Summary: Beam Manipulation Session

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ANL Theory Institute on Production of Bright Beams

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Beam conditioning (Sessler, Whittum, Yu, 1992): parabolic radial profile of energy

$$\Delta\gamma = \kappa_u (J_x + J_y)$$

where J_x and J_y are normalized actions, $\langle J_x \rangle = \epsilon_{Nx}$.

$$\kappa_u = \frac{1}{2\bar{\beta}} \frac{\lambda_u}{\lambda_r}$$

Useful parameter, a

$$a = \kappa_u \sigma_{zu}$$

For LCLS, the nominal $\beta = 18$ m,

$$\kappa_u = 5.8\ \mu\text{m}^{-1}, \qquad a = 130$$

For the nominal emittance 1 micron, $\Delta E = 5$ MeV.

For natural focusing of the undulator, $\beta = 72$ m, one needs conditioning 4 times smaller.

Doing conditioning before compression requires less correlated energy spread

$$\kappa = \kappa_u \frac{\sigma_{zu}}{\sigma_z}$$

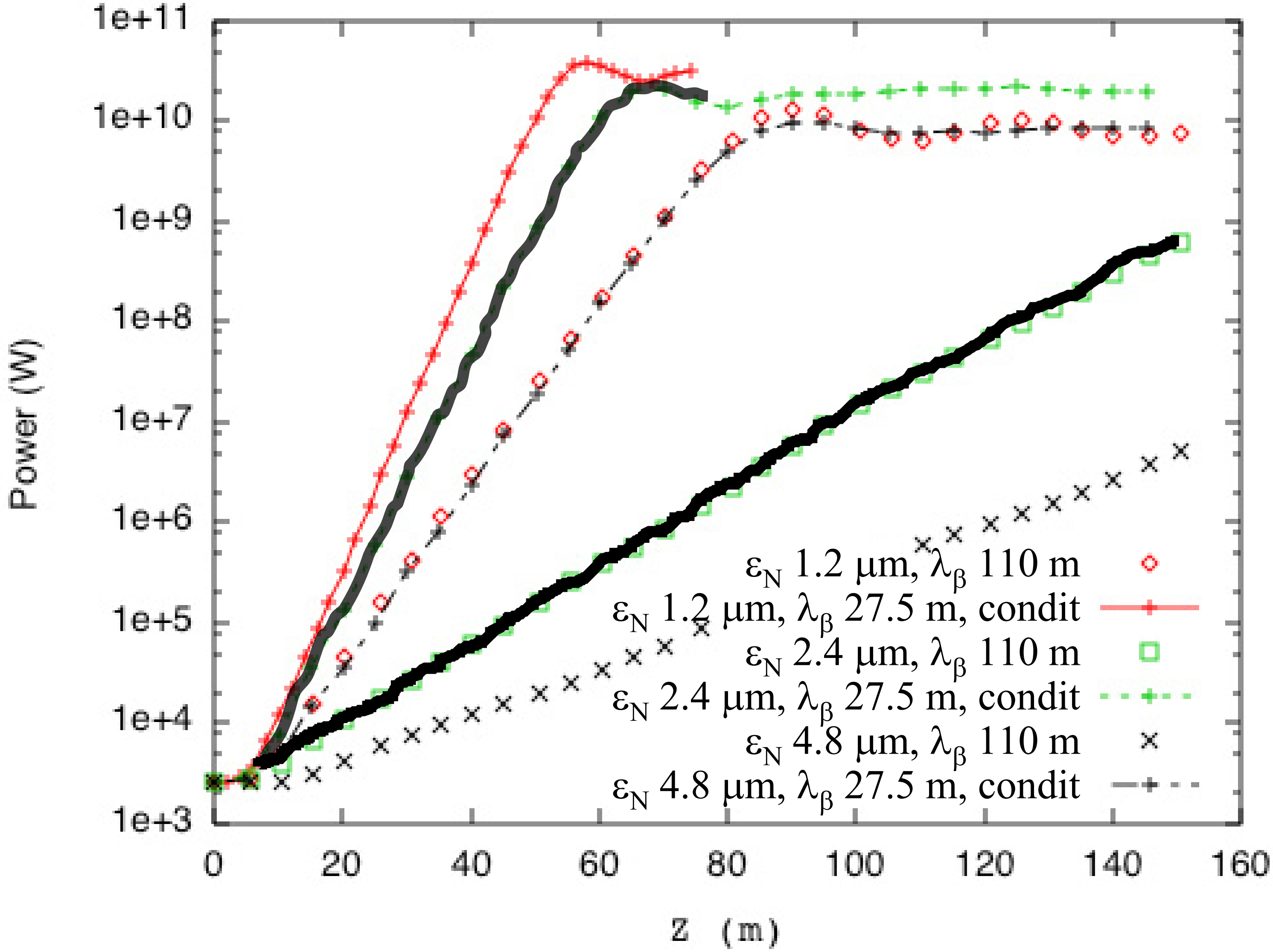
The parameter a does not depend on σ_z.

In the LCLS, the compression factor $\sigma_z/\sigma_{zu} = 40$ ($\sigma_z = 1$ mm, $\sigma_{zu} = 24$ μm).

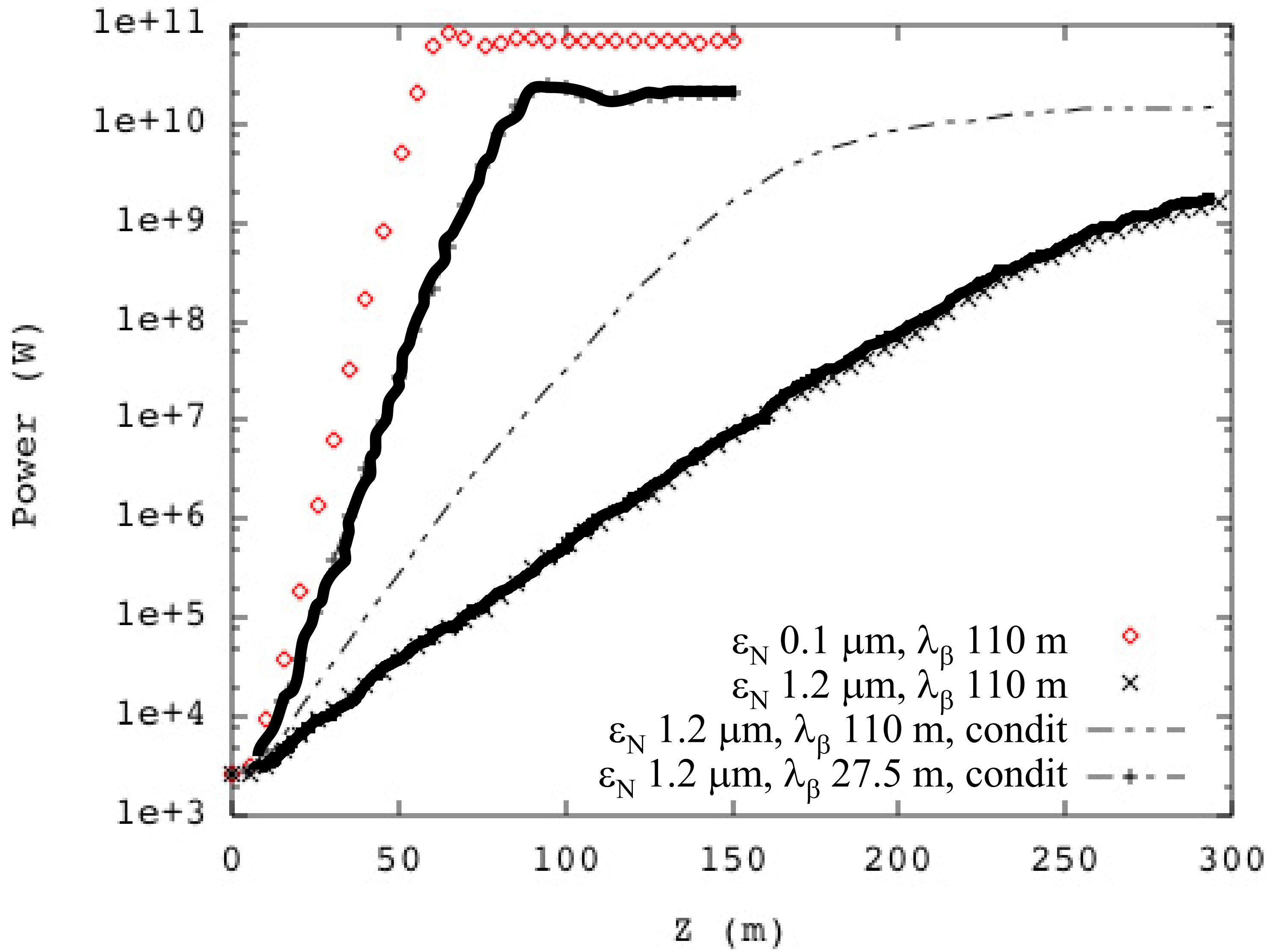
A. Sessler: if we have a conditioned beam ...

- larger transverse emittance can be used in emittance limited SASE FELS with the same performance
- or one gets smaller saturation length for the nominal emittance

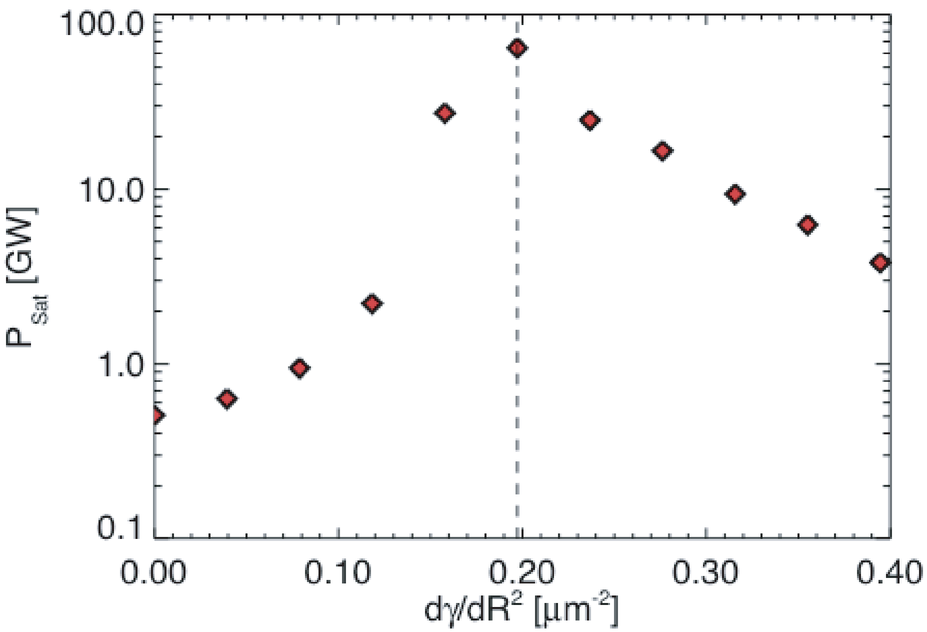
LCLS, vary emittance, optimal λ_β

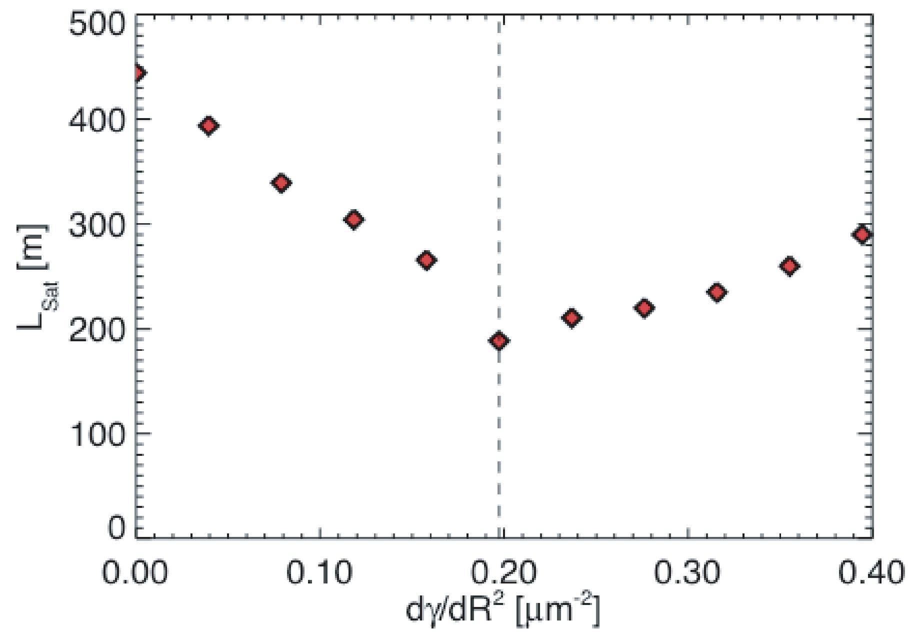


Greenfield FEL at 28 GeV



S. Reiche: effect of overconditioning and underconditioning

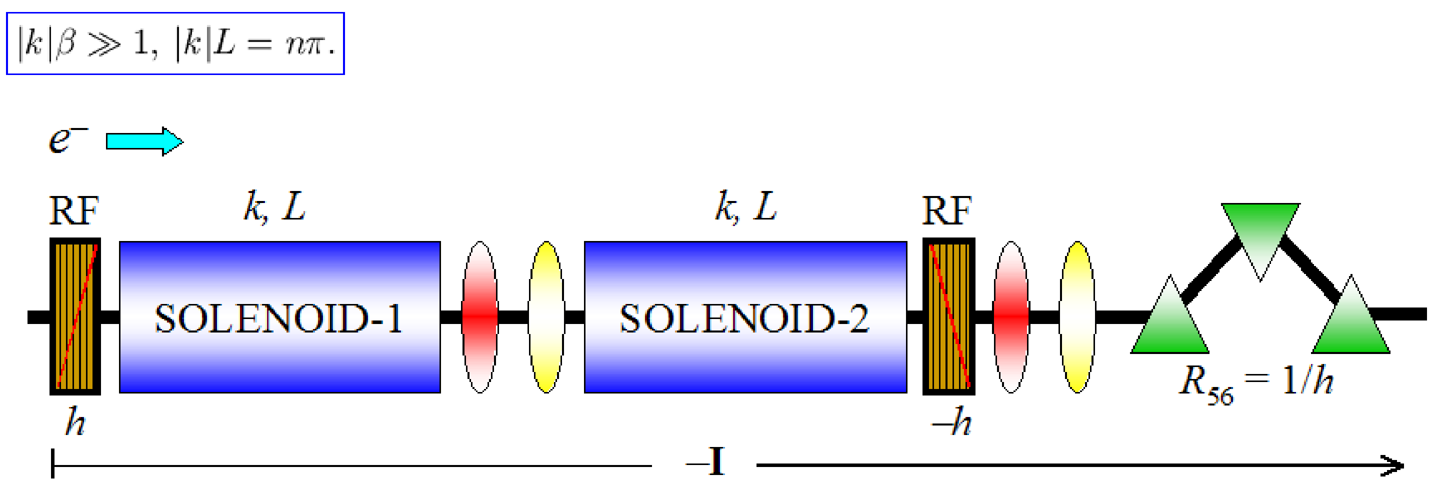




How do we condition the beam?

1. TM_{210} mode cavities in a lattice (Sessler, Whittum, Yu).
2. Using solenoids and RF-cavities (Emma, Stupakov).

'Two-Phase' FEL Conditioner



It turns out that this system gives a nasty side effect—large growth of the *projected* emittance, $\epsilon_f/\epsilon_i \sim a$ for single-phase, or even $\epsilon_f/\epsilon_i \sim a^2$ for a full conditioner. It is due to a large mismatch of the slices of the beam introduced by the conditioner.

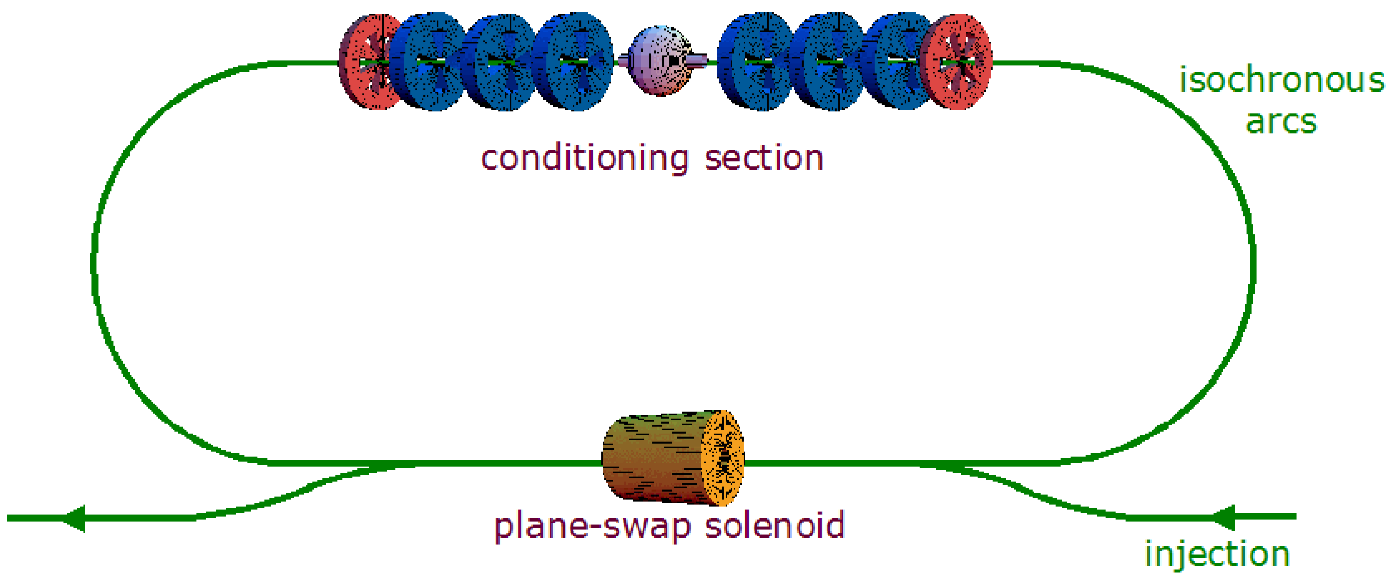
A. Wolski showed how to make conditioners that are matched. Hamiltonian:

$$H(J, \phi, z, \delta) = (\mu + \kappa z)J$$

The side effect of this conditioning is benign—phase rotation of slices of the beam.

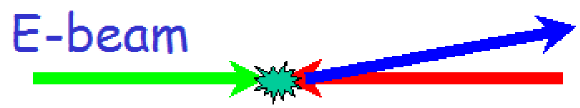
3. RF cavities + chromatic FODO beamline RF
4. TM_{110} mode cavity + sextupoles

The problem is that those conditioners are very weak, $\kappa \sim 4 \times 10^{-4}$ μm^{-1} $\rightarrow$ many passages $\rightarrow$ idea of the ring.



Unconventional approach to conditioning (Sessler, Esarey)

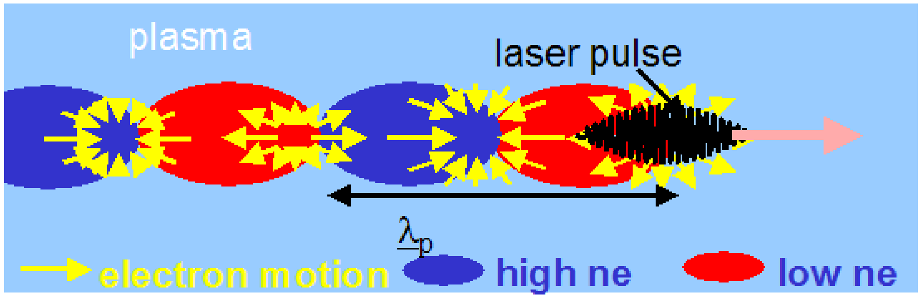
5. Laser backscattering



Pro: the process is not Hamiltonian, no side effects

Con: need large number of scattering, but the Thompson scattering cross section is small; heat the beam

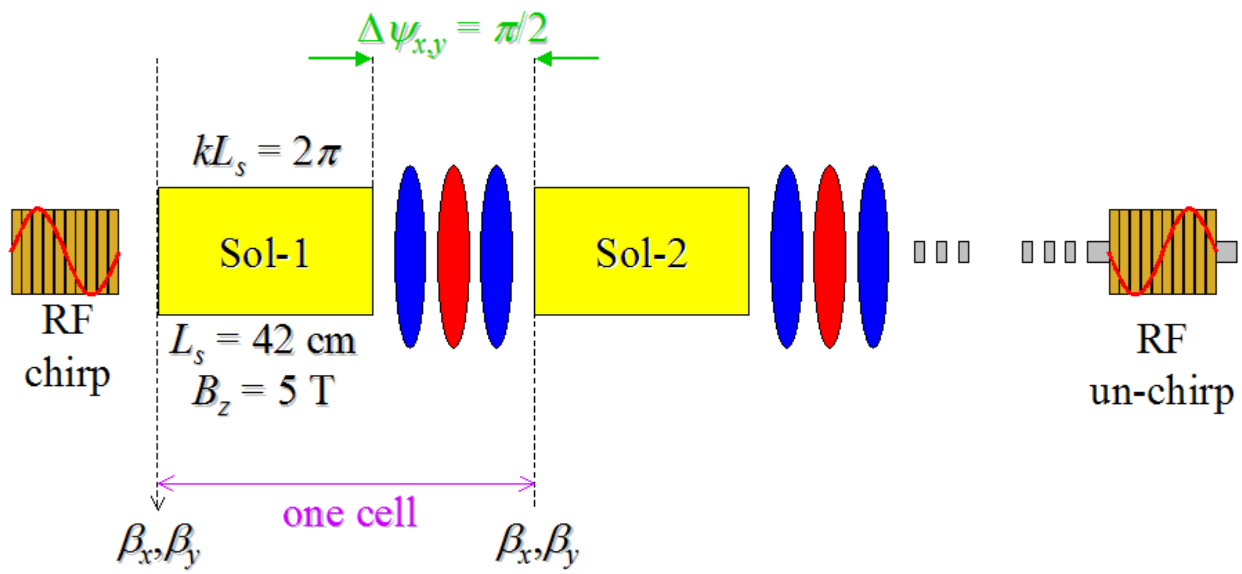
6. LWFA Conditioner

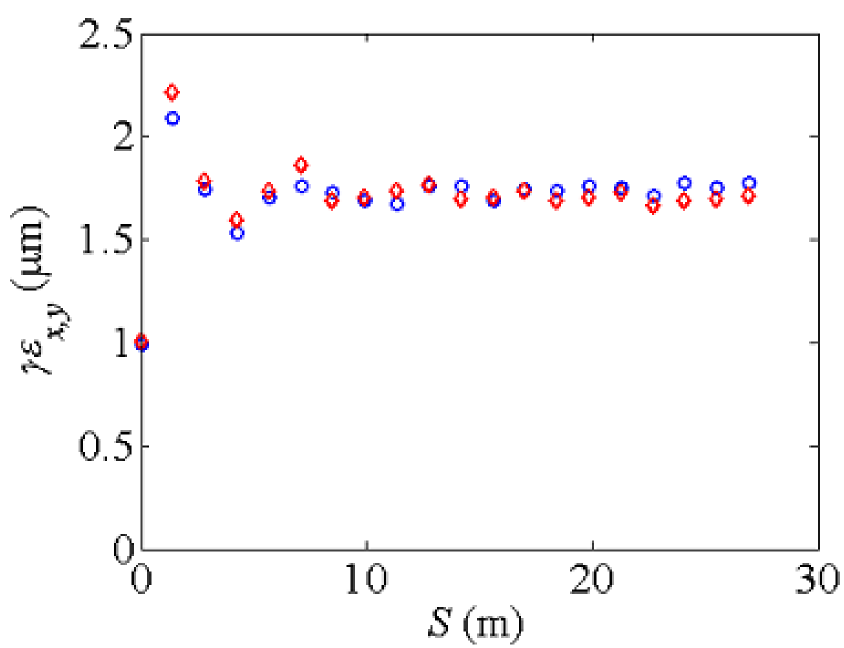


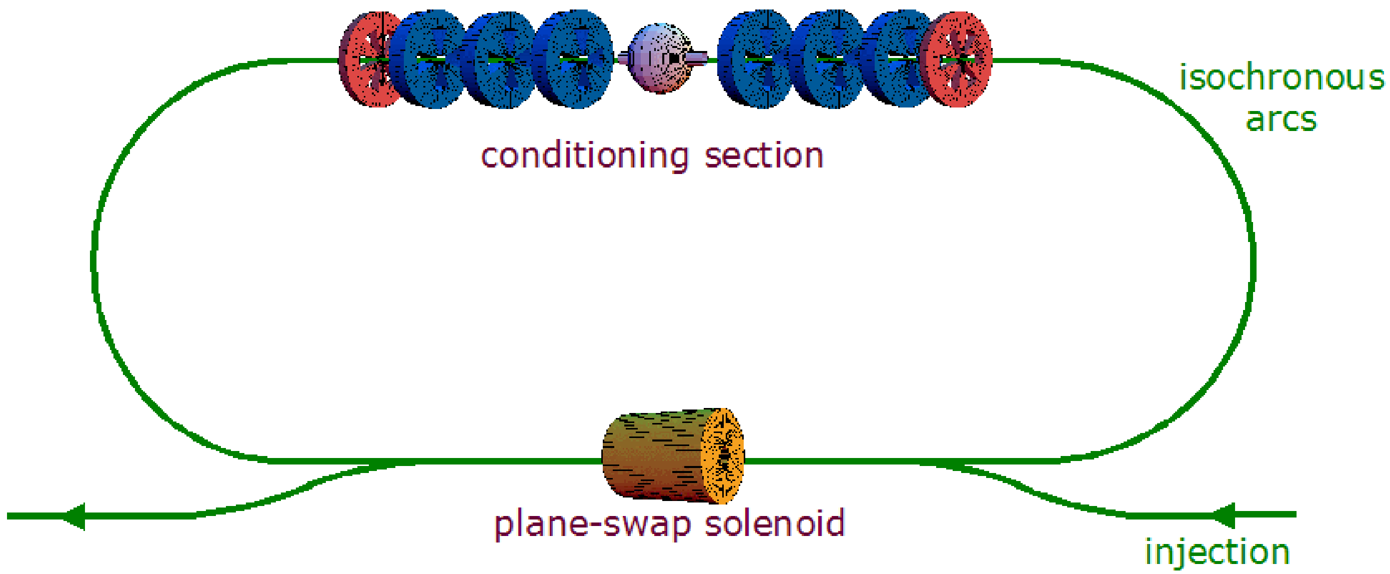
Pro: requires smaller laser energy

Con: large radial electric field, conditioning varies along the beam, more complex

One can do gentle conditioning even in unmatched system (Emma, Stupakov).



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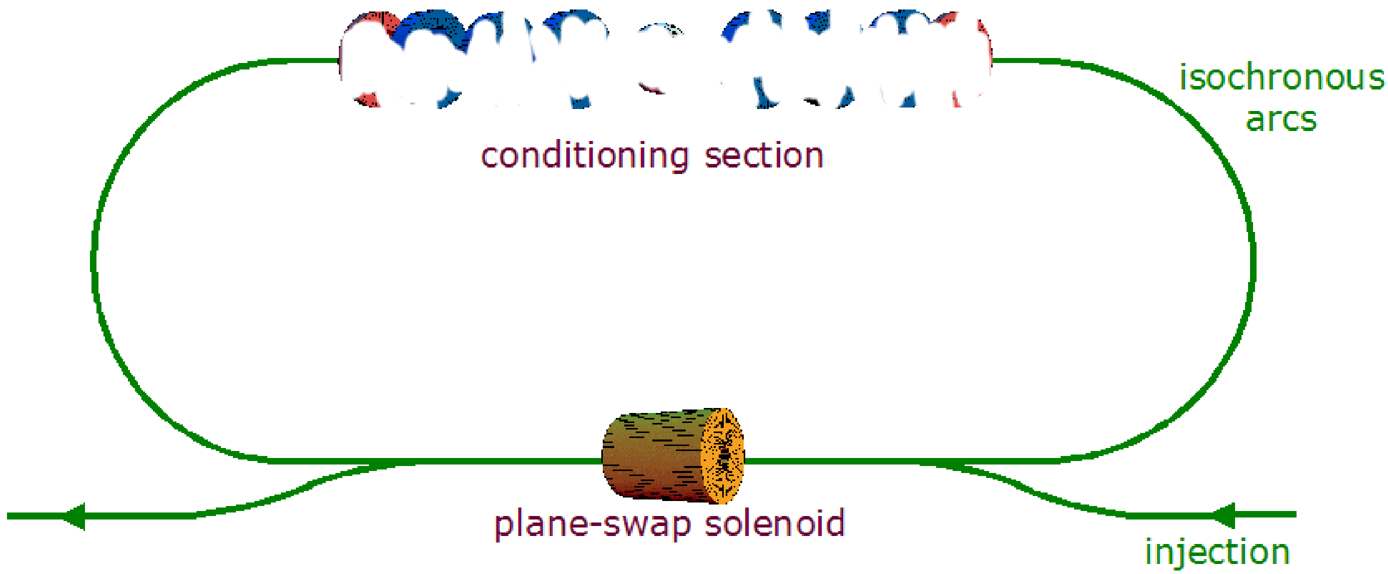
arcs
conditioning section
plane-swap solenoid
injection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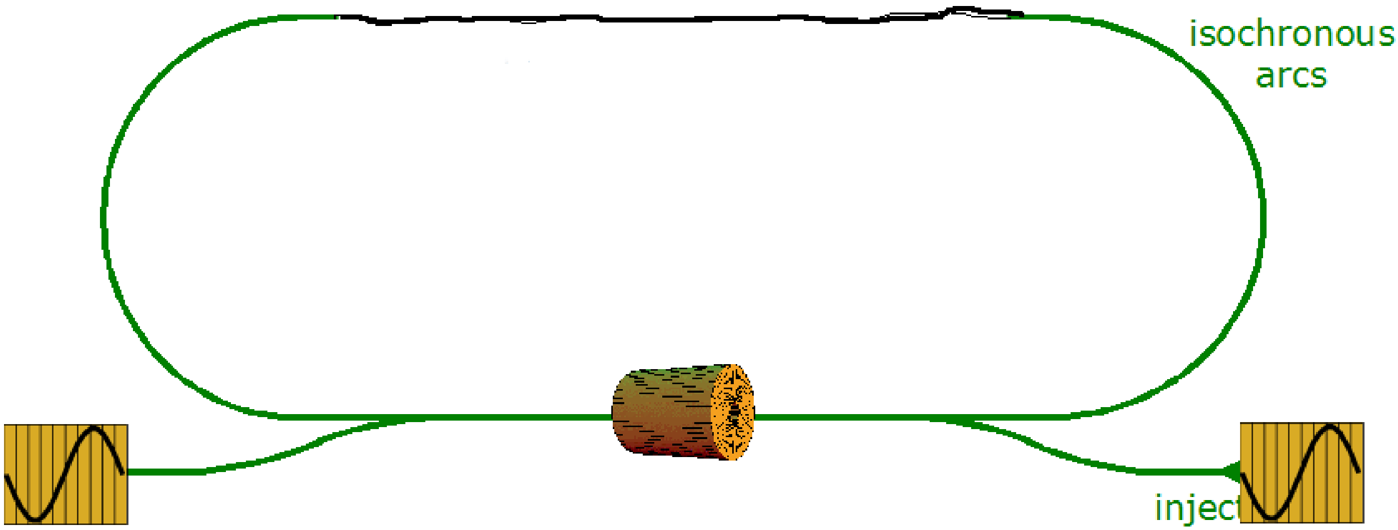
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What needs to be done?

1. SASE FEL theory and simulations

- 1D theory of SASE FEL for conditioned beam (S. Reiche)
- Simulations: overconditioning and underconditioning; vary beam emittance; include possible increase of the energy spread during conditioning; longitudinal variation of conditioning within the bunch; transverse coherence of the conditioned beam.
- Suppression of space-charge and CSR induced instability due to correlated energy spread

2. Continue work on conditioning techniques and identify the most promising candidate(s)

- A concept of ring conditioner seems very promising since conditioning in one stage/cell is relatively minor
- Better understanding/demonstration of the effect of emittance growth during conditioning, reconcile it with matched solutions of A. Wolski (K.-J. Kim)
- Are there any fundamental limitation of conditioning from Maxwell and Hamiltonian equations?
- Look more carefully at compression of conditioned beams
- S2E simulation of FEL with conditioner

3. Design of a proof of principle experiment

- Ring design of a ring based conditioner (energy, lattice, beam dynamics issues, etc.)
- Diagnostic of conditioning. Undulator radiation, a specialized energy analyzer (tomography).

Manipulation of 6D phase space of the beam

Emittance exchange: horizontal $\Leftrightarrow$ vertical, longitudinal $\Leftrightarrow$ transverse. The latter would open new horizons for FELs ...

A good subject for the next ANL Theory Institute!