EXTRACT from a

Summary of the S2 Task Force Meetings (accelerator module string test for the ILC) and Presentation of the S2 Task Force Report (complete talk see: xfel.desy.de/project_group 14/02/07)

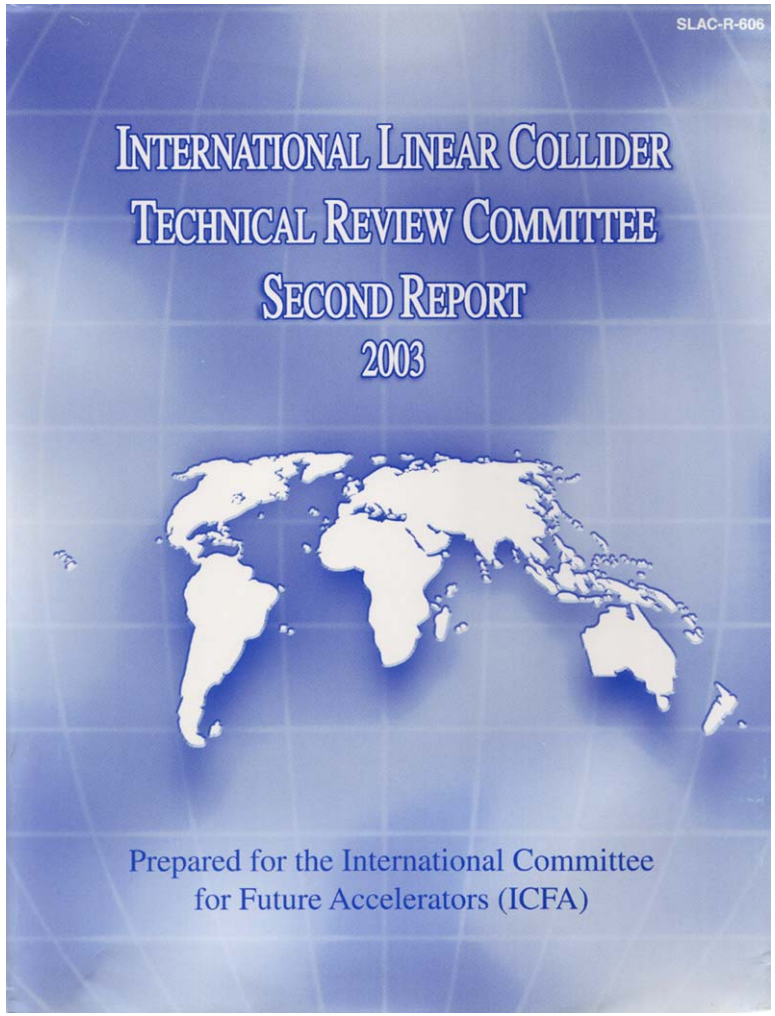
Hans Weise / 24.04.07

based on the S2 Task Force Report

presented by Tom Himel during the

Beijing GDR Meeting

Starting from the ILC-TRC Report 2003



TRC Working Group Members

Technology, RF Power & Energy Performance Group	Luminosity Performance Group
Daniel Boussard	**Gerry Dugan**
Adolphsen, Chris	Assmann, Ralph
Braun, Hans H.	Decking, Winfried
Chin, YongHo	Gareyte, Jacques
Edwards, Helen	Kozanecki, Witold
Hübner, Kurt	Kubo, Kiyoshi
Lilje, Lutz	Phinney, Nan
Logatchov, Pavel	Rogers, Joe
Pasquinelli, Ralph	Schulte, Daniel
Ross, Marc	Seryi, Andrei
Shintake, Tsumoru	Settles, Ronald
Toge, Nobu	Tenenbaum, Peter
Weise, Hans	Wolski, Andy
Wilson, Perry	Walker, Nick

R&D Mentioned in the ILC-TRC Report 2003

CHAPTER 9

Summary of R&D Work that Remains to Be Done for Individual Machines or Collectively for All Machines

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operating procedures.

ILC-TRC/Second Report 465

TRC Working Group Members

Technology, RF	Luminosity
Weise, Hans	Wolski, Andy
Wilson, Perry	Walker, Nick

Ranking 2: R&D needed to finalize design choices and ensure reliability of the machine

These R&D items should validate the design of the machine, in a broad sense. They address the anticipated difficulties in areas such as the architecture of the subsystems, beam physics and instabilities, and tolerances. A very important objective is also to examine the reliability and operability of the machine, given the very large number of components and their complexity.

R2 Issues

S2 Issues

ILC-TRC R2 Issues – TESLA *Energy*

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ILC-TRC 2003

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TESLA - *Energy*

• To finalize the design choices and evaluate reliability issues it is important to fully test the basic building block of the linac. For TESLA, this means **several cryomodules** installed in their future machine environment, with all auxiliaries running, like pumps, controls, *etc.* The test should as much as possible simulate **realistic machine operating conditions**, with the proposed **klystron**, **power distribution system** and with **beam**. The cavities must be equipped with their final HOM couplers, and their relative alignment must be shown to be within requirements. The cryomodules must be run at or above their nominal field for long enough periods to realistically evaluate their quench and breakdown rates. This Ranking 2 R&D requirement also applies to the upgrade. Here, the objectives and time scale are obviously much more difficult.

• …damping ring kicker…

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ILC-TRC R2 Issues – TESLA *Reliability*

CHAPTER 9

Summary of R&D Work that Remains to Be Done for Individual Machines or Collectively for All Machines

ILC-TRC 2003

TESLA – *Luminosity*

....

TESLA – *Reliability*

- The TESLA **single tunnel configuration appears to pose a significant reliability and operability risk** because of the possible frequency of required linac accesses and the impact of these accesses on other systems, particularly the damping rings. **TESLA needs a detailed analysis of the impact on operability resulting from a single tunnel.**

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Ranking 3: R&D needed before starting production of systems and components

These R&D items describe detailed studies needed to specify machine components before construction and to verify their adequacy with respect to beam parameters and operating procedures.

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S2 Task Force and its Charge

The **Global R&D board** set up the **S2 Task force** as one of several task forces, each assigned to develop a major part of the overall ILC R&D Plan.

Our charge was to determine the nature and size of system test(s) needed to validate ILC main linac technology. This includes the building and

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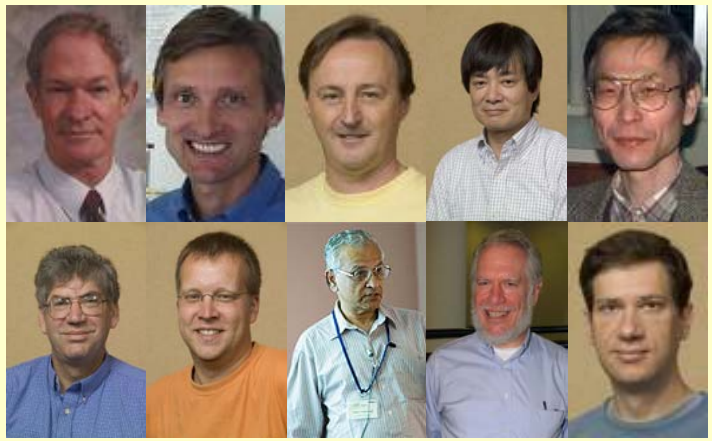
ILC Global R&D Board

Bill Willis, Chairman
Chris Damerell
Eckhard Elsen
Terry Garvey
Hitoshi Hayano
Toshiyasu Higo
Tom Himel
Lutz Lilje
Hasan Padamsee
Marc Ross
Andy Wolski



S2 Task Force Members

- **Hasan Padamsee (Co-Chair)**
- **Tom Himel (Co-Chair)**
- Bob Kephart
- Chris Adolphsen
- Hitoshi Hayano
- Nobu Toge
- Hans Weise

Consultants:

Sergei Nagaitsev
Nikolai Solyak
Lutz Lilje
Marc Ross
Daniel Schulte


Tom


Hasan


Bob


Chris


Hitoshi


Nobu


Hans


Sergei


Nikolay


Lutz


Marc


Daniel

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As the basic building block of the linac, the minimal string is one RF unit conta tially as in

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We v industrialization needs and planning for further system tests.

…proof of principle milestone of reliable production of...

Cavities	**S0**
Single cryomodules	**S1**

S2 Task Force Charge

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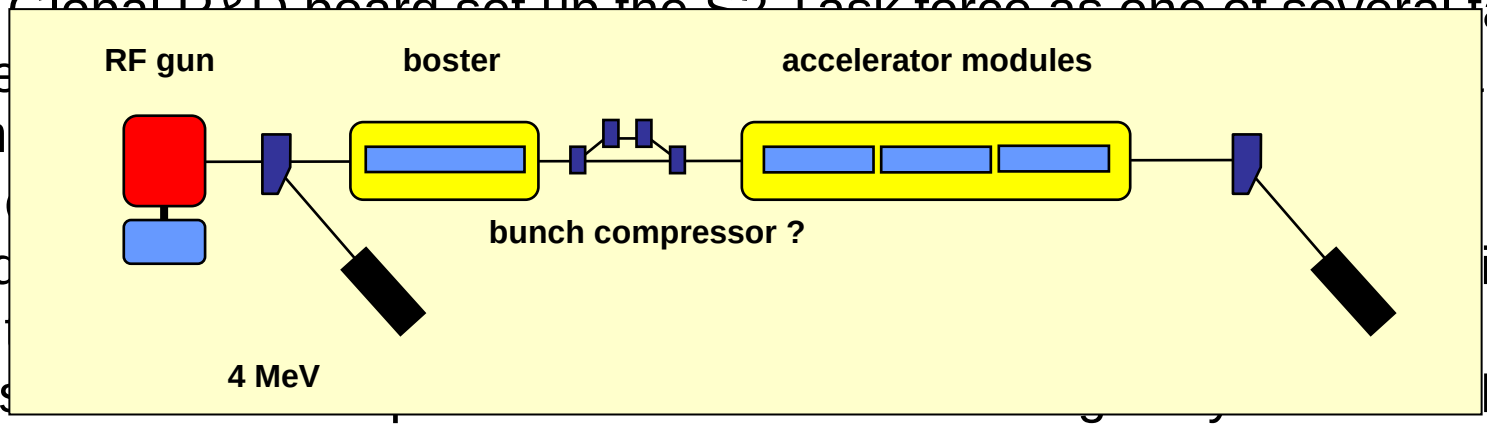

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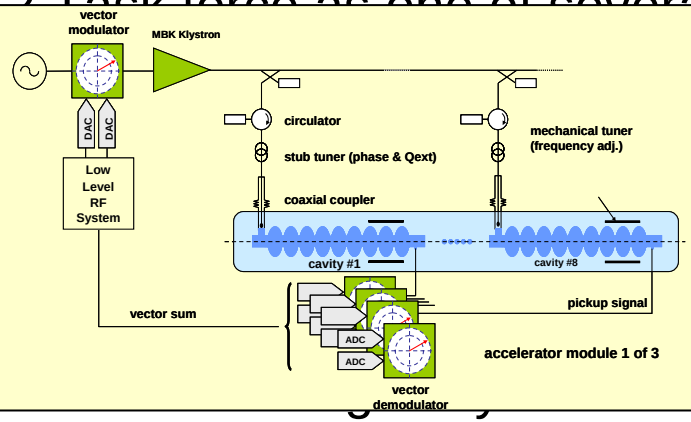

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General remarks on our work - methods and process

- Prepare a list of **reasons for doing system tests**. This list started with the R1-R4 items from the 2003 TRC report.
- Determine **how large a linac would be** needed for various beam and non beam related system tests.
- Understand **what components will be available** from the S0/S1 task force development of cavities and cryomodules. These components may be available “free” for use in a system test.
- **Look at how previous projects were industrialized** to give us an idea of how many cryomodules might be built as part of the industrialization effort. This could affect the size of a system test either by the need to test the industrial production or by having components available for “free” because they were produced as part of an industrialization plan.
- Look at **lessons learned from previous projects** as a guide to what system tests catch and miss and hence what we need.
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General lessons learned from operation of SRF accelerators

Different failures naturally require different types of precautions and counter-measures when it comes to technical specifics.

However, it appears fair to state that in order to maintain good, long-term operability of SRF-based accelerator systems:

- Accelerated tests should be done on components where possible. Examples are
  - **moving tuners** much more often than they would be moved in the ILC,
  - **rapid cool-down** of feedthroughs followed by tests for vacuum integrity,
  - **irradiating components**, and
  - **thermal cycling** a cryomodule pair to check for leaks and development of alignment problems. It is important to do these types of component tests in addition to the system tests.
- We should pay attention to long-term use of seemingly innocuous components in **realistic operating conditions**. We should not simply trust the catalog numbers.

XFEL, which is currently under construction, will offer critical operation experience from its daily operation as a major user facility. While the ILC cryomodule differs in important aspects from that of XFEL, the designs are still very similar and the lessons learned from XFEL will be important for the ILC.

Reasons for system tests

The S2 task force generated a **list of possible reasons for doing a system test**. The attempt here was to be complete. We have listed virtually all system tests we could think of. **It is not mandatory (or even reasonable) to do them all**. Some tests clearly demand too large a string to be practical. Others may need a more careful cost versus benefit of risk reduction analysis.

The tests fall into three broad categories:

1. Tests that are **too big to be practical**.
2. Tests that involve **statistical effects** where more is better and enough is too many to be practical.
3. Items that can be **fully tested**.

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Tests that are too big to be practical

Examples of this include:

- Checking that DFS steering really controls the emittance growth requires **well over 10 RF units.**
- A full check of cryogen flows and controls requires a **2.5 km string**. (Partial tests can be simulated with much less.)
- Checking that cavity misalignments don't cause emittance growth would require **200 RF units.**

Tests that involve statistical effects

We **cannot for-sure find all potential problems** in this category, but we can reduce the phase space. The larger the system test, the more likely we find a problem and the smaller the impact of an unfound problem will be. Examples of this include:

- **Checking reliability as good as required could require the full ILC** as some catastrophic but unlikely failure modes need to happen less than a few times in the total lifetime of the full ILC.
- **Measurements of dark current with a system test is problematic** as these depend on the random occurrence and location of field emitters. Note that a system test can be used to calibrate the effect of dark current on the radiation and heat load, but the statistical evaluation of the quantity of dark current is best done in the vertical test setups.
- **Long term testing of cryomodules** to evaluate degradation or other weaknesses before large scale series production begins. An example of this is the HOM failures in SNS caused by end wall heating due to field emission.

Items that can be fully tested

Examples of this include:

- Check what **gradient spread** can be **handled by the LLRF system**.
- Check for **heating due to high frequency HOMs**.
- Check **amplitude and phase stability of the RF** with respect to the beam.
- Check **static and dynamic heat loads**

Note that all of the tests in this third category can be done with a single RF unit.

It is primarily from this list of tests that we conclude the minimum size system test needed to confirm the performance of a new design is a single RF unit with ILC like beam.

As many tests are statistical in nature, a longer string test with several RF units or multiple tests with one RF unit would be better.

The statistical nature of some of the tests and the interaction of testing with industrialization (described in the next section) lead to the need for a larger second phase system test.

Possible system tests

Phase 0	test has already been mostly or completely done at existing facilities
1.x	relatively small test done as soon as we can manage it
2	larger test with industrially produced cryomodules
> 3	not practical to do or wait for the full XFEL or ILC
Probability	chance that the problem will occur and effect ILC if not performed
Consequence	gives the size of the problem

Table 3 List of poss … test. An "n" in that column in … tests should be done in. A … n manage it. (Dates are given i … icate tests that are not practical … mments" column typically incl … provide a crude estimate of the … fect the ILC if the test is not … sequence while having to run s … e, so a "large" probability does not necessarily mean close to 100%.

#	Description of test	# RF units needed	Must be in string?	phase	Need beam?	Comments	Proba-bility	Conse-quence	Risk
1	Test reliability of components. Of particular concern are components with long MTTR such as tuners, piezos, and couplers.	>1	n	0	n	With reasonable size test can catch major screw-ups, but can't assure we meet all MTBF goals.[12] Some items can be tested separately with accelerated tests. For example we may want to build specialized test setups for piezos and couplers and tuners to run them more often and stress them. TTF tests many items, but ILC has multiple design changes that require new tests.	large	large	large
2	Test beam based feedbacks. This may include steering, energy, and intra-train feedbacks.	1	y	0	y	Will be done at TTF and is gradient independent so further testing not essential. Tests with full ILC bunch train are needed. TTF will need MPS improvements to allow this for extended periods.	med	med	med

Possible system tests

#	Description of test	# RF units needed	Must be in string?	phase	Need beam?	Comments	Proba-bility	Conse-quence	Risk
3	Try a dirty vent on some cryomodules and see if things still work. This should be done both with and without a fast acting valve to see effects both of valve and of the dirty vent.	1	y	0	n	XFEL plans to test this. We should agree on a common design for the test so this XFEL test will also serve for the ILC. Tests need to go from small leaks to catastrophic ones, testing first for contamination (which would reduce gradient) and later for explosive failure of materials. This test is destructive.	small	large	med
4	Develop RF fault recognition and recovery software. Insure that adequate instrumentation is available to sense likely faults. (Coupler breakdowns, cavity quench, broken tuner motor, broken coupler motor, defective sensor…)	1	y	1.1	y	Much of this has been or is being done at TTF.	large	large	large
5	Evaluate cavity quench rates and coupler breakdowns along with the recovery times.	>1	n	1.2	y	This has been done at TTF, but not at ILC gradients hence it needs further testing. This can mostly be tested without beam, but interaction of LLRF and fields deposited by beam at various phase settings will require beam to study.	med	large	large

Possible system tests

#	Description of test	# RF units needed	Must be in string?	phase	Need beam?	Comments	Proba-bility	Conse-quence	Risk
6	Measure dark current (effects cryo load) including how much is accelerated and radiation (question for both electronics and people in tunnel with RF on).	1	y	1.2	n	Dark current increases a factor of 10 per 4 MeV. So if dark current is a problem, it can be solved by reducing the gradient. Most dark current issues will be explored with vertical, horizontal, and individual cryomodule tests. This gets the statistics needed on various locations of the emitters. The capture current is measured with a Faraday cup in those tests. Importance of the system test is to check the effect of captured dark current on cryo-load and radiation. Quads need to be tunable to high energy for this test so they will over-focus the dark current beam. TTF quads do not go to high enough field for this test. Effects may be simulated, but this experimental cross check would be nice.	med	med	med
7	Check what gradient spread can be handled by LLRF system. This test should be done with and without beam loading. Also test different phase with respect to beam for bunch compressors and deceleration.	1	y	1.2	y	This can be tested at TTF, but not with the full gradient or final hardware. If there are problems found here, they will either be fixed by a change in LLRF algorithms, or reduce the machine energy. It could affect the way we choose to sort the cavities by gradient into RF units.	large	small	med
8	Long term testing of cryomodules to evaluate degradation or other weaknesses before large scale series production begins	>1	n	1.2	n	SNS had HOM failures caused by end wall heating due to field emissions. TTF has seen no degradation. CEBAF saw degradation due to new field emitters. TTF is testing this, but ILC cryomodules will have significant differences in addition to the higher gradient.	large	large	large

Possible system tests

#	Description of test	# RF units needed	Must be in string?	phase	Need beam?	Comments	Proba-bility	Conse-quence	Risk
9	Check for heating from HOMs including in the absorber between the cavities. Also check static and dynamic heat loads.	1	y	1.2	y	Some HOM modes propagate down beam pipe, if not absorbed they correspond to 2 W/m of heating which is huge. Must check that inter CM absorbers work. TTF will test this in 2007. As ILC cavities have different spacing between cavities, HOM propagation will be different and the test must be repeated. **This test is the defining reason for providing beam in the string test.**	med	med	med
10	check beam phase and energy stability	1.5	y	1.2	y	This is mostly a test of the LLRF system. It requires energy and phase measurements of the ingoing and outgoing beam. The tightest phase specification is for the compressor. To test this properly will require 2 RF units. A reasonable test can be done with only 2 cryomodules and 2 klystrons and 2 LLRF systems. See the presentation at http://www.linearcollider.org/wiki/lib/exe/fetch.php?id=rdb%3Ardb_external%3Ardb_s2_home&cache=cache&media=rdb:rdb_external:nagaitsev_jan_12_2007.ppt	large	large	large
11	Measure x-ray emissions and evaluate adequacy of shielding for personnel protection before mass production of equipment	1	n	1.2	n	Can be done with smaller tests than a string test. Should still be verified in a string test as long as one is being done for other reasons.	small	small	small
12	Demonstrate to us and the world that we can make an RF unit to spec.	1		1.2	y	TTF has demonstrated this, but ILC has enough design changes that it needs to be demonstrated again. **For many people, this is the reason for a system test.**	med	large	large

Possible system tests

#	Description of test	# RF units needed	Must be in string?	phase	Need beam?	Comments	Proba-bility	Conse-quence	Risk
13	Does thermal cycling degrade a cryomodule (include alignment)	1	y	1.3	n	Dedicated test on two cryomodules (to test interconnects). Will be tested by XFEL if we don't change flanges and feedthroughs. Can test feedthroughs separately. Need to decide whether to use stretched wire or beam and HOM BPMs to measure alignment changes.	med	med	med
14	Check for cavity and quad vibration due to use of piezo tuners	0.33	n	1.3	n	This does not need a full system test. Check piezo with Horizontal test. It is unlikely to cause quad to move	small	small	small
15	Check for quad vibration with accelerometer or laser interferometer	0.33	y	1.3	n	This does not need a full system test. Better to check quad vibrations directly with accelerometer. This will change with different cryomodule designs. May be system issues that require full mockup (vacuum pumps, water pumps). Could measure how much it amplifies ground motion.	small	large	med
16	Provide an RF unit for LLRF tests for several years	1	y	1.3	y	Much can be tested at TTF, but need to stress the system which may not be allowed there. This work starts with phase 1.1 and finishes with phase 1.3.	large	large	large
17	Mock up actual tunnel layout to explore installation, maintenance, and repair issues prior to large scale construction of ILC,	2	y	1.4	n	TBD if this is done in a concrete tunnel or a plywood mockup. Can use components with problems left over from previous tests. Needs to be hooked up as though it will run, but does not need to operate. This could influence civil designs. It also makes a nice display to show dignitaries.	large	med	med
18	Show that we can internationally build this test system	1	y	2	n	Developing the required level of international cooperation to build and operate this test facility will be good practice for the full ILC.	med	large	large

Possible system tests

#	Description of test	# RF units needed	Must be in string?	phase	Need beam?	Comments	Proba-bility	Conse-quence	Risk
19	Evaluate performance of enough cryomodules reengineered for manufacturability and cost reduction to approve changes for mass production	??	n	2	n	Not doing this risks that a change thought to be minor results in major rework of machine elements. Must thoroughly test the final CM design.	med	large	large
20	Is cryomodule instrumentation (temperature and pressure measurements) adequate but not excessive (i.e. costly).	1	y	2	n	Likely that this can be sorted out without a string test	small	small	small
21	Provide a reason to build cryomodules that need to be built anyway to get industrialization going	>2	n	2	n	we may want large test facility to keep industrialization going while complicated project approval process plays out	med	med	med
22	test transport of cryomodules and mixing those of different regions	>2		2		Transport can be tested earlier without doing a full system test. XFEL will be testing transportability.	large	large	large
23	Check cryo control (maintain liquid levels, feedback time response etc.) and vibrations due to cryogen flows	2 to 4	y	4	n	XFEL will tell us this in 2012. TTF tests may already be adequate. Details of the size calculation for this are at http://www.linearcollider.org/wiki/lib/exe/fetch.php?cache=cache&media=rdb%3Ardb_external%3Astring_test_need_for_cryogenics_test.doc	small	small	small
24	Understand RF control issues in a system with many cavities and cryomodules distributed over a large physical space	>>1	y	4	y	Use long cables for phase reference between 2 RF units, but this could be done w/o RF units. See if there are any other reasons.	large	med	med

Possible system tests

#	Description of test	# RF units needed	Must be in string?	phase	Need beam?	Comments	Proba-bility	Conse-quence	Risk
25	Provide a test bed for evolving industrially produced cryomodules. Scale is set by preproduction that is ~10% of full scale ILC production per year and desire to test preproduction cryomodules before full production.	7-10?	n	5	n	Needs more thought. Probably not an S2 system test but rather a cryomodule test stand. Could be done by substitution of cryomodules in previous system test setups.	large	med	med
26	Check for emittance growth due to cavity misalignments	200	y	5	y	Beam wasn't accelerated in order to maximize sensitivity. Details of the size calculation for test and how the test would be done are at http://www.linearcollider.org/wiki/lib/exe/fetch.php?cache=cache&media=rdb%3Ardb_external%3Arequiredtestlinaclength-v6.ppt	small	small	small
27	Check for emittance growth before and after DFS steering	>10	y	5	y	10 RF units are marginal with RF gun and special purpose optics. Just 1-1 steering reduces emittance growth to less than we can measure. Details of the size calculation for this test are at http://www.linearcollider.org/wiki/lib/exe/fetch.php?cache=cache&media=rdb%3Ardb_external%3As2_21_july_2006_sergeinagaitsev.ppt	n/a	n/a	n/a
28	Check dispersion effects of following earth's curvature	>10	y	5	y	String needed is at least as long as one needed to check DFS steering.	small	small	small

Phase 2 system test

Possible change	vertical test	horizontal test	CM test stand?	MTBF Test ?	String test?	Beam Needed
Cavity shape	Y	Y	Y	N	Y	Y
Cavity Interconnect seals	Y	Y	Y	Y	N	N
cavity processing	Y	N	N	N	N	N
HOM	N	Y	Y	Y	Y	Y
instrumentation	N	M	Y	Y	M	M
cryogenic piping	N	N	M	N	Y	N
cavity mount	N	N	Y	N	Y	Y
slower tuner mechanics	N	Y	Y	Y	N	N
fast tuner piezo	N	Y	Y	Y	N	N
cold tuner moters	N	Y	Y	Y	N	N
tuner electronics	N	Y	Y	Y	N	N
main coupler	N	Y	Y	Y	N	N
RF cermanic feed thru	N	Y	Y	Y	Y	M
inst. Feed thru	N	N	Y	Y	N	N
Alignment scheme	N	N	Y	N	Y	Y
Quad location	N	N	Y	N	Y	Y
Quad mount	N	N	Y	N	Y	Y
radiation shield	N	N	Y	N	N	N
super insulation	N	N	Y	N	N	N
Vacuum Shell	N	N	Y	N	N	N
Assembly technique	N	Y	Y	N	N	N
Alignment scheme	N	N	Y	N	Y	Y
Quad location	N	N	Y	N	Y	Y
Quad mount	N	N	Y	N	Y	Y
radiation shield	N	N	Y	N	N	N
super insulation	N	N	Y	N	N	N
Vacuum Shell	N	N	Y	N	N	N
Assembly technique	N	Y	Y	N	N	N

List of tests that are needed after various types of design changes are made.

Schedule for completing the string tests

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

The schedule is technically limited by

- **the deliverables of the S0/S1 task forces**
- **and some constraints within the other R&D tasks**