UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI FISICA

INFN Istituto Nazionale di Fisica Nucleare

CONGRESSO DEL DIPARTIMENTO DI FISICA
University of Milan, Milan, Italy, June 28-29, 2017

Diagnostics of High Brilliance Radiation from Relativistic Beams

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Abstract

Over the last decade, the Instrumental Optics Group has developed a novel diagnostics technique (Heterodyne Near Field Speckle, HNFS) for the characterization of the coherence properties of Synchrotron Radiation (SR) emitted by relativistic electron beams. The technique relies on Fourier analysis of near field speckles, can be operated at X-ray wavelengths without any dedicated optics and has been validated at large-scale facilities. More recently, a collaboration has been started with the Beam Physics Group of the University of Milan in view of the production of X-ray radiation with Orbital Angular Momentum (OAM) by means of Thomson backscattering from a high brightness relativistic electron beam interacting with a helically phased laser pulse. The aim is to develop and implement a phase-preserving diagnostics technique, also suitable for X-rays.

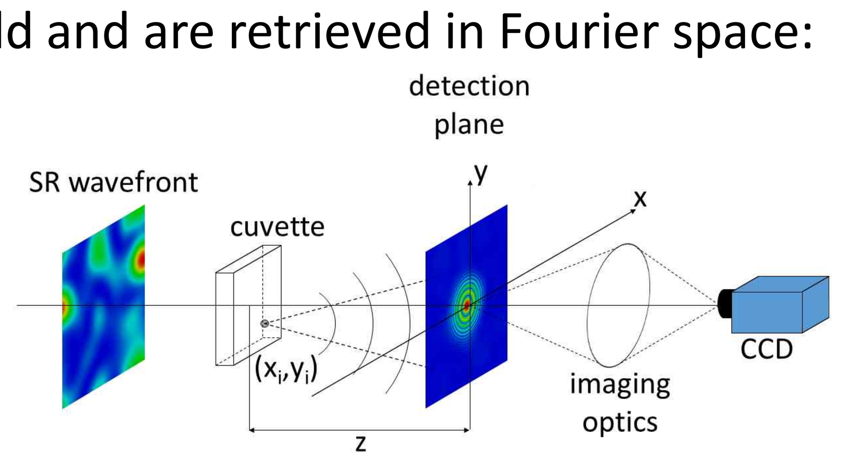
Heterodyne Near Field Speckles: basis of the technique

Spatial and temporal coherence properties of SR are described by the following field correlation functions:

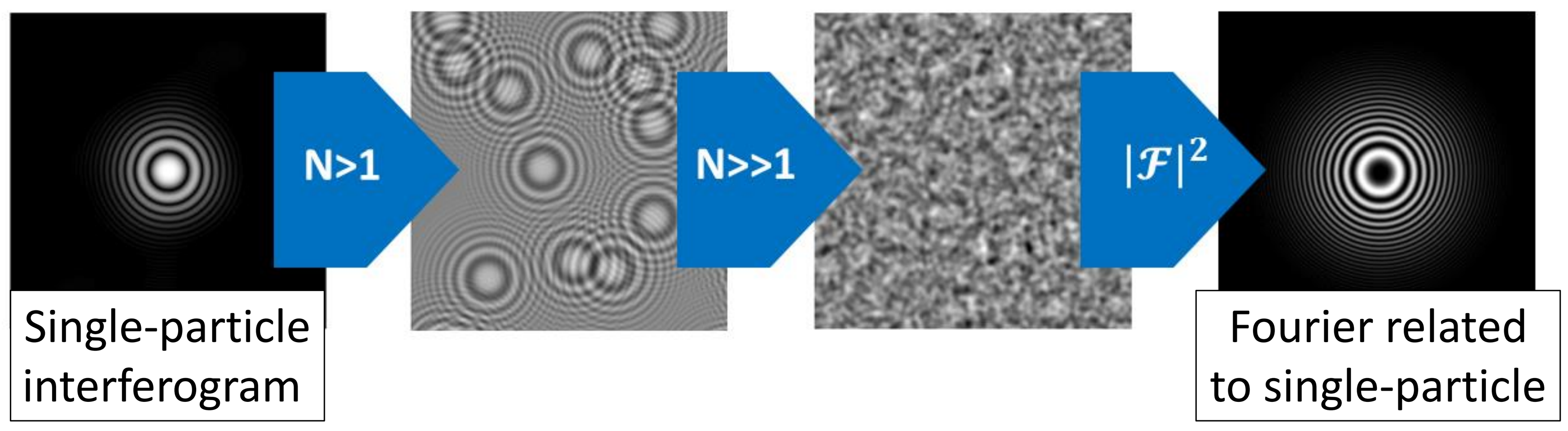
$$\mu(\Delta x) = \langle E(x)E^*(x+\Delta x)\rangle \qquad \text{Complex Coherence Factor (CCF)}$$

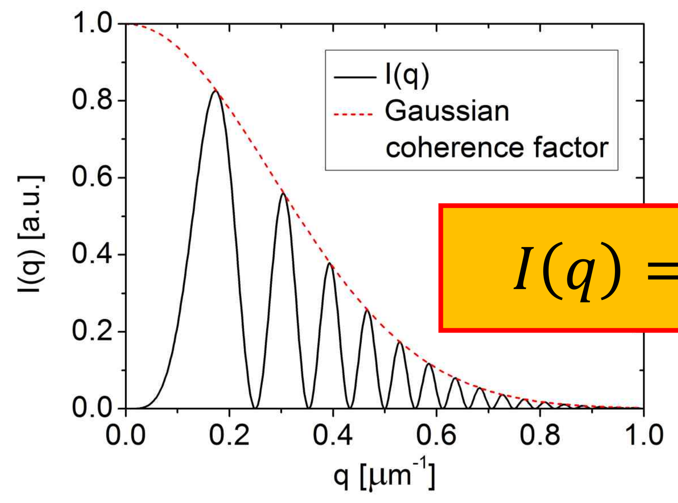
$$\mu(\tau) = \langle E(t)E^*(t+\tau)\rangle \qquad \text{Complex Degree of self Coherence (CDC)}$$

where $\langle\cdot\rangle$ denotes ensamble averages over a number of electron bunches. A clear manifestation of partial coherence is the loss of visibility in interference fringes. When SR impinges onto a suspension of nanoparticles, the weak scattered spherical waves interfere with the strong transmitted beam (heterodyne conditions). Coherence properties are thus conveyed by the resulting speckle field and are retrieved in Fourier space:



$$I = \langle|E_0 + E_s|^2\rangle = \langle|E_0|^2\rangle + 2Re\{\langle E_0^* E_s\rangle\} + \cancel{\langle|E_s|^2\rangle}$$





$$\boxed{I(q) = T(q)C(q)}$$

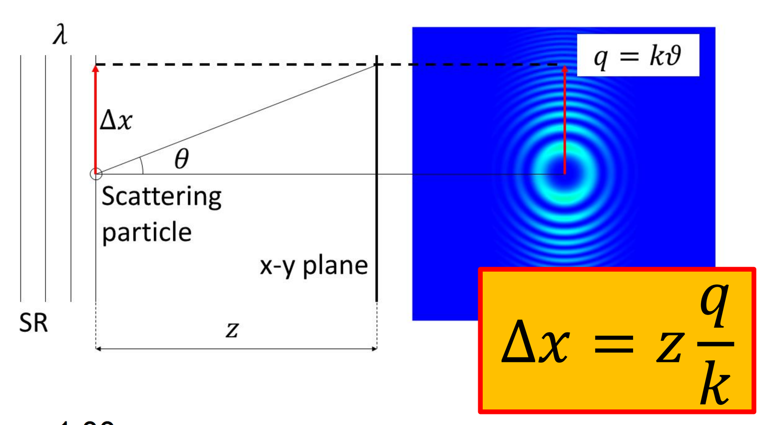
I(q): power spectrum

T(q): Talbot oscillations

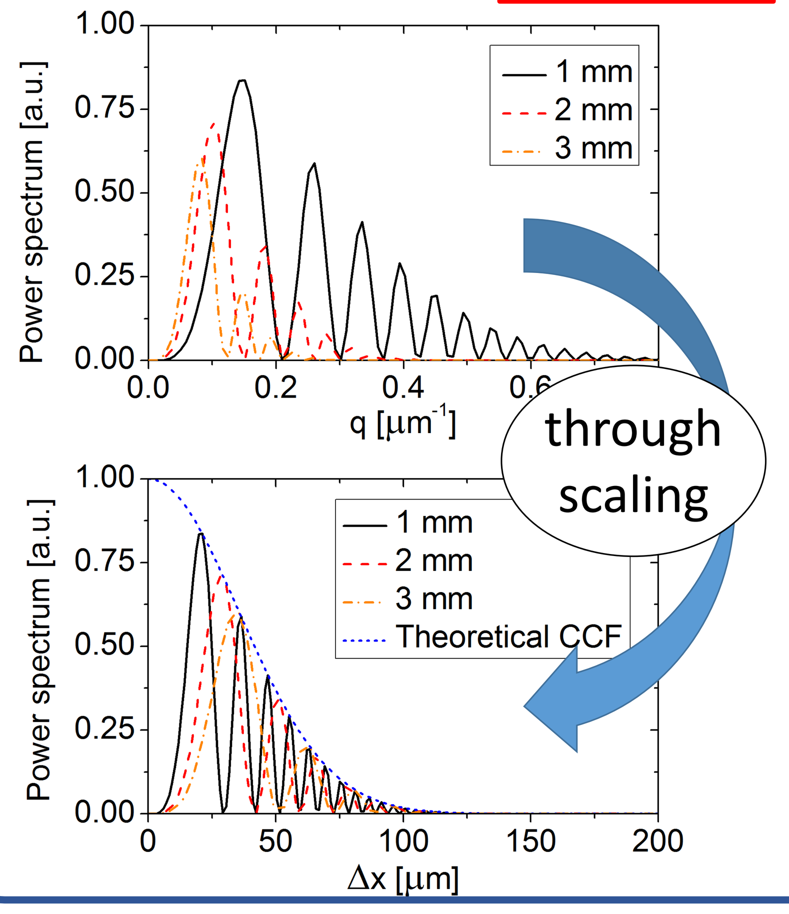
C(q): $|\mu(q)|^2$

Master curves for spatial and temporal coherence

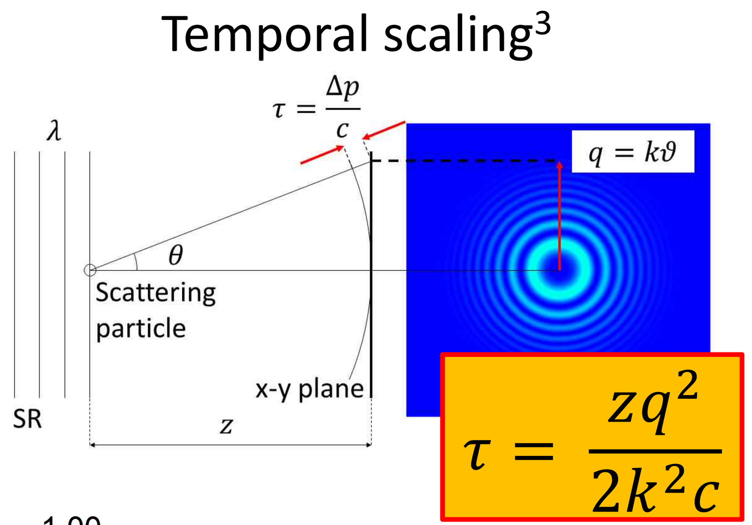
Spatial scaling[1,2]



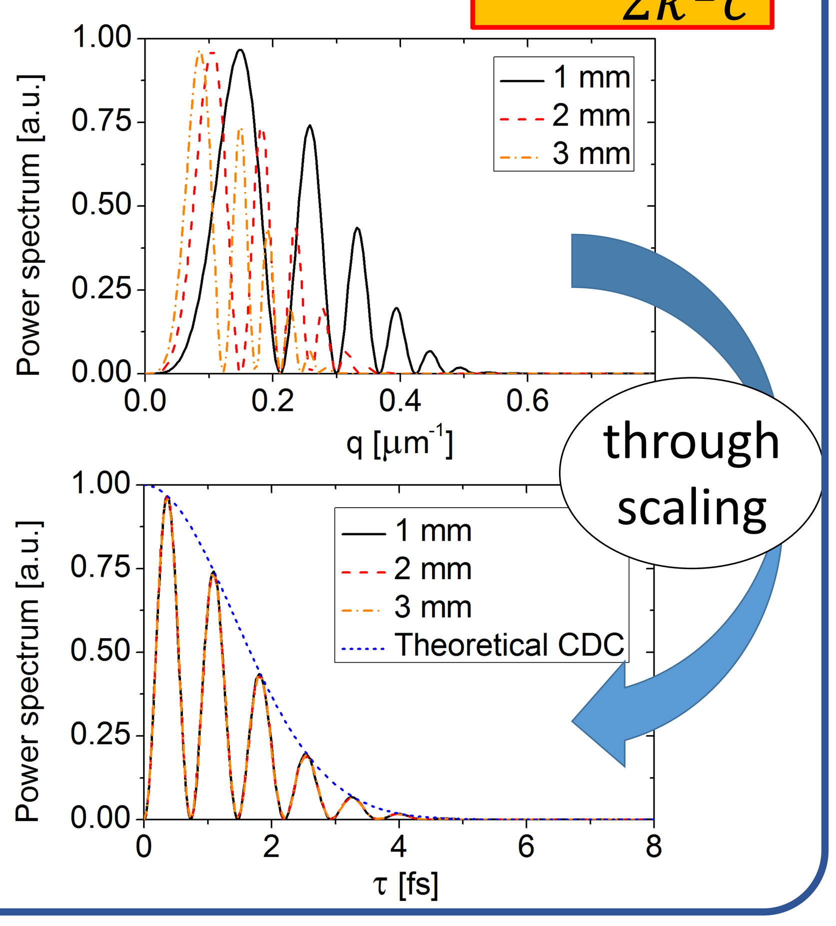
$$\Delta x = z\frac{q}{k}$$



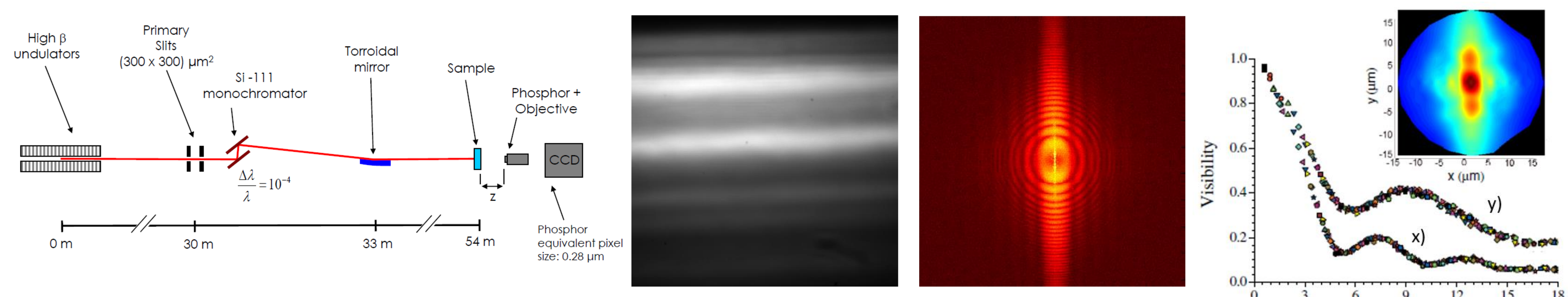
Temporal scaling[3]



$$\tau = \frac{zq^2}{2k^2c}$$

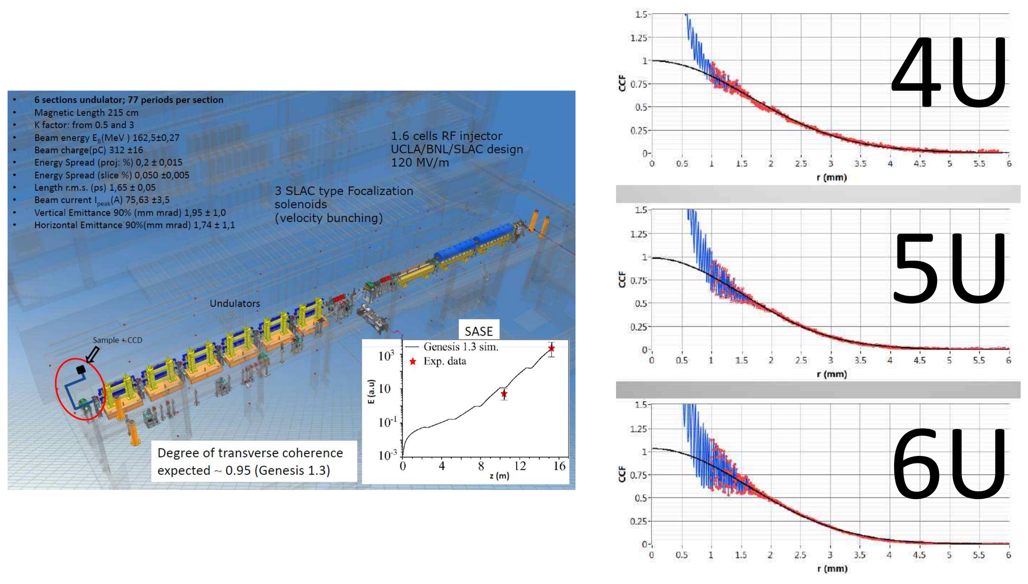


ESRF, Undulator, λ = 0.1 nm (2009)[1]

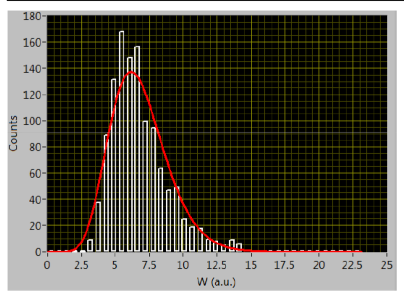


Hor: diffraction by primary slits (VCZ theorem applies).
Ver: beam size and divergence + double source (deformed toroidal mirror).

SPARC LAB, SASE FEL, λ = 402 nm (2014)[2]



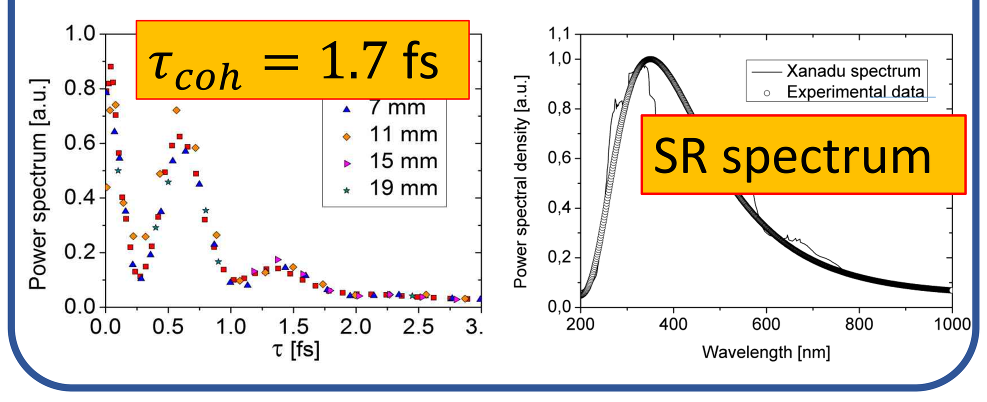
	σ_{coh}	$\sigma_{coh}/\sigma_{beam}$
4U	1.64 mm	0.70
5U	1.50 mm	0.80
6U	1.62 mm	0.82



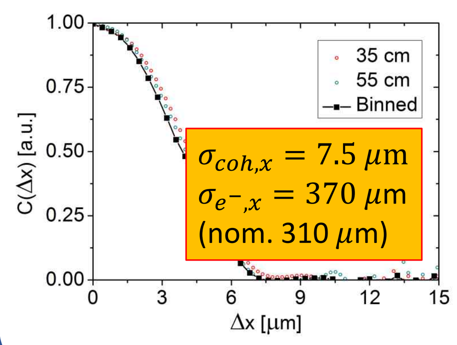
	M
4U	10.5
5U	6.5
6U	3.2

Lower sp. coherence than expected: hollow-core beam + longitudinal modes.

ALBA, Bending Magnet, λ = 350 nm (2016)[4]



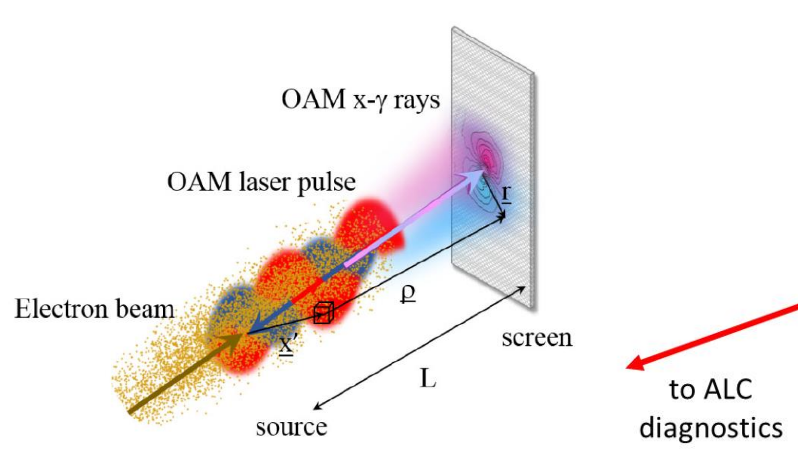
ALBA, Undulator, λ = 1 nm (2017, prelim.)

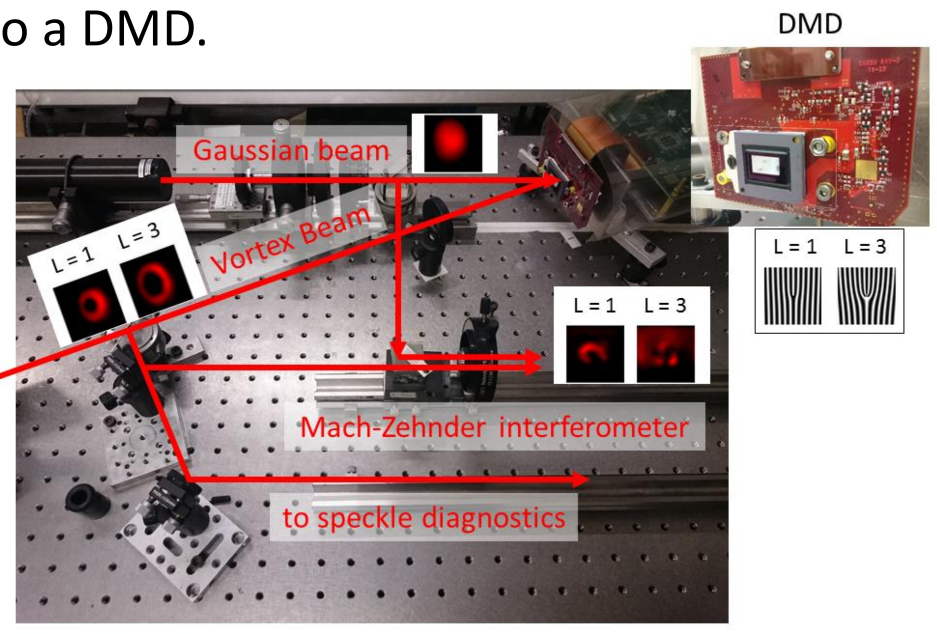


HNFS as emittance diagnostics (CERN FCC project)

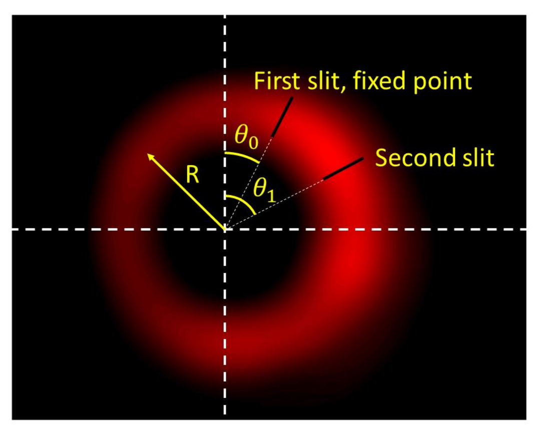
Asymmetric Lateral Coherence of OAM beams

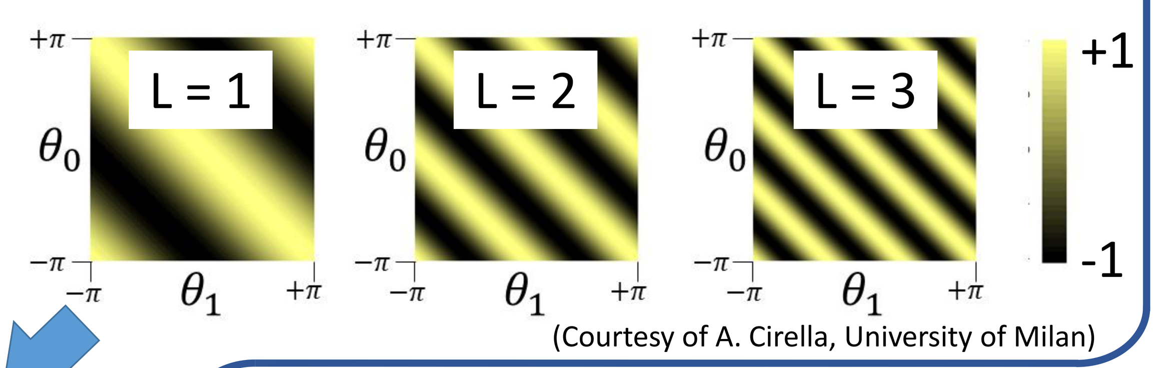
Relativistic electrons + helically phased laser = X-ray/γ Vortex Beams (VBs)[5]. We can produce and diagnose an optically-scaled VB by encoding a corkscrewlike phase modulation on a Gaussian laser beam with computer generated holograms projected onto a DMD.





Asymmetric Lateral Coherence[6] (ALC) is an off-axis, asymmetric double-slit interferometric technique. Azymuthally-arranged pairs of double slits allow measurements of vortex parity and topological charge.





(Courtesy of A. Cirella, University of Milan)

OAM 2D mapping of the real part (phase preserved) of

$$\gamma_c(R,\theta_0,\theta_1) = \frac{\langle E(R,\theta_0)E^*(R,\theta_1)\rangle}{\mathcal{N}}$$

[1] M. D. Alaimo, *et al.*, *Phys. Rev. Lett.*, **103**, 194805 (2009)
[2] M. D. Alaimo, *et al.*, *Opt. Express*, **22** (24) (2014)
[3] M. Siano, *et al*, *Opt. Express*, **23** (26) (2016)
[4] M. Siano, *et al*, under submission to *Phys. Rev. Accel. Beams*
[5] V. Petrillo, *et al*, *Phys. Rev. Lett.*, **117**, 123903 (2017)
[6] B. Paroli, *et al*, *Opt. Express*, **24** (22) (2016)