Beam-based alignment for the XFEL SASE1

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Motivation

- The electron trajectory through undulators less than a few μm is required for strong overlap between particle orbit and radiation cone in the XFEL undulators.
- Conventional alignment technique is not enough → beam-based alignment (BBA) with different beam energies is used.

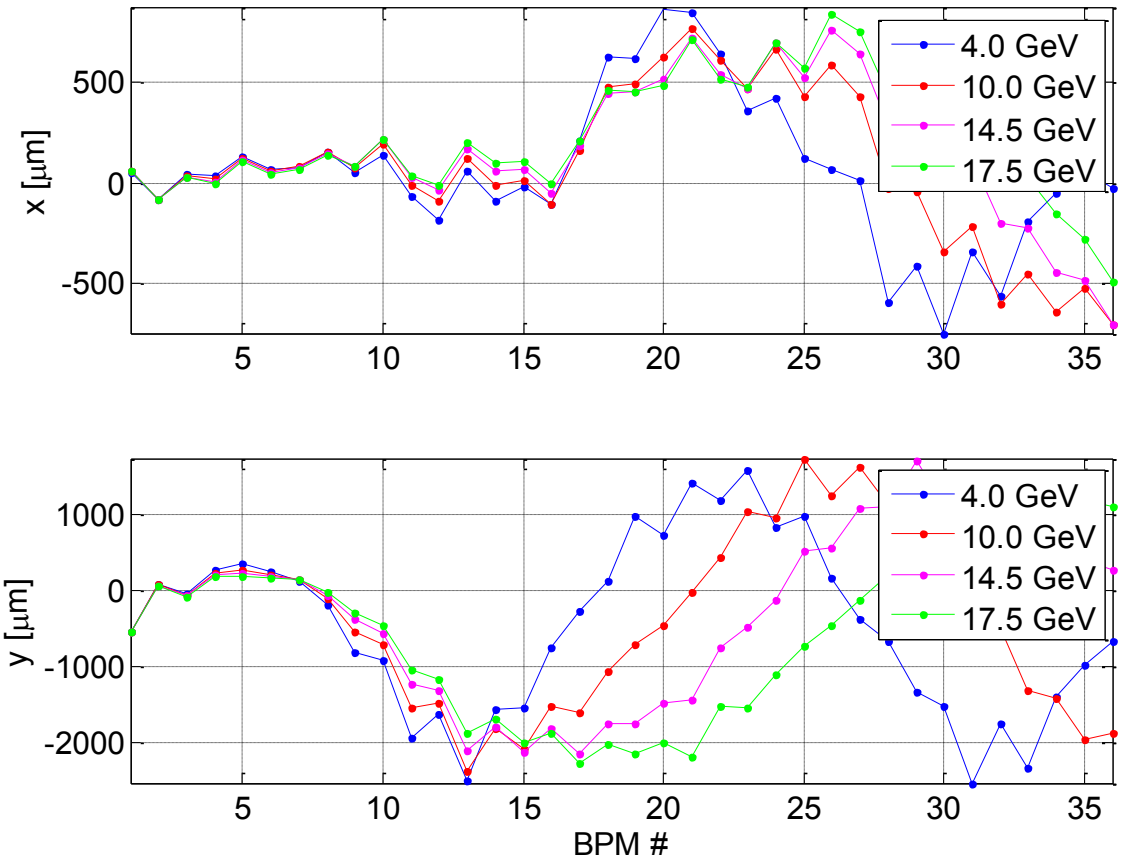
BBA Simulations

- LCLS method
- Simulation code : Elegant
- Errors
  - BPM rms resolution : 1 μm (±1 gaussian)
  - BPM rms offset : 100 μm (±3 gaussian)
  - QUAD rms offset : 100 μm (±3 gaussian)
- Fixed quadrupole field in SASE1
- Simulations for 100 random seeds

BBA steps (LCLS-method)

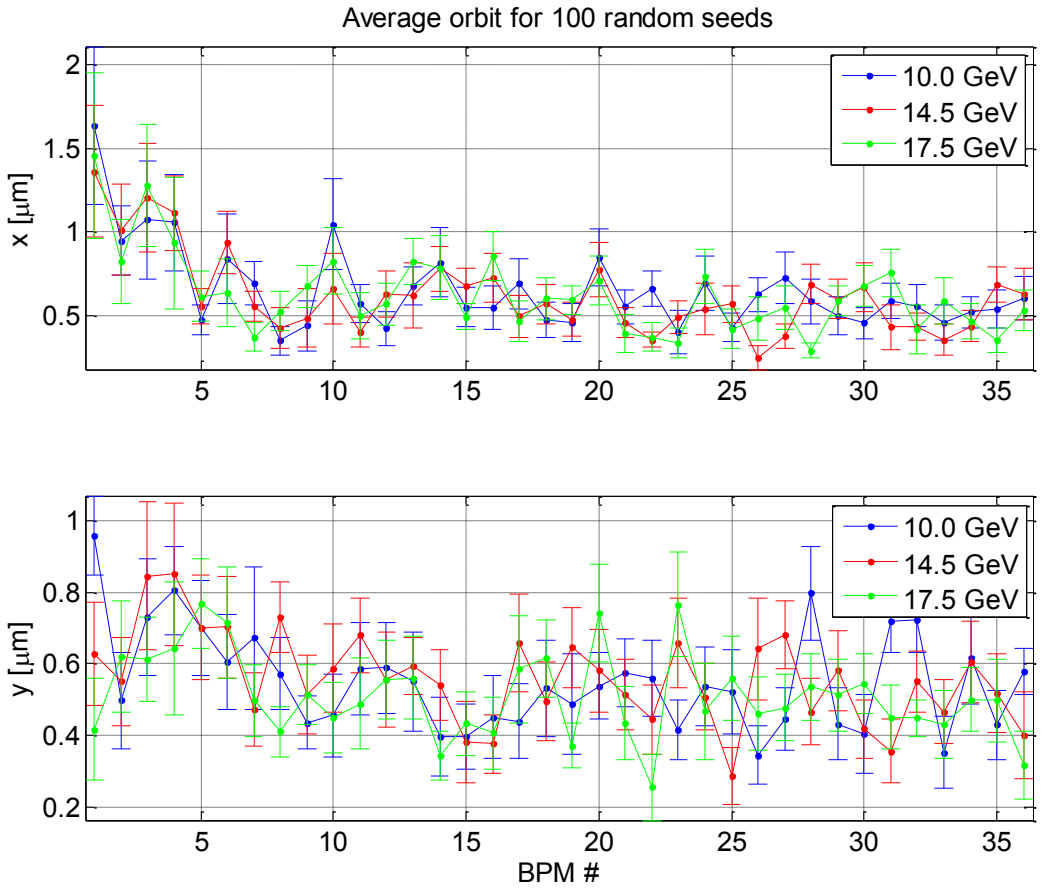
- Generate initial random quad & bpm offsets
- Make response matrices for 4 energies (4.0, 10.0, 14.5, 17.5 GeV)
- Save BPM readings for each energy
- Calculate quad & BPM offsets → Set to new positions for quad and correct the offsets for BPM
- Linear fit from corrected offsets → launch condition
- Steer BPM readings to ~ 0 using minimum number of quad-movers
- Several iterations until saturation

Orbit size with BPM & quadrupole errors



1 random seed

Average orbit size after 3 iterations



100 random seeds, absolute value

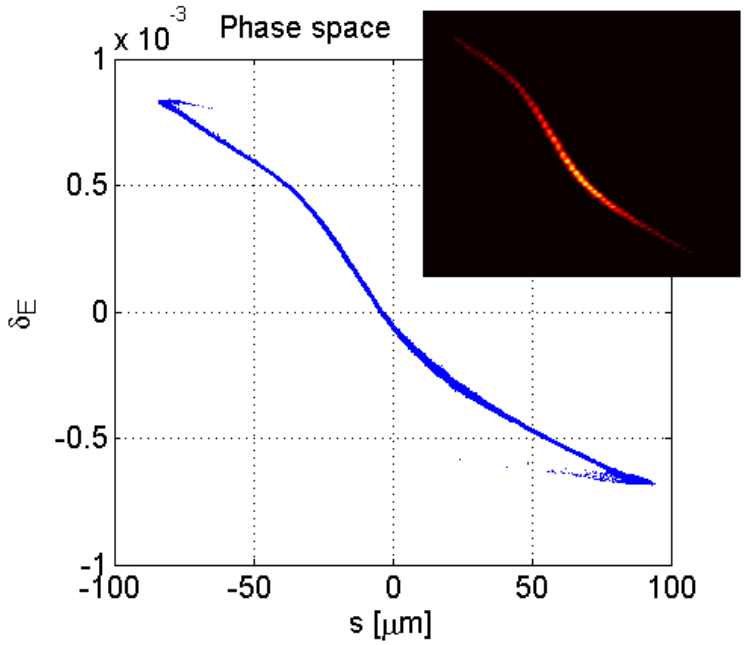
Orbit size decreases to a few μm after 2 or 3 iterations.

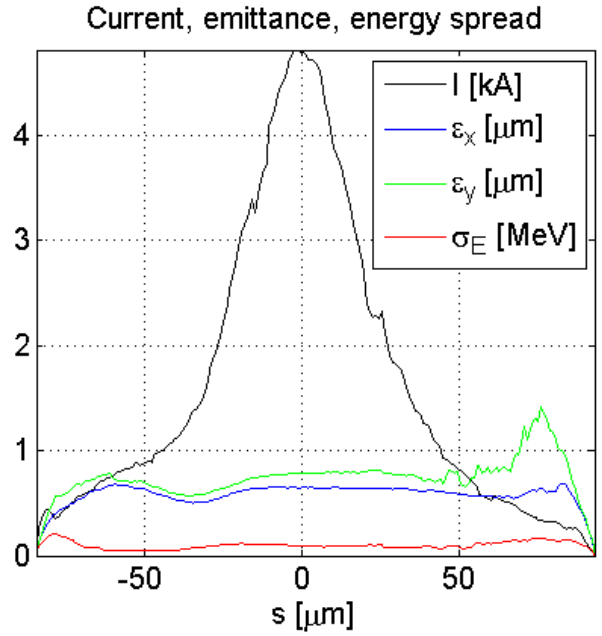
S2E for BBA

- Simulations
  - Beam charge : 1 nC

Program	XFEL lattice
Astra	Gun – ACC1
Elegant	After ACC1 – before SASE1
Genesis	SASE1

Beam profile after main linac





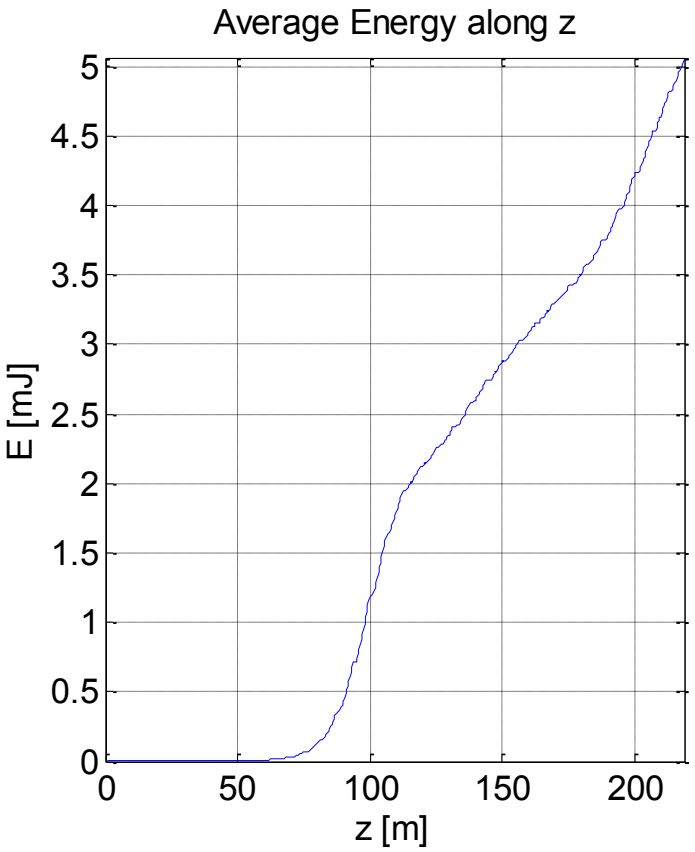
Remove about 3% bad particles in the analysis

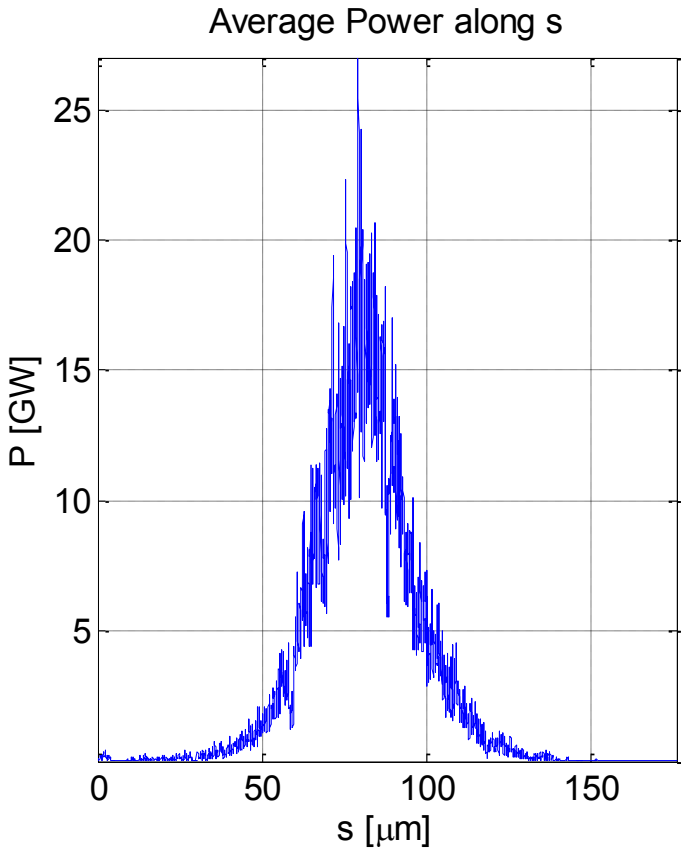
$\varepsilon_{proj,x}$ = 0.8 μm

$\varepsilon_{proj,y}$ = 2.9 μm

FWHM = 163.5 fs

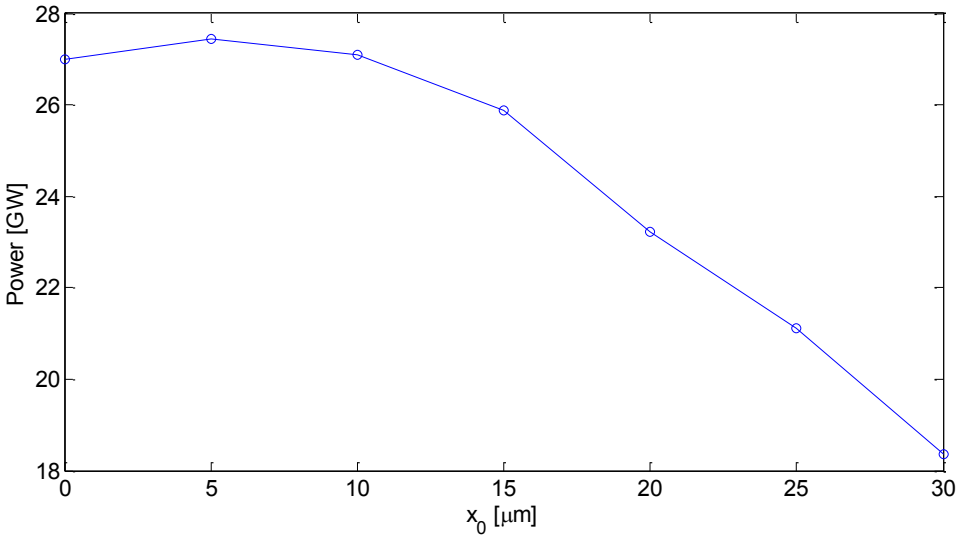
Average radiation energy & power at XFEL SASE1





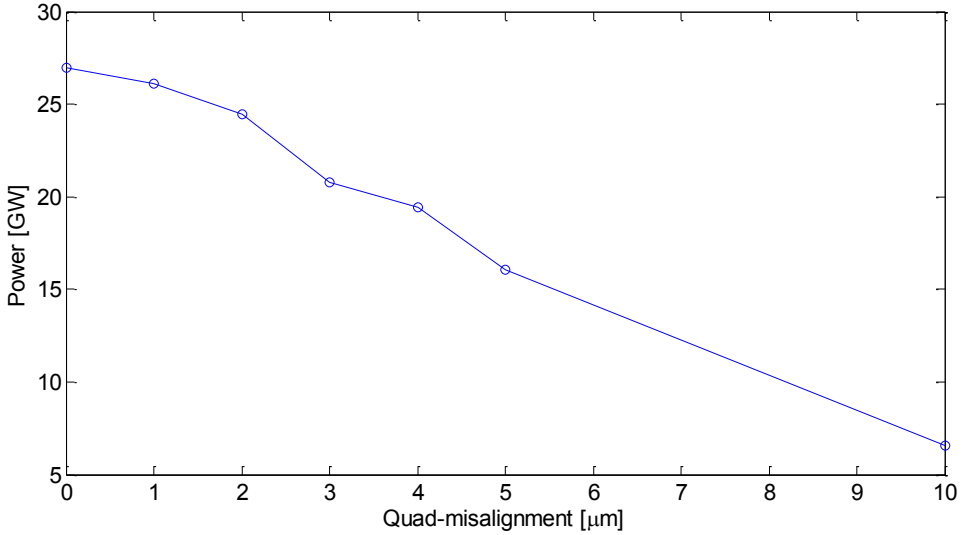
10 random seeds for shot noise

Average radiation power with initial x-position & quad-misalignment



Average radiation power vs. initial horizontal position (2 random seeds for shot noise)

Average radiation power vs. rms misalignments of quadrupoles (5 random seeds for misalignments & 1 random seed for shot noise)



Summary

- Achieved
  - Beam based-alignment technique of LCLS was applied to the XFEL SASE1.
  - Orbit size was decreased to about 2 μm after 2 ~ 3 iterations for 100 μm (±3) BPM and quadrupole offsets.
  - Average radiation power decreases more than 10 % for larger than 20 μm initial x-position and 3~4 μm quad-misalignment.
- To do
  - Other errors (quadrupole gradient error, mover calibration error etc.)
  - Decrease of radiation power for the distorted orbit (for more random seeds).