Introducing LEP3 *zero*

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TLEP3 day,

9 January2013

Contents

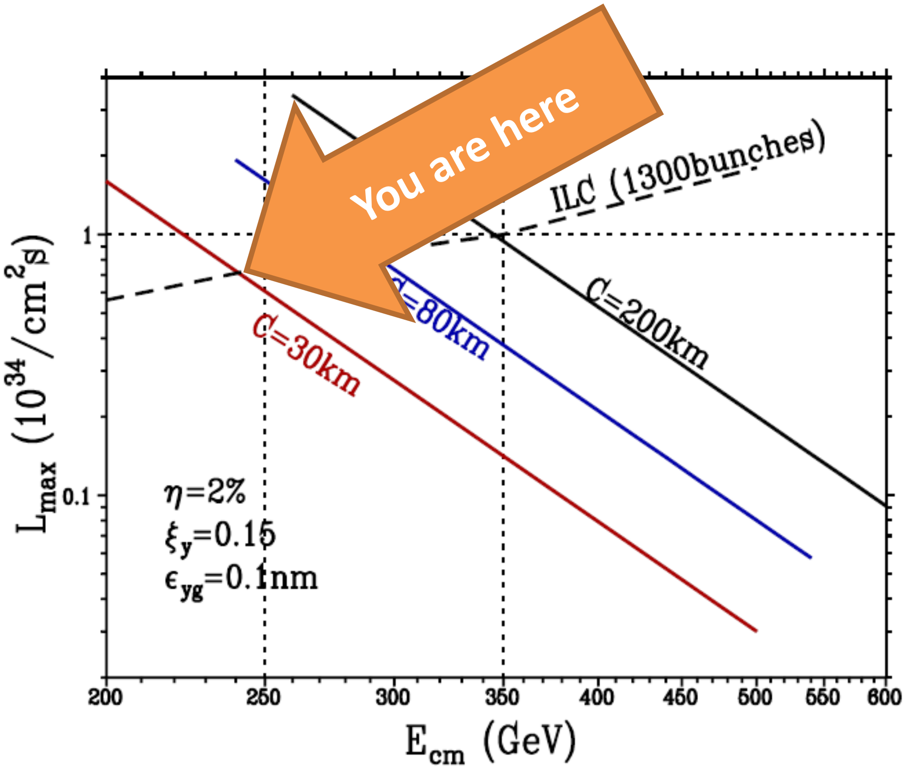
- What is the ultimate luminosity that a circular collider (running at the ZH threshold) can reach?
- Is there a way to go beyond this luminosity?

Background

K. Yokoya has shown the following plot (using V. Telnov's formulae)

example with

- η=2%
- ξ_y=0.15
- ε_{gy}=0.1nm



Due to a strange coincidence, the luminosity of circular and linear machines *per IP* at 240GeV E_{CM} are the same! (@η=2%)

…but what is the real limit on the luminosity of circular machines?

Luminosity limits

- What would be the ultimate limit of luminosity for LEP3 and TLEP?
- This is easy to calculate since we already face a series of “hard” limits:
  - Limit on the total power dissipated
  - Beam-beam limit
- (beamstrahlung limit is a “softer” limit under this definition since it affects the lifetime and could be mitigated in principle by flatter beams, higher acceptance and fast duty cycle) I will not concentrate on beamstrahlung here

Total power limit

We have limited the total power dissipated in the ring to a "reasonable" 100MW (50MW per beam). The formula of the total power loss, in convenient units, is:

$$P_{loss,total}[MW] = 1.4 \times 10^{-23} \times E^4 \; [GeV] \frac{f_{rev} n_b N_b}{\rho[km]}$$

This translates to

$$\frac{f_{rev} n_b N_b}{\rho[km]} = 1.7 \times 10^{16} s^{-1}$$ for E=120GeV, P=50MW

Luminosity and beam-beam

Head-on collisions:

- Luminosity is given by

$$L = \frac{f_{rev} n_b N_b^2}{4\pi\sigma_x\sigma_y} R_{hourglass}$$

- And the beam-beam parameter is

$$\xi_y = \frac{N_b r_e \beta_y^*}{2\pi\gamma\sigma_x\sigma_y}$$

- Therefore

$$L = \frac{(f_{rev} n_b N_b)}{2} \frac{\gamma}{r_e} \xi_y \frac{R_{hourglass}}{\beta_y^*}$$

Maximum luminosity

- So the maximum theoretical luminosity is

$$L = \frac{(f_{rev} n_b N_b)}{2} \frac{\gamma}{r_e} \xi_y \frac{R_{hourglass}}{\beta_y^*}$$

$$= 1.7 \times 10^{16} \times \rho[km]$$

Total power limit

$$= 8.42 \times 10^{17} cm^{-1}$$

Physical constants

Max. of 0.1

Beam-beam limit

For LEP3 this is $=6cm^{-1}$ $(0.6/0.1cm^{-1})$. For TLEP $=0.75/0.1cm^{-1}$.Difficult to go beyond that.

$$L_{max} = 4.3 \times 10^{33}\ cm^{-1} s^{-1} \times \rho[km]$$

Max. luminosity; notes

- I assume that we can reach the beam-beam limit. Beyond that:
  - Squeezing further in y is very challenging and does not help too much since it reduces the hourglass factor
  - Smaller emittances do not help
- If σ_z stays constant, a bigger machine gains linearly with the bending radius
- In principle, TLEP would give 3 times the luminosity of LEP3
- Luminosity can be improved by reducing σ_z coupled to higher β^* ($\rightarrow$higher RF frequency? – very challenging)

The numbers

- For head-on collisions and with vertical β^* of 1mm, the maximum achievable luminosities are:
- LEP3 (current design): $1.1\times10^{34}cm^{-1}s^{-1}$
- LEP3 (ρ = 3.1km) : $1.3\times10^{34}cm^{-1}s^{-1}$
- TLEP (ρ = 9km, E_{CM} 240GeV) : $4.8\times10^{34}cm^{-1}s^{-1}$

Can we do better?

- (I am not talking about improvements of 20% here…)
- With head-on collisions, very little margin
- If we move to a crab-waist scheme, we can improve on the apparent σ_z , but the beamstrahlung limit gets worse [beamstrahlung is proportional to $1/(\sigma_x \sigma_z)$], so this does not appear to be a good option
- There remain more exotic schemes: Charge compensation! (suggested by V. Telnov one evening in Protvino…)

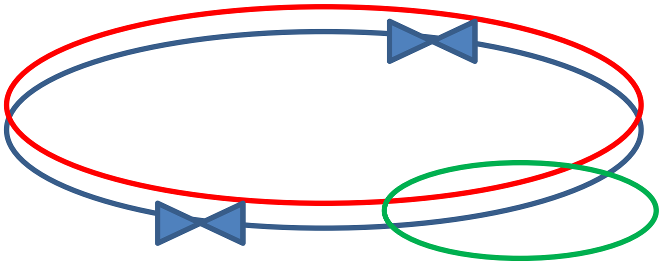
Charge compensation

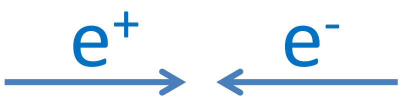
- The idea is simple: counteract the electric field of the incoming beam, and the beam-beam limit and beamstrahlung limit is not there any more!
- This is not as easy at it sounds, as the effect of the incoming beam is a non-linear lens diverging in both planes and difficult to simulate
- Many schemes have been proposed and tried over the years:
  - Electron beam compensation [indirect] on an (anti)proton beam (TEL, Fermilab)
  - Four-beam accelerators (DCI, Orsay, 1971)
  - Other schemes with electric wires next to the beam, multipoles, etc., to produce the same non-linear lens effect…
- It is fair to say that none of these schemes has had spectacular success, but CC remains an active field of study

Four-beam compensation

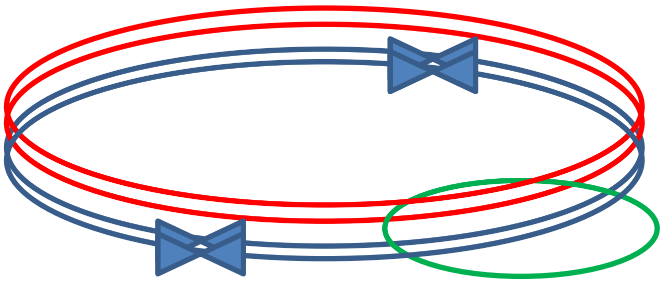
- DCI was not a spectacular success (no discernible gain seen), but 40 years have passed since then. ("*small initial bunch displacement errors lead to charge separation*" and "*a minute deviation from neutrality is amplified as the like-charge beams repel each other*")
  - Beam instrumentation is much better nowadays
  - The higher beam energy might improve things by faster damping
- The increase in costs for a four-beam solution is substantial…
- …but it merits a closer look

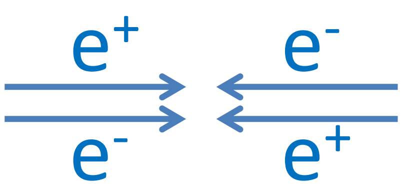
From LEP3/TLEP…



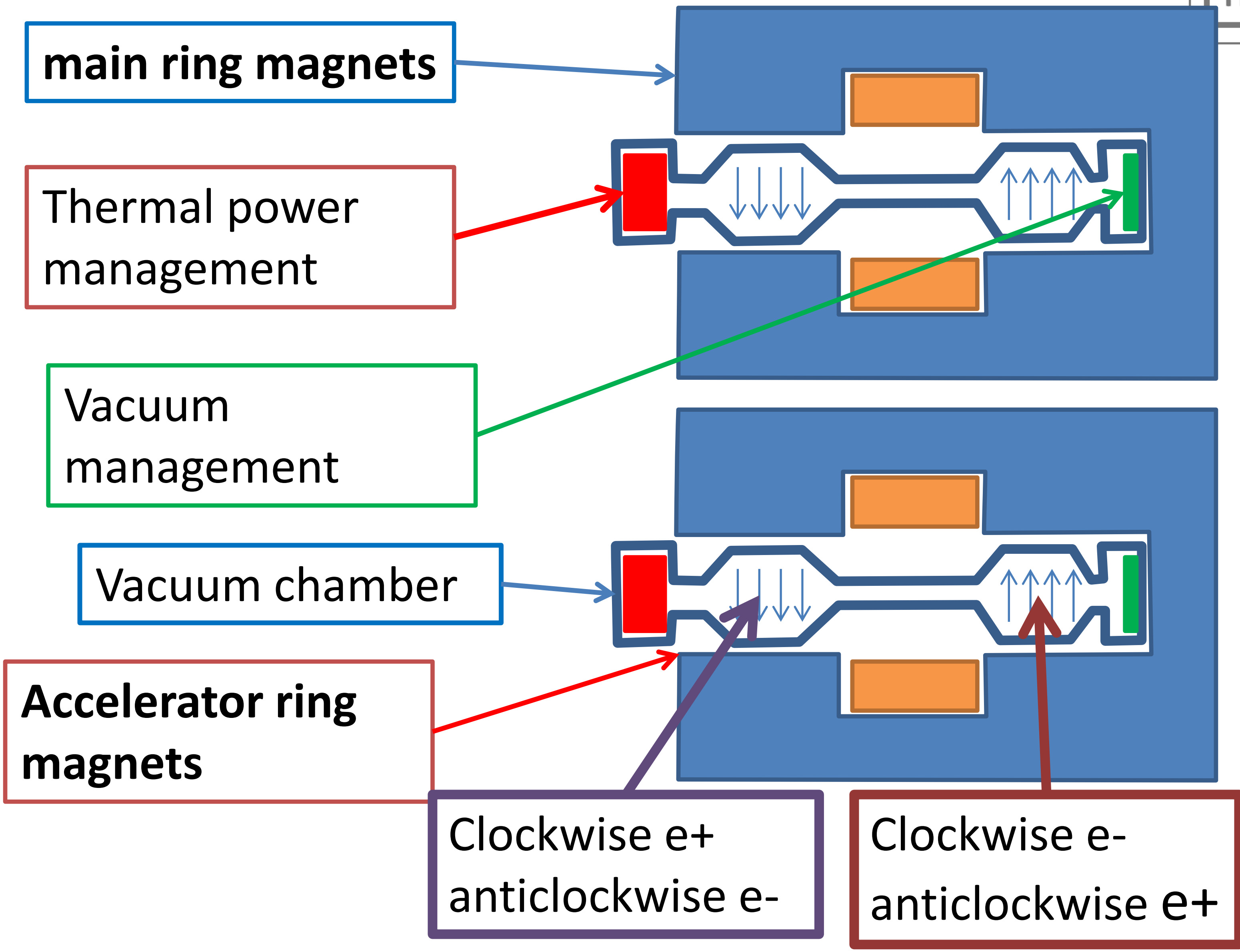


To LEP3 zero...





Artist's impression of LEP3zero



Next steps

- Listen to Valery's talk!
- Four-beam Monte-Carlo has been developed in the nineties by B. Podobedov and R.H. Siemann – could be resurrected

End

ADDITIONAL SLIDES

Tevatron electron lens TEL

- Improvement in proton lifetime of a factor 2 at high intensities