# Another look at IP parameters and luminosity of TLEP

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# Introduction

## Considered effects

- Beamstrahlung [*Restriction on the energy and luminosity of e + e - storage rings due to beamstrahlung - Telnov, V.I. Phys.Rev.Lett. 110 (2013) 114801 arXiv:1203.6563*].
- Modification of radiation integrals I3(energy spread) and I2(damping) leading to change of bunch length and energy spread.
- Equilibrium between opposite bunches length.

## Tools

- Computer simulation with Lifetrac [*D.Shatilov*] modified to include full spectrum of beamstrahlung, quasi strong-strong model.
- Analytical: more accurate calculation than by V.I.Telnov, quasi strong-strong model, radiation integrals.

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# Analytical (1): beamstrahlung

$$N(u > \eta E_0) = \frac{3}{4\sqrt{\pi}}\sqrt{\frac{\alpha r_e}{\eta}}\exp\left(-\frac{2}{3}\frac{\eta\alpha\rho}{r_e\gamma^2}\right)\frac{L\gamma^2}{\rho^{3/2}} \tag{1}$$

$$\tau_{bs} = \frac{1}{f_0 N} = \frac{1}{f_0}\frac{4\sqrt{\pi}}{3}\sqrt{\frac{\eta}{\alpha r_e}}\exp\left(\frac{2}{3}\frac{\eta\alpha\rho}{r_e\gamma^2}\right)\frac{\rho^{3/2}}{L\gamma^2} \tag{2}$$

$$L = \sqrt{\frac{\pi}{2}}\frac{\sigma_s}{\sqrt{1+\varphi^2}} \qquad \left(L_{Telnov} = \frac{\sigma_s}{2}\right) \tag{3}$$

$$\frac{1}{\rho_x} \approx \frac{1}{\rho_y} = \sqrt{\frac{\pi}{2}}\frac{N_p r_e}{\gamma\sigma_x\sqrt{1+\varphi^2}}\frac{1}{L} = \frac{N_p r_e}{\gamma\sigma_x\sigma_s} \tag{4}$$

$\alpha$ – fine-structure constant, $r_e$ – classical electron radius, $\eta$ – energy acceptance, $\rho_{x,y}$ – bending radius, $\gamma$ – Lorentz factor, $L$ – effective interaction length, $N_p$ – amount of particles, $\sigma_{x,s}$ – horizontal and longitudinal beam size, $\varphi$ – Piwinski angle, $N_{ip}$ – number of IPs

# Analytical (2): beamstrahlung

$$\frac{1}{\rho} = \sqrt{\frac{1}{\rho_x^2} + \frac{1}{\rho_y^2}} \approx \frac{N_p r_e}{\gamma \sigma_x \sigma_s}\sqrt{2} \quad \left(\frac{1}{\rho_{Telnov}} \approx \frac{N_p r_e}{\gamma \sigma_x \sigma_s} 2\right) \tag{5}$$

$$\Delta I_2 = \left(\frac{L}{\rho_x^2} + \frac{L}{\rho_y^2}\right) N_{ip} \tag{6}$$

$$\Delta I_3 = \frac{L}{\rho^3} N_{ip} \tag{7}$$

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# Analytical (3): comparison

## V.I.Telnov

$$\tau_{bs} = \frac{10}{f_0}\frac{4\sqrt{\pi}}{3}\sqrt{\frac{\eta}{\alpha r_e}}\exp\left(\frac{2}{3}\frac{\eta\alpha}{r_e\gamma^2}\times\frac{\gamma\sigma_x\sigma_s}{2r_eN_p}\right)\frac{2}{\sigma_s\gamma^2}\left(\frac{\gamma\sigma_x\sigma_s}{2r_eN_p}\right)^{3/2} \tag{8}$$

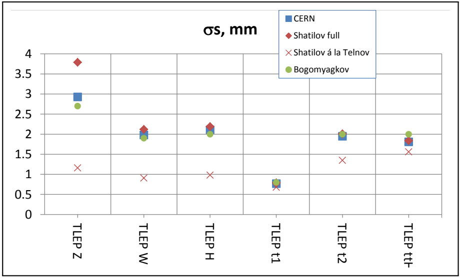
## Ours

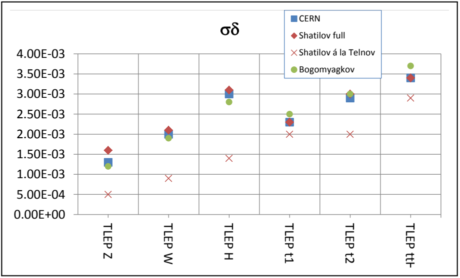
$$\tau_{bs} = \frac{1}{f_0}\frac{4\sqrt{\pi}}{3}\sqrt{\frac{\eta}{\alpha r_e}}\exp\left(\frac{2}{3}\frac{\eta\alpha}{r_e\gamma^2}\times\frac{\gamma\sigma_x\sigma_s}{\sqrt{2}r_eN_p}\right)\frac{\sqrt{2}}{\sqrt{\pi}\sigma_s\gamma^2}\left(\frac{\gamma\sigma_x\sigma_s}{\sqrt{2}r_eN_p}\right)^{3/2} \tag{9}$$

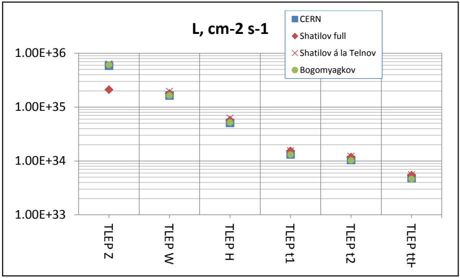
# Parameters $\Pi = 100$km *(24.09.2013 TLEP and CEPC IR designs)*

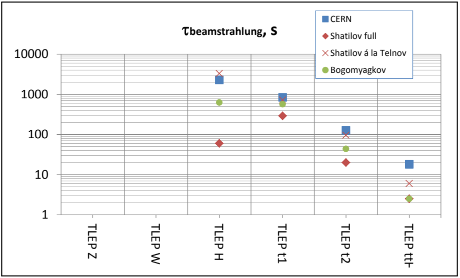
| | Z | W | H | t | | ttH, ZHH |
|---|---|---|---|---|---|---|
| $E_{beam}$, *Gev* | 45 | 80 | 120 | 175 | | 250 |
| Current[mA] | 1440 | 154 | 29.8 | 6.7 | | 1.6 |
| $N_{bunches}$ | 7500 | 3200 | 167 | 160 | 20 | 10 |
| $N_{particles}[10^{11}]$ | 4.0 | 1.0 | 3.7 | 0.88 | 7.0 | 3.3 |
| $\varepsilon_x[nm]/\varepsilon_y[pm]$ | 29.2/60 | 3.3/17 | 7.5/15 | 2/2 | 16/16 | 4/4 |
| $\beta_x^*[m]/\beta_y^*[mm]$ | 0.5/1 | 0.2/1 | 0.5/1 | 1/1 | | 1/1 |
| $\sigma_s[mm]$ | 2.93 | 1.98 | 2.11 | 0.77 | 1.95 | 1.81 |
| $F_{hg}$ hourglass | 0.61 | 0.71 | 0.69 | 0.90 | 0.71 | 0.73 |
| $L/IP[10^{32}cm^{-2}s^{-1}]$ | 5860 | 1640 | 508 | 132 | 104 | 48 |
| $\xi_x/IP$ | 0.068 | 0.086 | 0.094 | 0.057 | | 0.075 |
| $\xi_y/IP$ | 0.068 | 0.086 | 0.094 | 0.057 | | 0.075 |
| $\tau_L$, s | 5940 | 2280 | 1440 | 1260 | 1560 | 780 |
| $\tau_{bs}(\eta = 2\%)[s]$ | $>10^{25}$ | $>10^{6}$ | 2280 | 840 | 126 | 18 |
| $P_{SR}[MW]$ | 50 | 50 | 50 | 50 | 50 | 50 |

# Comparison *(24.09.2013 TLEP and CEPC IR designs)*

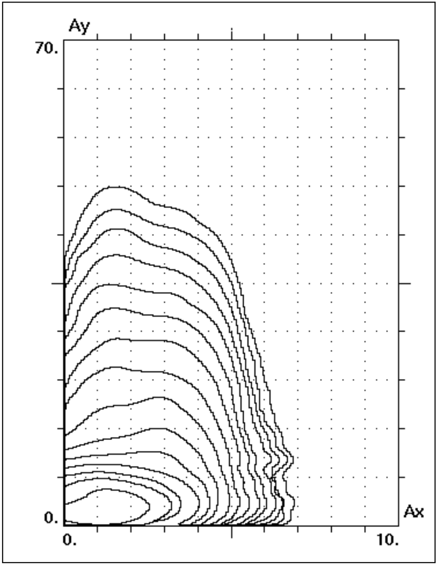




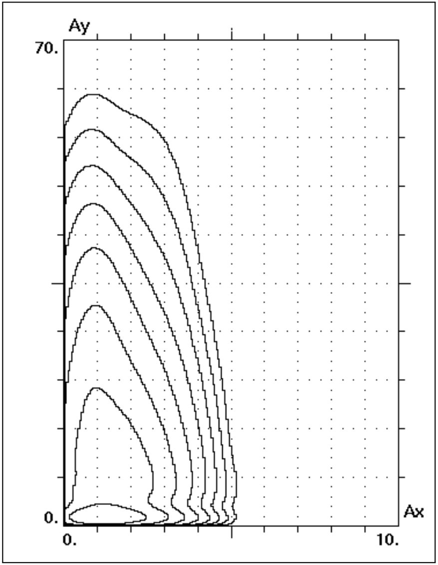




# TLEP Z transverse distribution (normalized betatron amplitudes)



Without beamstrahlung



With beamstrahlung

# Parameters $\Pi = 100$km, CRAB WAIST 1

Blue – value decreased, red – value increased.

| | Z | W | H | t | ttH, ZHH |
|---|---|---|---|---|---|
| $2\theta$, mrad | 70 | 70 | 70 | 70 | 70 |
| Current[mA] | 973 | 148 | 29 | 6.5 | 1.6 |
| $N_{bunches}$ | 7500 | 1600 | 133 | 20 | 5 |
| $N_{particles}[10^{11}]$ | 2.7 | 1.9 | 4.5 | 6.8 | 6.5 |
| $\varepsilon_x[nm]/\varepsilon_y[pm]$ | 0.14/0.7 | 0.44/0.22 | 1/2 | 2.1/4.25 | 4.3/8.68 |
| $\beta_x^*[m]/\beta_y^*[mm]$ | 0.5/0.8 | 0.5/0.8 | 0.5/0.8 | 1/0.8 | 1/0.8 |
| $\sigma_s[mm]$ | 6.3 | 5.4 | 7.5 | 8.5 | 10.1 |
| $F_{hg}$ hourglass | 0.98 | 0.94 | 0.9 | 0.76 | 0.67 |
| $L/IP[10^{32}cm^{-2}s^{-1}]$ | 24216 | 1663 | 550 | 95 | 10.7 |
| $\xi_x/IP$ | 0.014 | 0.008 | 0.006 | 0.01 | 0.004 |
| $\xi_y/IP$ | 0.208 | 0.06 | 0.065 | 0.04 | 0.015 |
| $\tau_L$, s | 1479 | 3271 | 1927 | 2531 | 5367 |
| $\tau_{bs}(\eta = 2\%)[s]$ | $>10^6$ | $>10^8$ | 12514 | 24204 | $>10^6$ |
| $P_{SR}[MW]$ | 36 | 50 | 50 | 50 | 50 |

# Parameters $\Pi = 100$km, CRAB WAIST 2

Blue – value decreased, red – value increased.

|  | Z | W | H | t | ttH, ZHH |
|---|---|---|---|---|---|
| $2\theta$, mrad | 70 | 0 | 0 | 0 | 0 |
| Current[mA] | 973 | 163 | 29 | 6.6 | 1.6 |
| $N_{bunches}$ | 7500 | 8500 | 1200 | 120 | 24 |
| $N_{particles}[10^{11}]$ | 2.7 | 0.4 | 0.5 | 1.15 | 1.4 |
| $\varepsilon_x[nm]/\varepsilon_y[pm]$ | 0.14/0.7 | 1.3/2.6 | 1/2 | 2.1/4.25 | 4.3/8.68 |
| $\beta_x^*[m]/\beta_y^*[mm]$ | 0.5/0.8 | 0.5/1 | 0.5/1 | 0.5/1 | 0.5/1 |
| $\sigma_s[mm]$ | 6.3 | 1 | 1.3 | 1.8 | 2.2 |
| $F_{hg}$ hourglass | 0.98 | 0.86 | 0.8 | 0.73 | 0.69 |
| $L/IP[10^{32} cm^{-2} s^{-1}]$ | 24216 | 2093 | 577 | 130 | 17 |
| $\xi_x/IP$ | 0.014 | 0.0857 | 0.095 | 0.07 | 0.029 |
| $\xi_y/IP$ | 0.208 | 0.0859 | 0.095 | 0.07 | 0.029 |
| $\tau_L$, s | 1479 | 2874 | 1840 | 1877 | 3426 |
| $\tau_{bs}(\eta = 2\%)[s]$ | $>10^6$ | $>10^{13}$ | $>10^7$ | 3009 | 3667 |
| $P_{SR}[MW]$ | 36 | 50 | 50 | 50 | 50 |

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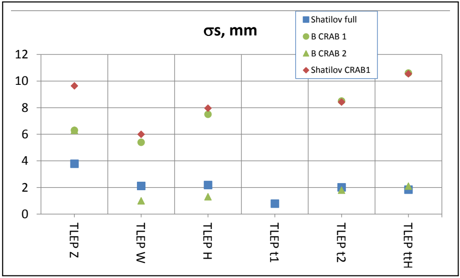

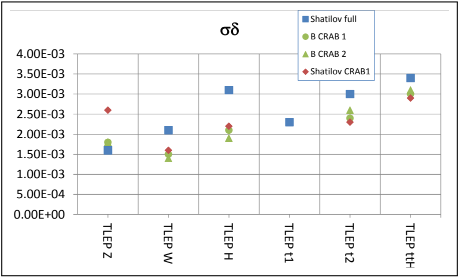

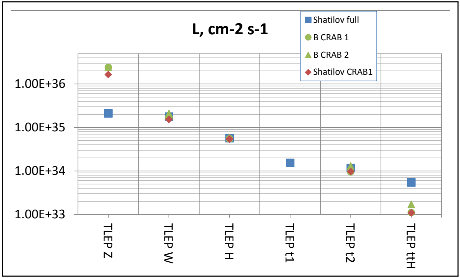

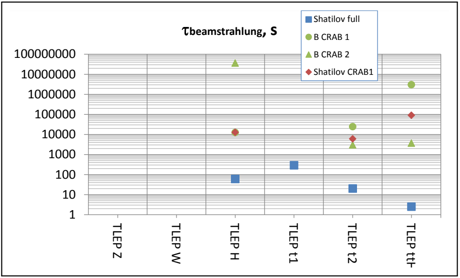

# Conclusion 1

- Consideration only of single beamstrahlung (V.I.Telnov approach) is not sufficient. Energy loss due to multiple beamstrahlung increases bunch length and energy spread, modifying in turn probability to emit photons.
- Particle with energy deviation might emit photon with smaller energy but higher probability in order to be outside of energy acceptance. Thus, the beam lifetime could be several times smaller.
- The proper way to consider influence of beamstrahlung is quasi strong-strong or strong-strong simulation with damping and noise excitation. Analytical approach does not consider all the effects, however gives sufficient estimation.
- At small energy (TLEP Z) damping is relatively weak which leads to large bunch lengthening, huge hour-glass, thus, to excitation of synchro-betatron resonances, with result of blown-up beam. Stronger damping at high energies suppresses these effects.

# Conclusion 2 *(B CRAB 2 vs Shatilov for 24.09.2013 CERN)*

- TLEP Z: $L = (2.1 \to 16.4) \times 10^{35}\, cm^{-2}s^{-1}$, crab waist
  - $2\theta = 0 \to 70$ mrad, $\sigma_s = 1.16 \to 1.88$ mm, $\varepsilon_x = 29.2 \to 0.14$ nm, $\varepsilon_y = 60 \to 0.7$ pm, $\beta_y = 1 \to 0.8$ mm, $N_p = (40 \to 27) \times 10^{10}$, $\tau_{bs} > 10^6$ s, limitation $\tau_L = 1479$ s.
- TLEP W: $L = (1.77 \to 2.09) \times 10^{35}\, cm^{-2}s^{-1}$
  - $2\theta = 0$ mrad, $\sigma_s = 0.91 \to 0.65$ mm, $\varepsilon_x = 3.3 \to 1.3$ nm, $\varepsilon_y = 17 \to 2.6$ pm, $\beta_x = 0.2 \to 0.5$ m, $N_{bunches} = 3200 \to 8500$, $N_p = (10 \to 4) \times 10^{10}$, $\tau_{bs} > 10^{13}$ s, limitation $P_{loss} = 50$ MW.
- TLEP H: $L = (5.67 \to 5.76) \times 10^{34}\, cm^{-2}s^{-1}$
  - $2\theta = 0$ mrad, $\sigma_s = 0.98$ mm, $\varepsilon_x = 7.5 \to 1$ nm, $\varepsilon_y = 15 \to 2$ pm, $N_{bunches} = 167 \to 1200$, $N_p = (37 \to 5) \times 10^{10}$, $\tau_{bs} = 60 \to 10^7$ s, limitation $P_{loss} = 50$ MW.

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# Conclusion 2 *(B CRAB 2 vs Shatilov for 24.09.2013 CERN)*

- TLEP t: $L = (1.53 \rightarrow 1.30) \times 10^{34}\, cm^{-2} s^{-1}$
    - $2\theta = 0$ mrad, $\sigma_s = 0.68 \rightarrow 1.4$ mm, $\varepsilon_x = 2 \rightarrow 2.13$ nm, $\varepsilon_y = 2 \rightarrow 4$ pm, $N_{bunches} = 160 \rightarrow 120$, $N_p = (8.8 \rightarrow 11.5) \times 10^{11}$, $\tau_{bs} = 300 \rightarrow 3009$ s, limitation $P_{loss} = 50$ MW.
- TLEP ttH & ZHH: $L = (5.41 \rightarrow 1.69) \times 10^{33}\, cm^{-2} s^{-1}$
    - $2\theta = 0$ mrad, $\sigma_s = 1.56 \rightarrow 2$ mm, $\varepsilon_x = 4 \rightarrow 4.34$ nm, $\varepsilon_y = 4 \rightarrow 8.68$ pm, $N_{bunches} = 10 \rightarrow 24$, $N_p = (33 \rightarrow 13.7) \times 10^{11}$, $\tau_{bs} = 2.4 \rightarrow 3667$ s, limitation $P_{loss} = 50$ MW.

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