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Design and Construction of the LCLS Undulator System by APS

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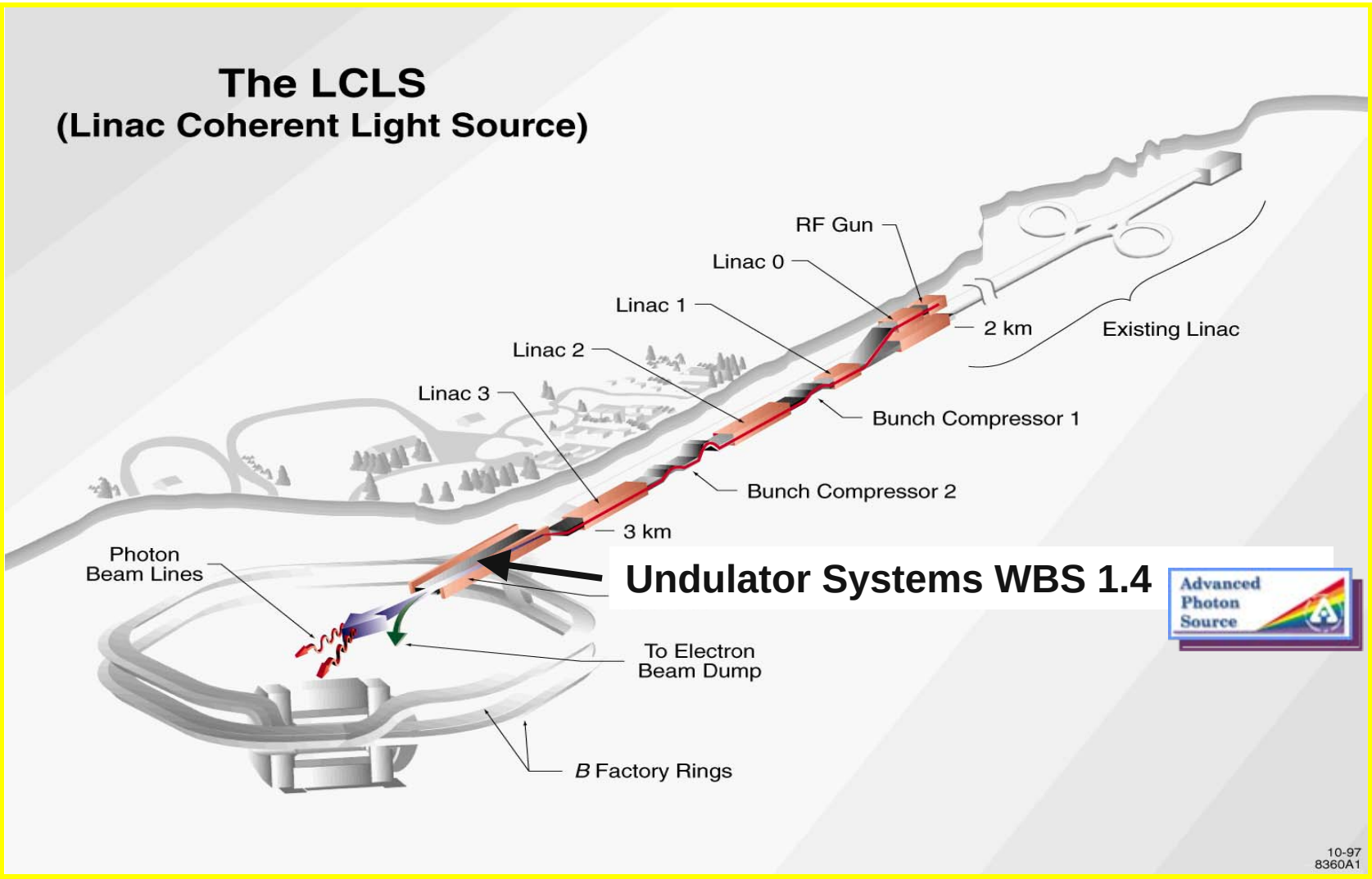
On behalf of the APS-LCLS team

August 27, 2008

A bit of a history

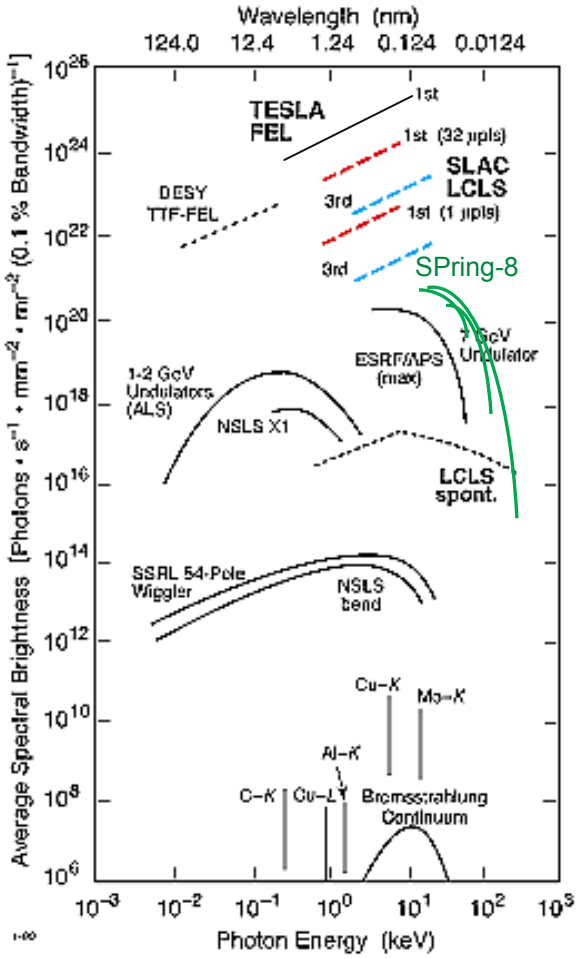
- APS joined LCLS collaboration in 1998
  - APS expertise in developments and construction of undulators
- APS became part of the LCLS construction project in 2003
  - Technical success of the LEUTL
  - Responsibility for undulators, mechanical and vacuum systems, electron diagnostics, control systems

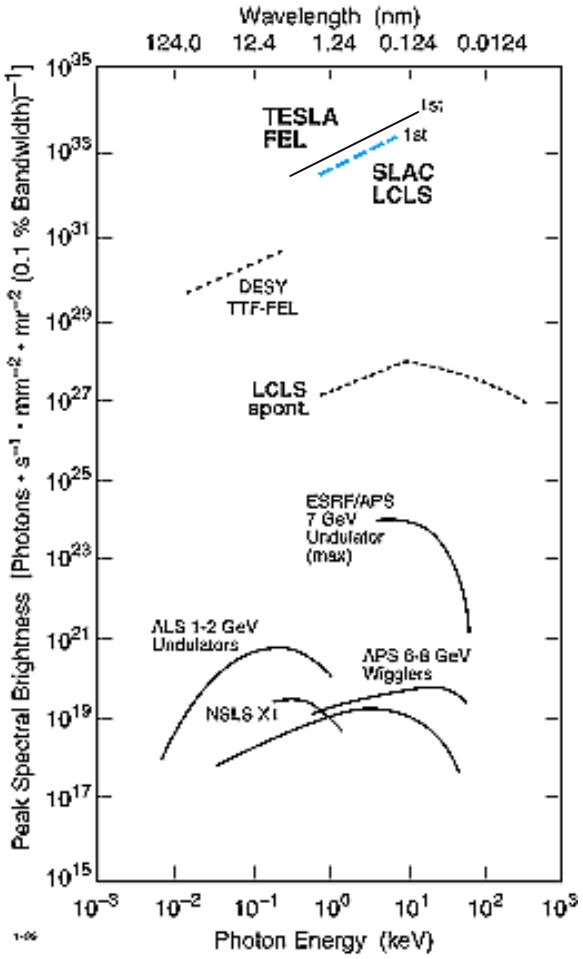
LCLS Layout


The LCLS
(Linac Coherent Light Source)
RF Gun
Linac 0
Linac 1
Linac 2
Linac 3
2 km
Existing Linac
Bunch Compressor 1
Bunch Compressor 2
3 km
Photon
Beam Lines
Undulator Systems WBS 1.4
Advanced
Photon
Source
To Electron
Beam Dump
B Factory Rings
10-97
8360A1

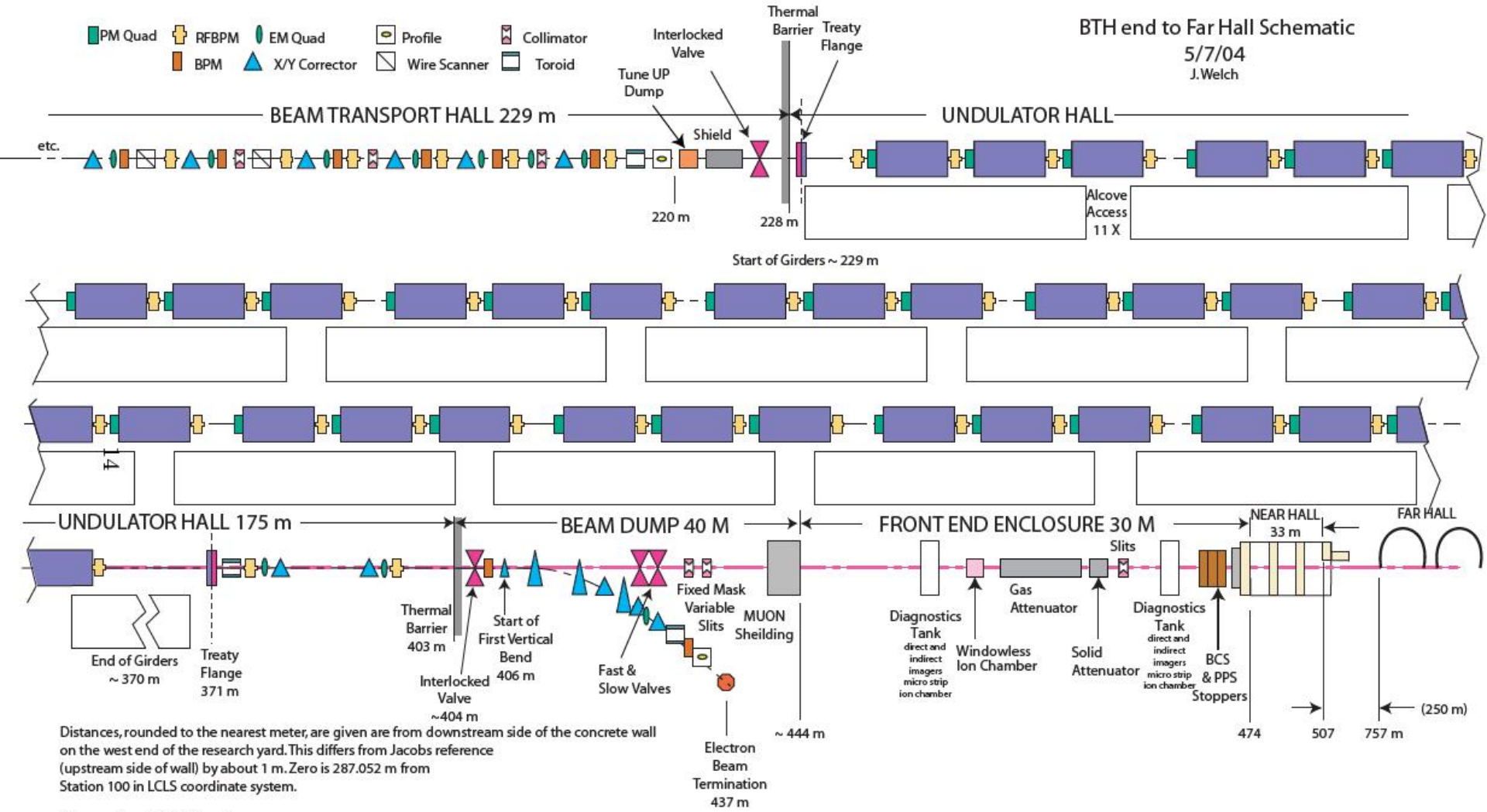
Capabilities/Technical Specifications

- Spectral coverage: 0.15 nm - 1.5 nm to 0.5 nm in 3rd harmonic
- Peak brightness: 10^{33} [photons/(s-mm^2-mr^2)]/ (0.1% bandwidth)
- Photons/pulse: 10^{12}
- Average brightness: 3 x 10^{22} [photons/(s-mm^2-mr^2)]/ (0.1% bandwidth)
- Pulse duration: <230 fs
- Pulse repetition rate: 120 Hz
- Upgrade – more bunches/pulse





Undulator Beam Line (between treaty flanges)



Distances, rounded to the nearest meter, are given are from downstream side of the concrete wall on the west end of the research yard. This differs from Jacobs reference (upstream side of wall) by about 1 m. Zero is 287.052 m from Station 100 in LCLS coordinate system.

Changes from 3/16/04 version:

Treaty flange locations are shown. Toroid moved to other side of treaty flange.

Dump line and Muon shielding moved 8 m upstream.

List of the Undulator Line Systems

- **1.4.2 Controls and Data Acquisition**
  - Micron level positioning system
  - Thermometry
  - Protection systems
- **1.4.3 Undulator Magnets**
    - Magnets
    - Poles
    - Strong-backs
    - Ancillaries – Mu shields, feet, translation stages, etc.
  - Mechanical supports, girders, and cam mover system
  - Multipole magnets – quadrupoles and correctors
- **1.4.4 Vacuum Systems**
  - Undulator vacuum chamber
  - Chamber support and leveling system
  - Ancillaries – bellows, pumps, short and long break chambers
- **1.4.5 Diagnostics**
  - Beam position monitors
  - Beam finder wire
  - X-ray detection - beam loss monitors and dosimetery

Undulator Production

- Undulator (40)
  - Magnets
  - Poles
  - Strong-backs
  - Ancillaries – Mu shields, feet, tuning shims, etc.
- Support and motion system (36)
  - Mechanical supports, girders, translation stages, and cam mover system
- Multipole magnets (40)
  - Quadrupoles and correctors

Undulator - Magnets

40 planar-hybrid, fixed-gap undulators were designed by the Argonne team for industrial mass production

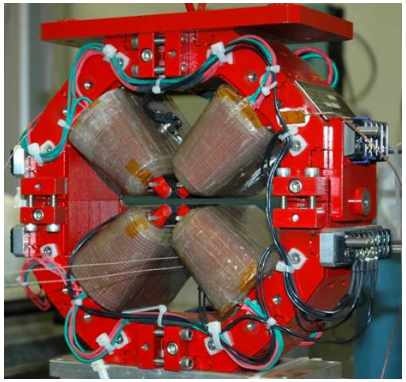
- Magnetic design
  - NdFeB magnets
  - Vanadium permendur poles
  - 30 mm period
  - K=3.71 so B_{eff}=1.325 T
- High-quality undulator magnetic field
- Magnetic tuning for phase errors and trajectory straightness
- Fixed gap with some tunability utilizing built in cant via undulator X-translation
- Phasing undulator ends

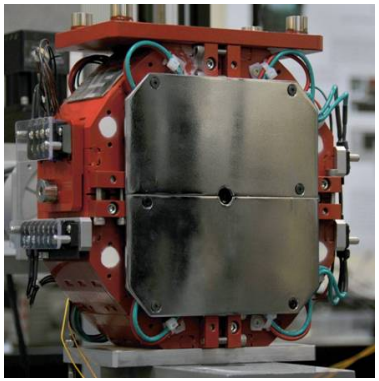
Component 	Material 	Quantity per undulator
Poles	VACOFLUX 50 Vanadium permendur	**450**
Magnets	N39UH (Nd-Fe-B type magnet)	**450**

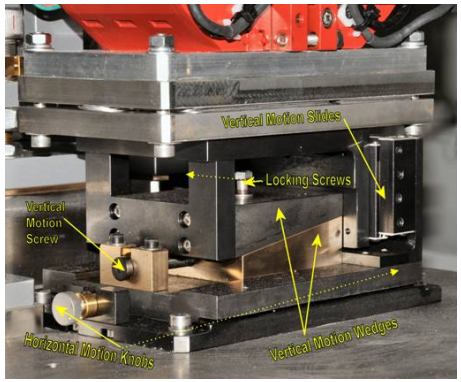
Undulator – Quadrupole Magnets with Correctors

- Each undulator girder has a quadrupole with correctors
  - designed for mechanical stability
  - air-cooled
  - low power dissipation
  - 40-lb quadrupole
  - supported by a stable, compact, rigid, stage that provides vertical and transverse adjustment of the magnet with a travel range of ±3 mm in both directions and a precision of 2 μm

Quadrupole Parameter	Value	Unit
Nominal integrated quad gradient	3.00±0.03	T
Maximum integrated quad gradient	4.0	T
Trim strength range	$\pm 3\times10^{-4}$	Tm
Trim stability	$\pm 3\times10^{-7}$	Tm
Trim settability	$\pm 1.5\times10^{-6}$	Tm
Center stability after fiducialization	±10	μm
Center stability during ±20% grad. chng	±3	μm
Center stability - short term (1h)	±1	μm
Center stability - long term (24h)	±3	μm
Gradient stability - long term (24h) rms	0.25	%
Roll tolerance	±20	mrad
Pitch tolerance	±15	mrad
Yaw tolerance	±15	mrad

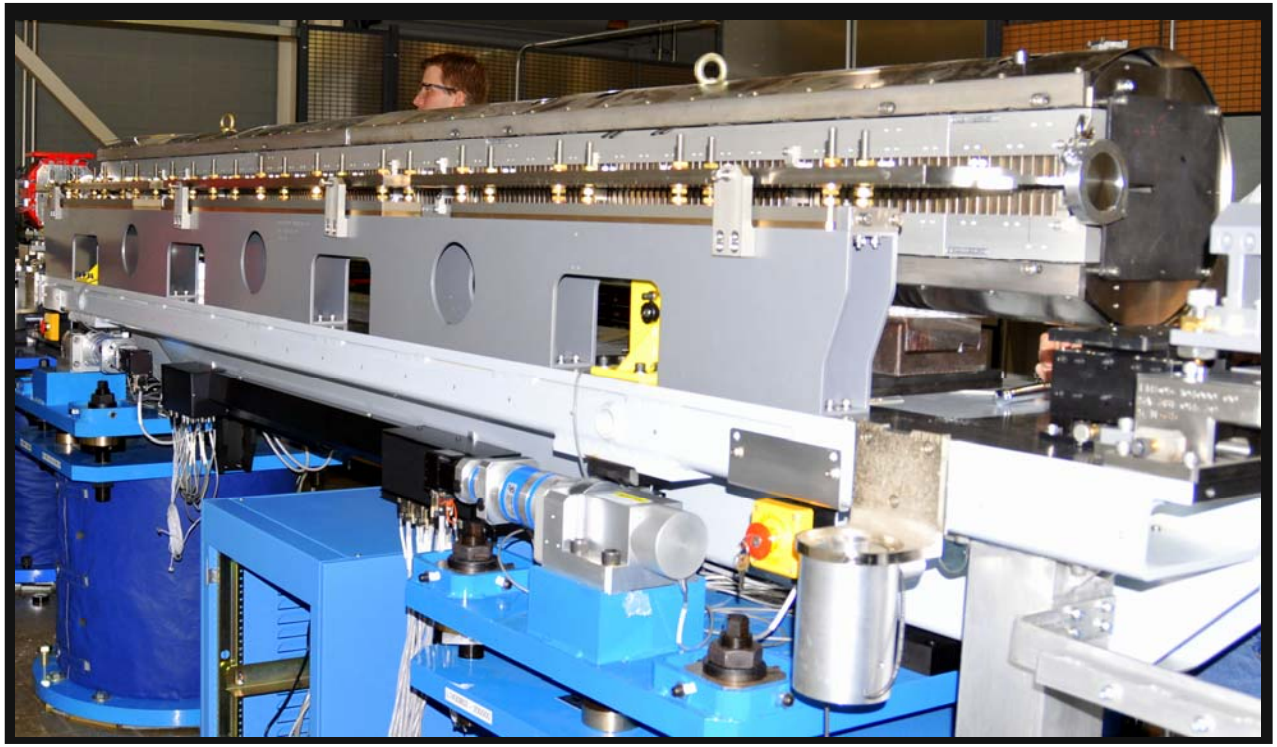




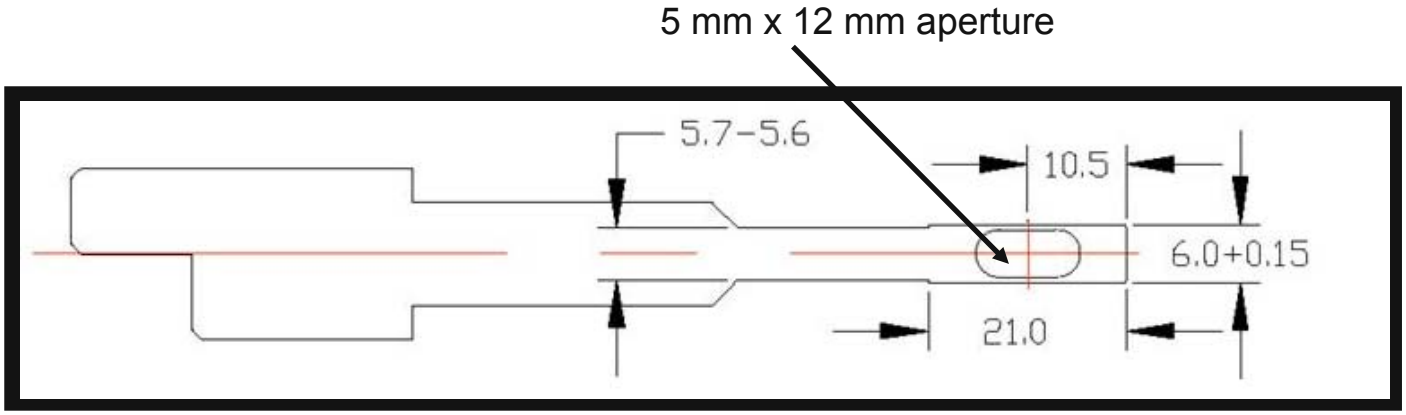


Vacuum Systems

- Vacuum chamber
  - 40 vacuum chambers produced; 33 required for beamline
  - 3.4 m aluminum extrusion; 5 mm x 12 mm aperture; 0.5 mm wall thickness
  - Internally polished; alumina sludge abrasive flow polishing (400 psi at ~ 30°C)
- Chamber support and leveling system
- Ancillaries – bellows, pumps, short and long break chambers

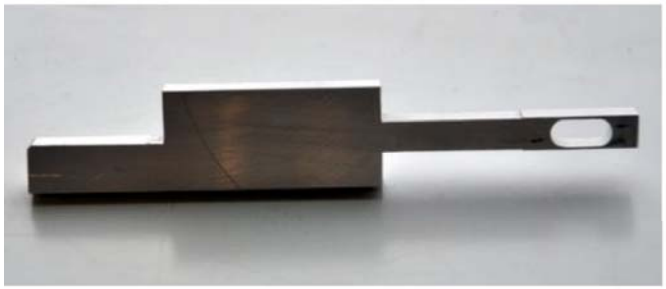


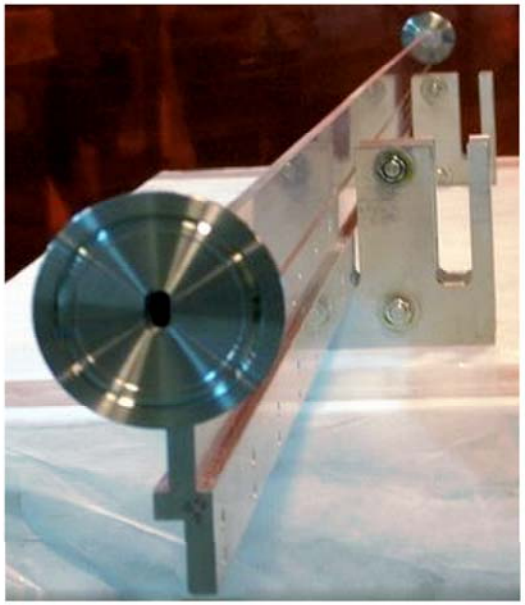
Vacuum Chamber



Extrusion

Machined cross section



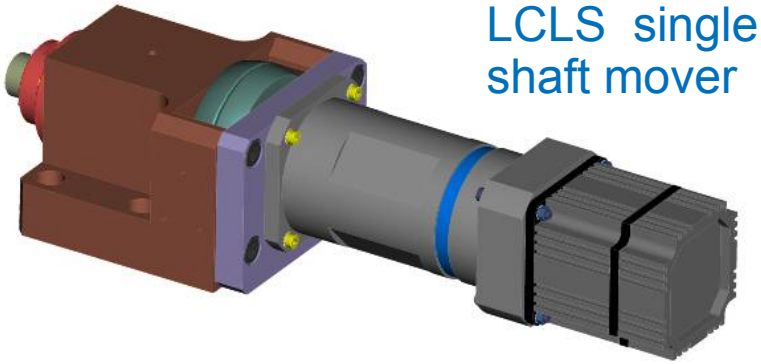


Chamber in production

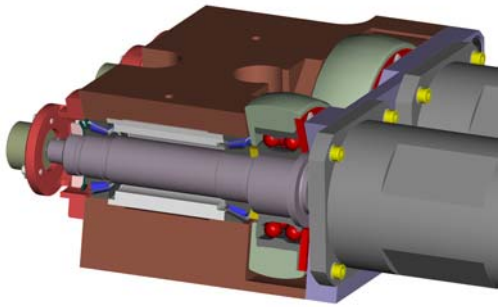
Controls and Data Acquisition – Cam Shaft Movers

Specifications and results:

- Precision and repeatability of cam-shaft system in both directions (vertically and transverse), measured on undulator ends, for pitch and yaw motion as well
  - The specification is ± 7μ
  - We achieved ± 2μ with a feedback and motion resolution of 0.13μ
- Precision and repeatability of transverse travel (80 mm) on linear stages
  - We achieved ± 5μ
- Precision of a K-value adjustment using transverse linear stages
  - We achieved ± 5μ
- Short term stability (10 hours) of the girder and undulator
  - The specification is ± 5μ
  - We achieved ± 3μ



LCLS single cam-shaft mover



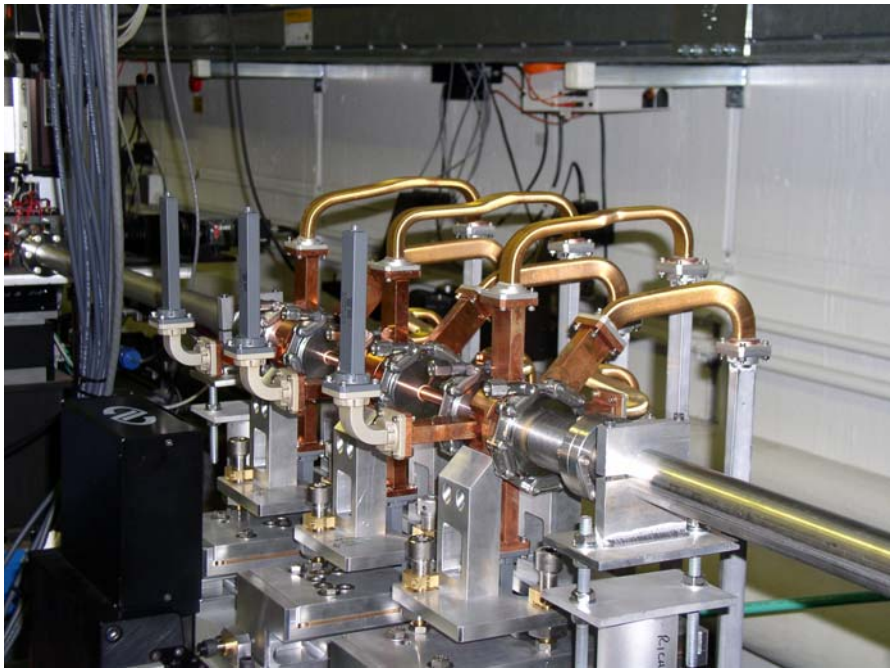
Detail of LCLS double cam-shaft mover

Controls and Data Acquisition

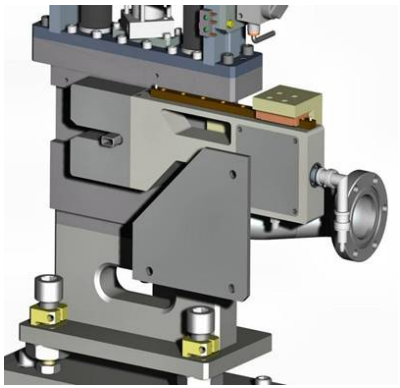
Undulator in-tunnel rack

Diagnostics

- Beam position monitors
- Beam finder wire
- X-ray detection - beam loss monitors and dosimetry



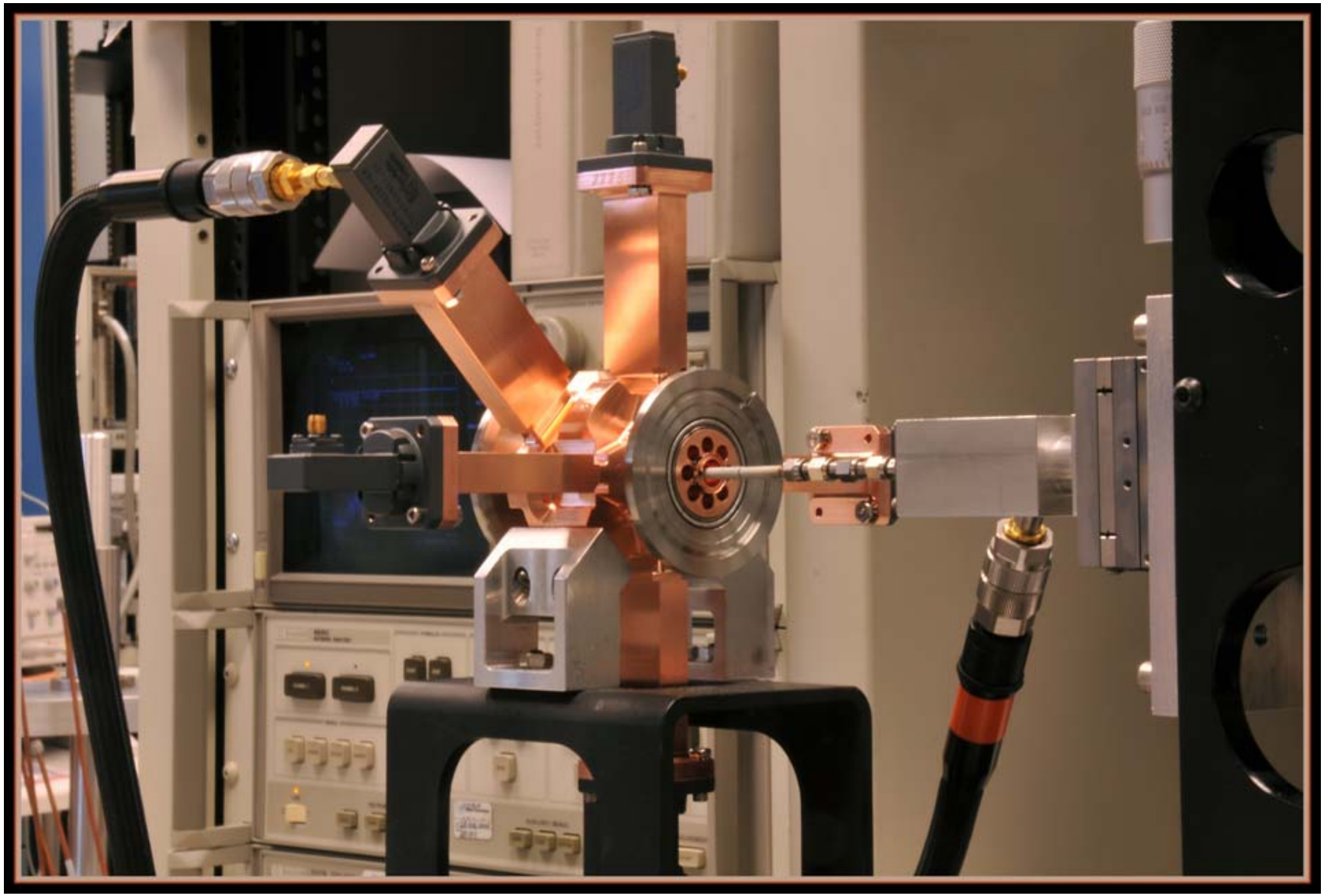
3 BPM tests



Beam Loss Monitor

Beam finder wire

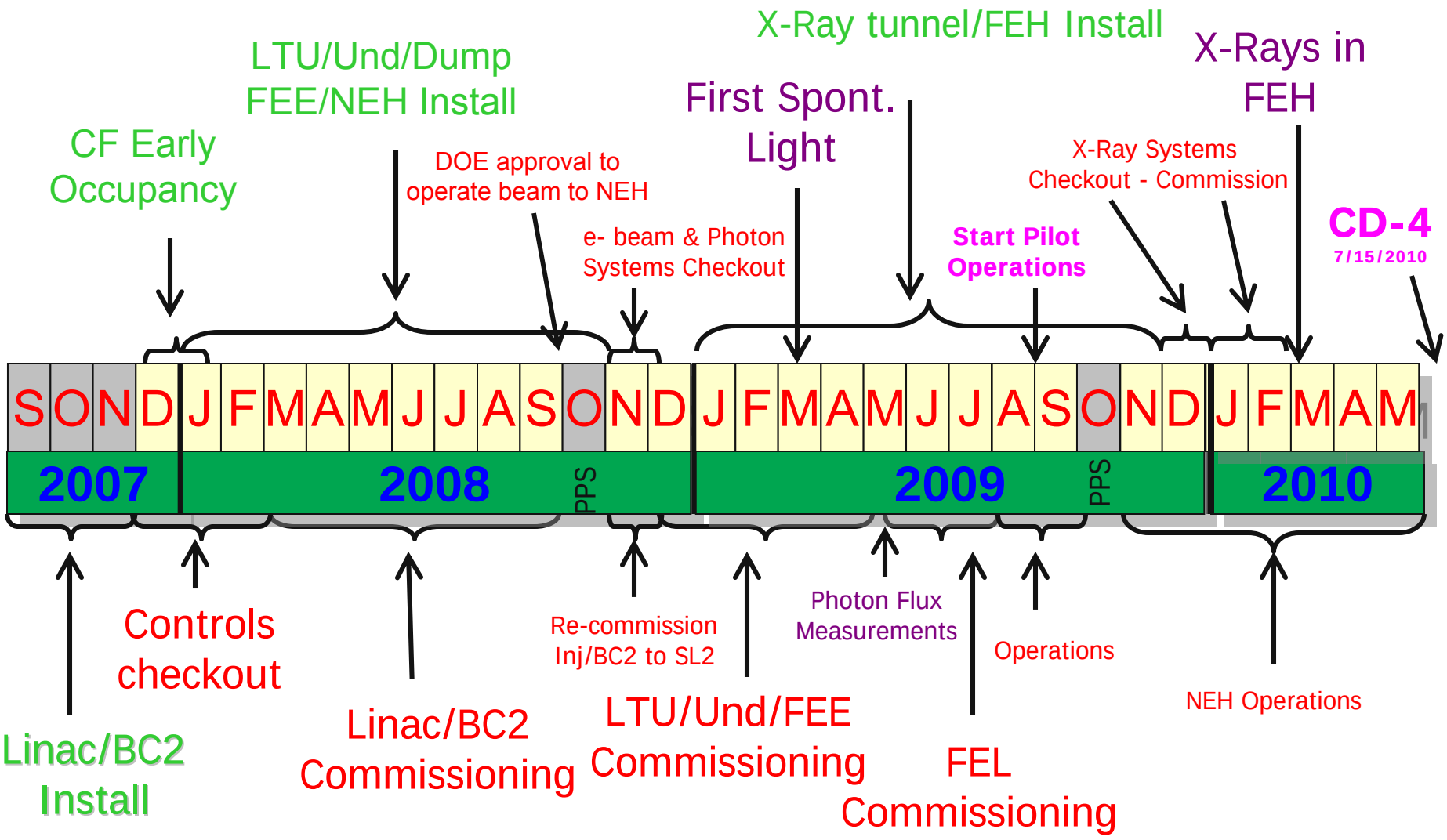
BPM Testing at Argonne



Single Undulator and Long Term Tests at Argonne

- Prototypes proved designs met specifications
- First Article Production Components fully integrated – any problems resolved before production
- Functions as a test stand and integration tool until all 33 systems are commissioned at SLAC

LCLS Installation and Commissioning Time-Line



LCLS project benefits APS

- APS continues to be at the cutting edge in the undulator technology
  - APS magnet measurement facility - one of the main benefactors
- APS excellence in the technology of extruded super smooth vacuum chambers will make possible future high current operations
- APS developed new generation of RF BPMs - one shot/one turn
- APS gained an experience in the mass production of undulators that could be important for the renewal project