Betatron Radiation Diagnostics for AWAKE Run 2

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The AWAKE experiment is a GV/m-class plasma wakefield accelerator (PWFA) at CERN

Proof-of-concept experiments in AWAKE Run 1 have demonstrated electron acceleration in a proton-driven wakefield [1]

AWAKE Run 2 aims to preserve witness beam quality throughout acceleration

New, non-intercepting diagnostics are required to measure the emittance of the accelerated electron beam

Core and defocused protons remain on axis and with a 1 mrad divergence, making a direct measurement challenging

We study betatron radiation spectroscopy as a possible solution, which may also provide information on injection dynamics

### Ion channel dynamics & betatron radiation

- An electron in an ion channel undergoes transverse oscillations due to focusing forces from the ion column, governed by the equation:
  \[
  \frac{d^2 x}{dt^2} + \frac{1}{\gamma} \frac{d \gamma}{dt} \frac{dx}{dt} + \frac{\omega_p^2}{2 \gamma} x = 0
  \]

  \[\omega_{\beta} = \frac{\omega_p}{\sqrt{2 \gamma}}\]

  This motion has a linear sinusoidal solution in the case of constant energy and a decaying amplitude and betatron frequency for a non-zero accelerating field [2], via the WKB approximation

- This motion results in synchrotron radiation, which has spectral characteristics determined by the distribution of single-electron orbits within the beam envelope [3]

- The emission at AWAKE is not straightforward to characterise with analytics for a number of reasons: the wiggler parameter \(\alpha_\beta \sim 1\); the radiating electron beam evolves significantly over 10 m; and the beam does not sit fully within the ion channel it generates

### Simulated emission for AWAKE

- A simulation approach can provide more accurate estimates for the betatron emission

- The Run 2 model developed by Olsen et al. [4], that determines matching and beam loading conditions, is adopted with the added consideration of betatron radiation

- QV3D is a quasi-static 3-dimensional PIC code that includes betatron radiation [5]

- A significant number of EUV photons fall at angles above 1 mrad for the matched baseline case, propagated over 10 m

### Injection scans

- Electron orbits map directly to radiation emission patterns [6]

- The matched baseline case is scanned between 1 and 2-dimensional offsets, and a wide mismatched beam

- The corresponding emittance evolution over 1 m is also shown

- These different injection scenarios could therefore be discriminated between with a betatron measurement

### Conclusions

- The betatron radiation from accelerated witness electrons at AWAKE Run 2 will, in the ideal matched case, be highly collimated (< 1 mrad) with the majority of photons falling between 10-1000 eV

- A significant number of EUV photons (10-100 eV) remain above 1 mrad. This could facilitate a partial measurement of the betatron spectrum, despite a background of defocused protons, using a rotating multilayered mirror with a central hole

- This measurement could also reveal the injection dynamics for each acceleration event