

TRANSVERSE EMITTANCE MEASUREMENT USING UNDULATOR HIGH HARMONICS FOR DIFFRACTION LIMITED STORAGE RINGS

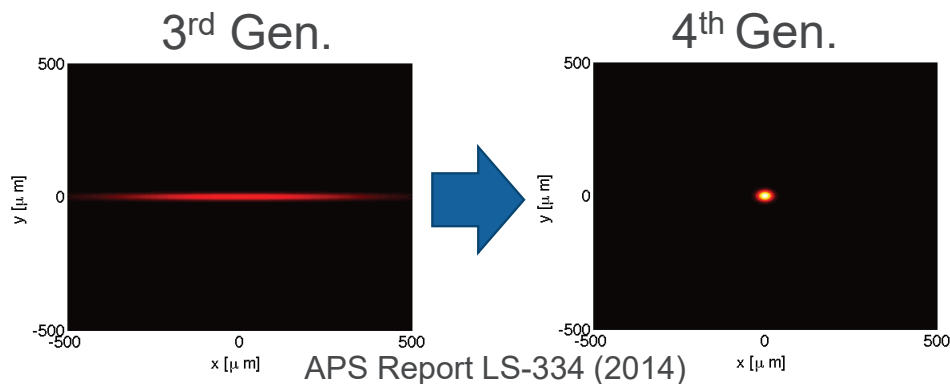


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12th September, 2019
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PRESENT AND UPCOMING STORAGE RINGS

- Diffraction Limited Storage Rings (DLSRs) open new frontiers in X-ray science



Parameter		APS	APS-U	Units
Energy	E	7.0	6.0	GeV
→ Horiz. emittance	ε_x	3100	41.7	pm rad
Horiz. beta	β_x	19.1	5.19	m
Vert. beta	β_y	3.20	2.40	m
Horiz. dispersion	η_x	167	0.39	mm
Energy spread	$\frac{\Delta E}{E}$	0.096	0.135	%

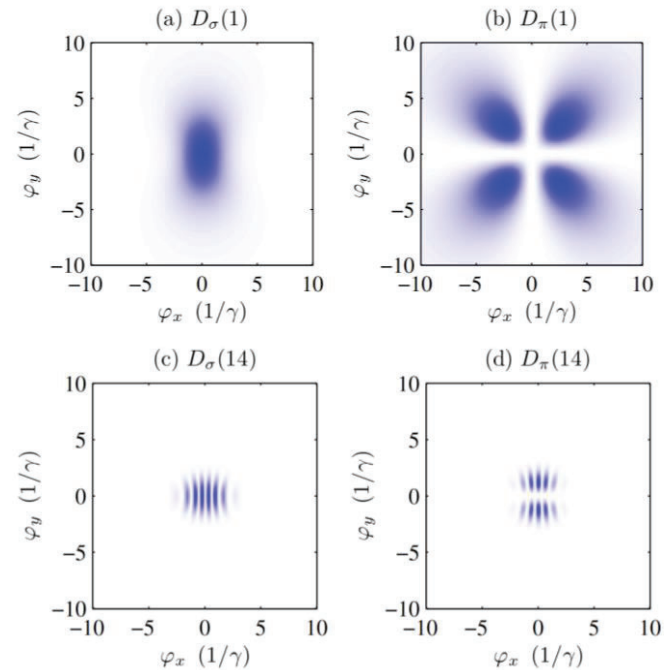
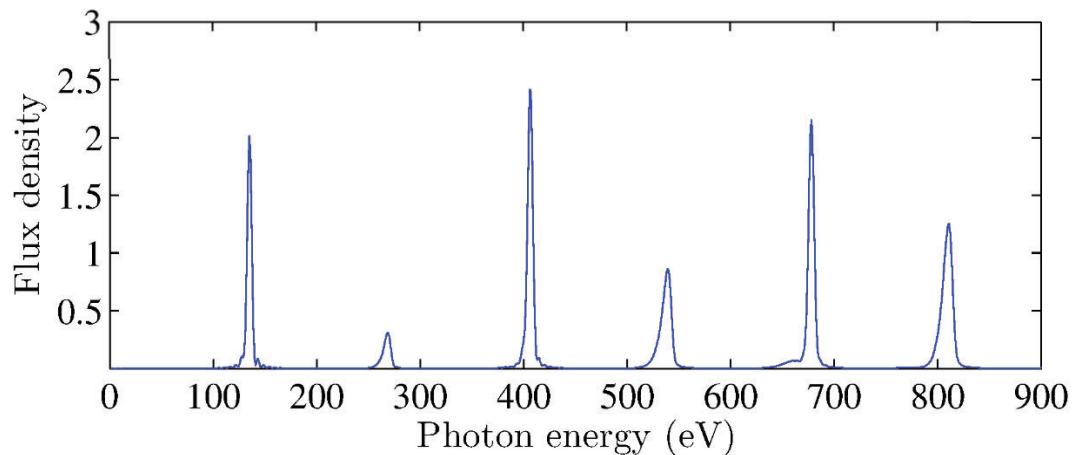
- Diagnostics needed to measure high brightness beams
- APS-U horizontal emittance will be a lot like vertical emittance in APS today
 - M. Borland, et al., in *Proc. IPAC'18, Vancouver, Canada, THXGBD1 (2018)*

EMITTANCE MEASUREMENT IN STORAGE RINGS

- Variety of techniques to measure \sim pm rad vertical emittance
 - Imaging (pinhole, Fresnel zone plate)
 - Interferometry/ π -polarisation
 - e.g. J. Breunlin *et al.*, NIMA, 803, p. 55 (2015)
 - Projection
 - B. K. Scheidt, *Proc. DIPAC2005*, Lyon, France, CTWM01, (2005)
- APS-U: dedicated bending magnet X-ray based emittance, energy spread monitors
 - B. Yang *et al.*, Proc. IBIC2016, Barcelona, Spain, TUPG66, (2016)
- Vertical undulator to measure vertical emittance
 - S. Takano, KEK Proceedings 97-20, pp. 18-29, Oct. 1997
 - K. P. Wootton, Proc. IBIC2015, Melbourne, Australia, TUCLA01, (2015)

CONCEPT – HORIZONTAL UNDULATOR

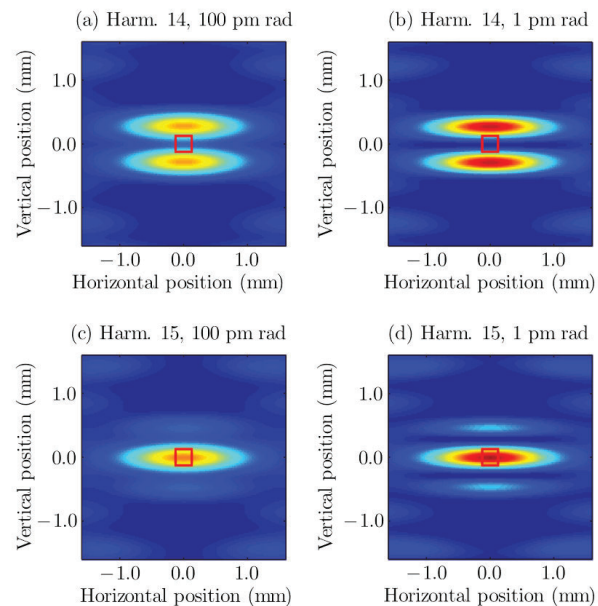
On-axis profile of undulator radiation



K. P. Wootton, et al., [PRSTAB, 17, 112802 \(2014\)](#)

PREVIOUS WORK – VERTICAL UNDULATOR

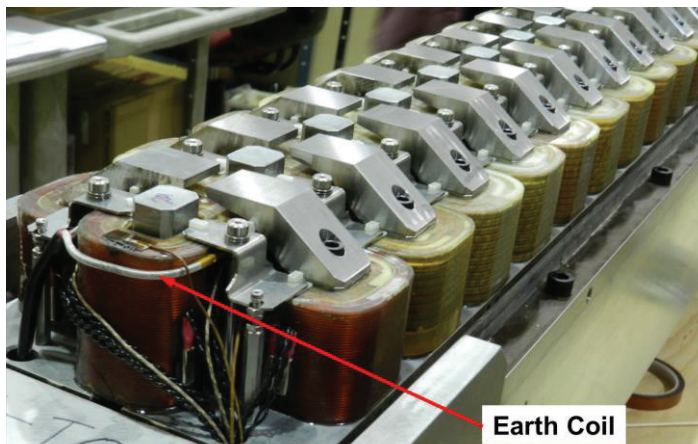
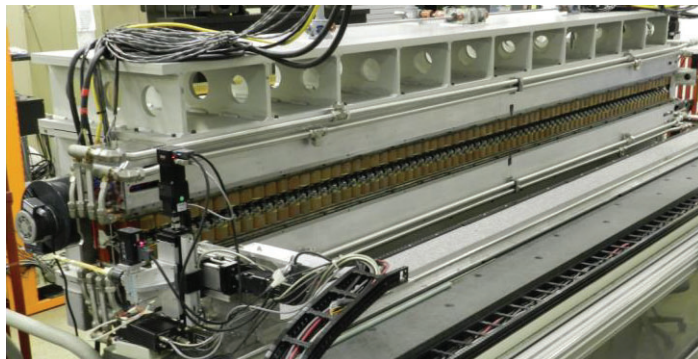
- Vertical undulator
 - APPLE-II operated in vertical polarisation mode
- High undulator harmonics
- Vary vertical emittance
 - Contrast of valley to peak ratio on-axis
- Measurement of undulator high harmonics demonstrated down to 0.9 pm rad
 - K. P. Wootton, et al., *PRSTAB*, 17, 112802 (2014)



K. P. Wootton, et al., *PRL*, 109, 194801 (2012)

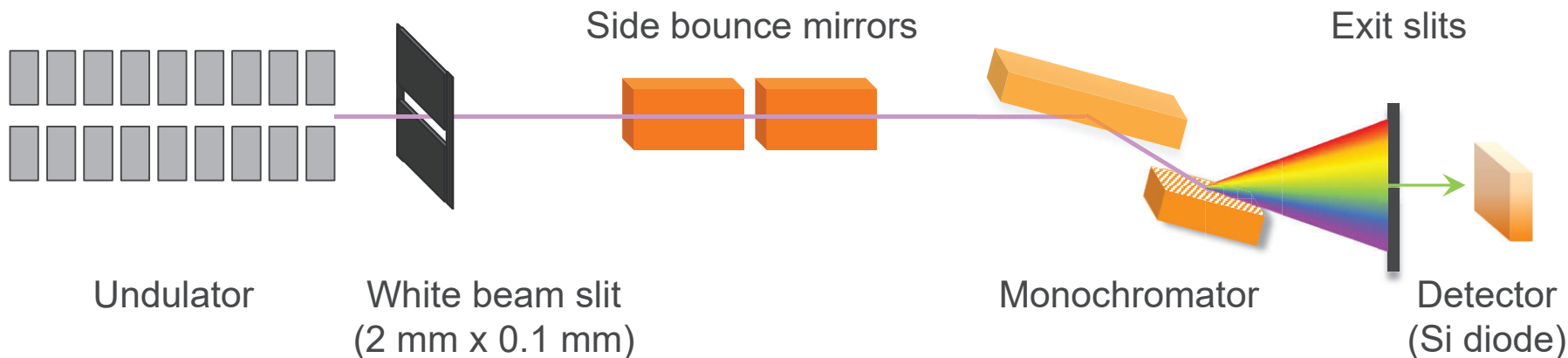
IEX UNDULATOR

- Intermediate Energy X-ray beamline
 - McChesney, et al., NIMA, 746, p. 98 (2014)
- Electromagnetic undulator, 12.5 cm period
- Horizontal, vertical, left and right-hand circular polarisations
- Quasi-periodic operation possible
 - Detunes higher harmonics
 - Not used in this study
- Characterise performance with APS, measure with APS-U



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APS – EXPERIMENT



- IEX undulator in vertical polarisation mode
- Undulator near maximum excitation (fundamental 461 eV)
- Vary vertical emittance through vertical dispersion wave (1%, 2%, 4%)
- Measure radiation profile of undulator 6th harmonic (2760 eV)

SIMULATIONS – PARAMETERS

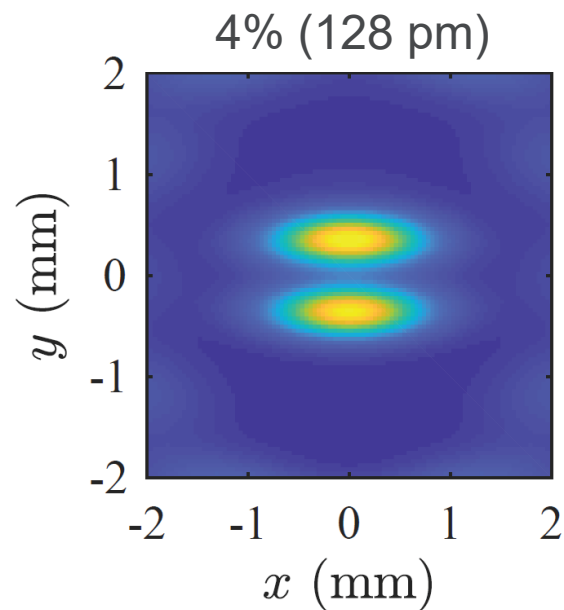
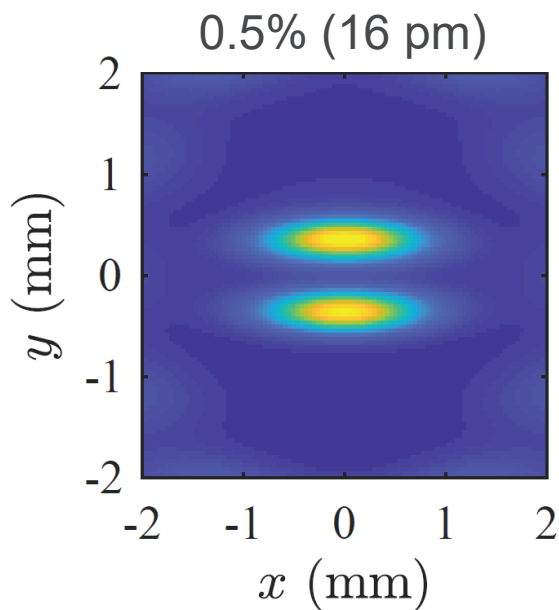
Main changes to parameters from APS to APS-U

- Horizontal emittance reduced
 - Operate ID in horizontal polarisation
 - Measure horizontal emittance
- Electron beam energy reduced
 - Access higher harmonics (8th)

Parameter		APS	APS-U	Units
Electron beam				
Energy	E	7.0	6.0	GeV
→ Horiz. emittance	ϵ_x	3100	41.7	pm rad
Horiz. beta	β_x	19.1	5.19	m
Vert. beta	β_y	3.20	2.40	m
Horiz. dispersion	η_x	167	0.39	mm
Energy spread	$\frac{\Delta E}{E}$	0.096	0.135	%
IEX undulator				
Peak magnetic field	B_x	0.322	-	T
→ Peak magnetic field	B_y	-	0.322	T
Undulator period	λ_u	0.125	0.125	m
Number of periods	n_u	38	38	-
→ First harmonic	ϵ_1	461	339	eV
IEX beamline				
White beam slits		28.8	28.8	m

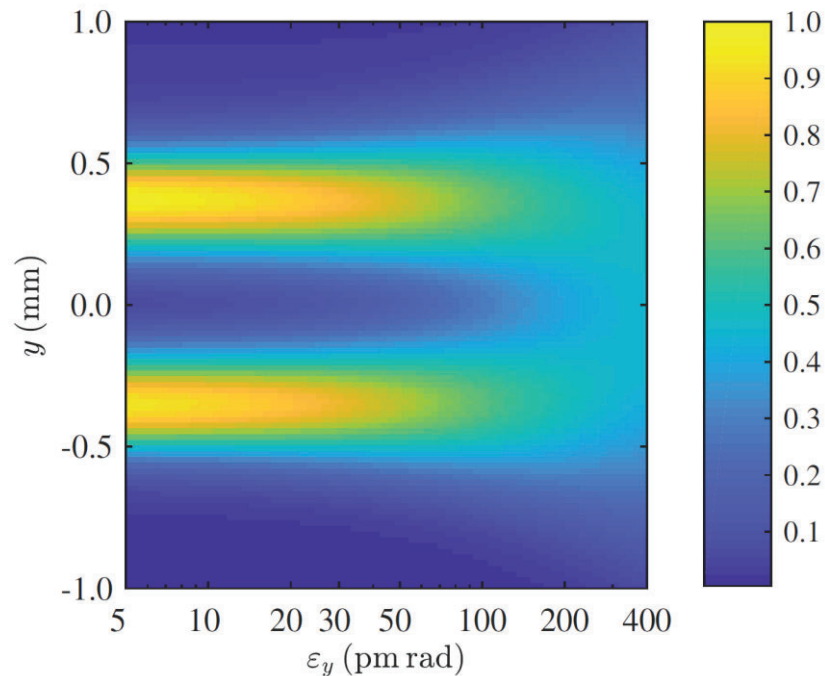
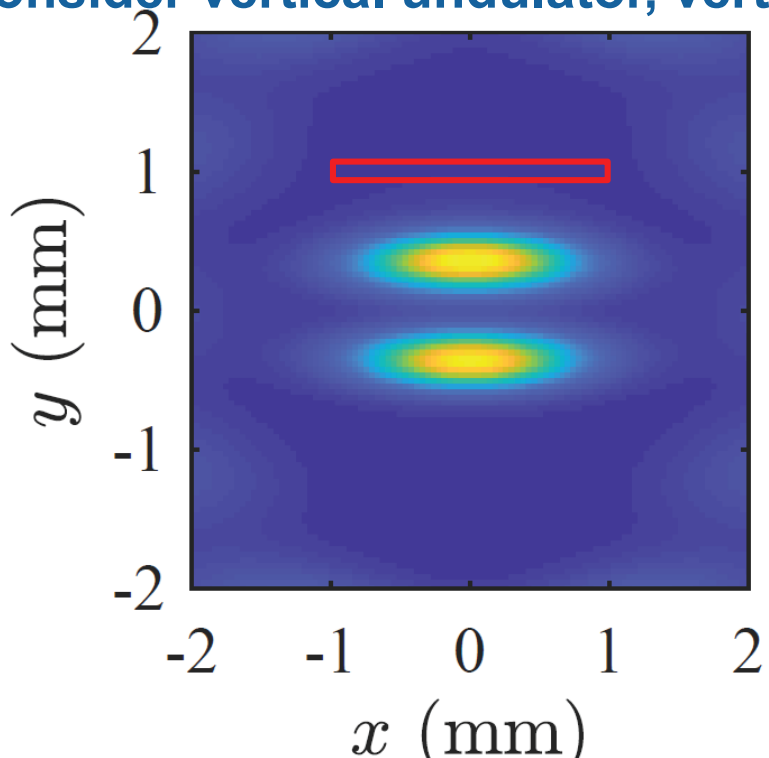
APS – SIMULATIONS

- SPECTRA 10.0
 - T. Tanaka and H. Kitamura, JSR, 8, 1221, (2001).
- Undulator fund. 461 eV
- Monochromator photon energy 2760 eV
- 28.8 m from ID centre
 - Position of white-beam slits



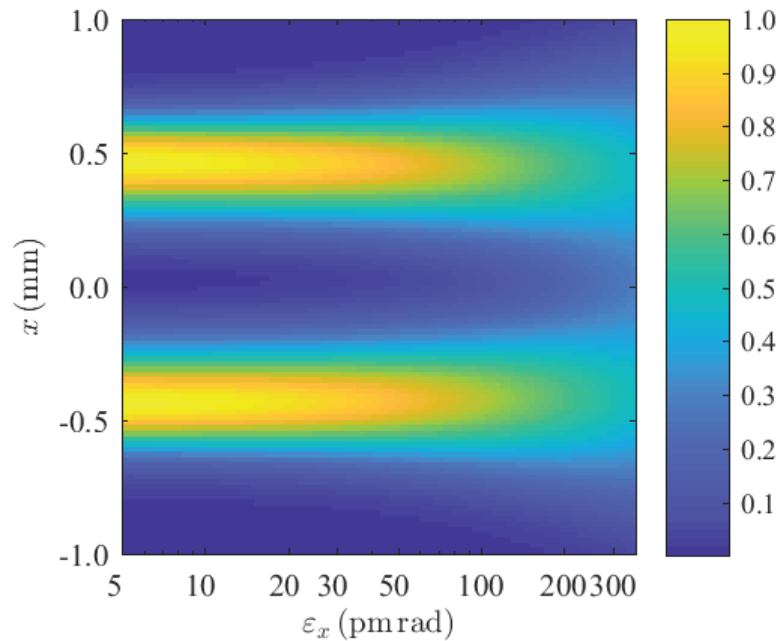
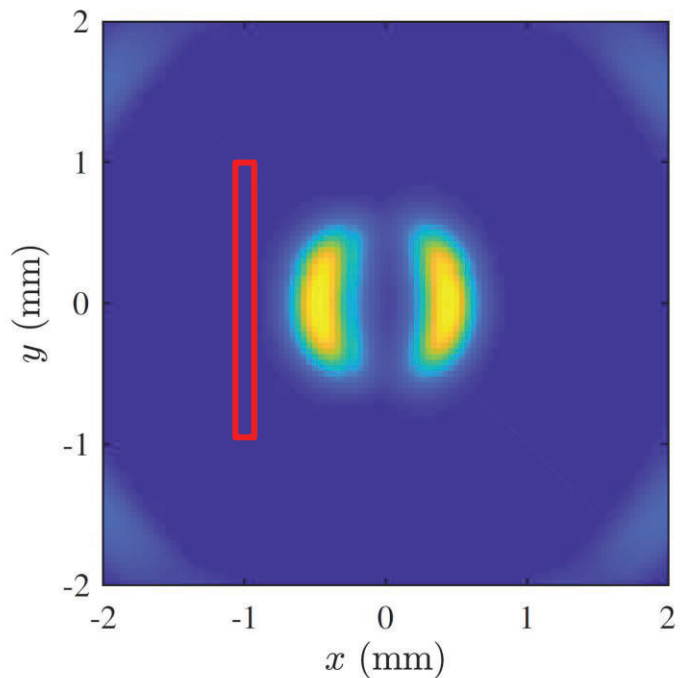
APS – SIMULATIONS

Consider vertical undulator, vertical emittance



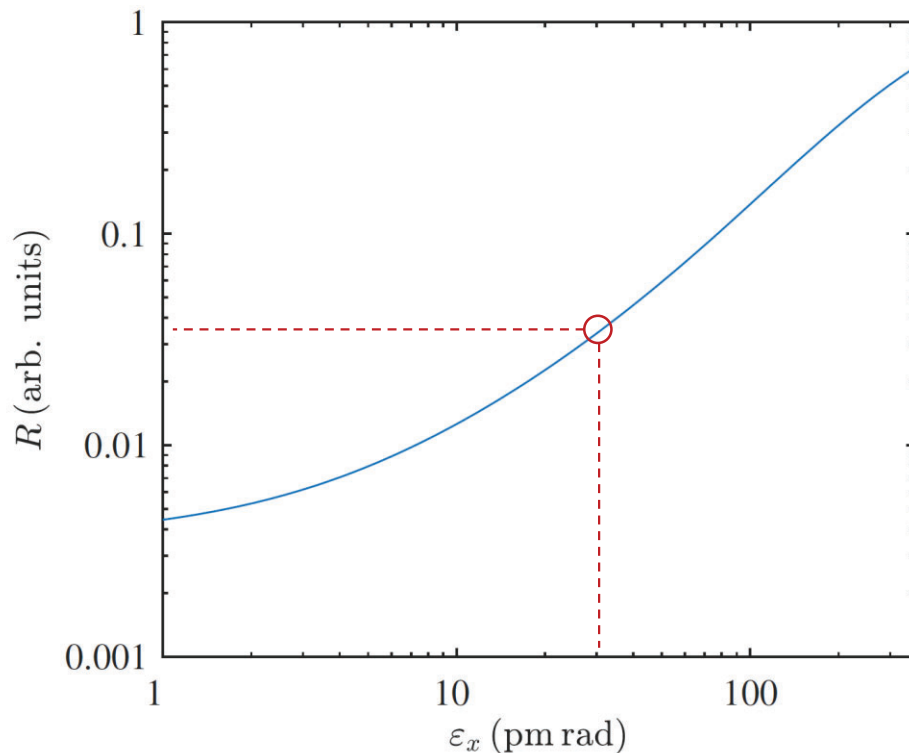
APS-U – SIMULATIONS

Consider horizontal undulator, horizontal emittance



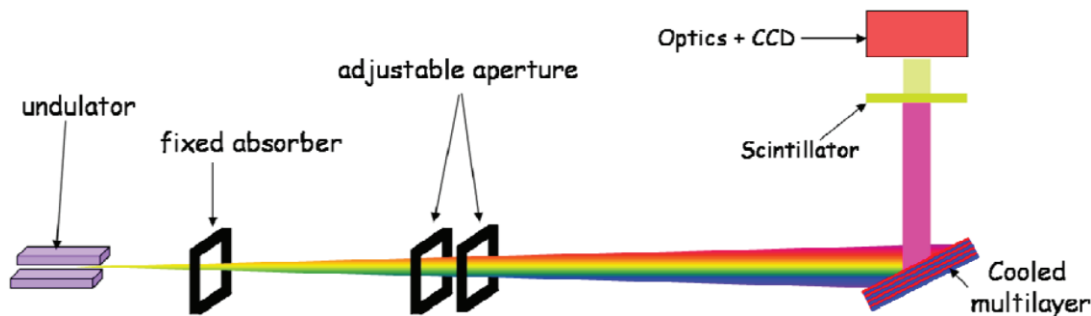
APS-U – SIMULATIONS

- Valley to peak ratio R
- At 40 pm, ratio of about 0.05
- Sensitivity extends to lower emittances
- Can increase R by operating with lower harmonics
- Measure vertical emittance using vertical undulator
 - Down to few pm rad
 - Previously demonstrated experimentally

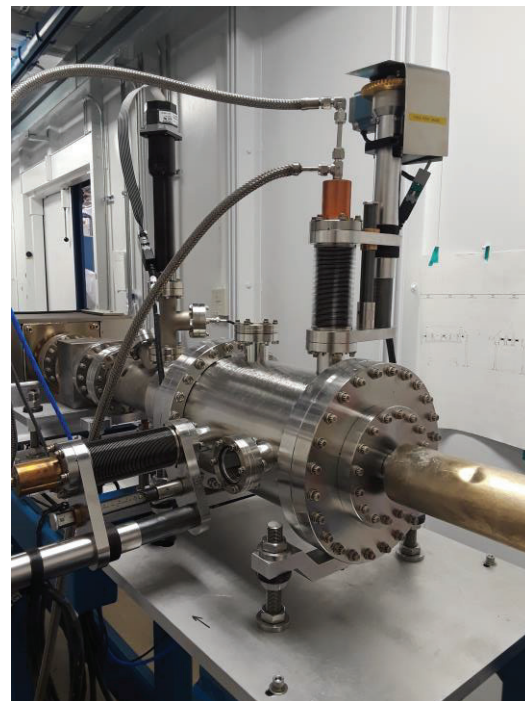


FUTURE WORK - DIAGON DETECTOR

- Direct measurement of angular profile of undulator radiation
 - K. Desjardins, et al., [AIP Conf. Proc., 879, 1101 \(2007\)](#)
- Multilayer reflects X-rays within a energy bandpass



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CONCLUSION

- DLSRs present new challenge to measurement of horizontal emittance
 - Existing techniques to measure vertical emittance are applicable
- At APS, IEX undulator and beamline operational for users
- Measured 30 pm vertical emittance in APS storage ring
 - Could be used to measure emittance during APS-U commissioning
- Present work first using a single photon energy
 - Enables DiagOn (or similar) pixel detector

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