TLEP power consumption and luminosity optimization

M. Koratzinos,

TLEP6 workshop

CERN, 17 October 2013

Contents

- TLEP power consumption: news since the last TLEP workshop
- TLEP luminosity optimization: theoretical limits and how to approach them

TLEP power consumption

- TLEP is an efficient Higgs factory, as we will see
- Although there are limitations on instantaneous power consumption, the real figure of merit is not power consumption. It is either
  - Energy per Higgs produced
  - Power per luminosity
- (Even more relevant is taking into account the ‘grey energy’ consumed for the whole project, the only viable estimate of which is the total project cost)

TLEP power consumption

- Nevertheless, the TLEP power consumption was the subject of intense debate over the summer.
- Initial power figures were given at the TLEP paper submitted to IPAC: M. Koratzinos et al., **TLEP: A High-Performance Circular e+e- Collider to study the Higgs Boson** (http://arxiv.org/pdf/1305.6498.pdf)
- A comment on these figures was published in the arXiv: M. Ross, **Wall-plug (AC) power consumption of a very high energy e+/e- storage ring collider** (http://arxiv.org/pdf/1308.0735.pdf)
- An explanatory note was also produced by TLEP and submitted to the arXiv: A. Blondel et al., **Comments on "Wall-plug (AC) power consumption of a very high energy e+/e- storage ring collider" by Marc Ross [arXiv:1308.0735]** (http://arxiv.org/pdf/1308.2629.pdf)

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Comments on "Wall-plug (AC) power consumption of a very high energy e+/e- storage ring collider" by Marc Ross

A. Blondel, M. Koratzinos, A. Butterworth, P. Janot, F. Zimmermann, R. Aleksan, P. Azzi, J. Ellis, M. Klute, M. Zanetti

(Submitted on 12 Aug 2013)

The paper arXiv:1308.0735 questions some of the technical assumptions made by the TLEP Steering Group when estimating in arXiv:1305.6498 the power requirement for the very high energy e+e- storage ring collider TLEP. We show that our assumptions are based solidly on CERN experience with LEP and the LHC, as well accelerators elsewhere, and confirm our earlier baseline estimate of the TLEP power consumption.

Comments:	6 pages
Subjects:	**Accelerator Physics (physics.acc-ph)**
Cite as:	**arXiv:1308.2629 [physics.acc-ph]**
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Submission history

From: John Ellis [view email]

[v1] Mon, 12 Aug 2013 17:21:15 GMT (105kb)

Points addressed

- TLEP has estimated that the wall-plug power consumption for TLEP at Ecm = 350 GeV would be about 280 MW
- M. Ross estimated about 416 MW. The main differences between the two power estimates arise from different assumptions about klystron operation, cryo-plant efficiency and heat removal.
- Our conclusions:
  - Our technical assumptions concerning these and other issues raised are based solidly on CERN experience with LEP and the LHC, as well accelerators elsewhere.
  - We see no reason to modify significantly the wall--plug power consumption for TLEP.

Klystron operation

- M. Ross argues that we cannot run the klystrons in ‘saturated’ operation, resulting in lower efficiency (55% instead of the claimed 65%). But LEP2 run clystrons at saturation. Our efficiency figure of 65% for the klystron efficiency is, we believe conservative and will be the subject of intense r&d

Cryo-plant efficiency

- We are using the figure achieved by the LHC (900W/W). The ILC TDR assumes 700W/W, so our figure is actually conservative

Cooling and ventilation

- Ventilation system: Contrary to M. Ross' statement, CERN has not decided to use transversal tunnel ventilation (with the possible exception of CLIC) – so our estimate stands
- Water cooling: this critically depends on a specific implementation.
- Nevertheless, for cooling and ventilation we have assumed a figure which is about 10% of the total power dissipation. LEP achieved 13%, so we believe that a careful design would bring us to the value stated in the paper.

Electrical distribution network

- in our estimate we did not include any electrical network losses, as they are dependent on the exact implementation of the electrical distribution system.
- Efforts will be made to ensure that the main electrical power consumers (the RF systems) will be located close to local utility high-voltage interconnect points. We consider that 5% is on the conservative side and we strive to achieve a figure closer to 3% for the electrical distribution network (8MW).

Power consumption: recap

- The design study will have as a goal to match and improve on the following numbers:

	TLEP 120	TLEP 175
RF systems	173-185 MW	
cryogenics	10 MW	34 MW
top-up ring	3 MW	5 MW
Total RF	186-198 MW	212-224 MW

(overall efficiency 54 to 59%)

Power consumption	TLEP 175
RF including cryogenics	224MW
cooling	5MW
ventilation	21MW
magnet systems	14MW
general services	20MW
Total	~280MW

For the most pessimistic scenario

Dominated by the RF efficiency where most effort will be devoted

TLEP figure of merit

TLEP
$HZ^0W^-W^+t\bar{t}$

TLEP	120GeV	175GeV
Total power	260MW	280MW
luminosity	4.8×10^{34}	1.3×10^{34}
experiments	4	4
Luminosity per MW	7.4×10^{32}	1.8×10^{32}

This is very competitive compared to other electron-positron collider projects

Energy consumed per Higgs produced: 6GJ or 2MWh

Luminosity optimization

- What does the luminosity of a circular collider depend on?
- It turns out that to first order it depends on very few parameters
- It depends linearly on:
  - The power consumption (the SR power pore specifically)
  - The size of the ring
  - The maximum achievable beam-beam parameter
- We then need to find parameters that can get as close as possible to these values

A step back: Major limitations

The major limitations of circular colliders are:

- Power consumption limitations that affect the luminosity
- Tunnel size limitations that affect the luminosity and the energy reach
- Beam-beam effect limitations that affect the luminosity
- Beamstrahlung limitations that affect beam lifetimes (and ultimately luminosity)

Energy reach

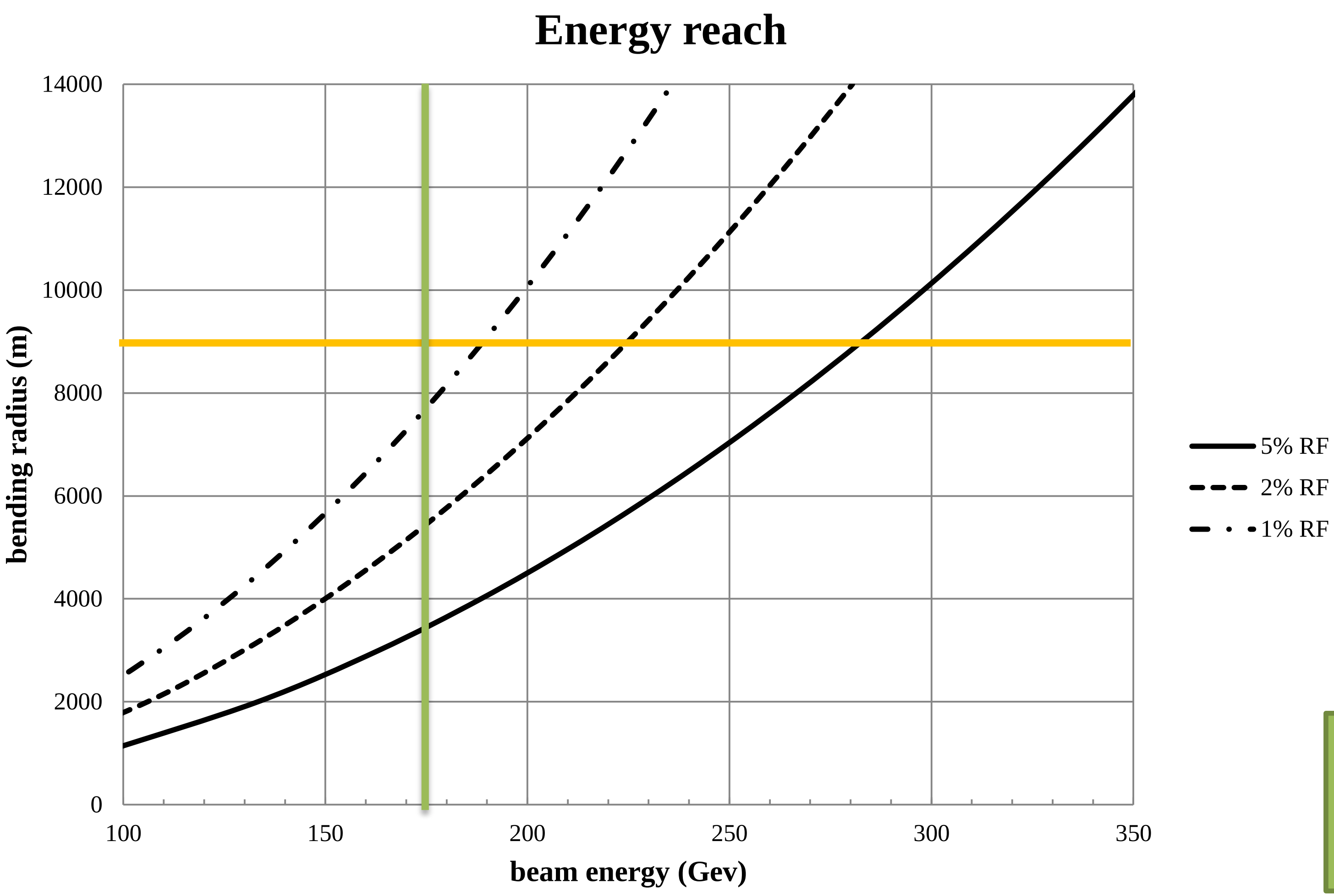
- In a circular collider the energy reach is a very steep function of the bending radius. To make a more quantitative plot, I have used the following assumptions:
  - RF gradient: 20MV/m
  - Dipole fill factor: 90% (LEP was 87%)
- I then plot the energy reach for a specific ratio of RF system length to the total length of the arcs

$$E_{loss}[GeV] = 8.85 \times 10^{-5} \frac{E^4}{r_{bend}} \quad \text{and} \quad L_{RF}\,[m] = \frac{E_{loss}}{20MeV}$$

Energy reach

TLEP

$HZ^0W^-W^+t\bar{t}$



Assumptions: 20mV/m, 90% dipole fill factor.

The three curves are for different ratio of RF length to total arc length

TLEP175 sits comfortably below the 1% line

LEP2 had a ratio of RF to total arc length of 2.2%

Luminosity of a circular collider

Luminosity of a circular collider is given by (head-on collisions)

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

Which can be transformed in terms of

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

and

$$P_{loss,total} = \frac{4\pi}{3} \frac{r_e}{{m_e}^3} E^4 \frac{f_{rev} n_b N_b}{\rho}$$

to:

Head-on collisions

Luminosity of a circular collider

TLEP

HZ⁰W⁻W⁺tt̄

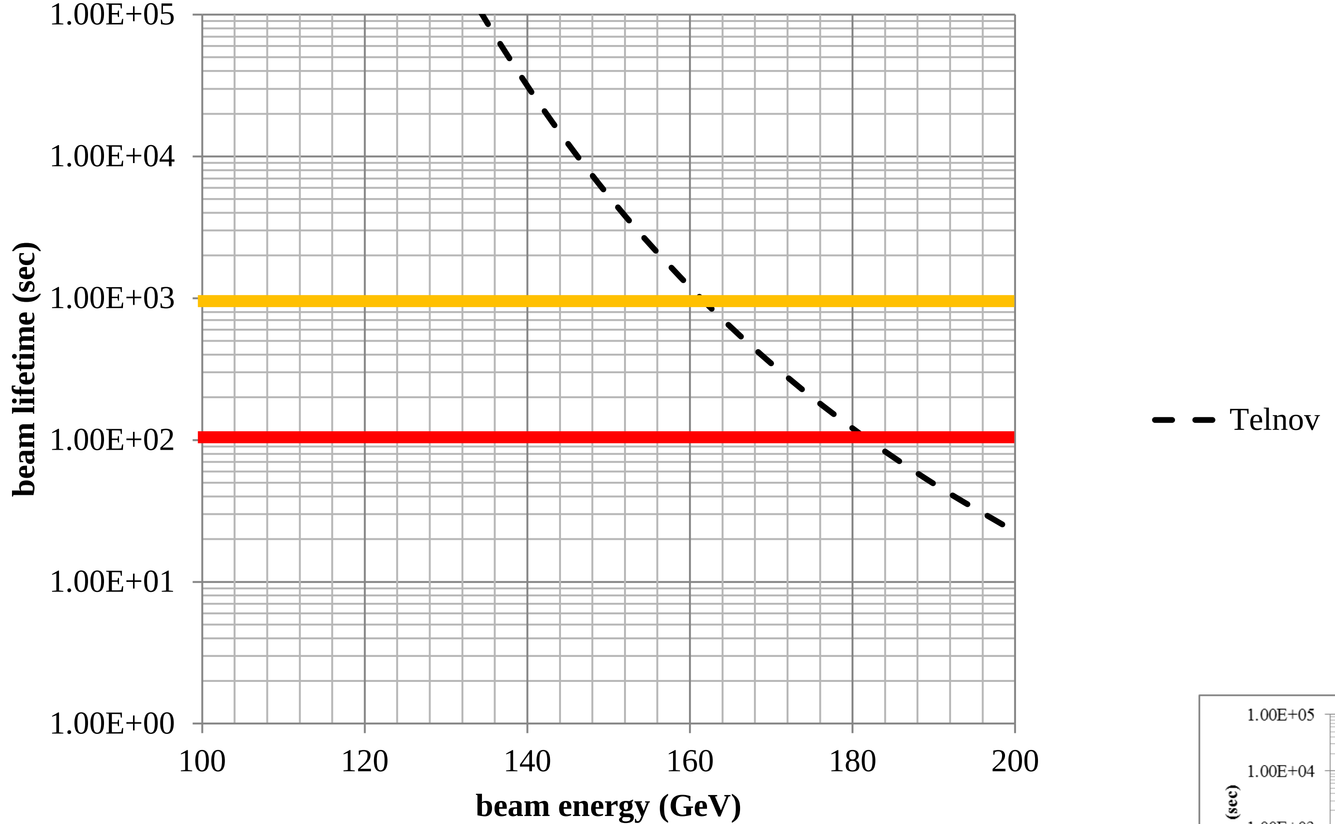
$$\mathcal{L} = \boxed{\frac{3}{8\pi}\frac{(m_e c^2)^2}{{r_e}^2}} \boxed{P_{tot}} \boxed{\frac{\rho}{{E_0}^3}} \boxed{\xi_y} \boxed{\frac{R_{hg}}{\beta_y^*}}$$

So, the maximum luminosity is bound by the total power dissipated, the maximum achievable beam-beam parameter (the beam-beam limit), the bending radius, the beam energy, β_y^*, and the hourglass effect (which is a function of sigma_z and beta*)

Beamstrahlung

- Analytical formula by Telnov used so far.
- Single-turn Guinnea-Pig simulation used which found the Telnov approximation pessimistic
- See talk of Anton BOGOMYAGKOV this morning
- Beamstrahlung gets worse at high energies, so they impact the design of TLEP-120 and TLEP-175

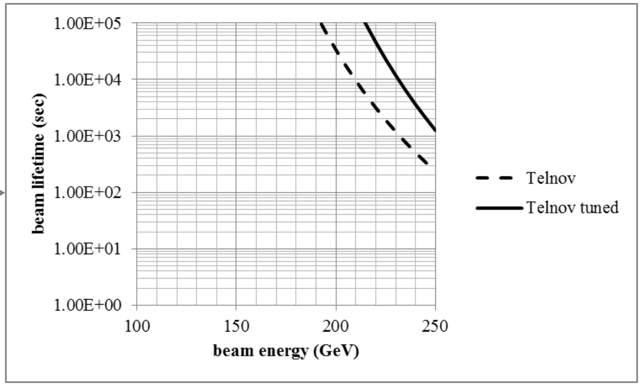
Beamstrahlung limitation



Plot on left is if we run with a value of the beam-beam parameter of 0.1
Above ~180 GeV is difficult to run without opting for a more modest beam-beam parameter value (which would reduce the luminosity)

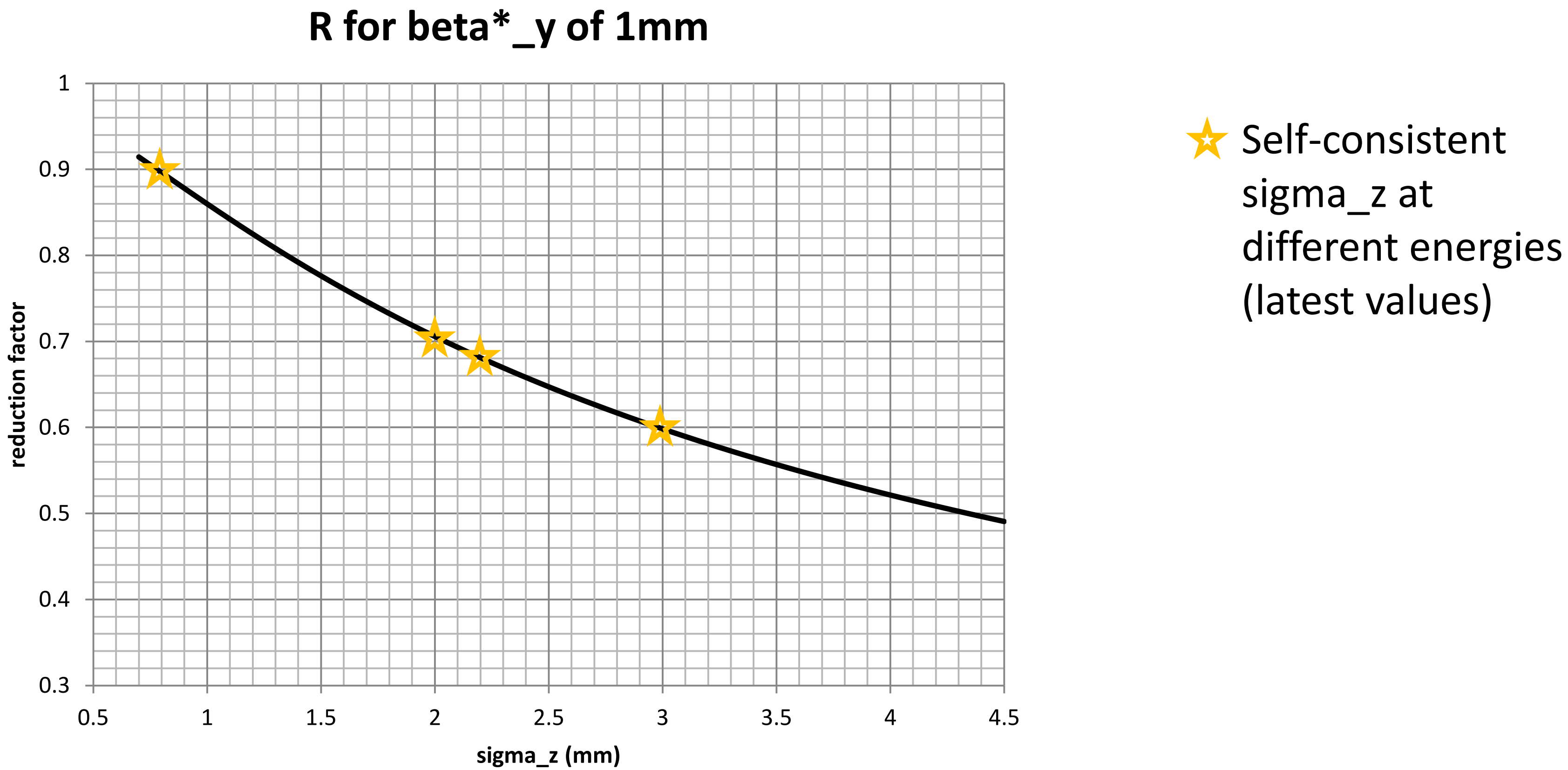
TLEP Latest parameter set, mom. acceptance 2.2%

Can even run at 250GeV with a beam-beam parameter of 0.05



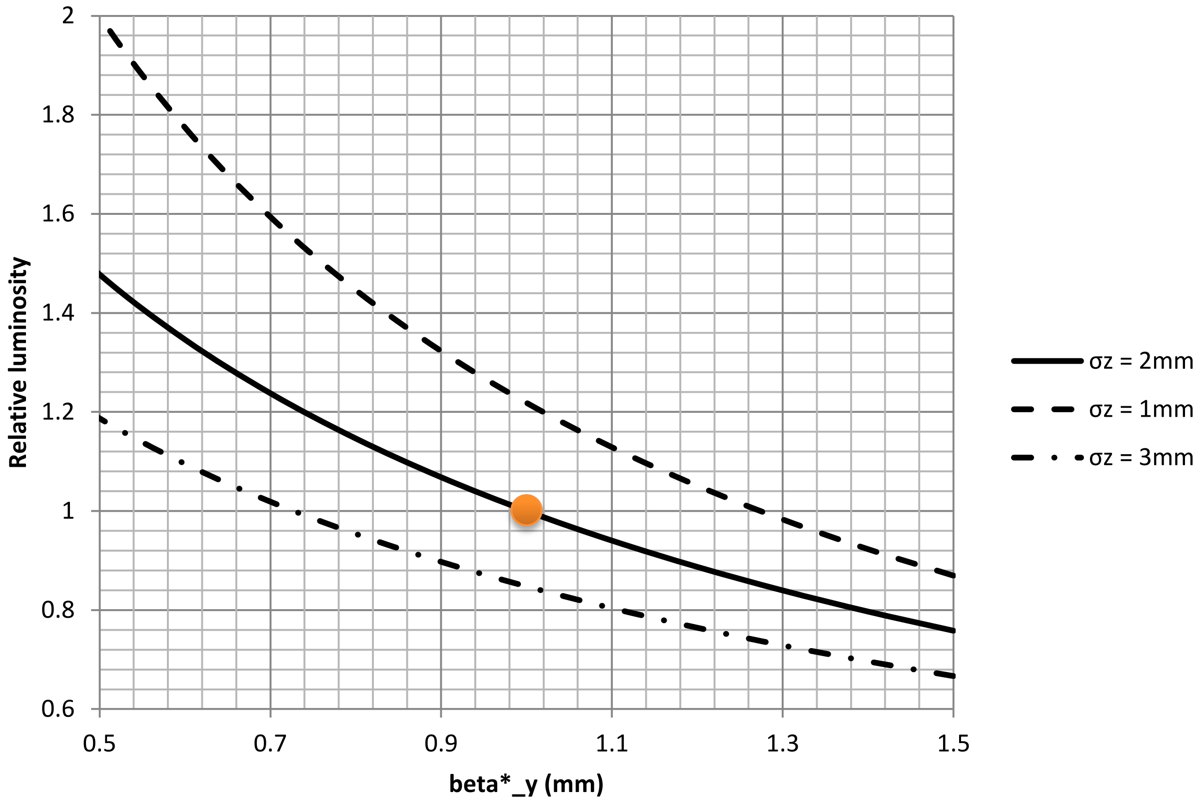
Beta* and hourglass

We are opting for an aggressive but I hope realistic β^*_y value of 1mm. σ_z beam sizes vary from 1mm to 3mm. In this range the hourglass effect is between 0.9 to 0.6



Beta* and hourglass

- Squeezing more gives a moderate improvement in luminosity, despite the bigger hourglass effect



For beam sizes of 2mm, squeezing from 1mm to 0.7mm improves luminosity by 24% Squeezing less to 1.5mm drops luminosity by -24%

Beam-beam parameter

The maximum beam-beam parameter is a function of the damping decrement:

$\xi_y{}^{max} = f(\lambda_d)$ where

$$\lambda_d = \frac{1}{f_{rev}\,\tau\,n_{IP}}$$

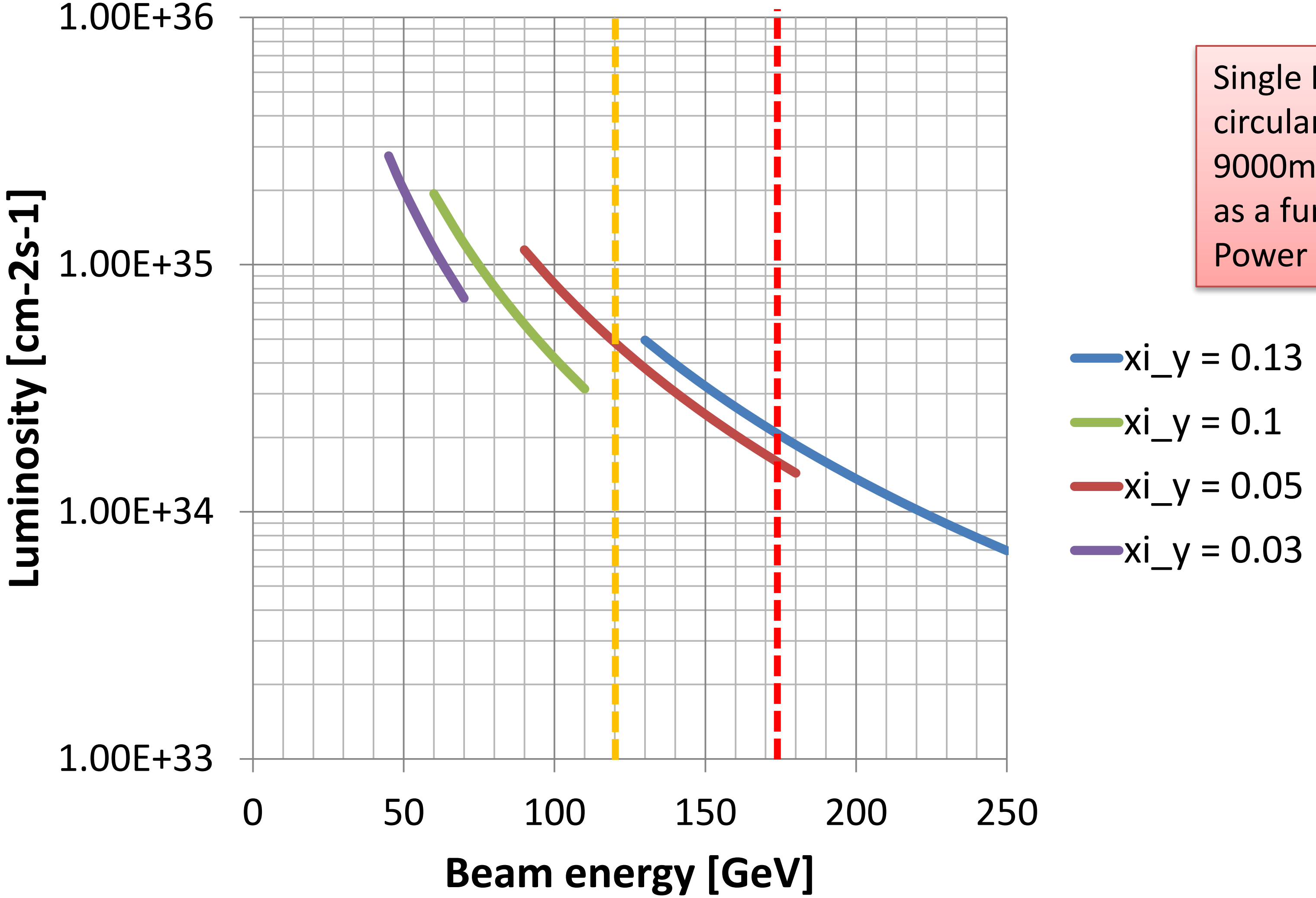
Or, more conveniently:

$$\lambda_d = \left(\frac{U_0}{E}\right)\frac{1}{n_{IP}} \; or \; \lambda_d \propto \frac{E_0{}^3}{\rho\;\; n_{IP}}$$

Expected luminosity vs energy

TLEP

HZ⁰W⁻W⁺tt̄



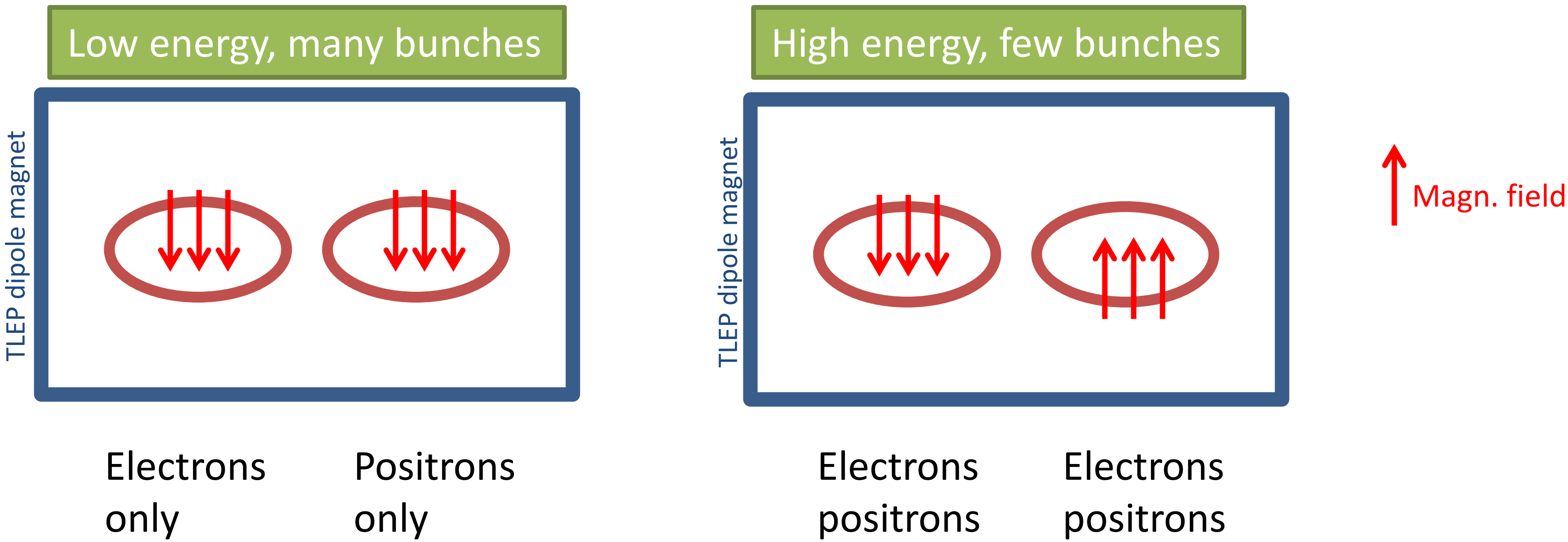
Single IP luminosity of a circular collider of 9000m bending radius as a function of energy. Power loss is 100MW.

Can we do better?

- Is there any way to increase the luminosity above the limits mentioned up to now?
- Crab waist scheme (but only effective at TLEP-Z?)
- Other solution: charge compensation!
  - Charge compensation: colliding beams with zero net charge (colliding 4 beams)
- CC was tried in the seventies without success
- It is time to revisit charge compensation and, if promising, keep it as an upgrade possibility
- Potential: increase luminosity limits by factors of 3 to 10 (this is a wish! Unsubstantiated)

One or two beam pipes?

- My input to the discussion of one vs two beam pipes:
- Charge compensation needs two beam pipes and also needs the ability to flip the magnetic field of one of the two rings



Strategy for lumi optimization

- Start from a specific ring diameter , power consumption figure and energy
- This defines the total current of the machine
- Define emittances, beta* values, sigma_z
- Compute number of bunches to be on the beam-beam limit (at low energies, increase emittances to avoid too many bunches)
- If beam lifetimes are below 100s, re-itterate by increasing the number of bunches

Published parameter set

TLEP $HZ^0W^-W^+t\bar{t}$

	TLEP Z	TLEP W	TLEP H	TLEP t
E_{beam} [GeV]	45	80	120	175
circumf. [km]	80	80	80	80
beam current [mA]	1180	124	24.3	5.4
#bunches/beam	4400	600	80	12
#e−/beam [10^{12}]	1960	200	40.8	9.0
horiz. emit. [nm]	30.8	9.4	9.4	10
vert. emit. [nm]	0.07	0.02	0.02	0.01
bending rad. [km]	9.0	9.0	9.0	9.0
κ_ε	440	470	470	1000
mom. c. α_c [10^{-5}]	9.0	2.0	1.0	1.0
$P_{loss,SR}$/beam [MW]	50	50	50	50
β^*_x [m]	0.5	0.5	0.5	1
β^*_y [cm]	0.1	0.1	0.1	0.1
σ^*_x [µm]	124	78	68	100
σ^*_y [µm]	0.27	0.14	0.14	0.10
hourglass F_{hg}	0.71	0.75	0.75	0.65
E^{SR}_{loss}/turn [GeV]	0.04	0.4	2.0	9.2
V_{RF},tot [GV]	2	2	6	12
$d_{max,RF}$ [%]	4.0	5.5	9.4	4.9
ξ_x/IP	0.07	0.10	0.10	0.10
ξ_y/IP	0.07	0.10	0.10	0.10
f_s [kHz]	1.29	0.45	0.44	0.43
E_{acc} [MV/m]	3	3	10	20
eff. RF length [m]	600	600	600	600
f_{RF} [MHz]	700	700	700	700
δ^{SR}_{rms} [%]	0.06	0.10	0.15	0.22
$\sigma^{SR}_{z,rms}$ [cm]	0.19	0.22	0.17	0.25
$\mathcal{L}$/IP[$10^{32}cm^{-2}s^{-1}$]	5600	1600	480	130
number of IPs	4	4	4	4
beam lifet. [min]	67	25	16	20

By definition, in a project like TLEP, from the moment a set of parameters is published it becomes obsolete and we now already have an improved set of parameters.
The new parameter set contains improvements to our understanding, but does not change the big picture.

IPAC13 TUPME040, arXiv:1305.6498 [physics.acc-ph]

Modifying the parameters

- The strategy we have adopted calls for a stable parameter set which would be modified, according to new knowledge, at not too regular intervals (twice a year?)
- Time is ripe for a new set of TLEP parameters (which from the day published would again become obsolete…)

parameter set to be modified

	TLEP Z	TLEP W	TLEP H	TLEP t
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This is a personal choice!

IPAC13 TUPME040, arXiv:1305.6498 [physics.acc-ph]

Conclusions

- TLEP power figures will be scrutinized thoroughly during the study, but seem to be in the right ballpark
- A simple formula for the maximum achievable luminosity has been presented
- Beamstrahlung seems that can be mitigated up to 175GeV, but complete simulation studies are needed
- Much more work is needed for a design proper.
- Exotic schemes might offer even more luminosity, so they should be pursued at an early stage, as might have repercussions on the design

end

THANK YOU