Advanced Accelerator R&D

Accelerator Research Departments A & B

Presented by:

E. R. Colby, ARDB

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Accelerator Research Department Missions

ARD

ARDA Mission:

The ARDA department has two primary missions, which are complementary:

•To support the Accelerator Department and PEP II

•To lay the theoretical and technical foundation for the next generation of particle accelerators.

ARDA also participates in special projects designed to advance the state of the art of accelerator physics; for example, the development of the Final Focus Test Beam and the construction of the Next Linear Collider.

ARDB

ARDB Mission:

The primary goal of ARDB research is to push the envelope of advanced accelerator technology, particularly in the areas of high-gradient (>GeV/m) acceleration and low-emittance beams.

Overview of ARDA

RUTH, Ronald D.

Deputies:
CHAO, Alexander W.
CAI, Yunhai
WANG, Juwen

ADMIN SUPPORT
BANGALI, Margie L.
§VALINE, Joan L.

LATTICE DYNAMICS
CAI, Yunhai
§KNIGHT, Thomas D
%WONG, Jerry
LEE, Martin J.
NOSOCHKOV, Yuri M.
PANICKER, Rahul (SRA)
YAN, Yiton T.

COLLECTIVE EFFECTS
STUPAKOV, Gennady V.
BANE, Karl L.
CHAO, Alexander
EMMA, Paul
HUANG, Zhirong
HEIFETS, Samuel A.
KRINSKY, Samuel (V)
NASH, Boaz (SRA)
%WARNOCK, Robert

SPECIAL PROJECTS
RUTH, Ronald D.
HERRMANNSFELDT, William B.

ADV. BEAM CONCEPTS
CHEN, Pisin
IRWIN, John
§NG, Johnny S. T. (FT)
REIL, Kevin (RA)
SHMAKOVA, Marina (RA)
THOMPSON, Kathleen A.
YASHIN, Aleksandr (SRA)

ADVANCED ELECTRONICS
FOX, John D.
BECKMAN, Liane (SRA)
HASSANPOUR-GHADY, Navid (SRA)
TEYTELMAN, Dmitry

RF STRUCTURES
WANG, Juwen
BABOI, Nicoleta (RA)
BOWDEN, Gordon B.
JONES, Roger M.
LEWANDOWSKI, James R.
%MILLER, Roger (FT)

HIGH POWER RF
TANTAWI, Sami
AGARWAL, Mukul (SRA)
DOLGASHEV, Valery (FT)
%FARKAS, David
GUO, Jiquan (SRA)
NANTISTA, Christopher
%WILSON, Perry (FT)
YEREMIAN, Anahid D. (Dian)
ZHOU, Yubo (SRA)

FT	FIXED TERM
RA	RESEARCH ASSOCIATE
SRA	STUDENT RESEARCH ASSISTANT
%	CASUAL EMPLOYEE AND/OR < 50% TIME
§	SAFETY COMM. MEMBER OR DEPT SAFETY REP
V	VISITOR

37 Members:
- 5 Faculty
- 23 Physicists and Engineering Physicists
- 6 RAs/SRAs
- 3 Admin. Support

Overview of ARDB

SIEMANN, Robert H.

ADMIN SUPPORT

§SEYMOUR, Angie
HIGASHI-SUEZAKI, Adrienne
%SANTO, Stephanie
%BOOGAR, Stephen

SAFETY

§KNIGHT, Tom<

BARNES, Christopher (SRA)
§ COLBY, Eric R. (FT)*
COWAN, Benjamin (SRA)
%FRYBERGER, David
HOGAN, Mark J.
JAVANMARD, Mehdi (SRA)
KOLCHIN, Pavel (SRA)
> MENEGAT, Albert
NOBLE, Robert
O'CONNELL, Caolionn (SRA)
PALMER, Dennis T.
SEARS, Chris (SRA)
§SPENCER, James E.

SRA STUDENT RESEARCH ASSISTANT
> HOME DEPT. IS KLYSTRON, ≤ 50% TIME IN ARDB
% CASUAL EMPLOYEE AND/OR ≤ 50% TIME
§ SAFETY COMM. MEMBER OR DEPT SAFETY REP
< HOME DEPT. IS ARDA, ≤ 25% TIME IN ARDB
* PANOFSKY FELLOW

16 Members:

- 1 Faculty
- 1 Panofsky Fellow
- 5 Physicists
- 7 RAs/SRAs
- 2 Admin. Support

Accomplishments of the Last Year

- 105 Publications, 30 in peer-reviewed journals
- Awards
  - **Boris Podobedov**, 2002 Dissertation Award from the APS Division of Physics of Beams for his thesis on Instabilities in the SLC Damping Rings.
  - **David Pritzkau,** 2003 Dissertation Award from the APS Division of Physics of Beams for his thesis on RF Pulsed Heating.
  - **Sami Tantawi**, 2003 USPAS Prize for Achievement in Accelerator Physics and Technology, for theory and technology of rf components for the production and distribution of very high-peak rf power
- Ph.D.s Awarded
  - **Brent Blue**, PhD degree awarded from UCLA in March 2003, "Plasma Wakefield Acceleration of an Intense Positron Beam"
  - **Sueng Lee**, PhD. degree awarded from USC in January 2002, "Nonlinear Plasma Wakefield Acceleration: Models and Experiments"
  - **Tomas Plettner,** PhD. degree awarded from Stanford in September 2002, “Proof-of-Principle Experiment for Crossed Laser beam Electron Acceleration in a Dielectric Loaded Vacuum Structure”
  - **Shuoqin Wang**, PhD degree awarded from UCLA in June 2002, "X-ray Synchrotron Radiation in a Plasma Wiggler”

Accelerator Research Department A

Groups:

- Lattice Dynamics
- Collective Effects
- Advanced Beam Concepts
- Advanced Electronics
- RF Structures
- High Power RF

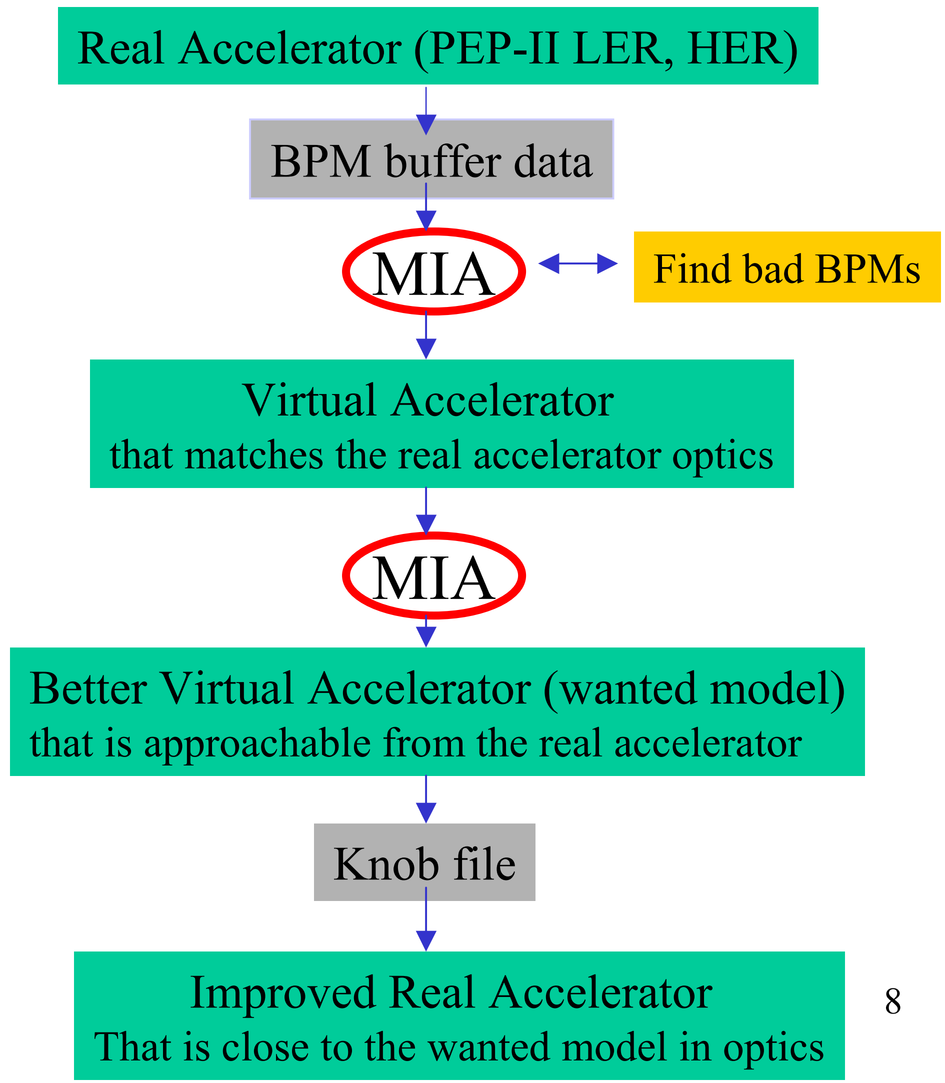
Current Activities

- Improve the performance of the PEP-II
  - Design lattice for the upgrades
  - Analyze and correct the machine optics
  - Simulate electron cloud instability and the beam-beam interaction
- Develop and maintain the object-oriented computer programs: LEGO and Zlib
- Study the long-range beam-beam effects in the Tevatron at Fermilab

Model-Independent Analysis

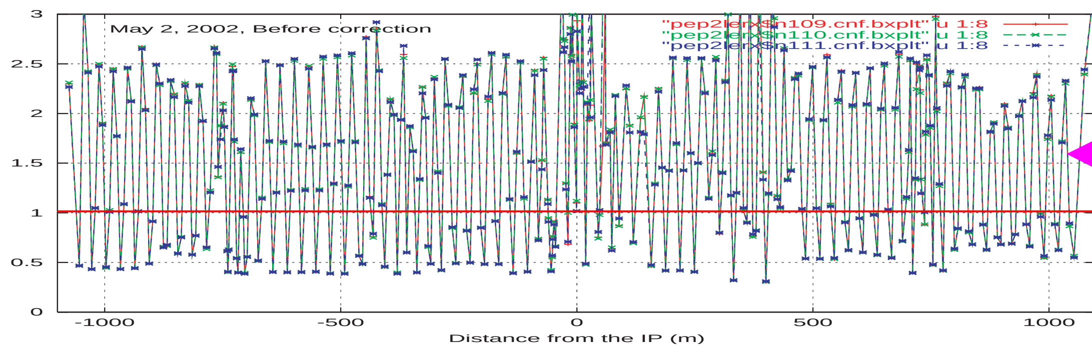
With a Model-Independent Analysis (MIA) of the massive BPM buffer data, we are able to obtain a computer model virtual accelerator that matches the real accelerator optics.

An optimized lattice can then be obtained by adjusting (fitting) a limited number of well-selected magnets and tested in the real accelerator.



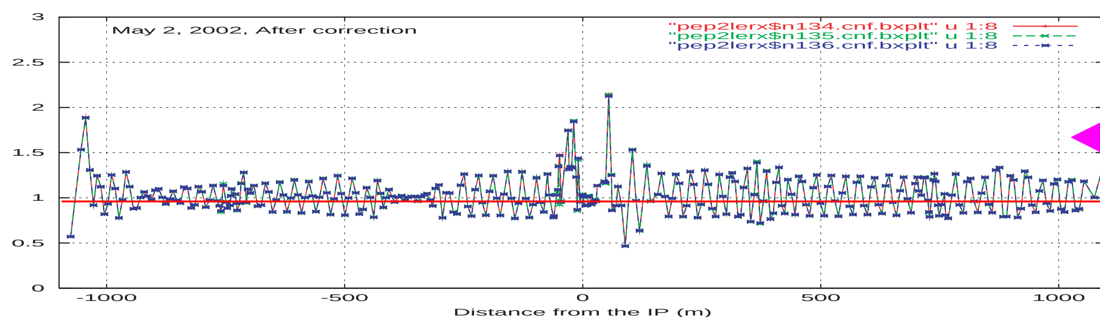
β Beating in the Low Energy Ring

$$\frac{\beta_x^{meas}}{\beta_x^{ideal}}$$



before correction

$$\frac{\beta_x^{meas}}{\beta_x^{ideal}}$$



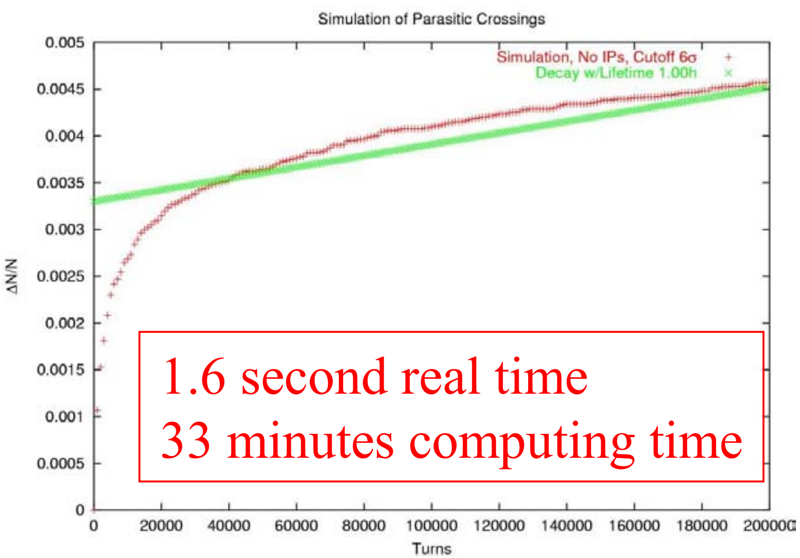
after correction

The horizontal β beating was reduced from 250% to 30% near the half integer resonance in May, 2002.

Tevatron Injection Lifetime Simulation

- Parallel strong-weak
- 10^6 particles-turns/second speed
- Runs on about 100 processors at NERSC
- 6D linear maps extracted from simulation of the Tevatron lattice
- Includes synchrotron oscillation

Simulation when the beam emittances are three times larger than the measured values



Recent and current topics of research

- Electron cloud effects in PEPII and NLC damping rings.
- Code development (LIAR, shielded coherent synchrotron radiation [CSR])
- Intra-beam scattering and impedance effects in rings.
- Roughness impedance in the LCLS undulator.
- **Microbunching instability due to CSR in rings (NLC) and bunch compressors (LCLS)**
- Study of design issues for LCLS
- Experiment on SPPS
- Space charge effects in plasma sources

Experimental observation of CSR Instability at ALS

(J. Byrd *et al*, PRL **89**(12), 224801, 2002)

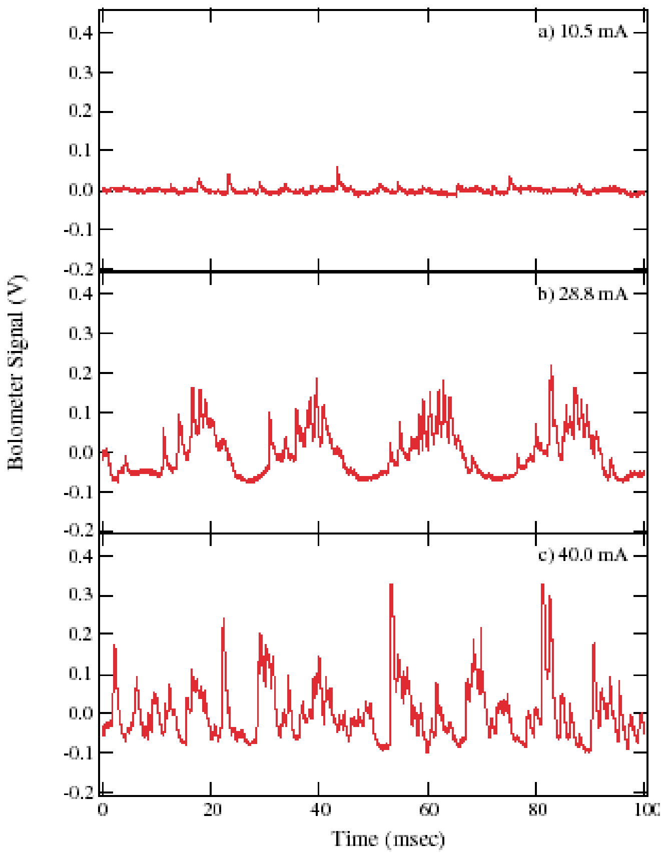


FIG. 1 (color online). Bolometer signal measured demonstrating bursting above threshold at three current values. Between 27 and 31 mA the bursts develop a periodic behavior. Above this current they appear more chaotic.

Theory: from Heifets, S., Stupakov, G., PRST-AB, **5**, 054402, (2002).

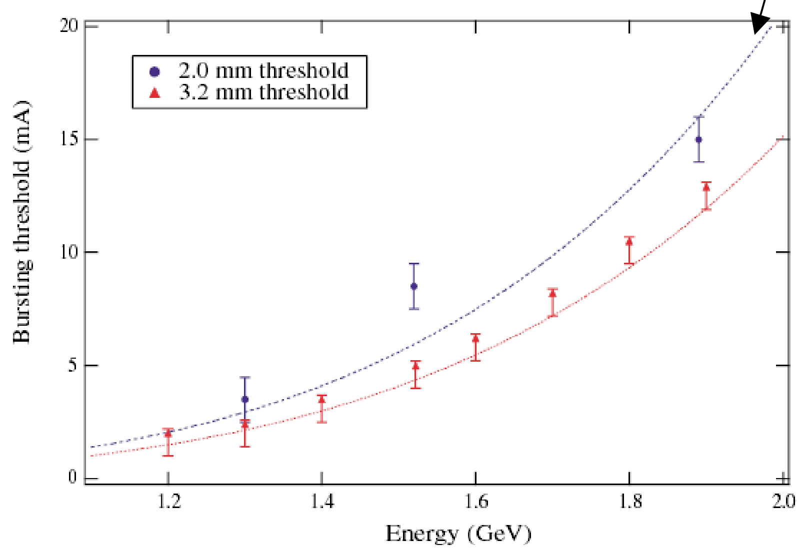
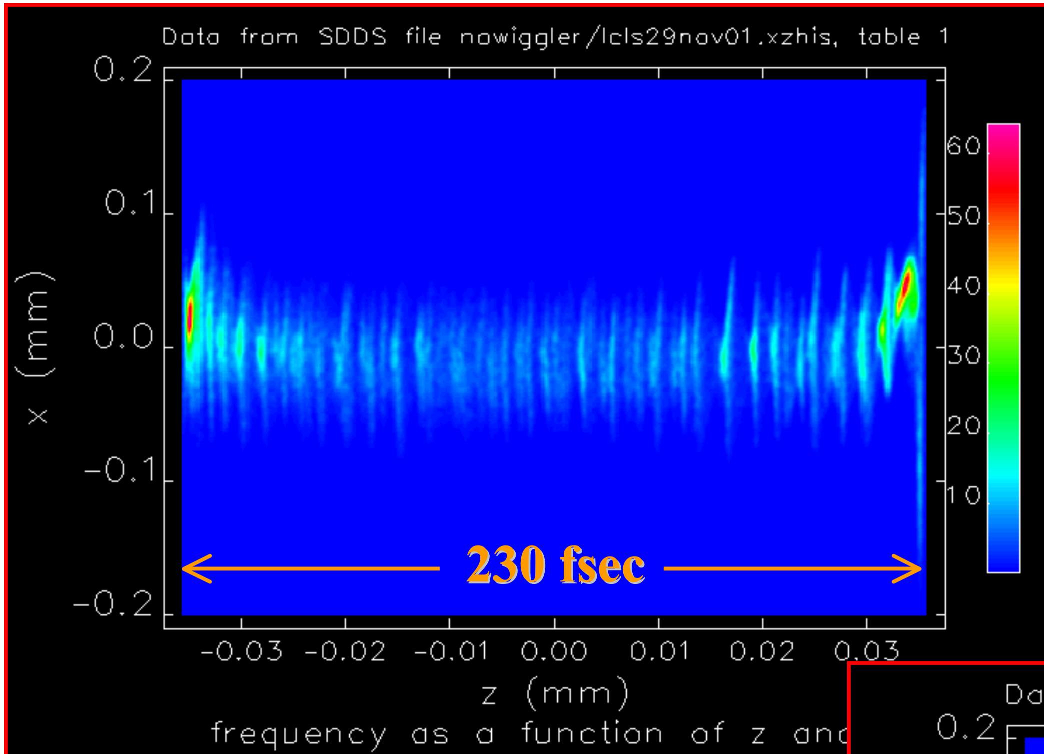


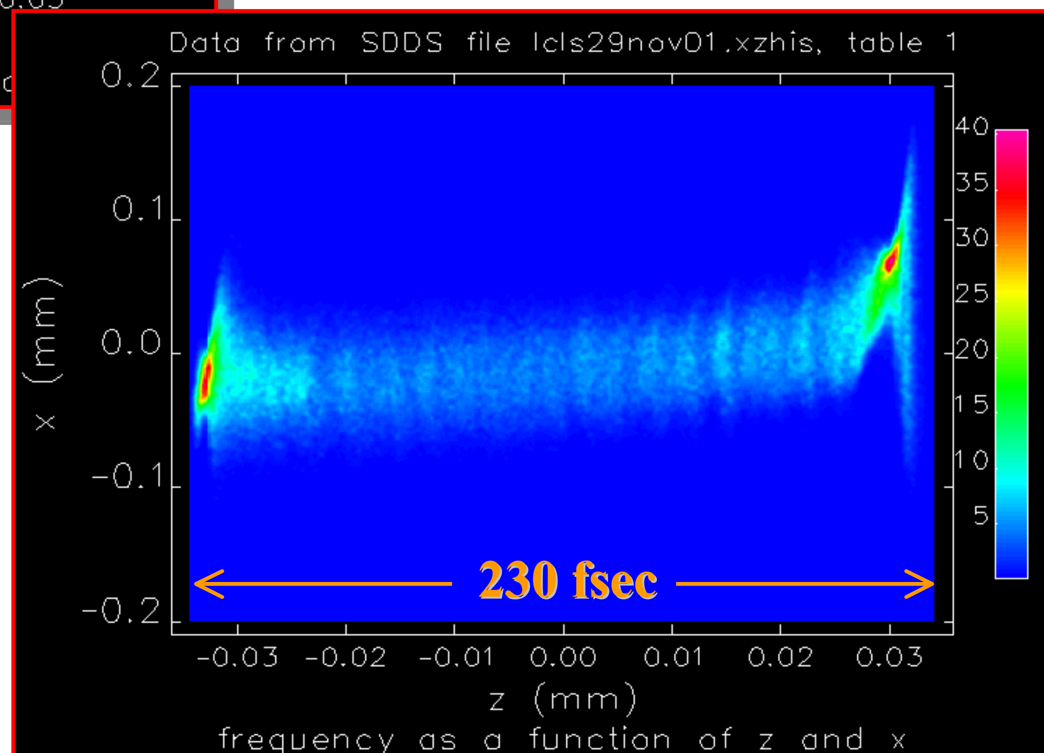
FIG. 4 (color online). Bursting threshold as a function of electron beam energy at 3.2 and 2 mm wavelengths. Data are shown as points. Calculated threshold using nominal ALS parameters at 3.2 and 2 mm wavelengths are shown as dashed lines.

Micro-bunching induced by coherent synchrotron radiation (CSR) in *LCLS* bunch compressors



Electron bunch (x vs. z) with incoherent energy spread of 8×10^{-6} at 14.3 GeV

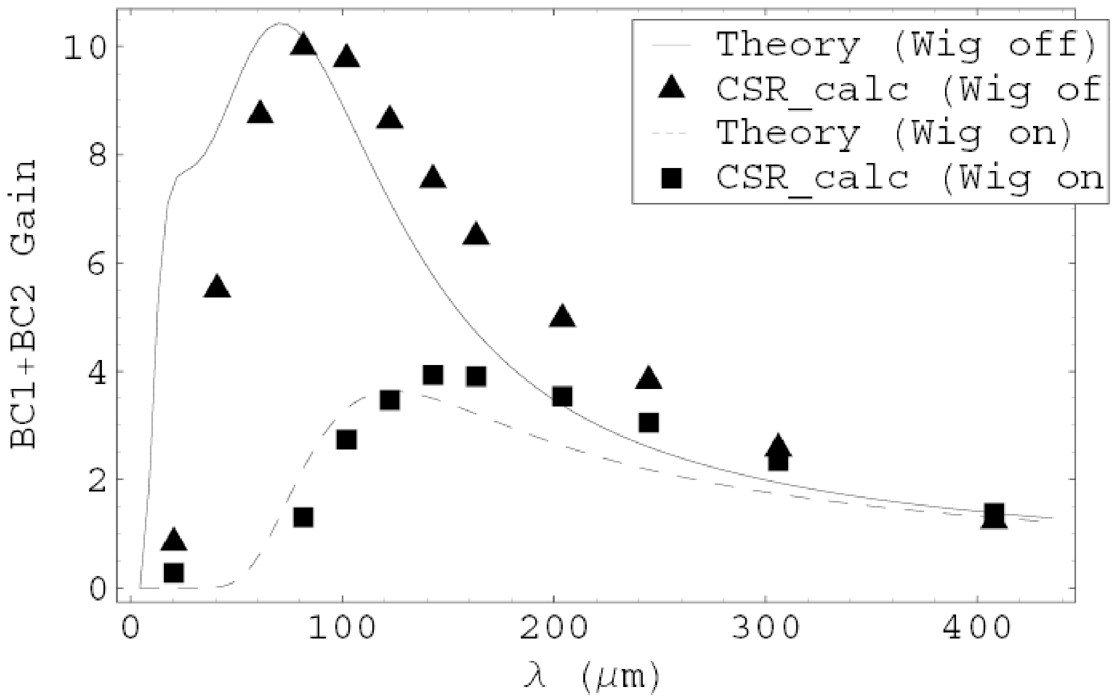
Same bunch, (x vs. z) with energy spread increased to 8×10^{-5} providing suppression of micro-bunching



Courtesy P. Emma

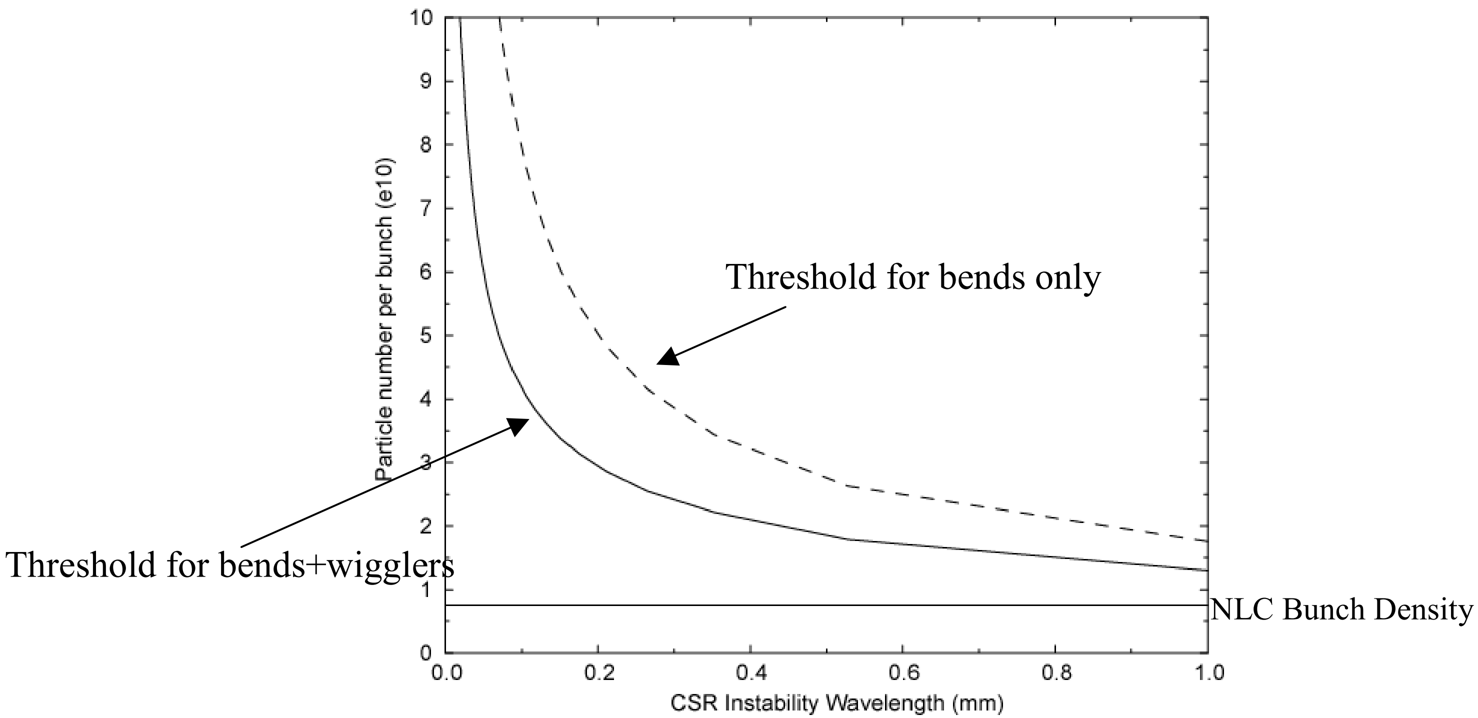
Collective Effects Group

The same instability may result in the microbunching of the LCLS beam in the bunch compressor (S. Heifets, S. Krinsky, G. Stupakov , PRST-AB, 2002; Z. Huang and K.-J. Kim, PRST-AB, 2002).



Gain factor G as a function of wavelength λ of the perturbation in the LCLS bunch compressor, $\sigma_\delta=3\cdot10^{-6}$, ε=1 μm. Solid line – theory, dots – simulations.

The CSR instability is studied for the NLC damping rings, with strong wigglers (J. Wu, T. Raubenheimer and G. Stupakov, in preparation).



Instability threshold for the NLC damping ring as a function of wavelength.

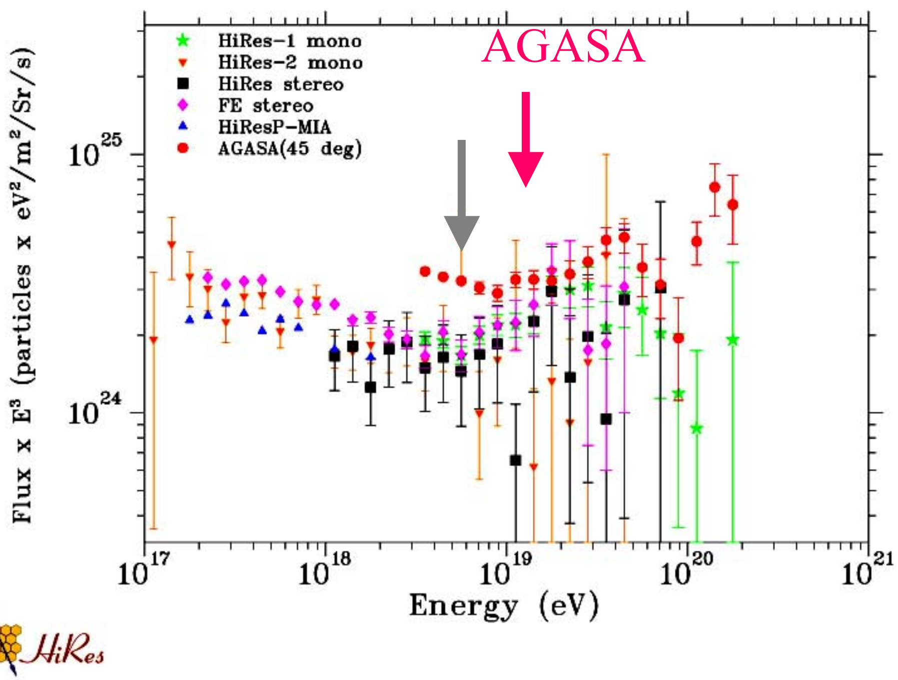
Particle Astrophysics and Cosmology

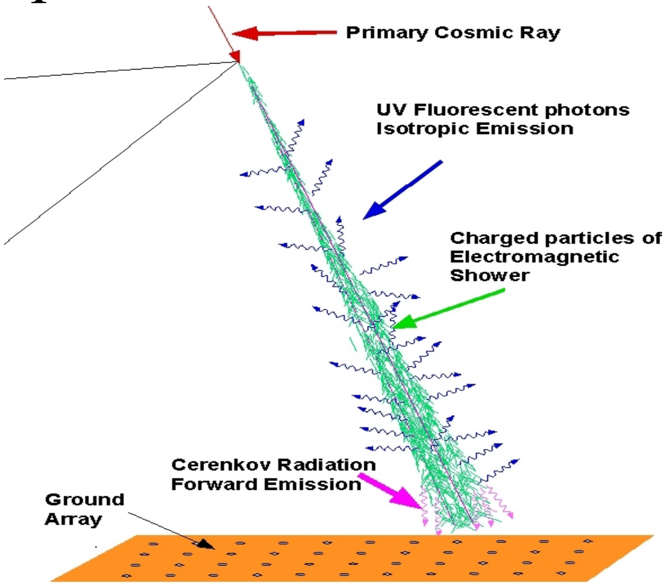
- Laboratory Astrophysics
  (Pisin Chen, Johnny Ng, Kevin Reil)
- FLASH (Fluorescence from Air in Showers)
  (Pisin Chen, Johnny Ng, Kevin Reil)
- Unruh Effect (Pisin Chen, Aleksandr Yashin)
- Gravitational Lenses (study of mass distribution in the galaxy clusters) (John Irwin, Marina Shmakova)
- Early Universe Simulation Code
  (Pisin Chen, John Irwin, Kathy Thompson, Marina Shmakova)
- Theoretical Studies of Black Holes, Early Universe Cosmology, Dark matter and Cosmic Rays (Pisin Chen, John Irwin, Kathy Thompson, Marina Shmakova)

E-165

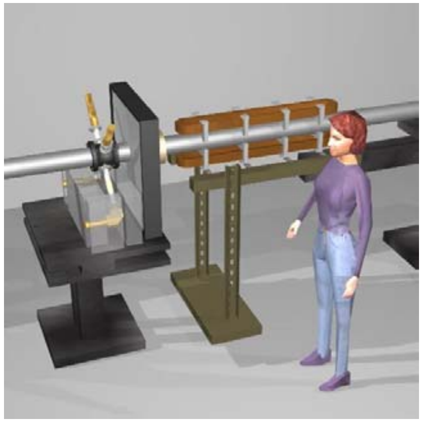
Astro-Beam Studies Group: ARDA

Discrepancy in the UHECR spectrum:





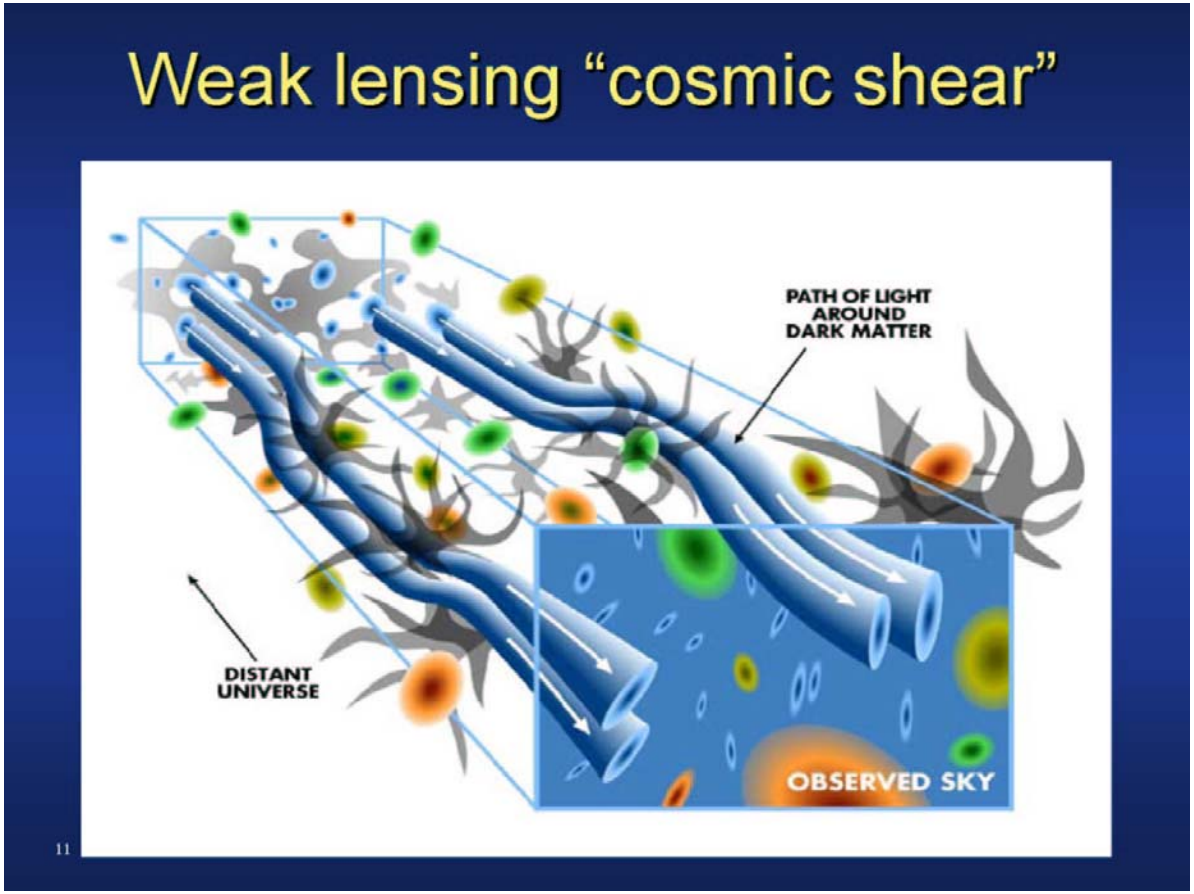
The SLAC beam can create an E/M shower analogous to a cosmic ray shower. A calibration on energy scale can then be performed.



Gravitational Lensing Or Cosmological "Final Focus" Systems

Astro-Beam Studies Group: ARDA

- Mapping of the dark matter and dark energy may be achieved by applying math methods used in beam optics. By examining the higher moments of images arriving at earth the location and mass of small clusters of dark matter can be determined.



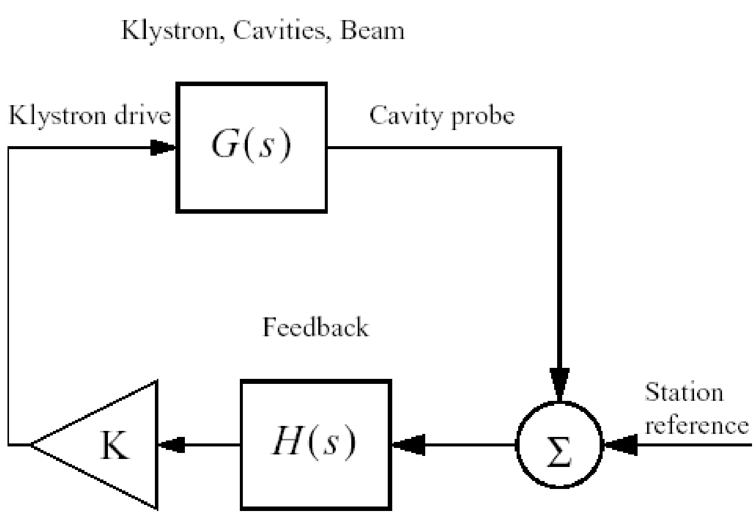
Requirements for low-level RF in PEP-II operation

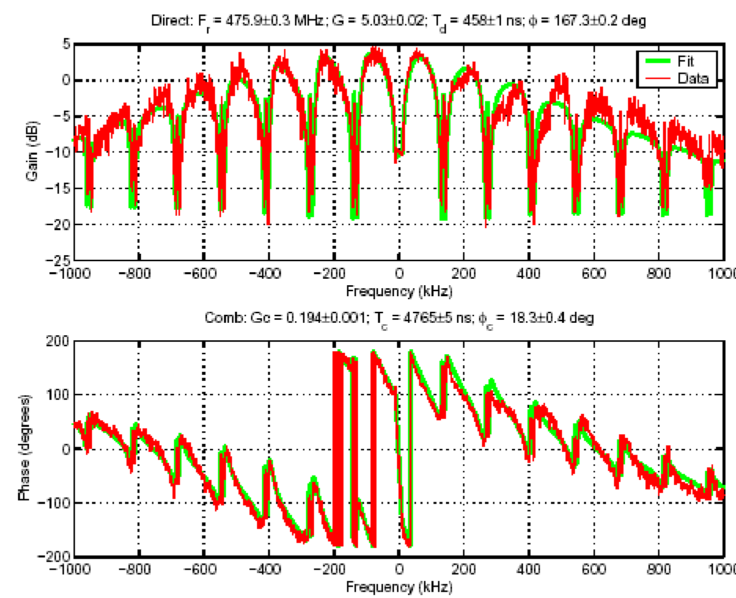
PEP-II RF feedback
- Direct, Comb loops
- Reduce Impedance seen by beam

Stability of closed loop response difficult to predict for high-current configuration
- Open-loop measurements unstable, cannot measure loop stability, predict operation

New Technique - measure closed loop response, fit 7 parameter model of RF system, cavities, beam
- Optimally adjust model parameters for desired stability, margins
- Transfer results to RF system

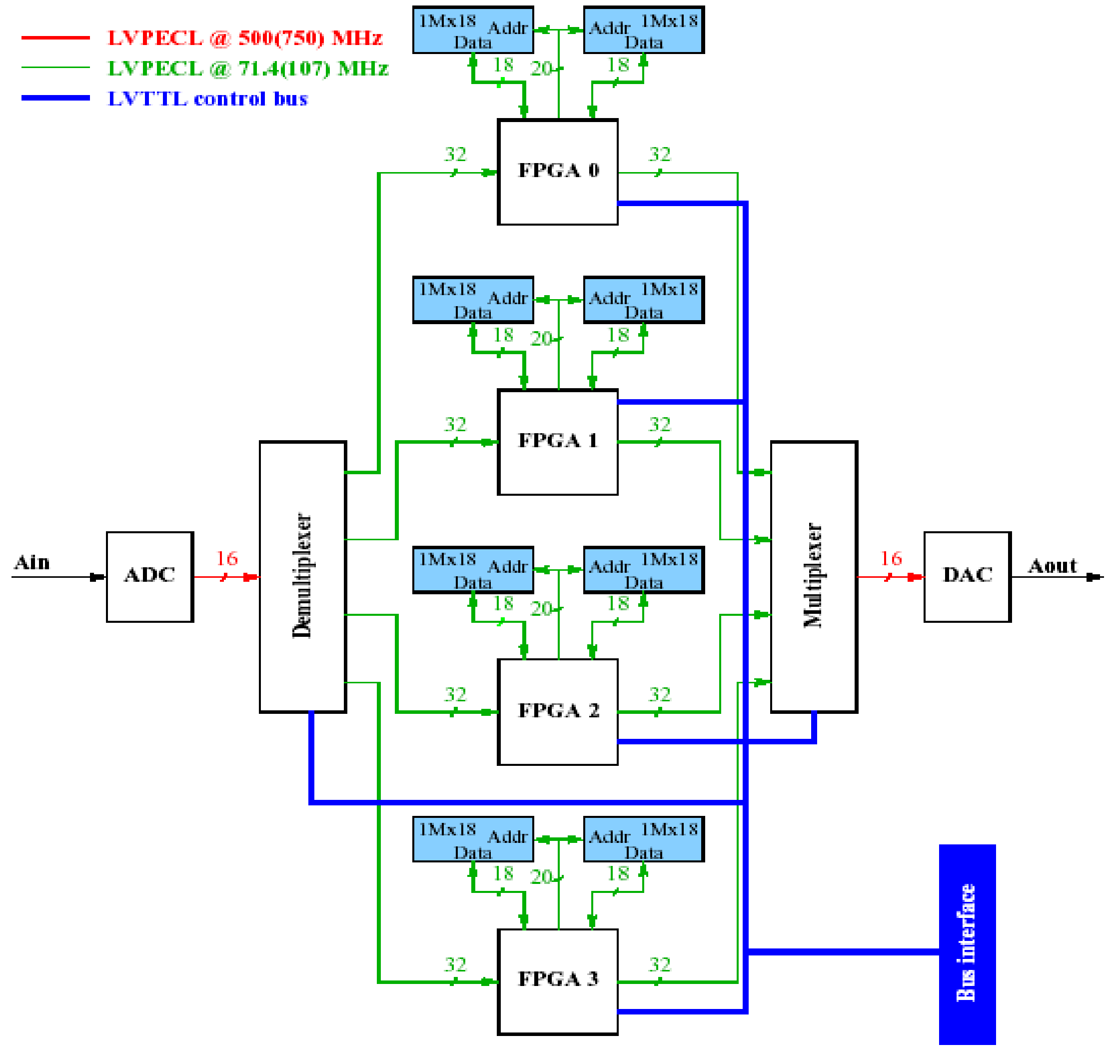
This technique is now used to configure PEP-II RF stations for High-current operation





GBoard 1.5 GS/sec. processing channel

- Next-generation instability control technology
- SLAC, KEK, LNF-INFN collaboration - useful at PEP-II, KEKB, DAFNE and several light sources.
- Transverse instability control
- Longitudinal instability control
- High-speed beam diagnostics (1.5 GS/sec. sampling/ throughput rate)
- Builds on existing program in instability control and beam diagnostics.
- Significant advance in the processing speed and density previously achieved.



Expected Progress in 2003/2004

PEP-II high-current commissioning -

- Measurement and control of bunch instabilities
- Analysis of the low-level RF systems and feedback stability.
- Test the low-group delay woofer channel, predict the performance limits of such control techniques.
- Commission and characterize the high-current damped-cavity kicker for PEP-II
- Design the low group delay woofer and control filter for production use in PEP-II, based on the experience from the lab evaluation model.

Quadrupole Mode Control Studies

- Follow-on DAFNE measurements of Quadrupole-mode instability control, expanding our initial results to include the electron ring. Publication on the general topic of dual-mode control feedback, with commissioning results.

GBoard Processing Channel

- Detailed design of the 1.5 gigasample (GBoard) processing channel (joint development project with KEK and LNF-INFN). Construct and evaluate critical high-speed functions of this architecture in FY2003, demonstrate key features at one of the labs in late 2003. For 2004 commissioning of a complete Gigasample/sec. feedback channel for routine use at a light source or collider.

Publications/Presentations at PAC-2003

D. Teytelman, "Survey of Digital Feedback Systems in High Current Storage Rings"(invited Talk)

L. Beckman, et al "Low-Mode Coupled-Bunch Feedback Channel for PEP-II"

F. Marcellini, et al "An Over-damped Cavity Longitudinal Kicker for the PEP-II LER"

Mission for RF Structures Group

Mission

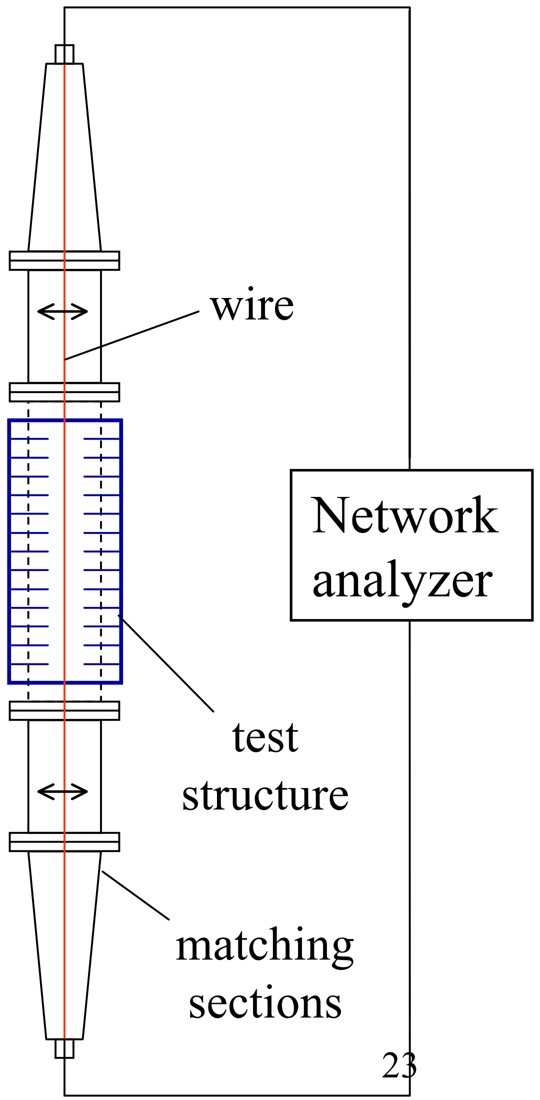
We design, engineer and test accelerator structures for future linear colliders operating under extremely high gradient conditions with superior properties in higher modes suppression.

The activities

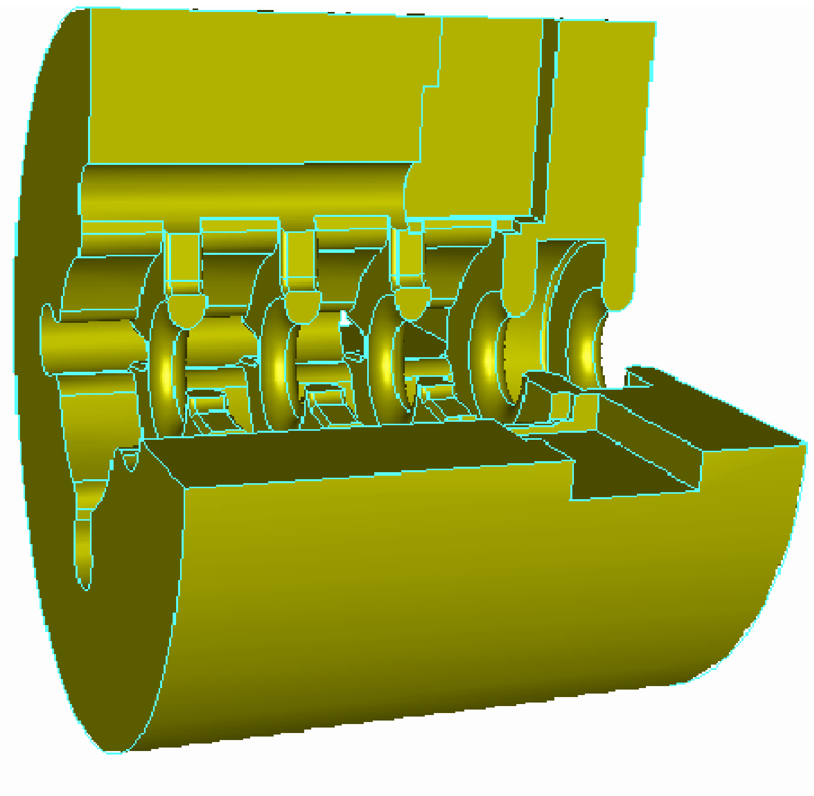
- Accelerator Theoretical Studies.
- Simulation and Computer Aided Accelerator Design.
- Mechanical Design.
- Fabrication Technologies Studies.
- Microwave Characterization.
- High Power Experiments.

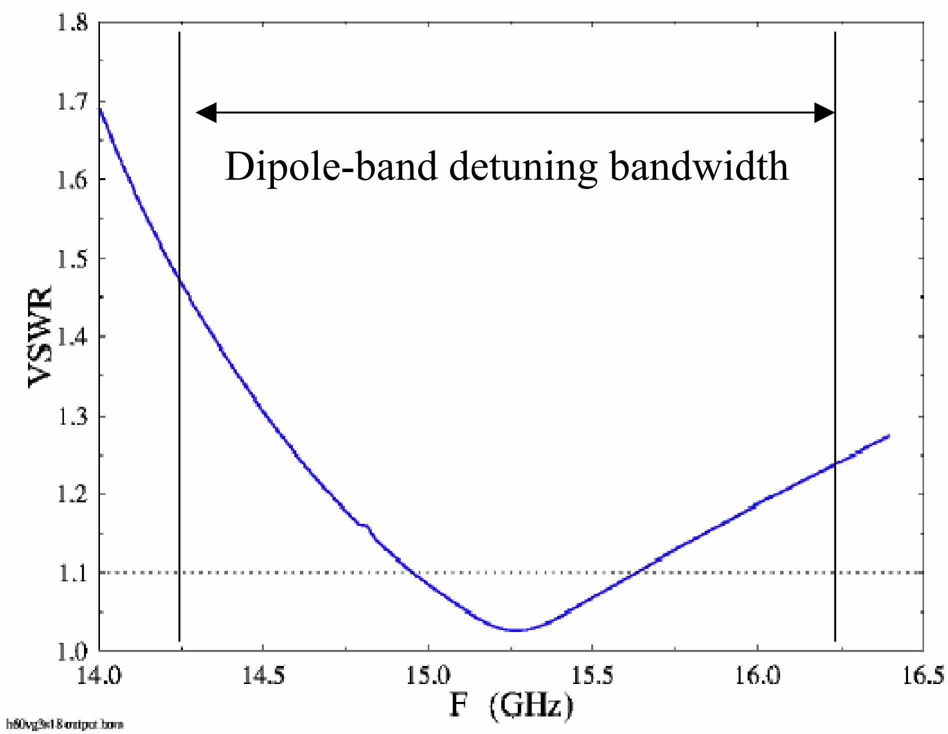
Wire Measurement of Wakefields

- Proposed by Sands and Rees
- Measure wake field by help of wire passing through structure to be measured
  - time domain ⇒ wakefield
  - <u>frequency domain</u> ⇒ modes
- Measure mode properties by measuring S21,
- $Z_\perp = f(S_{21})$
- kick factor = $\int Z_\perp$



High-Order Mode (HOM) Coupler Design For NLC Prototype Accelerator Structures

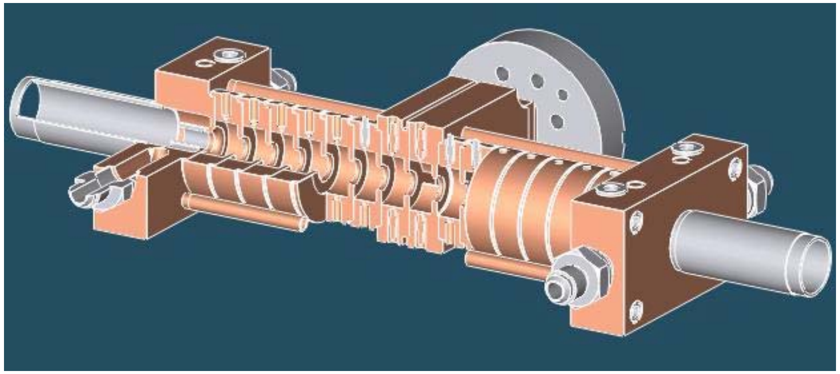


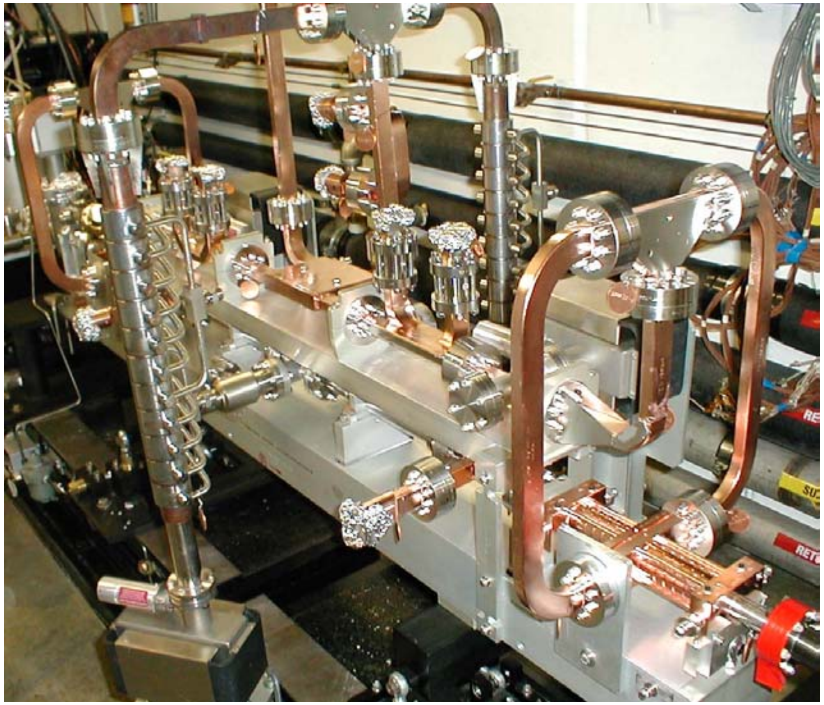


Standing Wave Structures

(15 Cells, 20 cm Long, 124 ns Field Rise Time)

- In NLC, standing-wave structures would operate at the loaded gradient of 55 MV/m.
- Of three pairs tested, one pair had breakdown rates of < 1 per 8 million pulses at this gradient and no discernable frequency change after 600 hrs of operation.
- Pulse heating in coupler likely limiting higher gradient operation – will be reduced for next test in May, 2003. .





Structure Plan for Year 2003

Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.

- Install H90VG3N (0.18, 150°, no slots) 92 MW — KEK/SLAC
- Install FXB-002 (0.18, 150°, no slots) 73 MW — FNAL
- Install H60VG3N (0.18, 150°, 6 slotted) 73 MW — KEK/SLAC
- Install SW20a375 x 2 — KEK/SLAC
- Install H60VG3S18 (0.18, 150°, slots, no HOM loads) 78 MW — KEK/SLAC
- Install FXB-003 (0.18, 150°, no slots) 73 MW — FNAL
- Fabricate cells for H75VG4S18. — Assemble H75VG4S18 — Install H75VG4S18 (0.18, 150°) slots, no HOM loads) 86 MW — KEK/SLAC
- Install CERNW/Mo (W/Mo iris) 100 MW — CERN
- Fabricate FXB 004-006 (H60VG3-18). — Install FXB 004 (one structure) 73 MW — FNAL
- Complete design and place cell order. — Install H60VG3R17 (0.17, 150°, no slots) 66 MW — SLAC
- Complete H60VG3S17 design with slots and HOM loads. — NLC Prototype

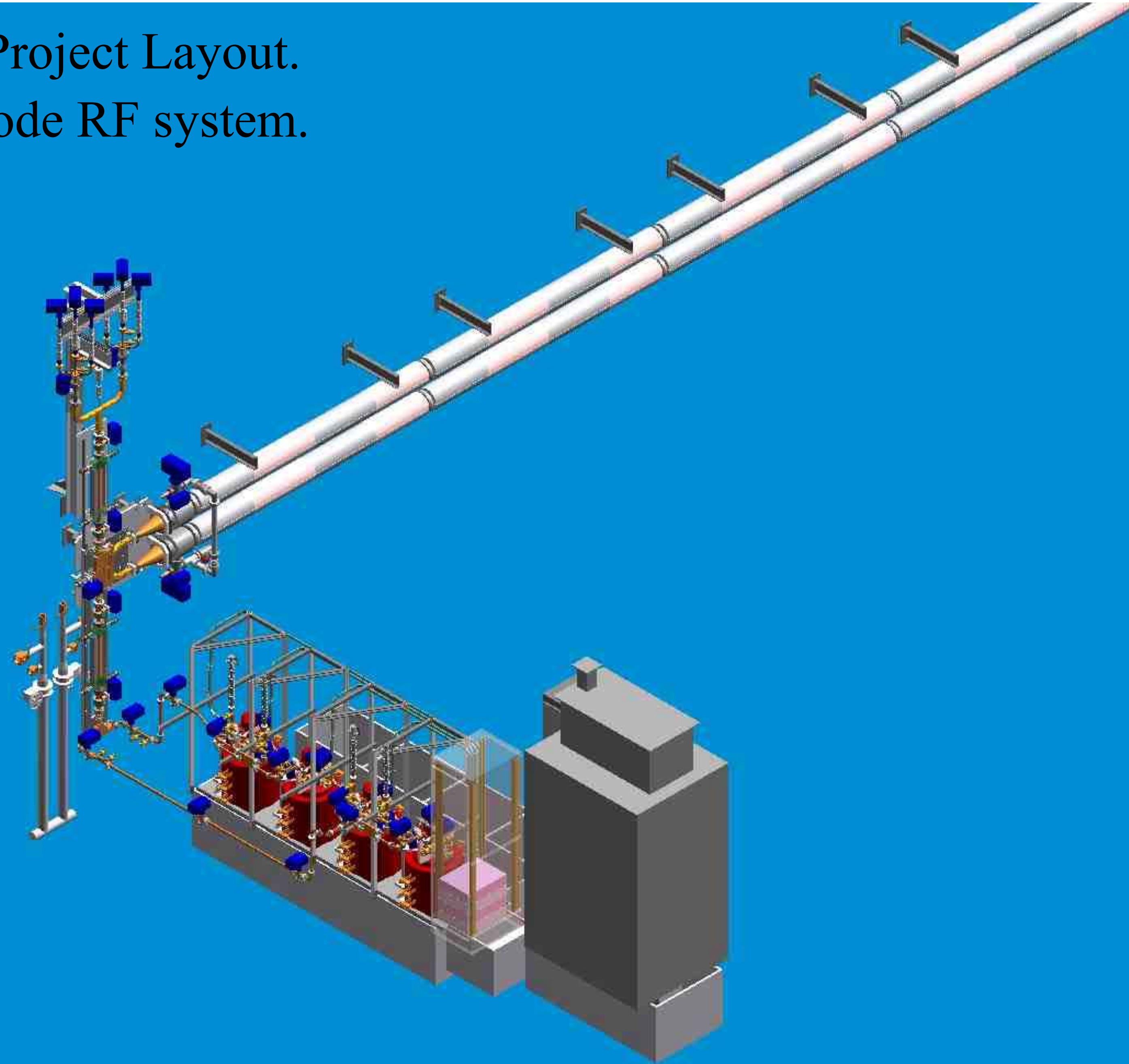
Group Activities

- RF Designs for the Pulse compression systems of the NLC and Accelerator Structure
    1. Overmoded and Multimode components
    2. Multimoded Delay Lines
    3. Accelerator structure couplers
    4. Novel RF accelerator Structures

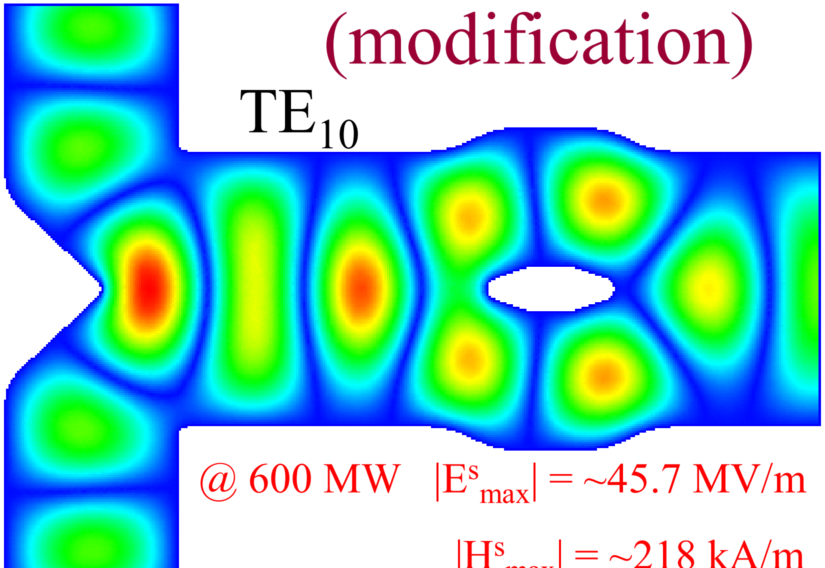
- Breakdown studies
    1. Experimental Studies
    2. Theoretical studies and simulations

- Advanced Solid state Components
    1. Overmoded nonreciprocal devices
    2. Overmoded Semiconductor devices

Phase-I 8-Pack Project Layout.
A Fully dual-mode RF system.

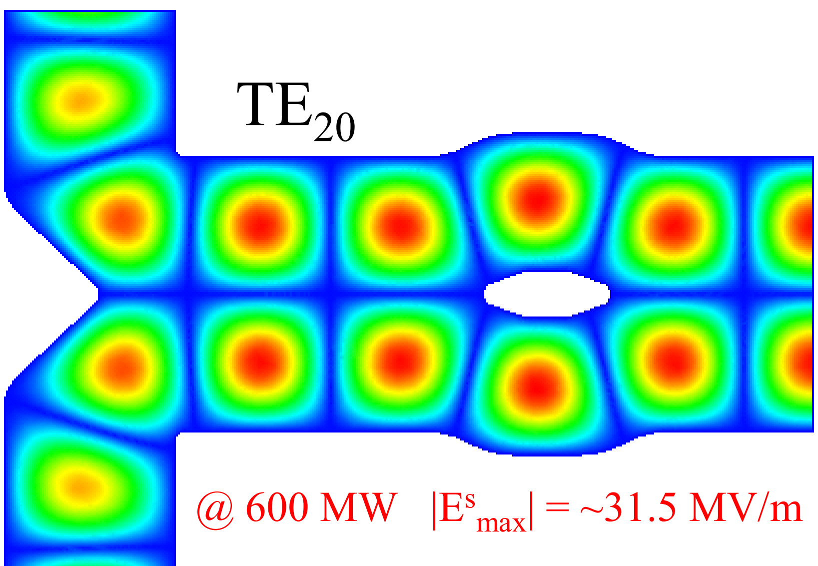


Dual-Mode Combiner/Splitter (modification)



@ 600 MW $|E^s_{max}|$ = ~45.7 MV/m

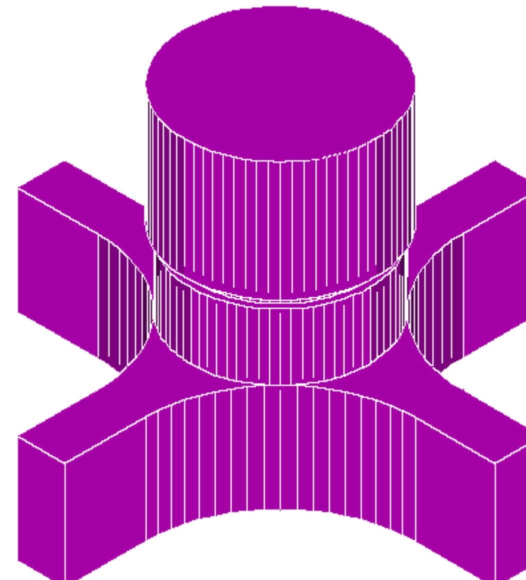
$|H^s_{max}|$ = ~218 kA/m



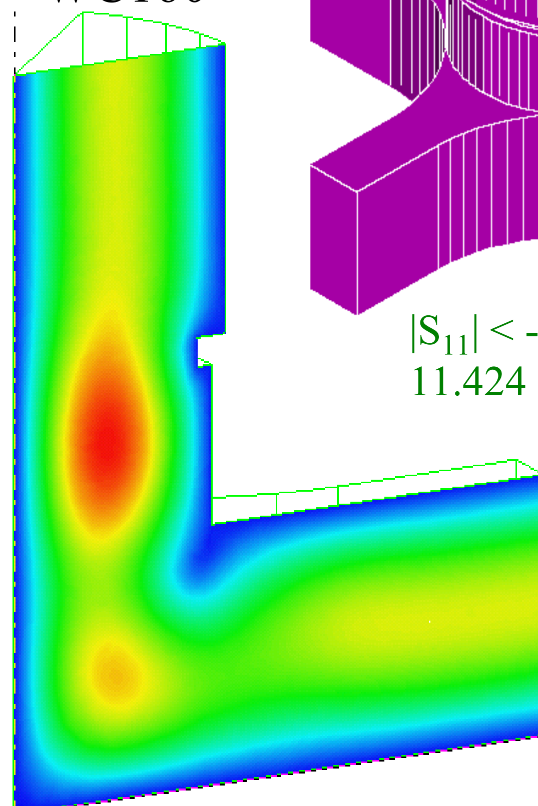
@ 600 MW $|E^s_{max}|$ = ~31.5 MV/m

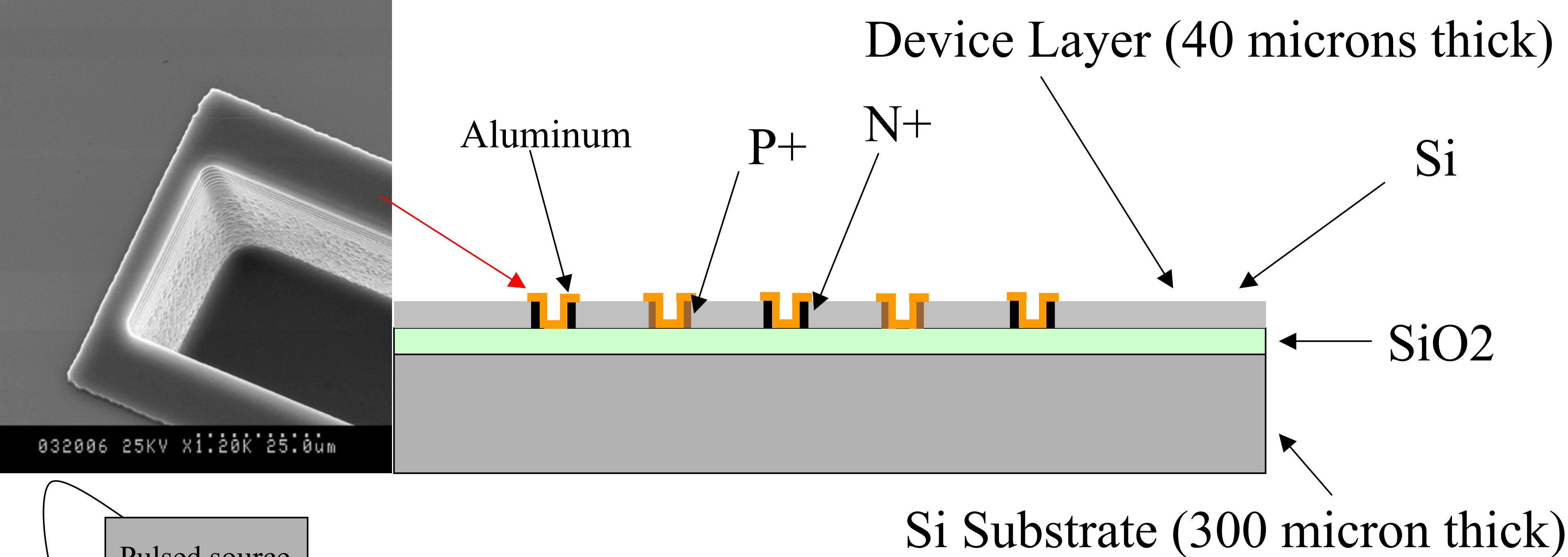
$|H^s_{max}|$ = ~73.9 kA/m

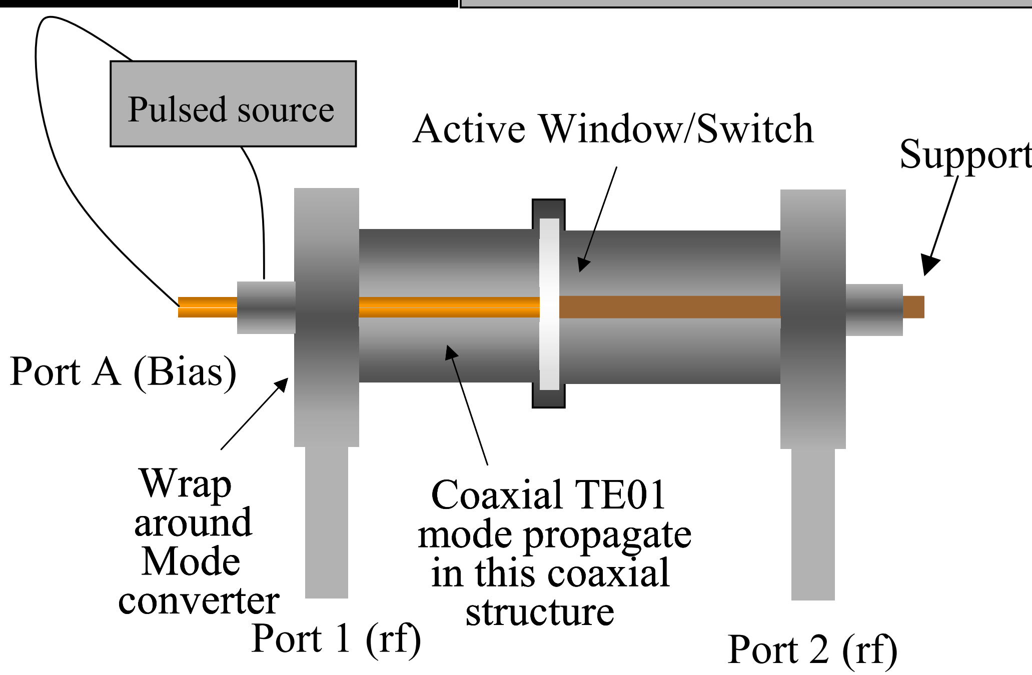
Quadrapod TE_{01} Power Splitter (modification)

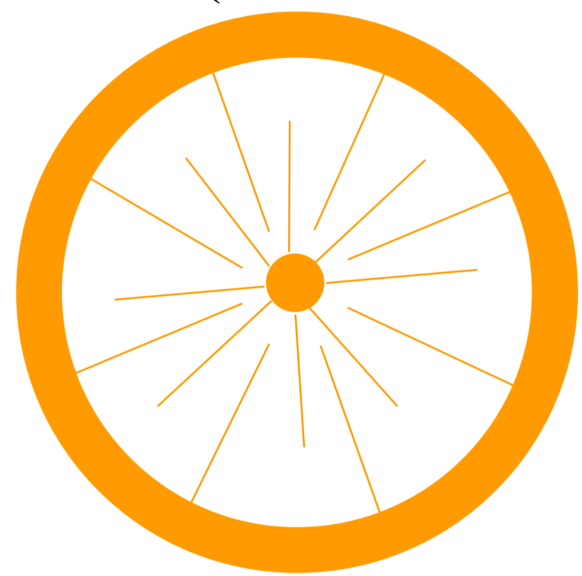


$|S_{11}|$ < -57 dB @ 11.424 GHz









The real Device Contains 180 PIN Diodes

New Fast RF Switch Configuration

Main Directions of the ARDB Program

- Plasma Wakefield Acceleration– A program to investigate the physics of beam-driven plasma wakefields with the ultimate goal of doubling the energy of a linear collider. (E157, E162, E164, E164x,…)

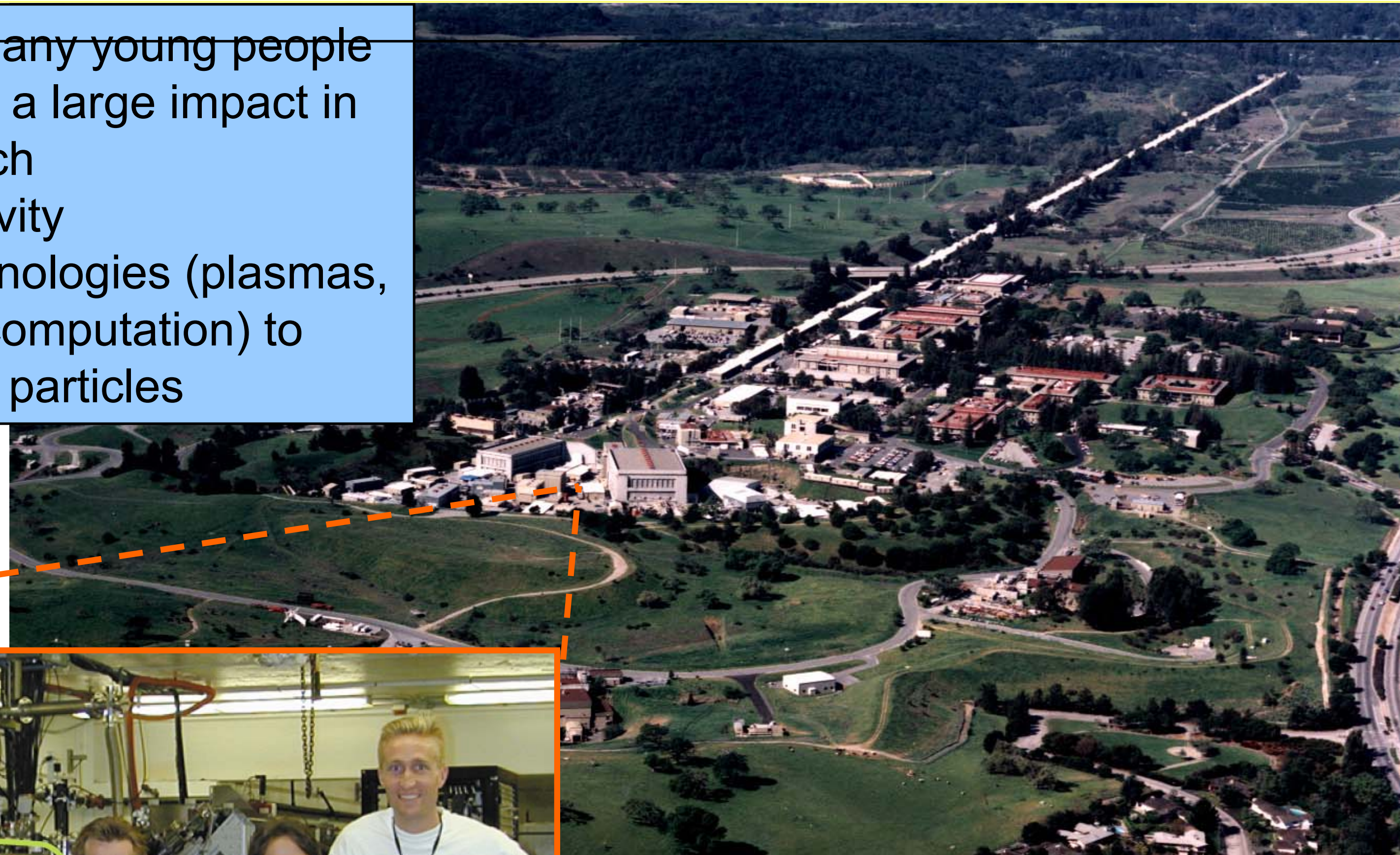
- Laser Acceleration of Electrons– A program to investigate the technical and physics issues of vacuum laser accelerators, with the ultimate goal of building a high energy linear collider. (LEAP, E163,…)

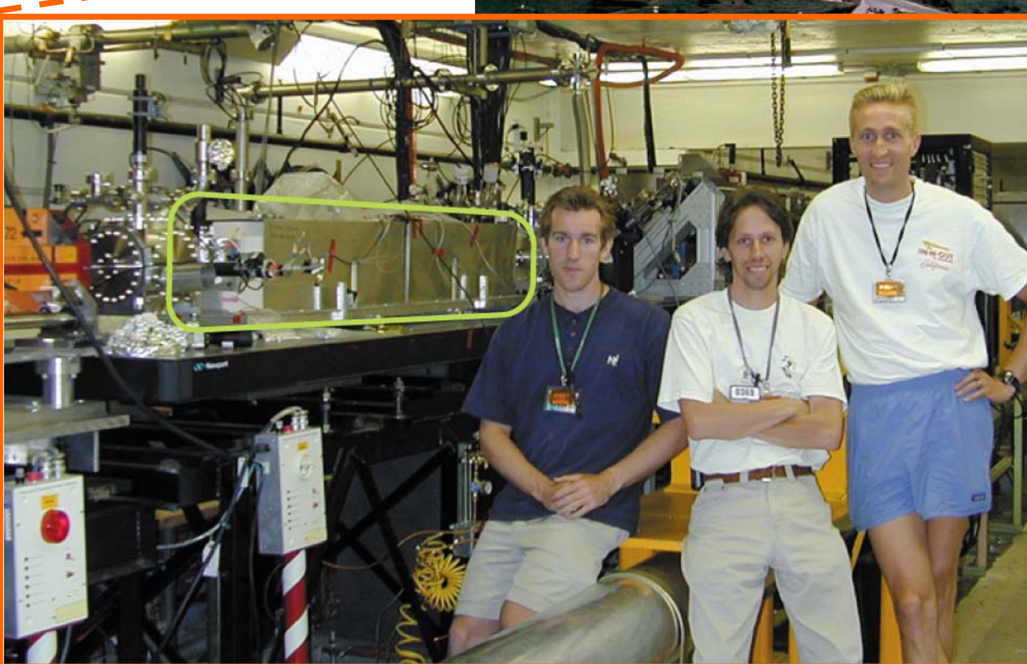
- ORION– a user-driven advanced accelerator research and development facility

Plasma Wakefield Acceleration: Who We Are & What We Do:

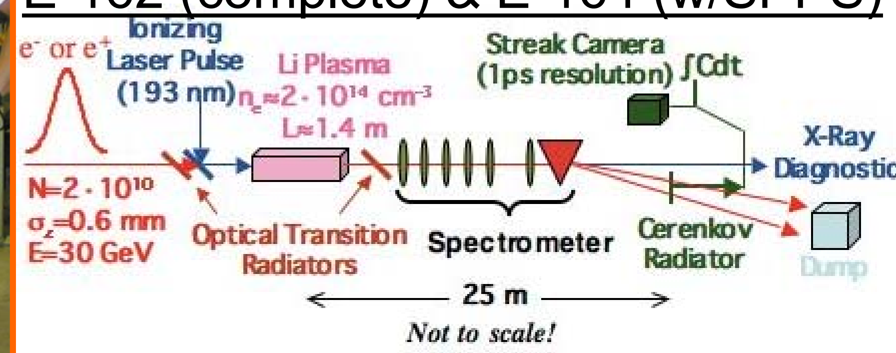
Small group with many young people
➪ individuals have a large impact in all areas of research

- Premium on creativity
- Apply various technologies (plasmas, lasers, advanced computation) to accelerate & focus particles





E-162 (complete) & E-164 (w/SPPS)

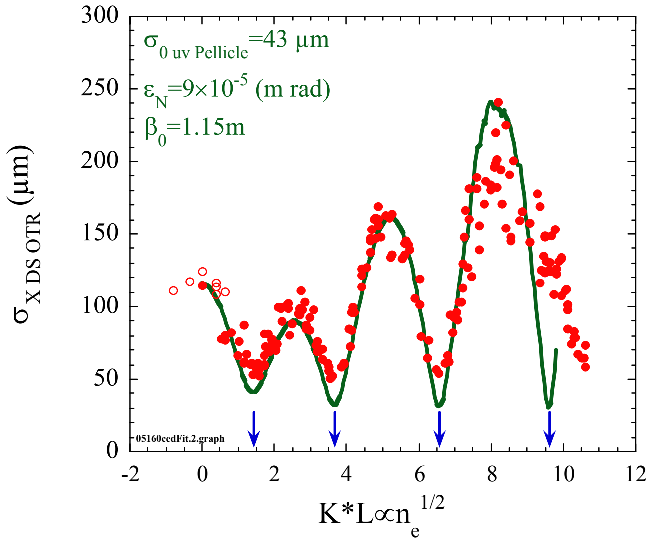


Beam-Plasma Experimental Results (4 Highlights)

[Breakout Presentation by Patrick Muggli this afternoon]

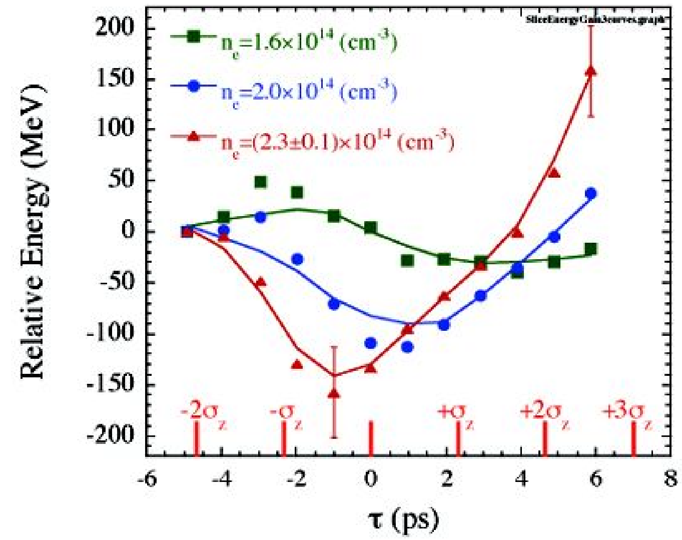
ARDB

Focusing



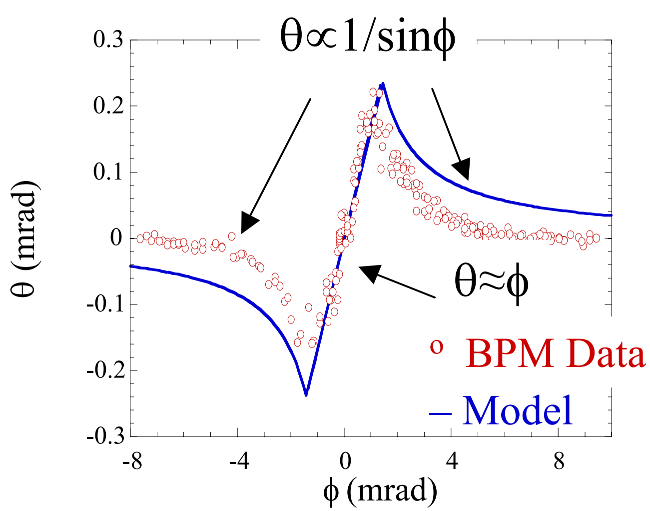
Physical Review Letters **88**, 154801 (2002)

Wakefield Acceleration



Manuscript in Preparation

Electron Beam Refraction at the Gas–Plasma Boundary



Nature **411**, 43 (3 May 2001)

X-ray Generation

Physical Review Letters **88**, 135004 (2002))

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E-164 & E-164X: Ultra-High Gradient Acceleration

Short Bunches (<100μm) in the FFTB Present A Unique Window of Opportunity

A Wide Range of

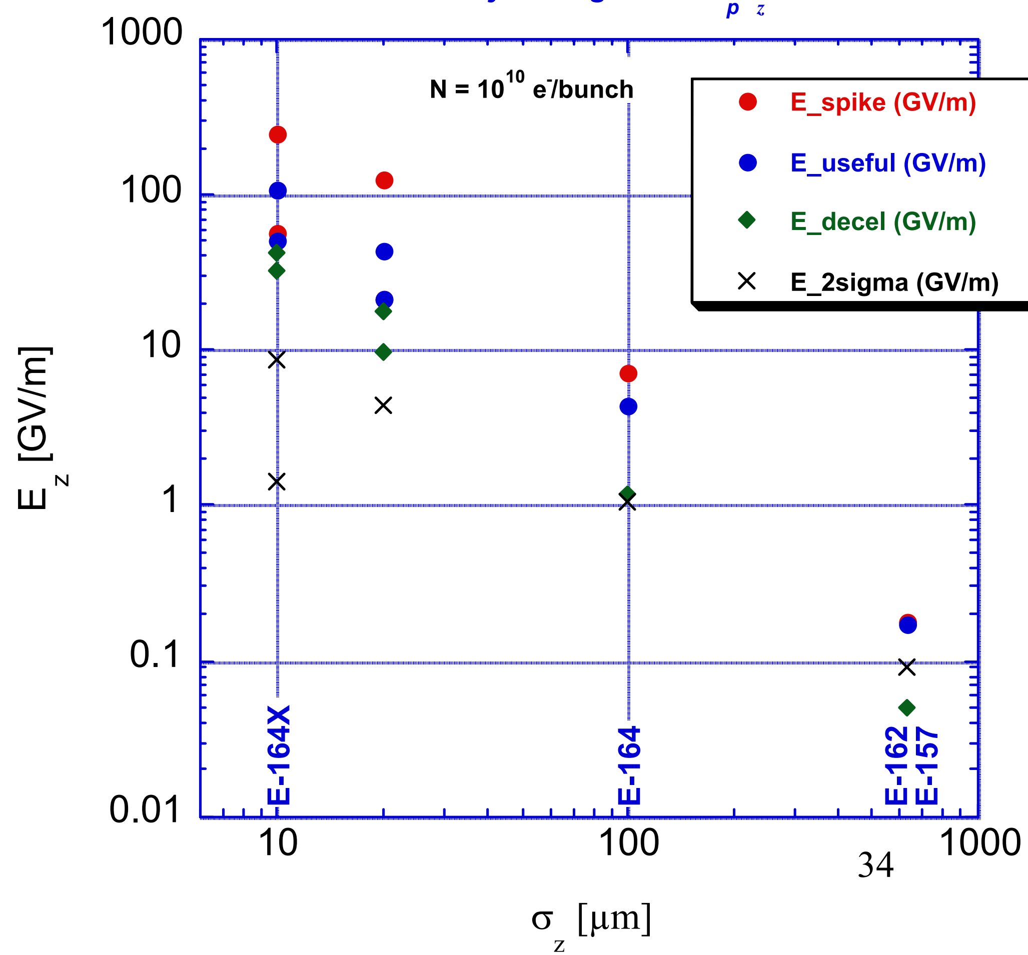
	E-162	E-164	E-164X
N	2×10^{10}	$1\text{-}2 \times 10^{10}$	1×10^{10}
σ_z(mm)	0.6-0.7	0.1-0.15	0.01-0.02
σ_r(μm)	>25	25	< 25
$\Delta\gamma/\gamma$ (r.m.s.)	0.4%	0.6%	1.5%
I_{peak}	1-3 kA	10-20 kA	50-100 kA
$\gamma\varepsilon_x$	50 μm	50 μm	50 μm
$\gamma\varepsilon_y$	5 μm	5 μm	5 μm

E_z(162) ~ 0.200 GeV/m
E_z(164) ~ 4 GeV/m
E_z(164X) ~ 30 GeV/m

Note: As the gradients get larger the plasma length will get shorter to stay within the energy acceptance of the FFTB dumpline.

OSIRIS PIC Simulations

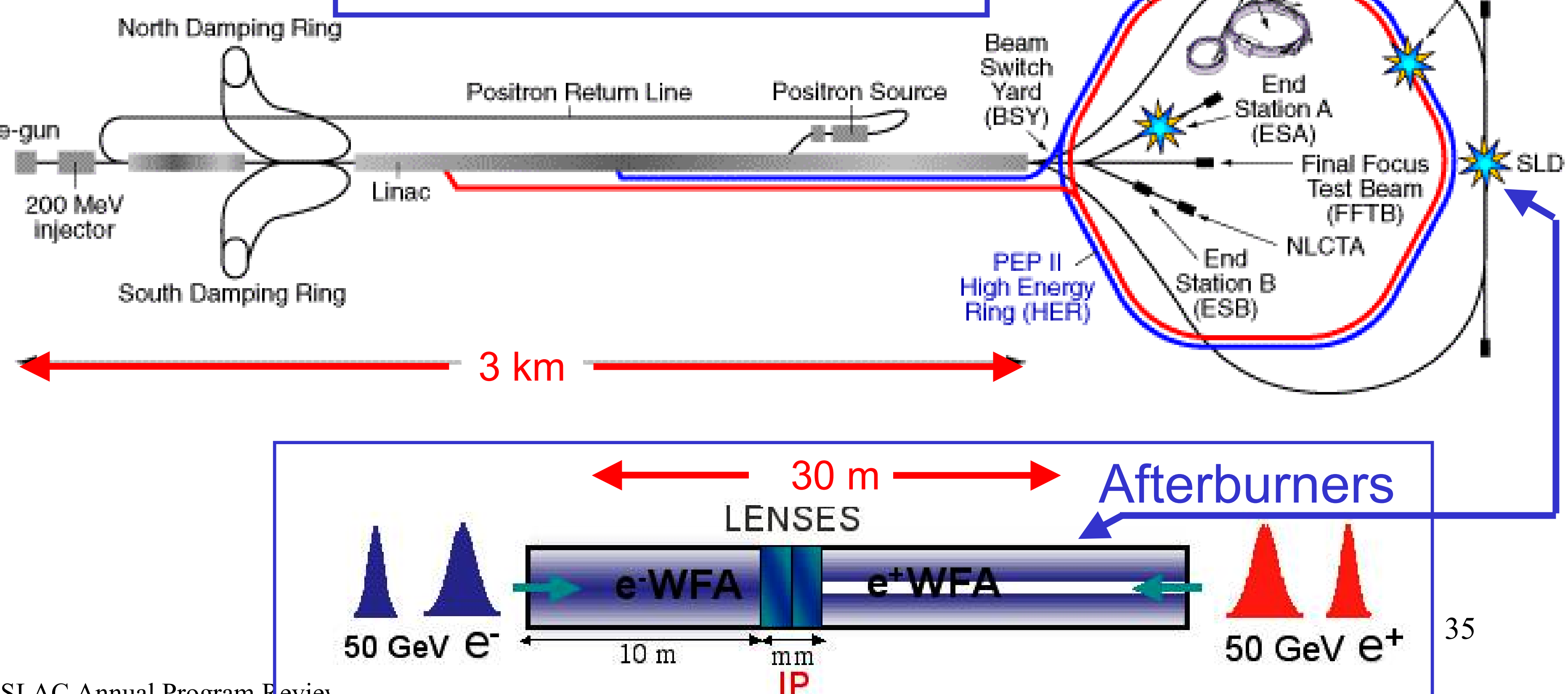
Plasma Density Changed For $k_p \sigma_z = 2^{1/2}$



Plasmas Have Extraordinary Potential

Investigating the physics and technologies that could allow us to apply the enormous fields generated in beam-plasma interactions to high energy physics via ideas such as:

A 100 GeV-on-100 GeV e^-e^+ Collider Based on Plasma Afterburners



E-164 & E-164X: Summary

- A rich experimental program in plasma physics ongoing at SLAC
- Primarily looking at issues associated applying plasmas to high energy physics and colliders
- In E-157 & E-162 have observed a wide range of phenomena with both electron and positron drive beams: focusing, acceleration/de-acceleration, X-ray emission, refraction, tests for hose instability…
- The collaboration has, over the past few years, developed both a facility for doing unique physics, but also many of the techniques and the apparatus necessary for conducting these experiments
- First E-164 Run is underway!
- E-164X has been approved with the goals of measuring accelerating gradients > 10 GeV/m and testing the viability of field ionized plasma sources.

Laser Acceleration

[Breakout presentation by Bob Noble this afternoon]

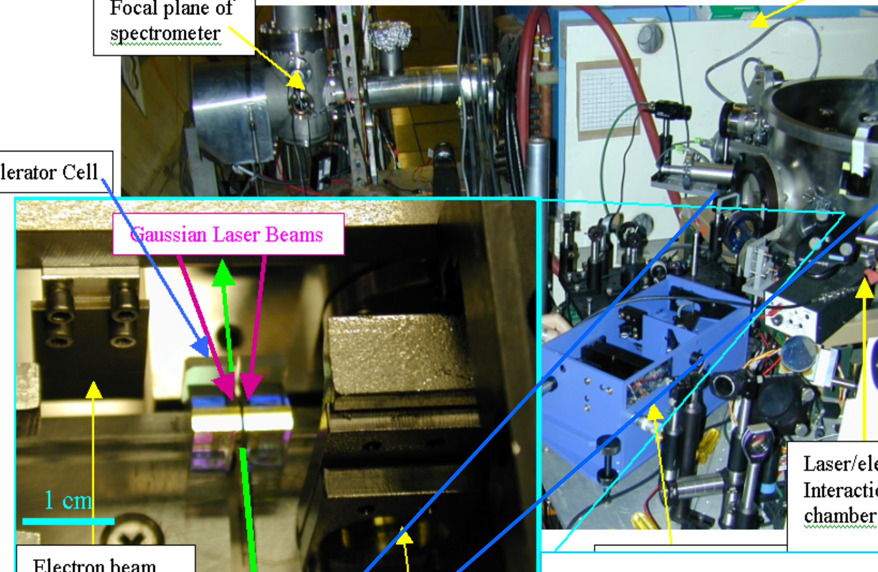
Laser Electron Acceleration Project (LEAP)

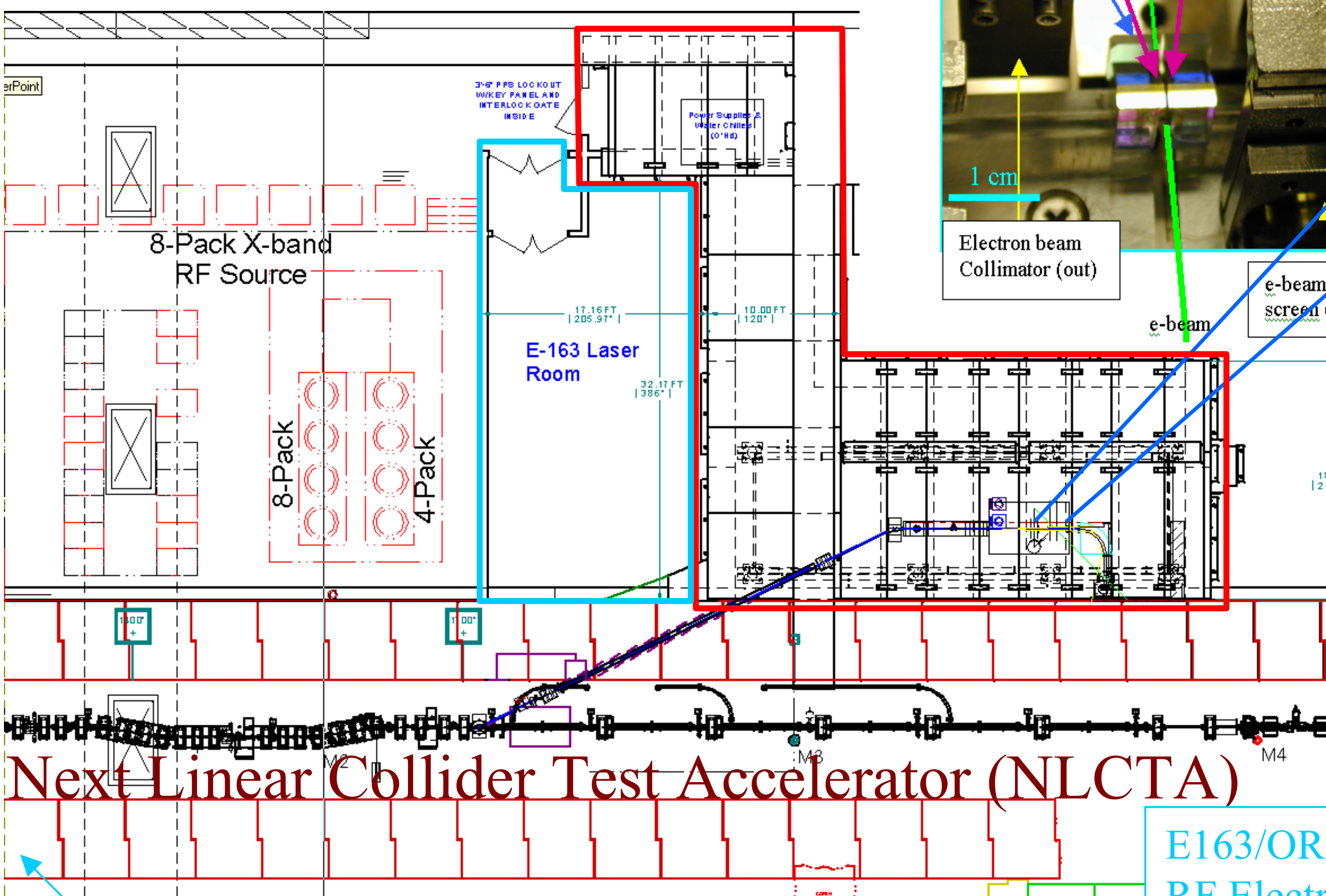
- Last experimental run June 2002
- Continuing work on laser pulse locking (achieved: 1 mV/fsec sensitivity!)

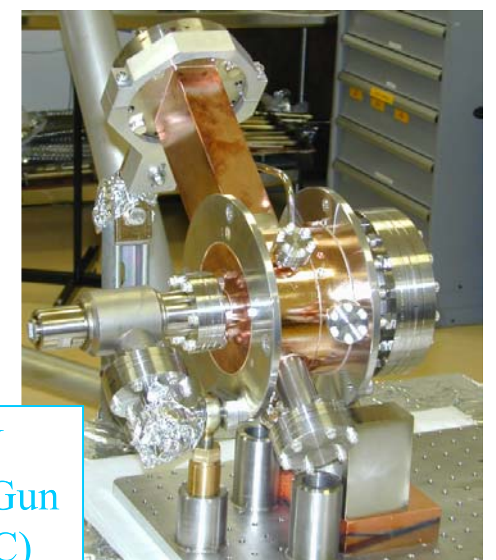
E163: Laser Acceleration at the NLCTA

- Proposed to SLAC EPAC September 24, 2001
- Approved by SLAC Director July 21, 2002
- Electron gun, experimental hall construction this fiscal year
- Laser room, beamline components fabricated in FY04
- Start-of-science in early CY05, sooner if ORION funds become available

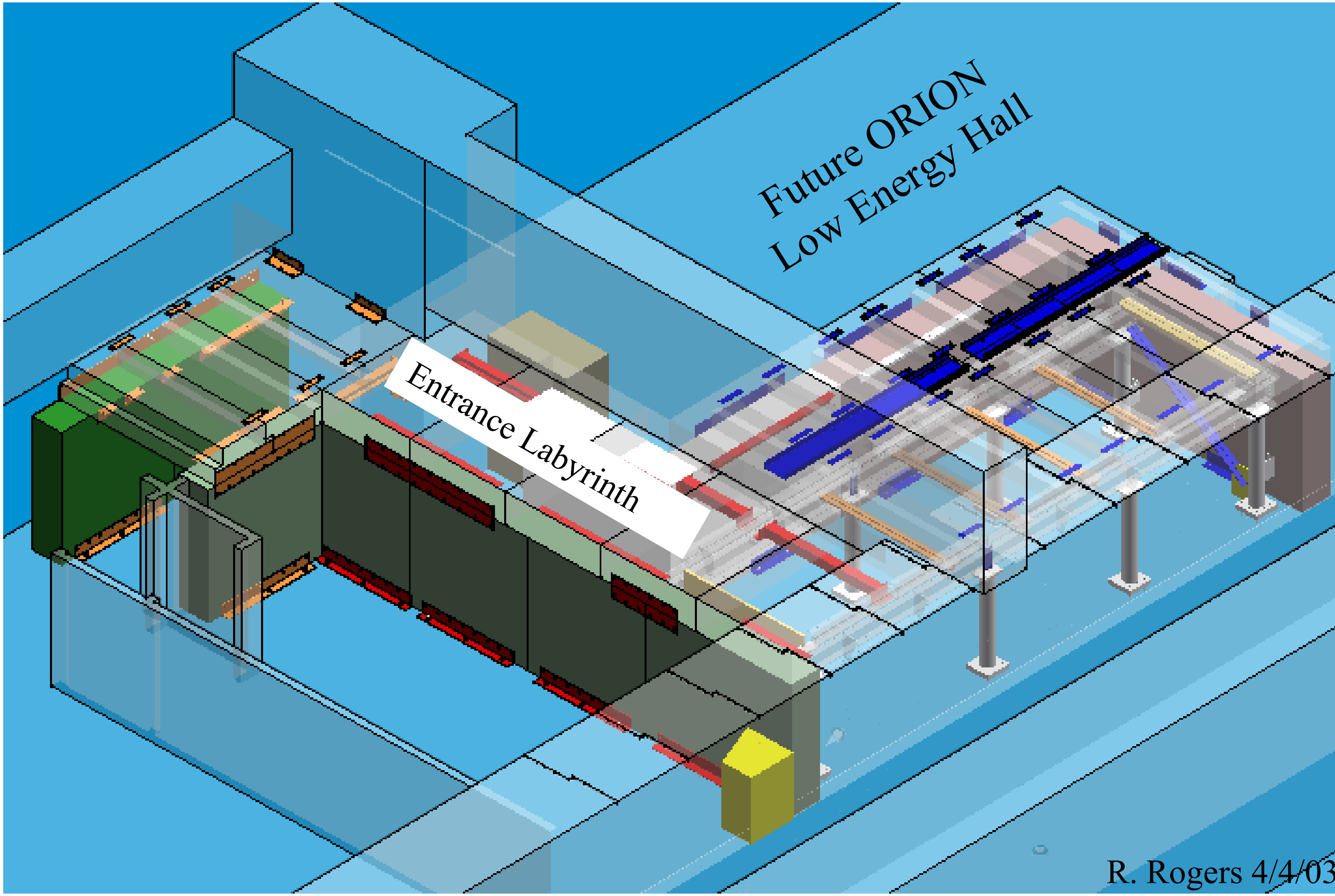
E163 Layout

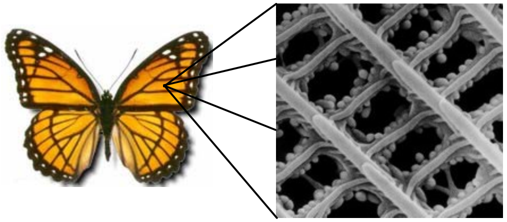

Focal plane of spectrometer
Spectrometer Magnet
Accelerator Cell
Gaussian Laser Beams
1 cm
Electron beam Collimator (out)
e-beam profile screen (Er:YAG)
e-beam
Laser/electron Interaction chamber
LEAP Apparatus


8-Pack X-band RF Source
8-Pack
4-Pack
E-163 Laser Room
17.16 FT
205.97"
10.00 FT
120"
32.17 FT
386"
M2
M3
M4
Next Linear Collider Test Accelerator (NLCTA)


E163/ORION RF Electron Gun (UCLA/SLAC)

E163 Experimental Hall





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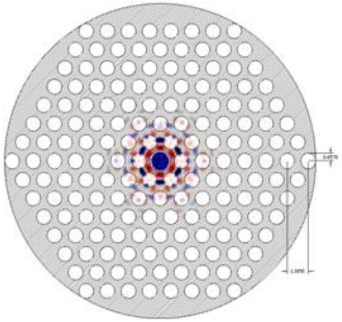
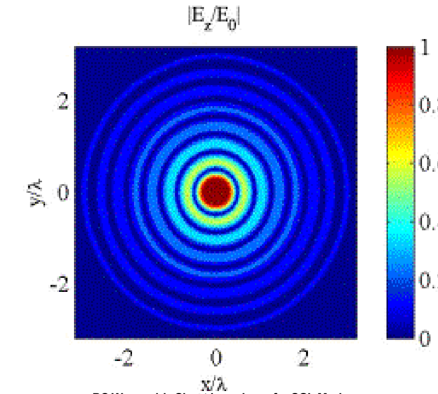
Photonic Band Gap Structure Development

- Learning to design structures (in collaboration with Prof. Shanhui Fan, Stanford University)
  - Photonic Band Gap Fiber (E. Lin, M. Javamard)
  - Hollow Bragg Fiber (L. Schächter)
  - 2D Photonic Crystal (B. Cowan)
- Make millimeter-wave scale models to test simulation and design
- Met with a vendor (Crystal Fiber, Denmark) to discuss custom fiber designs and will obtain samples to test

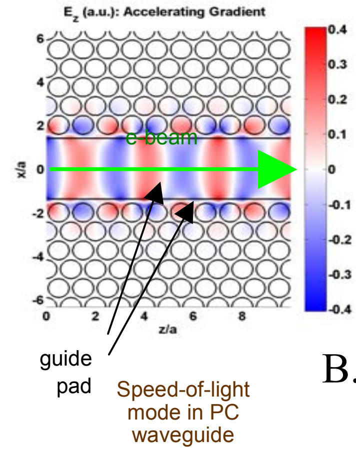


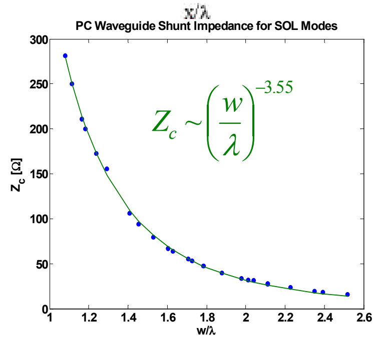
X. Lin, Phys. Rev. ST-AB, **4**, 051301, (2001).

M. Javanmard



L. Schächter





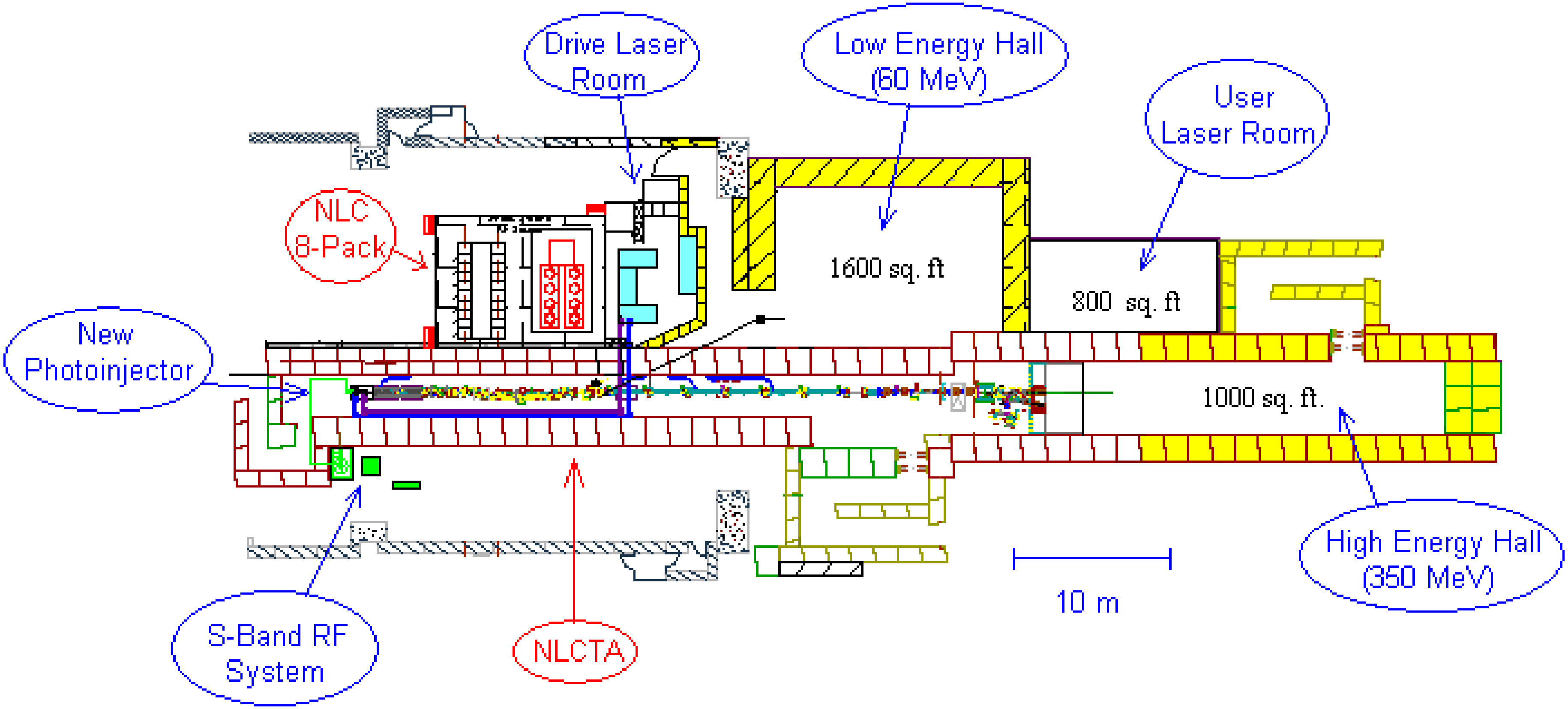
B. Cowan

Plans for the Coming Year

- LEAP
  - Continued material damage threshold studies
  - Continued pulse-envelope locking and phase locking studies
  - Photonic structure development and testing, including scaled-up millimeter-wave models
- E163
  - Complete civil construction
  - Design and fabricate beamline magnets
  - Assemble rf system for injector
  - Install beamline components

ORION Facility at the NLCTA

Conceptual Layout



- Feedback received from potential users at the 2nd ORION Workshop, Feb. 18-20, 2003.
- Attended by 85 enthusiastic participants from US, Europe, Asia!
- Working Groups on Beam-Plasma Physics, Laser Acceleration , Particle Sources, and Laboratory Astrophysics suggested many exciting new experiments!

Advanced Accelerator R&D Synopsis

ARDA

•Lattice Dynamics

MIA work to improve PEP-II, Tevatron; electron cloud and beam-beam interaction calculations for PEP-II and Super-B

•Collective Effects

CSR microbunching instability, including screening; collective effects in PEP-II upgrades; SPPS experiment; LCLS upgrades;

•Advanced Beam Concepts

FLASH, Laboratory Astrophysics, Gravitational Lenses, Early Universe Simulation Code

•Advanced Electronics

PEP-II high-current commissioning, Quadrupole Mode Control Studies, GBoard Processing Channel

•RF Structures

Prototype Structures for NLC, Compact HOM Damping Structures, Develop Automated RF QC and Tuning Systems

•High Power RF

8-Pack; high power circulators; RF breakdown phenomenon; active pulse compression system; highly multimoded delay lines; DLDS

ARDB

•Plasma Wakefield Acceleration

Demonstration of high gradient acceleration; upgrade to short pulses, higher gradients; field ionization demonstration

•Laser Acceleration

Materials studies; laser pulse and phase locking; photonic band gap structure design and testing; E163 construction and commissioning

•ORION

Scoping of facility; initial design work; construction