Report on the Workshop on positron sources for the International Linear Collider

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Abstract

This report gives an overview of the Workshop and highlights topics discussed on positron sources for the future Linear Collider. Among the various challenges, the topic on polarized positrons was emphasised. The workshop was held in Daresbury, 11-13 April 2005.

1. Introduction

The goal of this workshop was to discuss the possible solutions and options to produce polarized and non-polarized positrons for the future e^+-e^- linear collider. For the ILC, several positron source options are presently being considered. Another objective was to assess the outstanding R & D issues that will need to be addressed for each option and how best these issues should be addressed in the near future. Focus was put on the design of an ILC positron source in order to prepare presentations for the Snowmass meeting in August 2005

2. Short Overview

The workshop was well attended with 47 participants from Europe, USA, Japan and Russia. At the first session, a review of ILC parameters with emphasis on positron source demands was done. Then the status of existing positron sources was presented followed by issues related to conventional e^+ sources. For polarized positrons, undulator-based and Compton back-scattered e^+ source issues were deeply discussed. The second session was devoted to target material, properties and issues. The third session was dedicated to the positron capture considering the beam dynamics and the RF structures. The fourth session was devoted to polarized positron production: why the Physics needs polarized particles, how to produce polarized positrons, how to measure polarization? Finally a summary session was held to draw some conclusions in view of the Snowmass meeting.
The programme, list of participants and presentations can be found at the Web site [1].

3. Demands on Positron Sources

The technique to produce positrons is based today on 3 paths. The scope for ILC is to write a TDR (Technical Design Report) for 2008. As a first step, it is planned to elaborate a CDR (Conceptual Design Report) for the end of 2006. Therefore a choice of the base line configuration for positron production should be made for the end of 2005.
Figure 1 summarizes this approach.

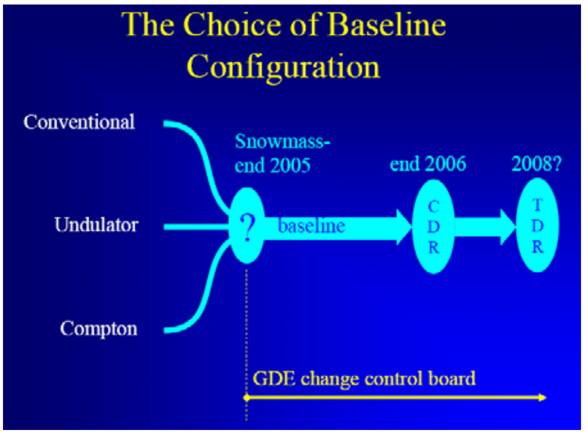

Figure 1: Possible positron base line configuration (from N. Walker/DESY)

The requests for the future linear colliders are given in the Table 1. Compared to the SLC for the number of e^+ per pulse, the CLIC design is a factor 12, NLC was a factor 30 and ILC is a factor 1000. Using conventional positron sources for ILC would be a great challenge.

Table 1: Positron sources related to linear colliders

	Rep rate Hz	# of bunches per pulse	# of e^+ per bunch	# of e^+ per pulse
SLC	120	1	5.10^{10}	5.10^{10}
CLIC (3 TeV)	100	154	4.10^{9}	$61.6.10^{10}$
NLC	120	192	$0.75.10^{10}$	$1.4.10^{12}$
TESLA (TDR)	5	2820	2.10^{10}	$5.6.10^{13}$
ILC (Nominal)	5	2820	2.10^{10}	$5.6.10^{13}$
ILC (Upgrade)	5	5600	1.10^{10}	$5.6.10^{13}$

Figure 2 shows schematically the three methods for producing unpolarized/polarized positrons. The conventional scheme which consists to produce e^+e^- pairs from electromagnetic showers generated by intense electron beams in thick amorphous targets, does not allow polarized positrons while the undulator-based and the Compton scattering do.
However the constraints related to these 2 last schemes are not negligible.

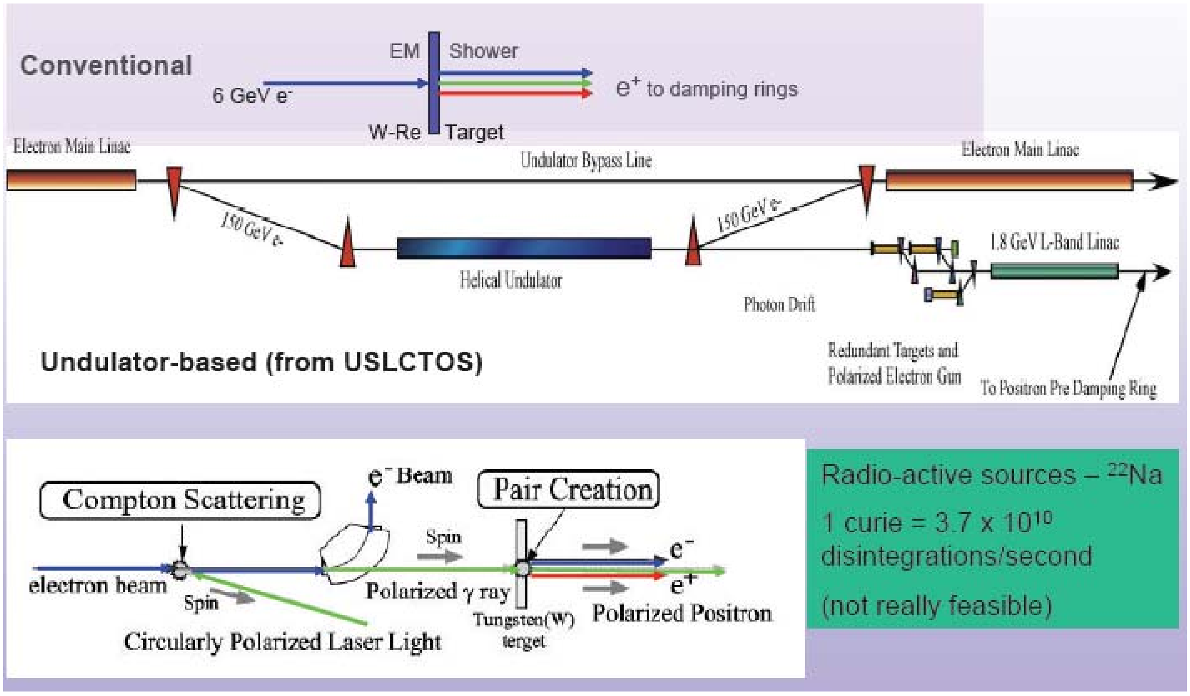

Figure 2: The 3 schemes for e^+ production (from V. Bharadwaj/SLAC)

Since the demand from Physics is so strong for polarized positrons, the workshop focused mainly on the 2 last schemes. For the Damping ring (DR), the design effort is concentrated on the e^+ DR. It is requested to reduce the emittance in 200 ms down to
$\gamma\varepsilon_x = 8.\ 10^{-6}$ rad.m and $\gamma\varepsilon_y = 2.10^{-8}$ rad.m
The injected emittance for positrons is obtained by simulation and gives = 0.01 rad.m.

4. Status of Positron Sources

Table 2 shows the status of positron sources as presented at the workshop. The e^+ yield for ILC is 0.150. It is interesting to note that the measured highest e^+ yields concern machines which have been shut-down (SLC, LIL, Orsay) or not implemented with e^+ (SOLEIL) or never built (VEPP-5). The existing positron sources today (less than 10) are mainly the synchrotron light machines that are far away from the ILC requests and use only the conventional scheme to produce positrons.

Table 2: Positron sources (Past and present)

POSITRON SOURCES

	Energy (GeV)	Current (A)	Rate (Hz)	Target Material	Thickness (r.l.)	Power Dep (kW)	Matching	RF* (MV/m)	Yield (/e-/GeV)
ILC	**6.00**	**2.E+10**	**5*2820**	**W-26Re**	**4.0**	**30.00**		**	**0.150**
SLC	30.00	4.E+10	120	W-26Re	6.0	4.00	FC+TS+S	19	0.030
APS	0.20	1.0	30	W	2.0	0.48	S		0.006
CESR	0.15	1.7	60	W	2.0	0.30	λ/4 PS+S	10	0.013
BEPC	0.15	2.4	25	W	1.7		TS+S	10	0.025
SPRING-8	0.25	10.0	8	W-10Cu	2.0	1.00	PS+S	17	0.012
KEK	4.00	2x10nC	50	W	4.0	0.40	λ/4 PS+S	14	0.015
ORSAY	1.00	1.0	25	W-2Cu-2Ni	7.0	0.50	FC+S	10	0.021
SOLEIL	0.34	0.7	10	W	2.0	0.14	λ/4 PS+S	15	0.020
DESY	0.40	1.5	50	W	2.0	2.00	λ/4 PS+S	14	0.025
VEPP-5	0.30	1000.0	50	W	2.5	0.02	FC+S	18	0.050
LIL	0.20	1.4	100	W	2.0	0.60	λ/4 PS+S	9	0.030

The SLC positron source comes closest to the ILC needs and it is not that close!
ILC source is ~ factor of 60 greater in flux and 8 in energy deposition into target.
**ILC Pulse length is 1 ms as opposed to ~ 1 μs that is typical for existing sources

Workshop on Positron Sources for the International Linear Collider 5 Vinod Bharadwaj, SLAC
Status of Existing Positron Sources – Daresbury , April 10, 2005 vinod@slac.stanford.edu

Note: FC accounts for Adiabatic Matching Device.

The e^+ target is one of the main challenges for the positron source and the capture system (magnets and RF) needs also a great care.

Reference [2] gives suggested ILC parameters from T. Raubenheimer

5. Target Issues

Many simulations and calculations are performed in various institutes. Several machines which have produced positrons for High Energy Physics have been analysed. Based on theory and experience, the following issues have been considered:
Energy deposition, power removal, radiation damages and mechanical fatigue. The different materials as potential candidates for the 3 types of positron sources and the issues related to the radiation environment have also been considered.

Conventional positron source has been studied for ILC. Figure 3 shows a possible layout. Assuming 5 pulses/s, a beam spot radius of 2 mm and other data given in Tables 1 and 2, the peak energy deposition is 0.7 J/g per bunch on back side of the target (Gaussian profile). A lot of simulations have been performed for the thermal stress, mechanical stress and radiation damages. A commonly acceptable limit is 0.5 DPA (Displacement per Atom). According to FLUKA and SPECTER simulations, this limit is reached after 3 years of operation.

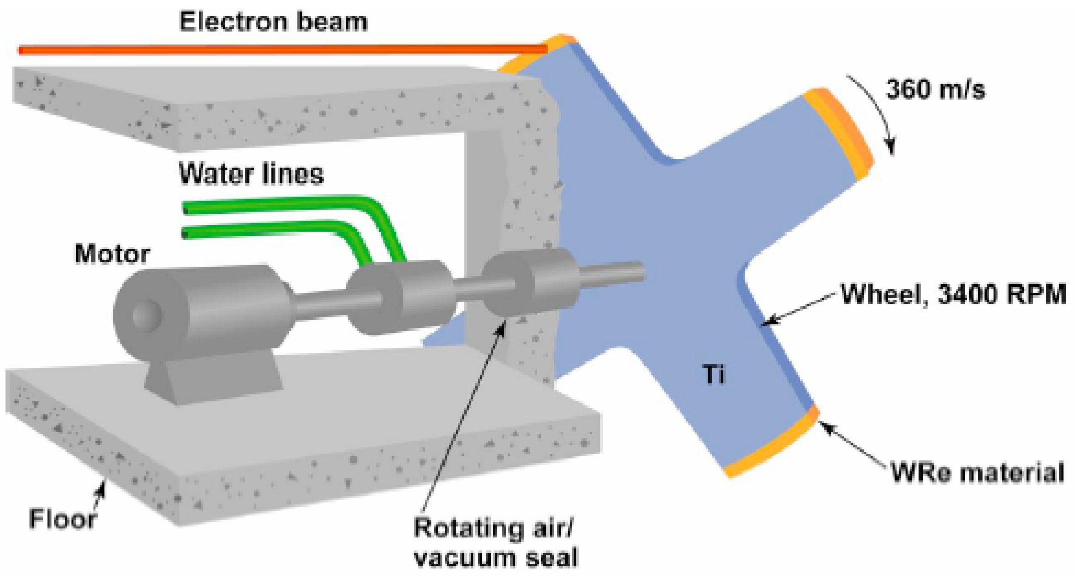

Figure 3: Conventional source target system layout (from W. Stein et al. / LLNL)

Undulator photon beam target has been deeply studied. Assuming the photon energy of 22 MeV, a beam spot radius of 0.75 mm, the peak energy deposition is 1.45 J/g per bunch on back side of the target. According to FLUKA and SPECTER simulations, the limit mentioned above of 0.5 DPA is reached after 1 year of operation.

The project IPPAK (ILC Positron Project At KEKB) at KEK was presented. Comparing some ILC parameters with the stored KEKB beam, one can see that the total beam power of KEKB is roughly twice the ILC Drive beam:
ILC: 6 GeV, 3 nC, 2820 bunches (50760 J)
KEKB: 8 GeV, 10 nC, 1300 bunches (104000 J).
Therefore by sending the stored KEKB beam to a test target, one could reproduce the target damage provoked in an ILC target.

The possibility to use a liquid target was presented and discussed.

Another approach was reported concerning the production of positrons based on channelling process. Experiments were carried out at CERN and at KEK. Figure 4 shows the positron enhancement obtained at CERN with a W monocrystal compared to an amorphous W target of the same thickness (4 mm): a factor 4 is clearly observed.
The e^+ are produced from primary electron beam energy of 10 GeV inside a target with a thickness of 4 mm. The monocrystal is oriented along the <111> axis. By changing significantly the angle of impinging electrons with respect to the crystal axis, the target behaves as amorphous. The number of electrons per pulse is 10^4. The pulse duration was 3.2 s with a repetition rate of 14.4 s.
At KEK, experiments were performed with W (Tungsten), Si (Silicon) and C (d) (Diamond) targets. Similar experimental results were obtained at CERN and at KEK, for W targets, regarding the enhancements.

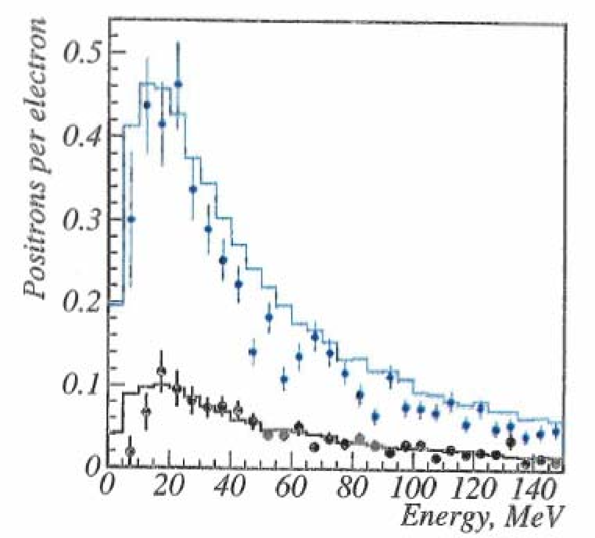

Figure 4: Positron energy distribution (from R. Chehab / LAL)
Blue curve (W monocrystal) --- Black curve (Amorphous crystal)

6. Considerations on Positron Capture

The main components for the positron capture are the following:
- Adiabatic Matching Device (AMD)
- Room temperature sections with high gradient embedded in a constant field (long solenoid)
- L-band klystrons (~ 10 MW)
- Insertion unit for beam separation and collimation
- Accelerating linac with periodic focusing.

Beam dynamics investigations have been performed in order to get a maximum positron capture in the 6-dimensional volume. The beam parameters have been optimised in the range of 250 MeV while the beam quality at the input of the Pre Damping ring should be preserved. Finally the goal is to obtain a reliable and reasonable design for the Positron Pre Accelerator.

7. Polarization aspects and studies

G. Moortgat-Pick gave a talk showing that the polarization is essential for Physics. The report can be find from:
http://www.ippp.dur.ac.uk/~gudrid/power/report.pdf

Three studies were presented and discussed at the workshop.
1) ATF (KEK) ; 2) E-166 (SLAC); 3) HeliCal (CCLRC/RAL)

At ATF, the polarized positrons are produced using Laser Compton back scattering.
At E-166, they are produced using a helical undulator at room temperature while at HeLiCal a feasibility study is carried out for a prototype based on superconducting helical undulator.

1) Figure 5 shows the layout of the experiment at KEK for the polarized positron.

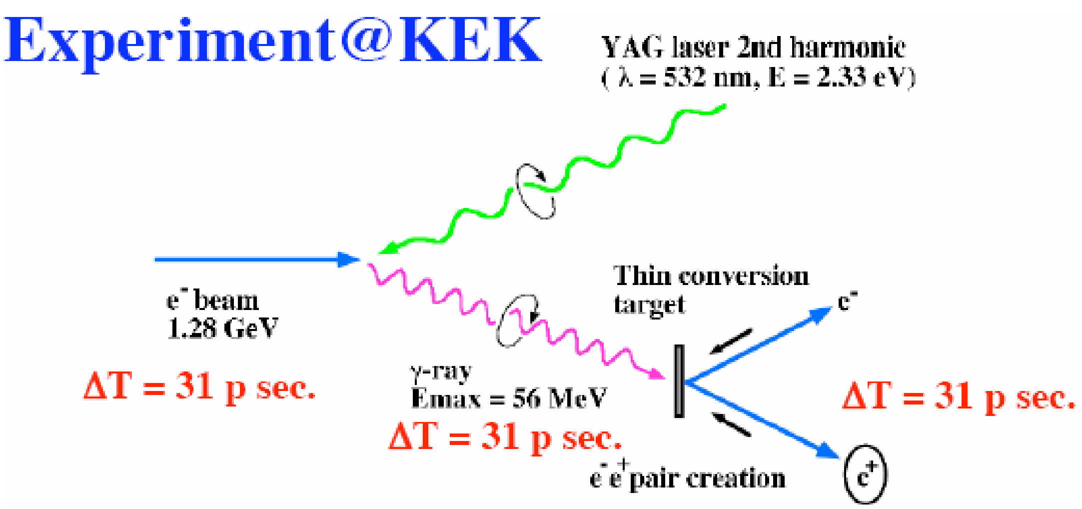

Figure 5: Layout of Laser back scattering for proof-of-principle demonstration (from M. Kuriki/KEK)

The experimental results show that polarization can propagate from the laser photons up to the e^+ beam.
The polarimetry for short pulses has been established. For a threshold energy of 21 MeV, the expected asymmetry is:
$A = (N_+ - N_-) / (N_+ + N_-) = 1.3\%$
The measurements of this asymmetry, using Cherenkov light, agree with the expected values. Positron beams have been produced with a polarization of 80 %.
A variant for the Compton scheme, using a storage ring and a Fabry-Perot laser cavity has been presented by K. Moenig (LAL/DESY-Zeuthen).

2) E-166 is an international experiment inside a collaboration composed of 47 members from 17 institutions. It runs on the FFTB facility at SLAC using the SLC beam. The beam energy is

50 GeV with a charge of 10^{10} e^- / bunch. The normalized emittances are $3x10^{-5}$ rad.m in both planes. The energy dispersion is 0.3 %. The rms beam sizes are 0.040 mm in both planes at the undulator. The nominal repetition rate is 30 Hz. The photons are produced from an helical undulator 1 m long, with a period λ = 2.4 mm and a K = 0.2.
Figure 6 shows the E-166 layout with some beam characteristics as measured in 2005. Polarized positrons have been produced from gammas generated in the helical undulator. The numbers of gammas and positrons agree with simulations.
The asymmetries measured for the photon flux and for the polarized positrons are well above the background. These results will be presented at Snowmass 2005 by A. Mikhailichenko.

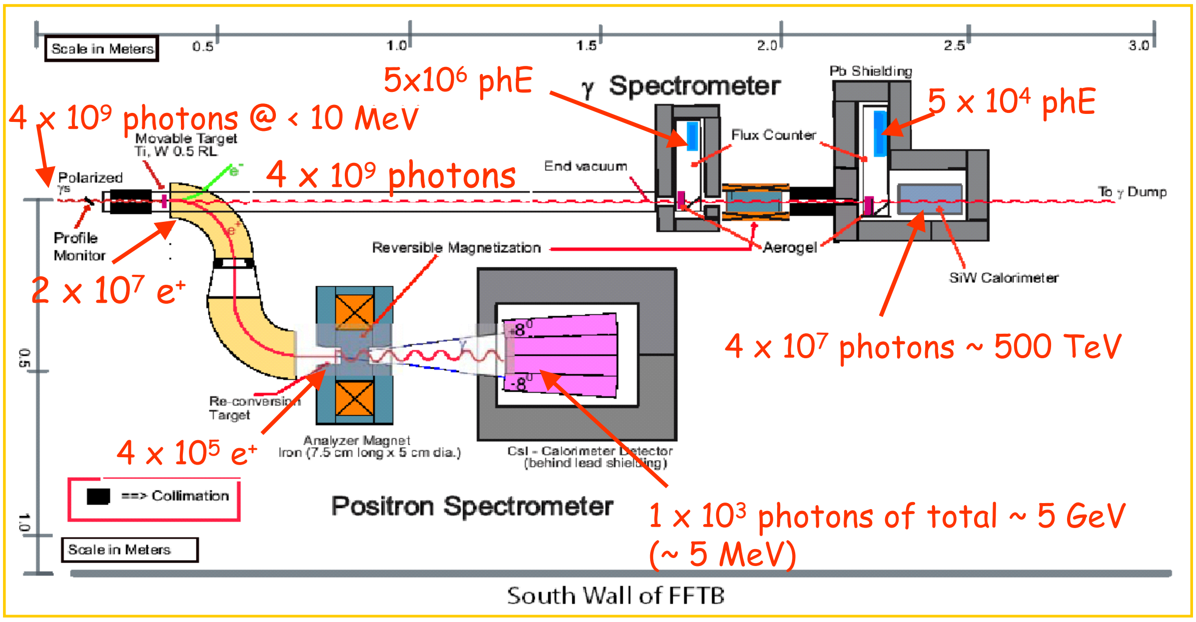

Figure 6: General scheme for E-166 (from A. Mikhailichenko)

E-166 experiment would be a good demonstration for the production of polarized positrons for the linear colliders regarding the following parameters: The photons are produced in the same energy range as for ILC. Target thickness and materials are similar for linear colliders. The polarization is the same as in linear collider. Of course the energy of primary electrons is in the range of 150 GeV or more and the length of the helical undulator should be in the range of 200 m.

3) The UK HeLiCal collaboration is working on a feasibility study in order to design a superconducting helical undulator. A first prototype has been built at RAL where preliminary cold tests gave good results. Magnetic field measurements are in preparation and the possibility to build 1 m-long undulator is investigated.

8. Conclusion

For positron sources in future Linear Colliders, many possible solutions and options have been discussed. The R&D challenges to meet the requested performance have been also addressed. Preparation for the Snowmass meeting, in August 2005, has been done in order to propose a final selection and design.

References

[1] http://www.astec.ac.uk/id_mag/IDMag_Helical_ILC_Positron_Production_Workshop.htm

[2] http://www-project.slac.stanford.edu/ilc/acceldev/beamparameters.html

Acknowledgements

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