ILC R&D at Fermilab and the SMTF Plan

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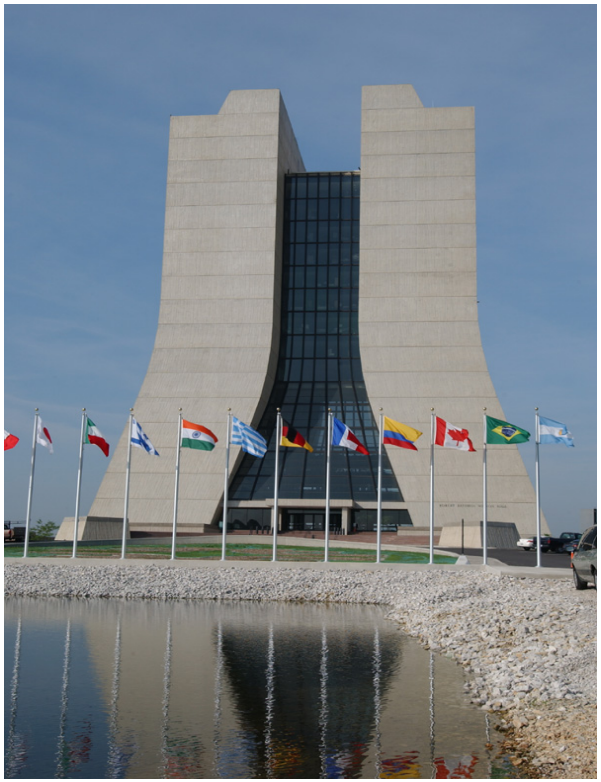
ILC R&D

Fermilab



An International Project → An International Laboratory

Recent News

- Fermilab has participated in the R&D of the both the X-Band and L-Band Linear Collider R&D.
- R&D status and need for resources required that the community must make a selection between the two technologies.
- ILCSC under ICFA formed a International Technology Recommendation Panel (ITRP).
- 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

The Fermilab Long Range Plan: Vision

- The Fermilab Director established the Fermilab Long Range Planning Committee (FLRPC) in the spring of 2003. The committee has completed its report and it is available at:

http://www.fnal.gov/directorate/Longrange/Long_range_planning.html

- The overarching vision is that Fermilab will remain the primary site for accelerator-based particle physics in the U.S. in the next decade and beyond. Two fulfillments of this vision are presented in the report:
  - As host to a Linear Collider Fermilab would be established as a world center for the physics of the energy frontier for decades.
  - If the linear collider is constructed elsewhere, or delayed, Fermilab would strive to become a world center of excellence in neutrino physics, based on a (SClinac) multi-MW "Proton Driver", still with significant LC participation.

The Fermilab Long Range Plan:
Recommendations

- In support of this vision the FLRPC report offers a series of recommendations:
  - Linear Collider recommendations aim at establishing leadership in two significant technical areas (e.g. linac and sources), playing a leading role in the major engineering systems test, and taking the steps necessary to allow Fermilab to make a strong bid to become LC host laboratory.
    - Goal is to establish Fermilab as a leading contender for host lab.
  - Proton Driver recommendations aim at establishing the physics case, and developing the SC linac technology to the point that a cost benefit analysis can be done and the linac/synchrotron technology selection made.
    - Leading to documentation sufficient to support CD-0 (establishment of mission need in the DOE system).

Fermilab is pursuing linear collider and proton driver R&D in parallel.
The cold decision allows close alignment of these paths.

International Performance Specification

- Initial maximum energy of **500 GeV**, operable over the range 200-500 GeV for physics running.
- Equivalent (scaled by 500 GeV/$\sqrt{s}$) integrated luminosity for the first four years after commissioning of **500 fb^{-1}**.
- Ability to perform energy scans with minimal changeover times.
- Beam energy stability and precision of 0.1%.
- Capability of **80%** electron beam **polarization** over the range 200-500 GeV.
- **Two interaction regions**, at least one of which allows for a crossing angle enabling $\gamma\gamma$ collisions.
- Ability to operate at **90 GeV** for calibration running.
- Machine upgradeable to approximately **1 TeV**.

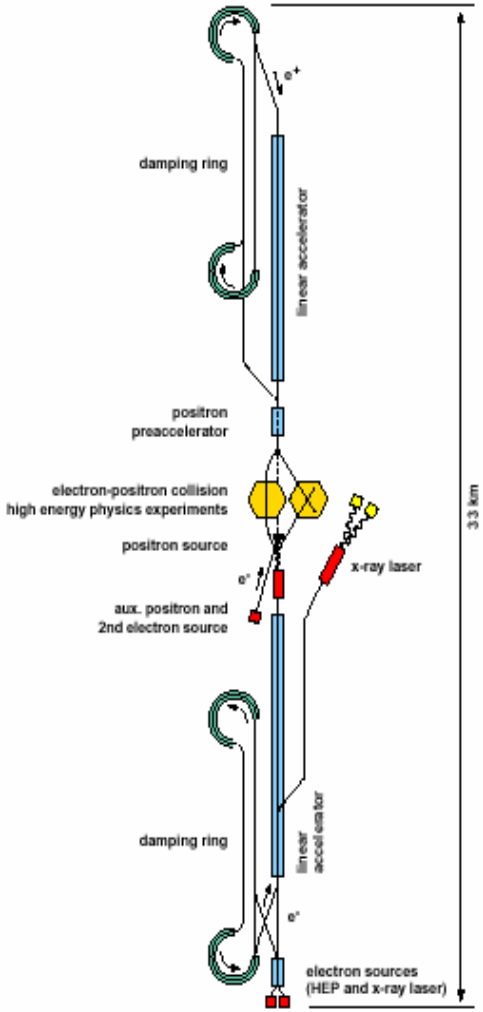
International Linear Collider:
Physical Layouts and Configurations

Two concepts developed to date:

- TESLA TDR
- USLCSG Study

Possible considerations:

- Energy/luminosity tradeoffs at "500" GeV
- Undulator vs. conventional e^+ source
- Upgrade energy
- Head on vs. crossing angle IR
- Upgrade injector requirements
- One vs two tunnels



TESLA TDR

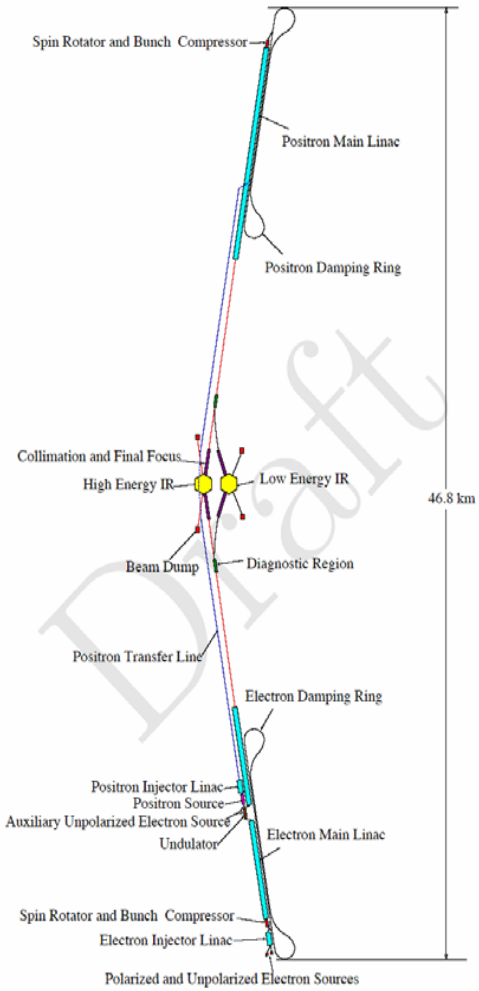


Figure 3.5.1.1: Overall Machine Layout, 500 GeV c.m.

USLCSG Study

ILC Performance Parameters

	TESLA/TRC		U.S. Study			
Center of Mass Energy	500	800	500	1000		GeV
Design Luminosity	34	58	26	38		$10^{33}cm^{-2}sec^{-1}$
Linac rf frequency	1.3		1.3			GHz
Unloaded/loaded gradient	24/24	35/35	28/28	35/35		MV/m
Pulse repetition rate	5	4	5			Hz
Bunches/pulse	2820	4886	2820			
Bunch separation	337	176	337			nsec
Particles/bunch	2	1.4	2			$x10^{10}$
Bunch train length	950	860	950			μsec
Beam power	11	18	11	23		MW/beam
$\gamma\varepsilon_H/\gamma\varepsilon_V$ at IP	10/.03	8/.015	9.6/.04			mm-mrad
σ_x/σ_y at IP (before pinch)	554/5	392/3	543/6	489/4		nm
Site AC power	140	200	180	356		MW
Site length	33		46			km
Tunnel configuration	Single		Double			

ILC has started discussion on coming up with a new parameter set and CRD.

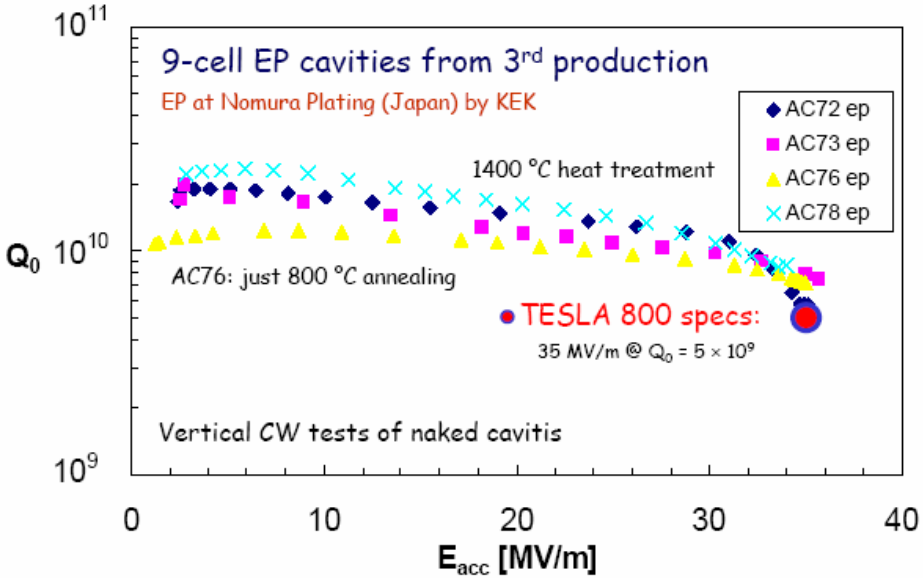
ILC Requirements and Challenges

Energy: 500 GeV, upgradeable to 1000 GeV

- RF Structures
  - The accelerating structures must support the desired gradient in an operational setting <u>and</u> there must be a cost effective means of fabrication.
    - 24-35 MV/m × 20 km
    - ~21,000 accelerating cavities/500 GeV
- RF power generation and delivery
  - The rf generation and distribution system must be capable of delivering the power required to sustain the design gradient
    - 10 MW × 5 Hz × 1.5 msec
    - ~600 klystrons and modulators/500 GeV
  - The rf distribution system is relatively simple, with each klystron powering 24-36 cavities.

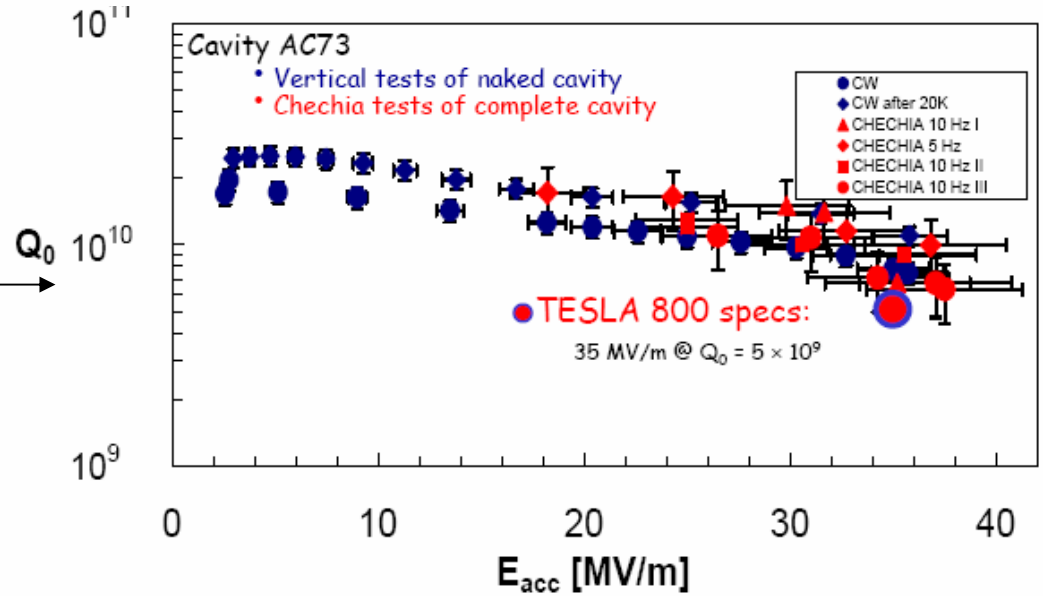
⇒ Demonstration projects: TTF-I and II(DESY); SMTF(USA-FNAL) in conceptualization phase

ILC Technology Status
Accelerating Structures



Vertical (low power test)

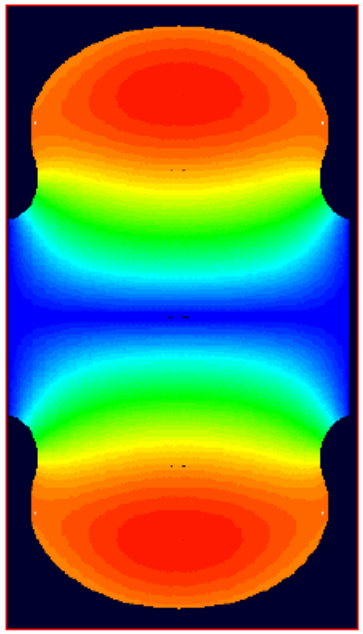
Comparison of low and high power tests (AC73)



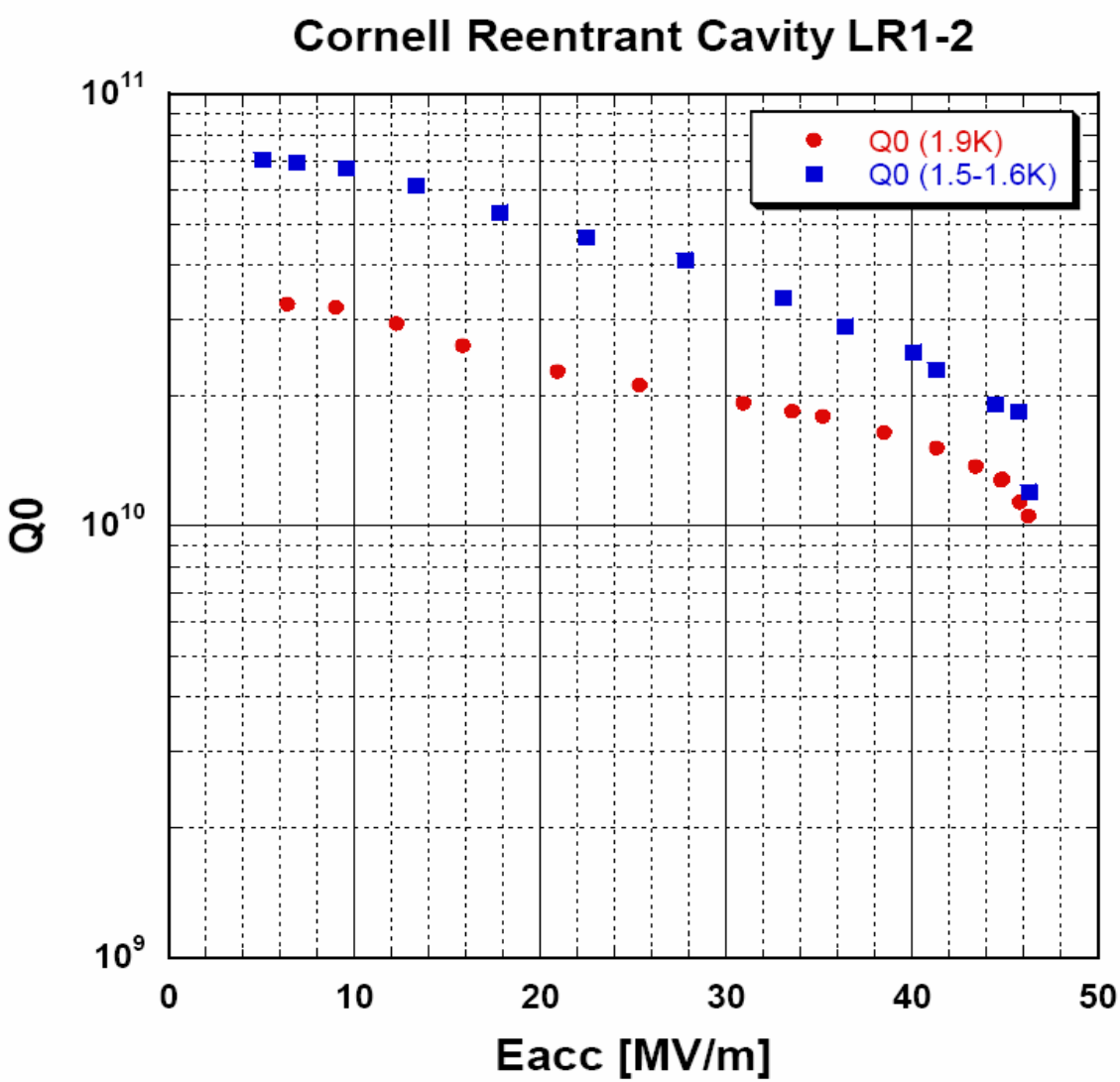
High Gradient Cavity R&D

Re-entrant

RE shape



Cornell University



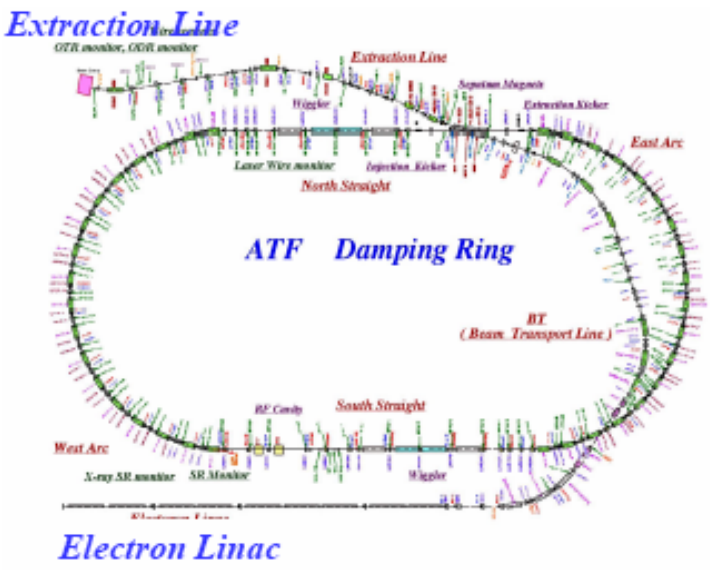
ILC Technology Status
RF Sources

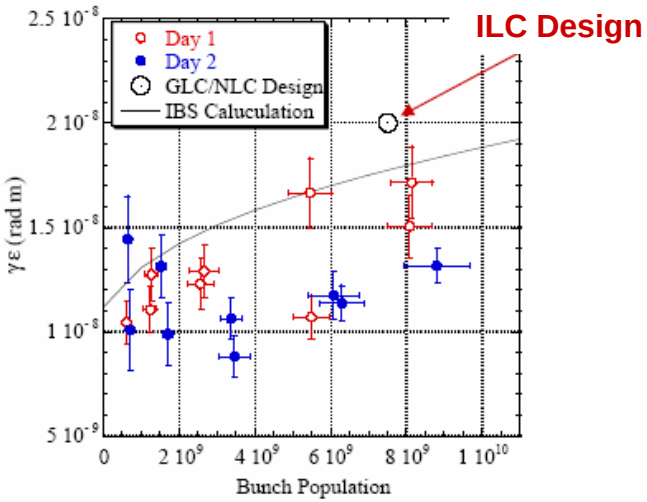
- Three Thales TH1801 Multi-beam klystrons fabricated and tested.
  - Efficiency = 65%
  - Pulse width = 1.5 msec
  - Peak power = 10 MW
  - Repetition rate = 5 Hz
  - Operational hours (at full spec) = 500 hours
  - Operational hours (<full spec) = 4500 hours
- Independent MBK R&D efforts now underway at CPI and Toshiba
- 10 Modulators have been built
  - 3 by Fermilab and 7 by industry
  - 7 modulators are in operation
  - Based on Fermilab design
  - 10 years operation experience

ILC Technology Status

Damping Rings

- The required emittances, $\varepsilon_x/\varepsilon_y$ = 8.0/.02 μm, have been achieved in the ATF at KEK





- Performance is consistent with IBS, however,
  - Single bunch, e^-
  - Circumference = 138 m

ILC Technology Status
Damping Rings

- The total length of the ILC beam pulse is:

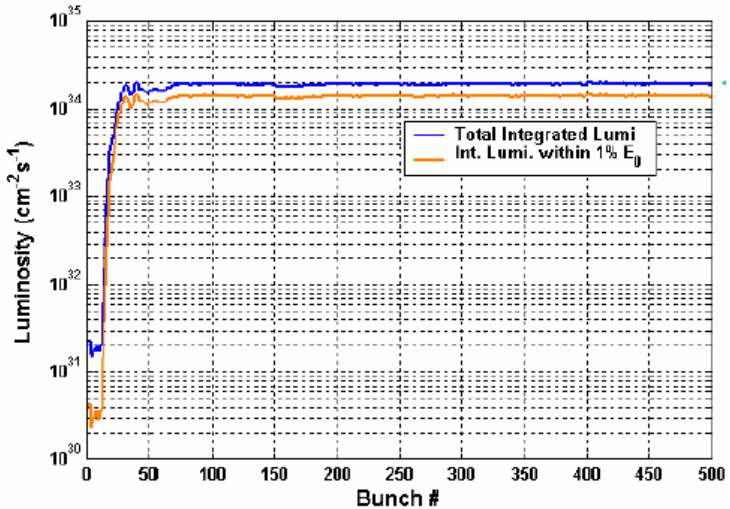
$$2820 \times 337 \text{ nsec} = 950\ \mu\text{sec} = 285 \text{ km (!)}$$

- This creates many unique challenges in the ILC damping ring design:
  - Multiplexing the beam ($\times$16 in the TELSA TDR)
    - Requires fast (~20 nsec rise/fall time kicker for single bunch extraction)
  - Circumference is still ~285/16 = 18 km
    - Space-charge is an issue because of the large C/ε_y (a first for an electron storage ring).
    - X/Y “transformer” used to mitigate.
- A number of ideas exist for reducing the circumference and associated challenges.

ILC Technology Status
Emittance Preservation

- Emittance growth budget from DR to IR is:
  - ×1.2 (horizontal), × 2.0 (vertical)

- Sources of emittance growth include:
  - Wakes
    - Single bunch controlled by BNS damping
    - Multibunch controlled by HOM dampers and tune spread
  - Alignment and jitter
    - ➢ Vertical dispersion × momentum spread = emittance growth
    - ➢ Controlled by alignment and correction algorithms (feedback)
    - ➢ Alignment tolerances ~300 mm, 300 mrad; BPM resolution ~10 mm



- Maintaining beams in collision
  - Intra-train feedback

ILC Technology Status

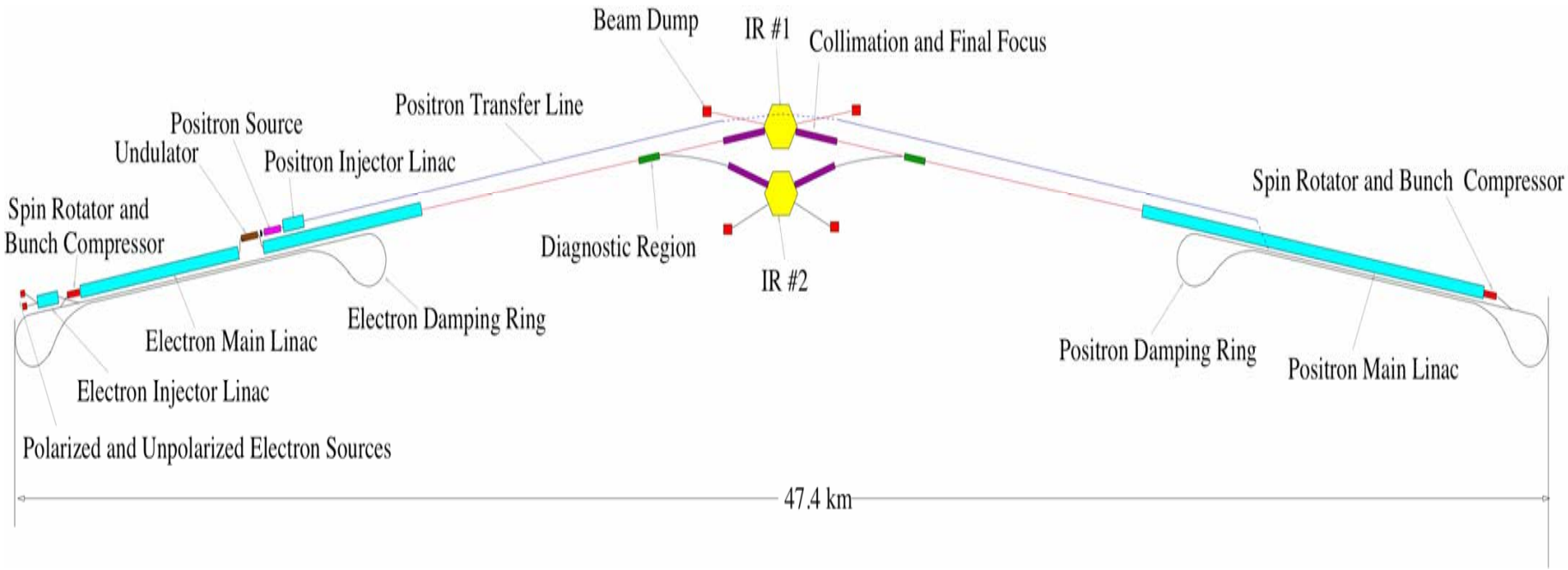
Examples of Outstanding Issues

- RF Structures and Source
  - Establish gradient goal
  - Develop US capability for fabricating high gradient cavities
  - Coupler design
  - Controls/LLRF
  - Industrialization
- Particle Sources
  - Conventional e+
- Damping Rings
  - Length of the current design
  - Common tunnel
  - Commissioning
  - New design concepts to reduce circumference
- Emittance Preservation
  - Alignment of structures inside cryomodules
  - Instrumentation and feedback systems
- Maintaining Beams in Collision
  - Feedback
  - Head-on IR?
- Machine Protection
  - Collimation systems
- Civil
  - 1 tunnel vs. 2
  - Near surface vs. deep

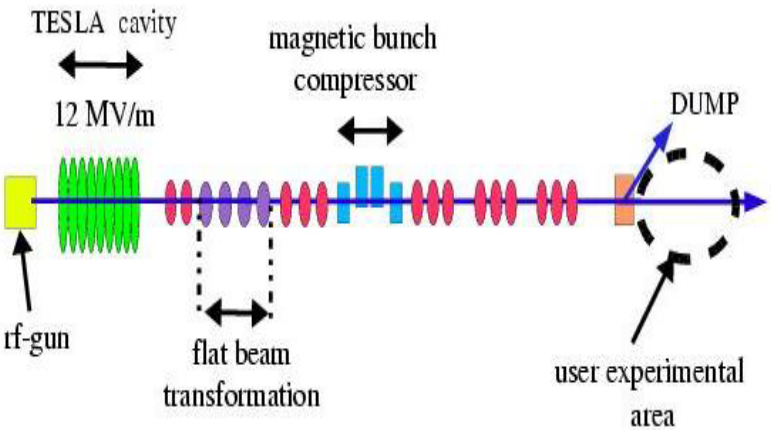
Fermilab: ILC R&D

- 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,cryo system and plant design
    - RF power for the Linac
    - Fast Kicker Development from Damping Ring
    - Source
  - 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, Muon, Fast Readout
- Collaboration & Outreach: Local Universities and ANL, National and International laboratories and Universities, Local public, State and Federal Government

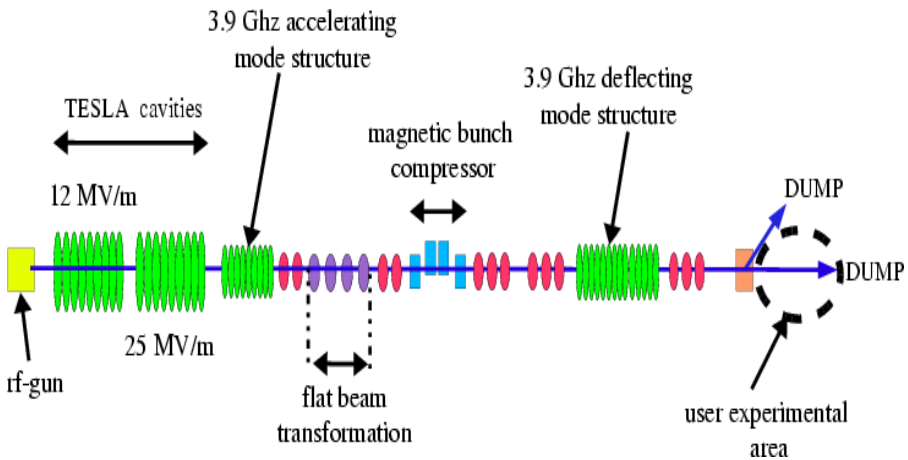
Reference Design



The Fermilab NICADD Photoinjector Laboratory (FNPL)

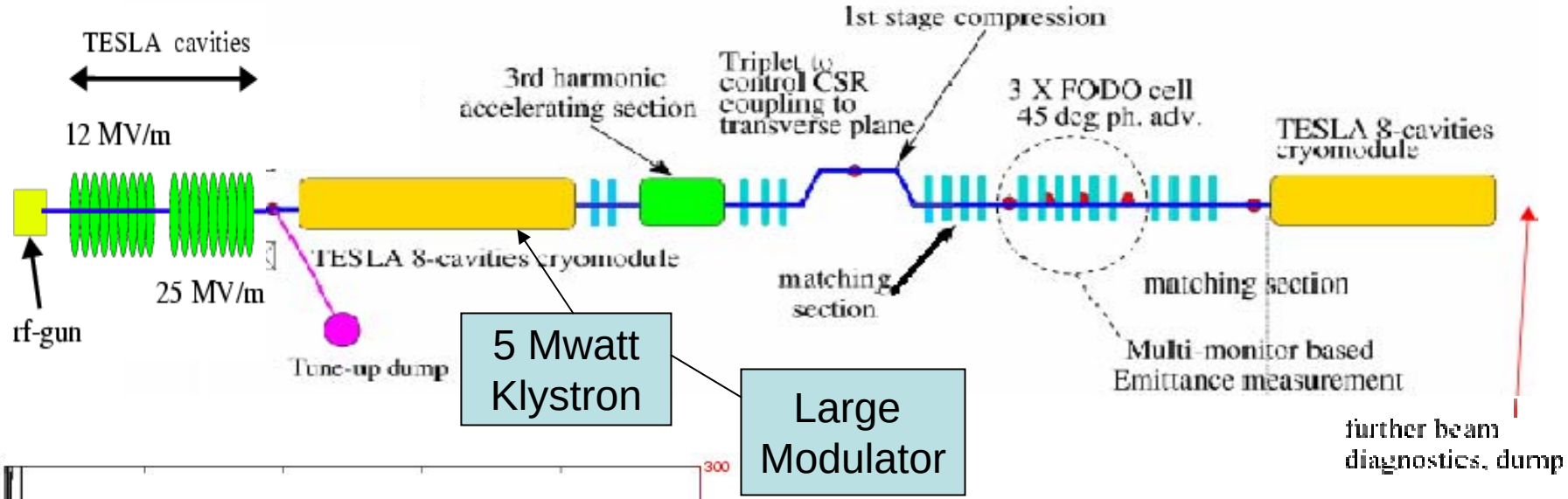


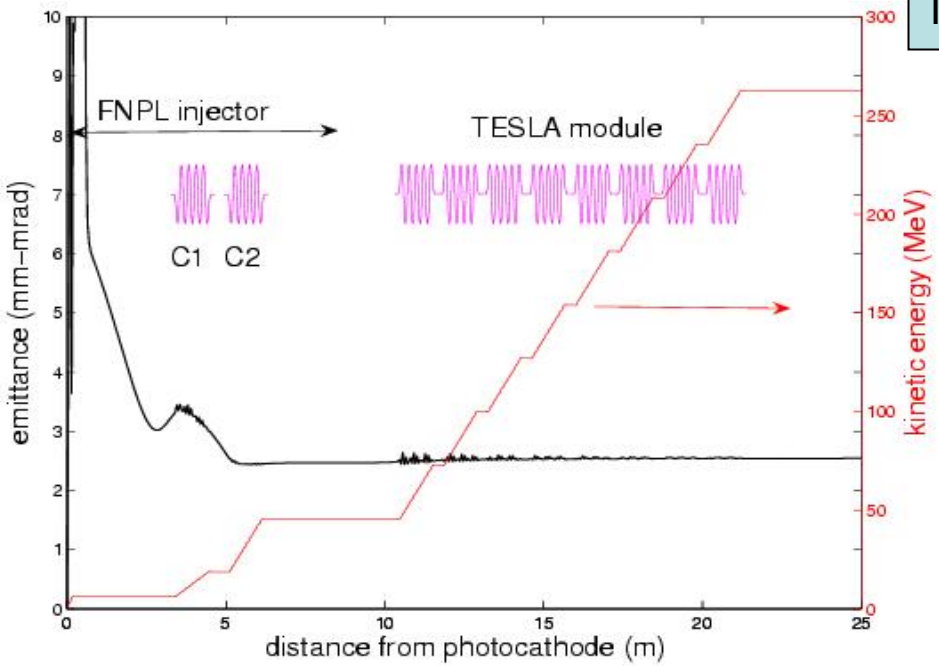
FNPL Upgrade



- 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

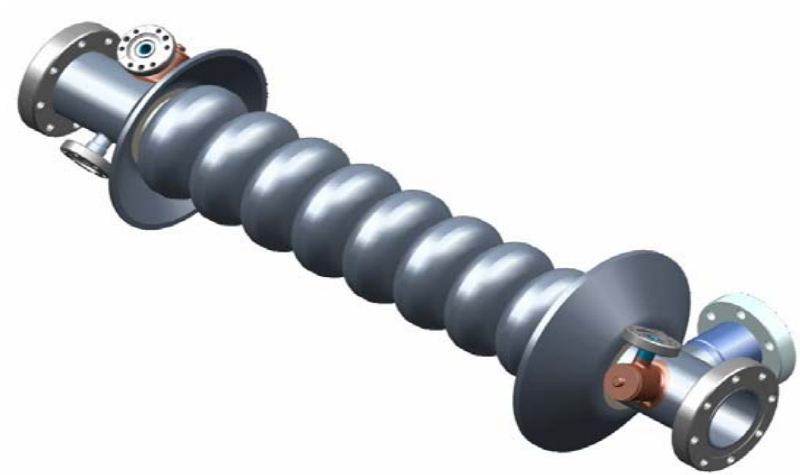
2nd Stage Upgrade of FNPL

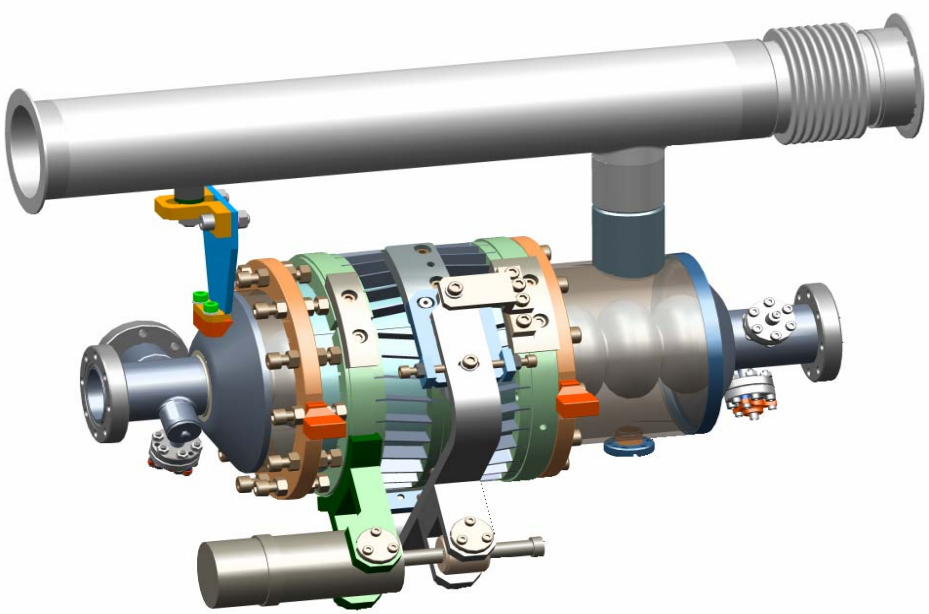




Example of transverse emittance (black) and kinetic energy (red) evolution for a 3.2 nC bunch (TESLA nominal charge). C1 and C2 are the two TESLA cavities to be operated in the FNPL upgrade (here operated at 12.5 and 25 MV/m average accelerating gradient). The upgraded FNPL injector extend from z=0 to z=8 m. The beam is then injected in a TESLA accelerating module. The magenta curves stands for the longitudinal fields, i.e. the location of the TESLA cavities.

3.9 GHz SCRF Cavities



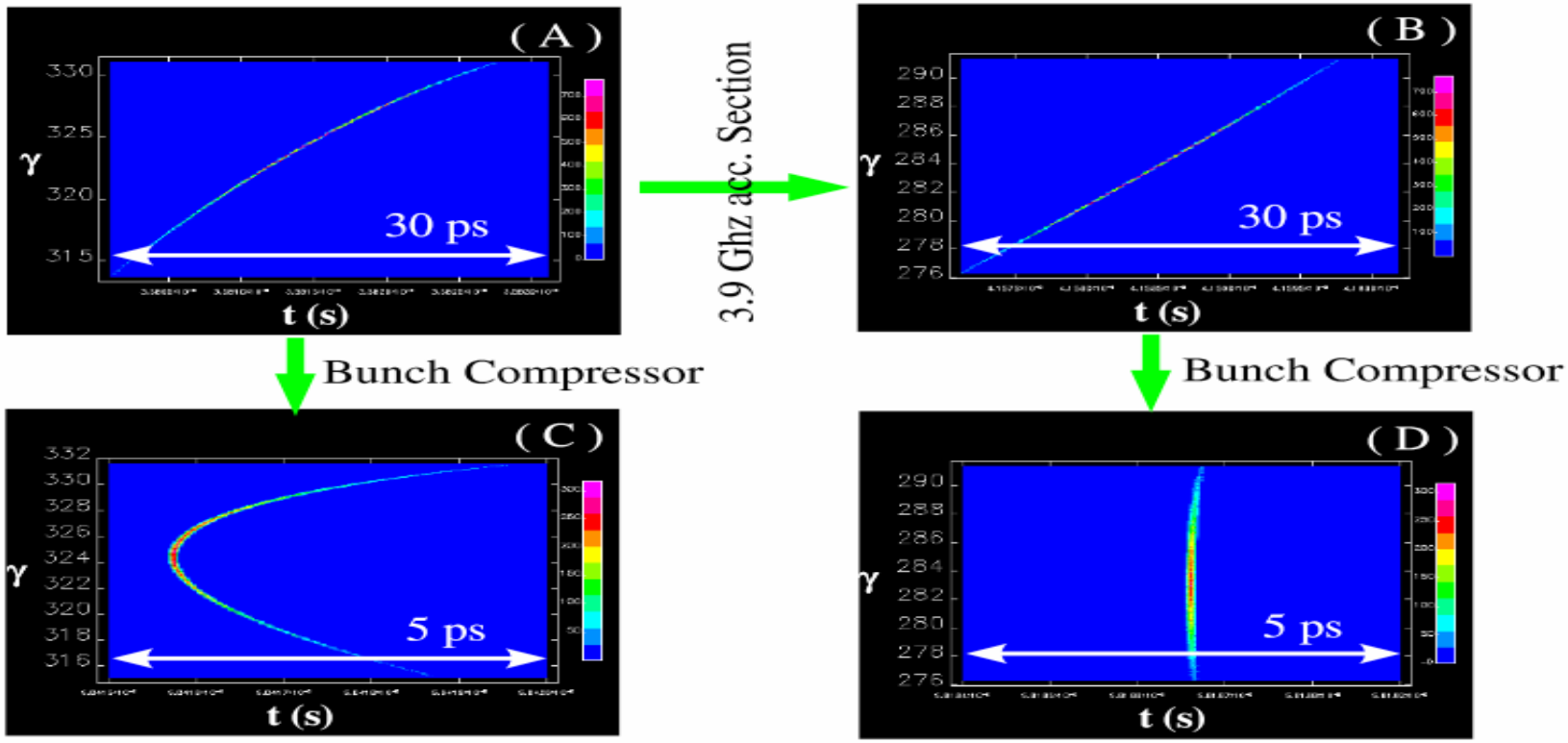


Status

- 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

3rd harmonic cavity in FEL

Improved Beam Characteristics

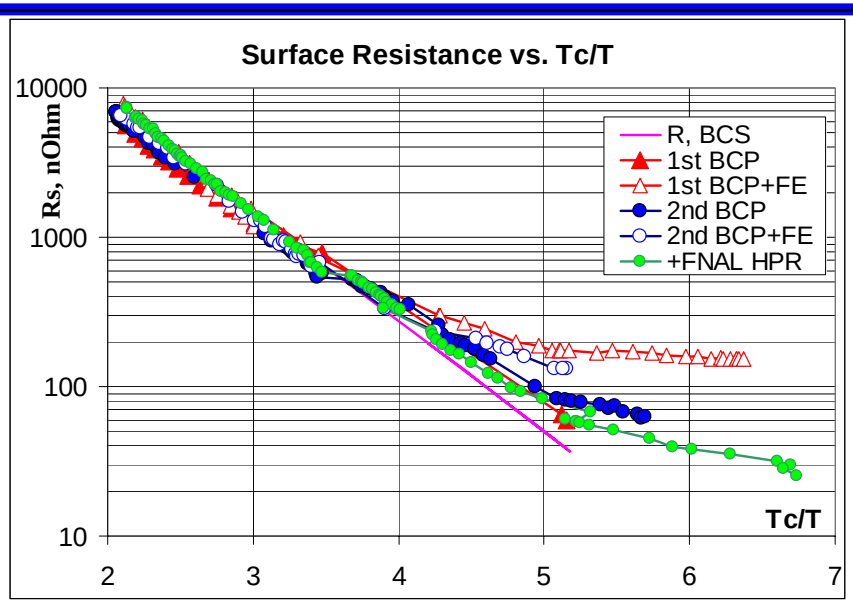


Using 3rd harm. TM_{010} cavities before bunch compressor in TESLA photo-injector allow reduce bunch length

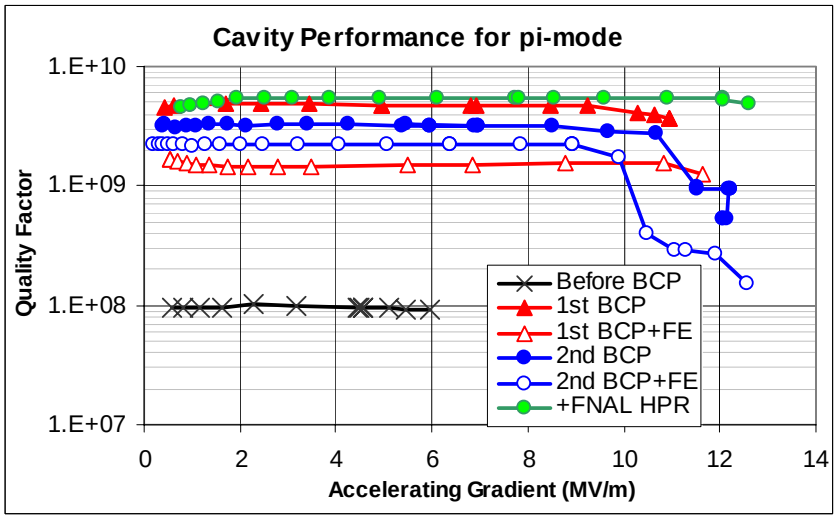
(Ph.Piot-FNAL)

Third harmonic 3.9GHz cavity was proposed to compensate nonlinear distortion of the longitudinal phase space due to cosine-like voltage curvature of 1.3 GHz cavities.

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



Q



Gradient Mv/m

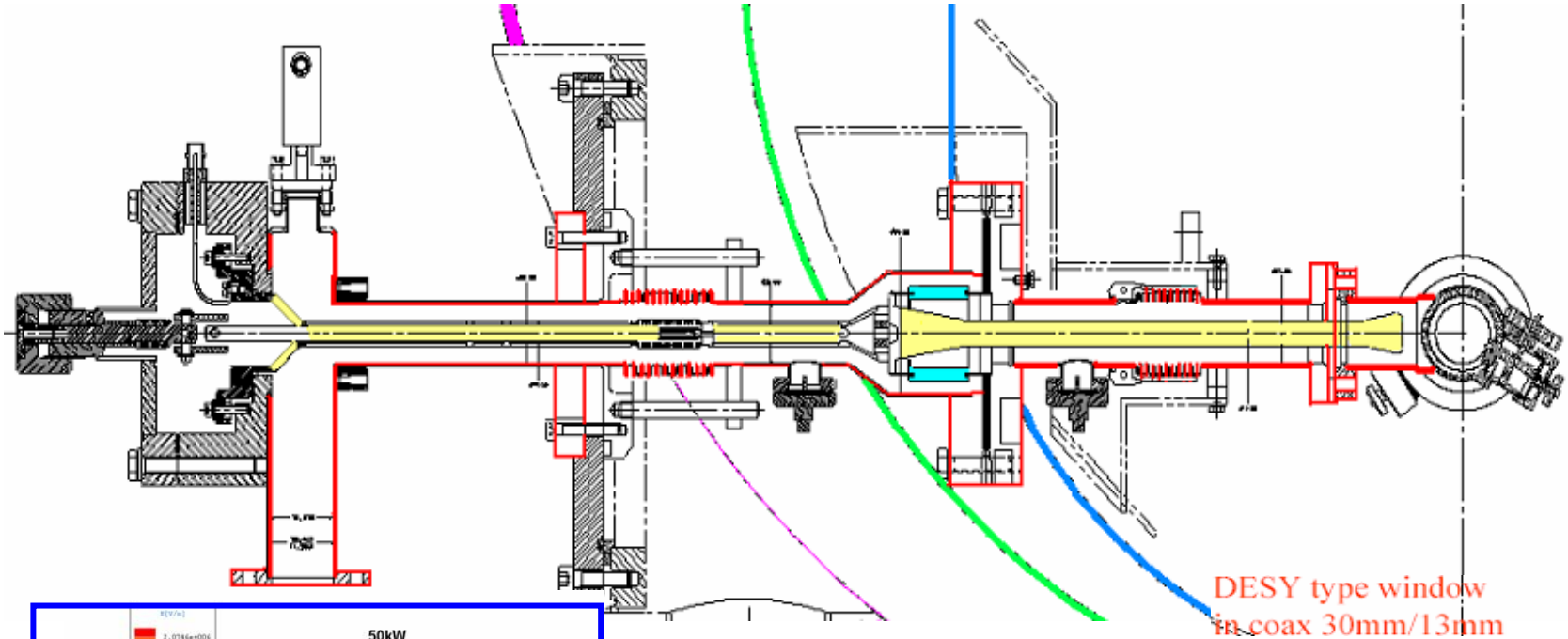
Test history

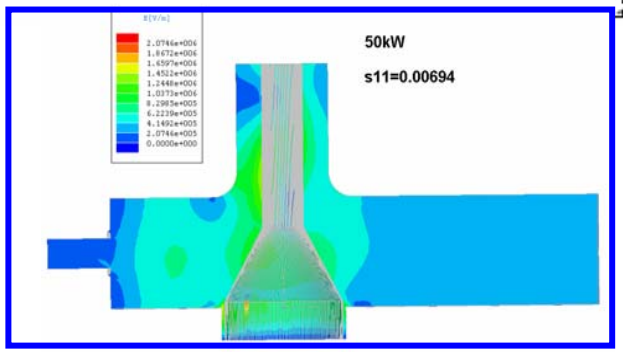
#1 – No BCP

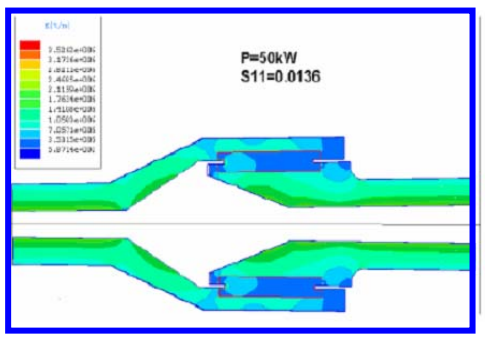
#2-5 - After100 μm BCP, HT, HPR(15') -JLAB

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

Fermilab Designed Coupler for 3rd harmonic cavity



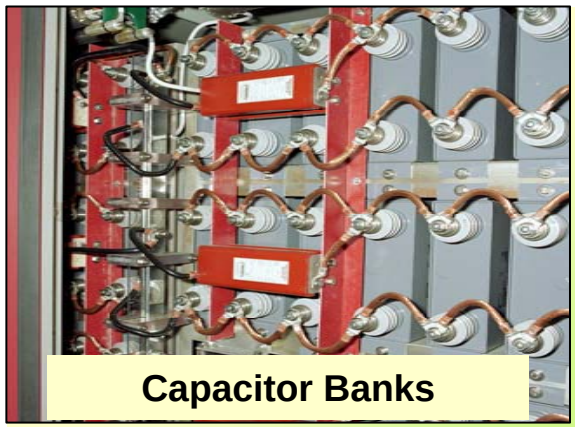


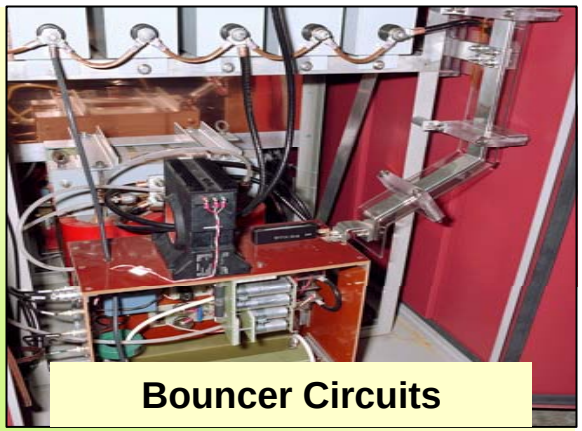


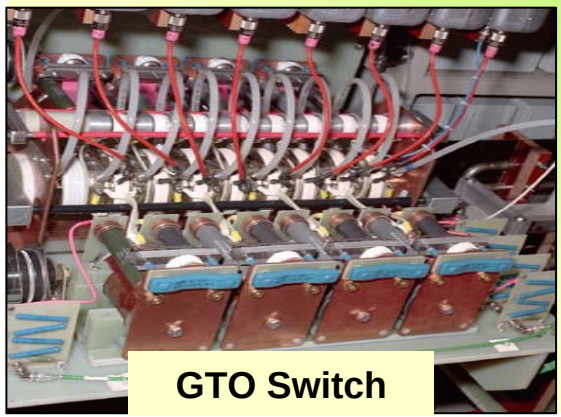
Fermilab also helped design 1.3 GHz couplers

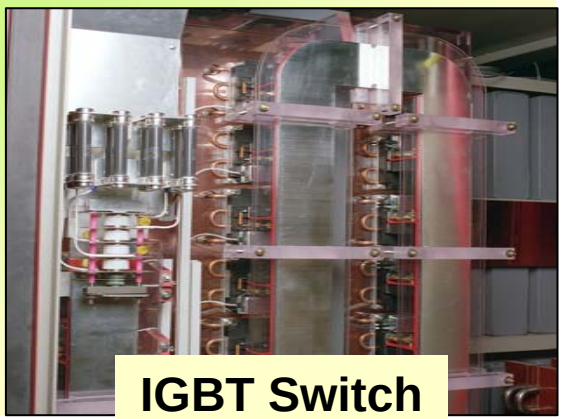
Power for ILC: Modulator

- Fermilab engineers analyzed several modulator alternatives. A high voltage switch was designed and developed to be reliable and protect the klystron.


Capacitor Banks

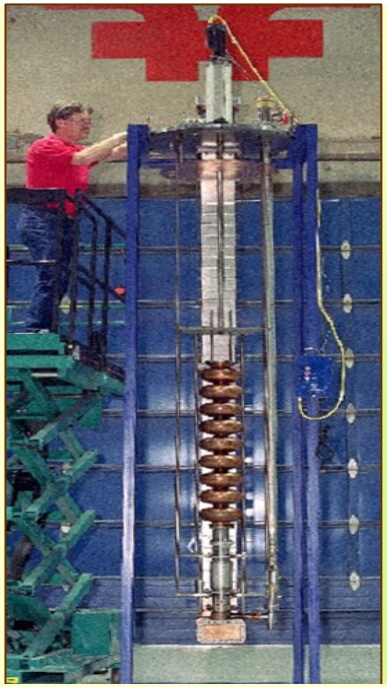

Bouncer Circuits


GTO Switch

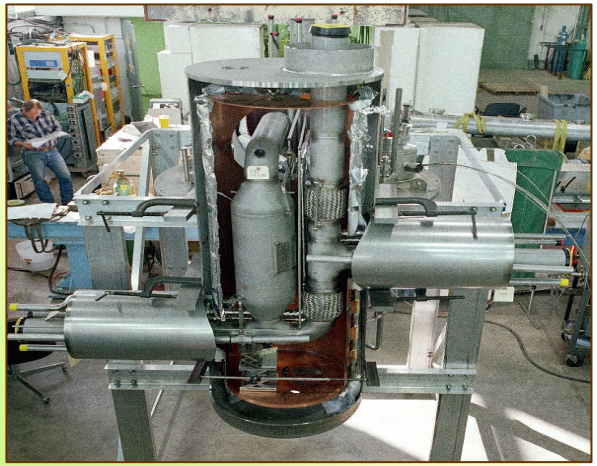

IGBT Switch

- Three modulators were built, assembled and extensively tested at FNAL. They were then disassembled, shipped and re-commissioned at DESY.

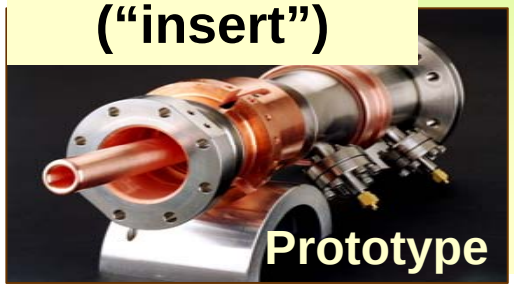
Cryogenics for ILC



Test fixture ("insert")



Vertical dewar assembly



Prototype input coupler

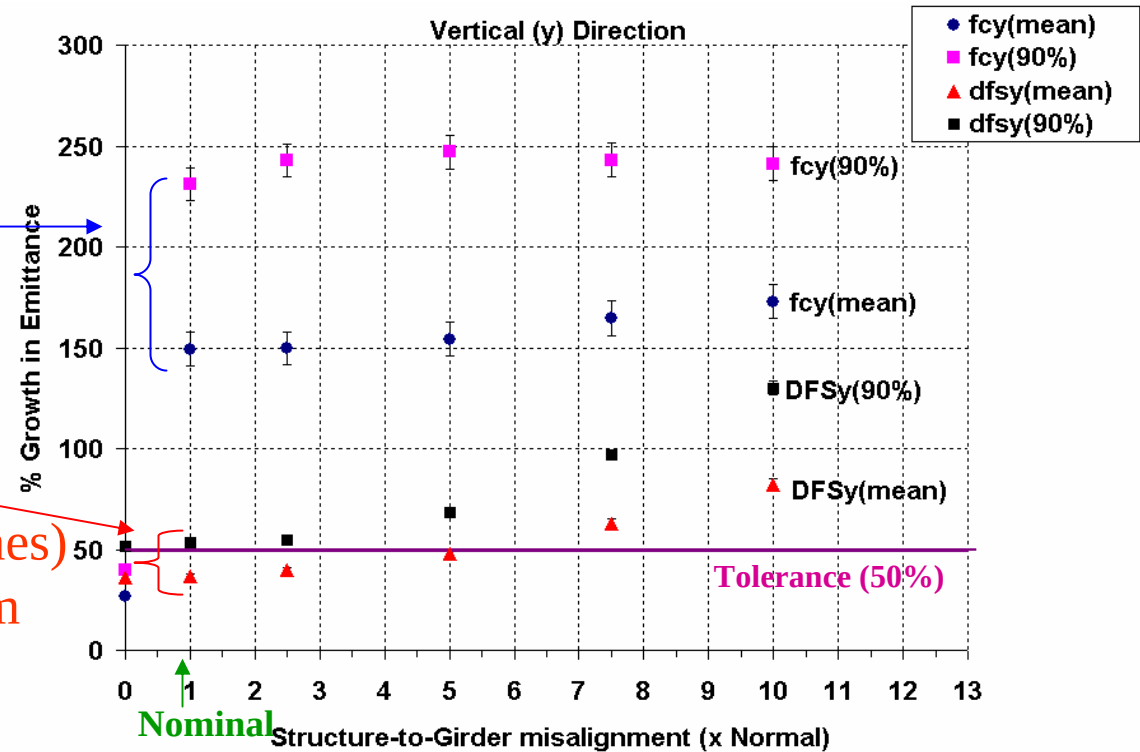
- Fermilab Tevatron is one of the world's largest cryogenic accelerator operating today.
- Fermilab made significant contributions to the TTF system planning and integration and provided many of the components.
- RF cavity test "inserts", the first version of the input couplers for TTF, two vertical test dewars, and the TTF feedbox assembly were among the devices designed and fabricated at Fermilab.

Low Emittance Transport Simulation

- Fermilab has full simulation capability for the Low Emittance transport of the beam from the Damping Ring to the IR.
- We have preformed several sets of calculations for the NLC Lattice.
- We are in process of starting these calculations for the ILC Lattice.

Example of NLC Calculations

- γe_y growth in FC:
  - ☞ remains almost constant (~ x5 nominal values), but
  - ☞ much above tolerance.
- $\gamma \varepsilon_y$ growth in DFS:
  - ☞ increases more rapidly.
  - ☞ mean within specs. (~x5 times)
  - ☞ 90% CFL can cause problem



Accelerator Technology

- Main Linac:
  - Fermilab proposes to take a leadership role in R&D of the cryogenic elements of the Main Linac.
  - We will participate in the Cavity to cryomodule fabrication R&D.
  - We want to participate in resolving the issues with the cryomodules. For example with low emittance preservation and vibration.
  - 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)

Superconducting Module & Test Facility

SMTF is envisioned as:

- A multi-laboratory collaboration on SRF development over a broad range of applications. The synergy of expertise will benefit all SCRF areas.

- A facility where different module types and linac systems can be tested (some with beam).

- An organization that will develop inter-laboratory collaboration (including non-US participation) on cold linac technology, including module development and fabrication.

- The area specific to ILC will be carried out under ILC direction.

- Fermilab has proposed to host of SMTF at the Meson East Area.

Fermilab Perspective on SMTF

- Following the ITRP recommendation the first imperative is establishment of US-based capability in the fabrication of high gradient superconducting accelerating structures.
  - Expanding upon existing scrf expertise at: Argonne, Cornell, Fermilab Jefferson Lab, MSU
  - Provisional goal is to have three U.S. and one European 1.3 GHz ILC cryomodules under test, with beam, by the end of 2008.

⇒ **Fermilab is committed to providing the US leadership with close coordination with the ILC-Americas collaboration.**

- From Fermilab point of view SMTF is the primary mechanism for providing this leadership while allowing us to simultaneously integrate our ILC and PD R&D activities.
- Infrastructure created for this purpose will be of more general utility to a variety of scrf-based U.S. projects (RIA, 4th generation light sources, ERL's, etc)

SMTF Program Goals

- Demonstrate for ILC 1.3 GHz cavity operation at 35 MV/m with beam currents up to 15 mA at a 1% duty factor in two cryomodules with 8 cavities each.
- Demonstrate for CW applications 20 MV/m cavity operation at Q values > 3E10.
- Demonstrate for the Proton Driver 1.3 GHz, $\beta \sim 0.5$-0.8, elliptical cavity operation at > 15 MV/m at Q > 5E9 and a 1% duty factor with multiple cavities being driven by one klystron.
- Demonstrate for the Proton Driver and related applications high gradient operation in pulsed mode of 1.3 GHz and 325 MHz, $\beta < 1$ cavities and cryomodules.
- Demonstrate individual cavity resonance control with multiple cavities driven from one klystron, using fast ferrite phase shifters, at both 1.3 GHz and 325 MHz
- Demonstration of RIA cavities and cryomodules.

Development of Cryomodule

Raw Niobium Material
Formed and Machined Components

Inspect
Machine
Etch
Clean
Test

Internal Cavity Section Welding

Half Cells
Dumbells
Multi Cells

Iris Weld
Equatorial Weld

End Section Fabrication Welding

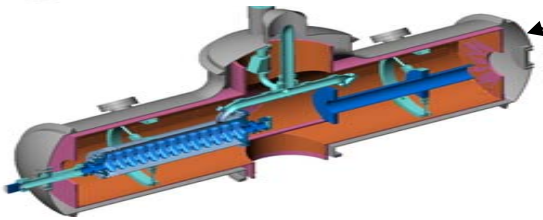
Antenna
Formteil
HOM Coupler
Beam Tube
Input Coupler
Flanges
End Half Cells
Adapter Ring

Bare Cavity Vertical Test

Install He Vessel

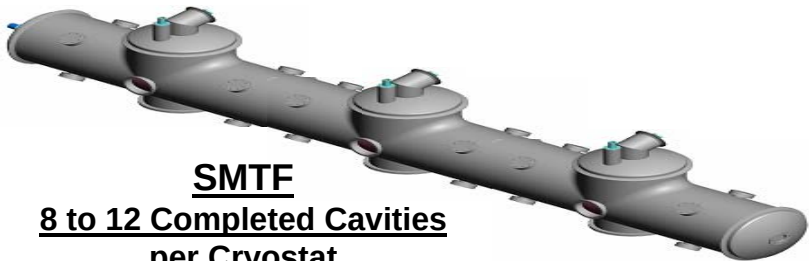
Completed Cavity

Completed Cavity Horizontal Test



1 or 2 Helium Vesseled Cavites
in Horizontal Test Stand

Delivery



SMTF
8 to 12 Completed Cavities
per Cryostat

US Laboratories Collaboration: A Model

Cavity Fabrication & Testing

↓

Cryomodule Assembly

↓

Testing at SMTF

- The cryogenic elements of the Linac are developed under Fermilab leadership in collaboration with US and International laboratories and tested at SMTF.
- We expect that in US the 1.3 GHz cryomodules will be developed in collaboration with Jlab, Cornell, ANL, LANL, Fermilab, SLAC and Industry.
- Expanding present industrial, laboratory, and university capabilities to contribute significantly is essential for the success of the ILC.
- Our goal at will be to work with and integrate industrial capabilities.

Specific Goals for ILC: SMTF

- Establish a high gradient, 1.3 GHz cryomodule test area at Fermilab with a high quality pulsed electron beam using an upgraded A0 injector.
- Fabricate four 1.3 GHz high gradient cryomodules (eight cavities each) using industrial and laboratory partners in the US.
- The fabrication R&D will be carried out as a collaborative effort under the leadership of Fermilab for the ILC-Americas organization.
- Test cryomodules and other rf components as fabrication and operation experience is acquired and designs are optimized.

Phases of ILC: SMTF

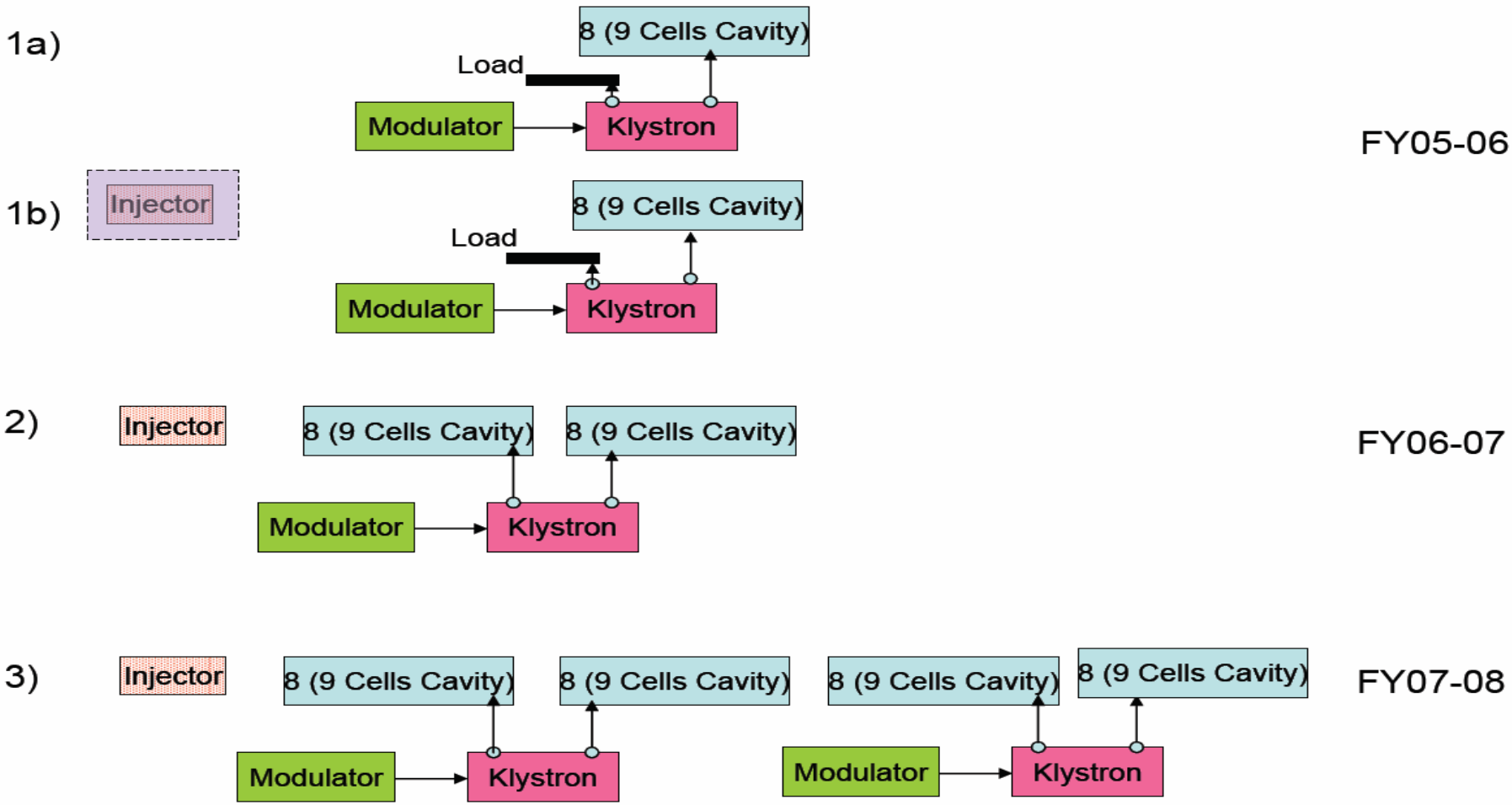
- We propose to bring into operation one cryomodule with the goal of demonstrating 35 MV/m cavity operation. It is expected that it may take more than one module iteration to achieve this gradient.
  - The A0 photo injector will be moved, installed and re-commissioned with the cryomodule (step 1) in order to perform beam measurements, which are discussed below.
  - We will initiate beam tests of a single ILC cryomodule utilizing the photo injector.
- We propose to bring into operation one SMTF-ILC rf unit, defined as two cryomodules each containing eight 9-cell cavities, one high power modulator, one 10 MW multi-beam klystron and perform beam measurements.
  - The injector will be upgraded to include the Fermilab built 3.9 GHz accelerating and deflecting cavities.
- We propose to bring into operation two SMTF-ILC rf units and associated rf power, instrumentation and controls.

What is an RF Unit ?

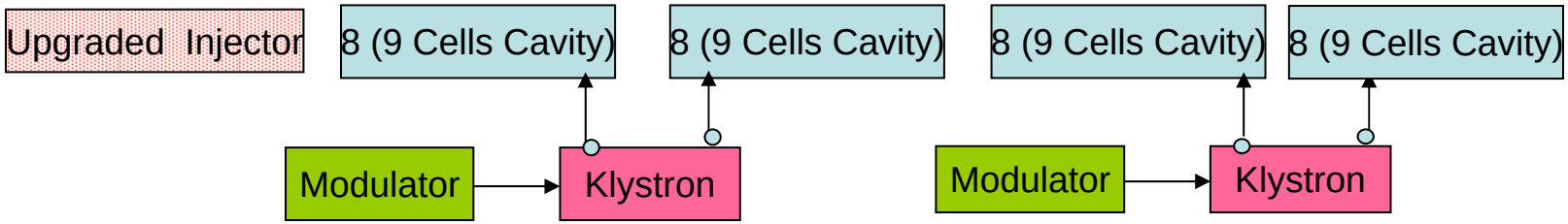
- An RF unit will eventually need to be defined for both the 500 GeV and 1 TeV ILC designs.
- In our discussions, we are moving towards an ILC with 35 MV/m, 1.3 GHz cavities for both 500 GeV and 1 TeV operation.
- The power sources currently being developed can provide 10 MW of rf power so it is natural to define an rf unit as the number of cavities powered by such a source (i.e., one modulator and one klystron).
- Given the state of cryomodule development and the desire to have some overhead in choosing the ILC beam current, we define an RF unit for test purposes as two cyromodules with eight TESLA-like (9 cell) cavities each.
- Assuming 6% transport losses, each cavity in the rf unit could be powered up to 530 kW with a 10% overhead. At 35 MV/m, a 15 mA beam could be accelerated, which is about 15% more current than in the TELSA 800 design.
- The present design of the ILC cryostat is based on the DESY design, which contains eight nine-cell cavities. It may be cost effective (needs study) for the ILC to have 12 nine-cell cavities per cryomodule.

SMTF: Three Phase Approach

1.3 GHz Cryomodule Test Facility



Two SMTF-ILC RF Unit Construction



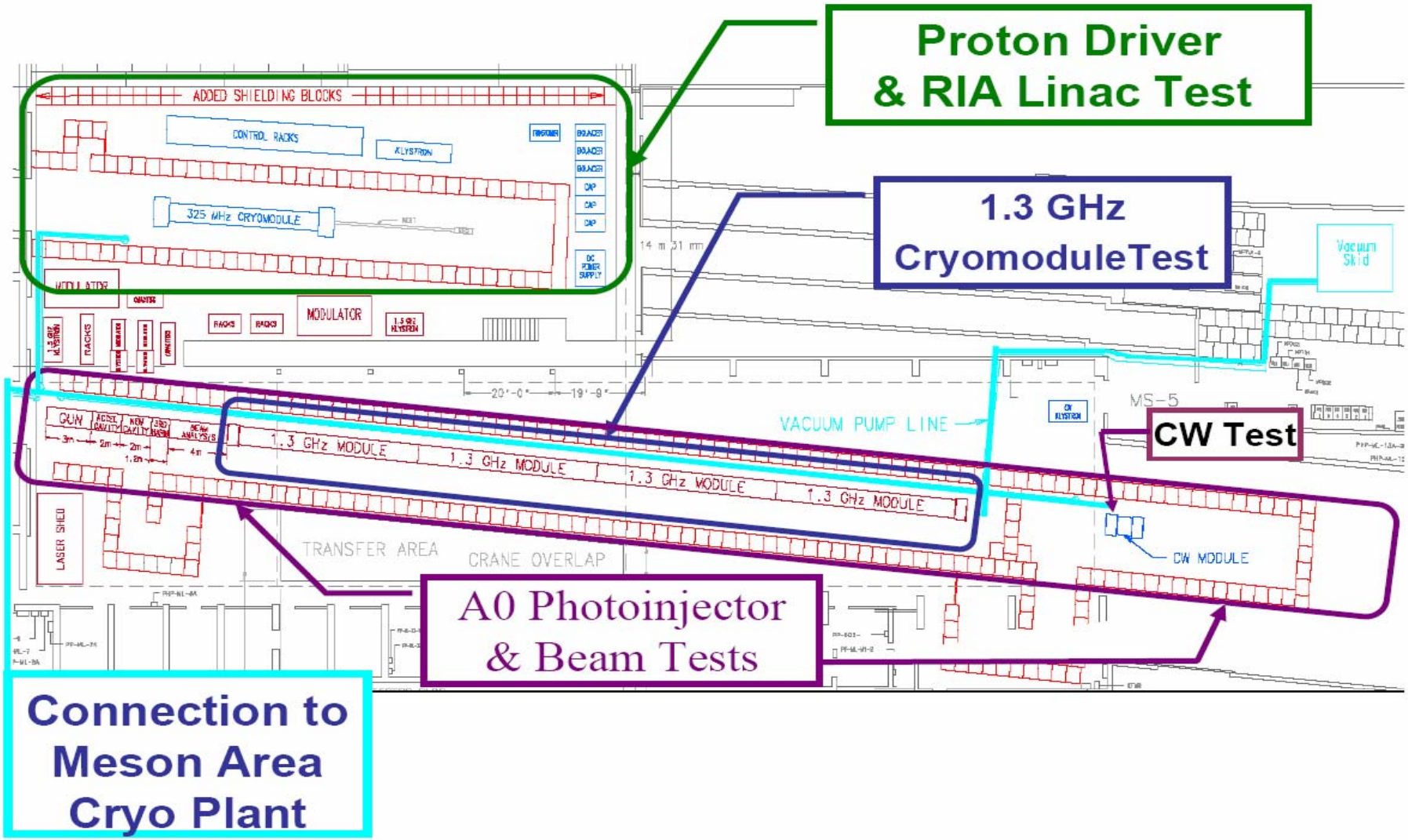
4 Cryomodule (32 cavities, HOM, blade tuners, He vessel, couplers) + 2 Klystrons + 2 Modulator + Controls

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

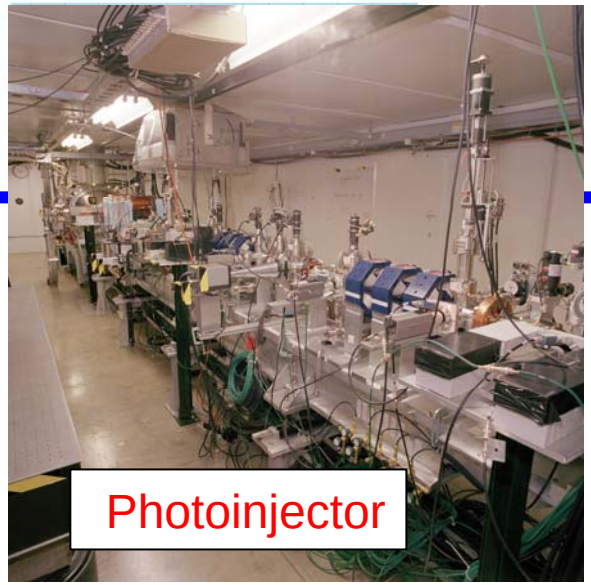
} Finish the construction already in progress.

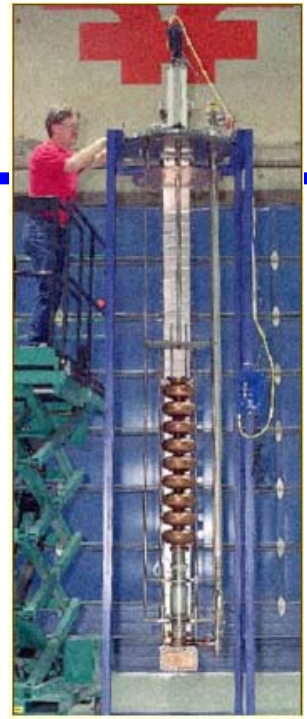
- FY05: Start fabrication of 1 cyromodule (8, 1.3 GHz cavities) (We are expecting to get 1 additional cryomodule from DESY)
- FY06-08: 3-4 cyromodule (8, 1.3 GHz cavities)
- FY05-07: 2 cryomodule (4, 3.9 GHz 3rd Harmonic cavities) FY05-07

FNAL Meson Area SM&TF Layout Concept



Meson Area Fermilab





Test fixture ("insert")

Fermilab

3.9GHz SRF cavity development
& HOM measurements

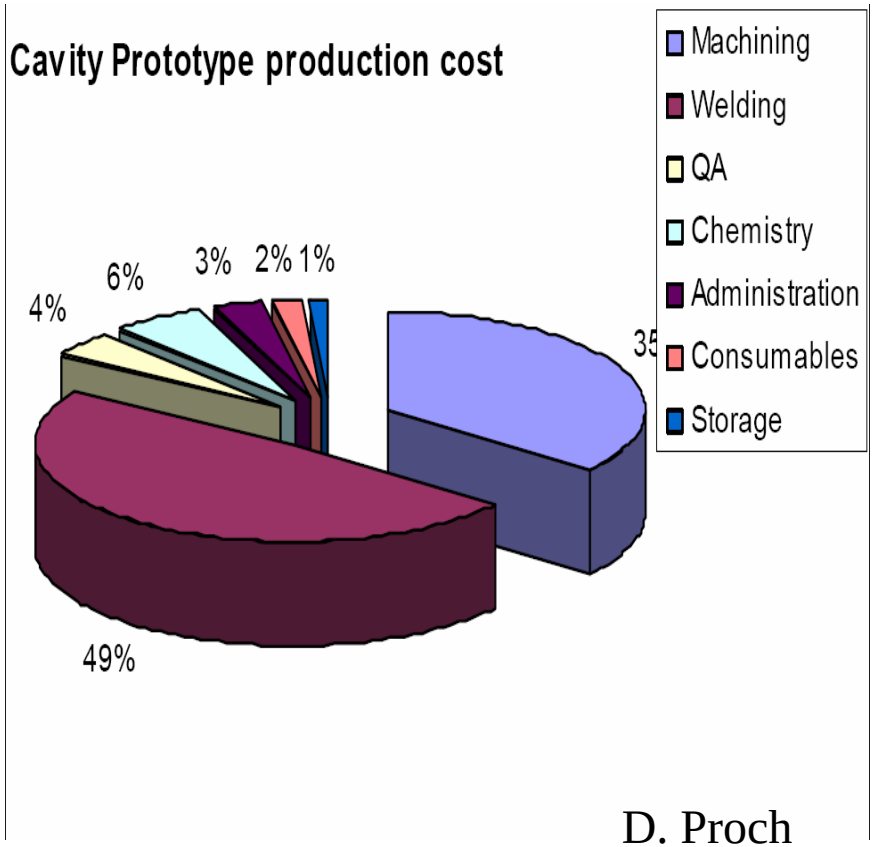
Technology Studies

- Determine the maximum operating gradient of each cavity & its limitations.
- Evaluate gradient spread and its operational implications.
- Measure dark currents, cryogenic load, dark current propagation, and radiation levels.
- Measure alignment of the quadrupole, cavities and BPM in-situ using conventional techniques (e.g. wire or optical).
- Measure vibration spectra of the cryomodule components, especially the quadrupole magnet.
- Measure system trip rates and recovery times to assess availability.
- Develop LLRF exception handling software to automate system and reduce downtime.
- Evaluate failures with long recovery times: vacuum, tuners, piezo controllers, and couplers.

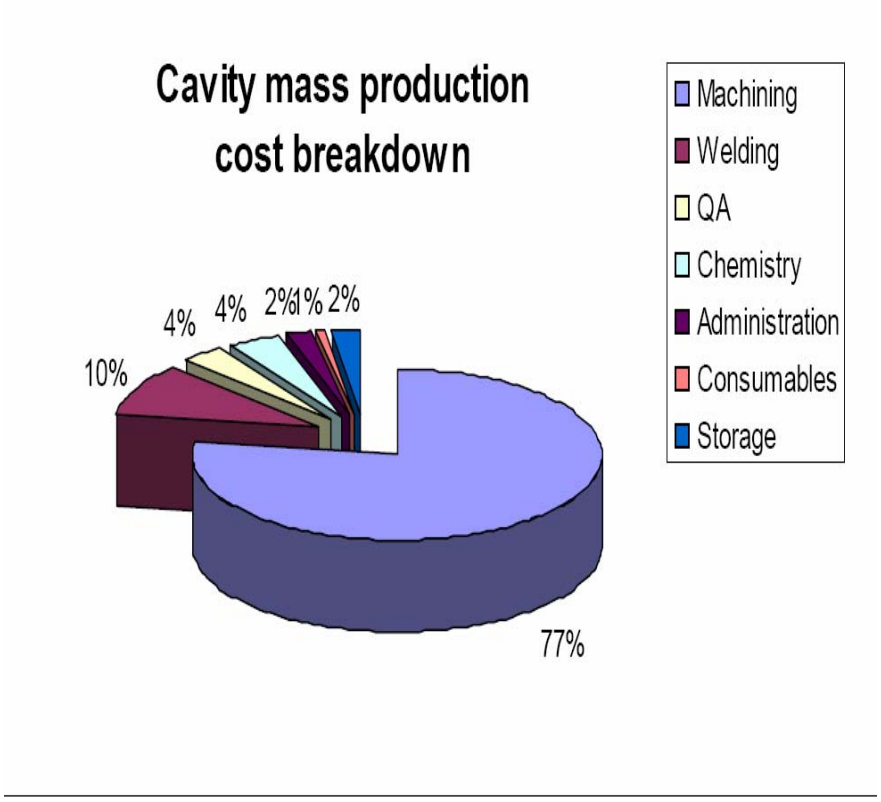
Physics Measurements

- Beam energy: a spectrometer would provide an independent and accurate measurement of the accelerating gradient (rf based techniques are not as accurate).
- Long-range wake-field characterization: Measure frequency spectra of bunch positions downstream of cryomodule to search for high Q cavity dipole modes that could cause beam break-up in the ILC. Correlate these data with HOM power measurements.
- Tests of low-level rf system: demonstrate that a < 0.1% bunch-to-bunch energy spread can be achieved in a 1 msec bunch train.
- Impact of the SCRF cavity on transverse beam dynamics: measure the beam kicks caused by the fundamental mode fields.
- Study beam centering based on HOM dipole signals.

Cost and Design Optimization



D. Proch



DESY is leading the effort in ILC/XFEL cost reduction.

Fermilab engineering will work with ILC collaborators in reducing the cost.

SMTF Expression Of Interest

- Expression of Interest for the Superconducting Module & Test Facility (SMTF) has been submitted to Fermilab director 10/29/04

Institutions Involved in Discussions

- Argonne Laboratory (ANL),
- Brookhaven (BNL),
- Cornell University,
- Fermilab, Jefferson Laboratory (JLAB),
- Lawrence Berkeley National Laboratory (LBNL),
- Los Alamos National Laboratory (LANL),
- MIT-Bates Laboratory,
- National Superconducting Cyclotron Laboratory (MSU-NSCL),
- Northern Illinois University (NIU),
- Spallation Neutron Source (SNS) at Oak Ridge,
- University of Pennsylvania
- Stanford Linear Accelerator Center (SLAC).

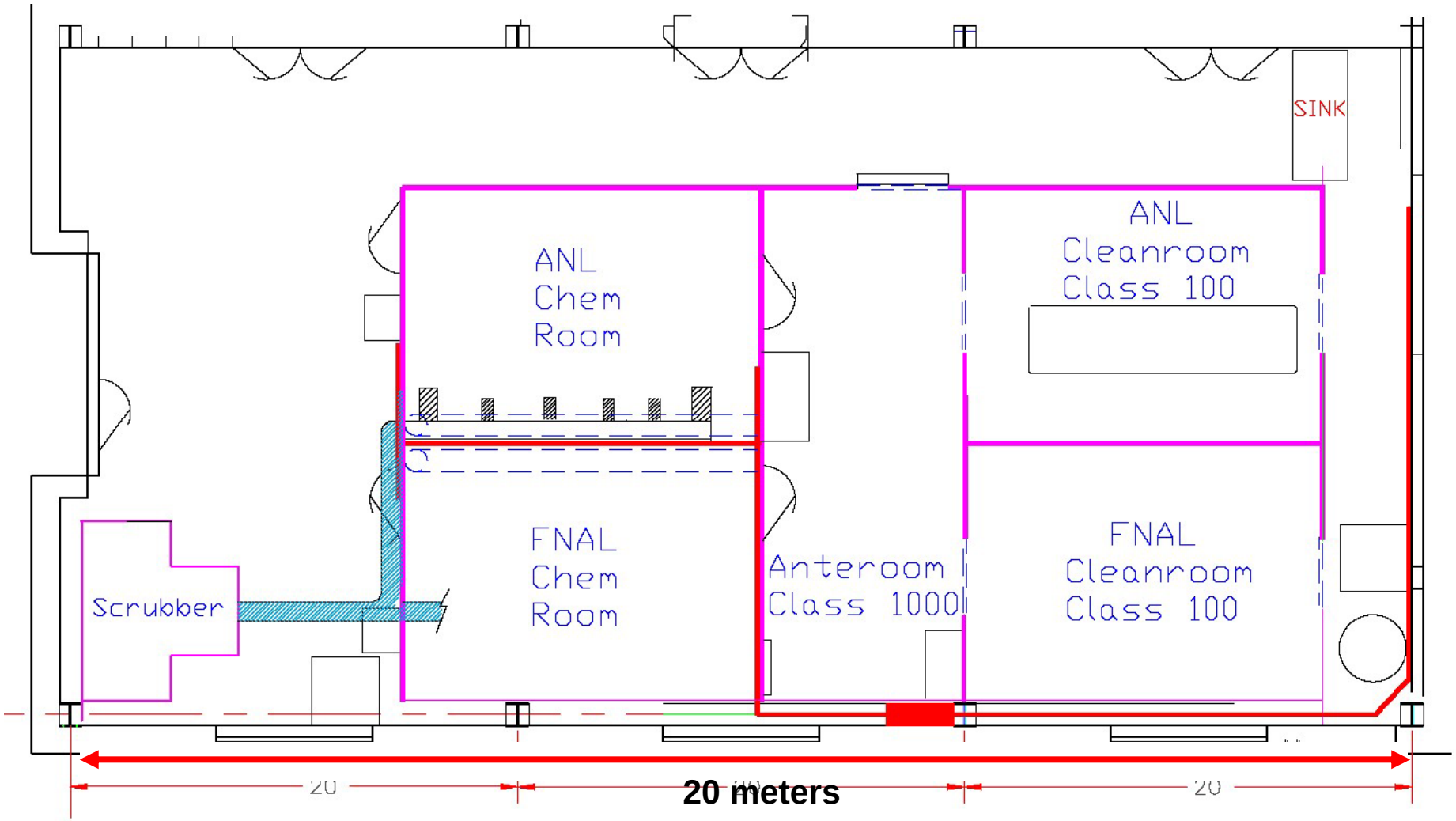
- International: DESY, INFN, KEK

- International Collaboration Discussion for SMTF proposal and world-wide co-ordination of ILC Cavity R&D
  - INFN
  - KEK
  - DESY
  - CAT, India
  - Korea

The ANL/FNAL Cavity Processing Facility

- **Can provide a valuable support facility for ILC development/cryomodule test facility (SMTF) at Fermilab**
- **Comprehensive surface processing capability for SC devices and related hardware using:**
  - **Buffered Chemical Polishing (BCP)**
  - **Electropolishing (EP)**
  - **Ultrasonic cleaning**
  - **Ultrapure high-pressure water rinsing**
  - **Cleanroom assembly of rf devices (single cavities, couplers)**
- **Layout, design and principal areas:**
  - **Two large sealed chemistry areas with a large air scrubber**
  - **Remotely controlled BCP and EP operations**
  - **A large clean anteroom (gowning & ultrasonic cleaning of hardware)**
  - **Two separate class 100 or better clean areas with a dedicated high pressure rinse capability**

The Joint ANL/FNAL SCRF Cavity Processing Facility at Argonne

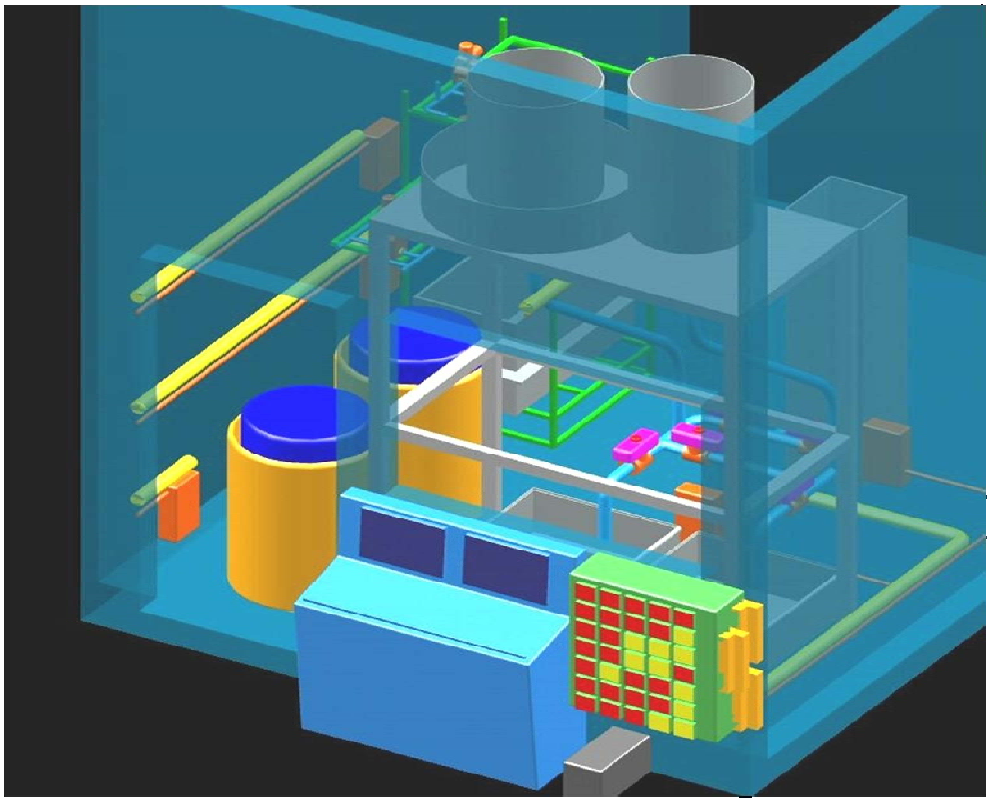


Phase I: The ANL/FNAL Chemistry Facility

Chemical Processing Rooms

Air Scrubber

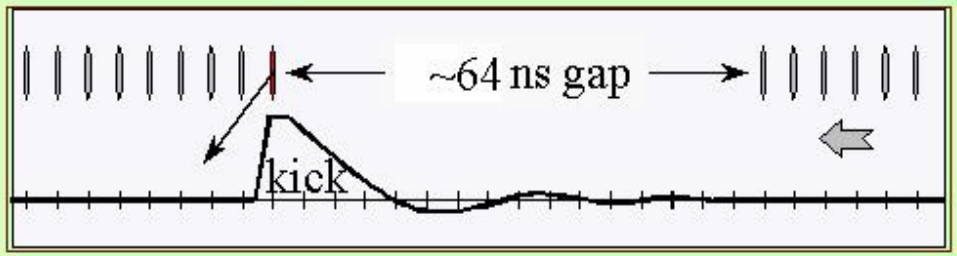
FNAL Chemistry Area for Beta=1 Cavities

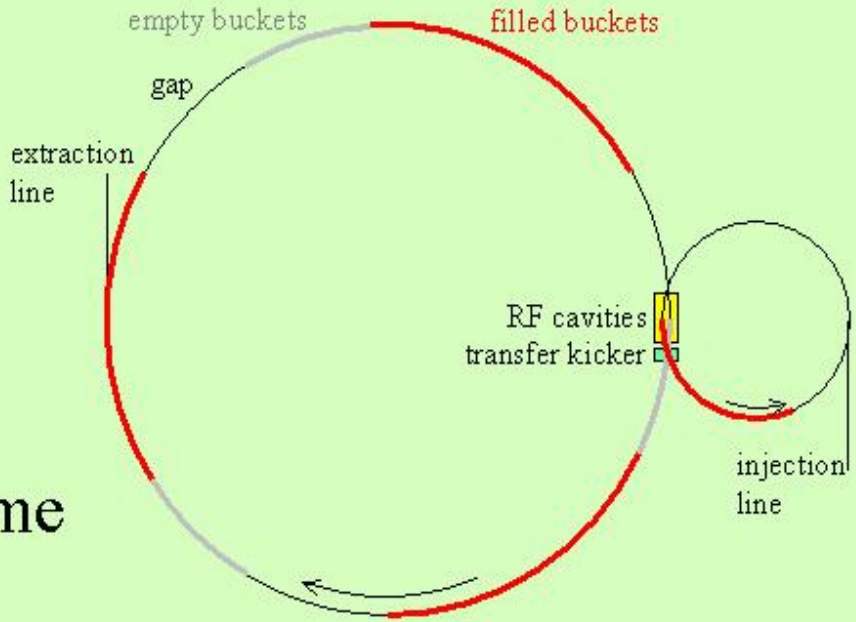


- **Suitable to handle 9-cell 1.3 GHz cavities for ILC**
- **Remotely controlled, semi-automatic operation**
- **250 liter acid handling capability**
- **<1 minute cavity fill/empty time**

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

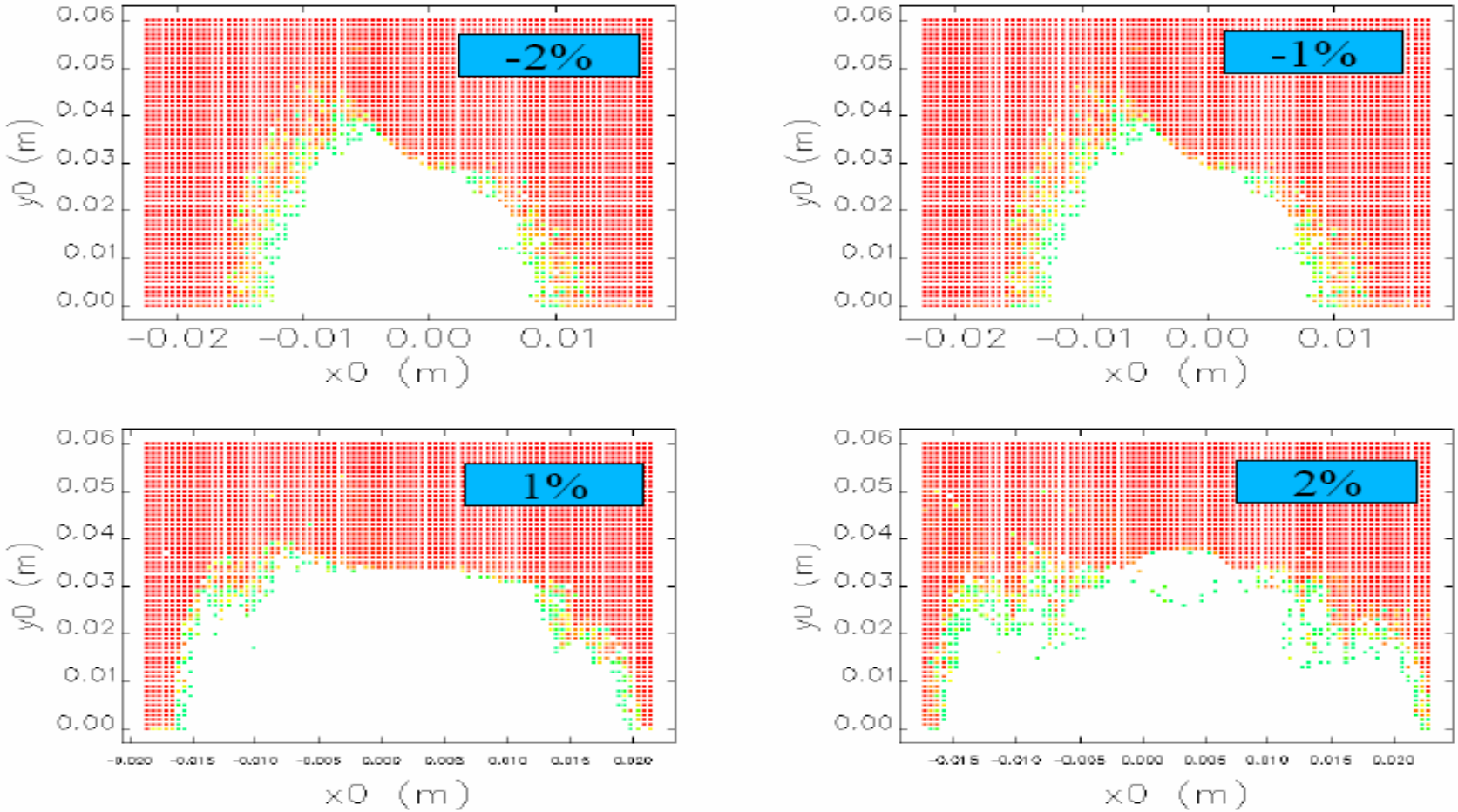
Aimin Xiao

Calculations for the 6-km Ring

- Dynamic aperture (DA) without errors
- DA for off-momentum
- Frequency map
- DA boundary with errors
  - Canonical wiggler, general magnet errors, orbit correction, tune correction, chromaticity correction.
  - 100 seeds to calculate the variation of dynamic aperture boundary
- These calculations are done using ANL code elegant. This code has been used for APS and its upgrade designs.

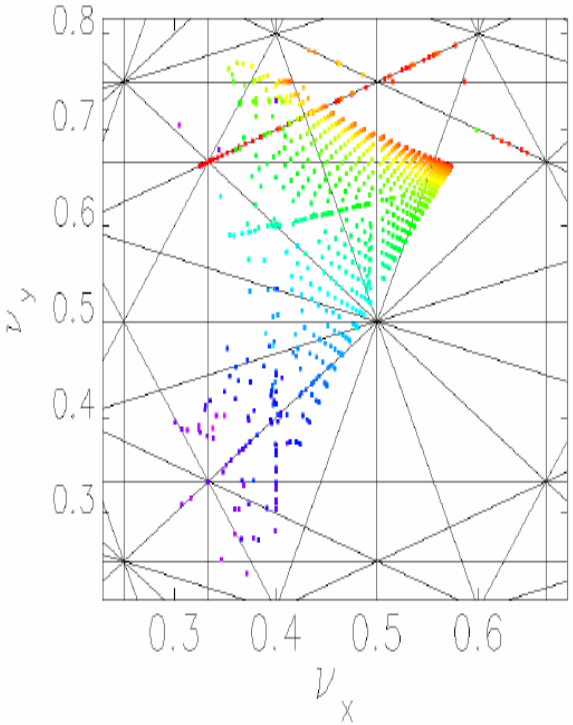
Damping Ring Collaboration with ANL

Off-Momentum Dynamic Aperture

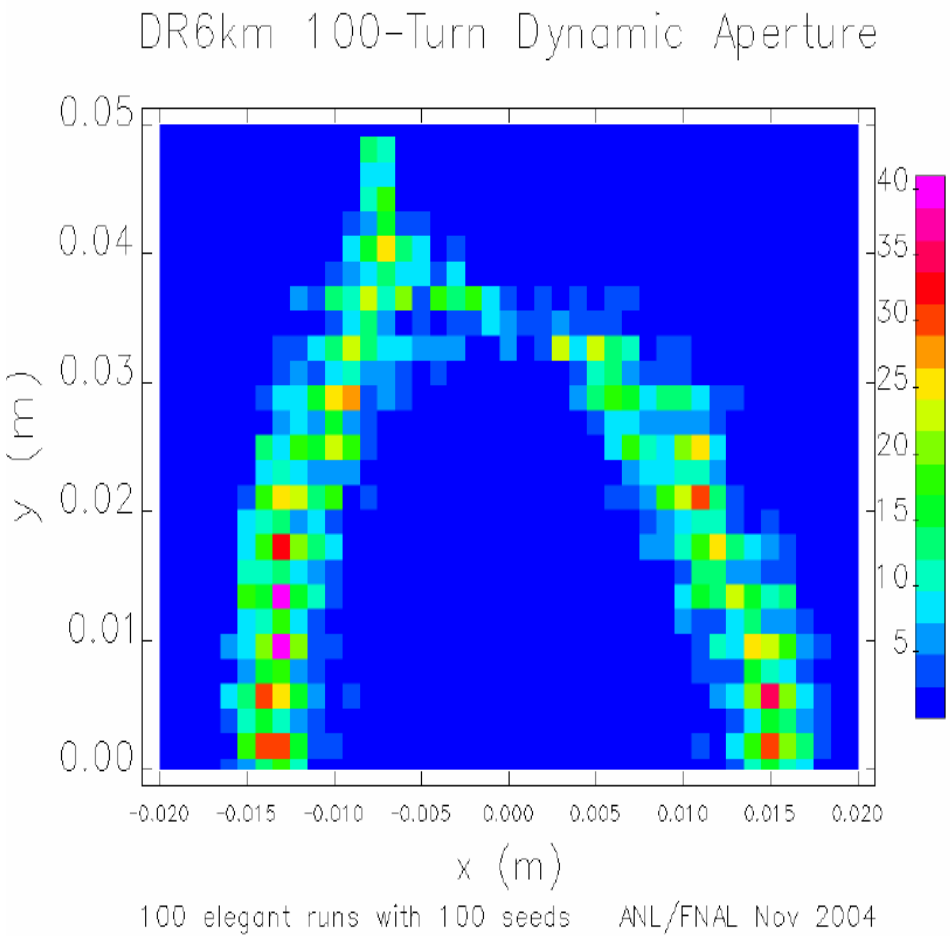


FNAL/ANL Damping Ring Simulation

Frequency Map Analysis

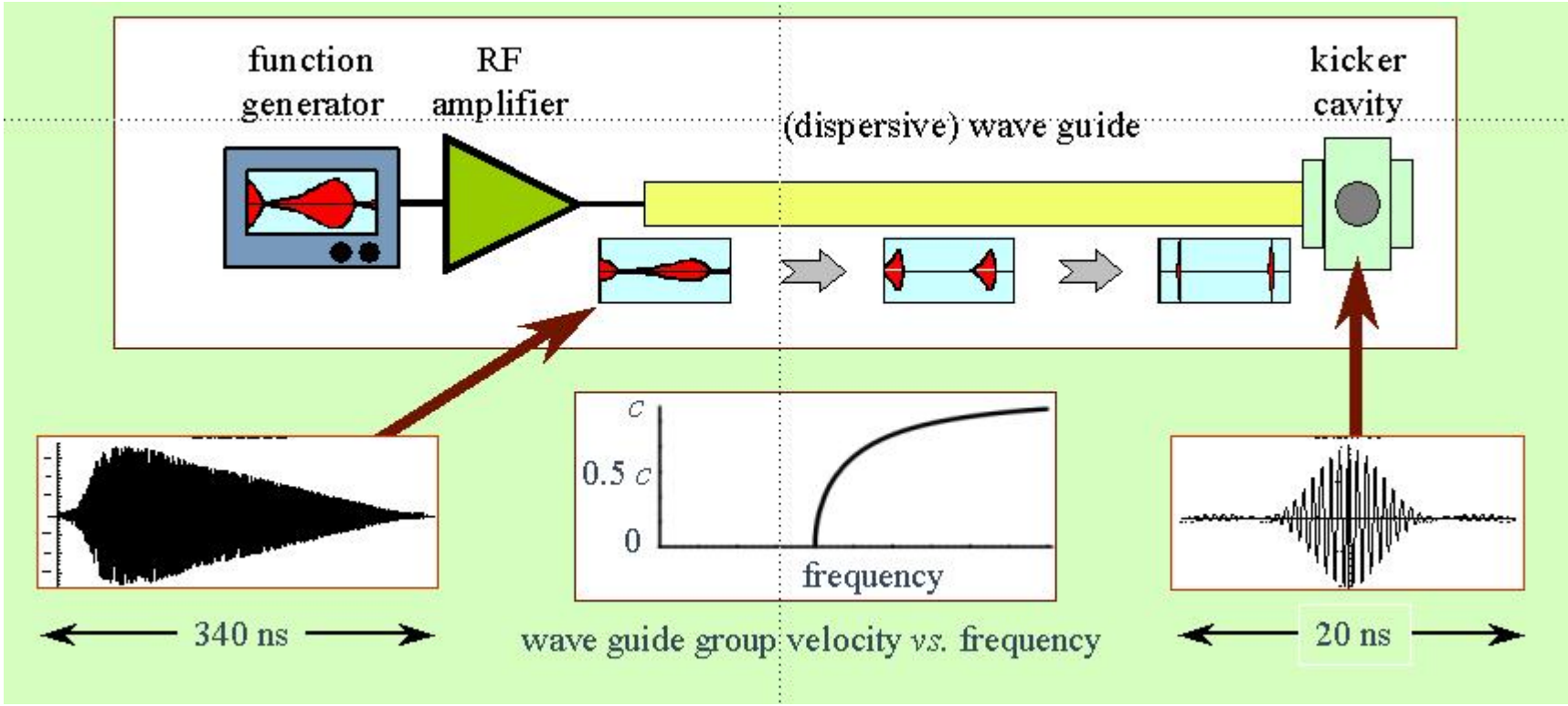


- 500-turn tracking, 20 kicks per element
- Color code shows change in tune
- 50 independent jobs, results collated with SDDS script
- Used ~50, 1.8 GHz CPUs simultaneously
- Took ~1 hour



– These calculations have just started

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.

Fermilab Site Studies

- Near Surface Design
- Baseline Site Studies
- 1 Tunnel Vs. 2 Tunnel
- NIU/FNAL: Hydrological and Ground Motion
- Radiation Shielding Studies
- Tunnel Cross Section Development
- Cooling Pond Vs. Cooling Tower

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.

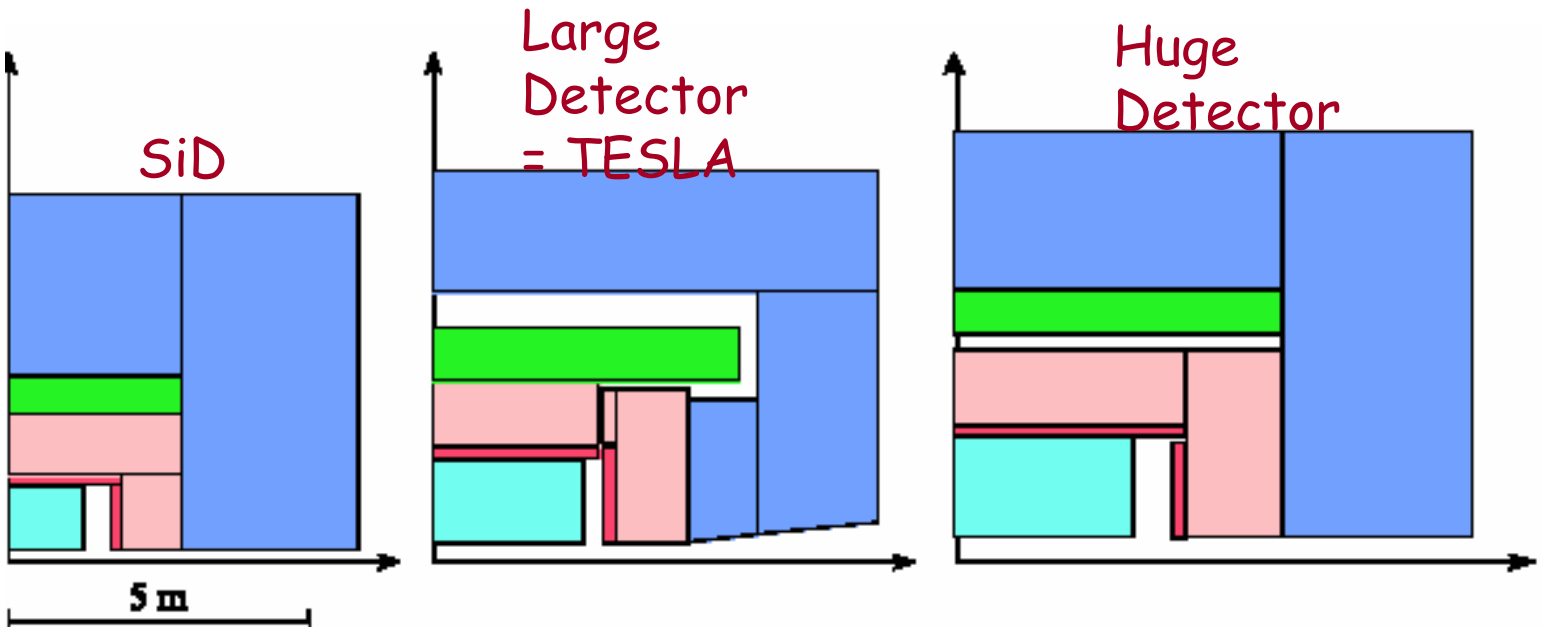
ANL, Fermilab, NIU, UTA, Colorado, ….

ILC detector concepts

Innovative names

For the moment three concepts have emerged (final meeting in Taiwan) and have been launched.

All detectors are BIG



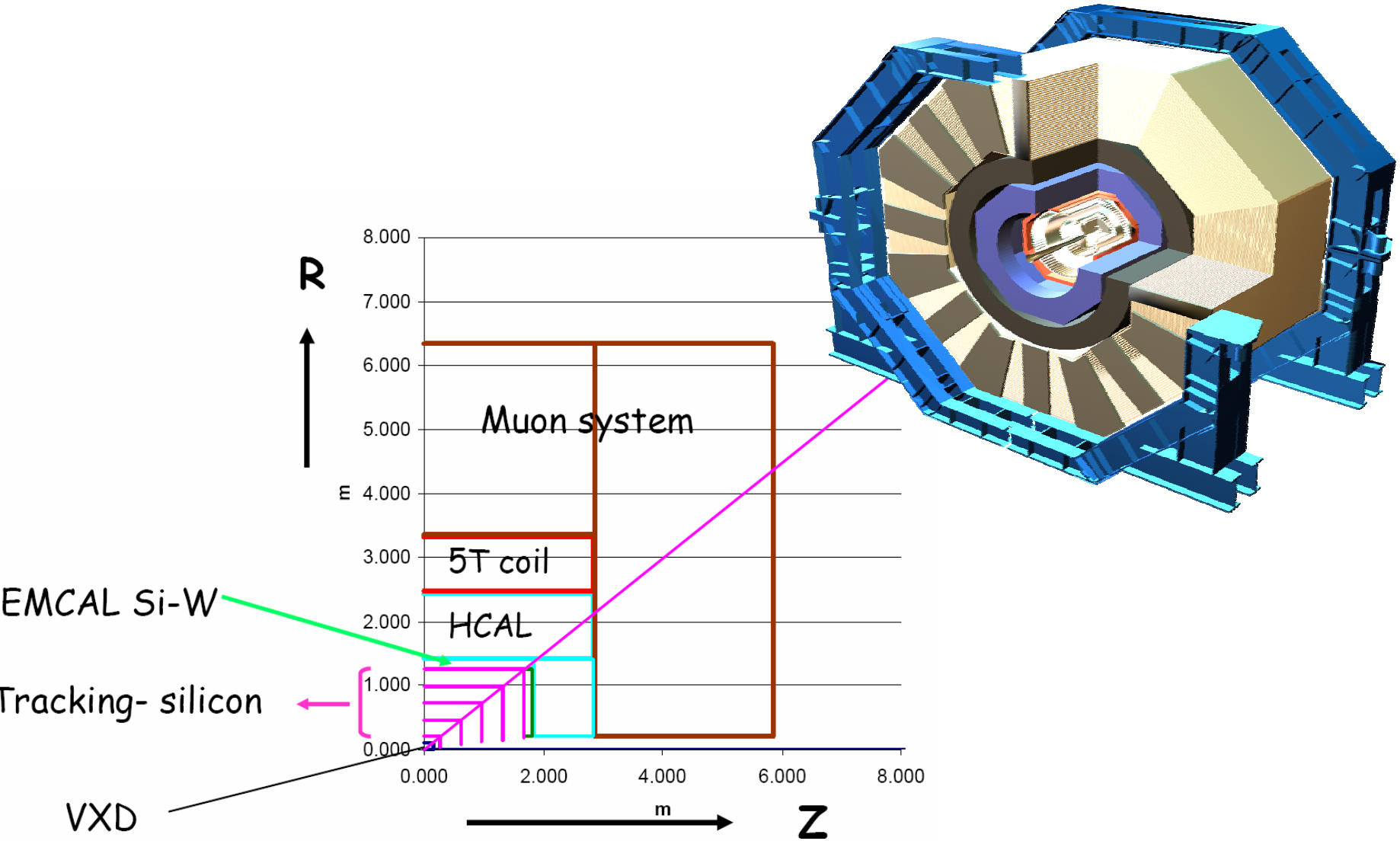
All Si tracking; smaller; hopefully cheaper with same performance.
Centered in US (SLAC & FNAL + Users)
Leadership at FNAL& SLAC *(Jaros/Weerts)*.
Had mtgs at Victoria & Durham

TPC based tracking + Si tracking
Centered in EU + some US
Just forming
Based on TESLA work = advantage

Similar to Large version, but Bigger.
Driven Asian interests mainly.
Official launch in Taipei

All global, but not easy.....

SiD Detector



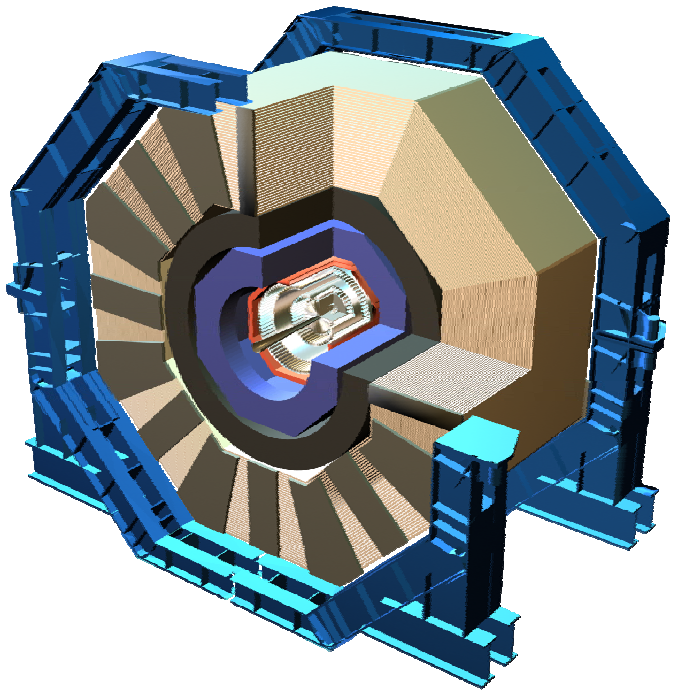
Goal of Detector design studies

- 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.

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

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

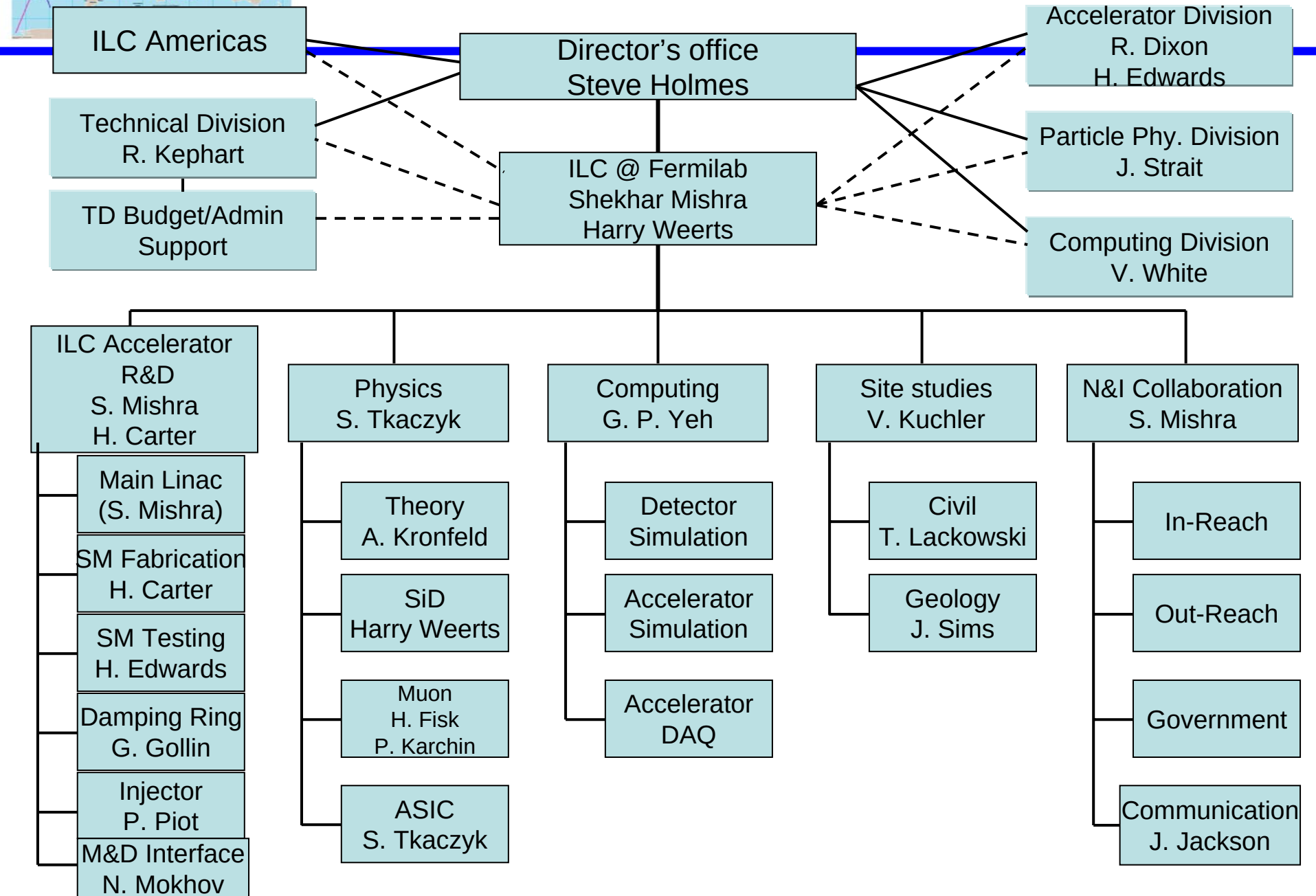
INTERACTIONS

Fermilab Community Task Force On Public Participation

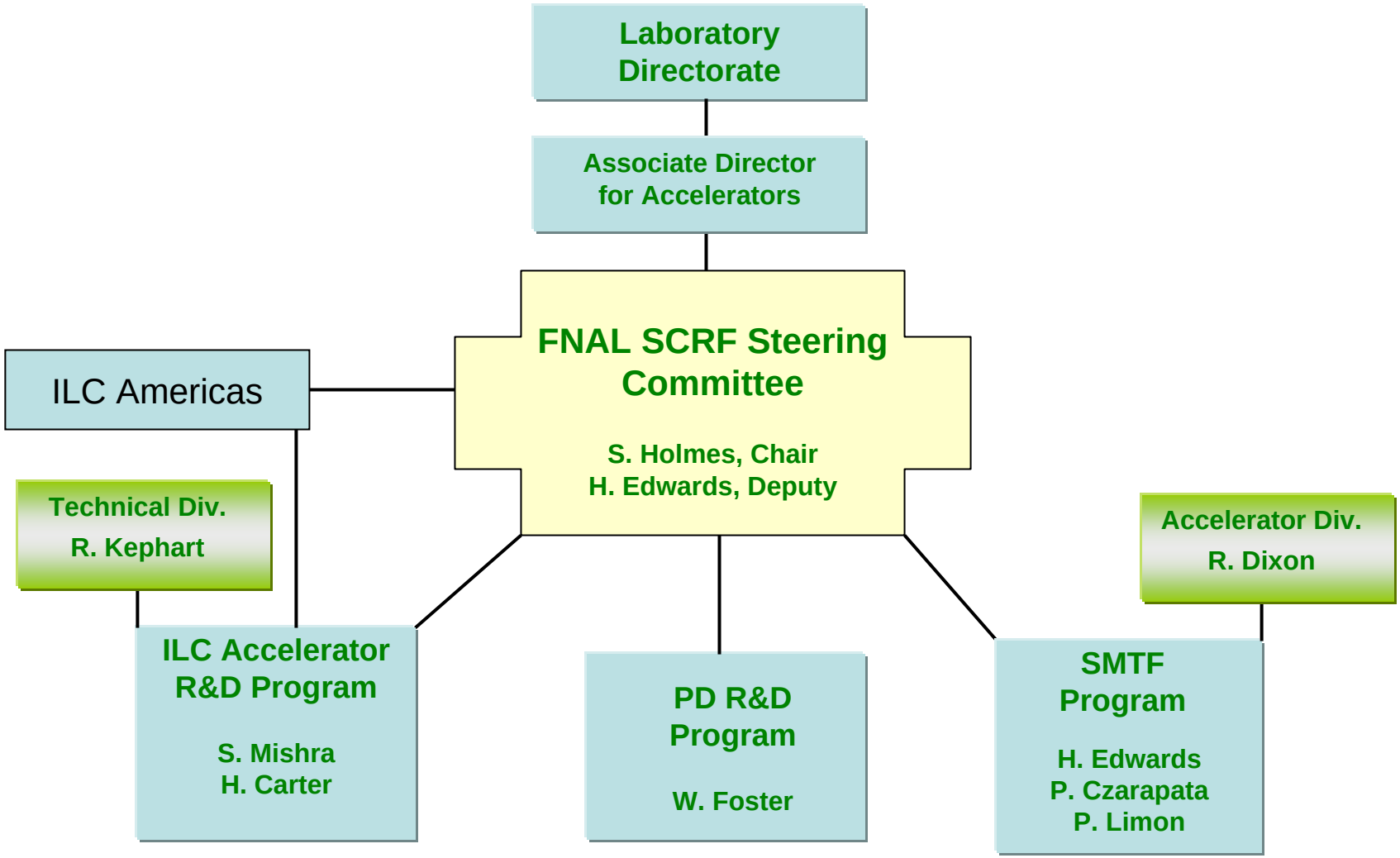
Fermilab Today

What's Up with the Linear Collider?

ILC-Fermilab Organization Chart



FNAL SCRF Projects Organization Chart (Draft)



Summary

- Fermilab is preparing to host ILC. We have propsed to host GDI.
- 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 have submitted the SMTF EOI.
- We will concentrate in a few areas of Detector R&D, building on our strength of other large detector projects.
- We will be developing the Fermilab Site.