Commissioning Experience at SLAC Linac Coherent Light Source (LCLS)

Commissioning Session

Workshop on Accelerator Operations 2010

Michael Stanek

Deputy Head, Accelerator Operations and Safety Division
SLAC National Accelerator Laboratory

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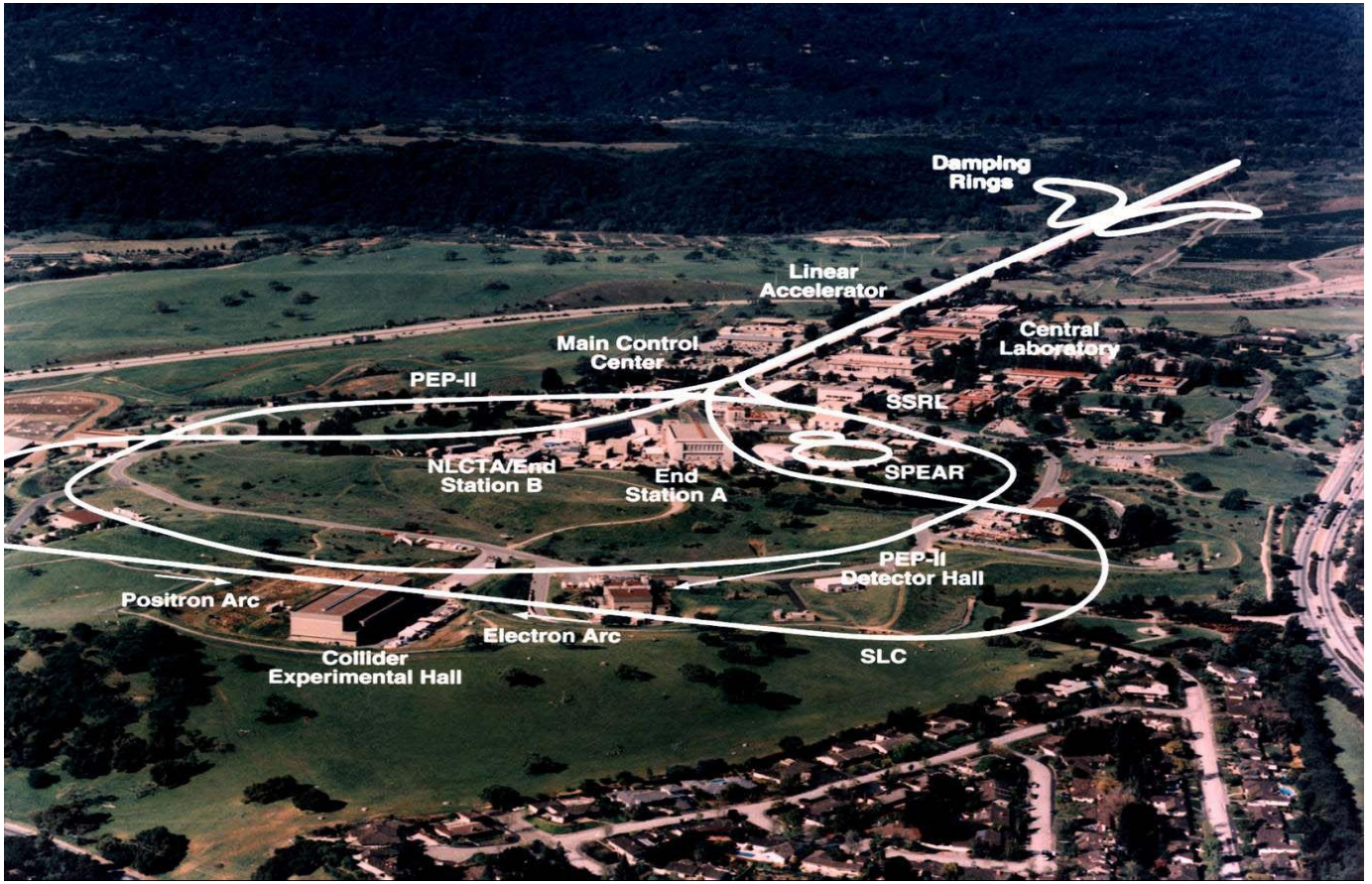
Stanford Linear Accelerator Center



- Operated by Stanford University for the U.S. Department of Energy.
- Approximately 1400 employees.
- 3000 users from universities and other labs world-wide.
- Established in 1962 to study high energy particle physics.

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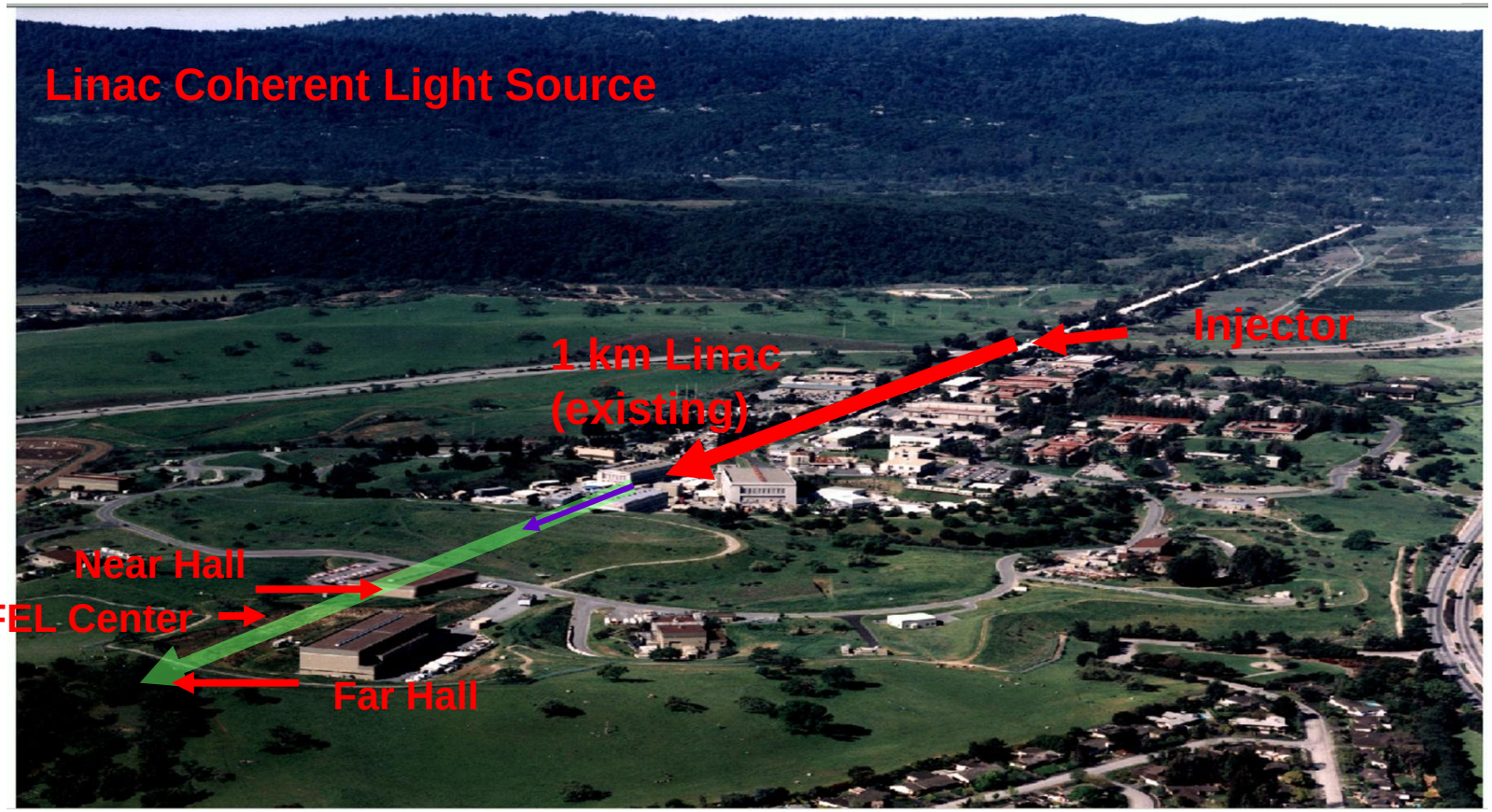
SLAC past

- High Energy and Particle Physics
  - 1966: 20+ GeV e- Fixed Target
  - 1972: 3 GeV e-/e+ Colliding beam storage ring (SPEAR ring → J/Psi particle)
  - 1980-1989: 14 GeV e-/e+ (PEP ring)
  - 1989-1998: 50 GeV e-/e+ SLAC Linear Collider (Z_0)
  - 1999-2008: PEP2 “B-factory” 9 GeV e- on 3 GeV e+ colliding beam storage rings

Latest addition: LCLS



~$300 M Project

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LCLS X-ray FEL key elements

Low emittance RF Photo-cathode Injector

- 250 pC → 1 nC
- 30 → 120 pulse/sec

4.0 -13.6 GeV electron Linac

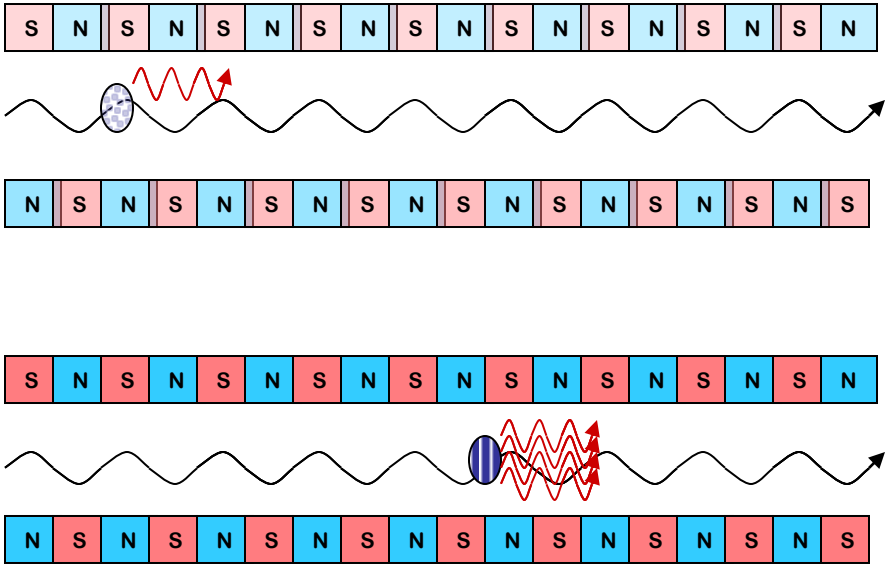
- Multi-stage bunch compression
- sub-picosecond electron bunches

130 meters of Undulator magnets

Coherent X-ray pulses

→ 0.8 – 8.0 KeV, < 100 fsec, 3 mJ/pulse

Self-Amplified Spontaneous Emission (SASE)



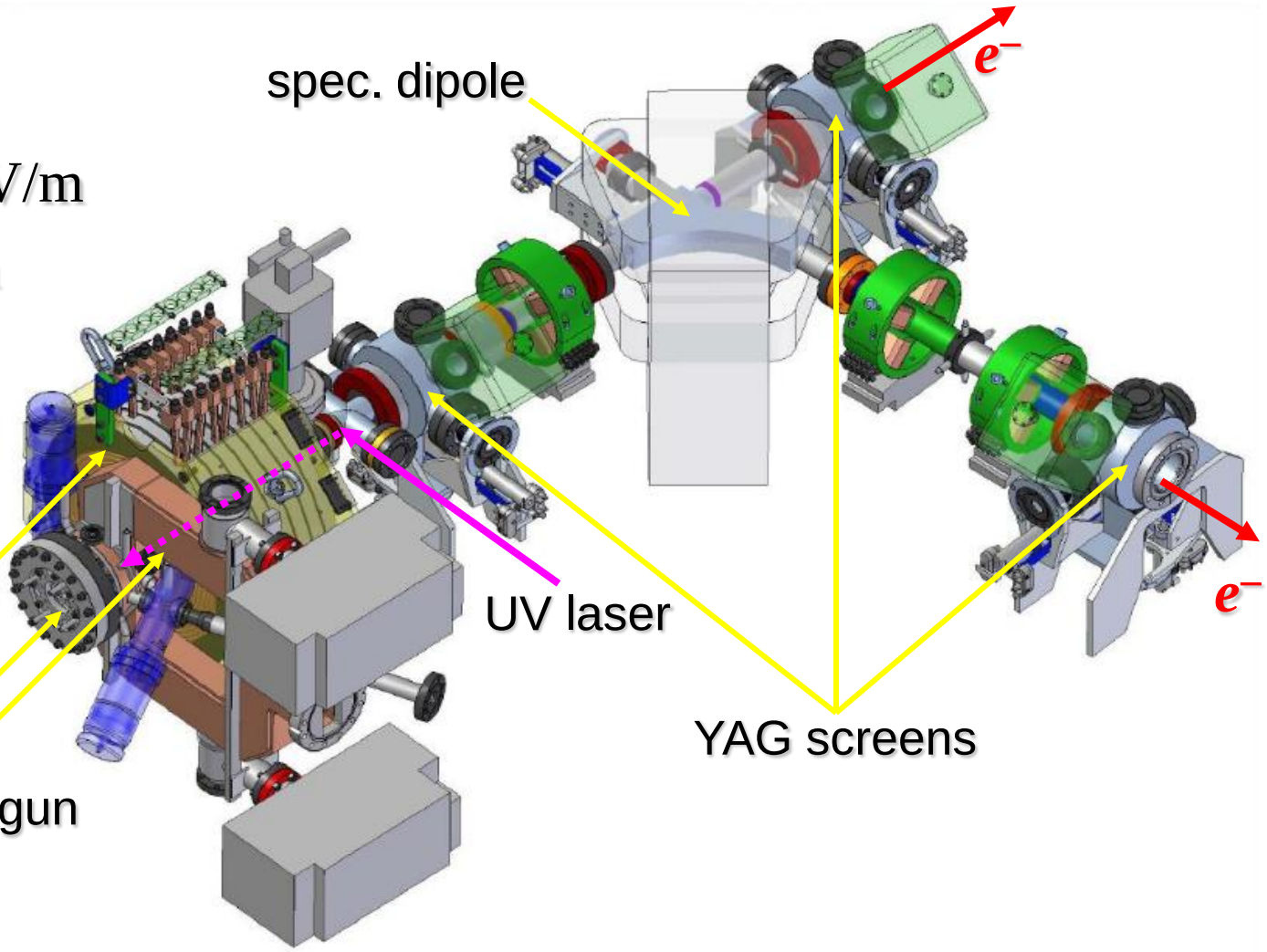
The electron beam and its synchrotron radiation are so intense that the electron motion is modified by the electromagnetic fields of its own emitted synchrotron light. Under the influence of both the undulator and its own synchrotron radiation, the electron beam begins to form micro-bunches, separated by a distance equal to the wavelength of the emitted radiation.

X-rays for Material Science

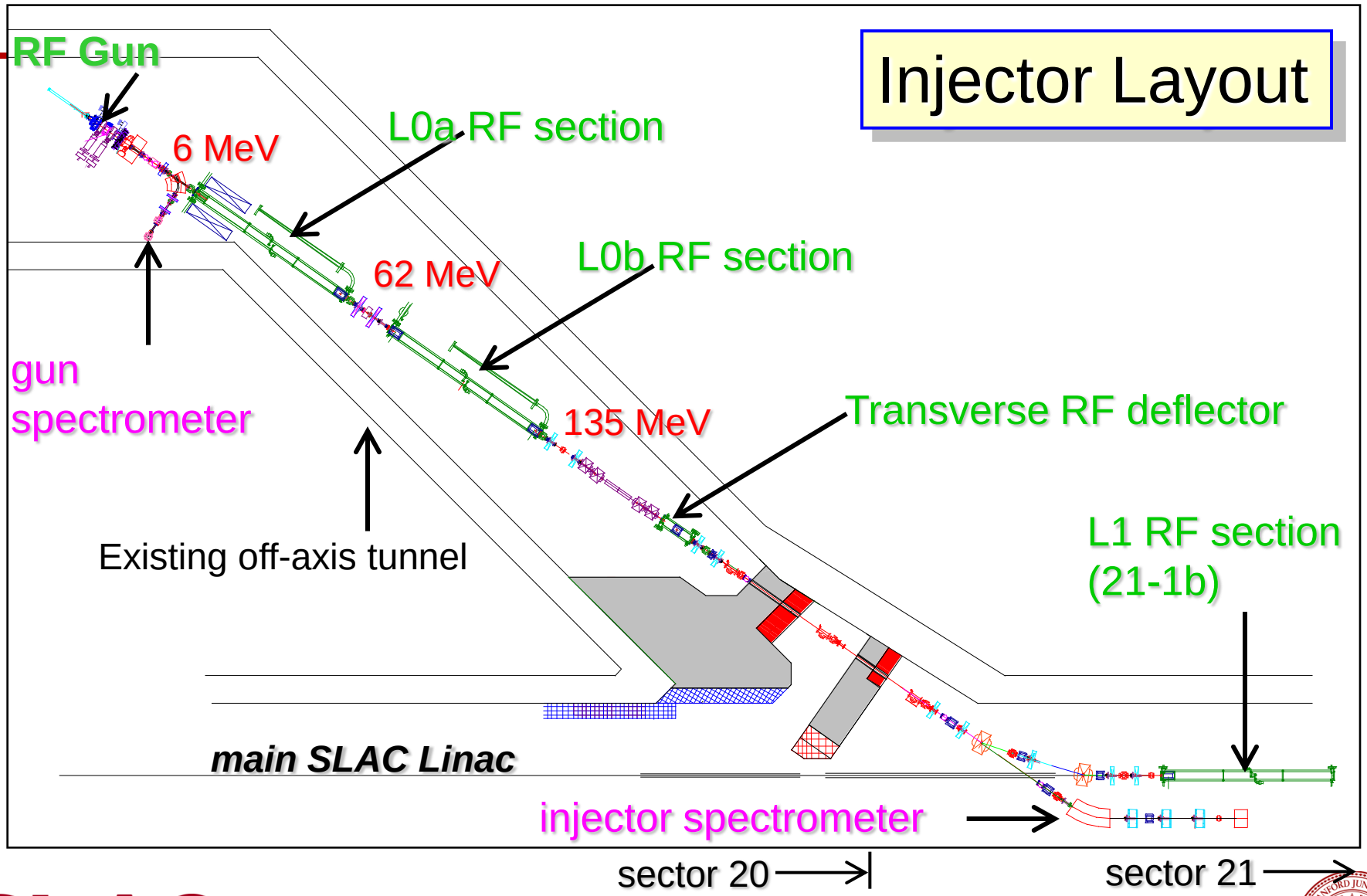
- High brightness, ultra-fast, ultra-small X-ray pulses
  - 800 nm – 1.5 A wavelength
  - Probe for Atomic, Molecular & Optical Science
  - X-ray Pump-Probe experiments
  - Coherent X-ray imaging
  - Matter in Extreme Conditions

RF Photo-Cathode Gun

- $Q = 1$ nC
- $f = 120$ Hz
- $G = 120$ MV/m
- $\gamma\varepsilon_{x,y} = 1$ μm
- $\Delta\tau = 10$ ps
- $I = 100$ A
- $E = 6$ MeV



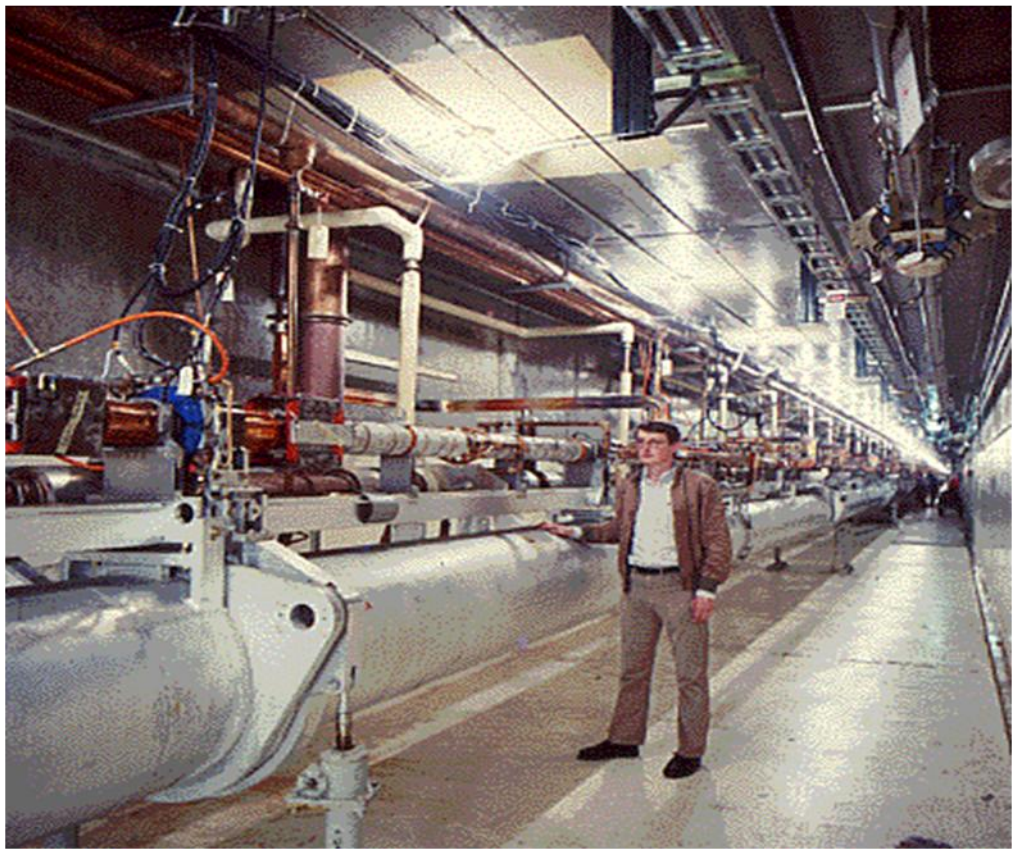
Injector Layout



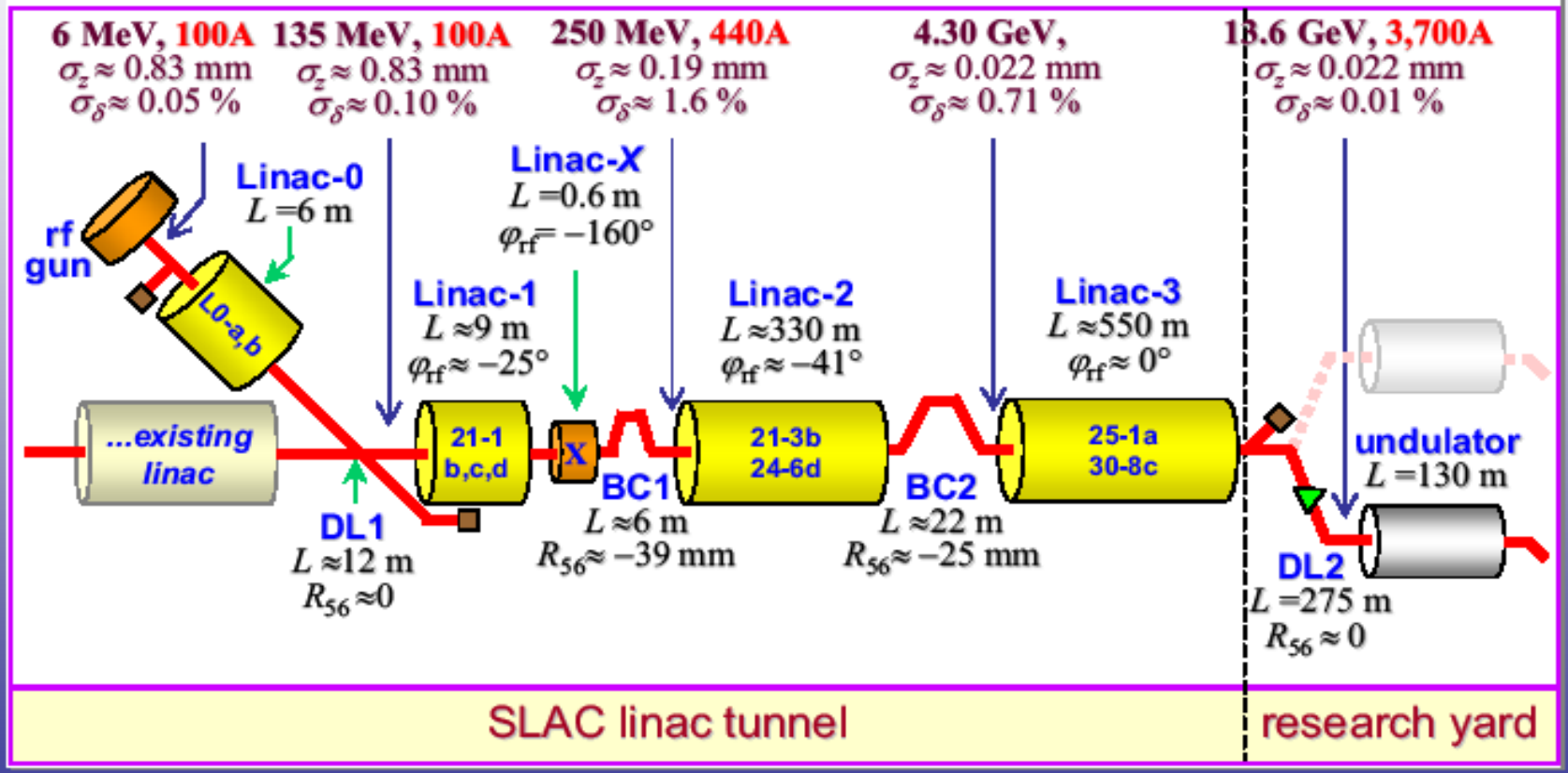
Use 1 km of existing Linac

- Legacy infrastructure & control system

- Some upgrades:
- 2 bunch compression chicanes.
- New BPM instrumentation
- Magnet power supplies



LCLS Accelerator and Compressor Schematic



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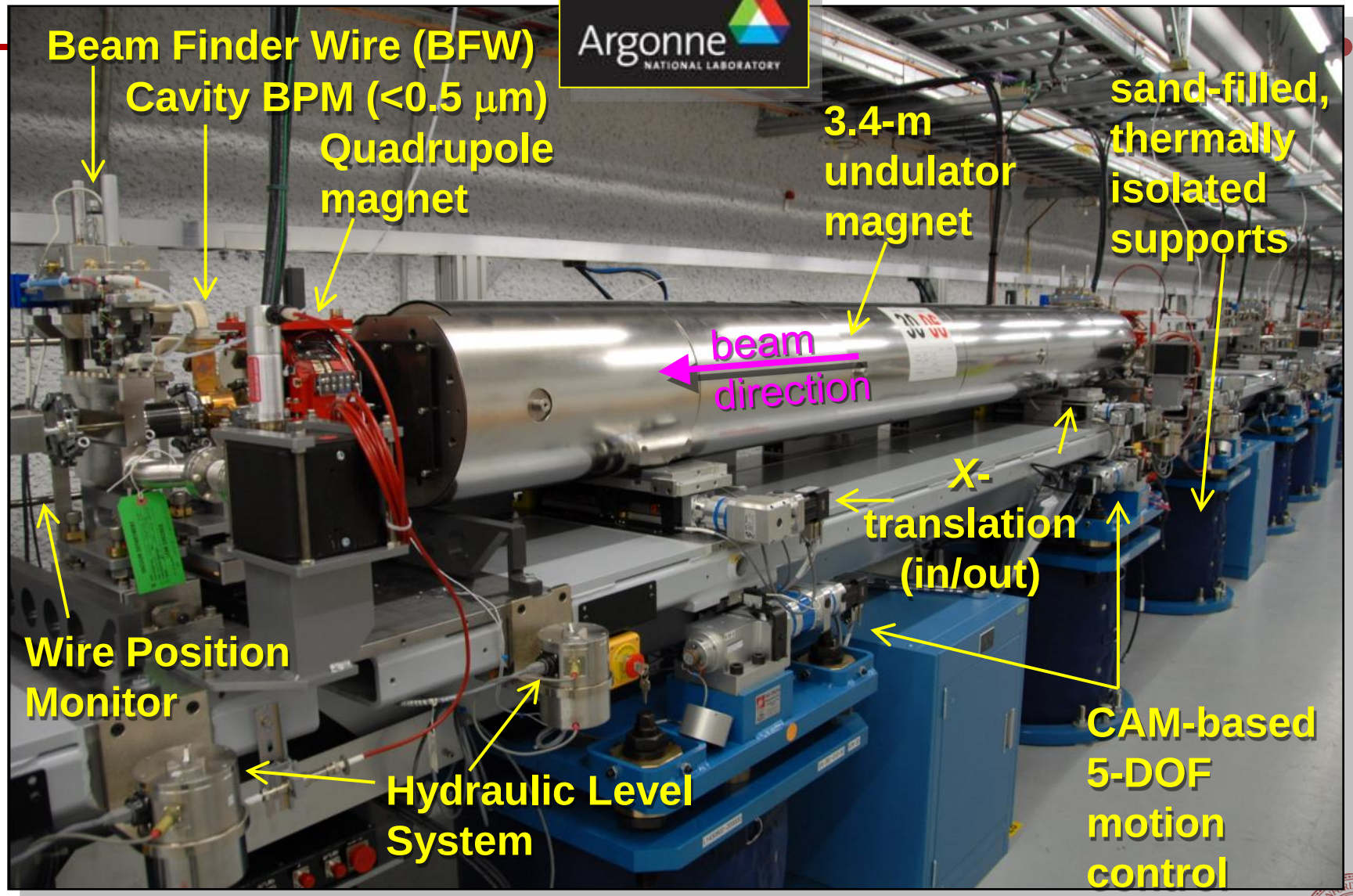
New Civil Construction & Beamlines

- Beam Transport Hall (above ground)
- Undulator Hall (underground)
  - Tunnel under hill for temperature stability
    - Air temp +/- 0.5 deg C for Undulator field quality
  - 33 Undulator Magnet girders
    - 3.4 m long
  - Integrated diagnostic instrumentation
    - BPM, Wire, Motion Control, Alignment
- Beam Dump
- Front End Enclosure (X-ray diagnostics)



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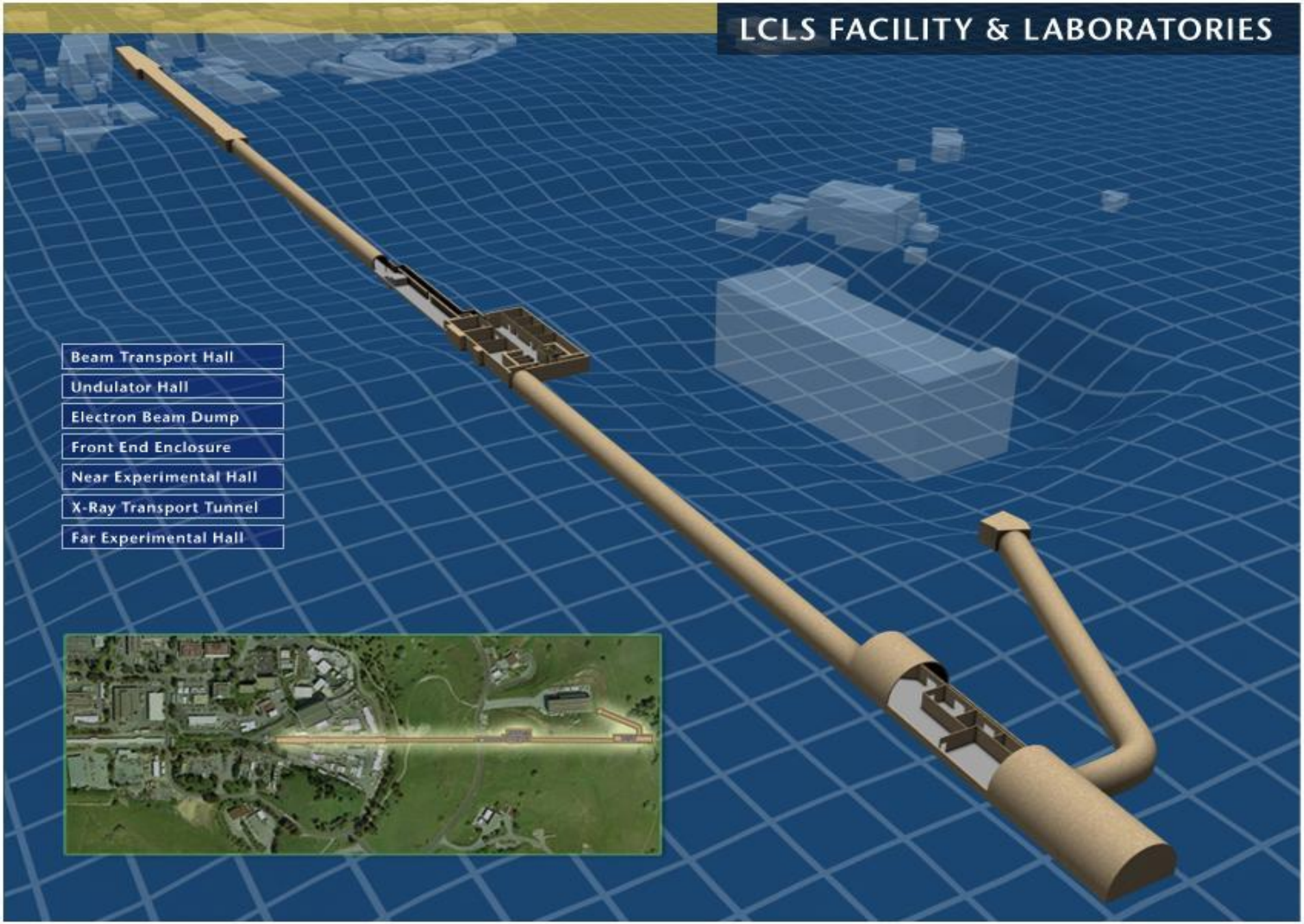
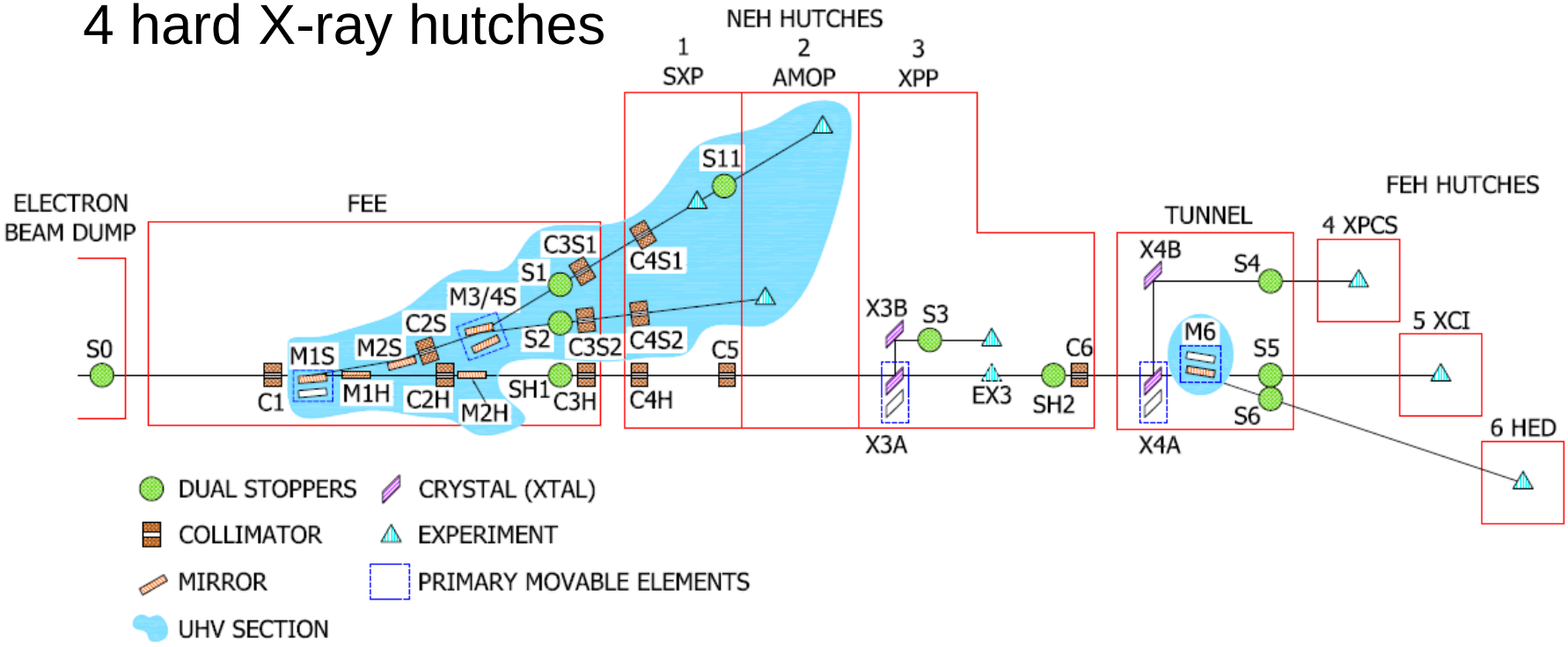
LCLS FACILITY MAP



New X-ray user facilities

2 soft X-ray &
4 hard X-ray hutches



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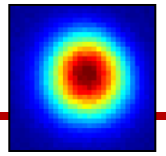
Remodeled Control Room
(see talk – P. Schuh - Control Room and Ergonomics session)
Sun
SUNRAY
2150
1845

Commissioning Time-Line

- Commissioning
- Project Milestones
- Installation Periods



First FEL Light

Injector Install

First e^- from gun

BC2 Install

PEP-II ends

LTU/Und Sys Install

First e^- to dump

FEE/NEH Install

Install Undulators

DOE Review

First Light in FEE

X-Rays in NEH

First Users

First Light in FEH

Project complete

J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J

Down | 2007 | Down | 2008 | Down | 2009 | Down | 2010

Injector

Linac/BC2

Linac

LTU/Und

FEL/FEE

NEH

FEH

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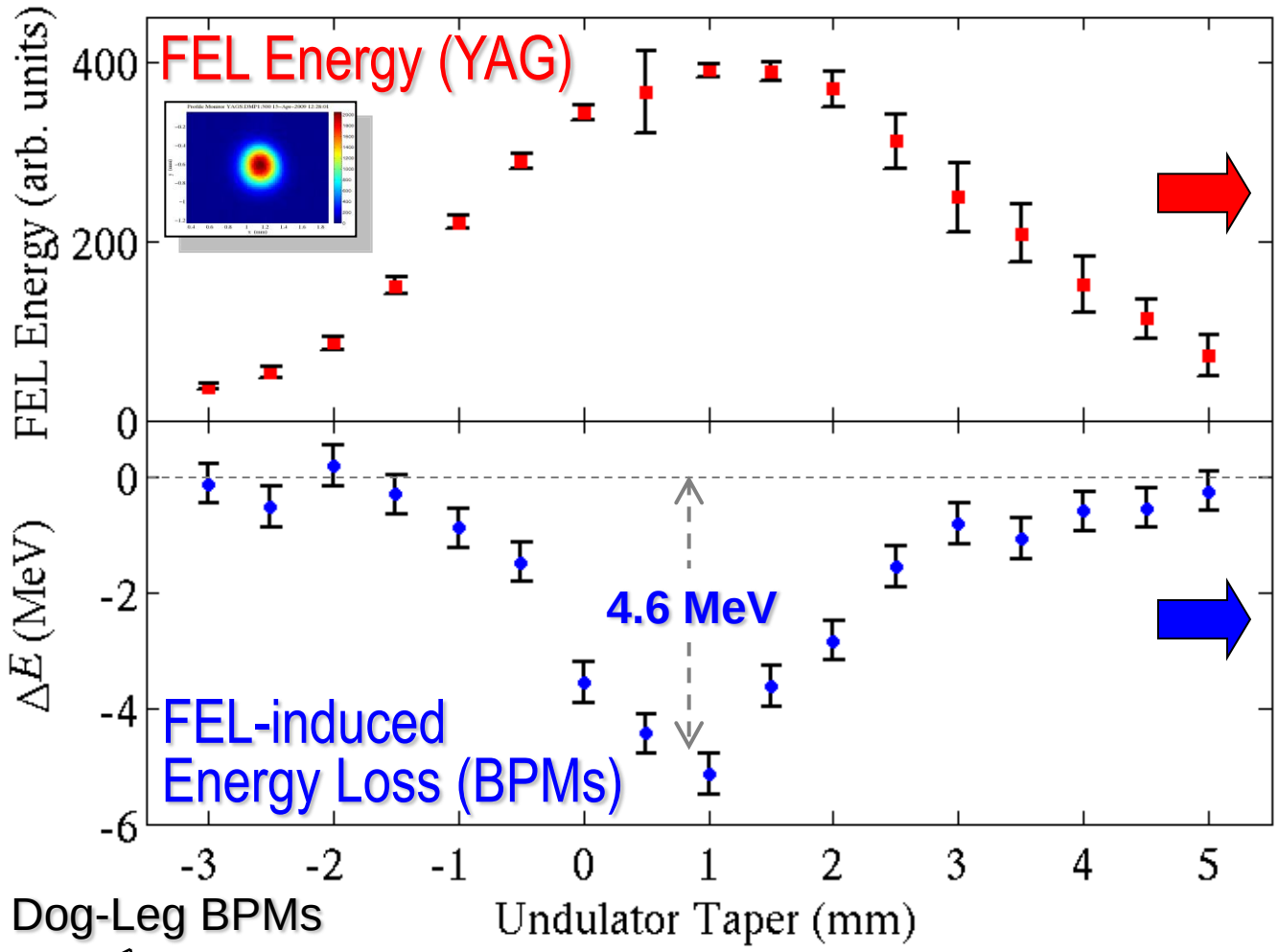
Success!

- First X-rays - April 2009
- Front End Enclosure & 1st Hutch – Sept 2009
- First X-ray user experiment – Sep-Dec 2009

- 2nd user Hutch planned May 2010
  - Alternate users every 12 hours

Undulator 'Taper Scan' Shows 1.1 mJ of X-rays



1.5 Å

Pixel sum of x-ray YAG screen CCD camera vs undulator *K*-taper

4.6 MeV at 0.25 nC = 1.1 mJ or **0.8×10^{12}** photons/pulse (15 GW at 75-fs FWHM pulse length)

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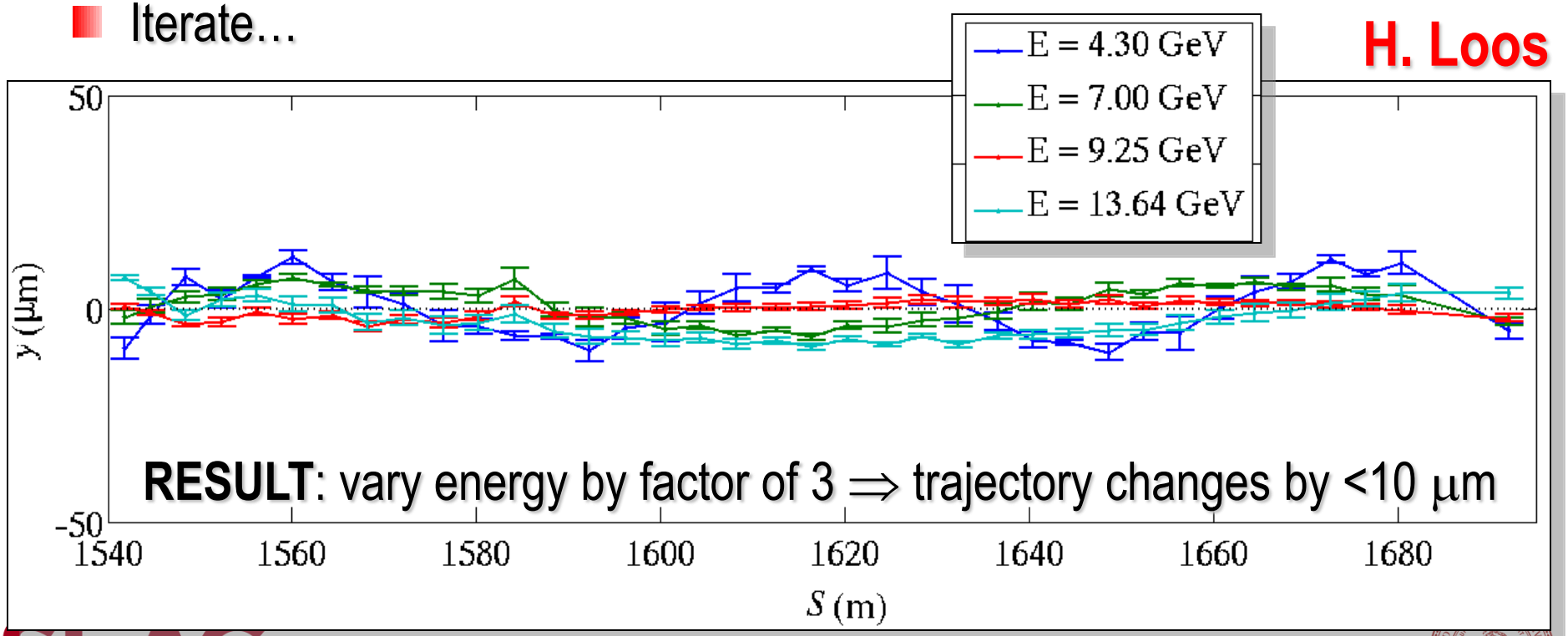
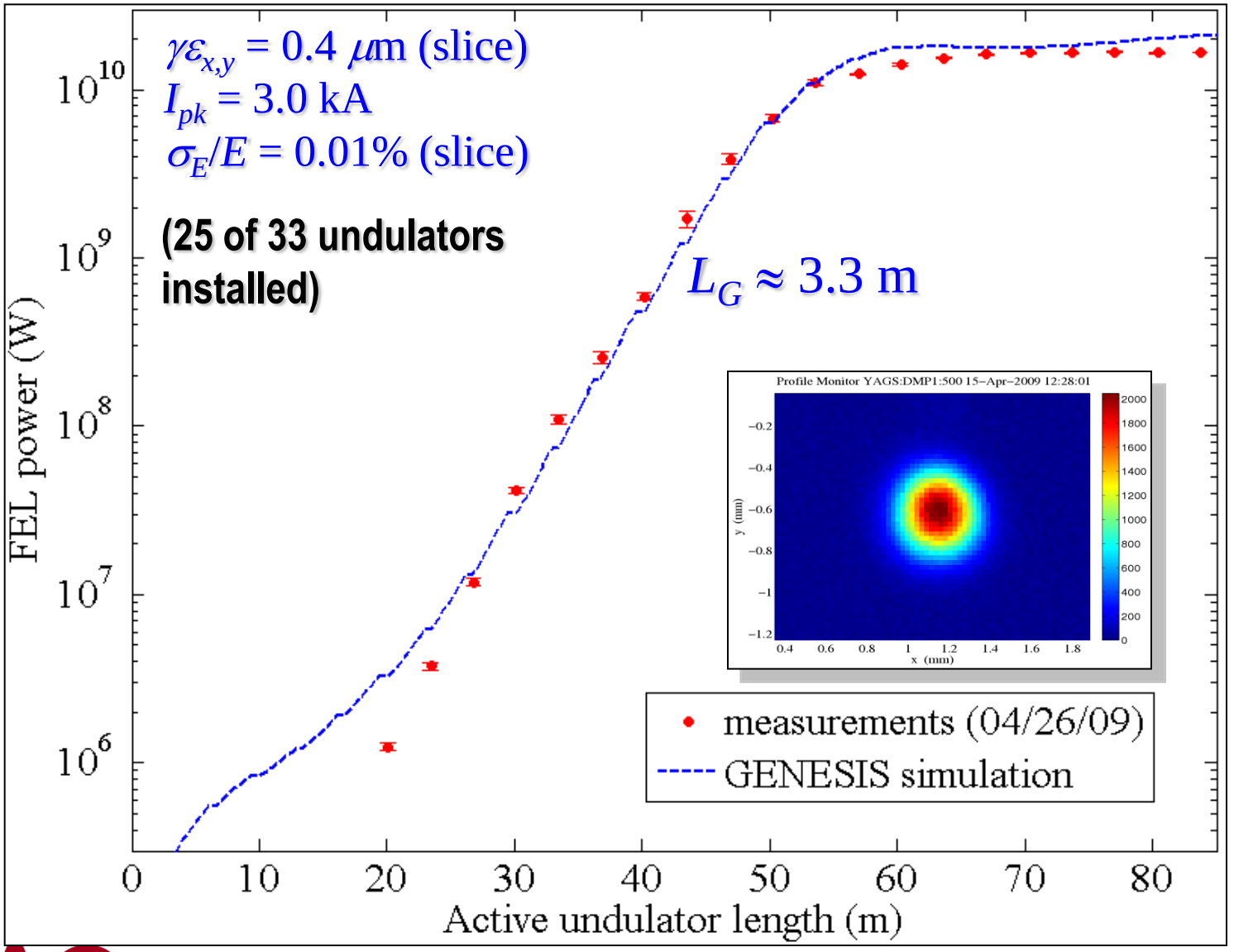
Beam-Based Undulator Alignment

- Measure undulator trajectory at 4 energies (4.3, 7.0, 9.2, & 13.6 GeV)
- Scale all linac & upstream transport line magnets each time
- Do not change **anything** in the undulator
- Calculate… (*Matlab* GUI)
- Move quads and adjust BPM offsets for dispersion free trajectory
- Iterate…

H. Loos



Undulator Gain Length Measurement at 1.5 Å



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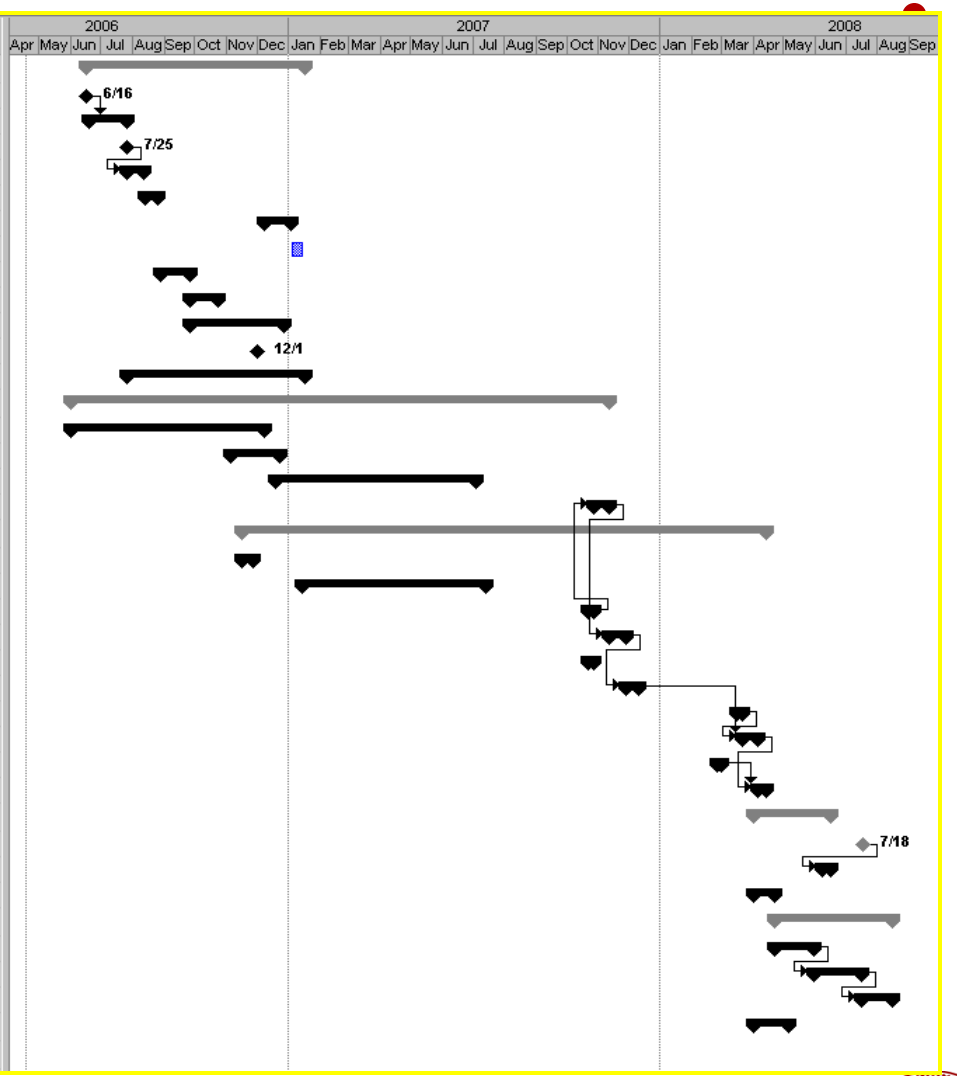
What has worked well?

- Dedicated, organized Commissioning team
  - Paul Emma, et.al.
- Early Operator involvement
  - Lectures from System Experts
  - Assist commissioning team on shift
  - Share control room with PEP2 operation
    - (until PEP2 shutdown 2008)
  - Experienced PEP2 operations organization
  - Clearly defined roles, responsibilities

Detailed Staged Commissioning Plan

	Task Name	Duration	Start
2	Drive Laser Commissioning	167 days	Fri 6/16/06
1	S20 ready for laser installation	0 days	Fri 6/16/06
2	Laser Installation	27 days	Mon 6/19/06
41	Laser Installation complete	0 days	Tue 7/25/06
42	S20 Laser Safety System	13 days	Wed 7/26/06
46	SLAC Laser Work	10 days	Mon 8/14/06
48	Temporal Characterization and Optimization	27 days	Fri 12/8/06
68	Active pointing refinement	10 days	Thu 1/4/07
69	Spatial Shaping	22 days	Mon 8/28/06
73	Characterization/Stability	20 days	Wed 9/27/06
81	Transport to Gun	75 days	Wed 9/27/06
101	UV beam on the cathode	0 days	Fri 12/1/06
102	EPICS Integration	140 days	Wed 7/26/06
3	Injector Commissioning	478 days	Thu 6/1/06
1	RF Gun Preparation	139 days	Thu 6/1/06
22	Pre-Beam Checkout of Injector beamline	41 days	Mon 11/6/06
42	Injector beamline commissioning	197.25 days	Tue 12/19/06
181	2008 Injector re-commissioning	15 days	Sun 10/28/07
4	Linac Commissioning	510.02 days	Fri 11/17/06
2	Pre-Beam Checkout to TD11 (after BC1)	7 days	Fri 11/17/06
10	Beam to TD11 stopper (after BC1)	180.25 days	Mon 1/15/07
107	Pre-Beam Checkout to TD21 (after BC2)	6 days	Mon 10/22/07
113	Beam to TD21 stopper (after BC2)	16.25 days	Sun 11/11/07
145	Pre-Beam Checkout to SL2 (in BSY)	6 days	Mon 10/22/07
151	Beam to end of linac on SL2 (50B1 on)	13.13 days	Wed 11/28/07
167	Pre-Beam Checkout to TDUND (before undulator)	6 days	Sun 3/16/08
173	Beam to TDUND stopper (before undulator)	15 days	Fri 3/21/08
211	Pre-Beam Checkout to Main Dump	3.5 days	Tue 2/26/08
217	Beam to main dump	8.02 days	Sun 4/6/08
5	Undulator Commissioning	76 days?	Wed 4/2/08
1	Undulator Hall Installation Complete	0 days	Fri 7/18/08
2	Undulator System Pre-Beam Alignment and Checkout	9 days?	Sun 6/8/08
34	Commissioning with Beam	21 days?	Wed 4/2/08
7	FEL_Commissioning	115 days?	Wed 4/23/08
1	Phase I - Spontaneous Radiation	38 days?	Wed 4/23/08
54	Phase 2 - FEL Radiation	47 days	Sat 5/31/08
103	Phase 3 - Transition to Operation	30 days	Wed 7/16/08
9	XTOD Commissioning	24 days	Wed 4/2/08
18	XES Commissioning	0 days	Wed 1/11/06



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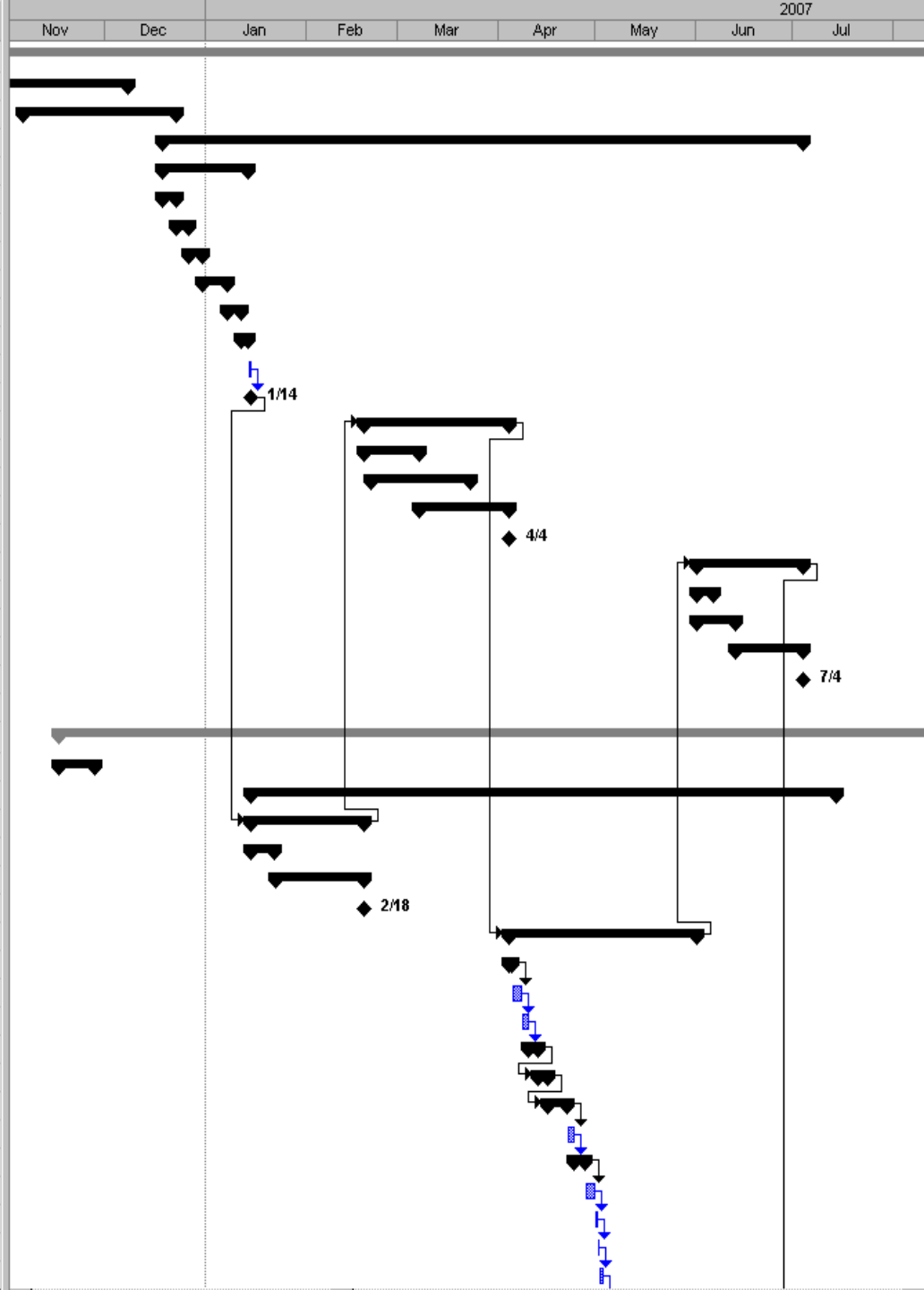
	Task Name	Duration	Start
3	**Injector Commissioning**	**478 days**	**Thu 6/1/06**
1	**RF Gun Preparation**	**139 days**	**Thu 6/1/06**
22	**Pre-Beam Checkout of Injector beamline**	**41 days**	**Mon 11/6/06**
42	**Injector beamline commissioning**	**197.25 days**	**Tue 12/19/06**
43	**First-pass commissioning/beam to SAB**	**26 days**	**Tue 12/19/06**
44	**Set Laser/RF Timing**	**4 days**	**Tue 12/19/06**
49	**Transport beam through GTL to YAG02**	**4 days**	**Sat 12/23/06**
54	**Transport beam into BXG dump**	**4 days**	**Wed 12/27/06**
59	**Transport beam to BXS dump**	**8 days**	**Sun 12/31/06**
78	**Time diagnostics**	**4 days**	**Mon 1/8/07**
87	**Timing and linac gradient calibration**	**2 days**	**Fri 1/12/07**
92	Rough steer with BPMs in full injector	1 day	Sun 1/14/07
93	Beam ready for transport to BC1 dump	0 days	Sun 1/14/07
96	**Second-pass commissioning/characterization**	**44.5 days**	**Mon 2/19/07**
97	**Gun and Solenoid characterization**	**17 days**	**Mon 2/19/07**
104	**Feedback and diagnostics commissioning**	**30.5 days**	**Wed 2/21/07**
111	**135MeV beam characterization**	**27.5 days**	**Thu 3/8/07**
136	Injector beam characterized	0 days	Wed 4/4/07
138	**Third-pass commissioning/machine studies**	**33 days**	**Fri 6/1/07**
139	**third pass 6MeV beam characterization**	**5 days**	**Fri 6/1/07**
162	**Optimization of 200pC configuration**	**12 days**	**Fri 6/1/07**
170	**Optimization of Highest "stable charge" config.**	**21 days**	**Wed 6/13/07**
179	Injetor optimization complete	0 days	Wed 7/4/07
181	**2008 Injector re-commissioning**	**15 days**	**Sun 10/28/07**
4	**Linac Commissioning**	**510.02 days**	**Fri 11/17/06**
2	**Pre-Beam Checkout to TD11 (after BC1)**	**7 days**	**Fri 11/17/06**
10	**Beam to TD11 stopper (after BC1)**	**180.25 days**	**Mon 1/15/07**
13	**First Pass Commissioning/beam to TD11**	**35 days**	**Mon 1/15/07**
14	**Establish beam on TD11**	**7.5 days**	**Mon 1/15/07**
25	**Verify Optics, Calibrate, and Phase**	**27.5 days**	**Mon 1/22/07**
52	Linac beam ready on TD11	0 days	Sun 2/18/07
54	**Second Pass Commissioning/characterization**	**57.75 days**	**Wed 4/4/07**
55	**Minimize DL1 energy spread**	**1 day**	**Wed 4/4/07**
57	Study BL11 CSR monitor	3 days	Thu 4/5/07
58	Linac access to fix problems	2 days	Sun 4/8/07
59	**Setup DL1 launch feedback**	**2.88 days**	**Tue 4/10/07**
64	**Setup energy feedback on L0/DL1**	**3.13 days**	**Fri 4/13/07**
72	**Setup longitudinal feedback on L1/BC1**	**6.25 days**	**Mon 4/16/07**
77	Linac access to fix problems	2 days	Sun 4/22/07
78	**Setup longitudinal feedback on L1/BC1**	**3.25 days**	**Tue 4/24/07**
83	Test TCAV0 bunch-length meas. sofware	3 days	Sat 4/28/07
84	Beam-base align critical quadrupoles	1 day	Tue 5/1/07
85	Center CE11 collimator in BC1	2 hrs	Wed 5/2/07
86	Record machine stability (traj, charge, etcx)	8 hrs	Wed 5/2/07



Commissioning Definition and Strategy

All components installed, aligned, connected, and initially verified by the system engineer, then commissioning starts.

Commissioning Sequence (1-4)

1. ***Pre-Beam Checkout (tunnel and MCC)***
   - Controls/software testing, check cameras, 'snail' hunt, etc
   - Magnet polarities, cable connections, verify motion-control, etc
2. ***Beam-based Hardware and Software Checkout***
   - Establish beam transport, RF setup, MPS/BCS tests, etc
   - Checkout of all wires, screens, BPMs, toroids, magnets, etc
3. ***First-Order Optics: Measurement and Correction***
   - Steering, transmission, oscillation data, feedback setup, etc
   - Beta and dispersion matching, beam-base align key quads, etc
4. ***Full Beam Characterization: Measurement and Correction***
   - Measure emittance, energy spread, distributions - correct
   - Measure beam sensitivities, optimize tuning, beam experiments

No (serious) emittance measurements until all hardware/software checked out!

LCLS Injector Commissioning Day

24-Hour Cycle (7 days/week, 1/2/07 to 9/1/07, 32 total weeks)

DAY SHIFT (8:00-16:00)
1 lead physicist, 1 physicist,
1 controls eng.,
1 LCLS operator, 1 laser operator

SWING SHIFT (16:00-24:00)
1 lead physicist, 1 physicist,
1 LCLS operator, 1 laser op on-call

OWL SHIFT (0:00-8:00)
1 LCLS operator, 1 laser op on-call

After PEP2-BaBar ended (2008),
Full attention of Operations crew
2-3 Ops, 1 Engineering op

Communication & Teamwork

- Accelerator Physicist – Operator handoff
  - Owl Shift left to operators
    - Complete measurements started by physicists
    - Tune accelerator within guidelines
    - Practice routine measurements
- Frequent commissioning team meetings
  - 08:00 (7 days/week), 16:00 (M-F)
  - Controls Deputy manages Software releases

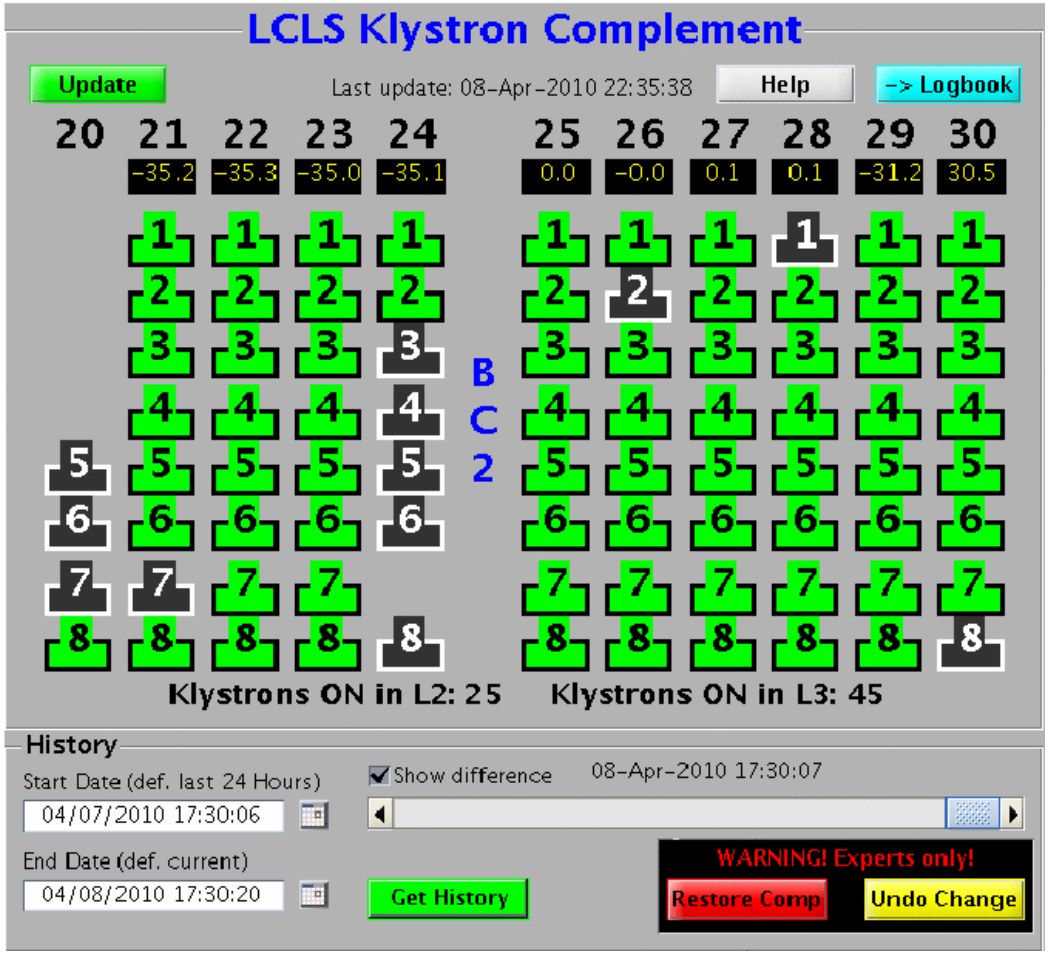
Organizational foresight

- Support group involvement in hardware:
  - Specification Development
  - Installation
  - Checkout
  - Commissioning
- Natural transition to Maintenance & Repair

Control System support

- Controls group provides infrastructure
  - EPICS, Network and IOC support
- High-level Applications minimal for start-up
- Heavy use of Matlab$_R$(The MathWorks^{TM})
  - Commissioning Physicists
  - Operators
    - Internal training
  - Controls group provides support
    - Training for Ops in EPICS, EDM screens

Operator Matlab GUI



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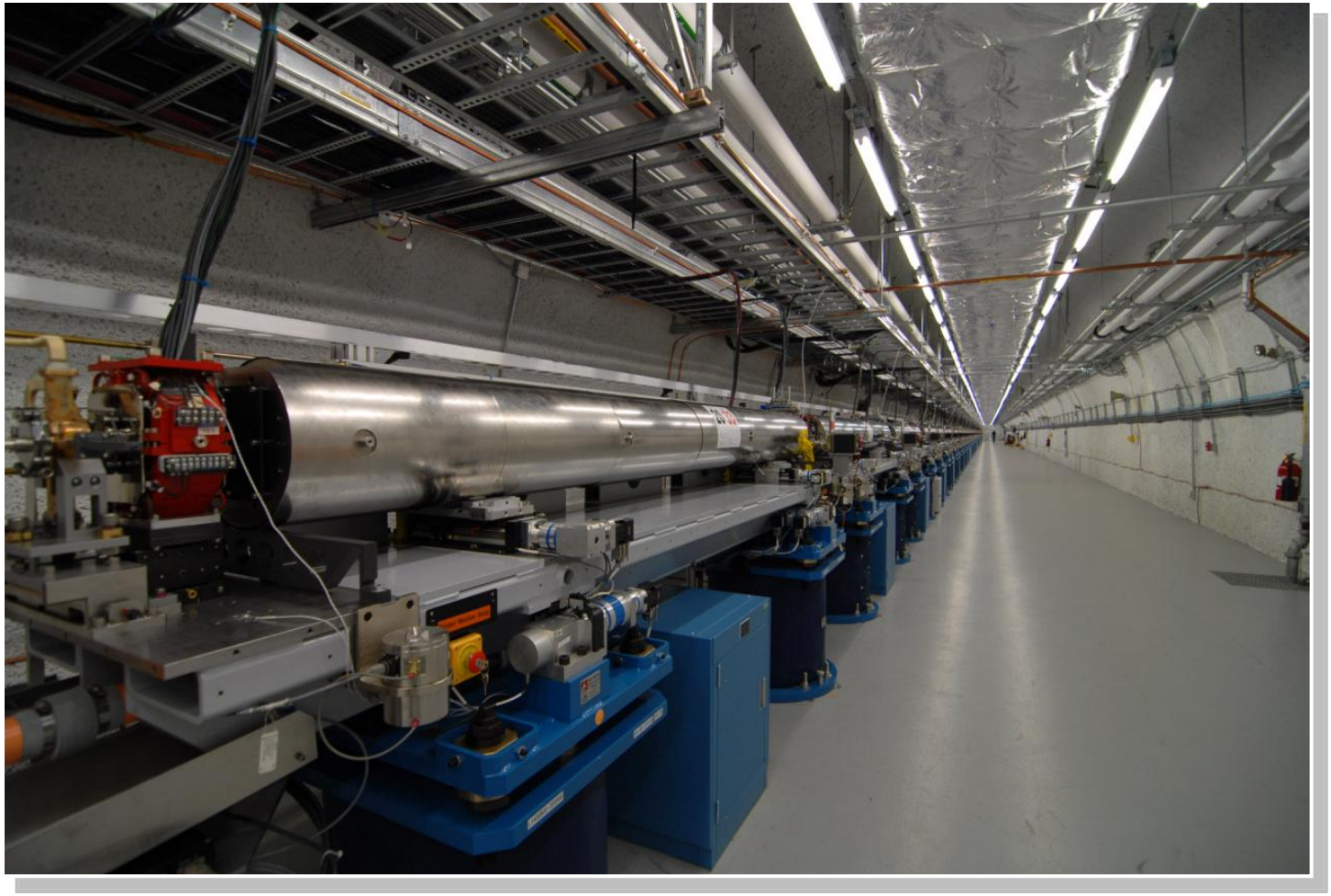
Flexibility

- Compromise between flexibility & discipline
  - Allow exploration by system experts during Commissioning
  - Tighter configuration control for operators during User runs
- Add simple diagnostics when schedules slip
  - Changing priorities for support groups
- Ops take over routine tasks, Experts move on to the next challenge

Challenges Ahead

- Advertised X-ray availability 95%
  - Technical challenges
    - Aging infrastructure with Linac
  - Cultural challenges
    - Different Operational mindset than High Energy Physics Experiments
    - Weekly (almost) shutdown days, short work list
    - Availability ‘budget’ for each system
  - First user run achieved goal (96%)
    - Additional complexity coming – multiple users

Thank you for your attention



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DIE LUFT DER FREIHEIT WEHT
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