MUON COLLIDER DETECTOR BACKGROUNDS*

M. A. C. Cummings*, S. A. Kahn, Muons, Inc., Batavia, Illinois, 60510
David Hedin, Northern Illinois University, DeKalb, Illinois, 60115
J. Kozminski, Lewis University, Romeoville, IL 60446

Abstract

Technological innovations in recent years have revived interest in muon colliders as the next generation energy frontier machine. Advances in muon cooling technology will make the focussing and acceleration of muons to TeV energies possible. The biggest challenge for muon colliders is that muons decay, but 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 compared to electrons. The challenge for the detectors in such machines is overcoming the large backgrounds from muon decays in the colliding ring lattice that will inundate the interaction region (IR) and will make triggering and data reconstruction a challenge. Developing simulation tools that can reliably model the environment of the muon collider IR will be critical to physics analyses. We will need to expand the capabilities of current programs and use them to benchmark and verify results against each other. In this paper we will discuss these processes and calculate the resulting particle fluxes into the muon collider detector volume.

INTRODUCTION

In 1996, a first comprehensive study [1] of muon colliders was done, including an extensive study of the backgrounds from muon decays in the IP region. Because of necessary shielding, particularly 20^{o} cones in the forward regions, to reduce decay backgrounds, the physics capabilities at a muon collider suffer some limitations. In recent years, however, muon collider designs have been revised, with new ideas to enhance performance. The low emittance approach yields the same luminosity with fewer 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. The instrinsic resolution on the energy of muons due to their large mass, give muon colliders an advantage to distinguish near degenerate states of the Higgs [1]. These advantages will depend on our ability to understand backgrounds muon decays will produce in the detector 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. This latter process is the subject of another paper in this conference [2]. We consider approaches for understanding these backgrounds.

*Work supported in part by DOE SBIR Grant 4738 · 10SC05447
macc@muonsinc.com

BACKGROUNDS

In contrast to hadron colliders, almost all backgrounds that arise in the lattice are associated with the products of the decaying muons that get into the detector region. The size of the beam related backgrounds are proportional to the number of muons per bunch. Recent efforts have been made to realistically evaluate backgrounds from muon decays inside the lattice of a collider ring. For a muon collider with 1.5 TeV center-of-mass energy with parameters listed in Table 1 we expect 8.6×10^5 muon decays per meter for both muon beams. The decay length for 0.75 TeV muons is $\lambda_D = 4\times10^6$ m. With 2×10^{12} muons in a bunch, one has 4.3×10^5 decays per meter of the lattice in a single pass, and 1.3×10^{10} decays per meter per second for two beams. The mean energy of electrons from muon decays is about a third that of the muons. 750 GeV muons will produce electrons with a mean energy of ~250 GeV, that travel to the inside of the ring magnets and radiate energetic synchrotron photons towards the outside of the ring. Electromagnetic showers induced by these electrons and photons inside the collider ring components generate intense fluences of muons, hadrons and daughter electrons and photons. This creates high background and radiation levels both into the ring and detector.

Table 1: Parameters for 1.5 and 3.0 TeV Muon Colliders

Parameter	**1st MC**	**2nd MC**
Center-of-Mass Energy	1.5 TeV	3.0 TeV
Energy of Each Beam	750 GeV	1.5 TeV
Luminosity	10^{34} cm^{-2}sec^{-}	$4X10^{34}$ cm^{-2}sec^{-}
Bunches per Fill	1	1
Muons/Bunch	2×10^{12}	2×10^{12}
Repetition Rate	15 Hz	12 Hz
Ring Circumference	2.6 Km	4.5 Km
Shielding Angle	10°	10°

SIMULATION APPROACH

We have developed a computer program package that can calculate accelerator-based backgrounds for a muon collider. The program is built on Muons, Inc.'s G4beamline [3], an interface to the Geant4 toolkit for the simulation of elementary particles passing through matter. We are studying background particle fluxes at key locations such as detector components and intersection

ISBN 978-3-95450-115-1

region beam-line elements. We have begun to apply this background study to the forward area of the shielding cones. Fig. 1 shows a G4beamline simulation of a muon collider IR.

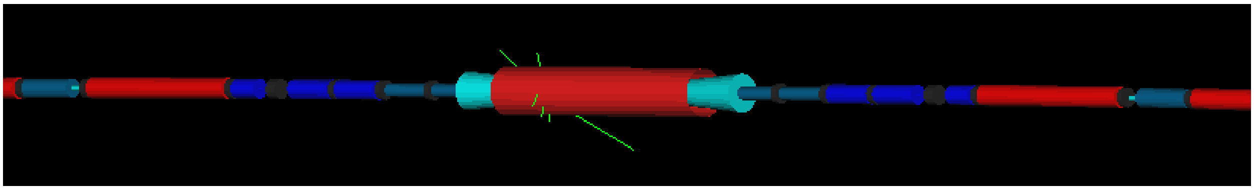

Figure 1: An extended view of the muon collider IR with forward shielding as modelled by G4beamline.

Software Benchmarks

The background particle fluences from G4beamline muon collider beam simulations have been compared to fluences calculated with identical lattices at the same detector locations using the "MARS15" program [3]. The approaches of MARS and Geant4 are very different, with different weighting and physics propagation techniques. Agreement of simulation results would be a strong verification marker, and mirrors efforts made in the 1996 study. The disparate approaches of MARS and Geant4 codes makes it less likely that any important physics gets overlooked. This is considered by the MAP collaboration as being a necessary and desirable procedure toward a robust Muon Collider design.

Simulation Packages

We have developed auxiliary programs that facilitate these comparison studies. *BruitDeFond* [5] can produce an ASCII file of G4beamline commands or the equivalent MARS.INP, GEOM.INP and FIELD.INP files that describe the ±75 m of muon collider interface region. *BeamMaker* produces a *BLTrackFile* that can be read by the G4beamline input card This same file is read by our version of Mars user subroutines for the beam description. The *BLTrackFile* contains e^{+} and e^{-} thrown with the Michel decay distribution and boosted to the laboratory frame. This helps to ensure that comparisons are done on equivalent output. Fig. 2 shows the geometry description for a MARS muon collider IR generated by the *BruitDeFond* package.

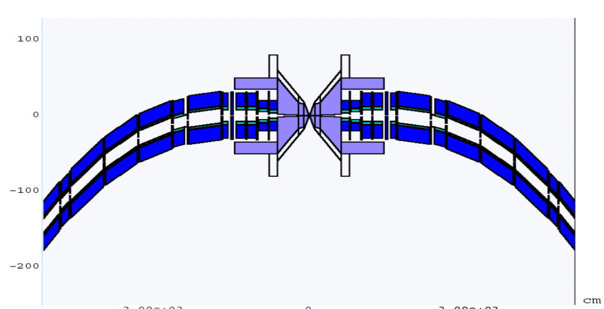

Figure 2: Layout of Mars Geometry Generated by *BruitDeFond* Package.

We have made some initial studies on the performance of Geant4 and MARS in backgrounds produces in the interaction region. Fig. 3 shows the schematic for the ssimulation studies. The final focus region used was designed by E. Gianfelice-Wendt [6]. There are significant differences in set up and generation between MARS and G4beamline, and there are some outstanding issues, such as the generation of neutrons and energy cut-offs.

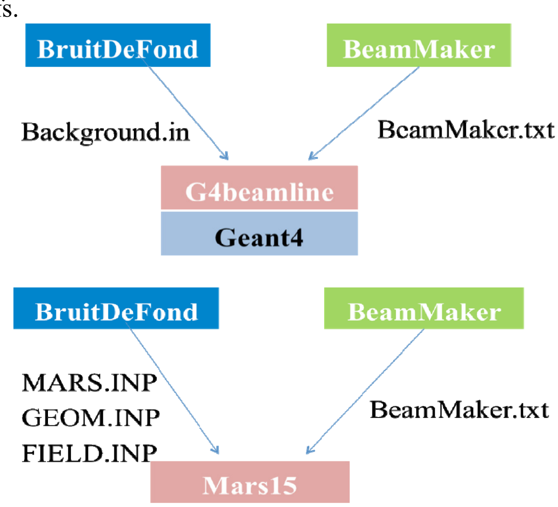

Figure 3: Schematic of inputs generated by *BruitdeFond* package for G4beamline (above) and MARS15 (below).

For the following in Fig. 4 graphs below, the muon collider configuration is as described above. In this particular study we used the 10° shielding cone. This requires three days on Northern Illinois NICADD cluster [7] running G4beamline, given the individual particle tracking, which is why there were fewer events generated than for MARS. In both cases, events carried a constant weight to normalize to 2×10^{12} muons/bunch, expected at a real muon collider. Detector planes positioned at SiD locations. Both vertex and tracker detector planes have equivalent SiD material description. Particles are scored as they pass through planes, and the plots in Fig. 4 show particle fluences (particles/cm^2 vs. radial distance from the beam in cm) for gammas, electrons, neutrons and charged hadrons. Calorimeter material is present, but there is no particle scoring in the calorimeter region.

There is generally good agreement for the electrons and gamma backgrounds between MARS and G4beamline. More problematic are hadronic backgrounds, G4beamline neutron data should fall off as 1/r as the MARS data does. This inconsistency and the lower energy neutron production will be studied more extensively.

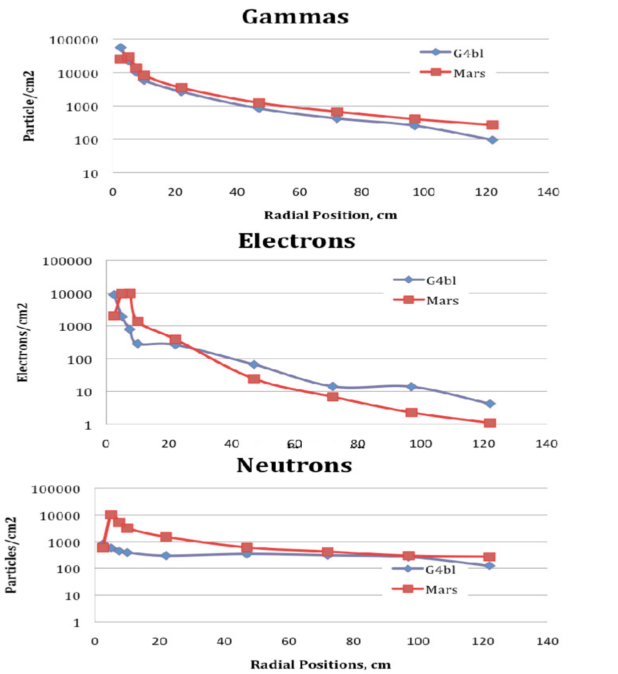

Figure 4: Particle fluences, gammas, electrons, and neutrons for G4beamline/ MARS comparison.

FORWARD DETECTOR STUDIES

With advances in particle detection and read-out technology in the years since the 1996 Muon Collider Feasibility Study, it will be possible to extend the detector coverage into the forward region that was previously considered unsuitable for particle detection. This may allow for the recovery of particle ID and some information on energy deposition and timing.

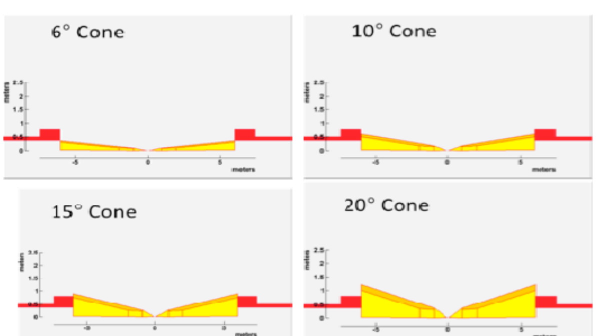

Figure 5: Conical Shielding configurations at angles ranging from 6 to 20 degrees.

FUTURE BACKGROUND STUDIES

We are undertaking improvements to G4beamline to enhance its capabilities for analysis of muon collider physics and detector design. We are increasing the output capacity of our simulations on the Northern Illinois NICADD cluster shown in Fig. 7. Other developments include the generation and study of Bethe-Heitler muons. We believe our *BruitdeFond* software package can be a

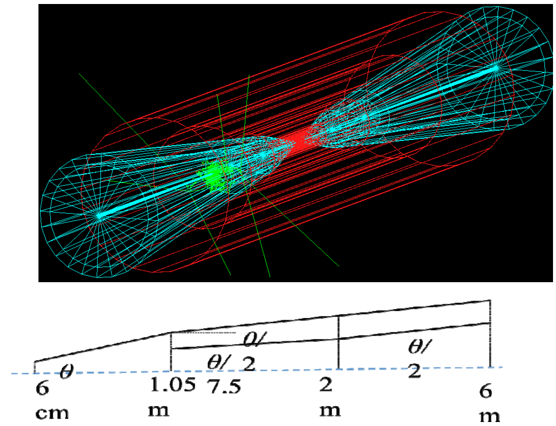

Figure 6: G4beamline simulation of decay electrons into the shield cone (from left). The shower is in green. Below is the profile for the forward shielding.

valuable development tool for the particle physics community and will facilitate more widespread participation of the particle physics community in muon collider physics studies. Understanding the environment of a muon collider IR will challenge all current physics modeling tools, and the comparison of detailed studies between two powerful programs such as MARS15 and GEANT4 will be necessary to understand the triggering and reconstruction issues that will be particular to this new kind of particle accelerator.

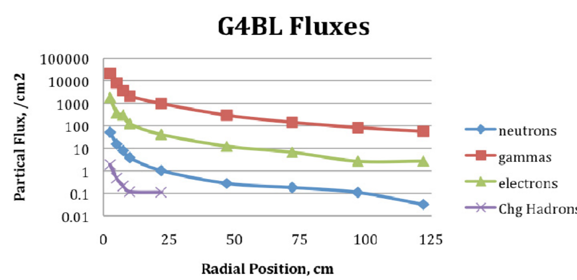

Figure 7: Particle fluxes vs. distance from beam.

REFERENCES

[1] *μ+μ- Collider: A Feasibility Study*, The μ+μ- Collider Collaboration, BNL-52503, FermiLab-Conf-96/092, LBNL-38946 (1996). http://www.cap.bnl.gov/mumu/pubs/snowmass96.html
[2] S. Kahn, et al, MOP040, this conference.
[3] T.J.Roberts, MOPPC084, this conference.
[4] N. Mokhov, "Muon Collider Detector Backgrounds and Machine Detector Interface", Transparencies shown at the Muon Collider Physics Workshop, Nov 10-12, 2009.
[5] S. Kahn et al, THP088, PAC11, April, 2011.
[6] Y. Alexahin et al., "Muon Collider Interaction Region Design", Proc. of IPAC'10, Kyoto, (2010).
[7] See www.nicadd.niu.edu//sysadmin/index.html

ISBN 978-3-95450-115-1