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TUP18

HZB Helmholtz Zentrum Berlin

HIGH-RESOLUTION INTERFEROMETRIC BEAM-SIZE MONITOR FOR LOW INTENSITY BEAMS

Monitoring the size of low-intensity beams at plasma-wakefield accelerators

ABSTRACT: Plasma-based accelerator technology is reaching a mature state, where applications of the beam for medical sciences, imaging, or as an injector for a future large-scale accelerator-driven light source become feasible. Particularly, the requirements for beam injection into a storage-ring-based light source are very strict with regards to beam quality and reliability. A non-invasive diagnostics greatly helps to reduce the commissioning time of the machine. We present a device suitable for online, non-destructive monitoring of the transverse spot size of the injected beam. In order to measure lateral beam sizes with a few-micrometer resolution, the technique uses an interferometric regime of coherent synchrotron radiation that is enabled by a sub-femtosecond short bunch-length. Simulations of the photon flux and the retrieval of the beam spot-size are performed for different bandwidth filters in order to define the bandwidth acceptance. Results show the potential of the proposed system that achieves precise retrieval of the complex degree of coherence at an extremely low photon intensity similar to those expected towards the plasma-acceleration injectors.

MOTIVATION

The work presented here has been published in [1]. This work emphasizes the calculations of bandwidth acceptance and beam-size retrieval error. For a more complete description see the citation.

- **Beam sizes in the tens of µm range** with **very low electron intensities** are expected in plasma-laser accelerators. These are very challenging to measure with the required resolution.
- The **short bunch length** at plasma-laser accelerators enables the non-destructive diagnostics using the enhanced photon flux provided by **coherent synchrotron radiation (CSR)** emission.
- The required micrometer resolution in beam-size measurements can be achieved in the **interferometric regime**. The interference is built by filtering the CSR with a **double slit** plate.

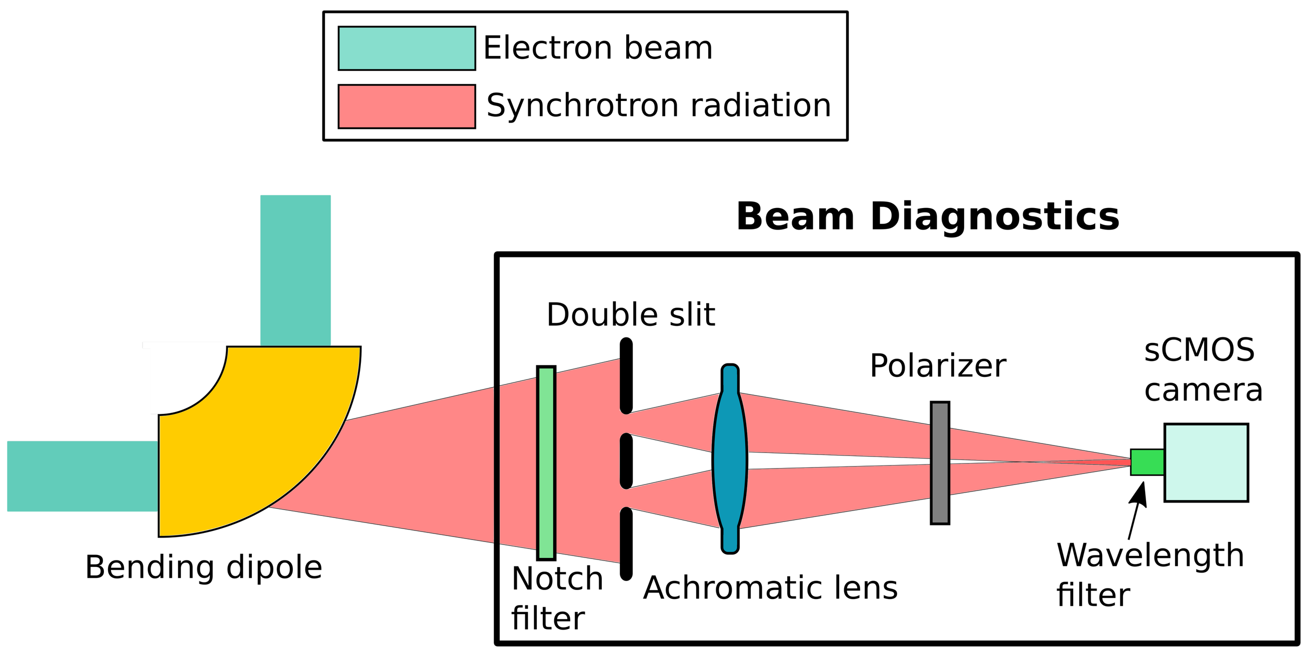

Figure 1: Sketch of the interferometric beam-spot size diagnostics device.

Table 1: Major beam parameters of research projects for a plasma-acceleration based injector relevant for our case study

	Energy (MeV)	$\gamma\epsilon$ (mm-(mrad)	Bunch charge (pC)	Bunch length (fs)	Beam size at $\beta_{x,y}$=1m (µm)
Athena$_e$ [2]	200	0.05	0.38-2.77	0.2-0.62	11
cSTART [3]	50	≤3	27.5	≤10	174
Shanghai LWFA [4]	490	≤3	50	/	15

METHODS

Visibility and beam-size retrieval for different bandwidths

- The finite emission source of the CRS is imprinted in the visibility factor of the interference pattern intensity (monochromatic photon beam):

$$I(x,y) = (I_1+I_2)\,\mathrm{sinc}^2\left(\frac{\pi w_x x}{\lambda f}\right)\mathrm{sinc}^2\left(\frac{\pi w_y y}{\lambda f}\right)\left[1+|\gamma_{12}|\cos\left(\frac{2\pi D_x x}{\lambda f}+\phi\right)\right]$$

Visibility

Wavelength

Beam spot-size

$$|\gamma_{12}| = e^{-2\left(\frac{\pi D_x \sigma}{\lambda L}\right)^2}$$

- However, the finite bandwidth of the photons distorts the interference pattern. This can affect the retrieved beam spot-size, limiting resolution.

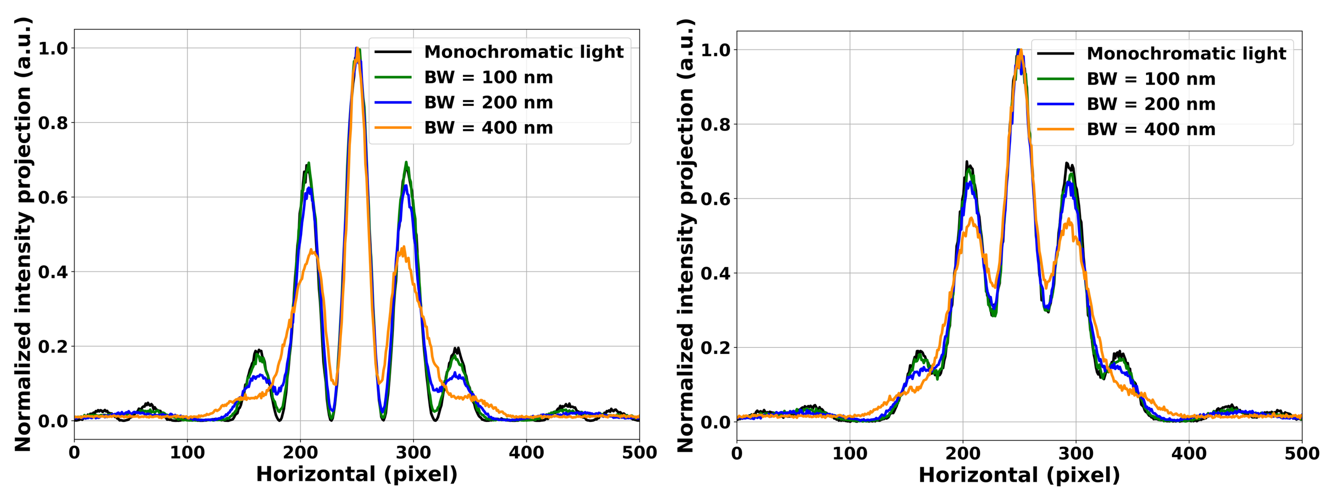

Figure 2: Simulated interference pattern at the detector for visibility values of $|\gamma_{12}|$ = 1.0 (**LHS**) and $|\gamma_{12}|$ = 0.5 (**RHS**). The simulations have been performed with 1e5 photon/s.

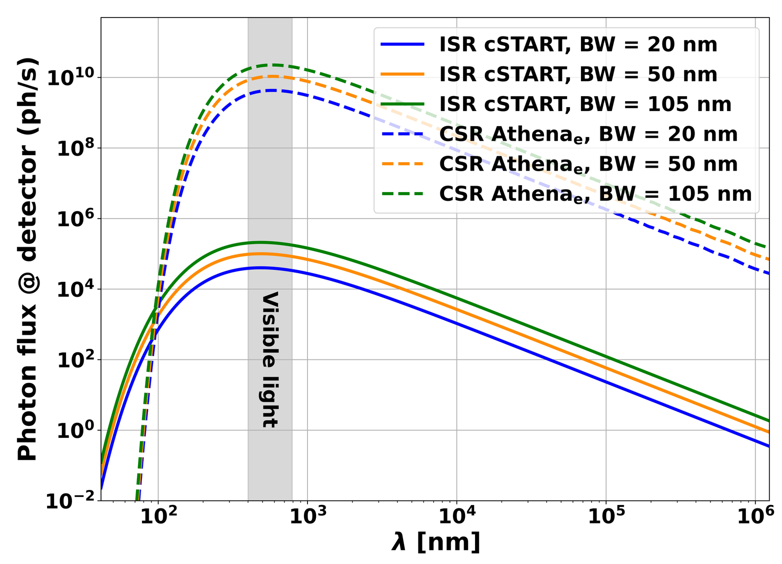

Figure 3: The results of the numerical simulations for the synchrotron radiation photon flux, performed with SPECTRA [5]. The photon flux is measured at the detector, behind the double slit plate and the bandwidth filter. The Athena$_e$ parameters from Table 1 have been used for this simulation. A larger bandwidth accepted at the detector will result in a larger photon flux, which results in higher signal to noise ratio. However, a larger bandwidth will also affect the interference pattern and, hence, the retrieved visibility (see Fig. 2). In order to have enough signal to noise ratio our device requires an operating limit of 2e4 photon/s.

RESULTS

Bandwidth acceptance determination

- The maximum bandwidth acceptance is defined to keep the relative visibility retrieval error under 5% in every case.

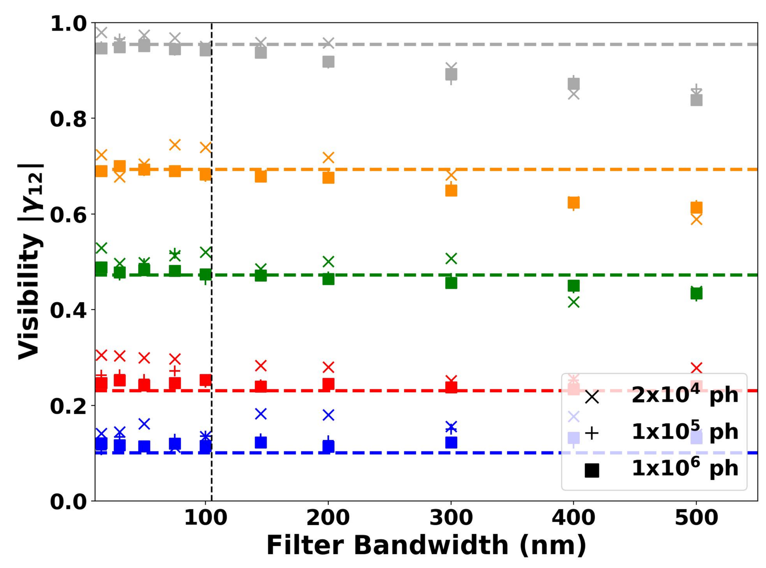

Figure 4: The recovered visibility is shown for different filter bandwidths, photon fluxes and different expected visibility values (in dashed horizontal lines). The retrieved visibility value is underestimated for large visibilities and overestimated for the lowest ones. The bandwidth acceptance is defined at 105nm, for larger bandwidths the retrieval error increases rapidly.

Beam spot-size measurement resolution

- The relative error of the beam size calculation as a function of the bandwidth at various visibilities are computed. This results in a spatial resolution of fewer than 1 µm for a BW of 105nm.

$$\Delta\sigma = \lambda L/\left(2\pi D\sqrt{2\ln|1/\gamma|}\right)\times|\Delta\gamma/\gamma|$$

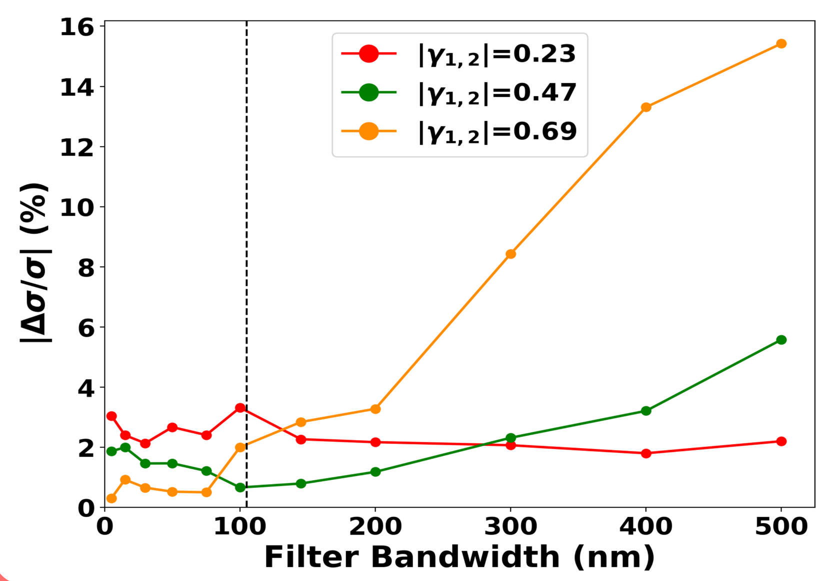

Figure 5: Relative error of the retrieved beam spot-size as a function of the bandwidth at intermediate visibility values, which depend on the beam spot-size and the experimental set-up

CONCLUSION

- The short bunch length expected in laser-plasma accelerators enables the use of CSR in the interferometric regime to measure the beam-size of low intensity beams with high resolution.
- The effects of the bandwidth acceptance for the device have been studied. Results show that enough signal to noise ratio together with 1µm resolution in beam-spot size can be achieved for the Athena$_e$ beam parameters with a bandwidth of 105nm.
- The working principle of the device under the expected photon flux conditions for laser-plasma accelerators has been proven in the MLS ring.

REFERENCES

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MORE INFORMATION

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