LEP Beam-Beam Limit

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Introduction

- The beam-beam limit in e+e- storage rings is a difficult subject, studied by many colleagues over the years. No complete overview in 10 min!
- Several limits can be defined and exist.
- Here: Experience at LEP.
- Empirical stochastic model for the achievable beam-beam parameter versus energy and time.
- Basically: Beam-beam interaction blows up vertical emittance which in turn limits achievable beam-beam parameter and luminosity.

Reference

THE BEAM-BEAM INTERACTION IN THE PRESENCE OF STRONG RADIATION DAMPING

R. Assmann and K. Cornelis, CERN, Geneva, Switzerland

EPAC 2000

REFERENCES

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LEP Measurements

Table 1: Overview of achieved beam energies, ξ_y, bunch currents, and transverse damping times in LEP.

Year	Beam energy [GeV]	Maximum ξ_y	Damping time [turns]	Bunch current [μA]
1994	45.6	0.045	721	320
1995	65.0	0.050	249	400
1996	86.0	0.040	107	525
1997	91.5	0.055	89	650
1998	94.5	0.075	81	750
1999	98.0	0.083	73	780
2000*	102.7	0.055	63	550

Theory I

Vertical beam-beam parameter

$$\xi_y = \frac{2 r_e e m_e c^2 \cdot \beta_y^*}{n_b \cdot i \cdot E} \cdot L$$

$$\xi_y^\infty = \mathrm{f}\left[\lambda_d\right] = \mathrm{f}\left[\frac{1}{f_{rev} \cdot \tau \cdot n_{IP}}\right]$$

Prediction S. Peggs

$$\xi_y^\infty \propto \lambda_d^{0.3}$$

Damping Decrement

Parametric Model

$$\xi_y = \sqrt{\frac{1}{A + (B \cdot i)^2}} \cdot i$$

simple stochastic theory of the beam-beam interaction to derive the relationship between the vertical beam-beam parameter and bunch current i

$$A = \left(\frac{2\pi \ e \ f \ \gamma}{r_e} \right)^2 \cdot \frac{\beta_x^*}{\beta_y^*} \cdot \varepsilon_x^0 \cdot \varepsilon_y^0$$

A is a machine and optics dependent number times the zero current (unperturbed) vertical emittance (if the horizontal beam-beam blow-up is small).

$$B = \frac{1}{\xi_y(i \to \infty)}$$

B gives the inverse asymptotic vertical beam-beam parameter

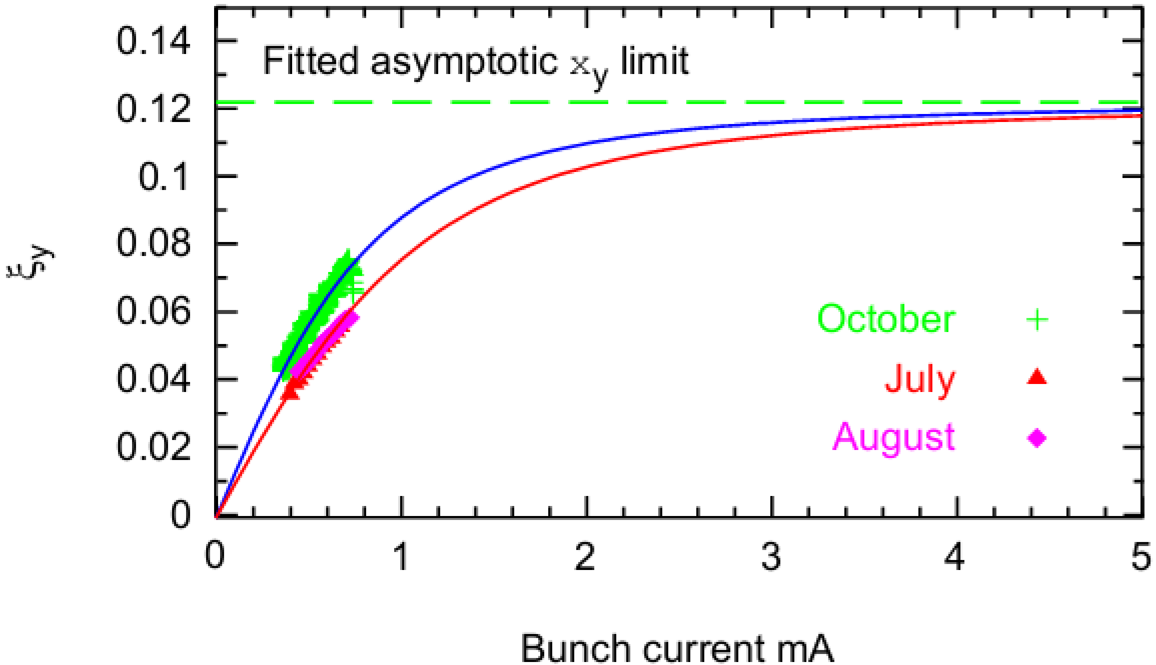


Figure 3: Three data sets at 94.5 GeV are fitted with the constraint of equal asymptotic beam-beam parameter ξ_y

Unperturbed Vertical Emittance

- Means: Vertical emittance unperturbed by beam-beam.
- For zero vertical orbit and therefore zero vertical dispersion, it is assumed to approach zero (of course it would then be limited by other effects).
- Here it is assumed that the driving blow-up will be generated by beam-beam, damped by radiation damping.

Beam-Beam Limits Luminosity

(Blowing up the Unperturbed Vertical Emittance)

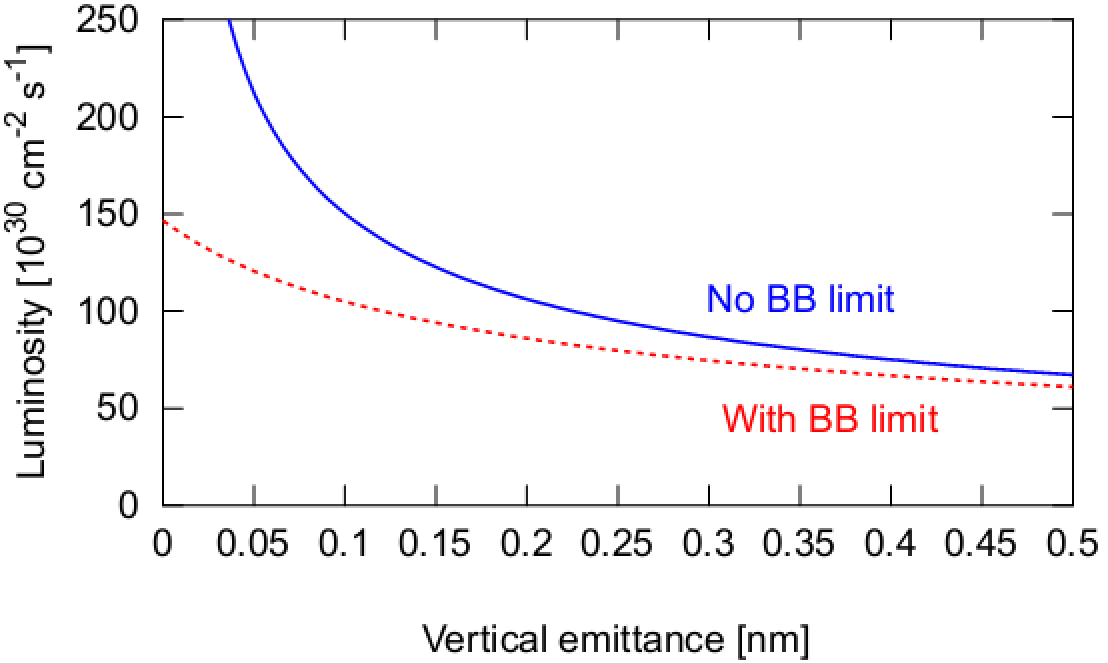
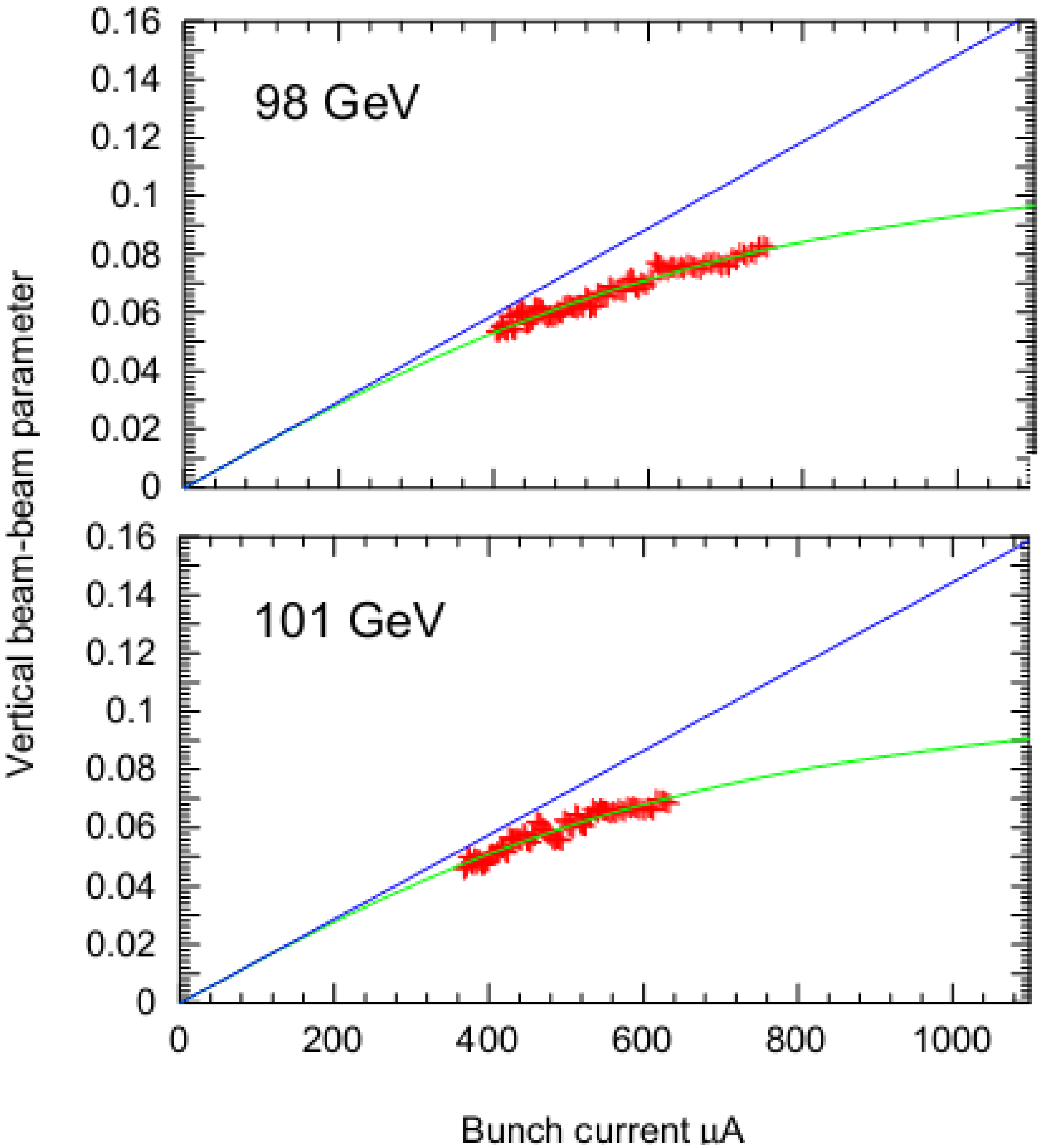


Figure 5: Predicted luminosity versus unperturbed vertical emittance (emittance at zero beam intensity). The calculation assumes a beam energy of 98 GeV and a bunch current of 750 μA. It is based on the fitted beam-beam limit of 0.115 for 98 GeV (Figure 4, top).



LEP Result on Scaling with Energy

$$\xi_y^{\infty} \propto \lambda_d^{\sim 0.4}$$

Conclusion

- Measured max. vertical beam-beam parameter:

  0.083

- Fitted, achievable vertical beam-beam parameter at ~100GeV:

  0.11 – 0.12

- Scaling with damping decrement:

$$\xi_y^{\infty} \propto \lambda_d^{\sim 0.4}$$