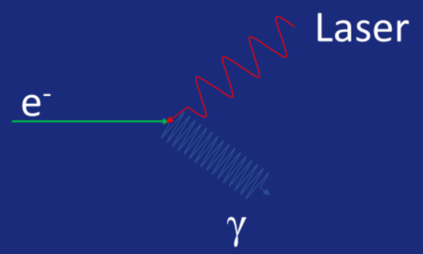

Design of a Tuneable Monochromatic Gamma Ray Source using Inverse Compton Scattering (ICS)

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Primary Supervisor: Laura Corner
Secondary Supervisor: Peter Williams

Outline:

- Applications of Monochromatic Gamma-rays
- ICS Theory
- Design of ICS experiment
  - Electron beam parameters
  - Laser parameters
- Gamma source characteristics
- Future work plan
  - Optical Cavities
- Summary

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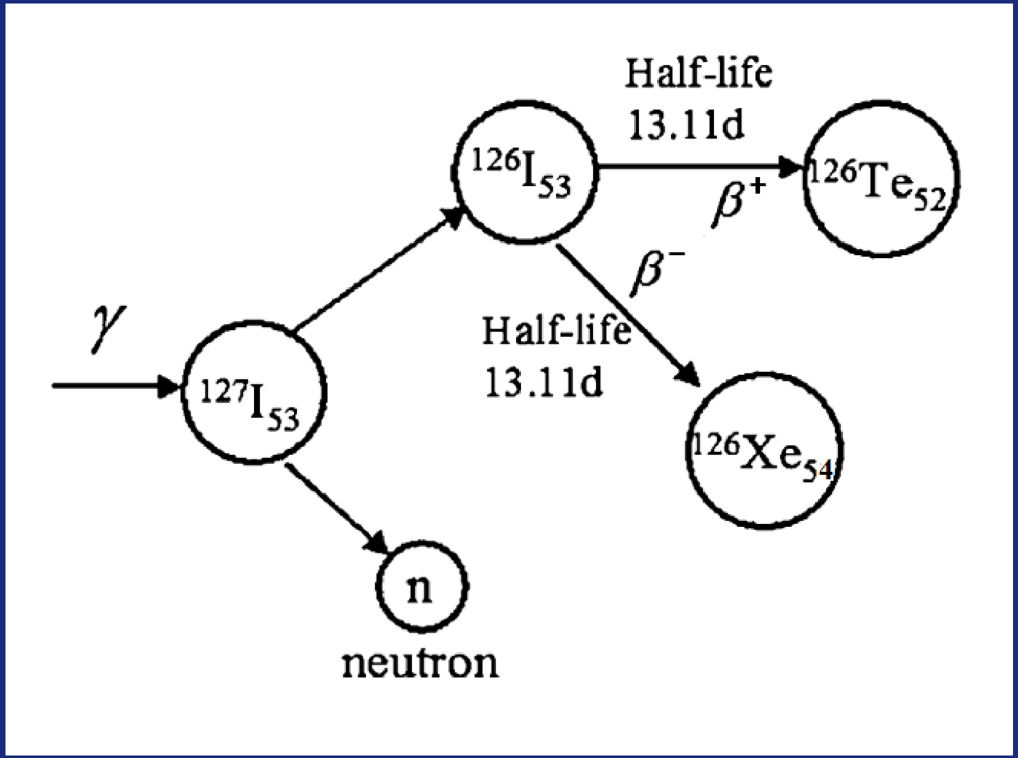
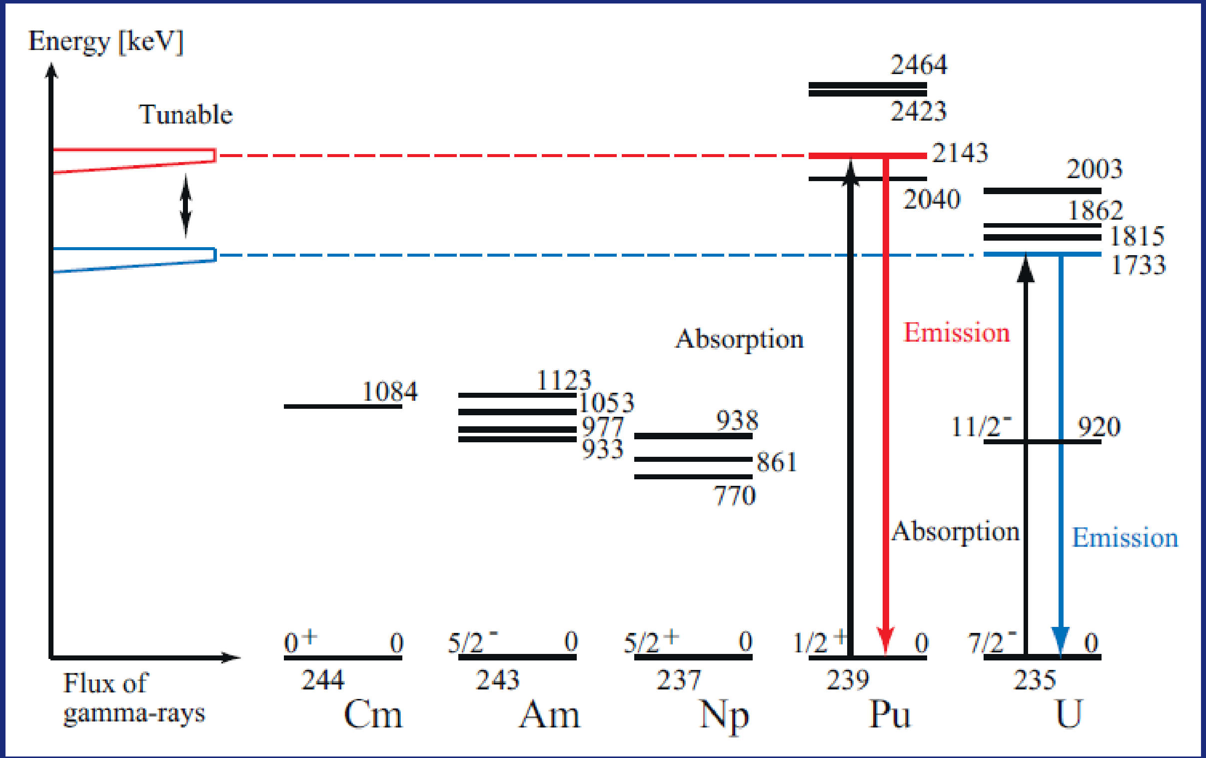
Applications of Monochromatic Gamma rays



Nuclear transmutation via (γ,n) reaction for treating nuclear waste or creating medical radioisotopes – source ~10 MeV is needed



Nuclear resonance fluorescence (NRF) for scanning and detecting nuclear material – Narrow bandwidth source of ~2 MeV is needed.

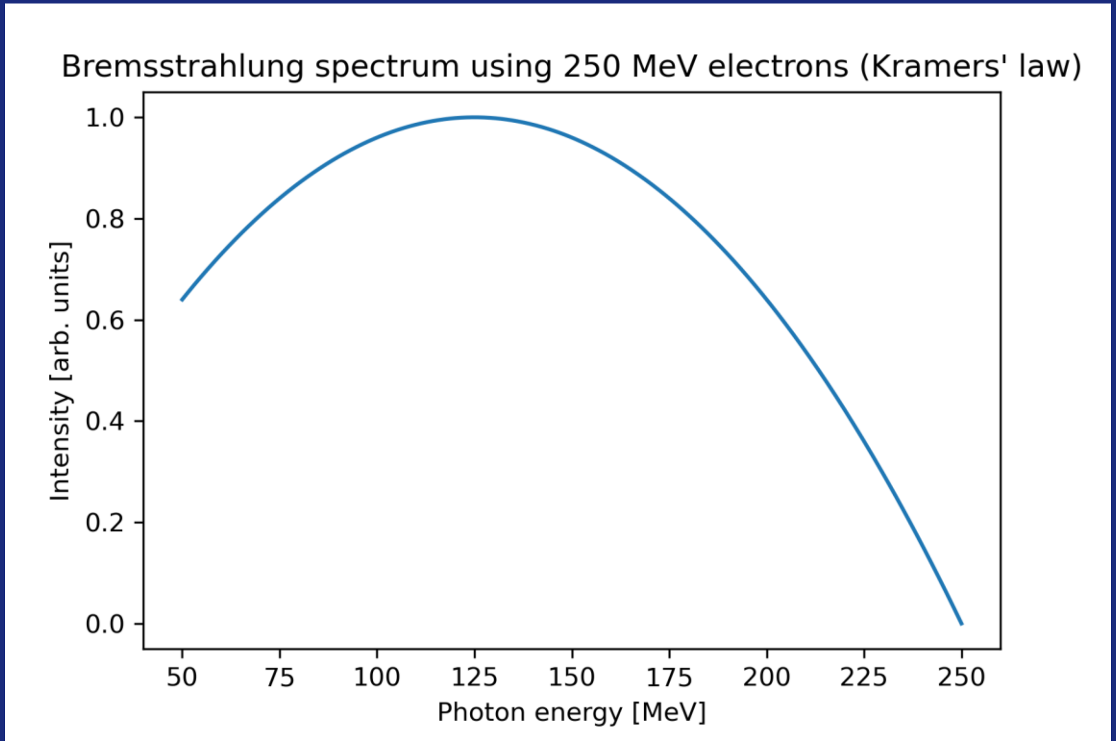
Li, D., et al. (2009) *Journal of Nuclear Science and Technology*, *46*(8), 831–835.

Hayakawa, T., et al. (2010) *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *621*(1–3), 695–700.

Why Inverse Compton Scattering?

Bremsstrahlung:

High energy but **not monochromatic**



Synchrotron:

Not high enough energy to generate MeV photons.

Characteristic energy is:

$$E = \frac{heB\gamma^2}{2\pi m_e}$$

e.g. B = 1 T, 1 GeV electrons results in 460 eV photons

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ICS Theory- Monochromatic Gamma rays

Energy of the source

$$E_\gamma = \frac{E_{laser}(1-\beta\cos(\phi'))}{1-\beta\cos(\theta)+(1-\cos(\theta'))E_{laser}/E_e}$$

Bandwidth of the source

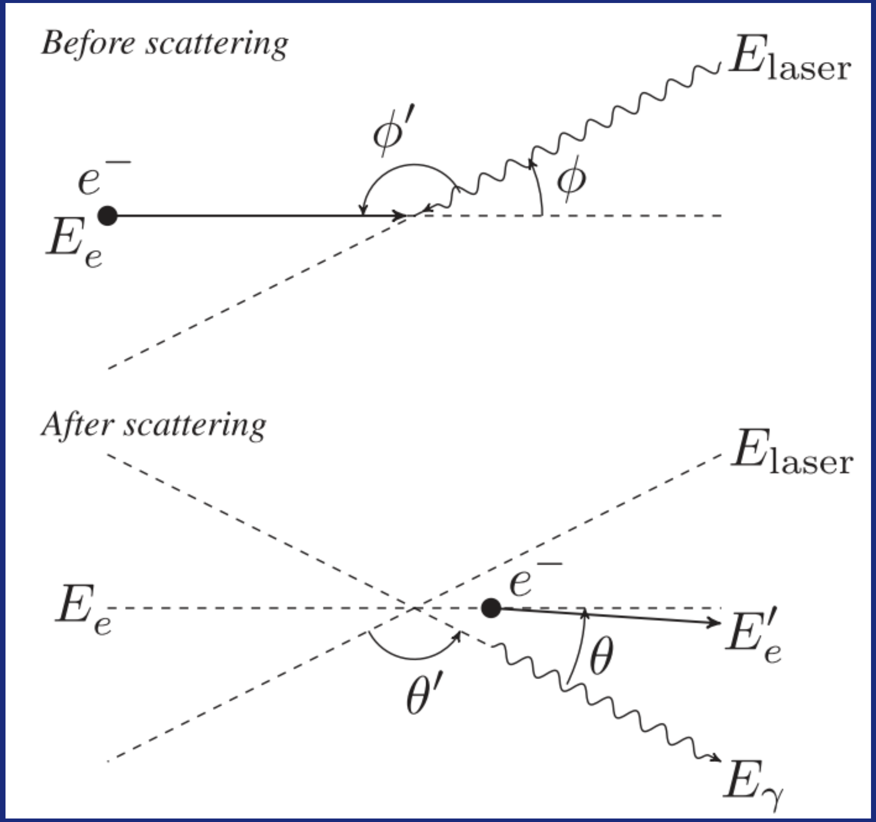
$$\frac{\Delta E_\gamma}{E_\gamma} = \sqrt{\left(\frac{\sigma_\theta}{E_\theta}\right)^2+\left(\frac{\sigma_e}{E_e}\right)^2+\left(\frac{\sigma_L}{E_L}\right)^2+\left(\frac{\sigma_\epsilon}{E_\epsilon}\right)^2}$$

Collimation

Electron Energy Spread

Laser Energy Spread

Emittance of the beam



Deitrick, K., et al. (2021). *Physical Review Accelerators and Beams*, *24*(5), 1–17. https://doi.org/10.1103/PhysRevAccelBeams.24.050701

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ICS Theory- **Collimation to reduce bandwidth**

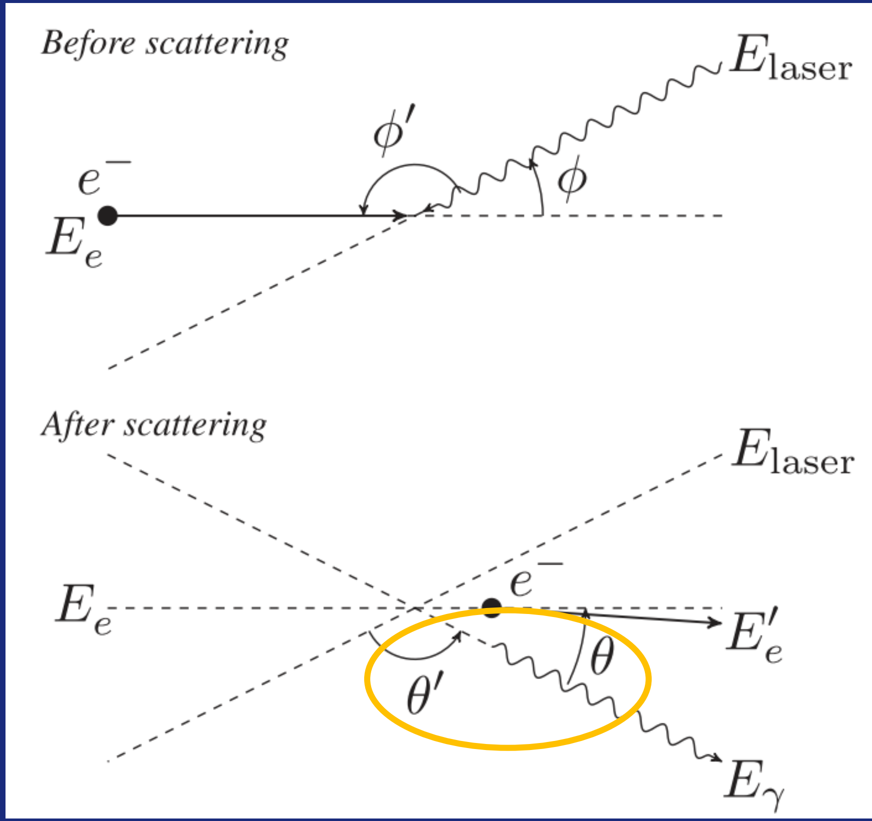
$$E_\gamma = \frac{E_{laser}(1-\beta\cos(\phi'))}{1-\beta\cos(\theta)+(1-\cos(\theta'))E_{laser}/E_e}$$

The energy of the scattered photon depends on the angle it scattered through.

Bandwidth of the source

$$\frac{\Delta E_\gamma}{E_\gamma} = \sqrt{(\frac{\sigma_\theta}{E_\theta})^2+(\frac{\sigma_e}{E_e})^2+(\frac{\sigma_L}{E_L})^2+(\frac{\sigma_\epsilon}{E_\epsilon})^2}$$

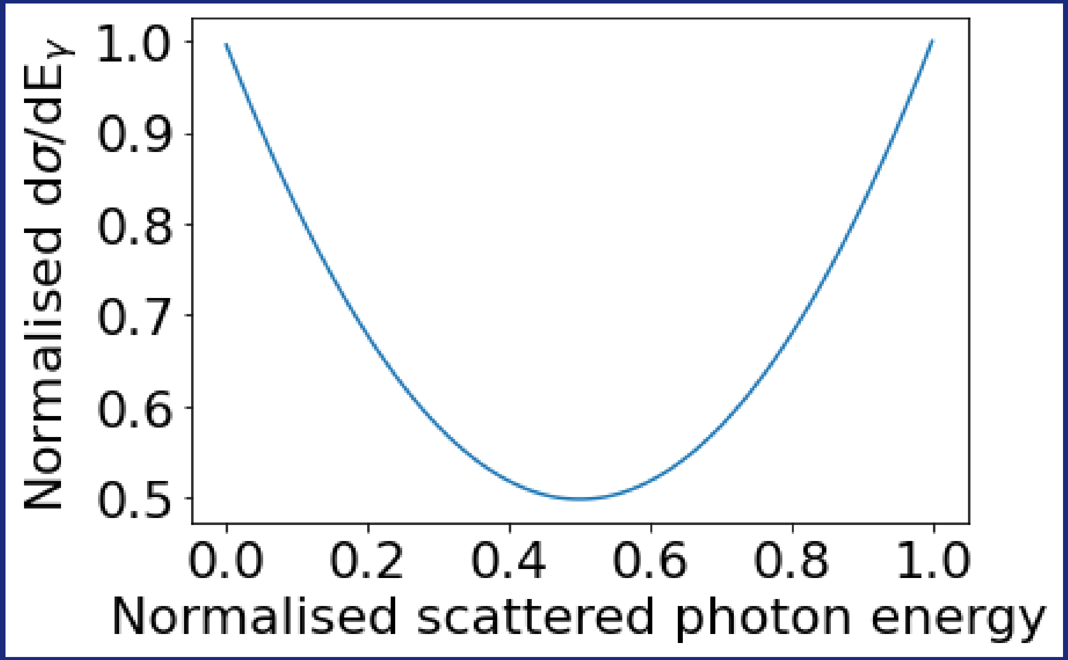
Collimating the scattered photons will exclude the photons scattered though larger angles, thus reducing the bandwidth of the source.

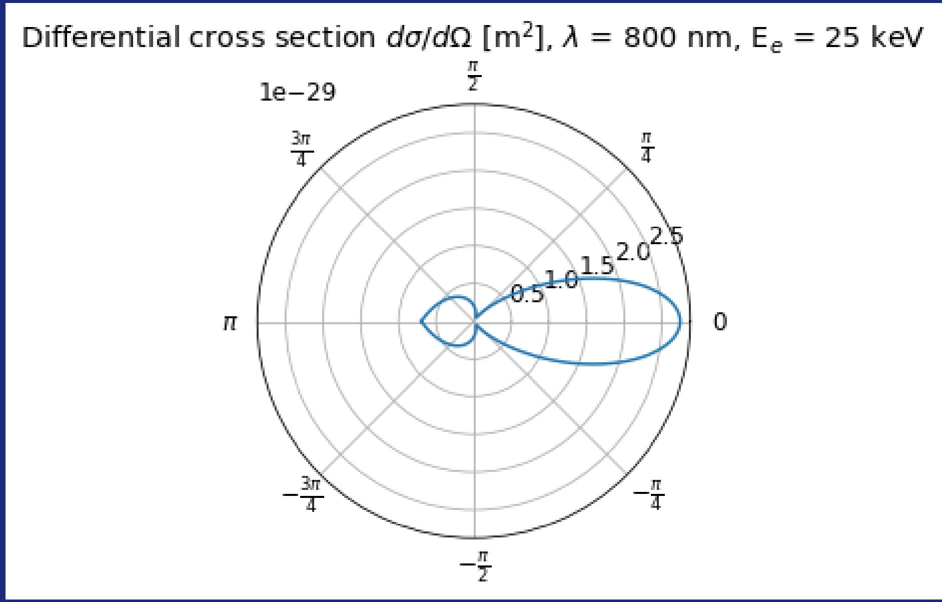


Deitrick, K., et al. (2021). *Physical Review Accelerators and Beams*, *24*(5), 1–17. https://doi.org/10.1103/PhysRevAccelBeams.24.050701

ICS Theory - Photon Production

- More photons are produced in the forward or backward directions because of the final Lorentz transform.





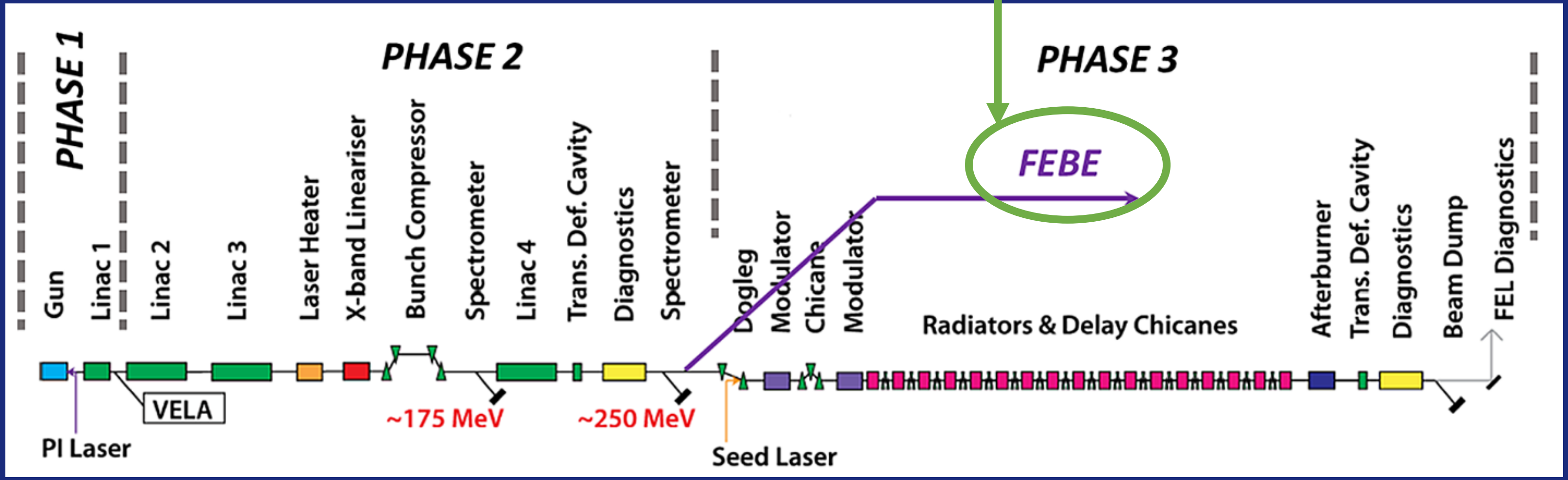
- Photons are produced in the forward direction into a θ = 1/γ cone.

Design of Experiment – Electron Beam

Electron beam parameters

Parameter	Quantity	Unit
Electron kinetic energy, E_e	250	MeV
Repetition rate, f	1–100	Hz
Bunch charge, eN_e	100	pC
Transverse normalised rms emittance, ϵ_N	1	mm-mrad
rms bunch length, $\Delta\tau$	0.73 (2.4)	mm (ps)
Absolute energy spread, ΔE_e	20	keV
Relative energy spread, $\Delta E_e/E_e$	8.00×10^{-5}	-
Baseline parameters		
β-function at the IP,[†] β^*	1.23	m
Electron bunch spot size, σ_{electron}	50	μm

CLARA accelerator & FEBE upgrade



Angal-Kalinin, D. et al. (2020). *Physical Review Accelerators and Beams*, *23*(4), 44801. https://doi.org/10.1103/PhysRevAccelBeams.23.044801

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Design of Experiment - Laser

Ti:Sapphire laser

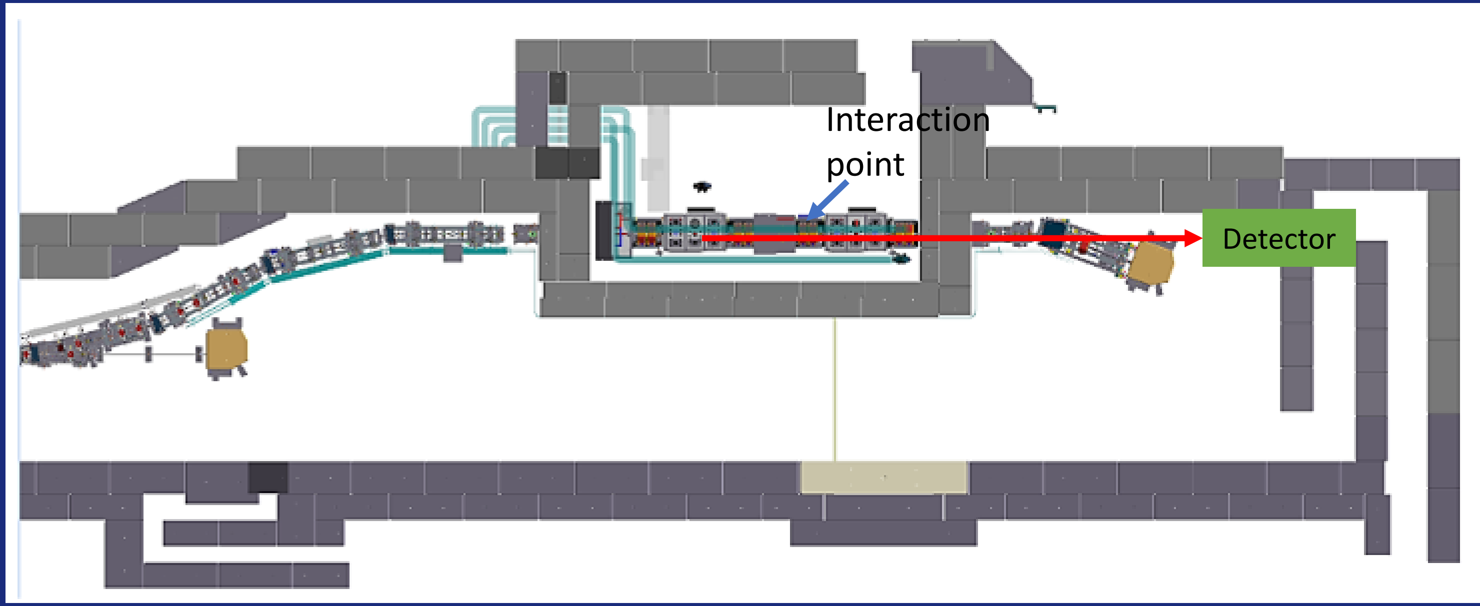
Nd:YAG laser

Parameter	Case A	Case B	Case C	Unit
Wavelength, λ_{laser}	800	800	1064	nm
Photon energy, E_{laser}	1.55	1.55	1.17	eV
Pulse energy, E_{pulse}	5.00	0.10	0.06	J
Number of photons per pulse, N_{laser}	2.02×10^{19}	4.03×10^{17}	3.21×10^{17}	-
Repetition rate, f	1	1	1–10	Hz
Rms spot size at the IP, σ_{laser}	45	45	45	μm
Crossing angle, ϕ	0	0	0	rad
Rms pulse length, τ_{laser}	0.01	2.00	21.23	ps
Normalised Laser Vector Potential, a_0	0.83	8.56×10^{-3}	2.71×10^{-3}	-
Rms spectral Bandwidth, $\Delta E_{\text{laser}}/E_{\text{laser}}$	0.03185	0.03185	10^{-4*}	-

* Estimated parameter, not available upon request.

Collimation of Gamma Source

- Gamma source will be collimated to reduce the bandwidth of the source and to reduce the flux before impinging on a detector 10 m away.
- The flux is reduced so that a detector would not be saturated and single photons events can detected, ~1000 photons per interaction event (assuming an efficiency of detector of 0.1%).



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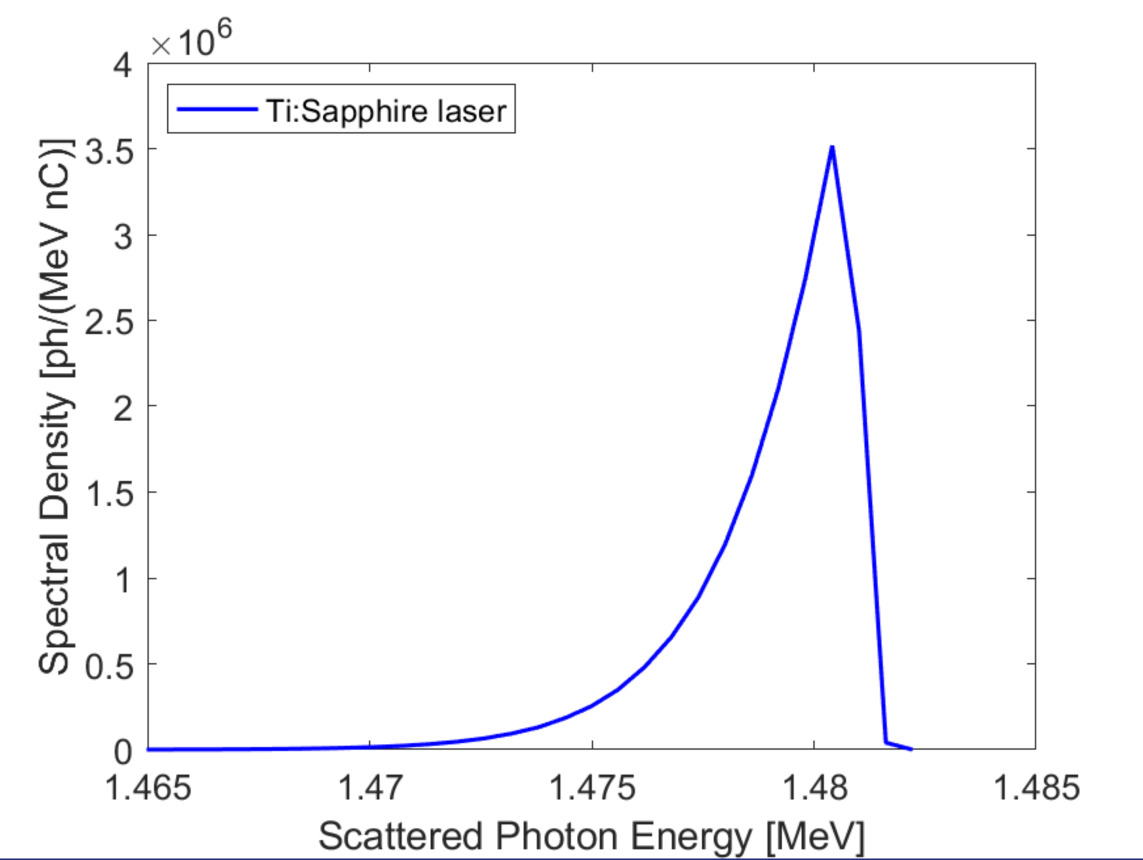
Gamma source parameters

Electron Energy (MeV)	Laser Case	Collimation Angle (mrad)	E^{γ}_{max} (MeV)	Source Bandwidth (%)
250*	B	0.070	1.481	3.17
250	C	0.078	1.115	0.092
600	B	0.024	8.441	3.15
600	C	0.029	6.369	0.193
2000	B	0.0065	90.702	3.10
2000	C	0.0079	68.974	0.615

* Proposed experiment for FEBE

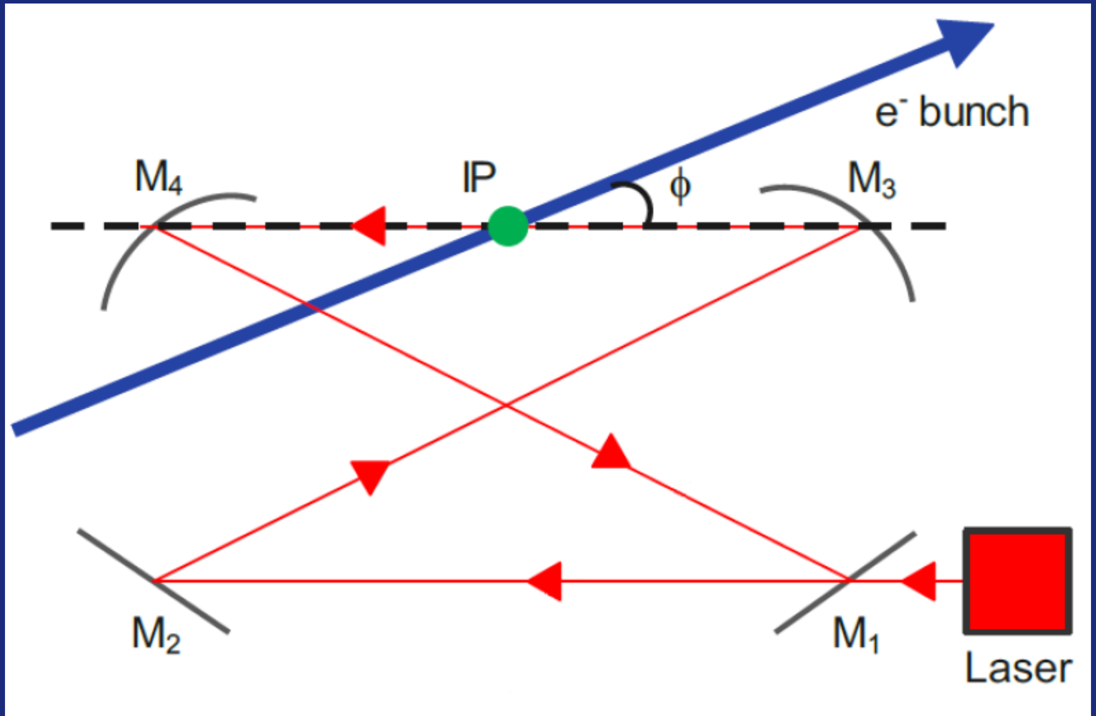


Optical Cavities future work

- Optical cavities recirculate the laser pulses to store power in the cavity

$$\mathcal{E}_0 = \frac{P_{\text{circ}}}{P_{\text{in}}}\Bigg| = \frac{1 - r^2}{(1 - ar)^2}.$$

- Can be used to increase the effective repetition rate of the laser pulses



Carstens, H. (2016). *Enhancement cavities for the generation of extreme ultraviolet and hard x-ray radiation*.

Joe Crone, thesis

Summary

- ICS is a method of producing tunable, high energy monochromatic photons.
- I am currently designing an ICS demonstrator experiment.
- I am undertaking a secondment to the Université Paris Saclay to learn about optical cavities, as this would be a major improvement for an ICS source.

Thank you for listening!

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Any questions?