

IDEAS FOR A FUTURE PEP-X LIGHT SOURCE[†]

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Abstract

SLAC is developing a long-range plan to transfer the evolving scientific programs at SSRL from the SPEAR3 light source to a much higher performing synchrotron source – PEP-X – a new storage ring that would occupy the existing PEP-II tunnel and support two experimental halls, each containing 16 x-ray beam lines. Operating at 4.5 GeV and 1.5 A with a horizontal emittance of 0.14 nm-rad, reached using 90 m of damping wigglers, PEP-X would have an order of magnitude higher average brightness and flux in the 1-Å x-ray range than any existing or planned future storage ring sources. Higher brightness in the soft x-ray regime might be reached with partial lasing in long undulators, and high peak brightness could be reached with seeded FEL emission. The status of preliminary studies of PEP-X is presented.

OVERVIEW

The future of x-ray science lies in the ability to exploit complementary features of photon beams, such as high average brightness vs. high peak brightness, high energy resolution vs. very short pulse length, and high flux vs. high coherence. While storage rings presently provide the first set of these complementary beam properties, linac-based FEL facilities now in construction promise to provide the second set. Future energy recovery linacs (ERLs) and high-repetition rate, superconducting linac FELs may ultimately offer high overall performance, but their implementations are subject to the success of extensive R&D over many years in the future.

SSRL at SLAC presently uses the SPEAR3 storage ring to provide 3rd generation-quality synchrotron radiation and experimental facilities optimized for selected x-ray techniques and scientific areas that employ high average brightness. With the LCLS, the complementary photon beam features of high peak brightness, short bunch length and high transverse coherence of 1-Å x-rays will also be provided at SLAC. Nevertheless, over time, SSRL users will seek enhanced performance over SPEAR3 and a new facility. With the recent termination of operation of the PEP-II B-Factory for the DOE's High Energy Physics program, it is only natural that SLAC should investigate what type of new high average brightness source could be implemented in the 2.2-km tunnel. To this end, a study group was formed in 2007 and, after considering a few conceptual options, it converged on the most practical as the initial machine of interest: PEP-X, a very bright, high-

flux storage ring having ~ 0.1 nm-rad emittance at 4.5 GeV and capable of operating at 1.5 A beam current [1]. While the group has not discounted the possibility of other options – an ERL source, for example – the PEP-X storage ring implementation provides a performance benchmark using known technology against which other future implementation possibilities can be compared. The preliminary study indicates that PEP-X could deliver a factor of ten or more higher brightness than existing or planned future storage ring sources (Fig. 1). The facility would support two experimental halls, each containing ~ 16 photon beam lines, typically 120 to 140-m long, but

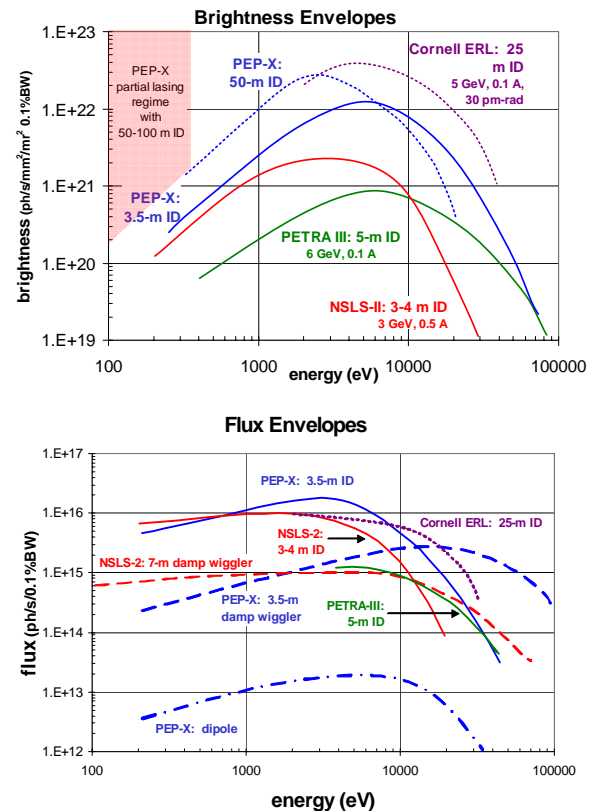


Figure 1: Approximate brightness and flux envelopes for PEP-X and other new light sources. Partial lasing in a 50 to 100-m ID may be possible at wavelengths > 3.3 nm, increasing brightness for one or two orders of magnitude. The envelope for the futuristic 5-GeV Cornell ERL [6], an R&D project, assumes a 25-m ID operating in either high-flux (31 pm, 100 mA) or high-coherence (8 pm, 25 mA) mode. PEP-X brightness may be enhanced by a factor of ~ 2 with optimized beta functions in ID straights and high-performance IDs.

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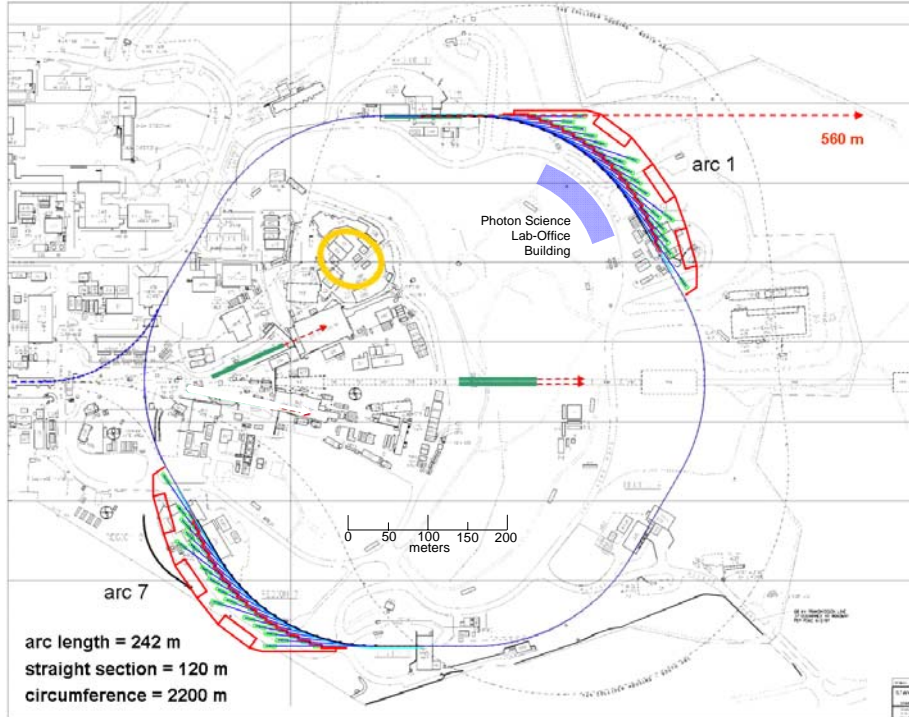


Figure 2: Conceptual layout of PEP-X light source with two experimental halls containing ~ 32 x-ray beam lines, up to 140 m long, with long beam lines (~ 560 m) accommodated in arc 1, and a future lab-office building. SPEAR3 is shown in yellow; green rectangles represent existing and future FEL undulators for the LCLS.

which could reach up to ~ 600 m (Fig. 2). Much higher brightness in the soft x-ray regime might be reached with partial lasing in long undulators (50-100 m) [2], and high peak brightness could be reached with seeded FEL emission. As is being explored for present-day storage ring light sources, rf crab cavities or other beam manipulation systems can be used to reduce bunch length in a section of the ring to the order of 1 ps or less [3]. Much of the PEP-II facility infrastructure would be reused, as would be some of its accelerators components (including rf, bunch feedback components, etc.).

LATTICE AND INJECTION

Following the PETRA-III model, a hybrid lattice has been investigated for PEP-X [4]. In our case, two of the six arcs contain DBA cells that provide a total of 30 straight sections, each 4.3-m long, for insertion device (ID) beam lines. The remaining four arcs contain TME cells in order to minimize emittance. More IDs can be accommodated in the 120-m long straight sections adjacent to the DBA arcs. The natural emittance of 0.37 nm-rad at 4.5 GeV is reduced to 0.09 nm-rad using at total of ~ 90 m of damping wigglers located in two of the long straight sections. Intrabeam scattering (IBS) causes the horizontal emittance to grow to 0.14 nm-rad with 1.5 A in 3400 bunches when the coupling is reduced to create an 8-pm-rad vertical emittance, the diffraction limit for 1-Å photons. Emittance growth from IBS becomes more significant as electron energy is reduced, negating any potential gain in brightness for lower energy photons that

Table 1: Machine parameters for PEP-X.

Parameter	Value
Energy	4.5 GeV
Current (operating/max)	1.5 / 3.0 A
# filled bunches / harmonic number	3400 / 3492
RF frequency	476.00 MHz
Circumference	2199.32 m
Damping wiggler length/period	89.3 m / 10 cm
Hor emittance @ 0A/1.5A ($\epsilon_v = 8$ pm)	0.094 / 0.14 nm
Beta at ID straight center* (x/y)	9.09 / 8.14 m
Beam size @ ID center, I = 1.5 A (x/y)	36 / 8 μ m rms
Beam diverg @ ID center, I=1. A (x/y)	4 / 1 μ rad rms
Bunch length (without/with harm cav)	2.5/5.0 mm rms
Lifetime @ 1.5A ($\epsilon_v=70/8$ pm, 5-mm σ_z)	110 / 42 min
ID straight section length/number in arcs	4.3 m / 30
Long straight section length / # for IDs	120 m / 2

might have been realized by reducing ring energy. Lower energy also exacerbates the onset of bunch instabilities [5]. Machine parameters are summarized in Table 1. Lattice development is discussed in more detail elsewhere in these proceedings [4].

The Touschek lifetime is < 1 h, even with a 3rd harmonic cavity that will lengthen the bunch by a factor of two to 5 mm rms. Frequent top-off injection will be needed if beam current is to be held constant to the order of 1% or better, as is now becoming the standard for ring-based light sources. To maintain 1% current constancy, 8 nC (~ 1.1 mA) must be injected every 1 or 2 seconds, distributed in 10 or more PEP-X bunches. The injection

kicker bump must be very well compensated to reduce the induced stored beam orbit transient.

Due to its very small dynamic aperture, PEP-X requires a low-emittance injected beam and minimal separation between injected and stored beam. While the PEP-II injection system, comprised of 12-GeV linac, electron damping ring and vertical injection configuration, are suitable for PEP-X, other accelerator programs at SLAC, such as the LCLS and FACET, may vie for this source in the future. In this case, it may be necessary to build a dedicated injector for PEP-X, most likely using available spare linac sections and klystrons. A low-emittance gun would be used to provide a train of 10-20 bunches per injection pulse, eliminating the need for a damping ring.

PEP-X PHOTON SOURCES

Parameters for representative PEP-X photon source magnets are shown in Table.2. Figure 3 depicts brightness for these sources. The undulator parameters are consistent with presently available commercial magnet technology. Further refinement of the PEP-X lattice should result in more optimized β -function values, yielding up to a two-fold increase in undulator brightness. Higher risk undulator designs utilizing cryogenically-cooled permanent magnets or superconducting magnets hold promise for higher performance but require some maturation of the associated technology.

The 1.5-A operating current for PEP-X was chosen to limit the power density from 3 to 5-m undulator sources to 1 MW/mrad², a demanding value that can be handled by present-day beam line front-end components ~50-60 m from the source, about half the beam line length.

A particularly challenging beam source would be a 50 to 100-m long soft x-ray undulator tuned to 3.3 nm or

Table 2: Representative PEP-X source magnet parameters.

	U23	U41	W50	bend
magnet	undulator	undulator	wiggler	dipole
period	23mm	41mm	50mm	n.a.
no. periods	150	85	70	n.a.
k_{\max} or B	2.26	5.97	7.85	0.49T
Ecrit (keV)	14.2	21.0	22.6	6.6
power (kW)	74	166	191	0.29 kW/mrad
power dens (kW/mrad ²)	1038	884	784	1.6

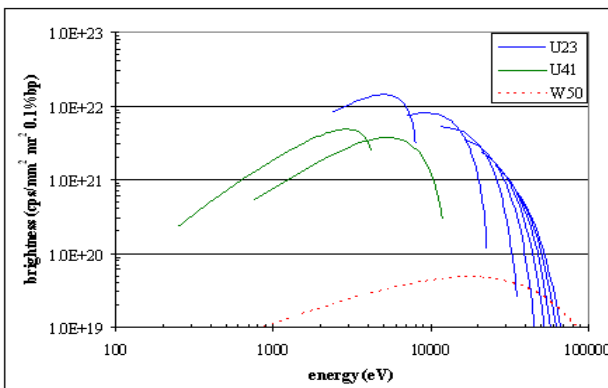


Figure 3: Brightness for 3.5-m IDs: 23-mm and 41-mm-period undulators and a 50-mm-period wiggler.

greater. With a fully coupled beam having ~0.07 nm-rad emittance and a peak current of ~270 A (1 mA in a 10-ps-rms bunch), the photon emission at the tuned wavelength would be enhanced by one or two orders of magnitude by the SASE FEL process operating on the stored beam. [2]. The drawback to this device operating with 1.5 A is the 4 MW of radiated power that must be accommodated by beam line components. Such a beam line would be a few hundred meters long. It is likely that this type of device would operate with lower total current in a few bunches.

PEP-X R&D

There are many challenges in designing PEP-X to perform as desired with sufficient stability and minimal degradation of beam brightness by beam line optical components. R&D topics include:

- further lattice development and beam dynamics study, including the effects of CSR
- developing high performance electron and photon BPMs, beam trajectory feedback systems and optics supports that can meet the tight stability requirements
- designing an effective 3rd harmonic cavity system
- developing practical rf beam manipulation components for creating short bunches
- continuing studies of unseeded and seeded lasing in long soft x-ray undulators
- improving beam line mask thermal designs and mirror-and monochromator-cooling technologies
- improving mirror polish/figures for preserving emittance and coherence
- advancing micro-focus optics

Many of these design challenges are shared by others involved with developing future high performance light sources, raising the potential for fruitful collaboration.

CONCLUSION

A preliminary concept for a future high brightness light source at SLAC has been developed that will serve as a benchmark for further investigations. The direction these studies take will depend on the specification of optimal source properties by a team of representative light source scientific users now being formed at SLAC.

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