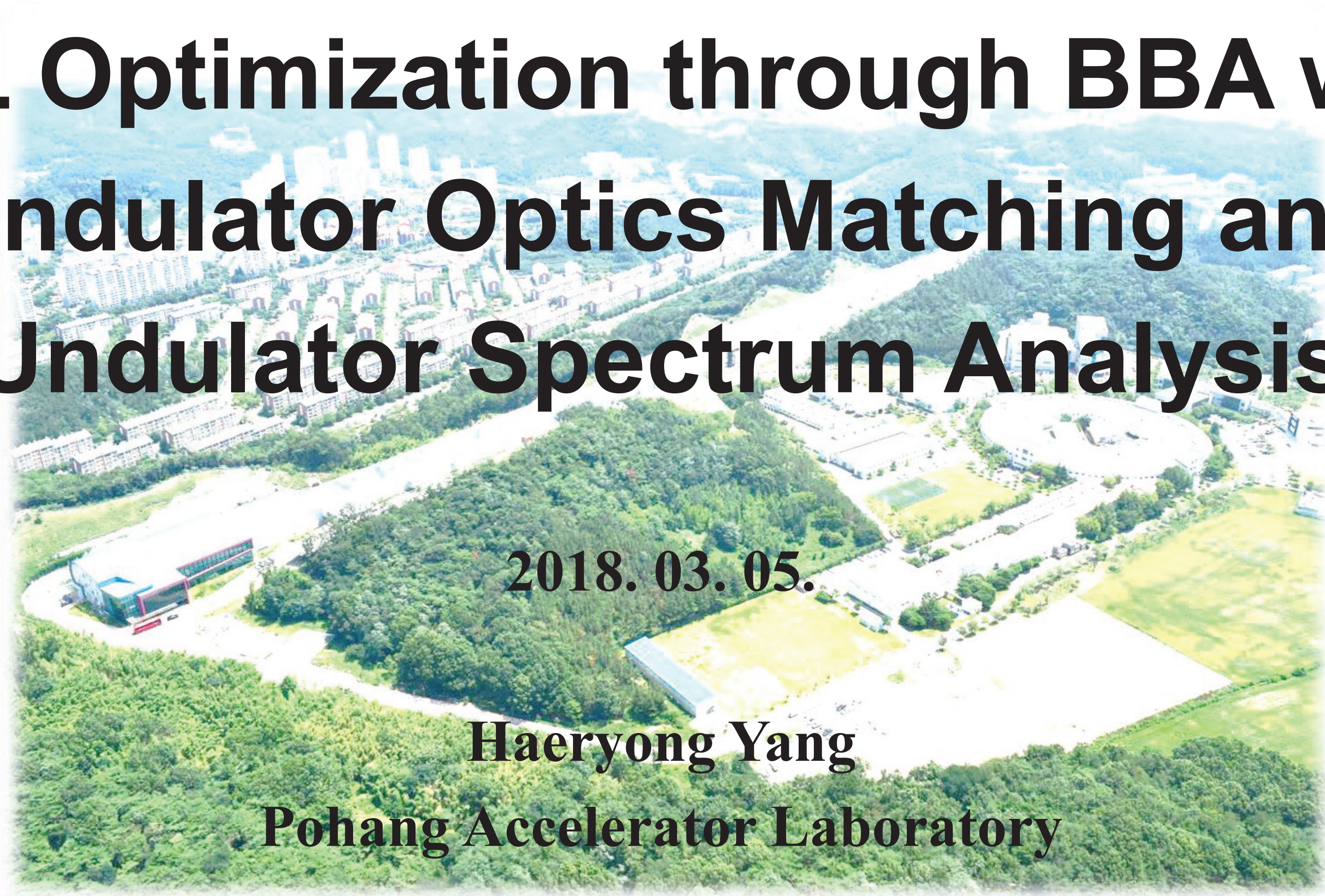


FEL Optimization through BBA with Undulator Optics Matching and Undulator Spectrum Analysis

2018. 03. 05.

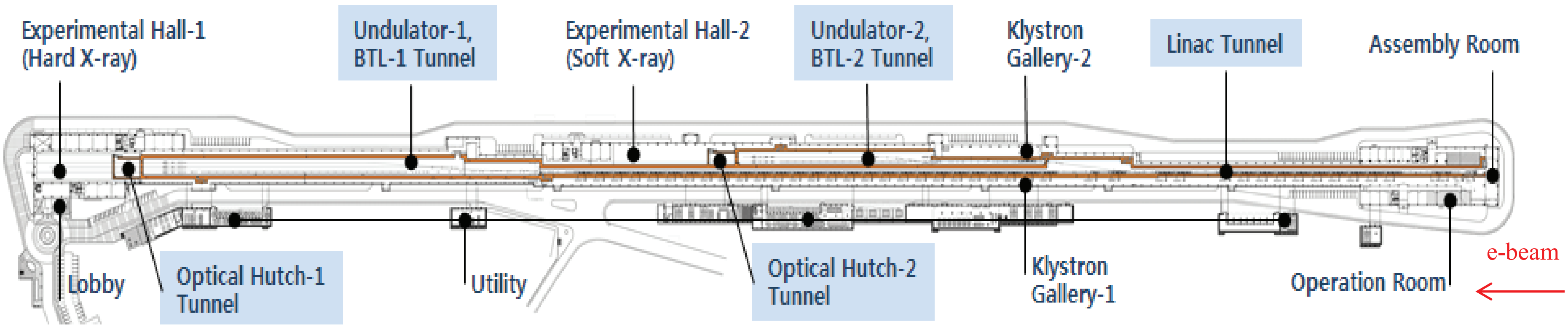
Haeryong Yang
Pohang Accelerator Laboratory


PAL-XFEL

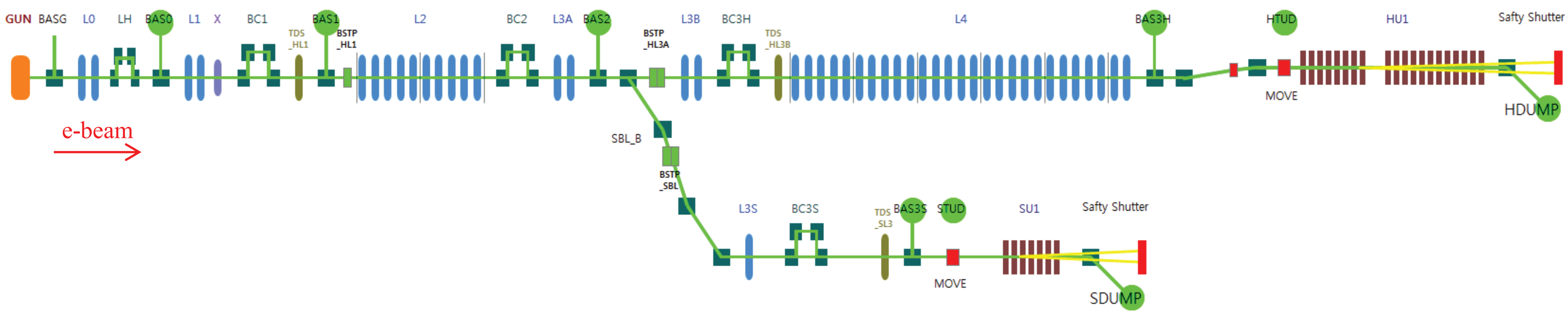
PAL-XFEL


PAL-XFEL
PLS II

PAL-XFEL



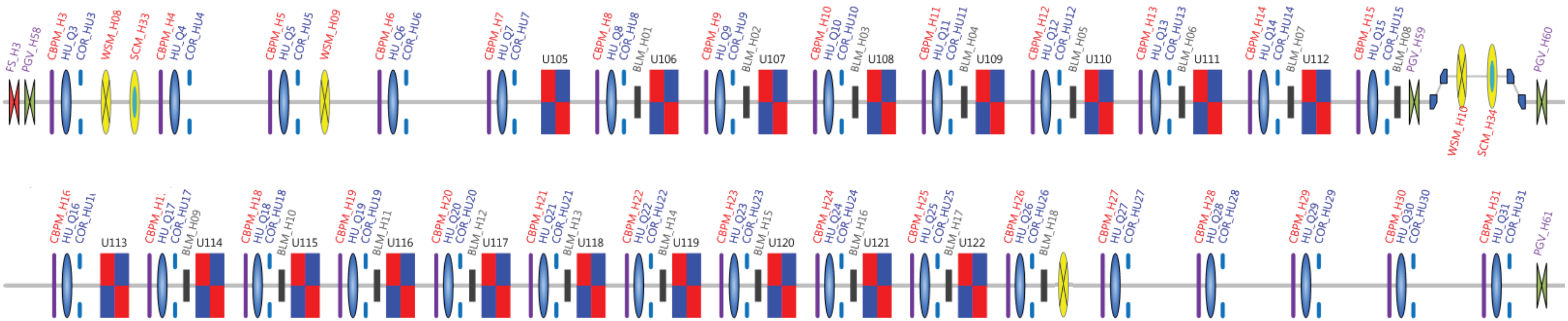
- **Schematic of PAL-XFEL**



- 1.1 km long, consist of hard x-ray line (HX), soft x-ray line (SX)
- 2.5 ~ 15 keV FEL in HX, 0.4 ~ 1.2 keV FEL in SX
- Injector, laser heater, 3 bunch compressors for each line, dog-leg in HX
- 43 S-band RF modules for GUN & ACC, 3 S-band RF modules for TDS, a X-band RF module for the linearizer

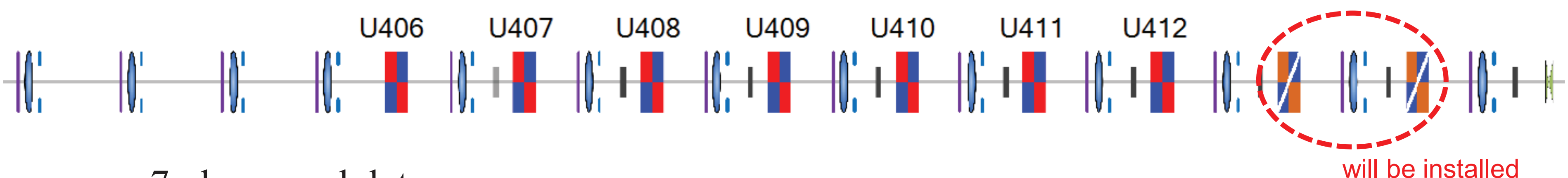
Undulator Section in PAL-XFEL (1)

Hard X-ray Line (HX)



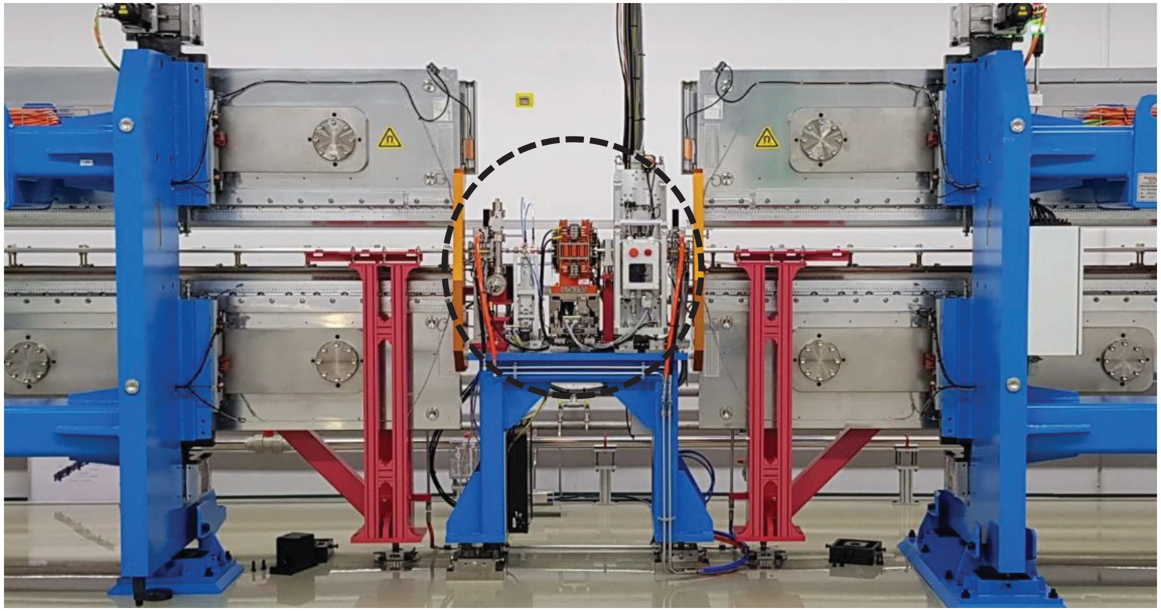
- 20 planar undulators
- Space without UND for self-seeding after 8th UND

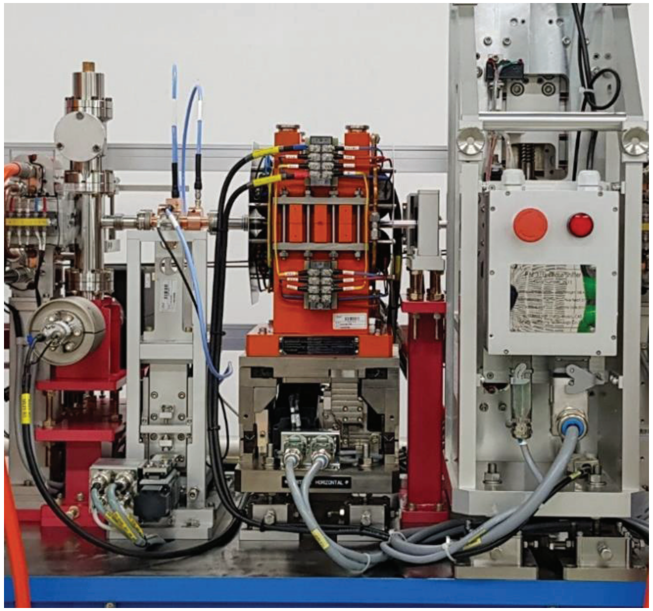
Soft X-ray Line (SX)



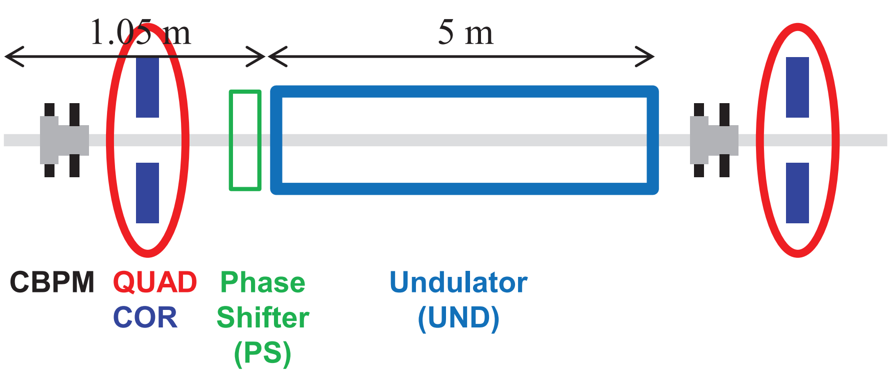
- 7 planar undulators
- Planning to install 2 helical undulators

Undulator Section in PAL-XFEL (2)





Configuration of UND section



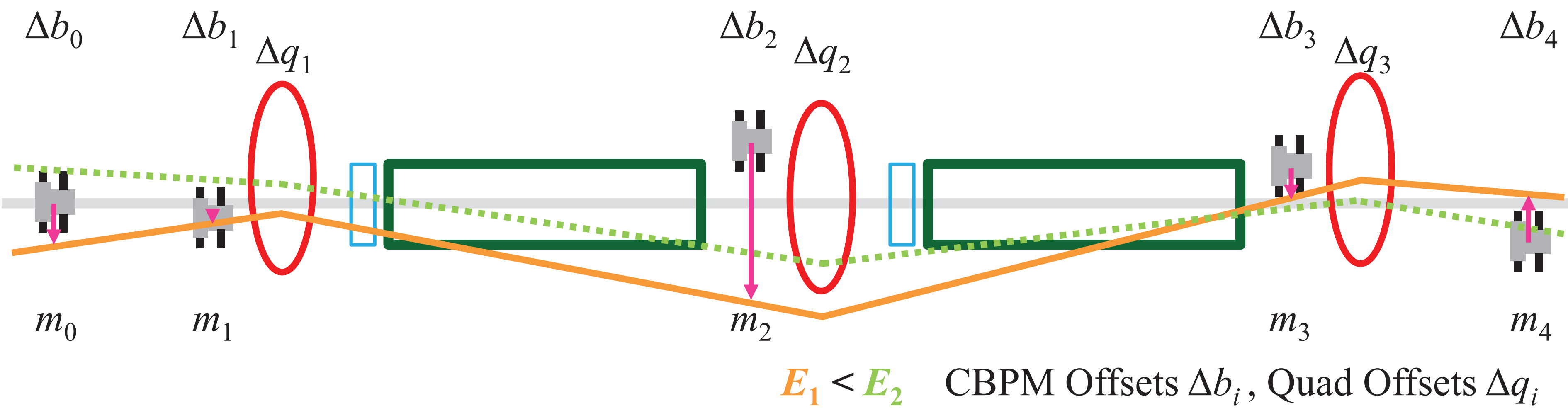
Device	Controlled parameters
CBPM	H/V-offset (in PV), H/V-position (by mover)
QUAD	Field, H/V-position (by mover)
COR	H/V-kick
PS	Gap
UND	Gap, V-offset

▪ Sequence of FEL Optimization in UND Section

- Beam Based Alignment (BBA) in undulator section
- e-beam size (β) matching in undulator section
- Undulator K-tuning
- Mid-plane scanning
- Phase shifter optimization
- Undulator tapering

Beam Based Alignment (1)

- **BBA measurement schematic** (Henrik Loos, LCLS FAC, June 8, 2009)



- Model beam position (m_j) at CBPMs as function of initial launch at 1st CBPM (x_i), quad offsets (Δq_i), CBPM offsets (Δb_i) ($\boldsymbol{m} = [\boldsymbol{R_x}\ \boldsymbol{R_q}\ \boldsymbol{R_b}][\boldsymbol{x}'\ \boldsymbol{\Delta q}'\ \boldsymbol{\Delta b}']'$)
- Calculate response matrix for 4 energies (4 ~ 10 GeV for HX)
- Measure ~200 orbits and average for each energy
- Generate final response matrix, Δq_i, Δb_i and apply Δq_i and Δb_i

Beam Based Alignment (2)

- **HU1 BBA** (conducted once or twice for a month)
  - ~5 iterations for under 10 μm deviation, ~15 min. for an iteration

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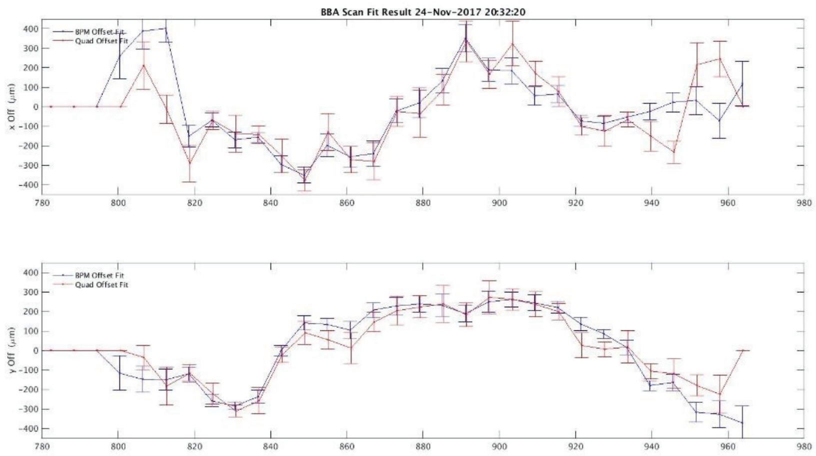

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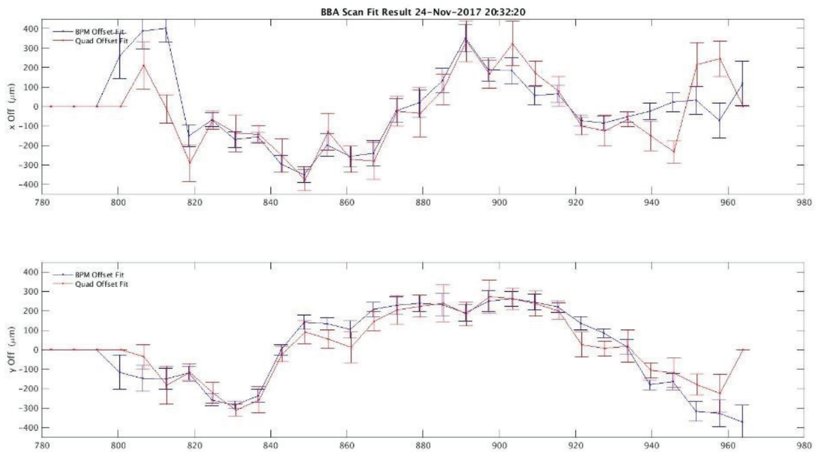

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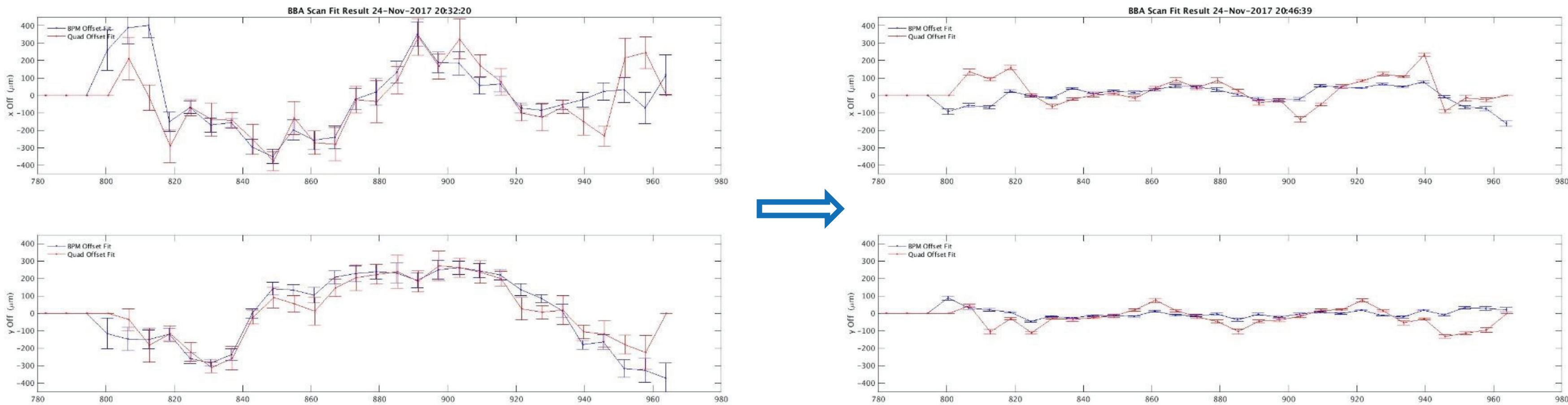

Beam Based Alignment (2)

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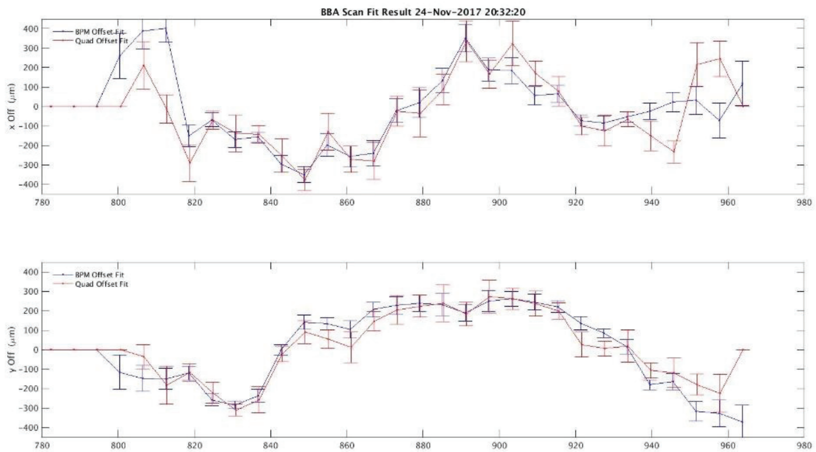

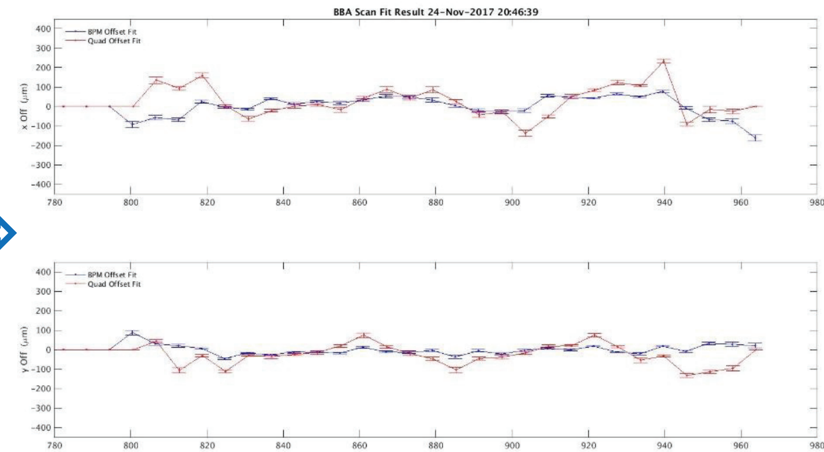

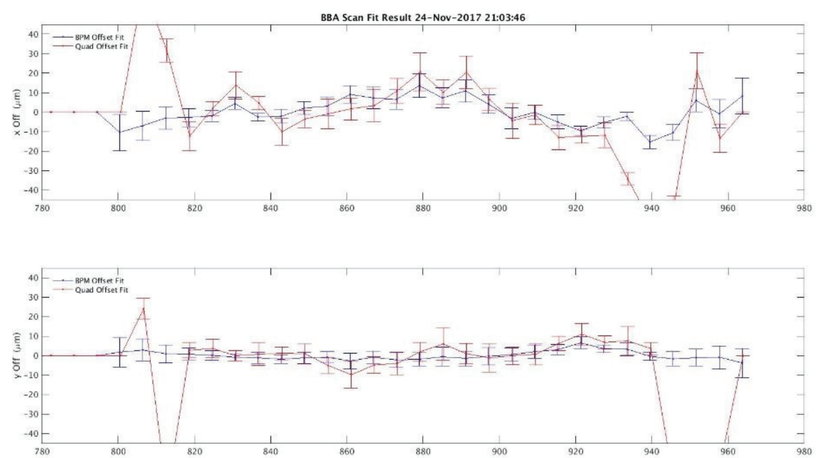

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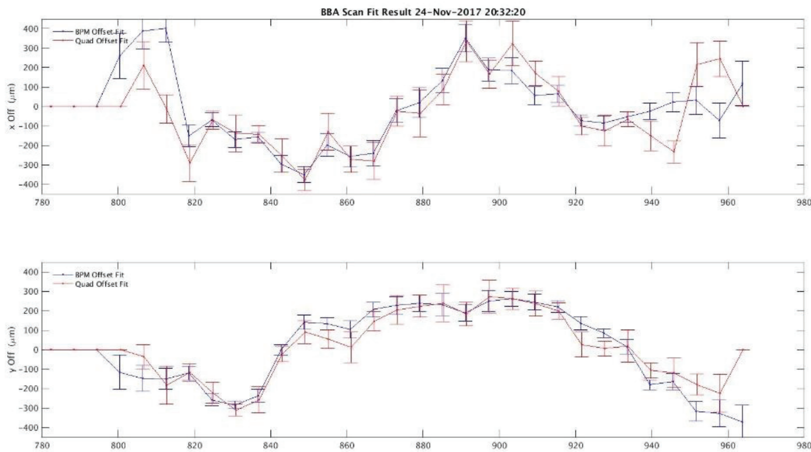

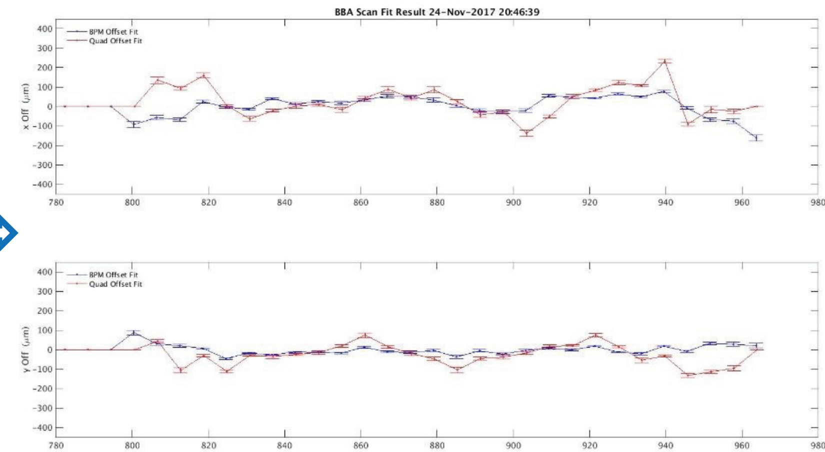

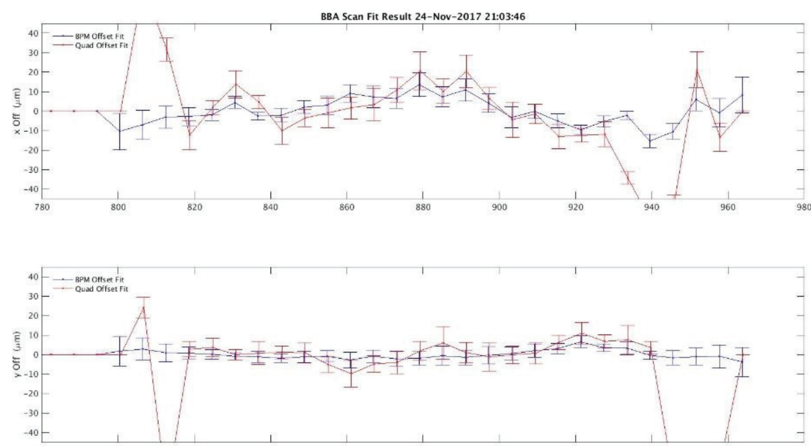

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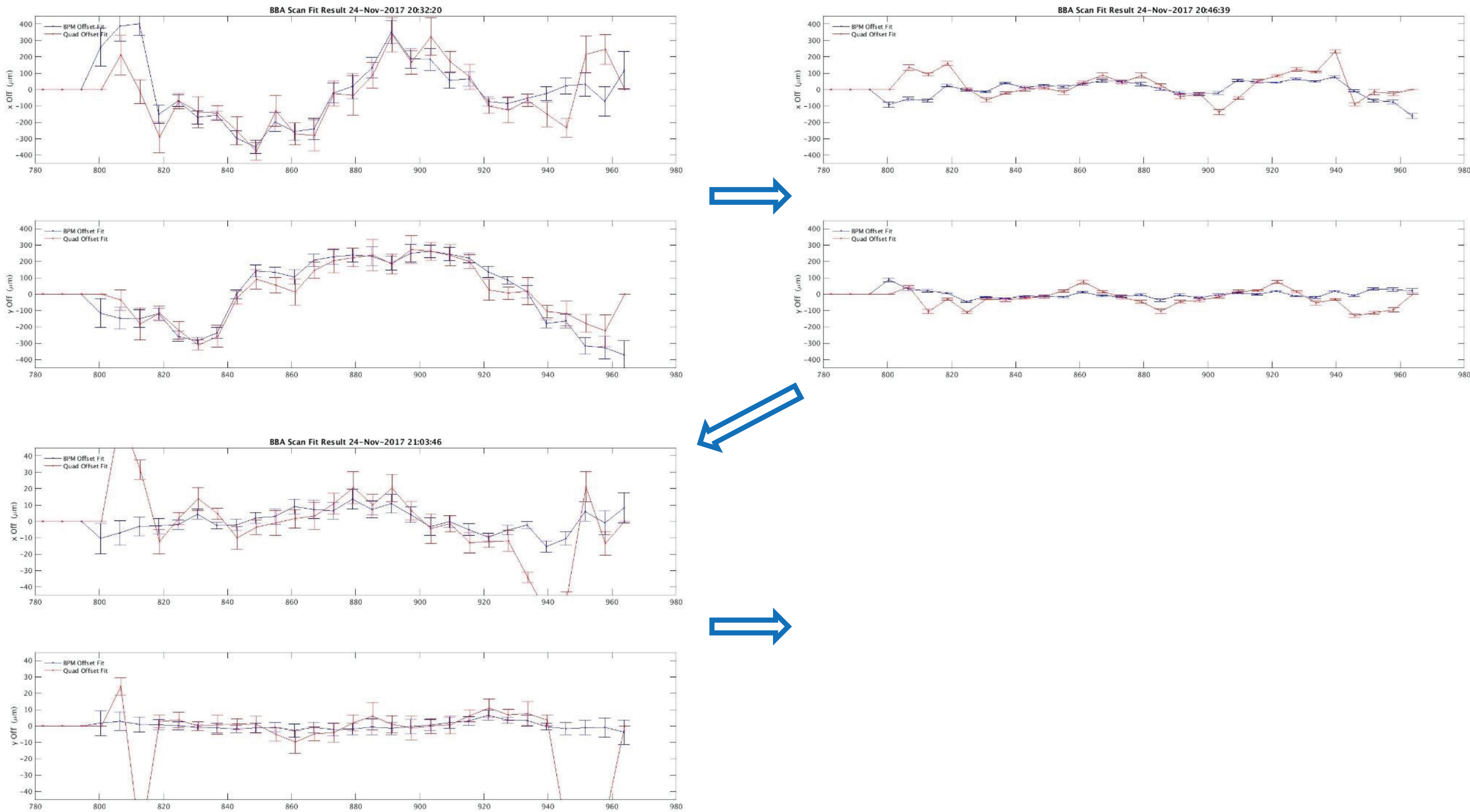

Beam Based Alignment (2)

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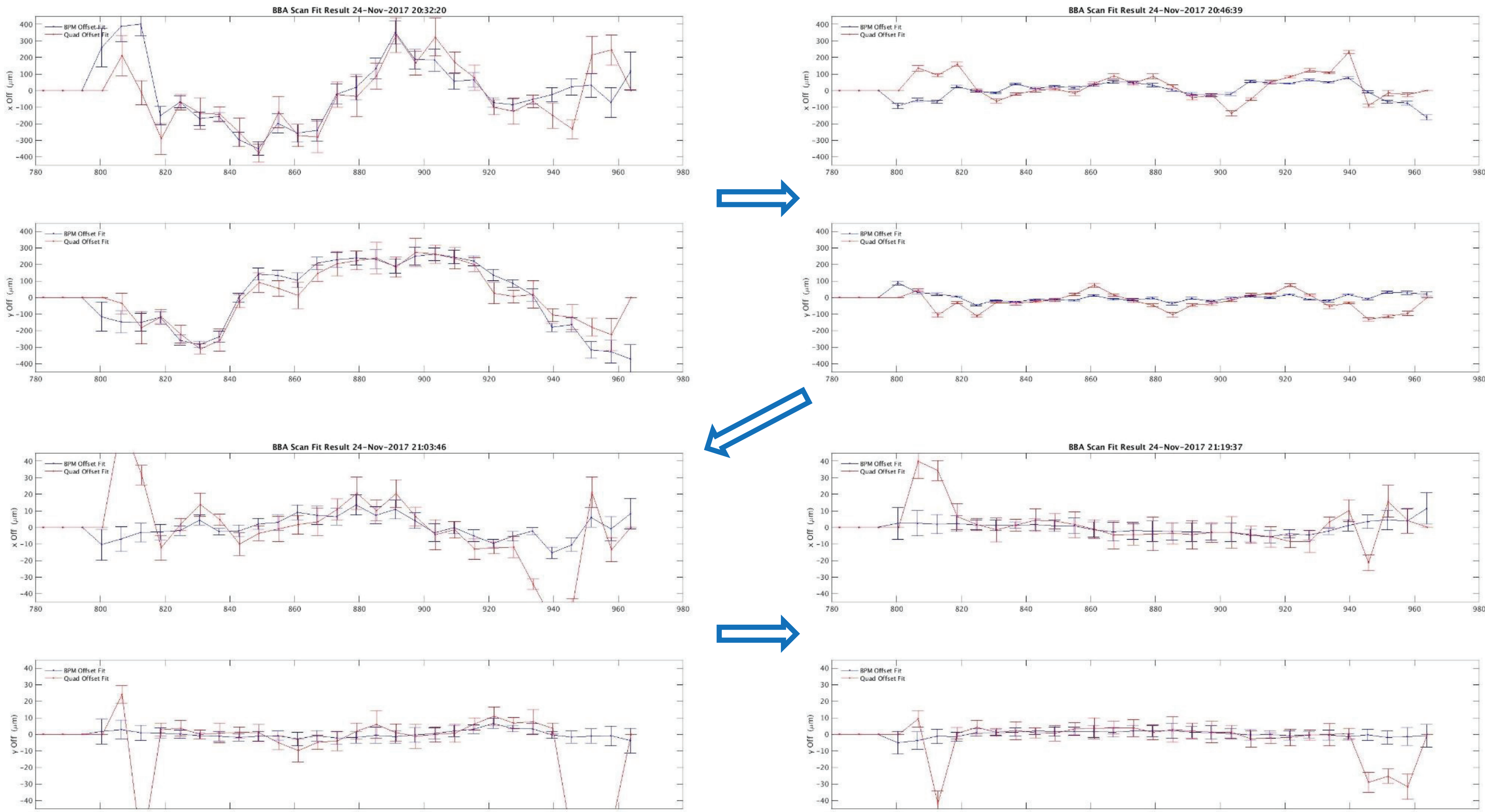
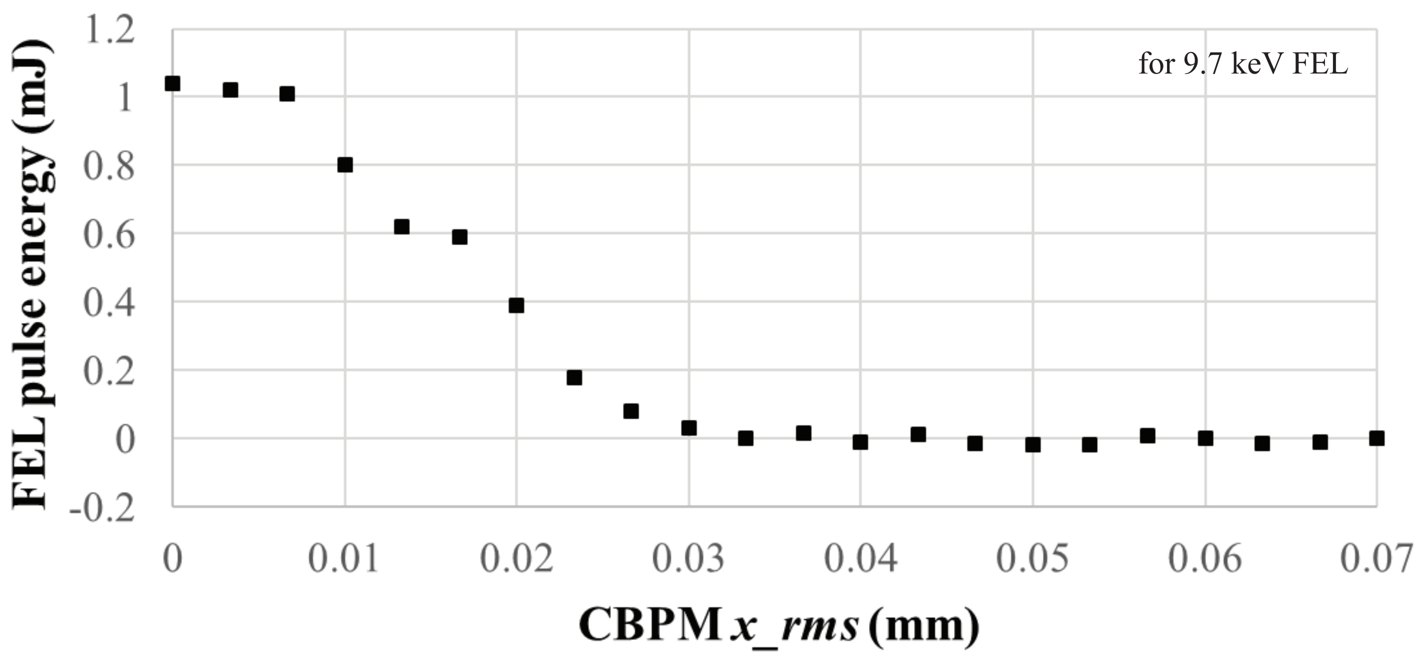


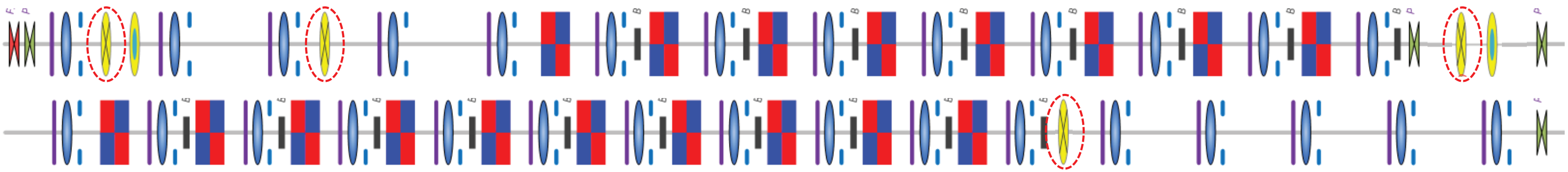
Beam Based Alignment (3)

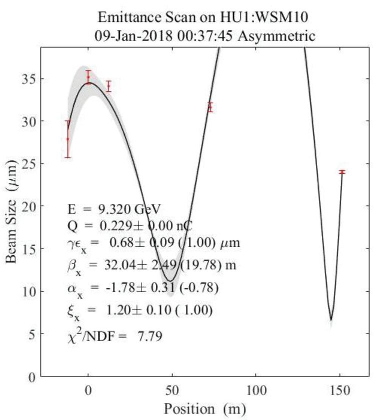
- **FEL power reduction**
  - ~20% reduction by ~10 μm(rms) orbit deviation from reference orbit

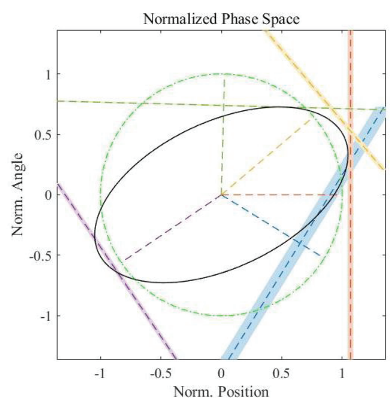


e-beam Size Matching

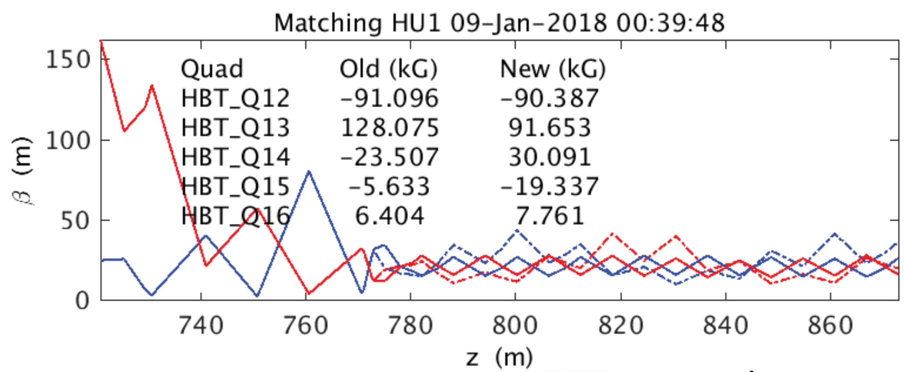
- **Measure twiss parameters**
  - Use 1 wire-scanner in HBTL and 4 wire-scanner in HX UND line

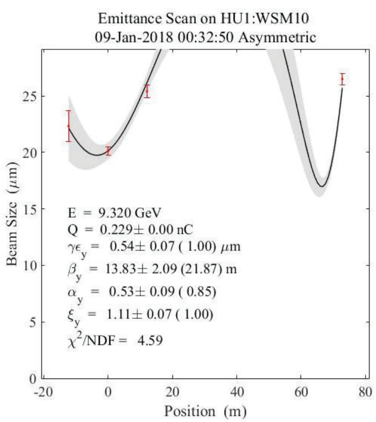


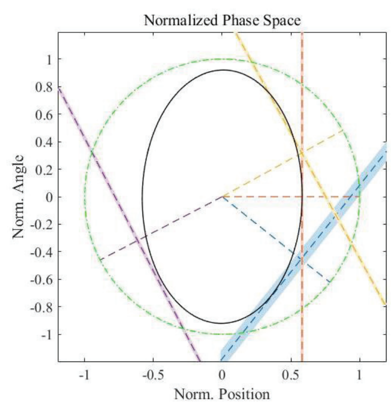




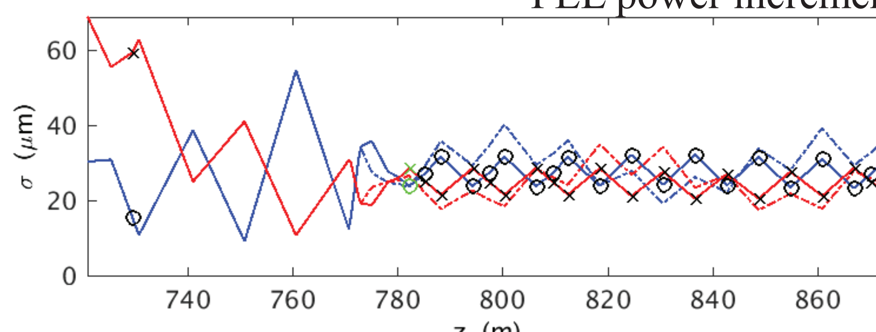
Calculate the field of matching quads







FEL power increment ~15%



▪ Schematic of Beamline (Optical Hutch)

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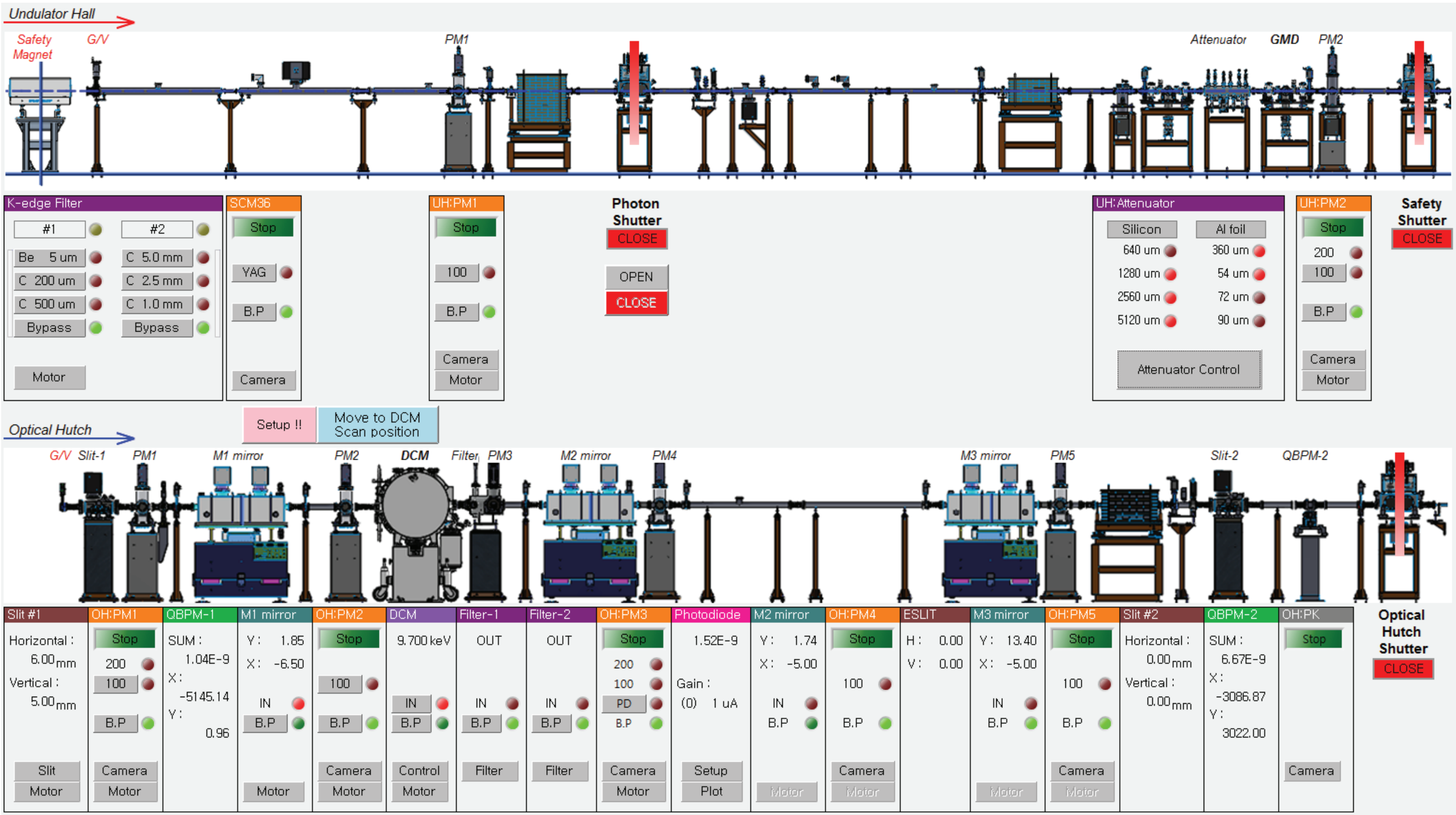
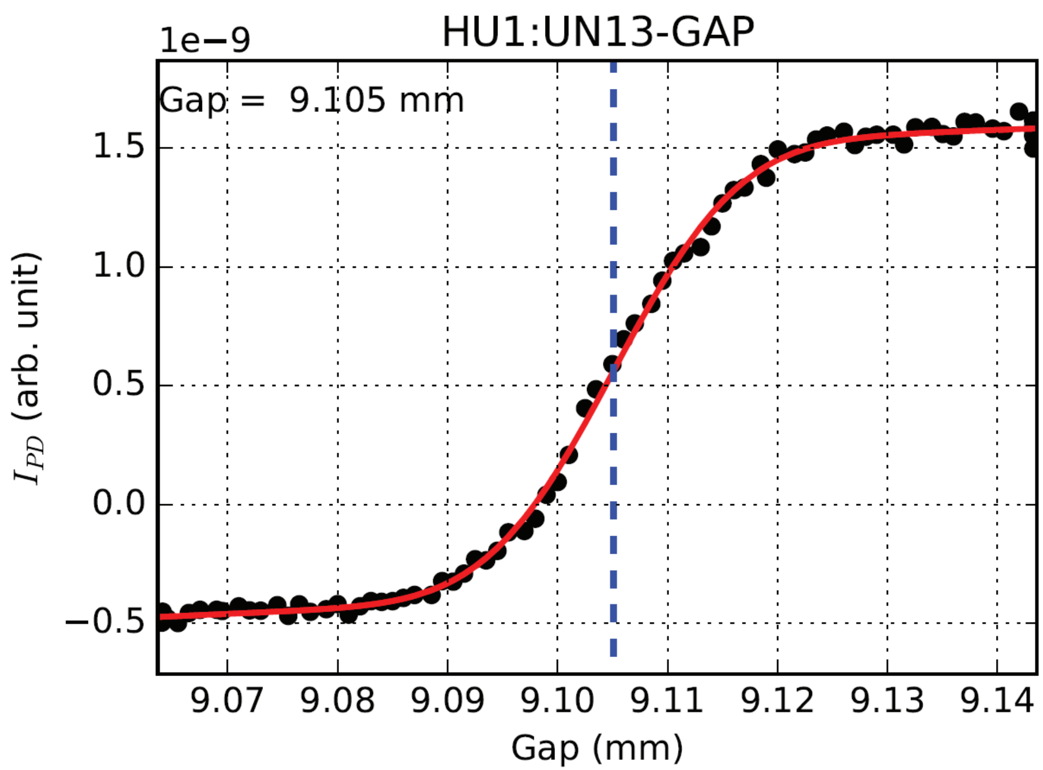


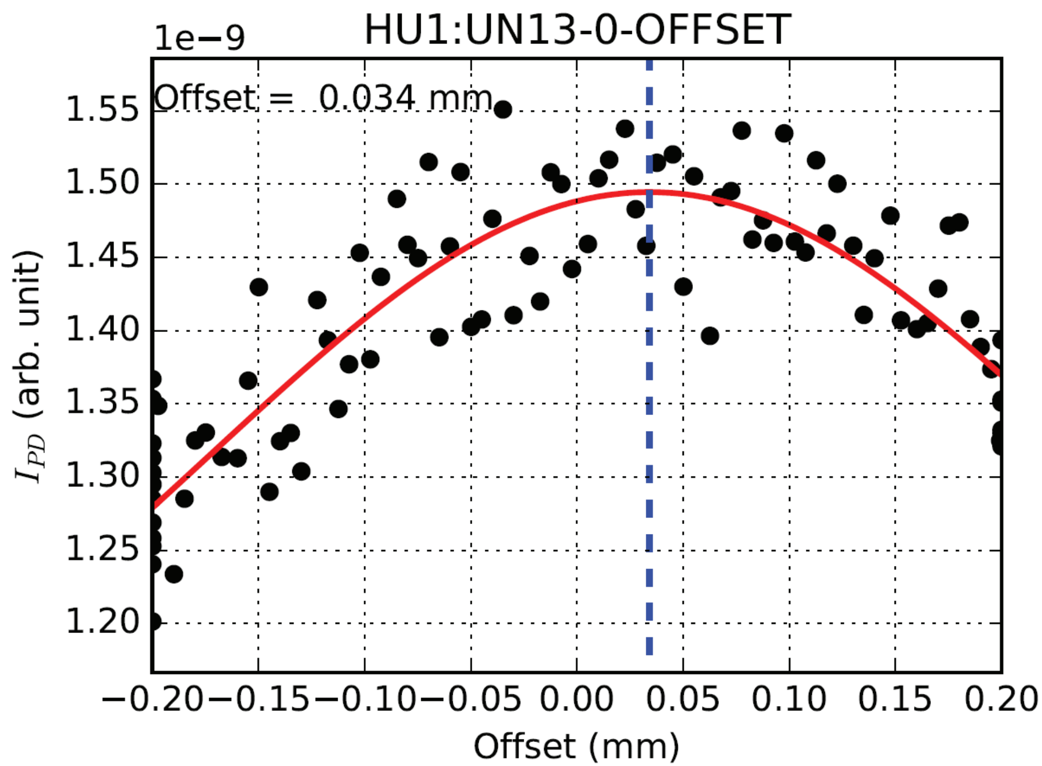
Undulator K-tuning

- **K-tuning**
  - Find UND gap for the target undulator K value by measuring the photon flux of the undulator radiation in the target energy (~7 keV, $\boldsymbol{K}$ = 1.87)
  - Use Double Crystal Monochromator (DCM) in Optical Hutch (OH)
  - Use uncompressed e-beams for less energy loss by the wakefield



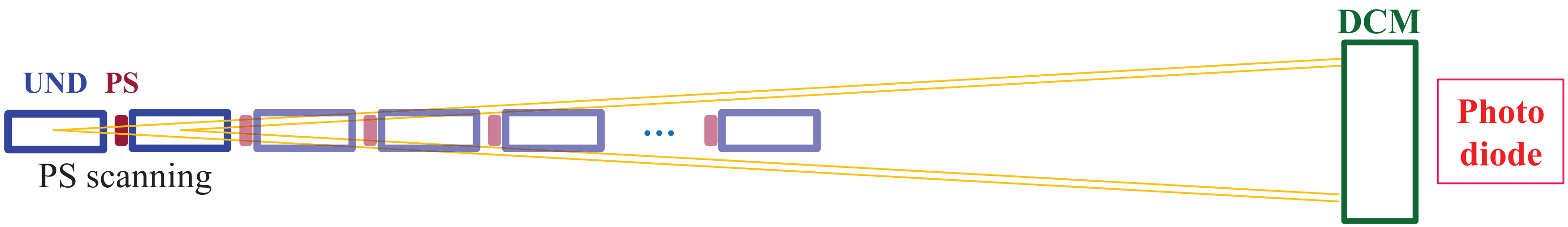
Mid-plane Scanning

- **Mid-plane scanning** (conducted with BBA)
  - Find UND mid-plane by scanning vertical offset of each UND
  - to use the maximum field region in UND
  - Use uncompressed e-beams for less energy loss by wakefields
  - If there is large difference (> 0.1 mm) of V-offset by this scanning, K-tuning should be conducted again

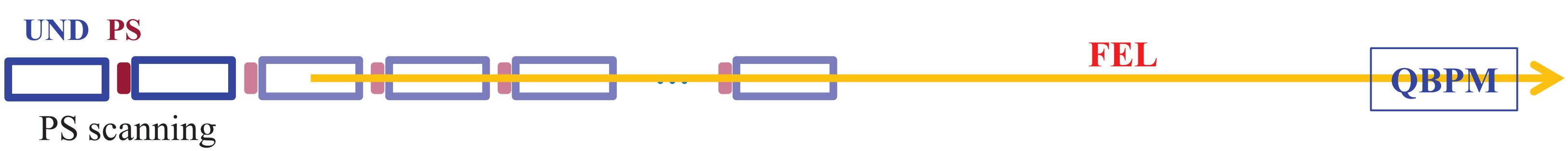


Phase Shifter Optimization (1)

- **PS scanning with undulator radiation**
  - Use ~ 7 keV radiation of 2 UNDs (K = 1.87)
  - PS scanning between 2 UND. Others are opened (gap = 40 mm)
  - Use uncompressed e-beams for less energy loss by wakefields

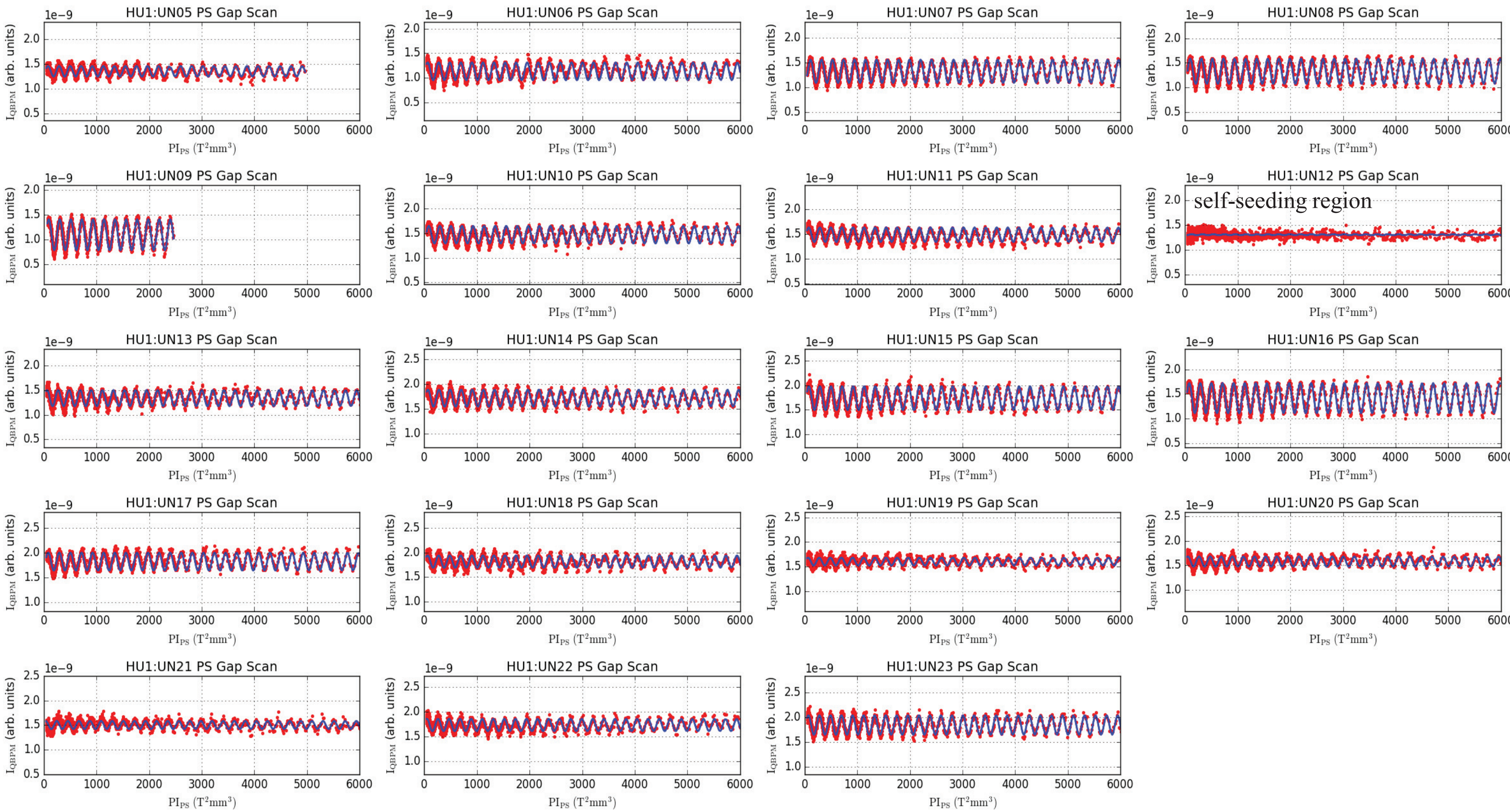


- **PS scanning with FEL**
  - PS scanning during measure the FEL power
  - e-beam and all UND gap setting for FEL generation
  - Useful for searching optimum PS gap in the tapering condition (FEL power is increased 2~3 times after PS optimization)



Phase Shifter Optimization (2)

- **PS scanning with undulator radiation (~ 7 keV)**



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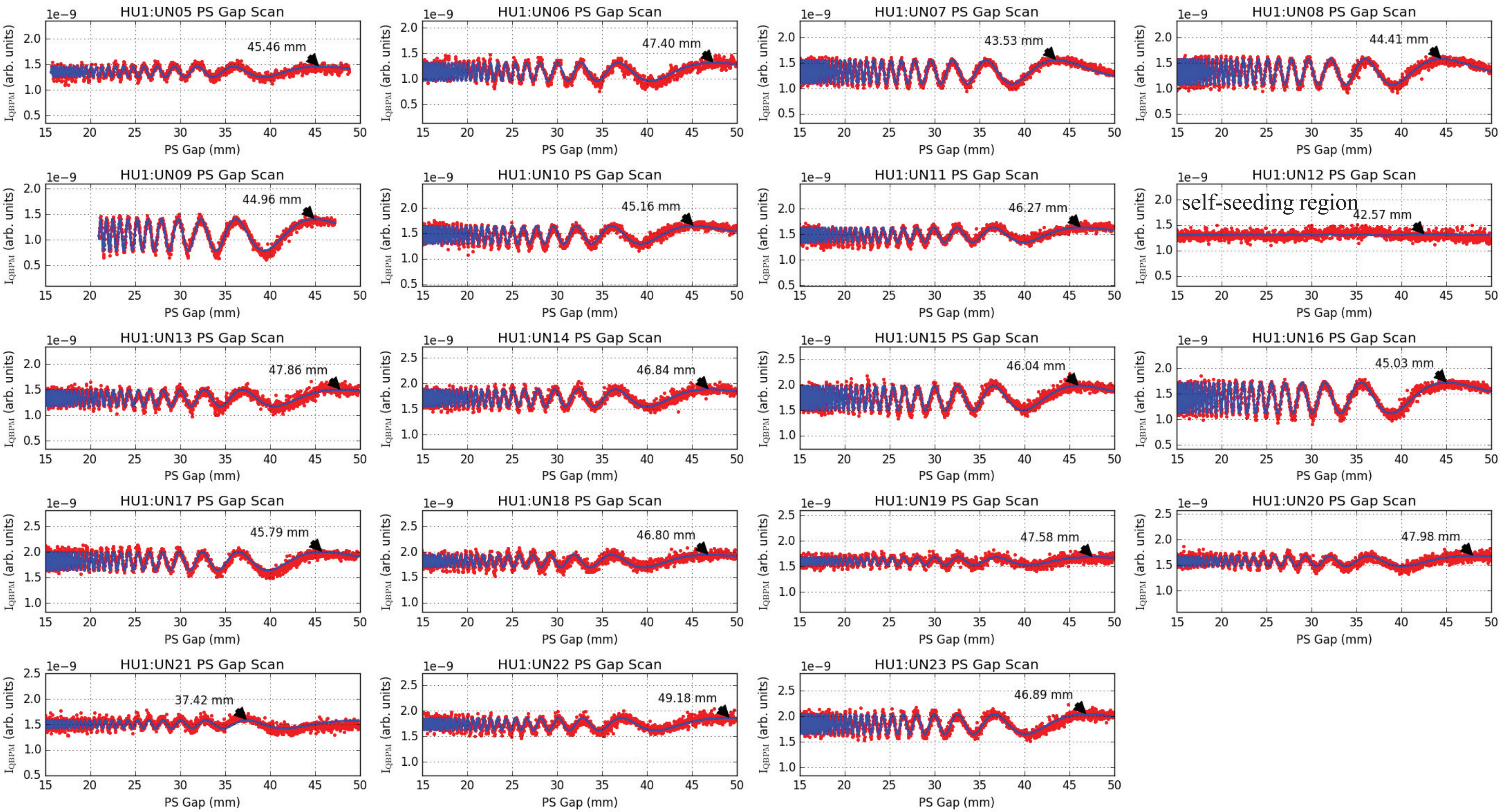

Phase Shifter Optimization (3)

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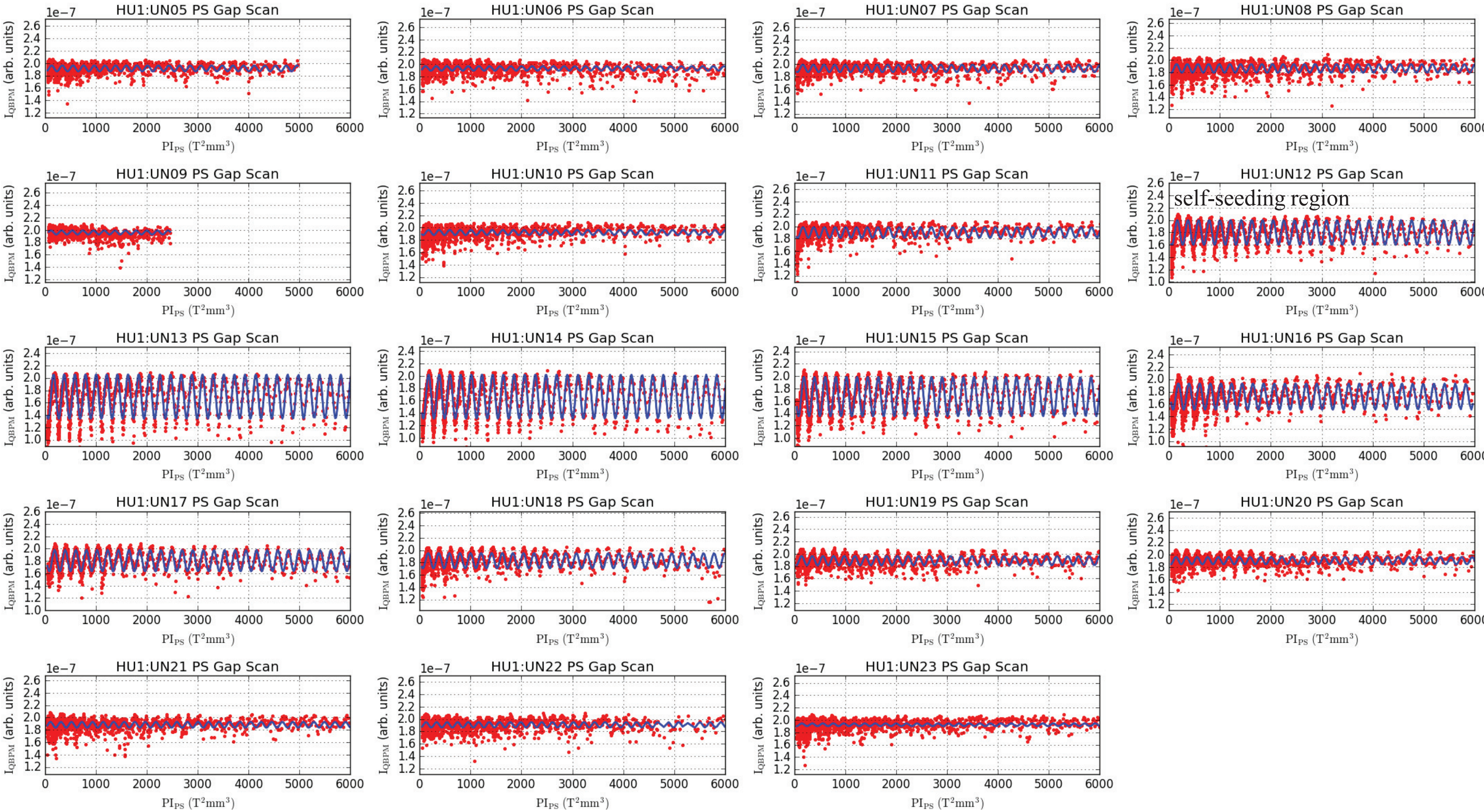
- **PS scanning with FEL (9.7 keV, 1 mJ)**



▪ Phase Shifter Optimization (3)

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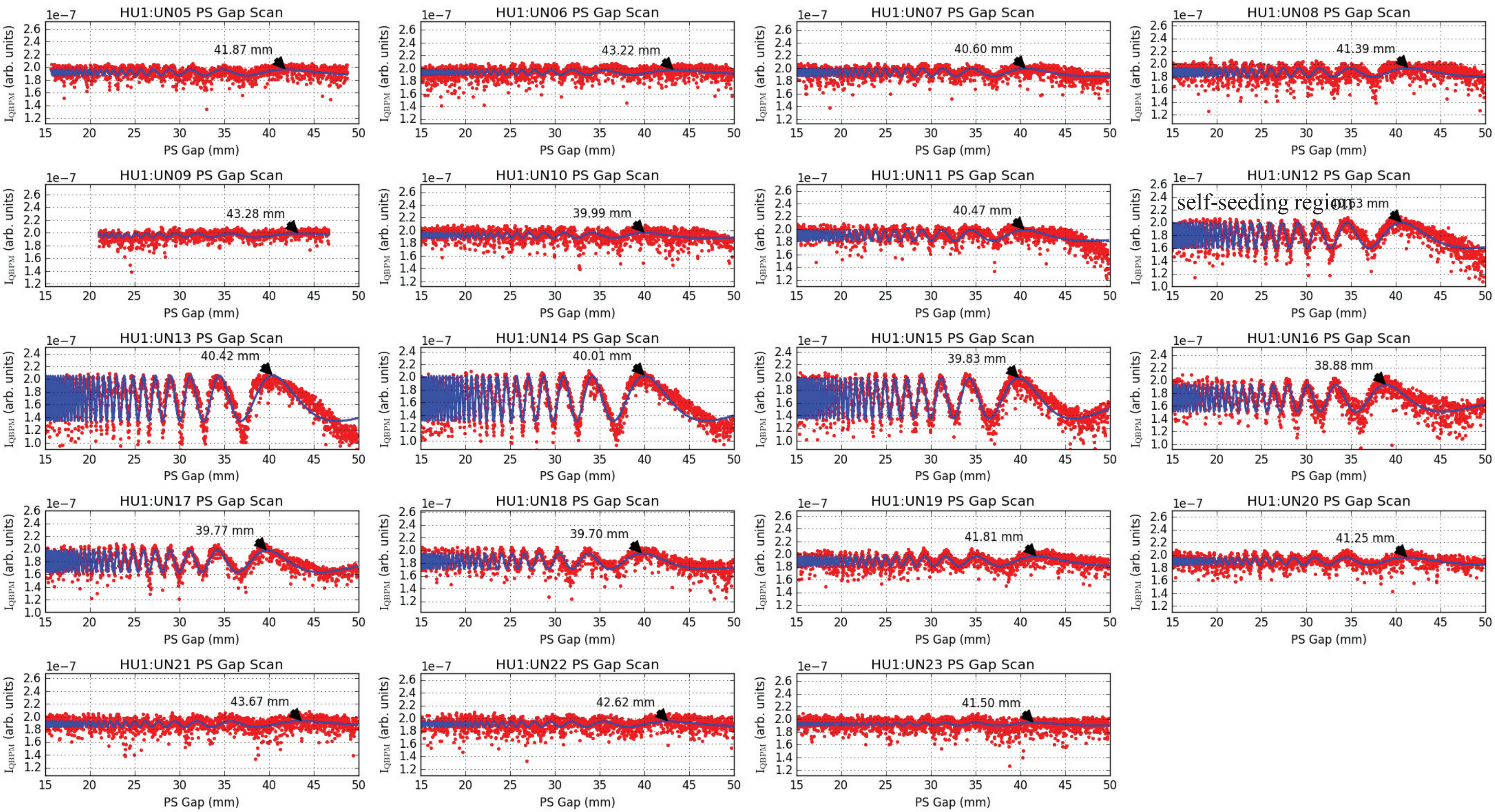
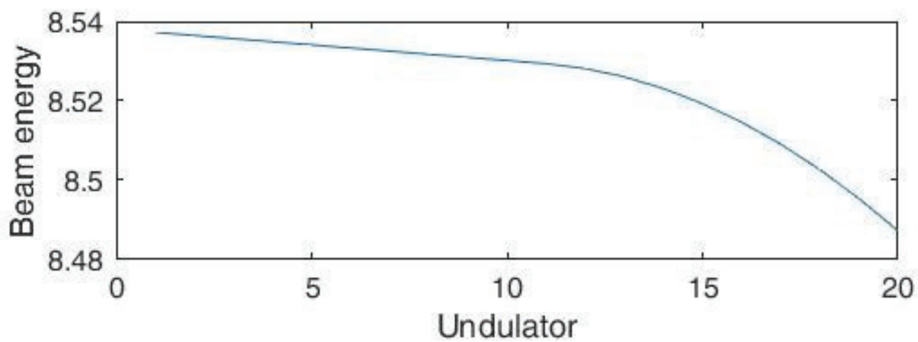
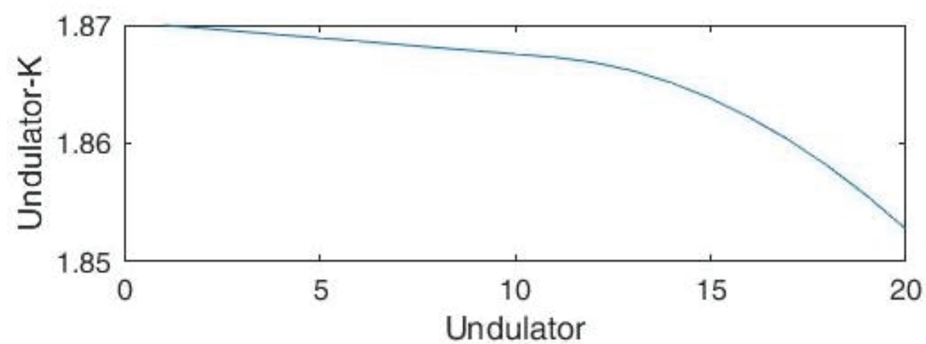


Undulator Tapering

- **Quadratic tapering**
  - Linear energy loss applied to UNDs before starting of FEL lasing (~ 11th UND for 9.7 keV FEL generation)
  - Quadratic energy loss applied to others
  - Calculated energy loss (by simulations) applied for tapering, but the applied energy loss can be controlled by HLA (High-Level Application)
  - FEL power maximized by PS scanning after tapering

- **Applied energy loss & *K* for 9.7 keV FEL generation**

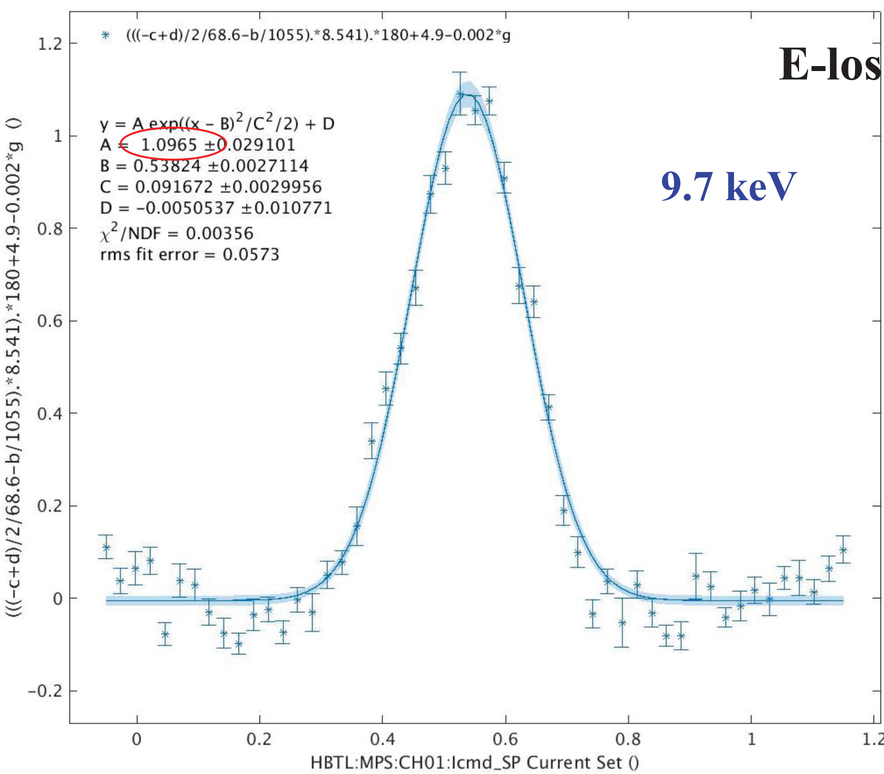


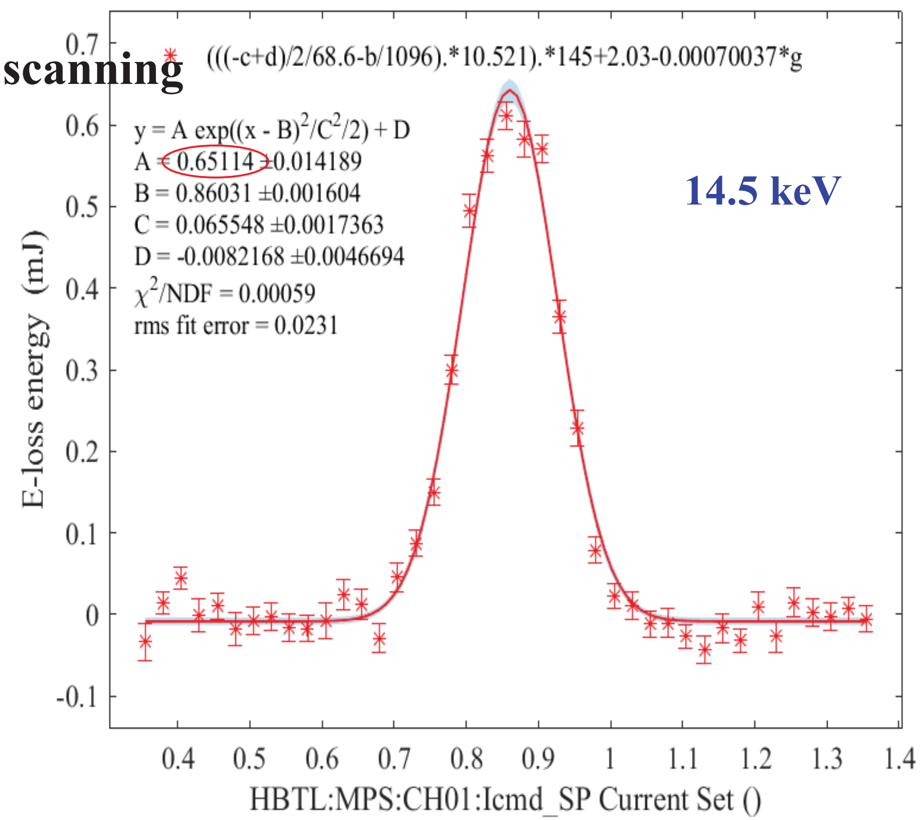


FEL Optimization

- **FEL pulse energy**
  - ~ 1.0 mJ for 7 ~ 10 keV FEL
  - ~ 0.7 mJ for 10 ~ 15 keV FEL

E-loss scanning





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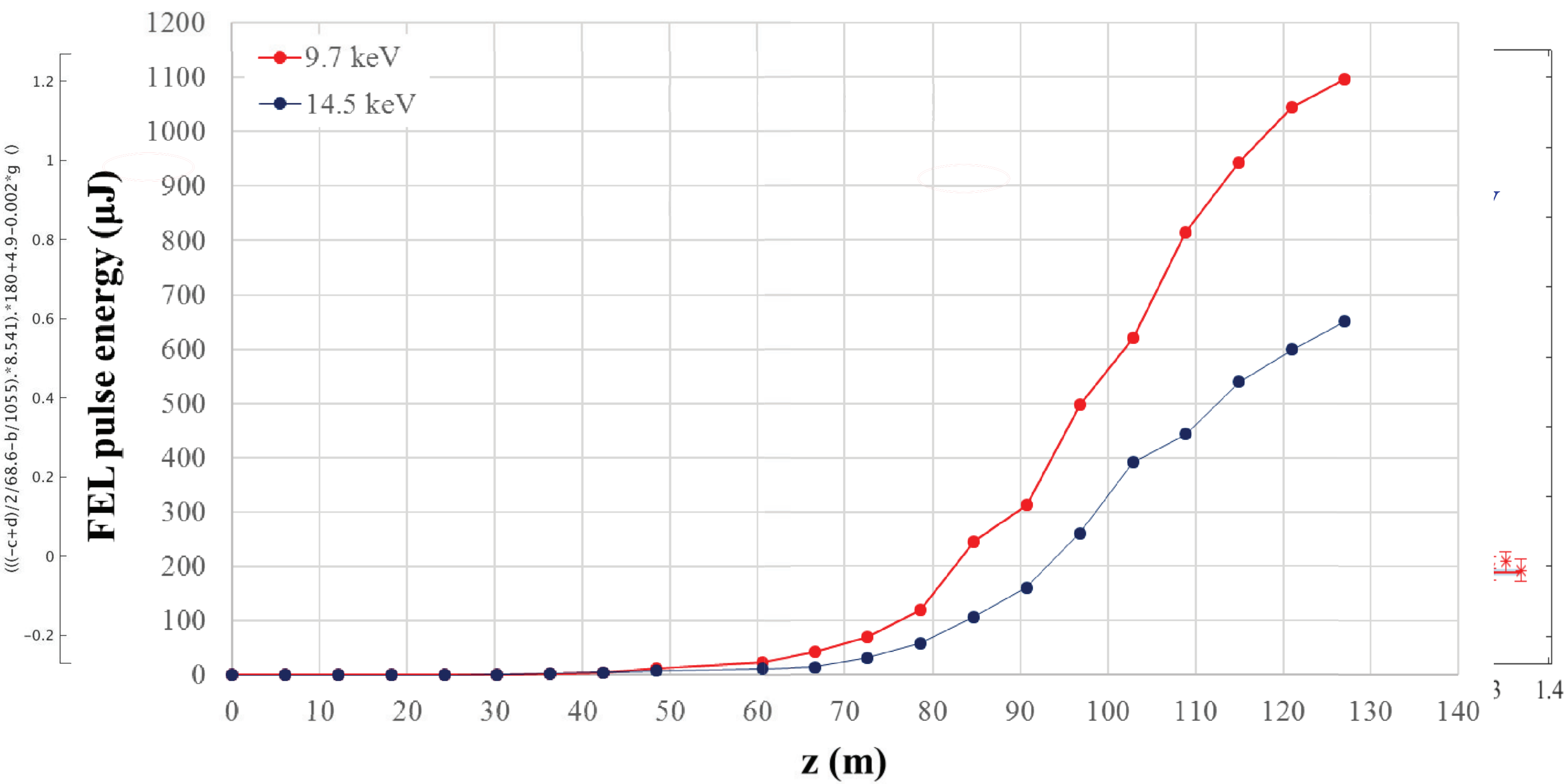

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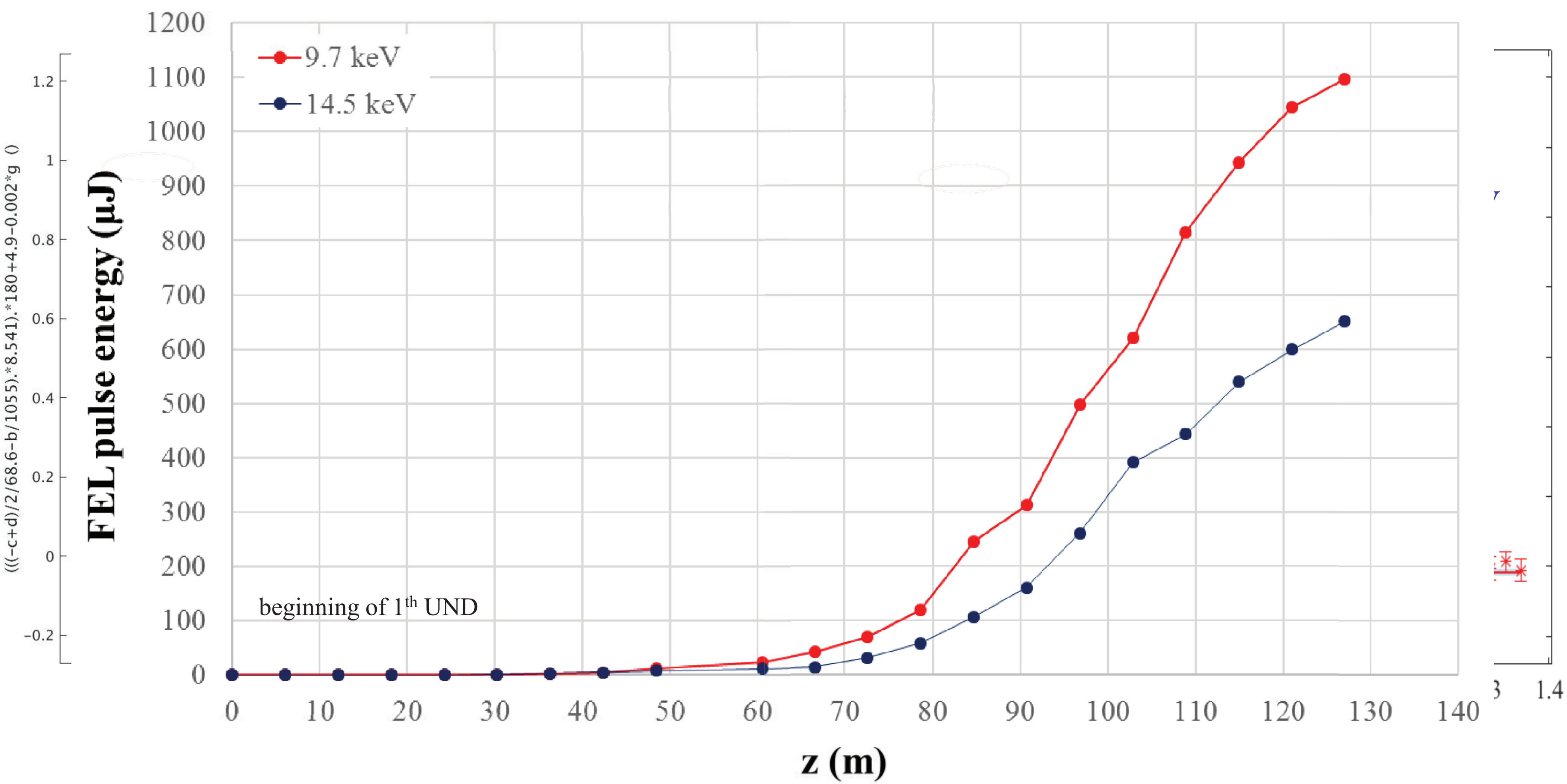

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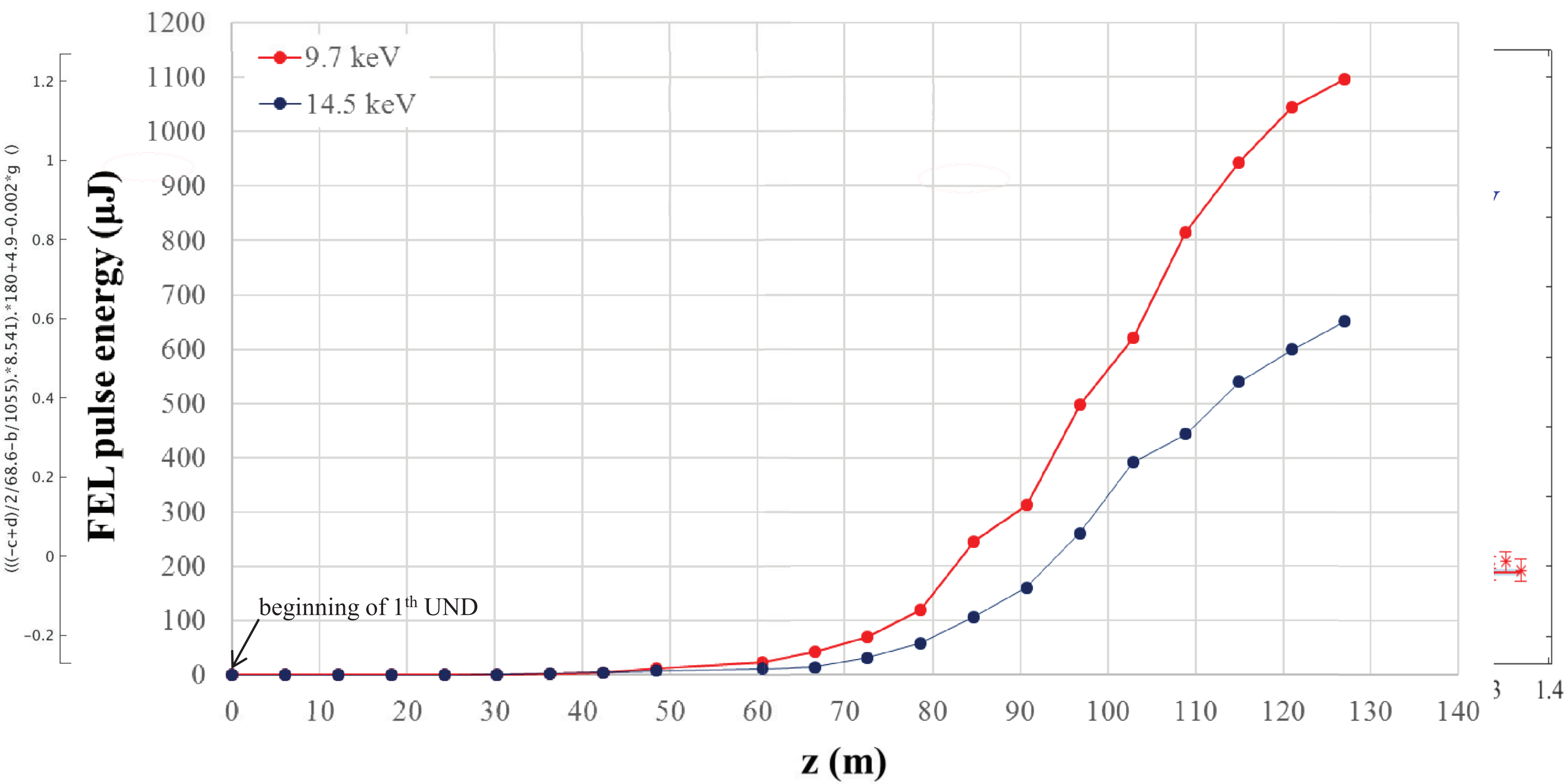

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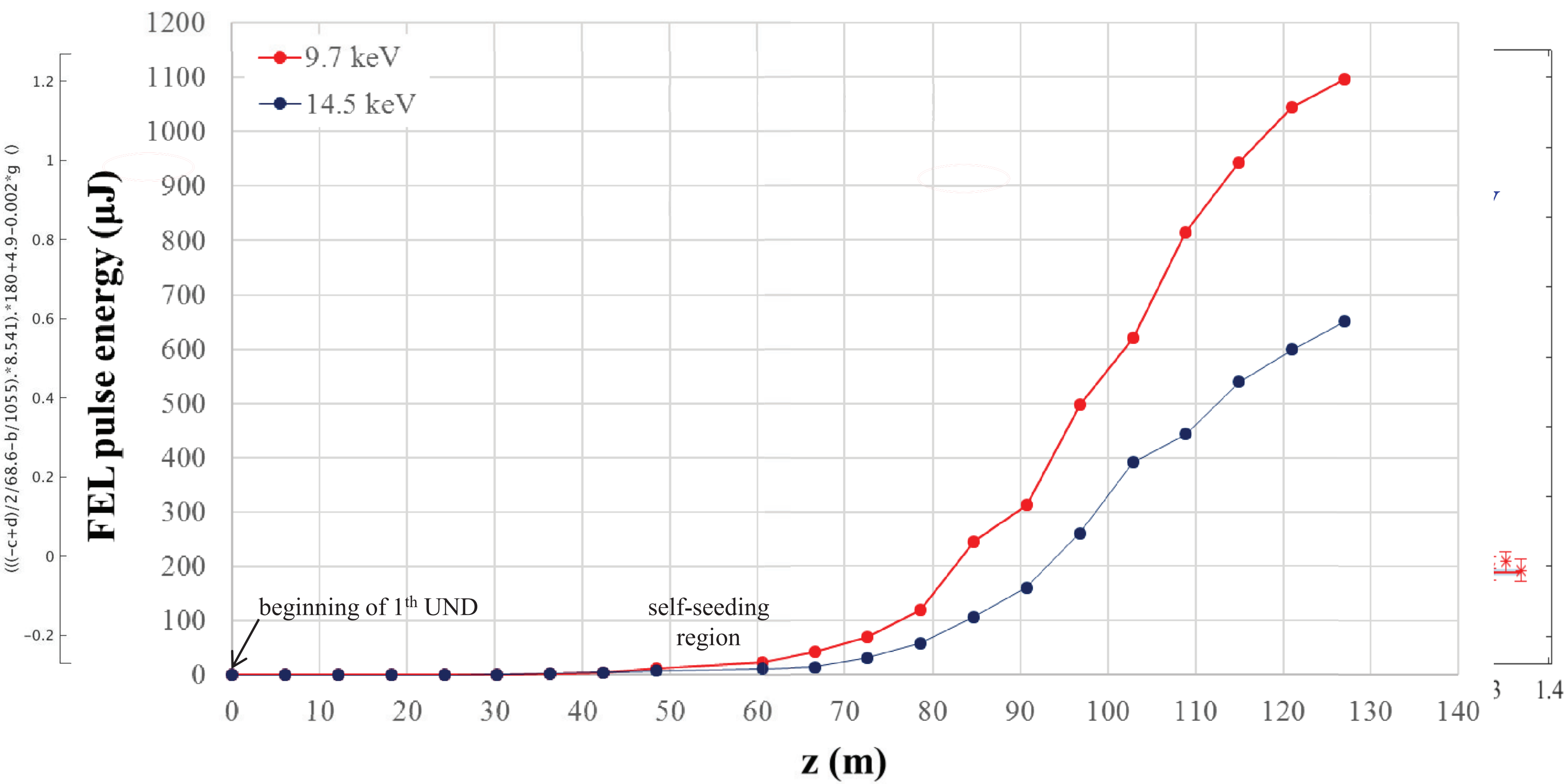

Summary

- **BBA for UND region**
  - ~20% FEL power reduction by ~10 μm(rms) orbit deviation from ref.
- **E-beam size (*β*) matching**
- **K-tuning**
  - Define the reference UND gap for $\boldsymbol{K}$ = 1.87
- **Mid-plane scanning**
  - to use the maximum field region in UND, conducted with BBA
- **PS optimization**
  - PS scanning with 2UND radiation → confirm & define the PS spec.
  - PS scanning with FEL (e-beam and UND setting for FEL generation)
- **Tapering**
  - Quadratic tapering applied by HLA
  - ~ **1.0 mJ** for 7 ~ 10 keV FEL, ~ **0.7 mJ** for 10 ~ 15 keV FEL


THANK YOU
PAL-XFEL