

# LASER DRIVEN LINEAR COLLIDER

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## Abstract

We represent the details of scheme allowing long term acceleration with  $>10\text{GeV/m}$ . The basis of the scheme is a fast sweeping device for laser bunch. After sweeping the laser bunch has a slope with respect to the direction of propagation. So the every cell of accelerating structure becomes illuminated locally only for the moment, when the particle is there. Self consistent parameters allow considering this type of collider as a candidate for post-ILC era.

## INTRODUCTION

This publication is further development of the scheme [1]-[5] for stable and long term acceleration in small accelerating structures. These structures excited locally for the time  $\sim 1\text{ps}$  only with power density  $\sim 0.3\text{ J/cm}^2$ .

Let us remind first, the method itself. The scheme we proposed [1]-[5] contains accelerating structures scaled down to a micrometer level. Excitation of each cell of the structure is going from the side through side opening. Local excitation arranged by sweeping the laser bunch along the accelerating structure in synchronism with instant position of accelerated bunch, Fig.1. We called this procedure Travelling Laser Focus (TLF).

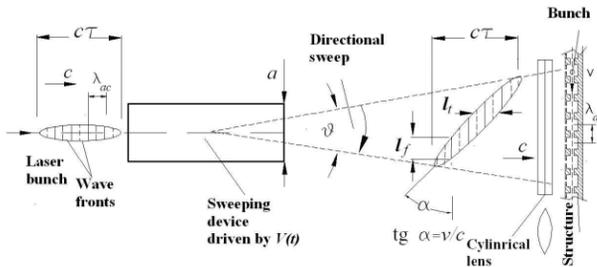


Figure 1: TLF principle of preparation of sloped laser bunch with the sweeping device. Bunch is moving from top to bottom *inside* the structure.

Sweeping device characterized by deflection angle  $\vartheta$  and by the angle of natural diffraction  $-\vartheta_d \cong \lambda/a$ , where  $a$ —is the aperture of the sweeping device which is of the order of the transverse laser beam size (Fig.1). The ratio  $N_R = \vartheta/\vartheta_d$  called the number of resolved spots (pixels) is a fundamental measure of the quality for any deflecting device. For laser radiation with the wavelengths  $10\mu\text{m} \geq \lambda_{ac} \geq 1\mu\text{m}$  the number of resolved spots can be reached 20-200. This number is an invariant under optical transformations. One can see, that the same number reflects reduction of the time, while every point of structure remains illuminated. Accelerator structures sectioned, having the length  $L \sim 3\text{cm}$ . so the pass-time through this structure going to be  $\tau \cong L/c \cong 100\text{ ps}$ . Meanwhile the time of illumination with TLF comes to  $\tau_{illum} \cong \tau/N_R \cong 1\text{ ps}$ . As the scale of structure is going down, (longitudinal) wakes are growing significantly,  $\sim \lambda^3$ .

So, high gradient required by the vital necessity to keep the ratio of wakes to acceleration field at reasonable level. This is in line, however with the desire to have higher gradient from economical point of view: higher gradient—more compact installation emerges. Basically the problem with laser acceleration is in ability of materials to withstand intense radiation. Experiments done show that the limit to damage is strongly dependent of the time of illumination; shorter the illumination time—higher density is allowable. For example, in [4] reported the density measured  $6\text{ J/cm}^2$  for  $1\text{ ps}$  pulse duration and  $10\text{ J/cm}^2$  for  $0.3\text{ ps}$  pulse. In our design the density comes to  $0.3\text{ J/cm}^2$  only, see below.

Accelerating structure serves for *confinement* of EM field in space. Its precise location defined by accuracy of fabrication, accuracy of positioning, how far from equilibrium the fields are and by physical limitations. So the structure can not be much larger, than the wavelength of laser radiation, otherwise the fluctuations in a process of the field establishment will generate unnecessary long living (in terms of period) perturbations with undesirable spatial structure.

Primary element of the scheme is the source of low emittance beam. We showed that the wiggler dominated ring can satisfy requirements [3]. Events at IP are going in deep quantum regime. Luminosity what can be achieved is far above the value suggested for ILC, giving significant margins for reduction of the bunch population.

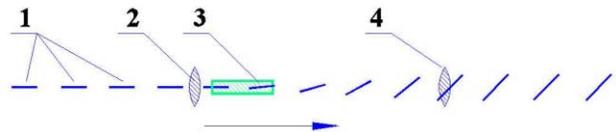


Figure 2: Dynamics of tilt. 1—is a sequence of laser bunches at the entrance, 2—is an (active) long-focusing lens, 3—is a sweeping device, 4—is a lens having focal point inside the sweeping device.

We would like to underline that the bunch is going inside the structure, pretty much as it is going inside usual RF structure. Only peculiarity here is that due to small dimensions, the laser radiation introduced into the each cell separately from the side hole.

The focal point of the laser beam is following the beam *in average*. Power reduction and shortening of illuminating time is equal numerically to the *number of resolved spots (pixels)*, associated with the sweeping device. The number of accelerating cells excited simultaneously is  $\sim l_f/\lambda_{ac}$ , where  $l_f \sim 100\lambda_{ac}$  is a spot size along the structure, Fig.1. Accelerating cells in a structure separated in longitudinal direction with distance  $\lambda_{ac}$ , so an electromagnetic field is in phase inside each cell. A cylindrical lens serves for the focusing of laser radiation in a transverse to the motion direction.

## SWEEPING DEVICE

For *multiple-prism* sweeping device with traveling wave  $\Delta\vartheta \cong 10^{-2}$  and  $N_R \cong 200$  can be reached, [7]. For such a sweeping device, a lot of electro-optical crystals can be used, *KDP, CdTe, CuCl, GaAs, ZnTe* [3].

Pulse generator with Inversely Recovered Diodes technique [4], [5] can be used for testing the sweeping device. Typical PS of this class operates with repetition rate up to 1MHz providing rise time down to 50 ps and voltage up to 30 kV. Size of this device is typically  $350 \times 150 \times 300 \text{ mm}^3$ . We expect that one sweeping device can feed 5-10 structures [7]. The number of structures defined by the depth of focus, created by lens 2 in Fig.2 because this is the only lens acting in longitudinal (to the beam motion) direction. Calculations show, that there is an optimum in the length of sweeping device and in the distance to the point of minimal longitudinal size [3]. The focal depth defined by Rayleigh length  $Z_R \cong \pi w_0^2 / \lambda \cong \pi N_R^2 \lambda$  where  $w_0$  stands for the laser beam spot size on the structure. The last number for  $N_R=100$  and  $\lambda \cong 1 \mu\text{m}$  comes to  $Z_R \cong 3 \text{ cm}$ . So in principle one sweeping device can feed two structures. This number can be increased significantly if the lens 2 in Fig. 2 and lens 4 in Fig. 6 made with electro-optical material and driven by external voltage so the focal distance changing in accordance with beam motion.

For optical triggering the filling of diode transition by carriers can be done with the help of laser pulse illuminating the diode. The second possibility lies in fast changing dielectric permittivity of switching element by the laser radiation.

The broad band traveling wave deflector uses crystals located in the middle of a waveguide. The power required for excitation of a waveguide having width  $\cong 5 \text{ cm}$ , height  $\cong 1 \text{ cm}$ ,  $\lambda \cong 5 \text{ cm}$ , to the level  $E_0 \cong 20 \text{ kV/cm}$  goes to be  $\sim 1.2 \text{ MW}$ , only [7]. This scheme has a potential to be transformed into strip-line system.

## ACCELERATING STRUCTURE

The latest measurements show that the damage threshold increases while the illumination time is shortening [4]. This was explained by saturation of impact ionization rate per unit distance. *Measured* threshold for 0.3 ps pulse was about  $10 \text{ J/cm}^2$ . For 1 ps pulse duration, the threshold measured was  $6 \text{ J/cm}^2$ . In our proposal the laser density comes to  $0.3 \text{ J/cm}^2$  only what is far below the damage threshold.

Example of accelerating structure represented in Fig.3. The width of the coupling holes defines a quality factor  $Q_{RF}$  of the structure. With the trimming covers the height of structure is about  $h \cong \lambda_w / 2$  and the cells have *inductive* coupling with outer space;  $\lambda_w$  stands for the wavelength in the cell. Calculations carried with GdfidL. The wake was found to be slightly inductive. Each structure is installed on a nano-table moved by a piezoelectric. Structures are cooled down to keep the

mechanical tolerances within the margins allowed. Monocrystal of Silicon with different types of conductivity can be used here. The final conclusion could be made after experimental work in this field.

Possibilities in fabrication are far beyond necessary for this structure. Mostly complete description one can find in [11]. So accelerating structure made with this technology can work with a Laser source of EM Radiation with wavelengths  $\lambda_{ac} \cong 1-10 \mu\text{m}$ .

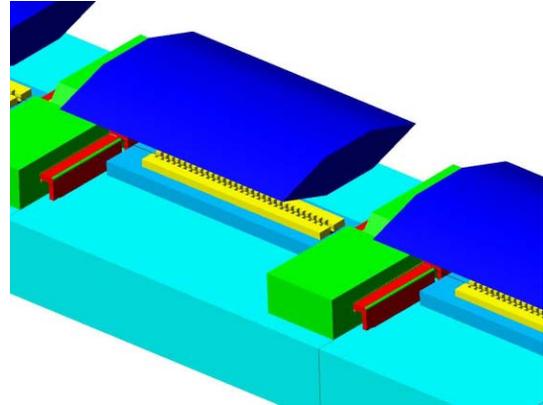


Figure 3: Structures located right below cylindrical lenses. Quadrupole lenses are seen here too.

## GENERAL SCHEME

General scheme at a glance is similar to the scheme linear collider, except the length.  $2 \times 10 \text{ TeV}$  collider has  $2 \times 1 \text{ km}$  only, see [12]. Elements of the scheme located on separate platforms aligned with help of sensors, installed at the end of each platform and touching the neighboring one. The sensors are similar to that used in tunneling microscope technique. This system could be made fast enough to exclude influence of ground motion, mostly intensive at lower edge of the spectrum.

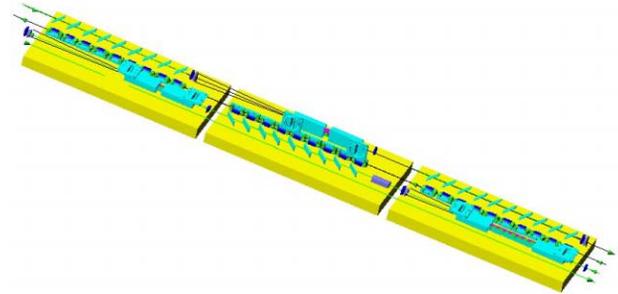


Figure 4: Accelerating table alignment and stabilization.

In Fig.4 on each table basically four channels are present: two the laser beam and two for the particles. Laser beam and the electron/positron beams first come along the accelerator, where their deflections and displacement collected. On the back way appropriate corrections applied. For laser beam electro-optical elements are used. For charged particles, usual electromagnets are used but scaled down to appropriate dimensions.

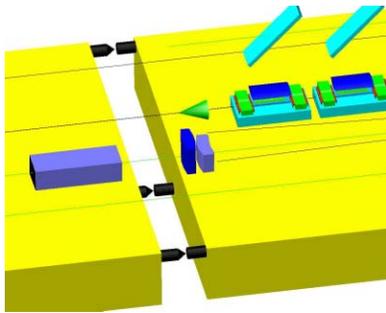


Figure 5: Set of distance-sensitive probes using tunneling effect (tunneling probes), arrange the triangle net for alignment of relative position of two neighboring tables.

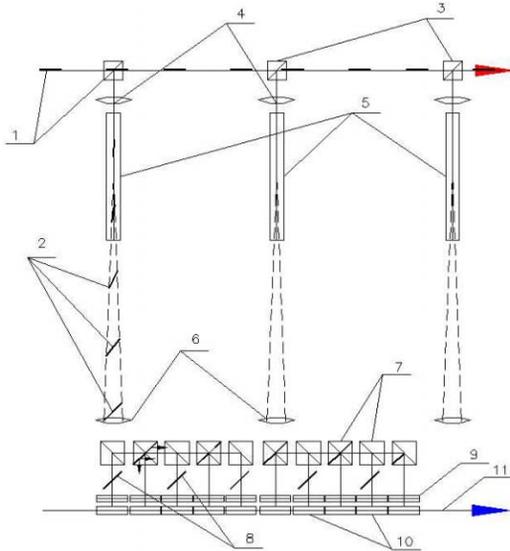


Figure 6: The scheme with active lens 4 feeds few accelerating structures 3cm-long each, 10, 1,2,8—is the laser bunches, 3,7—is the power splitter, 5—is sweeping device, 6—is the lens, 9—is cylindrical lens.

Wavelength	$\lambda_{ac} \cong 1\mu m$
Energy of $e^+$ beam	$2 \times 10 \text{ TeV}$
Luminosity	$10^{35} \text{ cm}^{-2} \text{ s}^{-1}$
Total two-linac length	$2 \times 1 \text{ km}$
Main linac gradient	$10 \text{ GeV/m}$
Bunch population	$3 \cdot 10^5$
Bunch length	$0.1 \mu m$
No. of bunches/train	30
$\gamma \varepsilon_x / \gamma \varepsilon_y$	$5 \cdot 10^{-9} / 1 \cdot 10^{-9} \text{ cm} \cdot \text{rad}$
Laser flash energy	$2 \times 3 \text{ J}$
Laser density@AC*	$0.3 \text{ J/cm}^2$
Illumination time	0.1 ps
Length of section	3cm
Laser flash energy	100 $\mu\text{J}$ /section
Repetition rate	1 kHz
Laser beam power	$2 \times 3 \text{ kW}$
Damping ring energy	2 GeV
Damping time	10ms
Wall plug power**	$2 \times 30 \text{ kW}$

\* AC stands for Accelerating Structure

\*\* Without supplementary electronics.

## CONCLUSION

Nano-technology available creates solid base for accelerator with *Travelling Laser Focus*. Illuminating time and total laser power reduction in this method defined by the number of resolved spots (pixels) associated with deflecting device. Lasers for the TLF method need to operate with  $\tau \approx 100 \text{ ps}$  pulse duration. Any point on accelerating structure remains illuminated by  $\sim 0.3 \text{ ps}$  only. Laser density on the surface of structure goes to be  $0.3 \text{ J/cm}^2$ . TLF method promises up to  $10 \text{ TeV/km}$  with  $3 \text{ mJ/m}$ .

With introduction of active long focusing lens the sweeping device allows feeding few accelerating sections rather than one-two in previous realizations of TLF idea. We conclude that acceleration in a laser-driven linac with TLF method is a present day technology and is guaranteed by existing technology. Testing of this method is a challenging task for accelerator physics.

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