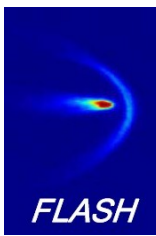


WORKSHOP ON THE MICROBUNCHING INSTABILITY III

INFN – LNF, Frascati
24-26 March 2010



Coherent Optical Radiation: Operational Experience @ FLASH

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A. Cianchi (University and INFN – Roma “Tor Vergata”)

K. Honkavaara, G. Kube (DESY – HH)

Non-Intercepting Devices

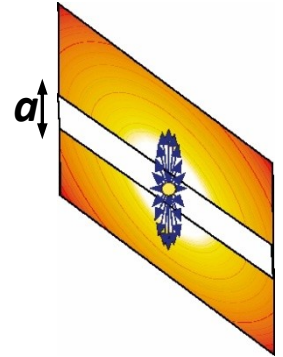
- Emittance measurements are often performed imaging a beam on a metallic screen

BUT

- Traditional diagnostic based on **OTR cannot be used for high power beam**
- All other intercepting devices are easily damaged or destroyed from these type of beams
- It is fundamental to **develop non intercepting alternatives** for emittance measurements
 - **Even more desirable after recent observations of COTR in linac-driven FELs**

Diffraction Radiation

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



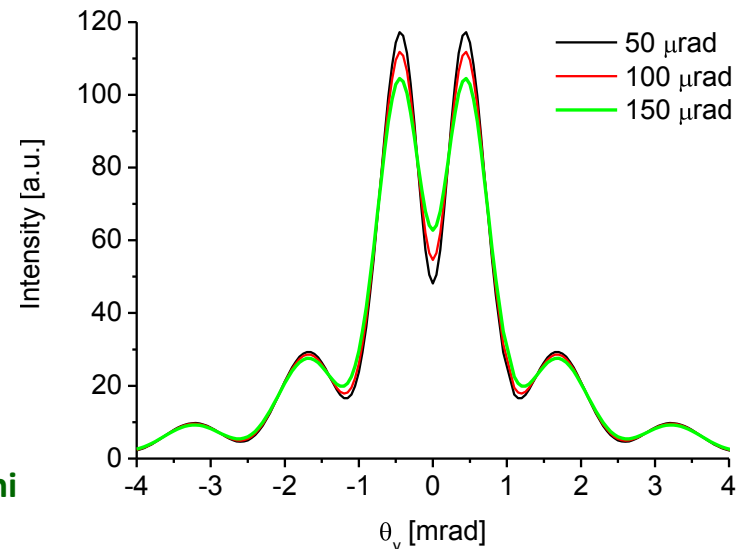
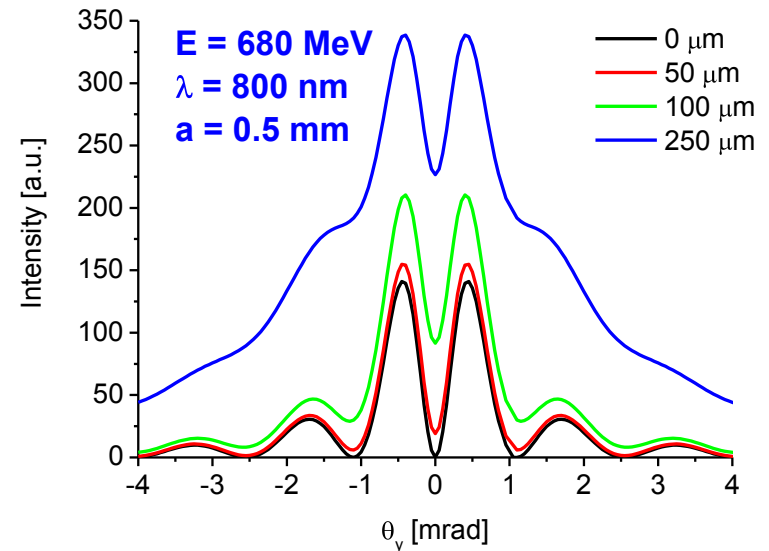
- The radiation intensity is $I \propto \frac{\gamma^2 \pi a}{\gamma \lambda}$
- DR impact parameter is $\frac{\gamma \lambda}{2\pi} \rightarrow$ if $a \left\{ \begin{array}{l} \gg \frac{\gamma \lambda}{2\pi} \\ \cong \frac{\gamma \lambda}{2\pi} \\ \ll \frac{\gamma \lambda}{2\pi} \end{array} \right. \begin{array}{l} \text{No radiation} \\ \text{DR} \\ \text{TR} \end{array}$

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

ODR as Transverse Beam Diagnostics

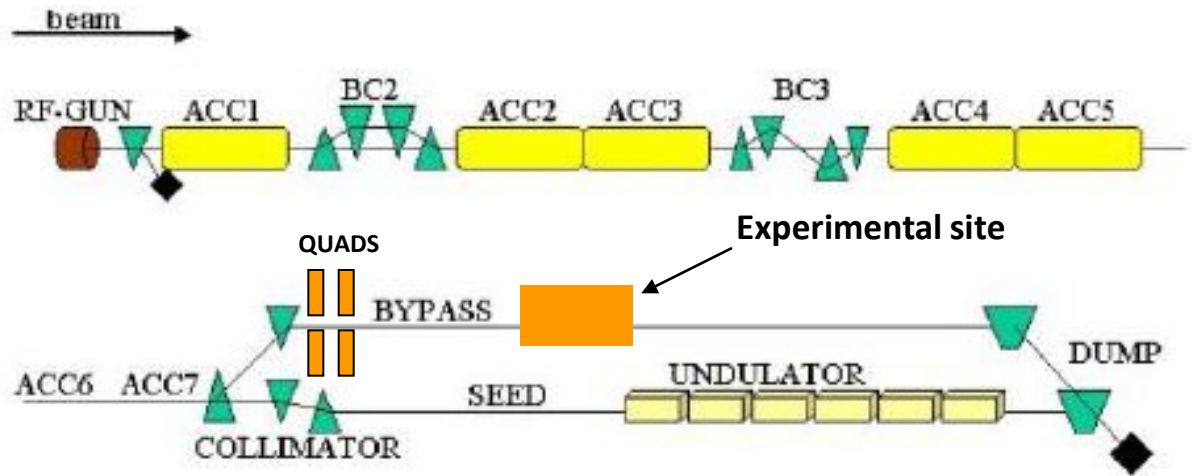
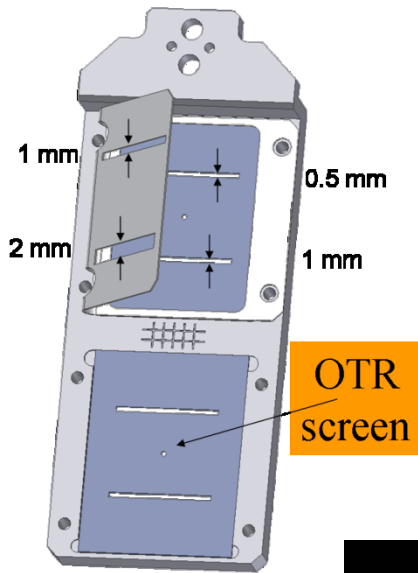
The **visibility of the interference fringes** can be used to **determine the transverse size** of a bunch of electrons crossing the slit:

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



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ODR Experiment @ FLASH



Double convex
coating with $f =$
DR angular dist

Achromatic doub
with $f = 250$ mm
for beam imagin



tsu CCD
(Model
8-LGLAG2)

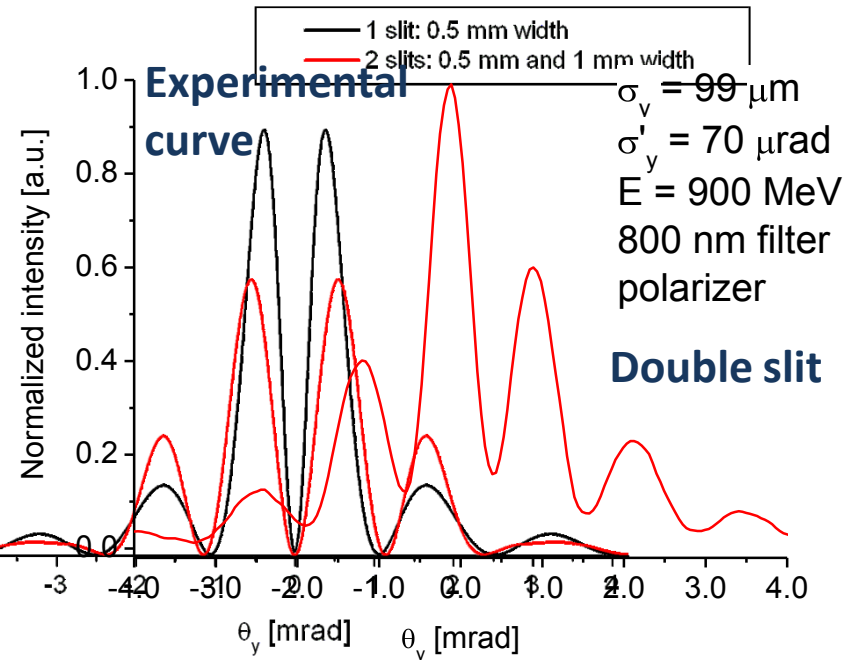
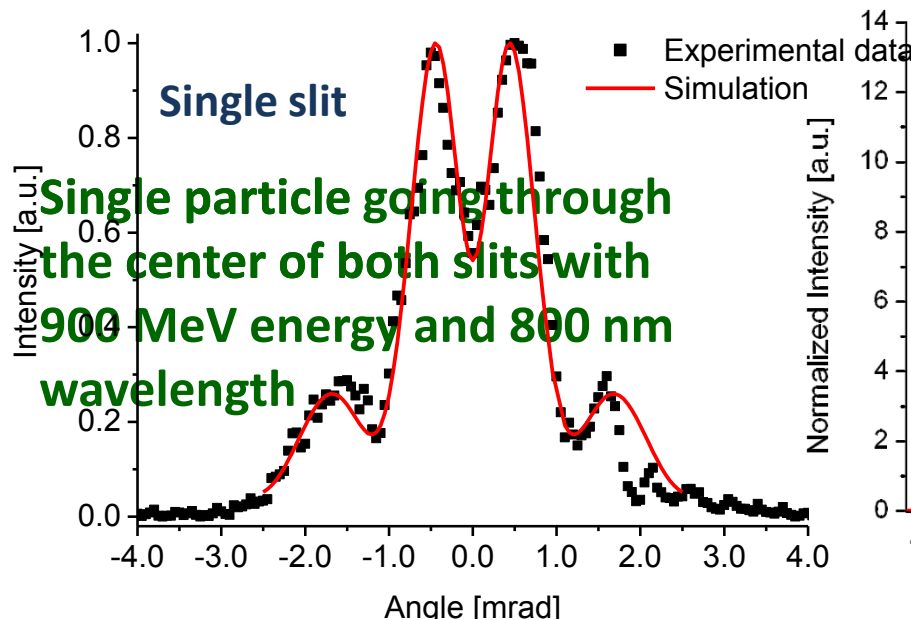
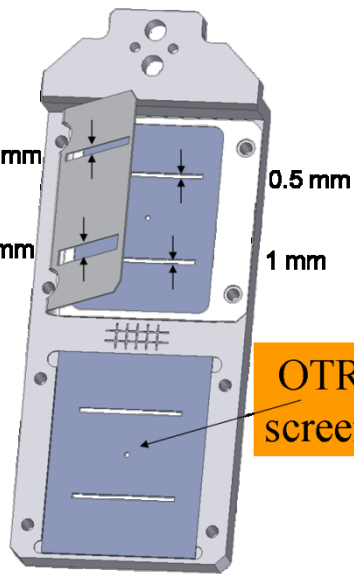
Hamamatsu Camera

- Back illuminated, **more than 80%** of quantum efficiency **at both 550 nm and 800 nm**
- Peltier cooled @ -55 °C
- No dark noise signal
- Integration time up to hours
- 30 bunches of 1 nC @ 5 Hz integrated for 1 second
=> **150 nC !**

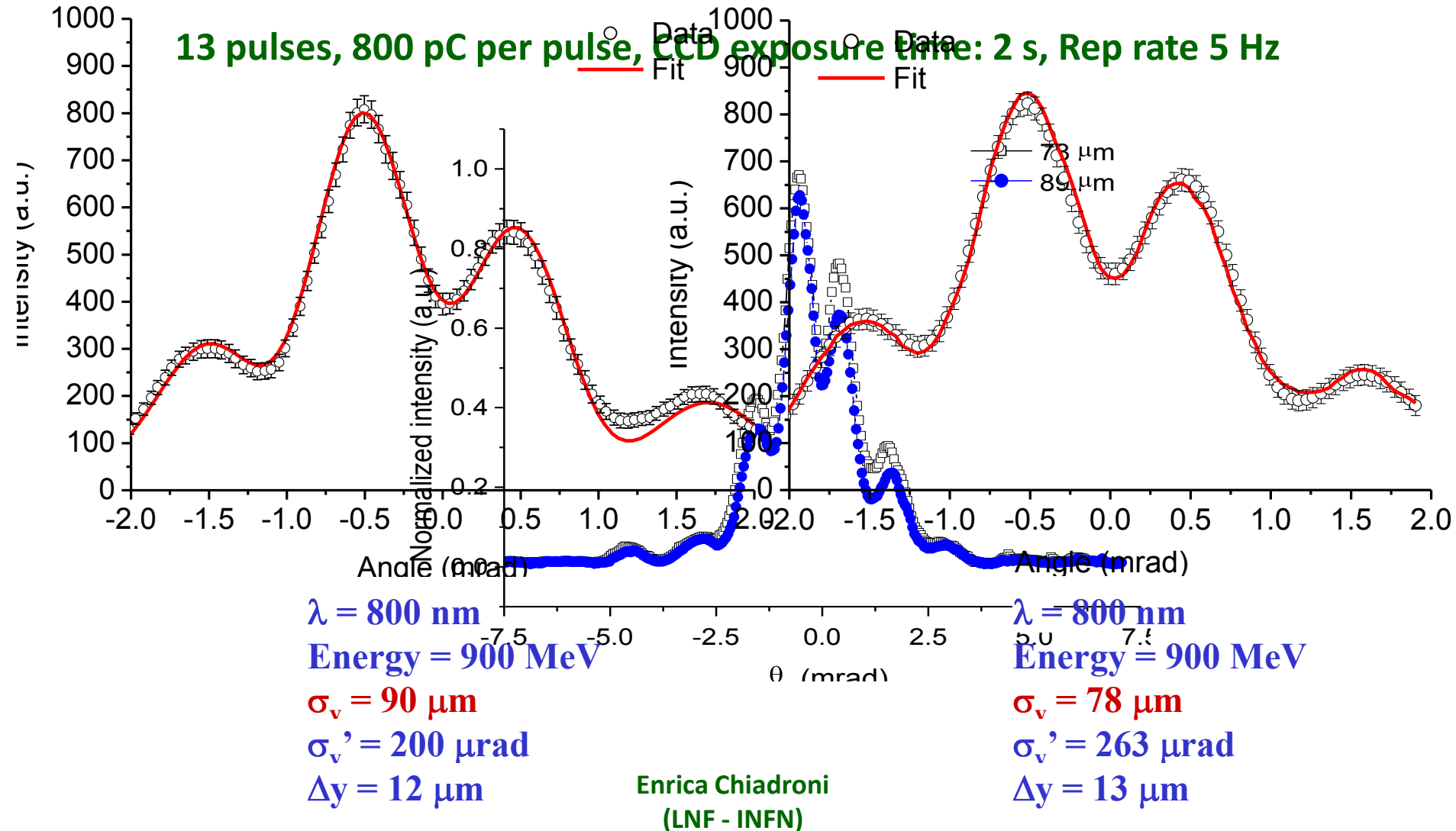
Optical Diffraction Radiation Interferometry (ODRI)

In case of **800 nm** wavelength 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.

The two interfering amplitudes have different intensity and angular distribution.



ODRI Angular Distribution for Two Different Beam Sizes



Coherent Radiation

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

$$I_{tot}(\lambda) = I_{sp} \left[N + N(N-1) F_{||}(\lambda) F_{\perp}(\lambda, \vartheta) \right]$$

in which I_{sp} is the intensity emitted by a single particle and $F_{||}(\lambda)$ and $F_{\perp}(\lambda, \vartheta)$ the bunch longitudinal and transverse form factors, respectively

$$F_{||}(\lambda) = \left| \int_{-\infty}^{\infty} S(z) e^{i \frac{2\pi}{\lambda} z} dz \right|^2, \quad F_{\perp}(\lambda, \vartheta) = \left| \int_{-\infty}^{\infty} T(\rho) e^{i \frac{2\pi}{\lambda} \rho \sin(\vartheta)} d\rho \right|^2$$

with $S(z)$ the longitudinal density and $T(\rho)$ the transverse distribution of the bunch.

If **part of the bunch emits coherently (no compression mode)**, then

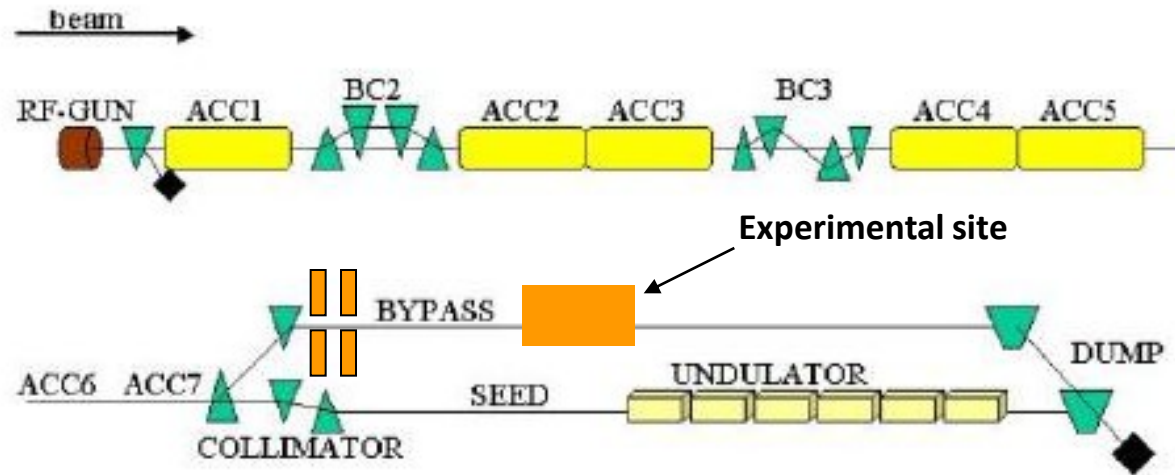
$$I_{coh} = N_{coh}^2 F_{||}(\lambda) F_{\perp}(\lambda, \vartheta) I_{sp} \Rightarrow I_{tot} \cong I_{sp} \left[N + N_{coh}^2 F_{||}(\lambda) F_{\perp}(\lambda, \vartheta) \right]$$

We assume the # of coherent particles remains the same at 800 nm and 550 nm.

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

FLASH Linac Settings



- **No compression mode** => on crest in both bunch compressors
- **No coherent emission** detected by any diagnostics **on the straight line**

BUT

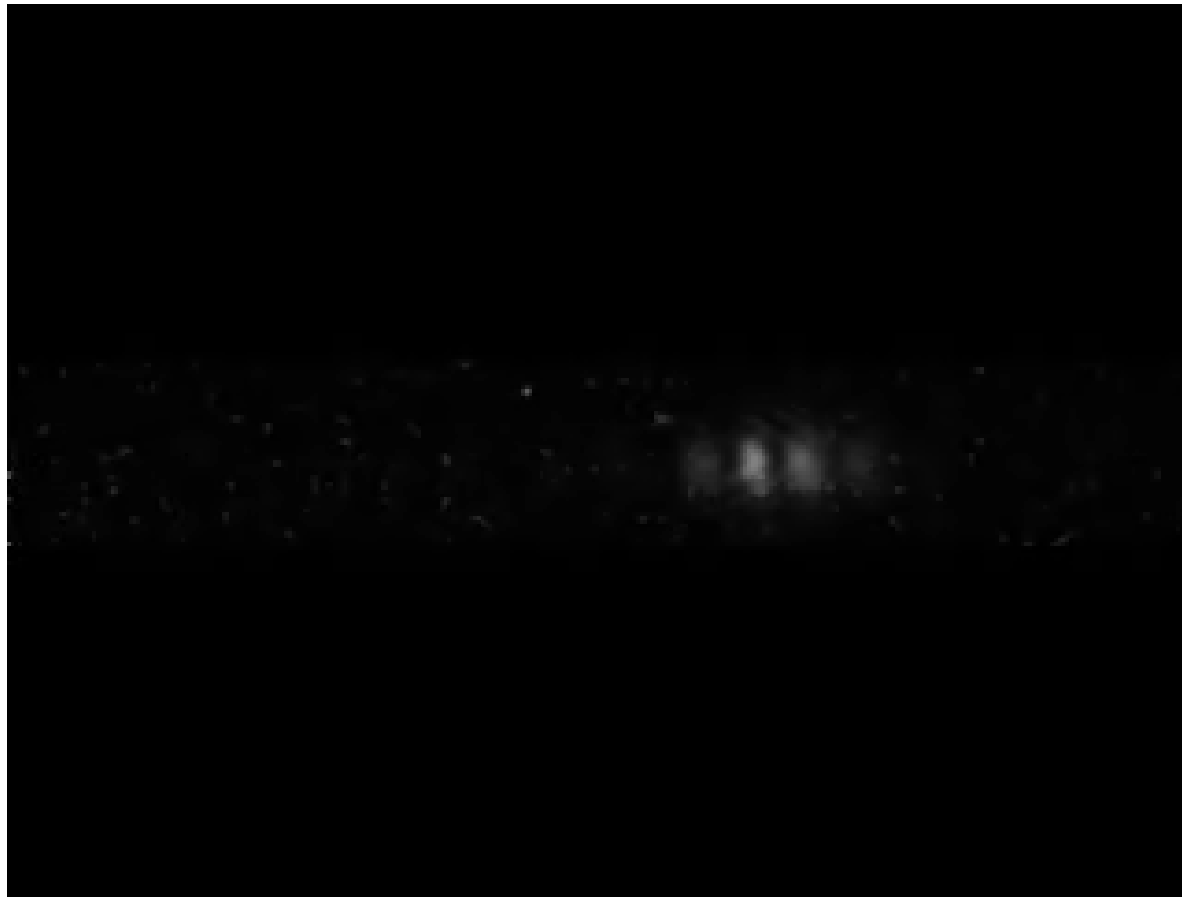
- Emphasized by the fact that the beam travels through a **dispersion section, i.e. the by-pass**
- Experimental evidences of **COTR/CODRI emission** due to u-bunching instabilities at ODRI station **strongly dependent on the trajectory**
 - **0.1% energy variation** as knob to turn coherent emission on or off

Coherent Optical Radiation

- **Fluctuation shot by shot more than 50% of intensity**
 - fluctuation of longitudinal modulation or of the number of particles which emits coherently
- **Charge fluctuation of 2%**

Coherent ODRI (CODRI) Angular Distribution

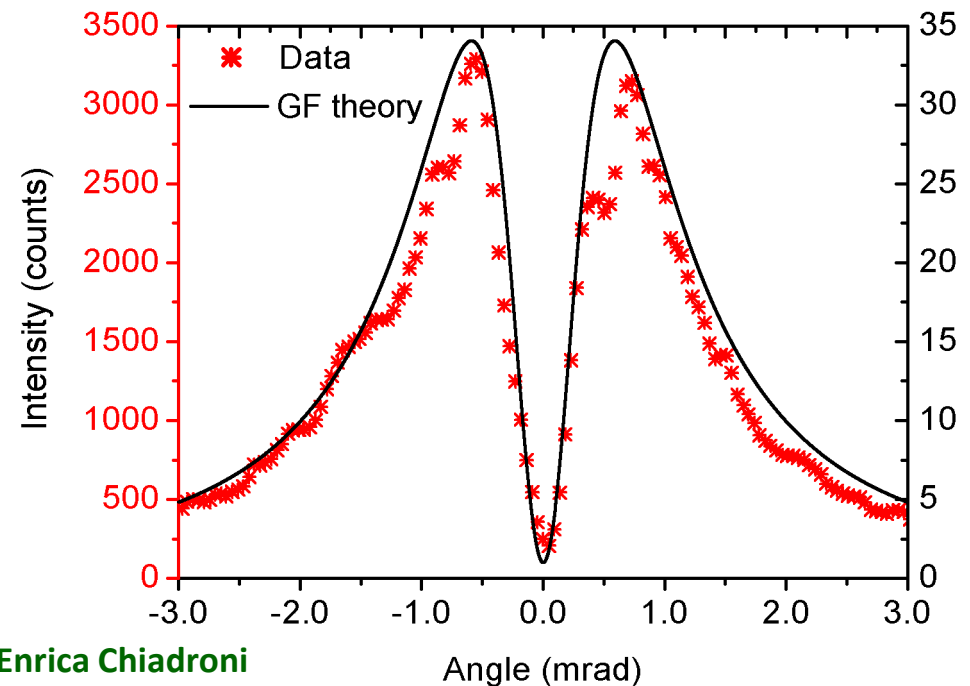
20 shots: 1 pulse 0.2 s



Coherent Optical Radiation

- This phenomenon has been observed in the **no-compression mode**
- **Fluctuation shot by shot more than 50% of intensity**
 - fluctuation of longitudinal modulation or of the number of particles which emits coherently
- **Charge fluctuation of 2%**
- **A great enhancement of total intensity** that could not be described by the incoherent emission theory

200 ms exposure time
1 micropulse
800 pC

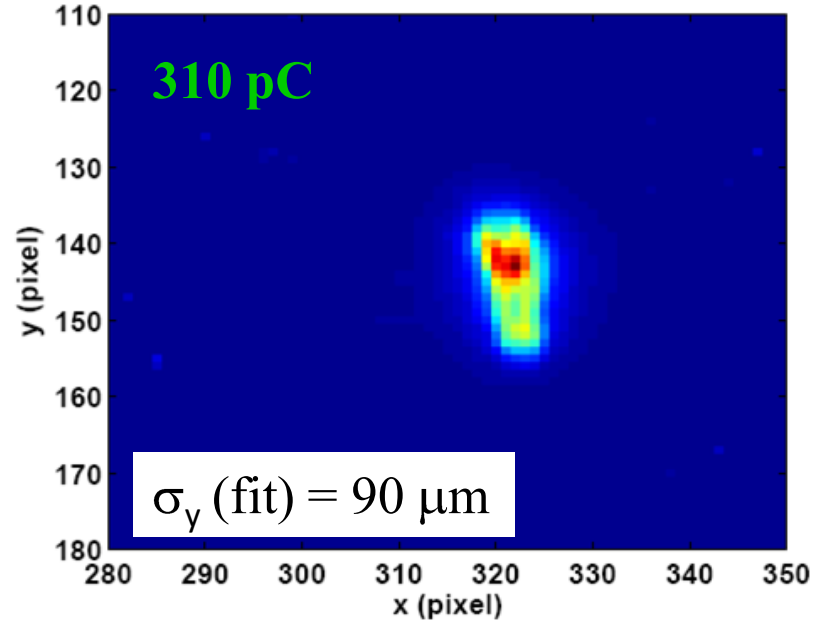
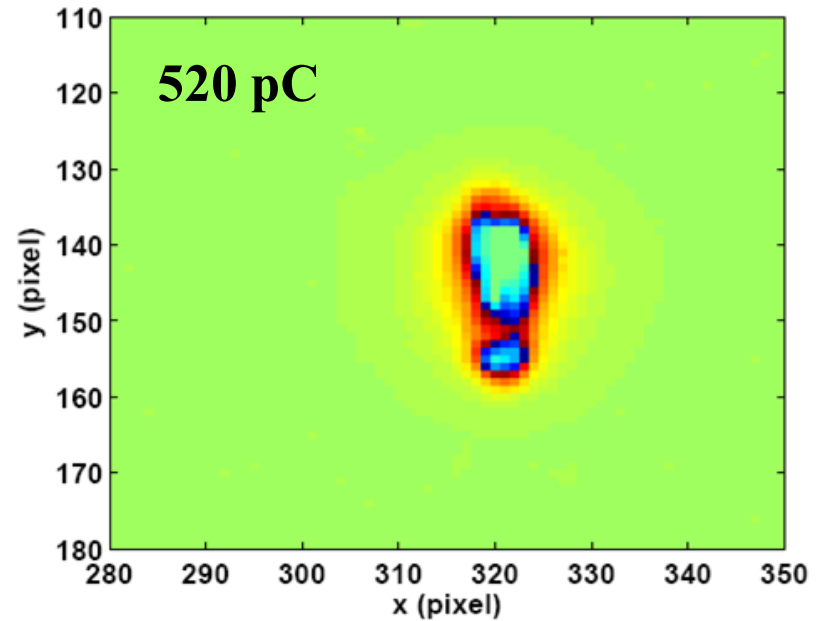
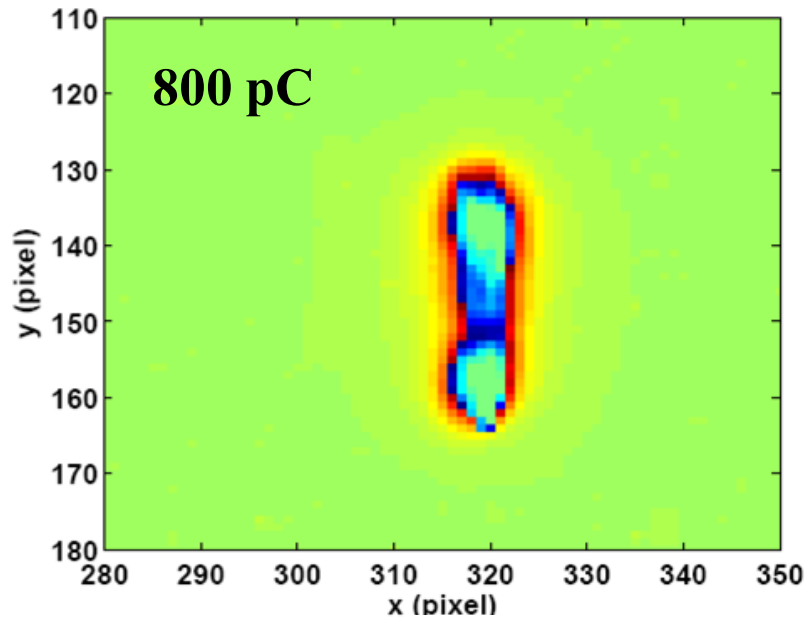


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- CCD often saturated not allowing always the measurement of beam size
 - Visible **structures in the OTR beam image**: we cannot evaluate because of the saturation and because of lack of resolution

OTR beam images



Coherent Optical Radiation

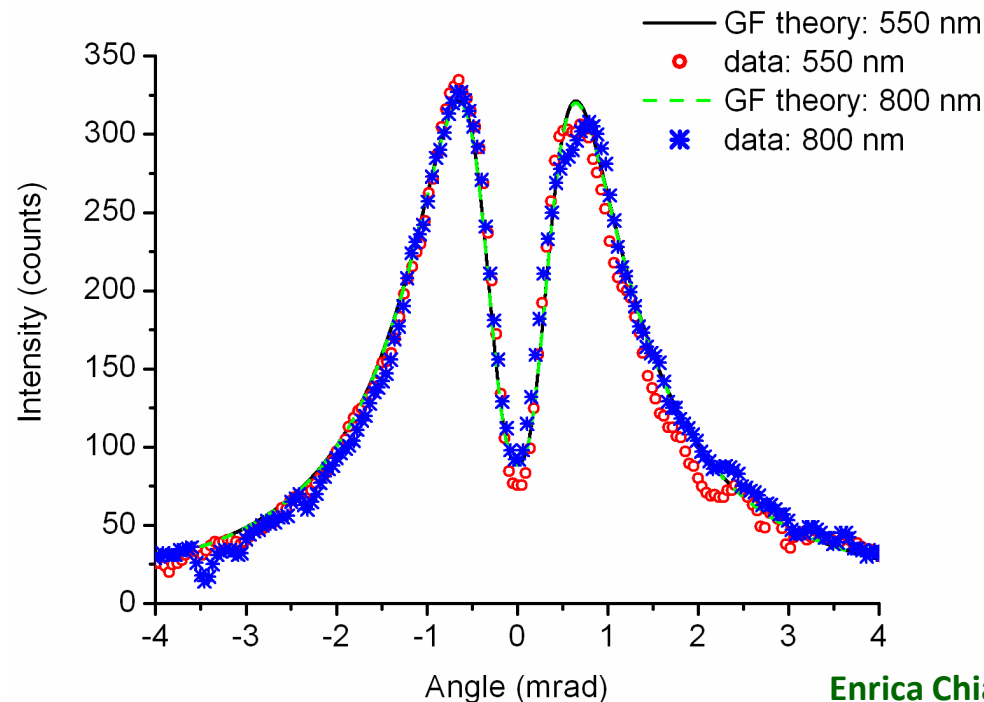
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- Big differences between 550 nm and 800 nm
 - unlike the **OTR incoherent emission** which has **white spectrum**

Coherent OTR vs Incoherent OTR

200 ms exposure time , 1 micro-pulse, 800 pC

Incoherent emission

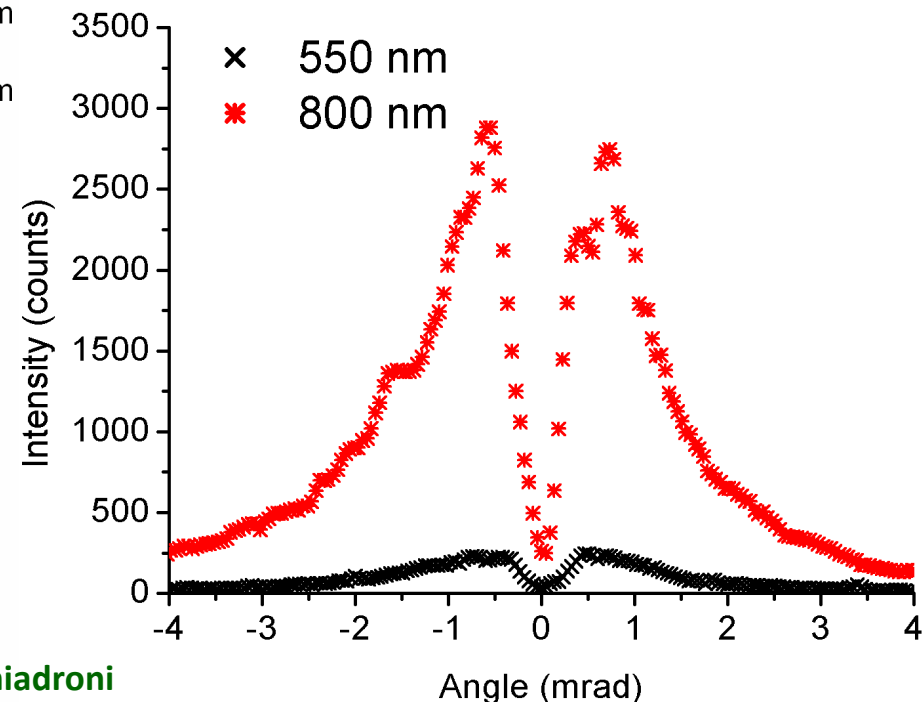
→ OTR angular distribution
does not depend on the wavelength



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Coherent emission

→ OTR angular distribution
shows dependence on the wavelength



Coherent Optical Radiation

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- Big differences between 550 nm and 800 nm
 - unlike the **OTR incoherent emission** which has **white spectrum**
- **Angular distribution with single pulse even down to 0.3 nC** (while more than 100 nC, integrated, in standard operation)!!!
- No relevant change with charge

Evaluation of μ -bunch length and # of coherent particles

- With the assumption of a longitudinal Gaussian-distributed beam and from the measured intensity at different wavelengths

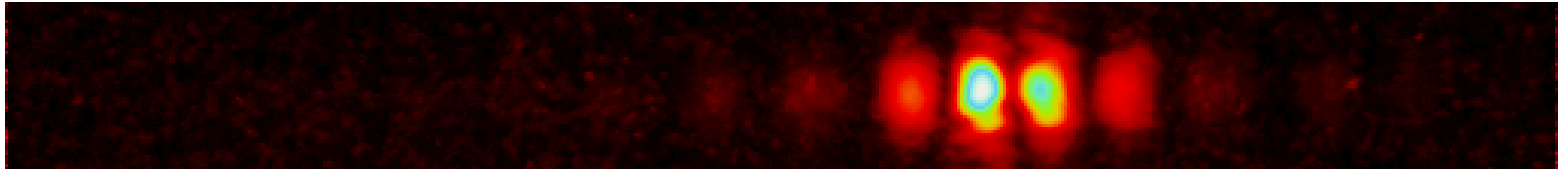
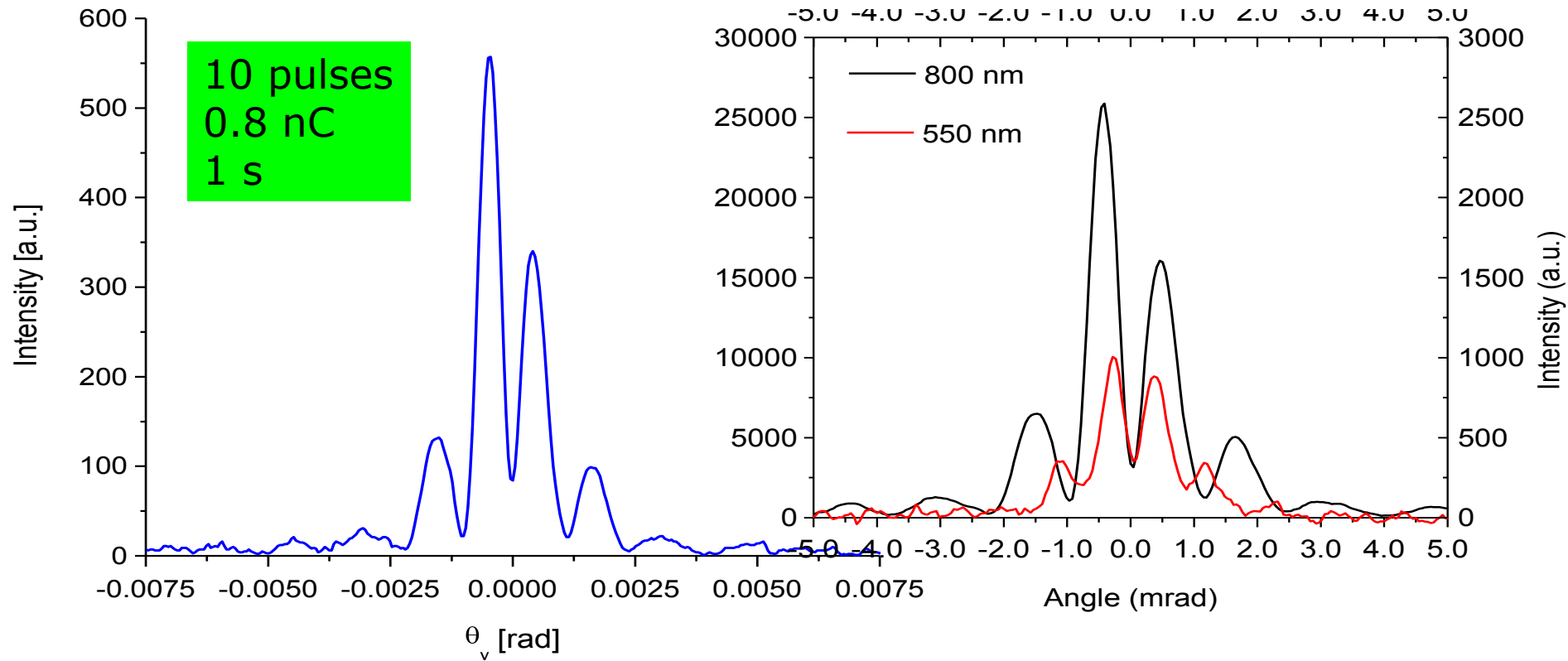
$$\frac{I_{tot}(\lambda_+) - I_{incoh}(\lambda_+)}{I_{tot}(\lambda_-) - I_{incoh}(\lambda_-)} \cdot \frac{I_{incoh}(\lambda_+)}{I_{incoh}(\lambda_-)} = \frac{f(\lambda_+)}{f(\lambda_-)}$$

$$\text{thus } \sigma_- = \sqrt{\frac{(\lambda_+ - \lambda_-)^2 \ln \left(\frac{I_{tot}(\lambda_+)}{I_{tot}(\lambda_-)} \right)}{(\lambda_+ - \lambda_-)'}}$$

- Once the form factor is evaluated, the number of particles which contributes to coherent emission can be determined if the incoherent emission is known

$$N_{coh} = \sqrt{N_e \frac{I_{coh}}{I_{incoh}} \frac{1}{f(\lambda_+)}}$$

Coherent ODRI Angular Distribution



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Coherent OTR Angular Distribution

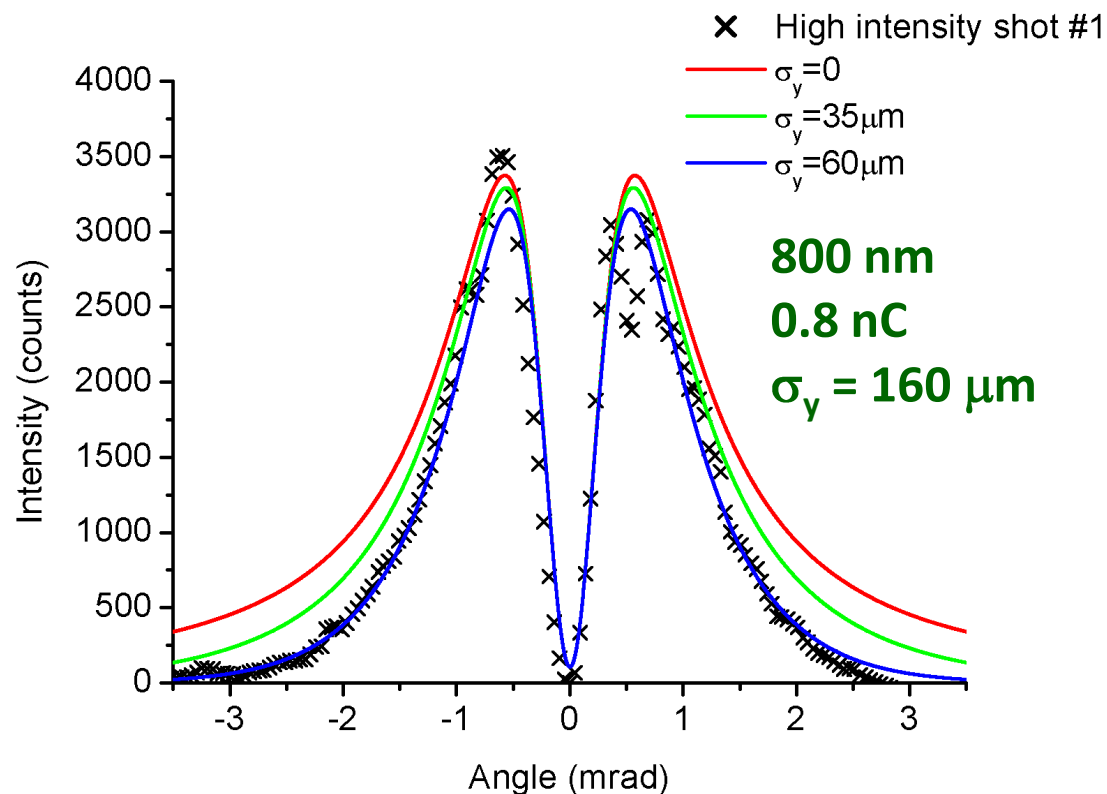
Reminding that the coherent term of the spectral angular distribution depends on the transverse form factor as

$$I_{coh} = N_{coh}^2 F_{||}(\lambda, F_{\perp}(\lambda, \vartheta)) I_{sp} \Rightarrow I_{tot} \cong I_{sp} \left[N + N_{coh}^2 F_{||}(\lambda, F_{\perp}(\lambda, \vartheta)) \right]$$

where, assuming a Gaussian distributed beam

$$F_{\perp}(\lambda, \vartheta) = e^{-\left(\frac{2\pi}{\lambda} \sigma_y \sin \vartheta\right)^2}$$

and the effect of the $\sin \vartheta$ dependence is evident at larger angles.



Conclusions

- Evidences of **coherence effects in the optical wavelength range** have been observed
- Both **COTR and CODRI angular distributions** have been detected resulting in a promising tool **to measure the transverse beam size**
- The phenomenon has been observed in the **no compression mode**
 - it is compression independent and **no effects** have been seen **on** any screen of **the straight line**
 - the coherent optical emission we observed can be attributed to a **microbunching in the visible-NIR range ($\approx 1 \mu\text{m}$ modulation) due to longitudinal density fluctuations**
- A preliminary analysis allowed us to quantify both the # of coherent particles ($\approx 10^{-4} N_e$) and the longitudinal part of the bunch which **contributes to the Coherent Optical Emission**