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LUMINOSITY STUDIES OF ASYMMETRIC CRAB CROSSING IN JLEIC*

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Abstract

The proposed Jefferson Lab Electron Ion Collider (JLEIC) currently plans to use a crab crossing scheme to maximize the available luminosity. It had been suggested that space and cost savings, as well as hadron beam quality improvements, could be realized by leaving the ion beam un-crabbed and increasing the crabbing angle of the electron beam. This and variations in-between equal and totally one-sided crabbing are examined for both JLEIC and LHC parameters, with various changes in crabbing angle and frequency studied to maximize luminosity.

INTRODUCTION

This work aims to determine whether it would be possible to use different crabbing angles in a collider system to get the type of luminosity increase that you would get from symmetric crabbing. Crabbing is the process whereby each bunch is given differential kicks along their length. In a collider where the beams cross at an angle, the rotation caused by crabbing would have the bunches collide nearly head-on, eliminating any luminosity reduction from the crossing angle [1]. The possibility of only crabbing one bunch has appeal for systems like the Jefferson Lab Electron Ion Collider (JLEIC) where it would be easier to crab the electrons than the protons.

In this work we use the formalism developed in [2]. Namely that in order to model the collision angle we recast our position equations as:

$$x_1 = x cos\left(\frac{\theta_c}{2}\right) - s sin\left(\frac{\theta_c}{2}\right) + \ldots \quad (1)$$

$$+ \frac{1}{k_{cr1}} sin[k_{cr1}(s-ct)] sin\left(\frac{\theta_{cr1}}{2}\right),$$

$$x_2 = x cos\left(\frac{\theta_c}{2}\right) + s sin\left(\frac{\theta_c}{2}\right) - \cdots \quad (2)$$

$$- \frac{1}{k_{cr2}} sin[k_{cr2}(s+ct)] sin\left(\frac{\theta_{cr2}}{2}\right),$$

$$s_1 = s cos\left(\frac{\theta_c}{2}\right) + x sin\left(\frac{\theta_c}{2}\right), \quad (3)$$

$$s_2 = s cos\left(\frac{\theta_c}{2}\right) - x sin\left(\frac{\theta_c}{2}\right). \quad (4)$$

Where the density function for a given dimension is,

$$\rho_q(q) = \frac{1}{\sigma_q \sqrt{2\pi}} e^{-\frac{q^2}{2\sigma_q^2}}, \quad (5)$$

And the total luminosity of the system is given as,

$$\mathcal{L} = \quad (6)$$

$$C_{\mathcal{L}} \iiint_{-\infty}^{\infty} \rho_x(x_1)\rho_z(s_1-ct)\rho_x(x_2)\rho_z(s_2+ct)\,dx\,ds\,dt,$$

where,

$$C_{\mathcal{L}} = \frac{c N_{b1} N_{b2} f_{rev} n_b}{\sqrt{\pi}\sigma_y} cos^2\left(\frac{\theta_c}{2}\right). \quad (7)$$

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In this system θ_c is the crossing angle of the bunches, and θ_{cr1} and θ_{cr2} being the crabbing angles on bunches 1 and 2 respectively. The terms k_{cr1} and k_{cr2} represent the wave numbers of the crabbing cavities, c is the speed of light, N_{b1} and N_{b2} are number of particles per bunch in bunches 1 and 2 respectively, while n_b is the total number of bunches. This formalism does not take the hourglass effect into account, it also doesn't model pinch or beam-beam effects.

JLEIC RESULTS

In the JLEIC case we use the baseline parameters as of summer 2018, listed in Table 1.

Table 1: The JLEIC Parameters Used in this Simulation

Parameter	Value
N_{b1}	0.98×10^{10}
N_{b2}	0.93×10^{10}
θ_c	25 mr
F_{crab}	952.6 MHz
σ_x, σ_y	30 µm
σ_z	1 cm

The original question posed in this work was whether or not we could gain full luminosity by only crabbing one of the beams and not the other. This would make the system simpler since it is easier to crab electrons than ions. We performed a numerical integration of Eq. 6 using Mathematica, and found that the equally crabbed bunches have a luminosity of 1.9×10^{33} cm^{-2}s^{-1}, the un-crabbed collisions have a luminosity of 4.48×10^{32} cm^{-2}s^{-1}, and the system where one is un-crabbed and the other double-crabbed has a luminosity of 4.52×10^{32} cm^{-2}s^{-1}. The short answer is that it doesn't work. However, if we plot out the luminosity of a system where one beam is un-crabbed, and we vary the crabbing of another, we get Fig. 1.

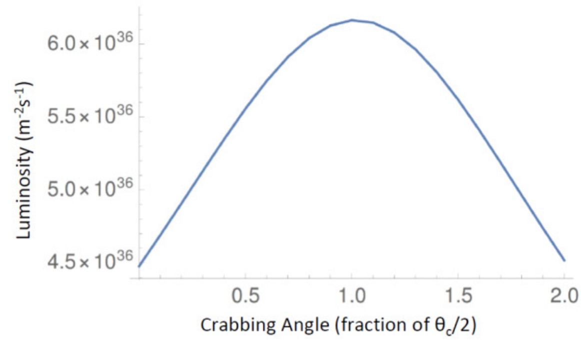

Figure 1: This plot shows the luminosity varying the crabbing angle of one bunch, while leaving the other un-crabbed.

If we expand this to varied levels of crabbing in both directions, then we will get what we see in Fig. 2.

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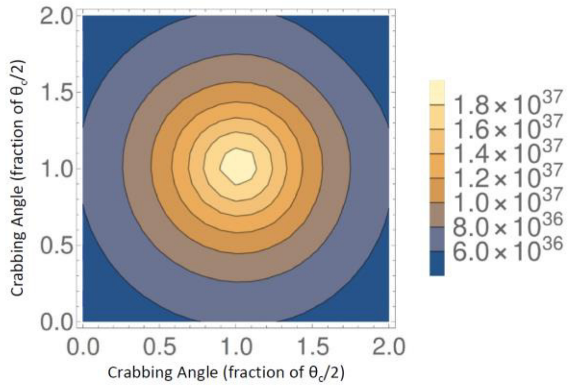

Figure 2: This plot shows the luminosity with both bunches having different crabbing angles.

LHC RESULTS

In order to calibrate the system, we also re-ran the numbers from [2]. The results of holding one beam to zero crabbing for both 400 MHz and 800 MHz crabbing frequencies, and varying the other are shown in Figs. 3 and 4.

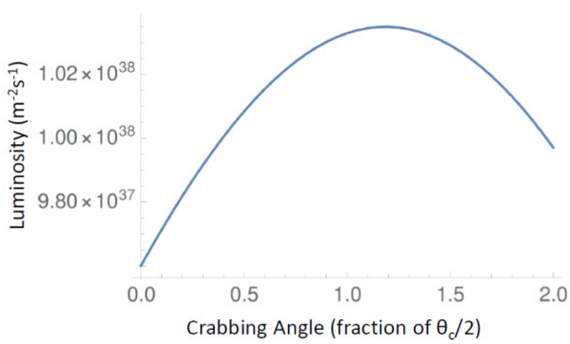

Figure 3: This shows the luminosity of the LHC with 400 MHz of crabbing on one bunch with the other uncrabbed.

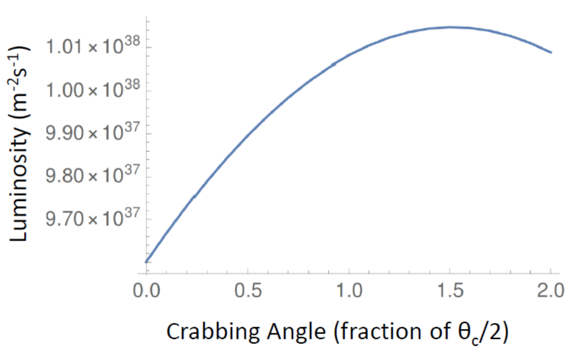

Figure 4: This shows the luminosity of the LHC with 800 MHz of crabbing on one bunch with the other uncrabbed.

Interestingly enough, more crabbing produces a higher luminosity for the higher frequency. In this case we see that there is an increase from the shaping of the bunch by the crab cavity. If we examine the plots where we vary the crabbing on both bunches, we once again see that equal crabbing gives the best results, though due to the longer bunch lengths and shallower angle these have different behavior from that seen in the JLEIC system. The results of these comparisons for the 400 MHz and the 800 MHz systems are shown in Figs. 5 and 6.

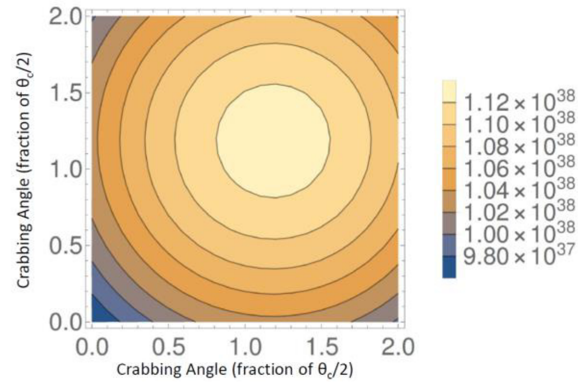

Figure 5: This plot shows the luminosity with both bunches having different crabbing angles for the 400 MHz LHC system.

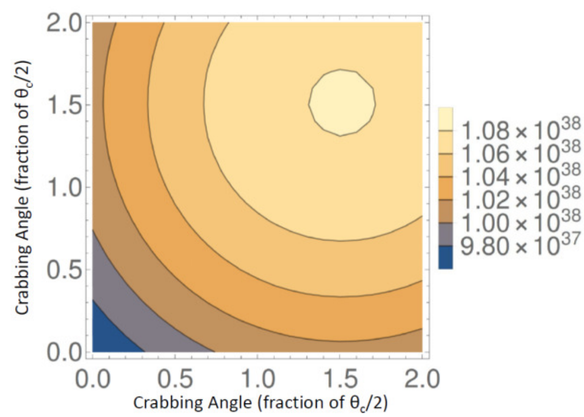

Figure 6: This plot shows the luminosity with both bunches having different crabbing angles for the 800 MHz LHC system.

CONCLUSIONS AND FURTHER WORK

While crabbing only one beam in the JLEIC system would have a 2/3 reduction in the overall luminosity, it could conceivably work as an initial configuration with the crabbing added to the proton beam as an upgrade. With longer bunches and a shallower angle like the LHC type of system there may be some use in this as a one-sided crabbing system.

REFERENCES

[1] R. B. Palmer, "Energy Scaling, Crab Crossing and the Pair Problem.", SLAC-PUB-4707, December 1988.

[2] Y. Sun *et al.*, "Crab Cavity Beam Dynamics Issues for an LHC Upgrade", CERN-AB-Note-2008-033