RMS Emittance Measurements Using Optical Transition Radiation Interferometry at the Jefferson Lab FEL

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Overview

- To apply Optical Transition Radiation Interferometry (OTRI) techniques to high current accelerators
- Investigate the ability of OTRI to measure complex beam distributions
- Further develop an all optical method of phase space mapping

First step: RMS emittance measurements

OTRI as an Emittance Diagnostic

Measure RMS beam size and RMS divergence at a waist condition to calculate the emittance

RMS emittance

$$\tilde{\varepsilon}_x = \left(\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2\right)^{\frac{1}{2}}$$

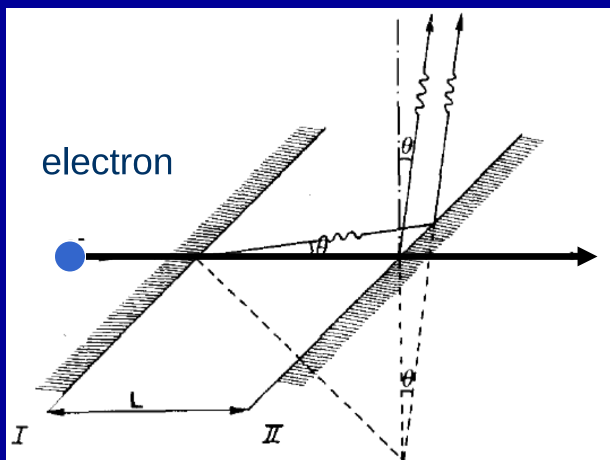
At a beam waist

$$\tilde{\varepsilon}_x = x_{rms} x'_{rms}$$

where: $x_{rms} = \sqrt{\langle x^2 \rangle}, \text{ and } x'_{rms} = \sqrt{\langle x'^2 \rangle}$

OTRI Basics

Two thin parallel metal foils

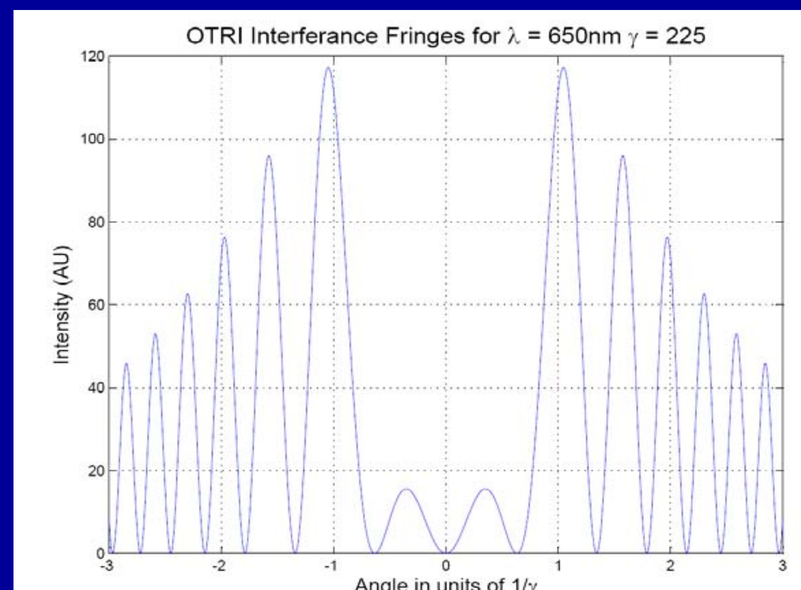


phase term

$$\phi = \frac{L}{L_v}$$

Vacuum coherence length

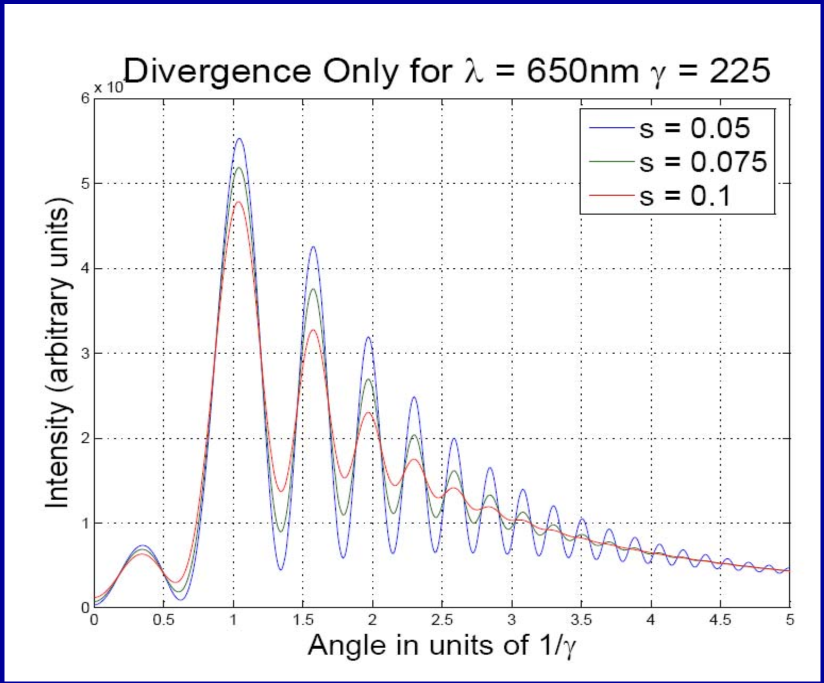
$$L_v = \left(\frac{\lambda}{\pi}\right)\left(\frac{1}{\gamma^{-2}+\theta^2}\right)$$



Spectral-angular distribution of two foil OTR

$$\frac{dI_{tot}}{d\omega d\theta} = \frac{\alpha}{\pi}\frac{\theta^2}{(\gamma^{-2}+\theta^2)^2}\left|1-e^{-i\phi}\right|^2$$

Effect of Beam Parameters on Fringe Visibility



Gaussian angular distribution function

$$P(\sigma,\theta)=\left(\frac{1}{2\sigma^2}\right)^{\frac{1}{2}} e^{\frac{-\theta^2}{2\sigma^2}}$$

Normalized divergence

$$s=\gamma\sigma$$

Interference fringes are highly sensitive to:

1. Optical bandwidth
2. Energy spread
3. Divergence

We want divergence to dominate the fringe visibility effects

- Narrow bandwidth filter makes bandwidth effects negligible
- Energy spread tolerance determined through simulation

Experimental Setup

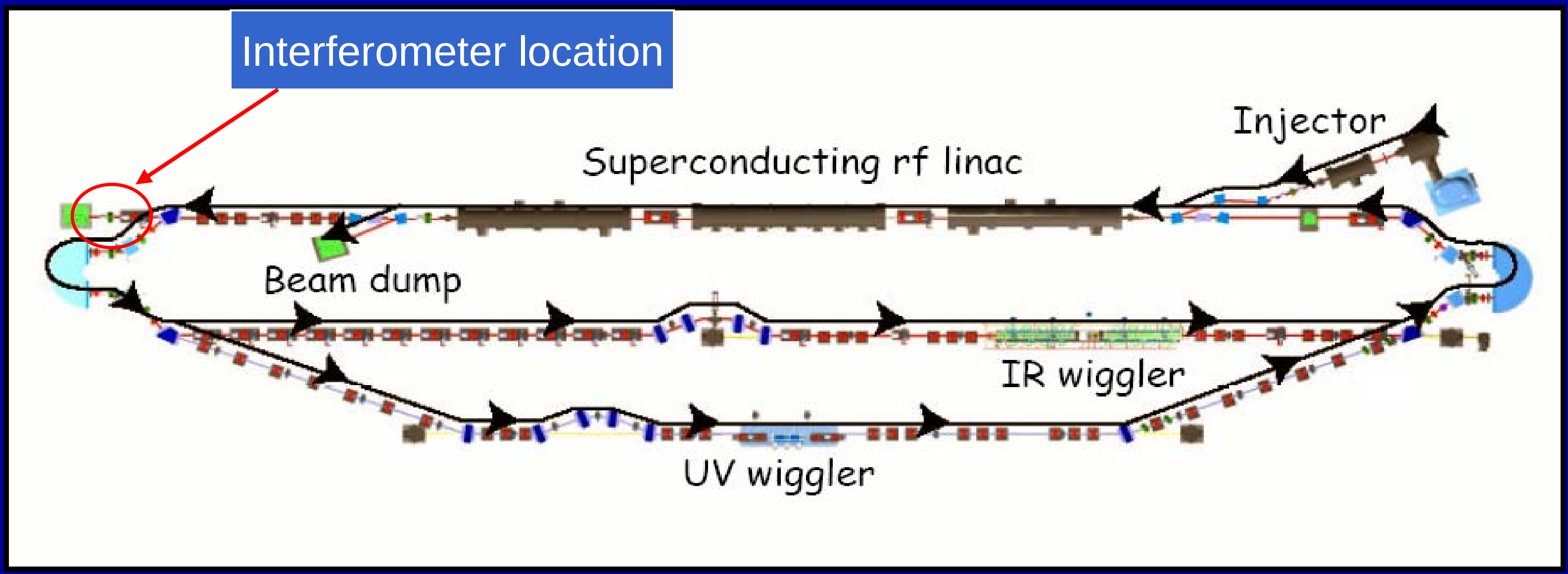
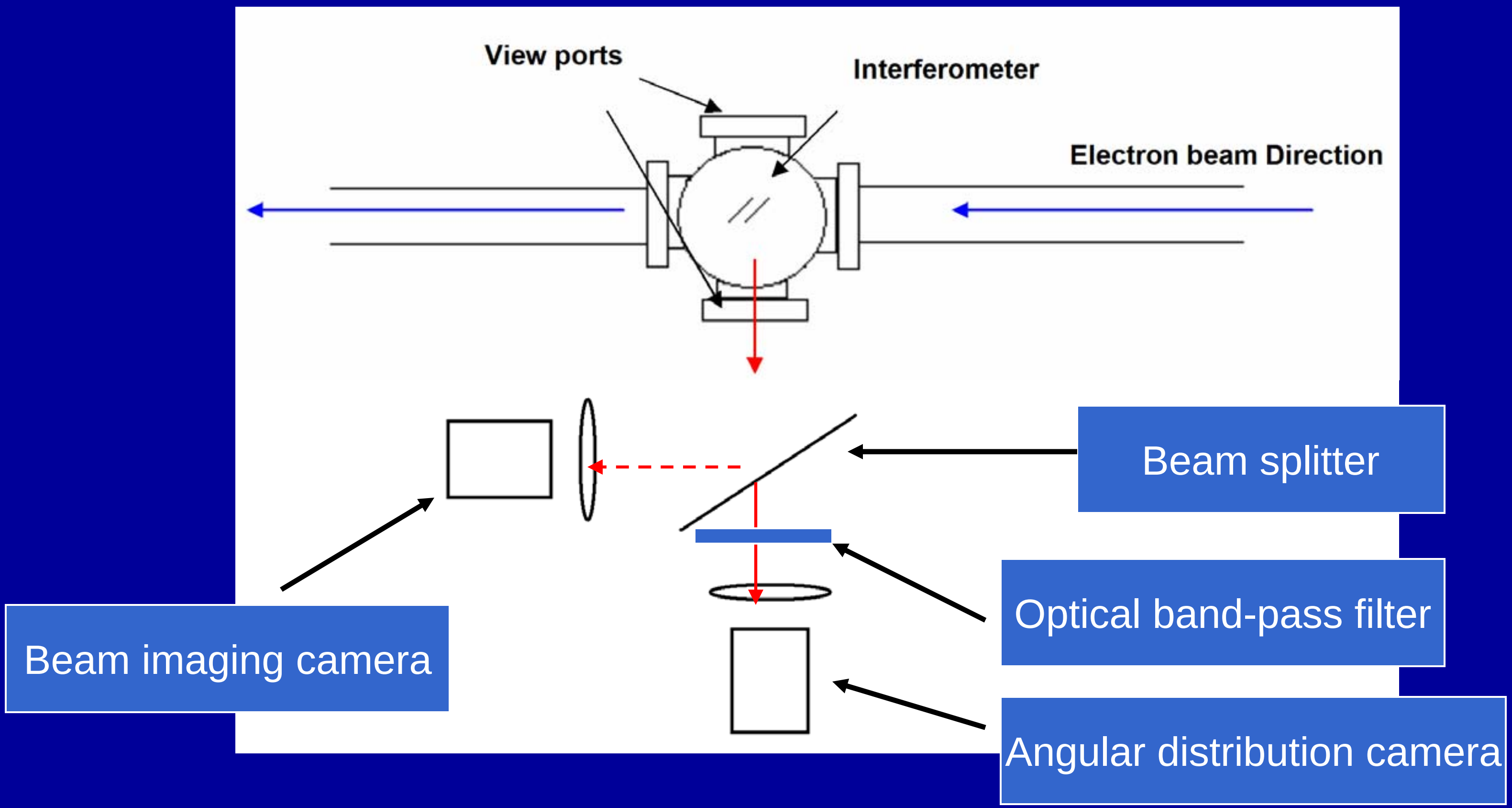


Image obtained from www.jlab.org

Experimental beam conditions

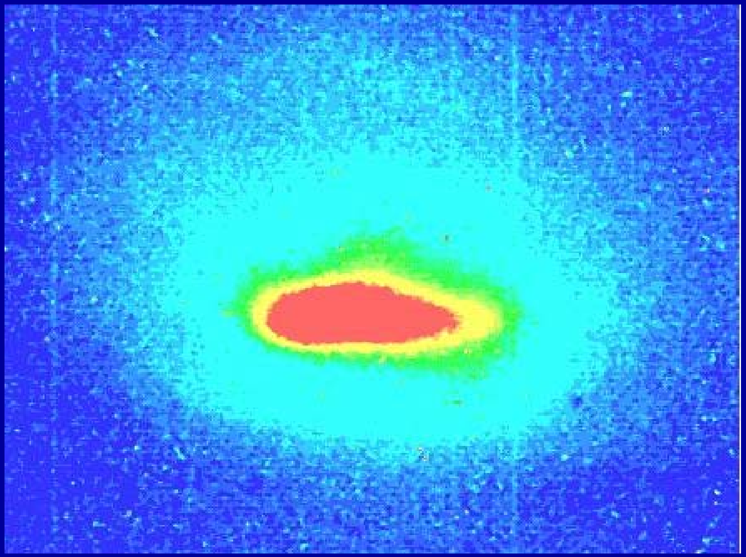
Beam Energy	115 MeV
Macro Pulse Width	100μs
Micro Pulse rep rate	2MHz
Charge per bunch	135 pC
Beam Current (Avg)	~150μA

Optical Arrangement

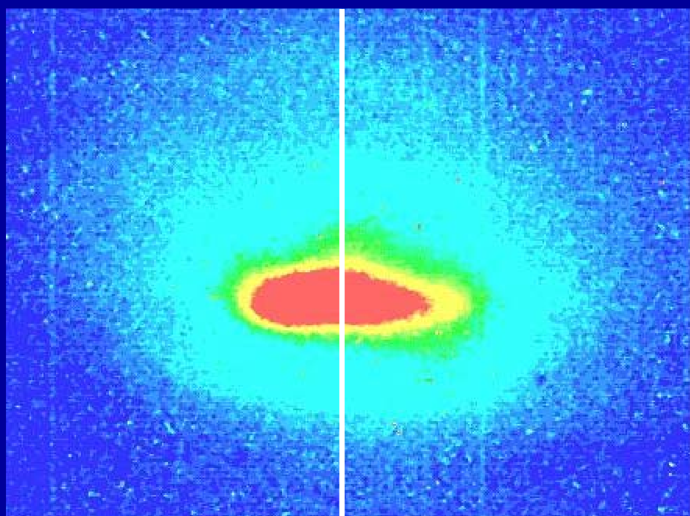


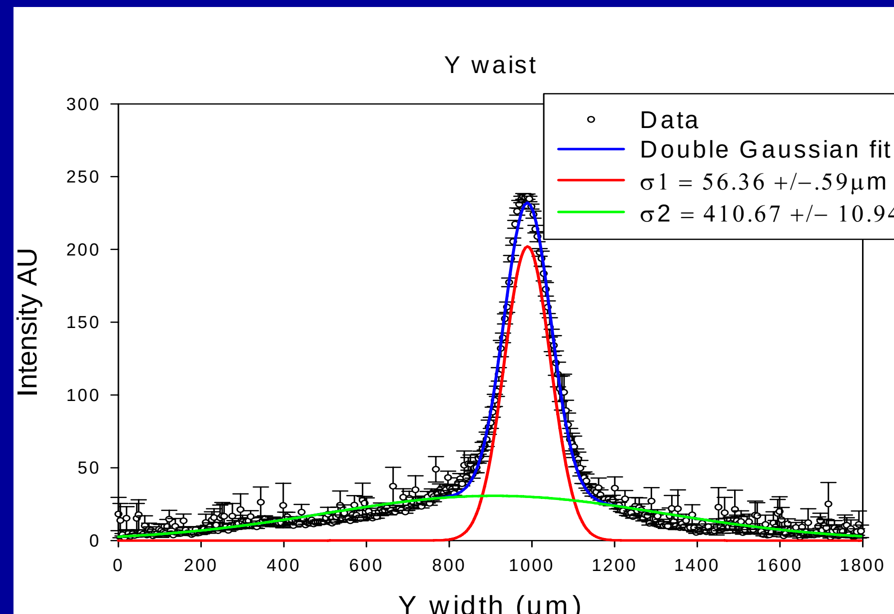
Beam Size Measurements

Beam image profile is complex



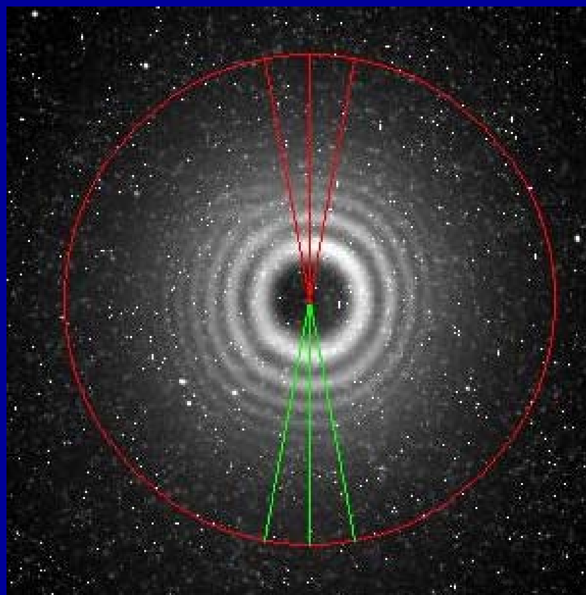
Beam Size Measurement



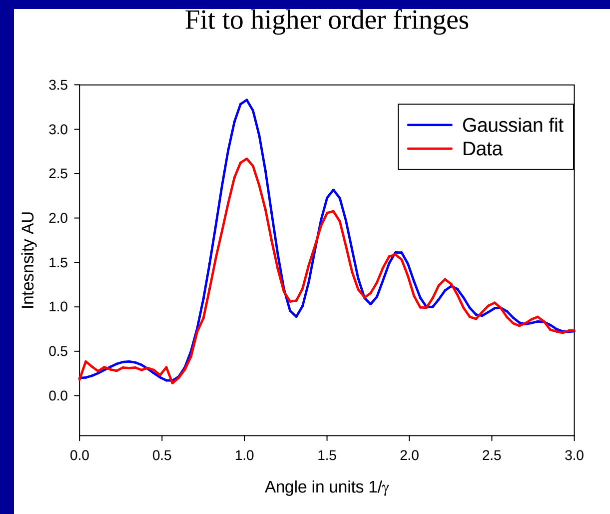


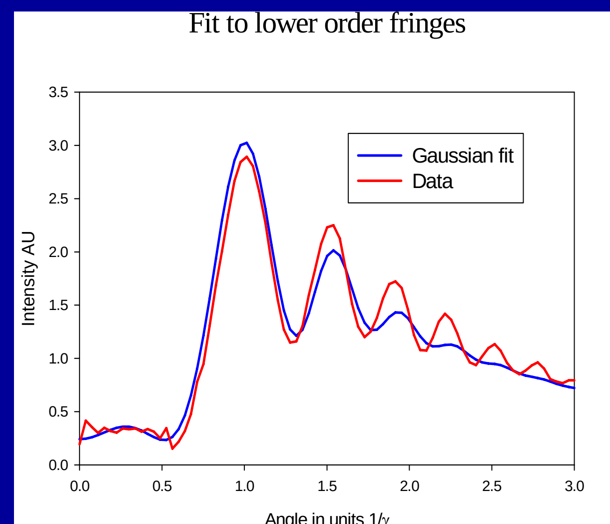
Waist	filter	σ1 (μm)	σ2(μm)
X	650x10 nm	134.4+/-1.4	380.1+/-5.6
X	450x10 nm	144.9+/-2.6	390.7+/-16.9
Y	650x10 nm	56.4+/-.59	410.7+/-11.0
Y	450x10 nm	49.4+/-1.0	380.5+/-14.8

Divergence Measurements



Simple Gaussian does not work

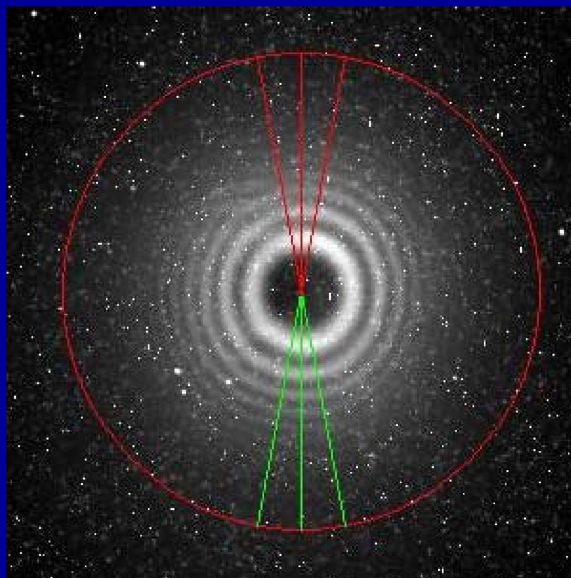


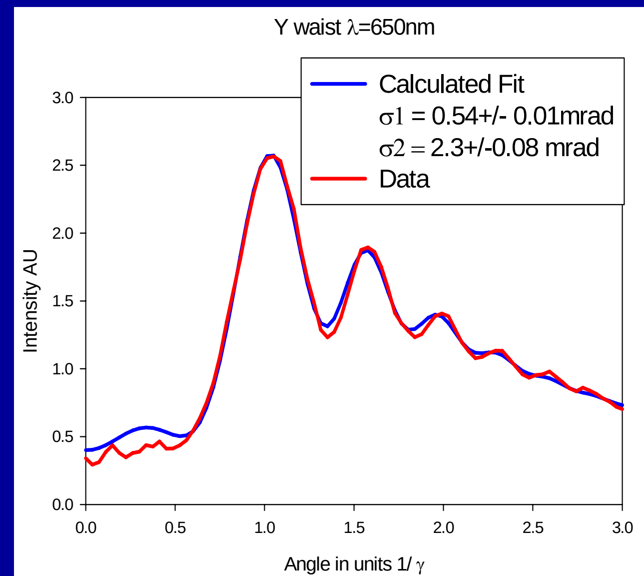


- Sector scan of far field image provides intensity profile
- Computer code used to fit intensity profile

Divergence Measurements

Two Gaussian fit works remarkable well





Waist	Filter	θ1 (mrad)	θ2 (mrad)
Y	650x10 nm	0.54+/-.01	2.3+/-0.1
Y	450x10 nm	0.55+/-0.01	2.4+/-0.08
X	650x10 nm	0.43+/-0.01	1.4+/-0.08
X	450x10 nm	0.45+/-0.01	1.3+/-0.07

Emittance Measurements

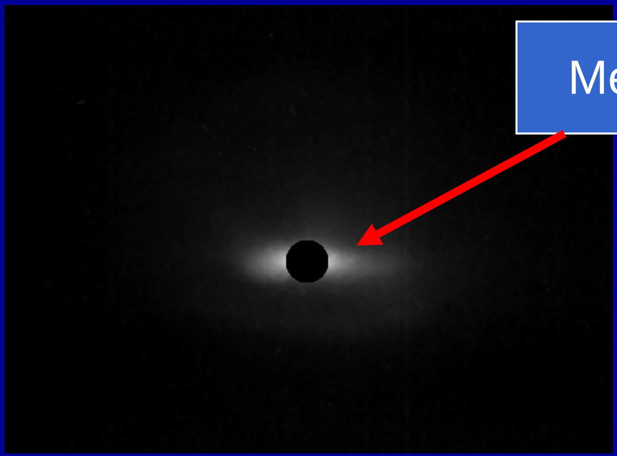
Waist	filter	Inner σ (mm-mrad)	Outer σ (mm-mrad)
X	650x10 nm	13 +/-.4	117.2 +/- 7.7
X	450x10 nm	14.7+/-.7	126.5 +/- 14.0
Y	650x10 nm	6.8 +/-.2	212.5 +/- 14.9
Y	450x10 nm	6.0 +/-.2	205.4 +/- 14.9

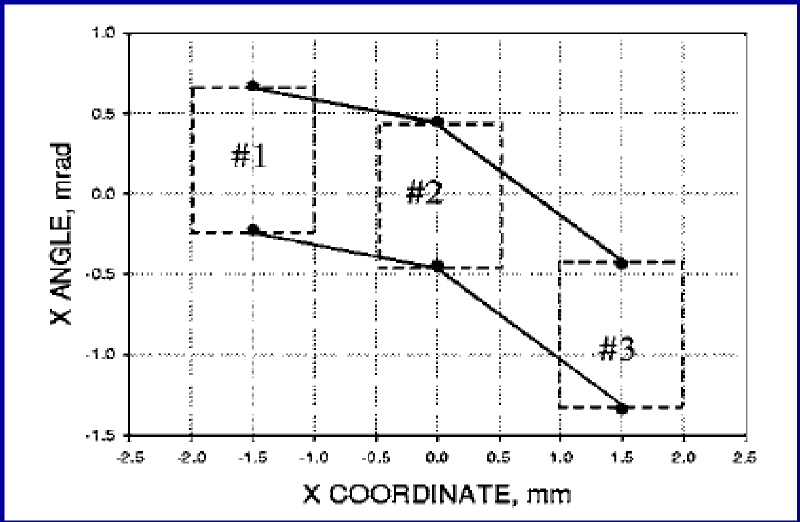
Conclusion

- OTRI has shown potential to measure multiple spatial and angular components within the beam
- Need to use a method to correspond spatial and angular data

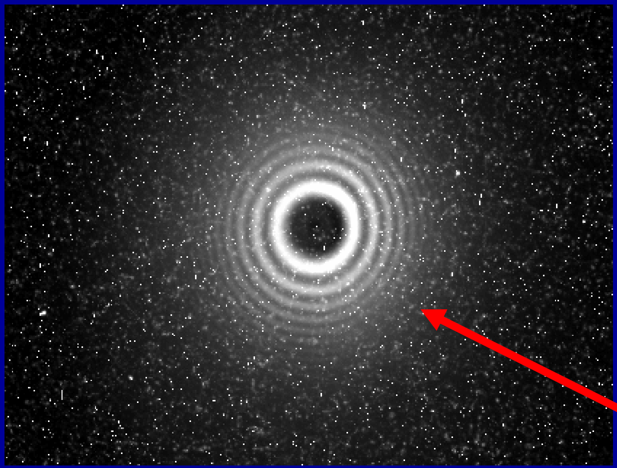
Next Step:
Optical Masking and Optical Phase Space Mapping

Measure position





R.B. Fiorito, et al., Ed. G.A. Smith and T. Russo "Optical Methods for Mapping the Transverse Phase Space of a Charged Particle Beam", Beam Instrumentation Workshop Conference Proceedings, AIP Conf. Proc. no. 648, p 187, (2002).



Measure divergence and centroid shift

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