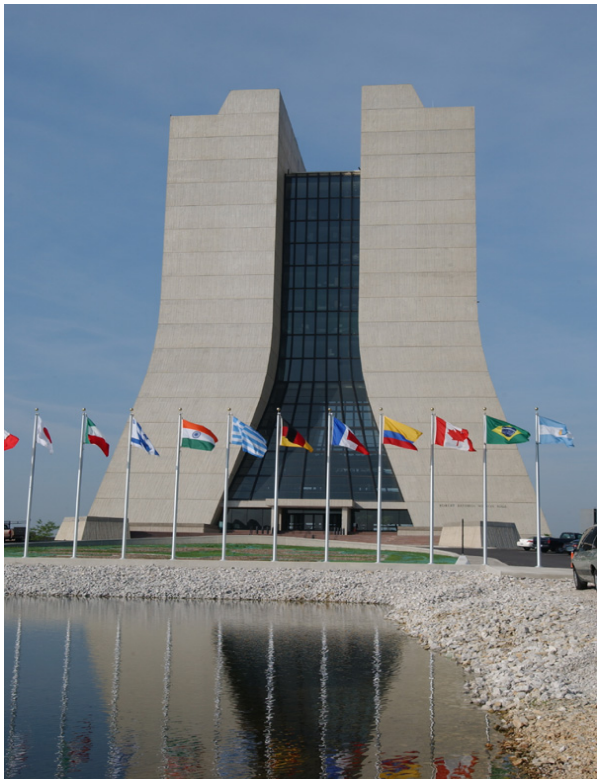
International Linear Collider R&D @ Fermilab

Shekhar Mishra

Fermilab



An International Project → An International Laboratory

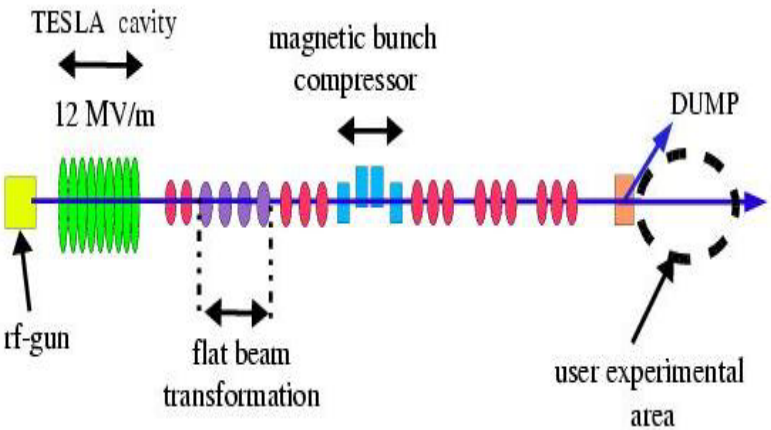
Introduction

- Fermilab has been participating in the R&D of both the “Warm” and “Cold” technology R&D.
- Fermilab Long Range Plan in Vision I: FNAL in 2020 hosting the Linear Collider
  - Fermilab at the center of future discoveries and understanding
  - Linear Collider in operation near Fermilab as major part of the laboratory activity
- On Aug. 20th 2004, the ITRP recommended the “Cold” Technology for the International Linear Collider.
- Fermilab has expressed publicly:
  - In the event of the cold recommendation “Fermilab is ready to provide the leadership in forming a U.S. collaboration to develop SCRF high gradient technology in coordination with the international community.”
  - Fermilab is the site for the International Linear Collider

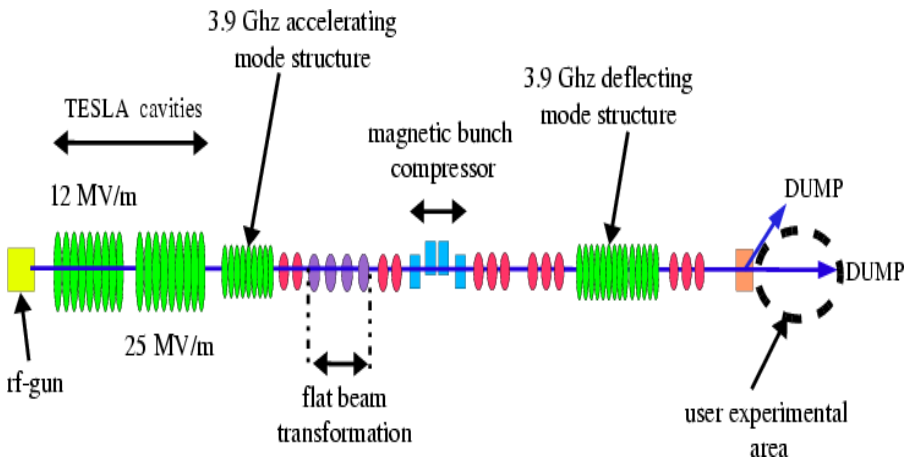
ILC R&D

- ILC Accelerator Physics and Technology R&D
  - Accelerator Technology
    - SCRF Existing Infrastructure: FNPL, 3rd Harmonic Cavity
    - Main Linac (Fermilab will seek to take major responsibility)
    - SCRF: Cavity, HOM, Blade Tuner, Coupler, He and Cryo-vessel, RF
    - Fast Kicker Development from Damping Ring
  - Accelerator Physics
    - Linac Design, Emittance Preservation Simulation
    - Damping Ring Design, Instability calculations
    - Collimation and Machine detector interface
    - Electron Source
- Civil: Near Fermilab site, Tunnel, Vibration studies
- Detector R&D: SID
- Collaboration & Outreach: Local Universities and ANL, National and International laboratories and Universities, Local public, State and Federal Government

The Fermilab NICADD Photoinjector Laboratory (FNPL)

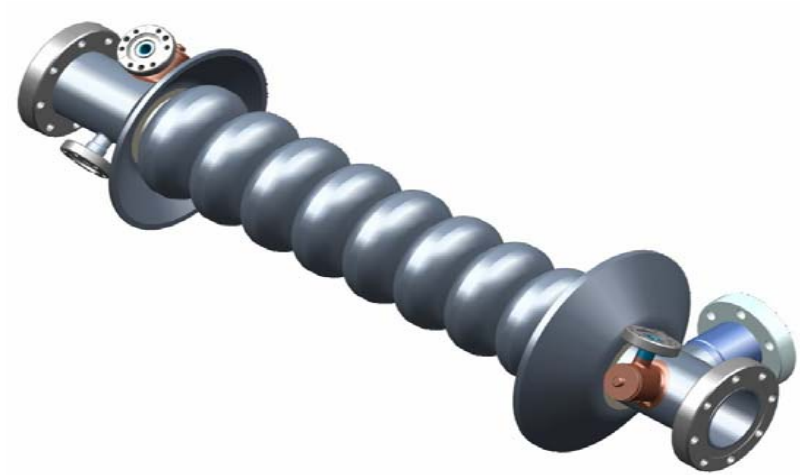


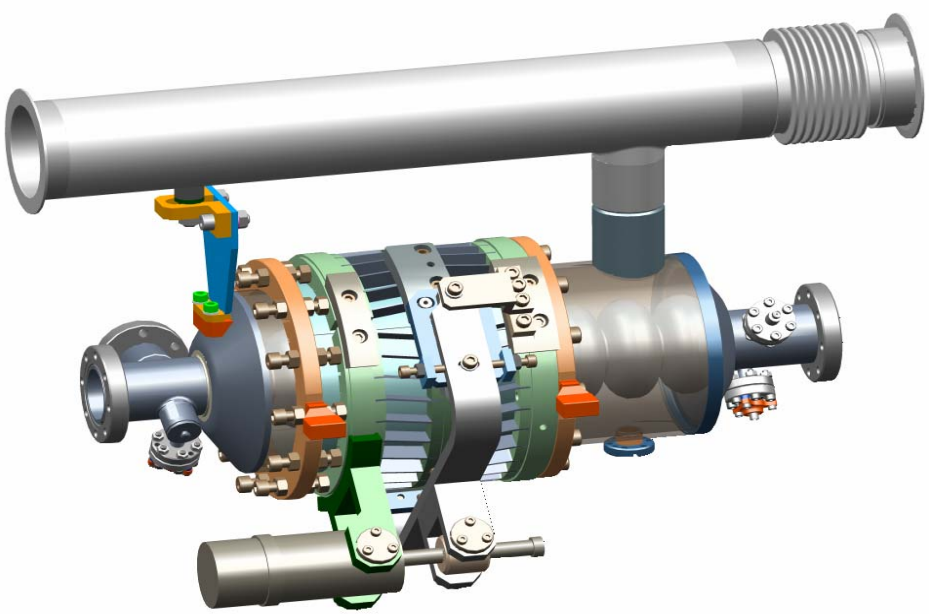
FNPL Upgrade



- 2nd incarnation of the TTF Injector II, with extended diagnostics,
- One normal conducting rf gun, one superconducting booster cavity
- Beam energy up to 16 MeV, bunch charge up to 12 nC
- Normalized emittance 3-4 π mm mrad (with 1 nC)
- Beam physics studies with high brightness beams
- Experimental area for advanced accelerator concepts
- Education of students

3.9 GHz SCRF Cavities

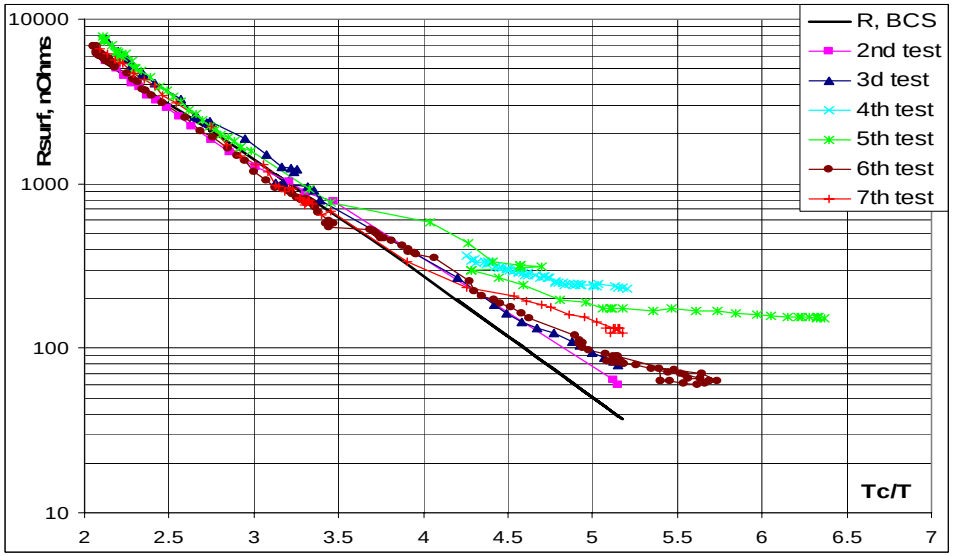


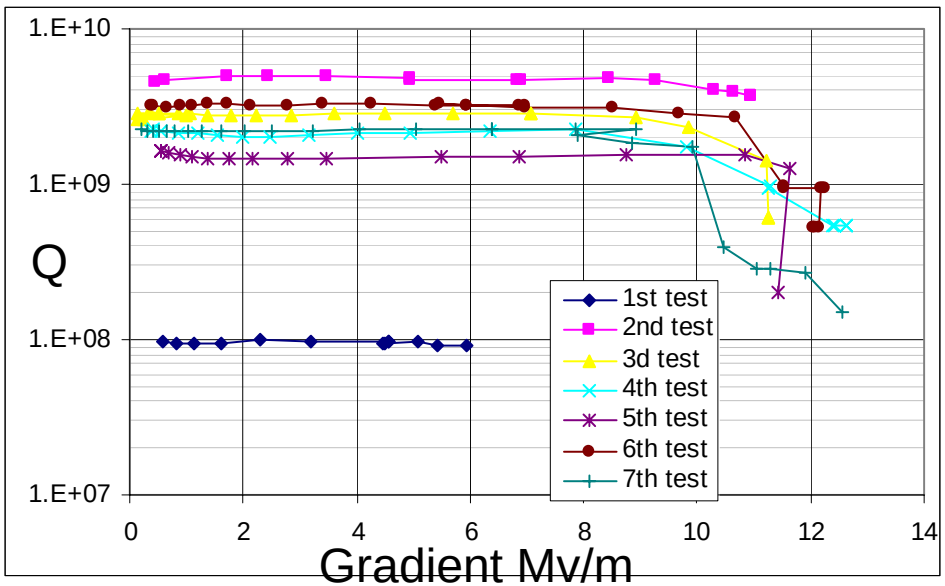


Status

- Cavity design is finished
- Built two 9-cell copper models
- Built one 3-cell Nb cavity
- 9-cell cavity in production
- Helium vessel in production
- Blade-tuner in production
- HOM studies in progress
- A0 cryomodule for single TM_{010} or TM_{110} cavities are under design

Cold Test of the 3-cell 3.9 GHz cavity in the Vertical Dewar





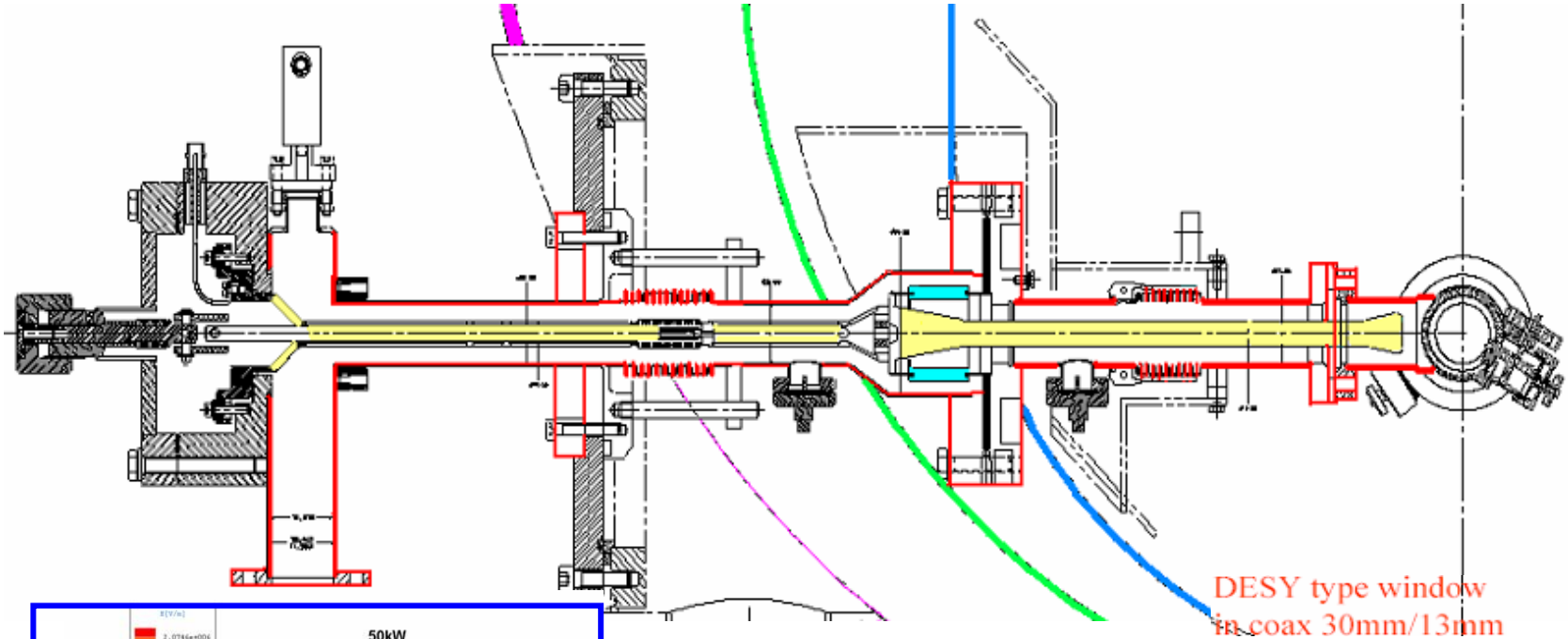
Test history

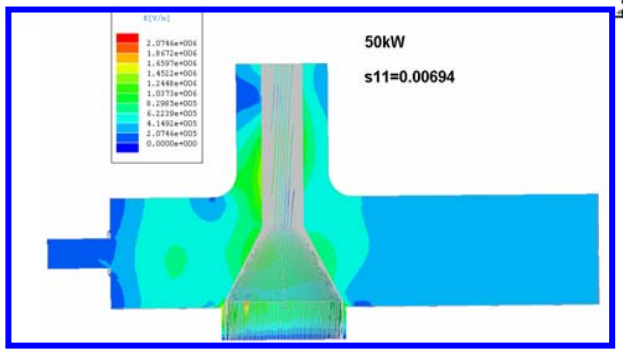
#1 – No BCP

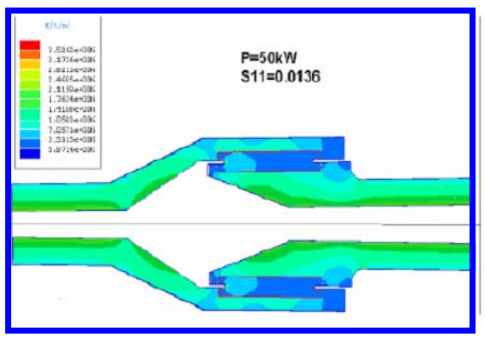
#2-5 - After100 μm BCP, HT, HPR(15') -JLAB

#6,7 – Additional 20 μm BCP, HPR(30')-JLAB

Fermilab Designed Coupler for 3rd harmonic cavity







Fermilab also helped design 1.3 GHz couplers

Accelerator Technology

- Main Linac:
  - Fermilab proposes to take a leadership role in R&D of the cryogenic elements of the Main Linac.
  - We want to participate in resolving the issues of the quadrupole and BPM placement in the cryomodule.
  - We expect to participate in general Linac Accelerator technology discussions: Alignment, Cavity support and Vibration, instrumentation, assembly etc.
  - Issue of the Linac layout, (1 vs. 2 tunnel)

US Laboratories Collaboration: A Model

Cavity Fabrication & Testing

↓

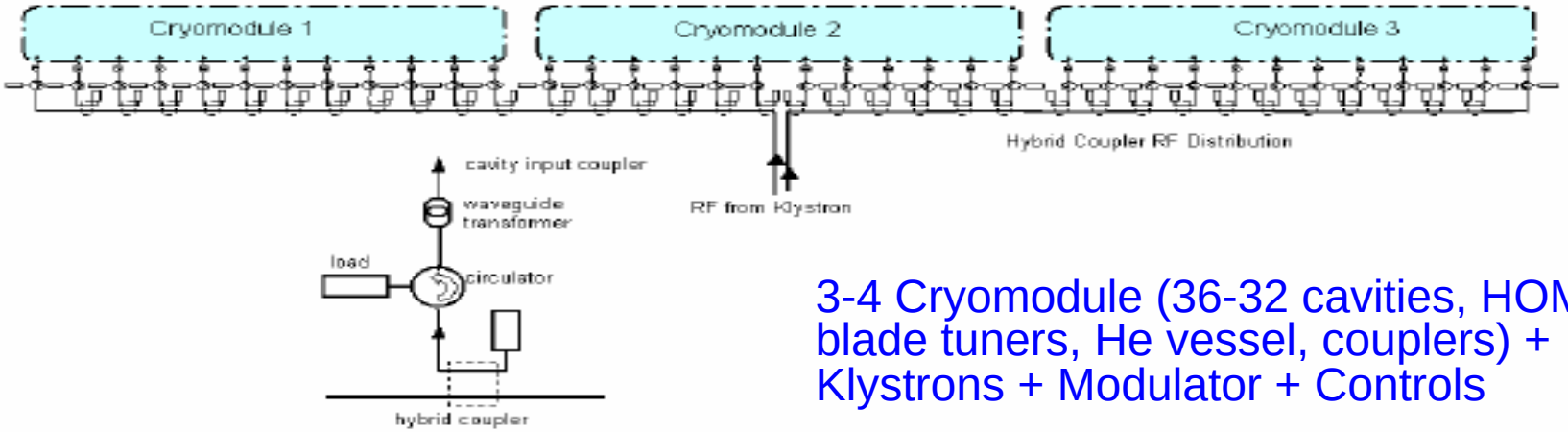
Cryomodule Assembly

↓

Testing at SMTF

- All cryogenic elements of the Linac are developed under Fermilab leadership in collaboration with US and International laboratories and tested at SMTF.
- We expect that the 1.3 GHz cryomodules will be developed in collaboration with Jlab, Cornell, ANL, LANL and Fermilab.
- 3.9 GHz cryomodules will be developed by the exisiting collaboration between Fermilab and ANL.
- The final assembly of the cavitity inside its He Vessel, Coupler, Quadrupole, BPM, Controls and cryostat and power takes place at Fermilab

One ILC RF Unit Construction



3-4 Cryomodule (36-32 cavities, HOM, blade tuners, He vessel, couplers) + Klystrons + Modulator + Controls

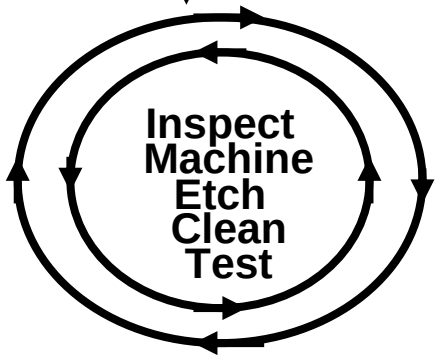
- FY05: 1 3.9 GHz cavity 3rd Harmonic
- FY05: 1 3.9 GHz cavity deflecting

} Finish the construction already in progress.

- FY05: Start fabrication of 1 cyromodule (8, 1.3 GHz cavities) (We are expecting to get 1 additional cryomodule from DESY)
- FY06-08: 3-4 cyromodule (8, 1.3 GHz cavities)
- FY05-07: 2 cryomodule (4, 3.9 GHz 3rd Harmonic cavities) FY05-07

Development of Cryomodule

Raw Niobium Material
Formed and Machined Components



Internal Cavity Section Welding

Half Cells
Dumbells
Multi Cells

Iris Weld
Equatorial Weld

End Section Fabrication Welding

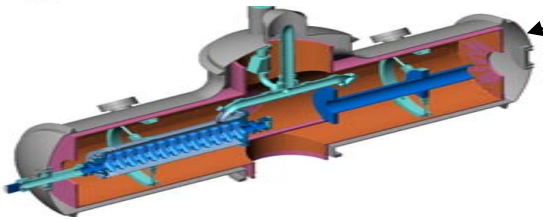
Antenna
Formteil
HOM Coupler
Beam Tube
Input Coupler
Flanges
End Half Cells
Adapter Ring

Bare Cavity Vertical Test

Install He Vessel

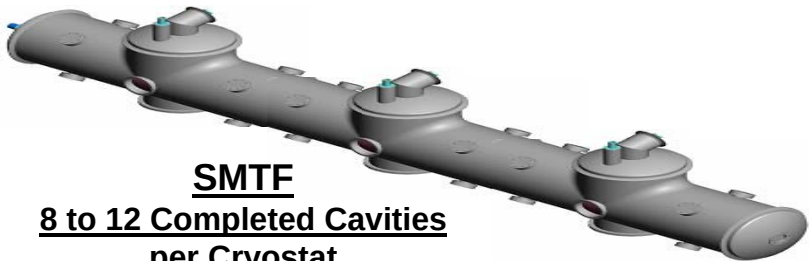
Completed Cavity

Completed Cavity Horizontal Test



1 or 2 Helium Vesseled Cavites
in Horizontal Test Stand

Delivery



SMTF
8 to 12 Completed Cavities
per Cryostat

Development of a 1.3 GHz Cryomodule: US Collaboration: A Model

- Lab A: Niobium to Bare Cavity, BCP, Vertical Test
- Fermilab: HOM, Single cavity He Vessel, Blade Tuner, Couplers
- Lab B: Electro-polishing, Assembly of the single cavity in He vessel, Horizontal test.
- Lab C: Cryostat
- Fermilab: Assembly of cavities, quads, BPM, controls in cryomodule

Superconducting Module Test Facility

- The goal is to develop U.S. capabilities in high gradient superconducting accelerating structures in support of the ILC and other accelerator projects of interest to the U.S. laboratories.

- A consortium of US laboratories and universities are proposing to construct a Superconducting RF Module Test Facility (SMTF) under the Fermilab leadership.

- Facilitate the formation of a U.S. SCRF accelerator collaboration that will eventually develop, along with our international partners, a design for the ILC main linac.

- It will facilitate state-of-the-art developments in high gradient and high Q SCRF cavities.

- Fermilab has proposed to host of SMTF.

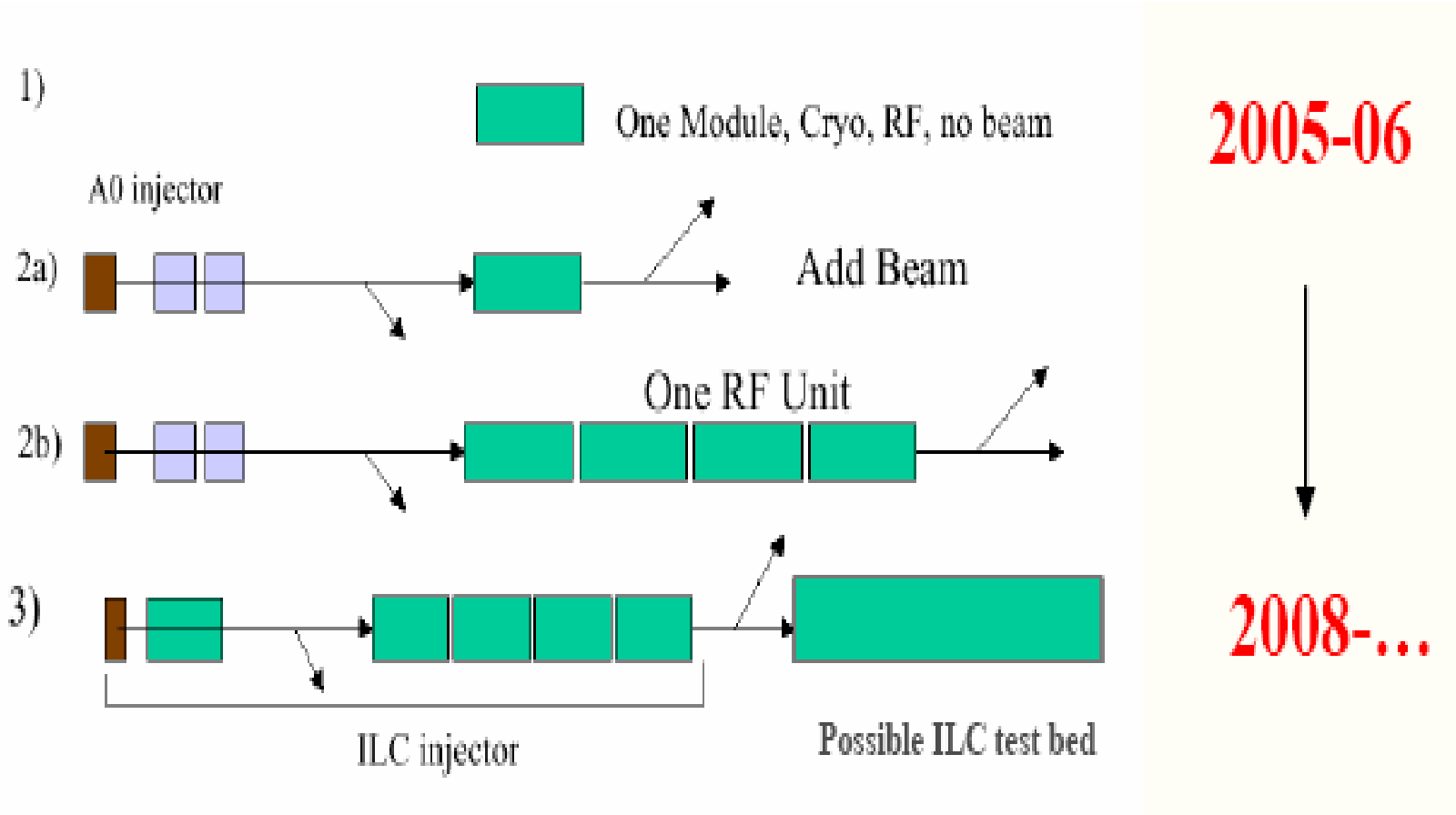
Specific Goals for ILC: SMTF

- Demonstration of superconducting cavities with > 35 MV/m accelerating gradients operating at 1.3 GHz, in pulsed operation with a 1% duty factor and with high beam loading.
- Development of U.S. industrial capability for the fabrication of high performance SCRF cavities and associated infrastructures. High gradient pulsed test area:
- Accelerate beam to ~ 1 GeV utilizing high performance accelerating cavities (> 35 MV/m, Q> 1e10).
  - An electron beam source (ILC quality beam) and accompanying diagnostics

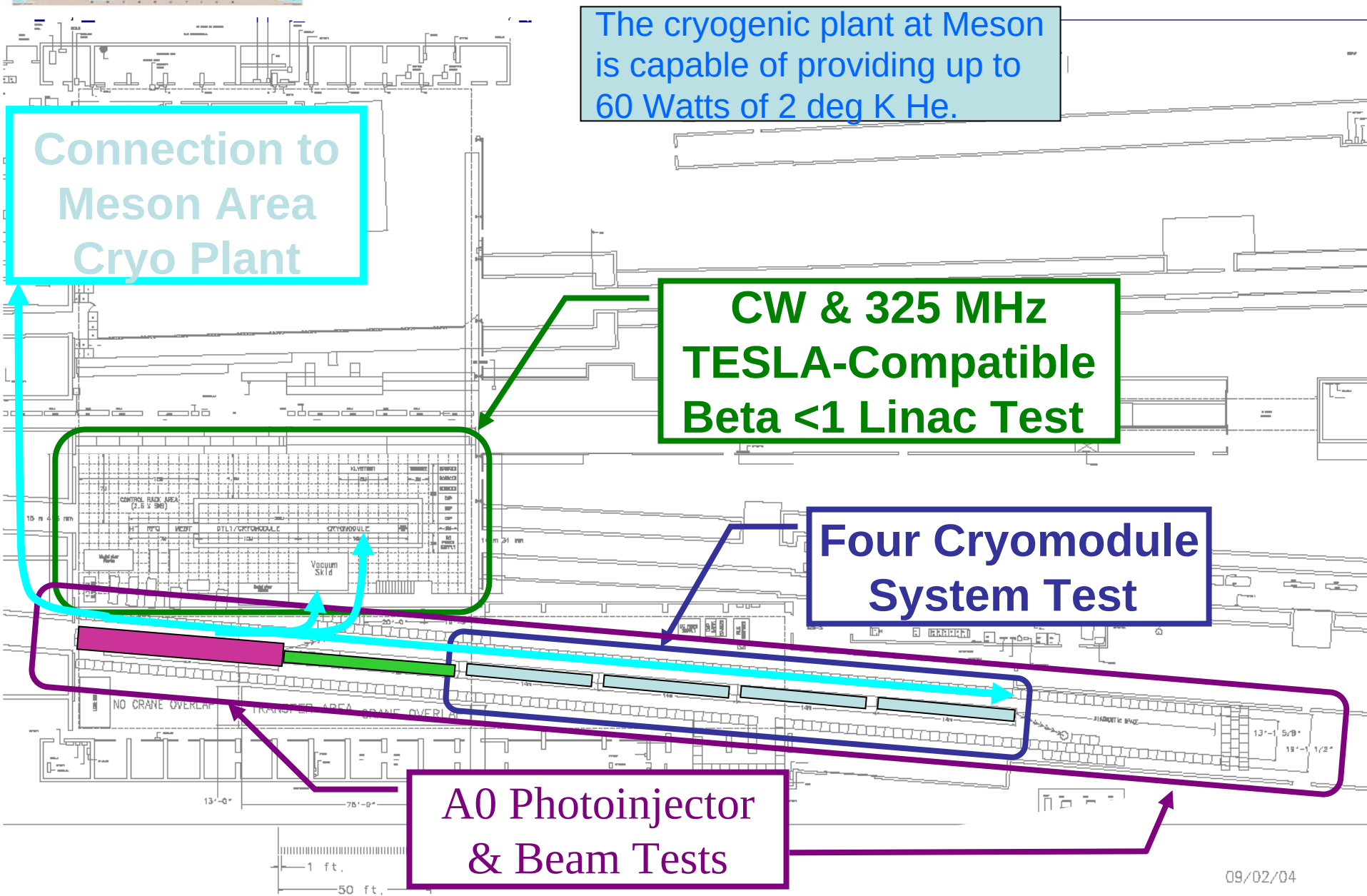
Phases of ILC: SMTF

- Phase 1:
  - Installation of infrastructure culminating in the rf power tests of a single ILC cryomodule within the high gradient pulsed test area.
  - This cryomodule is anticipated to be provided by DESY.
  - Relocation and re-commissioning of the Fermilab NICADD Photoinjector in the SMTF.
- Phase 2a:
  - Initiate beam tests of a single ILC cryomodule utilizing the photoinjector.
- Phase 2b:
  - A complete ILC rf unit, consisting of four high performance cryomodules, fabricated by the SMTF collaboration with industrial partners.
  - Install, and operate this rf unit with beam
- Phase 3: At the end of Phase II a very significant facility will exist with opportunities for evolution in a variety of directions.
  - We anticipate that future development of the facility beyond Phase 2b will be determined in consultation with the ILC Global Design Initiative

SMTF: Three Phase Approach



FNAL Meson Area SMTF Layout



SMTF Expression Of Interest

- Participating institutions are writing a EOI for the SMTF.
- This EOI is a outline of a plan that this collaboration wants to undertake in USA.
- The SMTF collaboration is going to meet at JLab on Sept. 30th 2004 to discuss the EOI.
- The EOI will be submitted to the Fermilab Director in the first week of Oct. 04.
- We anticipate that after some consultation with the DOE, Fermilab will respond with guidance on the next steps by the end of Oct. 04.

Agenda of SMTF Meeting @ Jlab

September 30, 2004

Chair: Nigel Lockyer (Agenda and goals of meeting) 8:00-8:15

1. Welcome, Swapan Chattopadhyay (JLAB) 8:15-8:20
2. Fermilab view of SMTF, discussions with ILC-America and ILC, Steve Holmes, (What is expected of the SMTF collaboration, Role of SMTF in ILC-America and ILC) (20 min +10 min) 8:20-8:50
3. SLAC perspective on SMTF and ILC, David Burke (20 min + 10 min) 8:50-9:20
4. JLAB perspective on the ILC R&D, SMTF and technology transfer to industry, Christoph Leeman/Swapan Chattopadhyay (20 min + 10 min) 9:20-9:50

Next three talks address three main areas of the SCRF R&D interest in US.

5. Goals of SMTF collaboration and discussions with TESLA, Helen Edwards (15 min + 5 min) 9:50-10:10
6. ILC Goals and Infrastructure Requirements, Shekhar Mishra 10:10-10:30 (15 min + 5 min)

Break 10:30-11:00

Chair: Townsend Zwart (MIT)

7. CW Cavity program goals and infrastructure Requirements, John Corlett (LBNL) (15 min + 5 min) 11:00-11:20
8. Proton Driver and beta < 1 cavity goals and Infrastructure requirements, G. William Foster (Fermilab) (15 min + 5 min) 11:20-11:40
9. View from DESY, Albrecht Wagner, (Phone/Video) 11:40-12:00

Lunch 12:00-1:00

10. Tour of SCRF facility at Jlab 1:00-2:00

Chair: Ilan Ben-Zvi (BNL)

11. Straw man plan for the cavity fabrication in US, Hasan Padamsee(Cornell)/ Warren Funk(JLAB) (Big picture of cavity fabrication, existing infrastructure in USA, what we will need for SMTF, industrialization of cavity fabrication) (30 min + 15 min) 2:00-2:45
12. Straw man plan for Cryomodule fabrication in US, P. Kelley (LANL)/Joe Preble(ANL)/Joel Fuerst(ANL) (Big picture of the cryomodule fabrication US, How do we transport cryomodule from DESY to Fermilab, How do we bui this infrastructure at US labs and industries) (20 min +10 min) 2:45-3:15
13. Fermilab infrastructure for SMTF, Peter Limon (20 min + 10 min) 3:15-3:45 (ILC talk #6, CW #7, Proton Drive #8)

Break 3:45-4:15

Chair: Kwang-Je Kim (ANL)

14. Status of EOI document, Nigel Lockyer (20 min + 10 min) 4:15-4:45
15. Communication and Outreach, Judy Jackson/Neil Calder 4:45-5:00
16. View from KEK, Nobu Toge (Phone/Video) 5:00-5:30
17. Discussion on SMTF organization, (Shekhar Mishra, Nigel Lockyer) 5:30-6:45

(We are requesting the following people to lead the discuss on these topics to start)

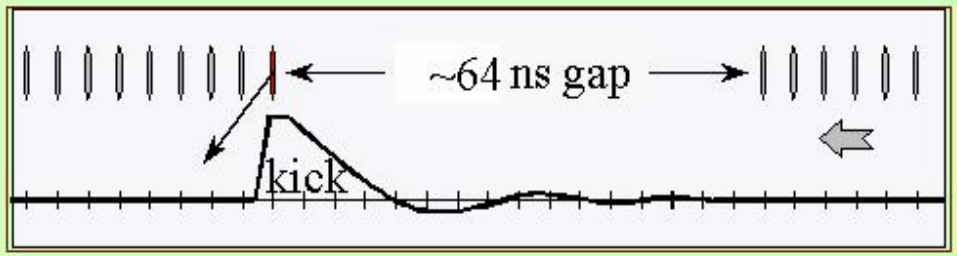
SMTF Organization, Swapan Chattopadhyay
Co-ordination with in USA laboratory and Funding Agencies, Steve Holmes
Co-ordination with US and international industries, Harry Carter (Fermilab)
University involvement, Mark Oreglia (Chicago)
Next step.

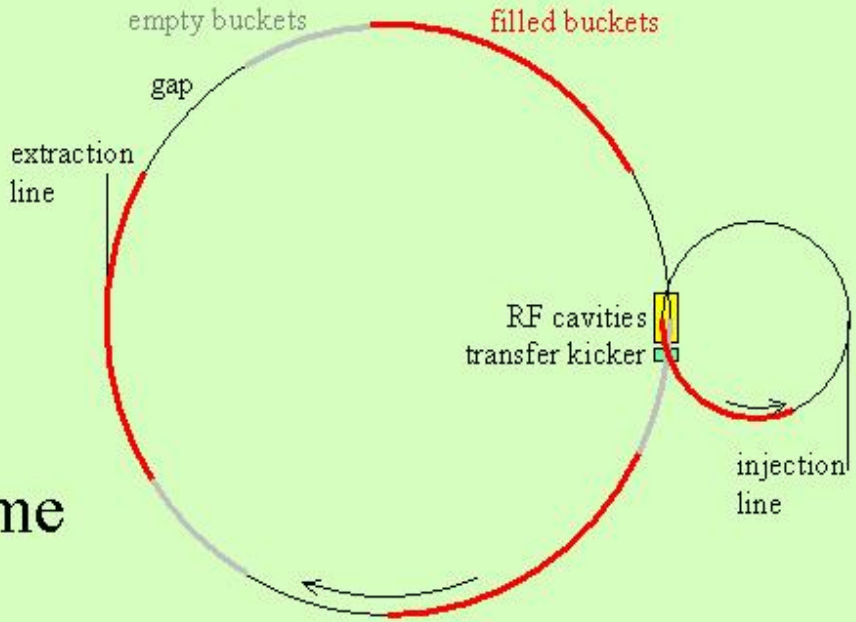
Dinner at a local restaurant

Open Meeting for SCRF

ILC: Small Damping Ring

Multi-Bunch Trains with inter-train gaps





- always inject and eject the last bunch in a train
- kicker rise time < 6 ns, but fall time can be ~gap length
- beam loading maintained by ~100 m ring with shared RF system
- ~6 km ring filled by transfers of undamped trains from the ~100 m ring

J. Rogers

Damping Ring

TESLA TDR Damping Ring 6.4.2

August 26, 2004

Lattice Parameters

Energy	E	5 GeV
Circumference	C	17 km
Revolution Frequency	f_0	17.634 kHz
RF Voltage	V_{RF}	50 MV
RF Frequency	f_{RF}	497.28 MHz
Harmonic Number	h	28200
Horizontal Tune	Q_x	76.310
Vertical Tune	Q_y	41.180
Synchrotron Tune	Q_s	0.0707
Momentum Compaction	α_p	1.22×10^{-4}
Natural Bunch Length	σ_z	6.04 mm
Natural Energy Spread	σ_δ	1.29×10^{-3}
Energy Loss per Turn	U_0	20.4 MeV
Horizontal Damping Time	τ_x	27.9 ms
Vertical Damping Time	τ_y	27.9 ms
Longitudinal Damping Time	τ_ϵ	13.9 ms
Natural Emittance	ϵ_0	0.508 nm
Horizontal Natural Chromaticity	ξ_x	-125
Vertical Natural Chromaticity	ξ_y	-62.5

Beam Parameters

Number of Bunches	n_b	2820
Bunch Spacing	$\Delta\tau_b$	20.1 ns
Particles per Bunch	N_0	2.0×10^{10}
Average Current	I	159 mA

ILC Small Damping Ring Version 0

August 26, 2004

Lattice Parameters

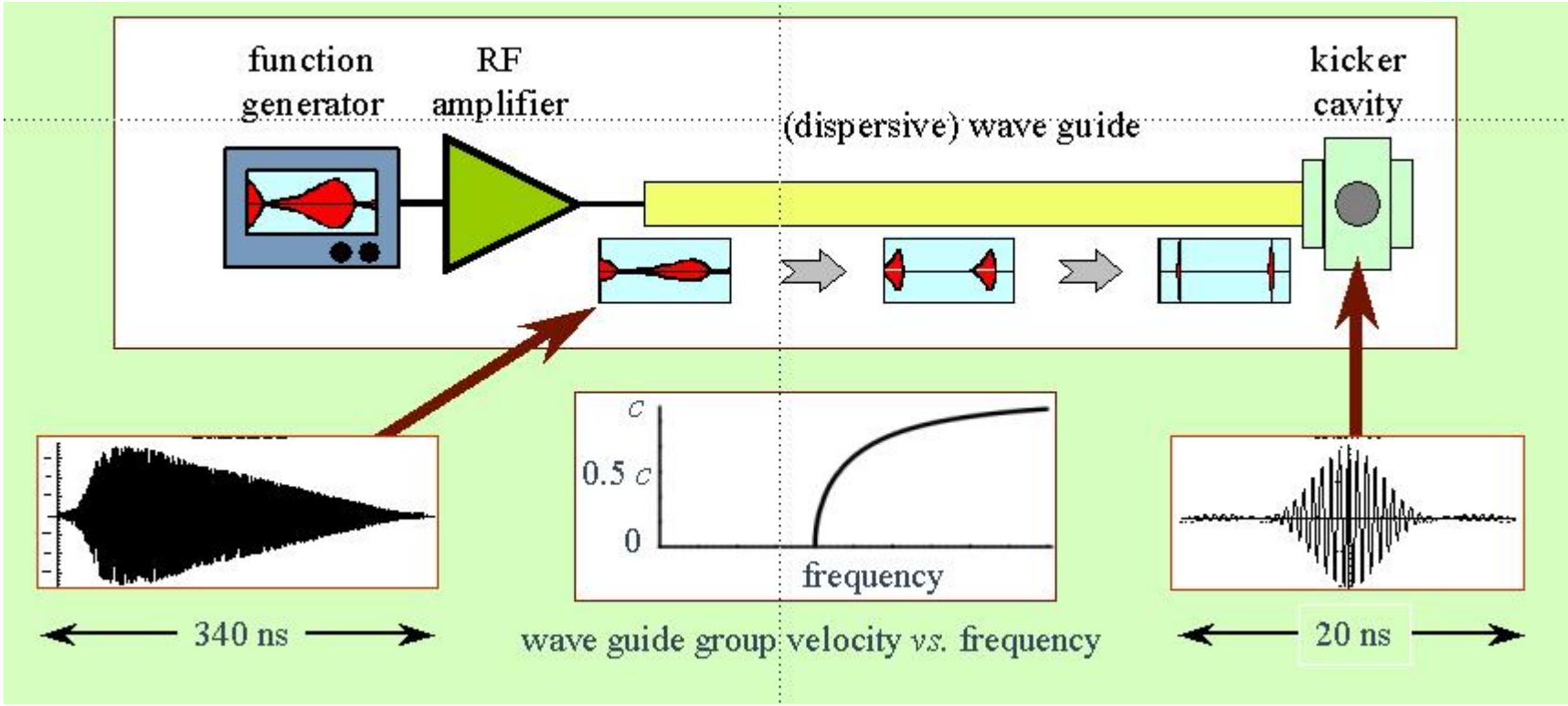
Energy	E	5.066 GeV
Circumference	C	6.114 km
Revolution Frequency	f_0	49.034 kHz
RF Voltage	V_{RF}	27.720 MV
RF Frequency	f_{RF}	500.00 MHz
Harmonic Number	h	10197
Horizontal Tune	Q_x	56.584
Vertical Tune	Q_y	41.618
Synchrotron Tune	Q_s	0.0348
Momentum Compaction	α_p	1.42×10^{-4}
Natural Bunch Length	σ_z	6.00 mm
Natural Energy Spread	σ_δ	1.51×10^{-3}
Energy Loss per Turn	U_0	7.73 MeV
Horizontal Damping Time	τ_x	26.7 ms
Vertical Damping Time	τ_y	26.7 ms
Longitudinal Damping Time	τ_ϵ	13.4 ms
Natural Emittance	ϵ_0	0.548 nm
Horizontal Natural Chromaticity	ξ_x	-74.4
Vertical Natural Chromaticity	ξ_y	-55.4

Beam Parameters

Number of Bunches	n_b	2820
Number of Bunch Trains		60
Bunches per Train		47
Bunch Spacing Within Train	$\Delta\tau_b$	6.0 ns
Spacing Between Trains		340 ns
Particles per Bunch	N_0	2.0×10^{10}
Average Current	I	443 mA

Aimin Xiao

A Pulse Compression Fourier series Kicker



This design is being developed by George Gollin in collaboration with Ralph Pasquinelli et al.

Damping Ring: Instabilities

RF and Beam Stability Issues (K.Y. Ng)

Single-Bunch			
Longitudinal	$\left.\frac{Z_0^{\parallel}}{n}\right\|_{\text{eff}} \lesssim 150\ \text{m}\Omega$	safe	Tesla 100 mΩ
Transverse	$\left.Z_1^V\right\|_{\text{eff}} \lesssim 2.34\ \text{M}\Omega/\text{m}$	safe with space charge	Tesla 1.8 MΩ/m
Multi-Bunch			
Longitudinal	$\tau \gtrsim 20$ ms $> \tau_{\text{damp}} = 13.5$ ms	safe	Tesla 134 ms
Transverse	$\tau^{-1} = 9600\ \text{s}^{-1}$ (5 turns)	safe with damper	Tesla 15300 s^{-1} (1.5 turns)
Electron Cloud			
w/o solenoids	$\tau \sim 3.3$ ms		
with solenoids	$\tau \sim 1$ s	safe	
Fast-Ion Instability			
preliminary simulations	emittance grows by $\sim e^{40}$, but $< 20\%$ with feed back		
RF			
12 sc cavities	syn. angle variation $< 0.09^\circ$ (beam loading) half bunch length increase ~ 0.5 ps		

Fermilab: The host of ILC

- Fermilab/Northern Illinios/U.S. is a natural host
- Scientific and engineering expertise in forefront accelerator and detector technologies
- Significant experience in construction and operations of large accelerator based projects.
- The flagship laboratory of U.S. high energy physics
- Strong scientific base, including two national laboratories and five major research universities.
- Geology ideally suited to a Linear Collider
- Transportation and utilities infrastructure system that could support LC construction and operations.

ILC Detector R&D

SiD

Silicon Outer Tracker
Fermilab/SLAC
Plus others

Muon Detection

Colo. State, UC Davis, Fermilab,
Northern Illinois Univ.,
Univ. of Notre Dame, Wayne State Univ.,
Univ. of Texas Austin, INFN Frascati

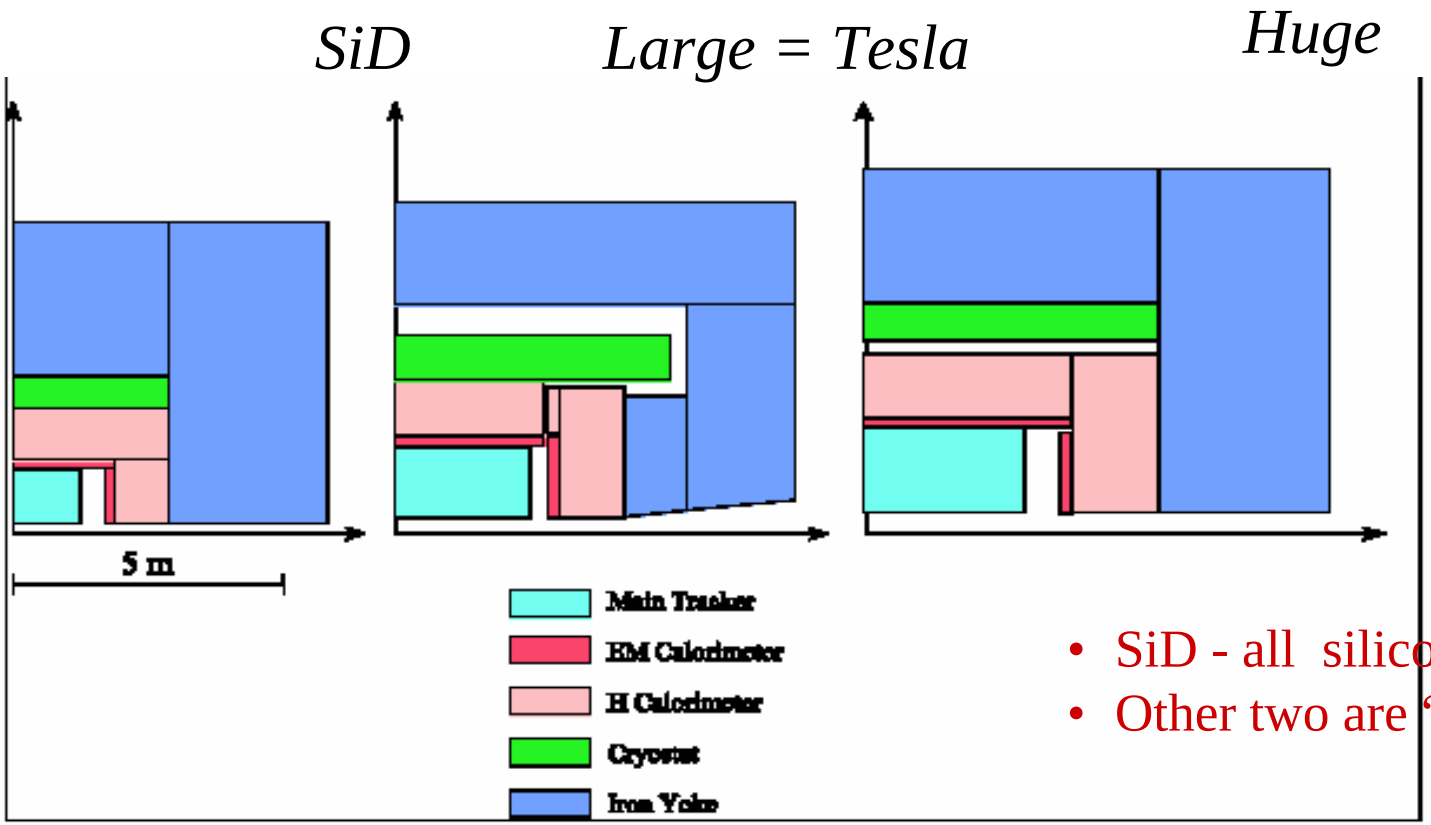
ASICS, Scintillator Cal, Test Beam etc.

ANL, Fermilab, NIU, UTA, Colorado, ….

3 Concepts in progress by 3 Regions

Up to the middle of 2004, all ILC detector activities in the world were on generic detector R&D

Since July of this year (Victoria, ALCPG mtg), detector concept design studies started & 3 concepts in progress:



- SiD - all silicon based tracking
- Other two are "TPC" based:

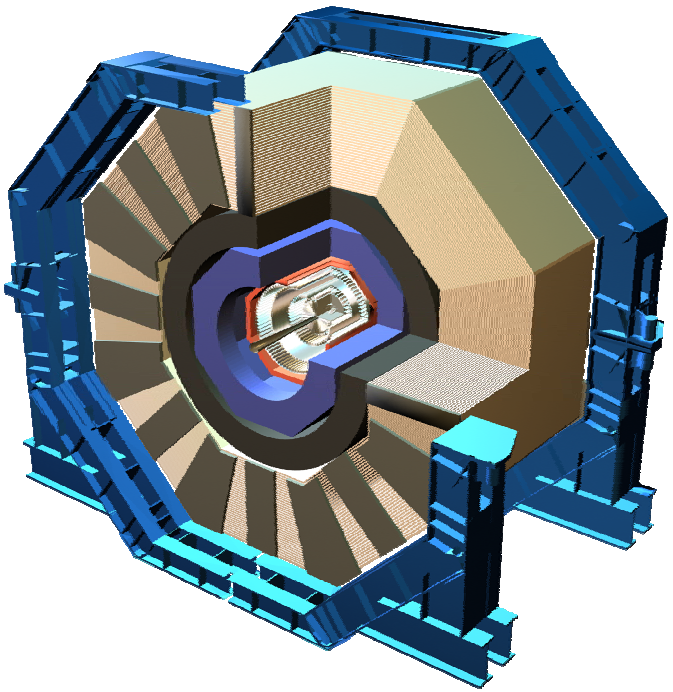
Goal of Detector design studies

- By end of 2005: CDR exists, incl. cost estimates & physics performance comparisons between designs.

SiD design study is current focus at Fermilab:

- Silicon tracker layout & design (SiDet: *Demarteau*, *Cooper*, ++)
- Muon detector expertise at FNAL by Muon R&D (*Fisk*, *Milstene*)
- ASIC developments (*Tkaczyk*, ASIC groups)
- Computing Division Liaison (*Yeh*)
- Effort lead by FNAL & SLAC (*Weerts & Jaros*)

- Hadron calorimetry expertise (ANL, NIU & UTA)
- Expect FNAL mechanical engineering on overall design, integration and support
- User institutions involved in simulation (Kansas State, +++)



SiD simulation

http://www-sid.slac.stanford.edu

FNAL site coming

Test Beam for ILC Detector Development at Fermilab

The ILC detector R&D groups are currently designing and building prototype detectors to be tested in electron and hadron test beams (~1 GeV to 150GeV).

A worldwide document outlining the testbeam needs has been written and specific proposal to Laboratories are being created.

Calorimeter prototypes will exist by beginning of next year.

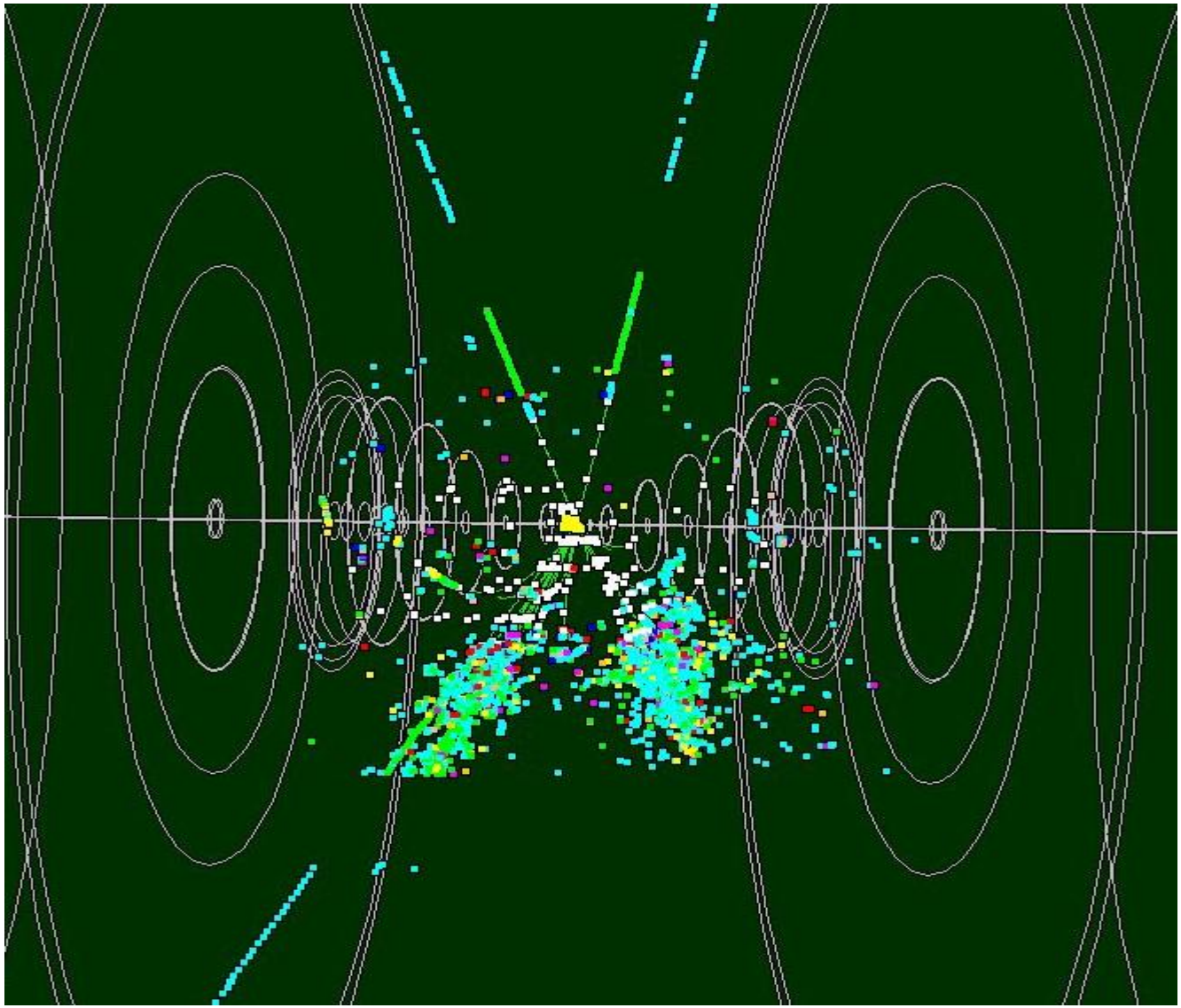
Needs of calorimeter R&D groups are most demanding and there has been a lot of interaction between FNAL testbeam coordinator (*E.Ramberg*) to see how ILC testbeam needs can be addressed at Fermilab.

NIU simulation study

500 GeV ZH event

$Z \rightarrow \mu\ \mu$

$H \rightarrow b\ b_{bar}$
(μ tag)



ASICS, Scintillator Cal, etc.

ANL, Fermilab, NIU, UTA, Colorado, ….

- ASICs for RPC and GEM FE & Readout: Fermilab w/ANL, NIU, UTA, .
- ASIC for HV – low current regulation, for APDs, Si PMs, etc. Fermilab: Wester, Tkaczyk, ..
- Thinning of Si for VTX w/Purdue; ASIC readout – CCD w/OU
- Test Beam tail-catcher - HCAL tests – structural engr/fabr
- Use of scintillator extrusion facility w/NIU NICADD

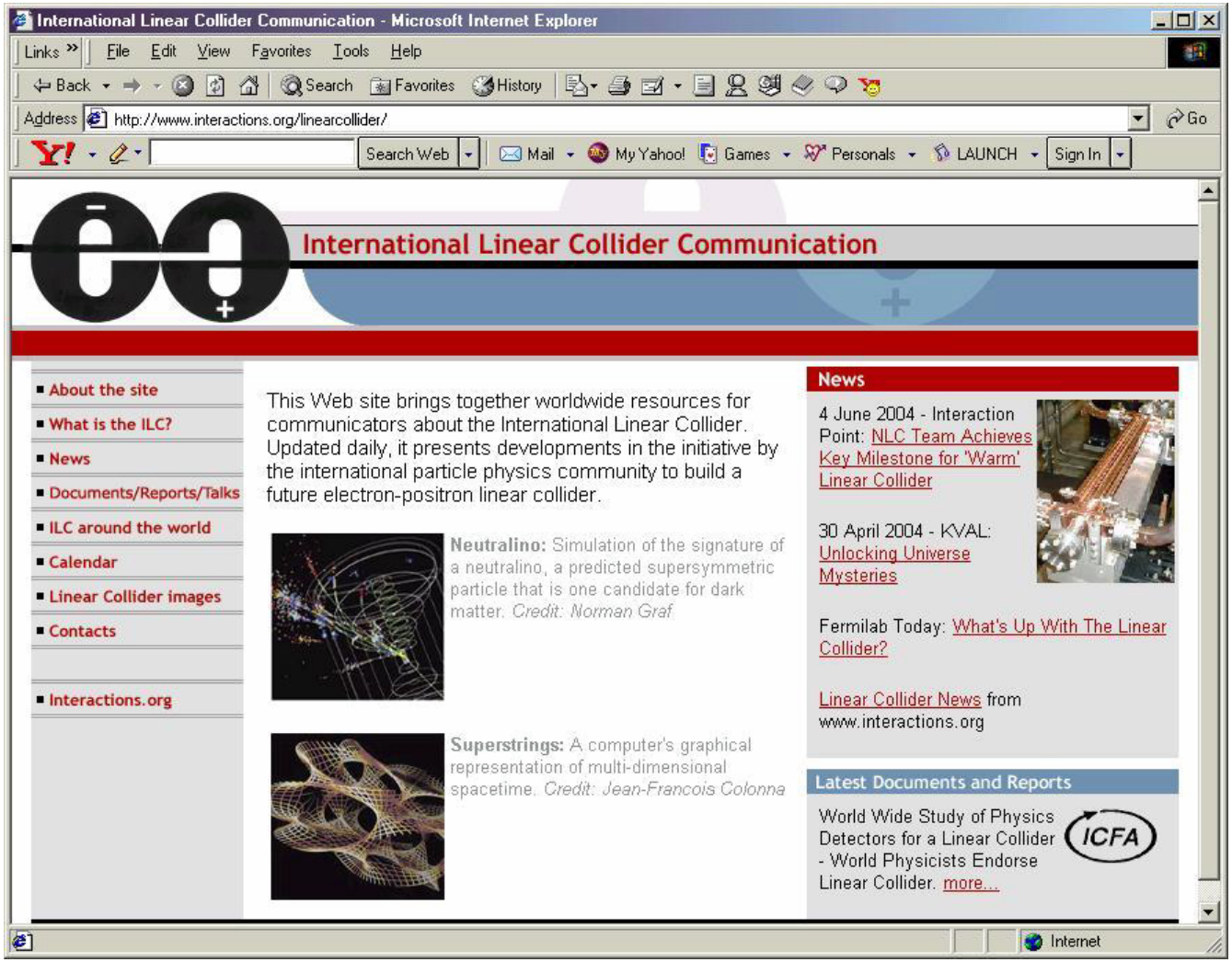
Focus of ILC Detector R&D

- Simulation studies: Performance of detectors and algorithms.
- R&D to provide firm understanding of detector technology:
  - Specifications for front-end, analogue and digital electronics.
  - Will detectors meet physics goals
  - Robust and test-beam hardened
  - Well enough understood engineering, procurement, manpower and assembly cost for CDRs and TDRs.
  - University, National and International involvement

Communication is key

- Among national and international partners
- With funding agencies
- Between Fermilab and SLAC
- With government
- With the media
- With our neighbors
- Within our own laboratory

Leadership From Fermilab



http://www.interactions.org/linearcollider/

Fermilab and ILC communication

- Leads Interaction Collaboration
- Government outreach
  - Met 9/22 with state, federal legislative affairs reps
- Public Participation
  - Community Task Force
- Fermilab ILC Outreach Group
- Fermilab Today ILC Series
- Colloquia, Talks, Workshops
- “Communication” at KEK

INTERACTIONS

Fermilab Community Task Force
On Public Participation

Fermilab Today

What's Up with the Linear Collider?

Summary

- Fermilab is preparing to host ILC.
- After the Technology Recommendation our ILC R&D effort is getting focused on SCRF Linac design.
- Fermilab will take a leadership role in the Main Linac design and construction. We take a secondary role in other parts of the accelerators like Source, Damping Ring, Machine and Detector Interface.
- We will concentrate in a few areas of Detector R&D, building on our strength of other large detector projects.
- Fermilab's ILC R&D effort gives the highest priority to openness and collaboration. We invite and welcome participation from any part of the nation and the world on this truly global project.