The International Linear Collider Accelerator R&D Program

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Outline

At your prior meetings you've heard about the fantastic scientific opportunities of afforded by the ILC...

My Charge: **IS THIS THING GOING TO WORK?**
(and what's it going to take to get there?)

Outline

- ILC Orientation
- Technology Requirements and Challenges
- Risk Elements
- R&D Program
- Fermilab Perspective

ILC Orientation
What is it?

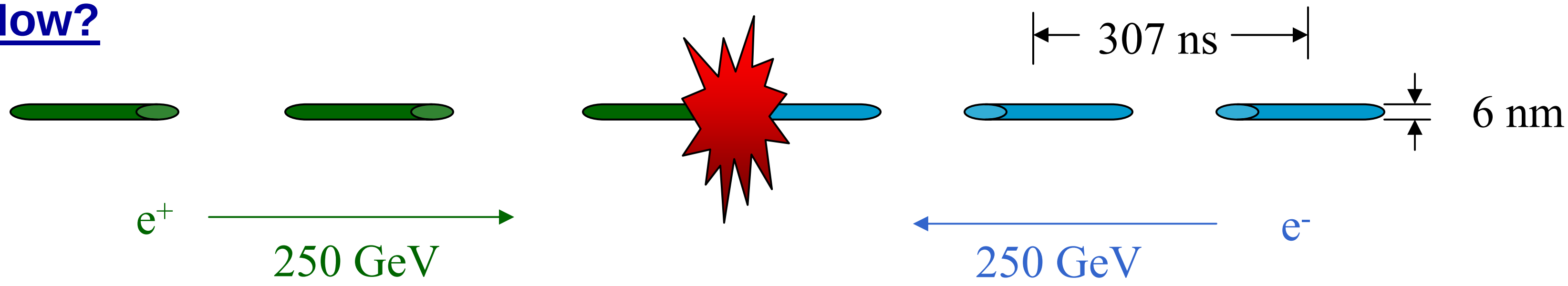
A facility for providing electron-positron collisions at an energy and luminosity sufficient to access to the physics frontier.

Performance Requirements

- **Energy: 500 GeV, extendable to 1000 GeV**
- **Luminosity: 500 fb^{-1} in first four years operations**

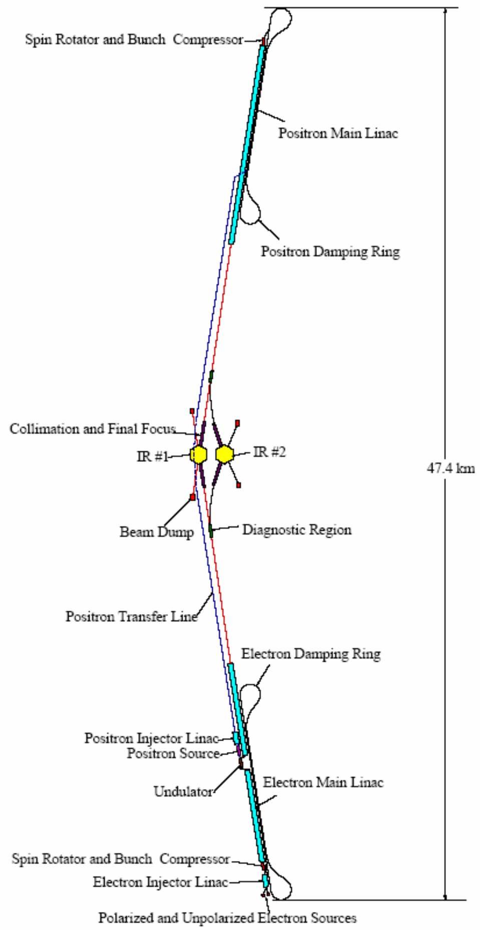
  (Luminosity is a measure of the rate at which e^+e^- collisions happen. It is related to the beam density and measured in fb^{-1}/year.)

How?



ILC Orientation

What does it look like?



Major Components:

- **Sources**: Provide electrons and positrons
  (e+ generated by electrons)
- **Damping Rings**: Reduce inherent beam dimensions ("emittance")
- **Bunch Compressors**: Reduce bunch length
- **Linac**: Accelerate
- **Beam Delivery/Final Focus**: Prepare, focus, and collide
- **Detector(s):** Observe

Length = 40-50 km

ILC Orientation
International/National Scene

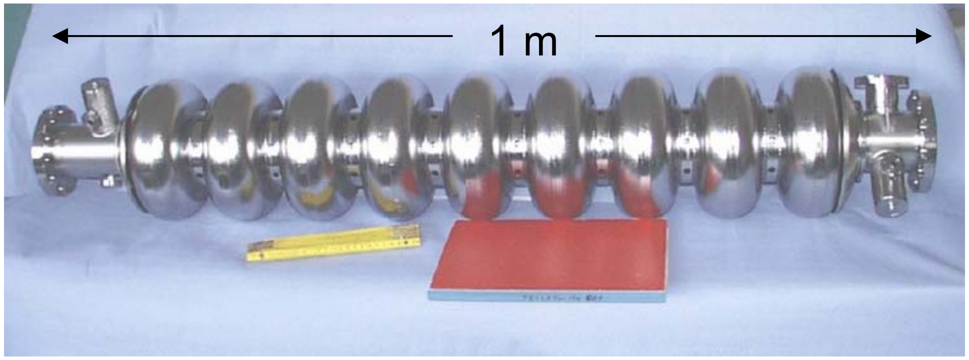
- International Linear Collider Steering Committee (ILCSC) established
  - Under auspices of ICFA
  - Charge: Promote construction of a linear collider through world-wide collaboration
  - International Performance Requirements document released
  - Technology decision made
  - Global Design Effort (GDE) established: B. Barish/Director
- US Linear Collider Steering Group (USLCSG) established
  - Charge: Coordination of U.S. R&D activities;
  - Preparation of the U.S. bid to host

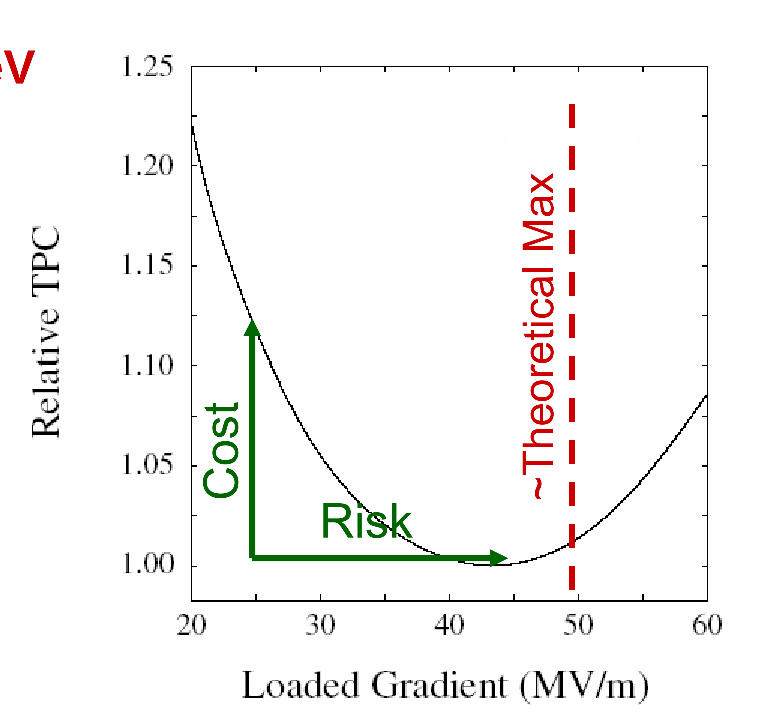
ILC Requirements and Challenges
Example Parameter Set

Center of Mass Energy	500	1000	GeV
Design Luminosity	2	3	$10^{34}cm^{-2}sec^{-1}$
Linac rf frequency	1.3		GHz
Accelerating gradient	30		MV/m
Pulse repetition rate	5		Hz
Bunches/pulse	2820		
Bunch separation	307		nsec
Particles/bunch	2		$x10^{10}$
Bunch train length	866		μsec
Beam power	11	23	MW/beam
σ_x/σ_y at IP	655/6	554/4	nm
Length of linac	24	48	km
Site AC power	180	356	MW

ILC Requirements and Challenges
Energy: 500 GeV, upgradeable to 1000 GeV

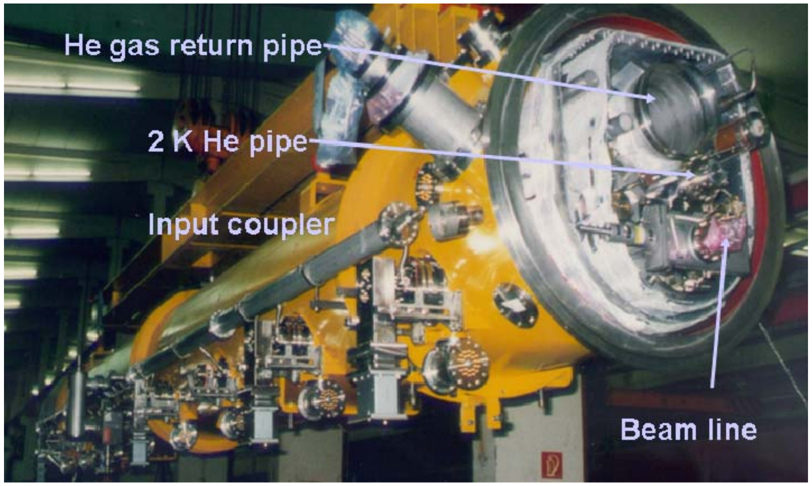
- Radio Frequency (RF) Accelerating Structures
  - Accelerating structures must support the desired gradient in an operational setting and there must be a cost effective means of fabrication.
  - **~17,000 accelerating cavities/500 GeV**
  - Current performance goal is 35 MV/m, (operating at 30 MV/m)





ILC Requirements and Challenges
Energy: 500 GeV, upgradeable to 1000 GeV

- Accelerating Structure Status
  - All high gradient superconducting cavities produced to date have been fabricated by European industry and tested by the TESLA collaboration.
    - Roughly 80-100 cavities
    - Five 8-cavity cryomodules in operation at the TESLA Test Facility (TTF) at DESY (Hamburg): @~23 MV/m
  - Six nine-cell cavities have tested successfully at >35 MV/m
    - Several single cell cavities at >40 MV/m (alternative shapes)
  - European X-FEL (4th generation light source) design goal of 28 MV/m
    - ~1000 cavities fabricated over 2006-2011



ILC Requirements and Challenges
Energy: 500 GeV, upgradeable to 1000 GeV

- RF power generation and delivery (klystrons and modulators)
  - The rf generation and distribution system must be capable of delivering the power required to sustain the design gradient:
  - The rf distribution system is relatively simple, with each klystron powering ~30 cavities.
- Status
  - Klystrons under development by three vendors (in Europe, Japan, and U.S.)
  - (Low cost) alternative under development at SLAC ("sheet beam")
  - Modulators meeting performance spec have been built and operated for the last decade.

ILC Requirements and Challenges

Luminosity: 500 fb^{-1} over four years

To produce the desired luminosity the specified beam densities must be produced within the injector system, preserved through the linac, and maintained in collision at the interaction region (IR).

$$L = \frac{f_{rep} n_b N^2}{4\pi \sigma_H \sigma_V} H_D \propto \frac{P_b}{E_{CM} \sigma_V} \sqrt{\delta_b \sigma_s} H_D$$

Beam Power (P_b)

Vertical Beam Size (σ_V)

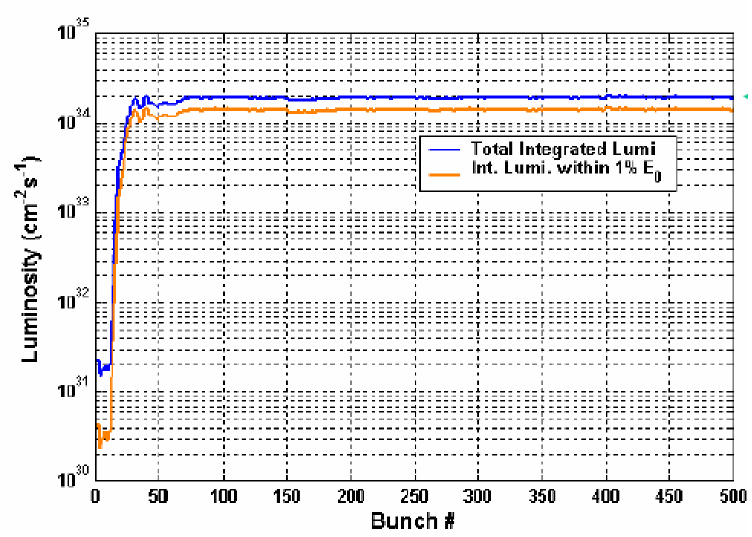
Requirements

- Sources
  - 2 × 10^{10} particles/bunch × 2820 bunches × 5 Hz
- Damping Rings
  - Emittance = 8.0 ×.02 μm^2
- Linac beam dimension growth allowance:
  - × 1.2 (horizontal); × 2 (vertical)
- Maintaining beams in collision
  - $\sigma_x \sigma_y$ = 655 × 6 nm^2

ILC Requirements and Challenges

Luminosity: 500 fb^{-1} over four years

- The required emittances have been achieved in a prototype damping ring at KEK. However:
  - Circumference = 138 m (vs. 6-17 km required for superconducting ILC)
- Control of beam dimension growth in linac requires:
  - Component alignment, stability tolerances of ~300 μm, 300 μrad; plus dynamic alignment control.
- Collision Challenges:
  - Beam size
    - ➢ Final Final Focus Test Beam (SLAC) achieved required de-magnification, but $\times$10 beam size
  - Maintaining collisions
    - ➢ Feedback required



ILC Risk Elements
Technical Performance/Energy

Energy = Gradient × Length

- Risk (Gradient)
  - Will the operating gradient be sufficient to support the energy goal?
- Potential mitigations
  - Establish realistically achievable gradient goal, based on modest extrapolation from current experience, consistent with fundamental limitations (~50 MV/m);
  - Design with operating margin relative to gradient goal;
  - Install over capacity within the facility (~5%);
  - Construct unfilled tunnel
- (Length: little risk the facility will come out shorter than designed!)

Assessment: Not the most serious risk. Risk reduction amenable to $$.

ILC Risk Elements

Technical Performance/Luminosity

Luminosity= $\int L \times dt$

- Risk (Peak Luminosity, L)
  - Significant extrapolation from experience: ~$10^4 \times$SLAC Linear Collider
    - ➢ Emittance capabilities of the source (esp. damping rings)
    - ➢ Emittance preservation in the linac
    - ➢ Maintaining beams in collision
    - ➢ Controlling detector backgrounds
- Potential Mitigations
  - Integrated simulations based on well characterized components, alignment capabilities, and site characteristics
  - R&D on feedback, feedforward systems
  - "Headroom"/alternative routes to same luminosity

Assessment: Luminosity goals are very aggressive (driven by physics requirements) and represent significant risk.

ILC Risk Elements

Technical Performance/(Integrated) Luminosity

Luminosity= $\int L \times dt$

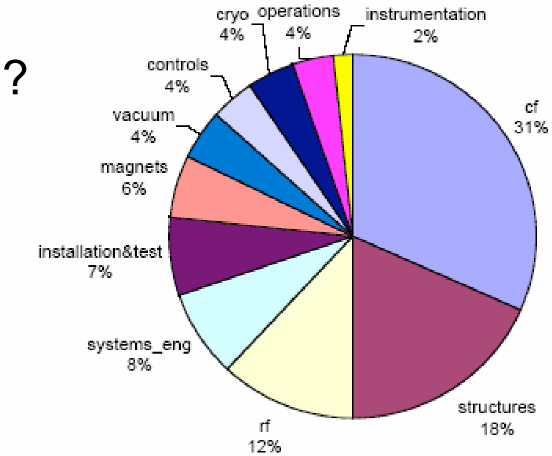
- Risk (Availability $\int dt$)
  - Can the facility achieve 75% “uptime” (actual/scheduled operations)?
  - Requires component mean time between failures (MTBF) typically a factor of $\geq$10 beyond current experience (~10^{6-7} hours).
  - Requires protection against uncontrolled loss of beam
- Potential Mitigations:
  - Operational modeling (complexity comparable to the Tevatron)
  - Design up front for high MTBF
  - Fail safe Machine Protection System
  - Redundant systems/installed overhead

Assessment: Availability goals are aggressive for a facility of this complexity and represent significant risk.

ILC Risk Elements

Cost Performance

- Risk
  - Can a reliable cost estimate be developed?
  - Significant experience base with components representing ~50% of cost
  - Balance represents significant extrapolation



- Potential Mitigations:
  - Well defined and controlled scope
  - Complete systems testing, technology transfer, demonstrated industrial capabilities and production models prior to construction start
  - Multiple component streams
  - Scope reduction strategies/scenarios identified up front

Assessment: Current estimate would carry significant contingency.
⇒ Conceptual Design Report (CDR) to provide much better handle.

ILC R&D Program
Strategy

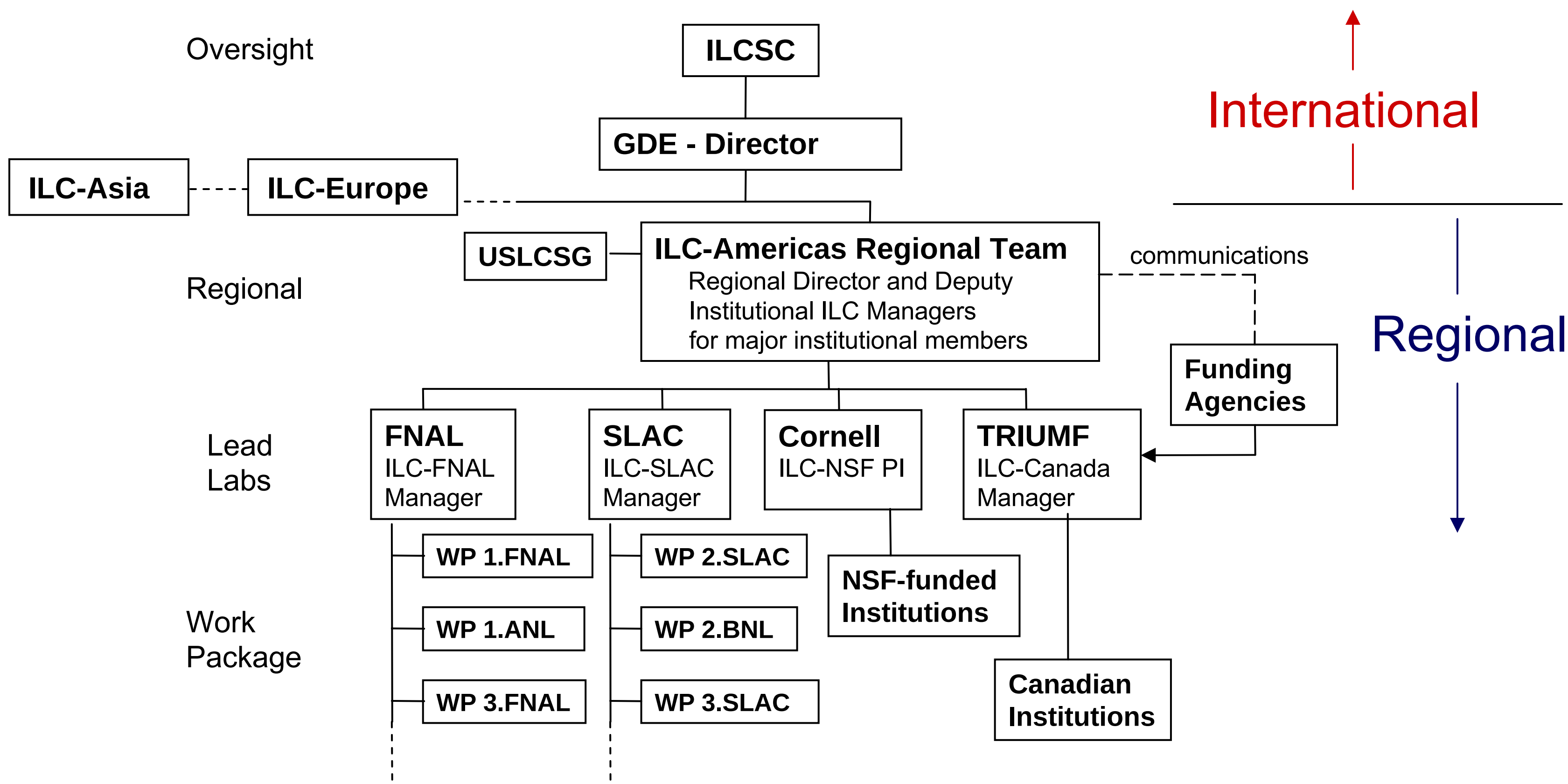
The purpose of the R&D program is to reduce risk.

- Goal: Develop a complete engineering design establishing high confidence performance and cost goals (by end of decade).
- Strategy
  - Target critical performance and cost risk elements
  - Systems simulations based on characterizations from prototypes
  - Demonstration projects to validate assumptions
- Program Elements
  - Prepare a CDR, supported by subsystem R&D
  - Construct and test prototypes
  - Technology transfer and industrialization
  - Integrated systems testing
  - Develop plans for conventional facilities and infrastructure
  - Prepare final site-specific engineering design(s)

~Time

ILC R&D Program

International/Regional Organization



ILC R&D Program

American Organization

Example North American ILC Matrix				XX=Lead lab		X=Participant					
Institution	Management	Accelerator Physics	Cryomodules Cryogenics	Cryomodule Test Facility	RF and Pulse Power	Sources	Damping Rings	Beam Delivery	IR and MD Interface	Instruments & Controls	Conv Facilities
Fermilab	XX	XX	XX	XX	X	X	X	X	X	XX?	XX
SLAC	XX	XX	X	X	XX	XX	X	XX	XX	XX?	X
ANL	X		X	X			X				
BNL	X							X	X		
Cornell	XX	X	X	X			XX				
JLab	X		X	X							
LBNL	X						X				
LLNL	X				X	X				X	
TRIUMF	XX					X					
Universities	X	X		X			X		X	X	

- Major initiatives & test facilities (US)
  - Significant presence within all major subsystems
  - Superconducting Module Fabrication and Testing Facilities
    - Industrialization (more advanced in Europe than US/Asia)
  - Integrated systems test (linac)
  - Modeling/simulations
  - Site Development

ILC R&D Program
Resource Requirements

- USLCSG model shows (through site select/decision to construct):
  - ~$450M (internationally shareable) costs
    - US share = $150M
  - ~$150M of US bid-to-host activities
- Accelerator scientist/engineer resources are estimated at:
  - ~400 person-years (American share)
  - ~150 FTE (peak, American share)
- Currently available AS/E resources within the USHEP program:
  - ~70 FTE – currently working on ILC R&D
  - ~140 FTE – currently engaged in accelerator operations (Tevatron, PEP-II, CESR); all scheduled to cease operations over 2008-2010.

$\Rightarrow$ **Resources exist to execute the ILC R&D program.**

ILC Construction
Resource Requirements

- The TESLA Technical Design Report estimated ~1400 person-years of accelerator scientist/engineers to construct.
  - USLCSG viewed this as a credible estimate.
  - ~250 FTE (peak, world-wide)
  - US share (if host) ~150 FTE
  - Well matched to the complement on hand at the end of the R&D program
    - Significant resources exist in non-HEP labs to back this up
    - (~100 accelerator physics grad students in the DOE system at end of 2003).

Bottom line: The accelerator scientists and engineers needed to execute the ILC R&D and construction programs exist within the HEP program or are in the pipeline. Availability at the start of construction depends upon continuity of support.

Fermilab and the ILC
Long Range Plan

- The Fermilab Long Range Plan establishes the ILC as the primary goal, with a world-leading neutrino program if the ILC were delayed or constructed elsewhere.
  - "The U.S. Department of Energy has expressed its interest in the possibility of hosting a linear collider, at Fermilab, subject to the machine being affordable and scientifically validated by physics discoveries at the LHC."
- The ILC cold technology decision has allowed close alignment of Fermilab's R&D programs in support of these goals.

Fermilab is pursuing ILC and Proton Driver R&D, in parallel, based on superconducting rf technologies.

Fermilab and the ILC
R&D Strategy

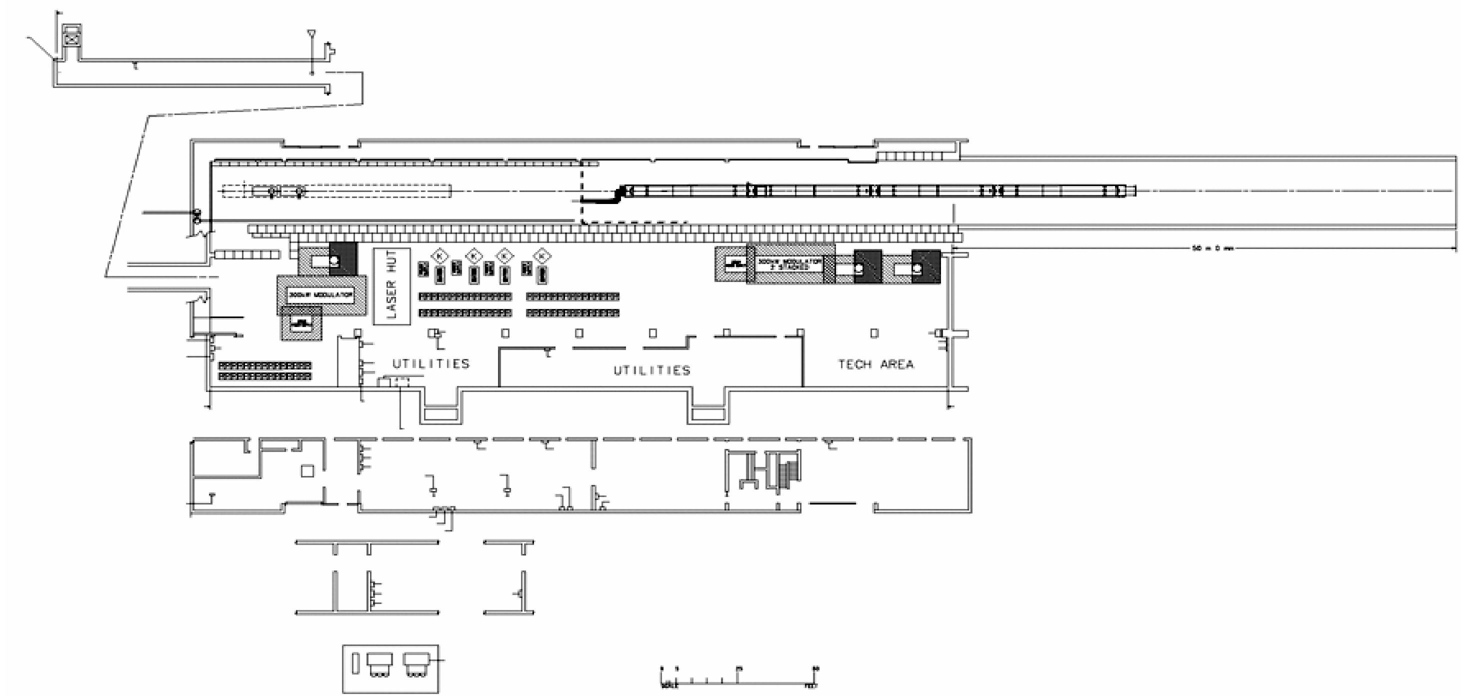
- Leadership of the America's regional effort in development of the SCRF technology base for ILC.
  - It is imperative to establish US-based capability in the fabrication of high gradient superconducting accelerating structures if the US is to compete to host.

    - Significant U.S. SCRF development and fabrication experience at: Argonne, Cornell, Fermilab, Jefferson Lab, Los Alamos, Michigan State…but at gradients significantly below 35 MV/m (SNS cavity fabrication by European vendor).
  - Fermilab is establishing facilities to fabricate and test US-produced ILC cavities and cryomodules with national and international partners.

Fermilab and the ILC

R&D Strategy

ILC Module Test Facility

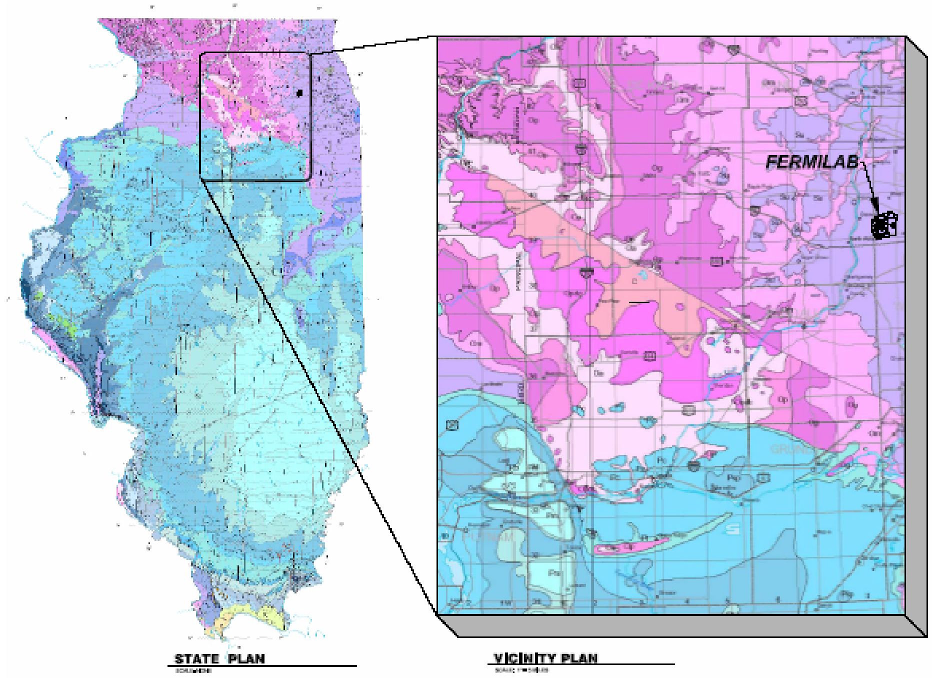


Collaborators: ANL, BNL, Cornell, FNAL, JLab, LANL, LBNL, MIT, MSU, NIU, ORNL, Penn, SLAC, (CAT, DESY, INFN, KEK)

Fermilab and the ILC
R&D Strategy

- Beam dynamics issues:
  - Low emittance transport through the linac: simulations (w/SLAC)
  - Damping ring design
  - Machine/detector interface issues

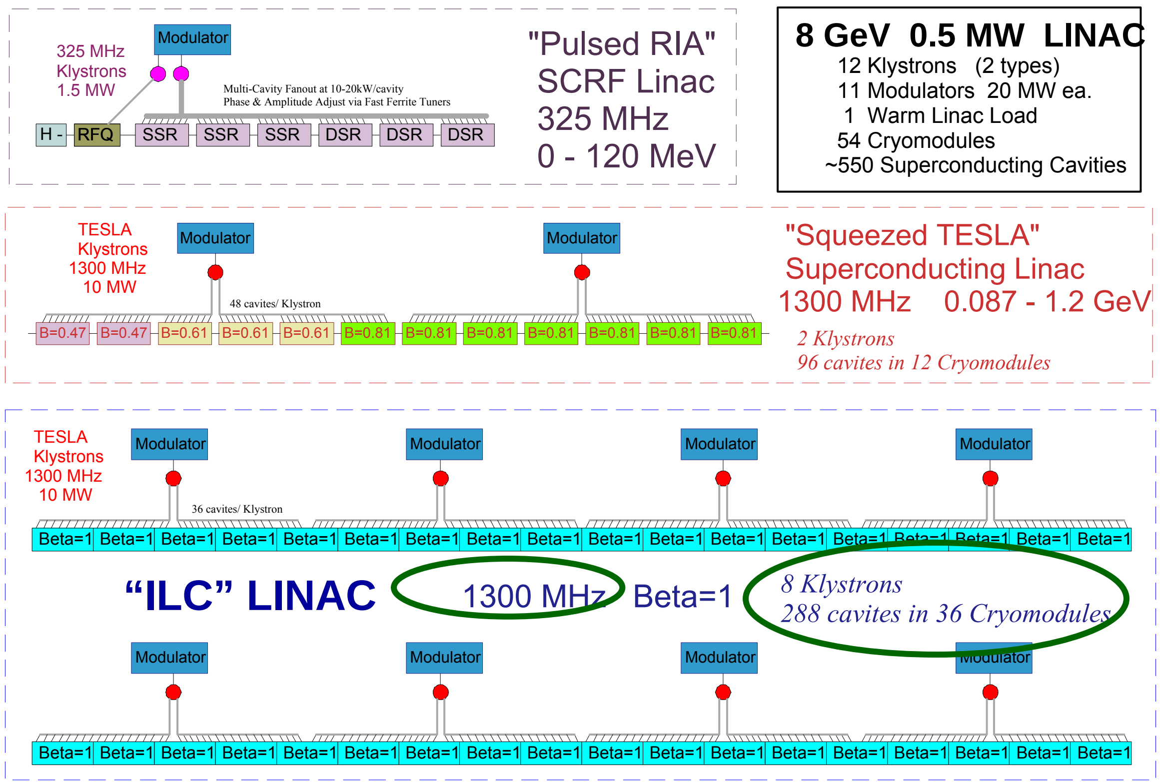
- Hosting activities
  - Site studies and characterization
  - Public outreach



The goal is to provide the US with the best possible host site for a prospective ILC bid.

Fermilab and the ILC

ILC Proton Driver Synergies



Motivation

High intensity neutrino source

Synergies with ILC

- SCRF capabilities
- Industrialization
- Systems testing

Fermilab and the ILC
Timeline/decision tree

- Over the next ~18 months Fermilab R&D activities are independent of the final destination:
  - Develop superconducting rf capabilities with domestic and international partners
  - Support GDE completion of ILC CDR with supporting R&D
  - Completion of Proton Driver CDR with supporting R&D
- A series of branch points then develops in response to the ILC CDR…

$\Rightarrow$ **See Pier Oddone’s presentation for discussion/details.**

Summary

- The ILC is an enterprise at the forefront of human knowledge and technical capabilities.
- ILC performance goals have been established.
  - Based on >10 years of R&D in U.S., Europe, and Japan
- ILC risk elements are identified and motivate an R&D program leading to a complete engineering design by the end of the decade.
  - CDR will establish an initial cost range and downstream R&D targets.
  - Simulations and industrialization will be key elements.
- The US R&D program has responded to the technology decision and is working within the international framework.
- Fermilab's R&D program is aligned with US aspirations for the future
  - SCRF R&D is the unifying technology theme
- Fermilab is committed to a leadership role in the ILC R&D program and to preparing to host the ILC when/if that decision comes.

References

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http://www.fnal.gov/directorate/icfa/International_ILCSC.html

U.S. Linear Collider Steering Group

http://www.slac.stanford.edu/~hll/USLCSG/

Machine performance specification

http://www.fnal.gov/directorate/icfa/LC_parameters.pdf

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http://tesla.desy.de/new_pages/TDR_CD/start.html

(USLCSG) U.S. Linear Collider Technology Options Study

http://www.slac.stanford.edu/xorg/accelops/OptionsReport/LC_opts_full.pdf

Technical Review Committee

http://www.slac.stanford.edu/xorg/ilc-trc/2002/index.html

References

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Fermilab ILC

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http://www-bd.fnal.gov/pdriver/