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A Photon Collider at TESLA

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Abstract

A photon collider is an option for a future e^+e^- linear collider. In this note the implementation of a photon collider at the superconducting machine TESLA is studied. Special attention is given to the laser system needed to convert electrons into high energy photons.

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A PHOTON COLLIDER AT TESLA

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A photon collider is an option for a future e^+e^- linear collider. In this note the implementation of a photon collider at the superconducting machine TESLA is studied. Special attention is given to the laser system needed to convert electrons into high energy photons.

1 Introduction

The aim of a photon collider is to study processes like $\gamma\gamma \rightarrow H \rightarrow b\bar{b}$, $\gamma\gamma \rightarrow W^+W^-$ and $\gamma\gamma \rightarrow$ SUSY [1] which needs a machine with an energy range from $\sqrt{s_{\gamma\gamma}} \sim 120\,\mathrm{GeV}$ up to the maximum possible energy. The photon collider has to be adapted to the bunch structure of TESLA, this means trains of 2800 bunches with 337 ns time between two bunches and a train repetition rate of 5 Hz. Especially the design of the conversion laser is completely driven by this bunch structure and thus not applicable for the warm technology.

The large disruption of the electron beams in the electron-laser interaction requires a beam crossing angle of about 35 mrad. The forward part of the $\gamma\gamma$-detector is completely driven by this crossing angle and the space needed for the laser pipes. The central part of the detector is assumed to be identical to the e^+e^- one, described in the TESLA TDR[2].

2 The Laser

The wavelengths of the most powerful solid state lasers are around $\lambda = 1\,\mu\mathrm{m}$ which is, with $x = 4.5$, almost ideal for $\sqrt{s} = 500\,\mathrm{GeV}$ [1]. The laser focusing for a diffraction limited laser is given by $\sigma_{L,r}(z) = \sigma_{L,r}(0)\sqrt{1 + z^2/Z_R^2}$, $\sigma_{L,r}(0) = \sqrt{\lambda Z_R / 2\pi}$ with Z_R being the Rayleigh length. It is thus not possible to vary the length and diameter of the laser focus simultaneously. If the Rayleigh length is chosen to be equal to the bunch length for head on electron laser collisions a laser pulse power of around 2 J is needed to reach a high conversion efficiency. This corresponds to a laser power of $2 \times 30\,\mathrm{kW}$ or 50 Mercury lasers from the Livermore fusion program [3].

As an alternative for TESLA it is proposed to recycle the photons using a resonant ring cavity. The total length of the cavity has to be $\sim 100\,\mathrm{m}$, matched to the inter-bunch time of TESLA. The cavity can be built around the detector where all mirrors are mounted outside the detector.

To keep the diffraction losses in the cavity low highly efficient mirrors are needed making a crossing angle between the beam and the laser necessary, which results in a smaller conversion probability. The size of the crossing angle is given by the Rayleigh length, determining the beam divergence and the angle where the beam is cut off, leading to diffraction losses and a broadening of the focal spot. This makes a complicated optimisation procedure necessary to determine the optimal Rayleigh length and mirror size.

The diffraction losses and the broadening of the focal spot have been calculated with the program GLAD [4]. Due to numerical problems the calculations had to be done for larger spot sizes and have been extrapolated to the desired ones around $\sigma = 15\,\mu$m. Fig. 1 a) shows that diffraction losses are no problem for small spot sizes. However, as seen in Fig. 1 b), small mirrors result in a significant broadening of the beam.

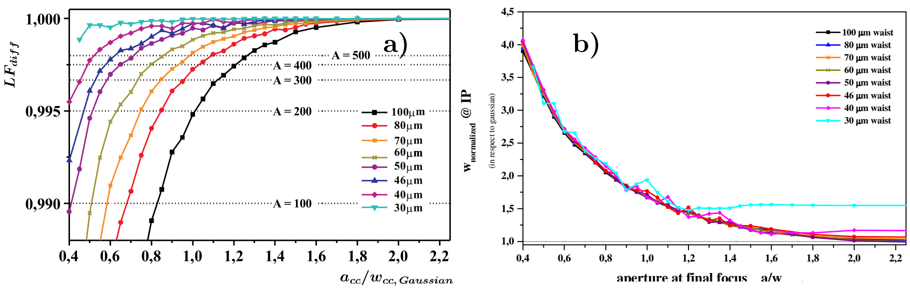

Figure 1: Diffraction loss (a) and diffractive broadening (b) as a function of the focusing mirror size in units of the beam divergence for different values of the laser focal size.

Fig. 2 shows the luminosity as a function of the collision angle for different cutoff parameters in the beam divergence. The crossing angle is calculated as the cutoff parameter times the beam divergence plus 17 mrad to ensure a sufficient distance of the mirror from the beam to install the focusing quadrupoles. The maximum is reached for relatively small mirrors. A mirror size of $a/w = 0.75$ and a crossing angle around 55 mrad, which is chosen in the rest of the study. These values are to be understood as a compromise between optimal luminosity and a not too large dead region at small angles. The corresponding Rayleigh length is 0.63 mm. With a laser pulse energy of 9 J, corresponding to a non-linearity of $\xi^2 = 0.3$ a luminosity of $\mathcal{L} = 1.1 \cdot 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for $z > 0.8 z_{\max}$ can be reached, consistent with [1].[a]

[a] Contrary to fig. 2 for this value of $\mathcal{L}$ the non-linearity parameter ξ^2 is included in the definition of $z_{\max}$.

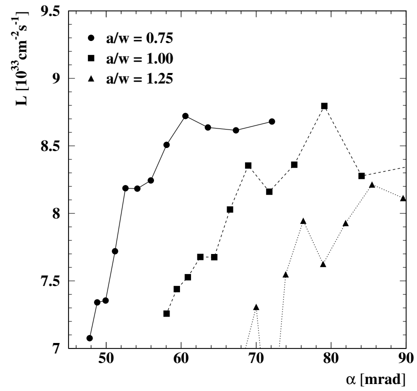

Figure 2: Luminosity as a function of the laser-beam crossing angle for different values of the beam cutoff for $\sqrt{s_{\gamma\gamma}} > 0.654\sqrt{s_{\mathrm{ee}}}$

To reach the required laser power tight tolerances for the mirrors have to be kept. The total length of the cavity has to be constant with a precision below 1 nm. Procedures for this have been developed in the framework of the gravitational wave antennas [5]. The mirrors of the telescope have to be stabilised with a precision of around 100 nm. The procedure for this still has to be developed.

A possible design of the laser resonator in the experimental hall is shown in figure 3.

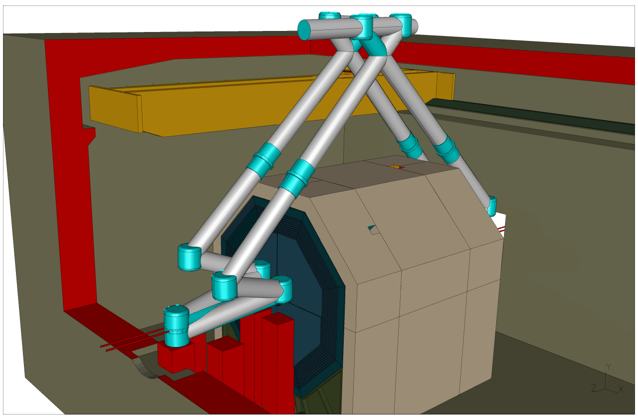

Figure 3: Design of the laser cavity around the detector

3 Detector and Backgrounds

The background in the detector is driven by the large disruption angle and the angle between the outgoing beam and the B-field. A photon collider will be operated with two e^--beams, so that direct background from pair production is smaller than in e^+e^-. However there is a large potential of background from backscattering at the detector exit. To protect the detector from this a tungsten mask around the beam- and laser pipes has to be added (see fig. 4). With this mask the total background in e^+e^- and $\gamma\gamma$ is about the same.

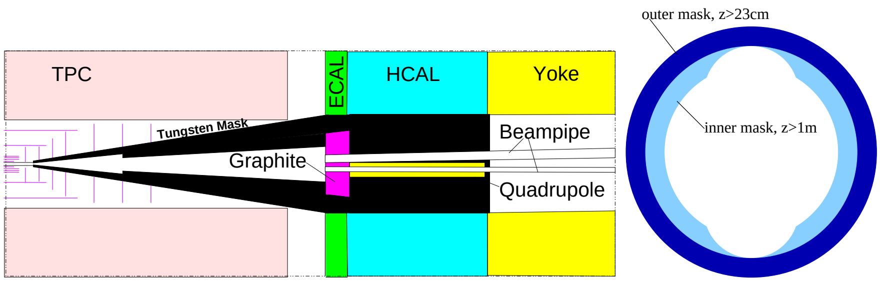

Figure 4: Design of the mask for the $\gamma\gamma$ detector, left:$x-z$-, right:$x-y$-projection.

4 Low energy $q\bar{q}-$Background

Because of the large luminosity and high cross section of $\gamma\gamma \to q\bar{q}$ at low $\sqrt{s}$ one to two pileup events will be overlaid in each bunch crossing depending on the running scenario. Roughly half of the charged tracks originating from these events can be be tagged by the vertex detector due to the separation of the vertices in the z-direction. The tracks from the pileup events are forward peaked, so that they can be largely rejected if the physics channel of interest is concentrated in the central region of the detector, like the production of Higgs bosons. However for physics channels that are also peaked in the forward region, like the production of W-bosons [6], the pileup events are a severe problem. Fig. 5 shows the W-mass spectrum from the $e\gamma \to We\nu$ analysis with and without pileup tracks [6]. After pileup rejection the spectrum gets significantly broadened and time stamping on the single bunch level is definitely needed.

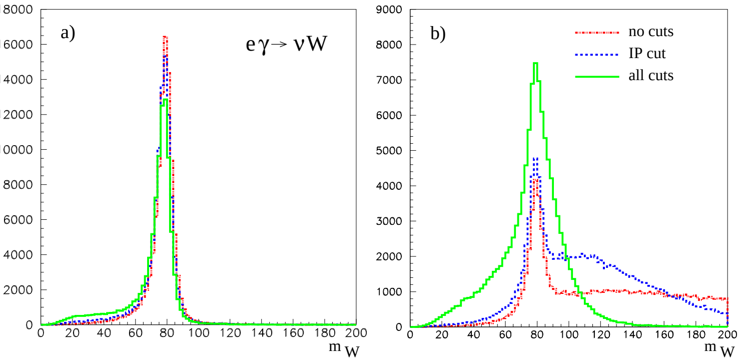

Figure 5: Reconstructed W-mass at the different levels of pileup rejection without (a) and with (b) overlaid pileup events in the e$\gamma \rightarrow$ Wν analysis.

5 Conclusions

According to present studies it is possible to implement the photon collider option at TESLA. A laser cavity to recycle the laser power is difficult, but no showstoppers have been found. Backgrounds in the detector are under control adding masks around the laser and beam pipes. With the high luminosities envisaged the pileup from overlaid $\gamma\gamma \rightarrow$hadrons events will become a problem and unique bunch tagging is mandatory.

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