Overview of XFELO parameters

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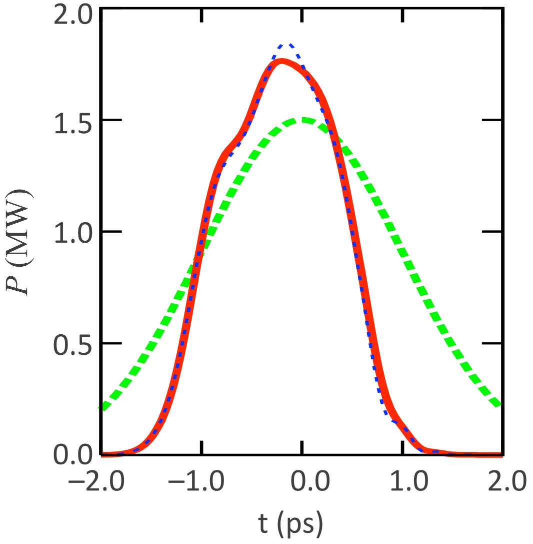
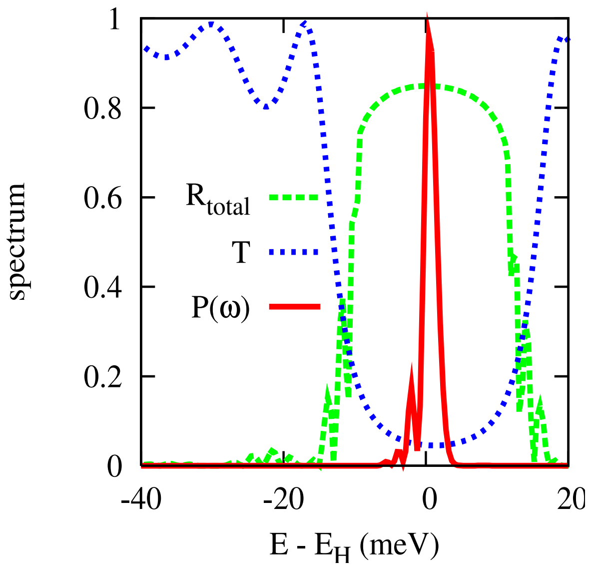
Joint ERL-FEL Session
ICFA Workshop of Future Light Sources
Thomas Jefferson National Accelerator Facility

“Canonical” Parameters and performance

γmc^2	7 GeV
Q	25 pC
I_{peak}	10 A
$\varepsilon_{x,n}$	0.2 mm-mrad
$\Delta\gamma mc^2$	1.4 MeV
L_{und}	52 m
G	0.36
R_{tot}	0.85
crystal	C(4 4 4)

P_{out}	1.7 MW
Photons/ pulse	1.1×10^9
ΔE_{FWHM}	1.95 meV
Δt_{FWHH}	1.58 ps





R.R. Lindberg, K-J. Kim, Yu. Shvyd’ko, and W.M. Fawley, *Phys. Rev. ST-AB.* **14,** 010701 (2011)

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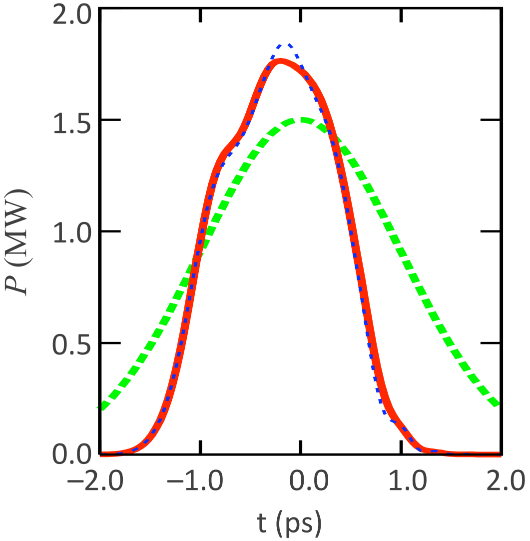
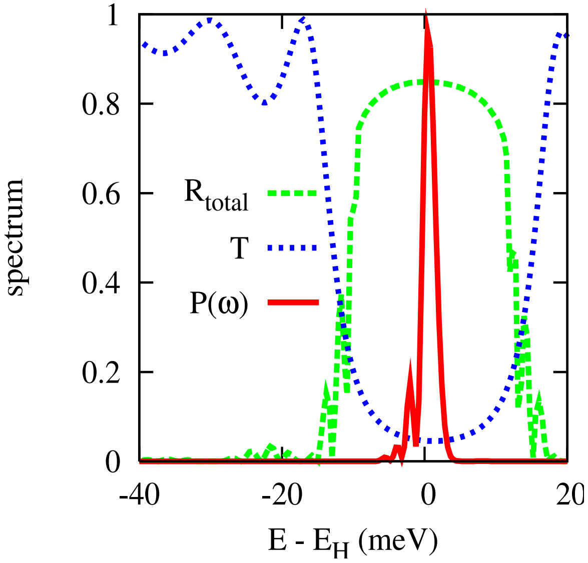
Compress the beam further to increase current and FEL gain





R.R. Lindberg, K-J. Kim, Yu. Shvyd’ko, and W.M. Fawley, *Phys. Rev. ST-AB.* **14,** 010701 (2011)

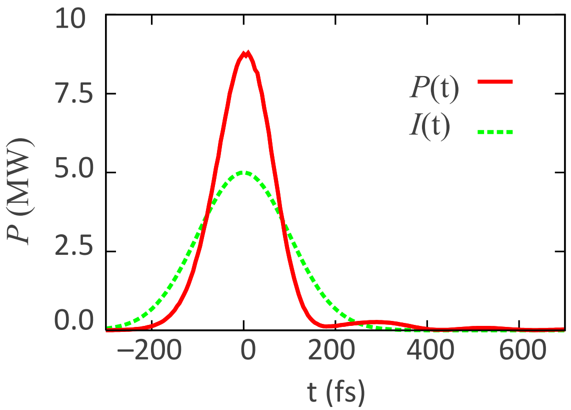
Higher current for more gain

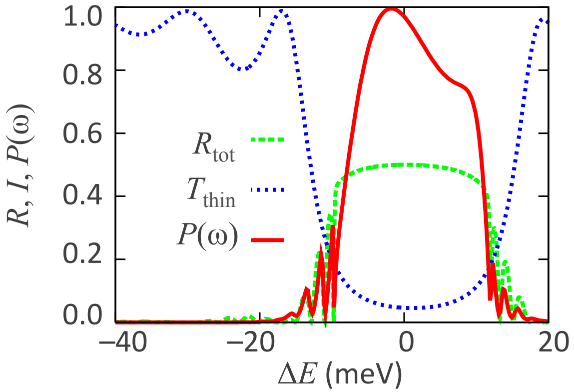
γmc^2	7 GeV
Q	25 pC
$\boldsymbol{I_{peak}}$	**10 A**
$\varepsilon_{x,n}$	0.2 mm-mrad
$\Delta\gamma mc^2$	1.4 MeV
$\boldsymbol{L_{und}}$	**52 m**
$\boldsymbol{G}$	**0.36**
$\boldsymbol{R_{tot}}$	**0.85**
crystal	C(4 4 4)

E_{beam}	7 GeV
Q	25 pC
$\boldsymbol{I_{peak}}$	**100 A**
$\varepsilon_{x,n}$	0.2 mm-mrad
$\Delta\gamma mc^2$	0.02%
$\boldsymbol{L_{und}}$	**20 m**
$\boldsymbol{G}$	**1.64**
$\boldsymbol{R_{tot}}$	**0.5**
crystal	C(4 4 4)

P_{out}	1.7 MW
Photons/ pulse	1.1×10^9
ΔE_{FWHM}	1.95 meV
Δt_{FWHH}	1.58 ps

P_{out}	8.4 MW
Photons/ pulse	8.7×10^8
ΔE_{FWHM}	15 meV
Δt_{FWHH}	170 fs





R.R. Lindberg, K-J. Kim, Yu. Shvyd'ko, and W.M. Fawley, *Phys. Rev. ST-AB.* **14,** 010701 (2011)

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crystal	C(4 4 4)

E_{beam}	7 GeV
Q	25 pC
I_{peak}	**100 A**
$\varepsilon_{x,n}$	**0.4 mm-mrad**
$\Delta\gamma mc^2$	1.4 MeV
L_{und}	40 m
G	**1.23**
R_{tot}	**0.5**
crystal	C(4 4 4)

P_{out}	1.7 MW
Photons/ pulse	1.1×10^9
ΔE_{FWHM}	1.95 meV
Δt_{FWHH}	1.58 ps

P_{out}	8.4 MW
Photons/ pulse	8.7×10^8
ΔE_{FWHM}	15 meV
Δt_{FWHH}	170 fs

P_{out}	1.1 MW
Photons/ pulse	8.2×10^8
ΔE_{FWHM}	15 meV
Δt_{FWHH}	165 fs

R.R. Lindberg, K-J. Kim, Yu. Shvyd'ko, and W.M. Fawley, *Phys. Rev. ST-AB.* **14,** 010701 (2011)

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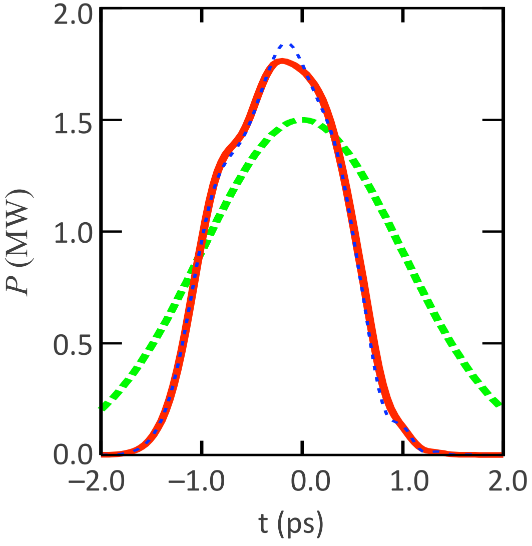
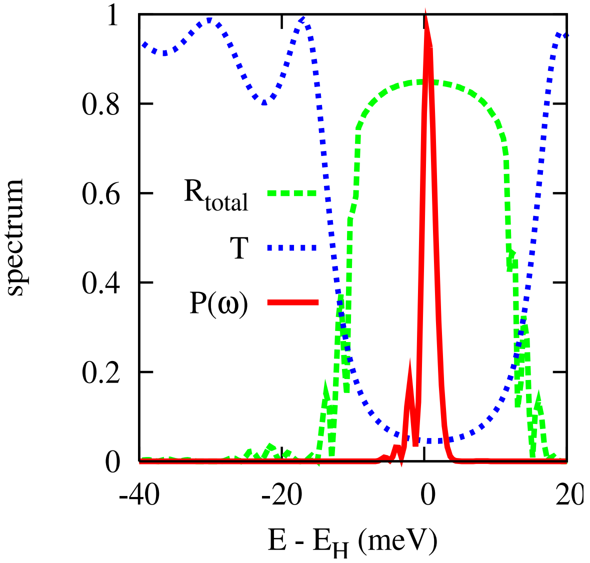
Beam brightness is far from optimal for our parameters

If emittance, energy spread (and/or temporal duration) decreased one can consider many other possibilities





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Negligible emittance: $\gamma\varepsilon_{x,n} \ll \dfrac{\lambda}{4\pi}$

$$\varepsilon_{x,n} \lesssim 0.01\ \mathrm{mm}\cdot\mathrm{mrad} \qquad \boxed{G \to 1.3}$$

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Negligible energy spread: $\dfrac{\Delta\gamma}{\gamma} \ll \dfrac{1}{2N_u}$

$$\Delta\gamma mc^2 \lesssim 100\ \mathrm{keV} \qquad \boxed{G \to 2.3}$$

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Both $G \to 11$

R.R. Lindberg, K-J. Kim, Yu. Shvyd’ko, and W.M. Fawley, *Phys. Rev. ST-AB.* **14,** 010701 (2011)

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$$\Delta\gamma mc^2 \lesssim 100\ \mathrm{keV} \qquad \boxed{G \to 2.3}$$

Both $G \to 11$

Halving emittance and energy spread:

$$\varepsilon_{x,n} = 0.1\ \mathrm{mm}\cdot\mathrm{mrad},\ \Delta\gamma mc^2 = 0.7\ \mathrm{MeV} \qquad \boxed{G \to 1.8}$$

R.R. Lindberg, K-J. Kim, Yu. Shvyd’ko, and W.M. Fawley, *Phys. Rev. ST-AB.* **14,** 010701 (2011)

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Δt_{FWHH}	1.58 ps

Negligible emittance: $\gamma\varepsilon_{x,n} \ll \frac{\lambda}{4\pi}$

$$\varepsilon_{x,n} \lesssim 10^{-2}\ \mathrm{mm}\cdot\mathrm{mrad}$$

$G \to 1.3$

Negligible energy spread: $\frac{\Delta\gamma}{\gamma} \ll \frac{1}{2N_u}$

Both

$G \to 11$

$$\Delta\gamma mc^2 \lesssim 100\ \mathrm{keV}$$

$G \to 2.3$

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$$\varepsilon_{x,n} = 0.1\ \mathrm{mm}\cdot\mathrm{mrad},\ \Delta\gamma mc^2 = 0.7\ \mathrm{MeV}$$

$G \to 1.8$

One way to decrease emittance is to decrease charge

R.R. Lindberg, K-J. Kim, Yu. Shvyd’ko, and W.M. Fawley, *Phys. Rev. ST-AB.* **14,** 010701 (2011)

Smaller emittance beams for XFELO

Decrease in emittance ~50%, energy spread by factor of 6, and width by 2 permits proposed XFELO in JAERI-KEK ERL design to operate 5 GeV and lower peak current*

Decrease in emittance by ~2.5, energy spread by factor of 14, and width by 4 permits lasing at the 3rd harmonic at 3.5 GeV†

As an extreme example of the possible uses of low charge, we have adapted the 1pC, ultra-short beams first proposed for high-gain FELs in the "single spike" regime¥

Q = 1 pC, σ_e = 250 fs ➔ I = 1.6 A

ε_{xn} = 0.062 mm•mrad ΔE = 250 keV

* R. Hajima and N. Nishimori, Proc. of 2009 FEL Conf

† Dai, H. Deng, and Z. Dai, Phys. Rev. Lett. **108**, 034802 (2012).

¥ J.B. Rosenzweig, et al.,, *Nucl. Instrum. Methods A.* **593,** 39 (2008).

XFELO using ultra-small emittance beam @ 1pC

γmc^2	7 GeV
Q	25 pC
I_{peak}	**10 A**
$\varepsilon_{x,n}$	**0.2 mm-mrad**
$\Delta\gamma mc^2$	**1.4 MeV**
L_{und}	52 m
G	**0.36**
R_{tot}	**0.85**
crystal	C(4 4 4)

E_{beam}	7 GeV
Q	1 pC
I_{peak}	**1.6 A**
$\varepsilon_{x,n}$	**0.062 mm-mrad**
$\Delta\gamma mc^2$	**250 keV**
L_{und}	52 m
G	**0.74**
R_{tot}	**0.5**
crystal	C(4 4 4)

P_{out}	1.7 MW
Photons/ pulse	**1.1×10^9**
ΔE_{FWHM}	1.95 meV
Δt_{FWHH}	1.58 ps

P_{out}	31 kW
Photons/ pulse	**5×10^6**
ΔE_{FWHM}	6.3 meV
Δt_{FWHH}	0.42 ps

XFELO using ultra-small emittance beam @ 1pC

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R_{tot}	0.85
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$\Delta\gamma mc^2$	**250 keV**
L_{und}	52 m
G	**0.74**
R_{tot}	0.85
crystal	C(4 4 4)

P_{out}	1.7 MW
Photons/ pulse	**1.1×10^9**
ΔE_{FWHM}	1.95 meV
Δt_{FWHH}	1.58 ps

P_{out}	500 kW
Photons/ pulse	**1×10^8**
ΔE_{FWHM}	6.3 meV
Δt_{FWHH}	0.42 ps

XFELO using ultra-small emittance beam @ 1pC

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Q	1 pC
I_{peak}	**1.6 A**
$\varepsilon_{x,n}$	**0.062 mm-mrad**
$\Delta\gamma mc^2$	**250 keV**
L_{und}	**35 m**
G	**0.39**
R_{tot}	0.85
crystal	C(4 4 4)

P_{out}	1.7 MW
Photons/ pulse	**1.1×10^9**
ΔE_{FWHM}	1.95 meV
Δt_{FWHH}	1.58 ps

P_{out}	500 kW
Photons/ pulse	**1×10^8**
ΔE_{FWHM}	6.3 meV
Δt_{FWHH}	0.42 ps

P_{out}	650 MW
Photons/ pulse	**1.2×10^8**
ΔE_{FWHM}	5.6 meV
Δt_{FWHH}	0.4 fs

Tevatron-size Ultimate storage ring

Michael Borland investigated the possibility of a Tevatron-sized ultimate storage, and found the settled on the following 2 damping undulators

11 GeV beam energy with 2 damping undulators

Geometric emittance = 1.1 pm Energy spread = 15.4 MeV

Bunch length ~8 ps @ 100 pC (I ~ 5 A)

Energy spread dominated, with single pass gain $\sim$1%

"Naïve" scaling to 7 GeV ➔ Energy spread = 6.3 MeV and negligible emittance

N_u = 500 ➔ G = 6%

N_u = 1000 ➔ G = 9%

Caveats: beam damping time probably quite long, how will other parameters change?

Storage ring-based XFELO not impossible, but the large natural energy spread makes this very challenging…is there an opportunity here?

M. Borland, "A Tevatron-sized Ultimate Storage Ring Light Source Based on the PEP-X Lattice," AOP-TN-2011-039 (2011)