10 keV Xrays FEL and CO_2 laser

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e-beam energy VS. laser wave length

- Goal: 10keV X rays

technology	Ebeam energy	Period	Scale
Normal undulator FEL (LSLS)	6 GeV	3 cm	~1.5 km
Microundulator	3 GeV	0.75 cm	~0.5 km
LWFA + undulator	4 GeV	1.5 cm	~100 m
Laser undulator (CO2 laser)	77 MeV	10 microns	~20 meters
Laser undulator (SS laser)	26 MeV	1 microns	

FEL with CO2 laser undulator
Summary of numbers

Electron beam energy	$E_e = 77.3\text{MeV}$
3D emittance	$\varepsilon_{nc} = 30.7\text{nm}$
Electron beam current	$I_e = 1.5\text{kA}$
Laser wavelength:	$\lambda_{laser} = 10.6\mu\text{m}$
Laser energy	$E_{laser} = 30\text{J}$
Laser duration (e2e flattop):	$\tau_{laser} = 30\text{ps}$
Saturation length	$L_{sat}(3\text{mm}) = 4.8\text{mm}$
Number of x rays per electron	$\dfrac{E_e}{E_X(3\text{mm})} \cdot \rho(3\text{mm}) = 8.6$
X ray energy:	$E_X(3\text{mm}) = 10\text{KeV}$

0.5ps x 30J beam is stretched to 30 ps.
~6% laser chirp will keep wavelength within 0.1% over the gain length.
Combination of chirping and longitudinal shaping is needed.

Wavelength scaling in LWFA

Laser power threshold: $$P_{bubble} > P_{crit} = \left(\frac{\tau[\mathrm{fs}]}{\lambda[\mu\mathrm{m}]}\right)^2 \cdot 30\ G\mathrm{W} = \left(\frac{\tau[\mathrm{fs}]/500}{\lambda[\mu\mathrm{m}]/10}\right)^2 \cdot 75\ T\mathrm{W}$$

Accelerated charge scales as: $$N_e \sim \lambda_{laser}\sqrt{\frac{P_{laser}}{P_{rel}}}$$

Final energy : $$\gamma_{\max} = 0.65\frac{c\tau_{laser}}{\lambda_{laser}}\sqrt{\frac{P_{laser}}{P_{rel}}}$$

10 micron laser beam will generate lower gradient then with 1 micron, but might solve problems for practical applications: higher charge, more stable, better controlled final energy.

Conclusion:

- 10 microns or longer wavelength is needed for laser undulator FEL (coherent Compton)
- 10 microns wavelength is preferential to generate high brightness sub 100 MeV beam with LWFA.
- CO_2 R&D is needed to generate ~40 J x 0.5 ps beam for LWFA and laser FEL unduator.

ATF Terawatt CO_2 Laser Story