SLAC Accelerator Science and Development Programs

Tor Raubenheimer

OHEP Site Visit

September 13th, 2010

Introduction

- Accelerator Research Division at SLAC
- Overview of HEP programs in ARD
- Accelerator Science
  - Beam Physics and Computing
  - SciDAC-2 COMPASS program
  - Direct Laser Acceleration
  - FACET: Advanced Accelerator User Facility
  - Plasma Wakefield Acceleration
  - High Gradient Microwave Acceleration
- Accelerator Development
  - X-band development
  - Accelerator Design programs
- Test Facilities for ARD

ARD Organization

Accelerator Research Division (Aug 2010)
Employees,
+Students *Department Associates/Emeritus

Raubenheimer, Tor *[Division Head]*
Bharadwaj, Vinod *[Deputy]*
Phinney, Nan *[Deputy-HEP]*

(Nagahashi, Naomi) *[ADMIN]*
(Valine, Joan) *[ADMIN]*
Ruth, Ronald *[Accelerator Education]*
Kenny, Joe *[Safety Coordinator]*

Colby, Eric
[Head, Advanced Accelerator Research]
(Noble, Robert) *[Deputy]*

Tantawi, Sami
[Grp. Ldr. Microwave]
Bowden, Gordon
Dolgashev, Valery
Lewandowski, James
Yeremian, Dian
*Farkas, David
Guo, Jiquan
*Miller, Roger H.
Neilson, Jeffrey
+Shumail, Muhammad
Wang, Juwen
*Wilson, Perry

Fox, John
[Grp. Ldr. Feedback & Dynamics]
+Bullitt, Alex
+Mastoridis, Themis
Rivetta, Claudio
+Turgut, Ozhan

(Colby, Eric)
[Grp. Ldr. Laser]
+Amimul, Ihsan
England, Joel
Laouar, Rachik
+McGuinness, Chris
+Mendez, Derek
Ng, Johnny
Noble, Robert
+Peralta, Edgar
+Soong, Ken
Spencer, Jim
Walz, Dieter

Hogan, Mark
[Grp. Ldr. Plasma]
+Frederico, Joel
Li, Selena
Litos, Michael

(Adolphsen, Chris)
[Head, RF &Linac Design]* (TBD) *[Deputy]
Bertsche, Kirk
Chu, Sam
McKee, Bobby
Nantista, Chris
Wang, Faya

Adolphsen, Chris
[Head, Accelerator Design]* (TBD) *[Deputy]
Himel, Thomas
Limborg, Cecile
Markiewicz, Thomas
Amann, John
Keller, Lewis
Lundgren, Steven
*Paterson, Ewan
Pivi, Mauro
Sheppard, John
Munro, Morrison
Weidemann,Achim
Zhou, Feng
Spencer, Cherrill
Sun, Yipeng
Sullivan, Mike

Cai, Yunhai
[Head, Beam Physics]* (TBD) *[Deputy]

(Cai, Yunhai)
[Grp. Ldr. Optics]
Nosochkov, Yuri
Wang, Min-Huey
Yan, Yiton

Stupakov, Gennady
[Grp. Ldr. Collective Effects]
Bane, Karl
Chao, Alexander
+Daniel Ratner
Jiao, Yi
Novokhatski, Sasha
Wang, Lanfa
*Warnock, Robert
Xiang, Dao

Huang, Zhirong
[Grp. Ldr. FEL Physics]
Ding, Yuantao
Fawley, Bill
Ruth, Ron
+Baxevanis, Panagiotis
*Herrmannsfeldt, Wm.
Wu, Juhao

Ko, Kwok
[Grp. Ldr. ACD]
Candel, Arno
Ge, Lixin
Lee, Lie-Quan
Li, Zenghai
Ng, Cho-Kuen
Rawat, Vineet
Schussman, Greg
Xiao, Liling

Hast, Carsten
[Head, Test Facilities]* (TBD) *[Deputy]
Chaiken, Alison
Cruz Jr., Juan
Dunning, Michael
Hudspeth, Carl
Jobe, Keith
McCormick, Doug
Nelson, Janice
Szalata, Zenon
Weathersby, Stephen

Frisch, Josef
[Head, Accelerator Physics & Engineering]
(Smith, Tonee)*[Deputy]*
Field, Clive
Fisher, Alan
Loos, Henrik
Rzepiela, Jeff
Petree, Mark
Smith, Steve
Smith, Tonee
Welch, Jim
White, Glen
Wittmer, Walter
Woodley, Mark
Yocky, Gerald

BES Accelerator R&D

- Three main programs:
- LCLS operational support
  - Beam optics and modeling
  - FEL physics and collective effects
  - Cathode development program
- LCLS-II design
  - Support for CDR
  - Injector design development
- Accelerator R&D
  - Echo Enabled Harmonic Generation experiment (Echo-7)
  - Future R&D on rf guns and high brightness sources

Overview of HEP Accelerator Science R&D

Four main topics supported by Accelerator Science B&R

- FACET Operations (including AIP's for FACET)
- Novel Acceleration R&D
  - Direct Laser Acceleration and E-163
  - Plasma Wakefield Acceleration (PWFA) and experiments
- High Gradient R&D
- Beam Physics and Computing (also discuss SciDAC program)

- Ramping up effort on PWFA as FACET is constructed
  - FACET Users meeting March 18-19
  - Lots of excitement
- Support for ASTA and partial support for NLCTA
  - Facilities support the High Gradient and E-163 programs

Overview of Accelerator Development R&D

Four main topics supported by Accelerator Development B&R

- Accelerator Design
- LHC project development
- X-band rf source development
- Test Facility infrastructure

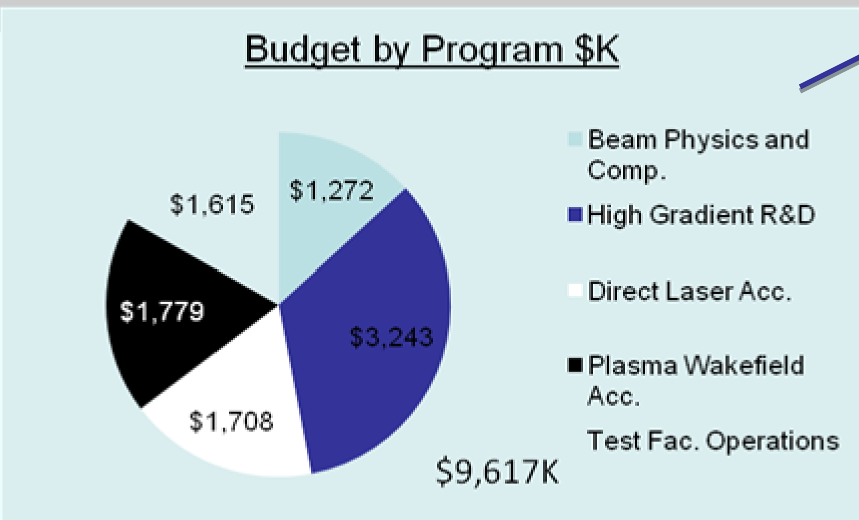
- Accelerator Design includes support for pre-project designs:
  - Super-B design effort
  - CLIC specific R&D (that is not covered by ILC funding)
- LHC Project Development
  - Supports efforts before LARP such as LLRF, PS2, & ecloud R&D
- X-band rf source development
  - Working to understand path forward

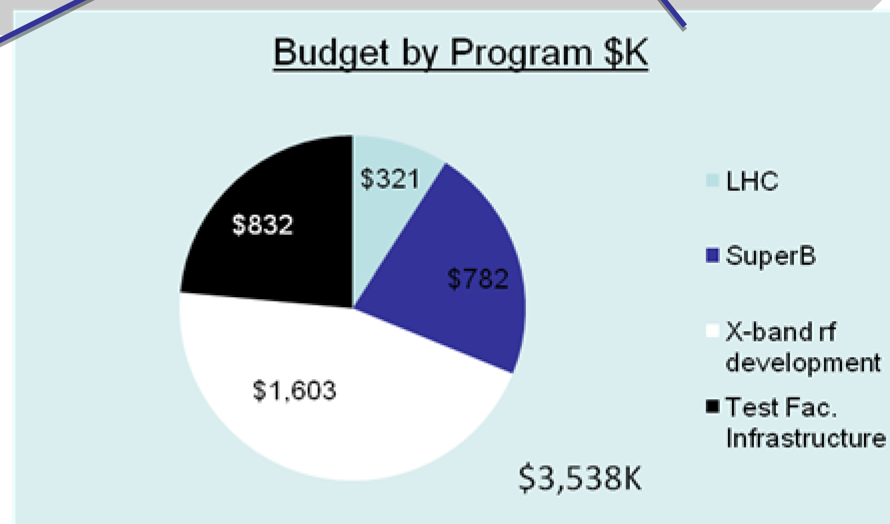
Development of Experimental Facilities

- Existing and upgraded accelerator R&D facilities
  - ASTA – rf test facility (50 MeV capability)
  - NLCTA – X-band linac (300 MeV capability)
  - End Station Test Beam – LCLS Linac (14 GeV)
  - FACET – SLAC Linac (23 GeV)
  - Range in capability is critical to support breadth of accelerator R&D
- Developing integrated plan for future experimental studies
- Planning for future Cathode Test Facility (CTF) and Injector Test Facility (ITF) to share ASTA and NLCTA
  - CTF would support high brightness source R&D and LCLS upgrades
  - ITF would support R&D on high brightness beam generation as well as beam manipulation

Financials – Accelerator Science and General Acc. Development

B&R	Description	FY 2009 Funding	FY 2010 Funding	FY 2011 Requested'	FY 2012 Scenario A' Super B
KA150102	Acc. Science*	$ 8,802	$ 9,030	$ 9,134	$ 10,508
KA1502011	General Acc Development	$ 4,052	$ 4,052	$ 3,452	$ 4,139





The difference between FY11 Budget and Request is the Carry-over reserved in the B&R code for higher indirects cost .

Budget Assumptions for FY11

Under-ran FY09 and expect to under-run in FY10

Accelerator Science budgets	FY09	FY10	FY11
Beam Physics and Computing	1502	1472	1272
High Gradient R&D	3465	3343	3243
Direct Laser Acceleration	1948	1609	1608
Plasma wakefield acceleration	1040	1263	1879
FACET Design R&D	200		
Test facility operations	1447	1847	1615
	9602	**9534**	**9617**

Accelerator Development budgets	FY09	FY10	FY11
LHC	643	753	121
Super-B	647	647	713
CLIC	258	378	
X-band rf development	1850	1879	1972
Test facility infrastructure	654	562	732
	4052	**4219**	**3538**

Discussion Outline

- Accelerator Science B&R
  - Beam Physics and Computing
  - SciDAC-2 COMPASS program
  - Direct Laser Acceleration
  - FACET: Advanced Accelerator User Facility
  - Plasma Wakefield Acceleration
  - High Gradient Microwave Acceleration
- Accelerator Development B&R
  - X-band development
  - Accelerator Design programs
- Test Facilities for ARD

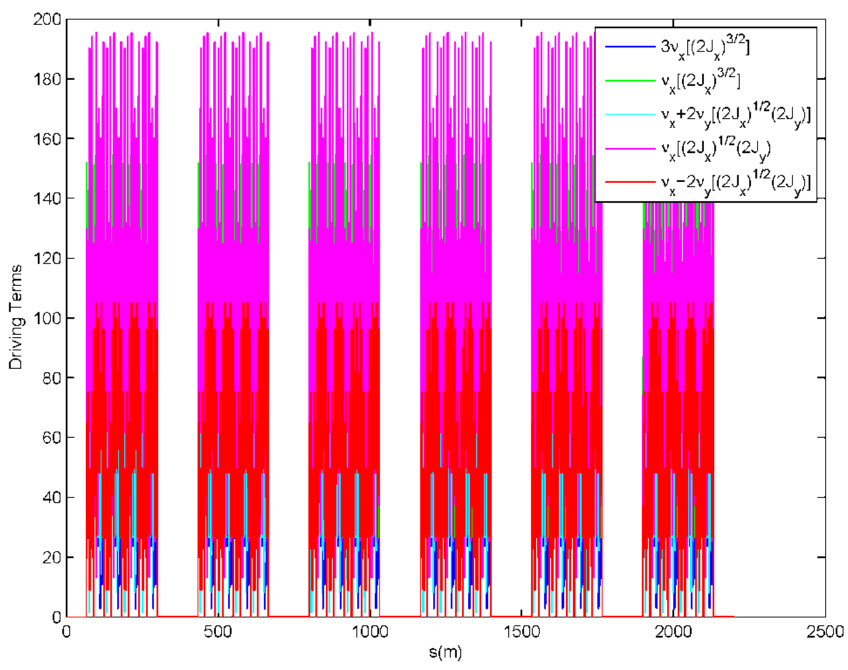
Beam Physics and Computing

- Mission and funding
  - Charged particle optics and accelerator design concepts
  - Analytical impedance calculation and collective effects
  - Electromagnetic computation and RF design
  - FEL physics and seeding schemes – supported by BES
- Highlights in FY10
  - Published 55 papers including 12 on peer-reviewed journals
  - Taught two courses at USPAS
  - Served on review committees, reviewed proposals, refereed journal papers

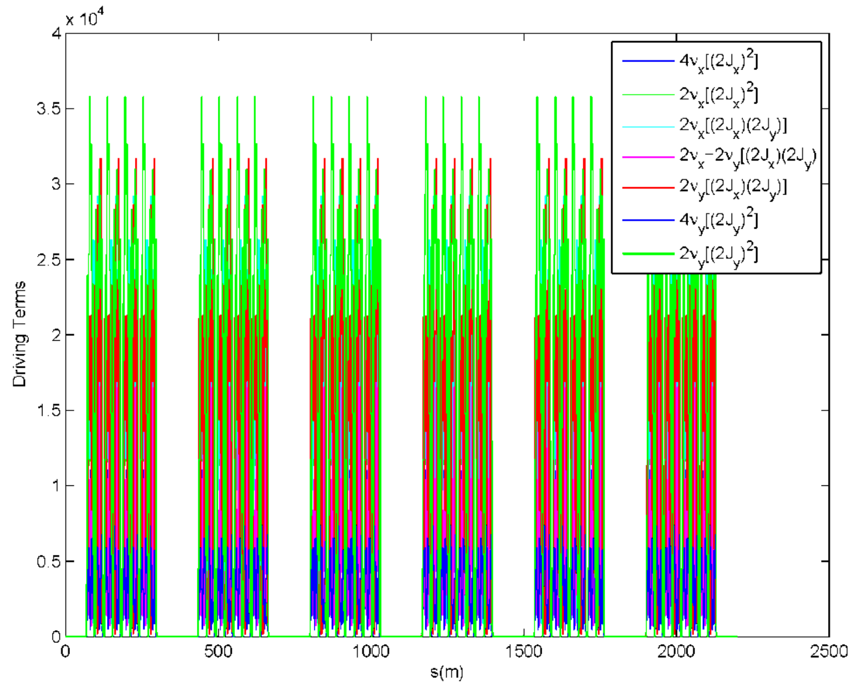
WBS4	WBS4 D	LSTM_SHORT	FY10 YTDACT	FY10 BDG K$	FY11 K$
8.06.07.01	**Beam Physics**	Allocated OH	526		
		Contract	0		
		M&S	63		
		SLAC	753		
		Travel	14		
	Beam Physics Total		**1,357**	**1,472**	**1,272**

Analysis of Nonlinear Resonances

Third-Order Achromat



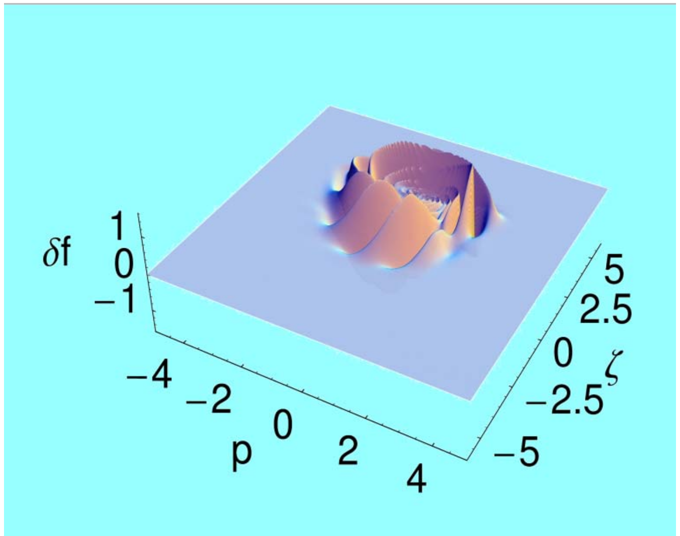
Fourth-Order Achromat ?



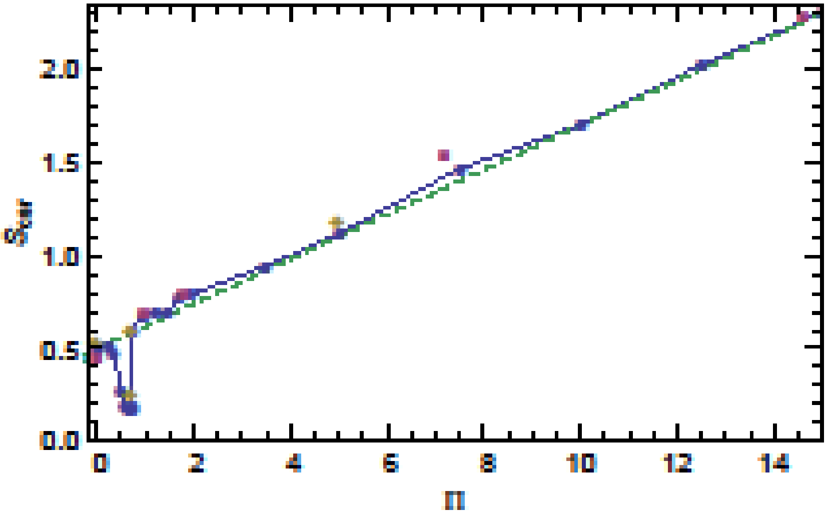
An invited talk at 8th International Conference in Charged Particle Optics, July 12-16, 2010, Singapore

Threshold of Microwave Instability

Phase space of the microwave instability.

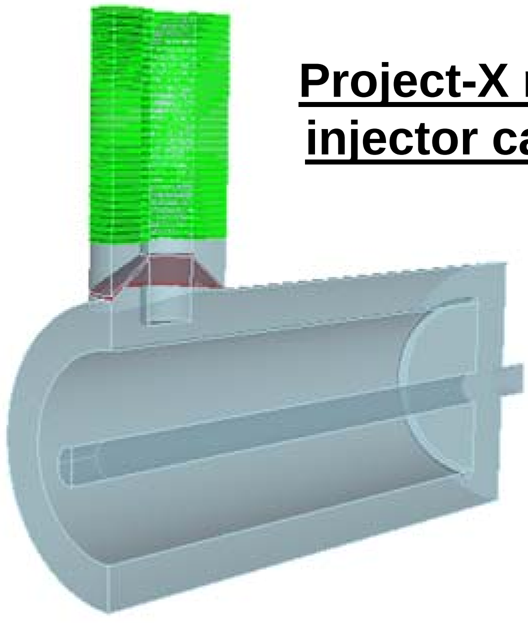


Scaling property of CSR threshold

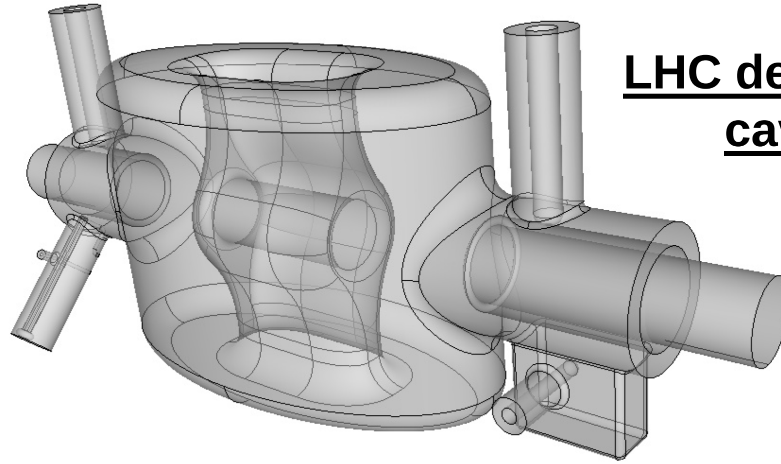


Two simulation codes were developed to study microwave instability driven by coherent synchrotron radiation. A simple scaling law based on the shielding parameter and normalized current was found. A paper is submitted for publication.

Accelerator Modeling using HPC

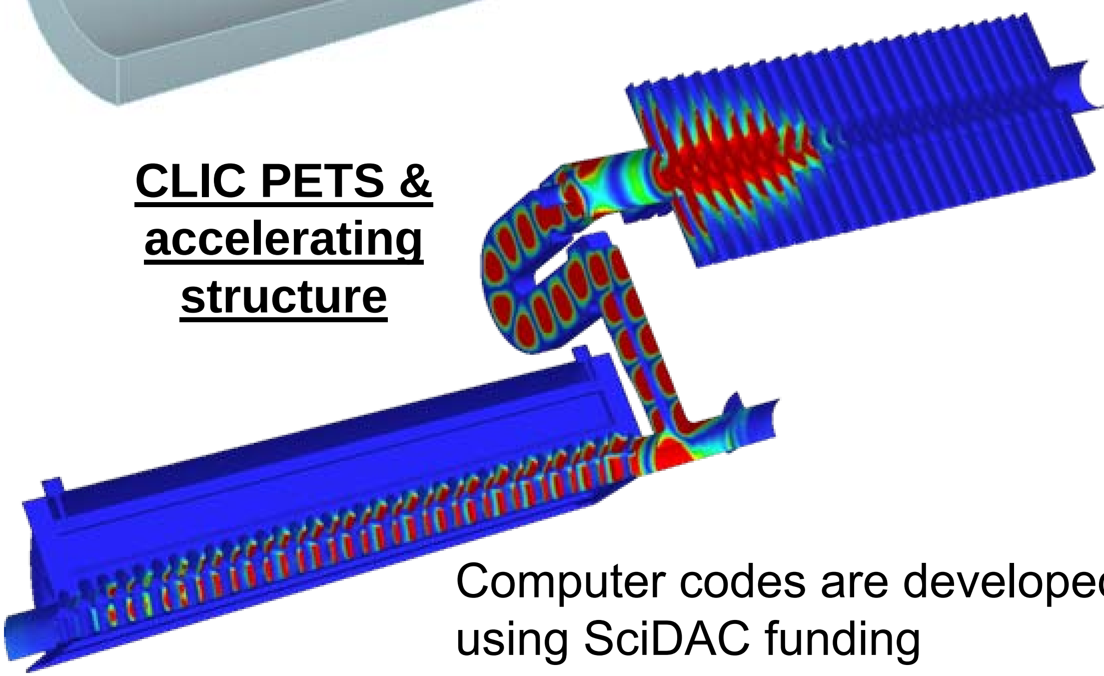


Project-X main injector cavity

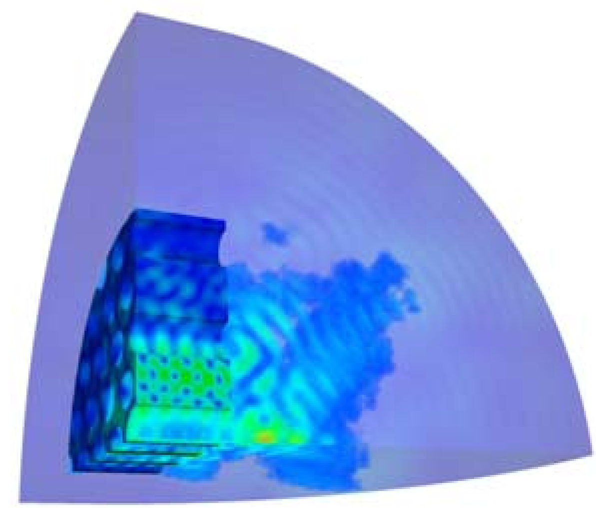


LHC deflecting cavity

CLIC PETS & accelerating structure



PBG fiber for laser acceleration



Computer codes are developed using SciDAC funding

Beam Physics and Computing Summary

- World-class group of physicists
  - Have had large impact on community: novel optics schemes, high brightness storage rings, classical impedance challenges, beam-ion and electron cloud effects, novel cavity concepts, …
  - Extensive simulation electromagnetic design for community

- HEP program is becoming challenged
  - Lack of HEP accelerator to motivate studies and provide data
  - Capabilities being eroded due to strong recruitment for LCLS/LCLS-II
  - HEP budgets are becoming tighter and we need to redirect further effort or find additional funding

SciDAC-2 COMPASS Program

- SLAC ComPASS project develops parallel electromagnetic codes to advance and optimize accelerator design through large-scale simulation
- Collaborations in **experimental diagnosis, advanced computing and applied math** solved the Jlab Beam Breakup problem
- First-ever simulation of the entire ILC cryomodule

HEP SciDAC

			FY10		FY11
WBS4	**WBS4 D**	**LSTM_SHORT**	**YTDACT**	**BDG K$**	**K$**
8.06.11.05	**SciDAC**	Allocated OH	204		
		M&S	2		
		SLAC	297		
		Travel	7		
	SciDAC Total		**511**	**615**	**634**

BES & ASCR SciDAC

			FY10		FY11
WBS4	**WBS4 D**	**LSTM_SHORT**	**YTDACT**	**BDG K$**	**K$**
8.06.11.05	**SciDAC**	Allocated OH	95		
		M&S	0		
		SLAC	141		
		Travel	0		
	SciDAC Total		**236**	**250**	**250**

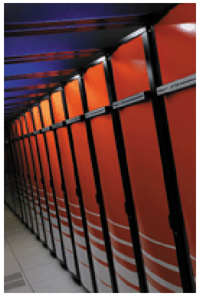
ACCELERATOR DIRECTORATE

ACE3P & High Performance Computing

ACE3P (Advanced Computational Electromagnetics 3P) Code Suite

https://slacportal.slac.stanford.edu/sites/ard_public/bpd/acd/Pages/Default.aspx

- conformal, higher-order, C++/MPI parallel finite-element based electromagnetic codes
- modules include Omega3P, S3P, T3P, Track3P, Pic3P and TEM3P
- supported by SLAC and DOE HPC Grand Challenge (1998-2001), SciDAC1 (2001-06),
  SciDAC2 (2007-12)



ACE3P runs on DOE Computing Resources at LBNL and ORNL to meet SciDAC, accelerator project and **ACE3P** code community needs.

Allocations –

NERSC (1) *Advanced Modeling for Particle Accelerators* **- 1M CPU hours**, renewable
(2) *SciDAC ComPASS Project* – **1.6M CPU hours,** renewable (shared)
(3) *Frontiers in Accelerator Design: Advanced Modeling for Next-Generation BES Accelerators* **- 300K CPU hours**, renewable (shared) each year

NCCS (1) **INCITE award** - *Petascale Computing for Terascale Particle Accelerator: International Linear Collider Design and Modeling* - **12M CPU hours** in FY10

Code Workshop and ACE3P Community

- 1st Workshop (CW09) – 15 attendees from 13 institutions
- 2nd Workshop (CW10) – **36 attendees from 16 institutions** that include

SLAC – 10, Cornell – 5, CERN – 2, LLNL – 2, NSCL – 2, LBNL – 1, Jlab – 1, Darsbury – 2, PSI – 2, IHEP - 1, U of London – 2, U of Manchester – 2, U of Oslo – 1, ODU – 1, FarTech – 1, Beam Power -1

http://www-conf.slac.stanford.edu/cw10/default.asp

Future of SciDAC Program

- Program has been very successful because of tight integration of computer scientists and accelerator physicists
- Developed a great suite of codes but have an ongoing challenge in code support and maintenance
  - Would prefer to provide dedicated support but may need to pursue an open-source model
- Future directions
  - SLAC is developing a plan in anticipation of a Call for Proposal for SciDAC-3 in the fall/spring
  - Challenging to recruit and retain top caliber computer scientists
    - Possible creation of lab-wide applied math/computer science group
  - Considering development of beam dynamics codes that would more directly tie to ongoing lab program

High Gradient Acceleration

- Accelerators have been primary tool to advance HEP frontiers
  - But accelerators have continued to increase in size and cost and appear to be approaching the limit that can be supported

  → Need new approaches to particle acceleration

- Many paths towards high gradient acceleration
  - RF source driven metallic structures
  - Beam-driven metallic structures

    } ~100 MV/m
  - Laser-driven dielectric structures
  - Beam-driven dielectric structures

    } ~1 GV/m
  - Laser-driven plasmas
  - Beam-driven plasmas

    } ~10 GV/m

Major focus at SLAC with 3 approaches having different risks and timescales

Direct Laser Acceleration

- Motivation
  - High gradient and high efficiency acceleration is possible
  - Fundamentally different accelerator technology
  - Breaks limitations set by high peak power tubes and lasers
- Mission and funding
  - Low charge, very-high-repetition rate beam format is the *only* scheme that has reasonable background at 10 TeV cm energies and does *not* seem practical with other technologies
  - Exploits large industrial effort in lasers and semiconductors

			FY10		FY11
WBS4	**WBS4 D**	**LSTM_SHORT**	**YTDACT**	**BDG K$**	**K$**
8.06.09.02	**Direct Laser Acc**	Allocated OH	403		
		M&S	439		
		Shop	24		
		SLAC	523		
		Travel	12		
	Direct Laser Acc Total		**1,401**	**1,609**	**1,608**

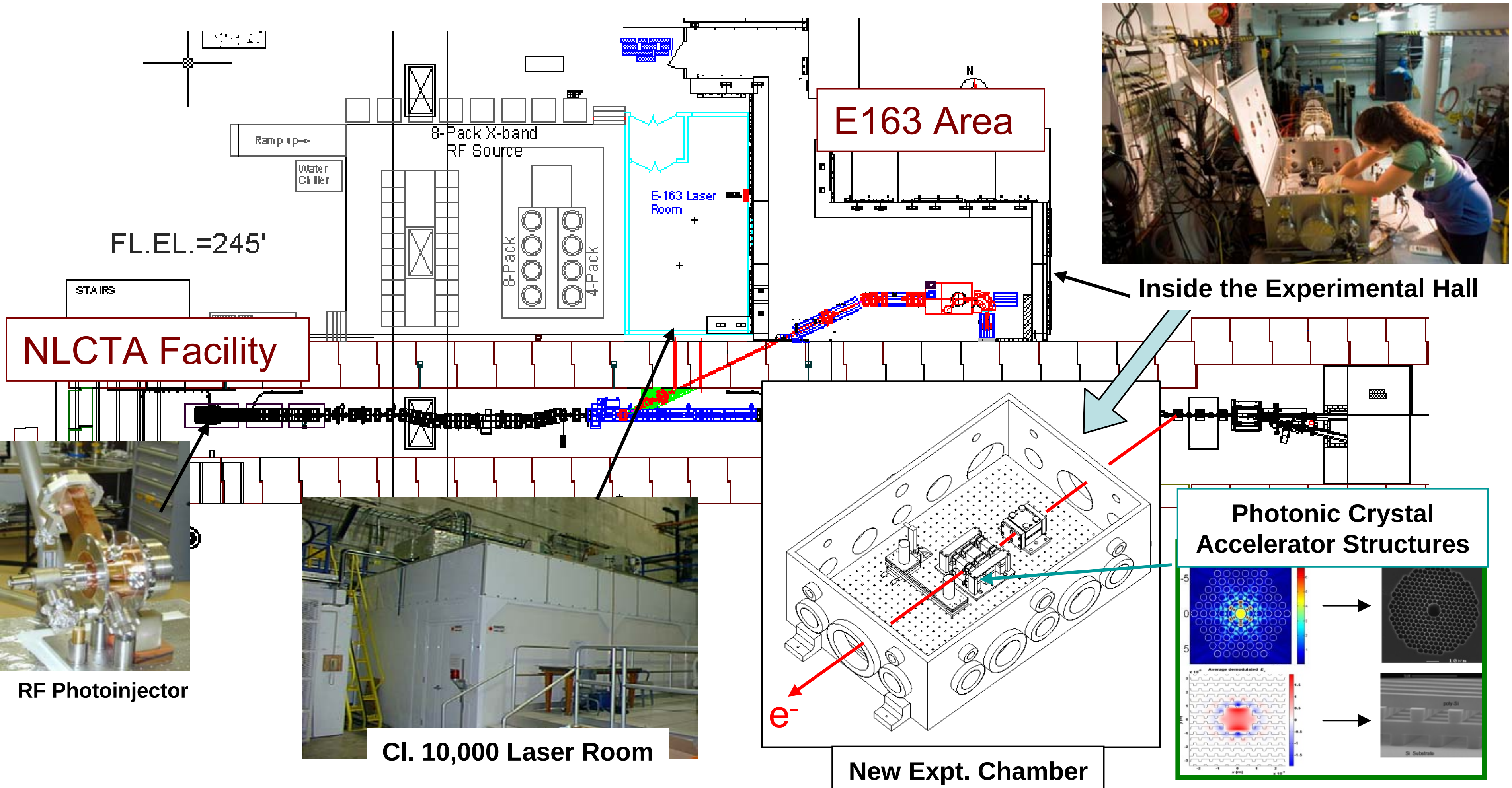
DLA Progress

- Experimentally demonstrated:
  - Optical bunch train production at 0.8 μm
  - Staged laser acceleration (bunch+accelerate) at 0.8 μm
  - Focusing of 60 MeV beams to 8x8 μm
- 8 papers (+1 in preparation) in the last 12 months
  - 2 are archival journal articles on computational techniques developed for Photonic Band Gap accelerators
- Made substantial progress on fabricating 100-1000λ interaction length structures
  - Silicon Woodpile: 9 of 17 layers successfully aligned and bonded
  - Silica PBG Fiber: (Incom SBIR) drawn fibers successfully down to ~4μm
  - Silica gratings: 0.8 μm structures fabricated
- Made substantial progress on input power coupler designs for PBGs:
  - 97% power efficiency design for woodpile structure
  - 23% power efficiency for PBG fiber

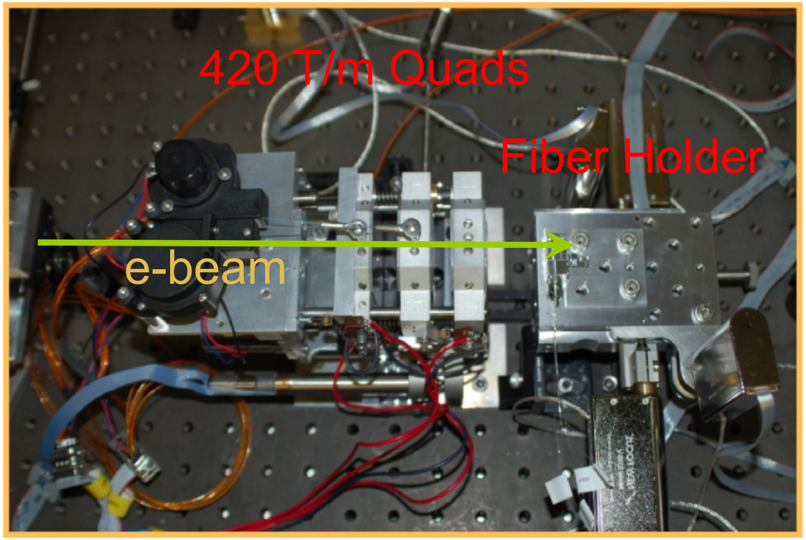
SLAC Laser Acceleration Program

Scientific Goal: Investigate physical and technical issues of laser acceleration using dielectric structures

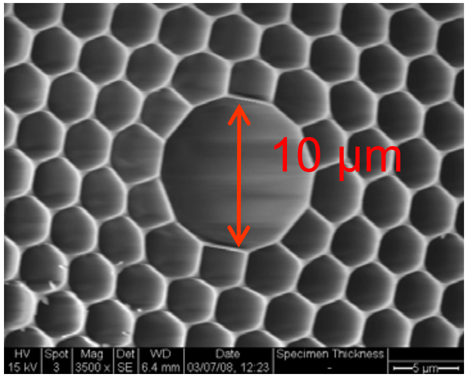
Accelerator structures at laser wavelengths (10,000x smaller than microwave)



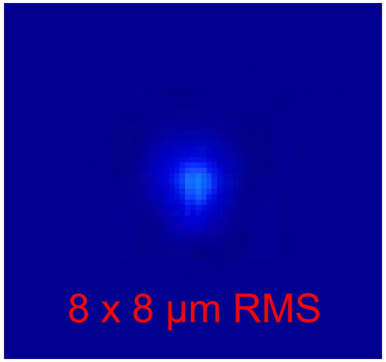
Tests of Dielectric PBG Fibers



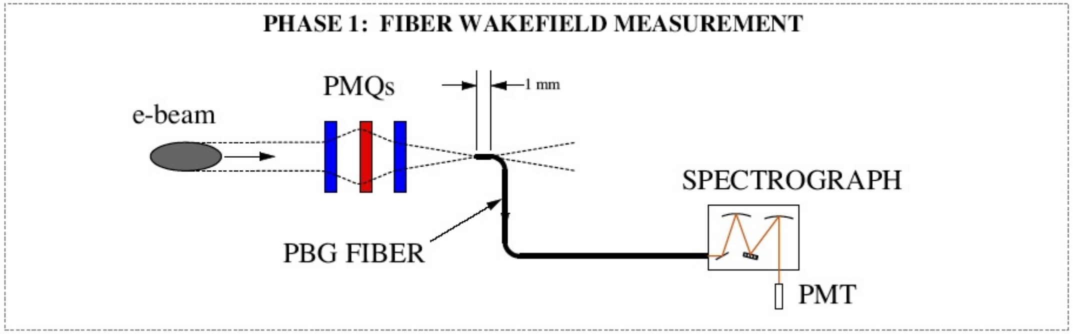
SEM image of HC-1550 fiber

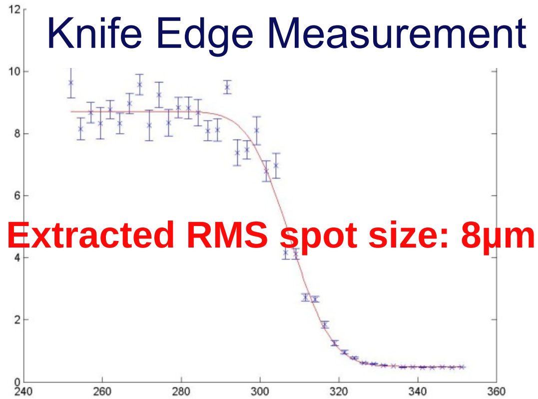


e-beam profile image at PMQ focus



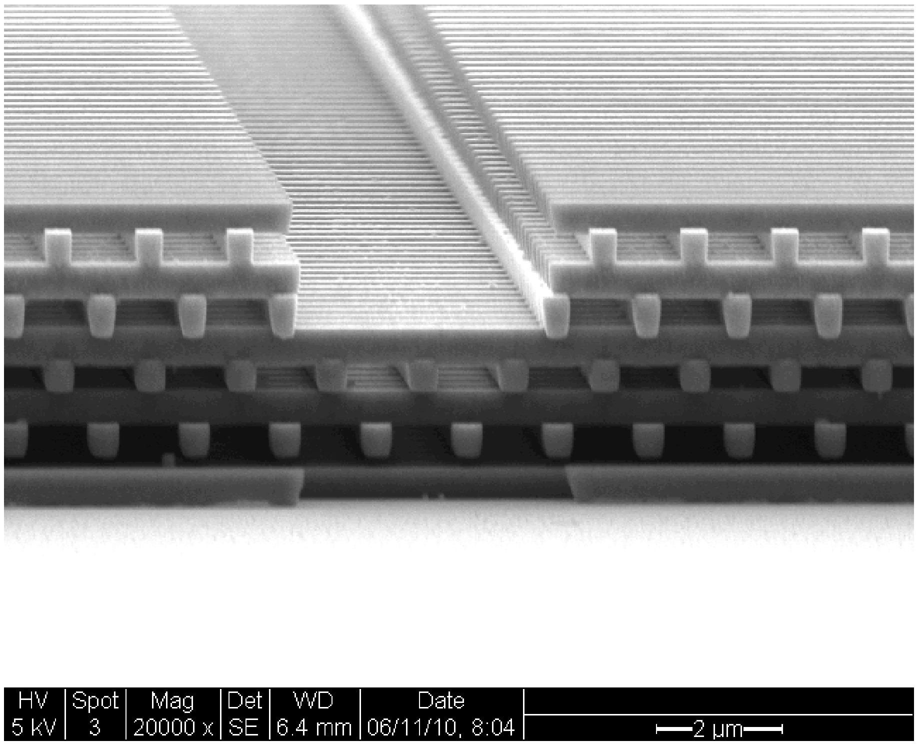
Experiment being built and operated by postdoc and graduate students





Fabrication of 3-D PBG Structure

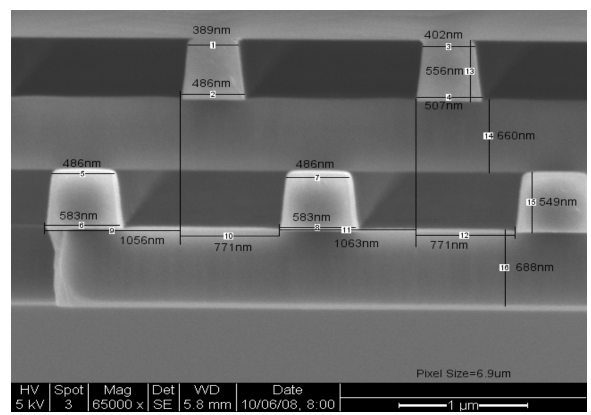
Silicon woodpile structure produced at the Stanford Nanofabrication Facility (SNF)



Fabricated by graduate students

Detailed Tolerance Studies of CDs

Process Version	Rod width base	Rod width top	Taper Angle	Layer Thickness	Alignment Offset	Period
3	389	486	9.89624641	556	142.5	1834
3	402	507	10.69429961	660	146	1827
3	486	583	10.01988665	549	161.5	1834
3	486	583	10.01988665	688	102.5	1808
3	311	441	9.575247964	516		2013
3	280	391	11.1759075	658		1721
3	379	509	11.04285784	559		
3	348	485	10.49147701	702		
2	438	556	13.12686302	506	412.5	1844
2	419	506	9.755861898	681	400	1838
2	469	525	5.75140209	556	522	1813
2	450	544	9.595956437	545	516	1857
2	384	455	7.092112957	643		1870
2	366	446	6.301068652	580		1832
2	446	527	5.850496153	527		
2	464	518	8.737992324			
1	434	529	10.43182293	542		1818
1	503	669	15.86761887	516		1789
1	483	649	15.86761887	584		
1	480	690	19.90374954	580		
average	420.85	529.95	10.55991867	586.7368421	300.375	1835.571
std	62.16808709	76.49594072	3.503712238	64.14206637	179.4061135	62.12112
version 3 mean	390.4285714	500	10.34633323	598	138.125	1839.5
version 3 std	74.27062003	65.09649431	0.57608771	73.11243787	25.14416765	95.24022
version 2 mean	429.5	509.625	8.276469191	576.8571429	462.625	1842.333
version 2 std	37.27887184	39.6157887	2.542079837	63.49128174	65.34188932	19.84607



Best achieved:

Width Variation:

<40 nm RMS (~λ/125)

Layer Thickness:

<65 nm RMS (~λ/75)

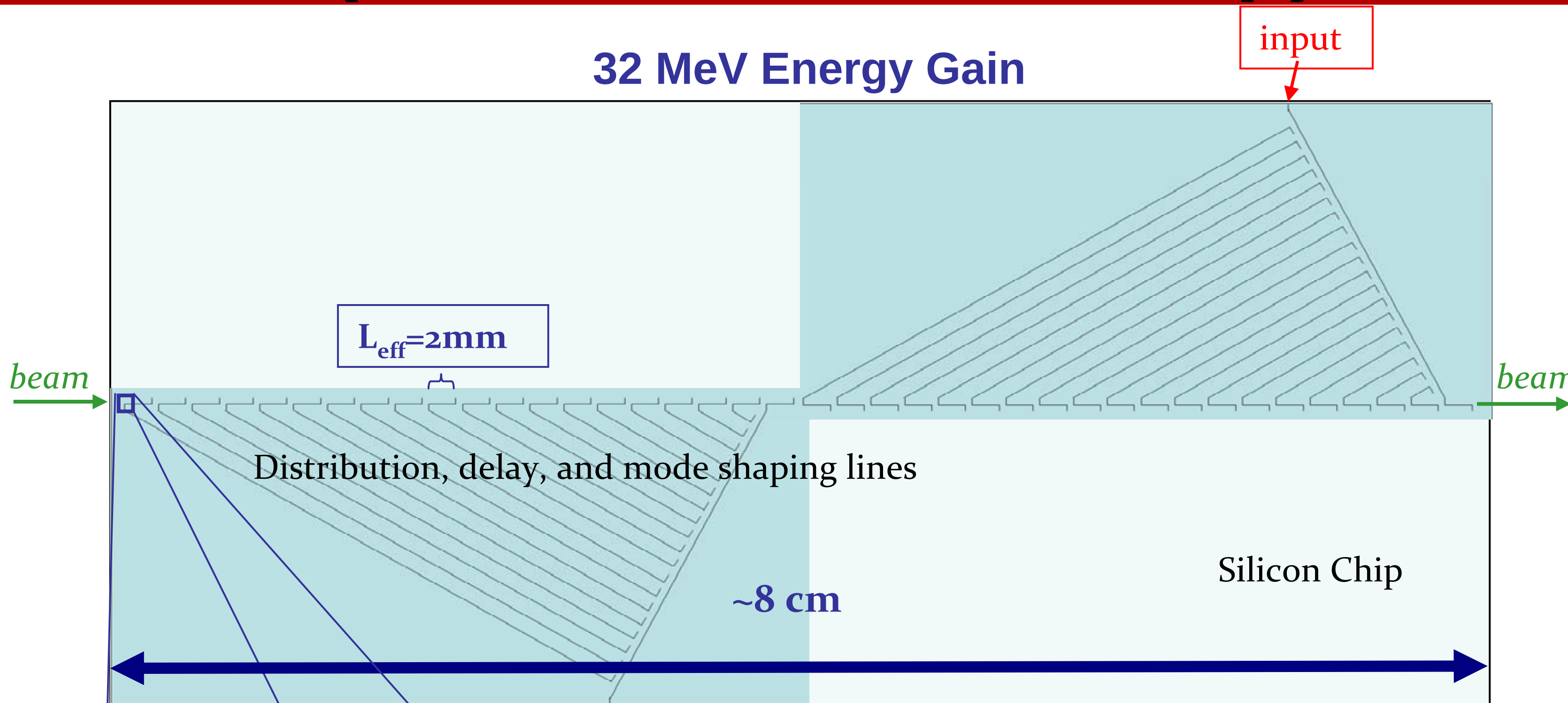
Layer Alignment:

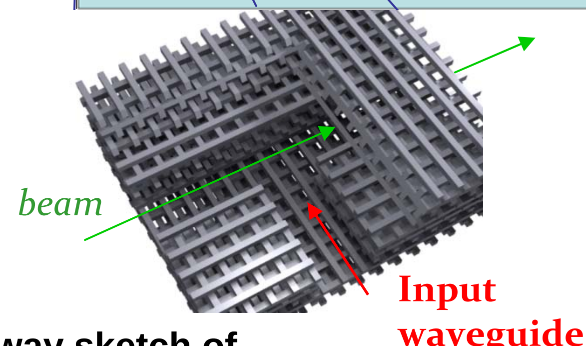
<65 nm RMS (~λ/75)

Measurement Technique Granularity: 7nm

Laser-Driven Dielectric Accelerator (Accelerator-on-a-chip)

32 MeV Energy Gain



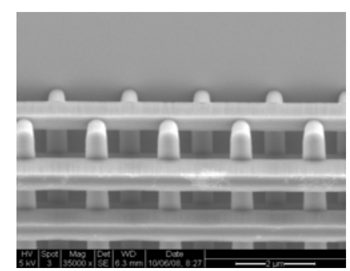


Fiber coupled input

λ=2 μm
20 μJ/pulse
1 ps laser pulse

Cutaway sketch of coupler region

Image courtesy of B. Cowan, Tech-X.



4-layer Structure Fabrication (completed at SNF)

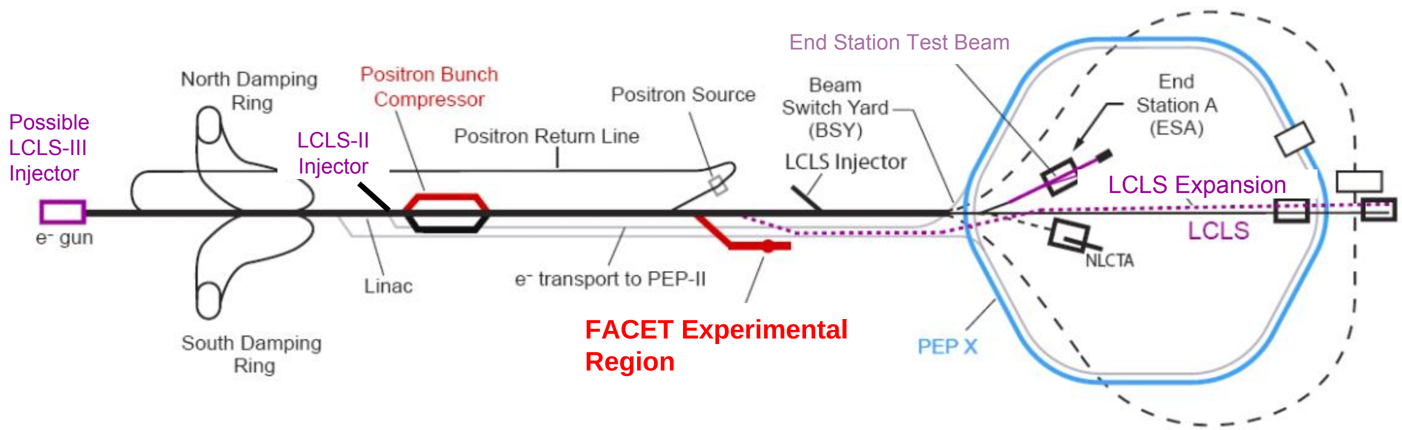
Image courtesy of C. McGuinness, Stanford.

DLA Program Summary

- Promise
  - Fundamentally different accelerator technology with promise for gradient, efficiency, compactness and economy
  - The *only* LC scheme with a beam format compatible with 10 TeV cm energies
- Issues
  - Experimental program has significant costs and risks
  - Seeking to grow collaborations
- Future Program
  - Demonstrate first laser-driven accelerator and assess gradient potential
  - Complete and fabricate fully integrated structures with power couplers
  - Develop high-brightness sources and beam transport techniques

Facility for Advanced aCcelerator Experimental Tests (FACET)

- FACET uses first 2/3 of SLAC linac → 23 GeV beams
- Compresses bunches in 3 stages → 10's of microns
- Focuses beams to ~10 micron spots transversely
- Unique beams with very high current density (~20 kA I_{peak})



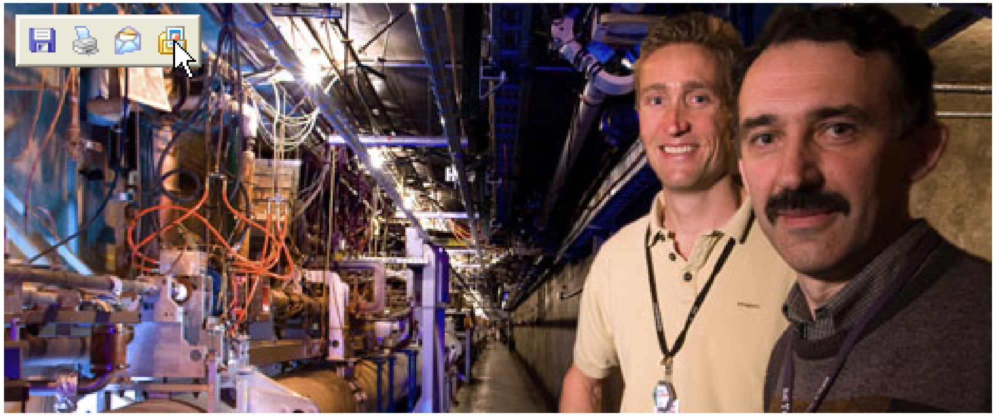
http://FACET.slac.stanford.edu

FACET FACILITY FOR ADVANCED ACCELERATOR EXPERIMENTAL TESTS

U.S. DEPARTMENT OF ENERGY

Search GO
SLAC WEB PEOPLE

SLAC NATIONAL ACCELERATOR LABORATORY



News and Events

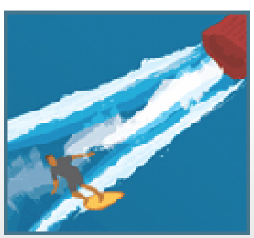
SLAC National Accelerator Laboratory to Receive $68.3 Million in Recovery Act Funding - March 23, 2009

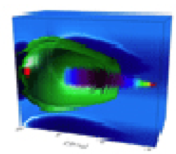
New Accelerator Technique Doubles Particle Energy in Just One Meter - February 14, 2007

» more

What Is FACET?

Advanced accelerator research promises to improve the power and efficiency of today's particle accelerators, enhancing applications in medicine and high-energy physics, and providing potential benefits for research in materials, biological and energy science. Experiments on future acceleration techniques require high-quality, forefront facilities.



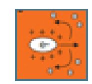


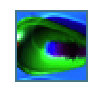
FACET—Facilities for Accelerator science and Experimental Test beams at SLAC—will study plasma acceleration, using short, intense pulses of electrons and positrons to create an acceleration source called a plasma wakefield accelerator. FACET will meet the Department of Energy Mission Need Statement for an Advanced Plasma Acceleration Facility.

» more

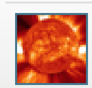
Research

With FACET, the SLAC linac will support a unique program concentrating on second-generation research on plasma wakefield acceleration.


Plasma Wakefield Acceleration


THz Radiation


Plasma Focusing


Dielectric Wakefield Acceleration

» more

FACET Users Workshop

FACET USERS WORKSHOP

Workshop on FACET experimental program March, 2010

SLAC NATIONAL ACCELERATOR LABORATORY

- Home
- Program
- Participant List
- Payment Information
- Accommodations
- Travel & Directions
- Visa Information
- FACET Experimental Area
- FACET Proposals
- FACET Public Site

Announcements

Presentations from the Workshop are now available for download.

» **view presentations**

FACET Users Workshop

March 18-19, 2010
Redwood Conference Room, Building 48
SLAC National Accelerator Laboratory
Menlo Park, California

Four working groups

- Plasmas Acc.
- Dielectric Acc.
- Crystals
- Materials

List of FACET Proposals

Unique experimental facility have led to variety of proposals

- Multi-GeV Plasma Wakefield Acceleration Experiments
- Wakefield Acceleration in Dielectric Structures
- Study of Ultrafast Processes in Magnetic Solids following Excitations with Electron Beams
- Investigations of Optical Diffraction Radiation as a Non-intercepting Beam-size Monitor at High Energy and Charge Density
- Determination of the time profile of 50 fs long bunches by means of coherent Smith-Purcell radiation
- Afterburner Based on Particle Acceleration by Stimulated Emission of Radiation at FACET (PASER)
- Letter of intent for a program of measurements for the CLIC study at the FACET facility

SLAC Accelerator Research Experimental program Committee (SAREC)

Committee Members:

Andrei Seryi (Chair, JAI)
Uwe Bergmann (SLAC)
Eric Esarey (LBL)
Jie Gao (IHEP)
Kathy Harkay (ANL)
Carsten Hast (SLAC, Scientific Secretary)
Georg Hoffstaetter ?? (Cornell)
Sergei Nagaitsev (FNAL)
Vitaly Yakimenko (BNL)
Kaoru Yokoya (KEK)
Frank Zimmermann (CERN)

The charge to the SAREC committee is:

1) evaluate the merit of proposed R&D in SLAC's experimental accelerator research facilities for advancing world-class accelerator science or accelerator technology
2) evaluate the feasibility of proposed R&D in SLAC's accelerator research facilities
3) review the progress of existing R&D in SLAC's accelerator research facilities

First meeting planned for winter 2011

FACET Construction Status

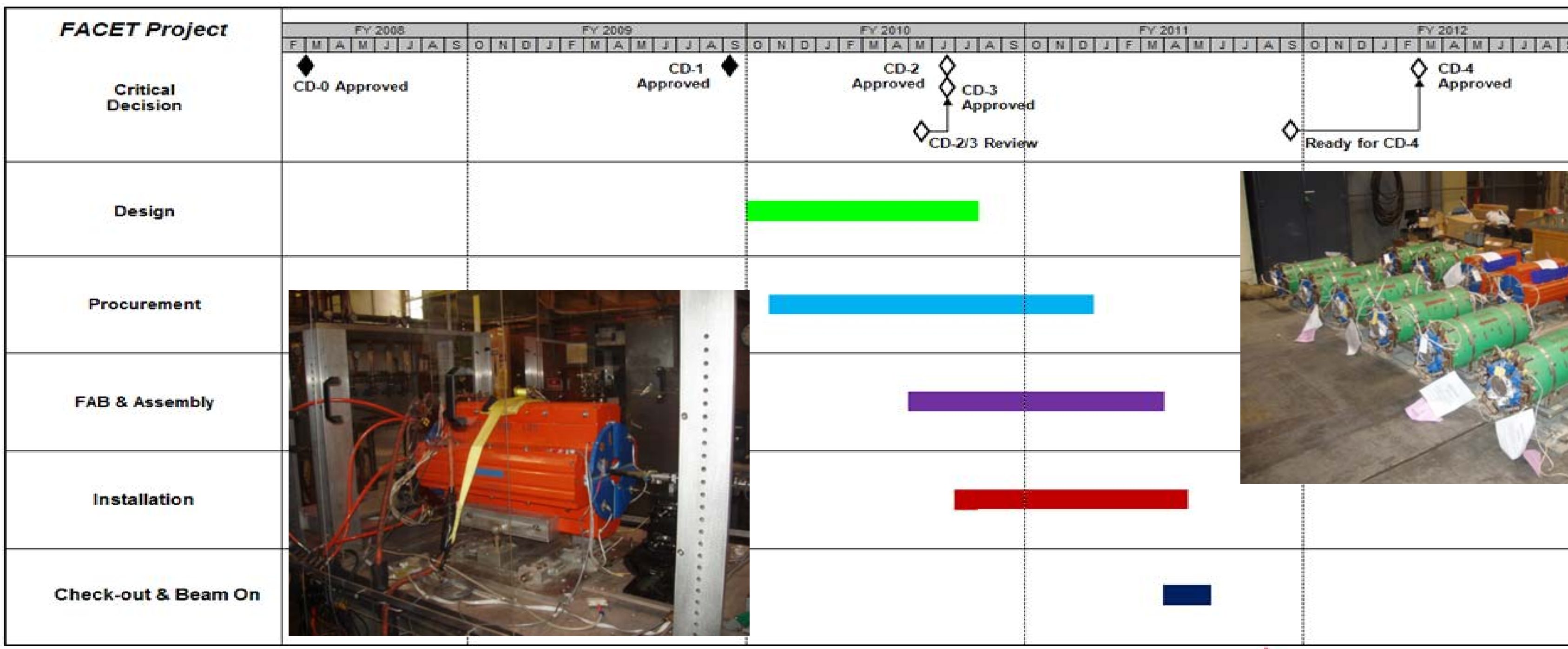
FACET received CD2/3 approval in July, 2010

Construction supported with ARRA funds

Linac upgrade AIP's with 4.3M$ of FY10 FACET ops funds

Construction is scheduled to complete in April, 2011

First beams expected in May, 2011



FACET Operation

- FACET should operate for 4 months a year as a user facility
- Original budget estimate was $6M/year to HEP for FACET operations including incremental cost of electricity, spares, and operations staff
- Developing bottom's up estimate for FY11
  - Believe that 6M$ should cover 2 months operation & commissioning
    - Planning for 2 months operation starting in July or August, 2011
    - Efforts begin two months earlier with hardware check-out and fixes
- Need to still understand longer-term staffing needs
- Will estimate FY12 costs for 4 months operation after scrubbing FY11 results
  - Concerned that it will be difficult to support program on 6M$/year

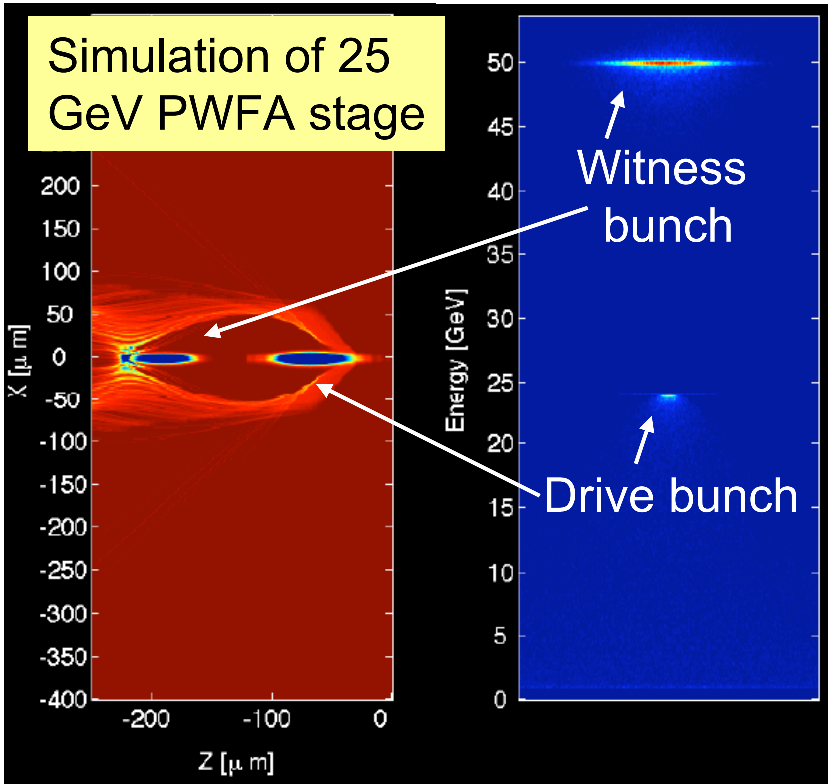
Plasma Wakefield Acceleration

- Mission and funding
  - Extraordinary gradient and high efficiency acceleration is possible
  - Science of beam/plasma interactions is rich and much remains to be explored
- Highlights
  - 9 Publications in last 12 months (3 in archival journals)
  - Graduated 2 PhD students (Ian Blumenfeld and Neil Kirby)
  - Developed high-fidelity models of drive/witness production for PWFA experiments at FACET

			FY10		FY11
WBS4	WBS4 D	LSTM_SHORT	YTDACT	BDG K$	K$
8.06.09.01	Plasma Wakefield Acceleration	Allocated OH	116		
		M&S	33		
		Shop	9		
		SLAC	157		
		Travel	9		
	Plasma Wakefield Acceleration Total		323	1,263	1,615

Challenges for Plasma-based Accelerators

- Luminosity drives many issues:
  - High beam power (20 MW) → efficient ac-to-beam conversion
  - Well defined cms energy → small energy spread
  - Small IP spot sizes → small energy spread and small $\Delta\varepsilon$
- These translate into requirements on the plasma acc.
  - High beam loading of e+ and e-
  - Acceleration with small DE/E
  - Preservation of small transverse emittances – maybe flat beams
  - Bunch repetition rates of 10's kHz
  - Highly efficient power sources
  - Acceleration of positrons



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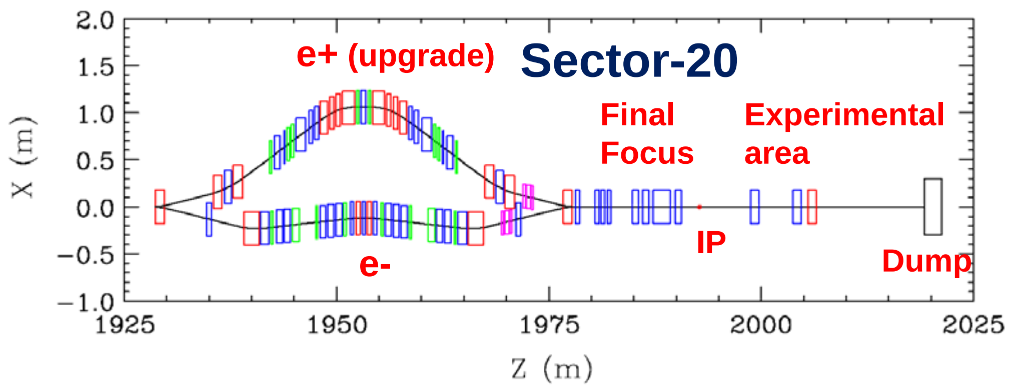
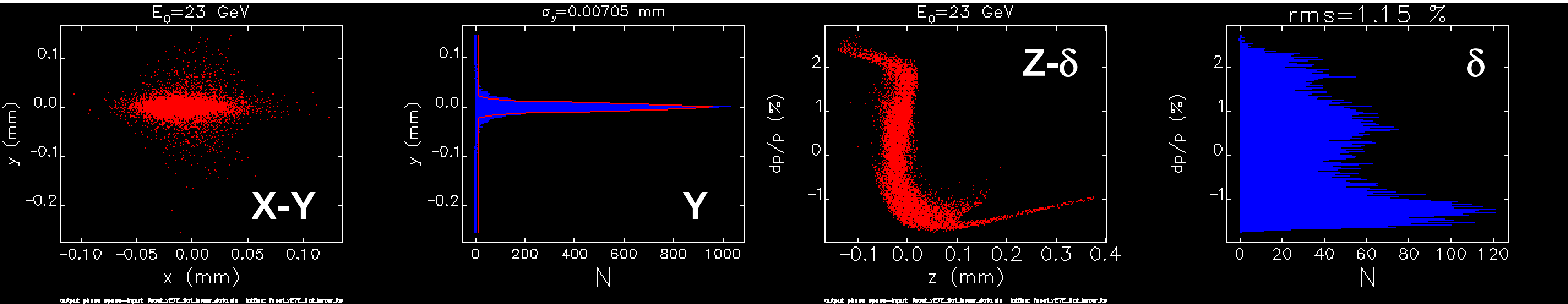
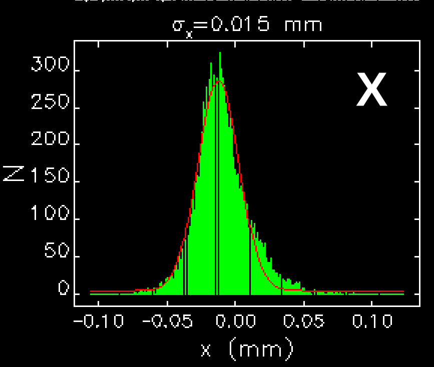
FACET Beam Simulations with CSR

Short bunch length in Sector-20 (60 to 20 μm) results in strong CSR effects leading to growth of horizontal beam size at IP. ELEGANT simulations:
σ_x = 11.6 μm with ISR ,
σ_x = 15.0 μm with ISR and CSR,
E = 23 GeV, N = $2 \cdot 10^{10}$ part/bunch

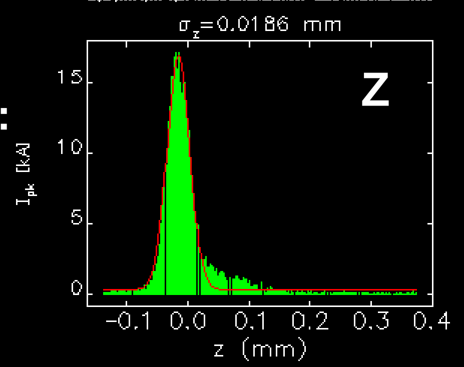


Beam profile and beam size at IP





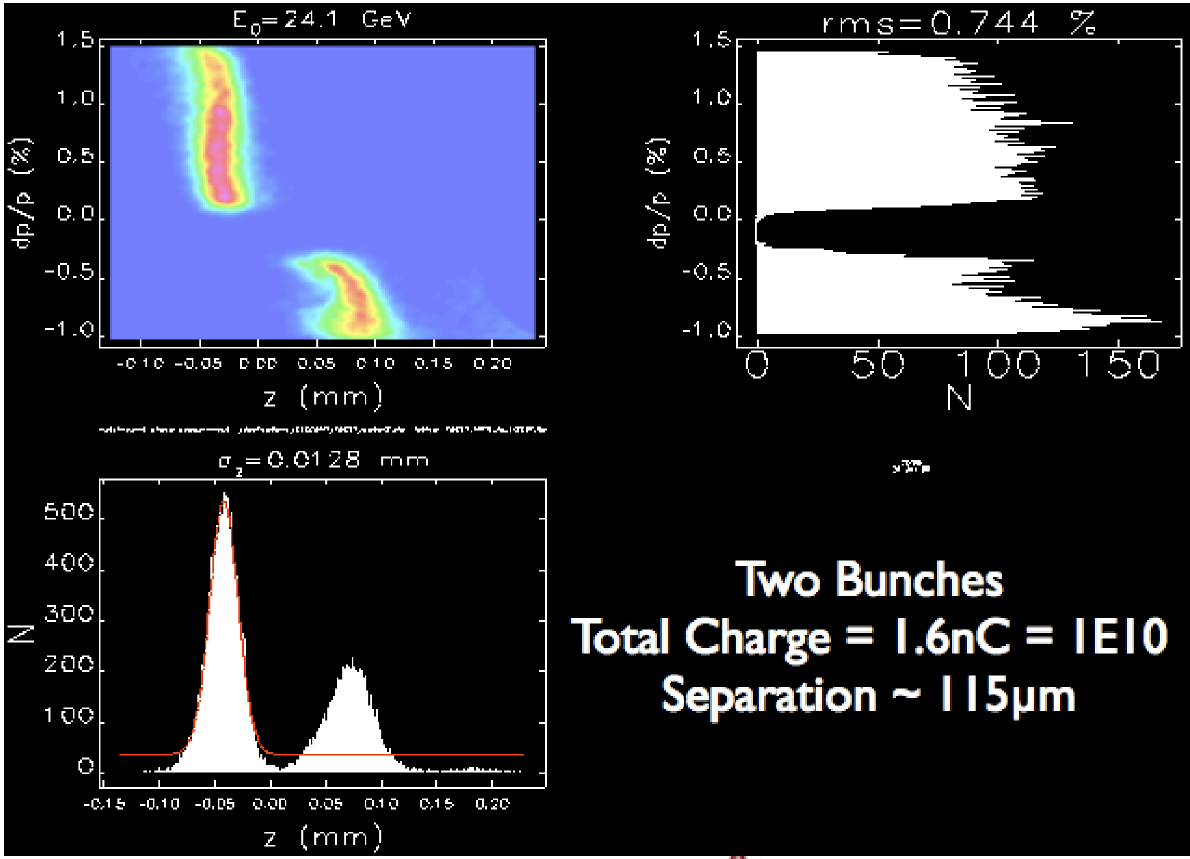
Gaussian fit X-Y size:
σ_x = 15.0 μm
σ_y = 7.1 μm



Gaussian fit bunch length:
σ_z = 18.6 μm

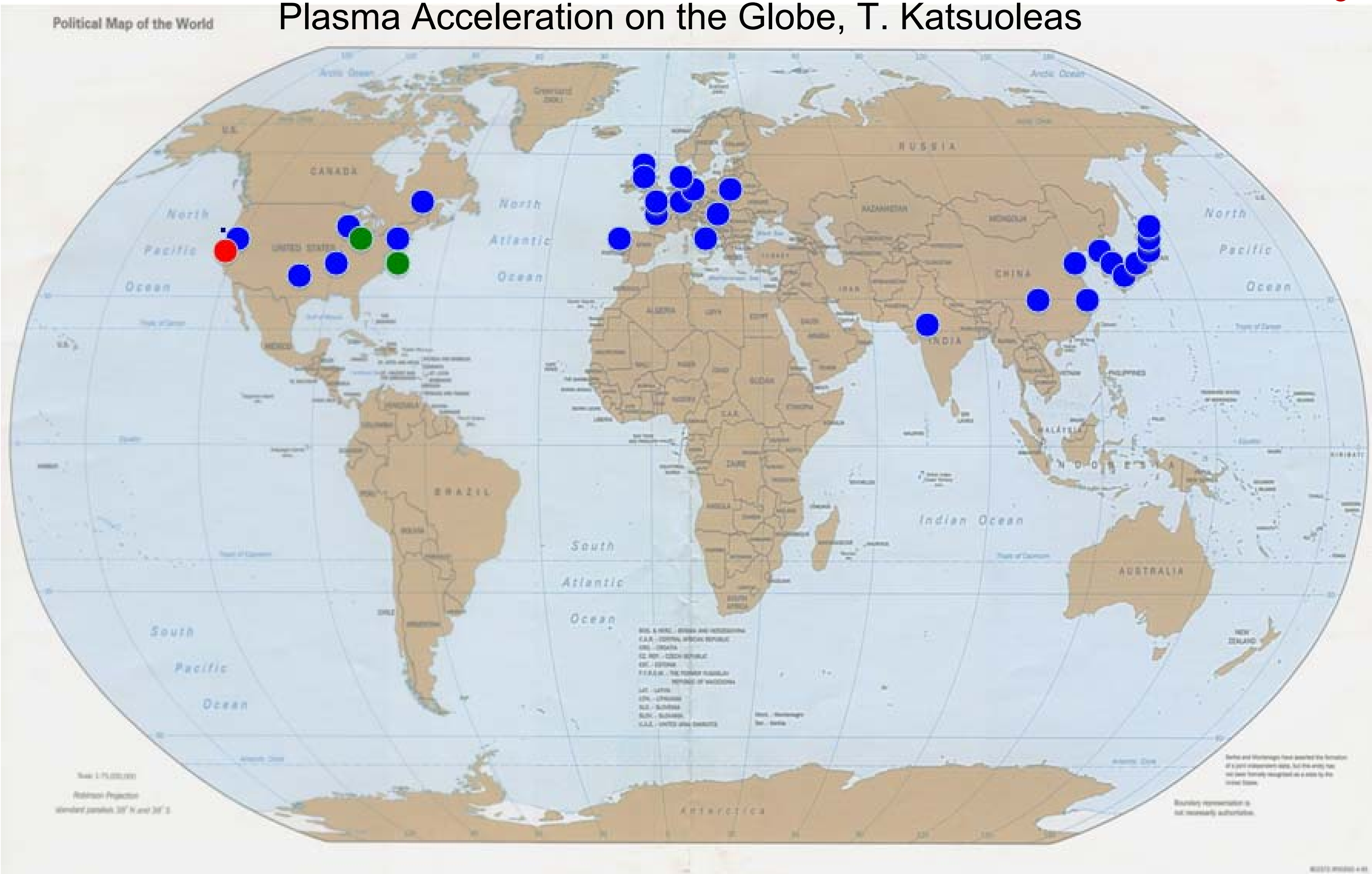
FACET: Two-Bunch Operation

- Critical to demonstrate drive/witness acceleration
- Use notch collimator in Sector-20 bunch compressor to generate two separate bunches
- Technique works for either e-/e- or e+/e+
- Varying collimator shape and position allows flexibility in two-bunch format



World-Wide Interest in Plasma Acc.

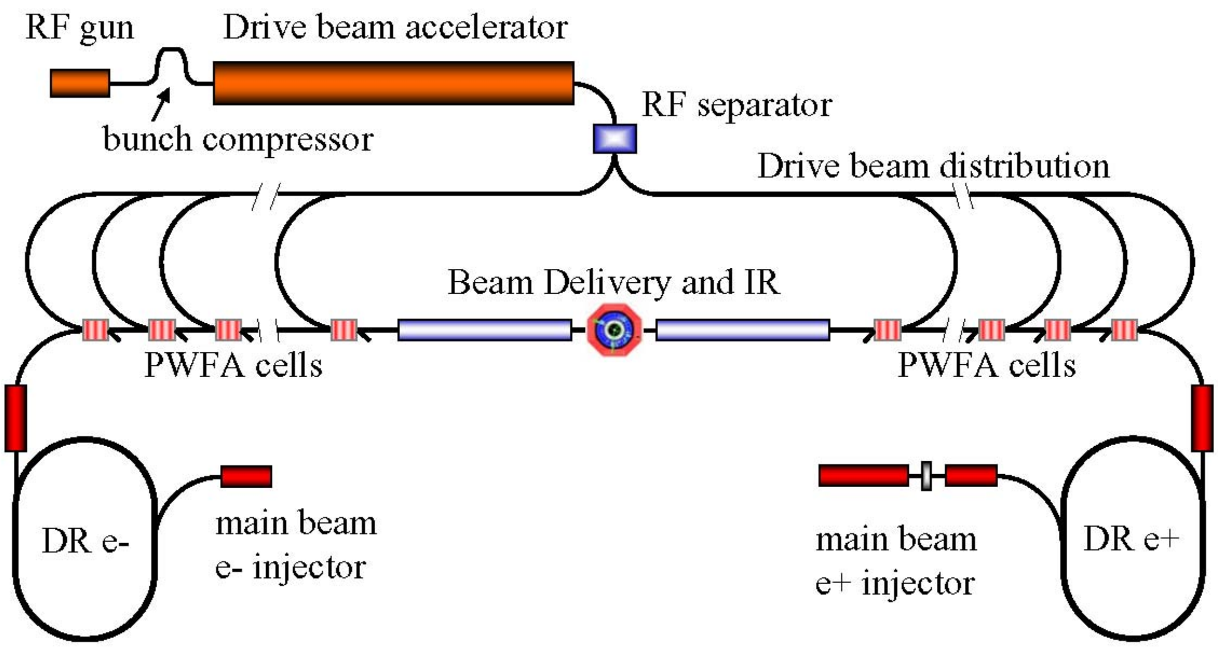
Plasma Acceleration on the Globe, T. Katsuoleas



● Laser Wake Expts ● Electron Wake Expts ● e-/e+ Wake Expts

Concept of Beam-Driven Plasma Linac

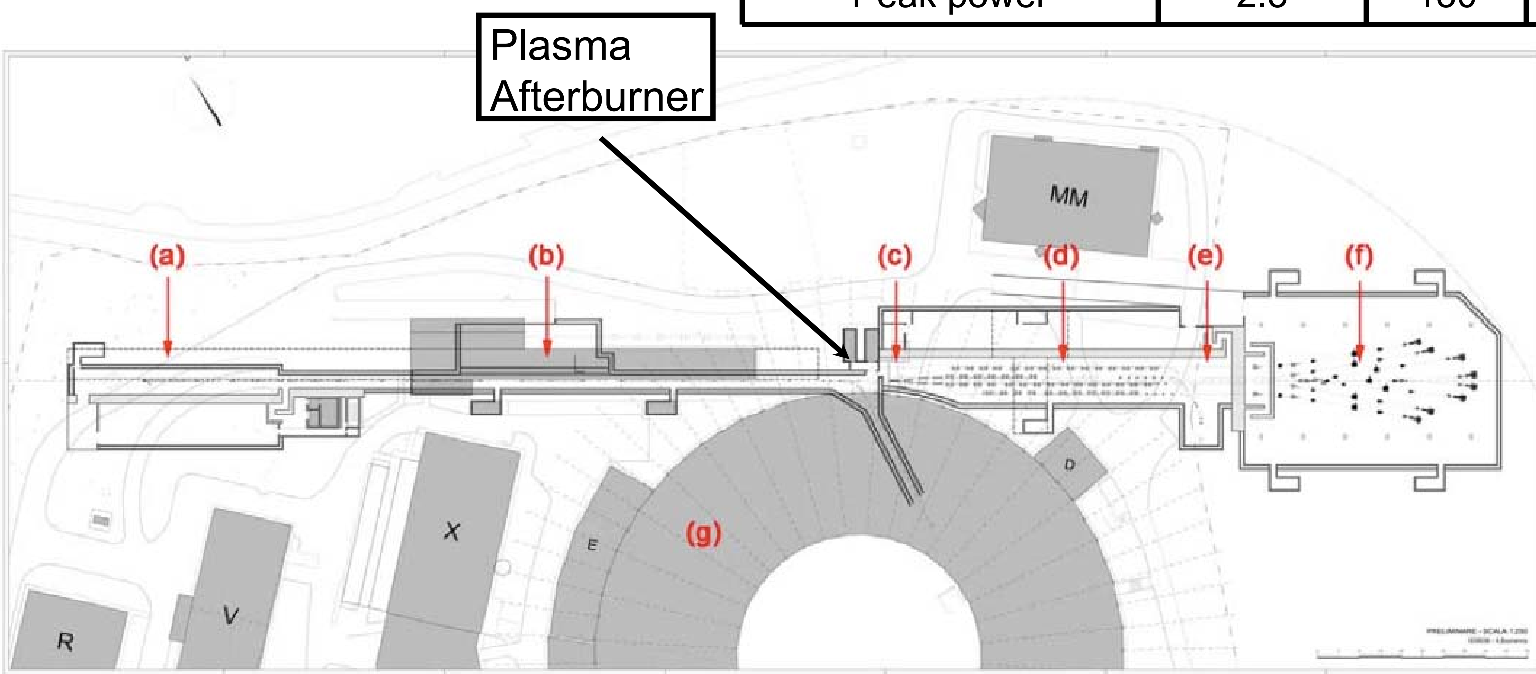
- Concept for a 1 TeV plasma wakefield-based linear collider
  - Use conventional Linear Collider concepts for main beam and drive beam generation and focusing and PWFA for acceleration
    - Makes good use of PWFA R&D and 30 years of conventional rf R&D
  - Concept illustrates focus of PWFA R&D program
    - High efficiency
    - Emittance pres.
    - Positrons
  - Allows study of cost-scales for further optimization of R&D



PWFA FEL Afterburner

- Use FACET PWFA concept as a simple upgrade for an FEL facility, doubling beam energy and quadrupling photon wavelength
- Likely 1st application of PWFA concept
- Preliminary parameters for FERMI@Elettra although specific case may be limited by CSR

Parameter	FEL-1	PWFA	Units
Wavelength	20	5	nm
Electron Beam Energy	1.2	2.4	GeV
Bunch Charge	0.8	0.25	nC
Peak Current	0.85	15	kA
Bunch Length (FWHM)	400	2	fs
Norm. Emittance (slice)	0.8-1.2	1.5	mm-mrad
Saturation length	23	19	m
Peak power	2.3	130	GW



PWFA Summary

- Issues
  - Need to increase staffing to support aggressive goals of the program and further develop collaborations
    - US-Japan program will likely include effort on PWFA
    - Working on applications of PWFA technology to encourage collaborators
- Future Program
  - Demonstrate narrow energy spread acceleration of electrons and positrons
  - Demonstrate emittance preservation of accelerated beams
  - Explore e- driven e+ acceleration (requires sailboat chicane)
  - Address engineering issues unique to plasma accelerators in preparation for a PWFA-based Linear Collider CDR

High Gradient Microwave Acceleration

- Mission and funding
  - We wish to understand the fundamental limitations on accelerator gradient in warm structures
  - The goal is to push the boundaries of the design to achieve:
    - Ultra-high-gradient; to open the door for a multi-TeV collider, Future Light sources, medical applications and national security and environment applications.
    - High rf energy to beam energy efficacy, which leads to an economical, and hence feasible designs
    - Heavily damped wakefields

WBS4	WBS4 D	LSTM_SHORT	FY10 YTDACT	FY10 BDG K$	FY11 K$
8.06.10.01	**High Gradient Research**	Allocated OH	1,043		
		M&S	138		
		Shop	875		
		SLAC	824		
		Travel	24		
	High Gradient Research Total		**2,904**	**3,343**	**3,243**

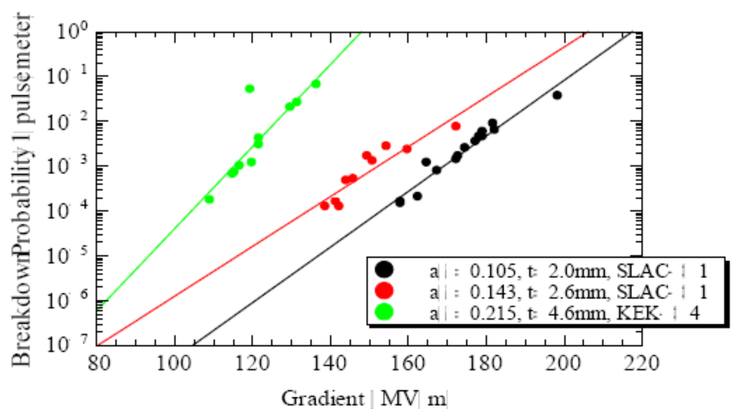
High Gradient Collaboration

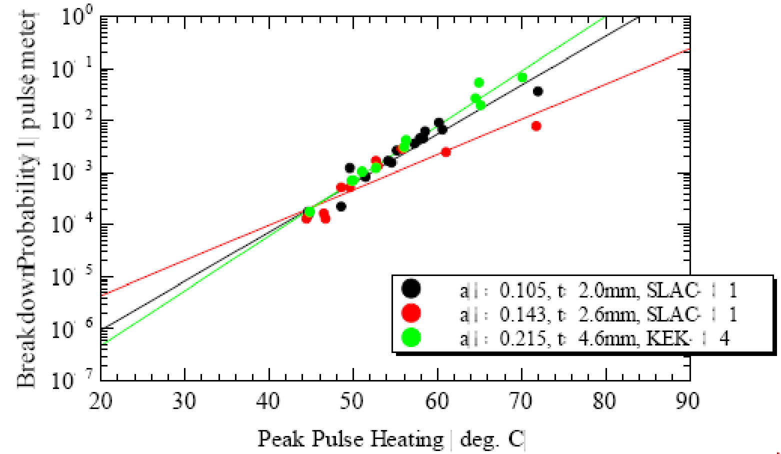
- The High Gradient collaboration includes: SLAC, NRL, MIT, University of Maryland and ANL, University of Colorado, SBIR companies, and others
- International collaboration which includes:
  - SLAC, CERN, KEK, INFN Frascati, and Cockcroft Institute
  - CTF3 Collaboration/CLIC, which is an international effort with great effect on high gradient research
- This lead to new advances in the state of the art including:
  - Advances in the theoretical modeling of the breakdown phenomenon
  - A new optimization methodology for accelerator structure geometries
  - An ongoing research on alternate materials
  - New types of structures

Measuring Breakdown Limits

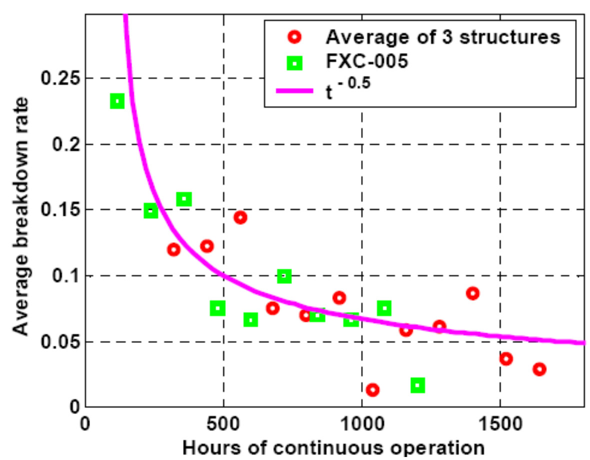
- The combination of analytic modeling, simulation and experiments have made great progress in understanding

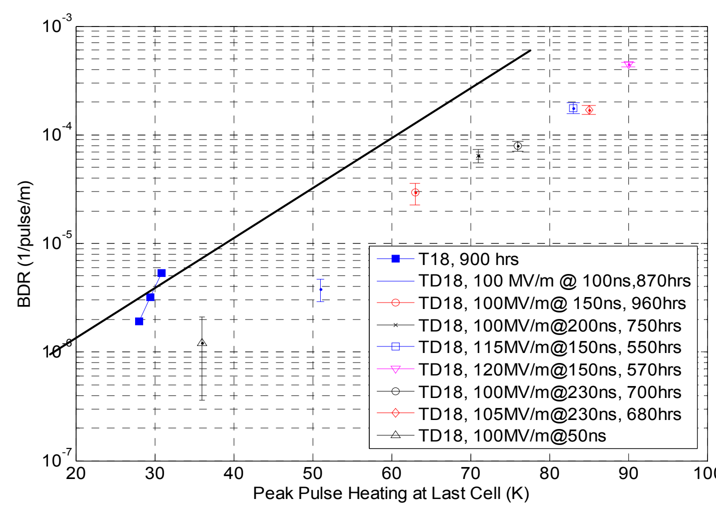
Results from ASTA facility





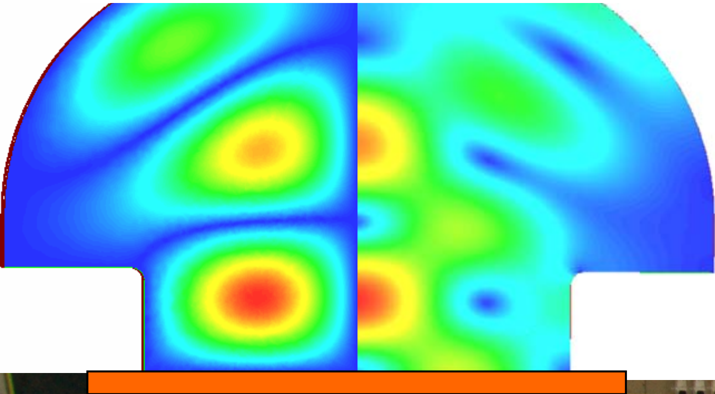
Results from NLCTA facility



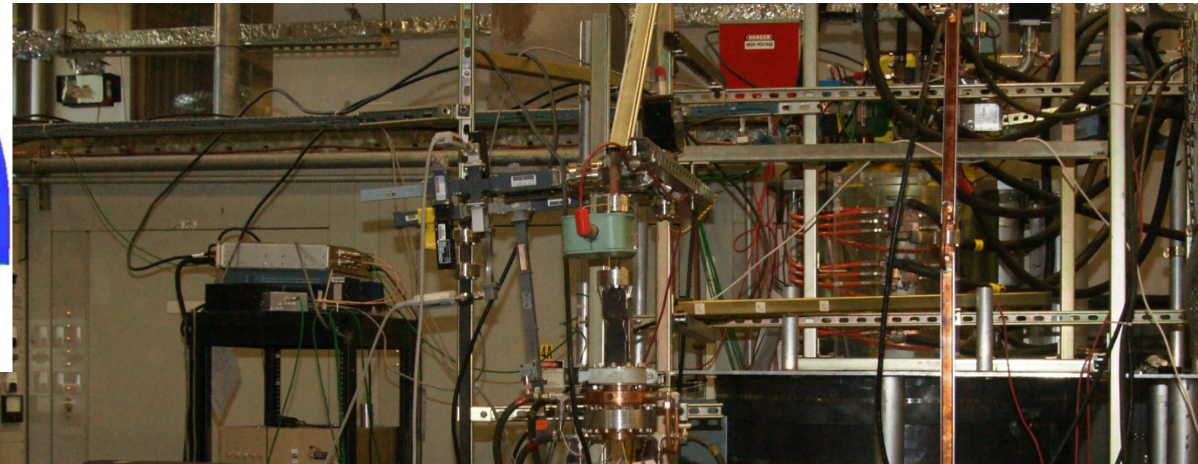


Understanding Accelerator RF Materials

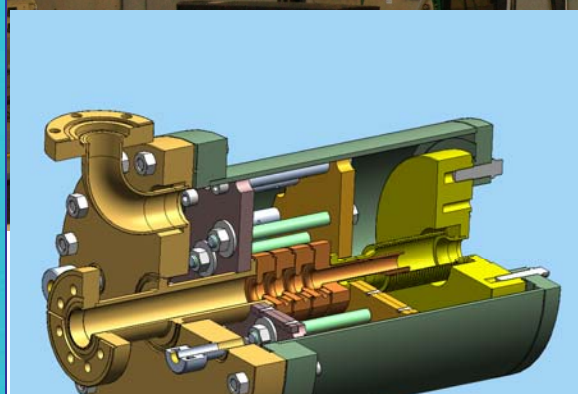
RF Cavity for ΔT Studies



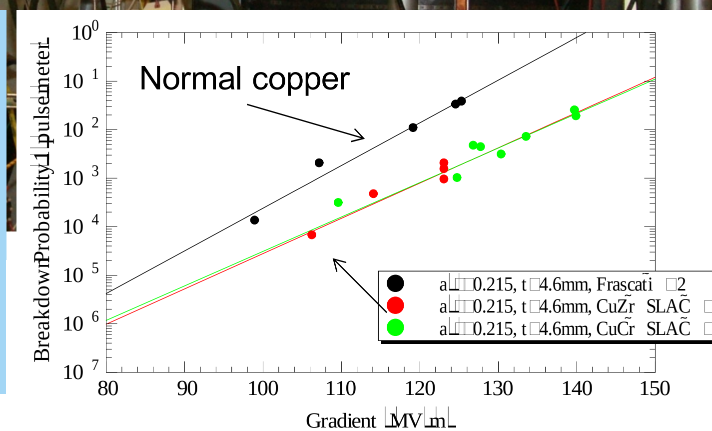
Investigating Cu and Cu-alloys, Ti, Mo, …



Annealed Copper with large grain shows crystal pattern because damage is different for each crysta orientation



Clamping Structure for testing copper alloys and other materials for accelerator structures



High Gradient Summary

- The high gradient program has established multi-cell structures operating near 100 MV/m and single cell structures at ~150 MV/m
  - Advanced concepts such as multimoded and multi-frequency structure, photonic band gap, and dielectric structures may pave the way to higher gradients
- Progress in R&D requires experimental facilities
  - Operation of facilities is costly → share between programs
- High Gradient accelerator structures will not achieve their potential without the development of efficient rf sources
  - With present source technology the cost-optimum is ~70 MV/m
- Need collaborative research towards improved rf source technology

X-band Rf Development

- Mission and funding
  - Develop x-band rf technology for world-wide applications
  - Collaborate with industry to transfer critical rf technology and practices while developing industrial vendors for x-band rf
- Highlights
  - Completing XL-5 klystron series; working on 5 new XL4 klystrons
  - Working closely with LLNL on 250 MeV linac and rf gun
  - Developing bottoms-up cost estimate for X-band technology and a proposal to develop next version of technology aimed at robustness
  - RFP for two industrial XL4 tubes

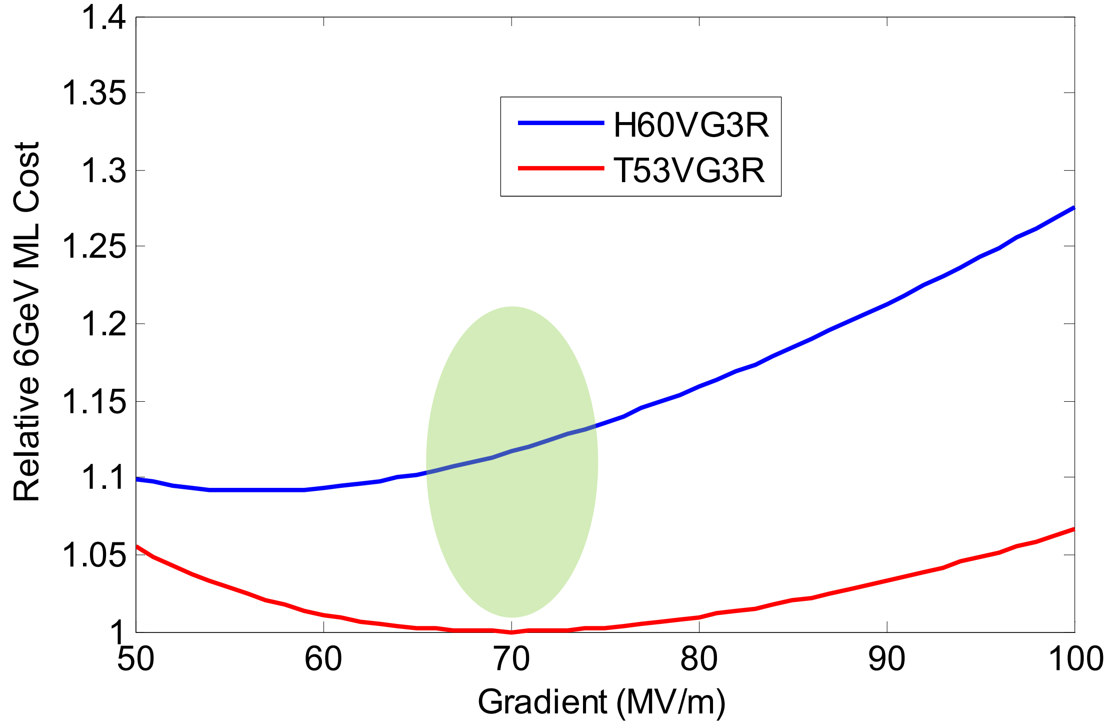
WBS4	WBS4 D	LSTM_SHORT	YTDACT	FY10 BDG K$	FY11 K$
8.06.08.04	X-band Linacs	Allocated OH	381		
		Contract	0		
		M&S	78		
		Shop	334		
		SLAC	277		
		Travel	4		
	X-band Linacs Total		1,075	1,879	1,972

Community Interest in X-band Rf Applications

- Lawrence Livermore National Lab (MEGa-ray ICS)
- Extreme Light Infrastructure – Romania (600 MeV ICS)
- LANL (hard X-ray FEL facility)
- PSI (extension of hard X-ray FEL facility)
- Trieste (extension of soft x-ray FEL facility)
- Daresbury (new soft x-ray FEL)
- Shanghai (new hard x-ray FEL)
- KVI / University of Groningen (soft X-ray FEL)
- PAL (new hard x-ray FEL)
- CERN (path towards a linear collider)
- NSLS-II (compact storage ring injector)

X-band Cost Optimization

- Working to improve cost estimates for X-band linacs
  - New engineer working on costing and cost optimization
- Expectation is X-band is ~50% cost of S-band and ~30% cost of L-band
  - Gather recent costing data from other projects



- X-band ~10M$ / GeV including tunnel
  - Assuming finished tunnel cost 25 k$/m, AC power + cooling power 2.5 $/Watt, and modulator efficiency 70%, klystron efficiency 55%

Applications Example: High Gain FELs

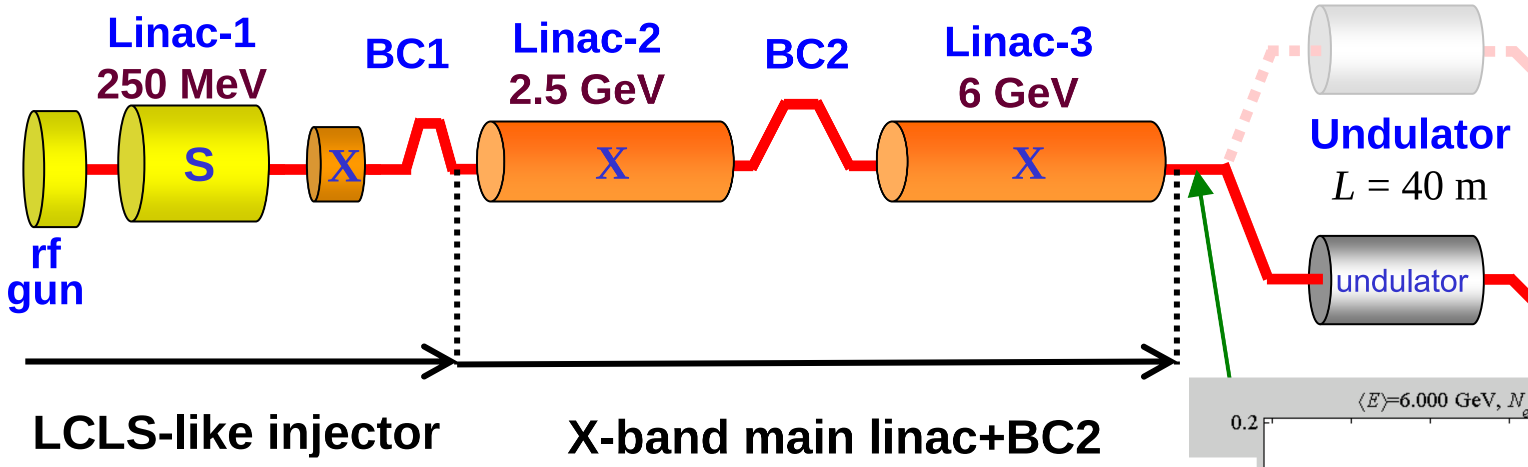
Current High-Gain FEL Projects (January 2008)

	SDL[1]	FLASH[2]	LCLS[3]	FERMI[4]	SCSS[5]	XFEL[6]	SPARX[7]	STARS[8]	SDUV-FEL[9]	WiFEL[10]	NLS[11]	LBL-FEL[12]	PSI-FEL[13]	Pohang[14]
Institution	BNL	DESY	SLAC	Elettra	Spring8	DESY	INFN	BESSY	SINAP	Wisconsin	RAL	LBNL	PSI	PAL
Location	New York	Hamburg	Stanford	Trieste	Hyōgo	Hamburg	Frascati	Berlin	Shanghai	Madison	Rutherford	Berkeley	Zurich	Pohang
Country	USA	Germany	USA	Italy	Japan	Germany	Italy	Germany	China	USA	UK	USA	Switzerland	Korea
Linac frequency	2.8 GHz	1.3 GHz	2.8 GHz	3 GHz	5.7 GHz	1.3 GHz	2.8 GHz	1.3 GHz	2.8 GHz	1.3 GHz	1.3 GHz	1.3 GHz	3 GHz	2.8 GHz
Linac technology	NC	SC	NC	NC	NC	SC	NC	SC CW	NC	SC CW	SC CW	SC CW	NC	NC
Linac energy	200 MeV	1 GeV	13.6 GeV	1.2 GeV	8 GeV	17.5 GeV	2.3 GeV	325 MeV	280 MeV	2.2 GeV	2.25 GeV	2 GeV	5.7 GeV	10 GeV
Radiation wavelength	800 – 266 nm	30 – 6.5 nm	1.5 nm – 1.5 Å	100 – 10 nm	~ 1 Å	1.6 nm – 1 Å	13 – 1.5 nm	70 – 40 nm	266 – 80 nm	100 – 1 nm	200 – 1 nm	100 – 1 nm	10 – 0.1 nm	10 – 0.1 nm
Repetition rate	10 Hz	5×30 Hz	120 Hz	10 – 50Hz	60 Hz	10×3250 Hz	50 Hz	1 kHz	10 Hz	1 MHz	1 kHz	1 MHz	10 – 100 Hz	100 Hz
FEL mode	Seeded	SASE	SASE	HGHG	SASE	SASE	SASE	HGHG	HGHG	HGHG	Seeded	Seeded	SASE	SASE
Status	Operating	Operating	Operating	Commis-sioning	Construc-tion	Construc-tion	Approved concept, Injector test facility operating	Concept	Concept, Injector built	Concept	Concept	Concept	Approved concept, Injector test facility (ITF)	Concept approval in 2010 ?
Estimated completions	Done	Done	Done	Done	ITF 2008 FEL 2011	~2014	ITF 2008 FEL ?	Canceled	ITF 2009 FEL ?	?	Canceled	?	ITF 2011 FEL 2016	?

[1] http://www.nsls.bnl.gov/facility/accelerator/duvfel/
[2] http://vuv-fel.desy.de/
[3] http://www-ssrl.slac.stanford.edu/lcls/cdr/
[4] http://www.elettra.trieste.it/FERMI/index.php?n=Main.HomePage
[5] http://www-xfel.spring8.or.jp/
[6] http://xfel.desy.de/
[7] http://www.sparx.it/
[8] http://www.bessy.de/?idcat=31&changelang=5
[9] http://adweb.desy.de/mpy/FLS2006/proceedings/HTML/AUTH0047.HTM
[10] http://www.wifel.wisc.edu/
[11] http://www.newlightsource.org/
[12] http://www.lbl.gov/Science-Articles/Archive/sabl/2007/Nov/APSI.html
[13] http://fel.web.psi.ch/
[14] http://epaper.kek.jp/FEL2008/papers/tubau05.pdf

- Comparable number of normal and super-conducting FEL sources
- High gradient needed in many cases due to compact site limitations
- To date, NCRF technology has been simpler and cheaper to implement (at least for small scale applications)
- Enables university-class accelerators

X-band Linac Driven Compact X-ray FEL



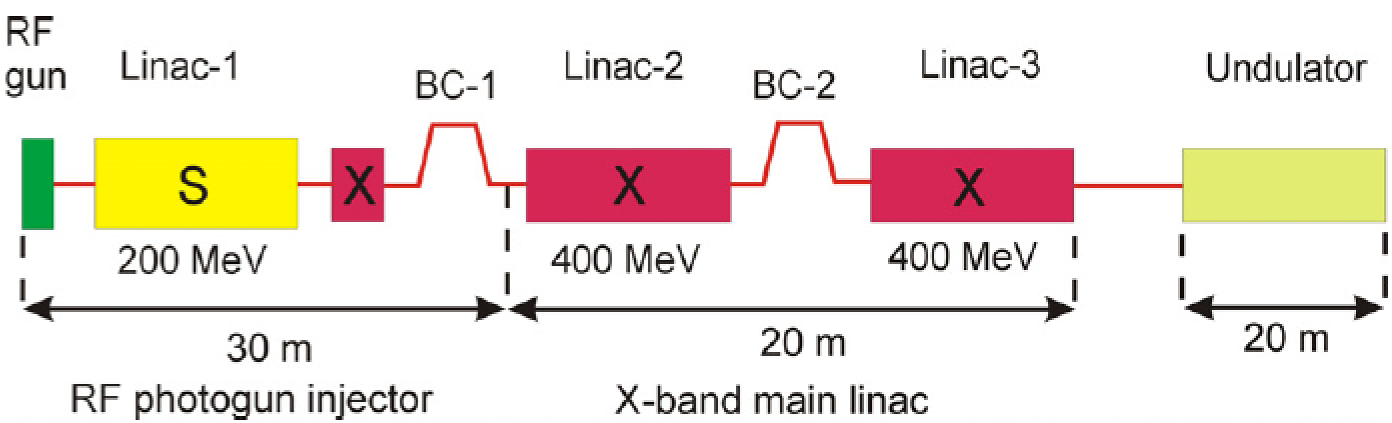
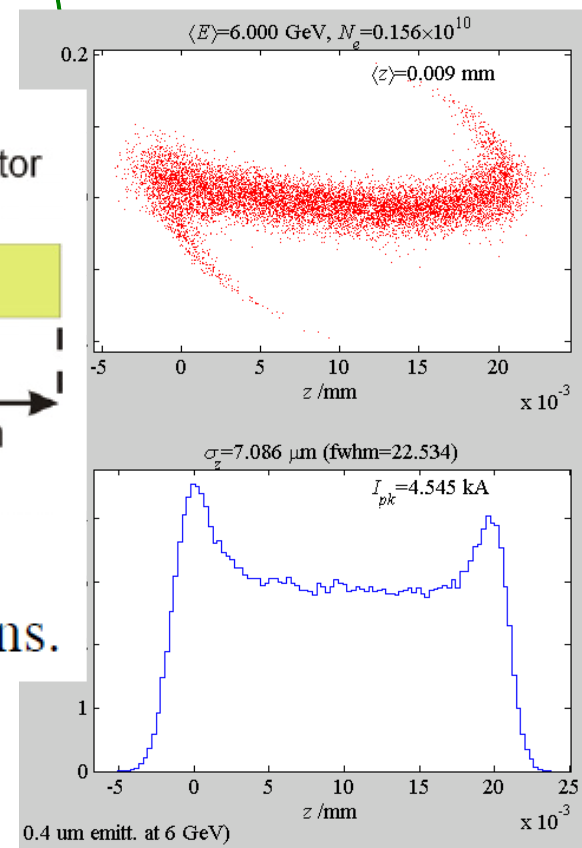


Figure 1: ZFEL machine layout showing major sections.



Workshop on X-band RF Technology

Workshop on X-Band RF Technology for FELs

March 5, 2010
SLAC National Accelerator Laboratory
Menlo Park, California

Followed: ICFA 'Future Light Sources 2010' Workshop with ~45 people attending

First Announcement: **WORKSHOP ON X-BAND RF TECHNOLOGY FOR FELs,** to be held at SLAC on the afternoon of March 5, 2010 1:30PM - 5:30PM.

Following the Future Light Source workshop at SLAC (see FLS 2010), there will be a workshop on the afternoon of March 5 that will:

1) Motivate the choice of X-band (11.4 GHz or 12 GHz) rf technology for a compact XFEL

2) Review the progress at SLAC and other labs in developing and manufacturing X-band components: modulators, klystrons and accelerator structures

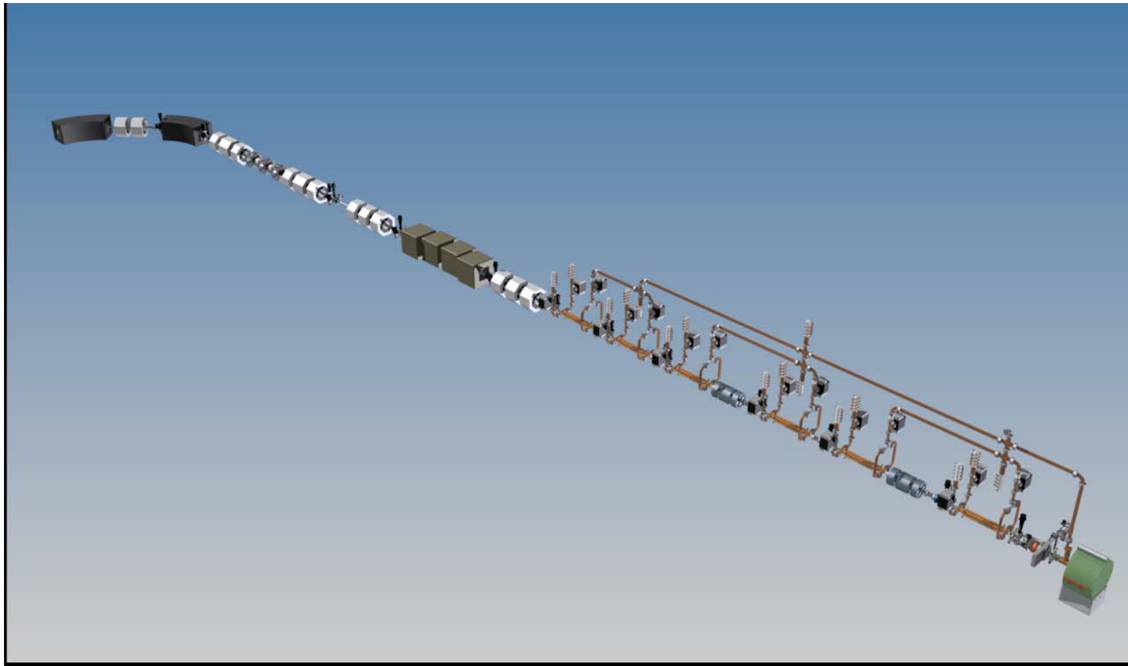
3) Provide a forum for vendors to present their X-band production capabilities.

The goal is to generate a broader interest by labs to develop compact X-band based FELs as an evolution beyond the current S-Band and C-band systems. We particularly encourage vendors to attend to help motivate this process.

- Many new compact XFELs proposed around the world
  (Shanghai, Pohang, PSI, FERMI, SPARX, KVI ZFEL, …)

Mono-Energetic Gamma Ray Source
(Example of X-band RF Application)

- Lawrence Livermore program to develop a compact source of MeV gammas
  - Excite nuclear resonance florescence lines for: Cargo scanning; nuclear fuel cycle optimization; stockpile stewardship; …
- Based on a 250 MeV X-band linac with intense laser for Compton backscatter source
  - Use SLAC structures, pulse compression and klystrons
  - Ultimate goal is compact portable system → high gradient desirable



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Why X-band Technology Development?
(Broad Applicability and Core Capability)

- High gradient X-band technology may offer a path to an LC
- High gradient linacs are needed across the Office of Science
  - Normal conducting linacs are mainstay of many state-of-the-art projects due to lower cost, higher gradients and reduced complexity
  - High frequency linacs offer potential for higher brightness beams because high gradient fields allow better beam control
  - Niche applications include: rf linearizers for bunch compression, rf undulators for rapid (polarization) control, rf deflectors for high resolution phase space measurement, medical/industrial linacs, …
- SLAC is the world leader in normal conducting linac design and rf systems
  - Core capability at SLAC not duplicated elsewhere in world
  - SLAC groups consulted for many challenging projects

X-band Development Summary

- The 15 year, ~200 M$ development of X-band technology for a linear collider produced a suite of robust, high power components.
- Most hardware EXISTS.
  - The XL4 klystron (developed in 1992) is ~20% efficient and has limited reliability → develop new option
- X-band technology affords a low cost, compact means of generating multi-GeV, low emittance bunches
- To facilitate X-band use, components must be industrialized and a small demonstration accelerator built
- X-band technology program would:
  - Enable compact low-cost linacs across the Office of Science
  - Strengthen SLAC role with rf industry and help bridge ‘the valley of death’
  - Maintain SLAC’s core competency in high power rf, a resource for the nation
  - Provide an option towards a TeV-scale linear collider: LC-X

Accelerator Design

- Mission
  - Develop specific accelerator designs: CLIC, LHC, Super-B, Project-X, … before dedicated funding exists to support the design
- Funding:

WBS4	WBS4 D	LSTM_SHORT	FY10 YTDACT	FY10 BDG K$	FY11 K$
8.06.06.02	**LHC R&D**	Allocated OH	303		
		M&S	2		
		SLAC	447		
		Travel	4		
	LHC R&D Total		**757**	**753**	**121**
8.06.07.03	**SuperB Accelerator**	Allocated OH	171		
		M&S	1		
		Shop	14		
		SLAC	220		
		Travel	31		
	SuperB Accelerator Total		**437**	**647**	**713**
8.06.07.05	**CLIC**	Allocated OH	190		
		M&S	3		
		Shop	122		
		SLAC	176		
		Travel	13		
	CLIC Total		**506**	**378**	**0**

Accelerator Design Summary

- CLIC: Reducing support for CLIC-specific R&D
  - Future funding either directly from CERN or through ILC ART
  - Have a number of MOU Addenda but have been slow to fund
- LHC: Accelerator Development funds are used to develop proposals for LARP and to support students
  - LLRF and E-cloud feedback proposals but also partial support for the crab cavity design and synchrotron radiation monitor
- Project-X: supported R&D before PX funding was available
  - Funded through Fermilab in FY10 and FY11
- Super-B: Program needs direction
  - Path unclear of Italian Super-B does not move forward

Test Facility Operations

- Mission
  - Test facilities group was created to operate accelerator research test facilities under new Accelerator Directorate protocols
- Highlights
  - Incorporated NLCTA and ASTA and made significant improvements
  - Developing support for FACET experimental area
  - Charged with coordinating ESTB construction and operation

Acc Sci B&R

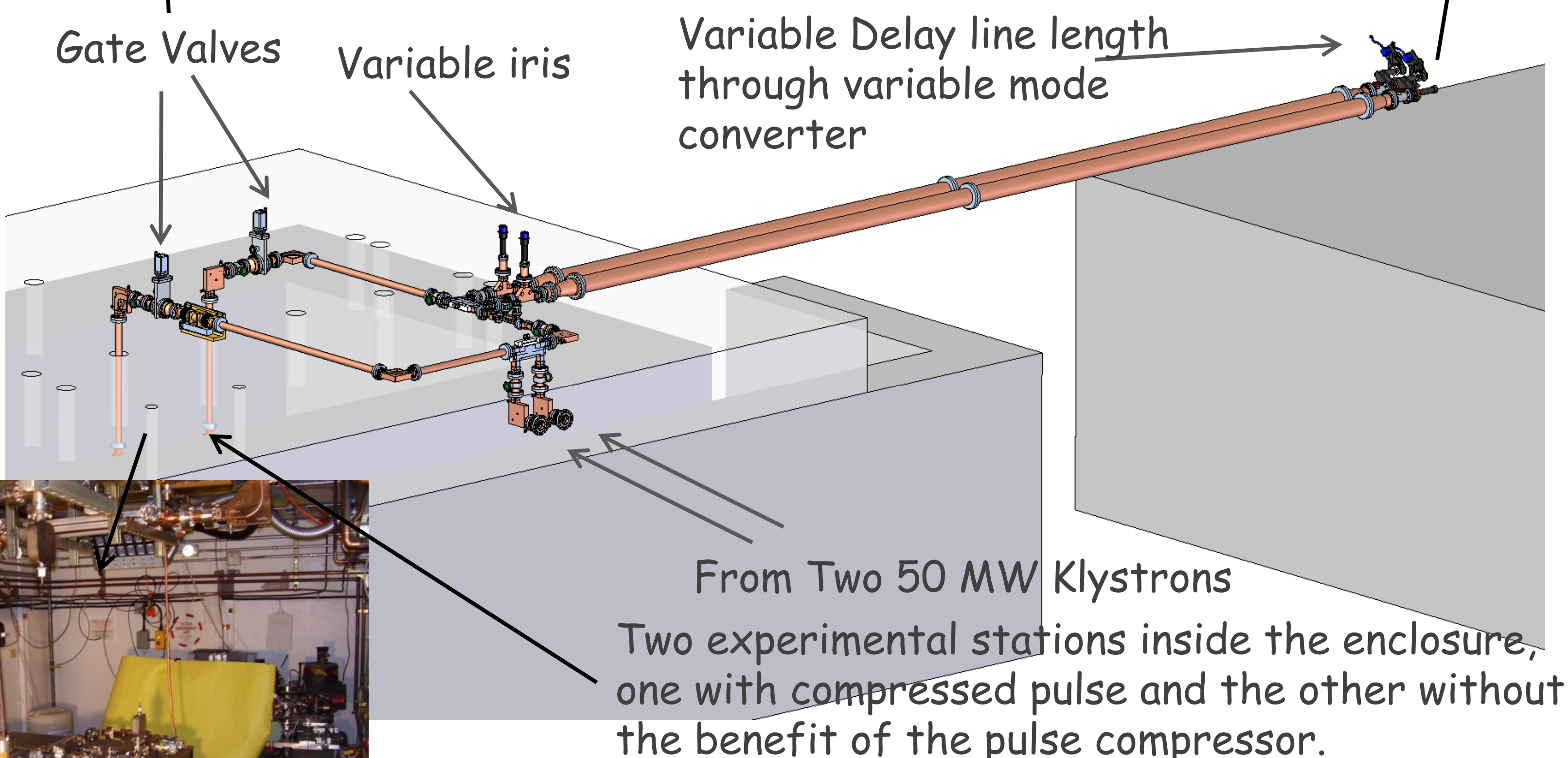
WBS4	WBS4 D	LSTM_SHORT	FY10 YTDACT	FY10 BDG K$	FY11 K$
8.06.04.03	NLCTA	Allocated OH	390		
		M&S	615		
		Shop	302		
		SLAC	295		
		Travel	0		
	NLCTA Total		**1,603**	**1,847**	**1,615**

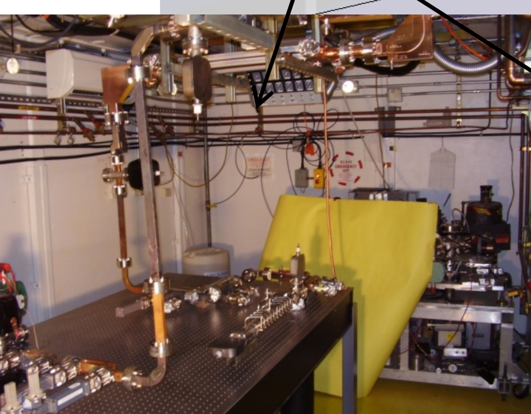
Acc Dev B&R

WBS4	WBS4 D	LSTM_SHORT	FY10 YTDACT	FY10 BDG K$	FY11 K$
8.06.04.XX	Test Facility Infrastructure	Allocated OH	140		
		M&S	9		
		Shop	109		
		SLAC	122		
		Travel	3		
	NLCTA Total		**383**	**562**	**732**

ASTA Test Facility

50 MeV capability
RF component testing
Future photocathode R&D
Rapid modifications possible

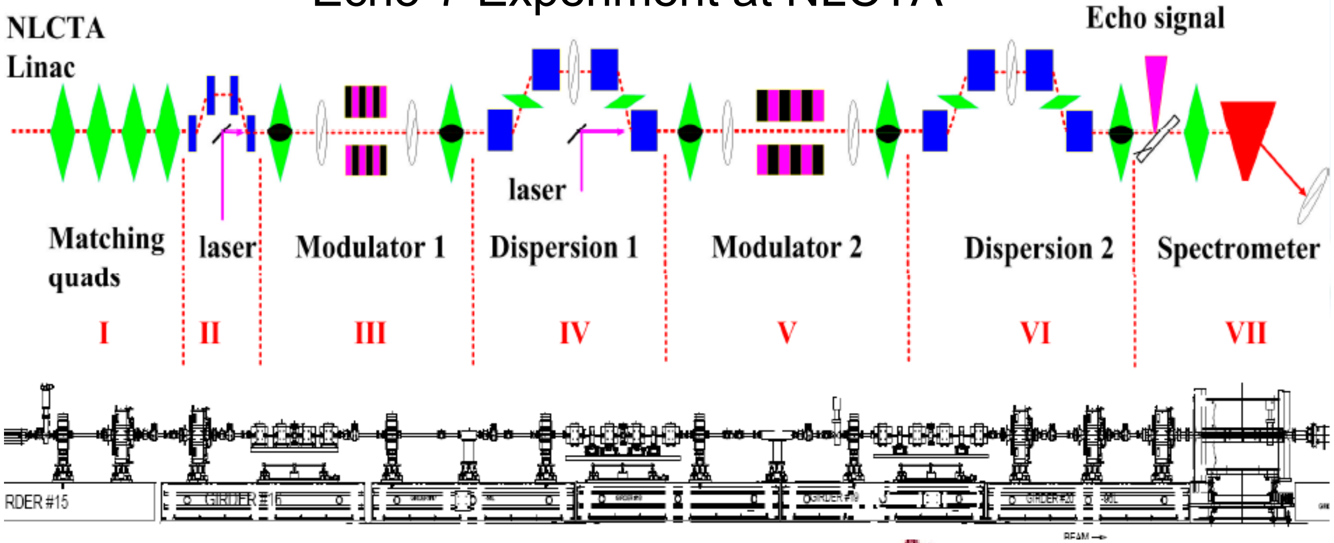




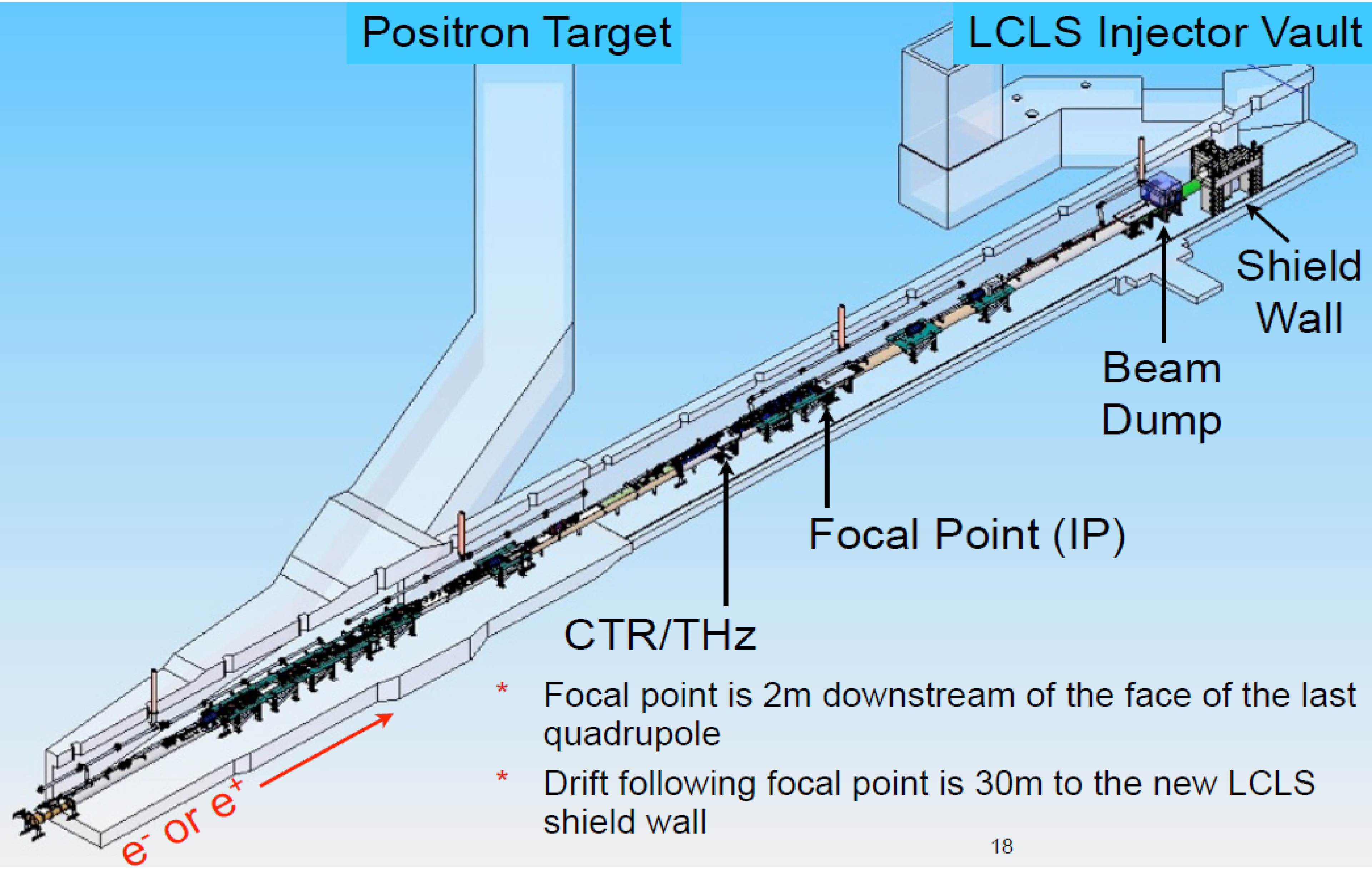
NLC Test Accelerator
RF Testing and Beam Dynamics

- Injector: 65MeV, ~0.3 nC / bunch
- 3 downstream X-band RF stations
  - 2 pulse compressors (240ns - 300MW max), driven each by 2 x 50MW X-band klystrons
  - 1 pulse compressors (400ns – 300MW /200ns – 500MW variable), driven by 2 x 50MW X-band klystrons.
- Shielding Enclosure:
  suitable up to 1 GeV
- S-band rf gun for low emittance beam and IR/UV laser systems for diagnostics and beam manipulation
- Extensive diagnostics to measure beam properties

Echo-7 Experiment at NLCTA



FACET Sector 20 Experimental Region



* Focal point is 2m downstream of the face of the last quadrupole
* Drift following focal point is 30m to the new LCLS shield wall

Test Facilities Summary

- Existing and upgraded accelerator R&D facilities
  - ASTA – rf test facility (50 MeV capability)
  - NLCTA – X-band linac (300 MeV capability)
  - End Station Test Beam – LCLS Linac (14 GeV)
  - FACET – SLAC Linac (23 GeV)
- Range in capability is important to support accelerator R&D
- Test Facilities group has taken charge of ARD Test Facilities as part of the new SLAC Accelerator Directorate
  - Full-cost accounting has increased costs for ESA/ESB/ASTA
  - Looking to expand programs into BES as well as HEP
- Created new experimental program review committee (SAREC) to review experimental accelerator R&D at SLAC

Accelerator Students and Postdocs

- Students
  - Panagiotis Baxevanis
  - *Alex Bullitt
  - *Joel Frederico
  - *Themis Mastoridis
  - *Derek Mendez
  - Rachik Laouar (visiting student)
  - *Chis McGuinness
  - Edgar Peralta
  - *Daniel Ratner
  - *Muhammad Shumail
  - *Ken Soong
  - *Ohzan Turgut
- Post-Docs
  - Jiquan Guo
  - *Yi Jiao
  - *Mike Litos
  - *Dao Xiang
  - Ziran Wu

* indicates contributions to poster session

Accelerator R&D Tour

- Tuesday (Tour 2a)
- Go to End Station B to visit:
  - X-band Development (Structure testing, HPRF)
  - L-band Development (Couplers, Modulators, HPRF)
  - E-163 Direct Laser Acceleration
  - FACET (posters)
  - ECHO-7 and beam dynamics
- Stop at ASTA on return to see:
  - X-band Research (Structure and component testing)
  - HGRF Materials Research (including SC materials)