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Direct Observation of Ultralow Vertical Emittance Using a Vertical Undulator

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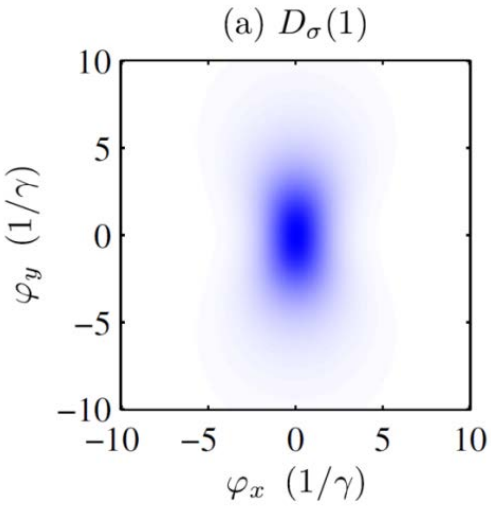
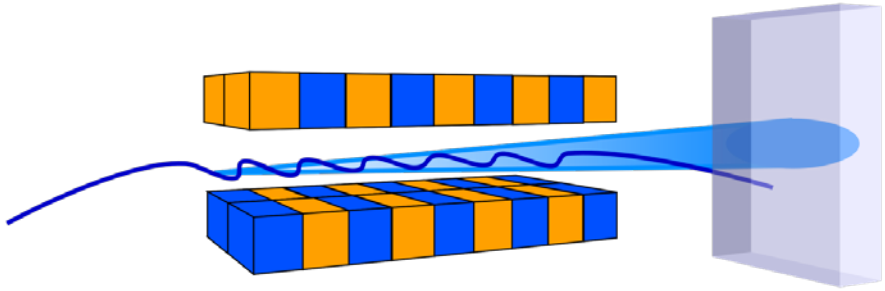
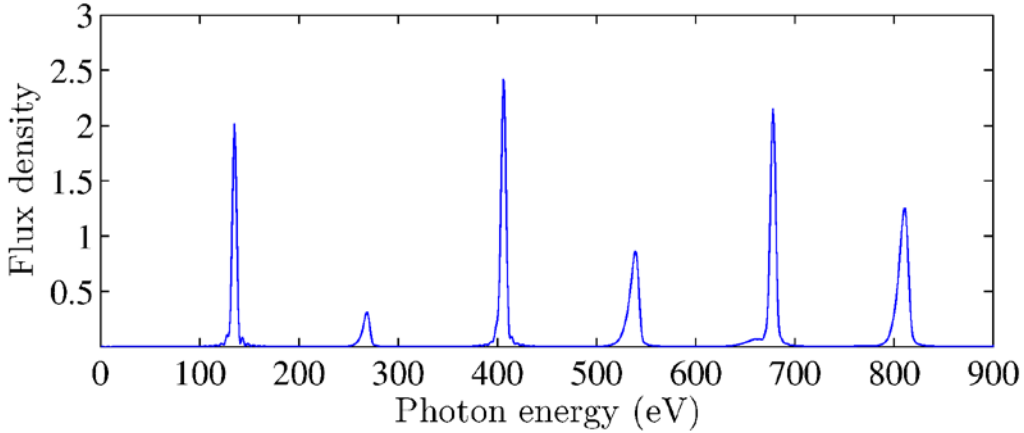
Undulator radiation – horizontal

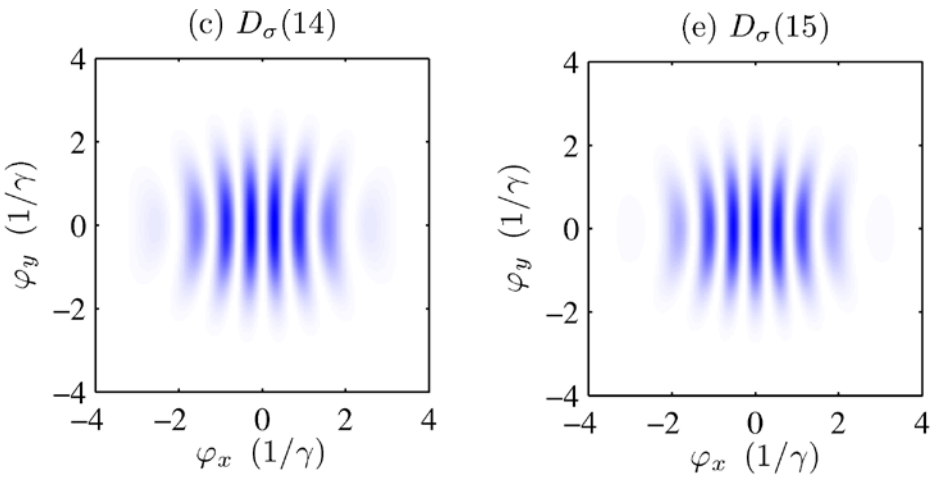




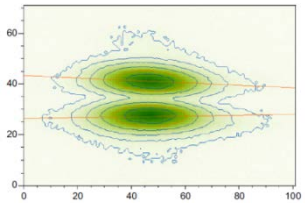


Wootton, et al., PRSTAB 17, 112802 (2014)

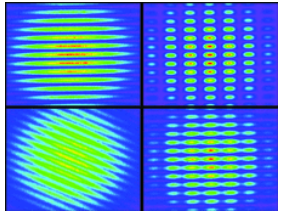
Undulator radiation – horizontal



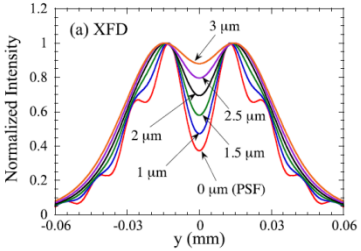
Wootton, et al., PRSTAB 17, 112802 (2014)



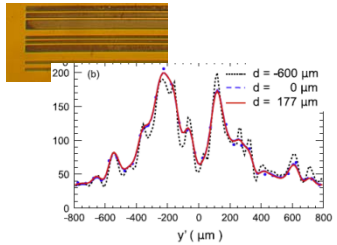
Andersson, NIMA 591, 437-446 (2008)



Masaki DIPAC01, PS17 (2001)



Masaki PRSTAB 18, 042802 (2015)

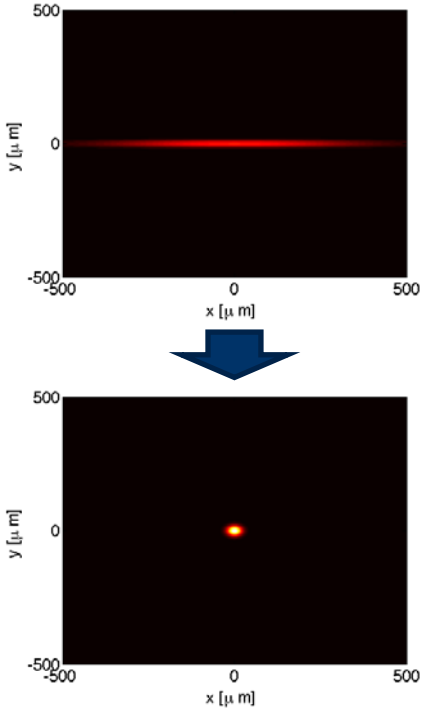


Alexander, NIMA 748, 96 (2014)

Motivation

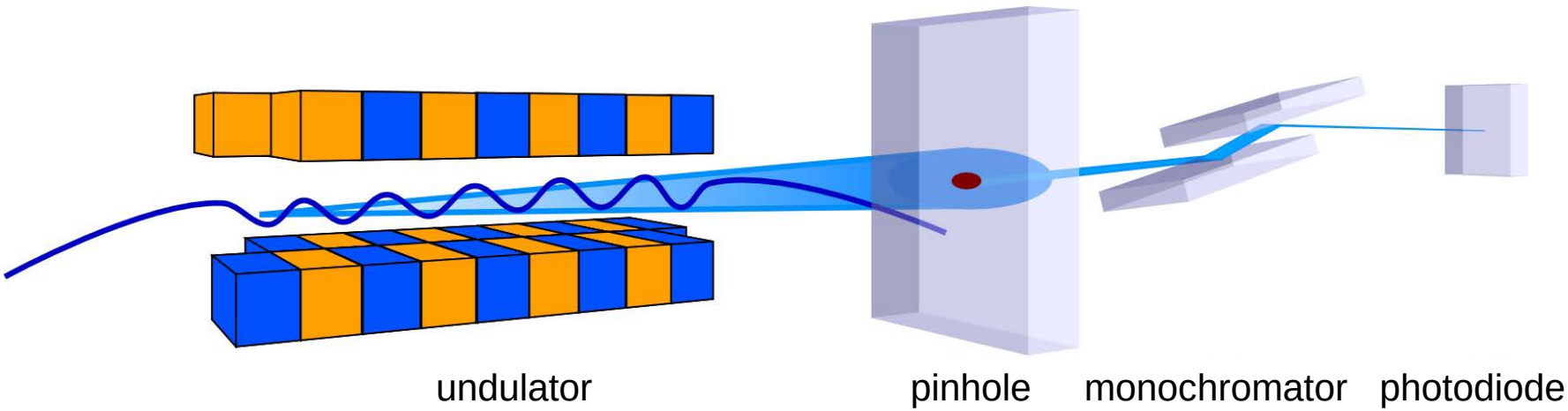
- Measurements of pm rad vertical emittances
  - Upcoming DLSRs, also pm rad horizontal emittances
- Experiment, simulations show undulator radiation sensitive to pm rad emittance
- Calibrate vertical undulator for direct measurement of pm rad vertical emittance in a storage ring

Electron beam



APS Report LS-334 (2014)

Vertical undulator diagnostic

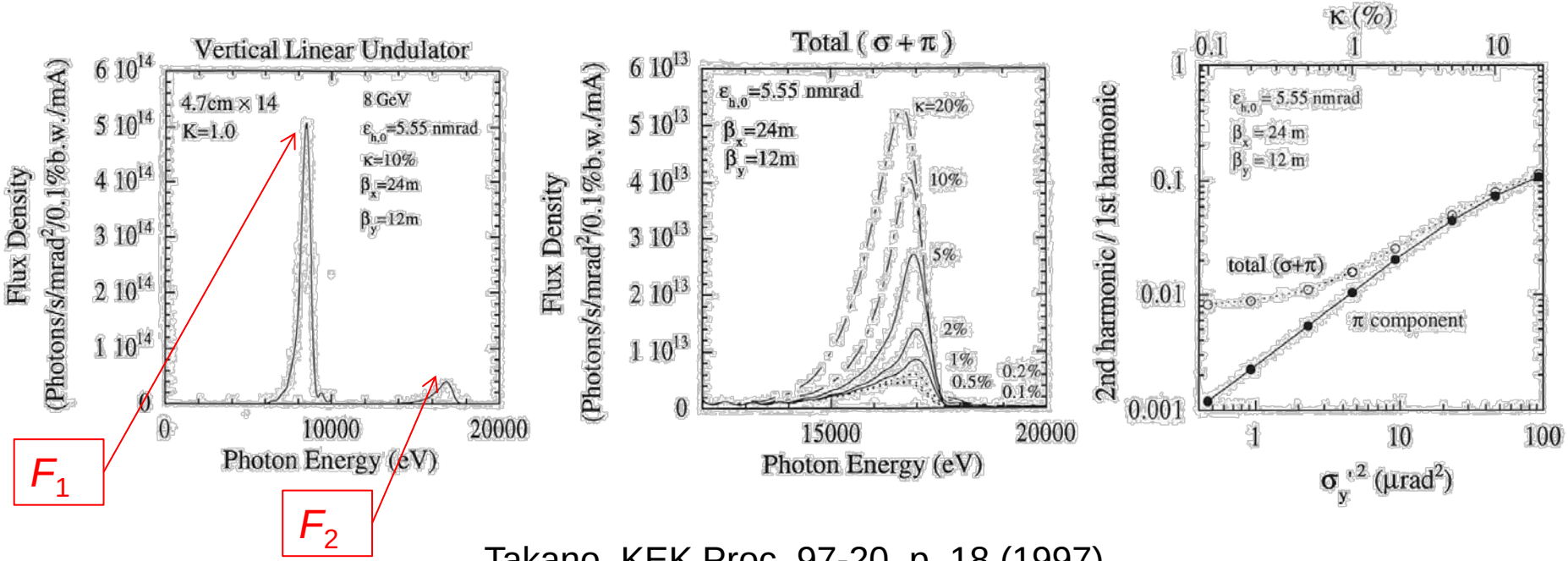


Wootton, et al., PRSTAB 17, 112802 (2014)

Very similar to:
Bahrdt, et al., PRL 111, 034801 (2013)

Vertical undulator diagnostic

- First simulations S. Takano 1997

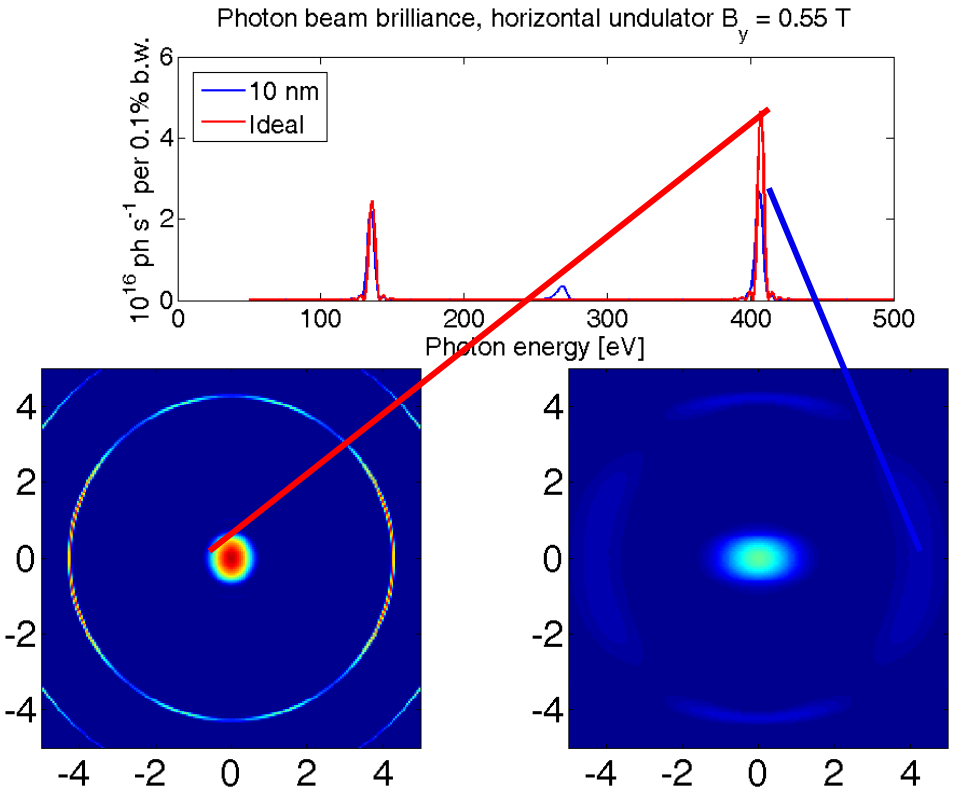


Takano, KEK Proc. 97-20, p. 18 (1997)

Undulator beam projection

Horizontal
Undulator
25 periods
75 mm period
K = 3.85

Pinhole
50 x 50 um
15m distance



Tanaka & Kitamura, JSR 8 1221 (2001)

Electron beam

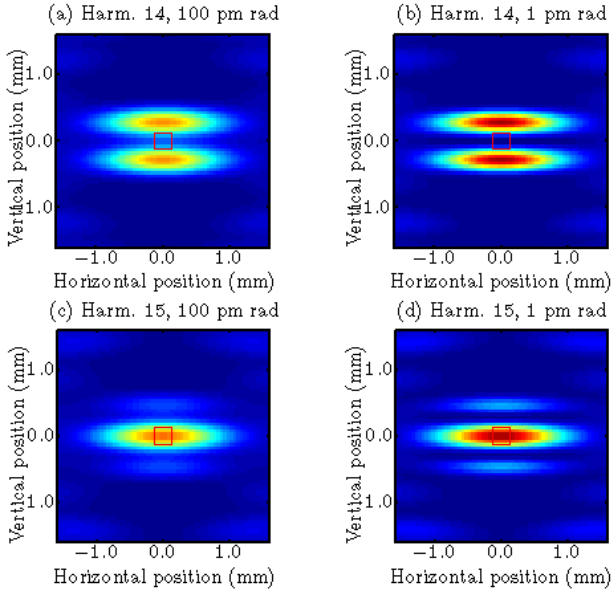
$\varepsilon_x = 10\ nm$

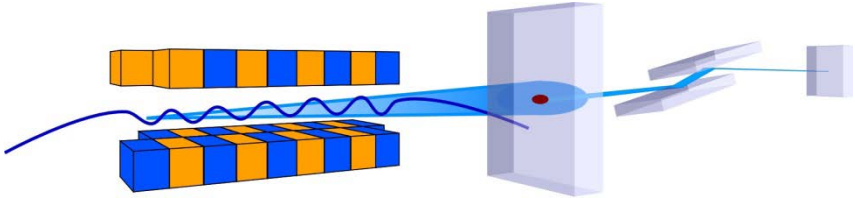
$\varepsilon_y = 100\ pm$

$\sigma_E = 0.11\%$

Undulator projection measurements

Vertical undulator

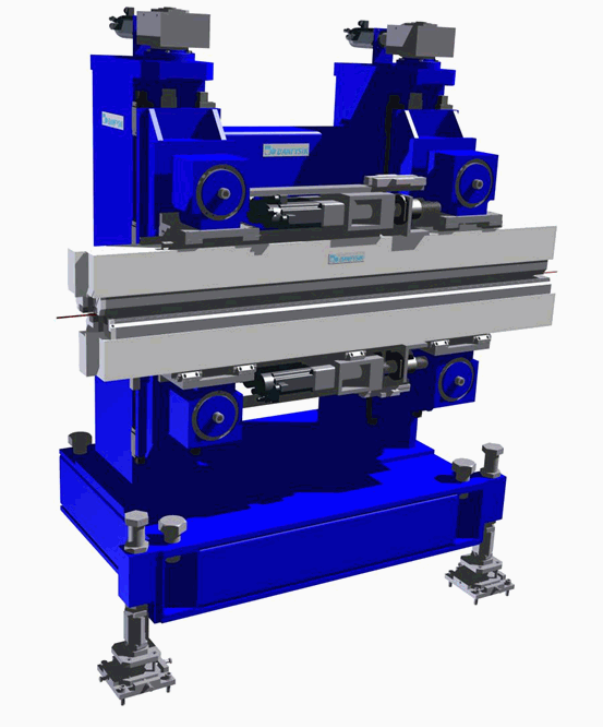


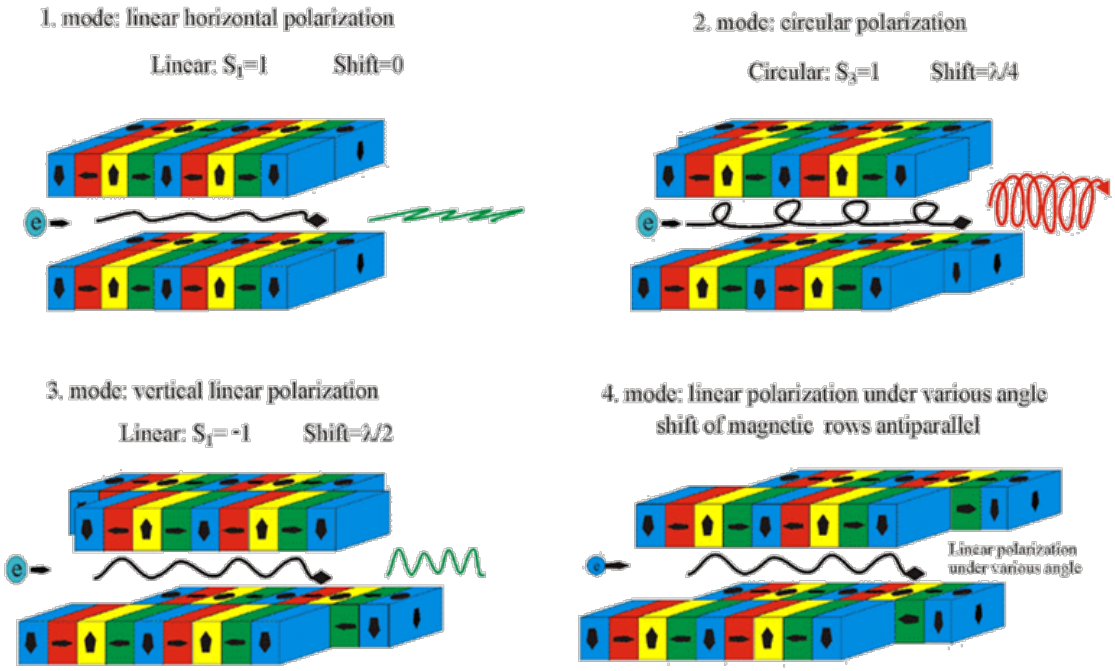


Undulator
25 periods
75 mm period
K = 3.85

Electron beam
$\varepsilon_x = 10\ nm$
$\varepsilon_y = 100\ pm$
$\sigma_E = 0.11\%$

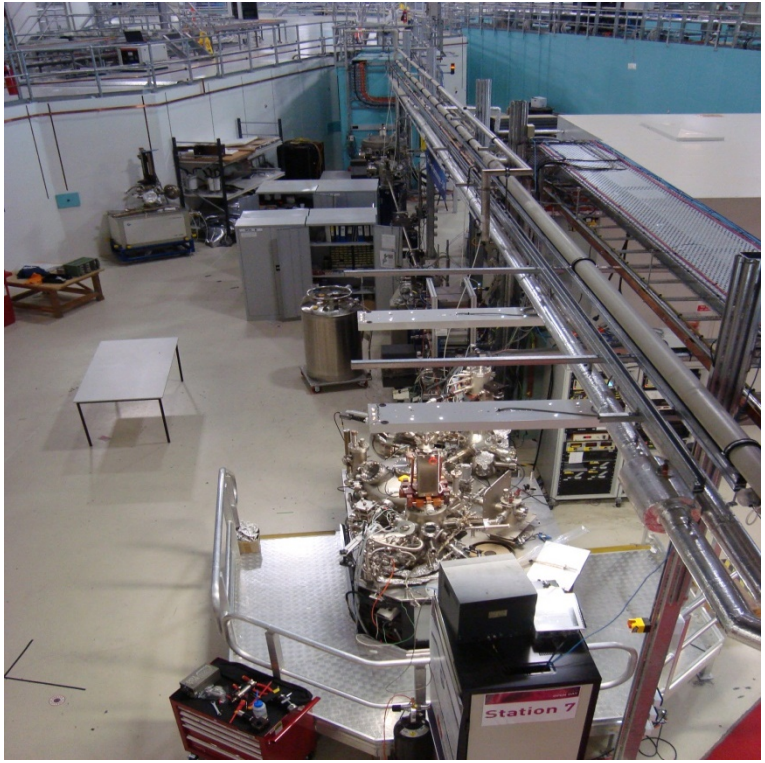
Advanced Planar Polarised Light Emitter-II
Modes of operation





Sasaki, NIM A 347, 83 (1994)

Soft x-ray undulator beamline



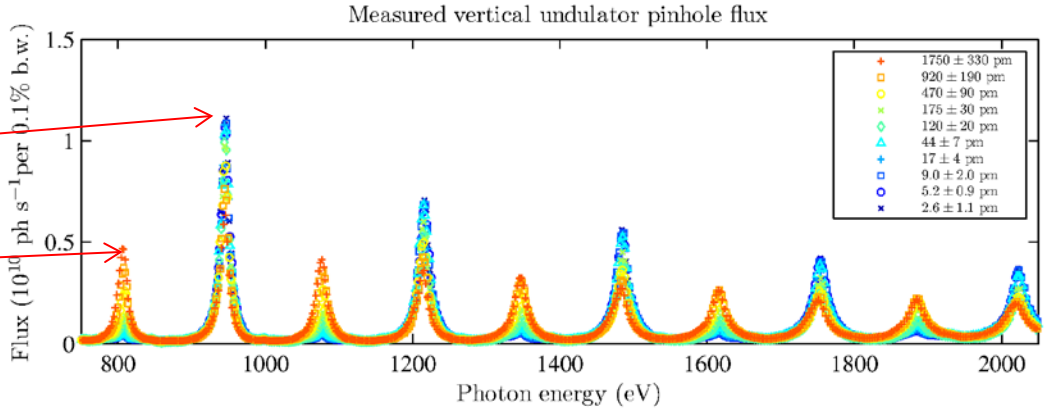
Measured undulator spectrum

- Measured

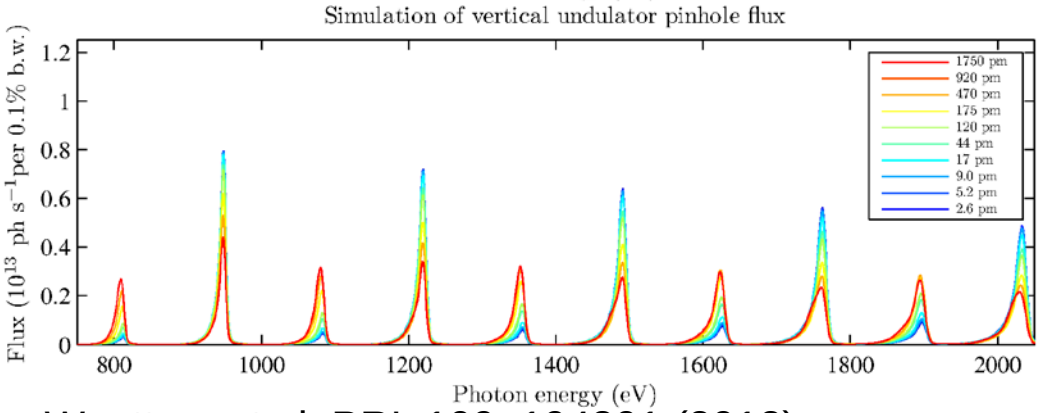
Flux ratio
F_{n-1} / F_n

F_7

F_6



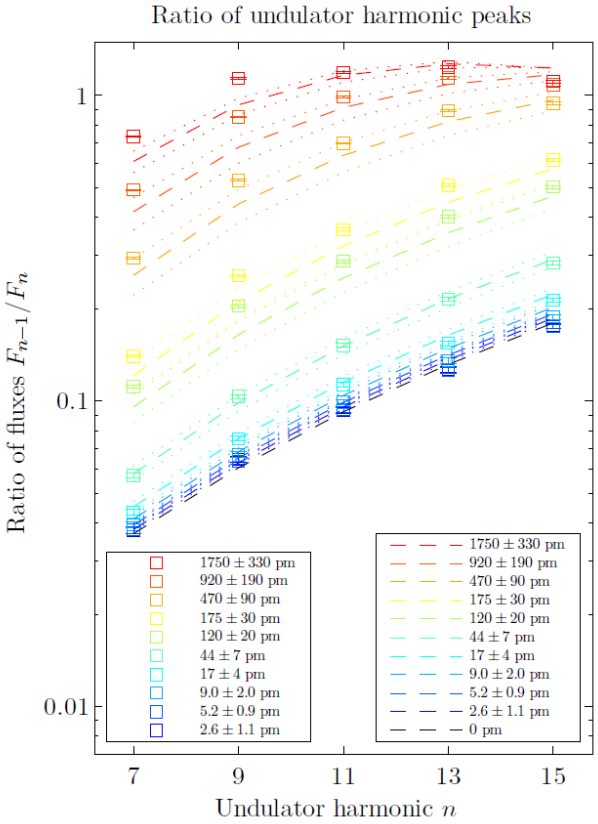
- Modelled



Wootton, et al. PRL 109, 194801 (2012)

Emittance envelopes

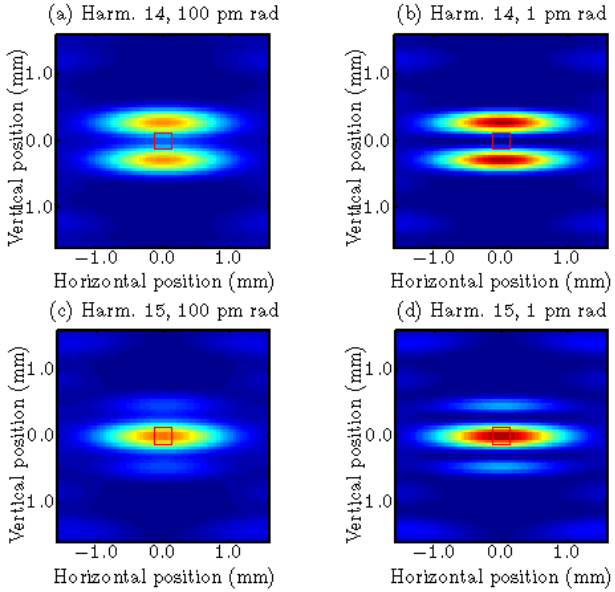
- Measured ratio of adjacent peaks
- F_{n-1}/F_n
- Envelopes of emittance from LOCO measurements
  - Fitted pinhole size of $260 \times 260\ \mu m^2$
- Sensitive to emittance, want emittance measurement

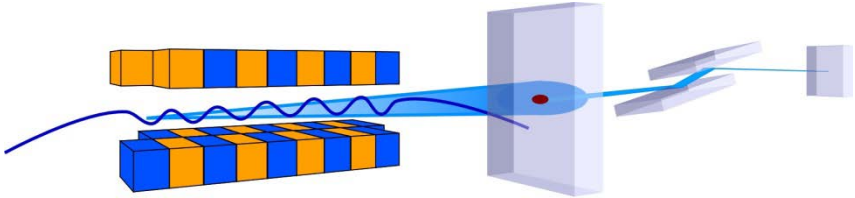


Wootton, et al. PRL 109, 194801 (2012)

Undulator projection measurements

Vertical undulator



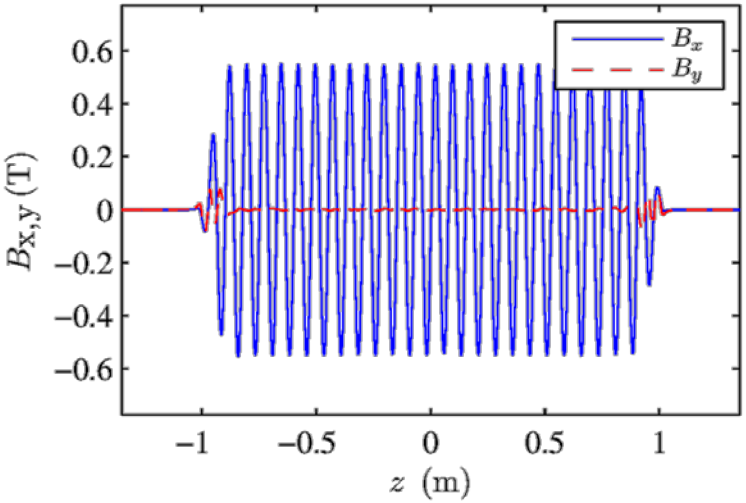


Undulator
25 periods
75 mm period
K = 3.85

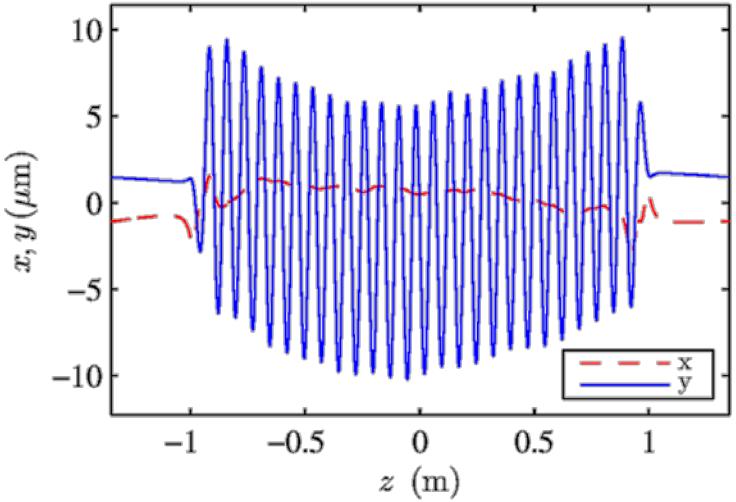
Electron beam
$\varepsilon_x = 10\ nm$
$\varepsilon_y = 100\ pm$
$\sigma_E = 0.11\%$

Simulation

Measured magnetic field



Simulated trajectory

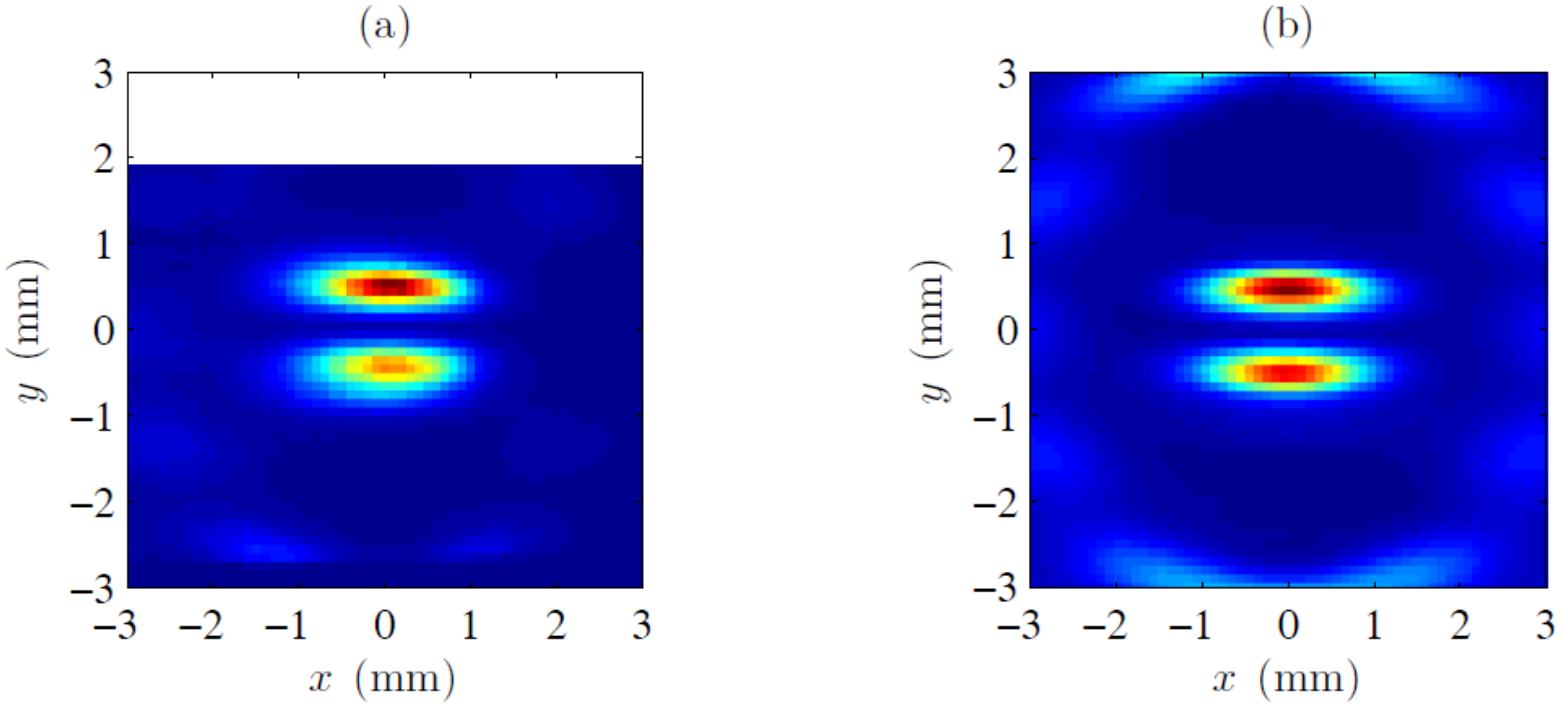


Ostenfeld, et al., PAC 2007, TUPMN006 (2007).

Measured profile, 6th harmonic

Measured profile

Simulation, measured field map



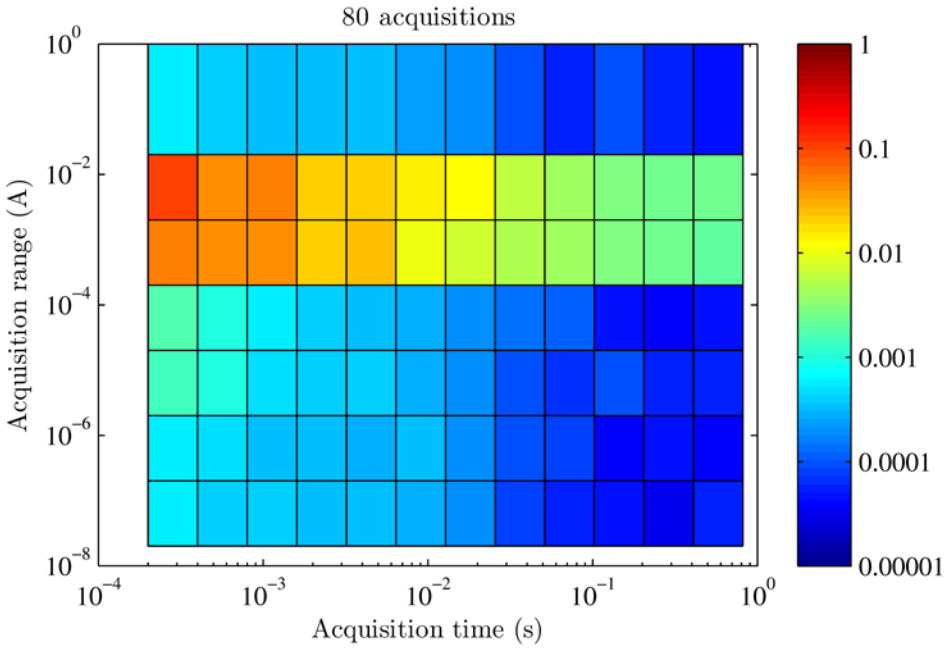
Wootton, et al. IBIC13, TUPF19 (2013)

Time averaging

- *n* acquisitions, mean μ

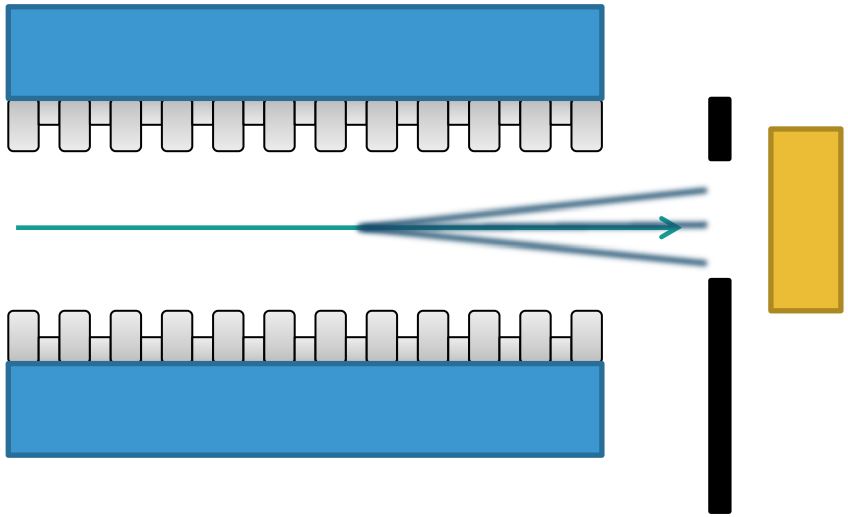
$$\delta\mu = \frac{\sigma}{\sqrt{n}}$$

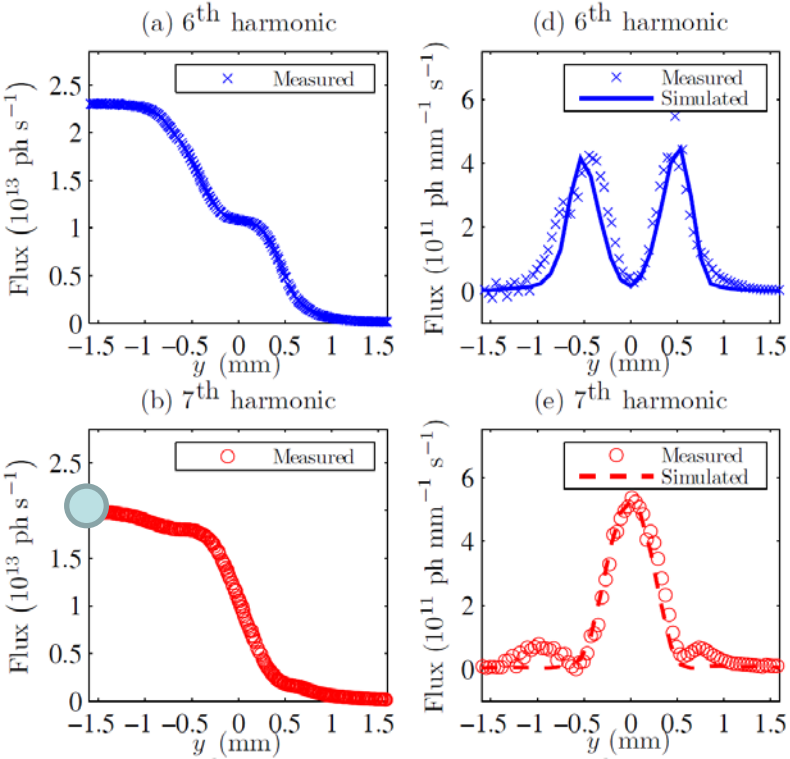
- Minimises statistical uncertainty
- Systematic uncertainty (pinhole position) remains



Wootton, et al. IBIC13, TUPF18 (2013)

Blade scans

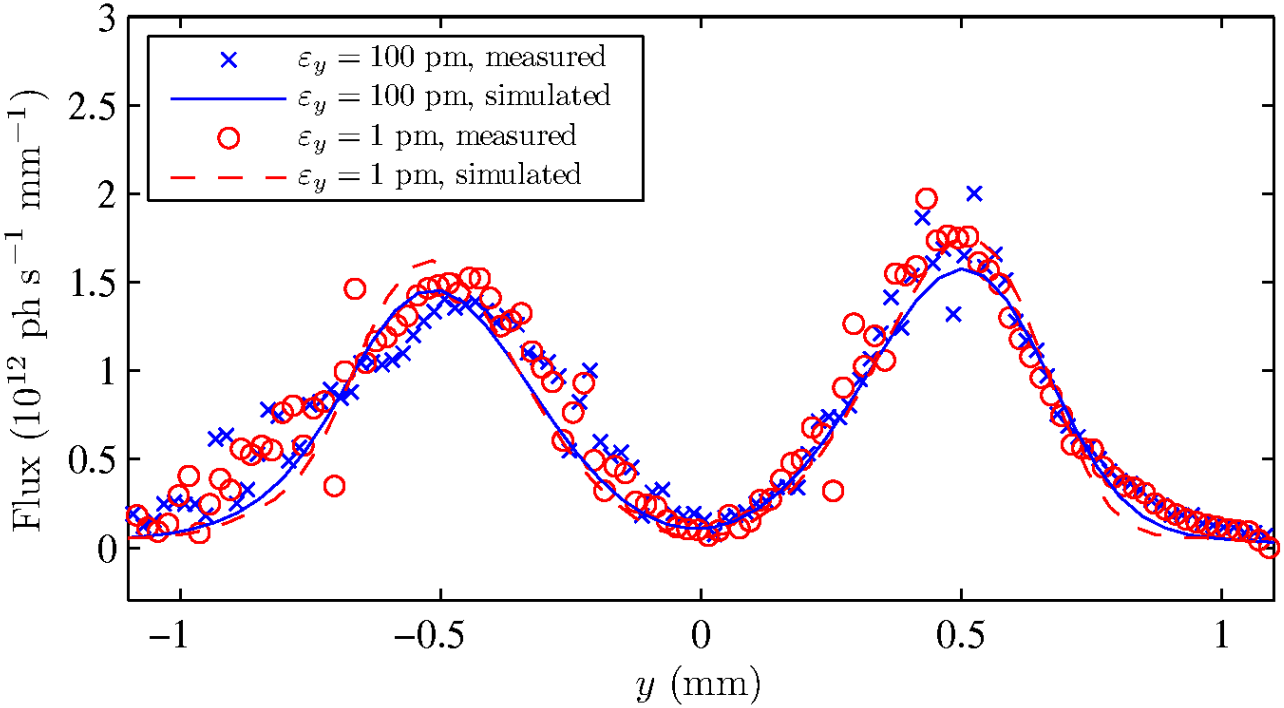




Wootton, et al. IBIC13, TUPF19 (2013)

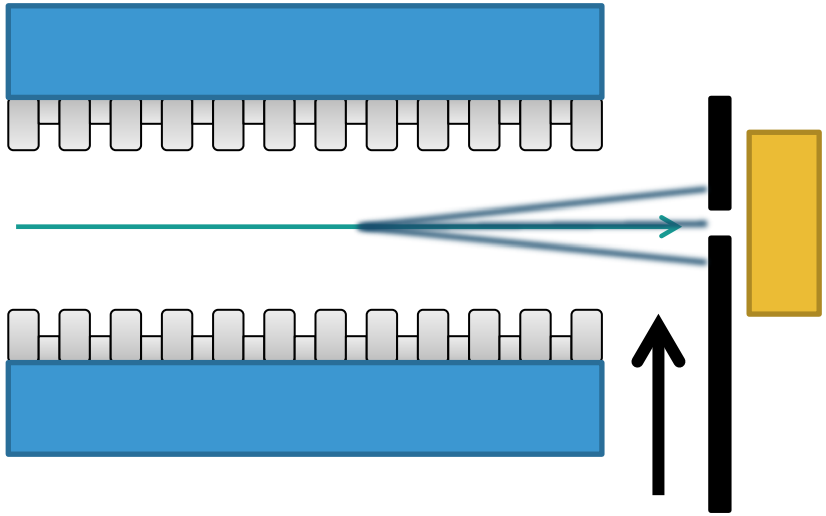
Blade scans - results

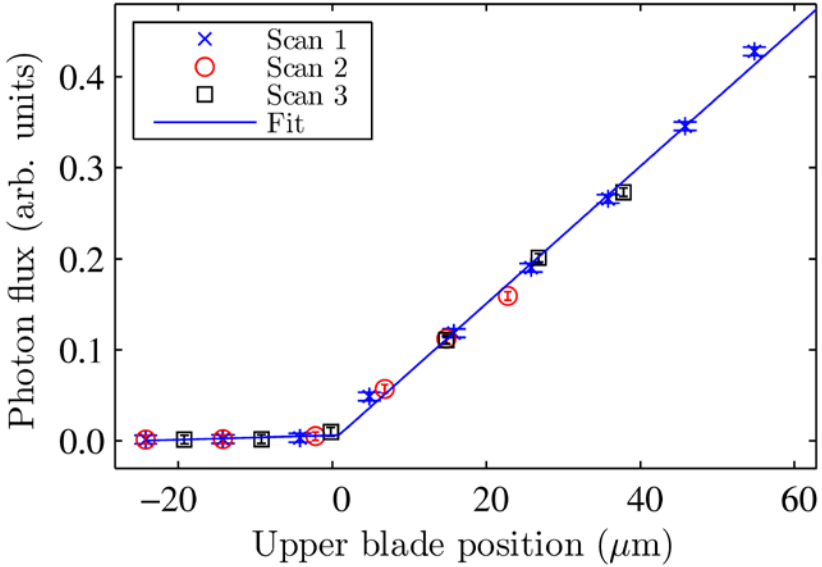
- Not sufficiently sensitive to pm rad emittances



Orbit bumps – pinhole size

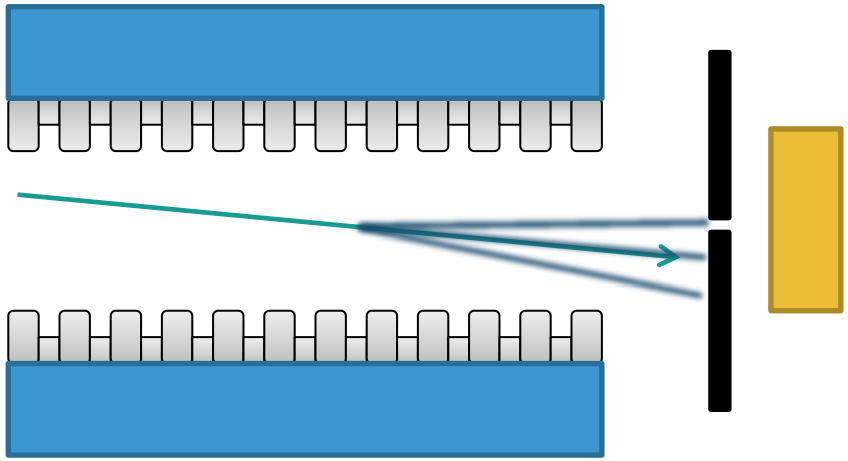
- Sensible pinhole size of 5 μm

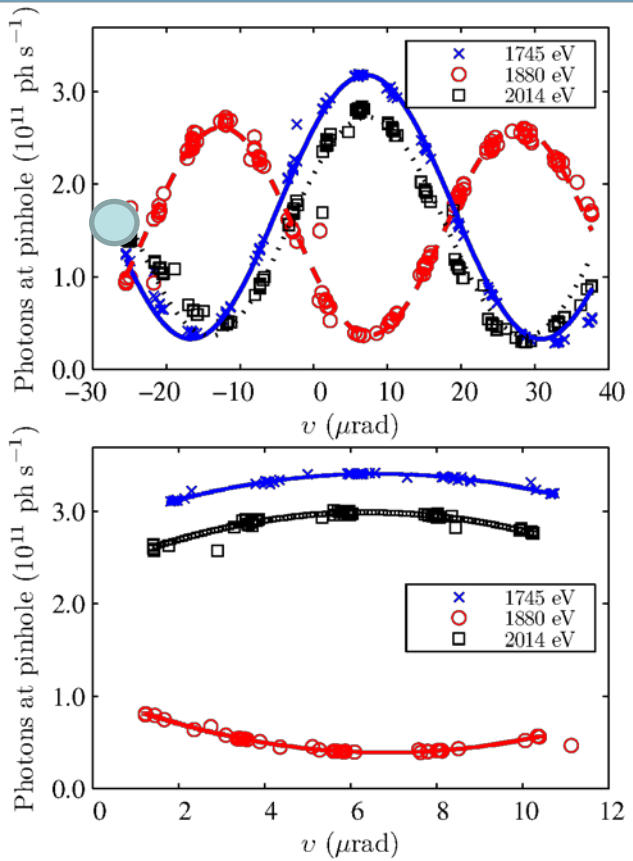




Wootton, et al. PRSTAB 17, 112802 (2014)

Orbit bumps

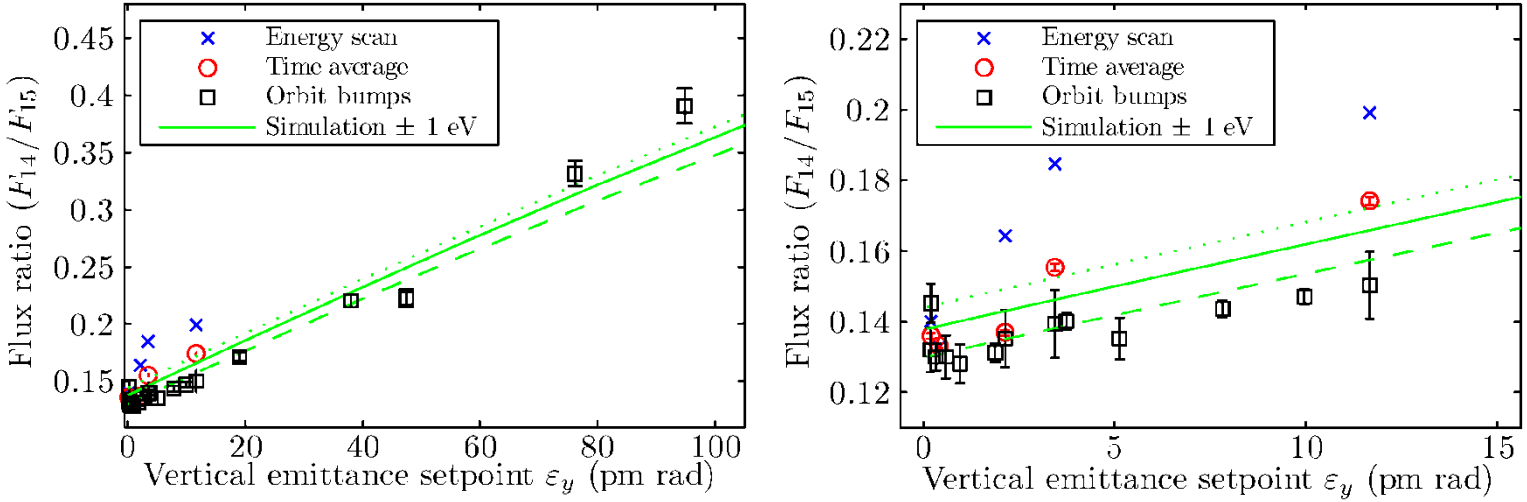




Wootton, et al. PRSTAB 17, 112802 (2014)

Emittance measurement

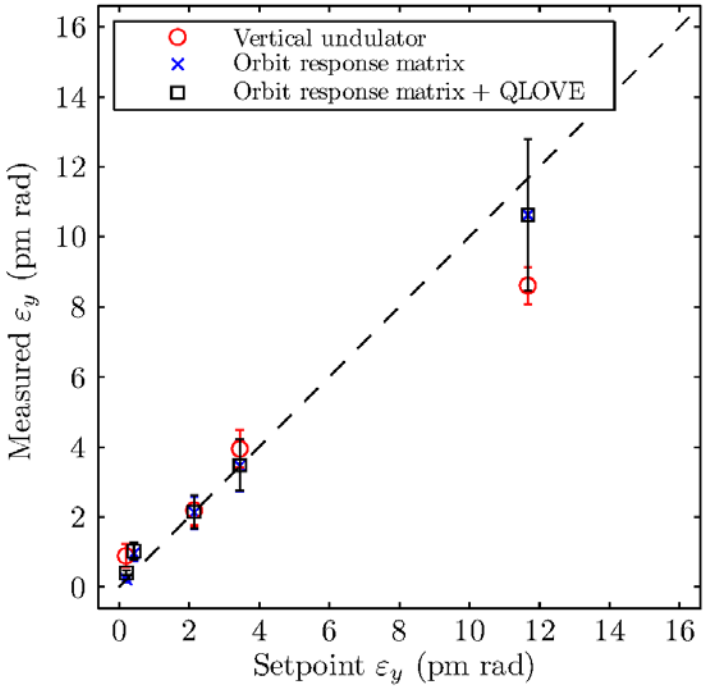
- Flux ratio measured using several approaches
- Simulated using measured field map



Wootton, et al. PRSTAB 17, 112802 (2014)

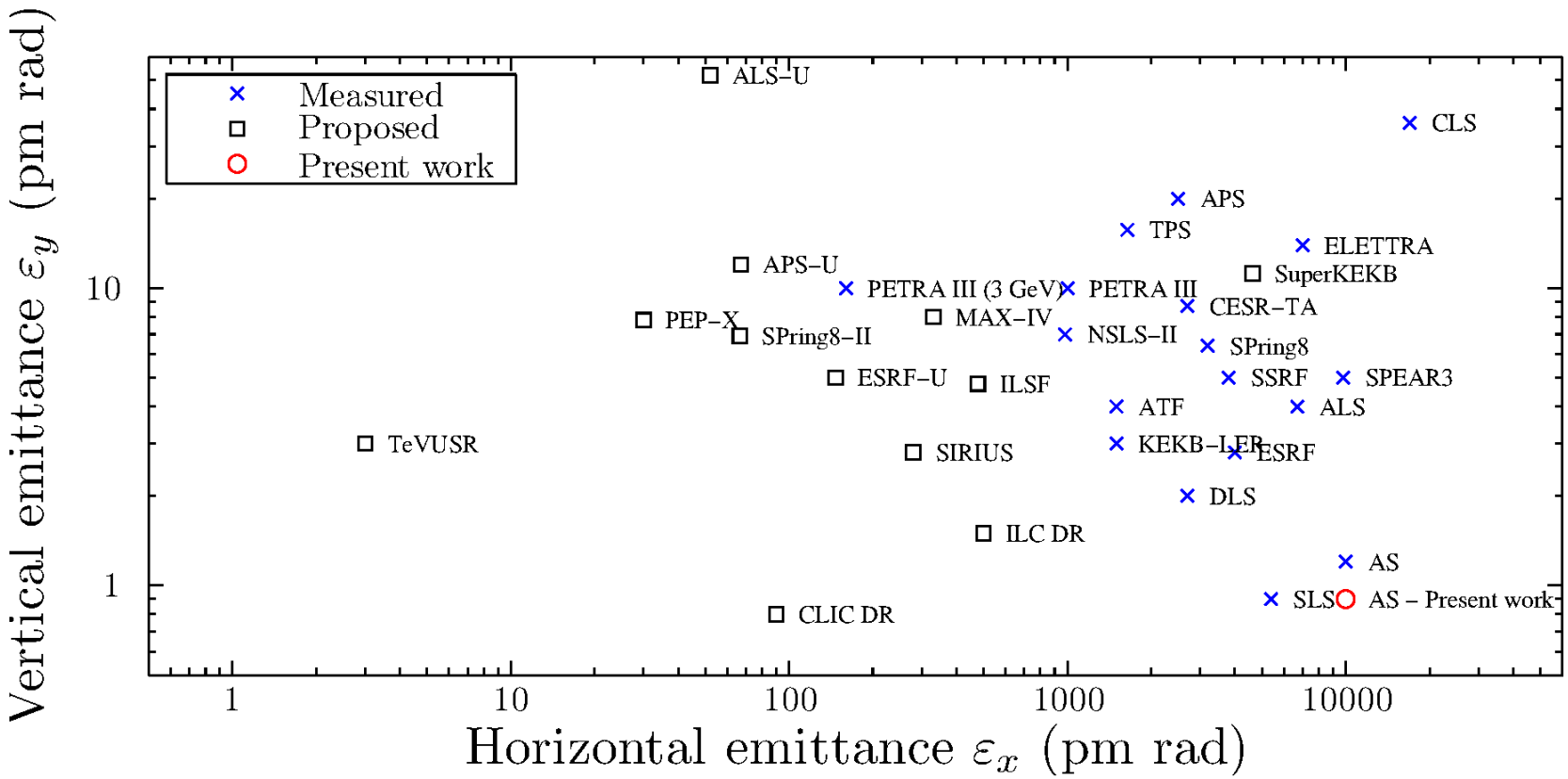
Emittance measurement

- Lattices with various vertical emittances
- Emittance measured using
  - Vertical undulator
  - LOCO + quantum limit
- Measurements agree within uncertainty, except lowest value
- $\varepsilon_y = 0.9 \pm 0.3$ pm rad



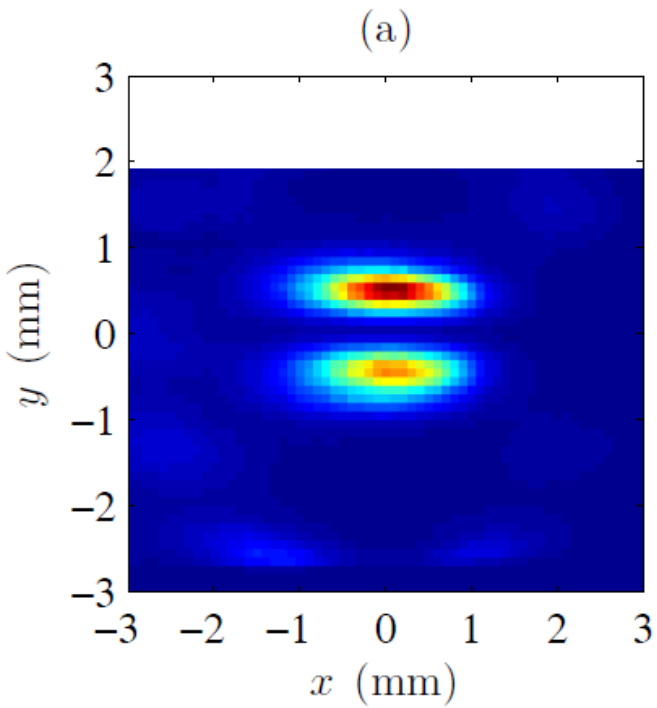
Wootton, et al. PRSTAB 17, 112802 (2014)

Present result



Discussion – DLSRs

- Brilliance optimised DLSRs
  - High undulator harmonics
  - Angular profile of undulator radiation departs significantly from typical Gaussian distributions
- Are photon beamlines prepared?

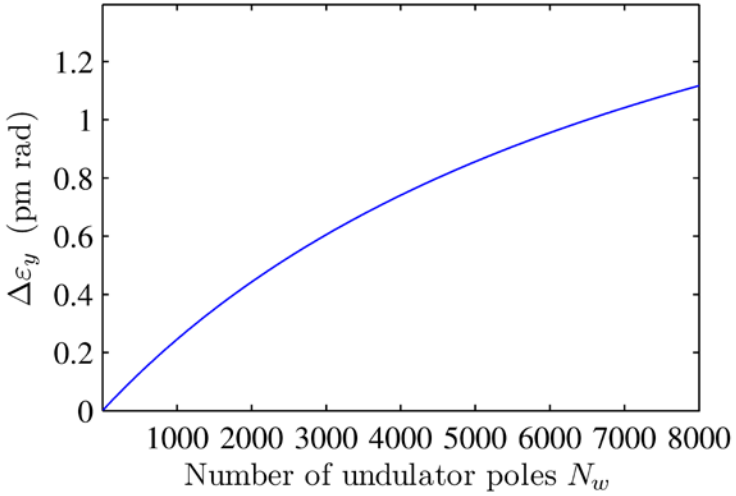


Undulator self-dispersion

- Undulator self-dispersion leads to growth of vertical emittance

$$\Delta\varepsilon_y = 0.012 \text{ pm rad}$$

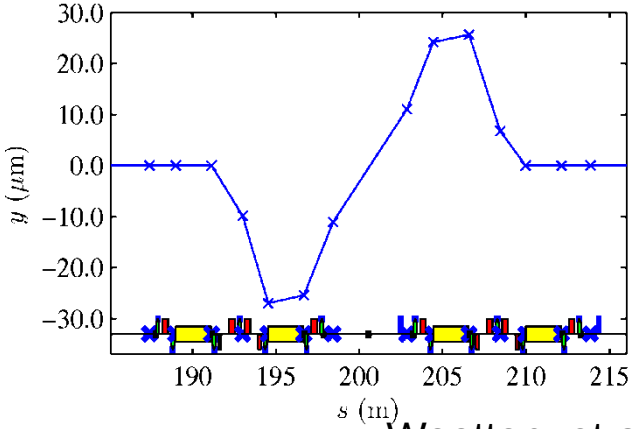
  - Wiedemann (1988) NIM:A 266, 24
  - Talman (2002) NIM:A 489, 519
- Negligibly small



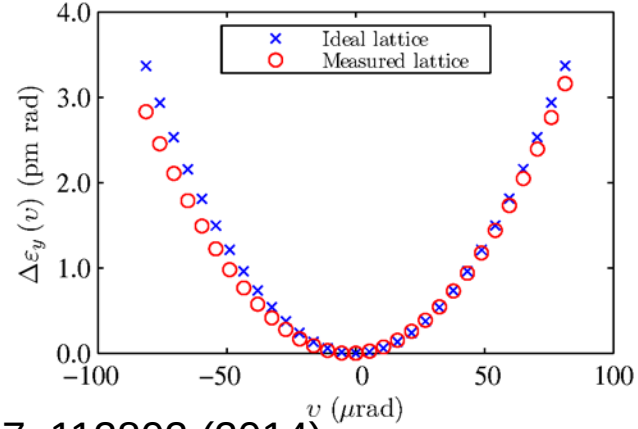
- 1 pm rad?
- 6500 undulator poles
- 240 m

Orbit steering

- Steering electron beam off-axis through sextupoles



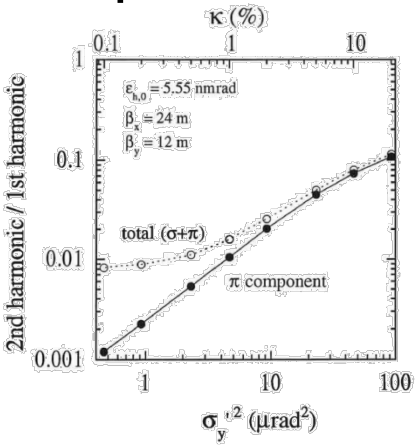
- AT model
- 10 μrad steering
- $\Delta\varepsilon_y = 0.07 \pm 0.01$ pm rad

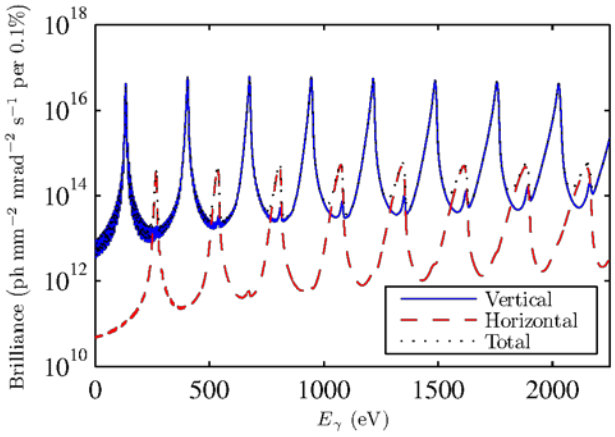


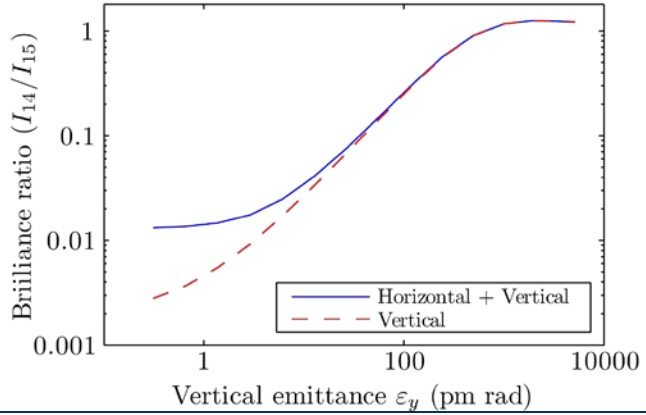
Wootton, et al. PRSTAB 17, 112802 (2014)

Where to? Polarisation

- Fixed pinhole diameter
- Linear polarisation







Where to? Polarisation

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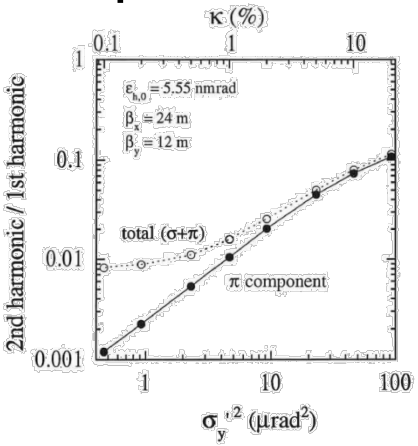
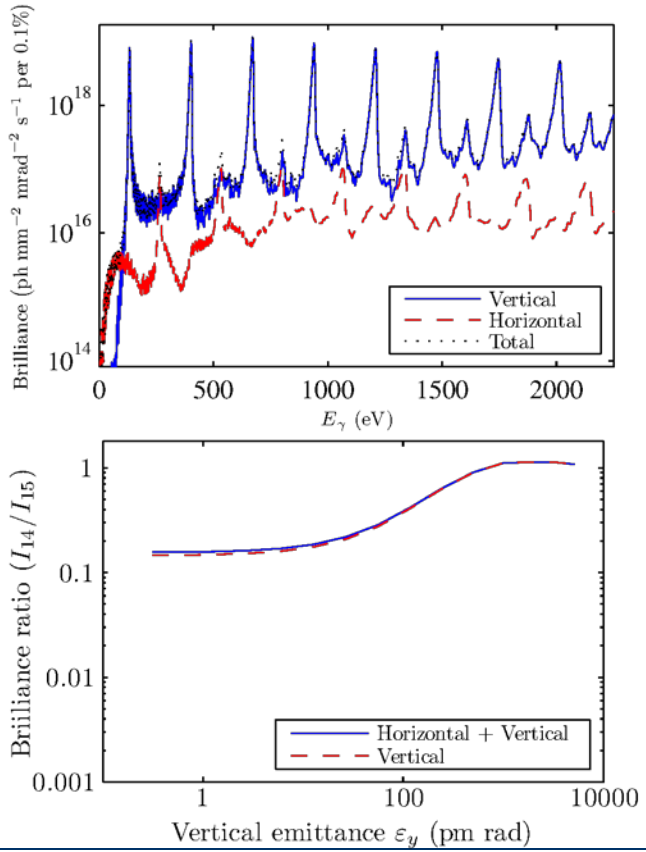


- Need undulator shimmed for vertical polarisation



Summary

- Direct emittance measurement based on vertical undulator
- Emittance evaluated from peak ratios
  - Smallest measured, $\varepsilon_y = 0.9 \pm 0.3 \text{ pm rad}$
- Angular distribution of undulator radiation departs from Gaussian approximations
  - Diffraction-limited light sources should be aware

Thank-you!

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