Resonant Diffraction Radiation from Inclined Targets as a Tool for Bunch Lengths Diagnostics

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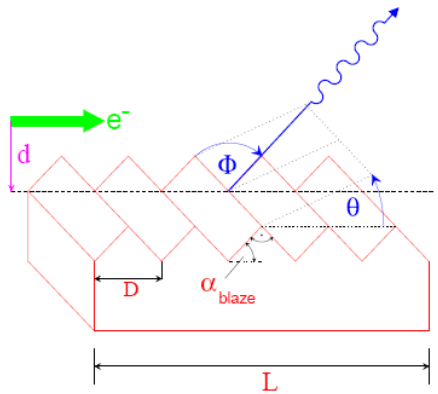
Contents

INTRODUCTION

Smith-Purcell Radiation



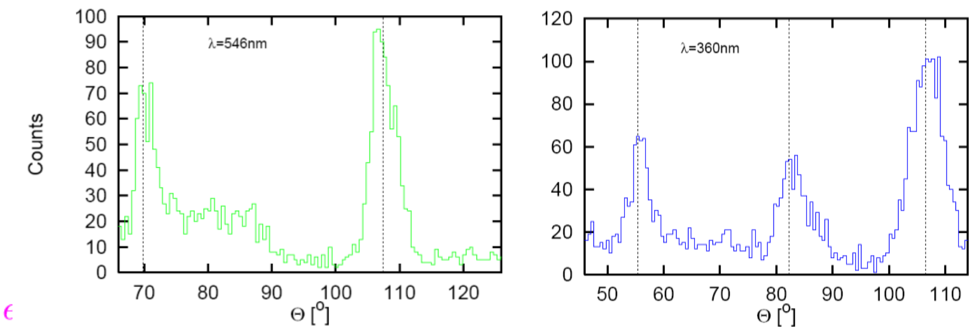
$$\frac{d\dot{N}}{d\Omega} = \alpha \cdot n \cdot \frac{I}{e} \cdot \frac{L}{D} \cdot |R_n|^2 \cdot \frac{\sin^2\theta \cdot \sin^2\Phi}{(1/\beta - \cos\theta \cdot \sin\Phi)^2} \cdot \epsilon$$

α	:	fine structure constant
n	:	diffraction order
I	:	beam current
e	:	elementary charge
D	:	spacing of grooves
L	:	grating length
d	:	distance between beam and grating surface
R_n	:	radiation factor, $R_n = R_n(\gamma, \theta, \Phi, \alpha_{blaze})$
θ, Φ	:	angle of observation
κ	:	evanescent scale, $\kappa = h_{int}^{-1} \cdot \sqrt{1 + (\beta\gamma\cos\Phi)^2}$
h_{int}	:	interaction length

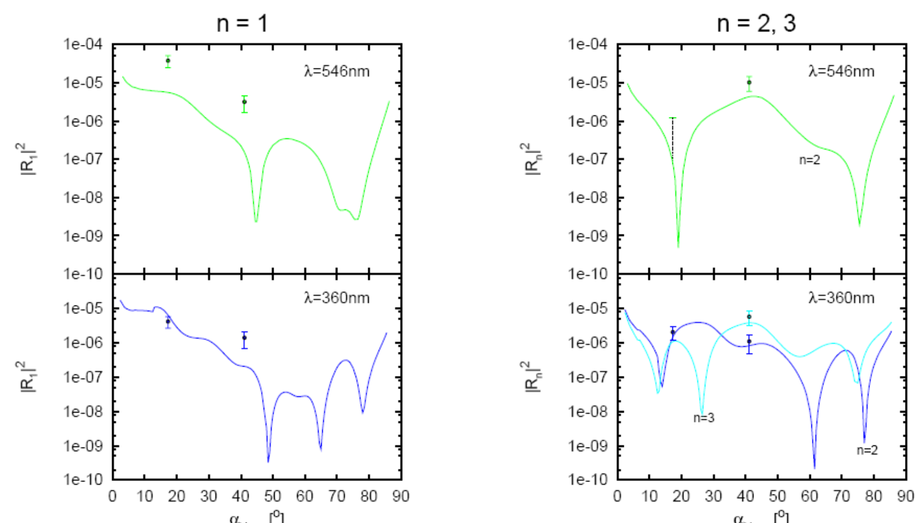
$$h_{int} = \frac{\beta\gamma}{4\pi} \cdot \lambda$$

- dispersion relation $n\lambda = D(1/\beta - \cos\Theta)$

E = 855 MeV, D = 833 nm, α_{blaze} = 41.12°



- radiation factor



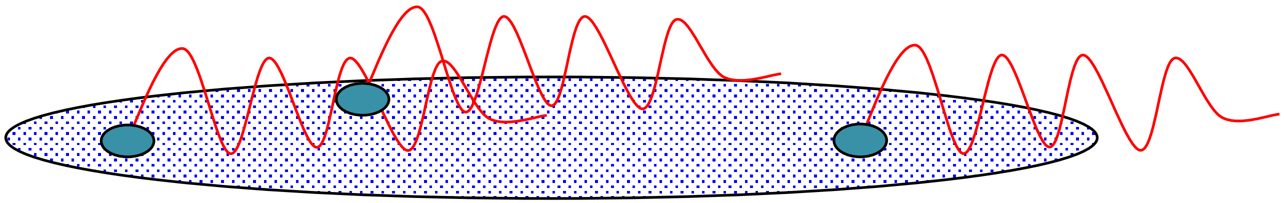
(Grating: D = 833 nm)

G.Kube et al., Phys.Rev. E 65 (2002) 056501

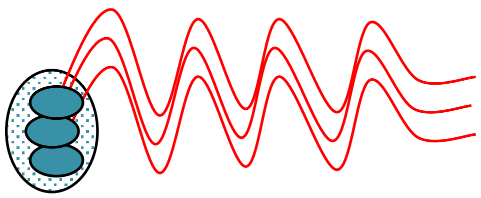
Longitudinal Radiation Coherence

- longitudinal coherence

long bunch ($\lambda<\sigma_z$)



short bunch ($\lambda>\sigma_z$)



Coherent Radiation Diagnostics

- coherent radiation diagnostics

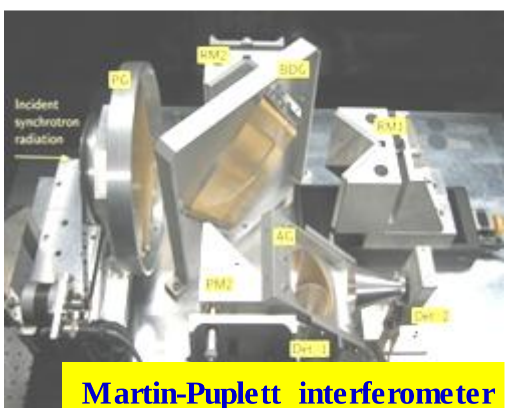
  - **principle:** bunch length/shape dependent emission spectrum of coherent radiation

$$\frac{dU}{d\lambda} = \underbrace{\left(\frac{dU}{d\lambda}\right)_1}_{\text{single particle spectrum}} \left(N + \underbrace{N}_{\text{no. of particles per bunch}}(N-1)\underbrace{|F(\lambda)|^2}_{\text{bunch form factor}}\right) \quad \text{with} \quad F(\lambda) = \int dz\, \underbrace{S(z)}_{\text{bunch profile}}\, e^{i\frac{2\pi z}{\lambda}}$$

- spectral decomposition and Fourier transform:
  → bunch length and shape

- transition radiation (TR), diffraction radiation (DR), Cherenkov radiation (ChR):
  - polychromatic angular distribution

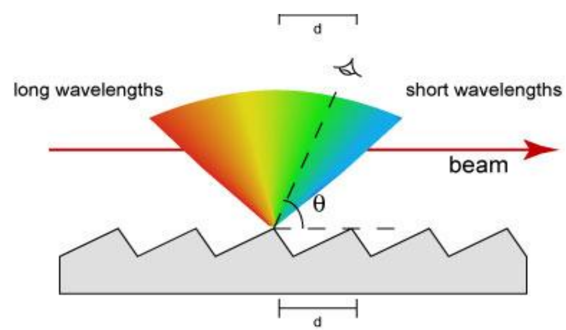
  → spectrometer for decomposition



Martin-Puplett interferometer

- Smith-Purcell radiation (SPR):
  - (virtual) photon diffraction at 1D grating
  - angular distribution wavelength-dependent

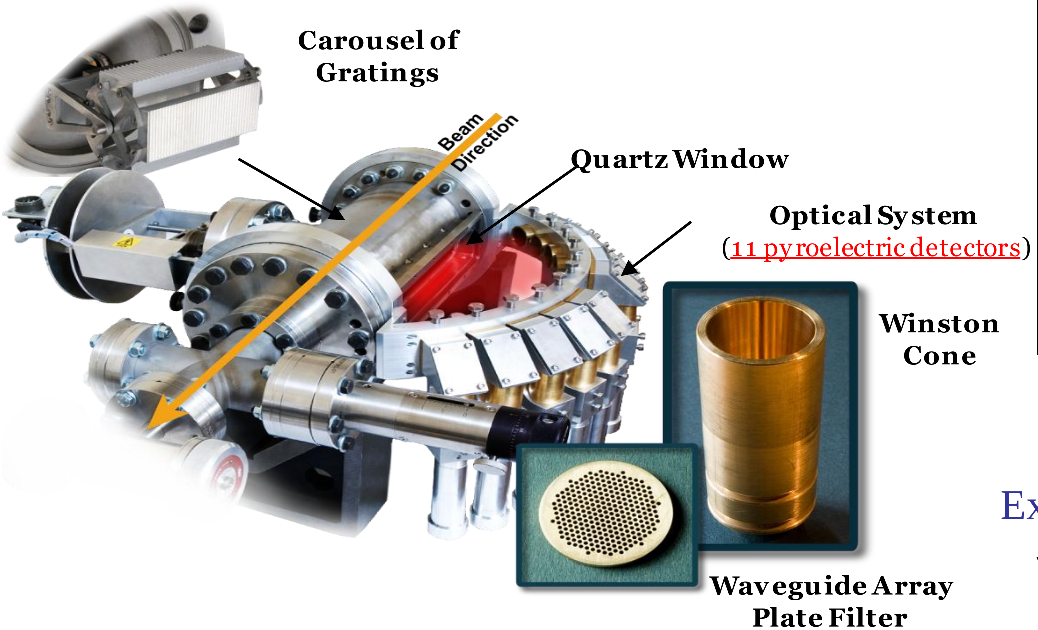
  → no additional spectrometer

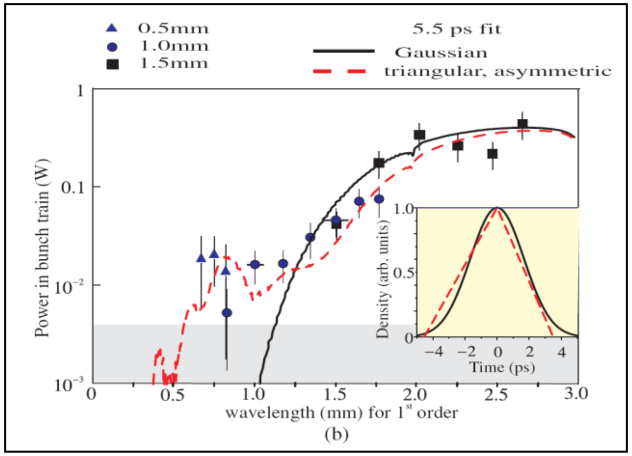


Coherent SPR Diagnostics

- bunch length monitor based on Smith-Purcell radiation

Measurement at 45 MeV, FELIX





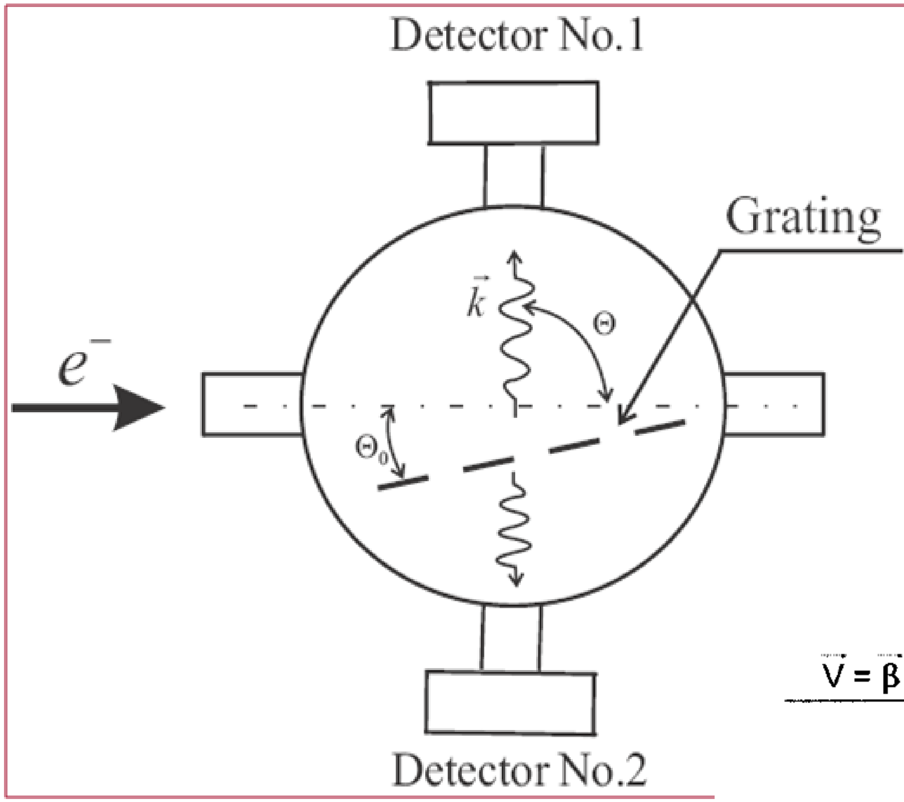
G. Doucas et al., PRST 9 (2006) 092801

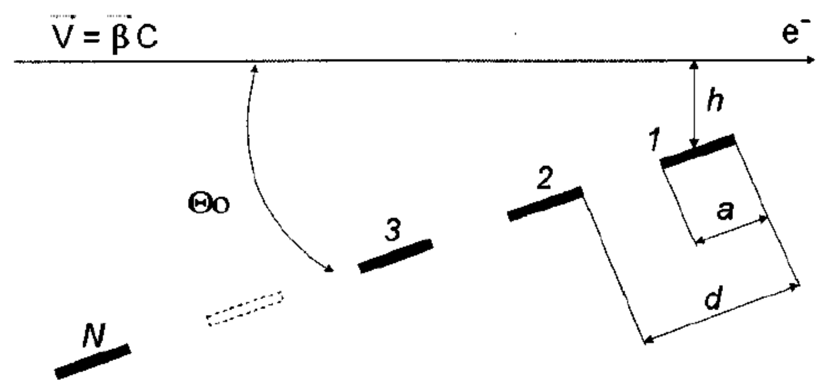
Experiment at 28.5 GeV, SLAC

V.Blackmore et al., PRST 12 (2009) 032803

Courtesy G. Doucas, V. Blackmore (Oxford)

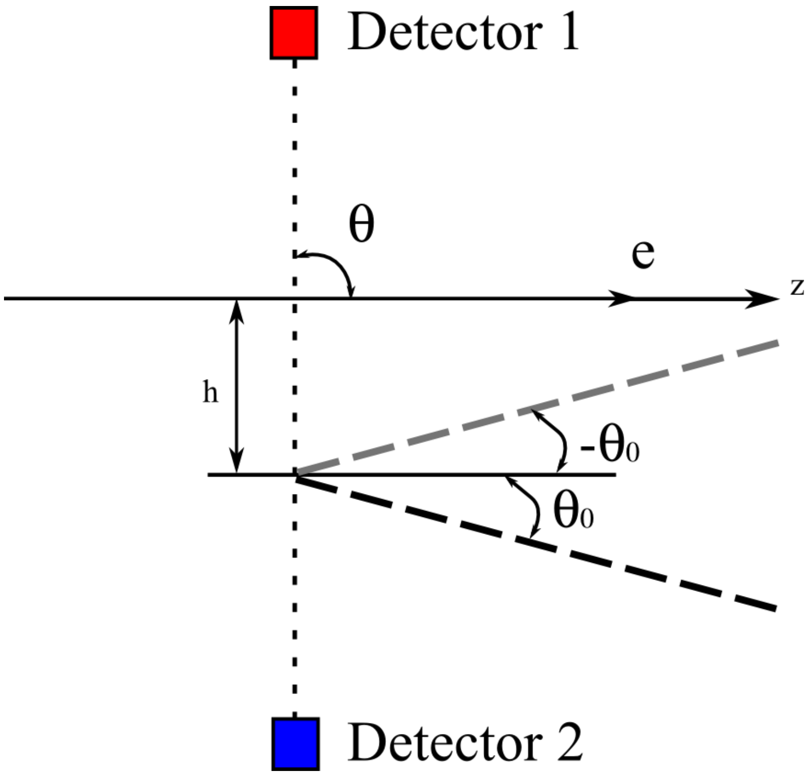
Proposed RDR Experiment





THEORETICAL BACKGROUND

Problem geometry



Beam parameters:
Energy – 165 MeV
Bunch length – 70 – 250 um
Bunch transverse sizes are << impact-parameter h=20 mm

Grating parameters:
Period – 700 um
Strip – d/2
Number of periods = 21
In transverse direction the grating is infinite
The grating thickness tends to zero
The grating is ideally conducting

The detectors are situated in the far-field zone
L > 400 mm

Calculation formulae

Following the generalized surface current method one may obtain the radiation field from the grating infinite in x direction as follows:

$$\mathbf{E^R}(\mathbf{r_0},\omega) = -i\frac{e^{ikr_0}}{r_0}\mathbf{k}\times\int_S dz\,[\mathbf{n},\mathbf{E_0}(k_x, y=0, z,\omega)]\,e^{-ik_z z} \qquad (1)$$

Here $\mathbf{k} = \frac{\omega}{c}\{ex, ey, ez\}$ is the wave-vector of the radiation, $\mathbf{n} = \{0,1,0\}$ is the normal to the grating surface, $\mathbf{E_0}(k_x, y = 0, z, \omega)$ is the Fourier component of the initial electron field. The last may be written as:

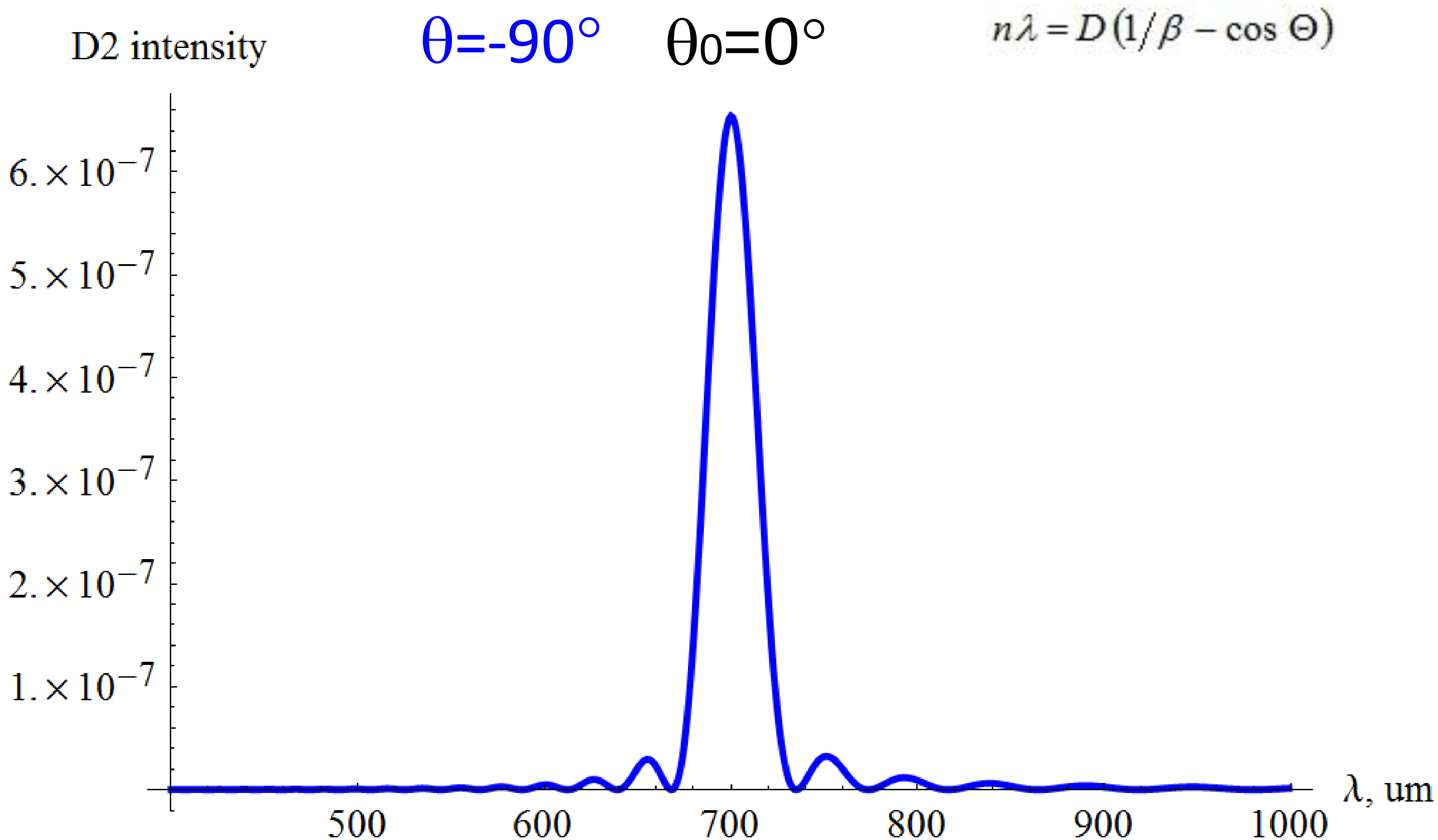
$$\mathbf{E_0}(k_x, y=0, z,\omega) = -\frac{ie}{2\pi\beta c}\exp\left[i\frac{\omega}{c}\left(\beta^{-1}\cos\theta_0 - \frac{\sin\theta_0}{\beta\gamma}\sqrt{1+(\beta\gamma e_x)^2}\right)\right]$$

$$\frac{\exp\left[-h\frac{\omega}{c}\left(i\beta^{-1}\sin\theta_0 + \frac{\cos\theta_0}{\beta\gamma}\sqrt{1+(\beta\gamma e_x)^2}\right)\right]}{\sqrt{1+(\beta\gamma e_x)^2}}$$

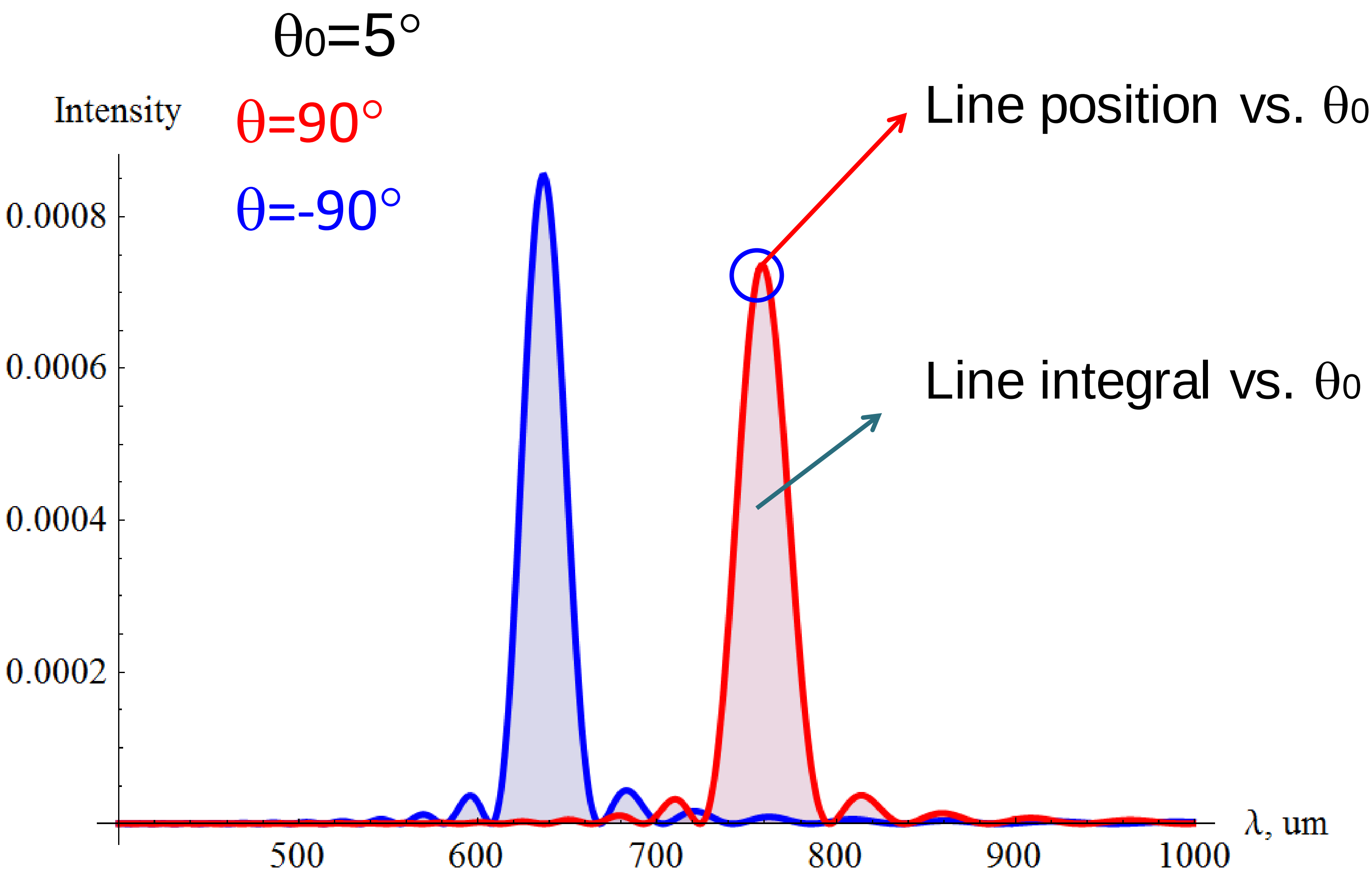
$$\left\{\beta\gamma e_x, \gamma^{-1}\sin\theta_0 - \cos\theta_0\sqrt{1+(\beta\gamma e_x)^2}, \gamma^{-1}\cos\theta_0 + \sin\theta_0\sqrt{1+(\beta\gamma e_x)^2}\right\} \qquad (2)$$

CALCULATION RESULTS

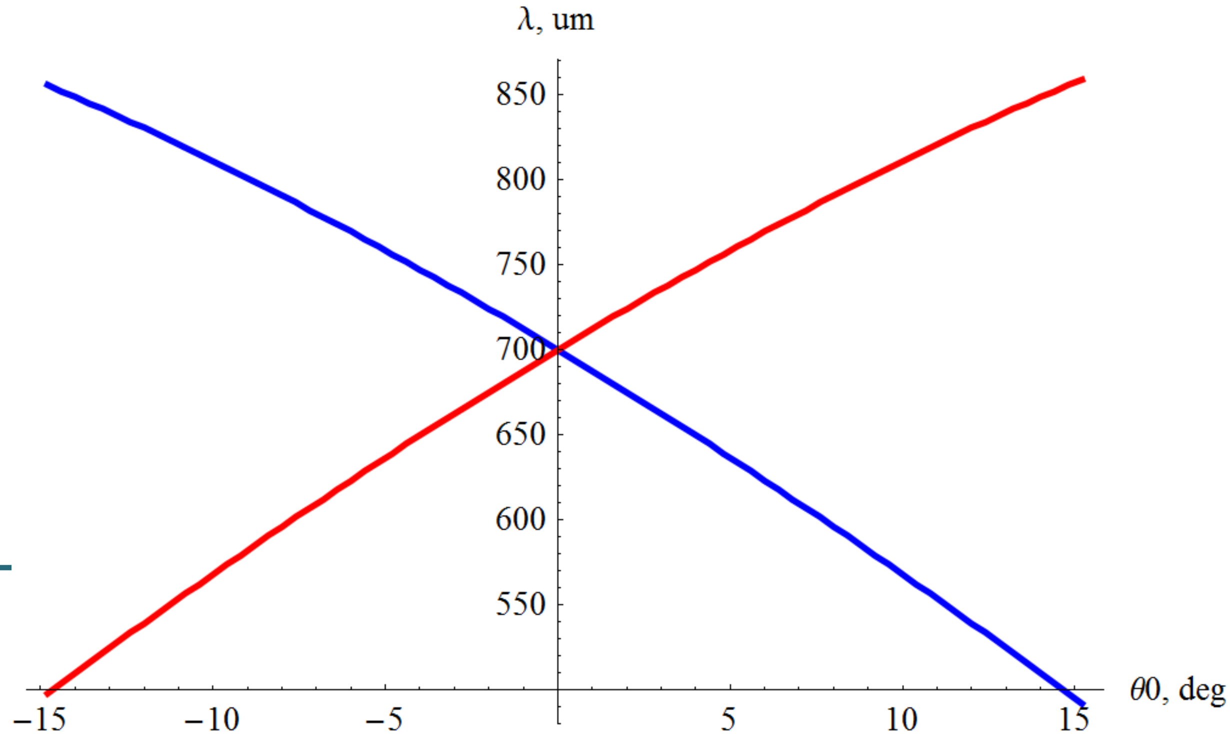
Incoherent Radiation Results (1)

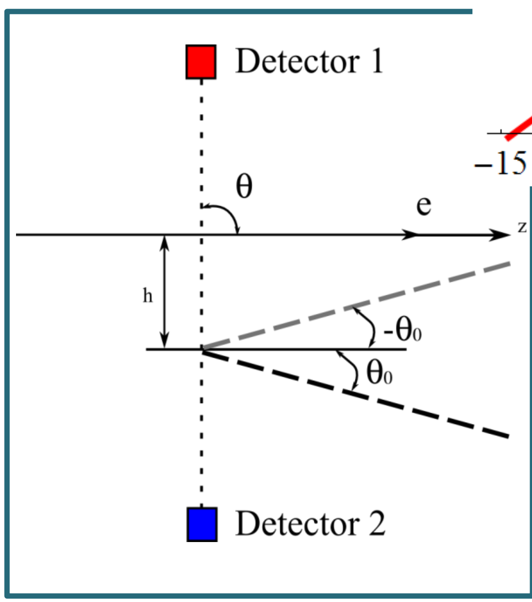


Incoherent Radiation Results (2)



Line Shift

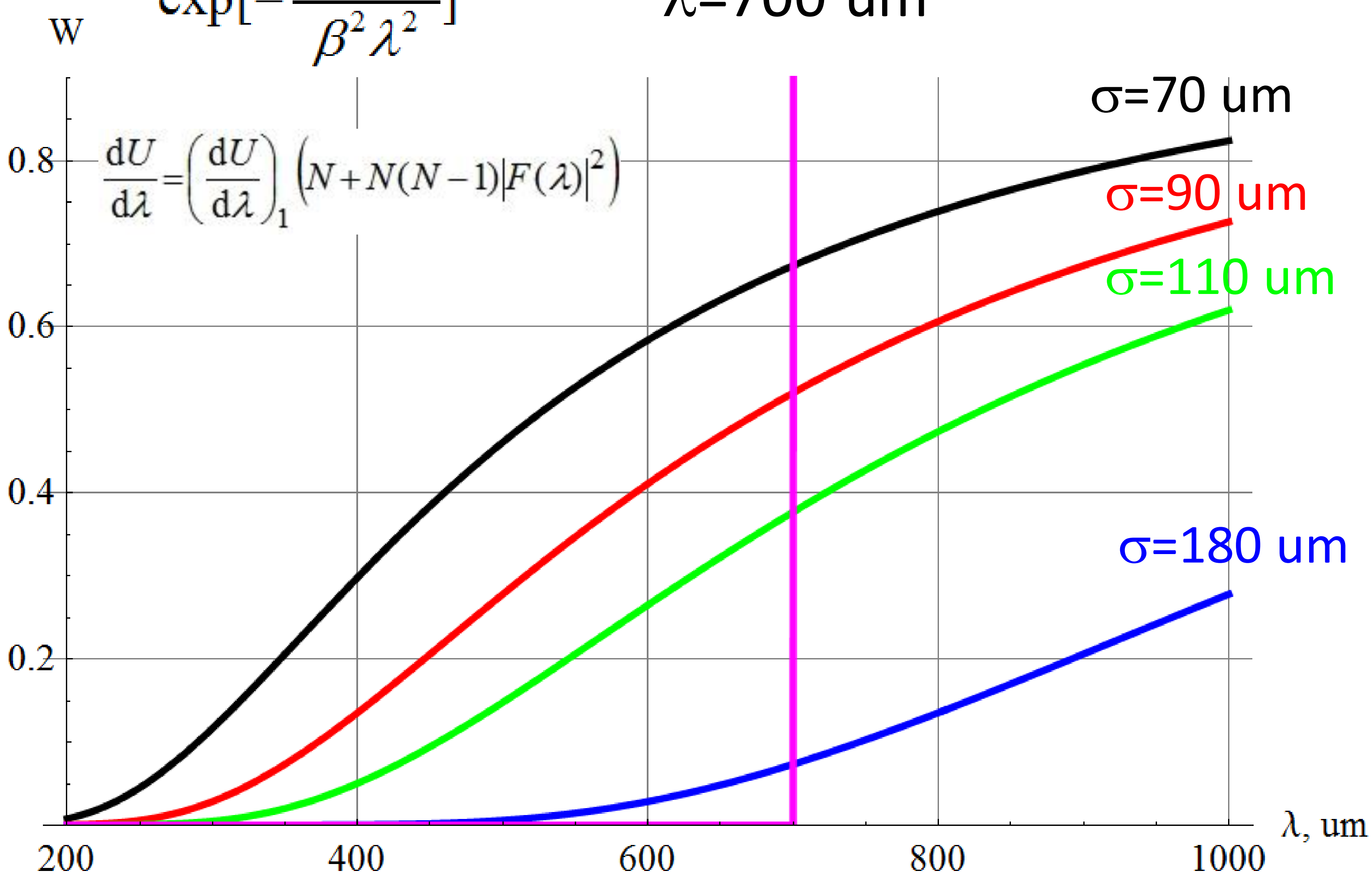

λ, um
850
800
750
700
650
600
550
−15
−10
−5
5
10
15
θ0, deg


Detector 1
θ
e
z
h
-θ0
θ0
Detector 2

Gaussian Bunch Form-Factor

$$\exp[-\frac{4\pi^2\sigma^2}{\beta^2\lambda^2}]$$

λ=700 um



D1/D2 ratio vs. θ_0

Fully coherent

σ=70 um

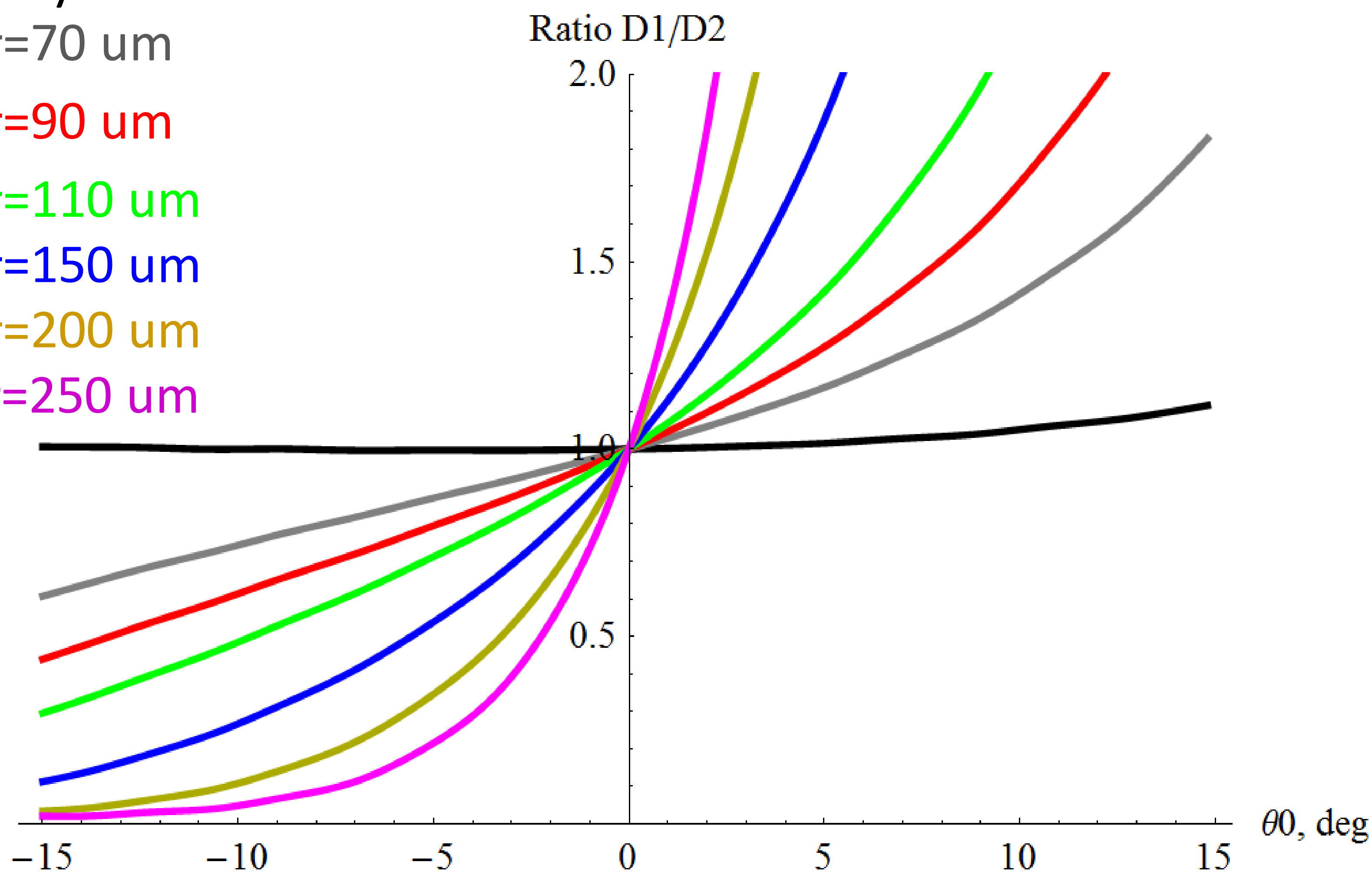
σ=90 um

σ=110 um

σ=150 um

σ=200 um

σ=250 um

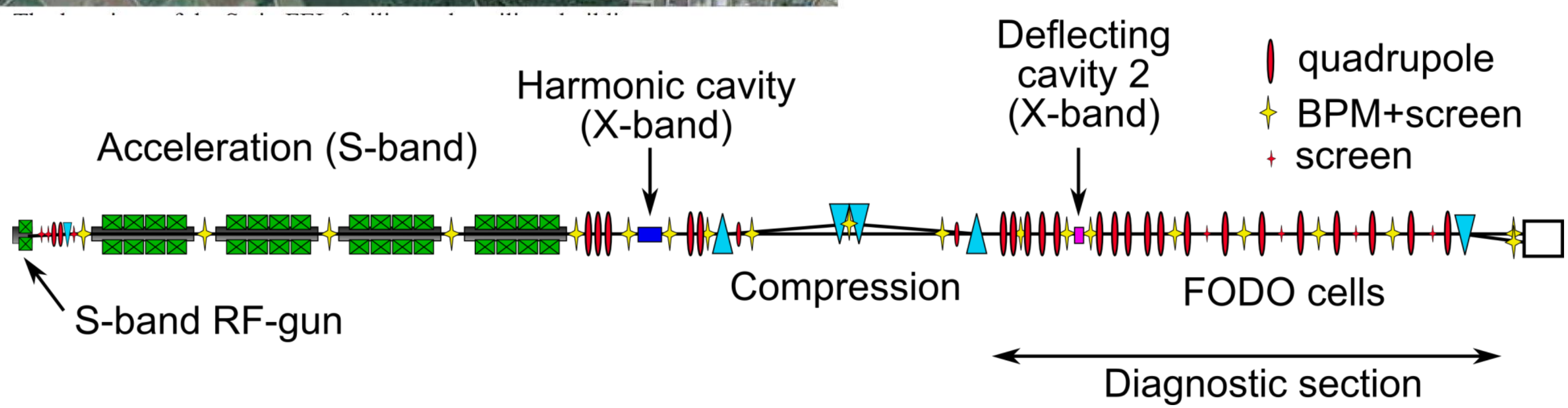


EXPERIMENT STATUS

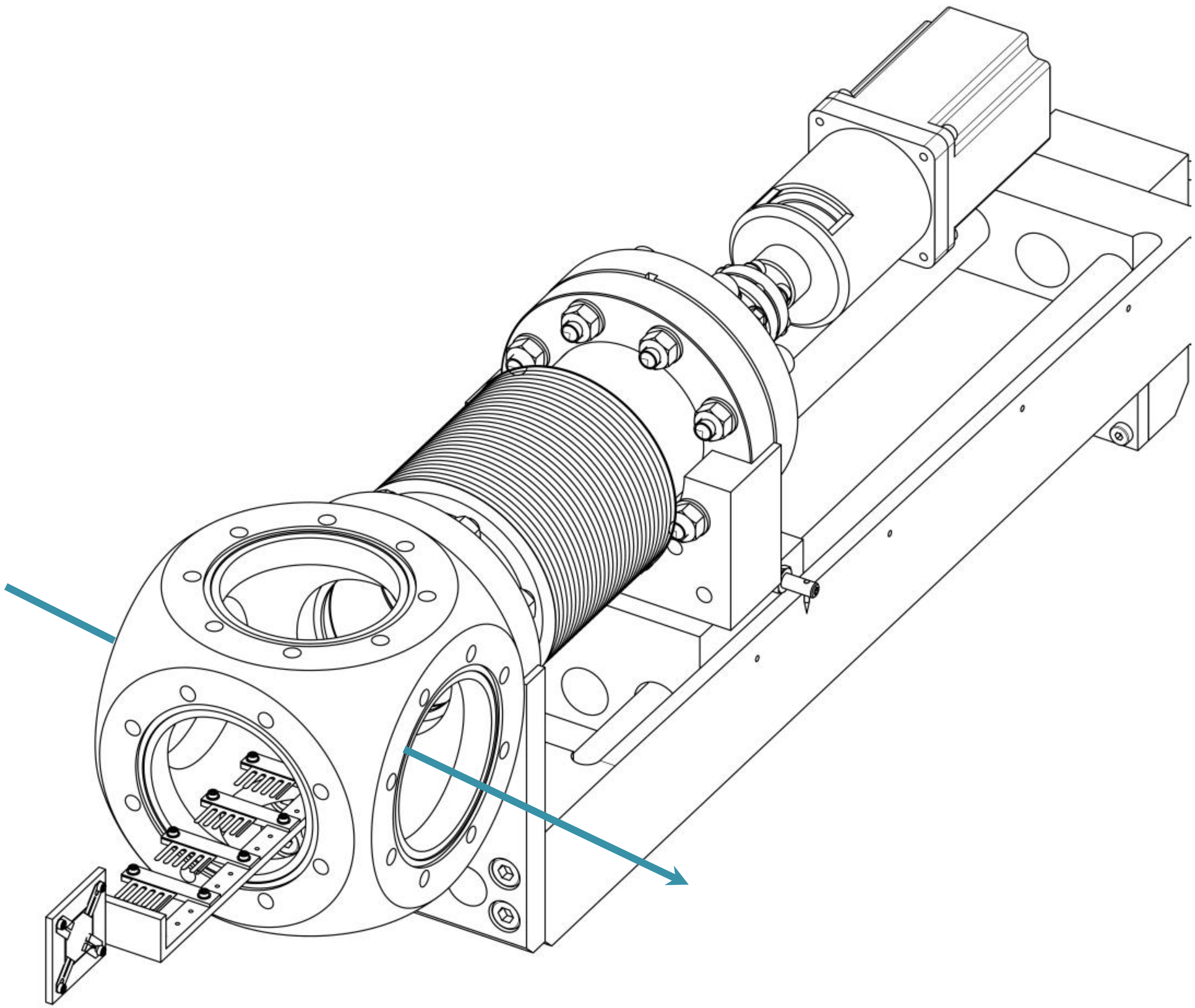
Accelerator

Beam parameters

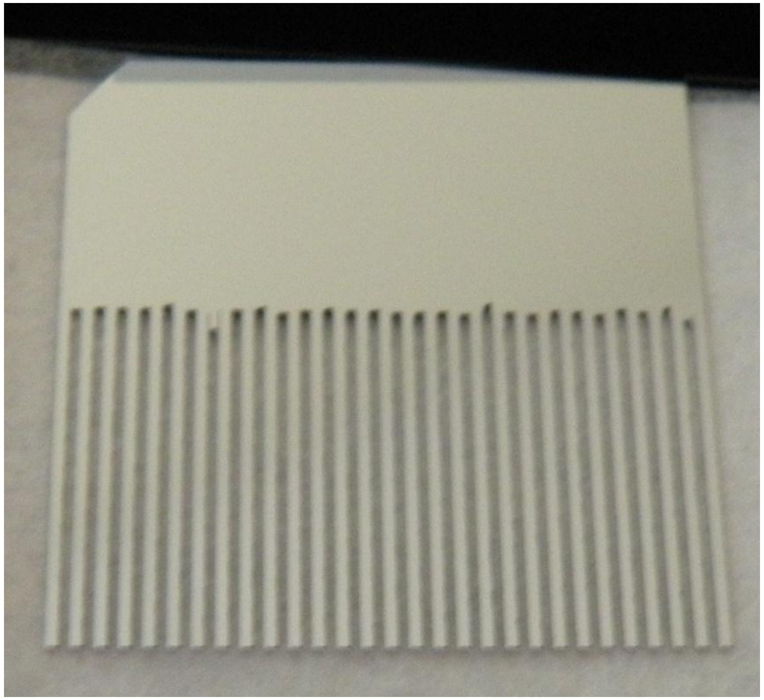
Parameter	Value
Electron energy	130,170,200,230 MeV
Bunch charge	10 – 200 pC
Bunch length	50 fs – 1 ps

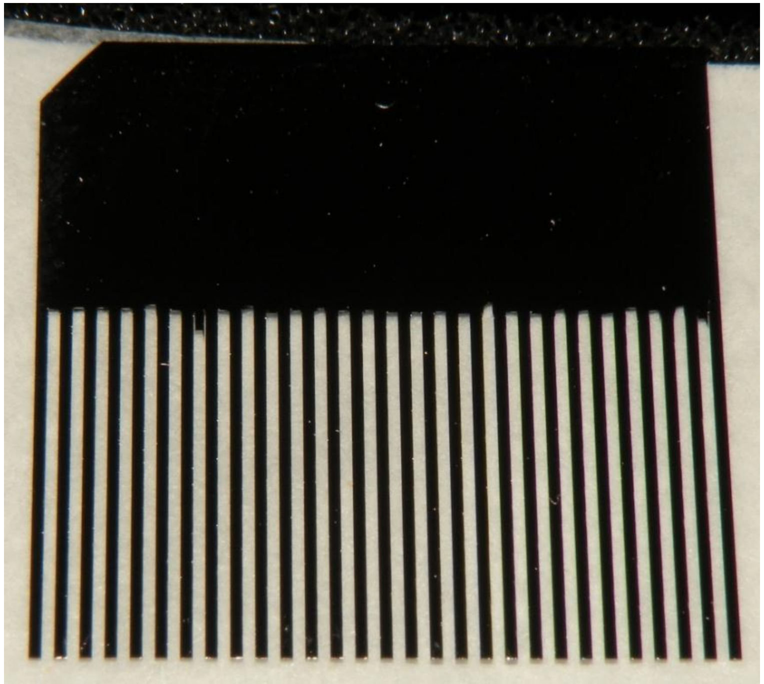


Experimental Setup



Gratings





100 um thick Si wafers
covered by 500 nm Mo
700 um period, 29 periods

Summary and Outlook

- Simple theoretical model exists and is used for calculation of CRDR characteristics.
- Experimental equipment is ready for vacuum installation, that is planned to be in the end of November 2011.
- Experiments will start probably early 2012.

THANK YOU FOR YOUR ATTENTION!