Direct Observation of Ultralow Vertical Emittance Using a Vertical Undulator

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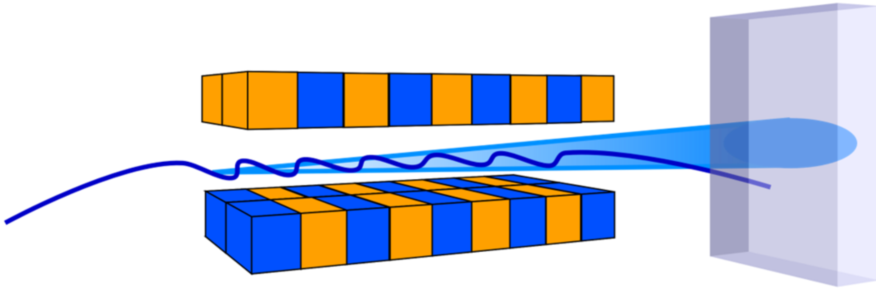
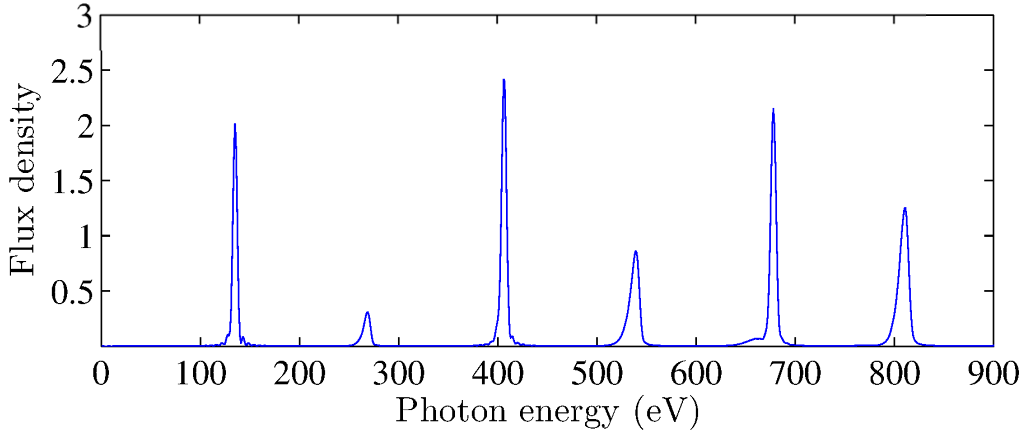
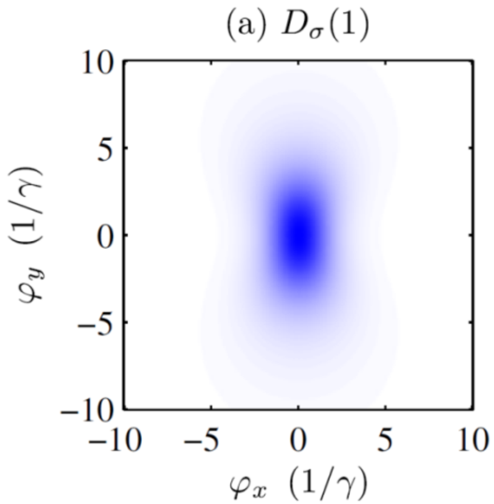
Undulator radiation – horizontal

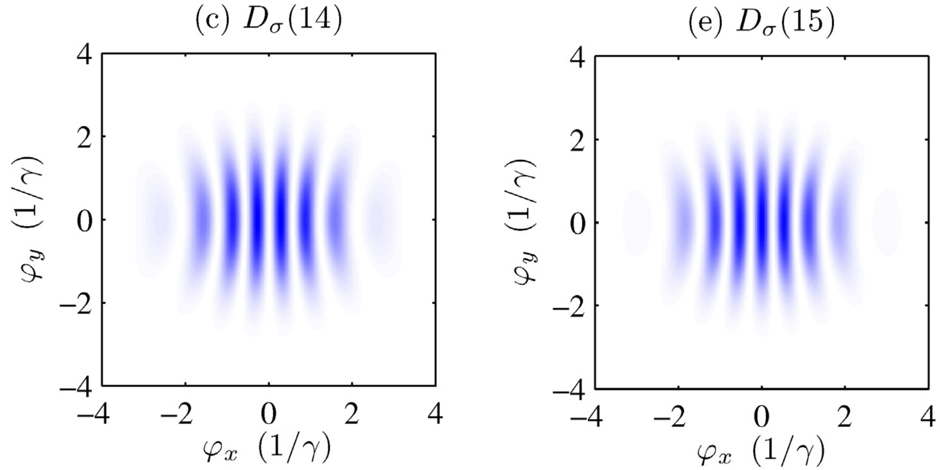




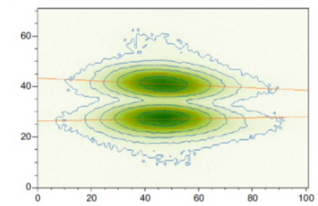


Wootton, et al., PRSTAB 17, 112802 (2014)

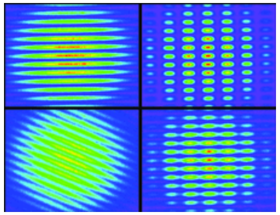
Undulator radiation – horizontal



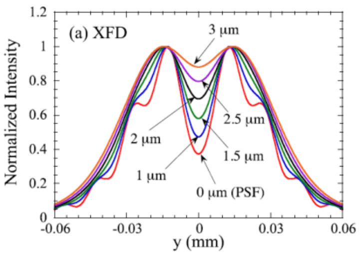
Wootton, et al., PRSTAB 17, 112802 (2014)



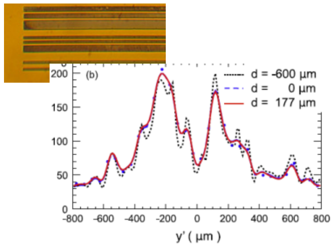
Andersson, NIMA 591, 437-446 (2008)



Masaki DIPAC01, PS17 (2001)



Masaki PRSTAB 18, 042802 (2015)



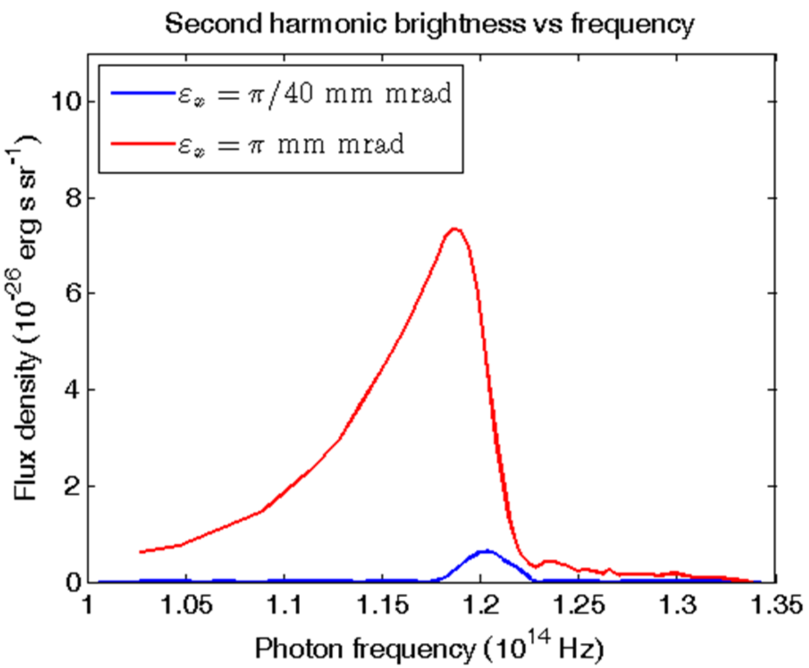
Alexander, NIMA 748, 96 (2014)

Motivation

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

Undulator spectra and emittance

- 'It is evident that the second-harmonic brightness is proportional to the beam emittance …'
  - Dattoli PRE 52, 6809-17 (1995)
- Where does this emittance dependence come from?

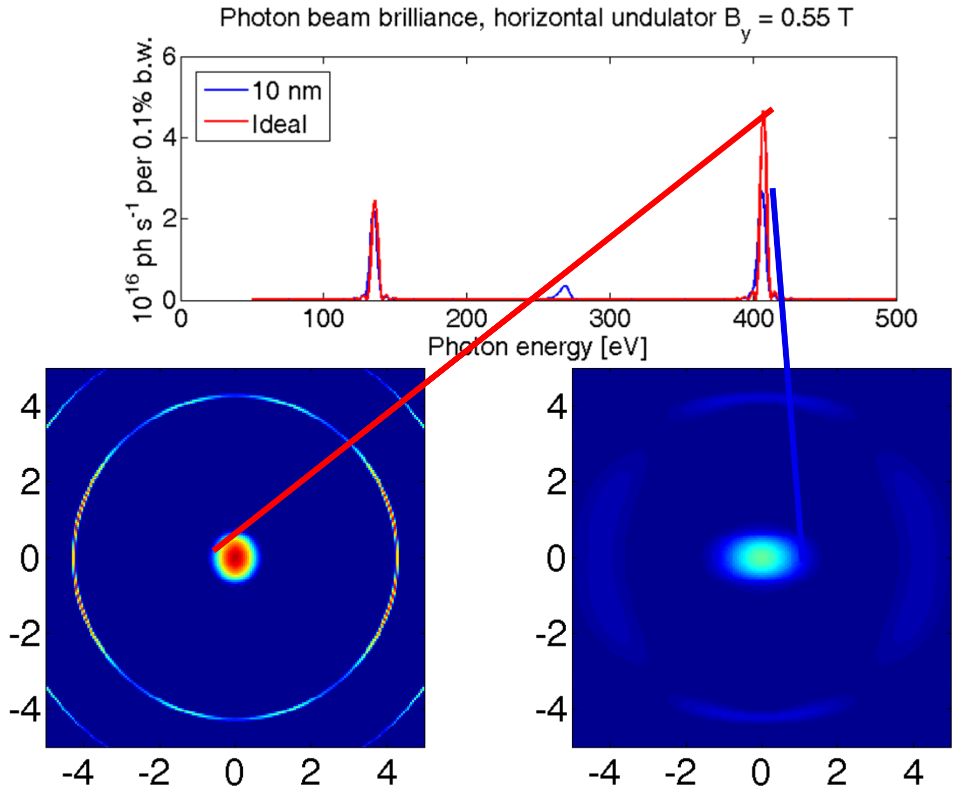


Dattoli PRE 52, 6809-17 (1995)

Undulator beam projection

Horizontal Undulator
25 periods
75 mm period
K = 3.85

Pinhole
50 x 50 um
15m distance



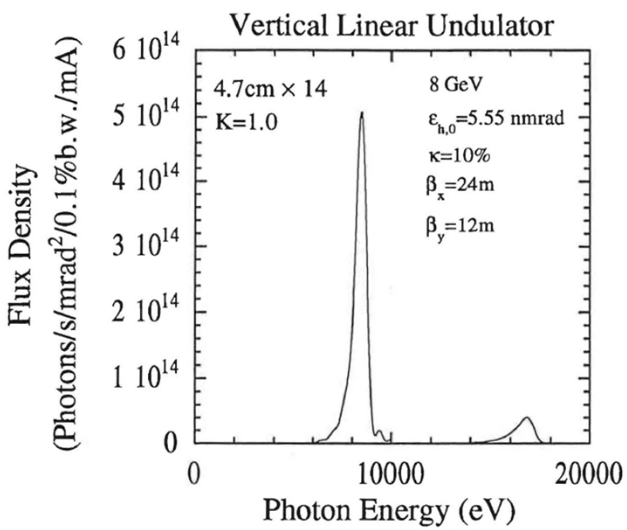
Tanaka & Kitamura, JSR 8 1221 (2001)

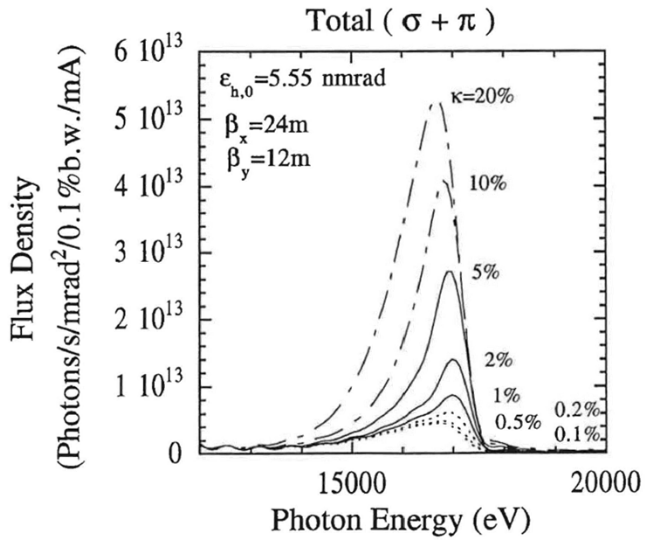
Electron beam
$\varepsilon_x = 10\ nm$
$\varepsilon_y = 100\ pm$
$\sigma_E = 0.11\%$

How do we measure photon beam brilliance?

Vertical undulator diagnostic

- First simulations S. Takano, 1997





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

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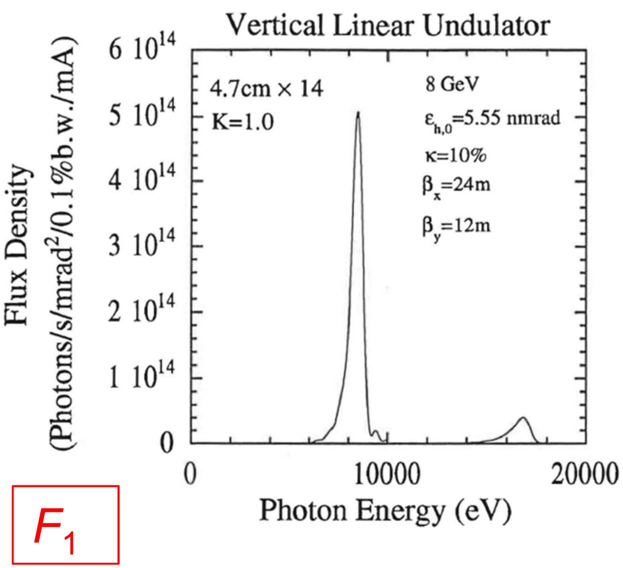

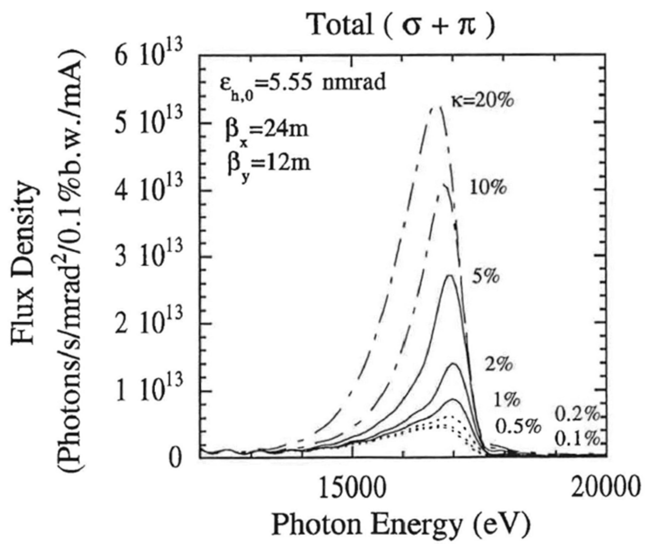

Takano, KEK Proc. 97-20, p. 18 (1997)

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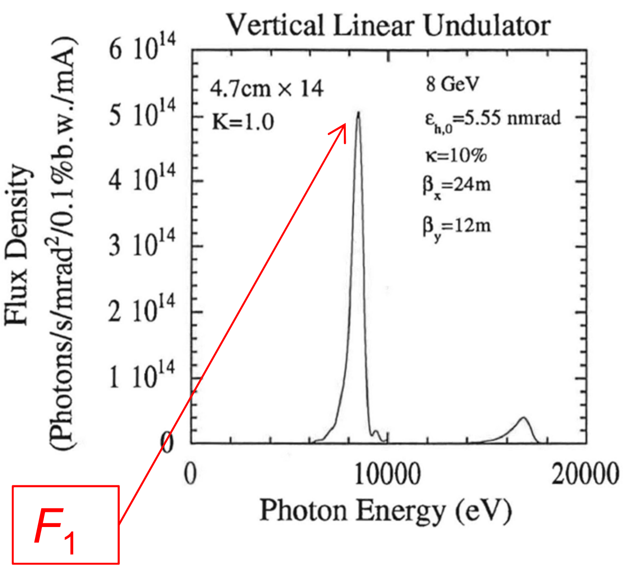

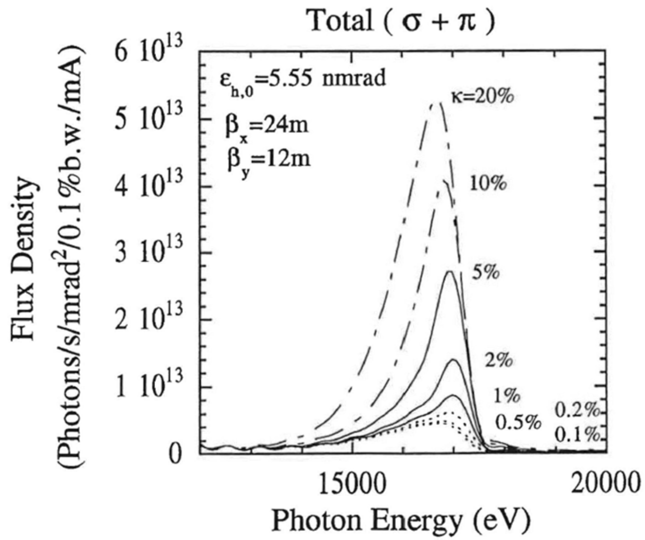

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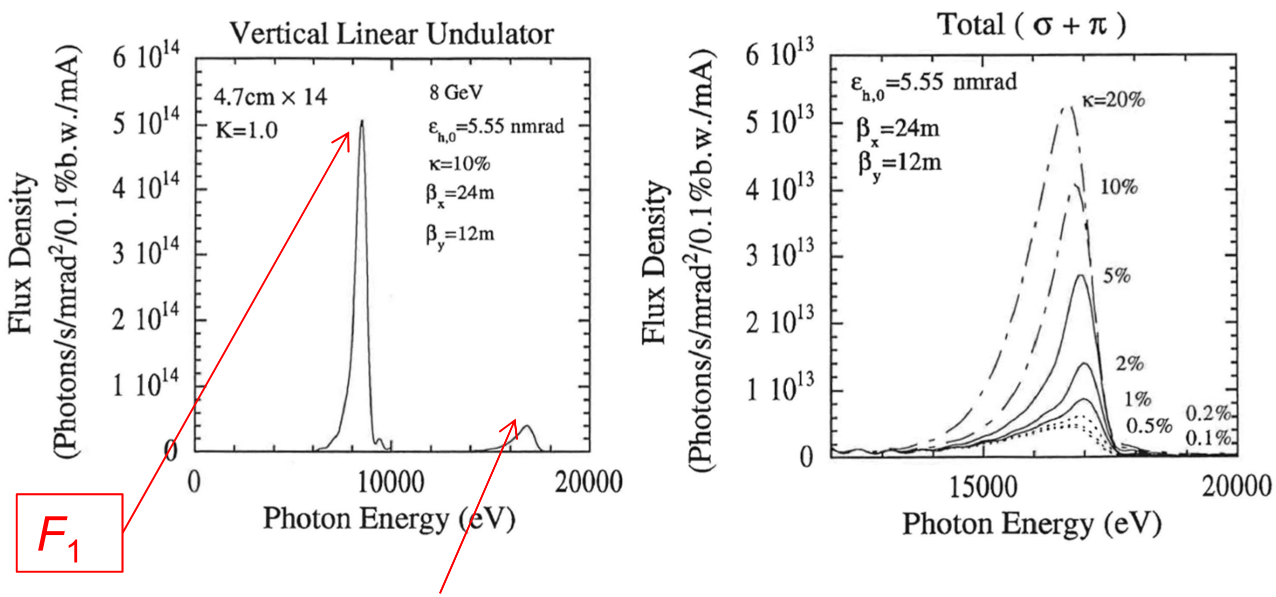

Takano, KEK Proc. 97-20, p. 18 (1997)

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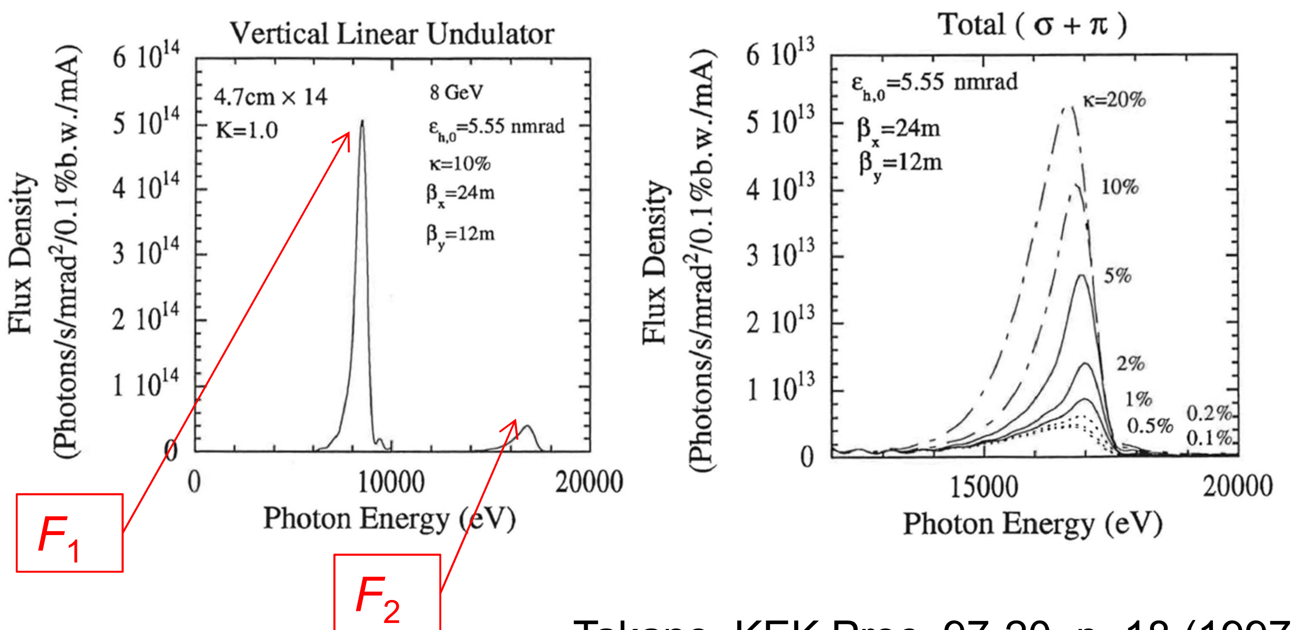

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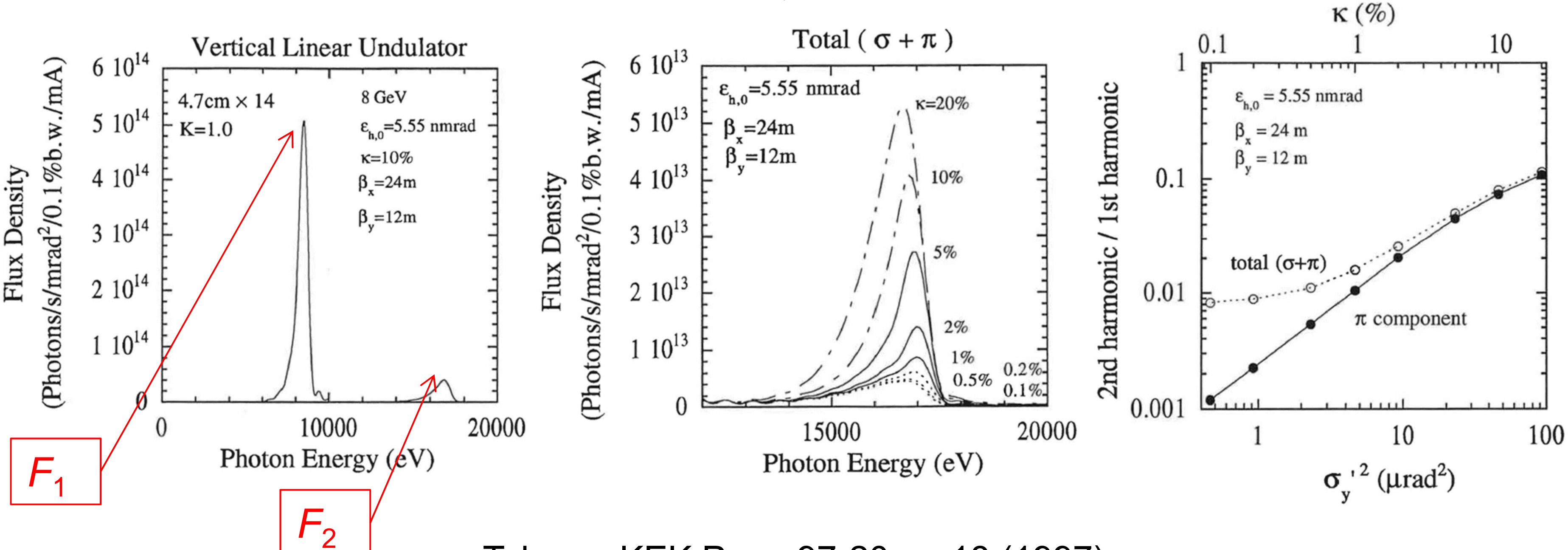

Takano, KEK Proc. 97-20, p. 18 (1997)

Vertical undulator diagnostic

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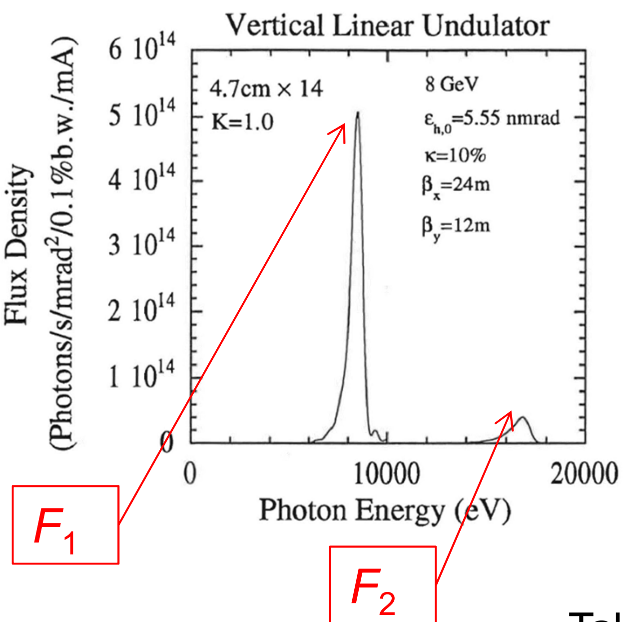
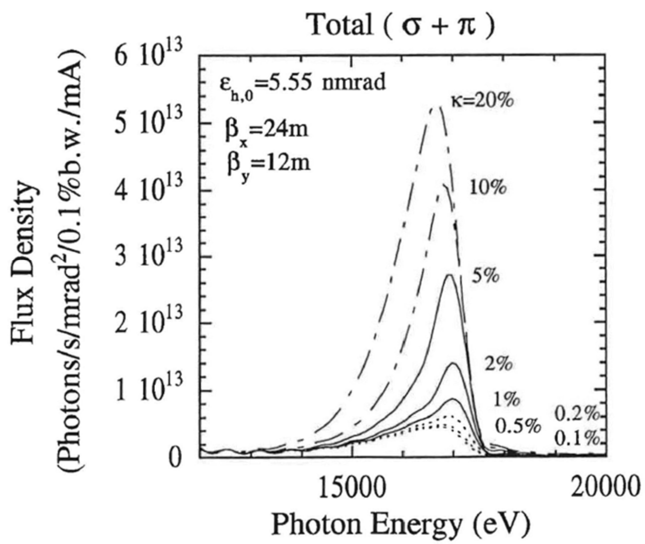
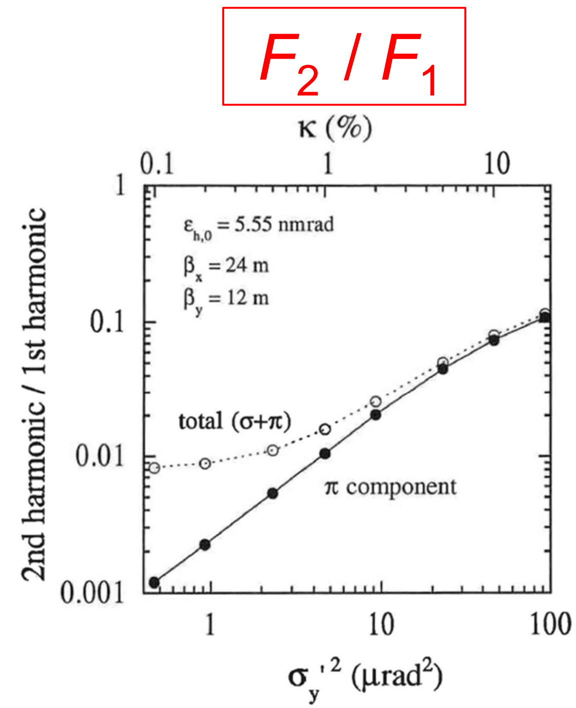
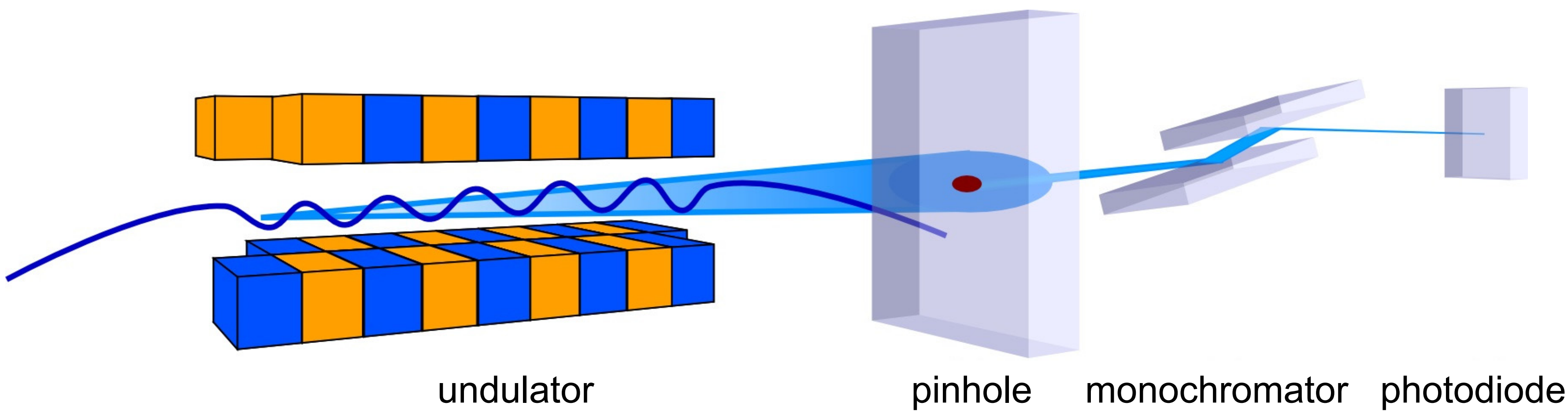






Takano, KEK Proc. 97-20, p. 18 (1997)

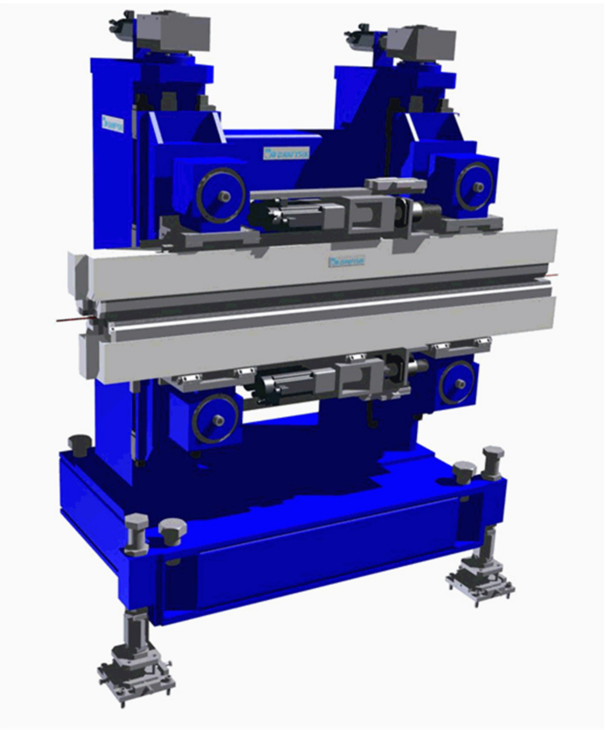
Vertical undulator diagnostic

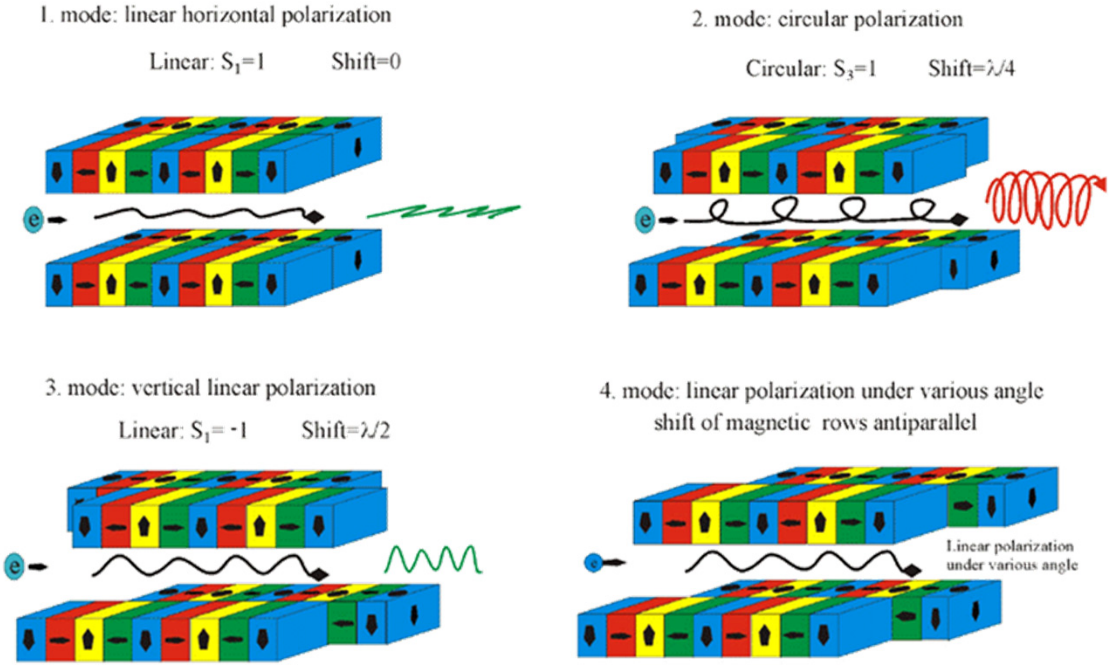


Wootton, et al., PRSTAB 17, 112802 (2014)

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

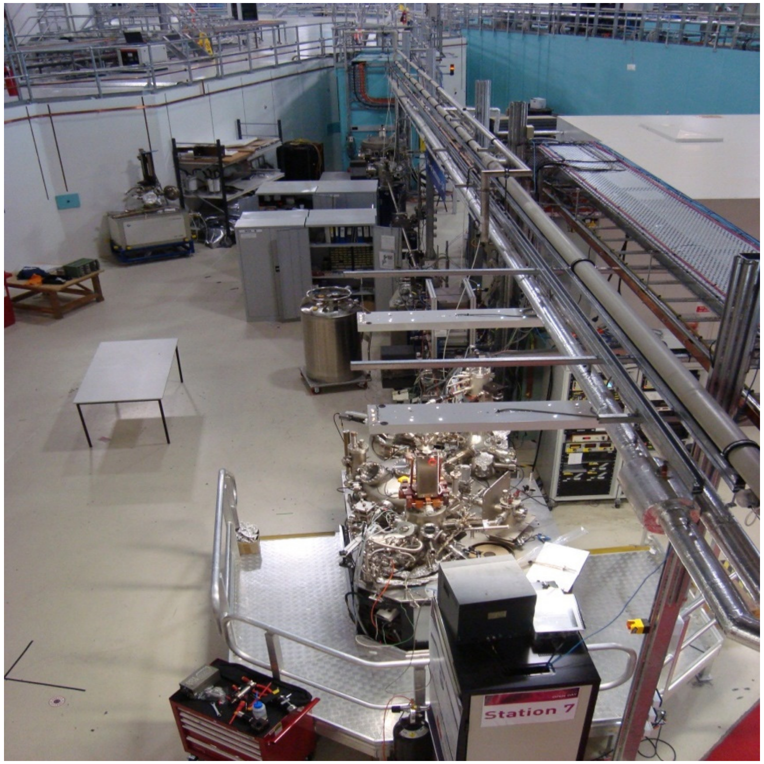
Advanced Planar Polarised Light Emitter-II
Modes of operation





Sasaki, NIM A 347, 83 (1994)

Soft x-ray undulator beamline

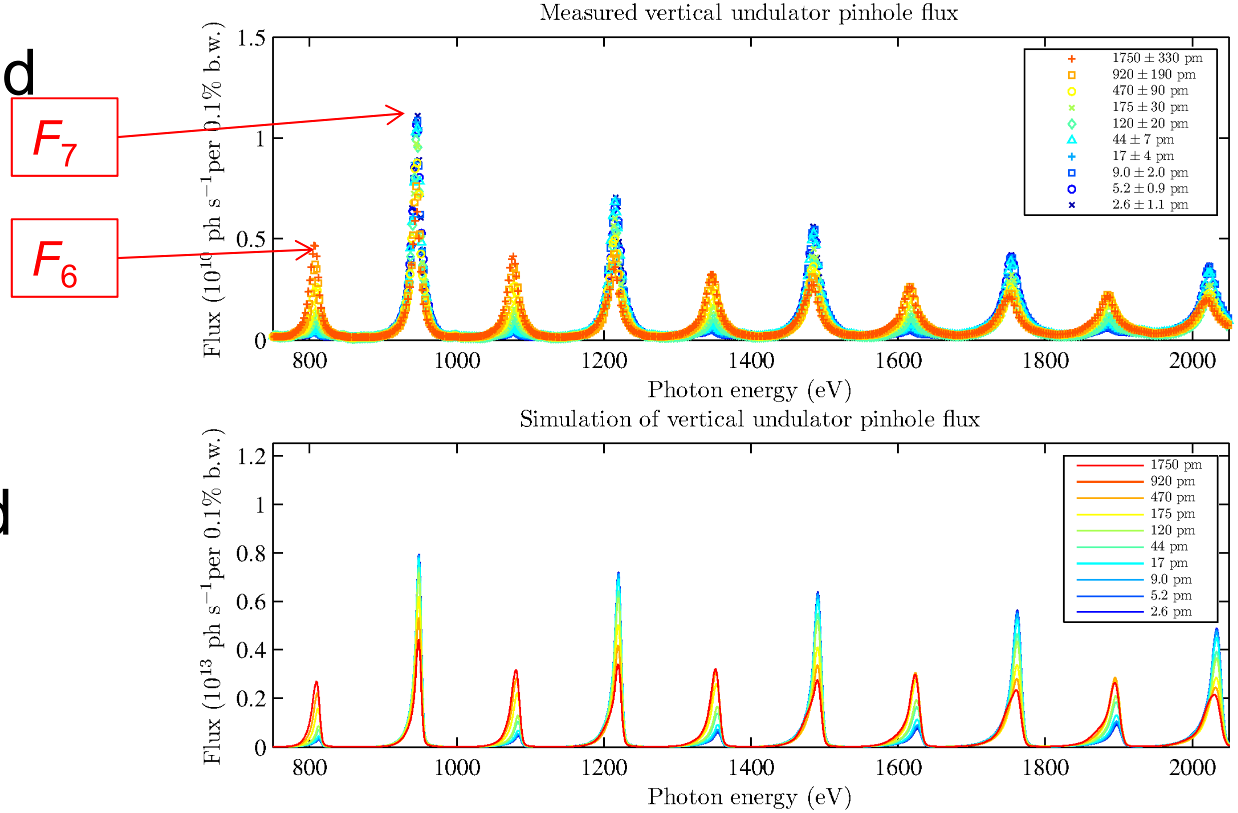


Measured undulator spectrum

- Measured

Flux ratio
F_{n-1} / F_n

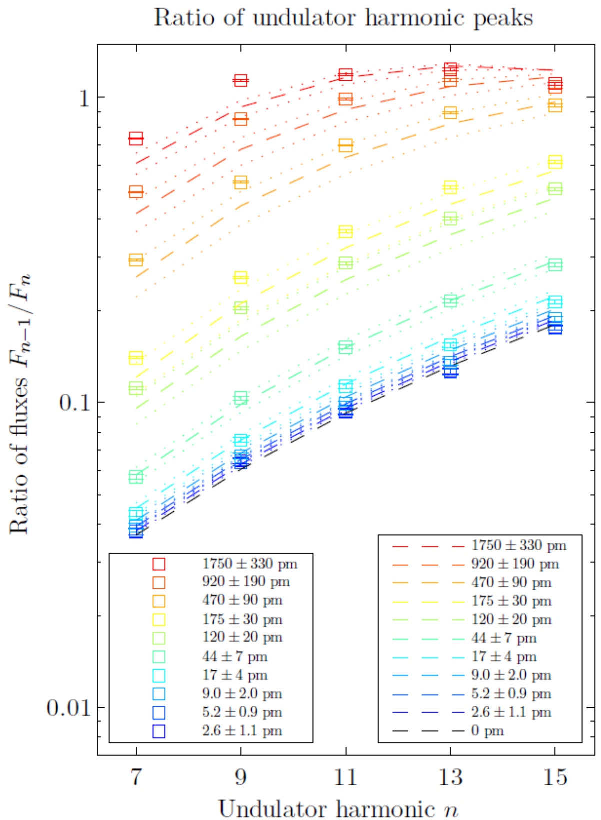
- Modelled



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

Emittance envelopes

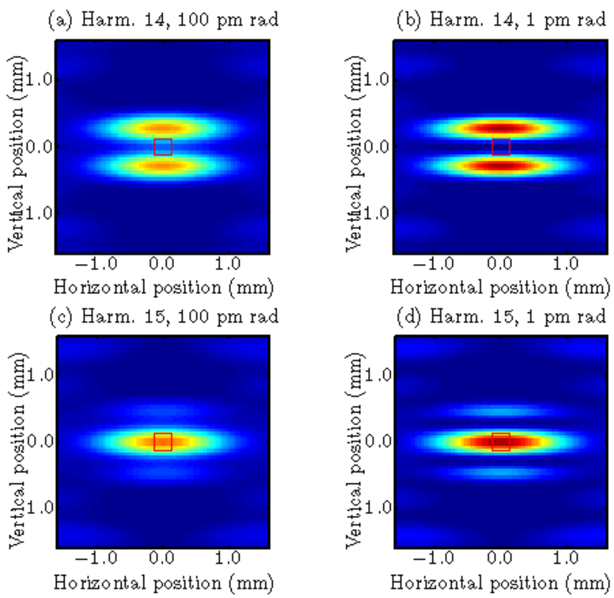
- Measured ratio of adjacent peaks
- F_{n-1}/F_n
- Envelopes of emittance from LOCO measurements
  - Fitted pinhole size of $260 \times 260\ \mu\mathrm{m}^2$
- Sensitive to emittance, want emittance measurement



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

Undulator projection measurements

Vertical undulator



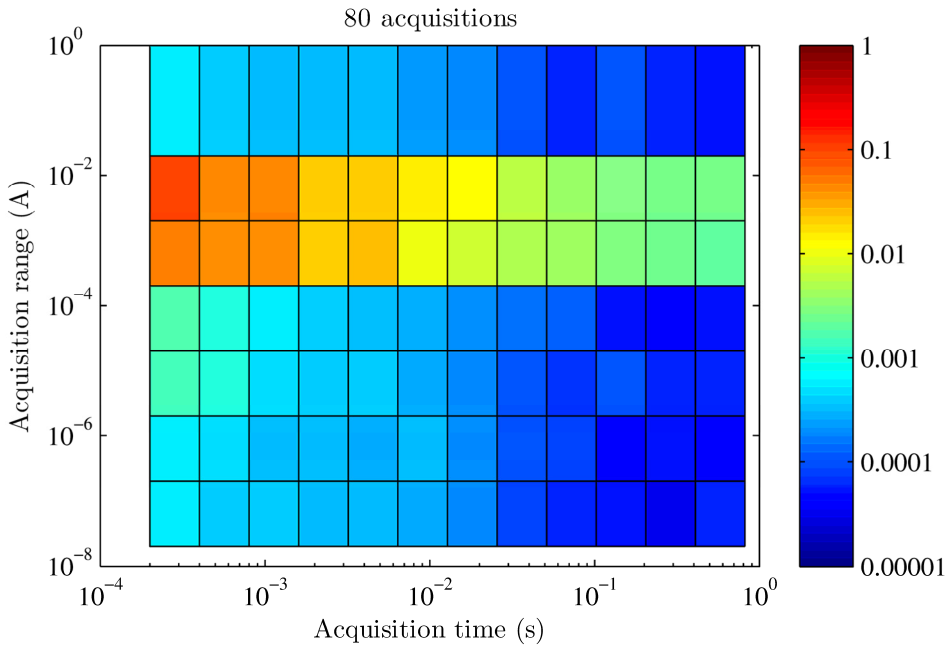
- Ideal model for undulator magnetic field
- Ideal distribution of undulator radiation
- Pinhole dimension fitted
- How can this be refined?

Time averaging

- *n* acquisitions, mean μ

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

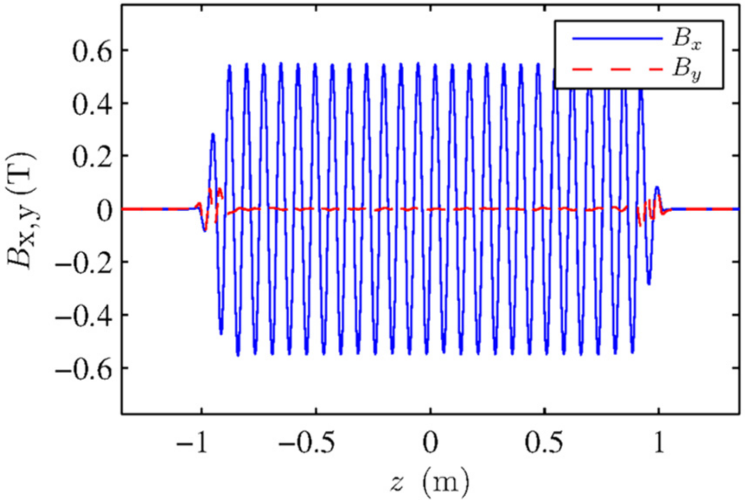
- Minimises statistical uncertainty
- Systematic uncertainty (pinhole position) remains
- Assumes beam not changing with time



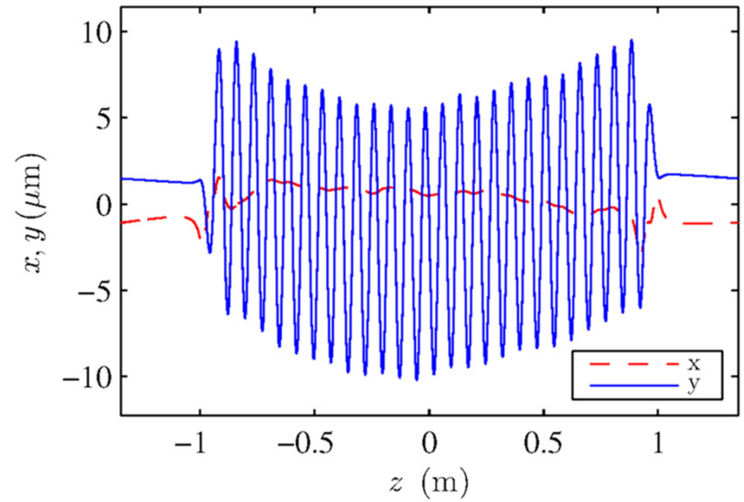
Wootton, et al. IBIC13, TUPF18 (2013)

Refined magnetic model

Measured magnetic field

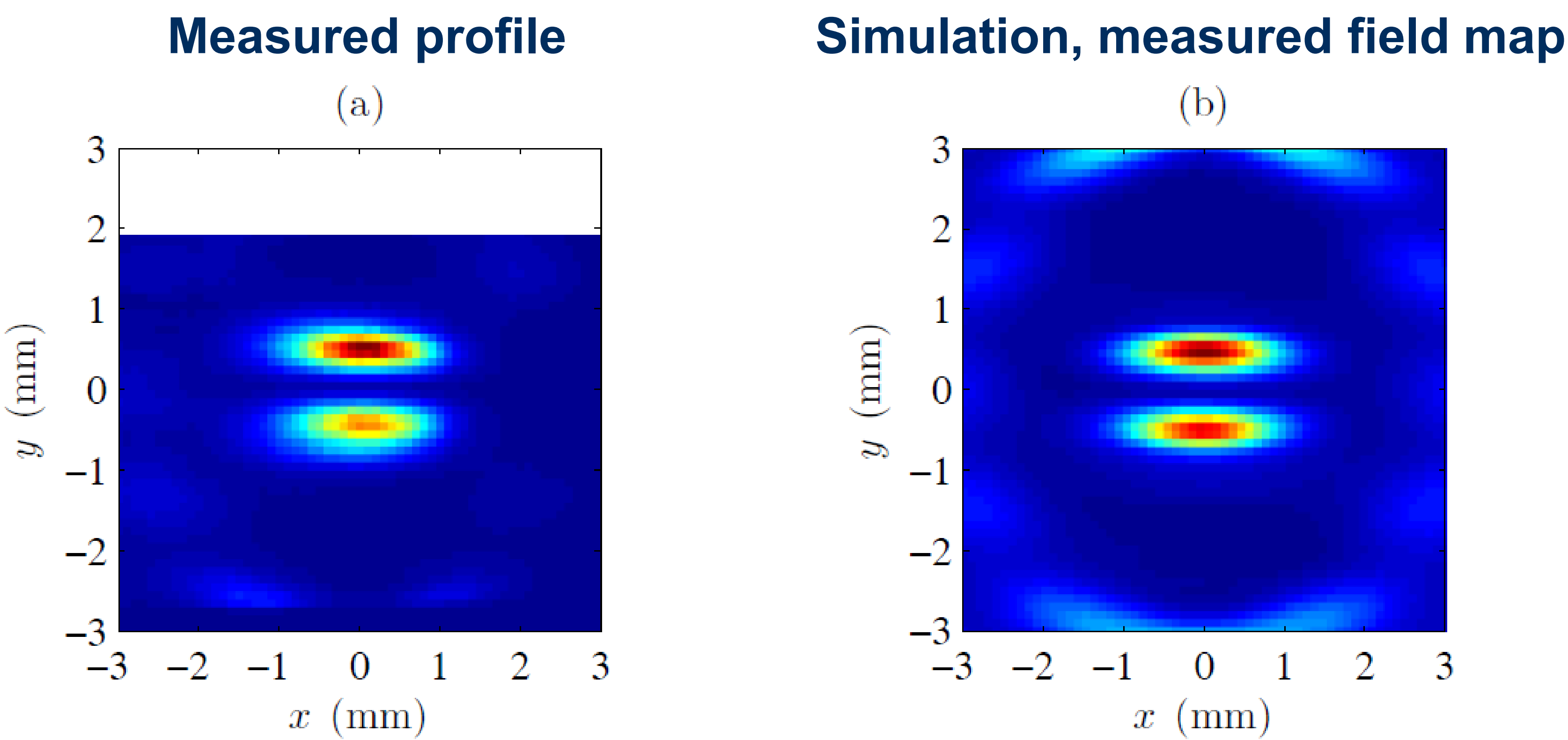


Simulated trajectory



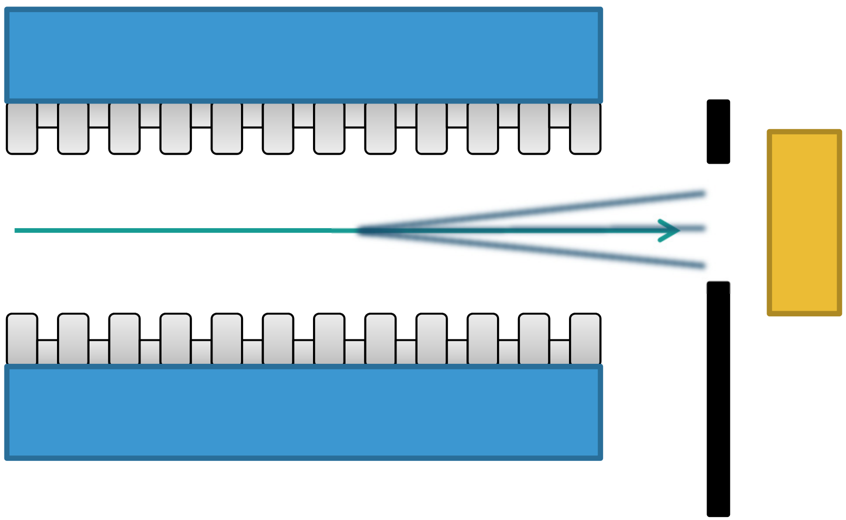
Ostenfeld, et al., PAC 2007, TUPMN006 (2007).

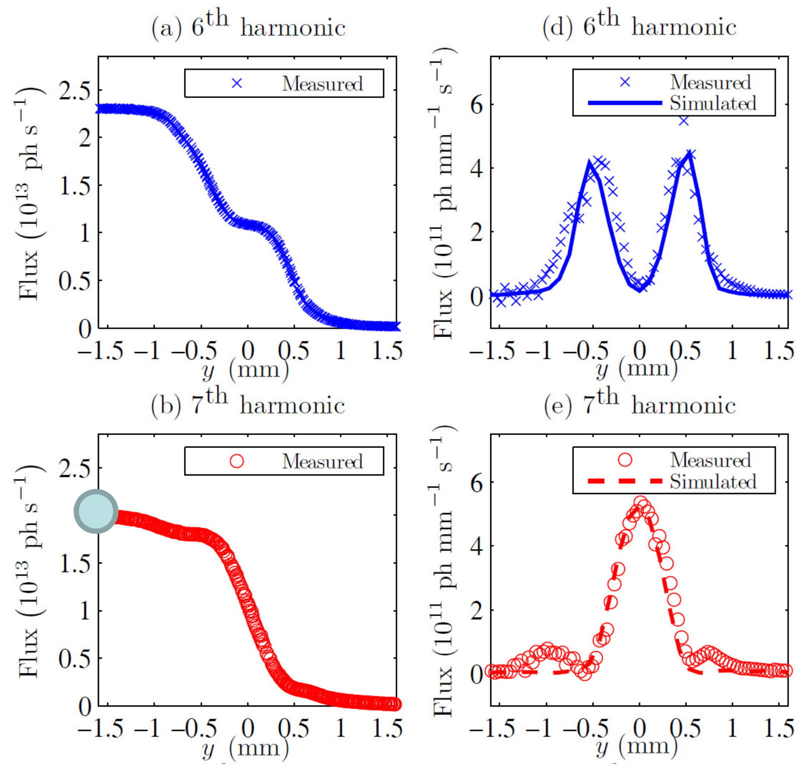
Refined magnetic model – results



Wootton, et al. IBIC13, TUPF19 (2013)

Blade scans

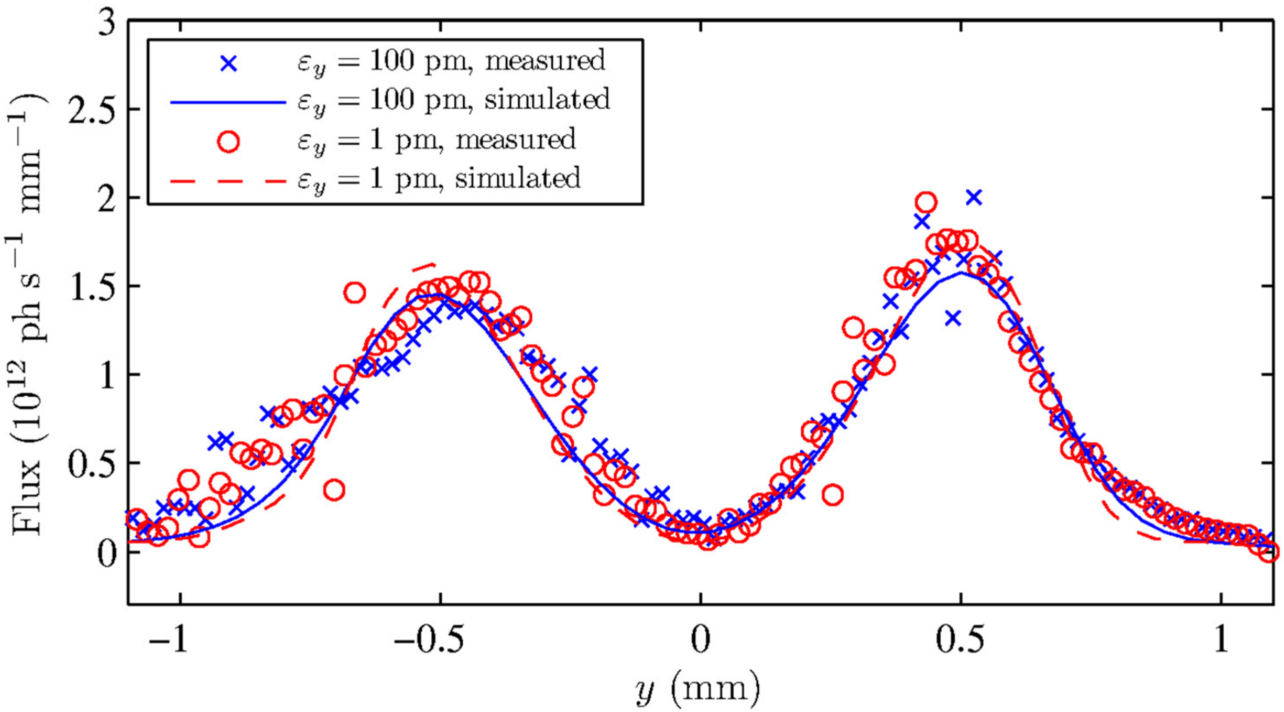




Wootton, et al. IBIC13, TUPF19 (2013)

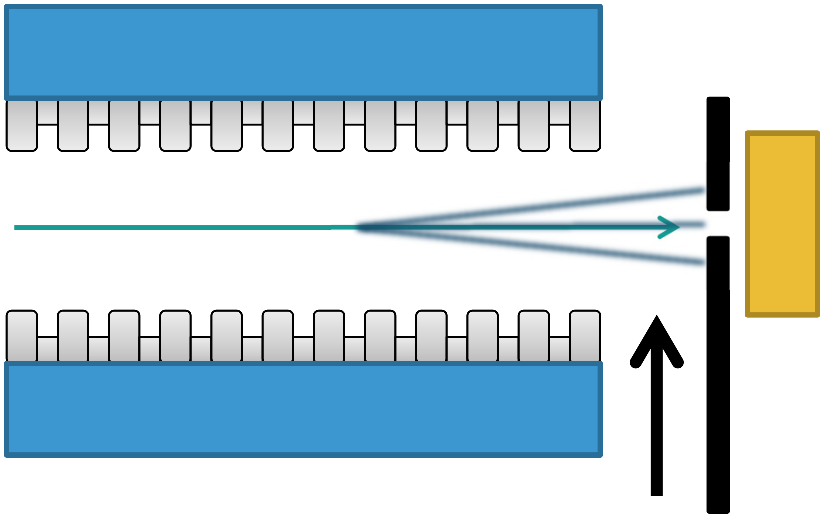
Blade scans – results

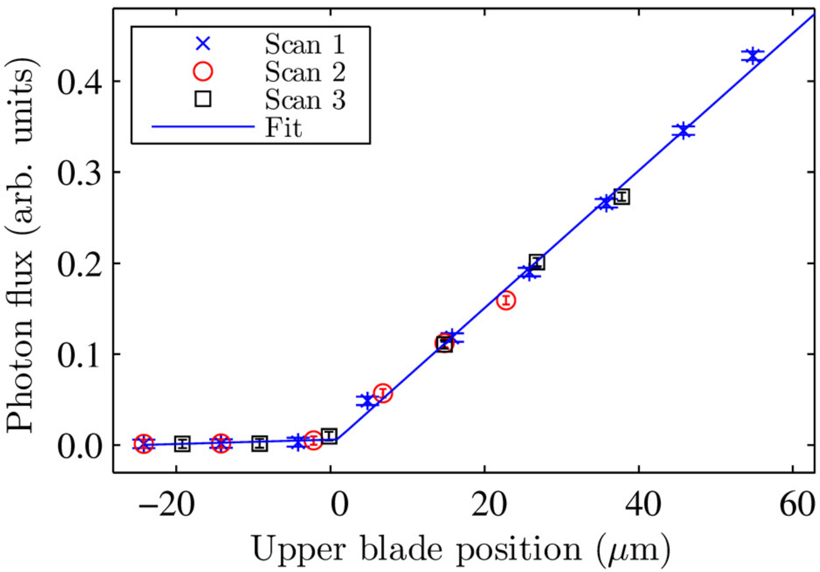
- Not sufficiently sensitive to pm rad emittances



Orbit bumps – pinhole size

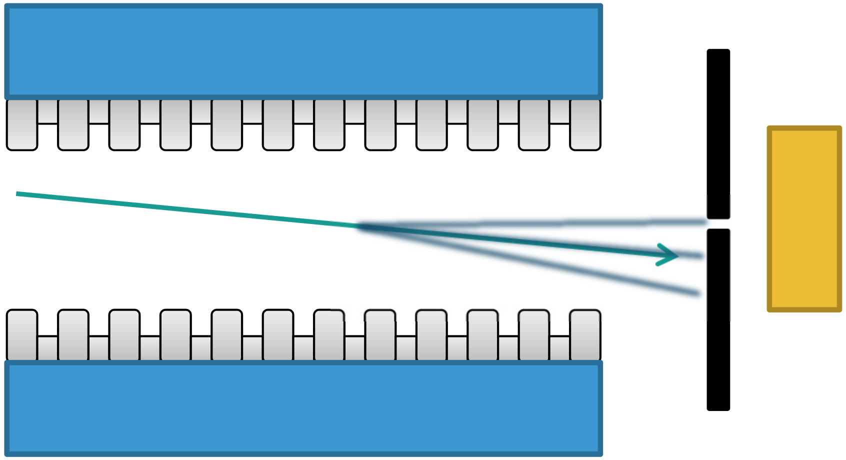
- Sensible pinhole size of 5 μm

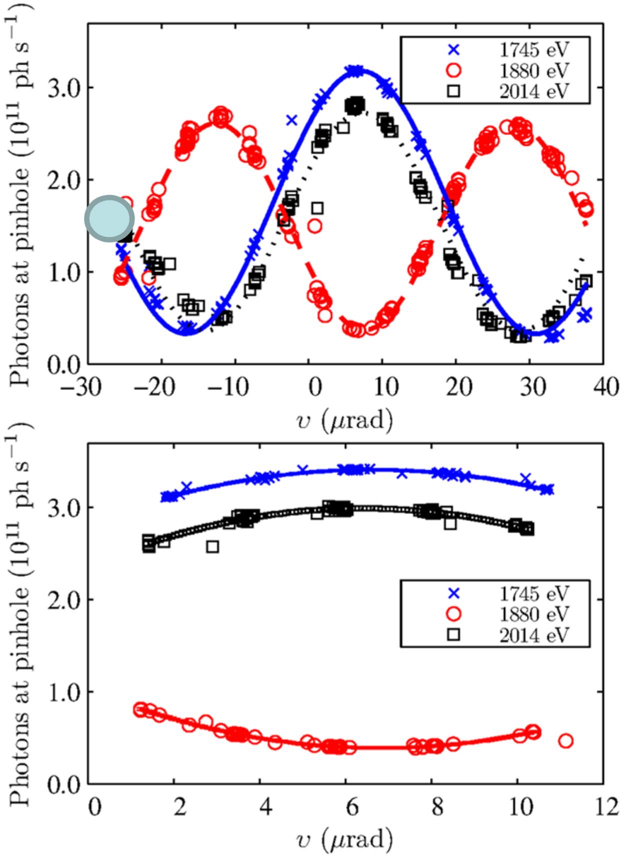




Wootton, et al. PRSTAB 17, 112802 (2014)

Orbit bumps

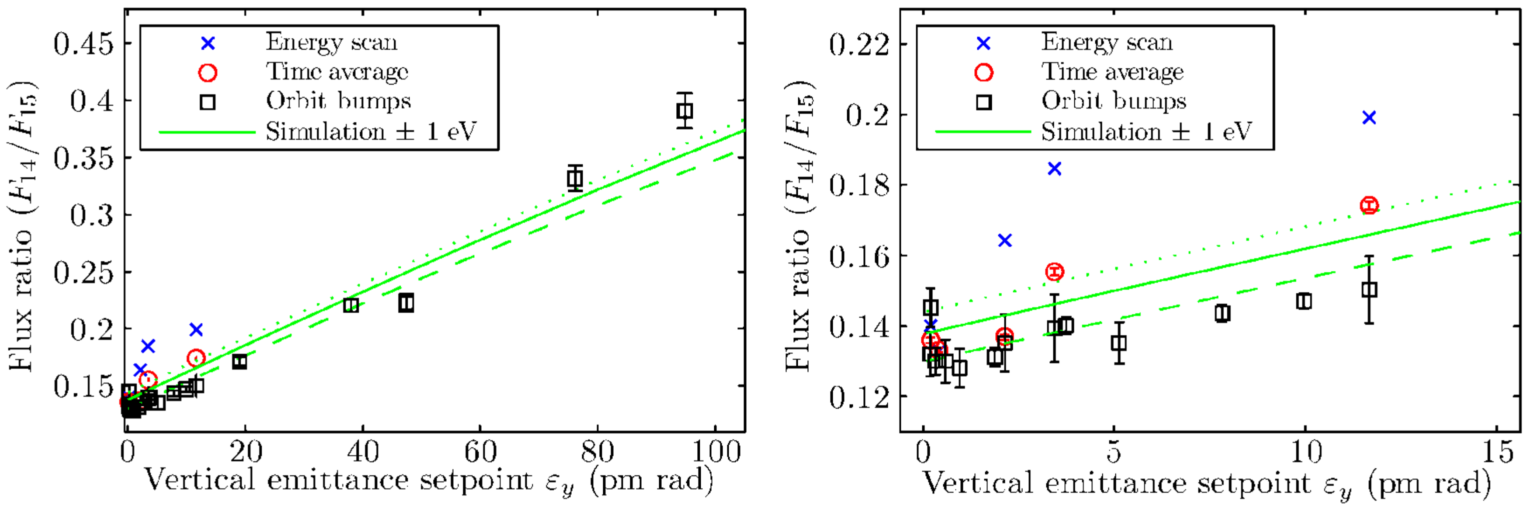




Wootton, et al. PRSTAB 17, 112802 (2014)

Emittance measurement

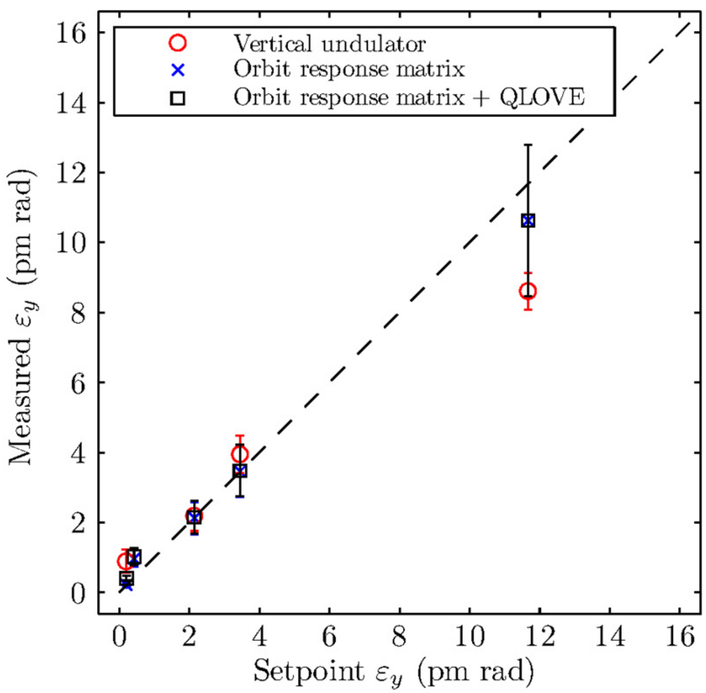
- Flux ratio measured using several approaches
- Simulated using measured field map



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

Emittance measurement

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



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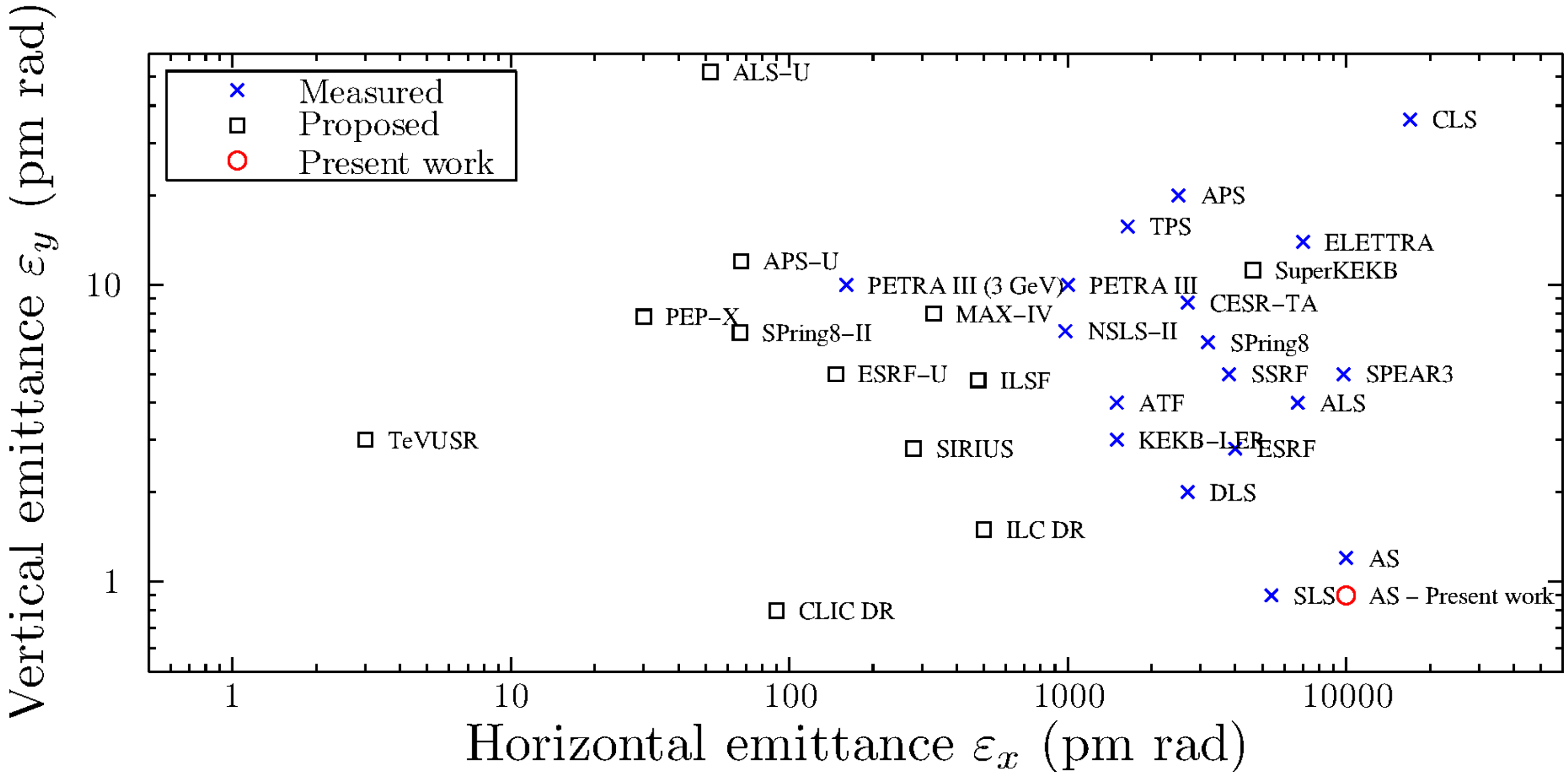
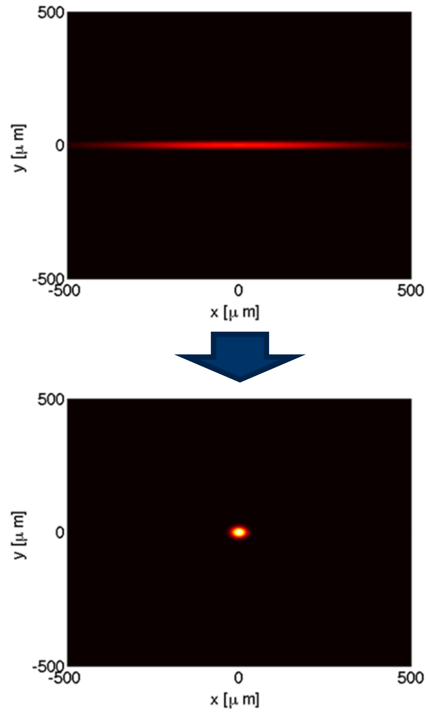
Discussion – present result



Discussion – DLSRs

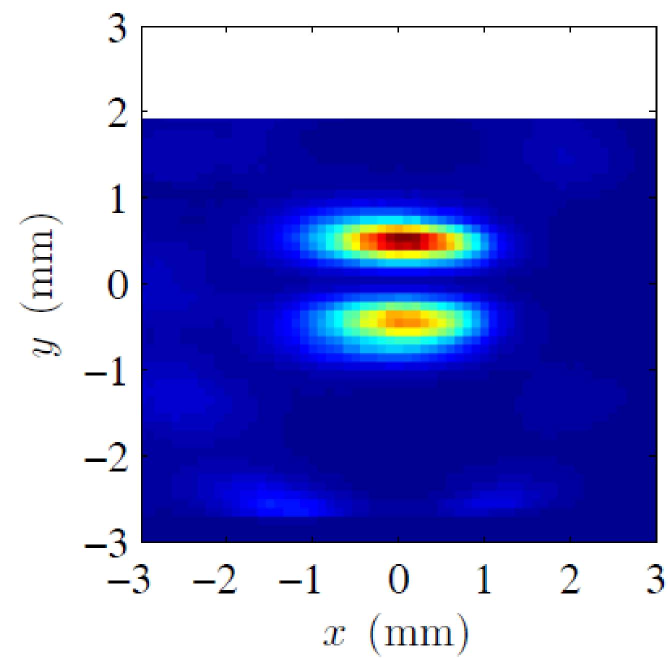
- Brilliance-optimised DLSRs
  - High undulator harmonics
  - Angular profile of undulator radiation departs significantly from typical Gaussian distributions
- Are photon beamlines prepared?

Electron beam



APS Report LS-334 (2014)

Undulator radiation

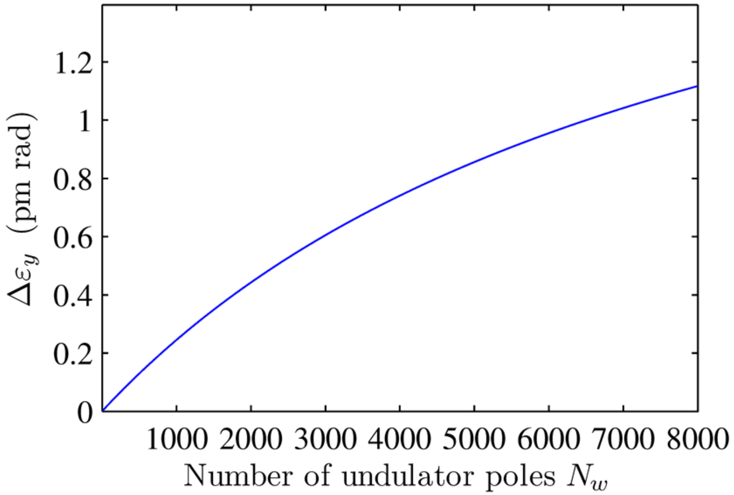


Discussion – self-dispersion

- Undulator self-dispersion leads to growth of vertical emittance

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

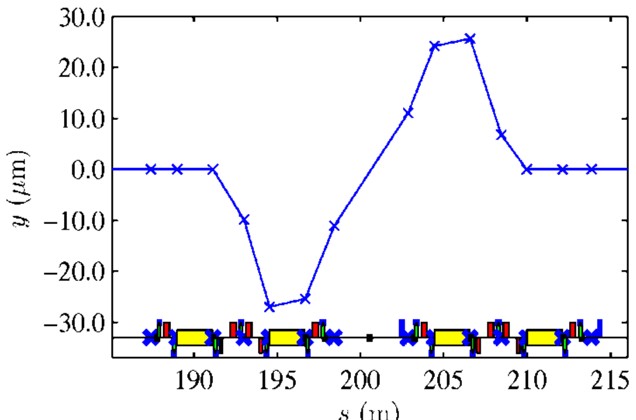
  - Wiedemann (1988) NIM:A 266, 24
  - Talman (2002) NIM:A 489, 519
- Negligibly small

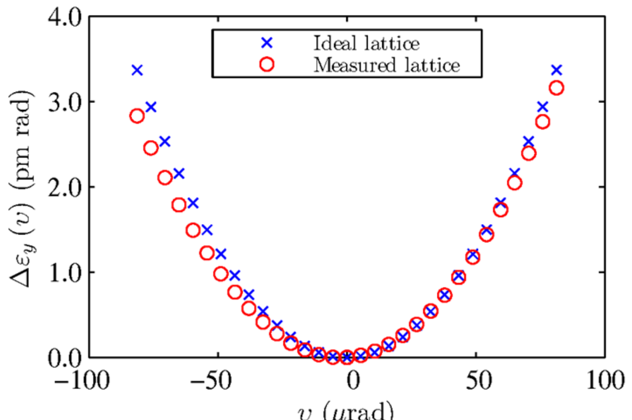


- 1 pm rad?
- 6500 undulator poles
- 240 m

Discussion – Orbit steering

- Steering electron beam off-axis through sextupoles
- AT model
- 10 μrad steering
- $\Delta\varepsilon_y = 0.07 \pm 0.01$ pm rad

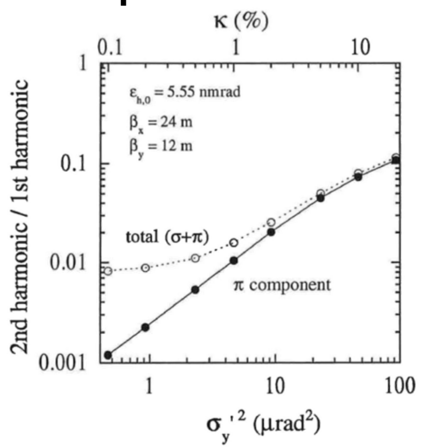


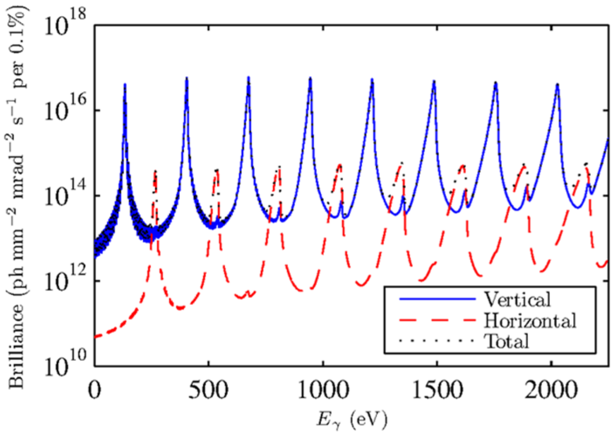


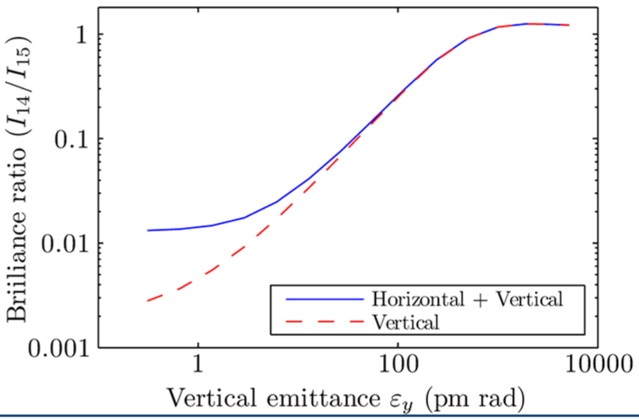
Wootton, et al. PRSTAB 17, 112802 (2014)

Where to? Polarisation

- Fixed pinhole diameter
- Linear polarisation







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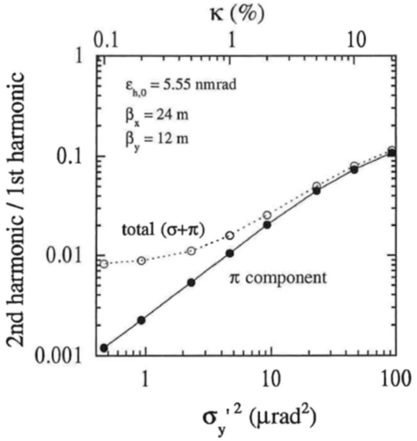
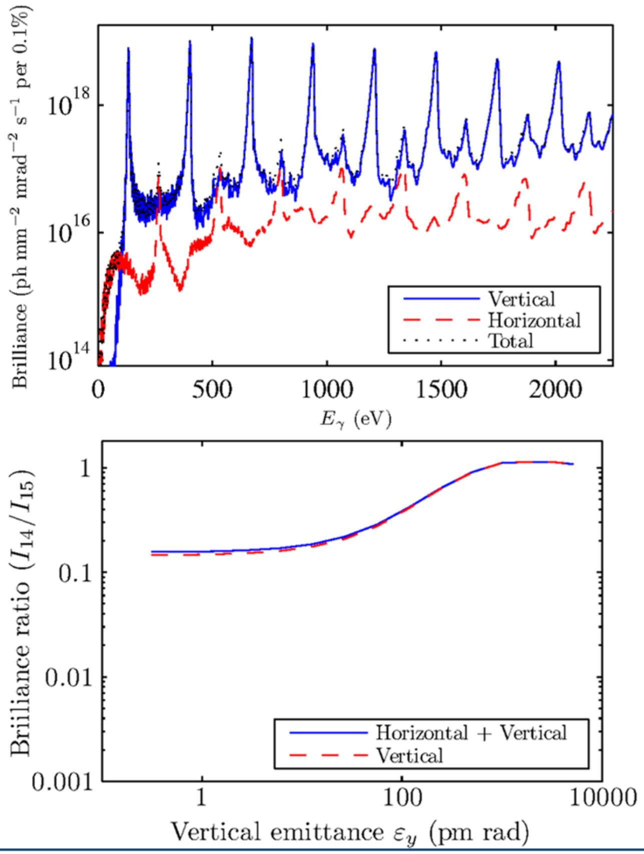


- Need undulator shimmed for vertical polarisation



Summary

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

Thank-you!

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ACAS Australian Collaboration for Accelerator Science

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