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Neutron Background Studies at the TESLA collider

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Abstract

An estimation of the neutron background in a detector for the 500 GeV e^+e^- TESLA linear collider is presented in this note. Neutrons are produced as secondaries if beamstrahlung photons, e^+e^- pairs or beam particles with reduced energies (radiative Bhabhas) hit parts of the detector or elements of the beam delivery system. A large amount of neutrons is generated inside the beam dumps. The number of the neutrons which reach detector components was calculated.

1 Introduction

An experiment at the future 500 GeV e^+e^- linear collider TESLA has to cope with various types of background. Neutrons which are produced in photo-nuclear-reactions are one such type. The photo-nuclear cross-section is dominated by the giant resonance with photon energies at about 10 MeV. Therefore all particles, mainly e^+, e^- and γ, hitting components of the beam delivery system and creating electromagnetic showers are able to produce neutrons. Neutrons which reach the vertex detector may cause damage to the silicon bulk of the CCDs. Via nuclear reactions neutrons produce a background in the TPC and calorimeter. For these reasons an estimation of the amount of the neutrons, that is expected in a detector at TESLA is very important.

The electrons and photons generating electromagnetic showers come from four different origins. When two bunches collide in the interaction region they are focused due to the strong electric field of the opposite bunch (*pinch effect*). Due to their bent trajectories the electrons and positrons in both bunches emit bremsstrahlung photons, so called beamstrahlung. The beamstrahlung photons are focused in a small cone around the beam axis so that they escape through the beam pipe. They can produce neutrons when they hit components of the beam delivery system such as collimators and the beamstrahlung dump. Besides the beamstrahlung photons e^+e^- pairs are produced during a bunch crossing (BX) via $\gamma\gamma \to e^+e^-$, $e\gamma \to ee^+e^-$ or $ee \to e^+e^-$ processes. These pairs either penetrate directly sensitive detector regions or they are bent in the magnetic field of the quadrupole magnets inside the mask and hit the coils or yokes of the magnets and produce neutrons as secondaries. A beam particle can also emit a hard photon via radiative Bhabha scattering. The photon will escape through the beam pipe, while the incident particle (e^- or e^+) is deflected and dumped inside the quadrupole magnets. A very large number of neutrons will be produced inside the main beam dumps of the extracted 250 GeV e^- and e^+ beams.

2 Simulation

To estimate the background which is produced during bunch crossings, namely beamstrahlung, pairs and radiative Bhabhas, the program GUINEA PIG [1] was used. GUINEA PIG calculates the four vectors of the beamstrahlung photons, pairs and particles of the spent beam. The production and tracking of neutrons was simulated using FLUKA [2].

2.1 Detector Description

The aim of these neutron studies was not a precise simulation of the signals in each detector channel, but a rough estimation of the neutron flux the subdetectors are exposed to. Hence a simplified description of the detector was used within FLUKA, but all general components which could potentialy have an influence on the neutron background rate were included. The subdetectors were not described in detail, but as homogenous regions of a material or compound. All details which were not considered to have a

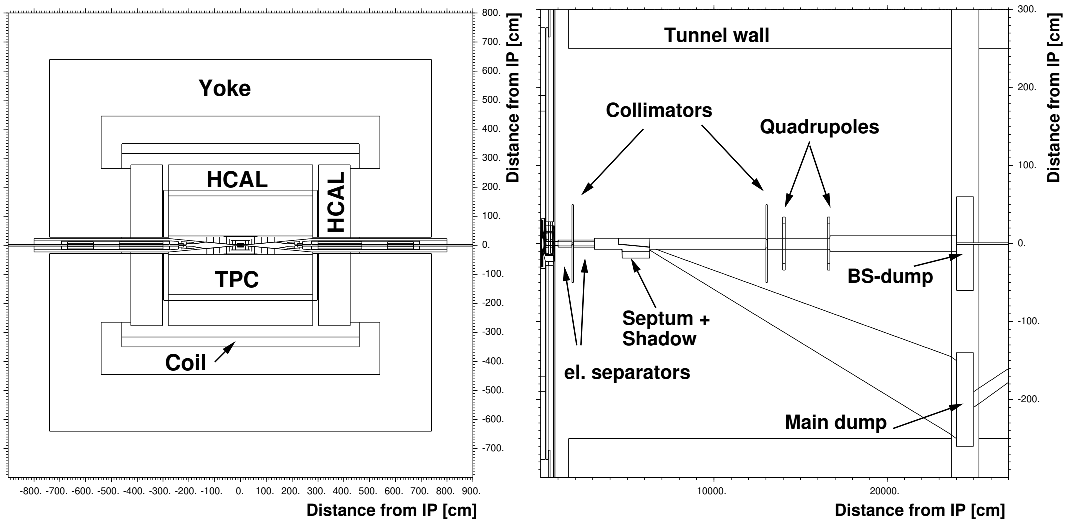

Figure 1: *Sktech of the detector (left) and of the region from detector to the beam dump (right).*

significant influence on the production and tracking of neutrons were neglected. The silicon option was chosen for the electromagnetic calorimeter, which was implemented as a homogenious body of tungsten. For the hadronic calorimeter a uniform mixture of 77 % (vol.) iron and 23 % (vol.) plastic was used. The detector yoke was described as a body of iron. The gap between the cylindrical part of the mask and the inner radius of the endcaps of the calorimeters and yoke was filled with parafin to reduce the neutron background. A magnetic solenoid field of 4 T was implemented in the description. Figure 1 shows the geometry of the detector as it was described in FLUKA, the upper plot of figure 2 shows a more detailed view of the mask region.

2.2 Beam Delivery System

All components of the beam delivery system on both sides between the interaction point (IP) and the dump halls, which are potential locations of neutron production, were taken into account: the two quadrupoles inside the mask (QFD2, QFF2), two quadrupoles further downstream (QFT3, QFT4), the electrostatic separators (ESEP1, ESEP2), the first septum magnet (MSEP) and the shadow screening its blade, as well as the two collimators (COLL1, COLL2). The magnetic fields of the quadrupole magnets were included. The electrostatic field of the separators was replaced by an equivalent magnetic field. This leads to the correct bending of outgoing particles from the IP, but also to deflection of incoming charged particles which in reality will not happen. Because all charged particles (radiative Bhabhas and pairs) which produce neutrons are outgoing, the replacement of the electric field can be used as an approximation. Beam extraction was implemented vertically.

3 Results

3.1 Neutrons from Pairs

Each Bunch Crossing $1.26 \cdot 10^5$ e^+ and e^- are generated via pair production with an average energy of about 2.5 GeV per particle. The neutron production by these pairs was simulated for one BX, using the four vectors of the pairs calculated by GUINEA PIG as the input for FLUKA. The pairs hitting material of the mask and quadrupoles lead to the production of in total 71482 neutrons per bunch crossing with a total energy of about 320 GeV. Figure 2 shows the location of neutron production. The neutrons are mainly produced inside the luminosity calorimeter (LCAL), the two quadrupole magnets inside the mask, the electrostatic separators in front of the detector and the first collimator at 18.5 m distance from the IP. Only about 2 % of the neutrons are produced at larger distances. The number of neutrons reaching subdetectors are listed in table 1.

For the calorimeters only neutrons were taken into account, which deposit energy[1] in the detector. Neutrons which were reflected without depositing energy in the calorimeter were not counted. All numbers are similar to the results of previous calculations [3]. The results presented in the TESLA Technical Design Report were calculated with the same simulation procedure as the results described here, but only 2/3 of a bunch crossing were simulated. The results after 2/3 BX can be found in table 4.

About 4000 neutrons/BX enter the TPC from its inner boundary. Most of them are reflected several times at the surface of the electromagnetic calorimeter which is surrounding the TPC. Counting each of these multiple crossings of a neutron results in roughly 15000 neutrons traversing the TPC per BX. In the simulation the electromagnetic calorimeter was described as tungsten only. If it is implemented as a mixture of lead and plastic instead of tungsten, as it was done to simulate the *Shashlik* option, the number of neutron crossings will be reduced to 8600 per BX.

The neutron flux through the layers of the vertex detector, intermediate tracker (SIT) and the forward tracking discs (FTD) can be found in table 2. The neutron flux is normalised to the silicon bulk damage by total non ionising energy loss (NIEL) of 1 MeV neutrons. The flux is calculated to be of the order of 10^9 1 MeV-equivalent neutrons per cm^2 and year for the most irradiated layers. This is acceptable for all options of the vertex detector, in particular for the CCDs for which radiation damage is most critical. Radiation hardness is less critical for the intermediate tracker and the forward tracking discs. The background estimation after reduced statistics as presented in the TESLA TDR are listed in table 5.

3.2 Neutrons from radiative Bhabhas

About $3.9 \cdot 10^4$ beam particles per BX loose energy at the IP due to radiative Bhabha scattering. The energy of these electrons and positrons after the emission of a photon is

[1]This is not equivalent to the neutron energy measured in the calorimeter, which will be much smaller than the total neutron energy.

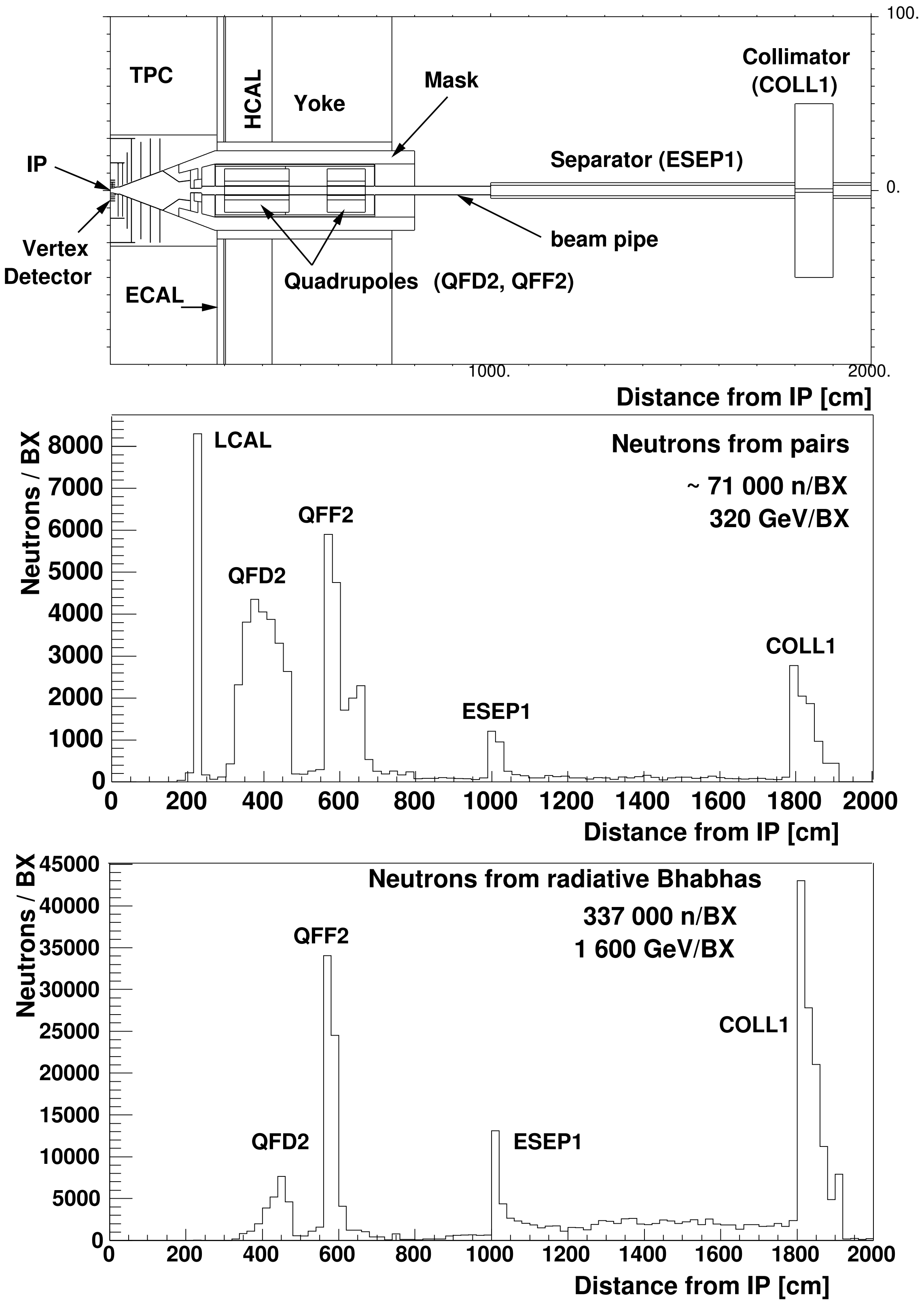

Figure 2: *Sketch of the mask and beam line geometry used with FLUKA (upper plot). Location of neutron production from pairs (middle) and radiative Bhabhas (bottom).*

detector	n from pairs [n/BX]	n from pairs [GeV/BX]	n from RB rad. Bhab. [n/BX]	n from rad. Bhab. [GeV/BX]
ECAL (barrel)	6194	4.69	72	0.009
ECAL (endcap)	2043	1.44	36	0.001
HCAL (barrel)	670	0.87	0	0
HCAL (endcap)	4029	8.03	3792	4.74
LCAL	4880	1.78	0	0
LAT	1642	1.12	0	0
instr. yoke	8429	31.6	54852	121.8
TPC	15070	8.29	132	0.001

Table 1: *Neutron hits per BX in several subdetectors. The energy values for the TPC specify the total energy of all neutrons crossing the TPC. For all other subdetector the energy deposited by the neutrons is listed.*

	flux [1 MeV n/(cm^2 year)]		
layer	vertex detector	intermediate tracker	forward tracker
1	$9.2 \cdot 10^7$	$6.4 \cdot 10^8$	$7.9 \cdot 10^8$
2	$7.7 \cdot 10^8$	$5.6 \cdot 10^8$	$9.1 \cdot 10^8$
3	$5.4 \cdot 10^8$	-	$1.4 \cdot 10^9$
4	$9.4 \cdot 10^8$	-	$1.2 \cdot 10^9$
5	$1.1 \cdot 10^9$	-	$1.4 \cdot 10^9$
6	-	-	$1.2 \cdot 10^9$
7	-	-	$1.2 \cdot 10^9$

Table 2: *Neutron flux through each vertex detextor layer (left column), intermediate tracker layer (middle) and forward tracking disc (both sides added) normalised to the non ionizing bulk damage of 1 MeV neutrons.*

on average 44 GeV per particle. To estimate the neutron production by radiative Bhabhas 3256 e^+ and e^- were tracked through the detector and beam line using FLUKA: Hitting components of the beam delivery system they produce about $3.37 \cdot 10^5$ neutrons per BX with a total energy of 1.6 TeV. Figure 2 (bottom) shows the distance from the IP of the neutron production due to radiative Bhabhas. Most of the neutrons are produced in the second quadrupole magnet inside the mask, in the electrostatic separators and the first collimator.

In spite of the larger number of neutrons produced by radiative Bhabhas compared to pairs they do not cause a significant amount of background in most detector components due to the larger production distance from the IP. The neutron background is negligible for the tracking devices, the electromagnetic calorimeter and the barrel region of the hadronic calorimeter. The inner boundary of the hadronic calorimeter endcaps is hit by about 3800 neutrons per BX. Most neutrons are produced close to the inner boundary of the endcaps of the instrumented iron yoke (muon system). On average 55000 neutrons deposit a total energy of 122 GeV in the iron yoke per bunch crossing. The values for one bunch crossing are summarised in table 1.

3.3 Neutrons from Beam Dump

Both the electron and positron beam are extracted downwards from the incoming beam behind the interaction region. At a distance of 240 m on either side from the IP the extracted beams are dumped into a water tank. Due to the high energy and the large number of particles from the extracted beams, an enormous number of neutrons is produced inside the water tanks and in the concrete wall, which shields the tanks.

To estimate the neutron background in the detector originating from the beam dumps, a two step FLUKA process was used. At the first simulation step 75000 electrons of an energy of 250 GeV were shot into a water tank. The simulation results in each electron generating on average 21 neutrons. This implies for all $2 \cdot 10^{10}$ electrons per bunch a neutron production rate of $4.3 \cdot 10^{11}$ neutrons per BX. Almost all neutrons are absorbed in the water tank or the surrounding concrete shielding. In the simulation only 75 neutrons escaped through the entrance window of the beam dump and 29 penetrated the concrete shielding, which translates to a neutron flux back into the tunnel of $2.8 \cdot 10^7$ neutrons/BX. These neutrons are carrying a total energy of 1270 TeV/BX.

In a second simulation step the neutrons escaping the beam dump were tracked towards the detector. The 104 neutrons found in step 1 were divided into 7 energy classes (see table 3). $9 \cdot 10^5$ neutrons of each energy class were tracked back from the entrance window of the beam dump in direction to the detector. A gaussian distribution was used for the direction of the neutrons with its maximum pointing straight back along the beam axis. The full widths half maximum of the gaussian was taken from the RMS value of the distribution of the azimuthal angle of the 104 neutrons escaping the beam dump which was 373 mrad.

class	energy range [GeV]	number of neutrons	mean energy [GeV]
1	$< 10^{-6}$	11	$4.9 \cdot 10^{-8}$
2	$10^{-6} - 10^{-5}$	5	$4.2 \cdot 10^{-6}$
3	$10^{-5} - 10^{-4}$	7	$4.2 \cdot 10^{-5}$
4	$10^{-4} - 10^{-3}$	4	$3.9 \cdot 10^{-4}$
5	$10^{-3} - 10^{-2}$	18	$3.9 \cdot 10^{-3}$
6	$10^{-2} - 10^{-1}$	41	$5.2 \cdot 10^{-2}$
7	$> 10^{-1}$	18	$1.4 \cdot 10^{-1}$

Table 3: *Energy distribution of the neutrons escaping the beam dump.*

Most of the neutrons (≈ 99.8 %) are absorbed in the tunnel wall. None of the simulated neutrons reaches detector components except the front side of the detector yoke. The yoke is hit by about 33000 neutrons per BX. Roughly 65 % of these neutrons have not interacted on they way from the beam dump to the detector, hence they arrive at the yoke with their initial energy. Figure 3 shows the distribution of the neutrons crossing a plane in front of the detector, parallel to the detector front. The circular contour of the tunnel can be seen clearly. The neutrons in this area come mainly straight from the beam dump. The neutrons which hit the tunnel wall or components of the beam delivery system before they reach the experiment hall are distributed equally over the whole plane. The two circular regions which are cut out from the tunnel contour are the projections of the two collimators onto this plane. The collimator (COLL1) at a distance of 18.5 m from the IP shields a circular region around the beam axis from neutrons. In this way the complete mask region is shielded. The circular sector with less neutron hits above the beam axis is shielded by the collimator (COLL2) at a distance of 130 m from the IP. For both collimators a radius of 50 cm was assumed.

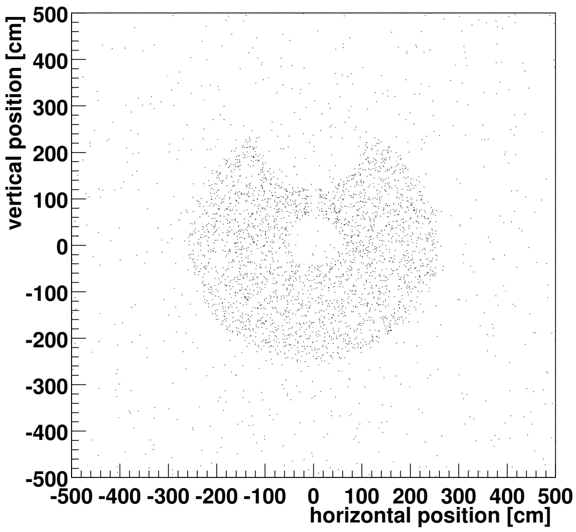

Figure 3: *Distribution of neutrons coming from the beam dump in a plane in front of the detector.*

3.4 Neutrons from Beamstrahlung

Each Bunch Crossing $6.35 \cdot 10^{10}$ beamstrahlung photons at an average energy of 5.1 GeV per photon are produced at the IP. These photons are focused along the beam axis. They do not contribute directly to the background in the detector, although when they hit material of beam line elements and the beamstrahlung dump they produce lots of secondaries which can propagate back to the detector.

For the background estimation $4 \cdot 10^5$ photons were simulated with FLUKA. None of them produces a neutron in the collimators, magnets or the shadow that is screening the blade of the first septum magnet. The reduction of the neutron production compared to previous studies [3] can be explained by a larger aperture of the collimators and the change from horizontal to vertical beam extraction. The cross section of the beamstrahlung at the front of the shadow (45 m distance from IP) can be seen in figure 4. The horizontal (vertical) stripe illustrates the position of the shadow in the horizontal (vertical) beam extraction scheme. The shadow is hit by many photons and contributes to the neutron background in the horizontal scheme. Using a vertical beam extraction as it is planned now the shadow is placed below the beamstrahlung cone.

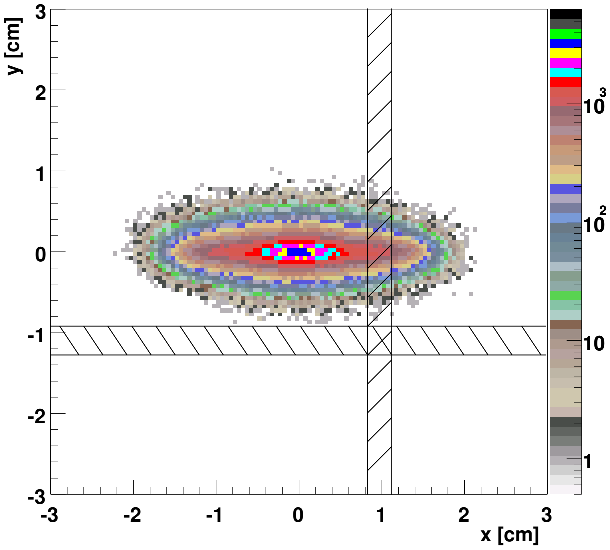

Figure 4: *Distribution of the beamstrahlung at a plane perpendicular to the beam axis at a distance of 45 m from the IP. The position of the shadow in a horizontal (obsolete) and the now favoured vertical beam extraction is symbolised by the lined boxes.*

The simulation shows that more than 80 % of the photons are absorbed in the beamstrahlung dump. Each photon creates on average 0.41 neutrons, leading to a number of $2.6 \cdot 10^{10}$ neutrons per BX. Hence, the neutron production in the beamstrahlung dump is one order of magnitude lower than in the main beam dump. After the simulation of $4 \cdot 10^5$ photons only a single neutron produced inside the beamstrahlung dump was scattered backwards inside the tunnel. This shows that the beamstrahlung dump can be neglected as a source of neutron background in the detector.

4 Conclusion

The production of neutrons from pairs, radiative Bhabhas, beamstrahlung and inside the main beam dump was studied. Only pairs produce a significant neutron background inside the tracking devices. Radiative Bhabhas produce a large number of neutrons in the second quadrupole inside the mask which causes a neutron background ($\mathcal{O}(50000)$ n/BX) inside the instrumented detector yoke (muon system). The neutron flux at the mask region of neutrons coming from the beam dump is negligible, because this region is screened by the collimators (COLL1). About 33000 neutrons from the beam dump per BX hit the front side of the yoke. The contribution of beamstrahlung to the neutron background can be neglected.

The neutron flux through the individual detector components is considered to be acceptable. In order to get a more precise understanding of the effect of the neutron background to each subdetector further investigations using a detailed detector simulation should be done.

detector	n from pairs [n/BX]	n from pairs [GeV/BX]	n from RB rad. Bhab. [n/BX]	n from rad. Bhab. [GeV/BX]
ECAL (barrel)	6031	4.9	60	0.008
ECAL (endcap)	1993	1.2	30	0.001
HCAL (barrel)	669	0.3	0	0
HCAL (endcap)	4000	8.2	3160	3.95
LCAL	4890	1.3	0	0
LAT	1633	0.9	0	0
TPC	14551	-	110	-
total number of produced n	70884	322	$2.8 \cdot 10^5$	1300

Table 4: *Neutron background created by pairs and radiative Bhabhas. These numbers are based on lower statistics than the values in table 1. They are quoted in the TESLA Technical Design Report.*

layer	vertex detector	intermediate tracker	forward tracker
	flux [1 MeV n/(cm^2 year)]	hits/BX	hits/BX
1	$1.4 \cdot 10^8$	95	21
2	$1.1 \cdot 10^9$	344	19
3	$7.9 \cdot 10^8$	-	53
4	$1.4 \cdot 10^9$	-	104
5	$1.4 \cdot 10^9$	-	92
6	-	-	96
7	-	-	93

Table 5: *Neutron background created by pairs in the silicon detectors. These numbers are presented in the TESLA Technical Design Report and are calculated with lower statistics than the background listed in table 2.*

References

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[3] N. Tesch, *Beam-Beam, Neutron ans Accelerator Background at TESLA*, talk given at the LC Workshop, Sitges, Spain, 1999; slights available at: http://www.desy.de/ lcnotes/notes.html