Inverse Free Electron Laser

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Group 2
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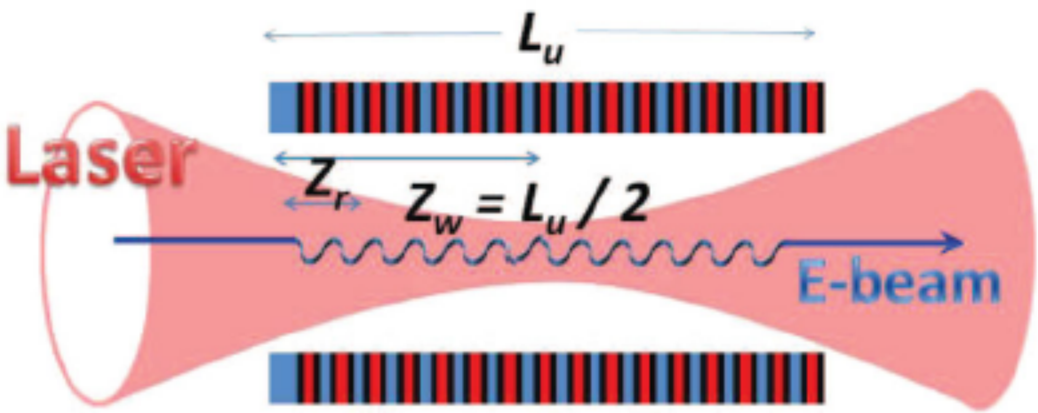
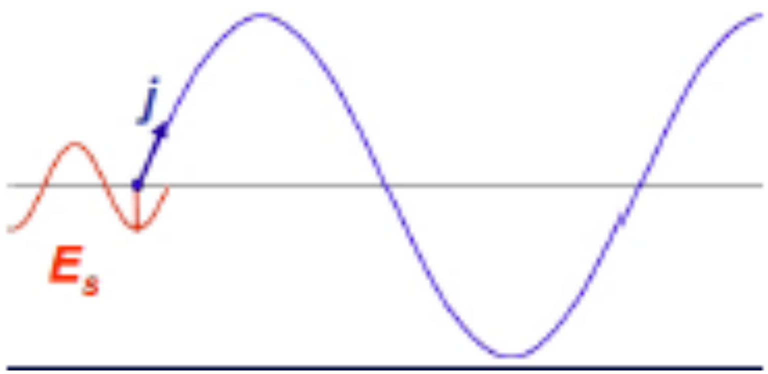
Components of IFEL



Src: Duris, PRSTAB 15,061301

- Ingredients:
  - Laser
  - Electron beam
  - Undulator

- Orient laser so that the electrons wiggle in the same direction as the laser polarization



Src: Tor Raubenheimer, Lec 2

Almost identical to FEL process, but energy transfer from radiation to particles. Hence Inverse-FEL!

Particle Dynamics

- 1D particle dynamics are described by:

$$\frac{d\gamma}{dz} = \frac{kK_l K}{\gamma} \sin\theta$$

$$\frac{d\theta}{dz} = k_w - k\frac{1 + K^2}{2\gamma^2}.$$

γ = normalized particle energy
k = ω/c = wave number of laser
K_l = eE_0/mc^2k = normalized laser vector potential
K = eB_0/mck_w = normalized undulator vector potential

θ= $k_w z$ + kz – ωt = ponderomotive phase

- The resonant condit ~72 GeV/m ase constant is:

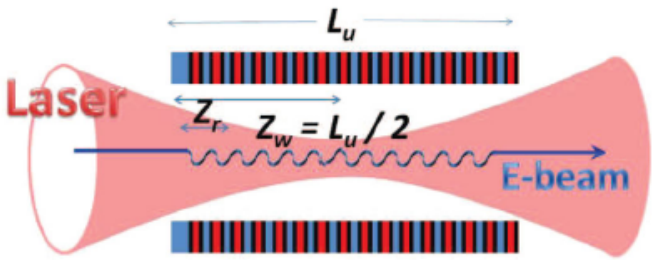
$$\gamma_r = \sqrt{k\frac{1 + K^2}{2k_w}}$$

$$\frac{d\gamma_r}{dz} = \frac{kK_l K}{\gamma_r} \sin\theta_r.$$

- As electrons reach higher energies, rate of acceleration decreases

Improving Beam Quality

- Laser
  - Circular polarization (double the performance)
  - Use guiding structures for laser
- Undulator
  - Tapering undulator period and gap
  - Tapering ponderomotive phase
- Electron beam
  - Pre-bunching
    - Cascaded/staged



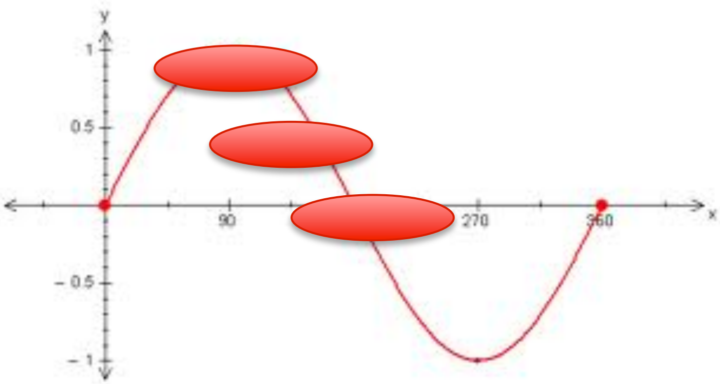
Tapering

- Tailor gap (Trace the laser spot size)
- Optimize ponderomotive phase
  - Constant at ~π/4
  - Increasing from ~0 (ease of trapping) to ~π/2 (gradient)
- Design undulator period and magnetic field

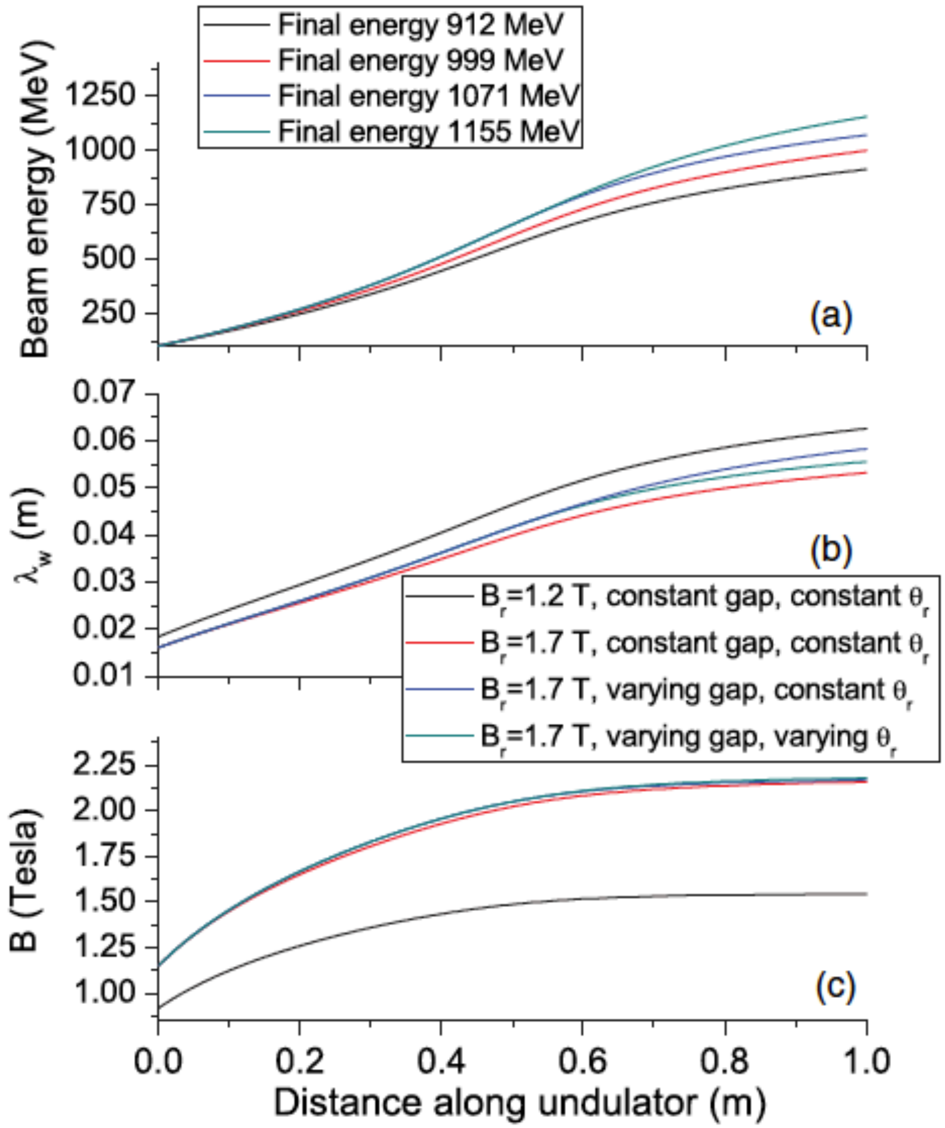
$$\gamma_r = \sqrt{k\frac{1+K^2}{2k_w}}$$

$$\frac{d\gamma_r}{dz} = \frac{kK_lK}{\gamma_r}\sin\theta_r.$$

$$B = 1.8B_r e^{-\pi g/\lambda_w}(1 - e^{-2\pi L_m/\lambda_w}).$$



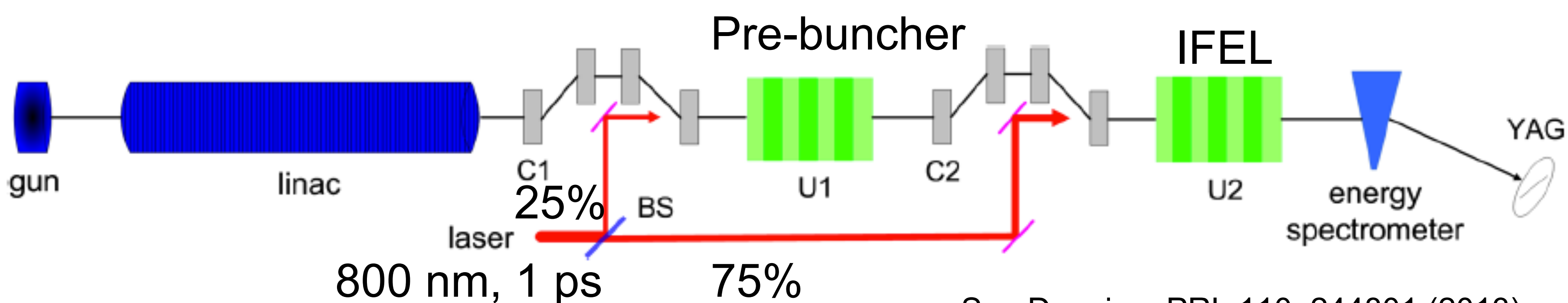
Tapering



Src: Duris, PRSTAB 15,061301

Prebunching

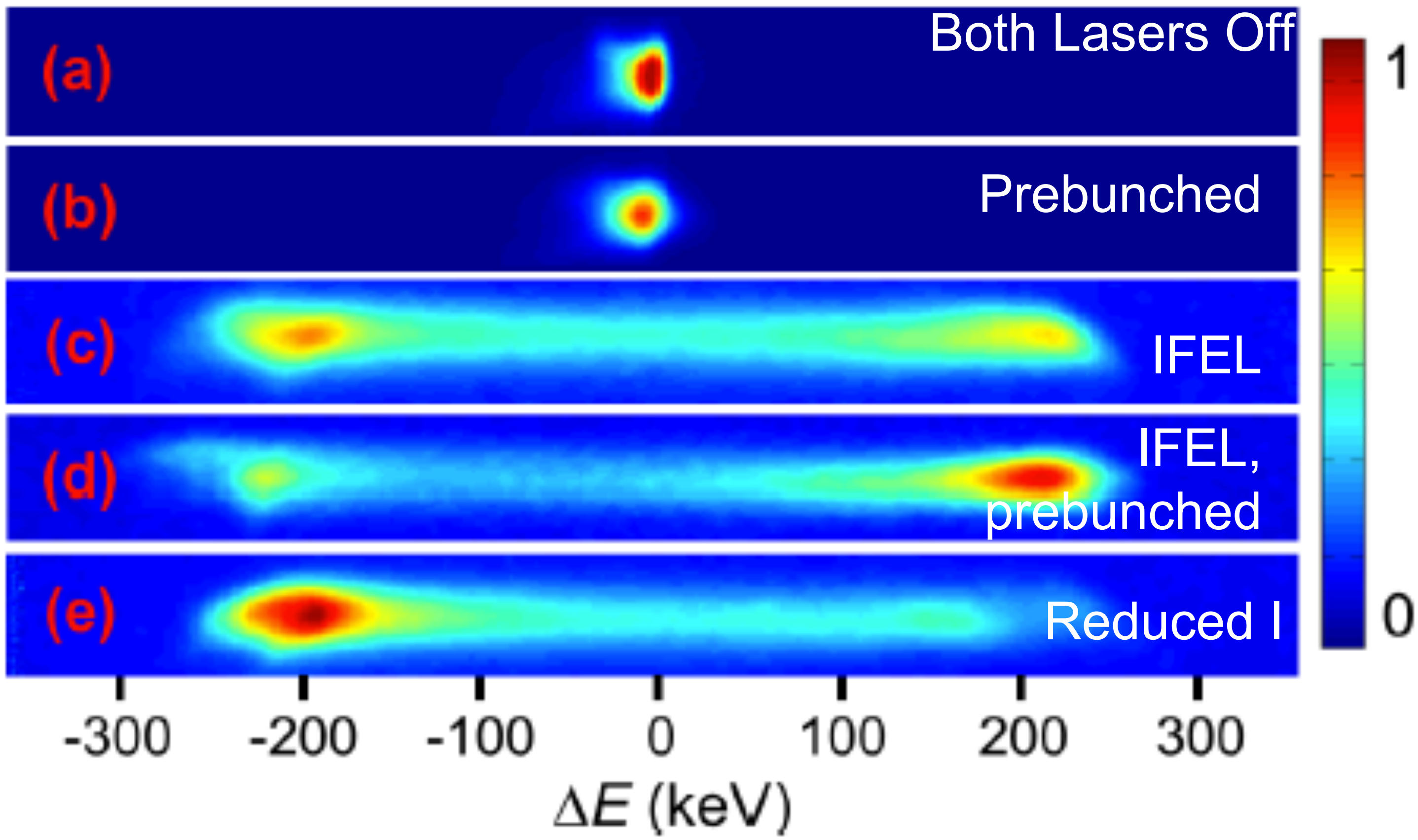
- Co-propagate low energy laser with e-beam in undulator
- Electron energy is modulated at the scale of the laser wavelength
- Going through a chicane converts the energy modulation into a density modulation



Src: Dunning, PRL 110, 244801 (2013)

Experimental Results

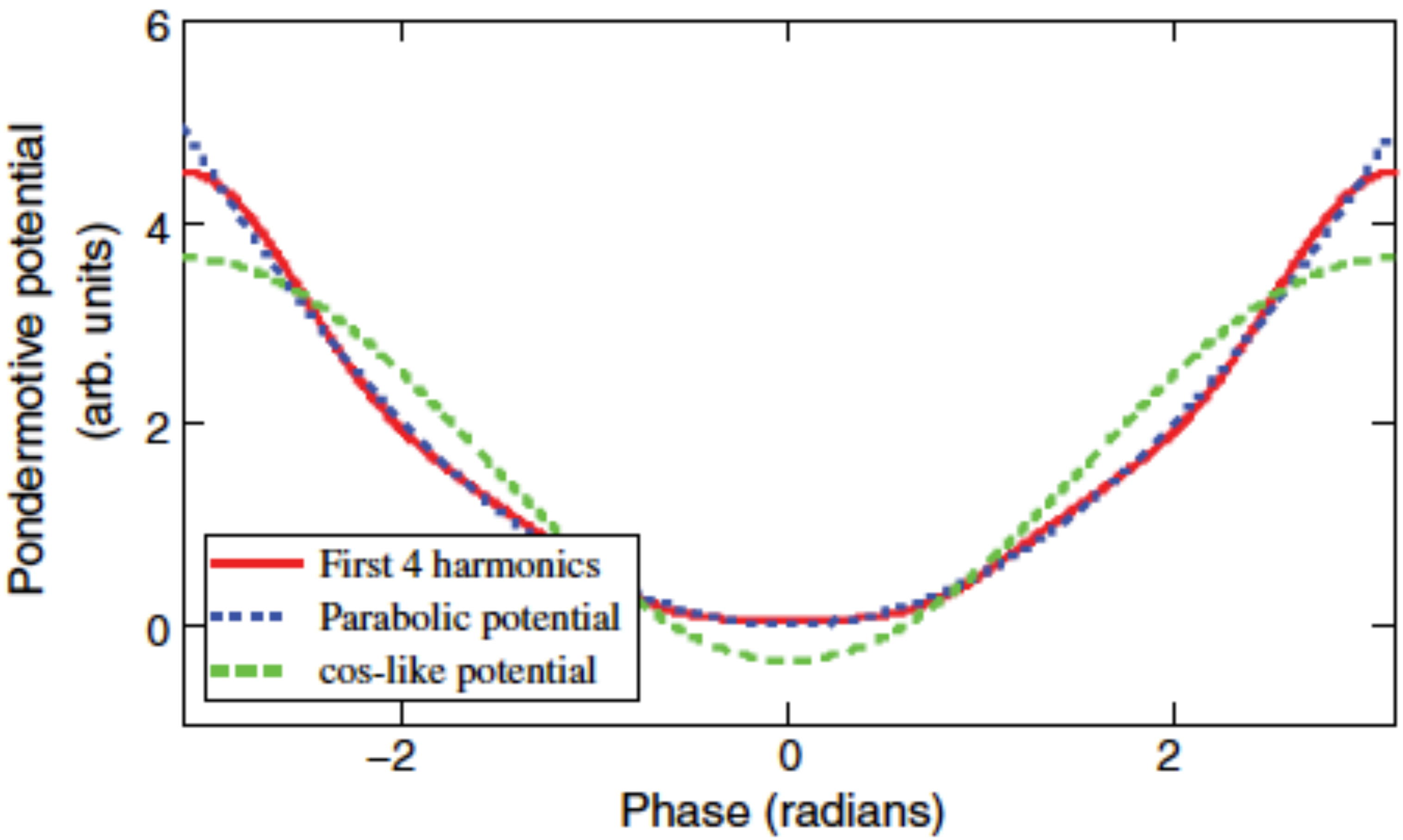
- 2013 - Two-stage IFEL at optical wavelength



E_0= 120 MeV

Src: Dunning, PRL 110, 244801 (2013)

Prebunching- Extreme Edition



Src: Duris, PRSTAB 15,061301

Proof-of-principle – CO_2 IR laser

2000: Demonstration of Staging

- Laser beam split into two
- First stage - weak laser (~24 MW) coupled with e-beam in undulator to microbunch e-beam into ~3 fs bunches to match laser period
- Second stage - microbunched e-beam sent through second undulator and phaselocked with ~300 MW laser to add or remove energy from e-beam, depending on phase delay between laser and particle bunches
- Observation of phase delay into particle acceleration/deceleration!

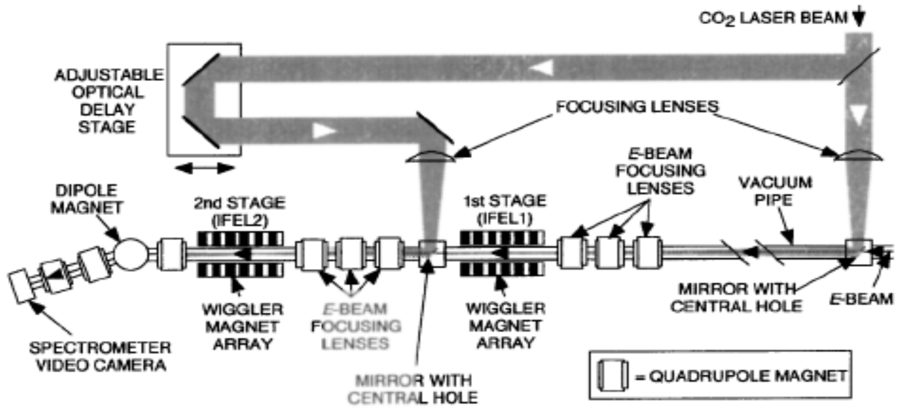
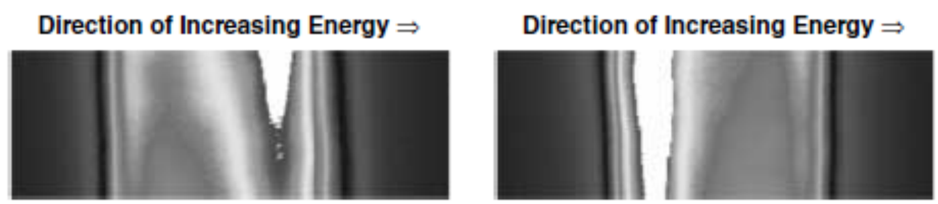


FIG. 1. Schematic layout for the STELLA experiment. For size reference, the distance separating the two IFELs is 2.3 m and the laser beams enter the beam line ≈6 m apart.



Limitation

- Maximum Achievable Energy ~few GeV
  - For higher energy gains, synchrotron radiation losses dominate further acceleration
  - Acceleration rate decreases at higher energies
    - For 10 GeV, ~ 0.5 GeV/m

E. Courant, C. Pellegrini and W. Zakowicz, Phys. Rev. A 32, 2813 (1985)
M. Dunning et al., Phys. Rev. Lett. 110, 244801 (2013)

Applications

- Compact 1-2 GeV source
  - Potentially high quality
- Use for:
  - Soft x-ray FEL driver
  - Inverse Compton Scattering for Production of Gamma Rays
  - Electron-Positron Collider
    - Motivated since finding Higgs boson at ~125 GeV range (which is accessible)

J. P. Duris, P. Musumeci, and R. K. Li, Phys. Rev. ST Accel. Beams 15, 061301 (2012)
M. Dunning et al., Phys. Rev. Lett. 110, 244801 (2013)

Conclusions

- IFEL
  - Is an accelerating scheme which operates by the laser and undulator conspiring to accelerate electrons
  - May lead to compact few GeV source in the future
  - Has energy gradients ~ 100 GeV/m theoretically attainable with current technology
  - Experiments have demonstrated staging
  - Has more room for parameter optimization

The End