Vertical Emittance Measurements using a Vertical Undulator

K.P. Wootton, G.N. Taylor, R.P. Rassool

The University of Melbourne

M.J. Boland, B.C.C. Cowie, R. Dowd, Y.-R.E. Tan

Australian Synchrotron

Y. Papaphilippou

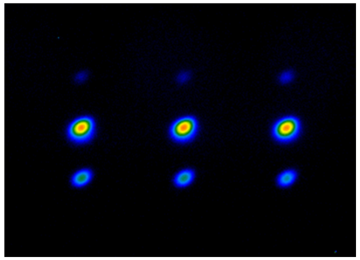
CERN

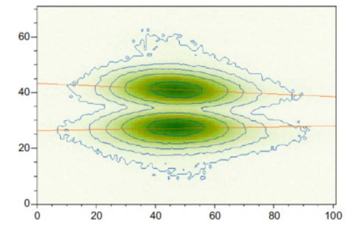
Motivation

- Collider damping rings and Super B-factory storage rings demand ε_y = 0.5-2.0 pm rad
- Collective effects lead to growth
  - Intra-beam scattering, electron cloud
- Storage ring light sources as test accelerators
  - SLS, ATF2, CESR, ASLS, Diamond, …
- Need measurements of vertical emittance

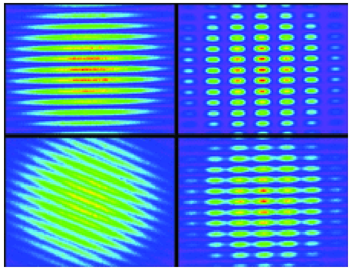
Synchrotron light vertical emittance monitors

- Three main approaches:
  - Imaging
  - Interferometry
  - Projection
- Quick diagnostic of storage ring
- Typically bending magnet
  - $\$\$\downarrow,\ \beta_y\uparrow,\ \eta_x\downarrow$
- Visible light, hard x-ray

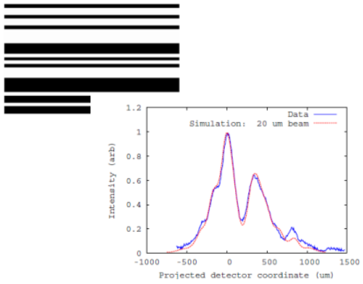




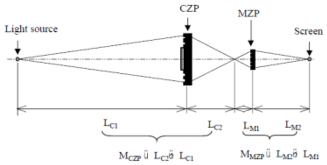
Andersson, NIMA 591, 437-446 2008



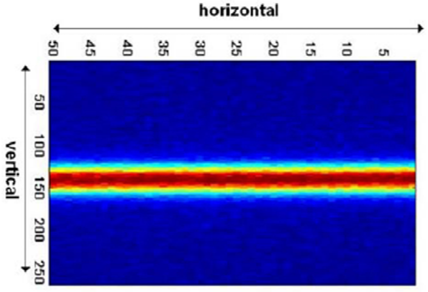
Masaki DIPAC01, PS17



Flanagan PAC09, TH5RFP048



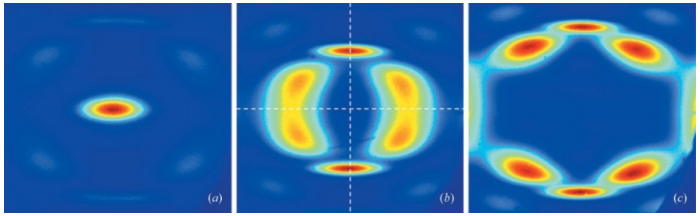
Nakamura PAC01, TPAH307



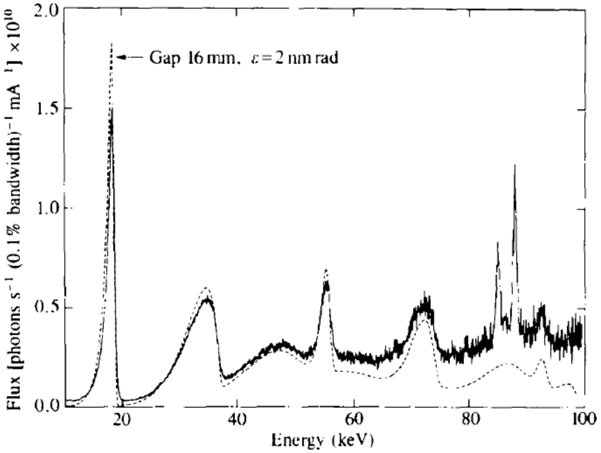
Scheidt, DIPAC05 CTWM01

Undulator diagnostics

- Focus on odd (useful!) harmonics
- **Horizontal undulators**
  - Imaging
  - Projection
  - Absolute spectral brilliance (pinhole flux)
- Energy spread, dispersion, ‘large’ emittance



Moreno JSR, 19 179-84 (2012)

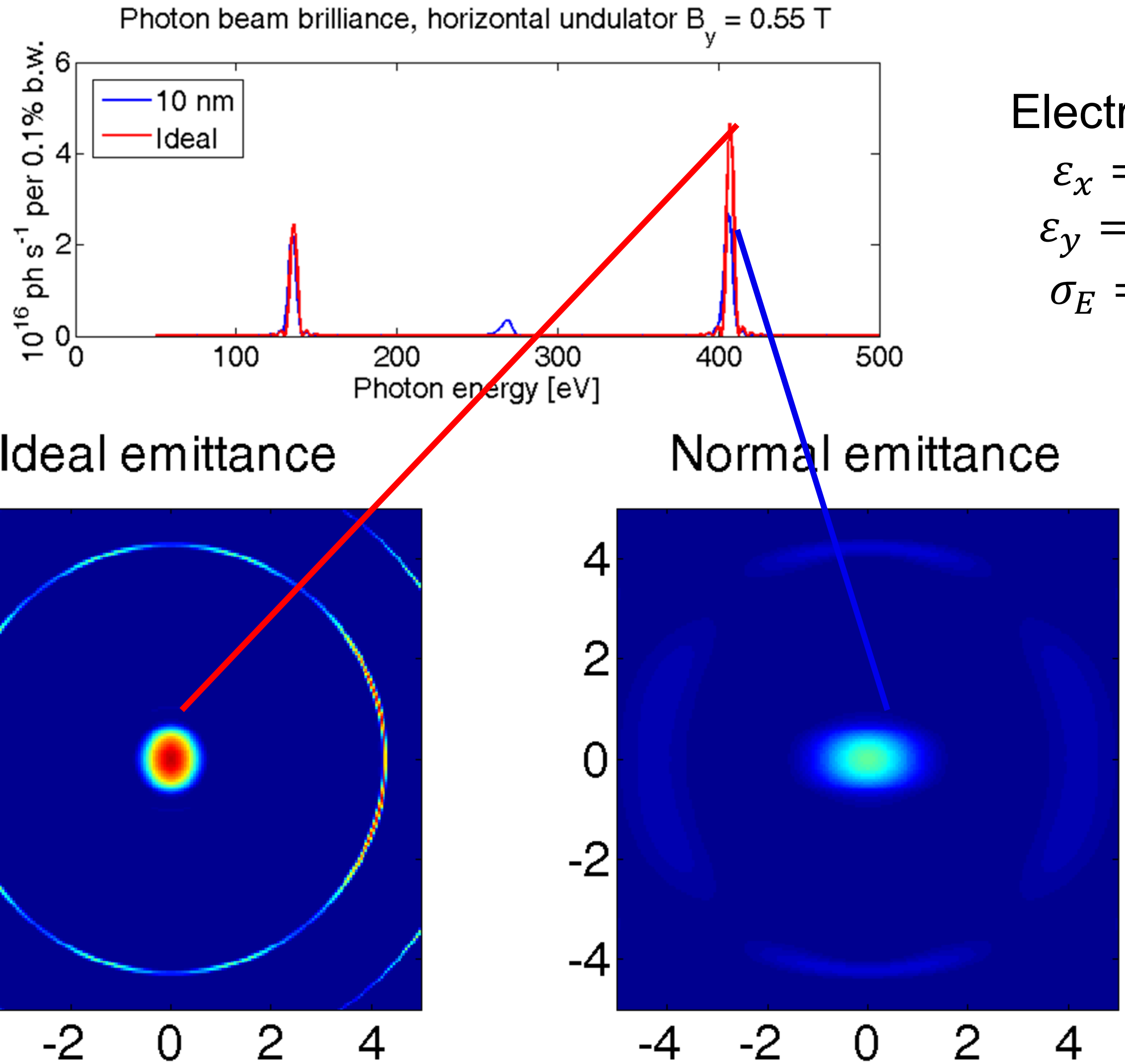


Hahn JSR 4, 1-5 (1997)

Undulator beam projection

Horizontal
Undulator
25 periods
75 mm period
K = 3.85

Pinhole
50 x 50 um
15m distance

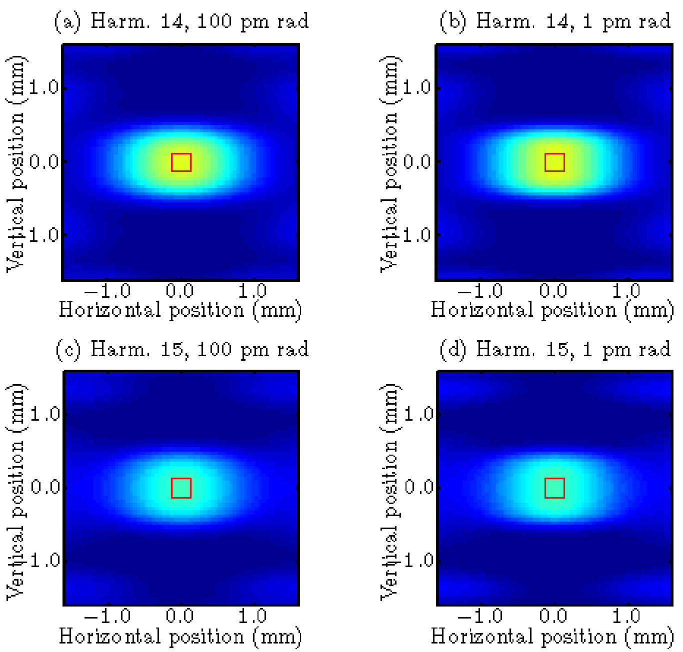


Electron beam
$\varepsilon_x = 10\ nm$
$\varepsilon_y = 100\ pm$
$\sigma_E = 0.11\%$

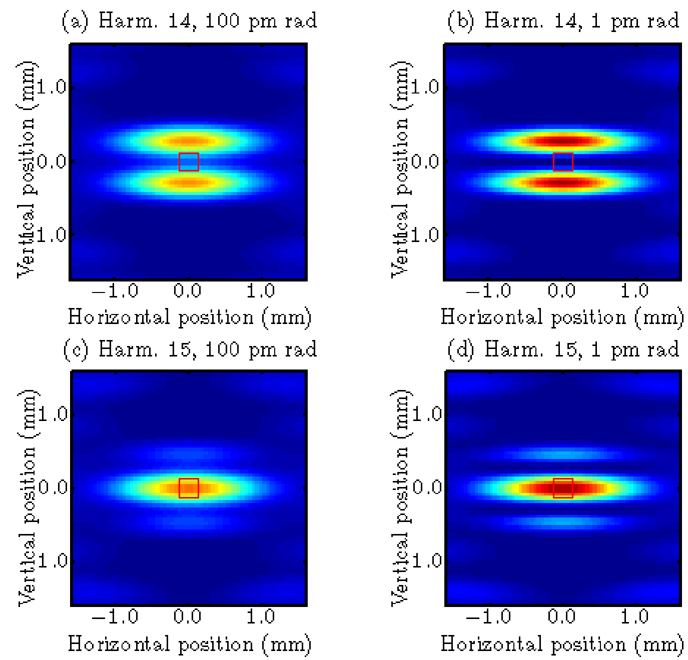
Tanaka & Kitamura, JSR 8 1221 (2001)

Undulator projection measurements

Horizontal undulator



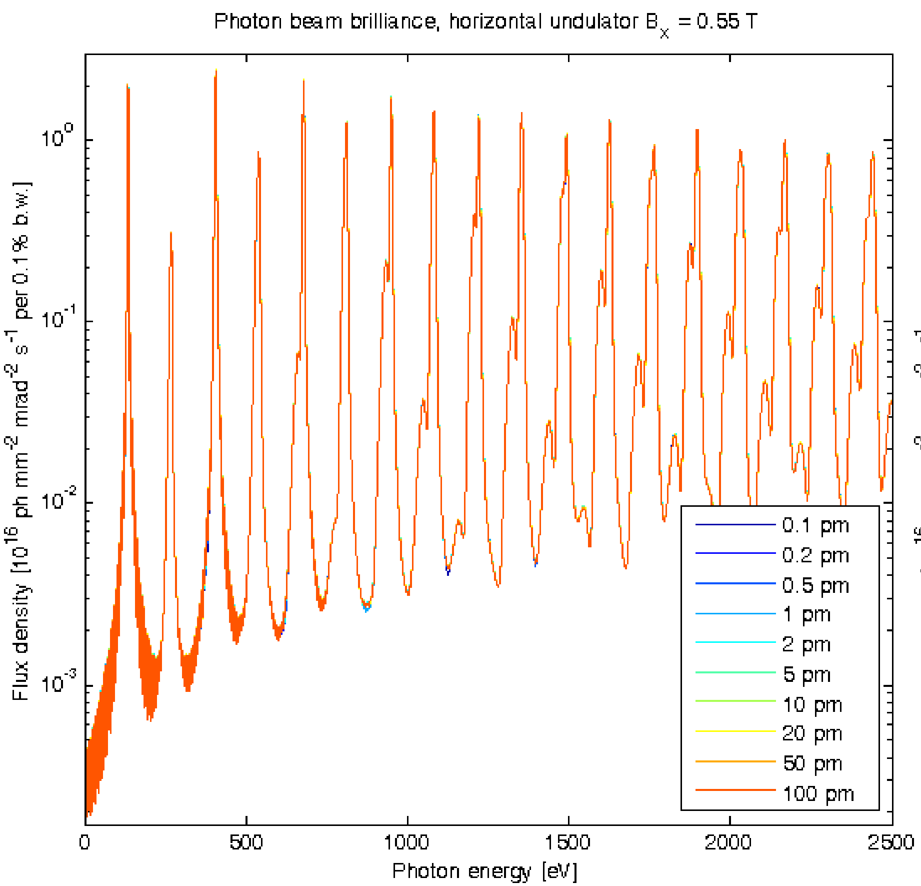
Vertical undulator

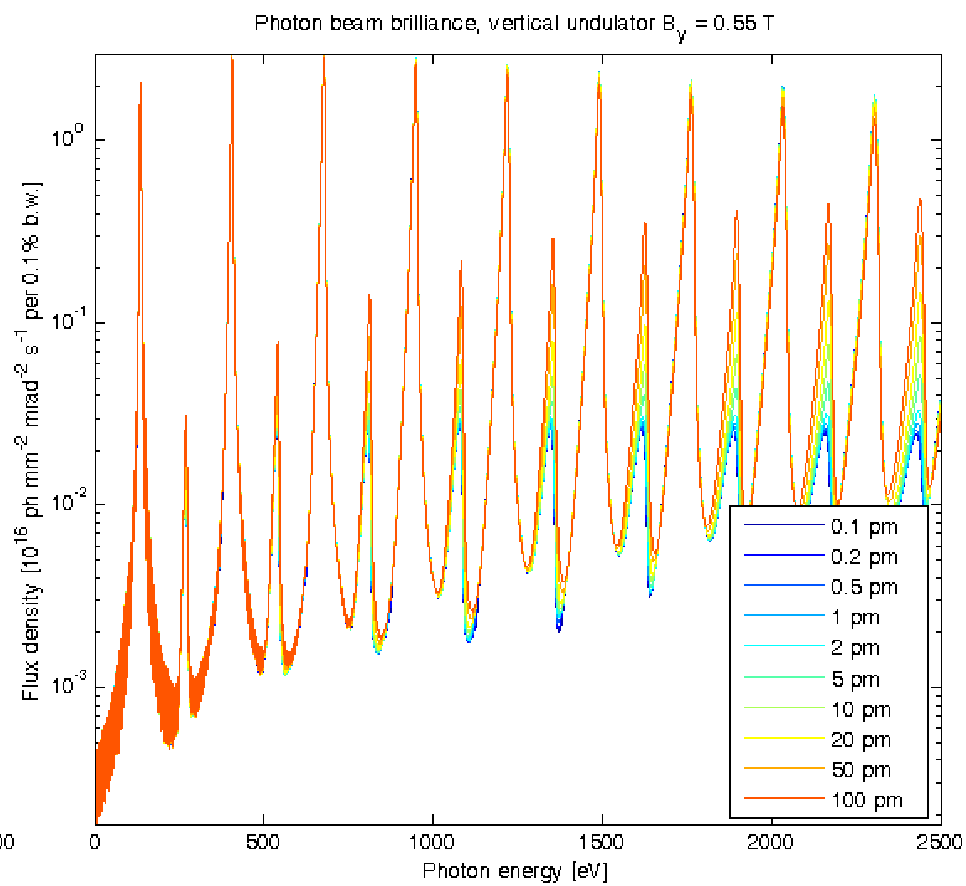


Undulator	Electron beam
25 periods	$\varepsilon_x = 10\ nm$
75 mm period	$\varepsilon_y = 100\ pm$
K = 3.85	$\sigma_E = 0.11\%$

Photon beam brilliance

- Horizontal undulator
  - No contrast
- Vertical undulator
  - Even harmonics





Fitting spectra

- 'It is evident that the second-harmonic brightness is proportional to the beam emittance …'
  Dattoli PRE 52(6) 6809-17 (1995)
- I add to this: … the emittance in the direction of undulations
  - How do we measure photon beam brilliance?

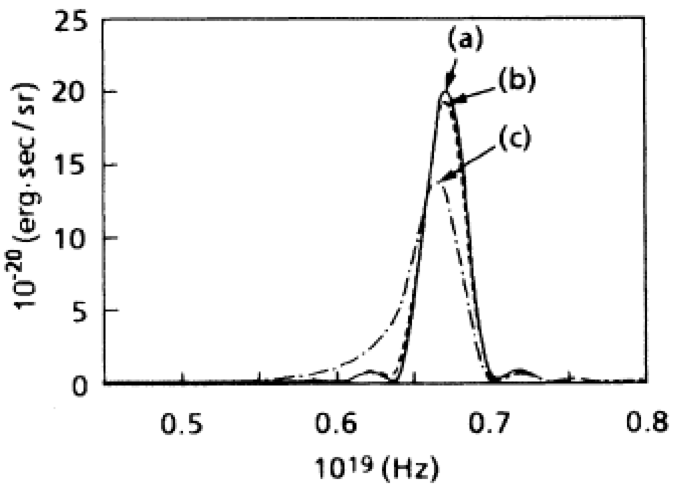
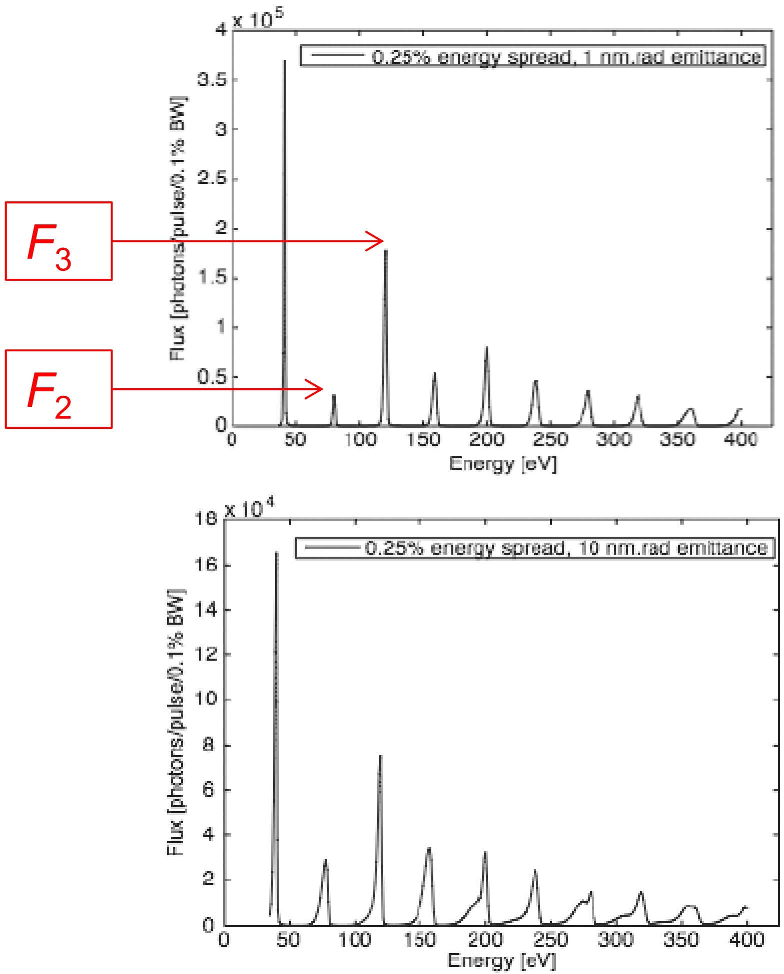


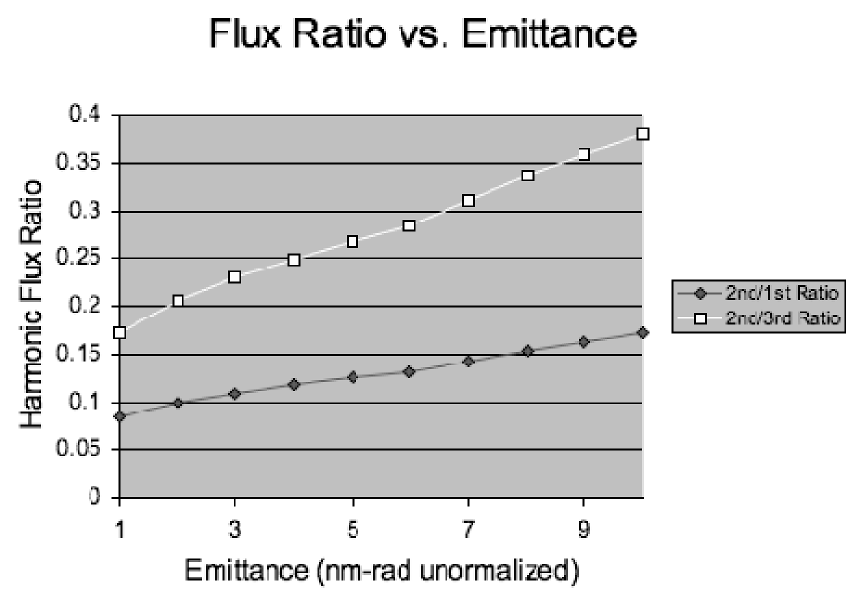
FIG. 1. First-harmonic brightness vs frequency parameters

Dattoli PRE 52(6) 6809-17 (1995)

Pinhole flux ratio

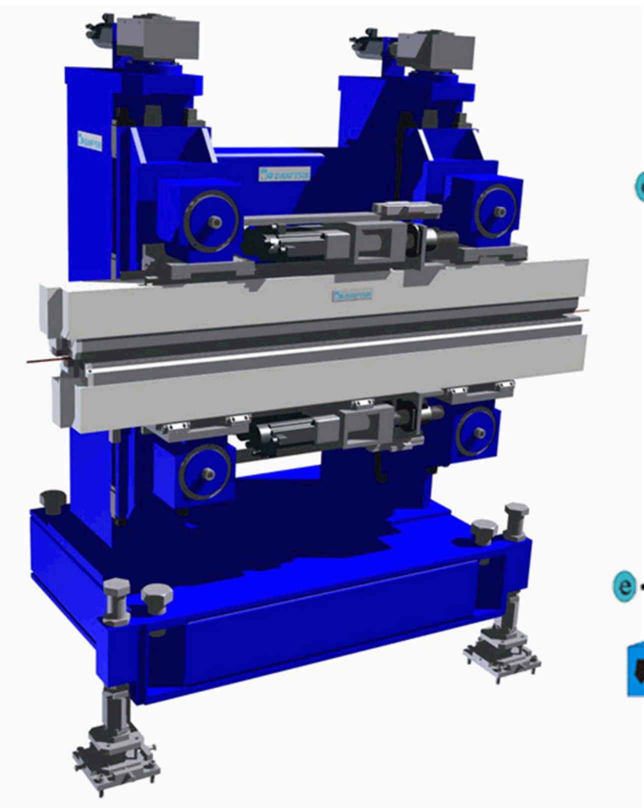


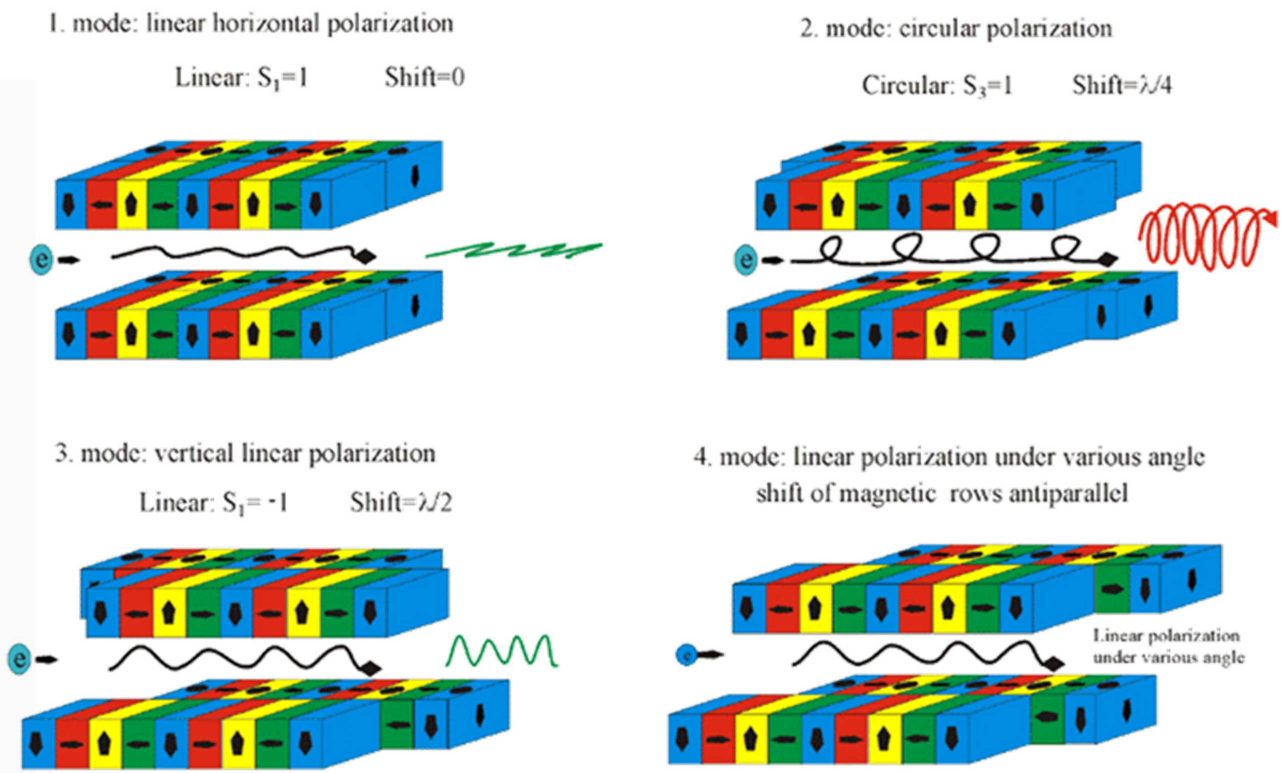
- Electron wakefield accelerator
- Flux ratio F_{n-1} / F_n



M. Bakeman et al., PAC 2009, WE6RFP074
M. Bakeman, et al., PAC 2011, MOP161

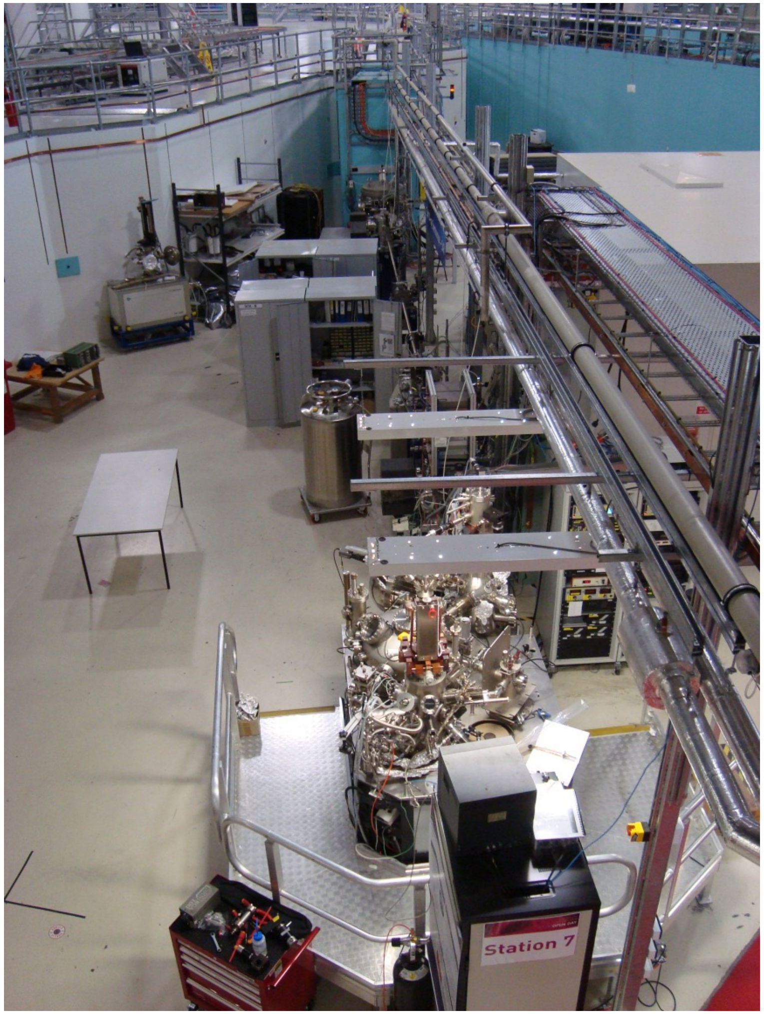
Advanced Planar Polarised Light Emitter-II Modes of operation





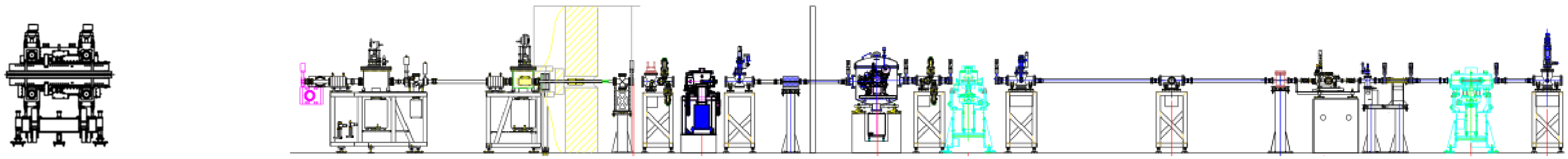
Sasaki, Nucl. Instrum. Methods A **347**, 83 (1994)

Soft x-ray undulator beamline



Soft x-ray undulator beamline

- APPLE-II undulator
- White beam slits first optical element
- All focussing, monochromator downstream

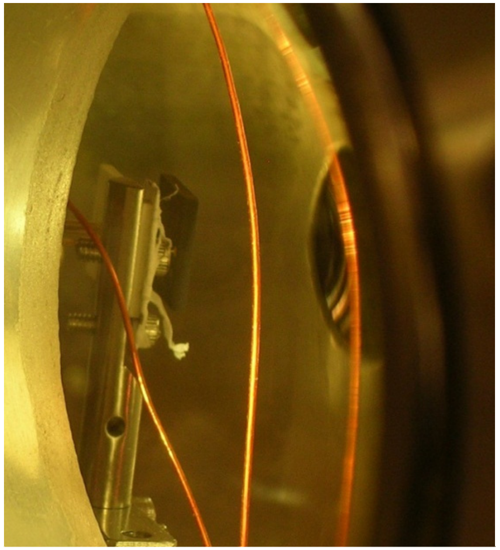


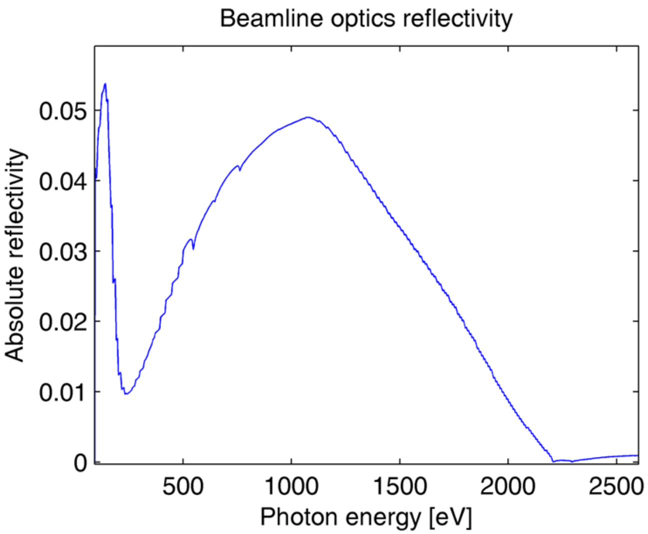
Detector

- Measuring vertical emittance with one large pixel!
- Beamline optics
  - Grating monochromator
  - Au-coated mirrors
  - Energy-defining slit
  - Photodiode (GaAsP, Si)

B.C.C. Cowie, et al., AIP Conf. Proc. 1234, 307 (2010)

- Au-coated mirrors
  - Transmission varies with photon energy





Photodiode choice

- Early experiments
  - Hamamatsu GaP/Au
- Ratio of peaks
- Absorption edges
  - Silicon photodiode
- Keithley picoammeter
  - Spans many orders of magnitude in current

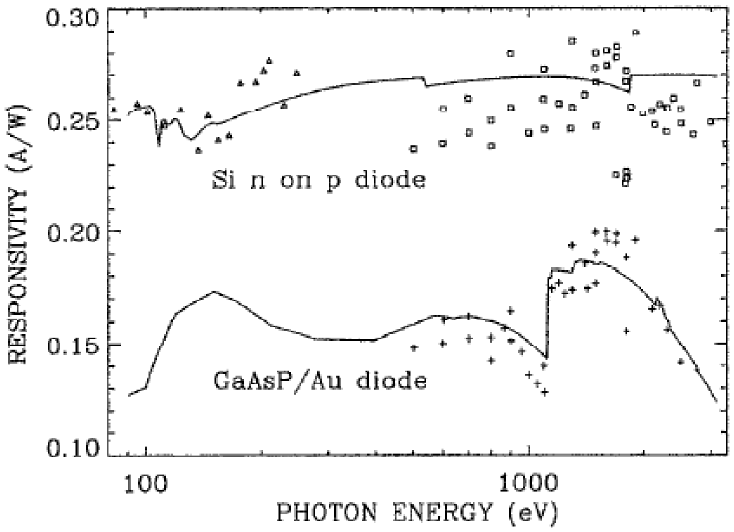


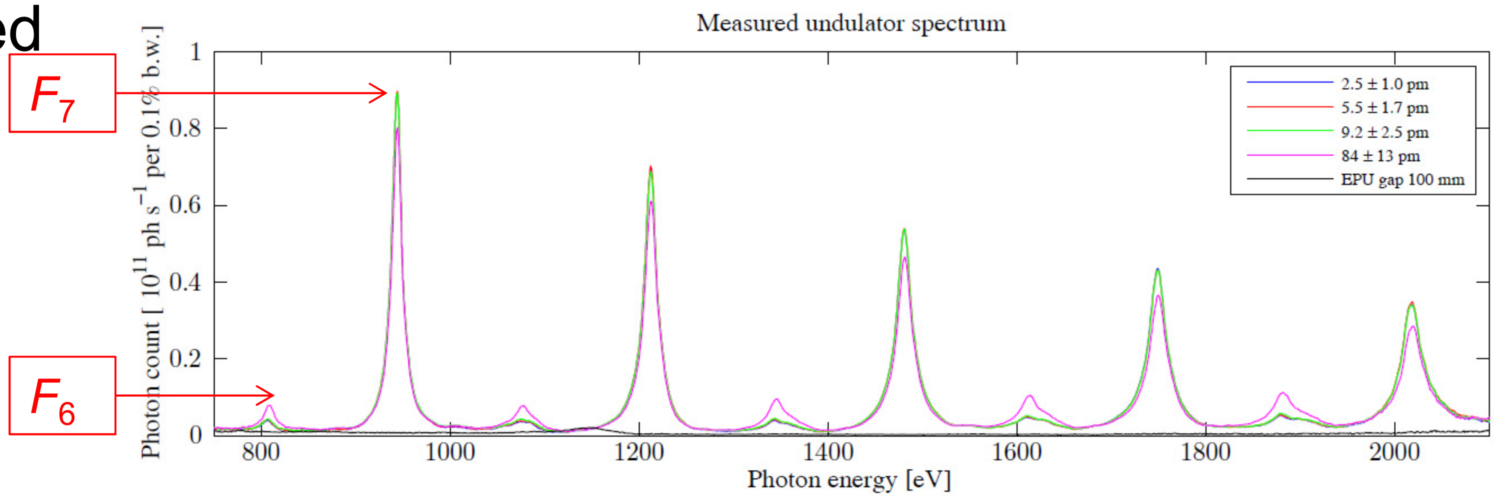
FIG. 2. Spectral responsivity of a Si *n* on *p* diode and a GaAsP/Au diode

Krumrey, Tegeler (1992) Rev Sci Instrum 63 (1), p. 797-801

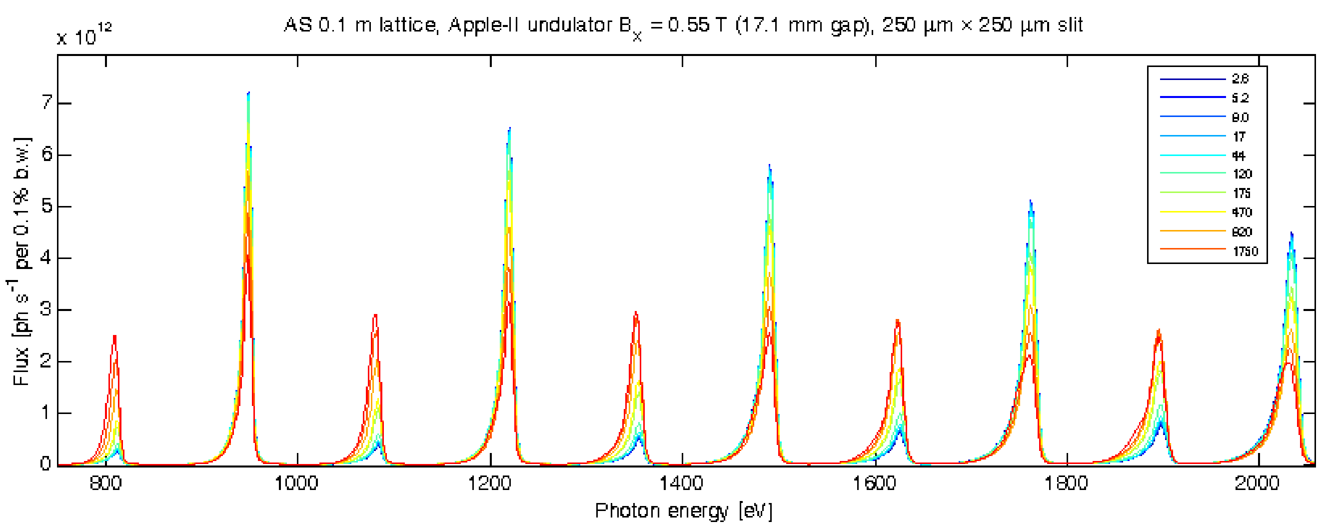
Measured undulator spectrum

- Measured

Flux ratio
F_{n-1} / F_n

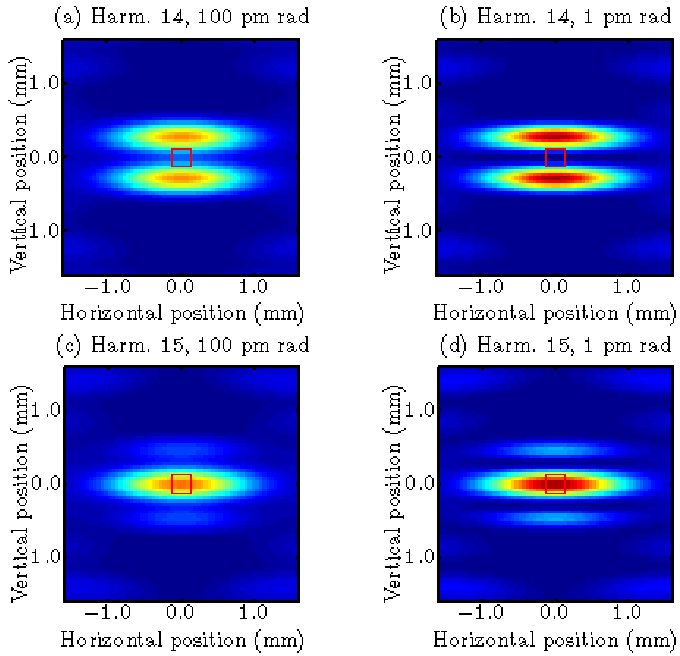


- Modelled



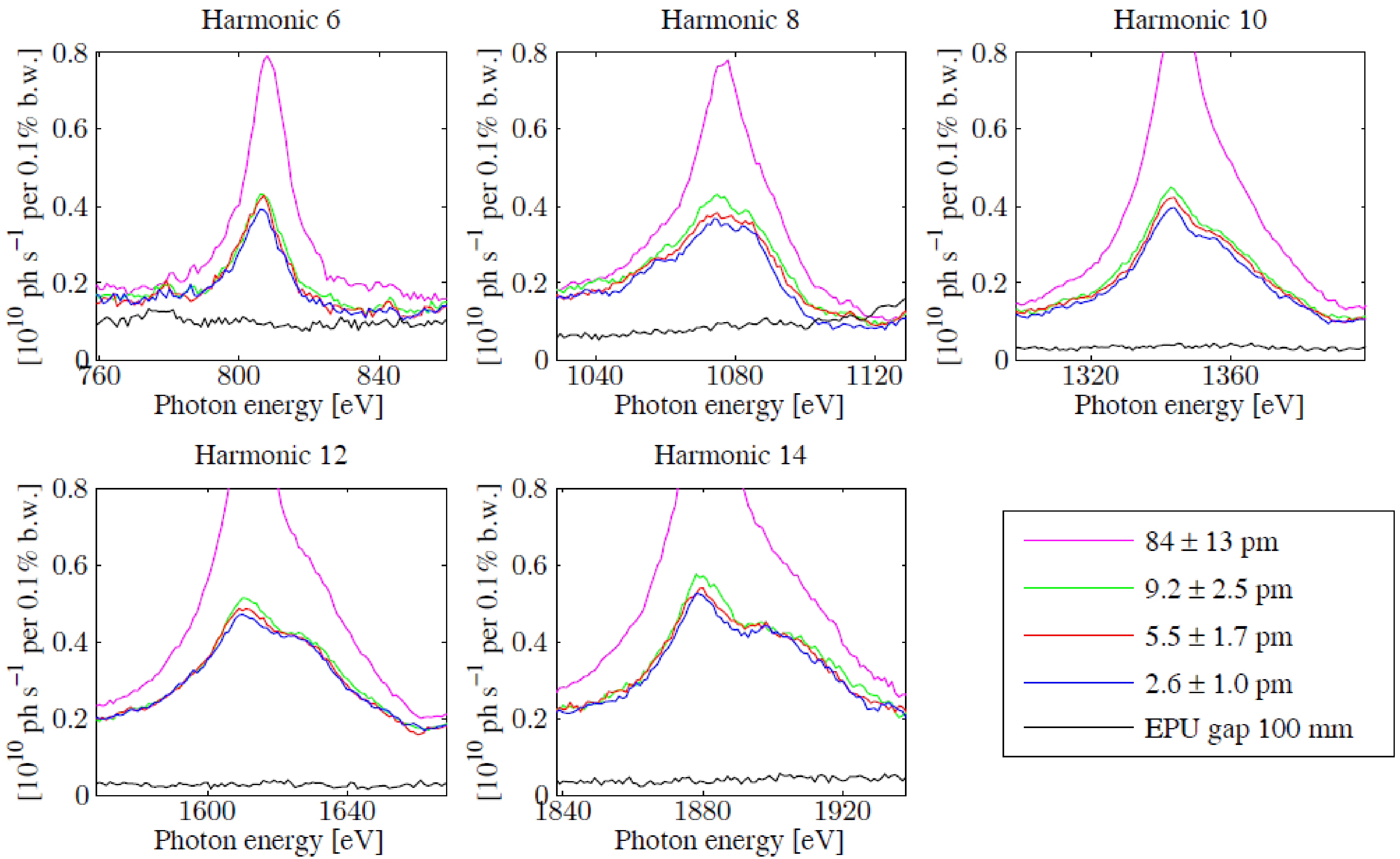
Undulator projection measurements

Vertical undulator



Undulator	Electron beam
25 periods	$\varepsilon_x = 10\ nm$
75 mm period	$\varepsilon_y = 100\ pm$
K = 3.85	$\sigma_E = 0.11\%$

Even harmonics



Even harmonics

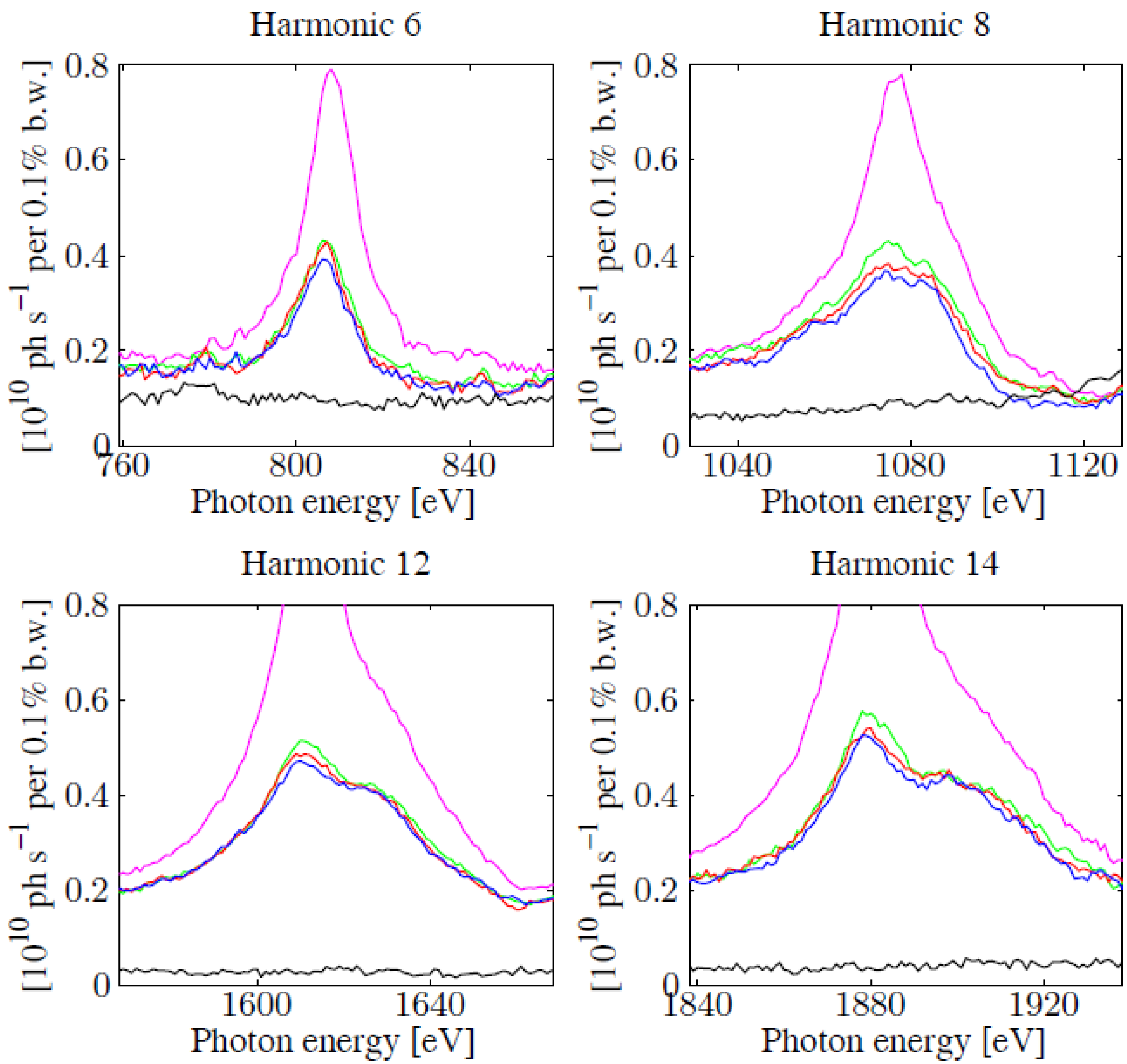
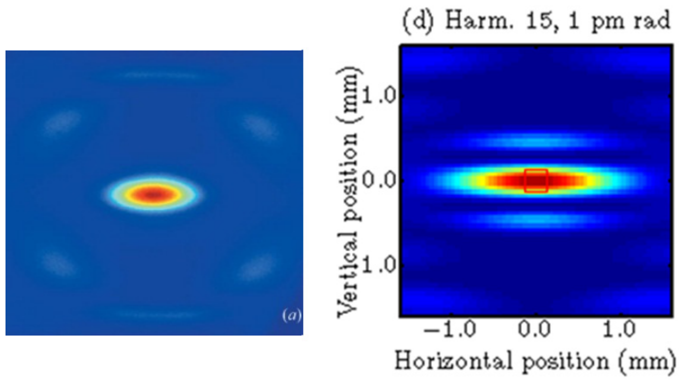


Table 1: Measured Flux Ratio F_{10}/F_{11}

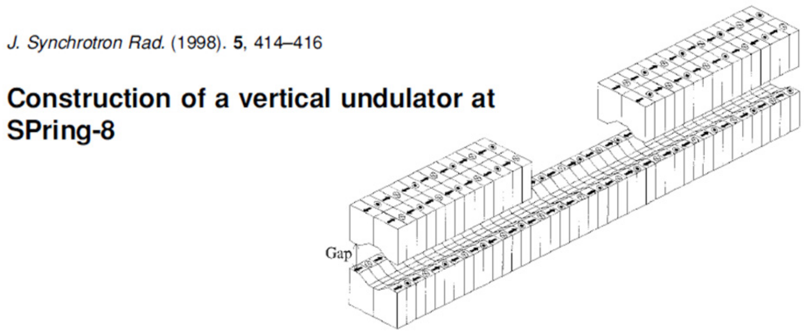
ε_y [pm rad]	F_{10}/F_{11}
84 ± 13	0.204 ± 0.006
9.2 ± 2.5	0.083 ± 0.005
5.5 ± 1.7	0.078 ± 0.005
2.6 ± 1.0	0.074 ± 0.005

Where to?

- Fixed pinhole diameter
- SOLEIL DiagOn (fixed energy 367.5 eV)
- SPring-8 BL45XU (vertical IVU)
- Higher undulator *K*



Moreno JSR, 19 179-84 (2012)



Tanaka JSR 5, 414 (1998)

Summary

- Undulator measurement of emittance is an old technique
  - Usually use horizontal undulator, horizontal emittance
  - Introduce vertical undulator, vertical emittance
- Measure pinhole spectra for different emittances
  - Pinhole much smaller than $1/\gamma$ undulator cone.
- Evaluate ratios of adjacent harmonics
  - Simulations of undulator flux
  - Knowing pinhole size, would fit for beam emittance
- New vertical emittance measurement for many electron storage rings

Thank-you!

k.wootton@student.unimelb.edu.au

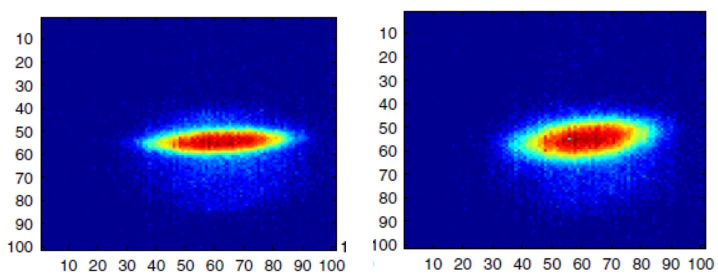
References

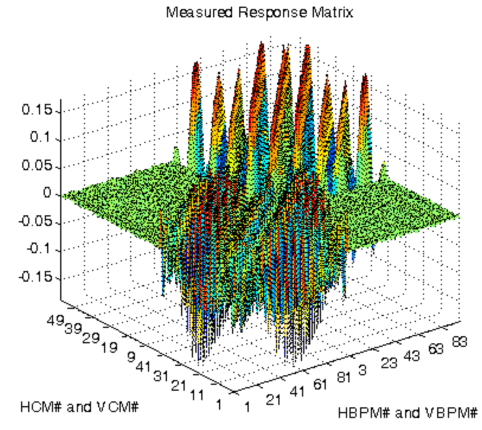
- Åndersson, NIMA 591, 437-446 (2008)
- Bakeman, et al., PAC 2009, WE6RFP074
- Bakeman, et al., PAC 2011, MOP161
- Boogert PRSTAB 13, 122801 (2010)
- Cowie, et al., AIP Conf. Proc. 1234, 307 (2010)
- Dattoli PRE 52(6) 6809-17 (1995)
- Dowd, et al., PRSTAB 14, 012804 (2011)
- Flanagan PAC09, TH5RFP048
- Hahn JSR 4, 1-5 (1997)
- Krumrey, Tegeler Rev Sci Instrum 63 (1), 797 (1992)
- Masaki DIPAC01, PS17
- Moreno JSR, 19 179-84 (2012)
- Nakamura PAC01, TPAH307
- Sasaki, NIM:A 347, 83 (1994)
- Scheidt, DIPAC05 CTWM01
- Shintake NIM:A 311, 453-464 (1992)
- Tanaka, et al., JSR 5, 414 (1998)
- Tanaka & Kitamura, JSR 8 1221 (2001)

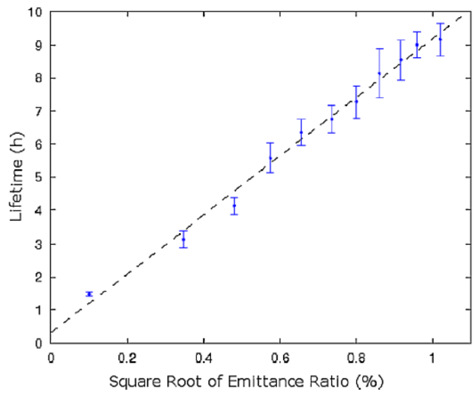
Extra slides

Indirect measurement

- Orbit response matrix fitting
- Touschek lifetime
  - Eigen as opposed to projected emittances
- Beam ellipse tilt (bending magnet)



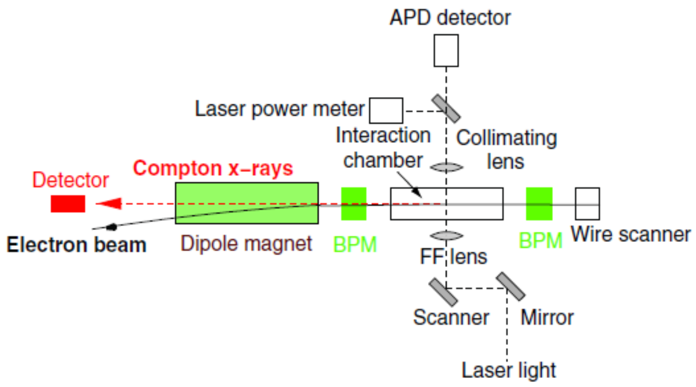




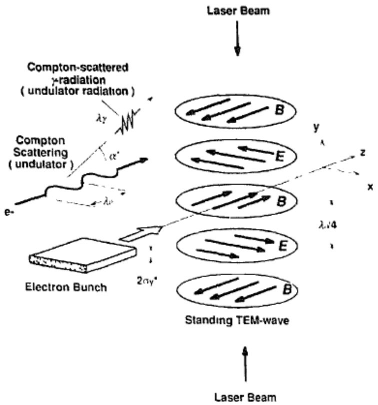
Dowd PRSTAB 14, 012804 (2011)

Direct measurement
Laser wire scanner

- Scanning laser waist through electron beam
  - Inverse Compton gamma rays
- Shintake monitor
  - Interference pattern narrower than laser waist



Boogert PRSTAB 13, 122801 (2010)



Shintake NIMA 311, 453-464 (1992)