ERL PARAMETERS FOR COMPTON POLARIZED POSITRON SOURCES

A.Variola#, C.Bruni, I.Chaikovska, O.Dadoun (LAL, Université Paris Sud, Orsay, France), R.Chehab (IPN Lyon, Université Lyon 1, Villeurbanne Cedex), M.Kuriki (Hiroshima University, Higashi-Hiroshima, Japan), T.Omori, J.Urakawa (KEK, Tsukuba, Japan), L. Rinolfi, A.Vivoli, F.Zimmermann (CERN, Geneva, Switzerland).

Abstract

One of the main challenges for also future linear colliders projects (ILC and CLIC) is to provide an efficient positron source that takes into account the constraint imposed by the target heating in the pair production. At present, different schemes have been proposed to produce high energy gammas to be converted in e^+-e^- pairs into an amorphous target [1,2,3]. One of them considers the possibility to boost the energy of the backscattered photons of a laser pulse by Compton effect [4]. This method is particularly attractive since the source is independent of the main Linac and since the photon and consequently the produced pair helicities are conserved in the scattering event. This implies that physics will have at its disposal both positron and electron polarized sources. Different solutions have been proposed to provide the electron beam for the Compton collision. They have to take into account one of the main constraints of this proposal that is the relative low value of the Thomson cross section. One of the possibilities is to design an ERL with relatively low repetition frequency and high charge per pulse and then to stack the produced positrons in an accumulation ring. Different considerations on this scheme will be illustrated and the main constraints discussed.

INTRODUCTION

After the LHC era the high energy physics community has already identified the facility that will perform precision measurements. To pass from a 'discovering' machine like the LHC, where the basic parameters are energy and luminosity, to the 'precision' physics it is necessary to explore the TeV energy range with a lepton collider. This will allow high energy collisions reducing the experimental noise, characteristic of the hadron machines. At present the accelerators community is studying two main projects with strong synergies: ILC and CLIC. These projects are in a phase where the machine design is being defined and the associated technologies tested. In this context one of the main critical aspects is the positron source. Actually, many critical points, associated with positron production and capture, have a strong impact on the machine design and parameters. The most important aspects and problems can be summarized as follows:

1) Positrons must be generated in a target by high energy gammas rays. This implies that after pair creation multiple scattering generates a wide angular and energy distribution of the positron bunch. So the positron source 6D emittance is huge in respect to the electron source one. Consequently, the positron source emittance is the damping ring's main constraint concerning the transverse and longitudinal and transverse acceptance (for example: $\gamma\,(A_x+A_y)$=0.09 m rad and $A_{long.}$= ± 25 MeV · 3.4 cm in the ILC case [1]). Moreover, it is evident that, owing to this large emittance value, the positron source determines also the required damping time in an injection cycle. This is a major constraint to be taken into account fixing the repetition cycle of the entire accelerator complex.

2) To increase the luminosity the future linear colliders require very high charge per bunch and many bunches per train. This implies a high current per pulse. In the ILC case it is impossible to obtain such a beam charge with a conventional positron source where an electron beam (drive beam) generates pairs via the bremsstrahlung gammas produced in the target. In fact, owing to the strong energy losses, the deposited energy will destroy the target and a consequent cooling system is not conceivable at present. This has a strong impact on the high energy gammas production mechanism. The best solution is to have only a gamma pulse impinging on the target avoiding the large energy losses contribution given by the degenerated low energy population of the drive beam.

At present two different schemes are proposed, either the generation of the gammas pulses by injecting the main beam through an helical undulator at very high energy (more than 150 GeV), or the production by Compton backscattering colliding 1-2 GeV e^- beams with laser pulses stacked in one (or more) passive optical cavities [4]. The Compton scheme has a lot of undoubted advantages, like the source independency with respect to the main linac and the required drive beam lower energy, but it suffers from the relative low value of the scattering cross section. So, to generate the gamma flux needed to produce, capture, transport and inject the required positron beams it is necessary to provide electron bunches and laser pulses intensities that are not achievable with the current technologies. The core of the ILC proposal [1] is based on the fact that the repetition rate of the machine (5 Hz) provides 200 ms for the positron generation. A continuous, high repetition frequency source can therefore provide a huge number of low charge bunches that can be stacked in a pre-damping or in the damping ring itself. So the low charge produced per bunch is compensated by the multiple injections in the same damping ring bucket [5].

#variola@lal.in2p3.fr

A STORAGE RING AS COMPTON SOURCE AND ITS CONSTRAINTS

The first proposal for a Compton gamma source to produce polarized positron was carried out in the JLC framework [6]. More recently, a new compact design was proposed for the ILC [4] and at present also CLIC considers it as an alternative solution [3]. It envisages a high current electron storage ring and a series of laser plus Fabry-Perot resonators for a multiple collisions. The feasibility of a Compton polarized positron source based on a storage ring leaves open some basic points. The two main constraints concerning a "storage ring" source are given by the a) beam dynamics and b) the required collision crossing angle. In other words:

a) In a Compton source the circulating beam is continuously interacting with a high intensity laser pulse. For each collision a statistical population of the electron bunch is subjected to photon scattering. The result is an induced energy spread that is proportional to the energy cut off of the Compton scattering [7], $\Delta E=4\omega_{ph}\gamma^2$, where ω_{ph} and γ indicate respectively the laser photon energy and the gamma relativistic factor. So, the fact that we can obtain very high energy gammas (20-30 MeV) for the efficient pair production with a relative low electron beam energy (1-2GeV) and with existing high power laser technology (fibre lasers has photons at~1µm wavelength), is counterbalanced by the fact that the same energy cut off degrades the energy spread of the circulating beam. In an infinite acceptance ring the longitudinal dynamics will attain the equilibrium between this quantum fluctuation and the longitudinal synchrotron cooling [8], but in the case, for example, of a 1.5 GeV ring and a 1 eV laser the maximum energy spread for a single collision is ~2.5%. This requires a very large longitudinal acceptance to avoid beam losses and anyway the large acquired energy spread will increase the bunch length as a function of the ring momentum compaction. Already from these considerations it is possible to understand that the longitudinal "Compton regime" dynamics is one of the critical aspects in the design of such a source and this is basically due to multiple collisions.

b) Besides the cross section, the gamma flux is determined by the luminosity of the electron bunch-laser pulse collision. It is well-known that the luminosity depends on the crossing angle of the impinging beam coupled with the longitudinal beam size [9] that in a storage ring is limited to 5-6 mm for 10nC charge. Shorter bunches will increase beam instabilities. Unfortunately, in the gamma generation scheme, the crossing angle is mandatory since, in the collision process, the produced gamma flux direction coincides with the electron bunch one. So in the head-on collision case an extremely high photon flux will impinge on the optical cavity mirrors resulting in irreversible damages. Therefore the solution is to apply a collision angle as illustrated in fig.1. The net rate loss depending on the electron bunch length and the crossing angle is shown in fig.2

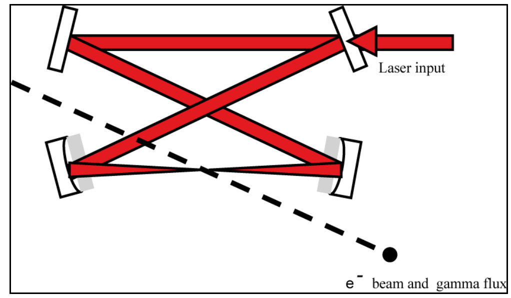

Figure 1: Geometry of the Compton collision for a four mirror optical resonator. The gamma flux will acquire the direction of the colliding electron beam.

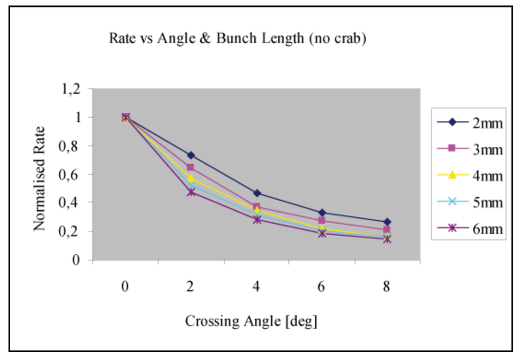

Figure 2: Rate losses as a function of the crossing angle and of the electron bunch length. For 6 mm beams the flux can be reduced also by a factor 5 for a crossing angle of 8 degrees. The laser pulse length is 0.3 mm

THE ERL SCHEME

To avoid the Compton ring's two main difficulties it is necessary to find a high repetition rate electron accelerator in which a bunch compressor can be inserted, and in which the Compton dynamics does not have such a limiting effect. The natural answer is an Energy Recovery Linac (ERL). In this device the bunch, after the interaction with the laser, is discarded. This allows compressing the bunch length before the interaction point, to have a not degraded bunch for each collision and to reduce the beam dump requirements. For all these reasons the ERL scheme is extremely attractive as far as the Compton source scheme is concerned. To evaluate the ERL feasibility for the Compton polarized positron sources different simulations have been worked out by means of the codes CAIN, EGS and PARMELA. In this way all the chain, from the gamma generation to the positron creation, capture and post acceleration, can be simulated. The parameters of two existing ERL, the JLAB and the JAERI devices, has been considered as electron bunch input [10]. The main results are displayed in table.1 where the positron bunch characteristics are calculated at the exit of the first stage of the capture section, at 150 MeV. It is possible to point out that considering a higher charge per bunch (JLAB case), there is a significant increase in capture efficiency. Taking into account 0.17 nC per bunch and a laser pulse of 0.5 J circulating in the optical resonator it will be possible to obtain a total population of 10^6 e^+/bunch.

Table 1

Captured e^+ bunch at 150 MeV	JLAB ERL	JAERI ERL
Yield e^+/γ [%].	1.17	0.7
Transverse geometrical emittance [mm mrad]	135	165
Energy spread [%]	6.8	6.7
Bunch length [mm]	6.1	4.8
Polarization	0.43	0.43

This means that, in the case of ILC and CLIC, it is necessary to inject thousands of bunches into the same bucket to fulfill the requirements. This is very difficult to achieve [5] but, in the ERL case, it is possible to increase the number of collision points with negligible impact on beam dynamics. Other simulations were performed to evaluate the efficiency of a multiple interactions region. The increase in gamma flux is linear at the beginning, but after a few collisions the energy spectrum degradation due to the Compton collisions reduces the efficiency. For a ten IPs line there is a gain of a factor five. It is efficient to consider five collision points where two lasers cross symmetrically in respect to the beam propagation axis. In this case a factor seven gain is obtained. This could reduce the injection requirements.

The Repetition Frequency Role

In the ERL (and in all the Compton sources) the collision repetition frequency plays a crucial role. This is a result of both the technological and scheme constraints:

a) As far as the technology is concerned the main constraints are the average power in the optical resonator and current in the ERL. In the case of ILC and CLIC it is necessary to provide over ten thousand e^+ bunches per second. Taking into account 1000 bunches stacking to achieve the nominal charge per bunch the minimum repetition frequency would be 10 MHz, if continuous injection were possible. Unfortunately the scheme timing [1] must at least provide the time for the injection and the cooling in the damping ring. So a minimal f_{rep} of 30 MHz is taken into account. The impact on the optical technology components is the following: for a 0.5 J circulating pulse in the cavity a stored power of 20 MW is envisaged. The main limitation is the power density accumulated on the high reflectivity mirrors coatings. This can be reduced with a configuration in which the parabolic mirrors are distant, increasing the beam size at the mirrors locations. The mirrors distance and the consequent minimal crossing angle are optimized by minimizing the repetition frequency. Concerning the laser, taking into account an amplification factor of 10^4 in the optical resonator, this requires a hundred watt (or a few hundreds) class laser. At present, these results are achieved using the fiber technology and different R&D programs aim at increasing the average power. On the other side, f_{rep} has an immediate impact on the average current and so on the charge per bunch. At present ERL devices run with 10 mA which results in a few hundreds pC per Bunch. In future ERL projects [10] the design current is one order of magnitude greater. This implies a strong relaxation on the multiple stacking requirements.

b) The repetition frequency also impacts the scheme parameterization. In fact, ERLs work in CW regime, but the polarized positron source needs some dead time for beam stacking and cooling. In this case it is recommended to minimize the repetition frequency, giving the injected bunches the maximum available time to cool down before a subsequent injection in the same bucket. This can have an impact on the ERL beam stability and must be carefully assessed. At present the running ERL machines work with repetition frequencies of over 70 MHz.

CONCLUSIONS

In the framework of the future lepton colliders projects, a strong constraint is given by the requirements for the positron sources. One of the possible solutions is given by the Compton sources. In this context the ERL design shows different attractive features. This scheme copes with the flux reduction given by the crossing angle in the collision point since in the ERL configuration the bunch compression before the interaction point is possible. Moreover, in respect to the storage ring solution, there should not be any critical aspects with regard to beam dynamics. At present the main limitation is given by the weak charge per bunch. This requires a careful parameterization of the machine, in which the repetition frequency plays a major role, and a very high stacking efficiency. In this framework an ERL machine which, at constant average current, provides a high charge per bunch with lower repetition frequency has various advantages. Future projects that could demonstrate ERL operation in the nC per bunch range should propose this scheme as the most interesting, as far as the Compton sources are concerned.

REFERENCES

[1] ILC reference design report, Accelerators,CERN-2007-006, ISSN 0007-8328
[2] H.Braun et al."CLIC 2008 parameters",CLIC Note 764.
[3] L.Rinolfi et al."The CLIC positron source based on Compton schemes", proceedings of this conference
[4] S.Araki et al."Conceptual design of a polarized positron source based on laser Compton scattering", LAL-05-94
[5] F.Zimmermann et al, "Stacking Simulations for Compton Positron Sources of Future Linear Colliders", proceedings of this conference
[6] T.Hirose et al. NIM. A 455 (2000),15-24
[7] P.Rullhusen, X.Artru, and P.Dhez, Novel Radiation Sources using Relativistic Electrons, World Scientific, Singapore, 1998
[8] Z.Huang and R.D.Ruth, "Laser-Electron Storage Ring," Phys. Rev. Lett., 80:976-979, 1998.
[9] T.Suzuki "General Formulae of Luminosity for Various Types of Colliding Beam Machines",KEK note 76-3
[10] Energy Recovering Linacs 2005 - Proceedings of the Beam Dynamics Workshop on Energy Recovering Linacs, NIM A Volume 557, (2006)