Non-invasive temporal bunch profile measurement by the Smith-Purcell interaction

ATF Proposal
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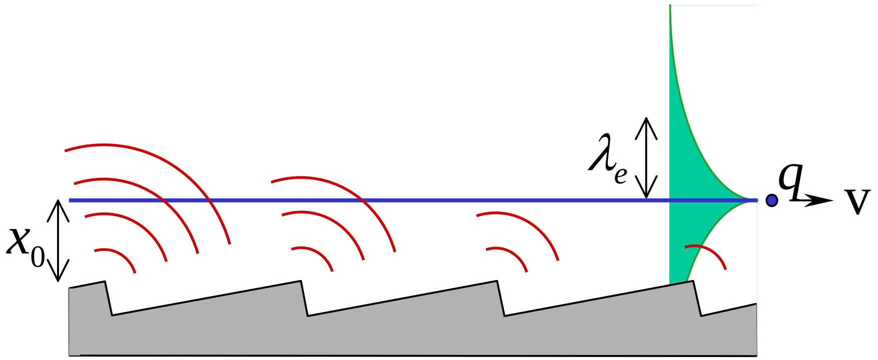
Smith-Purcell Radiation (SPR): periodic DR



<u>Dispersion relation</u>

$$n\lambda = c\,\ell/\mathrm{v} - \ell\cos\theta$$

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

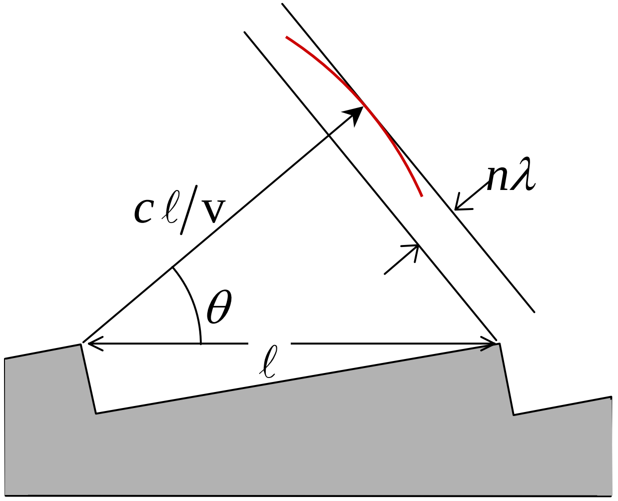
$$\omega_n = n\frac{2\pi \mathrm{v}}{1-\beta\cos\theta}$$

Evanescent length: $\lambda_e = \frac{\gamma \mathrm{v}}{\omega} = \lambda\frac{\gamma\beta}{2\pi}$

Optimum impact height: $\lambda_e = x_0 = \left(\sigma_X\right)_{\mathrm{beam}}$

Rolloff frequency: $\omega_{\max} = \frac{\gamma \mathrm{v}}{\left(\sigma_X\right)_{\mathrm{beam}}}$

Parallellism condition: $\mathrm{Tilt} \le \lambda_e / L$



Temporal profile encoded in coherence factor (*F*)

The radiant energy per steradian per unit length:

$$\frac{1}{L}\frac{\partial \varepsilon}{\partial \Omega} \propto N S_{inc} + N^2 F$$

$$F \propto \left| \int dt \, T(t) \, e^{i\omega t} \right|^2$$

$T(t)$ is the temporal bunch profile.

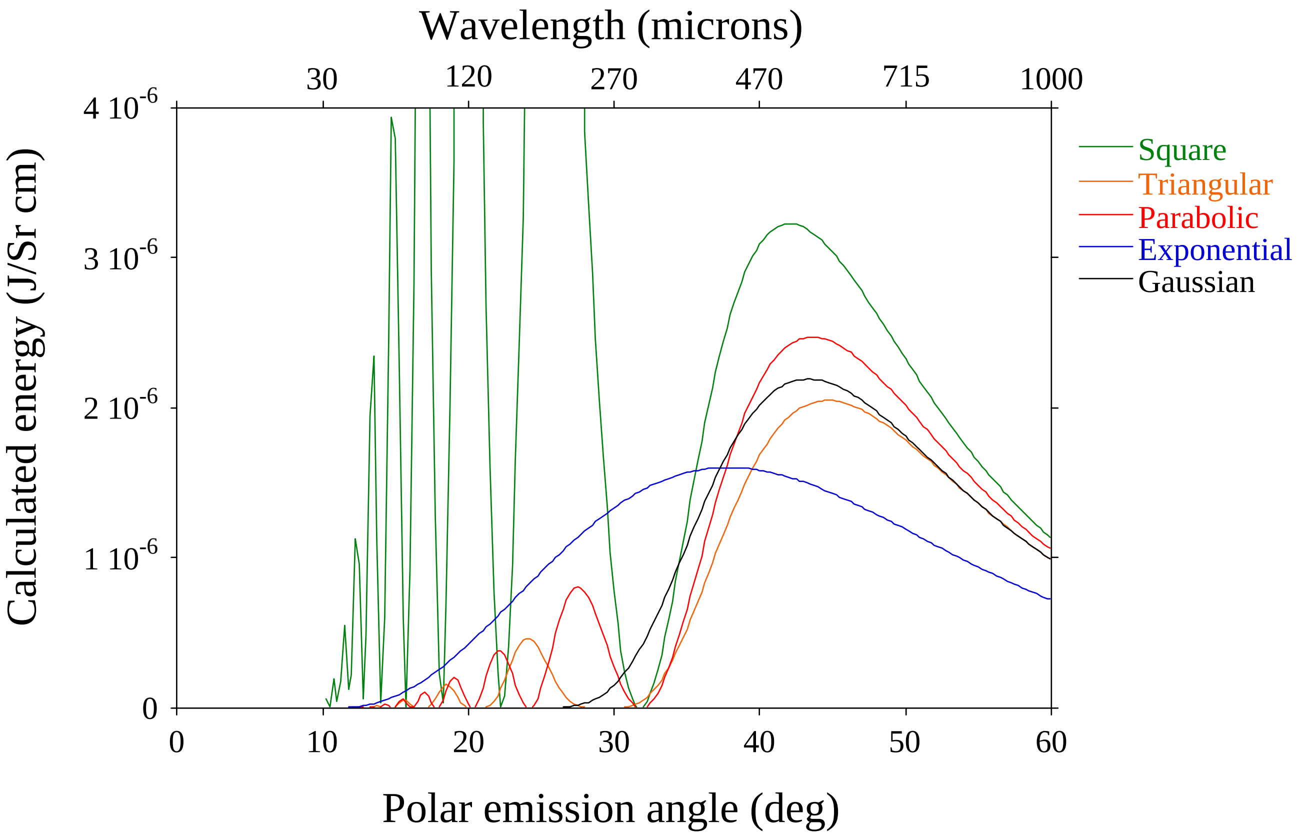
$N \sim 10^9$ is the number of electrons per bunch.

Emission is dominated by the coherent term.

Polar SPR intensity distribution by profile type

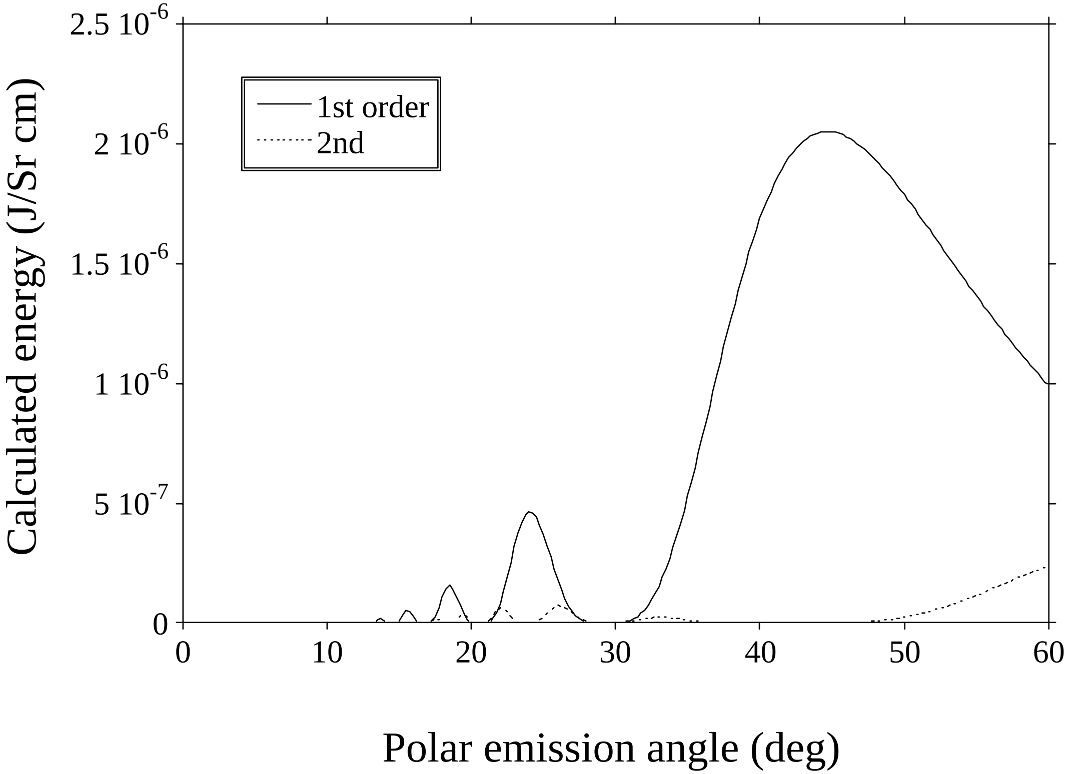
Beam: 0.5 ps, 0.2 nC, 50 μm waist.

Grating: 2 mm period, 10 deg blaze.



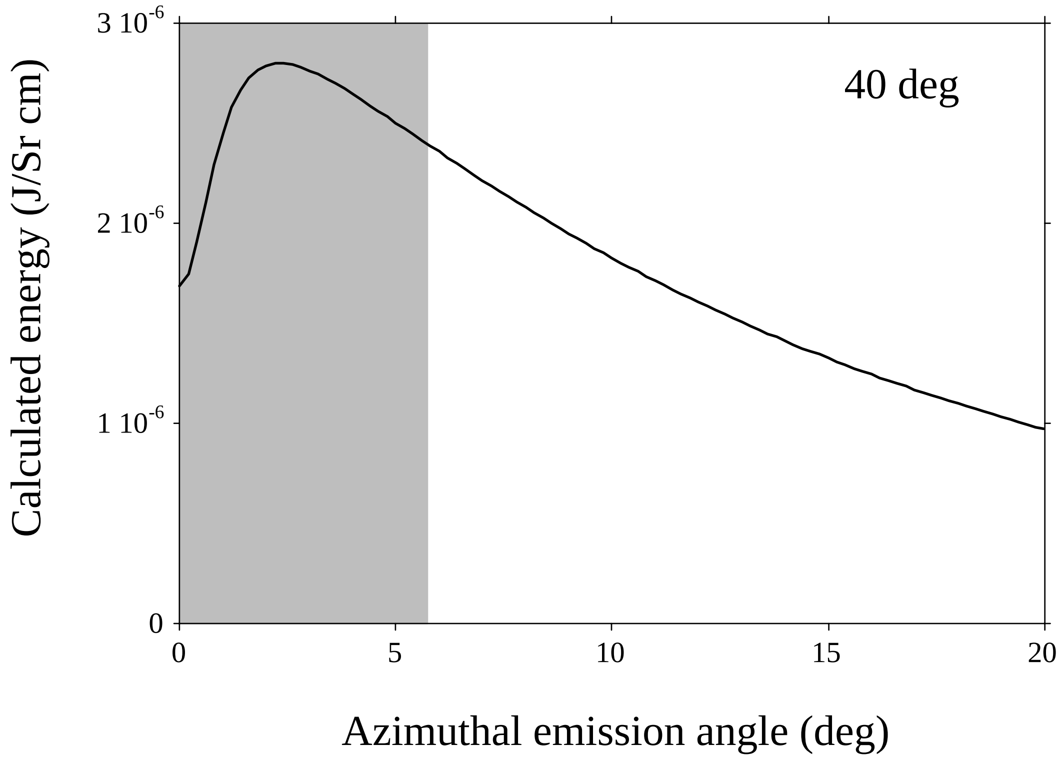
Higher order emission is negligible

Beam:	0.5 ps, 0.2 nC, 50 μm waist, triangular profile.
Grating:	2 mm period, 10 deg blaze.



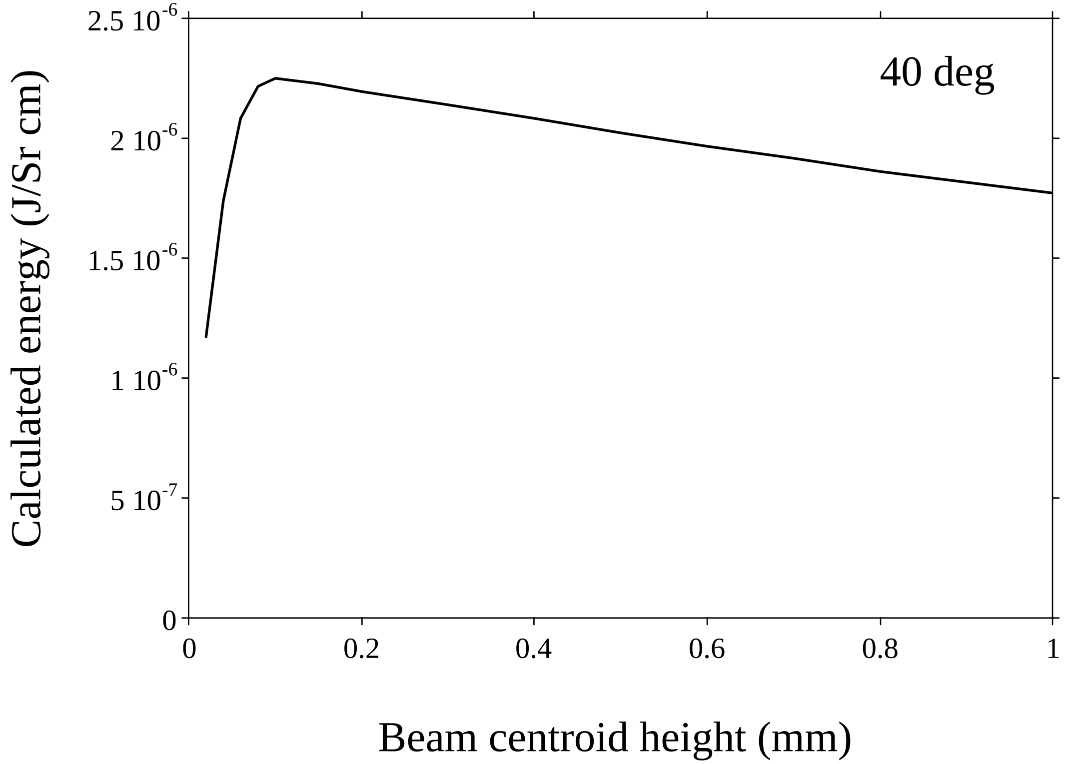
Azimuthal SPR intensity distribution

Beam: 0.5 ps, 0.2 nC, 50 μm waist, triangular profile.
Grating: 2 mm period, 10 deg blaze.



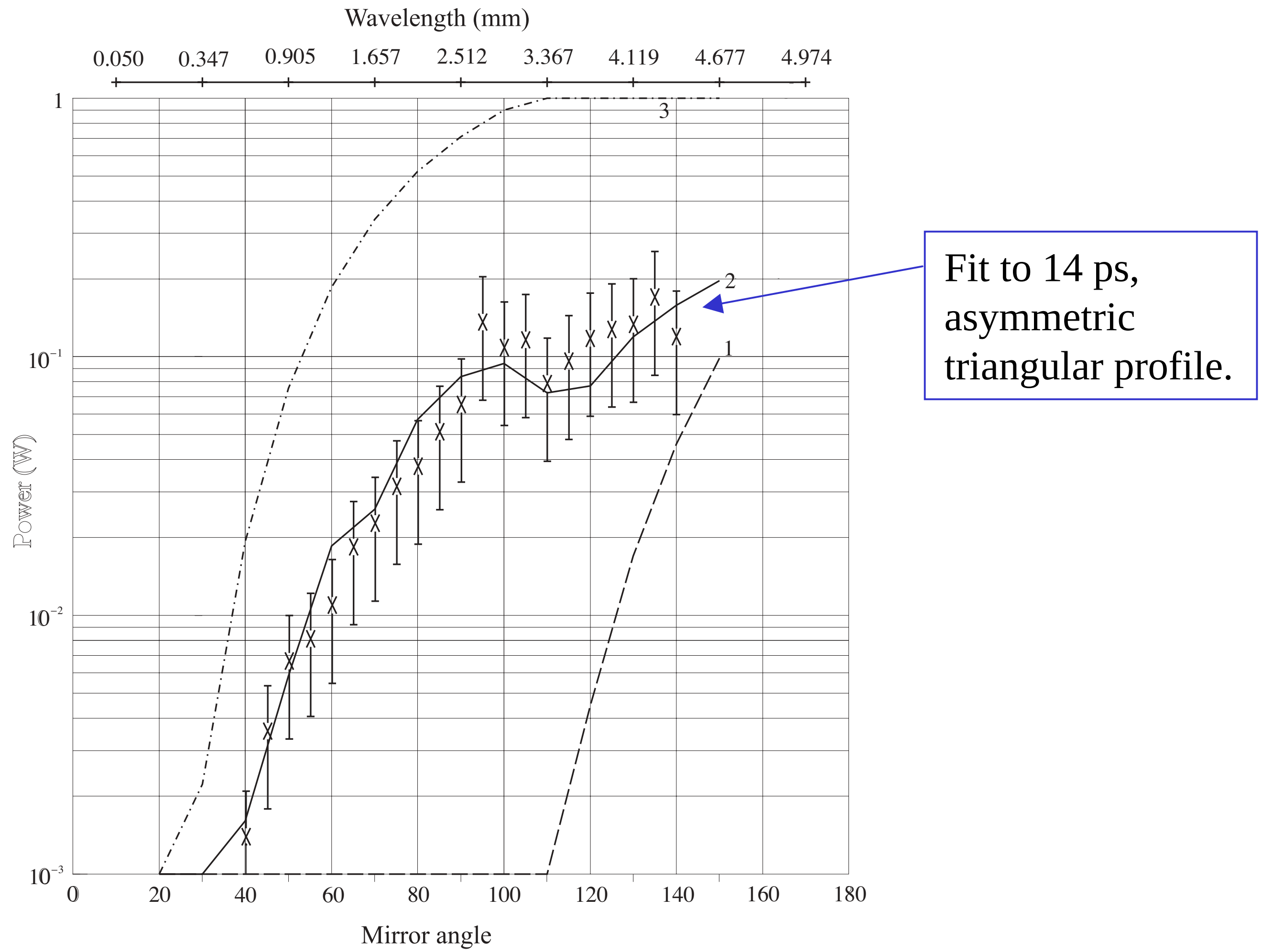
Weak dependence on impact parameter

Beam: 0.5 ps, 0.2 nC, 50 μm waist, triangular profile.
Grating: 2 mm period, 10 deg blaze.



➡ Operate with beam far from grating surface.

Smith-Purcell bunch profile measurement at ENEA



G. Doucas, M.F. Kimmitt, A. Doria, G.P. Gallerano, E. Giovenale, G. Messina, H.L. Andrews, and J.H. Brownell, 8th European Particle Accelerator Conference, Eur. Phys. Soc., 1870 (2002).

CURRENT short wavelength (10μm) SPR experiment:

- Investigate Smith-Purcell interaction at high energy.
- Explore feasibility of Inverse S-P acceleration.

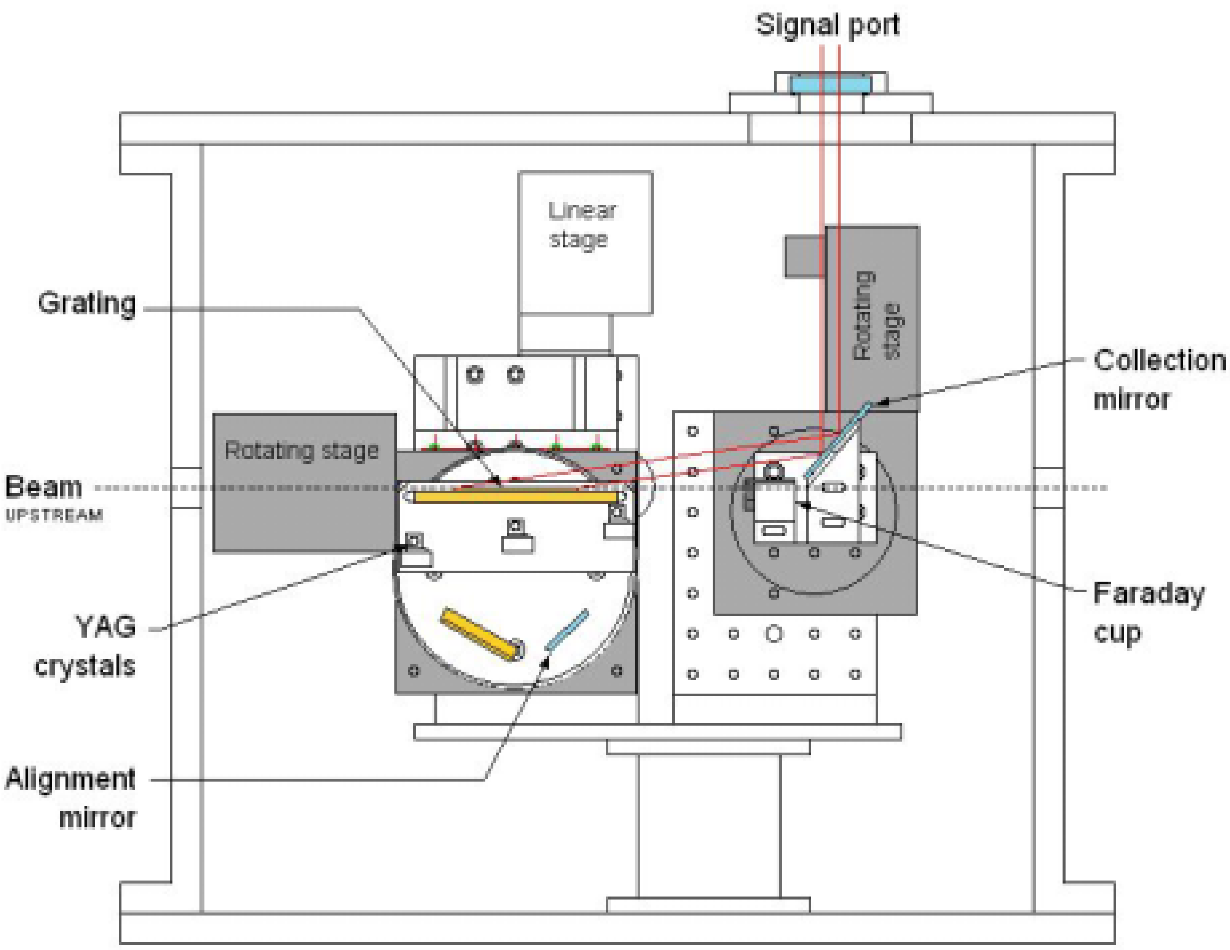
➡ Design the experiment for 10 micron fundamental emission.

- Constraint on beam size: $(\sigma_X)_{\text{beam}} \leq 80\mu\text{m}/n$ (order n)
- Parallelism constraint: Beam divergence $\leq 0.6\text{mrad}/n$
- Emittance constraint: $\varepsilon_N \leq \left(4.5/n^2\right)\pi$ mm mrad

➡ Pushing the limit of the ATF.

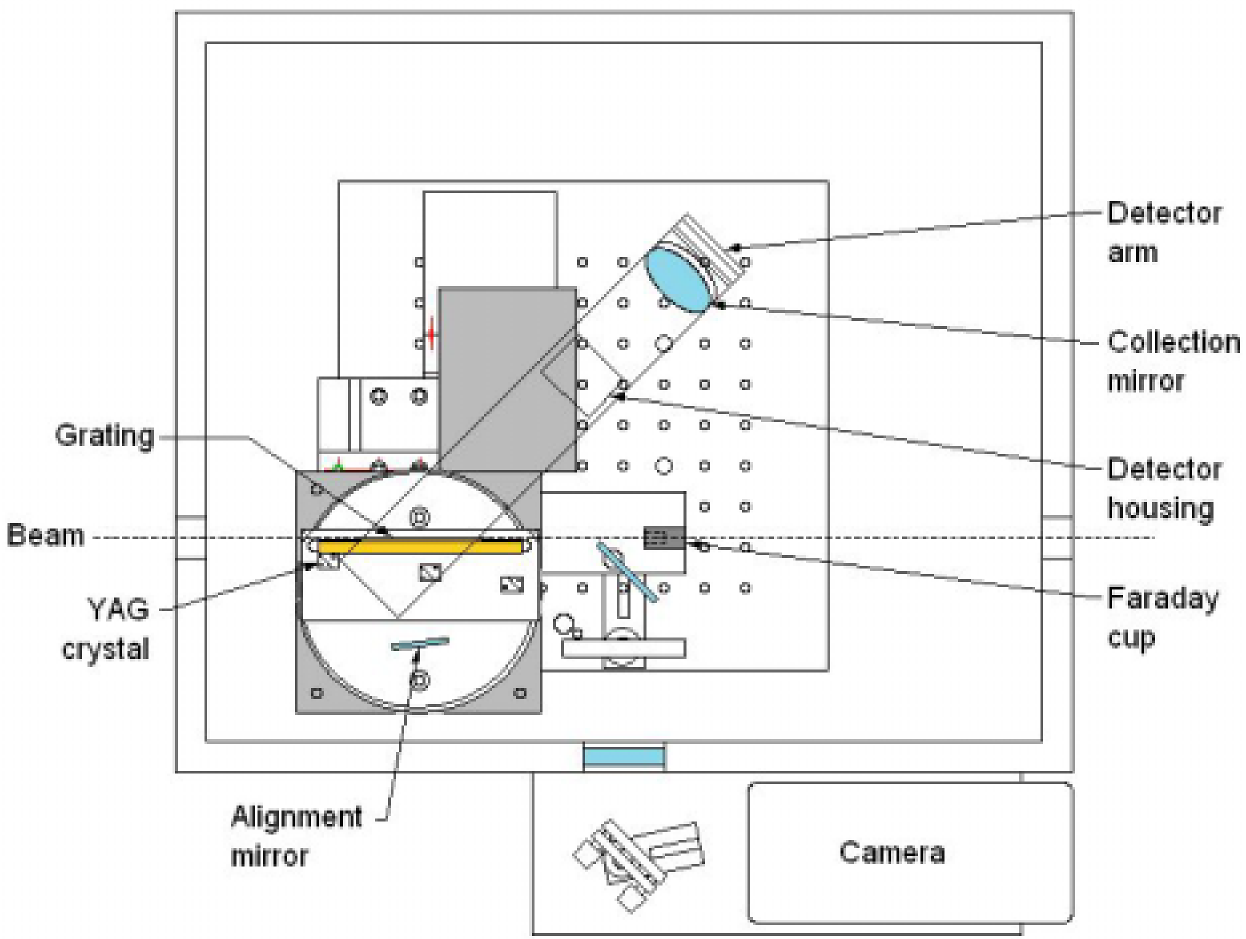
Impact radiation producing large background signal.

Current Experimental Setup for 10 μm SPR



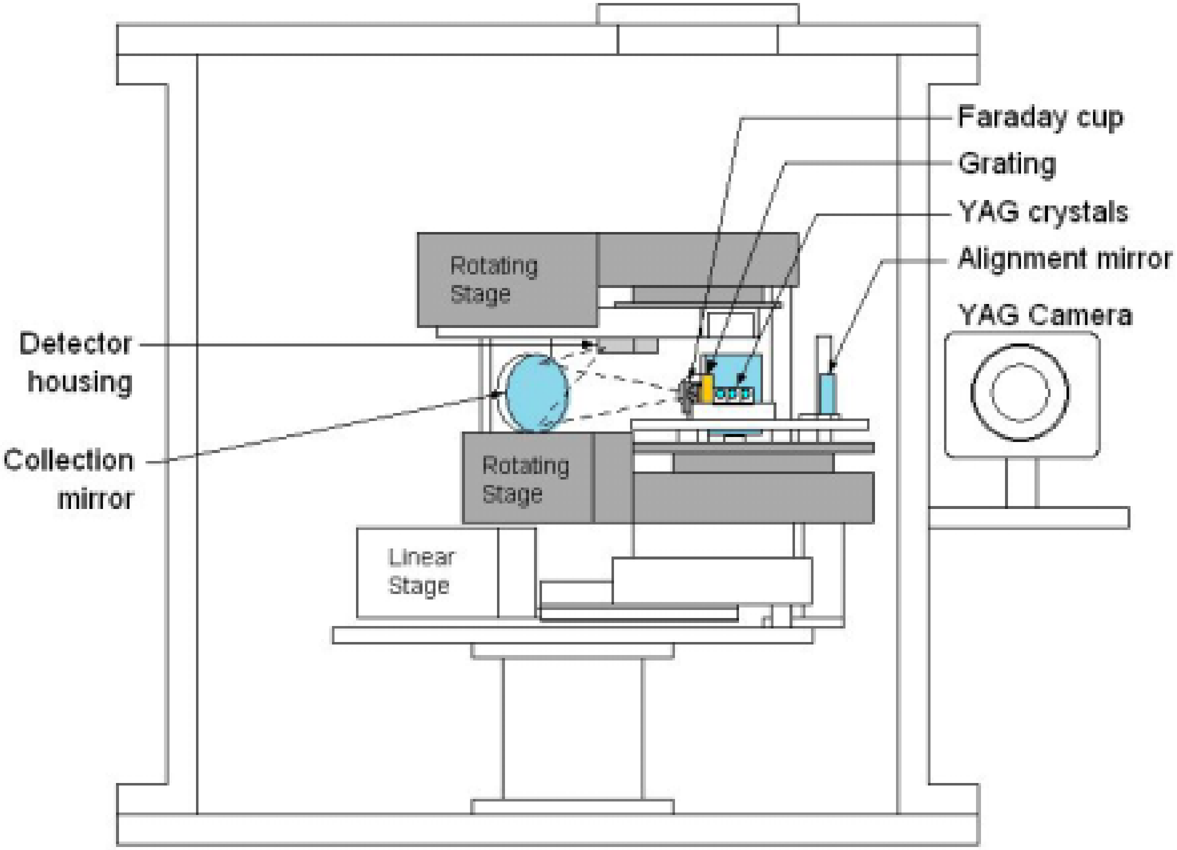
Proposed: Top view of setup

Same components as in current setup.



Proposed: Upstream view of setup

Structure supporting detector stage not shown.



Detection

Peak Signal ~ (1 μJ/Sr cm)(0.03 Sr)(15 cm) ~ 1 μJ.

Desired dynamic range > 1000.

Polar angle resolution = 1 degree.

Molectron pyroelectric pre-amplifier module with 2nd stage op-amp:

0.001-1000 μm flat response,
0.1 V/nJ,
<0.01 nJ noise floor @ 100KHz.

Internal, all-reflective detection avoids transmission losses,

at the risk of excessive noise pick-up.

Advantage of SPR for profile measurement

- Non-invasive: does not perturb the beam significantly.
- Signal larger than DR/TR by the number of periods, typically ~100.
- Signal inherently dispersed in frequency allowing direct measurement of the power spectrum. Single shot measurement feasible with detector array.
- Emission direction widely tunable through period and blaze.
- Simple.

Program

- Measure the average bunch profile. Examine profile sensitivity to beam tune. If all goes well, consider single-shot measurement.
- Six 3-day runs over 1 year.

Comments

- The setup is a (fairly) simple rearrangement of current components.
- All control systems have been developed, tested and are currently functioning.
- Focus and jitter tolerances are easily satisfied. The confusion from impact radiation experienced with short wavelength emission avoided with large impact parameter.