Emittance exchange for coherent bunching at X-ray wavelength

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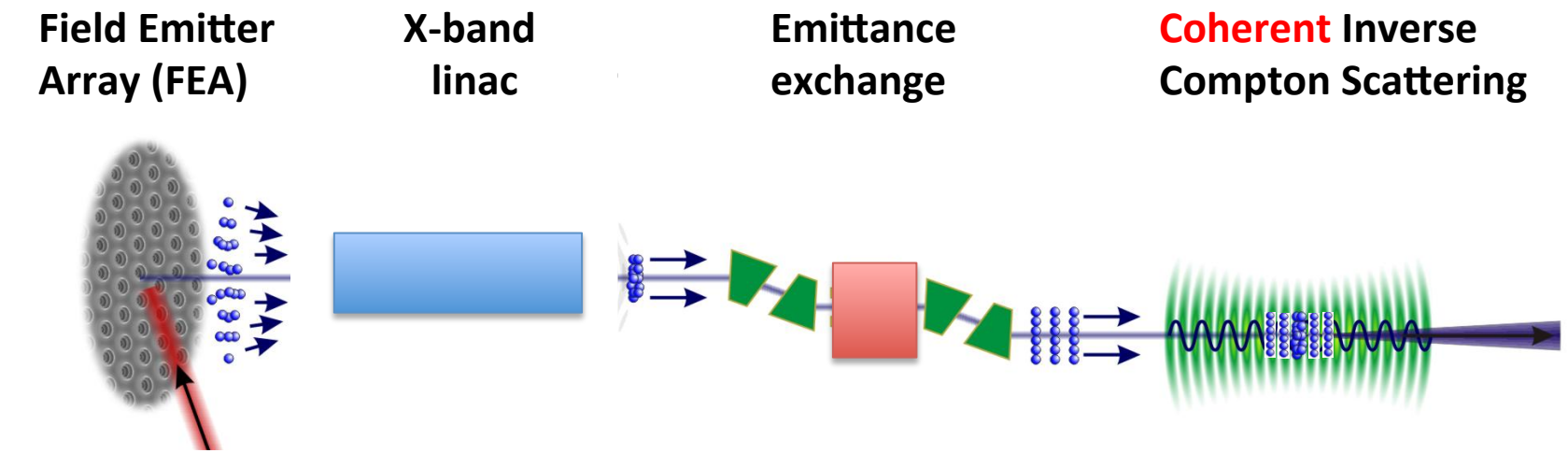
Massachusetts
Institute of
Technology

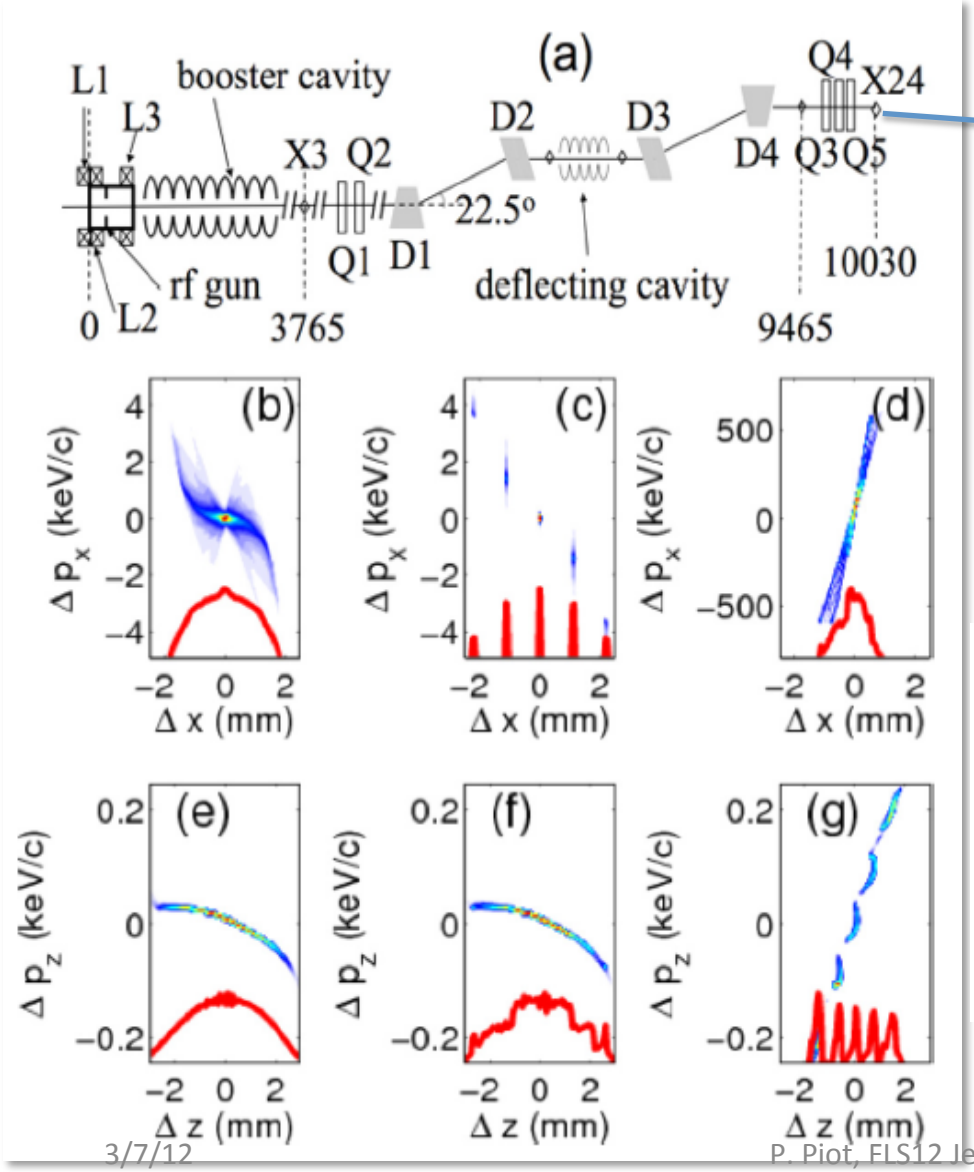
Ingredients for a compact super-radiant inverse Compton scattering (SRICS) source

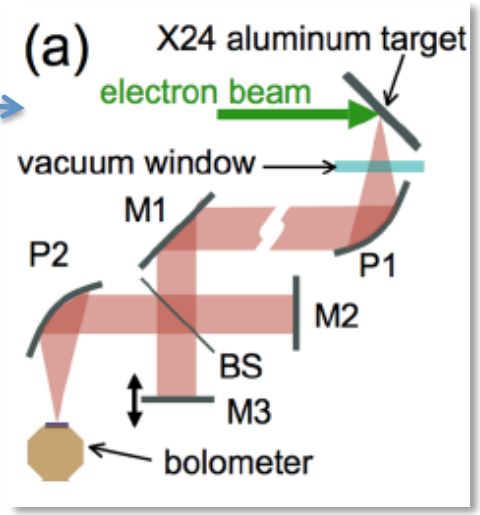
- Use photo-field emission array typically 400x400 field emitters (array size not optimized)

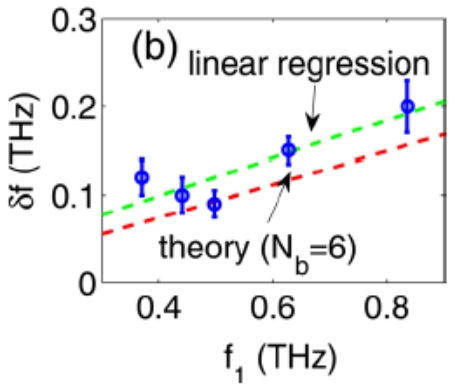


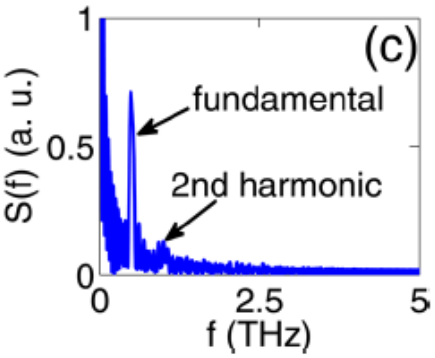
(adapted from F. Kärtner)

Proof-of-principle experiment: "Narrowband" THz CTR





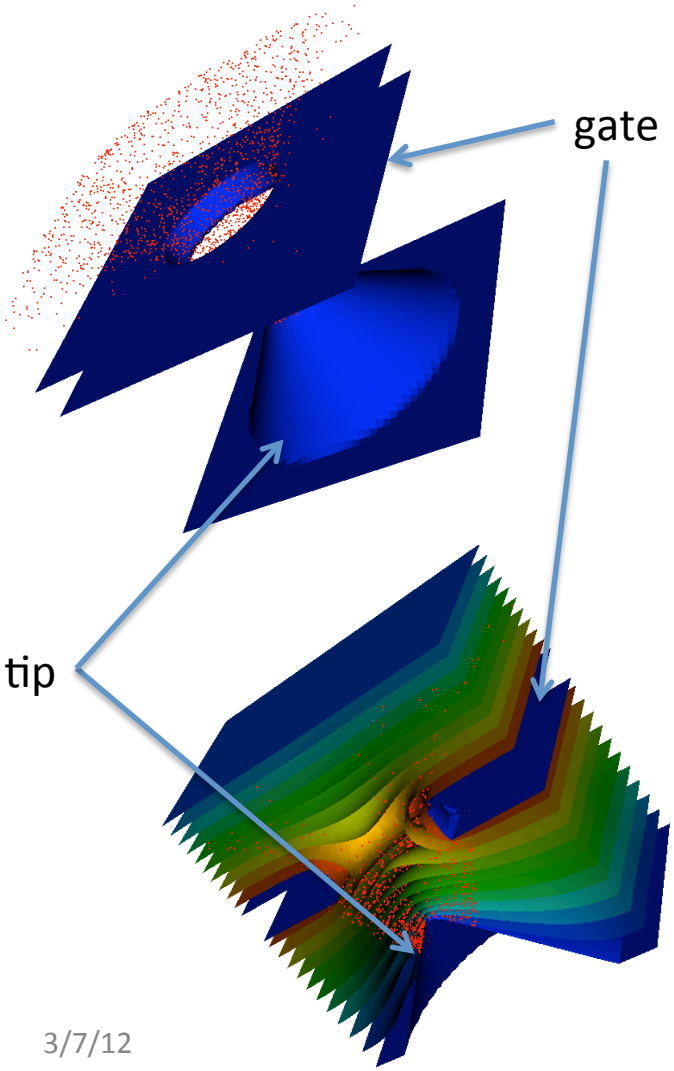


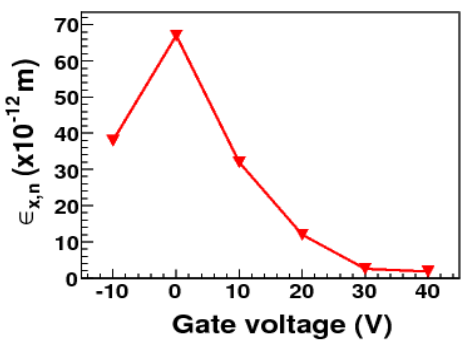


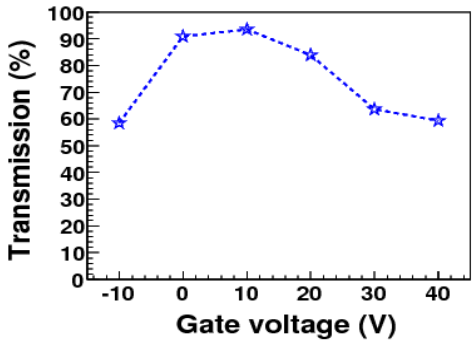
P. Piot et al. APL 98, 261501 (2011)

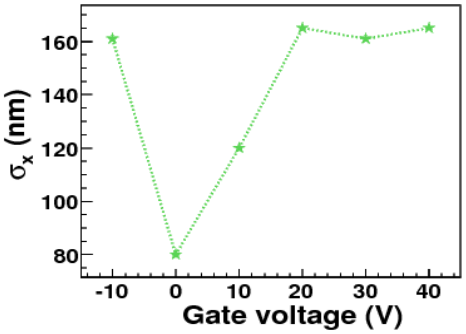
Photo-field emission from gated cathode

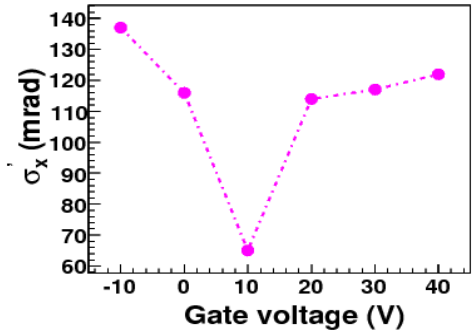
- Use photo-field emission array typically 400x400 field emitters (array size not optimized)











- Field emission modeled with Nordheim-Fowler emission's law implementation in Impact-T (point-to-point) and in process in VORPAL (Tech X),
- ~100 e- per tip.

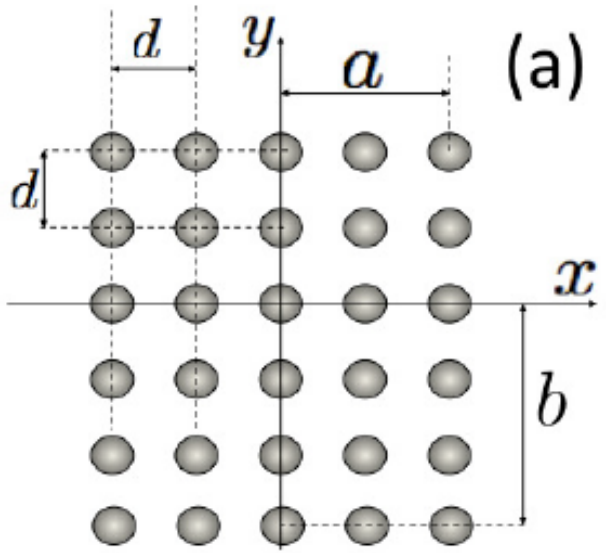
Field-emitter arrays

- Courant Snyder and Emittance of total bear related to single-beamlet parameters:

$$\varepsilon^2 = \varepsilon_0^2 + \langle \left(X' - \frac{X}{f} \right)^2 \rangle \frac{(p+1)a^2}{3p},$$

$$\beta = \frac{1}{\varepsilon} \left(\beta_0 \varepsilon_0 + \frac{a^2}{3} \frac{(p+1)}{3p} \right),$$

$$\alpha = \frac{1}{\varepsilon} \left(\alpha_0 \varepsilon_0 + \frac{a^2}{3f} \frac{(p+1)}{3p} \right).$$

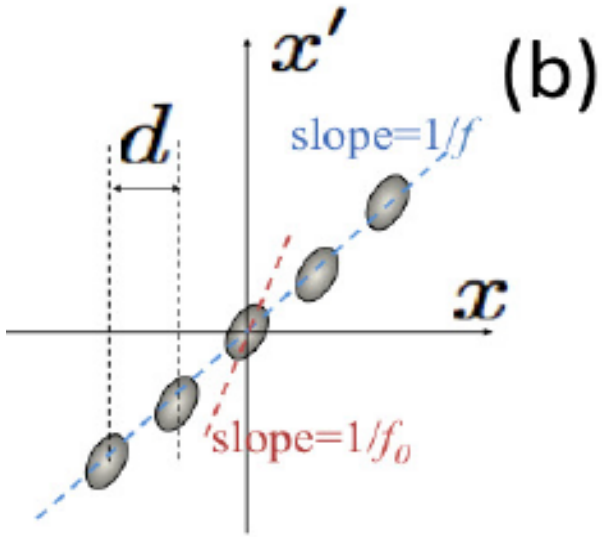


- Both a local and global correlations:

$$X' = \frac{1}{f_0} X$$

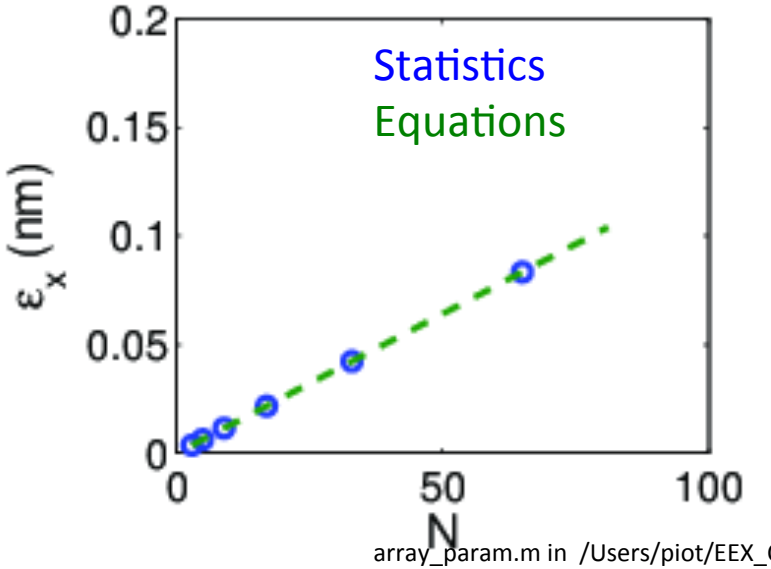
$$\langle x' \rangle_i = \frac{1}{f} \langle x \rangle_i$$

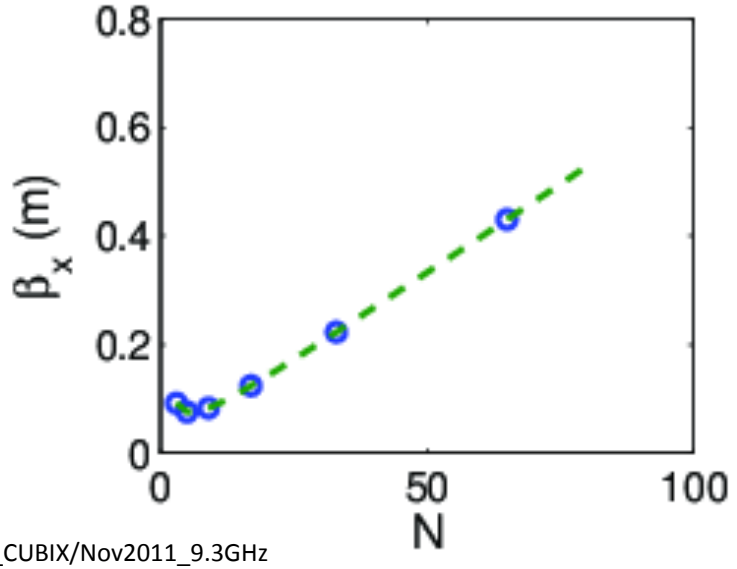
(X,X') are local phase space coordinate associated to one beamlet



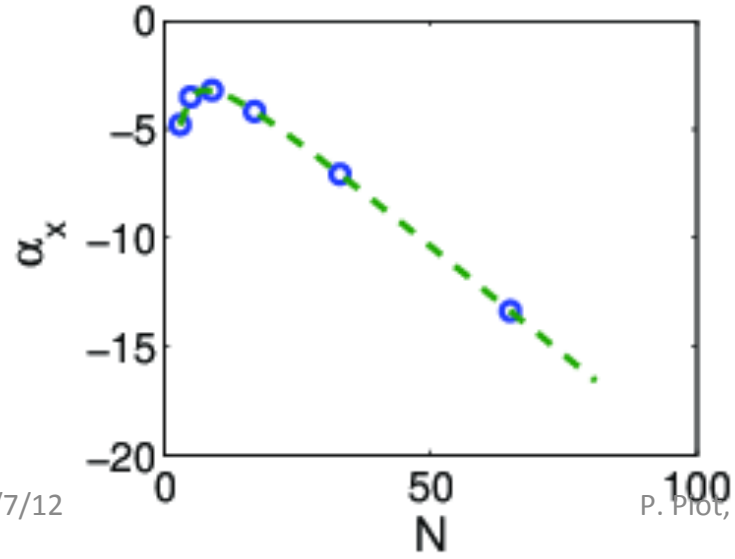
adapted from Rhee, Boulais, Phys. Fluids B 3 (7), 1781, July 1991

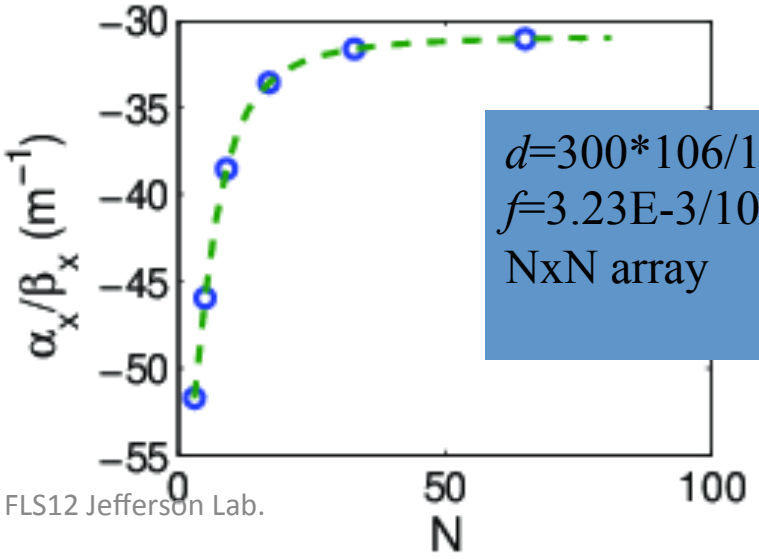
Field-emitter arrays (2)





array_param.m in /Users/piot/EEX_CUBIX/Nov2011_9.3GHz



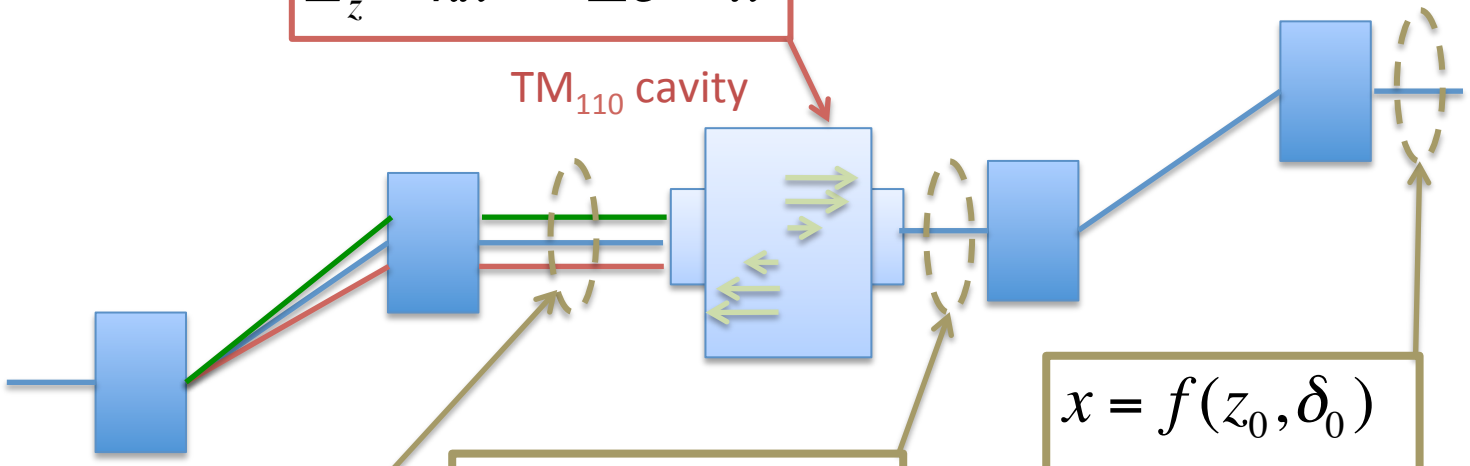


d=300*106/100 nm
f=3.23E-3/106E-6
NxN array

Phase-space exchange principle

$$B_y = \kappa z \Rightarrow \Delta x' \propto z$$
$$E_z = kx \Rightarrow \Delta\delta \propto x$$

TM$_{110}$ cavity



$$x = f(x_0, x'_0, \delta_0)$$
$$x' = x'_0$$
$$z = f(x'_0, z_0, \delta_0)$$
$$\delta = \delta_0$$

$$x = f(x_0, x'_0, \delta_0)$$
$$x' = f(z_0, \delta_0)$$
$$z = f(x'_0, z_0, \delta_0)$$
$$\delta = f(x_0, x'_0)$$

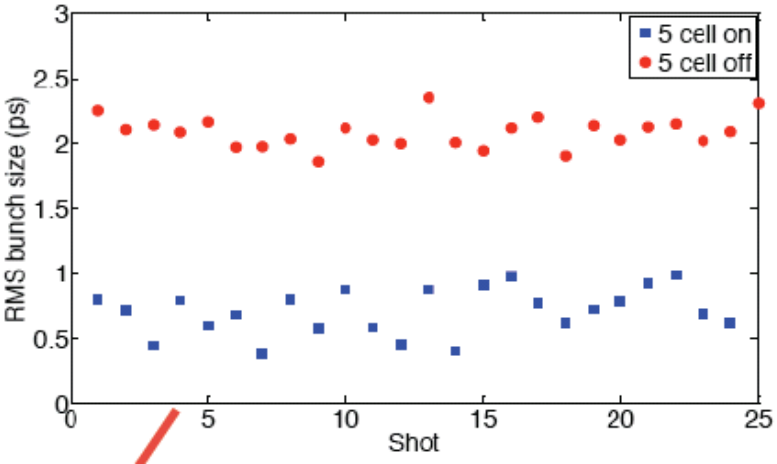
$$x = f(z_0, \delta_0)$$
$$x' = f(z_0, \delta_0)$$
$$z = f(x_0, x'_0)$$
$$\delta = f(x_0, x'_0)$$

Phase space coordinates swapped between (x,x') and (z,d) trace spaces.

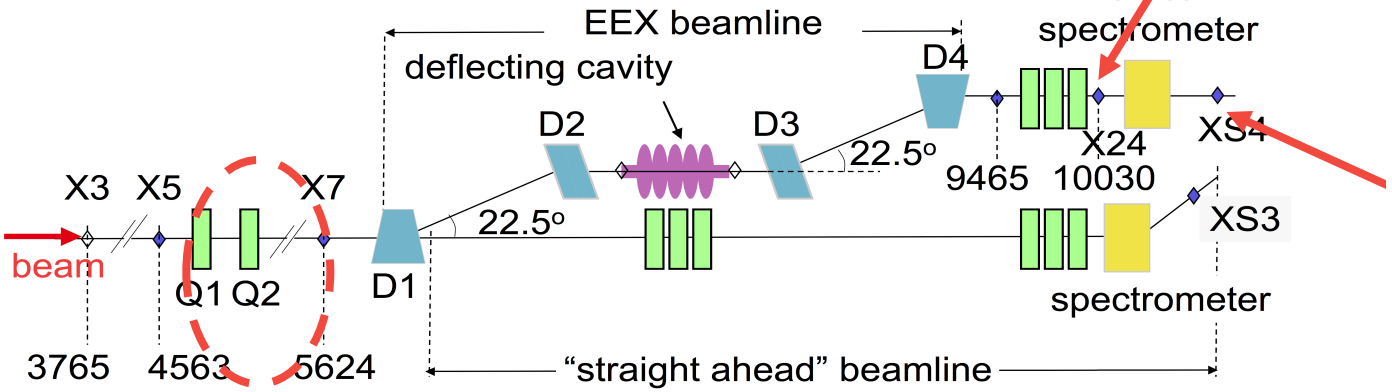
Proof-of-principle: emittance exchange

	Simulated		Measured	
	In	Out	In	Out
ε_x^n	2.9	13.2	2.9 ± 0.1	11.3 ± 1.1
ε_y^n	2.4	2.4	2.4 ± 0.1	2.9 ± 0.5
ε_z^n	13.1	3.2	13.1 ± 1.3	3.1 ± 0.3

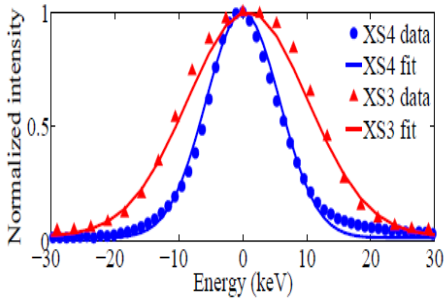
Bunch duration measurement with streak camera



$$\begin{cases} z = & -\frac{\xi}{\eta}x_0 - \frac{L\xi-\eta^2}{\eta}x_0' \\ \delta = & -\frac{1}{\eta}x_0 - \frac{L}{\eta}x_0', \end{cases}$$



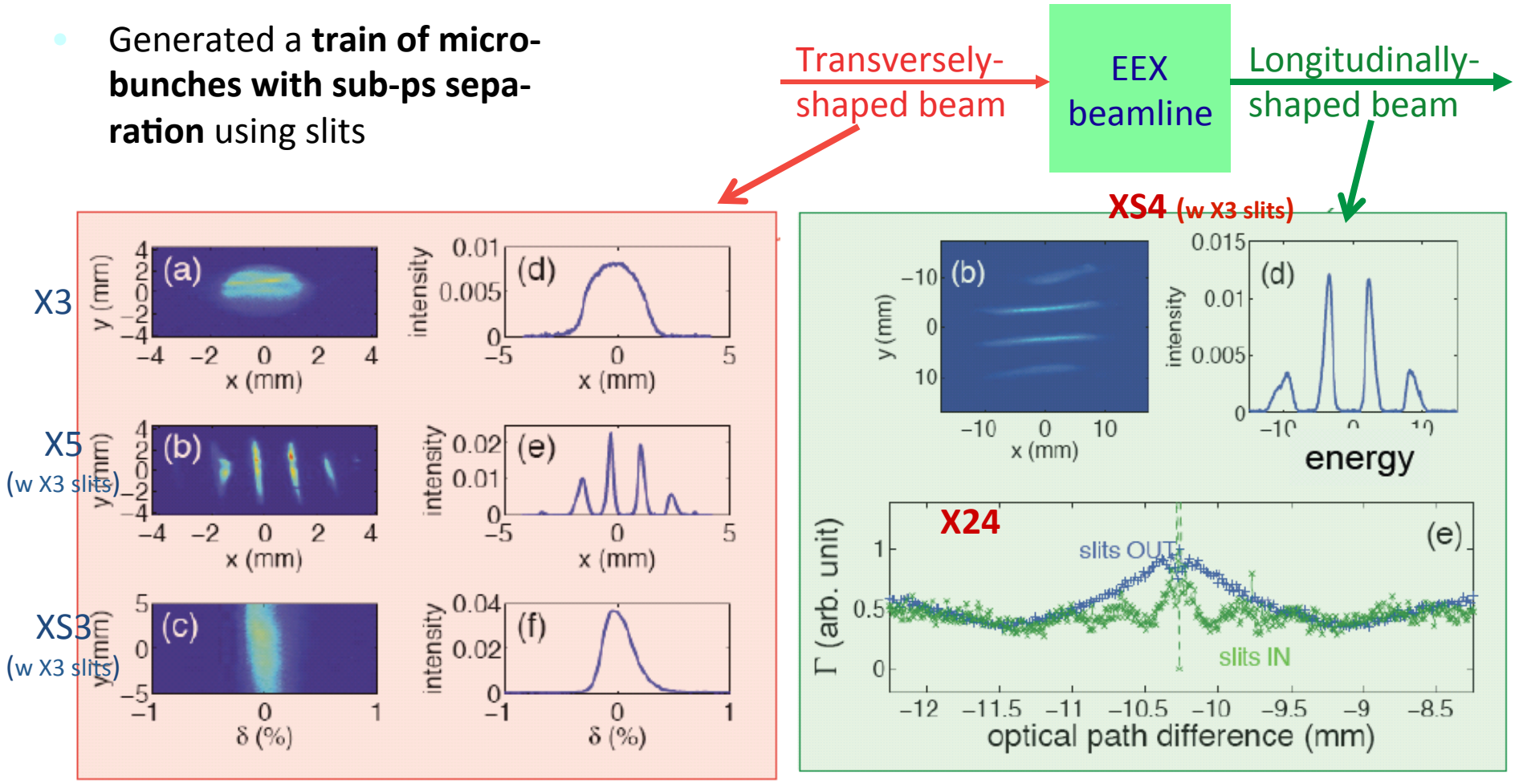
Energy spread



[J. Ruan et al., PRL 106 244801 (2011)]

Proof-of-principle: pre-bunching at the sub-ps level

- Generated a **train of micro-bunches with sub-ps separation** using slits



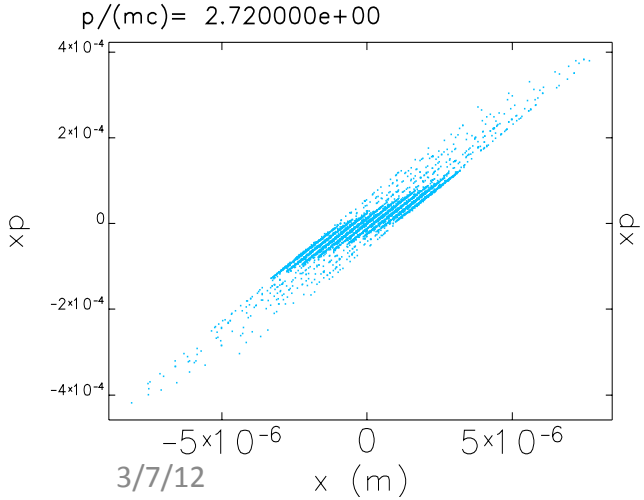
[Y.-E. Sun et al., PRL 105, 234801 (2010)
P. Piot et al., PRSTAB 14, 022801 (2011)]

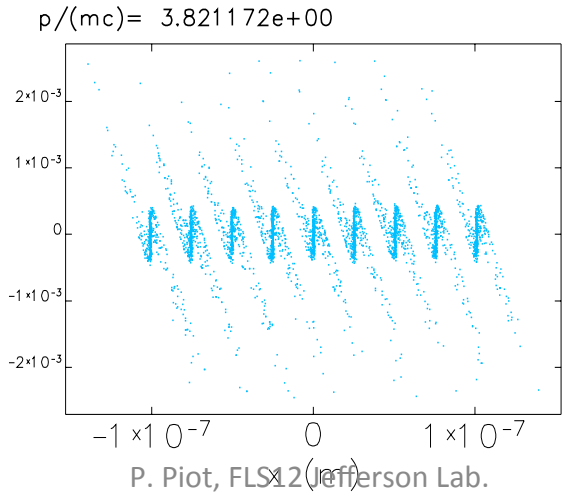
Combining the FE and EEX technologies

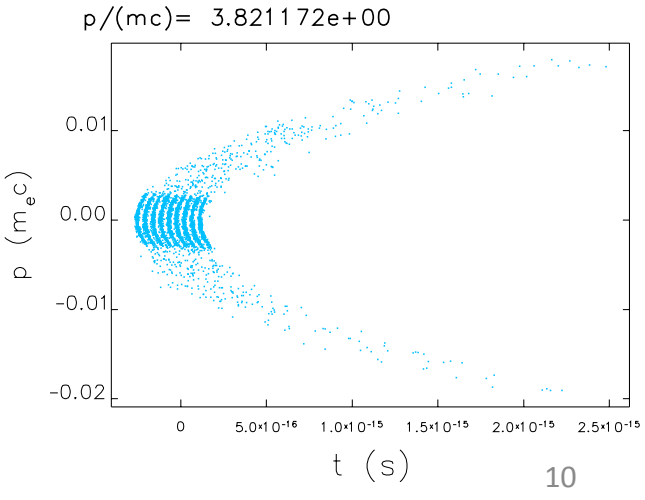
- Overall concepts (could do everything in one step)

Image/demagnify FE cathode

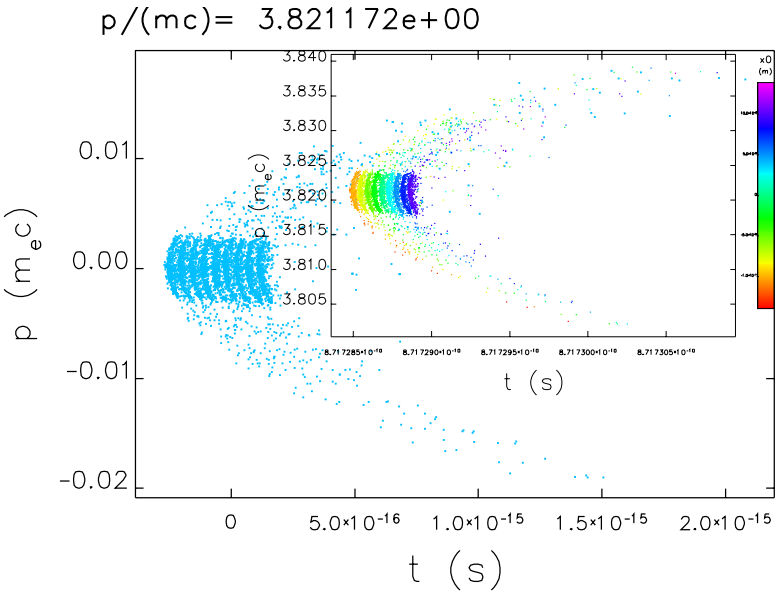
Mapping $(x_0, x'_0) \rightarrow (z, \delta)$ with tunable demagnification $\partial\delta / \partial x_0$

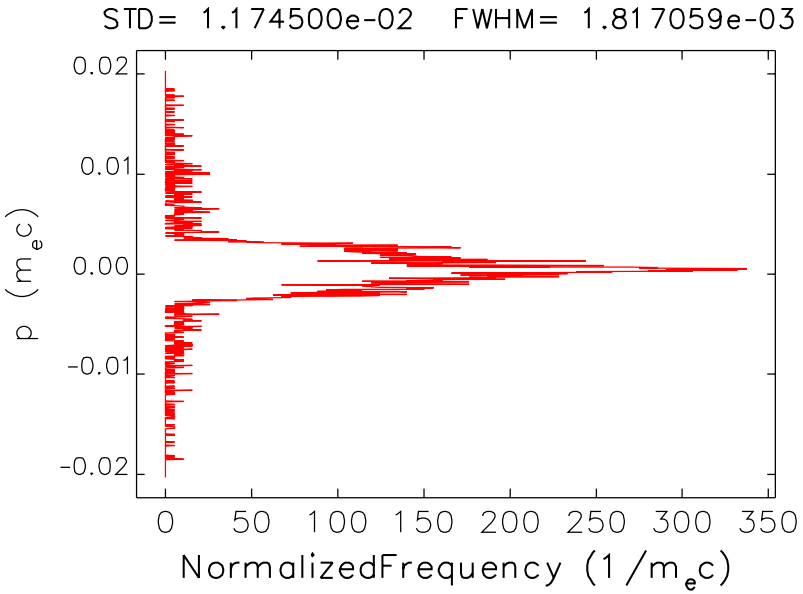


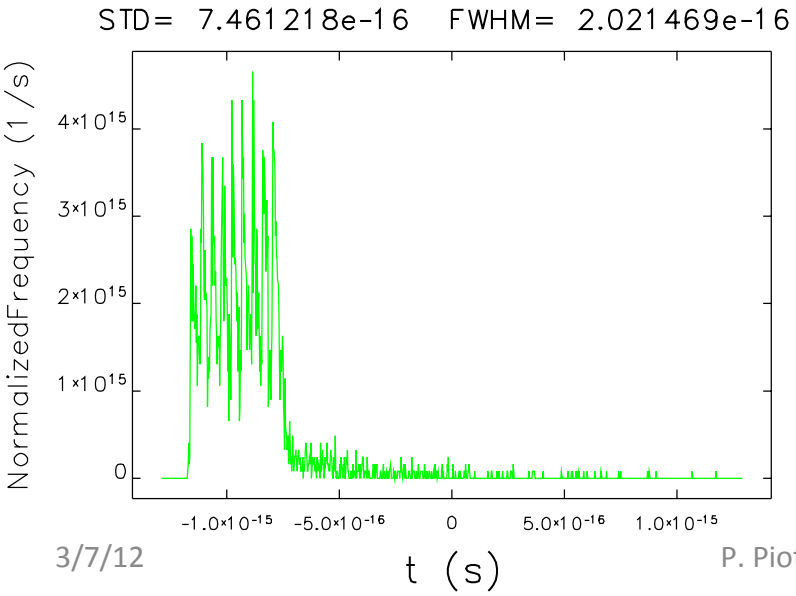


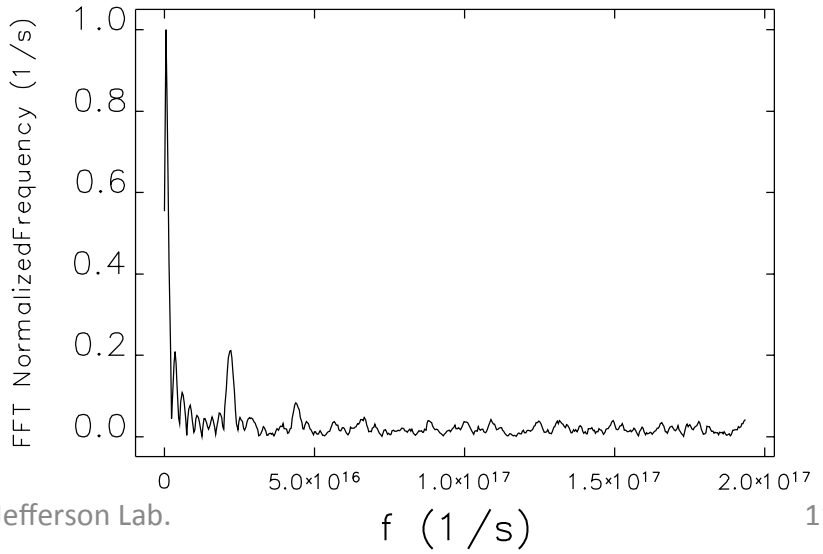


Example 9x9 array

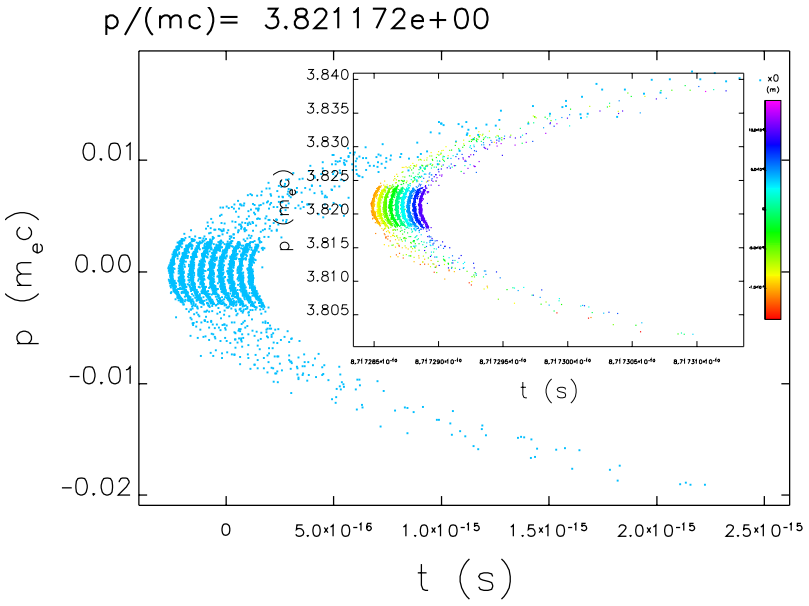


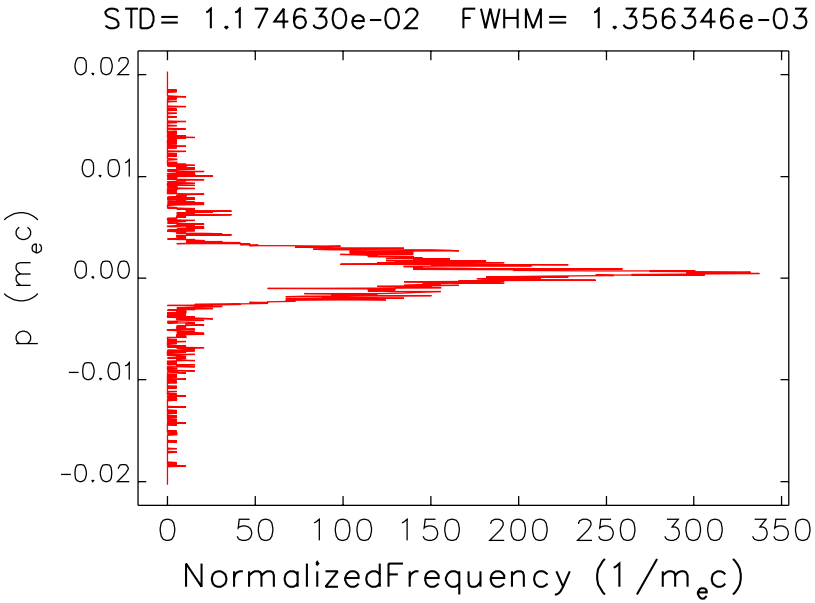


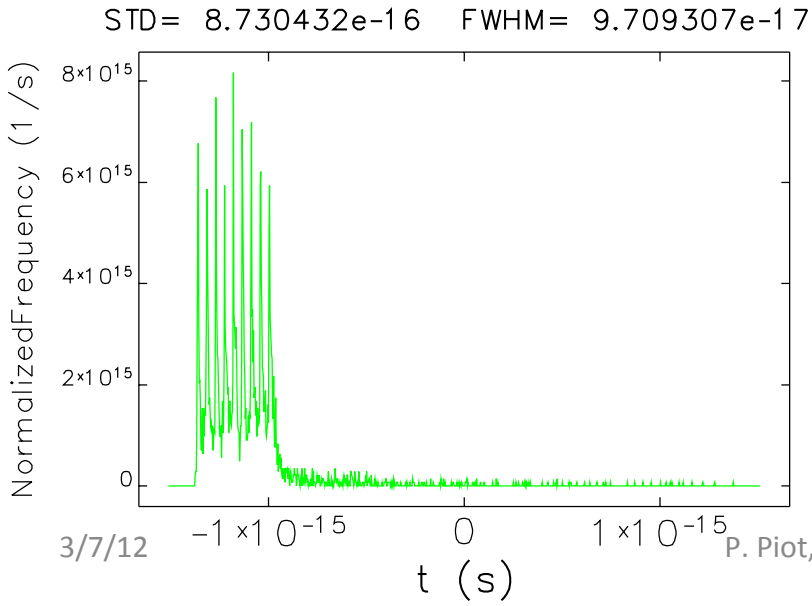


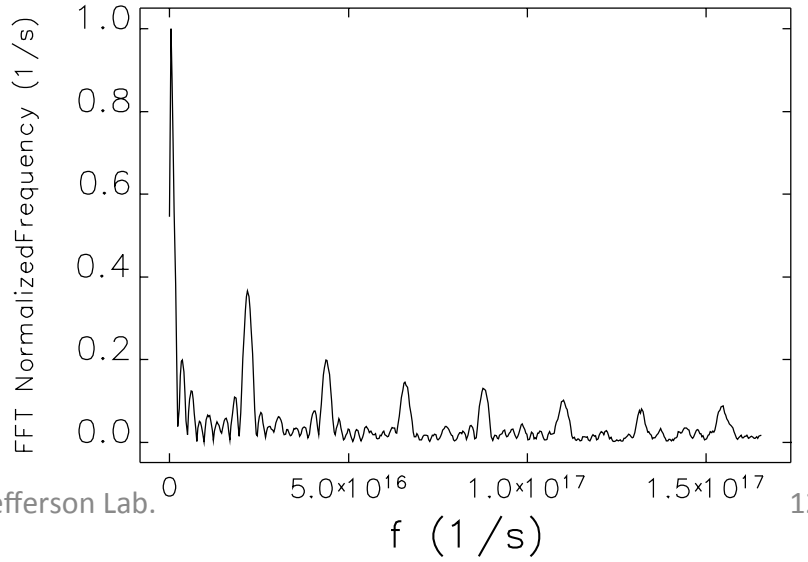


Example 9x9 array (2nd order sextupolar correction)

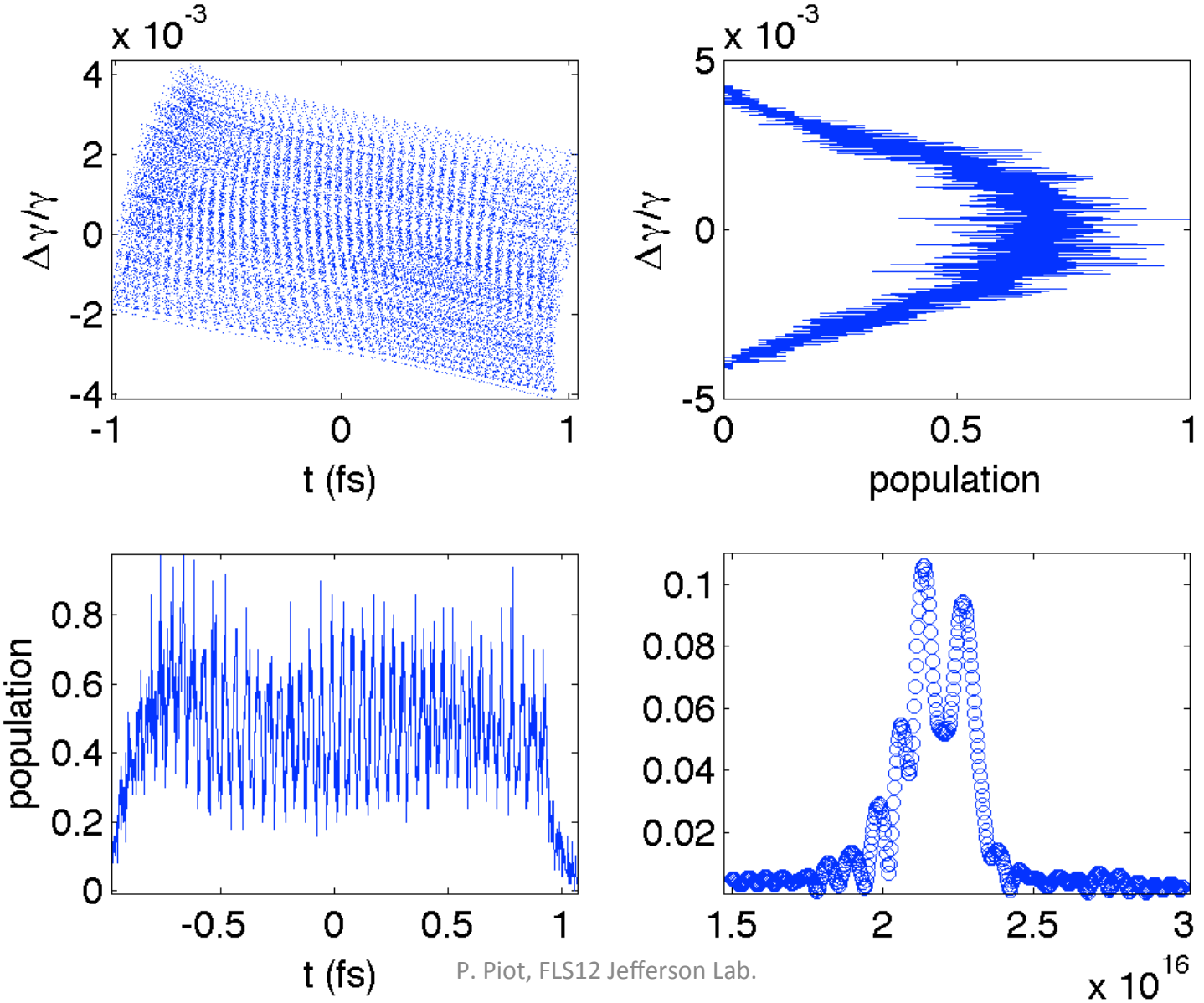








Start-to-end simulation (41x41 array)



Summary/Comments/Challenges

- Sanity check of concept prove the ISCS is viable.

- Currently working on improved model:

  - Photofield emission in VORPAL (combine ES/EM field),
  - Full model of the EEX needed (incl. hybrid deflecting cavity TM_{010}+TM_{110}),
  - Better model of ICS (modified Genesis and direct Lienard-Wichert approach)
  - Space charge in the entire beamline and its mitigation by choosing FE array aspect ratio (400x400 vs 1600x100 – also helps with aberration)