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COMMENTS ON THE POSITRON PRODUCTION SCHEME WITH GAMMAS OBTAINED FROM BACK SCATTERING OF LASER RADIATION[1]

Alexander Mikhailichenko

Cornell University, LEPP, Ithaca, NY 14853

Abstract. We would like to present a reaction to the proposal [1] of using laser back scattering process for generation of polarized gammas for further usage for polarized positron production. The main point of concern, missed in the published proposal, is a ponderoromotive kick delivered by intense laser bunch to the electrons.

INTRODUCTION

The scheme for polarized positron production proposed in [2] states, that "*The general idea of the method is that the circularly polarized photons are converted into* e^+, e^- *in a target. … Circularly polarized photons are produced in helical fields of minimal period. Much more interesting is to obtain such fields with the help of usual helical static fields and the electromagnetic waves. It may well be that the method of gamma production in helical crystals*[2] *can be useful in future.*" It was shown, that the method becomes practical (in terms of conversion efficiency) with the undulator having a length of ~150*m*.

So it is clearly seen that the method is a two-stage one: at first stage one needs to generate circularly polarized gammas and, at second, to convert these gammas in thin (in terms of radiation length, ~$0.5X_0$) target. Another important component of the method is the energy selection: higher energy of secondary positron –higher its polarization. The value of positron/electron polarization promised by the method was 80-90%, depending on the length of undulator [2]. Simply speaking, the longer the undulator–the narrower the energy selection is allowed, while keeping the total number of secondary positrons at the level satisfying a full regeneration of positrons normalized to IP. So first, one needs to generate the circularly polarized gammas in quantities allowing to cover inevitable losses during collection and, mostly important, to allow energy selection among secondary particles (positrons), just cast out ones with lower energy.

We would like to attract attention to the fact that electromagnetic waves (EM) considered from the very beginning. Laser radiation as a particular example of electromagnetic radiation was described in [3]. So this was the different way to obtain circularly polarized gammas within the framework of original proposal. The laser wave is treated as an EM undulator with the smallest period. As the process is going on in classical regime, the formulas are absolutely the same as for the undulator radiation. It looks that it is something different, but in reality it is just in linguistics. The mentioning of quantum mechanics and Compton scattering has nothing to do with the physics of

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[1] Work supported by NSF. Electronic version is available at:
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[2] Crystals with helical dislocations.

phenomenon and the method itself, as the energy of the radiated photon is much less than the energy of electrons. Again, *laser back scattering is just the way to obtain the circularly polarized photons*. One can only claim that it was shown, that the scheme for obtaining gammas from the laser scattering procedure is working in practice, i.e. all elements are functioning within technical/scientific possibilities.

Increasing the intensity of laser radiation does not bring the process to the quantum level; it just establishes radiation on second and so on harmonics (nonlinear effects).

Other items which require comments are: In [1], it is claimed that for the laser back scattering scheme the positron polarization is "in principle higher, than for undulator scheme". Indeed we can say that *polarization of secondary gammas is the same for both methods* and there are no advantages for the laser backscattering. This is a reflection of the fact that in the moving system of reference the number of the back/forward radiated photons is the same[3], as the physical nature is same. So if there is no angular selection and the observer just counting the quantas without referring to the energy, the number of left and right handed photons is the same. Polarization of quantas averaged over spectrum (angles) has zero value. Polarization appears after selection process applied to the secondary positrons: more energetic ones carry higher polarization. Additional enhancement on can obtain using collimation of photon beam. In this case all low energy photons, radiated in off axis direction will be cut. Namely these photons carry opposite polarization. One can recall the fact that the photons radiated with angle $\sim 1/g$ having half of maximal possible energy and they are linearly polarized. For undulator scheme, the photon cut-off energy near optimum is about 20 *MeV*, but polarization of gamma beam does not depend on the maximal energy of photons at all. It appears to be strange that some participating authors demonstrated high enough qualification in the past can sign the paper with the statement about higher polarization in laser back-scattering method.

Again, the quantum effects do not manifest at all, as the energy of secondary quantas is much less, than the energy of primary beam. In this process there is nothing from quantum effects, this is typical classical problem. And this is true for any scheme. But for example in gamma-gamma collider under consideration, the process is going in (deep) quantum regime.

Authors in [1] accept indulgently that the scheme with undulator seems to be technically easier to them. However, they claim that the undulator scheme implements of energy spread ~0.15% and there is a problem with vacuum, stability of undulator under radiation generated in undulator. First it is not clear as to what energy of the primary beam this is related to. For intermediate location of undulator, this energy spread will adiabatically decrease to IP. Lot of SC devices having a cold mass looking to the beam are working in different laboratories. Vacuum for SC undulator is not a problem at all.

The authors also claim that switching polarization is easier for the laser backscattering scheme. However, who said that this is difficult for undulator? It is very simple procedure too, not being more difficult than the switching of polarity in a solenoid. As the beam is small, the solenoid aperture is small also, so the stored energy is small sequently. Switching polarity for the next train, running with repetition rate 5-10 even 100 *Hz* is not a problem at all. This is well known to anyone who has built at least one

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[3] Laser radiation coming to the beam from 90^o is absolutely equivalent to the static field with the same period.

pulsed magnet. Also, the damping ring for ILC may require the rise time in a kicker magnet down to 5 nsec, but this is not surprising to anyone.

Let us compare first, the magnetic field strength in static undulator with the intensity of the laser pulse generating the same amount of photons. For the undulator having the length *L*, period λ_u the number of radiated photons is

$$N_\gamma \approx \frac{4\pi}{3}\alpha\frac{K^2}{1+K^2}\frac{L}{\lambda_u}, \qquad (1)$$

where $K = eH\lambda_u/(2\pi mc^2)$ –is the undulator (deflection) parameter. This formula has clear meaning and shows that at the length of formation, which is $l_u^f \approx 2\lambda\gamma^2 \approx \lambda_u$ the number of radiated photons is $\alpha = e^2/\hbar c$. Factor L/λ_u reflects the number of periods and the factor $K^2/(1+K^2)$ reflects suppression of radiation due to the difference in formation length calculated for *local* magnetic field in undulator and the $l_u^f \approx \lambda_u$.This equation can be transformed for $K \le 1$ to the form

$$N_\gamma \approx \frac{4\pi}{3}\alpha K^2\frac{L}{\lambda_u} \approx \frac{4\pi}{3}\frac{e^2}{\hbar c}\frac{e^2H^2\lambda_u^2}{4\pi^2m^2c^4}\frac{L}{\lambda_u} \approx r_0^2\frac{H^2}{\hbar\omega}L \approx \sigma_\gamma n_\gamma L \qquad (2)$$

where $n_\gamma \approx H^2/\hbar\omega$ stands for the equivalent photon density, $\omega = 2\pi c/\lambda_u$. The last expression is more suitable for the physicists. One can see that the photon density is high for undulator.

PONDEROMOTIVE KICK

Meanwhile the scheme with laser backscattering has one effect missed in published paper. This is a *ponderomotive* kick by laser bunch, having compact size and significant energy stored in this laser bunch. All these parameters tolerate to the conversion efficiency.

Parameters of primary KEK single-pass scheme proposed for JLC somehow satisfy developers. With ILC requirements the new parameters used in KEK project, require check-up, however.

The latest variant uses a damping ring assembled with 30 laser cavities. Supposed that perturbations are small and conversion of laser photons to the gammas is going with minimal perturbations, mostly like energy spread dilution. Even so the beam interacts with the laser ~100 times, then the laser switched off and the beam is cooled by SR. Then the process begins again.

Energy stored in one laser pulse in optical cavity used in the project is as big as *J*=600*mJ* in $\tau \cong 3ps$ pulse having dimensions $\sigma_\perp \cong \sigma_x \cong \sigma_y \cong 5\mu m$ and the wavelength $\lambda \cong 1\mu m$. So the ponderomotive kick might be mentionable here.

Really, the ponderomotive force defined by the deflection parameter, which is an analog of deflection parameter in undulator or wiggler,

$$A = \frac{eE\lambdabar}{mc^2}, \qquad (3)$$

where $\lambdabar = \lambda/2\pi$, $E(r_\perp, s)$ stands for electromagnetic field strength. So the expelling force acting to the electron goes to be [5]

$$\frac{dp_\perp}{dt} = -\frac{mc^2}{2\gamma}\frac{\partial A^2}{\partial r_\perp}. \qquad (4)$$

For the laser bunch with parameters indicated, electrical field strength can be estimated using energy J stored in the laser bunch as

$$\varepsilon_0 E^2 \times \pi\, \sigma_\perp^2 c\tau \cong J\,, \qquad (5)$$

where $\varepsilon_0 \cong \frac{1}{36\pi}10^{-9}[F/m]$ is permittivity of vacuum. The last formula gives for J=300mJ

$$E \cong \sqrt{\frac{600\times 10^{-3}}{\pi\, \sigma_\perp^2 c\tau \varepsilon_0}} \cong \sqrt{\frac{600\times 10^{-3}\times 36\pi}{\pi\, 25\times 10^{-12}\times 3\times 10^{8}\times 3\times 10^{-12}10^{-9}}} \cong 1\times 10^{12}[V/m]\,,$$

coming to deflection parameter

$$A = \frac{eE\lambda\!\!\!^{-}}{mc^2} \cong \frac{e\times 1\times 10^{12}\times 10^{-6}}{2\pi mc^2} \cong \frac{e\times 10^{6}}{2\pi mc^2} \cong \frac{1MeV}{2\pi\, 0.5MeV} \cong 0.3\,.$$

The integrated kick at collision point, according to (4) can be evaluated as

$$c\Delta p_\perp \cong -\frac{mc^2}{\gamma}A^2\frac{L_{eff}}{\sigma_\perp}. \qquad (6)$$

where L_{eff} stands for effective length of interaction, $\sigma_\perp \le L_{eff} \le c\tau$; For E=1.3GeV, $\gamma \cong 2.6\cdot 10^3$, the last formula gives majorette $\Delta cp_\perp \cong -7.7\times 10^{-3}mc^2$. For all 30 collision in worst case it goes to $\Delta cp_\perp \cong -0.23\, mc^2$ [*per/turn*] giving kick angle

$$r'_\perp \cong \frac{\Delta cp_\perp}{cp} \cong \frac{0.23}{\gamma} \approx 8.9\ 10^{-5} \sim 10^{-4}[rad/turn] \qquad (8)$$

This makes effect mentionable, as on the distance one meter this angle yields deflection ~100μm, which is much more than the laser bunch size. Even after a *single* interaction, for an angle 30 times less, the beam to the next interaction point practically misses the laser bunch there. At the next 100 turns the kick will either grow statistically, giving ~10 times bigger angle, $r'_\perp \cong 10^{-3}$ rad or linearly, what comes to even $r'_\perp \cong 10^{-2}$ rad. A detailed picture requires more efforts, but even so one can conclude that this effect is mentionable (at least). We think however, that this might be a real show-stopper indeed.

For the CO_2 laser integrally the situation is about the same. In addition we can recommend to the authors have a look more carefully onto the way on how CO_2 media amplifies the short pulses and what are synchronization possibilities in general. Few surprises could be expected there.

These are simple questions arising right after the first reading.

CONCLUSIONS

It is clear, that the way of gamma production with laser back-scattering is attractive by its potential ability to make positrons without involving high energy beam. This gives freedom in operation and potential possibility to test it in full scale in advance. Tests of *some* elements are not convincing. In that sense, the E-166 undulator-based experiment accomplished at SLAC recently and successfully demonstrated positron production in quantities and with polarization as predicted is much more convincing, than the laser scattering experiment at KEK. All this is true, however, but only if this method of gamma production is really (means practically) working.

We wrote in our publication [4] that the scheme for obtaining gammas from Compton (Thompson) back scattering proposed to NLC/JLC collider is not working for ILC. Instead of accepting this as a matter of fact, the KEK team decided to ramp up all parameters and change the philosophy from a single pass action to the stacking, involving more and more assumptions and people into the project. Insisting on this, they just made the situation more and more difficult for the team. In addition to a single installation working at the edge of technical consistency –SC collider with all supporting subsystems–they are trying to implement another one, which just amplifies the difficulties. Polarized positrons are an inevitable direction for all ILC programs, and it could not depend on absolutely problematic infrastructure.

As far as the particular argument that the undulator scheme for gamma production requires operational 150 *GeV* linac–that is true –without working linac, the scheme is not working. But if the linac is not generating 150 *GeV* electrons/positrons –what we are talking about?

In support of their idea the authors represent a detailed view of mirror holder. Although it might be educational for some members of the team, this part can not be a central element of the scheme–it is too simple. Much more serious questions are missed in this proposal. We hope that the authors of proposal will come to the only right conclusion—accept that their scheme, which might be useful for some particular usage in general–having nothing in common with the realistic system for the positron production for ILC.

My explanation of this persistence is that KEK team initially missed the reference [3] and claimed that this is a new method proposed at KEK (three years later, than this mentioned publication). That was announced widely, and it might be true in a part –it was new for KEK. Authors didn't even analyze seriously what was proposed before and what is the nature, or better to say what the proposal components are. So that is why they attract (mostly linguistics) differences to the description of the process of generation of circularly gammas for the method originated in [2] claiming that this is absolutely new method. Even after they learn that it was not new for others, they insist on original technical realization. This is true, however. So I think that it is hard to accept that the idea existed long before KEK publication [6]-[8], otherwise it is long enough time to make proper reference.

Technical realization of ILC must be based on clear and convincing principles. One can see that even if everything is working well it will be difficult to run ILC complex- it is practically at the edge of self-consistency by itself.

It is time to realize that engineering solutions must be as simple as possible.

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