9th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators

Optical Diffraction Radiation Interferometry as Electron Transverse Diagnostics

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The work has been supported by the European Comunity Infra-structure Activity under the FP6 “Structuring the European Reaserch Area” program (CARE, contract number RII3-CT-2003-506395)

OUTLINE

- For linear colliders and LINAC-driven FEL sources, the problem of measuring and controlling beam sizes is crucial
- High energy, high charge density beams require non-invasive diagnostics

LINEAR COLLIDERS & FEL

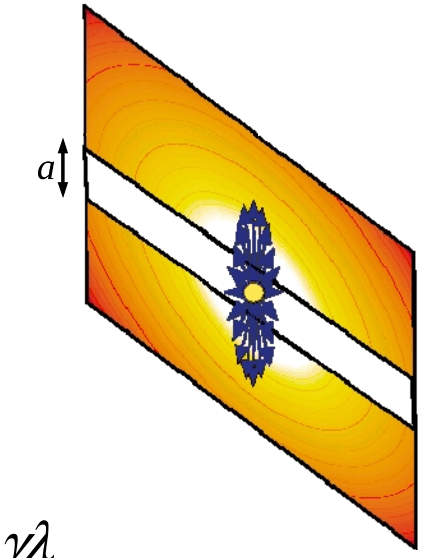
- beam sizes ≈ tens of μm
  - **Optical Diffraction Radiation as transverse diagnostics**
    - Position
    - Angular divergence
    - Transverse dimensions
    - Single shot emittance measurement

** **M. Castellano**, "*A New Non Intercepting Beam size Diagnostics Using Diffraction Radiation from a Slit*", Nucl. Instr. And Meth. in Phys. Res. A394, 275, (1997)

** **P. Karataev et al.**, "*Beam-Size Measurement with Optical Diffraction Radiation at KEK Accelerator Test Facility*", Phys. Rev. Lett. 93, 244802 (2004)

DIFFRACTION RADIATION

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



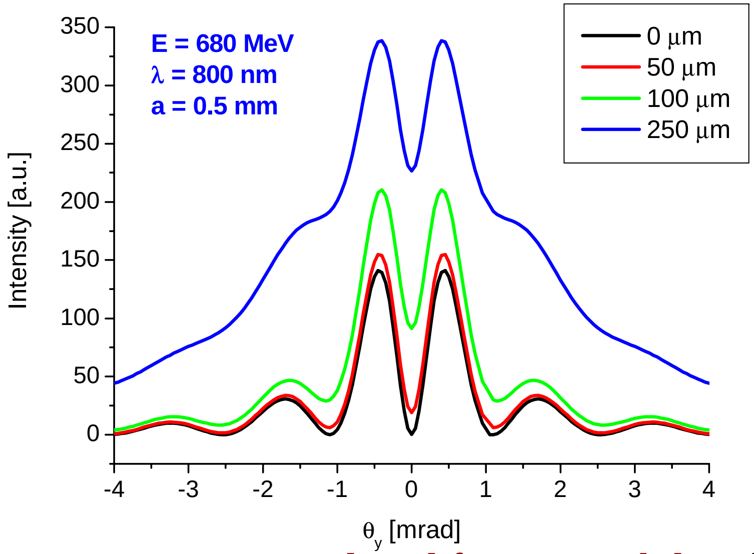
- The extension of the electromagnetic field of a relativistic particle is a flat circle of diameter $\gamma\lambda/2\pi$,

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

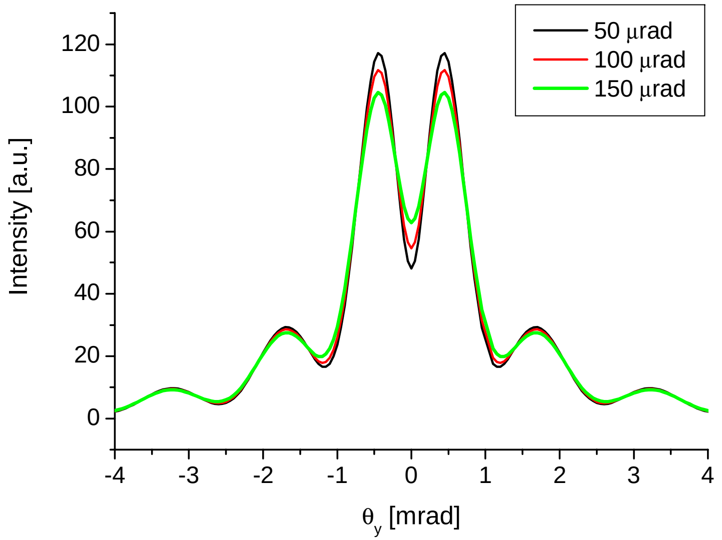
- DR impact parameter is $\frac{\gamma\lambda}{2\pi}$ ➔ if a $\begin{cases} >> \frac{\gamma\lambda}{2\pi} & \text{No radiation} \\ \cong \frac{\gamma\lambda}{2\pi} & \text{DR} \\ << \frac{\gamma\lambda}{2\pi} & \text{TR} \end{cases}$

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

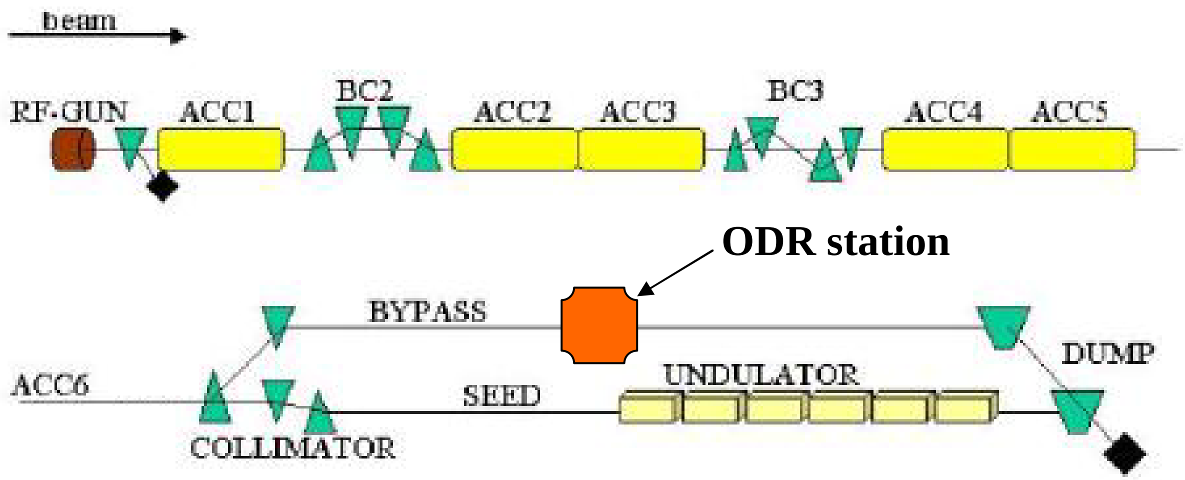
In 1997 M. Castellano suggested that the ***visibility*** of the interference fringes could be used to determine the transverse size of a bunch of electrons crossing the slit:

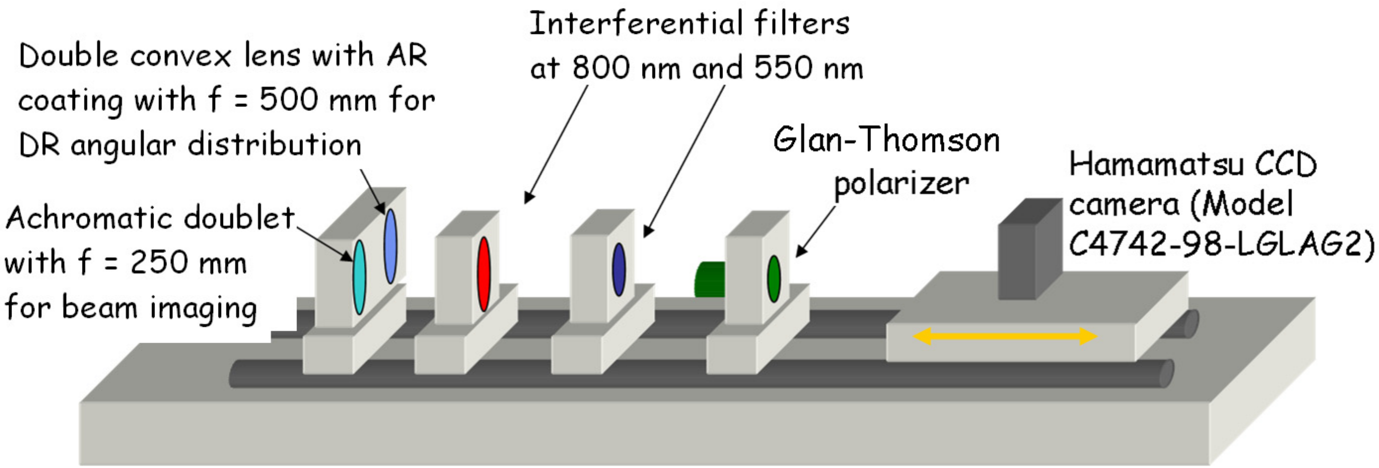


The beam angular divergence too gives rise to a reduced fringes visibility, but with a slightly different distribution, opening the way to a possible emittance single shot measurement with a very small perturbation of the beam.



ODR EXPERIMENT @ FLASH





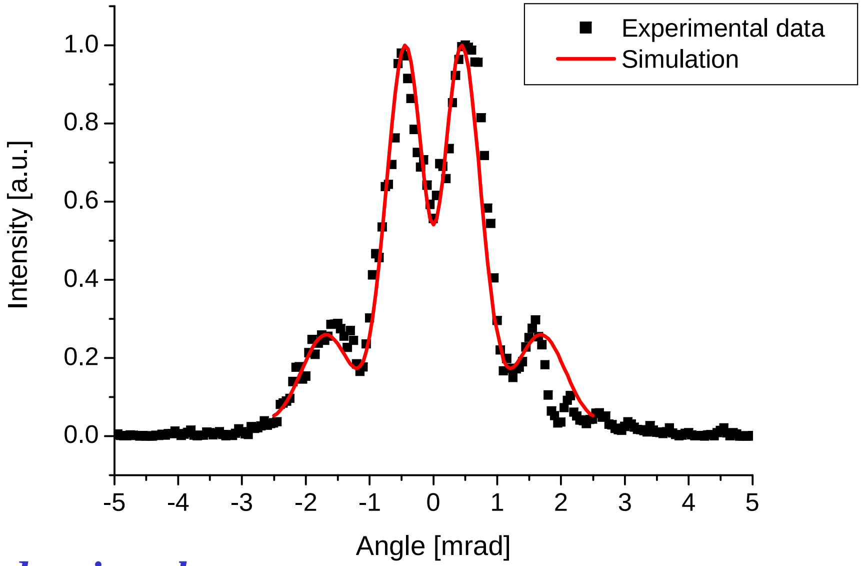
High Sensitivity Camera

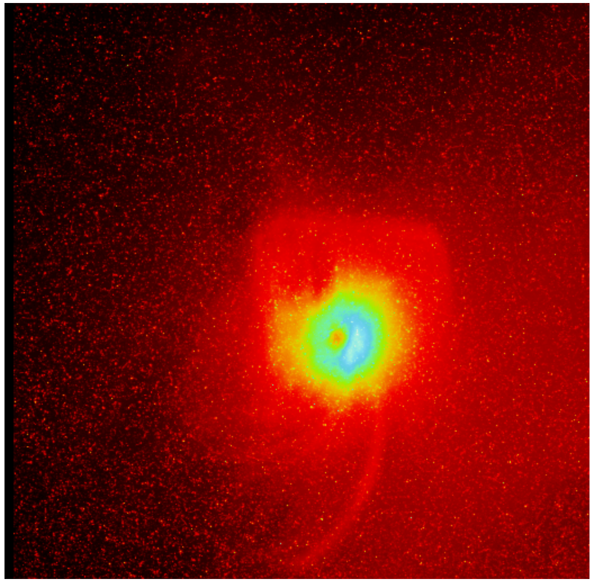
- High quantum efficiency
- Air Cooling -55˚C
- Long exposure time up to 2 hours

ODR ANGULAR DISTRIBUTION MEASUREMENT

The background has been a severe limitation (even at KEK) for a detailed and quantitative reconstruction of the beam parameters from the ODR angular distribution.
A big effort has been done in order to subtract the SR background via software.

This allowed us to prove a good qualitative agreement between the experimental data and the simulations.





Beam transport optimization

- 0.7 nC
- 25 bunches
- 2 s exposure time
- E_{beam} (nominal) = 680 MeV
- 800 nm filter and polarizer in

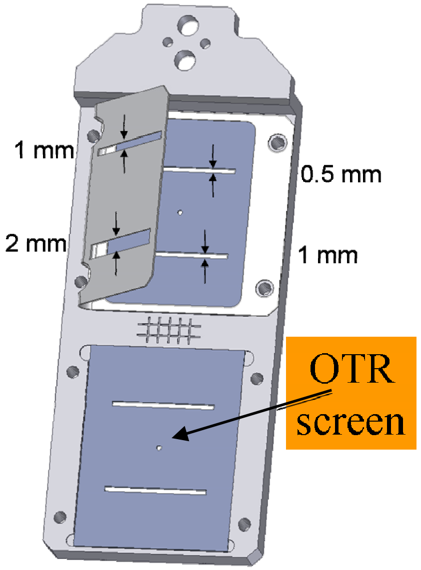
Simulation parameters:

- a = 0.5 mm
- Gaussian distributed beam
- σ_y = 80 μm
- σ'_y = 125 μrad
- E_{beam} = 610 MeV

E. Chiadroni et al.,
Non-intercepting electron beam transverse diagnostics with optical diffraction radiation at the DESY FLASH facility
NIM B 266 (2008) 3789–3796

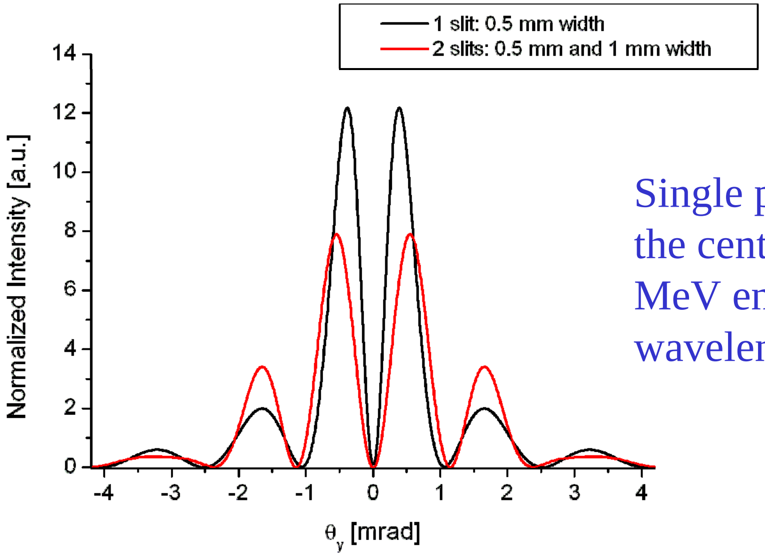
OPTICAL DIFFRACTION RADIATION INTERFEROMENTRY (ODRI)

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



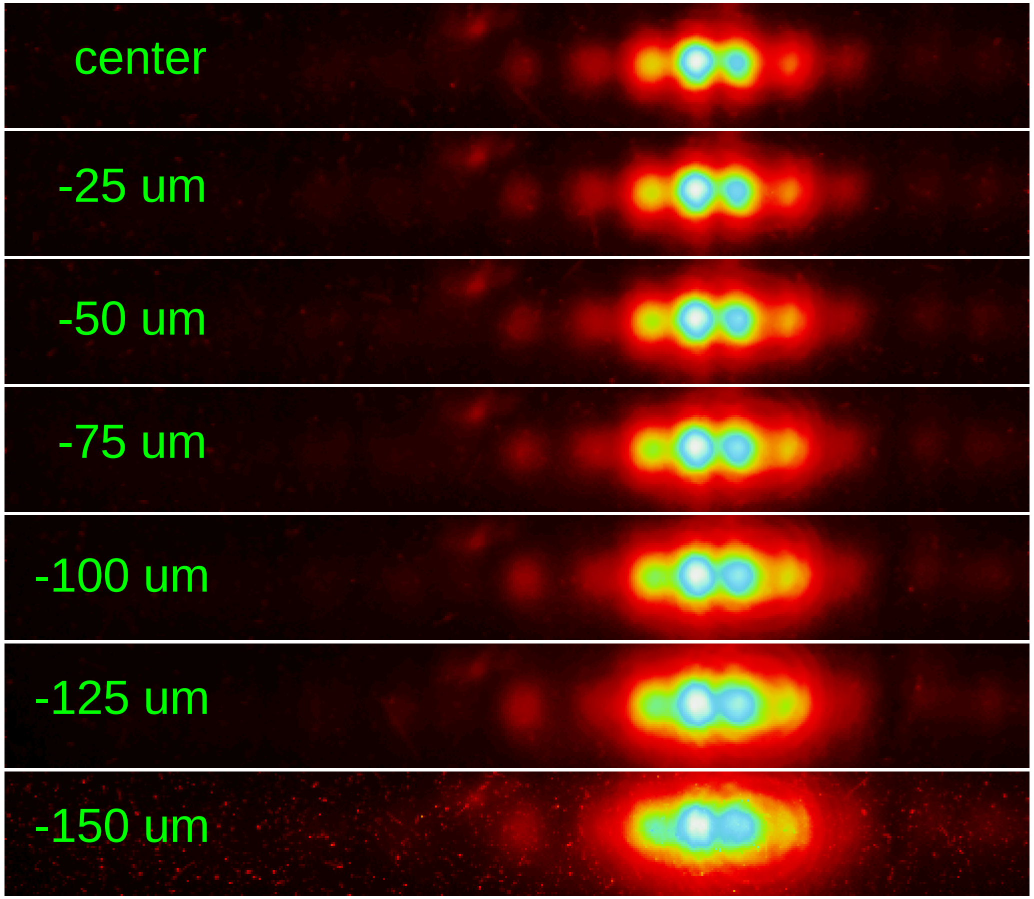
In the case of a wavelength of 800 nm and 1 GeV beam energy the 1 mm cut is not large enough to prevent the production of ODR in the forward direction, reflected by the screen and interfering with the backward ODR produced by the screen itself.

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

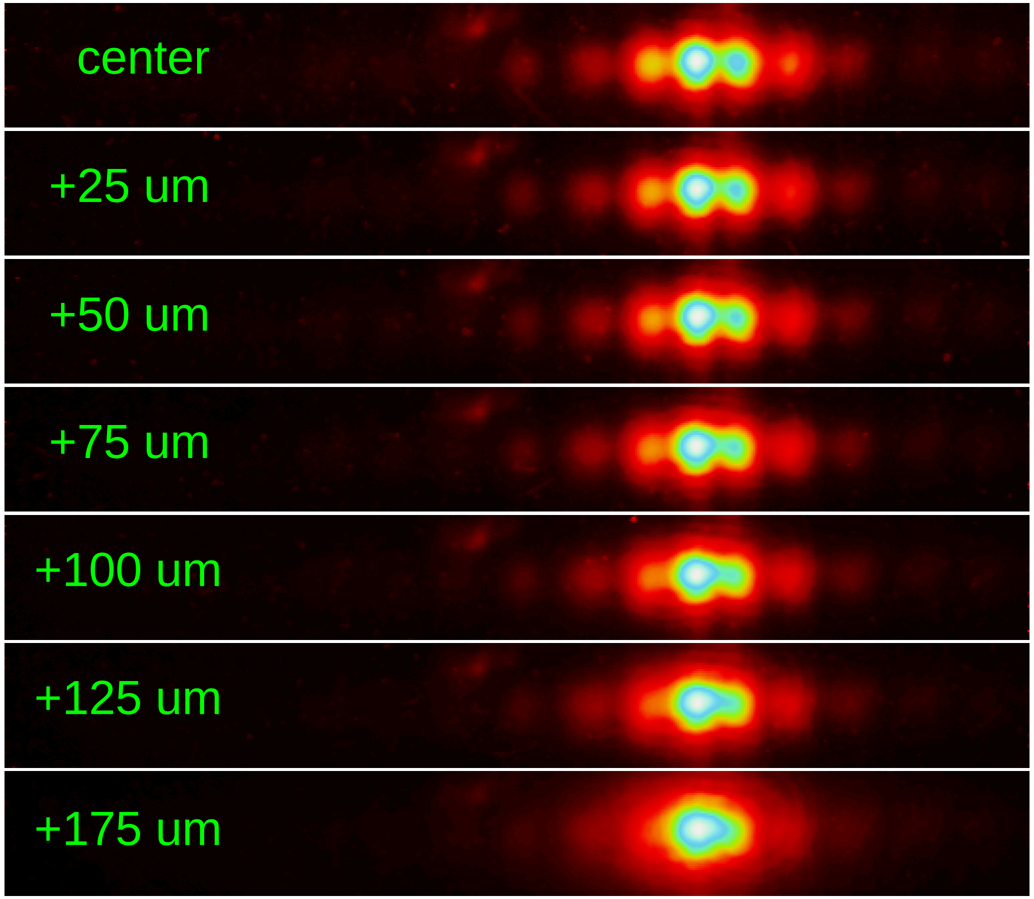


Single particle going through the center of both slits with 900 MeV energy and 800 nm wavelength

ODRI: Transverse Scan within the Slit (1)

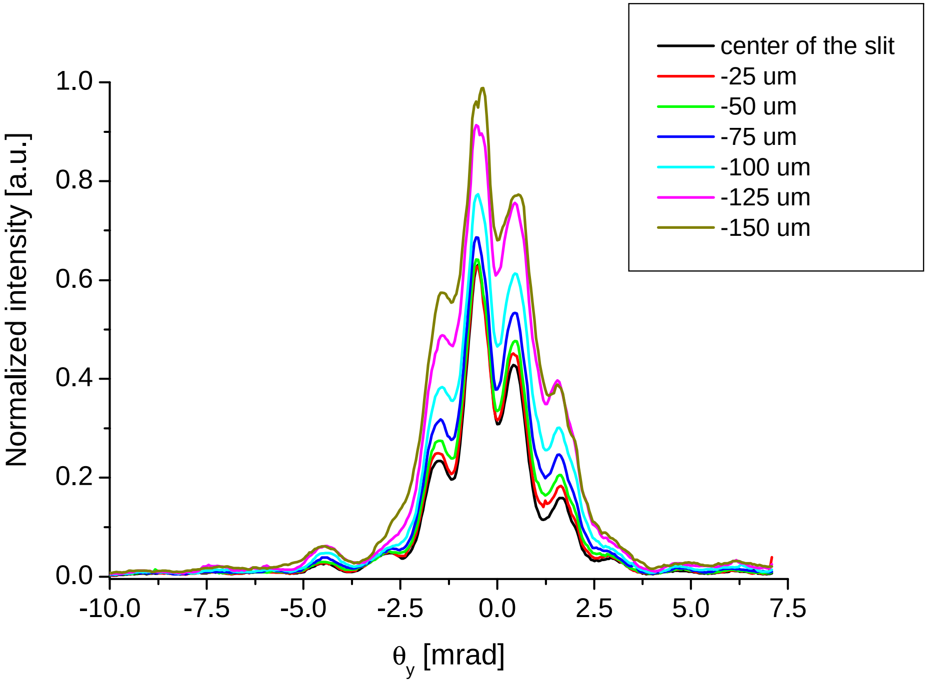


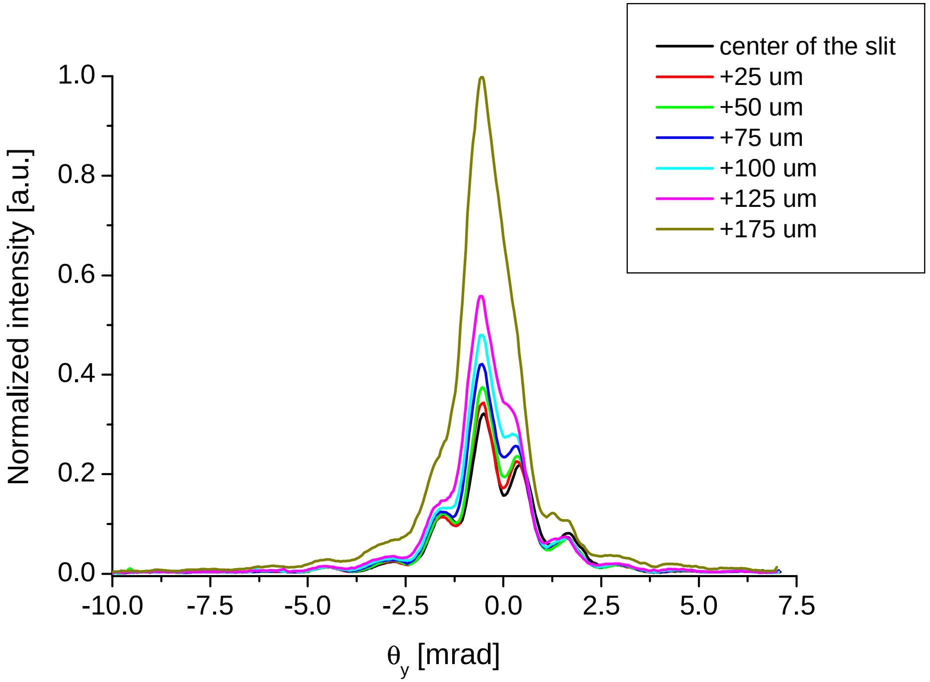
ODRI: Transverse Scan within the Slit (2)



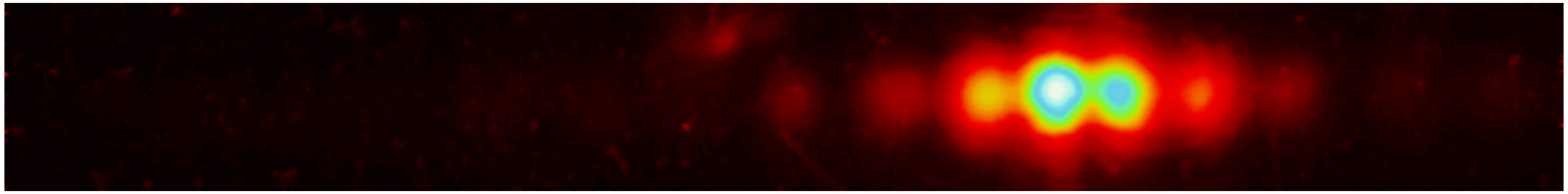
ODRI: Transverse Scan within the Slit (3)

0.8 nC, 13 pulses, 2 s

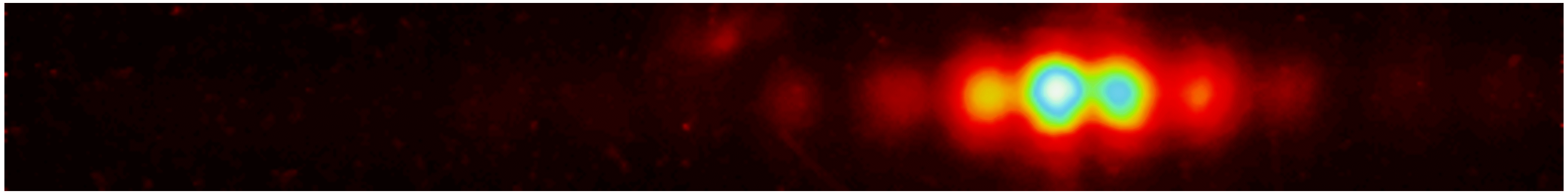


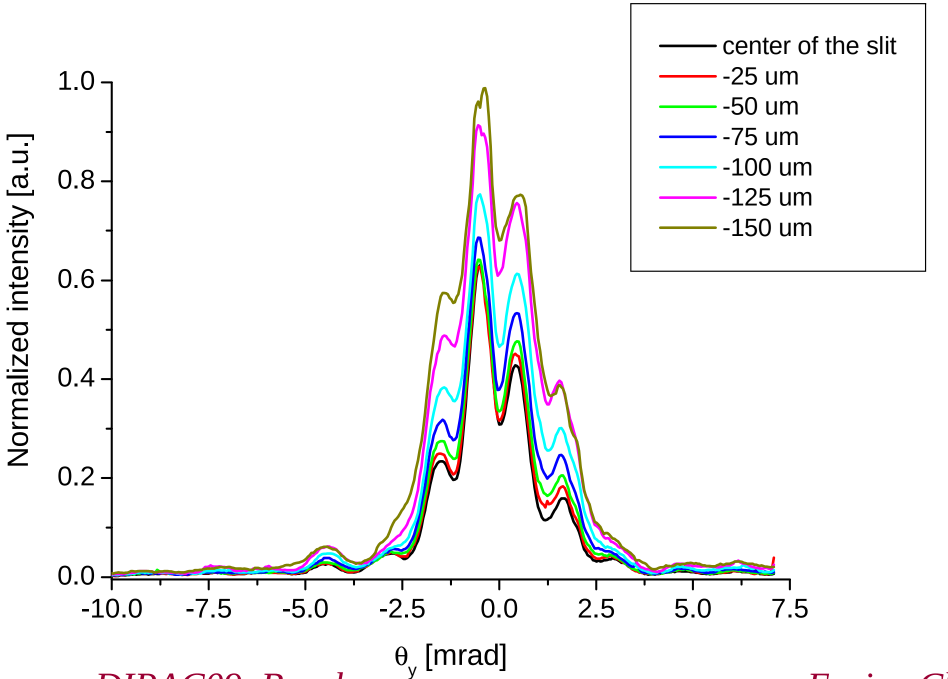


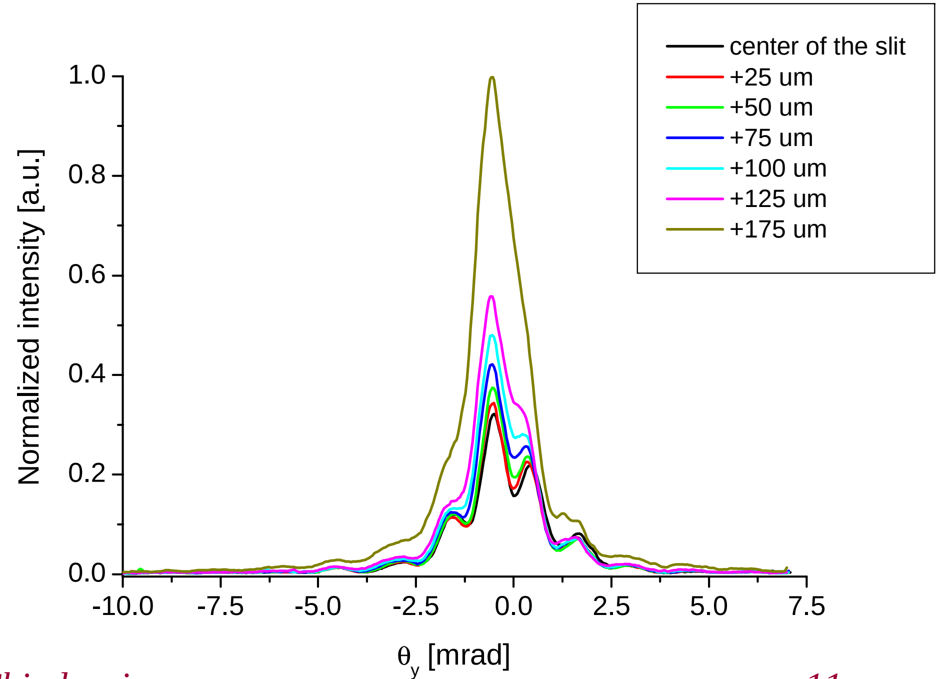
ODRI: Transverse Scan within the Slit



0.8 nC, 13 pulses, 2 s

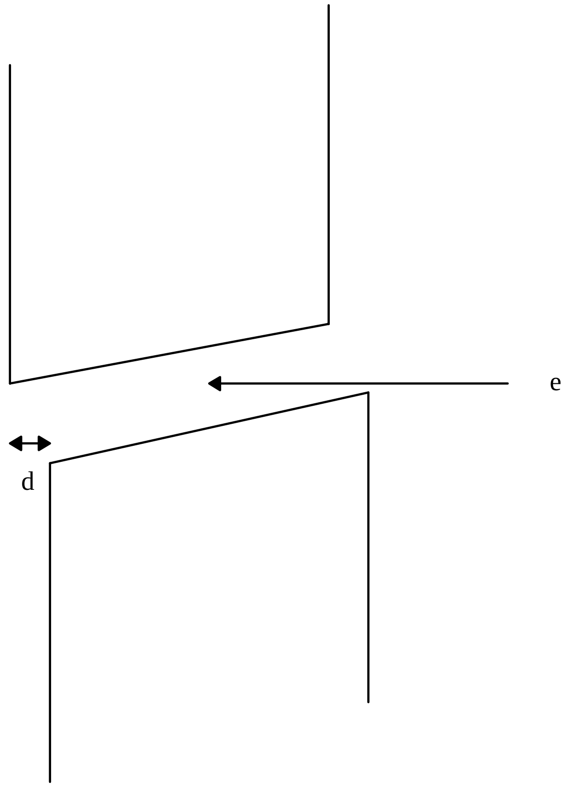






The strong asymmetry shown by the ODR experimental distributions can only be explained by considering the interference effects between the two half planes.

Suppose that the two half planes are parallel but not perfectly coplanar, 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

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

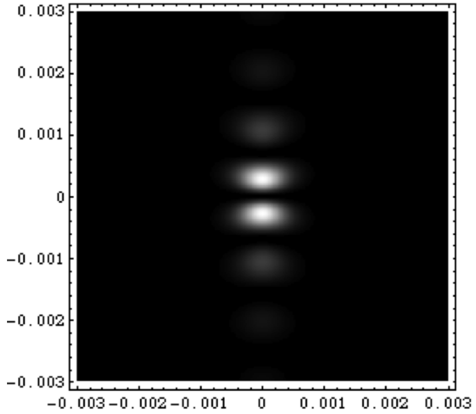
and the vertical polarization component of the total field becomes

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

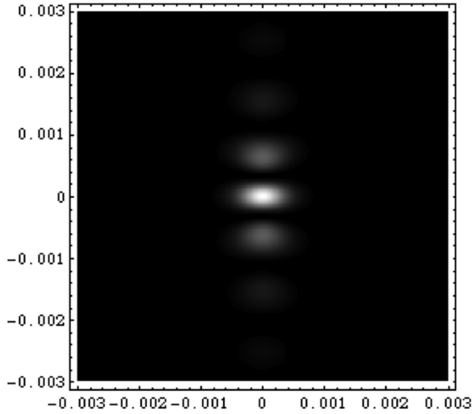
For a wavelength of 800 nm and an incidence angle of 45º the phase difference of π/2 is given by a difference in planarity of d = 70 nm.

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

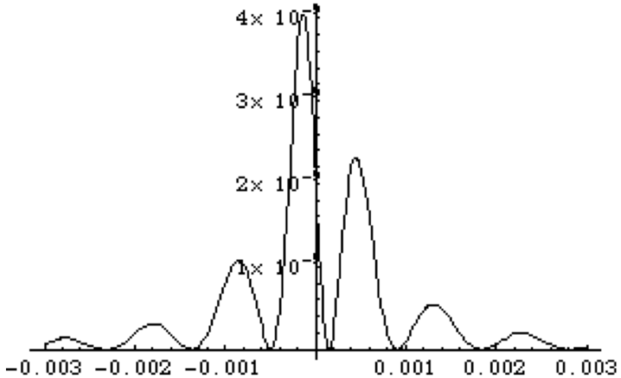
$\Phi=0$



$\Phi=\pi$

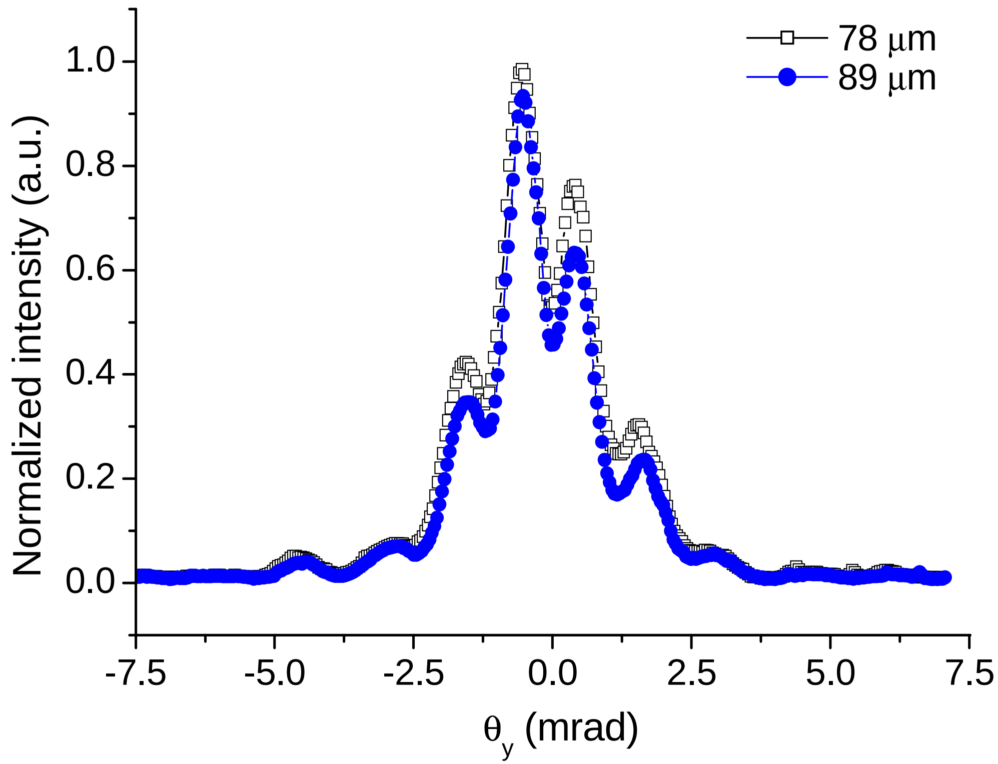


$\Phi=\pi/2$

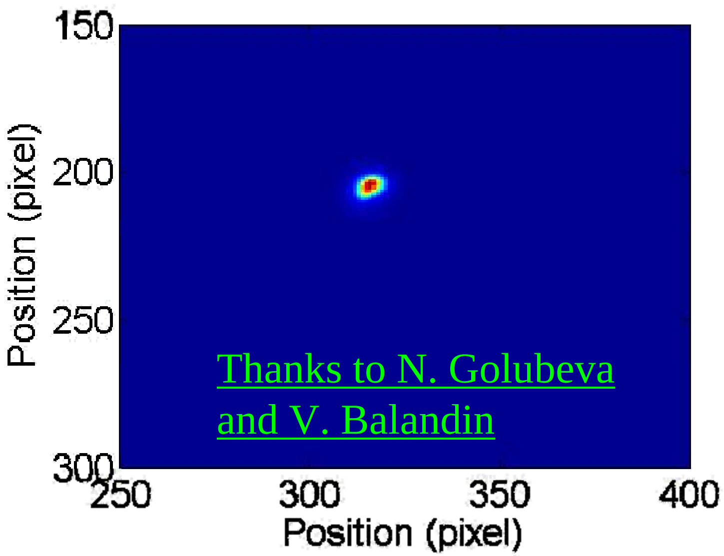


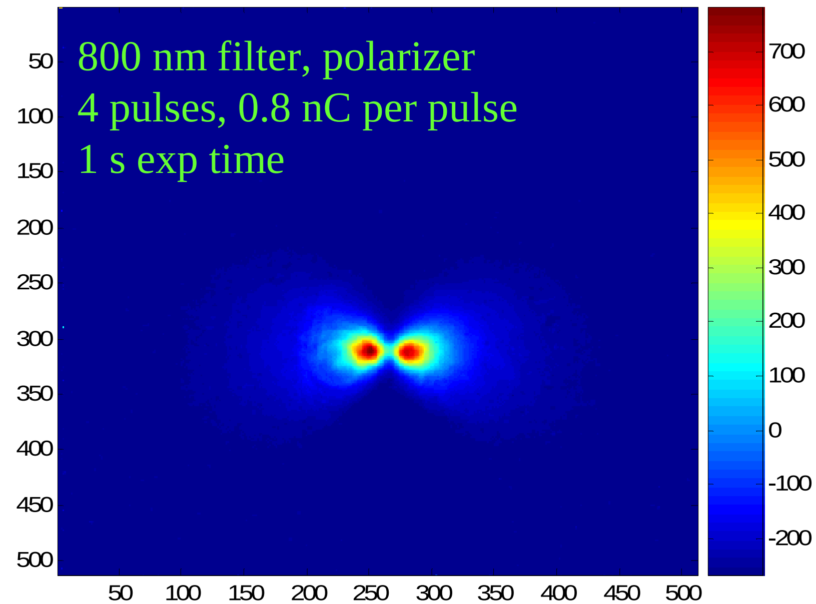
ODRI Angular Distribution for Two Different Beam Sizes

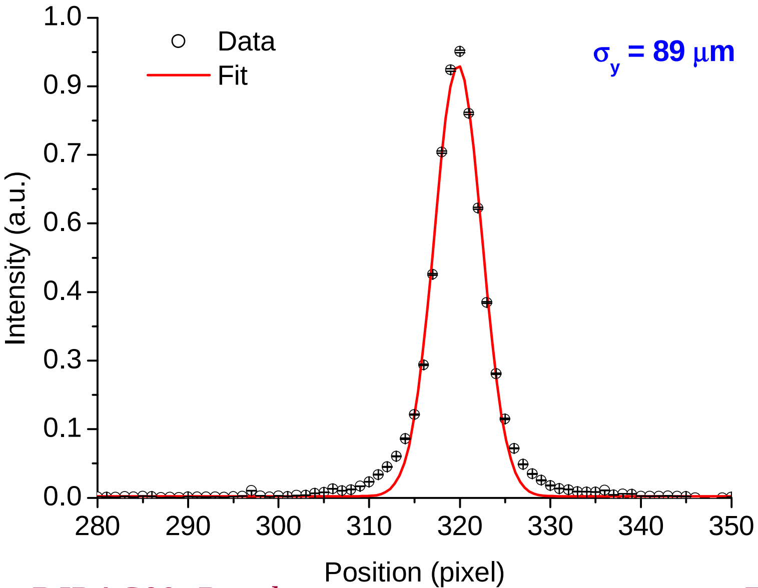
13 pulses, 0.8 nC per pulse, CCD exposure time: 2 s, Rep rate 5 Hz

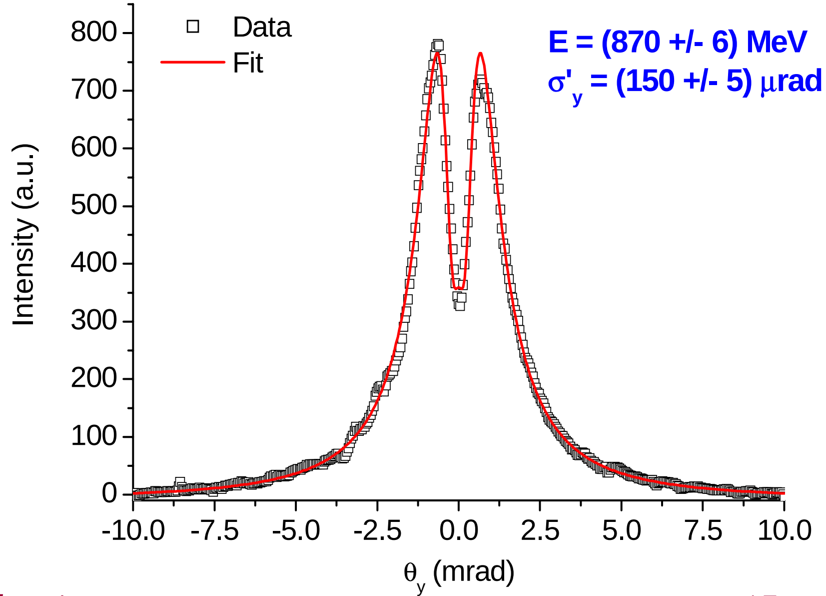


OTR IMAGE AND FOCAL PLANE



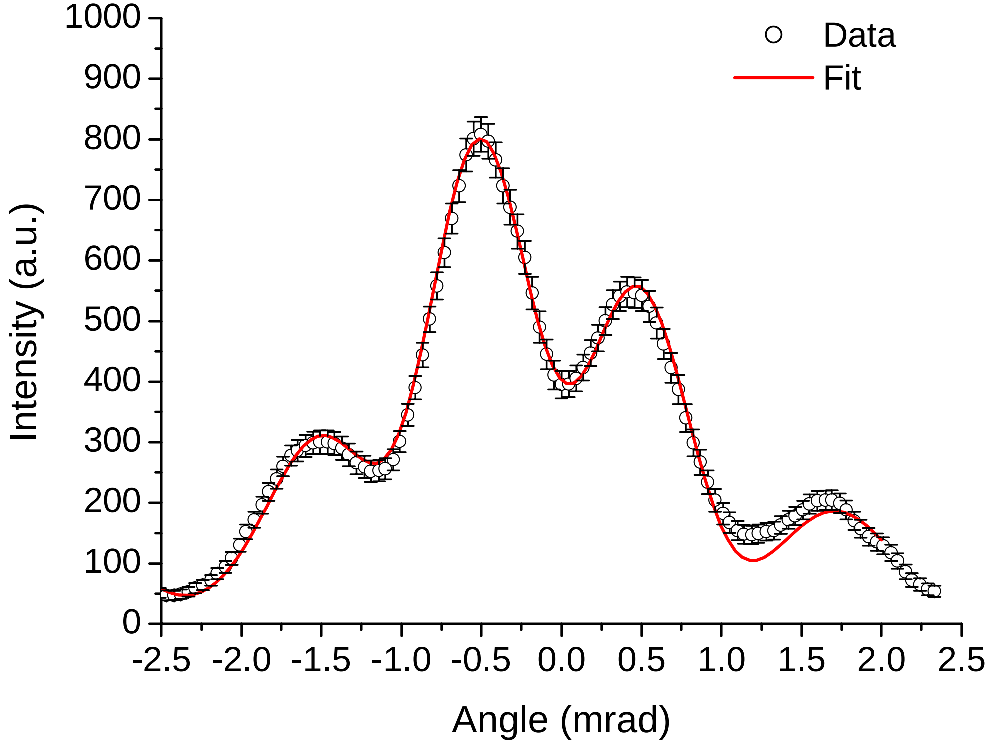






Fit Curve for ODRI Angular Distribution (1)

A Gaussian distributed beam both in size and angular divergence is assumed.



λ = 800 nm

Energy = 860 MeV

σ_y = 83 μm

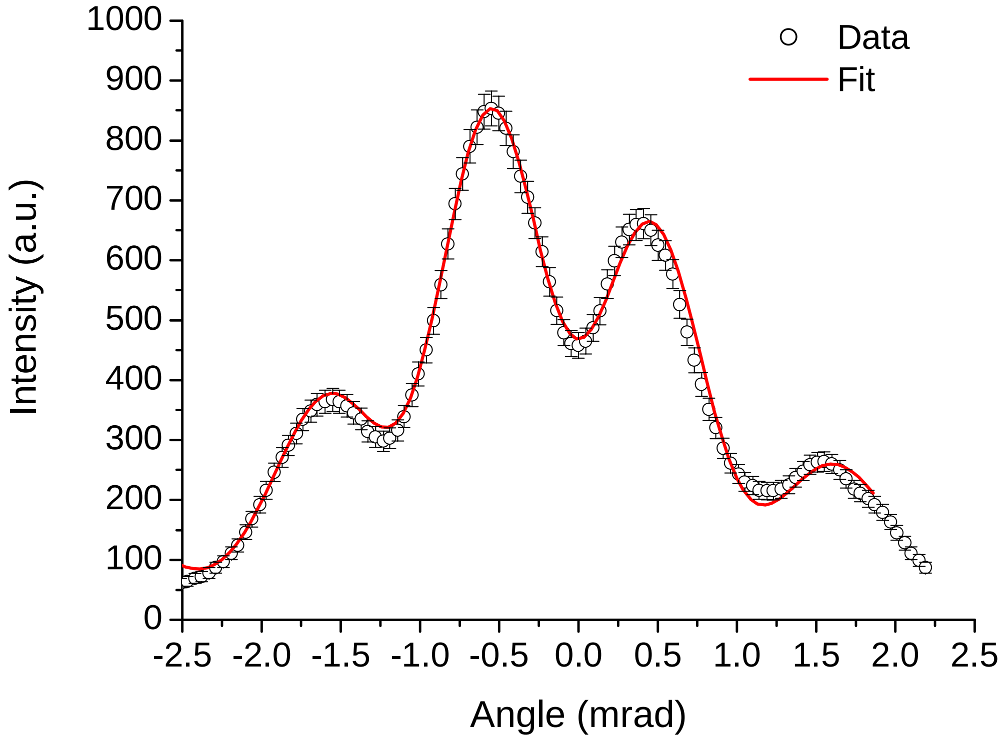
σ_y' = 200 μrad

Δy = 12 μm

L = 2 cm

L0 = 88 nm

Fit Curve for ODRI Angular Distribution (2)



λ = 800 nm

Energy = 865 MeV

σ_y = 70 μm

σ_y' = 263 μrad

Δy = 13 μm

L = 2 cm

L0 = 77 nm

CONCLUSIONS

- Diffraction Radiation is a versatile tool for both transverse and longitudinal diagnostics of high energy, high density electron beams

- DR is totally non-intercepting, allowing to fully characterize high density electron beams without loosing their quality

- We observed that Optical Diffraction Radiation Interferometry, better than ODR, allows us to
  - reduce SR background
  - increase the visibility of the interference fringes ➔ increasing the sensitivity to the beam dimension
  - separate the effect of beam size and offset within the slit

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