Study of Collective Interaction Control over e-beam Current Noise

T. Shaftan on behalf of A. Gover, A. Nause, E. Dyunin
Tel-Aviv University

April 3rd, 2009

Outlook

- Introduction
- Collective effects observed in modern FELs
- Concept of noise reduction in e-beam
- Proof-of-principle experiment at ATF
- Conclusions

Introduction

New Concepts:

- **Is it possible to reduce the beam current noise below the shot-noise level?**
- **Is it possible to enhance the coherence of X-UV FELs by reducing the input noise?**
- **What are the fundamental limits of FEL coherence?**
- **Notes:**
- In the art of microwave tubes, schemes for low-noise e-beam tube amplifiers were developed.
- Electron beam noise dynamics in the optical regime was observed in SLAC and DESY as COTR effects.

Electron beam fragmentation

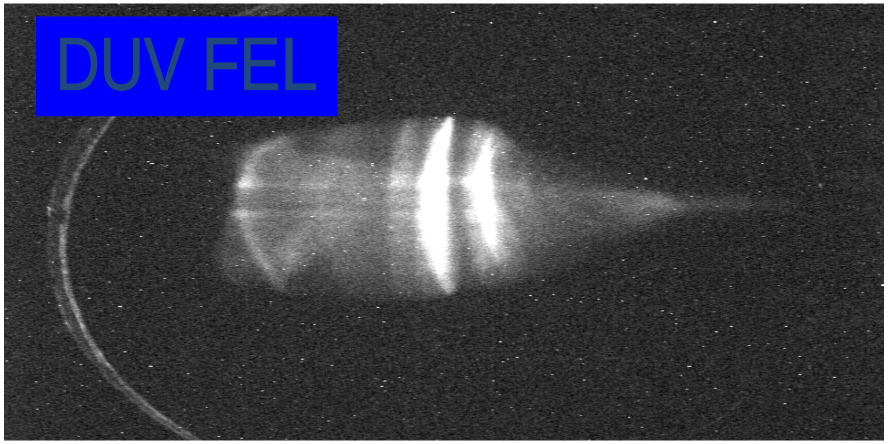
- "Zero-phasing" images from the spectrometer dipole revealed spiky structure with sub-picosecond period in the chirped beam energy spectrum

- Assuming that chirped bunch energy spectrum represents longitudinal density distribution → spikes could be treated as a spikes in the longitudinal bunch density (peak current)

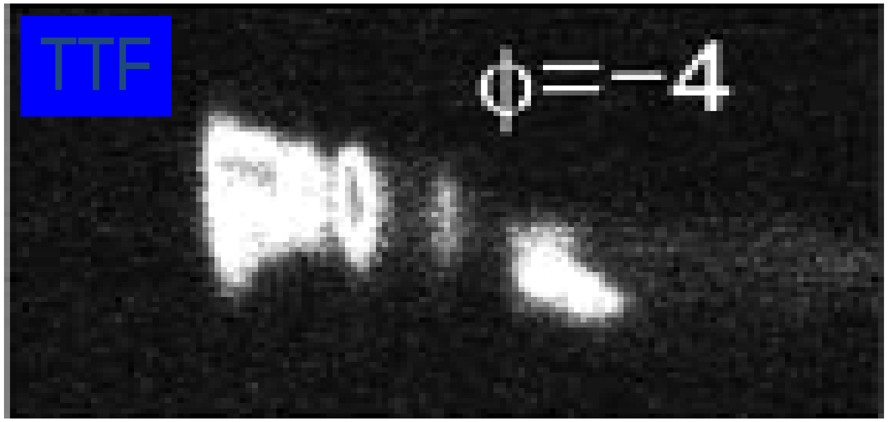
- Calculating FEL slippage length for lasing at 266 nm as 70 um , follows that the spike width is comparable or less than slippage length → must cause degradation of FEL performance

- Similar effect has been observed at TTF

W.S. Graves, et al., PAC 2001, p. 2860



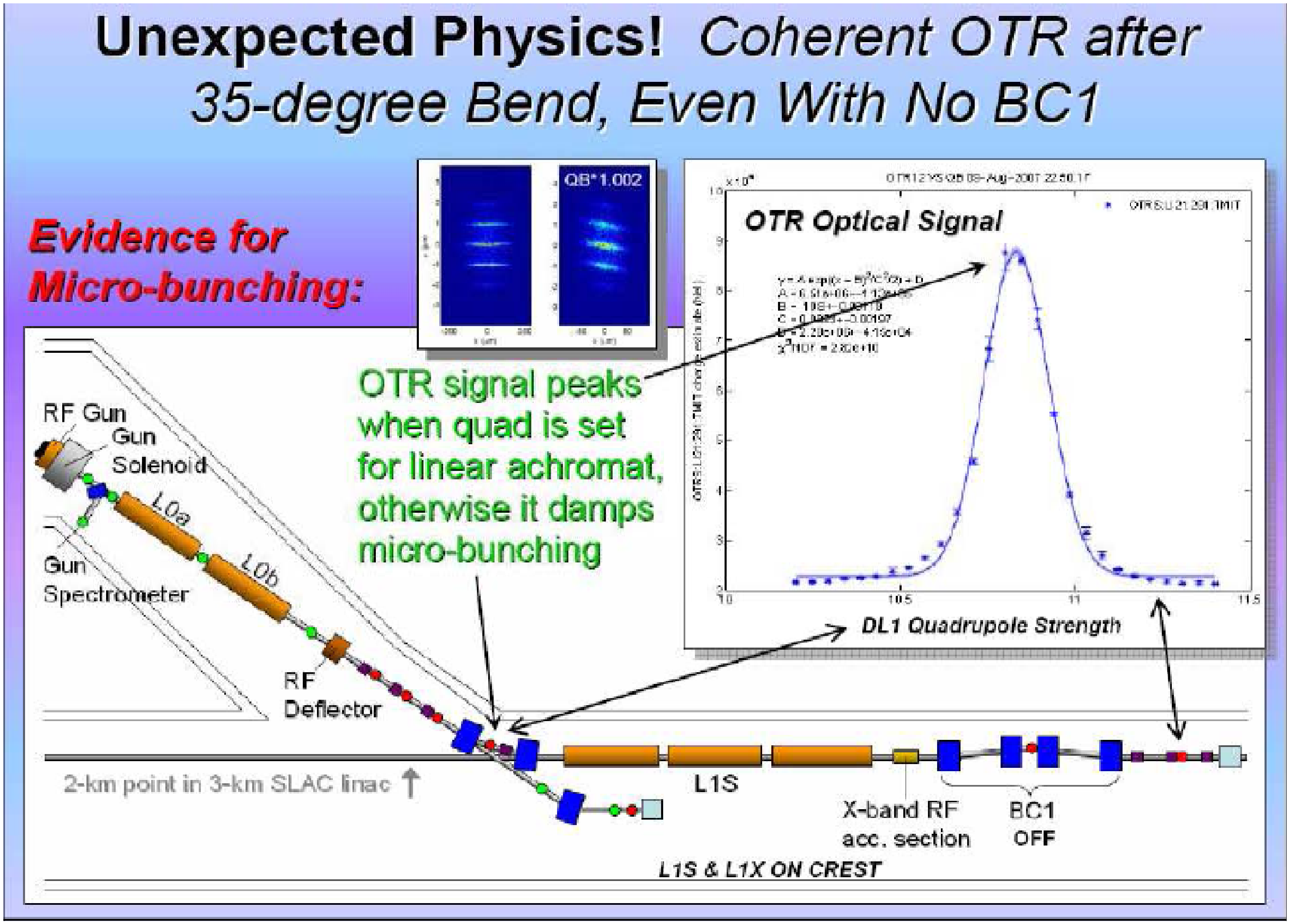
M. Huning et al., NIM A 475 (2001) p. 348



T. Shaftan and Z. Huang, Experimental characterization of a space charge induced modulation in high-brightness electron beam, PRST AB 7, 080702 (2004)

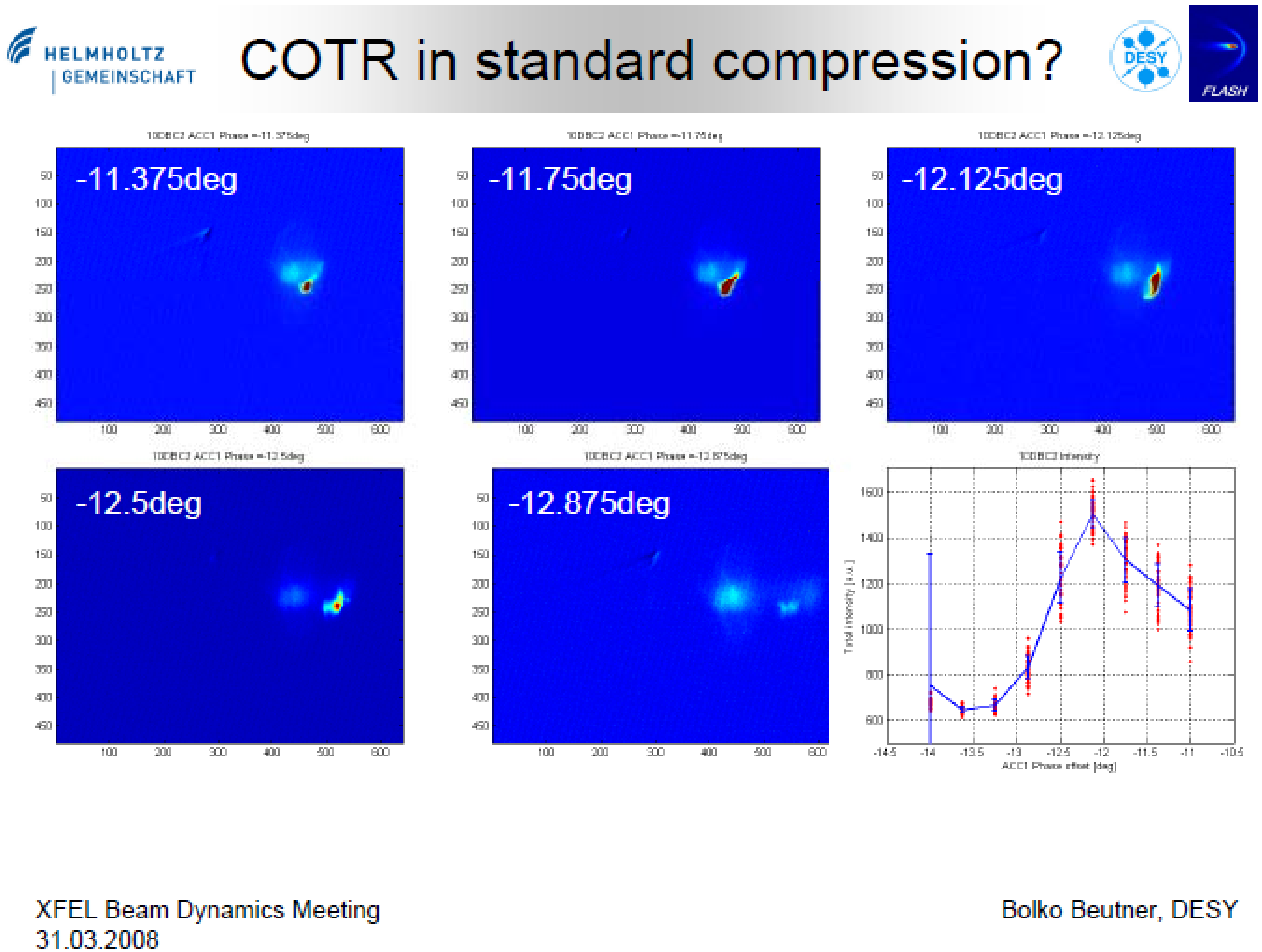
Coherent Optical Transition Radiation in LCLS/SLAC

D. Dowell, FEL Frontiers conference (Italy, Sept. 9-13, 2007)
R. Akre et al, Phys. Rev. ST-AB, 11, 030703 (2008)

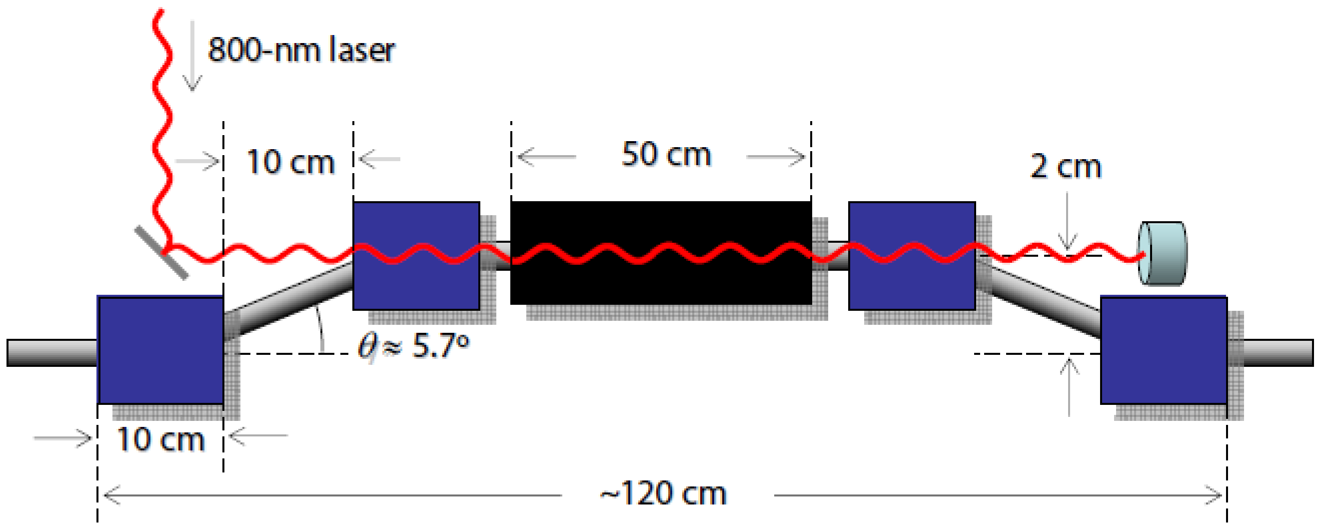


Coherent Optical Transition Radiation at FLASH (DESY)

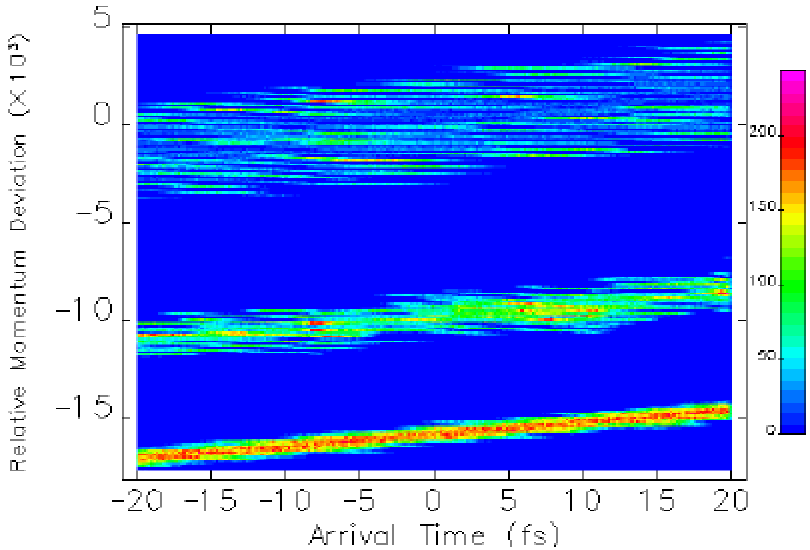
B. Beutner, XFEL Beam Dynamics Meeting, 2008



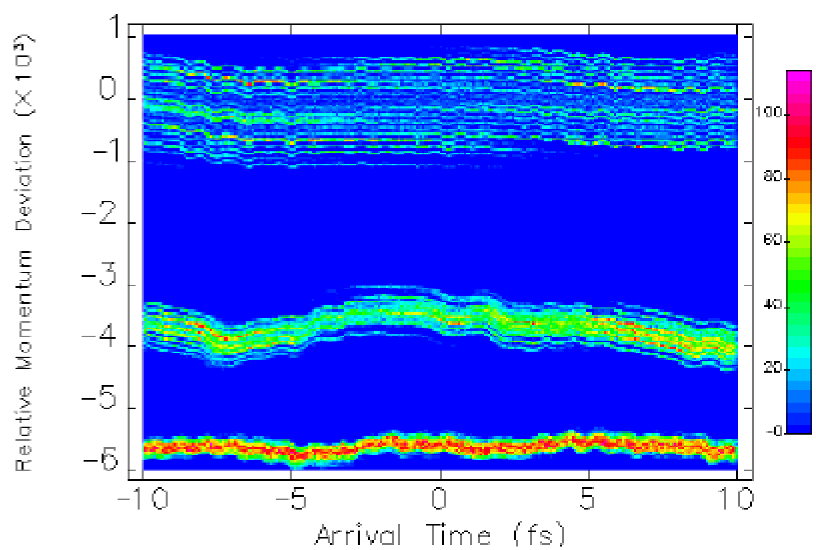
Laser-Heater at LCLS



Layout of the LCLS laser heater inside a magnetic chicane at 135 MeV



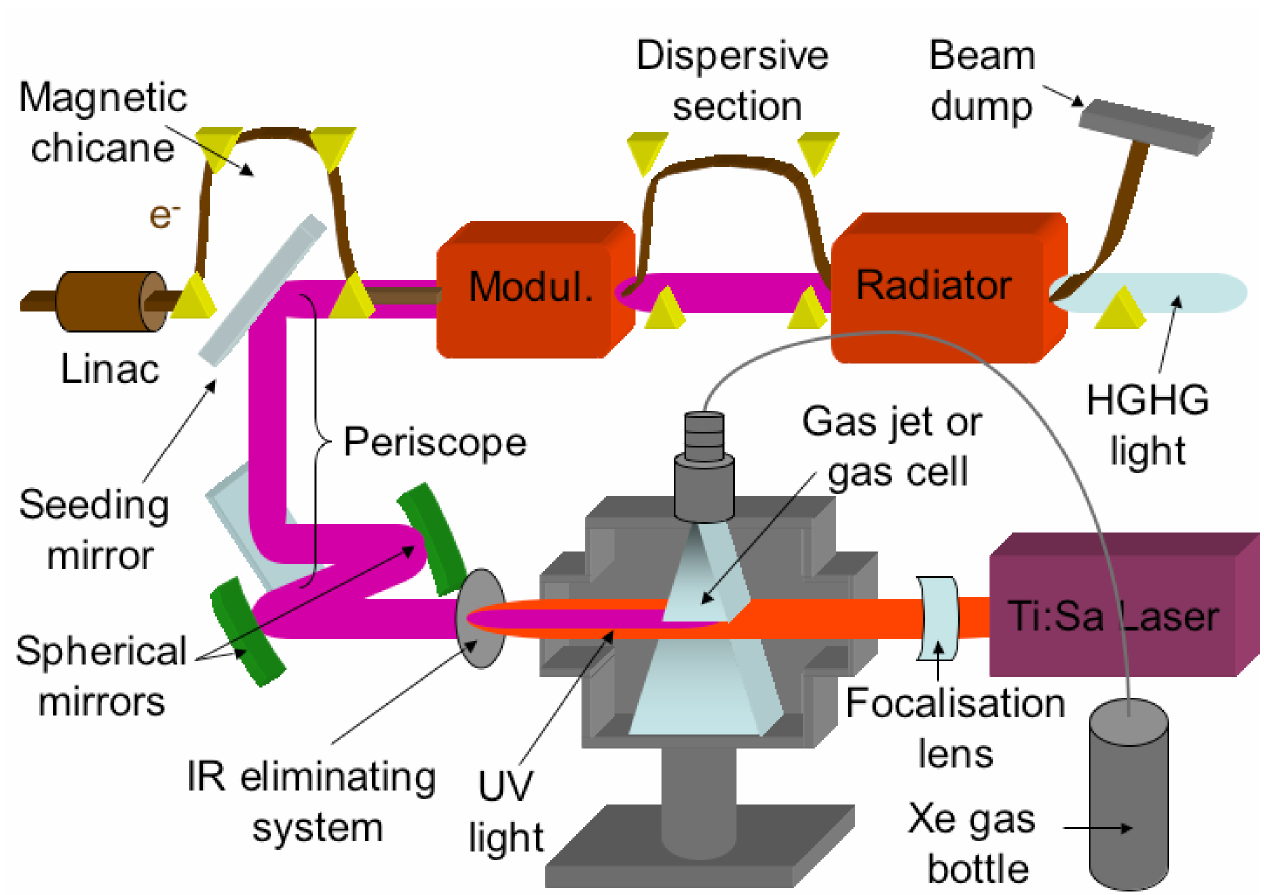
(a)End of BC2 at 4.5 GeV



(b)Undulator entrance at 14 GeV

Seeding the FEL of SCSS With the 13TH Laser Harmonic of a Ti: Sa Laser Produced in Xe Gas

G. Lambert, T. Shintake, SPring-8/RIKEN



Concept

Coherent Plasma Oscillation in a Drift Section

Current and Density oscillations along a drift section

$$\tilde{I}(L_d,\omega)=\left[\tilde{I}(0,\omega)\cos\phi_p - i\tilde{V}(0,\omega)\left(\sin\phi_p / W_d\right)\right]e^{i\phi_b(L_d)}$$

$$\tilde{V}(L_d,\omega)=\left[-i\tilde{I}(0,\omega)W_d\sin\phi_p + \tilde{V}(0,\omega)\cos\phi_p\right]e^{i\phi_b(L_d)}$$

$$\tilde{V}(z,\omega)=-\left(mc^2/e\right)\tilde{\gamma}(z,\omega)=-\left(mc^2/e\right)\gamma_0^3 v_0\tilde{v}(\omega)$$

(Chu's Relativistic Kinetic Voltage)

$$\phi_b=\frac{\omega}{v_0}L_d \qquad \phi_p=\theta_{pr}L_d \qquad \theta_{pr}=r_p\frac{\omega_p'}{v_0}$$

$$\omega_p'=\left(\frac{e^2 n_0}{m\varepsilon_0\gamma_0^3}\right)^{1/2}$$

W_d -- beam oscillation impedance

Quarter Period Plasma Oscillation in a Drift Section

$$\underline{For \quad L_d = \pi/2\theta_{prd}:}$$

$$\underline{\underline{M}} = \begin{pmatrix} 0 & -i/W_d \\ -iW_d & 0 \end{pmatrix} e^{i\phi_b}$$

$$\tilde{I}(L_d) = -ie^{i\phi_b}\tilde{V}(0)/W_d$$

$$\tilde{V}(L_d) = -ie^{i\phi_b}\tilde{I}(0)W_d$$

$$\underline{If \quad \tilde{V}(0) = 0,}$$

$$then: \quad \tilde{I}(L_d) = 0$$

$$\tilde{V}(L_d) = -ie^{i\phi_b}W_d\tilde{i}(0)$$

Random Signal Spectral Domain

$$\breve{I}(\omega) = \int_{-T/2}^{T/2} I(t) e^{i\omega t} dt$$

$$\breve{v}_z(\omega) = \int_{-T/2}^{T/2} v_z(t) e^{i\omega t} dt$$

$$\breve{V}(\omega) = -\left(mc^2/e\right)\gamma_0^3 v_0 \breve{v}_z(\omega)$$

Current Noise Transformation in a Drift Section

If $\overline{\mathrm{Im}\left(\breve{I}(0)\breve{V}^*(0)\right)} = 0:$

$$\overline{\left|\breve{I}(z,\omega)\right|^2} = \overline{\left|\breve{I}(0,\omega)\right|^2}\cos^2\phi_p + \frac{1}{W_d^2}\left|\breve{V}(0)\right|^2\sin^2\phi_p$$

$$\overline{\left|\breve{V}(z,\omega)\right|^2} = W_d^2\overline{\left|\breve{I}(0,\omega)\right|^2}\sin^2\phi_p + \left|\breve{V}(0)\right|^2\cos^2\phi_p$$

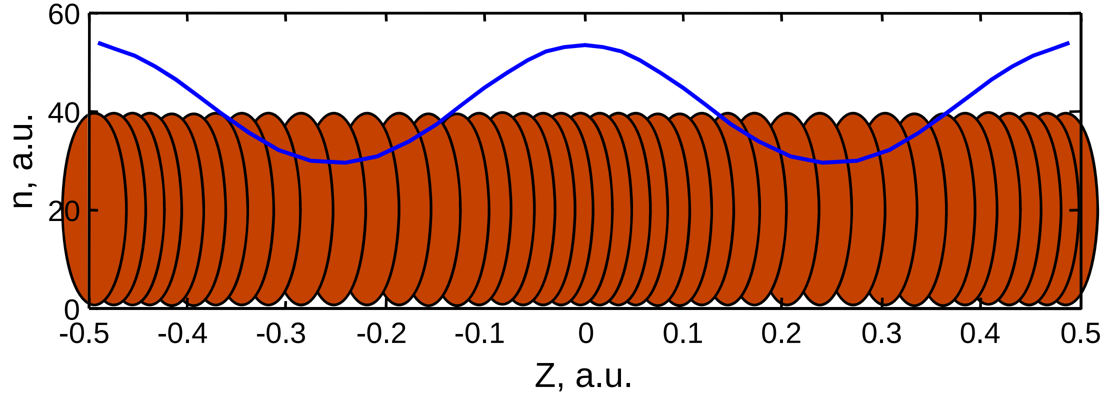
At $\phi_p = \theta_p L_d = \pi/2:$

$$\overline{\left|\breve{I}(L_d,\omega)\right|^2} = \overline{\left|\breve{V}(0,\omega)\right|^2}/W_d^2$$

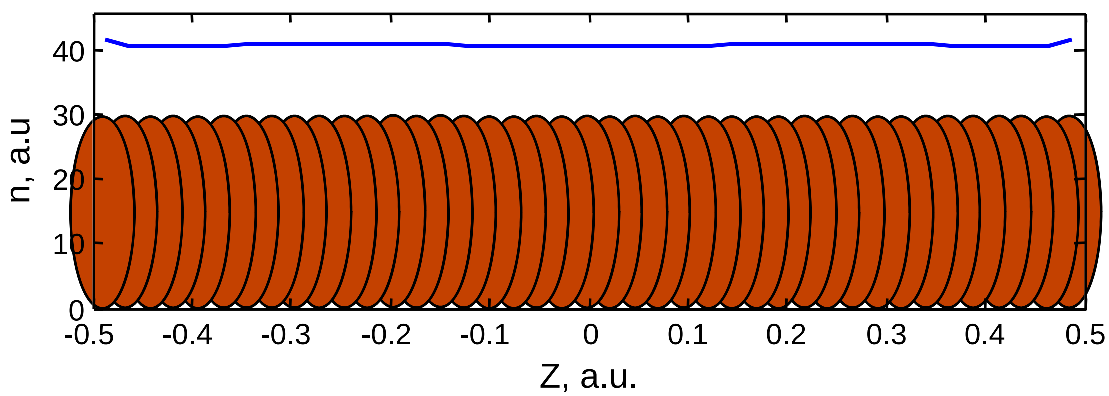
$$\overline{\left|\breve{V}(L_d,\omega)\right|^2} = \overline{\left|\breve{I}(0,\omega)\right|^2}/W_d^2$$

Dynamics of Beam Plasma Longitudinal Oscillation in a Drift Region (Moving Frame)

$t = 0$

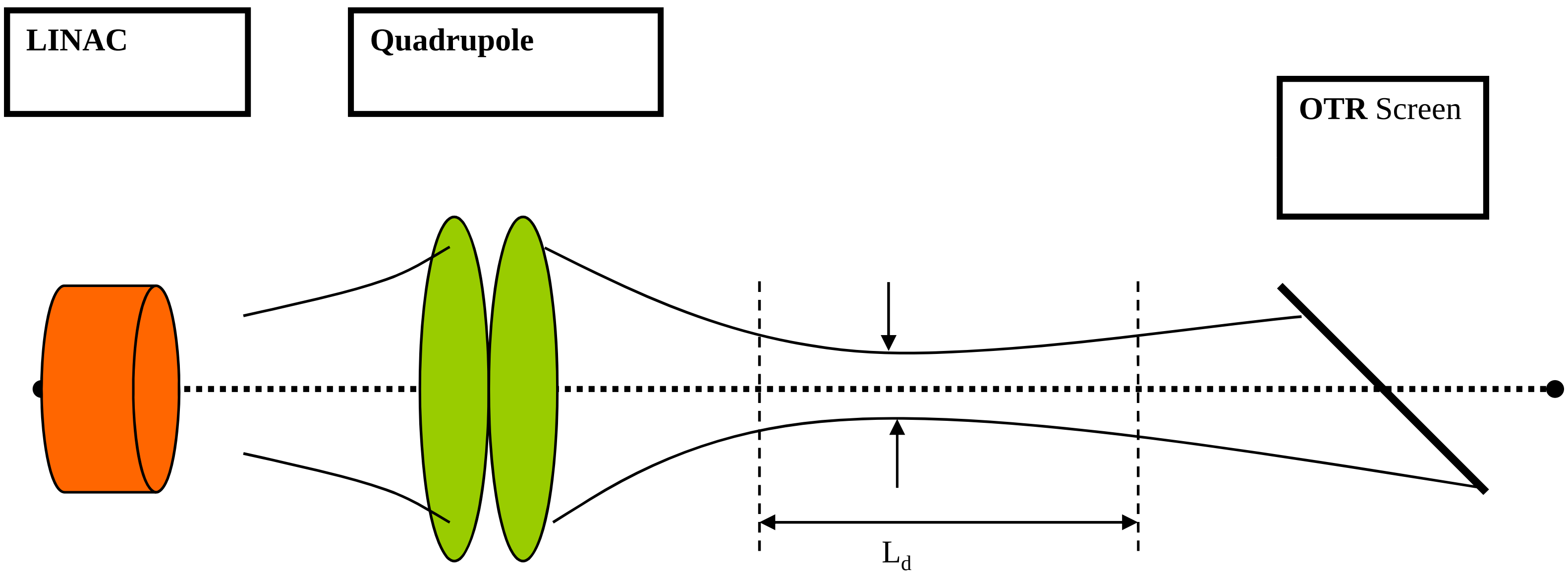


$t = \pi/2\omega_{pr}$



Experiment at ATF

Collective Interaction Drift Section as the Waist of a Free Propagation Beam

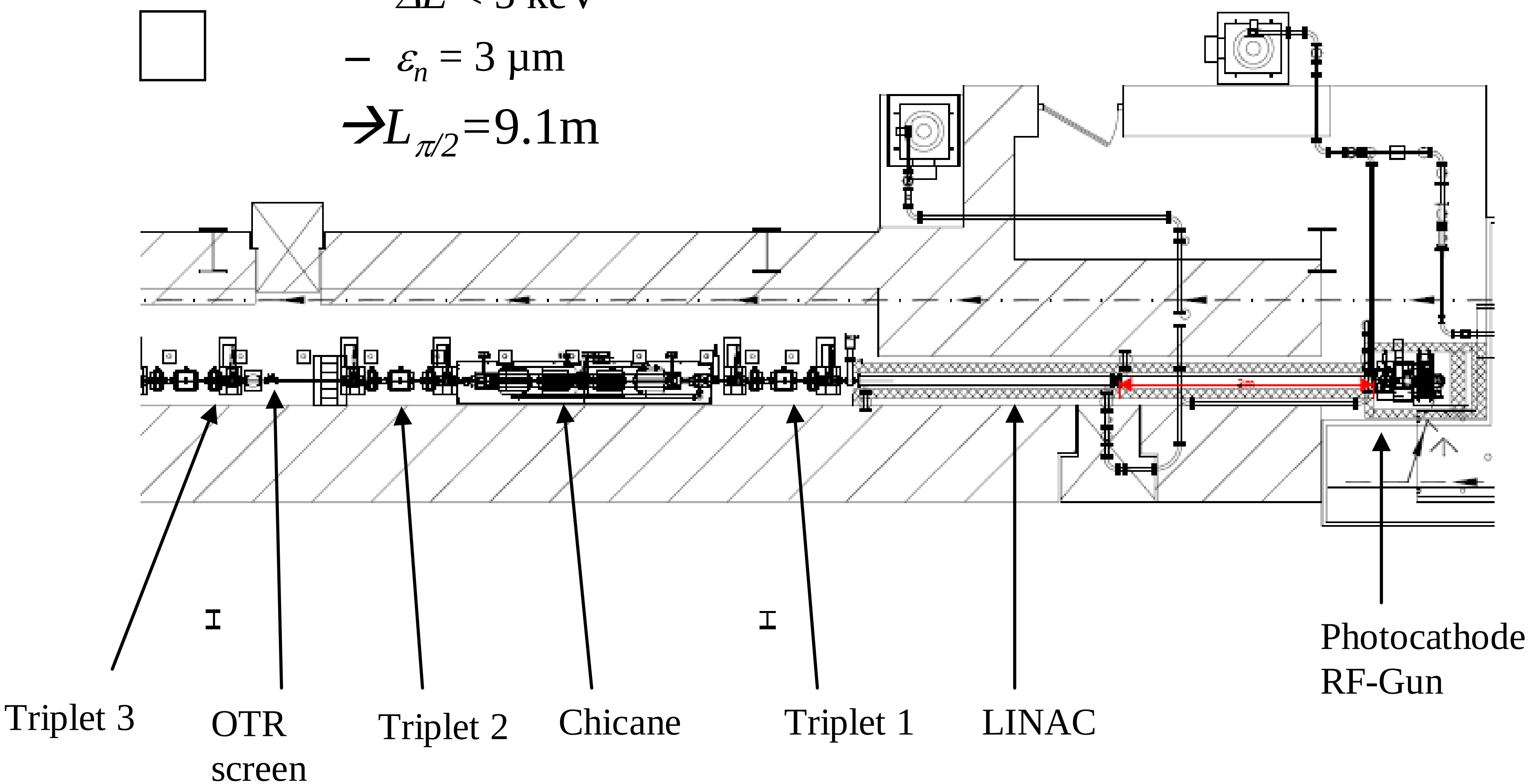


Experimental layout

- Beam parameters:
  - E_0=70 MeV
  - I_0=300 A
  - ΔE < 5 keV
  - ε_n = 3 µm

  → $L_{\pi/2}$=9.1m

- Observation at visible…IR wavelength range



Experimental Plan: 1st Year

- Equipment test, training and trial-operating of the accelerator.
- Learn to control the accelerated beam convergence using the quadrupole settings
- Characterize the beam parameters with existing diagnostic means.
- Collecting data of OTR images and OTR power measurements at OTR screen positions before the bend and along the beam line.

Experimental Plan: 2nd Year

- Studies of OTR current shot noise intensity at different beam focusing parameters. Taking data on the effects of dispersion by operating the chicane at varying parameters.
- Measurement of OTR intensity in an OTR screen positioned after the bend. These measurements will provide information on beam energy-noise by consideration of the parameter of the bend.

Conclusions

- Experimental evidence of strong collective effects in modern high-brightness machines
- Progress in understanding of physics behind these effects
- Search for cure against them
- Presented is new concept on manipulating electron beam phase space and suppressing microbunching
- Experiment at ATF will
  - Advance understanding of physics
  - Prove efficiency of new concept