DESIGN CONCEPTS FOR A NEXT GENERATION LIGHT SOURCE AT LBNL

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Jefferson Lab
Thomas Jefferson National Accelerator Facility

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for the NGLS R&D and Design Collaboration

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35th International Free-Electron Laser Conference
August 26-30, 2013

NGLS design driven by the X-ray science needs

Where are the *electrons*?

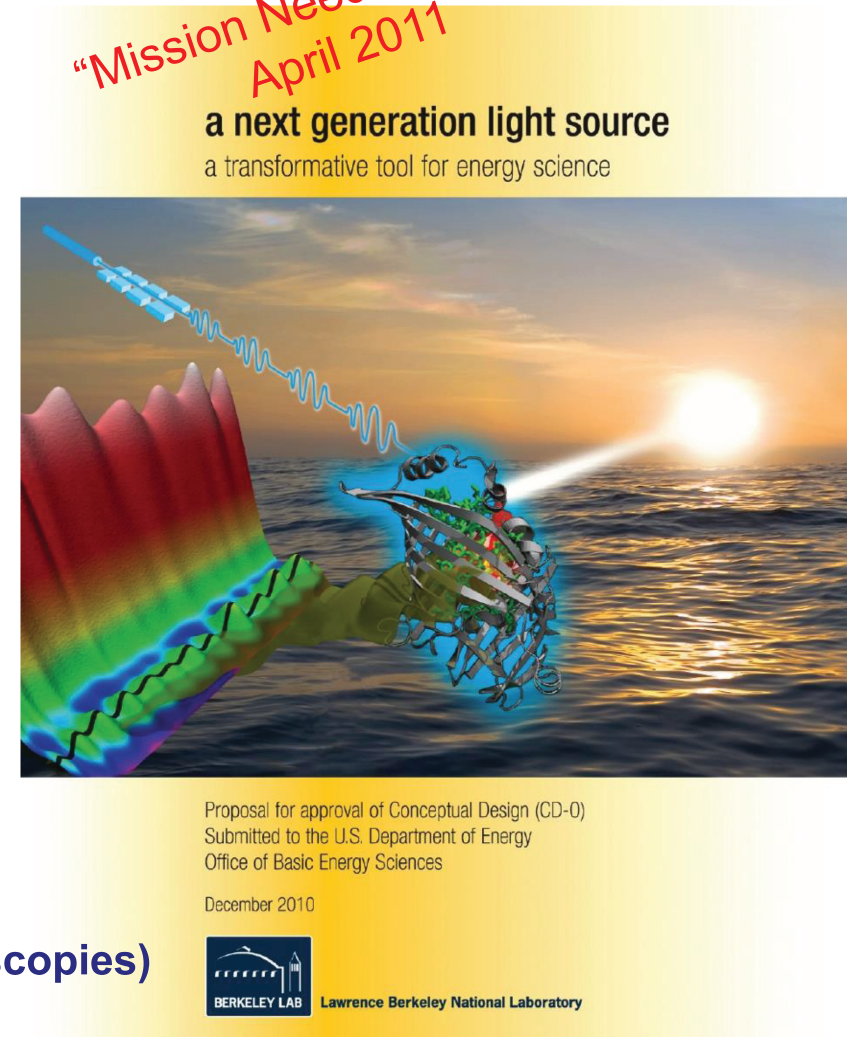
- **What are they doing? Why? How?**
- **Can they be controlled and manipulated?**

Chemical bonding & interacting electrons

- **Requires moderate peak power soft X-ray probes**
  - ***avoid disruption, control nonlinear processes***
- **High average brightness**
- **Ultrafast pulses**

- **NGLS provides missing capabilities to observe and control *function***
  - ✓ **Soft X-rays**
  - ✓ **Ultrafast**
  - ✓ **Full coherence**
  - ✓ **2-color (X-ray pump-probe, non-linear spectroscopies)**
  - ✓ **High repetition rate**

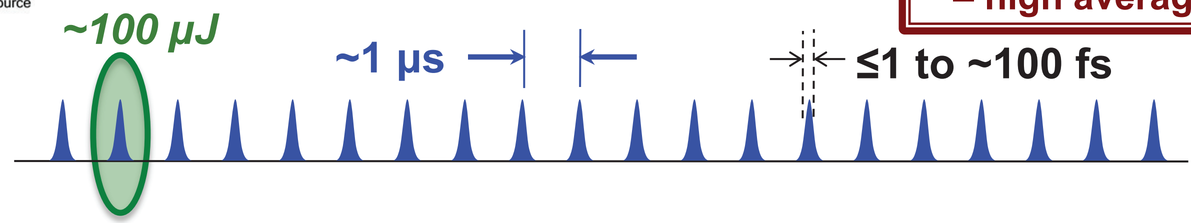
“Mission Need” approved
April 2011



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

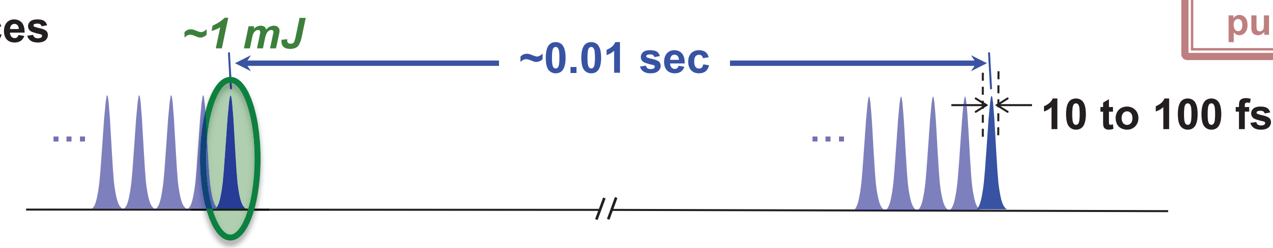
NGLS next generation light source

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



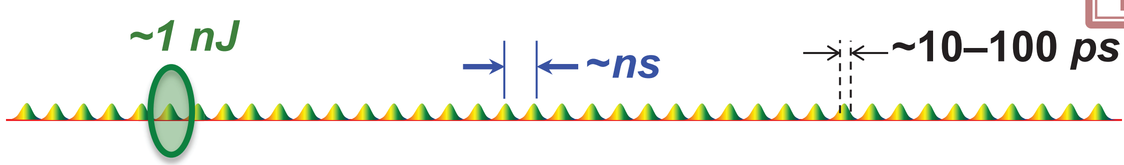
Today's X-ray laser sources

Intense coherent pulses at low rep rate



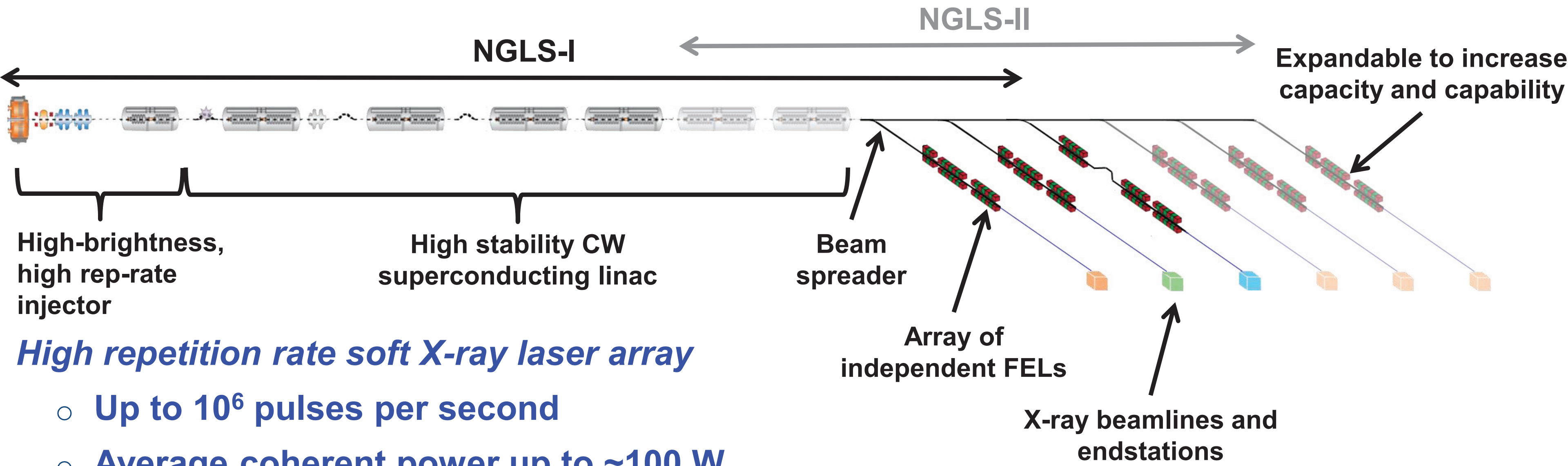
Today's storage ring sources

Weak coherent pulses at high rep rate



NGLS next generation light source

NGLS concept: science-driven design



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

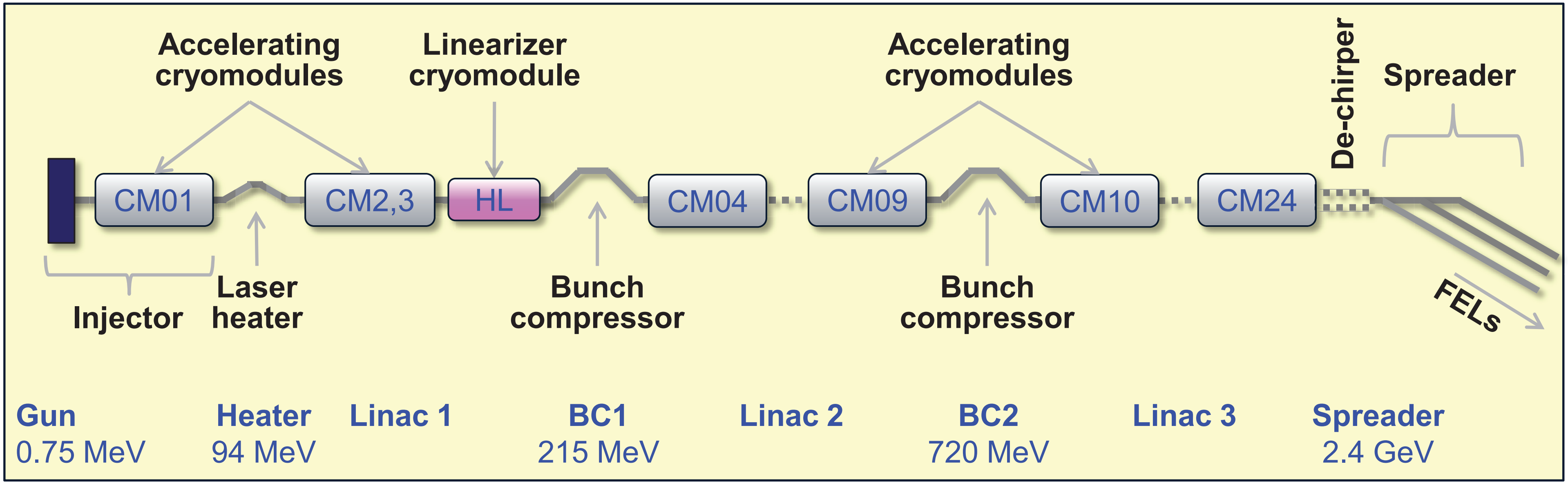
Tunable X-rays

- 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)

Linac layout



- "APEX" injector
- TESLA/ILC technology modified for NGLS
- Dechirper
- RF deflector-based beam spreader
- 3 initial seeded / self-seeded FELs

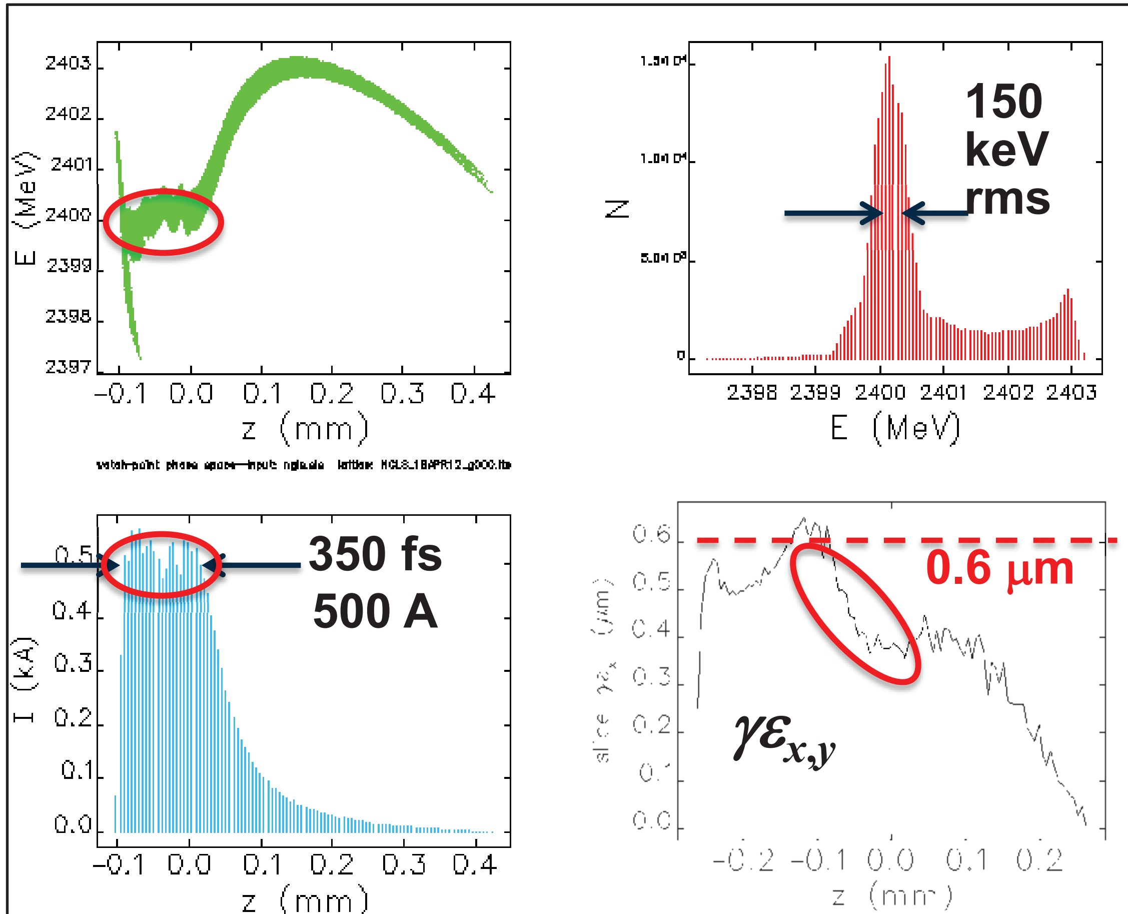
- 300 pC bunches
- 1 MHz bunch rate
- $\gamma\varepsilon_{\perp}$ = 0.6 μm
- σ_E = 150 keV
- I_{pk} = 500 A
- Final useable bunch 300 fs

MOICNO02
TUOANO01
TUPSO12

NGLS next generation light source

Linac beam dynamics

- *S2E modeling using ASTRA, ELEGANT, IMPACT, GENESIS, GINGER*
- *Electron beam and FELs meet requirements*

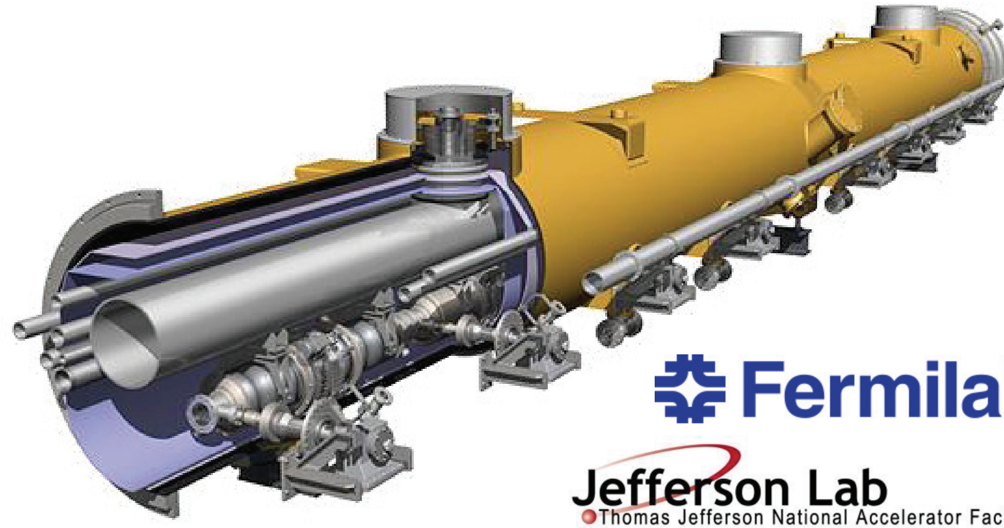


MOPSO66
MOPSO73
MOPSO65

NGLS next generation light source

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 MV/m**
  - **$Q_0 = 2x10^{10}$**
  - **Heat load @ 1.8K**
    - **~12 W / cavity**
    - **90–130 W / cryomodule**



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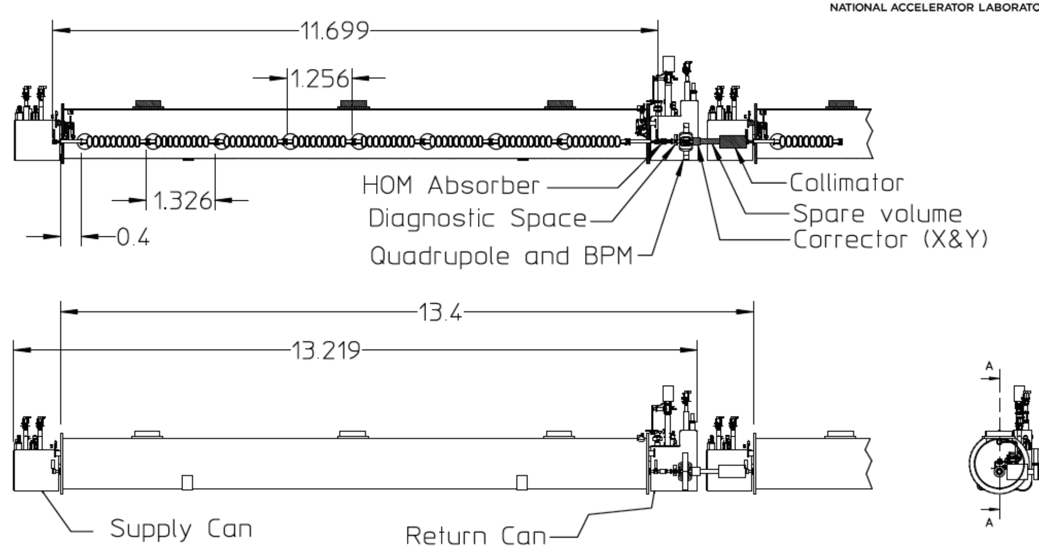
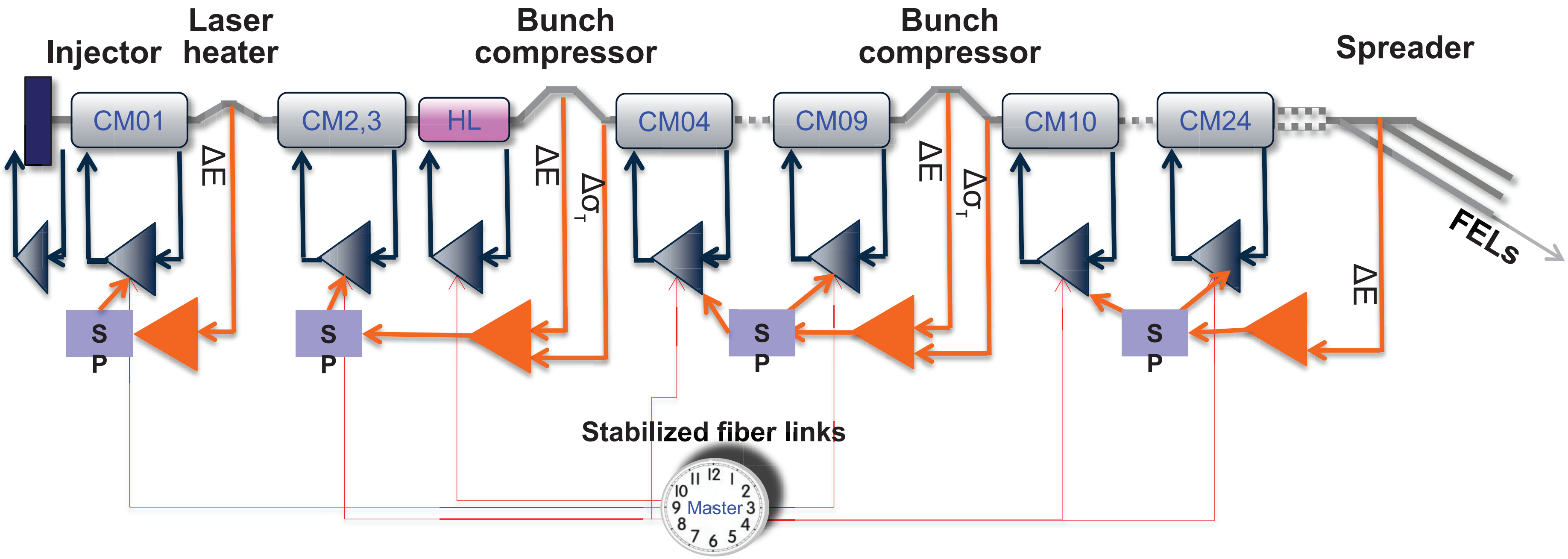


TUPSO12
TUPSO13

NGLS
next generation light source

CW superconducting linac and high bunch rate allow feedback for highly stable beams



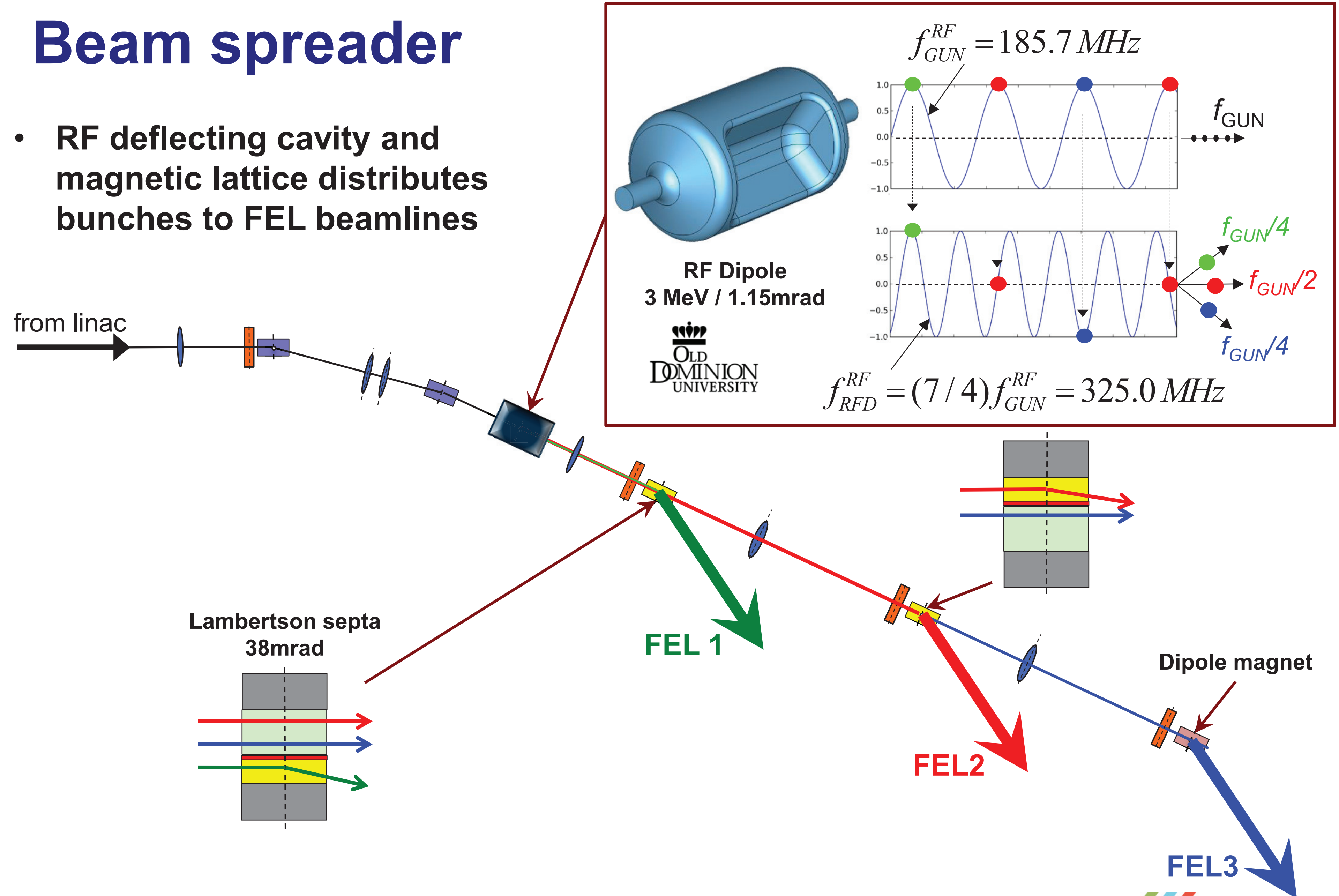
- **Goal of stability similar to existing storage rings**
- **Superconducting systems time constant long – does not react to perturbations**
- **CW measurements allow broadband feedback to control residual jitter**
  - **$\Delta E/E \sim 10^{-5}$**
  - **$\Delta\tau$ <10 fs**
  - **$\Delta x_{rms}/\sigma_x < 5\%$**

TUOANO01
TUPSO12

NGLS next generation light source

Beam spreader

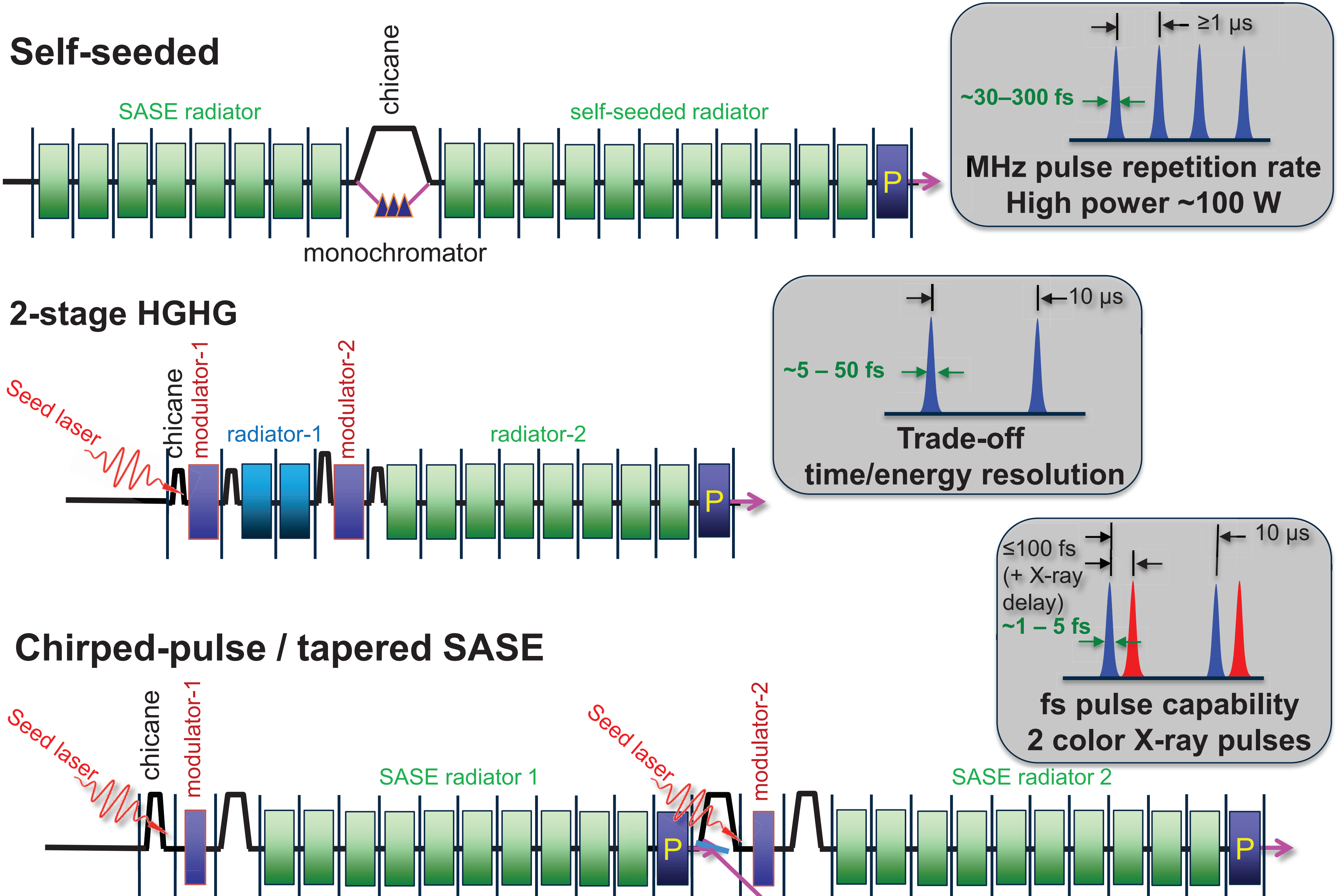
- **RF deflecting cavity and magnetic lattice distributes bunches to FEL beamlines**



TUOBNO03

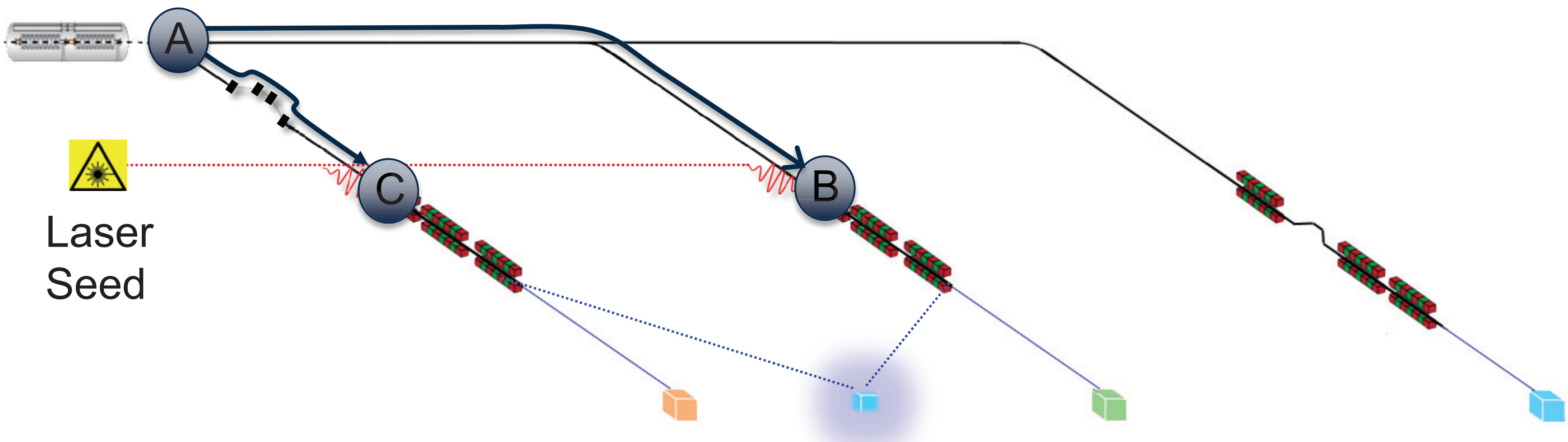
NGLS next generation light source

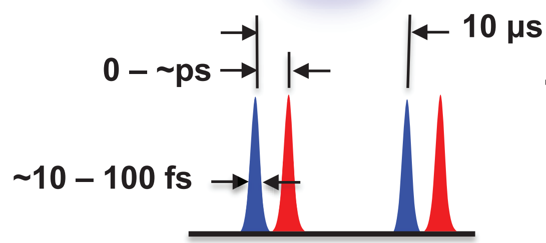
Three concepts developed for the initial X-ray lasers



WEPSO48, WEPSO73, THOBNO01

Alternate 2-color capability





Two-color endstation

- **Combines pulses from two separate FELs**
  - **Controllable photon energy**
  - **Full tuning range for each FEL**
  - **Controllable time delay**

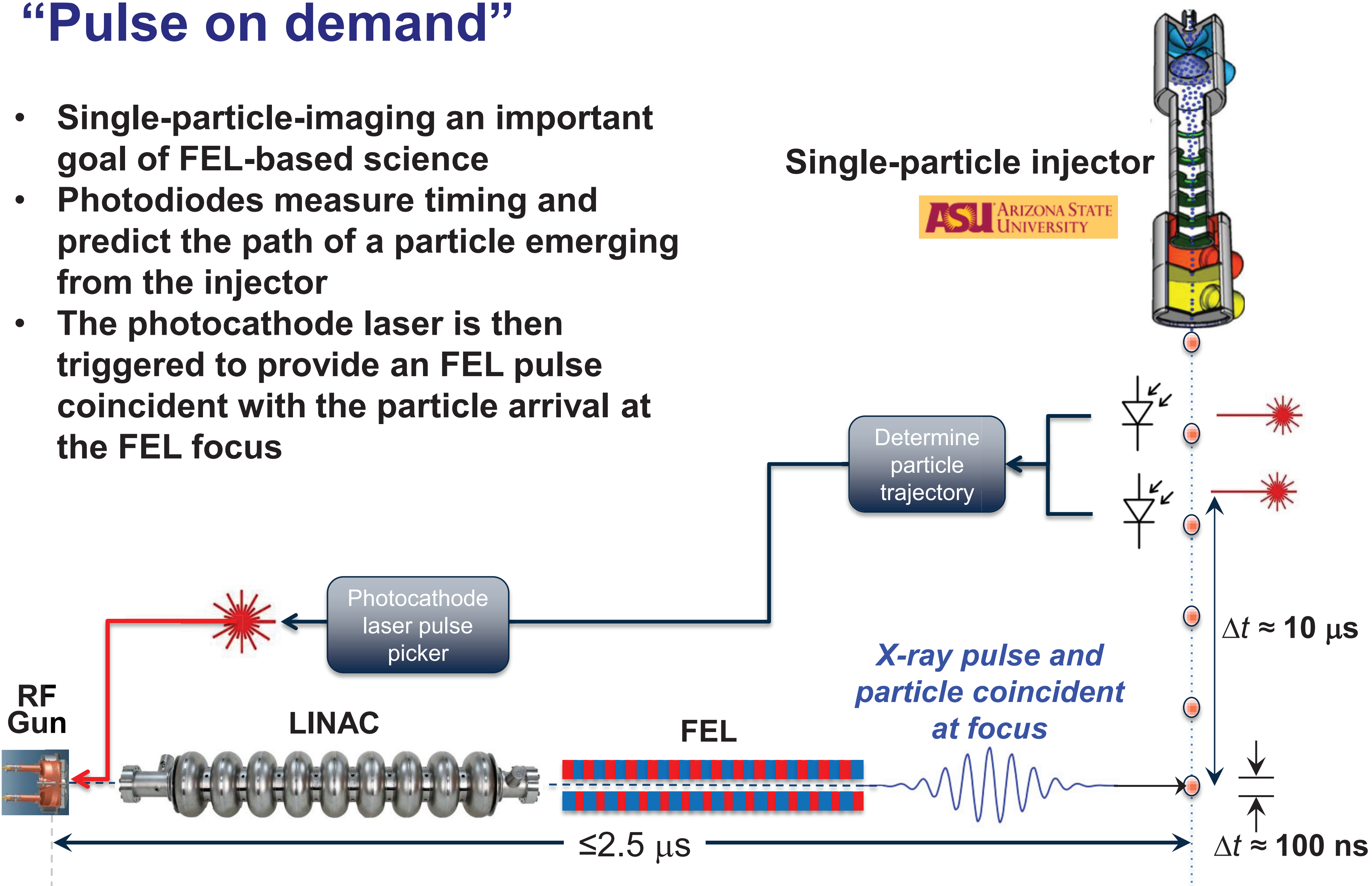
$$\Delta t\,[(A \rightarrow B) - (A \rightarrow C)] = n\tau_{RFgun}$$

Chicane provides ±0.6 ps variation in one arm
+ laser timing control
+ X-ray optics delay (~ps)

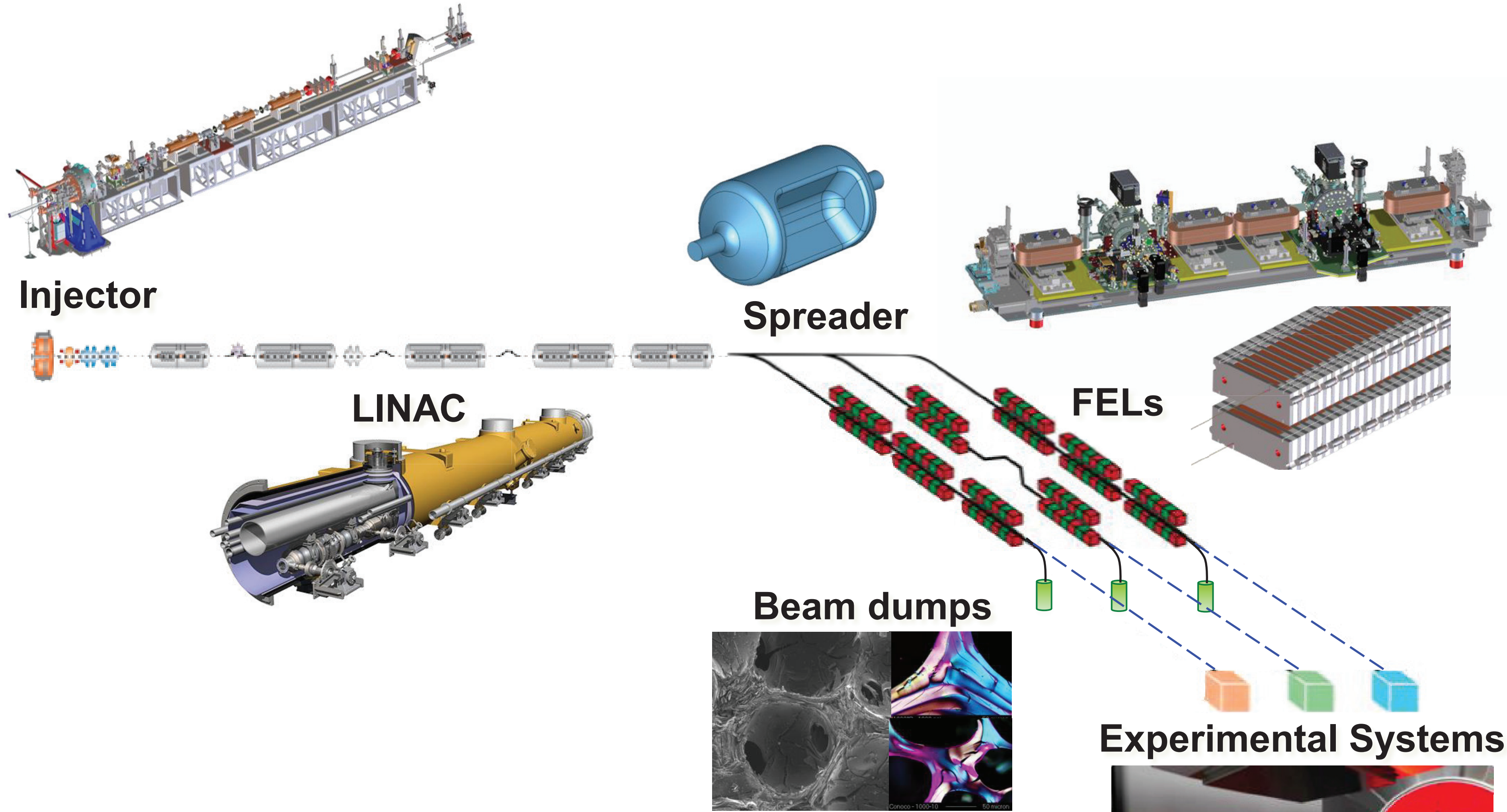
NGLS next generation light source

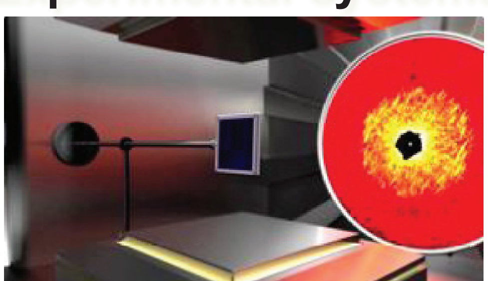
"Pulse on demand"

- Single-particle-imaging an important goal of FEL-based science
- Photodiodes measure timing and predict the path of a particle emerging from the injector
- The photocathode laser is then triggered to provide an FEL pulse coincident with the particle arrival at the FEL focus



NGLS technical challenges



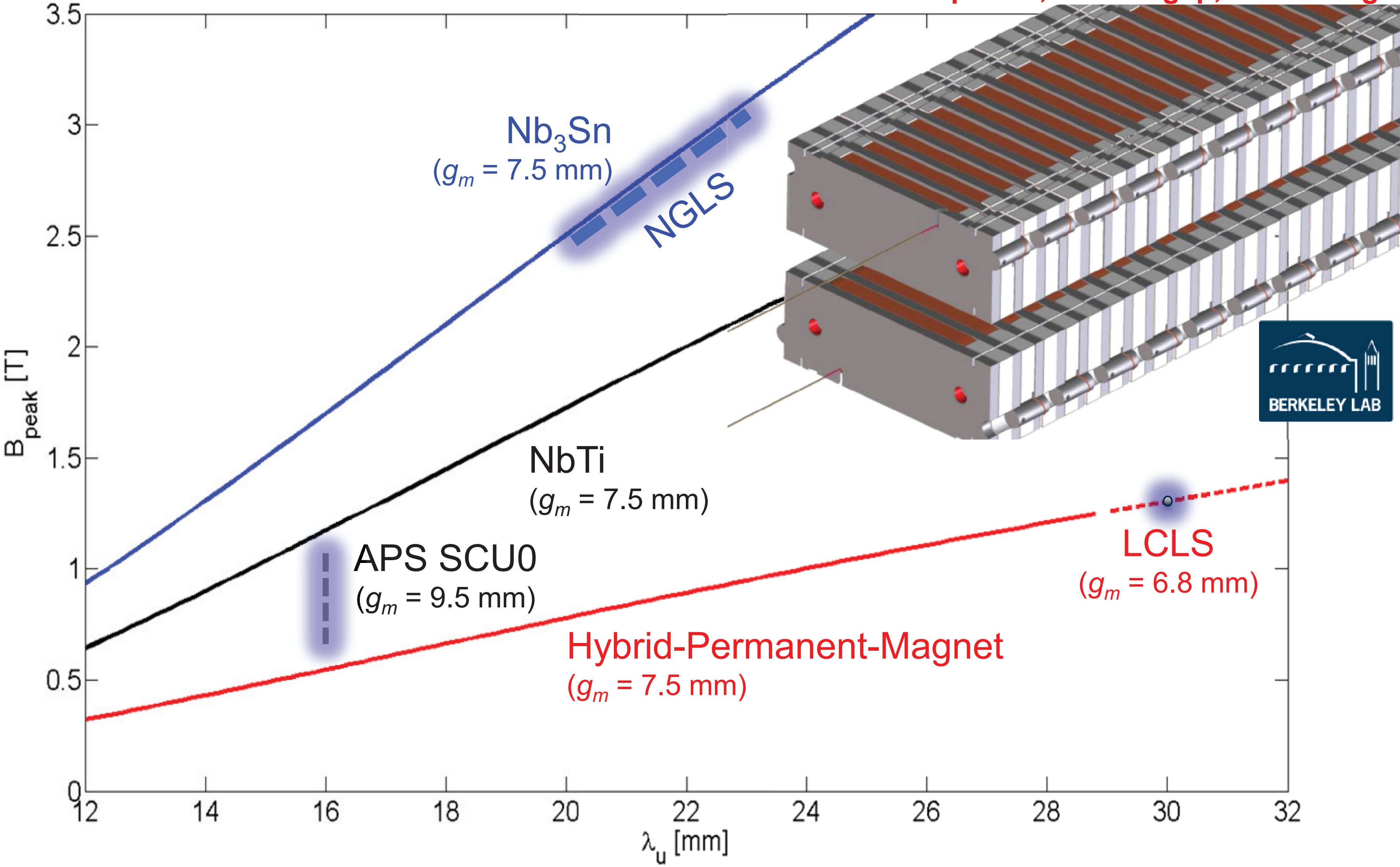


Challenges mostly in handling high rep-rate and high average power

NGLS next generation light source

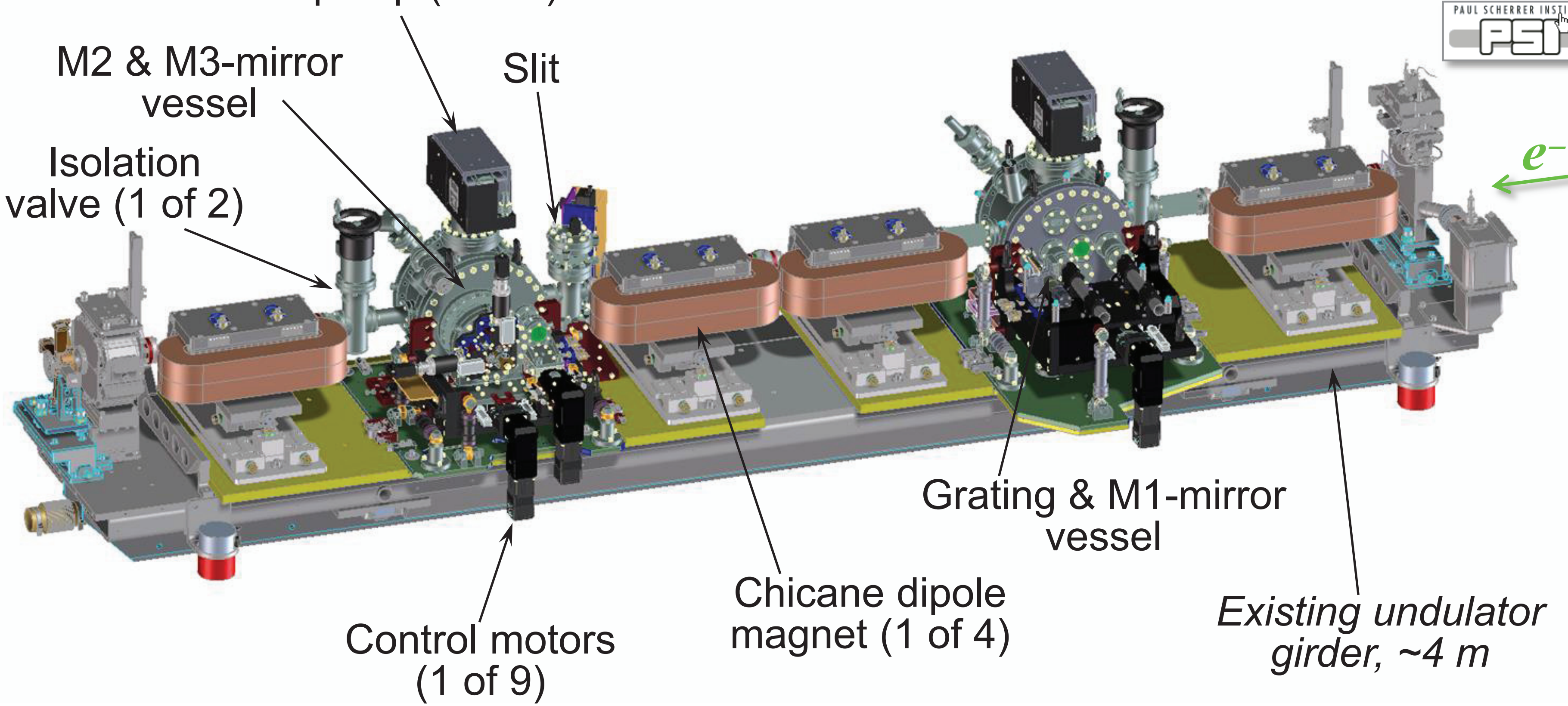
Undulator technology and R&D

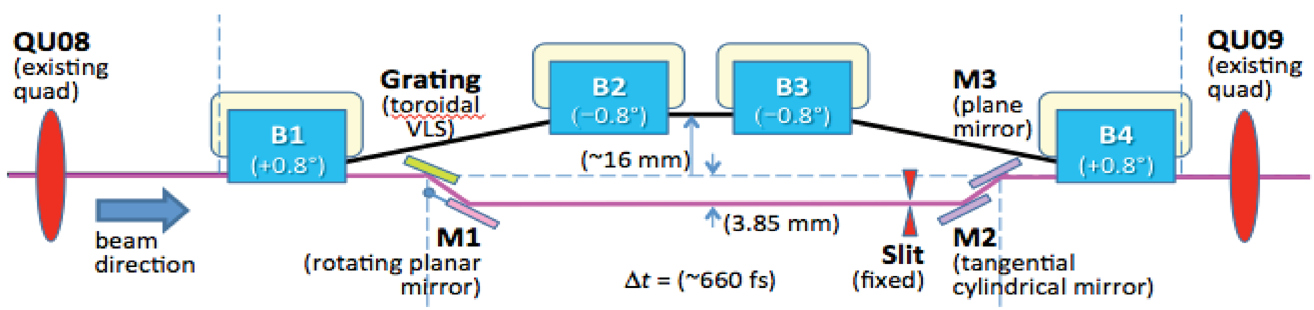
Nb_3Sn prototype
20 mm period, 7.5 mm gap, 50 cm length



Soft X-Ray Self-Seeding (SXRSS)

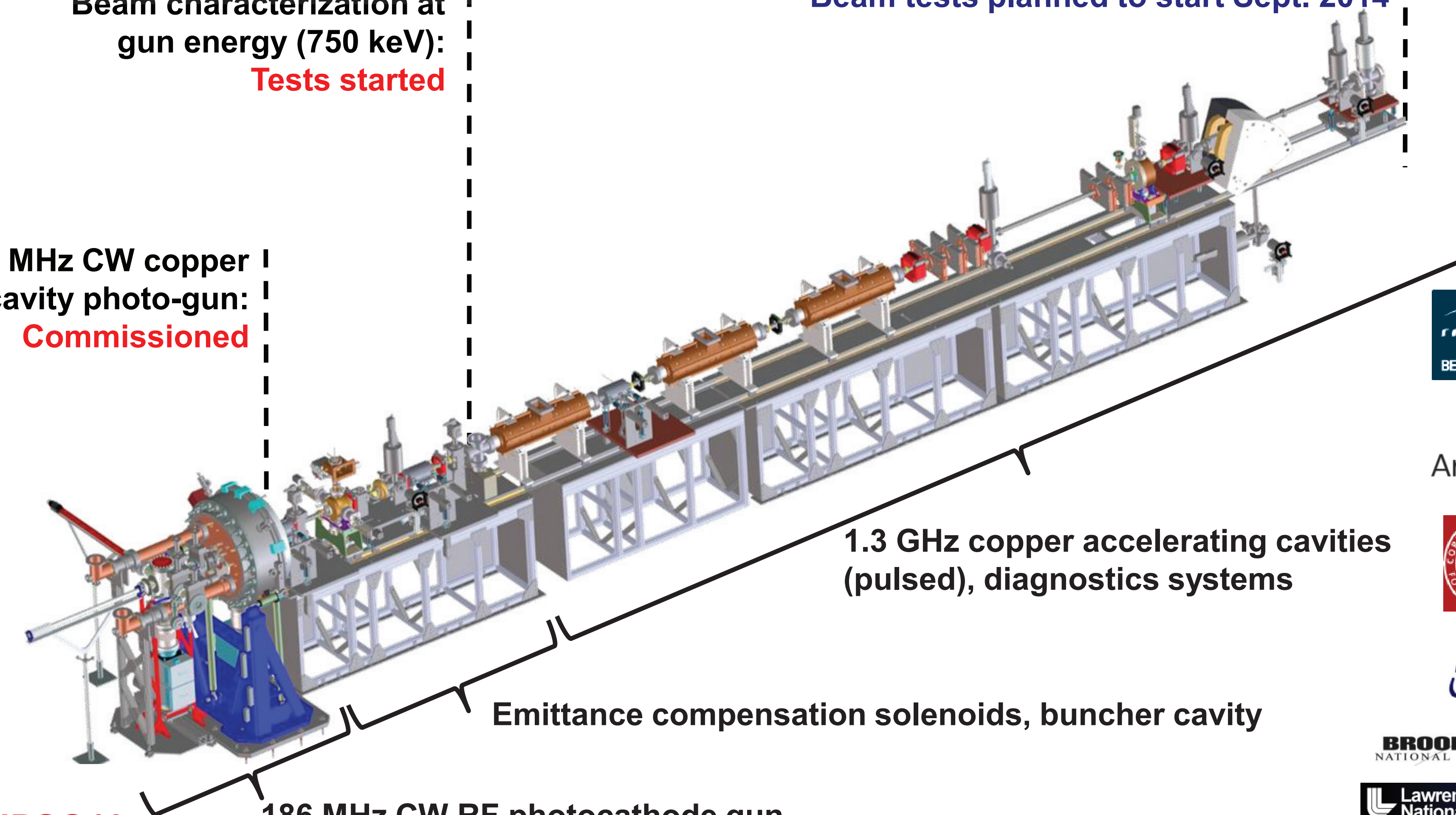
Hardware installation under way at LCLS
Plans for initial experiments this year





WEPSO52

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



TUPSO19
TUPSO69

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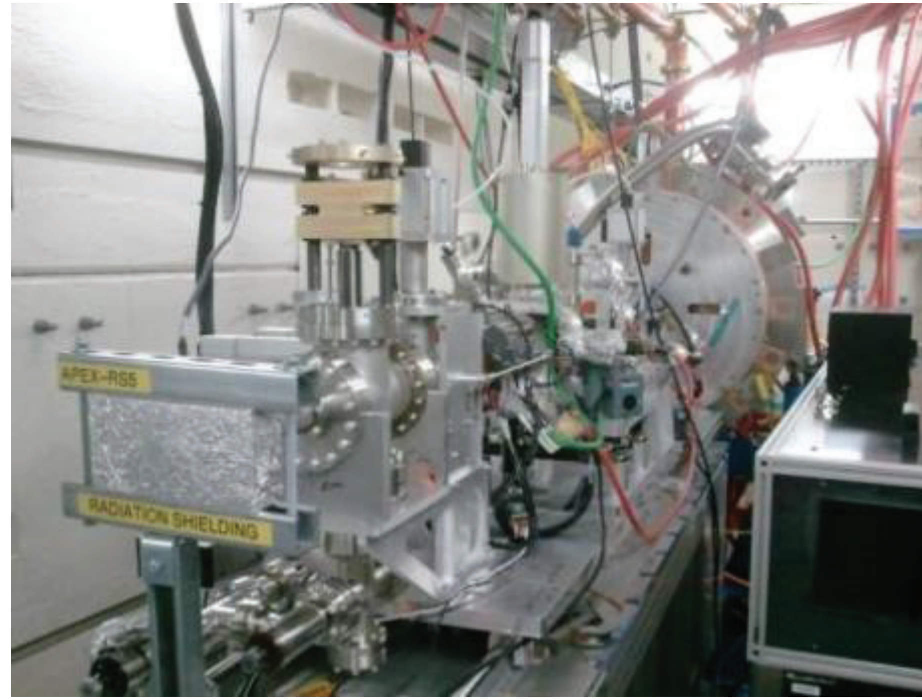
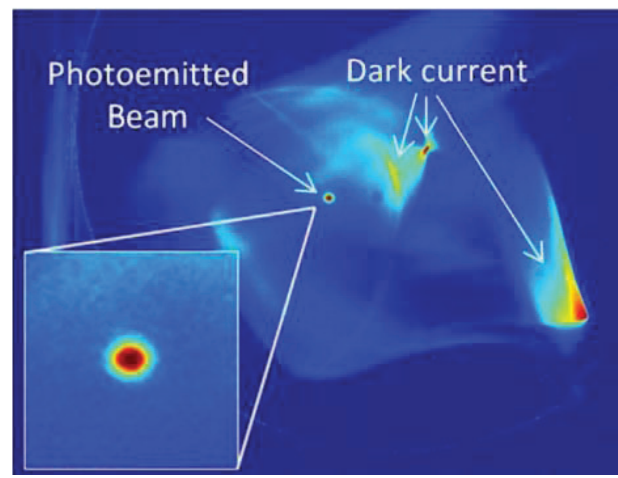
NGLS next generation light source

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





TUPSO19
TUPSO69

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next generation light source

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

➠ NGLS provides missing critical capabilities in X-ray science, needed to observe and control function of materials

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

NGLS R&D and design collaboration

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, Max Zolotorev

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

Dana Arenius, George Neil, Tom Powers, Joe Preble

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

NGLS-related papers at this conference

Paper ID	Title
MOPSO63	FEL X-ray Pulse Brightness Calculations
MOPSO65	Suppression of Wakefield Induced Energy Spread Inside an Undulator Through Current Shaping
MOPSO66	Start-to-end simulation of a Next Generation Light Source using the real number of electrons
MOPSO73	Suface Roughness Wakefield in FEL Undulator
TUOANO01	Towards high energy and timing stability in SCRF linacs
TUOBNO03	Design concept of an RF-based beam-spreader system for a Next Generation Light Source
TUOCNO05	Design concepts for a Next Generation Light Source at LBNL
TUPSO12	RF Design of the NGLS Linac
TUPSO13	Superconducting linac design concepts for a Next Generation Light Source at LBNL
TUPSO15	Beam Diagnostic Requirements for the Next Generation Light Source
TUPSO19	The Photocathode Laser System for the APEX High Repetition Rate Photoinjector
TUPSO69	Injector Design Studies for NGLS
TUPSO78	Design of a Collimation System for the Next Generation Light Source
WEPSO48	Simulation Studies Of FELs For A Next Generation Light Source
WEPSO52	Soft X-ray Self Seeding Project at LCLS
WEPSO68	Intra-beam Scattering Effect in EEHG
WEPSO73	High average power seed laser design for high reprate FELs
THOBNO01	Three Unique FEL Designs for the Next Generation Light Source