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THE SUPER COLLIDER REVISTED

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Abstract

We suggest a revised version of the Superconducting Super Collider (SSC) that employs the planned SSC first stage machine as an injector of 0.5 TeV protons into a powerful laser accelerator. The recently developed Non–linear Amplification of Inverse Bremsstrahlung Acceleration (NAIBA) concept dictates the scenario of the next stage of acceleration. Post "Star Wars" lasers, available at several laboratories, can be used for the purpose. The 40 TeV CM energy, a target of the SSC, can be obtained with a new machine which can be 20 times smaller than the planned SSC.

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The SSC as presently planned purports to accelerate protons to 20 TeV in C.M. collider apparatus. The eventual aim of this gigantic project is the verification of the existence of the ever so elusive Higgs boson predicted to have a mass of > 50 GeV. The dimension of this planned machine is, as is already known, colossal, with an estimated cost of several billions of dollars. Clearly the physics dictates the cost. However, one still wonders about possible cheaper alternatives. In this communication we propose a new accelerator that could reduce the dimension by more than an order of magnitude.

In a recent paper[1)], we proposed the non–linear amplification of inverse bremsstrahlung electron acceleration (NAIBEA) as a way of accelerating electrons to a very high energy with the aid of powerful lasers which are available at several laboratories, in conjunction with an optimally determined applied electric field. Similar effects are obtained with an applied magnetic field[2)]. In the work of Hussein and Pato[1)], the initial electron energy was taken to be about 35 MeV. To obtain similar effects with protons one would need an initial energy of about 70 GeV and a laser 10^4 more potent than the one used in Ref. 1.

Our proposal for a smaller Higgs machine is to inject protons with about 500 GeV energy (proton initial velocity $v_0/c = \beta_0 = 0.999998$), which is the energy attained in the first stage of the SSC, in conjunction with a poweful laser (say of a power of 6.6×10^{20} W/cm^2 for a wavelength of $\sim 5 \times 10^{-5}$ m). The laser wave would merely pump and subsequently remove a very large amount of energy into/from the protons. In fact, during a half cycle interaction with the laser, the protons are accelerated to about 1 TeV within a distance of $\frac{\beta_0}{1-\beta_0}\lambda = 25$ meters. No net energy is gained in a full cycle encounter with the laser. In the process of pumping/removing energy into/from the protons, the proton energy oscillates. To obtain net acceleration, one would require to change the maxima in the proton energy into inflection points. This is obtainable with an appropriate applied electric, E_{app}, or magnetic, B_{app}, field. Significant acceleration can be obtained (up to the TeV regime) with an array of E_{app} or B_{app} with interchanging signs placed in optimally determined positions[1,2]. The dimensions involved are not as great as those in the planned SSC machine. We now turn to a detailed analysis of the proposal.

To reach a proton energy of 20 TeV we need, an array of applied magnetic field of an intensity of about 10 teslas. The sign changes of this field are made at macroscopic distances dictated by the requirement that, the particle is well contained in the transversal direction $p_y(\varphi = n\pi) = 0$ where φ is the laser phase. These features of the physics become particularly transparent if we look at the equation of motions when the motion is ultrarelativistic in the z–direction,[1)]

$$\dot{p}_z = e\,\beta_y\left(E_y^{(0)} + B_{app}\right) \tag{1}$$

$$\dot{p}_y = -e\,\beta_z\,B_{app}\ , \tag{2}$$

and the energy equation ($\varepsilon = \gamma$ in unit of the rest mass of the particle)

$$\dot{\gamma} = e\,\beta_y\,E_y^{(0)}\,c\ . \tag{3}$$

In the above equations, $E_y^{(0)} = B_x^{(0)}$ is the laser electric field intensity and $\beta_i = \frac{v_i}{c}$. The applied constant magnetic field in the x–direction is B_{app}.

Now the solution of the above equations can be expressed in the form

$$\varepsilon = p_z - e\,B_{app}\,y + u_0 \tag{4}$$

$$p_y = p_y^{(0)} - e\,B_{app}\,z \tag{5}$$

$$p_z = \frac{1 + p_y^2 - (e\,B_{app}\,y + u_0)}{2(e\,B_{app}\,y + u_0)} \tag{6}$$

In Equation (4), u_0 is a constant determined from the initial conditions; $u_0 = \gamma_0\,(1 - \beta_0\cos\theta_0)$ where θ_0 is the injection angle.

It is obvious from Eq.(4) that to make ε increase, $B_{app}\,y$ must be made positive $(< u_0)$. From obvious arguments y is oscillatory so as to keep the particle in the path of the laser pulse. This means that p_y is also oscillatory. Thus $B_{app}\,z$ must oscillate. Since z is always increasing, one naturally reaches the conclusion that B_{app} should change sign at appropriate z,s , dictated by the machine characteristics.

Now the change in energy of the protons in the first stage of acceleration is given by[1)]

$$\Delta\varepsilon = \frac{e\,E_{y_0}^{(0)}\lambda}{\pi}\left[\frac{m\,c^2\gamma_0\;\beta_0\sin\;\theta_0 + \frac{e\lambda}{2\pi}E_{y_0}^{(0)}}{m^2\,c^4 + \beta_0^2\,\gamma_0^2\;m^2\;c^4\,\sin^2\theta_0}\right]\gamma_0\,\beta_0\,mc^2\,(1 + \beta_0\cos\theta_0) \tag{7}$$

where the laser electric field is represented by $E_y^{(0)} = E_{y_0}^{(0)}\,\text{sen}\,\varphi$, φ being the phase and λ the wave length, and θ_0 is the injection angle of the protons ($\cos\theta_0 = \hat{y}_0\cdot\hat{z}_0$). The over all change in energy, $\Delta\varepsilon_f$, of the proton after n inflection points (generated by n alternating sign magnetic fields (or electric fields)), is then, for $\gamma_0 \gg 1$,

$$\Delta\varepsilon_f = n\,\Delta\varepsilon \approx n\left[\frac{e\;E_y^{(0)}\lambda}{2\pi}\right]\left[\frac{2\sin\;\theta_0(1+\cos\;\theta_0)}{1 + \gamma_0^2\;\sin^2\;\theta_0}\right]\gamma_0^2 \tag{8}$$

or

$$(\Delta\gamma)_f \equiv n\cdot B\cdot\left[\frac{2\sin\;\theta_0(1+\cos\;\theta_0)}{1 + \gamma_0^2\;\sin^2\;\theta_0}\right]\cdot\gamma_0^2$$

where we have introduced the laser parameter $B \equiv e\,E_y^{(0)}\,\lambda/2\pi\,mc^2$. If we take $\gamma_0 = 500$, $n = 20$, $\theta_0 = 0.1°$, and $B = 0.5$, we reach the value of $\Delta\varepsilon_f \simeq 20$ TeV .

The important question we address ourselves to now is how long the accelerator tube will be. This is determined primarily by the intensity of the applied field B_{app}, and the injection angle θ_0 among other things such as the Doppler effect mentioned earlier.

To quantify the above discuss ion, we have used the NAIBA model to calculate the length of the proton accelerator taking for $\gamma_0 = 500$, $B_{app} = 5.14 \times 10^{-7} E^{(0)}_{y_0}$, $P = 6.6 \times 10^{20}\ W/cm^2$, $\lambda = 5 \times 10^{-3}$ cm and $\theta_0 = 0.02$. A laser pulse of a Gaussian shape with a width of $\Delta = 3\pi$ is employed. The result are shown in Figure 1. The applied magnetic field was made to change sign 11 times along the accelerator tube. The length of the accelerator tube, Δz, needed to reach 20 TeV energy is about 3.0 km. This value is consistent with the slightly improved version of the estimate made by HPK[2), namely

$$\Delta z \simeq 2\gamma_0^2 \left(1 + \nu_0^2\right) n\, \lambda / \left(1 + \bar{\beta}_y^2\, \gamma_0^2\right) \tag{9}$$

where ν_0^2 is the intensity of the laser pulse's vector potential[2), and $\bar{\beta}_y$ is an average value of the y–component of the particle velocity.

It is very important to realize that the over all characteristics of our machine is strongly dependent on the values of the available variables. An extensive analysis of optimization must be made in order to reach final conclusions concerning the size of the accelerator (as small as possible), the final energy of the protons (as high as possible), the laser and applied field intensities (as low as possible) and the injection angle, θ_0.

The new SSC which we are proposing here consists of two injectors of 0.5 TeV protons some 6.0 km apart. The protons are injected into two NAIBA linear accelerators of 3.0 km in length that face each other. The resulting collider energy in the center of mass system will be the same as the proposed 100 km circular collider. Clearly [illegible] questions remain to be answerd. The most important to our mind, is the luminosity [illegible] beam which should be about $10^{33}\ cm^{-2}s$. Since the luminosity is inversely propor[illegible] the intersection area of the two beams, this require[illegible] very small beam cross–se[illegible] In turn this implies a very small laser transversal [illegible]on. Our calculations i[illegible]

the proton dispersion in the y–direction is in the range of few mm's. This must be made smaller, possibly by using a combined applied electric and magnetic fields.

In conclusion, we have proposed in this paper a new linear super collider that is 20 times smaller than the planned SSC. The basic components of our proton accelerator are two 0.5 TeV proton injectors, two very powerful lasers $\left(P = 6.6 \times 10^{20} \frac{W}{cm^2},\ \lambda = 5 \times 10^{-3}\ cm\right)$ and an array of (~ 22) several powerful magnets $\left(B_{app} \sim 10\ teslas\right)$ with alternating signs. The values of these parameters can be easily changed to better the optimization of the machine. The question of radiation damping, an important one not considered here, will be discussed in Ref. 3).

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REFERENCES

1) M.S. Hussein and M.P. Pato, *Phys. Rev. Lett.* 68, 1136 (1992); M.S. Hussein and M.P. Pato, in preparation.

2) M.S. Hussein, M.P. Pato and A.K. Kerman, submitted for publication.

3) M.S. Hussein, M.P. Pato and A.K. Kerman, to be submitted.

FIGURE CAPTIONS

Fig. 1: The relativistic factor, γ vs. z. A Gaussian laser pulse with a width of $\Delta = 3\pi$ is used in the calculation (see text for details).