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DETECTOR BACKGROUND CONDITIONS AT LINEAR COLLIDERS*

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ABSTRACT

Detector backgrounds at the Stanford Linear Collider are discussed with emphasis on their sources, and methods of controlling them.

1. Introduction

There are two sources of backgrounds for a particle physics detector at an e^+e^- linear collider. The detector must function in the presence of debris from high-energy showers created when beam particles are accidentally or deliberately lost, and must coexist with synchrotron radiation created while focusing the beams to the Interaction Point (IP).

Of course both of these backgrounds exist at other types of accelerators, but in many ways the "once-through" design of a linear collider makes them more severe. Since far off-axis particles are not naturally removed, it is as if the detector is always trying to take data during injection.

At the Stanford Linear Collider (SLC) we are learning to diagnose and control these backgrounds within the constraints unique to linear colliders and the existing structure of the MARK II detector.

2. Synchrotron Radiation

Masking near and inside the detector is intended to attenuate the synchrotron photon flux from a nominal Gaussian beam before it reaches the active volume. In the case of the MARK II there are no direct paths for photons into the detector (see Fig. 1). Photons scattering several times, especially off the edges of masks, remain able to cause hits.

The density of a Gaussian beam drops off rapidly with radius. This is fortunate, since the number of photons radiated and their critical energy grow linearly with the radius of a particle's orbit in the quadrupole. Additionally, photons created at

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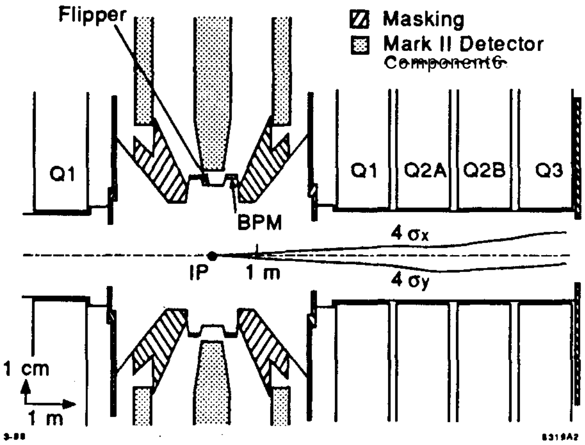

Figure 1: Detector masking layout of the MARK II. Particle orbits are shown for four times the nominal angular divergence in the horizontal (x) and vertical (y) planes.

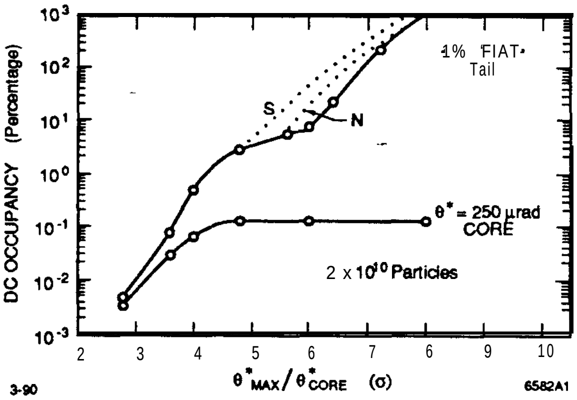

Figure 2: Detector occupancy as a function of aperture for two different assumed beams. See text for details.

higher radii have a much more favorable geometry for entering the detector. An excess of particles at large radii (i.e., a "tail") can thus cause significant problems. Figure 2 shows a calculation of the percentage of sense wires hit in the MARK II central drift chamber (vertical axis) as a function of the aperture of the beam collimation system of the SLC. This aperture is typically set at 5 to 6σ. The lower curve is for a Gaussian beam of 250 μrad angular divergence, similar to the core dimensions of the beam the SLC has been providing. The background is negligible, even without collimation. The upper curve shows a greatly increased background from a beam with 1% of the particles in a tail extending out to the edge of the collimator acceptance. The kink near the center of the plot is produced by particles that have

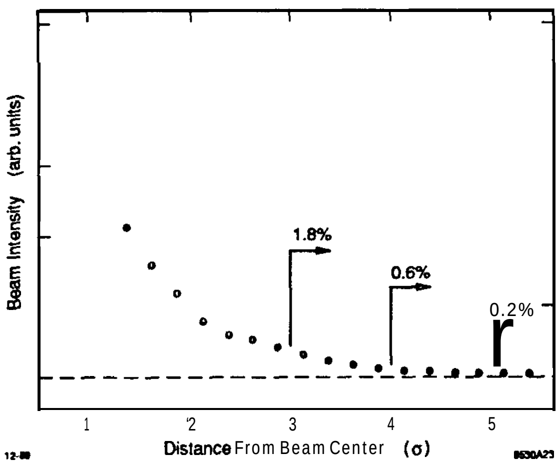

Figure 3: A beam profile measured in the SLC Final Focus System under normal running conditions. Collimation was set to typical values.

reached a large enough radius in the quadrupoles to cause the photons they radiate to strike unmasked sections of the beampipe near the IP.

The N and S curves give an indication of how the calculated background would change given possible misalignments of the internal masking.

3. Controlling Beam Tails

Excessive beam tails have been observed at the SLC (see Fig. 3), and their control has consumed a significant amount of operational and simulation effort.

Unfortunately, it is the nature of linear accelerators to produce non-Gaussian beams. Transverse wakefields’ and chromatic effects[2] are both capable of causing growth in the effective emittance of sections of the beam phase space. For example, wakefields act to move the trailing particles transversely away from the leading particles. Careful operation of the linac can minimize these effects, but in practice as much as 10% of the beam particles can still be found at radii beyond five times the core sigma of the beam.

The largest reduction is achieved with collimation; however, there are limits to how much of the beam can be removed this way. Electrons and positrons with 45 GeV of energy are hard to stop cleanly. Particles hitting within a few tens of microns of the edge of a jaw have a high probability of scattering back into the beam with only a small energy loss (see Fig. 4). With small beam cross sections, this new “edge scattered” population can be a significant part of the total beam striking the collimator. In a single pass collider these particles must be removed by

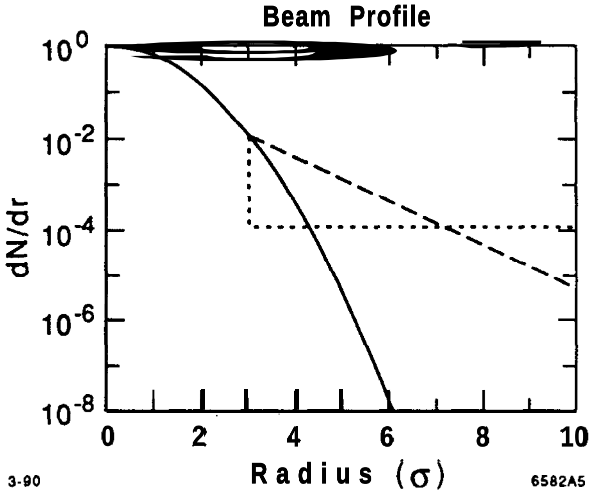

Figure 4: Schematic beam radial profiles. The solid line is a nominal Gaussian beam. The dashed line represents a typical tail before collimation. The dotted line represents the profile after a single set of collimators set at 3σ nominal. Note the large region filled in by edge scattering.

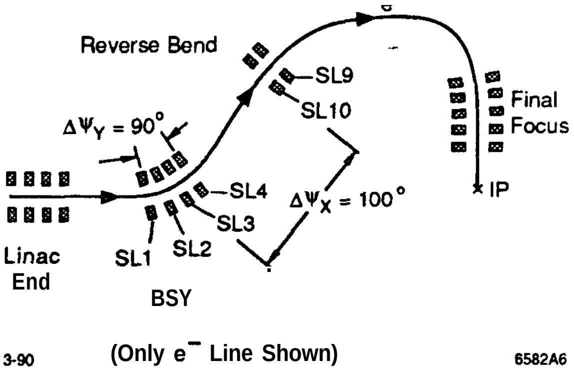

Figure 5: The general layout of SLC collimation. Sixteen movable collimator jaws are located at the end of the linac, 16 in each side of the Beam Switch Yard and Arcs, and 19 in each side of the Final Focus System.

collimation further downstream. Furthermore, intense bunches very near collimator surfaces can be deflected causing additional emittance growth.[3]

Collimation at the SLC is done in a number of locations (see Fig. 5). Primary collimation is done at the end of the linac by 16 separately adjustable jaws. Since both electron and positron beams are present, coupled steering constraints make it difficult to achieve well-controlled, independent cuts on the beam phase space. A momentum cut and some secondary collimation is done in the Beam Switch Yard (BSY) and the Arcs. Space in this area is filled with optical elements, the dispersion is typically nonzero, and it has not been possible to put collimators at optimal betatron phases.

Final collimation takes place in the Final Focus System (FFS), just before the IP. Although these collimators are well situated for primary collimation of tails produced by beam gas and optical imperfections in the Arcs, the resulting shower debris this close to the detector causes special problems. The radiation level must be reduced by about a factor of 10^5 between the collimator region and the detector. This is done with a combination of distance and shielding. Additionally, for every 10^4 particles hitting collimators, a pair of muons are produced via the Bethe–Heitler process. The probability of these muons reaching the detector range from unity to a few percent, depending on where in the FFS they are created. Installation of large toroidal shielding magnets has reduced this effect by about an order of magnitude, but it remains important to collimate as far upstream as possible.

It is also possible to reduce backgrounds by changing the optics of the FFS. Reducing the demagnification of the FFS decreases the angular divergence of the beam at the IP while increasing the spot size. This makes the beam, including the tails, smaller in the quadrupoles and thus reduces background. Although this will tend to reduce luminosity, the increased running efficiency due to lower background can make this a net gain in luminosity logged by the detector. Higher-order aberrations in the optics contribute to the spot size,[4] so the loss of luminosity with decreased angular divergence is small at first. Figure 6 shows the MARK II case, where lowering the angular divergence of the beam at the IP from 300 to 250 μrad makes a very large difference in the background. This corresponds to a loss in luminosity of approximately 25%.

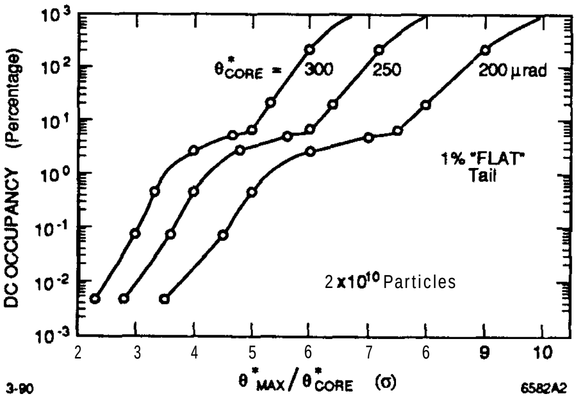

Figure 6: Detector occupancy as a function of aperture. Each curve assumes a different Final Focus System demagnification, which changes angular divergence at the Interaction Point. All simulated beams include a 1% "flat" tail.

Finally, one can limit the beam intensity. Although this costs luminosity, the rapid growth of wakefields and other collective effects with bunch population means that small changes in current can have large effects on backgrounds.

In practice, both restricted angular divergence and intensity are used to balance luminosity and background. The SLC is typically run at the highest currents possible without MARK II deadtime exceeding 15%. MARK II can take data until the occupancy of its drift chambers approach 20%. Above that, dead time from spurious charged track triggers[5] and from the long readout time associated with large numbers of -background hits increases very quickly, and the logged luminosity decreases.

4. Shower Background

From the very far off-axis tails there are problems with particles showering near the IP. At SLC the recent addition of vertex detectors provided a new view of backgrounds near the collision point (see Fig. 7). Simulation indicates the presence of charged particles with energies from 1 to 15 MeV is consistent with showers produced by 10–100 particles of 50-GeV energy hitting the Ml mask at the entrance to the final triplet (the Ml mask is shown at the right in Fig. 1).

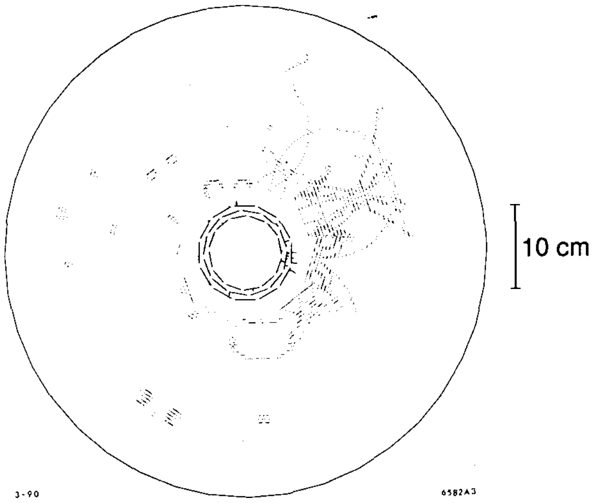

Figure 7: Backgrounds in the MARK II vertex detectors in a typical event. The looping charged particles have energies up to about 10 MeV. The centimeter sized dark areas are thought to be energetic electrons from scattering of photons.

Measures taken to control the number of particles at large radius in the quadrupoles reduce these showers in addition to reducing synchrotron radiation.

This background component.is much less stable than synchrotron radiation. It is common in the SLC for a klystron to misfire on several consecutive pulses.

The fast energy feedback cannot compensate for this short outage, and one or both beams are left about 250 MeV low in energy. Depending on where in the linac the fault occurs, a significant fraction of the beam can hit the momentum slits in the BSY or (due to betatron mismatches) the collimators at the end of the linac. Edge scattering then results in sudden large occupancies in the detector. A "klystron veto" system suppresses triggers in the detector when the accelerator control system detects this condition, but undetected misfires and bad pulses from other sources can cause significant dead time while the detector reads out a few events with very high occupancy.

The cure for all these close-in showers is thought to be careful control of the collimation to better remove secondary and tertiary particles. During the current SLC installation period, many of the BSY and Arc collimators are being repositioned so that they are better able to cut all sides of the beam phase space. Additional collimators are also being built for the end of the Linac to allow better cleanup of secondary particles before the collimators in the BSY.

Acknowledgments

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