NAPAC 2022

North American Particle Accelerator Conference
Hotel Albuquerque
Albuquerque, New Mexico
7-12 August 2022

Commissioning of the Linac Coherent Light Source-II (LCLS-II)

Yuantao Ding (*SLAC*)

For the Commissioning team

SLAC NATIONAL ACCELERATOR LABORATORY · BERKELEY LAB · Argonne NATIONAL LABORATORY · Cornell University · Fermilab · Jefferson Lab

U.S. DEPARTMENT OF ENERGY Office of Science

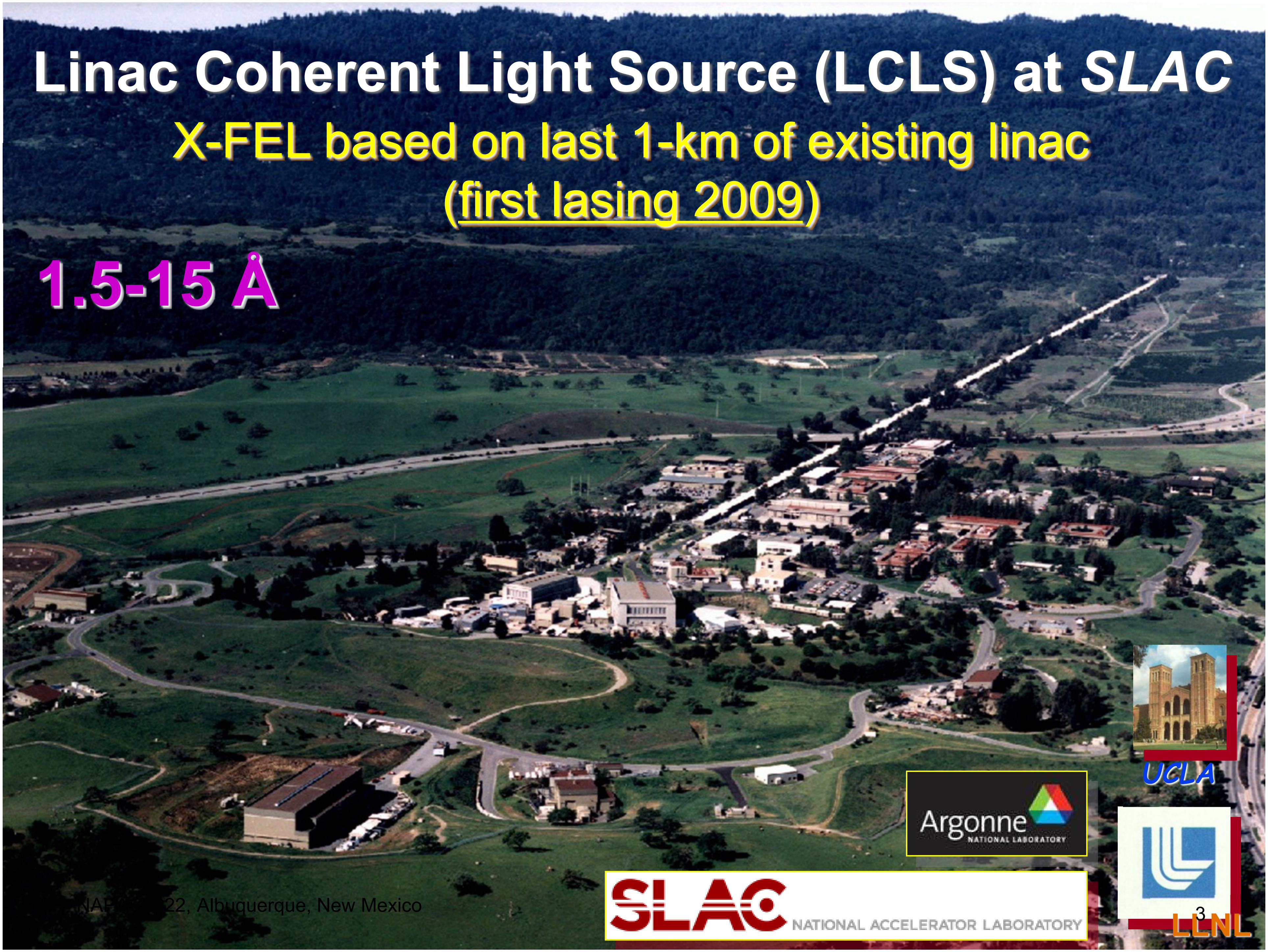
Outline

- LCLS-II Overview and Status
- LCLS-II Commissioning Phases
  - **Undulator** commissioning with Cu-linac (2020)
  - Early injector **gun/buncher** commissioning (2020)
  - **SRF cryomodule** commissioning (2022)
  - Gun restart and **100MeV Injector** commissioning (now)
  - **SC-linac beam** commissioning (Fall 2022)
  - **Lasing** with SC linac beam (2023 Jan.)
- LCLS-II Performance Goal and Next

Linac Coherent Light Source (LCLS) at *SLAC*

X-FEL based on last 1-km of existing linac
(first lasing 2009)

1.5-15 Å



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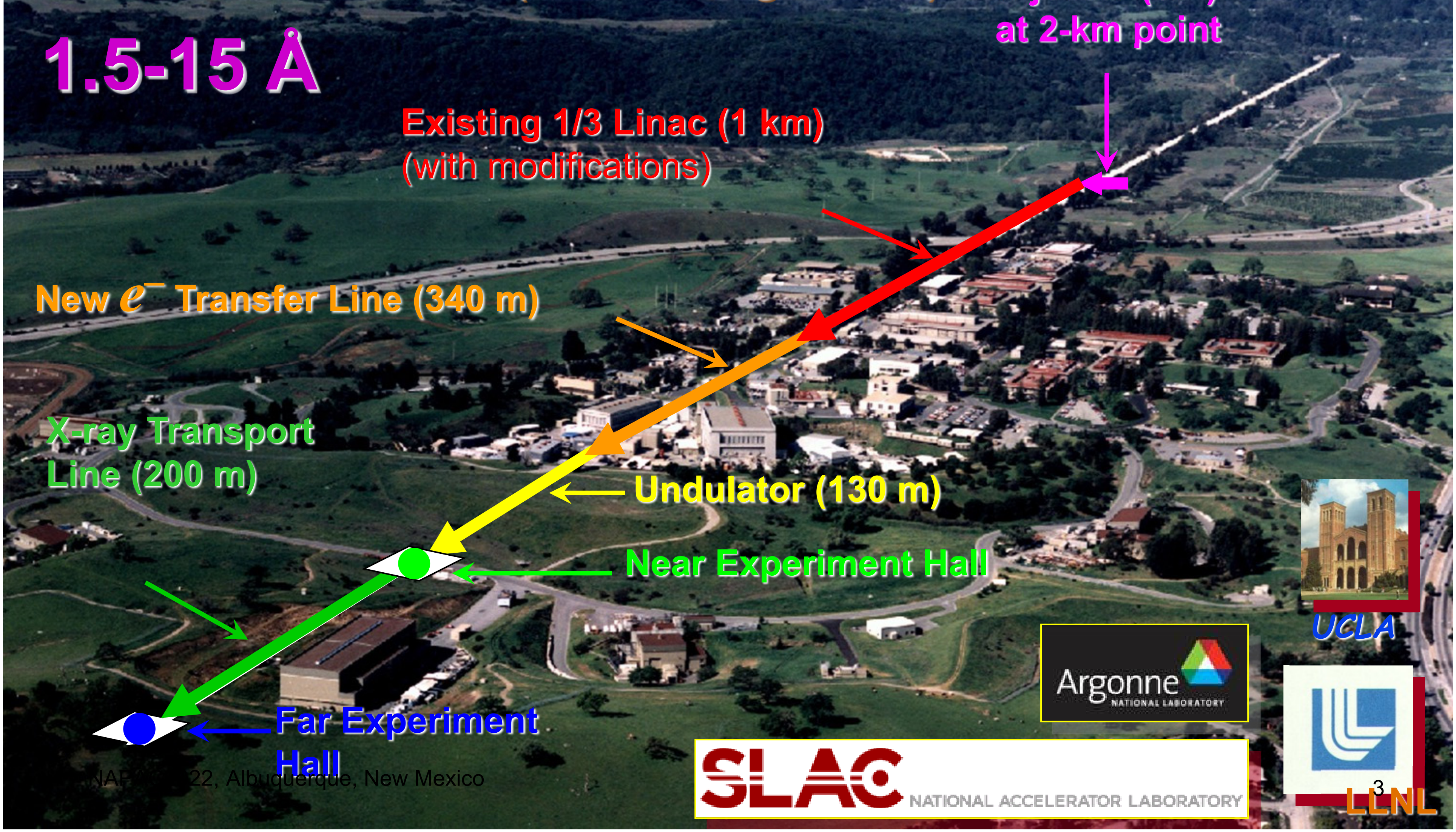
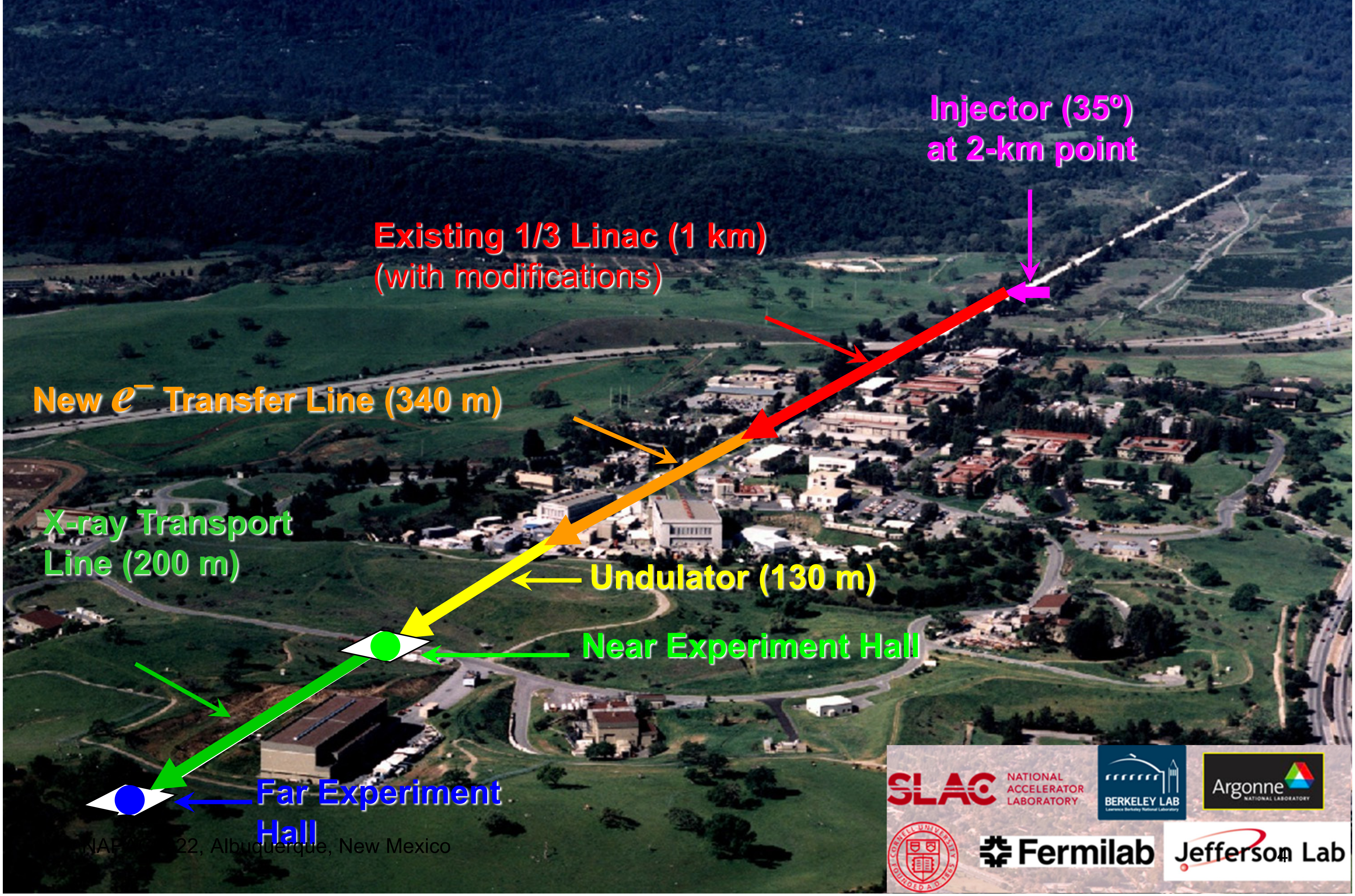
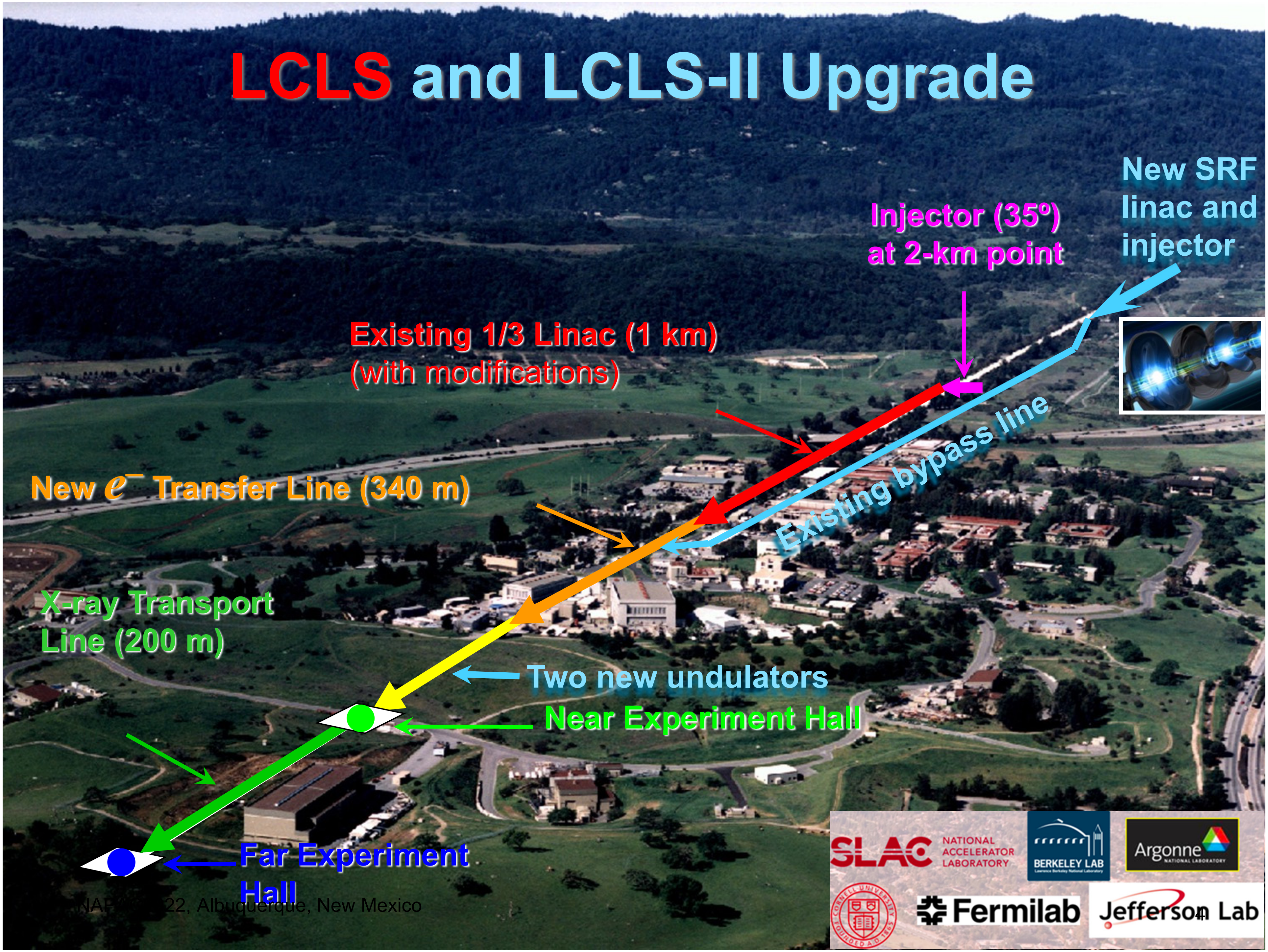
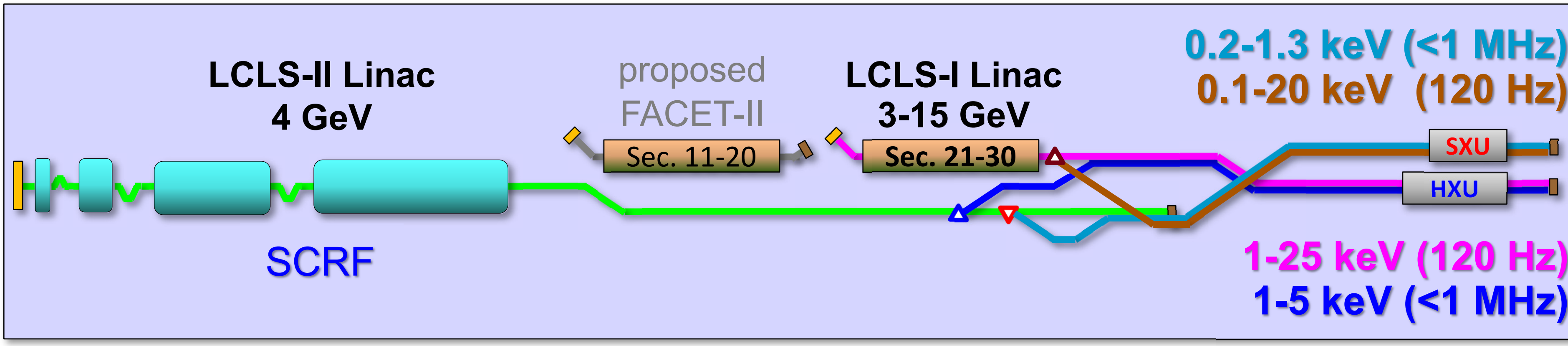


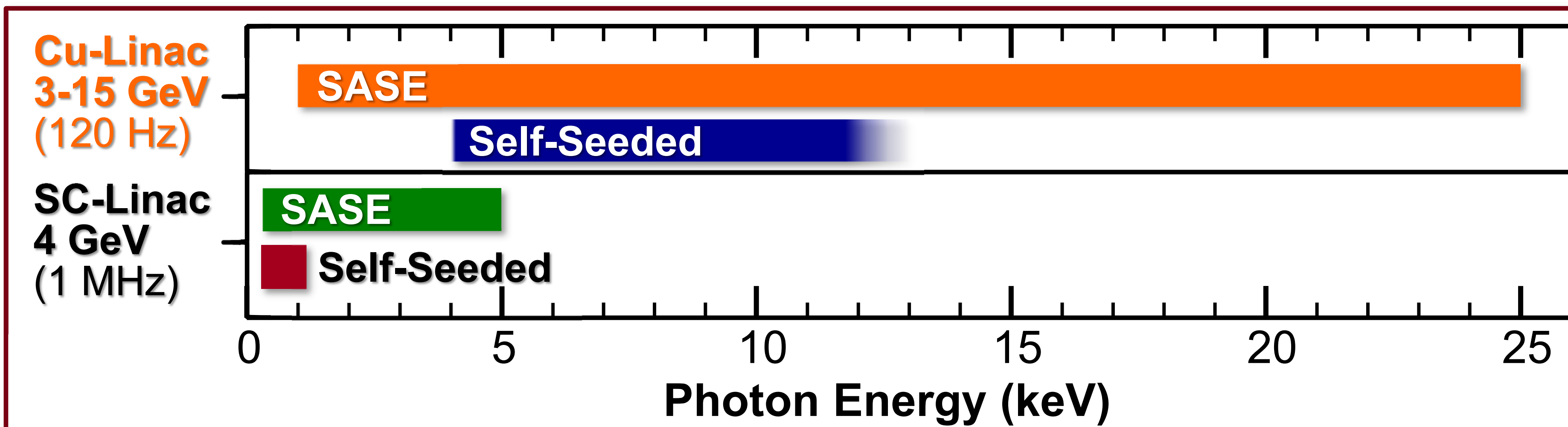
LCLS and LCLS-II Upgrade




LCLS and LCLS-II Upgrade
New SRF linac and injector
Injector (35º) at 2-km point
Existing 1/3 Linac (1 km) (with modifications)
Existing bypass line
New e^- Transfer Line (340 m)
X-ray Transport Line (200 m)
Two new undulators
Near Experiment Hall
Far Experiment Hall

LCLS-II Layout and Configuration Options





LCLS-II Accelerator Physics Design Features

- What is new in **LCLS-II**?
  - **CW, high rep rate beam:**
    - → SCRF technology
    - → SCRF beam dynamics
    - → Injector – CW VHF gun
    - → Diagnostics and feedback
    - → high stability
  - **Two variable gap undulator lines:**
    - → **Vertically** polarized HXR FEL
    - → **Flexible** configuration modes (fed by SC linac or Cu linac)
  - **High average beam power:**
    - → Beam heating
    - → Collimation and losses
    - → Beam dumps and radiation shielding
  - **Lower Energy (comparing to LCLS-I) and Long Transport**
    - → Space charge instabilities
    - → Microbunching instabilities
    - → Real number of particle tracking studies

Milestones of the LCLS-II Project for commissioning

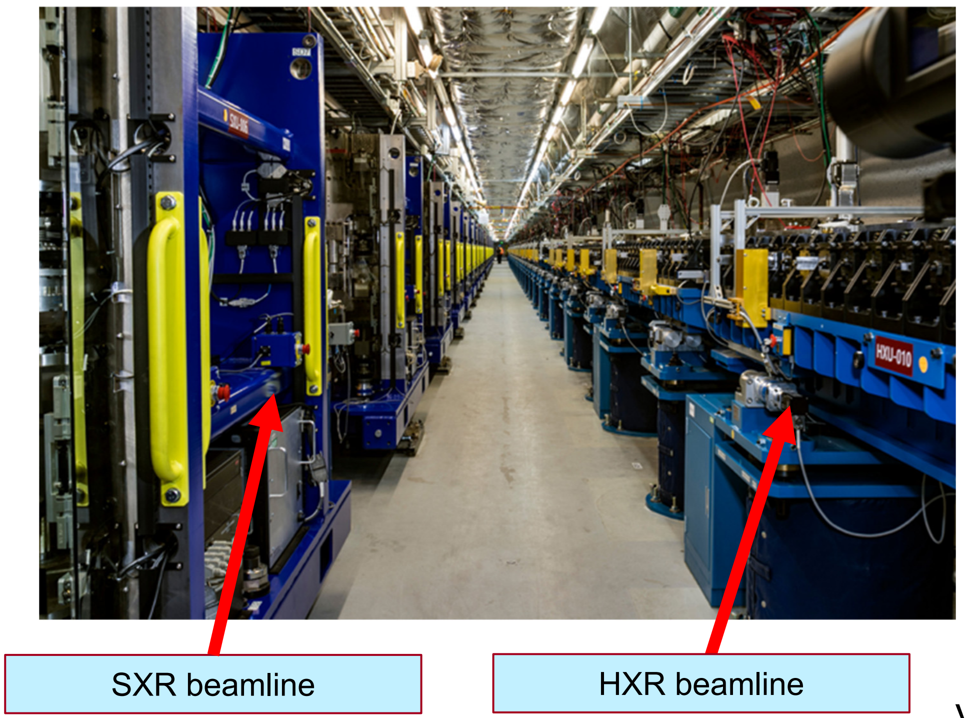
- Undulator commissioning with Cu-linac beam (2020);
- Early injector (gun/buncher) commission in 2019/2020.
- Entire LCLS-II beamline connected and under Vacuum (12/2021).
- Cryoplant at 2K (04/2022).
- SRF cryomodule commissioning at 4K/2K (03/2022).
- Restart the gun/buncher (03/2022).
- 100-MeV injector commissioning (07/2022).

- Next:
  - SC linac beam commissioning.
  - Kicker/Transport line to undulator.
  - Undulator lasing with SC-linac beam (Jan. 2023).

Undulator Operational from 2020 July

Two variable gap undulator systems

- HXR (1 - 25 keV w/Cu Linac; 1 - 5 keV w/SC Linac), w/32 undulators
- SXR (0.2-8 keV w/Cu linac; 0.2-1.3 keV w/SC Linac) , w/21 undulators



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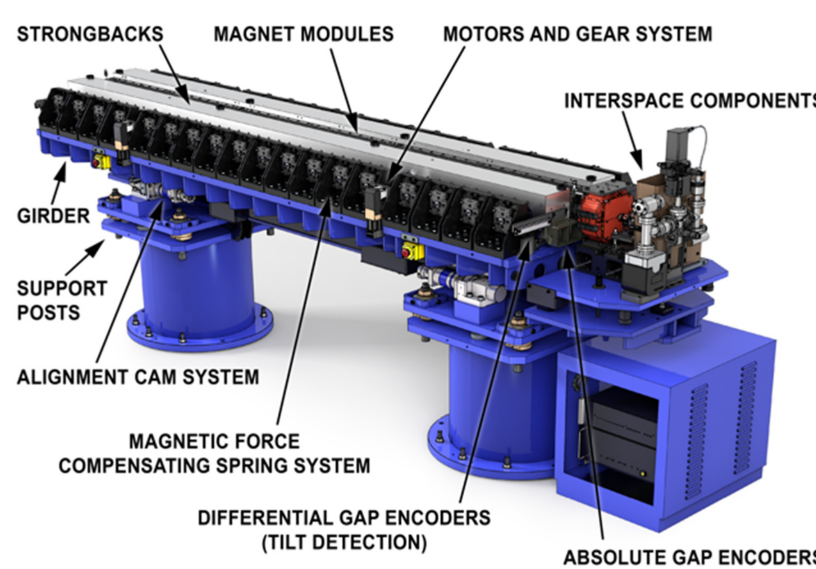
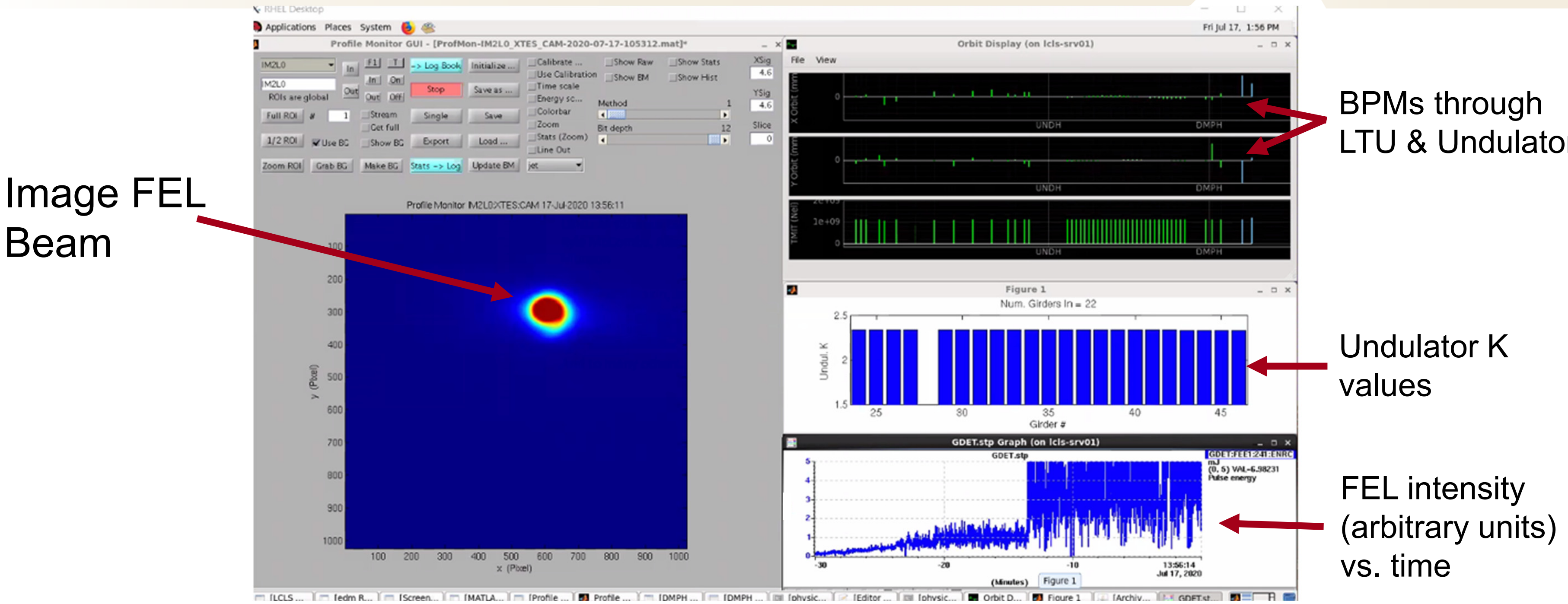
Horizontal Gap, Vertical Polarized Undulator (HGVPU)



Vertically polarized radiation can be deflected in horizontal plane with much less attenuation.
→ For example, the X-ray Correlation Spectroscopy (XCS) type experiments receives a brighter beam.

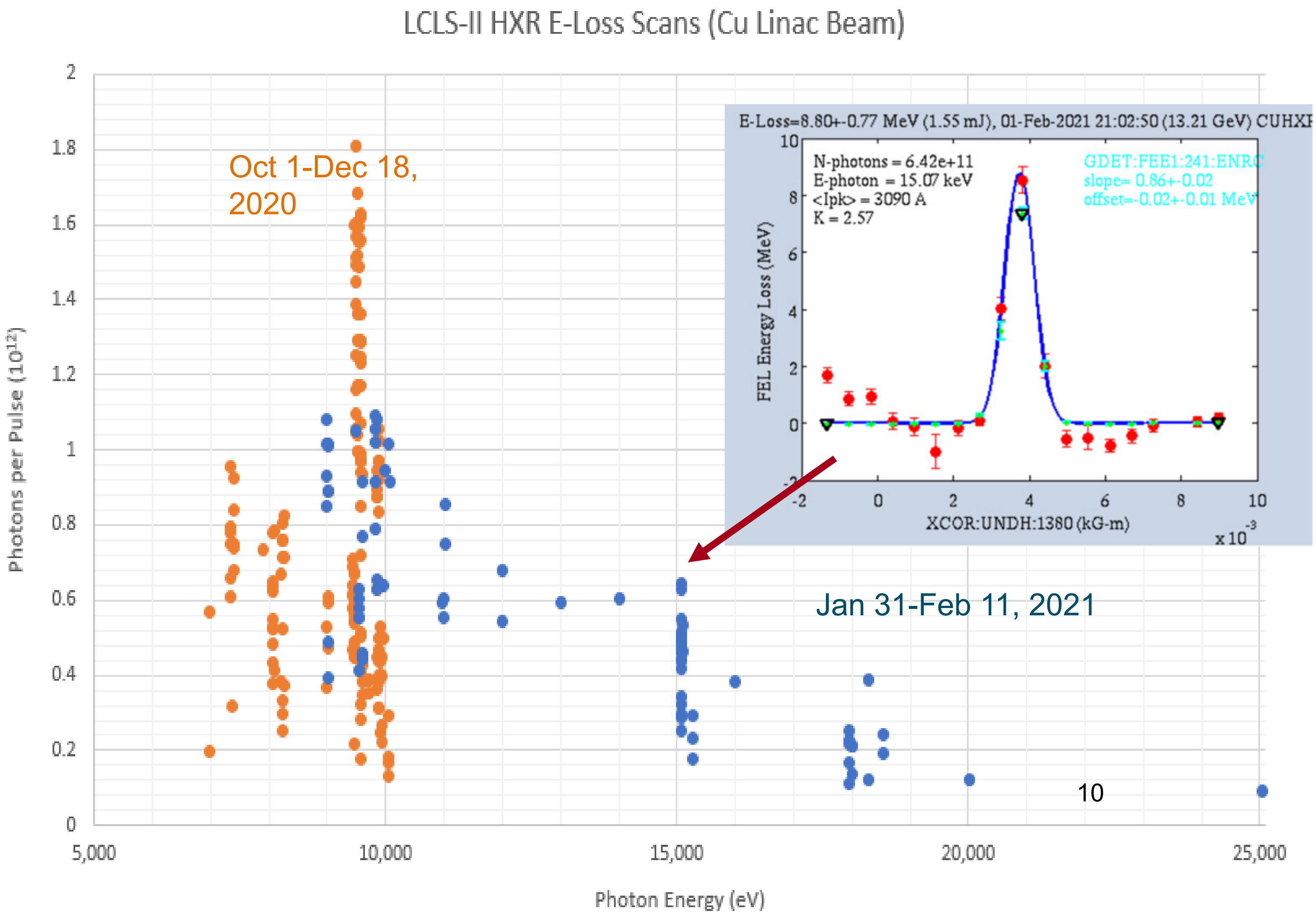
First Lasing of new HXR Undulator with ***Cu-linac beam*** 7/17/2020



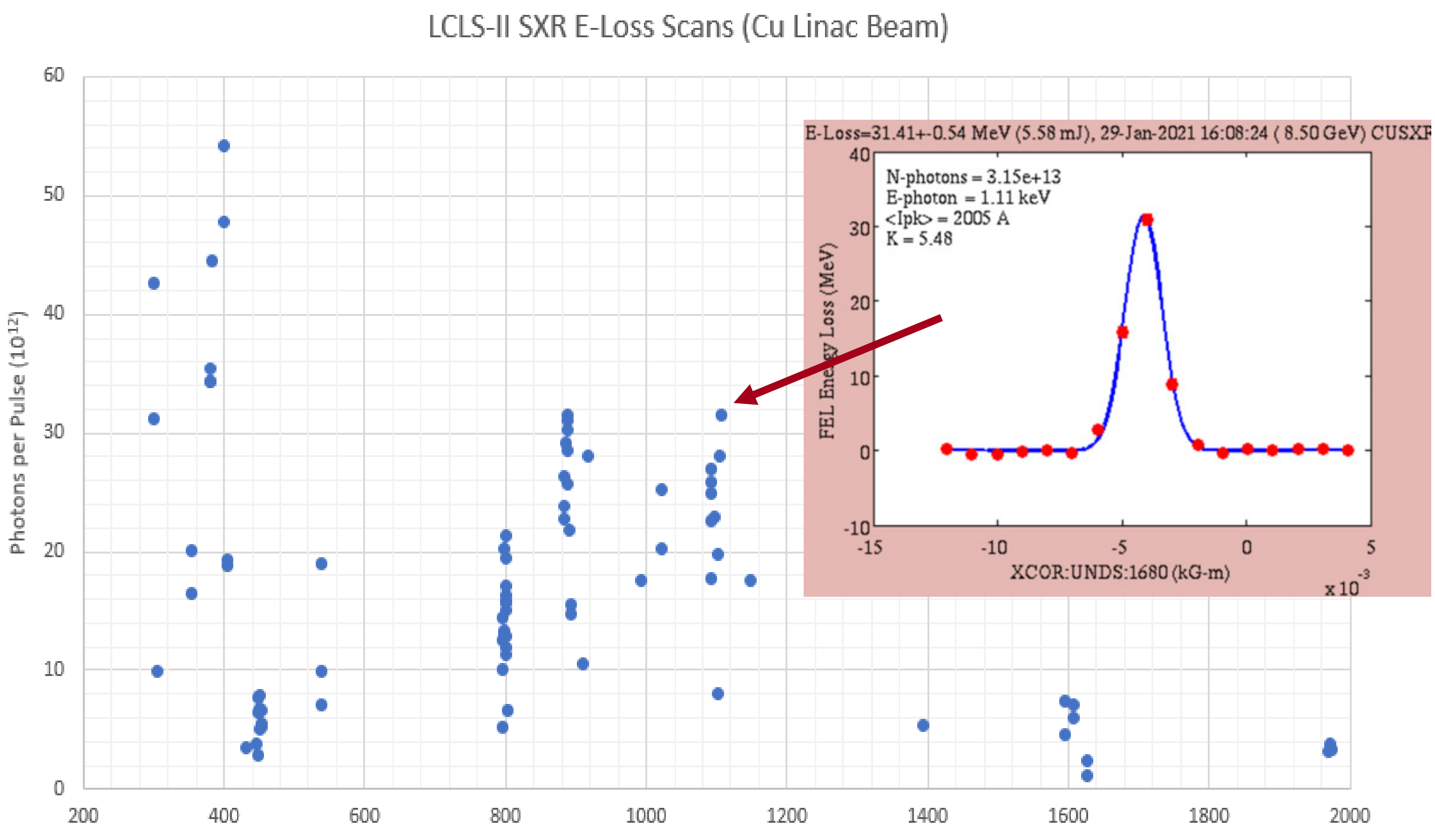
Link to Press Release: https://www6.slac.stanford.edu/news/2020-07-17-slac-upgraded-x-ray-laser-facility-produces-first-light.aspx

- HXR undulator commissioned in July 2020 **(Heiz-Dieter Nuhn et al.).**
- HXR user operation restarted in middle August 2020;
- SXR undulator started commissioning (stealing pulse at 10 Hz) from Aug. 2020.

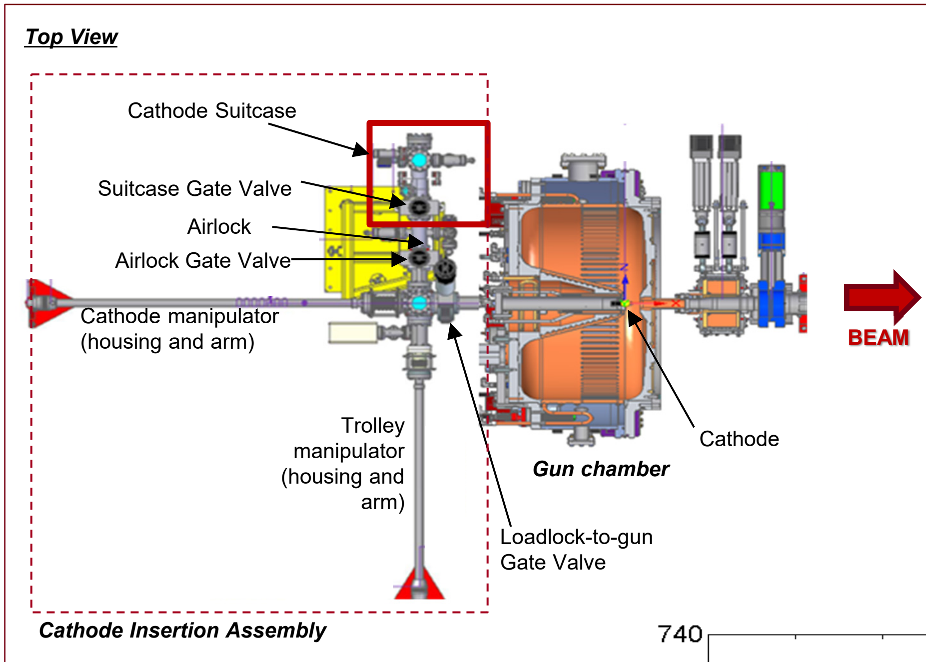
Measured HXR Intensity with Cu-linac beam



Measured SXR Intensity with Cu-linac beam



Early Commissioning of the CW Gun (2020)



- Delivering 5 keV FELs with 4 GeV E-beam requires very low emittance beam, a challenge for the (CW) gun.
- APEX gun, Gun/LEB Transition to Operation in 2020.
- Lots of upgrades after early commissioning:
  - Added collimator for dark current control;
  - Upgrade on LLRF, Gun/buncher tuner, solenoid motion, loadlock system etc.;
  - SLAC has grown Cs_2Te cathodes, QE>5%;
  - Laser operation at 1MHz.

Early Injector Commissioning (EIC) finished in June 2020;
Gun RF restarted in March 2022.

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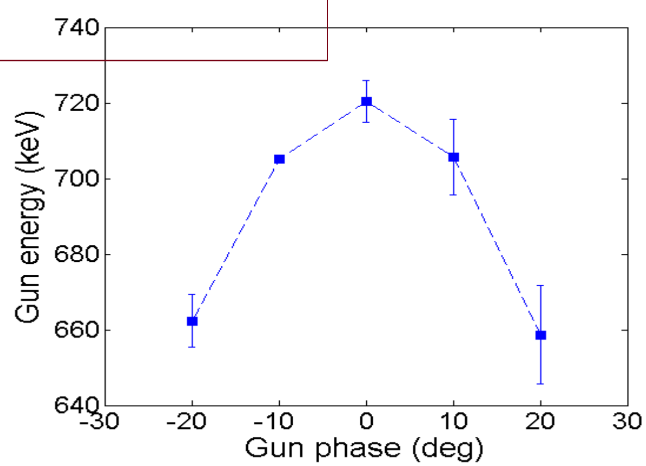
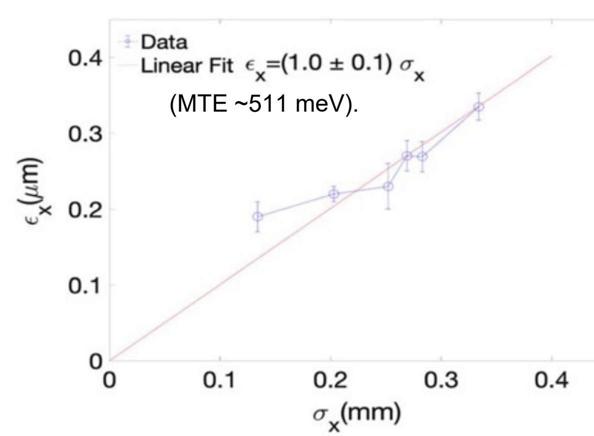


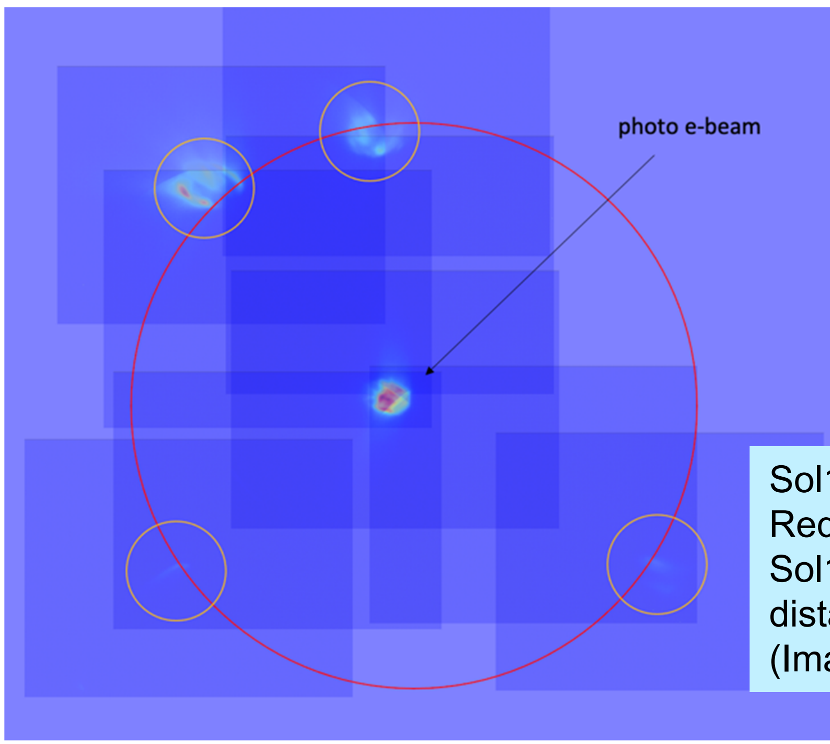
Thermal emit meas.



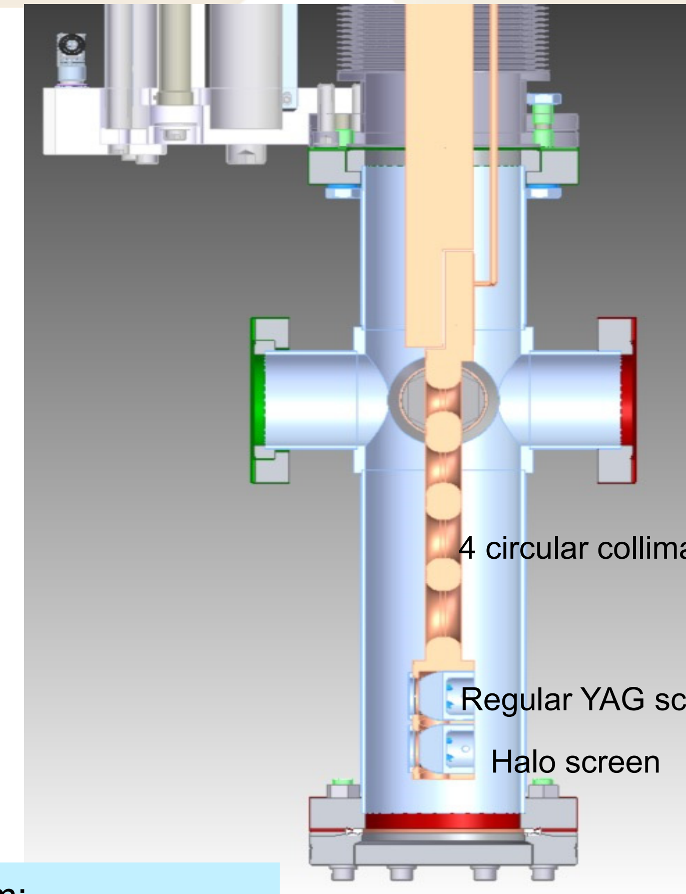
(F. Zhou et al.)

Dark Current suppression: Added Collimators before CM01 (2022)

- Gun dark current (2.5uA) was observed
- Replaced existing YAG screen with a multi-function device, which includes
  - 4 circular collimators (12 -24 mm dia.) for dark current reduction
  - 1 regular YAG and 1 halo monitor
  - 1 FC-like for dark current measurement

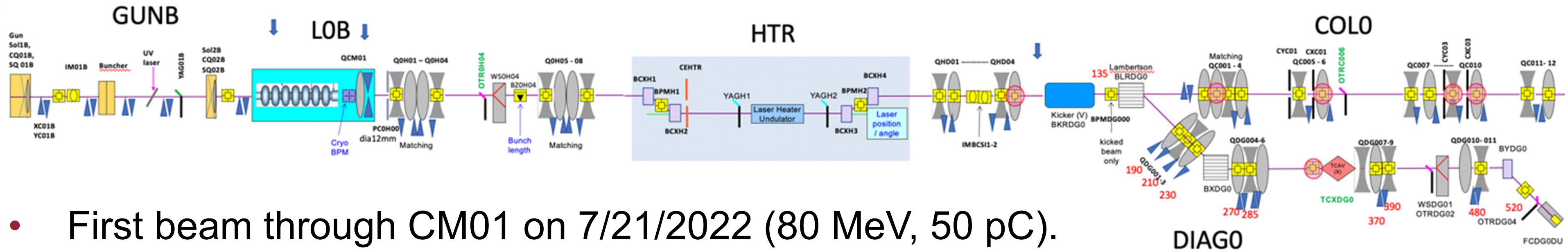


Sol1 =0.049 kG-m;
Red circle dia= 32mm;
Sol1 setting affects dark current distance to photo e-beam;
(Image courtesy T. Vecchione)



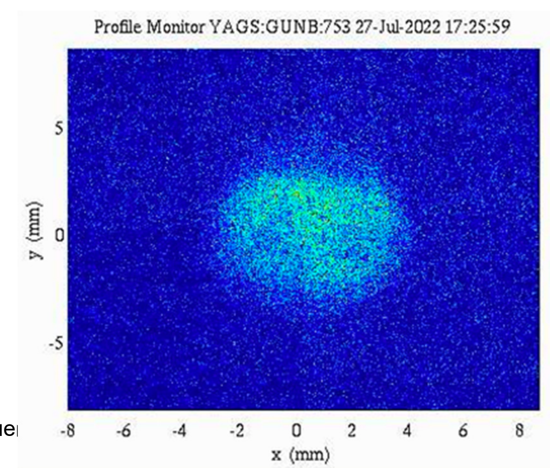
(F. Zhou, X. Liu et al.)

100 MeV injector progress

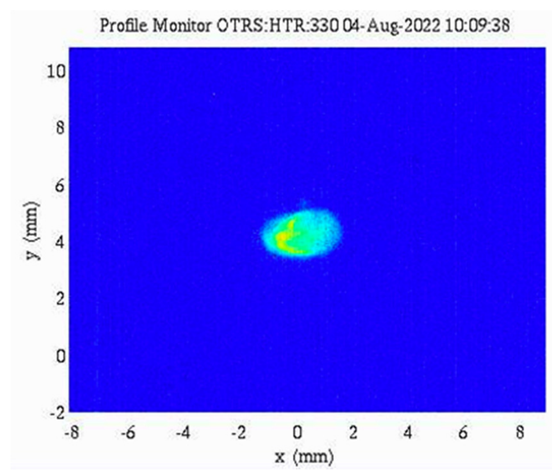


- First beam through CM01 on 7/21/2022 (80 MeV, 50 pC).
- Beam based hardware/software checked out;
- Performed first-round safety devices calibration (Average Current Monitors, Beam Loss Monitors etc.)
- Started to send beam to DIAG0 line on 8/2, beam characterization just started…
- **Stay tuned!**

750keV

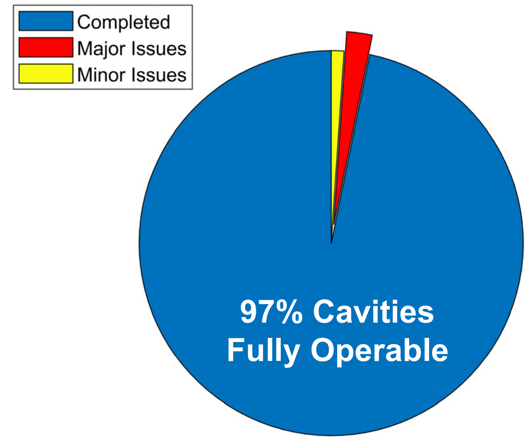


80 MeV



SRF Commissioning

- Superconducting linac was cooled for the first time in March
- **SRF cavities are now fully commissioned and the linac is stable at 2 K**
- Overall, performance has been excellent

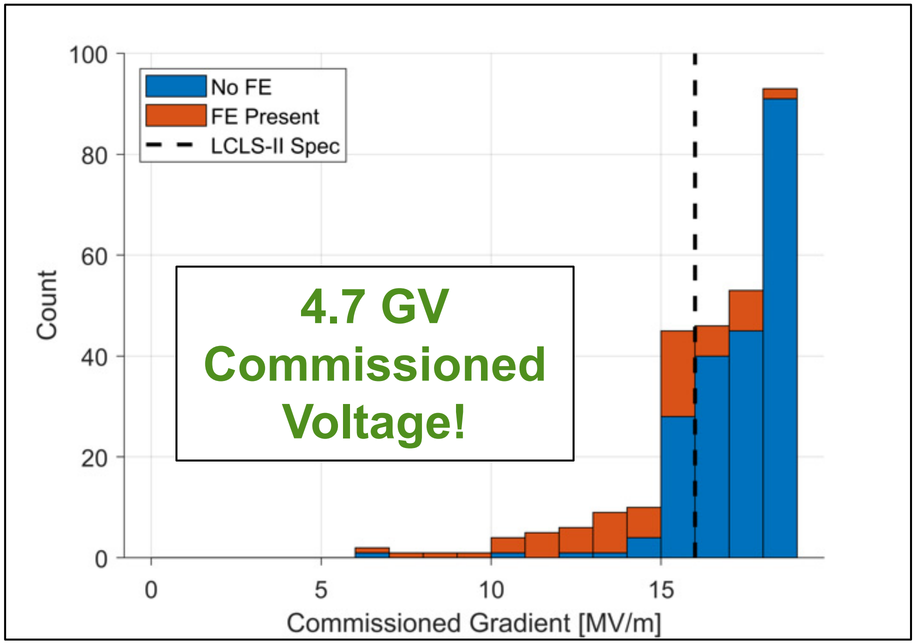


- Fast cool down to reach nominal Q_0 planned for this Fall
- Detailed measurement of cavity microphonics, Q_0, etc ongoing, **stay tuned!**

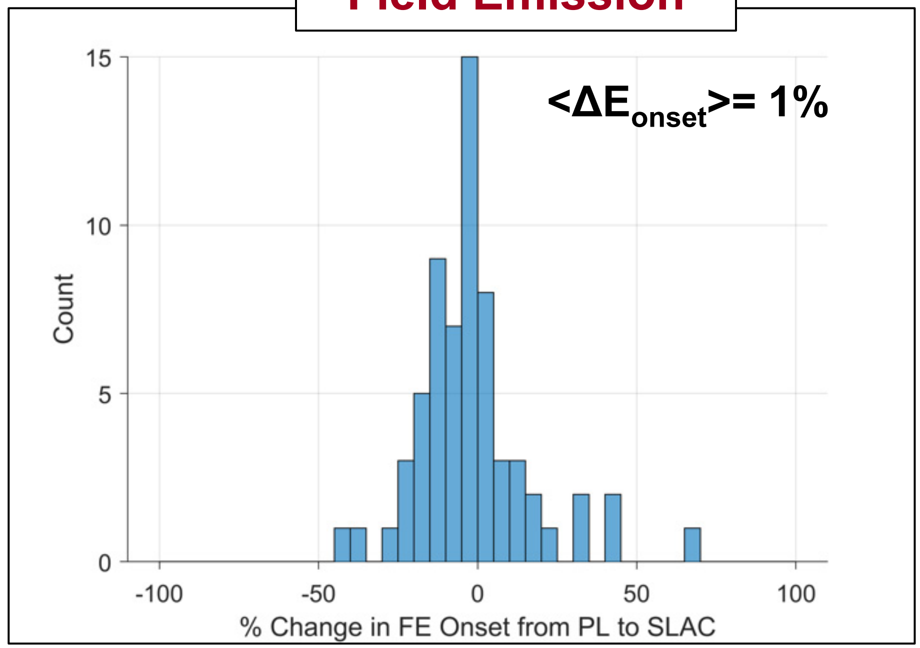
(D. Gonnella and the SRF team)

SRF Commissioning

Gradient Performance



Field Emission



SRF cavity performance has been excellent!

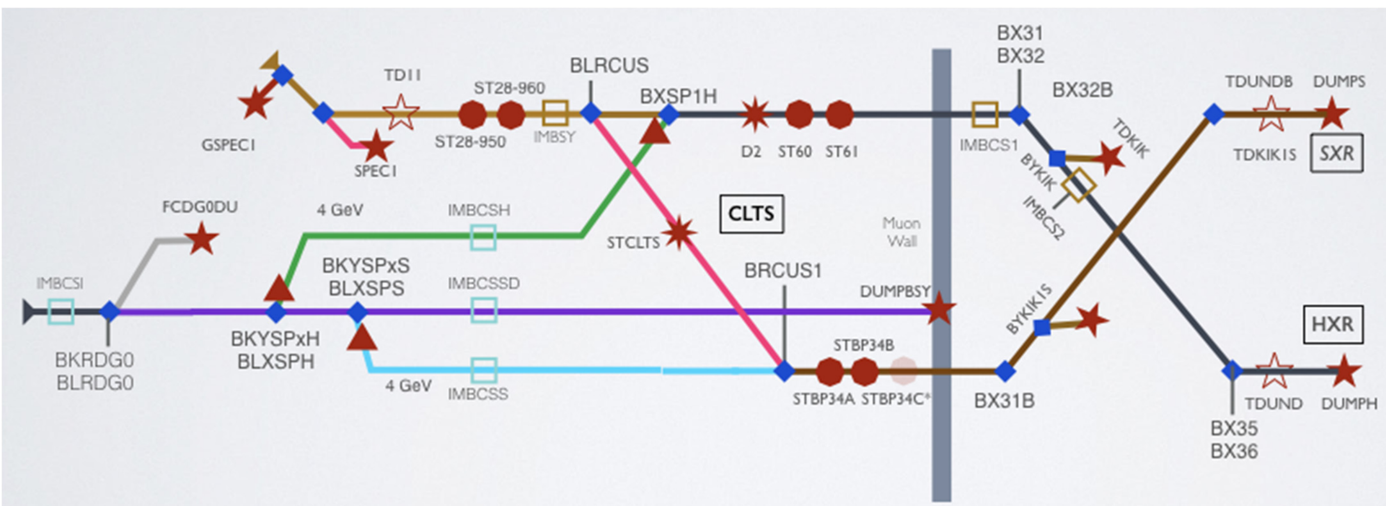
No field emission degradation observed from installation

(D. Gonnella and the SRF team)

Next Steps

SLAC

- 100 MeV injector commissioning (ongoing);
- Linac (>3.5 GeV) to BSY dump (Sep. 2022);
- Spreader/LTU to undulator entrance (Nov. 2022);
- FEL commissioning based on SC-linac beam (2023).



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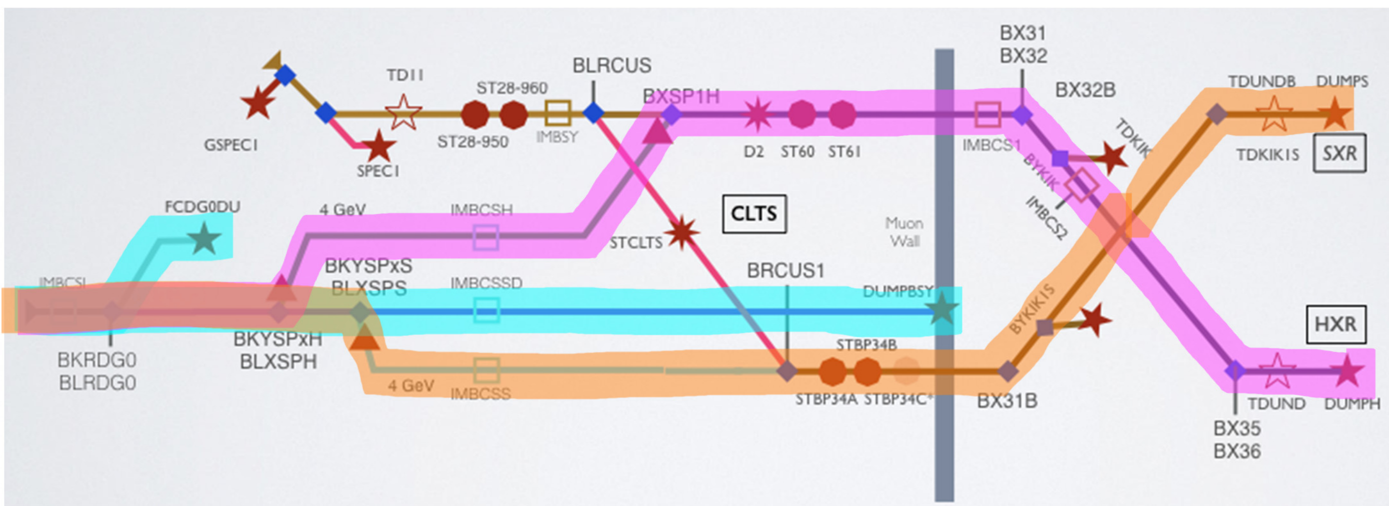

- Injector and linac to BSY dump are tuning modes for SC linac.

Commissioning Goals and Key Performance Parameters

Initial Commissioning Goal

Performance Measure	Threshold	Objective	Measurements
Variable gap undulators	2 (soft and hard x-ray)	2 (soft and hard x-ray)	Installation Complete, Commissioned with NC beams
Superconducting linac-based FEL system			
Superconducting linac electron beam energy	3.5 GeV	≥ 4 GeV	Spectrometer (magnet strength, screen)
Electron bunch repetition rate	93 kHz	929 kHz	BPM's, laser rate
Superconducting linac charge per bunch	0.02 nC	0.1 nC	Toroid, Faraday cup
Photon beam energy range	250–3,800 eV	200–5,000 eV	Absorption edges, spectrometer
High repetition rate capable end stations	≥ 1	≥ 2	N/A
FEL photon quantity (10^{-3} BW) per bunch	$5x10^{8}$ (10x spontaneous) @2,5 keV	> 10^{11} @ 3,8 keV	Gas energy monitor, Spectrometer
Normal conducting linac-based system			
Normal conducting linac electron beam energy	13.6 GeV	15 GeV	Spectrometer (magnet strength, screen)
Electron bunch repetition rate	120 Hz	120 Hz	BPM's, laser rate
Normal conducting linac charge per bunch	0.1 nC	0.25 nC	Toroid, Faraday cup
Photon beam energy range	1–15 keV	1–25k eV	Absorption edges, spectrometer
Low repetition rate capable end stations	≥ 2	≥ 3	N/A
FEL photon quantity (10^{-3} BW[a]) per bunch	10^{10} (lasing @ 15 keV)	> 10^{12} @ 15 keV	Gas energy monitor, Spectrometer

Achieved!

Threshold Key Performance Parameters define commissioning goals for Transition to Operations.

Summary

- **LCLS-II**, driven by SRF technologies, will deliver high repetition-rate CW FELs;
- The new machine will provide flexible operating modes, covering large photon energy range with either Cu-linac or SC-linac beam.
- Amazing progress has been made in the past years. New undulators, Cryoplant, Cryomodule systems, CW gun, Controls and Mechanical systems.
- The high-energy upgrade project, **LCLS-II-HE**, is adding 20 more cryomodules to boost the beam energy to 8 GeV and deliver harder x-rays in the future.

Thanks to the LCLS-II Project Team, and All the Teams from Engineer, Physics, Operations, Support groups.
Thanks for the Collaboration Teams and Support from our Partner Labs.


Thank
You
Vinaka
köszönöm
Kiitos
Maake
Asante
Shukria
Dhanyavadagalu
감사합니다
Dankscheen
спасибо
Kam Sah Hammida
ارك شكرا
Manana
Dankon
Diolch i Chi
Terima Kasih
Matondo
Dank Je
Mauruuru
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