TESSA – 266 nm options

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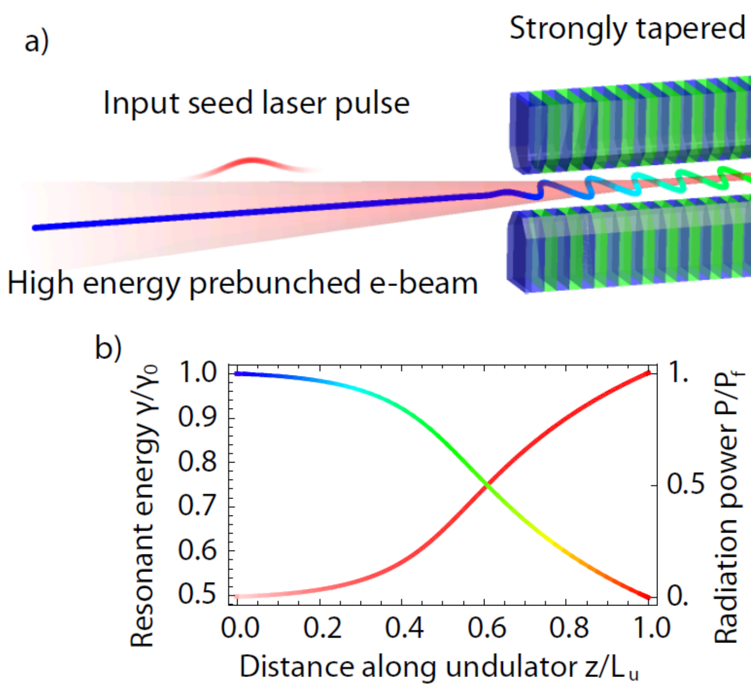
Outline

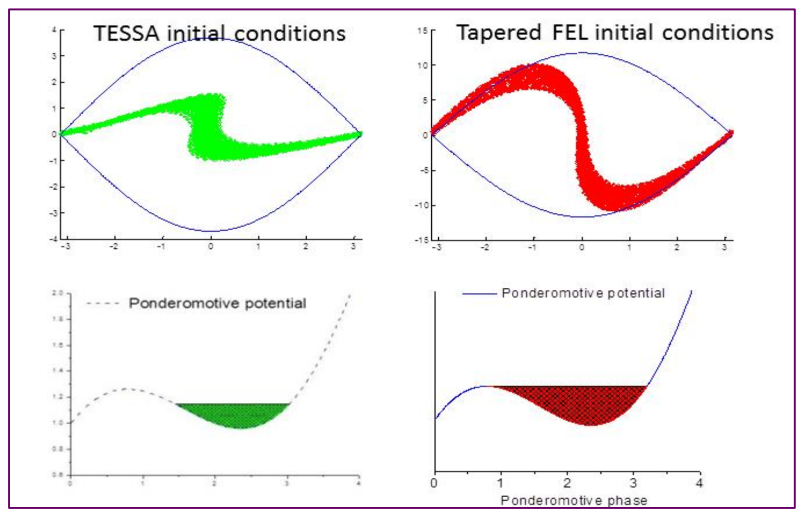
- Beam parameters
- Laser requirements
- TESSA-266 nm design
- Double buncher design
- Undulator design

Tapering Enhanced Stimulated Superradiant Amplification

- Reversing the laser-acceleration process, we can extract a large fraction of the energy from an electron beam provided:
  - A high current, microbunched input e-beam
  - An **intense input seed**
  - Gradient matching to exploit the growing radiation field

  GIT algorithm @ UCLA, but many others around (SLAC, DESY, Lund)



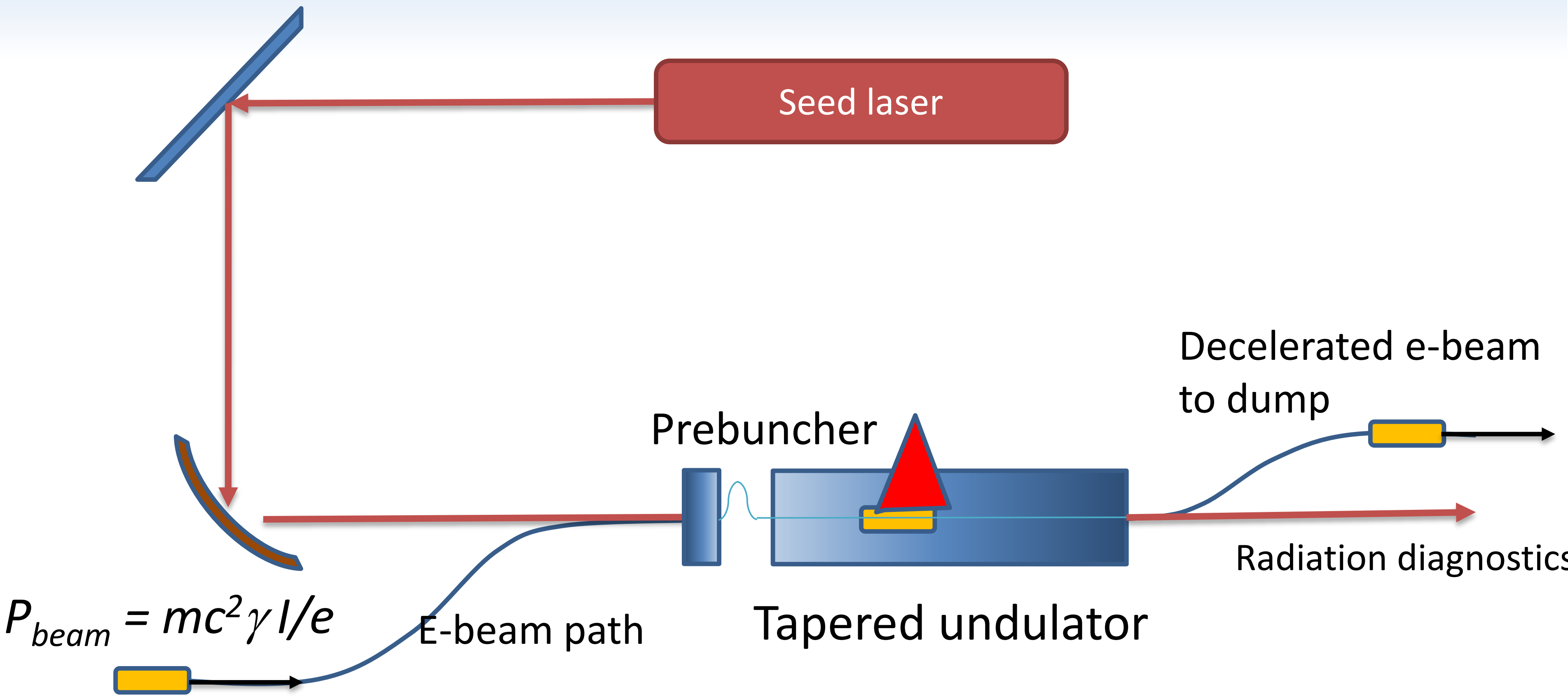


Duris et al. NJP (2015)

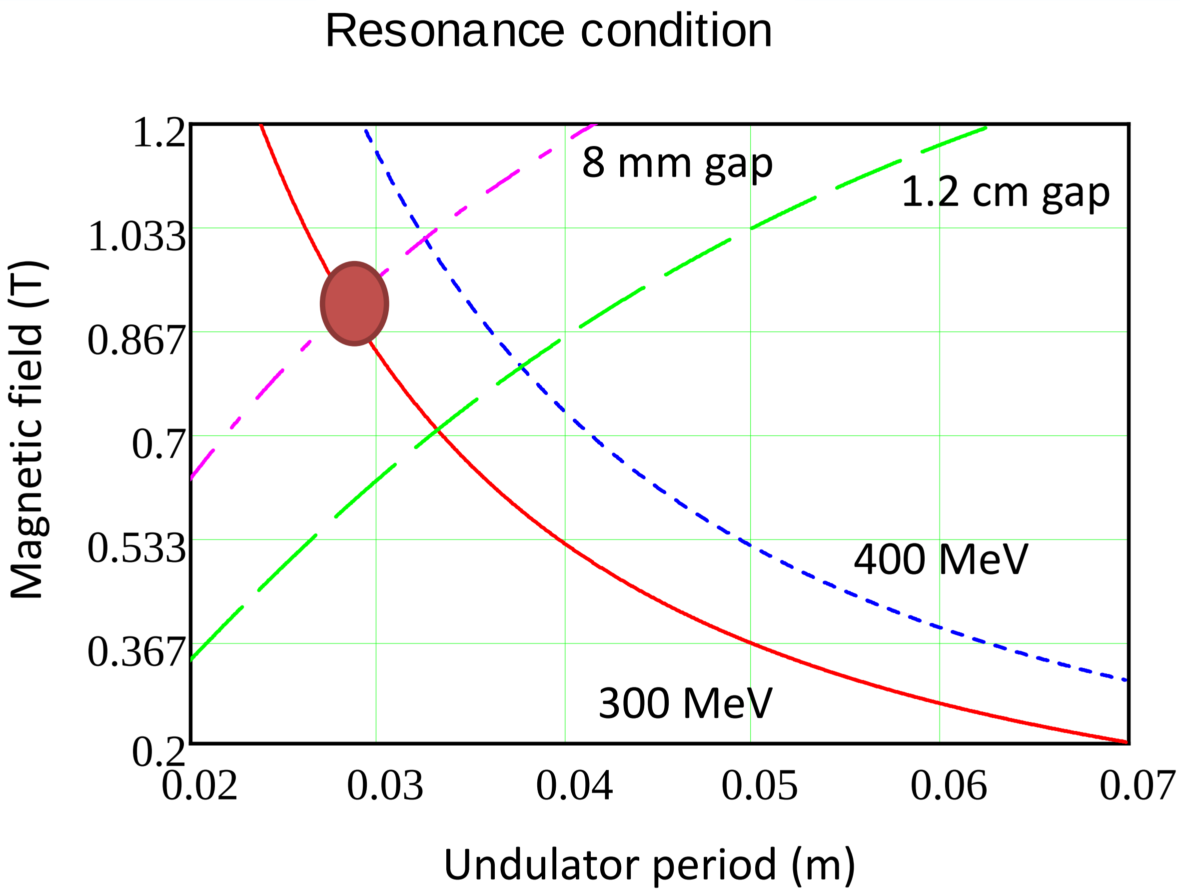
LEA TESSA-266 parameters

Beam Energy	300 MeV
Peak current	1 kA
Emittance	2 um
Energy spread	0.02 % - 0.1 %
RMS spot size in undulator	30 um – 40 um
Beta function	54 cm – 1 m
Undulator length	2 m
Radiation wavelength	266 nm
Seed power	1 GW
Interaction geometry	helical

Conceptual design of experiment

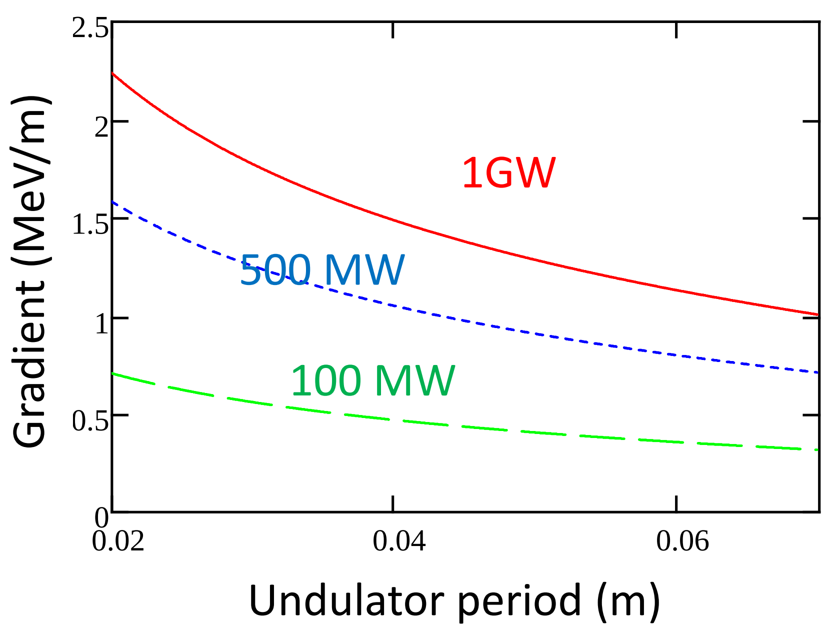


Resonance condition + Halbach-type helical undulator



Buncher design

- With P_0 = 1GW and 0.5 mm spot size a 25 cm modulator yields 0.4 MeV energy modulation >> uncorrelated energy spread after linac
- With 0.4 MeV/300 MeV, R56 = 50 um gets bunching at 266 nm
- Double buncher requires 3 times smaller DE (and 3-4 times larger R56), still larger than energy spread from linac.
- Total slippage ~ 300 fs

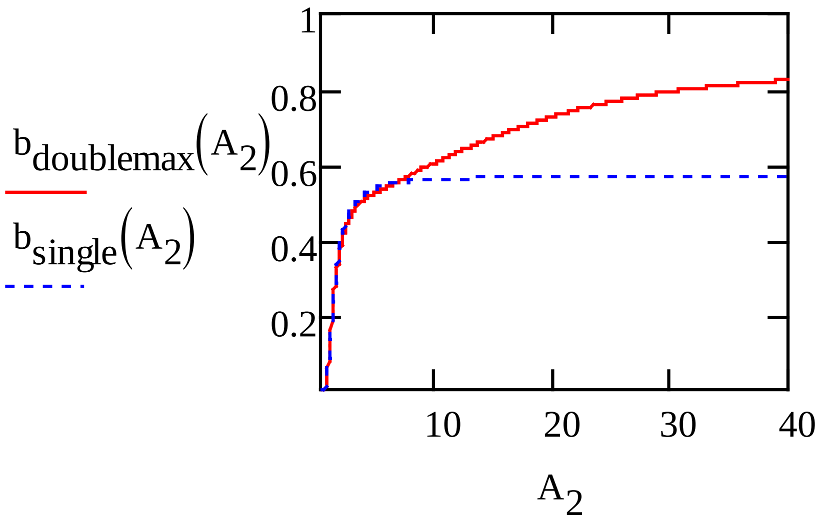


Double buncher need?

A_2 = energy modulation from second buncher normalized to beam intrinsic energy spread σ_E

Double buncher scheme really pays off when ponderomotive bucket from initial seed is much larger (i.e. 20 times) than σ_E

$$\frac{\delta\gamma}{\gamma}_{max} = \frac{2\sqrt{KK_l g(\psi_r)}}{\sqrt{1+K^2}}$$



For 1 GW input power and GV/m fields double buncher makes sense only if relative energy spread < 0.02 %

Laser requirements

Minimum pulse length is set mainly by slippage + e-beam bunch length -> 0.5 ps – 1 ps

1 mJ - 1 ps @ 266 nm Commercially available (~ 250 k$)

Upgrade existing GTF laser option (currently at UCLA)

Time-bandwidth oscillator + Nd: glass regen

0.4 mJ 2 ps @ 266 nm. Repetition rate < 10 Hz.

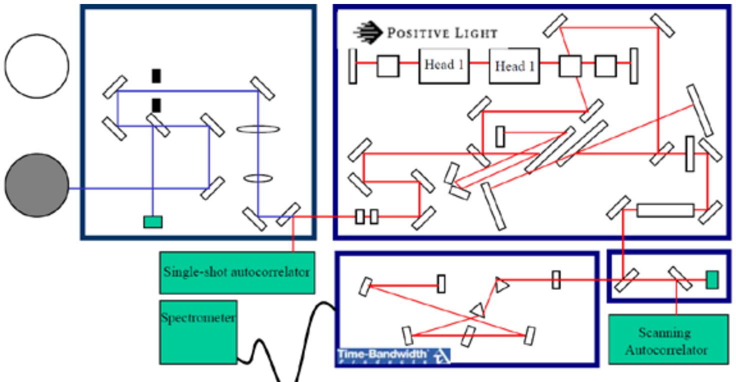


Fig. 1: A block diagram of the APS photoinjector drive laser system.

Table 1: Basic Parameters of the APS Photoinjector Drive Laser System

	Repetition rate (Hz)	Energy/power	Pulse length	Timing jitter
Oscillator (tbwp GLX 200)	119 MHz	120 mW @ 1053 nm	200 fs	200 fs
Amplifier	6 Hz	6 mJ @ 1053 nm 0.4 mJ @ 263 nm	2-10 ps	

Genesis Informed Tapering Scheme

Solve tapering equations with help of 3D FEL code Genesis

$$\frac{d\lambda_w}{dz} = -\frac{8\pi K_l K \,\mathrm{Sin}[\psi_r]}{1 + K^2 + 2\lambda_w K \frac{\partial K}{\partial \lambda_w}} \qquad K_l = \frac{e\lambda}{2\pi m c^2}\sqrt{2 Z_0 I_{\mathrm{crit}}}$$

Solve tapering period-by-period

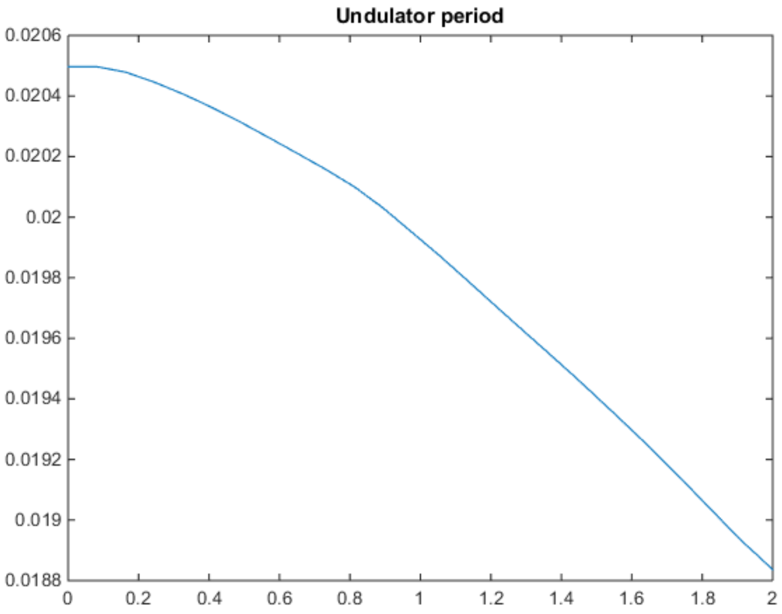
- Run Genesis on a period
- Select capturable particles (within the ponderomotive bucket)
- Measure min intensity seen by particles => threshold for capture
- Calculate new period and undulator parameter
- Saves taper as well as simulated data

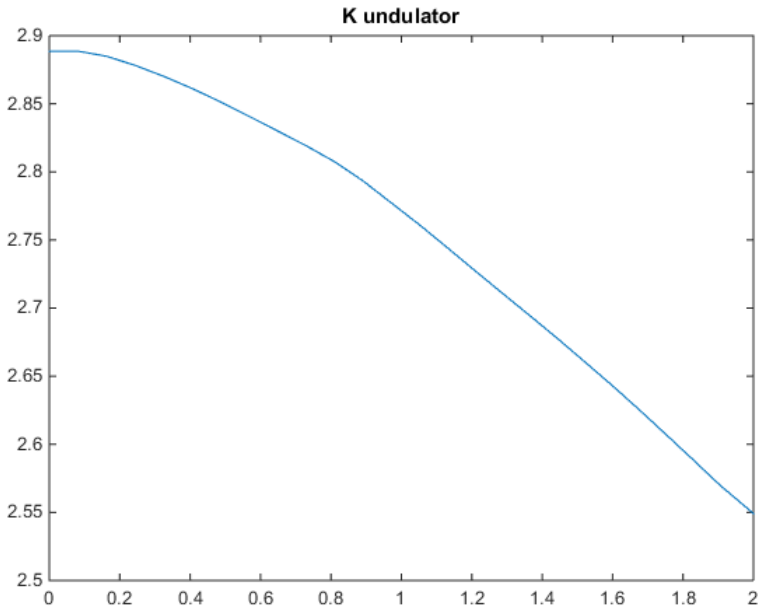
GITS offers options to dynamically optimize different simulated e-beam and radiation parameters: maximize power transfer, minimize detrapping, play with resonant phase, etc.

Originally developed for loaded IFEL design.

Generate optimal tapering profile

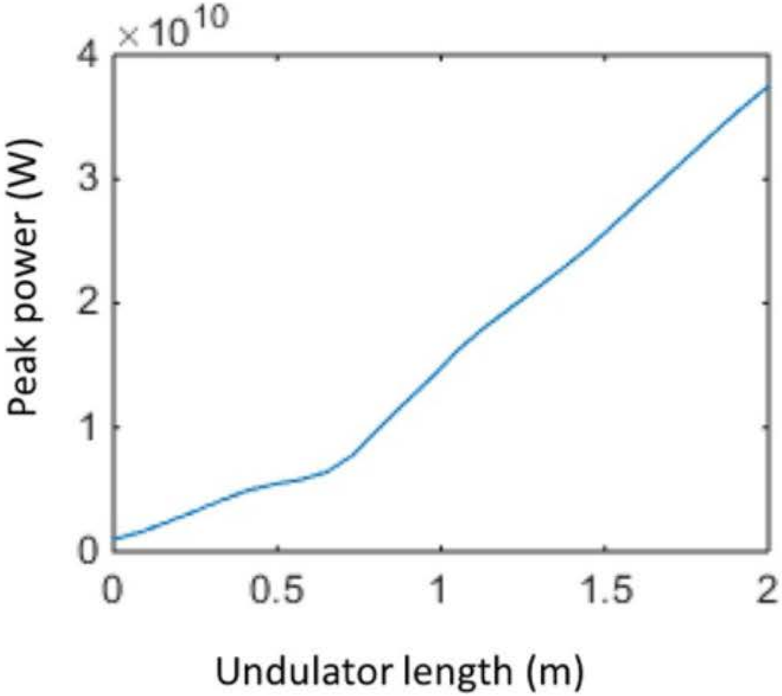
3 mm gap undulator, Br = 1.5 T, 30 micron matched beam size

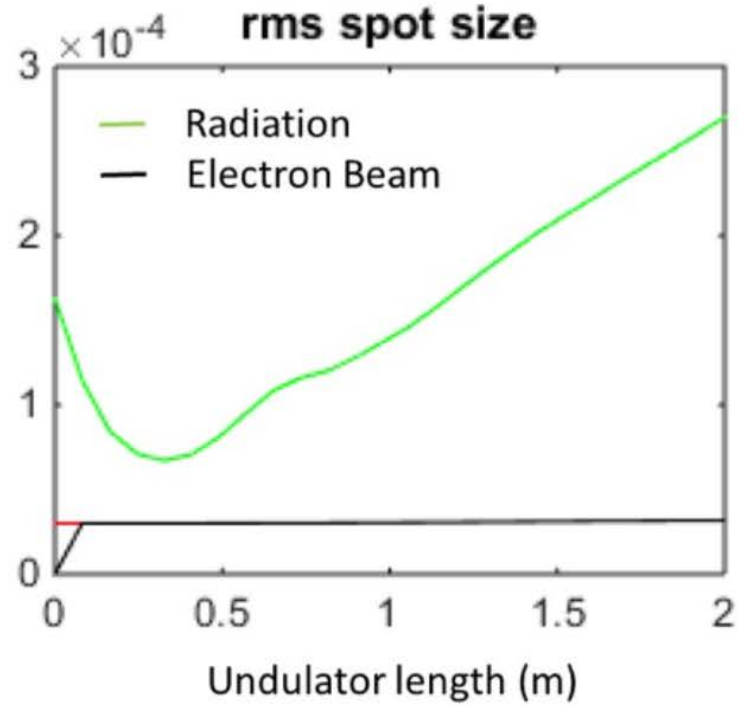




Radiation output

1 kA , 2 um emittance, 30 um rms spot size, using prebunched beam

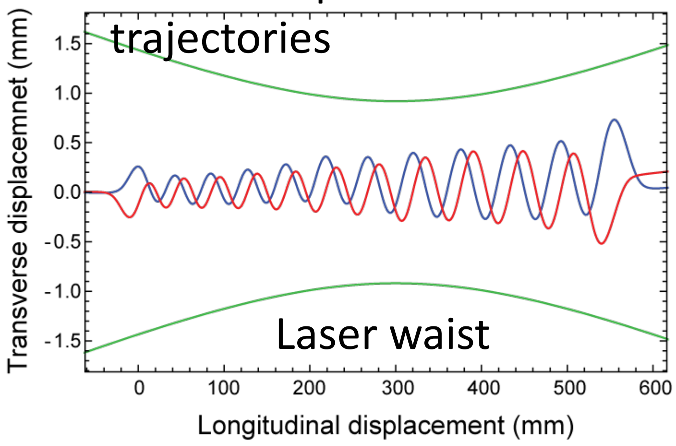


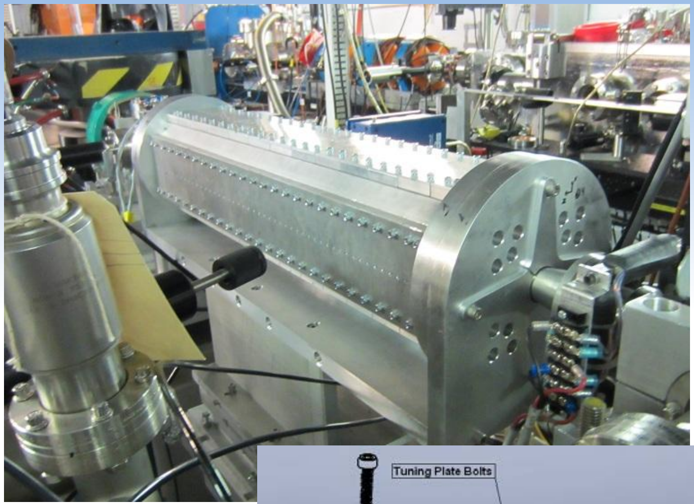


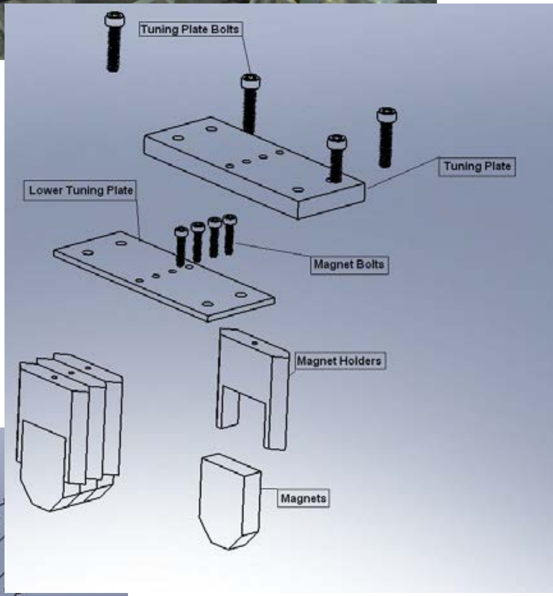
Helical undulator design

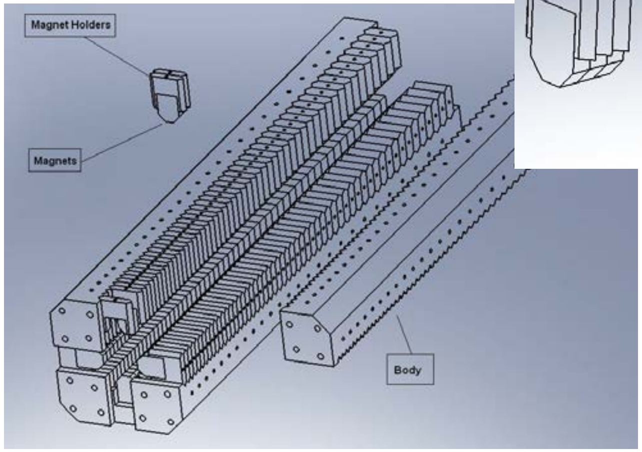
- First strongly tapered high field helical undulator
- 2 orthogonal Halbach undulators with varying period and field strength
- NdFeB magnets $B_r = 1.22T$
- Entrance/exit periods keep particle oscillation about axis
- Pipe of 14 mm diameter maintains high vacuum and low laser loses

Estimated particle trajectories









Tapered Helical Undulator technology

- 54 cm Rubicon undulator
  - Fairly inexpensive
  - Machine shop well prepared
  - It has been retuned multiple times
  - Still workhorse at ATF (no permanent magnet degradation after 4 years)
- Extend technology to 2 m
  - Magnetic forces study
  - Section breaks + in-undulator diagnostics
  - Vacuum pipe options

To do

- Use realistic beam distributions
- Optimize tapering including focusing channel
- Time-dependent simulations
- Full start-to-end