Luminosity loss in a Crab Cavity scheme

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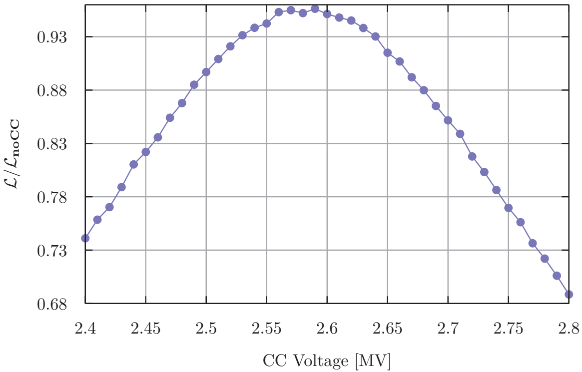
Luminosity loss in a CC scheme

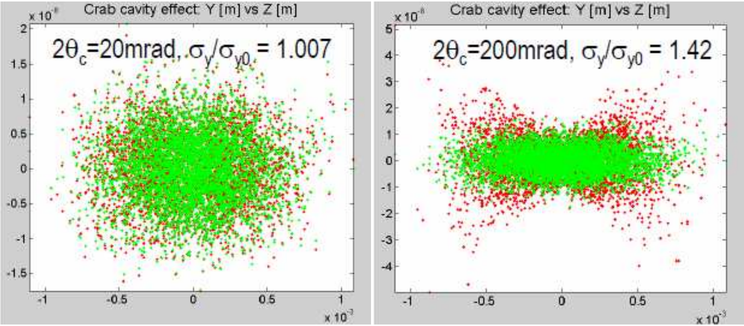
PLACET-GUINEA PIG simulations showed a luminosity loss of $\Delta\mathcal{L}/\mathcal{L}_{\mathrm{noCC}} = -5\%$ when comparing the expected luminosity in a perfect head on collision with the one expected in a CC scheme and $\theta_c/2 =$10 mrad. This was first pointed out by **I. Shinton** in the 5$^{\mathrm{th}}$ CLIC-ILC BDS+MDI meeting.

The non-linearities of the final focus explain the fact that the maximum luminosity is obtained for V_{cc} =2.58 MV while $V_{cc,nom}$ =2.40 MV.



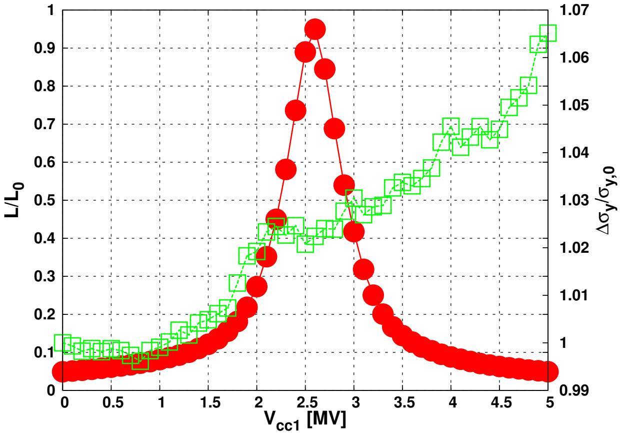
Vertical Beam Size Increase?

The crab cavity introduces a $\Delta p_x(z)$ which creates x orbit displacement through the sextupoles in the final doublet. This causes yy' and other beam distortions at the IP correlated with z. **A. Seryi** evaluated this for the ILC case, finding only significant vertical beam size increase for large crossing angles ($\sim$200 mrad).



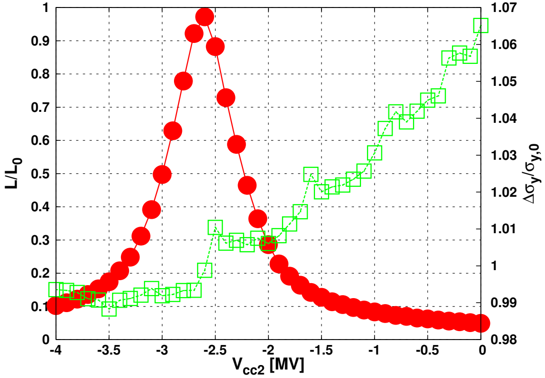
Luminosity Versus Beam Size for a Single CC

For the CLIC case ($\theta_c/2 = 10$mrad and $V_{cc} = 2.52$ MV) the expected beam size increase in both planes are $\Delta\sigma_y/\sigma_{y,0} \sim$**2.2%** and $\Delta\sigma_x/\sigma_{x,0} \sim$**0.3%**. However this result does not explain $\Delta L/L_0 = -5\%$.

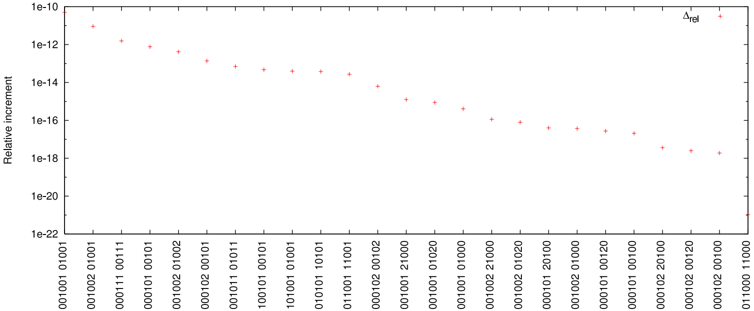


Luminosity Versus Beam Size for a Two CC scheme

A. Seryi proposes to add a second crab cavity with different polarity to compensate for the increase of the vertical beam size. However, some distortion in the horizontal one is also expected. In the CLIC case it was possible to recover up to $\Delta\mathcal{L}/\mathcal{L}_{\mathrm{noCC}}$= 98.5% by adding a second crab cavity at ΔL=5 m from the first and voltages of $V_{cc,1}$= 5 MV and $V_{cc,2}$= -2.4 MV.



Map coefficients calculated with PTC (up to 4th order) and beam sizes with MAPCLASS.



Comparing beam sizes with and w/o CC it is found that the terms T_{yyz}, $T_{yy'z}$, U_{yyzz} are the main contributors to the vertical beam size increase. The correlation between y, y' and z indicates the presence of a traveling waist.

Traveling Focus Equations

The crab cavity induces an horizontal and a energy kick z-dependent. This translates into a different focusing of the particles along the bunch length.

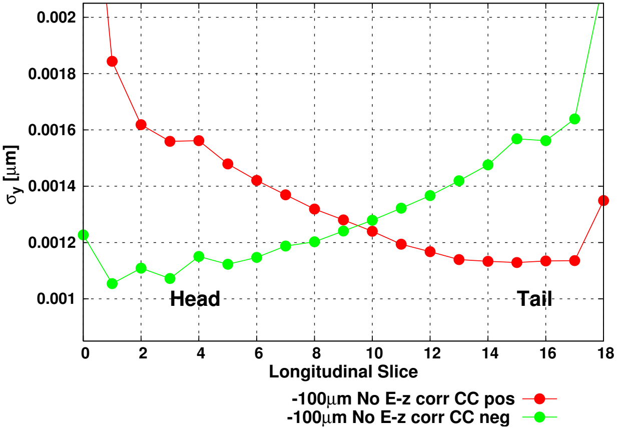
$$\frac{dp_y}{ds} = -\frac{\partial H_2}{\partial y} = Syx(s)$$

The bunch waist moves longitudinally during the collision.

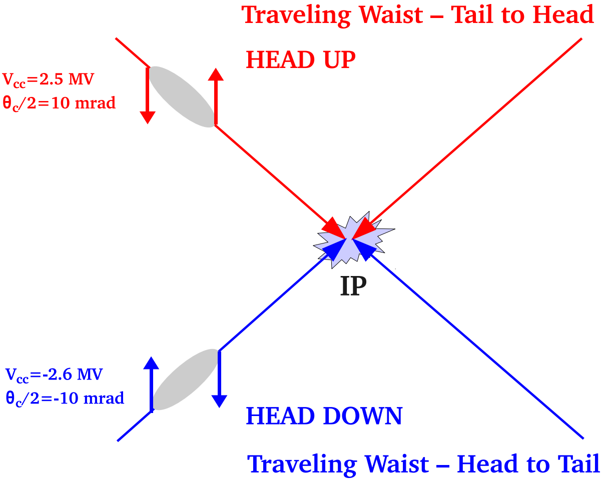
$$\sigma_{x,y}(s) = \sqrt{\epsilon_{x,y}\beta^*_{x,y}\left(1 + \frac{s^2}{\beta^{*2}_{x,y}}\right)}$$

Traveling Focus for Different Crossing Angles

The reason for the luminosity loss is explained from the fact that for the current layout the traveling waist goes from tail to head. Simply (in paper) changing the crossing angle fully recovers the luminosity with respect to the head on collisions.

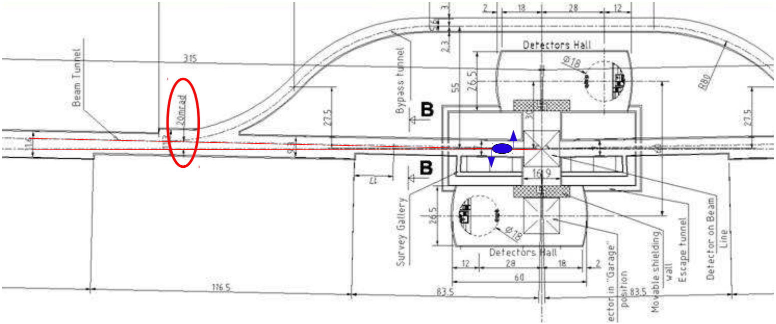


Traveling Focus for Different Crossing Angles



BDS civil engineering

Original civil engineering for the push and pull detector option at the IP. This beam delivery system line layout forces the head of the beam to be kicked up producing a traveling waist going from the tail to the head.

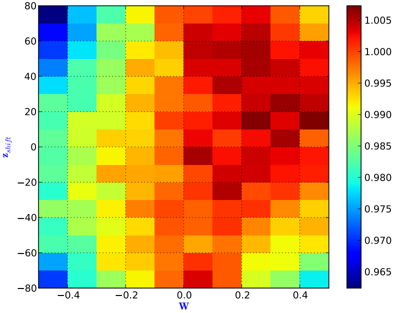


Possibility of Improving Further the Luminosity?

The loss of luminosity is now understood and recover by the correct crossing scheme. We analyze then the possibility of further improving the luminosity with either a traveling waist (W) or a waist shift (z_{shift}). The distribution at the IP is modified according to,

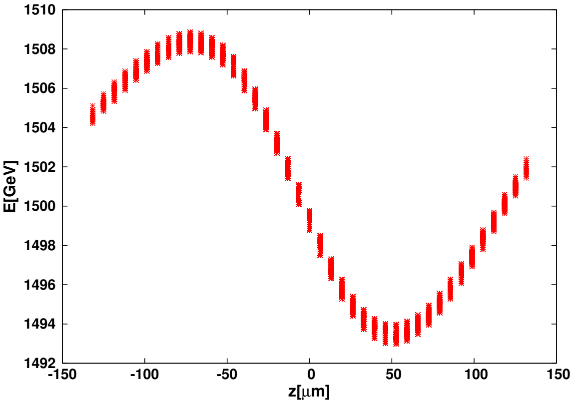
$$y = y_0 + W(z_0 + z_{\text{shift}})y_0'$$

Only a maximum of $\Delta L/L_0 \sim 0.5\%$ improvement is achieved.



Traveling Focus at the IP with E-z correlation

The longitudinal profile of the beam coming from the linac presents a sinusoidal wave, where the head has larger energy than the tail. An increase of the beam size in the tail appears with respect to the no wake fields case.



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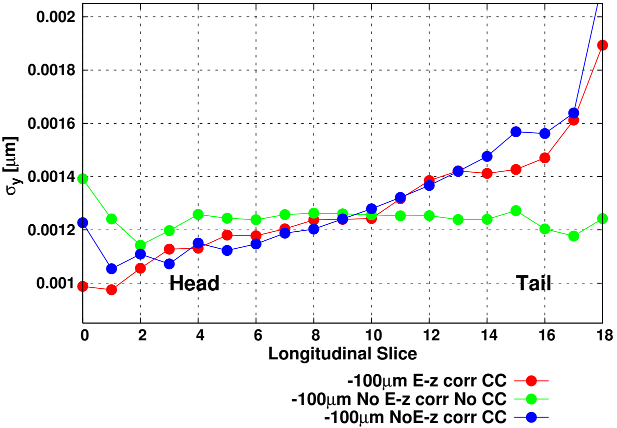
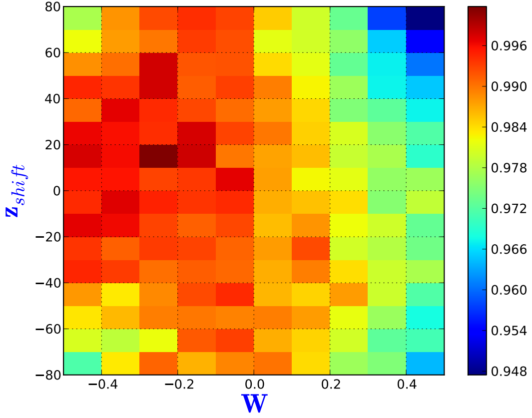


Possibility of Improving Further the Luminosity?

Again the expected improvement of luminosity is of $\sim 0.5\%$.



Summary

Summary table of expected luminosity with respect to head on collisions for various cases.

Case	**CC**	**E-z corr**	$\theta_c/2$	$\mathcal{L}/\mathcal{L}_{\text{Case 1}}[\%]$
1	No	No	0 mrad	100.0
2	Yes	No	10 mrad	95.0
3	Yes	No	-10 mrad	99.2
4	No	Yes	0 mrad	99.0
5	Yes	Yes	10 mrad	94.3
6	Yes	Yes	-10 mrad	99.8

Conclusions

- The crab cavity used to assure head-on collisions at IP together with the sextupoles in the final doublet generates a traveling waist scheme at the IP.
- In order to produce a traveling waist from head to tail the head of the beam has to be kicked down at the crab cavity. If the traveling waist goes from tail to head a 5% luminosity loss is expected.
- The current layout of the beam delivery system in the civil engineering drawings shows the wrong scheme for the traveling waist.
- The inclusion of the energy profile in the incoming beam from the linac would suggest a decrease of the luminosity due to the increase of vertical beam size in the tail, however it is not reflected in the results from GUINEA-PIG. Luminosity calculation slide by slide could help to understand it.