

The Effect of Fast Electron Scattering in Determining the Laser-Induced Electron Divergence

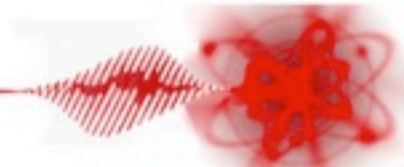
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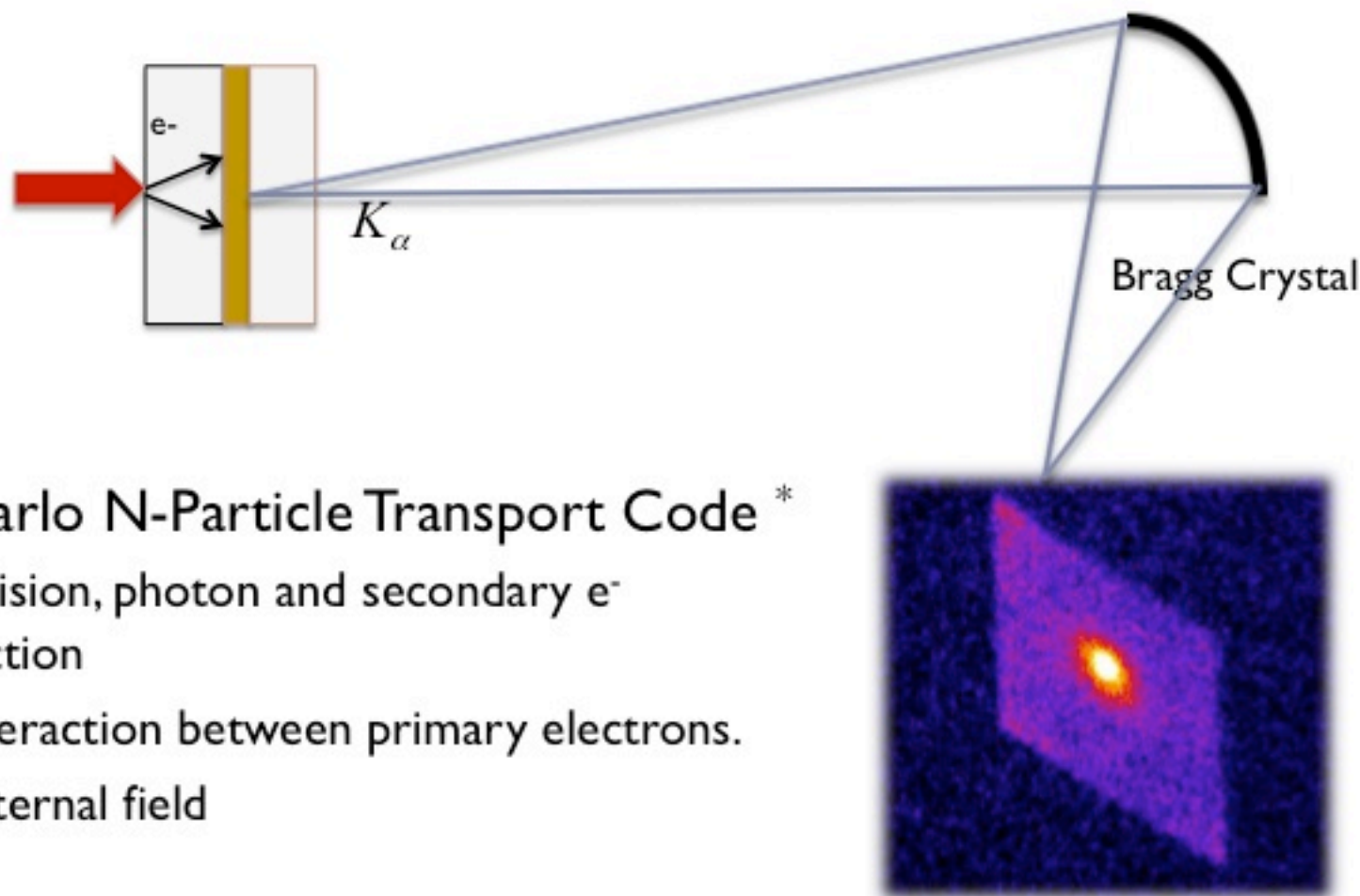
High Energy Density Physics Group
Scarlet Laser Facility



Outline

- ▶ Scattering effect in low Z and high Z materials
- ▶ Effect of the source size on beam divergence
- ▶ Comparison of mono-energetic and Maxwell energy distributions
- ▶ Beam divergence using a laser based electron source
- ▶ Conclusions

Motivation and Method



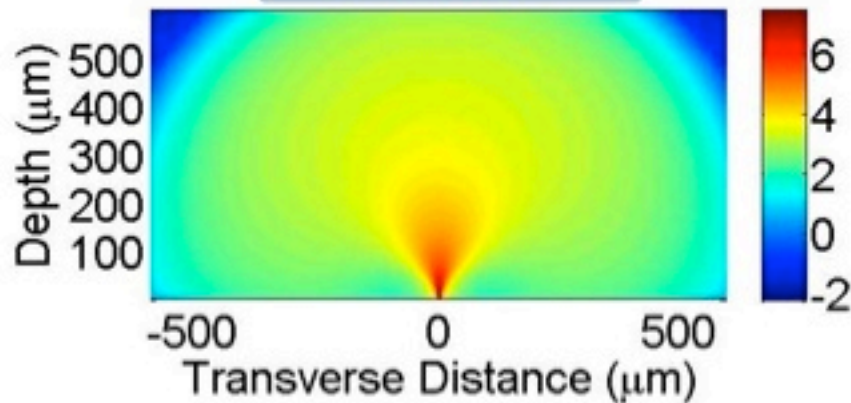
- ▶ Monte Carlo N-Particle Transport Code ^{*}
 - ▶ e-i collision, photon and secondary e^- production
 - ▶ No interaction between primary electrons.
 - ▶ No external field

▶ ^{*} D.B.Pelowitz etc. MCNPX User's manual, Version 2.5.0, LA-CP-05-0369 (2005).

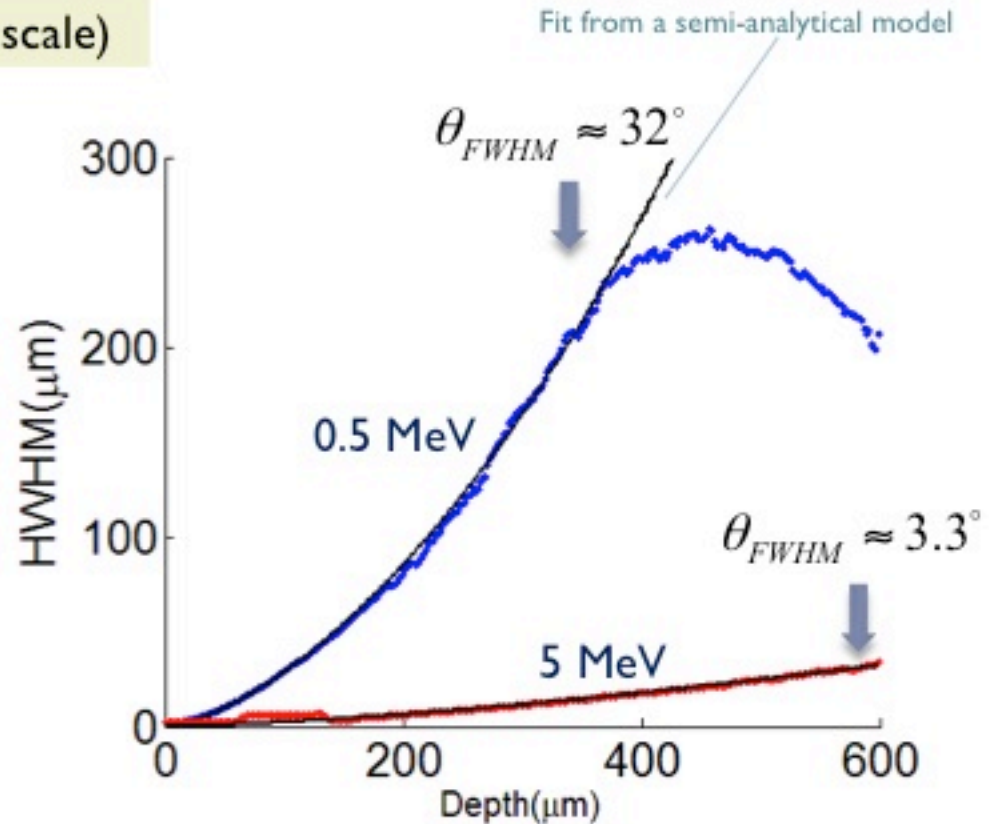
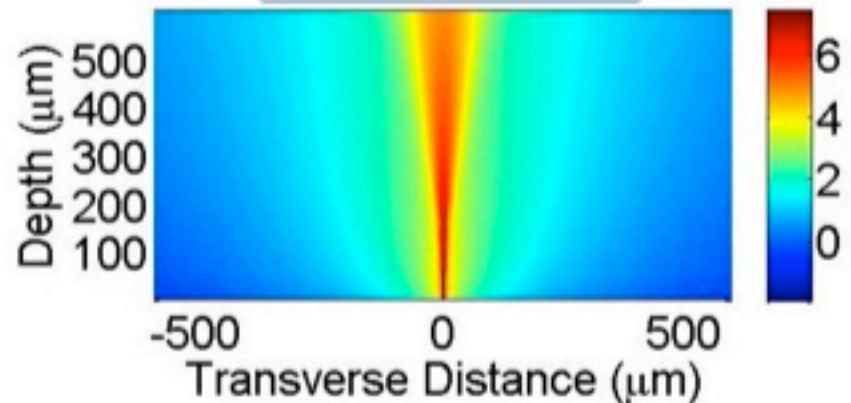
Simulations of Scattering of 0.5MeV and 5MeV Electrons in Al Target

Energy Deposition Density [MeV/cm³] (Log scale)

0.5MeV, Al



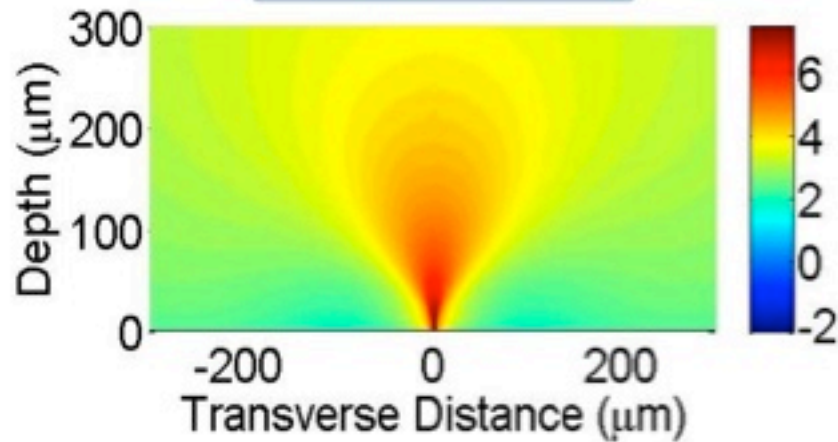
5MeV, Al



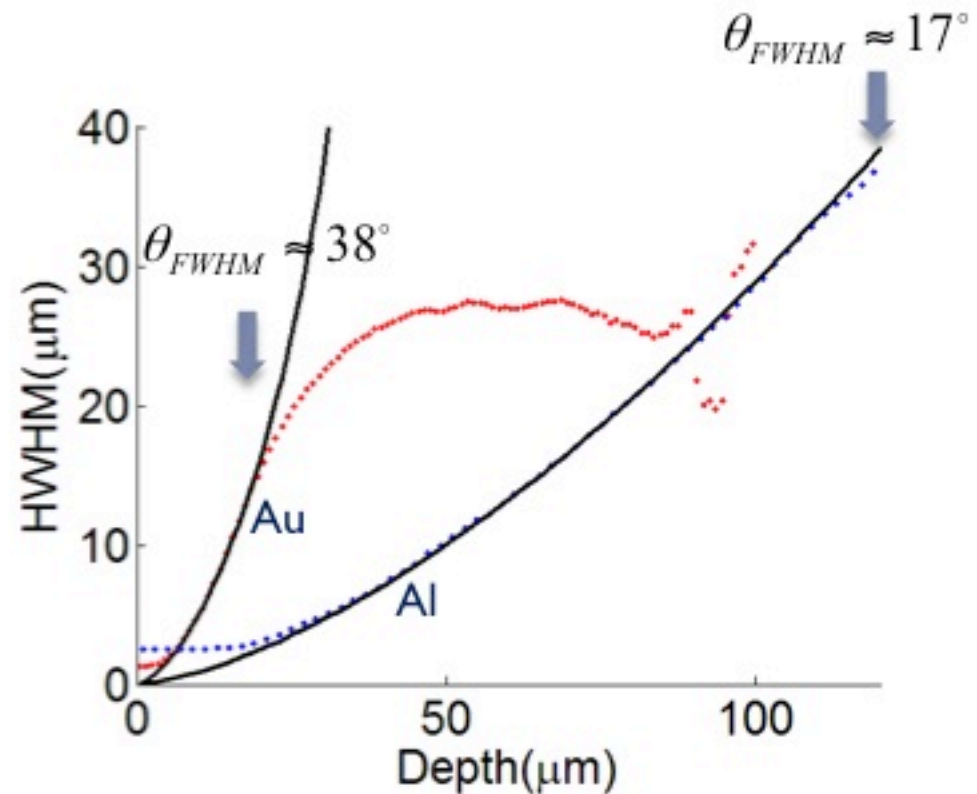
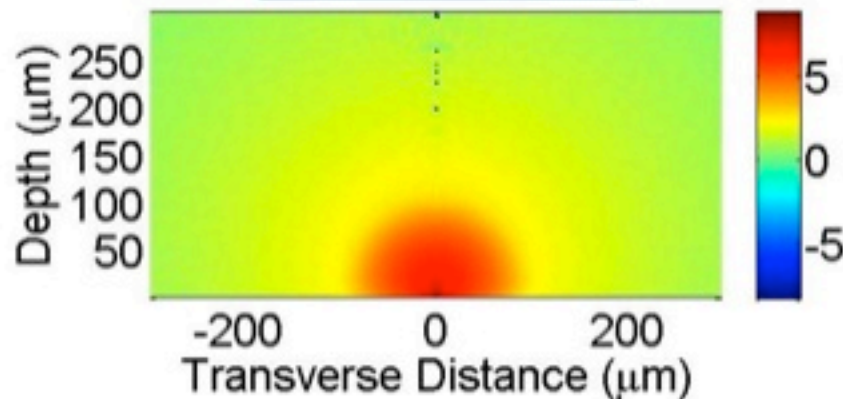
Scattering is more important for 0.5MeV electrons than 5MeV electrons.

Simulations of Scattering of Mono-Energetic Electrons in Low Z and High Z Targets

0.5MeV, Al



0.5MeV, Au

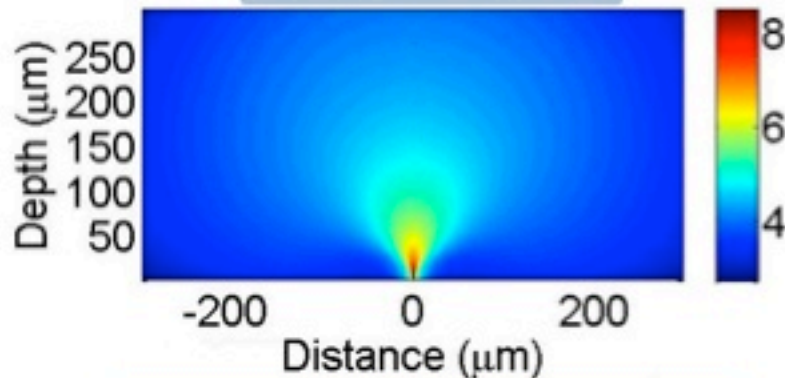


The higher the Z, the more important scattering is.

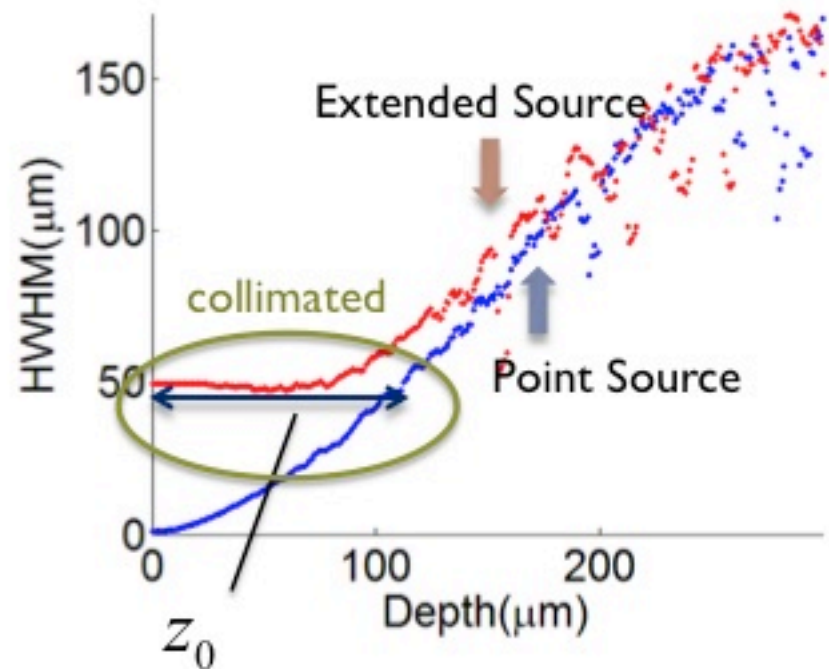
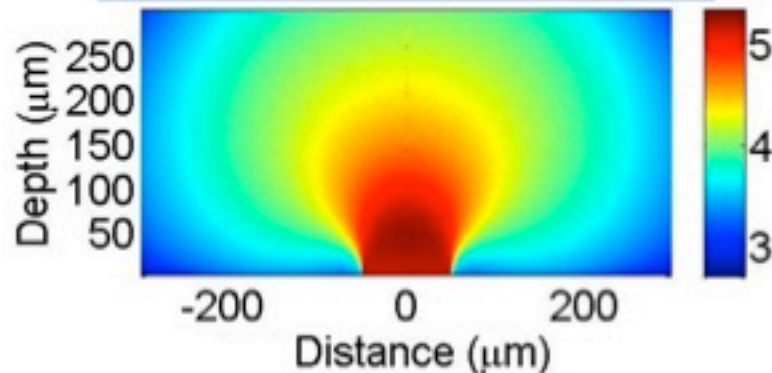
How Does The Source Size Affect Electron Beam Divergence?

► 1 MeV, Cu

Point Source



Extended Source: R=50 μm



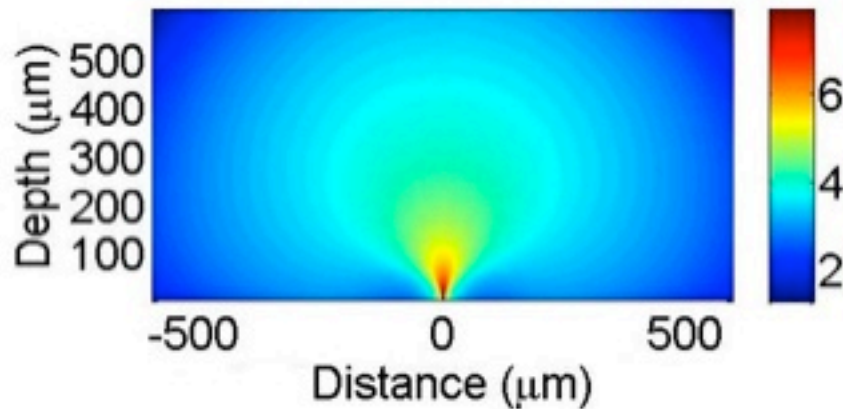
$$z_0 \propto \frac{r_0^{2/3} E^{2/3} A^{1/3}}{Z^{2/3} \rho^{1/3}}$$

- Divergence is evident for point source.
- Initial beam size can mask the divergence effect.
- Beyond a certain depth, we see same divergence due to scattering in both cases.

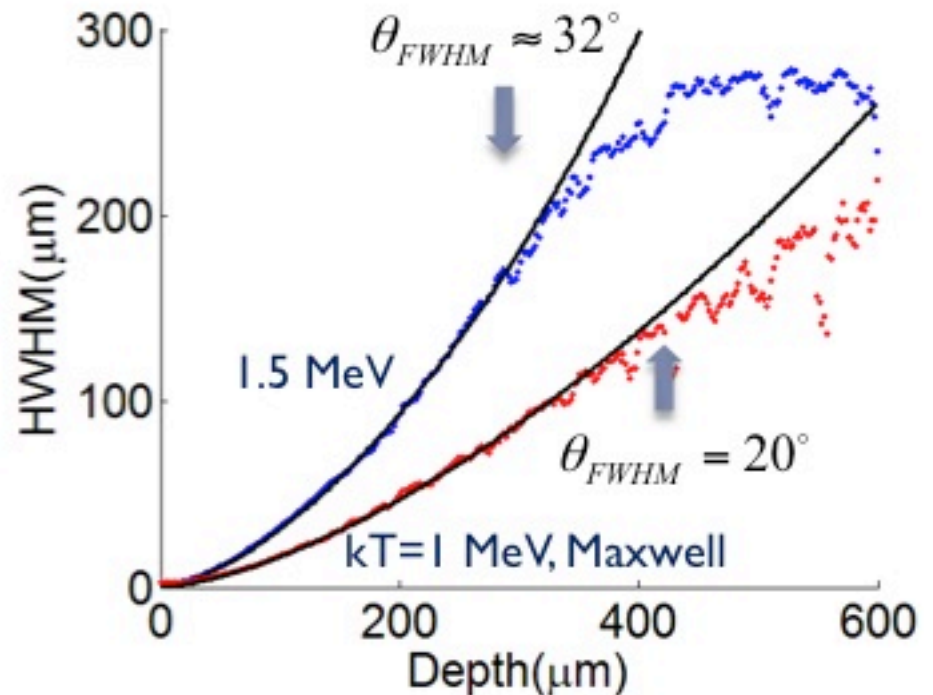
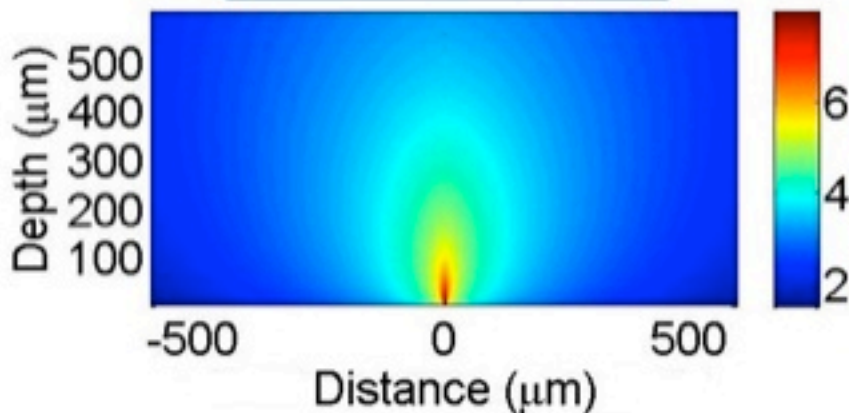
Maxwell Electron Energy Distribution Vs. Mono-Energetic Electrons

► Material: Cu

Mono E: 1.5MeV



Maxwell: $kT=1\text{MeV}$



Divergence is lower for electron beams with a Maxwell distribution than mono-energetic electrons.

Divergence Simulations with a 3D Source Based on Laser Profile and PIC Simulations

► Source Electron Distribution

$$\frac{d^3 f(\overbrace{r, \psi}^{\text{Position}}, \overbrace{E, \theta, \varphi}^{\text{Direction}})}{dS dE d\Omega} = \underbrace{n(r)}_I \cdot \underbrace{F_1(E)}_{II} \cdot \underbrace{F_2(\theta, \varphi)}_{III}$$

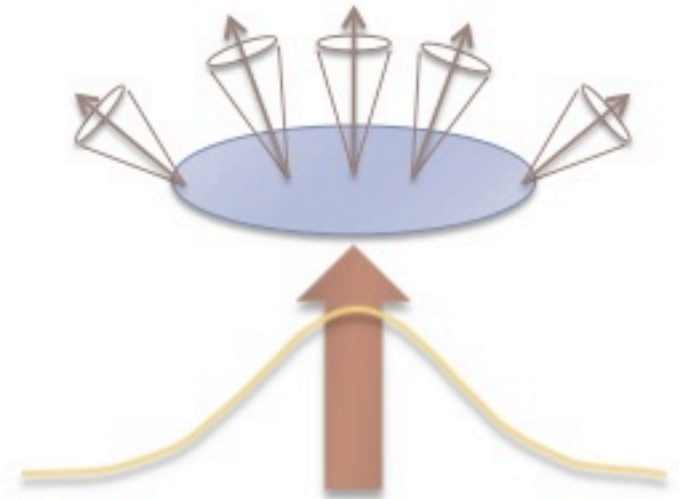
$$I = A \exp\left(-\frac{2r^2}{w_0^2}\right)$$

$$II = 2\sqrt{\frac{E}{\pi}} \exp(-E/kT(r)), \quad kT = 0.511 \left(\sqrt{1 + \frac{I_0 \exp(-2r^2/w_0^2) \lambda_0^2}{1.37 \times 10^{18} W \mu m^2 / cm^2}} - 1 \right) MeV^{**}$$

Wilks Scaling **

$$III = B \exp\left(-\frac{(\cos^{-1}(\sin \theta \sin \theta_r \cos \varphi \cos \psi + \sin \theta \sin \theta_r \sin \varphi \sin \psi + \cos \theta \cos \theta_r))^2}{\Delta \theta_0^2}\right)$$

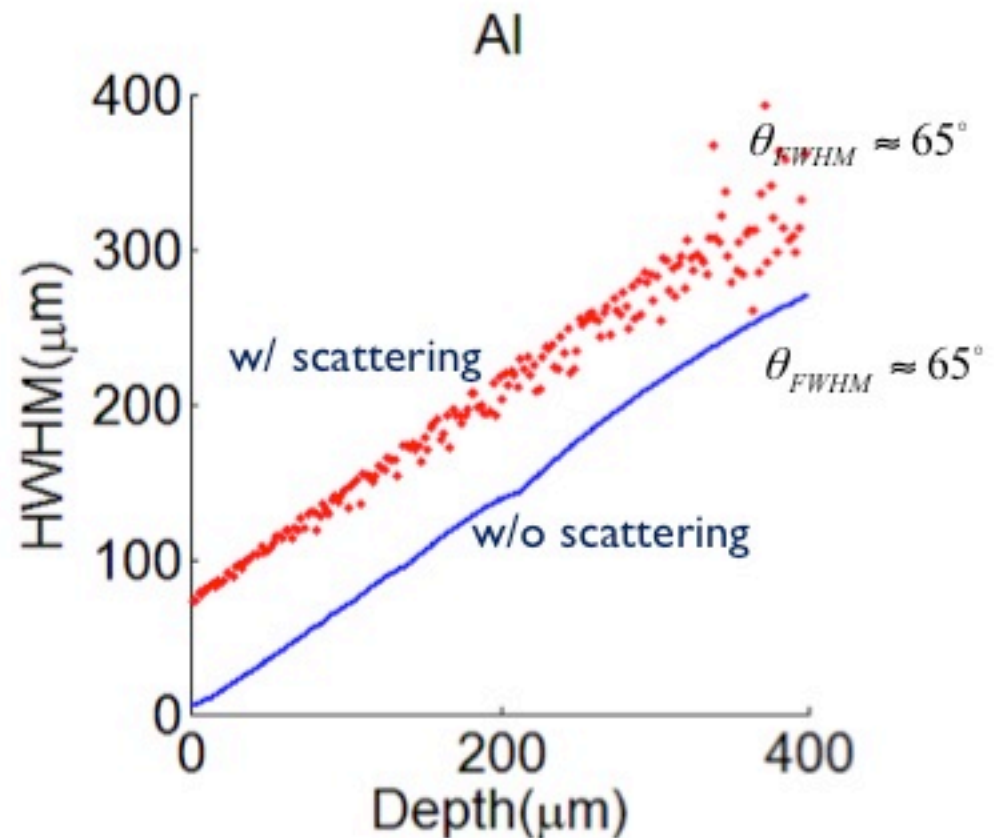
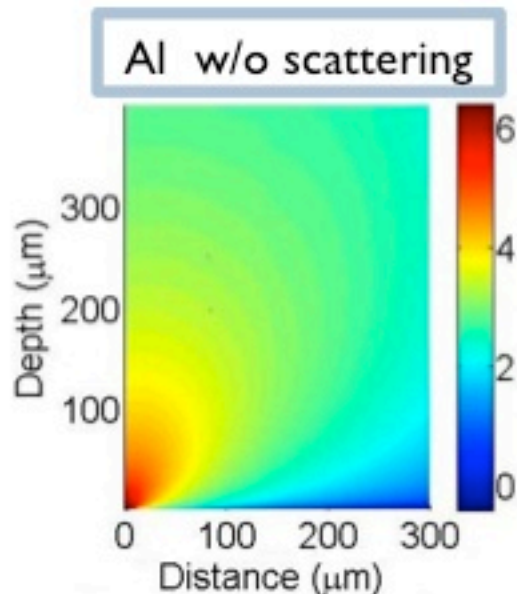
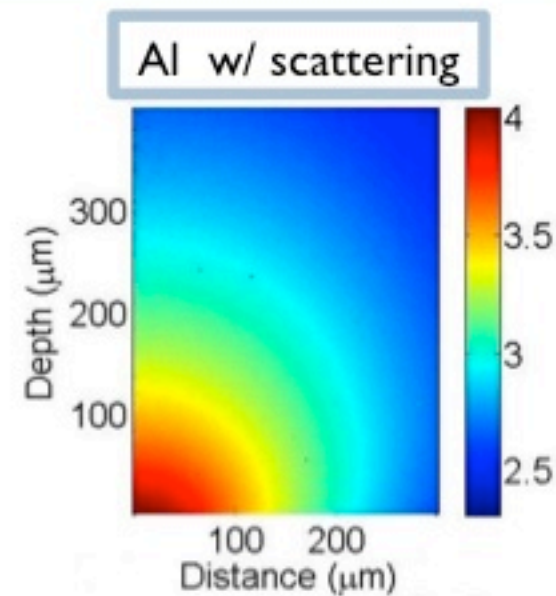
Debayle & Honrubia Source Divergence *



* A. Debayle, J. J. Honrubia, E. d'Humières, V. T. Tikhonchuk Phys. Rev. E 82, 036405 (2010)

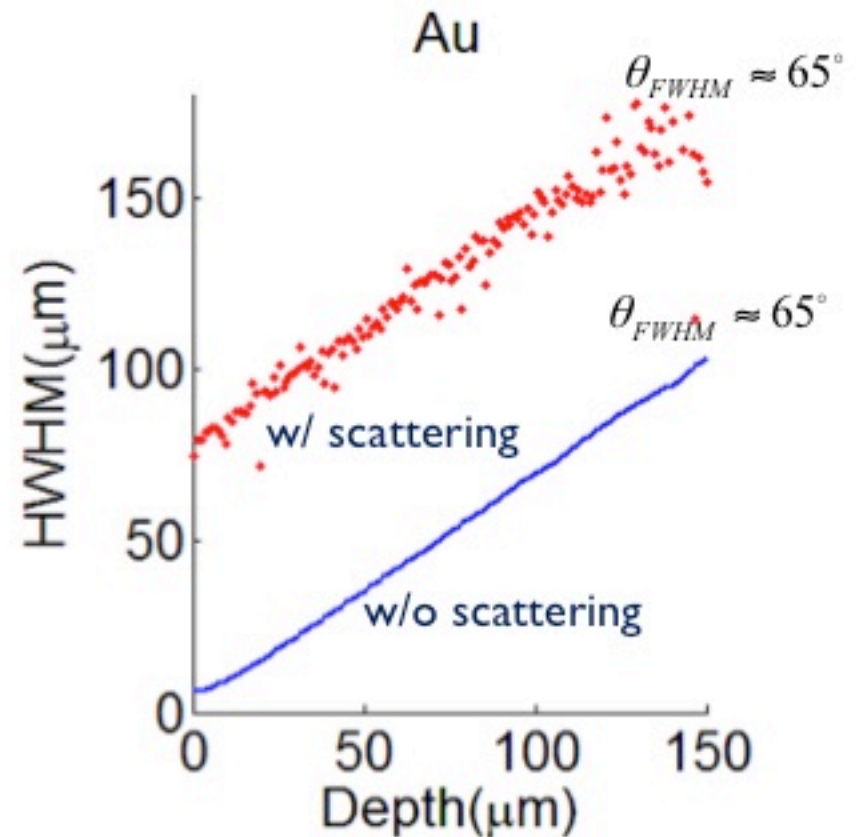
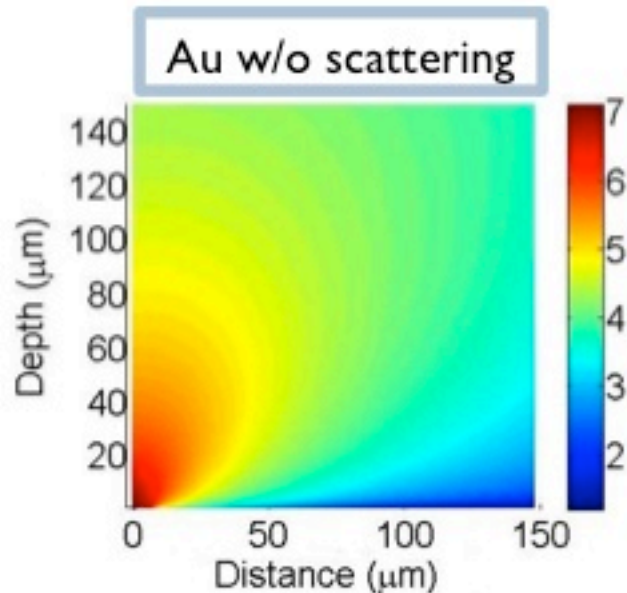
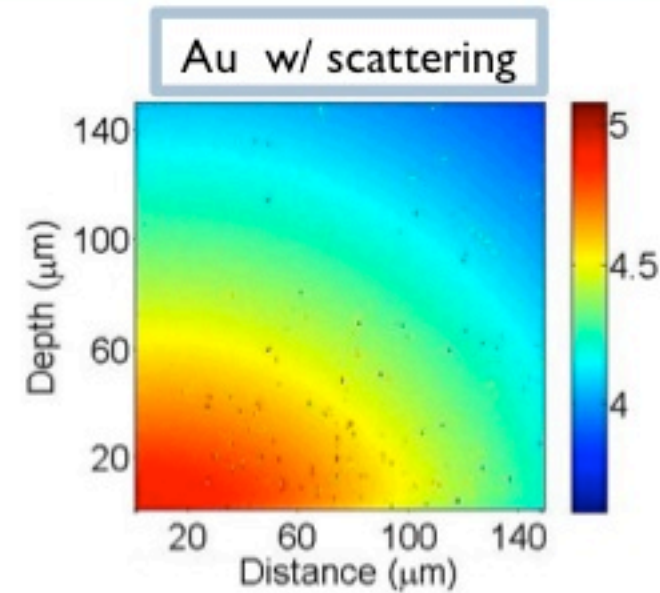
** S. C. Wilks, W. L. Kruer, M. Tabak, A. B. Langdon Phys. Rev. Lett. 69, 1383 (1992)

Electron Beam Divergence Simulation in Low Z Material with and without Scattering



HWHM at a given depth changes with and without scattering, however, divergence does not.

Electron Beam Divergence Simulation in High Z Material with and without Scattering



Same effects in high Z as in low Z material.

Conclusion

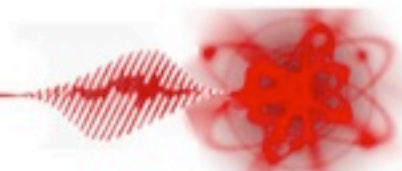
- ▶ Scattering influences the divergence of the beam:
 - ▶ Low energy electrons
 - ▶ High Z material
 - ▶ Thick Target
- ▶ Beyond a certain depth, beam divergence due to scattering is seen for both point and extended sources.
- ▶ Divergence is lower for electrons with a Maxwell distribution than those with a mono energy.
- ▶ With a laser based source:
 - ▶ Local beam size changes but divergence is the same
 - ▶ Same is true independent of Z

Acknowledgements

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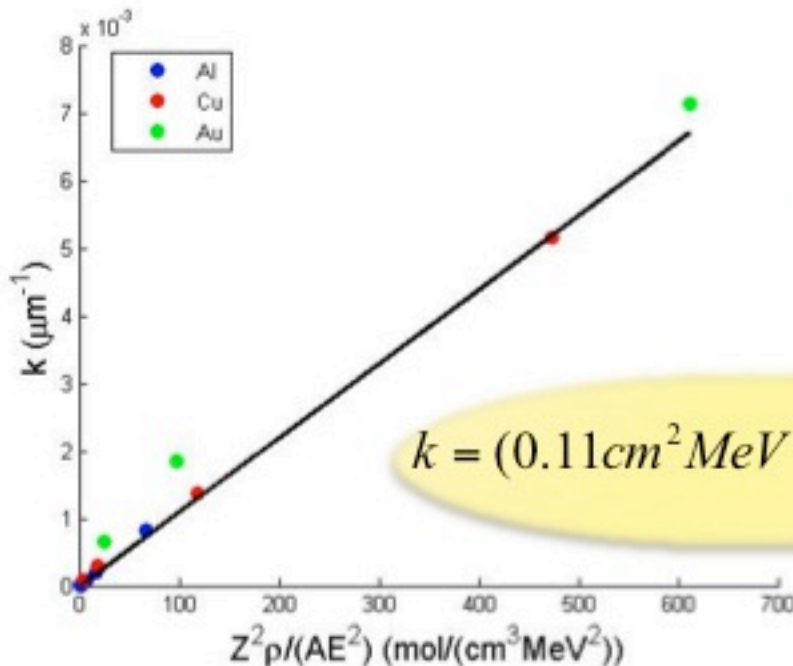
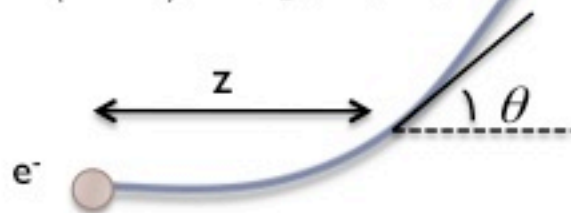
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Scattering Effect Estimation

average e^- trajectory

$$\langle \cos \theta \rangle = \exp(-k_1 \Delta s)^*$$



- ▶ Lower Z, higher E, smaller depth

Assume HWHM follows the same shape.

$$HWHM = z \frac{(kz - 2) + 2\sqrt{2/kz - 1} \tanh^{-1}\left(\frac{1}{\sqrt{2/kz - 1}}\right)}{kz\sqrt{2/kz - 1}}$$

For $kz \ll 1$,

$$HWHM = \frac{1}{3} \sqrt{2k} z^{3/2}, \theta_{FWHM} \approx \frac{2}{3} \sqrt{2kz}$$

$$\text{To see the scattering effect: } \frac{2\sqrt{2C}}{3} \frac{Z}{E} \sqrt{\frac{\rho t}{A}} > \theta_{\min}$$

Assuming $\theta_{\min} = 5^\circ$

For $500 \mu\text{m}$ Al,

To see scattering : $E < 3.5 \text{ MeV}$

For $400 \mu\text{m}$ Cu,

To see scattering : $E < 7.8 \text{ MeV}$