OBSERVATIONS ON MICROBUNCHING OF ELECTRONS IN LASER-DRIVEN PLASMA ACCELERATORS AND FREE-ELECTRON LASERS

A.H. Lumpkin[1], D.W. Rule[2], M. LaBerge[3], M.C. Downer[3]
[1]Fermi National Accelerator Laboratory, Batavia, IL, 60510 USA
[2]Silver Spring, MD 20904 USA
[3]Physics Dept, University of Texas-Austin, Austin, TX 78712 USA

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ABSTRACT

The periodic longitudinal density modulation of relativistic electrons at the resonant wavelength (microbunching) is a fundamental aspect of free-electron lasers (FELs). In one case, microbunching fractions reached 20% at saturation of a self-amplified spontaneous emission (SASE) FEL resulting in gains of 1 million at 530 nm. In that experiment the z-dependent gain of coherent optical transition radiation (COTR) was also measured. In laser-driven plasma accelerators (LPAs), microbunching at visible wavelengths has also been recently reported as evidenced by significant COTR enhancements measured in near-field and far-field images on a single shot for the first time. An analytical model for COTR interferometry (COTRI) addresses both cases. The broadband microbunching observed in the LPA case could act as a seed for a SASE FEL experiment with tunability in principle over the visible regime.

COTRI Equations

$$\frac{d^2W_1}{d\omega d\Omega} = \frac{e^2}{\hbar c}\frac{1}{\pi^2\omega}\frac{(\theta_x^2+\theta_y^2)}{\left(\gamma^{-2}+\theta_x^2+\theta_y^2\right)^2} \quad (1)$$

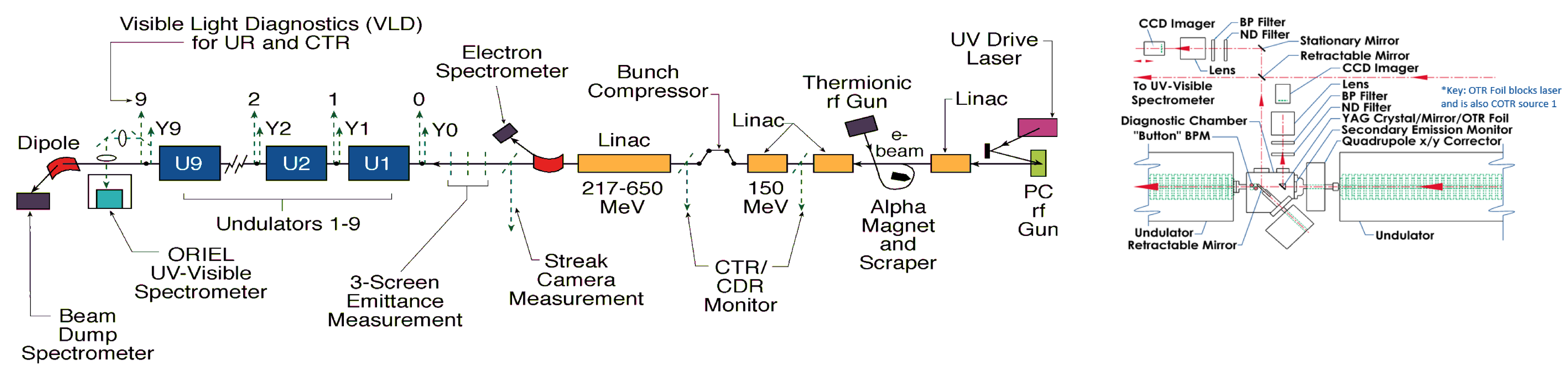
$$\frac{d^2W}{d\omega d\Omega} = |r_{\parallel,\perp}|^2\frac{d^2W_1}{d\omega d\Omega}\, I(\mathbf{k})J(\mathbf{k}) \quad (2)$$

$$I(\mathbf{k}) = 4\sin^2\left[\frac{kL}{4}\left(\gamma^{-2}+\theta_x^2+\theta_y^2\right)\right] \quad (3)$$

$$J(\mathbf{k}) = N + N_B(N_B-1)|H(\mathbf{k})|^2 \quad (4)$$

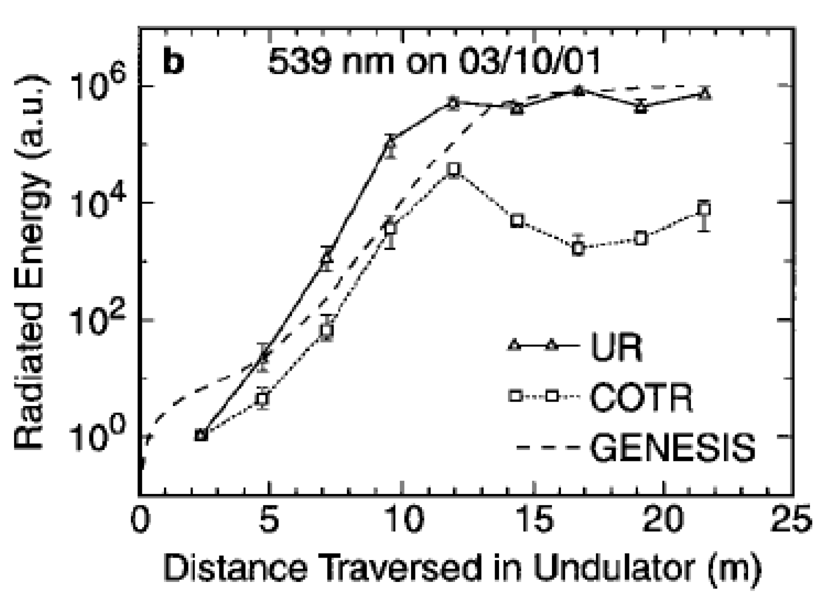
$$H(\mathbf{k}) = \frac{\rho(\mathbf{k})}{Q} = g_x(k_x)\,g_y(k_y)\,F_z(k_z) \quad (5)$$

COTR formalism developed for the SASE FEL case of microbunched electrons and far field imaging. (Rule and Lumpkin, PAC2001).

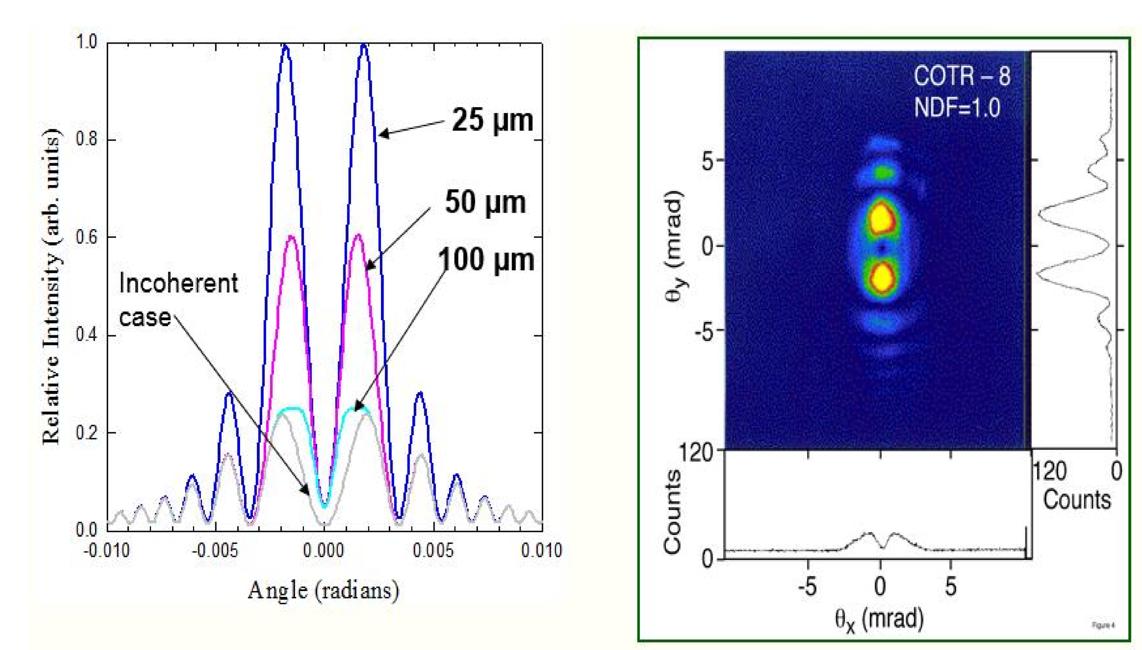


Schematic of the APS linac showing the visible wavelength SASE FEL and diagnostics stations circa 2002.

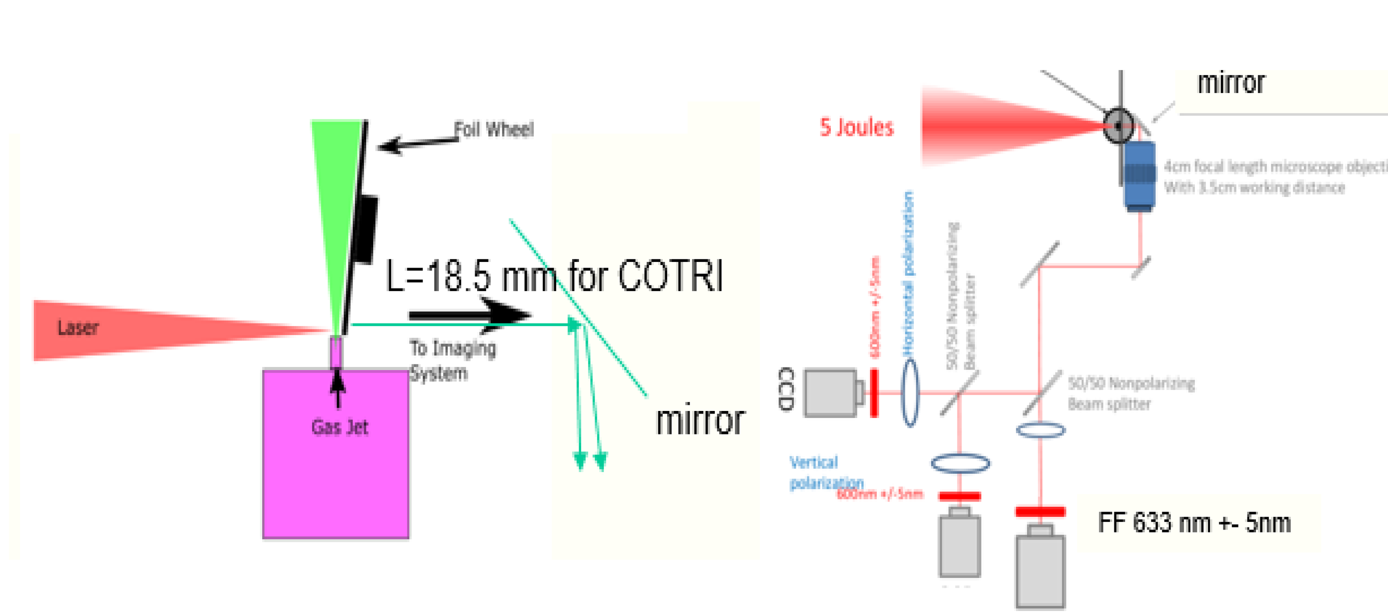
SASE FEL case with FEL gain of 10^6 and COTR gain of 10^5 at saturation (PRL 2002).



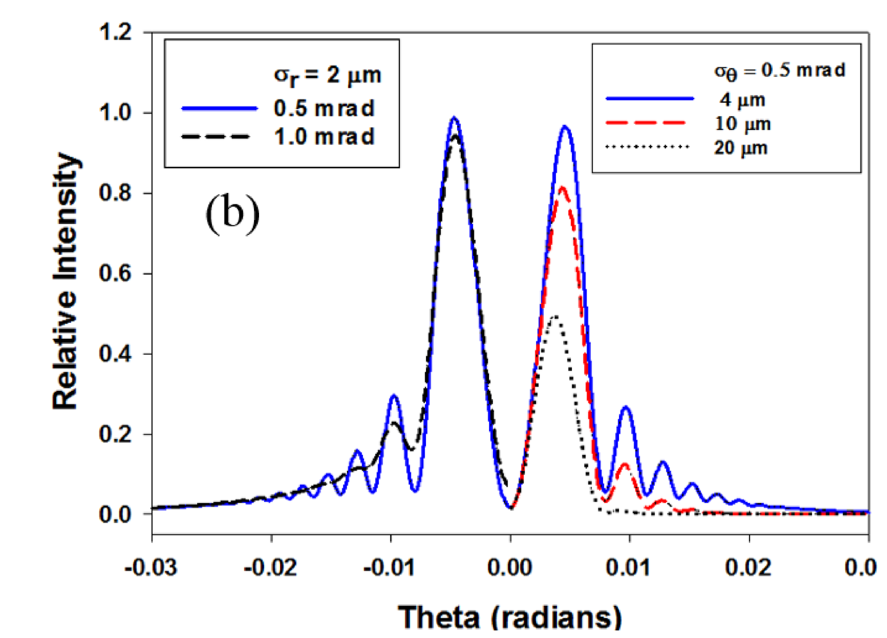
Far field angular distribution with asymmetric microbunched beam size with model at left.



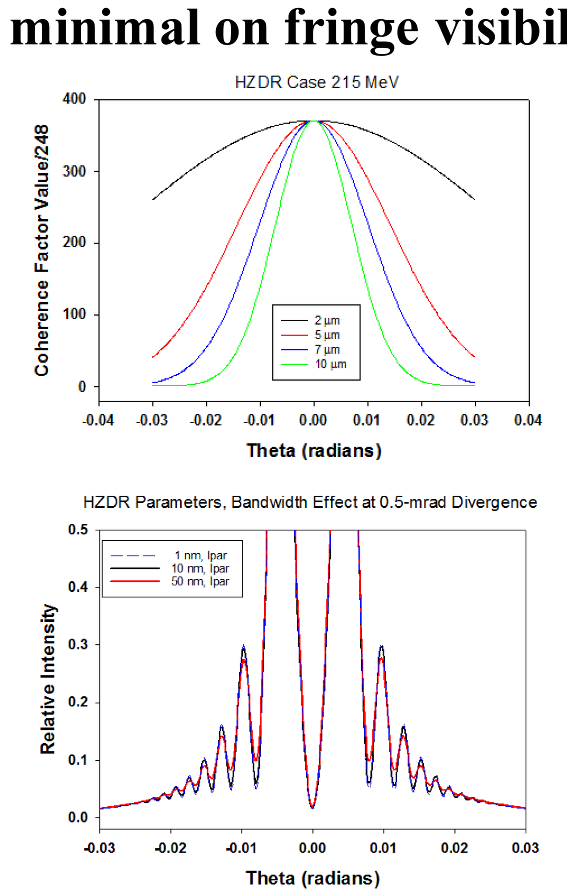
Schematic of LPA at HZDR (L) and single shot imaging diagnostics with near field (NF) and far field (FF) optics.



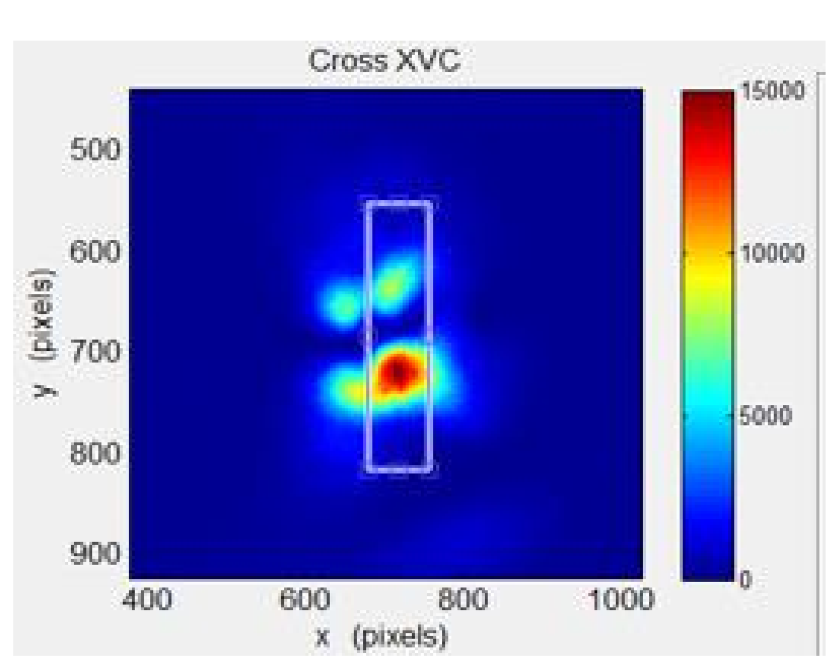
COTRI calculations showing a divergence effect for negative angles and beam-size effect for positive angles.



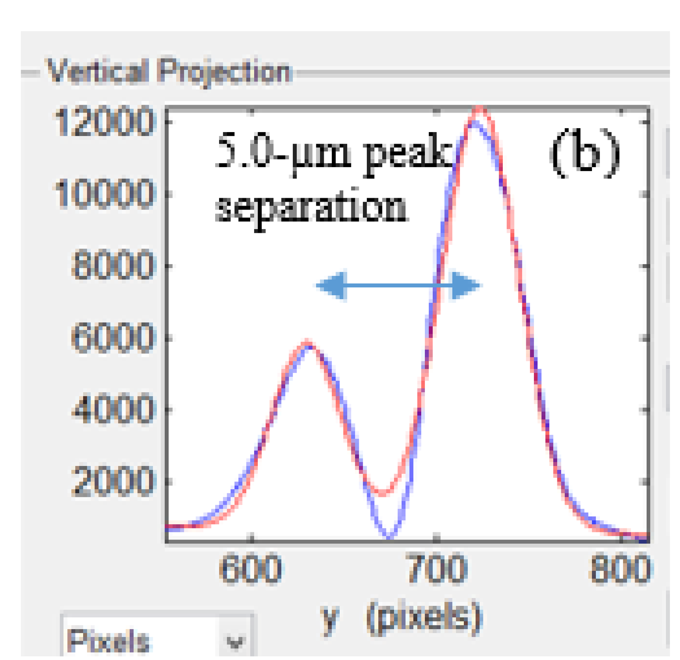
Coherence function versus angle using 2 µm beam size. Gain of 90,000. Lower: 10-nm bandwidth effect minimal on fringe visibility.



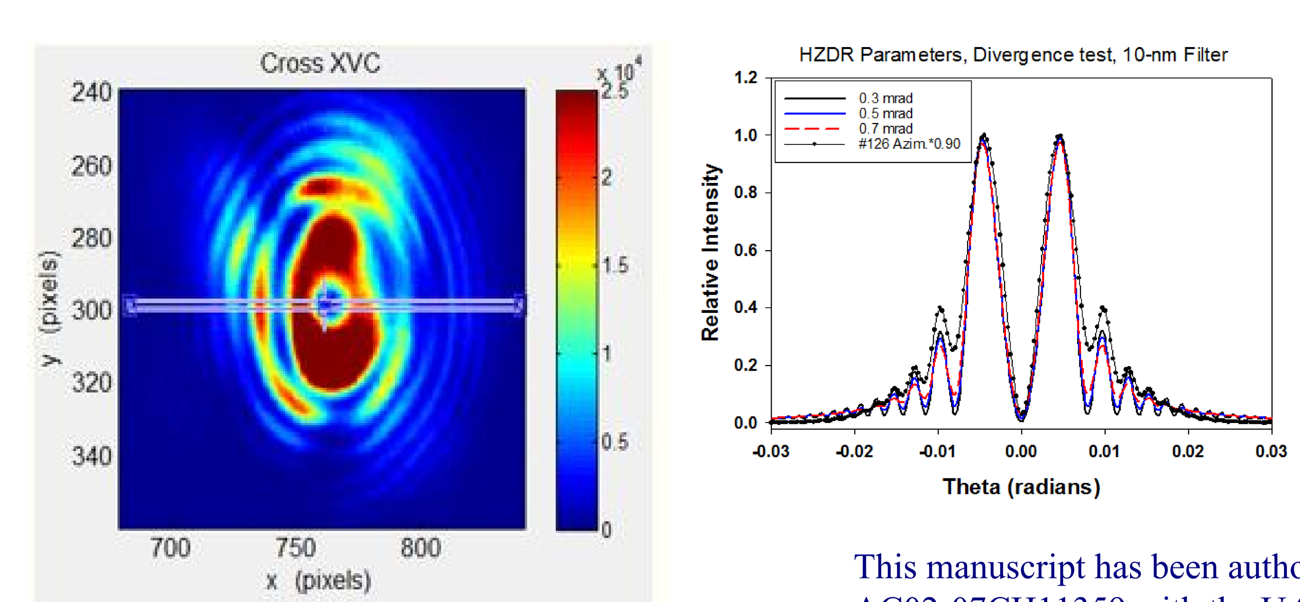
Near field vertically polarized image showing two pairs of coherent PSF lobes for two beamlets separated by 6 µm in x.



Vertical projection of right hand beamlet with 2-Gaussian fit to distribution. Lobe separation implies σ_y=2.2 µm.



Far-field image showing the angular distribution pattern with interference fringes using 633x10 nm BPF. Model σ_θ~0.5 mrad curve is closest to outer fringes at right. COTR gain of ~10^5 was estimated from the ND filters, 10-nm filter bandwidth, charge, and camera calibration.



SUMMARY

In summary, we revisited a visible light SASE FEL experiment where z-dependent microbunching diagnostics were implemented. An analytical model initially developed for this FEL case was compared to new results on an LPA. COTR gains were observed that rival the SASE FEL case at saturation (100,000) albeit with a much smaller beam size of a few microns. Such a beam may provide the prebunching for seeding an FEL.

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