Introduction

We present the R&D proposal for new target system including positron capture device in ILC positron source (conventional unpolarized positron source, helical undulator based source and Compton polarized source). At present the positron production scheme with SC helical undulator is a baseline because power dissipated in a solid target with conventional method by direct electron/positron conversion becomes too big and Compton scheme is not mature even though it has very attractive characteristics. However, recently A. Mikhailichenko proposed a liquid metal target, a liquid Lithium lens and solenoidal multi-turn lens for collection of positrons [1,2,3] instead of a spinning Ti rim having thickness about 14mm and a adiabatic matching device (AMD) in order to overcome the serious problems of rotating target system for the baseline undulator scheme. Also, we found that the conventional unpolarized positron production scheme involving the liquid metal target and the liquid Li lens is applicable as ILC independent positron source if the window of the liquid target and the Li lens is survived with ILC beam (see Appendix A which explains ILC conventional positron source driven by 700MeV electron beam. [4]).

Recently, BINP manufactured liquid 90%Pb+10%Sn target system and tested with 50kW electron beam for positron and neutron generation [5,6,7,8]. We have a possibility to test liquid target system including window of BN, Be and so on under the collaboration of BINP, KEK, LAL, IPNL, CERN, Hiroshima Univ. and Osaka Univ. if we will get several 100k$ budget support per year for three years. The contribution of BINP is essential for this R&D because BINP has a reliable prototype of the liquid metal target. Also, since BINP made a prototype of the liquid Li lens for antiproton collection, BINP has a possibility to design the liquid Li lens which is suitable to ILC positron production scheme.

In order to confirm the feasibility of above proposals, we have to proceed the R&D proposal with the BINP liquid target system including window of BN, Be and so on under the international collaboration of BINP, KEK, LAL, IPNL, CERN, Hiroshima Univ. and Osaka Univ.. Also, ILC liquid Li lens should be designed and tested.

On the other hand, recently a hybrid target system for CLIC and ILC conventional positron source which consists of a tungsten crystal target, a bending sweeping magnet and an amorphous tungsten as the converter was proposed by R. Chehab et al. [9]. So, Omori proposed new scheme to produce ILC positron beam (see Appendix B and C). It will make a possibility to design a independent positron production scheme for ILC. Also, since the synergy of ILC-CLIC project for e^+ generation working group should be increased by involving BINP, we would like to present the brief status of BINP R&D

about Liquid 90%Pb+10%Sn target system and adiabatic matching device (AMD or FC) in next section. Then, we want to propose our R&D at KEK.

Present status of BINP R&D

1. The present stage of BINP activity in liquid lead target development

20,000 hours of the liquid lead closed-loop operation was successfully done with cog-wheel pump. The liquid metal consist of 90% Pb and 10% (mass)Sn alloy at 300ºC. This prototype is shown in Fig. 1, which is small system. The shock-wave test of BN windows showed the dynamical stretch limit at the level of 39 GPa. For previous NLC design the value of 3 to 4 GPa was estimated. In the case of present ILC beam parameter this value will be even less (about 0.01 GPa) due to longer macro pulse.

The test of window braising technology was successfully finished with 50kW electron beam. This prototype is also specially designed for output window destruction test in KEKB ring or KEKB linac. If this R&D proposal will be accepted, it will be sent to KEK.

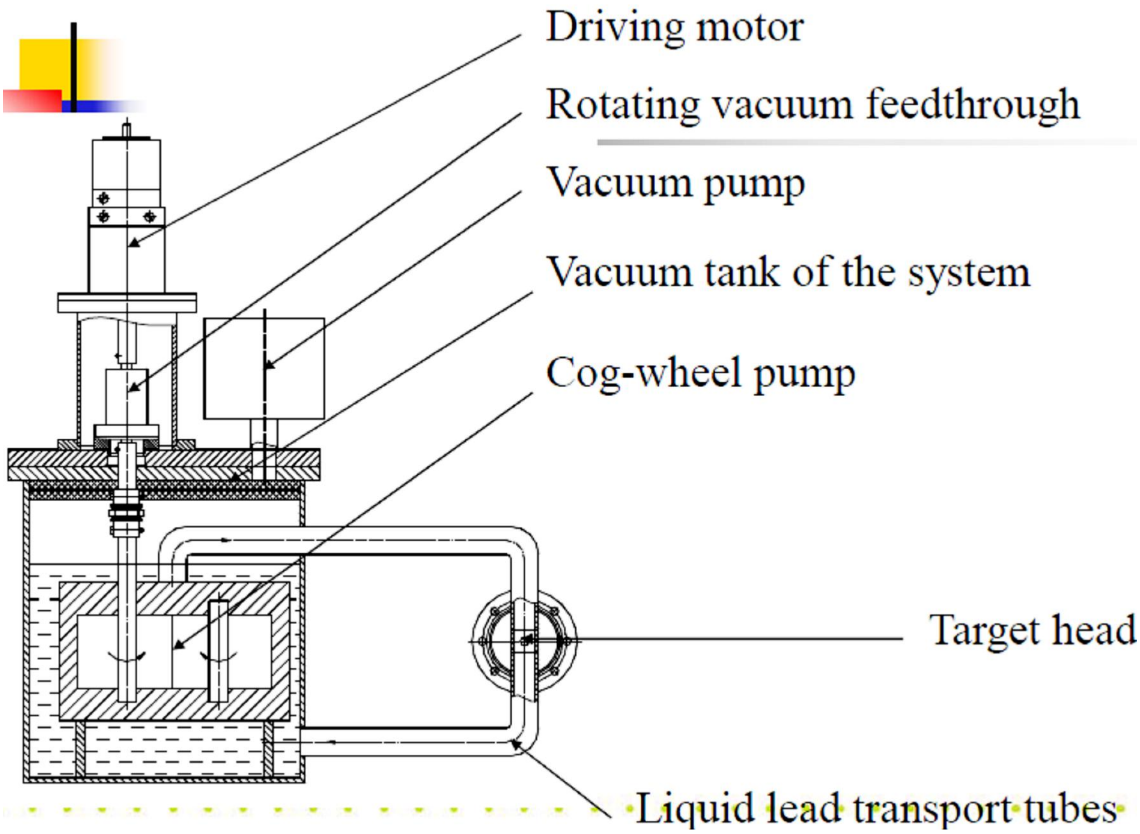

Fig.1 The prototype of liquid lead positron production target which is under commissioning with 50kW electron beam.

2. The present stage of BINP activity in Matching Device development

The successful test of VEPP-5 positron production system was performed. Flux Concentrator magnet (FC) was tested up to 70 kG (30 μs pulse duration) without saturation in positron yield. The investigation of the technical limit for maximum FC pulse duration is in progress. Flat face FC for 30 μs pulse duration, 10 T maximum field and good field quality for KEKB is under the tests now at BINP. It will be sent to KEKB linac for the upgrade of the positron production system soon.

R&D Purpose

Long macro pulse of ILC beam (1msec) leads to stronger kick-effect and decreasing of useful magnetic field maximum in FC magnet. High positron production rate leads to high activation level and radiation damages of positron production system elements. The R&D about high power liquid lead target in comparison with rotating solid-state Ti or WRe targets and effective matching device (Flux Concentrator or Lithium Lens) is essential and necessary for complete ILC engineering design.

Since the spinning target rim perturbs magnetic field as a result of eddy currents in rotating solid metal, the collection magnetic field must be zero or enough weak in a target region. Because the spatial distribution of the field of the Li lens is well confined, it is a good candidate as ILC positron capturing device.

Alexander Mikhailichenko usually considers low-k value undulator which is longer than present design undulator. Also, he considers the liquid metal target and the liquid Li lens. This is natural consideration because we want to use fundamental gamma-ray 20MeV to generate high polarization positron beam (polarization 60%) but this consideration makes more severe situation to the rotating target. Then, base-line positron group selected high k-value option but they have still target problem and capture device problem.

The main aims of proposed R&D are to determine the technical limit of driving beam intensity and pulse duration for each component of positron production system. Then, we want to optimize each component for the best integrated system performance according to proposed experimental results and the engineering design work. The technical limit for pulse duration should be determined.

New hybrid target system proposed by R.Chehab is very interesting to solve the target heating problem. Hybrid target consists of thin W crystal, bending magnet to sweep e-/e+ and amorphous W target which received gamma-ray, which consists of channeling gamma and Bremsstrahlung gamma. CERN CLIC firmly selected this scheme as a baseline for CLIC. So, we have to check the performance of this hybrid target system to make the possibility for the ILC positron target system clear.

R&D Schedule

Until early 2010, systematic experimental studies on Liquid 90%Pb+10%Sn target system with BN window and the hybrid target system will be proceeded at KEK. Also, we consider the engineering design work for liquid Li lens which is suitable to ILC beam with BINP. KEKB will test the FC system for the upgrade of the positron production system.

If we will establish the realistic design for the positron target system according to the systematic experimental results, the positron capture experiment at KEK will be proceeded around late 2010 and 2011 under the international collaboration.

Above R&D plans essentially depend on the budget situation, not manpower.

Short summary

Existing positron sources, which are in operation, haven't reached yet the limits of their application areas. Significant improvements in some directions may lead to about one order of magnitude increase in positron production rate by advanced target system which will be developed within a few years, if we succeed to perform the aggressive R&D studies. Conventional positron production technology has still some reserves for such up-to-date projects as International Linear Collider (ILC) or Super B-factory.

Appendix 0:

We are also considering the target test at ATF 1.3GeV linac end with 20 bunches/train. The maximum power of the beam is 83.2J. This is very useful in the case of a few 100μm(rms) beam size on the target. (See P.Logachev, APAC2007-TUC3MA03)

References

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[1] A.Mikhailichenko, EPAC2006-MOPLS108

[5] P.Logachev, APAC2007-TUC3MA03

[6] A.Antoshin, et. al., APAC2007-TUPMA122

[2] A.Mikhailichenko, PAC07-THPMS012

[3] A.Mikhailichenko, EPAC08-WEPP157

[7] M.Blinov, et. al., EPAC08-MOPC085

[8] A.Antoshin, et. al., EPAC08-MOPC-088

[9] X.Artru et al. Nucl. Instr.Methods B 266 (2008)3868-3875

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http://indico.cern.ch/getFile.py/access?contribId=67&sessionId=3&resId=1&materialId=slides&confId=30383

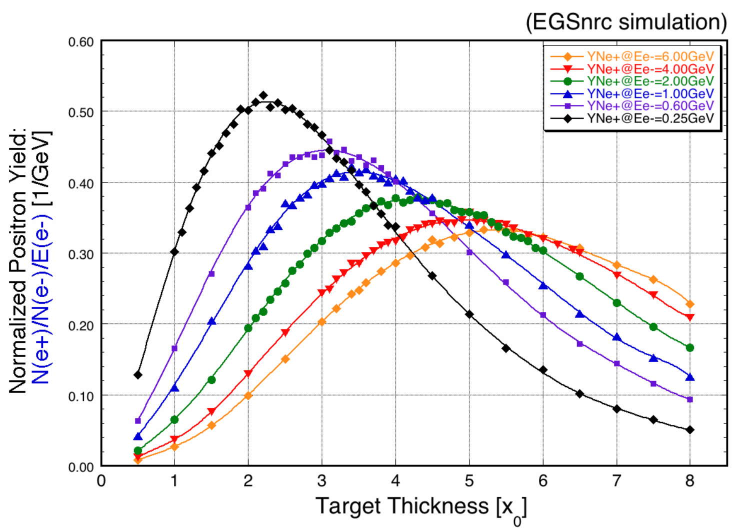
Appendix A:

ILC Positron Source driven by 700MeV electron beam has been discussed in ILC08 at Chicago. In this note, the scheme is described with additional information especially capture study. Possible modification and related studies will be discussed.

The primary electron beam for positron generation is made by a photo-cathode RF gun. The RF-gun is L-band Flash-type gun. The bunch intensity is 5.2nC and the pulse structure is identical that in main linac. To boost up this electron beam up to 700 MeV, one RF section, which consists from 3 cryomodules and 24 cavities, is necessary, but it requires two klystrons for higher bunch intensity.

The target for positron generation is liquid Pb-Sn with BN isolation window. The system is originally developed for neutron generation at BINP and proposed for ILC positron conversion target. This liquid metal target has principally very large potential as positron conversion target and the actual performance is limited by the vitality of the isolation window. BN has been selected because it has a large limit on the peak energy deposition density. The practical limit on the BN window is 10×10^{12} GeV/mm^2 , where the energy density is taken within 100ns duration, that corresponds to time constant of the shock-wave in BN window. In ILC case, the bunch spacing is 369ns and only one bunch is placed in the window, so the energy density is estimated to be 0.7(GeV)x10.3(nC)/e/1.0(mm^2) $=4.5\times10^{10}$ GeV/mm^2 , which is well below the limit. 1.0mm^2 spot is assumed. BN has another limit on the average power and it is 180kW. In this case, the average power is 0.7(GeV)x5.2nCx2625(# of bunches)x5(Hz)=49kW, which is also below the limit.

Lithium lens, which induces a strong focusing field for generated positrons, is employed for the capture optics. The field has only azimuthal component B_q and its amplitude is proportional to the radial position, *r*. This device has a large capture efficiency comparing to others including AMD. Although the exact capture efficiency and its enhancement is not studied yet, let us assume some enhancement on the capture efficiency C_{LL}. As we discussed later, the capture efficiency is qualified by assuming AMD capture optics. The bunch intensity for the drive electron beam is obtained based on the positron yield with AMD and the enhancement on the yield by LL comparing to AMD case. With the enhancement, the bunch intensity of the electron driver can be expressed as Q(nC)/C_{LL} , where Q(nC) is the required bunch intensity in AMD case and C_{LL} is enhancement by LL. In this note, C_{LL} is assumed to be 2.0 and this number should be confirmed anyhow.



A　positron capture simulation is performed. Positron distribution in the phase space is generated by NRC EGS4 simulation code. AMD capture device, which has 7.0 Tesla peak field, is assumed. The AMD field is connected to 0.5 Tesla solenoid field, which surrounds L-band capture RF section. The accelerating gradient of the L-band RF section is 25.0 MV/m. This gradient is significantly higher than that in RDR value(15.0 MV/m), but the enhancement on the capture efficiency is small and we do not expect any large correction. The positron capture is qualified by analytically by assuming acceptance on its transverse and longitudinal space. In transverse space, the positron satisfying the following condition is accepted: $(x/5.3)^2 + (p_x/11)^2 =< 1.0$, where x and p_x are coordinate (mm) and its momentum (MeV/c). The longitudinal acceptance is assumed to be 15mm (50ps) and bunch lengthening by velocity variation, spiral motion in AMD and L-band RF section, are accounted. Fig. 1 shows the positron yield per electron normalized by the electron beam energy in GeV.　By taking the normalized yield with 600 MeV driver energy, 0.44/GeV at $3X_0$,　the yield with 700 MeV drive beam energy is obtained as 0.44*0.70=0.31. To obtain 3.2nC positron per bunch,　10.3nC bunch intensity is necessary.　By assuming 2.0 as the enhancement by Lithium lens, C_{LL} , the required bunch intensity becomes 5.2nC.

There are many ambiguities on this scheme. The positron yield calculated by NRC EGS4 likely to have up to 20% systematic error. C_{LL} is just an assumption and it should be confirmed by some study. The positron yield is calculated by assuming a general acceptance, but it should be compatible to ILC-DR acceptance. Variations on these critical parameters, may have big impacts on the scheme, however, such variations can be adjusted by changing the bunch intensity and energy of the electron driver. For example, if the positron yield was 20% less for AMD and C_{LL} is 20% less, the total yield becomes 64%, but it can be recovered by increasing the energy and/or intensity of the electron driver by 60%. The critical points are the following

- The bunch intensity should be reasonable.
- The target and capture device (Liquid Pb-Sn target and LL) should be vital and the operation point is within the tolerances.

The reasonable bunch intensity can be obtained by a simulation once other beam parameters are defined. The most ambiguous point of this scheme is the second point, the practical limits on the target and capture device, because the higher energy on the electron driver tends to more damage. The reality of this scheme strongly depends on the vitality of these devices and the experiments to examine this limits are essential.

Appendix B:

POSITRON SOURCE TESTS WITH THE KEKB LINAC

LAL-Orsay and IPN-Lyon with the collaboration of Budker Institute and Tomsk Nuclear Physics institute on one side and KEK on the other side, have operated a series of experiments and tests on positron sources using channelling radiation in crystals. The experiments carried out at CERN (WA 103) and in KEK, being complementary, have brought useful determinations of the positron yield and of the positron phase space.

The very special conditions and constraints for a positron source dedicated to the future linear colliders require additional measurements in order to get a complete description of such sources which showed very promising characteristics. First of all, the very intense beams in ILC require an accurate study of the behaviour of the target due to an important density of deposited energy. The total deposited energy and the maximum density of energy deposited have to be determined in order to prevent the target failure as occurred on the SLC target. From the other side the energy distribution of the positrons must be known with accuracy in order to choose the appropriated matching device for maximizing the accepted yield. The chosen positron source of this kind is the *hybrid source* based on the use of a crystal as a radiator and an amorphous tungsten as the converter. The two elements *radiator* and *converter* are separated by a distance of 2-3 meters; in between a sweeping magnet allows sweeping of all or part of the charged particles coming out from the crystal. Such a solution has been selected for the unpolarized source of CLIC.

In the framework of the studies presented above, we should recommend the following measurements

- Measurement of the permanent amorphous target heating: a system of thermocouples may be a solution.
- Measurement of the instantaneous heating on the exit face of the amorphous target. Such heating is not homogeneous leading to mechanical stresses induced by the temperature gradients. An infrared camera with a good spatial resolution would be an interesting way to complete this measurement.
- Measurement of the positron yield
- Measurement of the positron energy spectrum

The available energy at the KEKB test linac: 4 to 8 GeV is very interesting for that purpose. An intensity of 1-3 nC per bunch is also wished.

The following physicists have expressed a strong interest in these tests:

KEK: J.Urakawa, T.Omori, T.Suwada, T.Kamitani

Hiroshima: T.Takahashi, M.Kuriki

IPNL: X.Artru, R.Chehab, M.Chevallier

LAL: A.Variola, O.Dadoun

BINP: V.M.Strakhovenko

CERN

Appendix C: The 300Hz generation option of ILC positron source

The 300 Hz generation option is a conventional positron source driven by a electron beam. The beam has the characteristic multi-bunch structure. One RF pulse accelerate three mini-trains with inter mini-train gaps. This package of three mini-trains is named triplet in this article. Each mini-train contains 44 bunches. The linac is operated in 300 Hz.

ILC requires tremendous number of positrons in a pulse. This makes positron production in ILC very challenging. However, the repetition of the ILC, 5 Hz, is rather slow. We have 200 m sec interval between two pulses. In the 300 Hz option, we produce positrons in rather long time, 30 m sec, in order to make target issue easy. In this article, we assume the modified LowP parameter for the short damping ring option[1], so one pulse of ILC beam has 1320 bunches. In the baseline design, we make 1320 bunches in 0.63 m sec. On the other hand, in the 300 Hz option, we make 1320 bunches in 30 m sec and use remaining 170 m sec for damping.

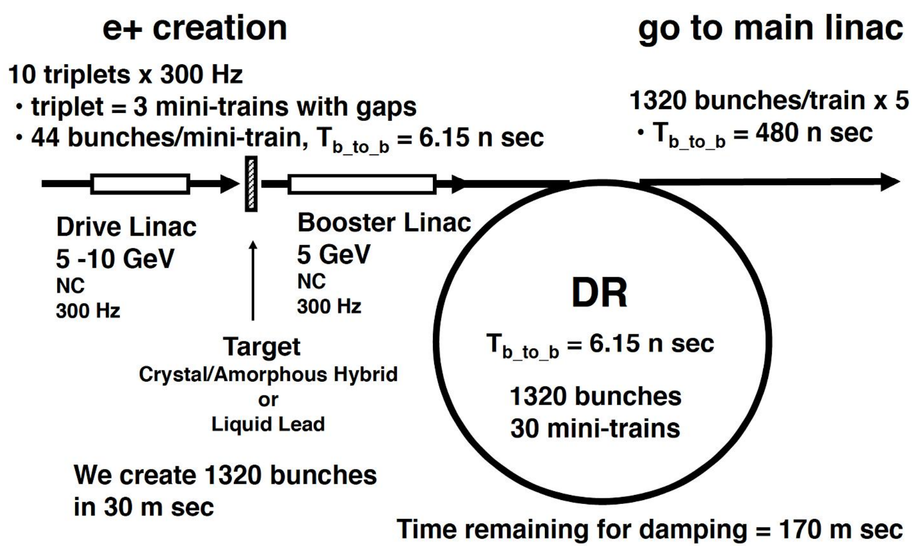


Figure 1: Schematic view of the 300 Hz option

Figure 1 shows the schematic view of the 300 Hz option. In ILC, we can employ different bunch structures and pulse structures in the positron source, in DR, and in the main linac. In the 300 Hz option, we employ the triplet mini-train structure in the positron source (Figure 2) and the mini-train structure in DR. Bunch-to-bunch separation in the mini-train is 6.15 n sec. A mini-train contains 44 bunches. The length of the mini-train is 264 n sec. The triplet contains three mini-trains. So, a triple contains 132 bunches. Therefore we need 10 triplets to form 1320 bunches. There are gaps between mini-trains in a triplet. This inter mini-train gap is 123 n sec. This triplet structure is required to match the bunch timing structure to the fill pattern of DR. Those triplets are produced by

[1] The detail of the modified LowP parameter for the short damping ring option is not decided yet. So parameters used in this article is a hypothetical ones.

the electron beam which has the same timing structure. The repetition rate of triplet is 300 Hz. So we have 3.3 m sec between two triplets. By the rotation of the target in 3.3 m sec, different triplet hit different parts of the target. The tangential speed of the target rotation which can achieve this condition is only 5 - 10 m/sec. This is factor 10 or more smaller than that of the baseline design.

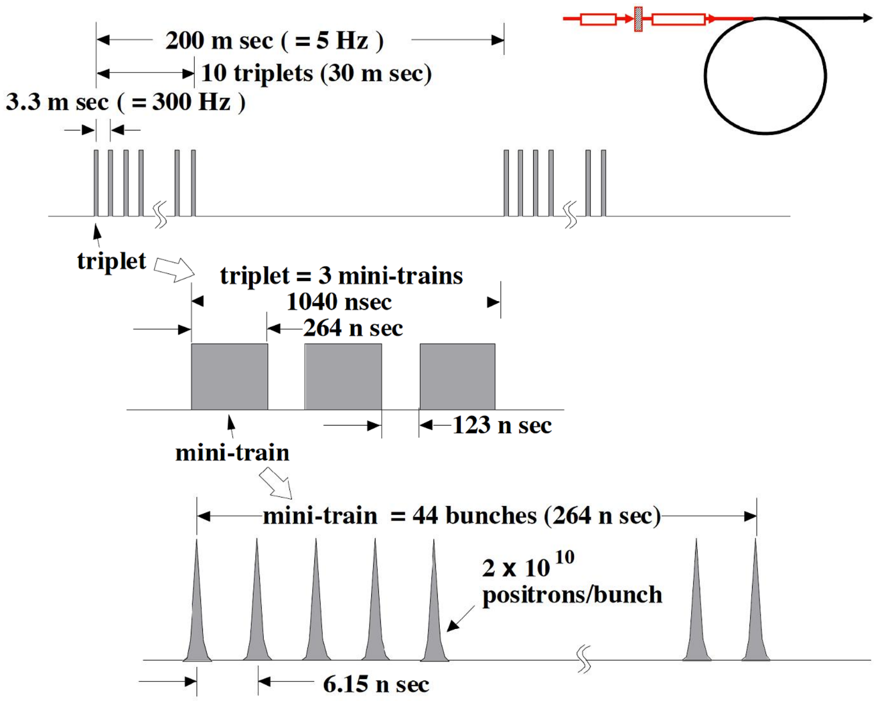


Figure 2: Timing structure in the positron source.

In the 300 Hz option, the target dose not need to survive hitting of 1320 bunches, it have to survive hitting of only 132 bunches. This condition is similar to that of the e+ sources for the warm linear colliders such as NLC/GLC (Table 1). For example the GLC bunch parameters are: 0.7x10^10 e+/bunch, 300 bunches/train, 1.4 n sec bunch-to-bunch separation, and 150 Hz repetition rate. The product of the bunches in a triplet (or in a train for GLC) and the number of positrons in a bunch is approximately the same in both the 300 Hz option and GLC. Therefore, we assume the thermal/schock load of the target is the same in the the 300 Hz option and in GLC. According to the past study which were done for GLC, we need two or three targets to deal with the thermal/schock load in the 300 Hz option, if we employ the solid metal rotation targets.

	The 300 Hz option	GLC
(a) Number of positrons per bunch (a)	2 x 10^{10}	0.7 x 10^{10}
Bunch to bunch separation	6.15	1.4
(b) Number of bunches in a triplet / a train	132 (44x3) in a triplet	300 in a train
Repetition rate of triplets / trains	300 Hz (triplet)	150 Hz (train)

Table 1: Comparison of the 300 Hz option and the GLC positron source. The product of (a) and (b) is about 2 x 10^{12} in both the 300 Hz option and GLC.

There are two new candidates of the e+ production target which may have potential to survive the hitting of 132 bunches with one target. They are the crystal-amorphous hybrid target and the liquid lead target. Those targets have significantly higher survivability than the solid metal targets. For example, a simulation shows that the peak energy deposit density in the hybrid[2] target is 3 - 5 times smaller than that in the simple metal target[3]. This means the hybrid target has 3 - 5 times larger survivability. So we assume to employ either the hybrid target or the liquid lead target, and to use only one target instead of 2 - 3 targets.

In the hybrid target, the crystal radiator is very thin, for example 1/3 X_0. Therefore energy deposit on the radiator is small. So, we assume the radiator is not rotating. On the other hand, the amorphous converter is thick, for example 4 X_0, we need rotation to avoid target destruction. However, as already explain, the required rotation speed is rather slow, 5 - 10 m/s in tangential speed, we assume that the rotation is not so difficult.

When we employ the liquid lead target, it dose not rotate. Instead, the liquid lead should flows 5 - 10 m per seconds. This flow avoids boiling of the liquid lead and removes the heat from the target window.

The design of the flux concentrator for the capture system is much easier in the 300 Hz option than that in the baseline design. In the baseline design, 0.63 m sec pulse length is required to the flux concentrator. This is about 1000 times longer than the pulse length of the existing flux concentrators. We need very big jump from the existing technology. On the other hand, in the 300 Hz option, the required pulse length is about 1 micro seconds. This is approximately the same as that of the existing flux concentrators. We can use the existing technology.

After the target and capture, we need a 300 Hz normal conducting linac to boost positron energy to 5 GeV. Then we employ a kicker which pulse length is about 1 micro seconds and which repetition rate is 300 Hz to send triplet to the DR. Stacking of the e+ bunches is not necessary.

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2 We assume a combination of a thin crystal tungsten plate as a radiator and a thick amorphous tungsten plate as a converter.

3 We assume thick amorphous tungsten plate.

After the damping, bunches are extracted from the DR by the fast kicker and are sent to the bunch compressor then to the main linac. The fast kicker enables the bunch-by-bunch extraction. The bunch-to-bunch separation is 480 n sec after the extraction (Figure 3). This part is the same as that of the baseline design.

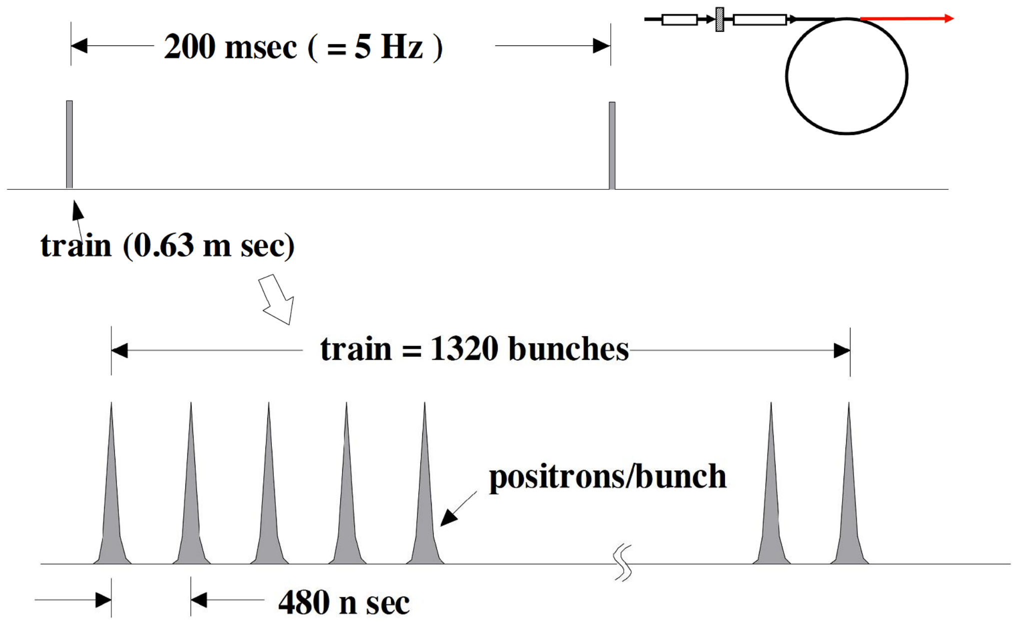

Figure 3: Timing structure in the positron source.

Appendix D: 2 GeV Drive Linac for positron production

According to the reference [4], we scale the beam parameters and discuss the possibility as the independent positron source system for ILC in the case of 2GeV drive SC linac. The reference [4] described a metal converter (WRe) and an Adiabatic Matching Device (AMD) composed of a Flux Concentrator and a DC magnetic field along the e^+ Pre-Injector linac. Also, the extensive beam dynamics simulations were described for the e^+ production in the target and for the e^+ capture in the matching and focusing sections. After parameter optimization, the transverse and longitudinal acceptances were proposed for the CLIC e^+ production as the normalised transverse of 9×10^{-2} rad.m (edge at 3σ), the longitudinal acceptance of $\Delta E=+/-10$ MeV (edge), $\Delta t=90$ps (edge), $\Delta z=27$mm (edge) and $\Delta p/p=1\%$ (full width). These values are acceptable for ILC case. Table 7 in the reference [4] requests us following beam parameters for ILC case.

Primary beam : 2GeV, 2.84 x 10^{10} electrons/bunch, rms spot (radius) on target 2mm, bunch length (rms) 3mm

Above scaled values are optimistic because we do not include the space charge effects. However, this CLIC design assumed 7.0 T for the peak field and 0.5 T for the constant field as the AMD, we have a possibility to use 10.0 T for the peak field or the liquid Li lens and 1.3 GHz L-band Linac will be used instead of 1.5 GHz Linac for the Pre-Injector linac. We expect the increase of the capture efficiency due to the improvement of the capture components and the design of ILC damping ring.

We have to consider the deposited energy density in a small volume inside the target, evaluate it and compare with the result of the SLAC beam experiments, in order to estimate the destruction limit of the target system. The peak energy density in a small volume is essential for the fatigue phenomena that cause the target destruction. The beam energy of ILC is 20 times larger than this CLIC e^+ production design, so we have to use liquid target with strong low material window, of which survival will be demonstrated by beam experiment. Regarding the shock-wave in the case of the ILC beam, BINP already evaluated no problem because of large bunch spacing of ILC.