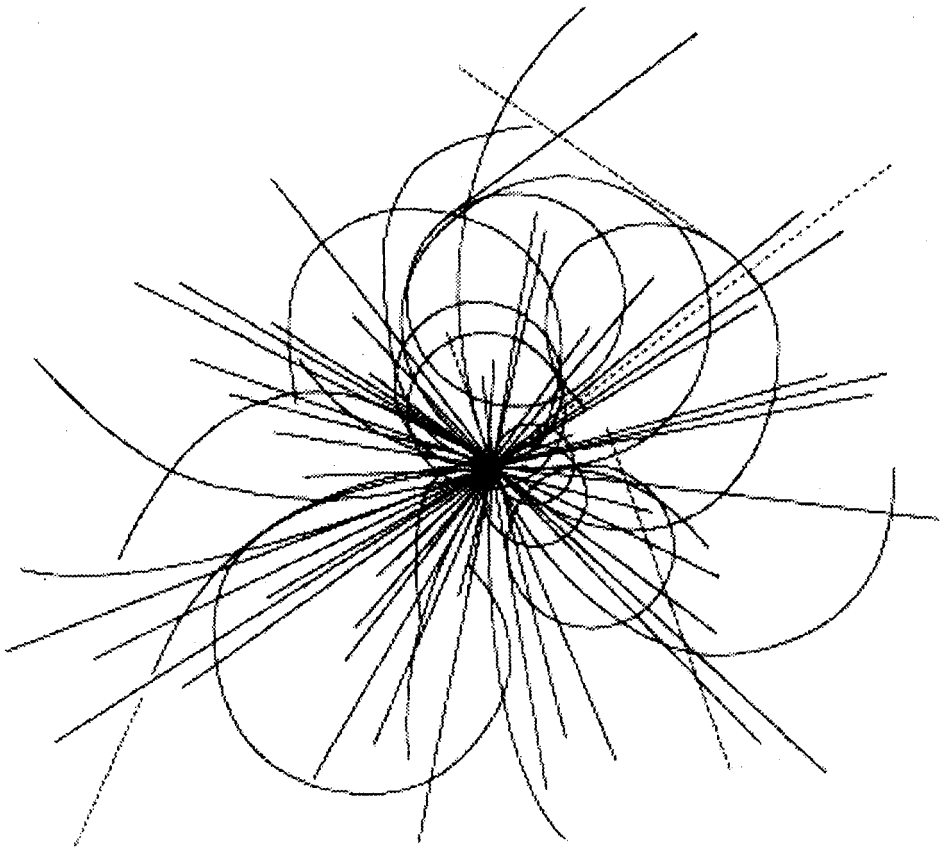
SSCL-Preprint-483

SSCL-Preprint-483
June 1993
Distribution Category: 414

M. Diwan

Radiation Environment and Shielding at the SSC



Superconducting Super Collider Laboratory

RADIATION ENVIRONMENT AND SHIELDING AT THE SSC

Milind V. Diwan
26 June 1993
Physics Research Division, SSC Laboratory, Dallas, Texas.

INTRODUCTION

Much higher radiation levels are expected at the SSC compared to all previous colliders because of the increased center of mass energy (40 TeV) and the increased luminosity ($10^{33}cm^{-2}s^{-1}$ for a general purpose high $P_{\perp}$ detector, and $10^{32}cm^{-2}s^{-1}$ for the proposed B detectors). We have performed a comprehensive study of the radiation environment for the proposed GEM detector[1] at the SSC. As a result of this study, we have developed a shielding scenario that will ensure that the detector will operate with its design performance for at least 10 years at the standard luminosity of $10^{33}cm^{-2}s^{-1}$. We define a standard SSC year (SSCY) as 10^7 s.

The main concerns of our study have been:

- The charged particle, neutron, and photon fluxes, and the hit rates generated in the inner tracker and the muon spectrometer.
- The radiation doses delivered, especially to the inner tracker layers, the endcap and forward calorimeter components, and the beam line components within and near the experiment.
- Radioactivation of the inner and forward parts of the detector and the beam line, and levels of radioisotopes generated in the experimental hall.

While much of our study was specific to the detector geometry proposed for the GEM experiment, many of the results are applicable to other SSC experiments. In particular, the general considerations of energy loss in the collision hall presented in Section 2 should be applicable to the proposed B-physics experiments. In Section 3, we present some results specific to GEM, and we draw conclusions specific to proposed B-physics detector geometries such as BCD[2-3] .

ENERGY DEPOSITION

There are three major sources of radiation: local beam loss in the collider tunnels; interactions of the 20 TeV proton beams with the residual gas in the beam pipe; and particle production at the interaction point. The contributions of each of these sources to the total particle fluence and the deposited energy will depend on the luminosity. At the standard SSC

---

1 "GEM Technical Design Report," presented by the GEM Collaboration, SSC-SR-1219, April 30, 1993.
2 "Bottom Collider Detector," SSC-EOI0008, May 25, 1990.
3 "Comparison of BCD and COBEX strategies for B Physics at Hadron Colliders," K.T. McDonald, Princeton-HEP-92-11.

luminosity of $10^{33}cm^{-2}s^{-1}$ the radiation levels will be dominated by the particle production at the interaction point.

Beam loss in the walls of the beam pipe occurs simultaneously around the accelerator. The beam size is large in the final focus quadrupoles near the interaction points (IP), so the beam loss is particularly severe in these regions. Using the MARS12 code system[4-5], we have estimated neutron and charged particle fluxes due to this beam loss by making simulations of proton orbits around the accelerator and of the hadronic cascades due to the lost protons. For the interaction region geometry anticipated for GEM, we find that the contribution from this source is negligible. We expect the same conclusion to hold for the B detector, unless there are dramatic changes in the low beta quadrupole magnets.

The particle fluxes due to interactions of 20 TeV beam protons with atoms of the residual gas (beam gas interactions) in the evacuated beam pipe was computed using the MARS12 code system. The calculation assumed a pressure of 10^{-8} torr of nitrogen in the warm regions of the beam pipe (which extends up to the low beta quadrupoles located 35 m from the interaction point). A density of 4.0×10^8 N_2 molecules/cm^3 was assumed for the cold regions of the beam pipe inside the magnets. The cross section of 20 TeV protons (50 mb/nucleon) is such that this density corresponds to a loss of 1.7×10^{11} protons/m/SSCY from the two rings in the 100-m-long experimental hall. We used the value of 2×10^{11} protons/m/SSCY, which includes a small contribution from protons whose orbits are disturbed by the other interaction regions.[6] The details of the calculation are shown in Reference 1. Beam gas interactions as far as 60 meters away from the interaction point contribute to the particle fluences in the central cavity of the detector. The secondaries from the interactions are directed towards the interaction point. They further interact in the forward edges of the calorimeters producing a shower of particles near the beam line in the central cavity. For GEM, we have estimated that at the standard SSC luminosity ($10^{33}cm^{-2}s^{-1}$) the contribution to low energy neutron flux due to beam gas interactions is less than 3% everywhere in the detector. The contribution to the charged hadron flux at a radius of 10 cm from the interaction point is about 6%. The beam gas hadron flux is distributed approximately flatly in radius (R) in the central cavity, but the charged hadron flux from p-p collisions falls as $1/R^2$.

At the nominal B detector luminosity of $10^{32}cm^{-2}s^{-1}$ the contribution from beam gas interactions near the beam line will become significant, since the machine current, 1.3×10^{14} protons/ring, is expected to remain the same. The exact numbers will depend on the geometry of the forward elements. The number of beam gas interactions may be reduced by demanding a vacuum better than 10^{-8} torr, but this may not be practical for a B-physics detector because of the lack of space for pumps in the forward regions.

---

4 I. Baishev, A. Druzhdin, and N. Mokhov, SSC-306, 1991.

5 N. Mokhov, "MARS12 code system," Presentation in the Simulating Accelerator Radiation Environments Workshop, Santa Fe, New Mexico, Jan. 1993, to be published. Also see N. Mokhov, MARS10 Code Manual, FERMILAB-FN-509, 1989.

6 N. Mokhov, Collider ARC PDRR, May 26-27, 1993.

Now we examine the contribution from p-p collisions at the interaction point. We used the event generator DTUJET[7] to estimate the energy deposited in the detector and in the nearby beam line elements by 40 TeV p-p interactions. Figure 1 shows the fraction of the total energy from the interaction point emitted as a function of pseudorapidity.

DTUJET produces a pseudorapidity (η) plateau of 7.5 charged particles per unit pseudorapidity (for $-5 < \eta < 5$) and mean transverse momentum of 0.6 GeV in agreement with extrapolation of data from lower energies. There is no data in the far forward regions ($|\eta| > 6.0$); therefore, we assign an error of a factor 2 to the distribution of total radiated energy. For a detector covering $|\eta| < 6$, we see that roughly 5% of the energy is deposited in $3 < |\eta| < 6$ and more than 90% of the energy escapes the detector. At least part of this energy must be intercepted in a thick collimator placed in front of the low beta quadrupoles. This reduces the heat load on the cryogenic magnets and the radiation damage to the coil insulation. For GEM, we have chosen a 3 m (16.7 interaction lengths) deep iron collimator with a 25 mm diameter inner aperture placed 32 m from the interaction point. For a lower luminosity B detector the inner diameter of the collimator can be larger. Unfortunately, the errors on these calculations are such that it is conservative to assume that we need a collimator with the smallest possible inner aperture.

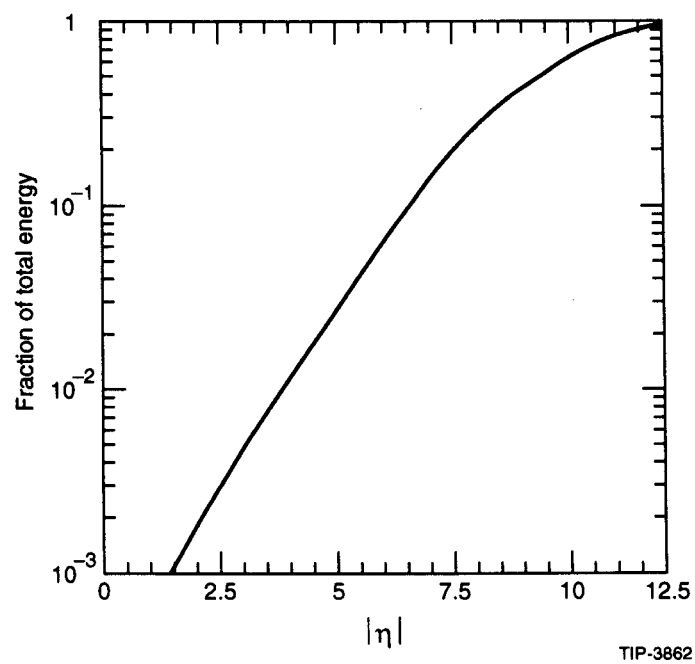


Figure 1. Fraction of the total energy from the interaction point emitted as a function of pseudorapidity.

---

7 J. Ranft, et al., in "Multiparticle Dynamics," Seewinkel, Austria, 1986. J. Ranft, Presentation in the Simulating Accelerator Radiation Environments Workshop, Sante Fe, New Mexico, Jan. 1993, to be published. See also J. Ranft, et al., UL-92-7 and UL-HEP-93-01, Leipzig, Germany. We have used the February 1, 1993 version of DTUJET.

The amount of energy lost from the collider at the interaction point (4.0×10^9 TeV/s and 4.0×10^8 TeV/s for lower luminosity) is greater than the beam loss in the accelerator magnets near the interaction point (approximately 4.0×10^7 TeV/s) or the beam loss in the residual gas of the vacuum pipe (4.0×10^7 TeV/s). The energy intercepted by the forward calorimeters (5%) is less than the energy into to the collimators (about 30%). Due to the proximity of sensitive detectors to the forward calorimeters, both the collimator and the forward calorimeter regions will be the dominant sources of background neutron and photon fluxes. For a lower luminosity detector beam gas interactions contribute a large fraction of the background near the beampipe.

SHIELDING CONSIDERATIONS

In this section, we briefly describe the shielding designed for the GEM detector and draw some conclusions for the proposed B-physics experiments. Figure 2 shows the detector and shielding configuration for GEM. The detector can be divided in three parts for shielding consideration: the central tracker cavity, the calorimeter covering $|\eta| < 5.8$, and the muon system.

The Central Tracker Cavity

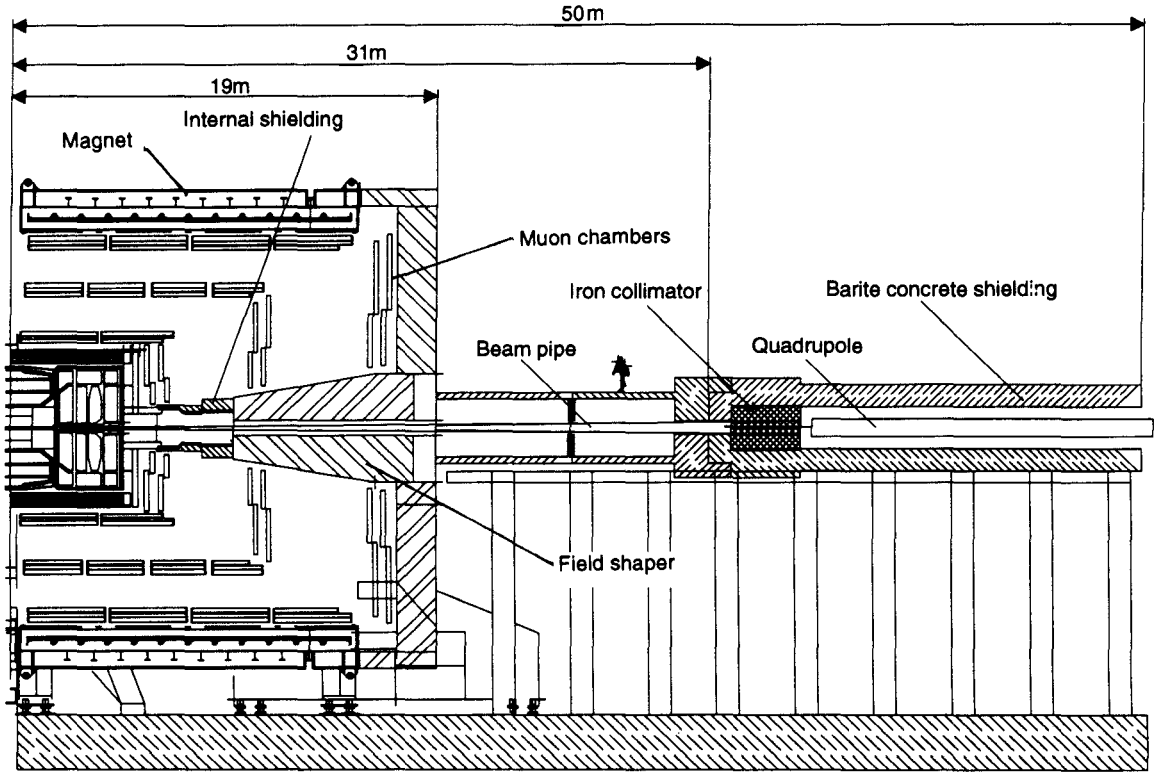
The main concerns in this region of the detector are random hit rates due to albedo neutrons and photons and the total radiation dose to the sensitive detector elements such as the silicon tracker. An earlier SSC Laboratory Central Design Group report, SSC-SR-1033[8], addressed the radiation environment in the central detector cavity. The albedo neutron and photon fluxes in the central cavity are affected by the volume of the cavity, the composition of the electromagnetic calorimeter, and by the shielding material placed in front of the calorimeter. The neutron flux scales as $1/R^2$, where R is the characteristic dimension of the central cavity. Furthermore, the flux is proportional to (1+A), where A is the mean number of reflections that a neutron experiences before being absorbed. For the GEM detector, we plan to place borated polyethylene on the surfaces of the calorimeter to reduce the flux of albedo neutrons by fast absorption. With this shielding in place, we calculate the average flux of neutrons of all energies to be about 4×10^{12} n/cm^2/SSCY. The average flux of photons above 100 keV will be about 6×10^{12}/cm^2/SSCY. These calculations were performed using the LAHET-MCNP code system.[9] The single rates in the central cavity are dominated by the charged particles from the interaction point. The lifetime of the innermost silicon strip detector, placed 10 cm from the interaction point, is also dominated by the

---

8 D.E. Groom, "Radiation Levels in the SSC Interaction Regions," SSC-SR-1033, June 10, 1988.

9 "User Guide to LCS: the LAHET Code System," Richard E. Prael and Henry Lichtenstein, Los Alamos National Laboratory, LA-UR-89-3014, Sep. 1989. "MCNP: A General Monte Carlo Code for Neutron and Photon Transport," Judith F. Briesmeister, LA-7396-M Rev. 2, Sep. 1986. "Radiation Calculations using LAHET/MCNP/CINDER90," Proceedings of the II International Conference on Calorimetry in High Energy Physics, Corpus Christi, LA-UR-89-3014, Oct. 1992.

a)



b)

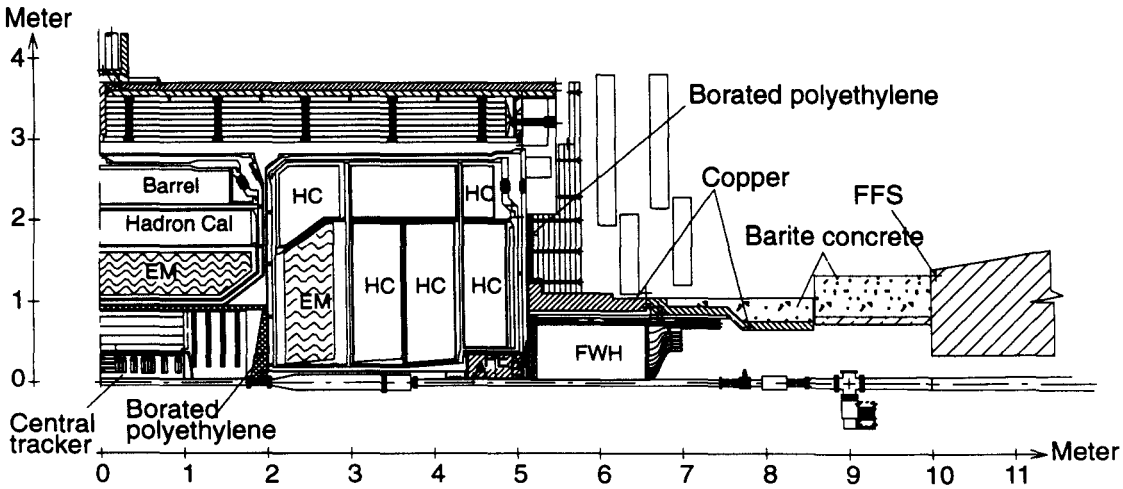


Figure 2. Detector and shielding configuration designed for GEM. a) Elevation view of half of the detector and shielding around the collimator and the quadrupole. b) Details of the shielding near the GEM calorimeter.

radiation dose due to the charged particles. The dose at standard luminosity to a detector placed R cm from the beam line is 50 Mrad/(R/cm)^2/SSCY. We expect the silicon to survive about 10 years at standard luminosity ($10^{33}cm^{-2}s^{-1}$).

For the B-physics detectors, the luminosity will be lower ($10^{32}cm^{-2}s^{-1}$), the tracking volume will be larger than a general purpose detector like GEM. Also, for some B detector designs a more open geometry is contemplated. All of the above differences will lower the neutron and photon albedo fluxes to about 10^{11}/cm^2/SSCY. The lower luminosity should allow operation of silicon detectors as close as 1 cm to the interaction point. Other systems such as RICH detectors, time of flight counters are also needed for the B detector. Hit rates and damage to these systems need to be accessed.

Calorimeters

The main concern for these systems is the radiation dose in the forward calorimeters. The maximum dose at the inner corners of the forward calorimeter is dominated by electromagnetic showers. The hadronic dose is distributed over a much larger volume that the electromagnetic dose as expected from the ratio of interaction length to radiation length. For GEM, we have chosen to place the forward calorimeter close, 4.5 m, from the interaction point. This choice has resulted in a compact design with no gaps through which neutrons can escape and cause random hits in the muon system. The maximum doses at standard luminosity to forward calorimeters expected in GEM are 400 Mrad/SSCY at the inner edge with 10 Mrad/SSCY of hadronic dose distributed uniformly in the $3 < |\eta| < 5.8$ region. For the lower luminosity B detector, the forward systems will probably be farther away from the interaction point with corresponding decrease in the maximum dose.

Muon System

We have spent considerable effort in reducing random hits due to neutrons and photons in the muon chambers. The largest sources of neutrons in the detector are the collimator and the forward calorimeters. The muon chambers are approximately 10 times more sensitive to photons than to neutrons. Most of the photons in the muon system, however, are produced by interactions of neutrons. Therefore, we have concentrated on removing neutrons as close to their sources (the collimator and the forward calorimeter) as possible. We have accomplished our goal by hermetically sealing the entire beam line. The thick calorimeter serves as a shield in the central region; the concrete and the field shaper shield the beam pipe, the collimator, and the quadrupoles. We have computed the neutron and photon fluxes using

the GEANT-CALOR[10,11,12] and the LAHET-MCNP code systems. The computations were performed with and without the shielding shown in Figure 2. The fluxes without the shielding are in the range of 10^{11} - 10^{12} neutrons/cm^2/SSCY at standard luminosity through the muon system. The photon flux is about 30% of the neutron flux. The shielding shown in Figure 2 reduces these fluxes by about two orders of magnitude.

As explained in Section 2, the lower luminosity at the B detector will reduce the contribution to particle fluxes in the muon system due to p-p interaction by a factor of 10, but the contribution due to beam gas interactions will remain the same. Therefore, one should expect a reduction of only about a factor 5 or a flux of few times 10^{11} neutrons/cm^2/SSCY in the muon system without shielding. The exact distribution will depend on the choice of detector geometry and the size of the hall. It is likely that the muon system will produce the trigger for the B detector. The trigger requirements, along with the muon chamber technology and the granularity, will determine the amount of shielding necessary. The experience from designing GEM suggests that a closed geometry is preferable to open geometries, which might be easier to construct. Thick concrete shielding around the beam line up to the tunnel entrance will probably be needed.

After a choice of the B detector geometry, calculations with one of the above mentioned code systems should be performed to assess the background rates and shielding.

The radiation task force for GEM consisted of the following individuals: Gerry Chapman, Joe Coyne, Milind Diwan, Yuri Efremenko, Yuri Fisyak, Vladimir Gavrilov, David Lee, Mike Marx, Roger McNeil, Nikolai Mokhov, Brent Moore, Kate Morgan, Vasiliy Morgunov, John Rutherfoord, Laurie Waters, Bill Wilson, and Craig Wuest.

I thank Linda Fowler for typesetting this paper on such short notice.

---

10 "CALOR: A Monte Carlo Program Package for the Design and Analysis of Calorimeter Systems," T.A. Gabriel, J.D. Amburgey, B.L. Bishop, ORNL/TM-5619, Apr. 1977. "User's Guide for the FLUNEV Code," J.M. Zazula, Desy-internal-rep D3-90-66, Jan. 1990. "FLUKA and KASPRO Hadronic Cascade Codes," J. Ranft, Erice 1978, Proceedings, Computer Techniques in Radiation Transport and Dosimetry.

11 Y. Fisyak, K. McFarlane, L. Roberts, GEM-TN-92-162, 1992.

12 C. Zeitnitz, T.A. Gabriel, "The GEANT-CALOR Interface," III Conference for Calorimetry in High Energy Physics, Proceedings (to be published), Corpus Christi 1992. C. Zeitnitz, T.A. Gabriel, "The GEANT-CALOR Interface," International Conference on Monte Carlo Simulation in High Energy and Nuclear Physics, Proceedings (to be published), Tallahassee, 1993. See also J.O. Johnson, T.A. Gabriel, "Development and Evaluation of a Monte Carlo Code system for analysis of Ionization Chamber Responses," ORNL/TM-10196, July 1987.