A Proposed Beam-Beam Test Facility COMBINE

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A PROPOSED BEAM-BEAM TEST FACILITY COMBINE*

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Abstract

The COmpact Machine for Beam-beam Interactions in Non-Equilibrium systems (COMBINE) is a proposed, dedicated, beam-beam test facility. The base design would make use of a pair of identical octagonal rings (2.5 meters per side) one rotated 180 degrees from the other, meeting at their common interaction point. These would be fed by an electron gun producing up to 125 keV electrons. The low energy will allow for beam-beam tune shifts commensurate with existing colliders, some linac-ring type systems, and will also allow for an exploration of the predicted effects of gear-changing, which would be performed using a variable pathlength scheme. The low energy, and small size will allow for cost effective research, simulation code benchmarking, as well as training opportunities for students.

INTRODUCTION

The beam-beam effect is the name of the mutual lensing action that occurs when beams collide with each other in a collider. This effect can broadly be divided into coherent and incoherent effects. Coherent effects will cause any offsets between the two beams to become deflections in the orbits of those beams. Incoherent effects are the lensing actions which alter the phase space of the beam itself. Coherent interactions are studied parasitically in existing colliders, but incoherent effects are more difficult to measure. We propose a dedicated, low energy facility that would economically measure incoherent beam-beam effects. The size and construction of this machine would also allow us to test theoretical, yet untested configurations, such as linac-ring, and gear-changing.

Linac-ring systems are collider configurations where a stored beam in a ring collides with a linac that constantly replaces its bunches. This is the design for the LHeC [1]. This can cause stability issues in the stored beam, since offset jitter in the linac will not damp out the way it does in a ring-ring system. An oppositely charged beam-beam system like this has been modeled as a part of the LHeC project, and leads to a well-defined growth rate [2].

Gear-changing is a system where each ring of a collider holds a different harmonic number of bunches [3]. These bunches are kept colliding with each other either by changing the pathlength of one of the rings, or by changing the relative velocities of the bunches. For example, in a 4 on 3 gear changing system the 3-bunch beam would be moving at 4/3 the velocity of the 4-bunch beam. This can allow for collisions between beams of different particle masses at medium energy without altering the pathlength of one of the beamlines. Such a system has drawbacks, since each bunch interacts with each other bunch, any offsets will affect the entirety of both beams, an example of this is shown in Fig 1.

a)
b)

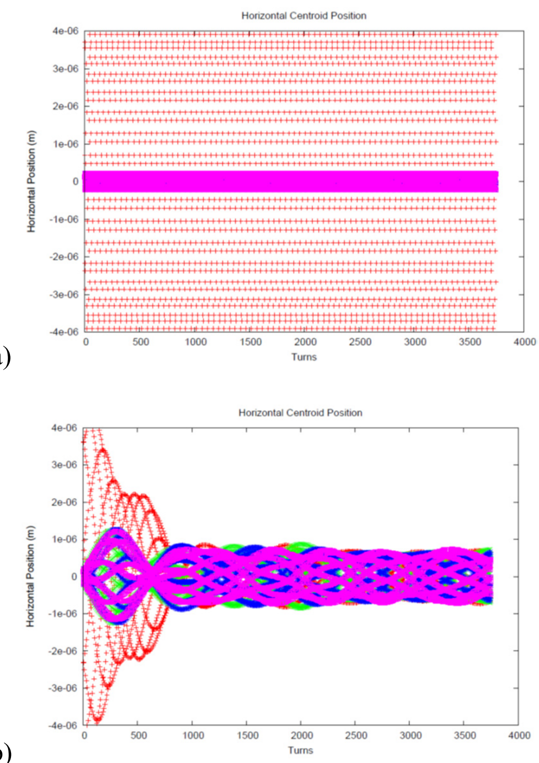

Figure 1: In a) we see a 3 on 4 gear-changing system without beam-beam interactions. One beam is offset, while the others stay centered. In b) we see the same system, but with beam-beam turned on where the beam centroids all equilibrate.

Gear-changing was theoretically examined for possible use in RHIC, and a theoretical resonance condition was derived. Testing gear-changing at RHIC is possible but would require invasive adjustments to the interaction region and has not been attempted. A gear-changing system has been demonstrated using the Double ElectroStatic Ion Ring ExpEriment (DESIREE) at Stockholm University [4, 5]. DESIREE's beams however are not intense enough to test the resonance condition derived in [6].

$$\xi_{beam-beam} > \frac{1}{4n} \quad (1)$$

This machine would also be small and inexpensive enough to either be built at a national laboratory, or at a university. The small size and lower operation costs of a

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machine of this type would also be useful to expand the pipeline of prospective accelerator physicists as a platform for student research. This would operate in a similar manner to the University of Maryland Electron Ring (UMER) [7], which, since beginning operations in 2004, has led to 16 M.S. Degrees and 24 Ph.D. degrees [8].

THE DESIGN OF THE MACHINE

Gear-changing experiments performed with DESIREE, as well as space charge experiments done at UMER [9] have directly informed the design of the proposed machine; a COmpact Machine for Beam-beam Interactions in Non-Equilibrium systems (COMBINE). The genesis of COMBINE is the fact that if DESIREE had electrons instead of ions, a combination of the higher bunch charge, and higher charge to mass ratio would put Eq. (1), within reach.

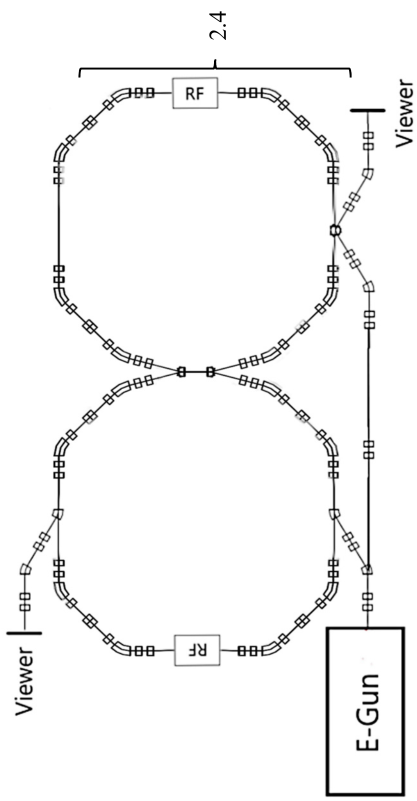

Figure 2: Here we see the rings together with the injection and extraction systems. Since we have a single electron gun we will fill both rings with it, leading to the only break in symmetry between the rings.

The experiments performed on DESIREE showed the importance of detailed diagnostics, and RF sources to maintain longitudinal bunching. UMER has shown the desirability of extraction line based diagnostics, and the usefulness of viewer base phase space tomography. Both machines also showed the usefulness of low energy machines as tests for larger concepts.

COMBINE was designed to be cost effective and make use of existing equipment. The source of this machine would be an electron gun originally designed as part of Jefferson Lab's EIC electron cooler project. This gun is capable of producing bunches of up to 125 keV, and up to 130 pC, with a thermal normalized emittance of 5 mm-mr. This would feed two rings of identical construction, oriented in such a way that they will have a single collision point. A schematic diagram of this machine is shown in Fig. 2.

The main diagnostics in this design are BPMs placed around each ring, as well as a pair of viewers that will be used to chart the phase space of the beams after a given number of turns. These measurements will be done both with pepperpots, as well as phase space tomography.

Since both rings will be fed from the same source the only way to perform gear changing is to change the path-length, so a pair of Thomson rails will be added to the design.

Each ring is primarily composed of double bend achromats, which allows for a compact footprint as well as dispersion free sections for RF, injection, extraction and collisions. For cost savings, the interaction region is formed by reducing the bending in two of the dipoles. The physical layout of one of the constituent rings, as well as its optics are shown in Fig 3.

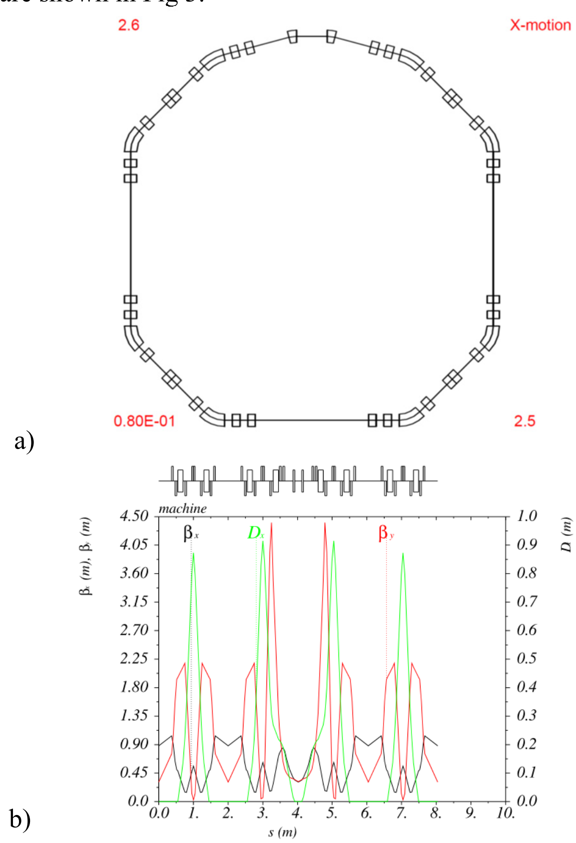

Figure 3: One of the storage rings in the proposed machine is shown in a), while the lattice of this machine is shown in b).

The design of the interaction region gives a β* variability of about 20%. The experiments will use round beams, thus making the emittance the determining factor of the beam-beam tune shift, though the variability will allow for some spot size effects to be mapped out. The RF system

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Table 1: A Selection of Energies and Bunch Charges for the COMBINE Collider

	50 keV 50 pC	50 keV 100 pC	100 keV 50 pC	100 keV 100 pC
$N_{particles}$	3.13×10^8	6.25×10^8	3.13×10^8	6.25×10^8
Kinetic Energy	50 keV	50 keV	100 keV	100 keV
$\gamma_{relativistic}$	1.0978	1.0978	1.1957	1.1957
$\beta_{relativistic}$	0.4127	0.4127	0.5482	0.5482
$\beta^*_{x,y}$	.5 m	.5 m	.5 m	.5 m
ε_{xy} (geometric)	11 mm-mrad	11 mm-mrad	7.63 mm-mrad	7.63 mm-mrad
$\sigma_{x,y}$	2.35 mm	2.35 mm	1.95 mm	1.95 mm
$\xi_{beam\text{-}beam}$	.0057	.0116	.0077	.0154
$\Delta Q_{space\ charge}$	.0141	.0282	.0089	.0179

has a maximum design voltage of 1 kV, to maintain longitudinal stability. The energy of the beam is too low for there to be an activation hazard, though there may be a mild x-ray hazard when the machine is operating.

PLANNED EXPERIMENTS

The experiments for COMBINE would be staggered as the machine is built and commissioned. The experiments will broadly encompass 4 areas.

The first round of experiments will be using one ring only. All new colliders have their own idiosyncrasies so operating a single ring will aid in determining control procedures for the entire machine. A single COMBINE ring would also function well as a space charge machine similar to UMER. This would also allow for us to create a baseline of the beam so that we can compare later collider data.

The next round of experiments would be using a linac-ring system, by filling the ring used in the previous experiments with a stored beam, and colliding a fresh beam from the source through half of the other ring. This would act like a linac-ring system, we could add a controlled jitter to the beam, and measure the emittance growth rate, as well as the evolution of the phase space of the stored and linac beams.

Next, we would study ring-ring collisions mapping out the evolution of the phase spaces of each of the beams as they evolve over a given number of turns.

Finally, we would study gear changing. The beam-beam tune shift for the resonance condition for a 25 on 26 gear changing system would be 0.01, and .0078 for a 33 on 32 bunch system. As can be seen in Table 1, this is achievable by COMBINE, with a variable pathlength provided by the Thomson rails in one of the rings. Furthermore, we could map out the changes to the phase space of the stored beams as they equilibrate.

CONCLUSION

In this work we have detailed the design for a small test machine that would be dedicated to studying the beam-beam effect. It could be built and operated either at a natio-nal lab or a university. If built this would allow for detailed studies of the beam-beam effect in conventional ring-ring colliders, as well as in more novel collider designs such as linac-ring, and a gear-changing system. Machines of this type are relatively inexpensive to operate and could aid in the pipeline of future accelerator physicists.

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