Letter of Intent for Ultrashort Optical Pulse Development for the LCLS

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Abstract

The need to produce pulses on the femtosecond timescale cuts across many disciplines in fundamental and applied sciences, the main reason being that many electronic processes occur in this timescale. The baseline design of the LCLS, with the nominal 255 femtosecond optical pulse length is 2 orders of magnitude shorter than the state-of-the-art of the most modern Synchrotron radiation sources. This, in itself, is a most significant advance that will open up novel scientific opportunities. Nevertheless, from the LCLS workshops [1] it is clear that an improvement from 255 femtoseconds to <50 femtoseconds in optical pulse length will have a major impact on at least two general areas of research, molecular dynamics, and bio molecular structure determination. Undoubtedly, the scientific communities will keep asking for shorter and shorter pulses. The realization of 50 femtosecond or less LCLS x-ray pulses will be tremendously important for some classes of experiments and significantly enhance the future capabilities of the LCLS. In this Letter of Intent (LoI) we set out a proposal for a series of experiments and development efforts aimed at extending the present design capabilities of the LCLS to generate even shorter x-ray pulses than the nominal 255 femtosecond baseline.

Background

The authors have considered several paths for producing ultrashort pulses from the LCLS [2] based on either shortening the *electron* bunch utilizing (magnetic) compression, or shortening the *x-ray* pulse utilizing x-ray optical techniques. The x-ray optical techniques fall into 2 categories: time-slicing techniques that extract a narrow slice of the x-ray pulse in time; and, the more desirable, but technically more difficult, x-ray optical compression techniques that compress the pulse in time while preserving the number of photons.

The x-ray-optical and electron-bunch-length techniques for achieving shorter pulses are not independent as both require a manipulation of the electron beam to produce an "energy chirp" which is a (nearly linear) relation between electron kinetic energy and longitudinal position along the bunch. In electron-bunch-length compression, magnetic chicanes exploit this relationship to produce shorter trajectories towards the tail of the bunch and longer trajectories towards the head of the bunch. This results in an overall shortening or compression of the electron bunch. In the x-ray optical techniques, an energy chirp in the electron bunch is necessary to produce a corresponding energy chirp in the photon bunch, which is exploited to spectrally select a short time slice of the photon bunch or to compress the bunch by altering the path length of its spectral components using an arrangement of dispersive x-ray optics.

Magnetic electron-bunch-length compression is already implemented in the baseline LCLS design in order to achieve the peak currents necessary for SASE to occur. Detailed modeling with the existing LCLS electron transport codes show that increasing the momentum spread along the bunch, and increasing the strength of the magnetic fields of the compressors can achieve further compression of the electron bunch resulting in shorter x-ray pulses. The same codes were also used to explore methods of introducing an energy chirp into the FEL beam and to quantify the magnitude of the energy chirp that can be delivered to the optical systems. In all, 4 beam line parameter decks were developed that achieved shorter electron bunch length and / or energy chirps of up to 2%. The major risk/uncertainty in these calculations is the emission of Coherent Synchrotron Radiation that becomes very severe, as the bunch gets shorter in the compressors. The radiation effects are subtle and require careful re-evaluation now that the LCLS baseline has been set.

We studied several optical methods for exploiting the estimated photon energy chirp to shorten the LCLS pulse. The performance of two time-slicing schemes was calculated in detail. Tatchyn [3] calculated the performance of several candidate mutilayer mirrors having very small energy-bandwidth for time-slicing achieving slices in the 10s of femtosecond range. Bionta [4] showed how an off-axis zone plate could deliver focused, time-sliced pulses of < 50 femtoseconds. Although the calculations are robust in these two cases, both schemes rely on thick multilayer structures that are at or beyond the current state-of-the-art.

X-ray optical compression is a more challenging problem. Solutions involving reflection gratings require large gratings and long optical paths. Suitable geometries must be worked out consistent with the LCLS baseline beam layout. A possible solution

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proposed by Chapman utilizes a novel asymmetrically cut thick multilayer to disperse the beam at higher angles resulting in a more compact device. The fabrication of such a device is currently at or beyond the state-of-the-art.

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Although the above-mentioned studies are encouraging, as they show several possible paths toward achieving shorter LCLS pulses, the feasibility of any of the schemes studied remains to be proven. The electron-bunch manipulation calculations need to be re-evaluated using the latest LCLS configuration and current understanding of the wake field issues. The Coherent Synchrotron Radiation estimates need to be strengthened. More design work on optical slicing and compression needs to be done using the latest LCLS beam codes. Methods for fabricating the optical elements of the most promising schemes must be developed.

It is the authors' intent to submit a proposal for Ultrashort Optical Pulse Development for the LCLS. The proposal will outline research and development efforts aimed toward demonstrating the feasibility and eventually delivering the instrumentation for providing ultrashort optical pulses from the LCLS. The proposed work will involve 1) Updating and refining the electron beam chirp models, 2)detailed calculations supporting conceptual designs for pulse compression and time-slicing schemes, 3) demonstration of fabrication techniques for the x-ray optical components in the promising concepts, and 4) preliminary design and cost estimates for a pulse shortening scheme for the LCLS. We estimate that the R&D effort will require approximately $400K to $800K, with the final instrument cost to be in the range of $1M to $2M.

We look forward to submitting a full proposal for this work in the near future.

References

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3] *Multilayer-Based Radiation Pulse Slicers for Linac Coherent Light Source (LCLS) Applications*, R. Tatchyn, LCLS-TN-00-17, December 22, 2000.

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