# Positron Production for the S-Band and TESLALinear Colliders

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## Abstract

Future linear colliders require positron sources with intensities up to two orders of magnitude higher than the existing ones. This would be very difficult to realize with conventional sources. A more reasonable way is to use photons generated in a wiggler or a superconducting helical undulator which are converted into positrons in a thin target. In order to ensure the passage of the beam through the wiggler or undulator without mechanical damage and to provide a small radiation spot size of the photons on the target, the horizontal and vertical emittances are limited. For economical reasons it is advantageous to use the disrupted high energy electron beam after the collision to generate the photons. The demands on the emittance and the specific beam properties after the interaction region (IR) require a careful handling in the following capture optics for both the TESLA and the S-Band linear collider.

It has been found that it is rather simple to fulfill the requirements on the unpolarized positron source for both linear collider schemes. The realization of a polarized source for TESLA is more difficult but possible whereas the polarized source for the S-Band linac is still under study.


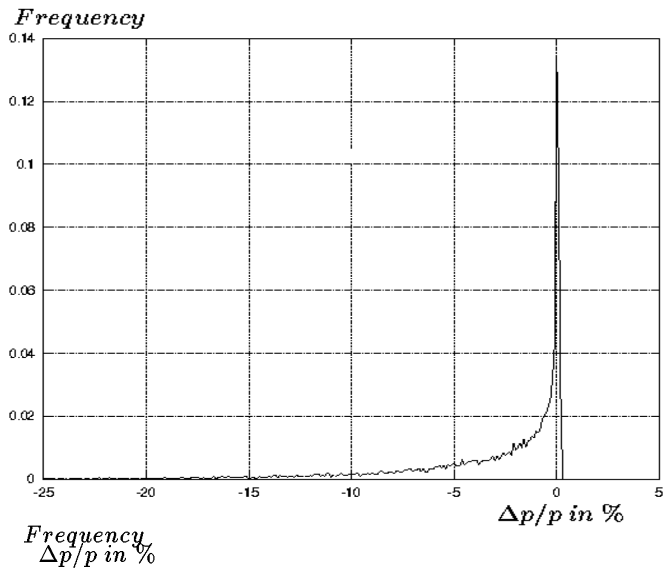


Figure 1: *Distribution of energy deviation of the disrupted beam for the TESLA linear collider.*

## Introduction

Based on the idea of V.E. Balakin and A.A. Mikhailichenko [1] the concept to realize a high intensity positron source using the disrupted electron beam has been worked out by K. Flöttmann [2] It has been shown that a 35m long planar wiggler is sufficient to produce the photons for the unpolarized source, while the polarized positron source needs a 120m long superconducting helical undulator. From aperture limitations in these devices the captured spent beam has to fulfill certain emittance requirements.

An additional constraint exists for the polarized positron source. Analytical calculations (see [2]) of higher harmonics of undulator radiation show that the emitted photons have different polarization properties related to the angle of emission with respect to the electron path through the undulator.

For using the circular polarized radiation on the target it is not only important to focus the electron beam such that the emitted photons hit the target in a certain area. It also has to be ensured that no mixture of photons with different spin orientations dilutes the polarization of the positrons.

The requirements on the emittances from ref.[2] are shown in tab.1

| | hel. undulator (pol. source) | wiggler (unpol. source) |
|---|---|---|
| $\varepsilon_x/\mathrm{rad}\cdot\mathrm{m}$ | $5\cdot 10^{-10}$ | $1\cdot 10^{-8}$ |
| $\varepsilon_y/\mathrm{rad}\cdot\mathrm{m}$ | $5\cdot 10^{-10}$ | $6\cdot 10^{-9}$ |

Table 1:
*Maximum tolerable beam emittances for the planar wiggler and the helical undulator.*

## The beam after the IR

Due to the very strong beam-beam force the particles perform oscillations around the beam axis during the bunch crossing. The particles are receiving kicks depending on the relative displacement of the orbits. This effect, called disruption, causes a broadening in the angular distribution after the IP. The beam size remains nearly constant or even decreases due to the focussing pinch effect.

The oscillating particles emit high energy synchrotron radiation (so-called beamstrahlung). This statistical process causes a broad energy spread of the disrupted beam

| | | S-Band | TESLA |
|---|---|---|---|
| $\beta_x/\beta_y$ | [mm] | 3.10/0.34 | 6.06/0.66 |
| $\alpha_x/\alpha_y$ | [rad] | 1.88/0.49 | 1.94/0.93 |
| $\varepsilon_x/\varepsilon_y$ | [m-rad $\cdot 10^{-12}$] | 34.5/0.88 | 113.0/1.2 |
| $\sigma_x/\sigma_y$ | [nm] | 326/17.2 | 825/28.6 |
| $\Delta E_{mean}$ | [%] | 2.76 | 3.15 |

Table 2:
*Beam properties behind the IR for the S-Band and TESLA linear collider*

and a mean energy loss of the order of 3.0% of the initial energy. A non negligible part of the beam has lost more than 10% energy.

Fig.1 shows the energy distribution after the interaction for TESLA. The energy distribution for the S-Band linac looks similar.

For all investigations a data set of roughly 12000 particles was created with a beam-beam simulation program by R. Brinkmann [3] using the parameters at the interaction point for the TESLA [4] and S-Band linear collider [5] Tab.2 shows the beam properties behind the interaction.

## The spent beam separation

The disrupted electron beam leaving the IR must be separated from the oncoming positron beam to avoid parasitic interactions.

The bunch spacing of 212.4 m for the TESLA linear collider allows to separate the beams over a long distance. Therefore a crossing angle is not needed. The spent beam is focussed by the FFQ doublet for the oncoming beam.

An electrostatic separator is proposed to extract the spent beam from the oncoming beam line. The separator consists of electrostatic and magnetic deflectors combined in the same unit to provide deflection of the outgoing beam and not to effect the incoming beam [6].

Since the vertical emittance after the interaction is about two orders of magnitude smaller than required, it is sufficient to compensate only the horizontal chromaticity.

## Boundary conditions for the design

For a most cost efficient way of integrating the positron source into the collider layout, the collimation system and the radiation production device with the target and the following positron capture optics has to fit into the tunnel of the oncoming positron beam.

The chromatic effects which would increase the emittance by three orders of magnitude have to be compensated by a chromatic correction system (CCS).

Even with an optimized achromatic system it is not possible to transport the whole beam from the IR on through the capture optics and afterwards through the wiggler or undulator. Thus the low energy tail of the beam has to be collimated.

To fulfill the demands on the emittance the spent beam has to be separated from the oncoming beam as smoothly as possible to avoid emittance growth due to quantum fluctuations.

## Methods

To investigate the feasibility of the positron source for the TESLA and S-Band linear collider a tracking code which simulates the beam transport including the quantum emission was set up.

The tracking step width was chosen such that the average number of the emitted photons per step was much smaller than one. Then the process of photon emission follows the Poisson distribution and the probability of radiating more than one photon per step was low.

To consider the geometrical boundary conditions a program was developed which allows to study both the beam optics and the geometry of the capture system with regard to the oncoming positron beam line.

The chromatic fit was done taking into account the asymmetric energy distribution and the phase space distribution after the IR. During the interaction the particles on axis are not deflected by the oncoming beam. The deflection increases with the distance to the bunch center due to the net coulomb force. After a maximum has been reached, the kick strength decreases with increasing distance. Thus the horizontal phase space exhibits an S-shape.

The goal energy bandwidth of the CCS was divided into 10 intervals. For each energy a set of 9 test trajectories was created representing the initial phase space distributions.

Each trajectory was supplied with a weight factor to represent the energy spectrum and two weight factors representing the phase space densities of the complete ensemble.

The chromatic aberrations by optimizing the sextupole strengths in the beam line such that the effective emittance at the end of the CCS was minimized.

## Results for the TESLA linear collider

An optical system has been developed which fits the boundary conditions of the tunnel geometry (see fig 2).

After tracking all particles through the capture system the emittance as a function of the energy deviation was estimated. So it was possible to find out the particles which had to be collimated along the beam line to fulfill the emittance requirements.

The remaining beam after the collimation has been focussed providing a small radiation spot size on the target and avoiding that particles hit the wiggler or undulator, respectively.

It has been found that 83.2 % of the particles can be captured to produce radiation for the unpolarized source in a 35 m long wiggler.

A polarized source using radiation produced in 120 m long superconducting undulator with an aperture of 2.5 mm can be realized using up to 61.7 % of the initial spent beam.

As worked out in [2] a capture efficiency of 70 % of the spent beam would fulfill the demands on the positron production rate with a safety factor of 2. Hence both positron sources are feasible for the TESLA linear collider.

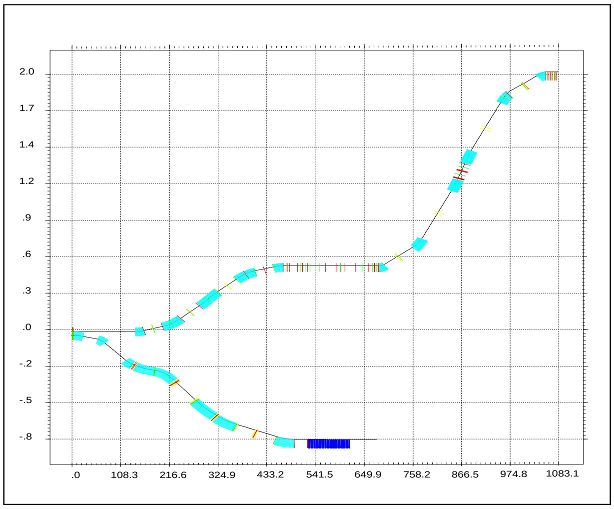


Figure 2: *Beam line for the disrupted beam with the 120 long undulator (lower branch) and the oncoming positron beam (upper branch) for the TESLA linear collider [7]. At the end of the capture optics the separation is 1.3 m*

### Peculiarities for the S-Band linear collider

For the S-Band collider the bunch spacing of 6ns would cause a parasitic interaction with the oncoming beam after 0.9 m. To protect the oncoming from the disrupted beam and from the high power beamstrahlung a crossing angle of 6 mrad is foreseen.

Thus the disrupted beam after the IR enters the final focus quadrupoles (FFQ's) for the oncoming positron beam about 12 mm displaced from the axis in the pole tip region. The magnetic field in this region has higher order multipole terms which cause an additional increase of the horizontal emittance due to geometric aberrations.

The field was analyzed and the particles were tracked through it.

It has been found that 83.4 % of the spent beam at the end of the horizontal and vertical achromatic section fulfill the emittance requirements for the unpolarized source.

The polarized positron source for the S-Band linear collider is still under study.

### Conclusion

It has been shown that both positron sources can be realized for the TESLA machine. The capture efficiency for the polarized source could even be increased by changing the horizontal $\beta$-function at the IP by a factor of 2. This would cause a luminosity loss only by a factor $1/\sqrt{2}$ but the efficiency would rise up to 85 - 90 %

For the S-Band linear collider it is possible to drive the unpolarized source taking the beam after the FFQ's only with a chromatic correction of the downstream optical elements.

To realize the polarized source a multipole analysis of the FFQ fields along the path of the disrupted beam through it and a following correction of their influence looks very promising.

### References

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