DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

Frascati, March 24, 1993

Note: **IR-2**

PRELIMINARY BACKGROUND CALCULATIONS for DAΦNE

Michael K. Sullivan
Intercampus Institute for Research at Particle Accelerators
SLAC P.O. Box 4349, Stanford, CA 94309

ABSTRACT

This note summarizes my work while I was at the Istituto Nazionale di Fisica Nucleare (INFN) at Frascati, Italy. It presents a preliminary investigation of detector backgrounds from the DAΦNE machine that used some of the software tools developed at SLAC to study similar detector background issues for the SLAC PEP-II *B* factory design [1].Two sources of background were looked at: Synchrotron Radiation (SR) and degraded beam particles from beam-gas bremsstrahlung and Coulomb scattering. The critical energy of the SR generated by the beams is so low that there is no detector background from these photons. The radiation produces some heating of the beam pipe (1–2 W) near the Interaction Point (IP). Background from degraded beam particles primarily comes from the drift region between 2.5 and 5 m from the IP with a smaller contribution from the region that is 6.5 to 10 m upbeam of the IP.

SYNCHROTRON RADIATION

My initial effort at Frascati was to familiarize myself with the details of the Interaction Region (IR) design and to estimate backgrounds from SR generated by the incoming beams. The SR part of the study assumes a zero emittance beam ($\varepsilon_x = \varepsilon_y = 0$). The finite size of the beams tends to broaden the energy spectrum of the generated photons when the beams travel through quadrupoles. The predominate radiation, however, comes from bending the entire beam as opposed to the radiation produced by focussing and defocussing the beam. We define “radiation fan” as that radiation produced by bending the entire beam.

Figure 1 is a layout of the IR using the Day One Optics for the machine. In the figure, the scale of the x dimension is greatly expanded with respect to the z dimension. This optics design does not include a detector, but the figure indicates the acceptance of the KLOE detector anyway. The first concern was whether or not detector background was produced by the SR fans generated by the offset incoming beams in the final focusing triplets and by the splitter magnets located 5 m from the IP. The fans generated by the beams as they travel through the triplet magnets do not seem to be a problem; the generated photons intercept the beam pipe downstream of the IP. Figure 2 shows the radiation fan generated by the incoming beam as it travels through the second quadrupole in the final triplet and Figure 3 shows the radiation fan generated by the beam as it travels through the third quad in the triplet. Both figures indicate that the generated radiation passes the IP. For a 3 cm radius beam pipe, the radiation from these two quads strikes the pipe 17 cm downstream of the IP. If the beam is displaced by 2 mm, the radiation strikes the beam pipe only 10 cm downstream of the IP. If the beam pipe has a radius of 3.4 cm, the radiation strikes the pipe 30 cm downstream of the IP. Clearly, where this radiation strikes the beam pipe depends on the exact details of the pipe design.

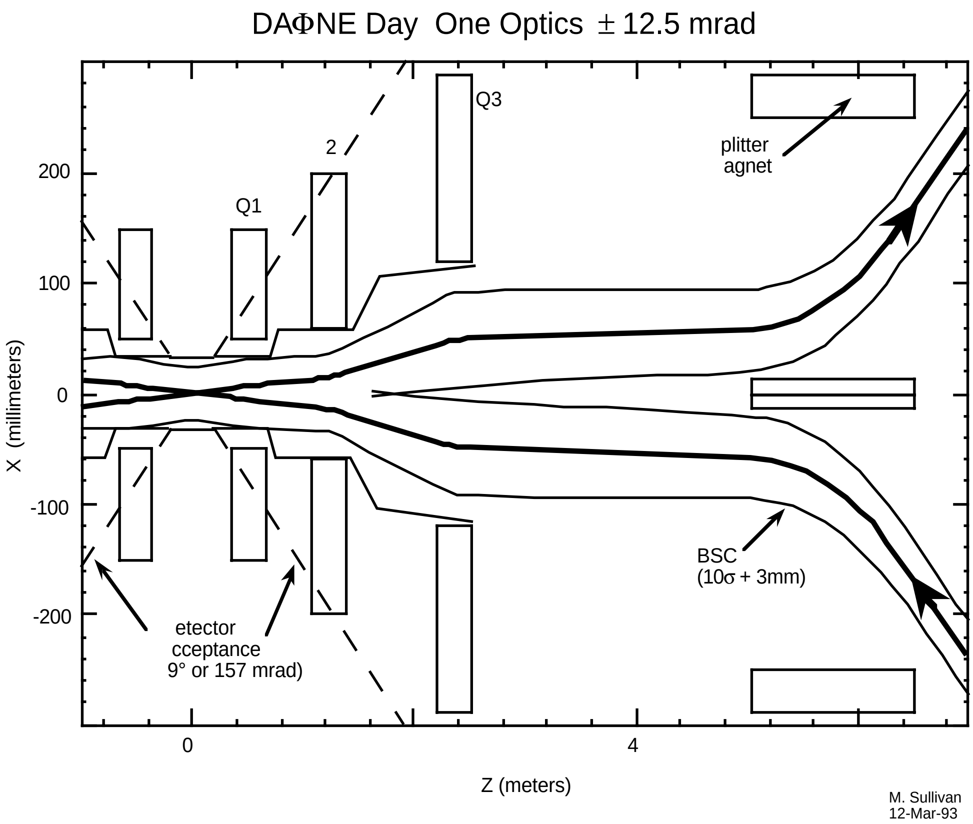

Figure 1. Layout of the IR region. Note the expanded scale for the X dimension.
The beam pipe drawn in the figure is only a conceptual design.

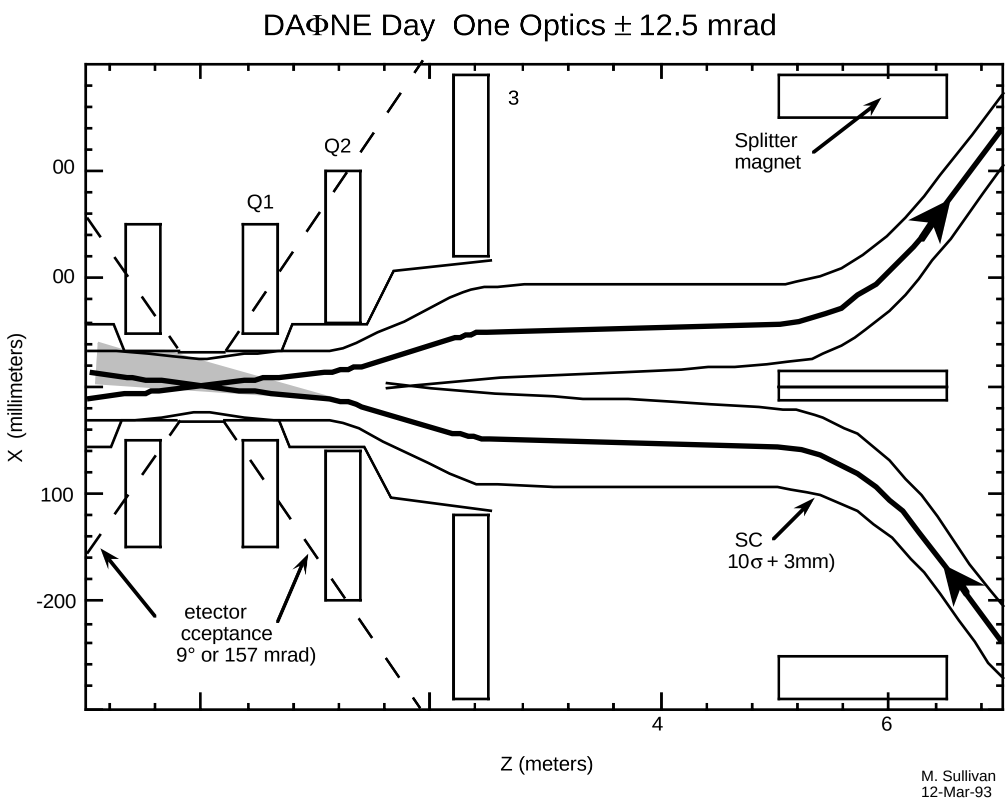

Figure 2. Synchrotron radiation fan from the beam going through Q2.
The radiation first strikes the beam pipe 17 cm downstream of the IP for a 3 cm radius pipe.

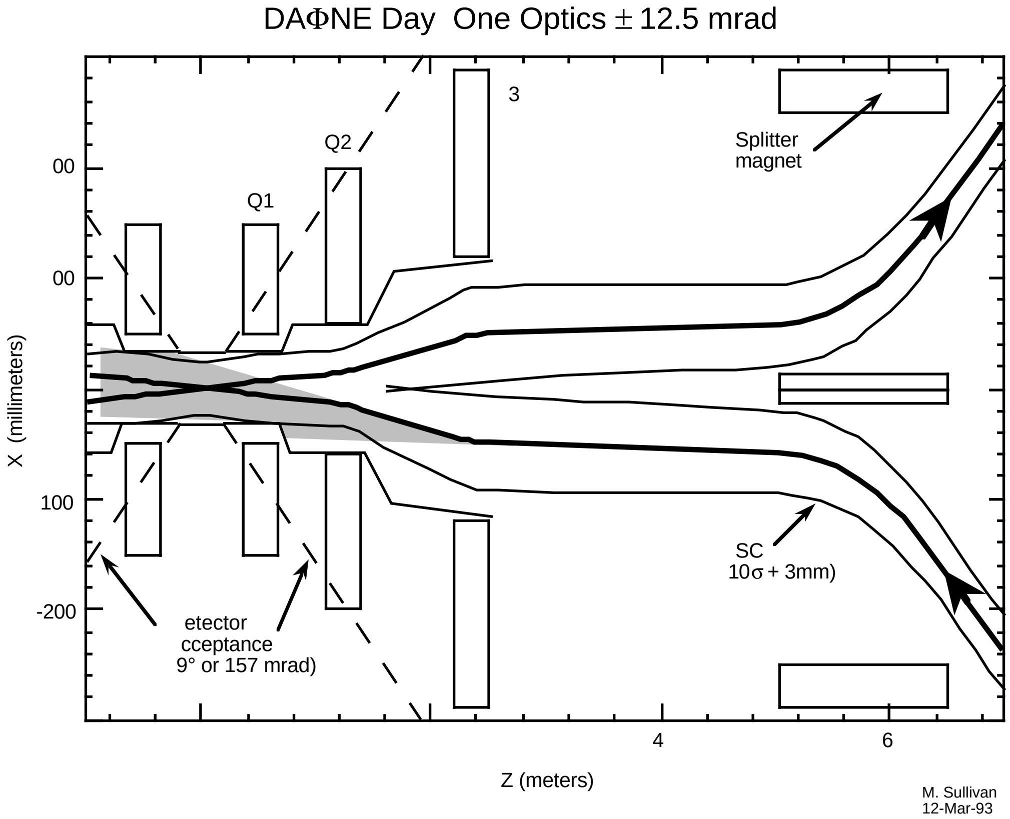

Figure 3. Synchrotron radiation fan from the beam going Q3. The radiation strikes the beam pipe behind Q1 and the beam pipe 17 cm downstream of the IP for a 3 cm radius pipe.

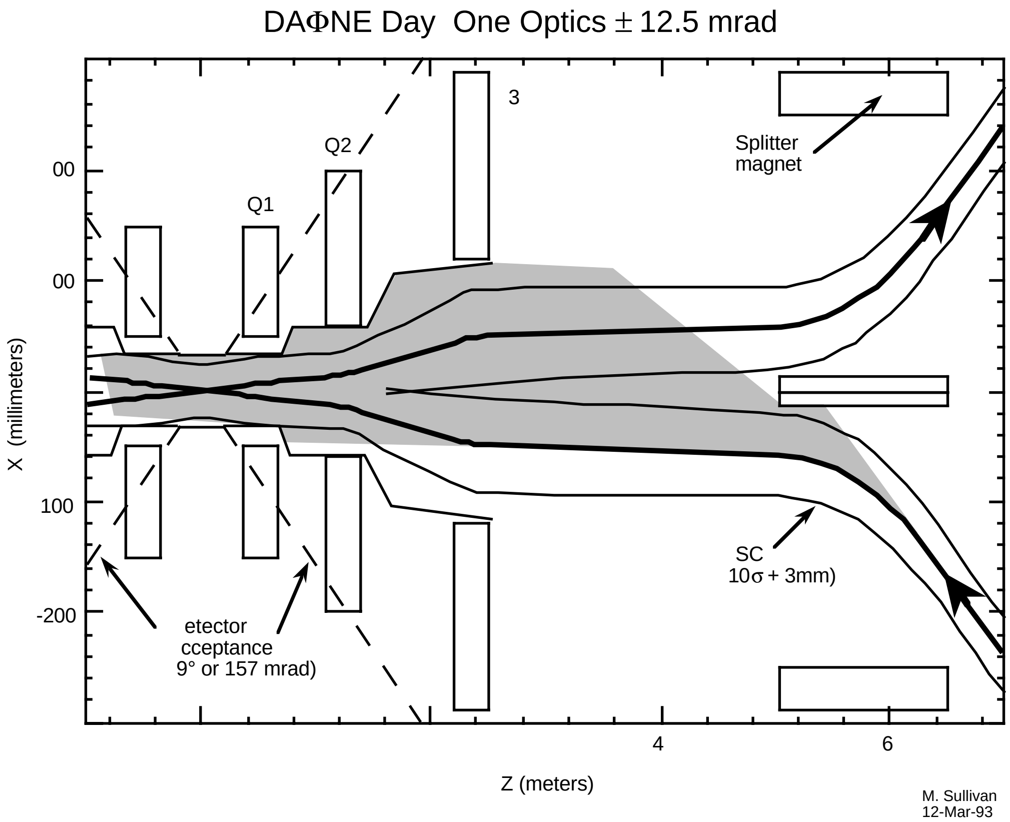

Figure 4. Synchrotron radiation fan from the beam going through the splitter magnet.

On the other hand, the radiation fan generated by the beam as it goes through the splitter magnet produces a spray of photons that strike the beam pipe in the detector region. Detector region, in this case, is defined to be the beam pipe ±10 cm from the IP. Figure 4 shows the radiation fan generated by the beam as it travels through the splitter magnet. Closer inspection revealed that the critical energy of the radiation from the splitter magnet is only 29 eV. This means that only 2.5×10^{-17} of the produced photons are greater than 1 keV. The DAΦNE design calls for a 500 µm thick Be beam pipe for the detector region. Figure 5 is a plot of the transmission coefficient as a function of photon energy for a slab of 500 µm thick Be. The photons used to produce the plot strike the Be with normal incidence. Since the number of photons with enough energy to penetrate the beam pipe is so small, essentially no photons produced by SR come out of the beam pipe. Hobey DeStaebler of SLAC has mentioned that when the beam goes through the fringe field of a bend magnet the critical energy of the photon spectrum from SR can increase. This increase can be as much as a factor of ten [2-5]. However, the magnetic field must be weak and the effective length of the fringe field must be short before this effect becomes significant. I have not investigated this in detail, but it does not look like the SR photons generated by the fringe field of the splitter magnet contribute to detector backgrounds.

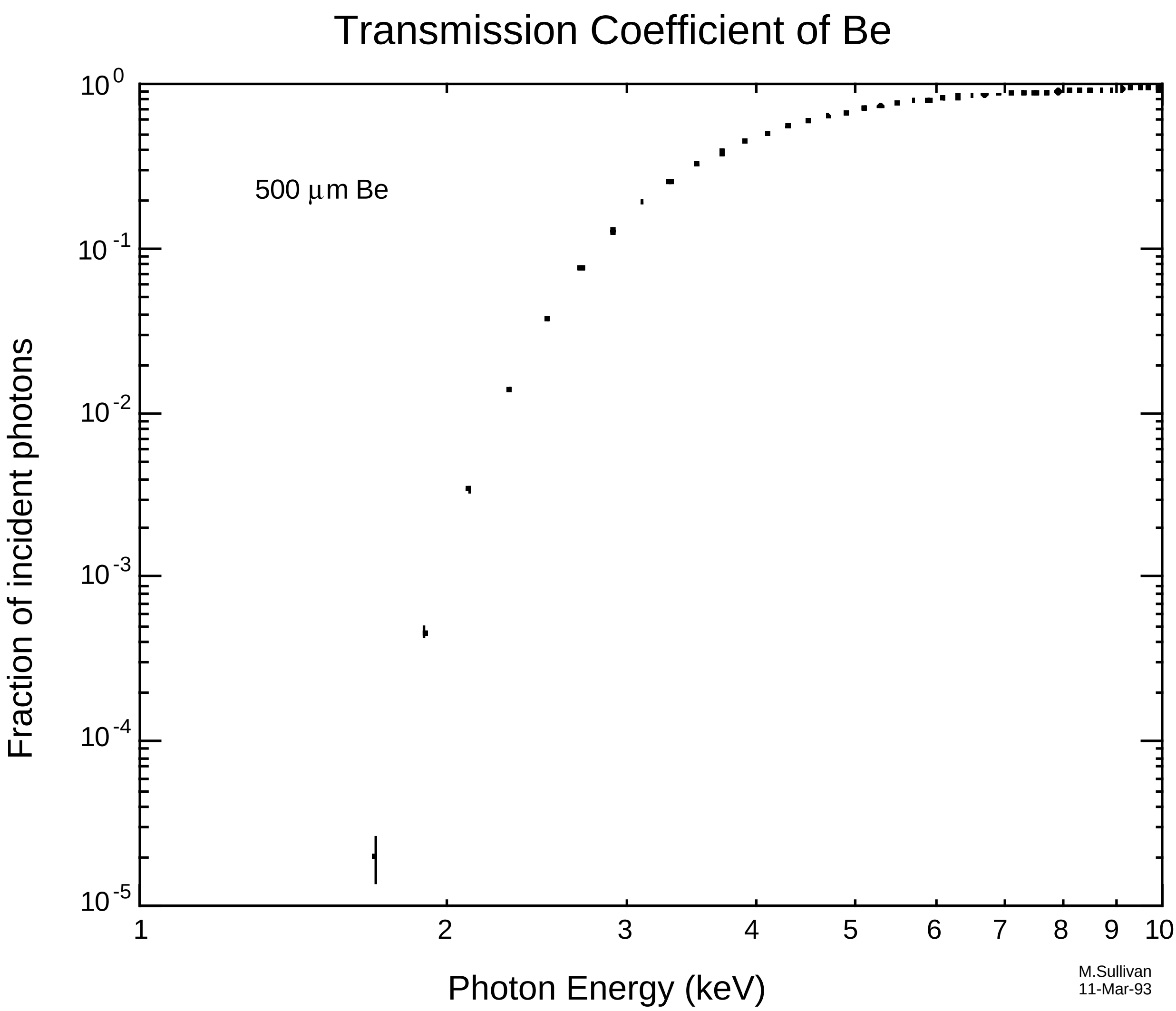

Figure 5. Plot of the fraction of incident photons that penetrate 500 mm of Be. The photons in this plot strike the Be surface with normal incidence.

The fact that the SR-generated photons do not get out of the beam pipe does not remove all concerns about this radiation. The other main issue is how much power from this radiation is incident on the inside of the beam pipe near the IP. Figure 6 is a scale drawing of a suggested beam pipe geometry near the IP. This is a difficult part of the beam pipe to cool so it is helpful to get some understanding of where the SR power strikes the beam pipe. Figure 6 indicates schematically where most of the SR power is deposited. The figure shows two sections of the radiation fan that comes from the splitter magnet. Each section contains about 1 watt of power. One of fan sections misses the upstream beam pipe and deposits all if its power on the downstream end of the central beam pipe. The other section roughly divides its power between the upstream beam pipe and the downstream end. In effect, because of the small angle of incidence, the SR from the two splitter magnets deposits an extra 1-2 watts of power on the ends of the central beam pipe and deposits no power on the center section of this beam pipe. The vertical height of the spot, from the intrinsic angular spread of the SR, is about 10 mm. All of these calculations neglect the finite size of the beam. The fact that the beam has nonzero transverse dimensions will smear out the power spots somewhat. Assuming the beam pipe has a 3 cm radius out to 66 cm from the IP (see the schematic beam pipe drawing in Figures 1-4), then the radiation fans from the Q2 and Q3 magnets will deposit 2.5 and 3.0 watts of power respectively on the pipe between 17 and 66 cm from the IP.

Synchrotron Radiation from the Splitter Magnet.

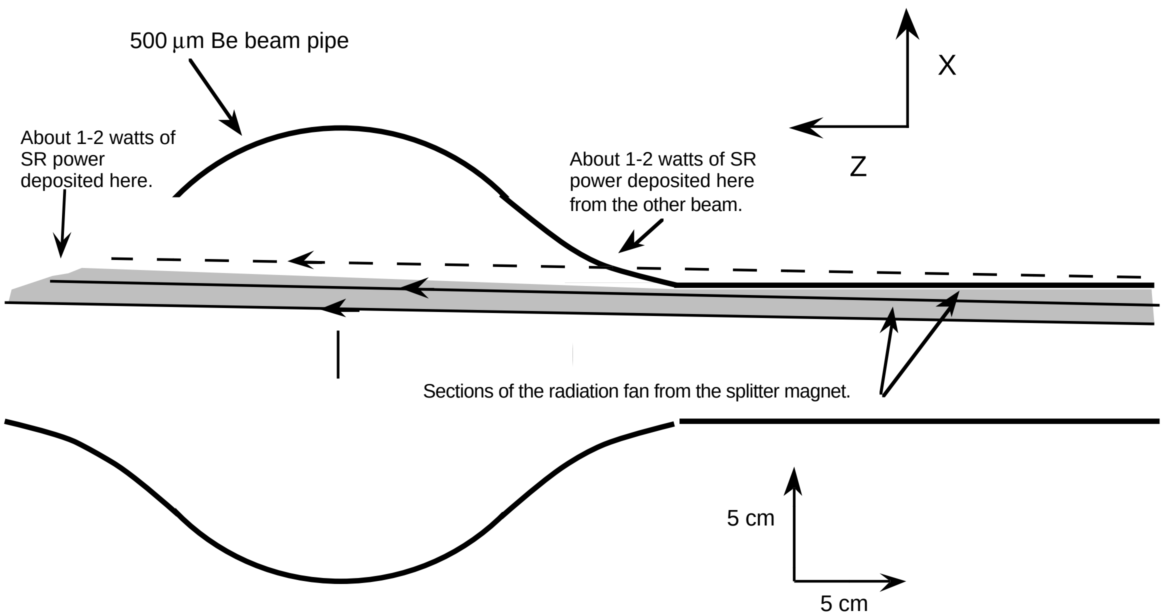

Figure 6. Schematic of a suggested beam pipe. The lines with arrows indicate sections of the radiation fan from the splitter magnet. Each section has about 1 watt of power.

LOST BEAM PARTICLES

The next effort was to move a version of Beam-Gas TURTLE from SLAC to the INFN VAX cluster and to get the program running. Beam-Gas TURTLE is a specialized version of Decay TURTLE (Trace Unlimited Rays Through Lumped Elements), a program developed at SLAC to follow beam particles and the daughters that result from a two-body decay of a beam particle through a transport line [6]. Beam-Gas TURTLE and DECAY TURTLE use the same beam line element notation as defined in TRANSPORT [7]. After finding and fixing a couple of bugs left in the program when the code was converted from PATCHY to FORTRAN, I put together an input deck (DAFNE_D1.TURTLE) using the DAΦNE Day One optics. The results of running this input deck through the Beam-Gas TURTLE program (TUR107_VAX.FOR) is summarized in Table 1.

Table 1.
DAΦNE Day One Optics Lost Beam Particle Background Estimates.

5-FEB-93
M. Sullivan

	Beam-gas Bremsstrahlung				Coulomb scattering	
	Hard ($0.2E_0 < E_\gamma < 0.99E_0$)		Soft ($0.02E_0 < E_\gamma < 0.2E_0$)		Hard ($0.67 < \theta < 500$) (mrad)	Soft ($0.33 < \theta < 0.67$) (mrad)
Normalization (prob./crossing)	9.9^{-8}		1.8^{-7}		1.1^{-5}	3.5^{-5}
	charged	photons	charged	photons	charged	charged
Aperture at 2.5 m						
plot count	12950	2972	6237	2807	49	0
rate (kHz)	472	108	420	189	202	0
Ave. E (MeV)	348	244	432	39	510	0
Ave. E / µsec	164	26.4	181	7.4	103	0
where from fraction						
0.0—2.5 m	0	0	0	0	0	0
2.5—5.0 m	0	0	0	0	0.14	0
5.0—6.5 m	0.39	1.00	0.11	0.99	0.59	0
6.5—10. m	0.59	0	0.86	0	0.22	0
> 10. m	0.03	0	0.03	0.01	0.04	0
Aperture at 0.1 m						
plot count	635	14	0	30	1	0
rate (kHz)	23*	0.51	0	2.0	4.1	0
Ave. E (MeV)	320	297	0	37	510	0
Ave. E / µsec	7.4*	0.15	0	0.07	2.1	0
where from fraction						
0.0—2.5 m	0.10	0	0	0	0	0
2.5—5.0 m	0.85	0	0	0	1.00	0
5.0—6.5 m	0.06	1.00	0	1.00	0	0
6.5—10. m	0	0	0	0	0	0
> 10. m	0	0	0	0	0	0
Aperture at –0.1 m						
plot count	523	25	0	19	6	0
rate (kHz)	19.1*	0.91	0	1.3	25*	0
Ave. E (MeV)	334	224	0	44	510	0
Ave. E / µsec	6.4*	0.20	0	0.07	12.6*	0
where from fraction						
0.0—2.5 m	0.09	0	0	0	0	0
2.5—5.0 m	0.86		0	0	0.67	0
5.0—6.5 m	0.09	1.00	0	1.00	0	0
6.5—10. m	0	0	0	0	0.17	0
> 10. m	0	0	0	0	0.17	0
Surface at –0.36 m						
plot count	629	25	2	28	15	0
rate (kHz)	23	0.91	0.13	1.9	62	0
Ave. E (MeV)	338	232	430	38	510	0
Ave. E / µsec	7.7	0.21	0.06	0.07	31.5	0
where from fraction						
0.0—2.5 m	0.08	0	0	0	0.27	0
2.5—5.0 m	0.88	0	0	0	0.33	0
5.0—6.5 m	0.04	1.00	0	1.00	0.13	0
6.5—10. m	0	0	0	0	0.20	0
> 10. m	0	0	1.00	0	0	0

* Highest rate sources for the ± 0.1 m surfaces.

NOTES CONCERNING THE TABLE

1. General

The beam is traced from the exit of the wiggler magnet to the IP.

This total distance is 13.6 m (we are tracing the long arc).

The triplet magnets inside the detector are treated as bend magnets with a gradient to account for the focusing aspects of these quadrupoles.

The beam particles are generated using gaussian distributions in x and y which are scaled by the beam σ_x and σ_y . The beam sigmas are calculated using the given horizontal and vertical emittances (ε_x = 1000 nm-rad, ε_y = 10 nm-rad).

2. Normalization

The normalization numbers in the table are the number of events per crossing for each plot count. The normalization numbers assume the following (see DECAYTURT.DOC in D17:[MIKESUL.BREM] for more details):

Vacuum pressure	=	10^{-9} Torr.
Particles/bunch	=	9×10^{10}
The residual gas	=	N_2

In order to get the rates in the table, the following is also assumed:

Beam current	=	5.3 A
Number of bunches	=	120
The crossing frequency	=	368 MHz

The rate is calculated using the following formula:

$$\text{Rate (Hz)} = \text{(plot count)} \times \text{(normalization)} \times \text{(crossing freq.)}$$

The energy entry in the table is the average energy in MeV of the particles that strike a given aperture or surface. The response time of most detector systems is on the order of a µsec, so included in the table, is the average energy per µsec that strikes a given aperture or surface.

3. Hard and Soft

The energy spectrum of the beam-gas bremsstrahlung photons is divided into two regions called “Hard” and “Soft”. Separate runs are made for each region in order to increase statistics for the Hard region. The Hard region includes photons generated with an energy between 0.2 to 0.99 of the beam energy. The Soft region includes photons with an energy range between 0.02 and 0.2 of the beam energy (see the “60” cards in the input deck).

This same idea is used for the Coulomb scattered beam particles. In this case, the regions are separated by small and large angle scattering. The Hard region includes the particles with a scattering angle between 0.67 mrad and 500 mrad and the Soft region includes angles between 0.33 mrad and 0.67 mrad. The table shows that there is no contribution from the Soft region of Coulomb scattered particles. Therefore one does not need to investigate smaller scattering angles.

These regions (for both beam-gas and Coulomb) can be adjusted by modifying the "60" cards in the input deck.

4. Source of Lost Particles

The sections of the table labeled “where from fraction” give some indication of where the lost beam particles originated. In the table, the beam trajectory is divided into five regions as follows:

Region	Comments
0.0–2.5 m	This region is the last 2.5 m before the IP. It includes the final triplet quadrupoles.
2.5–5.0 m	This is the drift region between Q3 and the splitter magnet. It would include the compensating solenoid for the KLOE or FI.NU.DA. beam optics.
5.0–6.5 m	This region is the splitter magnet.
6.5–10. m	This region is essentially the space between the splitter magnet and the first dipole.
> 10. m	The beam line modeled in the input file starts at 13.6 m from the IP, so this region includes the first dipole and the space between the dipole and the wiggler magnet.

The number in the table associated with a particular region and a particular background is the fractional amount of background particles (plot count) coming from the chosen region.

For example, if we select the beam-gas bremsstrahlung tail entry in the table and, in addition, look at the charged particle category, then for the mask at 2.5 m we find that 0.39 of the charged particles that strike this mask come from the region that is 5.0–6.5 m from the IP which is the splitter magnet. In a similar manner, we find that 0.59 of the charged particles that hit this mask originate from the 6.5–10. m region and 0.03 come from the region that is > 10. m from the IP. These three numbers should total up to 1.0 within round off errors. Looking over at the next column, which tabulates information on the source of the photons generated by the beam-gas bremsstrahlung events, we find that all of these particles (1.00) come from the region inside the splitter magnet (the 5.0–6.5 m region).

5. Apertures

In TURTLE, apertures are defined as planes perpendicular to the beam line each with a hole whose dimensions are specified on the input line that defines the aperture. When a particle strikes an aperture that particle is stopped. When a particle goes through a counting surface (i.e. a histogram) the particle is not stopped but continues on down the beam line. The apertures and surfaces in Table 1 are defined as follows:

Aperture at 2.5 m.
An elliptical aperture with x radius = 11 cm and y radius = 3.5 cm. The aperture is centered on the midpoint between the two beams.

Aperture at 0.1 m.
A circular aperture with radius = 5.0 cm centered on the incoming beam.

Aperture at –0.1 m.
A circular aperture with radius = 5.0 cm centered on the beam.

Counting surface at –0.36 m.
An elliptical aperture with x radius = 4.5 cm and y radius = 4.0 cm centered on the beam.

SUMMARY, CONCLUSIONS, AND PRESENT STATUS

Synchrotron radiation generated by the final focus triplet quadrupoles and by the splitter magnets does not contribute to detector backgrounds. Radiation from magnets farther upstream does not reach the interaction region, consequently there is no contribution to detector backgrounds from synchrotron radiation.

The splitter magnets are the only magnets that significantly contribute to beam pipe heating near the collision point. The radiation from these magnets amounts to about 1–2 watts of power deposited on each end of the central large beam pipe.

The dominant contribution to detector backgrounds from lost beam particles comes from the Hard part of the particle distributions (both beam-gas bremsstrahlung and Coulomb scattering). I see almost no contribution from the Soft regions as described in the table notes. The background from the Hard part of the distributions is essentially all coming from the degraded beam particles; the photons from beam-gas bremsstrahlung contribute very little.

Using the Day One Optics, with the apertures as defined in the table notes, one finds the total rate into the detector region to be about 60 kHz from one beam. This assumes a vacuum of 10^{-9} Torr and a full current (5.3 A) machine. I should emphasize that these numbers are preliminary. Modifying the geometry or optics can change these numbers, but I think the order of magnitude is correct. The 60 kHz is the rate particles from these backgrounds are incident on the inside of the beam pipe. It is not a rate for particles that exit the beam pipe nor is it a trigger rate for the detector. A more detailed simulation of the detector is needed in order to obtain an estimate of how much these background particles contribute to a trigger rate. I have not looked at the angular distribution of these particles as they hit the beam pipe (the distribution should be strongly peaked in the forward direction) but this information is available from the program.

Almost all of the particles that strike the detector region are created in the 2.5 m region between the triplet quads and the splitter magnet (see Figure 7). About one third of the particles generated by Coulomb scattering come from the four meters behind the splitter magnet (essentially between the splitter and the first dipole). Improving the vacuum in these regions should improve the detector background rate.

I started putting together a KLOE machine lattice. However, I found that it is nontrivial to include the detector solenoid in the program for background calculations and I would need to understand how to do this before proceeding. On the other hand, it is quite easy to include the compensating solenoid. I did include the compensating solenoid with the Day One Optics and masking geometry to look at the influence the compensating solenoid has on the background. I saw virtually no difference within statistics. This test was done quickly and I feel it should be rechecked.

The next step that I see is to put together a KLOE lattice input file that approximates the lattice as well as possible. I think that having an accurate geometry near the IP (beam pipe dimensions, magnet apertures, etc.) will be more important than having an exactly correct machine lattice as far as estimating detector backgrounds is concerned.

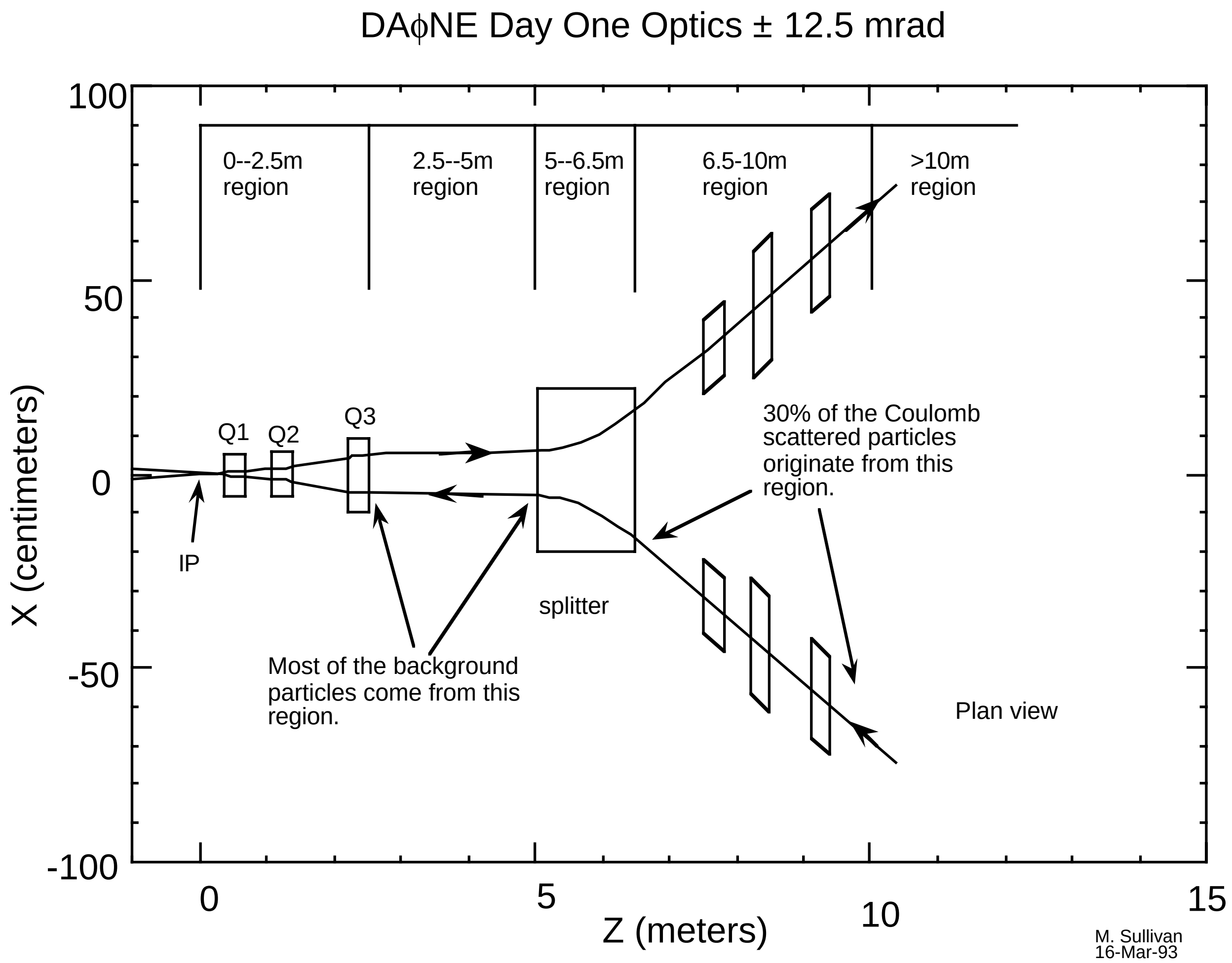

Figure 7. Almost all of the background particles originate from the region between Q3 and the splitter magnet. 30% of the Coulomb scattered particles come from the region upbeam of the splitter magnet.

ACKNOWLEDGMENTS

I would like to thank all of the people at the Istituto Nazionale di Fisica Nucleare who helped me while I was there and made my stay so enjoyable. Special thanks go to Caterina Biscari and Marica Biagini for their tireless willingness to answer my questions and to give me more information about DAΦNE. I would also like to thank Pina Possanza for cheerfully taking care of all the logistics and paperwork needed for my stay in Italy.

REFERENCES

[1] "An Asymmetric *B* Factory Based on PEP", Conceptual Design Report, LBL PUB-5303, SLAC-372, Feb. (1991).
[2] R. Coisson, Phys. Rev. **A20**, 524 (1979).
[3] R. Bossart, *et. al.*, NIM **164**, 375 (1979).
[4] R. Coisson, NIM **143**, 241 (1977).
[5] V.G. Bagrov, *et. al.*, NIM **208**, 167 (1983).
[6] D.C. Carey, *et. al.*. SLAC-246 (1982).
[7] K. L. Brown, *et. al.*,CERN 80-04, (1980).