

FEBRUARY 25, 2026

# Upgrade Planes for the LEA at Argonne



A. NASSIRI

# Acknowledgement

Special thanks to W. Berg, M. Borland, J. Dooling, D. Meyer, P. Piot, B. Popovic, V. Sajaev, T. Smith, Y. Sun, G. Waldschmidt, and K. Wooten.

# outline

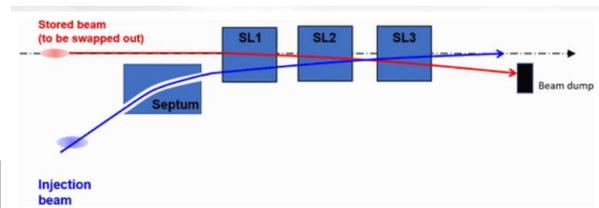
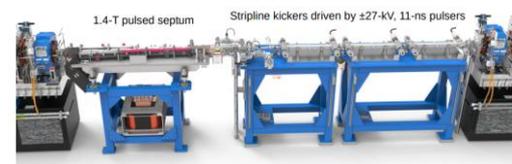
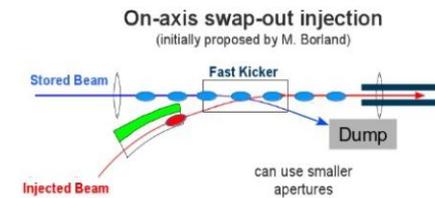
1. Introduction – APS Upgrade
2. LEA early history (LEUTL)
3. APS Linac Enhancements and Recent LEA activities
4. Outlook
5. Summary

# 1. Introduction

- The upgraded APS now generates X-ray beams that are up to 500 times brighter than before and sports nine new experiment stations built to take full advantage of those enhanced beams.

- APS Accelerator Complex

- New storage ring uses a multi-bend achromat (MBA) that provides an extremely low natural emittance of 42 pm and was the first user facility to be operated in swap-out mode



Booster: 0.35-7 GeV, 1 Hz

Linac: S-band, 450 MeV, 30 Hz

Storage ring: 6 GeV, 200 mA, 59 ID, 2 fill patterns

PAR: 300-475 MeV, 1 Hz, 1-20 nC

Linac Extension Area (LEA)



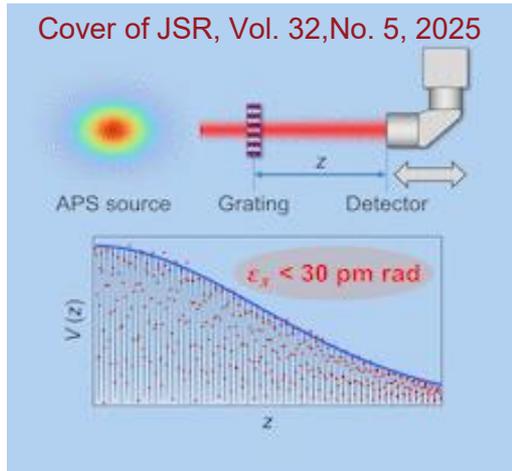
AFOSR - NSF Scientific Opportunities with Compact, High Intensity Accelerators

A. Nassiri

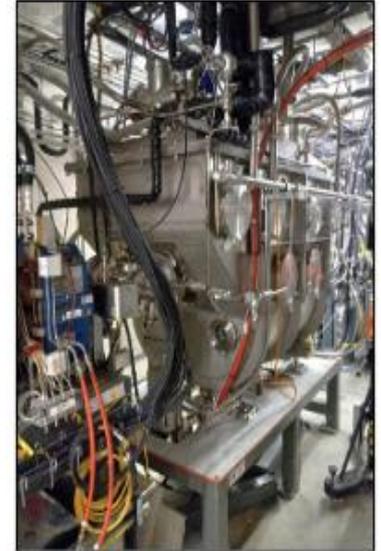
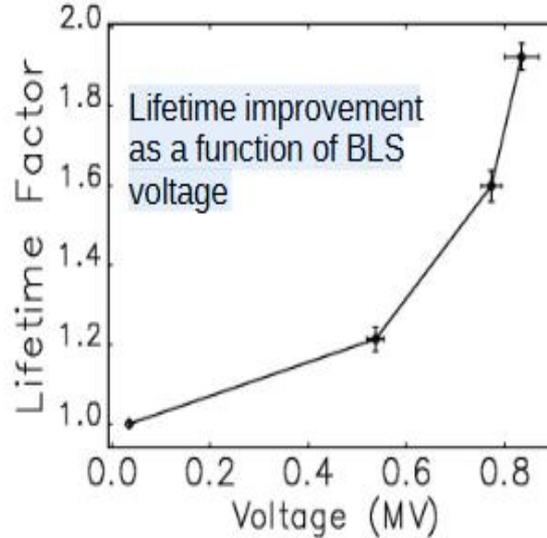
# 1. Introduction

- APS measured 30 pm emittance at full coupling\*
  - Extreme focusing required to achieve low emittance resulted in small dynamic aperture and short lifetime.
  - On-axis swap-out injection was adopted to tolerate small dynamic aperture
    - Operation on coupling resonance and bunch-lengthening cavity (BLS) are used to increase lifetime.

## Grating interferometry for transverse coherence and source size measurements



\*V. Sajaev, et al.



## 2. LEUTL/LEA Brief History

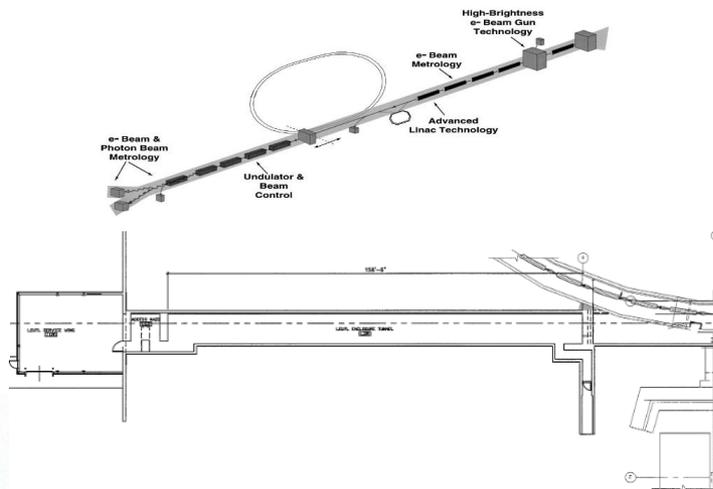
- LEUTL constructed circa 1998
- Commissioning of LEUTL began in December 1998
- Technology demonstrations of free-electron laser (FEL) concepts
- Approval for routine operations granted June 2001
- Linac Coherent Light Source (LCLS) Beam Position Monitor (BPM) Test in 2007
- Revival as the Linac Extension Area beginning circa 2015
- Internal approval for commissioning LEA beamline granted February 2023

## 2. LEUTL- SASE Demonstration\*

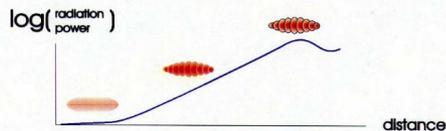
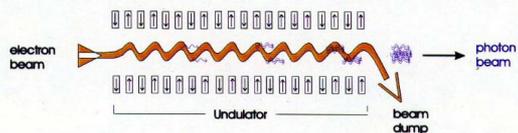
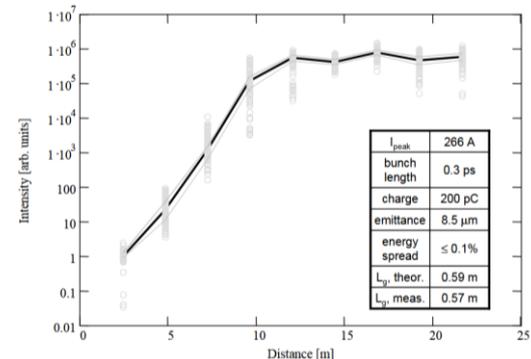
- The APS SASE FEL achieved saturation at 530 nm on 23 September 2000, and at 385 nm on 30 September 2000.

Parameters for the LEUTL SASE-mode FEL operation

Wavelength (mm)	256	120	40
Electron energy (MeV)	270	400	700
Normalized emittance (mm mrad)	$5\pi$	$5\pi$	$3\pi$
Energy spread (%)	0.1	0.1	0.1
Peak current (A)	150	150	500
Undulator period (mm)	27	27	27
Magnetic field (T)	1.2	1.2	1.2
Undulator gap (mm) (fixed)	5	5	5
Cell length (m)	2.4	2.4	2.4
Gain length (m)	0.8	1.5	0.9
Undulator length (m)	$8 \times 2.4$	$12 \times 2.4$	$9 \times 2.4$



### Optical Intensity Gain



\*S. Milton, et al.

Length	$9 \times 2.4$ m
Period	3.3 cm
Gap	9.4 mm
Field	1 T
K	3.1
Intermodule gap	$\sim 38$ cm

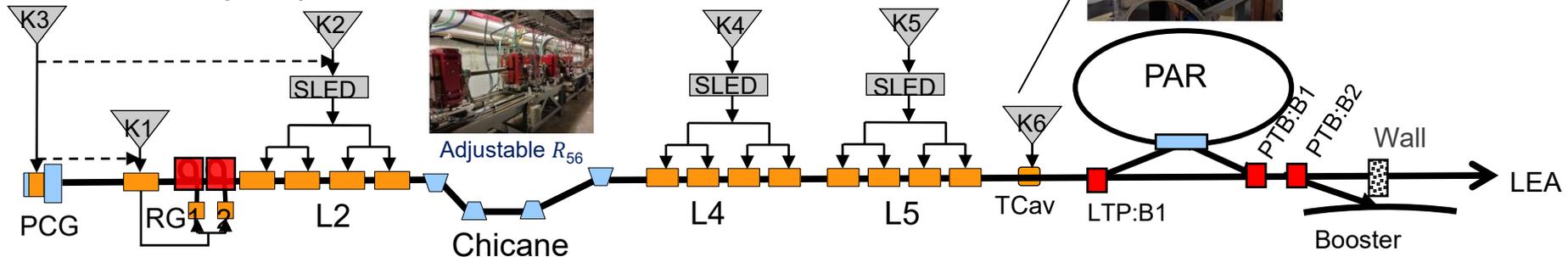
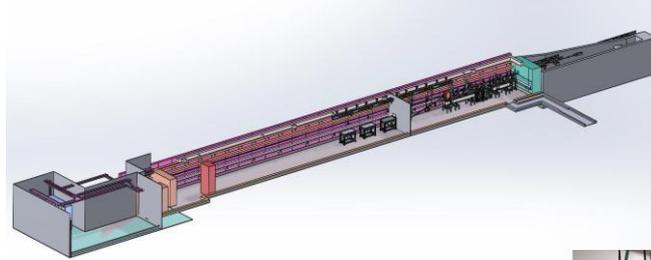


Beam properties:

- Peak current, 266 A
- Bunch length, 0.30 ps, rms
- Normalized emittance, 8.4 mm (rms)
- Energy spread, 0.10% (rms).
- Theoretical gain length is 0.59 m, measured gain length is 0.57 m.

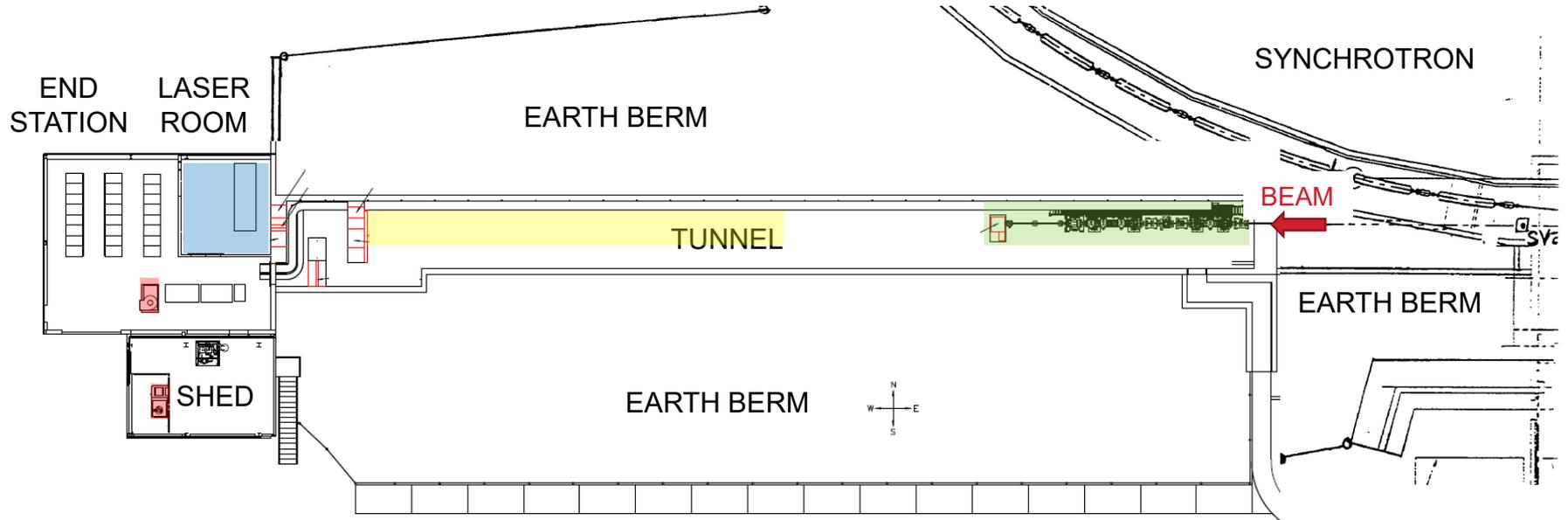
### 3. Transition to Linac Extension Area (LEA)

- Linac Extension Area (LEA) is new name for prior Low Energy Undulator Test Line (LEUTL).
- Electron beam test area for new accelerator components, technologies
- ~53 m length enclosure, ~17 m length beamline
- APS linac provides electron beam
- Three electron sources
  - RF thermionic gun (x2)
  - Photocathode gun
- SLAC-type 2856 MHz linac accelerates electrons to ~450 MeV
- Beam transport passes PAR, Booster to LEA enclosure



### 3. LEA Layout

- LEA Beamline
- Future 2856 MHz structure, SLED conditioning
- 30 MW, 50 MW 2856 MHz test stands
- LEA Laser Room



### 3. Motivation (1)

- APS injector chain includes variety of electron sources
- A variety of electron beam formats are available to LEA
  - High peak current of photocathode gun (PC) suitable for FEL
  - PAR may be suitable for experiments where ~1 ps bunch lengths are not required

Parameter	Units	PC	TC	PAR
Charge per cycle	nC	0.3	1.0	20
Bunch charge	nC	0.3	0.007	20
Bunch length	ps	1	1	1000
Bunches per cycle	...	1	29	1
Bunch spacing	ns	...	0.35	...
Repetition rate	s <sup>-1</sup>	6	30	1

Variety of sources that few test beams have available

### 3. Motivation (2)

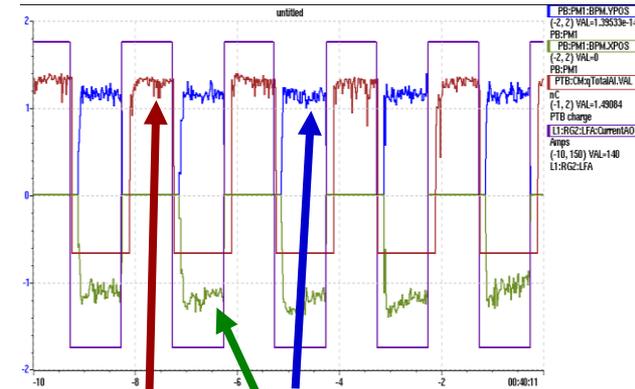
- In addition to operating APS, one goal of ASD is to perform research to advance concepts of future light sources and be utilized for advance R&D in accelerator technology and beam physics
- LEA beamline provides low-beta insertion region for testing accelerator components
  - LEA supports Compact Accelerators for Future Light Sources.
- LEA is the host of a BES-funded R&D program on structure-wakefield acceleration.
- LEA is added to the beamNetUS program starting in FY2026



LEA supports strategic accelerator research goals of ASD

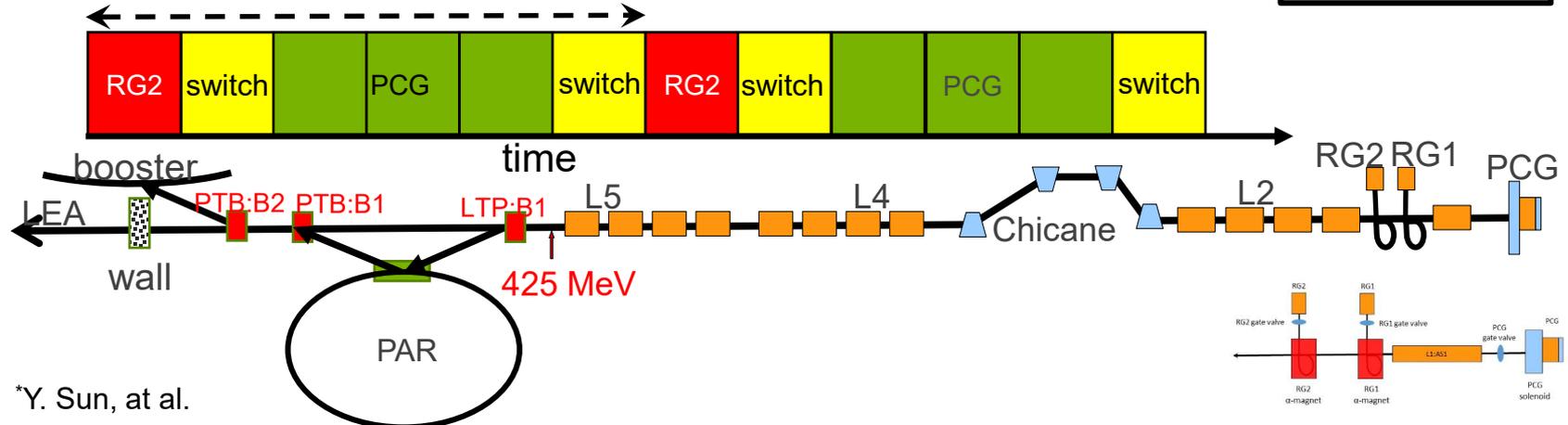
# Fast Interleaving\*

- **Interleaving Operation** of two different rf gun beams in the linac:
  - RG2 beam → PAR → Booster → Storage Ring
  - PCG beam → LEA
- Interleaving was demonstrated with the old APS SR in Oct. 2017.
- The new fast alpha magnet will enable fast interleaving with APSU storage ring:
  - APS top-up cycles: 2 minutes
  - **APSU swap-out period: as short as 10 seconds**  
2 minutes → 10 seconds



RG2 beam  
PTB bunch  
charge

X and Y position  
of PCG beam at  
Par-Bypass

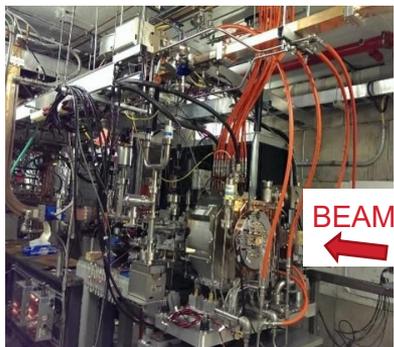


\*Y. Sun, at al.

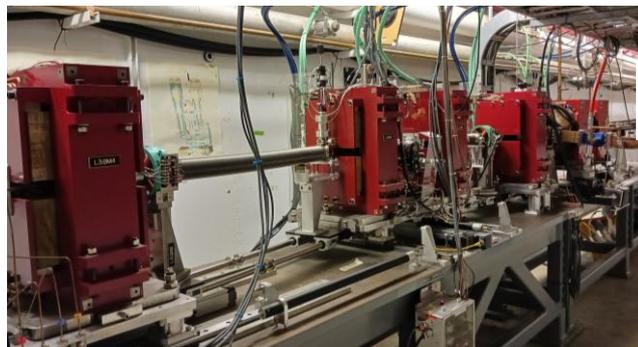
# 3. Hardware for Accelerator R&D

APS Linac: 425+ MeV, 30 Hz, 1 nC/bunch

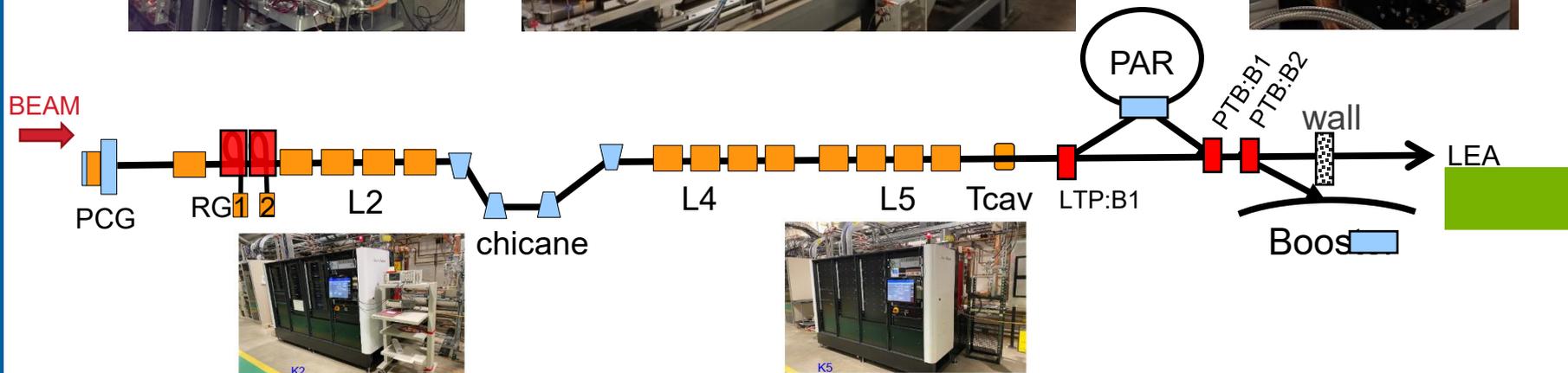
Photocathode RF electron gun



Adjustable  $R_{56}$  bunch compressor

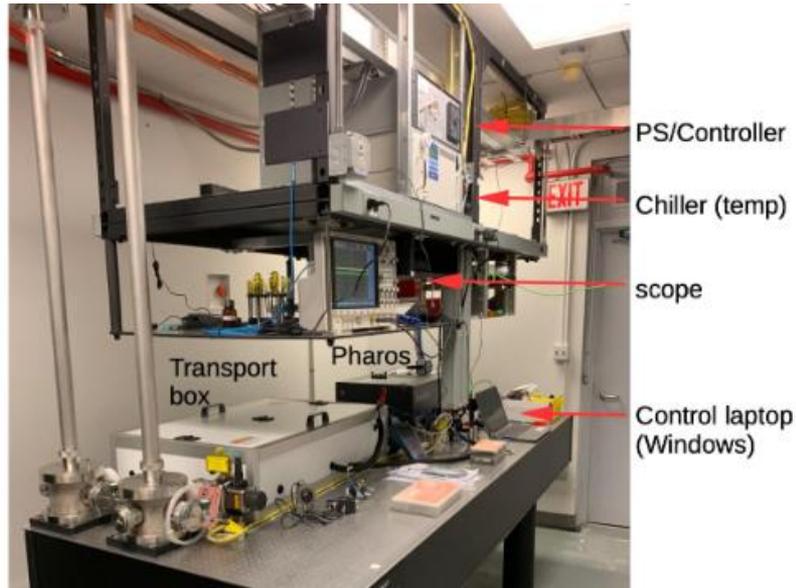


S-band transverse deflecting cavity



# Hardware for Accelerator R&D\* (2)

- A new 4 mJ, IR Yb-based Pharos laser by Light Conversion is installed  
Operating @ 68 MHz



\*J. Dooling



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*AFOSR - NSF Scientific Opportunities with Compact, High Intensity Accelerators*

*A. Nassiri*

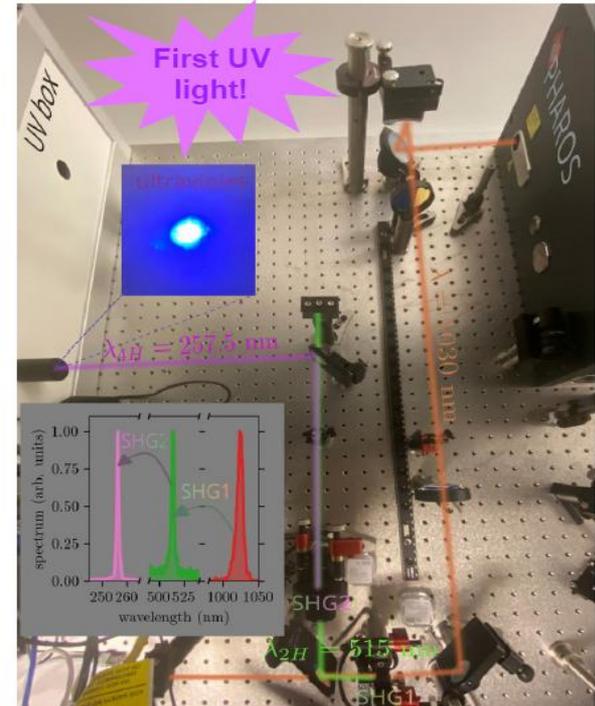


# Hardware for Accelerator R&D (3)

- High-brightness mode of the photoinjector with new laser
  - Sub-micron normalized emittance @ 100 pc to LEA\*

Parameters	Nominal	Range
wavelength (nm)	1030	~20 nm BW
Energy (mJ)	4	< 4
OSC freq. (MHz)	68	2856
Regen Amp output freq. (Hz)	30	<1200
Pulse duration (fs)	~450	450~5000

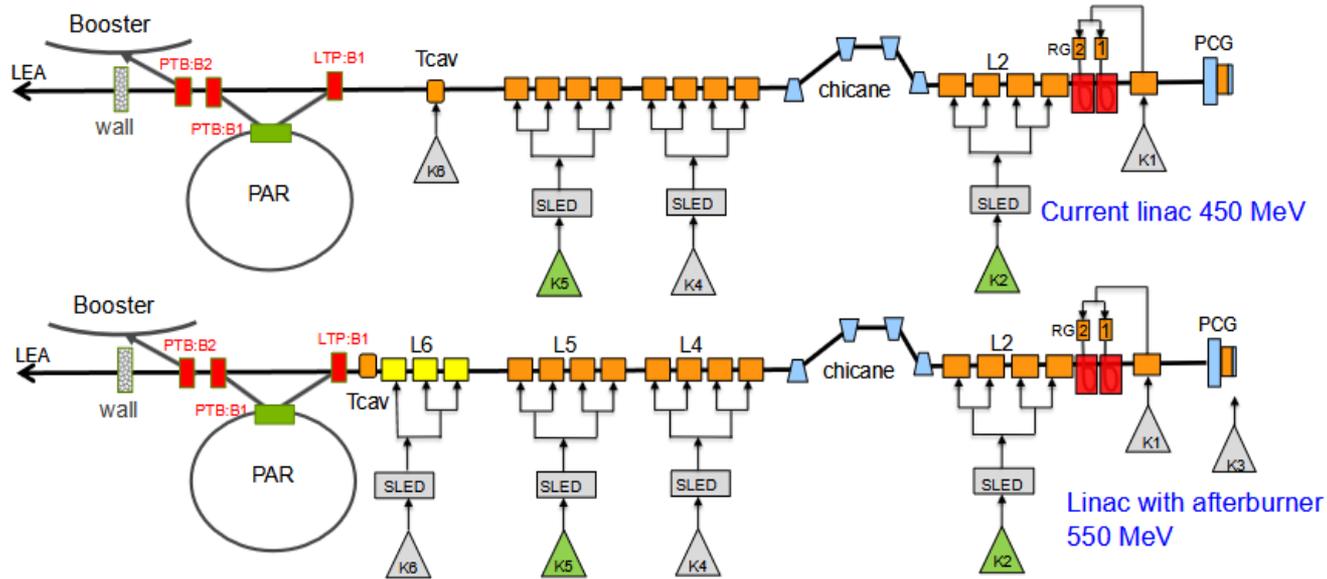
IR→UV harmonic conversion of the laser was successfully commissioned.



\*P. Piot

# Linac afterburner<sup>1</sup> – 550 MeV\*

- Adding 3 accelerating structures
- PAR power system upgrade



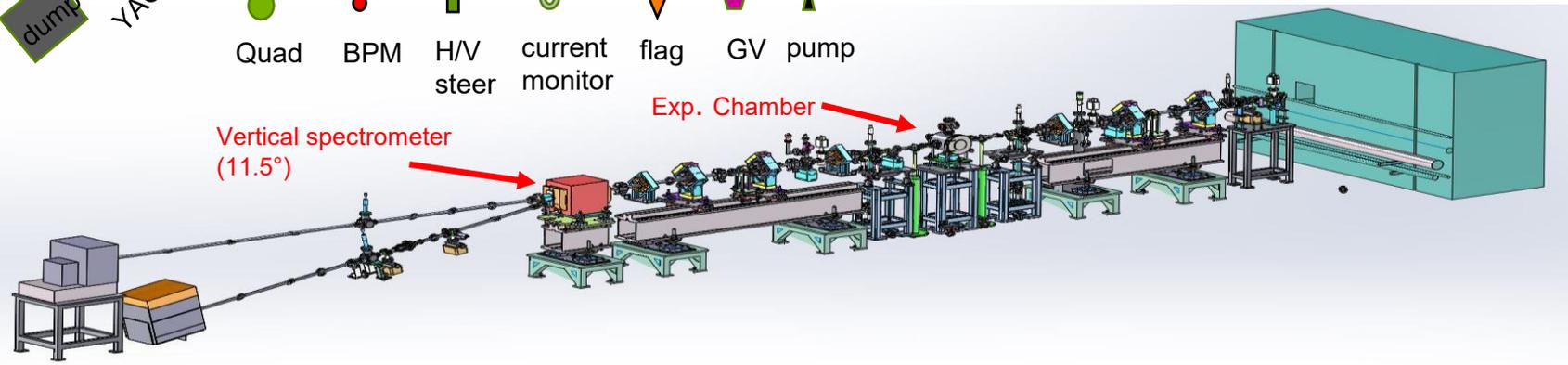
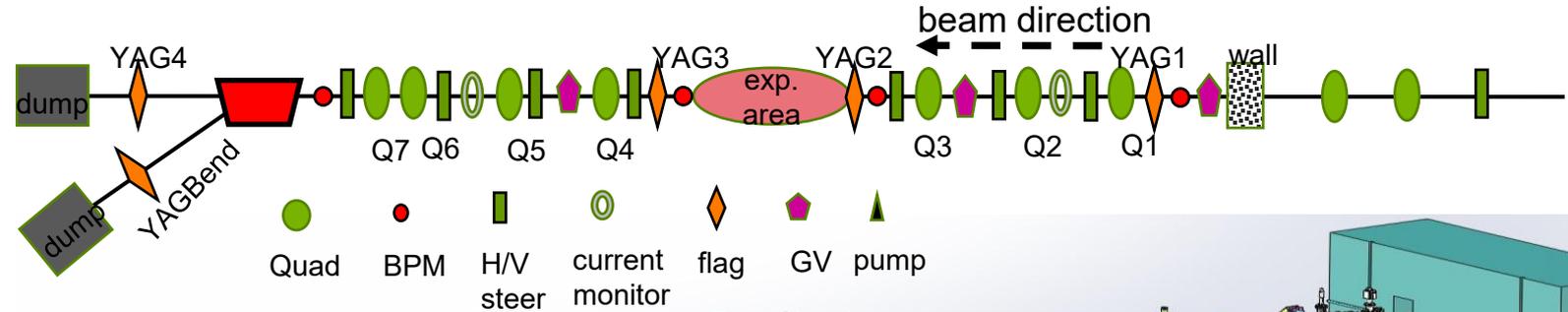
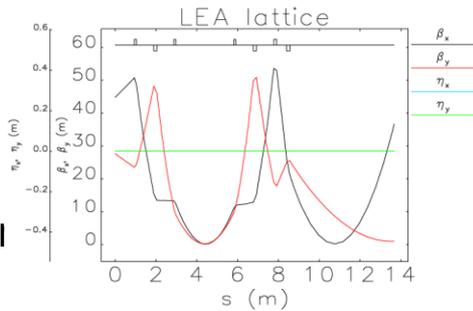
\*PAR upgrade is also needed for 550 MeV beam(dipole power supplies, PFN cables for pulsed magnets etc.)

<sup>1</sup>M. Borland

# 3. Hardware for Accelerator R&D (2)

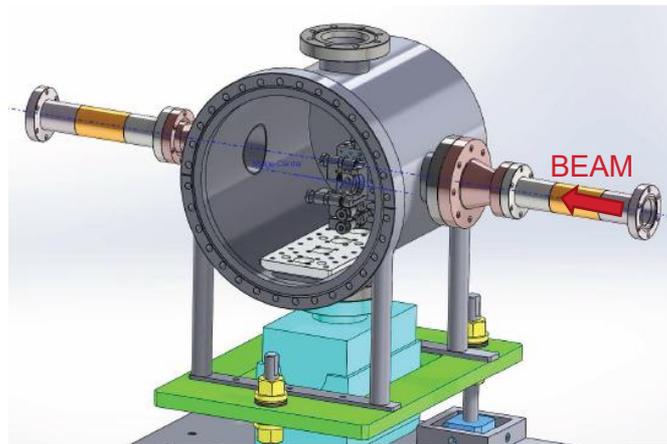
## LEA Beamline

- 300–500 MeV electron beam
- 15 m installed length
- Insertion region supporting round or flat beams

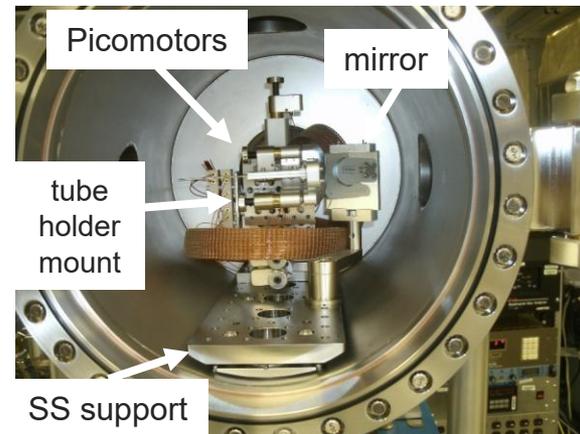


# 3. Hardware for Accelerator R&D (3)

## Experimental Chamber

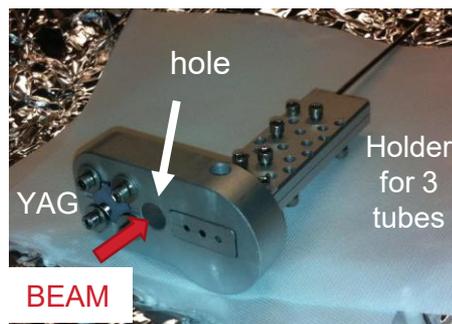


Ultra-high vacuum chamber

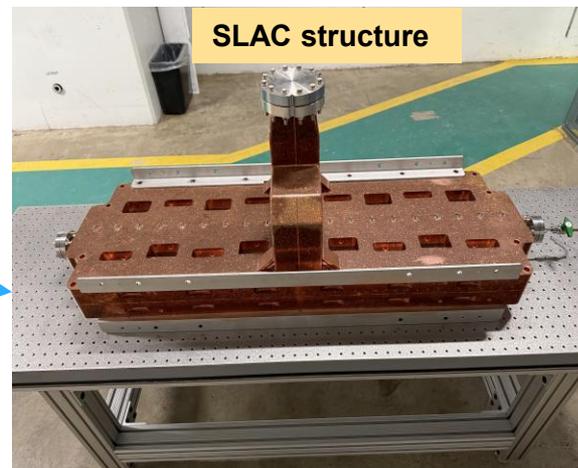


Under vacuum in the lab

Inside view



# 3. RF Systems



## LEA – Summary (2)

- Receives electrons from the APS linac (up to 450 MeV – upgradable to 500/550 MeV).
- The APS linac includes a high-brightness 2.856 GHz photocathode RF gun. With appropriate laser timing, APS can produce the C<sup>3</sup>-compatible pulse format (5.26 ns spacing — every 15th S-band bunch).
- Two S-band RF sources on-site: a 30 MW modulator/klystron and a 50 MW solid-state modulator/ klystron — usable for structure conditioning and beam tests.
- Utilities (AC power, deionized cooling water, HVAC) present; concrete pad adjacent suitable for LN2 tank and truck access through APS service tunnel.
- EPICS-based control infrastructure and access/interlock radiation monitoring already installed.
- A laser room is available within the LEA end-station.
- Preparing is underway to test an S-band version of the SLAC C-band (C<sup>3</sup>) structure (SLAC/ANL Collaboration Agreement)

# Future APS Linac and LEA Plans

## Short term:

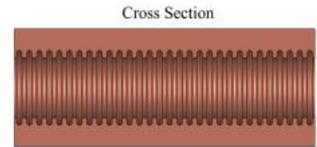
- Upgrade the remaining APS Linac rf system to solid-state modulators and 60 MW klystrons – increase linac beam energy to 500 MeV – 550 MeV including new digital LLRF

## Long term:

- Install and test CWA in LEA with APS beam.
- Possible upgrade of the APS linac rf structures to new high-gradient structures (could be C-band).
- Provide C-band rf system in LEA, interleaving with S-band rf system to support C-band RF R&D.

### 3. Future APS Linac and LEA Plans (2)

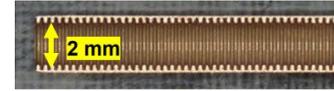
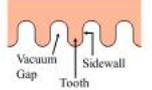
- Argonne Sub-Terahertz Accelerator (ASTAR)
  - 180 GHz Wakefield Accelerator utilizing a Corrugated Waveguide
- Two experiments planned for LEA
  - Breakdown testing of 10 cm corrugated waveguides
    - Reach design accelerating gradient (90 MV/m)
    - Explore sub-THz, short pulse regime
  - Beam offset monitor testing
    - Offset beam generates dipole mode (190 GHz)
    - Test redesigned beam offset monitor
- Self contained experimental apparatus
  - YAG Screens
  - Photodiodes
  - Ion pumps



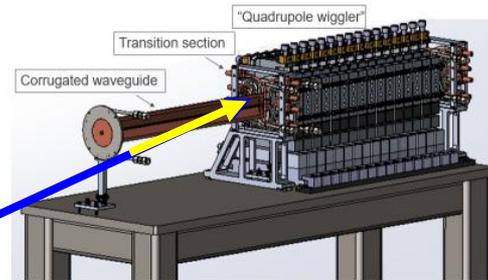
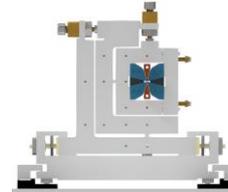
End View



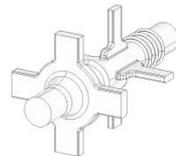
Corrugation Profile



A. Siy et al., PRAB, December, 2022



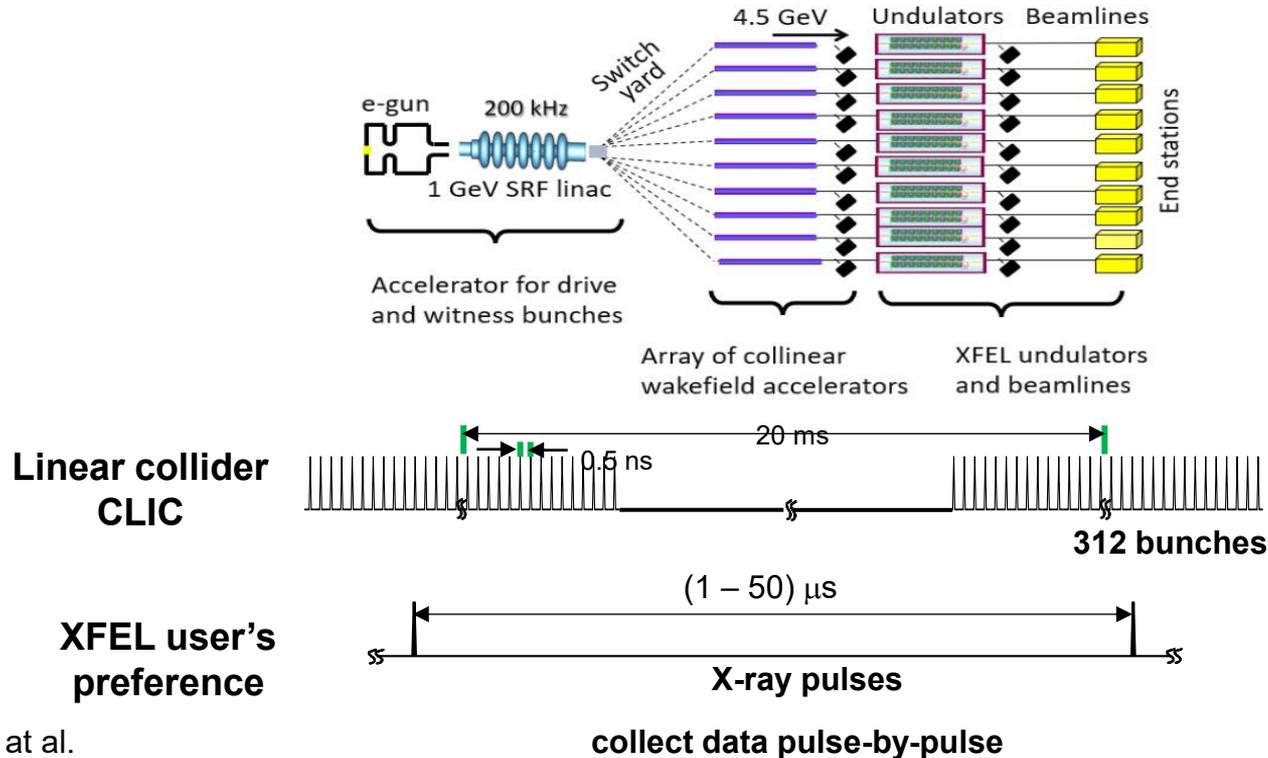
Transition Section



### 3. Millimeter Wavelength Accelerator XFEL\*

## Goal:

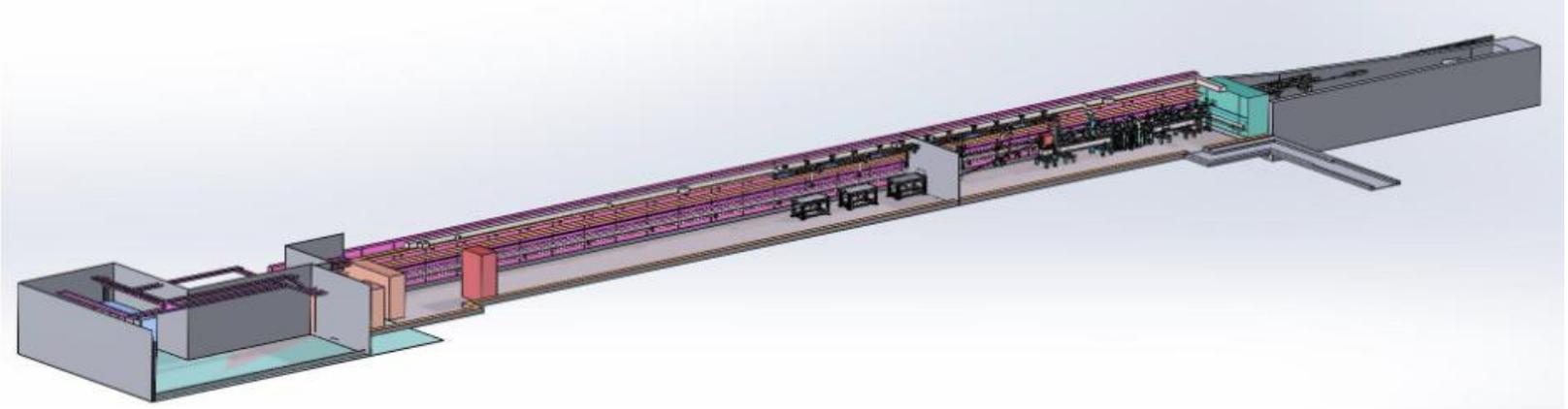
High repetition rates, attosecond pulses, and full coherence



\* Zholents, et al.

# LEA - Summary

- LEA is a flexible test enclosure at the Advanced Photon Source (APS) intended for demonstrations of new accelerator concepts and technologies. It formerly housed the LEUTL.
- Enclosure length  $\approx$  48–50 m; width 3.66 m; height 2.74 m — adequate for the 3-cryomodule C<sup>3</sup> demonstrator (27 m of active length).
- A movable-wall labyrinth allows wheeling large accelerator equipment in without restacking shielding.



## 4. Summary (2)

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*Thank you!*

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