Fermilab Linear Collider R&D

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Linear Collider Accelerator R&D

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- Introduction
- Accelerator Physics Studies at Fermilab
- Status of Current (TESLA and NLC) R&D
- Summary

Introduction

- Fermilab is the only laboratory in the US that is collaborating on both warm (NLC) and Super-conducting (TESLA) linear collider accelerator technology R&D.
- Accelerator Physicists and Engineering staff from Technical Division and Accelerator Division have contributed significantly to both the Linear Collider designs, including the US site studies for the Linear Collider sites in Illinois and California.
- Fermilab Particle Physicists are working on four major detector components R&D and coordinating some simulation efforts.
- Recently, Fermilab Director has charged a group to vigorously participate in the Linear Collider Accelerator R&D.

Accelerator Physics Studies

- The key to the success of the Linear Collider is production and transport of low emittance beam to IR.
- At Fermilab's accelerator physics effort we have decided to look at
  - Damping Rings for TESLA and Pre-Damping Ring for NLC
  - Emittance preservation in LINAC and alignment requirements.
  - Electron Beam Physics modeling tools

TESLA Damping Ring

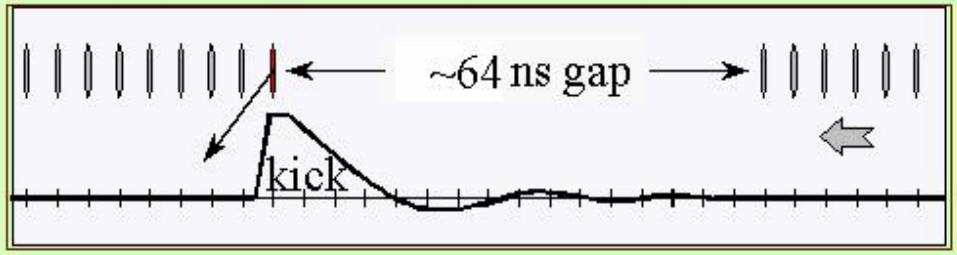
- TESLA design of Linear Collider requires 2820 bunches of electrons at ~335 nsec spacing. This makes the TESLA Damping Ring rather long. US studies have raised some questions about the TESLA Damping Ring.

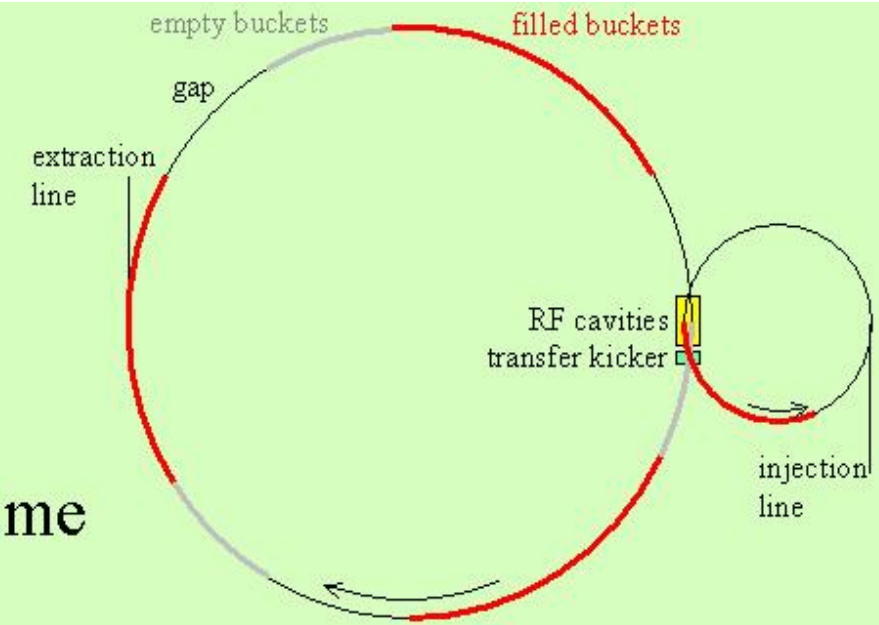
- The present design of the TESLA Damping Ring though technically sound is 17 kms long. The key limitation being faster kicker. It shares the tunnel with main Linac so there is some commissioning time issues.

- We are investigating several ideas on a faster kicker scheme by developing a common lattice design. We are developing conceptual design(s) for these kickers and how to test its performance.

Damping Ring Studies

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

Comparison of two designs

Parameter	Small ring (e^+/e^-)	Dogbone (e^+/e^-)
Energy	5 GeV	5 GeV
Circumference	6.12 km	17 km
Horizontal emittance γe_x	2.5×10^{-6} m	8×10^{-6} m
Vertical emittance γe_y	0.02×10^{-6} m	0.02×10^{-6} m
Transverse damping time τ_d	28 ms / 44 ms	28 ms / 50 ms
Current	444 mA	160 mA
Energy loss/turn	7.3 MeV / 4.7 MeV	21 MeV / 12 MeV
Radiated power	3.25 MW / 2.1 MW	3.2 MW / 1.8 MW
Tunes Q_x, Q_y	62.18, 28.38	72.28, 44.18
Chromaticities ξ_x, ξ_y	-112, -64	-125, -68

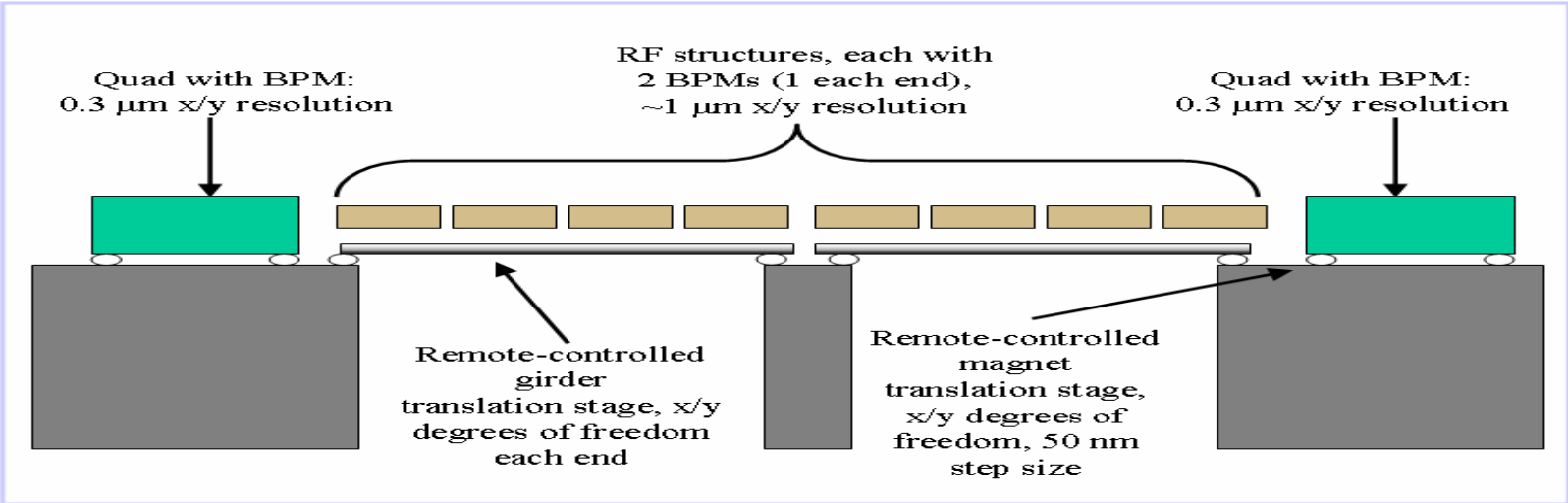
We are working on further developing these Kicker ideas.

Low Emittance Transport in NLC Linac

- Damping Rings generate Low Emittance Beam. This Emittance must be preserved through, Bunch Compressor, Main Linac and the Beam Delivery System.
- Emittance Budget in NLC Main Linac from DR extraction: ~3% in horizontal and 50% in vertical plane.
- Emittance growth in the Linac is caused by
  - Single Bunch: Transverse wakefield resonantly drives the tail of bunch in betatron oscillation
  - Multi Bunch: Leading bunch deflects trailing bunch center.
  - Incoherent Sources: Misalignments and quadrupole errors
  - Ferbrication error (Straightness of RF structure and HOM frequency error.) reduces the effect of LR wake suppression.

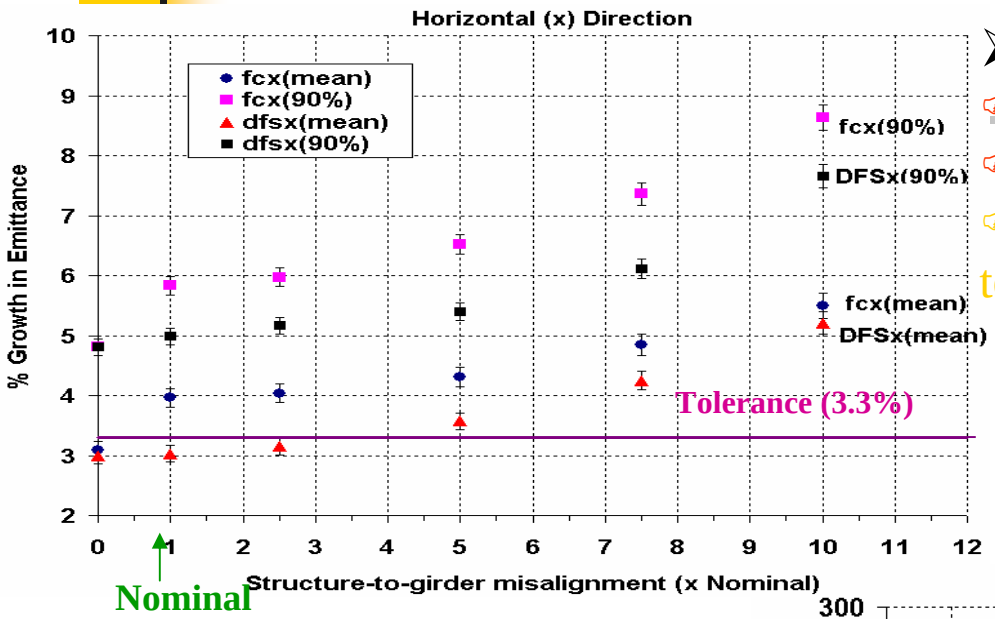
Study of Beam Based Alignment

- Alignment tolerances can not be met by *ab initio* installation.
- Quads and RF structures need to be aligned with beam-based measurements.
- Two methods
  - French Curve: Read all BPMs, compute magnet moves, align RF
  - Dispersion Free Alignment



- ☞ Remotely controlled Translation Stages for quads and RF girders
- ☞ High resolution BPMs in Quads and RF structures

Structure-to-Girder Offset



- $\gamma\varepsilon_x$ growth in DFS and FC:
  - ☞ DFS: mean (~ x2.5) within tolerance
  - ☞ DFS: 90% CFL can create problem
  - ☞ FC: both mean and 90% limit beyond tolerance even for nominal values.

Nominal Values

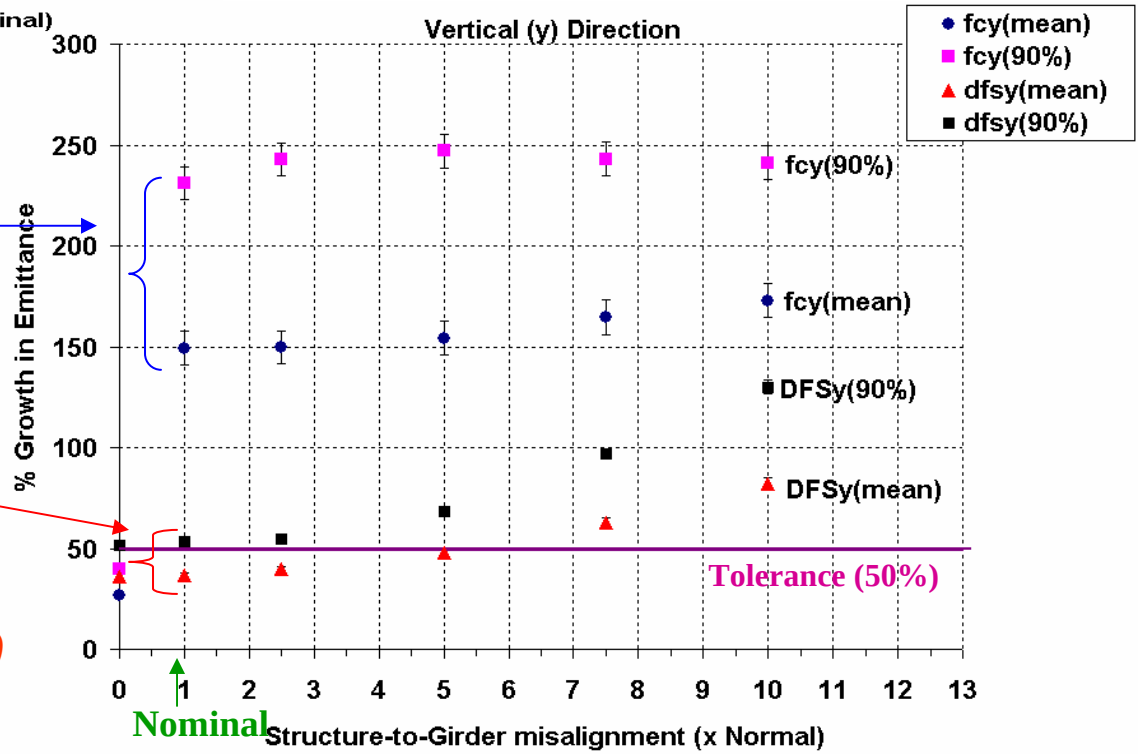
Rms offset in x-direction : 75 μm

Rms offset in y-direction : 25 μm

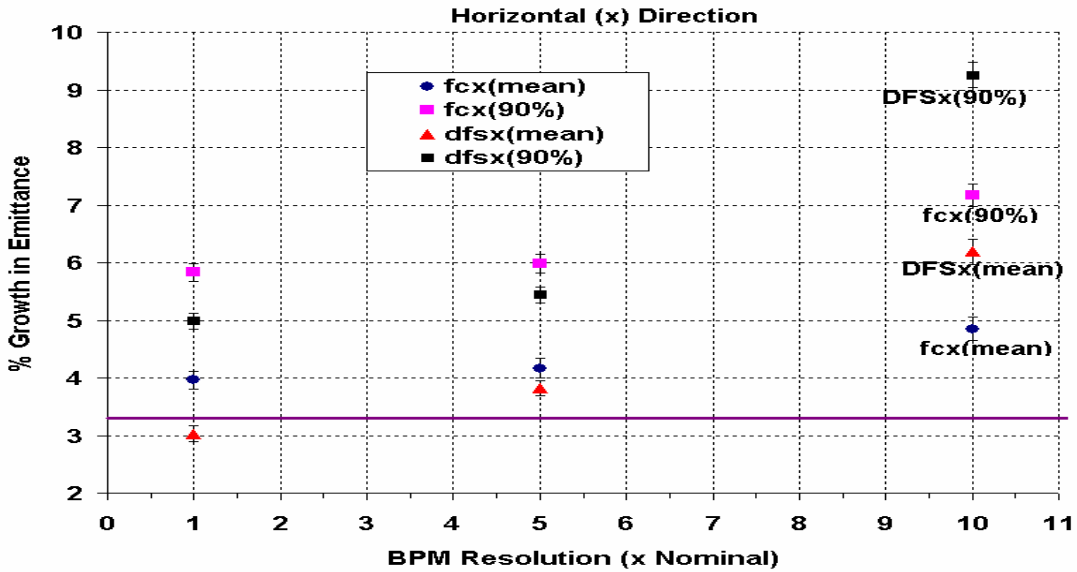
- $\gamma\varepsilon_y$ growth in FC:
  - ☞ remains almost constant (~ x5 nominal values), but
  - ☞ much above tolerance.

- $\gamma\varepsilon_y$ growth in DFS:
  - ☞ increases more rapidly.
  - ☞ mean within specs. (~x5 times)
  - ☞ 90% CFL can cause problem

(machine should be "mean" seed !!)



BPM Resolution



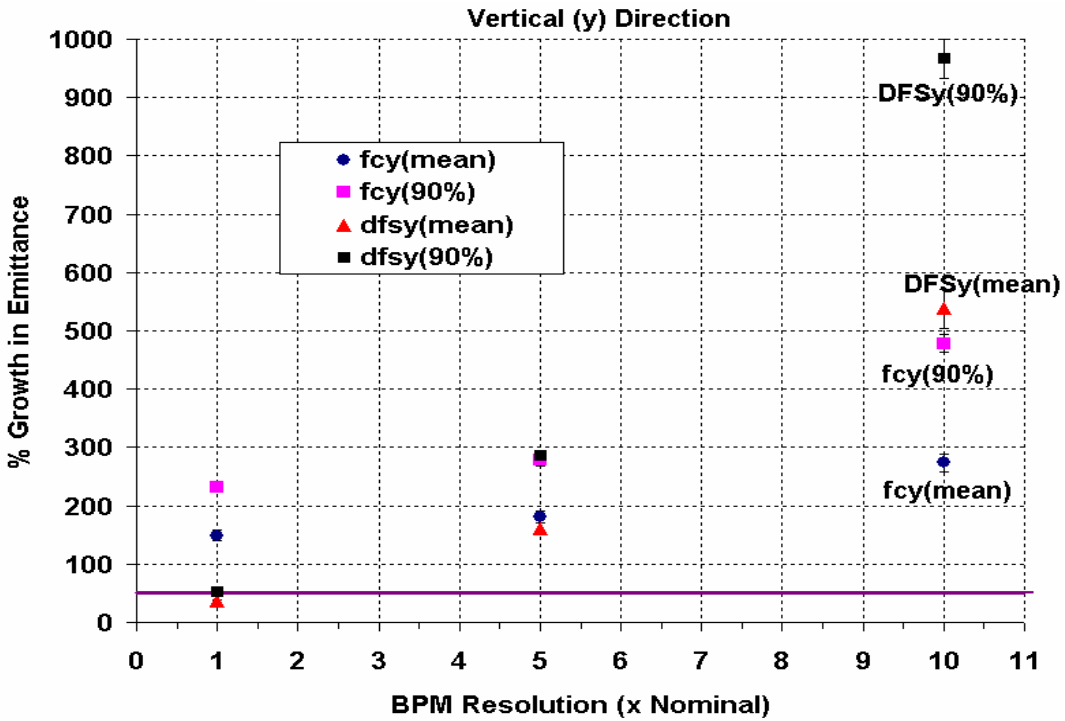
- $\gamma\varepsilon_y$ & $\gamma\varepsilon_x$ growth in FC:
  - ☞ lesser dependence, but,
  - ☞ much above tolerance.

Nominal Values

Rms offset in x-direction : 0.4 μm

Rms offset in y-direction : 0.4 μm

- $\gamma\varepsilon_y$ & $\gamma\varepsilon_x$ growth in DFS:
  - ☞ depends heavily on BPM resolution.
  - ☞ should remain within Nominal values.



Engineering Test Facility for LC

- At present there are Test Facilities at SLAC, KEK and DESY that are designed to do LC R&D.
- We believe that next generation of LC Engineering Test Facility is needed for a complete system test of the Linear Collider and accelerator physics.
- Establish confidence that an LC, as designed, can be constructed for the cost specified, on the schedule specified, and it will meet the performance specification. The scope of such a facility needs to be defined.
- To be most effective this proposal should be developed by the International linear collider collaboration. We assume that the emerging design would go to the Global Design Organization as a proposal.

Thoughts on the Scope of ETF

- There are three main Categories of issues ETF could be build to address Accelerator Engineering Issues including cost, Accelerator Physics Issues, Management and International Collaboration
- It should have the capability to do perform beam studies.
- ETF could be 1% demonstration machine for the technology chosen by ITRP in the final machine configuration.
- It could be a development facility for the Instrumentation, controls etc needed for the LC.
- It could be a development facility for one of a kind device.
- It could be used for industrialization/ later testing of the major component.

NLC R&D Overview

- X-Band RF Structure Design and Fabrication
  - Review of cell table of SLAC disk design, construction with local industry, QC of the RF disk
  - Frequency tuning of the single disk (if needed).
  - Fabrication of 60 cm RF structure
  - Frequency tuning of the assembled RF Structure
- RF Design work
  - Design of the Fermilab wave guide coupler for FXB, FXC and FXD Structures
  - FXD HOM extraction design and analysis
  - Design of Fermilab Structure FXE
- Vibrations studies

RF Structure Factory

RF Quality Control Clean Room (Class 3000)

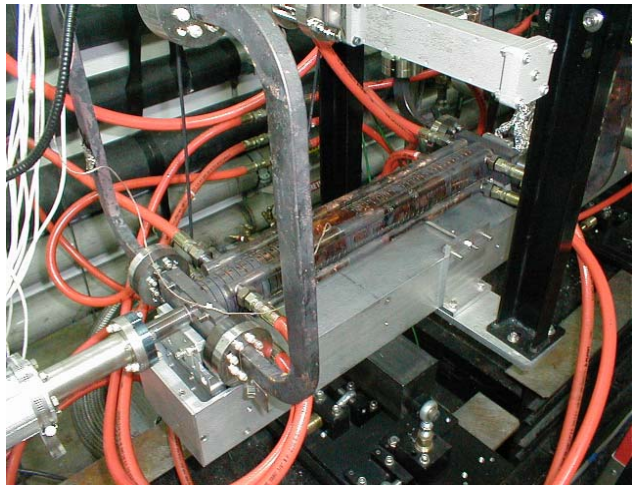
- Brazed structures, no diffusion bonding

A Structure during Bead-Pull Measurements & Tuning

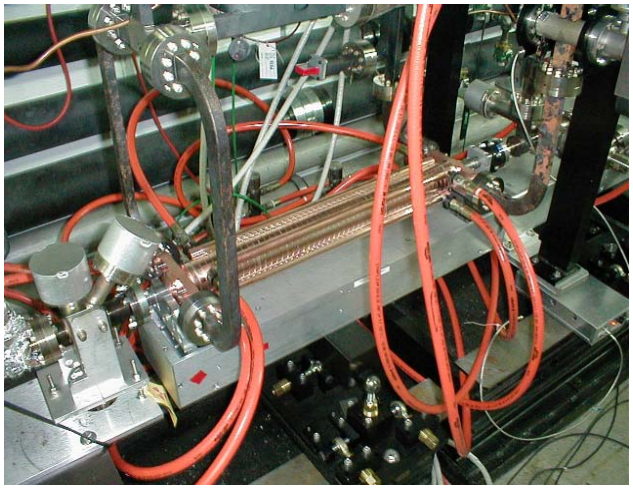
- Disks & Couplers are precision machined, no diamond turning (industrial vendors)

FX-band Structures at NLCTA

- Four structures currently operating at NLCTA were fabricated by Fermilab.
- FXB-006 is the first structure built by anyone to achieve NLC specification for gradient and breakdown rate (<0.1 breakdown/hour @ 60 Hz, 400 nsec, 65MV/m)



FXB-006

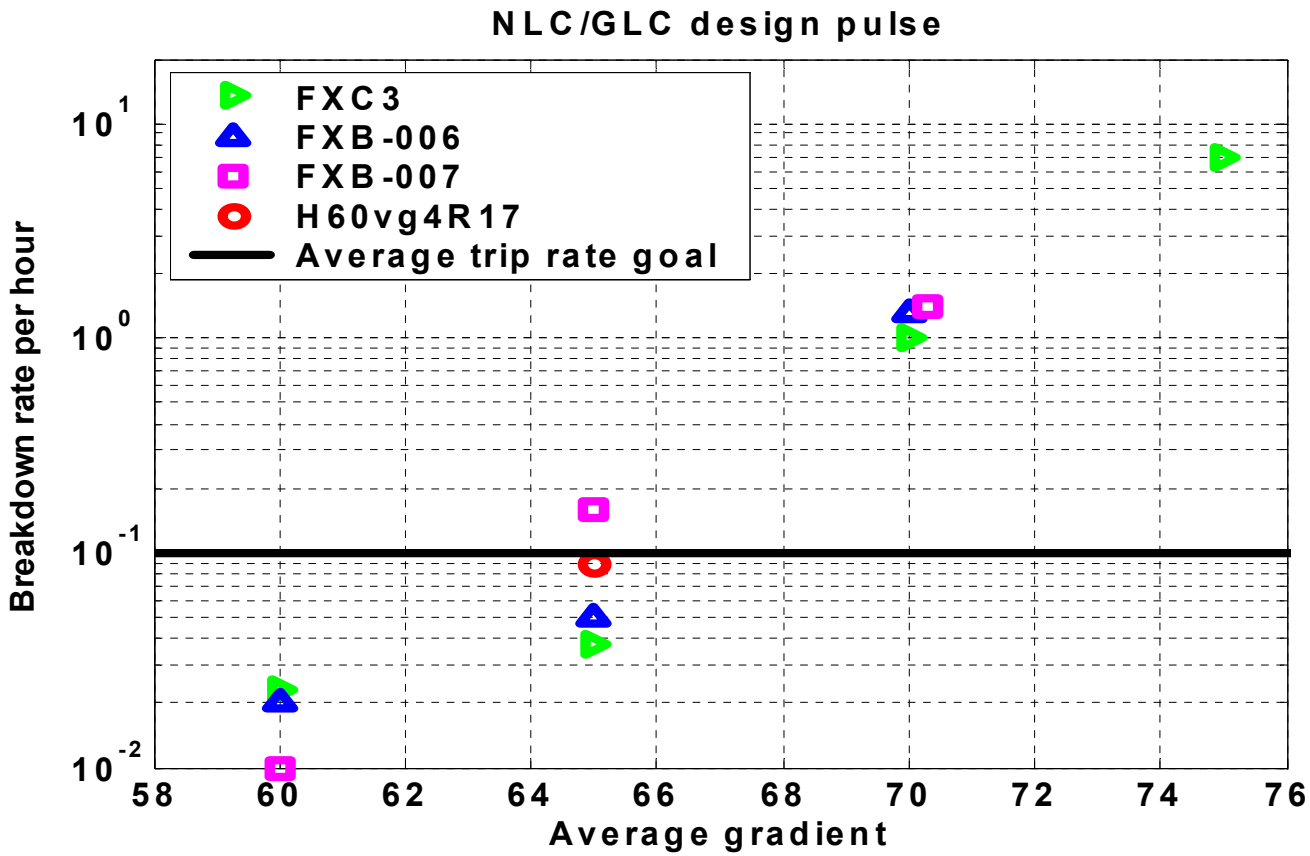


FXC-001

- FXC003 has also met the NLC design goals.

Processing results from the 4 latest NLC/GLC prototype structures

3 out of 4 exceed breakdown rate requirements at 65 MV/m

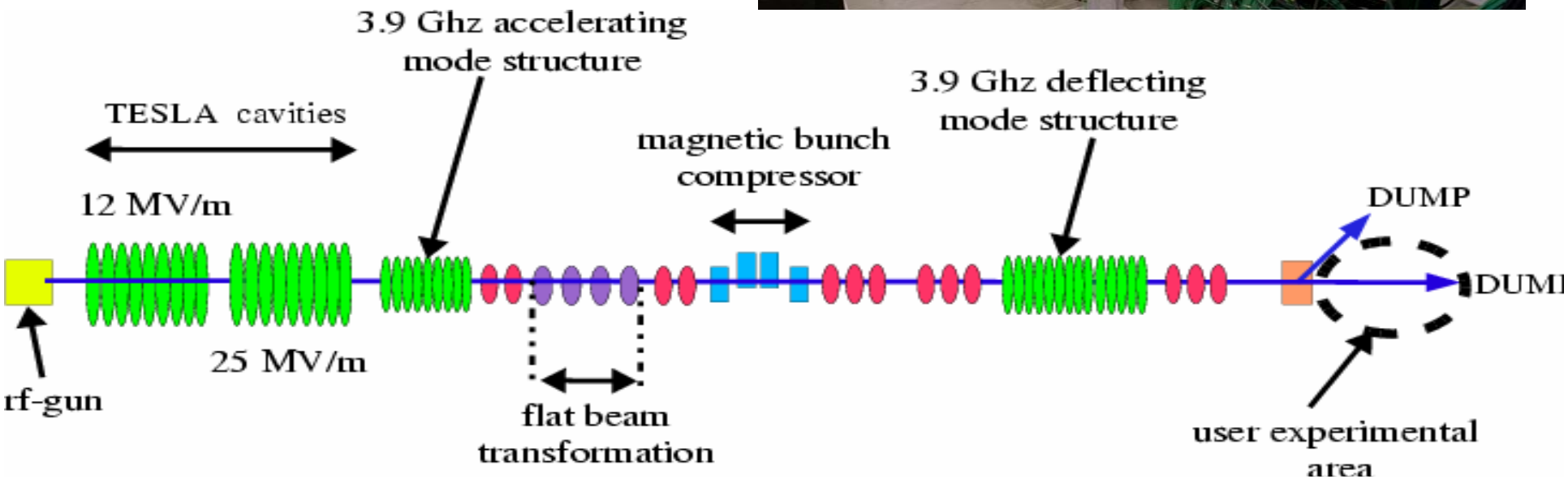


- Out of 3 Fermilab Structures in NLCTA to date 2 meets the R1 requirement in contrast to several structures produced by other labs.

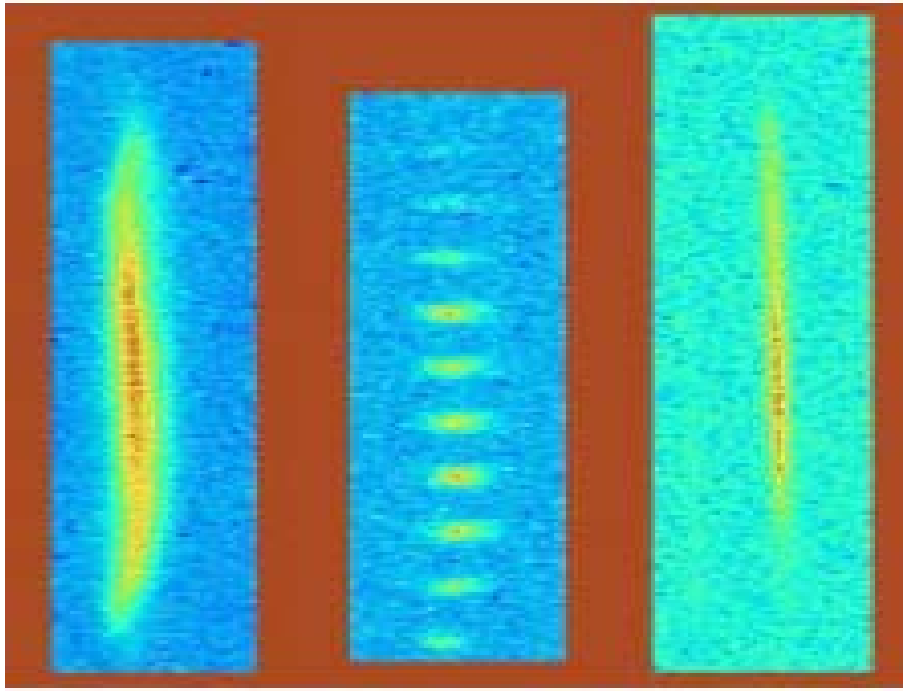
Overview of SCRF activities

- Linear Collider R&D
  - For TESLA we built modulators and electron guns for TTF at DESY (AD) and designed vertical test dewars and cryostats
  - The A0 photo-injector at FNAL is very similar to TTF and uses TESLA acceleration cavities
  - We also are designing and building a 3.9 GHz 3rd harmonic cavity. The purpose is to diminish the beam energy spread so that the electron pulse length can be made very short via a magnetic chicane
- CKM
  - FNAL has been doing R&D to build 3.9 GHz transverse kick cavities for an experiment proposed at FNAL that needs an RF separated K beam
- Proton Driver
  - FNAL has a design study in progress for an intense Proton Source based upon a 8-GeV SC linac

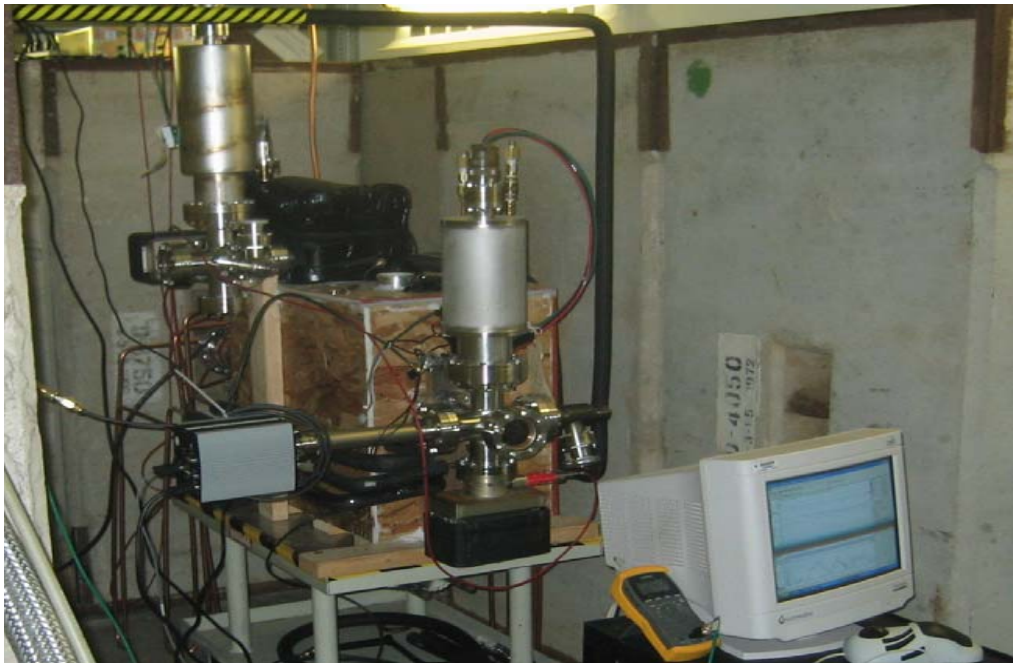
Fermilab NICADD Photo Injector Laboratory



Fermilab: TESLA Beam R&D



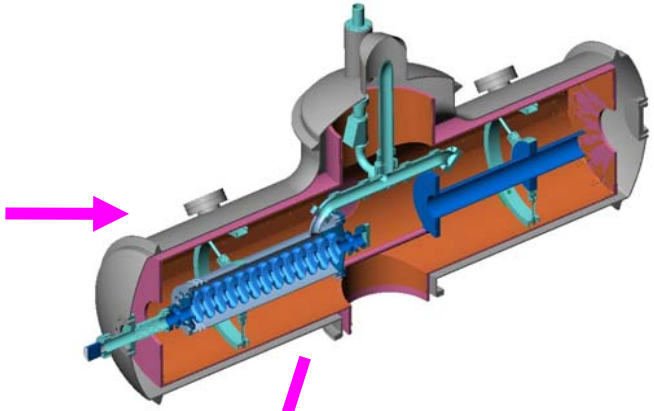
The TESLA QUALITY flat beam. 5 μm in the horizontal and 40 μm in the vertical plane.

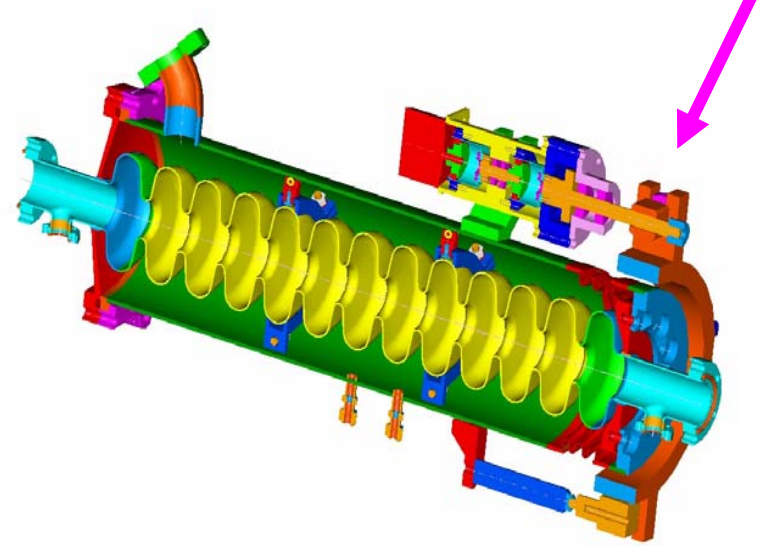


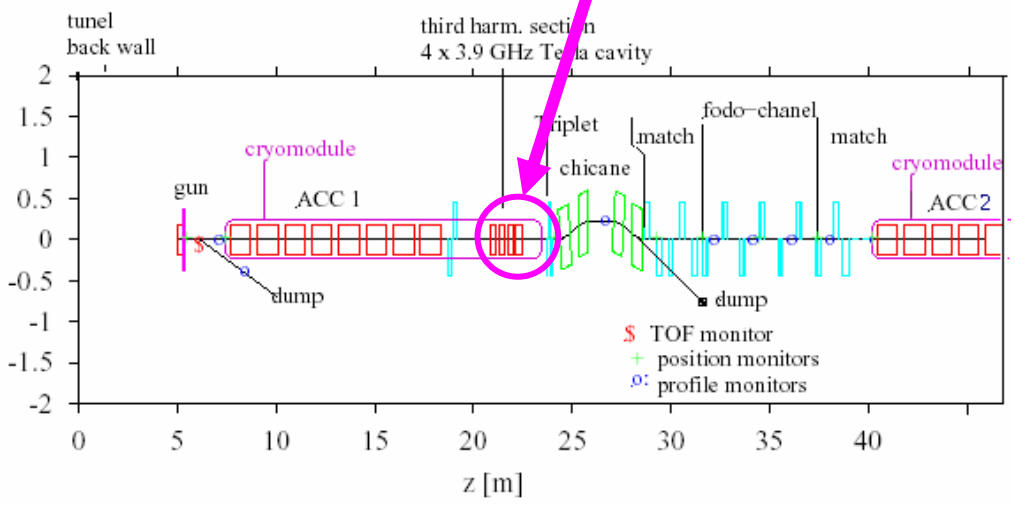
Polarized RF Gun

SCRF R&D

- Building our capabilities for the future
  - Develop and build elements of a SRF module fabrication and test infrastructure
  - Design and build a prototype of a 3.9 GHz accelerating cavity for the Photo-Injector Test Stand
  - Develop a microphonics compensation system

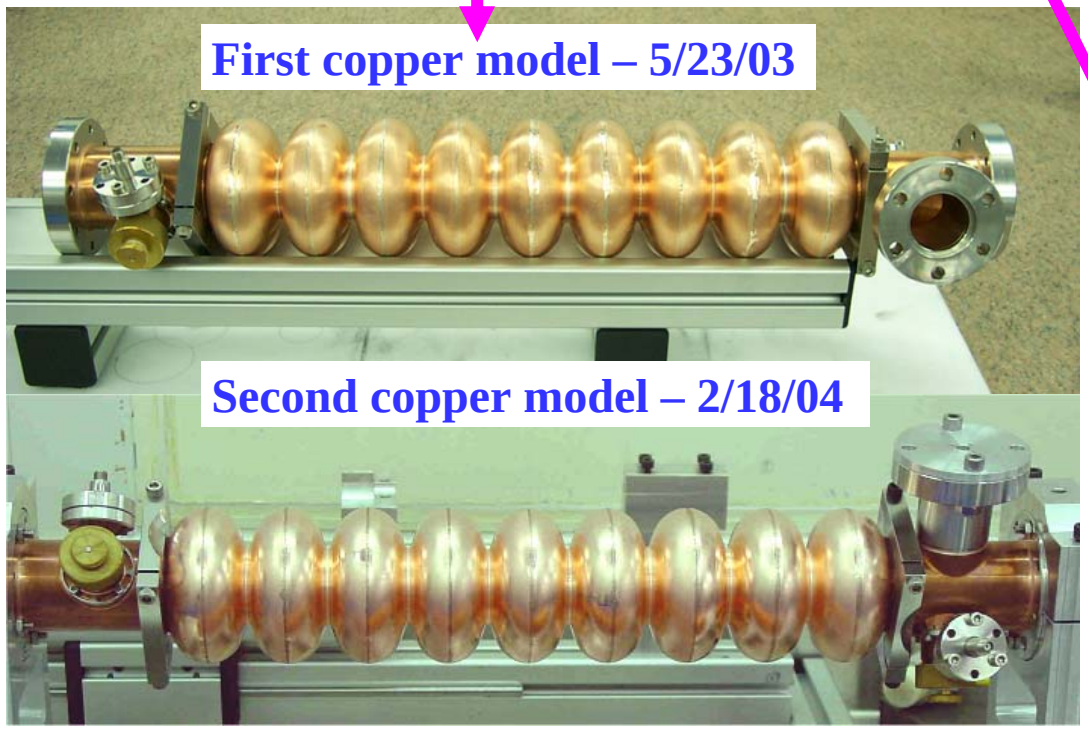






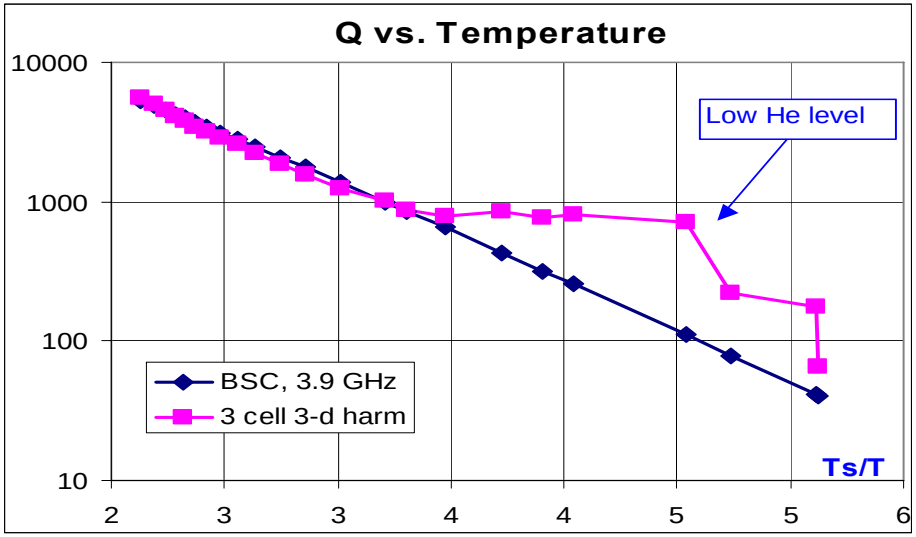
3.9 GHz accelerating cavity

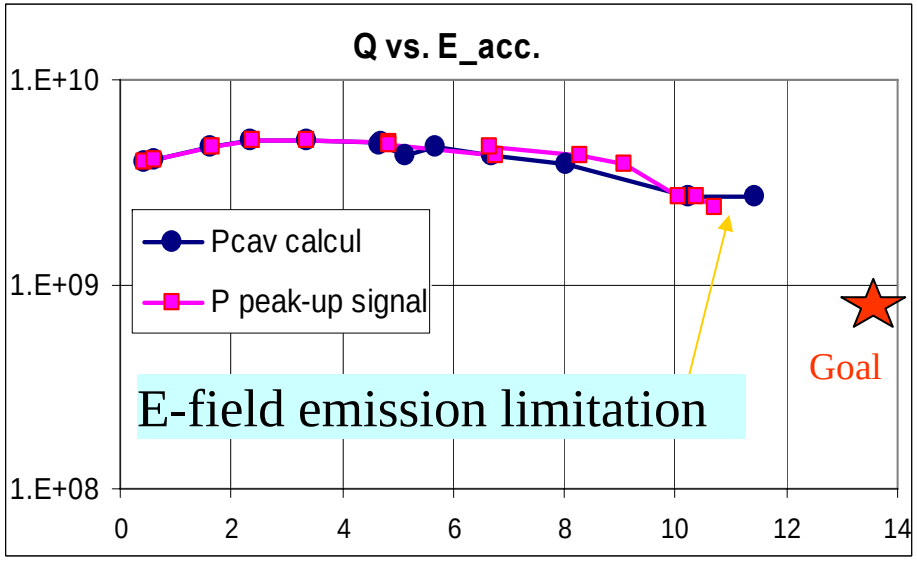
- **9-cell cavity and helium tank design and fabrication**
- **HOM coupler design and fabrication**
- **Cell and cavity design and prototyping**



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

Tested after 140 µm BCP, heat treatment and HPR





Linear Collider @ Fermilab

- Fermilab/Northern Illinios/U.S. is a natural host
  - Fermilab
    - Scientific and engineering expertise in forefront accelerator and detector technologies
    - Significant experience in construction and operations of large accelerator based projects.
    - The leadership mantle of U.S. high energy physics
  - Northern Illinois
    - 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.

Linear Collider Site Studies

- **Four Complete Design Solutions Have Been Developed.**

  IL and CA X Band Linear collider

  IL and CA Superconducting

- **Design Solutions Include Design Summaries, Cost Estimates, Drawing Sets and Project Schedule Information**

Summary

- Fermilab has made significant contributions to both the NLC and TESLA R&D.
- Fermilab is aligning itself to be a significant player in the Linear Collider with a serious goal to host it at or near Fermilab.
  - We will continue and expand our efforts in the accelerator, detector and IL site studies.
  - We are increasing our effort in the accelerator physics in Main Linac and Damping Ring.
  - We are proposing that a LC Engineering Test Facility (warm or cold to be in line with technology decision) is needed. The scope this facility needs to be defined.
- We are increasing Fermilab and Illinois presence within the LC collaboration(s) world wide.