THE NGLS SWAN SONG:

DESIGN CONCEPTS FOR A NEXT GENERATION LIGHT SOURCE

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for the NGLS R&D and Design Collaboration

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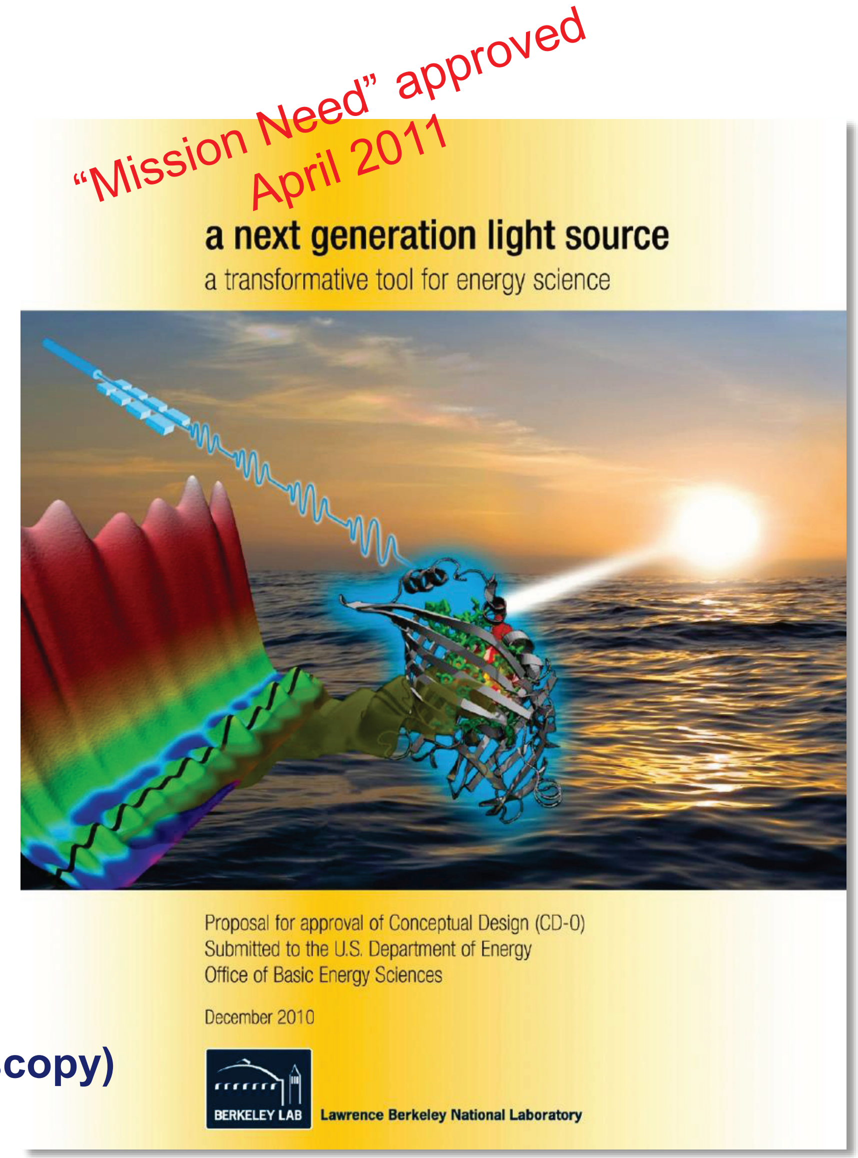
A concept design driven by X-ray science needs



Science requirements

- Soft X-ray probes
- High average brightness
- Moderate peak-power
- Ultrafast pulses, coherence

NGLS R&D work geared toward a design of a 4th generation FEL-based Light Source:

- ✓ **Soft X-rays**
- ✓ **Ultrafast**
- ✓ **Coherence**
- ✓ **2-color (X-ray pump-probe, non-linear spectroscopy)**
- ✓ **High repetition rate (SC CW Linac)**

A high average power X-ray laser facility with high rep-rate CW beam and flexible pulse format

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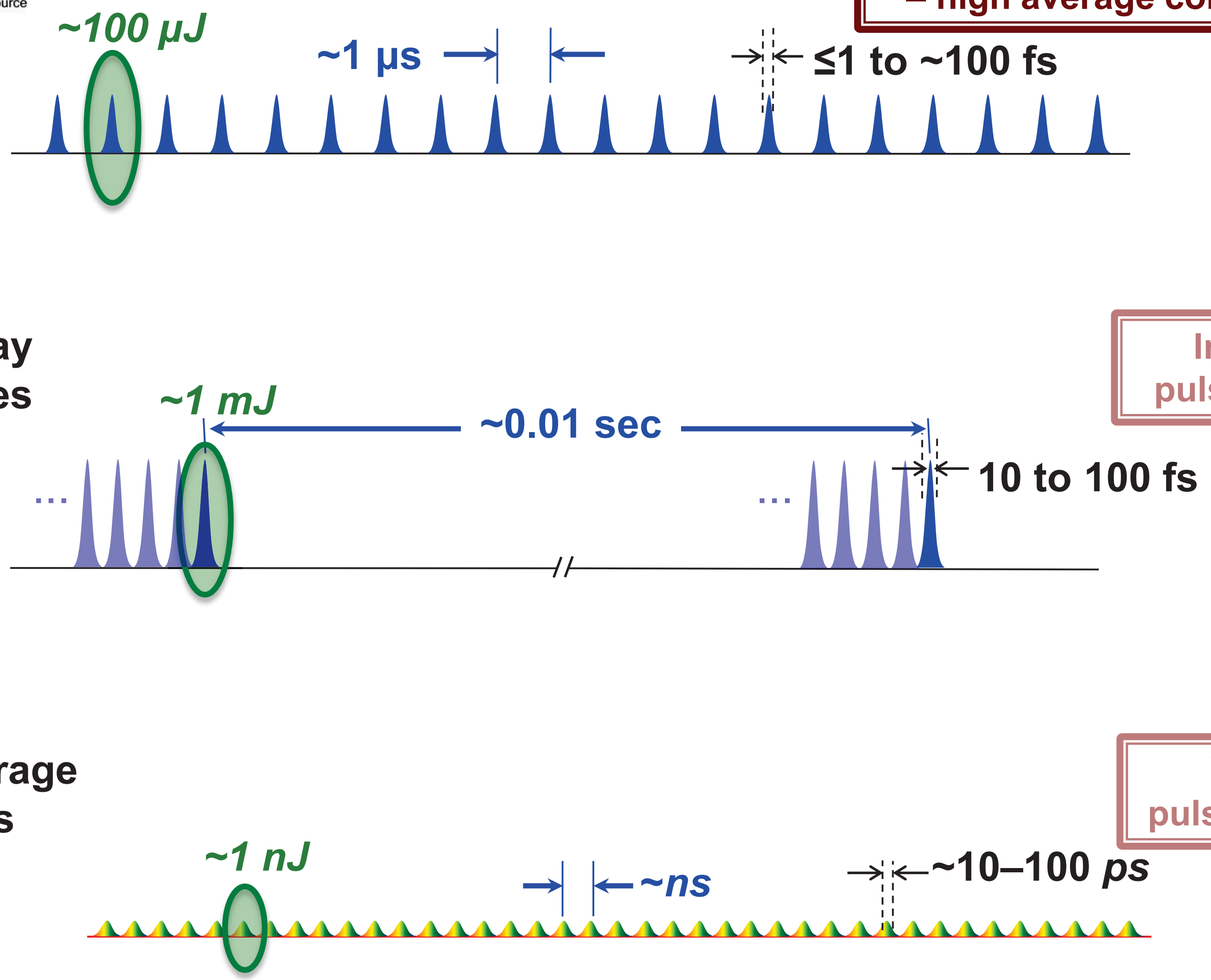
Intense coherent pulses at high rep rate – high average coherent X-ray power

Today's X-ray laser sources

Intense coherent pulses at low rep rate

Today's storage ring sources

Weak coherent pulses at high rep rate



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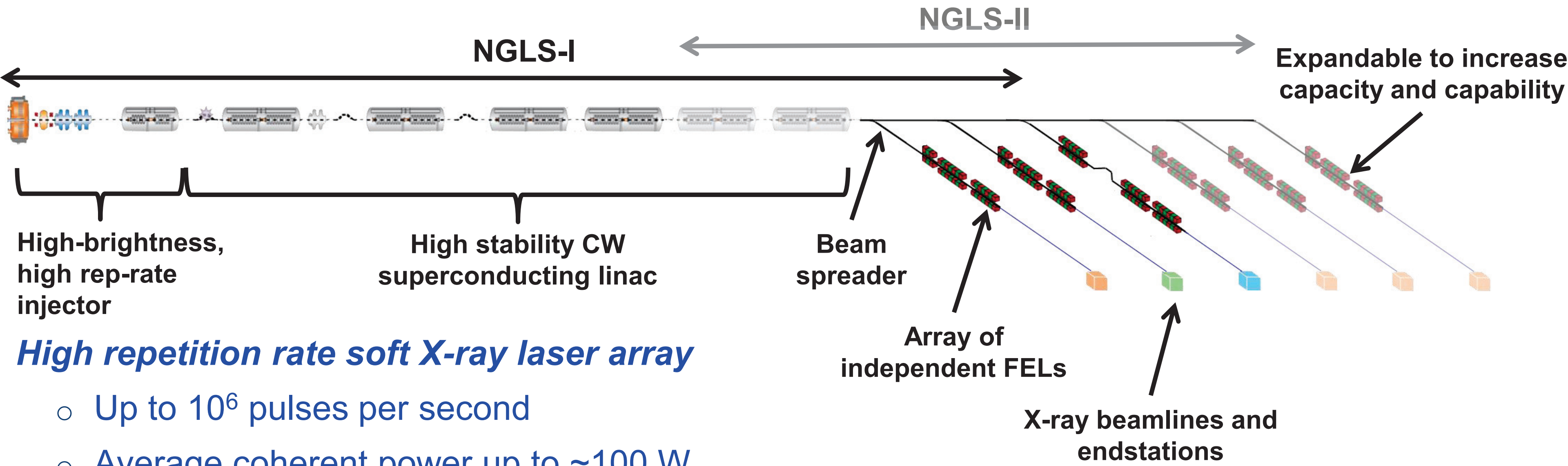
Layout and radiation characteristics



High repetition rate soft X-ray laser array

- Up to 10^6 pulses per second
- Average coherent power up to ~100 W

Spatially and temporally coherent X-rays (seeded)

- Ultrashort pulses from ~1 fs to ~300 fs
- Narrow energy bandwidth to 50 meV

Tunable X-rays

- Adjustable photon energy from 100 eV – 1.25 keV, 2 keV achievable [baseline, 2.4 GeV]
- Moderate to high flux with 10^{10} – 10^{12} photons/pulse

Expandable

- Capability (e.g. higher photon energy, higher repetition rate)
- Capacity (multiple FEL beamlines)

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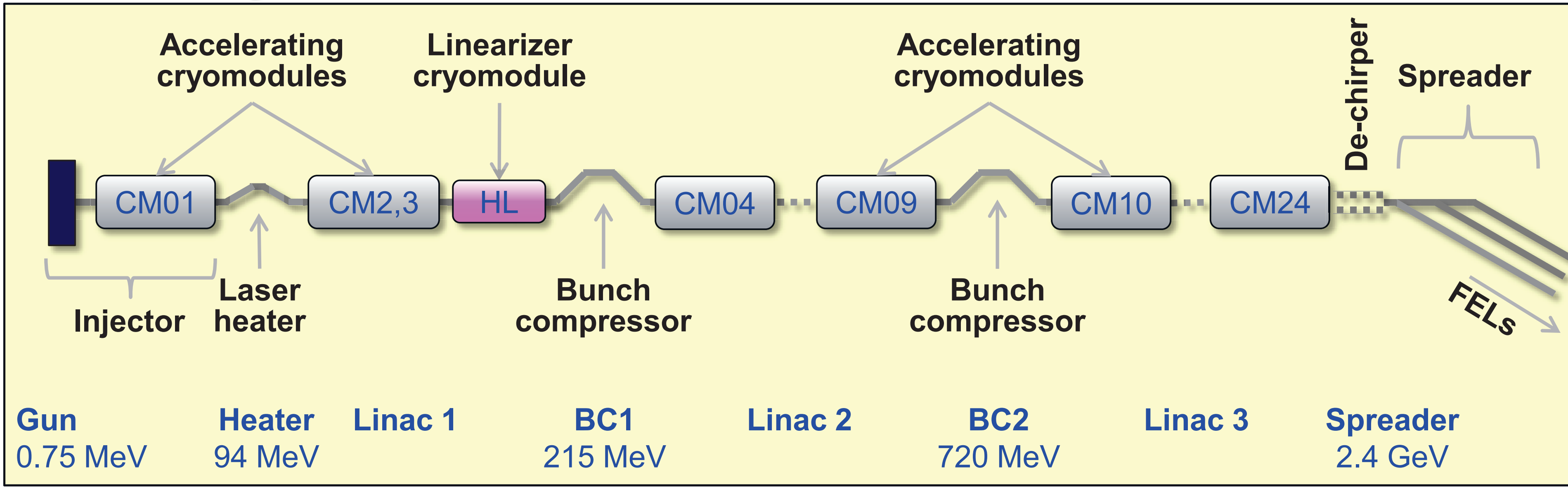
Linac layout

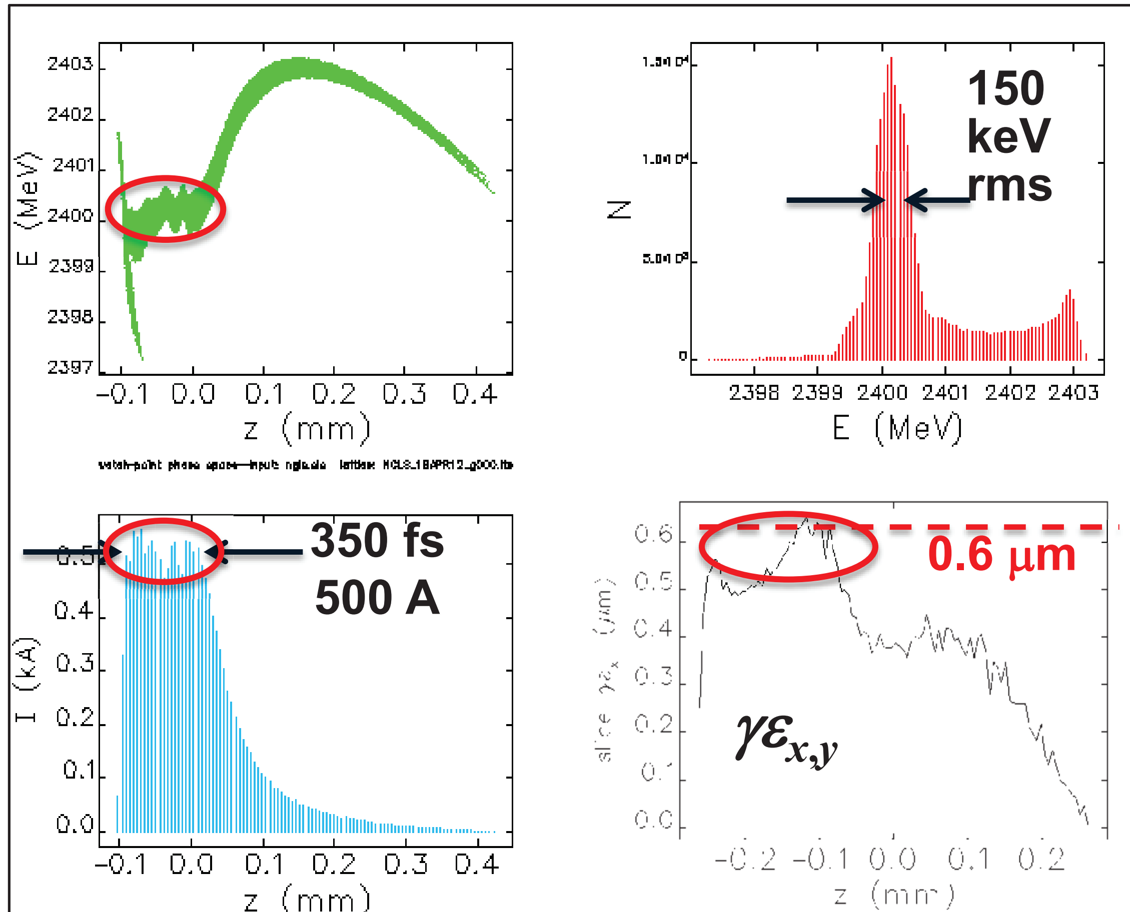


- **"APEX" injector**
- **TESLA/ILC SC structure technology** *(modified for NGLS)*
- **One or two-stage compression**
- **"Dechirper"**
- **RF deflector-based beam spreader**
- **3 initial seeded / self-seeded FELs**

- **300 pC bunches**
- **1 MHz bunch rate**
- $\gamma\varepsilon_{\perp}$ **= 0.6 μm**
- I_{pk} **= 500 A**
- σ_E **= 150 keV**
- **Final useable bunch 300 fs**

Linac beam dynamics

- ***S2E modeling using ASTRA, ELEGANT, IMPACT, GENESIS, GINGER***
- ***Special attention to minimization of microbunching instability, CSR-induced emittance growth***
- ***Electron beam meets requirements for FEL***



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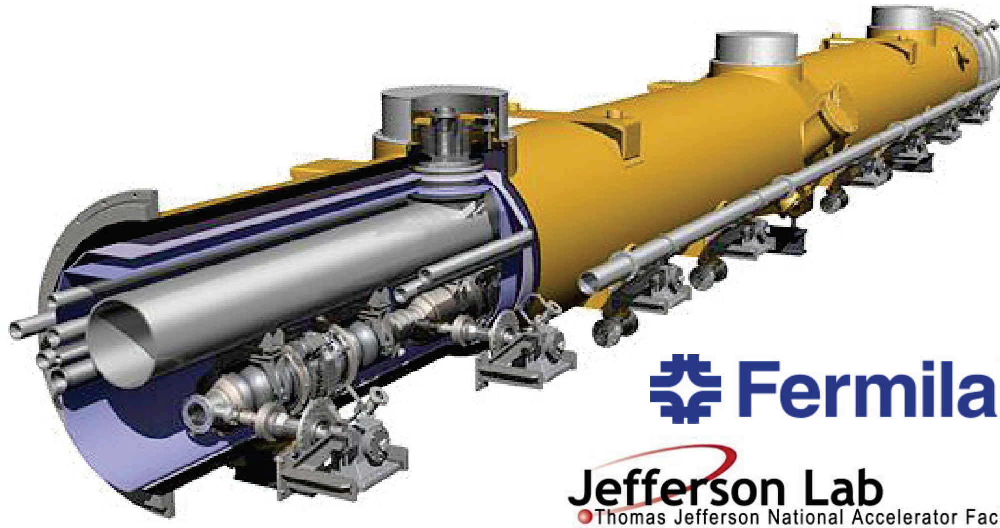
Cryomodule concept

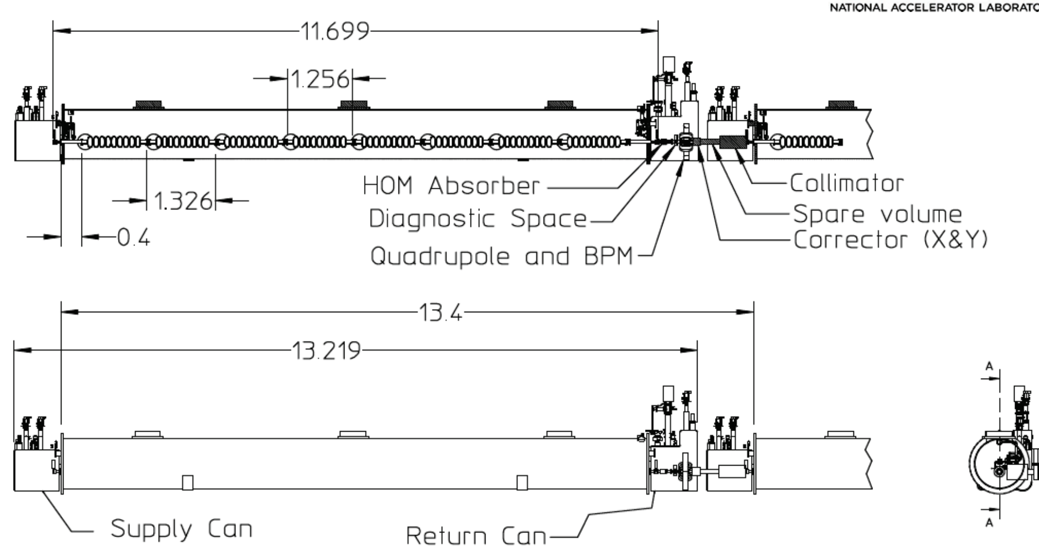
- **TESLA/ILC (1.3 GHz) technology modified for CW operation in NGLS**
- **Use existing expertise, designs, infrastructure, industrialization**
  - **Discrete cryomodules each with cold/warm end transitions**
  - **Magnets, diagnostics & HOM absorbers in warm sections**
  - **Distribute 5 K liquid, cool to 1.8 K at cryomodule**
  - **E ~14-16 MV/m**
  - **$Q_0 = 2 \times 10^{10}$**
  - **Heat load @ 1.8K**
    - **~12 W / cavity**
    - **90–130 W / cryomodule**



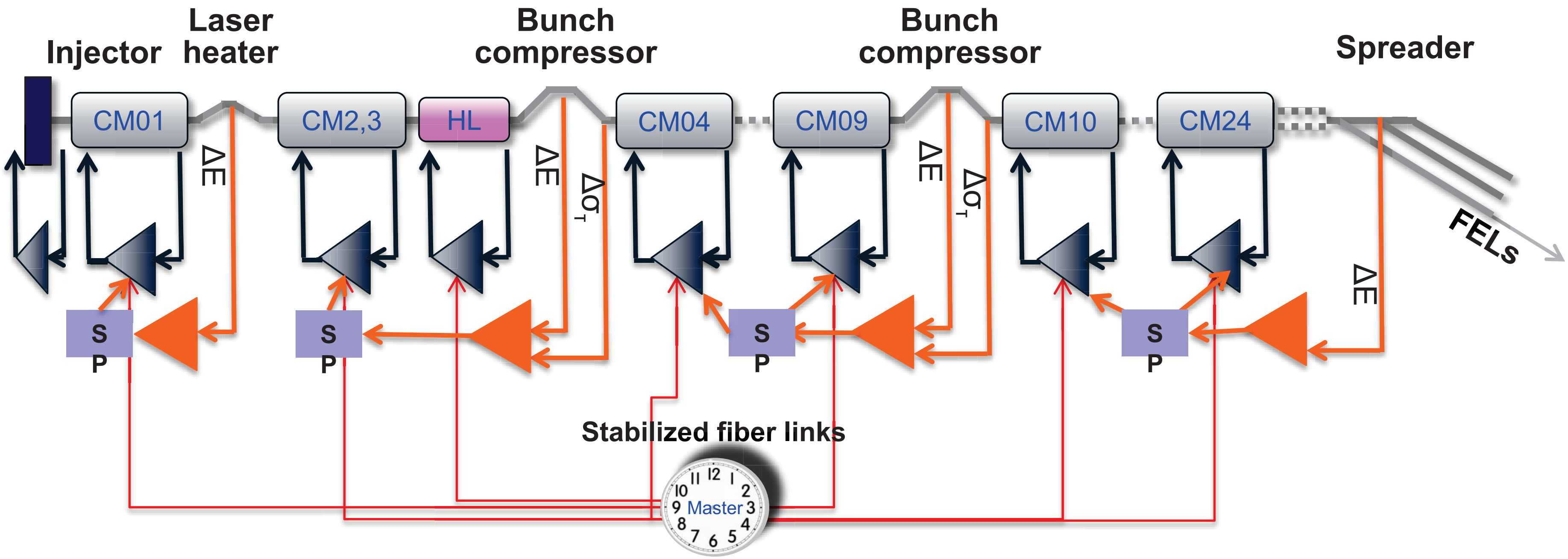
Fermilab

Jefferson Lab
Thomas Jefferson National Accelerator Facility

SLAC
NATIONAL ACCELERATOR LABORATORY



CW superconducting linac + high bunch rate + fast feedback = highly stable beams



- Goal of stability similar to existing storage rings
- CW measurements allow broadband feedback to control residual jitter

- $\Delta E/E \sim 10^{-5}$
- $\Delta\tau < 10$ fs
- $\Delta x_{rms}/\sigma_x < 5\%$

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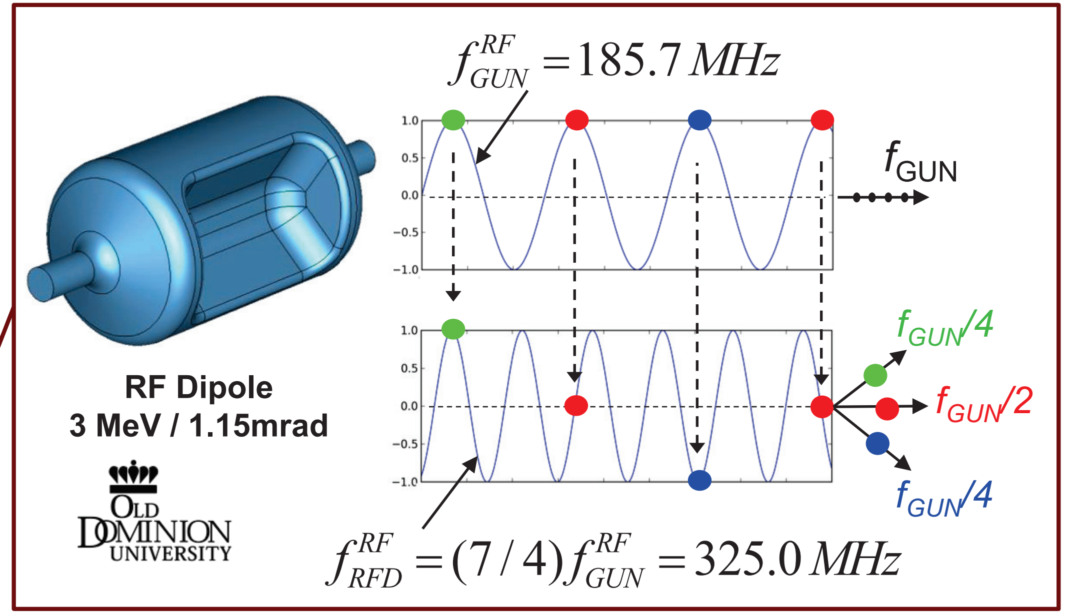
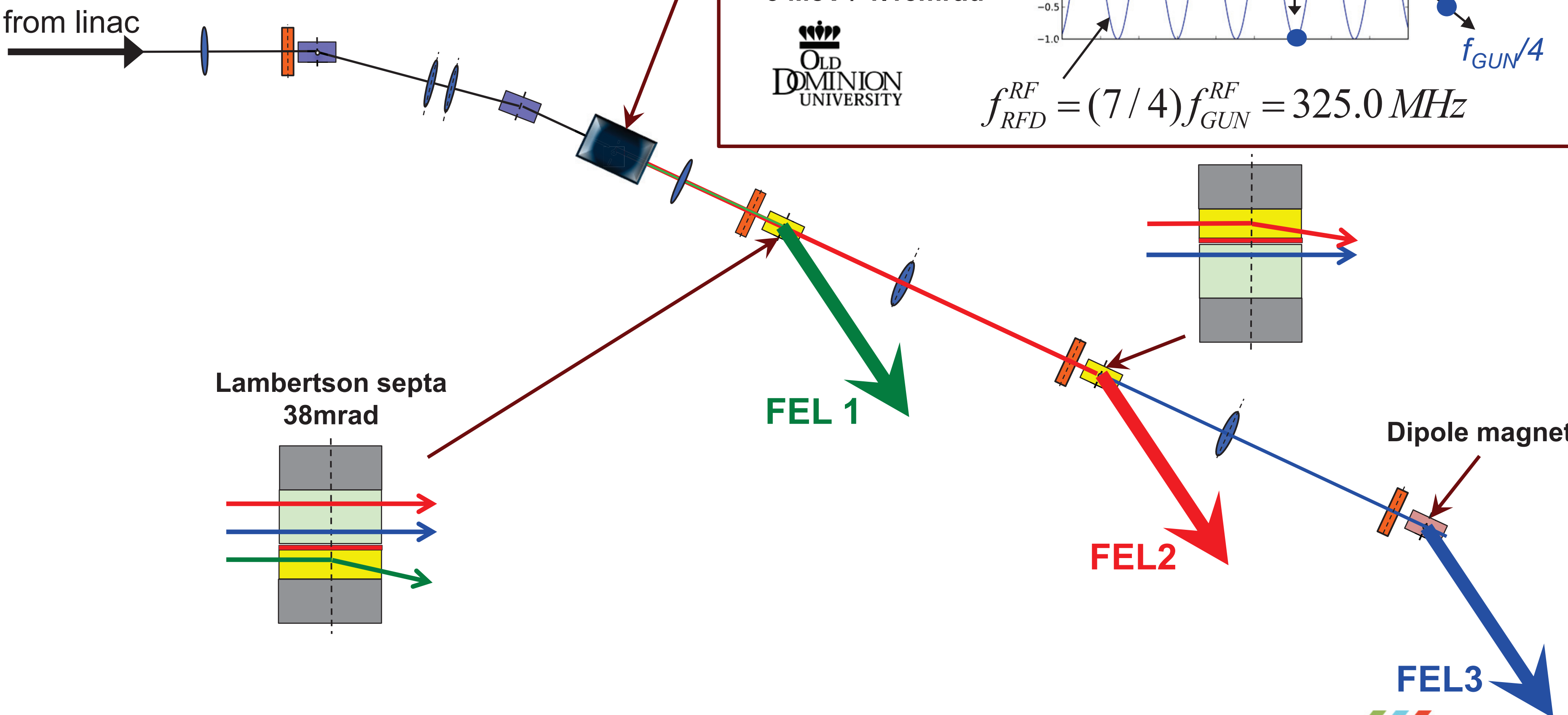
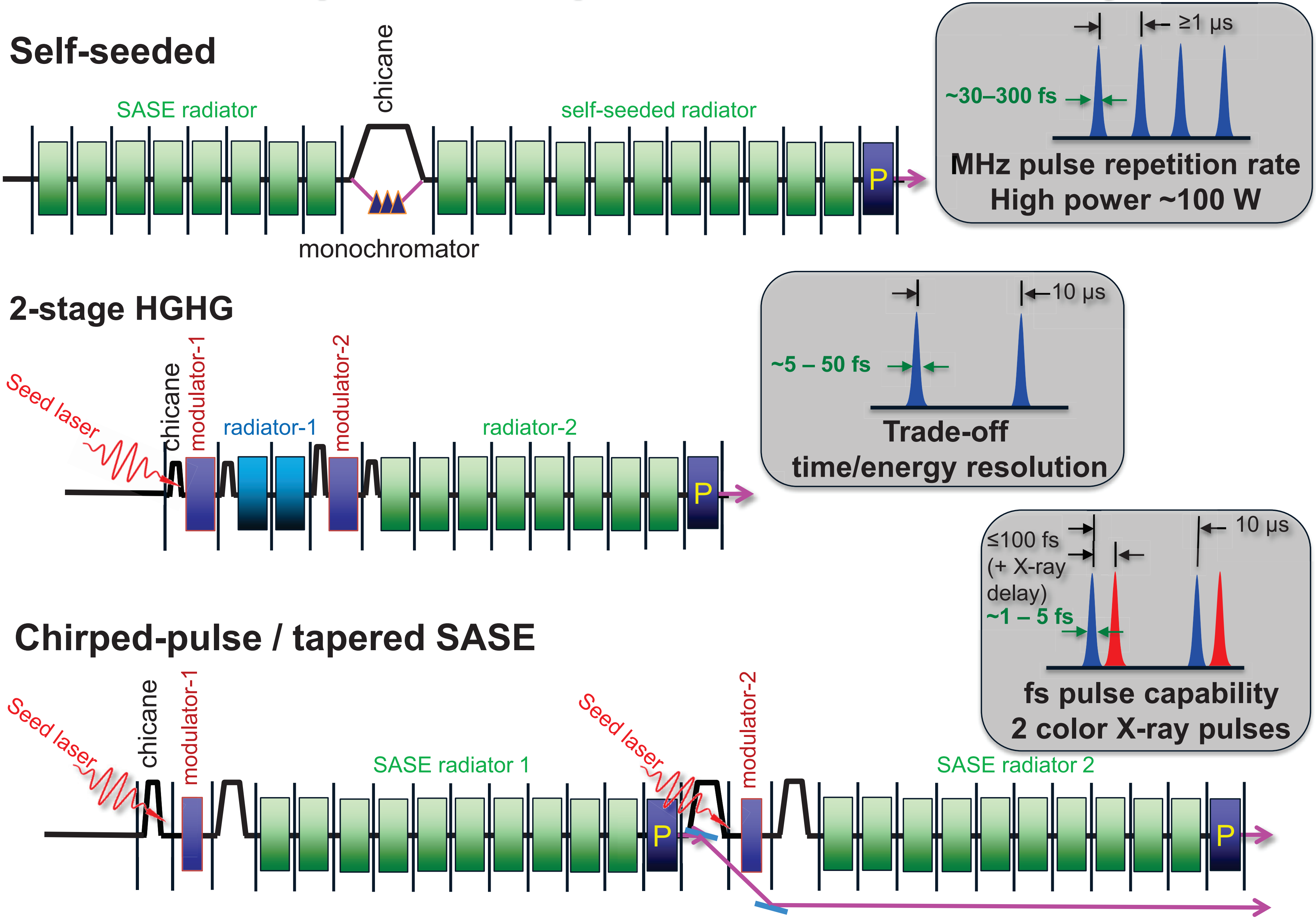
Beam spreader

- **RF deflecting cavity and magnetic lattice distributes bunches to FEL beamlines**
  - ***Flexible time structure***



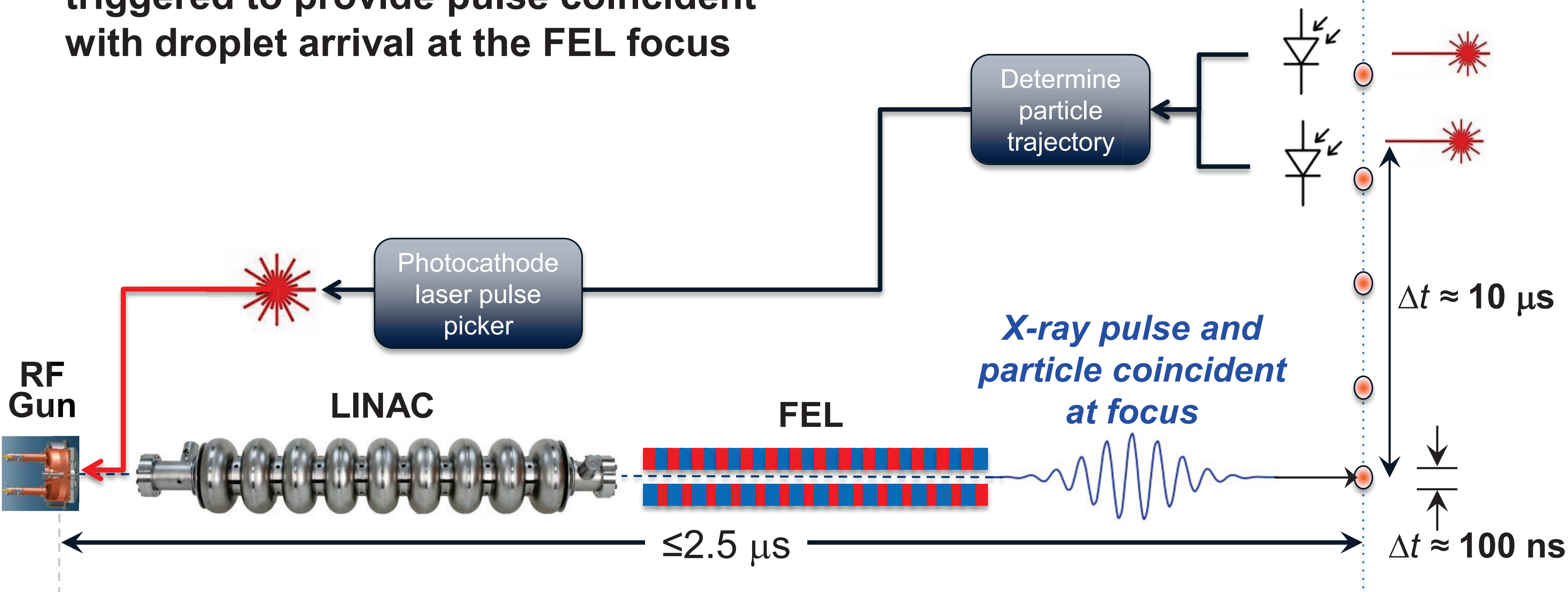


Three concepts developed for the initial X-ray FELs

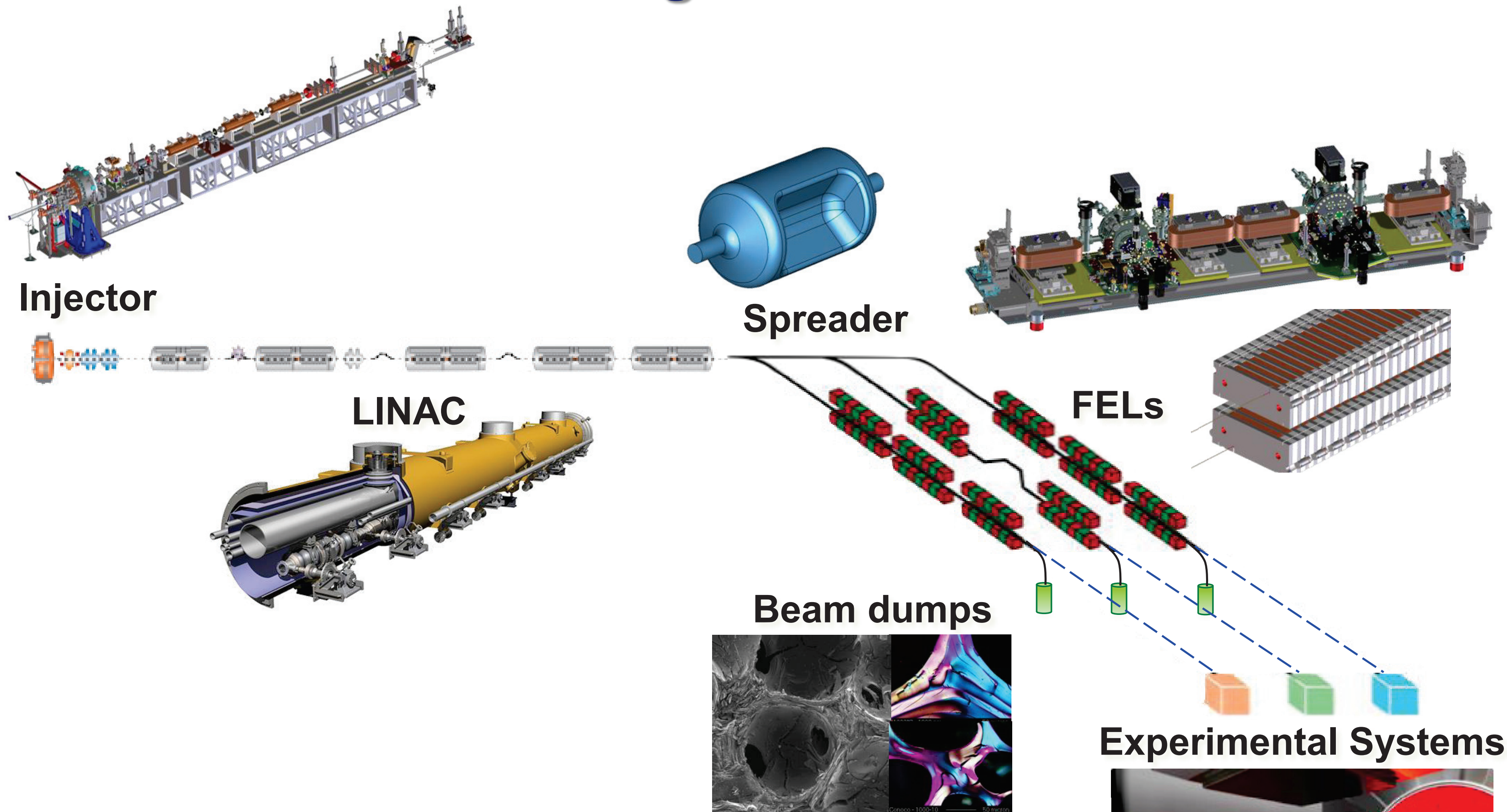


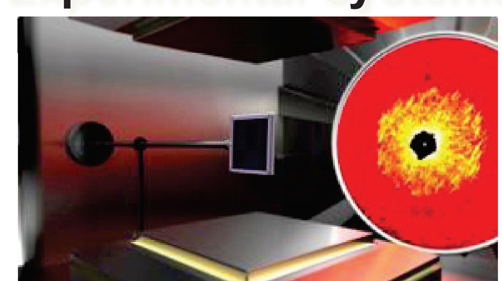
“Pulse on demand”

- **Photodiodes measure timing and predict the path of droplet from dispenser**
- **The photocathode laser is then triggered to provide pulse coincident with droplet arrival at the FEL focus**



NGLS technical challenges





Challenges mostly in handling high rep-rate and high average power

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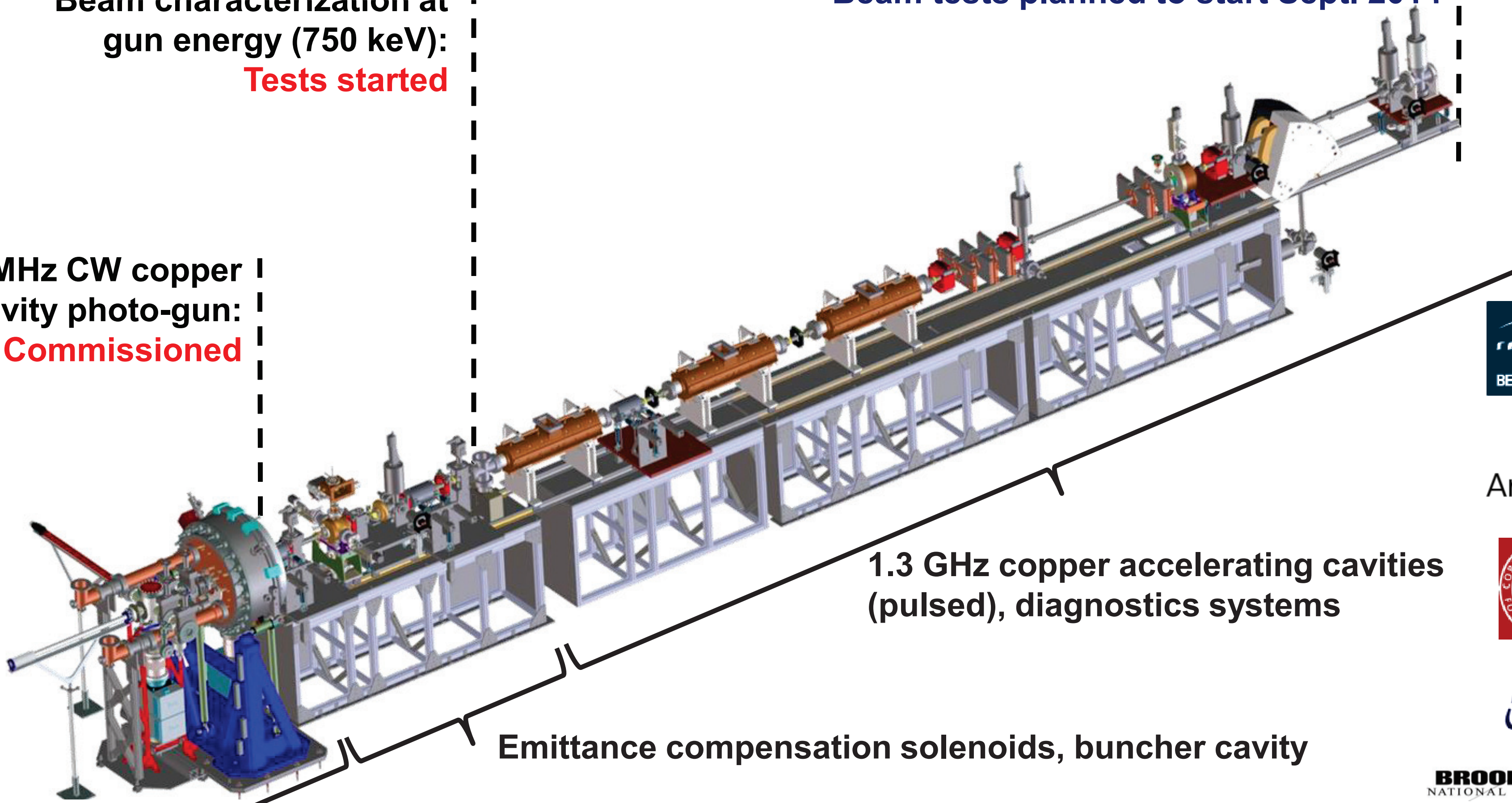
Advanced Photoinjector Experiment (APEX): Demonstrate MHz high-brightness electron source

Beam characterization at 15–30 MeV
6-D brightness measurements:
Beam tests planned to start Sept. 2014

Beam characterization at gun energy (750 keV):
Tests started

186 MHz CW copper cavity photo-gun:
Commissioned



1.3 GHz copper accelerating cavities (pulsed), diagnostics systems

Emittance compensation solenoids, buncher cavity

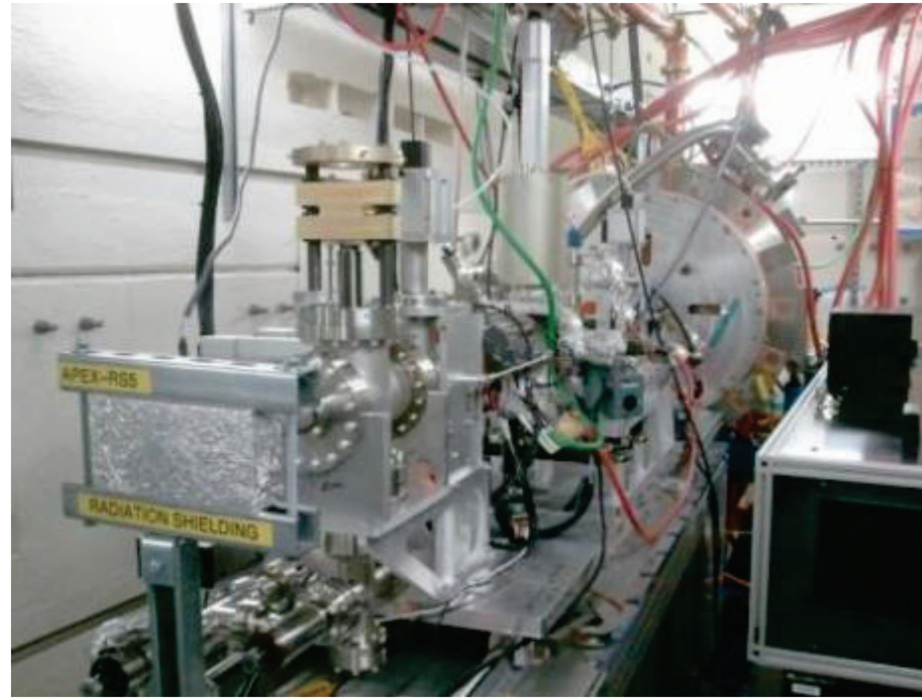
186 MHz CW RF photocathode gun

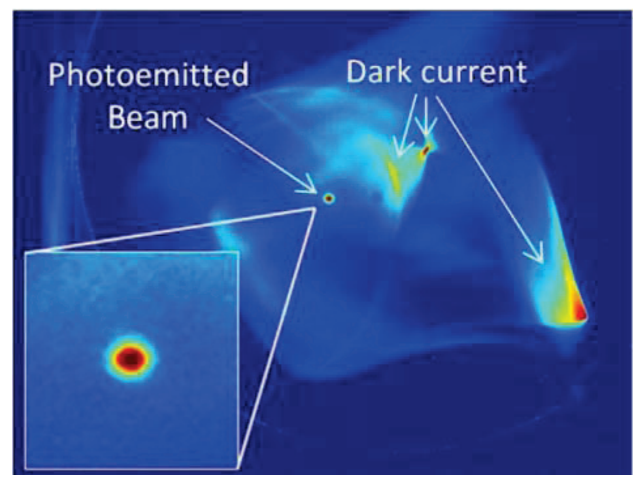
APEX on track, gun technology demonstrated

- **Gun operating at full RF power**
  - *120 kW*
- **Dark current characterized**
  - *~1 nA close to exit of gun*
- **Excellent vacuum demonstrated**
  - *$8x10^{-10}$ Torr with RF on*

- **Photo-emitted electron beam energy demonstrated (750 keV)**
- **MHz photoemission from high-QE cathode demonstrated**
  - *Cs_2Te, 1 W Yb-fiber laser*

- **Good lifetime in initial measurements**
  - *10%–>4% after 40 C extracted*





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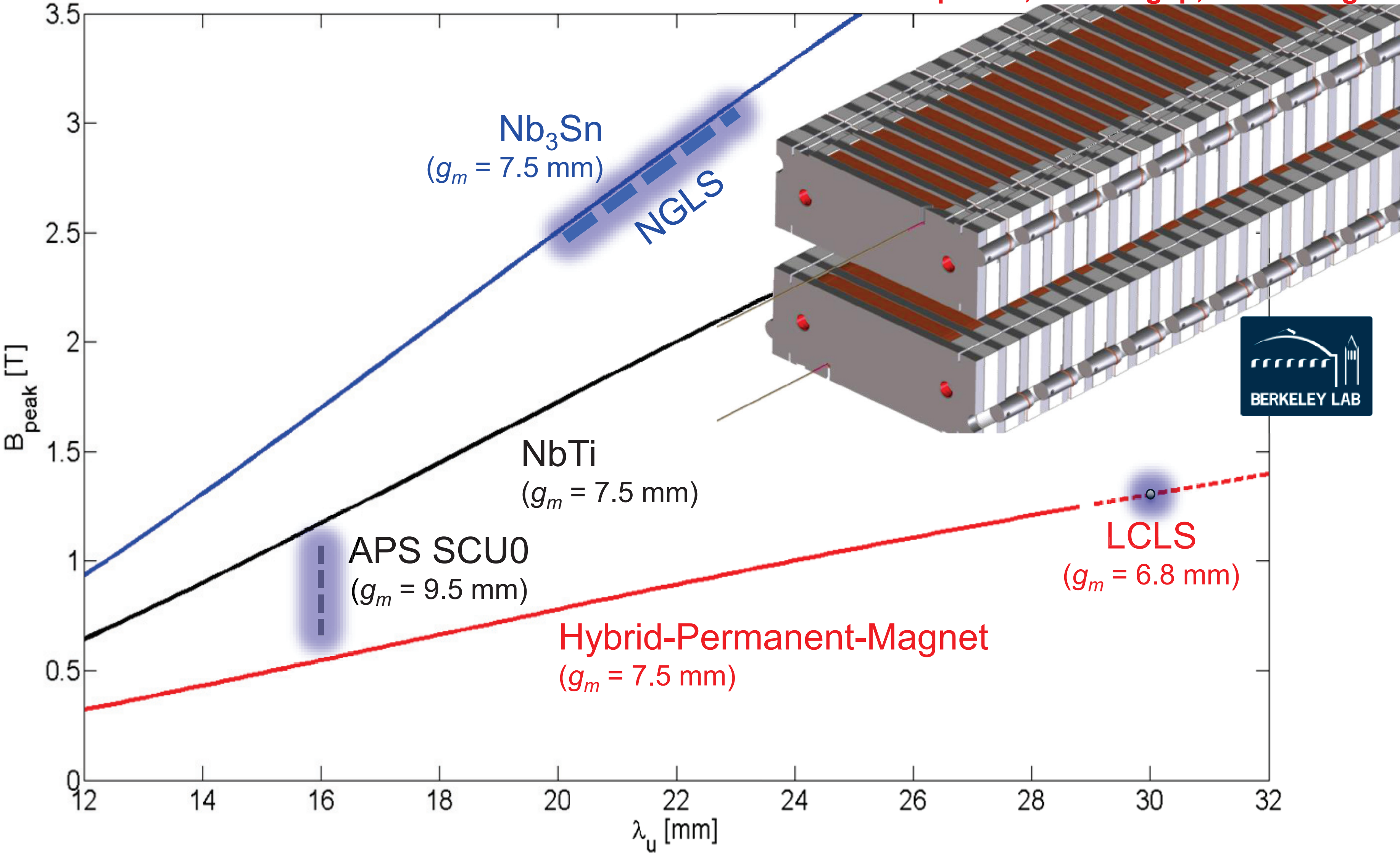
Undulator technology and R&D

Nb_3Sn prototype
20 mm period, 7.5 mm gap, 50 cm length



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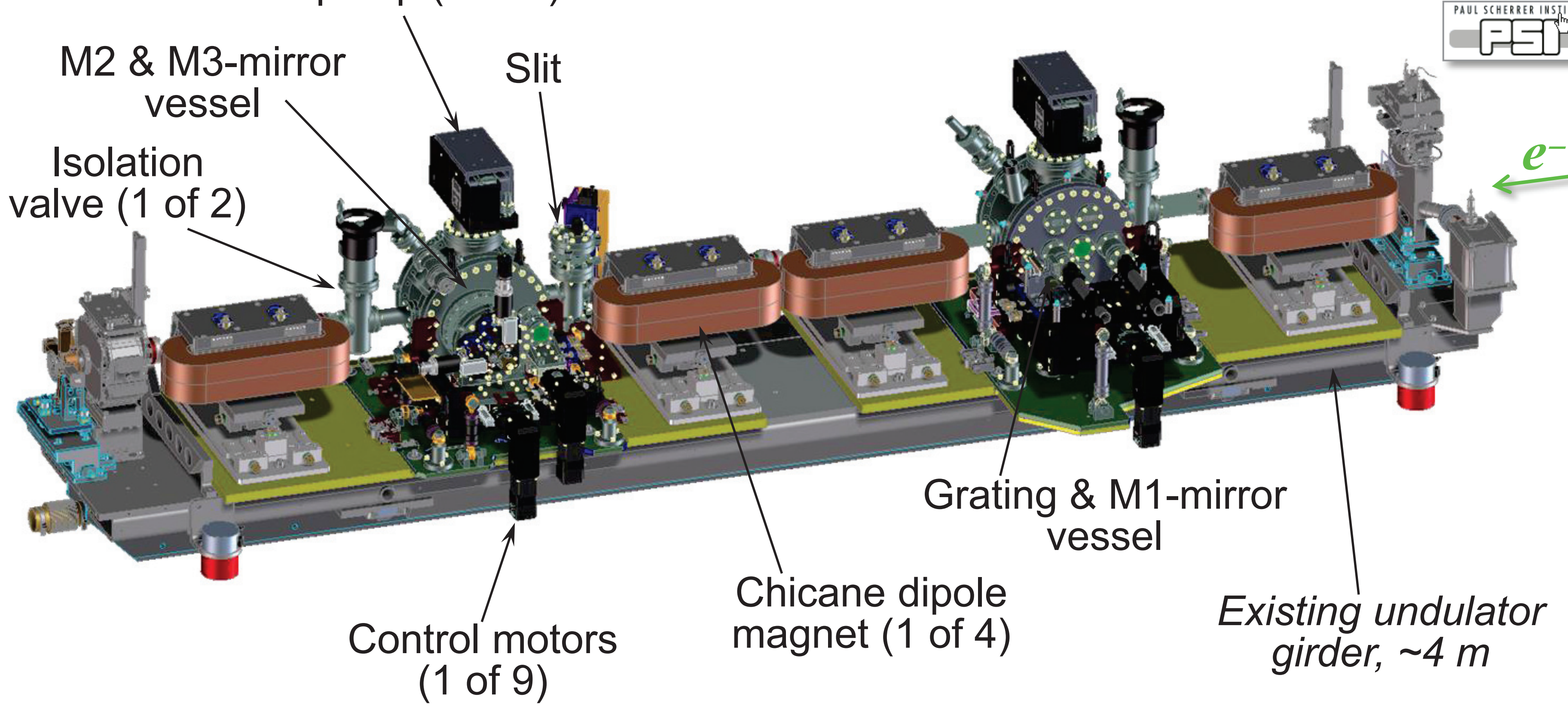
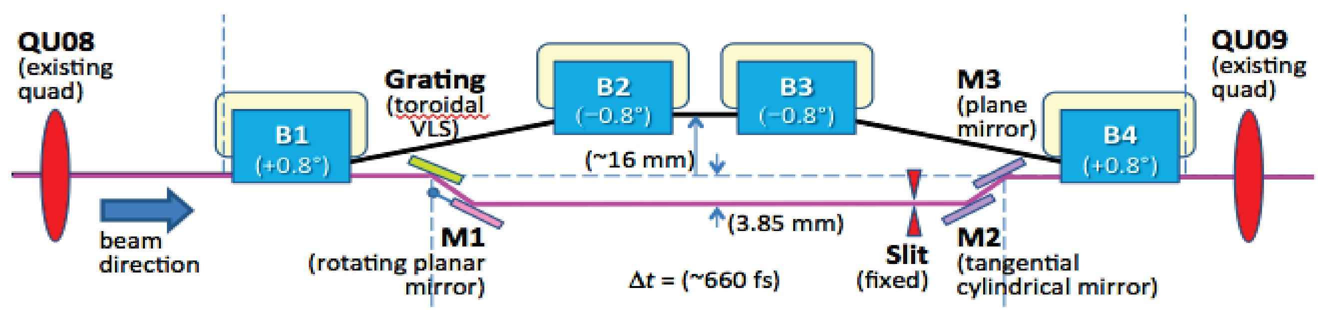
Soft X-Ray Self-Seeding (SXRSS)

Hardware installation under way at LCLS
Plans for initial experiments this year





Summary

The NGLS collaboration has developed a science-driven design concept for a future FEL facility

- **Multi-beamline soft X-ray laser array**
- **Powered by a high-stability CW superconducting linac**
- **High repetition rate (MHz) and uniform time structure**

➠ **Provide missing capabilities in X-ray science, (needed e.g. to observe and control function of materials)**

- ✓ **Soft X-rays**
- ✓ **Ultrafast**
- ✓ **Full coherence**
- ✓ **2-color (X-ray pump-probe)**
- ✓ **High repetition rate**

The NGLS design effort has now come to an end.

- ***We hope that many of the ideas developed will find good use in the next FEL light source to be built in the USA***

NGLS R&D, design collaboration

BERKELEY LAB: Arnaud Allezy, Diego Arbelaez, John Byrd, John Corlett, Charlotte Daniels, Stefano De Santis, William Delp, Peter Denes, Rick Donahue, Lawrence Doolittle, Paul Emma*, Daniele Filippetto, James Floyd, Joseph Harkins, Gang Huang, Jin-Young Jung, Derun Li, Tak Pui Lou, Tianhuan Luo, Gabriel Marcus, Marco Monroy, Hiroshi Nishimura, Howard Padmore, Christos Papadopoulos, Chris Pappas, Stefan Paret, Gregory Penn, Massimo Placidi, Soren Prestemon, Donald Prosnitz, Houjun Qian, Ji Qiang, Alessandro Ratti, Matthias Reinsch, David Robin, Fernando Sannibale, Robert Schoenlein, Carlos Serrano, John William Staples, Christoph Steier, Changchun Sun, Marco Venturini, Will Waldron, Weishi Wan, Tony Warwick, Russell Wells, Russell Wilcox, Sergio Zimmermann, Alexander Zholents**, Max Zolotorev

Fermilab: Camille Ginsburg, Robert Kephart, Arkadiy Klebaner, Thomas Peterson, Alexander Sukhanov

Jefferson Lab, Thomas Jefferson National Accelerator Facility: Dana Arenius, George Neil, Tom Powers, Joe Preble

SLAC National Accelerator Laboratory: Chris Adolphsen, Karl Bane, Yuantao Ding, Zhirong Huang, Chris Nantista, Cho-Kuen Ng, Heinz-Dieter Nuhn, Claudio Rivetta, Gennady Stupakov

*Now at SLAC. ***Visiting from ANL.*