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# **The International Linear Collider and Fermilab**

**Michael Witherell**  
**Fermilab Colloquium**  
**September 15, 2004**

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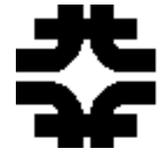
# Outline

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- Physics context
- The Fermilab program and the International Linear Collider
- The technology decision
- Fermilab's role in the future

# Electroweak Symmetry Breaking



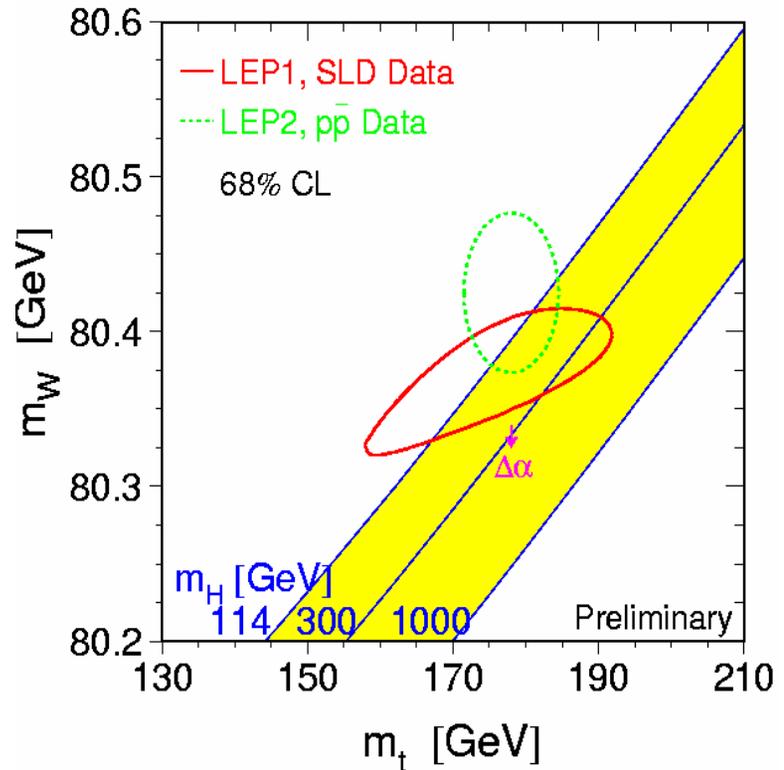
## What causes the Higgs field?

- The data so far is consistent with a SM Higgs, but

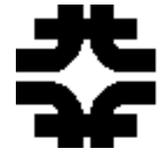
## We will know a lot in a few years.

- Improved top and W mass measurements now
- Search for Higgs soon at the Tevatron & LHC

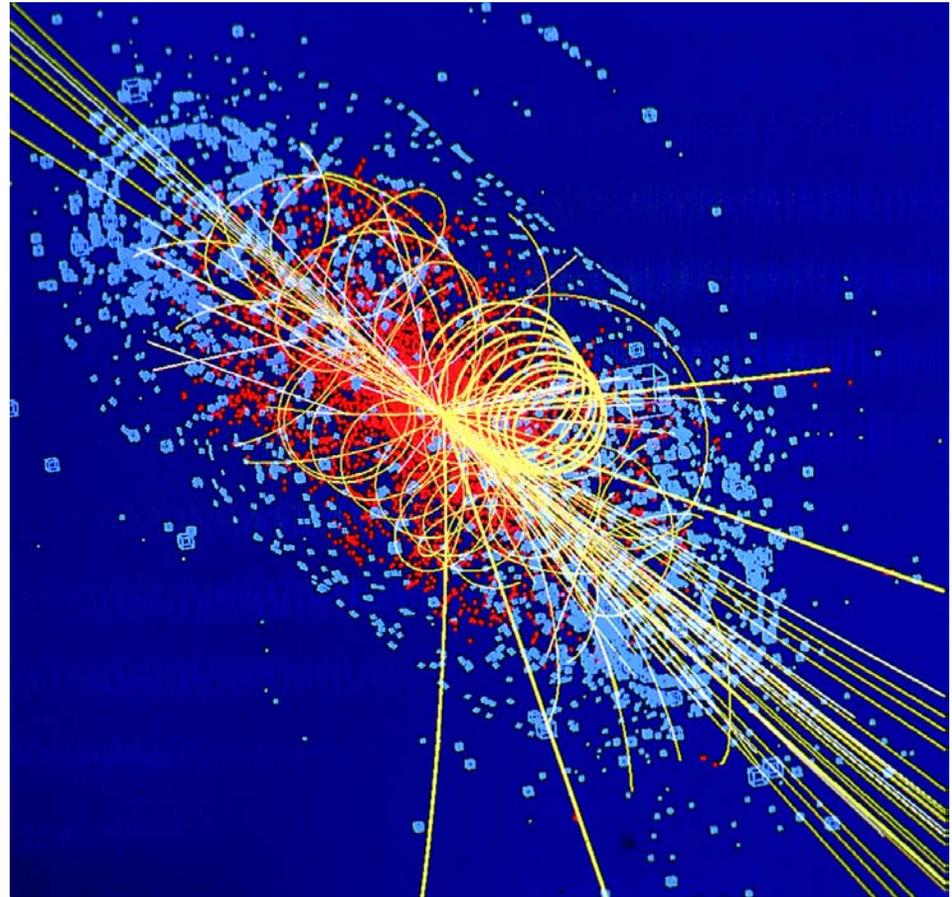
## What sets the mass scale?



# Large Hadron Collider



- If a SM Higgs exists, either it will be seen at the Tevatron or it will be discovered with the first substantial data samples analyzed by CMS and ATLAS at LHC.
- Discovery of a Higgs boson is just the start of exploring this new force, however.



# What if we do observe a Higgs boson?

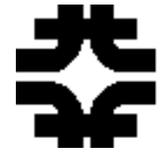
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- Does the Higgs generate
  - W and Z masses?
  - fermion masses?
  - its own mass?
- Does it have  $J^{PC} = 0^{++}$ ?
- Is it just one of the multiple Higgs bosons predicted in Supersymmetric models?
- Is it accompanied by other new particles?

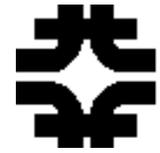
# Exploration of the Higgs sector with a linear collider

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- $e^+e^- \rightarrow Z H$  gives a large clean sample of tagged Higgs bosons independent of decay mode.
  - LHC makes good measurements of major Higgs BRs.
  - ILC makes few % measurements even on minor decays.
- ILC and LHC together will be powerful in deciding what kind of Higgs it is, and unlocking the underlying nature of the new physics at the TeV energy scale.
  - Couplings to fermions quite different in SUSY models, except in limit of high  $M_A$
  - LC separates SUSY Higgs from SM Higgs up to very high  $M_A$ .
  - ILC can measure spin-parity of Higgs.

# Unification of forces



Are the four forces unified at very high energy?

- In the SM, 3 forces which are not quite unified

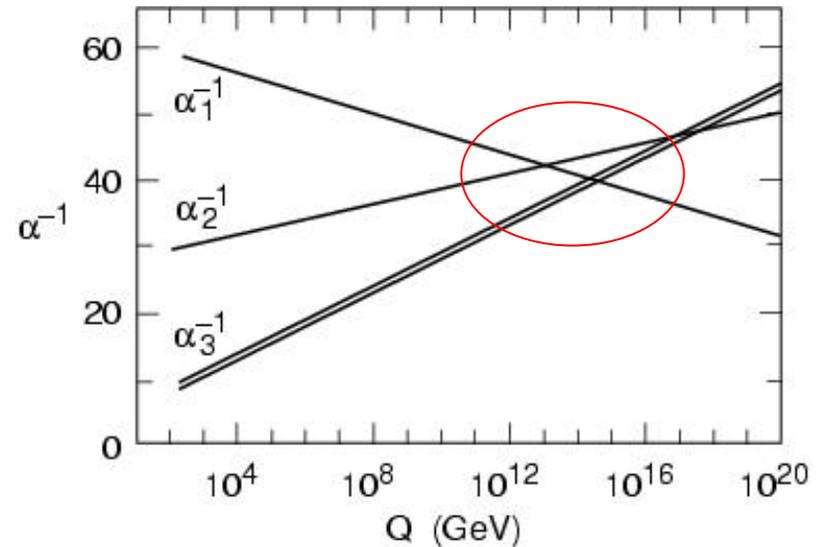
Why is gravity so weak?

Why is  $F_{\text{grav}} \approx 10^{-42} \times F_{\text{elec}}$ ?

Why is  $M_W \ll M_{\text{Pl}}$ ?

Why is  $M_H \ll M_{\text{Pl}}$ ?

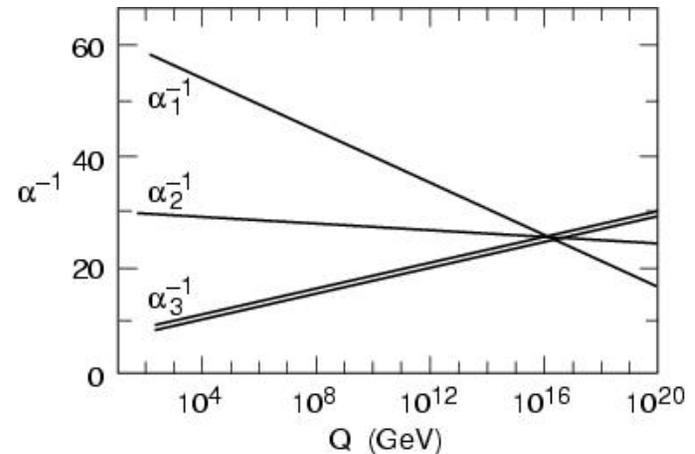
We are looking for a mechanism to stabilize the Higgs mass and keep it from rising to the Planck scale.



# Some possible answers

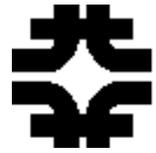


- **Hidden Extra Dimensions**
  - They can be used to disperse the intrinsic strength of gravity, making it seem weak to us.
  - Ultimate scale of physics: quantum gravity
- **Supersymmetry**
  - It stabilizes the Higgs mass.
  - It is necessary in string theory.
  - It leads to unification of gauge forces.
  - It fits as dark matter.
- **Strong Dynamics**
  - Higgs boson may be fermion-pair composite, analogous to Cooper pairs
- **Something we have not thought of yet**



# Exploring the Supersymmetric World: an example

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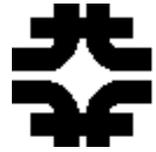
What is the nature of supersymmetry breaking?

Understanding spectrum is crucial, but difficult.

- LHC
  - finds evidence of supersymmetry
  - measures several mass differences.
- ILC
  - finds sleptons
  - makes precise measurements of couplings and masses
- Complete understanding of the TeV scale allows us to extrapolate to the underlying physics at higher energy scales.

# Linear Collider physics

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- A number of experts have written talks describing the physics opportunities at a linear collider in more depth than I can here.
  - In fact I have made use of them in what I have done.

See <http://www.interactions.org/linearcollider/>

and at

<http://www.interactions.org/cms/>  
click [resources](#) and then [talks database](#)

# Linear Collider

(MW to HEPAP subpanel 6/2001)

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- The Subpanel was charged to make recommendations on the next U.S. facility.
- You must choose clearly one of three recommendations on a linear electron-positron collider:
  - The U.S. should propose to be the host for a linear collider built by an international collaboration.
  - The U.S. should not pursue building it here, but should take a strong role in building one somewhere else (e.g. DESY or KEK).
  - The U.S. should not take a major role in a linear collider.
- This decision should not be delayed further.

# Linear Collider recommendation

(MW to HEPAP subpanel 6/2001)

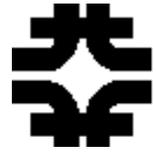


- **The subpanel should recommend construction of a linear collider in the U.S., built as an international project, with the optimum technical design.**
  - The physics case for the LC with a 1st stage at  $\sim 500$  GeV is very strong. We need a linear collider to study our most compelling physics issues – the physics of the TeV scale.
  - We know enough to make the choice now.
- **The subpanel should also**
  - emphasize the need to develop a true international collaboration;
  - encourage the comparative evaluation of technology.

# Linear Collider at Fermilab

(MW to HEPAP subpanel 6/2001)

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- We propose to the U.S. and to the international HEP community that we work together to build a linear collider at or near the Fermilab site.
  - There is a consensus in the HEP community that the site should be near an existing laboratory if possible.
- Fermilab is an excellent site for a linear collider.
  - strong base of expert manpower and infrastructure
  - excellent locations nearby
  - none of the problems, including political, associated with a green field site
  - good geology
  - political environment as good as any other U.S. site

# Linear Collider at Fermilab

## (MW to Users' meeting 6/2004)

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- Fermilab is planning the next steps for either technology choice, in collaboration with international partners.
- Fermilab is bidding to host the central project office for the global design team.
- Fermilab will prepare a bid to host the Linear Collider
  - A site near Fermilab has unique advantages, both in cost and in schedule for building the new facility.
  - The model for building and operating the LC is fundamentally different from past HEP projects.
    - Several laboratories around the world of HEP will build and operate the LC as an international project.
    - Host laboratory would take a leading role, but not as dominant role as CERN in LHC.

# Linear Collider R&D Charge

(MW to Users meeting 6/2004)

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Charge letter to S. Mishra, head of Fermilab linear collider R&D:

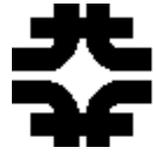
- **Begin now, do not wait for technology decision.**
  - Prepare a plan to build Fermilab's role for each technology.
- **Develop a LC site plan.**
  - Identify sites and characterize geology.
  - Advance discussion with surrounding communities.

In addition to the accelerator effort:

- **Design a detector matched to the physics.**
  - Grow the Fermilab role in physics and detector studies.

# Fermilab in 2020

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- The overarching vision for Fermilab in 2020 is that it will be the primary site for particle physics accelerators in the U.S.
- The most favorable outcome for particle physics is that a linear collider is built within a short distance from here by an international collaboration of laboratories.

# Vision I: FNAL in 2020 hosting the Linear Collider

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- Linear Collider in operation near Fermilab
  - Fermilab at the center of future discoveries and understanding
  - Major part of Lab activity
- Neutrino Program
  - Based on improvements to the accelerator complex and the experiments over the next ten years
- Large Hadron Collider Program
  - Accelerator and experiment: Fermilab leading center for CMS physics
- Other experiments at FNAL
  - As physics demands
  - Quark Flavor may still be key
  - Other programs
- Astroparticle physics, Accelerator R&D
- Non-particle science

# The Fermilab program will address all of these questions, and more.

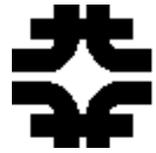
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1. Are there undiscovered principles of nature: new symmetries, new physical laws?
2. How can we solve the mystery of dark energy?
3. Are there extra dimensions of space?
4. Do all the forces become one?
5. Why are there so many kinds of particles?
6. What is dark matter?  
How can we make it in the laboratory?
7. What are neutrinos telling us?
8. How did the universe come to be?
9. What happened to the antimatter?

# The Present Fermilab Physics Program

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- The existing proton accelerator complex makes possible a very exciting physics program over the next decade.
  - Run II physics program with  $4\text{-}8\text{ fb}^{-1}$  for each detector by 2009
  - Neutrino physics program with the NuMI beam (startup in early 2005!) and the Booster neutrino beam
  - BTeV program: next generation in quark flavor physics from 2009-13
  - smaller experiments using slow extracted beam
- Strong program of experiments offsite
  - LHC program: US-CMS and LARP
  - Astroparticle physics program: SDSS, Auger, CDMS, and more

# Side trip: Future options in neutrinos

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- The U.S., DOE Office of Science, and Fermilab have invested a great deal in the state-of-the-art long baseline neutrino facility.
- We should get as much science benefit from this investment as possible.
  - MINOS will operate for a good long exposure of neutrinos.
  - NO $\nu$ A would add a capability for sensitive  $\nu_e$  detection and more size.
- One can follow the neutrino physics with a stepwise approach based on physics evolution and available resources.
  - Adding Proton Driver and Supersize Detector would make it possible to keep doubling the “neutrino integrated luminosity” every few years.
  - steps of perhaps  $\sim$ \$1/2 B each

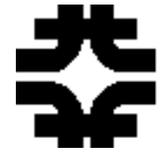
# Side trip: Neutrinos worldwide



- The U.S. has a range of possible medium-large neutrino initiatives to consider, in addition to exploiting the current program.
  - NO $\nu$ A, reactor neutrino experiment, 2 double- $\beta$  decay experiments, proton driver, larger detectors, longer baselines
- Outside the U.S. also:
  - T2K and Double-Chooz approved
  - MW proton sources, Hyper-K, reactor neutrino experiments, double- $\beta$  decay experiments, longer baselines

We think the science benefit per \$M of the stepwise Fermilab approach at Fermilab makes this an essential part of the worldwide program.

- The DOE Office of Science and NSF will need to shape a future neutrino program from these many exciting options and sell it to the keepers of the budget.
- The shape of the neutrino program here and worldwide will adapt to several developments over time, including that of the ILC.



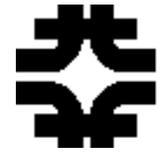
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# International Organization and Technology Decision

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# International Linear Collider Steering Committee

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## Directors

CERN	Robert Aymar	DESY	Albrecht Wagner
FNAL	Michael Witherell	KEK	Yoji Totsuka
SLAC	Jonathan Dorfan		

## LC Steering Group Chairs

Asia	Won Namkung	Europe	Brian Foster
N. America	(Jonathan Dorfan)		

## Other

Chair	Maury Tigner	China	Hesheng Chen
Russia	Alexander Skrinsky	Other	Carlos Garcia Canal
Asia	Sachio Komamiya	Europe	David Miller
N. America	Paul Grannis		
Secretary	Roy Rubinstein		

# ICFA and the Linear Collider

ICFA Report, J. Dorfan, ICHEP 2004

- ICFA has been helping guide international cooperation on the Linear Collider since the mid 1990's. Major steps:

1995: First ILC TRC Report, under Greg Loew as Chair

1999: ICFA Statement on Linear Collider

2002: ICFA commissioned the second ILC TRC Report, under Greg Loew as Chair

2002: ICFA establishes the International Linear Collider Steering Group (ILCSC) with Maury Tigner as Chair

# International Technology Recommendation Panel (ITRP)

ICFA Report, J. Dorfan, ICHEP 2004

- The next major step towards the realization of a global linear collider is the creation of an internationally-federated design team. The ILCSC is in the midst of establishing such a team
- A critical prerequisite for starting the work of the global design team is the requirement of a single option for the RF technology to power the main linacs

ICFA formed the International Technology Recommendation Panel (ITRP) to recommend the optimal choice of RF technology

# International Technology Recommendation Panel (ITRP)

Jean-Eudes Augustin ICFA Report, J. Dorfan, ICHEP 2004

Jonathan Bagger

Barry Barish (Chair)

Giorgio Bellettini

Paul Grannis

Norbert Holtkamp

George Kalmus

Gyung-Soo Lee

Akira Masaike

Katsunobu Oide

Volker Soergel

Hiroataka Sugawara

- **Yesterday, the ILCSC and ICFA met to review the ITRP recommendation. ITRP Chair made a presentation accompanied by a 2.5 page Executive Summary that encapsulates the recommendation**
- **ICFA/ILCSC unanimously endorsed the recommendation**

# **ITRP**



## **Linear Collider Technology Recommendation**

**Barry Barish  
ILCSC/ICFA Special Meeting  
IHEP, Beijing  
19-Aug-04**

# Departing from Korea



*International Technology Recommendation Panel Meeting  
August 11 ~ 13, 2004. Republic of Korea*

# The Charge to the International Technology Recommendation Panel

## General Considerations

The International Technology Recommendation Panel (the Panel) should recommend a Linear Collider (LC) technology to the International Linear Collider Steering Committee (ILCSC).

On the assumption that a linear collider construction commences before 2010 and given the assessment by the ITRC that both TESLA and ILC-X/NLC have rather mature conceptual designs, the choice should be between these two designs. If necessary, a solution incorporating C-band technology should be evaluated.

Note -- We have interpreted our charge as being to recommend a technology, rather than choose a design

# The Recommendation

- We recommend that the linear collider be based on superconducting rf technology (from Exec. Summary)
  - This recommendation is made with the understanding that we are recommending a technology, not a design. We expect the final design to be developed by a team drawn from the combined warm and cold linear collider communities, taking full advantage of the experience and expertise of both (from the Executive Summary).
  - We submit the Executive Summary today to ILCSC & ICFA
  - Details of the assessment will be presented in the body of the ITRP report to be published around mid September
  - The superconducting technology has features that tipped the balance in its favor. They follow in part from the low rf frequency.

# Some of the Features of SC Technology

- The large cavity aperture and long bunch interval reduce the complexity of operations, reduce the sensitivity to ground motion, permit inter-bunch feedback and may enable increased beam current.
- The main linac rf systems, the single largest technical cost elements, are of comparatively lower risk.
- The construction of the superconducting XFEL free electron laser will provide prototypes and test many aspects of the linac.
- The industrialization of most major components of the linac is underway.
- The use of superconducting cavities significantly reduces power consumption.

***Both technologies have wider impact beyond particle physics. The superconducting rf technology has applications in other fields of accelerator-based research, while the X-band rf technology has applications in medicine and other areas.***

# Remarks and Next Steps

- The linear collider will be designed to begin operation at 500 GeV, with a capability for an upgrade to about 1 TeV, as the physics requires. This capability is an essential feature of the design. Therefore we urge that part of the global R&D and design effort be focused on increasing the ultimate collider energy to the maximum extent feasible. (from Exec Summary)
- A TeV scale electron-positron linear collider is an essential part of a grand adventure that will provide new insights into the structure of space, time, matter and energy. We believe that the technology for achieving this goal is now in hand, and that the prospects for its success are extraordinarily bright. (from Exec Summary)

# We Live in Extraordinary Times

ICFA Report, J. Dorfan, ICHEP 2004

- Just as it did with the LHC in the 1990's, ICFA has a very strong focus on facilitating the wishes of the worldwide HEP community – in this era of the 2000's it is to establish a fully international TeV Linear Collider
- At no time in the history of particle physics has the scientific landscape presented us with such an exciting spectrum of unanswered questions! The LHC will make major discoveries that challenge that agenda, but to engage the fullness of the scientific quest will take discoveries from a companion TeV Linear Collider
- The stage is now set to proceed forward to realize expeditiously an international design for a TeV linear collider.....

.....ICFA encourages the international HEP community to unify enthusiastically in support of this exciting mission



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# Implications for Fermilab of the Technology Decision

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# Fermilab and the ILC

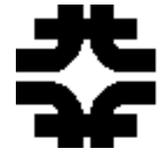
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- Large HEP laboratories will anchor the design and associated R&D effort on the ILC...
  - DESY, Fermilab, KEK, SLAC will take the lead. Fermilab has had the smallest effort until now, but will build up, concentrating on SCRF.
  - CERN is focusing on LHC for now, may do more later.
- but many other institutions will be lending intellectual and technical strength to the effort.
  - In the US., for example, Cornell, LBL, LLNL, BNL, ANL, JLab, and several universities will contribute.
- Fermilab and SLAC will share the leadership of the U.S. effort on the ILC.

# Fermilab's role in light of the technology decision

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- Fermilab has presented publicly its vision for the future as developed within the Fermilab Long Range Plan:
  - host lab for an internationally constructed and operated Linear Collider;
  - home to a world-leading neutrino program
- Fermilab will now grow the ILC effort.
  - We can double effort quickly, grow from there.
  - We have submitted a bid to host the GDI/CT
- We continue to express our desire to be host laboratory for the ILC.

# Fermilab's role in light of the technology decision

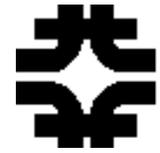
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- Fermilab expressed publicly
  - that we were committed to significant ILC participation independent of the technology chosen;
  - that an advantage of the cold technology would be the opportunity for an integrated approach to the two possible futures in the Fermilab long-range plan;
  - that in the event of a cold decision Fermilab would be ready and able to assume the leadership role in establishing a U.S. collaboration to push the SCRF development under the aegis of an international LC organization.
- Fermilab will now follow through on that commitment.

# Fermilab as a site for the ILC

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- Fermilab has unique advantages as a site.
  - best option for a site nearby an operating HEP lab
  - large supply of trained and talented people
  - very good geology
  - modest power and construction costs
  - central location(!)
- The particle physics community is coming to the conclusion that the best opportunity for building the ILC is near Fermilab.

# Fermilab Plans

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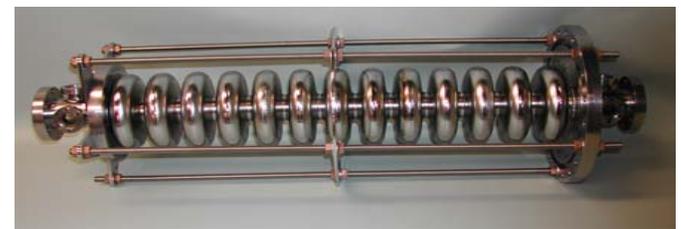


- Establishment of US-based capability to design, build, and test SC accelerating structures
  - Superconducting Module Test Facility in MEast will serve linear collider, proton driver, and light source R&D needs
  - The ILC goals and detailed design will emerge from discussions with national and international partners.
- Areas of Fermilab involvement in ILC (entering a period of discussion with international partners)
  - lead role in building an engineering test facility for major linac systems, meeting needs of global ILC effort
  - possible role in several other subsystems
  - detector R&D and test beam work
- Bid to host
  - siting and civil studies
  - public outreach

# Fermilab ILC Efforts to Date

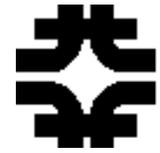


- NLC
  - X-band structures fabrication
    - 5 of the 8 structures at successful NLCTA test were built by Fermilab
  - Civil/siting studies
- SCRF
  - Operation of 15 MeV photoinjector (identical to TTF injector)
  - SCRF cavity development for FNPL and CKM
- Extremely talented scientific & engineering group in place with ability to work on warm or cold structures

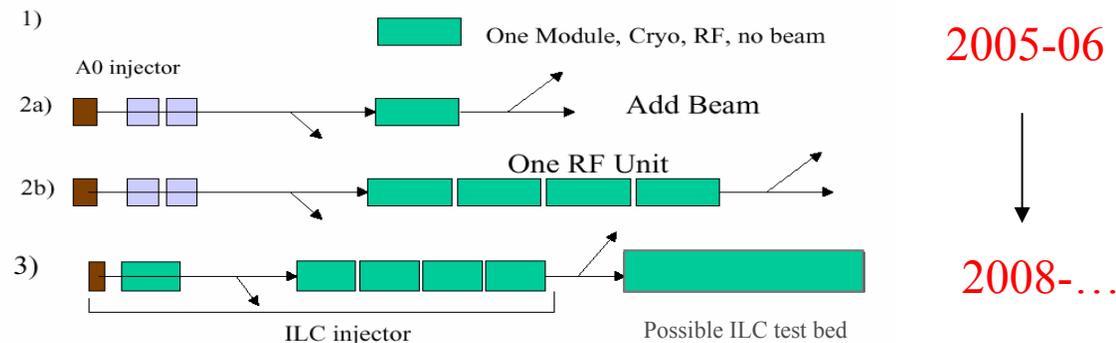


⇒ **Bottom line: By redirecting x-band and focusing SCRF more strongly on ILC Fermilab can effectively double resources in FY05.**

# Fermilab Plan



- It is essential to establish U.S. capability in the fabrication of high gradient SRF structures.
  - Fermilab commitment to provide U.S. leadership following cold decision
- Focus has been on a test facility at Fermilab (aka SMTF—Superconducting Module Test Facility).
  - Interested partners: ANL, BNL, Cornell, FNAL, JLab, LANL, LBNL, MIT, MSU, ORNL, SLAC
- Concept of a possible evolution:





# To hear more

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- Steve Holmes and Shekhar Mishra will give a wine & cheese seminar:  
Linear Collider R&D: Fermilab Plans  
on Friday, Sept. 24.
- Come and find out more.

# Detectors for the Linear Collider

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- It is also time to get serious about detectors for the linear collider.
- The Worldwide Study of Physics and Detectors for Future Linear  $e^+e^-$  Colliders has been leading this effort, but it is becoming more focused.
- Fermilab involvement (examples)
  - Andreas Kronfeld is a member of the International Organizing Committee.
  - Slawek Tkaczyk and Gene Fisk lead the LC Physics and Detector Study Group in PPD-EPP
  - Harry Weerts and John Jaros are coleading the Silicon-based detector design study.
  - Meson Test Beam Facility (Eric Ramberg)
- Talk to them to see how to get involved.

# Summary

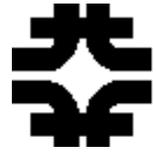
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- Fermilab's vision for its future is to be the home of the primary accelerators for particle physics in the U.S.
- Fermilab's vision for U.S. particle physics is that it should have a central role in the worldwide program to take full advantage of the scientific revolution ahead of us.
- The fullest realization of these hopes would be the construction of the International Linear Collider near Fermilab by a global consortium of particle physics laboratories.
  - We must do what we can to make this possible.
  - We also must get the most science we can from the evolving program with the proton accelerator complex.
- The Fermilab needs to get involved and take charge of shaping the laboratory's long-term future.

# Finally

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- Fermilab has the opportunity to help lead the particle physics community to a new era of discovery:
  - LHC and ILC exploring physics at the TEV scale
  - Worldwide exploration of neutrino mysteries and quark flavor physics
  - Understanding the nature of dark matter and dark energy
- We must put this exciting possibility forward to our government and society and ask for their support.