Accelerator Facilities and R&D at SLAC

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Forum on Particle Accelerator Projects in Mexico: Present and Future

Guanajuato, Mexico

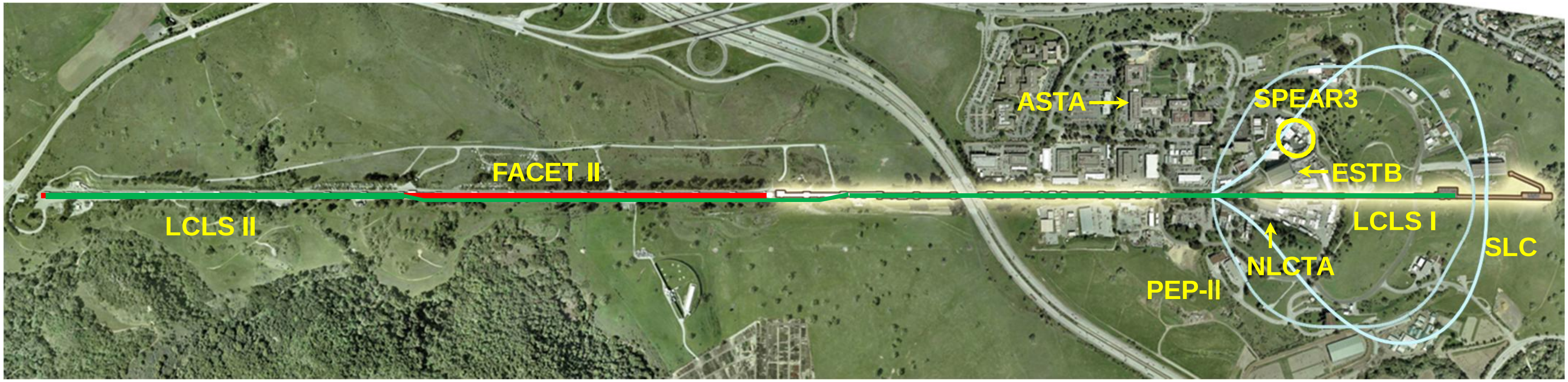
November 12, 2015

Outline

- **SLAC accelerator facility overview**
- **Light source development**
- **Advanced accelerator R&D program**
- **Accelerator technology development for multiple applications**

  (medical, security, industrial, environmental)

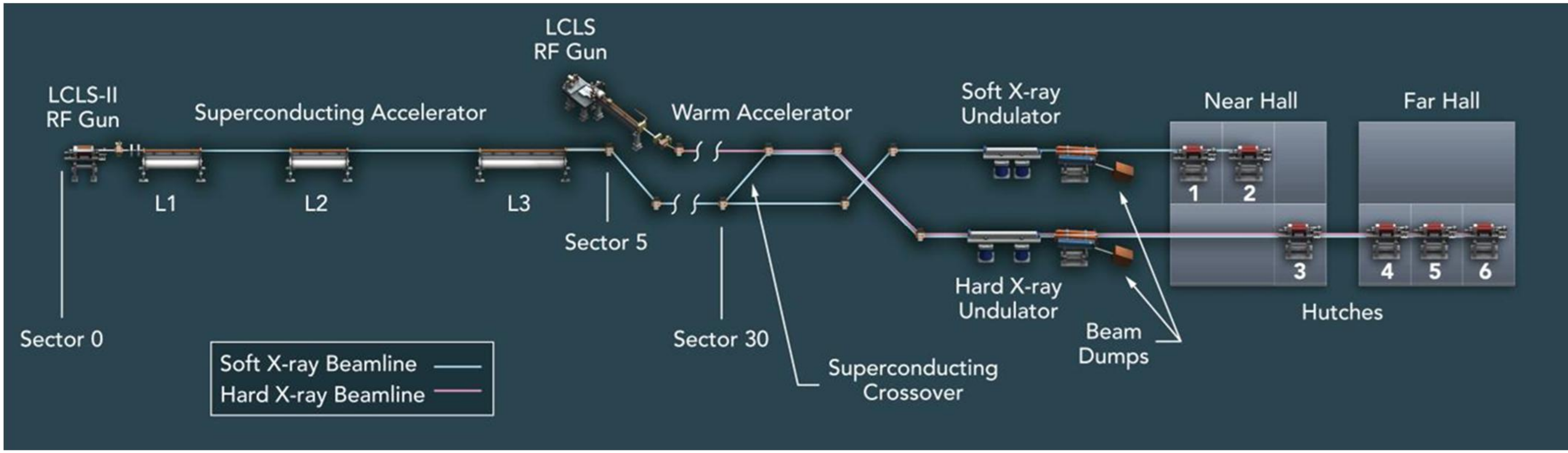
SLAC accelerator and test facilities

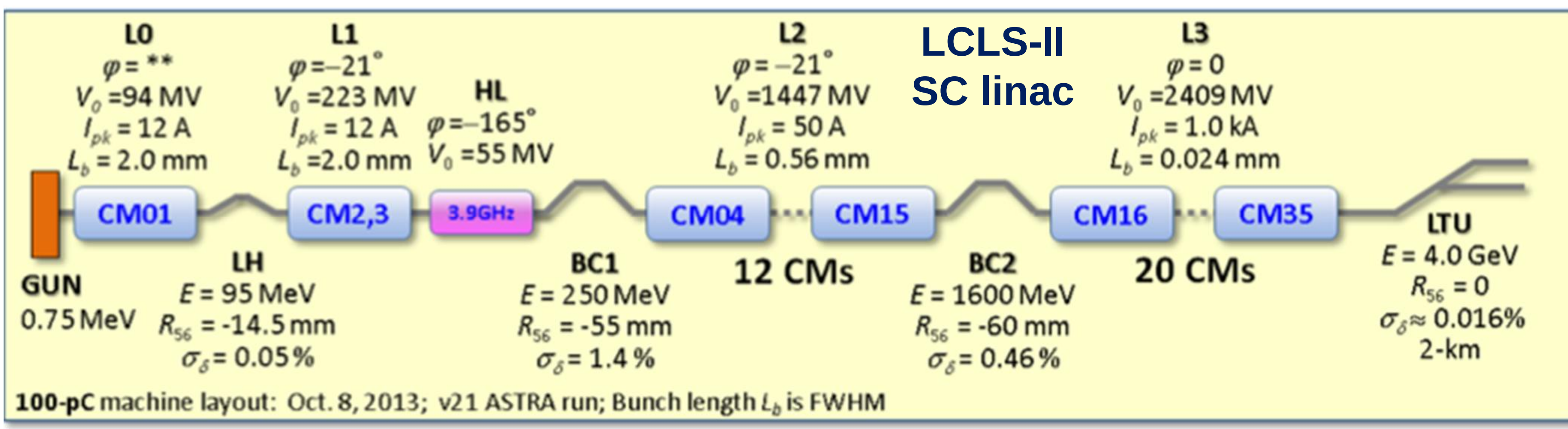


SLAC linac: > 50 years old


LCLS Injector (Sector 20)
LCLS Linac (Sectors 21-30)
LCLS Beam Transport
LCLS Undulator Hall
LCLS Near Experimental Hall
LCLS Office Building (901)
LCLS X-ray Transport/ Optics/Diagnostics
Endstation Systems
Endstation Systems
LCLS Far Experimental Hall (underground)

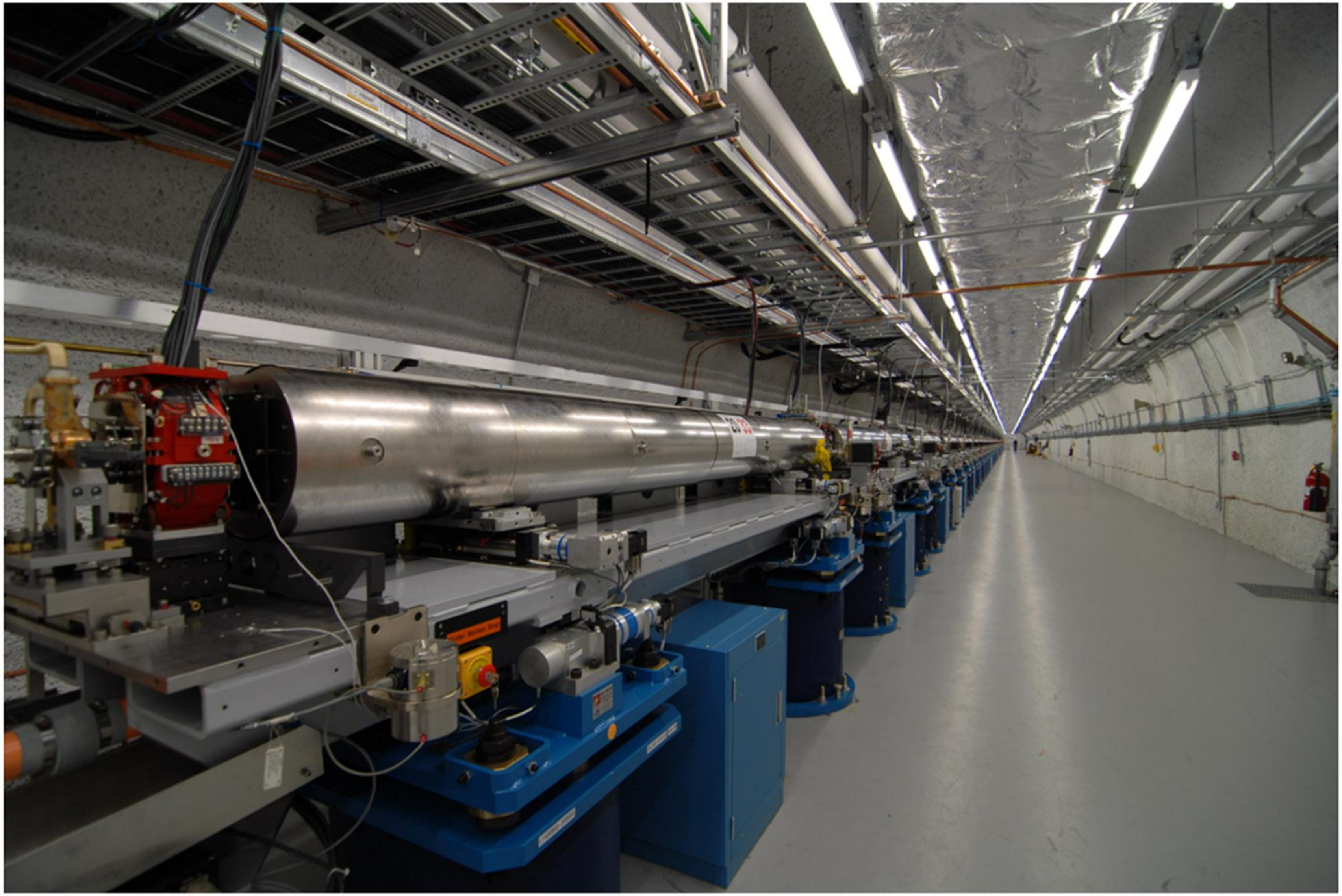
LCLS-I and II linacs



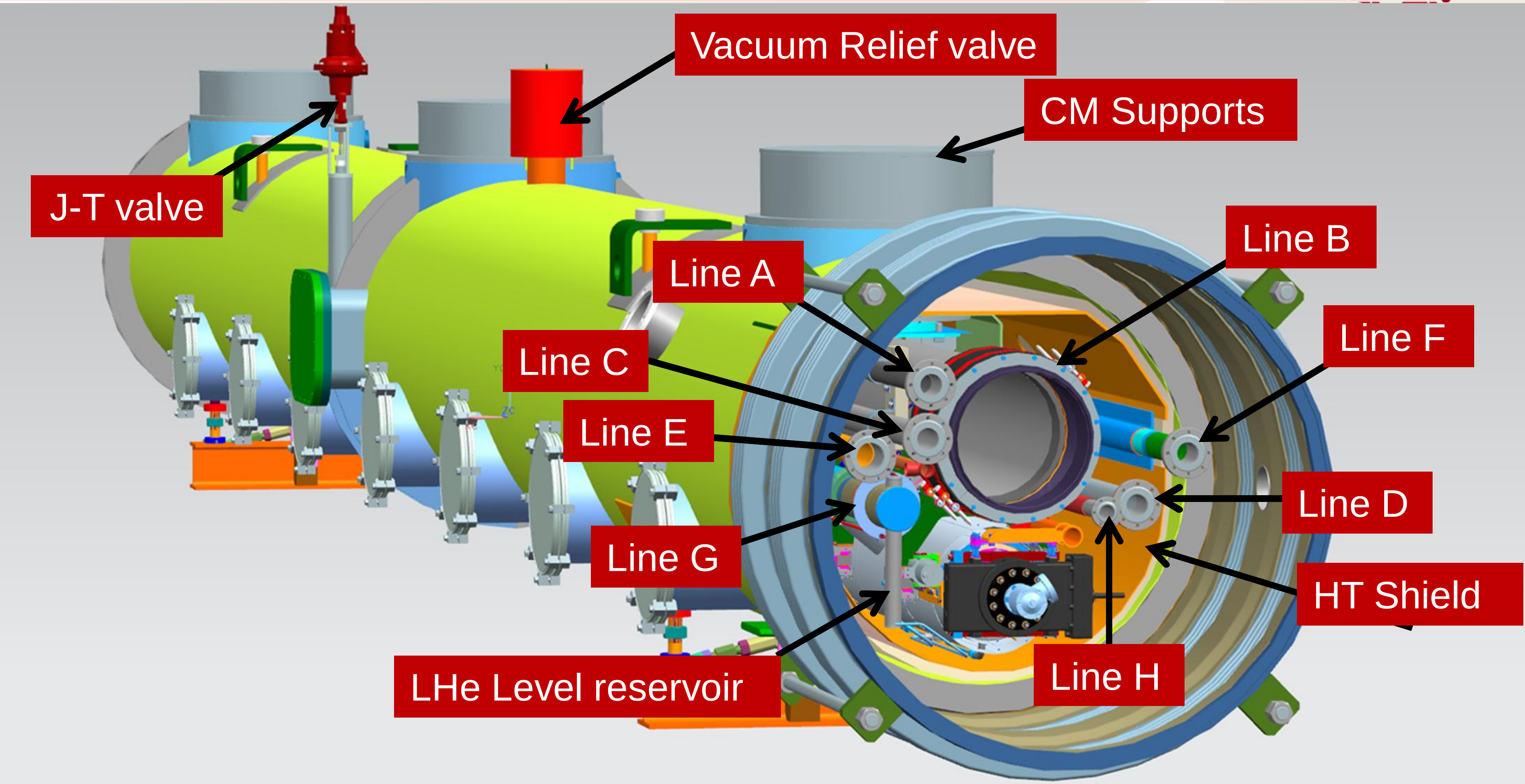


LCLS Undulator Hall: where X-rays are produced

SLAC



LCLS-II cryomodule in 3-D

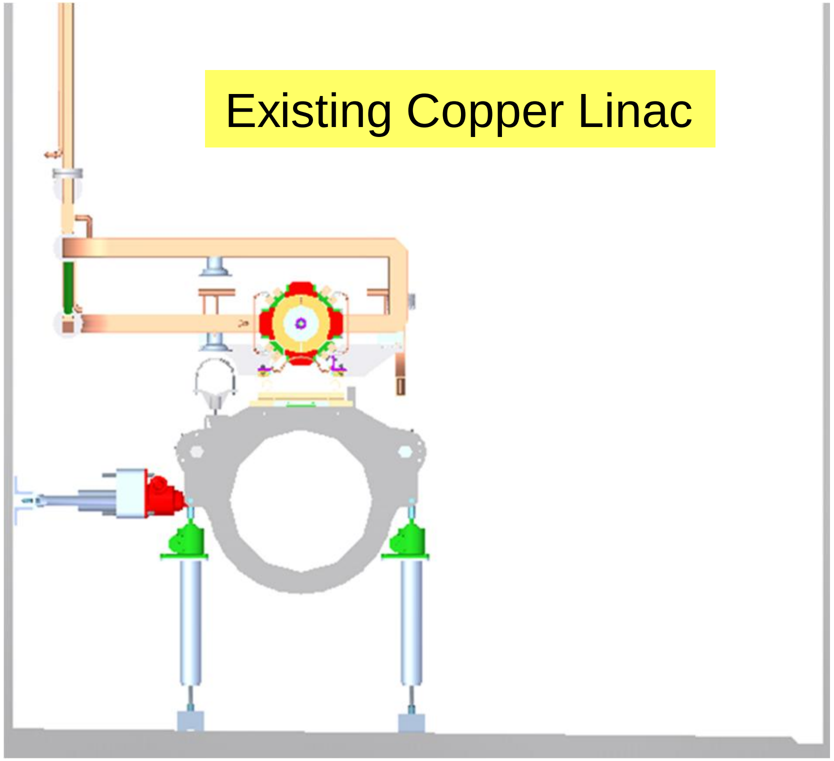


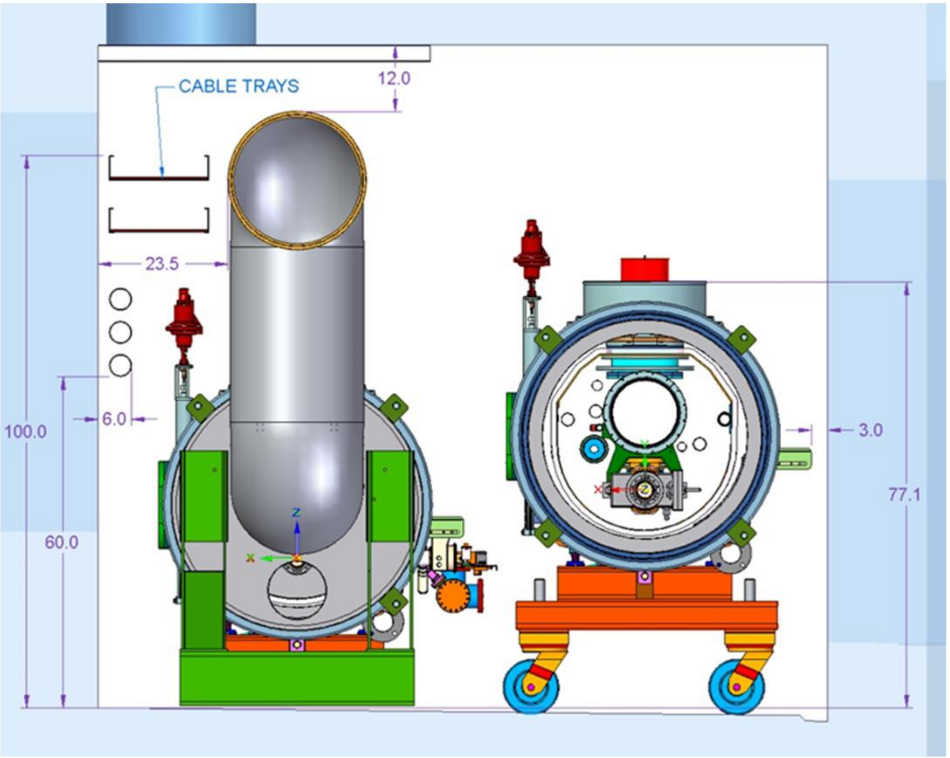
A. 2.2 K subcooled supply
B. Gas return pipe (GRP)
C. Low temperature intercept supply
D. Low temperature intercept return
E. High temperature shield supply
F. High temperature shield return
G. 2-phase pipe
H. Warm-up/cool-down line

Re-purposing the SLAC tunnel

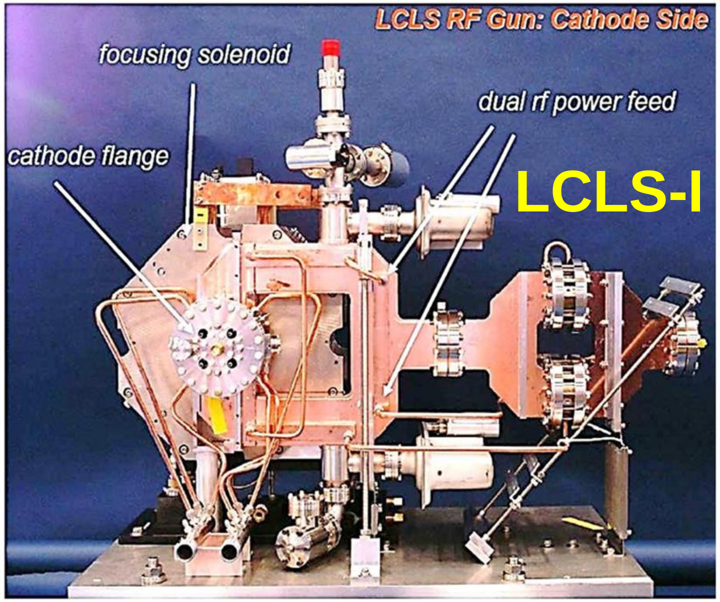
<u>SLAC Linac Tunnel: 11 wide x 10 feet high</u>

It will be a tight fit!



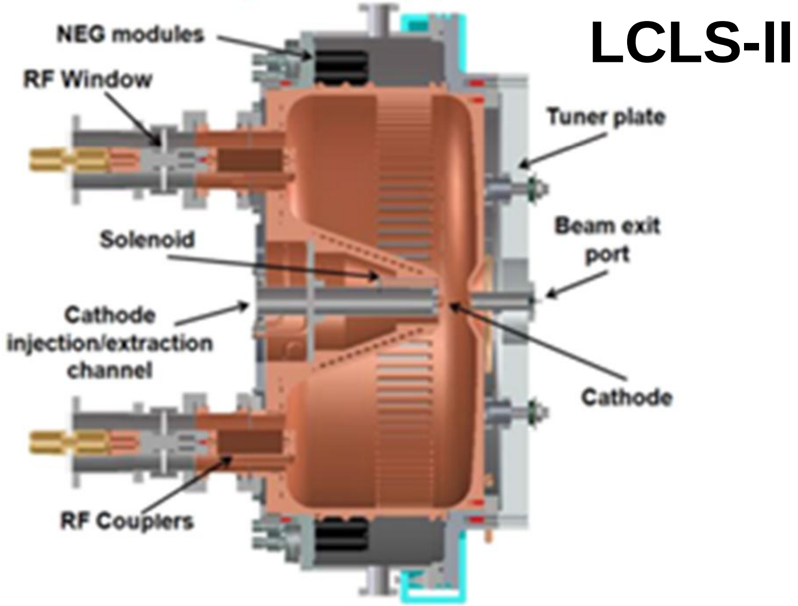


LCLS-I and LCLS-II photocathode guns



Gun Parameters	Nominal	Range
Frequency (MHz)	2856	-
Cathode Material	Cu	
QE [10^{-4}]	1.2	1-1.5
Charge [nC]	2	1-5
Peak RF Field [MV/m]	120	100-130
Peak RF Power [MW]	10	7-12
RF Repetition Rate [Hz]	120	1-360
Gun Energy [MeV]	6	5.5-6.2
Energy Spread [keV]	~1	0.1-5

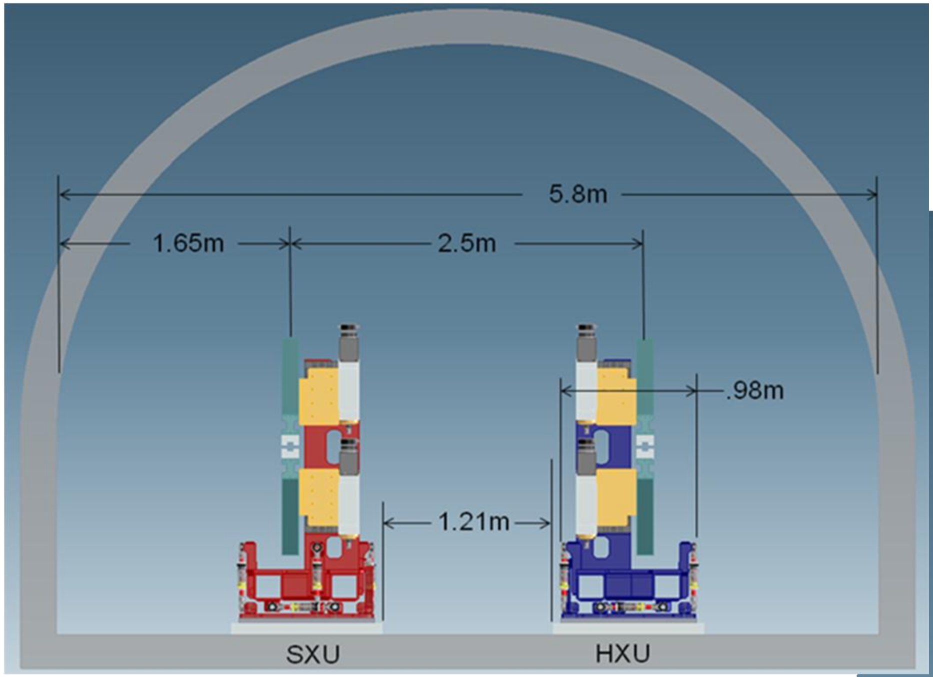
Frequency	186 MHz
Operation mode	CW
Gap voltage	750 kV
Field at the cathode	19.47 MV/m
Q_0 (ideal copper)	30887
Shunt impedance	6.5 MΩ
RF Power @ Q_0	87.5 kW
Stored energy	2.3 J
Peak surface field	24.1 MV/m
Peak wall power density	25.0 W/cm²



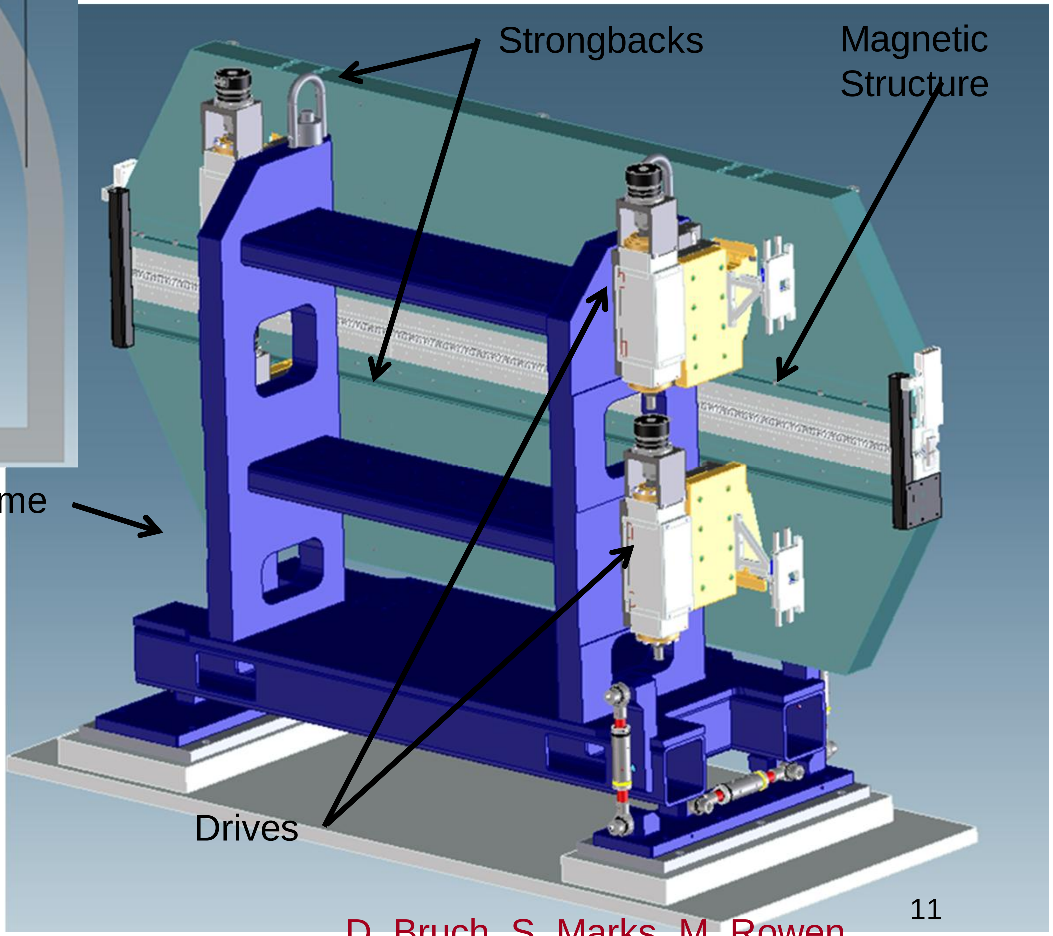
J. Staples, F. Sannibale, S. Virostek, CBP Tech Note 366, Oct. 2006

K. Baptiste, et al, NIM A 599, 9 (2009)

Replace existing LCLS undulator with HXR and add SXR



LBNL VG Undulator Design



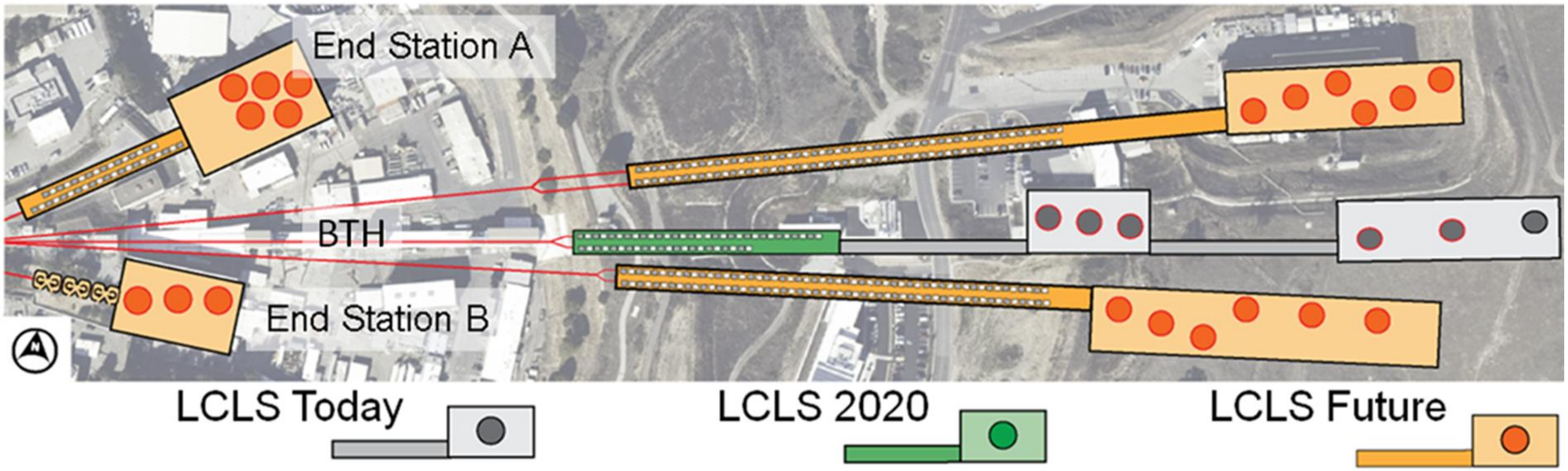
Well on our way to a full scale prototype as part of LCLS-II$_{\text{Phase I}}$

D. Bruch, S. Marks, M. Rowen

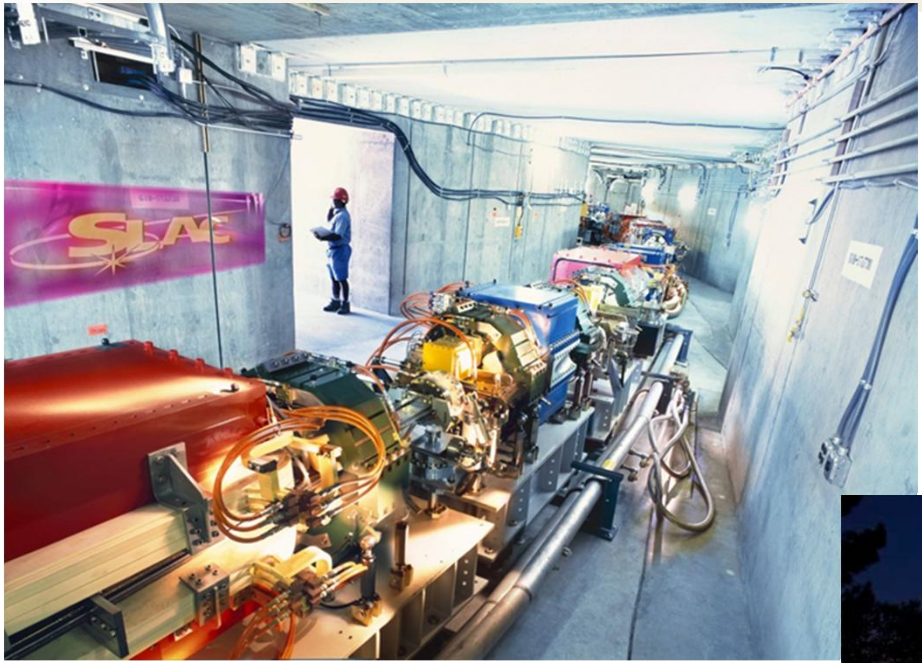
Future LCLS facility expansion

SLAC has extensive infrastructure that will allow expansion

- New tunnels are possible north and south of existing LCLS tunnel (complete design for LCLS-II$_{\text{Phase I}}$) and could be optimized for long, high pulse energy, hard X-ray FEL's
- Original research halls: ESA and ESB suitable for shorter, soft X-ray FEL's



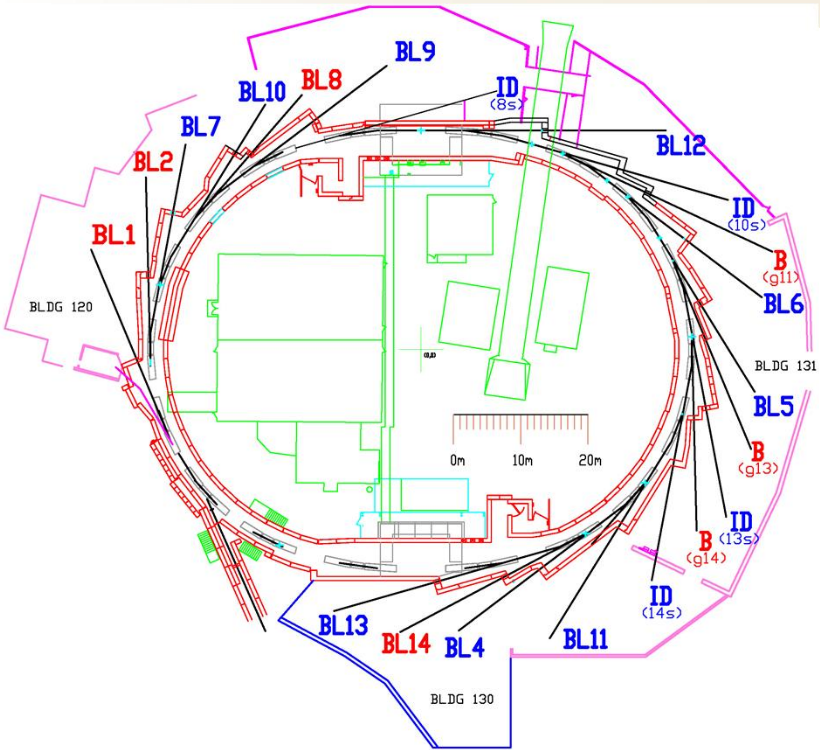
SPEAR3: a light source for SSRL

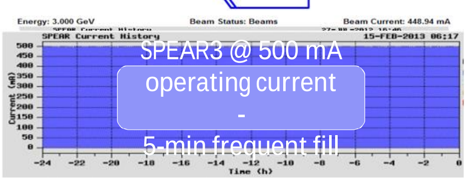


- 3 GeV, 500 mA
- Top-off injection every 5 minutes
- 9.8 nm-rad emittance → <u>6 nm-rad</u>
- SPEAR3 MTBF 87 hrs
- 5200 hours @ 98.4% uptime (FY14)

- SSRL operates 26 BL w/32 stations
  - Full build-out ~36 beam lines
- SSRL supports ~1,600 user annually
  - Annual growth ~5%
  - Could support 2,200+ users
- >500 journal pubs/yr ~ 28% hi-impact
- ~90 thesis per year

SSRL Beamlines





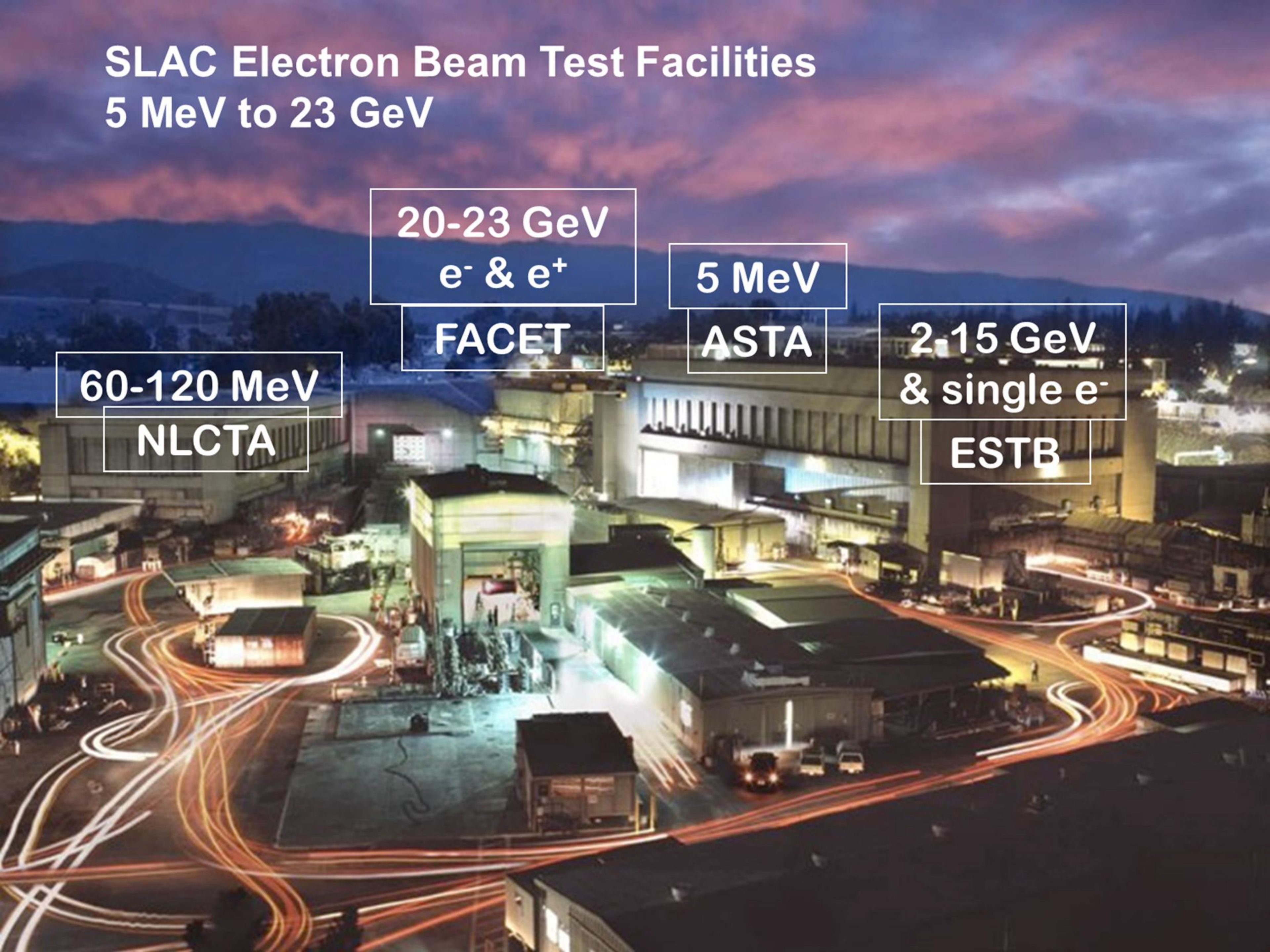
SPEAR3 @ 500 mA operating current - 5-min frequent fill

A: Applied Sciences
G: Geosciences
M: Materials Sciences
C: Chemical Sciences
L: Life Sciences
P: Physical Sciences

Full/partial BES supported
Non-BES supported (Structural Molecular Biology)

Beam Line	Source Type	Area of Research	Major Techniques
Materials			
BL1-5 / Facility	BM	M, A, C, G	Small and Wide Angle X-ray Scattering
BL2-1 / Facility	BM	M, A, P	Powder/Thin Film Diffraction
BL7-2 / Facility	ID/W	M, P, C, G	X-ray Scattering
BL10-2b / Facility	ID/W	M, P, L, G	X-ray Scattering
BL11-3 / Facility	ID/W	M, A, C	X-ray Diffraction
BL6-2c / Facility	ID/W	C, M, L, A, G	Transmission X-ray Microscopy
BL5-4 / Partner	ID/U	P, M	Angle Resolved Photoemission Spectroscopy
BL8-1 / Facility	BM	M, A	Core Level & Valence Band Photoemission Spectroscopy
BL8-2 / Facility	BM	M, A, C	Photoemission Spectroscopy
BL10-1 / Facility	ID/W	M, C, L, A	Photoemission Spectroscopy, NEXAFS
BL13-1 / Facility	ID/U	M, P	Soft X-ray Scanning Transmission X-ray Microscopy
BL13-2 / Partner	ID/U	C, M	Soft X-ray Photoemission Spectroscopy / XAS
BL13-3 / Facility	ID/U	M, P	Soft X-ray Coherent Scattering
Chemistry/Catalysis			
BL2-2 / Facility	BM	A, P	X-ray Absorption Spectroscopy / MicroXAS Imaging
BL2-3 / Facility	BM	L, G, C, M	MicroXAS Imaging
BL4-1 / Facility	ID/W	G, C, M, A	X-ray Absorption Spectroscopy
BL4-3 / Facility	ID/W	C, G, L, M	X-ray Absorption Spectroscopy
BL6-2b / Facility	ID/W	C, M, L, A, G	XES, RIXS, X-ray Raman, (XAS Imaging)
BL10-2a / Facility	ID/W	M, P, L, G	XAS Imaging
BL11-2 / Facility	ID/W	G, C	X-ray Absorption Spectroscopy
BL14-3a / Facility	BM	L, G, C, M	Tender X-ray XAS
BL14-3b / Facility	BM	L, G, C, M	Tender X-ray MicroXAS Imaging
BL7-3 / Facility	ID/W	L, C	X-ray Absorption Spectroscopy
BL9-3 / Facility	ID/W	L	X-ray Absorption Spectroscopy
SMB			
BL4-2 / Facility	ID/W	L, M	Small Angle X-ray Scattering/Diffraction
BL7-1 / Facility	ID/W	L	Macromolecular Crystallography
BL9-1 / Facility	ID/W	L	Macromolecular Crystallography (R&D)
BL9-2 / Facility	ID/W	L	Macromolecular Crystallography
BL11-1 / PRT	ID/W	L	Macromolecular Crystallography
BL12-2 / PRT	ID/U	L	Macromolecular Crystallography
BL14-1 / Partner	BM	L	Macromolecular Crystallography

SLAC Electron Beam Test Facilities
5 MeV to 23 GeV



SLAC Accelerator Test Facilities

FACET (Facility for Advanced Accelerator Experimental Tests, 20 GeV):

- High gradient acceleration techniques (e.g. PWFA)
- High brightness beam and novel radiation techniques (e.g. for FELs, THz, γ-rays)
- High speed material science (e.g. fs magnetic switching)

NLCTA (NLC Test Accelerator, ~200 MeV X-band):

- X-band technology development (gun, linac, tcav, rf undulator, etc.)
- FEL seeding and beam manipulation R&D (BES)
- Direct laser acceleration
- Medical radiation tests

ESTB (End Station Test Beam, 2-16 GeV, single e-):

- Detector R&D, LC MDI, radiation tests

ASTA (Accelerator Structure Test Area, < 50 MeV, S- and X-band power):

- Gun and RF structure testing and processing (HEP and BES)
- UED (BES)

FACET is a National User Facility

Primary Goal: Demonstrate a single-stage high-energy plasma accelerator for electrons.

- Meter scale ✓
- High gradient ✓
- Preserved emittance
- Low energy spread ✓
- High efficiency ✓

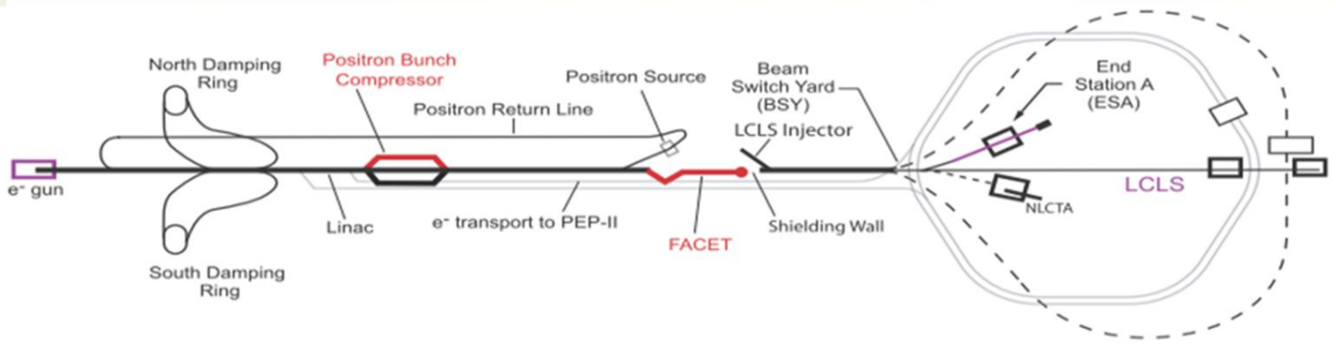
Timeline:

- Commissioning (2012) ✓
- Drive & witness e^- bunch (2012-2013) ✓
- Optimization of e^- acceleration (2013-2015)
- First high-gradient e^+ PWFA (2014-2016)

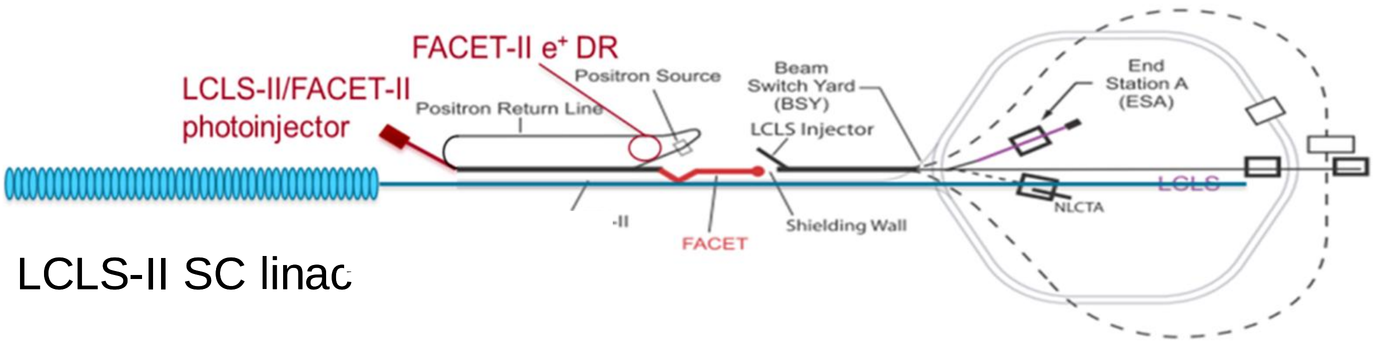
FACET user program is based on high-energy high-brightness beams and their interaction with plasmas and lasers

From FACET to FACET-II

FACET today



FACET-II



Three main stages:

- electron beam photoinjector (e$^-$ beam only)
- positron damping ring (e$^+$ or e$^-$ beams)
- “sailboat” chicane (e$^+$ and e$^-$ beams)

Benefits of particle accelerators

Today, besides their role in scientific discovery, particle beams from some 30,000 accelerators are at work worldwide in areas ranging from diagnosing and treating disease to powering industrial processes

The accelerators of tomorrow promise still greater opportunities:

- Next-generation particle beams represent cheaper, greener alternatives to traditional industrial processes.
- They can give us clean energy through safer nuclear power, with far less waste.
- They can clean up polluted air and water; deliver targeted cancer treatment with minimal side effects.
- They contribute to the development of new materials.
- As tools for inspecting cargo and improving the monitoring of test ban
- compliance, accelerators can strengthen the nation's security.
- And of course they serve as tools for scientific discovery for high energy physics, nuclear physics, materials and chemical sciences, etc.

Overall goals for SLAC Accelerator Directorate

Maintain world-class accelerator science program

- World-class programs in beam physics theory, advanced computation, and accelerator design
- Operate SLAC's unique accelerators and test facilities
- Develop plasma- and laser-based advanced acceleration concepts

Maintain a crucial, enabling role in technology development for future energy frontier colliders and other applications

Maintain NC technology support base for applications across OS

Develop novel RF source and accelerator technology for higher efficiency and compactness – from MHz to THz

Develop and industrialize RF sources for future accelerators

Establish customer base for RF technology developed by SLAC (including medical applications)

Train next generation of accelerator scientists and engineers

Light Source and Related Technology Development

The world is moving to ever brighter ring sources

SLAC

2-bend achromat

BNL: NSLS-II (2014): 3 GeV,
<1000pm x 8 pm, 500 mA (New)

7- bend achromat

Sweden: MAX-4 (2016): 3 GeV,
230 pm x 8 pm, 500 mA (New)

5- bend achromat

Brazil: SIRIUS (2016/17): 3 GeV,
280 pm x 8 pm, 500 mA (New)

1st multi-bend achromat ring upgrade

France: ESRF-II (2020): 6 GeV,
160 pm x 3 pm, 200 mA (New)

U.S. Proposals

APS-U: 6 GeV, 60 pm x 8 pm,
200 mA (Upgrade Proposal)

ALS-U: 2 GeV, 50 pm x 50 pm,
500 mA (Upgrade proposal)

Other possible 4GSRs: Japan (Spring 8, 6 GeV), China (HEPS, 6 GeV), Germany (PETRA-IV), France (SOLEIL), Switzerland (SLS, 2.4 GeV), Italy (ELETTRA) and others are developing plans

Science case for brighter, more coherent sources

Scientific Opportunity

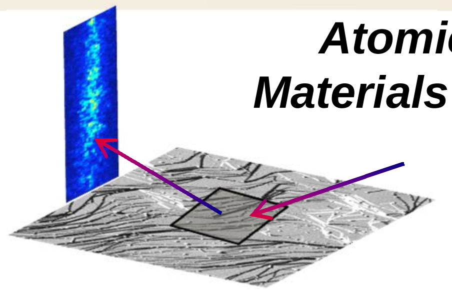
Understanding and control of ***nanometer-scale heterogeneity and fluctuation dynamics*** in matter.

Breakthrough Techniques

Transverse coherence (i) enhances **coherent diffraction imaging**, (ii) allows **nanoscale spectroscopies**, and (iii) transforms **photon correlation spectroscopy**.

Simultaneous Advances in Theory and Experiment

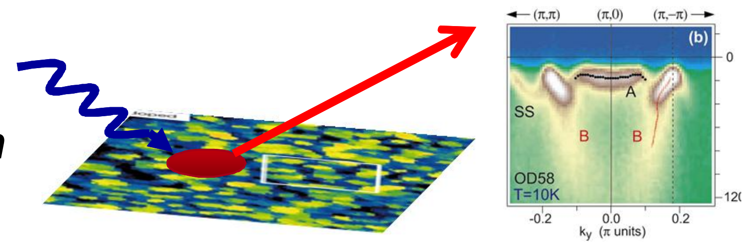
Length/time scales of theory and experiment are converging. DLSRs provide probes for systems that can be simulated with high fidelity.



Atomic-to-Nanoscale Control in Materials Synthesis and Functionality

Synthesis: nm Imaging and ns Dynamics via Coherent Scattering in Challenging Environments

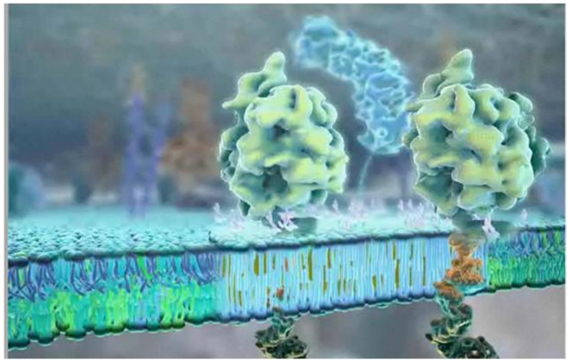
Intrinsic Electronic Heterogeneity in Correlated Electron Materials



Superconductors and Magnetic Materials: Electronic Structure with Sub 10-nm Spatial Resolution

Structure and Dynamics of Biological Materials

Lipid Rafts: Membrane Protein Structure and Dynamics in Non-Periodic Environments



Spectral brightness and coherence

Spectral brightness: photon density in 6D phase space

$$B_{avg}(\lambda) \propto \frac{N_{ph}(\lambda)}{(\varepsilon_x(e-) \oplus \varepsilon_r(\lambda))(\varepsilon_y(e-) \oplus \varepsilon_r(\lambda))(s \cdot \%BW)}$$

Coherent fraction:

$$f_{coh}(\lambda) = \frac{\varepsilon_r(\lambda)}{(\varepsilon_x(e-) \oplus \varepsilon_r(\lambda))} \cdot \frac{\varepsilon_r(\lambda)}{(\varepsilon_y(e-) \oplus \varepsilon_r(\lambda))}$$

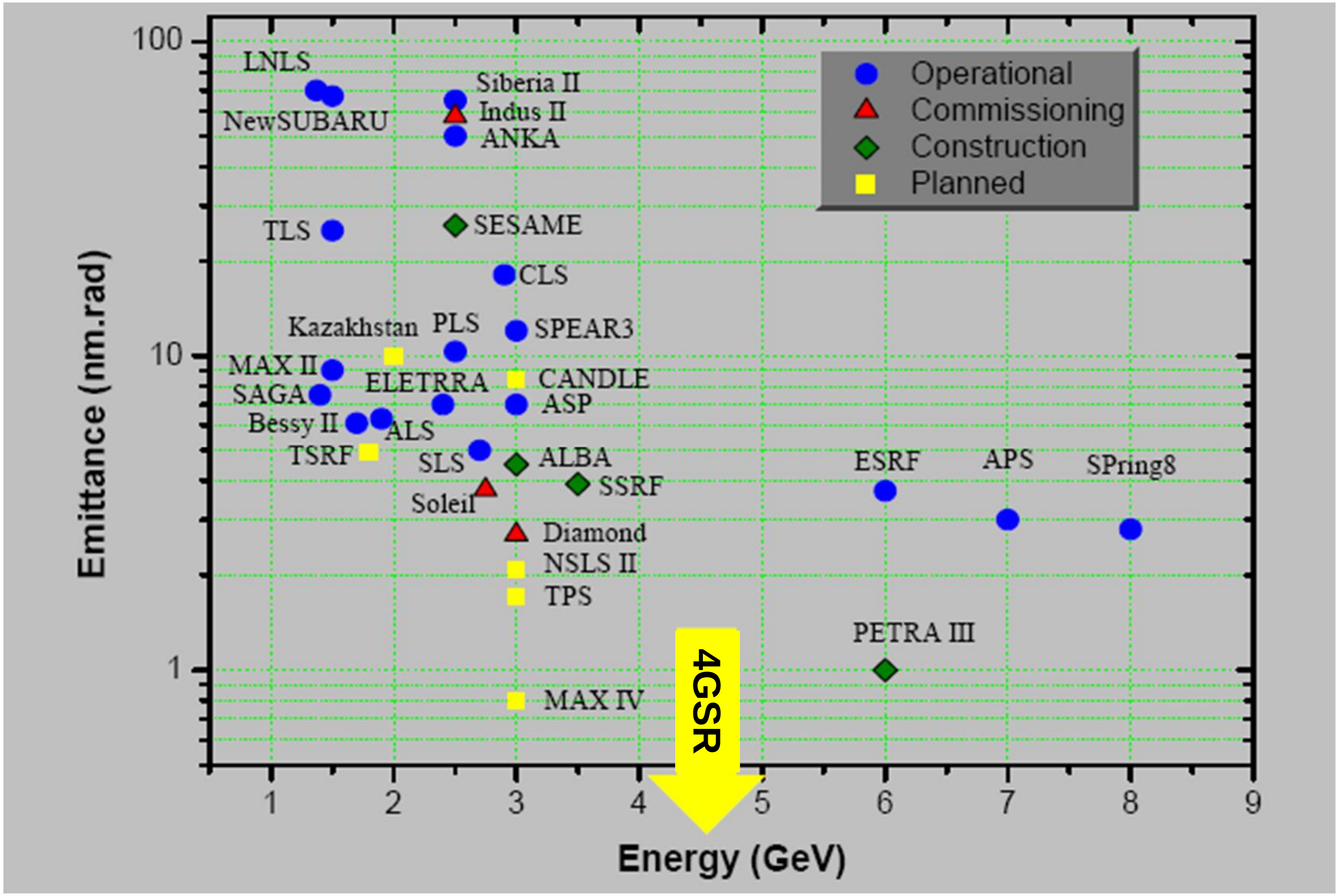
Coherent flux:

$$F_{coh}(\lambda) = f_{coh}(\lambda) \cdot F(\lambda) = B_{avg}(\lambda) \cdot \left(\frac{\lambda}{2}\right)^2$$

$$\boldsymbol{\varepsilon_0(e-) = F(\nu, \text{cell}) \frac{E^2}{N_{dip}{}^3} \propto \frac{E^2}{C^3}}$$

$$\boldsymbol{\varepsilon_r(\lambda) \approx \frac{\lambda}{2\pi}}$$ **(= 16 pm for λ = 1Å)**

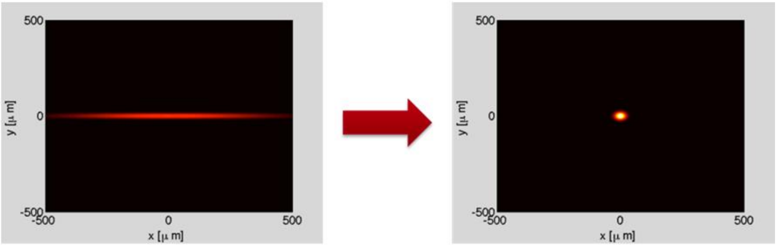
The state of SR light sources



Z. Zhao, SSRF

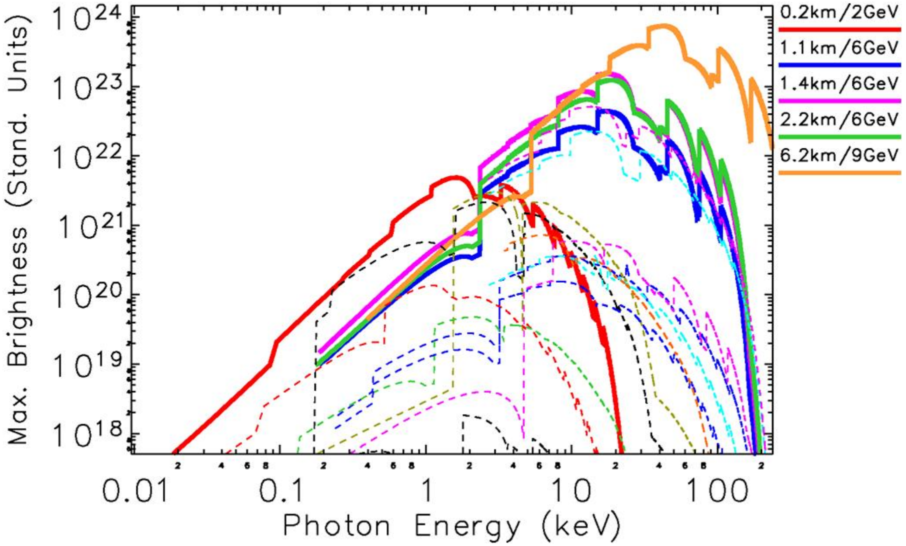
Properties of 4GSRs

- Small horizontal and vertical beam dimensions and the possibility of "round" beams – good for X-ray optics, minimal need for aperturing

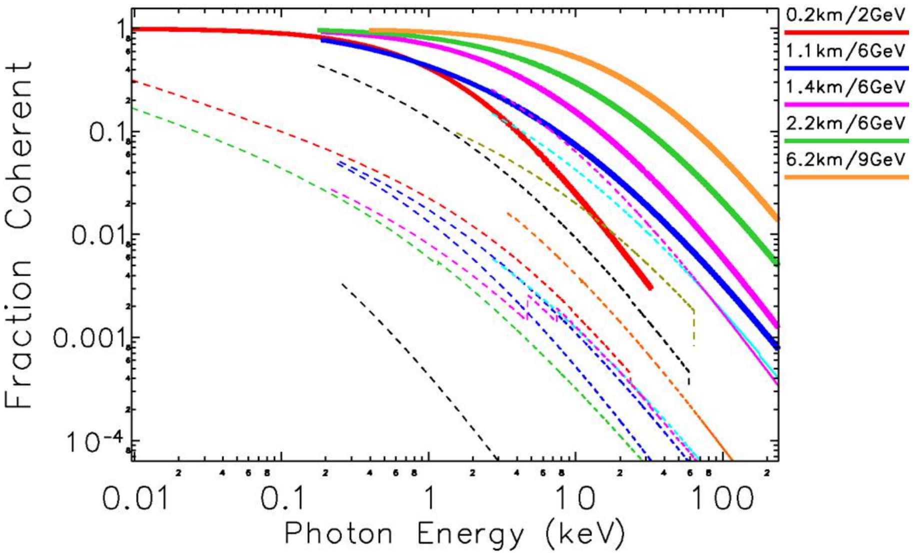


courtesy of C. Steier

Brightness



Coherent Fraction



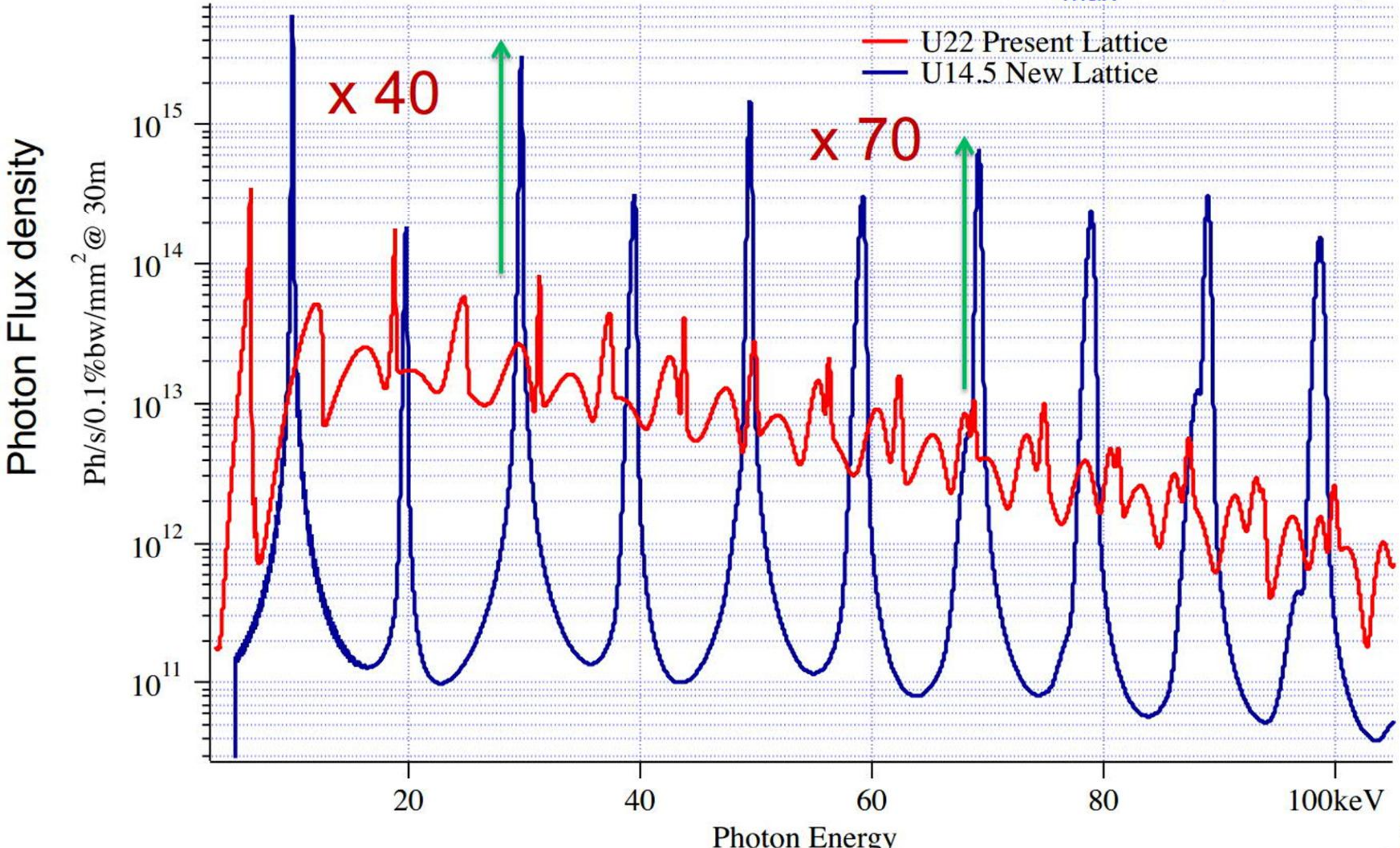
Parameters provided by facility contacts.

Compiled by M. Borland for BESAC Sub-Committee meeting, July 2013.

Properties of 4GSRs – cont.

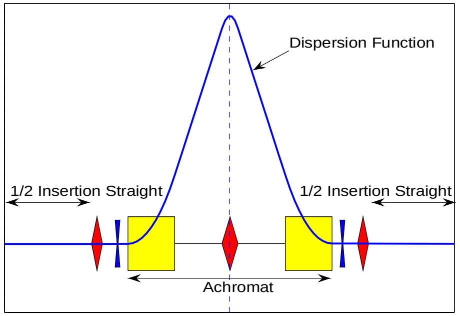
2 m IVUs & CPMUs: U22 Min. Gap 6 mm, K_{max}=1.7

U14.5 Min. Gap 4 mm, K_{max}=1.7 (CPMU)

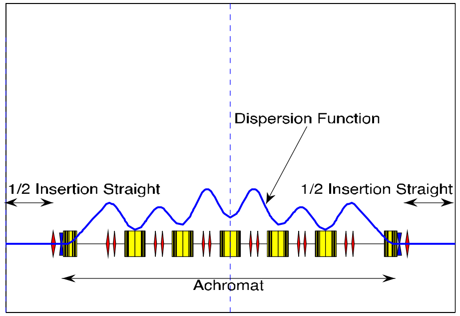


4GSRs: why now and not earlier?

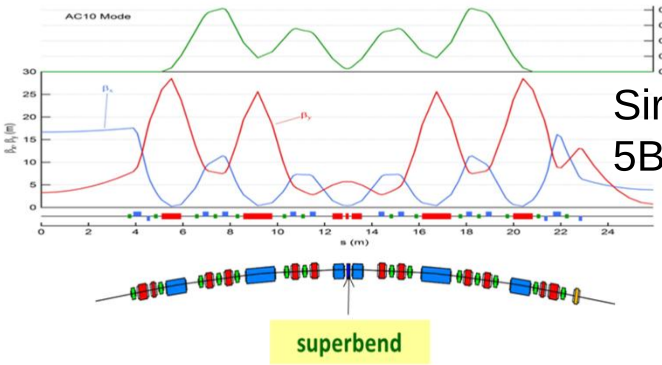
DBA



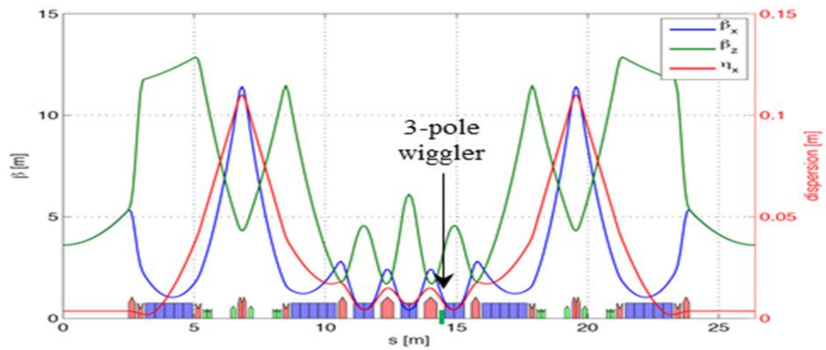
7BA



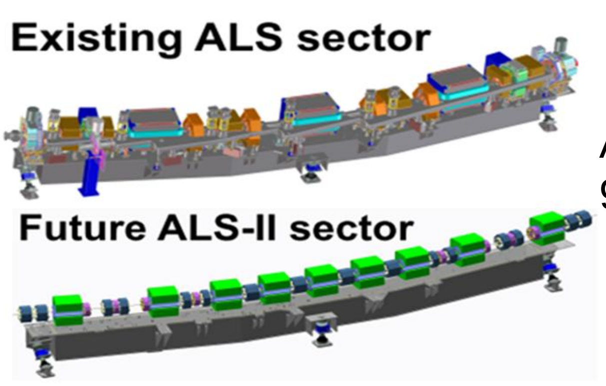
proposed by D. Einfeld and others in mid-1990s, implemented for MAX-IV



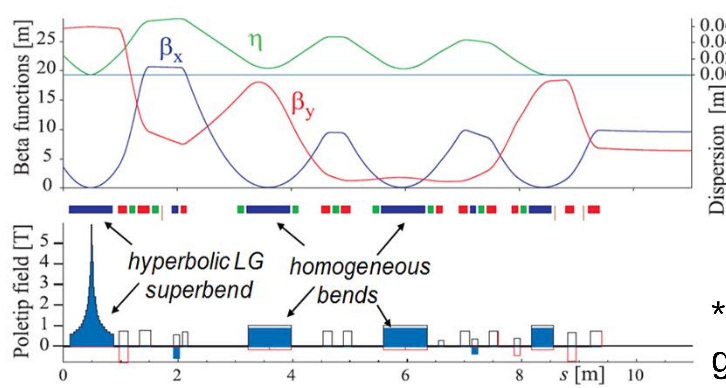
Sirius 5BA



ESRF hybrid 7BA + LGDs*; APS-U similar



ALS-U 9BA



SLS reverse bend + LGDs

*LGD: longitudinal gradient dipole

4GSRs: why now? – cont.

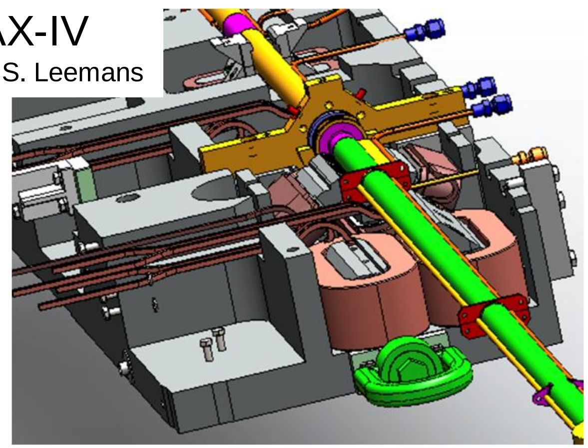
Compact magnet and vacuum technology

- **NEG-coated vacuum chambers** enable small apertures to enable high magnet gradients

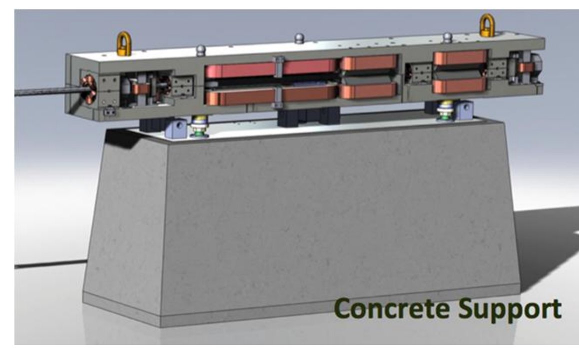
  Pioneered at CERN, used extensively at Soleil, and adopted for MAX-IV and Sirius MBA lattices

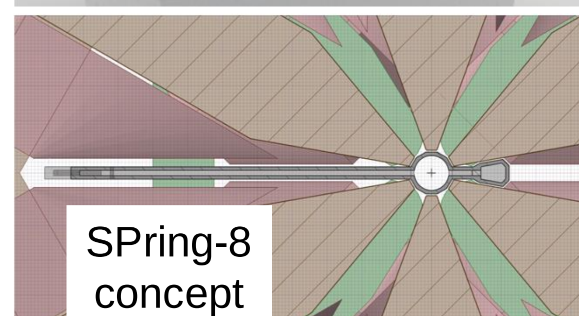
- **Precision magnet pole machining** for small aperture magnets, **combined function magnets**, tolerance for magnet crosstalk (e.g. MAX-Lab)

MAX-IV
Courtesy S. Leemans



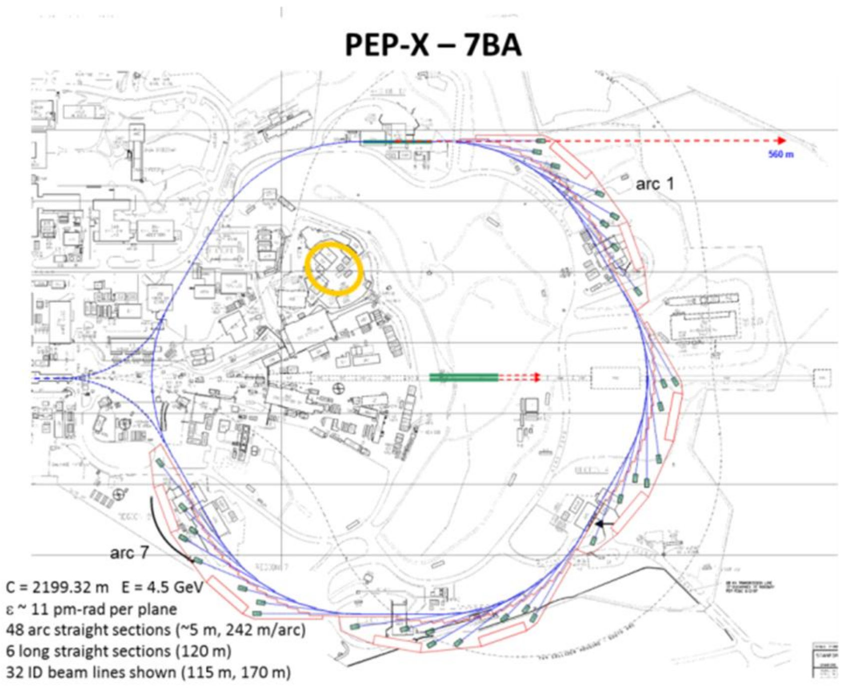
heater tape for in-situ NEG bake-out Sirius

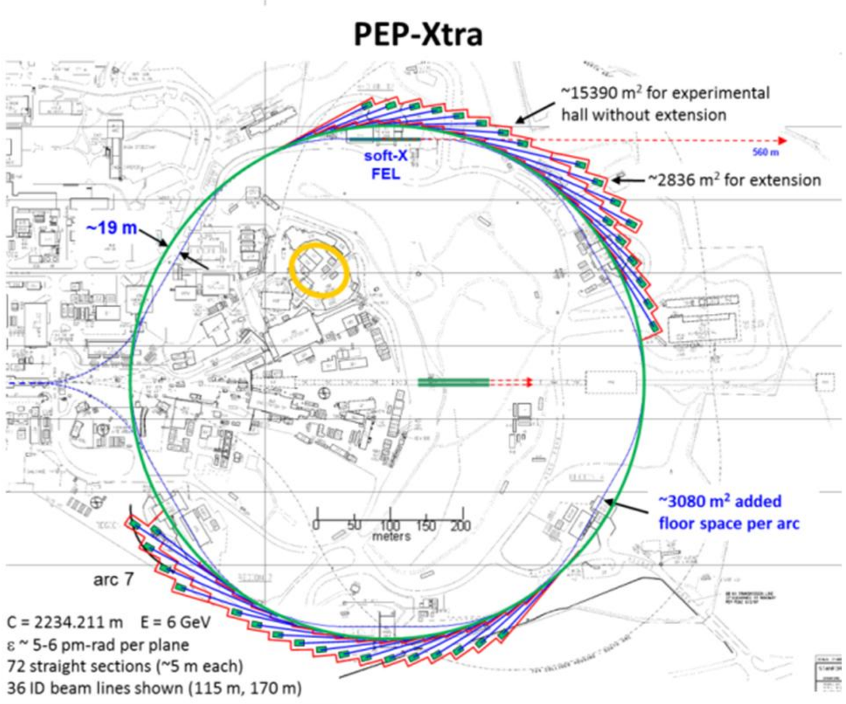




SPring-8 concept
K. Soutome

SSRL Future: PEP-X?





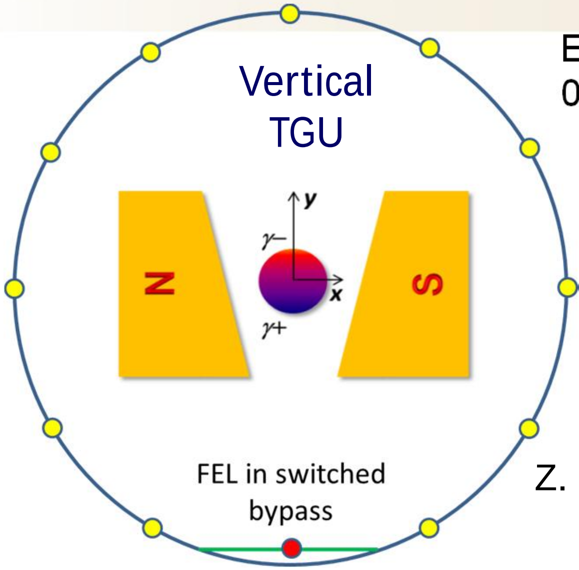
11 pm per plane @ 6 GeV, 200 mA

< 5 pm per plane @ 6 GeV, 200 mA

diffraction-limited emittance for 1 Å ($\lambda/4\pi$ - $\lambda/2\pi$) = 8-16 pm-rad

Note: an ERL is also considered for PEP-X

SASE on DLSR with transverse gradient undulator



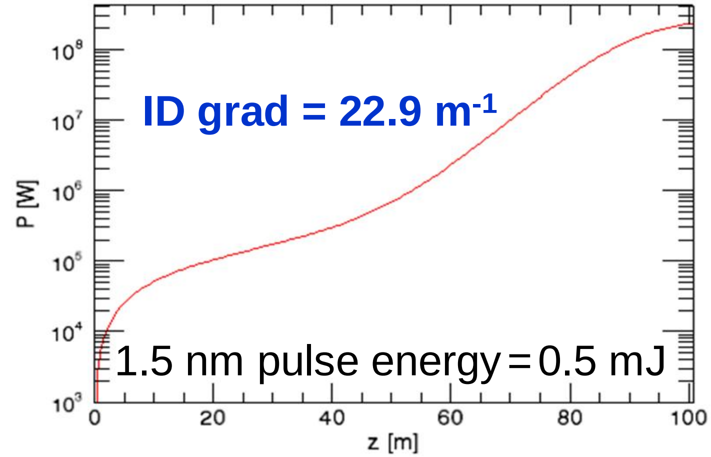
E = 4.5 GeV $\varepsilon_{x/y}$=160 / 1.6 pm $\delta E/E = 1.6\mathrm{x}10^{-3}$ rms   Q = 0.75 nC η_y = 0.05 m $\beta_{x/y}$ = 16 / 50 m σ_β = 52 mm σ_η = 78 mm λ_u = 3 cm K = 3.7

σ_z= 1ps I_{pk} = 300 A λ_{ph} = 1.5 nm

Bunch switched into FEL bypass (10-100 kHz)

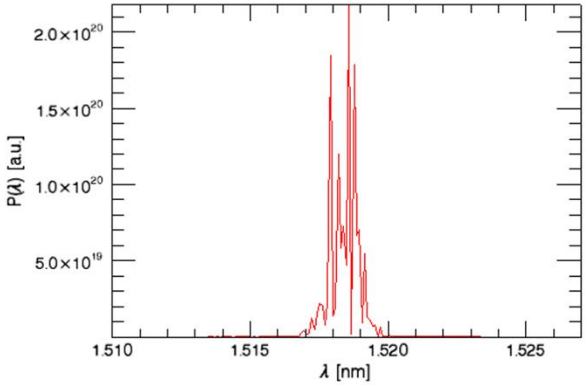
Z. Huang, Y. Cai, Y. Ding

IPAC 2013



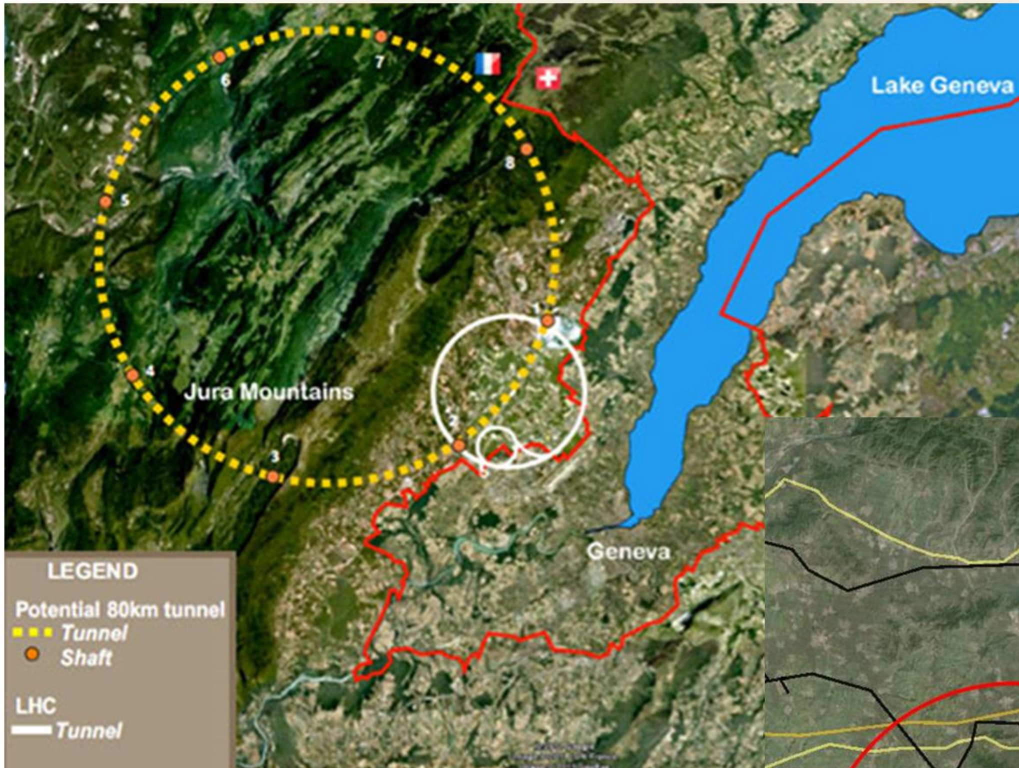
Reduce longitudinal emittance to reach high peak current – a challenge for future ring designers!

8 CEBAF SC cavities in a cryomodule produce 108 MV for longitudinal focusing



Hard XFEL oscillator? – K-J Kim

Future multi-TeV circular colliders – Higgs Factory



CERN

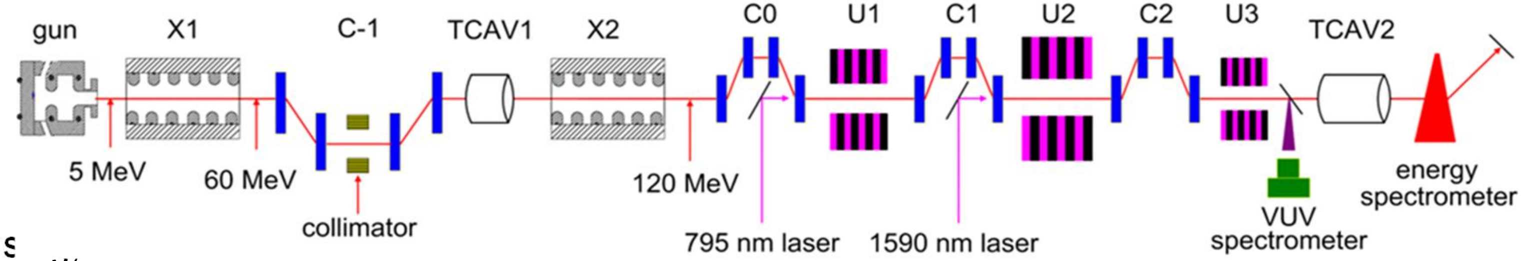
- 80-100 km circumference
- 90-400 GeV CM e+/e-
- 100 TeV p-p

China
IHEP

FEL accelerator R&D

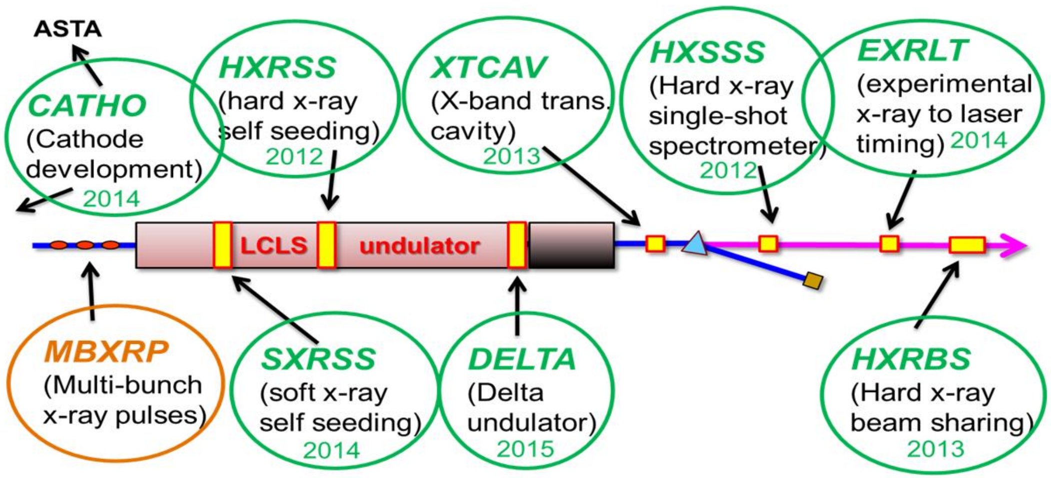
FEL research aimed at increasing photon pulse energy, reducing bandwidth, improving timing synchronization, increasing pulse repetition rate, producing 2-color photons, etc.

NLCTA: laser-electron seeding and manipulation (EEHG, ECHO, HGHG, QHG, OAM)



E. Hems
Raubenheimer et al

LCLS: FEL self-seeding, diagnostics, fs timing, enhanced photon power, etc.



fs timing, synchronization, measurement

* Coordinated program between AD (Huang) and LCLS (Hastings)

Present and future R&D

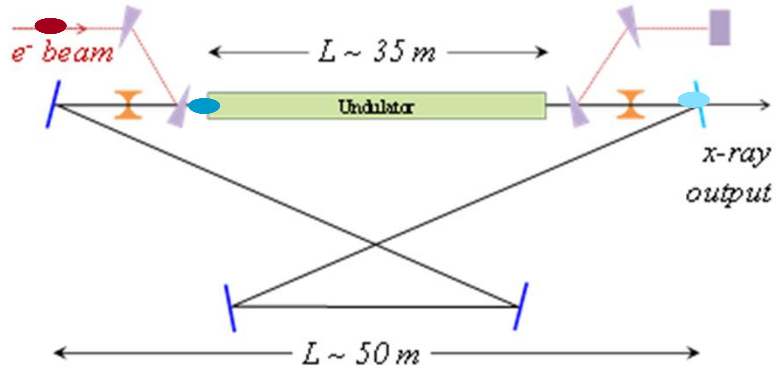
Near-Term (~3 years) (enhance LCLS-I)	**Mid-Term (~5 years)** (enhance LCLS-II)	**Long-Term (~10 years)** (beyond LCLS-II)
Dechirper	Delta-II undulator	SCU (w/ *ANL* & *LBNL*)
Beam shaping and microbunching studies	External seeding studies	TW FEL
Multi-bunch operation	High-rep. rate timing	XFELO
Attosecond X-ray pulses		

- Projected R&D budget $6M-$7M per year including theory, simulations and design efforts.
- Long-term R&D items require further investment.

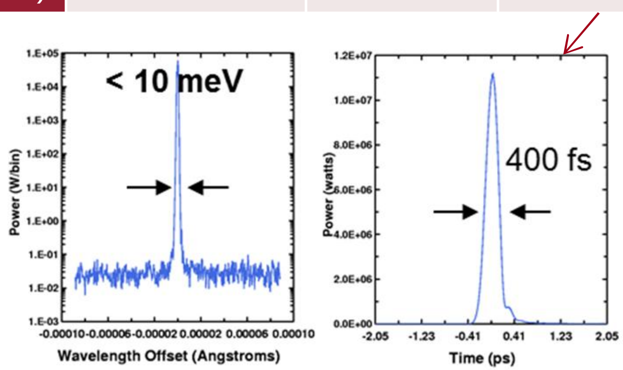
Ultra-small bandwidth X-ray FEL Oscillator

- XFELO: **~meV** fully Fourier-limited FELs
- X-ray recirculation builds/preserves seed, **highly stable steady state output**
- **For MHz rep-rate machines**: *LCLS-II, EuXFEL, PEP-X, PETRA-IV*
- Large, stable cavity a major question
- *All components proven:* ***Propose design, assemble and demo the first proof of principle, low loss, 10s m-scale HXR cavity***
- ***Planning a science workshop next June***

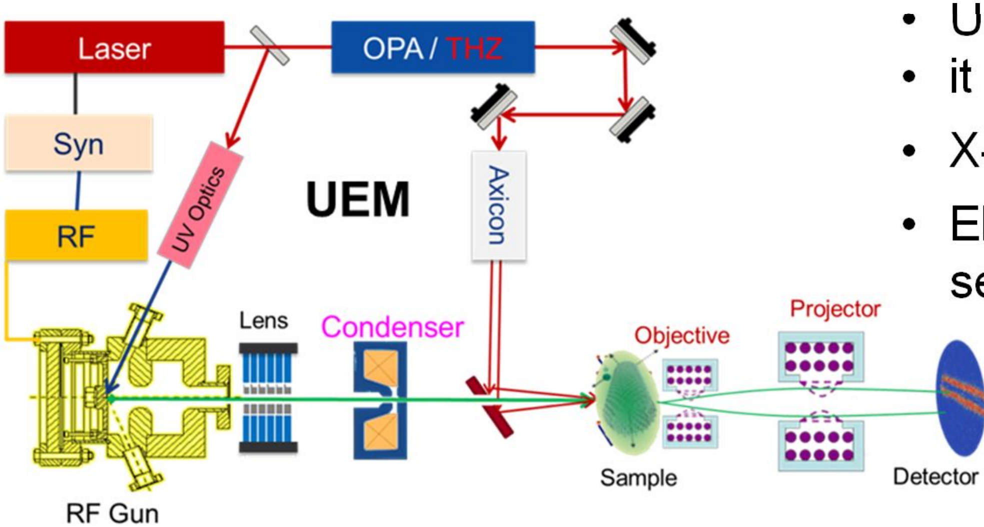
Tim Maxwell et al., IPAC2015



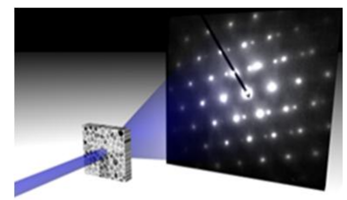
	Synchrotron Beamlines	LCLS-II 3rd Harm.	LCLS-II 14 keV Harm. XFELO
Avg. Flux (ph./s)	~$10^{(10 \text{ to } 12)}$	6×10^{12}	**3×10^{14}**
Avg. Spec. Flux (ph. / s / meV)	~$10^{(9 \text{ to } 11)}$	10^{9}	**4×10^{13}**

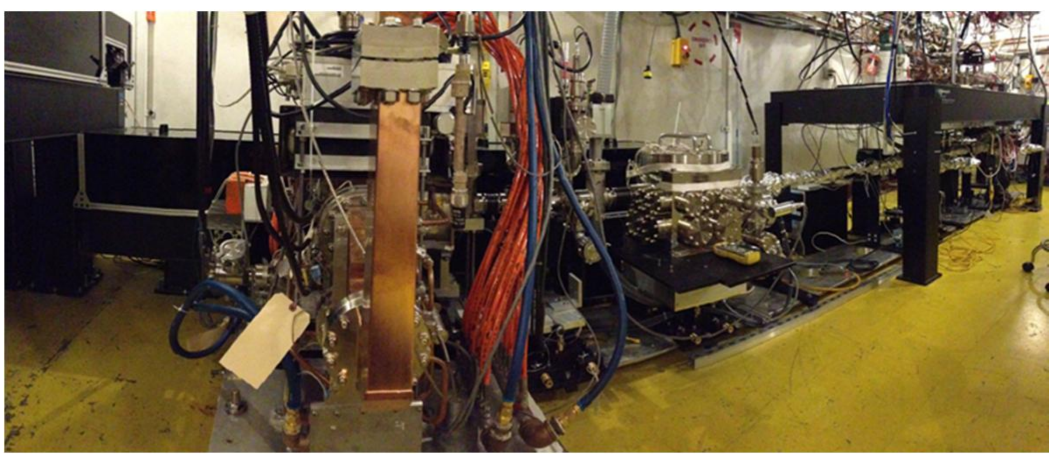


Ulrafast Electron Diffraction (UED)

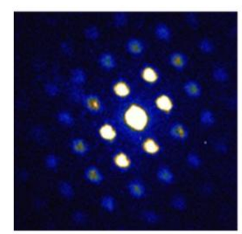


- UED probes lattice dynamics -
- it probes atom locations
- X-rays probes electron locations
- Electrons have high interaction cross-section – can probe dilute gases



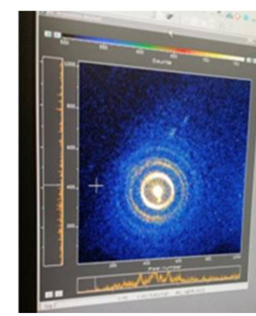


ASTA



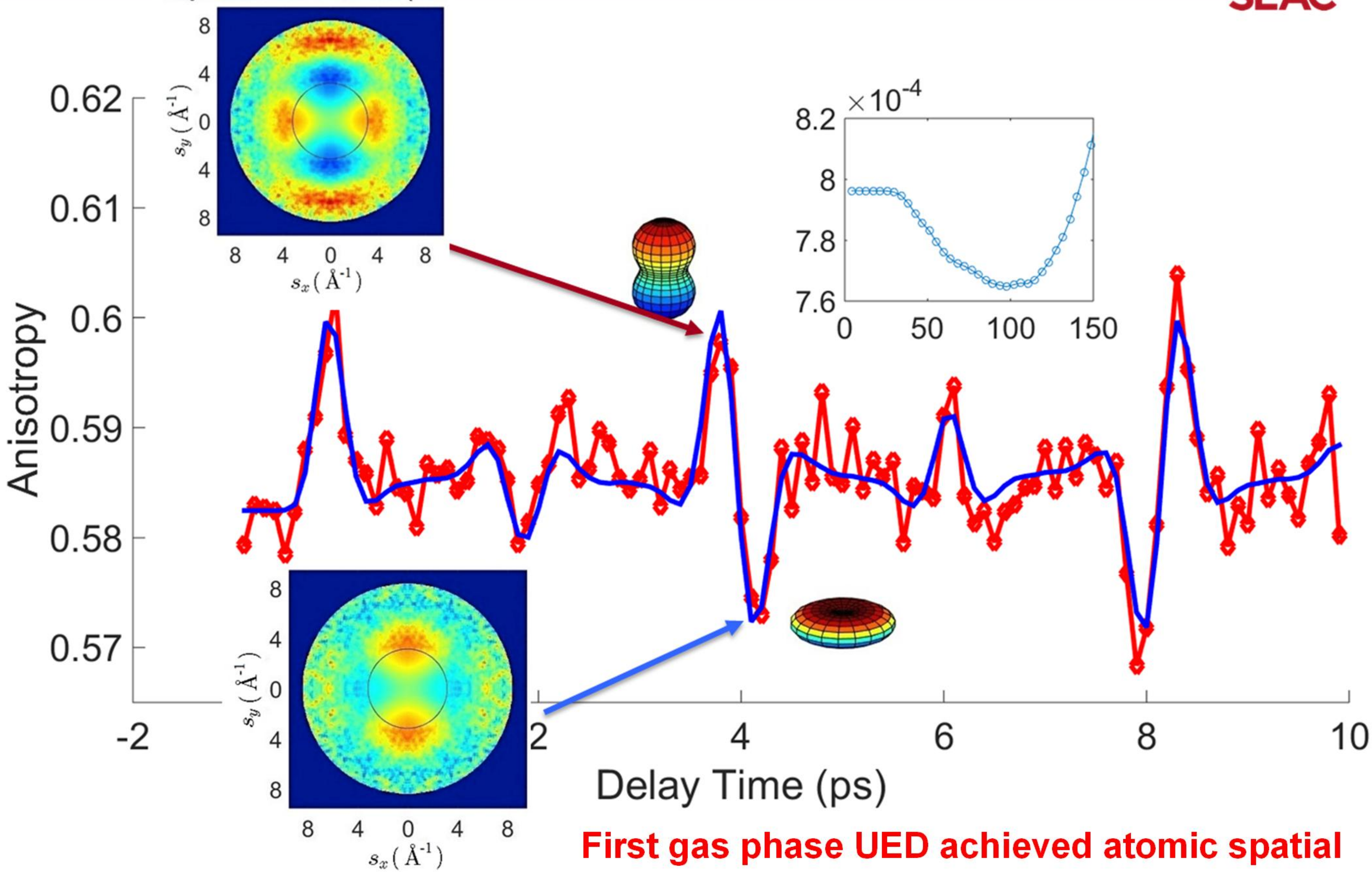
Au

Bi



- 1st diffraction patterns (hours after 1st operation)
- 4-month implementation in ASTA

UED: N_2 vibration quantum revival observed



First gas phase UED achieved atomic spatial temporal resolution simultaneously!

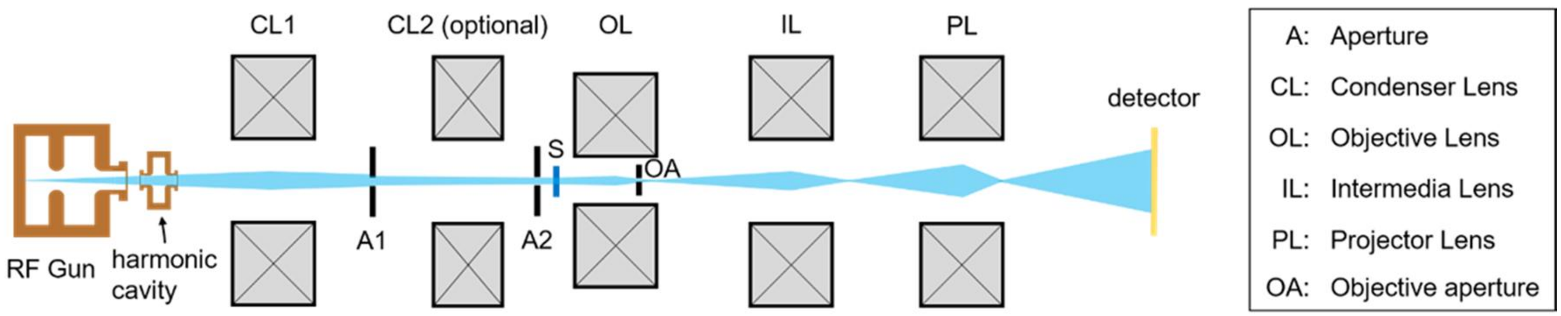
Submitted to Nature communication

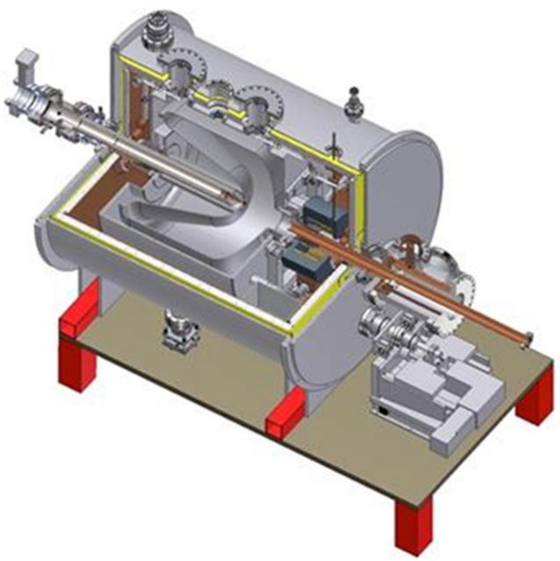
Ultrafast Electron Microscopy (UEM) – proposed

XJ Wang, Renkai Li

Goal: nanometer spatial resolution, picosecond time resolution

Existing instruments have 10-nanometer, few nanosecond resolution





200-MHz superconducting RF gun (WiFEL)

- High duty-factor, high average current
- Higher gradient and output energy than DC guns
- Improved stability compared to NC guns
- Low energy spread for short bunches

Advanced Accelerator R&D

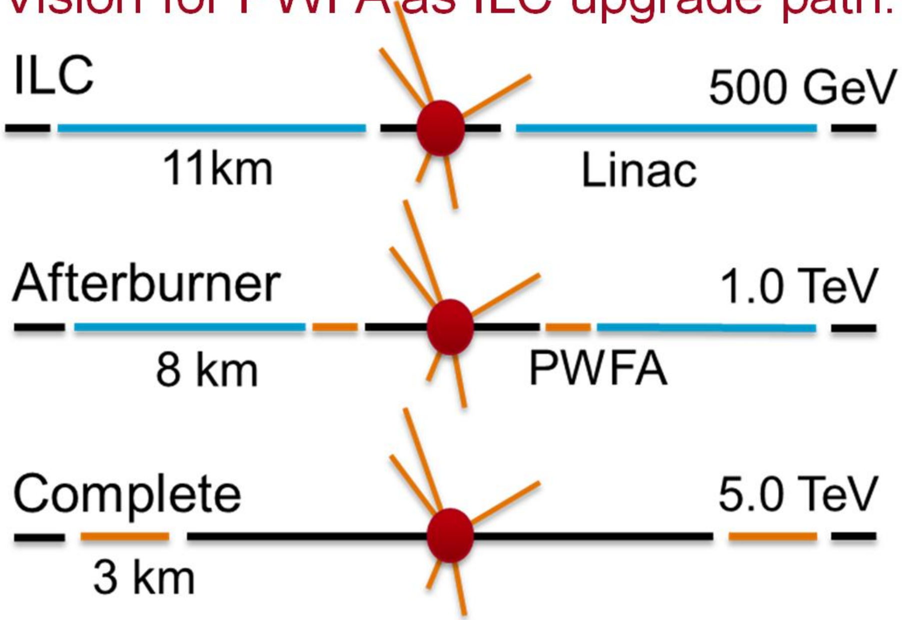
Plasma wakefield acceleration (e- and e+, FACET)

SLAC

HEP Mission

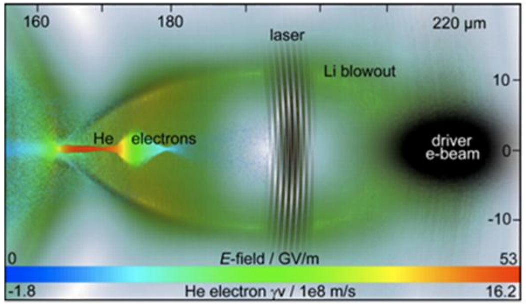
- Demonstrate Plasma Wakefield Acceleration Stage (10-100 GeV/m)

Vision for PWFA as ILC upgrade path:



User Facility

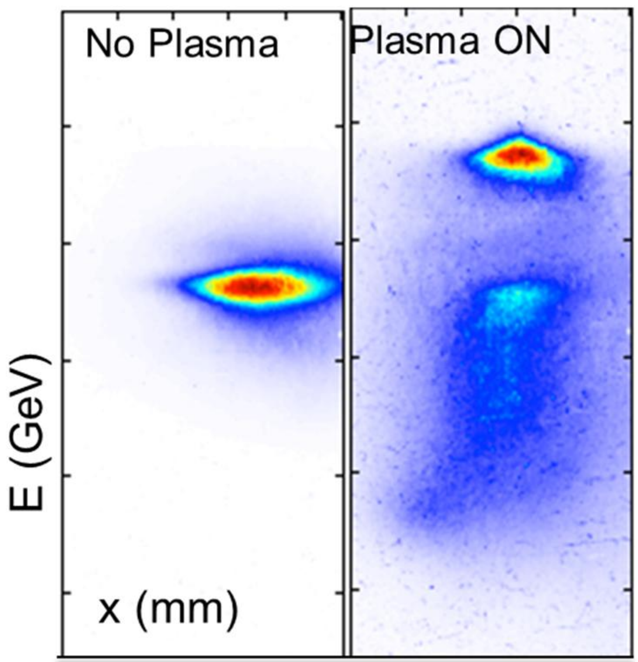
- High-energy high-density electron beams for user experiments



- Generation of and experiments with e- beams of unprecedented brightness
- Delivering highest intensity THz fields with V/Å strength
- Unmatched gamma ray source

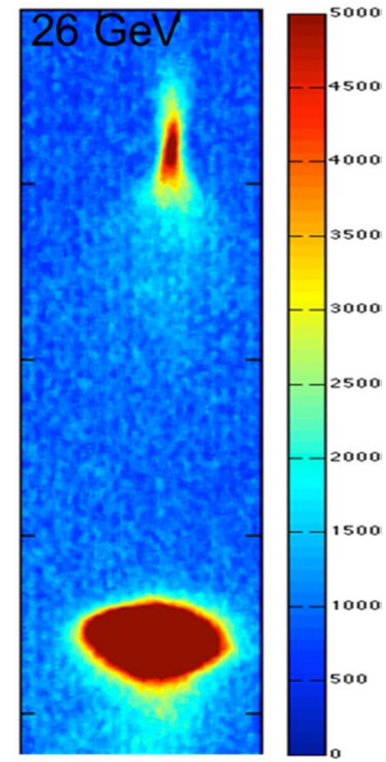
A cornerstone for worldwide advanced accelerator R&D leading to future HEP collisions, delivering broad range of user experiments

High-Efficiency Acceleration of an Electron Bunch in a Plasma Wakefield Accelerator



2 GeV Energy Gain
~2% dE/E
~30% efficiency

Nature ***515****, 92-95*
(November 2014)



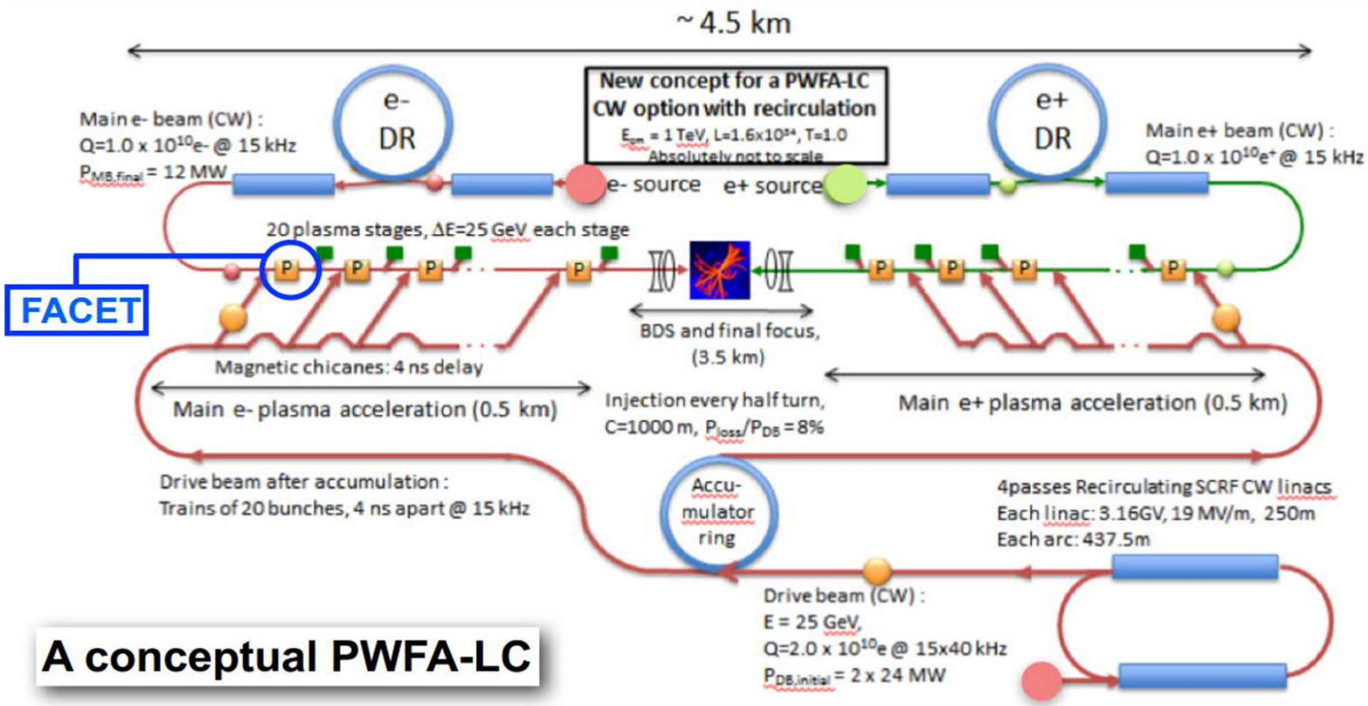
Single shot with
6 GeV Energy Gain

Optimization of electron PWFA in H_2 plasma is the focus of ongoing run

FACET in the Middle of the 2nd Phase of PWFA

SLAC

- SLAC FFTB demonstrated electron acceleration with 50GeV/m for 85cm
- FACET addresses issues of a single stage
- FACET-II staging, high-brightness beams



A conceptual PWFA-LC

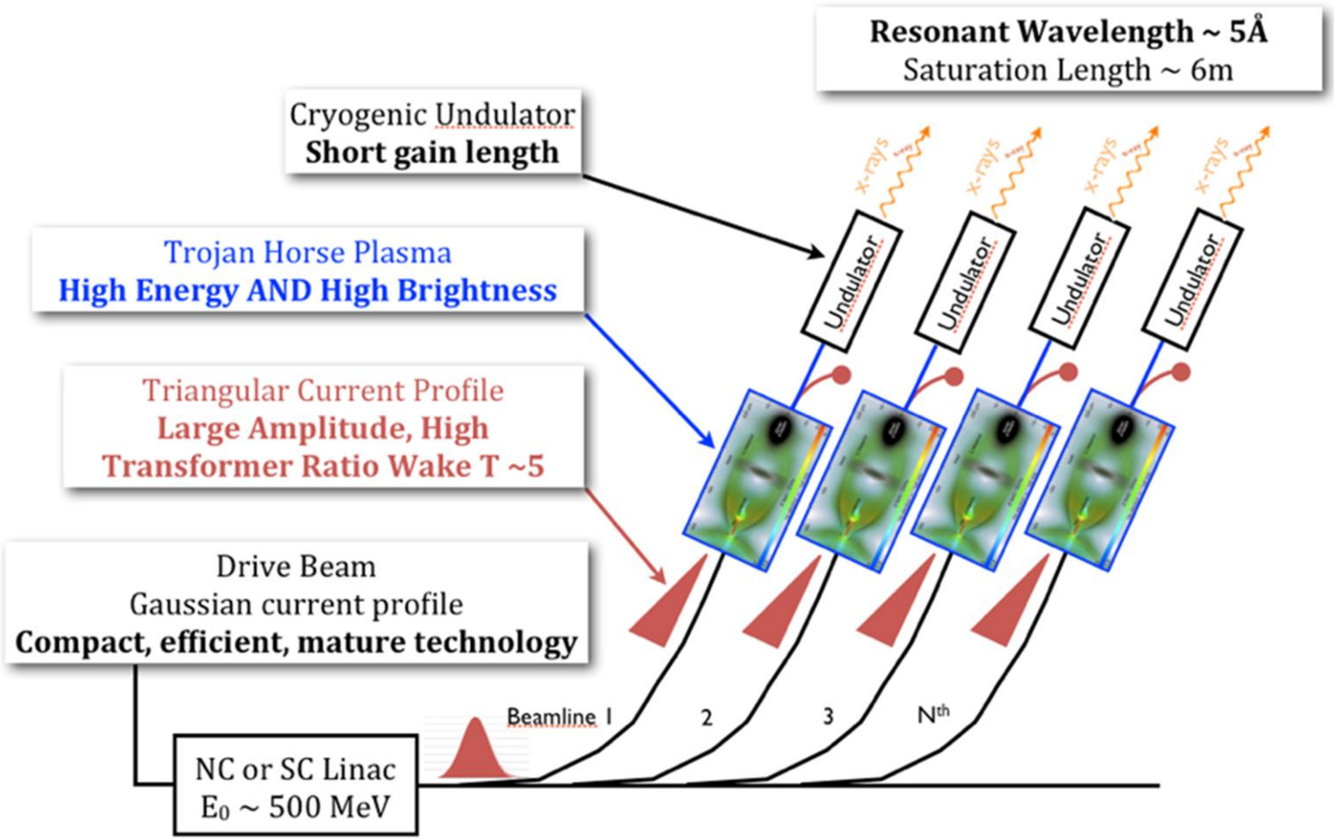
E_{cm} = 1 TeV
L = 10^{34} cm^{2}s^{-1}
Efficiency$_{\text{wall plug}}$ ~ 11%

SLAC-PUB-15426
http://arxiv.org/abs/1308.1145
E. Adli *et al*, IPAC14

FACET-II program will optimize positron acceleration and investigate issues of staging multiple plasma cells for very high energy

Imagine a new generation of light sources

Plasma-Based FEL Concept

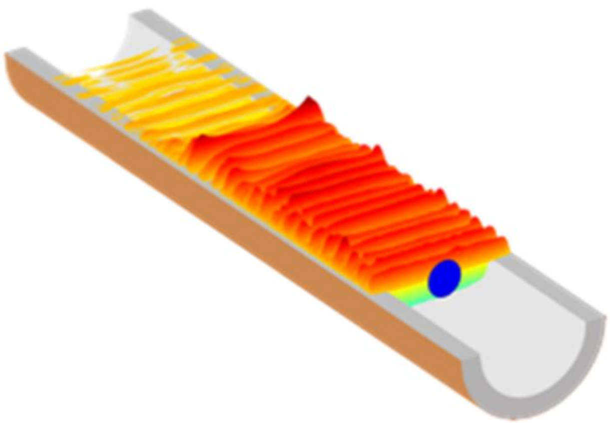


Drive Beam	
Charge	3nC
Energy	500 MeV
Rep Rate	1MHz
Bunch length	210μm, ramped
Peak Current	8.5kA
Normalized Emittance	2.25 mm-mrad
Trojan Horse (plasma)	
Plasma Density	10^{17} e^-/cc
Plasma Length	20 cm
Transformer Ratio	5
Trojan Horse (beam)	
Charge	3 pC
Energy	2.5 GeV
Energy Spread	$2x10^{-4}$
Normalized Emittance	$3x10^{-8}$ m-rad
Peak Current	300A
Bunch length	12 fs
Brightness	$7x10^{17}$ A/m^{2}rad^2
Undulator Parameters	
Period	9 mm
K	2
Number of periods (N)	660
Radiation Parameters	
Wavelength	5.4 Å
Single pulse energy	50 μJ
Number of Photons	$>10^{11}$
Peak Power	1.6 GW

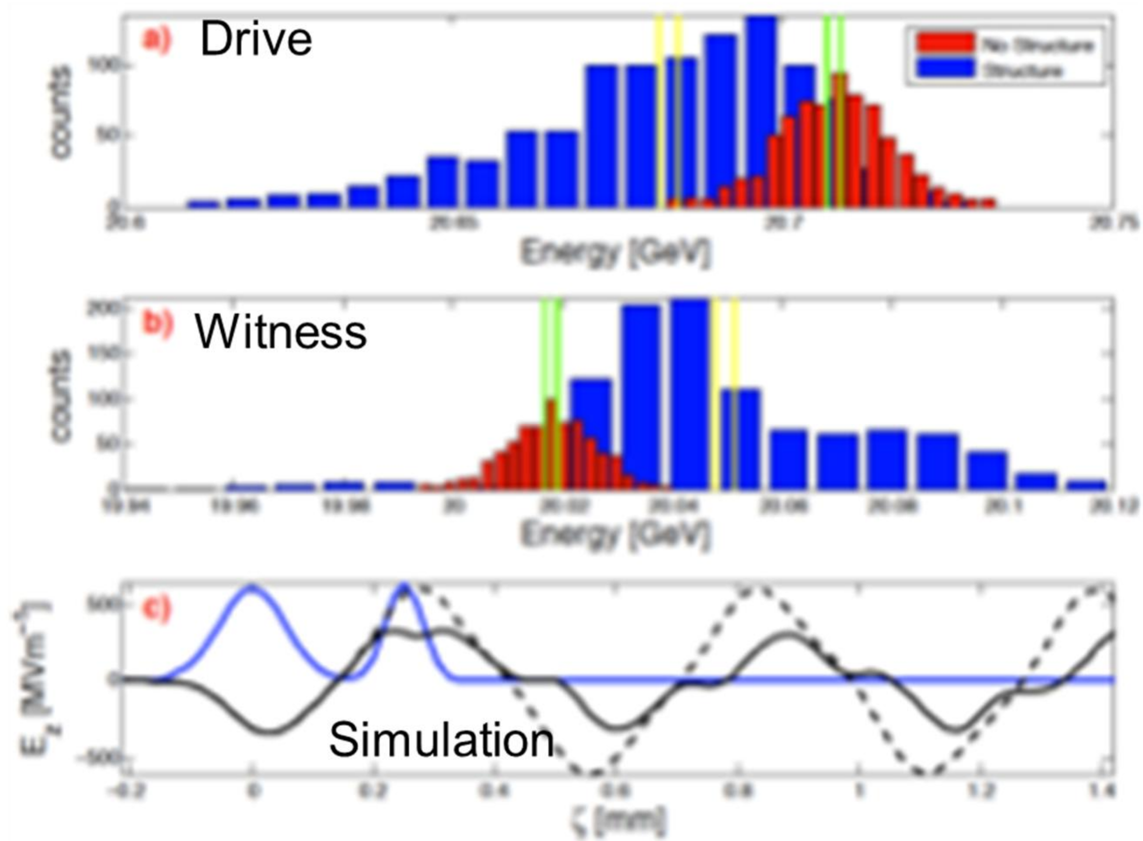
Leverage high rep-rate beam drivers with plasma as source of high-brightness high-energy electrons

Record Performance for Dielectric Wakefield Acceleration (E201)

Quartz tubes
15cm long
300µm diameter



67% efficiency



1.3 GV/m fields from Energy loss with single bunch (FY14, FY15 Run 1)
250/315 MeV/m in two-bunch configuration (New FY15 Run 2)

Dielectric Laser Acceleration (DLA) Concept

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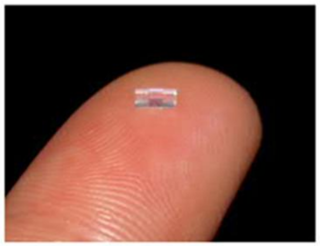
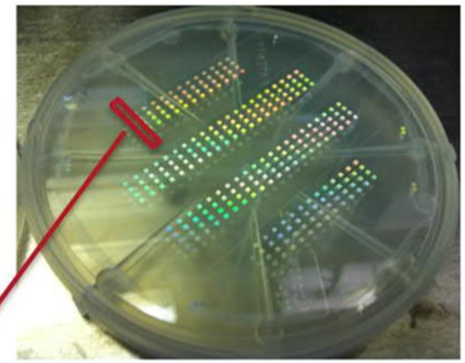


laser-driven microstructures

- **lasers:** high rep rates, strong field gradients, commercial support
- **dielectrics**: higher breakdown threshold → higher gradients (1-10 GV/m), leverage industrial fabrication processes

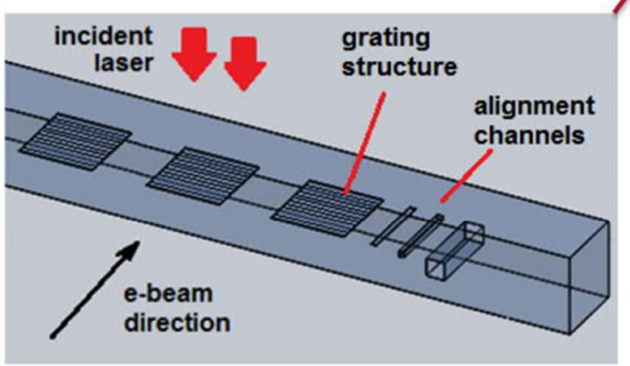
"Accelerator-on-a-chip"

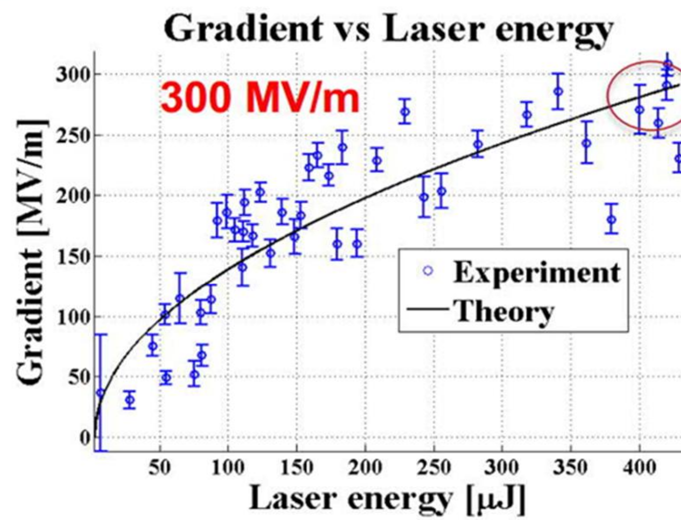


bonded silica phase reset accelerator prototypes fabricated at SLAC/ Stanford

Goal: lower cost, more compact, energy efficient, higher gradient

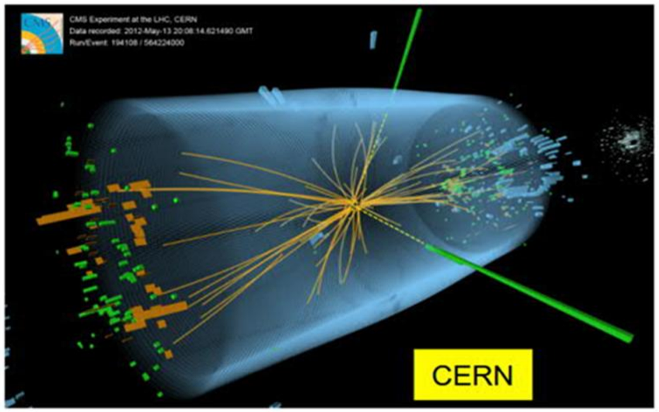
Wafer is diced into individual samples for e-beam tests.



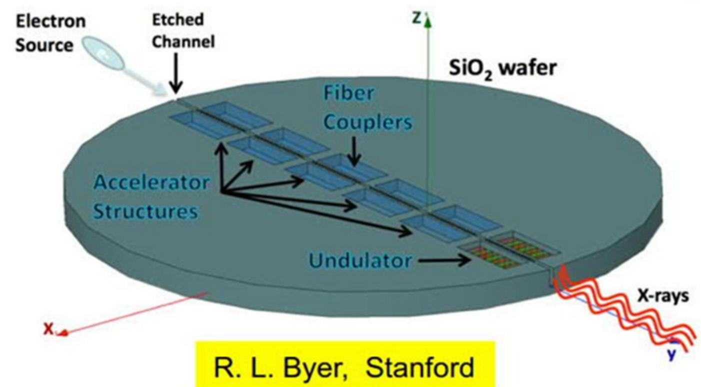


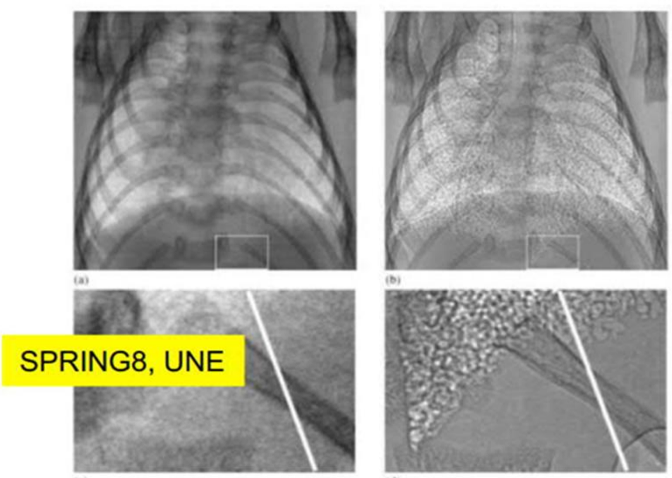
DLA Applications

linear collider or Higgs factory



university-scale light source





medical imaging

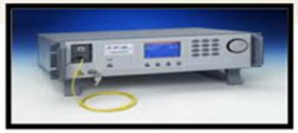
portable cancer treatment

DLA Applications: Linear Collider

P. Bermel, et al, "Summary of the Dielectric Laser Accelerator Workshop," **NIM-A** 734, 51-59 (2014).

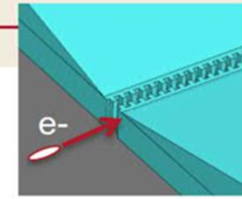
SLAC

6 fiber lasers per
6" wafer module
2 kW per laser



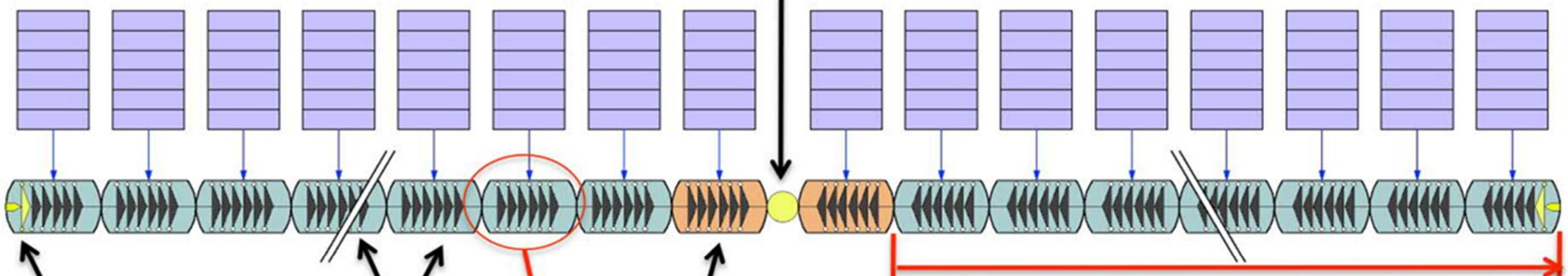
Thulium fiber laser λ=2 μm

IPG PHOTONICS



concept for 1 DLA accelerator structure (E. Peralta)

Interaction Point



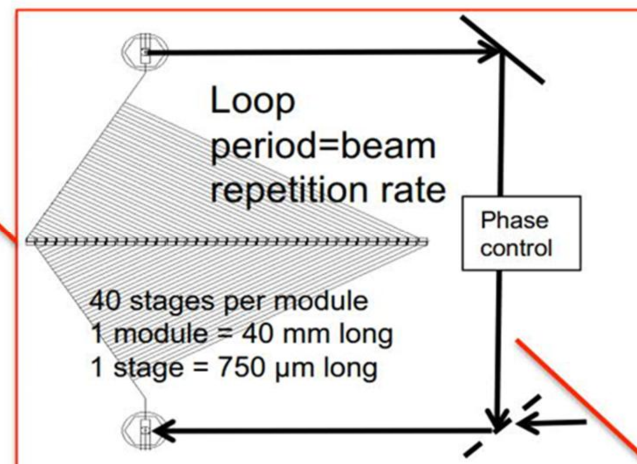
0.5 TeV ⇔ 500 m ⇔ 15,700 lasers

needle emitter and injector module

accelerator wafers

final focus and steering wafers

Parameter	Units	CLIC 3 TeV	DLA 3TeV	DLA 250 GeV
Bunch Charge	e	3.7e9	3.0e5	3.8e5
Rep Rate	MHz	5e-5	20	60
Beamstrahlung E-loss	%	**28.1**	**1.0**	**0.6**
Enhanced Luminosity / top 1%	cm-2/s	2.0e34	3.2e34	1.3e34
Wallplug Power	MW	582	374	152



Accelerator Technology Development for Multiple Applications

DOE Accelerator Stewardship Program

DOE HEP Accelerator Stewardship

SLAC

Track 1 (results in 5-7 years):

a) Particle Therapy Beam Delivery Improvements (reduced size, increased speed, etc.);

b) Ultrafast Laser Technology Program;

c) Energy and Environmental (E & E) Applications of Accelerators (treating potable and waste water, removing pollutants from stack gases, increasing the energy efficiency of industrial material processing, remediating water-borne and soil-borne contaminants, replacing radioactive sources in sterilization applications)

Track 2:

Long-term generic accelerator R&D to improve theory, computational tools, and fundamental physical and technical understanding of accelerator science.

Applications: beam physics, advanced computational methods for accelerator design and analysis, beam diagnostics and feedback control, new superconducting materials, new materials and coatings for accelerator components, novel power sources for accelerators, new particle sources, novel magnet designs, novel lattice designs, and novel technologies for secondary beam production.

High power accelerators for E & E applications

SLAC

Table 2. Target performance for high power electron accelerators for E&E applications:

	Type 1 Demo/Small Scale	Type 2 Medium Scale Low Energy	Type 3 Medium Scale High Energy	Type 4 Large Scale High Energy
Example Applications	*R&D, Sterilization, industrial effluent streams*	*Flue Gas, Waste water*	*Wastewater, sludge, medical waste*	*Sludge, Medical waste, Env. remediation*
Electron Beam Energy	0.5-1.5 MeV	1-2 MeV	10 MeV	10 MeV
Electron Beam Power (CW)	>0.5 MW	>1 MW	>1 MW	>10 MW
Wallplug Efficiency	>50%	>50%	>50%	>75%
Target Capital Cost*	<$10/W	<$10/W	<$10/W	<$5/W
Target Operating Cost†	<1.0M$/yr	<1.5M$/yr	<1.5M$/yr	<12M$/yr

*Total cost of the accelerator, including all supporting systems (e.g. power, cooling, control, safety).

†Total operating cost including all labor, supplies, repairs and electricity costs.

SLAC-affiliated response to 2015 Stewardship call

Track 1:

- Medium Scale Low Energy High Power Linac (1-2 MeV, >1MW) for E&E application (F. Wang, Z. Li)
- Extreme high efficiency normal conducting accelerators for energy and environment applications (V. Dolgashev)
- The application RF energy modulator as a fast scanning tool for Hadron Therapy Machines (S. Tantawi)
- High Efficiency Deflected Beam RF Source for Accelerator Applications (M. Franzi)
- 1-MW CW 1.3-GHz Klystron with 90% Efficiency (J. Neilson)

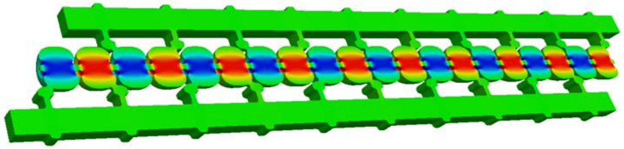
Track 2:

- THz-Driven Electron Gun (S. Tantawi)
- Nanotip electron sources: towards a laser driven medical accelerator on a chip (R. Byer)
- Parallel Procedures to Optimize Accelerator Cavity Geometries (J. Hicken, M. Shepard)
- High Stability Synchronization and Timing Distribution Techniques for Next-
- Generation Accelerator and FEL facilities (J. Fox, P. Enge)

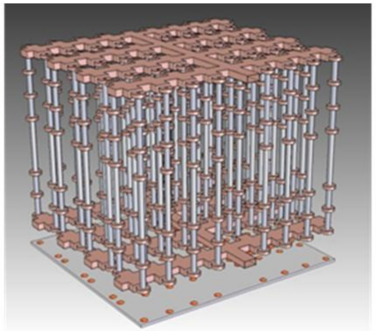
Novel RF technology is major contributor to stewardship applications

RF Technology

- Novel RF acceleration (high gradient, high rep rate, novel sources, high efficiency klystrons, etc.)
- L-band modulators (ILC, MAP, PX)
- X-band RF gun
- NLCTA and ASTA ops
- ECA: RF breakdown



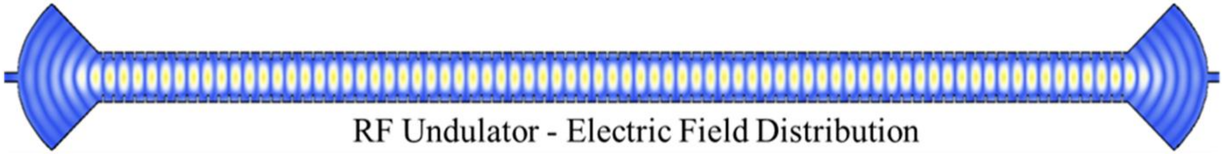
efficient linac power distribution



multi-beam klystron

Future Goals:

- Initial designs for transformational RF sources and structures, extending to THz
- Explore scientific, medical, industrial and applications using new technology

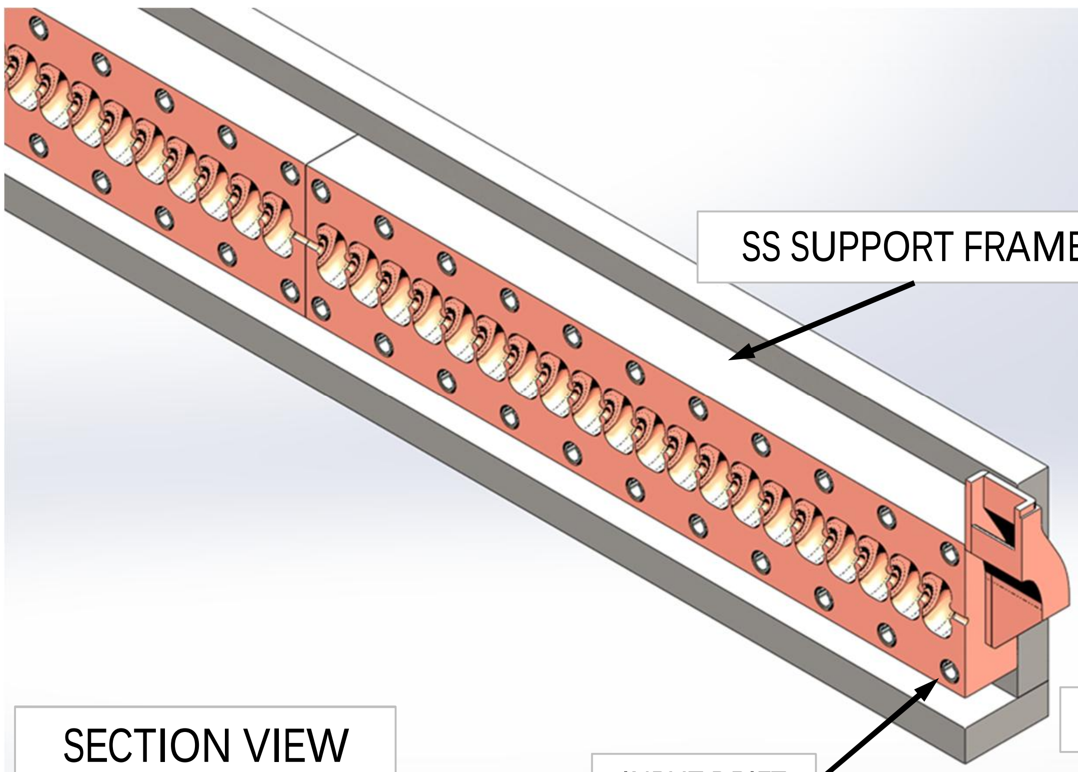


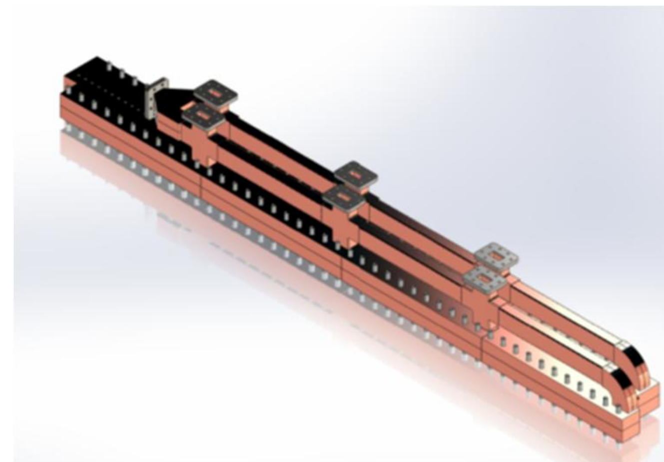
RF Undulator - Electric Field Distribution

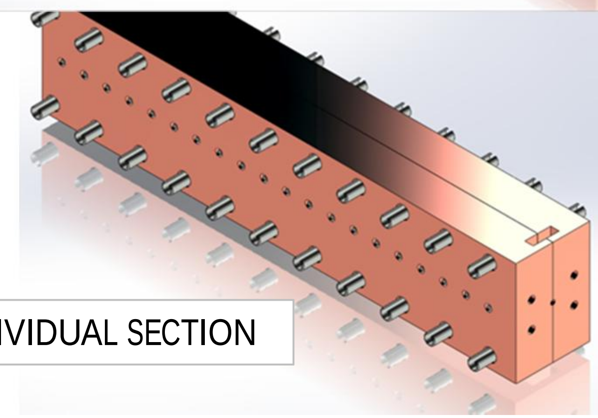
Distributed coupling X-band linac fabrication

Four Sections are Joined Together to make Full Accelerator Structure

Accelerator Assembly with Four Sections of 20 Cells each (80 Cells Total)







100-GHz open accelerating structure experiments show possibility of ~ 0.5 - 1 GeV/m accelerators

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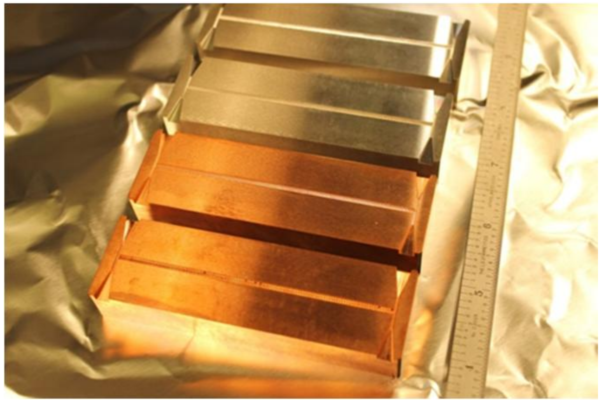
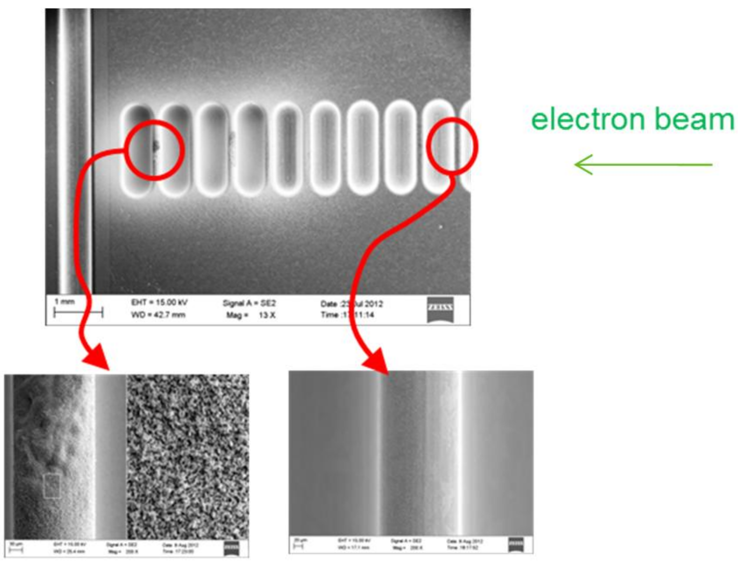
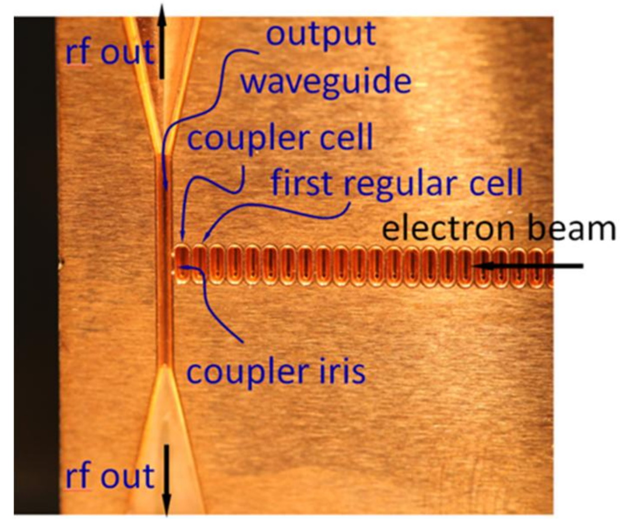




1st iris – breakdown damage, peak surface fields ~0.5 GV/m

9th iris – no breakdown damage, peak surface fields > 0.2 GV/m, pulse length ~3ns



2015-2017 R&D plan

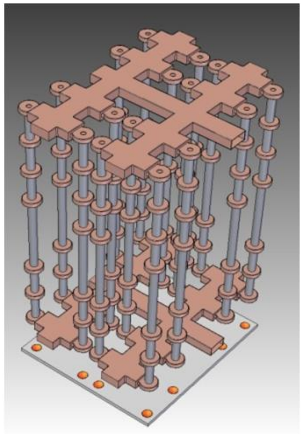
- FACET Tests: we are planning experiments with new diagnostics at both 100 GHz and 235 GHz.

Beyond 2017:

- Implement a full system at freqencies > 100 GHz powered by stand alone rf source.

V.A. Dolgashev, SLAC, 17 January 2015

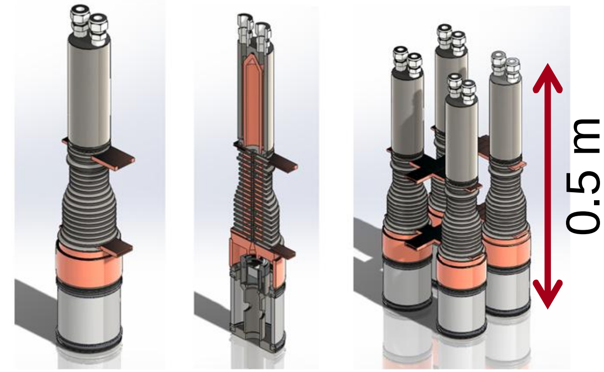
Compact efficient RF power sources



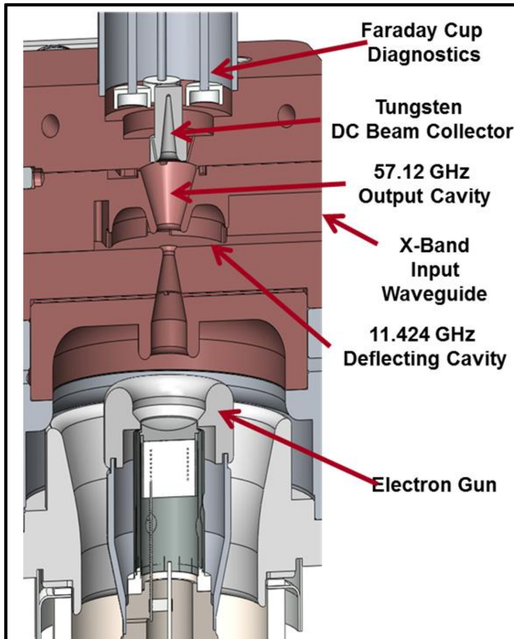
Most compact possible configuration:
The number of beams is (2N)2; where N is the division ratio for single splitter

No electromagnets, focusing is done with Permanent Periodic Magnets (PPM)

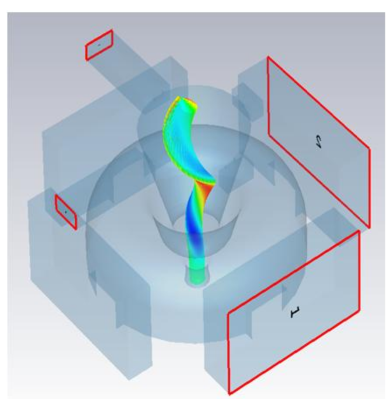
- low voltage
- simplified gun structure and no oil;
- efficient inexpensive modulator
- possibility of using gridded cathodes



Multi-beam klystron

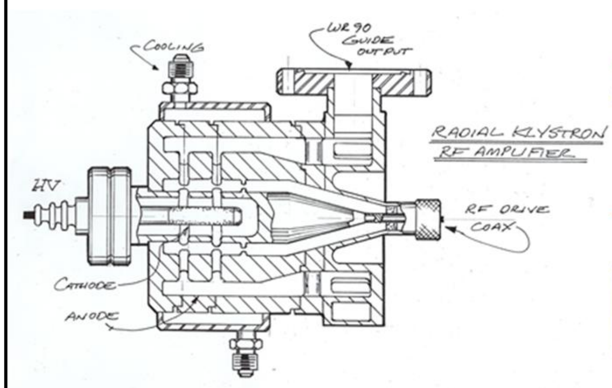


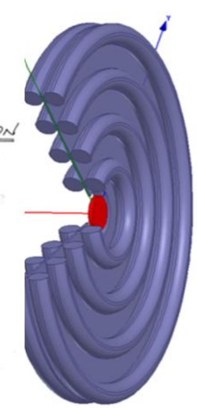
V-band Device uses over-moded cavities for high frequency generation (57.12 GHz)



Multi-dimensional (radial) klystron

- Beam expands under space charge forces→magnetic focusing is not required
- High current, low voltage.





Summary

- SLAC accelerator science and research programs are diverse and productive.
- SLAC accelerator expertise and test facilities are critical resources for numerous physics and stewardship programs
- SLAC accelerator expertise and test facilities are critical resources for educating the next generation of accelerator physicists and engineers.

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And thank you to our MePAS hosts in Guanajuato!