11.1 Background

The luminosity of a high energy collider determines the production rate of the particles of interest to the high energy physicist. The luminosity is ultimately limited by the dilution of the particle beam phase-space from effects that increase with particle beam density, such as intra-beam scattering (IBS) and beam-beam effects.

The established beam cooling techniques, electron cooling and stochastic cooling, are ineffective in emittance preservation for very high energy beams. For the former it is extremely difficult to implement at relativistic energies with a notable example being the electron cooling system with 4.3 MeV electrons in Fermilab’s Recycler to cool 8 GeV anti-protons prior to injection into the Tevatron [1]. In the case of stochastic cooling-invented by Simon Van der Meer [2] which famously won him a share of the 1984 Nobel Prize for the cooling of anti-protons used in CERN’s Proton-Antiproton collider- it becomes ineffective at the large particle beam density reached in a collider. This is due to the limited bandwidth of pickup and kicker, which for a state-of-the-art stochastic cooling system is about 8 GHz[3]. Therefore, to combat emittance growth novel beam cooling techniques, like the Optical Stochastic Cooling (OSC) and the Coherent-electron-Cooling (CeC), are being vigorously pursued [4].

The OSC, first suggested Mikhailichenko and Zolotorev[6] and later refined by Zolotorev and Zholents[7], is similar in concept to the ordinary stochastic cooling but makes a transition from microwaves to optical wavelengths and thereby dramatically increases the operating bandwidth of the cooling system by approximately 4-orders of magnitude. This is accomplished by replacing the pickup and kicker plates with undulators tuned to an optical frequency. In the transit-time version of the OSC a particle passes through the Pickup-Undulator (PU) where it radiates a wave-packet with a pulse duration of a few 10’s of femtoseconds. Upon exiting the PU the particle is propagated through some fraction of the machine arc and/or a dedicated bypass-chicane, and into the Kicker-Undulator(KU). The wave-packet meanwhile is transported through an optical system consisting of an optical amplifier and lenses to image it into the Kicker-Undulator (KU). The optics of the bypass beam line are designed so that the transit time of the charged particle, from PU to KU depends on its momentum and betatron amplitude in the PU. The wave-packet meets its parent particle in the KU and their interaction gives a small kick in energy to the particle that reduces momentum error and betatron amplitude.

Since the sign and amplitude of the kick is determined by the relative arrival time of the particle and wave-packet, if the total path length of both the optical system and chicane are properly set, a decrease in the particles momentum error occurs. Additionally, by coupling the horizontal and longitudinal phase-spaces via dispersion in the PU and KU, damping of the particles Courant-Synder invariant occurs. The design of the bypass is such that this corrective process is simultaneously occurring for all particles in the bunch and thus the beams momentum spread and horizontal emittance is reduced.

It was estimated that had the Tevatron (proton-antiproton collider) been equipped with an OSC system to mitigate dilution of the phase space of the antiprotons during a store, a doubling of integrated luminosity could have been achieved[8].

The goal of this proposal is to demonstrate the OSC in the Cornell Electron Storage Ring (CESR) at amplifier gains required for hadron or heavy-ion cooling. Presently there are two attempts at a proof-of-principle demonstration of the OSC with electrons; in CESR and also in the Integrable Optics Test Accelerator (IOTA) at Fermilab. Currently both groups are interested in first demonstrating the so called ‘passive’ OSC where the undulator wave-packet is simply refocused into the KU without amplification. Such a demonstration is a critical first step but a passive OSC scheme would not be effective in a collider where theory predicts an amplifier gain of 20-30dB is required.

A road block towards effective amplification in the current attempts is they rely on a relatively short bypass which puts severe restrictions on the amplifier design; most notably the amount of optical delay that can be afforded to the amplifier. To overcome this, we propose taking advantage of the existing storage ring arc to extend the path length of the charged particles with respect to the light, obviating the need for a chicane bypass. The differential path length is increased from a few mm to nearly 60 cm, relaxing the constraints on the amplifier so that 20-30dB of gain is achievable.

For this scheme to be successful we must first demonstrate stability of the light path which can be accomplished by feeding back on an interference pattern generated with a narrow-band laser propagating through the light path. Having done this the passive OSC can be demonstrated and finally the amplifier, developed in parallel with the previous steps, can be inserted to demonstrate high-gain active OSC in CESR.

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