HESHBEAM — A PROGRAM WITH A GRAPHICAL USER INTERFACE FOR CALCULATION OF THE LUMINOSITY SPECTRUM AND THE DIFFERENTIAL LUMINOSITY

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Abstract

The paper presents a program with a Graphical User Interface for solving the luminosity spectrum and the differential luminosity. Instead of using the particles-in-cells method, the code is based on analytical solutions and experimental results. The user creates with the GUI an input data file, which contains only a few numbers of parameters, such as the beam size at the IP, the number of particles and the center-of-mass energy. The beam, with a round or elliptical cross-section, is described by a uniform or a gaussian density function in transverse and longitudinal direction. In all cases the program makes use of the analytical solutions for the beam-beam energy loss, the deflection angle, the luminosity spectrum and the differential luminosity. The results for several Linear Collider designs and different disruption numbers are obtained and compared with other numerical solutions. The numerical examples demonstrate clearly the accuracy of this method.

1 INTRODUCTION

The luminosity $\mathcal{L}$ in Linear Colliders during the interaction of e$^+$e$^-$ beams is not constant. At the interaction point (IP) $\mathcal{L}$ is dependent on the time and will be different from $\mathcal{L}_0$.
There are two different kinds to analyse the change of luminosity:
1.) The first part we consider a spectral representation of the luminosity which is investigated in dependence of the center-of-mass-energy for the colliding electron and positron beams. On the basis of the beamstrahlung effect the energy loss influences the bending of the trajectories. The whole center-of-mass-energy decreases during the collision and define an energy range of an undisturbed E_{cm0} to a center-of-mass-energy with maximum radiation loss $E_{cm} = E_{cm0} - \delta_{max}$. In this range we assign every energy value to a luminosity number, this relation is called the luminosity spectrum $\mathcal{L}$. The spectral representation of the luminosity $\mathcal{L}$ is a function of the center-of-mass energy E_{cms}. We found, that the center-of-mass energy E_{cms} decreases during the penetration process ($E_{cms} \leq E_{0cms}$). This entails a spread of the luminosity spectra to smaller center-of-mass energies.
2.) Instead of the spectrum the luminosity is analysed in the time domain, usually with the derivation $\frac{d\mathcal{L}}{dt} = f(t)$. In the calculation we distinguish between two regimes, the weak-focusing regime corresponding to the disruption range $D =]0, 1]$ and the transition region $D =]1, 10]$. The disruption factor D can be defined as

$$D = \frac{N\alpha_s L\hbar c}{2\sqrt{3}m\gamma_v{}^2\sigma_{r_0}{}^2} = \frac{N\sigma_z r_e}{\gamma_v\ \sigma_{r_0}{}^2} \ , \qquad (1)$$

with the lorentzfactor

$$\gamma_v = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \ . \qquad (2)$$

For the transition region we derived the equation

$$\frac{d\mathcal{L}}{dt} = \mathcal{L}_0 \frac{c}{\sqrt{\pi}\sigma_z} \frac{e^{-\frac{c^2t^2}{\sigma_z^2}}}{(t-t_f)^2 \frac{9}{16}\frac{c^2}{\sigma_z^2}\frac{D}{2} + \frac{16}{9}A^2\frac{2}{D}} \ . \qquad (3)$$

σ_{r_0}	:	beam cross-section without beam-beam loss
σ_z	:	beam length
N	:	particles per bunch
m	:	electron mass
r_e	:	electron radius
A	=	σ_z/β^*
β^*	:	betatron function at the IP
t_f	:	focal time

Figure 1 shows $\frac{1}{\mathcal{L}_0}\frac{d\mathcal{L}}{dt}$ as a function of time for the disruption $D = 0.7$, the time t is in units of σ_z/c.

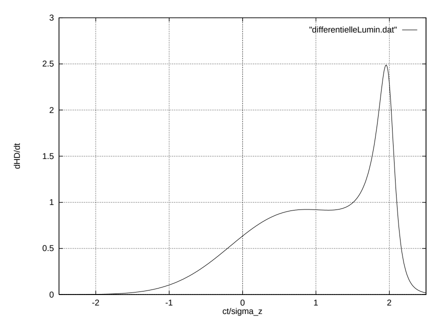

Figure 1: Differential luminosity $\frac{1}{\mathcal{L}_0}\frac{d\mathcal{L}}{dt} = f(ct/\sigma_z)$ for $D = 0.7$.

2 THE GRAPHICAL USER INTERFACE

The methods for solving the luminosity spectrum and the differential luminosity are being integrated into a single, flexible, easy-to-use software system, called HeShBeam. The interface is based on the tool Tcl/Tk due to J.Ousterhout [5] for developing graphical interfaces. It is independet of the numerical code. This software is intended to support all steps involved in the examination of

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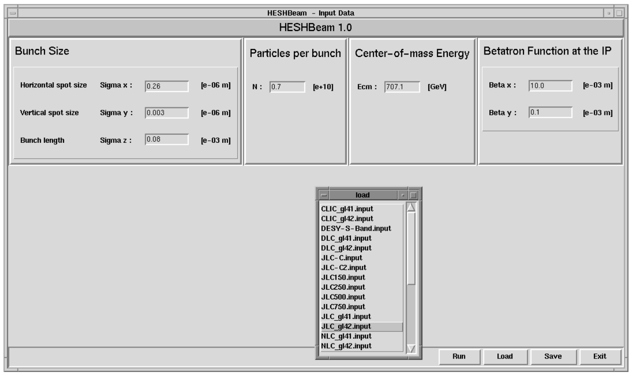

Figure 2: Input-window with file menue to open an existing file.

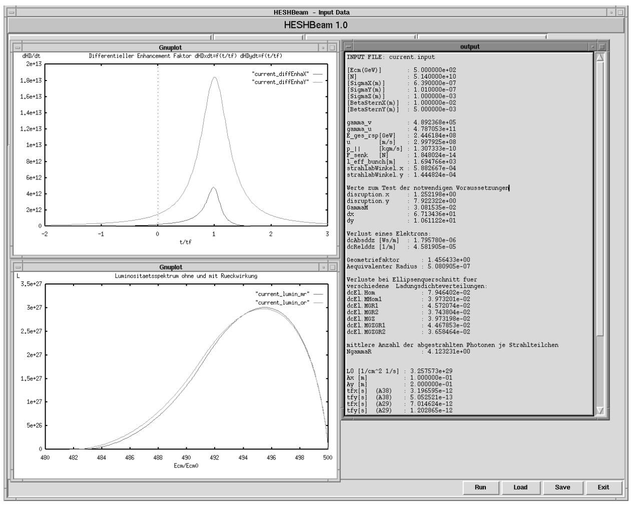

Figure 3: Result-windows: Table with average values, luminosity spectrum and the differential luminosity.

the luminosity change at the IP by state-of-the art numerics and visualization.

The first official version of HeShBeam has been released in January 1997, still isn't complete, the full version for Unix and Win95 will be available in June 1997.

HeShBeam is run in an interactive mode where the user types in commands and parameters to initiate and control the solution process and to view or output the results. First, the user creates with the input-window only a few numbers of parameters, such as the beam size at the IP ($\sigma_x, \sigma_y, \sigma_x$), the number of particles per bunch N, the center-of-mass energy E and the betatron function at the IP (β_x^*, β_y^*). Each parameter-file can be saved and changed in the input-window (figure 2).

The menu in the input-window (figure 2) contains the commands `run, load, save` and `exit`. The command `run` starts the numerical calculation and the results appear in another window, as shown in the figure 3.

3 ALGORITHMIC KERNEL

Let us briefly discuss some of the essential steps of the algorithmic kernel of HeShBeam. The computer program is divided into subroutines carrying out the following task:

1. If the set of parameters satisfies
$$\frac{N\ \sigma_{x,y}}{\gamma_u\ \sigma_z} \gg 1 \quad , \tag{4}$$
then the beam is described by gaussian density functions
$$n_r(r,t) = \frac{1}{\sigma_r^2(t)} \exp\left(-\frac{r^2}{2\sigma_r^2(t)}\right) , \tag{5}$$
$$n_z(z_j) = \frac{1}{(2\pi)^{3/2}\sigma_{z_j}} \exp\left(-\frac{{z_j}^2}{2{\sigma_{z_j}}^2}\right) . \tag{6}$$

2. Which regime, the weak-focusing regime or the transition region ?

3. Determine the average relative beam-beam loss :
$$\delta_c = \frac{4}{3}\sqrt{\frac{3}{\pi}}\, 8\ln\left(\frac{9}{8}\right)\frac{r_e^3 N^2 p_\parallel c}{BLm_0c^2}\left(\frac{1+\beta}{2}\right)^2 \beta^{-3} \quad , \tag{7}$$
with the total particle energy
$$E = mc^2 = \gamma_u m_0 c^2 \approx \frac{p_\parallel}{|\vec{u}|}c^2 \quad , \tag{8}$$
and the effective length
$$L = 2\sqrt{3}\sigma_L = 2\sqrt{3}\,\gamma_v\,\sigma_z \quad . \tag{9}$$
B : effective beam cross-section
$\beta = v/c$

4. The spectral representation of the luminosity $\mathcal{L}$ is a function of the center-of-mass energy E_{cms}. This entails a spread of the luminosity spectra to smaller center-of-mass energies. An expression of $x = \frac{E_{cms}}{E_{0cms}}$ which consists of two areas was determined.
$$\mathcal{L}(x) = \begin{cases} \mathcal{L}_1 & \text{for } 1-\delta_{max}/2 \le x < 1 \\ \mathcal{L}_2 & \text{for } 1-\delta_{max} \le x \le 1-\delta_{max}/2 \end{cases} \tag{10}$$
$$\mathcal{L}_1(x) = \mathcal{L}_0\big[(1-x)+(1-x)\cdot \cdot(\ln(\delta_{max}) - \ln(1-x) - 2\ln 2)\big] \tag{11}$$
$$\mathcal{L}_2(x) = \mathcal{L}_0\big[\delta_{max} - (1-x) - (1-x)\cdot \cdot(\ln(\delta_{max}) - \ln(1-x))\big], \tag{12}$$
where δ_{max} is the maximum energy loss of the beam-beam radiation.

5. Differential luminosity:
For the transition region we derived the equation
$$\frac{dH_D}{dt} = \frac{c}{\sqrt{\pi}\sigma_z}\frac{e^{-\frac{c^2t^2}{\sigma_z^2}}}{(t-t_f)^2\frac{9}{16}\frac{c^2}{\sigma_z^2}\frac{D}{2}+\frac{16}{9}A^2\frac{2}{D}} \quad . \tag{13}$$

4 CONCLUSION

In this paper we have presented our program HeShBeam. The results obtained from ABEL, SCHROEDER, HeShBeam for TESLA1, SLC, NLC are in agreement, but there are some discrepancies with the results of RBEAM, TRACKIT, HeShBeam for TESLA1-3. More detailed analysis of our results is available [9][10], but due to space limitation it is not included here.

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