Inverse Compton Scattering Gamma-Ray Source at ASTA

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Outline

- **ICS light source concept**
- **Applications of intense gamma ray beams**
- **ICS at ASTA**
- **Conclusions**

Inverse Compton Scattering (ICS)

- ICS X-rays are generated via Doppler shift, when optical laser beam is scattered off the relativistic electrons
- ICS is directional and quasi-monochromatic

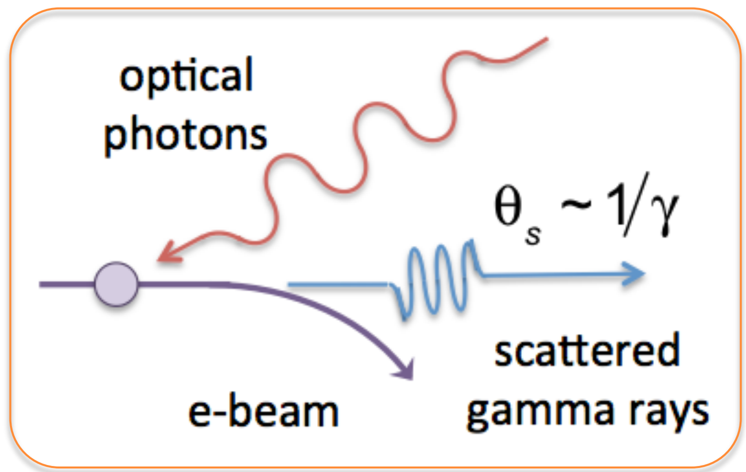
$$k_s \approx 4\gamma^2 k_0 \left(\frac{1}{1 + a_L^2 + \gamma^2 \theta_s^2} \right)$$

$$\sigma_{ICS} \approx \sigma_{th} \quad \text{for} \quad \gamma << 10^5$$

$$\sigma_{th} = \frac{8\pi}{3} r_e^2 = 6.65 \times 10^{-25} \ \text{cm}^2$$

$$N_s \approx \left(\frac{N_0 \sigma_{ICS}}{A} \right) N_e$$

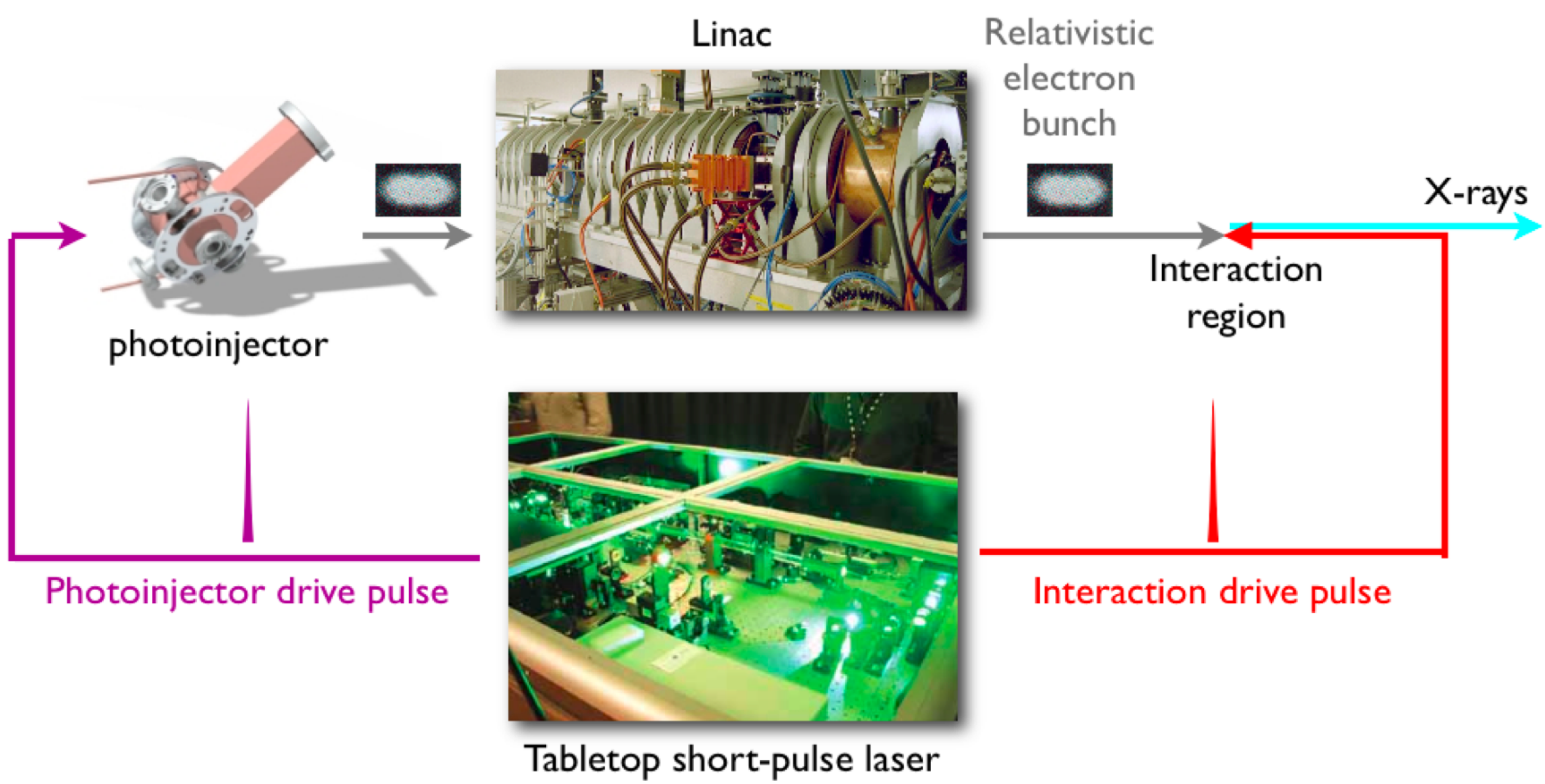
$\sim 10^{19\text{-}24+5}$



- Maximum X-ray yield: 1 ph. per electron

Photoinjector driven ICS

- Intense picosecond beams such as produced by photoinjectors enable high performance ICS sources.



Source bandwidth

- ICS has finite intrinsic bandwidth (besides the off-axis off-axis red-shift):
  - ✓ laser 3D focus
  - ✓ e-beam emittance
  - ✓ laser bandwidth
  - ✓ e-beam energy spread

$$\frac{\Delta k_x}{k} \approx \sqrt{2\left(\frac{\varepsilon_x}{\beta_x}\right)^2 + 2\left(\frac{\lambda}{4\pi Z_R}\right)^2}$$

$$\frac{\Delta k_l}{k} \approx \sqrt{\left(\frac{\Delta\lambda}{\lambda}\right)^2 + 4\left(\frac{\Delta\gamma}{\gamma}\right)^2}$$

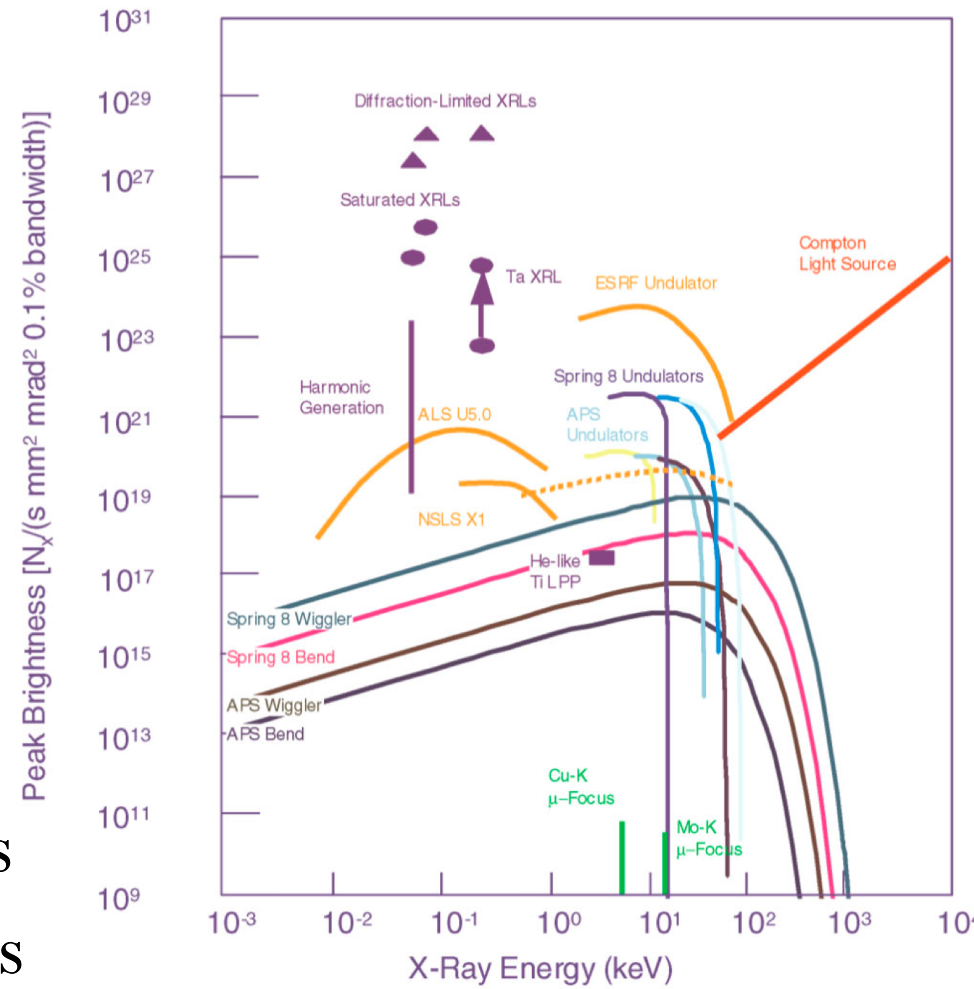
- 1 nC, 1 J, 10 μm RMS spot size at IP results in an X-ray flux of ~ 10^9 ph. in $1/\gamma$ opening angle per interaction
- On-axis photon flux in 1% bandwidth ~ 10^7-10^8 ph.

System requirements

- Historically, ICS was aimed at hard X-rays medical applications (i.e. phase-contrast imaging)
- Most practical applications require photon flux of $\sim 10^{11}$ cps in 1 % bandwidth
- After single shot optimization ICS requires 10^3-10^4 interactions per second (e-beam bunch trains, laser intracavity, high rep. rate)
- Stand-alone high rep. rate ICS systems suitable for practical applications are yet to be demonstrated

ICS gamma ray source

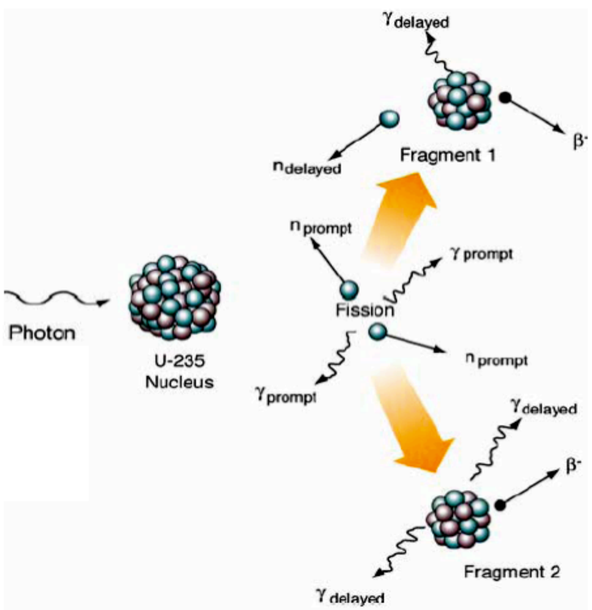
- High efficiency at high energy (~ 1% energy extraction efficiency, like FEL!)
- Directionality (~1 mrad)
- Source brightness scales like ~ γ^5 !
- Uniqueness – light sources do not reach MeV energies

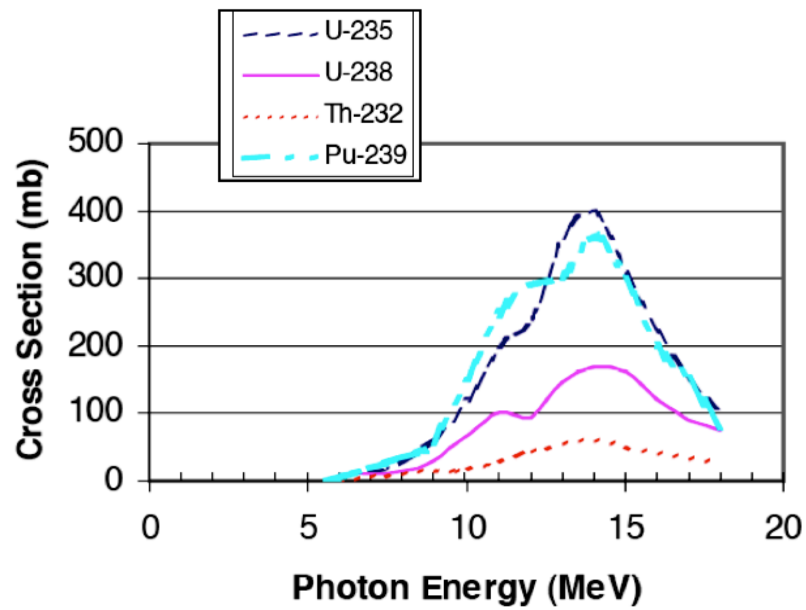


[F.V. Hartemann *et al.*, *PR ST AB* **8**, 100702, 2005]

Applications: nuclear threat detection

- Gamma-ICS source can be used for stand-off detection of concealed special nuclear materials (SNM) via photofission at large range distances

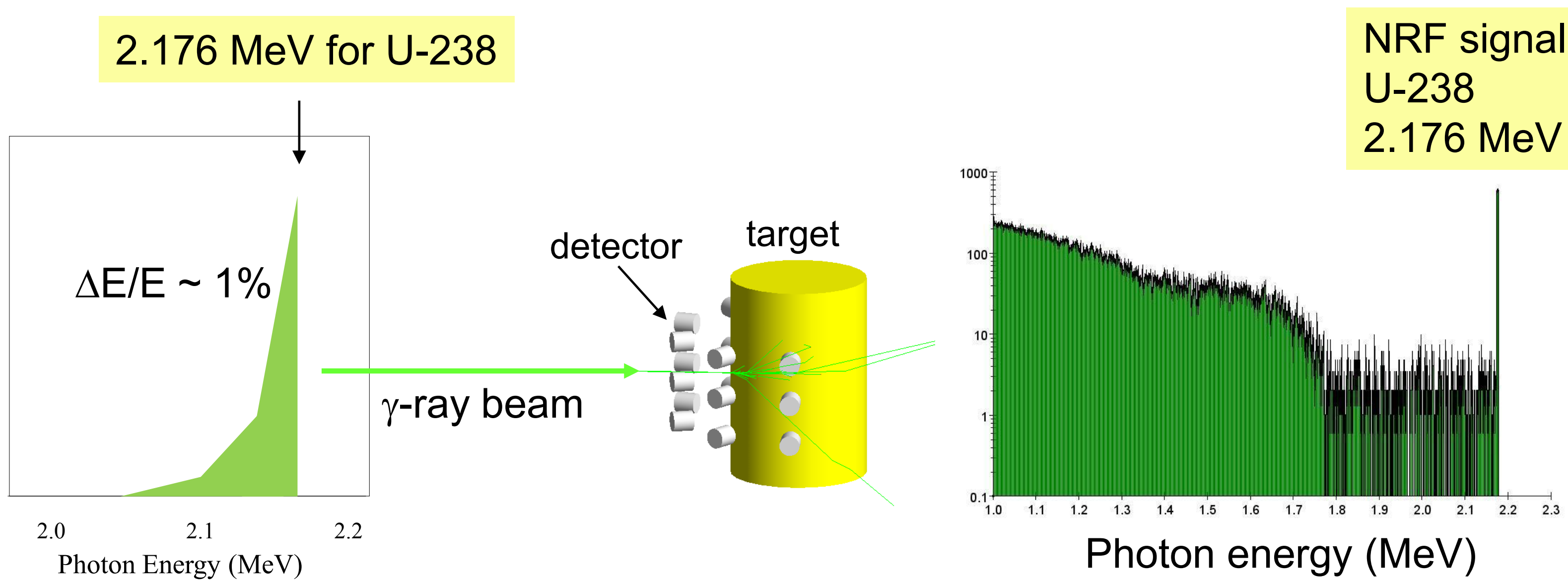




[J.L. Jones *et al.*, Neutrons Workshop at ONR, October 2006.]

Applications: nuclear waste analysis

- Nuclear resonance fluorescence (NRF) has also been proposed for SNM detection
- Also, important practical application of NRF is spent nuclear fuel casks inspection

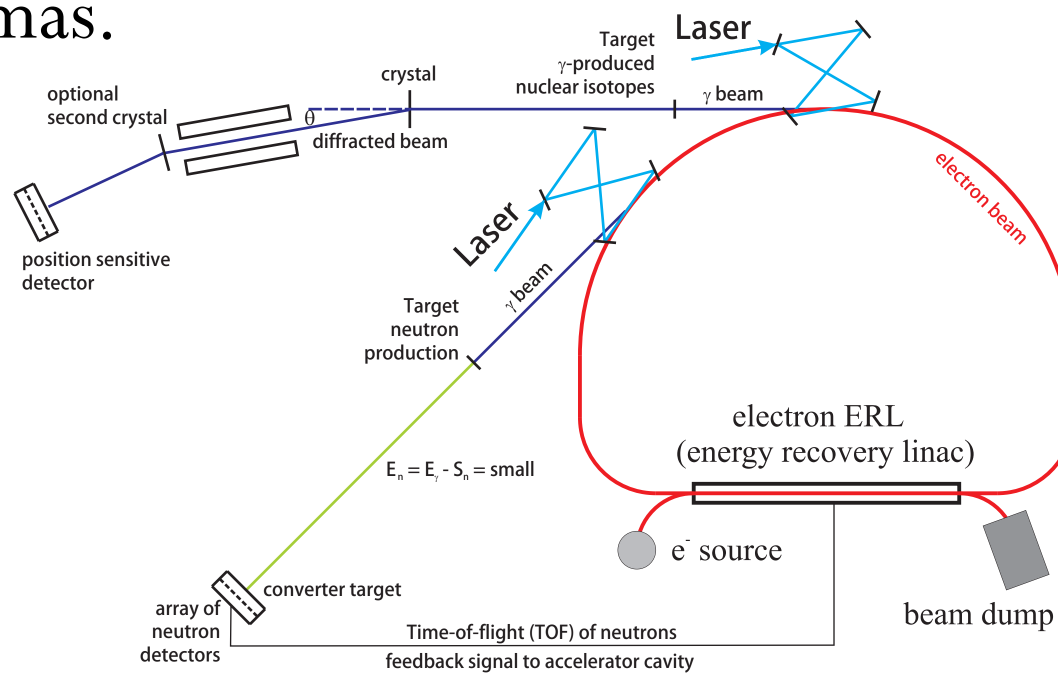


[R. Hajima, Japan Atomic Agency ERL Group (2008)]

Applications: medical isotopes R&D

- ERL based gamma ray sources for isotopes production
- Even more interesting is generation of specific activity radioisotopes via photo-excitation by tuning to specific energy gammas.

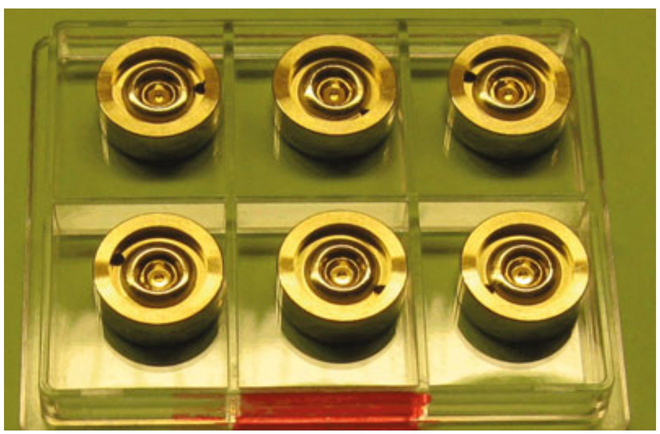
mother isotope	$T_{1/2}$	daughter isotope	$T_{1/2}$
^{44}Ti	60.4 a	^{44}Sc	3.9 h
^{52}Fe	8.3 h	^{52}Mn	21 m
^{68}Ge	288 d	^{68}Ga	68 m
^{81}Rb	4.6 h	^{81}Kr	13 s
^{82}Sr	25.0 d	^{82}Rb	76 s
^{90}Sr	28.5 a	^{90}Y	64 h
^{99}Mo	66 h	^{99m}Tc	6.0 h
^{188}W	69 d	^{188}Re	17 h
^{224}Ra	3.7 d	^{212}Pb*	10.6 h
^{224}Ra	3.7 d	^{212}Bi*	61 m
^{225}Ac	10 d	^{213}Bi*	45 m

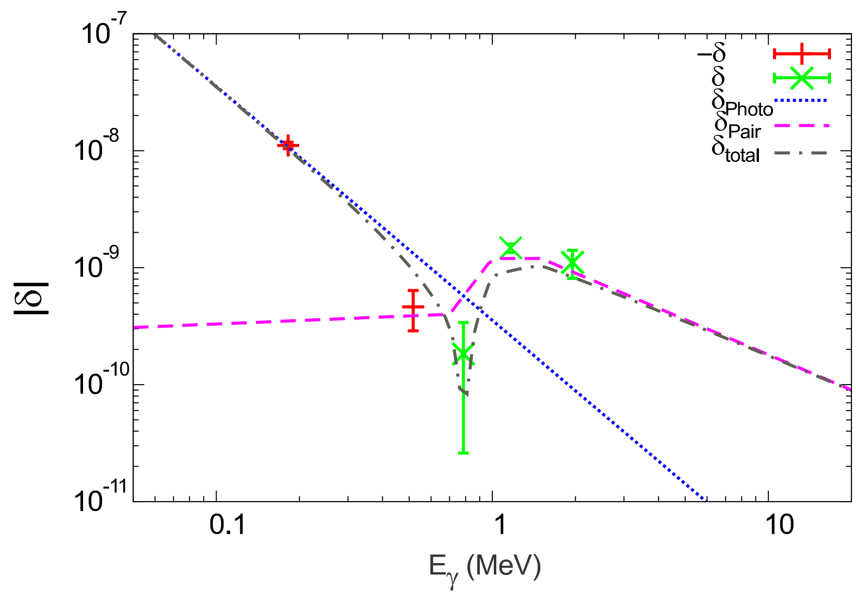


[D. Habs, P.G. Thirolf *et al* " Medical Application Studies at ELI-NP", 2012]

Applications: new nuclear physics

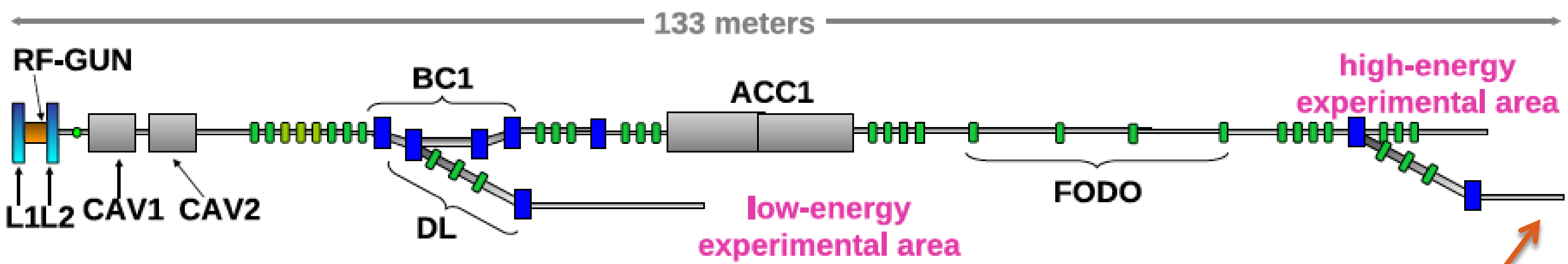
- Probing nuclear matter
- Observation of "refractive" behavior above 0.7 MeV:
  - possibility of making gamma-ray optics
  - possibility of ultra-monochromatic gamma beams (1E-6)





[D. Habs *et. al.* " The Refractive Index of Silicon at γ Ray Energies", PRL 2012]

Gamma ICS @ ASTA



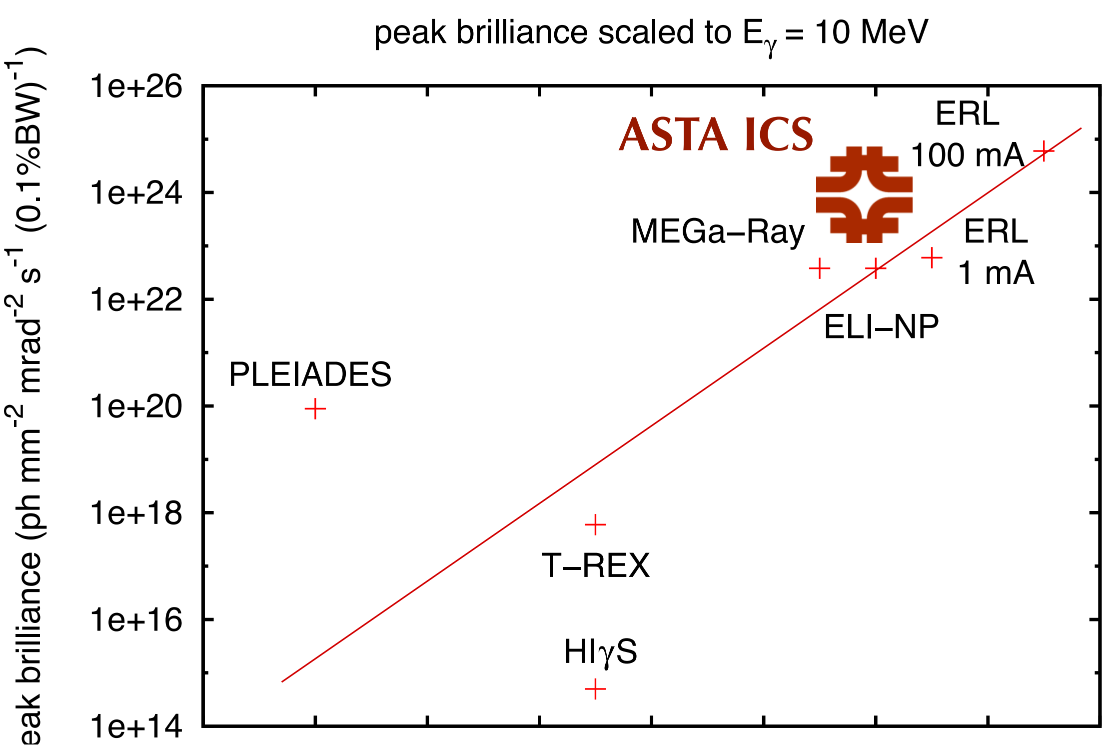
E-beam	
Charge	3 nC
Bunch length	~ 10 ps
Normalized emittance	~ 5 μm
Energy	500-1000 MeV
RMS spot size @ IP	~ 20 μm
Beta function	~ 10 cm
Laser	
Pulsed energy	~ 300 mJ
Wavelength	~ 1 μm
Raleigh range	5 mm

Gamma rays (single shot)	
Total single-shot flux	~ 10^9
Gamma-rays energy	5-20 MeV
Flux in 1 % bandwidth	~ 10^7

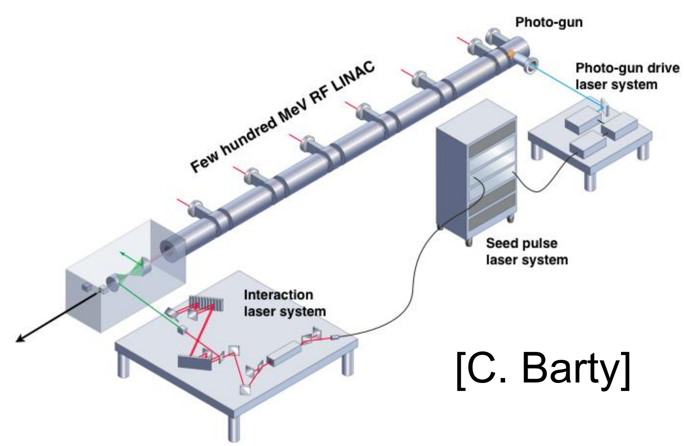
Pulse train mode	
Rep. rate	3 MHz
# of bunches in macropulse	~ 10,000
Average flux in 1% BW	~ 10^{12} cps
Average power of gamma flux	~ 1 W

Gamma ICS @ ASTA

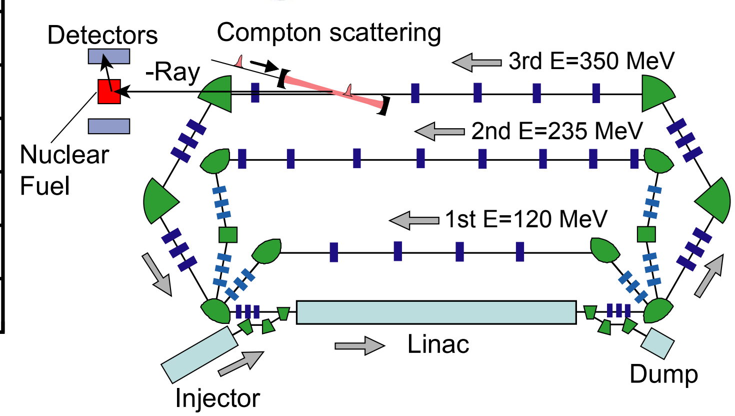
- ASTA ICS projected performance is in line with the most ambitious future ICS facilities



[Habs, D.; Köster, U, Applied Physics B **103**, 2011]



[C. Barty]



[R. Hajima]

Elements of the ICS system

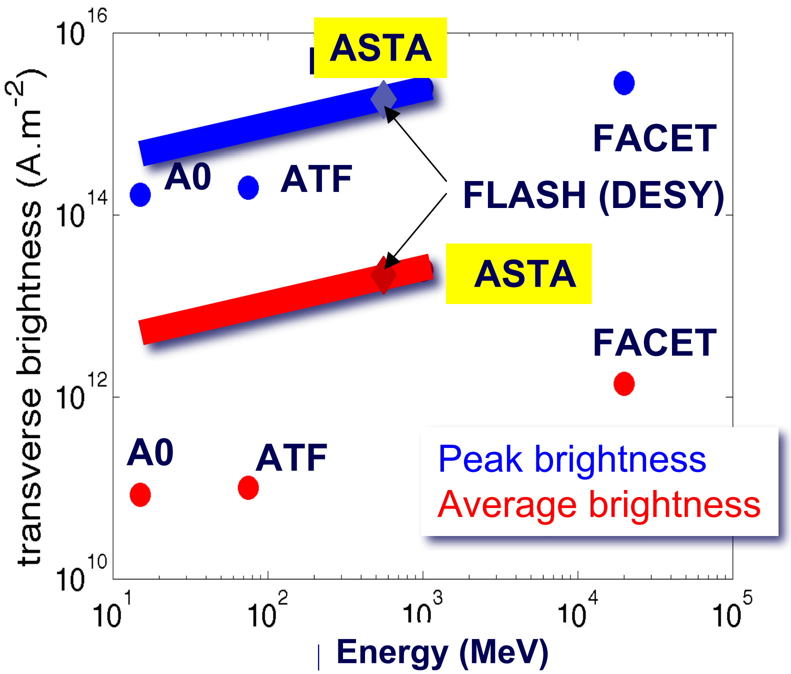
- ✓ High duty cycle accelerator
- Laser amplifier (25 μJ → 5-10 mJ) and transport
- Laser intracavity (to get up to 1 J at IP)
- Dedicated beamline
- Interaction chamber (including final focus system)
- Gamma ray transport through the beam dump
- Large dynamic range gamma ray detectors

Risks

- E-beam delivery and optimization for ICS is relatively low risk assuming it follows ASTA linac commissioning and beam studies
- ICS system integration and commissioning are of moderate risk (synchronization and alignment control, optical damage and thermal issues). Leveraged on RadiaBeam ICS experience at ATF-BNL, plus the ongoing development of a high rep rate laser wire scanner at Cornell ERL
- Laser system is higher risk, and requires design study

Conclusions

- Average e-beam power and energy range at ASTA makes it an ideal and uniquely suitable facility for intense gamma ray source in the US
- Such source has many interesting applications, and very likely to attract a dynamic users community
- The cost and risk profiles are very moderate
- Thank you!



[P. Piot, AARD@ASTA, Dec. 5, 2011]