Charge compensated ring e+e- higgs factory

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Preface

This talk is not a proposal which I like and want to push forward, it is just consideration of a method to overcome a physical limitation on the e+e- luminosity due to beamstrahlung. This method (may be technically unrealistic) allows, in principle, to increase the luminosity up to one order of magnitude (for the same SR power).

Introduction

The idea to collide 4 beams (e+e- with e+e-) is more than 40 years old. Beams are neutral, there are no collision effects, sound nice.

Such 4-beam e+e- collider on the energy 2E~2 GeV, DCI, was build in 1970th in Orsay. There were hopes to increase the luminosity by a factor of 100 compared to the normal 2-beam e+e- case. But the result was confusing: the maximum luminosity was approximately the same. The reason - instability of neutral e+e- beams: small displacement of charges leads to the charge separation in opposing beam and thus to development of instability and the loss of the beam neutrality, appearance of tune shifts and corresponding resonances. The attainable beam-beam parameter ξ was approximately the same as without neutralization.

The same 4-beam approach was considered in 1980th for linear colliders in order to suppress beamstrahlung. However, simulation (and theory) have shown that the kink instability develops during the (one pass) beam-beam collision, and attainable luminosity is lower than in 2-beam collisions. beamstrahlung is suppressed only at rather low luminosities.

Due to these reasons the idea of charge neutralization in e+e- collisions was dismissed. Then why I am discussing it again?

The above exercises with 4-beam neutralization of beam collisions have shown that this method does not help to increase the beam-beam parameter ξ_y (and the disruption parameter $D=4\pi\xi_y \sigma_z/\beta_y$). However, it should work at ξ_y attainable in 2-beam collisions (or, may be, somewhat lower.

We have such case at e+e- Higgs factory. Their luminosities are limited by beamstrahlung (beam lifetime). Using 4-beam charge compensation one can suppress the beamstrahlung and increase the luminosity keeping the same ξ_y as for 2 beam collsions.

Does it has sense, what is possible increase of the luminosity?

For head-on collisions it give only a factor of 2-3 at 2E=240 GeV, no big sense.

However, in the crab-waist scheme (which gives absolutely no profit in the beamstrahlung-dominated ring colliders) the situation is much more attractive. Comparing luminosities for crab-waist colliders suggested by Oide (without accounting of beamstrahlung) with those corrected on beamstrahlung (tables I and II in V.Telnov, arXiv:1203.6563) one can see possible profits

2E(GeV)	240	400	400	500
L_{nb}/L_b	16	33	43	25

Here
nb-no beamstrahlung
b- with beamstrahlung

This already deserves a consideration!

Crab-waist collisions

$$\xi_y = \frac{N r_e \beta_y^2}{\pi\gamma\sigma_x\sigma_y\sigma_z} \quad \text{for} \quad \beta_y \approx \sigma_x/\theta \qquad \mathcal{L} \approx \frac{N^2 f}{2\pi\sigma_y\sigma_z\theta} \approx \frac{N^2\beta_y f}{2\pi\sigma_x\sigma_y\sigma_z} \approx \frac{N f \gamma \xi_y}{2 r_e \beta_y}$$

Additional requirement from beamstrahlung

$$\boxed{\frac{N}{\sigma_x\sigma_z} < 0.1\eta\frac{\alpha}{3\gamma {r_e}^2}}$$

Let us take a beamstrahlung dominated c-w collider. In order to increase L by some factor one should increase ξ_y/β_y by the same factor. This leads to the increase of the beam field ($N/\sigma_x\sigma_z$) which should be kept constant using beam neutralization. Noticing that $\xi_y \propto (N/\sigma_x\sigma_z)\beta_y^{3/2}$ one gets the required degree of neutralization

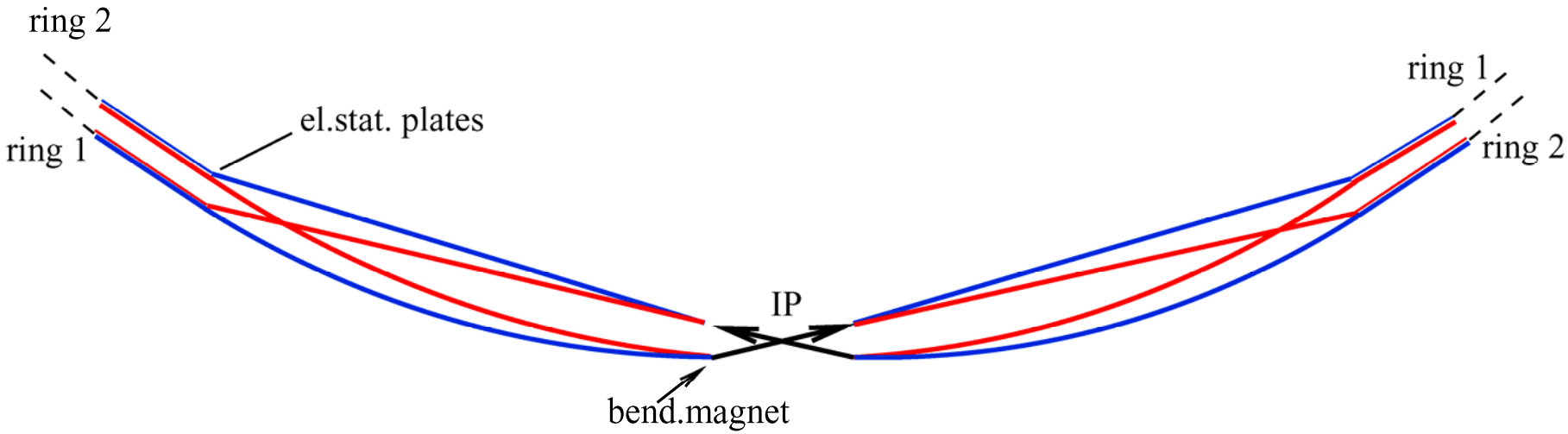
$$\frac{\Delta N}{N} = \frac{(\xi_c/\xi_{nc})^{1/2}}{(L_c/L_{nc})^{3/2}}$$

here
c-charge compensated
nc-noncompensated

If $\xi_c = \xi_{nc}$, then for the increase of the luminosity by a factor of 10 one needs $\Delta N/N=0.03$. For more pessimistic case $\xi_c = 0.5\,\xi_{nc}$ and the same $\Delta N/N=0.03$ one can get 8.25 times increase of L.

The above consideration shows that the increase of the luminosity by a factor of 10 looks possible for all energies above 2E=240 GeV.
A possible gain could reach a factor 25-40 for 2E=400-500, but this requires unrealistically high degree of neutralization (< 0.5-1%).

Scheme of a charge compensated crab-waist e+e- ring collider



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Problems:

1) Crab-waist collisions assume collisions at some horizontal angle, that requires 2 rings with electrostatic separators near IP and inside rings, plus one rings for injection, 3 rings in total.
2) Combining of two beams to one beam in the bending magnet (that should be place between the IP and the final focus) looks problematic due to SR is the magnet (leads to the increase of the beam size at the IP). Should be checked.
3) All systems should work ideally, small displacement of beams at IP (like 0.2 σ_y) leads to a very short beam lifetime. SR from IP can be used for the feedback.
4) After the refilling of the bunch it has larger sizes and displacement. One should avoid collisions of such bunch at IP until a full damping.
5) others

Conclusion

❖ A very preliminary consideration shows that the charge compensation in 4-beam collisions allows to suppress the beamstrahlung and thus to increase the luminosity up to one order of magnitude. Such gain can be obtained only using the crab-waist scheme of collisions.

❖There are many technical problems. Stoppers are not excluded.

❖May be this method is too complicated and unrealistic, nevertheless it is interesting, because allows, in principle, overcome a physics limit on luminosity due to beamstrahlung.

❖Probably, this scheme should be considered somewhat in more detail (before rejection).

❖In competition with other Higgs factories the ring e+e- collider has advantage as most reliable and cheapest project. Would it be more attractive, if it will have 10 times larger luminosity, but less reliable and more expensive?