X-RAY BEAM PROFILE MONITOR

gratefully acknowledging:

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### FCC-ee from a BI perspective

(M. Wendt, eeFACT22)

<table>
<thead>
<tr>
<th>Parameter [4 IPs, 91.2 km]</th>
<th>Z</th>
<th>WW</th>
<th>H (ZH)</th>
<th>ttbar</th>
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<td>beam energy [GeV]</td>
<td>45</td>
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<td>120</td>
<td>182.5</td>
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<td>horizontal beta* [m]</td>
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In the arcs (Zh): $\sigma_x \sim 100 \, \text{μm}$, $\sigma_y \sim 7 \, \text{μm}$

Vertical FCC-ee beam size in the IPs $\ll$ current beam sizes in LS
Vertical FCC-ee beam size in the arcs $\sim$ current beam sizes in LS
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FCC-ee from a BI perspective

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One of the most convenient ways to measure the beam size in LS is to analyze the emitted Synchrotron Radiation (SR). The high energy of the FCC-ee beams calls for the utilization of X-ray interferometry.
Contents

1. Interferometric beam size measurements
2. The X-ray Heterodyne Near Field Speckles (X-HNFS) technique
3. Results at ALBA
4. Ongoing R&D activities
5. Conclusions
SR transverse coherence

The average size and shape of the coherence areas are described by the Complex Coherence Factor (CCF):

\[
\mu(\Delta x) = \frac{\langle e(\hat{x})e^* (\hat{x} + \Delta \hat{x}) \rangle}{\sqrt{\langle |e(\hat{x})|^2 \rangle \langle |e(\hat{x} + \Delta \hat{x})|^2 \rangle}}
\]

Example: Gaussian CCF
The Van Cittert and Zernike theorem

The CCF of SR is the Fourier transform of the transverse profile of the source (e⁻ beam)

Average size of SR coherence areas from e⁻ beams:

$$\sigma_{coh} \sim \frac{\lambda}{\theta} \sim \frac{\lambda R}{\sigma_{beam}}$$
Interferometric beam size measurements

The visibility of interference fringes provides a direct measurement of the transverse coherence of the emitted SR, from which the beam size/profile is retrieved by means of the VCZ theorem.
**X-HNFS: overview**

Light through a disordered ensemble of nanospheres forms random speckles

- Fully 2D, high-resolution
- Suitable for X-rays

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M. D. Alaimo et al., *PRL* 103, 194805 (2009)
M. Siano et al., *APX* 6, 1891001 (2021)
M. Siano et al., *PRAB* 25, 052801 (2022)
X-HNFS: single particle

$I = |e_0 + e_s|^2 = |e_0|^2 + 2\Re\{e_0 e_s^*\} + |e_s|^2$

High-frequency fringes are localized away from the center: spatial scaling
X-HNFS: many particles

\[ I = \sum_{i=1}^{N} |e_{s,i}|^2 = |e_0|^2 + \sum_{i=1}^{N} 2\Re\{e_0 e_{s,i}^*\} + \sum_{i=1}^{N} e_{s,i} \]

\[ I(q) = N \cdot I_0 \cdot S(q) \cdot \left| \mu \left( \frac{z \bar{q}}{k} \right) \right|^2 \cdot 2 \left[ \sin \left( \frac{zq^2}{2k} \right) \right]^2 \]

M. D. Alaimo et al., PRL 103, 194805 (2009)
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**X-HNFS setup at NCD-SWEET (ALBA)**

- **Beamline**: SWEET (ALBA)
- **Setup Components**:
  - E-beam
  - SR
  - Nanospheres
  - Si(111)
  - YAG:Ce
  - 45° Mirror
  - CMOS
- **Parameters**:
  - $\lambda = 0.1$ nm
  - $z$ (up to 1.2 m)
- **Materials**:
  - silica (SiO$_2$) spheres, 500 nm, in water

**Optical Setup**: YAG + mirror + optics + CMOS

**Probe**: silica (SiO$_2$) spheres, 500 nm, in water
Results at NCD-SWEET (ALBA)

**Coupling scan**: by changing the machine coupling $\kappa$, we vary the vertical beam size at NCD.

Minumum beam size measured with current setup: **4.5 µm**
Ongoing R&D activities

- Design of a dedicated X-HNFS dipole beamline for beam diagnostics @ ALBA
- First studies on monochromator material (W/B4C)

- Design of a dedicated X-HNFS beamline
- Dipole source
- First tests in 2024

- Preliminary studies on monochromator
- Energy range: 20 - 30 keV
- Peak energy: 24 keV
- Bandwidth: 1% - 5%

- Preliminary heat load evaluation on monochromator
- Air / water cooling

XOP simulations for W/B4C

(U. Iriso)
Ongoing R&D activities

- Numerical studies to optimize bandwidth, sample material and detected signal
- Development of a beam profile monitor based on X-HNFS and advanced solid targets

- Full SRW simulations
- Fourier-optics-based simulations
- Evaluate temporal coherence
- Optimize beamline parameters
- Numerical simulations of X-ray scattered signal
- Compare and validate different approaches (Mie theory, ADA, …)
- Identify best materials for targets
- Development of X-HNFS instrument
- Solid targets for continuous on-line operations at FCC-ee
- New screens to maximize light yield and detected signal
Summary and outlook

Current status:

• Development of a novel 2D beam profile monitor based on X-HNFS
• Validated at the NCD-SWEET undulator beamline at ALBA with hard X-rays
• X-HNFS can resolve few-µm beam sizes (down to 4.5 µm with current setup)

Many ongoing R&D activities for applications to FCC-ee, including (but not limited to):

• Design of a dedicated X-HNFS dipole beamline at ALBA for beam diagnostics
• First studies on monochromator bandwidth and materials
• Numerical studies on wavefront propagation to optimize beamline parameters
• Investigations on different materials and advanced solid targets to improve SNR
• Development and optimization of an X-HNFS instrument with higher resolution
Thank you for your attention.