Synchrotron radiation from Thomson back-scattering of laser-accelerated electron beams

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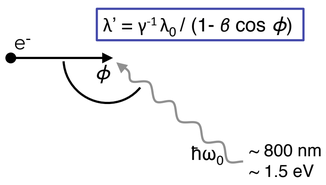
Inverse Thomson Backscattering

(Optical) Undulator equation

$$\lambda = \frac{\lambda_0}{2\gamma^2(1-\beta\cos(\phi))}\left(1+\frac{a_0^2}{2}+\gamma^2\theta^2\right)$$

Doppler effect – moving receiver

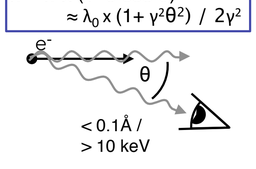
$\lambda' = \gamma^{-1}\lambda_0 / (1-\beta\cos\phi)$



Angle between 'undulator' and electron

– moving source

$\lambda'' = \lambda'(1-\beta\cos\theta) \approx \lambda_0(1+\gamma^2\theta^2)/2\gamma^2$



Angle between observer and electron direction (small angle approximation)

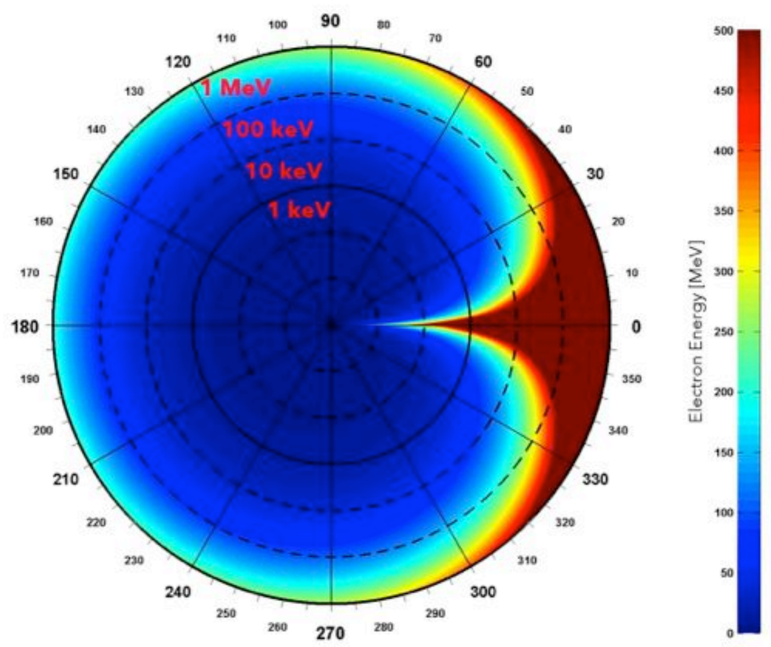
Strong motion in transverse plane effects longitudinal motion.

$$\beta_z(t) \simeq 1 - \underbrace{\frac{1+a_0^2}{2\gamma^2}}_{} + \frac{a_0^2}{4\gamma^2}\cos 2k_0 t \qquad \beta_x(t) = \frac{a_0}{\gamma}\sin(k_0 t)$$

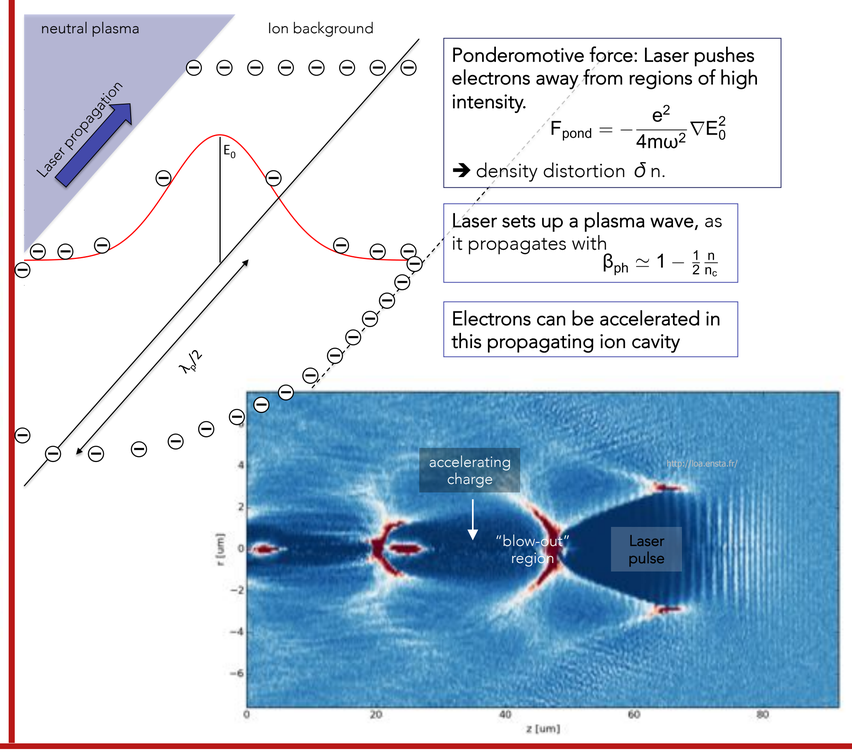
Effective Lorentz factor $\gamma' = \gamma / (1+a_0^2/2)^{1/2}$

a_0 is equivalent to peak angular deflection parameter *K*.

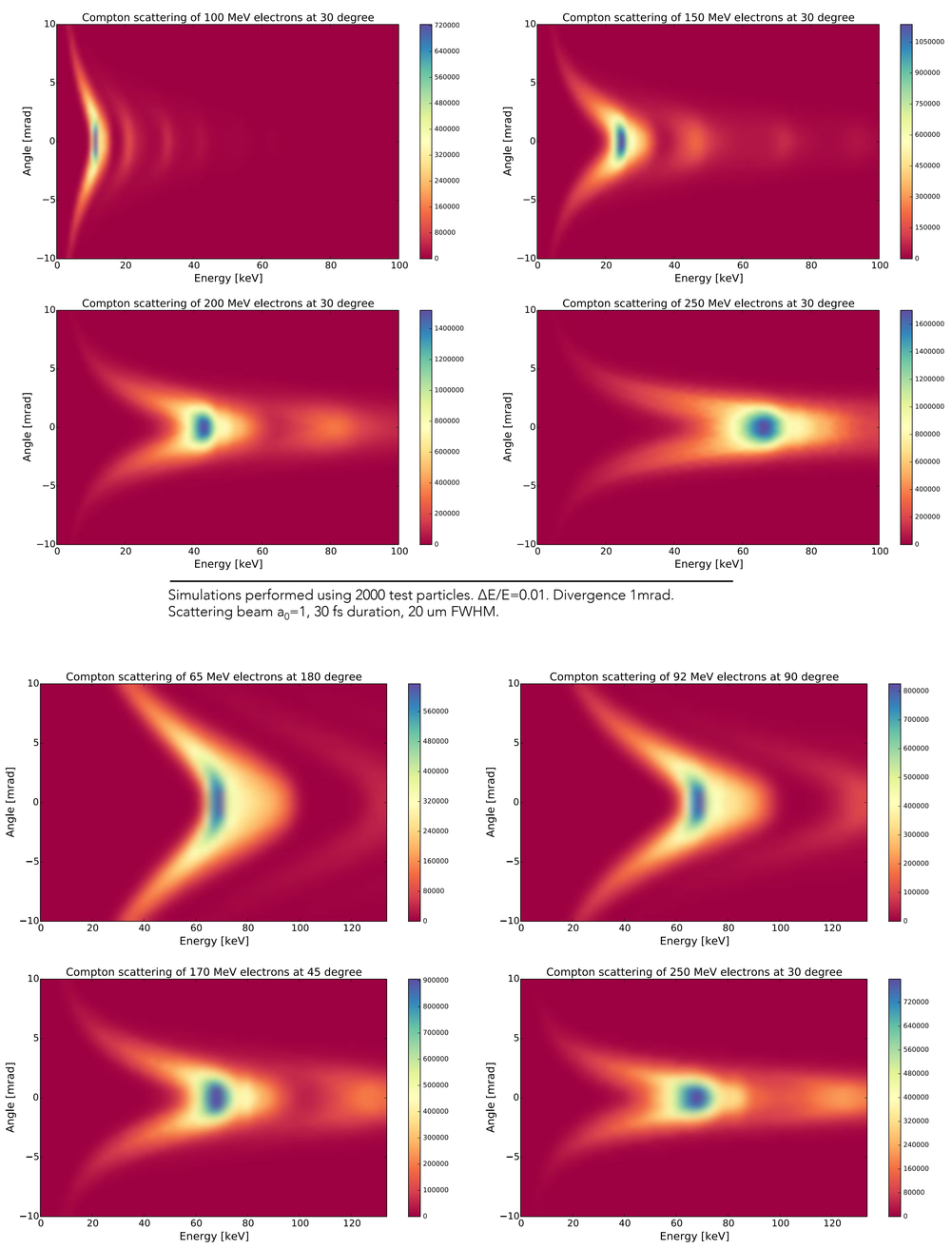
Difference to K in conventional undulators
a_0 evolves during interaction



Laser-Wakefield Acceleration in a nutshell



Simulating X-ray spectra for LWFA parameters



Simulations performed using 2000 test particles. ΔE/E=0.01. Divergence 1mrad.
Scattering beam a_0=1, 30 fs duration, 20 um FWHM.

Simulations performed using 2000 test particles. ΔE/E=0.01. Divergence 1mrad.
Scattering beam a_0=1, 60 fs duration, 20 um FWHM.

- The spectral width is influenced by the beam divergence, energy spread and the scattering beam amplitude a_0.
- The main limiting factor for mono-energetic LWFA beams is currently the beam divergence.

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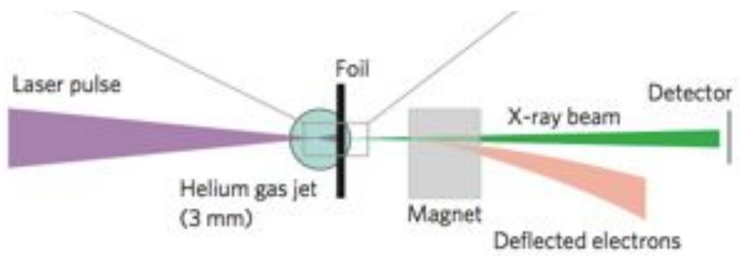
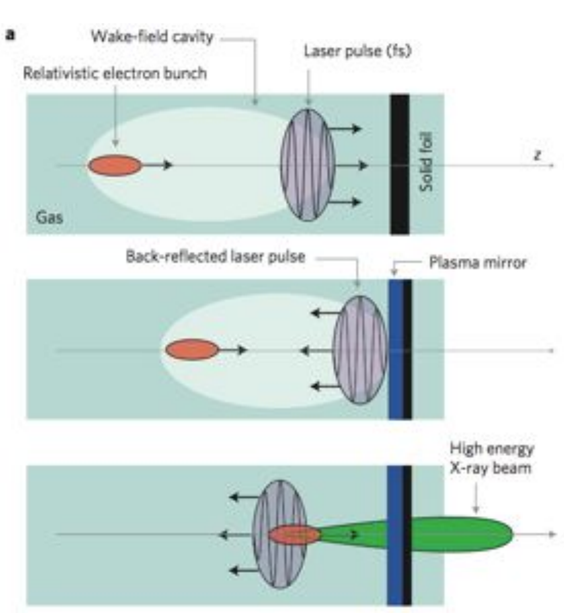
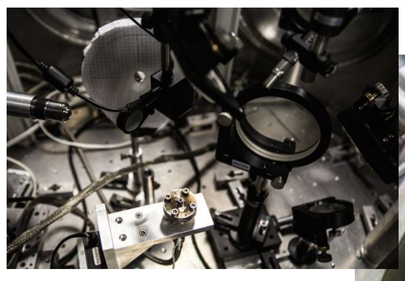
Thomson-Backscattering using Plasma-Mirror

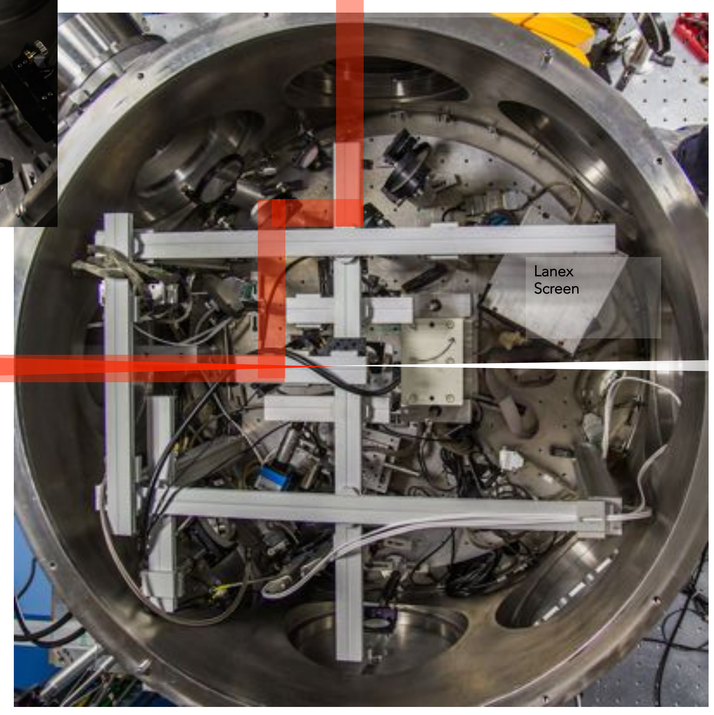
- Instead of a second laser pulse, we use the primarily laser pulse for scattering
- The laser is reflected using a foil that acts as plasma mirror and immediately scatters with the electrons in its proper wake.





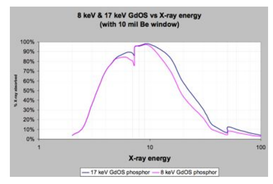
~ 1.6 J, ~30 fs
(65 % of 2.5 J)

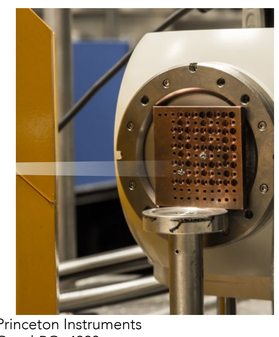




~ 0.9 J on target

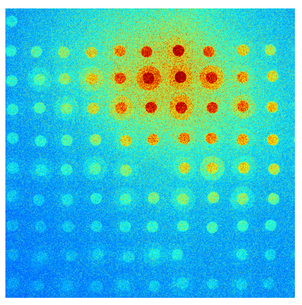
Spherical mirror
(700 mm)
~ 50-55 % of energy in focal spot





Princeton Instruments
Quad-RO: 4320
2084 x 2084 imaging array | 24um x 24um pixels

Beam divergence, stability and intensity



Pointing stability over 50 shots :
8.3mrad / 6.4 mrad

Beam divergence :
ϑ_x = (12.7±3.6) mrad
ϑ_y = (13.0±4.0) mrad

Maximum counts :
Foil close to jet (Compton dominated)
N_{counts}= 748 ± 330
(For best shots (N>1000, ~ 25%) : N_{counts}= 1231 ± 235)
Foil far from jet (Bremsstrahlung dominated)
N_{counts}= 381 ± 39

Reconstructed intensity profiles

Simulated X-ray spectrum for a measured electron profile

Simulation performed using 5000 test particles. ΔE/E=0.05. Divergence 5mrad. Scattering beam a_0=1, 30 fs duration, 20 um FWHM.