Radiation Induced by Relativistic Beams Passing Over a Diffraction Grating

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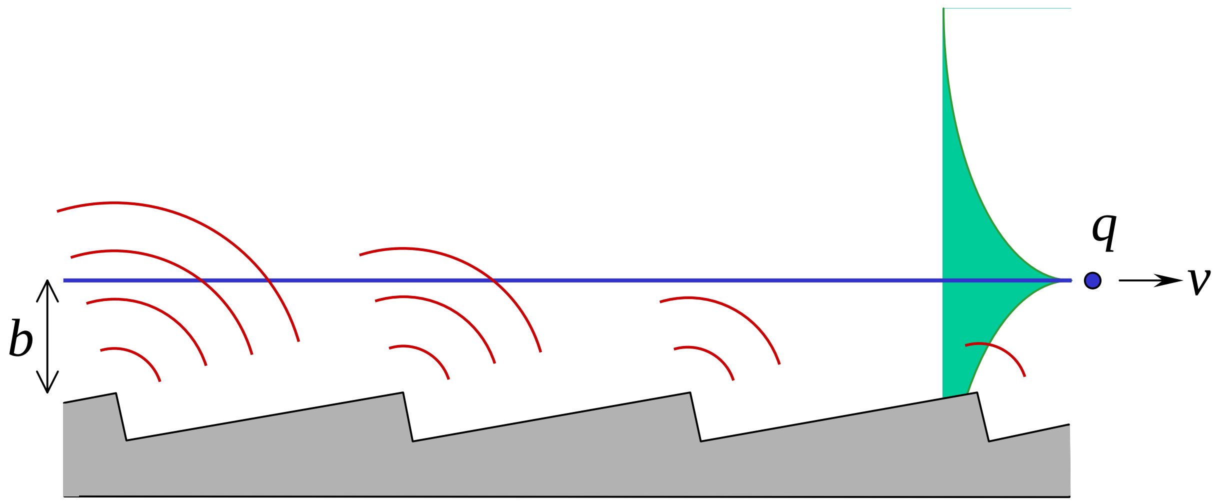
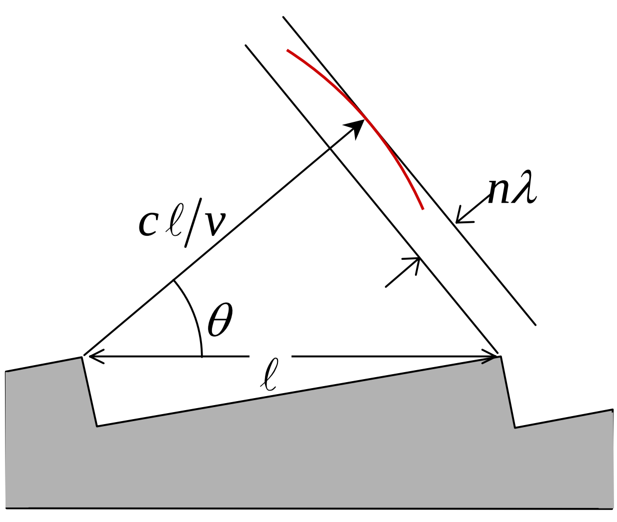
Outline

- 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.:

$$\left.\frac{\partial U}{\partial\Omega}\right|_{\text{peak}} = 0.04\frac{q^2}{\varepsilon_N}\beta^2\gamma^2(\gamma-1)GNB_1$$

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

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

ATF experimental parameters

- 45 MeV $(\gamma = 90)$
- $\varepsilon_N = 1\pi$ mm mrad
- 400 pC per bunch $\left(N = 2.5\times 10^9\right)$
- 3 ps bunch length
- Radial ♦ = 60 ❍m
- Period = 1 mm
- Grating length = 15 cm

Peak performance:

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

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

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

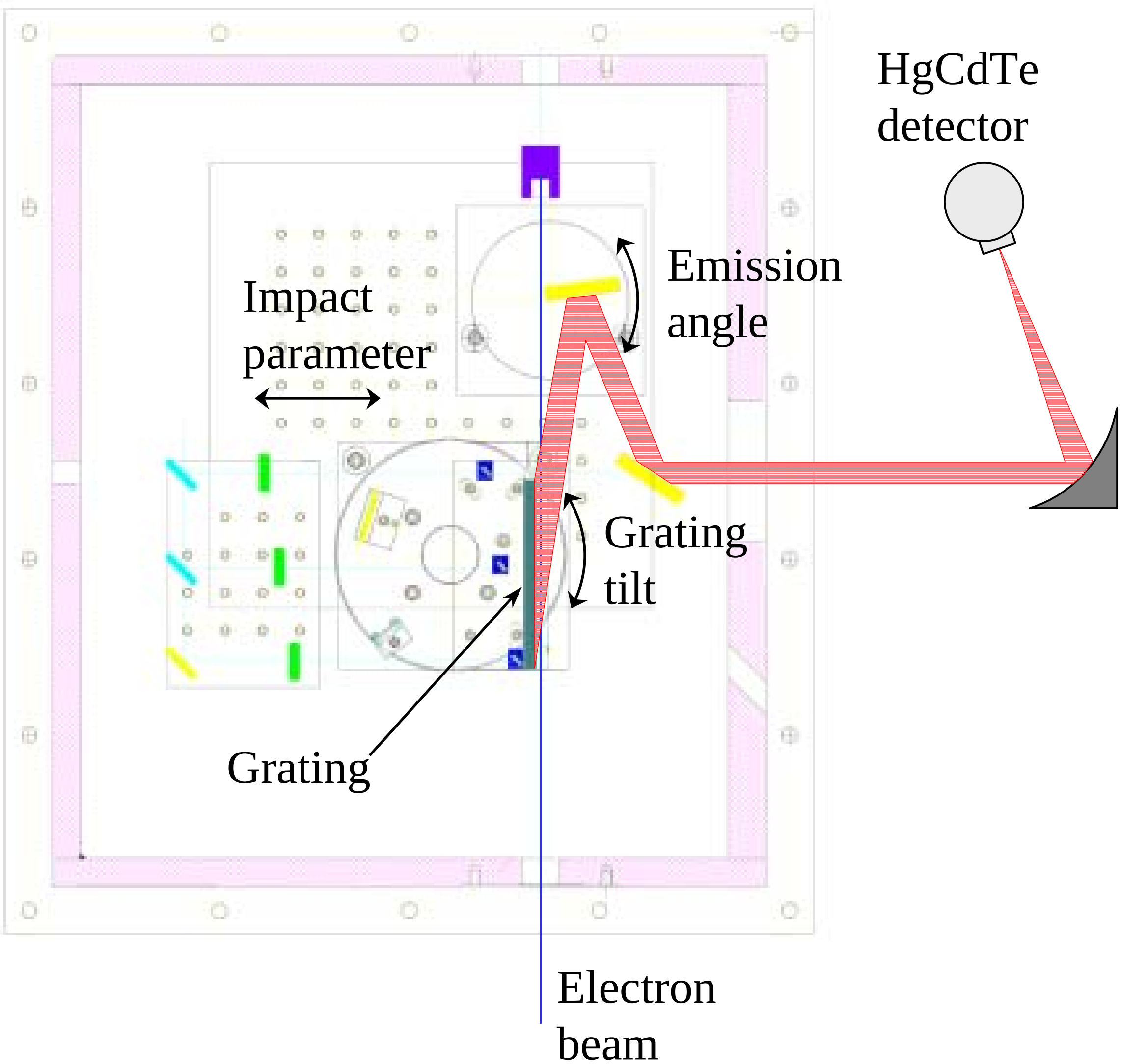
Measured intensity:

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

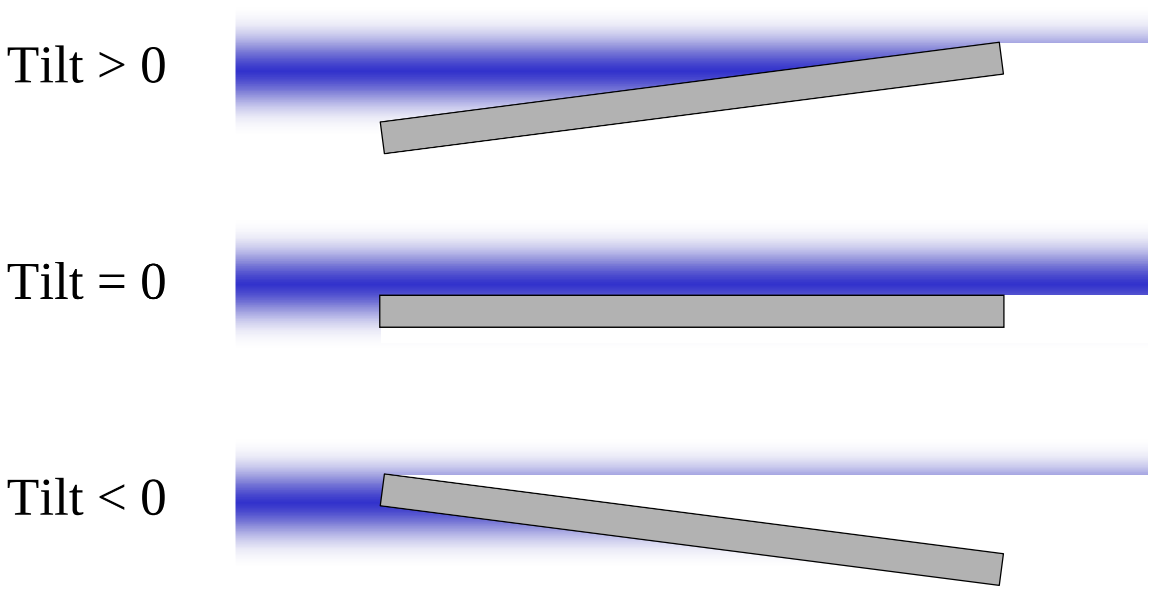
$$\theta_{\text{peak}} = 10 \text{ degrees}$$

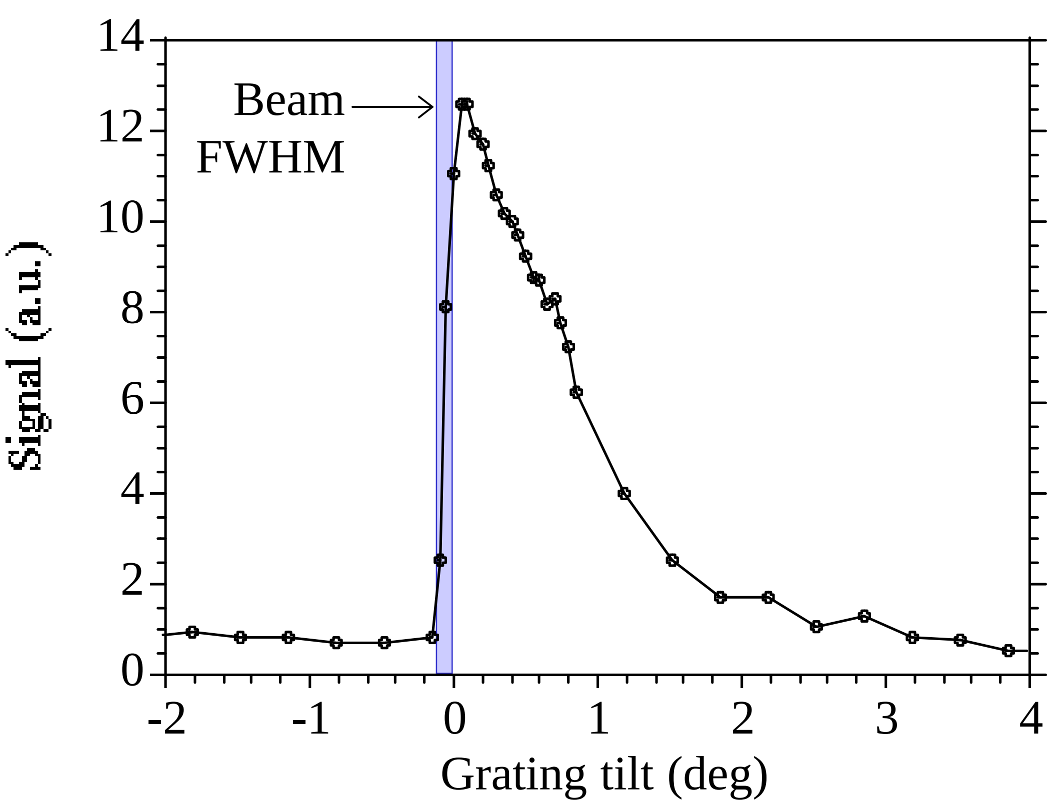
$$\lambda_{\text{peak}} \cong 2-4\ \mu\text{m}$$

ATF Experimental Setup

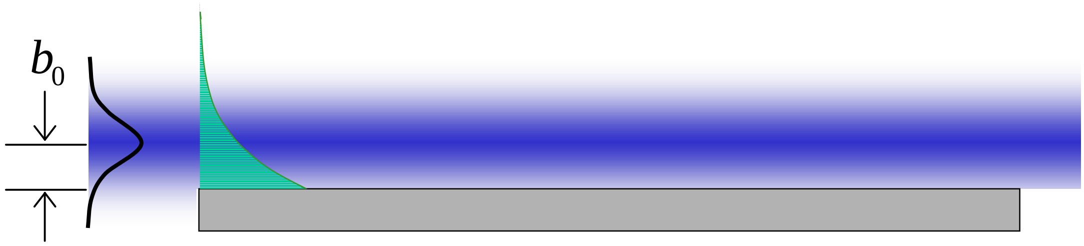


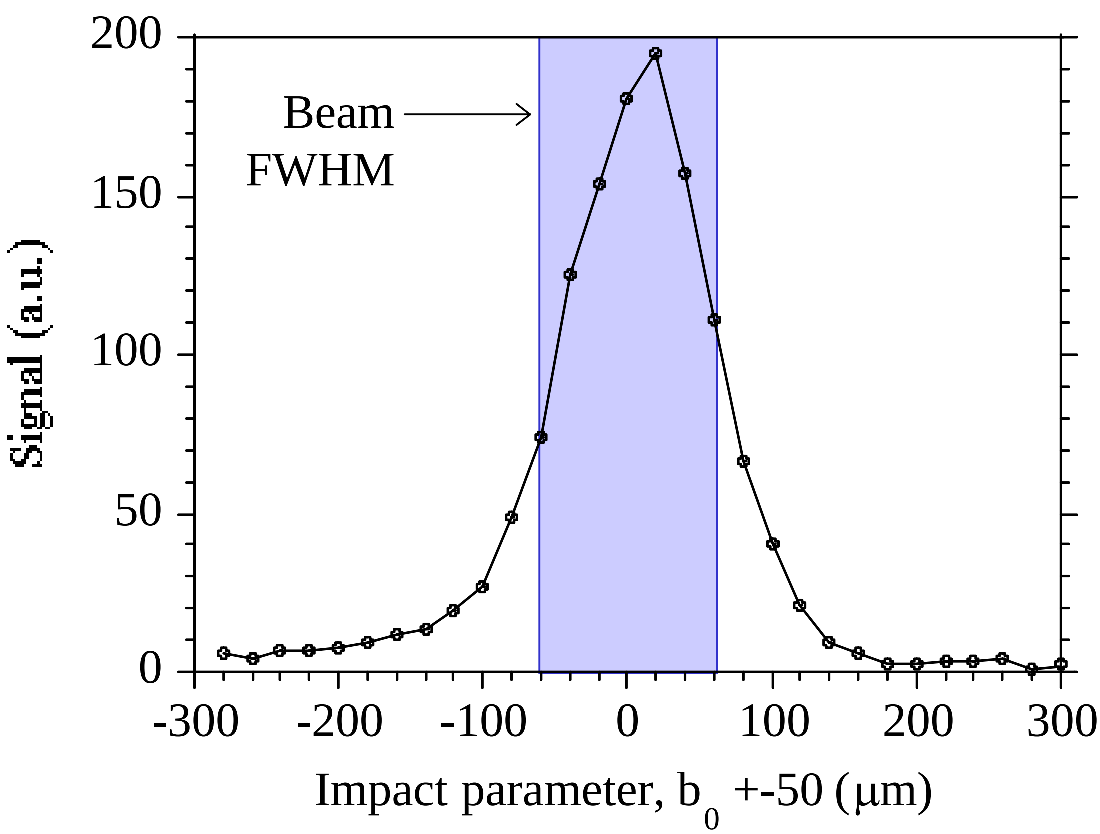
ATF data: Grating Tilt scan



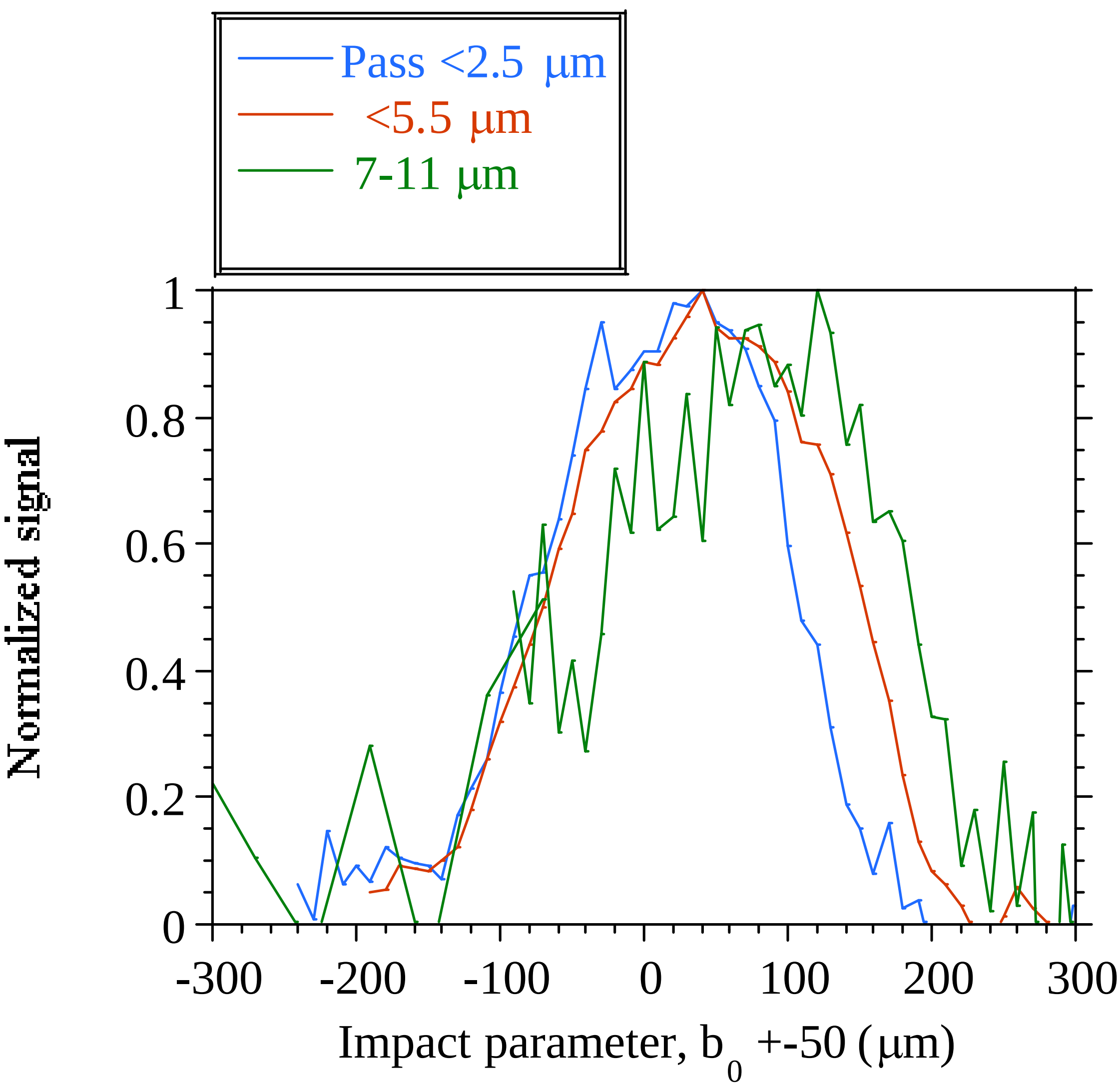


ATF Data: Impact scan

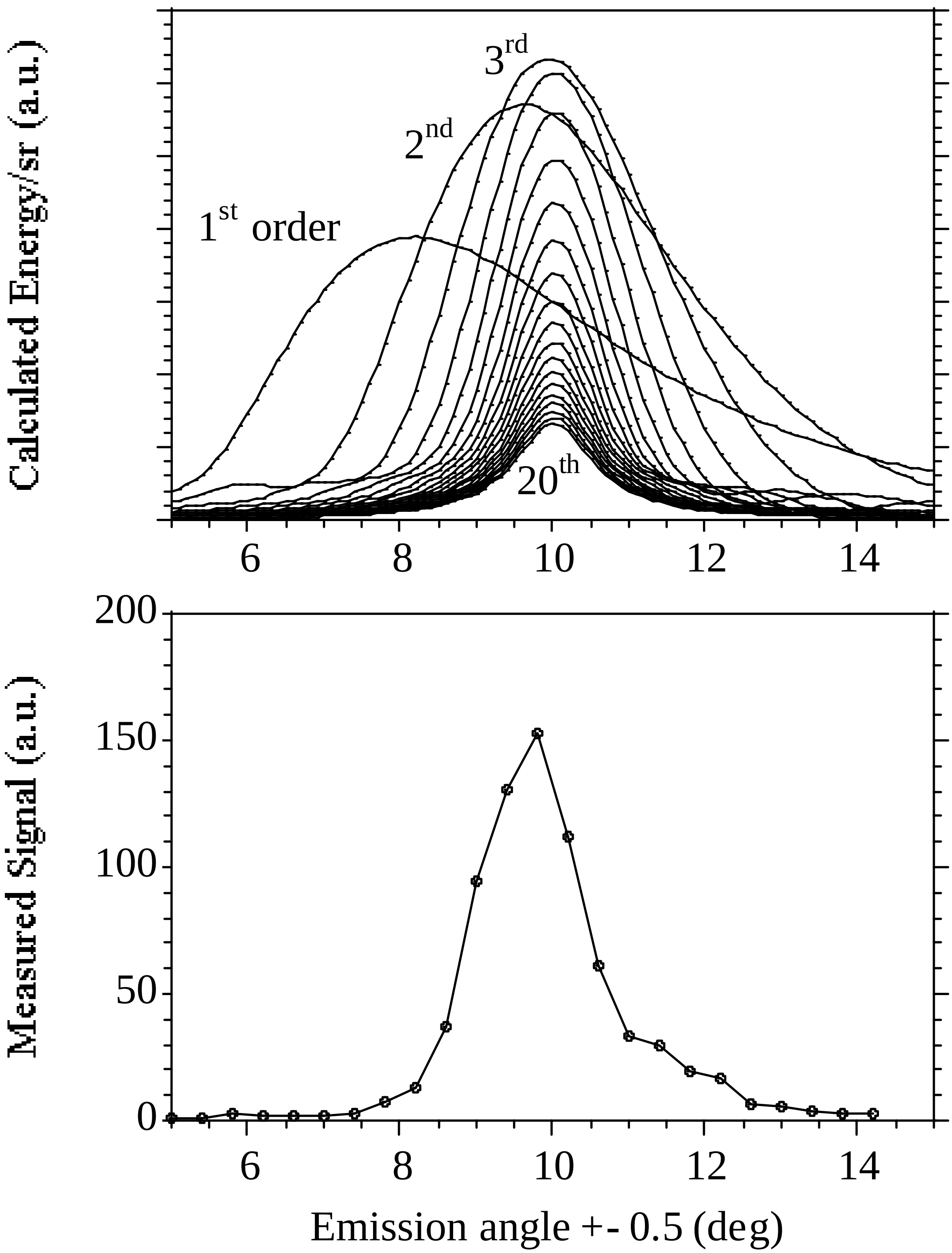




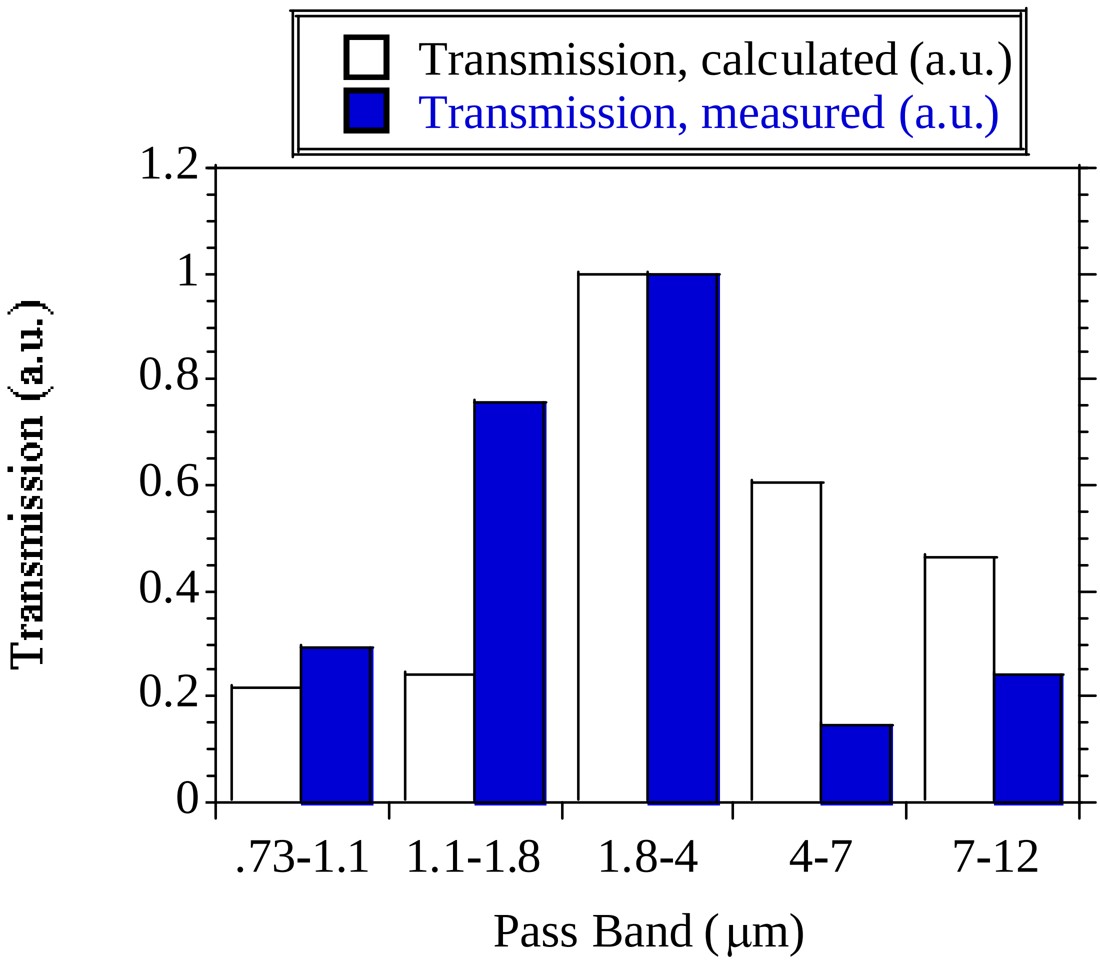
ATF Data: Impact scan
Transmission filter series



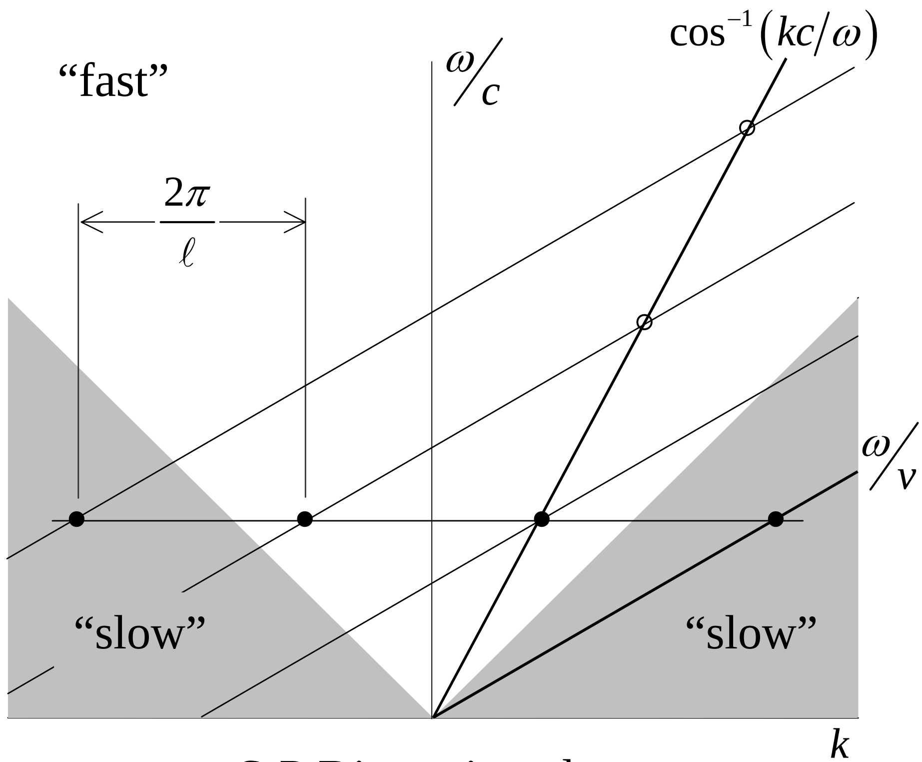
ATF Data: Emission angle scan



ATF Data: Transmission Filter series



SP-SASE Theory



S-P Dispersion plane

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

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

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

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

Conclusion

- Data from the ATF experiment are consistent with forward emitted radiation from the grating surface at a peak wavelength of 3 μm. We observe 10% of the predicted energy.

- Convective S-P gain theory implies a gain length of 10 cm for the ATF experiment.