MODELING LOST-PARTICLE BACKGROUNDS IN PEP-II USING LPTURTLE *

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Abstract

Background studies during the design, construction, commissioning, operation and improvement of BaBar and PEP-II have been greatly influenced by results from a program referred to as LPTURTLE (Lost Particle TURTLE) which was originally conceived for the purpose of studying gas background for SLC. This venerable program is still in use today. We describe its use, capabilities and improvements and refer to current results now being applied to BaBar.

ORIGIN OF LPTURTLE

At SLAC, for many years, electron-positron collisions have been the mainstay of the High Energy Physics program. Thus, the study of background processes characteristic of these beams of light particles have also been of interest. With the construction of the world's first linear collider, with its long transport lines, it was realized that new tools would be useful for the investigation of the background from electrons or positrons interacting with the residual gases contained within the 1.4 km beamlines. Small angle scattering of the beam particles from the Coulomb scattering process could generate beam halo that could accompany the beam for long distances. Shorter ranged, but equally detrimental are background γ's and $e^{\pm}$ emanating from beam-gas bremsstrahlung. This latter process, with the γ's directed in a straight line and the $e^{\pm}$ having an energy loss, usually do not generate background unless the scatter occurs close to the detector downstream of the large bend magnets. Concurrent with SLC conceptualization a new charged particle beam optics program DECAY TURTLE [1] became available. This was a modification of the program TURTLE [2], a ray tracing program that included higher order optical and geometric aberrations. It was realized by several SLAC physicists [3] that the 2-particle pion decay (one charged daughter plus one neutral daughter) could be replaced by Coulomb scattering and Bremsstrahlung; in both cases, the scattered charged particle retains its mass (that of the electron) while the massless neutral particle is retained (brems.) or discarded (Coulomb). Additional modifications of DECAY TURTLE would then allow evaluation of background rates from both Coulomb and Gas-Bremsstrahlung scattering.

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SCATTERING PROCESSES

For Coulomb scattering the differential cross section is found in Rossi [4] as the modified Rutherford Scattering Formula for small angles

$$d\sigma/d\omega = K/(\theta^2 + a^2)^2, \tag{1}$$

where θ is the polar scattering angle, a takes account of screening of the nuclear charge by atomic electrons, and

$$d\omega = 2\pi\theta d\theta = \pi d(\theta^2), K = \frac{4N(Zr_e)^2}{A(E/m_e)^2}, a = \frac{Z^{1/3}}{(137E/m_e)}.$$

For Bremsstrahlung, Rossi gives the cross section

$$\frac{d\sigma}{dk} = \frac{1}{k}L(1 - u + (3/4)u^2), \tag{2}$$

where $L = [\frac{16\alpha}{3}\frac{N}{A}(Zr_e)^2\ln(183/Z^{1/3})$, k is energy of radiated photon, $u = k/E$, and where Z and A are the charge and mass numbers, N is Avogadro's number, r_e is the classical electron radius and $\alpha = \frac{1}{137}$ is the fine structure constant.

The cross sections for the two interactions of interest are proportional to $Z \cdot Z$, so H_2 can be neglected whereas the abundant CO is well represented by N_2 . For simplicity the gas is assumed to be 1 nTorr N_2 distributed uniformly around the ring. The density of N_2 at this pressure is $6.4 \cdot 10^7 N_2$ atoms/cm^3. The $e^{\pm}$ per bunch at 1 A ring current are used to calculate absolute rates. Thus the results are normalized to events/beam crossing-nT-A. Weighting with a vacuum profile can be added.

CREATING LPTURTLE INPUT

The PEP-II [5] machine optics evolves; descriptions in MAD [6] code of running configurations are constantly being updated. Taking these new optics to a completed description in LPTURTLE format is a process of many steps starting with writing a full MAD Twiss table to file (Fig. 1). This file contains a complete description of all optical elements and values of important beam parameters at prescribed points of path-length. There is one known exception, wherein an important parameter is missing from this table, which can cause some difficulty and that is the failure to include the quantities FINT and HGAP, describing the extent of the fringe fields for the bend magnets. The data in this table is processed using Perl code to generate a description of the ring using the TURTLE input protocol. The PEP-II Interaction Point (IP) represented a special challenge to characterize the superposition of a yawed

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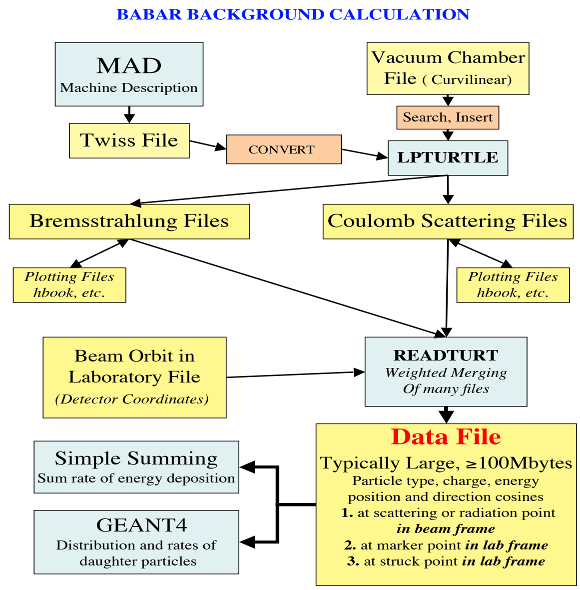

Figure 1: Flow chart of the processes from PEP-II design description to input for GEANT4 background simulations

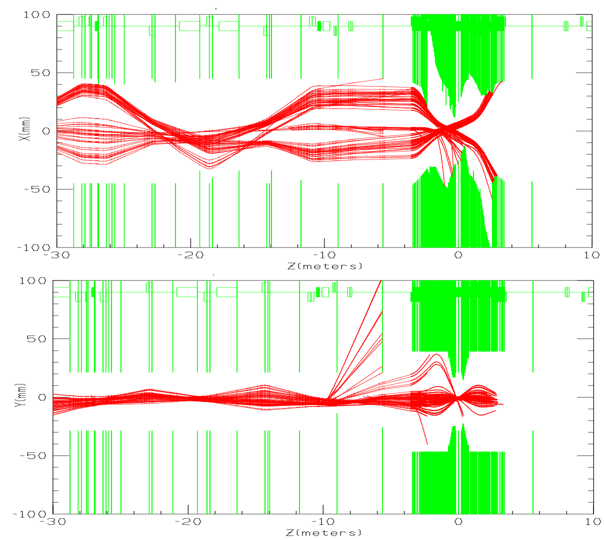

Figure 2: X-Z and Y-Z TOPDRAW plots of Bremsstrahlung particles near the LER IP, located at $Z = 0$. Apertures are green, particle tracks are red

detector solenoid field onto that of the beamline magnets within the detector. These beamline quads and bend magnets were represented as zero length devices nesting small increments of the axial solenoid field. The effect of the 3.5 mrad yaw of the detector was represented by incremental vertical kicks. Translating these unusual features in the MAD representation was subject to error. To check for errors, it was required to generate two input decks one to be run using TURTLE code and the other TRANSPORT, because of subtle differences in the way each code treats bending magnets. The TRANSPORT code was used to check for survey and optical errors and helped diagnose problems with the TURTLE code.

From engineering drawings and spread sheets a description of the beam line apertures is obtained and converted to an ASCII table containing the positions of the limiting apertures along the beamline and the extent of each aperture wrt to the beam in plus and minus directions of the transverse coordinates. Apertures in LPTURTLE can be elliptical or rectangular and are specified to best match the given chamber shape.

This data is used in two ways. In long regions where the vacuum pipe is smooth, the sizes are put directly into the MAD-TURTLE conversion code thereby inserted into the beamline file. In regions where the apertures are changing rapidly, i. e. near the IP, another matching code is used that reads both the aperture and the beamline files, matches locations along the path and inserts the appropriate aperture in the beamline file.

CAPABILITIES

LPTURTLE allows the user a great deal of control to perform the desired physics tasks. Selectable are the processes (Coulomb or brems.), the range of kinematic variables (scattering angles, energy loss), the region where scattering takes place and the region where stopped particles are to be registered (usually limited to within the detector). The capabilities of two graphical outputs are available: TOPDRAW [7] and PAW [8]. In Fig. 2 an example of a TOPDRAW plot shows bremsstrahlung particles striking the LER vacuum chamber within the BaBar detector. Note that only particles that strike within eight meters of the IP are retained for study. Also, note the high density of apertures required to emulate the complicated vacuum chamber geometry with its synchrotron radiation masks near the IP. This density required the automatic aperture matching and insertion code earlier mentioned.

In the plot of the x-z plane it is clear that it is the off-energy positrons bending off-axis in the magnetic fields, that are hitting the chamber. These particles exhibit betatron oscillations typical of charged particles. Photons behave differently, because they are not affected by these fields; in the curvilinear coordinate system they have the appearance of being deflected sharply at dipoles where it is the beam-following coordinates that actually change direction. This can be seen in the y-z plane at z=-10 meters where the photons appear to be kicked upward, when, in fact, the beam is being deflected downward by a vertical bending dipole. Again, in Fig. 2 one sees that at Z= -27 meters there is a concentration of particles that have a large transverse offset in the +X direction in the x-z plane. These particles are candidates for elimination by collimation. In similar plots of Coulomb scattering (not shown) it is even clearer that halo clusters exhibiting large amplitude betatron oscillations can propagate the entire 2 km circumference of the ring. Studies of the dependence upon the scattering and circumferential location versus location of detector hits using PAW can guide the placement of background suppressing collimators. Guided by the TOPDRAW plots and an understanding of the machine functions, the user places markers in the input to LPTURTLE at potential collimator locations. At that location (s = accumulated pathlength) the program then stores the transverse positions, angles and value of s, i.e. (x, x', y, y', s) of the scattered particle into a single PAW ntuple. Besides these user-chosen ntuple entries, special parameters describing the scattered particles are always available in the ntuple. These parameters for only the particles striking the user specified region are 1) the value of s where the scatter occurred, 2) particle type, ($e^{\pm}$ or γ) 3) energy, 4) x, x', y, y', s at the struck point.

In Fig. 3 and Fig. 4 are examples of the use of PAW for the LER PEP-N proposal; applying cuts allowed for efficent study of the effect of collimation. Extensive investigation of collimation in the PEP-II rings for BaBar have been carried out and are reported elsewhere in this conference [9].

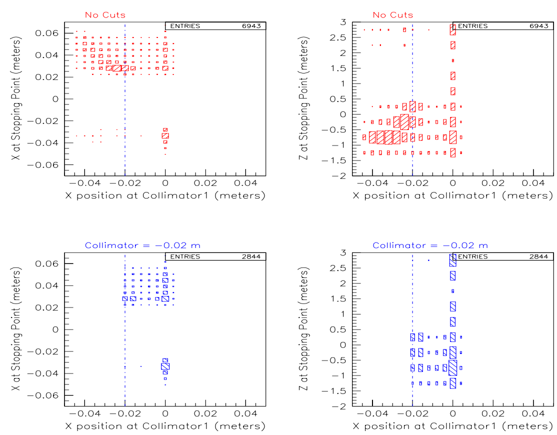

Figure 3: PAW plots of LER beam collimator studies for PEPN, with cuts of particles for $X \leq 20$ cm

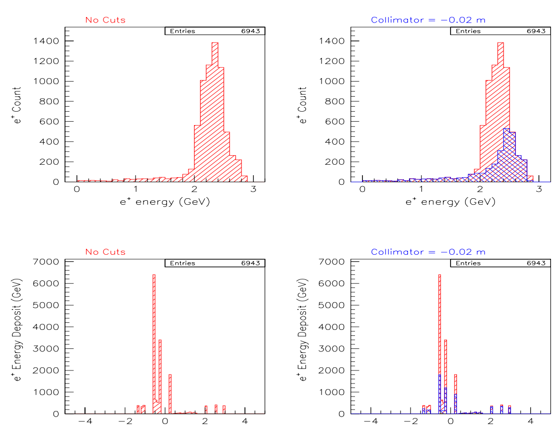

Figure 4: PAW histograms showing decrease in particle count and energy deposited (blue hatching) with collimator cut

INPUT TO GEANT4

LPTURTLE is also used (Fig.1) to provide scattered beam particle events to the BaBar [10] detector physicists [11] using GEANT4 in their study of sources of background. This data is provided as an ASCII file containing as many as one half a million events. Parameters for each event describe the type of event, energy and charge of particle, and in the detector coordinate system the launch direction cosines and the location of the hit on the vacuum chamber. It was important to verify the agreement for the coordinates of the hit between the two programs to ensure consistent descriptions of the geometry and fields. Such agreement was difficult to achieve because one program performs entirely in the beam curvilinear system whereas the second operates in the lab. Currently, for the LER ring good agreement has been achieved, as reported elsewhere in this conference [11].

CONCLUSION

LPTURTLE has served the detector physics community for many years. Its capabilities are varied and provide useful insight into background sources. Recently, the mating with GEANT4 has met with success for the PEP-II LER ring.

ACKNOWLEDGMENTS

The authors are indebted to Hobey DeStaebler for reconstructing his calculations that were incorporated into code more than 20 years ago. His description of the necessary algorithms and methods used in the modification the Decay Turtle code were used to guide those early programmers. We understand that J. Mathews of John Hopkins Univ. wrote much of the initial code. D. Coupal of SLAC but now in private industry contributed many enhancements including the addition of the PAW capability. A. Snyder of SLAC introduced the TOPDRAW capability. Furthermore, we wish to express our appreciation to T. Geld, G. Bower and W. Lockman for their great patience and skill in mating LPTURTLE with GEANT4.

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