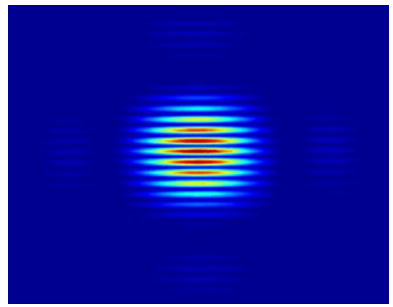
INTENSITY IMBALANCE OPTICAL INTERFEROMETER BEAM SIZE MONITOR



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Australian Synchrotron

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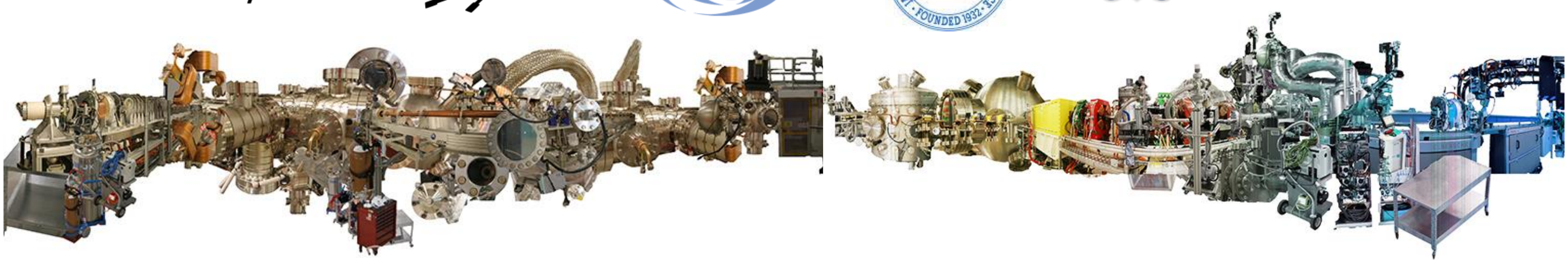
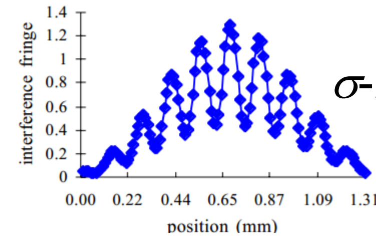


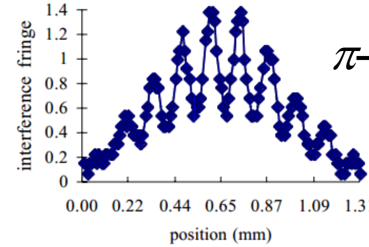
Artwork by Chris Henschke

Interferometer for Beam Size Measurements

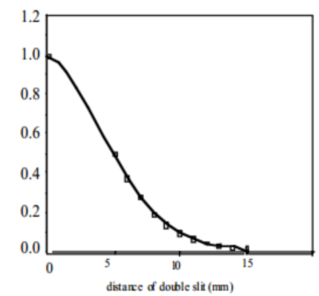
- Mitsuhashi apparatus first demonstrated on accelerators in 1997 – T. Mitsuhashi, PAC'97.
- Uses an optical two slit interferometer to measure the absolute value of the complex degree of coherence $|\gamma|$ and then determine the source size.
- Measured the π- and σ-polarisation phase shift, the $|\gamma|$ variation and phase variation with slit separation and determined the vertical beam size



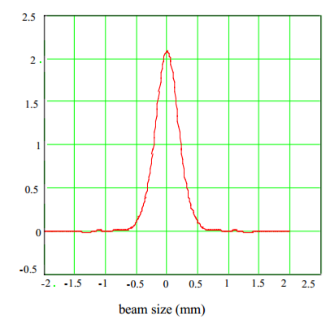
σ-mode



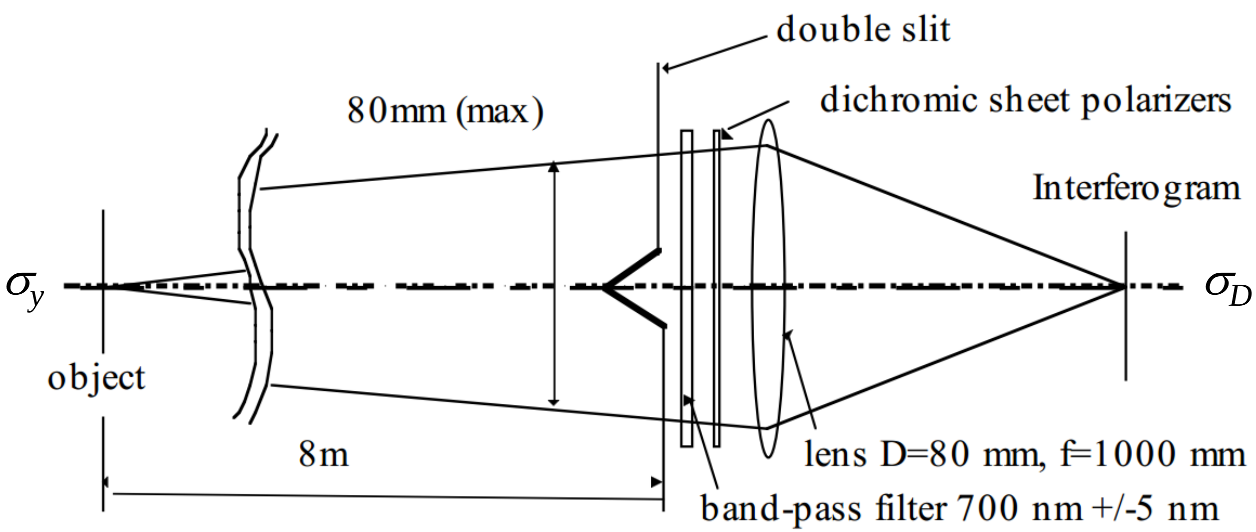
π-mode



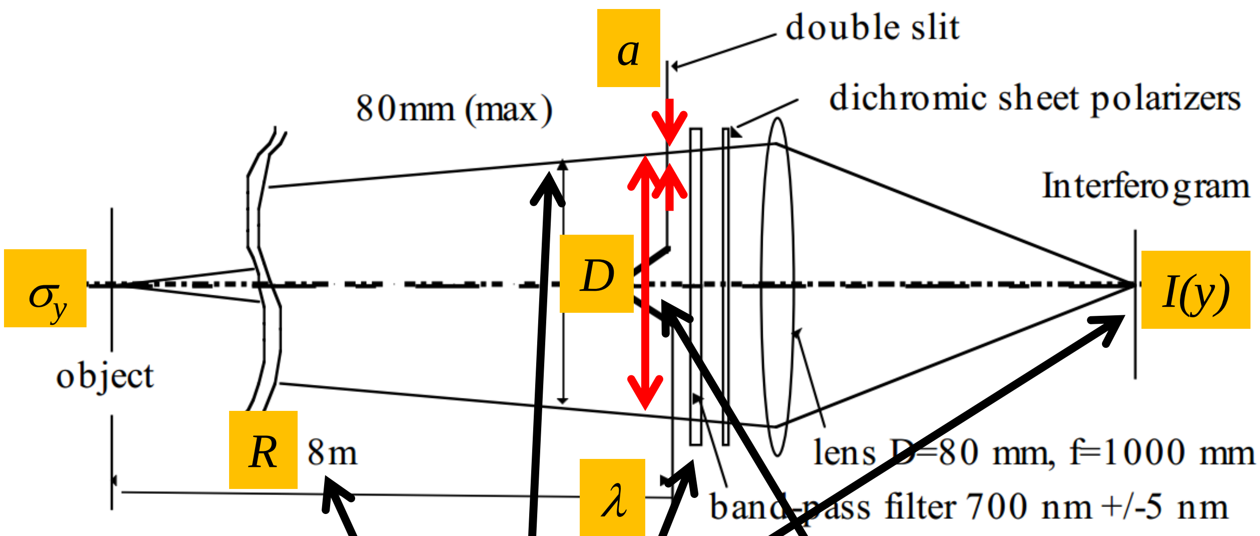
σ_D



σ_y

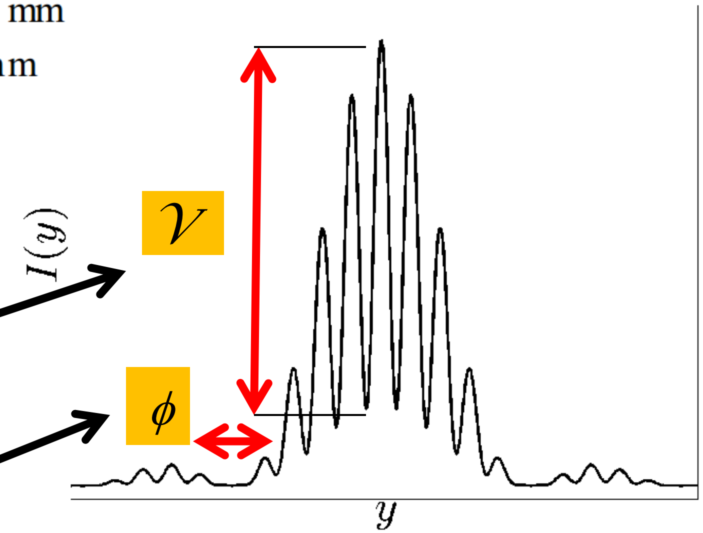


Measurement meets Theory



$$\mathcal{V} = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

$$\mathcal{V} = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}|\gamma|$$



$$I(y) = I_0 \mathrm{sinc}\left(\frac{2\pi a}{\lambda R}y\right)^2 \left[1 + |\mathcal{V}| \cos\left(\frac{2\pi D}{\lambda R}y + \phi\right)\right]$$

D and *y* Fourier Pair

Want to know the distribution of the beam in y, so measure its Fourier pair and transform!

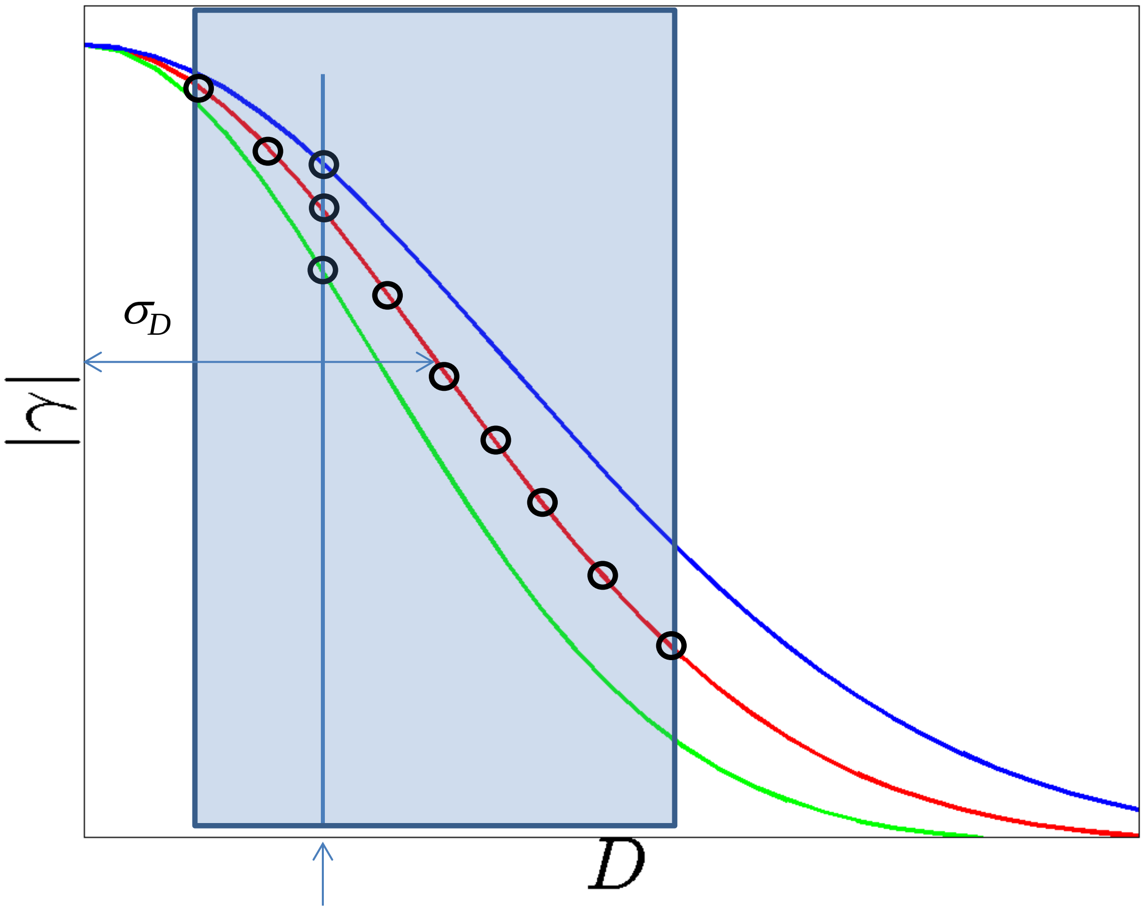
Measure γ as a function of D over the range of the beamline acceptance

$$\gamma = \exp\left(-\frac{D^2}{2{\sigma_D}^2}\right).$$

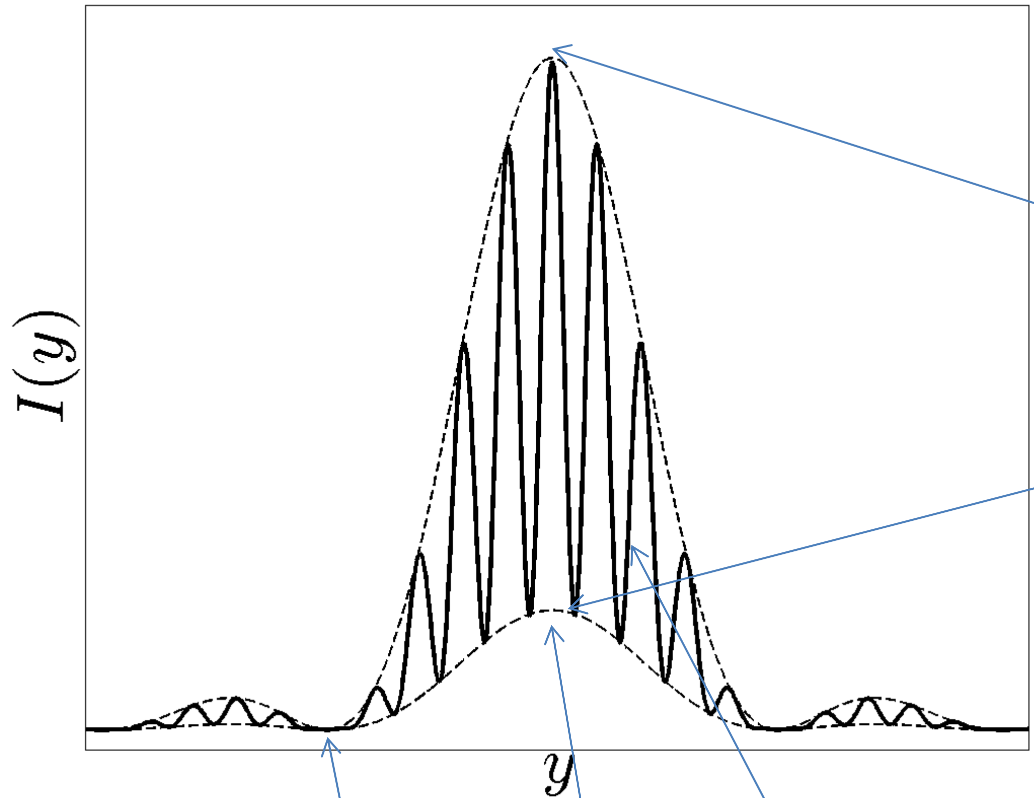
Then choose a fixed D and determine the beam size from the measurement of the visibility

$$\sigma_y = \frac{\lambda L}{2\pi\sigma_D}.$$

$$\sigma_y = \frac{\pi D}{\lambda R}\sqrt{\frac{1}{2}\ln\left(\frac{1}{|\gamma|}\right)}.$$



Interference Pattern Analysis



Under optimal condition, simply take I_{max} - I_{min} to get the visibility

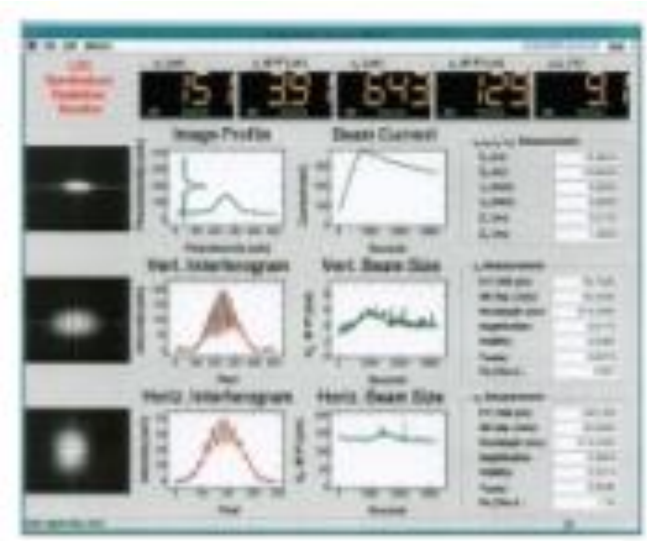
$$\mathcal{V} = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

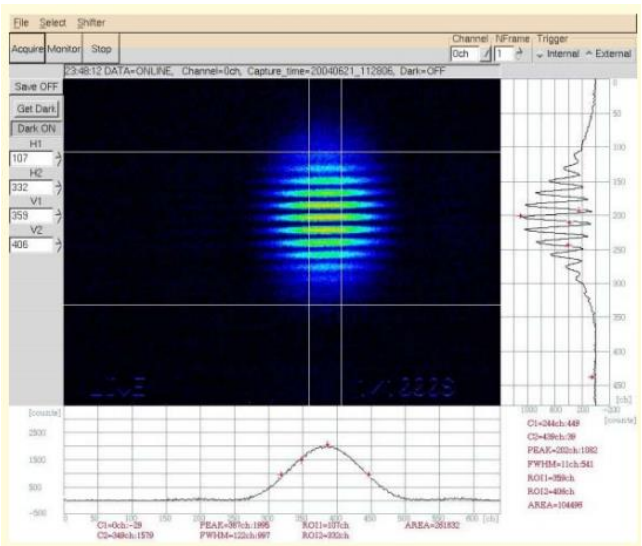
No need to fit, can simply determine the beam size from

$$I(y) = I_0 \mathrm{sinc}\left(\frac{2\pi a}{\lambda R} y\right)^2 \left[1 + |\mathcal{V}| \cos\left(\frac{2\pi D}{\lambda R} y + \phi\right)\right]$$

Standard Online Monitor Condition

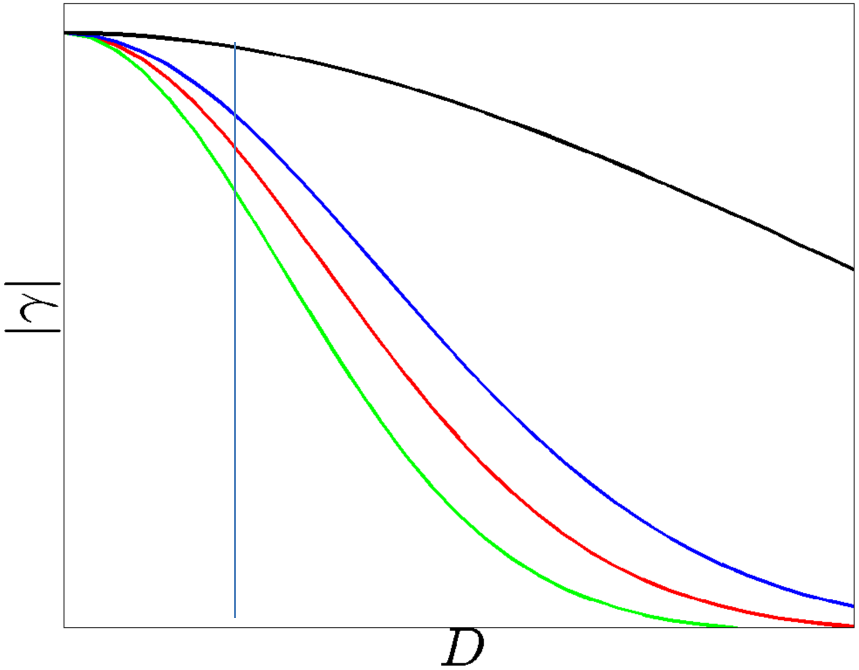
- Requirement
  - $I_1 \approx I_2$
  - Narrow bandwidth small 10-90 nm
  - σ-polarisation (phase shift of pi-polarisation, washes out pattern)
  - Linear intensity response of the CCD
  - Accurate background subtraction
  - Orbit feedback to keep beam stable
- Can use $(I_{max} - I_{min})/(I_{max} + I_{min})$ without the need to fit the pattern
- Fast (few ms) and accurate beam size monitor.





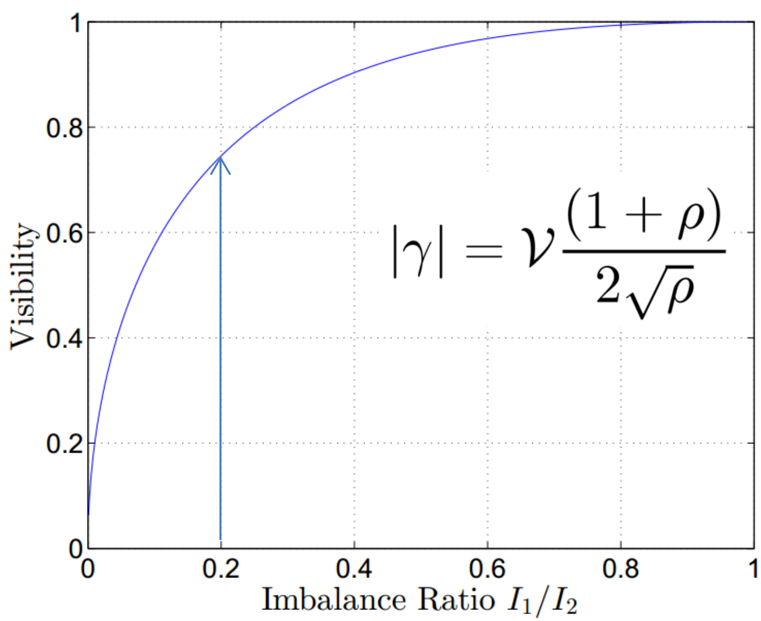
Limitation of optical beam size monitors

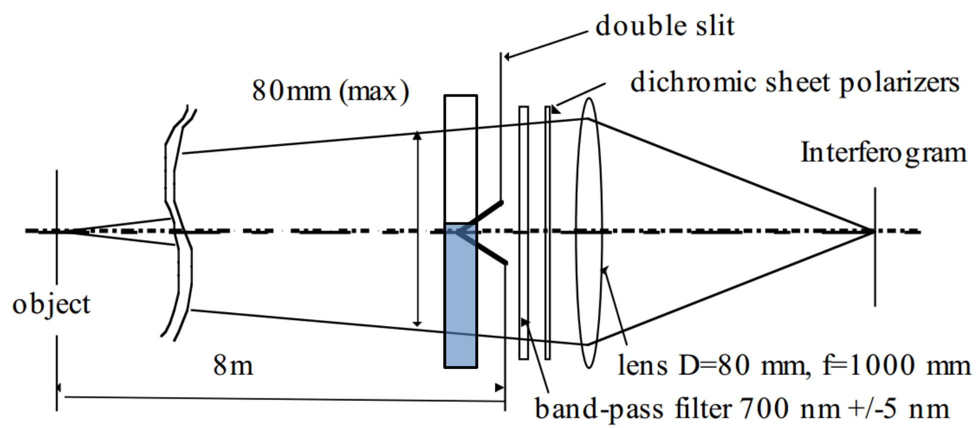
- For very small beams ~1 μm, $\mathcal{V}$~1
- I_{min} sits in the noise floor of the imaging system
- Slit separation limited by opening angle of light from the beamlir

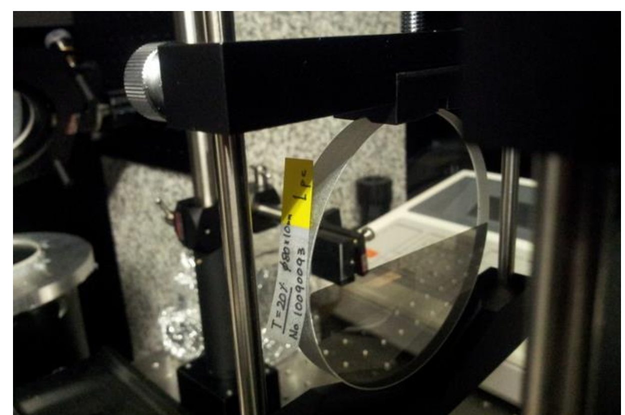


Solution: Intensity Imbalance Method

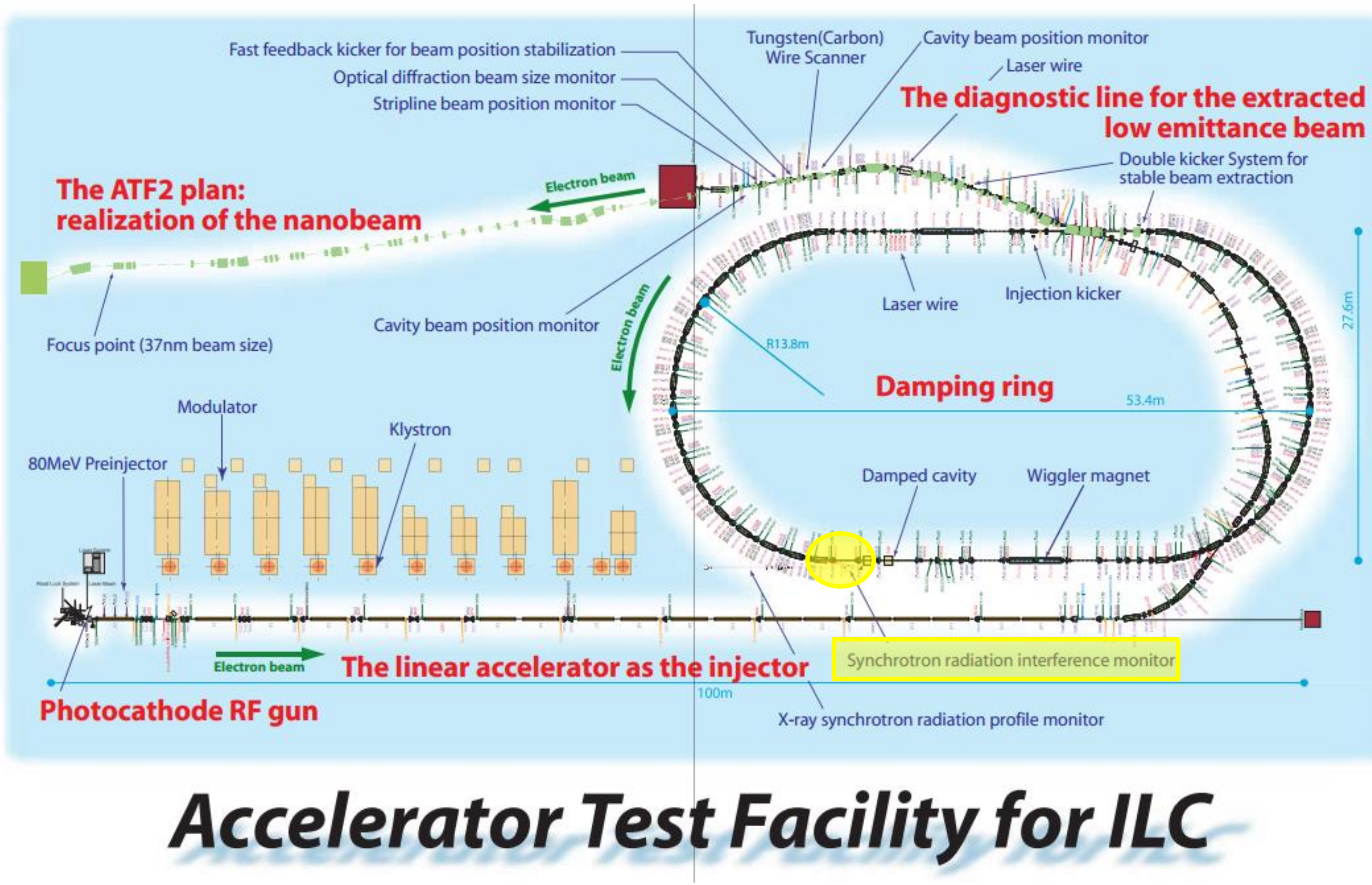
- Introduce a know attenuation at one of the slits to reduce the visibility in a controlled way using a half coated optical flat to preserve the path lengths.
- Require large imbalance ratio to significantly effect the visibility.
- Used $\rho = I_2 / I_1 = 0.2$



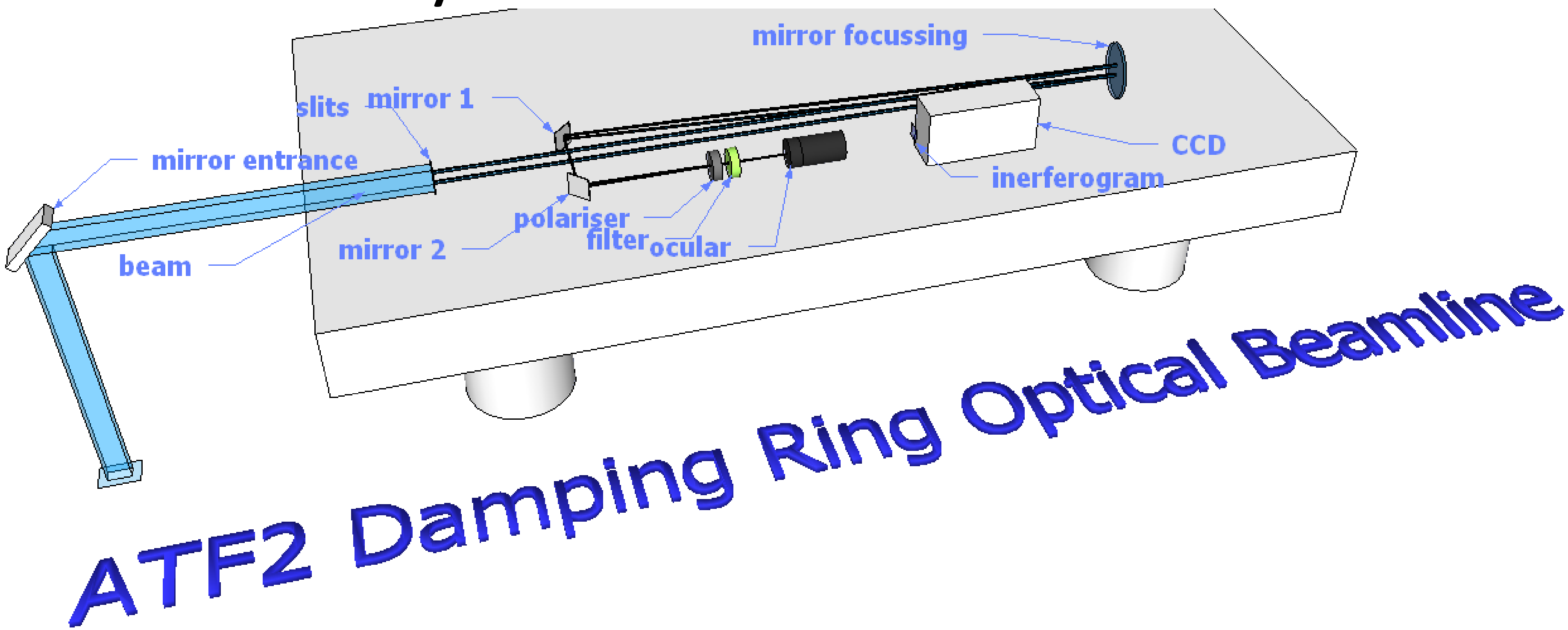




Test at ATF2 Optical Light Monitor



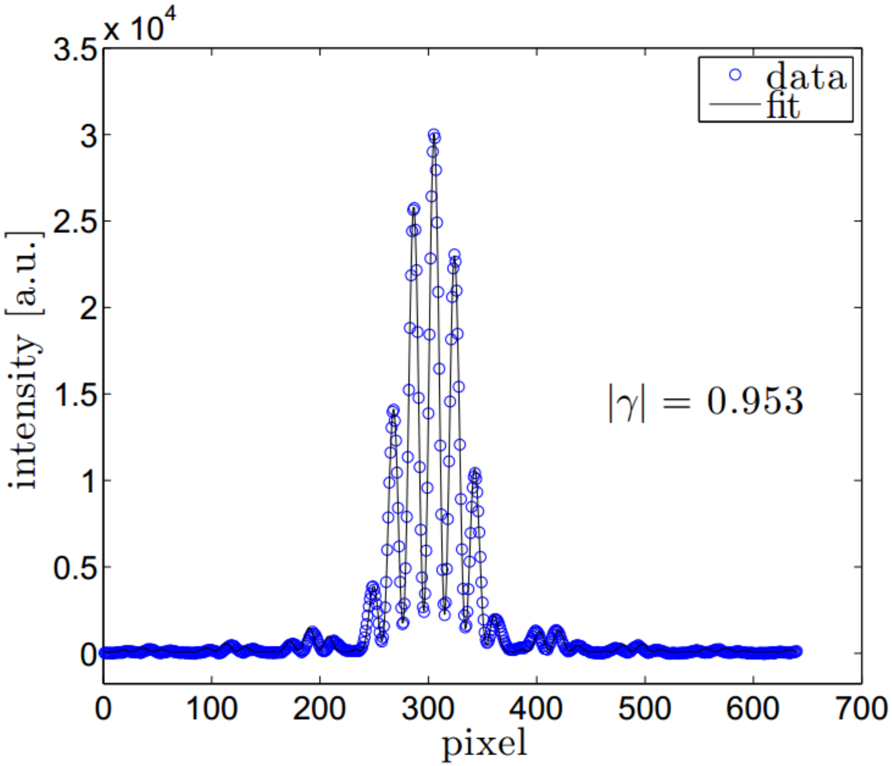
Intensity Imbalanced Interferometer



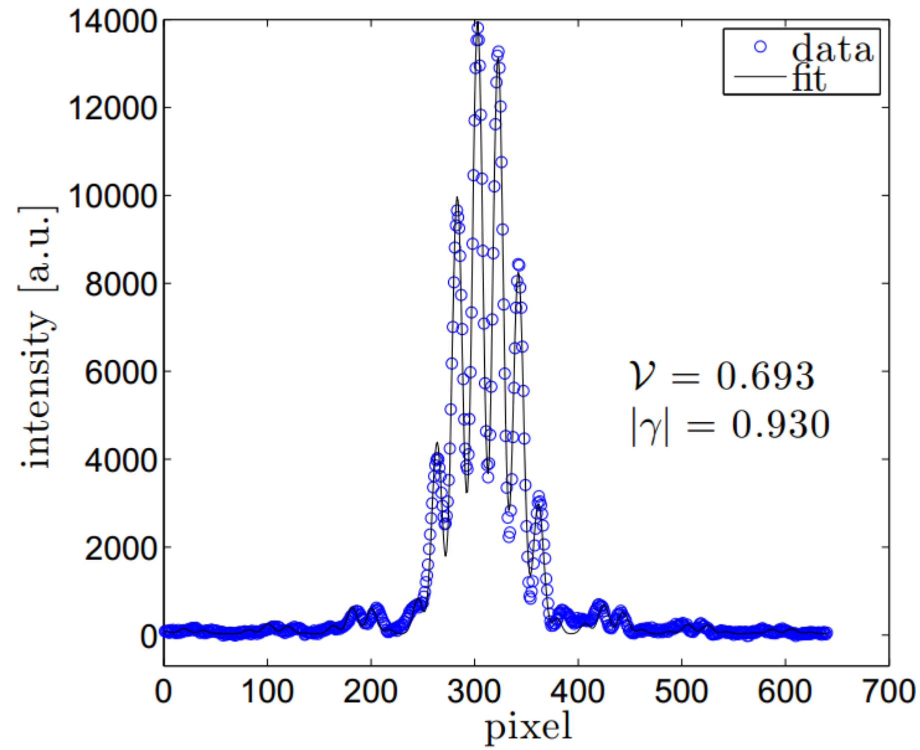
- Developed in 2006 at ATF2 – T. Naito and T. Mitsuhashi, PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 9, 122802 (2006).
- Includes latest design using reflective optics and wider bandpass filter.
- Focussing mirror can be more easily made with smaller aberrations than a refractive lens and a wider bandpass filter allows more light to the sensor.

Beam Size Measurement at ATF2

Balanced



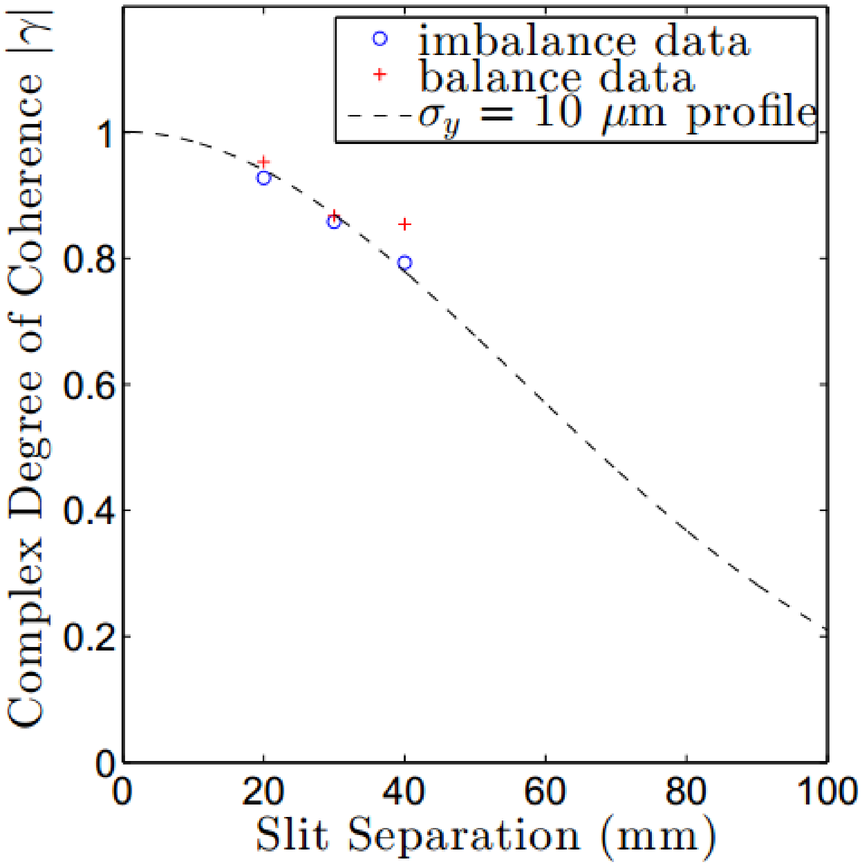
Imbalanced 20%



Shot to shot beam variations limit the ability to compare data

Slit Separation Scan

- Seems to be less spread in the data with the imbalance setup
- Beam size in reasonable agreement with x-ray measurement
- Principle works but needs to be tested with a more stable beam
- Tried at the ASLS storage ring



Australian Synchrotron

- User lightsouce facility
- 10 beamline for x-ray and IR experiments
- 3 GeV storage ring
- Part of damping ring collaborations
- Achieved ε_y = 1.2 pm
- Need better diagnostics to measure smallest beam sizes < 5 μm

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **14**, 012804 (2011)

Achievement of ultralow emittance coupling in the Australian Synchrotron storage ring

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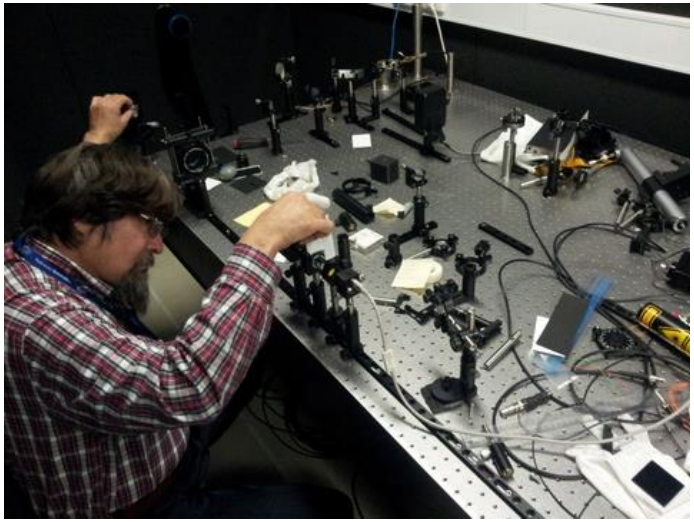
Australian Synchrotron, 800 Blackburn Road, Clayton, 3168, Australia
(Received 16 April 2010; published 29 January 2011)

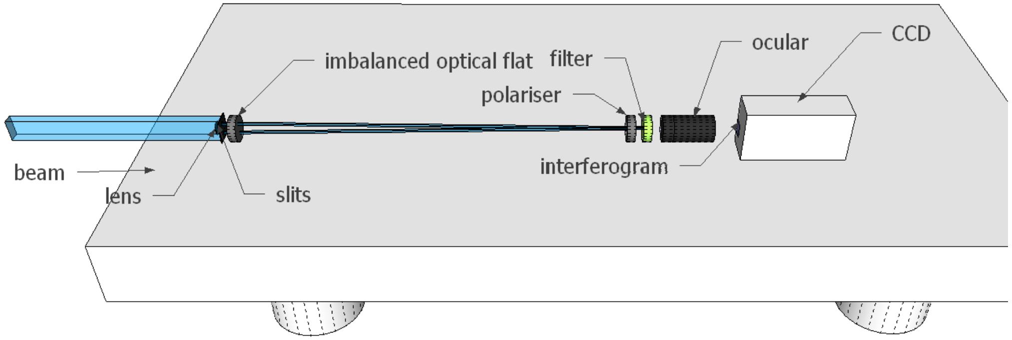
Investigations into producing an electron beam with ultralow vertical emittance have been conducted using the Australian Synchrotron 3 GeV storage ring. A method of tuning the emittance coupling (ϵ_y/ϵ_x) has been developed using a machine model calibrated through the linear optics from closed orbits method. Direct measurements of the beam emittance have not been possible due to diagnostic limitations, however two independent indirect measurements both indicate a vertical emittance of 1.2–1.3 pm rad ($\epsilon_y/\epsilon_x = 0.01\%$). Other indirect measurements support the validity of these results. This result is the smallest vertical emittance currently achieved in a storage ring.

Optical Diagnostic Beamline Measurements

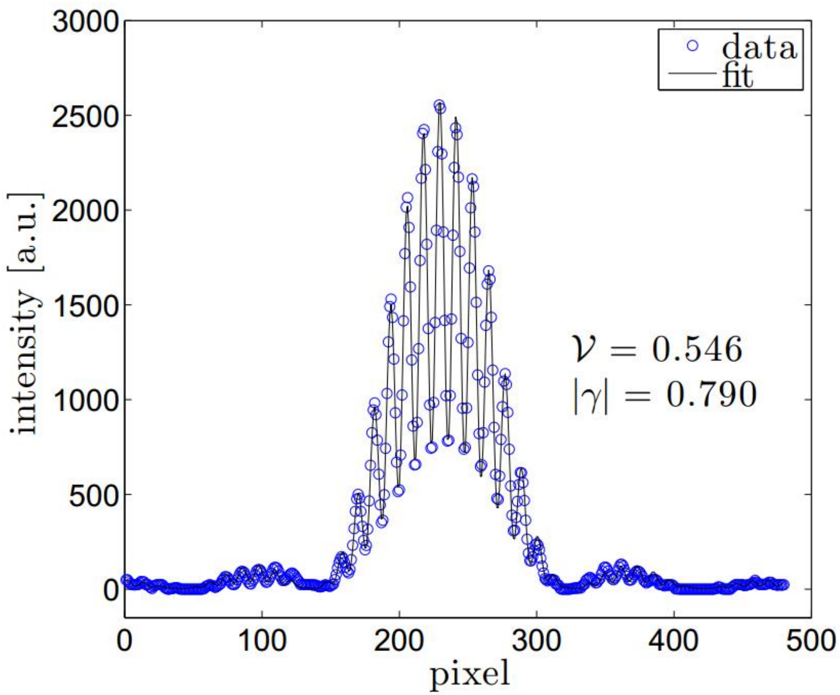
Synchrotron Light user facility, 10 beamlines plus two diagnostic beamlines



Optical diagnostic beamline interferometer setup

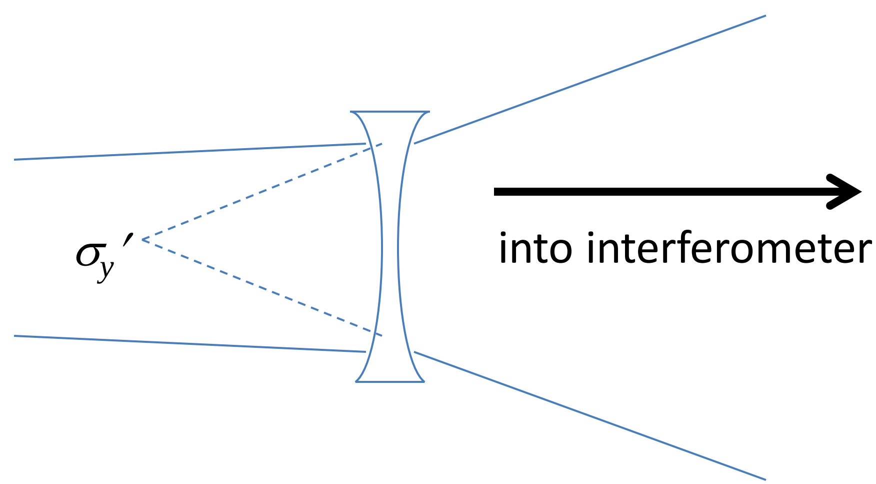


Measured Source and Virtual Source Sizes



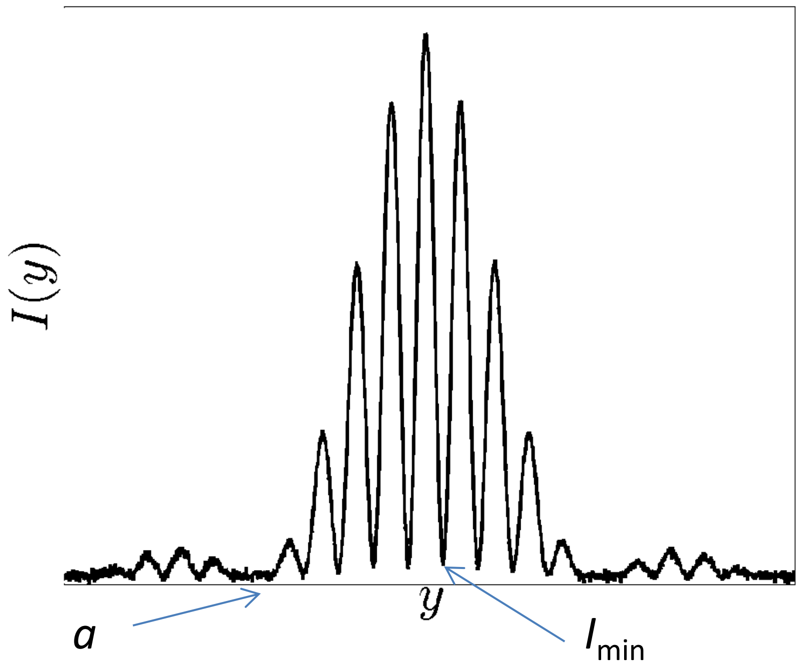
beam mode	$\mathcal{V}$	$\lvert\gamma\rvert$	σ_y (μm)
Balance skew zero	0.795	0.804	58
Imbalance skew zero	0.546	0.790	61
Balance skew user	0.707	0.734	69
Imbalance skew user	0.484	0.704	74

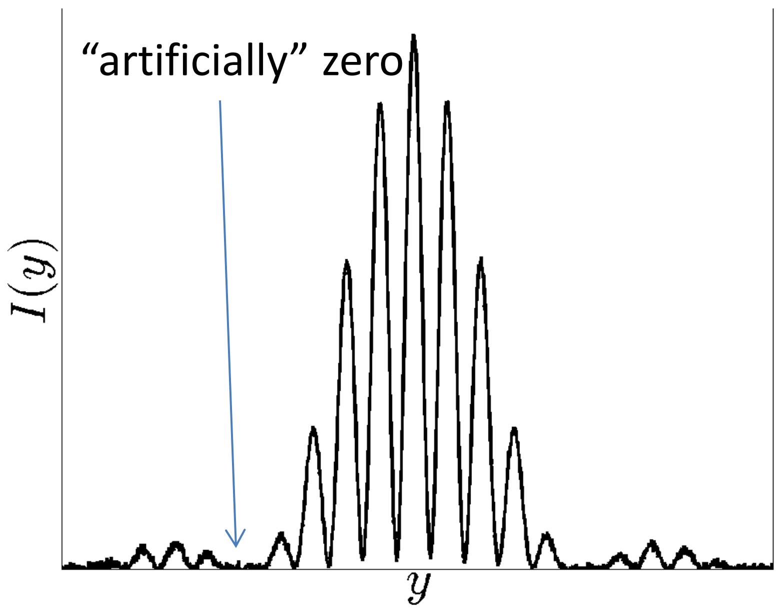
- Clearly observed beam size changes going from 1% coupling in user beam mode to skew quadrupoles off
- Have not yet had beamtime to try minimum coupling settings
- Beam size still large, so created a virtual source to test interferometer
- Demagnified source by 24
- Expected ~2.5 μm, measured ~2.6 μm



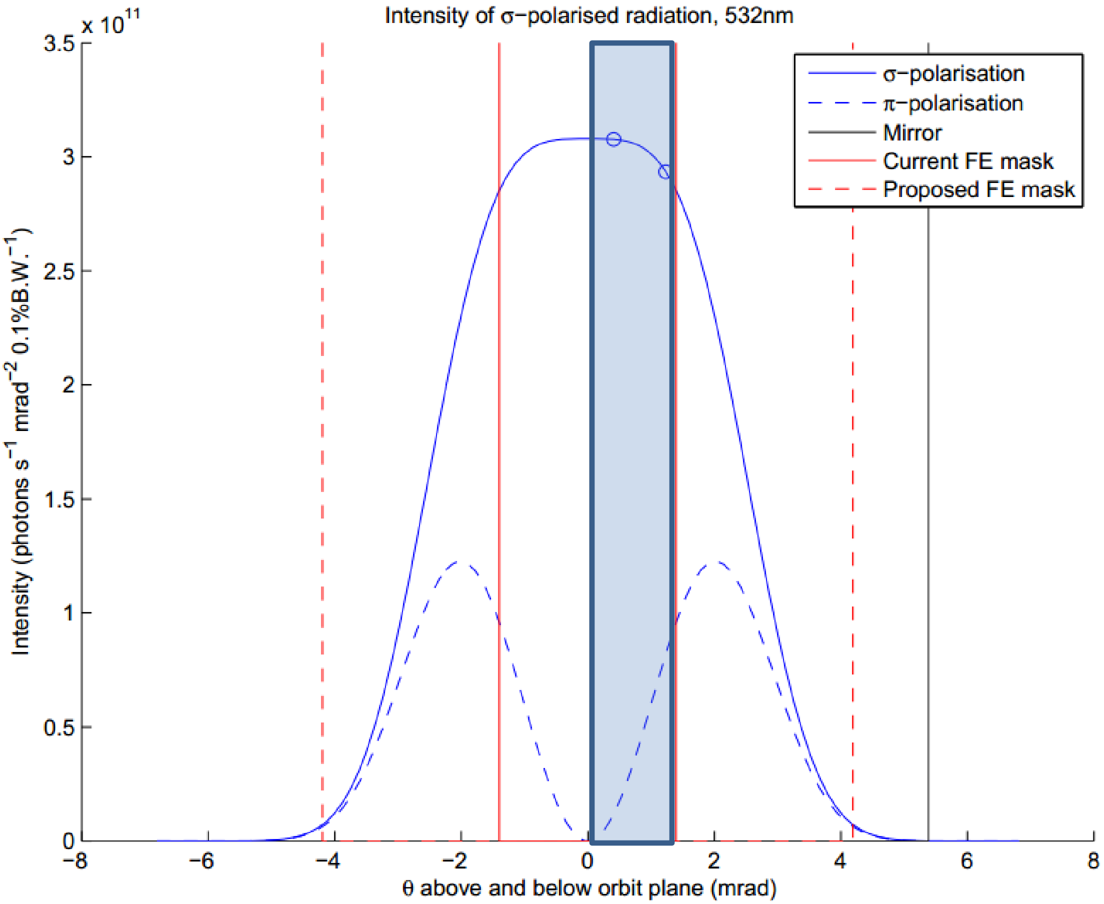
CCD Performance is Critical

- Need to be able to observe the CCD noise floor to determine the background accurately to measure the absolute intensity.
- Some CCDs perform onboard noise reduction that results in zero value pixels that can distort the measurement (ASLS suffered from this).
- Need a linear response in the range of the maximum and minimum of the interference fringes.





ASLS beamline limitations



- X-ray frontend, not optimised for visible light.
- Extraction mirror only takes top half of the fan.
- Imbalance method analysis used to improve the accuracy of the beam size measurement.
- Need to carefully measure I_1 and I_2 to correct for the imbalance

Summary and Further Development

- Successfully demonstrated the intensity imbalance interferometer method with measurements at ATF2 and ASLS.
- Plan to take measurements at ASLS after next mechanical realignment scheduled for late 2012.
- Combine with vertical undulator method to improve vertical emittance tuning technique.
- Design a new optical beamline with a dedicated frontend and large opening angle.
- Continue to work on damping ring collaboration.

Thank you to:
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Supporters – including ASLS, ACAS, KEK, JSPS, UoM and Agilent