Beam Dynamics

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DOE High Energy Physics Review
June 2-4, 2004

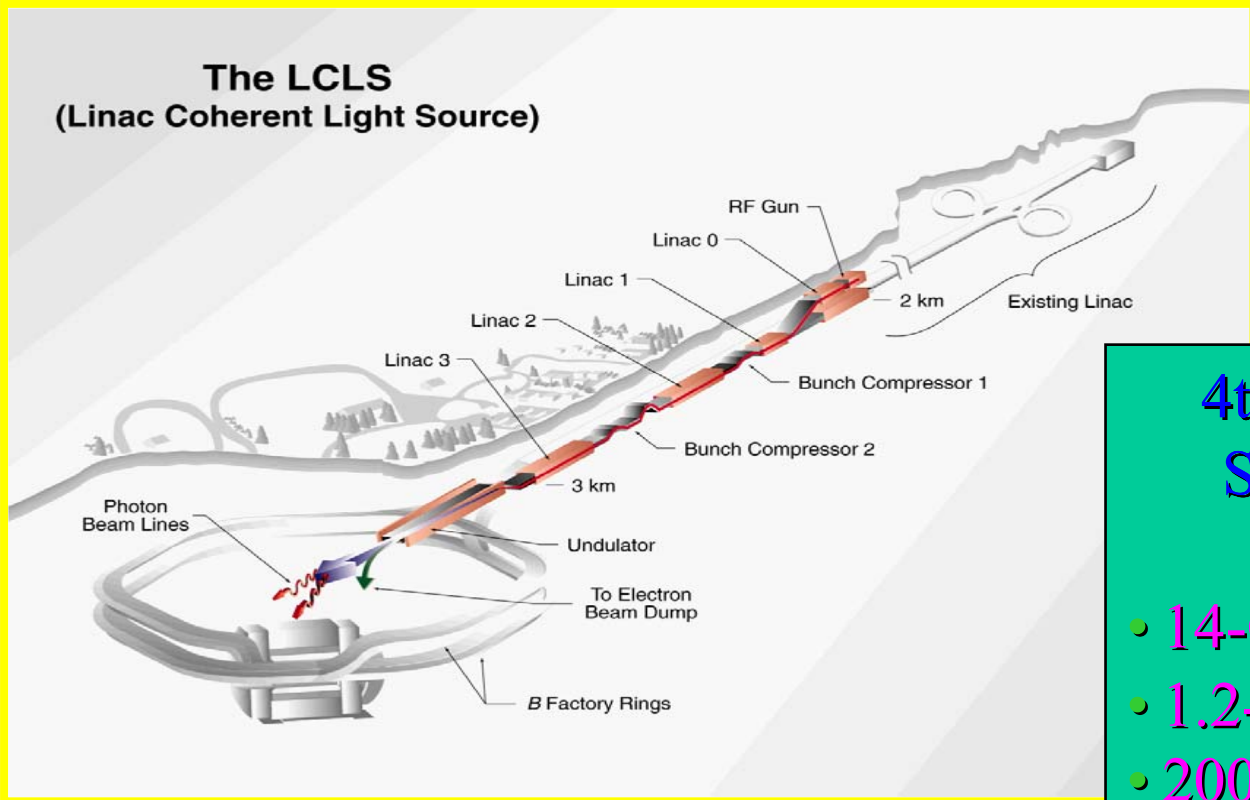
Beam Dynamics Research in ARDA

- Broad expertise in many areas: lattice design, collective effects, electron cloud, beam-beam interaction, FEL physics.
- Support of all major projects in the lab: PEP-II, NLC, LCLS.
- Application of accelerator physics to other areas of research, e.g., weak gravitational lensing in astrophysics.

Outline

- Generation of short X-ray pulses in LCLS
- Laser heater for LCLS
- Dark currents in NLC structures
- Model Independent Analysis (MIA) of PEP-II
- Simulation of beam-beam interaction for PEP-II
- Electron cloud effects in LER
- Higher moments gravitation lensing

Linac Coherent Light Source (*LCLS*)



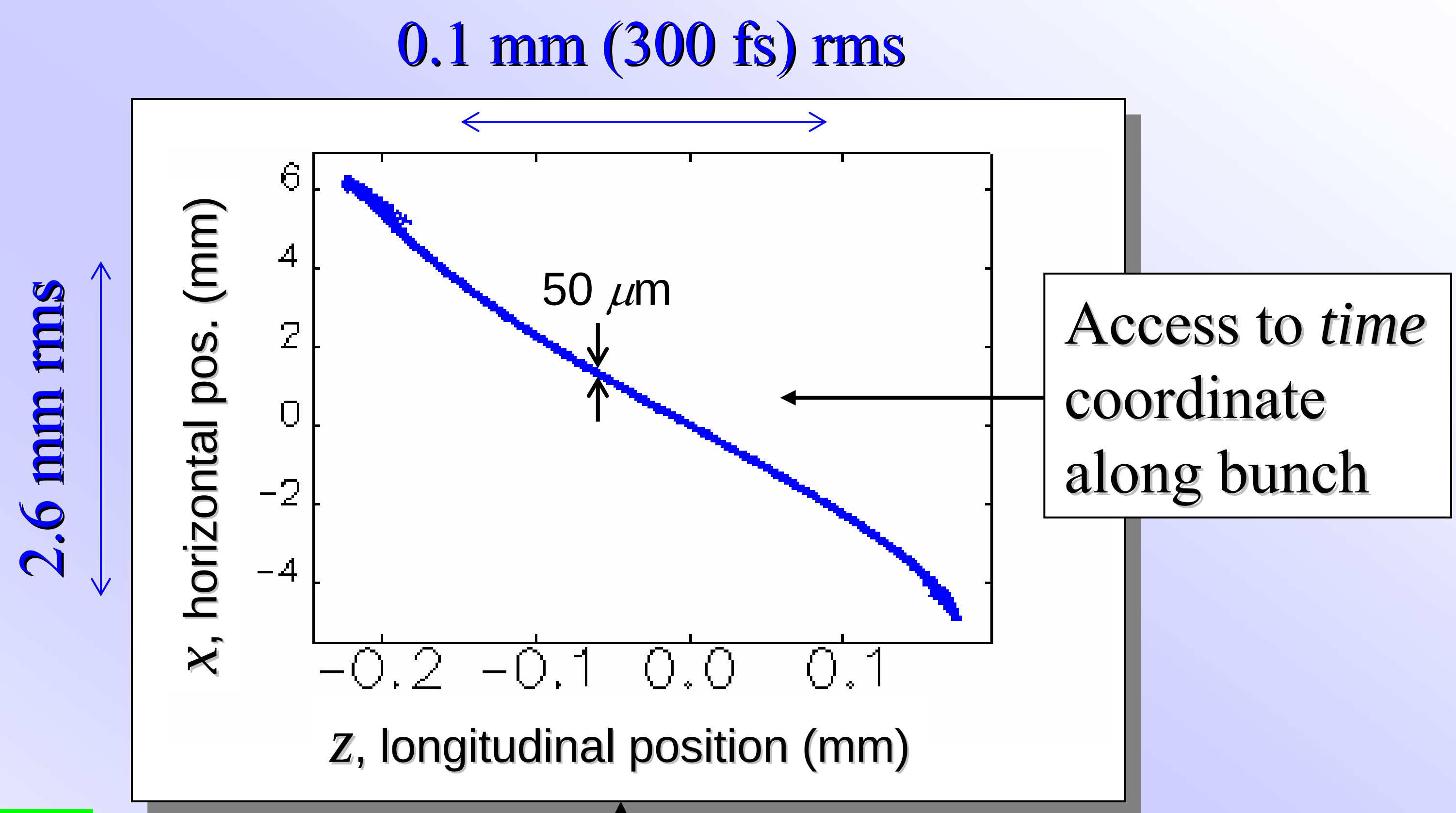
4th-Generation *X*-ray SASE FEL Based on *SLAC* Linac

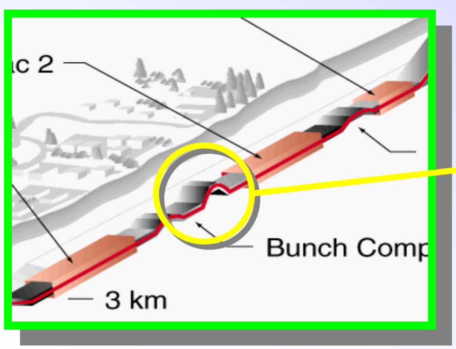
- 14-GeV electrons
- 1.2-μm emittance
- 200-fsec FWHM pulse
- 2×10^{33} peak brightness

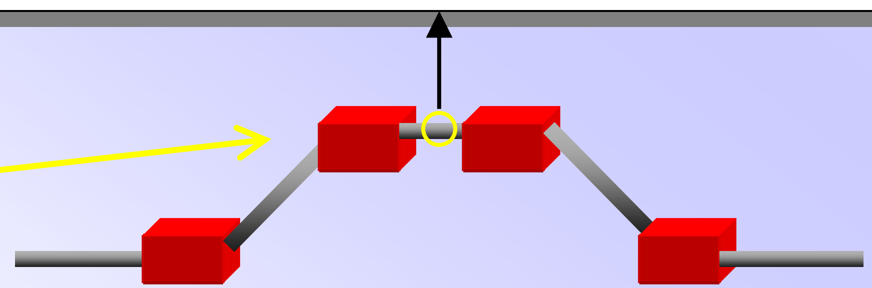
There is a strong interest from potential users in shorter pulses of X-rays.

P. Emma, M. Cornacchia, K. Bane, Z. Huang, H. Schlarb (DESY), G. Stupakov, D. Walz, ***PRL, vol. 92, 2004.***

Exploit *Position-Time* Correlation on e^- bunch at Chicane Center

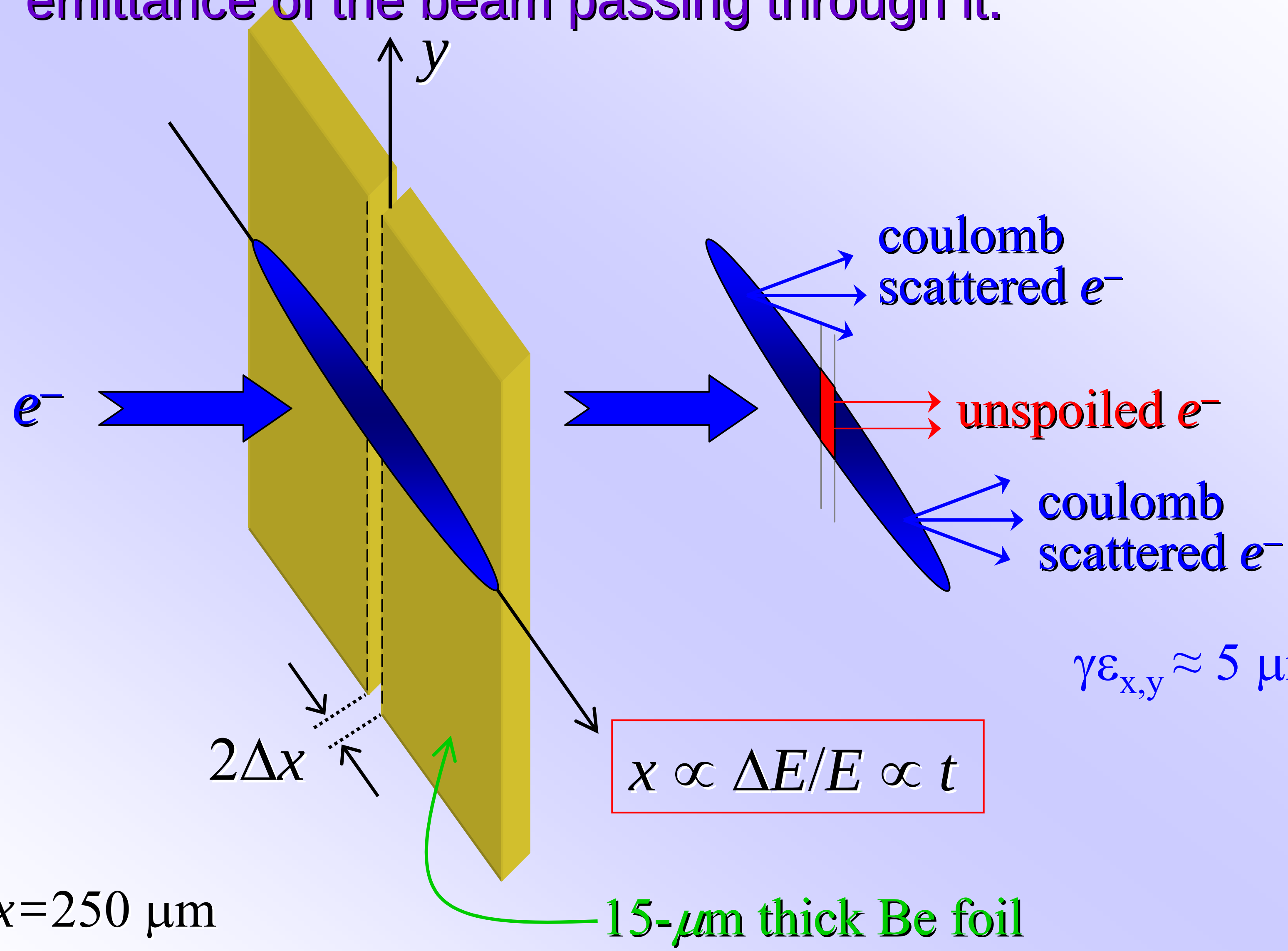






LCLS BC2 bunch compressor chicane
(similar in other machines)

Add thin slotted foil in center of chicane. The foil "spoils" emittance of the beam passing through it.



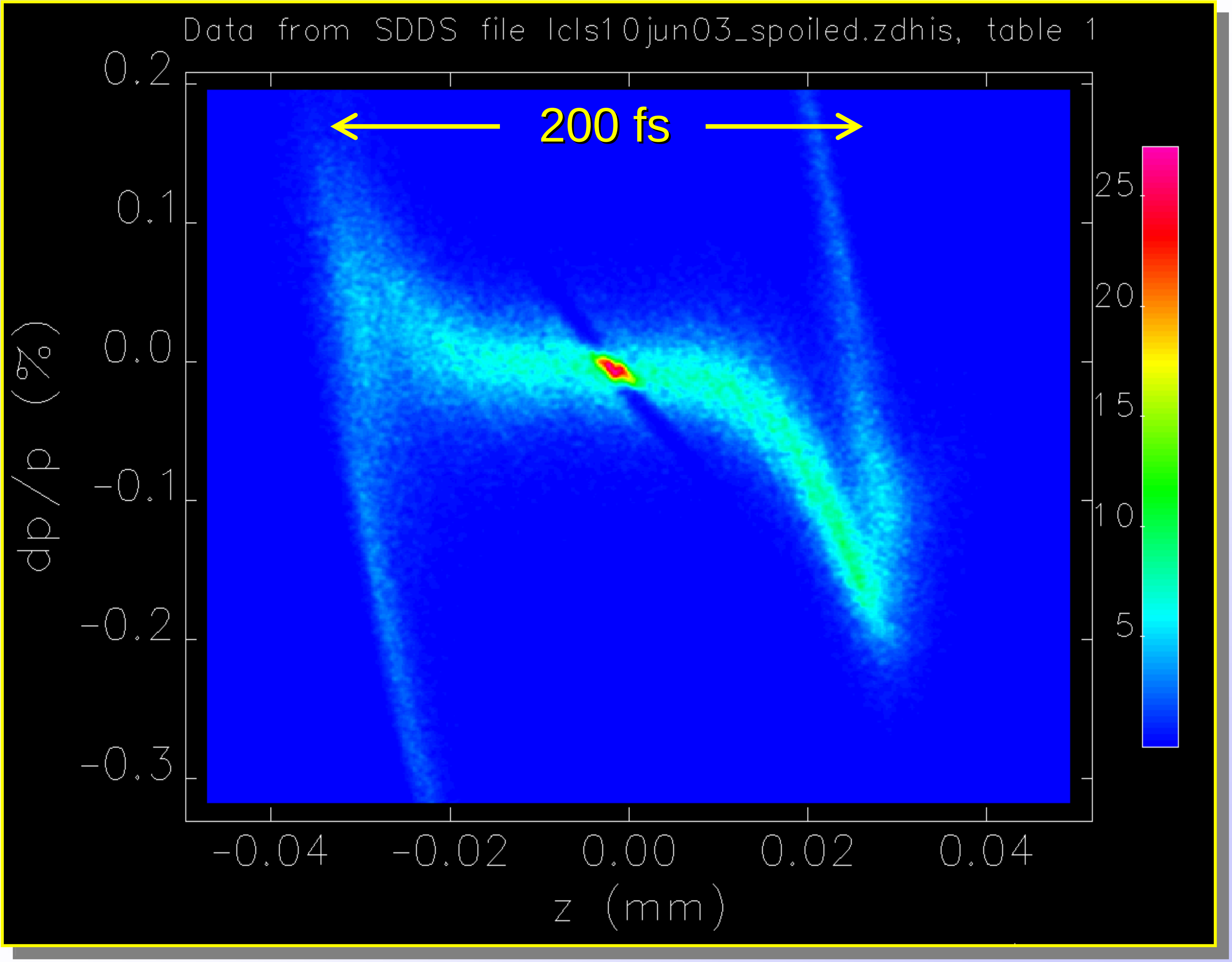
$\gamma\varepsilon_{x,y} \approx 5\ \mu m$

$x \propto \Delta E/E \propto t$

$2\Delta x = 250\ \mu m$

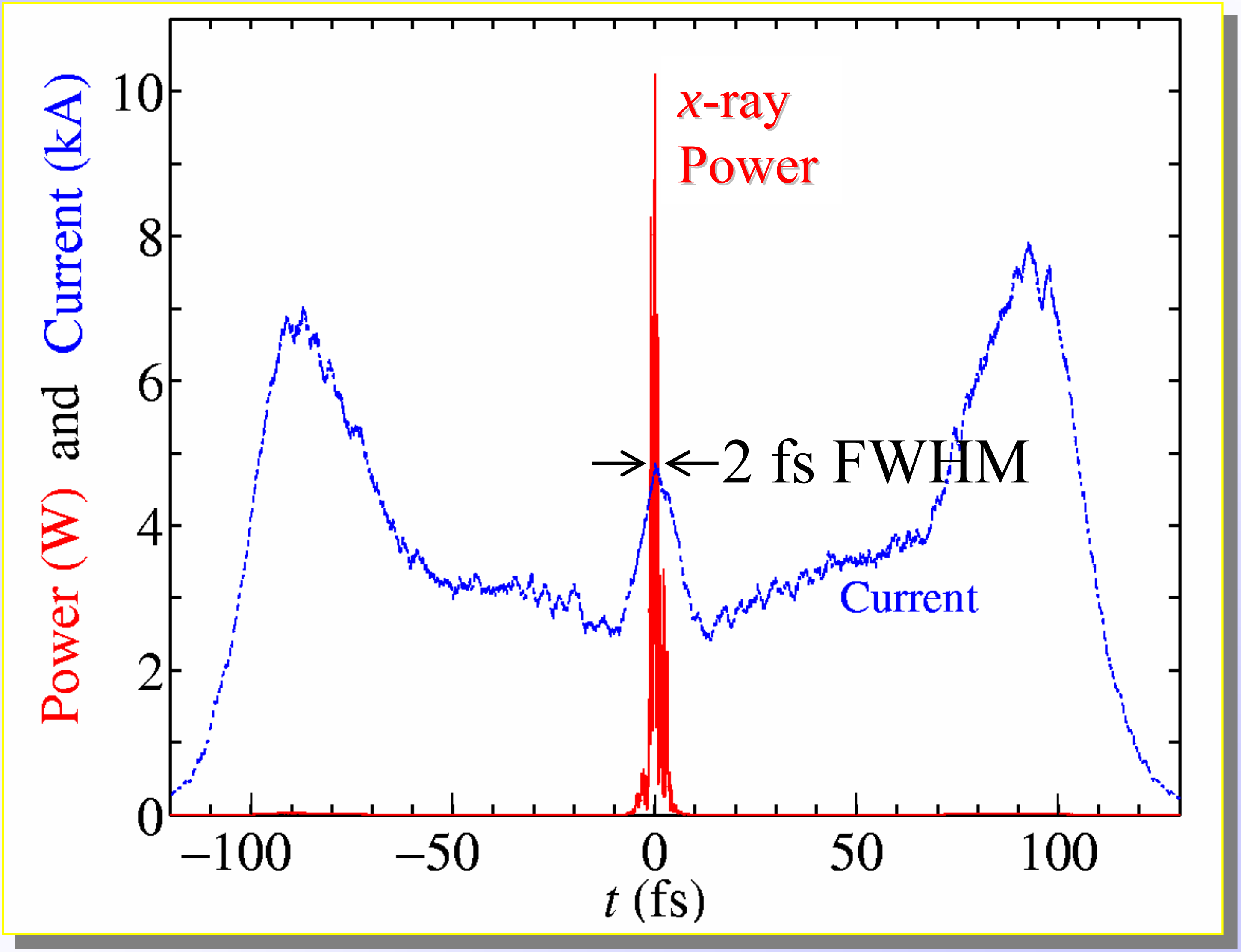
Track 200k macro-particles through entire *LCLS* up to 14.3 GeV

$\Delta E/E$



Genesis 1.3 FEL code

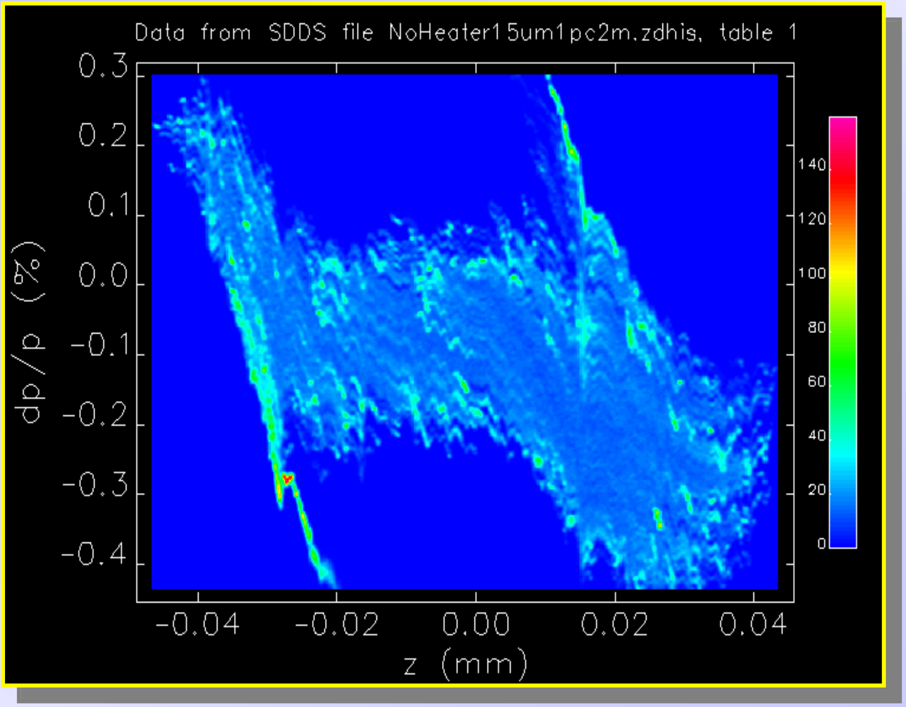
$z \approx 60$ m



Micro-Bunching Instabilities

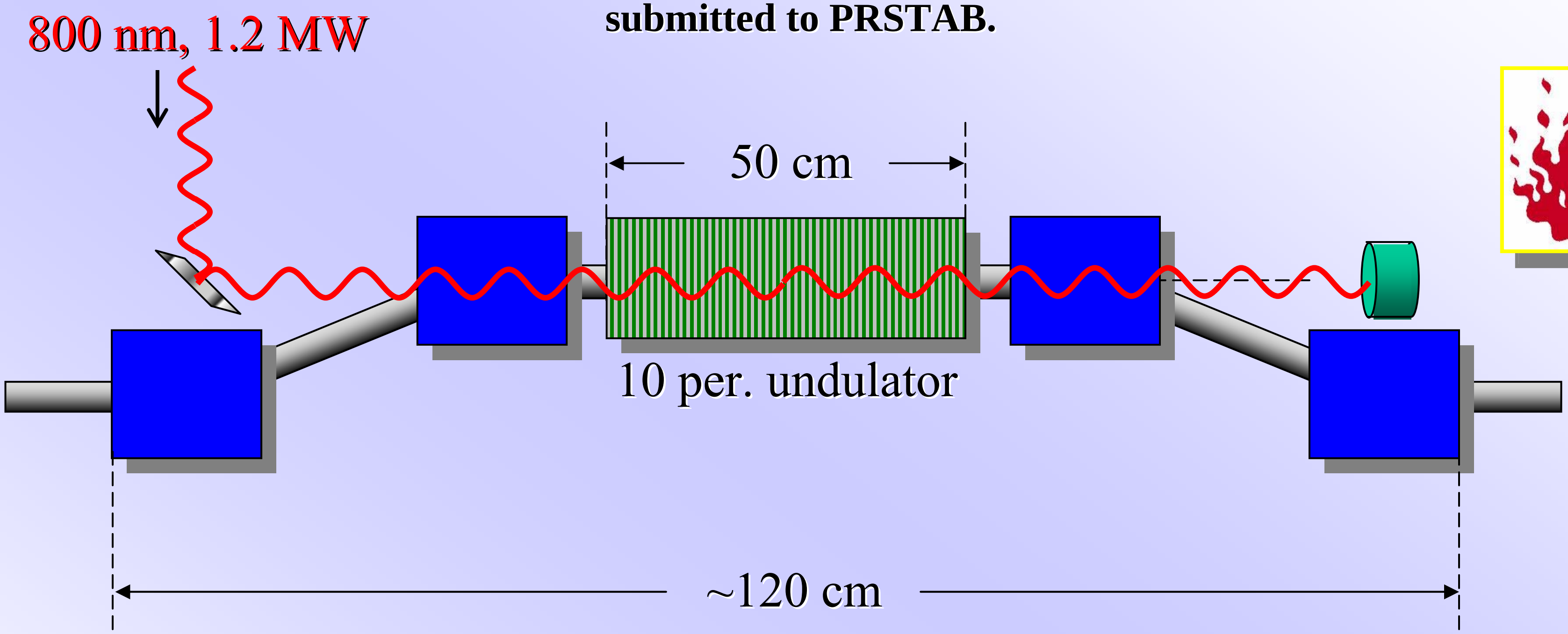
- FEL instability needs very "**cold**" e^- beams (small *e* and *E*-spread)
- Such a cold beam is subject to other "undesirable" instabilities in the accelerator (**CSR**, Longitudinal Space-Charge=**LSC**, wakefields)
- Parmela simulations and TTF measurement indicate $\Delta E \sim 3$ keV
- Accelerated to 14 GeV and compressed ×36 $\rightarrow \Delta E \sim 1\times10^{-5}$, too small to be useful in FEL (no effect on FEL gain when **<1×10^{-4}**)

Final long. phase space at 14 GeV for initial 15-μm, 1% seed



Laser Heater for Landau Damping

Z. Huang, M. Borland (ANL), P. Emma, J. Wu, R. Carr, C. Limborg, G. Stupakov, J. Welch, submitted to PRSTAB.



- Laser-electron interaction in undulator induces energy modulation (at 800 nm) $\Rightarrow$ 40 keV rms
- Inside weak chicane for laser access and time-coordinate smearing (emittance growth negligible)

laser spot much bigger than e^- spot:

$P_0 = 37$ MW

$w_0 \approx 3$ mm

$\sigma_{x,y} \approx 200\ \mu$m

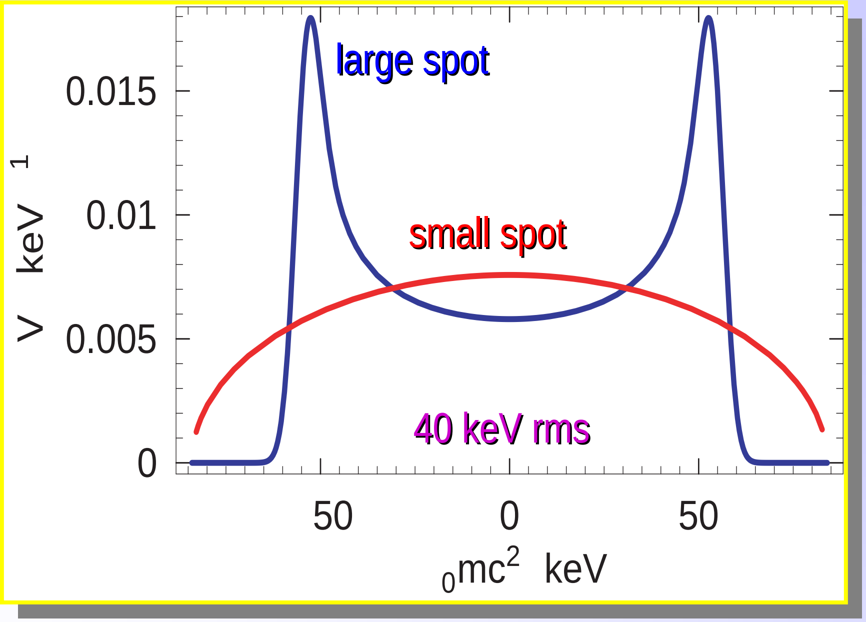
laser spot similar to e^- spot:

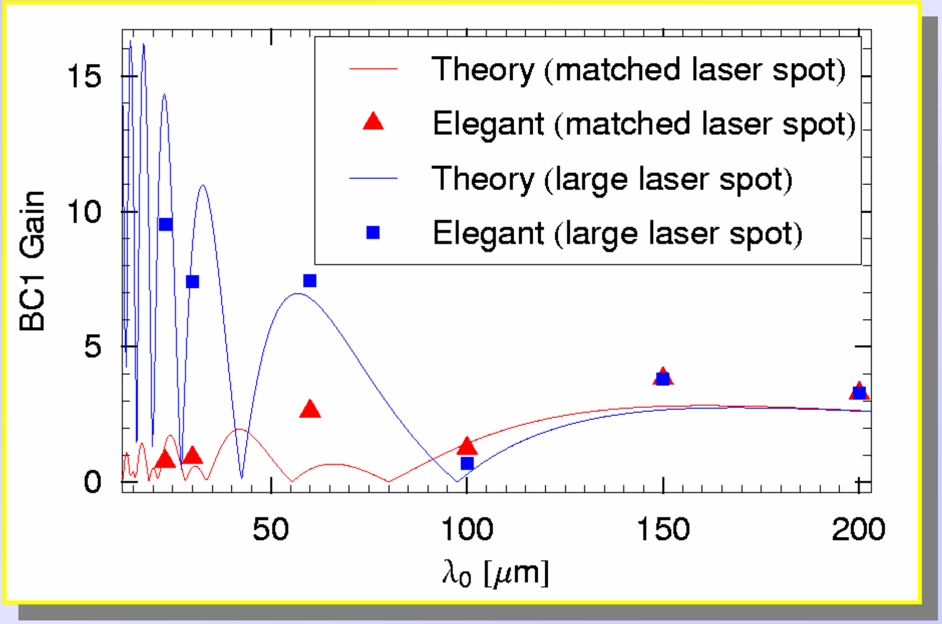
$P_0 = 1.2$ MW

$w_0 = 350\ \mu$m

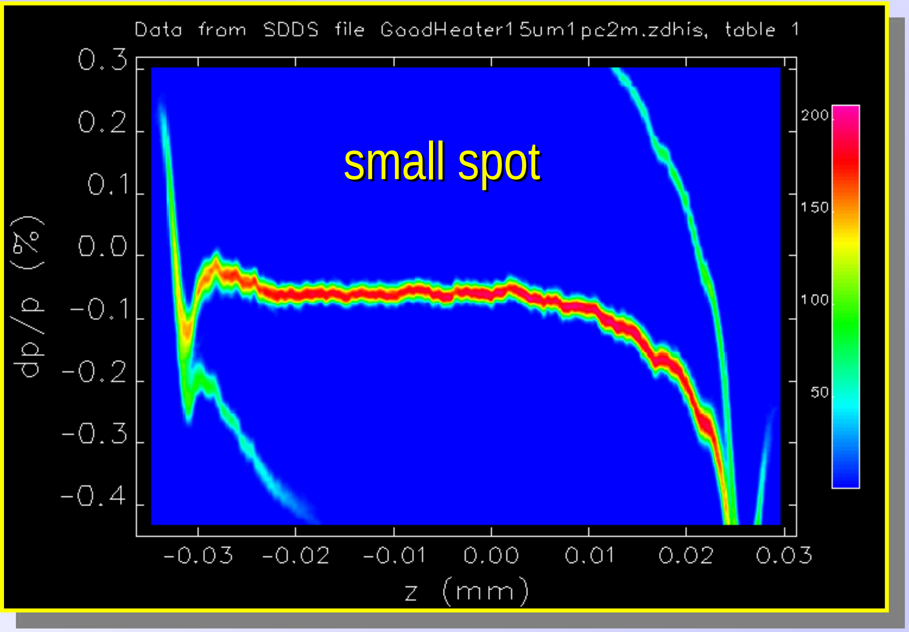
$\sigma_{x,y} \approx 200\ \mu$m

800-nm structure then gets smeared by chicane: $\Delta\sigma_z \approx \langle x'^2\rangle^{1/2} |\eta_x| >> \lambda\!\!\!^{-}$

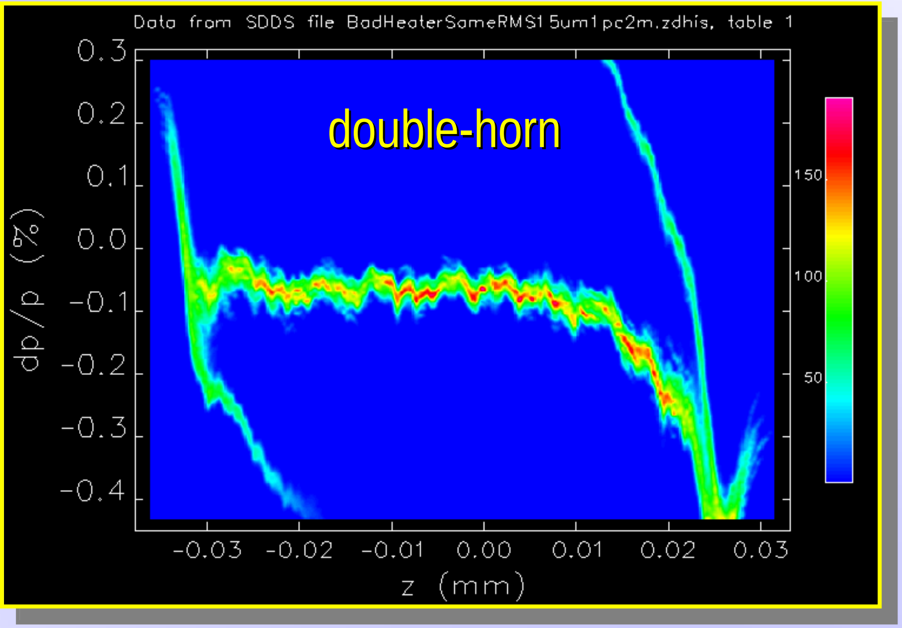




$w_0 = 350\ \mu m, P_0 = 1.2$ MW

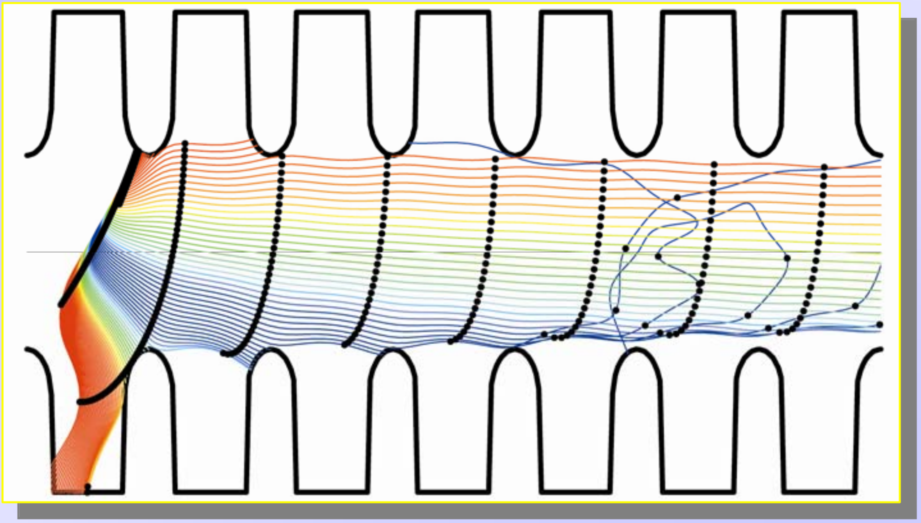


$w_0 = 3$ mm, $P_0 = 37$ MW

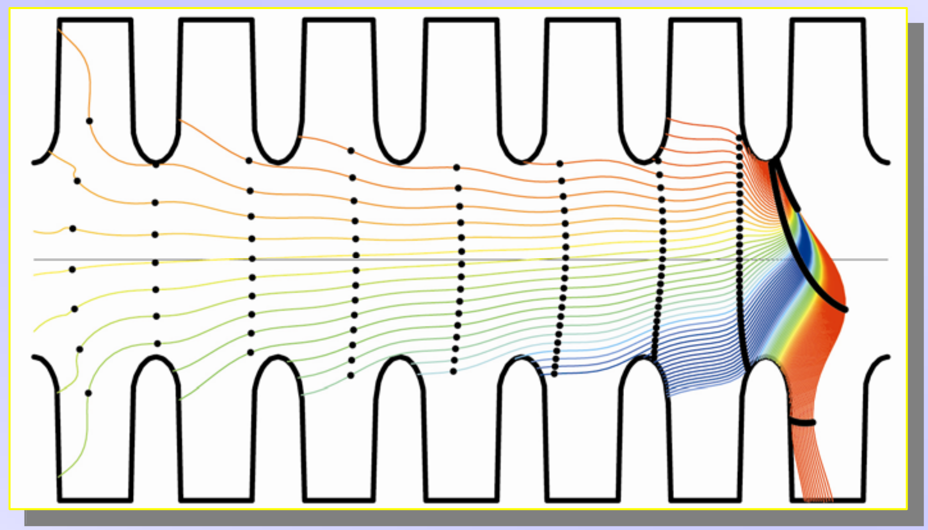


Simulation of Dark Current in NLC Structures

- What is the effect of dark current on the main linac bunch?
- How much current is captured? How far does it propagate? To what energy is it accelerated?
- Relation between dark current and breakdowns?



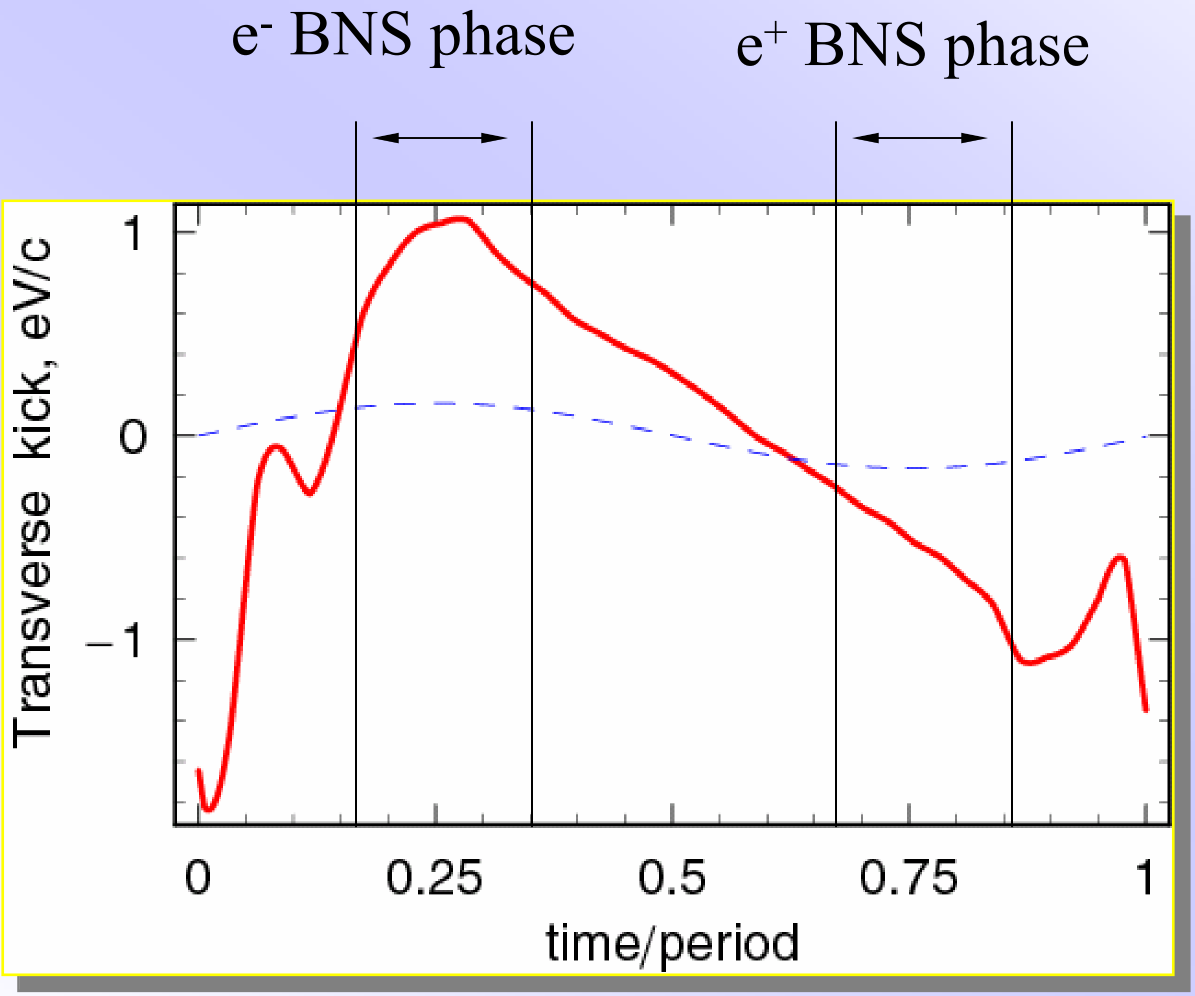
Simulation of dark currents in the H60VG3 disk loaded RF structure for different locations of the emission points (large current – blue, small current – red).

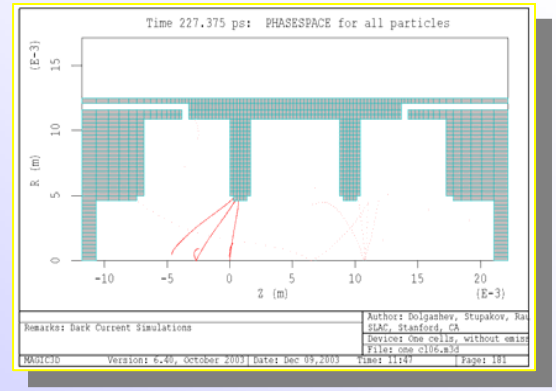


E_{acc}=65 MeV/m.

K. Bane, V. Dolgashev, G. Stupakov.

Beam Kick due to Dark Current





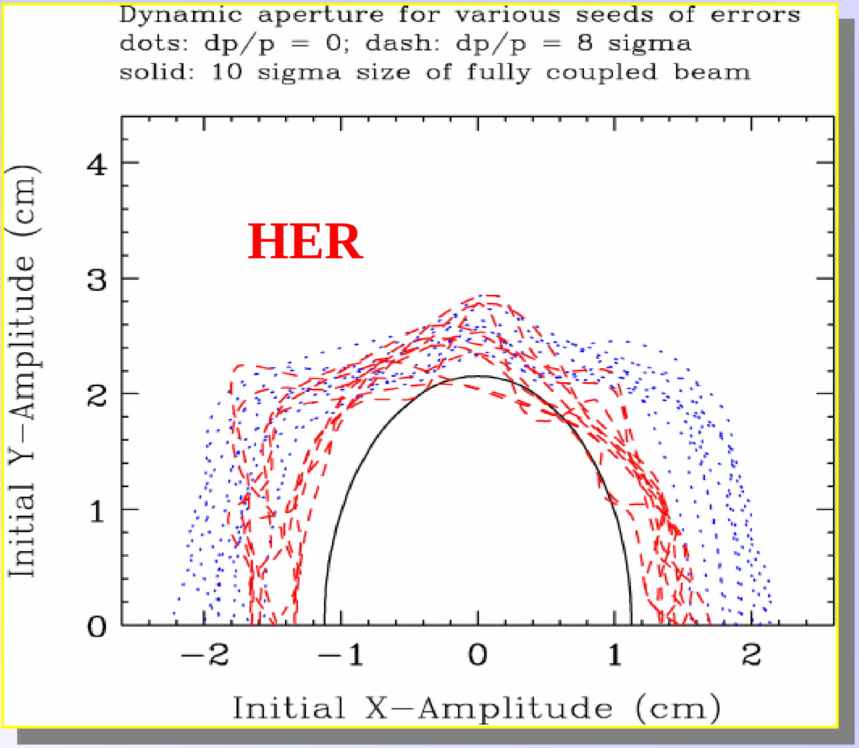
Geometry

J. Wu, V. Dolgashev

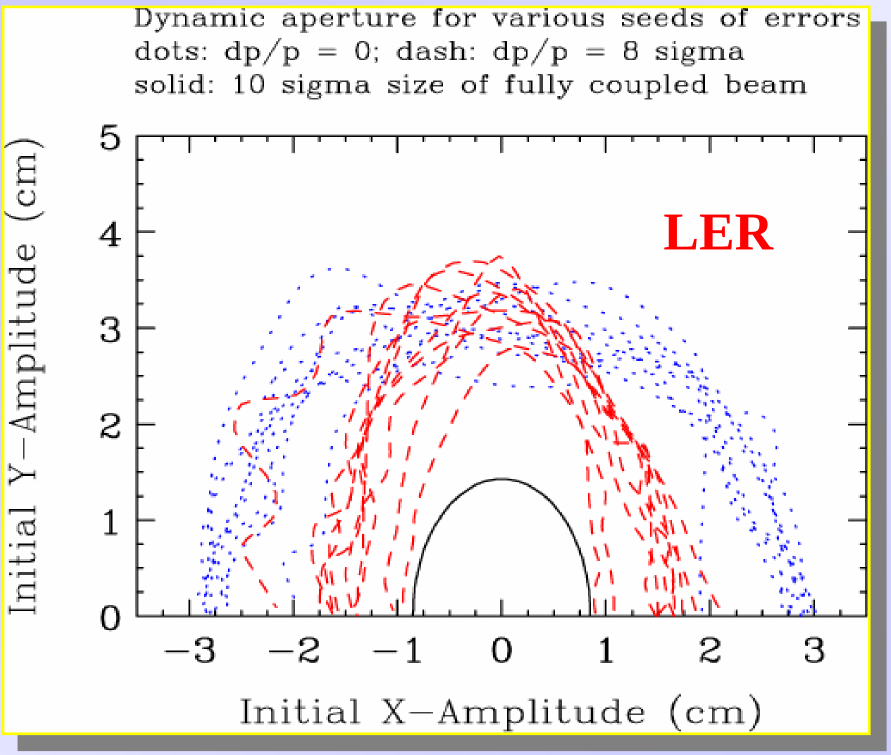
Integrated kick to the bunch *vs.* accelerating phase

Kick is normalized to average generated current of 1 mA.

Low-Beta Optics for PEP-II Future Upgrades



$\beta_y^* = 7$mm (CDR 15-20mm) lattices for both rings have been designed with adequate dynamic aperture



The lattice has been tested in the High Energy Ring and beam lifetime appears no problem

Y. Nosochkov

Model-Independent Analysis (MIA) for PEP-II Performance Improvement

- Betatron oscillations are resonantly excited in the ring and the beam position is measured at every BPM location turn by turn. FFT translates this into 8 numbers at each location, (x_1, y_1), … (x_4, y_4) (conjugate linear orbits). One then extracts, from these 4 orbits, not only the phase advances but the transfer matrix components R_{12}, R_{32}, R_{14}, R_{34}

$$R^{ab}_{12} = \frac{x^a_1 x^b_2 - x^a_2 x^b_1}{Q_1} + \frac{x^a_3 x^b_4 - x^a_4 x^b_3}{Q_2}$$

$$R^{ab}_{32} = \frac{x^a_1 y^b_2 - x^a_2 y^b_1}{Q_1} + \frac{x^a_3 y^b_4 - x^a_4 y^b_3}{Q2}$$

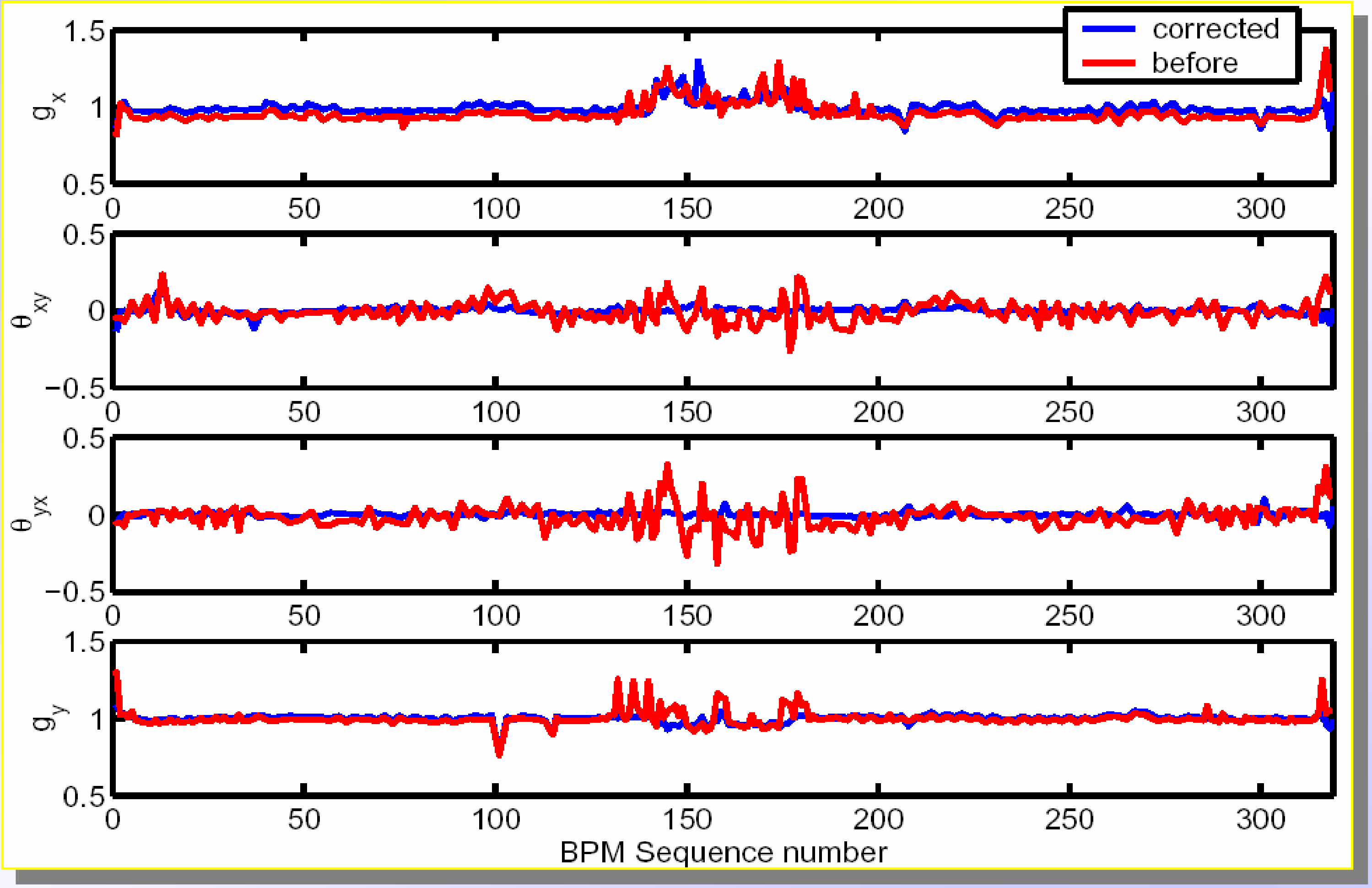
$$R^{ab}_{14} = \frac{y^a_1 x^b_2 - y^a_2 x^b_1}{Q_1} + \frac{y^a_3 x^b_4 - y^a_4 x^b_3}{Q_2}$$

$$R^{ab}_{34} = \frac{y^a_1 y^b_2 - y^a_2 y^b_1}{Q_1} + \frac{y^a_3 y^b_4 - y^a_4 y^b_3}{Q_2}$$

- Fitting those R_{ik} elements into the lattice model greatly improves the accuracy of the model.

Y. Yan,Y. Cai

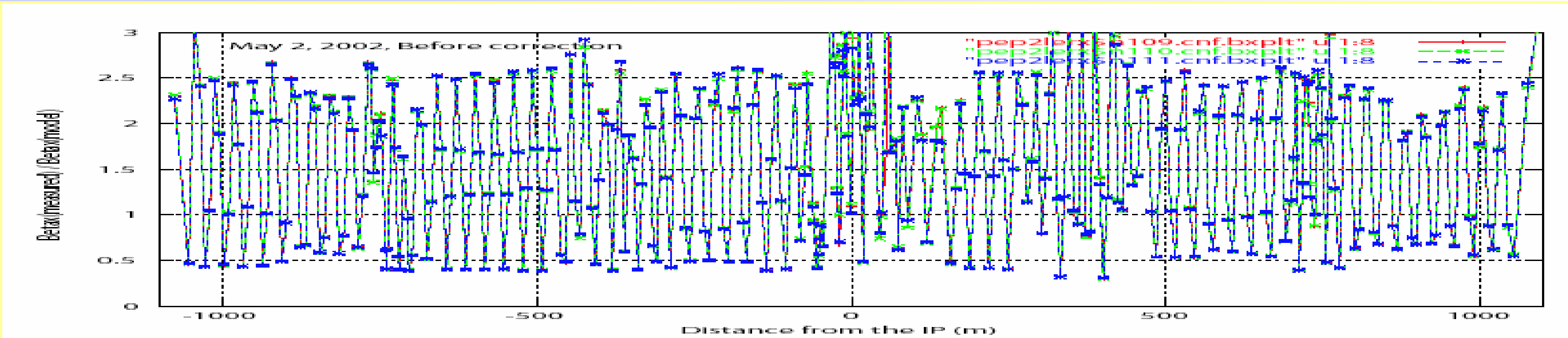
MIA Figured out BPM Errors



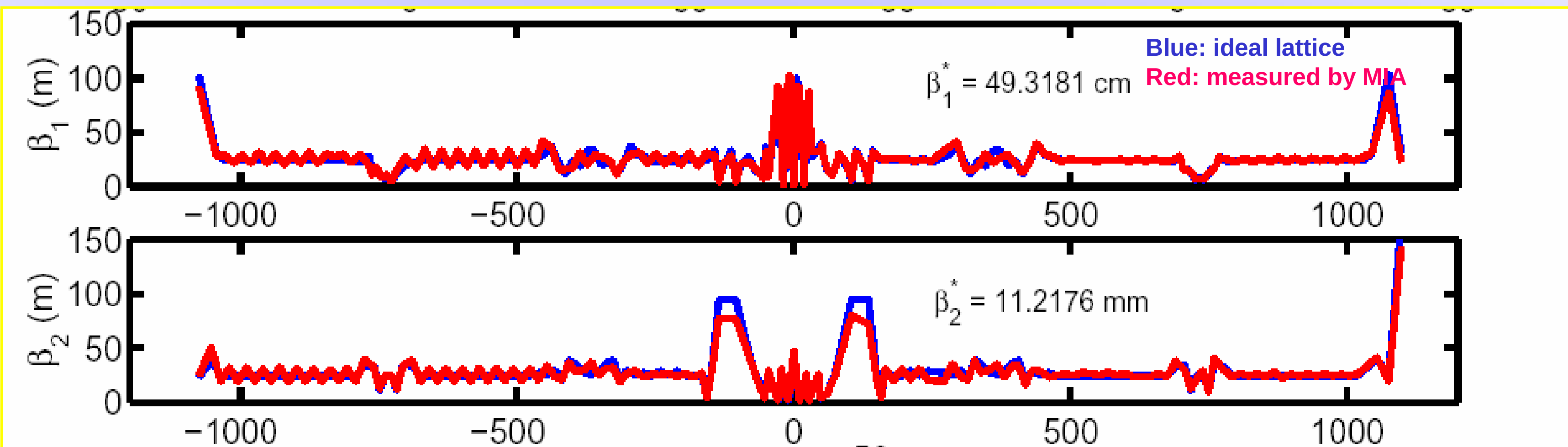
$$x^{(measured)} = g_x\, x^{(beam)} + \theta_{xy}\, y^{(beam)}$$

$$y^{(measured)} = g_y\, y^{(beam)} + \theta_{yx}\, x^{(beam)}$$

MIA helped to bring LER working tune to near half integer

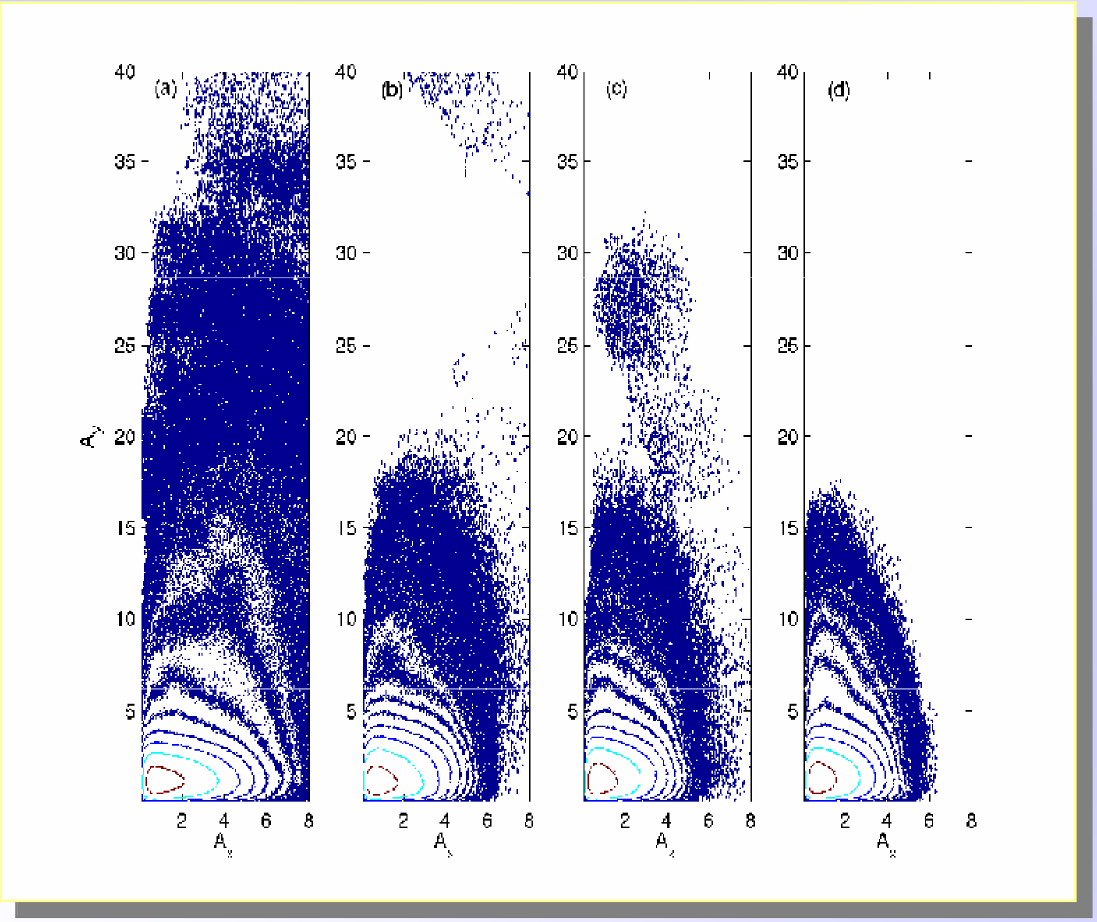


Without MIA, near half integer working tune large beta beat was observed.



Both LER and HER have been brought to work at near half integer working tunes ([ν_x]=0.516) since May 2003. β beat is small, linear coupling is fine, IP tilt angle is fine.

Simulation of Beam-Beam Lifetime in the Low Energy Ring of PEP-II



$\nu_x = 0.5081$ $\tau = 1\,\text{min}$

$\nu_x = 0.5125$ $\tau = 16\,\text{min}$

$\nu_x = 0.5142$ $\tau = 100\,\text{min}$

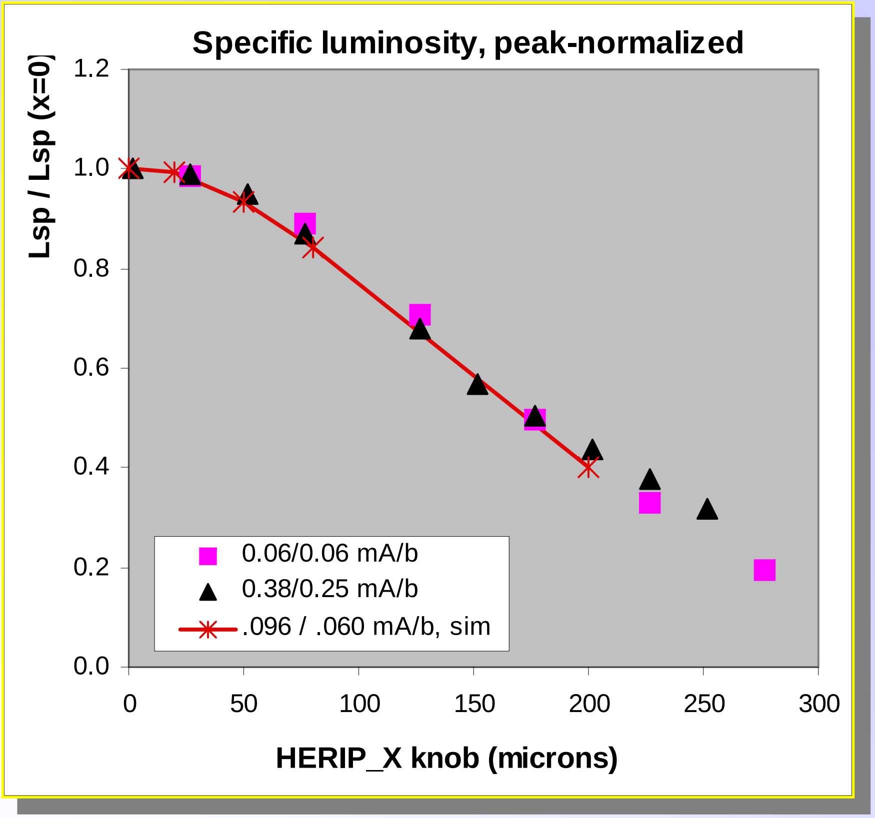
$\nu_x = 0.5152$ $\tau = \infty\,\text{min}$

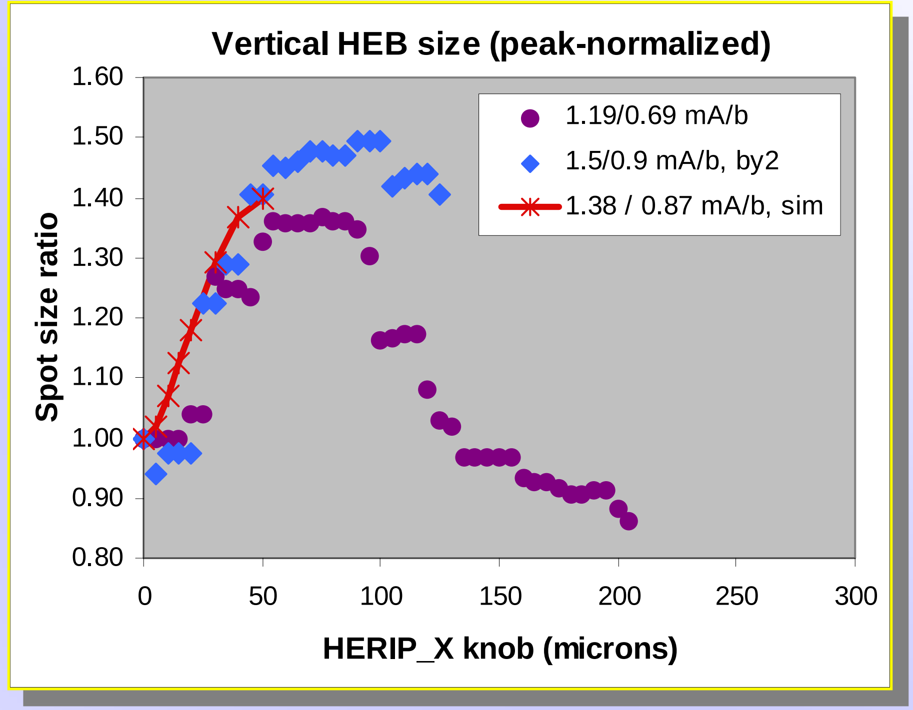
- Nonlinear lattice included in the simulation additional to beam-beam interaction
- The core distribution is not disturbed much by the nonlinearity in the ring while the tail is strongly effected.
- Lifetime is consistent with observation in the machine

Y. Cai

Simulation BBI - Benchmark Against Experiments at PEP-II

Electron beam was scanned horizontally across the positron beam as the luminosity and beam sizes were recorded.





Largest beam blowup seen in σ_y^-

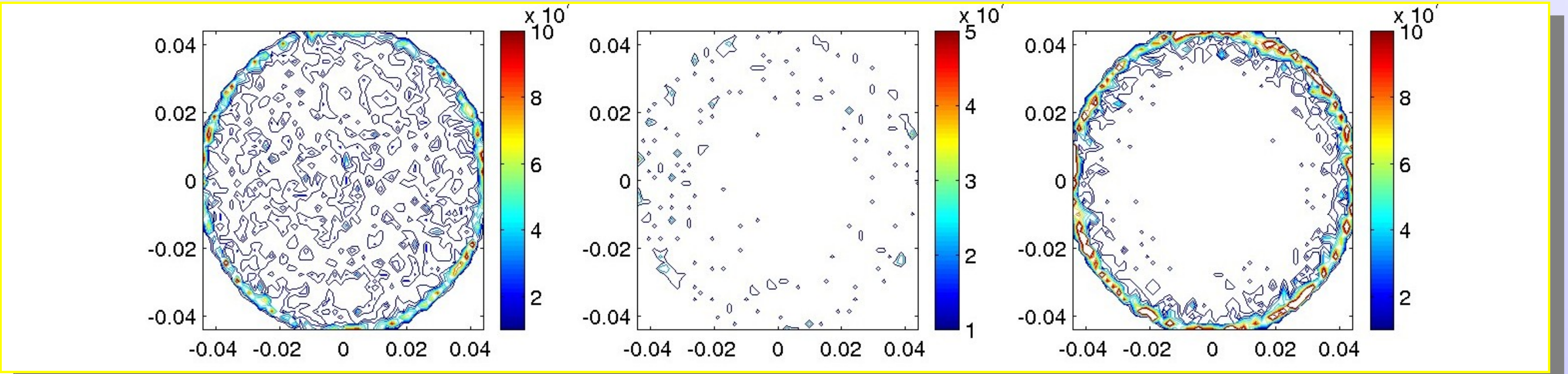
W. Kozanecki, J. Seeman, Y. Cai, and I. Narsky

Electron Cloud and Cyclotron Resonances in Positron Ring

Simulation of generating electron cloud in the presence of solenoid field is carried out recently for the PEP-II.

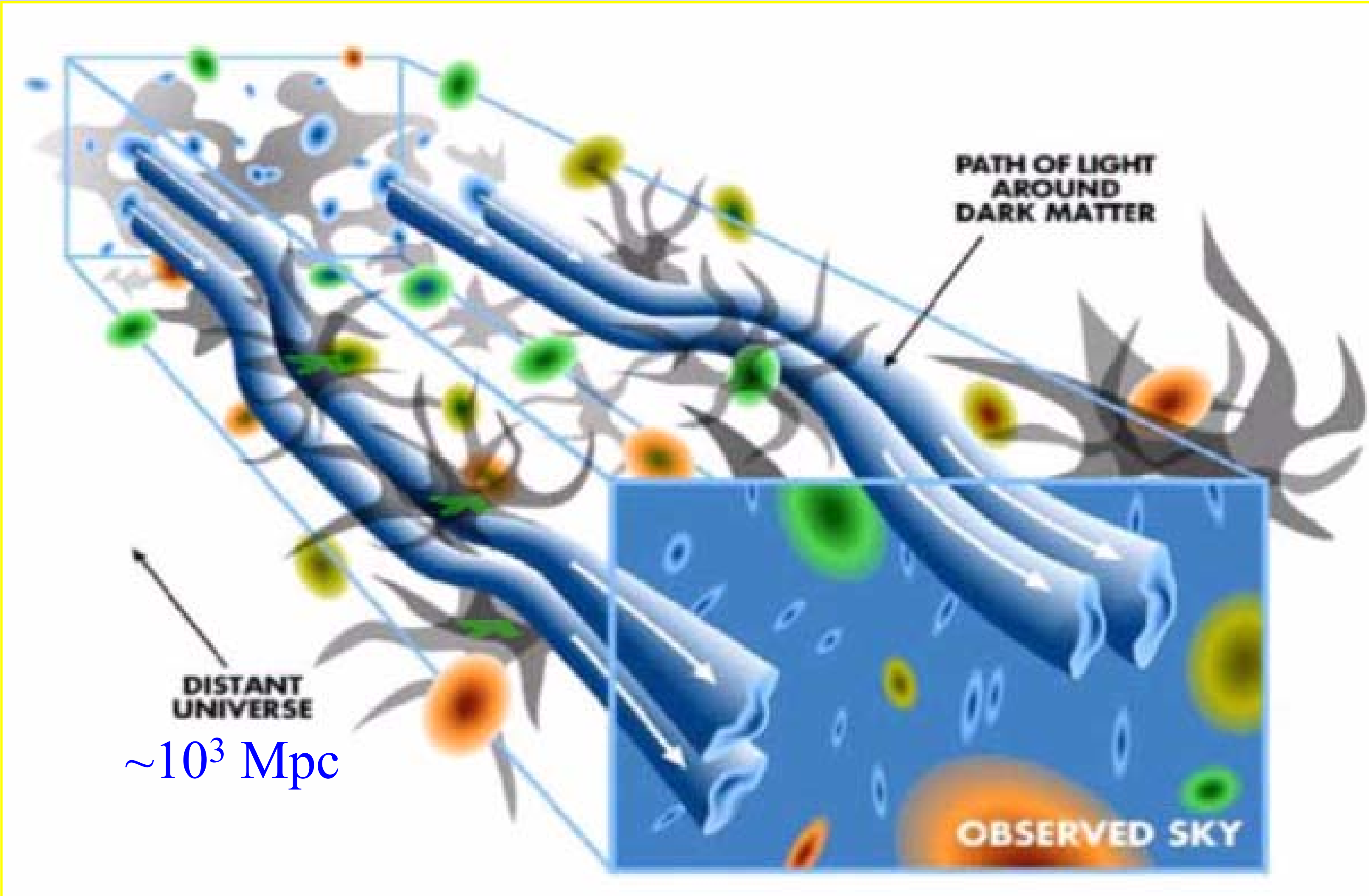
Resonance condition: bunch spacing is equal to half cyclotron period in dipole magnetic field

No solenoid 10 Gauss 20 Gauss



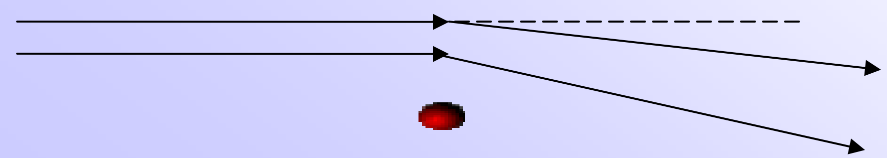
Y. Cai, M. Pivi, M. A. Furman, *Phys. Rev. ST Accel. Beams*, **7**, 024402 (2004)

Higher Moments Gravitational Lensing



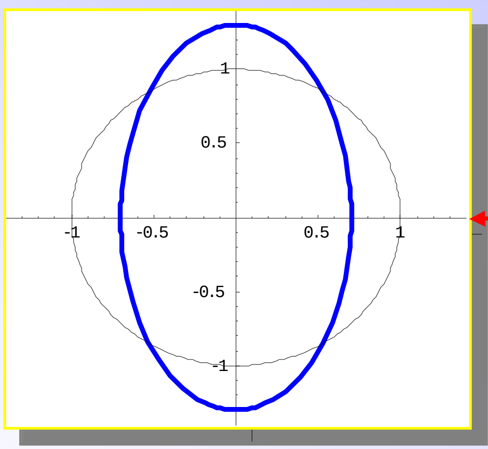
J. Irwin, M. Shmakova

Light Deflection from a Concentrated Mass

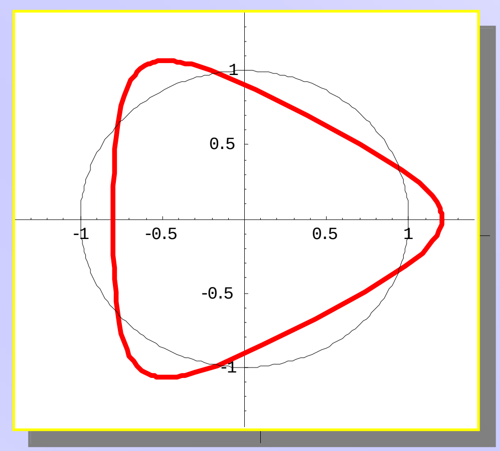


$$\Delta x' = -\frac{4MG}{x} = -\frac{4MG}{x_0 + \Delta x} = -\frac{4MG}{x_0}\left(1 - \frac{\Delta x}{x_0} + \left(\frac{\Delta x}{x_0}\right)^2 + \ldots\right)$$

$$\Delta x' + i\Delta y' = -\frac{4MG}{x_0 + (\Delta x - i\Delta y)} = -\frac{4MG}{x_0}\left(1 - \frac{(\Delta x - i\Delta y)}{x_0} + \left(\frac{\Delta x - i\Delta y}{x_0}\right)^2 + \ldots\right)$$



Quadrupole

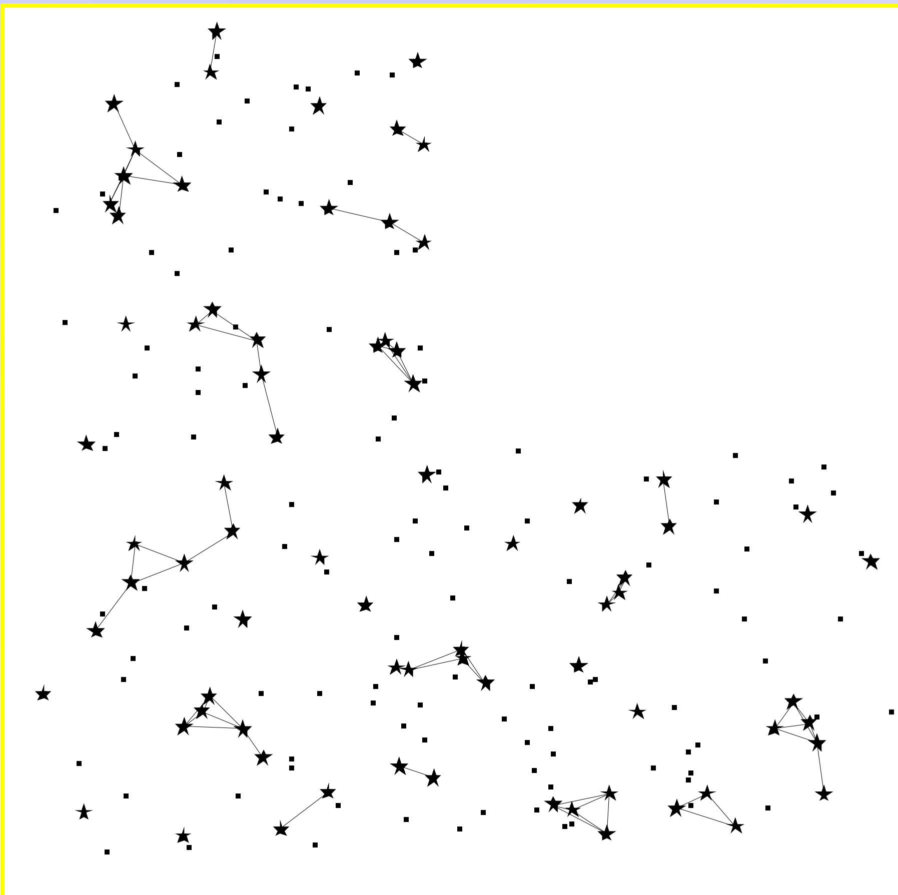


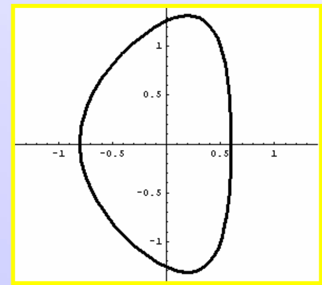
Sextupole

Quad and sextupole orientation are correlated!

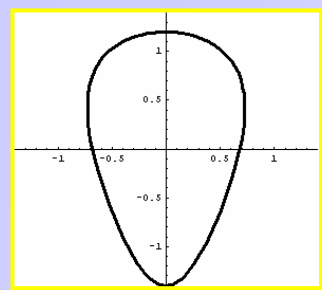
Clumping Studies

Curved galaxies among all “strong” galaxies from Hubble Deep Field North. Lines join curved galaxies separated by less than 290 pixels.





“Curved” means proper orientation of sextupole and quadrupole components (“star” symbols).



“Aligned” shape