OPTICAL DIFFRACTION RADIATION INTERFERENCE AS A NON-INTERCEPTING EMITTANCE MEASUREMENT FOR HIGH BRIGHTNESS AND HIGH REPETITION RATE ELECTRON BEAM

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On behalf of ODRI collaboration

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34th International Free Electron Laser Conference

ODRI Collaboration

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- LNF
  - M. Castellano, E. Chiadroni, M. Migliorati

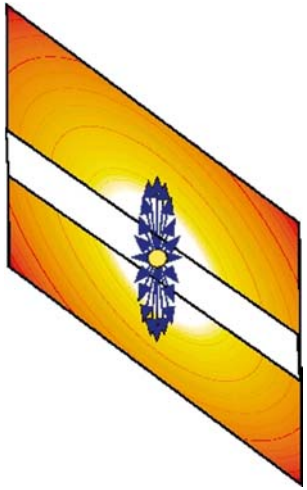
- Desy Hamburg
  - K. Honkavaara, G. Kube, N. Golubeva, V. Balandin

Goal

- High Brightness / High repetition rate beams deposit unsustainable amount of energy in intercepting device
- Our goal is the development of a new non-intercepting (and hopefully non-disturbing) diagnostic in order to measure the emittance in a parasitic way

Diffraction Radiation

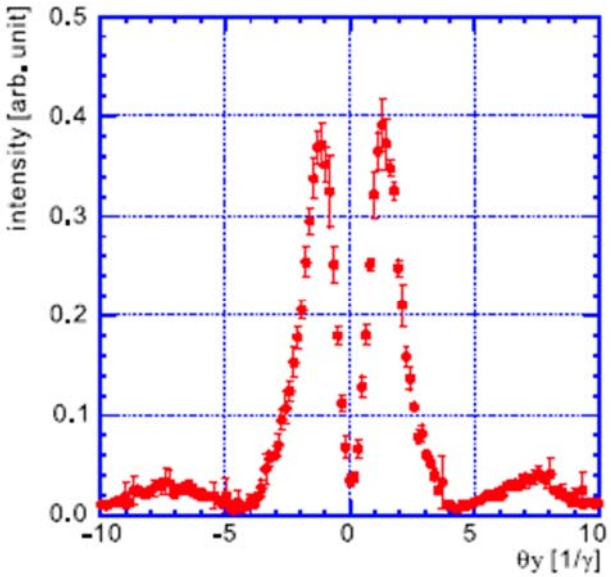
- The charge goes into the hole without touching the screen
- The electromagnetic field of the moving charge interacts with the metallic screen
- No power is deposited on the screen
- The angular distribution of the emerging radiation is affected by the beam transverse size, the angular spread and the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



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

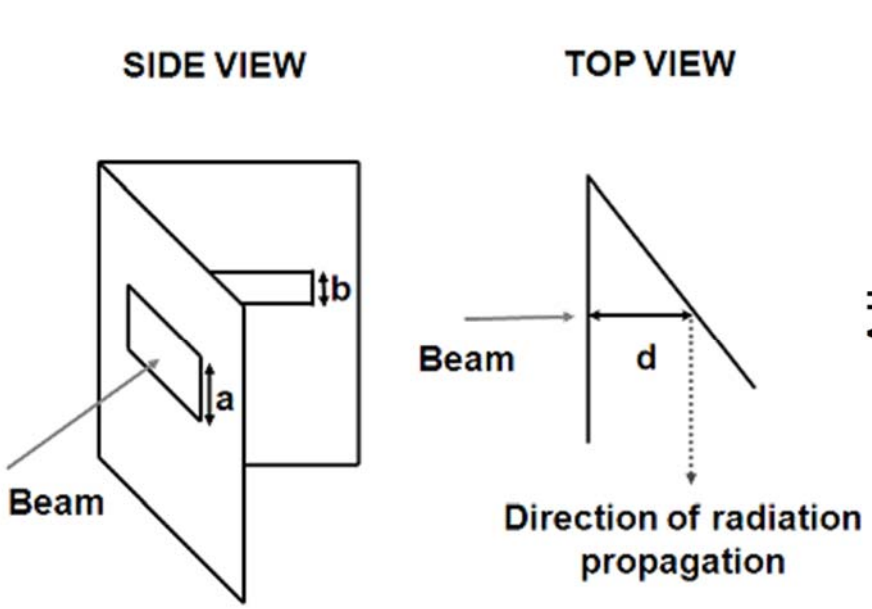
First experiment @ KEK

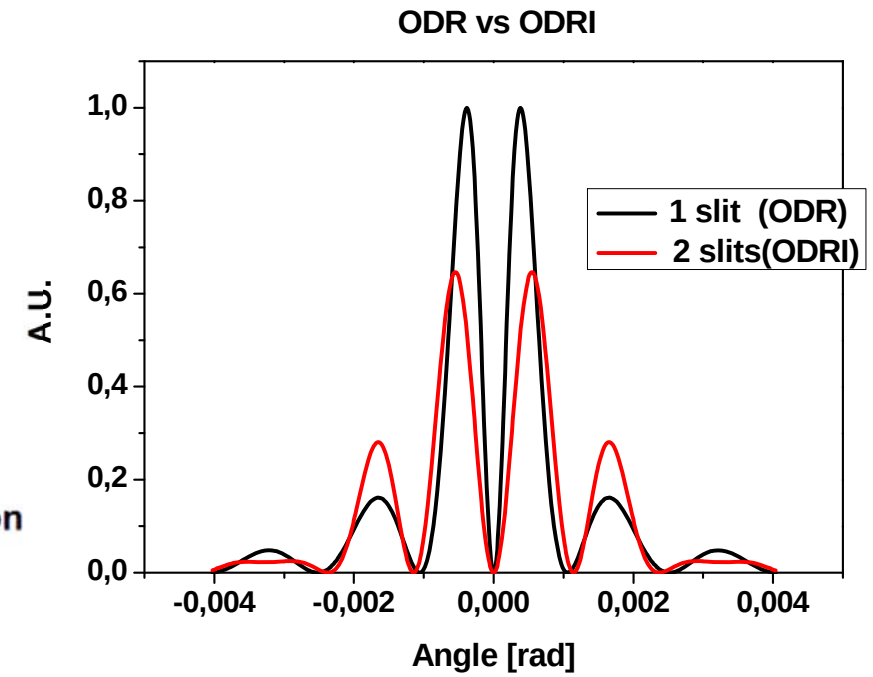
P. Karataev et al., "*Beam-Size Measurement with Optical Diffraction Radiation at KEK Accelerator Test Facility*", Phys. Rev. Lett. 93, 244802 (2004)



- **Weak signal vs strong background, coming mainly from Synchrotron Radiation**
- **Precise control of the beam position inside the slit needs a complementary diagnostics**

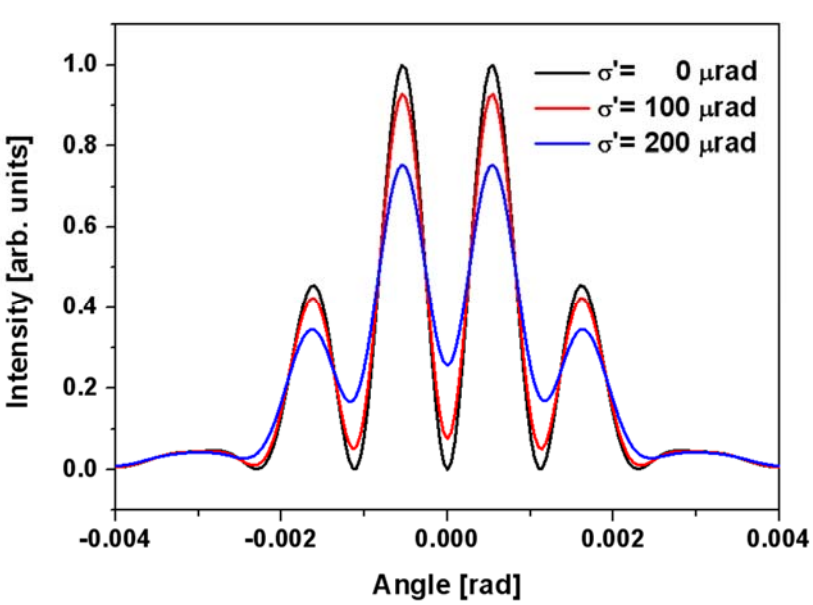
Introducing ODRI



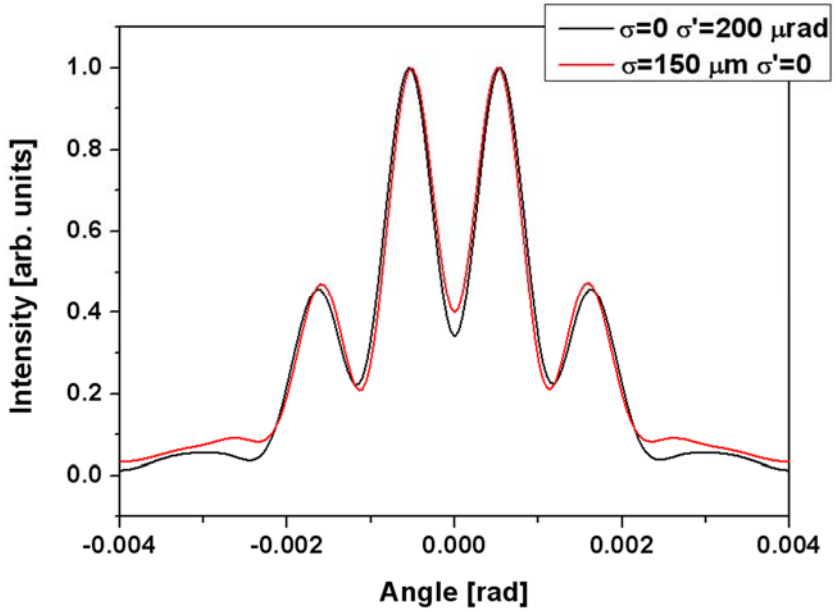


Optical Diffraction Radiation Interference

Collinear slits



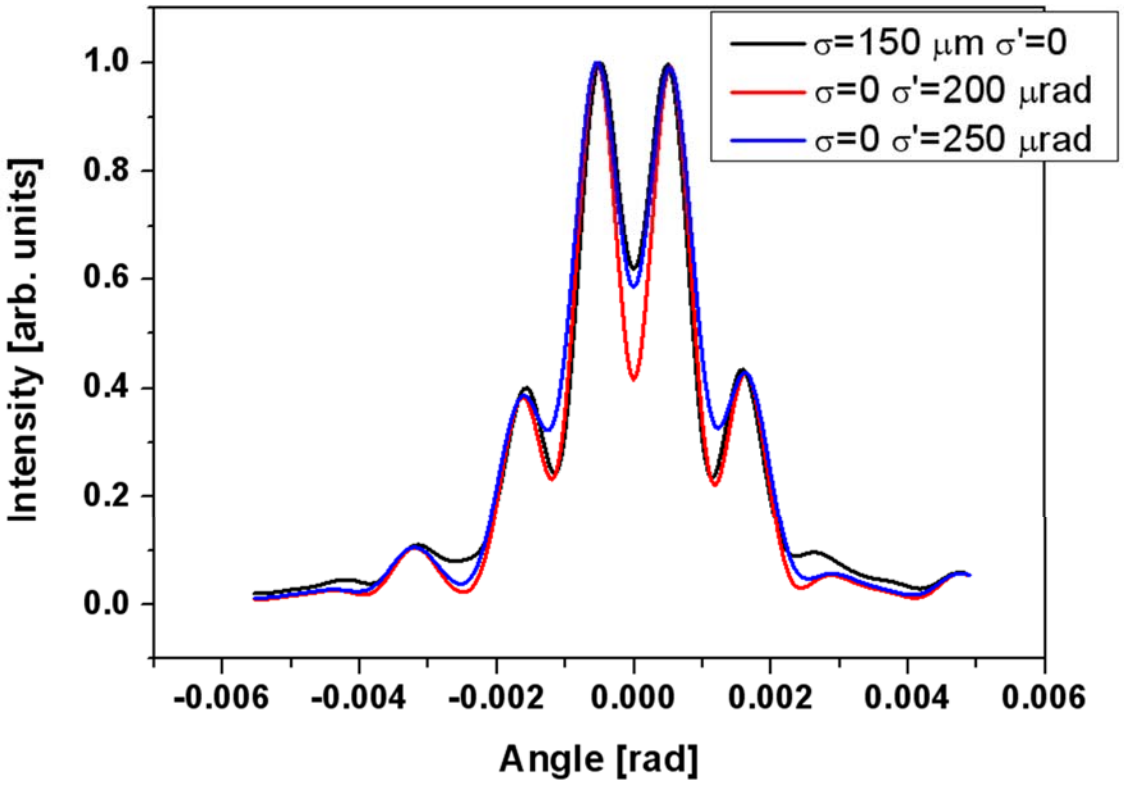
Point like beams with different angular spreads



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

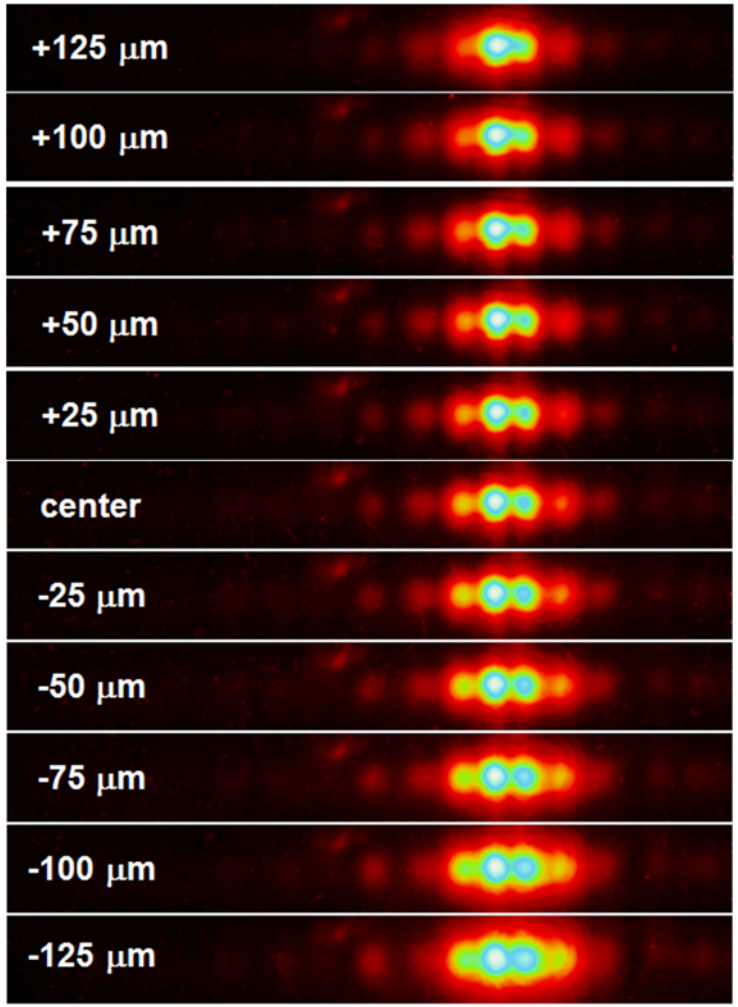
Non collinear slits

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



Angular distribution

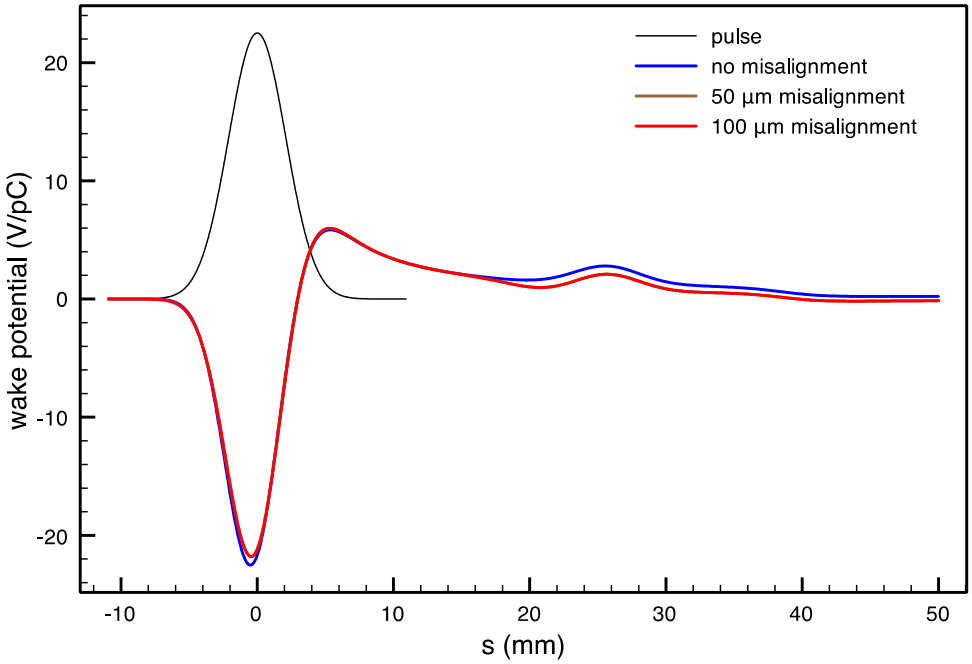
- We moved together the two slits with respect to the beam position.
- The slit misalignment resolves in an asymmetric distribution from top to bottom, solving the problem of the complementary diagnostic



Longitudinal wake

$$K_{l\|} = \int_{-\infty}^{\infty} W_{P\|}(z)\rho(z)dz \quad \textbf{(V/C)}$$

$$\sigma_\varepsilon^2 = \int_{-\infty}^{\infty} \left(W_{P\|}(z) - K_{l\|}\right)^2 \rho(z)dz \quad \textbf{(V/C)}^{\,2}$$



$K_{L\|}$ =13.5 V/pC ➔ (200 pC) ➔ 2.7 keV

σ_ε =7.8 V/pC➔(200 pC)➔1.6 keV➔(1 GeV)➔1.6e-6

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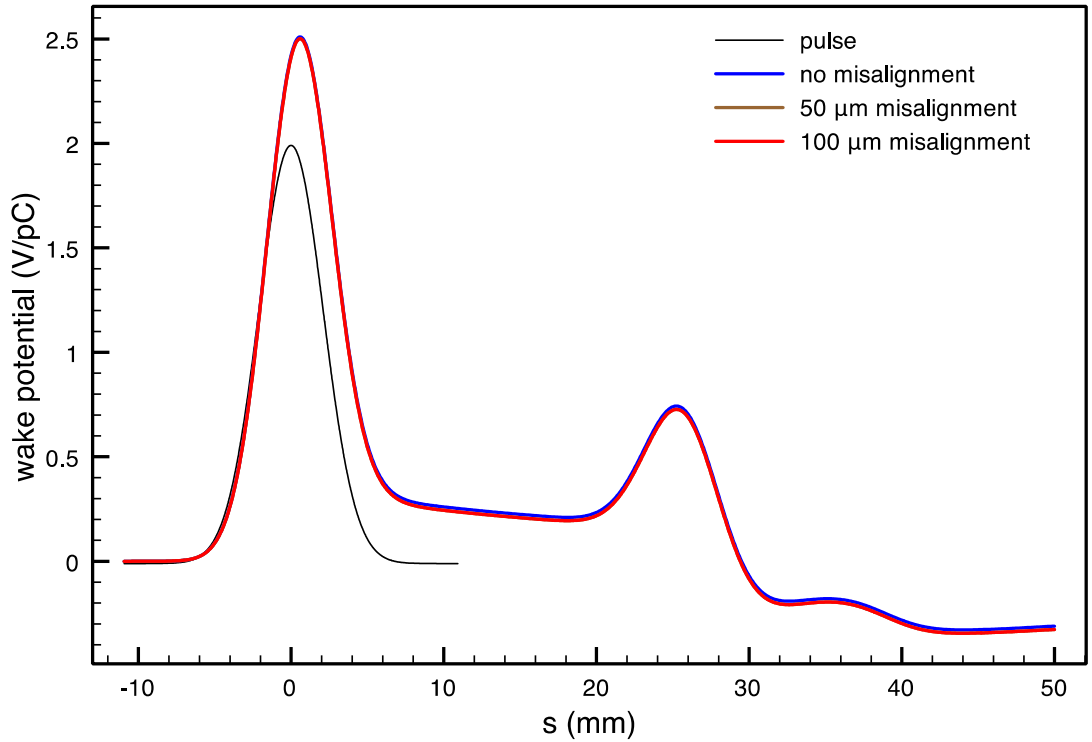
Transverse horizontal wake



independent of the vertical misalignment of the first perpendicular slit (small displacements)

y'_c=1.8 V/pC ➔ (200 pC) ➔ 0.36 keV ➔ 3.6e-7 rad

$\sigma_{y'}$ =0.68 V/pC ➔ (200 pC) ➔ 0.14 keV ➔ 1.4e-7 rad

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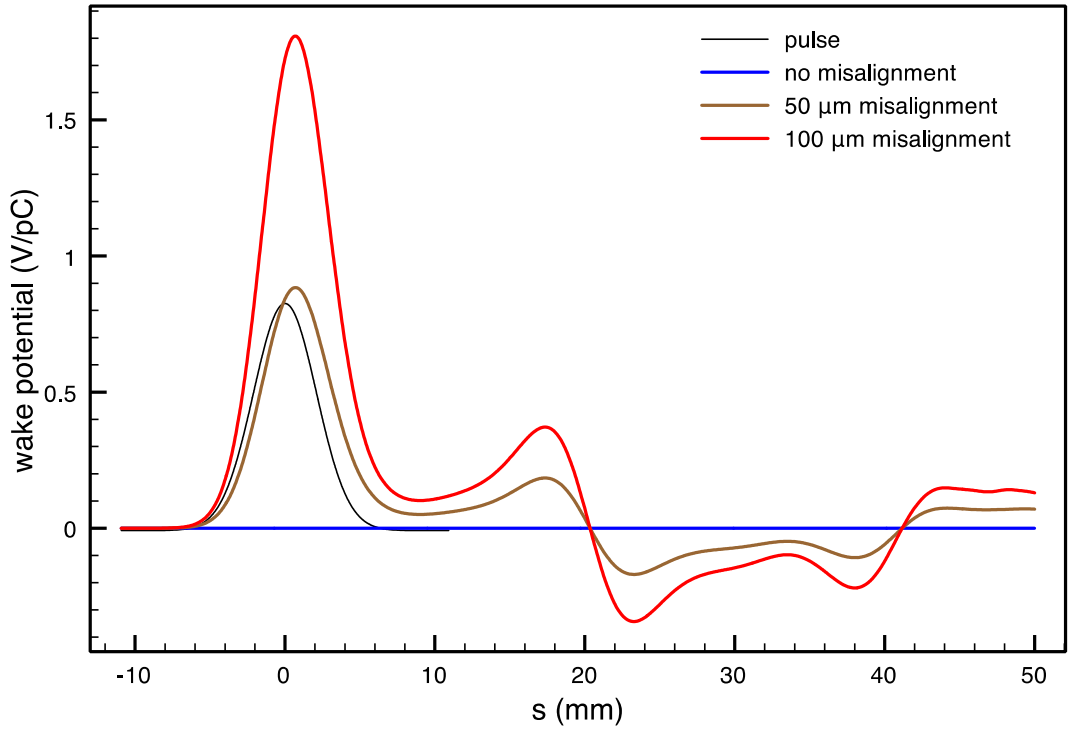
Transverse vertical wake



linear with the vertical misalignment of the first perpendicular slit (small displacements)

y'_c=0.63 V/pC ➔ (200 pC) ➔ 0.13 keV ➔ 1.3e-7 rad

$\sigma_{y'}$ =0.25 V/pC ➔ (200 pC) ➔ 0.05 keV ➔ 5e-8 rad

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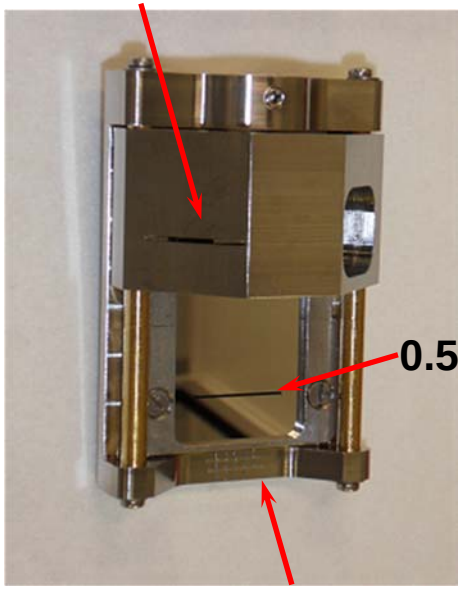
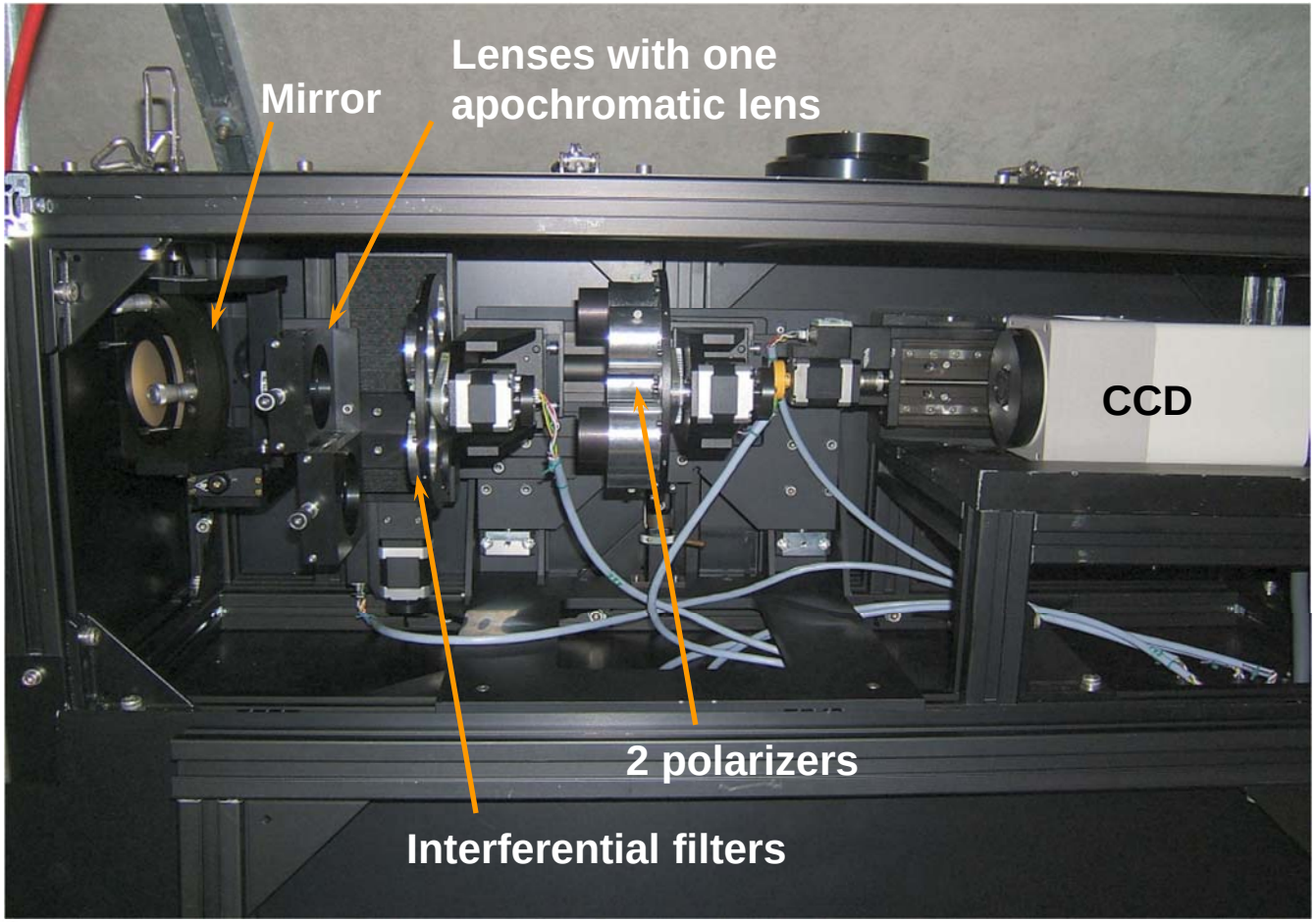
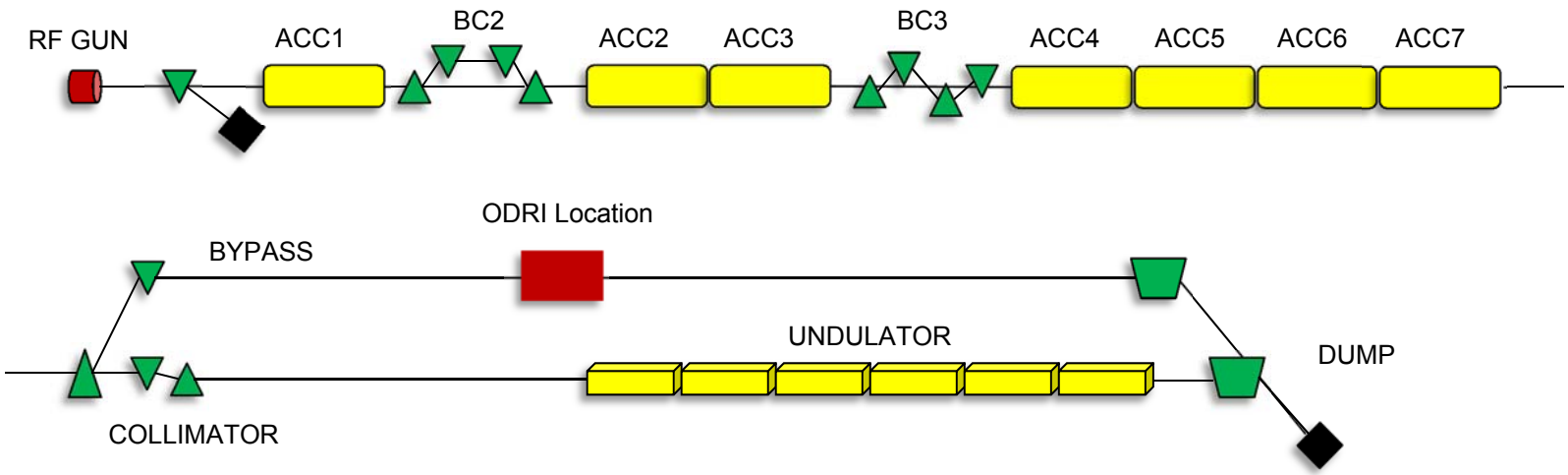
Experimental Setup



Optical System



Experiment @ FLASH



FLASH is an excellent linac for this experiment:

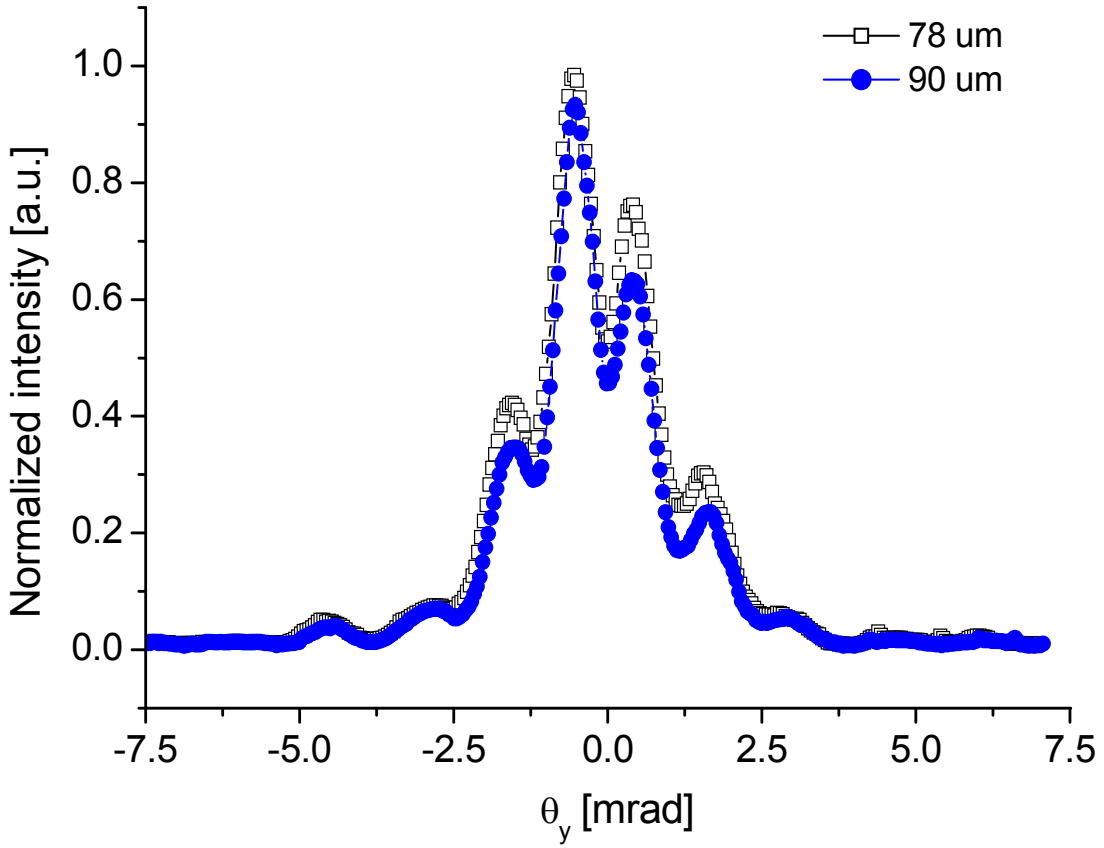
- **High energy up to *1 GeV***
- **Large number of bunches (up to 30) with high charge (up to 1 nC)**
- **Long collaboration history & big support**

Two different spots

OTR beam
78±4 μm
90±4 μm

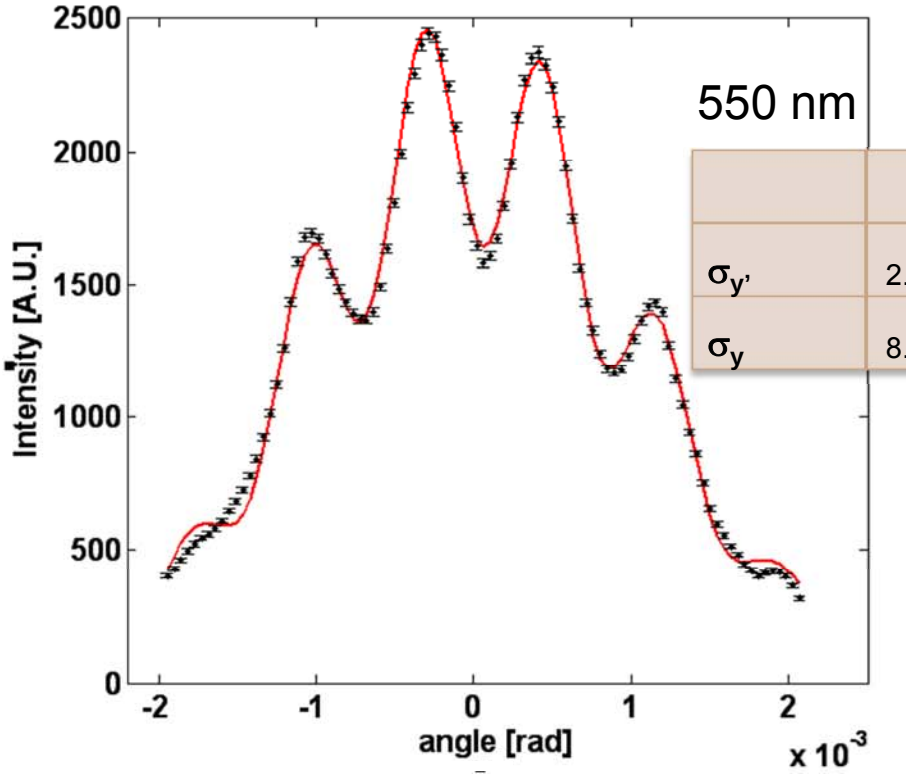
ODRI beam

82 μm
94 μm,

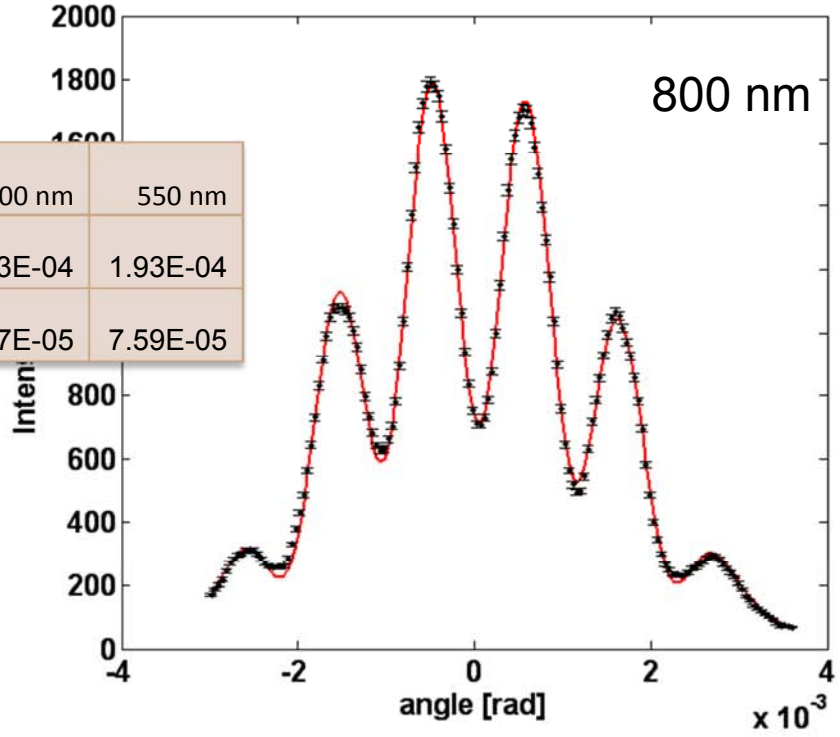


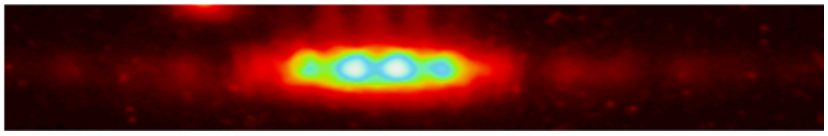
A. Cianchi et al. Physical Review Special Topics – Accelerators and Beams 14,102803 (2011)

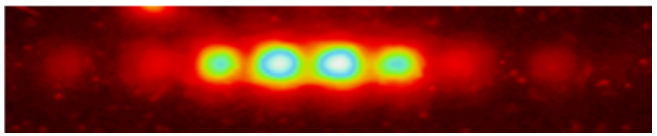
Different wavelength



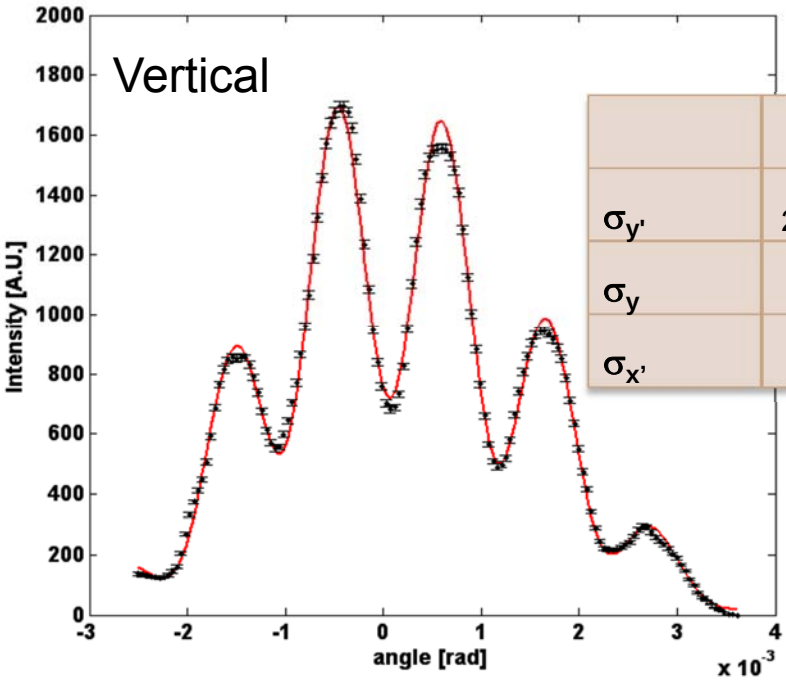
	800 nm	550 nm
$\sigma_{y'}$	2.03E-04	1.93E-04
σ_y	8.07E-05	7.59E-05



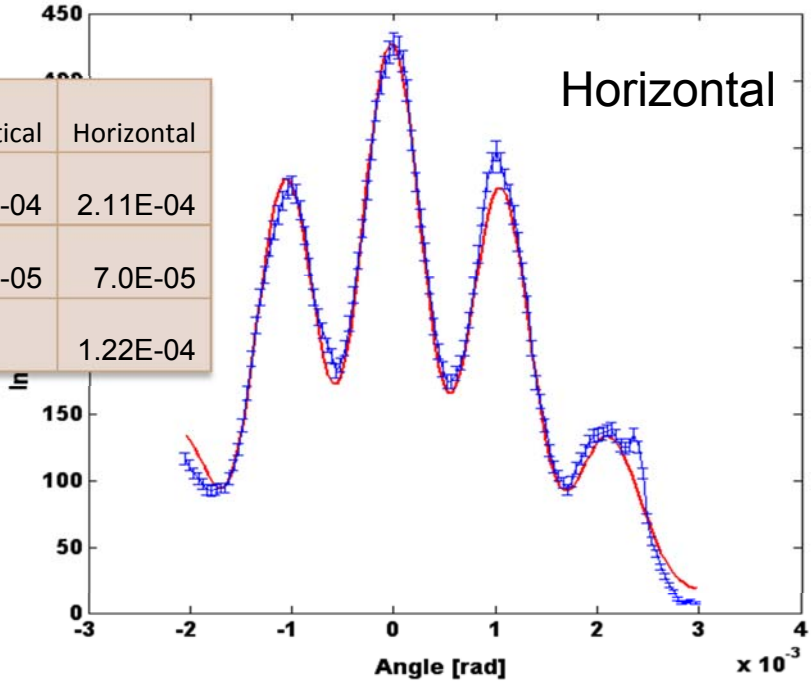


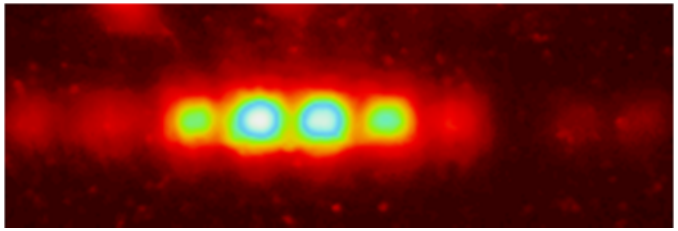


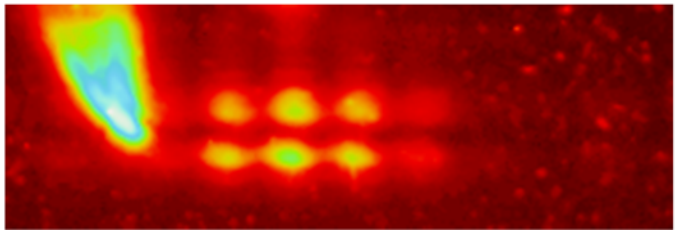
Horizontal polarization



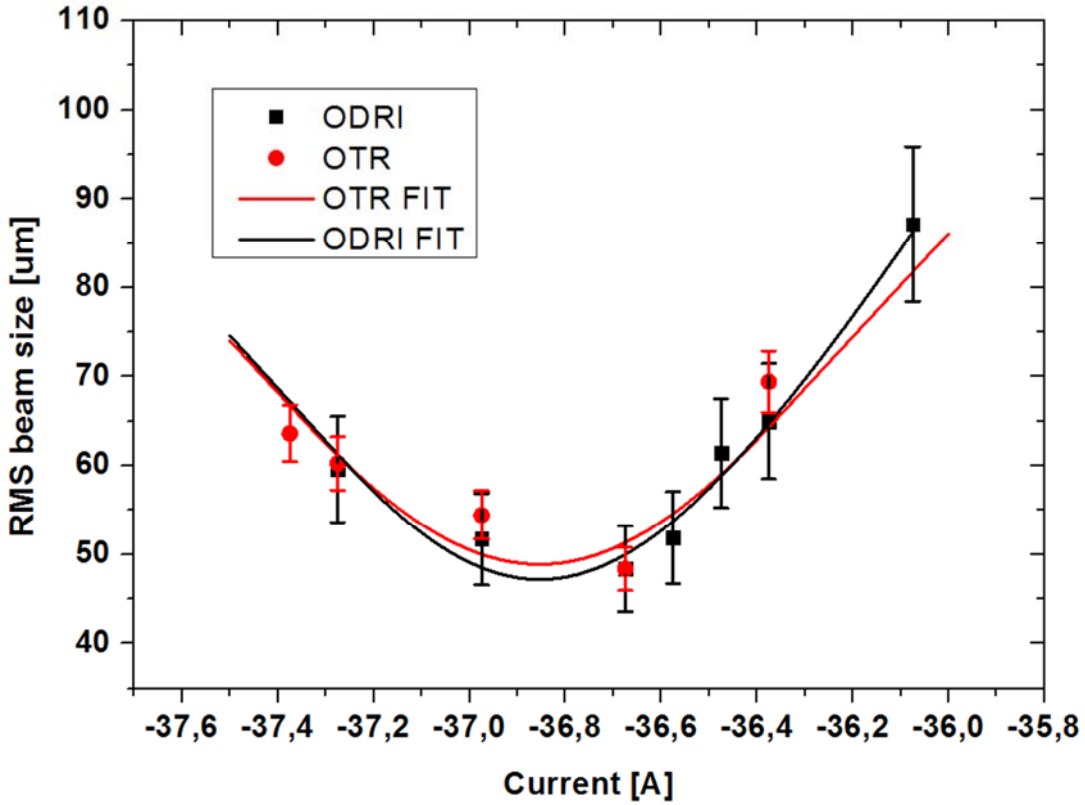
	Vertical	Horizontal
$\sigma_{y'}$	2.03E-04	2.11E-04
σ_y	7.7E-05	7.0E-05
$\sigma_{x'}$		1.22E-04







Quadrupole Scan



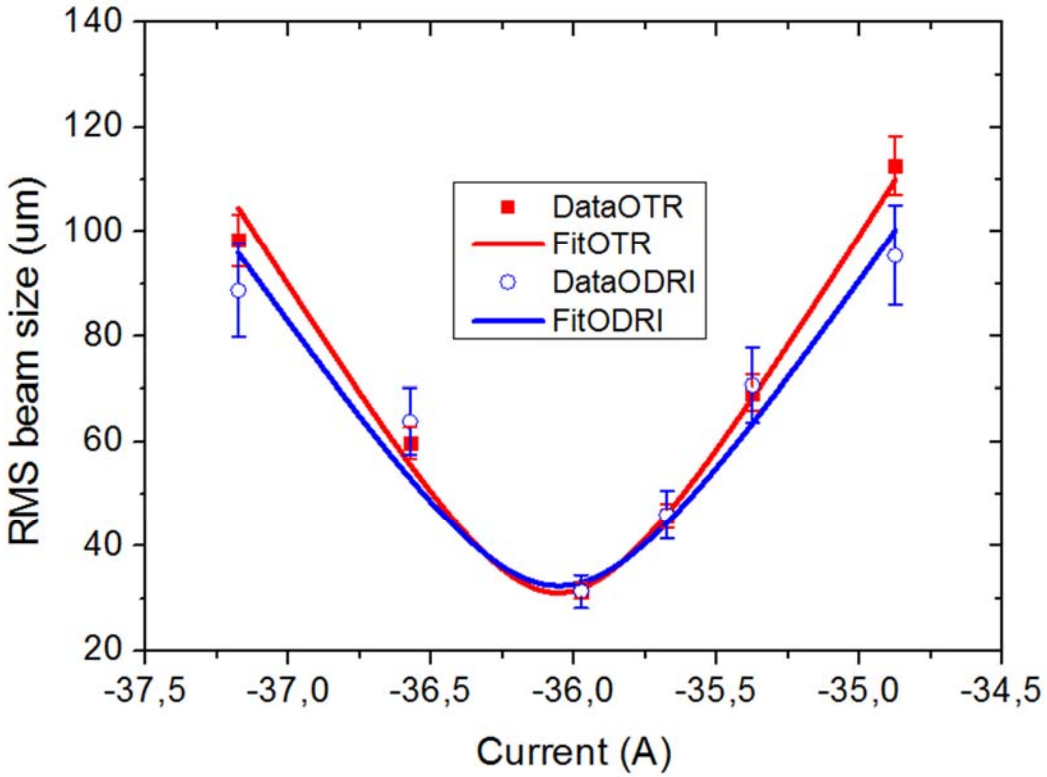
RUN I

λ=800 nm

ε_{y_ODRI}=(3.8±1.3) mm-mrad

ε_{y_OTR}= (3.7±1.2) mm-mrad

Emittance II



RUN II

λ=500 nm

ε_{y_ODRI}=(2.23±0.85) mm-mrad

ε_{y_OTR}= (2.37±0.46) mm-mrad

We have a dream...

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

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

- 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 just 2 measurements in 2 different position to evaluate the emittance in a totally non-intercepting an non-disturbing way

Conclusions

- ODRI is an improvement with respect to ODR. Main advantages are
  - Suppression of SR background
  - Slits displacement to avoid complementary diagnostic and to discriminate between σ and σ'
- ODRI could be a candidate to be a parasitic diagnostic for high brightness / high repetition rate beams.
- We realized the first non-intercepting emittance measurement.
- The capability to measure both σ and σ' paves the way to 2 screens non-intercepting emittance measurement
- The work is in progress…

Thank you

感謝