Electron Beam Alignment Strategy in the LCLS Undulators

Heinz-Dieter Nuhn, SLAC / LCLS

fel 06
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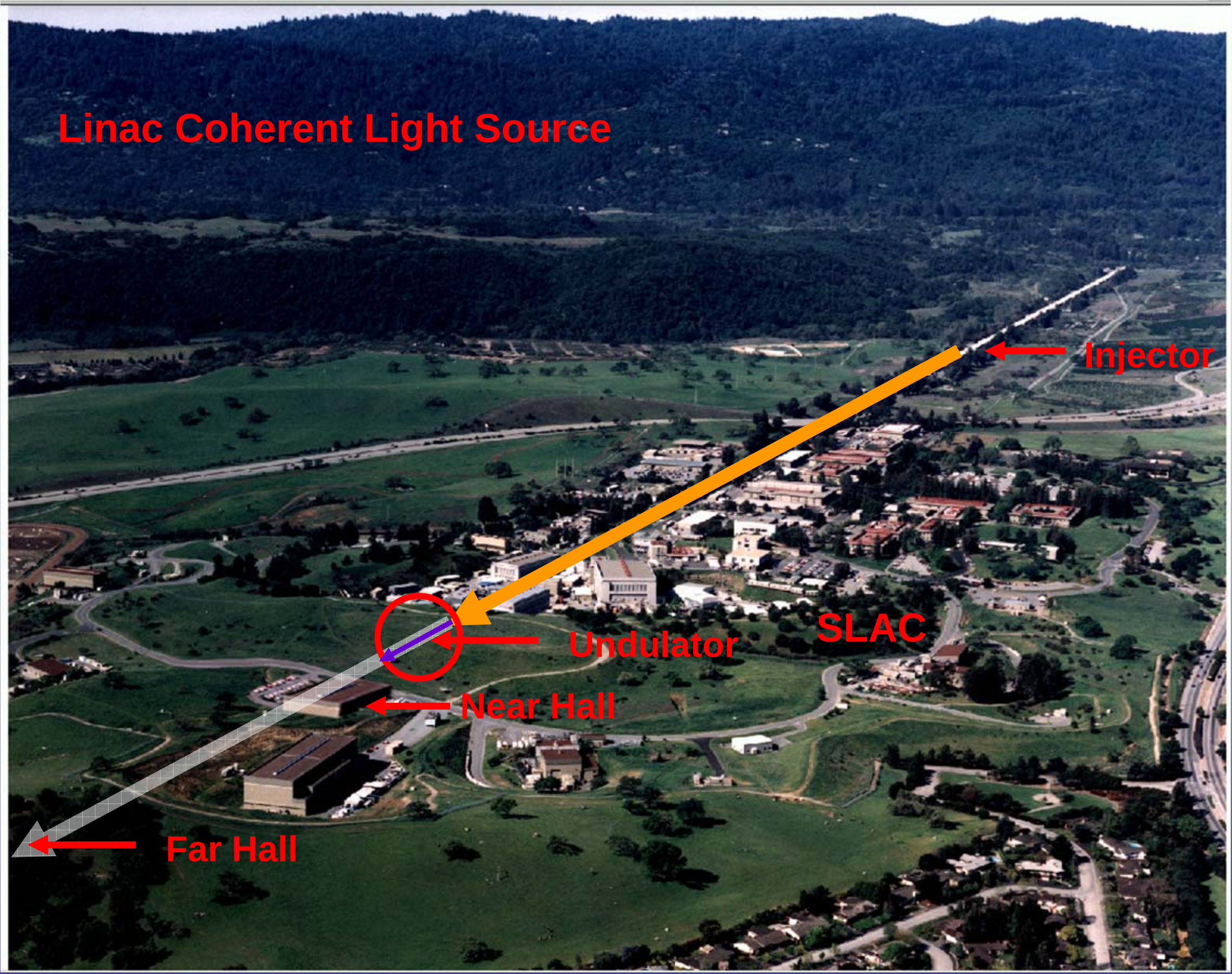
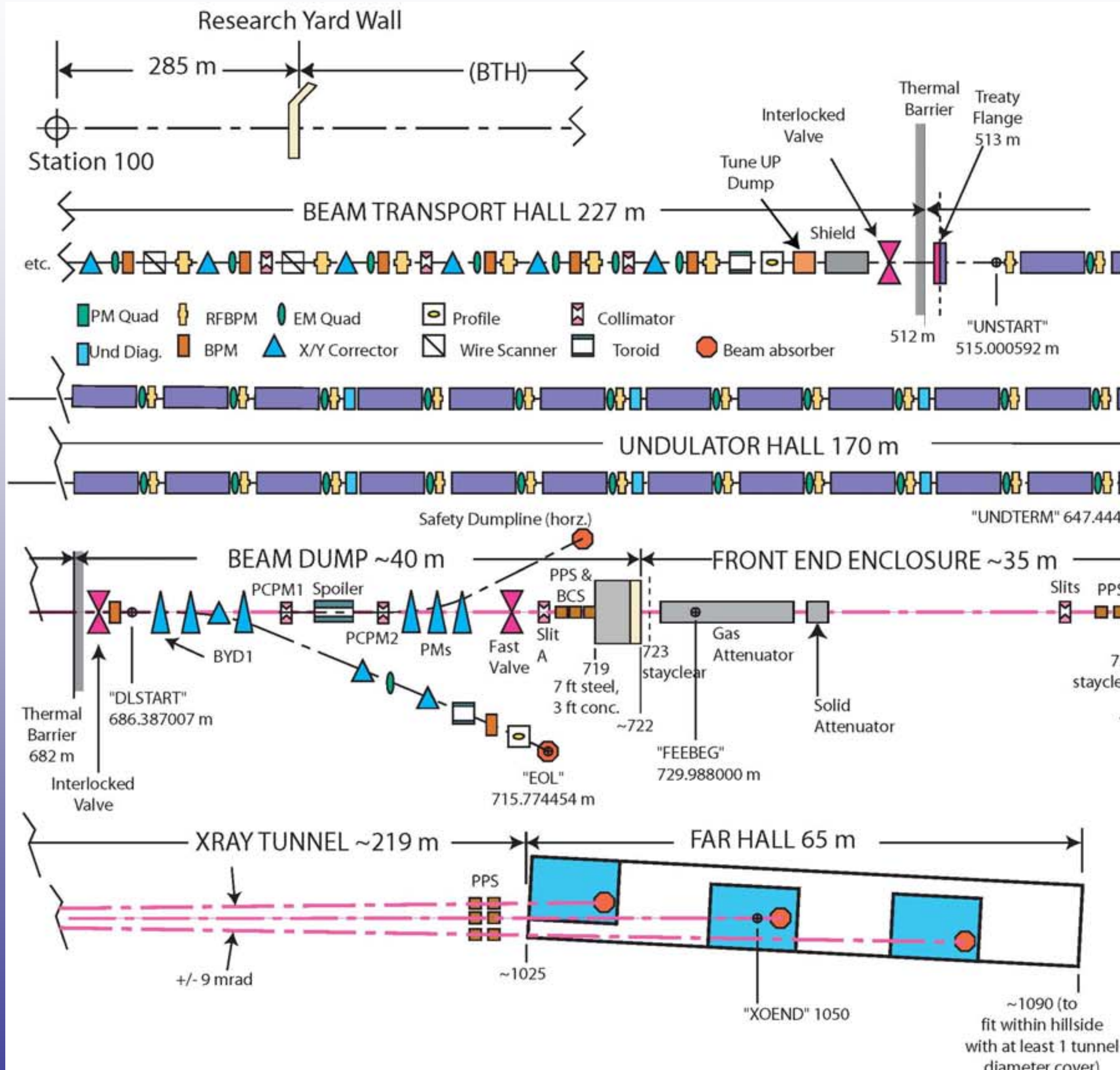
- Undulator Overview
- Tolerances
- Controls
- Monitoring
- Alignment Diagnostics System
- Task Scheduling

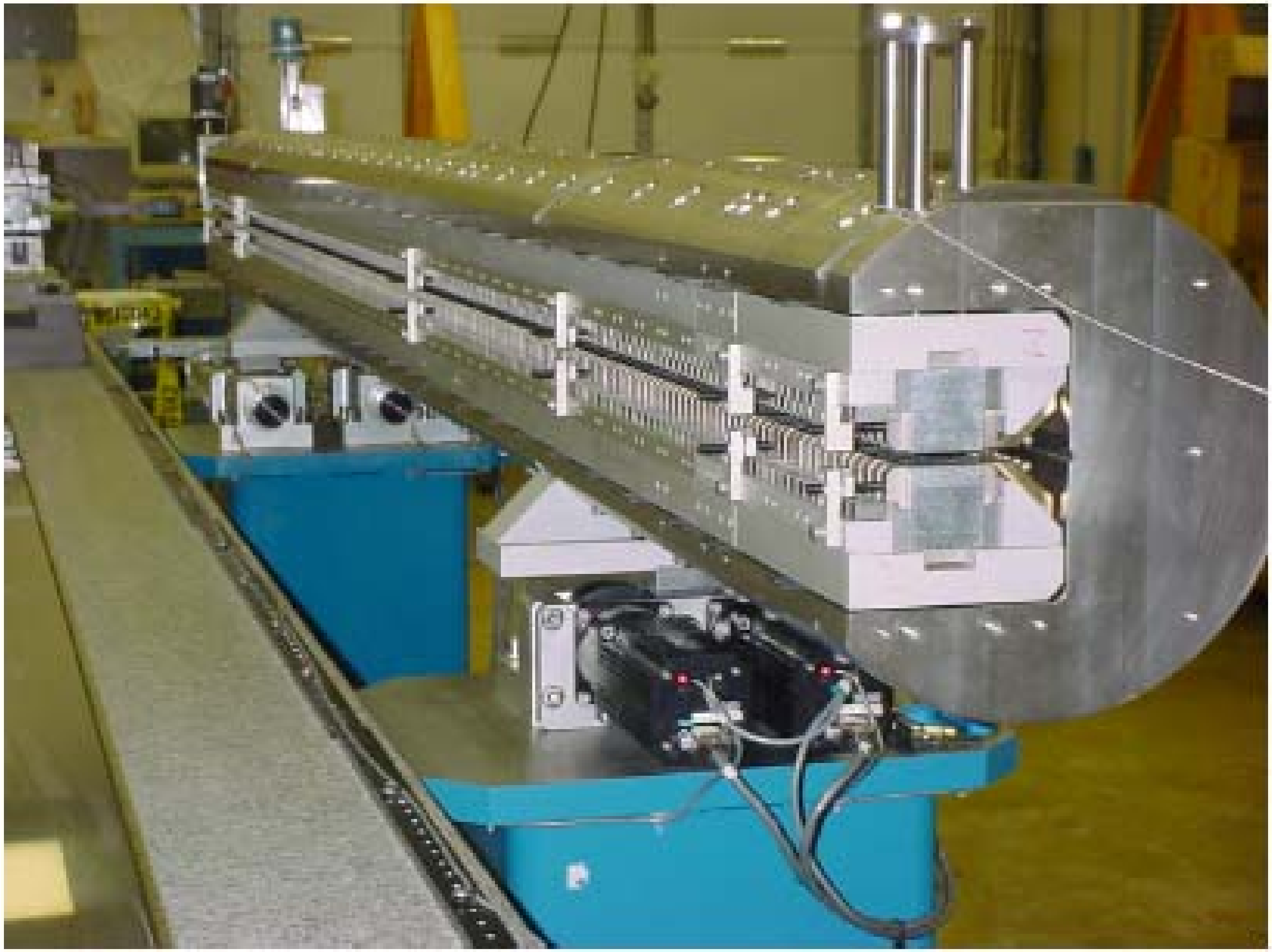
Collaborators: *Paul J. Emma* *Catherine M. LeCocq*
Georg L. Gassner *Franz Peters* *Robert E. Ruland*


Linac Coherent Light Source
Injector
SLAC
Undulator
Near Hall
Far Hall



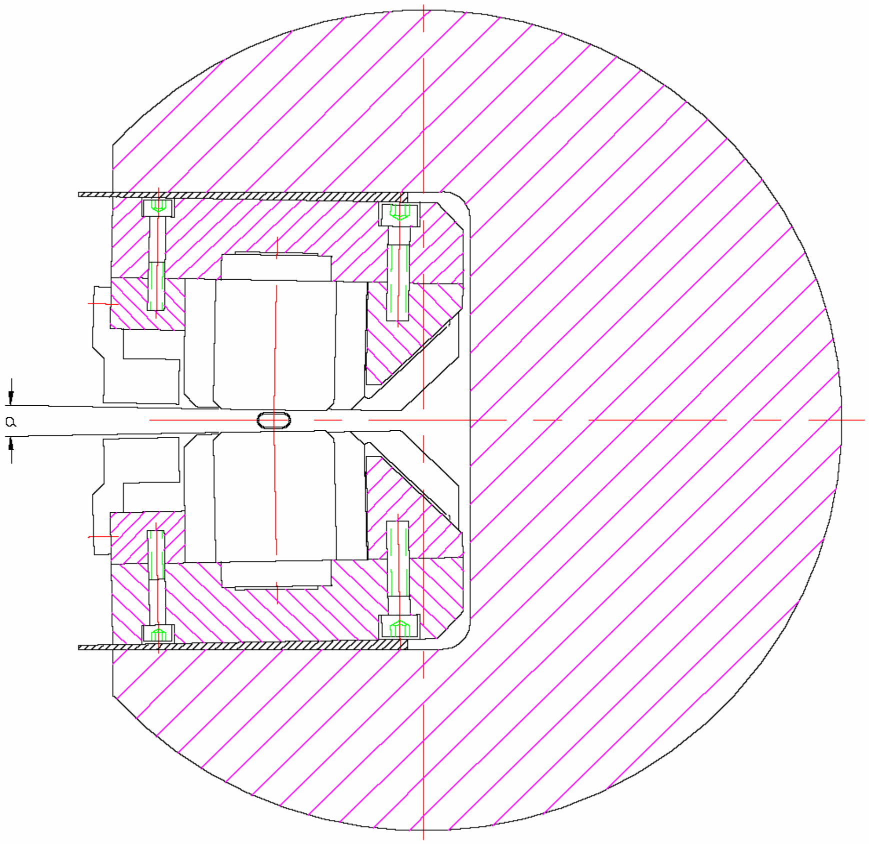
1) Except where preceded by a "~", locations and lengths of building boundaries ar elements are basic dimensions and should be considered exact. Locations refer to LCLS z' coordinates.
2) Beamline elements and locations are derived from PRD 1.9-001 which is derived from the MAD survey output LTU-LCLS27JUN05.PRINT for the optics.
3) Building lengths were adjusted to resolve beam dump location conflict, more shielding in the beam dump, extended Near Hall, accommodate a longer FEE and a longer Far Hall without extending out of the hill, and new definition of NEH size from outer to outer walls.
4) New Beamline Datums are included.
5) The Dumpline is shortened by taken 2 m of length from the western end.
6) The UH is shortened by 5 m and shifted westward 2 m.
7) Flipper mirror vertex and opening angle are defined
8) Undulator configuration changes
9) NEH location shifted eastward 2 ft.

Undulator Segment Prototype



LCLS Undulator Module Pole Canting

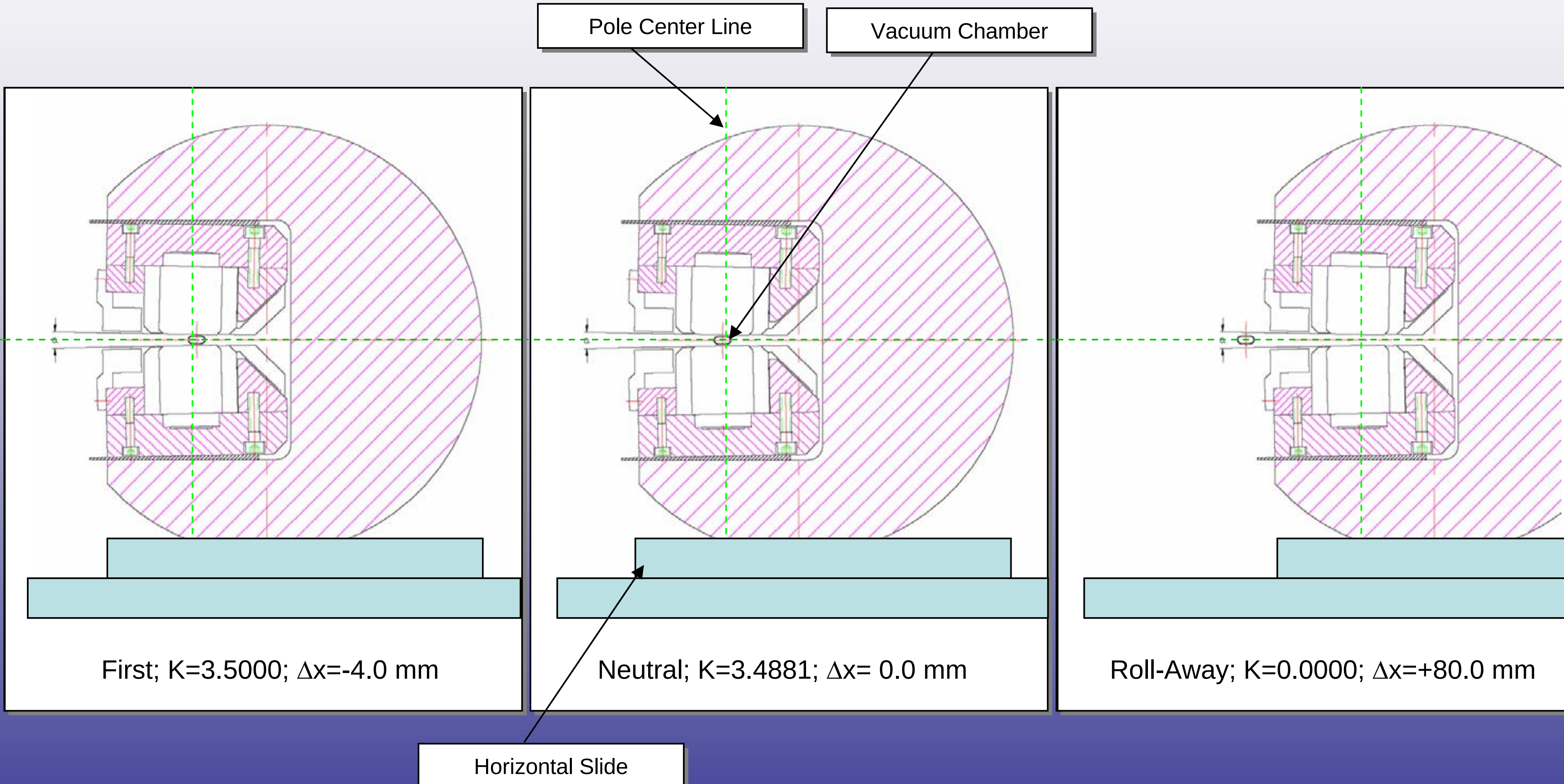
- Canting comes from wedged spacer
- 4.5 mrad cant angle
- Gap can be adjusted by lateral displacement of wedges
- 1 mm shift means 4.5 µm in gap, or 8.2 G
- B_{eff} can be adjusted to desired value



LCLS UNDULATOR CROSS SECTION WITH THE WEDGED SHIMS
(angle a is exaggerated)

Heinz-Dieter Nuhn, SLAC / LCLS
nuhn@slac.stanford.edu

Undulator Roll-Away and K Adjustment Function



Requirements for Optimum SASE Gain

- *Overlap control*
  - *Electron beam and x-ray field need to overlap so that the separation of their centers stays below 7.4 µm (rms)*
  - *Requires straight line trajectory for electron beam to stay with the radiation field*
- *Phase control (Phase Shake)*
  - *Phase between electrons and electric field needs to be controlled to ±10° of optical wavelength, which is (±4.2 pm at 1.5 Å)*
    Will be done through
    - *Undulator field tuning*
    - *Beam Steering [Requiring straight line to 2 µm (rms)]*
- *Undulator K Control (Average Phase)*
  - *Will be done through*
    - *Undulator field tuning*
    - *Keeping electron beam close to undulator axis*

Focus of the Alignment Task

- *Quadrupoles*
  - *Misalignment will steer beam*
  - *Necessary to align quadrupoles with respect to a straight line*
  - *Position control requirement : < 1 µm*
  - *Requires Beam Based Alignment*
- *Undulators Segments*
  - *Misalignment will change K*
  - *Tolerances: 80 µm (rms) vertical; 140 µm (rms) horizontal*
  - *No effect on steering ! => Difficult to detect.*
  - *Addressed by common girder alignment of fiducialized components*

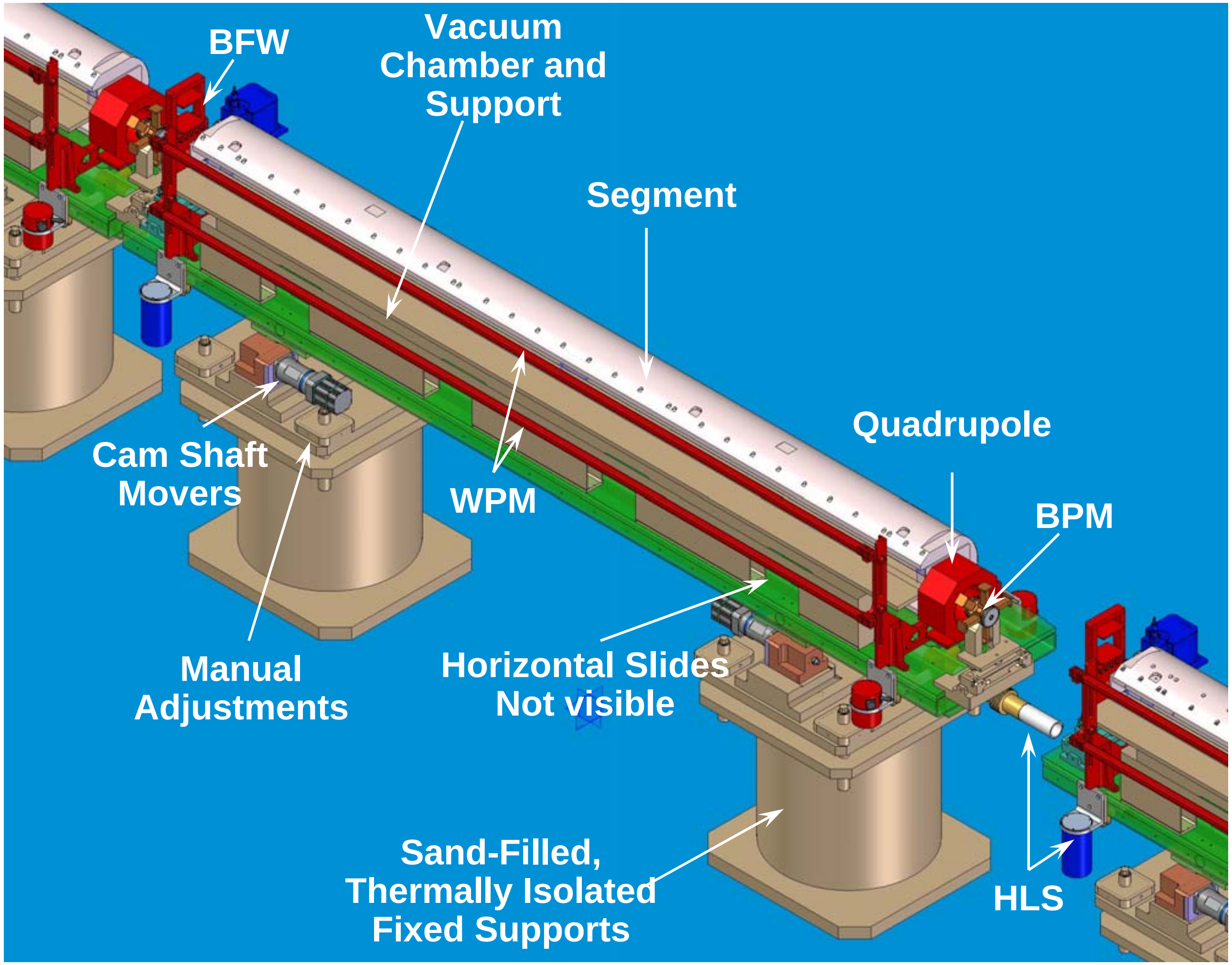
Solution for Quadrupole Alignment Requirement

- *Mount quadrupoles on remote controlled supports (cam-shaft movers) and use their off-axis fields for steering.*
- *Use Beam-Based Alignment (BBA) with beam energy variation (4.3 GeV – 6.2 GeV – 13.6 GeV) to detect and cancel error fields along the undulator line, i.e., remove dispersion, by*
  - *Detecting energy dependence of the trajectory using RF Cavity BPMs*
  - *Moving the quadrupoles transversely to minimize the effect*
- *Net result: the quadrupoles will get aligned in the process*
  - *Algorithm has been found to work in simulations*
  - *We believe BBA to be essential for achieving X-Ray FEL gain*

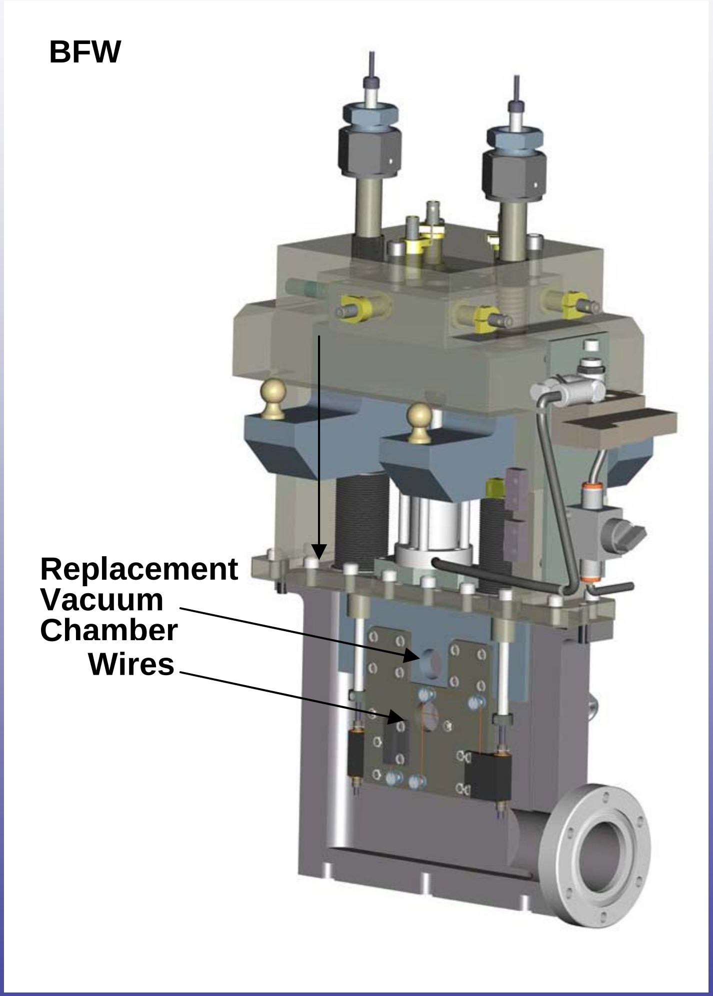
Solution for Segment Alignment Requirement

- *Install beam position sensing elements with absolute readout capability at either end of each segment*
- *Choice for down stream location : Quadrupole*
- *Choice for up stream location : Beam Finder Wire (BFW)*
- *All three components (BFW, Segment, Quadrupole) will be fiducialized, i.e., their magnetic axes will be measured with respect to their tooling balls.*
- *They will be mounted on a common girder structure and aligned on a Coordinate Measuring Machine (CMM) with micron level accuracy*
- *Girders will be moved during BBA to correct the quadrupole positions to achieve the required kick (mostly removal of initial kick), at the same time aligning the down stream end of the undulator segment*
- *The other girder end will then be moved to bring the wires of the BFW in collision with the beam, to align the upstream ("loose") end*

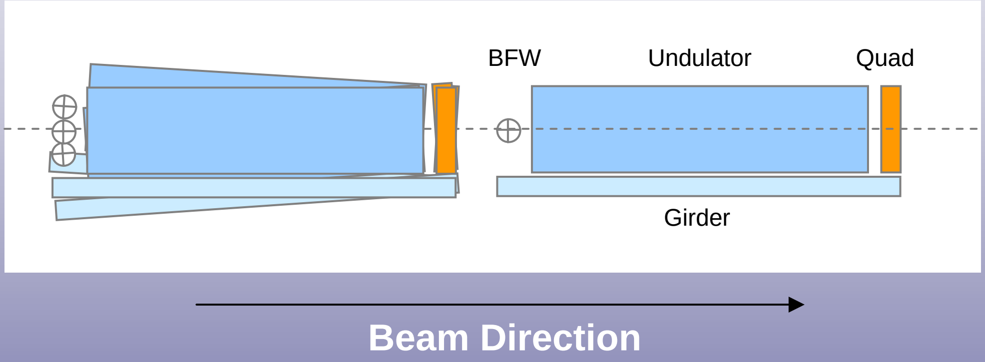
LCLS Undulator Components



Beam Finder Wire (BFW)



A misaligned undulator will not steer the beam. It will just radiate at the wrong wavelength.
The BFW allows the misalignment to be detected.
(also allows beam size measurements)



Planned Applications

- *Loose End Alignment*
- *Beam Profile Scanning*

Alignment Tolerances

Electron Beam Requirements	Value	Unit
Electron Beam Straightness (rms)	2	µm
Launch position radius (rms)	7.3	µm
Launch angle radius (rms)	0.26	µrad

Component Monitoring and Control Tolerance	Value	Unit
Horizontal / vertical quadrupole and BPM position stability	±2	µm
Expected ground motion amplitude	1	µm/day

Tolerances for Girder Alignment in Tunnel	Value	Unit
Initial rms uncorrelated x/y quadrupole alignment tolerance wrt straight line	100	µm
Undulator Segment yaw / pitch tolerances (rms)	240 / 80	µrad

Tolerances for Component Alignment on Girder	Value	Unit
Horizontal alignment of quadrupole and BPM to Segment (rms)	125	µm
Vertical alignment of quadrupole and BPM to Segment (rms)	60	µm
Horizontal alignment of BFW to Segment (rms)	100	µm
Vertical alignment of BFW to Segment (rms)	55	µm

Summary of Alignment Controls

- *Manually Adjustable Controls:*
  - *Cam shafts relative to fixed support:*
    x [12 mm range]; y [25 mm range]; z [12 mm range]
  - *Quadrupole, BFW, BPM, and vacuum chamber relative to segment:*
    x, y, and z [range >1 mm]
- *Remotely Adjustable Controls:*
  - *Girder x, y, pitch, yaw, roll [±1.5 mm in x and y on either side]*
    - *Enables alignment of all beamline components to the beam axis.*
    - *Roll control is to be used to compensate roll errors*
  - *Undulator x position [80 mm range]*
    - *Provides control of the undulator field at beam location.*
    - *Horizontal slide stages move each undulator segment independently of girder and vacuum chamber.*

Summary of Alignment Monitors

- *Hydrostatic Leveling System (HLS)*
  - *Monitored Degrees of Freedom are: y, pitch, and roll*
- *Wire Position Monitoring System (WPM)*
  - *Monitored Degrees of Freedom are: x, (y), (pitch), yaw, and roll*

ADS

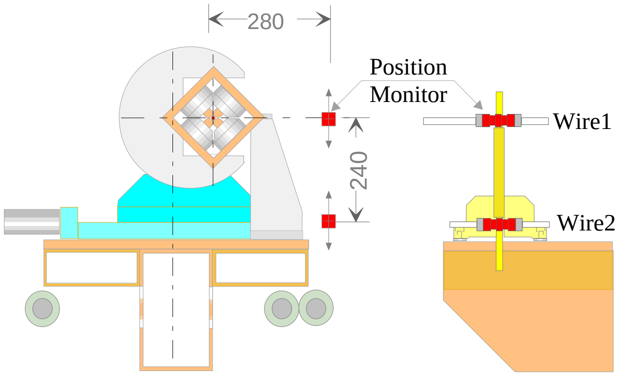
- *Temperature Sensors*
  - *In support of ADS readout corrections, undulator K corrections, and component motion interpretation.*
- *Beam Position Monitors**
  - *Monitored quantities are: x and y position of electron beam*
- *Quadrupoles**
  - *Monitored quantities are: electron beam x and y offset from quad center*

*Transverse Locations Tracked by ADS

Alignment Diagnostic System (ADS)

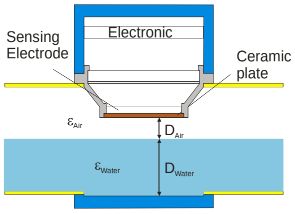
Wire Position Monitor system (WPM)

- ***Resolution*** < 100 nm in X & Y direction
- ***Instrument Drift*** < 100 nm per day
- ***Moving Range*** ±1.5 mm in X & Y direction
- ***Availability*** Permanent, no interrupts



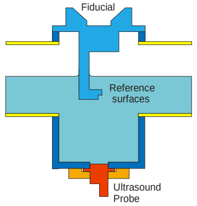
X and **Y**, can be measured
Roll, **Jaw** & **Pitch** can be calculated.

Hydrostatic Leveling System (HLS)



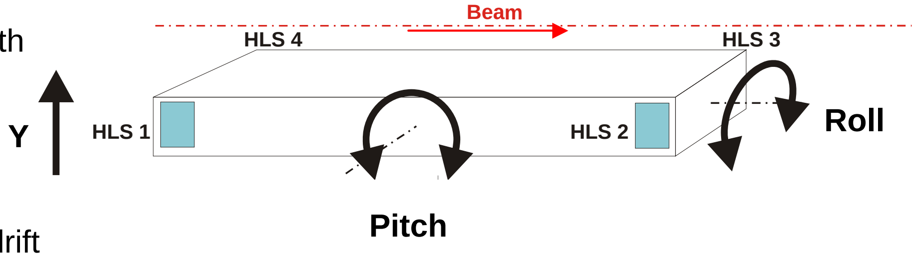
Capacitive Sensor

- ***Precision*** < 1 μm
- ***Instrument Drift*** ~1-2 μm / month



Ultrasound Sensor

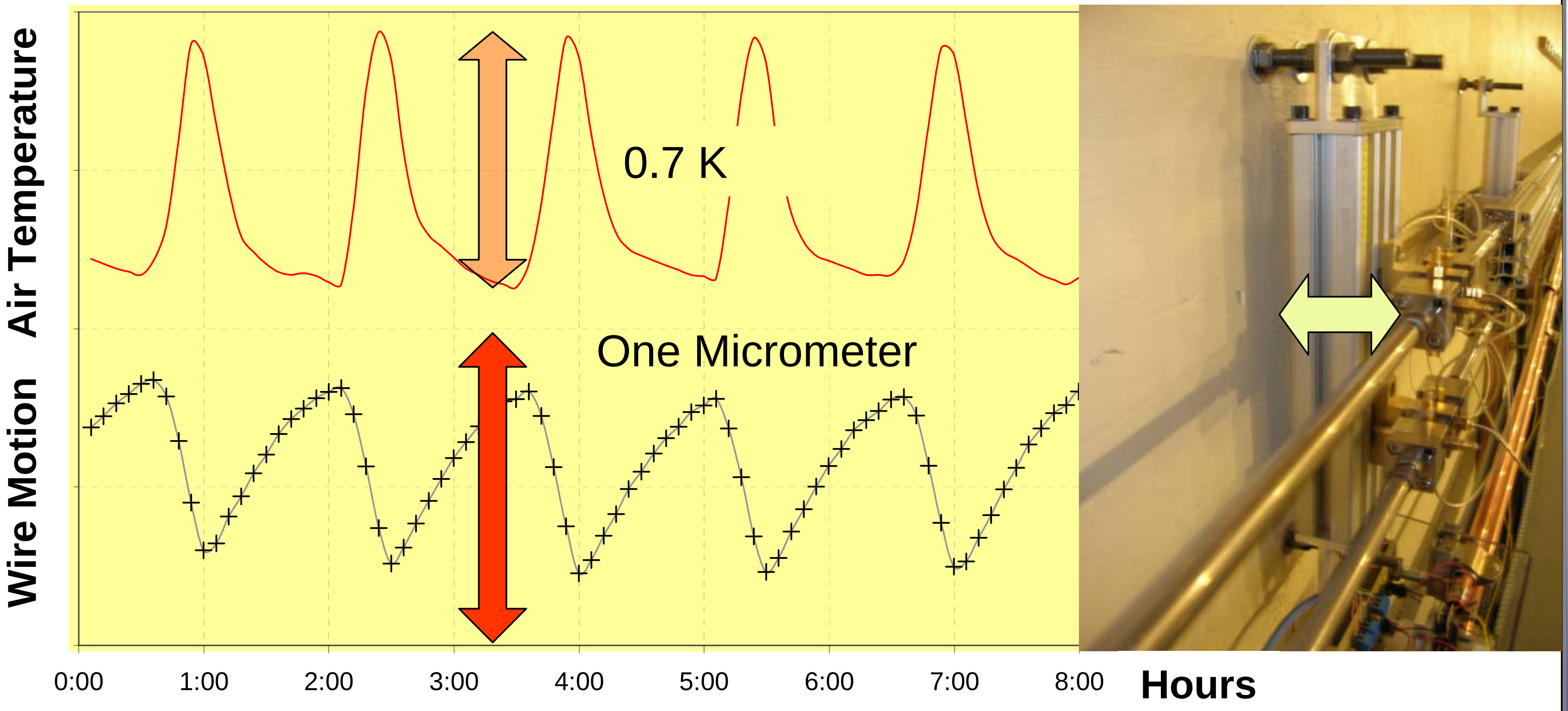
- ***Precision*** < 0.1 μm
- ***Instrument Drift*** potentially no drift



Y can be measured
Roll & **Pitch** can be calculated.

- ***Availability*** 10 min settling time after motion

WPM Resolution Test at SLAC Sector 10



Wire to wall motion correlates with air temperature cycle

Controlling Girder Motion

- *Girder motion will be caused by*
  - *Ground Motion*
  - *Temperature Changes*
  - *CAM Rotation*
- *Girder motion will be monitored in 2 ways:*
  1. *Directly, through the **ADS***
  2. *Indirectly, through impact on electron beam trajectory (as detected by BPMs)*
- *Girder Positions will be frequently corrected using the cam movers.*

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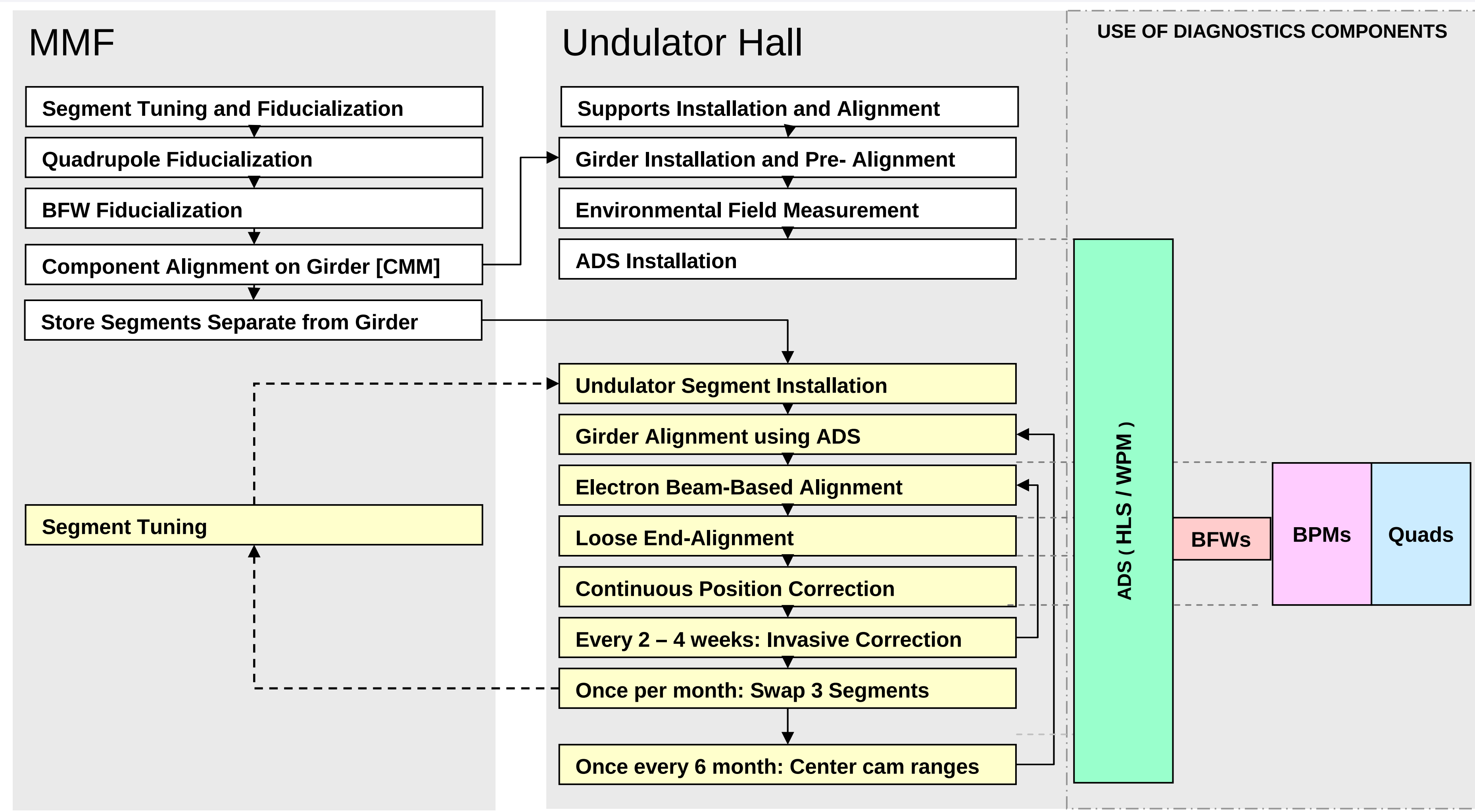
Alignment Tasks Scheduling Diagram



Conclusions

- *The X-ray-FEL puts very tight tolerances on magnetic field quality, electron beam straightness, and segment alignment*
- *These tolerances can be achieved through Beam Based Alignment based on BPMs and quadrupoles (by scanning beam energy)*
- *BPMs, quadrupoles, and undulator segments will be kept aligned relative to each other in the presence of ground motion through common girder mounting.*
- *Main tasks of the conventional alignment are*
  - *Component fiducialization and alignment on girders*
  - *Conventional alignment of girders in the Undulator Hall as prerequisite for BBA*
- *The Alignment Diagnostic System measures and enables the correction of girder movement due to ground motion and temperature changes*
- *A strategy is in place to establish and maintain the straight electron beam trajectory required to achieve FEL gain at x-ray wavelengths*

Thank you
for your attention