Photon Diagnostics for Undulator Alignment

In collaboration with: Advanced Photon Source APS, Argonne National Laboratory

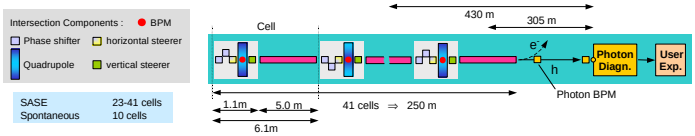
Goals & Features

- **Trajectory alignment**
- **Gap adjustment**
- **Phase tuning**

- complementary to electron diagnostics
- using the spontaneous emission
- spatial distribution and/or integral intensity
- Þ **precise relative alignment**

- One common diagnostics assembly for all cells within a branch
- Scheme depends on gap drive to switch on/off single segments
- Avoids installation of identical components which have to be calibrated against each other
- Avoids increased separation length between segments (debunching)

Layout



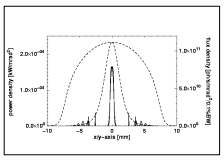
- Parameter basis: TDR 2001 - SASE1 (representative for all TESLA undulator systems)
  E_e = 25 GeV, I_e = 1 nA, ε_n = 1.6 mrad mm, β = 45 m, $\Delta E_e/E_e = 10^{-3}$, λ_U = 60 mm, N = 83 periods, B_0 = 0.67 T or K_{rms} = 2.65

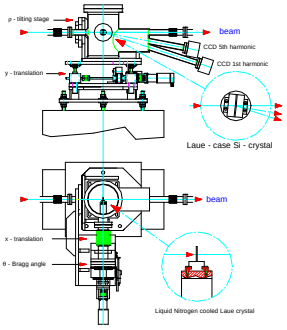
Hardware setup

- Photon BPMs, Sensitivity ~1µm
  Position-sensitive ionization chambers
  backgammon electrodes (Spring8) [6]

- Imaging Station
  Observation of 1st and 5th harmonic
  ⇒ absolute energy scale
  - Laue crystals, d ~ 200 µm
    Si(111) θ=9.17°, Si(333) θ=5.49°
    visual field ∅~5 mm
  - fluorescent screen, fibre optic taper, 6µm fibres
    screen : CCD = 1 : 2.4
    integrated in vacuum window
  - CCD array, 12 µm² (16 bit requirement)
    1024×1024 pixels, 50 kHz (limited by readout noise), readout ~ 20 s/image

  Þ resolution ~ 5 µm²/pixel



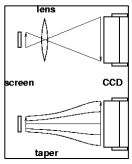


- **Spontaneous beam ® Integral properties**

PIN diode or calorimeter put into direct beam
1 mW (50 W) for single pulse (cw) per undulator segment

- **SASE beam**

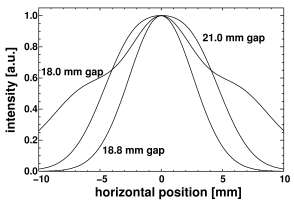
diamond crystal (Laue)
reflected beam:
gain and spectrum
detection by PIN diode or calorimeter
transmitted beam:
overall background



Lens
variable imaging ratio and resolution
only 5% transmission

Fibre
less adjustment
~70% transmission

Emittance measurements at PETRA II



$$e \approx \frac{s^2}{b_L}, \quad b_L = b_0 - 2La_0 + L^2\frac{1+a_0^2}{b_0}$$

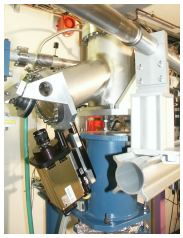
β_0	55.0 m
α_0	-0.19
L	107.7 m
λ_U	33 mm
N	121

Observation energy : 21.23 keV
Line scan through intensity maximum
Gauss fit & background subtraction
Machine & undulator effects
⇒ simulation ⇒ emittance

E	σ of Gauss fit	hor. emittance
11.2 GeV	2.56 mm	21 nmrad
variation of σ by 10% ⇔ ε change of 3 nmrad		

Emittance Monitor Set-up – comparable to situation at XFEL

- Monochromator location 107.7m from source point
- Cryogenically cooled silicon crystal in Laue geometry,
- Conversion to visible light by flourescent screen on an aluminum plate
- Image recording by 12 bit grey scale CCD with 26 pixel/mm resolution
- Main background contribution: scattered light from crystal, high energy background directly from beamline. ⇒ Laue crystal
- Observing the screen at a 90° via mirror, electromechanical shutter



U.Hahn, H.Schulte-Schrepping, SRI 2003, AIP proceedings

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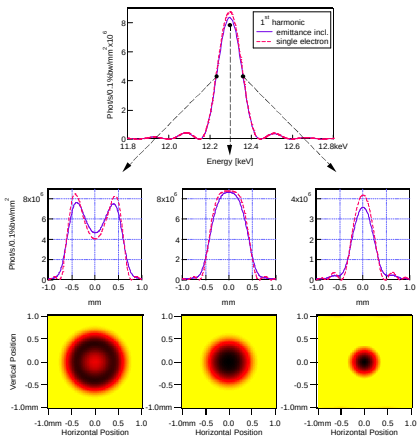
Trajectory alignment



- Required accuracy:
  10µm lateral
  0.2µrad angular

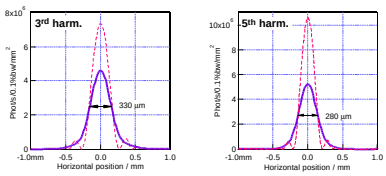
Observation of *spontaneous* radiation of 1st, 3rd, 5th harm.
Detuning (~‰) to higher energy
⇒ narrowing of radiation cone, intensity drop

Same center of gravity for all spatial distributions
⇒ trajectory alignment works independent of possibly incorrect gap setting

3rd and 5th harmonics slightly detuned (~‰) to higher energies

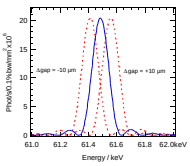
mean line width ~330 µm and center of gravity determination with ~7% accuracy of FWHM
Þ 20 µm in 100m distance or 0.2 µrad angular resolution

distinction of tilted versus shifted orbit → photon BPM



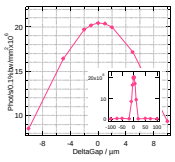
significant emittance influence for higher harmonics

Gap adjustment

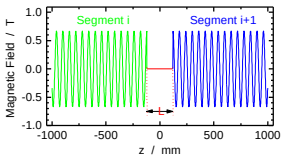


Required precision ~3µm
observe radiation at fixed MC energy (5th harm. ~62keV)
reference gap = 23mm (open)

Þ 3µm deviation ⇔ ~8% intensity drop



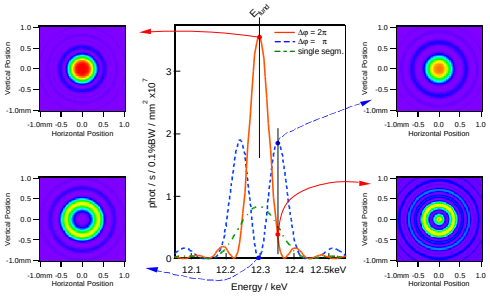
Phase tuning



- Phase advance between two undulator segments:

$$\frac{L}{2g^2 l_R} = \frac{L}{l_0\left(1+K_{RMS}^2\right)} = h \qquad \Delta j\,[rad] = 2p\,h$$

for L=1.1m, λ_R =3.5Å, γ=50000
⇒ η=0.629 or Δφ = 226° (L'→0.65m ⇒ η →1)



Measurement at constant energy E_{fund} while shifting the phase

Þ flux variation ~400 for φ advance π→2π

Phase shifter: Air cooled 3-magnet chicane
2p advance for λ_R=3.5Å, γ=50000 (Δl=0.1m, l_m=50mm)
⇒ B ~ 0.1T