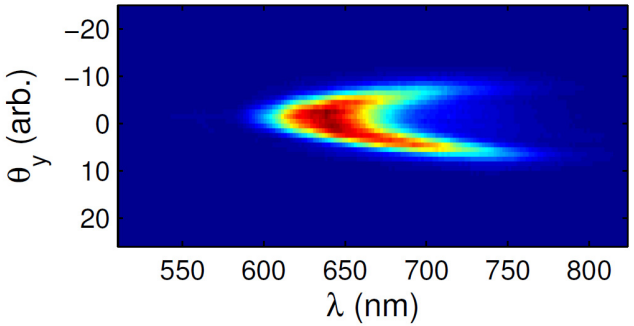
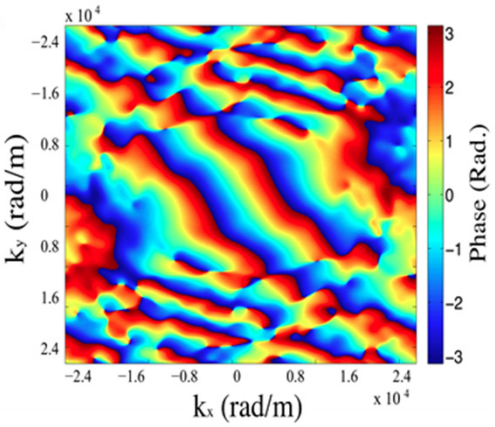
UCLA



Collective Dynamics and Coherent Diagnostics of Microbunched Relativistic Electron Beams



Agostino Marinelli

UCLA-SLAC

IPAC 2015,

May, 7 – Richmond,VA

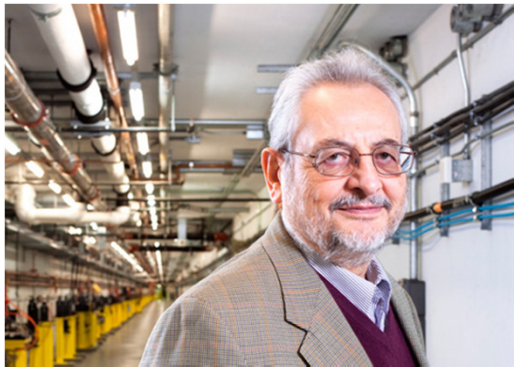
U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

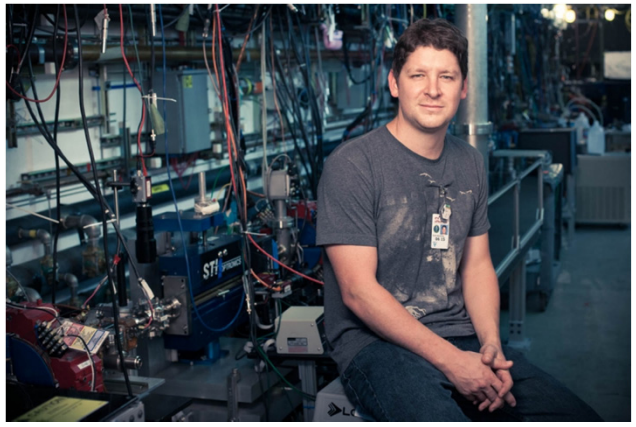
Acknowledgements

Gigi Palumbo

Jamie Rosenzweig



Claudio Pellegrini



Erik Hemsing

Acknowledgements

- ... my colleagues and friends at SLAC, UCLA, University of Rome and INFN.
- The APS Thesis Prize Committee for honoring me with the 2015 Outstanding Thesis Research Prize and Inviting me here.

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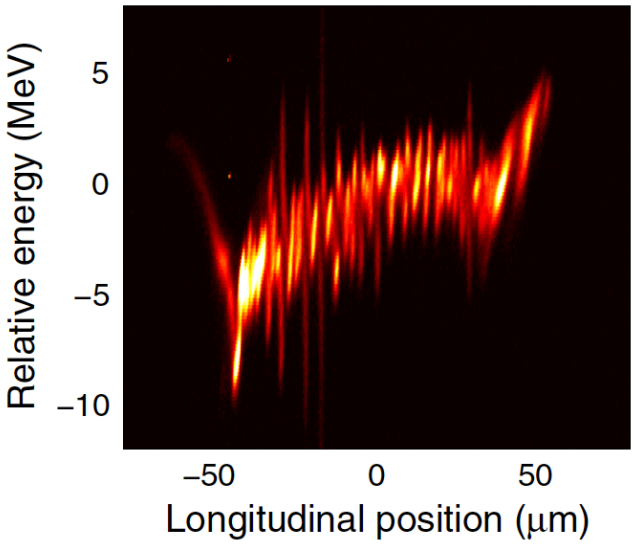
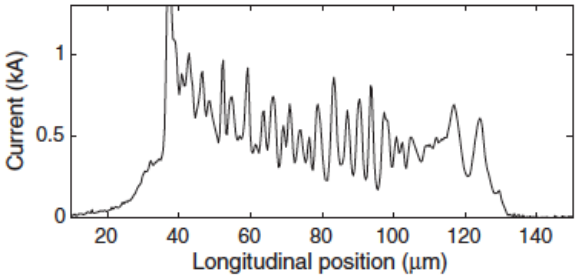
- My family for their constant love and support.






Microbunching





PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **18,** 030704 (2015)

Time-resolved imaging of the microbunching instability and energy spread at the Linac Coherent Light Source

Microbunching appears in many high-brightness accelerators (e.g. LCLS)

Can seriously degrade performance of the machine…

Topics of my doctoral work:

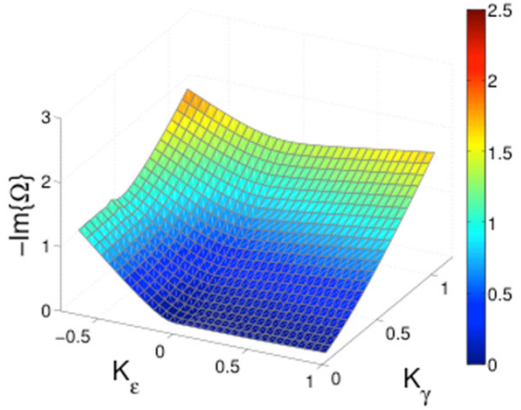
How is microbunching generated?

How does it evolve?

How can you measure it?

How can you use it?

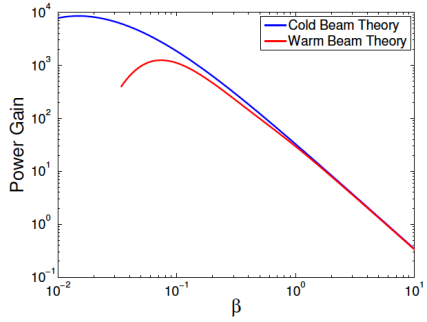
mensional Theory of Space-Charge Interactions



Analysis of space-charge interactions in terms of plasma-waves

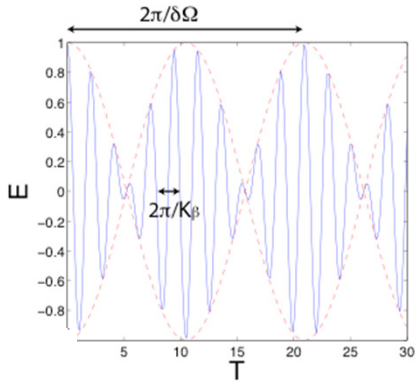
$$\left(\frac{1}{D^2}\nabla_\perp^2 - 1\right) E_z = -\int E_z(\vec{X}')\Pi(\vec{X},\vec{X}')d^2\vec{X}'$$

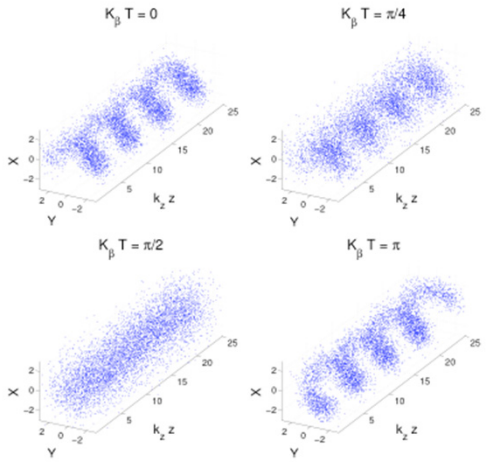
$$\Pi(\vec{X},\vec{X}') = \int_{-\infty}^{0} \frac{Te^{-\frac{(K_\gamma T)^2}{2} - i\Omega T} e^{-\left(\vec{X}^2+\vec{X}'^2-2\vec{X}\cdot\vec{X}'\cos K_\beta T\right)\frac{(1+iK_\epsilon T)}{2\sin^2 K_\beta T}}}{2\pi \sin^2 K_\beta T} dT.$$



Suppression of microbunching gain due to emittance

Emittance induced anisotropic Landau damping





PHYSICS OF PLASMAS 18, 103105 (2011)

Three dimensional analysis of longitudinal plasma oscillations in a thermal relativistic electron beam

Agostino Marinelli,[1,2] Erik Hemsing,[1] and James B. Rosenzweig[1]

Plasma-Betatron Beatwaves

The Longitudinal Space-Charge Amplifier

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 13, 110701 (2010)

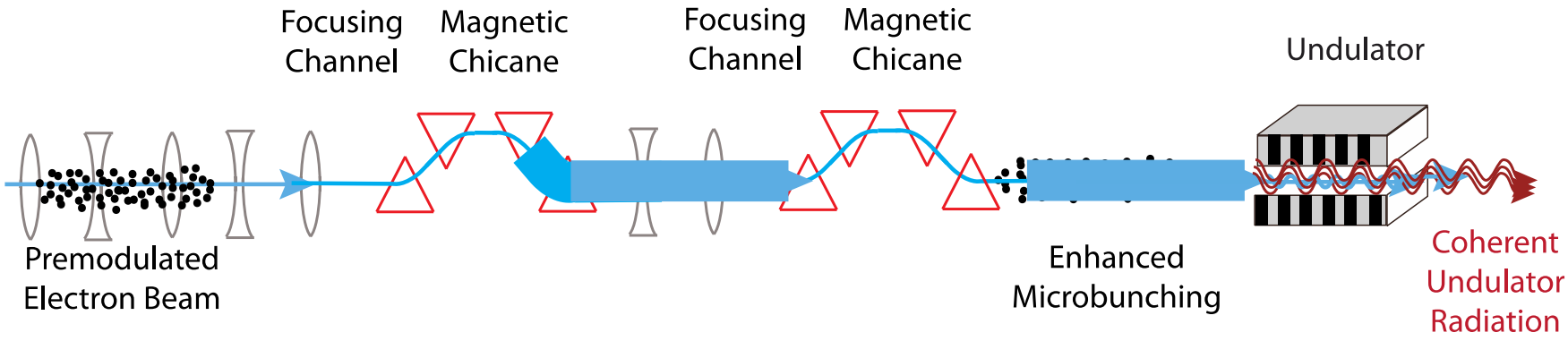
Using the longitudinal space charge instability for generation of vacuum ultraviolet and x-ray radiation

E. A. Schneidmiller and M. V. Yurkov
Deutsches Elektronen-Synchrotron (DESY), Notkestrasse 85, D-22607 Hamburg, Germany
(Received 1 April 2010; published 13 November 2010)

-Inexpensive (short undulator)

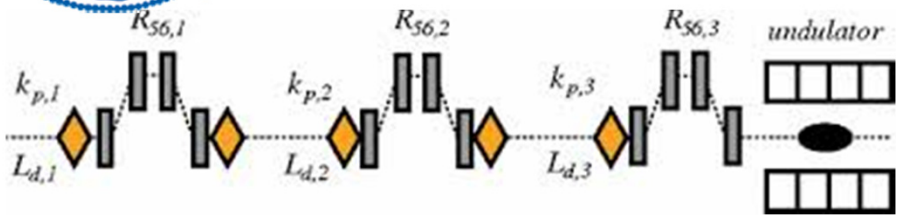
-Alternative to FEL for broadband (e.g. attosecond pulses)

-Can be used for coherent electron cooling



Experimental Demonstration
...t Optical Wavelengths (NLCTA)

SLAC

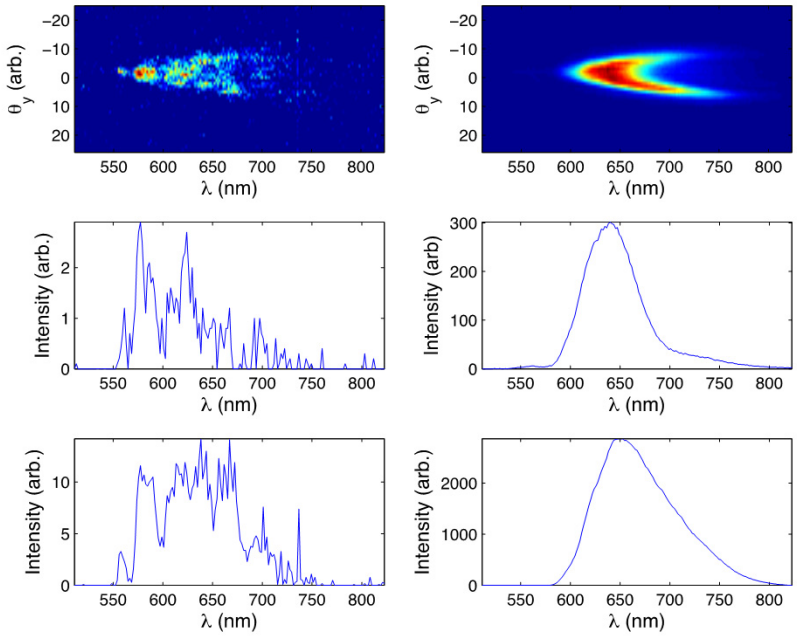


3 chicanes + 10 period undulator
R56 = 4mm, 2.5mm, 1.5 mm

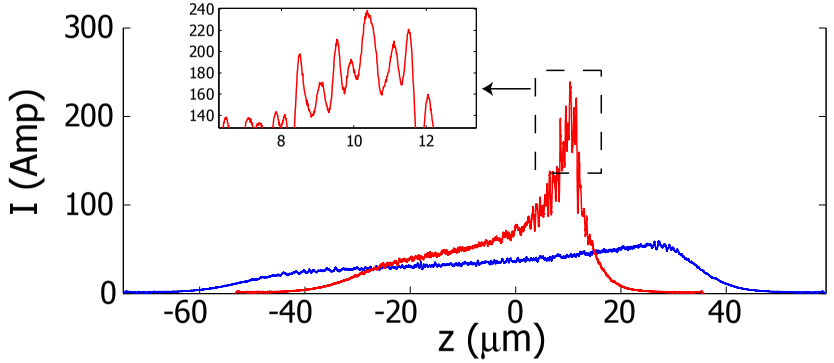
Microbunching gain confined to leading peak containing ~20% charge…
Local microbunching gain ~ 15000

Moderate compression

High Compression



Single-spike from compression:
-short leading current peak



PRL 110, 264802 (2013) PHYSICAL REVIEW LETTERS week ending 28 JUNE 2013

Generation of Coherent Broadband Photon Pulses with a Cascaded Longitudinal Space-Charge Amplifier

A. Marinelli,[1,*] E. Hemsing,[2] M. Dunning,[2] D. Xiang,[2] S. Weathersby,[2] F. O'Shea,[1] I. Gadjev,[1] C. Hast,[2] and J. B. Rosenzweig[1]

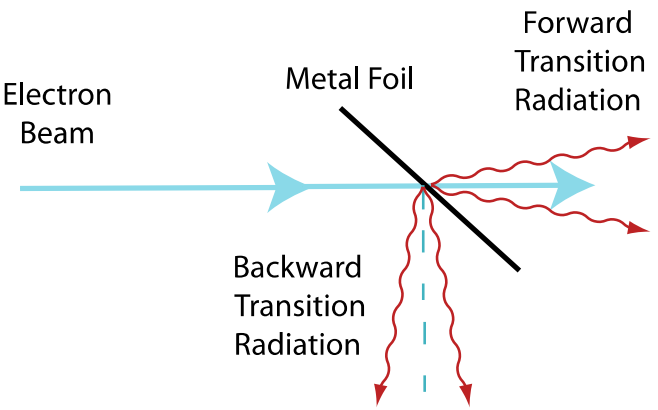
econstructing Microbunching Distribution

SLAC

$$\frac{dP}{d\omega d\Omega}|_{1-part} = \frac{e^2}{4\pi^2 c}\frac{sin^2(\theta)}{(1-\beta^2 cos(\theta))^2}$$

$$\frac{dP}{d\omega d\Omega}|_{coh} = \frac{dP}{d\omega d\Omega}|_{1-part}|B(k_x,k_y,k_z)|^2$$

$$B(k_x,k_y,k_z) = \frac{1}{N}\#_n\, e^{"ik_x x_n" ik_y y_n" ik_z z_n}$$

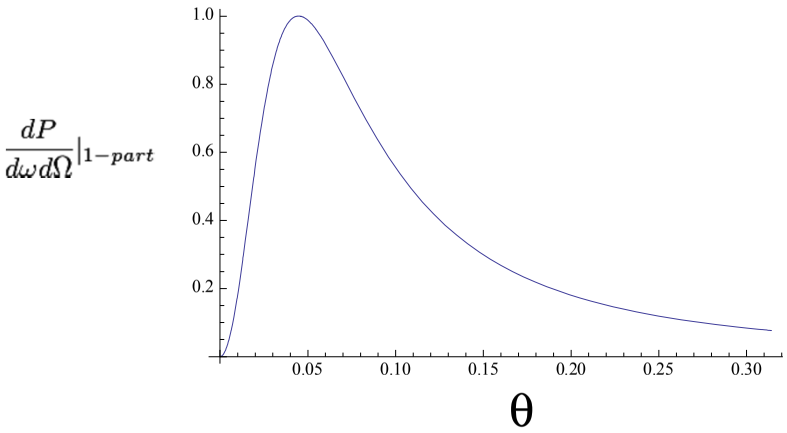


From a single-frequency far-field measurement we can recover $|B^2(k_x,k_y,k)|$

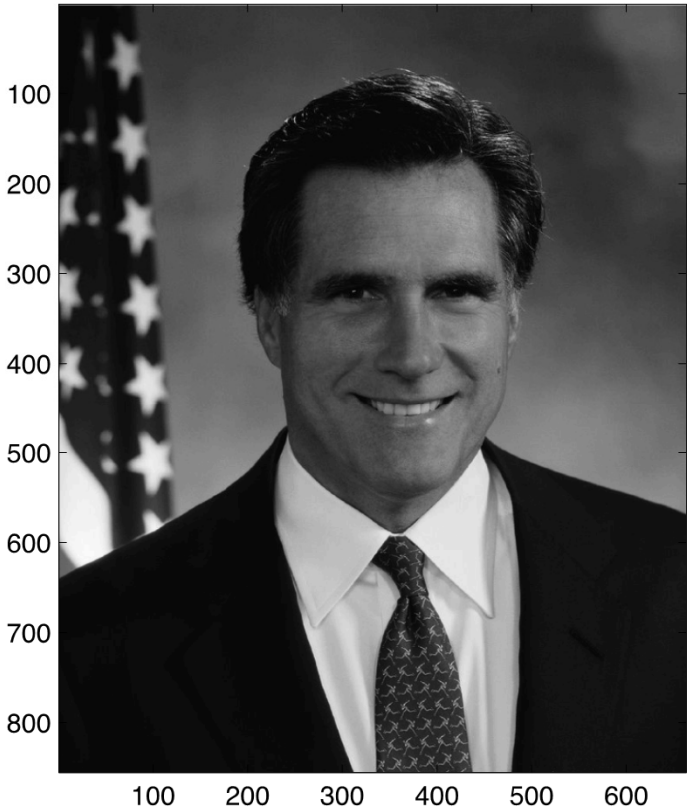
We are interested in

$$b(x,y,k) = \int e^{-ik_x x - ik_y y} B(k_x,k_y,k)\frac{dk_x dk_y}{(2\pi)^2}$$

Phase information on B is needed to recover the signal in x-y space!!



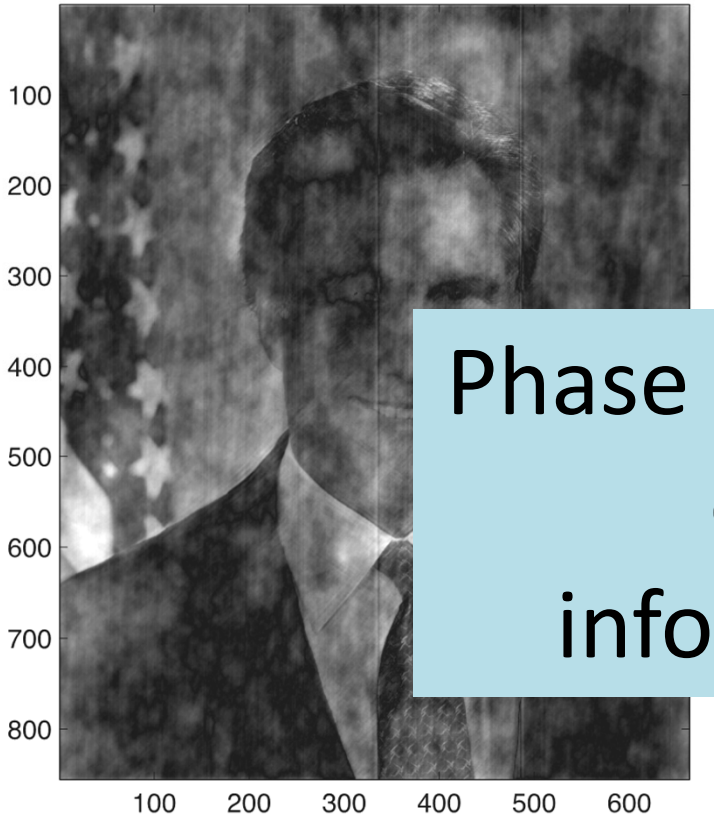
How Important is Knowledge of Phase?



$$IFFT(|Obama_K|e^{iArg(Obama_K)}) = Obama(X,Y)$$

$$IFFT(|Romney_K|e^{iArg(McRomney_K)}) = Romney(X,Y)$$

How Important is Knowledge of Phase?



Phase carries most of the information!!

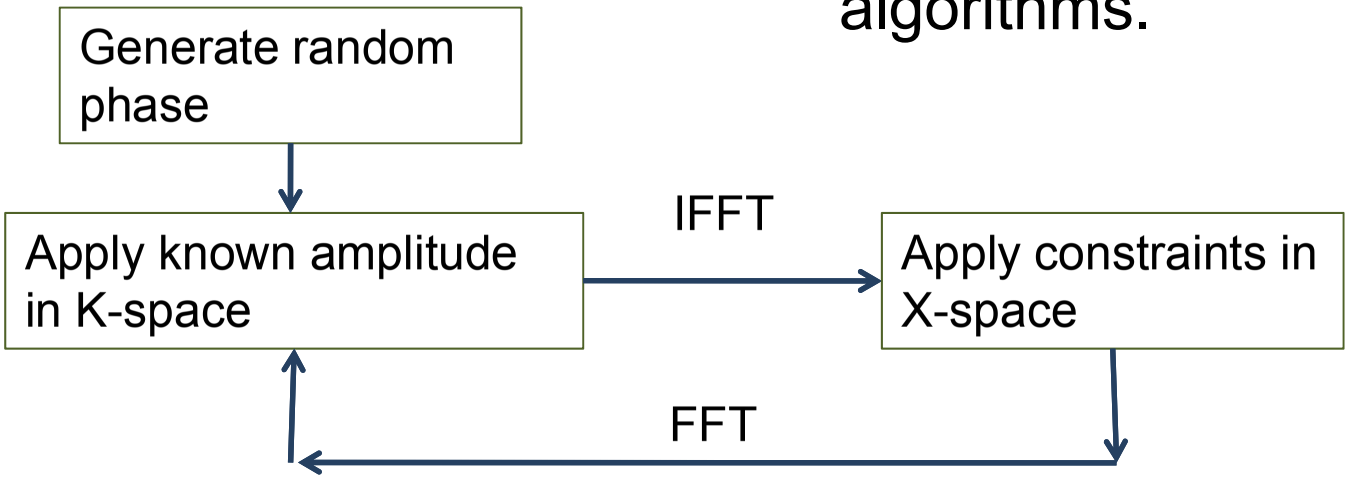
$$IFFT(|Obama_K|e^{iArg(Romney_K)}) \approx Romney(X,Y)$$

$$IFFT(|Romney_K|e^{iArg(Obama_K)}) \approx Obama(X,Y)$$

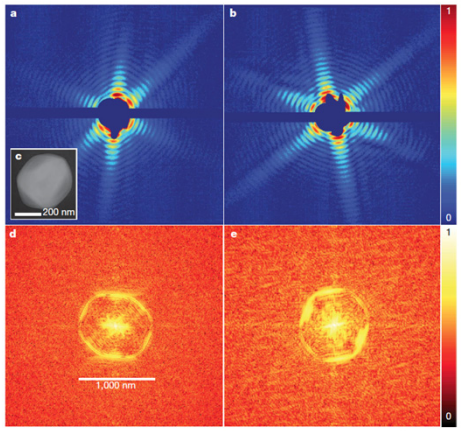
Phase Retrieval Algorithms

SLAC

Phase information can be recovered by means of iterative retrieval algorithms.

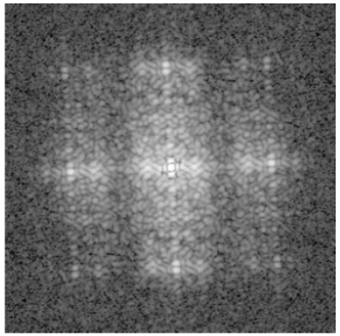


Typically:
-domain constraint
-positivity constraint

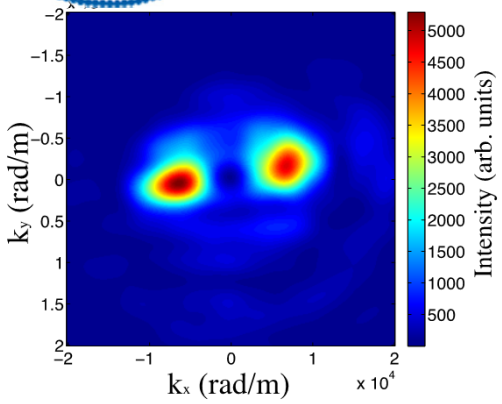


M. Marvin Seibert et al.
Nature ***470, 78–81 (03 February 2011)***
doi:10.1038/nature09748

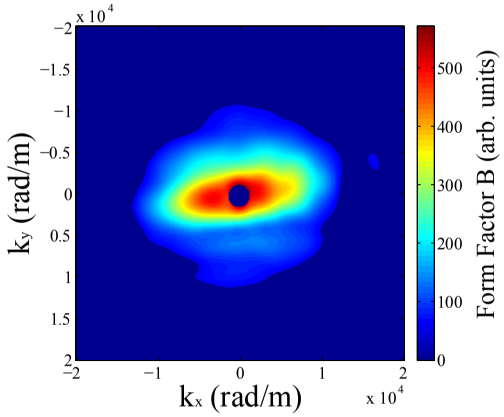
J. Miao et al. Nature ***400, 342-344 (22 July 1999)***



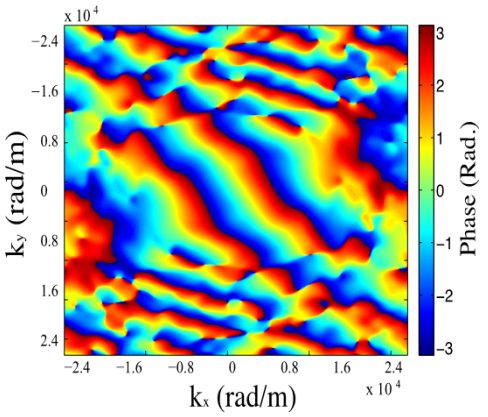
xperiment at 800nm (NLCTA)



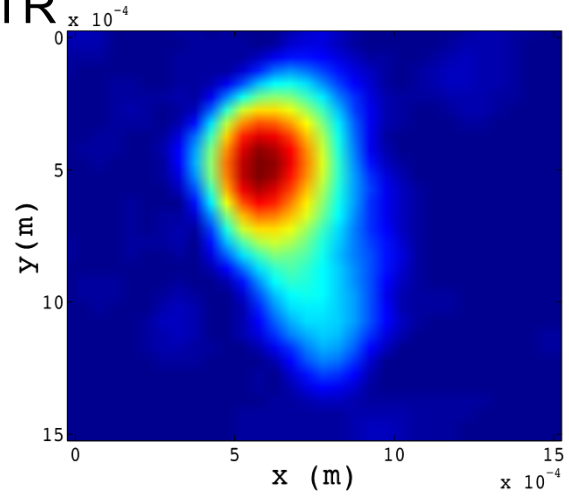
Far Field COTR



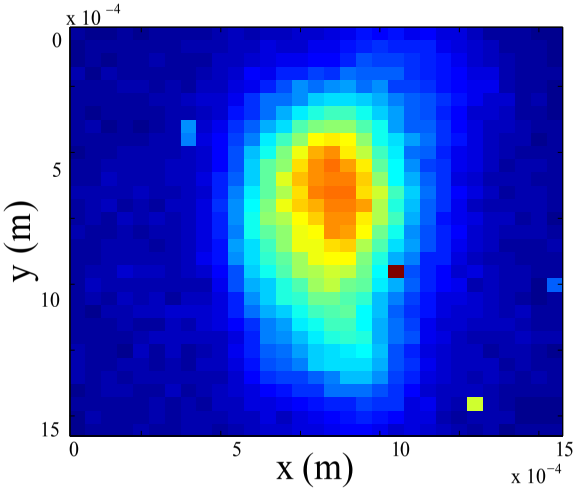
$|B(k_x,k_y)|$



Phase{$B(k_x,k_y)$}

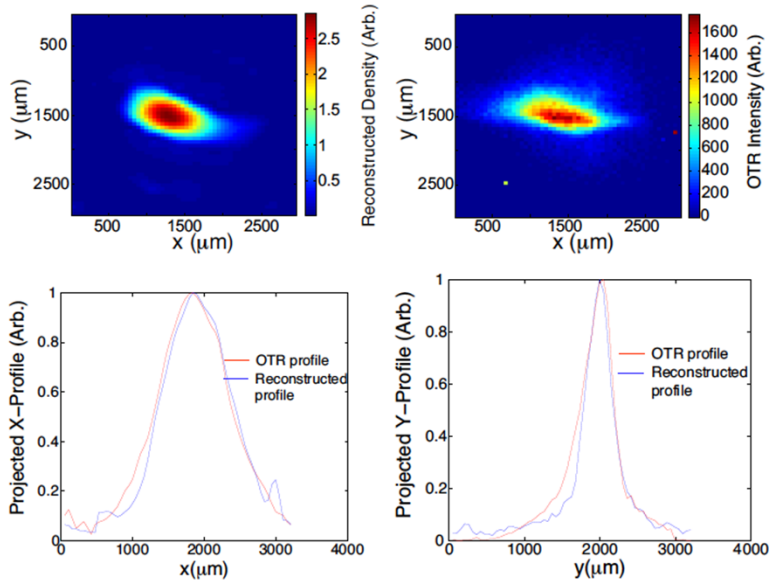


Reconstructed Microbunching



Near Field Incoherent OTR

Experiment at 800nm



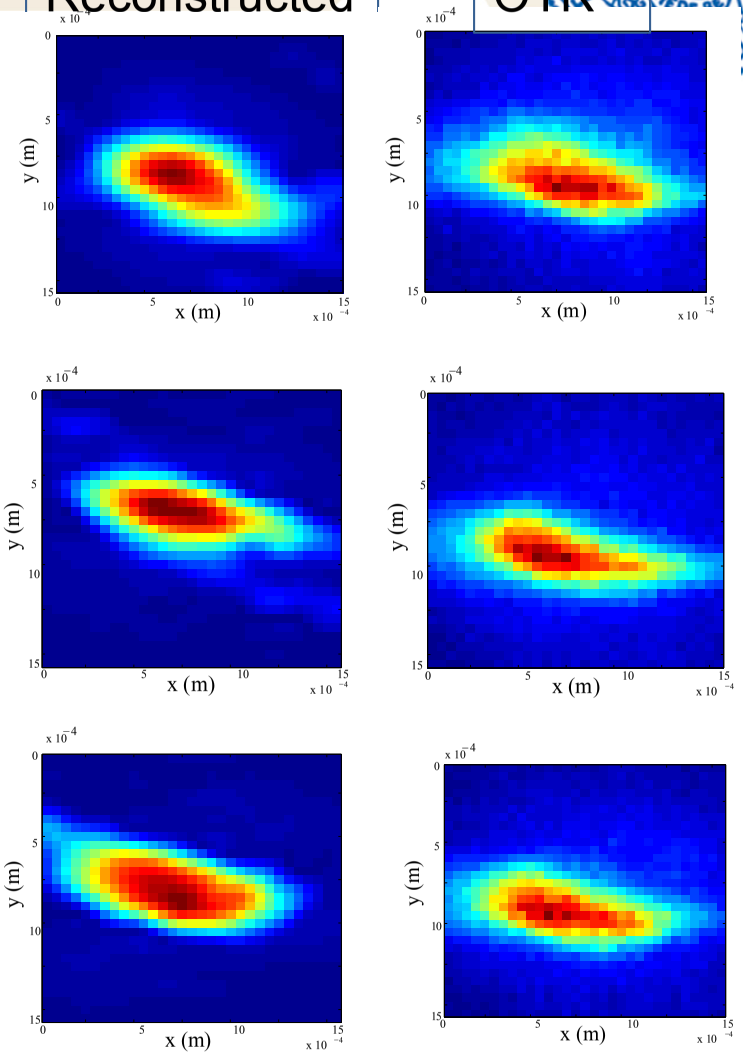
$$\sigma_{x,rec} \simeq (334 \pm 48)\mu m$$
$$\sigma_{x,OTR} \simeq (343 \pm 33)\mu m$$
$$\sigma_{y,rec} \simeq (172 \pm 52)\mu m$$
$$\sigma_{y,OTR} \simeq (167 \pm 49)\mu m$$

PRL 110, 094802 (2013) PHYSICAL REVIEW LETTERS week ending 1 MARCH 2013

Single-Shot Coherent Diffraction Imaging of Microbunched Relativistic Electron Beams for Free-Electron Laser Applications

A. Marinelli,[1] M. Dunning,[2] S. Weathersby,[2] E. Hemsing,[2] D. Xiang,[2] G. Andonian,[1] F. O'Shea,[1] Jianwei Miao,[1] C. Hast,[2] and J. B. Rosenzweig[1]

Reconstructed OTR



Conclusions

The theory of the microbunching instability has been addressed in the context of the kinetic theory of plasmas.

The generation of single-spike broadband radiation with a longitudinal space-charge amplifier was demonstrated.

Microbunching distribution can be reconstructed by means of coherent diffraction imaging methods.