Demonstration of fresh slice self-seeding in a hard X-ray free electron laser

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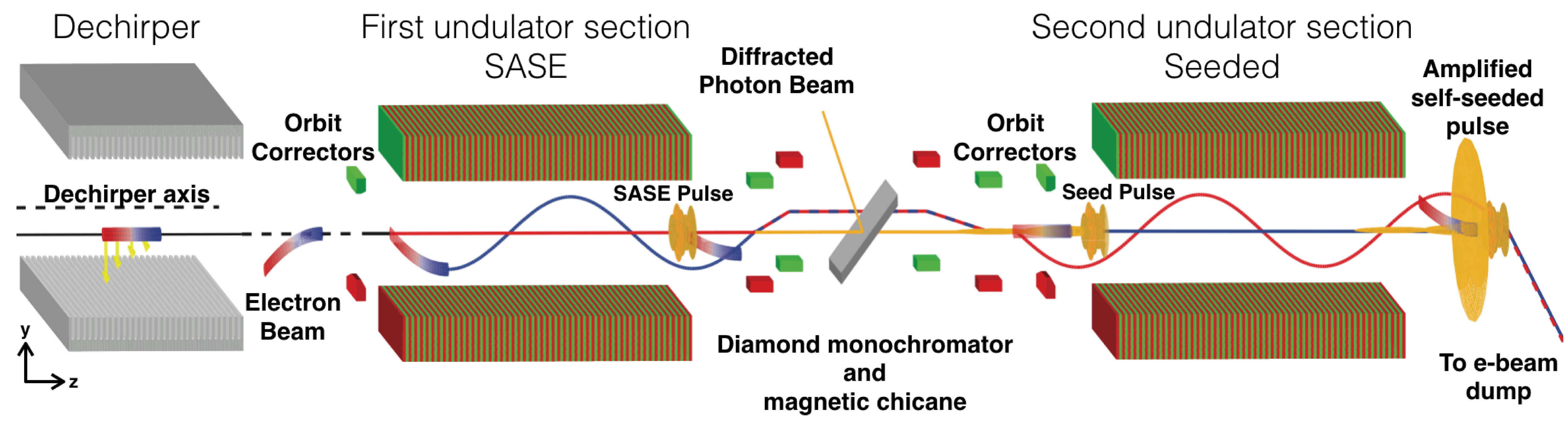
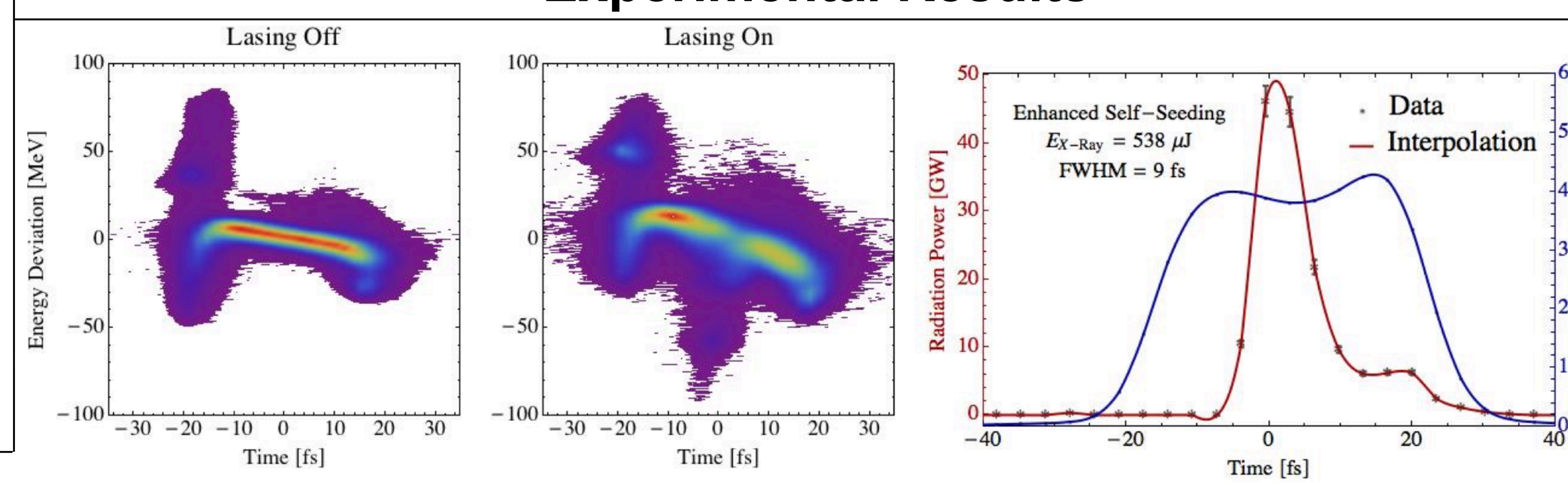
Abstract

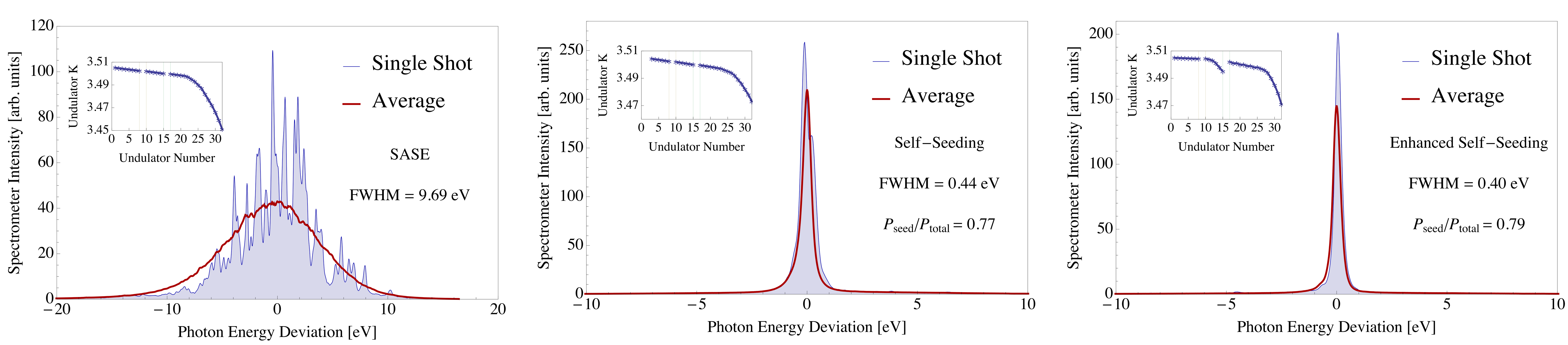
We present results of the first experimental demonstration of fresh slice self seeding, or Enhanced Self-Seeding (ESS) in a hard X-ray Free Electron Laser (XFEL). In the experiment, performed at the Linac Coherent Light Source (LCLS), a slice of the electron beam is used to generate a strong SASE signal, reaching saturation before the self-seeding monochromator. The signal is filtered and used to seed another electron beam slice with a small energy spread, that amplifies it. This extends the capability of self seeded XFELs by producing high peak power, short pulses, not limited by the duration set by the self-seeding monochromator. The scheme utilizes a parallel plate dechirper to impart a spatial chirp on the beam, and appropriate orbit control to lase with different electron bunch slices before and after the monochromator. The performance of the ESS method is analyzed with start-to-end simulations for LCLS. The simulations include the effect of the parallel plate dechirper and propagation of the radiation field through the monochromator. The radiation properties of ESS X-ray pulses are compared, for the same electron beam parameters, with the SASE mode and the standard self-seeding mode of FEL operation.



Experimental Results

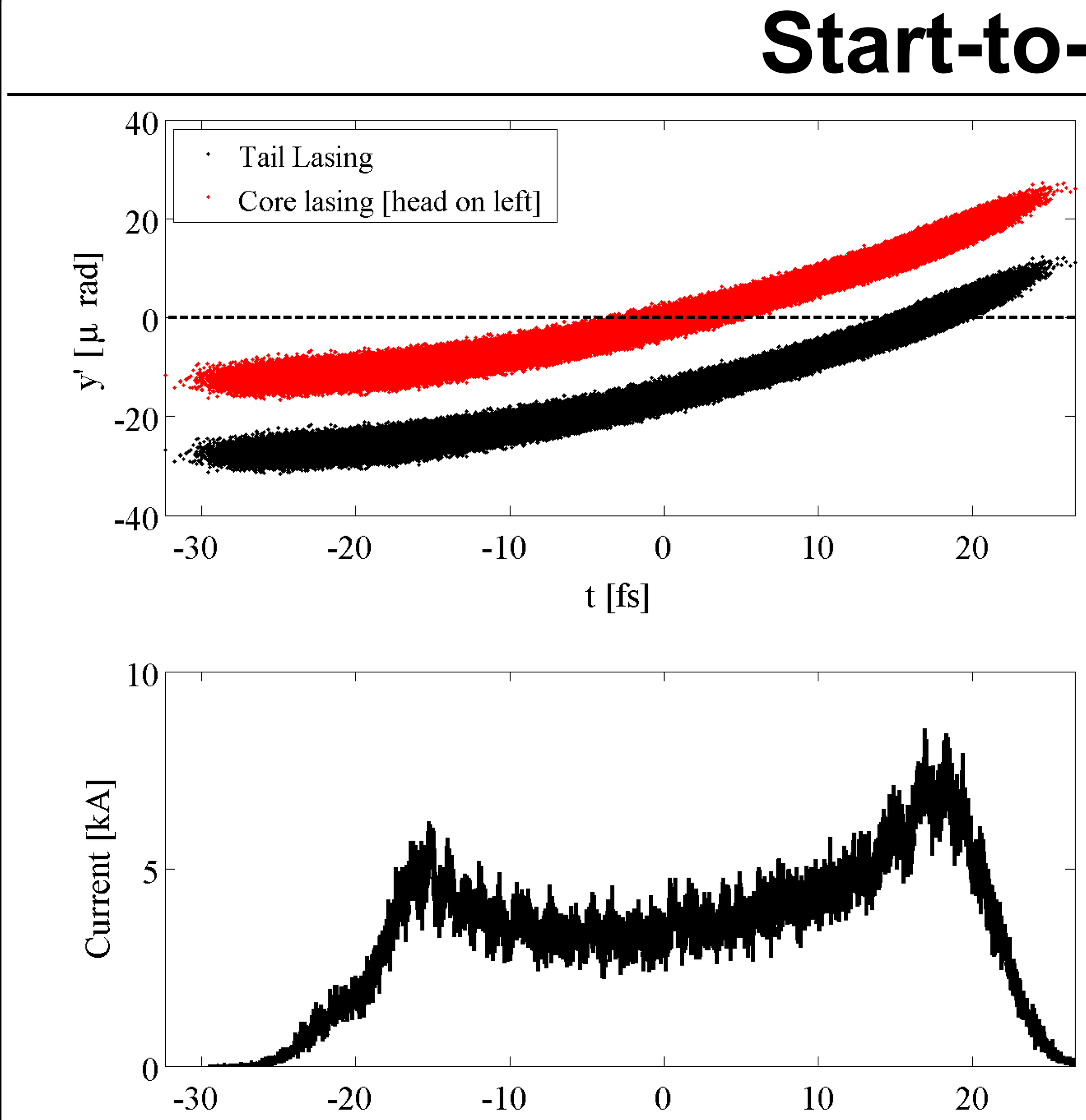


<u>Fig. 1</u>: Single shot longitudinal phase space for the ESS experiment. The tail lasing electrons (t=20 fs) generate the ~ 6 GW SASE before the monochromator. The core electrons (t=0 fs) exhibit large energy loss and amplify the seed in the second undulator section to 50 GW power.

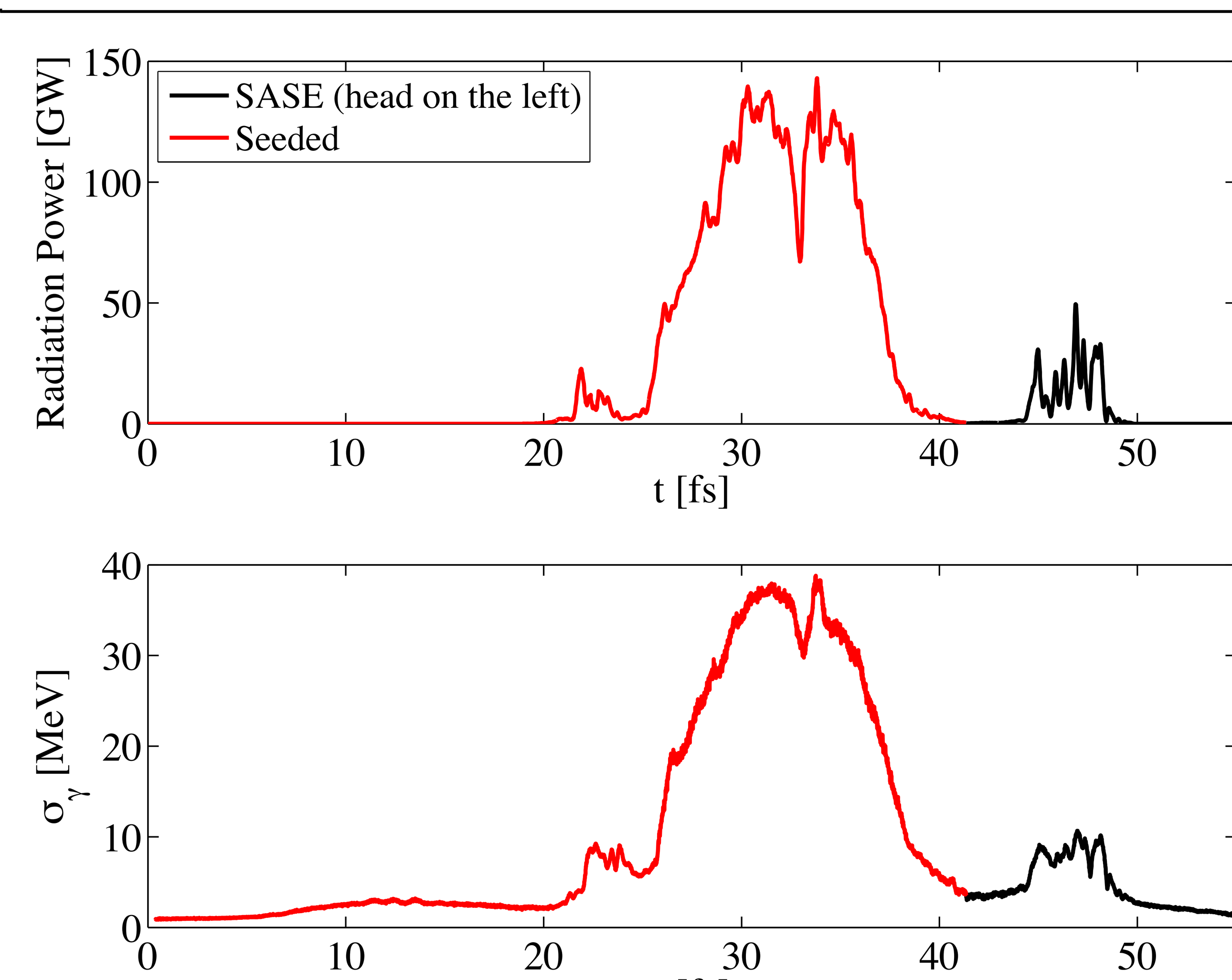


<u>Fig 2</u>: Single shot and average spectra for SASE, self-seeding and ESS. The bandwidth of ESS is around 24 times narrower than SASE and the pulse duration around 4 times shorter than SASE and self-seeding, giving an increase in brightness of a factor of 12 and 2 respectively.

Start-to-end simulations



- SASE power before the diamond monochromator is 15 GW, a factor of 15 larger than typical values for regular self-seeding



- Seeded power at the undulator exit is ~ 120 GW in 10 fs, matching the intensity for the best experimental shots.

Conclusion

- We present the experimental demonstration of a novel seeding method, ESS, to increase the extraction efficiency and brightness of X-ray FELs
- We compare the performance of this method with SASE and self-seeding measuring a brightness increase of 12 and 2 times respectively.
- Comparison with simulation matches experimental intensity for the best shots.
- This experimental demonstration opens the door to very high peak power, high efficiency, multi-TW XFELs in the future.

References

(1) A. Lutman *et. al.*, accepted in Nature Photonics (2016)
(2) C. Emma *et. al.*, submitted for publication (2016)
(3) C. Emma, K. Fang, J. Wu, and C. Pellegrini PRAB **19** 020705 (2016)
(4) E. Prat, F. Lohl, S. Reiche, PRSTAB **18**, 100701 2016