A NEXT GENERATION LIGHT SOURCE FACILITY AT LBNL

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Technology of a Next Generation Light Source

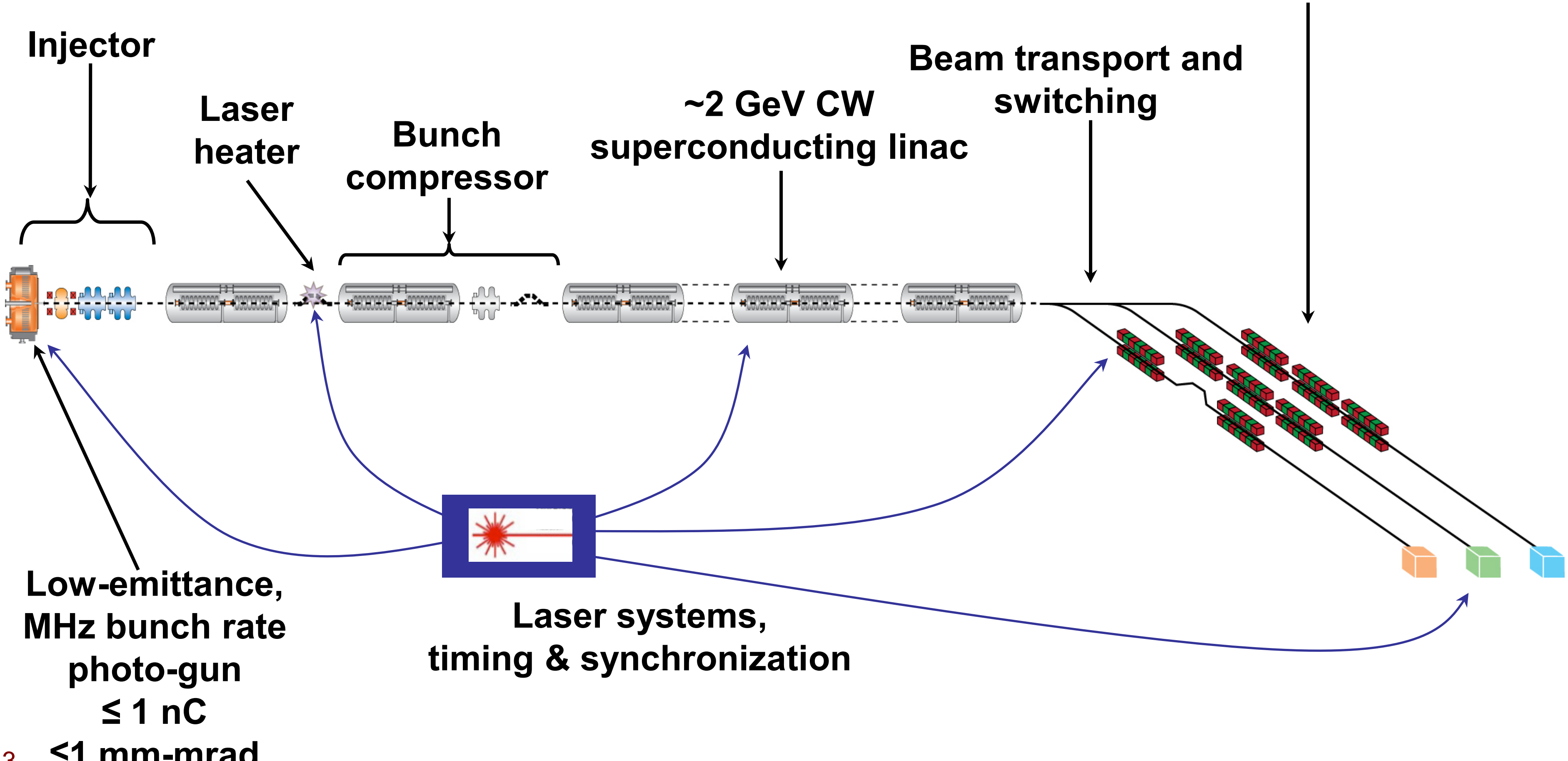
- **High brightness electron beams**
- **X-ray free electron lasers**
- **High-power optical lasers**
- **FEL seeding**
- **Optical manipulations**
- **CW superconducting accelerator**
- **High repetition rate injector**

  - **Intense X-ray pulses from VUV to hard X-ray**
  - **High average power X-ray beams**
  - **Control of pulse duration**
  - **Control of pulse energy**
  - **Spatial coherence**
  - **Temporal coherence**
  - **Generation of shorter wavelengths in harmonic stages**
  - **Precise synchronization**
  - **Shorter undulators**

Next Generation Light Source (NGLS) – a new class of X-ray laser

Array of (ultimately 10) configurable FEL beamlines

- ***100 kHz CW pulse rate***
- ***Capability of one FEL having MHz rate***
- ***Independent control***
- ***Each FEL configured for experimental requirements***



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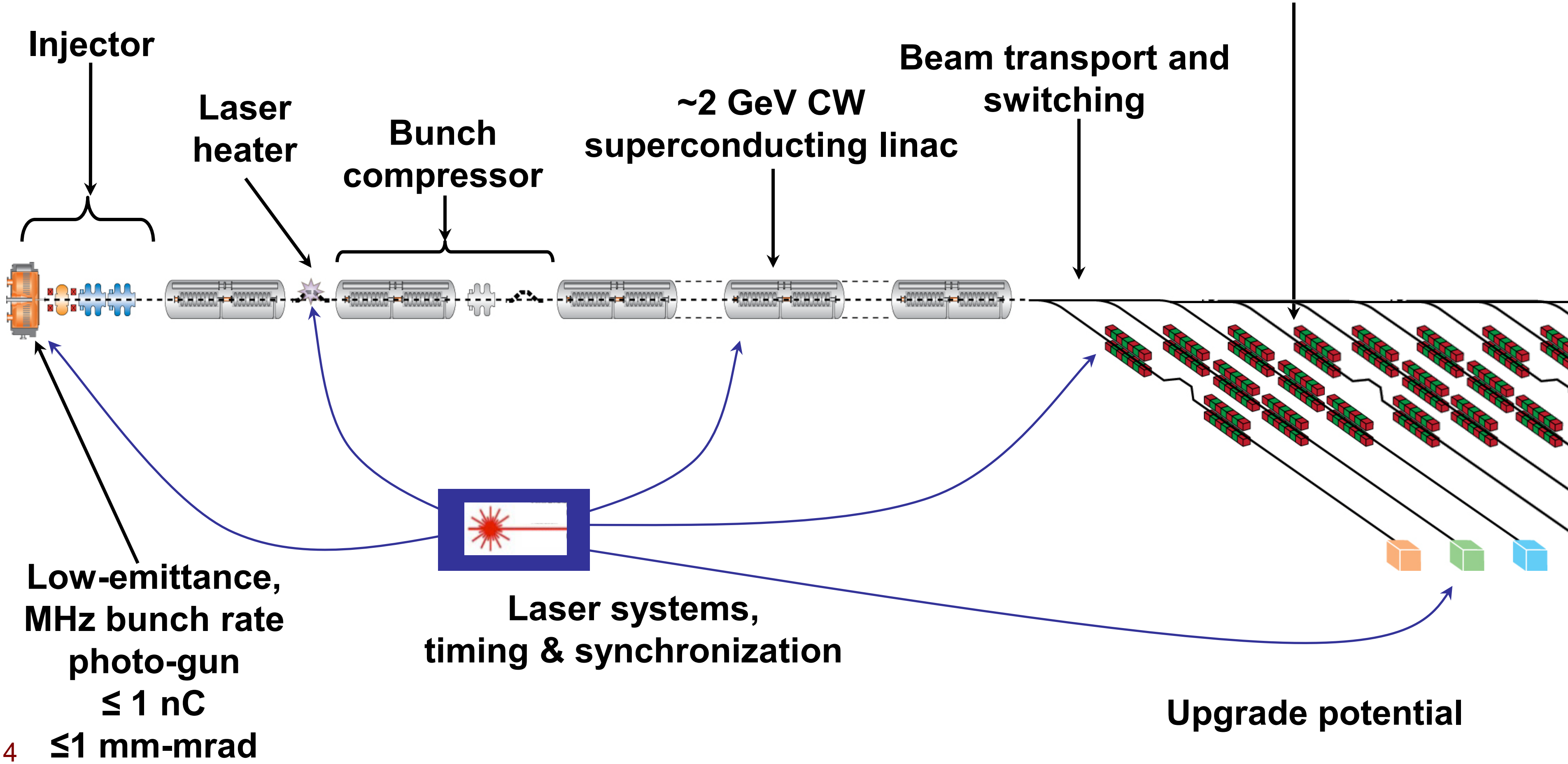

NGLS – unprecedented power, ultrafast pulses, high repetition rate

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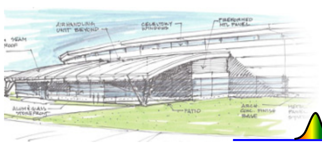
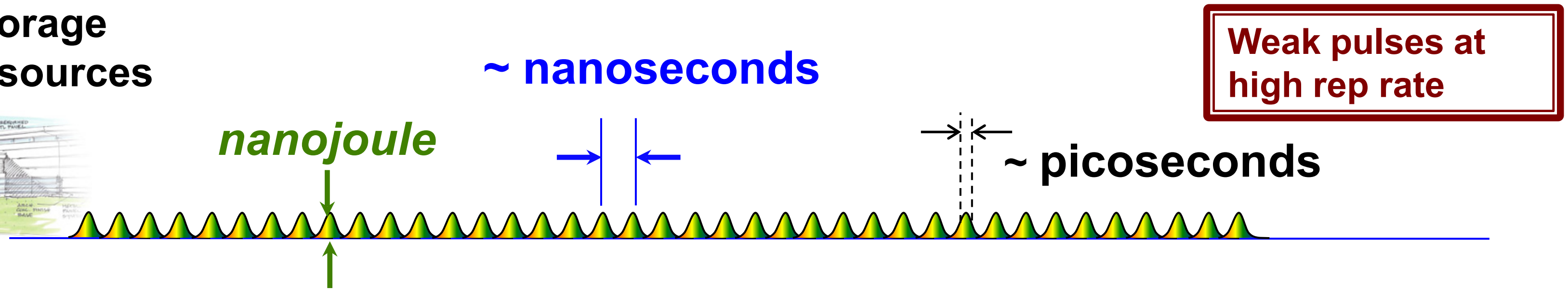
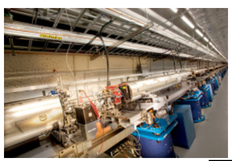
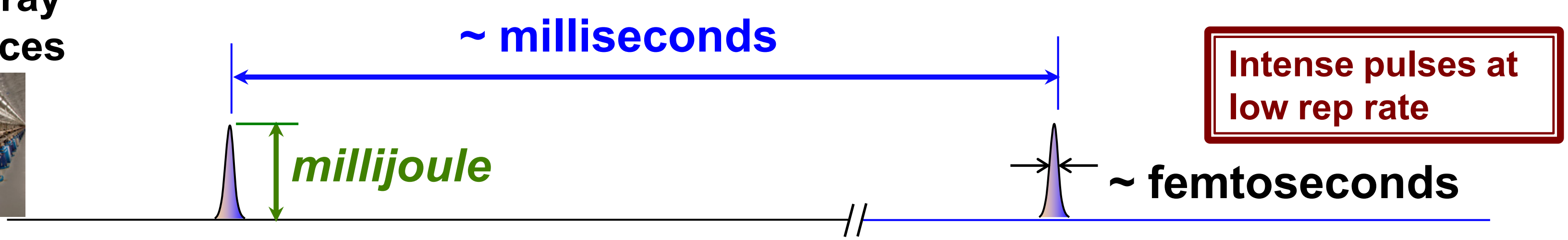
Today's storage ring x-ray sources



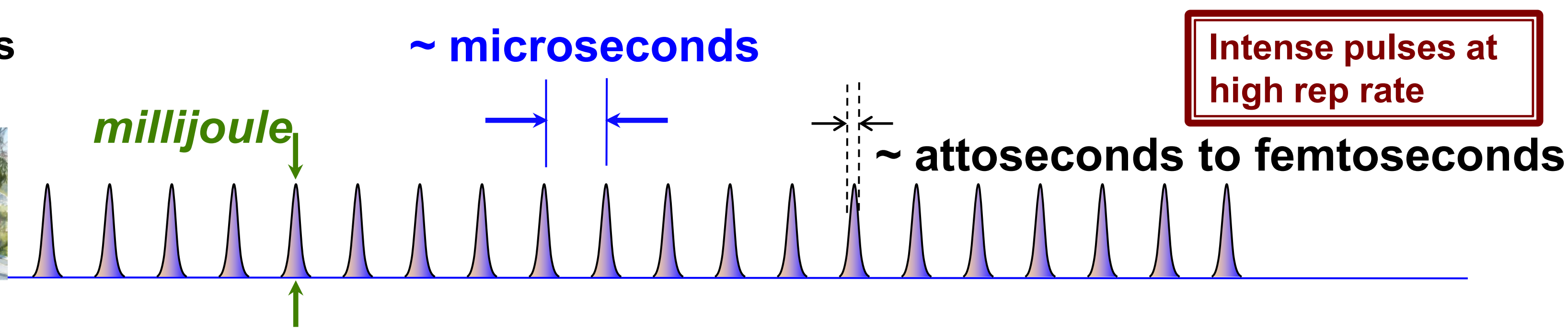


Today's x-ray laser sources





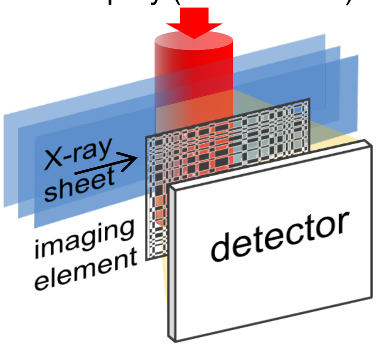
Tomorrow's NGLS



Science-driven accelerator design

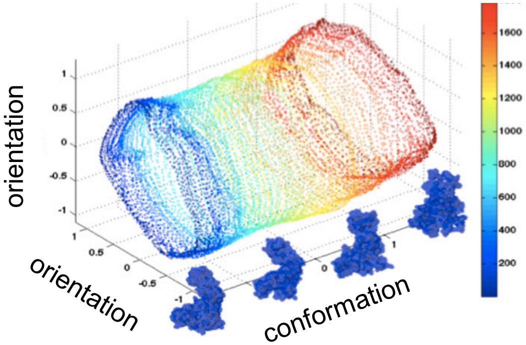
- **We have worked with a broad community over four years to develop a proposal for a Next Generation Light Source**

NGLS high repetition rate X-ray laser: a transformative tool for energy science



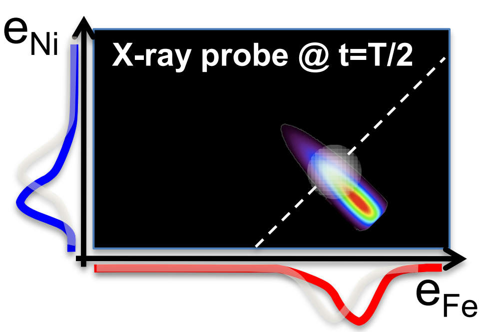
- **Imaging**

  Take pictures from stills to movies while identifying the chemical species, on ultrafast timescales



- **Structure**

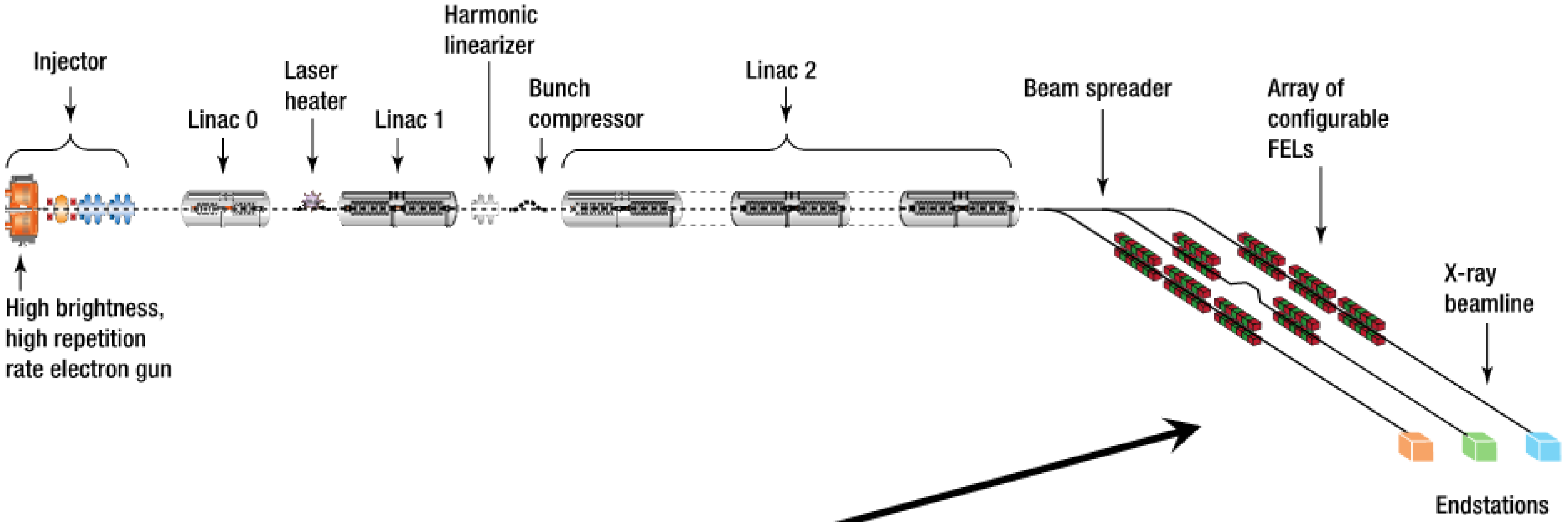
  Track the changes in positions of the atoms in proteins as they act, relating structure to function



- **Spectroscopy**

  Multiple pulse and non-linear techniques

NGLS – operating characteristics



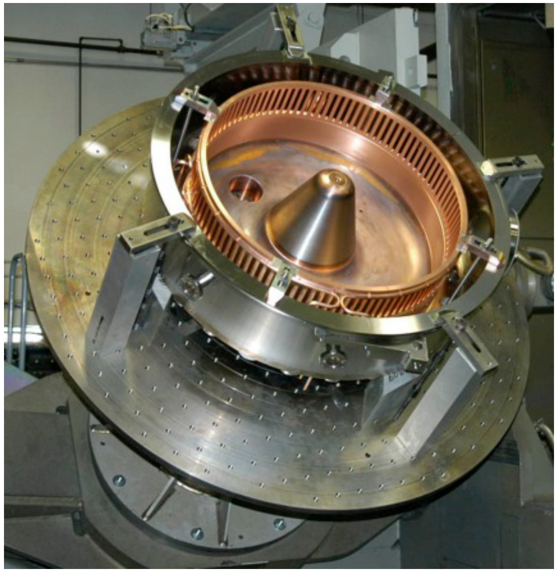
- High repetition rate FEL array
  - X-ray energy range ~0.25 – 1.2 keV
    - Fundamental, harmonics may also be used
  - Pulse length ~0.25 – 250 fs
  - Bandwidth $5x10^{-5}$ – ~1% (FWHM at ~1 nm)
  - Peak power ≤1 GW
  - Average power ≤100 W

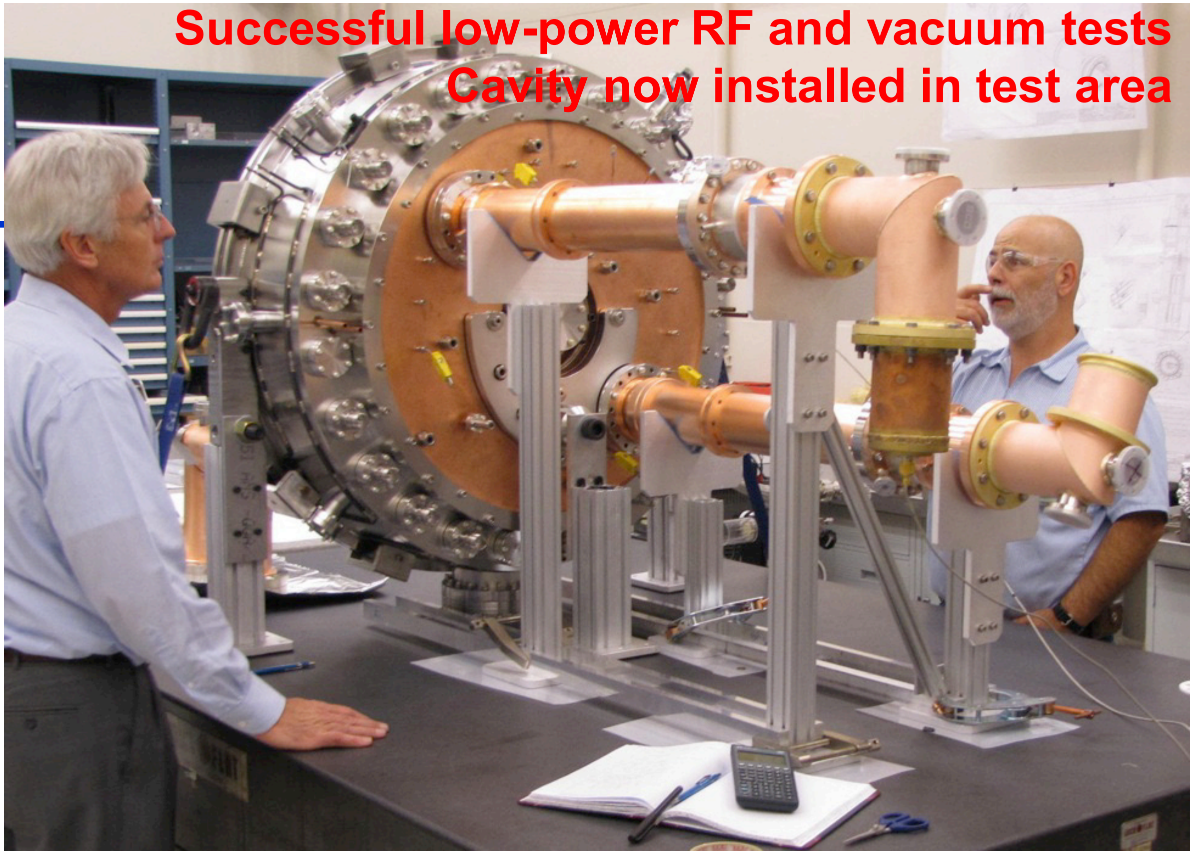
Baseline electron beam parameters

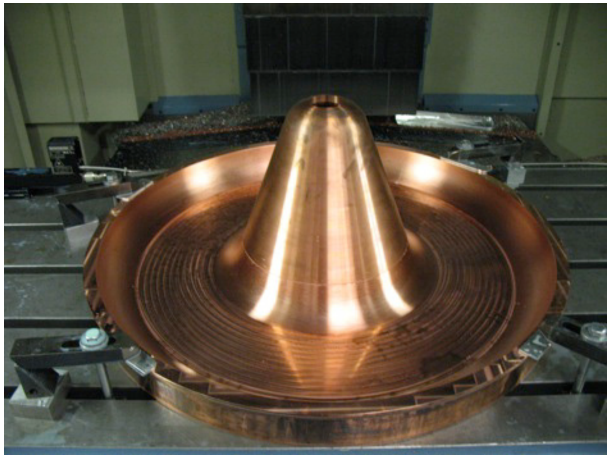
- **Baseline parameters reflect single point design study**
  - **Chosen to meet science needs**
  - **At minimal machine costs**
  - **Flexibility around these choices**
    - ***Performance range will be further refined in future studies***
- **Parameters have been achieved or are close to demonstrated performance**

Parameter	
Bunch charge (pC)	300
Repetition rate (MHz)	
Out of linac	1
Into FEL	0.1-1
Average current (mA)	0.3
Bunch length (fs)	
Out of injector (FWHM)	~5000
Into FEL (usable bunch core)	250
Peak current (A)	
Out of injector	>40
Into FEL (in usable bunch core)	>500
Emittance (slice, normalized, mm-mrad)	
Out of injector	<0.6
Into FEL	0.6
Emittance (projected, normalized, mm-mrad)	
Out of injector	0.7
Into FEL	0.73
Energy spread (slice, rms, keV)	
Out of injector	<4
Into FEL (in usable bunch core)	50

R&D: MHz rep-rate photocathode gun

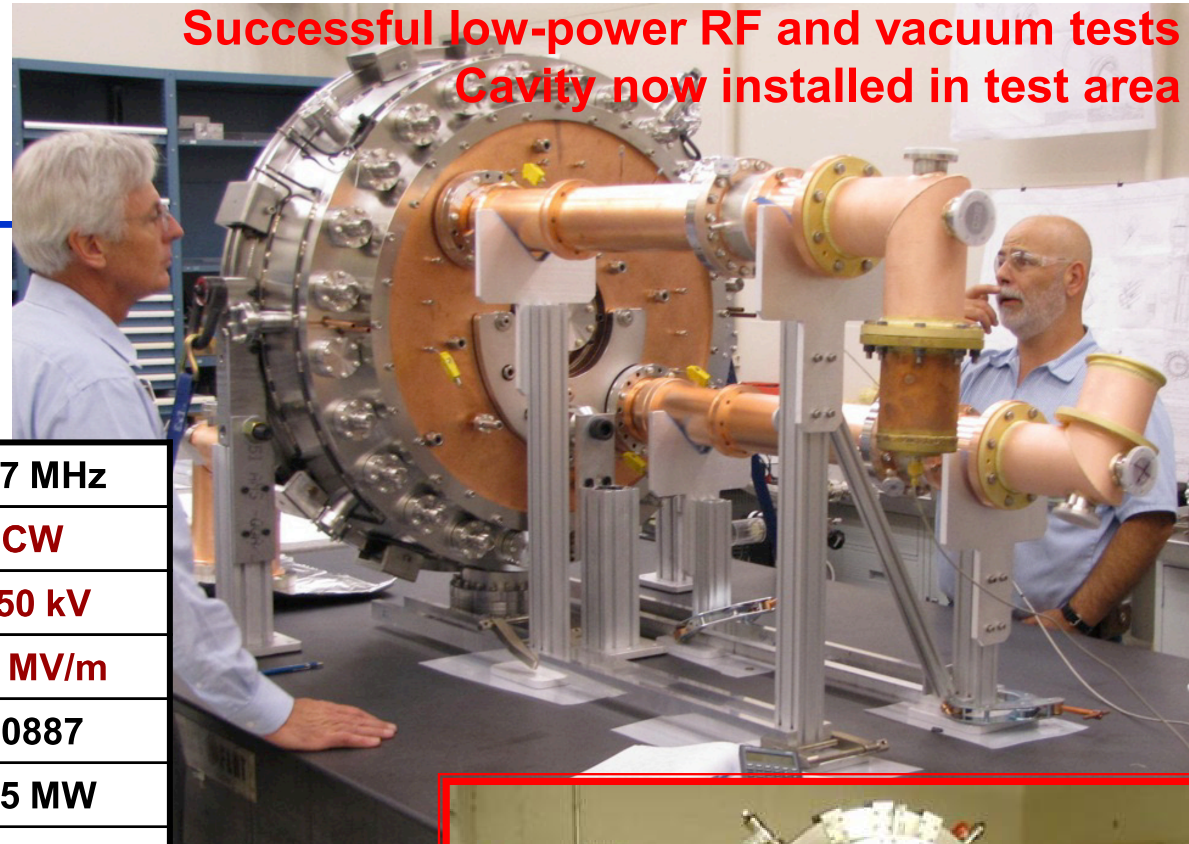


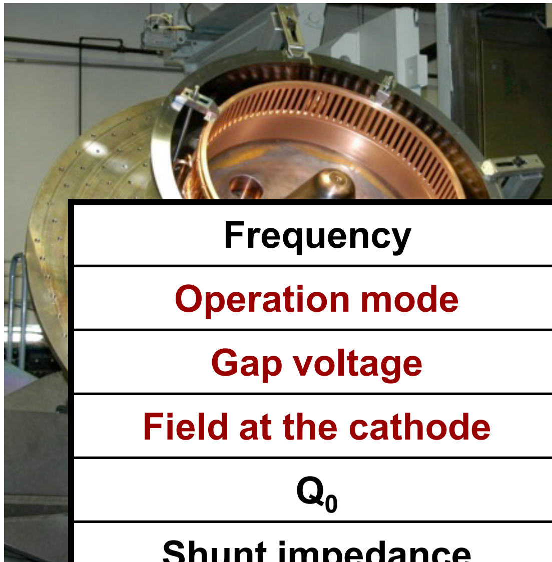


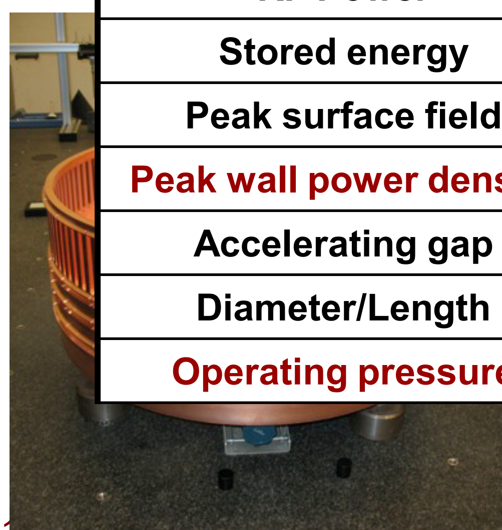


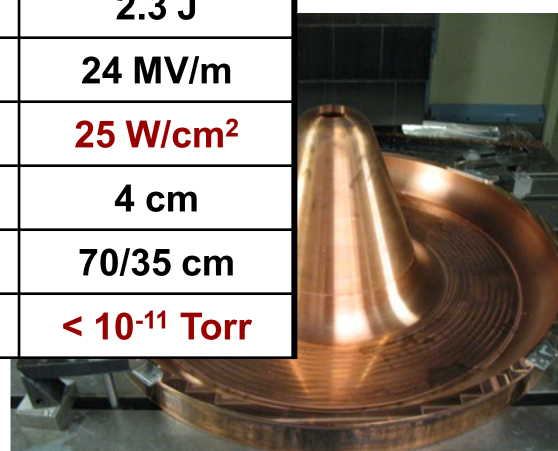
R&D: MHz rep-rate photocathode gun

Successful low-power RF and vacuum tests
Cavity now installed in test area



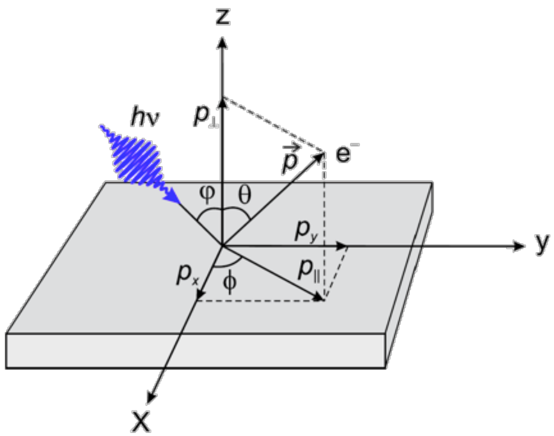


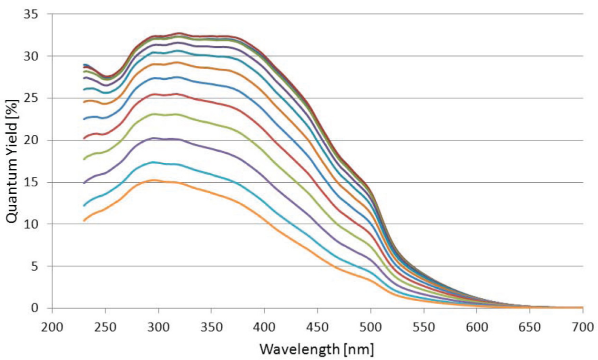


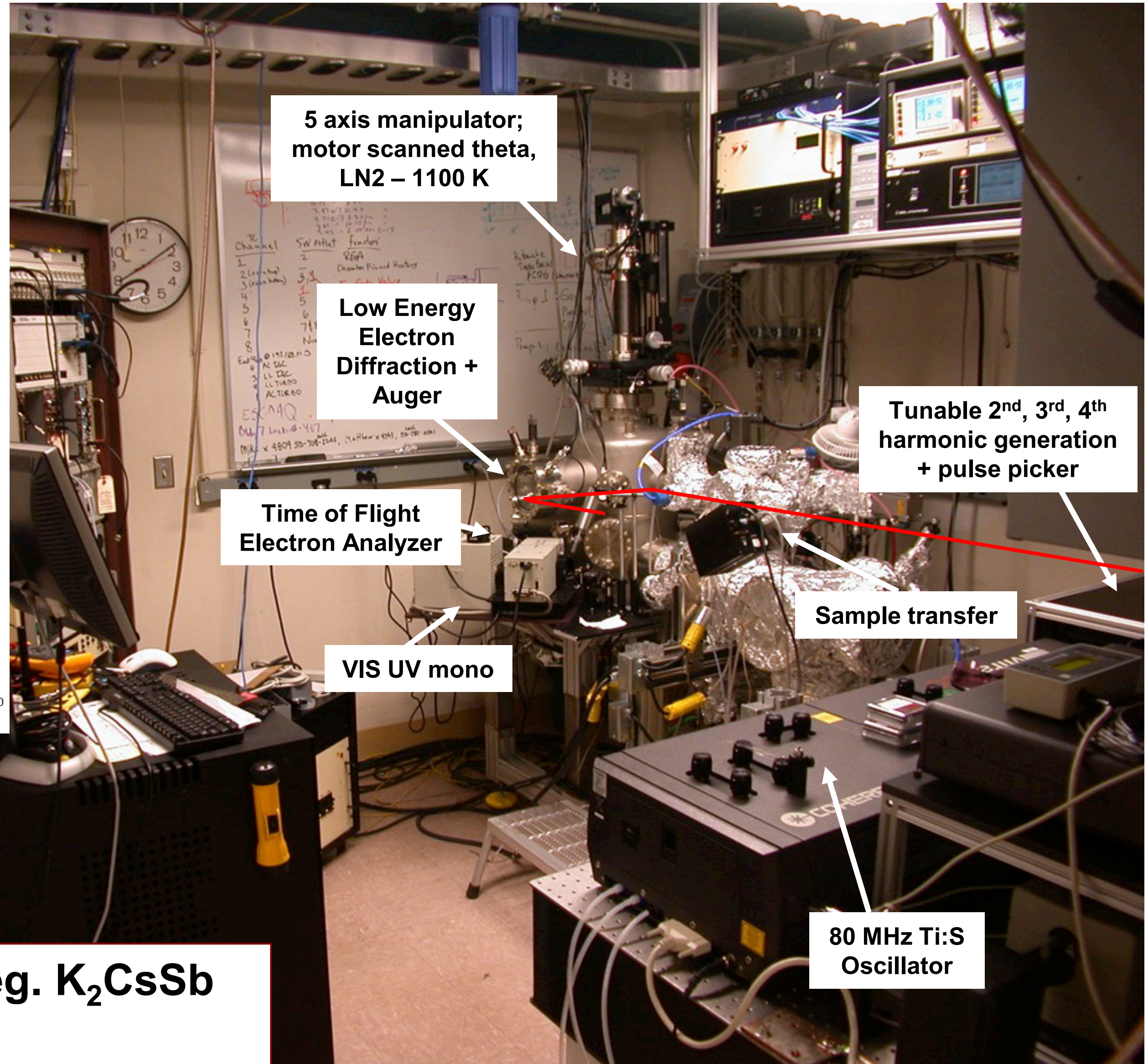


Frequency	187 MHz
Operation mode	CW
Gap voltage	750 kV
Field at the cathode	19 MV/m
Q_0	30887
Shunt impedance	6.5 MW
RF Power	90 kW
Stored energy	2.3 J
Peak surface field	24 MV/m
Peak wall power density	25 W/cm^2
Accelerating gap	4 cm
Diameter/Length	70/35 cm
Operating pressure	< 10^{-11} Torr

R&D: High quantum efficiency photocathodes

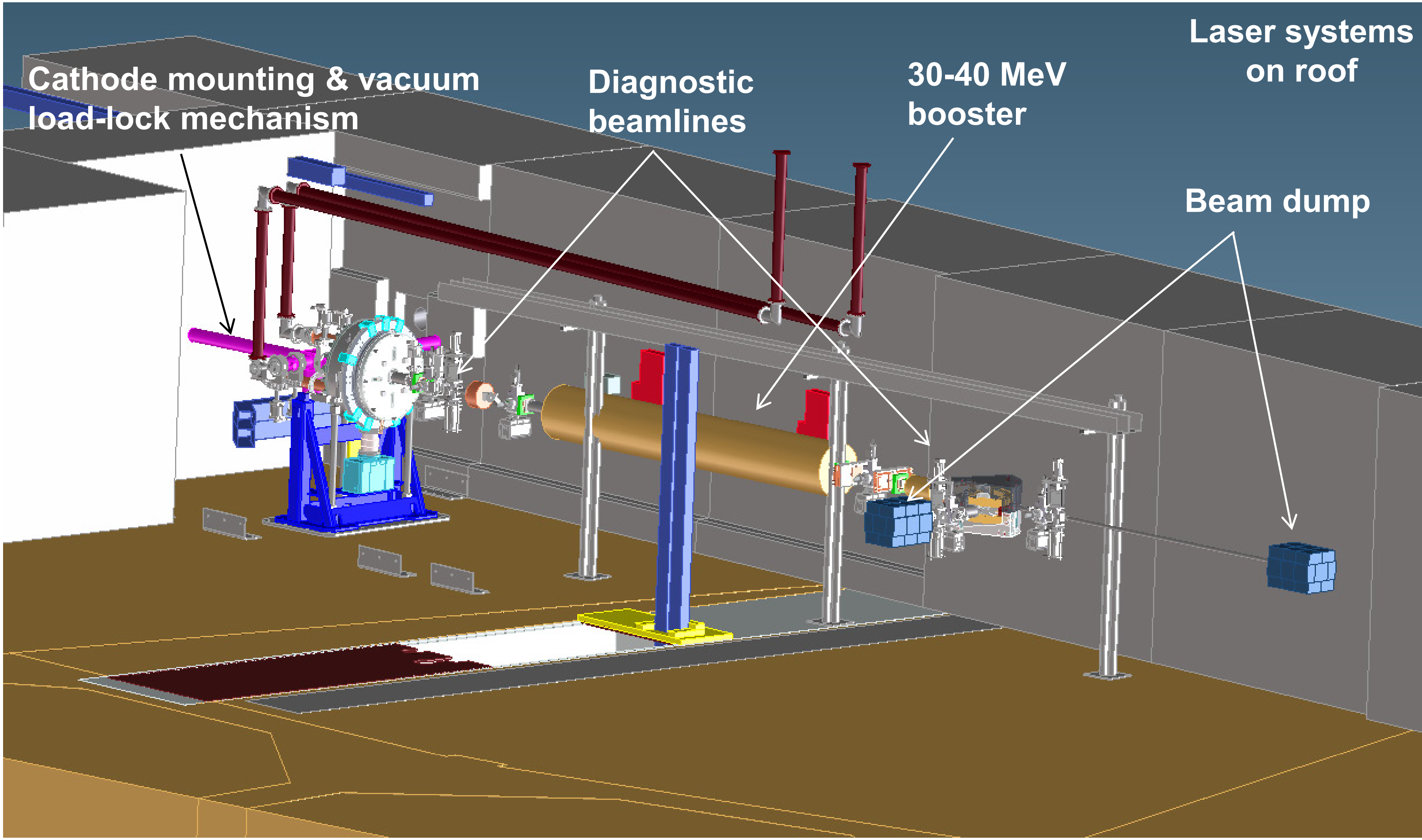






- Alkali antimonides eg. K_2CsSb
- Cs_2Te

R&D: APEX – Advanced Photoinjector EXperiment



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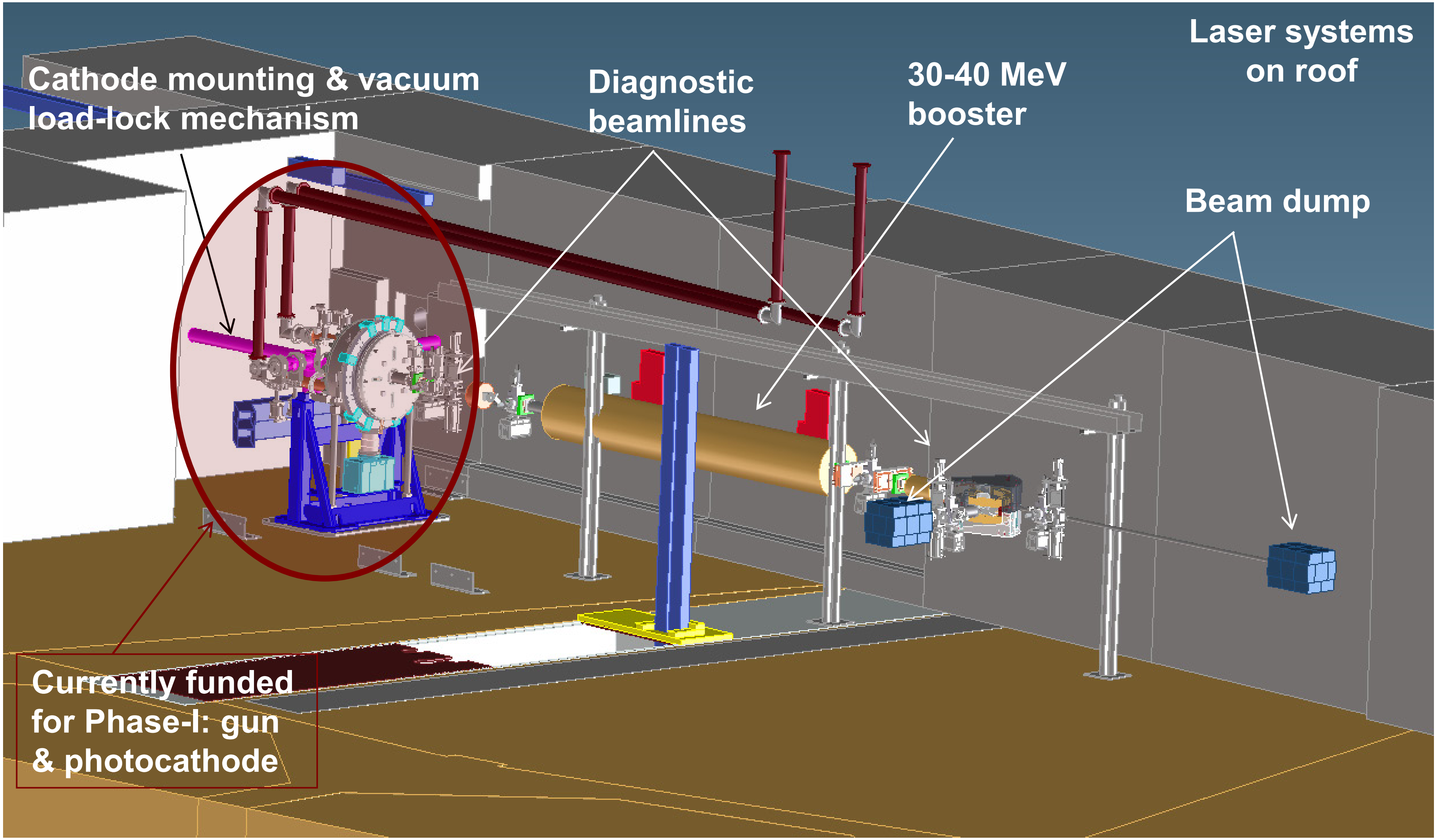
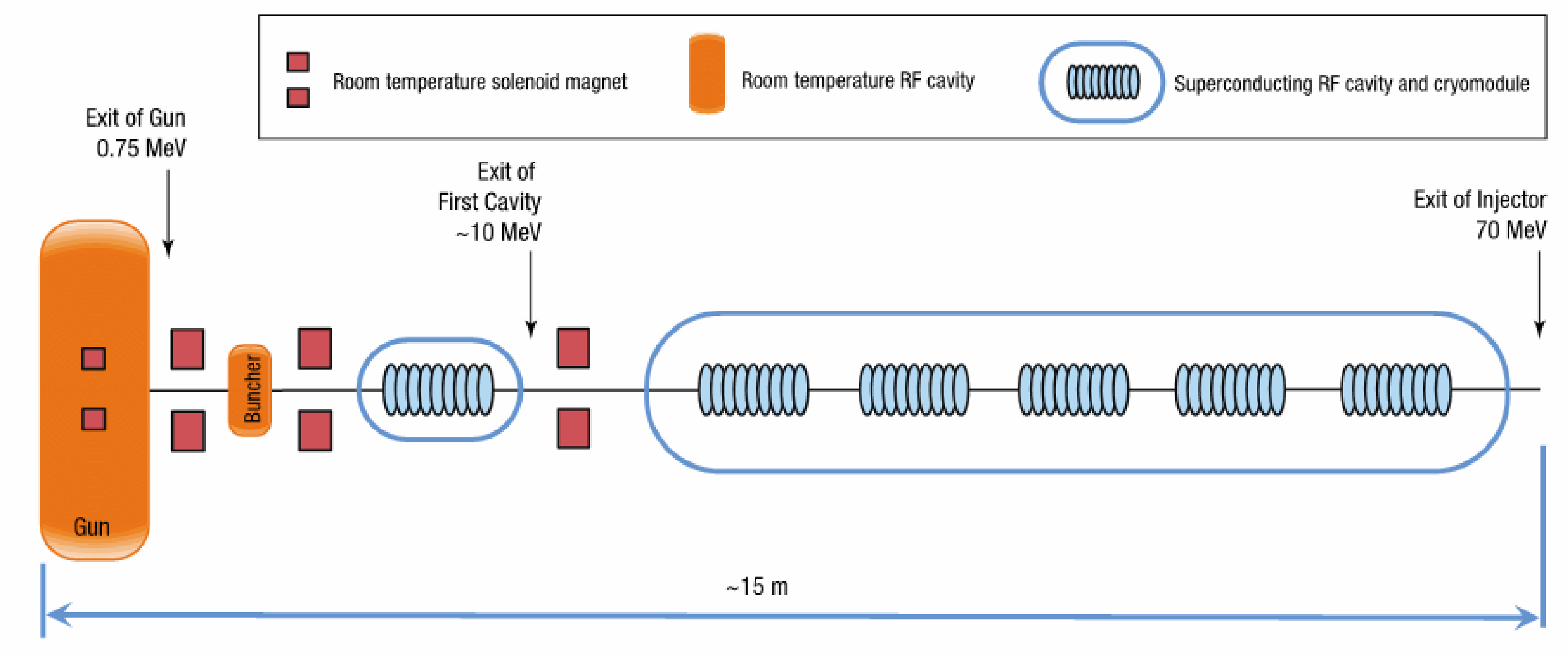
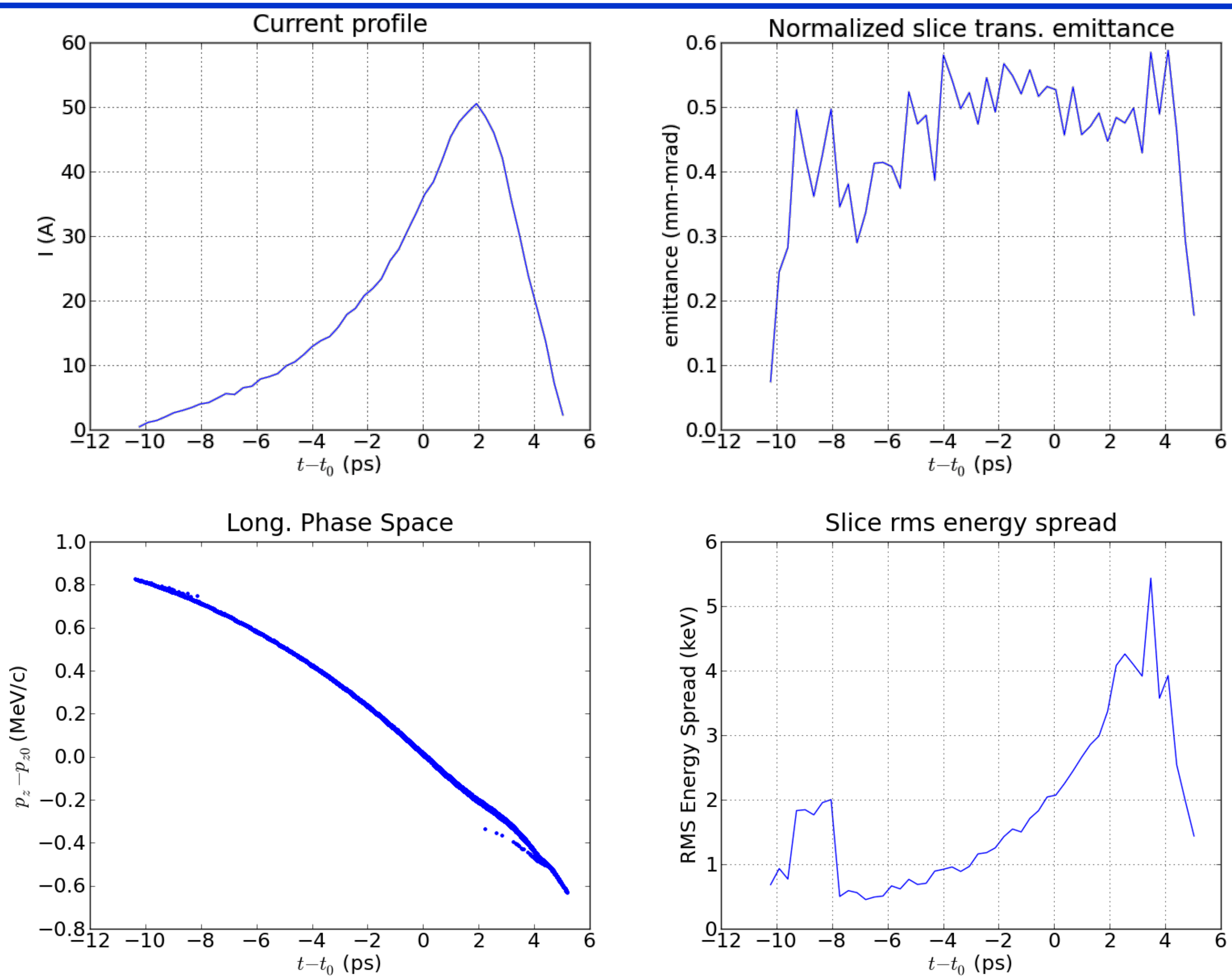


Injector schematic



- **Ballistic bunching**
- **Velocity bunching**
- **Emittance compensation**

Injector beam dynamics modeling



Injector beam dynamics modeling

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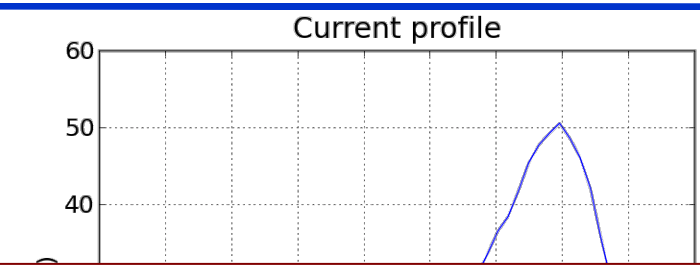
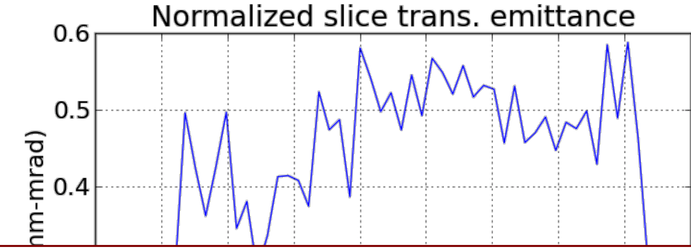
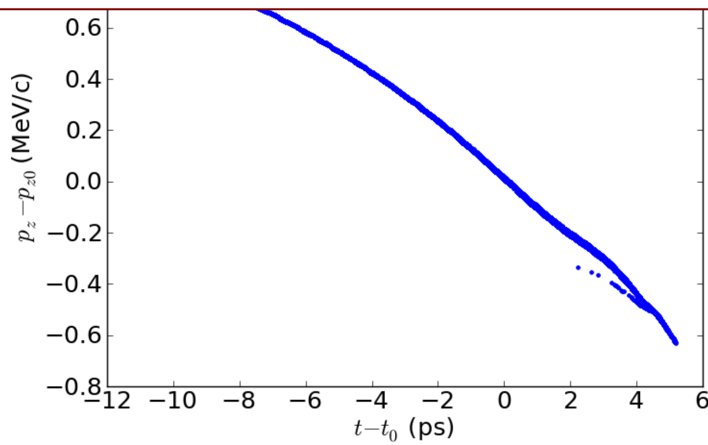


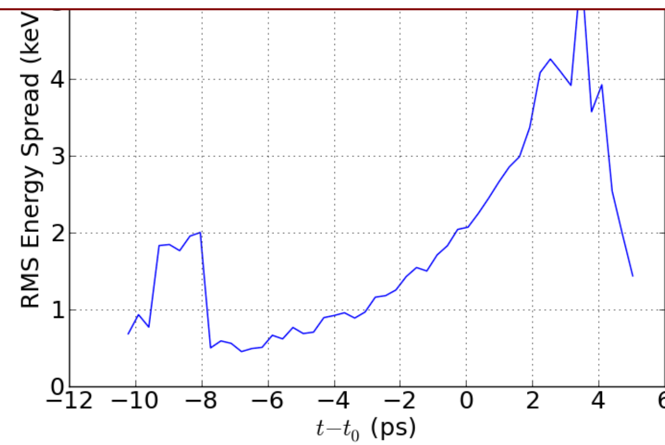


D. Filipetto et al, "Low Energy 6D Beam Diagnostic for APEX, the LBNL VHF Photo-injector," **WEP222**

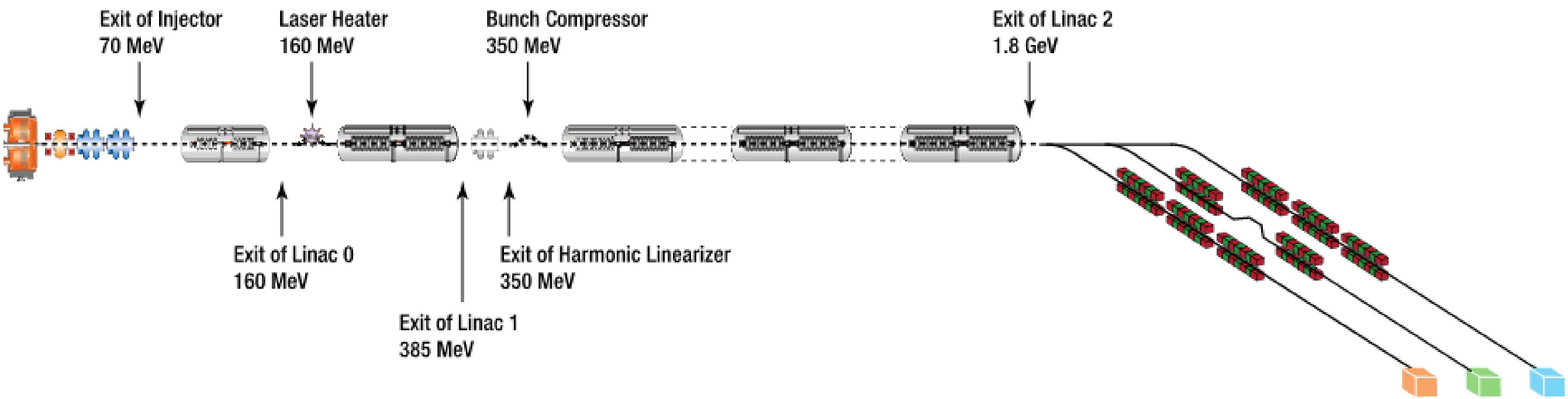
C. F. Papadopoulos et al, "Photoinjector Beam Dynamics for the APEX Project," **THP200**

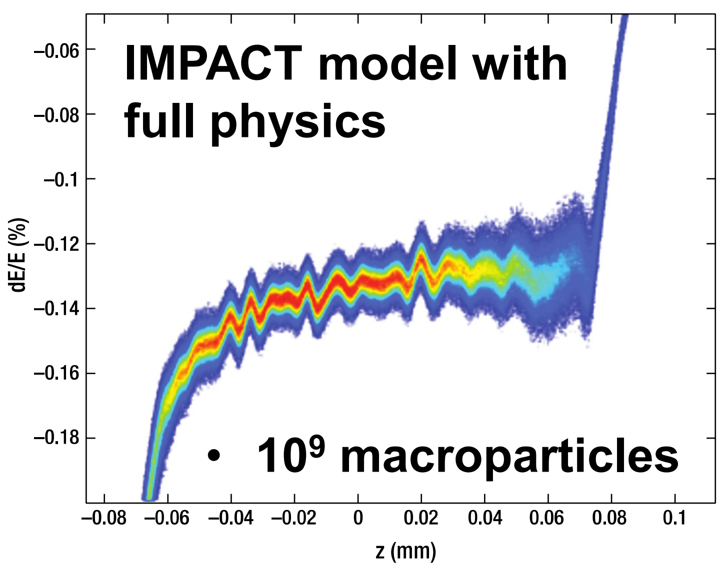
J. Feng et al, "Drive Laser System for APEX the Advanced Photo-injector Project at the LBNL," **THP222**

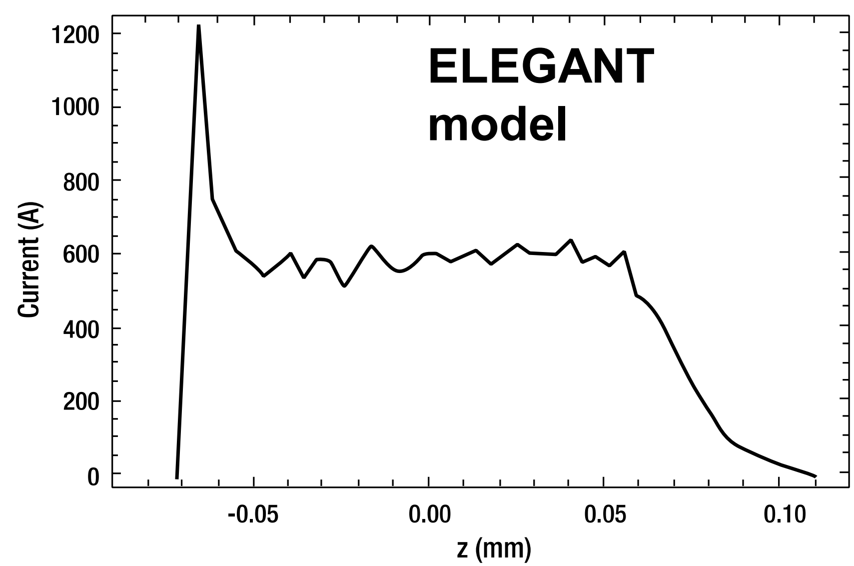




Linac schematic and beam dynamics modeling

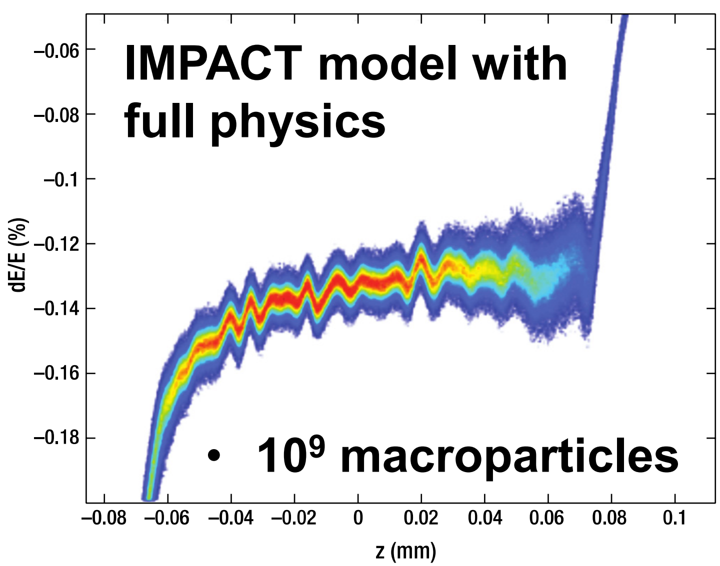


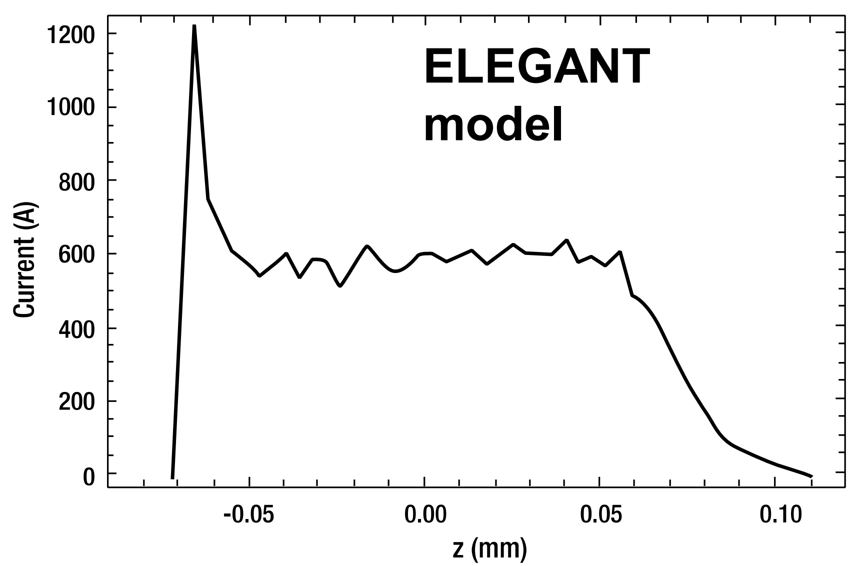




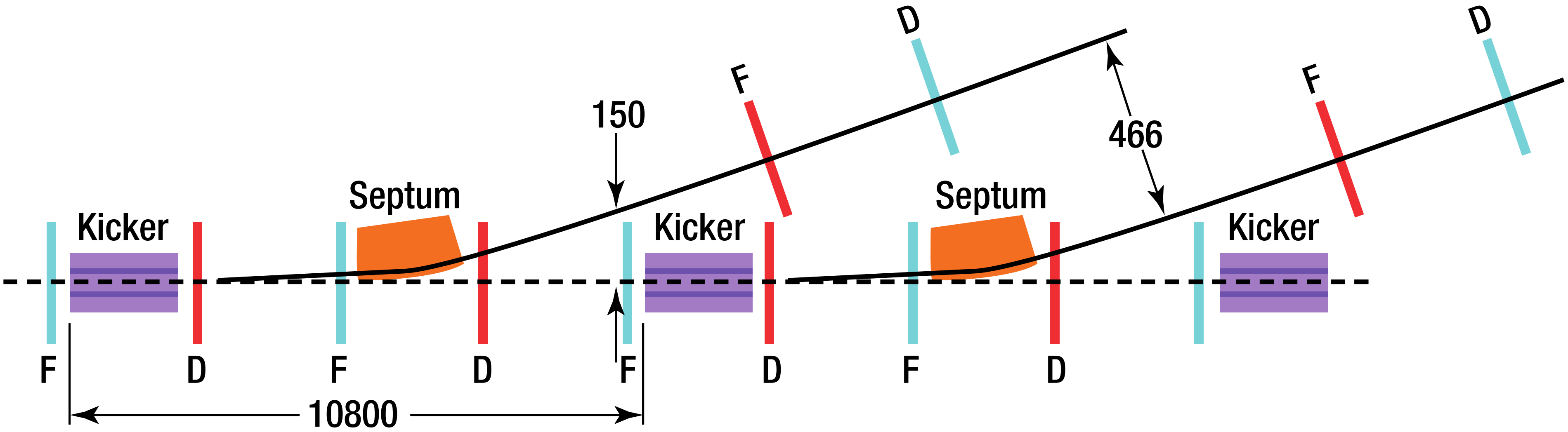
Linac schematic and beam dynamics modeling

M. Venturini et al, "Studies of a Linac Driver for a High Repetition Rate X-rays FEL," THP180





R&D: beam spreader kicker



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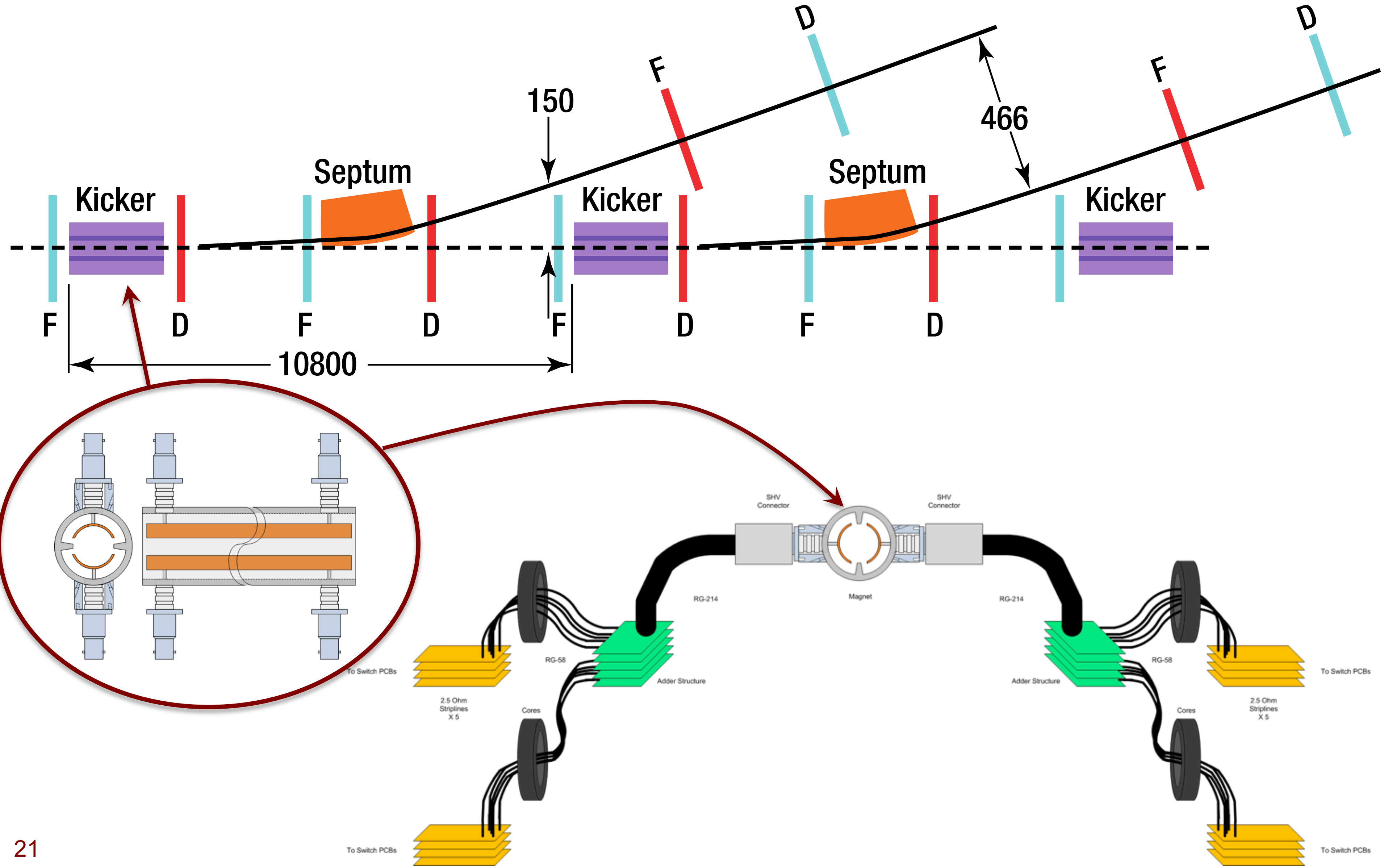

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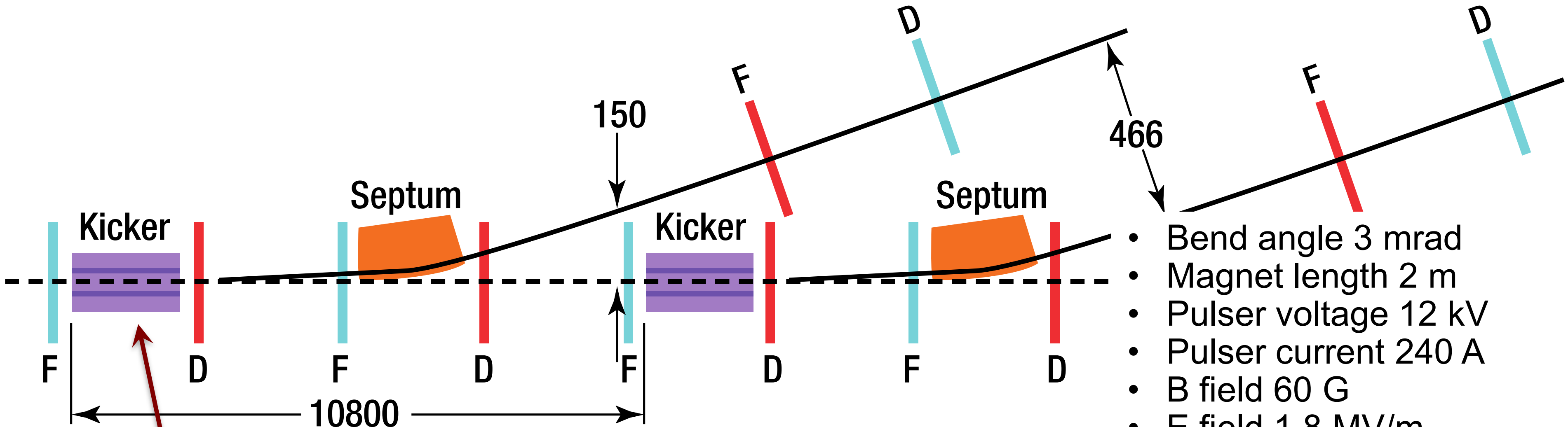
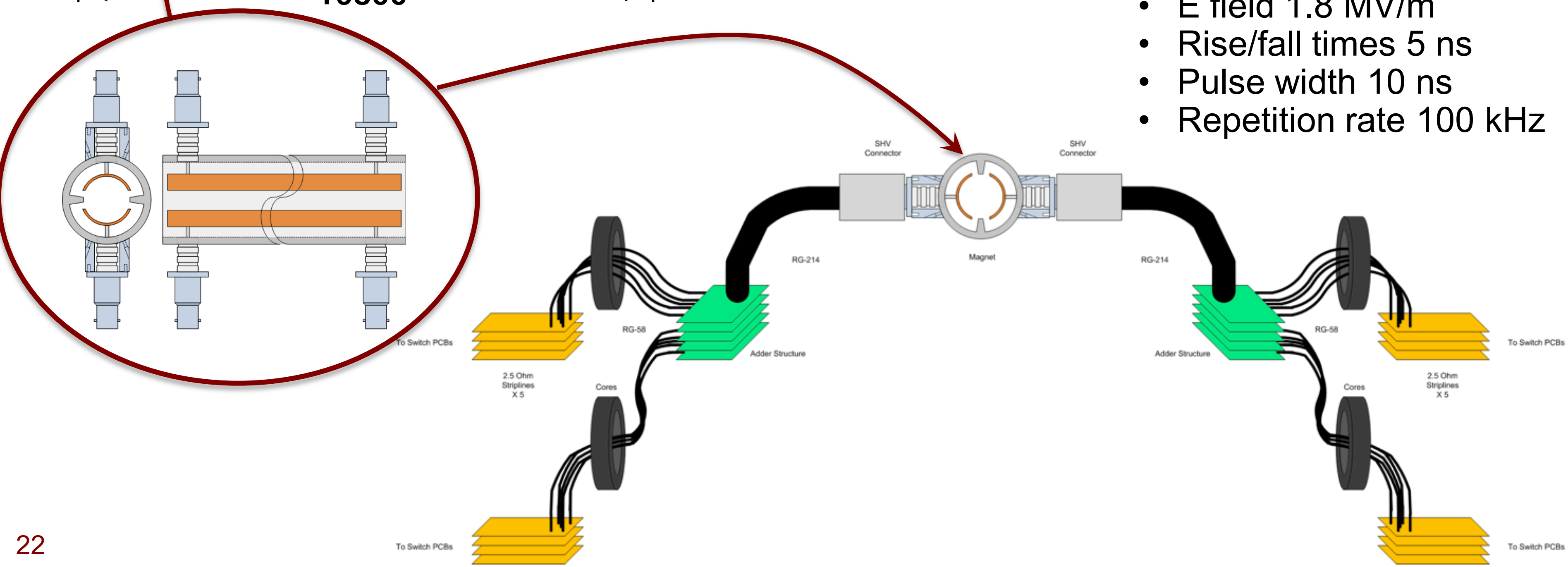
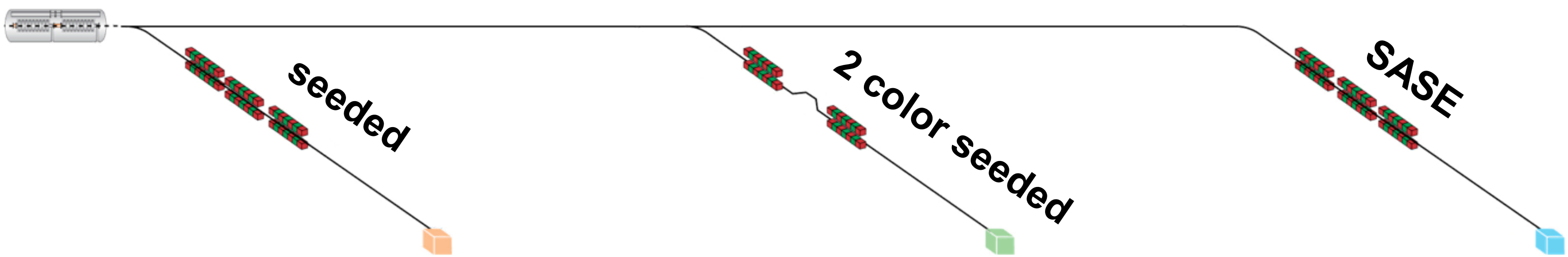
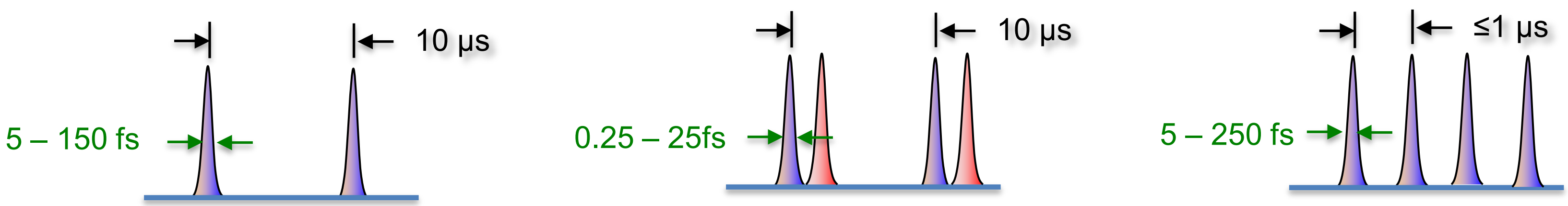


- Bend angle 3 mrad
- Magnet length 2 m
- Pulser voltage 12 kV
- Pulser current 240 A
- B field 60 G
- E field 1.8 MV/m
- Rise/fall times 5 ns
- Pulse width 10 ns
- Repetition rate 100 kHz



Three initial FEL beamlines to span the science case





- **High resolution**
- **~Time-bandwidth limited**
- **10^{11} – 10^{12} ph/pulse**
- **10^{-3} – 5×10^{-5} bandwidth**

- ***High-resolution spectroscopy***
- ***Diffract-and-Destroy (with harmonics)***

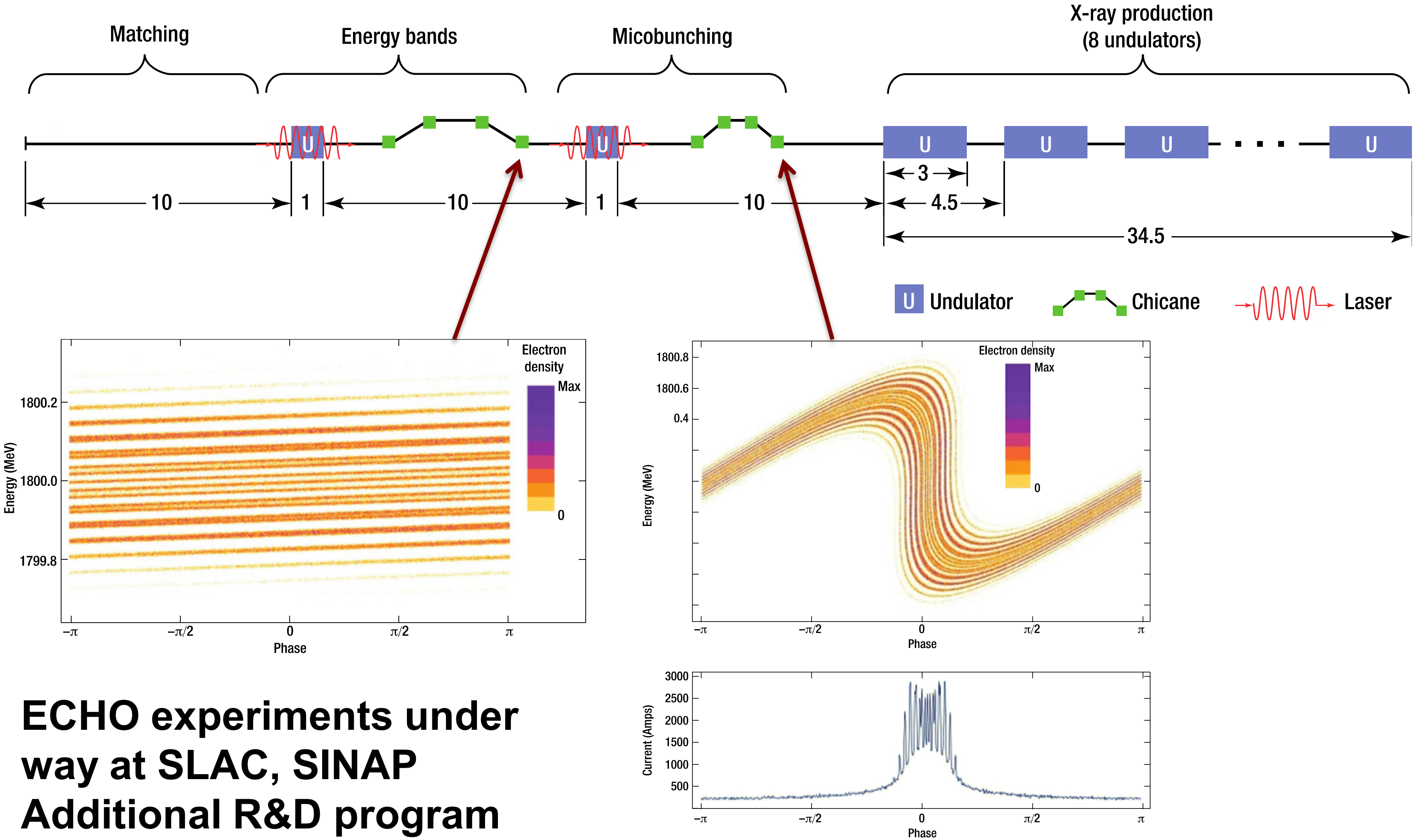
- **Ultra-fast**
- **250 as pulses**
- **2 color**
- **10^{8} ph/pulse**

- ***Multidimensional spectroscopy***

- **Highest rep rate**
- **High flux**
- **10^{11} - 10^{12} ph/pulse**
- **100 W**

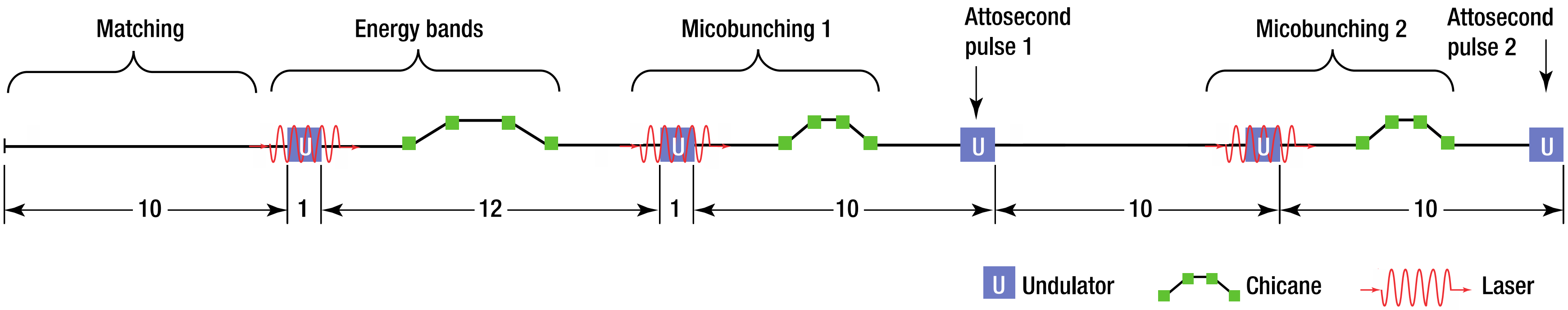
- ***Diffract-and-Destroy (at highest rate)***
- ***Photon correlation spectroscopy***

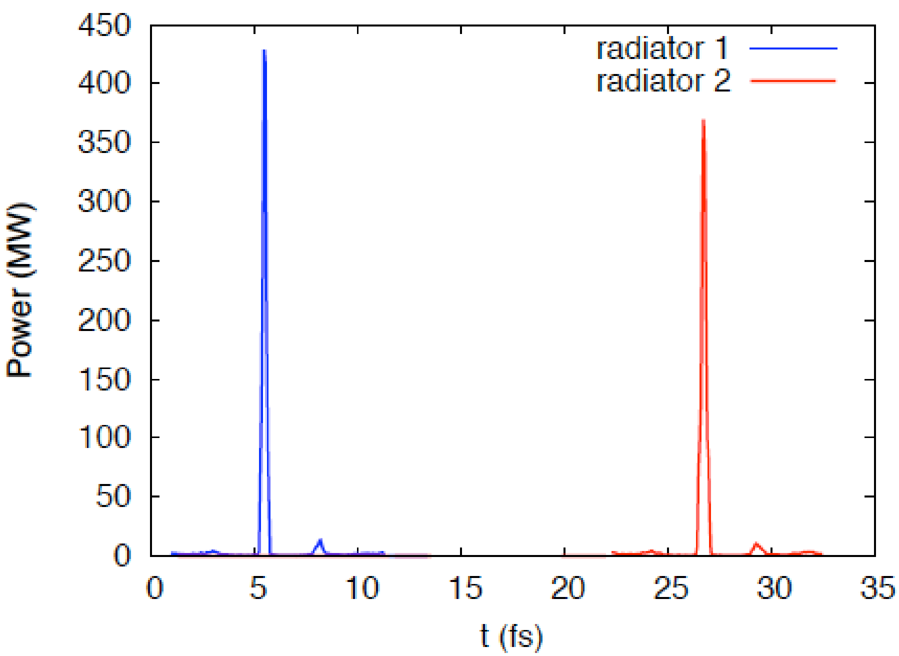
Beamline 1: ECHO seeded

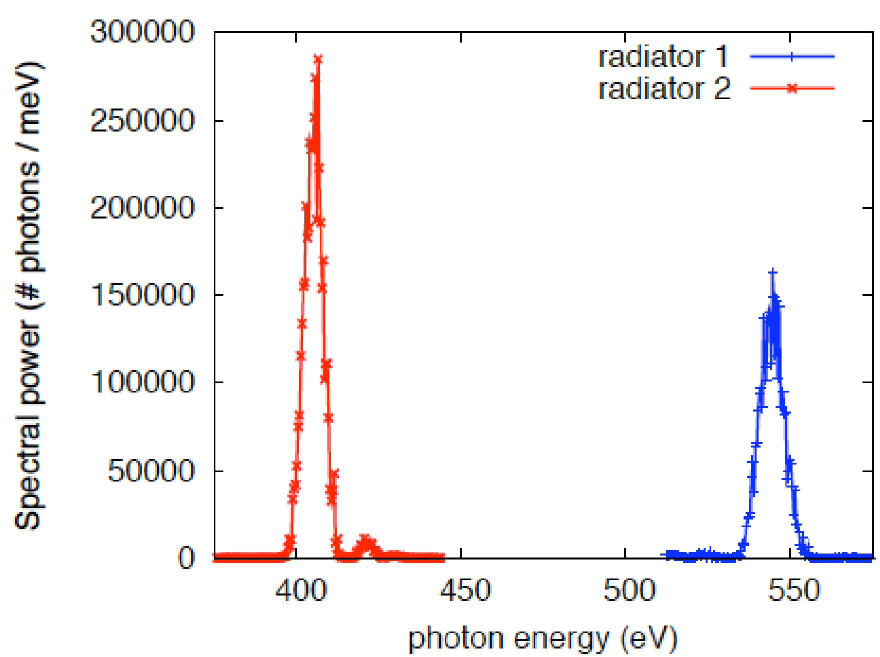


- **ECHO experiments under way at SLAC, SINAP**
- **Additional R&D program under development**

Beamline 2: ECHO seeded 2-color attosecond



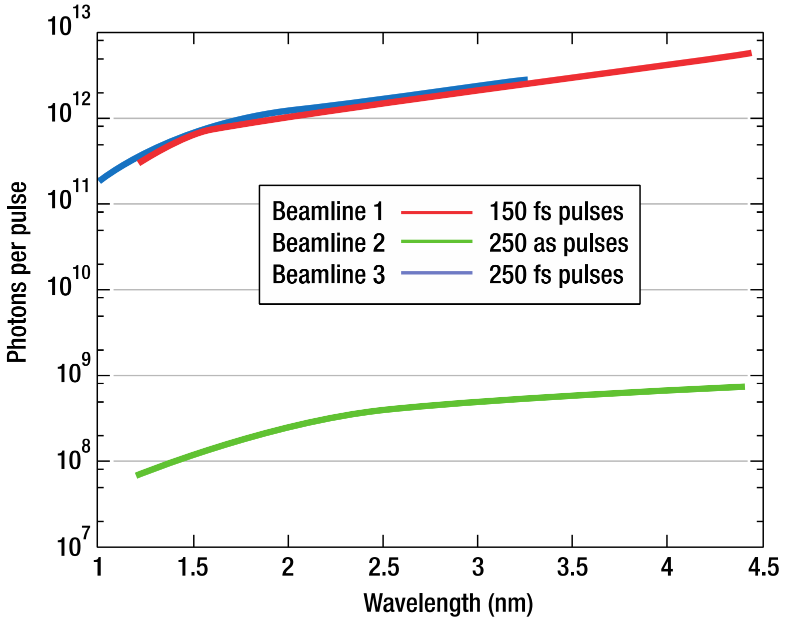




A. Zholents, G. Penn, “Obtaining two attosecond pulses for X-ray stimulated Raman spectroscopy”, NIM–A, **612**, 2, (January 2010)

Initial performance of first 3 beamlines

	Beamline 1	Beamline 2	Beamline 3
Type	Seeded, narrow-bandwidth	2–color seeded	SASE
Feature	Short coherent pulses	2-color X-ray pump/probe with adjustable delay and attosecond pulses	High average flux and brightness
Pulse length (fs, FWHM)	5 – 150	0.25 – 25	~5 – 250
Wavelength range (fundamental, nm)	1.2 – 4.5 (1.0 – 0.28 keV)	1.2 – 4.5 (1.0 – 0.28 keV)	1.0 – 3.3 (1.2 – 0.38 keV)
Maximum repetition rate (kHz)	100	100	1,000
Total photons/pulse	~10^{11} (150 fs, 1.2 nm) ~10^{12} (150 fs, 4.5 nm)	~10^{8} (sub-fs)	~10^{11} (250 fs, 1 nm) ~10^{12} (250 fs, 3.3 nm)
Photons per 6D coherence volume	~10^{11}	~10^{8}	~10^{10}
Peak power (GW)	~0.1 (1.2 nm) 1 (4.5 nm)	~0.05 (1.2 nm) 0.1 (4.5 nm)	~0.1 (1 nm) 1 (3.3 nm)
Average power (W)	~1 (150 fs, 1.2 nm) 10 (150 fs, 4.5 nm)	~0.001 (sub-fs) 0.1 (fs)	~0.1 (5 fs, 1 nm) 100 (250 fs, 3.3 nm)
Power in 3rd harmonic relative to fundamental (%)	~0.1 (1.2 nm) 1 (4.5 nm)	~ 1	~0.1 (1 nm) 1 (3.3 nm)
Relative bandwidth (%, FWHM)	~0.005 (150 fs, 1.2 nm) 0.02 (150 fs, 4.5 nm)	>=1.4 (sub-fs)	~ 0.2 (1 nm) 0.5 (3.3 nm)
Polarization	Variable, linear/circular	Variable, linear/circular	Variable, linear/circular



NGLS project status

- Pre-conceptual design studies
- LBNL submitted "Proposal for approval of Conceptual Design" to US Department of Energy, December 2010
- DOE presented "Mission Need" for an NGLS in March 2011
  - Hoping for confirmation of "CD0"
  - LBNL would lead the writing of a Conceptual Design Report, due around October 2013

A Next Generation Light Source facility at LBNL – Summary

- **Pre-conceptual design studies for a high repetition rate FEL array**
  - High repetition rate injector (1 MHz)
  - CW Superconducting linear accelerator
  - Bunches spread to an array of independent soft X-ray FELs
  - Control of X-ray pulses using a variety of FEL designs
  - High average X-ray power (up to ~100 W)
    - Flexible platform for future expansion

- **R&D in critical technologies supported by DOE BES and LDRD**
  - Gun
  - Photocathodes
  - Kickers
  - FEL seeding (at SLAC)

- **Conceptual design approval is hoped for in the near future**

Thank you for your attention

NGLS – other papers at this conference

- **D. Filipetto et al, "Low Energy 6D Beam Diagnostic for APEX, the LBNL VHF Photo-injector," WEP222**
- **C. F. Papadopoulos et al, "Photoinjector Beam Dynamics for the APEX Project," THP200**
- **J. Feng et al, "Drive Laser System for APEX the Advanced Photo-injector Project at the LBNL," THP222**
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