



Radiation Induced by Relativistic Beams Passing Over a Diffraction Grating

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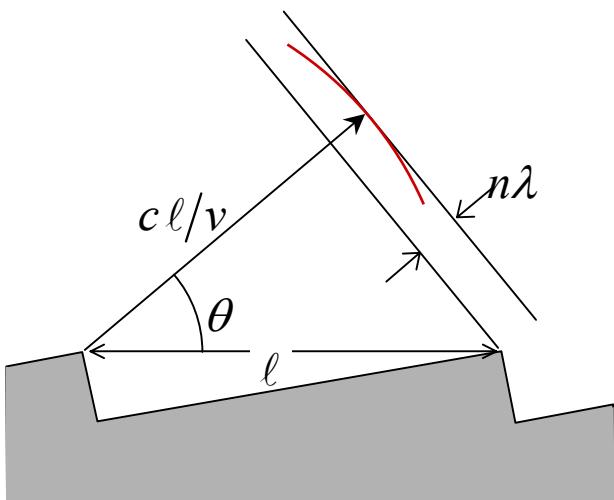
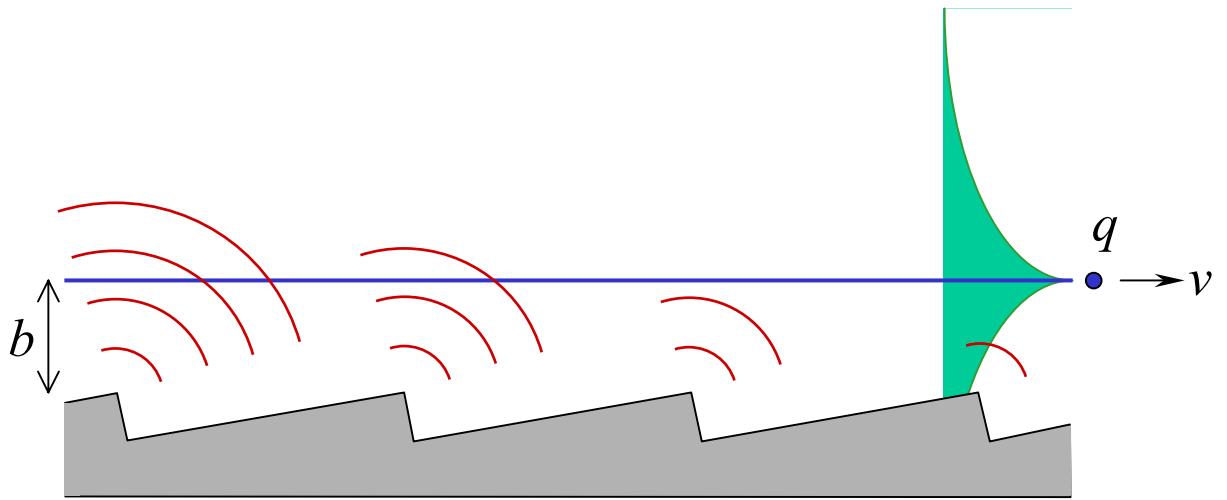
Brookhaven National Laboratory

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Outline

- Spontaneous Smith-Purcell radiation (SPR) can be intense.
- Data from the ATF experiment indicate SPR in the near infrared.
- Convective S-P gain theory implies SASE regime within reach.

Smith-Purcell radiation



Dispersion relation:

$$n\lambda = c\ell/v - \ell \cos\theta$$

$$\lambda_n = \frac{\ell}{n} \left(\frac{1}{\beta} - \cos\theta \right)$$

Spontaneous SPR theory: Surface current model

“*Spontaneous Smith-Purcell radiation described through induced surface currents,*” PRE **57**(1), 1998, p. 1075.

$$\frac{\partial^2 U}{\partial \Omega \partial \omega} = \frac{\omega^2}{4\pi^2 c^3} \left| \int dt \int d\mathbf{r} \hat{\mathbf{k}} \times \hat{\mathbf{k}} \times \mathbf{J} e^{-i(\omega t - \mathbf{k} \cdot \mathbf{r})} \right|^2$$

$$\frac{\partial U}{\partial \Omega} = \sum_n \frac{q^2 \ell}{4\pi^2 n} L \left(\frac{\omega_n}{c} \right)^3 e^{-\frac{2\omega_n b_0}{\gamma \beta c}} G \left\{ N B_1 + N^2 B_2 \tilde{Y} \tilde{T} \right\}$$

- N Number of electrons per bunch,
- L Grating length,
- b_0 Beam centroid impact parameter,
- γ Relative electron energy,
- G Grating efficiency (~ 0.1),
- B_1, B_2 Convolution of beam profile and evanescent decay,
- \tilde{Y} Transform of bunch transverse spatial profile,
- \tilde{T} Transform of bunch temporal profile.

Optimized given energy and emittance, w/o coh. enh.:

$$\left. \frac{\partial U}{\partial \Omega} \right|_{\text{peak}} = 0.04 \frac{q^2}{\epsilon_N} \beta^2 \gamma^2 (\gamma - 1) G N B_1$$

$$\theta_{\text{peak}} = \cos^{-1} \left(\sqrt{(\gamma - 1)/(\gamma + 1)} \right) \approx \sqrt{2/\gamma}$$

$$\lambda_{\text{peak}} = 2\pi b_0 / \gamma \beta$$

ATF experimental parameters

- 45 MeV ($\gamma = 90$)
- $\varepsilon_N = 1 \pi \text{ mm mrad}$
- 400 pC per bunch ($N = 2.5 \times 10^9$)
- 3 ps bunch length
- Radial $\bullet = 60 \text{ O}\mu\text{m}$
- Period = 1 mm
- Grating length = 15 cm

Peak performance:

$$\left. \frac{\partial U}{\partial \Omega} \right|_{\text{peak}} \cong 2 \text{ nJ/sr}$$

$$\theta_{\text{peak}} = 8.5 \text{ degrees}$$

$$\lambda_{\text{peak}} \cong 3.5 \mu\text{m}$$

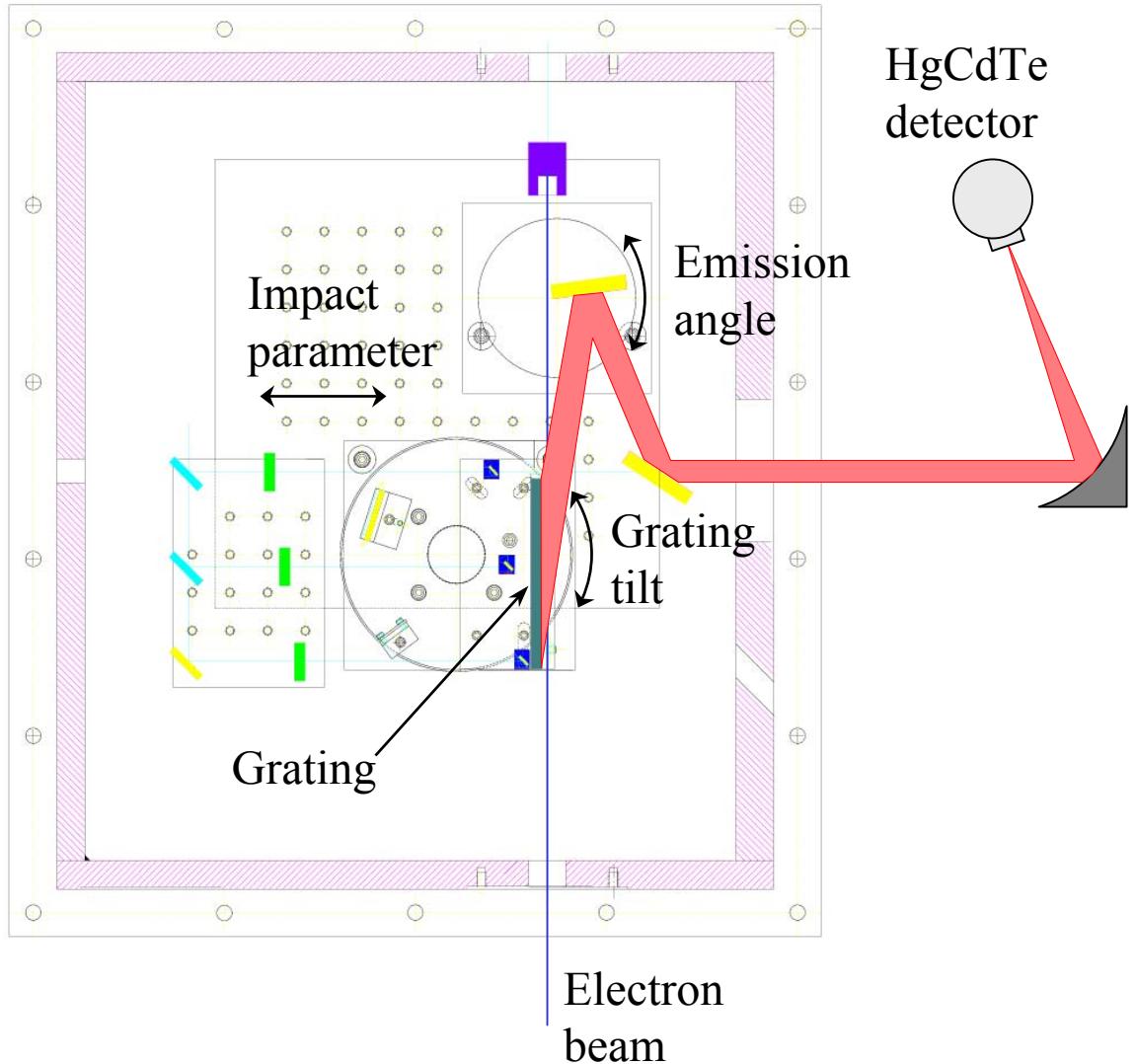
Measured intensity:

$$\left. \frac{\partial U}{\partial \Omega} \right|_{\text{peak}}^{\text{meas}} \cong 0.2 \text{ nJ/sr} \rightarrow 40 \text{ nJ/sr cm}^2 \text{ (Brightness)}$$

$$\theta_{\text{peak}} = 10 \text{ degrees}$$

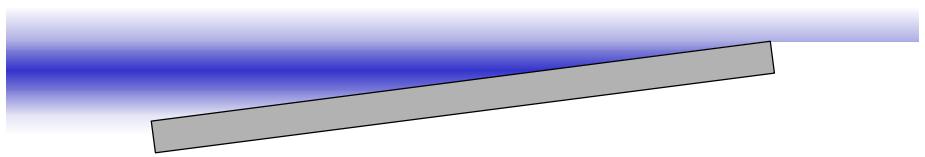
$$\lambda_{\text{peak}} \cong 2 - 4 \mu\text{m}$$

ATF Experimental Setup

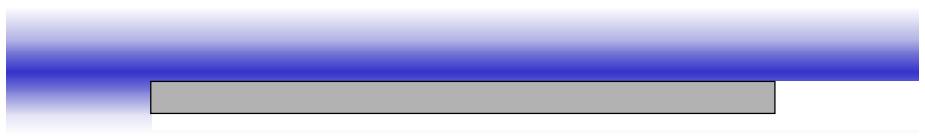


ATF data: Grating Tilt scan

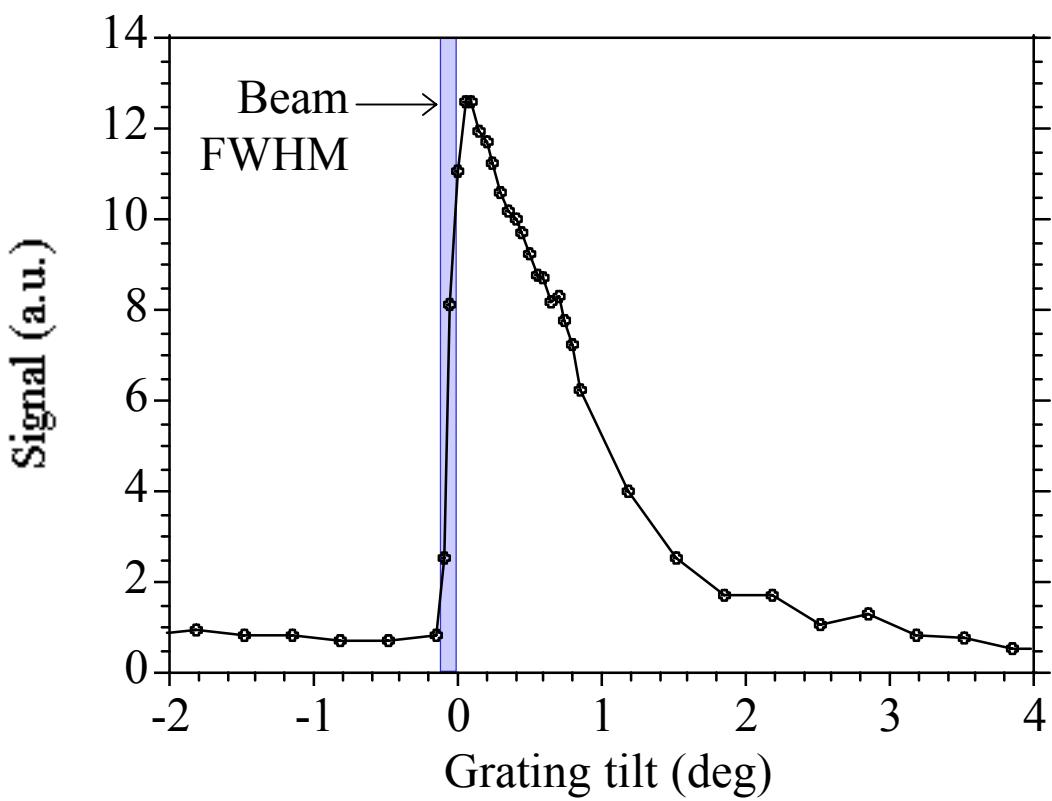
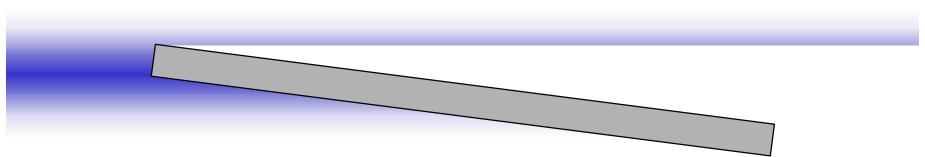
Tilt > 0



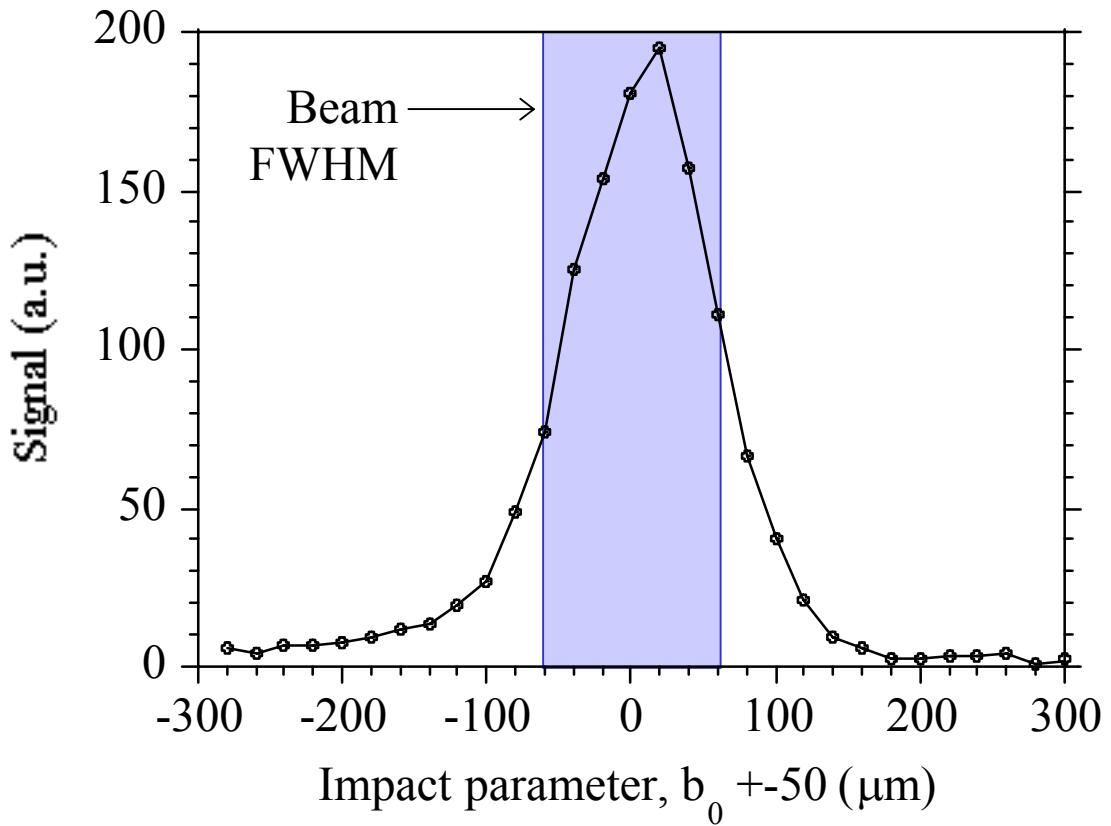
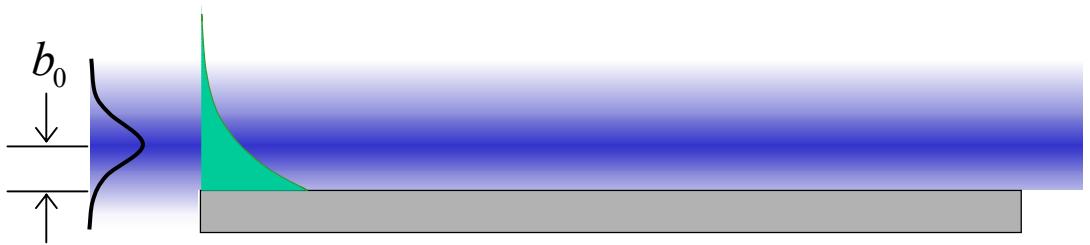
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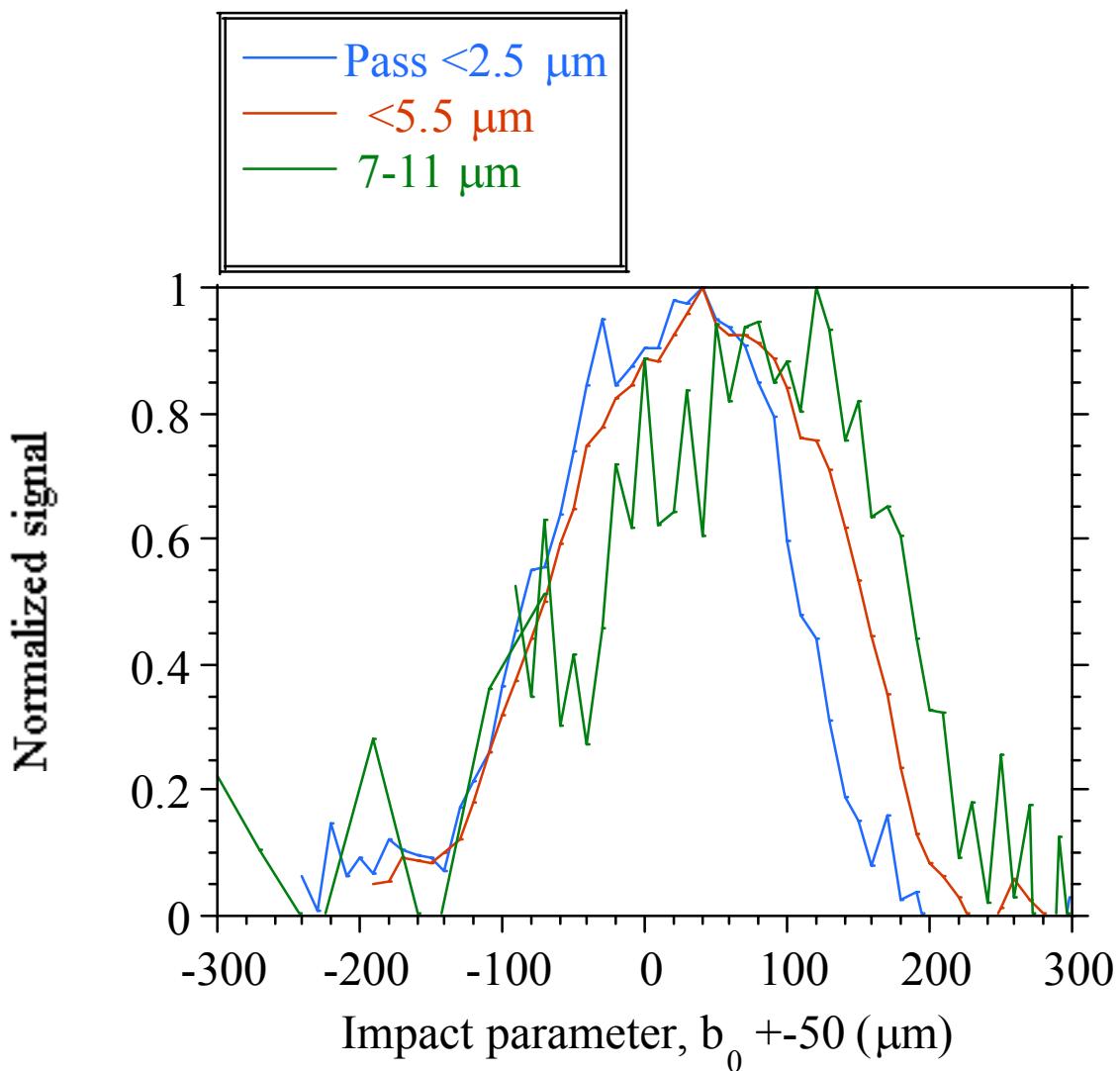
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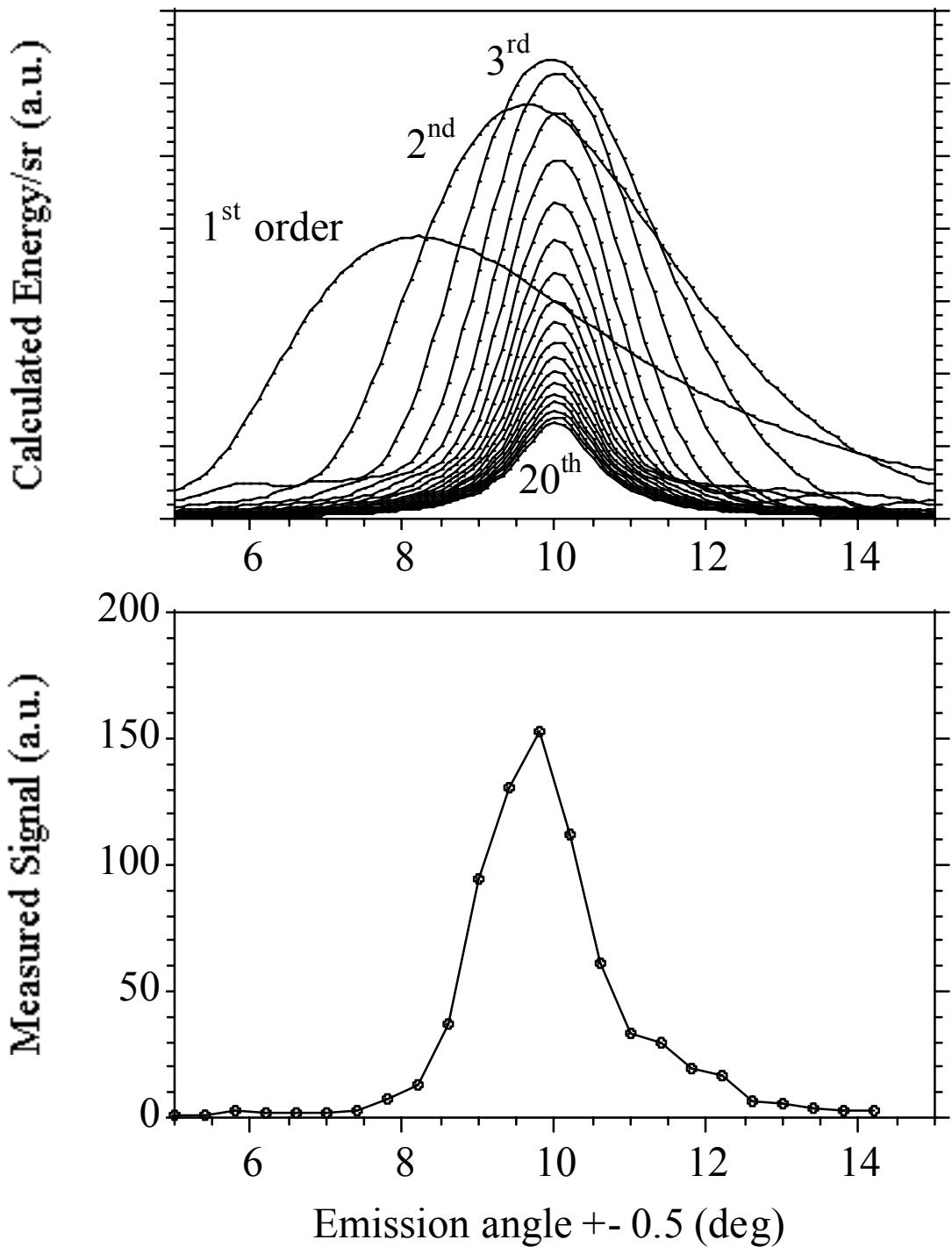
ATF Data: Impact scan



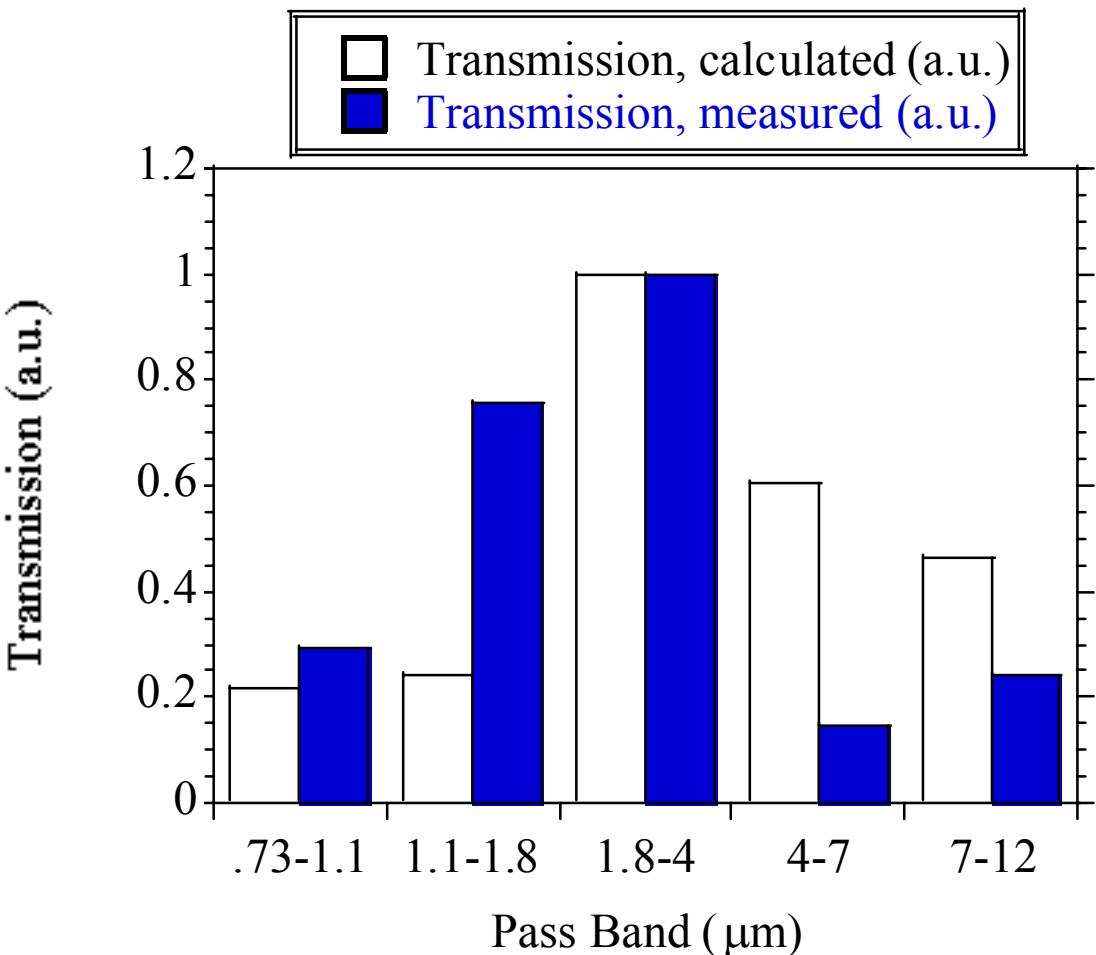
ATF Data: Impact scan Transmission filter series



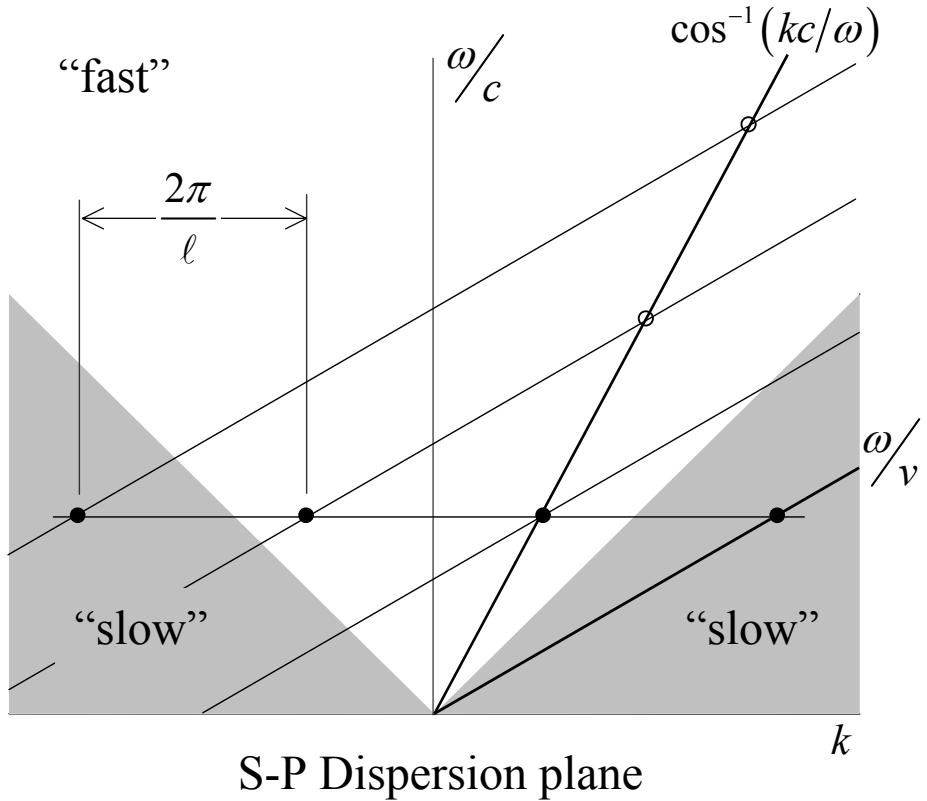
ATF Data: Emission angle scan



ATF Data: Transmission Filter series



SP-SASE Theory



$$I_n^{\text{sp}}(z) \propto e^{\alpha_n z}$$

$$\alpha_n \cong \sqrt{3} \left[\frac{I}{(\beta\gamma)^3 mc^3/q} \frac{2\pi\omega_n}{c\beta\gamma^2} \frac{B_1 e^{-\frac{2\omega_n b_0}{\gamma\beta c}}}{A_{\text{mode}}} \right]^{\frac{1}{3}}$$

$$\left. \frac{1}{\alpha} \right|_{\text{ATF}} \cong 10 \text{ cm}$$

$$\left. \alpha L \right|_{\text{ATF}} \cong 1$$

Conclusion

- Data from the ATF experiment are consistent with forward emitted radiation from the grating surface at a peak wavelength of 3 Om . We observe 10% of the predicted energy.
- Convective S-P gain theory implies a gain length of 10 cm for the ATF experiment.