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Workshop on Future Light Sources: FLS 2023

SCU Development at the LCLS for Future FELs

Patrick Krejcik

G. Bouchard, D. Caltabiano, G. Gassner, Z. Huang, E. Kraft, B. Lam, A.M. Montironi, C. Nantista, D.C. Nguyen, H-D. Nuhn, X. Permanyer, Z. Wolf, Z. Zhang, **SLAC**

E. Antliker, J. Byrd, J. Fuerst, E. Gluskin, Y. Ivanyushenkov, M. Kasa, I. Kesgin, M. Qian, Y. Shiroyanagi, **ANL**

Argonne NATIONAL LABORATORY

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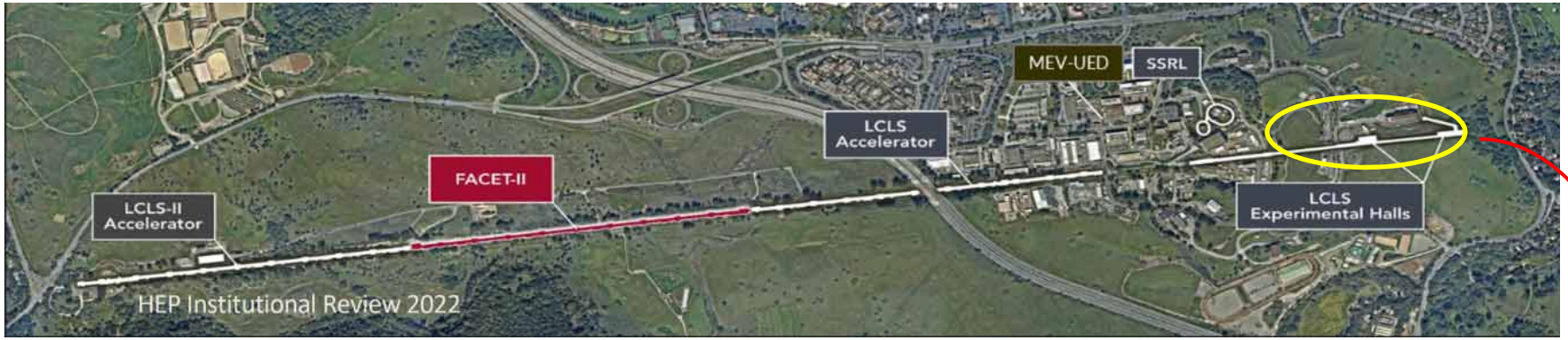
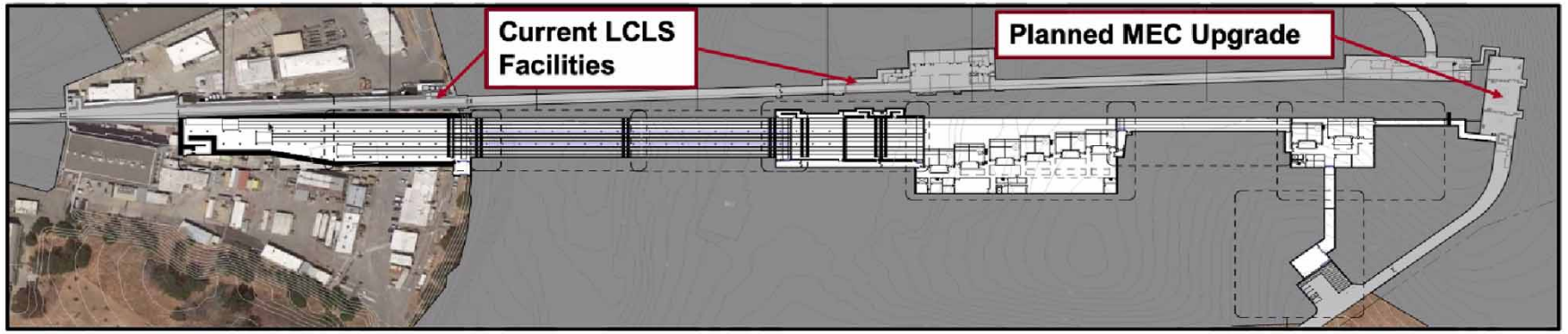
LCLS long-term plans include multiple FEL beamlines

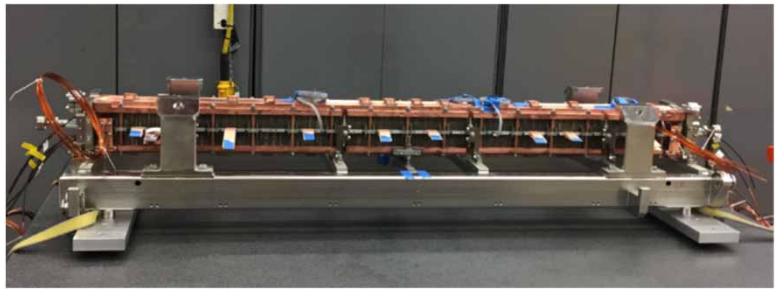


- How to maximize the number of new, user beamlines?
  - Compact SCUs are the answer!



SCU State-of-the-Art in US storage ring light sources

- NbTi SCUs have been installed and tested on the APS
  - Two planar, one helical SCUs are being used
- Nb_3Sn SCUs have been built at LBNL and ANL
- A Nb_3Sn SCU has been tested on the APS



LBNL Nb_3Sn SCU

ANL APS-U SCU CM

- In 2015, ANL built a 1.5m NbTi SCU that met all requirements except for the kicks at entrance and exit
- ANL is building NbTi SCUs up to 1.9m in magnetic length for the APS-U project.

LCLS would like to take advantage of SCUs for FELS

- Higher fields
- Larger gap for same period; shorter period for same gap as PMUs
- Shorter gain length
- Higher photon energy reach
- Conveniently tunable
- Radiation hardness
- Multi FEL beamlines in a single cryomodule

SLAC-ANL SCU Collaboration

- Leverage off ANL's expertise in building SCU insertion devices for storage rings, and considerable experience in SC magnet R&D
- Combined with SLAC's experience in FEL user operation
- Joint funding to build an SCU FEL prototype for installation in the LCLS hard x-ray undulator beamline
- Two or three module after-burner in the HXR line to test beam-based alignment and measure FEL gain by 2026.
  - And be design-ready for a full SCU FEL beamline at LCLS

Unique features of an SCU-based FEL

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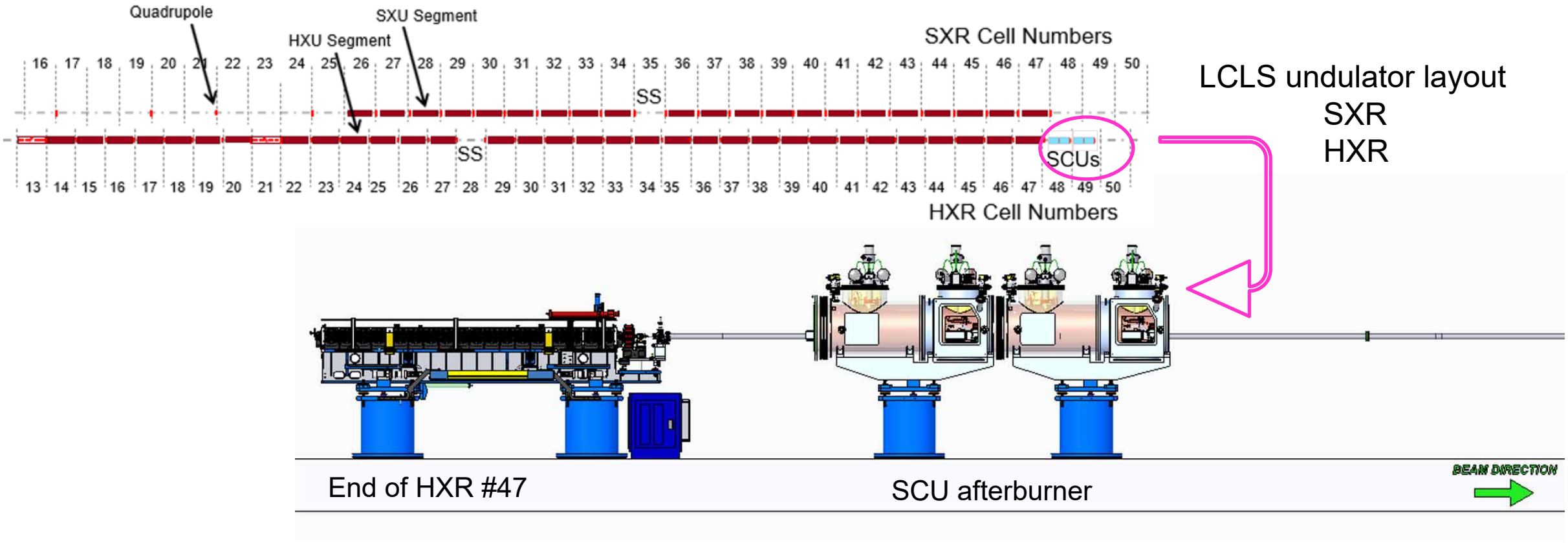
What distinguishes storage ring SCUs from an FEL?

- FEL beamline module comprises of an undulator core, quadrupole, phase shifter and RF cavity BPM
- Entire FEL beamline must be optically straight
  - And end-kicks from the undulator must be eliminated
- Beam-based alignment requires each module to be remotely adjustable with micron precision
- Short average gain length only realized with high packing fraction in the FEL modules

SCU Prototype Installation at end of LCLS HXR



- SCU parameters chosen to match FEL resonance of existing HXR undulators
- Cryomodule design will be extendable into a full-length FEL beamline

Modular design approach

- LCLS design approach is to make self-contained modules comprising of
  - Undulator core, phase shifter, quadrupole, and RFBPM
- Modules are to be hard-bolted to each other and share a common shield vacuum without warm transitions
  - Inter-undulator spacing is minimized to give the shortest average gain length
- Consequently, modules cannot be externally aligned
  - Cold mass is to be supported on internal precision movers to allow beam-based alignment of each undulator section
- Follow LCLS experience with SC linac assembled in long, rigid sections with a common shield vacuum.

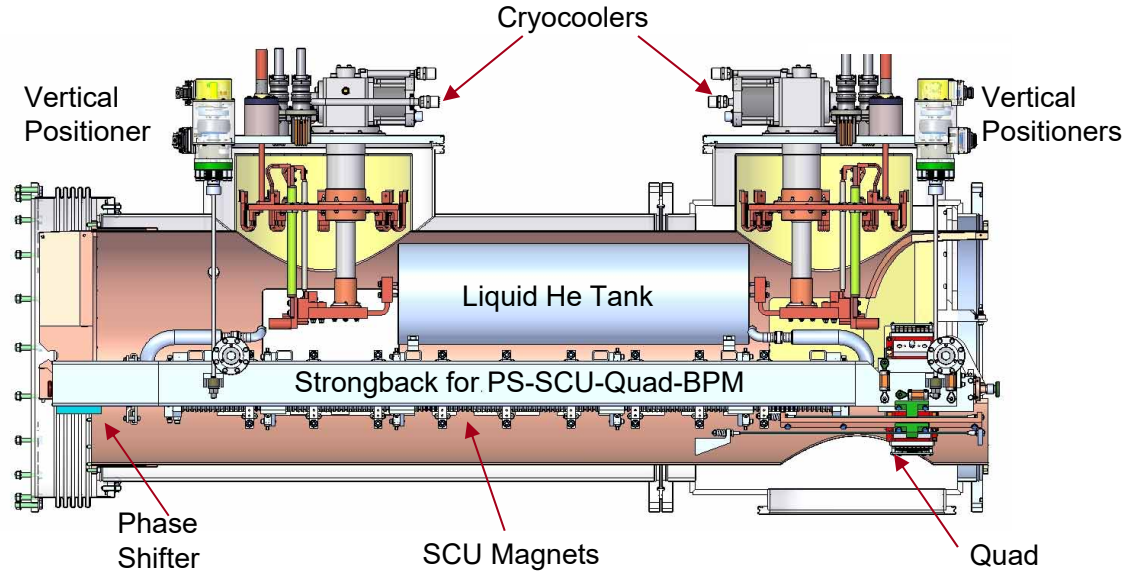
Prototype Design Choices

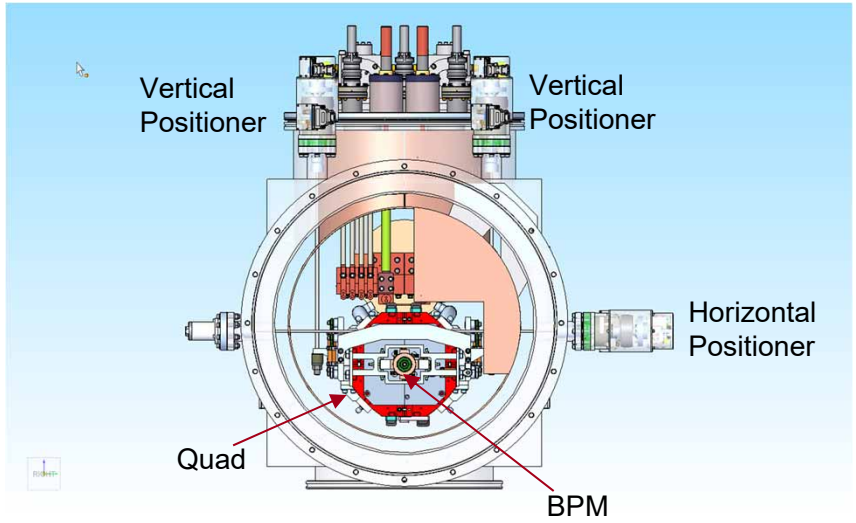
Superconductor material: NbTi at 4 K (other superconductors will be considered for future FEL testing)

SCU period & polarization: 21-mm period and vertical polarization (matching FEL wavelength of HXUs)

Alignment method: Internal vertical and horizontal position adjustments with linear actuators

Beamline components: Phase Shifter-SCU Magnets-Quad-BPM, all operate at cryogenic temperature

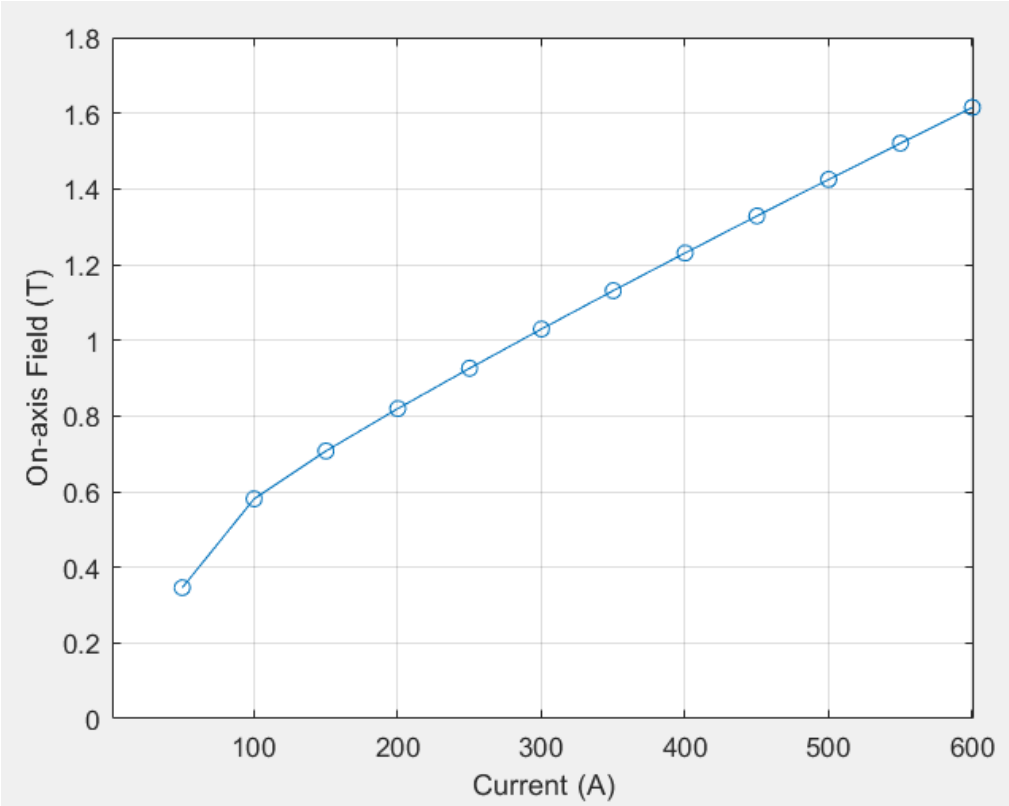




SCU Baseline Design Parameter Overview

Parameter	Baseline
Superconductor	NbTi
Period length (mm)	21
Number of periods / SCU	≥ 71 *
SCU magnet length (m)	≥ 1.5 m *
Gap (mm)	8
Magnetic field at 600 A (T)	1.6
K_{peak} at 600 A	3.14

Excitation curve for 21mm NbTi SCU with 8 mm gap

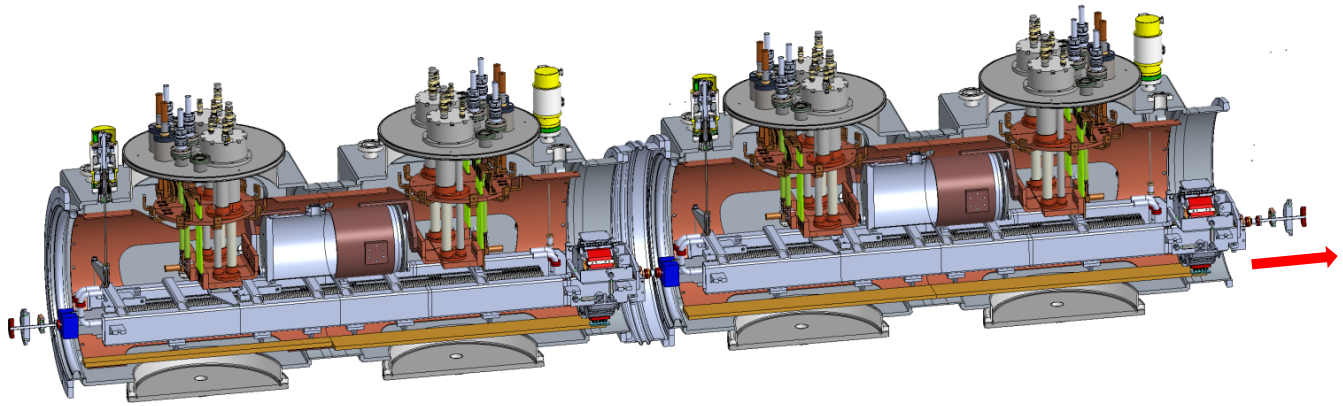


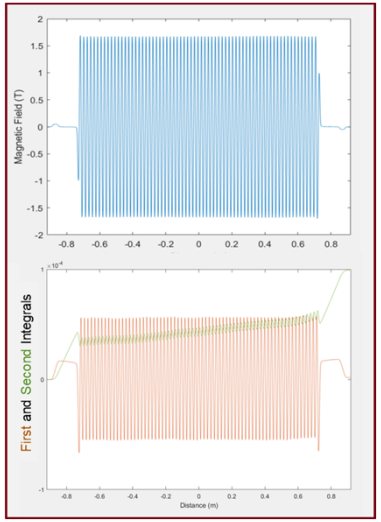
* SCU magnet length with a good chance of high-quality magnetic field at the moment.

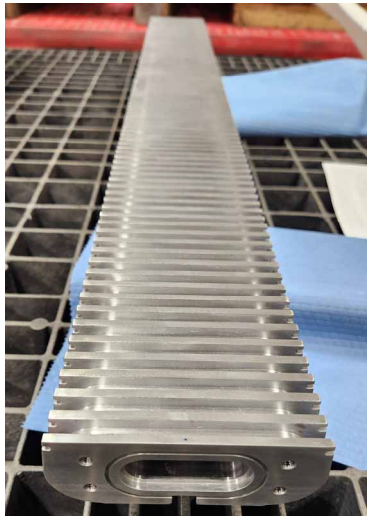
Current Status of the Project

ANL

- Completed the magnetic design including the end correction coils
  - The fields below are for the LCLS SCU with the end corrector magnets
- Has taken delivery of a prototype machined undulator core.
- Completed the cryogenic design of the modular cryomodule, including cryocoolers for the prototype test





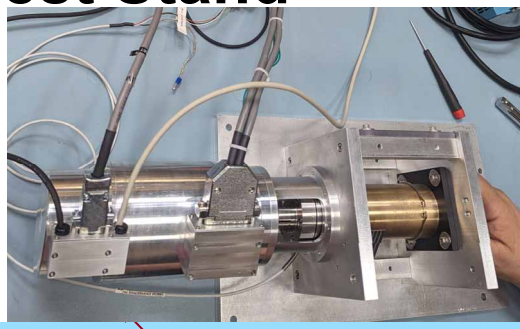


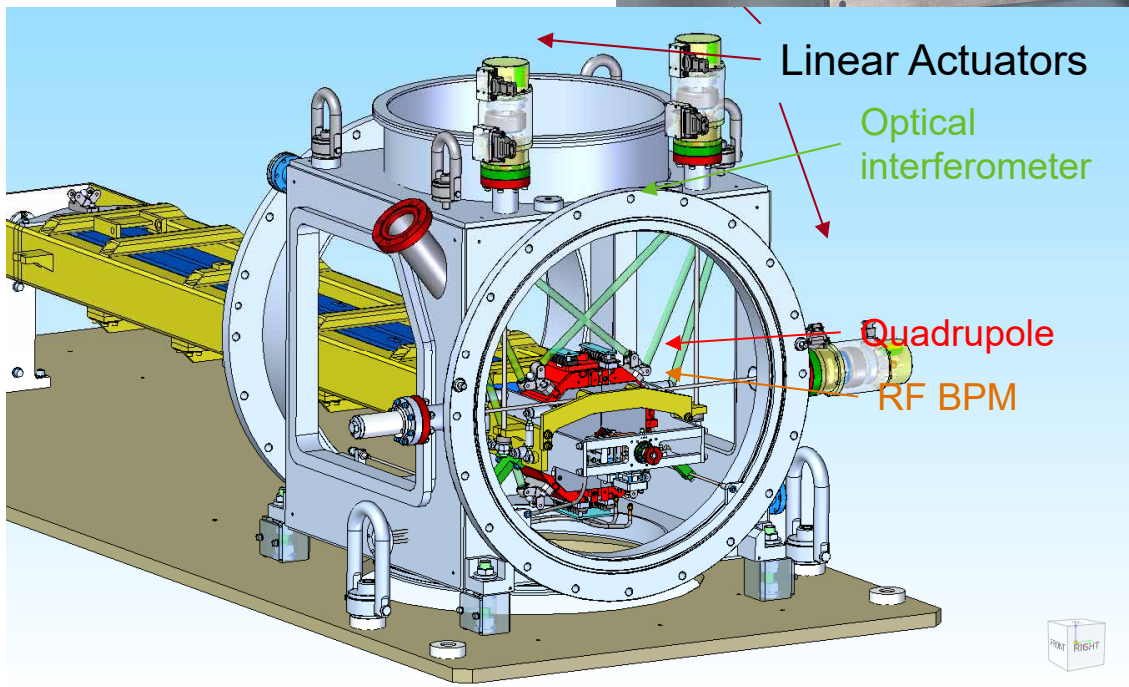
Current Status of the Project

SLAC

SLAC

- Completed the design and fabrication of **Precision Alignment Test Stand**
- Phase 1 testing:
  - Flanges and chamber removed for CMM calibration of linear movers
  - And set up of internal optical interferometers
  - Measurement of vibration modes
- Internal strongback supports the:
  - undulator cores, quadrupole, RF BPM
- The test stand prototypes all the mechanical features of the cryomodule





Vacuum and Cryogenic testing of the Precision Alignment Test Stand

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Phase 2 test

- Will confirm micron reproducibility of the internal alignment when the cryomodule is under vacuum

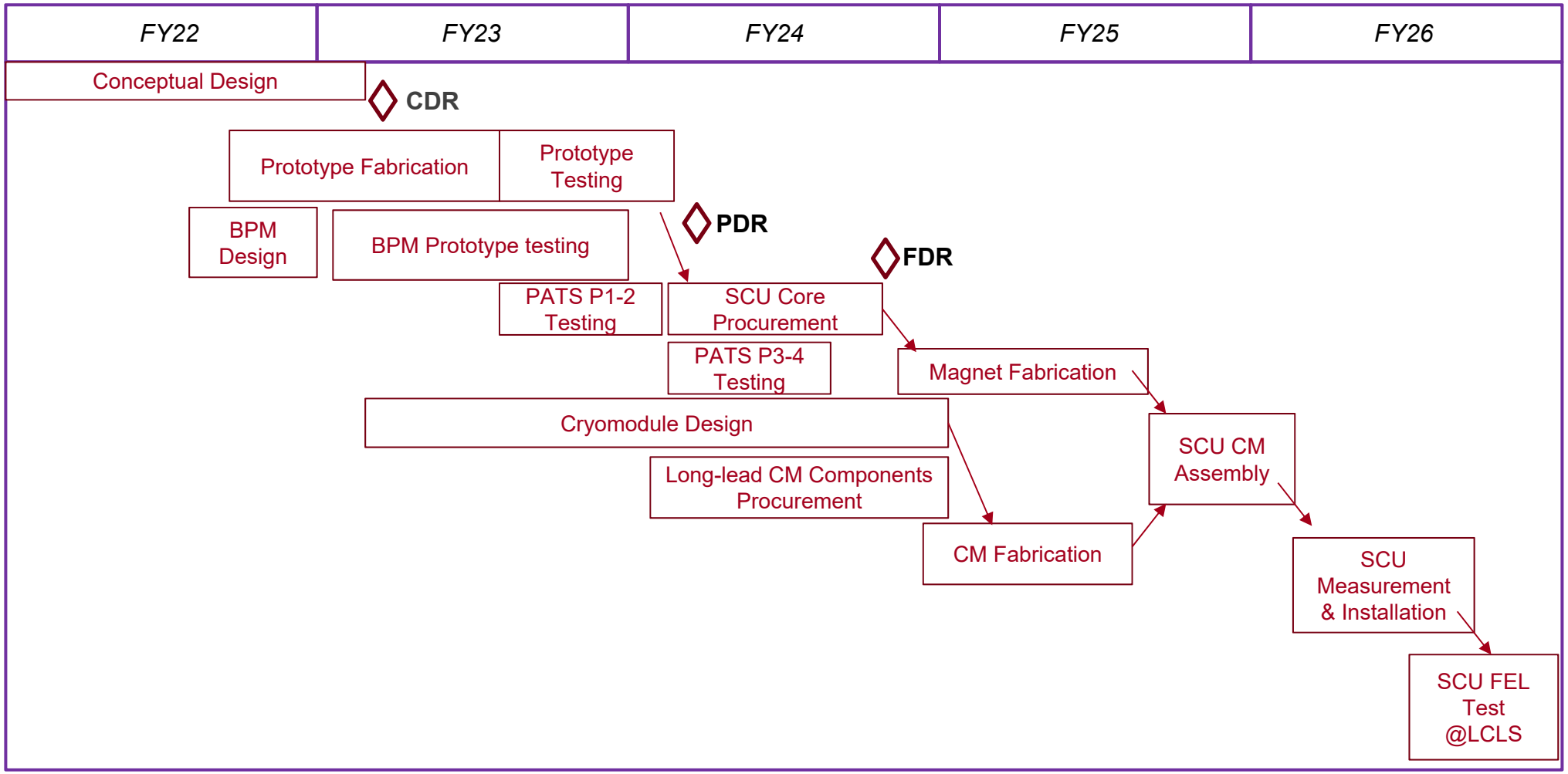
Phase 3 test

- Will confirm micron reproducibility of the internal alignment when cryogenically cooled and thermally cycled.

Phase 4 test

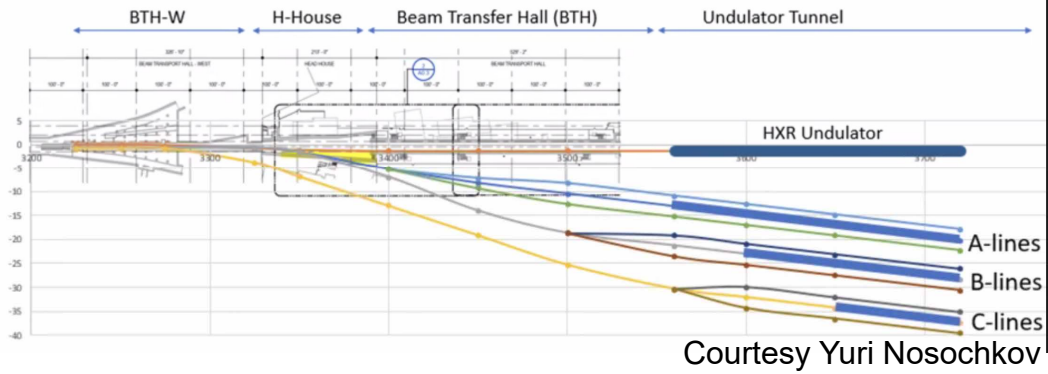
- Magnetic measurements of quadrupole magnetic center before and after cooling.
- Confirm RF properties of cavity BPM at cryogenic temperatures.

Schedule for the SCU Prototype Beam Test



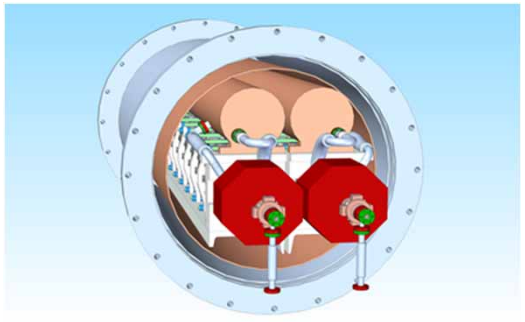
Longer-term FEL SCU Research

- Design layout for a multi-beamline FEL at LCLS-X



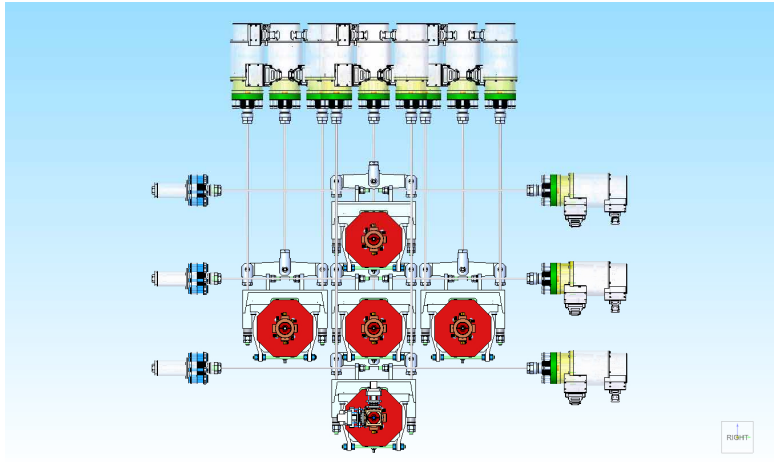
Courtesy Yuri Nosochkov

- Two-undulator cryomodule layout



see also J. Byrd's talk

- More ambitious Five-undulator layout
  - Individually aligned undulators, each with its own set of movers
  - Sensitivity to electron beam launch angle jitter from the kickers is minimized by choosing planar vertical gap undulators top and bottom, plus planar horizontal gap undulators left and right.



Summary

- The SCU development program is a major initiative to keep US facilities at the forefront of X-ray FEL performance.
- SCUs will enhance the power and wavelength reach at LCLS, and provide the technology for compact, multiple FEL beamlines.
- The SCU prototype will demonstrate beam-based alignment and FEL gain measurement in a realistic FEL environment in 2026.
- Testing is now beginning on a precision alignment test stand for the internal alignment control of the cold mass in the cryomodule.