Optical Diffraction Radiation as a Diagnostics Tool at FLASH

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**DESY - HH*

DESY FLASH Seminar

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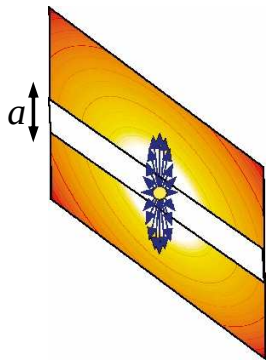
Diffraction Radiation



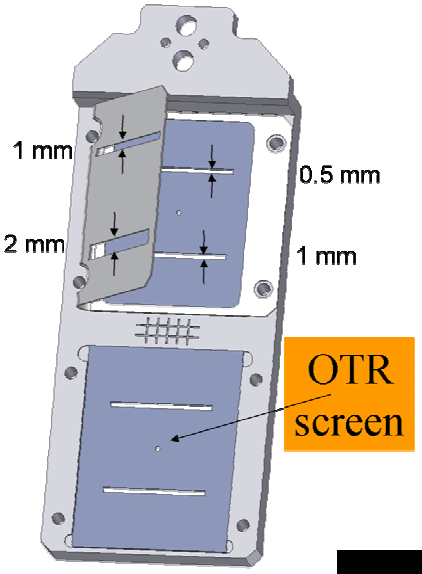
- DR is produced by the interaction between the EM fields of the traveling charge and the conducting screen

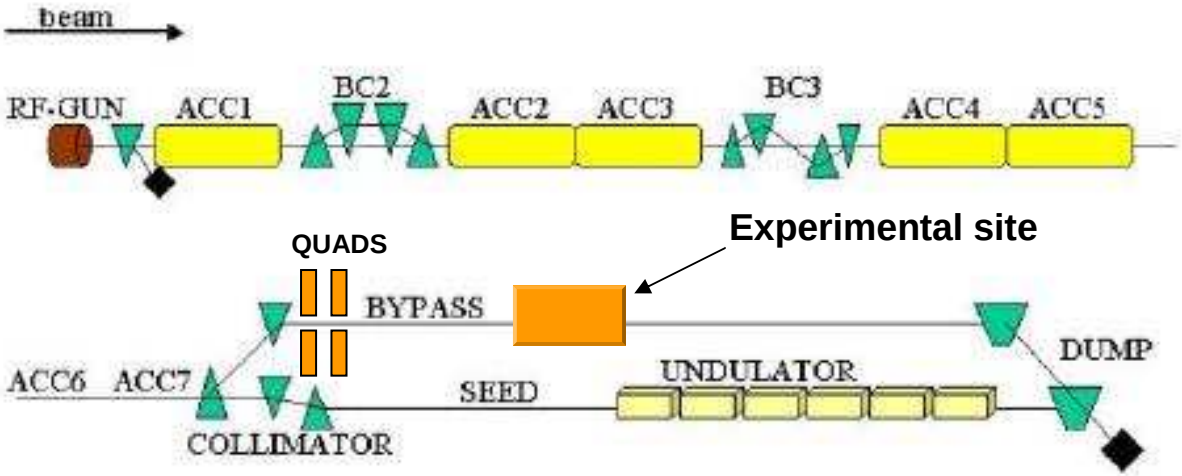
- The radiation intensity is $I \propto e^{-\frac{2\pi a}{\gamma\lambda}}$

- DR impact parameter is $\frac{\gamma\lambda}{2\pi}$ ➔ if a $\begin{cases} >> \frac{\gamma\lambda}{2\pi} & \text{No radiation} \\ \cong \frac{\gamma\lambda}{2\pi} & \text{DR} \\ << \frac{\gamma\lambda}{2\pi} & \text{TR} \end{cases}$

- Excellent candidate to measure beam parameters **parasitically**

ODR Experiment @ FLASH





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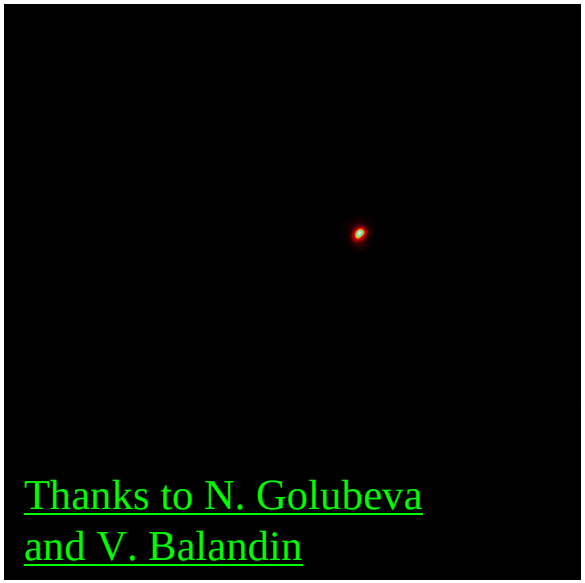
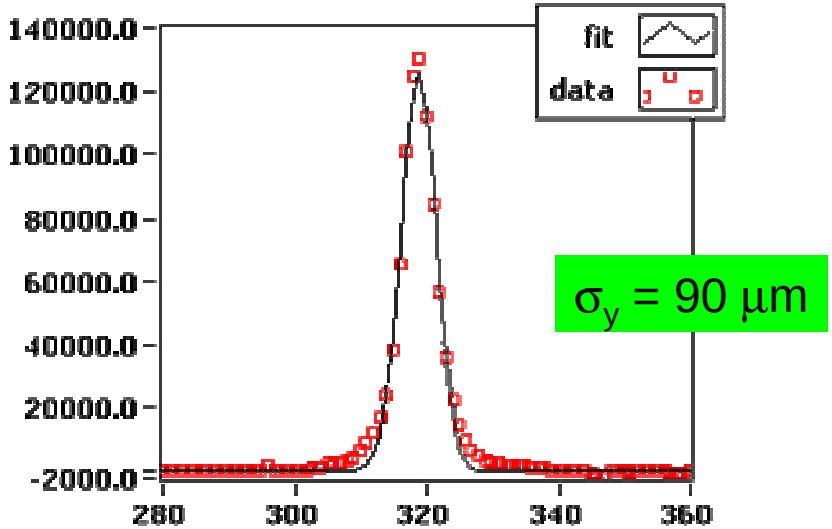
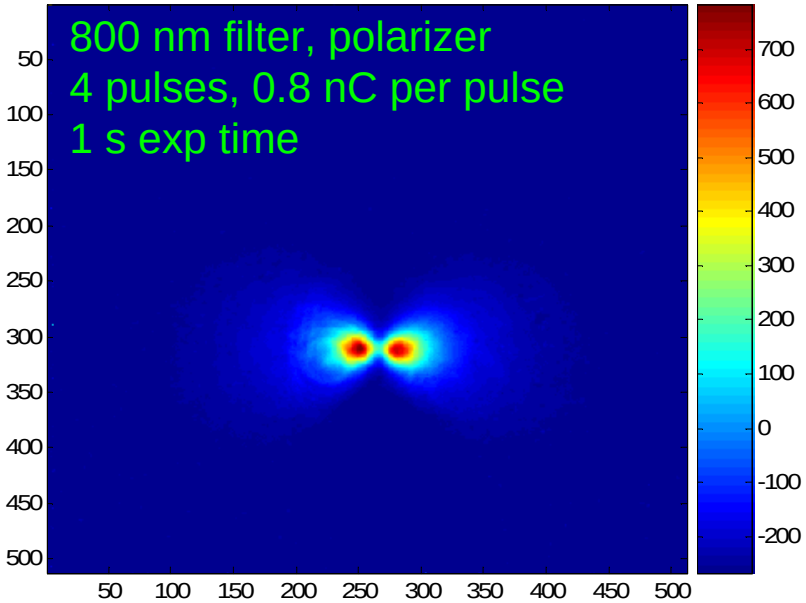
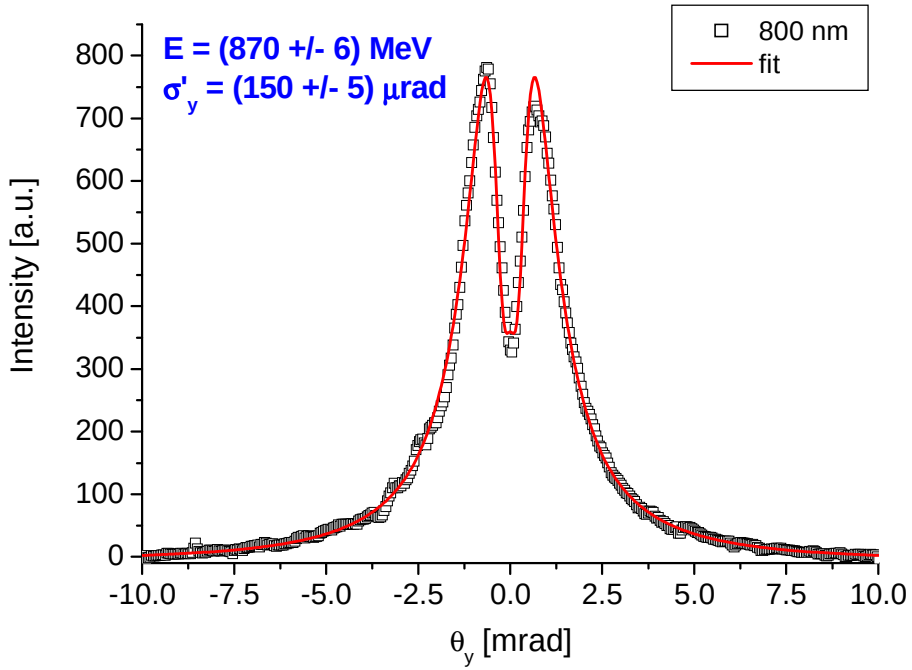
OTR Image and Focal Plane



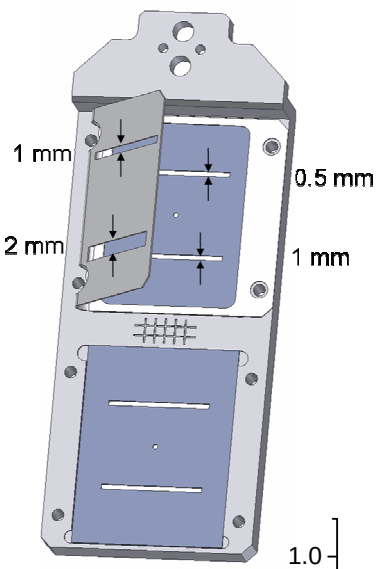






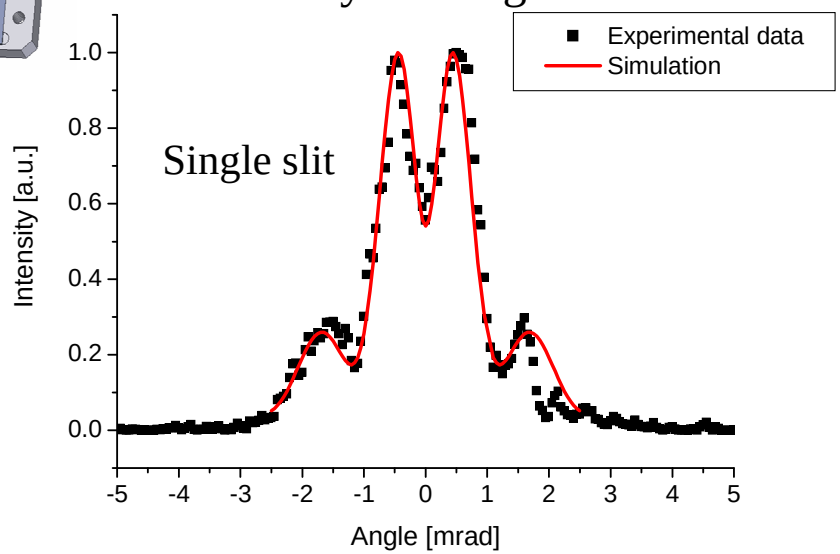
Optical Diffraction Radiation Interferometry (ODRI)

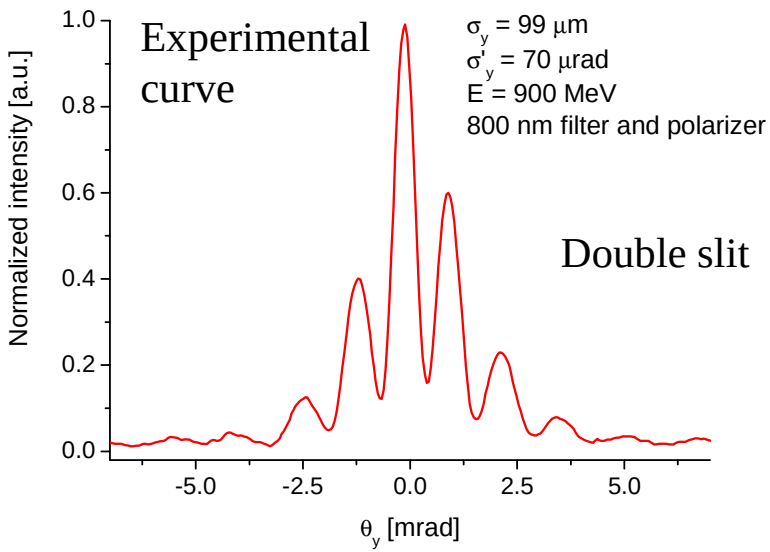
To reduce the synchrotron radiation background, we mounted a stainless steel shield in front of our ODR screen, with a larger cut in it.



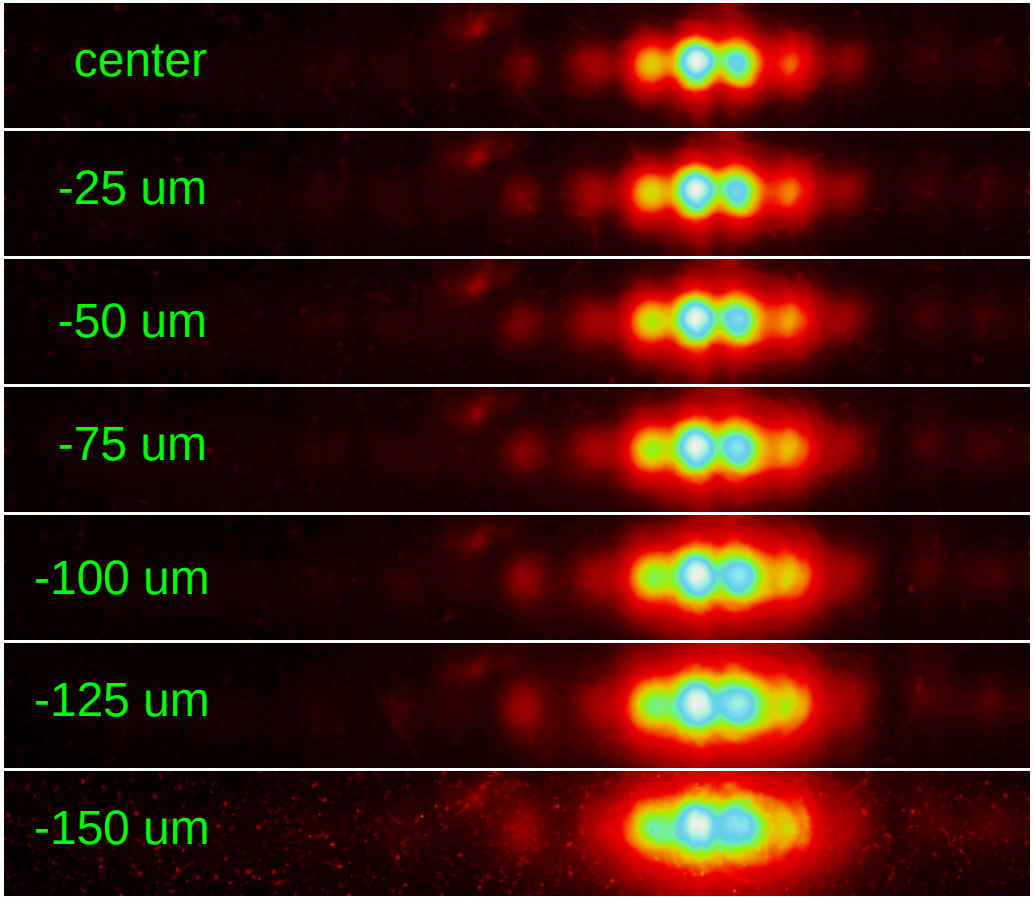
In the case of a wavelength of 800 nm and 1 GeV beam energy the 1 mm cut is not large enough to prevent the production of ODR in the forward direction, reflected by the screen and interfering with the backward ODR produced by the screen itself.

An ODR analogous of the Wartski interferometer used for OTR, with the difference that in this case the two interfering amplitudes are different in intensity and angular distribution

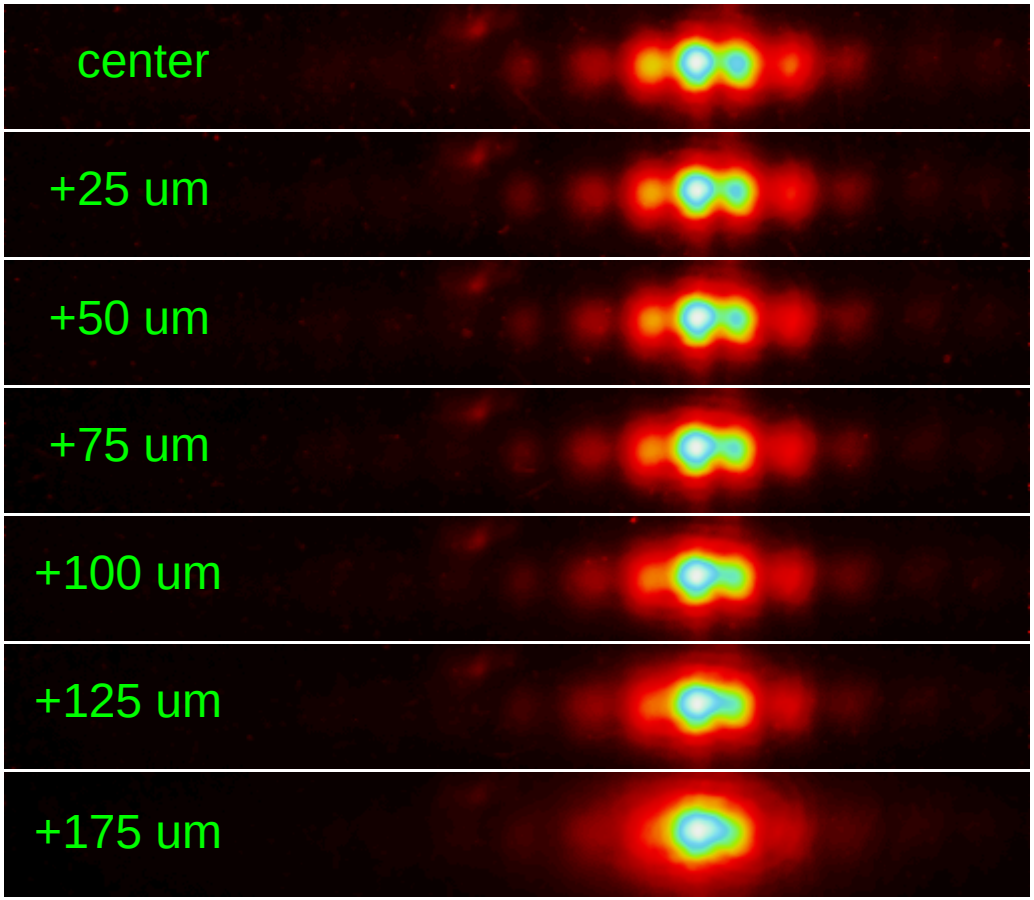




ODRI: Transverse Scan within the Slit (1)

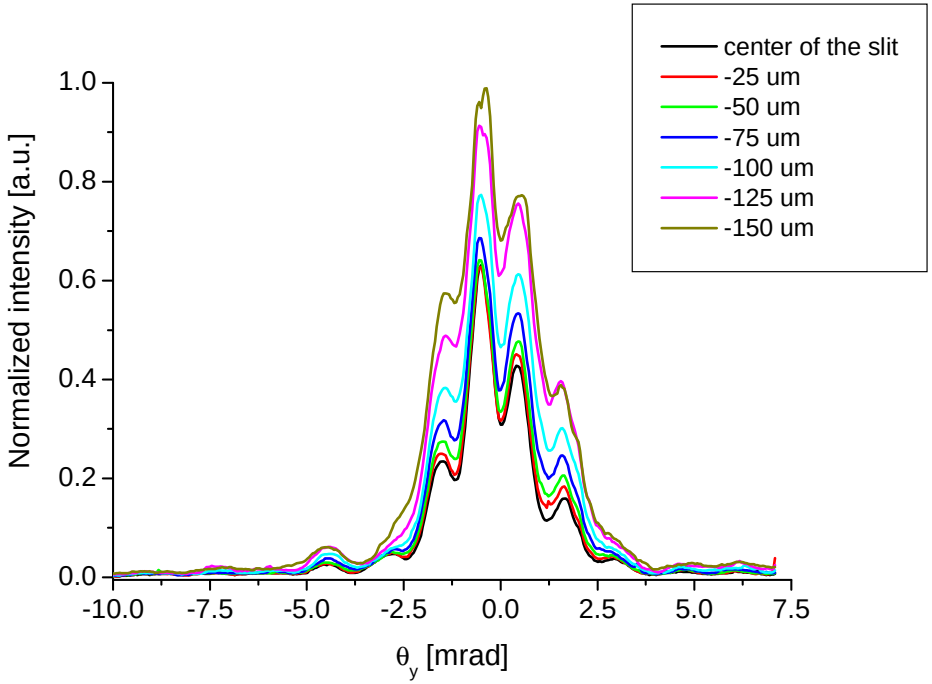


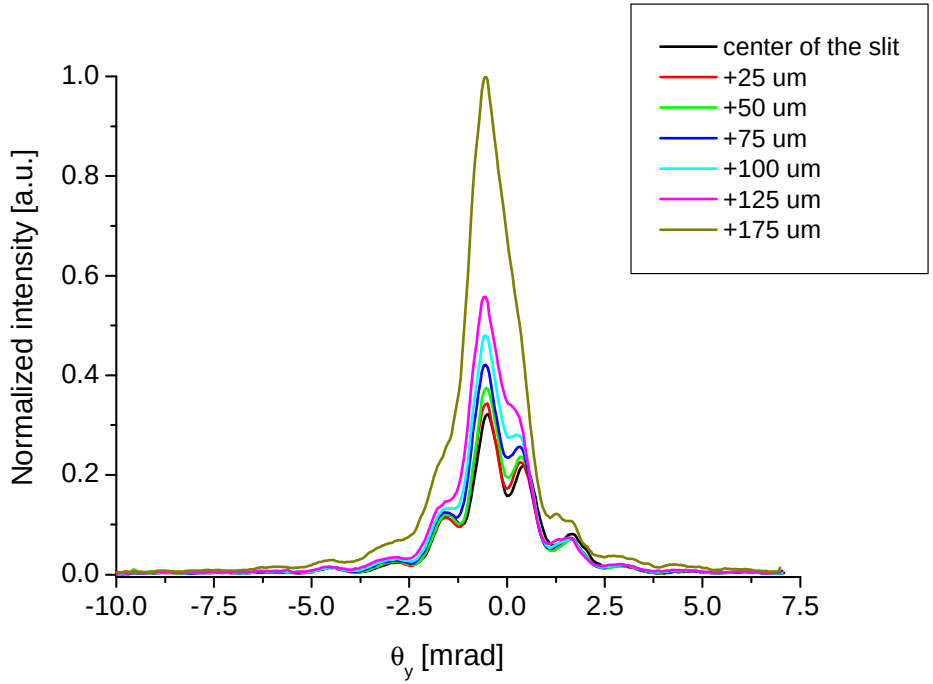
ODRI: Transverse Scan within the Slit (2)



ODRI Angular Distribution

0.8 nC, 13 pulse, 2 s, σ = 90 μm

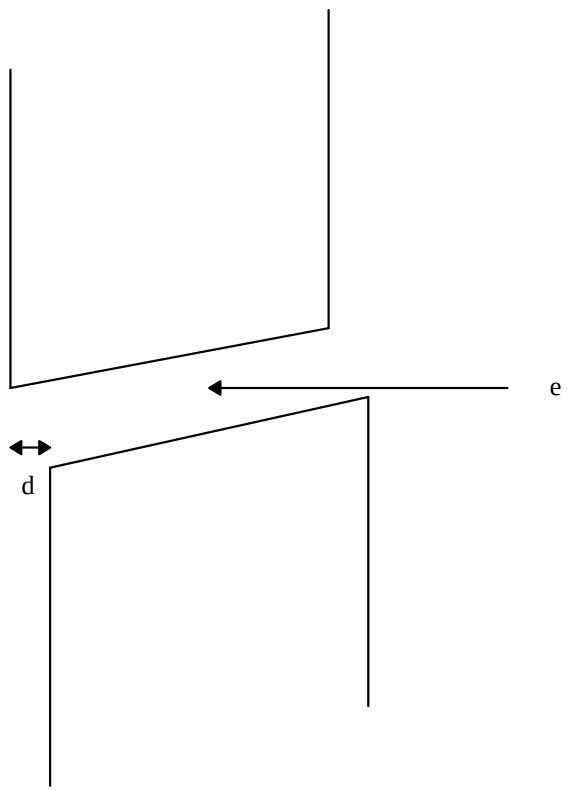




Strong differences going from one side to the other

The strong asymmetry shown by the ODR experimental distributions can only be explained as an interference effect between the two half planes of the slit.

Suppose that the two half planes are parallel but not perfectly coplanar, as in the picture, the field of a particle incident with angle α will be "reflected" by one



half plane earlier than by the other.
The phase difference between the two fields, in the approximation of d<<γλ and β ≈ 1, is

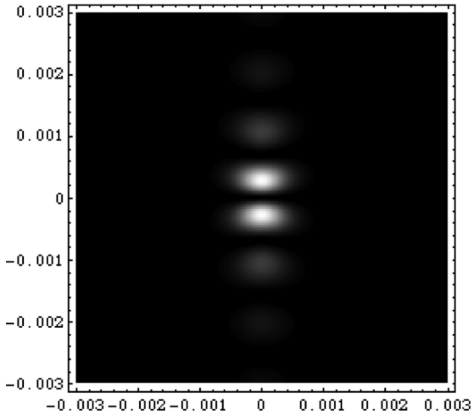
$$\phi = \frac{4\pi d}{\lambda \cos\alpha}$$

and the vertical polarization component of the total field becomes

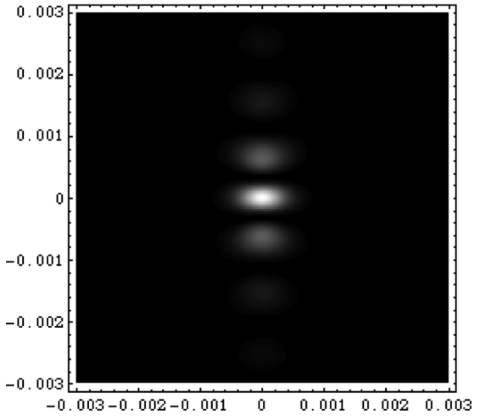
$$E_y = \frac{e^{-a(f-ik_y)}}{f-ik_y} - e^{i\phi}\frac{e^{-a(f+ik_y)}}{f+ik_y}$$

The effect of the phase factor is of preventing the perfect cancellation of the real part of the field amplitude in the interference effect, resulting in a “mixing” of the real and imaginary parts

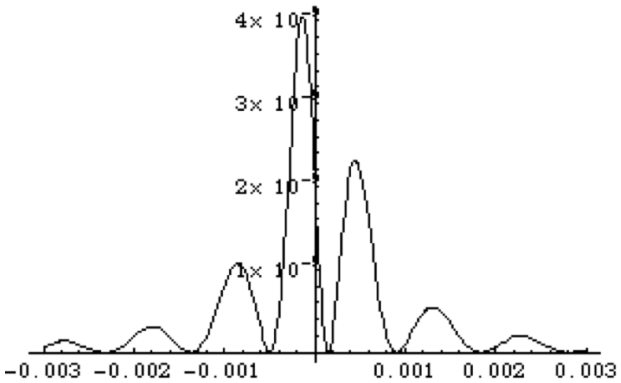
$\Phi=0$



$\Phi=\pi$



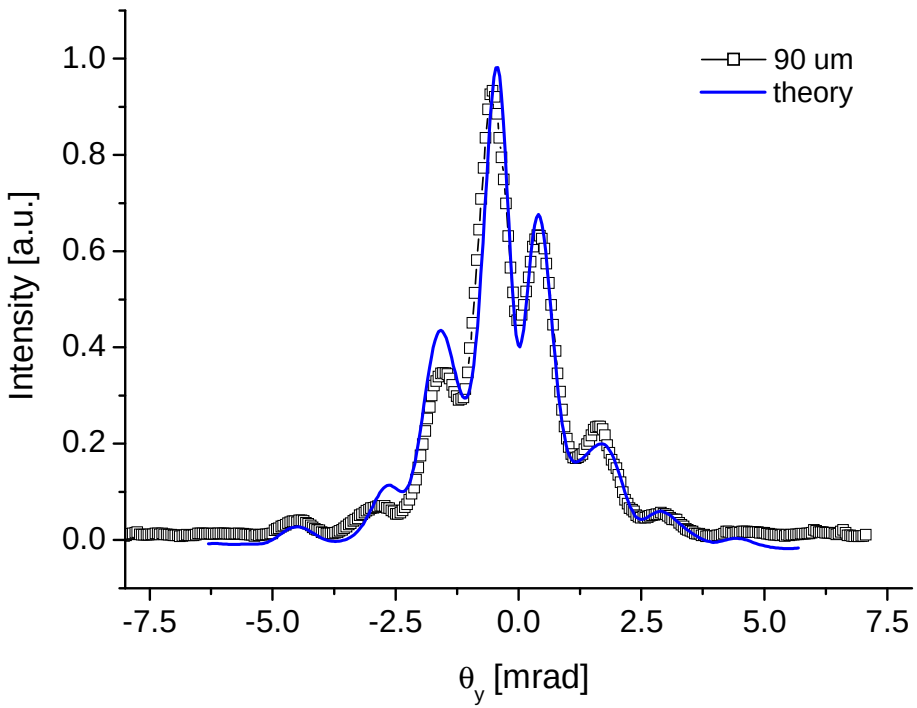
$\Phi=\pi/2$



For a wavelength of 800 nm and an incidence angle of 45º the phase difference of $\pi/2$ is given by a difference in planarity of d = 70 nm.

This means that

- this effect is not completely controllable and must enter in the general fit evaluation
- depending on the thickness of the aluminum layer, the relative phase can be changed as required



The theoretical curve has been calculated assuming the transverse beam size, the angular divergence and the energy known , as measured by fitting the OTR, and varying:

i) the phase difference between the two half planes of the 0.5 mm slit, which takes into account their non-coplanarity

ii) the misalignment between the two slits

iii) the phase difference between the two slits.

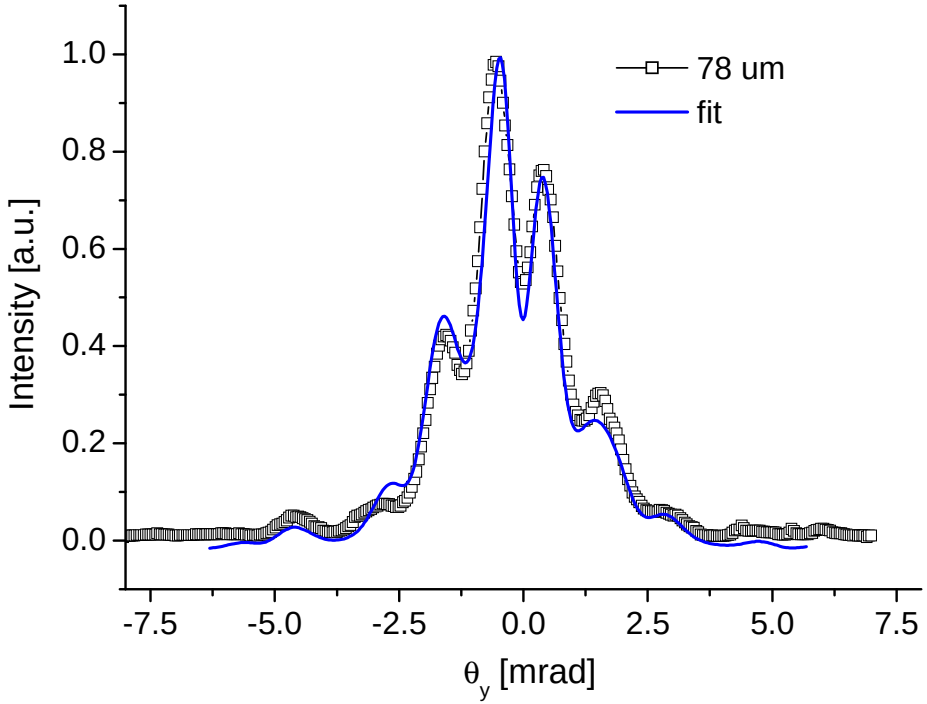
We assume a Gaussian distributed beam both in size and in angular divergence.

ODRI angular distribution for a smaller beam size

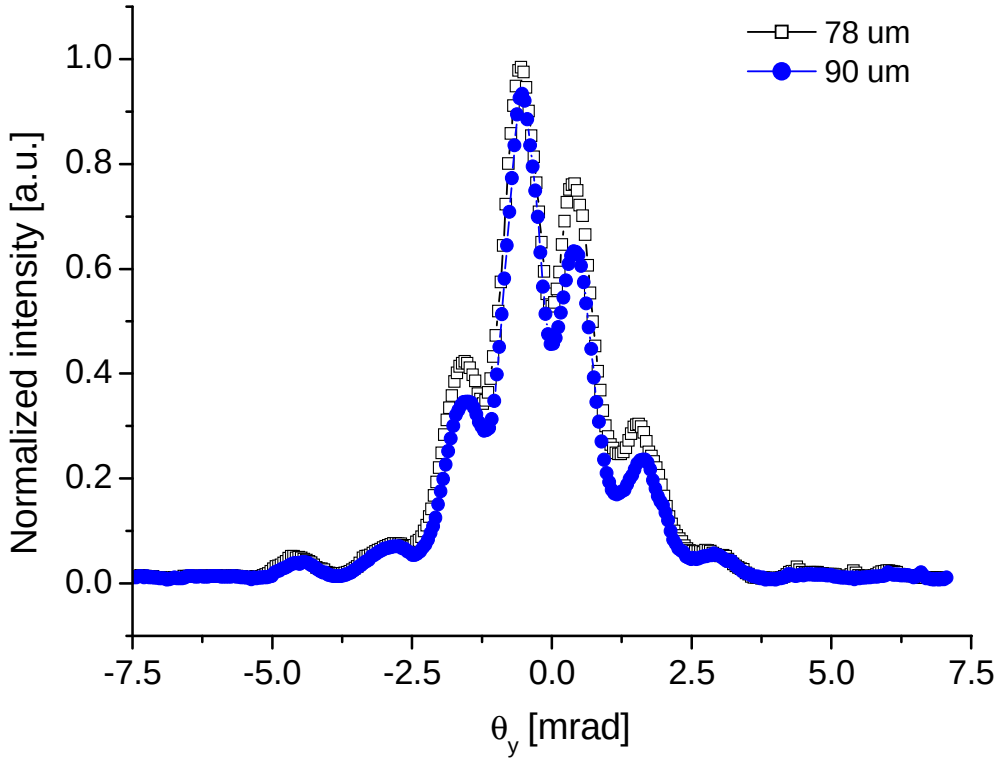
The scan has been repeated with a smaller transverse beam size

$$\sigma_y = (78 \pm 4)\ \mu m.$$

The ODRI angular distribution is compared with the theory assuming a misalignment between the two slits of 130 μm and a phase difference between the two half planes of the 0.5 mm slit corresponding to a misalignment of 70 nm.



Comparison between the ODRI angular distribution for different beam sizes



COTR & CODRI Evidence

The total radiation intensity emitted by a bunch of electrons is given by

$$I_{tot}(\omega) = I_{sp}(\omega)[N + N(N-1)F(\omega)]$$

in which I_{sp} is the intensity emitted by a single particle and $F(\omega)$ is the form factor of the bunch, defined as

$$F(\omega) = \left| \int_{-\infty}^{\infty} dz S(z) e^{i\frac{\omega}{c}z} \right|^2$$

with $S(z)$ the longitudinal density distribution of the bunch.

The form factor is typically different from zero for wavelengths equal or longer than the bunch length.

If part of the bunch emits coherently, then $I_{coh} = N^2_{coh} F(\lambda)$

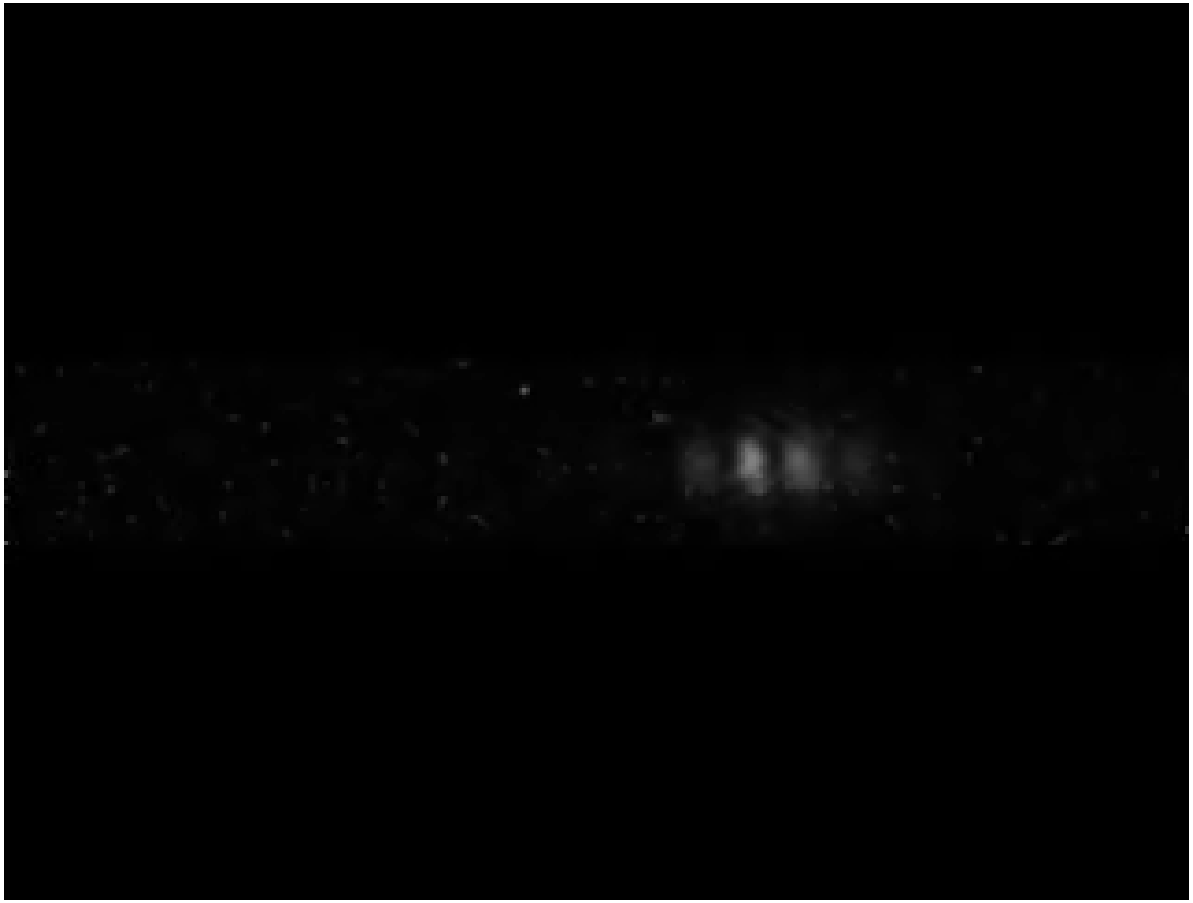
$$\Rightarrow I^{OTR}_{tot} = I^{OTR}_{sp}(\theta,\gamma)[Ne + N^2_{coh} F(\lambda)]$$

We expect a different behavior at 800 nm and 550 nm w.r.t. the OTR incoherent emission.

Coherent Optical Diffraction Radiation Interferometry (CODRI)

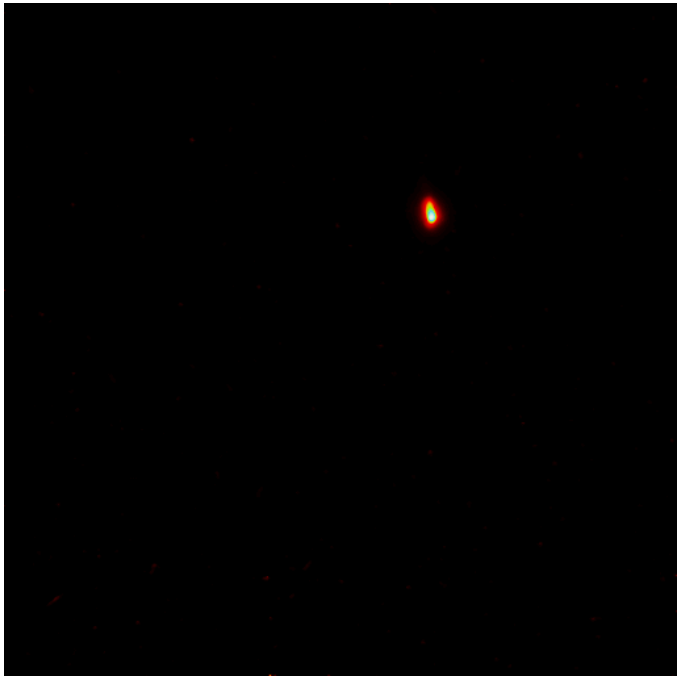
- Fluctuation shot by shot more than 50% of intensity
- Charge fluctuation was about 2%
- Total intensity greatly enhanced
- Big differences between 550 nm and 800 nm
- Angular distribution with single pulse even down to 0.3 nC (while more than 100 nC, integrated, in standard operation)!!!

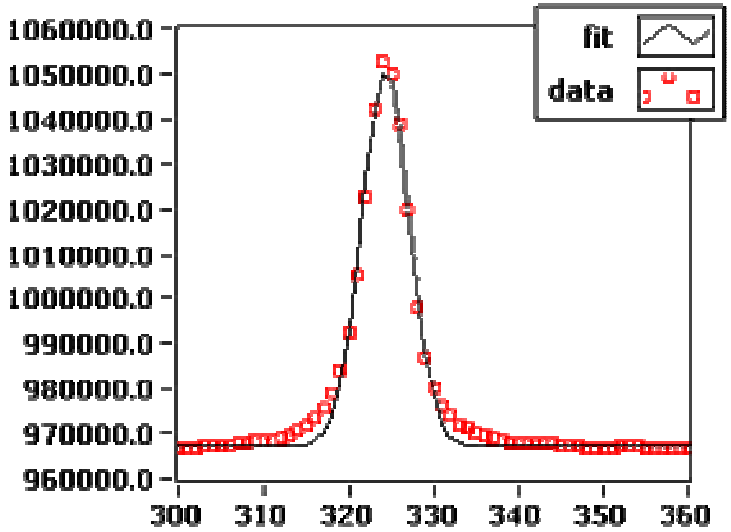
1 pulse
0.2 s



Beam @ the Beginning of the Shift

Thanks to N. Golubeva and V. Balandin

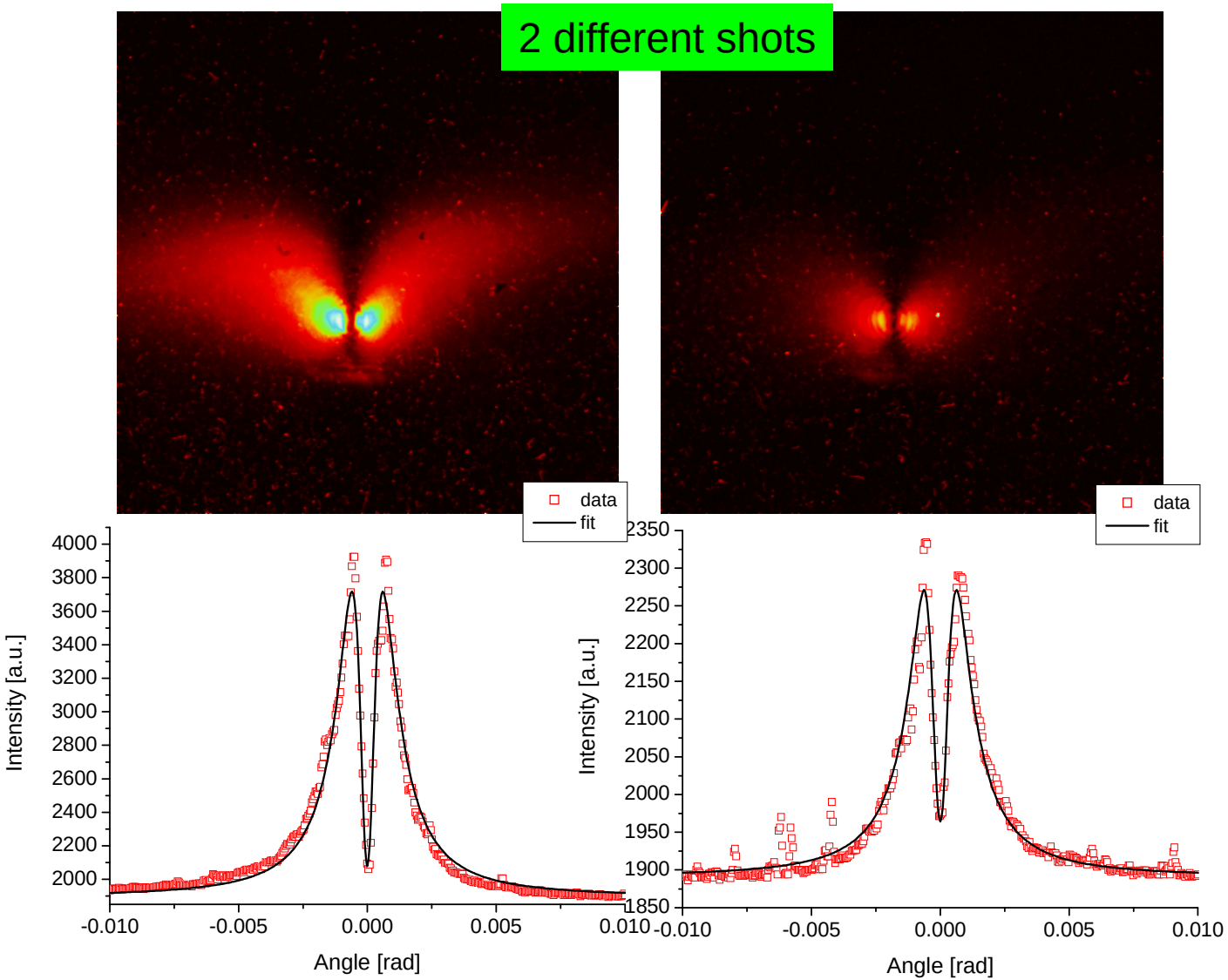




σ_y = (98 ± 3) μm

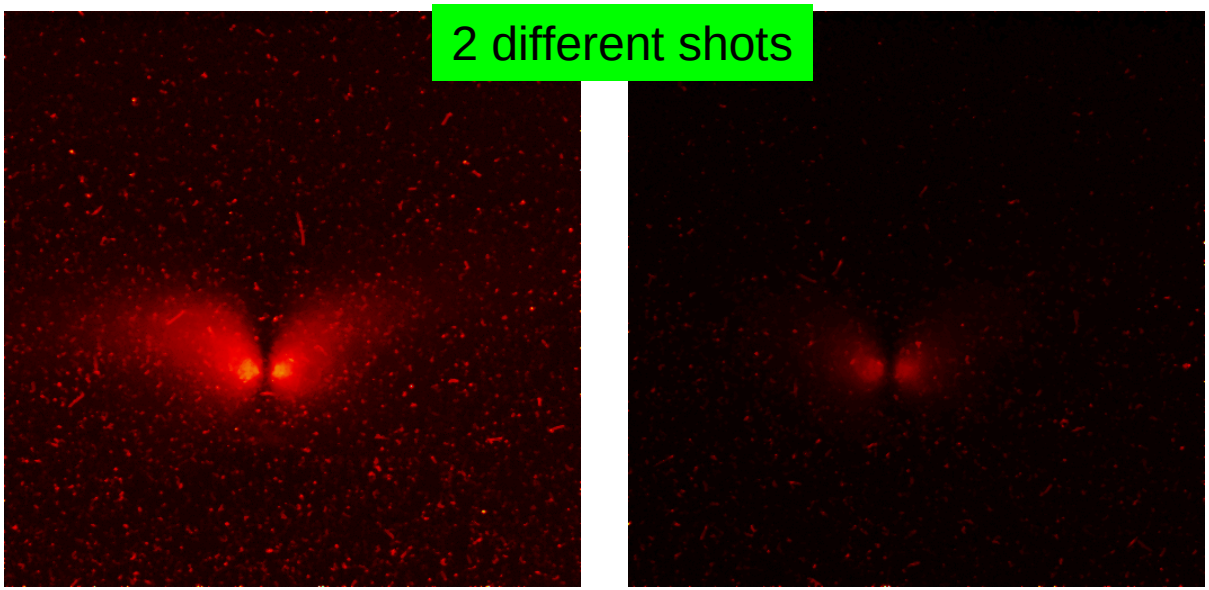
OTR angular distribution: 800 nm

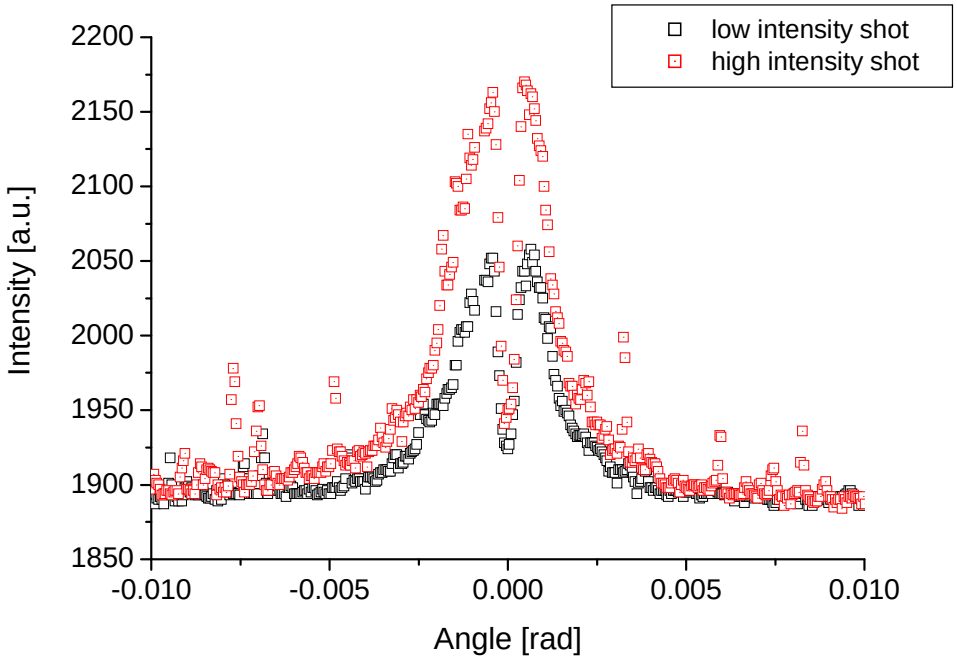
1 pulse, 5 Hz, 0.2 s, 0.8 nC



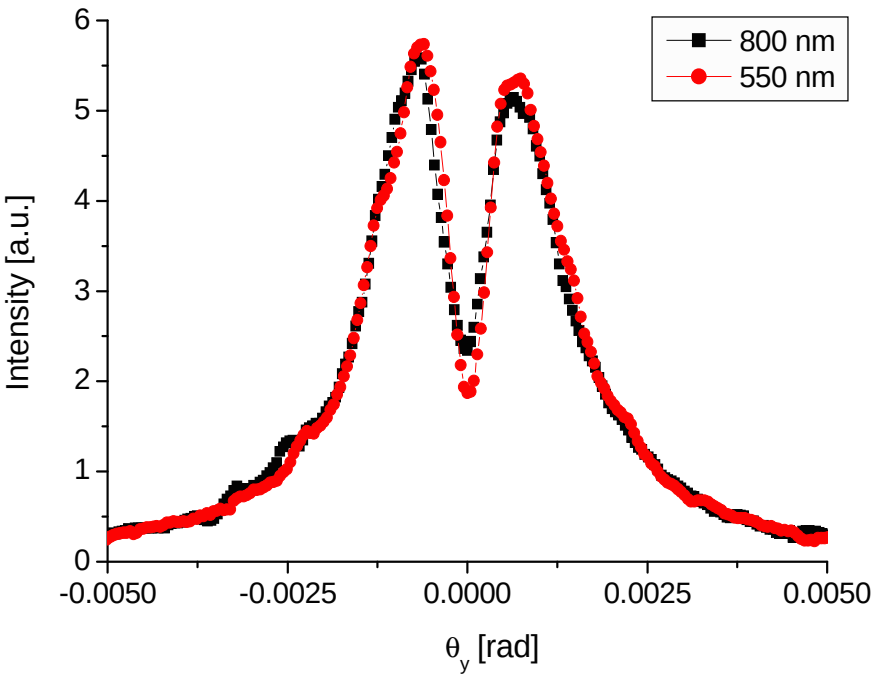
OTR angular distribution: 550 nm

1 pulse, 5 Hz, 0.2 s, 0.8 nC

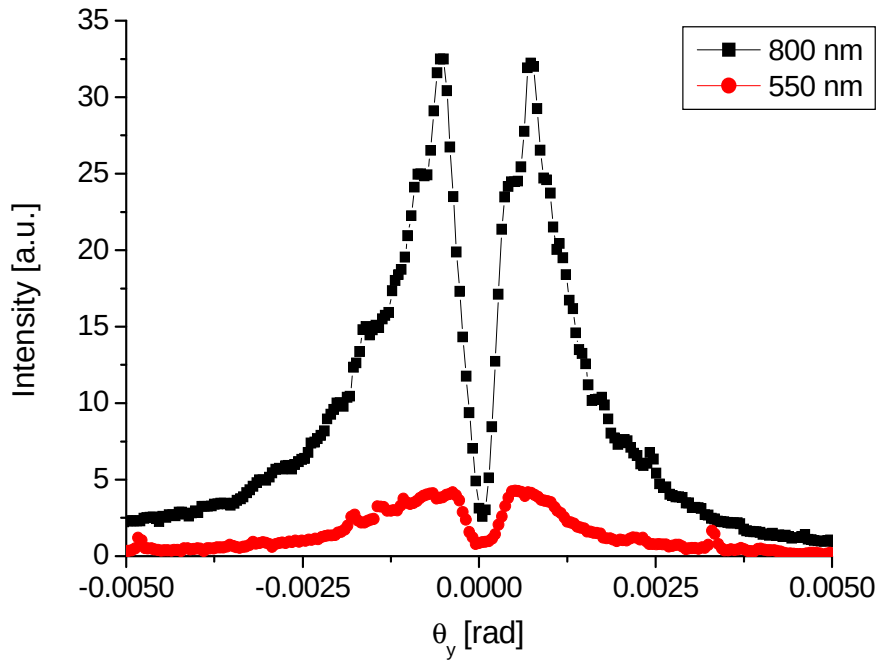




OTR & COTR



Incoherent emission

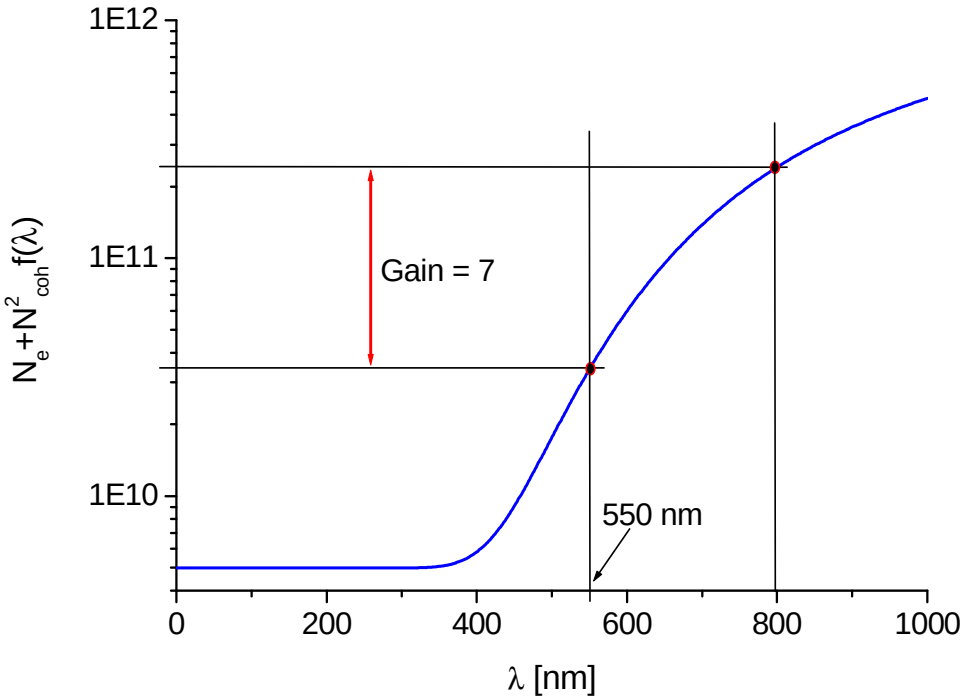


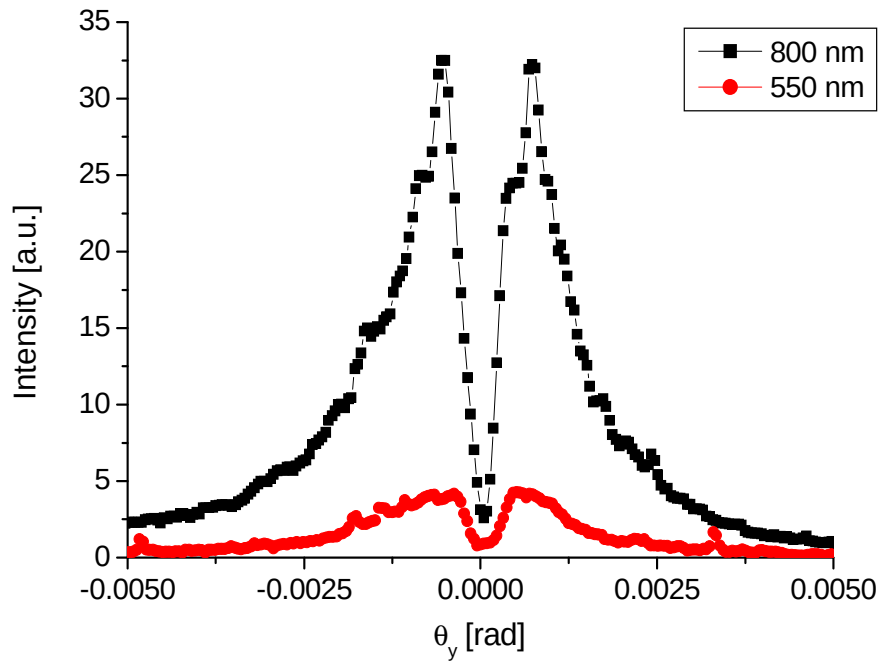
Coherent emission

0.8 nC
1 pulse
0.2 s

COTR @ 800 pC

Q=800 pC ➔ $N_e = 4.972*10^9$



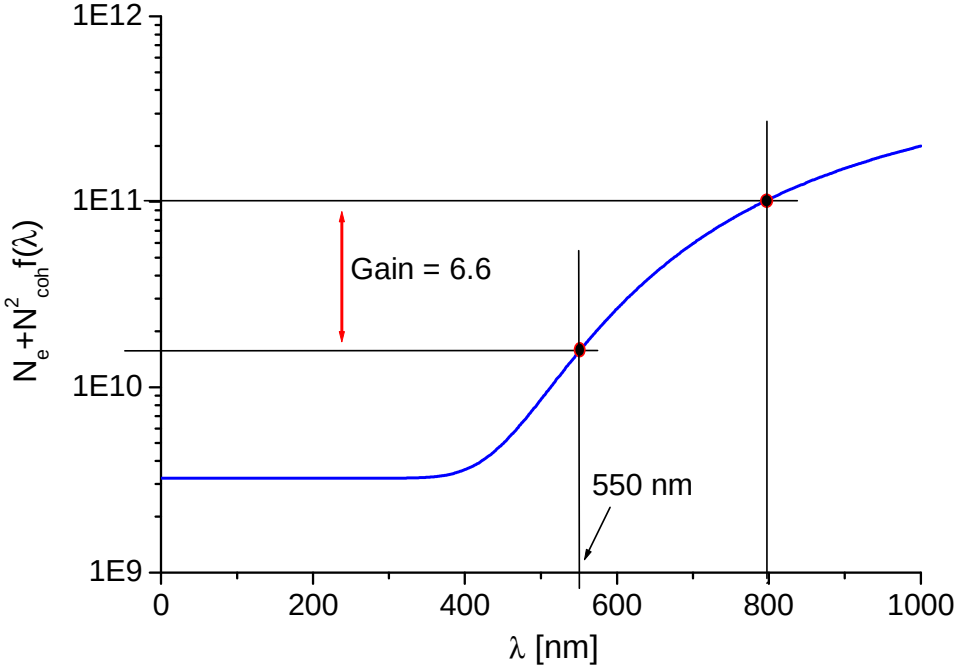


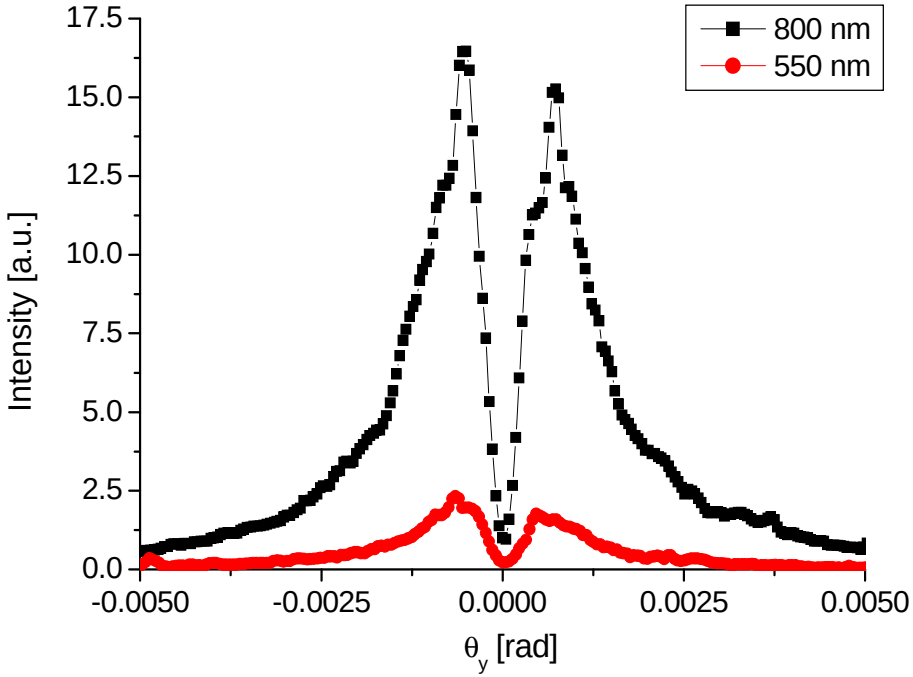
$$f(\lambda) \propto e^{-\left(\frac{\sigma_z}{\sqrt{2}\lambda}\right)^2}$$

with σ_z = 1.5 μm and $N_{coh} = 1.243*10^6$

COTR @ 520 pC

Q=520 pC ➔ $N_e = 3.232*10^9$

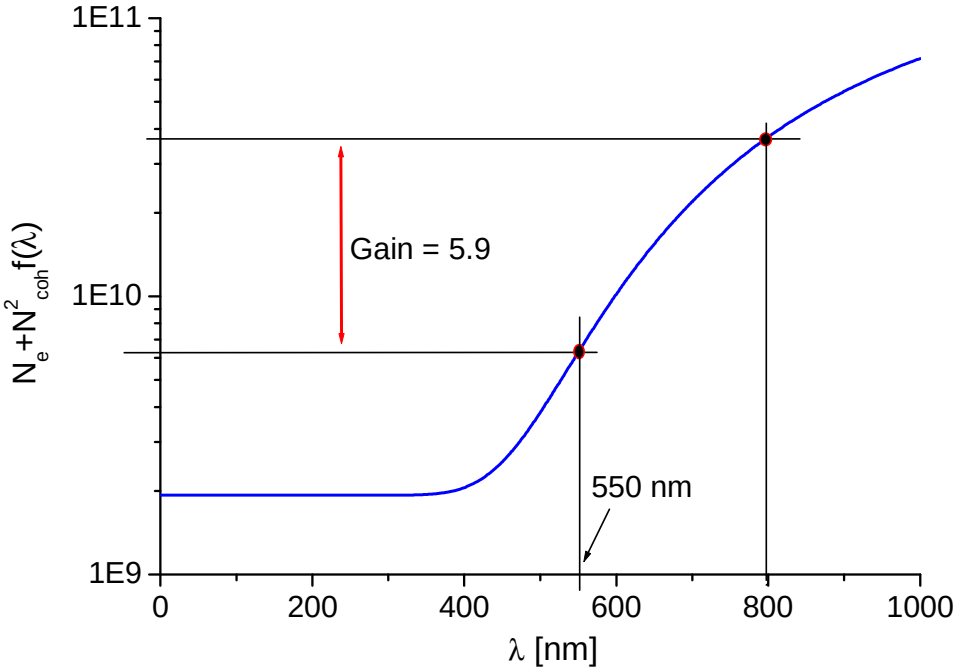


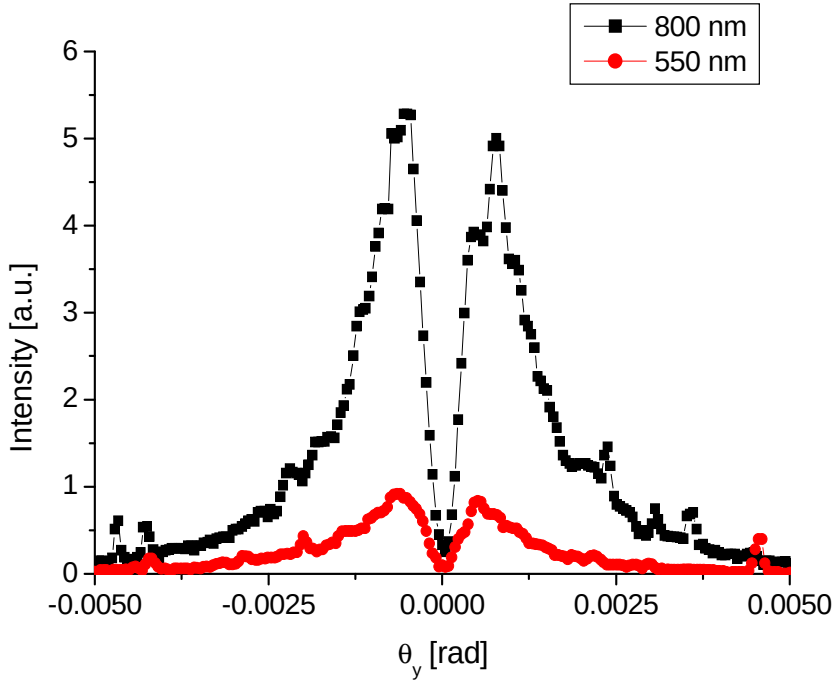


$N_{coh} = 8.08*10^5$

COTR @ 310 pC

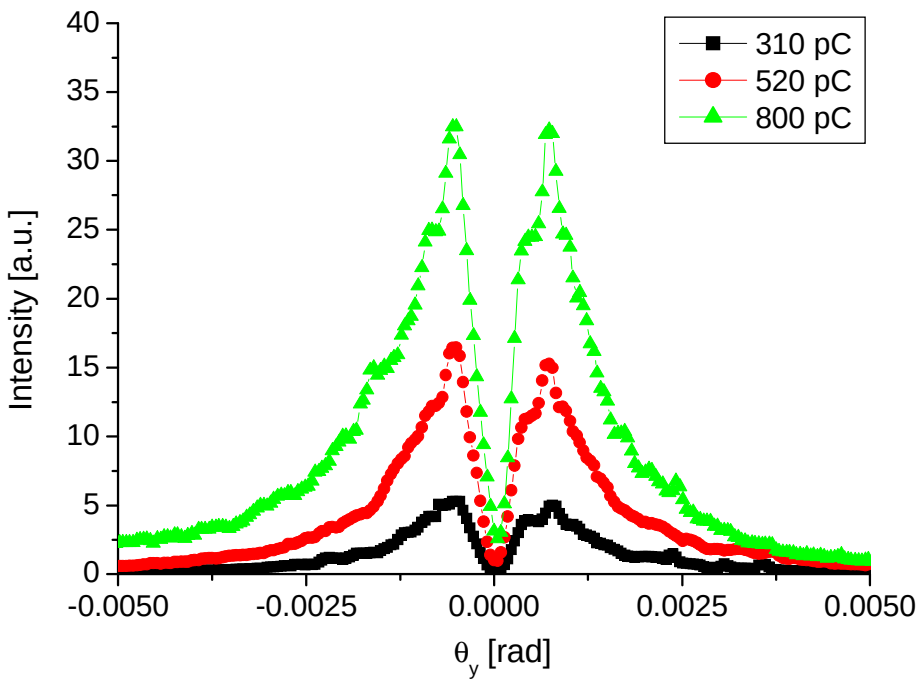
Q=310 pC ➔ $N_e = 1.927*10^9$



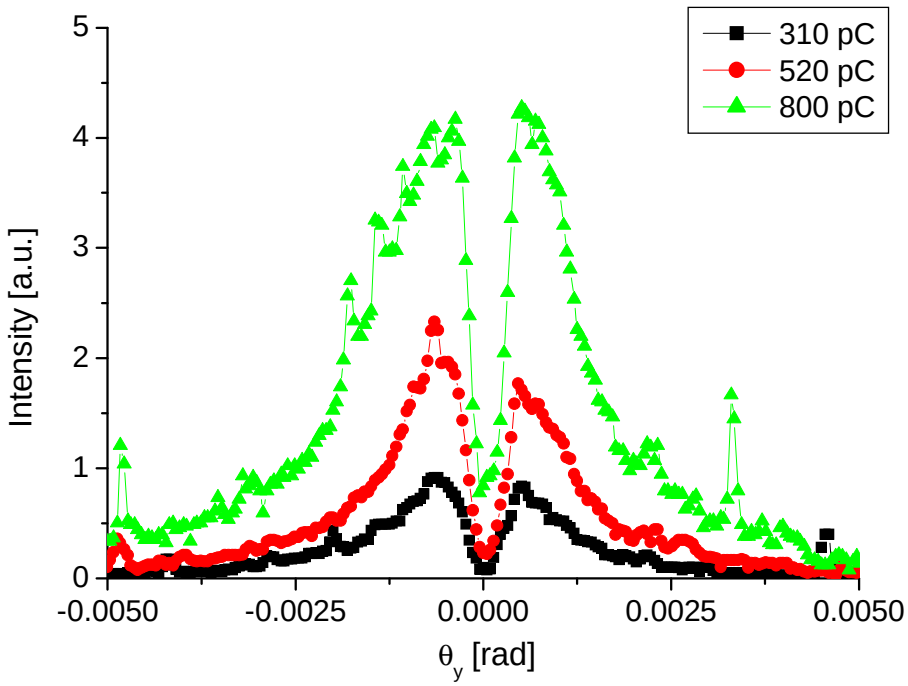


$N_{coh} = 4.817*10^5$

Dependence on Charge



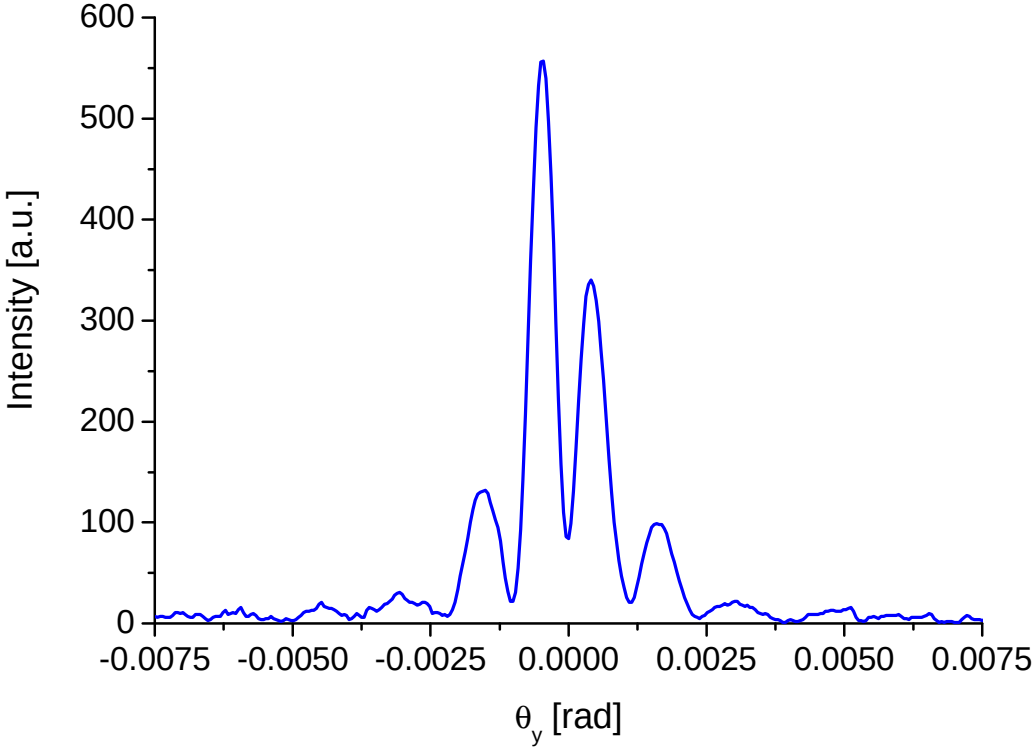
800 nm

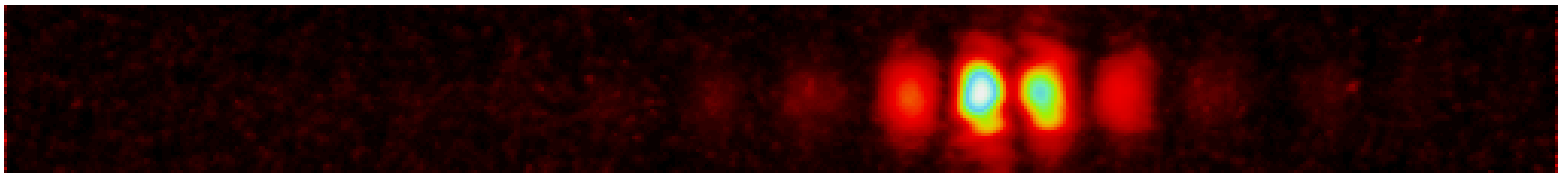


550 nm

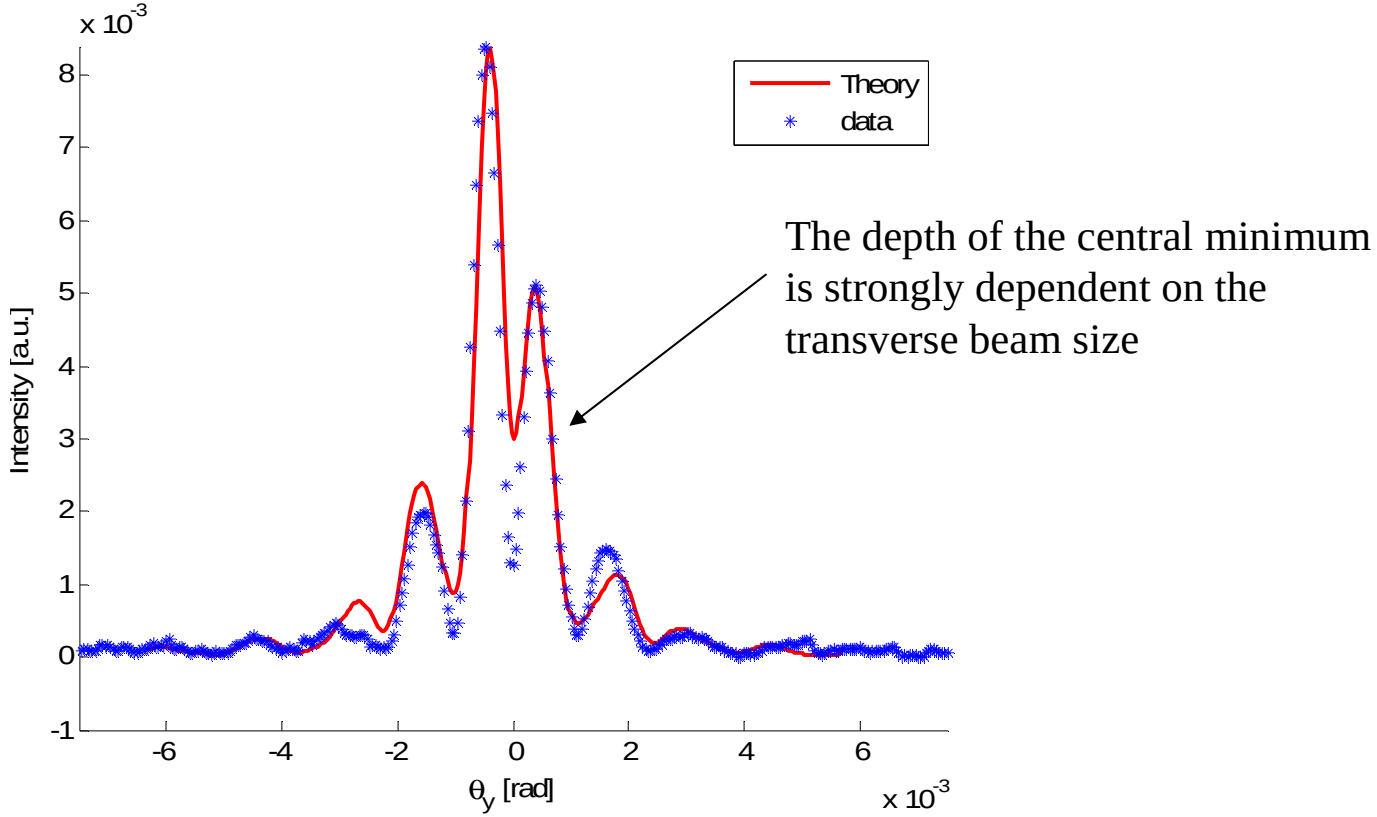
CODRI

10 pulses
0.8 nC
1 s





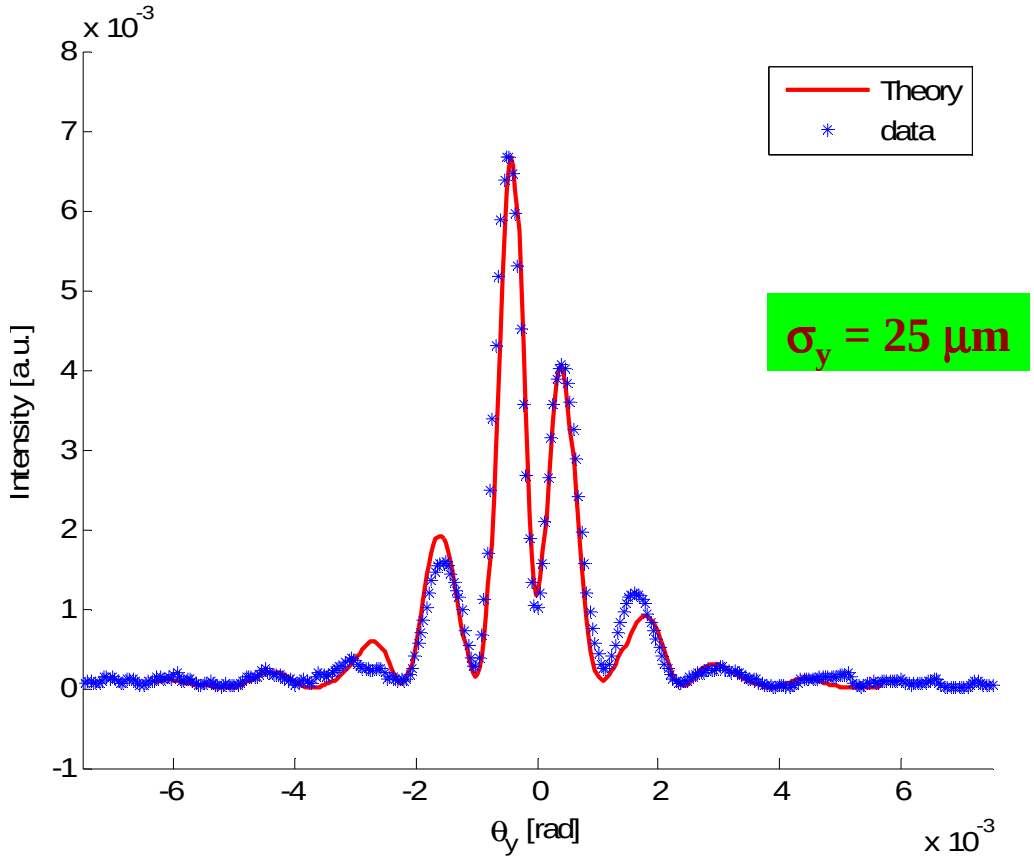
CODRI: A comparison with the theory (1)



The theoretical curve is calculated assuming the following measured parameters:

σ_y = 98 μm
σ'_y = 75 μrad
E = 860 MeV

CODRI: A comparison with the theory (2)



Conclusions

- DR is totally non-intercepting, allowing to fully characterize high density electron beams without loosing their quality
    - It could be interesting to apply this technique to high brightness machine (XFEL, ILC)

- The DR angular distribution is affected, in different ways, both by beam size and divergence allowing a single shot emittance measurement in a phase space waist

- DR angular distribution strongly depends on the target
    - Even machining imperfections can be controlled in order to study new effects

- We use Optical Diffraction Radiation Interferometry which, better than ODR, allows us to distinguish different effects

- Evidences of coherence effects in the optical wavelength range have been observed

- A preliminary analysis allowed us to quantify both the transverse and longitudinal part of the bunch which contributes to the Coherent Optical Emission

Acknowledgements

✓ We are grateful to Nina and Vladimir for their fundamental help in setting the machine up and for significant discussions

✓ Thanks to the shift crew

✓ Thanks to Ben Polzin

✓ Thanks to Luciano Cacciotti and Rossano Sorchetti

✓ THANKS FOR THE ATTENTION