Topical Workshop on "Emittance Measurements for Light Sources and FELs"
29-30 January 2018 - ALBA Synchrotron

Beam size using OTR/ODR techniques

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Motivation

- Diagnostics is the “organ of sense” of an accelerator
  - Instrumentation for **daily check**
    - *profile measurements, beam position, charge, …*
  - Instrumentation for **commissioning and** accelerator **development**
    - *emittance, bunch length, feedback, stability, …*

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- **Optical Radiation based techniques**
  - **emittance retrieval** $\varepsilon_{rms} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$

rms size

$$\sigma_x^2(z) = \langle x^2\rangle = \frac{1}{N_e}\sum_j x_j^2$$

rms divergence

$$\sigma_{x'}^2(z) = \langle x'^2\rangle = \frac{1}{N_e}\sum_j x_j'^2$$

correlation

$$\langle xx'\rangle = \frac{1}{N_e}\sum_j x_j x_j'$$

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  - matching conditions in FELs, **plasma-based accelerators**, …

Typical numbers

$$k_p = \frac{2\pi}{\lambda_p}$$

$$\lambda_p(\ m\ ) \approx 3.3\ 10^4 n_p^{-1/2}(cm^{-3})$$

$$\gamma = 1000$$

$$n_p = 10^{16}\ cm^{-3}$$

$$\varepsilon_n = 1\ mm\ mrad$$

Matching condition

$$\beta_{matching} = \frac{\sqrt{2\gamma}}{k_p}$$

$$\sigma_{matching} = \sqrt{\frac{\beta_{matching}\varepsilon_n}{\gamma}} \approx \mu m$$

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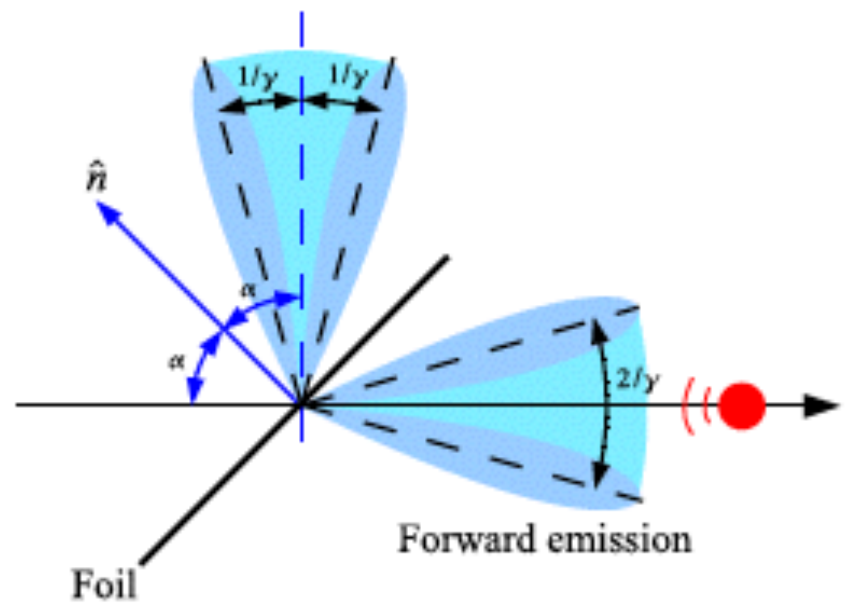
Transition Radiation

- **Instantaneous emission**

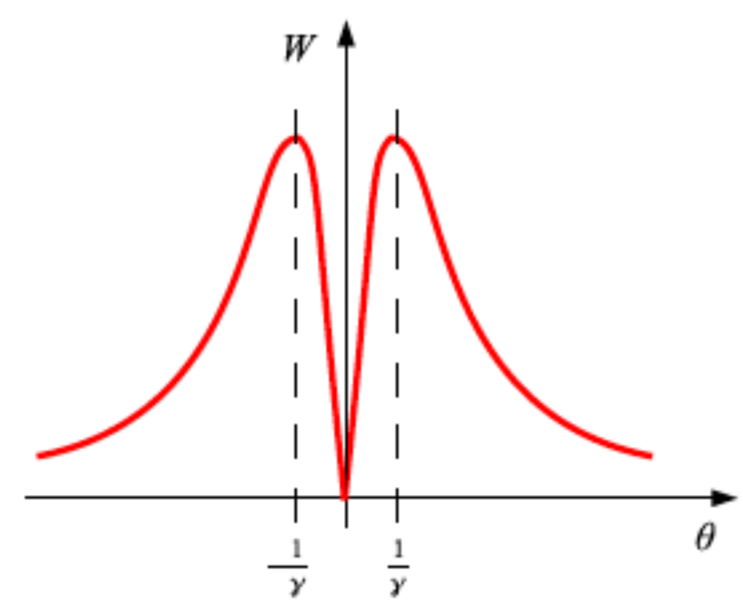
  $\lambda/c \sim fs\ scale$

- linearity
  - no saturation effects
- **high resolution**
  - near point source diffraction limit
  - limited by the optics
- **surface effect**
  - no dependence on the target thickness
- **small perturbation to the beam** (for small target thickness)
  - non destructive at 1 GeV, 1 μm thickness foil
- weak dependence of the OTR power on $\gamma: \quad W \propto \ln(2\gamma),\ \gamma \gg 1$
- **radially polarized**
- low photon yield, $N_{ph} \sim \alpha$



Courtesy of E. Bravin

$$\frac{d^2W}{d\Omega d\omega} \approx \frac{Nq^2}{\pi^2 c}\left(\frac{\theta}{\gamma^{-2}+\theta^2}\right)$$



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Instantaneous heating

Courtesy of V. Balandin, N. Goulbeva

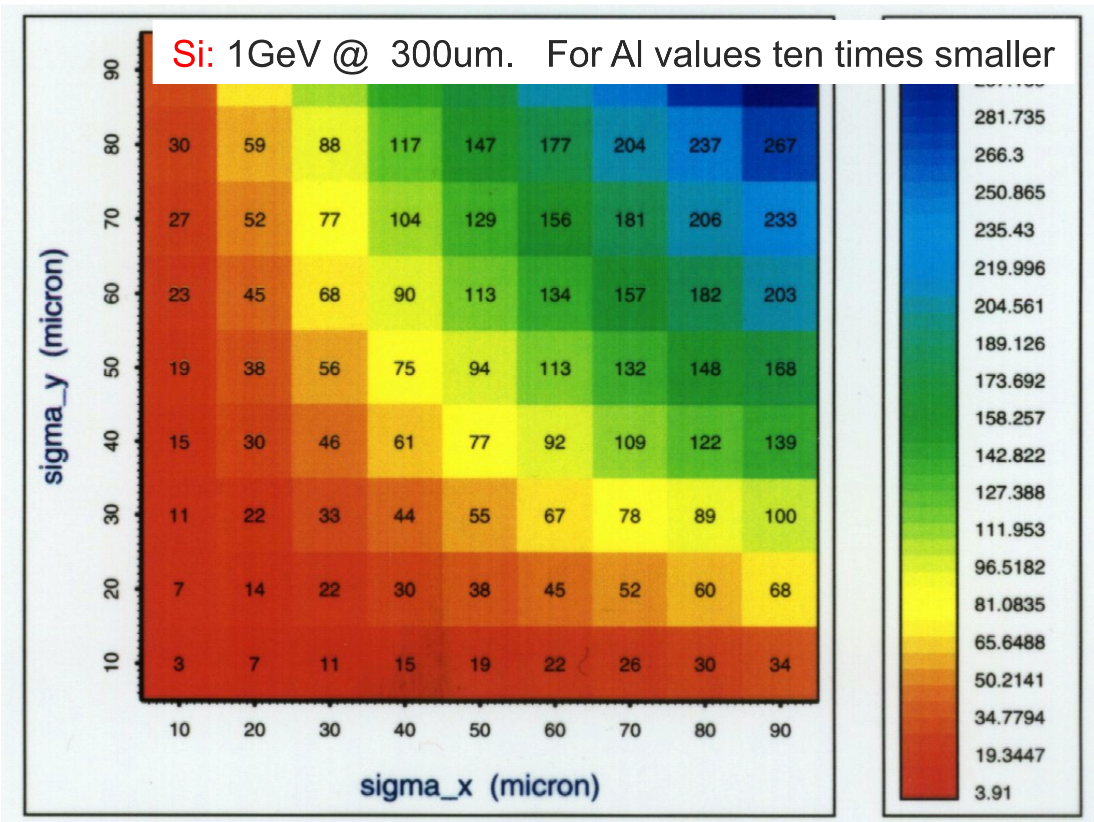

Figure 1: Number of bunches ($Q_b = 1\,nC$) at which Si foil (300 microns) is below the stress limit ($\Delta T = 1230°$). The energy is 1 GeV.

When a bunch hits the OTR, assuming a Gaussian spatial distribution, it rises its temperature according to

$$\Delta T^{+}(r) = \frac{\partial E}{\partial z}\frac{eN}{c_p \pi \sigma_x \sigma_y}\exp\left(-\frac{r^2}{2\sigma_x \sigma_y}\right)$$

Table 2: This Value Refers to a Starting Temperature T_0 of 320 K.

LINAC	ΔT^{+}	MTBF
SPARC	0.5 K	2×10^{14} years
ELI-GBS (Al)	113 K	20 ms
ELI-GBS (Si)	146 K	2 years

ELI-NP case

Due to beam energy deposition on the OTR targets an instantaneous temperature increase of **113 K for the aluminum and of 140 K for the silicon** is expected in the worst case scenario (**32 bunches, 250 pC/bunch**).

M. Marongiu et al.,
Design issues for the Optical Transition Radiation screens for the ELI-NP Compton gamma source, Proceedings of IPAC2016, Busan, Korea, MOPMB017

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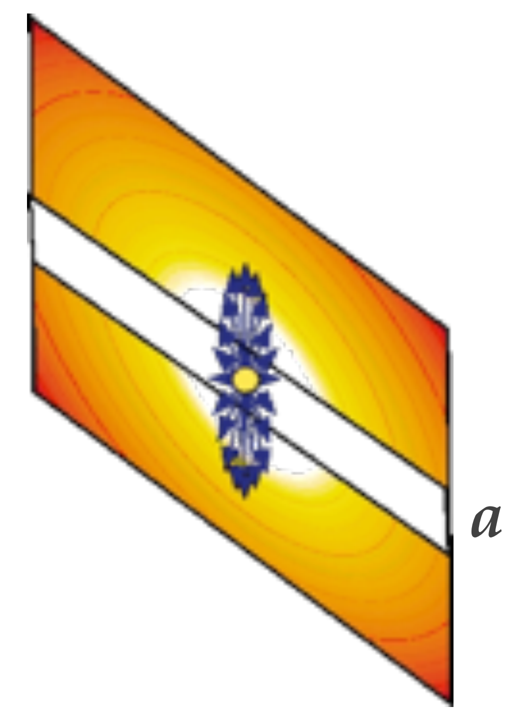
Diffraction Radiation

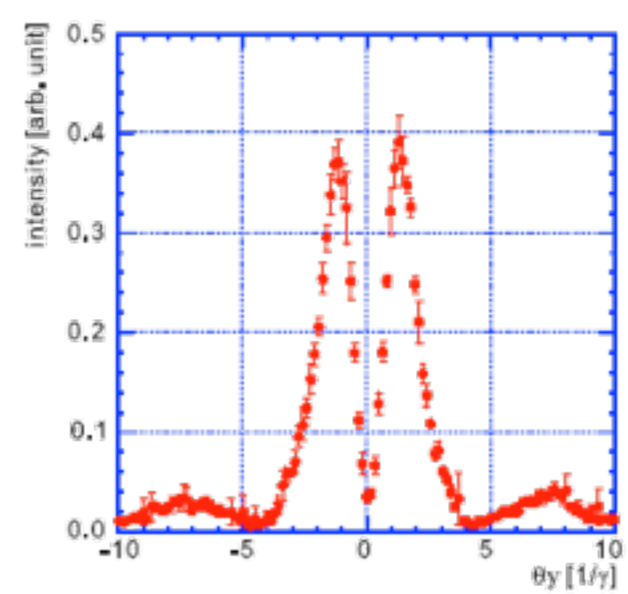
- The charge goes into the hole without touching the screen
    - **non-intercepting**
- The electromagnetic field of the moving charge interacts with the metallic screen
- **No power is deposited on the screen**
- The angular distribution of the emerging radiation is affected by the beam transverse size, the angular spread and <u>the position inside the slit</u>
- Rectangular slit

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



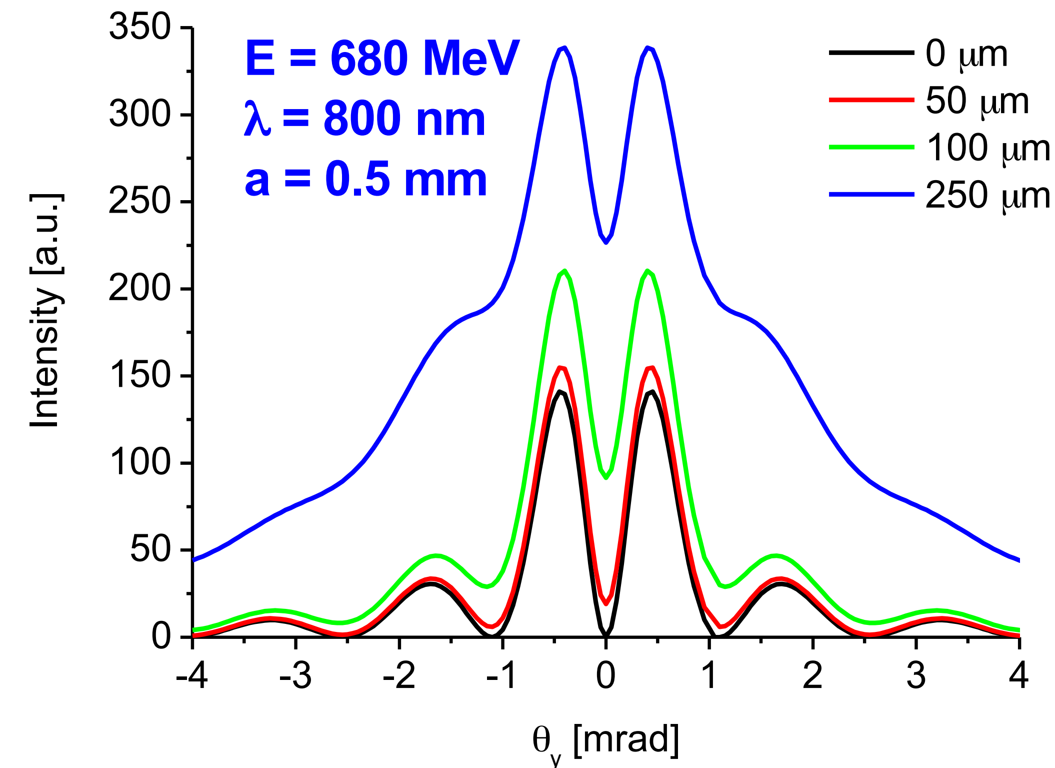
M. Castellano,
Nucl. Instrum. Methods Phys. Res., Sect. A **394**, 275 (1997)

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

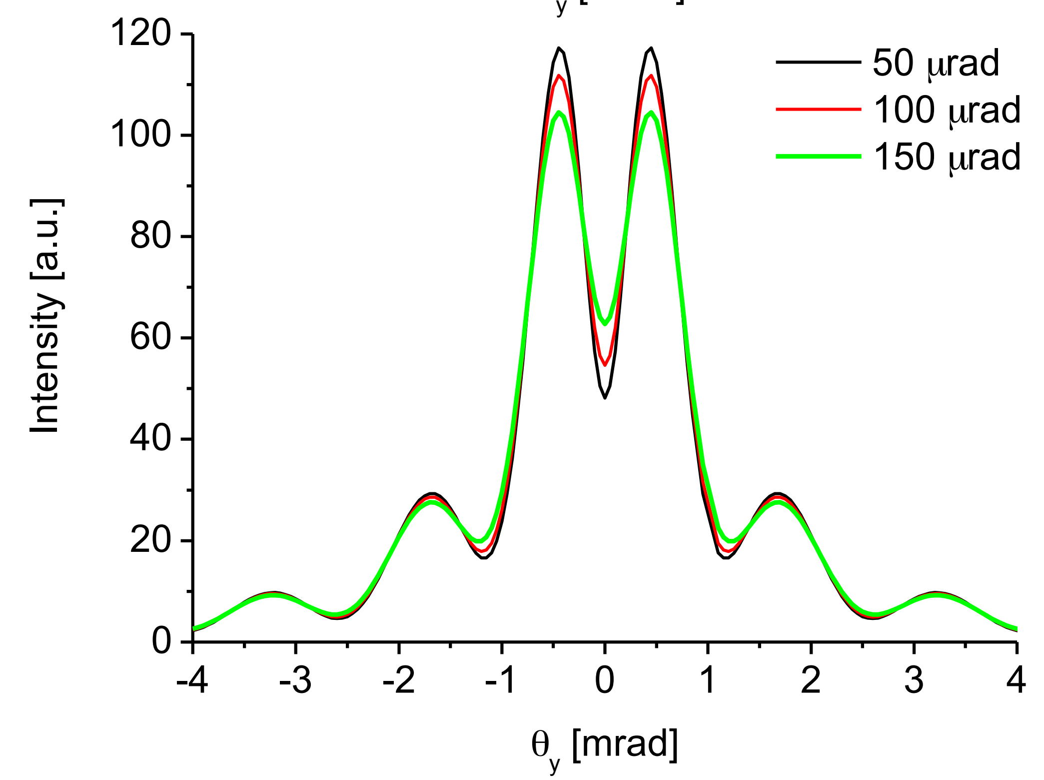


DR Angular Distribution

- The visibility of the interference fringes can be used to determine the transverse size of a bunch of electrons crossing the slit



- The beam **angular divergence** gives rise to a **reduced fringes visibility**, opening the way to a possible single shot emittance measurement.



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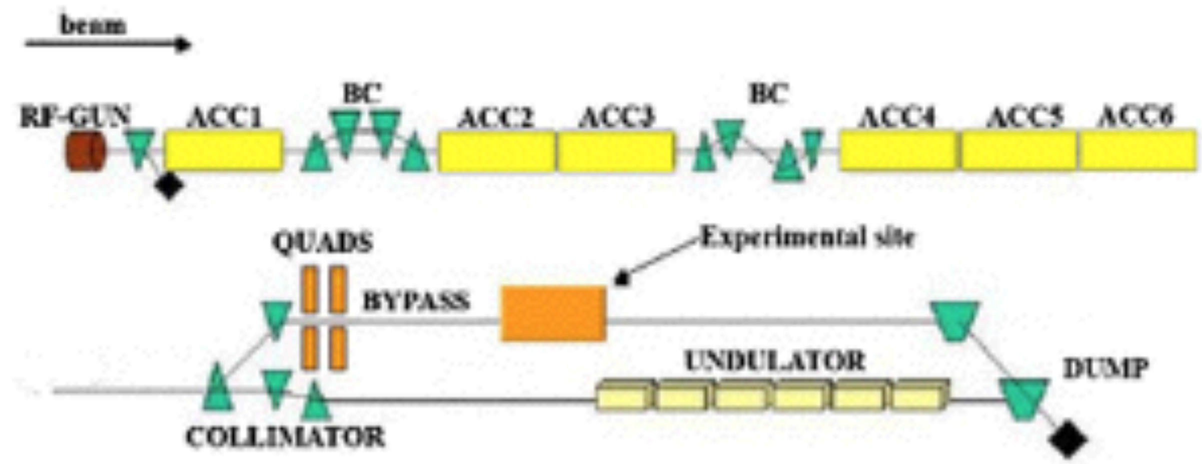
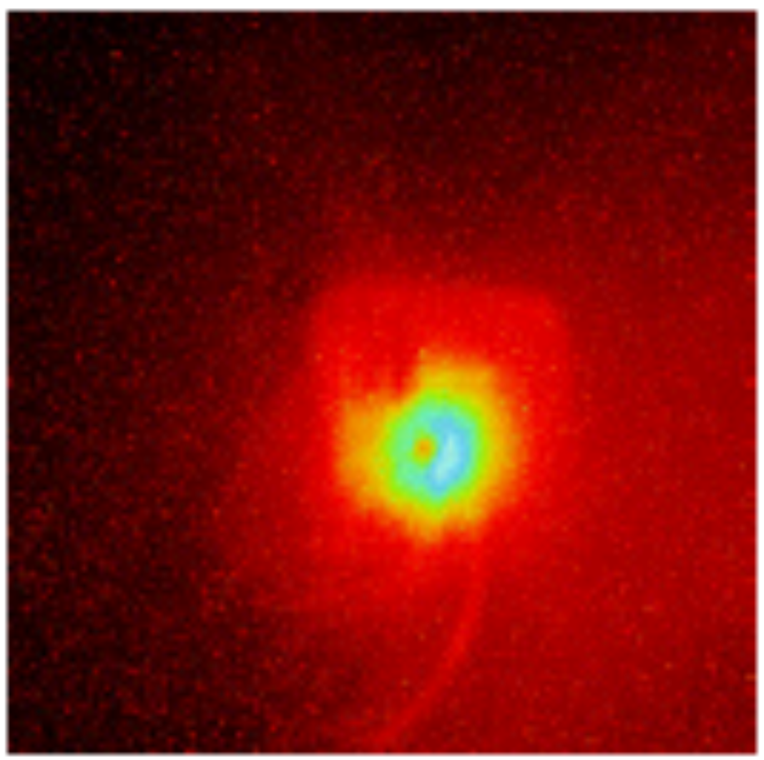
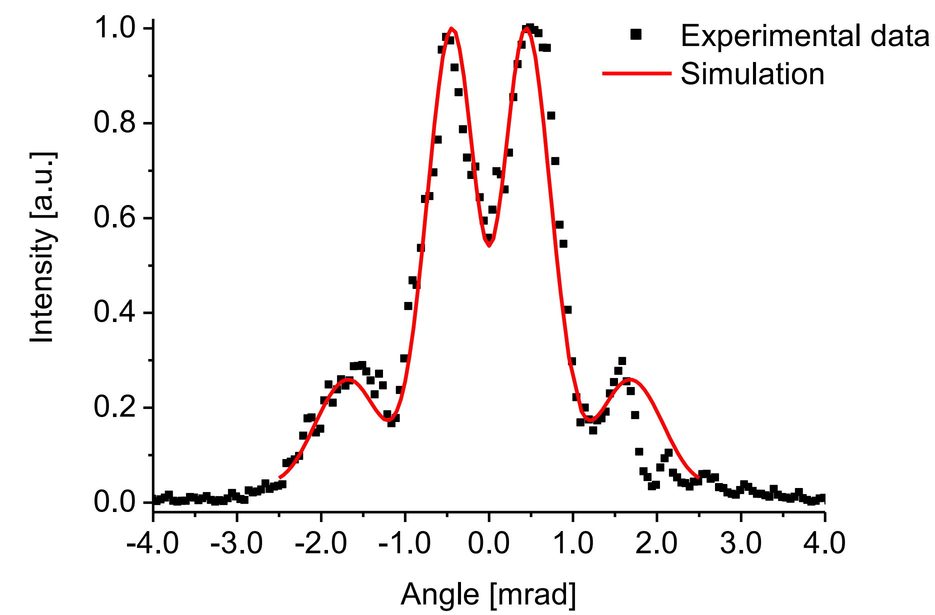
Single slit geometry

Measurements were done at FLASH (DESY)



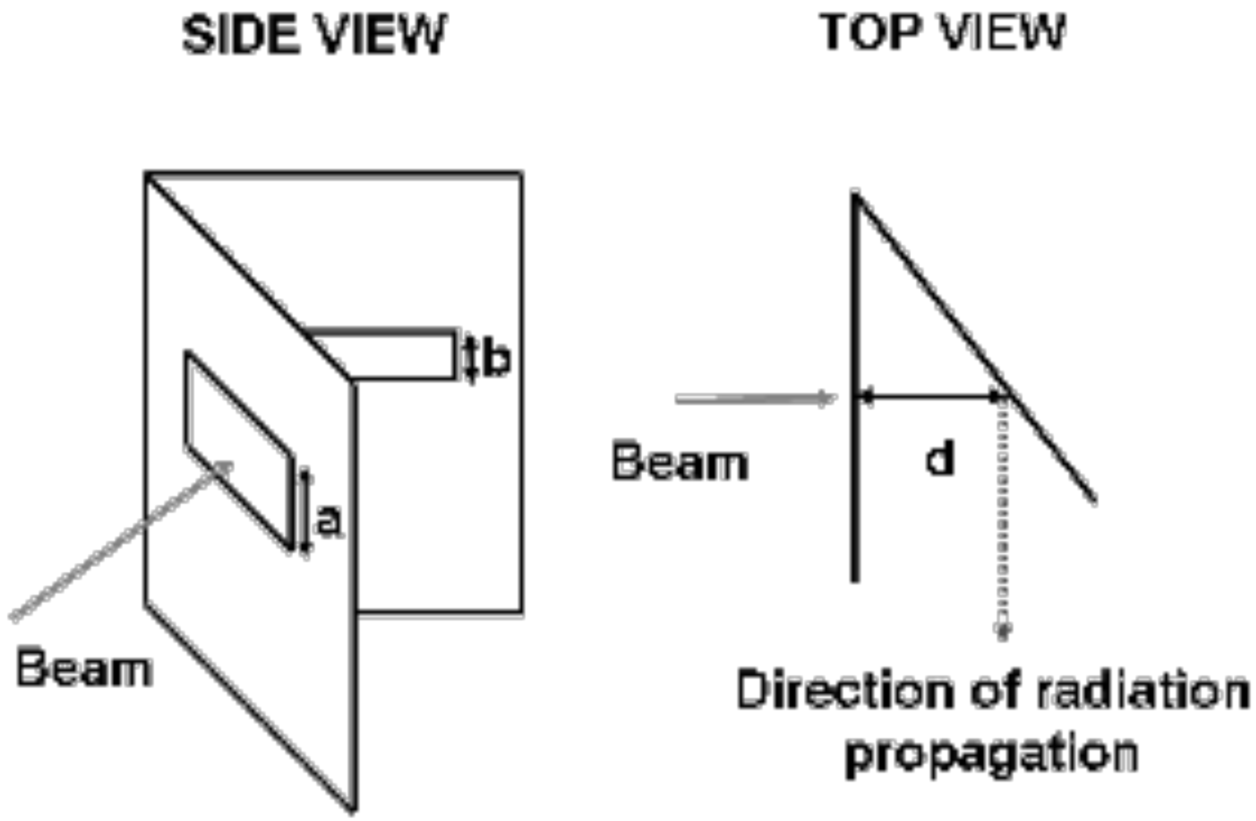


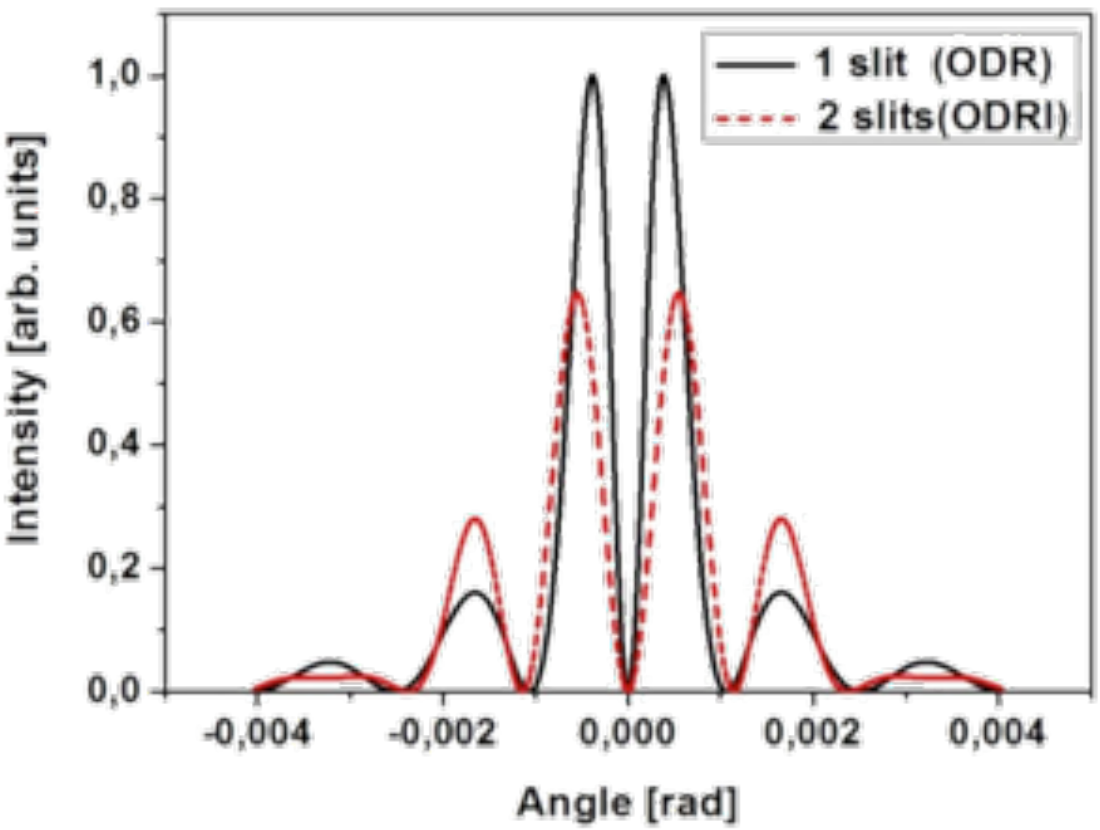


Mainly synchrotron radiation, coming from bending magnets and quadrupoles upstream, and reflected from the vacuum chamber walls

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

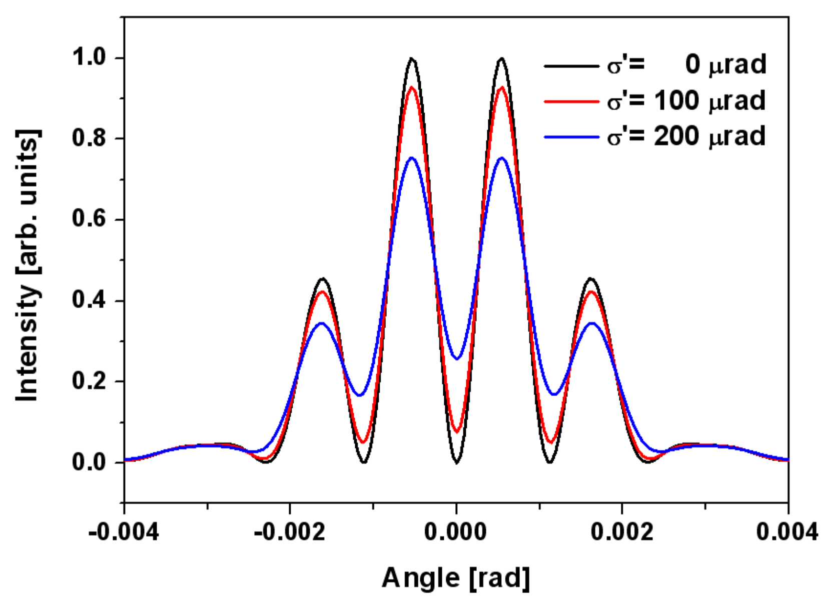
DR from two slits



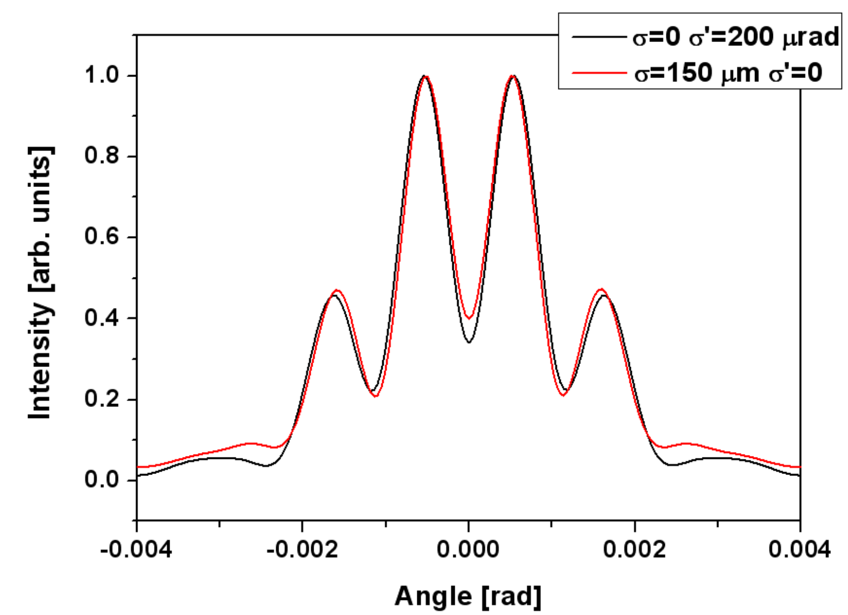


Optical **D**iffraction **R**adiation **I**nterference (ODRI)

Effect of non collinear slits



Point like beams with different angular spread



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

A. Cianchi et al.,
Non-intercepting electron beam size monitor using optical diffraction radiation interference,
PRST AB **14**, 102803 (2011)

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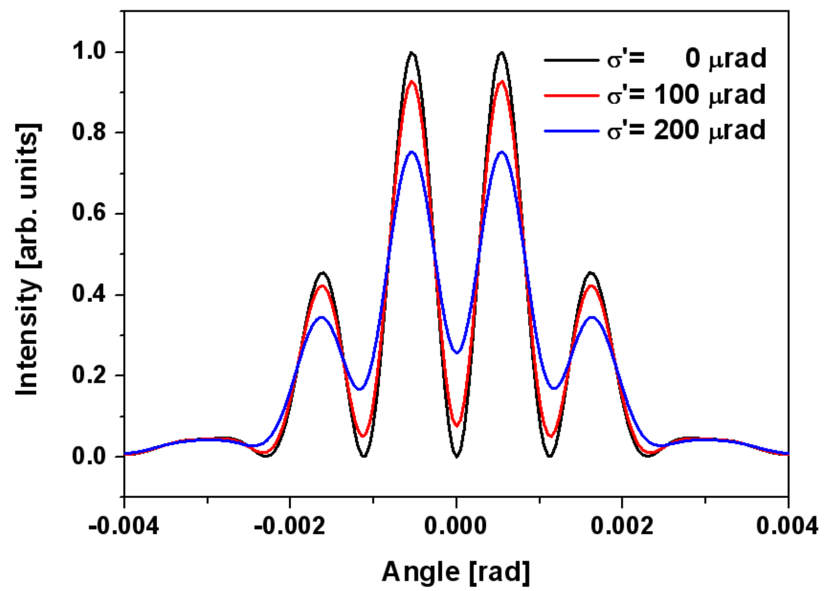

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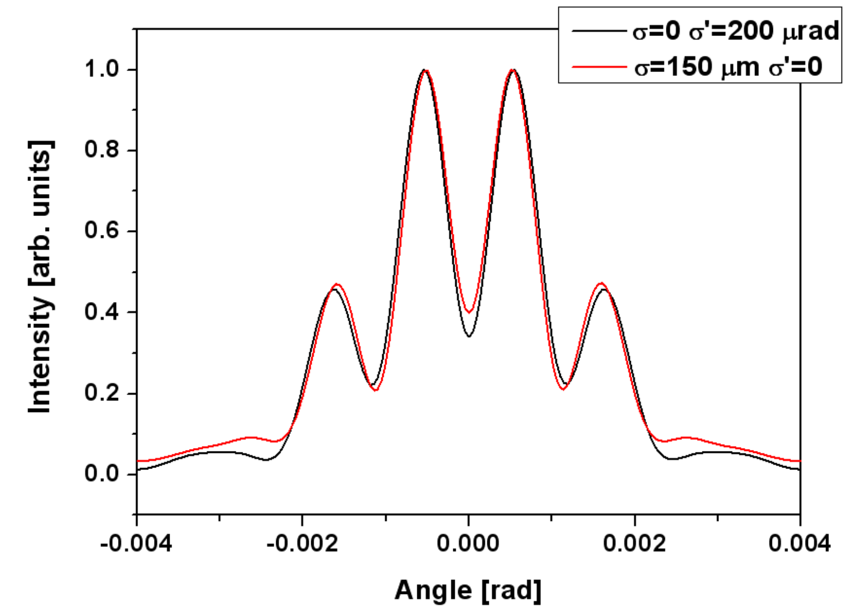

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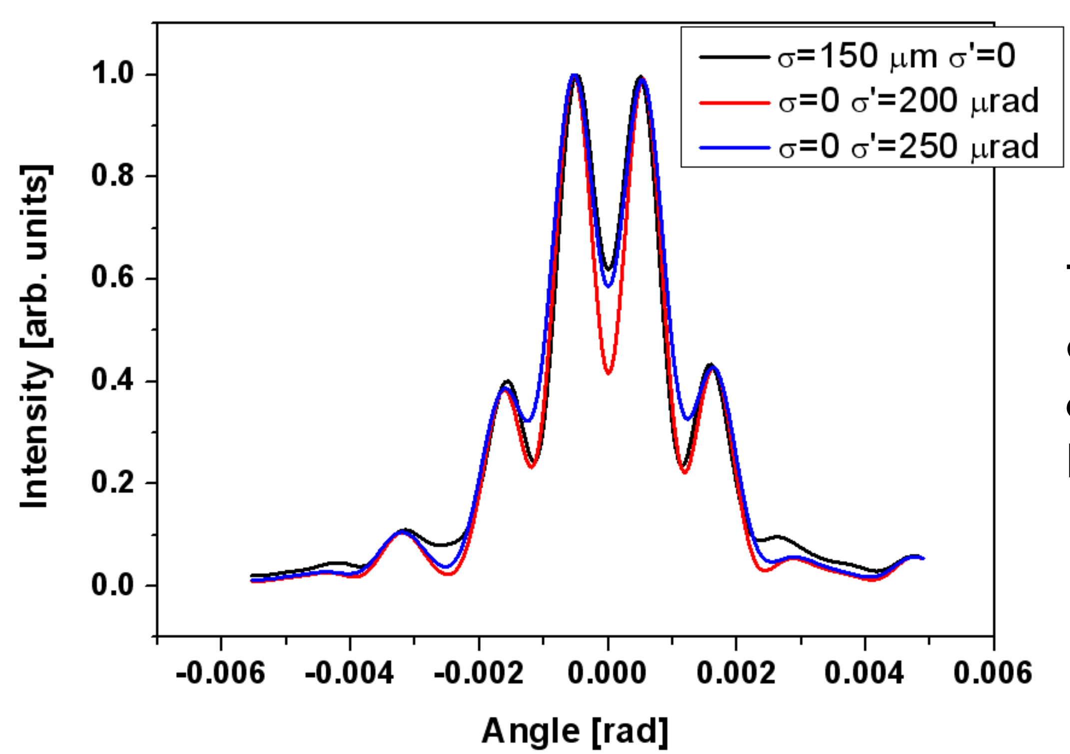

The 50 μm offset between the slits is enough to avoid mixing between the contributions of angular spread and beam size

A. Cianchi et al.,
Non-intercepting electron beam size monitor using optical diffraction radiation interference,
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ODRI Angular distribution

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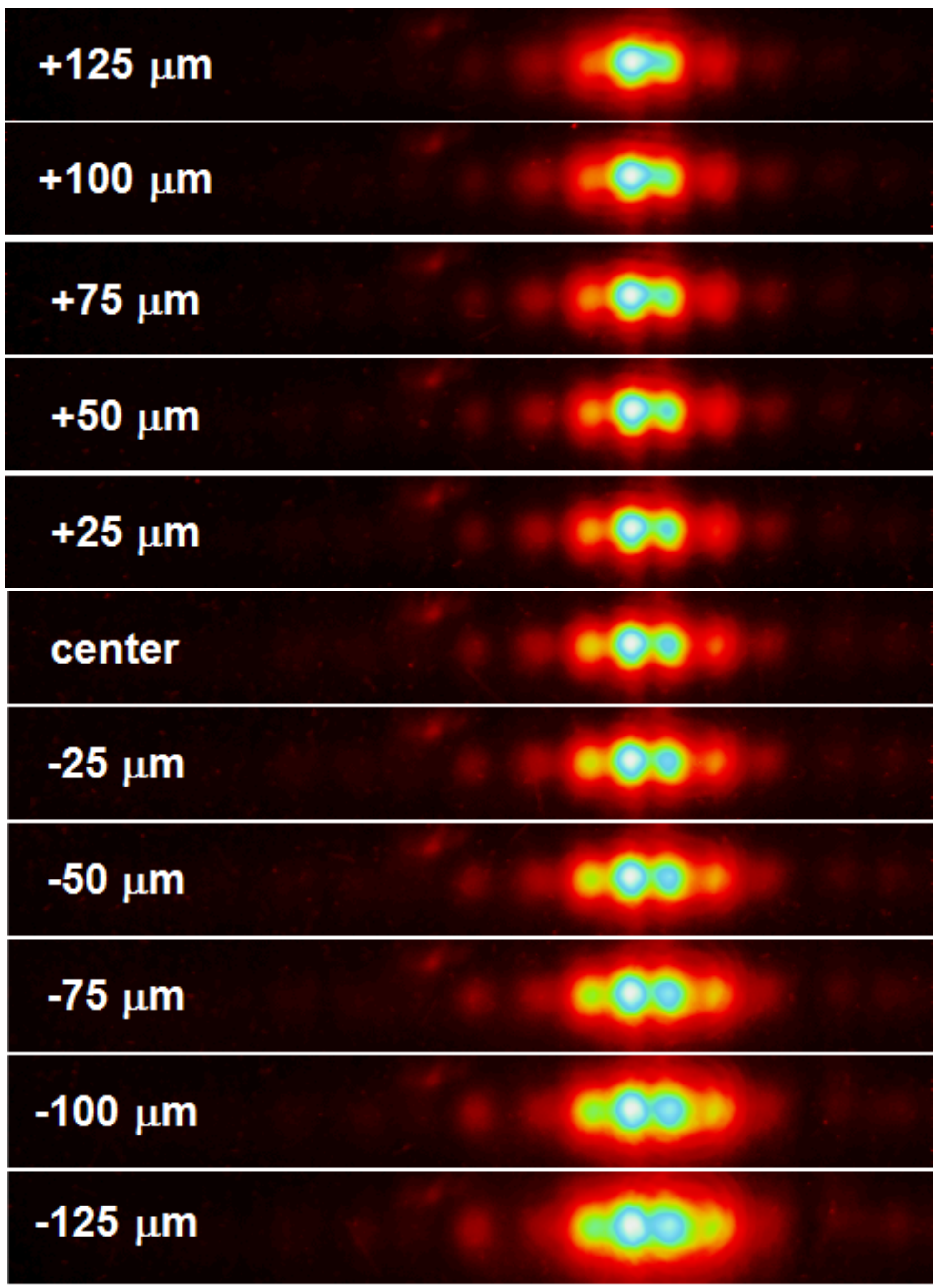
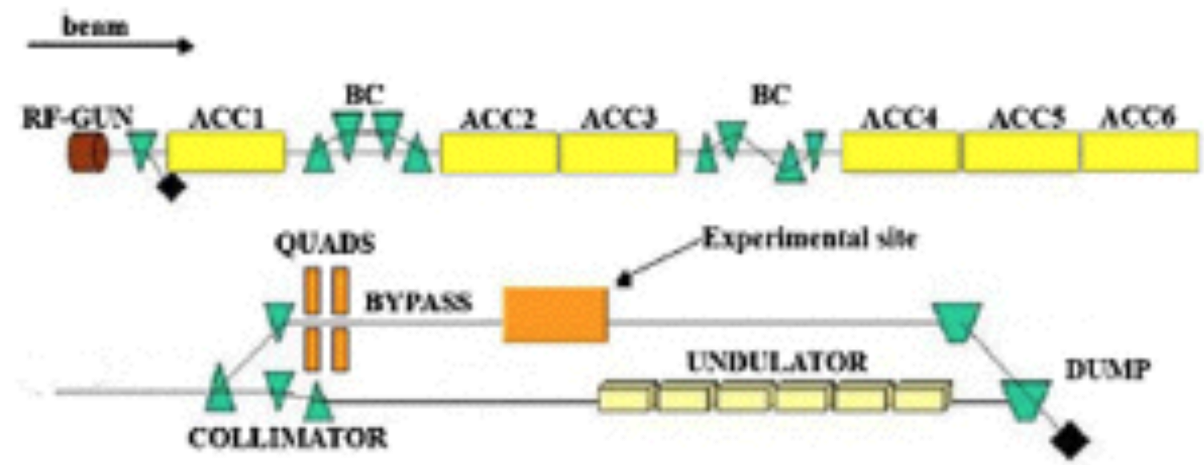
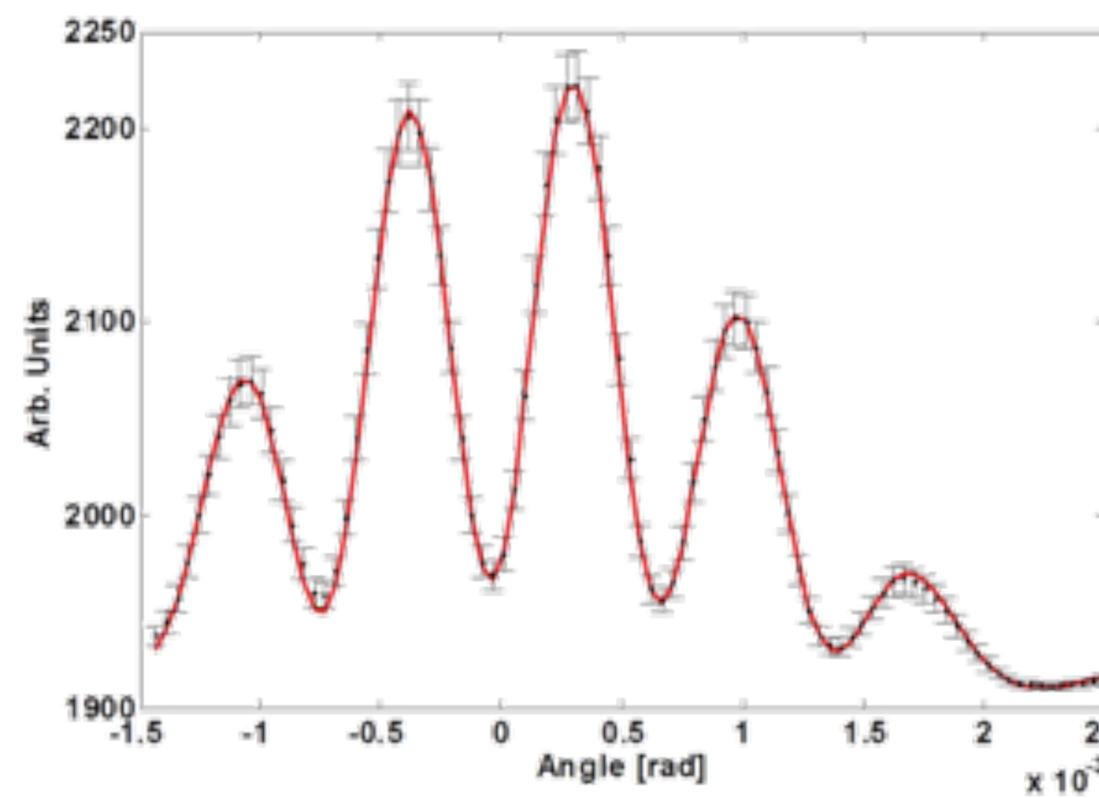




1 GeV, up to 30 bunches,
up to 1 nC/bunch,
10 Hz rep rate



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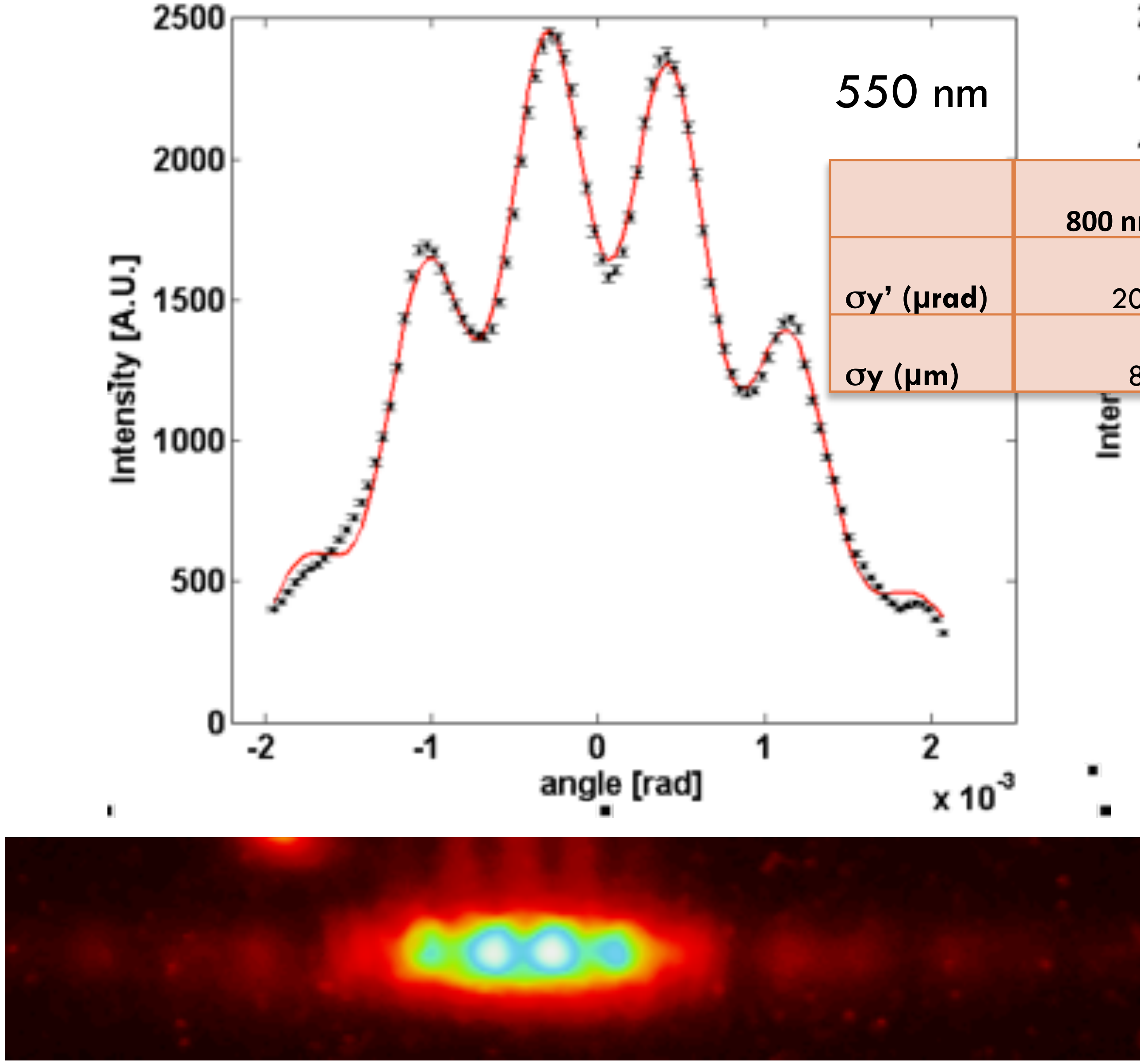
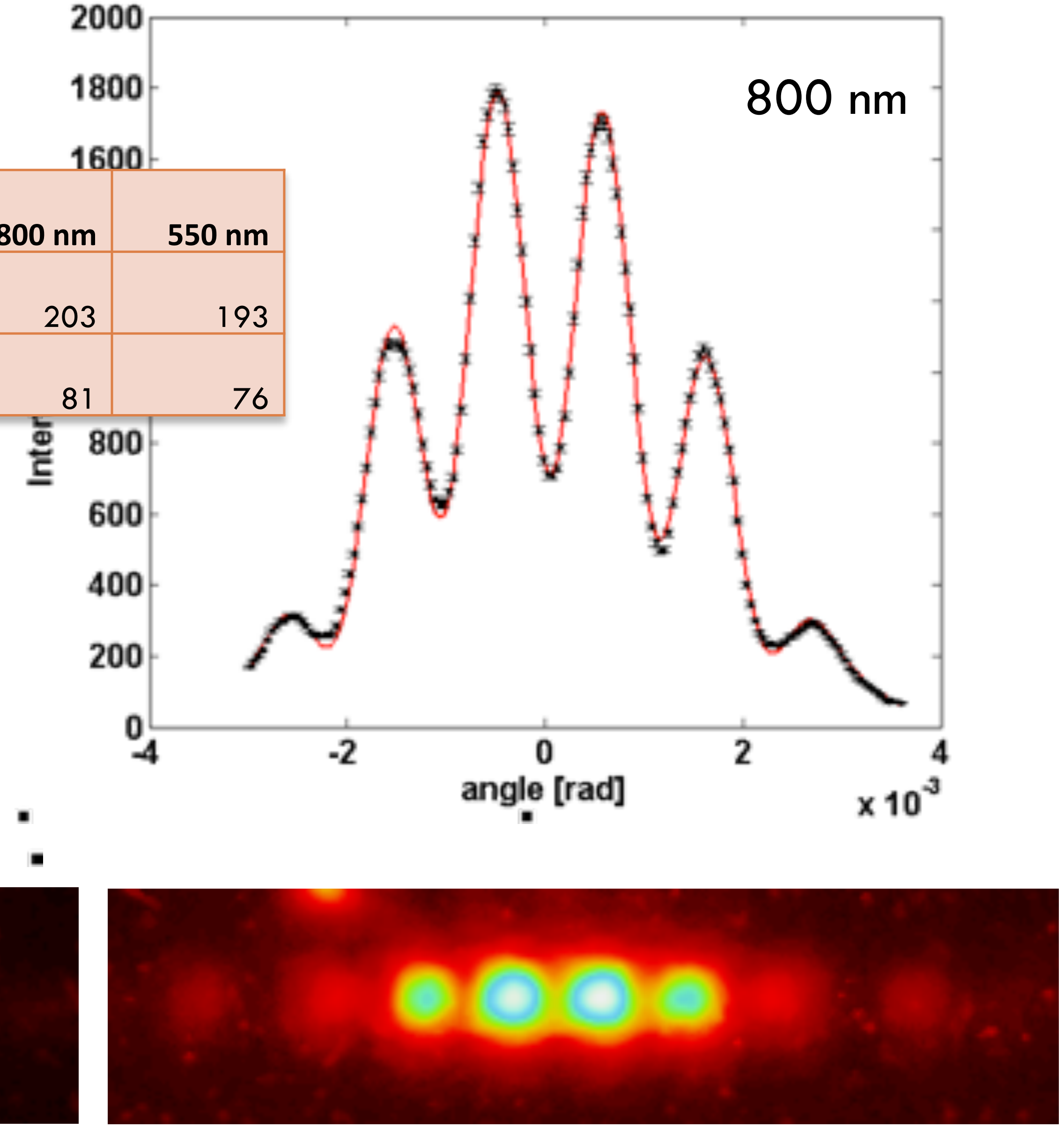
Effect of different wavelengths





	800 nm	550 nm
σy' (μrad)	203	193
σy (μm)	81	76

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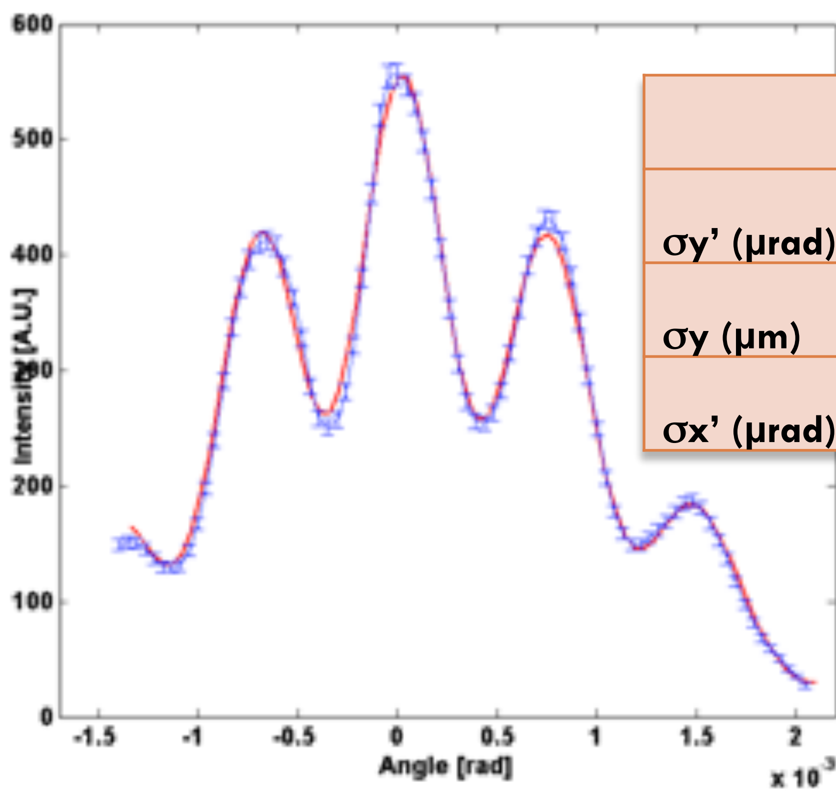
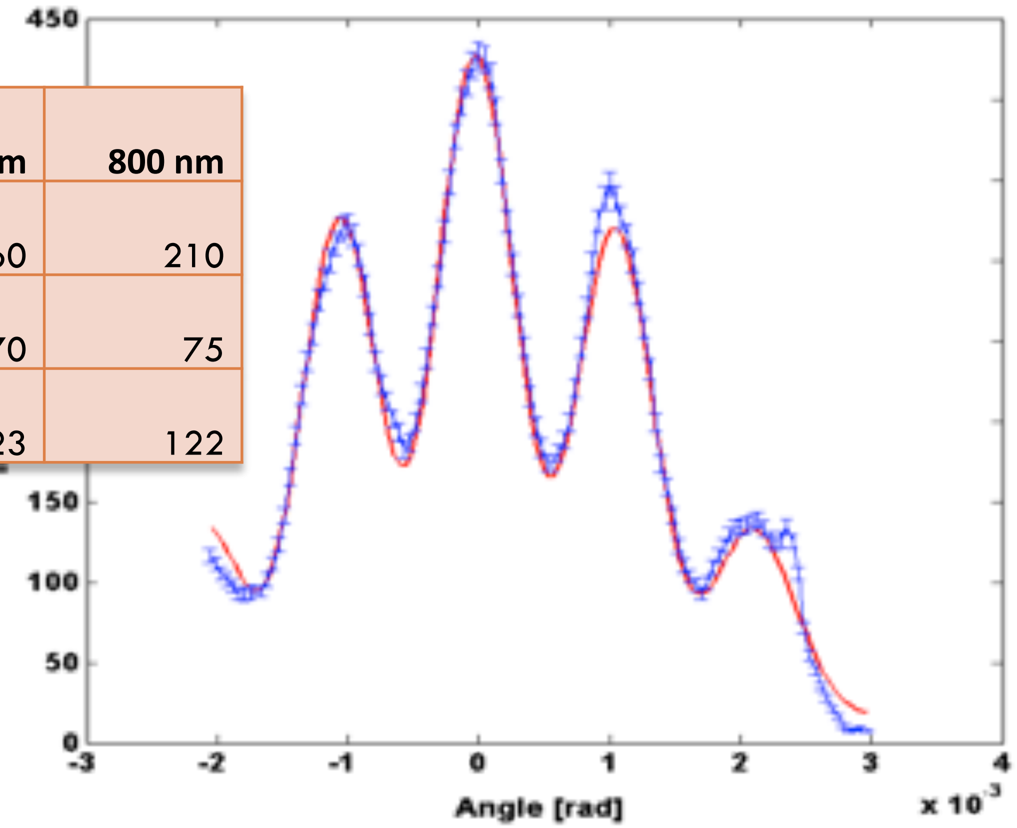
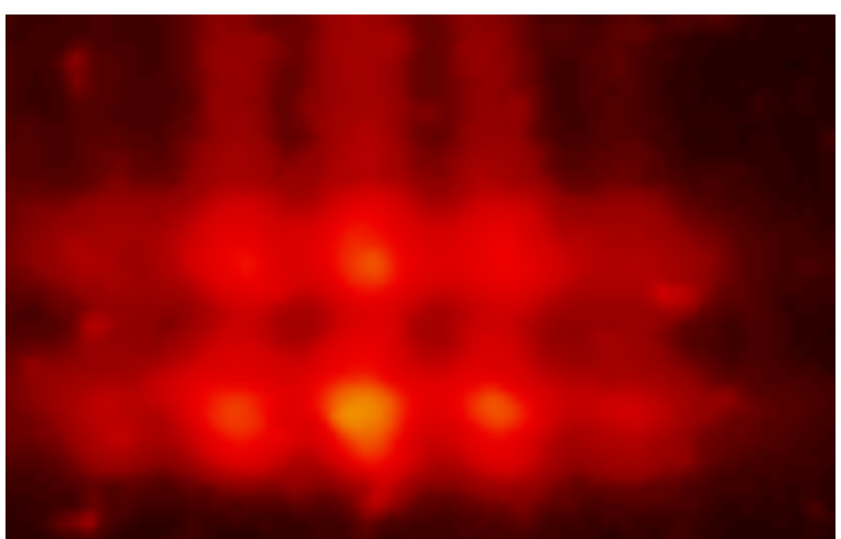
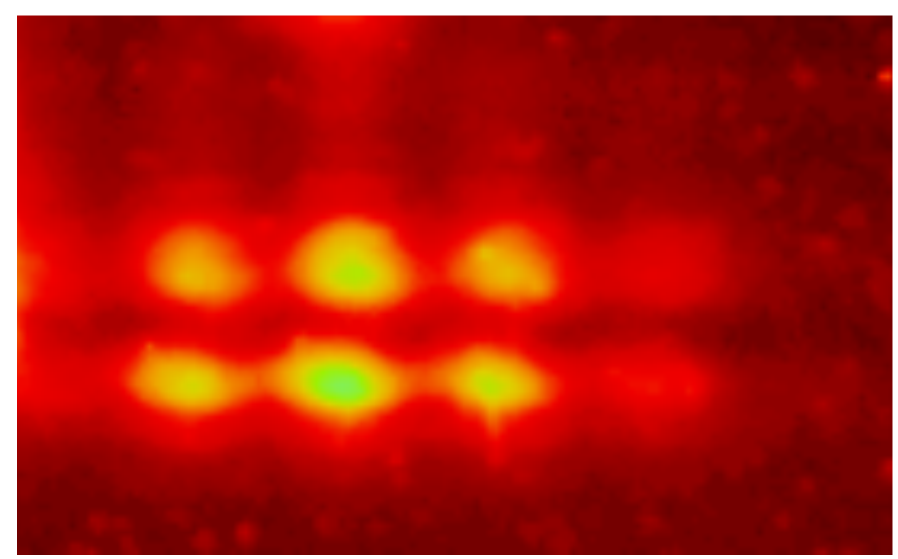
Horizontal polarization



	550 nm	800 nm
σy' (μrad)	160	210
σy (μm)	70	75
σx' (μrad)	123	122







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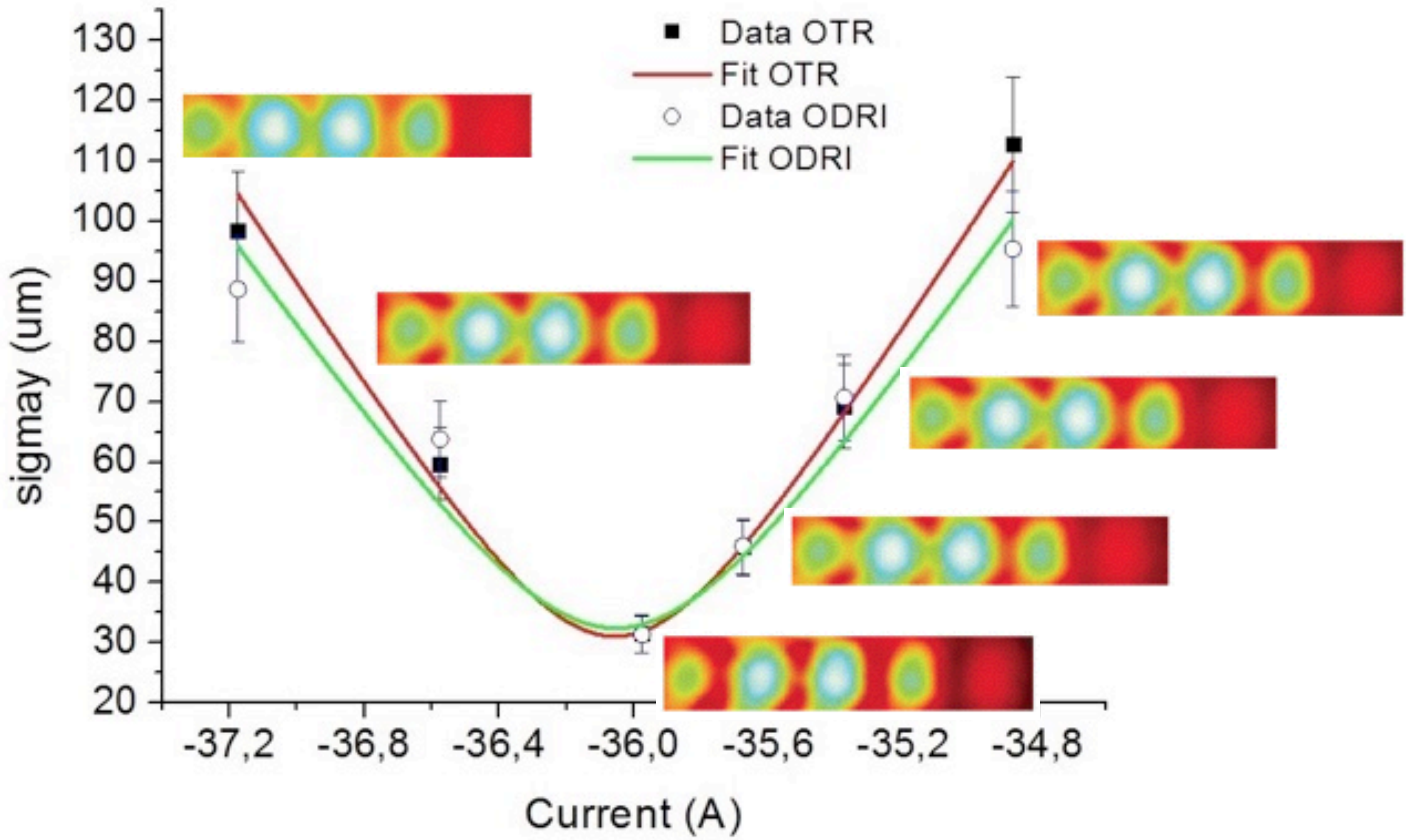
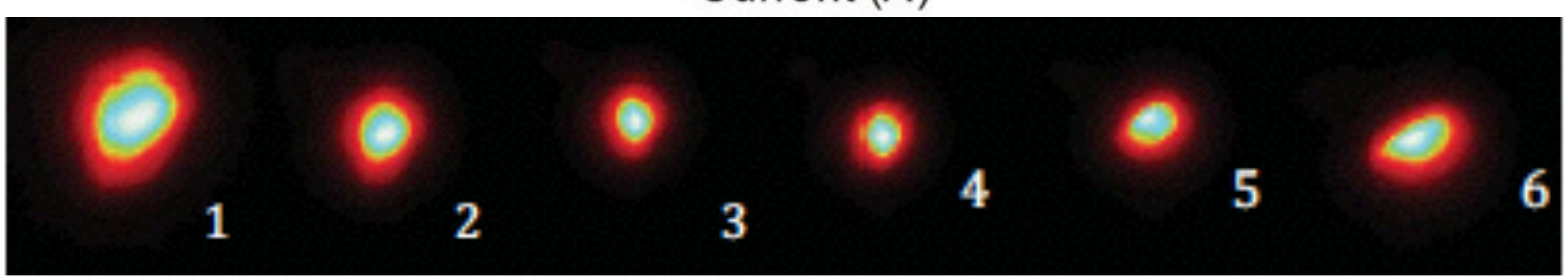
Non-intercepting quadrupole scan

1 GeV
20 pulses
200 pC/pulse
10 Hz
2 s CCD integration time
=> **80 nC** integrated charge



OTR images
1 pulse, 200 pC



ε=2.3 (0.4) mm mrad for the ODRI and ε=2.4 (0.4) mm mrad for the OTR

A. Cianchi et al.,
First non-intercepting emittance measurement by means of optical diffraction radiation interference
New Journal of Physics **16** (2014) 113029

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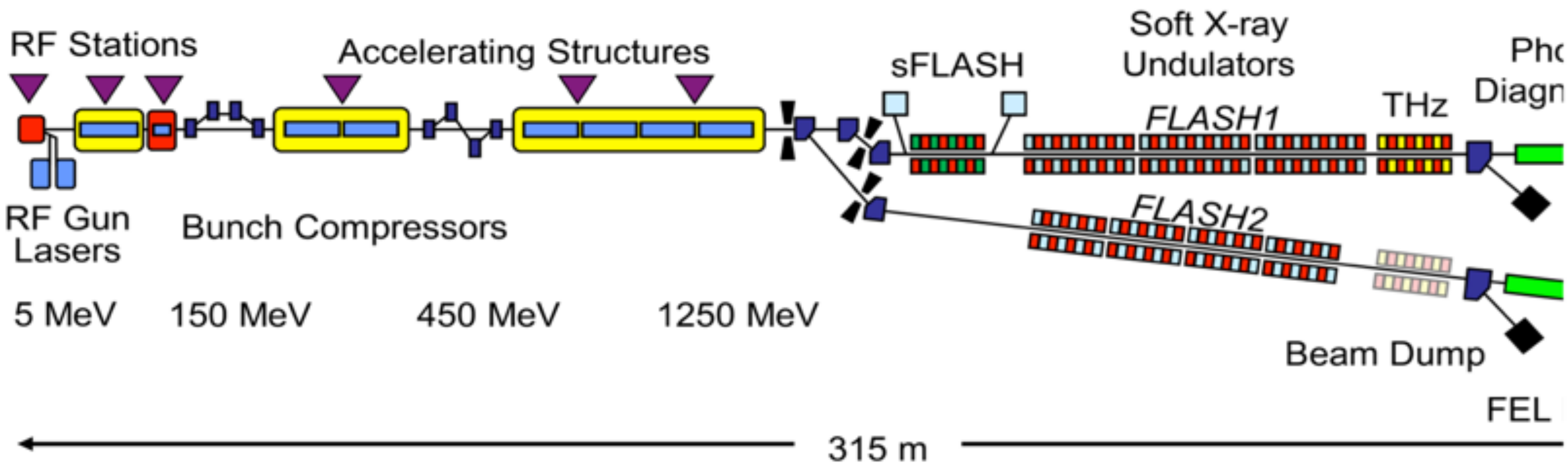
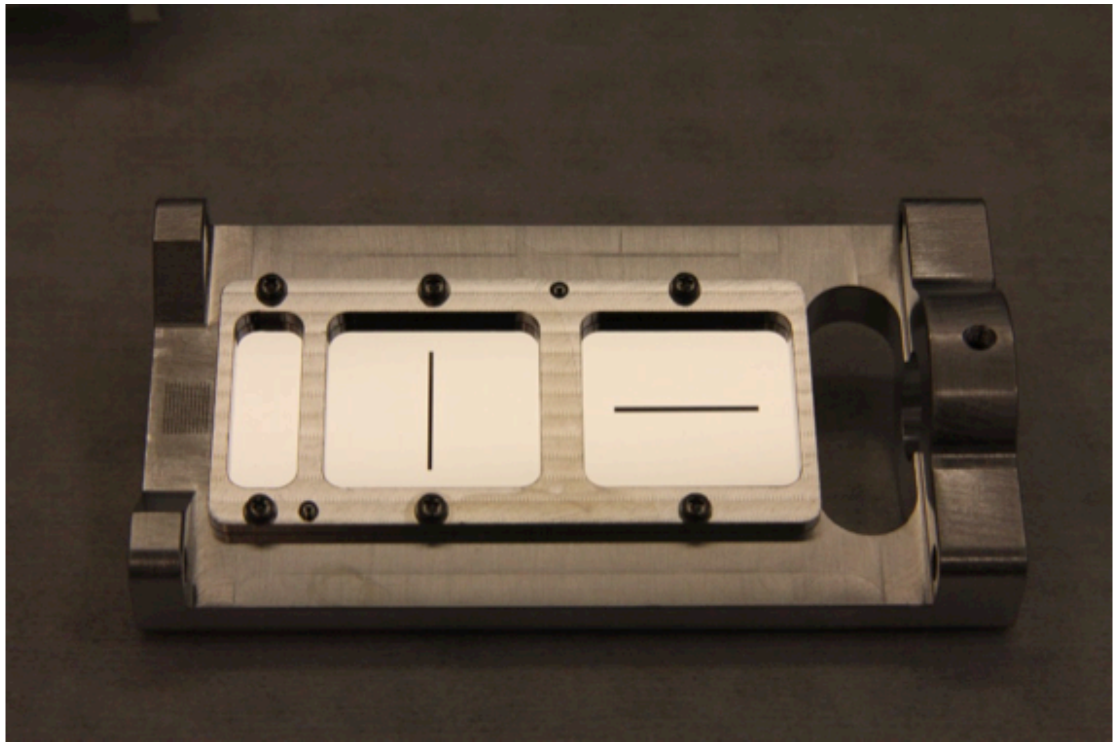
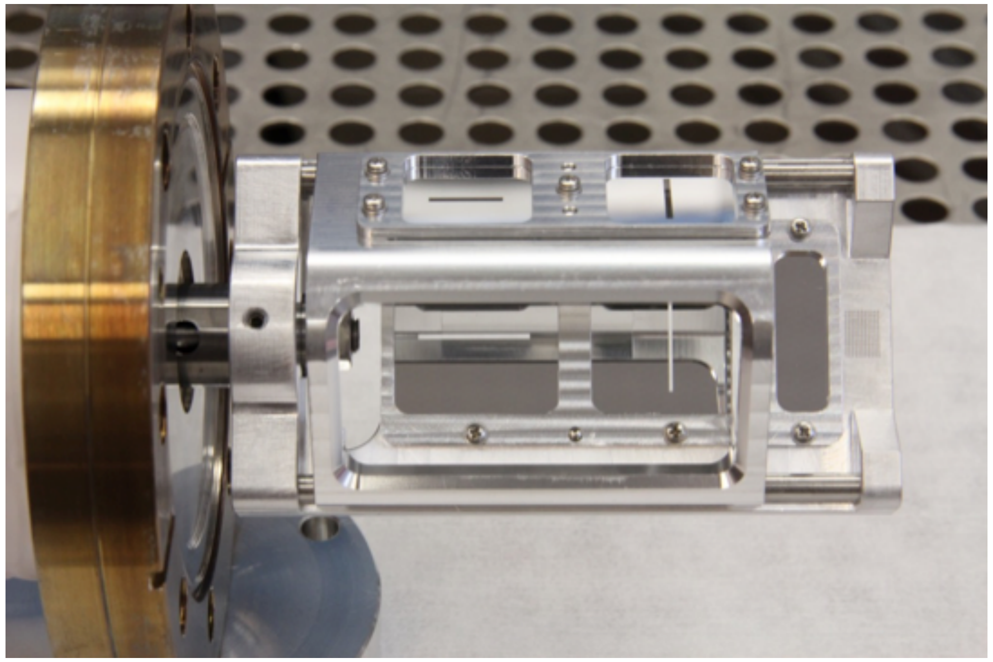
The Next Future







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Conclusions

- **ODR allow for non intercepting emittance measurements**, avoiding heat deposition
  - The first complete non-intercepting quadrupole scan has been reported
- ODR is mainly polarized in the plane perpendicular to the slit edge, but information on the plane parallel to it can be extracted and a lot needs to be investigated
- **ODRI allows** not only to suppress synchrotron radiation background, but mostly **to avoid mixing of beam size and angular divergence contribution**
- From ODR angular distribution, we get the beam size but not the profile
  - **ODR imaging**
    - real time monitoring of the **beam position** in the direction perpendicular to the slit edge (with μm scale resolution)
    - retrieval of the **beam profile** by deconvoluting the image with the point spread function

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