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CALCULATION OF DETECTOR BACKGROUNDS AT TEV LINEAR COLLIDERS*

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ABSTRACT

It is necessary to carefully design masks and beam lines to prevent the high energy physics detector from being inundated with background particles from a high energy linear collider. Presented here are preliminary calculations on two of the three expected backgrounds: (1) photons from synchrotron radiation produced in the final focus quadrupoles, and (2) electrons which lose energy due to beamstrahlung and are then bent into a mask or quadrupole by the field of the opposite beam. The former can be controlled with proper masking. The later may pose a problem so further calculations are needed. Work was also done on the third expected source of background: electrons in the tail of the beam which hit masks where showers are made whose products enter the detector. This work was very preliminary and is not included in this write-up. All the calculations here are based on the 1 TeV center-of-mass linear collider design of R. Palmer and the final focus design of K. Oide which can be found in these proceedings. Extrapolations to other accelerator designs should be straightforward.

BACKGROUNDS FROM SYNCHROTRON RADIATION

As an electron goes through the bend and quadrupole fields of the final focus, it emits synchrotron radiation photons. These photons may enter the detector either directly or by penetrating or being reradiated from a mask. The goal of the mask design is to minimize the number of photons entering the detector. From SLC design studies, this number must be kept below about 1000 photons or the occupancy of the detector is high enough to degrade its pattern recognition capabilities. This is the first of many times the existing 100 GeV SLC design will be used as a benchmark to which our new 1 TeV Linear Collider (TLC) design will be compared.

The first step in the calculation is to make a scale drawing of the quadrupoles near the Interaction Point (IP). For the TLC the final quadrupoles have an inner bore $100\,\mu m$ in radius and cover a distance of 0.4 to 1.2 meters from the IP. Using the β functions from Oide's design, the trajectory of a particle at five standard deviations is superimposed on the drawing. Since synchrotron radiation (SR) is emitted tangentially to the electron's trajectory (the opening angle of $1/\gamma$ is negligible) it is easy to estimate where the radiation will hit. One can also estimate the range of standard deviations of electrons which will generate photons to hit a certain mask or quadrupole. The number of photons radiated by an electron is given by

$$N_\gamma = 2.06\ (\frac{E_{\text{beam}}}{100\ \text{GeV}}) \cdot \theta\ (\text{m}R)\ ,$$

where θ is the bend angle of the electron. Putting this all together with the fact that there are a total of 2×10^{11} incident electrons per pulse we can now calculate how many photons will hit the quadrupoles. Electrons between 2.8 and 3.6 σ will produce 1.1×10^9 photons which will hit the quadrupoles on the far side. Electrons outside 5σ will produce 1.4×10^5 photons which will hit the quadrupoles on the side of the incoming beam. The critical energy of these photons will be about 50 MeV.

This is a lot of photons especially when you consider that they are hitting a quadrupole which is inside the detector. Let's put in the best mask allowed by the constraints of detector acceptance (down to 10°) and see what happens. A 3.5 cm radius tungsten (because it is dense and has a large Z) rod which completely surrounds the quadrupoles and goes to within 20 cm of the IP just stays within the allowed 10°. In the center of this rod is drilled a $120\,\mu$m radius hole to a depth of 15 cm. For the next 5 cm the hole narrows to a $100\,\mu$m radius. For the next 80 cm we have the quadrupole with its $100\,\mu$m bore which is contained inside the tungsten mask. Making and aligning a mask with such a small hole in it may seem difficult, but compared to making the quadrupole it really isn't.

The purpose of this mask is to make it so the shower products from photons which hit the quadrupoles have a very small solid angle to enter the detector. The angles of the primary SR photons are so small that no photon can hit the $120\,\mu$m part of the hole since it is shadowed by the $100\,\mu$m part of the hole. So, to get to the detector a photon must either penetrate through the tungsten or make its way through a 15 cm long pin hole. The solid angle to get through the pin hole is 1000 times smaller than the equivalent in the SLC design. Photons penetrating the mask dominate.

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Calculations of the penetration probability were done by H. DeStaebler using the electromagnetic shower simulation (EGS). Photons with a 50 MeV critical energy synchrotron radiation spectrum were simulated hitting the tungsten 15 cm from the end of the rod. For each incident photon only 0.004 came out the end. However, 0.17 came out the side of a 3.5 cm radius rod. Similarly, 0.02 and 0.002 came out of 6 and 10 cm rods, respectively. Given the 10^9 photons hitting the quadrupoles, this reduction factor is insufficient. Two improvements are needed to get an acceptable background.

The first improvement of 10^4 comes easily. We need to account for the 4 mR crossing angle of the beams, which is specified in the TLC design for other reasons. Because of this crossing angle, the outgoing beam doesn't have to go through the $100\,\mu$m bore of the quadrupole. Instead it goes 1.6 mm off to the side where there can be a larger hole. The crossing angle was originally put in the design so the disrupted electron beam would not have to pass through the center of the quadrupole. It has the same benefit for the outgoing SR photons. As long as the hole in the side of the quadrupole is at least $200\,\mu$m in radius no SR photons will hit it.

This still leaves us with the $0.17 \times 1.4 \times 10^5 = 2.4 \times 10^4$ photons which hit the quadrupole on the side of the incoming beam and penetrate the 3.5 cm thick mask around the quadrupole. This is a factor of 20 more than the detector can handle. The mask cannot be made thick enough to reduce this without encroaching on the solid angle reserved for the detector. The solution we arrived at was to increase the size of the quadrupole. Palmer redesigned the TLC with a quadrupole aperture of $10\sigma_{\text{beam}}$ instead of $6\sigma_{\text{beam}}$. This resulted in only a 10–20% reduction in the design luminosity while giving a very large reduction in the calculated synchrotron radiation background (there are many fewer particles outside 8σ than outside 5σ).

Having solved the toughest problem, let's look farther upstream to see if there are other magnets which will cause SR problems. The next quadrupole is 13 m from the IP. It is much weaker ($k = -.0249$ compared to the -3.416 of the quadrupole closest to the IP). It is also five times longer, so its field is very weak. The critical energy of the SR should be about 0.1 keV. This is so low that there is no problem stopping them from reaching the detector.

Finally, consider the last bend magnet which is 100 m from the IP. Only the last part of the bend which sweeps the beam past the $100\,\mu$m radius hole in the quadrupoles at the IP matters. This bend angle is $100\,\mu\text{m}/100\,\text{m} = 1\ \mu$ R. Hence, we expect 2×10^6 photons heading towards that hole. Note that only 1% of these photons will actually hit the inside bore of the quadrupole. The rest will pass right through and hit someplace well downstream of the detector. This still leaves 10^4 photons hitting the inside bore of the quadrupole inside the detector. Since the bend has a 0.144 kG field they will have a critical energy of 2.4 MeV. This is an uncomfortably large number of high energy photons being deposited inside the quadrupole. A significant number will penetrate the 3.5 cm thick mask. To fix this the last couple of microradians of the bend should be made with a lower field (a soft bend) to reduce the critical energy by about a factor of 25.

In summary, with moderate redesign we can avoid having synchrotron radiation contribute significantly to the detector's background. Note that the $100\,\mu$m radius of the quadrupoles sets the radius scale. Hence the minimum radius of a vertex detector will be determined by detector technology rather than the few hundred micron limit that background considerations set.

BACKGROUND DUE TO BEAMSTRAHLUNG FOLLOWED BY DISRUPTION

In the design of the TLC a maximum disruption angle is calculated. This is the maximum angle an outgoing electron has due to the kick it receives from the electromagnetic fields of the opposing positron bunch. The pinching of one beam by the other is included in the calculation. This maximum disruption angle is used to determine the crossing angle of the two beams to ensure there is a hole in the side of the quadrupole large enough to accept the outgoing beam. Not included in the calculation is the fact that an electron may lose energy due to beamstrahlung (synchrotron radiation in the field of the opposing beam) and thus be disrupted more. In some designs with a large beamstrahlung parameter it is possible for an electron to lose a large fraction of its energy in a single radiation event.

To see if beamstrahlung followed by disruption could be a source of background we made a simple computer model. The oncoming beam was considered to be Gaussian in z but very thin in y, and much wider in x than in y. Note that the TLC design has a 100:1 $x : y$ aspect ratio. Disruption of the oncoming beam was ignored. An electron was allowed to radiate up to 99.9% of its energy at any z from -0.5 to 3.5 σ_z. Electrons starting at 2, 3, 4, 6 and 8 σ_y were considered. The path of each electron was calculated by integrating the equations of motion out to $z = 5\sigma_z$. The outgoing angle was then calculated. For the case of no radiation the answer obtained agreed with previous calculations (0.25 mR). The largest disruption angle seen for an incident electron which radiated less than 99% of its energy at y less than $4\sigma_y$ was 1.1 mR. This should just manage to make it through the hole in the side of the quadrupole. However, the largest disruption angle seen when an electron was allowed to radiate up to 99.9% of its energy at a y up to $8\sigma_y$ was 2.7 mR. Such an electron would certainly hit the face of the quadrupole in the present design.

Time did not allow the calculation of the probability of such an event. The fact that there are 2×10^{11} electrons per pulse and that just a few electrons hitting the quadrupole will cause serious background problems for the detector certainly gives cause for worry. There are also arguments saying that the problem should be worse in the x direction than in the y direction. A more complete calculation is needed to see if we have a serious background here.