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LASER DRIVEN LINEAR COLLIDER*

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Abstract

We continue the detailed description of the scheme allowing long term acceleration with >10GeV/m in multi-cell microstructures side-illuminated by laser radiation. The basis of the scheme is a fast sweeping device for the laser bunch. After sweeping, the laser bunch has a slope ~45° with respect to the direction of propagation. So every cell of the microstructure becomes excited locally only for the moment when the particles are there. Self consistent parameters of collider based on this idea allow consideration this type of collider as a candidate for the near-future accelerator era.

INTRODUCTION

The goal of our development is an acceleration scheme with Traveling Laser Focus (TLF) for a long term stable acceleration of charged particles in tiny structures excited through the side openings [1]-[3]. The TLF method promises ~10GeV/m with power density at the location of accelerator structure ~0.3J/cm^2, while the illumination time for any point of structure is ~0.3ps only. In our last publications [6], [7] we introduced the way to compensate the difference in distances from the sweeping device to structures by fast changing the focusing properties of electro-optically controllable lenses in accordance with location of focused laser spot on sequenced accelerating structure.

In current publication we propose to use for this purpose correction lenses-one for each structure. We also compare the method of generating TLF by the sweeping device and with the grating. We also review the parameter list of laser driven collider able to deliver luminosity ~10^{35}cm^{-2}s^{-1} at 1TeV.

THE CONCEPT

The concept of feeding accelerator structure with sloped laser pulse is represented in Fig.1. Here the accelerating

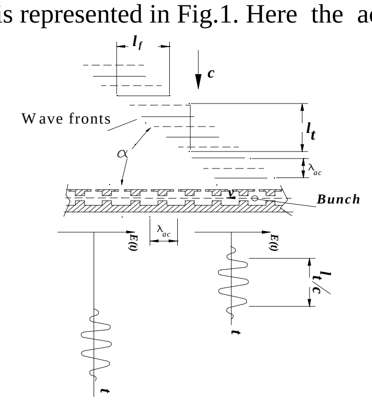

Figure 1: The concept of TLF illumination [1]. The time dependence of the field at two different locations along the structure is represented on the graphs at the bottom. Bunch has a velocity directed to the left.

structure is a 2p type as the period of structure is equal to wavelength of laser radiation l_{ac}. $E(t)$ in Fig.1 represents the time dependence of the electric field in the gap of cells at two different locations. The EM field phases in neighboring cells are the same. The particle meets accelerating phase in the cell's gap *inside* the structure and decelerating phase it meets in the narrowing between cells where the field is exponentially lower. This is similar to an ordinary accelerating structure with long transit tubes. So there is no slippage between particle and accelerating field *by definition*. Slope (tilt) of the laser bunch a defined by the speed of particle, $\tan a = v/c$, so $a = 45°$ for relativistic particles. The slope could have deviations from the linear one, as this affects the average accelerating gradient only [3]. Illumination time is $t @ l_t / c$, $l_f ° l_t$, Fg.1, while the laser bunch length $ct @$ 3 cm.

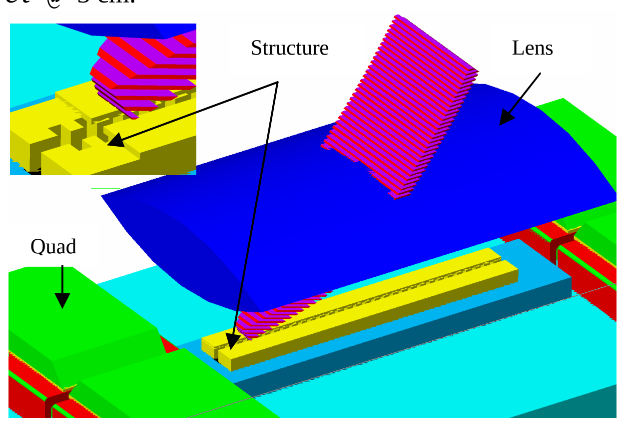

Figure 2: 3D view on structure, lens, laser bunch and quadrupoles. Wave fronts are shown schematically also.

To increase the power density at the orifice of each cell, the low-dispersion cylindrical lens used here to focus in transverse direction, similar to the very first proposal for usage of such lens made in [8]. But this is *not* a far field structure, nor the grating which originally considered in [8]. We are using a structure proposed in [9] as a basis. A small but important change is that we suggested the height of the structure be~ l_{ac}/2 and covered it from the top, so it looks now like a muffing-tin one partially open from one side [10]. This gives *inductive* coupling between each cell and the outer space, eliminating electric field enhancement at the coupling orifice (hole) [3].

3D view on the structure, lens and laser bunch is represented in Fig. 2. In this picture the wave-fronts are shown schematically as the slices across the laser bunch. It is clearly seen how transverse focusing by lens increases the power density at the openings. So there is no influence of diffraction of any kind applicable here at the

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structure side entrance. Basically the structure used for the purposes of accurate positioning of the EM field and for carriage out the wake photon(s) inevitable in the process of acceleration (two-photon Feynman's diagram in lowest order).

In contrast with structure-based schemes, in plasma driven schemes the accurate EM field positioning is not possible. This caused by fluctuations of charge forming the field boundary as a result of much smaller charge density in plasma ~10^{16}/cm^3, compared to electron charge density in conducting materials ~10^{23}/cm^3. So the media of plasma cannot confine the EM field steady centered, like electron plasma in metals doing this. So the long term acceleration in plasma driven acceleration schemes *not possible*, see [3]; (acceleration of *positrons* is not realistic in plasma methods also).

TECHNIQUES FOR GENERATION OF SLOPED LASER BUNCH

The first technique, which was developed earlier [1], uses sweeping techniques. The second one originated later in [4], [5], suggests a diffracting grating for generation of laser pulses with sloped shape.

Sweeping of laser pulse

In this case the length of laser bunch is about the length of the accelerating structure, Fig.3. Diffraction angle for sweeping device is $J_d^s \cong l_{ac}/a$ where *a~L–* is the aperture of the sweeping device. The lens installed in front of the sweeping device has the focal point at the structure. All transverse dimensions could be changed by appropriate optics but the ratio of deflecting angle J_{sw} to the diffraction angle–so called number of resolved spots of sweeping device $N_R = J_{sw}/J_d^s$~100 –remains the same.

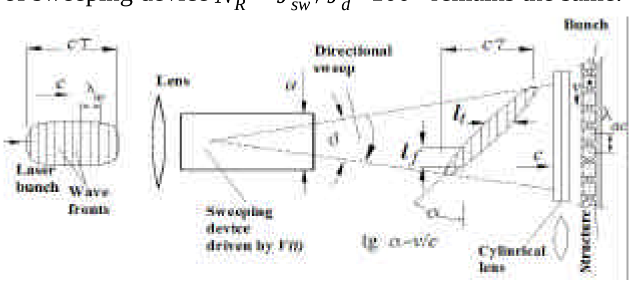

Figure 3: TLF principle of preparation of sloped laser bunch with the sweeping device [1]. Electron bunch is moving from the top to the bottom inside the structure.

For sweeping of cm-long laser bunch a multi-prism device feed with traveling wave EM pulse suggested in [3]. This EM pulse has a slope along the bunch ~few kV arranged either by the pulser, synchronized by the laser pulse itself or a cm-wavelength RF. In last case the laser pulse appearance is synchronized with RF phase. A few examples of the engineering of the sweeping device can be found in [7].

Usage of diffracting grating

In this section we would like to briefly discuss the other method of the creation of sloped laser bunch with the help of diffraction grating, see Fig. 4. First of all the laser bunch must be short in this method with time duty which is equal to the effective laser duty in previous method, l_t. The pulse must have the width about twice the length of the accelerating structure which could be arranged with appropriate telescopic optics. In Fig.4 the incoming laser bunch hits the grating which has a tilt of 63° with respect to direction of propagation. The effective length of the accelerating structure, which might be located at the bottom chosen the same as in previous section, $L @ ct$. The geometric relations are clear from the Fig.4. As it follows from the principle of operation of grating, formation of reflection in necessary direction requires many periods and involves small area ~*d* on the grating only, Fig.4. This inevitably extends the laser pulse length. Really, the diffraction angle in this case is $J_d^g \cong \sqrt{l/d}$, where the area involved in formation of reflection chosen for comparison with the sweeping method as small as $d \gg l_f @ l_t$.

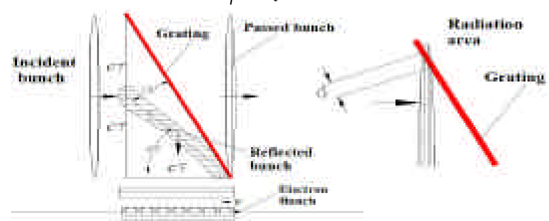

Figure 4: Geometry of changing the slope of laser bunch with (semi-transparent) grating, on the left. To the definition of effective radiation area, on the right.

For the sweeping device we have $l_t \cong L/N_R \cong a/N_R$. So for comparison of these two schemes, we represent the diffraction angle as $J_d^g \cong \sqrt{lN_R/a}$. The ratio of diffraction angles in these two methods goes to be

$$J_d^g/J_d^s \cong \sqrt{l_{ac}N_R/a}/(l_{ac}/a) \cong \sqrt{N_R a/l_{ac}} .$$

With some optimization of grating profile this could be improved, probably, to $J_d^g/J_d^s @ N_R$ at the best. So the advantage of using the sweeping device is obvious-it gives much smaller laser spot size in longitudinal direction. The difference is ~100 times minimum in favor of the sweeping device.

SCHEME FOR LONG TERM ACCELERATION

The scheme for long term acceleration with sweeping device is represented in Fig. 5. The long term acceleration means the ability to accelerate low-emittance bunch of charged particles without its degradation. A very important component is the ability of the acceleration of positively charged particles (positrons) in a view of arrangement of collisions at high energy. One sweeping device can serve for few structures (~10). For compensation of difference in distances from the sweeping device to the structure, special lenses used here (marked as Correction lenses in Fig.5). Together with the lens installed in front of sweeping device the lenses make focus on particular structure.

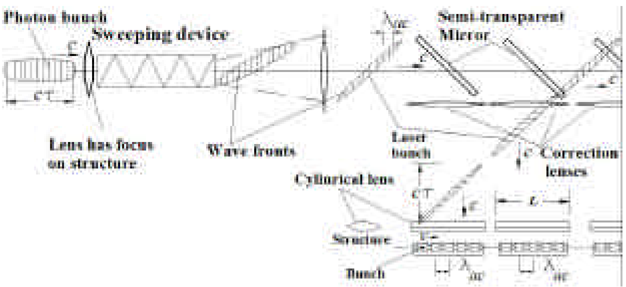

Figure 5: Long term acceleration system with sweeping device. Optical amplifiers could be installed between mirrors or in front of each cylindrical lens.

The distance between the mirrors and the structure might be minimal, as the correction lenses are thin.

One engineering realization of scheme from Fig.5 is represented in Fig.6. Here one can see the accelerating structures behind the cylindrical lenses, quadrupoles made with nanofabrication technologies, some optical elements and sweeping devices. These sweeping devices realized as a series of electro-optical prisms located inside a rectangular waveguide. One waveguide at the right shown with cut.

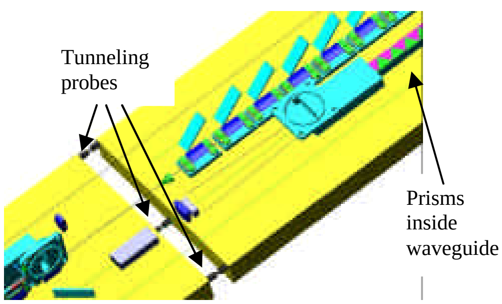

Figure 6: Alignment of platforms with triangular set of tunneling probes.

If the tunneling probes have depth resolution $\Delta \cong 0.01$nm, the basis ~10cm, then deviation of other end of optical table having length~2m will be 0.2nm, i.e. $\sim 2 \cdot 10^{-4}\, \lambda_{ac}$.

CONCLUSIONS

Preparation of sloped laser bunch with the grating looks much worse compared with the sweeping device.

In contrast with grating, which requires very short laser pulses, the sweeping device operates with long laser pulses. Amplification of such laser pulse becomes an easy task in this scheme.

In Table 1 there are represented parameters of Laser Driven collider for modest 1TeV final energy. We intentionally keep repetition rate low -1kHz while the laser system can operate up to MHz level-this is matter of full power available and adequate cooling of structure.

Despite the repetition rate is high compared with ILC, there is no problem with preparation of low-emittance bunches in a damping ring-remember the total length of the train is 30 μm only, so in a medium size ring a lot of trains could be held simultaneously. The gap between trains is defined by the possibilities of the extraction kicker only and could be made rather small. Total charge is much less than in ILC ring also. Polarized electrons and positrons are always on agenda for high energy collisions. Details of accelerating complex such as damping rings and other installations one can find in [3].

Table 1. Parameters of laser Driven Collider

Energy of $e^{\pm}$ beam	2×1 TeV
Total two-linac length	2 ×100 m
Wavelength	$\lambda_{ac} \approx 1$μm
Luminosity	10^{35}cm^{-2}s^{-1}
Main linac gradient	>10 GeV/m
Bunch population	3 10^5
Bunch length	0.1 μm
No. of bunches/train	<30
$\gamma\epsilon_x / \gamma\epsilon_y$	$5{\times}10^{-9}/1{\times}10^{-9}$cm-rad
Laser flash energy	2 × 0.3J
Laser density@AS*	0.3 J/cm^2
Illumination time	<0.3 ps
Length of section	<3cm
Laser flash energy	100 μJ/section
Repetition rate	1 kHz
Laser beam power	2 × 0.3kW
Damping ring energy	2 GeV
Damping time	5ms
Wall plug power**	2×3 kW

* AS stands for Accelerating Structure

** Without supplementary electronics.

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