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# Inverse Free Electron Laser Accelerators for Driving Compact Light Sources and Detection Applications

Particle Accelerator Conference 2011


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RadiaBeam Technologies

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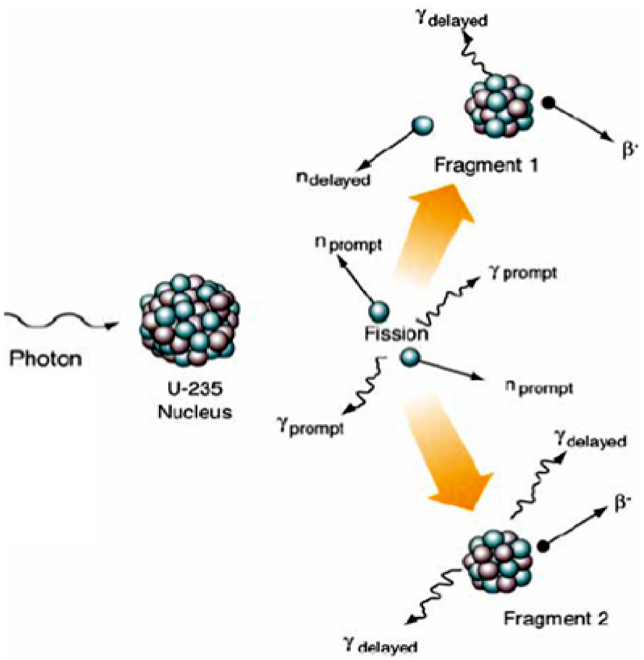
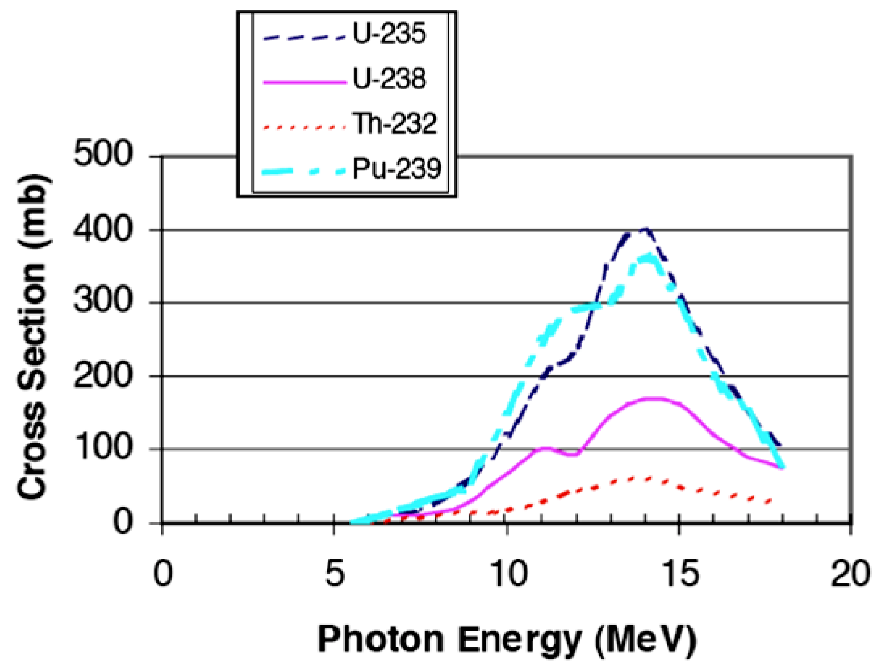
# Photofission

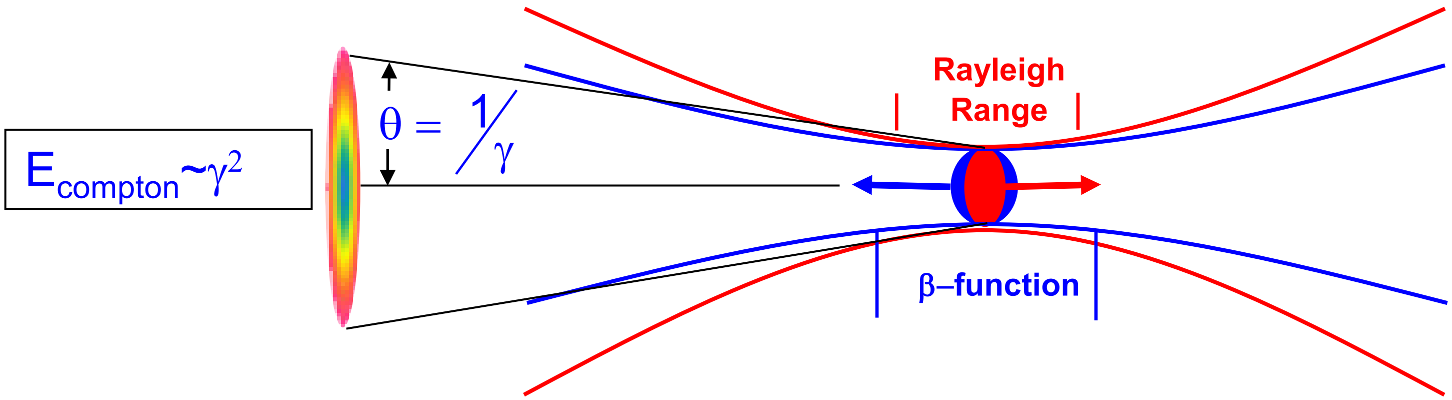
- Photon-induced fission produces signals of prompt neutrons and gammas and delayed neutrons and gammas
- Delayed neutrons/gammas are a characteristic signal of **SNM**




How to produce the >6 MeV photons for photofission?

# Inverse Compton Scattering (ICS)




Dose: $$N_s \approx \frac{N_e N_\gamma \sigma}{2\pi\left(x_e^2 + x_L^2\right)}$$

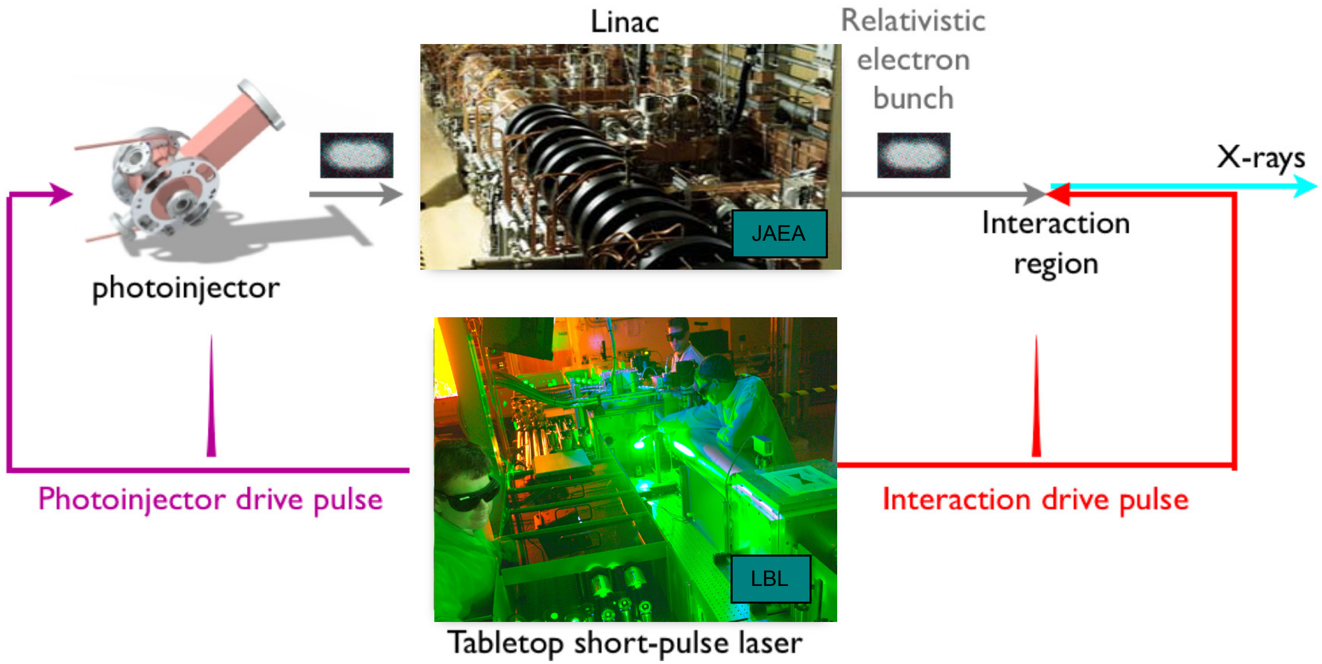
Bandwidth: $$\frac{\varepsilon_{nx}^2}{2x_e^2} > \frac{2\Delta\gamma}{\gamma}, \frac{\Delta\omega_0}{\omega_0}, \frac{\left\langle a_0^2 \right\rangle}{2}$$

- $10^8$ photons/interaction, narrow bandwidth
- Joule class laser + >500 MeV electron beams

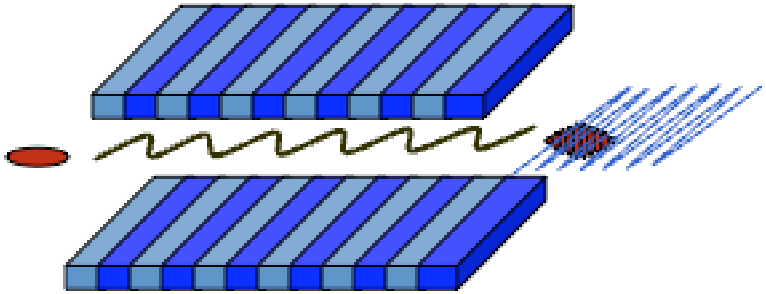
1. R.W. Schoenlein, Science, 274, 236-8 (1996)
2. R.P. Fischer, et. al., Proc. 2001 Particle Accel. Conf. (2001)
3. W. J. Brown, et al., Phys. Rev. ST-AB, **22**, n. 3 (2004)
4. S. Kashiwagi, et. al., Nucl. Instrum. Methods Phys Res. A, **455**, (2000)
5. F. Sakai, et al., Proc. of SPIE, **5196**, 156-162
6. F.E. Carroll, AJR, **181**, 1197-1202 (2003)
7. A. Fukasawa, Nucl. Instrum. Methods Phys Res. B, **241**, (2005)
8. A. Agafonov, et. al., AIP Conf. Proc., **879**, 79-82 (2007)

# ICS gamma source challenges

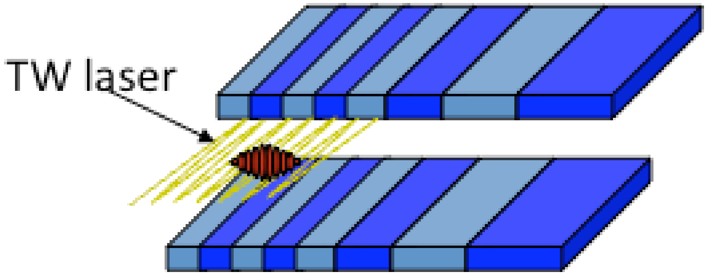
- ICS efficiency (beam quality, control, feedbacks, AO, etc.)
- Good photon flux (laser recirculation, high rep rate)
- Compactness (high gradient linac technologies, IFEL)
- System cost (technology and market evolution)



# IFEL as accelerator driver for ICS



FEL



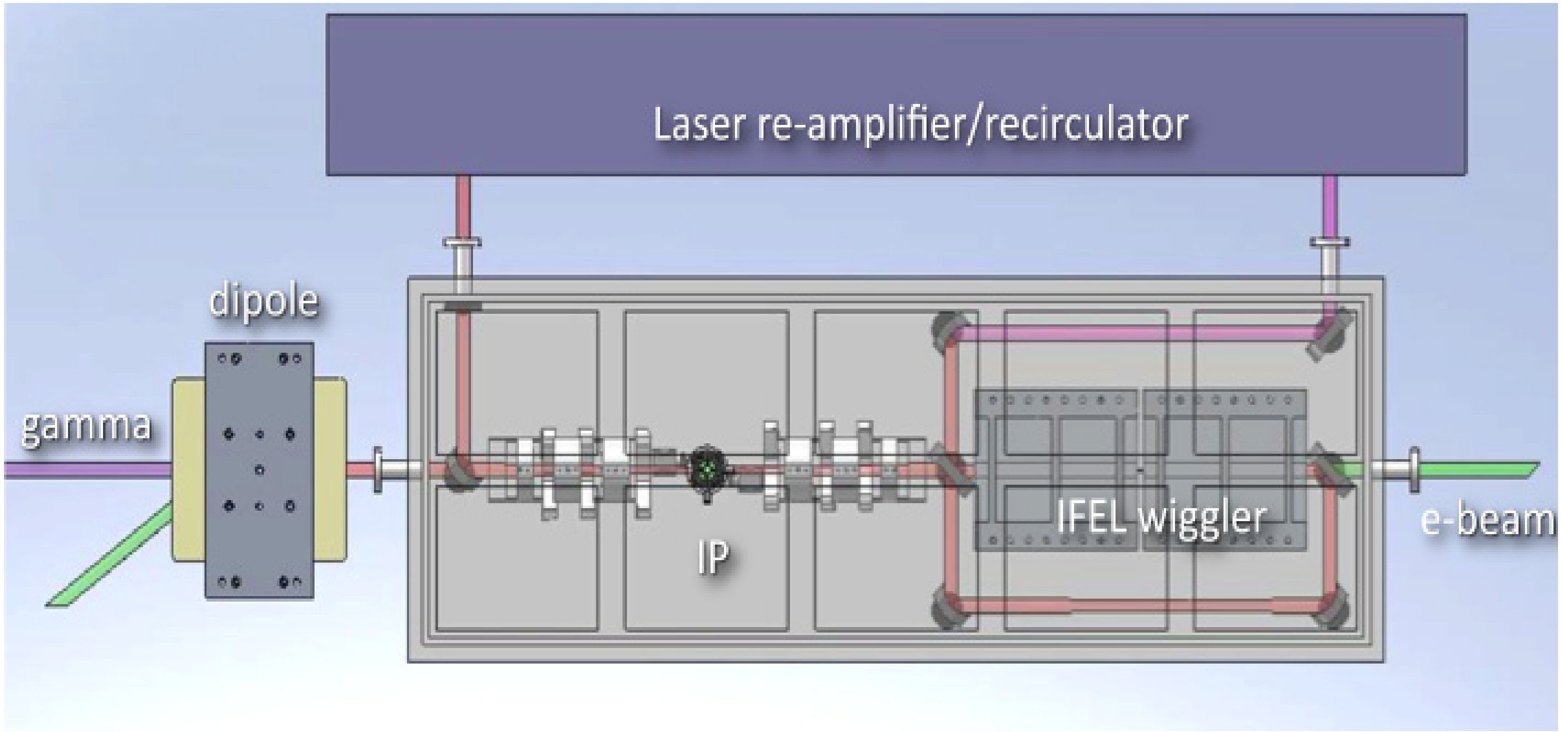

IFEL

Resonance Condition

$$\gamma_r^{\ 2} \cong \frac{\lambda_w}{2 \cdot \lambda} \cdot \left(1 + \frac{K^2}{2}\right)$$

- Long interaction length
- High output energy stability defined by the wiggler geometry
- No fundamental limit on the gradient (far field accelerator)
- Preservation of e-beam quality/emittance and high capture simulated
- Reprates through laser recirculation greatly increases average power

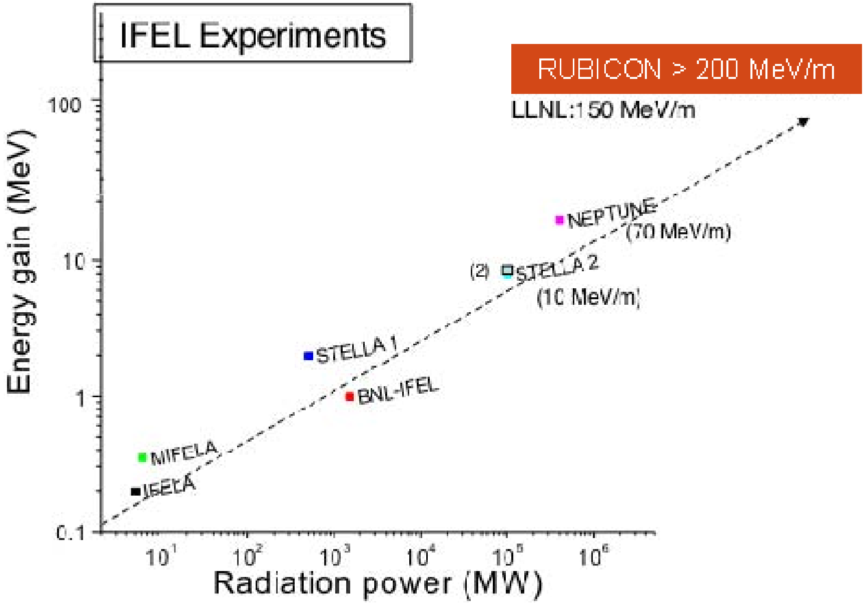
# Integrated IFEL-ICS system




- IFEL uses same laser as ICS, and allow up to 700 MeV/m gradient
- Laser Recirculation increases average power

# IFEL evolution

- DOE HEP funded IFEL R&D since 90’s, but recently stopped
  - Not in the energy space where HEP cares, >100 GeV
- IFEL suitable for 200 MeV - 2GeV, small footprint accelerators



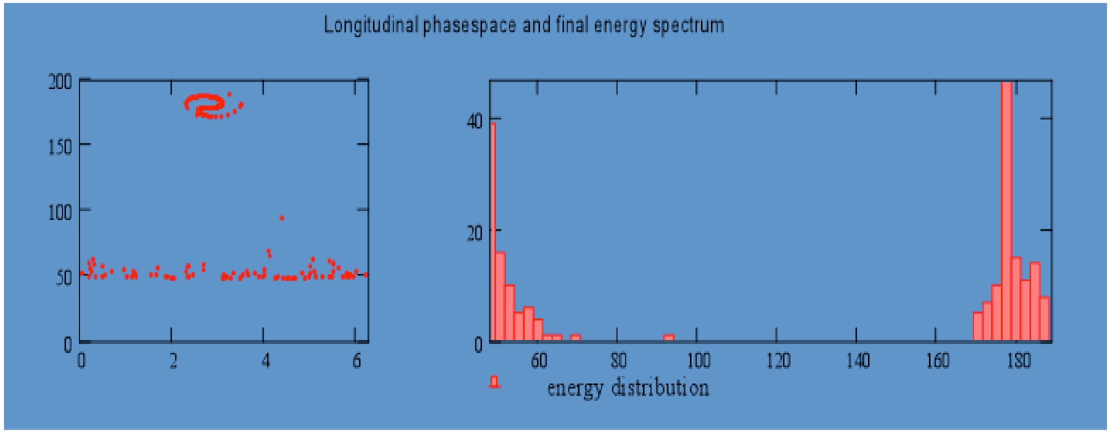

*RadiaBeam-UCLA-BNL-IFEL-CollaboratiON

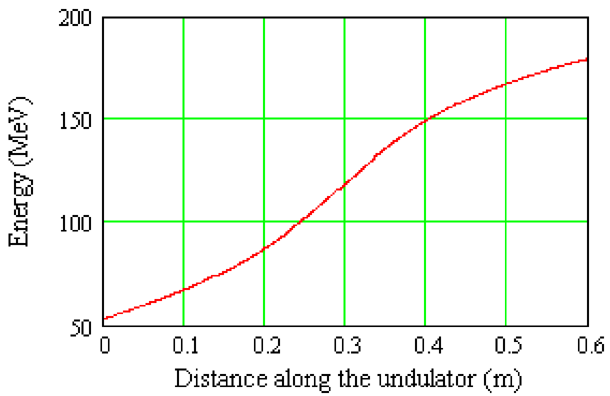
# RUBICON Parameters

| System Parameters | RUBICON parameters | Practical system parameters |
| --- | --- | --- |
| Electron beam energy (initial-final) | 50 – 150 MeV | 75 – 700 MeV |
| Laser wavelength | 10.6 μm | 0.8 μm |
| Average accelerating gradient | ~ 200 MeV/m | > 600 MeV/m |
| Laser seed power | 0.5 TW | 5 TW |
| Laser size (at focus) | 550 μm | 180 μm |
| Laser Rayleigh range | 9 cm | 15 cm |
| Wiggler length | 60 cm | 100 cm |
| Wiggler period (initial-final) | 4.2 mm – 7.1 cm | 1.6 cm – 5.6 cm |
| Wiggler peak field (initial-final) | 0.54 – 0.89 T | 0.8 – 1.35 T |

Demonstrate gradient and energy gain significantly larger than with conventional RF structures

# RUBICON Initial design



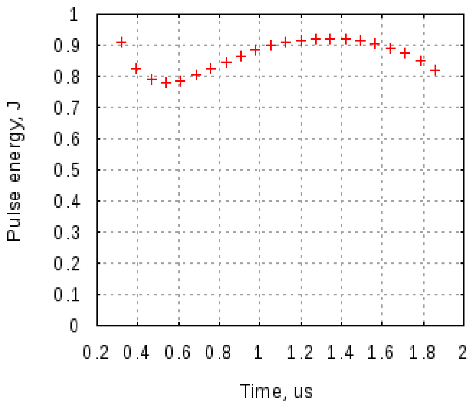

IFEL Scaling
(see Musumeci at PAC 2011)

$$\Delta\gamma^2 \cong 12\sqrt{2}\,\frac{e_0\sqrt{Z_0}}{mc^2}\sqrt{\frac{z_r}{\lambda}}\sqrt{P}\overline{K} \cong 6\cdot 10^{-4}\sqrt{\frac{z_r}{\lambda}}\sqrt{P(W)}\overline{K}$$

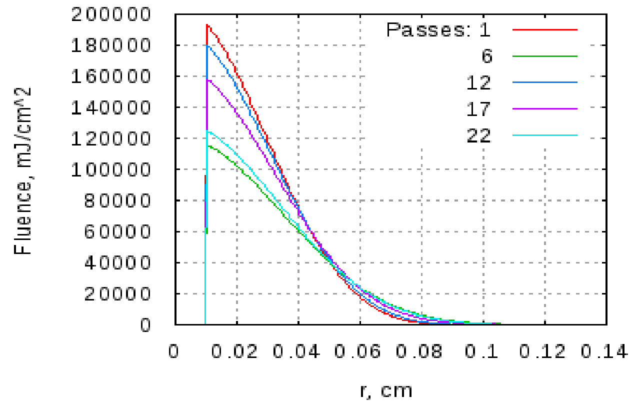
**Experimental Objectives**:

1. IFEL acceleration gradient (~ 200 MeV/m), and good capture (> 50%) in ½-meter at ATF
2. Laser recirculation-reamplification
3. IFEL-ICS system in a pulse train mode

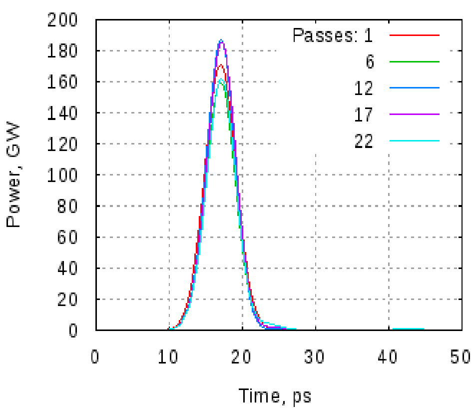
# RUBICON ATF laser recirculation studies



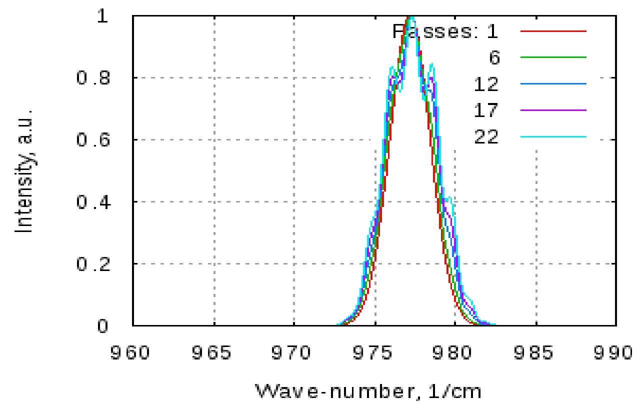

Passes through an active cavity




Spatial distribution

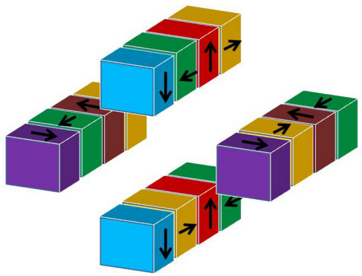


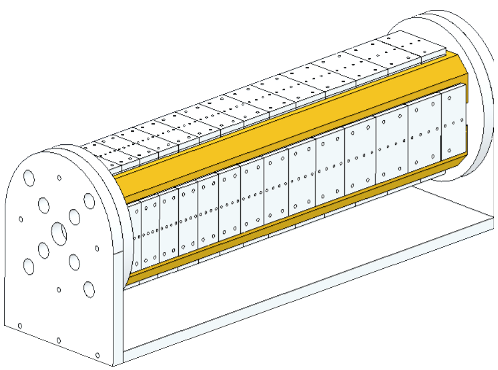

Temporal envelope

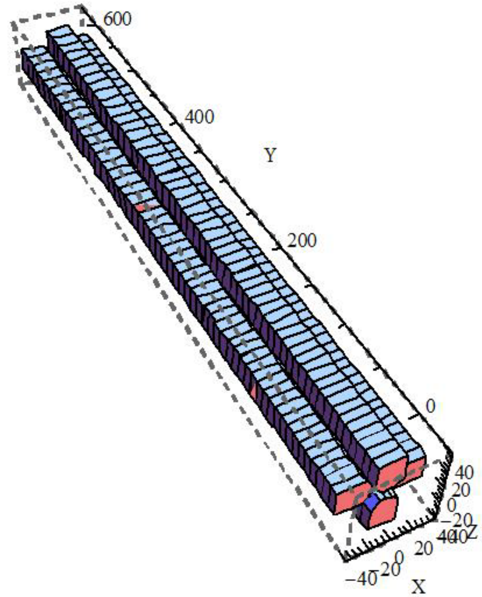


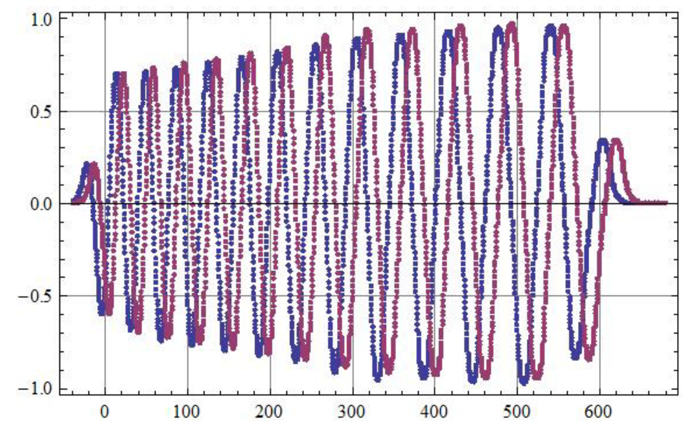

Spectral evolution

# RUBICON Undulator Design





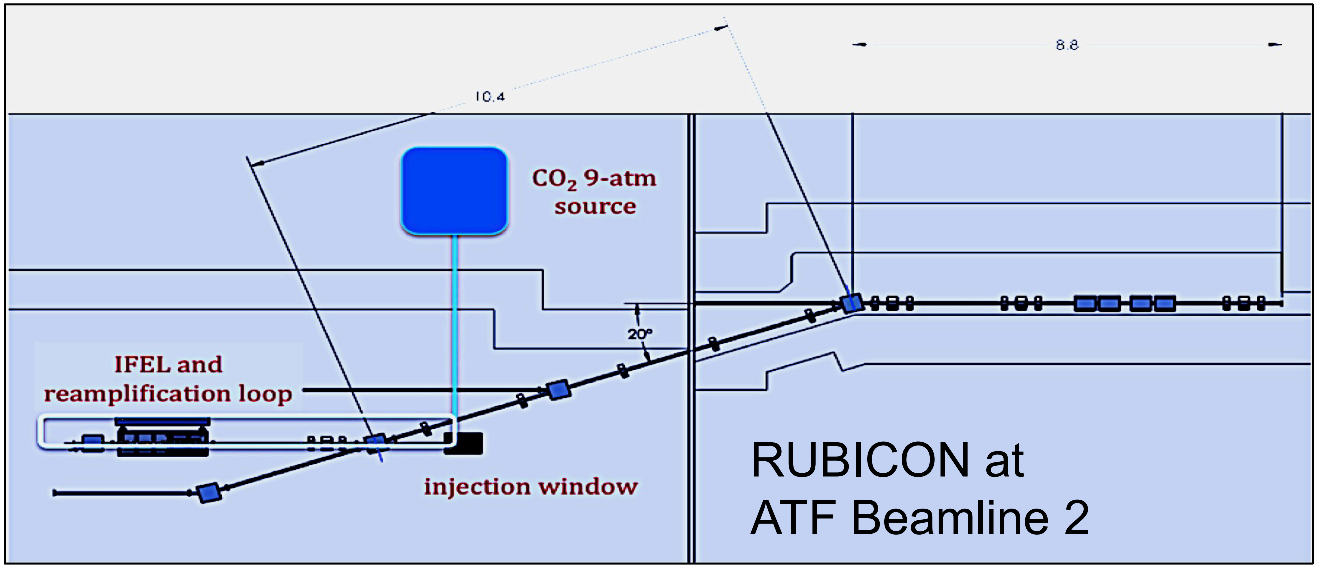



- Helical undulator field, superposition of two Halbach arrays rotated 90 degrees wrt each other and shifted by ¼ period
- Designed with suit of 3-D magnetostatic solvers, including Maxwell 3D, Ampere, and RADIA to maximize IFEL performance

# RUBICON Timeline

1. Demonstration (~ 200 MeV/m) in a half-meter long undulator at ATF, BNL (2011).
2. Development and experimental demonstration of laser recirculation-reamplification scheme for pulse train mode (2012-2013).
3. Development of a combined ICS/IFEL system in a pulse train mode (2013-2014).

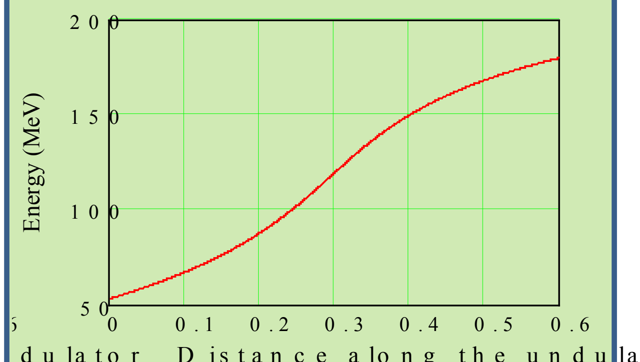


# High Gradient IFELs

### RadiaBeam UCLA BNL IFEL Collaboration (RUBICON)

Strongly tapered optimized helical permanent magnet undulator

ATF @ BNL
0.5 TW $CO_2$ laser
50 MeV -> 180 MeV in 60 cm
130 MeV energy gain
220 MV/m gradient

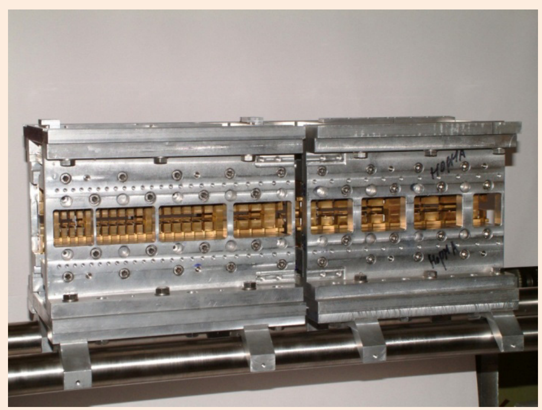



### LLNL-UCLA IFEL experiment

Reuse UCLA- Kurchatov undulator

Use 5 TW 10 Hz Ti:Sa
50 MeV -> 150 MeV in 50 cm

High rep rate allows beam quality measurement



**IFEL Posters for details**
MOP102 – Musumeci
MOP127 – Anderson

**ICS gamma source**
THP002 – Murokh

**Industrial Exhibitor**
417-RadiaBeam Technologies

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# Conclusion

- High energy ICS is an ideal technology for photo-fission detection applications. R&D is necessary to improve average power and compactness of ICS gamma sources.
- IFEL is a promising technology to reduce cost and footprint of the ICS gamma sources and 4$^{th}$ generation compact light sources.
- RadiaBeam is actively engaged into development of high average power (recirculated) gamma ICS source and IFEL (RUBICON), in collaboration with UCLA and BNL.
- This work is supported by DTRA (Defense Threat Reduction Agency).