while the Escalator's longitudinal position is determined by the specific point at which the RTML beamline's entry into the linac tunnel is desired. The total length and composition of the DR Stretch is to be determined.

Escalator

This beamline consists of a vertical arc, a coasting FODO lattice at a shallow angle, and an additional vertical arc. The purpose of the Escalator is to transport the damped beam from the beamlines listed above, which are at the elevation of the DR housing, to the beamlines listed below, which share the main linac tunnel. Depending on the exact layout adopted for the ILC, there may also be some horizontal bending sections in the Escalator; however, all bend magnets will be either pure-vertical or pure-horizontal bends. The Escalator section also contains 3 stoppers with burn-through monitors which are part of the Personnel Protection System (PPS), and are used to ensure the safety of workers in the main linac when beam is present in the Skew Correction section.

Return Line

This beamline is a coasting FODO lattice which runs anti-parallel to the main linac in the same tunnel. Its purpose is to transport the beam from the escalator to the extreme upstream end of the ILC site, where it is turned around and transported forward again to the IP.

Transverse Collimation

This is an additional collimation system, which is needed to collimate beam halo particles generated in the Damping Ring Stretch, Escalator, and Return beamlines. Unlike the Transverse Collimation section near the DR extraction point, the Transverse collimation system which follows the Return line cannot be protected by the simple expedient of stopping damping ring extraction since it is too far away from the damping rings and therefore too many bunches are already in the RTML before extraction can be switched off. The second Tranverse Collimation system relies on the general ILC MPS, which uses pilot bunches and polling of correctors and other devices to ensure the safe passage of the beam through the ILC. The second Collimation section also contains the beam position monitors which are used for trajectory correction via feed-forward across the Turnaround.

Turnaround

This beamline reverses the direction of travel of the beam so that it is headed in the direction of the main linac. The purpose of the turnaround is to allow the bunch-by-bunch trajectory measurements to be fed forward over a shorter path length to the Trajectory Correction section. The turnaround will introduce emittance growth from synchrotron radiation:the baseline "cat-bone" style turnaround (with a 90 degree bend followed by a 262 degree reverse bend) limits emittance growth to about about 9% of the emittance at extraction from the damping ring. The turnaround also contains spoilers and absorbers for collimation of off-energy particles generated in the Return line or via multiple coulomb scattering from the collimators in the second collimation section.

Spin Rotator

This beamline uses 4 strong solenoid magnets to allow the beam polarization vector to be set to any orientation desired by the experimenters. The first half of the system contains two solenoids which are powered in series and separated by an Emma rotator (a beamline which performs a +I transformation in the horizontal plane and a -I in the vertical), to allow the polarization to be adjusted without introducing coupling from the solenoids. This is followed by an achromatic arc of approximately 8 degrees, which completes the turnaround of the beam trajectory; the arc is followed by another pair of solenoids separated by an Emma reflector. The combination of the two solenoid pairs and the bending system allows the polarization to be pointed in any direction required by the experimenters.

Trajectory Correction

This beamline is a simple FODO array with 2 horizontal intra-train dipole correctors separated by 90 degrees in betatron phase, and 2 vertical intra-train correctors with the same phase separation. Bunch-by-bunch trajectory information is measured in the upstream <u>collimation</u> h section, and fed forward to this location to correct the beam jitter generated in the damping ring and during extraction (i.e., by jitter in the extraction kicker amplitude or driven by quad vibrations in the Return line).

Emittance Measurement and Coupling Correction

This beamline uses a set of 4 laser wire profile monitors to make sure that the emittance correction is properly performed. The current baseline calls for a system which can measure only the projected vertical and horizontal emittances, but cannot measure the full beam matrix, the normal mode emittances, or the coupling terms. The emittance measurement station must be capable of measuring emittances during multibunch operation, using many bunches to measure the emittance within 1 train, and must also be

capable of measuring emittances during single-bunch operation, using many pulses (at 5 Hz) to complete one measurement. This section also contains a system with 4 skew quads, similar to the Skew Correction section described above, immediately upstream of the emittance measurement station. This is necessary due to the large number of betatron wavelengths between the initial Skew Correction Section and the Emittance station.

First Stage Bunch Compressor

The first stage bunch compressor is divided into the following subregions:

- An RF section which generates the necessary correlation between longitudinal position and energy. This section contains 24 9-cell RF cavities arranged in 3 cryomodules of 8 cavities each, based on the assumption that this is the cryomodule configuration which will be used for the ILC main linac. Because the bunch is long in this section, relatively strong focusing is used to limit the emittance growth from transverse wakefields: quad spacing is 1 quad per cryomodule, with 90 degree phase advance per cell in x and y. The cavities are phased near the zero-crossing (-100 degrees is typical), and require gradients of up to 18.4 MV/m. There are no spare modules in this section, but there is a spare klystron and modulator which can be connected to the cryomodules via an RF switch in the event that the BC1 klystron or modulator should fail.
- A wiggler based on 6 90 degree FODO cells with chicanes placed in the space between each pair of quads (12 chicanes total). Each chicane contains 8 bend magnets, with bends 1 and 8 in each chicane powered in series by one power supply and bends 2, 3, 4, 5, 6, and 7 each comprising an additional string of magnets (ie. The wiggler proper has a total of 7 bend strings). There are also 3 bends at the upstream end of the wiggler and 3 at the downstream end for dispersion matching; these 6 bends can all be powered in series from a single power supply. The wiggler also contains normal and skew quads for tuning the horizontal and vertical dispersion, instrumentation for measuring beam energy, and adjustable energy collimators which can tolerate being struck by several bunches without being damaged.
- A longitudinal diagnostics section, which permits measurement of the central energy, energy spread, arrival time, and bunch length. This section includes an approximately 35 cm-long dipole-mode RF structure ("crab cavity") which is room-temperature and operates at S-band. The structure is used as part of the bunch length diagnostic system.
- A short region which extracts the beam from the straight-ahead channel to a tune-up dump. This region is equipped with pulsed bends (which can driven by a DC power supply or else pulsed to take bunch trains out to the tune-up dump) and also with a set of kicker magnets (which can rise from zero to full strength in 100 nsec or less, which permits a subset of the train to be extracted).

Second Stage Bunch Compressor

The second stage bunch compressor is divided into the following subregions:

- An RF section that generates the necessary correlation between longitudinal position and energy. This section contains 384 9-cell RF cavities arranged in 48 cryomodules of 8 cavities each. There is 1 quad per 2 cryomodules and a phase advance of 60 degrees is used in each plane. Of the 48 cryomodules, 3 are spare and 45 must be accelerating the beam. The phase of the RF is between -22 degrees and -58 degrees depending on the exact configuration, and the maximum gradient required in the accelerating sections is 31.1 MV/m.
- A wiggler with optics identical to the wiggler in the first-stage bunch compressor, but with weaker bends. Also, the bends used for dispersion matching are longer than in the BC1 wiggler.
- A longitudinal diagnostics section, which permits measurement of the central energy, energy spread, arrival time, and bunch length. This section has one dipole mode structure which is identical to the one in BC1.

Launch into Main Linac

The launch into the main linac performs the final conditioning of the beam necessary for main linac injection. This region includes a station for the measurement of projected emittances. There is also an extraction line which permits DC extraction, train-by-train extraction (via pulsed bend magnets), or sub-train extraction (via kicker magnets with 100 nsec or less rise time), similar to the system at the end of BC1.

Parameter Tables

Beam Parameters

Parameter	Nominal Value	HighLumi Value	LongDRBunch Value		
init momentum	5 GeV/c				
init espread	0.15%				
init emit	$8 \mu m \times 20 nm$				
init x jitter	1.0 σ?				
init bunch length	6 mm	6 mm	9 mm		
final bunch length	0.3 mm	0.15 mm	0.3 mm		
final momentum	15.0 GeV/c	13.0 GeV/c	15.0 GeV/c		

final espread	1.1%	2.5%	1.6%	
final x jitter	0.1 σ?			
ISR emit growth	0.90 μm	0.74 μm	0.90 μm	
emit growth budget 1.0 μm ×4.0 nm?				

All system lengths and element counts are approximate pending development of lattice files describing the RTML baseline configuration.

Magnet Counts

Region	Bends	Quads	Sextupoles	Dipoles	Kickers	Solenoids	Septa
Skew Correction 1	0	16	0	18	0	0	0
Emittance 1	5	8	0	6	8	0	4
Collimation 1	0	12	0	18	0	0	0
DR Stretch	0	36	0	54	0	0	0
Escalator	16	34	0	51	0	0	0
Return	0	336	0	504	0	0	0
Collimation 2	0	12	0	18	0	0	0
Turnaround	116	66	0	99	0	0	0
Spin Rotator	6	45	0	67	0	4	0
Skew Correction 2	0	16	0	18	0	0	0
Emittance 2	0	15	0	22	4	0	0
BC1	103	29	0	27	8	0	0
BC1 Extraction	8	7		10	2		4
BC2	102	55	0	28	0	0	0
BC2 Extraction	10	9		13	2		6
Linac Launch	5	15	0	22	10	0	0
Total	371	711	0	975	34	4	14

1.3GHz RF Components in Bunch Compressors

Region	Cavities	Modules	Klystrons
BC1	24	3	1+1
BC2	384	48	16
Total	408	51	17+1

NC S-Band Dipole-Mode RF components (for diagnostics)

Region	Structures	Klystrons
BC1	1	1
Linac Launch	1	1
Total	2	TBD

Instrument Counts

Region	BPMs	Wires	BLMs	OTR Screens	Phase Monitors
Skew Correction 1	12	0	0	0	0
Emittance 1	8	4	0	0	0
Collimation 1	12	0	0	0	1
DR Stretch	36	0	0	0	0
Escalator	34	0	0	0	0
Return	336	0	0	0	0
Collimation 2	12	0	0	0	0
Turnaround	60	0	0	0	0
Spin Rotator	45	0	0	0	0
Emittance 2	15	4	0	0	0
BC1	27	0	1	1	1
BC1 Extract	6	0	0	1	0
BC2	52	0	0	0	0
BC2 Extract	9	0	0	1	0
Linac Launch	15	4	1	2	1
Total	679	12	2	5	3

System Lengths

Region	Length
Skew Correction 1	27 m
Emittance 1	27 m
Collimation 1	400 m
DR Stretch	600 m
Escalator	600 m
Return	13200 m
Collimation 2	400 m
Turnaround	218 m
Spin Rotator	82 m
Emittance 2	27 m
BC1	238 m
BC1 Ext	60 m
BC2	758 m
BC2 Ext	63 m
Linac Launch	89 m
Total	16789 m
Total excluding Extraction lines	16666 m
Length of Footprint	1263 m

Justification

The emittance measurement station immediately downstream of extraction is required because of the well-known sensitivity of the extracted beam emittance to beam position in the damping ring septum magnet. Only some form of emittance measurement system immediately following the extraction can be used to determine the optimum extraction orbit for emittance preservation. Since the beam is stopped just after the emittance section during access to the linac or other parts of the ILC, it is necessary to have an emittance diagnostic at this location which can operate during full power extraction from the ring and which is non-invasive, thus the complement of laser wires. The skew quads upstream of the emittance station are used to correct coupling from the DR extraction septum and are tuned by minimizing the projected emittance measured on the subsequent laser wire scanners as a function of skew quad settings.

During SLC operation, calculations of likely beam halo populations due to linac scattering processes did not explain the large observed beam halo, which was removed by collimators at the high-energy end of the SLAC linac. Because of the end-linac ILC beam parameters (energy, power, and emittance), it will be quite difficult to collimate the beam halo at the high-energy end of the linac. The risk of intense halo formation in the damping ring is mitigated with a relatively simple collimation section in the RTML, where the energy and beam power are relatively low and the geometric emittance relatively large. Because of the large scattering potential in the DR stretch, escalator, and return lines, an additional simple collimation system is required immediately upstream of the turnaround.

The intra-train jitter requirements for the extraction kicker are extremely tight (0.07% RMS), and represent a luminosity risk for the ILC. In addition, the tight vertical beam jitter requirement imposed at the IP by the strong disruption (0.05 sigmay) also represents a luminosity risk. The jitter measurement and feedforward permit that risk to be mitigated. The turnaround is required to delay the arrival of the beam sufficiently for the beam jitter data to be processed and the jitter correction to be applied to the magnets. It also permits the beam to be turned around from the "outbound" direction to the "inbound" direction, which is required to accommodate the central Damping Ring complex.

The polarization of the beam is rotated into the vertical to preserve it during storage in the damping ring. The polarization at the IP has to be completely adjustable and tunable, and the adjustment/tuning is not permitted to dilute the emittance. The most straightforward method identified is to use solenoidal spin rotators with the lattice properties described above to cancel out the emittance growth from xy coupling that the solenoids would otherwise generate. Since the solenoids rotate the polarization from vertical to horizontal, the 8 degree arc between the two solenoid pairs is required to rotate the polarization from horizontal to longitudinal; thus the first solenoid pair plus the arc puts the polarization in the longitudinal; if the first solenoid pair is turned off and the second pair is turned on, horizontal polarization is generated; if both solenoid pairs are turned off, the polarization remains oriented in the vertical.

Since the coupling correction of the paired solenoids is not likely to be perfect, the coupling correction and diagnostic lattices are required to globally correct any residual coupling. In principle a single set of skew quads might be acceptable to correct the coupling errors from the DR septum, the spin rotators, and all the coupling errors in between; in practice this is a very large number of betatron wavelengths, and recent studies have shown that positioning the skew quads immediately upstream of the wire scanners used to tune them (as opposed to 20-40 betatron wavelengths away) dramatically improves the convergence of coupling correction. For this reason we have elected to include two skew correction sections.

Bunch compression in the ILC is a necessity, given the opposing requirements of the damping ring (where long bunches are needed to limit collective effects) and the IP (where short bunches are needed to match the small values of betay which are mandated by the high luminosity goals). This compression is complicated by the large longitudinal emittance generated by the damping rings, which means that bunch compression leads to large energy spread after compression. Because of the energy spread, a single stage for compression from 6 mm to 0.3 mm RMS length was already marginal, and shorter bunches such as 0.15 mm RMS, which are required in the parameter tables, are not achievable in a single stage. The two-stage system works around this by accelerating the beam between stages of compression to limit the maximum fractional energy spread at any point in the ILC. The large and complex configuration of the wigglers is driven by the requirements of flexibility in the initial and final bunch lengths and by the requirements of dispersion tuning quadrupoles which do not introduce betatron mismatches or x-y coupling.

The final emittance measurement station is required to tune the emittance of the large energy spread beam generated by the compressor, prior to injection into the main linac. The collimation in the main linac launch is primarily machine protection segmentation: it ensures that a mistuned or mis-steered beam in the RTML will not result in a machine protection incident in the main linac. This segmentation is vital to simplify design of the active MPS.

Required R&D

The following R & D steps are required in order to produce a complete design for which the cost can be estimated:

- Tuning and tolerance studies (analytic and simulation). Since tuning studies are often fairly sensitive to the details of the simulation, it is necessary that this step be taken by at least two different people/groups working semi-independently. The exact effort required for this study is hard to estimate as nobody has yet made a serious attempt at studying the combined transverse and longitudinal tuning of any RTML lattice for any linear collider design. Since the RTML tuning is in a much less mature state than the main linac, unpleasant surprises are a possibility that can't be ruled out.
- Development of component and system tolerance specifications.
- Review of component and system tolerance specifications by qualified engineers.
 Depending on the outcome of this step, further iterations of the design, tuning, and tolerancing studies listed above may be required.

It is worthwhile to note that, compared to the other regions of the ILC, the RTML pushes the limits of technology in very few places. The electromagnets can easily be designed to fall within the limits of existing accelerator magnet technology; the RF components are duplicates of the main linac versions, and in fact are generally down-rated in their power and gradient requirements; the pulsed kickers for extraction of a runaway beam are based on similar technology to the system at the end of the main linac, and benefit from the much lower beam energy compared to the latter system; the bunch length monitors can be based upon very successful systems in use elsewhere for the measurement of much shorter bunches. The main technological issue for the RTML is likely to be the required RF system phase stability, which is on the order of 0.1 to 0.2 degrees of L-band. This phase stability must be maintained for a period which is long enough for a beam-based feedback to determine that an unacceptable phase change has occurred, as indicated by variation in the beam arrival times at the IP; thus, a stability period of a few seconds is probably sufficient.

Lattice Files

The lattice files for the baseline configuration will be made available at the ILC RTML wiki page as soon as they are prepared:

http://www.linearcollider.org/wiki/doku.php?id=rdr:rdr as:rtml lattice.

Alternatives

Description

Single Stage Bunch Compressor

Another possible cost savings would be to return to a single-stage bunch compressor similar to what was included in the TESLA design. Note that although the site length table implies a site savings of almost 1 km per side, this is partially compensated by the fact that the beam energy at the end of the RTML is reduced from around 15 GeV to 4.4 GeV, and thus the linac must be lengthened in this option; as a result the actual net savings is about 0.5 km per side, plus all 100 of the BC2 bends and about 30% of the BC2 quads and RF elements. Such an option can only be pursued if the emittance tuning strategies for the RTML and main linac can be shown to function reliably in the presence of an RMS energy spread in excess of 4%, and if the parameter sets assuming a longer bunch in the damping ring or a shorter bunch at the IP are eliminated. Because this change to the design would reduce the parameter reach of the ILC, the Low Emittance Transport working group at Snowmass 2005 does not favor pursuing this alternative.

Shorter Two Stage Bunch Compressor

At the Snowmass workshop of August 2005, a design for a two stage bunch compressor with short single chicanes in place of the wigglers used in the baseline. This design has compression capabilities comparable to the baseline design (ie, both the nominal 300 micrometer RMS bunch length and the shorter 150 micrometer RMS length can be achieved),

but uses a single chicane for each stage of compression, rather than the 12 chicanes used in the baseline design. This design eliminates about 190 bends per side from the total BC1/BC2 system, along with about 25 quads per side. The site-length savings is about 400 m per side relative to the baseline. Since this design eliminates the emittance-tuning features of the wiggler in the baseline, and eliminates the symmetries of design which make those features possible, there is a risk of unacceptable emittance dilution which must be studied. In particular, the tuning strategy and installation tolerances of the shorter system must be carefully reviewed. Because the shorter two-stage bunch compressor design has not been studied to the same degree as the longer design, it is the longer design which has been selected as the baseline. However, it is highly recommended that this alternative be studied, since a design does exist and since, if this design proves tractable from the point of view of emittance tuning, it would permit a significant cost savings without sacrificing performance or parameter reach.

Lattice files for the shorter two-stage bunch compressor can be found <u>here</u>.

Required R&D

If the RTML is to be built with a single-stage bunch compressor, more intense studies of emittance preservation in the presence of a larger RMS energy spread will be required. In addition, it will be necessary to verify that the damping ring can achieve its required stability stability with short (6 mm RMS) bunches, and to verify that IP conditions will be tolerable with long (0.3 mm RMS) bunches.

If the RTML is to be built with the shorter two-stage compressor, more intense studies of emittance preservation will be required, concentrating on the absence of dedicated dispersion tuning quadrupoles.

Appendix B

Subject: cost metric for CR#19

To: Nobu Toge From: Peter Garbincius

Date: Wed, 08 Nov 2006 08:31:08 -0600

Here is what I said at today's CR #19 CCB hearing: $CR \ \#19/(Vancouver \ RTML + RTML \ part \ of \ CR \ \#18) = 18\%$

Peter