Introduction to the US Linear Collider Technology Options Study

http://www.slac.stanford.edu/xorg/accelops/

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Paris

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Outline

- Introduction
- Accelerator system reference designs
- Design variants
- Availability design and simulation
- Civil construction and siting
- Cost and schedule estimates
- Risk assessment
- Conclusion

Introduction

- This study was carried out by of the United States Linear Collider Steering Group (USLCSG), which was established following a recommendation of the 2002 HEPAP Subpanel on Long Range Planning.

- To address certain items in its charge:
  - Provide an evaluation of options for building the linear collider involving factors such as scientific requirements, technical feasibility, risk, cost, initial facility parameters, upgradeability of alternate technologies, and the implications of different sites;
  - Prepare the elements of a U.S. bid to host the linear collider,

the USLCSG Executive Committee asked its Accelerator Subcommittee to carry out an evaluation of options for a US-sited linear collider.

LC Options Task Force membership and chronology

Task force members

Table 1.1.2.2: U.S. Linear Collider Option Evaluation Task Forces

Member	Institution
Accelerator Physics and Technology Design[a]	
Chris Adolphsen	Stanford Linear Accelerator Center
Gerald Dugan[b]	Cornell University
Helen Edwards	Fermi National Accelerator Laboratory
Mike Harrison	Brookhaven National Laboratory
Hasan Padamsee	Cornell University
Tor Raubenheimer	Stanford Linear Accelerator Center
Cost and Schedule	
David Burke[b]	Stanford Linear Accelerator Center
John Cornuelle	Stanford Linear Accelerator Center
David Finley	Fermi National Accelerator Laboratory
Warren Funk	Thomas Jefferson National Accelerator Facility
Peter Garbincius	Fermi National Accelerator Laboratory
Mike Harrison	Brookhaven National Laboratory
Steve Holmes	Fermi National Accelerator Laboratory
Ray Larsen	Stanford Linear Accelerator Center
Theodore Lavine	Stanford Linear Accelerator Center
Cindy Lowe	Stanford Linear Accelerator Center
Tom Markiewicz	Stanford Linear Accelerator Center
Hasan Padamsee	Cornell University
Brett Parker	Brookhaven National Laboratory
Kem Robinson	Lawrence Berkeley National Laboratory
John Sheppard	Stanford Linear Accelerator Center
Russ Wells	Lawrence Berkeley National Laboratory
Andy Wolski	Lawrence Berkeley National Laboratory
Siting and Civil Construction	
David Burke	Stanford Linear Accelerator Center
Clay Corvin	Stanford Linear Accelerator Center
David Finley	Fermi National Accelerator Laboratory
Steve Holmes[b]	Fermi National Accelerator Laboratory
Vic Kuchler	Fermi National Accelerator Laboratory
Marc Ross	Stanford Linear Accelerator Center
Availability Design and Specification	
Paul Czarapata	Fermi National Accelerator Laboratory
Helen Edwards	Fermi National Accelerator Laboratory
Tom Himel[b]	Stanford Linear Accelerator Center
Marcus Huening	Fermi National Accelerator Laboratory
Nan Phinney	Stanford Linear Accelerator Center
Marc Ross	Stanford Linear Accelerator Center

- USLCSG Charge: Jan 2003
- Task force meetings

Meeting Date	Location
April 14, 2003	Fermi National Accelerator Laboratory
June 15-16, 2003	Stanford Linear Accelerator Center
August 27-28, 2003	Fermi National Accelerator Laboratory
October 13-14, 2003	Fermi National Accelerator Laboratory

- Report writing/editing: Oct-Dec 2003
- Discussions with USLCSG, and at DESY and KEK: Dec. 2003-Feb. 2004
- Release: March 2004

Accelerator System Reference Designs

- Two options were developed: a warm option, following the design of the GLC/NLC Collaboration, and a cold option, similar to the TESLA design at DESY.

- Both options have been developed and evaluated in concert, using, as much as possible, similar approaches in technical design for similar accelerator systems, and a common approach to cost and schedule estimation methodology, and to risk/reliability assessments.

- For each option, the accelerator design task force has prepared a reference design configuration description. The reference designs for both options satisfy the physics-based machine requirements specified in the USLCSG Scope Document prepared by the American Linear Collider Physics Group (ALCPG).

USLCSG/ALCPG Key Physics Requirements

- initial energy E_{cm} = 500 GeV
- upgrade energy: at least E_{cm} = 1000 GeV
- integrated luminosity 500 fb^{-1} in the first 4 years of physics running, corresponding to a design luminosity of 2×10^{34} $cm^{-2}s^{-1}$
- electron beam polarization 80%
- an upgrade option for positron polarization
- crossing angle at the collision point
- site consistent with two interaction regions, with one capable of γ-γ and e^--γ collisions

These requirements are consistent with those specified by the Parameters Subcommittee of the International Linear Collider Steering Committee.

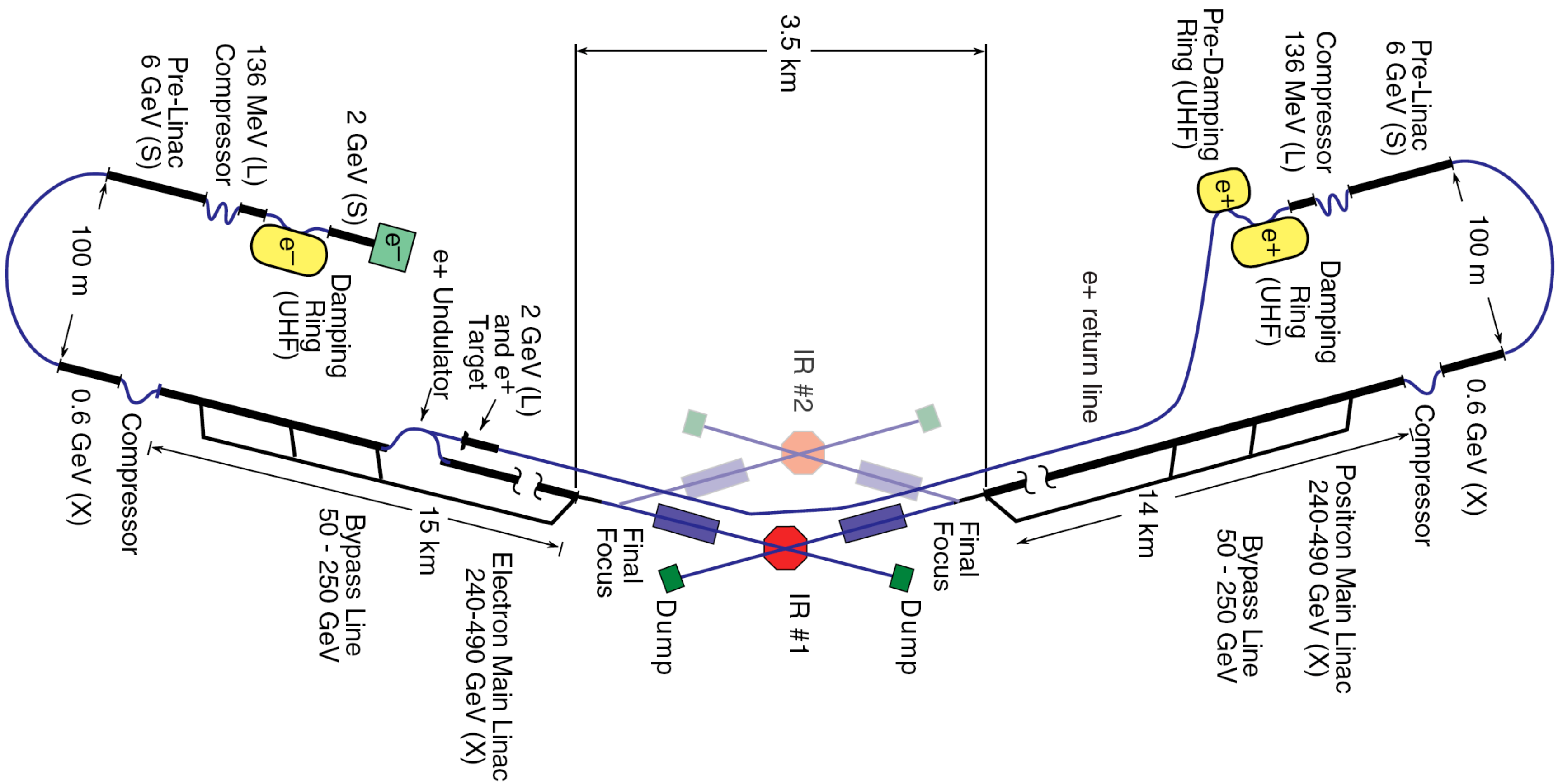
Accelerator Systems Reference Designs

In order to facilitate the comparison between the two linear collider technology options, the designs have been crafted with as much commonality as possible. Thus, both designs

- use an undulator-based positron source, capable of being upgraded to provide polarized positrons, driven by a 150 GeV electron beam
- have almost identical beam delivery systems and IR configurations;
- have the same initial stage energy reach, up to about 625 GeV;
- are upgradeable to 1 TeV without additional underground construction;
- require no change to the injector parameters for the upgrade to 1 TeV.

X-band Reference Design

X-band reference = 2003 NLC configuration with undulator e+ source

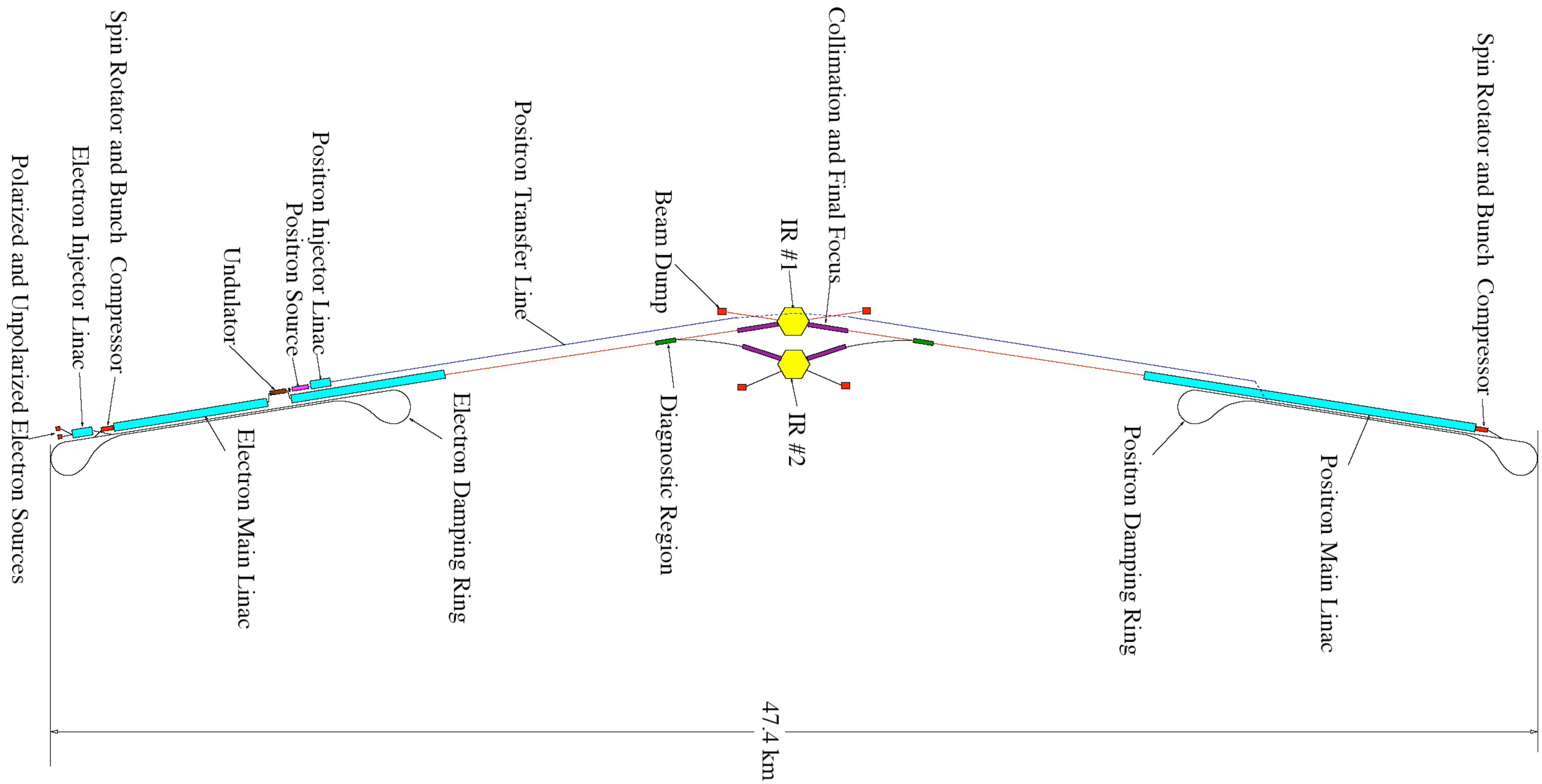


L-band Reference Design

- The L-band reference design follows, for the most part, the design outlined in the TESLA TDR. Major changes made to the TESLA design are:
  - An increase in the upgrade energy to 1 TeV (c.m.), with a tunnel of sufficient length to accommodate this in the initial reference design, assuming a gradient of 35 MV/m.
  - Improvements to the wigglers and vacuum systems of the damping rings,
  - The choice of 28 MV/m as the main linac design gradient for the 500 GeV (c.m.) machine.
  - The use of a two-parallel-tunnel architecture for the linac facilities.
  - NLC-style beam delivery system and IP configuration.
  - Vertical emittance at the IP = 40 nm-rad, vs. 30 nm-rad in the TESLA TDR. This change reflects recent simulations both in the U.S. and Europe, which indicate larger emittance growth in the cold main linacs than originally anticipated.

USLCSG

L-band Reference Design



Comparison of reference design key parameters

Warm option upgrade energy reach is 30% higher than warm

500 GeV cold linacs are x2 longer than warm linacs

Cold option $\mathcal{L}$ is 25% higher than warm

Baseline cold option AC power is 30% less than warm

Parameter	**X**	**L**	**X**	**L**
C. M. Energy/Energy Reach [TeV]	0.5/0.625	0.5/0.625	1/1.3	1/1
Loaded rf gradient [MV/m]	52	28	52	35
2-linac total length [km]	13.4	27.0	26.8	42.5
$\gamma\varepsilon_x$(IP) [μm-rad]	3.6	9.6	3.6	9.6
$\gamma\varepsilon_y$(IP) [μm-rad]	0.04	0.04	0.04	0.04
$\mathcal{L}_g$ [10^{33}cm^{-2}s^{-1}]	14.2	14.5	22.2	22.7
D_y	12.9	22.0	10.1	17.3
H_D	1.46	1.77	1.41	1.68
$\mathcal{L}$[10^{33}cm^{-2}s^{-1}]	20.8	25.6	31.3	38.1
Number of main linac klystrons	4520	603	8984	1211
Number of main linac RF structures	18080	18096	35936	29064
Peak RF power per structure [MW]	56	0.28	56	0.35
Average power per beam [MW]	6.9	11.3	13.8	22.6
Linac AC to beam efficiency [%]	6.6	17.0	7.1	15.3
Site Operating AC power [MW]	260	179	454	356

Design variants

Five design variants were considered, which could offer the possibility of cost reduction or performance enhancement relative to the reference design.

Variant	Impact evaluation
–Single Tunnel (cold only)	Cost, availability
–Conventional positron source (warm & cold)	Cost/schedule, availability
–35 MV/m as initial gradient (cold)	Cost
–Cavity superstructures (cold)	Cost
–DLDS pulse compression (warm)	Cost

Cost/schedule and availability impacts will be discussed in subsequent slides

Availability design and simulation

- Goal:
  - establish top-level availability requirements for the collider, allocate these requirements down to major collider systems, and investigate feasibility
- Method:
  - Based on data from existing machines, budget a set of MTBFs, MTTRs that give a reasonable overall availability. The budgeted MTBFs, MTTR's were required to give 15% downtime.
  - Write a simulation that, given the MTBFs, MTTRs, numbers and redundancies of components, and access requirements for repair, can calculate average availability and the integrated luminosity per year.
  - The linacs and DRs were modeled in detail down to the level of magnets, power supplies, power supply controllers, vacuum valves, BPMs …But, due to time constraints, other regions were simulated as monolithic units.

- More details in talk by N. Phinney tomorrow morning at 9:10 am in Auditorium Poincare

Availability design and simulation

Results

- Using nominal present day MTBF's for components in the main linacs and DR's, neither option's reference design can realize the unavailability goal of 15%.
- To achieve the 15% unavailability goal, the MTBF's of component in the DR's and main linacs needed to be improved by a factor of about 4.
- For both options, a crude estimate of the cost associated with this reliability upgrade is about 2% of the total project cost.

Availability design and simulation-design variants

Cold Option-1, tunnel:

- With the improved MTBF's, the cold 1 tunnel simulation gives a downtime of 25%, vs. 15% for the 2 tunnel case. To regain 15% downtime, the linac and DR component MTBF's must be further improved by a factor of 3, and the energy overhead increased to 8%. A crude estimate of the cost of this reliability upgrade is about 3% of the total project cost.

Convention vs Undulator e+ Source:

- Undulator e+ source has much more downtime especially during commission period. The availability model indicates that over a few year running period, the annual integrated luminosity could be 18% lower for an undulator positron source as compared to a conventional one. During commissioning, it would be far worse--up to a factor of two.
- Completely due to undulator source needing well tuned high energy electrons.

Civil Construction and Siting

- Two representative U.S. sites studied:
  - One in Illinois, one in California
  - Two designs per site: L-band and X-band
  - Civil design criteria in all instances are based on the requirements described in the reference design configurations.
  - Cost estimates used average of CA and IL costs.

- Primary distinguishing features between the cold and warm designs are:
  - Facility footprint: cold/warm = 46/34 km (cold is 35% longer)
  - Cryogenic infrastructure for the cold linac
- Both designs are based on two parallel tunnels bored through hard rock.
  - One tunnel accommodates the linac and the second houses support equipment. This configuration leads to minimal surface presence over the extended length of the linac in the two machines

- In both cases two interaction regions are provided along with a campus with support buildings.

Cost and schedule estimates-Goals and strategy

- Provide a comparison of the costs of facilities built according to the warm and cold reference designs given by the Accelerator Design Task Force.
  - "Provide", not "Make". We did not set out to make new estimates for either technology, but to provide a level comparison of the two options.
  - We used, but did not verify, cost estimates made by the TESLA and NLC/GLC Collaborations – particularly for the purchase price of main linac components.
  - Extrapolations in unit costs from present-day R&D to the high-volumes needed to build the collider are a source of risk in the cost estimates. Extrapolations of up to factors of three to five were made for the components of the cold cryomodules, and as high as six for some of the warm copper components. The overall extrapolation is somewhat larger for the warm technology because of the larger number of small repetitive components involved.
  - Cold damping ring re-estimated by LBNL to account for changes in specifications (wigglers, vacuum systems, magnet support systems)
  - Comparison based on a U.S. Total Project Cost (TPC), but omitting land, detectors, escalation, and contingency.
  - Beam delivery costs, and many "common" costs, set equal for warm and cold.

Cost and schedule estimates

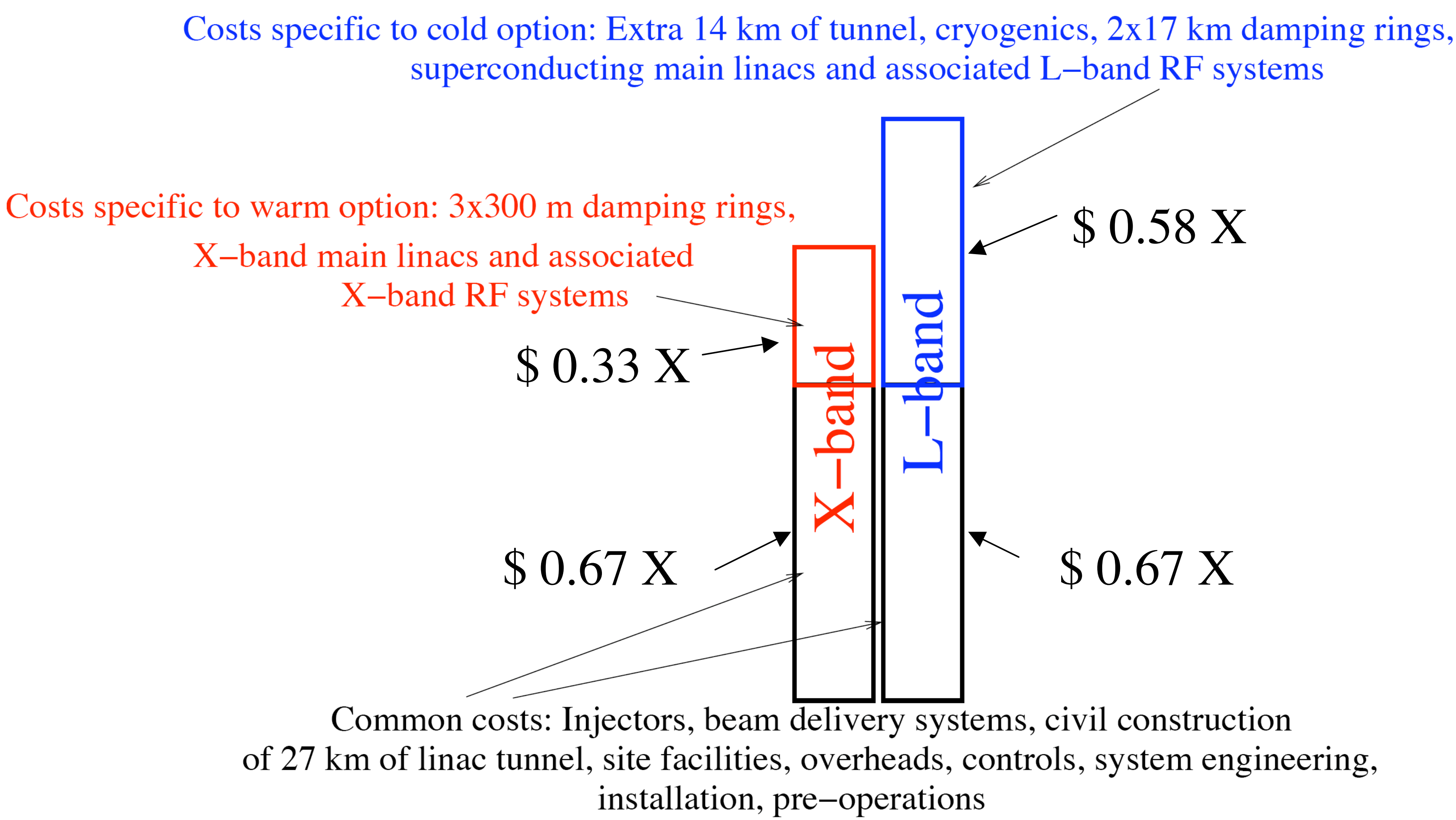
Sources of information:

NLC and JLC Collaboration Cost Estimates, TESLA Cost Estimates (TESLA TDR and information from visits), FNAL Analysis of TESLA Cost Estimates

Cost Comparisons

- The major differences in the estimated costs between colliders built with the cold and warm technologies can be traced to the lower gradient of the cold accelerator technology, requiring a longer linac and tunnels, and the longer bunch train used with the cold technology, which requires a more extensive damping ring.
- We do not present absolute costs in this study, only relative cost ratios between the two options.

Cost and schedule estimates-Cost comparisons



Cost and schedule estimates-Cost comparisons

- The estimated total project cost for the cold machine is 25% ± 10% greater than for the warm machine:

  (\$ cold-\$ warm)/(\$ warm) = 0.25±0.10.

- The quoted uncertainty assumes a ±15% (rms) (35% FWHM range) uncertainty in the specific costs, and ignores correlations within those costs.
- The 1 TeV upgrade will cost approximately the same amount for either option. The actual cost will depend significantly on when it is done.

Cost and schedule estimates-Project Schedule

- Created "storyboard" project schedules for each reference design and the conventional e^+ source variant. The schedules in these storyboards were "technology limited" with budget constraints essentially ignored.
- Milestone targets were set as follows:

2004	Technology recommendation, and formation of international project team.
2005	Start of work on international proposal (CDR).
2007	Completion of international engineering design (TDR).
2008	International project agreements and site selection.
2009	Start of on-site construction.
2015	End of construction.

- We found that, provided appropriate funding during construction, the time needed to build and commission a collider can be independent of the choice of linac technology

Cost and schedule estimates-design variants

Variant	Technology	Cost Impact (% of TPC)	Schedule Impact
Single Tunnel	Cold	Reduction of 2%	Lengthen
35 MV/m	Cold	Reduction of 3%	None
Superstructure	Cold	Reduction of 3%	None
DLDS	Warm	Reduction of 8%	None
Conventional e^+	Both	None	Shorten

- **Single tunnel:** Cost reduction of 5 % for civil construction offset by estimated cost increase of 3% to achieve needed reliability.

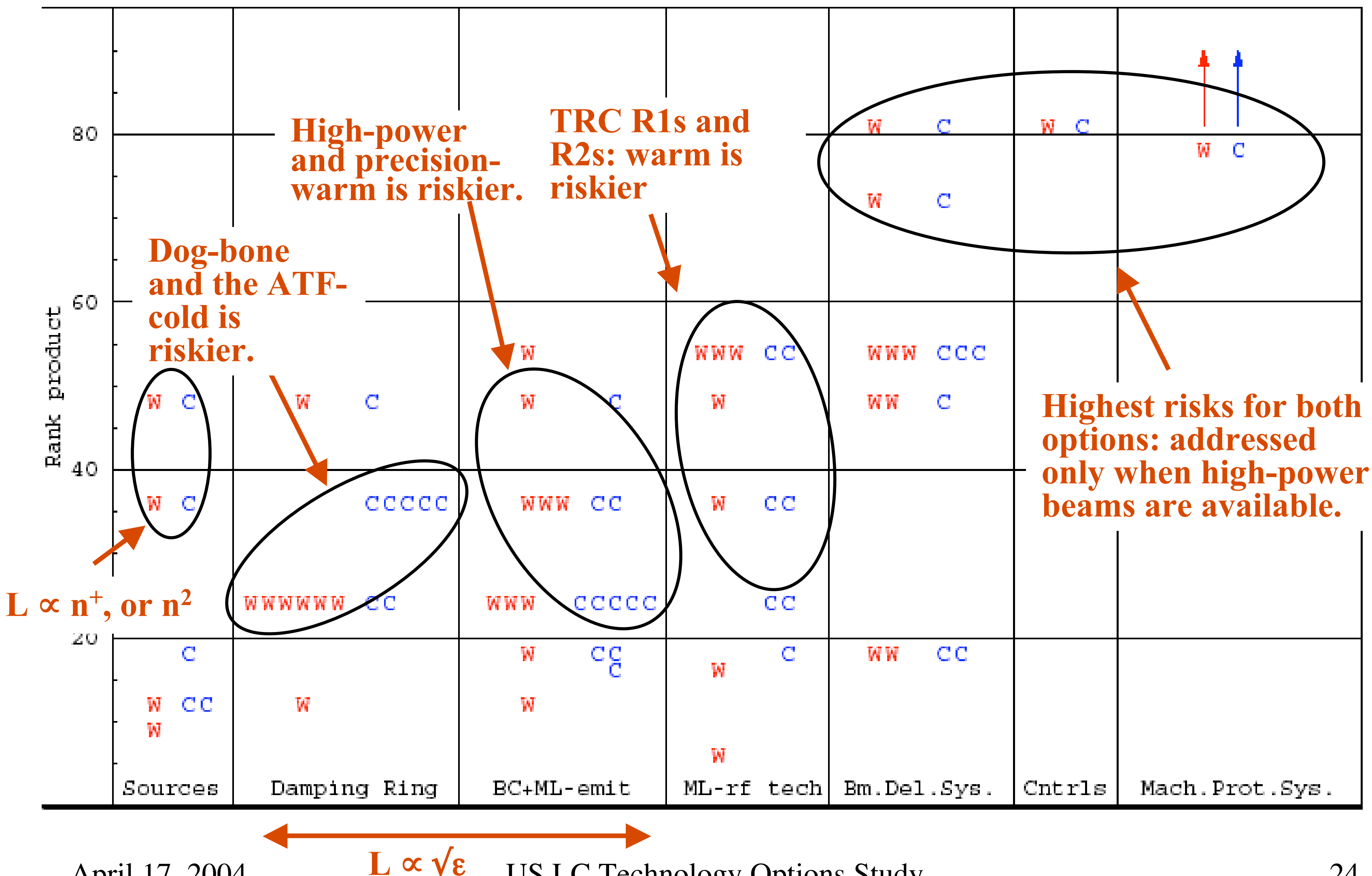
- **Conventional e^+ (both options):** No cost impact if the initial conventional e+ source configuration includes the space required in the linac to later install the components of the undulator-based source and the tunnel needed for the positron transfer line.

Risk Assessment Process

1. Define the Project Mission (ALCPG Physics requirements)
   – Construct a collider with initial cms energy 500 GeV that can be upgraded later to 1 TeV, deliver 500 fb^{-1} integrated luminosity within the first 4 years of physics running, and run concurrently with the LHC.
2. Identify and analyze important ways the Project could fail to achieve its Mission.
   – A Risk Assessment Task Force, comprised of people from each of the other Task Forces, identified 42 potential failures that pose significant threat to the Project Mission.
3. Assess the risks. Four factors make up our definition of the risk posed by a potential failure:
   - The source or reason for a potential failure.
   - The severity of the failure as characterized by its impact on the project mission goals.
   - When in the course of the linear collider project the failure will occur or become apparent.
   - The consequence of the failure characterized by what would have to be done to overcome it.
4. For each of these factors we established a Description and numerical Ranking. Each of the 42 risks was assigned a Rank for each factor, according to the Description that fit best.

•Details presented in a talk tomorrow at 8:50 am in Auditorium Poincare

Risk Assessment Rank Product Summary



Conclusions

• The two technology options examined in this study have different challenges, advantages, and disadvantages, and differ in many details.

• We found that, within relative factors of 30% or less, the two approaches would provide similar technical performance at roughly equivalent cost.

• The two options can have similar levels of availability, with comparable overall levels of risk, and can be realized on roughly the same schedule.

• These two options are at comparable levels of development, and both have the potential to provide a viable route to a linear collider which meets the requirements of the USLCSG.