Accelerator Technology and High Gradient Collaboration

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Three Faculty members,
Eleven Staff members
One Research Associate
Three Graduate students

Outline

- The US High Gradient Collaboration for Multi TeV Linear Collider
  - Introduction
    - Collaboration structure and management
    - Proposed Work at University of Maryland
    - Proposed work at MIT
    - Collaborative work with ANL and NRL
    - Testing of CERN structures
  - SLAC's program on high gradient research
    - Budget and resources
    - Basic Physics Experimental Studies.
    - RF Sources
    - RF technology developments at 11.424 GHz and at 30 GHz
    - Pulsed heating experiments and superconducting material testing.

Outline Continued

- Technology Research
  - Solid state RF sources
  - Applications of RF ideas to optical acceleration
  - Novel FEL and Light Sources Technologies

- Advanced Concepts for the ILC
  - Fundamental mode Couplers
  - RF distribution system

- Advanced Electronics and Research Efforts in Accelerator Dynamics and Instability Control

- LCLS and ILC Components and System Development

US Collaboration on High Gradient Research for a Multi-TeV Linear Collider

- Current Members:
  - Laboratories:
    - Argonne National Laboratory
    - Lawrence Berkeley National Laboratory
    - Naval Research Laboratory
    - Stanford Linear Accelerator Center (Also the host of the collaboration)
  - Universities :
    - University of Maryland
    - Massachusetts Institute of Technology

US Collaboration on High Gradient Research for a Multi-TeV Linear Collider

- Business Associates
  - Omega-P, Inc.
  - Calabazas Creek Research, Inc.
  - Haimson Research Corporation
  - Tech-X Corporation
  - Communications and Power Industries

- Foreign Colleagues
  - CERN
  - KEK

US Collaboration on High Gradient Research for a Multi-TeV Linear Collider

- Governance Structure
  - Spokesman
    - Selected to lead this effort by the directors of SLAC and Fermilab at the request of the DOE, Prof. Ronald Ruth of SLAC
  - Advisory Council
    - Prof. Sami Tantawi of SLAC (11.4 GHz research/overall technical coordination);
    - Dr. Richard Temkin of MIT (high frequency research and RF source development);
    - Dr. Gregory Nusinovich of UMD (theory and code development)
    - Dr. Wei Gai of ANL (other experimental programs).
  - Scientific Secretary
    - Dr. Christopher Nantista of SLAC has been selected to be the current collaboration Scientific Secretary.

Goals

- The purpose of this collaboration is to perform research to determine the gradient potential of normal-conducting, rf-powered particle beam accelerators, and to develop the necessary accelerator technology to achieve those high gradients.
- Harnessing the momentum of the concluded NLC/JLC development programs and working in conjunction with the ongoing CLIC studies, the collaboration will explore the possibility of pushing the useable acceleration gradient from the 65 MV/m reliably achieved in NLC structures up towards 180 MV/m or higher.
- Advancing the state-of-the-art in this area is essential to the realization of a post-ILC, multi-TeV linear collider using two-beam rf power generation.

Scope

- This collaboration should not be viewed as an umbrella for general research into RF accelerator technology or other advanced accelerator techniques.
- For example, the general development of RF sources, modulators, and RF components are not included in this effort.
- Specific technology may be included, provided that it is required for achieving the goals expressed in the introduction.
- As our research proceeds, the collaboration may enhance or limit the scope of our work plan to include additional techniques or technologies which address the primary goal of the achievement of high acceleration gradient.

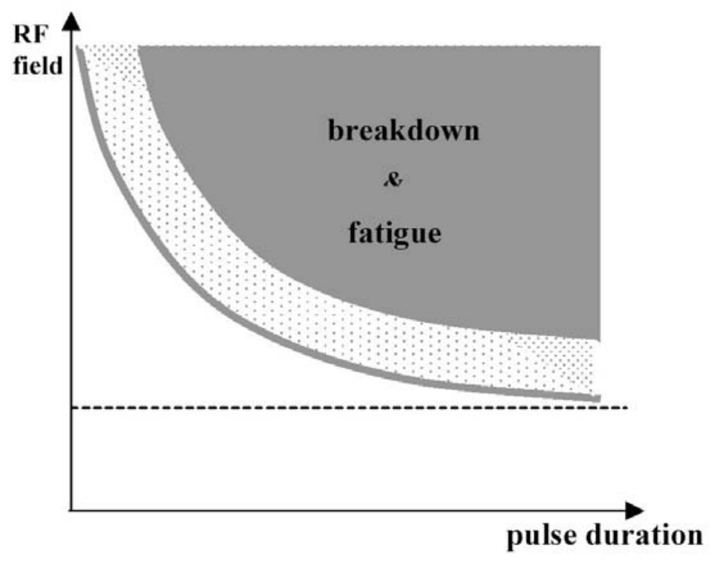
INSTITUTE FOR RESEARCH IN ELECTRONICS & APPLIED PHYSICS

University of Maryland program

Gregory Nusinovich et. al.

Theory and modeling of physical effects limiting reliable operation of high gradient accelerating structures

Goal: identification of the boundary between non-destructive (dotted) and destructive (dark grey) regions of operation in various structures



Nondestructive effects – dark current, multipactoring, Destructive – RF breakdown.

Multipactoring in metallic and dielectric-loaded structures: stationary and non-stationary theory

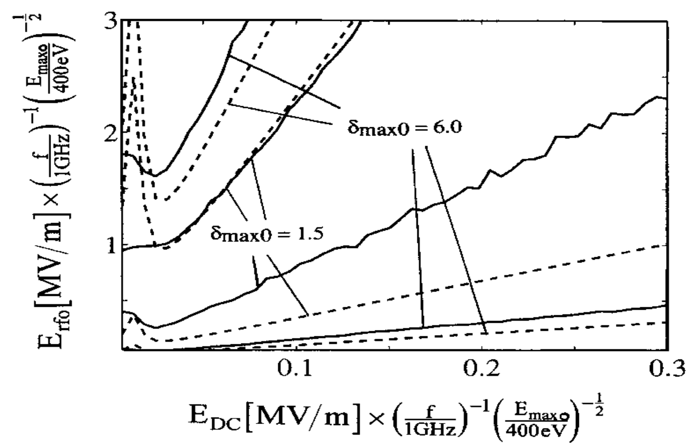
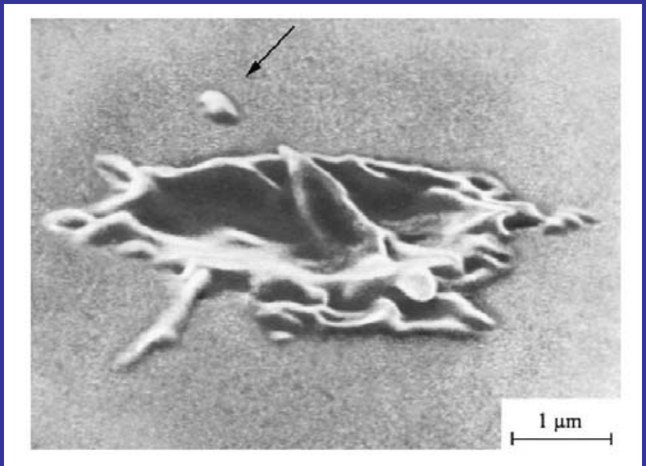


FIG. 5. Multipactor regions derived analytically (dashed) compared with the ones obtained through Monte Carlo simulations (solid) for $\delta_{max0} = 1.5$ and $\delta_{max0} = 6.0$. Here, $E_{0m}/E_{max0} = 0.005$.

The theory of dielectric-loaded structures will be developed in application to joint NRL-ANL X-band experiment.
Non-stationary theory + XOOPIC simulations

Analysis of the dark current will include studies of field emission from the irises of structures used at SLAC and CLIC, (thermal-field emission theory, geometric models of field enhancement, statistics of emission site non-uniformities and random profile models included).

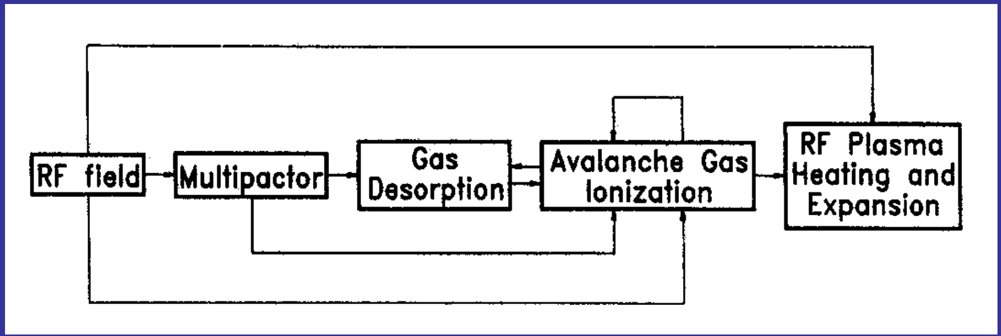
<u>Destructive RF breakdown</u>: formation of craters and their clusters (collaboration with SLAC)



Two scenarios of the RF breakdown:

a) Direct breakdown,

b) Breakdown via multipactoring

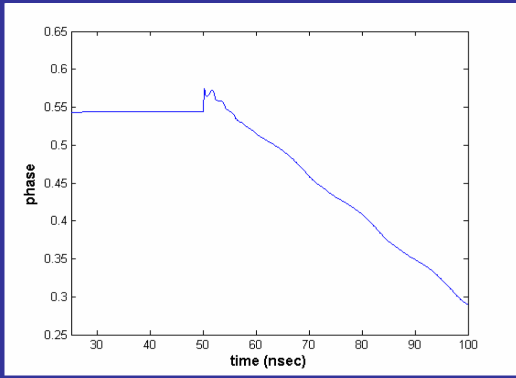


<u>Novel structures</u>: PBG and quasi-optical structures allow for stronger damping of wake fields – operation with shorter pulses.

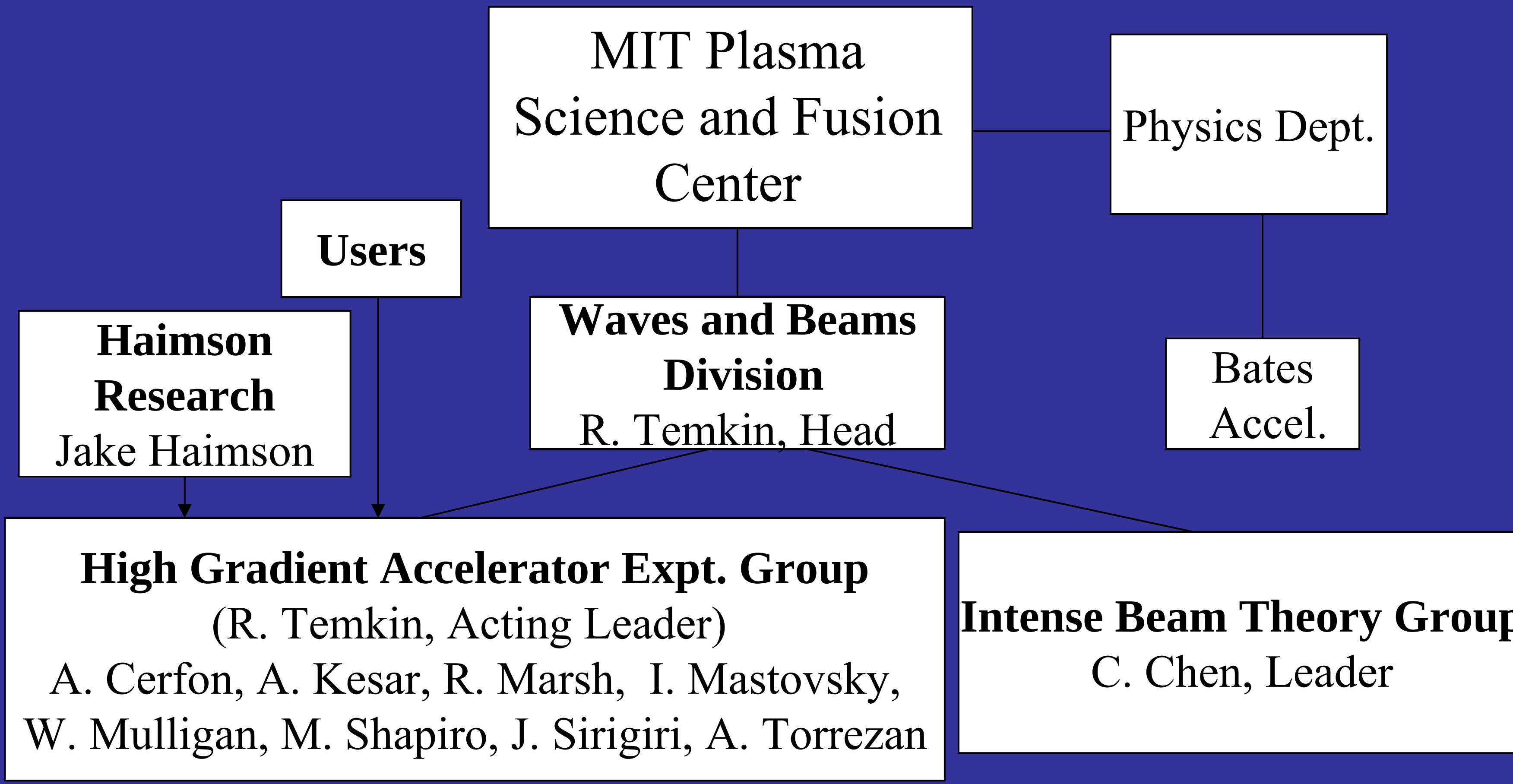
Pulse heating and RF breakdown issues to be addressed. (Collaboration with MIT and Omega-P)

<u>Gyrotron oscillators</u> for testing high-gradient structures (30 GHz - CLIC frequency) .

Phase sensitivity to voltage variations in free-running and phase-locked devices. (Collaboration with SLAC and MIT)



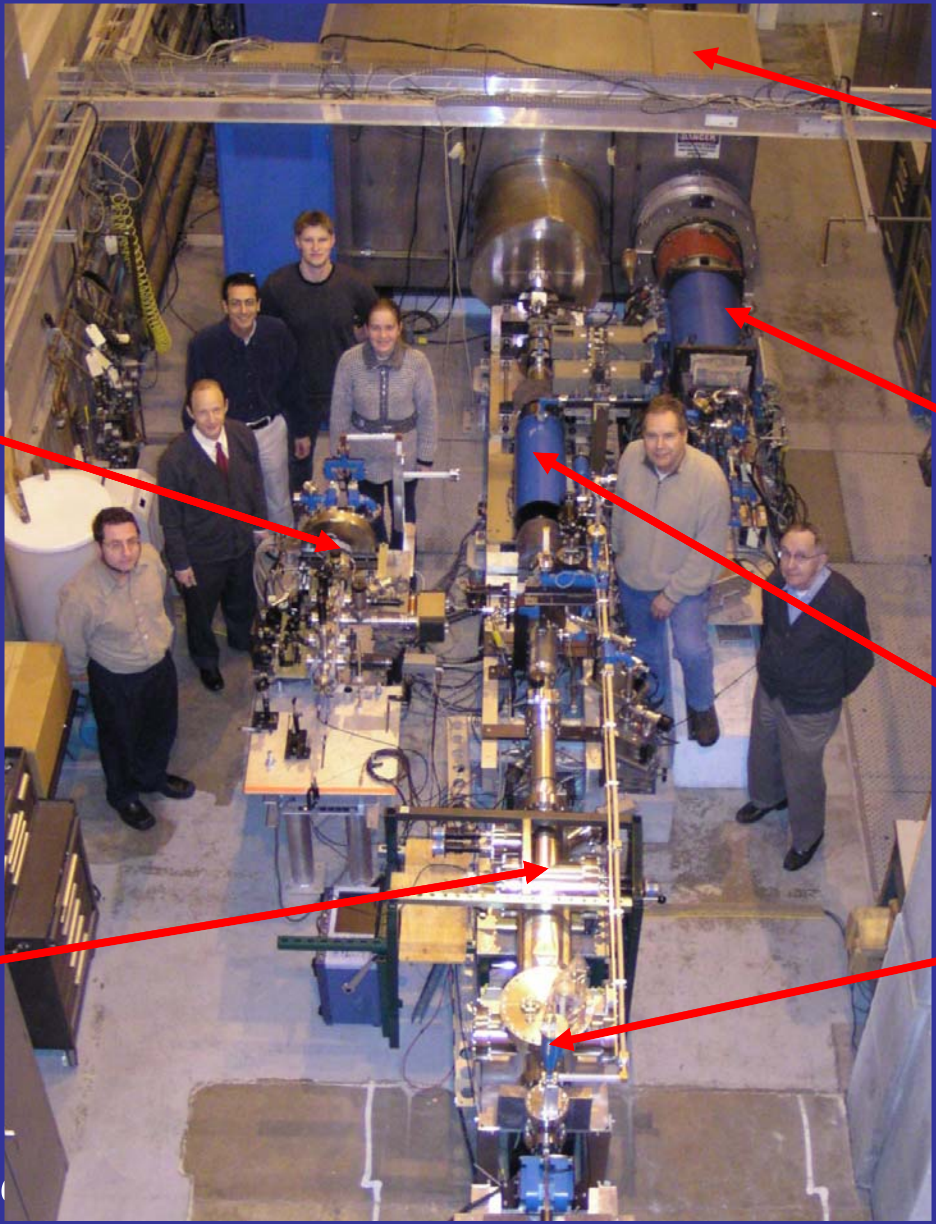
MIT Accelerator Research



17 GHz Accelerator Laboratory

RF Break-down / RF Gun Test Stand

THz Smith-Purcell Expt.



Modulator
700 kV, 780A
1 μs flattop

Klystron 25 MW
@ 17.14 GHz

25 MeV Linac
0.5 m, 94 cells

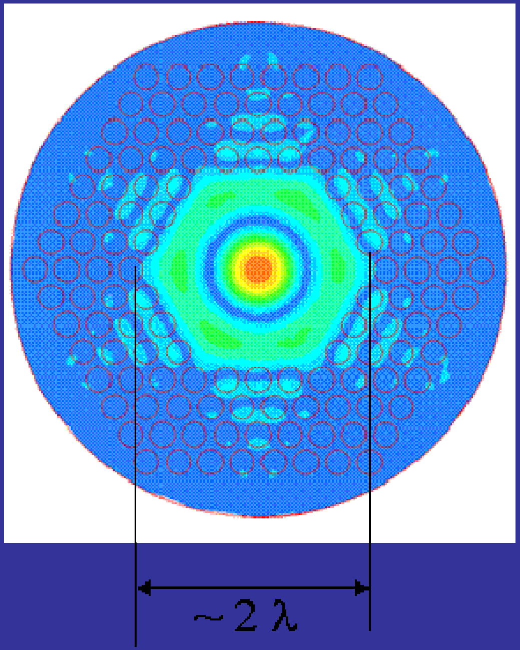
Novel High Gradient Structure / Photonic Bandgap Test Stand

Proposed Use of Existing 17 GHz Facility

- Test RF Breakdown in novel structures
  - Test at 17 GHz with up to 10 MW at > 200 ns.
- Already demonstrated to > 300 MeV/m
- Optical diagnostics.
- Electron Beam / Dark Current diagnostics.
- User Friendly

Examples of Proposed Novel Structure Research

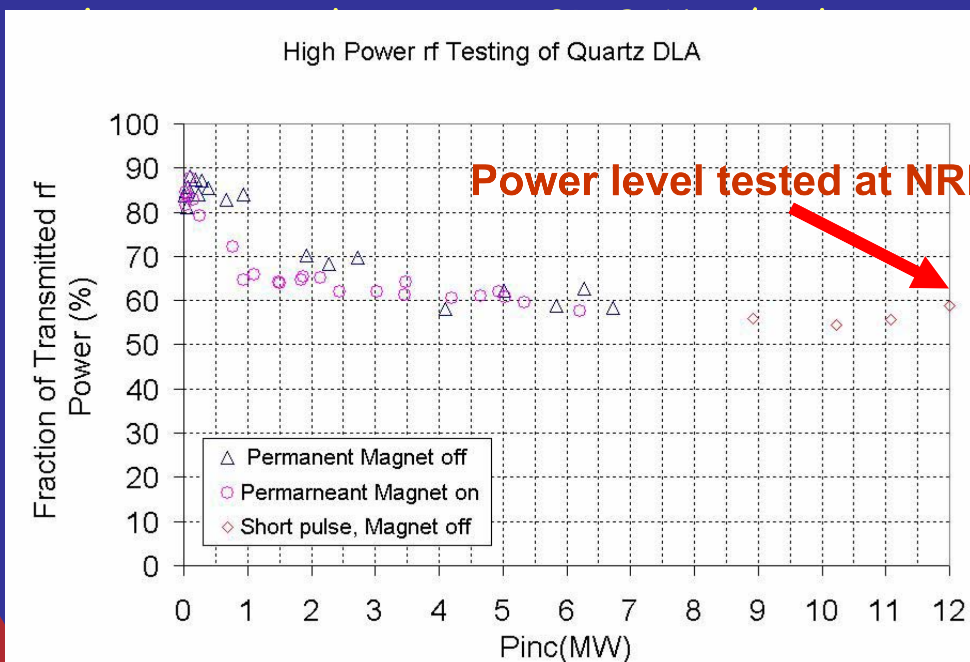
- Novel structures "outside of the box"
- MIT Examples:
  - Dielectric Photonic Bandgap Structures
  - High order mode accelerators
    - Shapiro et al., PAC03
  - Surface mode accelerators
    - Shapiro et al., PAC05
- New Ideas
  - Specific new proposals have been developed by MIT

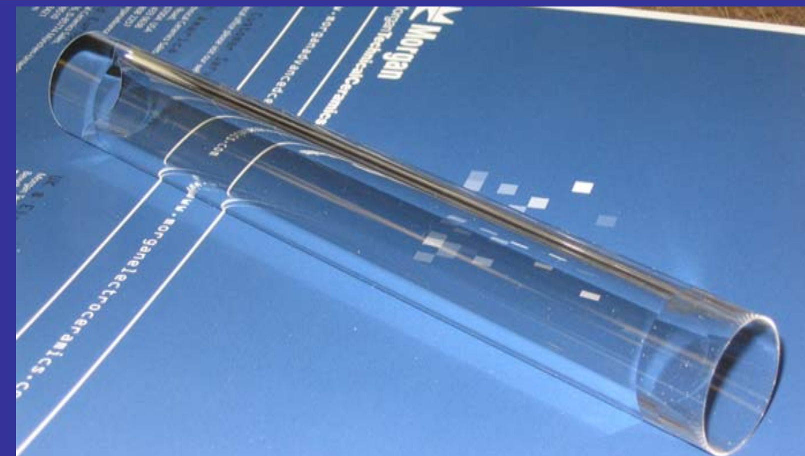


TM_{02}–like mode

A Quartz tube fabricated and tested at NRL, up 12 MW. More power needed. Higher power (10 – 50 MW) planned at SLAC this fall.

Parameters	Value
Material	Fused Silicon
Inner Radius	8.97mm
Outer Radius	12.08mm
Dielectric Const	3.78
Group Velocity	0.38c
R/Q	3.614kΩ/m





High Power RF-Technology

22.8-30 GHz RF Sources and related technologies

- Several RF sources have been proposed at these high frequencies, including, gyrotrons, gyroklysrons, sheet-beam klystrons, magnicons, Harmonic Converters, etc.

- The Gyrotron is our best bet for a workhorse device in a short period of time.
  - If we buy this device only CPI can do it and they will probably team with MIT and Maryland for theoretical support.
  - If we make it we will use the same people with the addition to SLAC's experience to make electron guns. In this case we will have all the world experts working on this at the same time. It will also force us to talk to each other and collaborate.
  - No mater what this is a research device and the risk is high.
  - All the first and second generation experts, within the US, on Gyro devices are in this collaboration

- We have been successful in getting the rest of the collaboration to follow our lead on this matter!

Budget and Facilities for the High Gradient Program

- 2006 budget is $125k for all high gradient activities including RF sources at 30 GHz , Active pulse compression at 30 GHz, SLAC's experimental program and support for other labs.
- Plus $50 for testing of CERN structures and finishing remaining NLC tests
- 2007 estimated budget is ~375k to 675k. At the lower limit we will have a reasonable program at SLAC, at the upper limit we may be able to take some steps towards realizing an RF source at 30 GHz.
- We have informed the DoE that if there is supplemental money for the collaboration our first priority is to jump start the 30 GHz source developments

Budget and Facilities for the High Gradient Program (continued)

- NLCTA (3 RF stations, one Injector, one Radiation shielding)
  - Two 240ns pulse compressor, 300 MW peak, powered by two X-band 50 MW klystrons (used mainly for CERN and NLC type experiments)
  - One 400/200 ns pulse compressor, 500 MW peak, powered by 2 X-band 50 MW klystrons (Modulator is in final stage of construction)
  - 65 MeV injector with a 1 nC charge/bunch
  - Shielding enclosure suitable for up to 1 GeV
- Klystron Test Lab (2 RF stations, 2 modulators, 2 shielding enclosures)

  RF Stations
  - Stations 6 and 8, two 50 MW klystrons that can be combined and a variable length pulse compressor that can produce up to 500 MW (under construction).
  - Station 4, 50 MW klystron,

  Modulators
  - Station 2, ~500 kV, ~200 A modulator
  - Station 3, 500 kV, ~xxx A modulator

  Radiation Shielding
  - A shielding enclosure suitable for up to 100 MeV (ASTA Bunker)
  - A shielding enclosure suitable for up to 5 MeV

Most of the RF stations were not available this year because of either reconstruction or priority conflict with other lab programs such as LCLS. We have asked our management for a dedicated facilities for the High Gradient work. We will try to use both ASTA and the two-pack at NLCTA as the prime facilities for this research

2006-2007 ASTA TESTS:

In the summer of 2006 the LCLS Gun #1 tests will be tested with an S-band RF source in the structure in order to condition the gun, measure dark current and visualize possible breakdown with video.

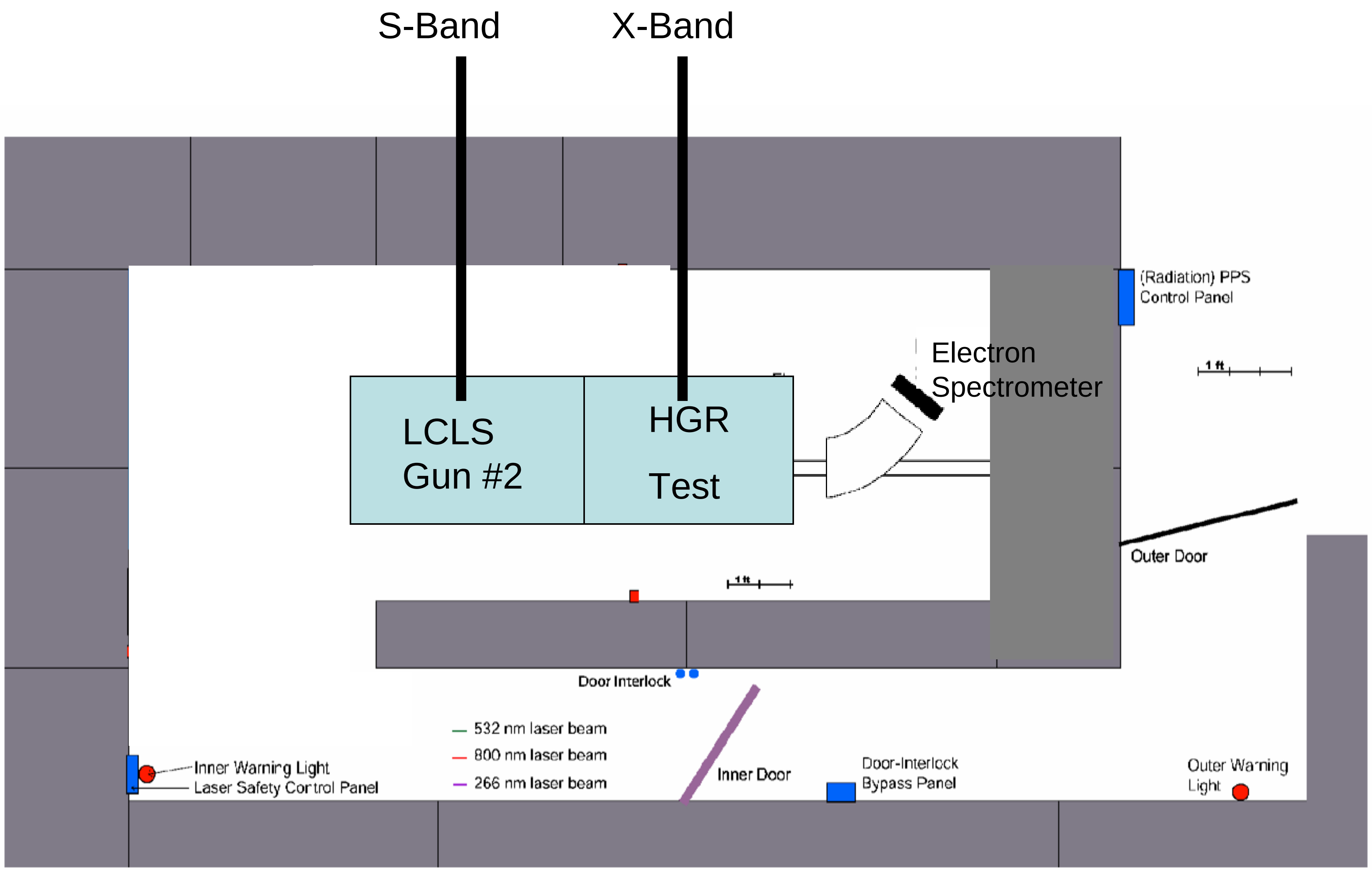
In the fall of 2006 the HGR program will test the SLAC/KEK cell and/or the ANL dielectric structure.
In January of 2007 LCLS gun #2 will be tested with a laser in ASTA.

2006-2007 ASTA Schedule:

June – September: S-band to test LCLS gun #1 under RF

October – December: X-band to test High Gradient structures

January – December 2007: Shared time between HGR test and test of LCLS gun #2, S & X band available



ASTA – Accelerator Structure Test Area – Fall 06

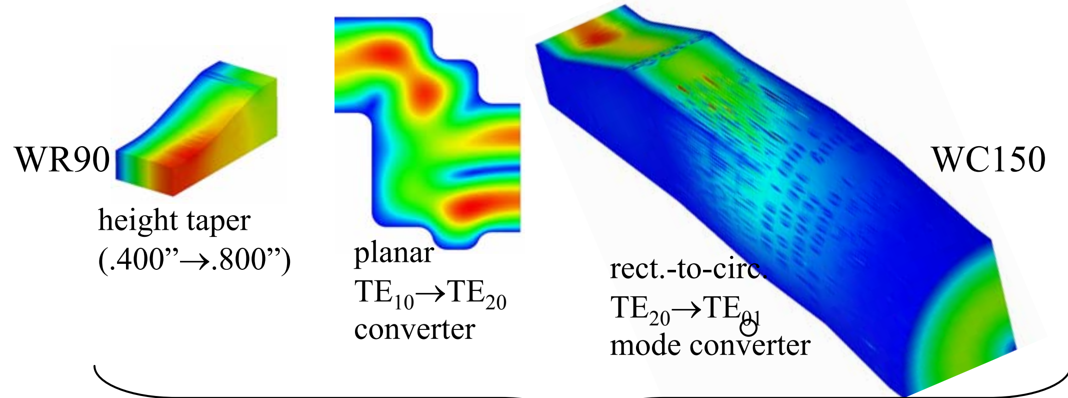
Stephen Williams

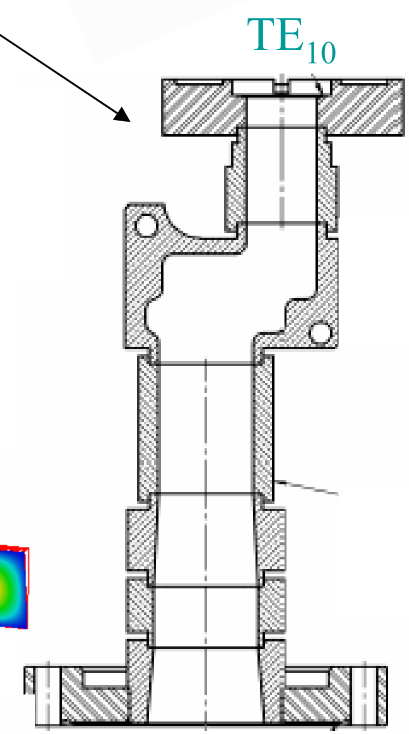
2006 SLAC program

- Support for Other x-band facilities and experiments
- Rebuilding of X-band RF infrastructure at ASTA
- Reconfiguring the 2-pack facility
- Building a test setup for pulsed heating and superconducting material characterization
- Material characterization by electron beams (V. Dolgashev/KEK, funded by KEK)
- Testing waveguide and structures at NLCTA
  - Molybdenum waveguide
  - CERN structures
  - NLC structures
- Designing Active RF pulse compression switches at 30 GHz for use at CERN and later at SLAC

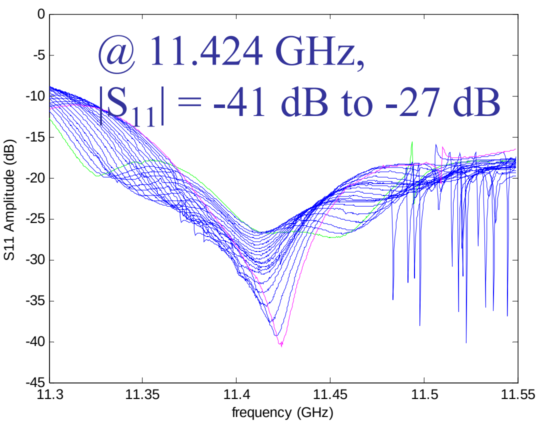
SLAC is not only supporting other labs in terms of SLAC's experimental facilities but also in terms of components and the developments of these components

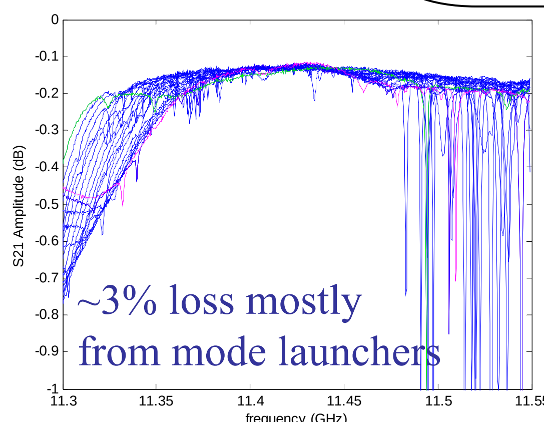
WR90-WC150 TE_{01} Mode Launcher

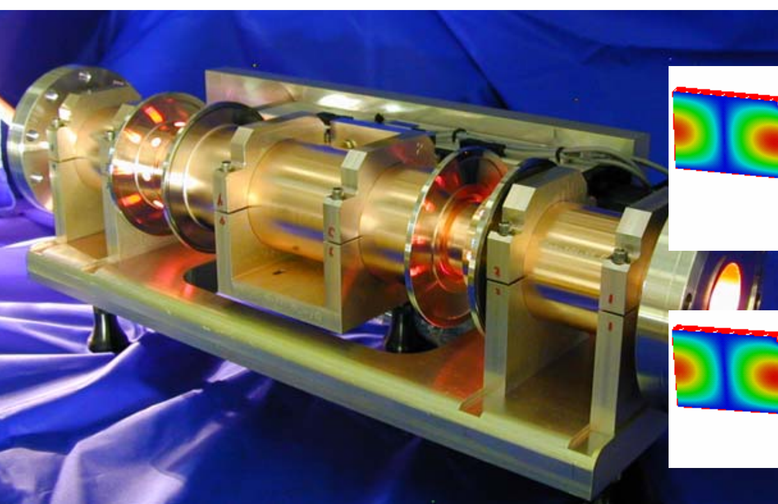


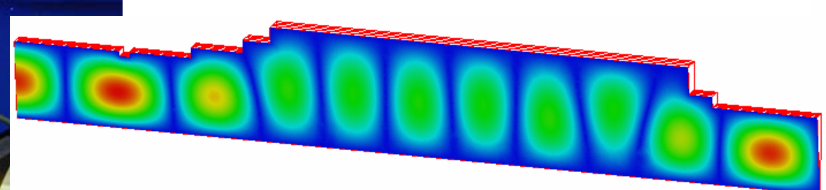


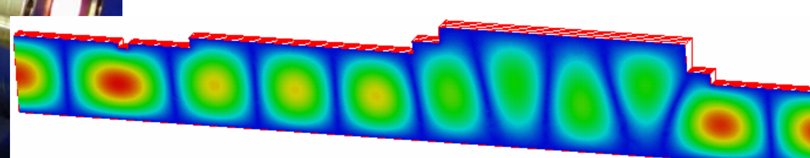
Circular TE_{01} Mode Slide Phase Shifter for NRL/ANL



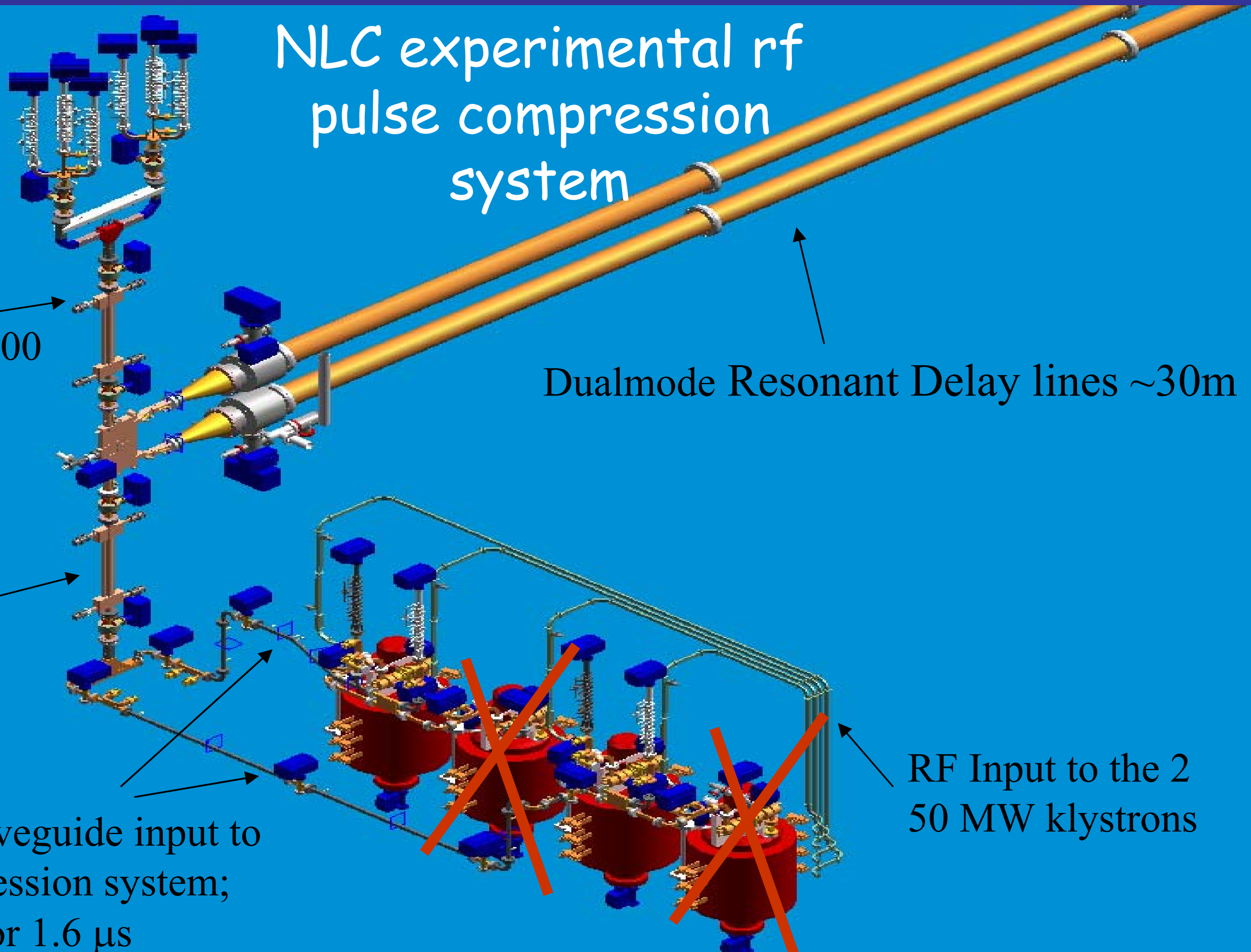




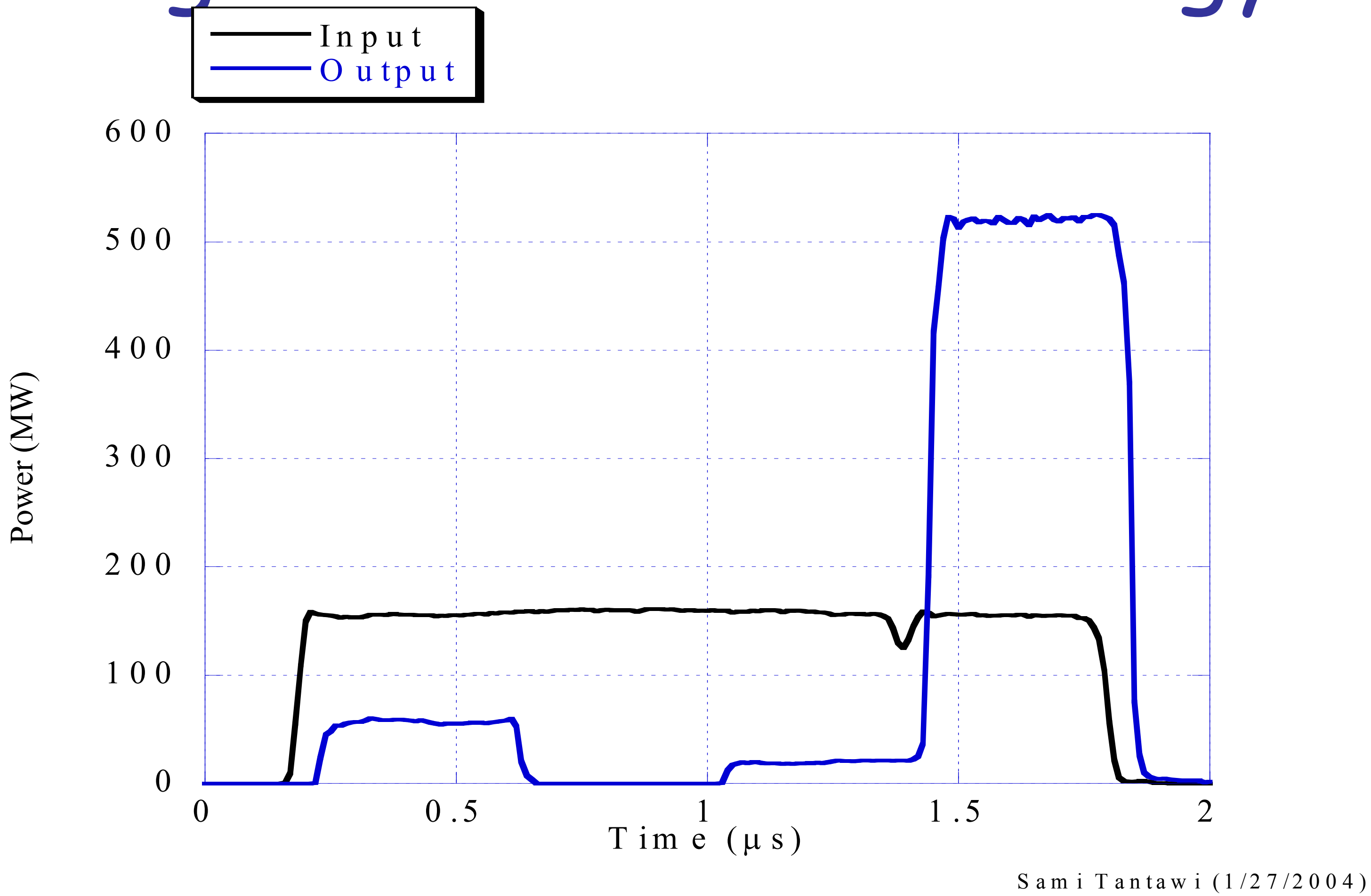




Ultra-High Power Multimoded Pulse Compression Systems Modified by removing two klystrons and using a new modulator



High Power RF-technology

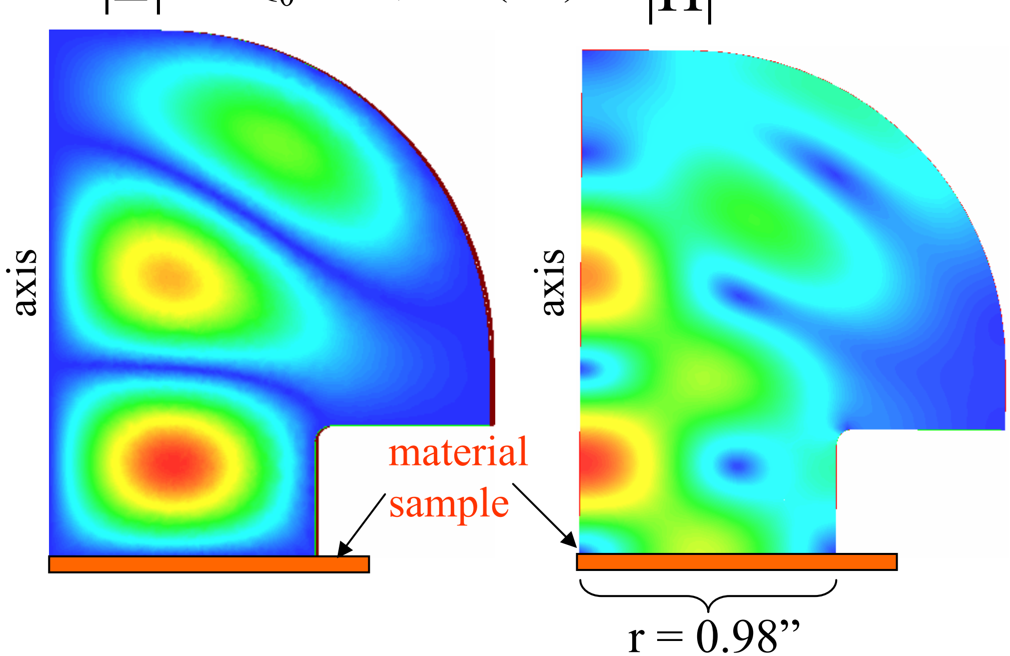


Output of the Experimental NLC Pulse Compression System

Superconducting Materials Test Cavity

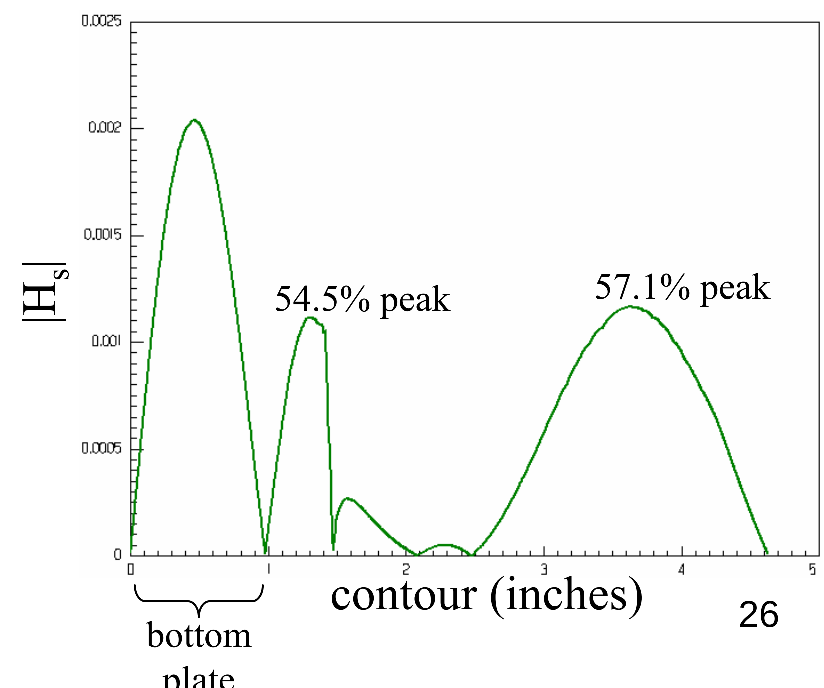
TE$_{013}$-like mode

Q_0=~45,000 (Cu)



Features:

- No surface electric fields (no multipactor)
- Magnetic field concentrated on bottom (sample) face
- Purely azimuthal currents allow demountable bottom face (gap).

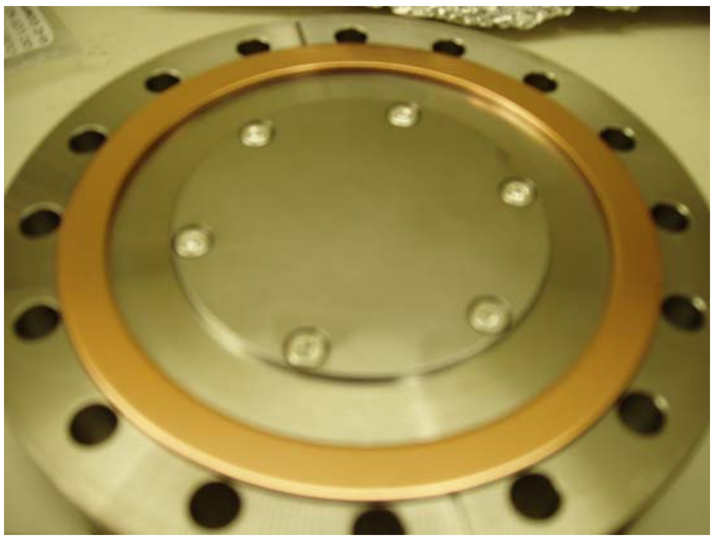


X-band (~11.424 GHz):

- high power available
- fits in cryogenic dewar
- small (3") samples required

"Cold" Tests (Room Temperature)

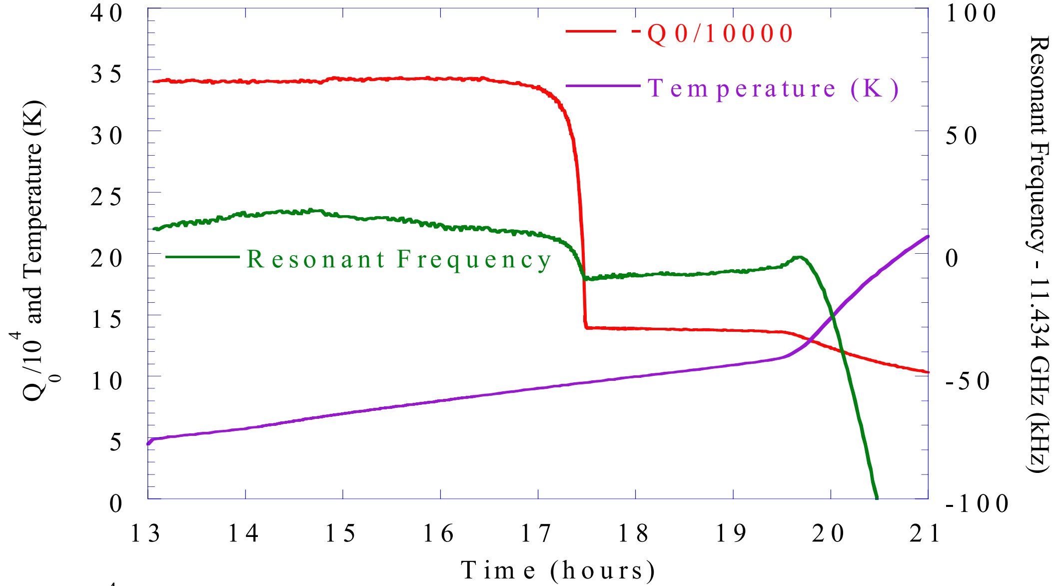
	HFSS (Cu)	Copper	Niobium
f_r	11.424	11.4072	11.4061
Q_L	30,991	29,961	20,128
β	0.4383	0.4611	0.2728
Q_0	44,575	43,775	25,619
Q_e	101,694	94,944	93,906



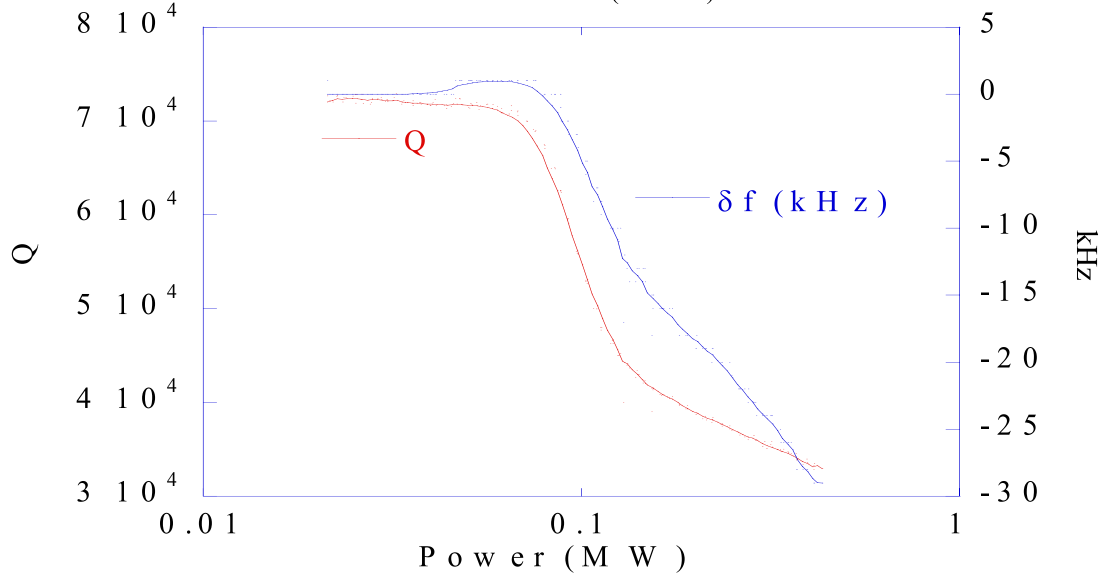
Nb sample mounted in bottom flange

HP 8510C Network Analyzer

Fundamental Research in RF Superconducting Materials



Low-power test



High-power test

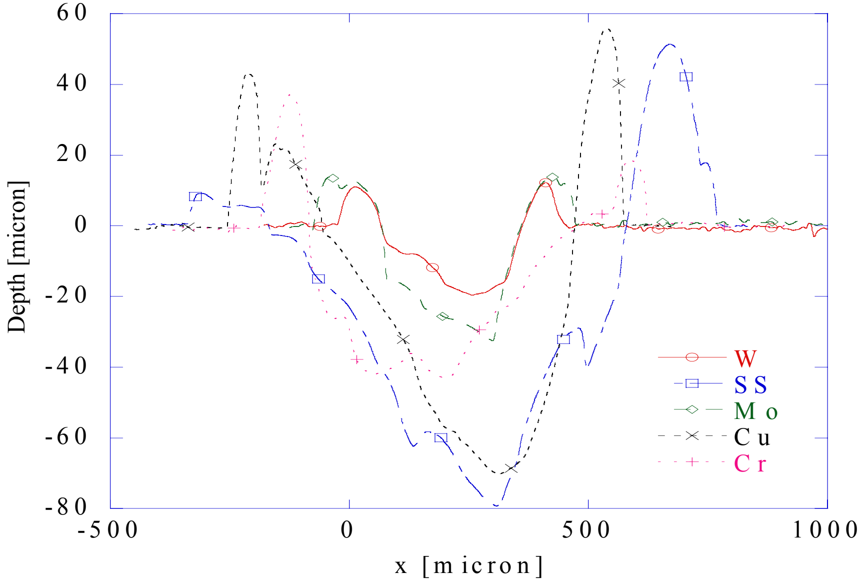
New test setup for inexpensive accurate characterization of high-field RF properties of materials and processing techniques

Sami Tantawi et. al.

Material Characterizations

(Funded by KEK)

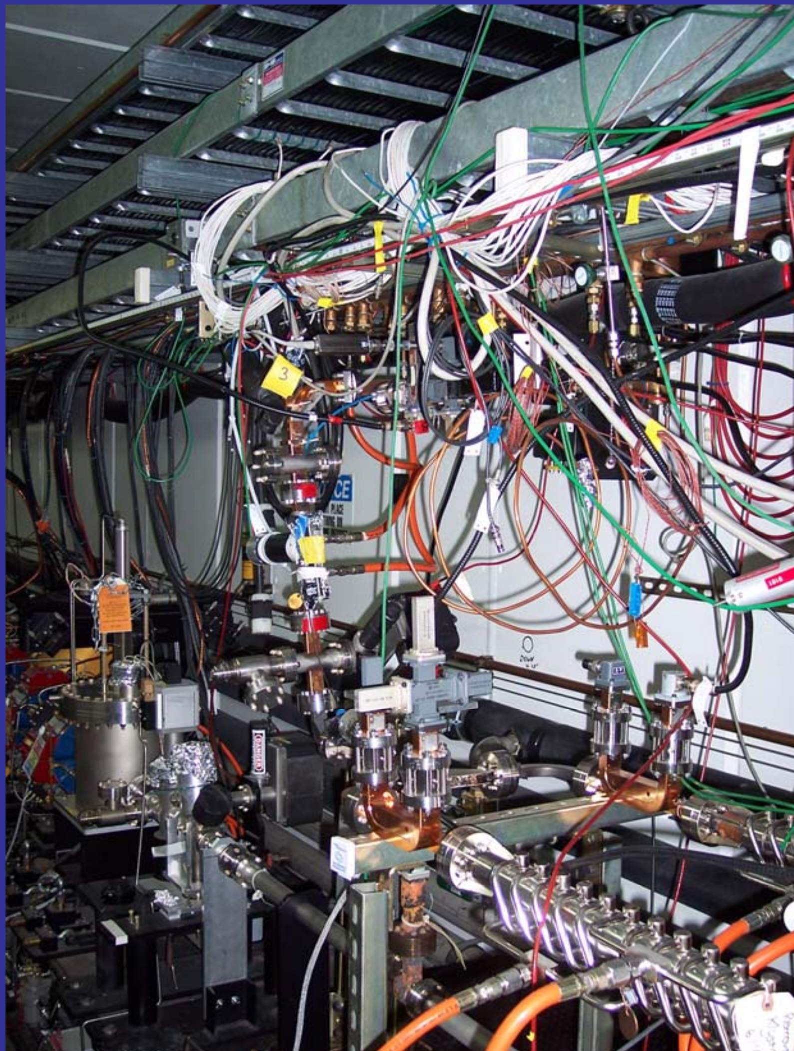
Profile of craters from 150 keV electron beam on 5 different metals: Tungsten, Molybdenum, Copper, Chromium, and Stainless Steel

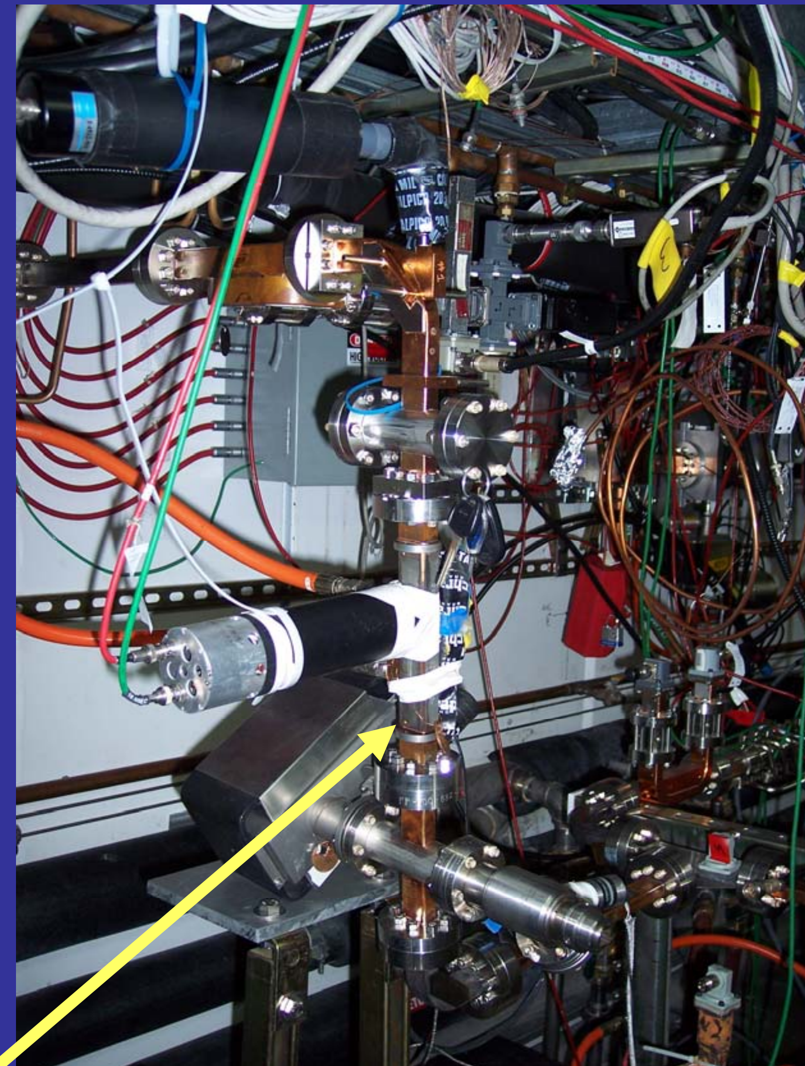


Understanding material electron bombardment interaction (Central to breakdown theory as developed by P. Wilson/V. Dolgashev)
SLAC/KEK collaboration: V. Dolgashev (SLAC),Y. Higashi (KEK), T. Higo (KEK)

Processing of molybdenum waveguide

- **Goal:** Study arc-resistant metals
- Preliminary data shows stainless steel and molybdenum have superior to copper breakdown performance (molybdenum is less lossy)
- Processing behavior is different from that of copper (also limited sampling)
- Further study limited by availability of rf sources

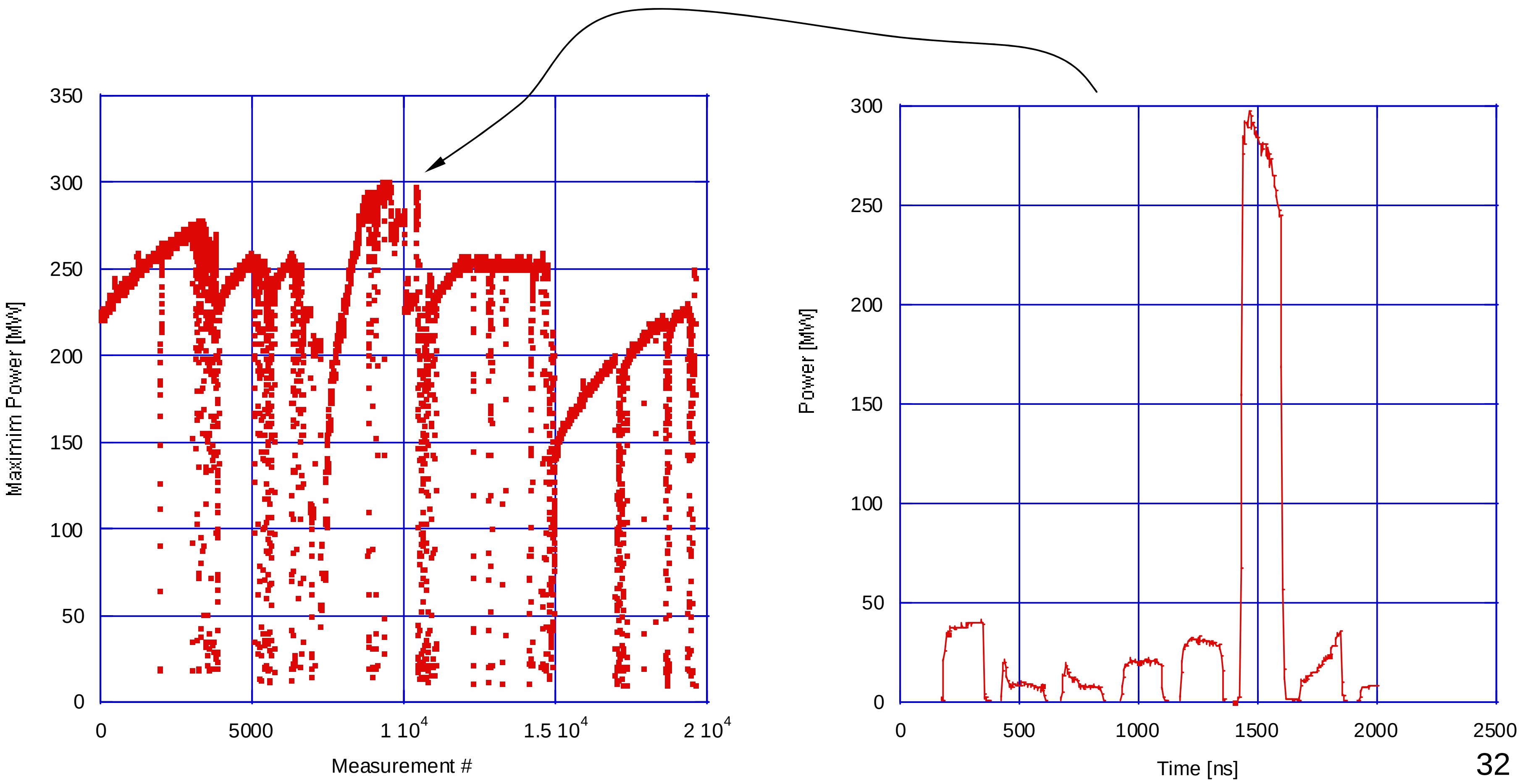




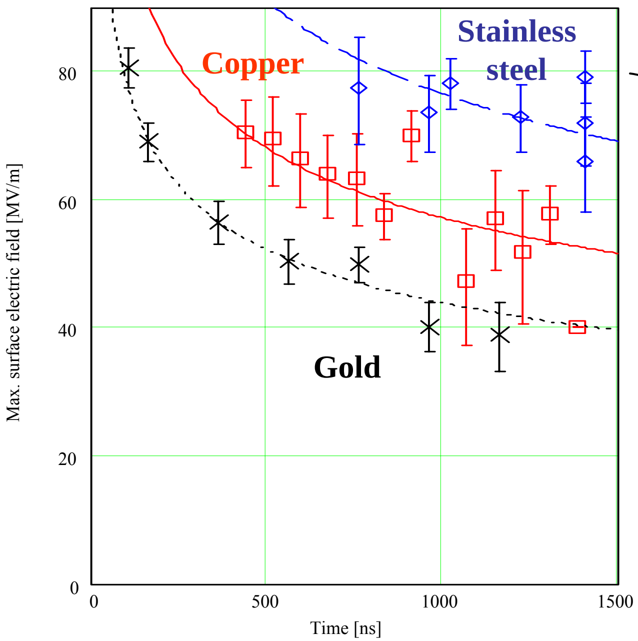
Molybdenum
Waveguide

Processing of molybdenum waveguide

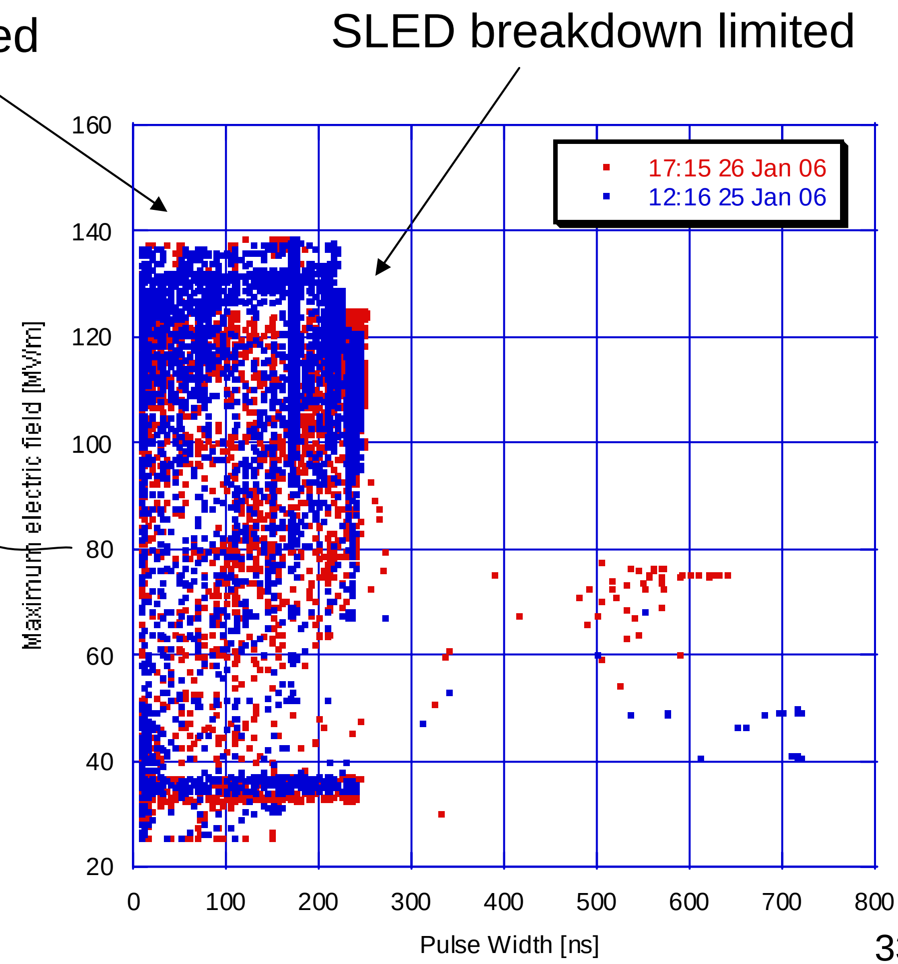
Measurement 9500, 1216_25jan06



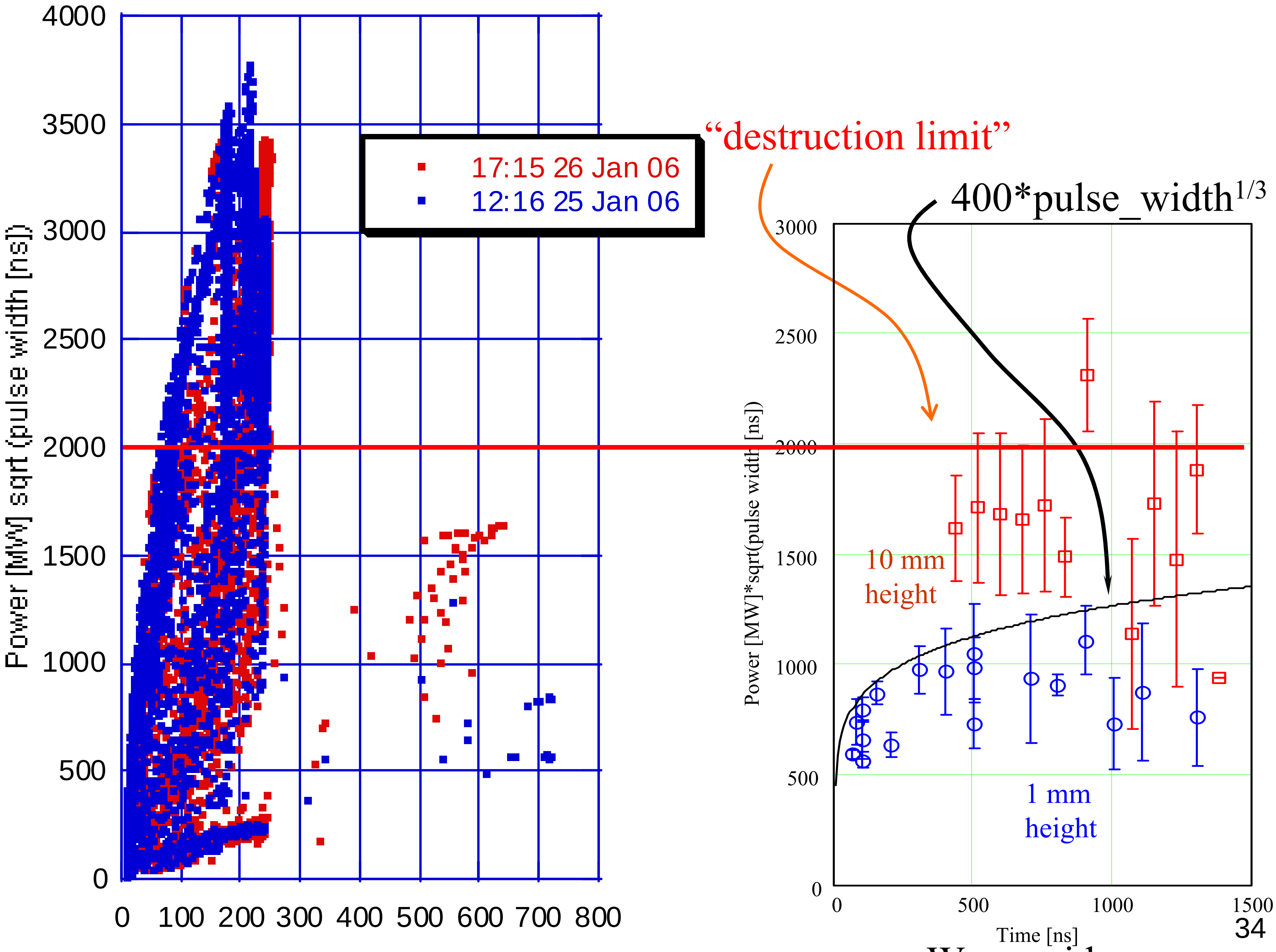
Processing of molybdenum waveguide



Maximum breakdown electric fields
for different materials



Processing of molybdenum waveguide



Waveguides

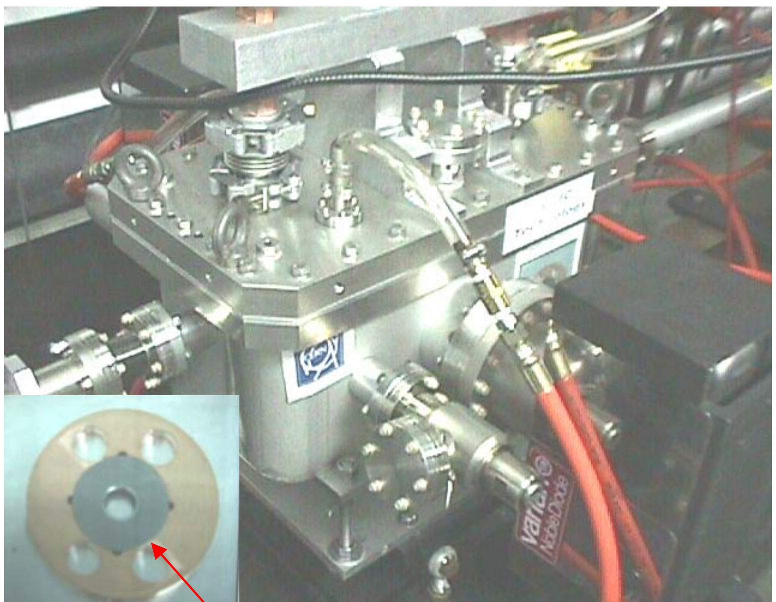
NLC and CLIC X-band Structure Program in FY06

- Evaluate CERN clamped Tungsten-iris structure
  - Completed: performed worse than Copper NLC structures
- Evaluate SLAC/KEK 75 cm NLC structure
  - Longer than the ‘standard’ 60 cm NLC prototypes
  - Tests at nominal temperature (45 degC) complete - performed better than expected – currently evaluating it at 10 degC
- Evaluate Cu and Mo CERN HDS structures
  - Structures being assembled
- Measure breakdown rate with double pulse -vs- pulse separation in an NLC structure – not yet started
- Test hermetically sealed NLC structure – parts acquired

L. Laurent, C. Adolphsen

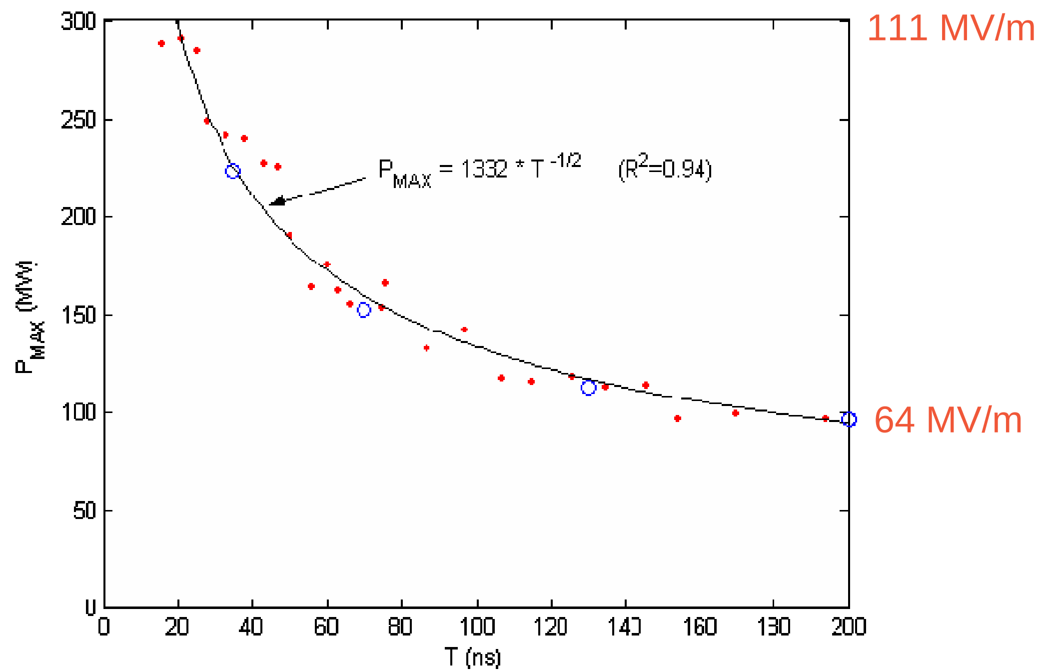
CERN X-Band Accelerator Structure with Tungsten Iris Inserts

Photo of Setup and Cell



Tungsten Insert

Power vs Pulse Length

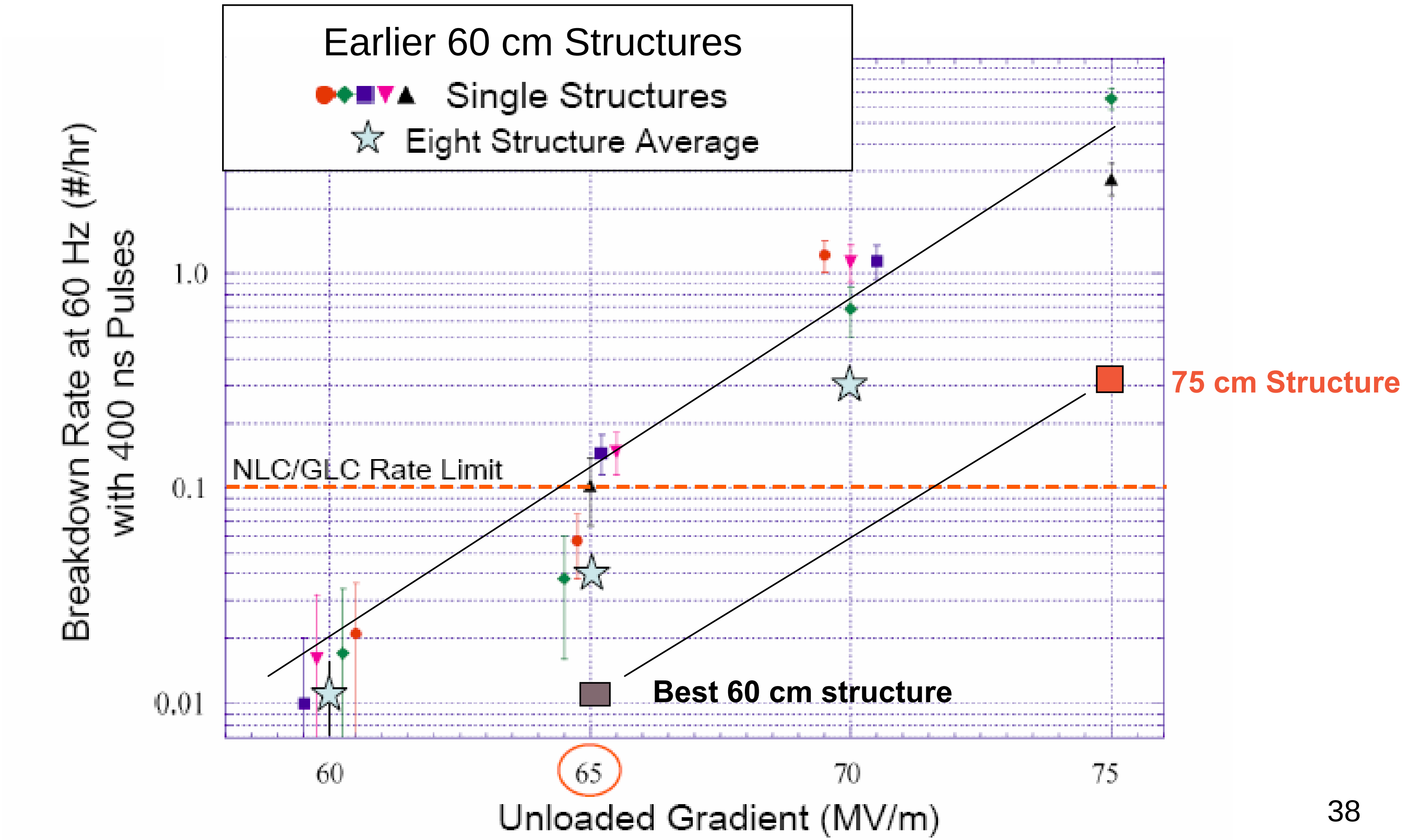


Dots = Achieved Initially with ~ 60 breakdowns / hr
Circles = After 1750 hrs of processing with 10-20 breakdowns / hr

W-Structure Conclusions

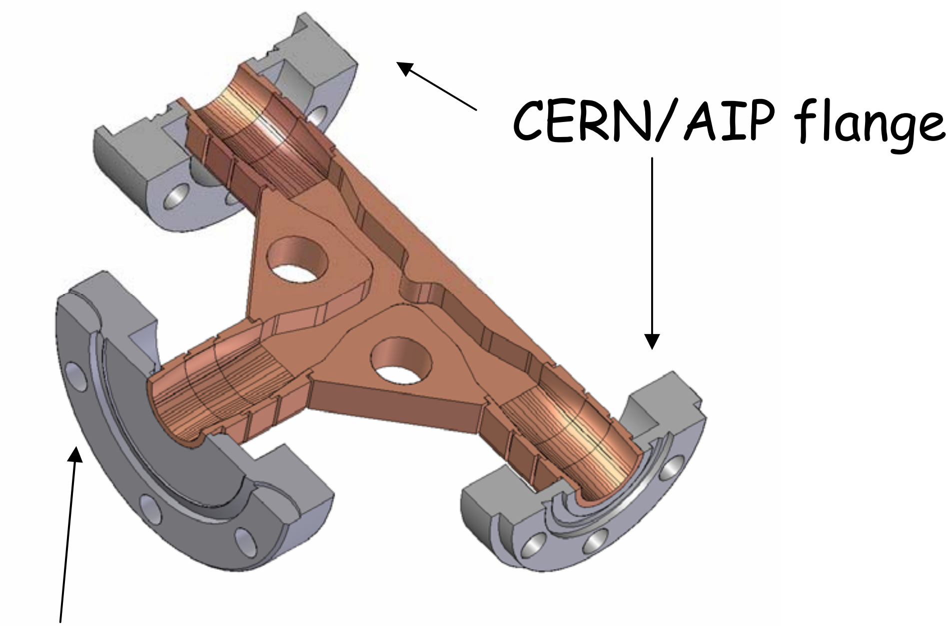
- No significant improvement with continued rf processing.
- Tungsten performed much worse than copper structures:
  - W-structure: 200ns, 63 MV/m (10-20 bds/hr)
  - Cu-structure: 250ns, 100MV/m (<10 bds/hr) in recent test.
- Reprocessing was necessary when returning to any given pulse length in order to reach previously achieved power levels.
- Observed characteristic breakdown “spitfests”: One breakdown initiates multiple breakdown events.

Test of a Longer (75 cm -vs- 60 cm), Higher Input Power NLC Structure



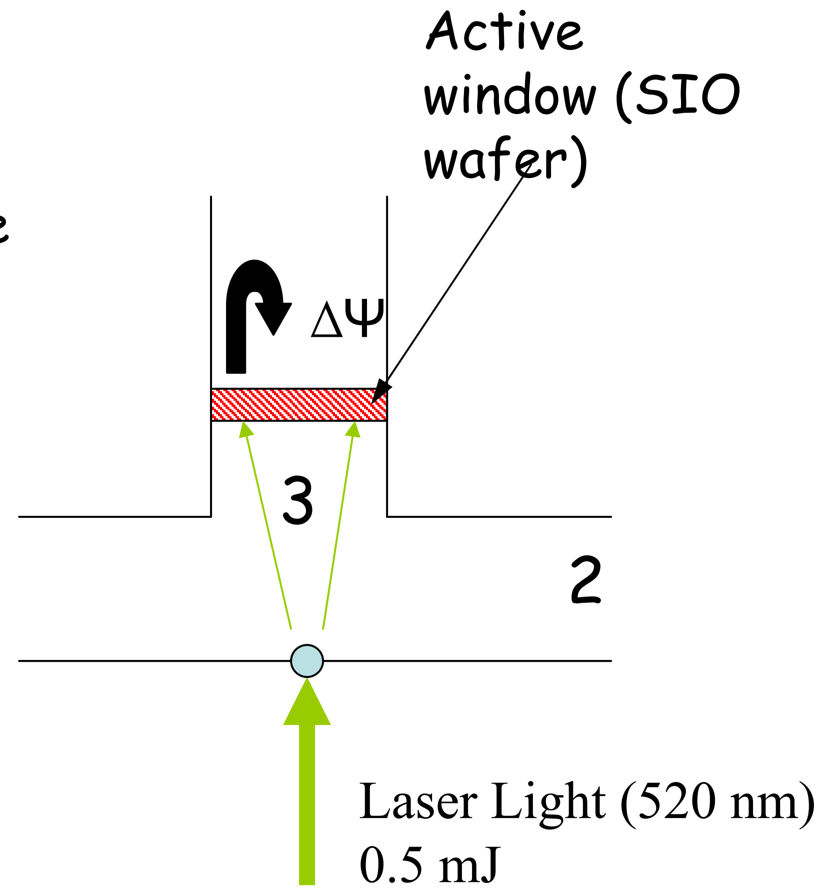
Design of the Switch Module

- Using an oscillator source requires an active pulse compression system.
- CERN also needs an active pulse compression system because of the difficulty of *fast* switching of the driving beam phase.
- Collaboratively we will developed this system based on our old ideas of optically controlled RF pulse compression system.



Switch Installed here

30 GHz TE_{01} Tee



SLAC's future program on high gradient research

- Novel Accelerator Structures.
  - Distributed coupling accelerator structure (to leverage as much as possible what we learned about geometrical effects)
  - Dielectric Accelerator structures at high frequency (we may be able to do experiments at 90 GHz if the CCR Inc 10 MW gyroklystron test is successful)
  - Heavily damped structures are being studied at CERN, MIT and University of Colorado.
- Basic Physics experimental studies
  - We have two vehicles for these studies
    - Waveguides
    - Single cell accelerator structures

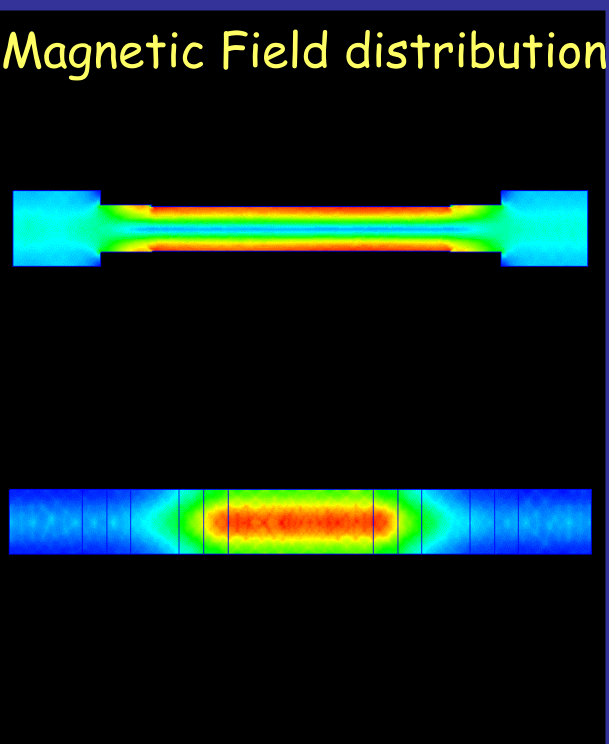
Future Work (2007)

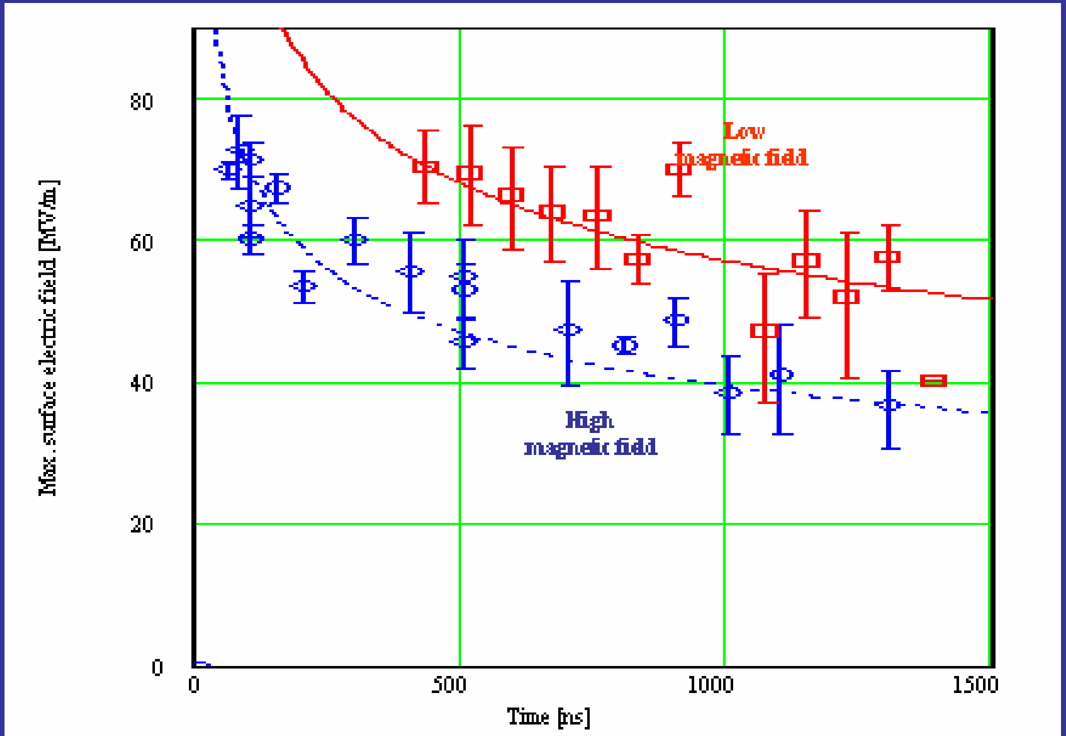
- Operation in two facilities (ASTA and the two-pack)
- Testing of single Cell Accelerator structures
- Testing of Waveguides with different materials
- Characterizing high magnetic field response of materials from SLAC, CERN, KEK, JLabs, SNS, and LANL
- Progress on 30 GHz RF source
- Realization of 30 GHz Active pulse compression system
- Progress on Breakdown theory
- Extended collaboration with MIT, U of Maryland, and ANL

SLAC's future program on high gradient research

Waveguides studies

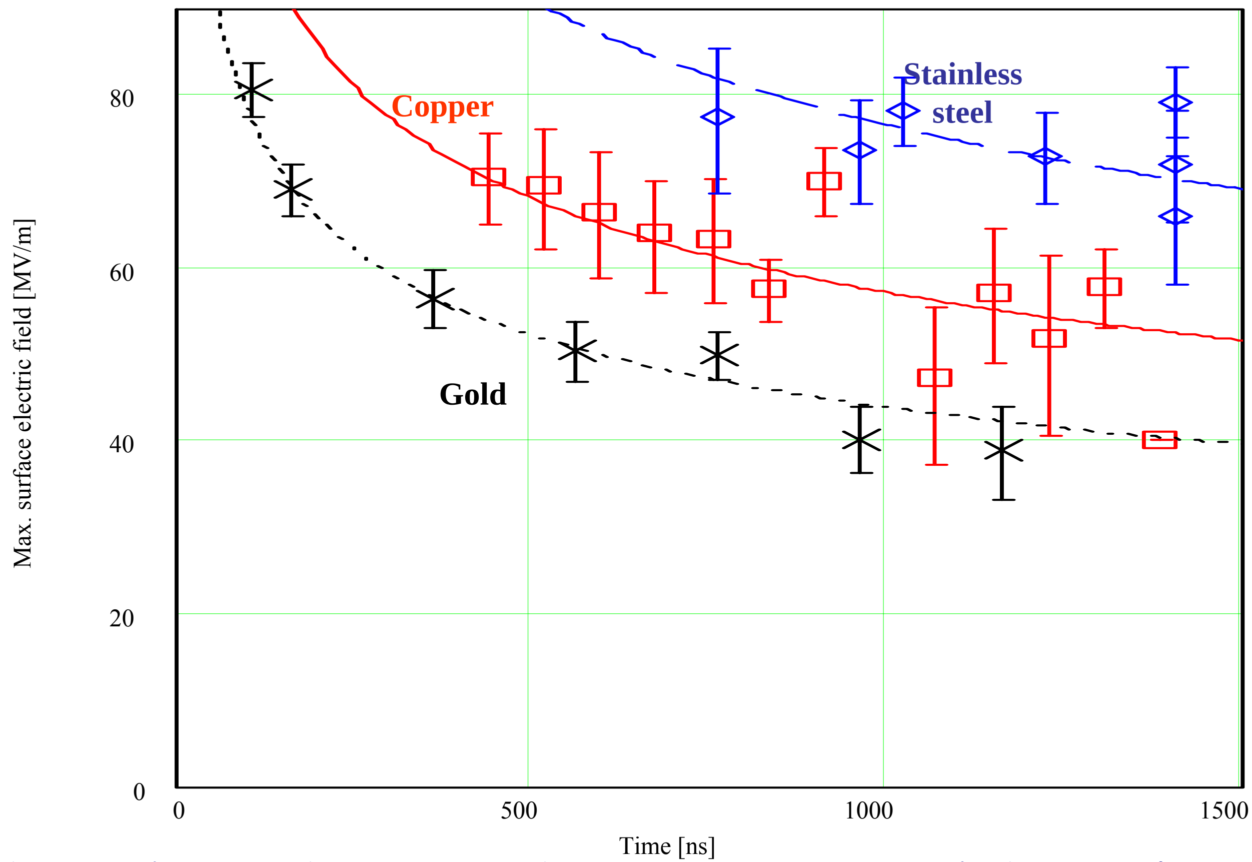
Two waveguide with identical electric field fro a given power distributed over the same area and completely different magnetic field distribution





Material Dependence

1. Planned waveguide tests
   Molybdenum waveguide
   Stainless steel high magnetic field waveguide
   Chromium waveguide



Waveguide High Gradient Study Maximum breakdown electric fields for different Materials

Single Cell Accelerator Structure Motivations Motivation

Goals

- Study rf breakdown in practical accelerating structures: dependence on circuit parameters, materials, cell shapes and surface processing techniques

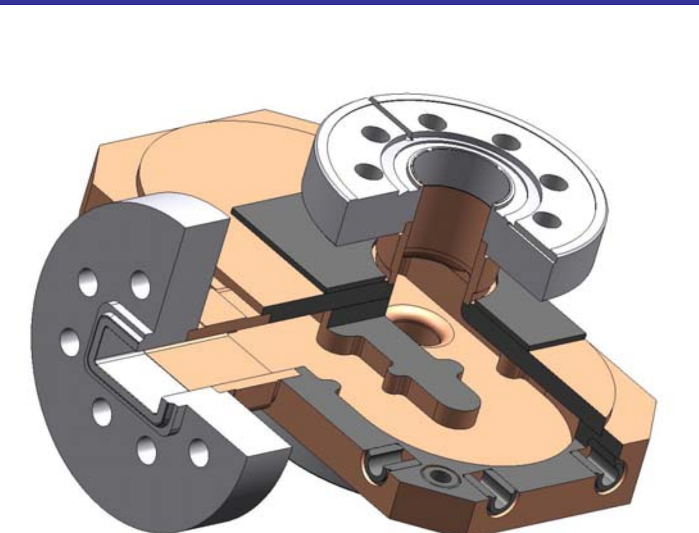
Difficulties

- Full scale structures are long, complex, and expensive

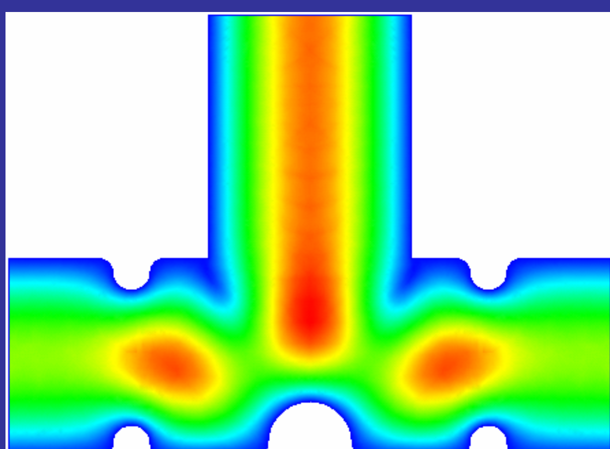
Solution

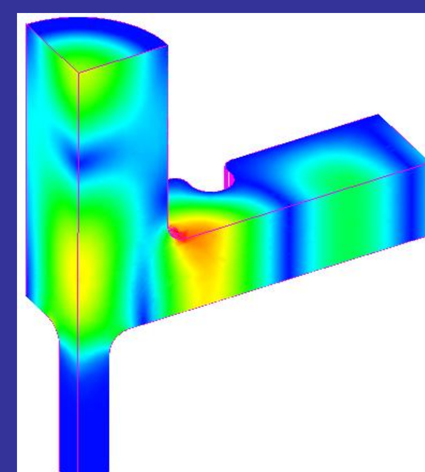
- *Single cell Traveling wave (TW)* and *single cell standing wave (SW)* structures with properties close to that of full scale structures
- Reusable couplers

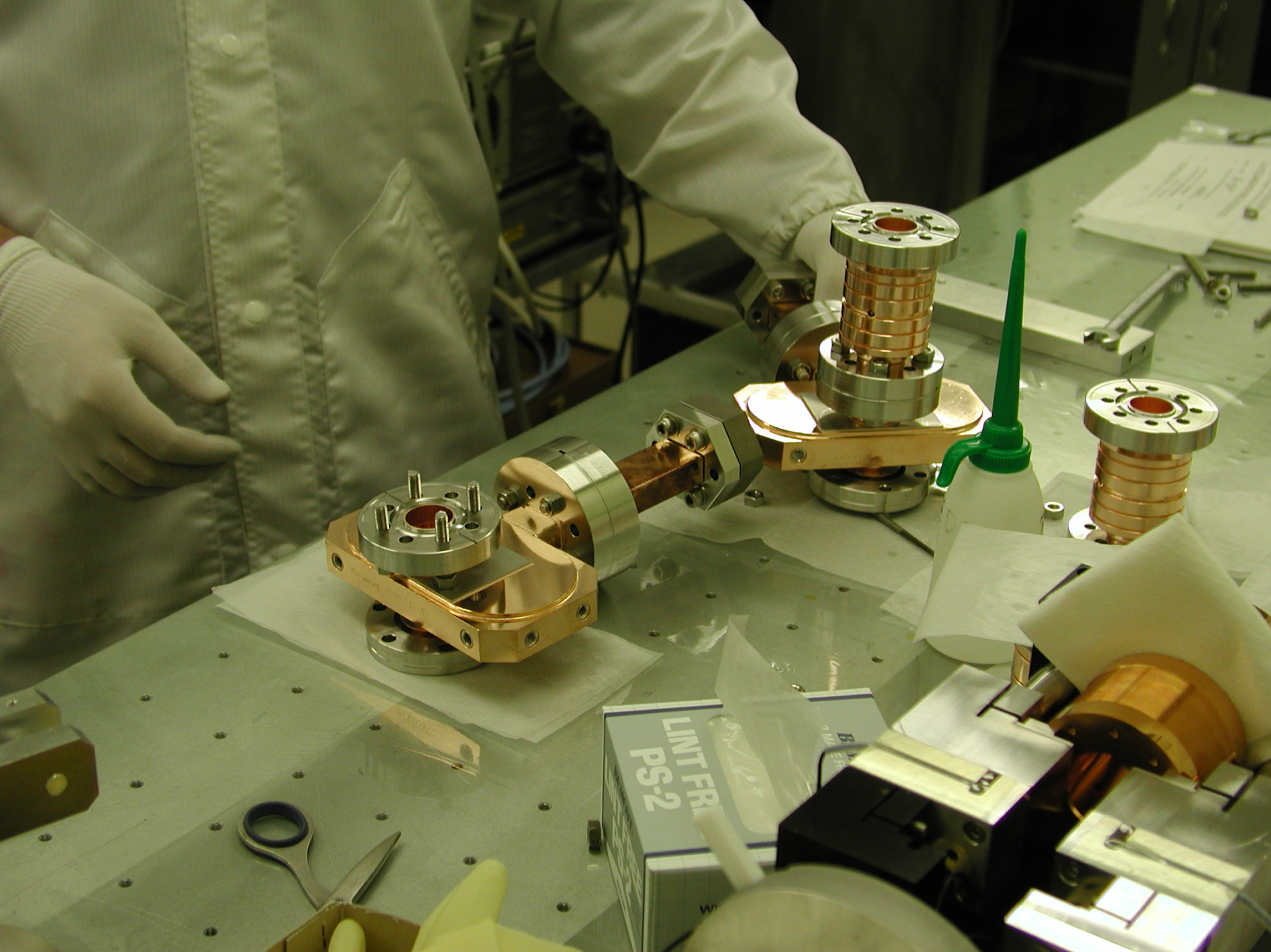
TM_{01} Mode Launcher



Cutaway view of the mode






PS-2

Structure Fabrication

- **SLAC**: Mode launchers and copper TW structures
- **KEK**: Copper, molybdenum-copper, molybdenum SW and TW structures

Planned Experiments

- RF breakdown *vs.* circuit parameters (SW *vs.* TW)
- RF breakdown *vs.* different surface processing technique (light etching, high pressure water rinsing, baking)
- RF breakdown *vs.* different materials: copper, molybdenum, molybdenum-copper

Field Emission, the "Root" of Breakdown

Breakdown Sequence: Field emission > Ohmically heats surface to release gas > Ionizes gas to plasma > Plasma ions accelerated back to/along surface > Heating releases more gas > Plasma growth and breakdown

The core requirement: Field emission

Extrinsic sources (debris, machining defects) of FE are mostly eliminated by careful fabrication and cleaning. Then, minimize the number of opportunities for contamination in the assembly and installation of the structure.

Intrinsic sources can be mostly controlled through process: 1) Use the best quality material to start (reduce numbers of impurity inclusions and unconsolidated grains), 2) Minimize etch time and time spent at elevated temperature, to prevent raised grain edges and facetting (hillock growth).

Now we switch subjects to other branches of Technology Research and Developments

Mission for RF Structures Group

We design, engineer, and test

Variety of Accelerator Structures with Superior Properties and High Gradient Performance. We support the accelerator R&D programs at SLAC including the ILC and LCLS.

Our activities span

Design Theory and Practice, Simulation, Structure Related Beam Dynamics Studies, Fabrication Technology, Microwave Measurement, Structure Characterization and High Power Experiments.

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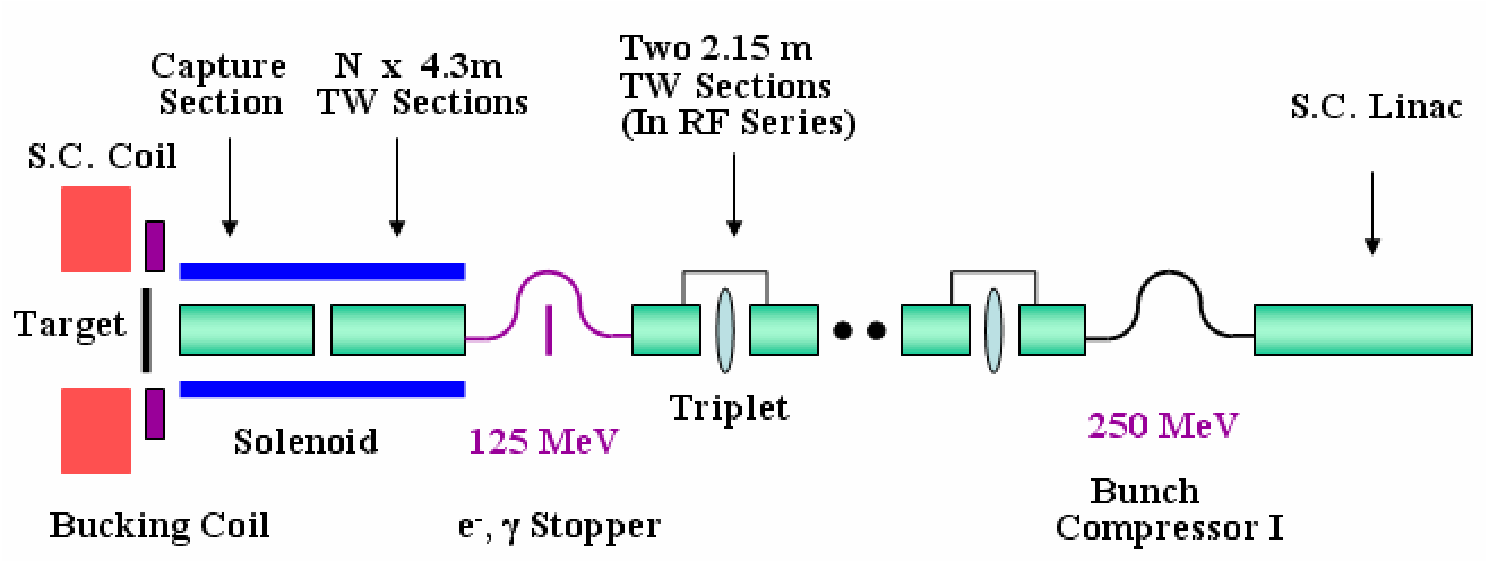
Studies on L-Band Normal Conducting Accelerating Structures for ILC e^+ Source



Proposed an Improved Alternative Structure Design for Positron Source with Mechanical Simplicity, Effective Cooling and Lower Pulsed Heating:

- Capture sections: Simple π mode short SW sections.
- Pre-Acceleration: High phase advance TW structures.

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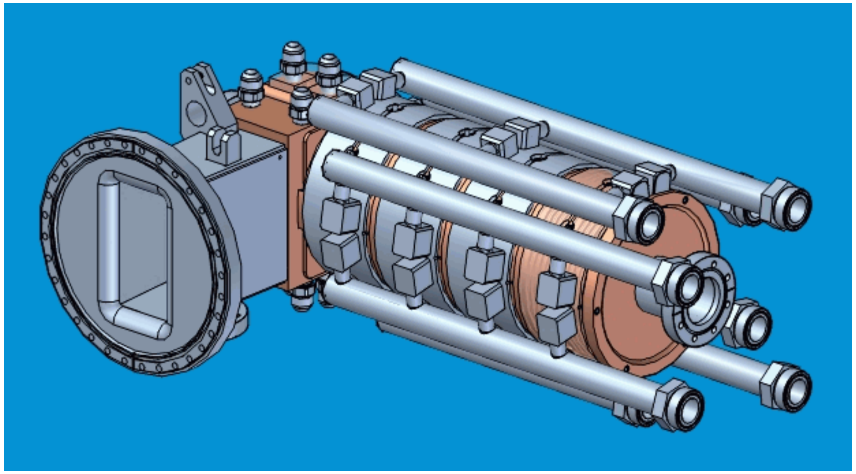
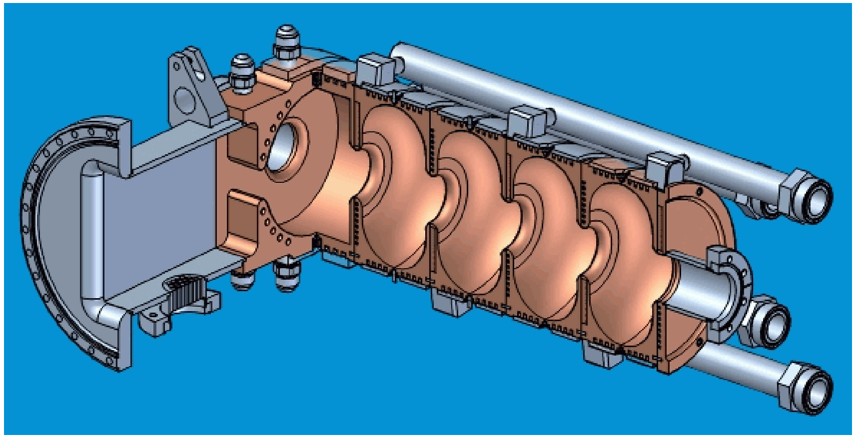
L-Band Normal Conducting 5-Cell Test Structure for the ILC Positron Capture Section

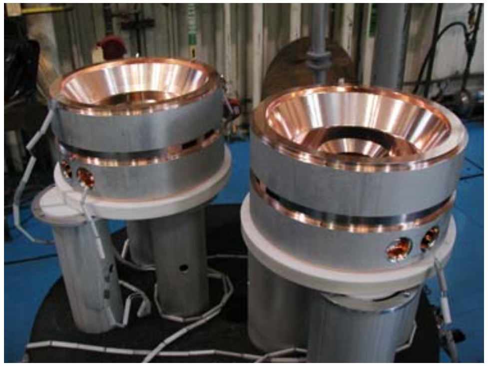
5-cell Structure Parameters

Cell Number	5
Aperture 2a	60 mm
Disk thickness	18 mm
Q	29700
Shunt impedance r	34.3 MΩ/m
RF Pd at 15 MV/m	3.6 kW/cell
Particle Pd	6.2 kW/cell
ΔT (Average/Transient) °C	3.1 / 0.8





Regular cells are in final machining stage. The cold test will be in the end of June.



L-Band window flanges after fabrication

Schematic drawings of a 5-cells test structure for the ILC positron source capture section

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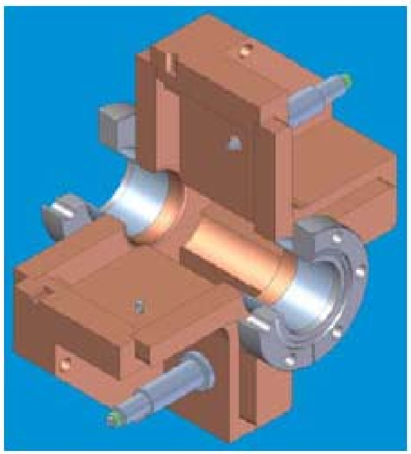
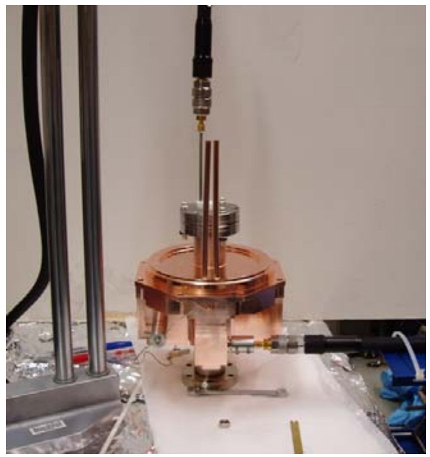
Other ILC Related Activities

Characterization of the ILC S-Band BPMs



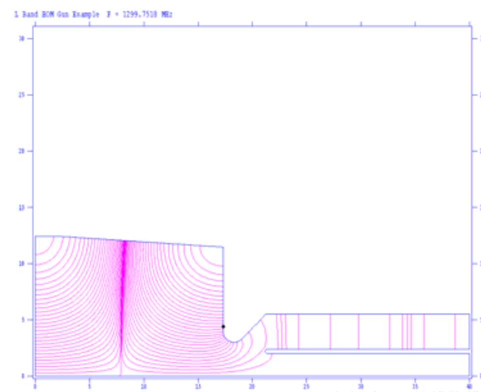
A Cutaway View of BPM



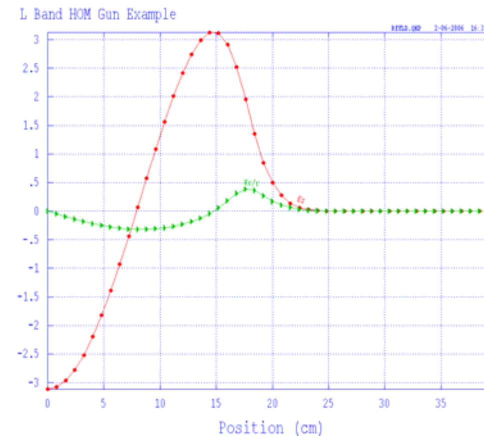
A PBM under Microwave Test

	Design	Measurement
TM11 Mode	2856 MHz	2856 + 1-3 MHz $\Delta\|fx-fy\|<0.75$ MHz
Loaded Q_L	550	420 - 550

Design Studies for L-Band HOM RF Gun



Cavity Profile



Field Distribution along axis

- 50Ω input coaxial line with beam pipe aperture 4 cm.
- Larger cell output aperture of 5 cm
- Adjustment of field flatness by outer wall tapering
- Ep/Ec=1.46
- 3.92 MW RF power needed for 40 MV/m electrical field on cathode surface.

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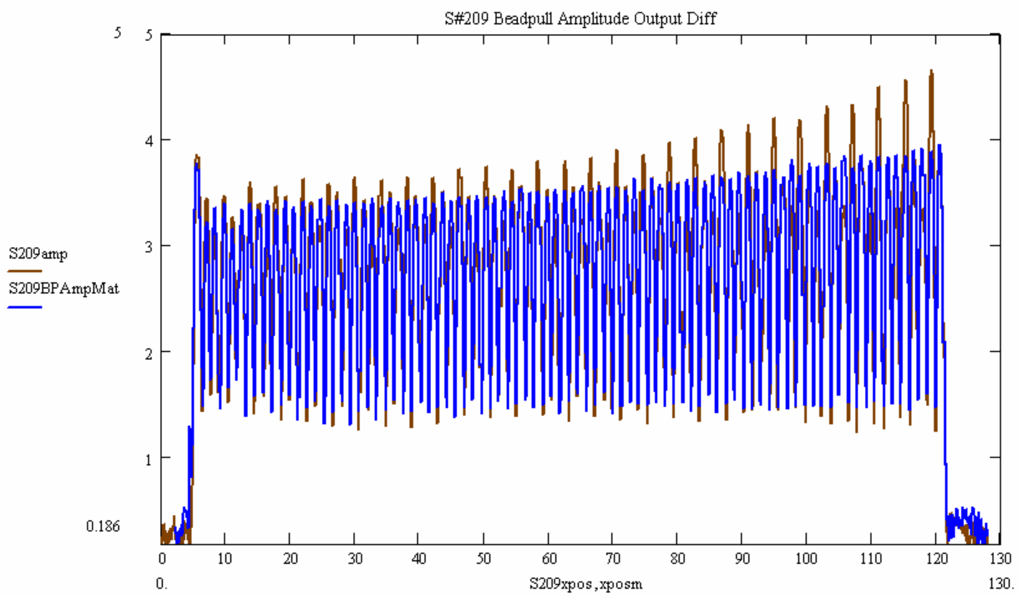
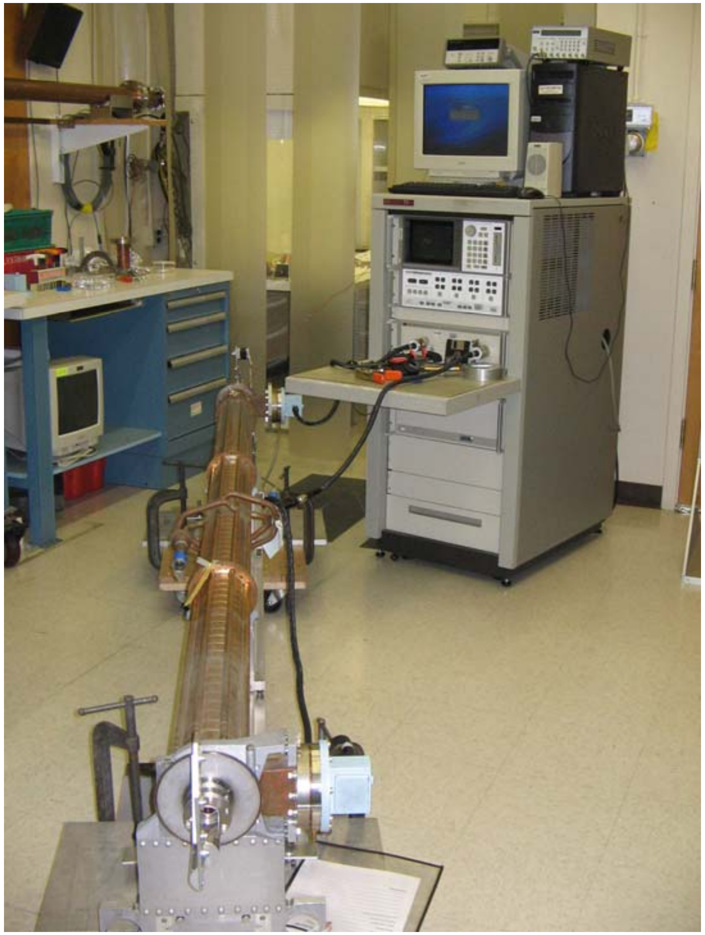
RF Structure Related Work for LCLS

- **Measure and evaluate two 9.5 ft S-Band accelerator sections for LCLS new beam line.**
- **Measure and evaluate six 10ft S-Band accelerator sections in order to pick 2 as booster sections which will follow the microwave gun.**
- **Will tune and characterize two 10 ft booster sections after modification of the frond end with new double input waveguides.**



Electric field amplitude along a 10ft S-Band Accelerator section before (brown) and after (blue) tuning output coupler.



Horizontal microwave measurement and bead-pulling set-up.

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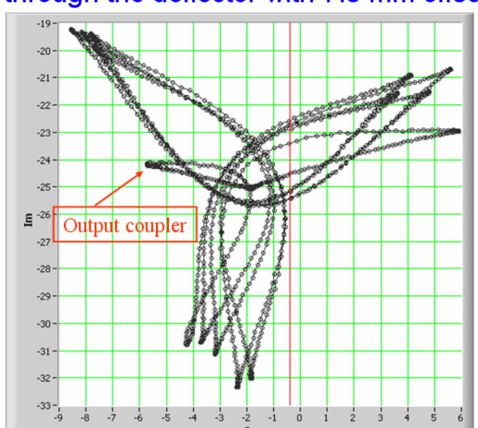
RF Structure Related Work for LCLS

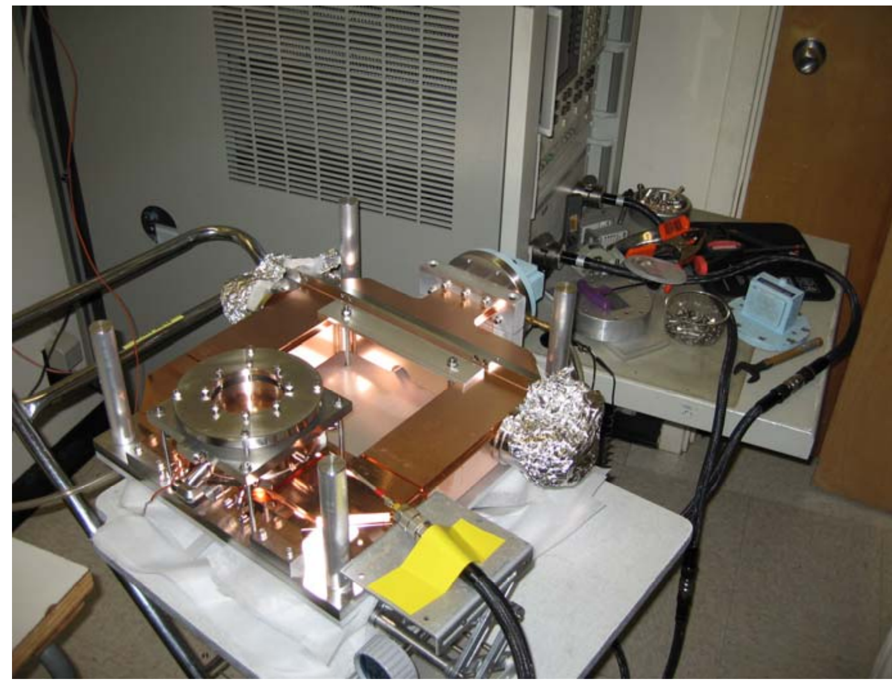
Evaluation and characterization of a RF Deflector

Complex reflection while a 8mm bead pulling through the deflector with 7.5 mm offset



Notice the HEM11 mode phase is 40/2=20° off for the output coupler. The calculated df/dφ=0.7 MHz/degree, therefore the output coupler is 14 MHz higher in frequency.

Tuning and characterization of the RF Gun with double input waveguides



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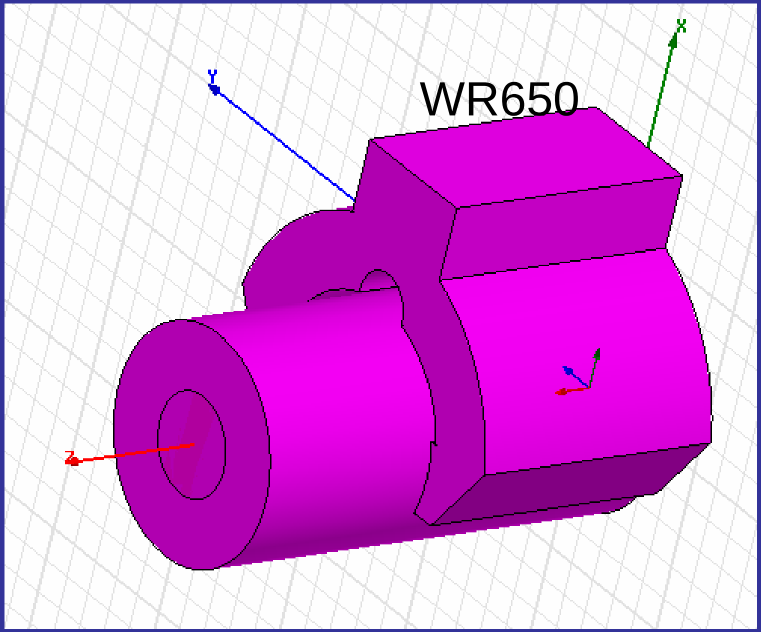
Advanced Concepts for the ILC

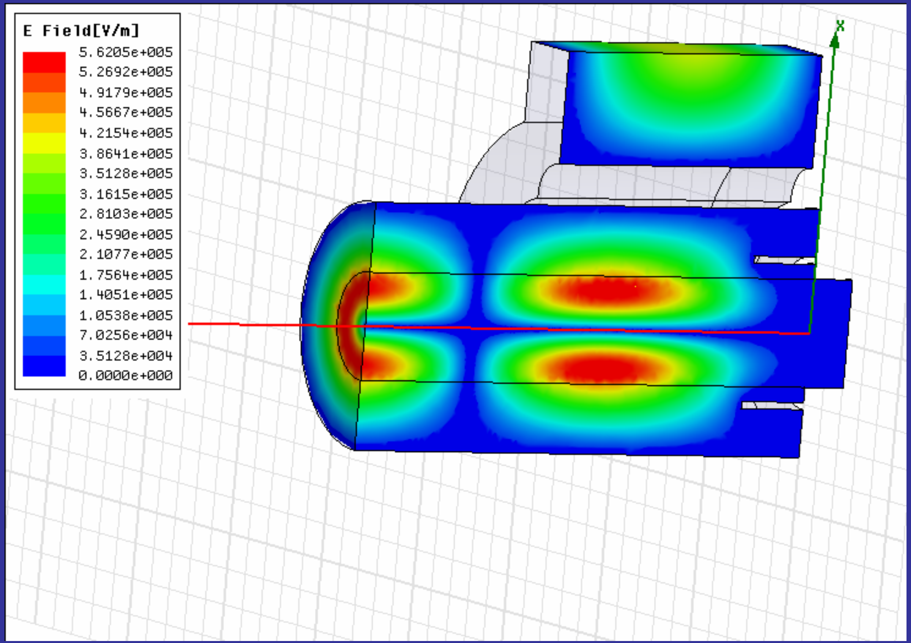
- At the moment all of these are just paper designs and theoretical developments.
- some of the concepts might get funded through other channels (SBIR/STTR, Collaboration with other institute such as KEK, etc., or hopefully by the GDE if the concept is mature enough)

  - Fundamental mode Couplers
  - RF distribution system
  - RF sources
  - RF undulators for positron production
  - Fast Kickers for the damping Ring.
  - Active switches for charging and discharging superconducting cavities

Advanced Concepts for ILC

- Novel Fundamental mode coupler



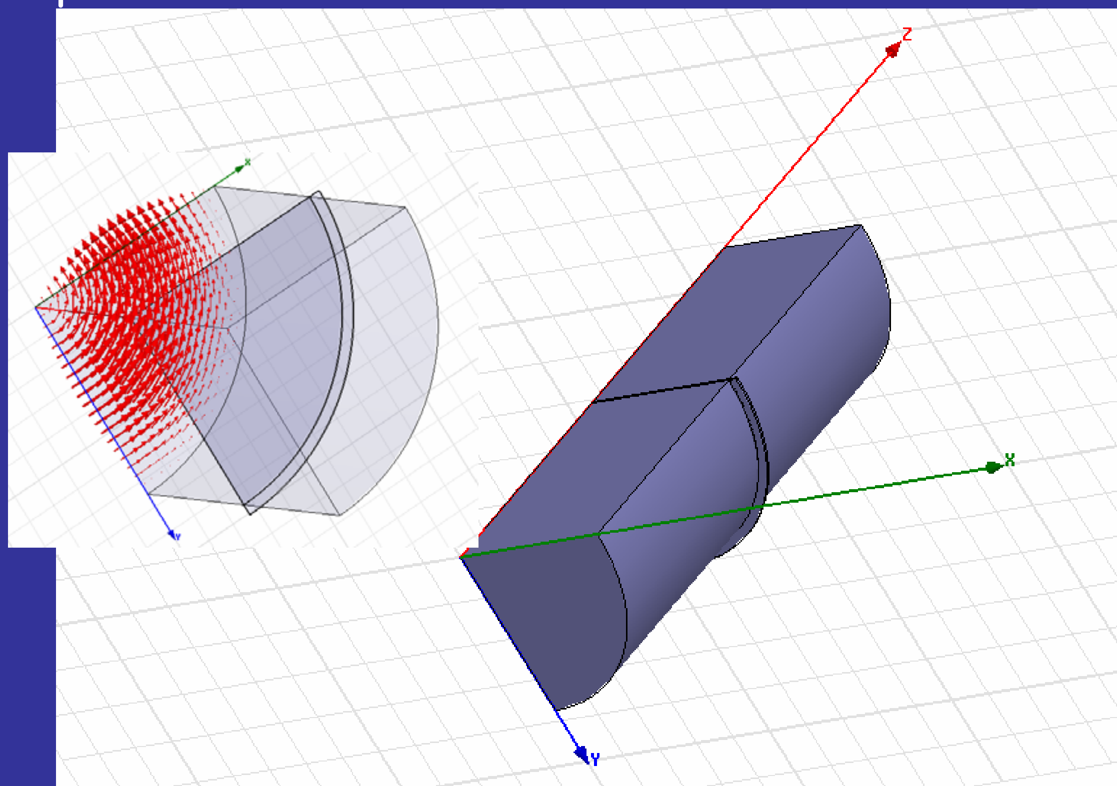


Using TE_{01} Mode launcher for a dielectric loaded waveguide can make an exceptional fundamental mode couplers No electric field lines normal to any surface, hence the hope for a multipactor-free structure

Advanced Concepts for ILC

Novel Fundamental mode coupler

- To test these ideas KEK volunteered the ceramics
- We applied for STTR/SBIR fund to build the device
- The concept could lead also to novel circulators and switches

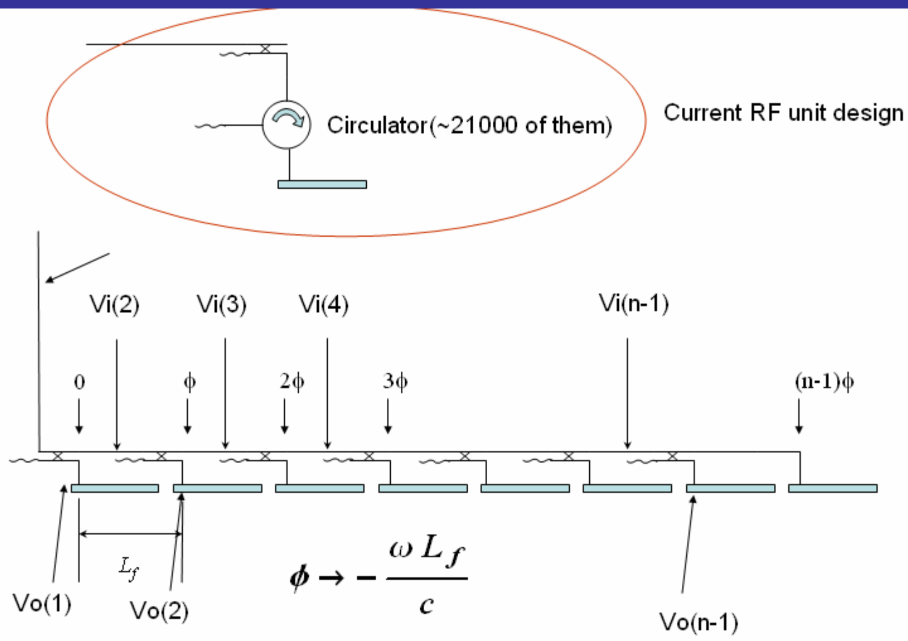


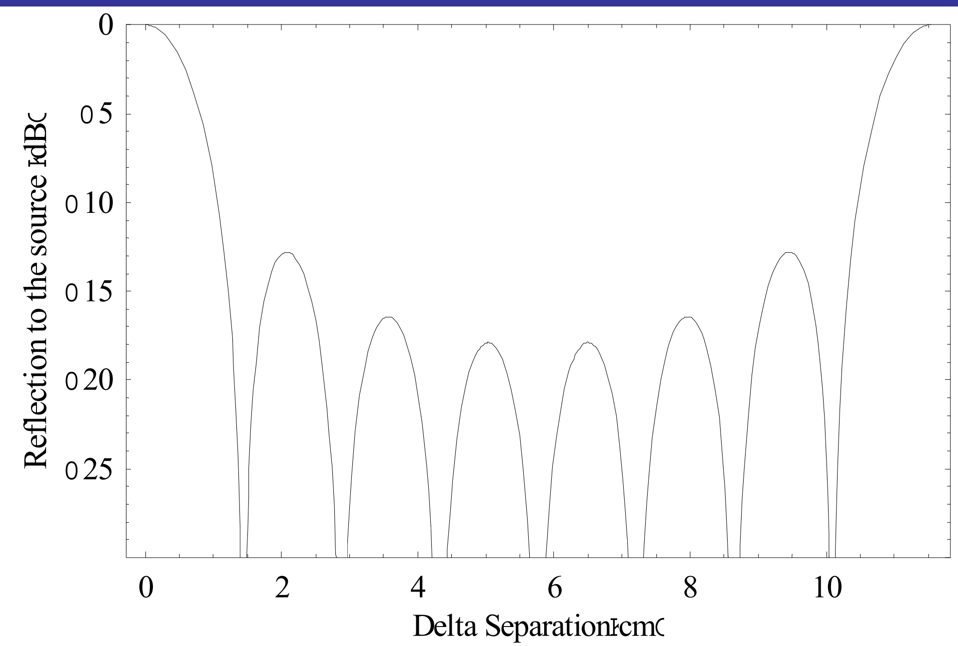
Further one can have a physical gap as large as 1 cm with out any loss of RF power.

Advanced Concepts for ILC

RF distribution system

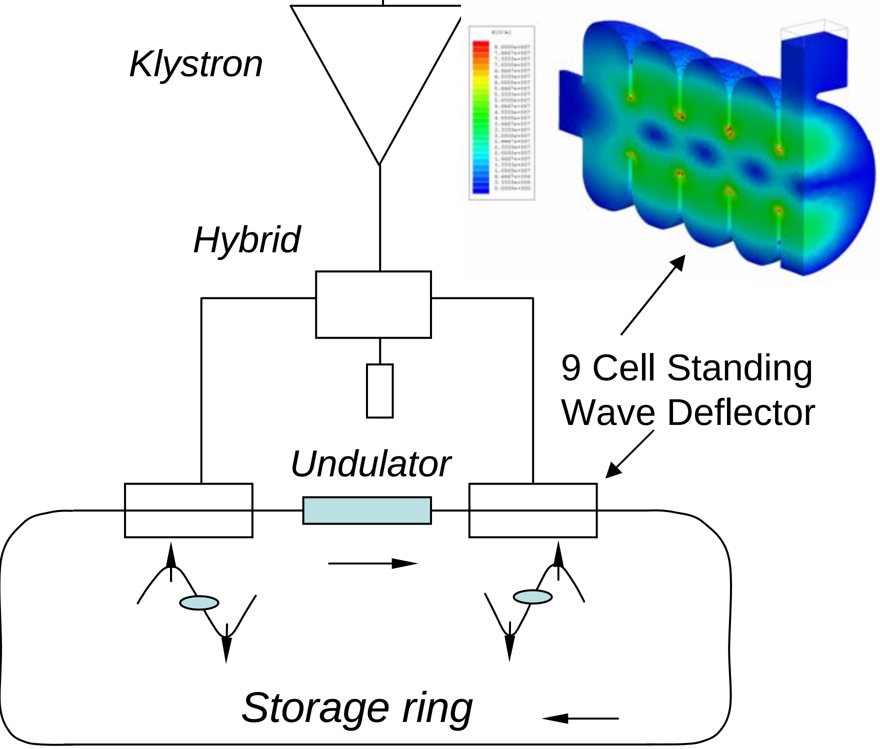
- we made the only mathematical model for this system.
- These ideas are being tested by KEK



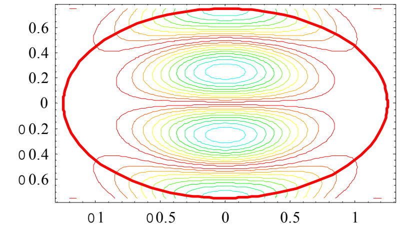


If one couples 8 or more accelerator structures ideally one would eliminate circulators at a minimum their number could be reduced by a factor of 8.

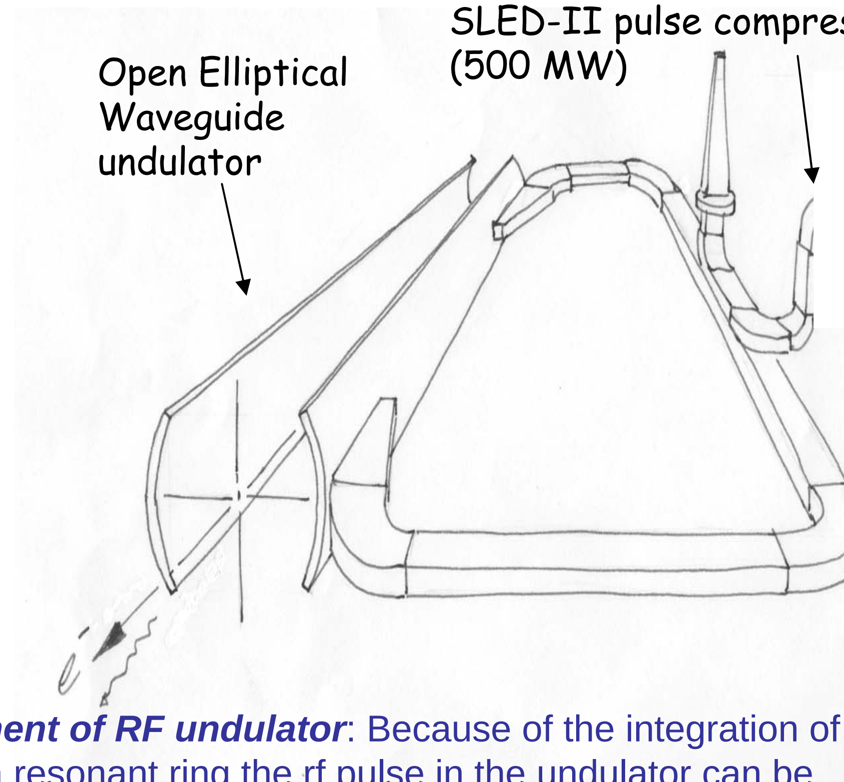
Novel FEL and Light Sources Technologies



Surface electric field for 5 MW of input power, maximum filed ~70 MV/m



Ratio between peak surface field/Field at the center is 1/5



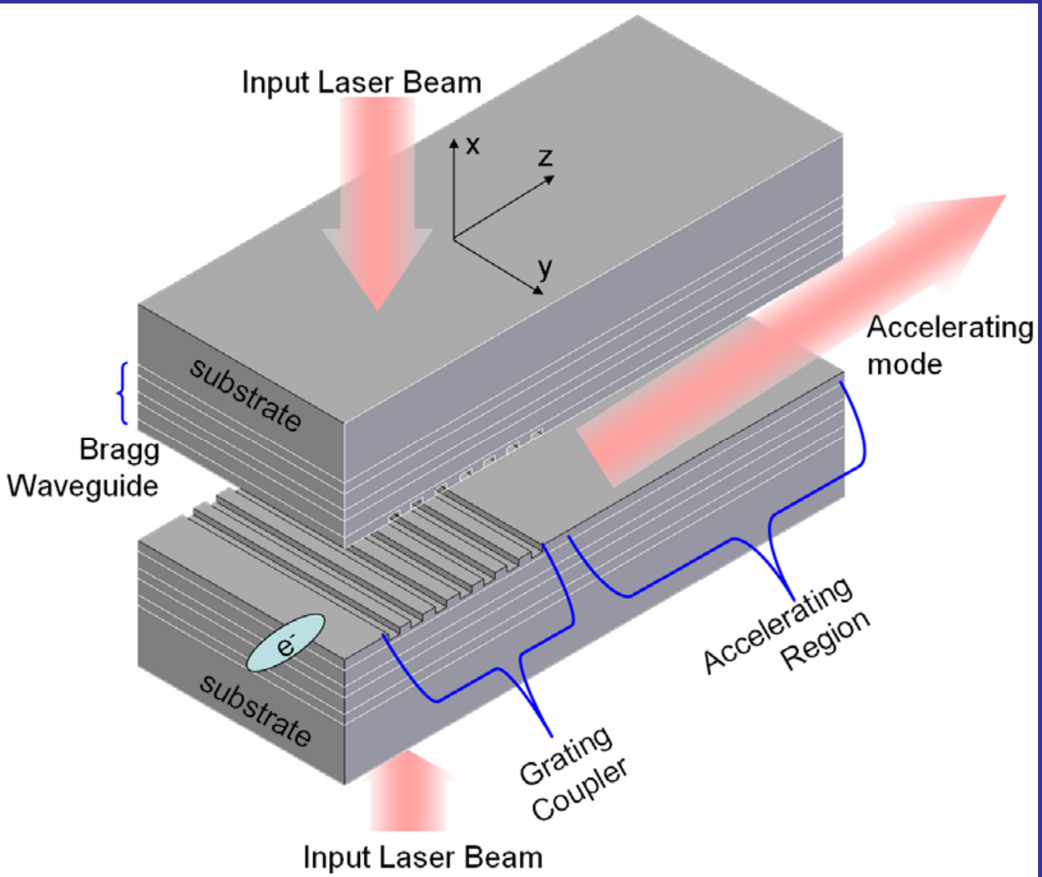
Proposed bunch compression techniques for ultra-short light (x-ray) pulses from synchrotron storage rings (in collaboration with M. Borland from APS)

Development of RF undulator: Because of the integration of RF pulses in a resonant ring the rf pulse in the undulator can be smoothed. Further, the ring can have a multiplication factor of more than 10, resulting in 5 GW of RF power through the undulator waveguide.

S. Tantawi and V.Dolgashev

Optical Dielectric Accelerator

- Low intrinsic loss at near infrared ~ 0.2dB/km
- High damage threshold supports accelerating gradient ~ 1GV/m
- High power laser source available

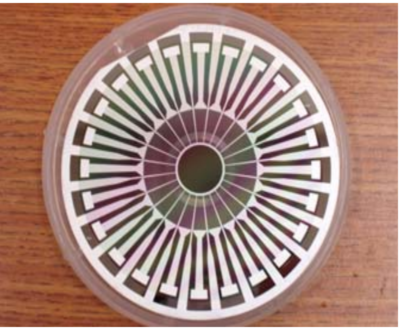


Optical all-dielectric planar accelerator structure

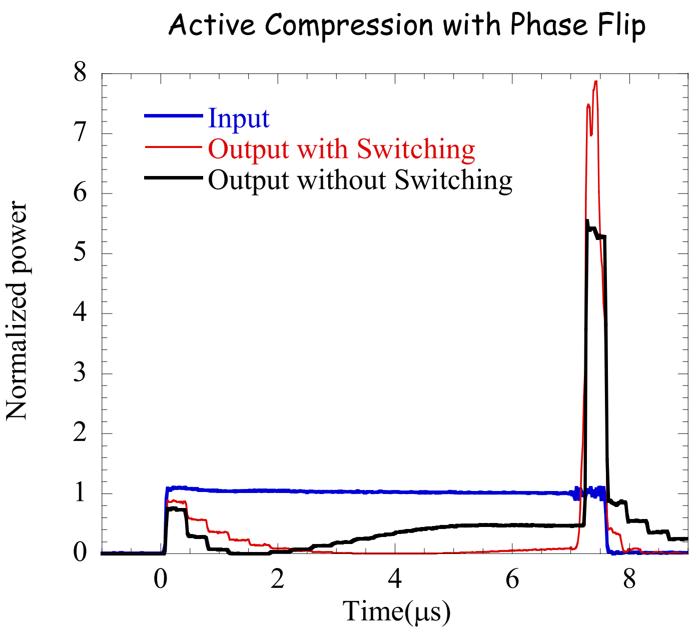
- Accelerating mode guided by the Bragg waveguide
- Grating coupler couples laser light from the side and converts it to accelerating mode
- Waveguide and coupler can be fabricated with micro-processing technology

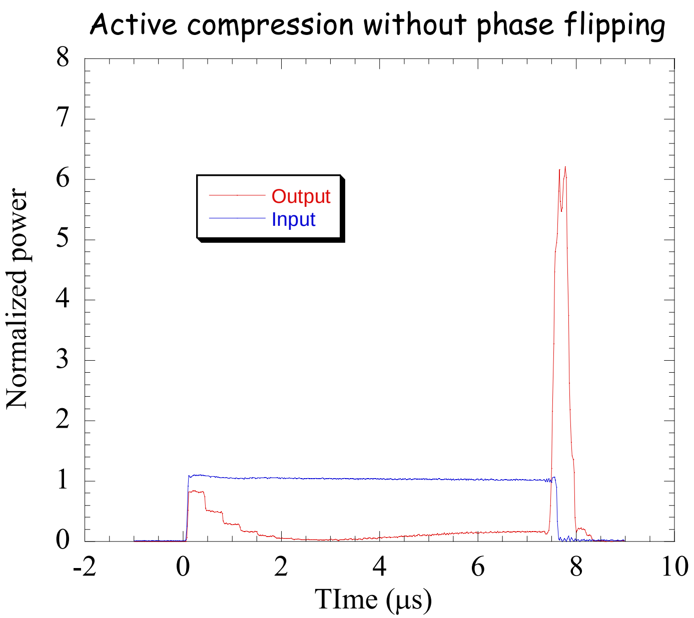
Ultra High Power RF Components and Systems

- Active pulse compression systems and ultra-high-power solid-state devices,
- Novel low field fundamental mode RF couplers
- A new concept of spatially combined devices for ultra-high power semiconductor switches and RF sources .



Active Window





Active Pulse compression using 960 spatially combined PIN diodes Pulsed at 700 Volts

Jiquan Guo and Sami Tantawi

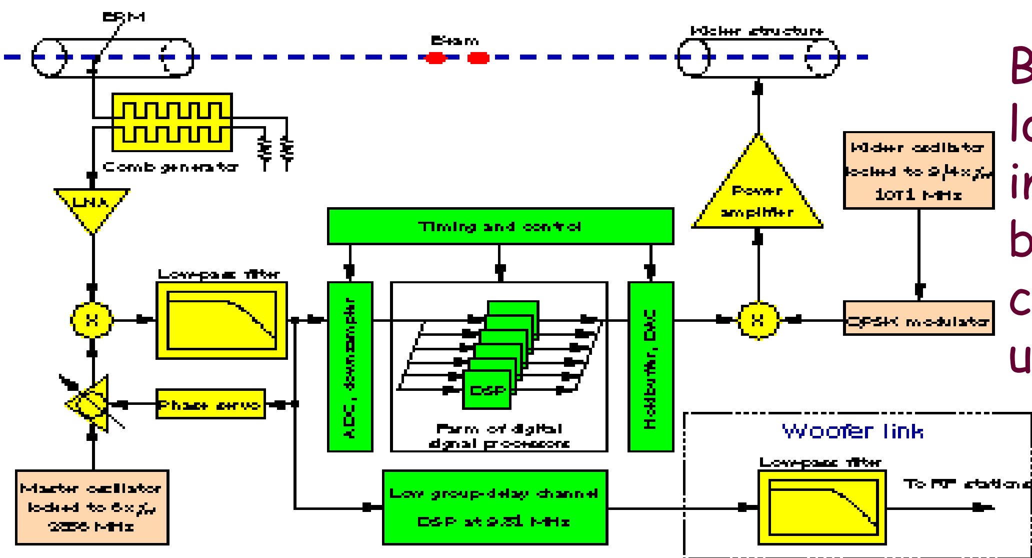
Beam Instabilities, Instrumentation and Control

Accelerator Technology Research

J. Fox, H. Dong, T. Mastorides, C. Rivetta, D.Teytelman, D. Van Winkle

Advanced Electronics and Research Efforts in Accelerator Dynamics and Instability Control

- Instability control formalism and machine diagnostics for accelerators and light sources including beam instability measurement and dynamics control, LLRF system stability and impedance control.
- Development of simulation models, techniques to model Beam- RF system interactions, studies of accelerator dynamics
- Technology Development - 13 instability control systems built/commissioned for US, European and Asian Labs
- Next-generation reconfigurable signal processing (demonstrated at KEK, PEP-II, Dafne, BESSY-II, PLS, SPEAR-3, ATF)



Broadband (bunch by bunch) longitudinal feedback system as used in PEP-II. This system samples 1746 bunches (238 MHz sampling rate) and computes correction signals using a using a parallel processing DSP farm

Recent Achievements - Our efforts were central in achieving PEP-II record 10^{34} luminosity via control of coupled-bunch instabilities and RF system dynamics.

J. Fox et. al.

ARDA Advanced Electronics Major Activities in 2004/2006

PEP-II High Current Instability studies, RF Dynamics Control - Critical for PEP-II Operations

- Coupled-bunch studies (HOM driven instabilities), tuning/configurations of LFB systems
- Fault file analysis tools and RF diagnostics
- LLRF model-based configuration tools, station tuning, operations oversight
- Nonlinear time-domain LLRF-Beam simulation - allows development of new control techniques
- Predictions for operations, evaluation of future higher current configurations, luminosity increases

Technology Development

- Gboard -1.5 GS/sec. reconfigurable processor - prototype tested at PEP-II, DAFNE,KEKB
- Low Group Delay Woofer - commissioned, allows increased HER and LER currents
- Klystron Linearizer - prototypes tested in LER

Publications

- Conference papers (EPAC and PAC), Journal papers, Internal MAC reviews, Internal talks

Teaching (Stanford Applied Physics, US Particle Accelerator School)

Contributions- Feedback and Transient-domain Analysis

Grow-Damp measurement (30 ms, 15 ms open-loop)

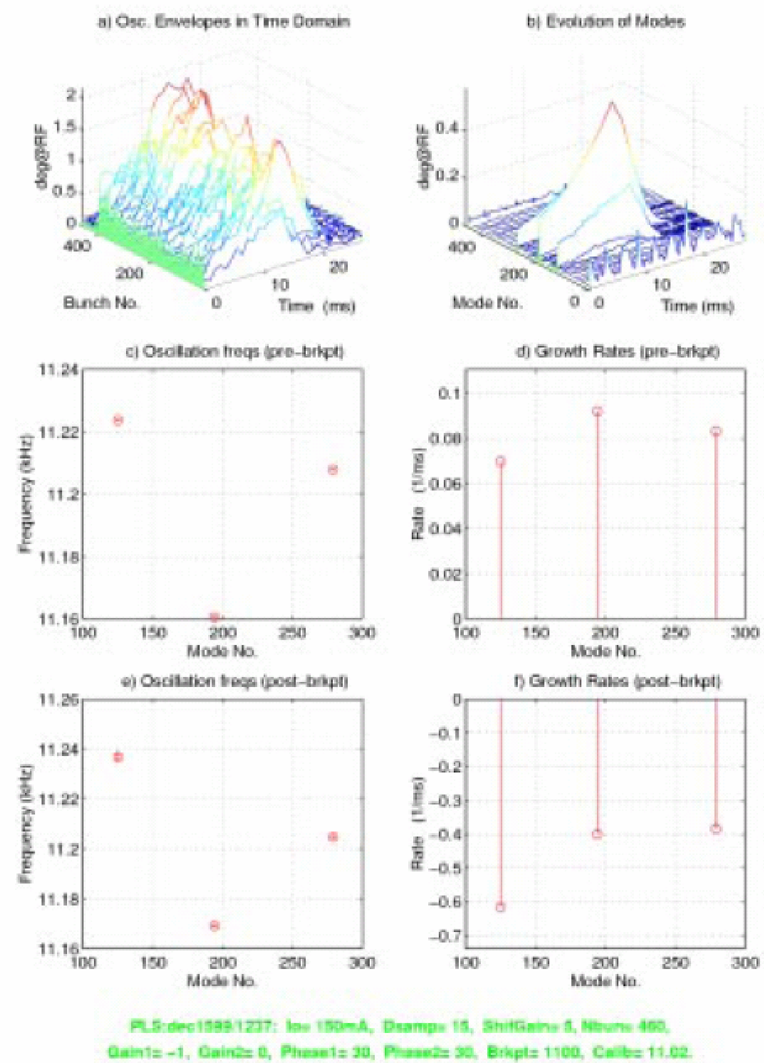
All filled bunches participate in the modal motion - there are three strong eigenmodes in this transient. Fitting complex exponentials to the modal motion we extract estimates of the modal eigenvalues for both open and closed-loop parts of the transient.

A very powerful technique to measure modal instability growth rates and non-invasive frequency-resolved measurement of impedance. High-current margins can be established using optimal control techniques as a function of beam current, RF system configuration, etc

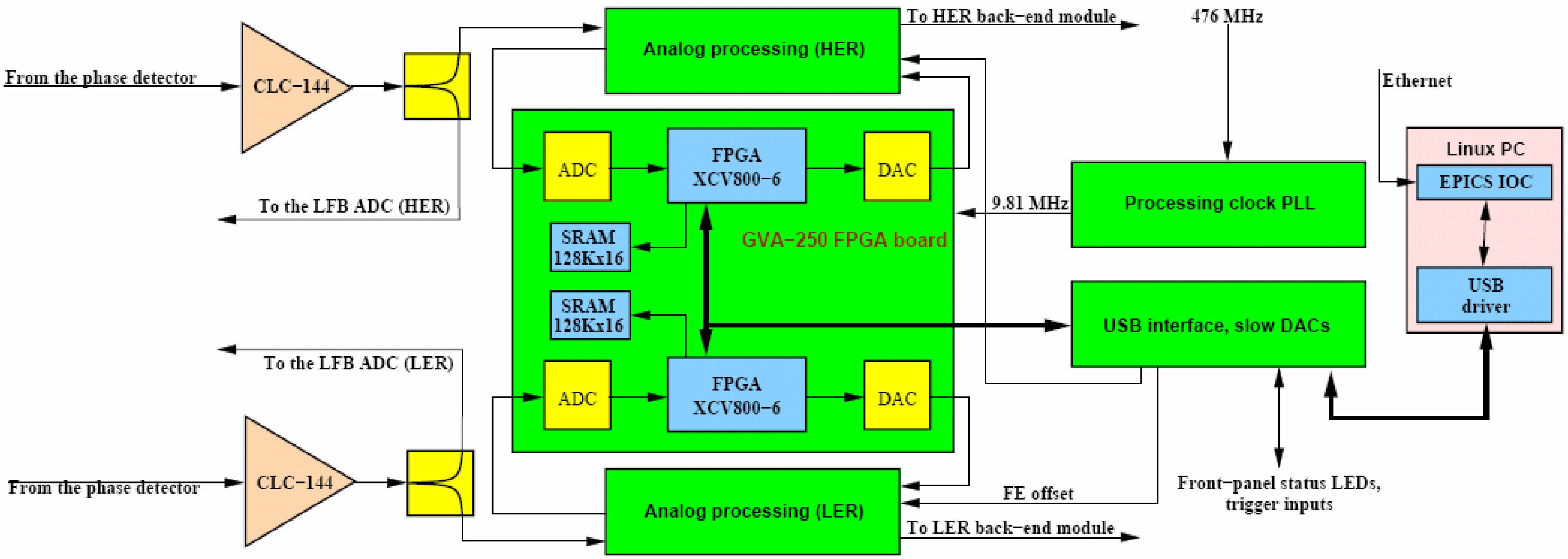
Two APS Dissertation Prizes in Beam Physics (2001 Shyama Prabhakar and 2003 Dmitry Teytelman) for the development and application of these techniques

This transient- instability measurement technique uses common codes and formalism for both longitudinal and transverse measurements. Used at labs around the world.

These techniques allow operation of PEP-II at 2X design currents, allow quantitative knowledge of instability margins.



Low group-delay woofer - increased PEP-II Currents



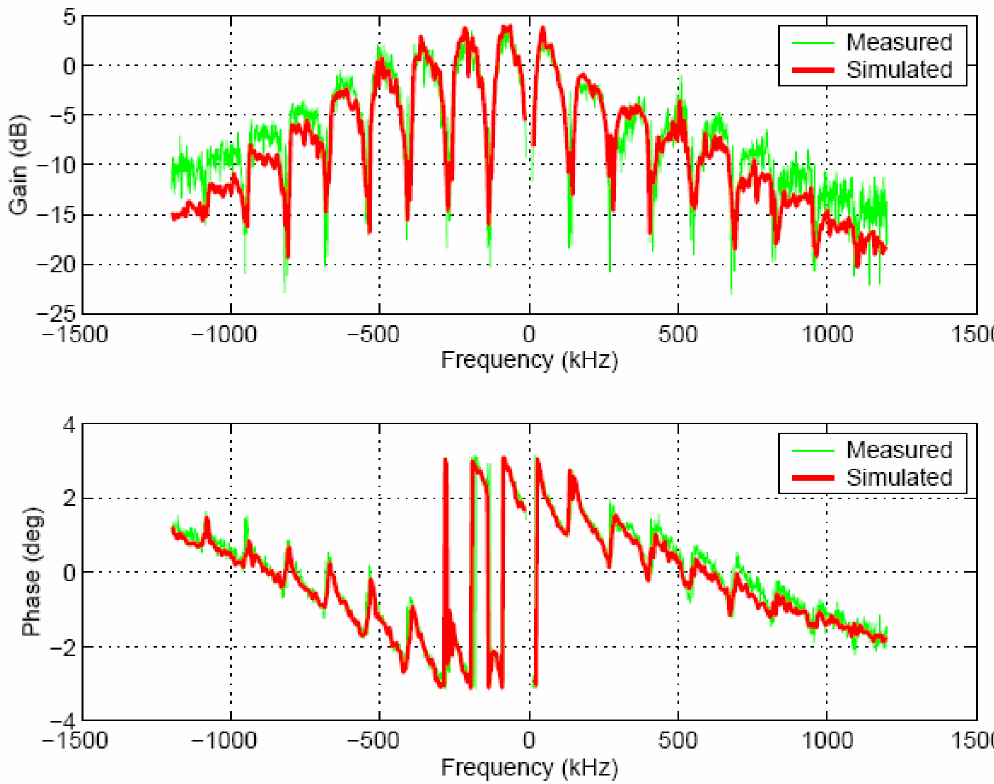
The LGDW improves low-mode instability control via a 32 tap FIR filter, with a 9.81 MS/s processing rate. Decoupled low-mode and HOM channels allow independent optimization of loop gains and dynamic ranges. EPICS user interface panels via IOC and software.

Prior to HER LGDW commissioning we were limited to 1380 mA with very tight margins - running with 1 -3 longitudinal aborts per day. With the LGDW HER currents increased to 1850mA, with much better margins.

Development of time-domain RF system model

Main limitation in predicting longitudinal stability at higher beam currents is the uncertainty in estimating the growth rates of the fundamental-driven eigenmodes

Impedance reduction via the LLRF feedback loops is critical, however the effectiveness of these loops is difficult to predict due to klystron saturation.



Recent efforts

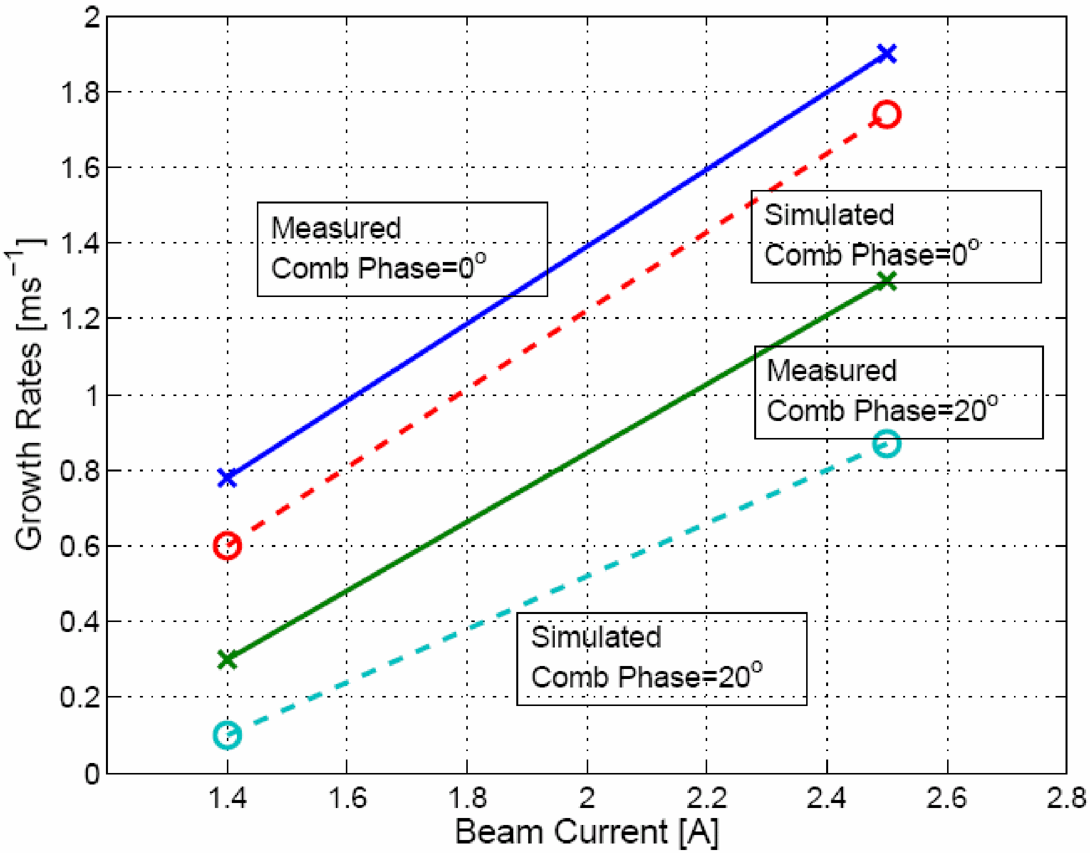
- **Simulation configured using identical model-based techniques used in actual LLRF systems. Simulation instabilities measured via same codes used to analyse machine data**
- **Validate time-domain model using parameters extracted from an RF station transfer function measurement**
- **Transfer function extracted from the time-domain simulation data agrees very well with the transfer function of the physical station.**

Applications -LLRF-Beam Simulation Model

The simulation allows insight in new techniques to stabilize the LLRF control loops and improve the impedance control of the direct and comb loops.

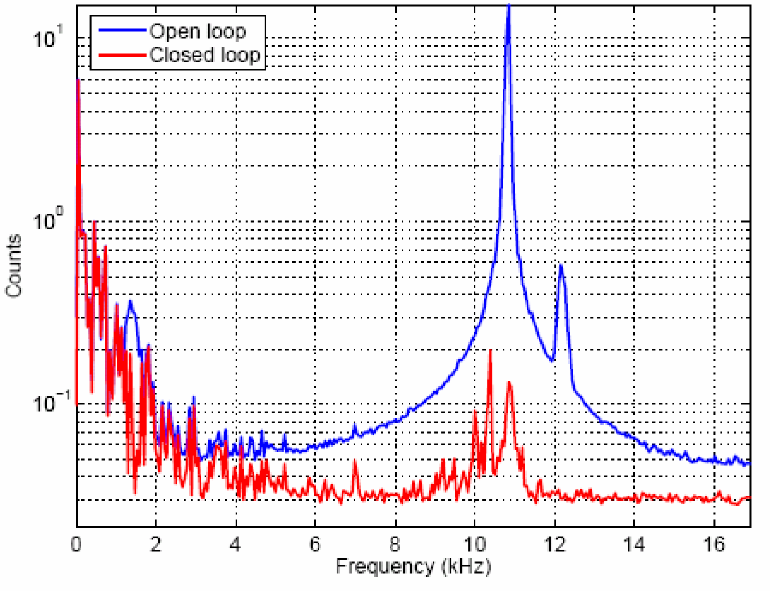
A new idea - improve the effectiveness of the impedance control via trade-off in the stability of the LLRF control loops. First understood and analysed via the simulation, this comb loop rotation technique was tested in the LER.

The model correctly predicts the fastest-growing instabilites - more significantly it was verified that the growth rates in the PEP-II LER are reduced by more than a factor of two via adjustment of the comb loop feedback. Such techniques are vital to increasing PEP-II currents.



Gproto reconfigurable signal processor

The next-generation feedback channel (Gproto) has been commissioned at PEP-II, KEK-B, DAFNE and ATF.The figure shows the impact of longitudinal control on the beam at the ATF damping ring - the feedback reduces the residual motion by two orders of magnitude.The residual motion of the beam is also seen in the measured x-size. The feedback control reduces the cross-section for multi-bunch and single-bunch cases.



This reconfigurable architecture allows one design of hardware to be used at multiple accelerators. This platform can scale to 1.5GS/sec. control rates for feedback and beam instrumentation

Klystron Linearizer -Evaluation and Prototypes

Technique to add linearity within LLRF Direct and Comb loops - Evaluated in PEP-II

Improves stability of LLRF loops, noise in RF system, applications to other high-power systems

Technology - RF path (gilbert cell muliplier), detection via diodes, baseband feedback path

- High Power Test Stand Tests, lab test results,4 linearizers installed in LER, tested with beam

Features - 476 MHz center frequency, 1 MHz closed-loop bandwidth

- 15 dB amplitude non-linearity correction range
- Dynamic gain compensation via software in microcontroller (10 Hz bandwidth)

Conclusions

High Gradient Collaboration and Work at SLAC

- A coordinated effort for high gradient research in the US has been organized.
- A consensus on the research direction for building a 30 GHz RF source has been established.
- A test setup for testing material properties under high magnetic RF field conditions has been built and tested.
- We tested several structures including molybdenum waveguide and CERN structures.
- We have supported other labs with X-band components.
- Our future experimental program will rely on both the ASTA facility and the Two-Pack at NLCTA.
- The intensity of the program next year will depend on the budget and facilities availability. This also applies to the high frequency source.
- We have made progress towards a laser-activated pulse compression system at 30 GHz.

Conclusions (continued)

Technology Research and Developments

- We have made several studies (paper studies so far) of advanced concepts for ILC.
- We have taken first steps towards a practical optical accelerator. The device has been designed and is under construction. We have developed, for the first time, a practical scheme for coupling a Gaussian laser beam into an accelerating mode.
- Our work also spanned several developments for future light sources and FELs, including the generation of ultra short bunch and RF undulators.
- We have made progress towards active pulse compression with spatially combined semiconductor devices.

Advanced Electronics and Instability Control

- Our work in instability control - accelerator dynamics and technology developments include modeling, dynamics and optimal control techniques. Resulting technology and systems are in use around the world.
- LLRF stability and impedance control efforts resulted in PEP-II luminosity of 10^{34}.

Support of Ongoing SLAC Programs

- We participate in the ILC R&D programs including design studies of NC accelerator structures for e+ source and e- source, design and test of a 5-cell test section, and design of a polarized electron gun.
- We support the accelerator structure related work for the LCLS including tuning and measurement of a variety of injector accelerator sections and the RF gun.

General Comments

- The group serves an important educational function for graduate students and post docs.
- The group supports lab programs, including ILC, PEP-II, and LCLS. Our role is crucial for all these programs.