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At 5 TeV center-of-mass energy, collective effects are a prominent feature of electron-positron collisions, contributing to backgrounds and energy-spread, and suggesting a practical limit on the charge per bunch. To circumvent such collective phenomena we examine collision of neutral beams, with particular attention to the effect of mismatch and instability.

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At 5 TeV center-of-mass energy, collective effects are a prominent feature of electron-positron collisions, contributing to backgrounds and energy-spread, and suggesting a practical limit on the charge per bunch. To circumvent such collective phenomena we examine collision of neutral beams, with particular attention to the effect of mismatch and instability.

1 INTRODUCTION

The exploration of high-energy physics has progressed over the last 50 years only by continuous and inspired invention [1]. Today, blessed with a surfeit of predictions for the 5 TeV frontier [2], we are unable to reach the energy required. The problem, for linear colliders is this: to reach high luminosity with a reasonable site power we must produce *small* beams in collision. However, small beams interact collectively and pinch each other [3].

As a particle encounters the oncoming beam at the interaction point, its trajectory is bent and it radiates "beamstrahlung" photons, with a spectrum characterized by the parameter

$$Y = 1.1\times10^{2}\,\frac{\gamma N_b r_e^2}{(1+R)\sigma_y\sigma_z}\ ,$$

the ratio of average photon energy to incident electron energy. Here r_e = 2.82x10^{-13} cm is the classical electron radius and N_b is the number of particles per bunch. The quantity $R = \sigma_x/\sigma_y$ is the aspect ratio of the beam at the IP, σ_x and σ_y are the rms spot sizes in collision, σ_z is the rms bunch length, and $\gamma = E_{CM}/2mc^2$ is the Lorentz factor for an electron.

It is instructive to parameterize the collider scalings by Y. We abbreviate $W = \sigma_z Y / r_e\gamma$. The average fractional energy loss of an electron in collision is given by [4]

$$\delta \approx 6.6\times10^{-5}\,WY\left[1+(1.5Y)^{2/3}\right]^{-2}\ .$$

The number of particles per bunch is

$$N_b \approx 8.5\times10^{-3}\,W\left(\frac{\sigma_y}{r_e}\right)(1+R)\ ,$$

and the bunch crossing rate may be expressed in terms of luminosity

$$f \approx 2.1\times10^{4}\,\frac{L\sigma_T}{W^2}\,\frac{R}{(1+R)^2}\ ,$$

where σ_T ~ 6.7x10^{-25}cm^2 is the Thomson cross-section. Site power P may be expressed as

$$P \approx 3.5\times10^{2}\,\frac{mc^2\gamma}{\eta}\,\frac{L\sigma_T}{W}\left(\frac{\sigma_y}{r_e}\right)\frac{R}{1+R}$$

where η is the efficiency of conversion of wall-plug energy to beam kinetic energy. Finally, the colliding beams serve to focus each other with focal length ~σ_z/D_y, where the disruption parameter is

$$D_y = 1.7\times10^{-2}\,\frac{W^2}{Y}\left(\frac{\sigma_y}{r_e}\right)^{-1}\ .$$

Center-of-mass energy, luminosity and site power constrain all variables as functions of δ and Y (and R). Additional restrictions should be considered with care; we tentatively consider the following: (1) control energy resolution in collision: $\delta < 0.1$ (2) control backgrounds: Y < 0.2. If we accept these constraints as equalities, all parameters, but R, follow directly. For example, at 5 TeV center of mass energy, a useful event rate requires luminosity of order L ~ 10^{35}cm^{-2}s^{-1}. Perceived operating costs limits P to, let us say, 500 MW. With δ = 0.1 and Y = 0.2 one finds W ~1.6x10^4, β_y~σ_z~0.1cm, D_y~1.5x10^3, and other parameters as in Table 1.

Table 1 Naive collider scalings at 5 TeV.

$\sigma_y \approx 5\times10^{-7}\eta\left(1+\frac{1}{R}\right)\mathrm{cm}$
$f \approx 1.4\times10^{6}R(1+R)^{-2}\ \mathrm{Hz}$
$N_b \approx 5\times10^{8}\eta(1+R)$
$\varepsilon_{ny} \approx 1\times10^{-7}\eta^2\left(1+\frac{1}{R}\right)^2 \mathrm{m-rad}$

The relatively long bunch length has implications. For a linac operating with a pure sinusoidal accelerating waveform (*i.e.*, a conventional linac), the bunch length constrains the linac wavelength to λ ~ $53\sigma_z/\delta^{1/2}$, where δ is the percent rms energy spread for the beam. The momentum bandwidth of the final focus system [5] constrains δ. For example δ ~ 0.2% implies a linac operating at S-Band or longer wavelengths. Gradients are limited at long wavelengths due to breakdown and trapping [6] and even at a gradient of 50 MeV/m, the linac

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