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Spray Electron Beam for Tests of Linear Collider Forward Calorimeter Detectors in SLAC End Station A

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Introduction

One of the challenges for NLC detector instrumentation is to design robust detectors for the far forward direction near the electron and positron beams exiting from the collision point. Detectors in the forward regions that can measure the spray of mostly low energy (few GeV) electromagnetic debris from the collisions are envisioned to serve as luminosity monitors. Measurements of the energy and angular distribution of the low energy flux can be used to extract information about the e+e- beam shapes. In addition forward calorimeters will be used to look for high energy (hundreds of GeV) electrons and positrons expected from some types of high energy interactions . Detecting high energy electrons or positrons, or putting limits on the non-observation of them, in the far forward region is important for eliminating certain physics backgrounds from searches for interesting new particles. It is known from recent simulations (see for example Maruyama, Ref [1], and Fig 1 and Fig 2 below) that the regions around the exiting e+ and e- beams are flooded with a sea of low energy e+e- pairs produced in the e+e- collisions. The low energy pairs spiral along the strong magnetic field of the main detector solenoid and are channeled out and deposited onto the front face of any detector trying to measure in the far forward direction. Much work is in progress by various groups to find detector technology and design with sufficient resolution in energy and time to operate in this harsh environment. The purpose of this note is to describe a method for producing a spray beam of electrons in the few GeV energy range with intensity, spacial density, and time structure similar to that expected from the pair background in the NLC that could be useful for testing prospective detector technologies.

The method proposed is to utilize existing components of the SLAC Beam Switch Yard (BSY) and A-line to deliver a beam of few GeV electrons that fills the aperture of the beamline entering End Station A (ESA). This would be accomplished by directing the SLAC electron beam onto an existing Be target in the BSY and then using the A-line to select electrons from the shower spray out of the Be target in a variable momentum range. The time structure, energy, and intensity of the spray beam could be widely varied. This note describes the devices to be used, possible operating parameters, and the expected range of rates of electrons and the small background of hadrons that could be produced.

NLC Pair Flux Parameters To Be Simulated in Tests

The primary electron beam for this test beam would be the main SLAC electron beam

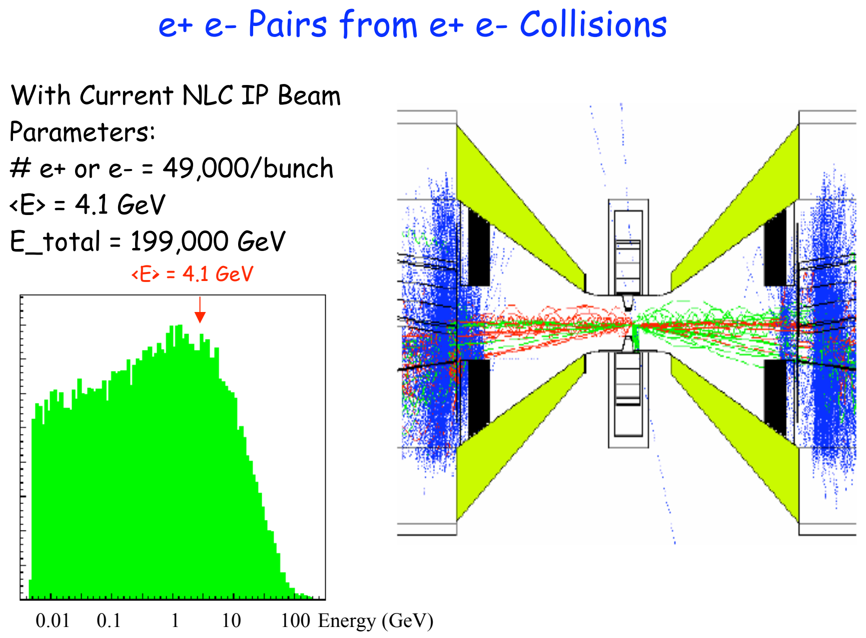

Figure 1: Electron-positron pair flux into the forward detectors at the NLC per e^+e^- bunch collision from simulations by T. Maruyama, Ref [1].

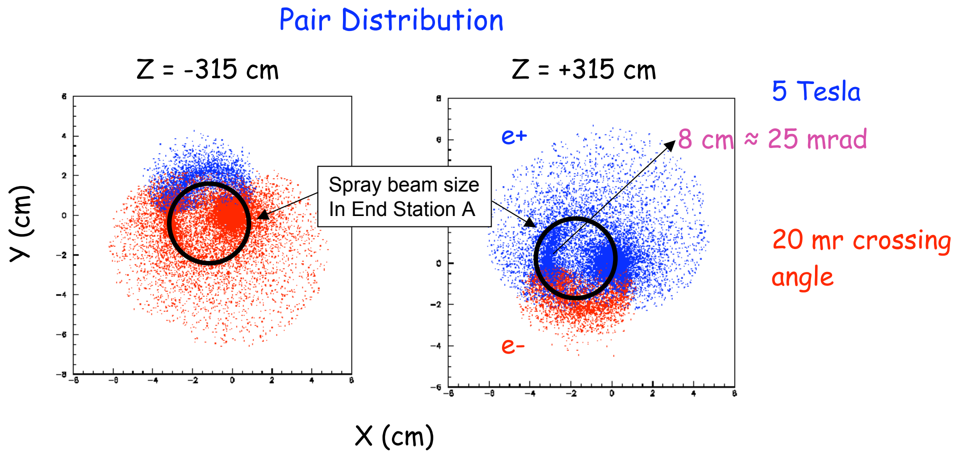

Figure 2: Spatial distribution of electron-positron pair flux into the forward detectors at the NLC per e^+e^- bunch collision from simulations by T. Maruyama, Ref [1]. Also indicated is the size of the electron spray beam in End Station A described in this note.

in any of a number of possible configurations. The energy, intensity (electrons/pulse), and time structure of the primary beam can be arranged to generate the secondary electron beam to simulate various features of the expected pair flux at the NLC shown in Fig 1 and Fig 2 below. For each e+e- bunch collision there is expected to be approximately 49,000 e+ or e- mostly at energies below 10 GeV, with the peak in the flux around 1 GeV and an average energy of 4 GeV deposited onto the forward detectors. The spatial distribution on the forward detectors seen in Fig 2 is formed by the energy and charge dependence of the channeling in the solenoid field, and results in several large blobs of energy deposited over tens of cm^2. Two jobs for the forward calorimeter detectors would be: 1) integrate the pair background spray from each bunch collision to determine the luminosity, 2) measure the spatial, energy, and time distribution of the pair flux to extract information about the beams in collision and, 3) identify and measure the energy of any single high energy electrons or positrons in the presence of the large energy deposit from the pair background. This requires a detector with good spatial granularity, fast time response to avoid confusion from multiple collisions, and reasonable energy resolution to separate the high energy signal from the sea of low energy background.

Primary Electron Beam and Production Target

The method of the proposed test beam technique is to use the Be target to convert high energy incident electron beam with small emittance into a shower spray beam with wide energy and angle distribution at lower energy. A small slice of the spray can be selected by the energy and angle acceptance of the A-line and delivered to ESA with spatial distribution covering the full aperture of the collimator (3C1, 1.5 inch ID) at the entrance to ESA (approx 11 cm^2), as illustrated in Fig 2. The momentum setting of the A-line can be used to select the energy slice. The intensity can be varied over many orders of magnitude using a combination of laser intensity at the gun and the opening of the A-line SL10 slits. The pulse time structure can be either short-pulse single-bunch beam, two short bunches with spacing variable from 5.6 to 400 ns, or long pulse trains of bunches up to 100 ns long.

One mode of operation of this test beam would be to produce secondary electron beams from single SLAC beam bunches with intensities covering the range 10 to 10^5 electrons/pulse in the energy range around 2 to 10 GeV to test the single bunch response of the detectors. Another mode of operation would produce spray electrons from a series of primary electron bunches in each SLAC beam pulse. The normal SLAC long-pulse bunch spacing is 0.3 ns. Modifications of the laser timing at the electron gun are under study that could achieve the 1.4 ns bunch spacing similar to the NLC design to test the multiple bunch time response of the detectors.

The key item of SLAC equipment needed to produce the secondary beam is the existing Be target in the SLAC BSY. This target was previously used to generate secondary beams of pions and protons in ESA for tests of the GLAST detectors, Ref [2]. The layout and a raytrace of the BSY in the region of the Be target and the entrance to the A-line is shown in Fig 3. The Be target is made of three slabs of Be, arranged along the beam line to give a total target of dimensions 15.24 cm thick along the beam, 0.475 cm horizontal width, and more than 5 cm vertical height. The total radiation length along the beam is 0.427 radiation lengths. The target is remotely insertable. The Be is water cooled and can be used with beam intensity of 3×10^{10} electrons/pulse at 30 GeV and 60 pulses/second. It is instrumented with two horizontal and two vertical SEMs (thick shower emission foils) mounted in front that are used to optimize the steering of the incident beam.

Secondary Beam Properties

For normal operation of beam into ESA when the Be target is not inserted, a combination of the pulsed magnets PM1 and PM5 and DC magnets B1 and B2 are used to bend the beam by 0.5 degrees to the North into the A-line through the aperture of the dump/collimator D10. For operation to produce hadrons in ESA the bend magnet B2 immediately down beam from the Be target is turned off. With B2 off and the rest of the A-line magnets on, a flux of secondary particles produced at 0.5 degrees enter the A-line and some are accepted into ESA. An example of the (estimated) flux of secondary hadrons and positrons for beam of 30 GeV and 3×10^{10} electrons/pulse from Ref [3] is shown in Fig 4. With B2 off the large forward-going flux of electrons from the multiple scattered transmitted beam and secondary electrons and positrons from electromagnetic showers is allowed to go forward into dump D10 and dump D2 down beam from D10 in the straight ahead beam line. This produces a beam in ESA that is a mixture of hadrons (mostly pions) and electrons (positrons). The pion flux decreases at low momentum due to the decay in flight in the 280 m path from the Be target to ESA.

For this proposal we would operate with the Be target inserted and B2 magnet on set at the normal setting in conjunction with the A-line momentum setting. With B2 on the large flux of forward going electrons and positrons are deflected horizontally in a sheet of flame, most of which crash into the D10 dump. A portion of the deflected spray enters the A-line and can be transmitted to ESA. The hadron flux (mostly pions) produced in the Be is also deflected by B2, and a small portion will enter the A-line. The pion contamination to the electron beam varies with the beam energy and A-line momentum setting, but is generally very small.

We have calculated an estimate of the intensity of spray electron beam in ESA for various settings of incident beam energy and A-line momentum using a simple GEANT3 model of the important components. The model includes the Be target, the B2 magnet (modeled as 1 m long) and the A-line aperture in D10 (1.56 inch horizontal, 0.97 inch vertical hole oriented at 0.5 degrees from the incident beam and located 75 m down beam from the Be target). Since the spray beam properties are not much influenced by the incident beam phase, space we set the incident beam radius to 1 mm with no angular divergence.

The model includes multiple scattering and all electromagnetic shower processes down to 100 MeV. Electrons are followed and scored when they enter the D10 aperture, but not followed further into the A-line. The D10 aperture will accept a wider range of angles and momenta than will subsequently be transmitted to ESA. To estimate the A-line acceptance we use the nominal values given in the SLAC "Blue Book" [4], where ray traces show (Fig 20-21, Ref [4]) that beam starting at the middle of the pulsed magnets PM1-PM5 with radius 0.3 cm, angular divergence $\Delta\theta = \Delta\phi = 10^{-4}$ radians, and momentum spread $dE/E = \pm 1.6\%$ will pass through the fully open SL10 slits. Our model counts spray electrons which enter the D10 hole that had entered B2 within the above nominal A-line acceptance and considers that all of these would enter ESA. This assumes that particles are not lost on apertures down

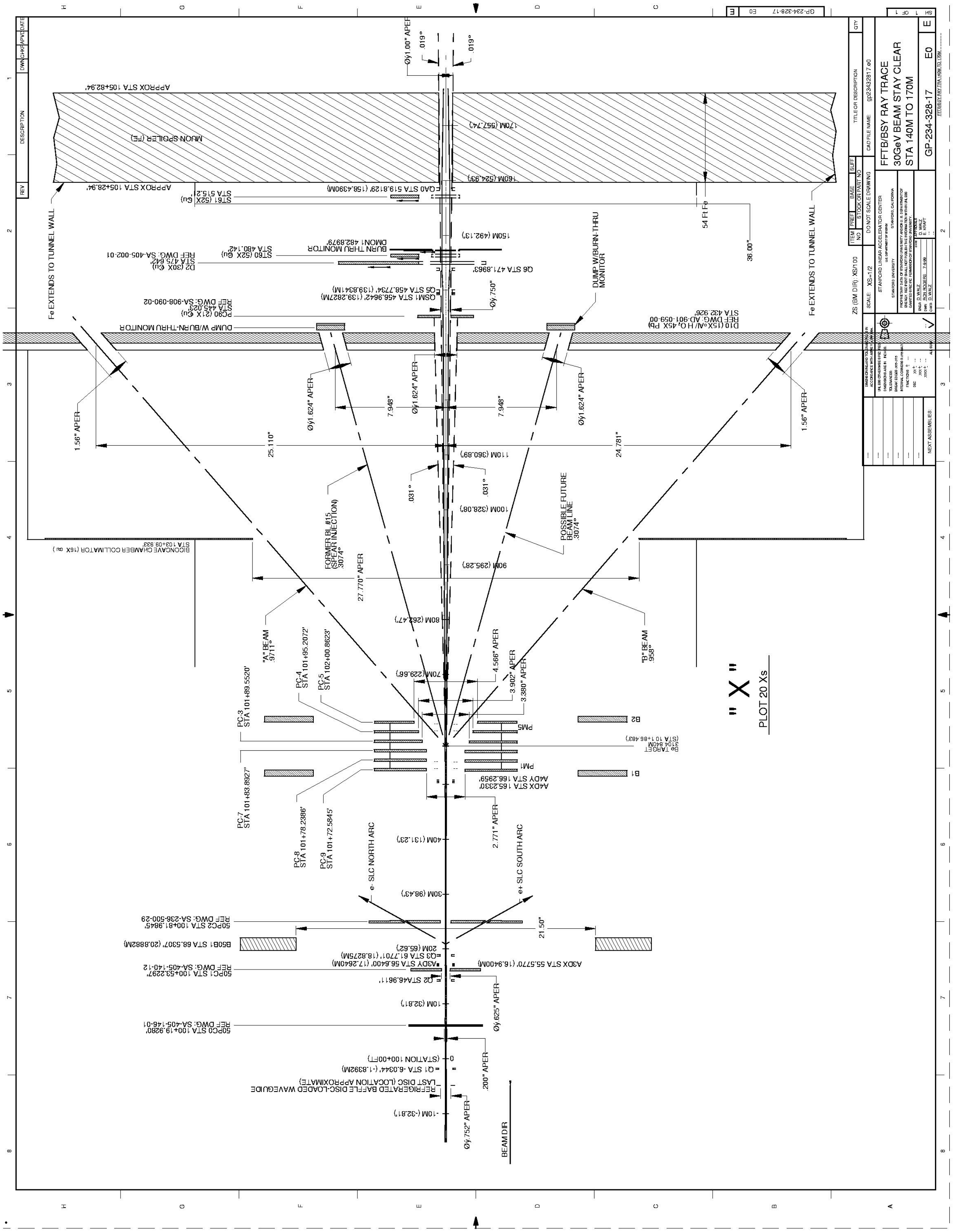

Figure 3: Ray trace of the SLAC beam switch yard in the region of the Be target and the tune up dump D10 (unreleased drawing from Ron Rogers, SLAC). The items used in the present simulation are: the Be target located in the middle of the pulsed magnet string PM1-PM5, the bend magnet B2 immediately down beam of PM5 and the aperture in D10 into the A-line at 0.5 degrees to the North of the straight ahead beam.

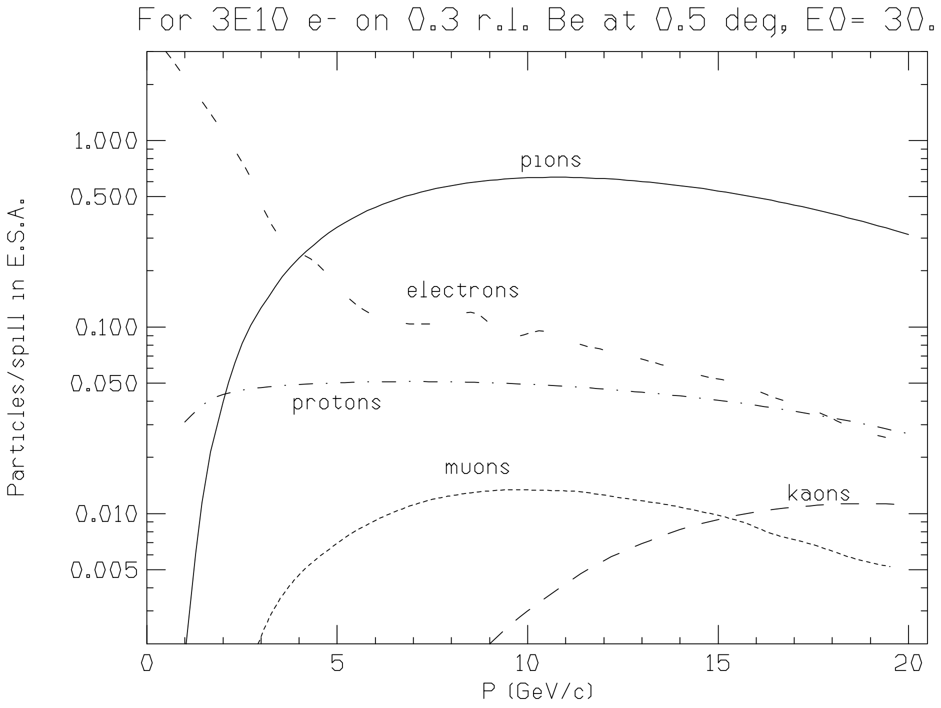

Figure 4: Predicted rate/pulse in ESA for pions, protons, kaons and positrons verses momentum setting of the A-line with B2 magnet off, from Ref [3]. This figure assumes beam energy of 30 GeV with 3×10^{10} electrons/pulse incident on the Be target.

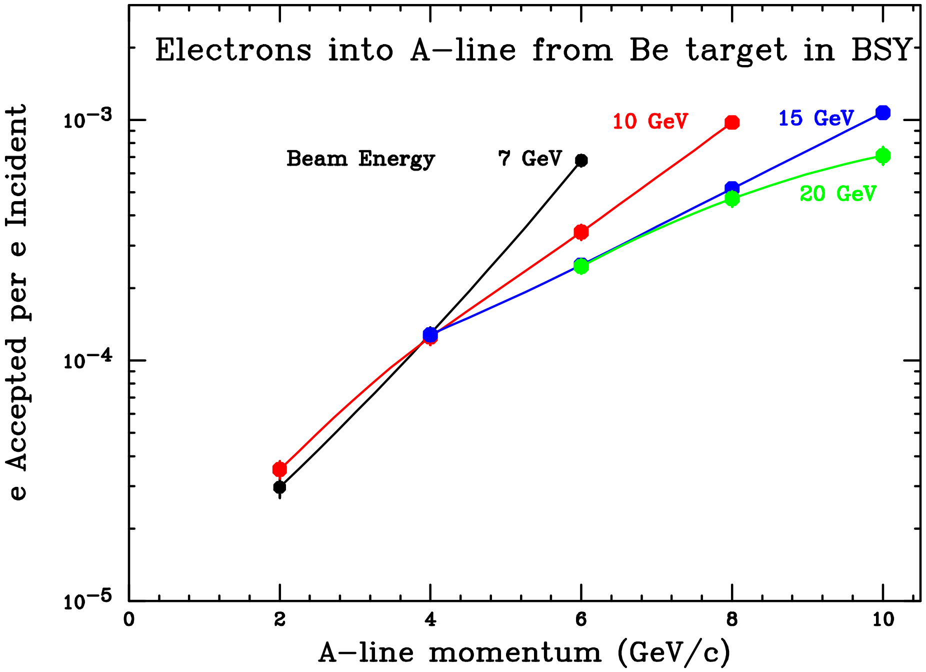

Figure 5: Fraction of electrons per electron incident on the Be target in SLAC BSY that are accepted by the A-line into End Station A for various values of beam energy versus A-line momentum setting with magnet B2 on. Monte Carlo statistical errors are the size of the dots or smaller.

beam of SL10. This model is a an approximation of the actual acceptance that is probably accurate to better than a factor of two, and is adequate for this rate estimate. Further studies are needed to find settings of the A-line quadrupoles to optimize the transmission of the large emittance beam after SL10 and minimize generation of secondary spray on collimators in front of ESA. In any case there is sufficient intensity available to achieve adequate rates in ESA even if some beam is lost after SL10.

The expected rates for spray electrons in ESA per electron incident on the Be for various beam energies and A-line momentum settings are shown in Fig 5. The pattern of accepted rates versus incident energy and A-line momentum is determined from a convolution of effects from showering and multiple scattering in the Be and the subsequent bending and filtering by the A-line. At a given beam energy the rate decreases as the A-line momentum is decreased due to the fall off of flux in the radiative tail from electromagnetic showers. For a given A-line momentum above about 4 GeV, the accepted flux decreases with beam energy due to the decrease in flux at lower energy in the radiative tail. As the figure shows, there is a wide range of beam energy and A-line momentum values that can be used to achieve spray flux at a given momentum. For example, at 4 GeV the rate acccepted/incident $= 1.25 \times 10^{-4}$ would give a flux of 1.25×10^{6}/pulse for an incident pulse of 10^{10} e/pulse. This can be reduced to the useful range of 10 to 10^{5} per pulse by combinations of closing the SL10 slits and reducing the laser intensity at the source.

The pion contamination in the electron beam can be estimated from the hadron rates in Fig 4 and from facts of life in hadron electroproduction. The main features needed are that the production yield at the target varies with the log of the incident electron energy, ln(E), and that the angular distribution at small angles (0 deg to about 2 deg) is nearly flat for hadron momenta up to about 7 GeV (see for example Fig C.2-14 in the SLAC Users Handbook, [5]). This means that for our purposes we can use values calculated for pion production at 0.5 deg that make it into ESA with B2 off, including decay in flight, because the small bend in B2 has little effect on the pion flux entering the A-line. We can then scale rates from beam energy of 30 GeV using ln(E)/ln(30). From Fig 4 we find 30 GeV incident beam with intensity of 3×10^{10}/pulse produces only 0.3 pions/pulse at 4 GeV. At 7 GeV beam energy this would give only 0.15 pions/pulse. The corresponding electron flux would be 3.9×10^6 giving a flux ratio electron/pion of more than 10^6. This ratio of electron-to-pion flux is high at all reasonable beam energy and A-line settings because the pion flux at forward angles is relatively flat and uneffected by B2 while the enormous electron spray at near forward directions is deflected into the A-line by B2.

Operational Considerations

While there are a wide range of beam energy and A-line settings settings that can give the desired spray flux, there are some operational considerations that may influence the choices made. The main consideration is the amount and direction of the unwanted spray of electrons and positrons deflected into D10 by B2. The D10 dump can absorb more than 100 kW and the D2 dump in the forward beamline can absorb approximately 20 kW of power, which is more than adequate. For example 10^{10} e/pulse at 28 GeV and 10 hz gives 4.5 kW beam power. Most beams anticipated for these tests would be lower power than that. The beam energy and A-line settings would probably be chosen to minimize the spray power consistent with generating the desired spray beam momentum. In general this means operating the beam energy somewhat above the desired spray beam momentum so the spray accepted originates in the radiative tail near the beam energy rather than far from the beam energy in lower energy part of the tail. This delivers a lower amount of unwanted spray power into D10 to achieve a given spray beam momentum. For example, while it is possible to get 4 GeV spray electrons using incident beam of 20 GeV, it is more likely to be desirable to use beams in the 7 to 10 GeV range. The A-line aperture in D10 has a larger momentum and angle acceptance than the subsequent A-line, so some of the flux accepted by the D10 hole is lost on collimators before the SL10 slits (PC10, PC12, PC14, PC17). Keeping the beam power low minimizes the spray in these areas. The exact beam energy choice will also be influenced by what is easily achievable in the accelerator.

The choice of incident beam intensity may be influenced by the desire to keep it high enough so it can be monitored in the linac BPMs. This may dictate operating with a relatively high flux of spray into D10 that is then reduced to the desired rate by closing the SL10 slits. Closing the SL10 slits will also reduce the momentum range of the spray in ESA from the wide open SL10 value of ±1.6% accordingly.

Secondary Beam Monitoring

To make the proposed spray beam a useful tool, it will be necessary to provide some instrumentation to measure and monitor the flux in ESA. Beam position monitors are not needed for a beam which fills the pipe. Flux intensity measurements for setting up the beam line parameters and monitoring the beam during the course of data runs would be needed. In the intensity range 10 to 10^5 electrons/pulse none of the existing toroids will work. The intensity is too low to be seen on ZnS screens or in SEM detectors. The most likely instrumentation that will be needed is a Čerenkov counter (atmospheric gas perhaps a meter long) in the beam line somewhere up beam of the test station in ESA and an electromagnetic calorimeter detector, such as lead glass or other sampling type calorimeter, down beam of the instrument test station. The Čerenkov counter could measure the spray beam intensity for every SLAC beam pulse to aid in achieving the desired rates and serve as a continuous beam intensity monitor during data runs. It could be calibrated and cross checked at low intensities with a calorimeter operated while the NLC detectors being tested are removed from the beam. A measurement of the beam profile shape in x and y could be made with a set of quartz fiber fingers connected to multi-anode PMT's. A fairly simple, easy-to-build detector of this type using scintillator fibers was used to measure low intensity hadron and electron beams (few particles per pulse) in the GLAST tests[2].

References

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[3] R. Arnold, P. Bosted, S. Rock, Z. Szalata, "Proposal to Produce a Hadron Test Beam for GLAST in E.S.A., (unpublished), December 22, 1998.

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[5] SLAC Users Handbook(1968), Boyarski, Fig C.2-14 and fits on page C.2.8.