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Electron Beam Diagnosis Using K-edge Absorption of Laser-Compton Photons

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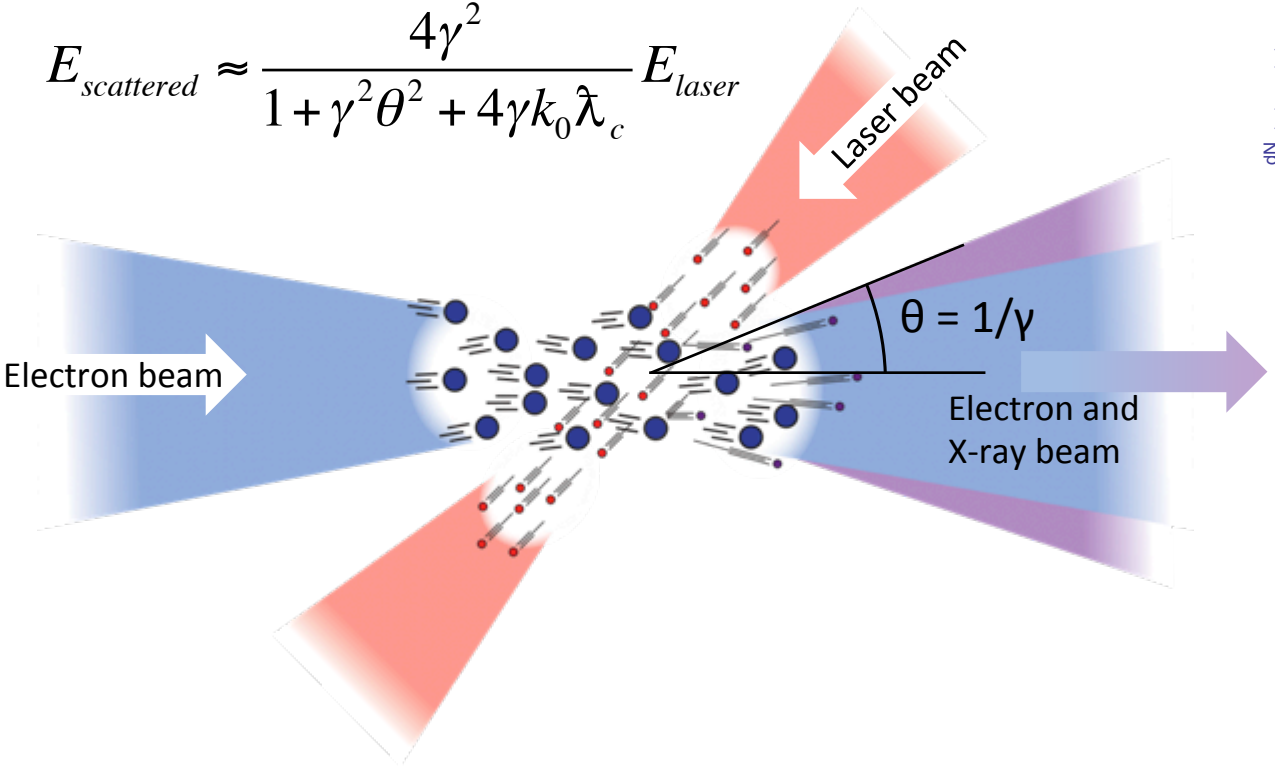
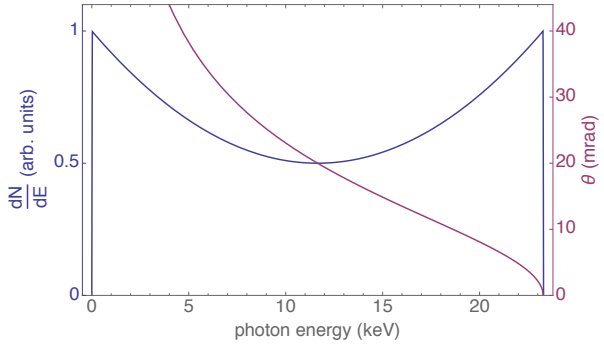
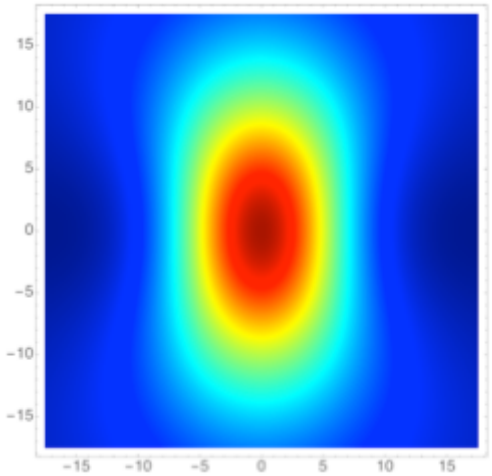
Laser-Compton photon generation

$$E_{scattered} \approx \frac{4\gamma^2}{1+\gamma^2\theta^2+4\gamma k_0 \lambda\!\!\!^{-}_c} E_{laser}$$



Spectrum and angle correlation

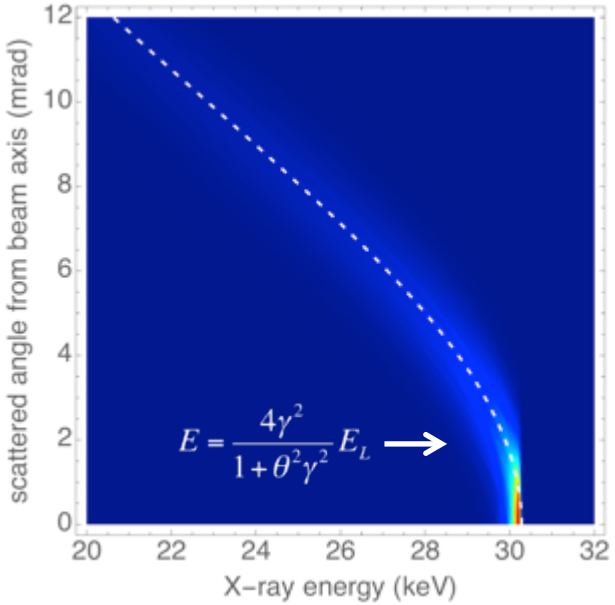




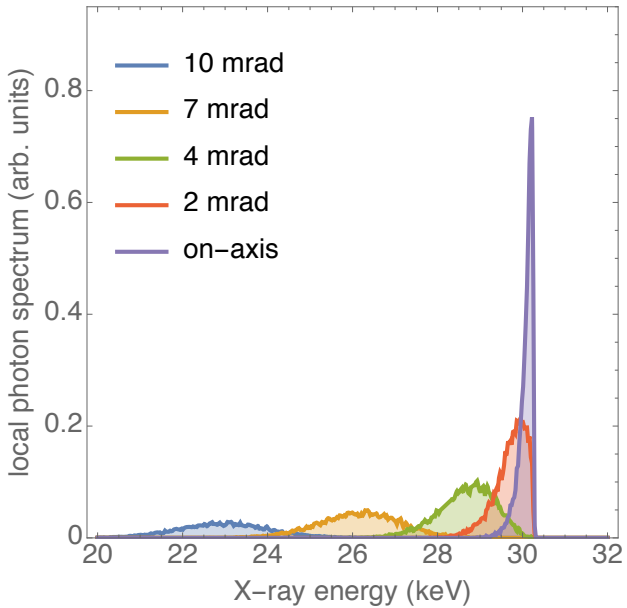
Effect of e^- beam divergence on Compton spectrum

beam energy E_e	energy spread σ_E	beam divergence σ_θ	laser wavelength λ_L
28.6 MeV	0.06% rms	1 mrad rms	532 nm

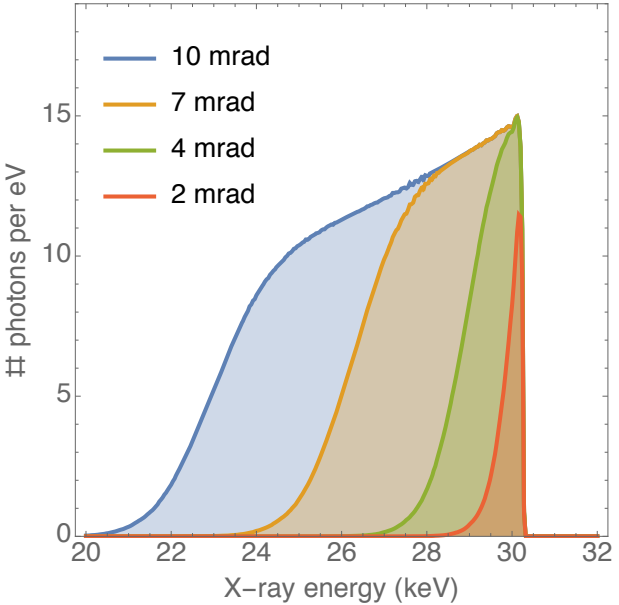
angular spectrum



local spectrum



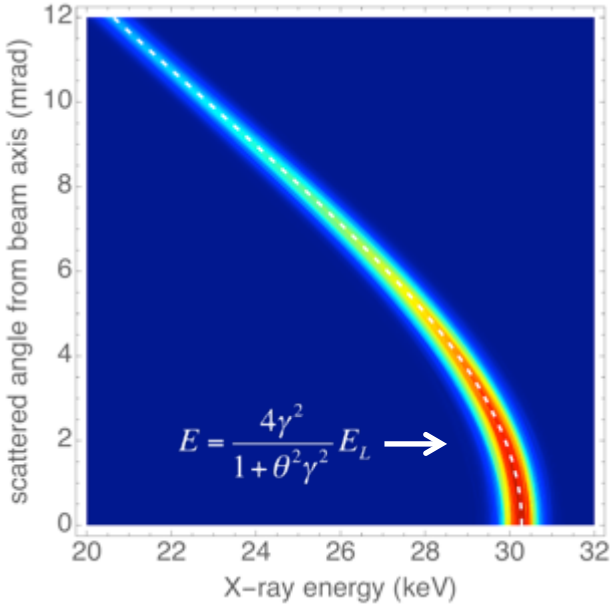
integrated spectrum



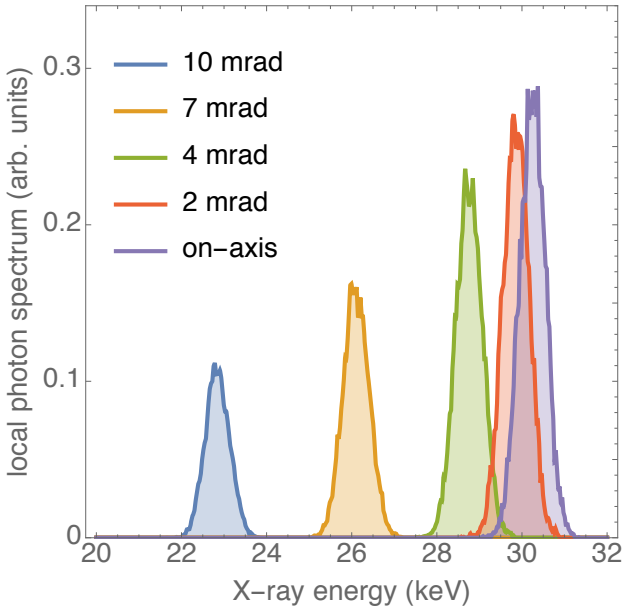
Effect of e^- beam energy spread on Compton spectrum

beam energy E_e	energy spread σ_E	beam divergence σ_θ	laser wavelength λ_L
28.6 MeV	0.5% rms	0.2 mrad rms	532 nm

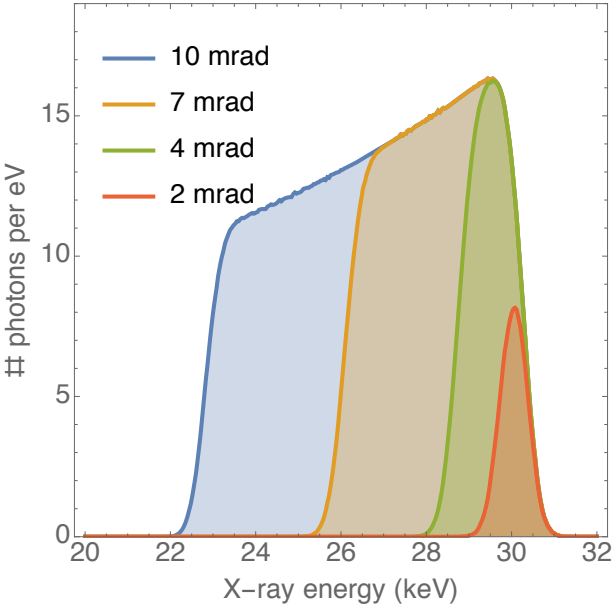
angular spectrum



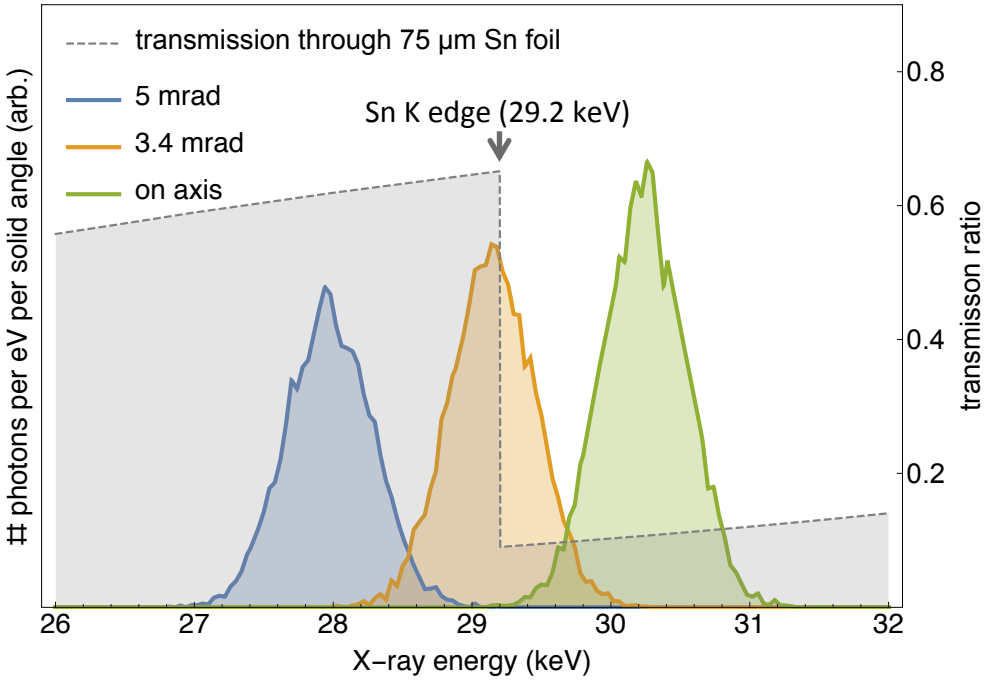
local spectrum

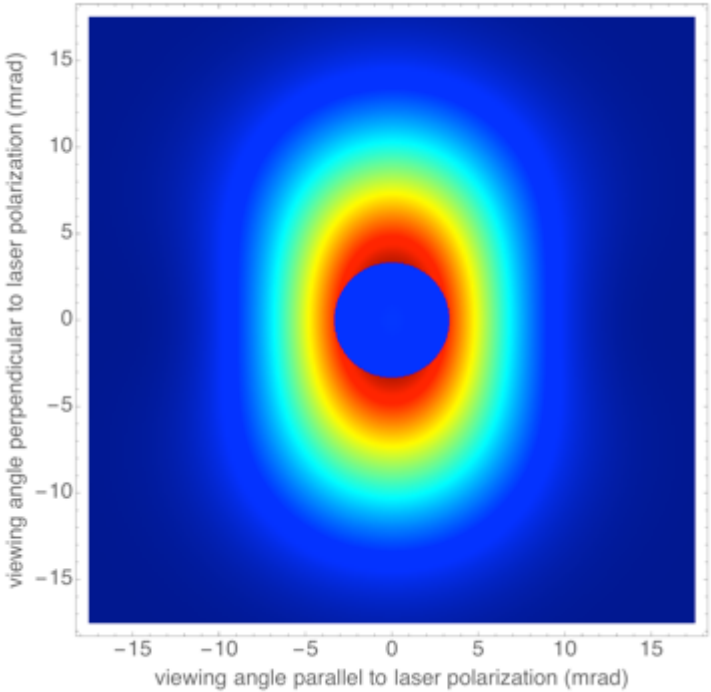


integrated spectrum

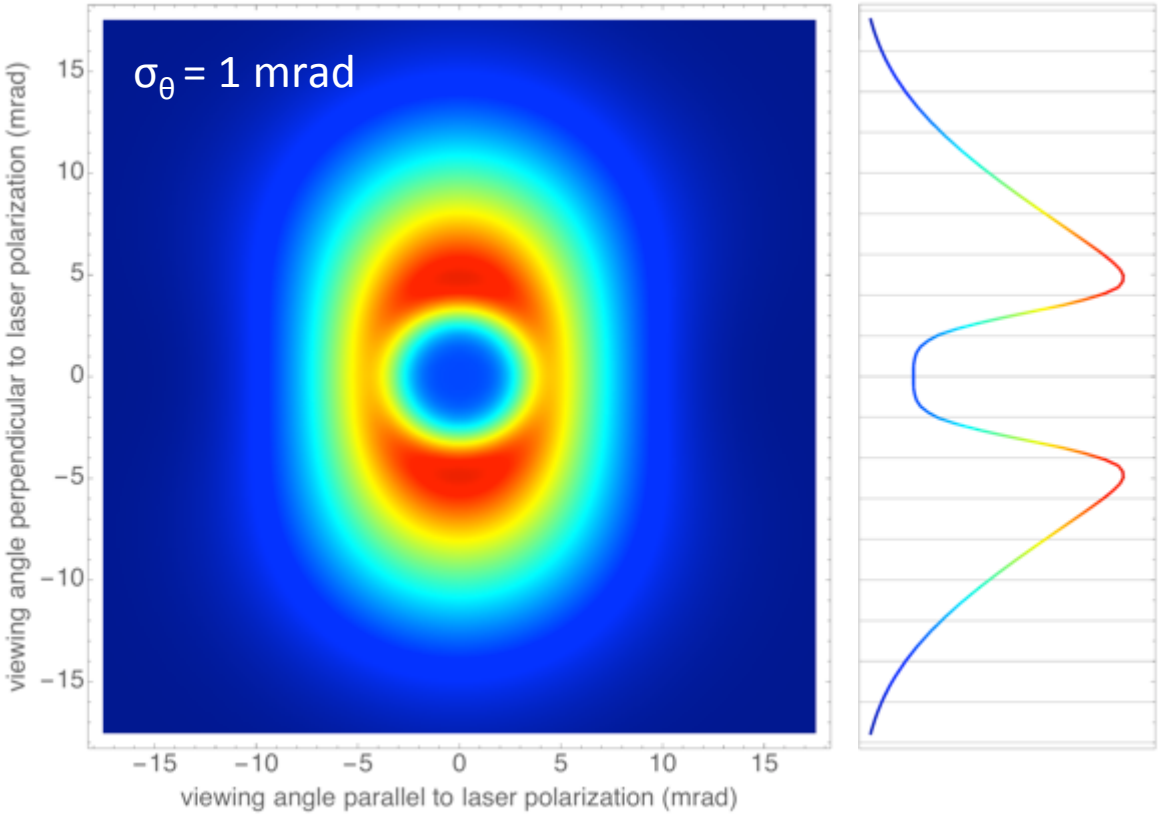


K-edge absorption filtering





Edge blurring due to spectral bandwidth

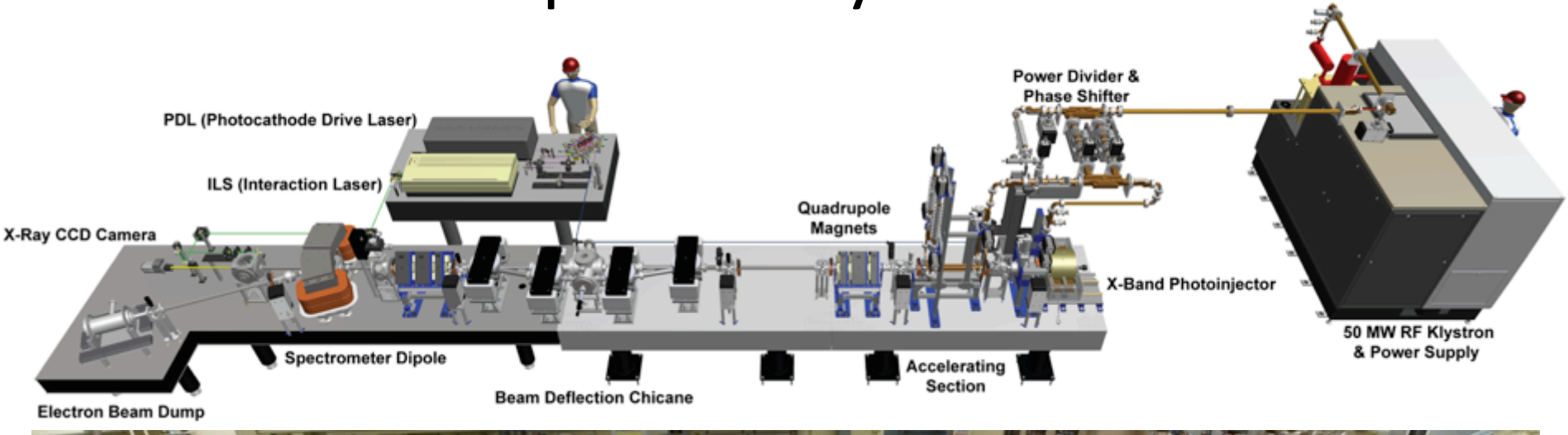


Hole radius: cone angle θ_K

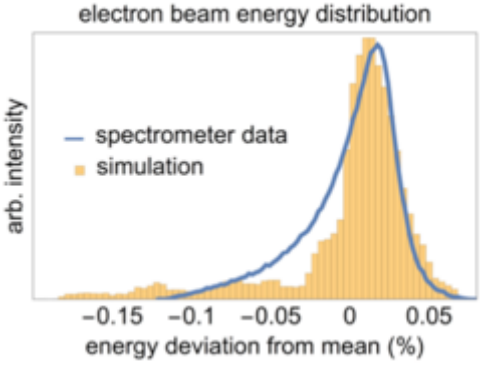
$$\theta_K \approx \sqrt{\frac{4E_{laser}}{E_K} - \frac{1}{\gamma^2}}$$

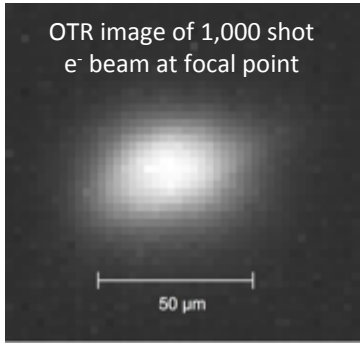
- Electrons with different energy create K-edge holes of varying sizes
- Electrons moving in different directions create holes centered at different locations

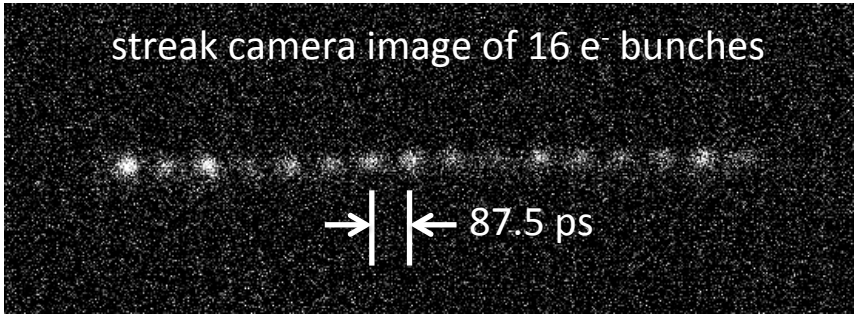
Laser-Compton X-ray Source at LLNL



LLNL X-band Electron Linear Accelerator







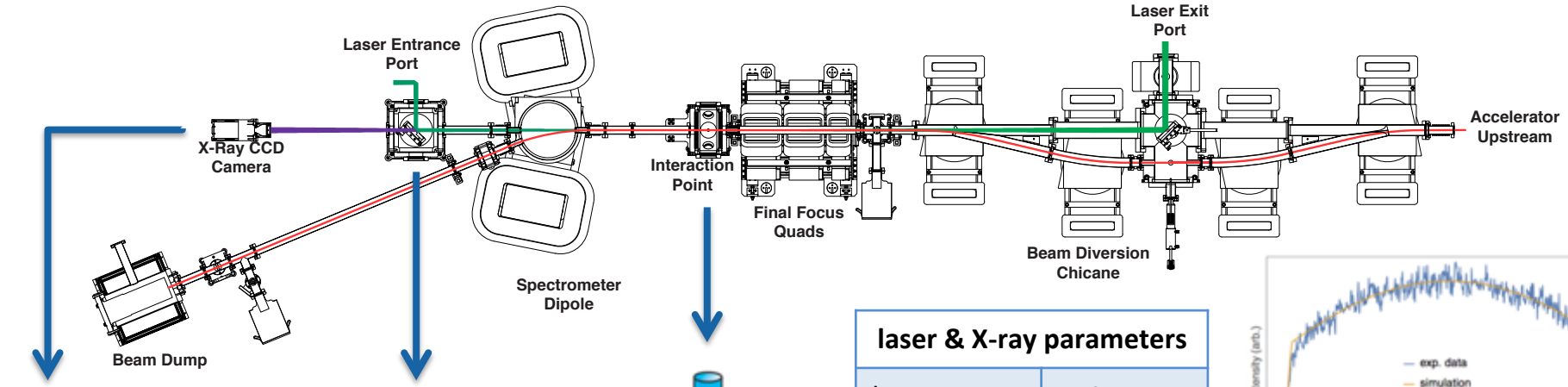
- LLNL/SLAC photoinjector[1]
  - 185 MV/m, ~7 MeV
- 1 T53 accelerating section
  - 45 MV/m, ~30 MeV
- 50 MW klystron, modulator
- up to 16 bunches per pulse

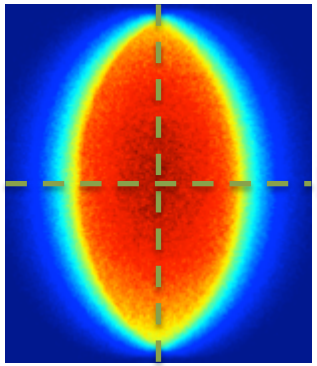
measured e- beam parameters	
energy	< 30 MeV
charge	10-200 pC
bunch length	2 ps*
spot size	14 µm x 11 µm
pos. jitter	5 µm x 2 µm
energy spread	0.03%
energy jitter	0.06%
emittance	0.3 mm-mrad
RF frequency	11.424 GHz
rep. rate	10 Hz

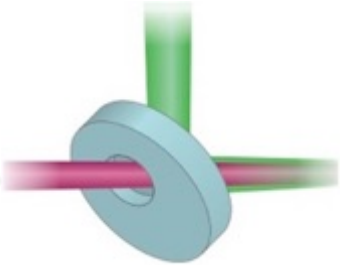
*PARMELA simulation value

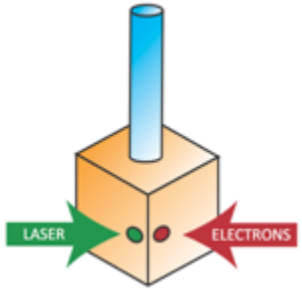
[1] R. A. Marsh et al., PRSTAB **15**, p. 102001

Laser-Electron Interaction

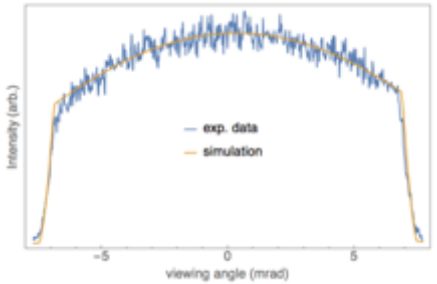


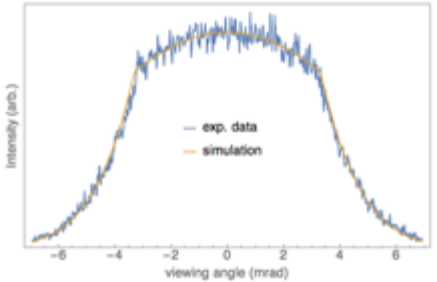




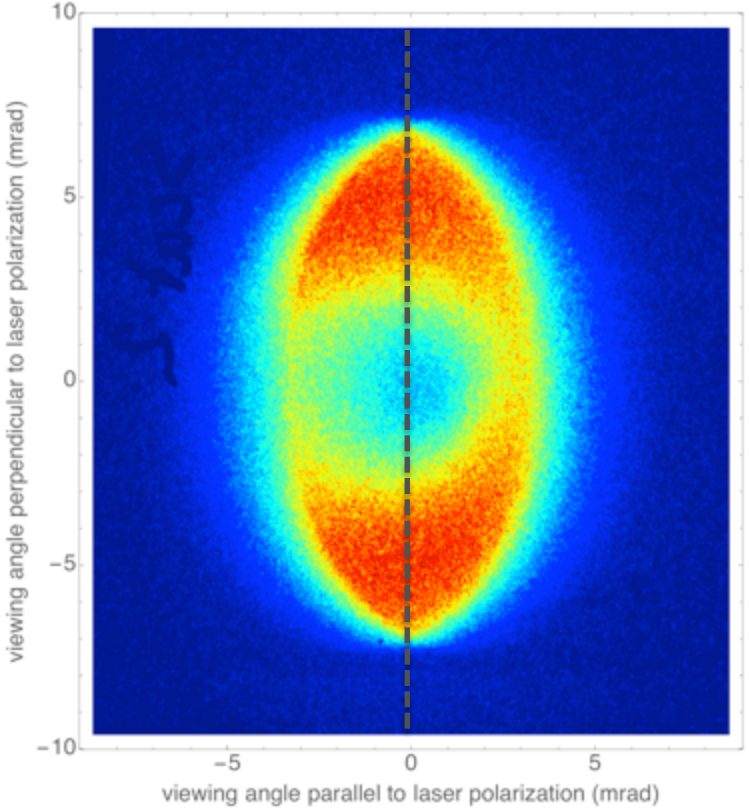


laser & X-ray parameters	
laser energy	750 mJ
wavelength	532 nm
pulse length	6.5 ns
beam waist	50 µm
X-ray energy	30 keV
X-ray flux	3×10^5/shot

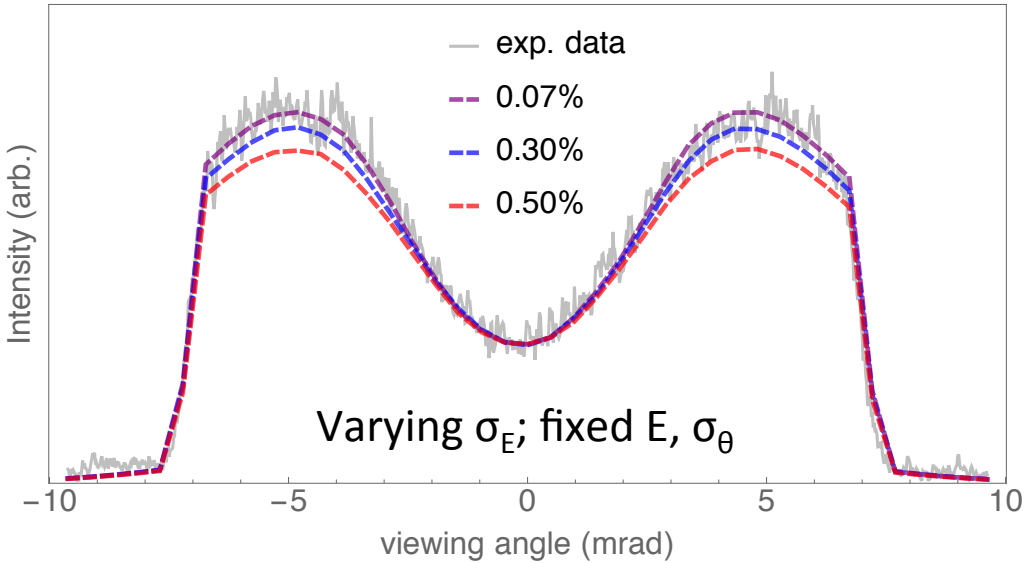




Beam reconstruction by iterative matching



- 75 μm thick Sn foil, 30 min. integrated image plate
- 3 match parameters: E, σ_E, σ_θ (Gaussian jitter)



Analysis of the method

- Advantages
  - Simple setup, no special equipment necessary (other than the laser)
  - Mean energy can be measured to very high accuracy
  - Parameter limiting the beam quality can be measured with high accuracy
  - Coupled with a beam spot size measurement, can give emittance
- Disadvantages
  - Limited number of suitable K-edge materials
  - More parameters may be needed to accurately model spectrum/divergence
  - Non-limiting parameter cannot be measured accurately

Summary

- Compton scattered spectrum of laser with electron beam contains information about the beam's energy and divergence
- K-edge filtering and iterative matching can be a simple, useful technique in determining beam parameters
- The K-edge filter method was demonstrated with LLNL's 30 MeV linac electron beam producing 30 keV X-rays with Sn filter
- The method gives precise energy measurement and can give quick divergence and energy spread estimates
- Divergence can be combined with an independent spot size measurement for emittance calculation