Gamma-ray source applications with LWFAs

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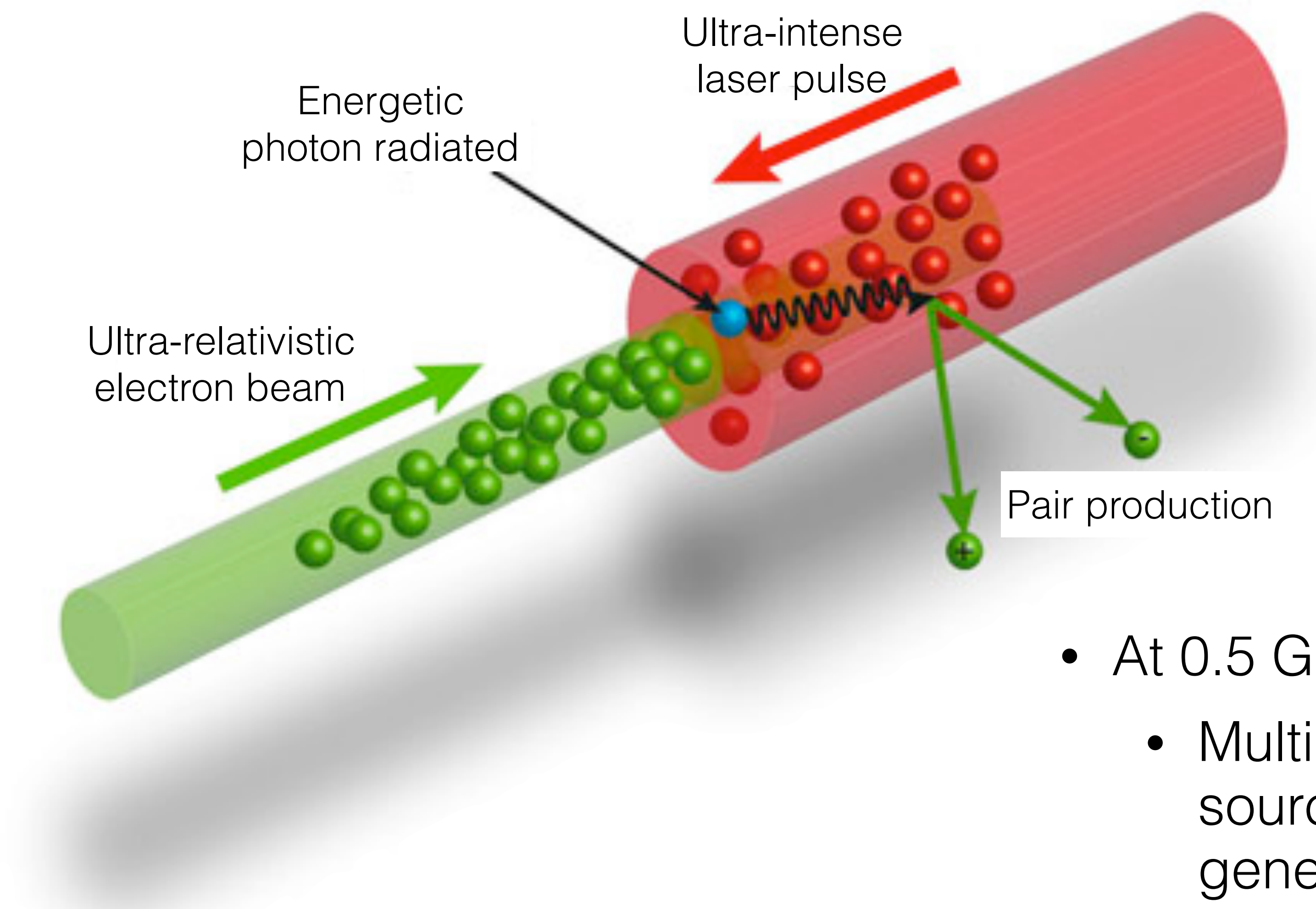
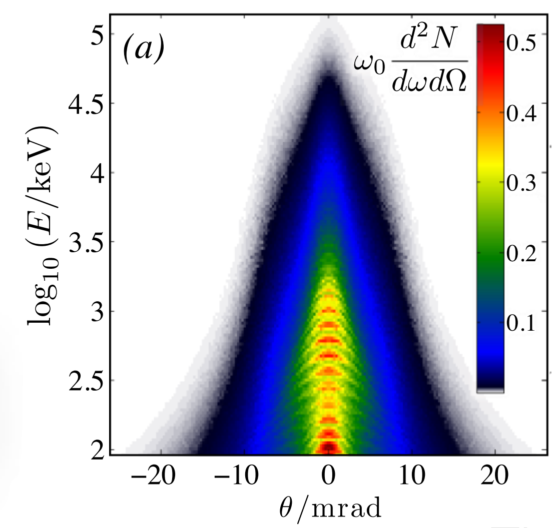
Electron acceleration and nonlinear inverse Compton scattering





Energetic Gamma ray beam (through nonlinear Compton scattering)

Thomas PRX (2012)

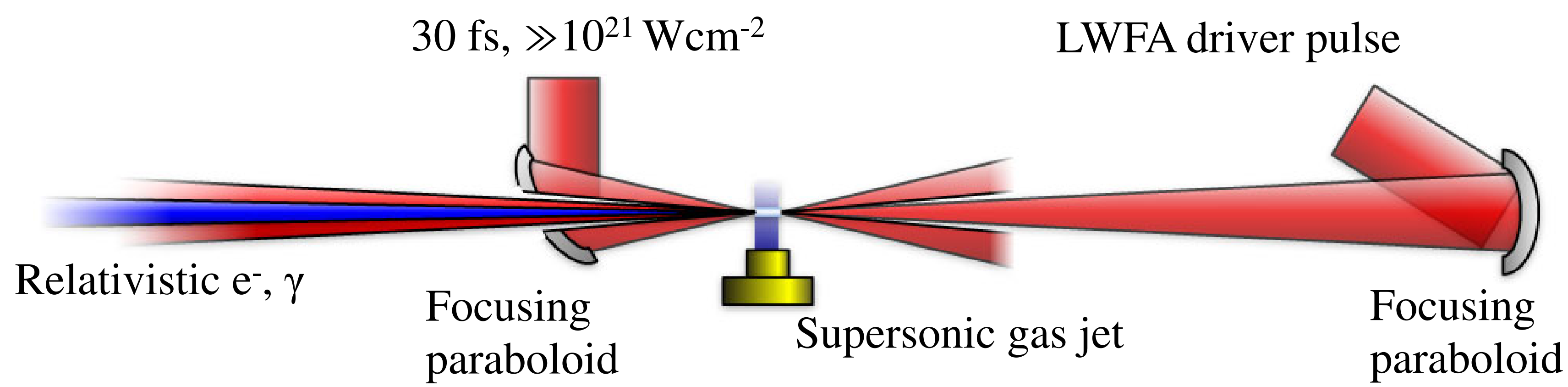
- At 0.5 GeV, 10^{21} Wcm^{-2}….
  - Multi photon Compton Scattering: Photon source with peak brightness comparable to 4th generation light source (10^{29} photons mm^2 mrad^2 / 0.1%bandwidth)
- At 3.5 GeV, 10^{23} Wcm^{-2}….
  - Transition to strong field QED regime: electron-positron pair cascade
  - nonlinear / manybody QED

- Emission of **extremely bright gamma ray beam**

Wakefield based gamma-ray sources

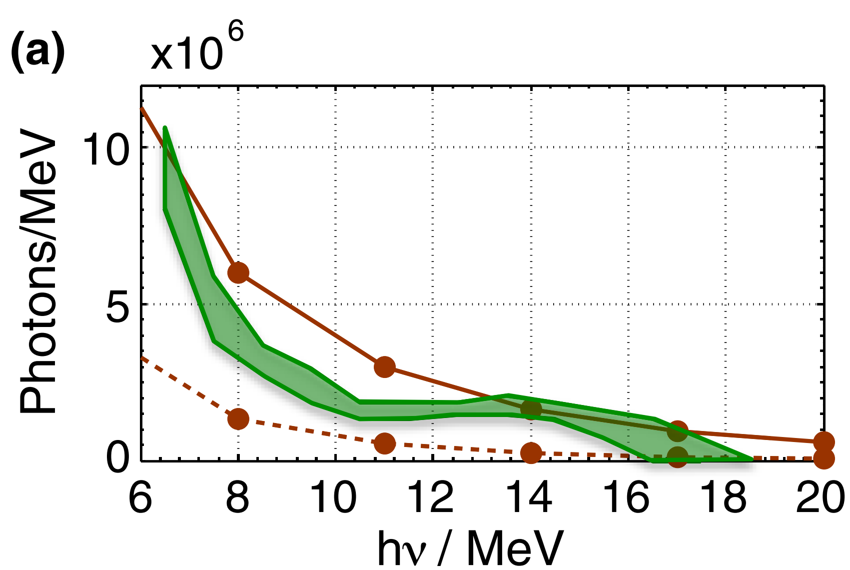
All optical
Compton source

Ta Phuoc Nature Pho. (2012)
Chen PRL (2013)
Powers Nature Pho (2014)
Sarri PRL (2014)
Khrennikov PRL (2015)

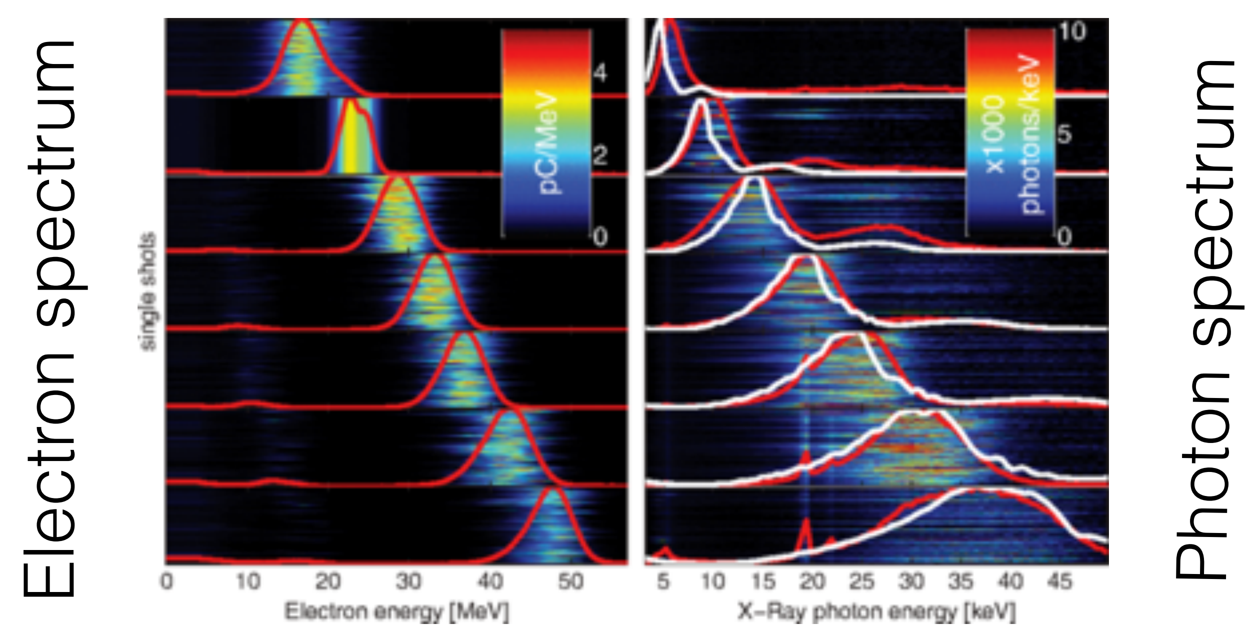


Tunable monochromatic photon source…

Nonlinear Compton scattering



Sarri PRL (2014)



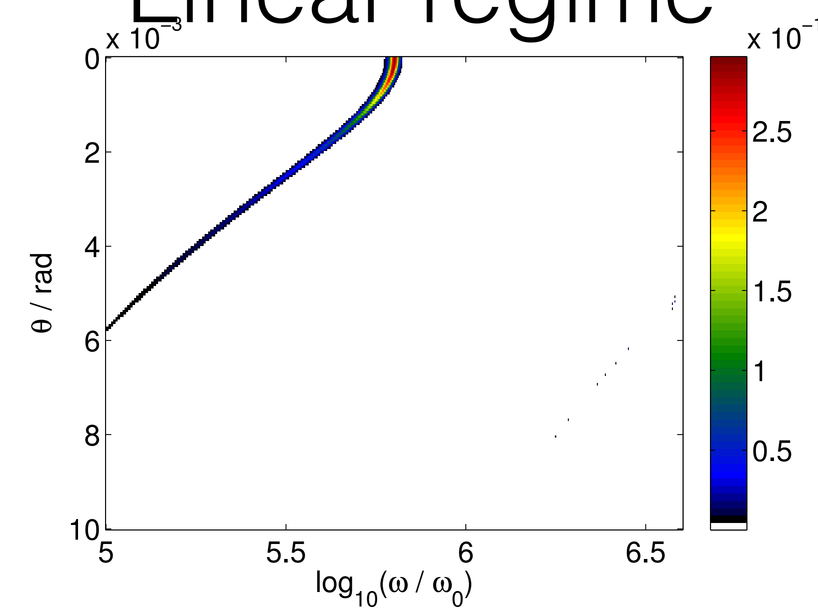
Khrennikov PRL (2015)

Properties of ICS photons

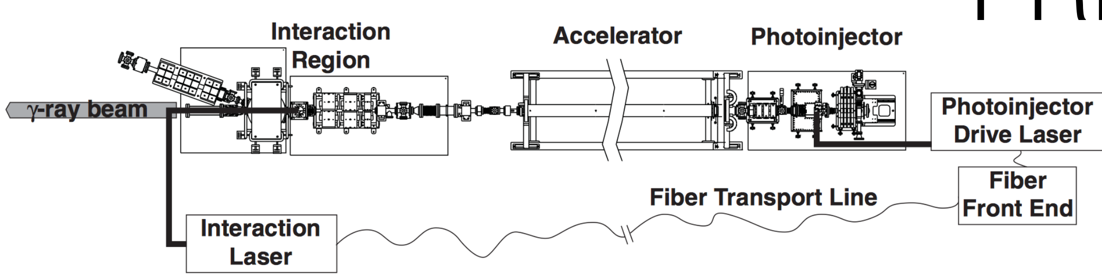
Table 3. Recent Compton scattering x-ray and γ-ray sources with RF accelerator technology.

Facility	Accelerator	Electron energy (MeV)	Laser	Laser energy (J)	Photon energy (MeV)	Spectral bandwidth (%)	Flux (photons s^{-1})	Year
HiγS	Storage ring	1200	FEL	0.15	1–158	1–10%	10^8	1996 [131]
PLEIADES (LLNL)	S-band Linac	54–57	Ti : Al_2O_3	0.4	0.04–0.08	~few%	10^8	2000–2004 [132]
T-REX (LLNL)	S-band Linac	120	Nd : YAG	0.15	0.075–0.9	~10%	10^6	2005–2008 [133]
NewSUBARU (Japan)	Storage Ring	1000	Nd : YVO_4	CW	6.6–17.6	17%	10^5	2003 [134]
THOM-X	Storage Ring	50–70	Fiber – FB	2.5×10^{-6}	0.05–0.09	NA	NA	In construction [135]
PHOENIX	Superconducting linac	22.5	Ti : Al_2O_3	0.1	0.08–0.013	4.5%	10^5	2013 [136]
ELI-NP	S/C-band linac	19.5	Ti : Al_2O_3 -OR	0.3	6.6–17.6	0.5%	$>5 \times 10^8$	In construction [129]

Linear regime

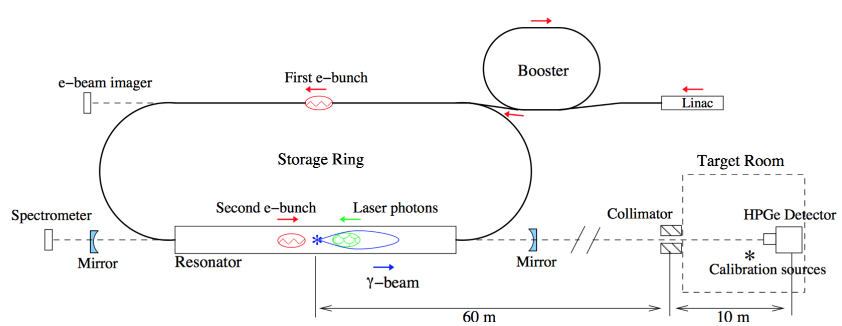


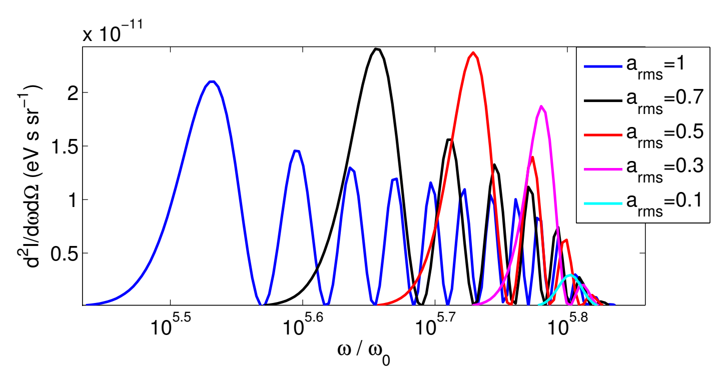
T-REX



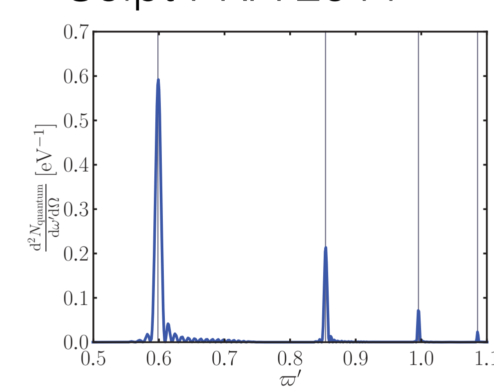
$$E_\gamma = \frac{2\gamma^2 (1 - \cos\phi)}{1 + \gamma^2\theta^2 + a_0^2/2 + 2\gamma\omega_0\lambda_c/c}\hbar\omega_0$$

HIGS

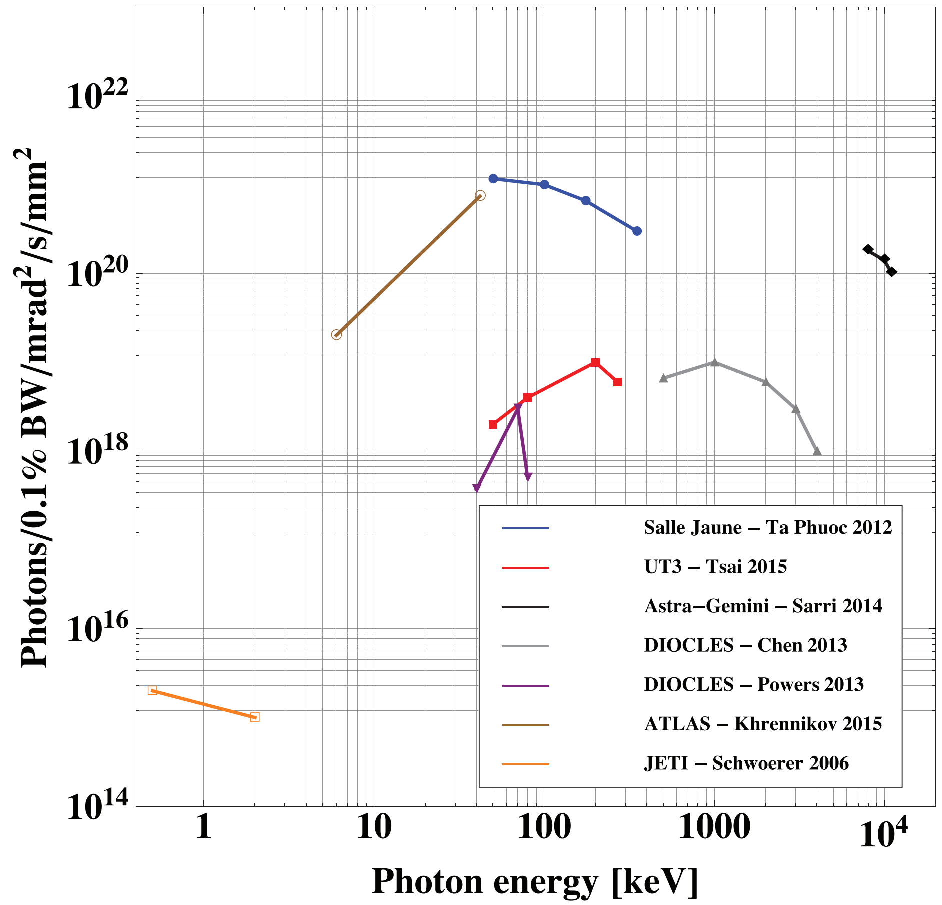




Seipt PRA 2011



Brightness of various experimental ICS sources

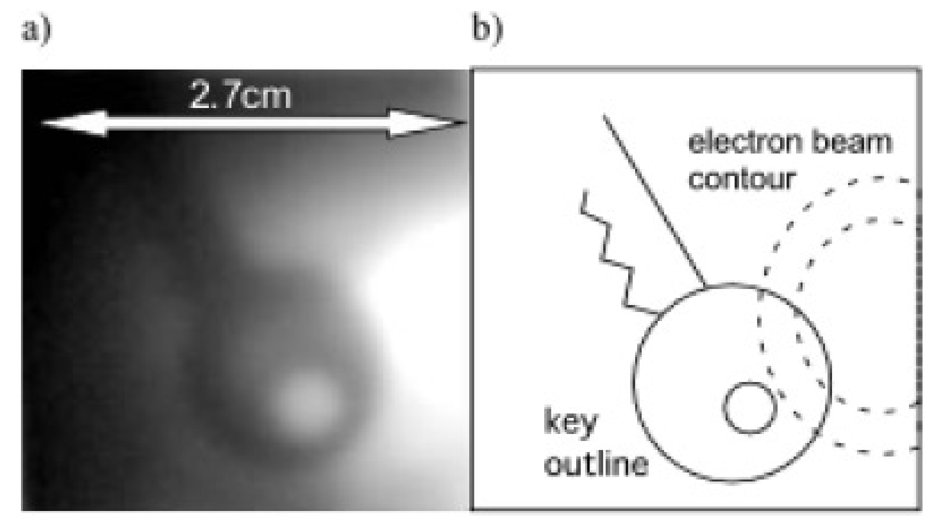


Albert PPCF 2016

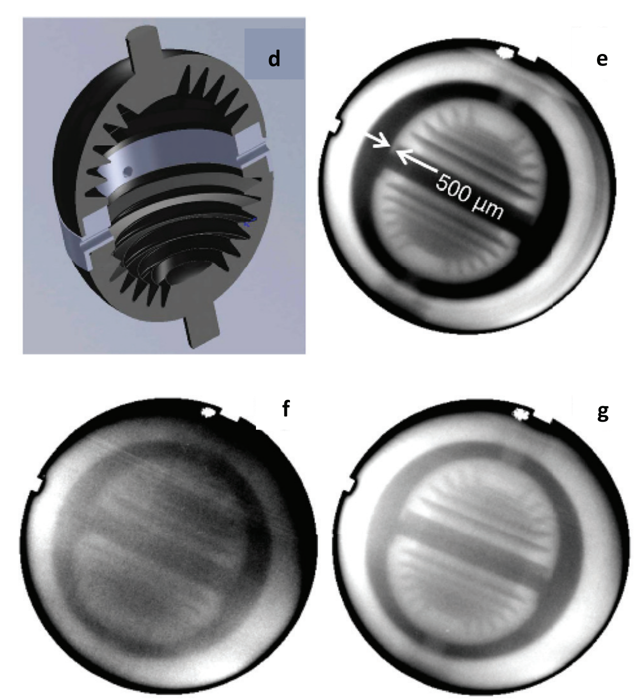
Laser facility	Pulse energy E_1, E_2 (J)	Pulse duration τ_1, τ_2 (fs)	Spot size (μm)	$a_{0,1}$, $a_{0,2}$	Electron density (cm^{-3})	Photons /shot	X-ray energy (keV)	Year
Salle Jaune (LOA)	1	35	17	1.2	10^{19}	10^8	50–200	2012 [111]
DIOCLES (U. Nebraska)	1.9, 0.5	35, 90	20, 22	1.9, 0.4	10^{19}	10^7	70–9000	2013 [97, 123, 124]
ATLAS (MPQ)	1.2, 0.3	28, 28	13, 25	4.4, 0.9	5×10^{19}	NA	5–42	2015 [125]
JETI (Jena)	0.333, 0.037	85, 85	∼3,3	3, 0.8	6×10^{19}	3×10^4	0.4–2	2006 [121]
UT3 (UT Austin)	0.8	30	12	1.6	$1.4–2.2 \times 10^{19}$	2×10^7	75–200	2015 [122]
Astra-Gemini (RAL)	18, 18	42,42	27, NA	5.4, 2	3.2×10^{18}	10^7	6000–18 000	2014 [126]

Radiography

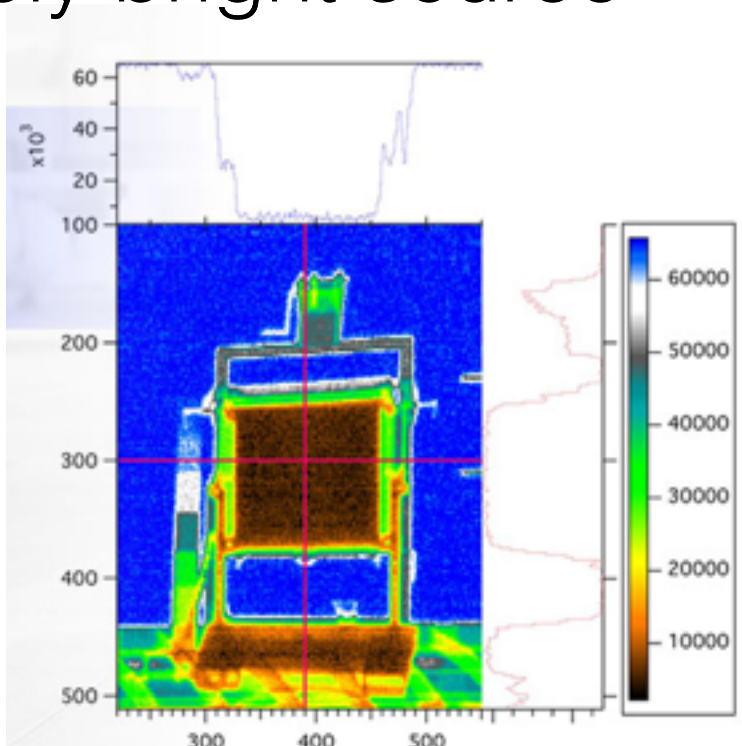
- LWFA electrons can be used to generate bremsstrahlung
- Useful for radiography applications
- Nonlinear Compton can produce extremely bright source



Mangles Las. Part. Beams (2006)

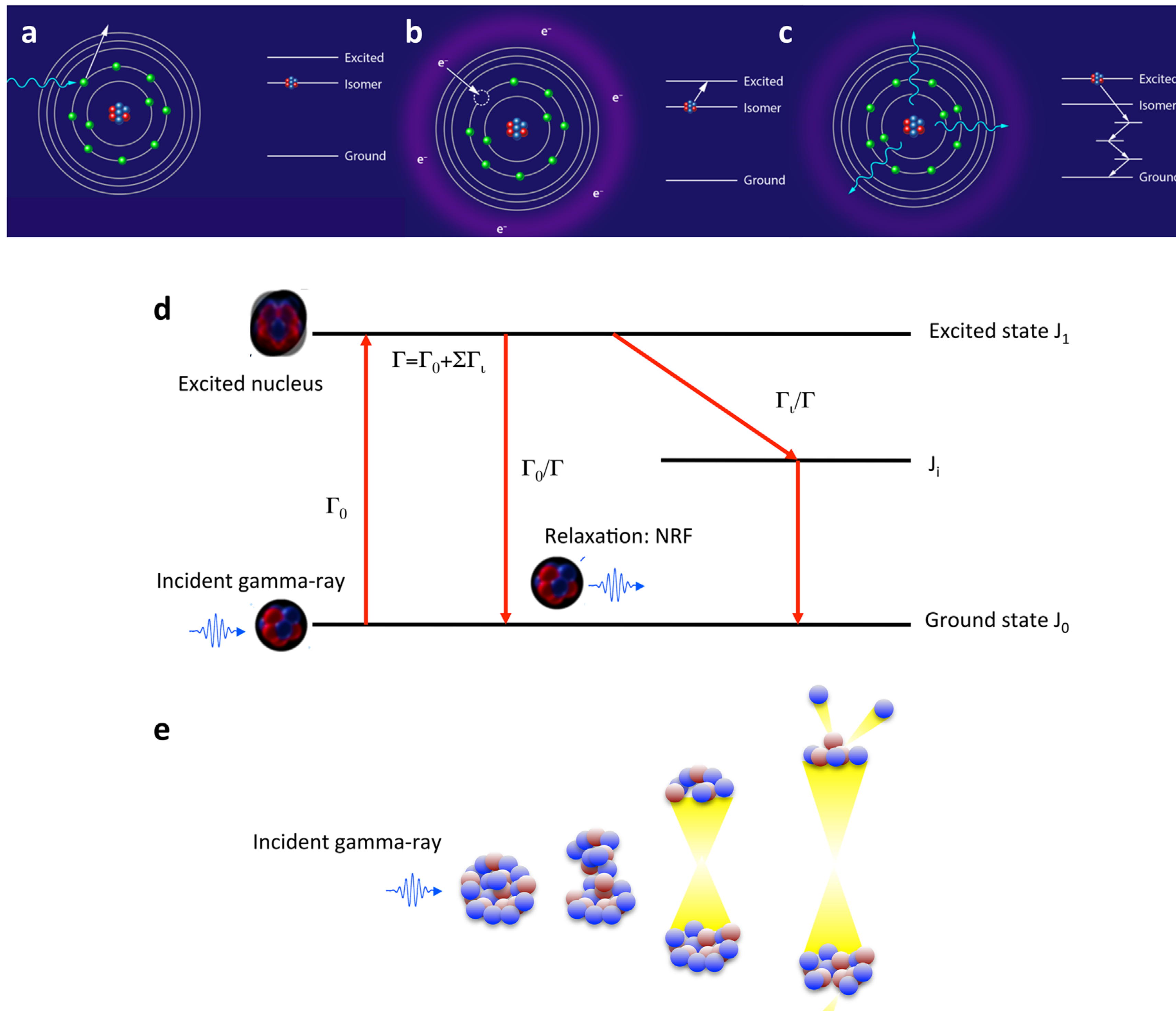


Courtois Phys. Plasmas (2013)

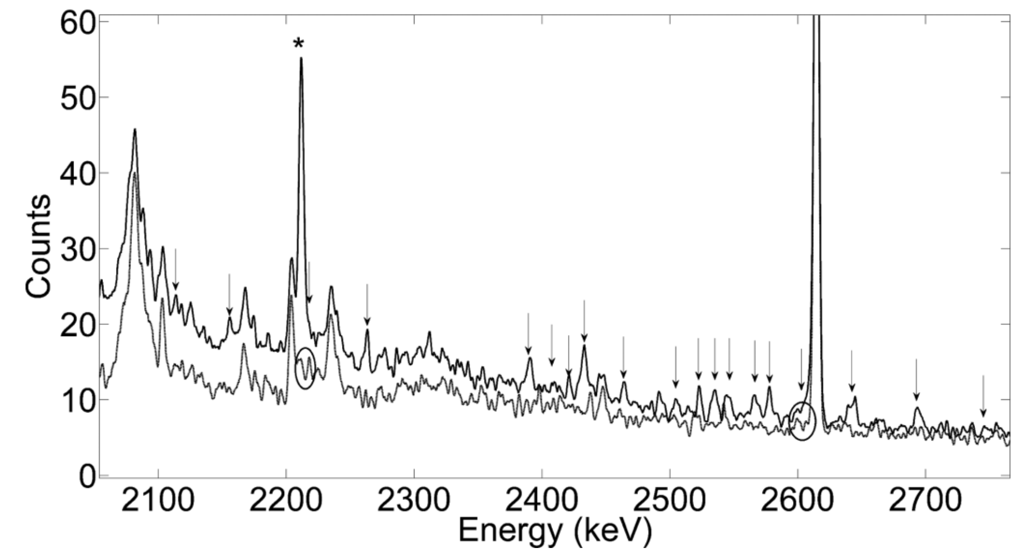


Nuclear processes triggered by LWFA gamma rays

- NEEC (needs FEL)
- NRF
- PhotoFission

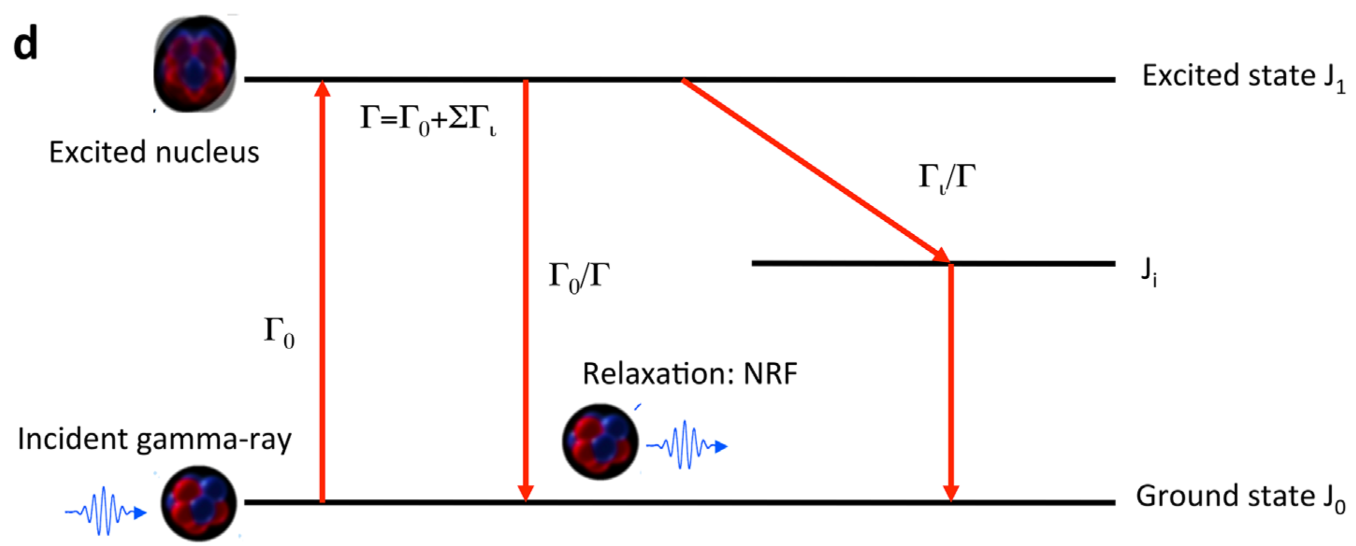


NRF

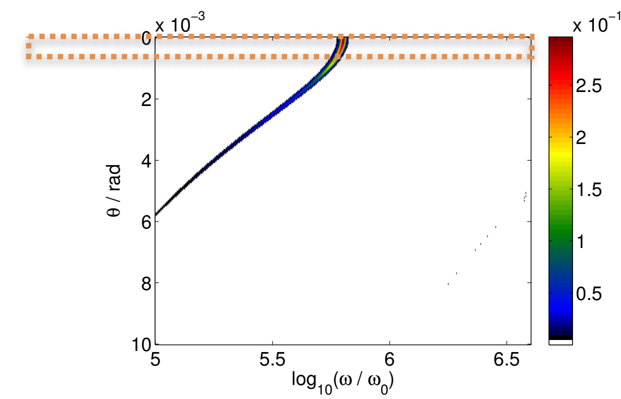


Quiter PRB (2012)

- Gamma-ray excitation of nucleus
- Fluorescence line widths $\Delta E/E \sim 10^{-6}$
  - Below Ge detector resolution
  - -> narrowband gamma ray source to excite specific lines



Bandwidth affected by different factors



- For direct backscattering

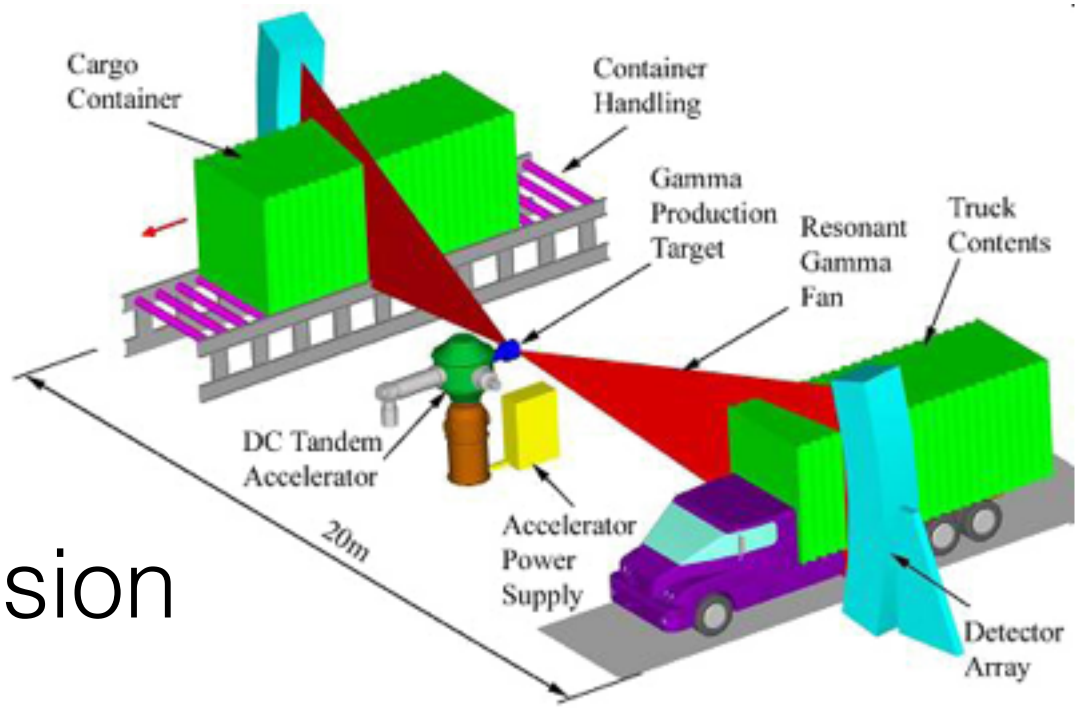
$$E_\gamma = \frac{2\gamma^2}{1+\gamma^2\theta^2+a_0^2/2+2\gamma\omega_0\lambda_c/c}\hbar\omega_0$$

- For direct backscattering

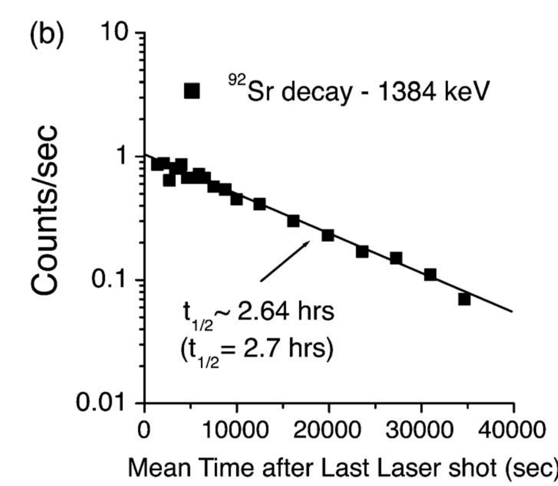
$$\left(\frac{\Delta E_\gamma}{E_\gamma}\right)^2 \approx (a_0\Delta a_0)^2 + \left(2\gamma^2\theta\Delta\theta\right)^2 + \left(\frac{2\omega_0\lambda_C}{c}+\frac{2+\theta^2}{\gamma}\right)^2\Delta\gamma^2$$

- Line width strongly affected by energy spread of electron beam, angular variation of emission, laser field strength and Compton shift

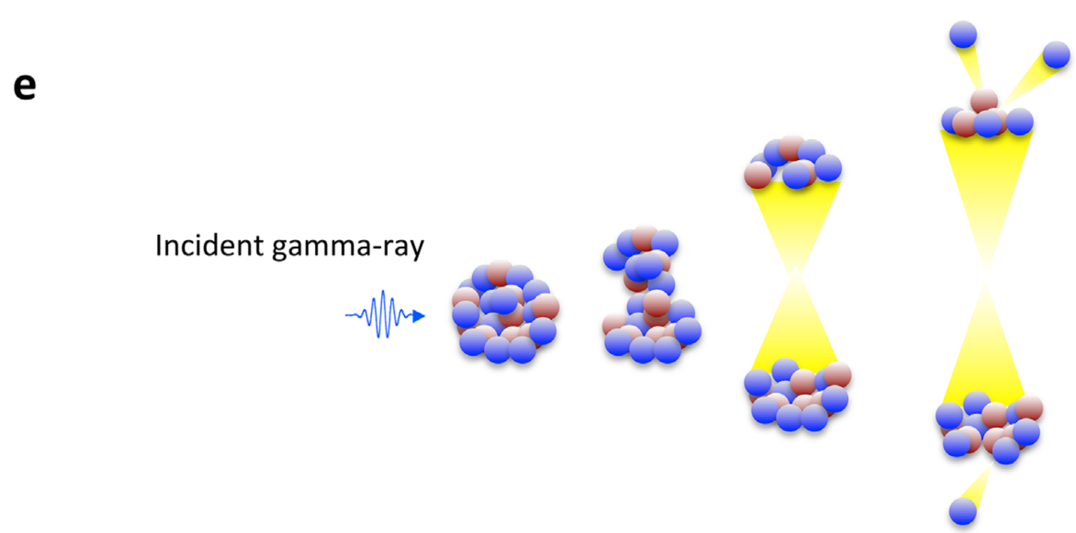
Photofission and transmutation

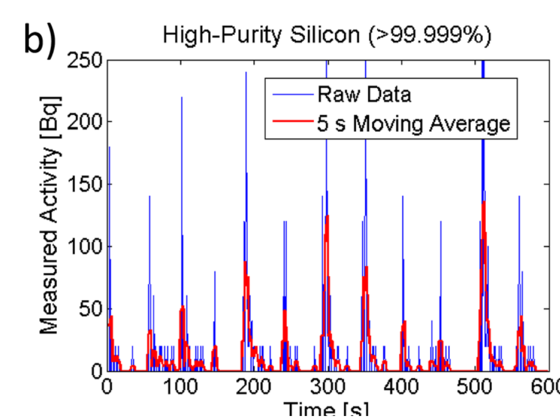


- ~5 MeV photons can trigger fission
- Useful for active interrogation
  - Also transmutation of nuclides
  - No need for narrowband source



Reed J. Appl. Phys. (2007)





Schumaker Phys. Plasmas (2014)

Conclusions

- LWFA reasonably competitive with existing RF Compton sources (if rep-rated, not counting broad energy spread)
- Needs:
  - MeV photon energies - means few 100 MeV electrons for 1μm lasers
  - Energy spread/emittance and energy stability is limitation for LWFA use for NRF applications (10^{-6} ideal, but even 10% may be useful)
  - High rep-rate (but not too high)
  - High efficiency to be practical
  - Stable / fieldable system

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