Optical Diffraction-Transition Radiation Interferometry and its Application to Beam Diagnostics

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Incoherent ($\lambda << \sigma_l$) OTR Diagnostics

- **Near field imaging**: beam's spatial distribution
- **Far field imaging** (angular distribution):

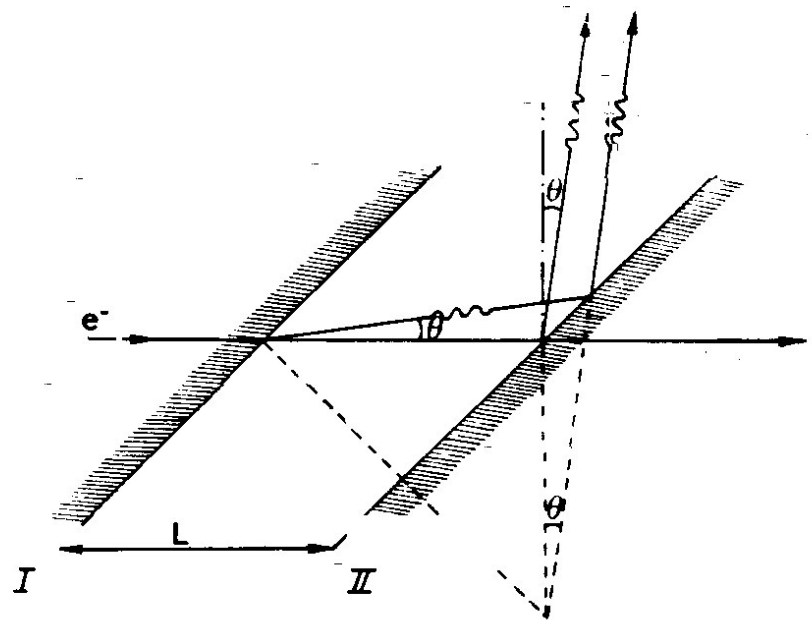
  rms* divergences (x', y')

  rms* trajectory angle

  energy spread

***rms measurements: requires focusing to a beam waist**

OTR Interferometry Diagnostics

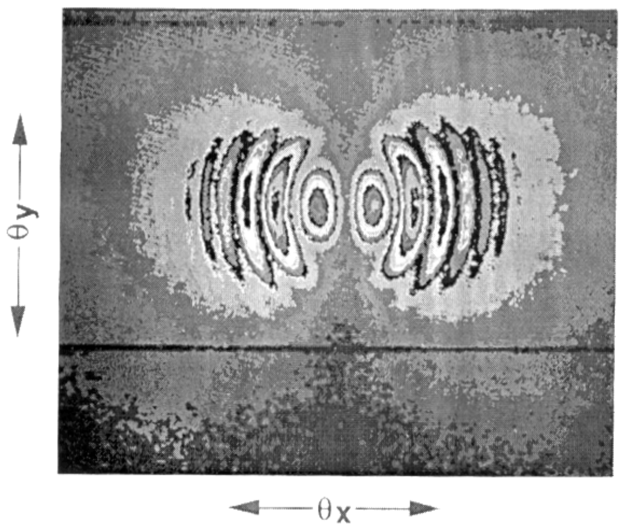


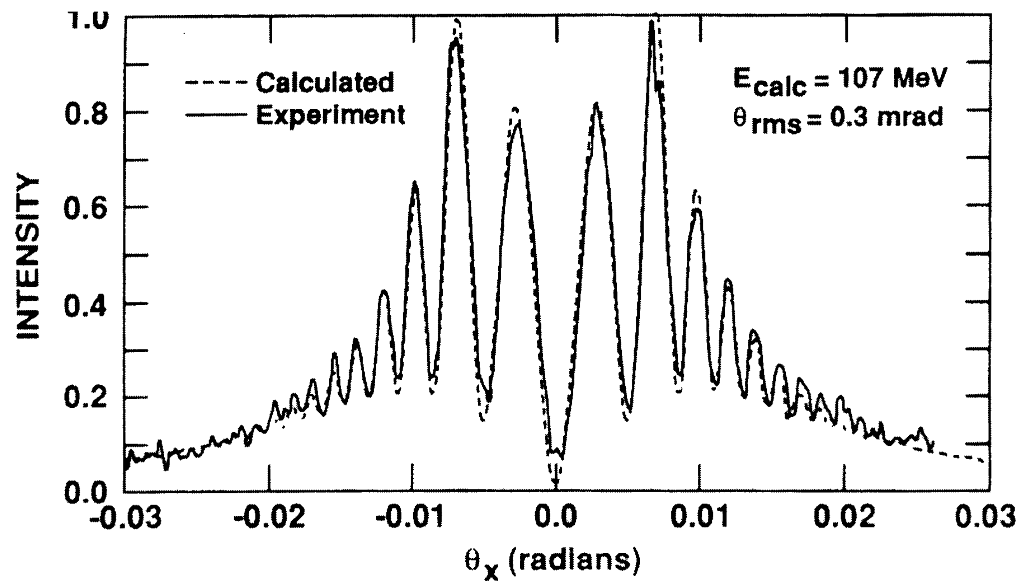
$$\frac{d^2 I_{TOT}}{d\omega d\Omega} = \frac{4\alpha}{\pi^2 \omega} \frac{\theta^2}{(\gamma^{-2} + \theta^2)} \left| 1 - e^{i\phi} \right|, \quad \phi = L / L_V, \quad \boxed{L_V = (\lambda / \pi)(\gamma^{-2} + \theta^2)^{-1}}$$

- Angular distribution of OTRI highly sensitive to λ, γ , θ , $\Delta\theta$, ΔE
- For typical high energy beams effect of ΔE negligible when

$$\Delta\gamma / \gamma \ll \gamma \Delta\theta_e$$

Example of beam divergence diagnostic using polarized OTRI: Boeing FEL Accelerator*





Fit to data typically gives: E ~ 1% and s_{rms} ~ 10 % precision.

*R. Fiorito and D. Rule, "Optical Transition Radiation Beam Emittance, Diagnostics" in AIP Conf. Proc. 319, R. Shafer ed. 1994

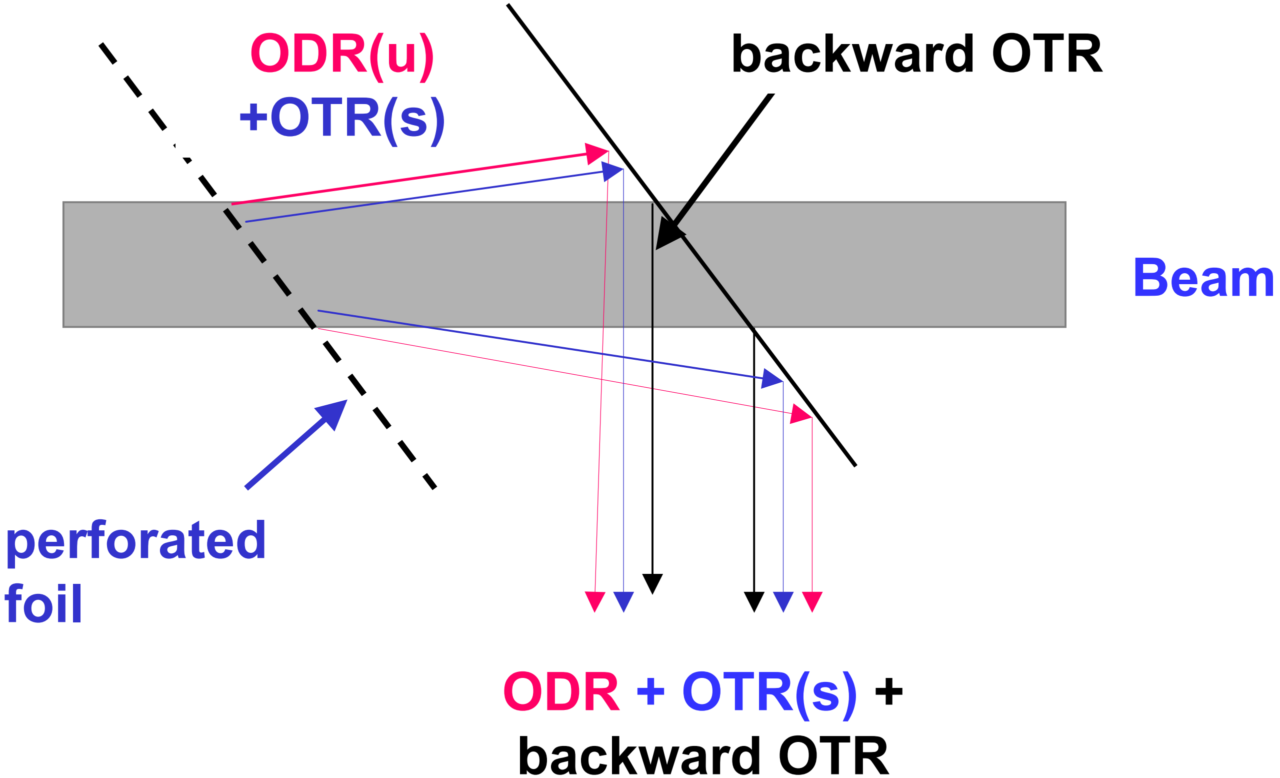
Limitations of conventional OTRI divergence diagnostics

1. Scattering in the first foil
- low energy beams
- very low emittance beams

2. Coherence length $L_v \sim \gamma^2\lambda$
- low energy beams (L too small)
- very high energy beams (L too big)

Optical Diffraction-Transition Radiation Interferometry*

- Perforated first foil overcomes scattering limit of conventional OTRI
- Extends OTRI diagnostics to low energy and/or low emittance beams



*A. Shkvarunets. R. Fiorito and P. O'Shea, Nuc. Instrum. and Meth. B, 201, 153-169 (2003)

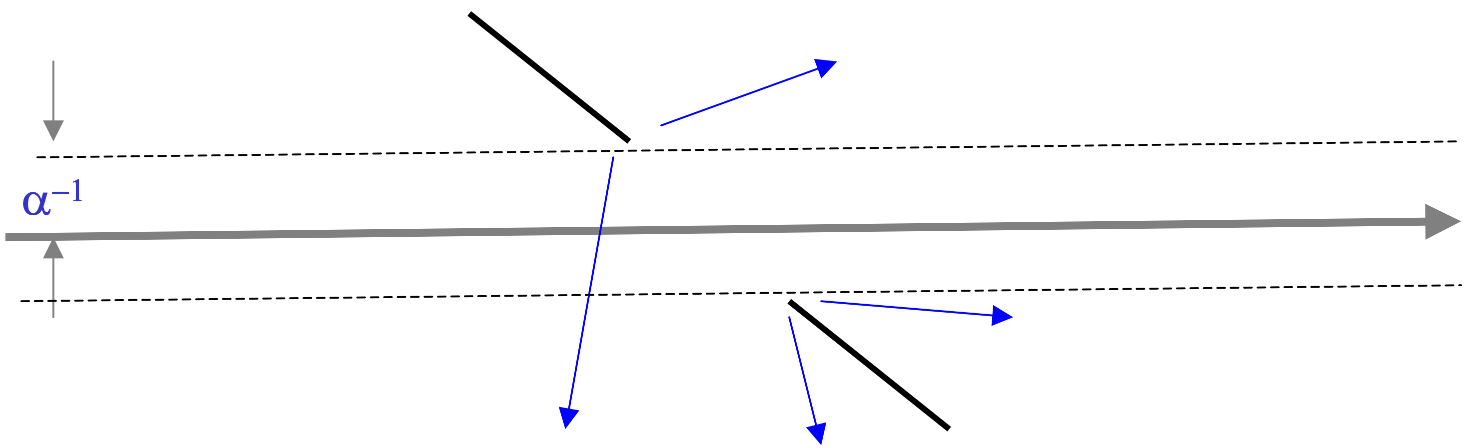
OPTICAL DIFFRACTION RADIATION

(produced by interaction of the field of the electron with a boundary)

DR Impact Parameter: $\alpha^{-1} = 2\pi/\gamma\lambda$,

α^{-1} is the range of the radial field of the charge: $E_e \sim K_1(\alpha r)$

when $\alpha^{-1} < \gamma\lambda$, substantial DR produced

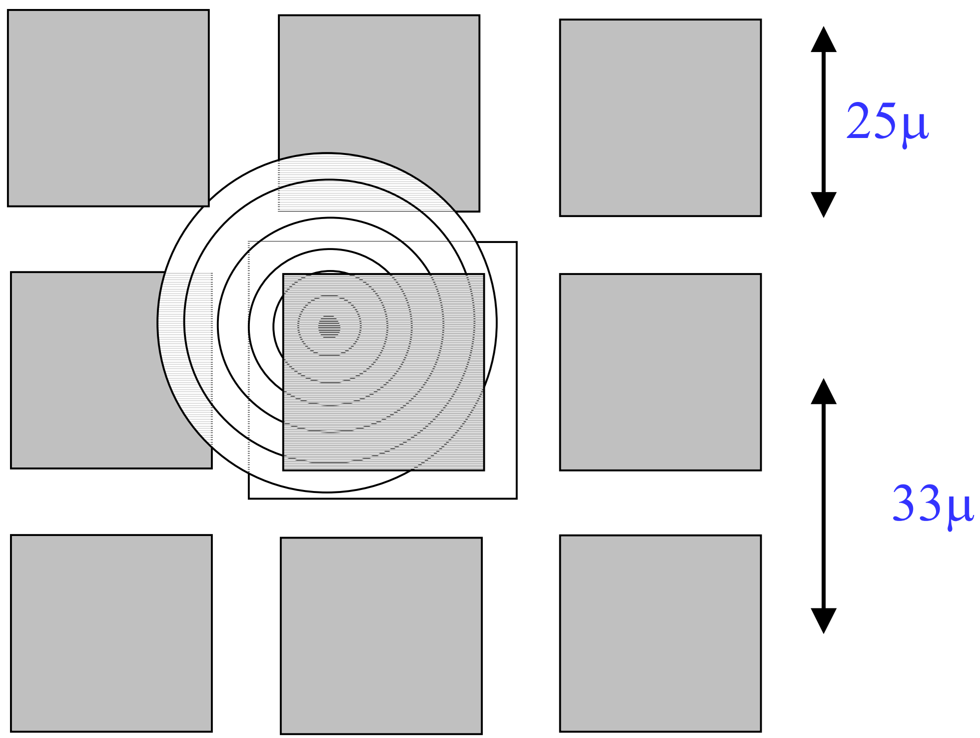


Note: angular distribution of DR depends on beam divergence, energy spread

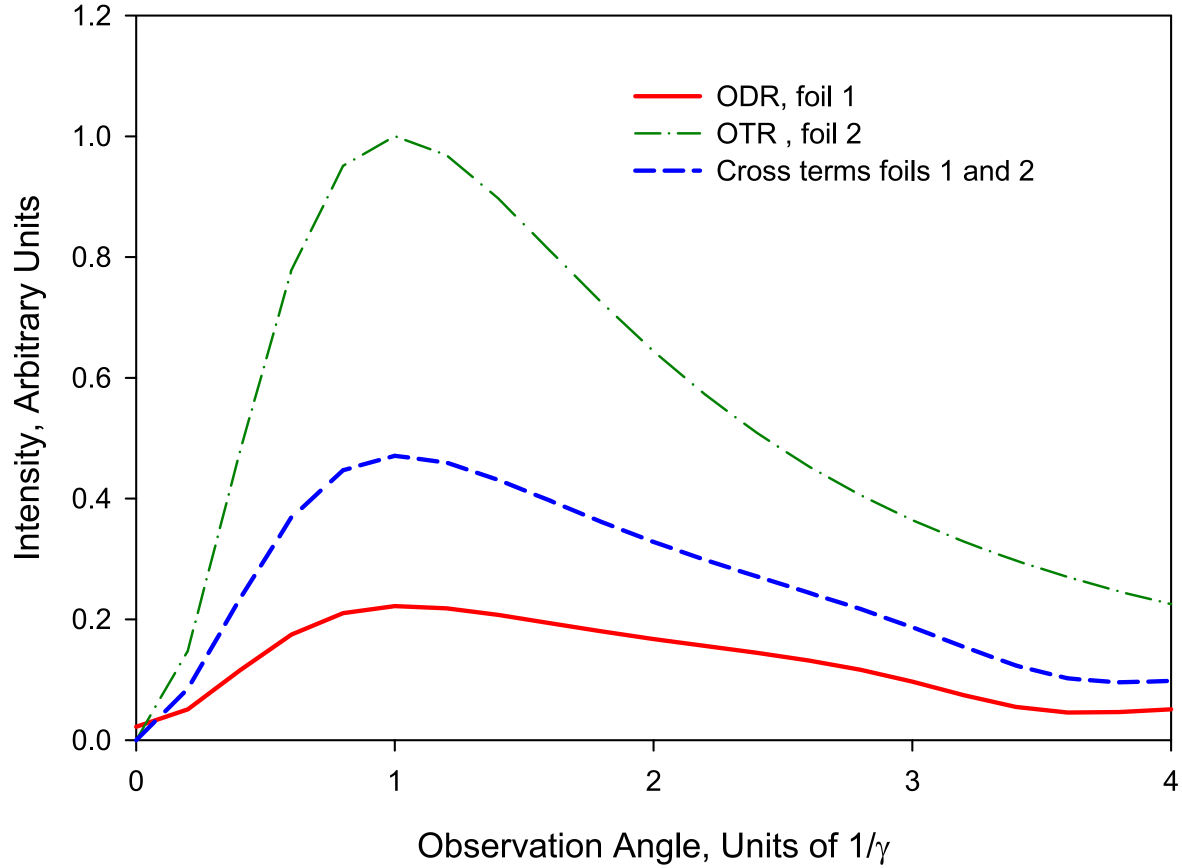
beam size and position; same coherence length applies : $L_v \sim \gamma^2\lambda$

ODR and OTR generated in a Metallic Micromesh

Grid of rectangular holes in a 5 micron thick Copper mesh showing the passage of a single electron through one hole and the surrounding electron field:

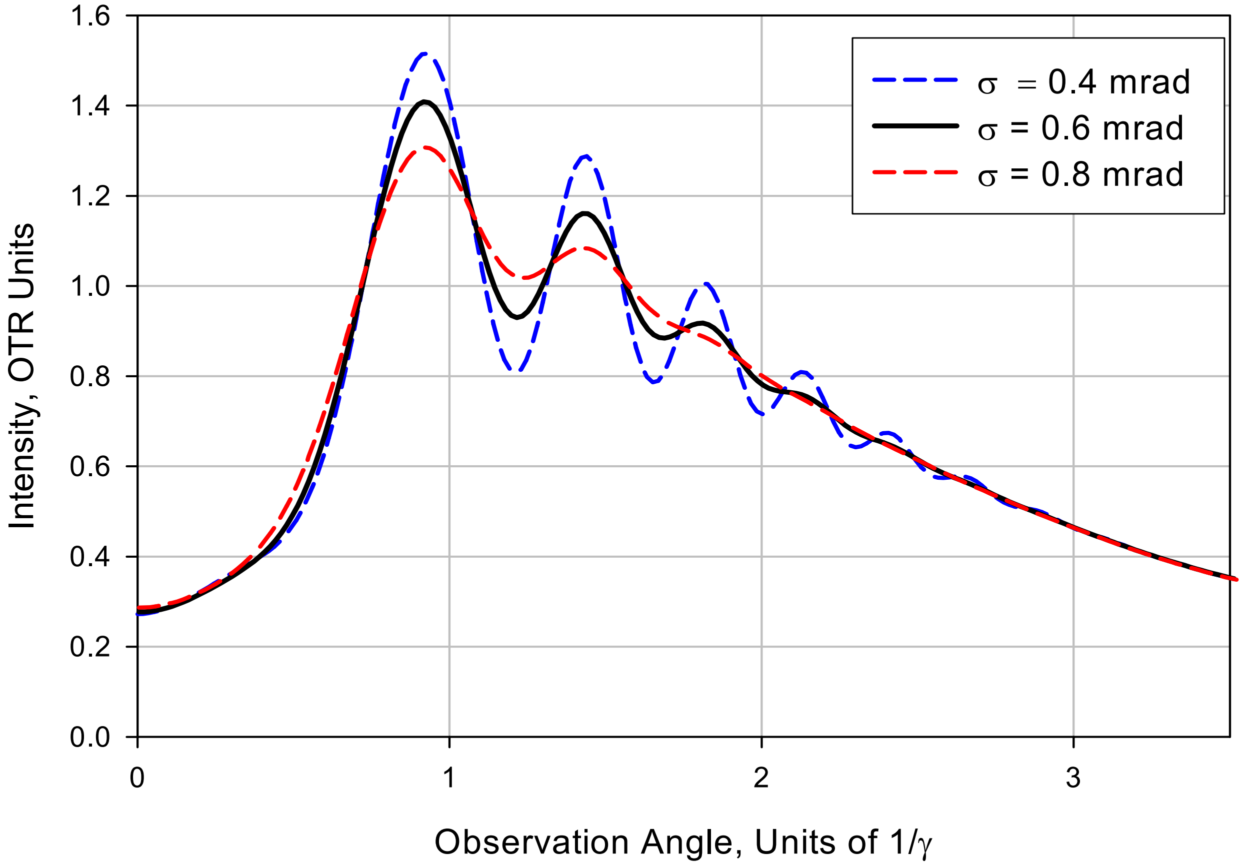


ODR and OTR intensities per electron for the unscattered portion of the beam (Simulation Code)



ODR-OTR INTERFERENCES

E = 95 MeV , J_s/J_u = 1.28; d = 36.6mm; λ = 650nm; $\Delta\lambda$ = 70nm; σ_f = 2.3mr

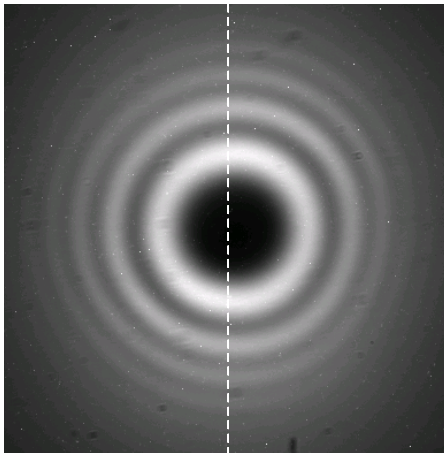


$\gamma\sigma \sim 0.1$

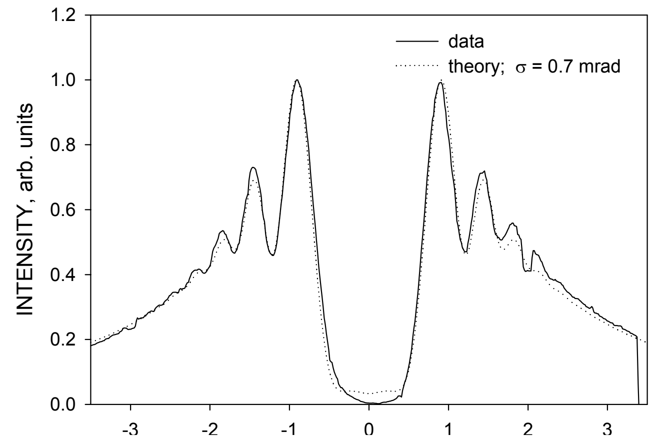
Comparison of OTR and ODTR Interferograms for 95 MeV Beam at NPS

(Vertical (y) beam waist, I_{avg} = 1uA, λ = 650 x 70 nm)

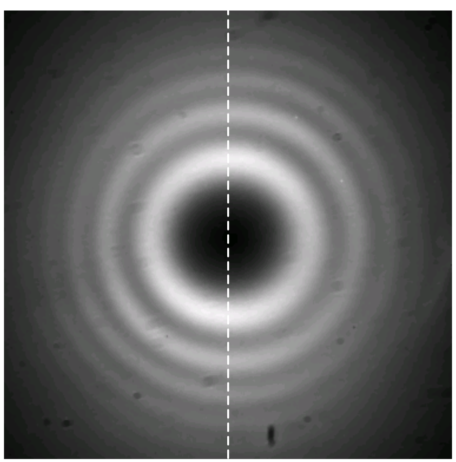
vertical (θ_v) scans



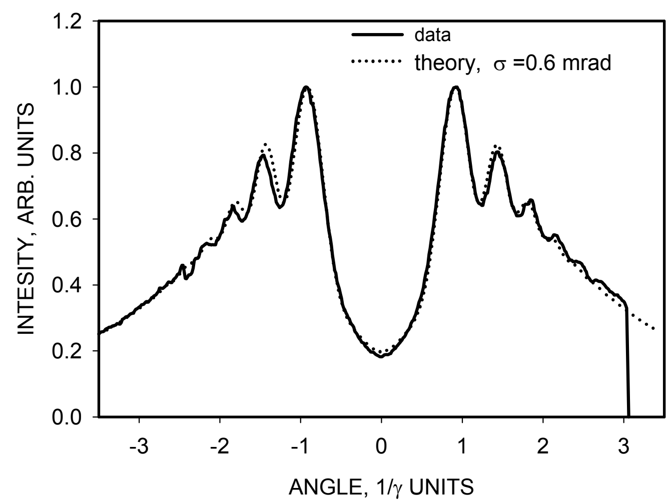
OTRI



θ_y



ODTRI



θ_x

***R. Fiorito , A. Shkvarunets and P. O'Shea, "Measurement of electron beam divergence using OTR-ODR interferometry", to be published in Proc. of PAC03, May 11-16, 2003, Portland , OR.**

Goals of ATF Experiments

• Develop ODTRI divergence diagnostic for moderate energy, low emittance beams **Note: ATF normalized divergence ~ 0.01 mrad**

NPS normalized divergence ~ 0.10 mrad

• Show that ODTRI can extend the range of OTRI divergence diagnostics

• Measure the x, y rms divergences of the ATF beam and compare

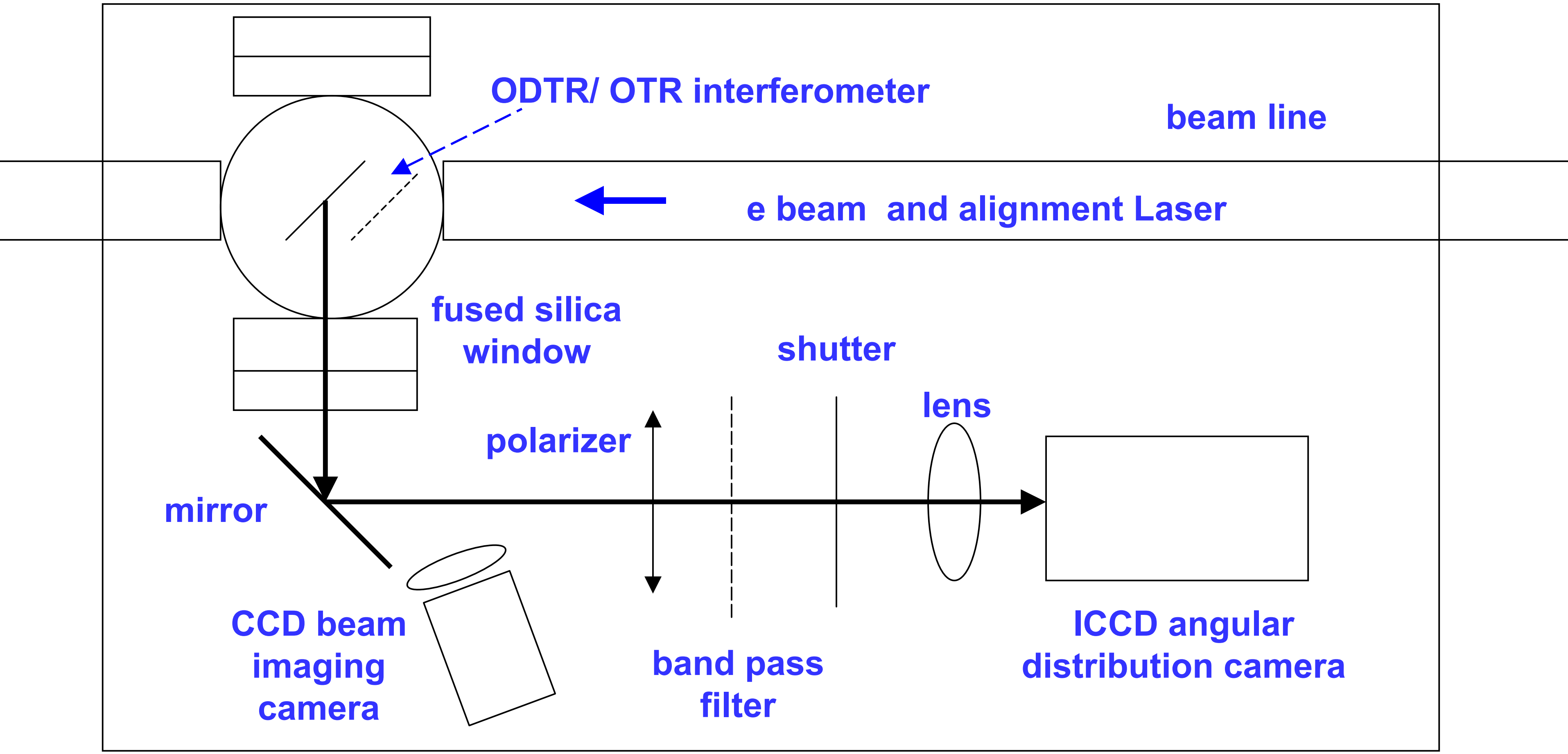
with other techniques to quantify the accuracy and sensitivity of ODTRI diagnostics

Challenges of ATF Experiments

- low emittance: small change on fringe visibility
- Low average current: I_{ATF} ~ 0.8 nA :: I_{NPS} ~ 0.8 μA
- Signal to Backround: limited by x-rays   S/B ~ 2
- Space limitations
- Interferences from other experiments on beam line

ODTRI Experimental Setup on ATF Beamline 2

(Top-View)

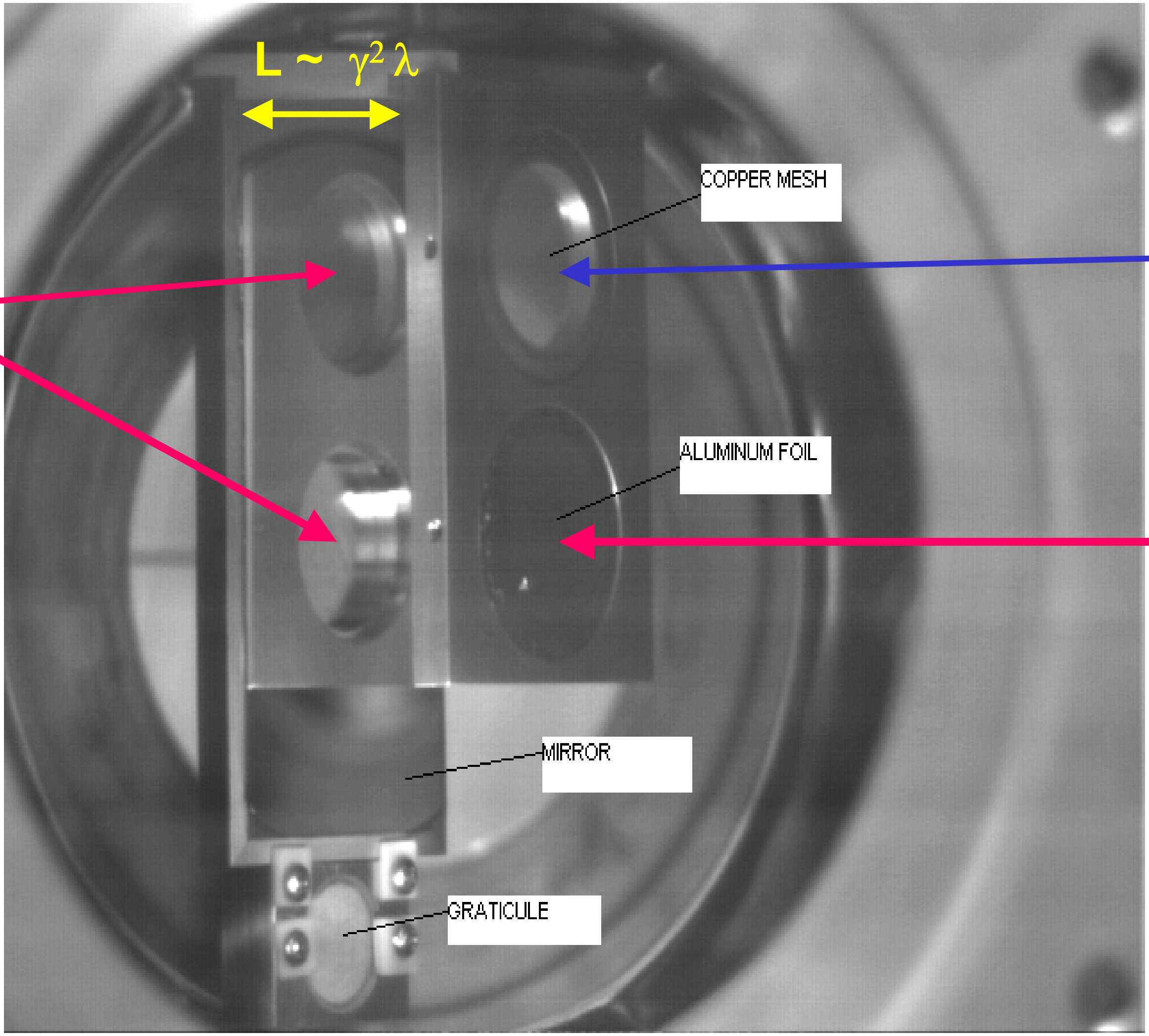


ODR-OTR - OTR-OTRI Interferometer

(Side – Observer's View)

Backward

OTR



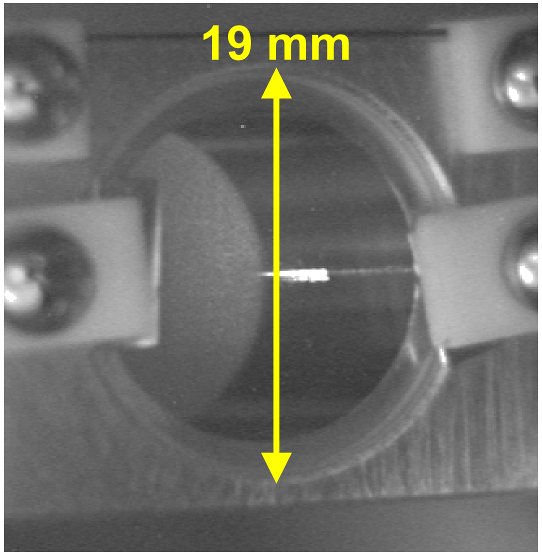
Forward
ODR +OTR

Forward OTR

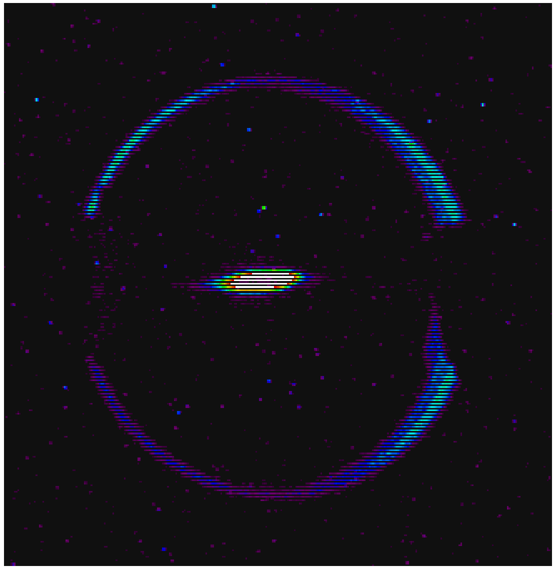
Beam
Direction

Results of Experiments to Date

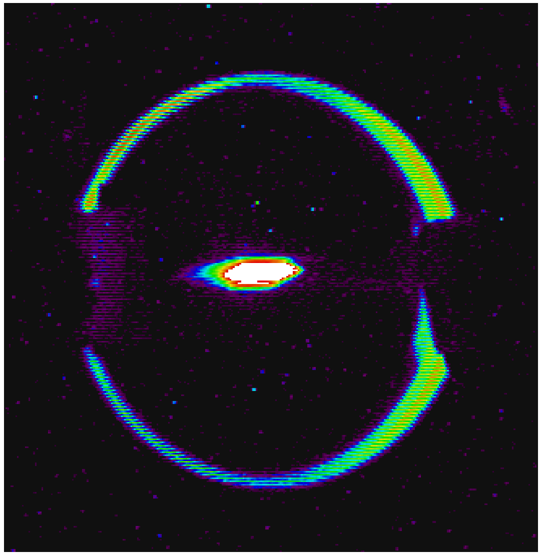
Beam Size and Position Monitoring at ATF with Cherenkov Radiation from Glass Graticule



Low Charge

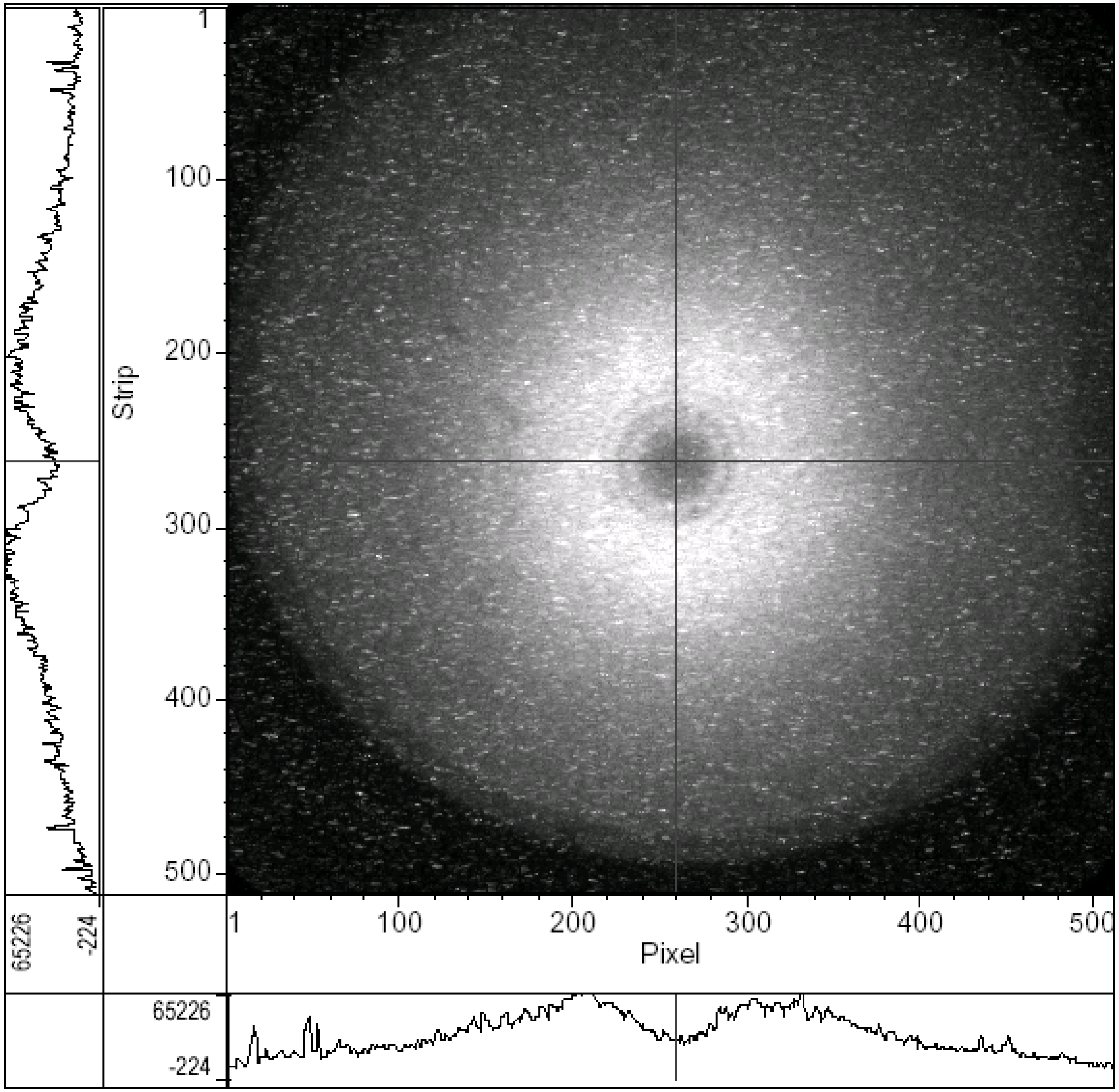


High Charge

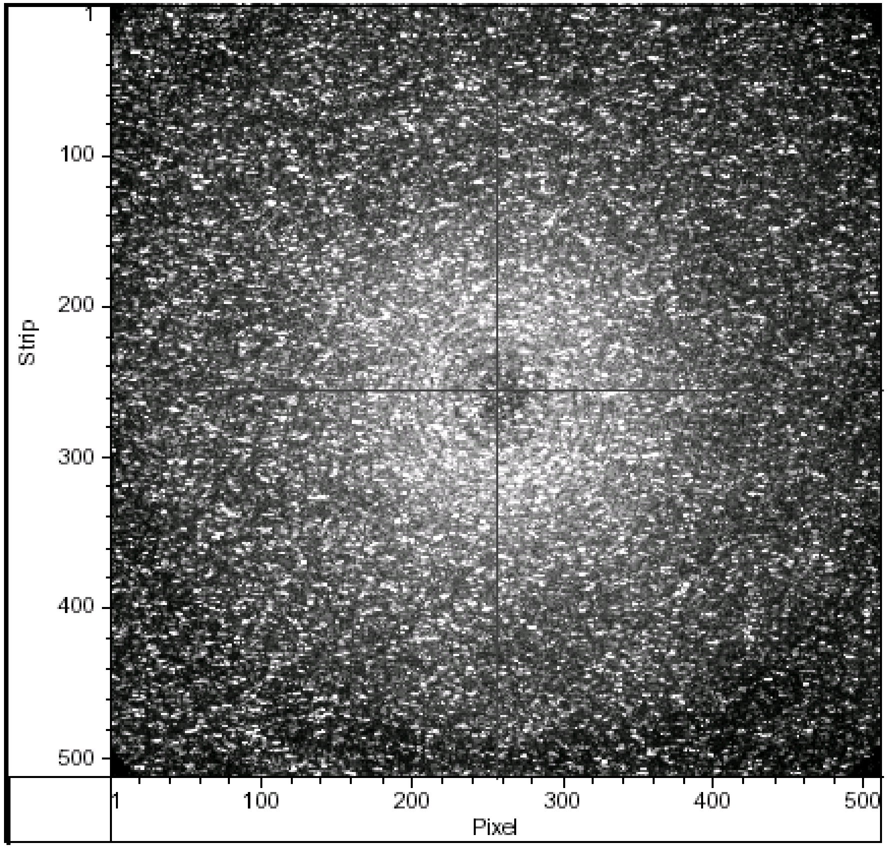


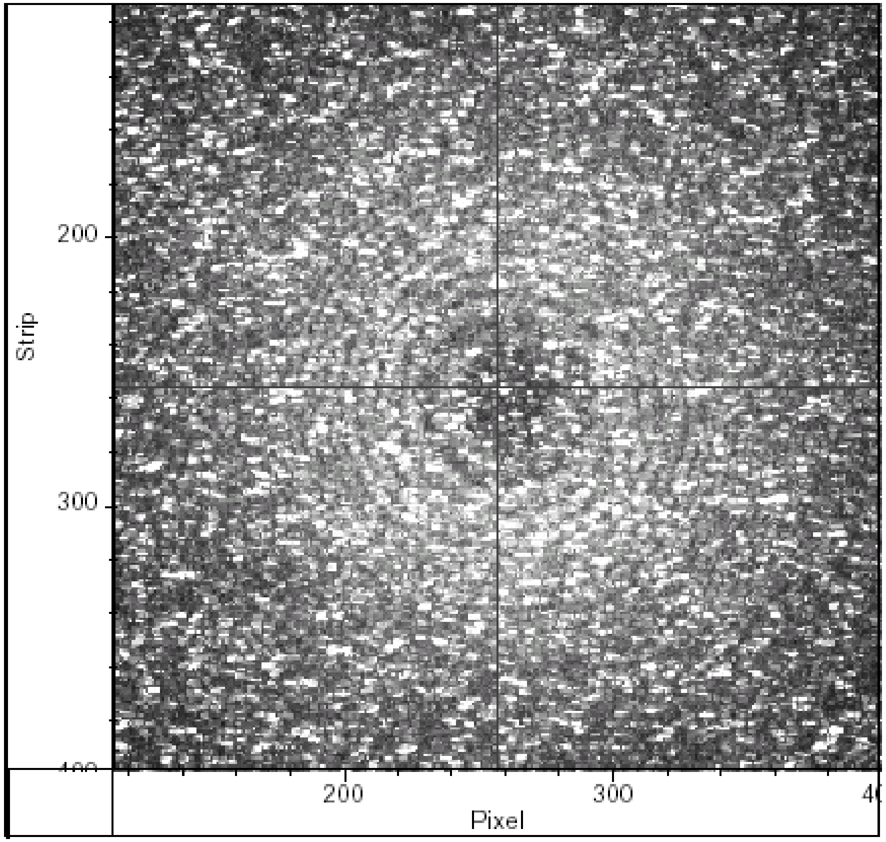
Observation of Farfield ODTRI at ATF using Gated ICCD Camera

(E= 50 Mev, 135mm f.l. lens, 250 gates, 10ns width, λ = 644 x 80nm)



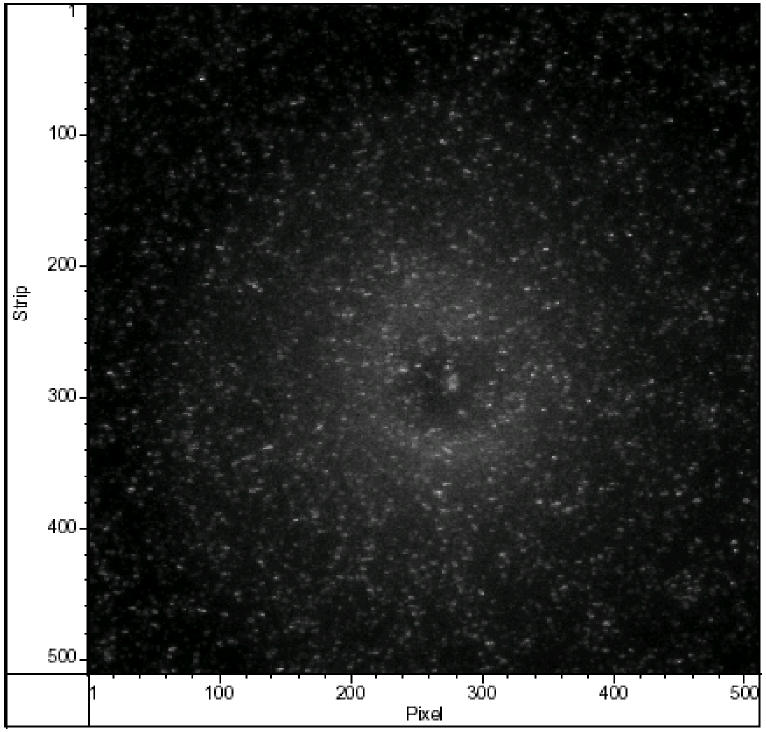
ODTRI_250gates_10nsgate, λ = 600 x 9nm



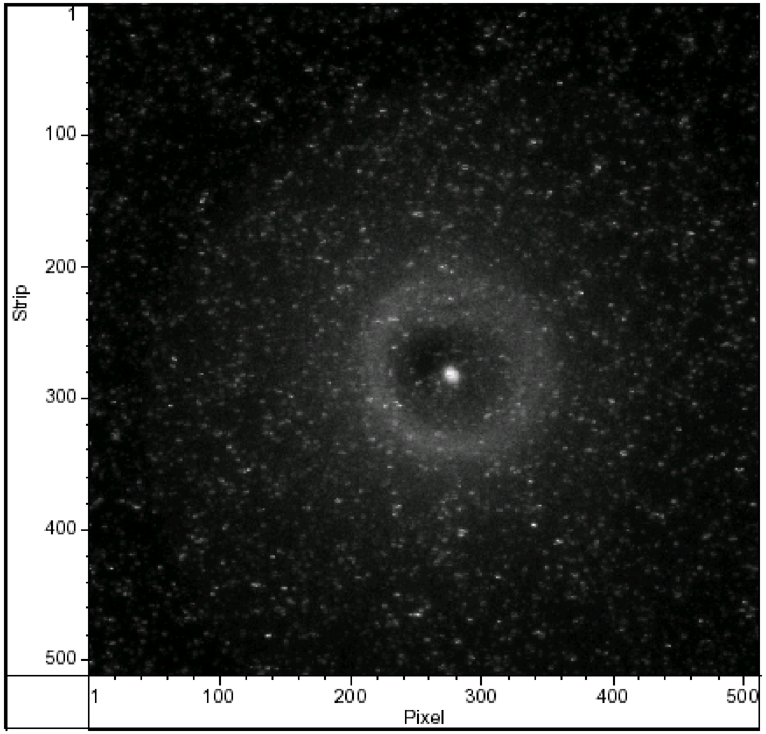


Optical Radiation From Upstream Dielectric Tube (DWE)

Cu_mesh_120gates_255gain



mirror_120gates_255gain



Addressing Signal/Background problem:

Work in Progress

- **Gating:** limited to decreasing d.c. optical radiation only because beam related optical radiation and x-rays coincident with pulse)
- **Move and shield ICCD Camera to floor level (3 feet below beamline):** problems of physical space around beamline, alignment of optics and field of view limitations

1/05/2004 Data: ODTRI from Cu mesh: Effect of Limited Field of View