BEAM INDUCED DETECTOR BACKGROUNDS AT A MUON COLLIDER*

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Abstract

Muon colliders are considered to be an important future energy frontier accelerator. It is possible to build a large muon collider as a circular machine, even at multi-TeV energies, due to the greatly reduced synchrotron radiation expected from muons. In addition to the same physics processes present in an electron collider, a muon collider will have the potential to produce s-channel resonances such as the various Higgs states at an enhanced rate. For a muon collider with 750 GeV/c $\mu^+\mu^-$ with 2×10^{12} μ per bunch we would expect 8.6×10^5 muon decays per meter for the two beams. The energetic electrons from muon decays will produce detector backgrounds that can affect the physics. These backgrounds include electrons from muon decays, synchrotron radiation from the decay electrons, hadrons produced by photo-nuclear interactions, coherent and incoherent beam-beam pair production and Bethe-Heitler muon production. In this paper we will discuss these processes and calculate particle fluxes into the detector volume from these background processes.

INTRODUCTION

Historically electron-positron colliders have provided measurements of new phenomena in high energy physics. However as the energy of e^+e^- colliders increase the energy loss due to bremsstrahlung in circular and beamstrahlung in linear colliders eventually limits the maximum energy that these machines can achieve. Since the radiation loss of a charged particle is inversely proportional to m^4, a $\mu^+\mu^-$ collider should have the potential of achieving a higher center of mass energy than an e^+e^- collider. The potential to perform physics with a muon collider will largely be determined by how well one can suppress the accelerator based backgrounds that will be present in the collider ring. The source of most accelerator related backgrounds in a muon collider is associated with the decay of the muons. Consequently the backgrounds are dependent on the number of muons per bunch circulating in the collider rings. Table 1 shows the parameters that describe the muon collider with 1.5TeV center-of-mass energy that is being studied. The table shows that each beam has 2×10^{12} muons per bunch. There will be 8.6×10^5 muon decays per meter for both muon beams. The 750 GeV muon decays produce energetic electrons with a mean energy of 260 GeV. As these electrons do not have the designed momentum of the collider ring they will likely interact with the beam chamber walls or shielding producing electromagnetic (EM) showers. In addition to the decay electron EM showers, these electrons will produce synchrotron radiation in regions with large transverse magnetic fields that are present in the collider ring. The EM showers in material can photo-produce hadrons as well as muon pairs (Bethe-Heitler muons). The Bethe-Heitler muons can be energetic and can penetrate magnets and shielding materials. These muons can enter into the detector region. A previous study on an earlier muon collider design [1] showed that these backgrounds could be controlled with a large 20° conical shielding block that obscured the forward and backward regions of the detector.

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Table 1: Parameters to Describe the Muon Collider Ring

Parameter	Value
Center-of-mass energy	1.5 TeV
Each Beam Energy	0.75 TeV
Luminosity	10^{34} cm^{-2}sec^{-1}
Bunches per Fill	1
Muons/Bunch	2×10^{12}
Repetition Rate	15 Hz
Ring Circumference	2.6 km

SIMULATIONS

This study uses the G4beamline program [2] to simulate the muon decay electrons in the muon collider ring. An auxiliary program was used to manage the collider ring lattice geometry and parameters, the shielding and the detector description [3]. The lattice used for this study is described in reference [4]. This program writes the input file for G4beamline and Mars [5] allowing for the rapid changes to the lattice and shielding. A comparison of the G4beamline results with the Mars results is given in another paper submitted to these proceedings [6]. Figure 1 shows the magnetic elements of the muon collider interaction region design [7] for ±75 m from the interaction point. The dipole magnets are shown in red while the focusing (defocusing) quadrupoles are shown in green (blue). Surrounding the interaction point there is a 10° tungsten conical shield to prevent beam backgrounds from entering the detector region. An enlargement of the 10° shielding cone is shown in Figure 2. The outer surface of the tungsten shield has a layer of borated polyethylene to absorb neutrons. The shielding outside the final focus quadrupoles is shown in red and was comprised of tungsten and borated polyethylene for this study.

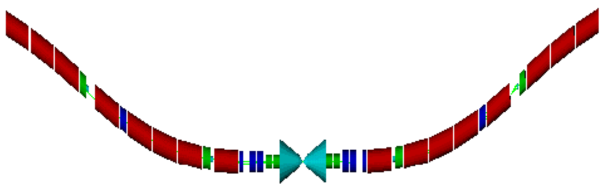

Figure 1: Model of the muon collider lattice in the vicinity of the interaction region. The figure has a transverse to longitudinal aspect ratio of 10 to make the elements visible.

Decay electrons produced uniformly along the muon reference trajectory are tracked in G4beamline. The electrons are generated with the Michel energy distribution and boosted to the laboratory frame yielding the electron energy distribution shown in Figure 3. The decay electrons do not have the design momentum of the collider ring and consequently will hit the magnets, collimators and shielding. The collimators between magnets have elliptical apertures that are five times the muon beam size at that point and will reduce the electromagnetic backgrounds incident on adjacent magnets. The decay electrons in the interaction region itself can interact with the tungsten conical shielding to produce electromagnetic showers which will be a source of photons and neutrons, some of which can punch-through to the detector.

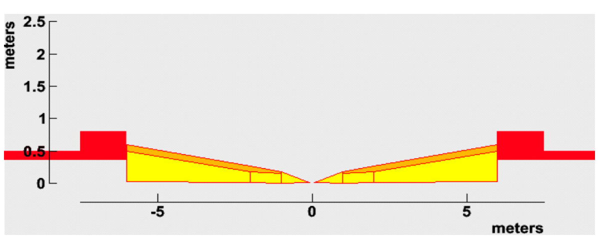

Figure 2: Schematic of the 10° shielding cone in the interaction region. The yellow material is tungsten and the orange material is borated polyethylene. The red material is shielding surrounding the final focus quadrupoles.

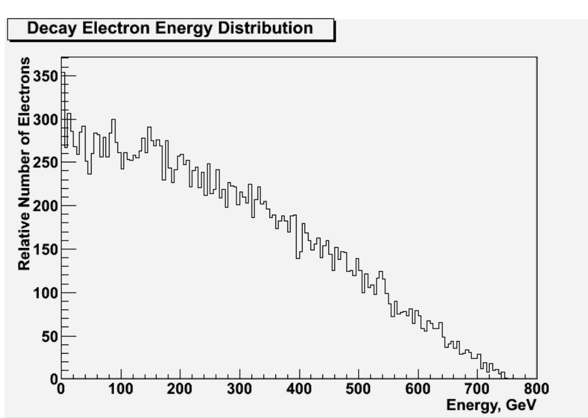

Figure 3: Energy distribution in GeV of electrons from muon decays.

FLUX CALCULATIONS

In order to examine the fluxes of background particles reaching the detector region, cylindrical flux scoring planes have been placed at the positions corresponding to those of the vertex and tracking planes proposed for the SiD detector [8]. Figure 4 displays the geometry of the the detector planes as mapped out by the particle hits. Figure 5 shows the fluxes of gammas (upper left), electrons (upper right) and neutrons (lower left) as a function of the longitudinal position z as they pass through the radial detector plane at r=47 cm. The flux is normalized to 2×10^{12} muons per bunch. The graph separates the particles coming from the positive and negative beams. The gammas tend to come from the center where the shielding is thinner. The neutrons are present for all z increasing near the ends of the detector plane.

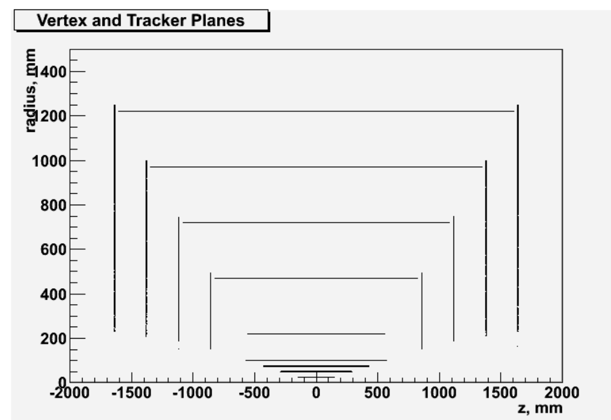

Figure 4: Vertex and tracker planes in the detector. The geometry is mapped out by the particle hits.

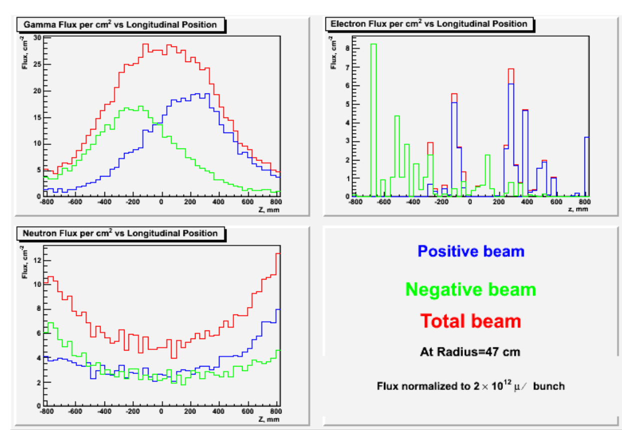

Figure 5: Longitudinal position of γ, e and n passing through the tracker plane at r=47 cm.

Figure 6 shows the particle fluxes crossing the detector planes as a function of the plane radius. The particles have a minimum kinetic energy of 200 keV. The flux is normalized to 2×10^{12} muons per bunch for each muon beam. The large neutron flux at large radius is due in part to their long life time.

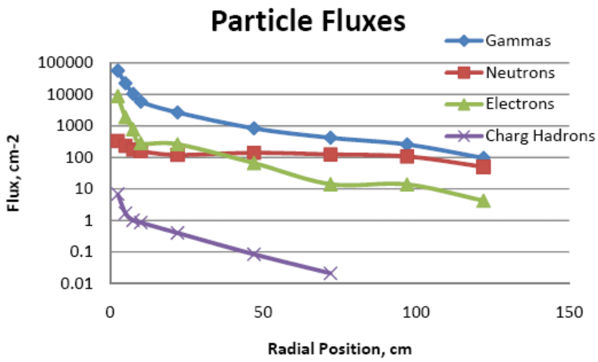

Figure 6: Fluxes for particles crossing detector planes as a function of the plane radius. The fluxes are normalized to $2{\times}10^{12}$ muons per bunch for the two muons beams.

SHIELDING CONE

The shielding cone is effective in reducing the accelerator backgrounds that arrive at the detector. However it removes a significant fraction of physics acceptance. We have studied the amount of background as a function of the cone angle. Keeping the inner surface of the cone unchanged from Figure 2, we have scaled the other dimensions with the tangent of the cone angle. Figure 7 shows the gamma and neutron fluxes as a function of the shielding cone angle. The muon collider design in ref. [1] used a cone angle of 20° which minimizes the effect of the accelerator backgrounds. More recent studies are looking at using a 10° shielding cone angle [9]. The 10° shielding cone would allow more background into the detector region. More study is necessary to determine how easy it would be to reject these backgrounds. In addition the physics requirements will be an important input into the shielding design.

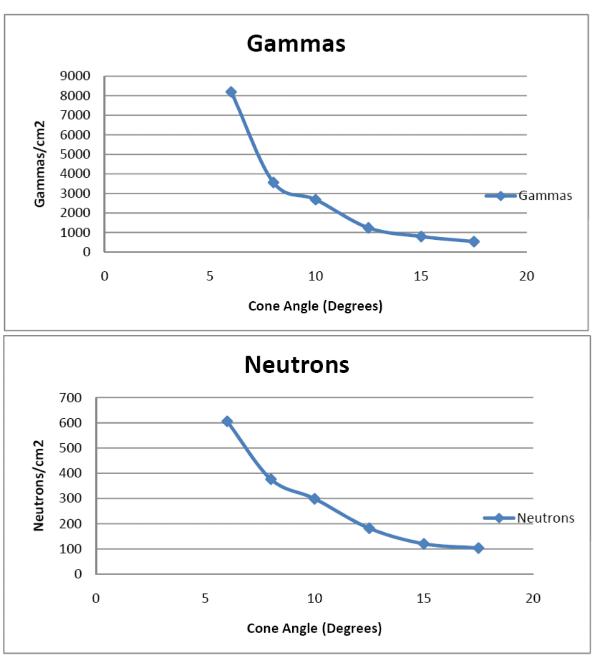

Figure 7: Gamma and neuron fluxes as a function of the shielding cone angle. Flux is normalized to $2{\times}10^{12}\mu$ per bunch.

CONCLUSIONS

We have presented initial results for the calculations of accelerator backgrounds expected in a muon collider using the G4beamline simulation program. We are currently verifying our calculations by comparing the results to those produced in Mars. We are formulating a future program to look at backgrounds from Bethe-Heitler muon pair production and planning to look at how to reject these accelerator backgrounds in the detector.

ACKNOWLEDGEMENT

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