Non-intercepting electron beam size monitor using optical diffraction radiation interference (ODRI)

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Outlook

- Importance of Non Intercepting Diagnostic
- Optical Diffraction Radiation vs Optical Diffraction Radiation Interference
- Non collinear apertures
- Experimental setup
- Results
- Horizontal polarization
- Future applications?

High Brightness Machines

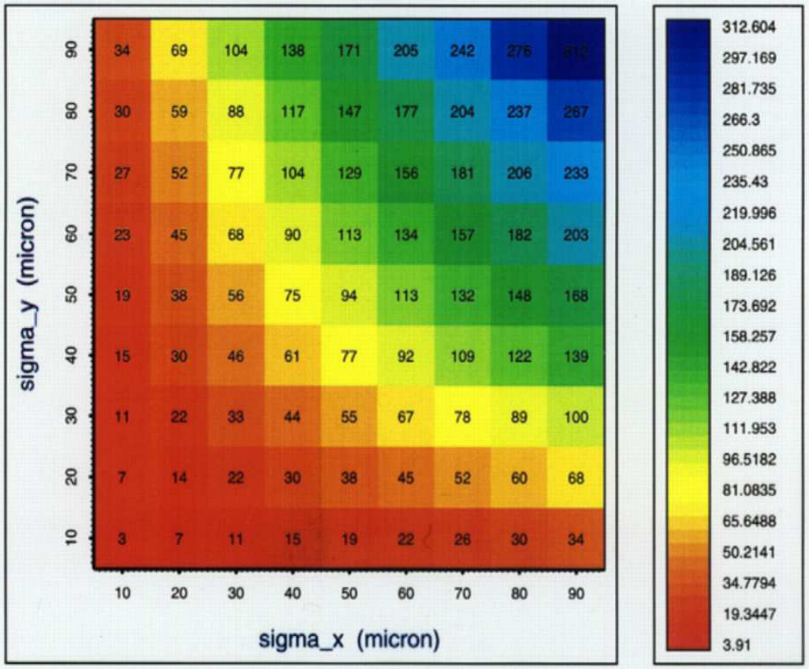


Figure 1: Number of bunches ($Q_b = 1\,nC$) at which Si foil (300 microns) is below the stress limit ($\Delta T = 1230°$). The energy is 1 GeV.

V. Balandin, N. Golubeva

$$\overline{B} = \frac{2I}{\pi^2 \varepsilon_x \varepsilon_y} \text{[A/(m-rad)}^2\text{]}$$

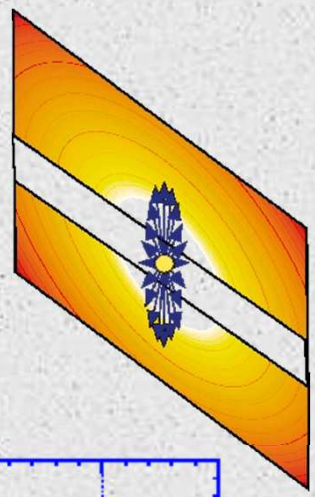
High density power beam can substantially damage or destroy a foil or a wire scanner

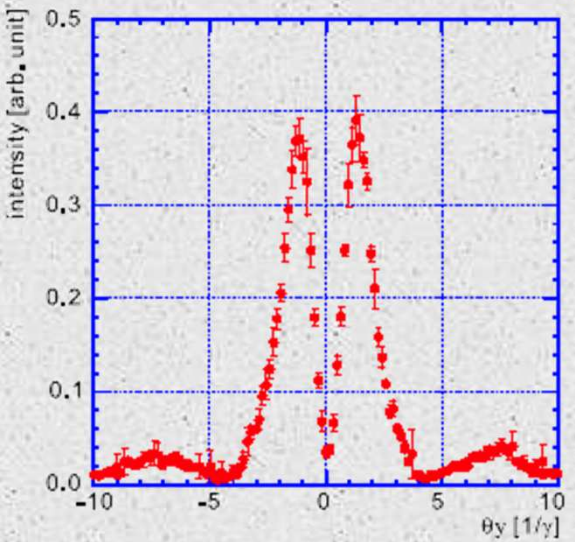
Possible alternatives are multishots devices such as Wire scanner (intercepting) and Laser wire

Optical Diffraction Radiation (ODR)

- The charge goes into the hole without touching the screen
- The electromagnetic field of the moving charge interacts with the metallic screen
- No power is deposited on the screen
- The angular distribution of the emerging radiation is affected by the beam transverse size, the angular spread and the position inside the slit
- M. Castellano, Nucl. Instrum. Methods Phys. Res., Sect. A 394, 275 (1997).

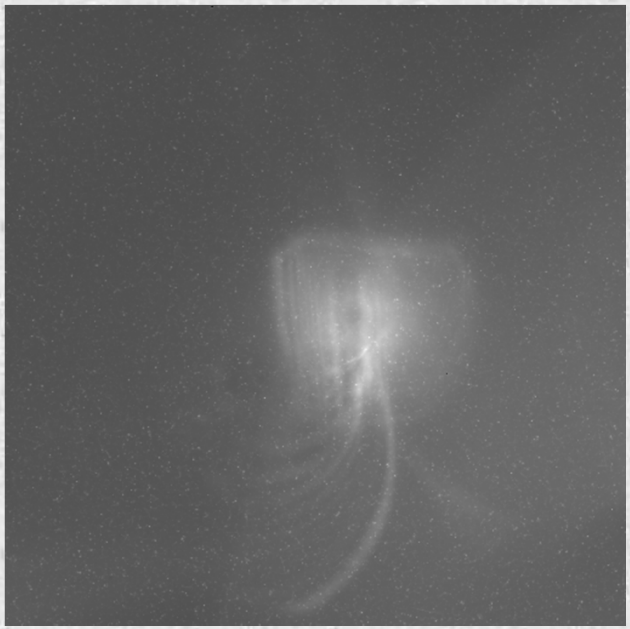
$$I \propto e^{-\frac{2\pi a}{\gamma\lambda}}$$

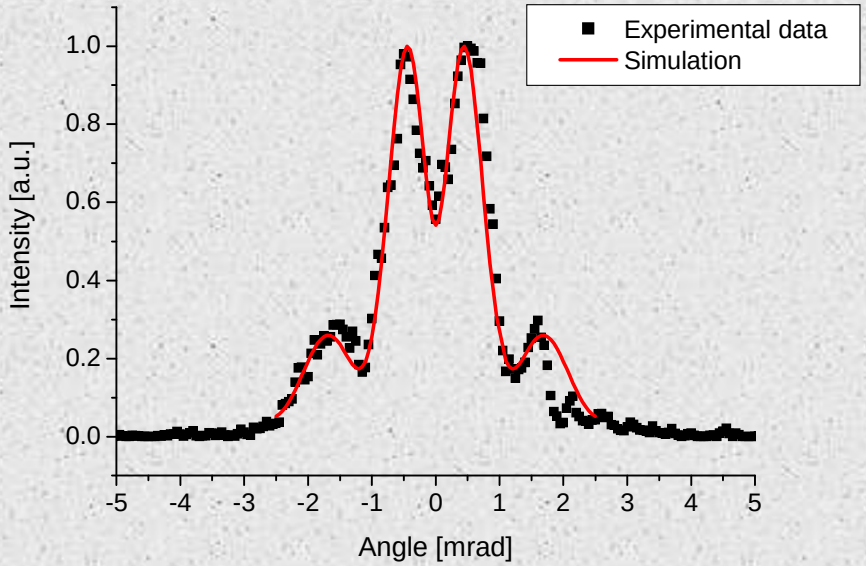




P. Karataev et al., "*Beam-Size Measurement with Optical Diffraction Radiation at KEK Accelerator Test Facility*", Phys. Rev. Lett. 93, 244802 (2004)

Background noise

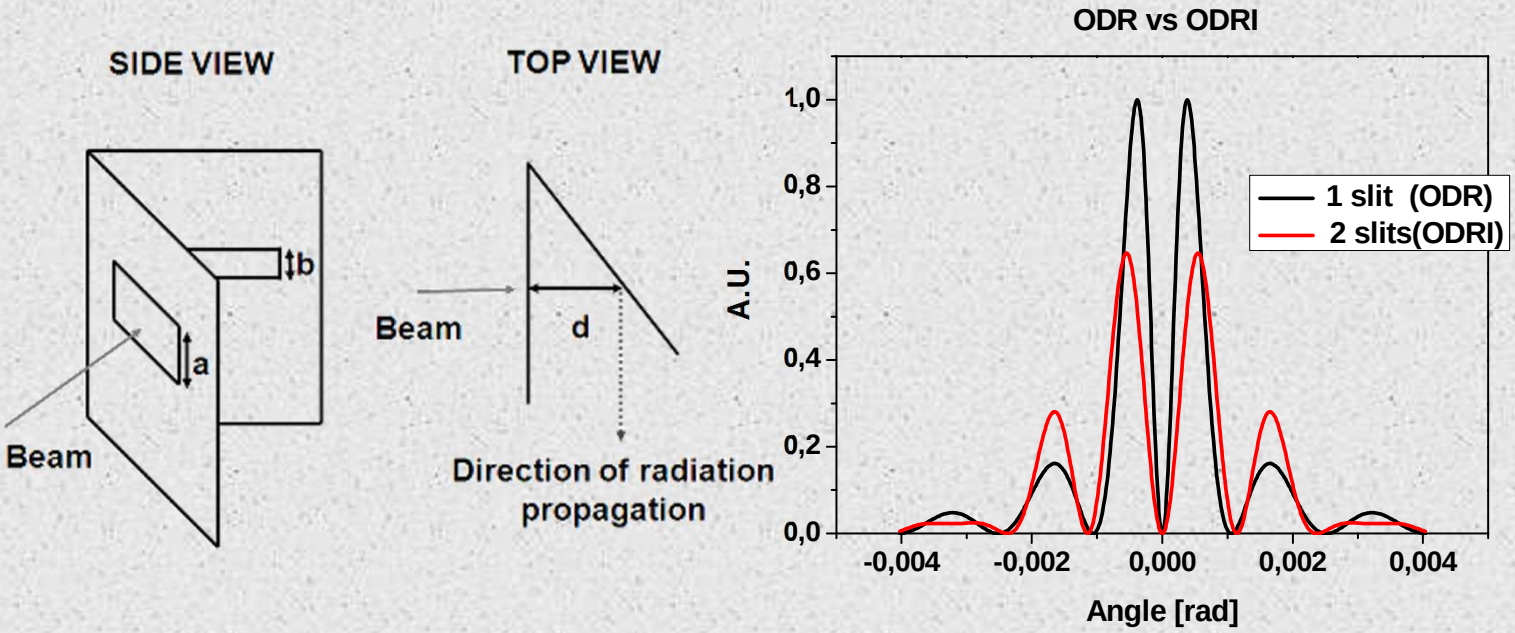




Mainly Synchrotron radiation, both directly coming for bending magnets and reflected from the vacuum chamber walls

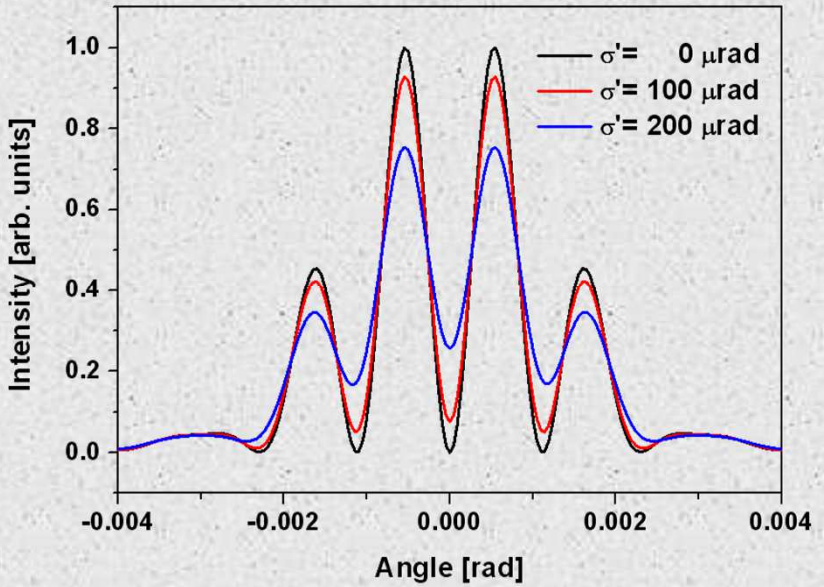
E. Chiadroni et al.,
Non-intercepting electron beam transverse diagnostics with optical diffraction radiation at the DESY FLASH facility
NIM B 266 (2008) 3789–3796

Two slits geometry (ODRI)

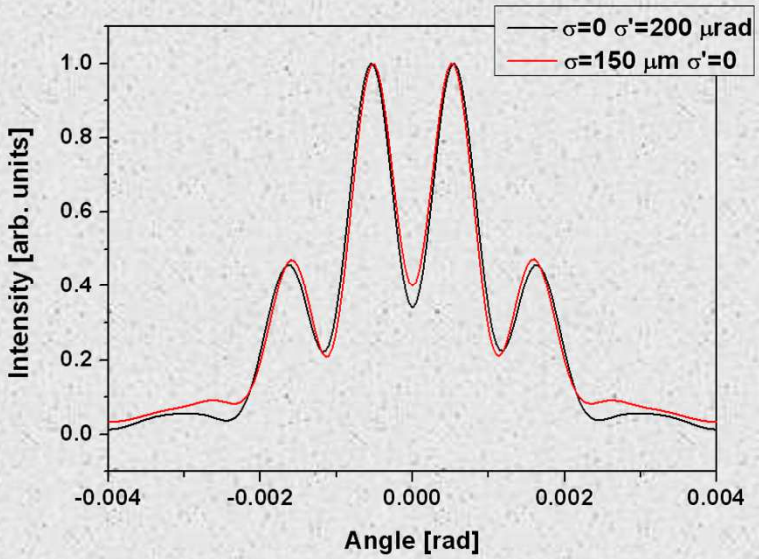


Optical Diffraction Radiation Interference (ODRI)

Collinear slits



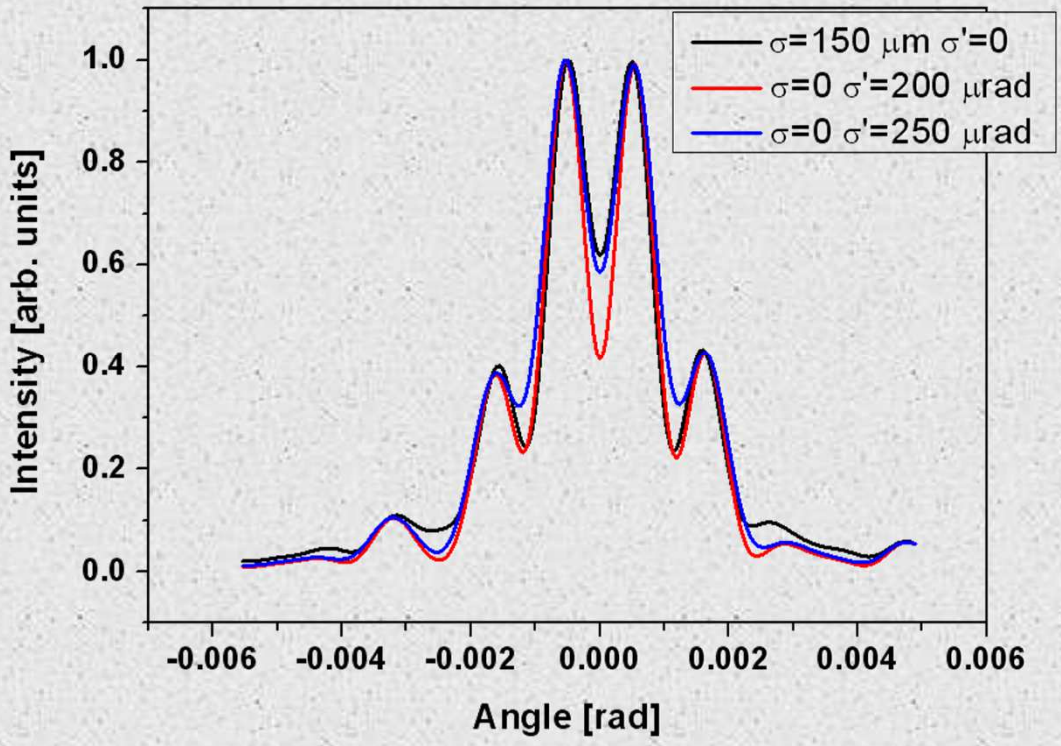
Point like beams with different angular spread



Possible confusion between the contribution of the angular spread and the beam dimension

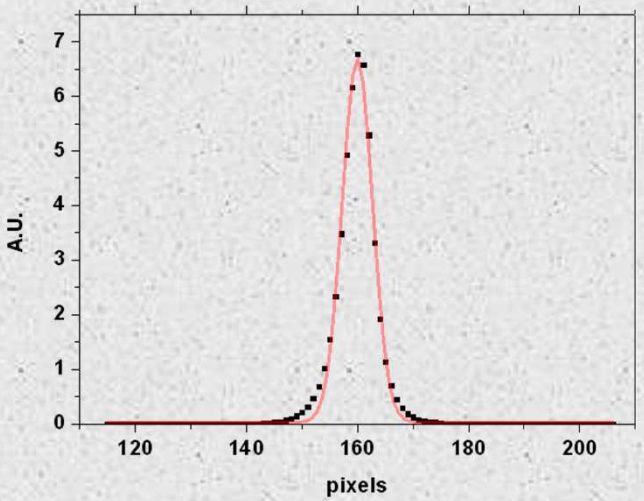
Non collinear slits

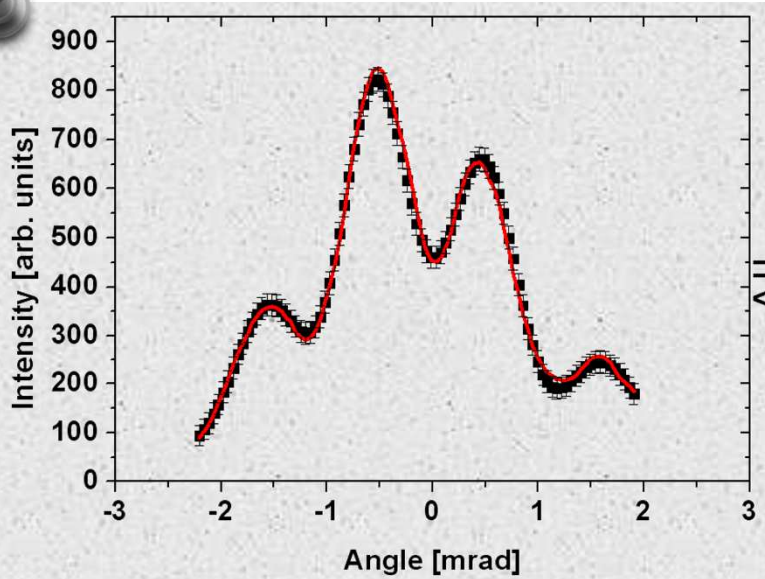
The 50 μm offset between the slits is enough to avoid mixing between the contributions of angular spread and beam size

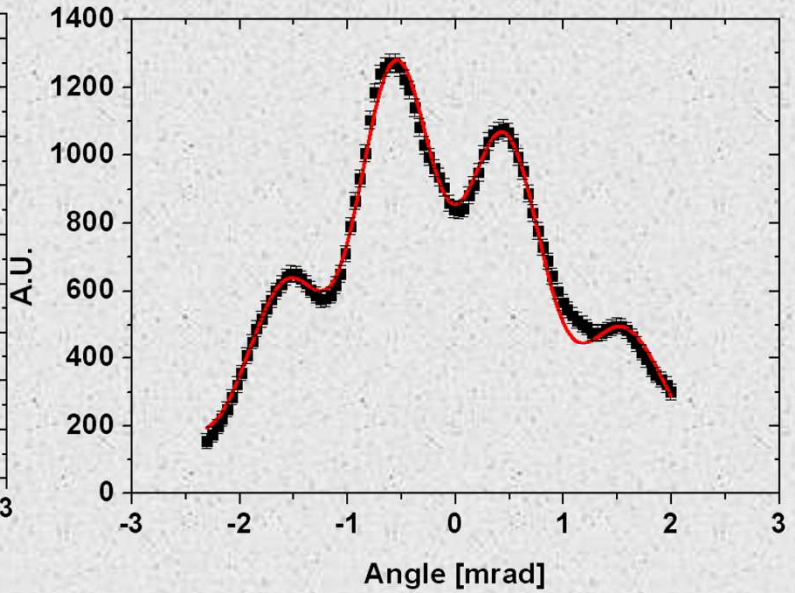


Approximations and formulas

- Perfect metal
- Filter bandwidth negligible
- Beam energy spread negligible
- Beam Gaussian both in y and y'
- Slit parallelism correction (M. Castellano, E. Chiadroni, A. Cianchi, "Phase control effects in optical diffraction radiation from a slit", Nuclear Instruments and Methods in Physics Research A 614 (2010) 163–168)
- Numerical code





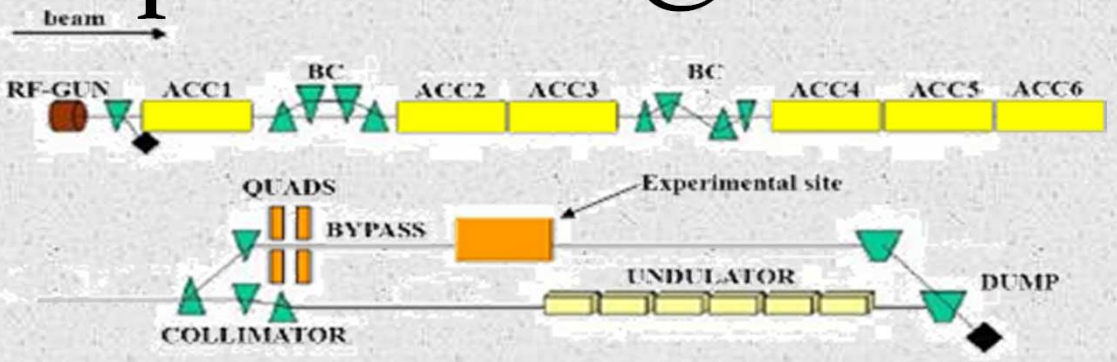


RMS Beam Size (μm)	82	78
RMS angular spread (μrad)	260	310
Displacement in respect to the second slit (μm)	-6	-55
Misalignment between two slits (μm)	110	113

A divergence of about 320 *μrad can be estimated from a quadrupole-scan emittance* measurement carried out under the same experimental conditions

A. Cianchi et al. Nonintercepting electron beam size monitor using optical diffraction radiation interference, PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 14, 102803 (2011)

Experiment @ FLASH

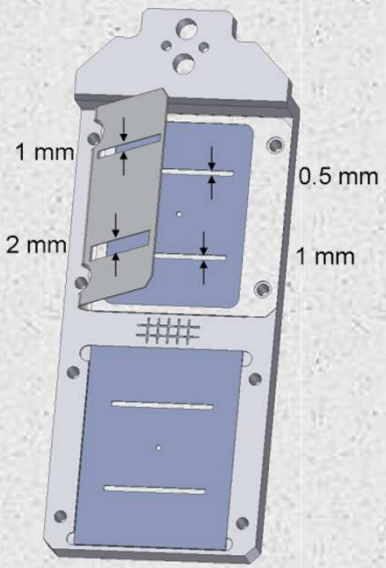


FLASH is an excellent linac for this experiment:

- High energy up to *1 GeV*
- Large number of bunches (up to 30) with high charge (up to 1 nC)
- Frequency repetition 10 Hz
- Long collaboration history

Hardware evolution

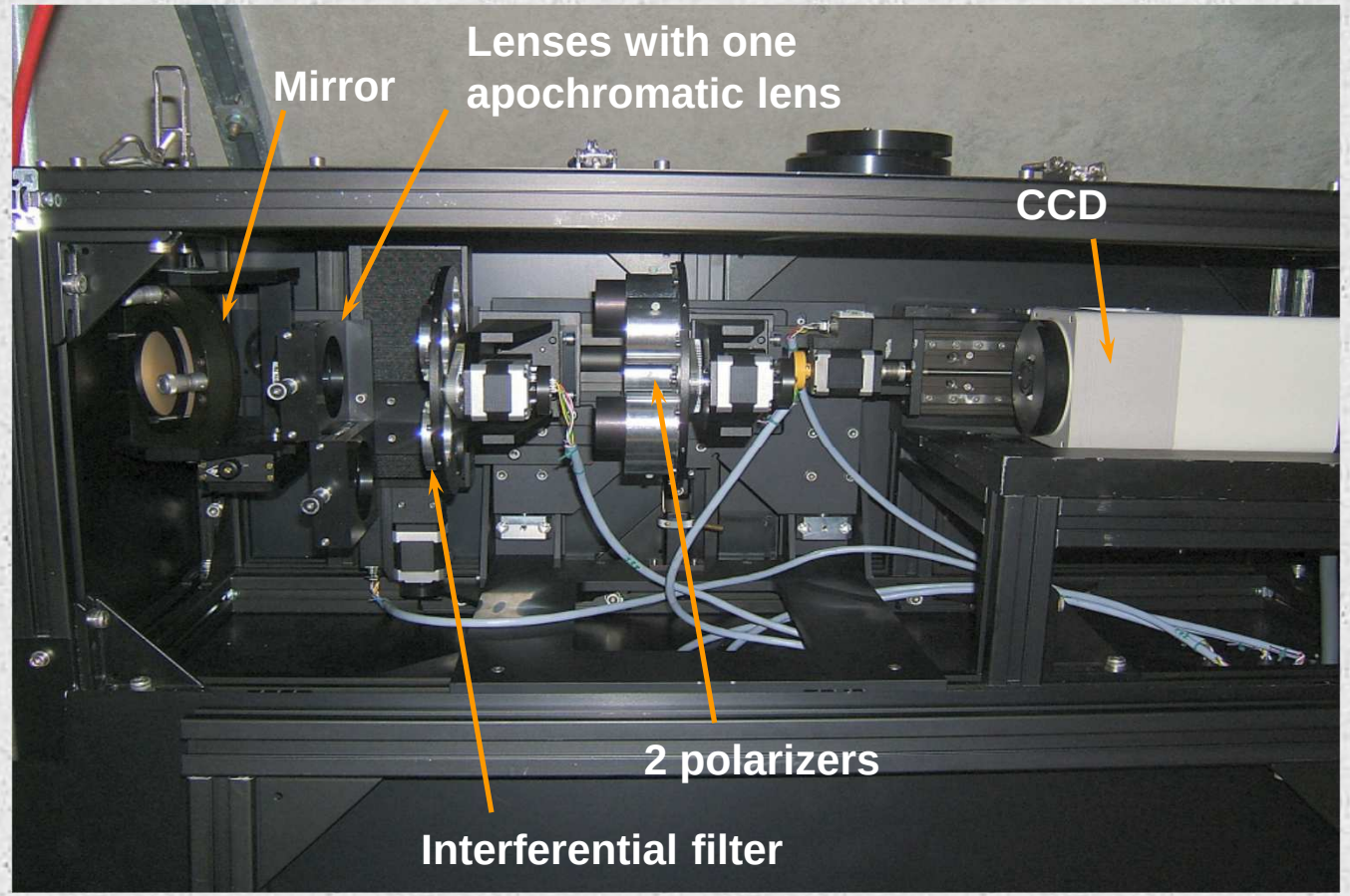
- New design in the mover



Old screen holder

New screen holder

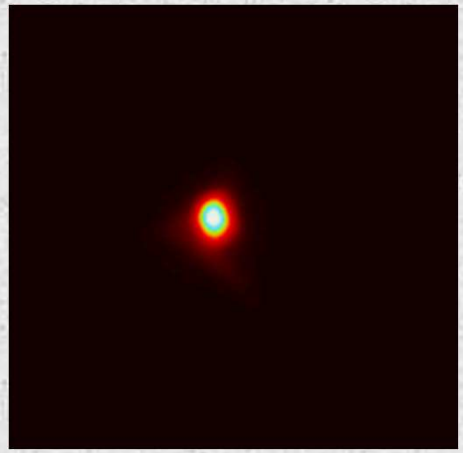
Experimental Setup



Christian Wiebers (optical system) & Hans-Christian Schroeder (apochrom. Lens)

Transport to 57BYP

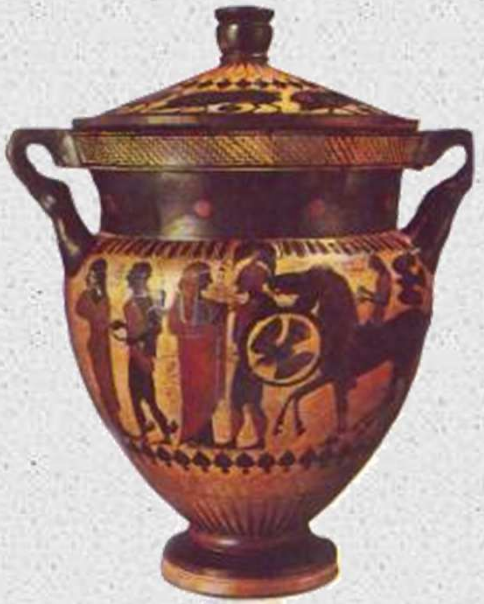
- Thanks to Vladimir and Nina was possible to achieve quickly a very nice beam spot with sigma about 80 μm



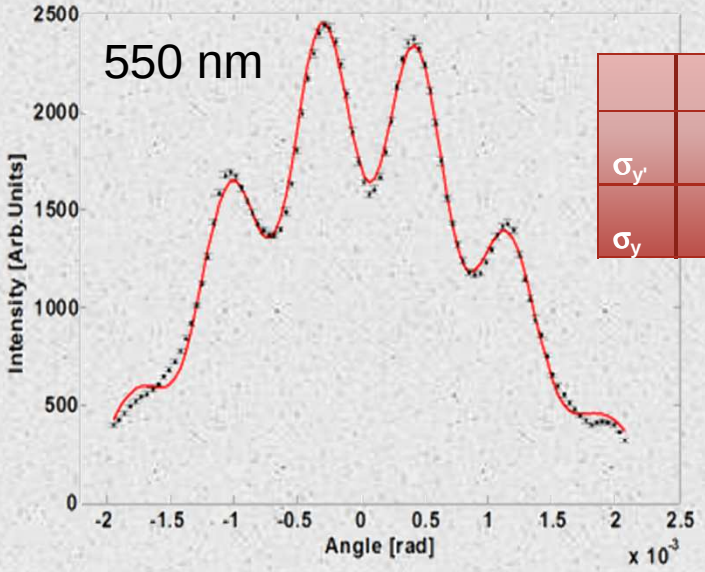
BUT….

Pandora

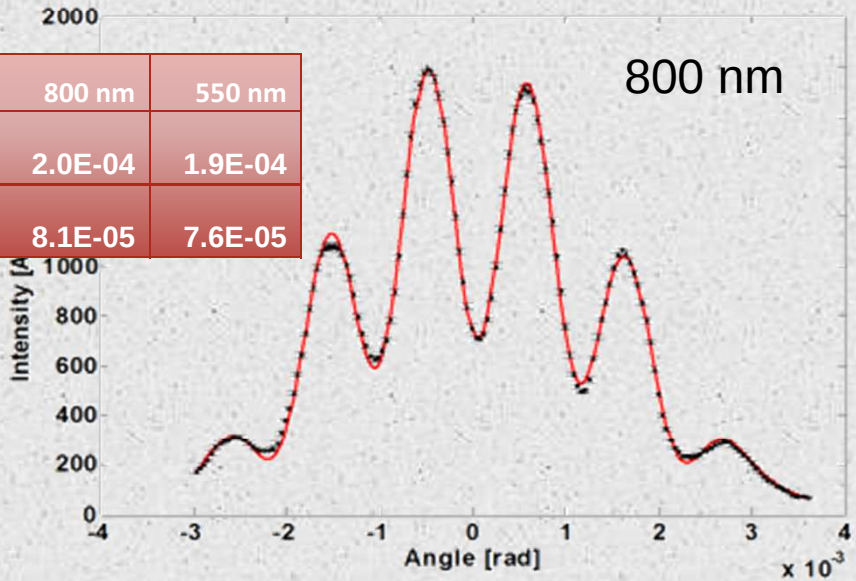
In Greek mythology Pandora was the first woman created by Zeus to punish mankind
In FLASH life is here to punish the hybris of the people that want to go to the bypass line

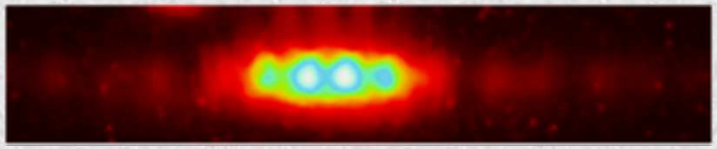


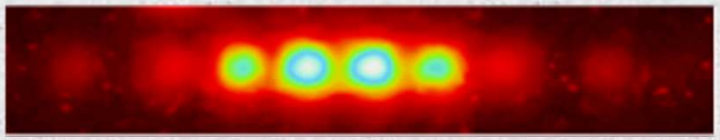
Different wavelengths



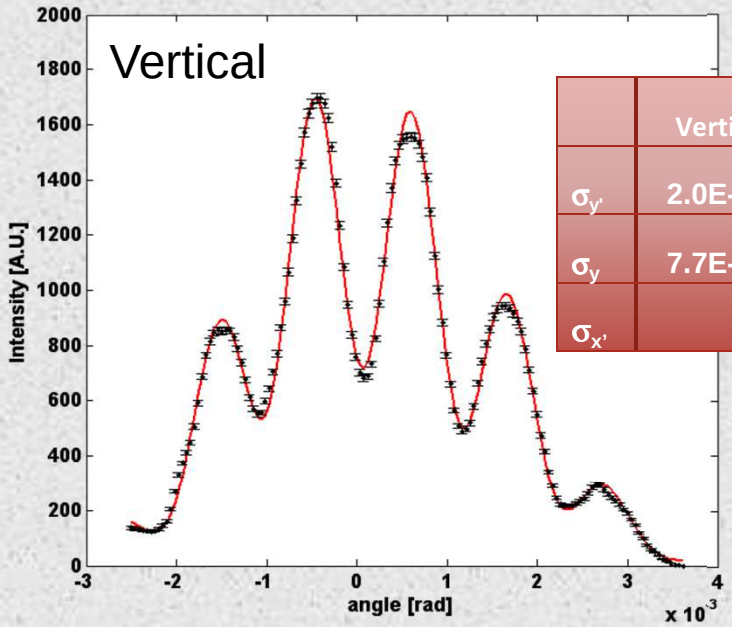
	800 nm	550 nm
$\sigma_{y'}$	2.0E-04	1.9E-04
σ_y	8.1E-05	7.6E-05



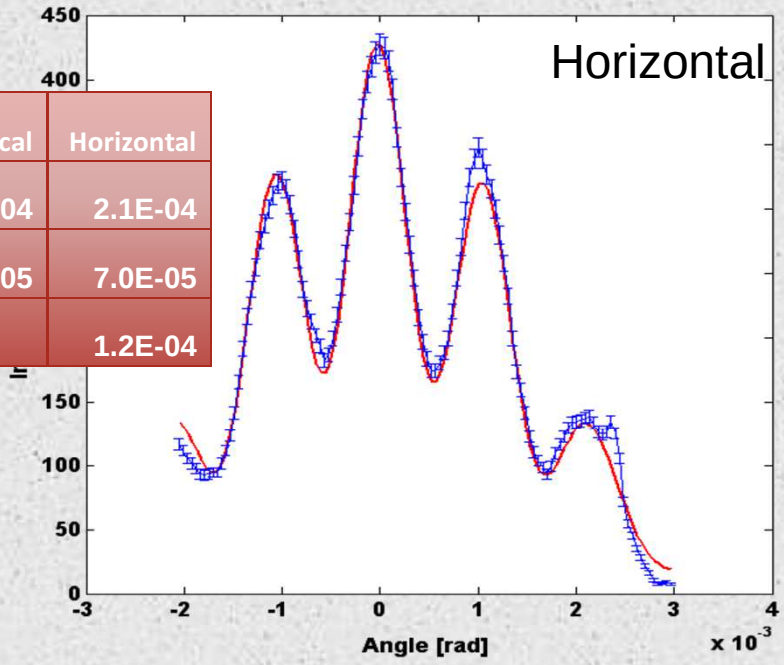


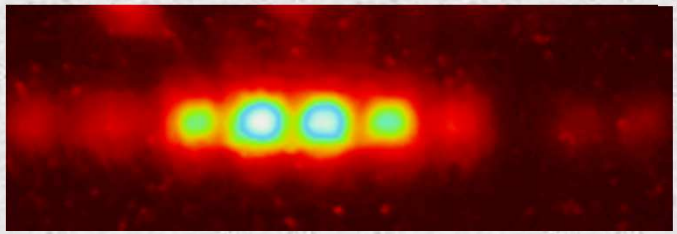


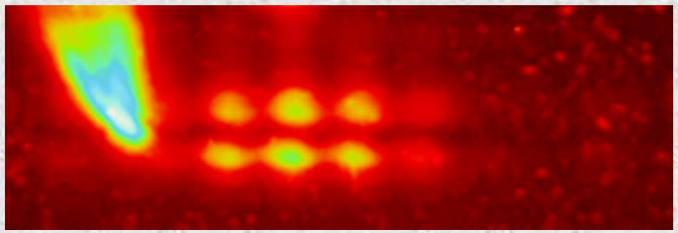
Horizontal polarization



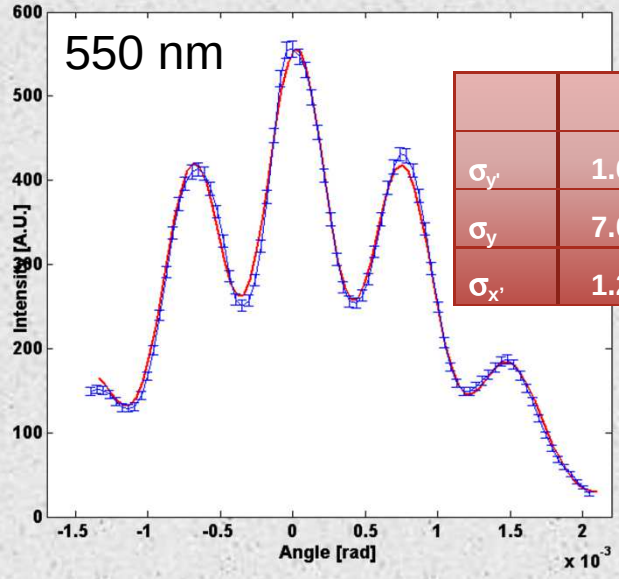
	Vertical	Horizontal
$\sigma_{y'}$	2.0E-04	2.1E-04
σ_y	7.7E-05	7.0E-05
$\sigma_{x'}$		1.2E-04



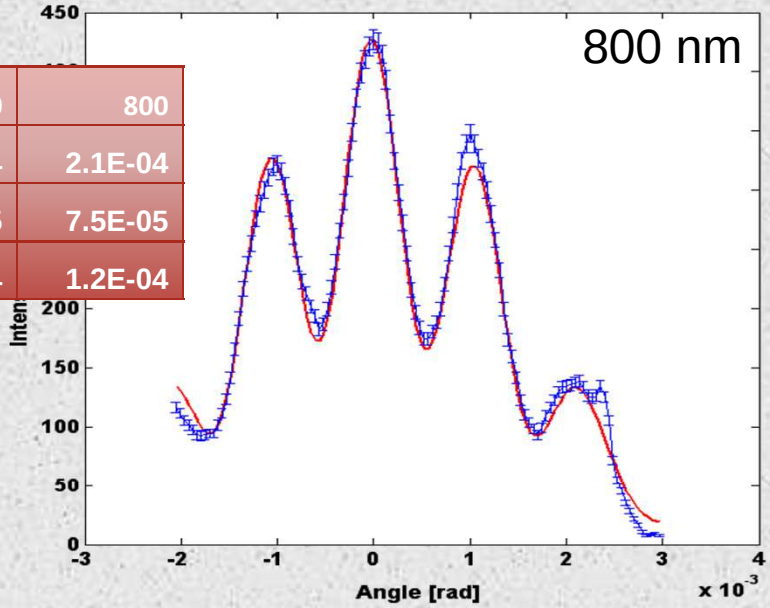


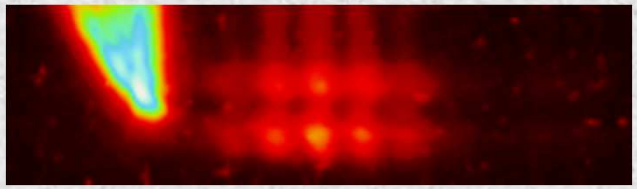


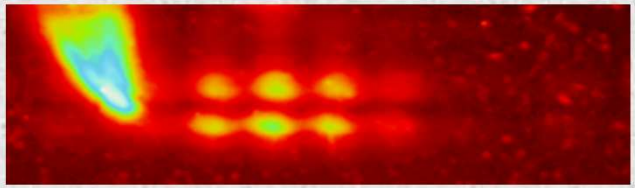
X polarization



	550	800
$\sigma_{y'}$	1.6E-04	2.1E-04
σ_y	7.0E-05	7.5E-05
$\sigma_{x'}$	1.2E-04	1.2E-04



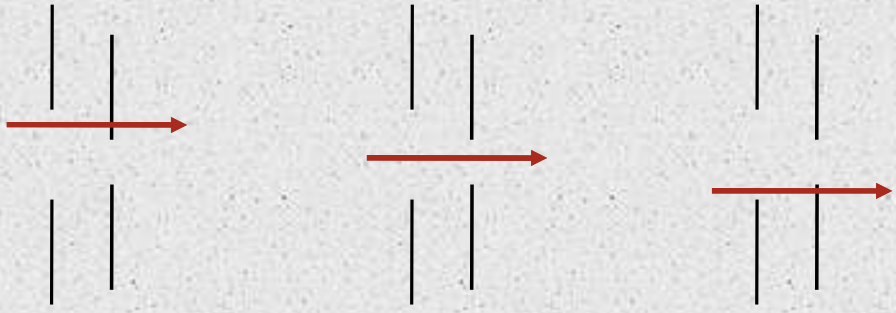




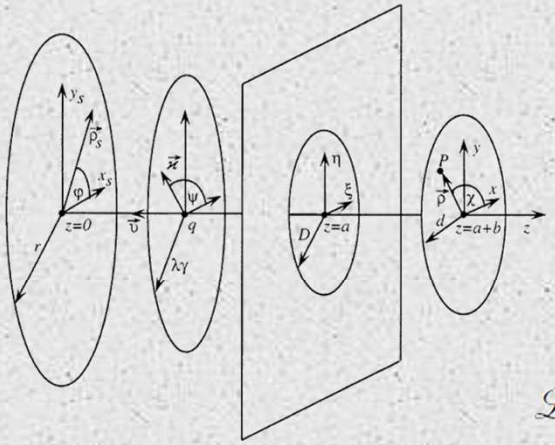
Formulas

$$E_y^P(k_x,k_y)=\frac{e}{4\pi^2 c}\left[\frac{e^{-\left(\frac{a}{2}+y\right)(f-ik_y)}}{f-ik_y}-\frac{e^{-\left(\frac{a}{2}-y\right)(f+ik_y)}}{f+ik_y}\right]$$

$$E_y^{up}(k_x,k_y)=\frac{e}{4\pi^2 c}\left[\frac{2ik_y}{k_y^2+f^2}+\frac{e^{-\left(y+\frac{a}{2}\right)(f-ik_y)}}{f-ik_y}-\frac{e^{-\left(y-\frac{a}{2}\right)(f-ik_y)}}{f-ik_y}\right]$$



Exact formula



$$E_{x,y}(P,\omega) = \frac{q}{2\pi^2 v}\frac{k^2}{ab}\int \mathrm{d}\rho_s\,\rho_s \int \mathrm{d}\varkappa \frac{\varkappa^2 J_1(\varkappa\rho_s)}{\varkappa^2+\alpha^2} \mathrm{e}^{\mathrm{i}(k/2am)\rho_s^2}$$

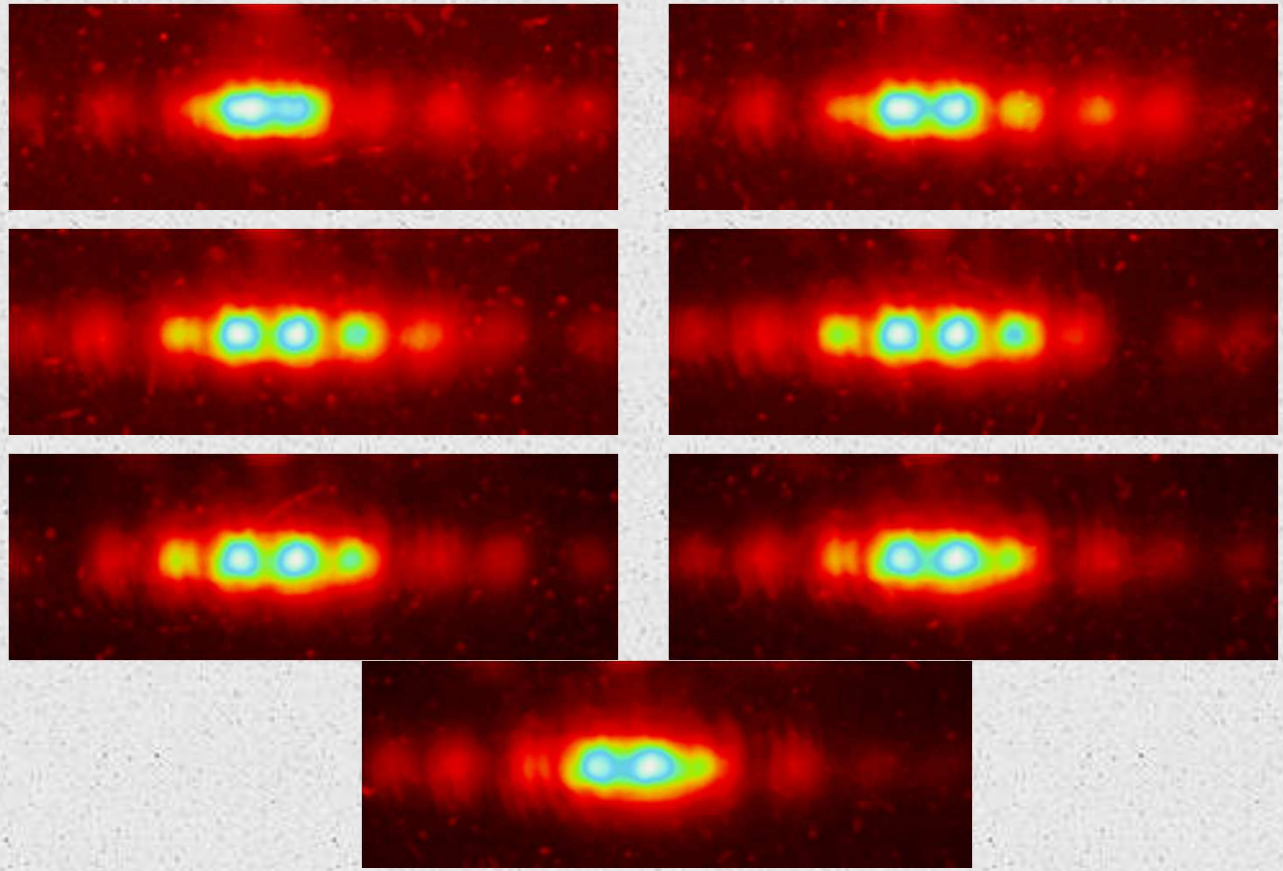
$$\times \int \mathrm{d}\varphi \begin{Bmatrix} \cos\varphi \\ \sin\varphi \end{Bmatrix} \mathrm{e}^{-\mathrm{i}(k/am)\rho\rho_s\cos(\varphi-\chi)} \mathscr{L}(p)$$

$$\mathscr{L}(p) = 2\pi \mathrm{e}^{\mathrm{i}(k/2bm)p^2} \int_0^D \mathrm{d}\zeta\,\zeta \mathrm{e}^{\mathrm{i}(km/2b)\zeta^2} J_0(k\zeta p/b)$$

$$p = \sqrt{\rho^2 + (b^2/a^2)\rho_s^2 + 2(b/a)\rho\rho_s\cos(\varphi-\chi)}.$$

M. Castellano, A. Cianchi, G. Orlandi, V.A. Verzilov, *Effects of diffraction and target finite size on coherent transition radiation spectra in bunch length measurements, Nuclear Instruments and Methods in Physics Research A 435 (1999) 297-307*

Scan with the 1 mm slit



•0.5 mm slit out off center about -70 μm
•1 mm slit moved from -66 μm to +200 μm

To improve

- Horizontal polarization features not fully understood
- Check the impact of two completely different beam aspect ratios
- An analytic formula would be better than a MonteCarlo code

To do

- A total non intercepting emittance measurement using the quadrupole scan technique
- Compare the result with conventional quadrupole scan
- Check if it is possible to have the same result just using only two different values of the quads current

The σ matrix

$$\gamma x^2 + 2\alpha x x' + \beta x'^2 = \varepsilon = \gamma_0 x_0^{\ 2} + 2\alpha_0 x_0 x_0' + \beta_0 x_0'^2$$

$$\sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{pmatrix} = \varepsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix}$$

$$\sigma_{11} x^2 + 2\sigma_{12} x x' + \sigma_{22} x'^2 = 1$$

$$\sigma_1 = M \sigma_0 M^T \qquad M(s_1 s_2) = \begin{pmatrix} C & S \\ C' & S' \end{pmatrix}$$

Multiple profile monitors

$$\sigma_{i,11} = C_i^2 \sigma_{11} + 2 S_i C_i \sigma_{12} + S_i^2 \sigma_{22}$$

$$\sigma_{i,22} = C_i'^2 \sigma_{11} + 2 C_i' S_i' \sigma_{12} + S_i'^2 \sigma_{22}$$

- There are 3 unknown quantities but 2 equations!
- $\sigma_{i,11}$ is the squared rms beam size
- $\sigma_{i,22}$ is the squared rms divergence
- C_i and S_i are the element of the transport matrix
- We need 2 measurements in 2 different position to evaluate the emittance

Future possibilities

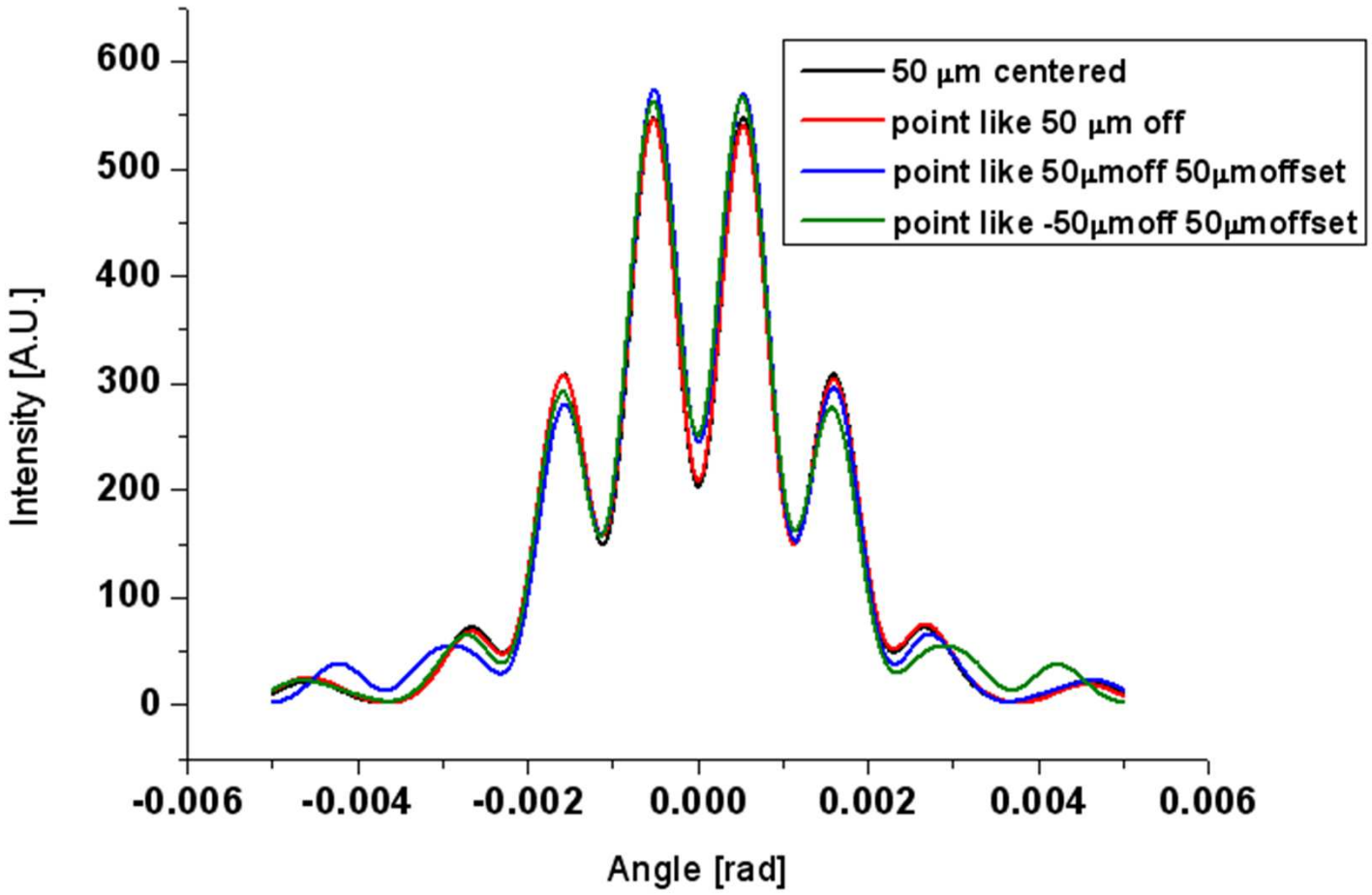
- For emittance measurement multiple screens are required in order to estimate the beam size in at least three different locations
- With ODRI two parameters can be measured in principle in one shot, σ_y and $\sigma_{y'}$
- So only two stations are required, both non intercepting, paving the way to a totally parasitic emittance measurement

Conclusion

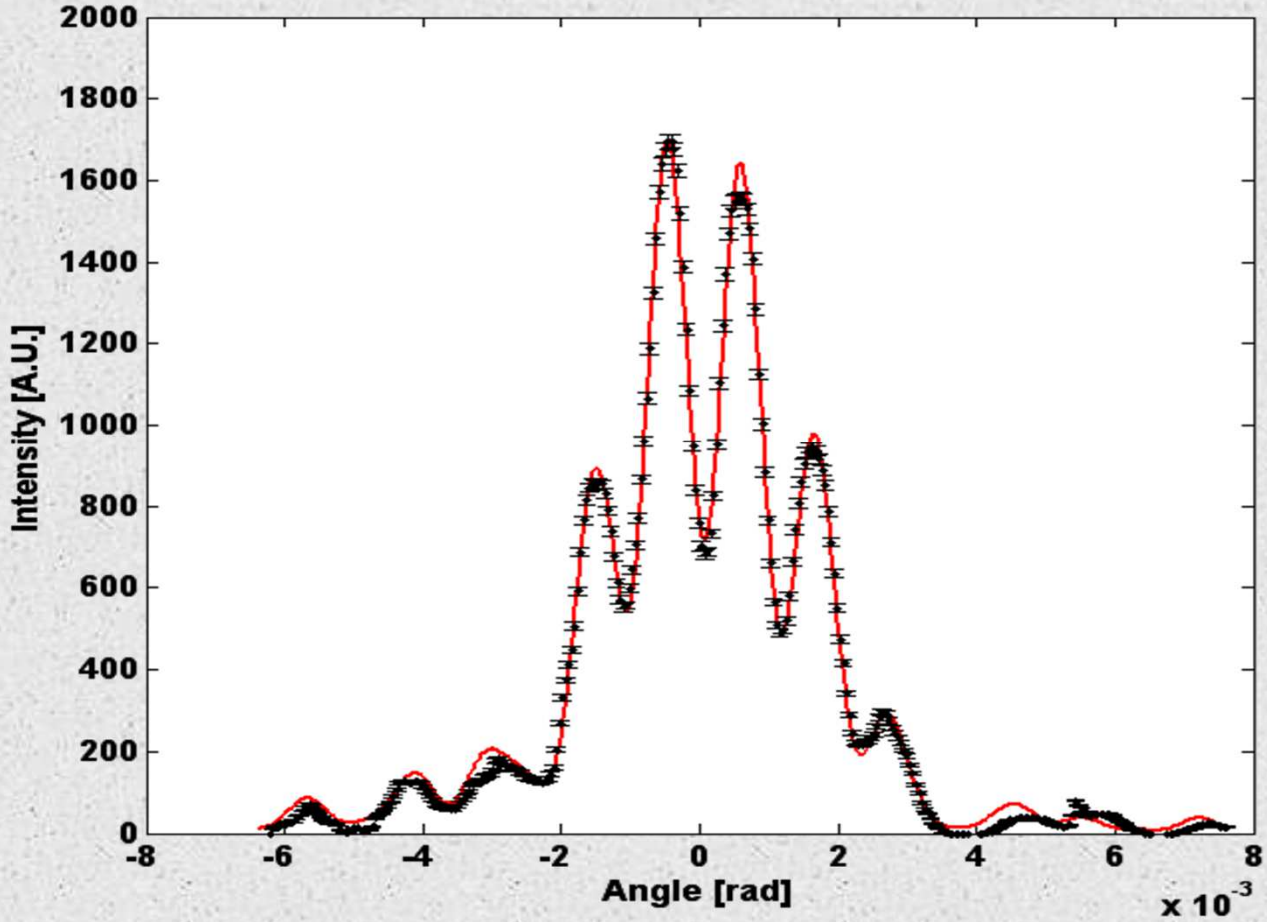
- ODRI is in developing
- ODRI dramatically reduce or eliminate the problem of background
- Asymmetric configuration resolves parameters ambiguities
- New measurements are foreseen to make a totally non intercepting emittance measurement

Thank you for your attention

Importance of side peaks



All data


Intensity [A.U.]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-8
-6
-4
-2
0
2
4
6
8
Angle [rad]
x 10^-3