SUMMARY OF ERL USES AND APPLICATIONS SESSION - ERL 2022

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Abstract

The International Workshop on Energy Recovery Linac (ERL 22) contained the session ERL uses and applications.This focused on potential uses and applications such as light sources, electron coolers, and lepton colliders. The goal was to discuss possible applications and proposed experiments which require an ERL, or can improve the performance by using ERL. The session comprised 10 presentations, two delivered virtually. In this report, we summarize these presentations.

INTRODUCTION

The talks presented at the uses and applications session split into topics as follows:

- 4 talks about Light sources includes FEL, lithography and γ-ray
- 1 talk about Electron coolers
- 2 talks about Nuclear physics
- 3 talks about High energy colliders

ERL APPLICATION ON LIGHT SOURCE

The stringent demands of synchrotron radiation users has led to improvements in brilliance of light sources. Two major directions have been developed in the last decade. One is toward diffraction-limited storage rings (DLSRs), which use multi-bend achromatic lattices to provide higher brightness radiation via a high-quality stored electron beam. The other direction is toward a CW X-ray Free electron laser (FEL) to generate high average brightness radiation. Prior to advancements in DLSR, ERLs were considered for driving spontaneous undulator radiation sources, but this became less attractive in comparison to the DLSR due to the lower technology readiness.
Prof. Zhao presented a new method for high repetition rate, fully-coherent pulse generation using angular-dispersion induced microbunching (ADM) on an ERL. Enhancing radiation power and coherence in this way is an intriguing "halfway house" between the DLSR and fully coherence XFEL pulses. To enhance the microbunching, a round to flat emittance converter can be applied at the exit of the photoinjector. A conceptual design of an ERL light source based on this method was presented as shown in Fig.1. A careful study demonstrates the production of fully coherent radiation with brightness 5–6 orders of magnitude higher than that of a DLSR with the same beam energy, and a much higher repetition rate compared with a CW-FEL without energy recovery [1]. The main challenges are the 100 mA photoinjector and the HOM BBU effect. These challenges can be addressed by electron gun and SRF cavity R& D.

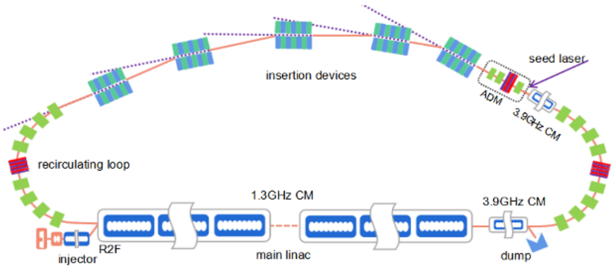

Figure 1: Schematic layout of a multi-radiation light source based on an ERL using ADM.

Developing ERLs for commercial applications will increase the ERL community. An ERL-based EUV-FEL has strong potential to be the next-generation commercial lithography light source - provided sufficient investment from industry and government is realised. This is because ERLs enable the high average radiation power required for a lithography source. There are several issues with existing commercial lithography apparatus' using laser-produced plasmas (LPP). These include contamination of tin debris in the light source, and stochastic effects caused by chip defects. Future EUV sources will require average powers of at least 1.5 kW-2.8 kW per scanner, which cannot be achieved by an LPP source. Dr. Nakamura presented an ERL-based EUV-FEL light source that can produce high-power EUV above 10 kW and is upgradeable to shorter wavelengths down to 6.6 nm [2]. Additionally, polarization control is enabled for high numerical aperture design. Importantly the electricity consumption per wafer produced is estimated to be significantly smaller in comparison to the LPP method, 0.7 MWe per 1 kW EUV for an FEL vs 4.4 MWe per 1 kW EUV for LPP. The main challenges are the high cost of R&D and operation, as well as potential mirrors and reticle damage by high peak power light.

ERL FOR GENERATING γ-RAY AND ITS APPLICATIONS

An ERL can produce high flux, high energy resolution γ-rays via Inverse Compton Scattering (ICS). γs in the 1-100 MeV range have multiple potential applications in diverse areas such as national security, transmutations of nuclear waste, photofission studies, medical areas, isotope production, and so on. Due to the energy-angle correlation of ICS,

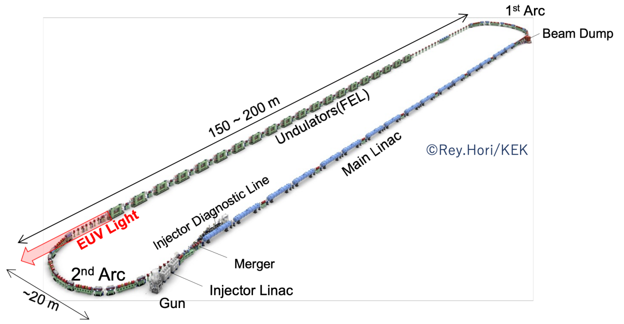

Figure 2: An schematic layout of the ERL based FEL-EUV for lithography.

mono-energetic and high brightness γ-ray beams can be produced. ERLs have the potential to exceed the spectral flux produced by existing storage ring based facilities by at least two orders of magnitude. This opens the way toward industrial R&D and applications in addition to pure photo-nuclear physics academic activities. Dr. Kayran discussed two proposed ERLs (PERLE and ER@CEBAF) that could be used to generate γ-ray in addition to their main goals [9]. One of γ-ray major users is nuclear reactions using photon beams. The major advantages of nuclear physics are the pure electron-magnetic interaction, selectivity of different modes, and high resolution as described in Dr. Beck's talk [6].

ERLS FOR NP EXPERIMENTS ON FIXED TARGET AND GAS JET

The Dark Light experiment has been proposed to search for a new, bosonic mediator between dark matter and the constituents of the visible matter in the universe via direct production in electron-proton scattering. The proton radius puzzle is another unanswered problem relating to the size of a proton using different measurement methods. For both topics, an ERL can provide excellent beam quality and high luminosity for either thin film target or gas jet experiment as shown in Fig. 3. Dr. Bernauer's presentation tells us the motivation of two physics experiments and pointed out that the ERL can meet the experimental requirements [8]. The Mainz energy-recovering superconducting accelerator (MESA), aiming to begin operation in 2025, is dedicated to such measurements. Prof. Hug showed the progress of the MESA construction progress and discussed the expected performance and proposed experiments [7]. Depending on the experiment running, MESA will be able to switch between external-beam and energy-recovery modes.

ERL FOR ELECTRON COOLER

Bunched beam (as opposed to DC) electron cooling needs a high current, high-quality electron beam. For lepton-hadron colliders such as the Electron Ion collier (EIC) in the energy range of 100-275 GeV, Strong Hadron Cooling (SHC) can boost luminosity by a factor of 3-10. The required high-energy (up to 150 MeV), high brightness electrons beam with

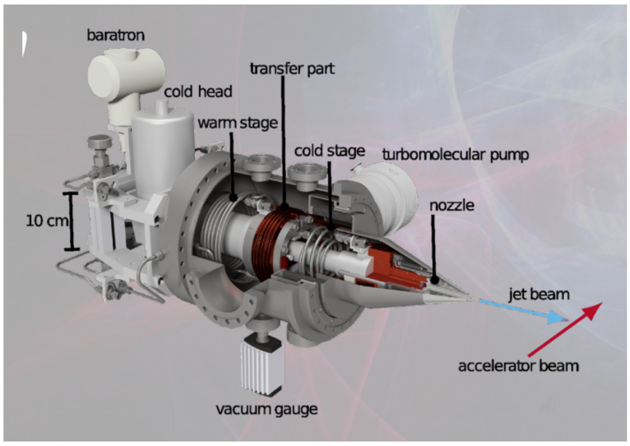

Figure 3: An 3D model of gas jet experiment set up

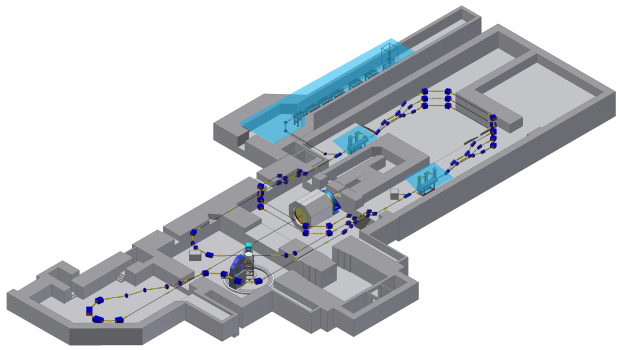

Figure 4: MESA facility schematic drawing

100 mA average current only can be generated by an ERL. For the EIC, Coherent electron Cooling (CeC) is the baseline amplification method chosen to produce SHC, because of its high predicted cooling rates [3]. The cooling needs < 3 mm-mrad normalized transverse emittances, 10^{-4} small energy spread, and intensity fluctuations less than twice the Poisson noise of the beam. The ERL also provides beam for the precooler to cool initial injection hadron emittance. Therefore, the ERL has to work at an unusually large energy range, from 13 MeV to 150 MeV. Such an ERL would possess parameters beyond the state of the art. A linear optics initial design for the EIC cooler ERL has been developed. The challenges of both SHC and ERL will be addressed in the next few years through careful design and R&D.

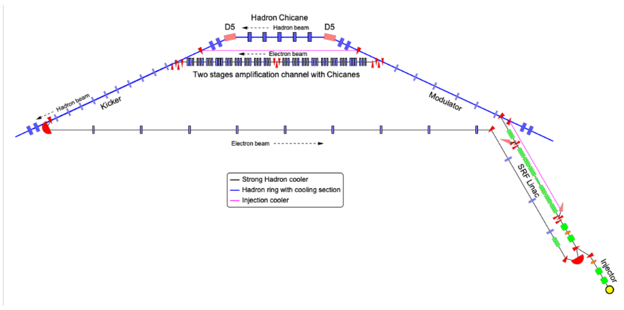

Figure 5: An schematic layout of SHC facility for EIC.

ERLS FOR HIGH-ENERGY COLLIDERS

Future energy frontier particle accelerators are among the most exciting, complex, challenging, and expensive research instruments performing high-precision measurements confirming the fundamentals of physics, and broadening new research horizons. Using ERLs for high-energy colliders has generated increasing interest in recent years due to favourable operational cost comparisons to conventional storage ring and linac based facility proposals. In this workshop, at the introduction session and beam dynamics session, A. Hutton delivered two talks that discussed this topic at a high level. In this session, three electron-positron colliders based on the ERL were presented by Prof. Litvinenko and Dr. Konoplev, and a muon collider was proposed by Prof. Serafini. The major advantage of using an ERL in comparison to a storage ring is that there is no limitation on allowable beam-beam tune shift and IP chromaticity due to a single collision. Also one can reduce the SR power radiated, thereby reducing operational cost.

Prof. Litvinenko proposed ReLiC and CERC: two versions of polarized electron-position colliders. In particular, ReLic has the novel feature of separators for counter propagating bunch trains to avoid beam-beam effects (Fig. 7). It has potential to achieve very high luminosity at very high energies in comparison to the established $e^{-}e^{+}$ collider design projects as shown in Fig. 6 [4].

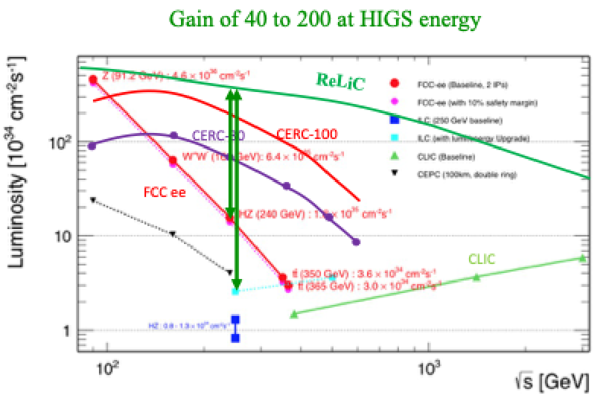

Figure 6: Comparison of the proposed e-e+ colliders luminosity as the function of $\sqrt{s}$

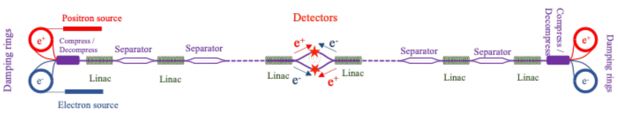

Figure 7: ReLic collider layout

Dr. Konoplev proposed another novel design of merging circular and linear systems, and applications of dual axes cavities, aiming to maintain high beam quality, high luminosity, and high energy efficiency as shown in Fig. 8. The concept presented can be potentially used to reach ultimate energy frontiers in high-energy physics and to generate synchrotron radiation for users. The aluminum and copper dual-axis asymmetric cavities have been constructed and tested.

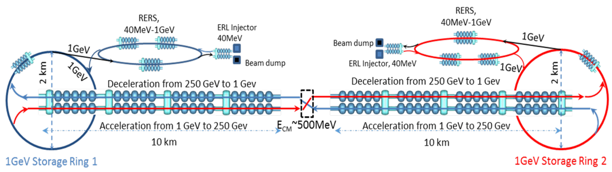

Figure 8: Circular-Linear energy recovery accelerator using dual axes asymmetric cavities.

Dr. Serafini presented a new scheme for muon beam generation utilising pair production from interactions of electron and photon beams as shown in Fig. 9. This opens the way to a new muon collider paradigm based on muon sources conceived with primary colliding beams delivered by 100 GeV-class energy recovery linacs interacting with hard-X ray free electron lasers. This contrasts with the established method of generating muons as tertiary beams from pion decay, where pions are produced on target driven by a primary proton beam. The challenge is to achieve the requested luminosity of the muon collider by adopting a strategy of low muon fluxes/currents combined with ultra-low emittances, utilising the high brightness of both the electron and photon primary beams.

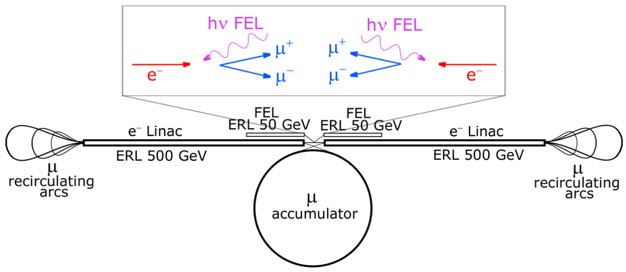

Figure 9: Twin Linac scheme for generating muon beam

RECOMMENDATIONS

ERLs have the advantage of generating high currents and excellent-quality electron beams. Many ERLs have been developed in the last several decades. However, a number of them have then been either terminated after R&D stage or after the prototype stage. Increasing the impact and finding users from nuclear physics, material science, basic energy science or biology science, et al are important for ERL development. Leveraging the existing (cBETA, bERLinPro, cERL and S-DALINAC) and near term future (MESA and PERLE) ERLs as R& D facilities for applications will help to reduce risks for the larger scale ERLs required to enable the future applications outlined here. Funding should therefore preferentially support these ERLs completion, upgrades and operations.

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