A Program for Accelerator Based Backgrounds for a Muon Collider

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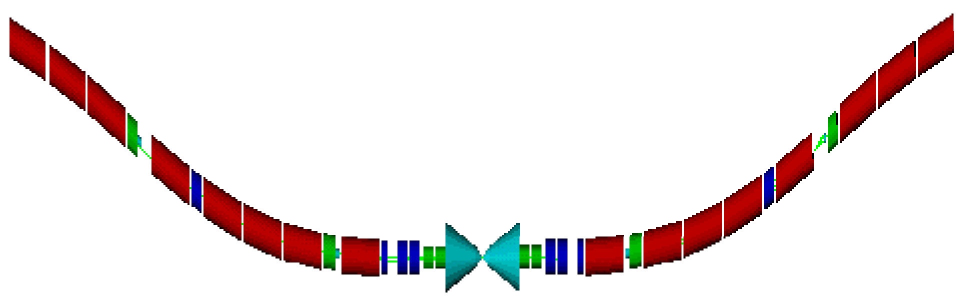
Background on Muons, Inc. and NIU

- Muons, Inc. is a small company composed primarily of physicists that earns a large fraction of its money from SBIR grants from DOE.
- We have just been awarded (in June) a phase I grant in collaboration with Northern Illinois University to simulate accelerator backgrounds for a Muon Collider.
  - This is a new project for us consequently we are light in results at this point. We are describing our plan of action.
  - Our team include
    - Steve Kahn, Mary Anne Cummings, Tom Roberts, Muons, Inc.
    - Dave Hedin, Aaron Morris, NIU
    - Joe Kominski, Lewis University
- As part of my personal experience, I worked with Iuliu Stumer to calculate muon collider backgrounds circa 1997.
  - For those calculations we used Geant 3.21
  - These calculations along with MARS provided mutual confidence in the understanding of accelerator backgrounds to a muon collider.

What Did We Promise?

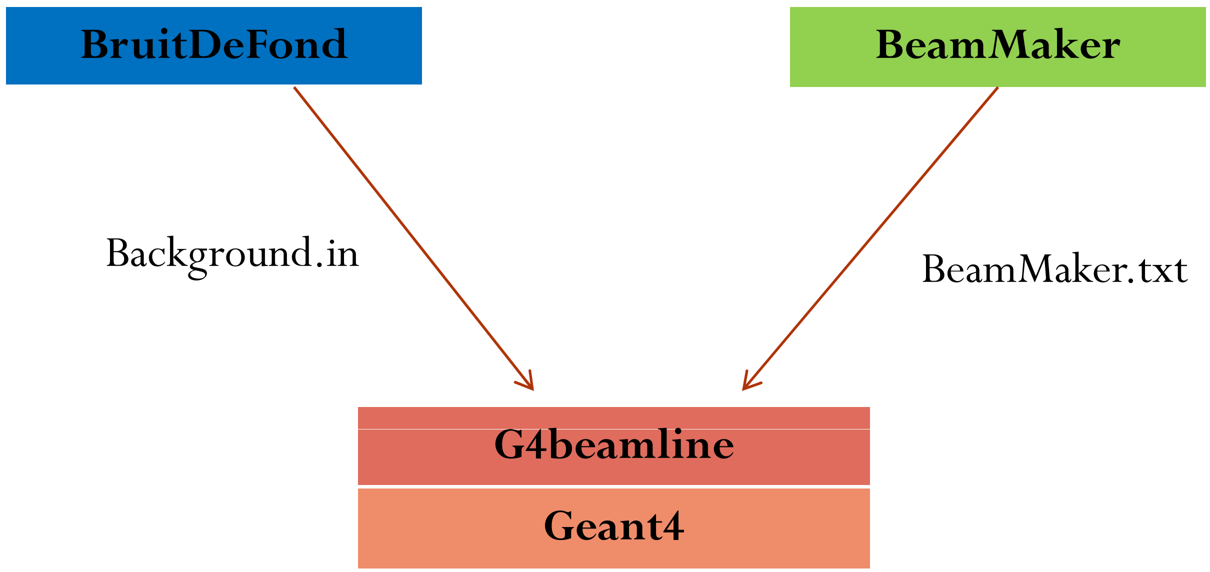
- The development of a Monte Carlo package to simulate muon accelerator backgrounds.
  - The package should be able to accept a MAD lattice description.
  - Provide particle fluxes.
  - Output a file of background events for use with the physics analysis.
- Verification of the MC package by comparing to MARS.
- Evaluate the shielding necessary for a muon collider detector.
  - What cone angle do we need?
- Develop output format for background events so they can be used for physics analysis.



The Simulation Package

- Simulate accelerator based backgrounds in the muon collider intersection region.
- This package will use G4beamline. (To be described)
- The program input uses the *MAD* lattice description of collider beam
  - We are currently the Eliana Gianfelice-Wendt's recent lattice for our studies.
  - Using the *MAD* lattice description allows rapid adjustment to changes in the collider lattice design.
- Model material in beam line and detector interface.
  - Reasonable description of magnet material and magnetic fields.
    - Accommodate special kinds of magnets such as open mid-plane dipoles
    - Dipoles are arcs! Significant magnet sagitta with 10 m long dipoles
  - Masks and collimators
  - Conic shielding
- Requirements
  - Establish muon closed orbit
  - Assume that muon can decay anywhere along the orbit.
    - Track decay electrons as primary particles
- Scoring energy deposition.

What exists and is being developed



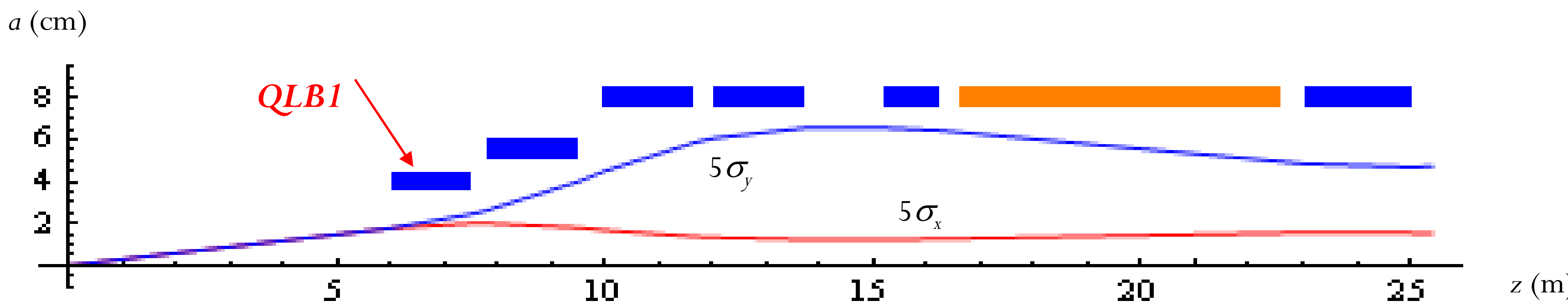
The G4beamline Program

- This program provides an interface to the *GEANT4* toolkit that allows the user to perform particle tracking simulations without having to code in C++ or to compile the program himself.
- The input to *G4beamline* is a script of line commands that describe the geometry, fields and other parameters to setup the simulation.
  - The input format is particularly well suited for beam line descriptions with dipole, quadrupole, etc. beam elements.
- *G4beamline* makes effective use of graphics for verifying geometry setup and visualization of particle tracking.
- *G4beamline* is freely available to the community (the price is right) at http://G4beamline.muonsinc.com

The *BruitDeFond* Program

- The *BruitDeFond* program creates an input file to G4beamline that describes the intersection region of a muon collider.
- The collider configuration is meant to be flexible and uses the MAD element description.
  - We currently have modeled ±75 m from the IP.
  - We are currently using Eliana Gianfelice-Wendt's recent lattice.
- Magnet description is important. Currently all magnets are described by *multipole* command.
  - Quadrupole description similar to Kashikhin design (used in the MARS analysis).
    - Material is described my multiple tubes of Nb_3Sn, SS collar, Fe yoke.
  - Dipole description is currently cosθ surrounded by a steel yoke.
    - This will evolve to an open mid-plane model.

Final Focus Region of E. Gianfelice-Wendt's New Lattice

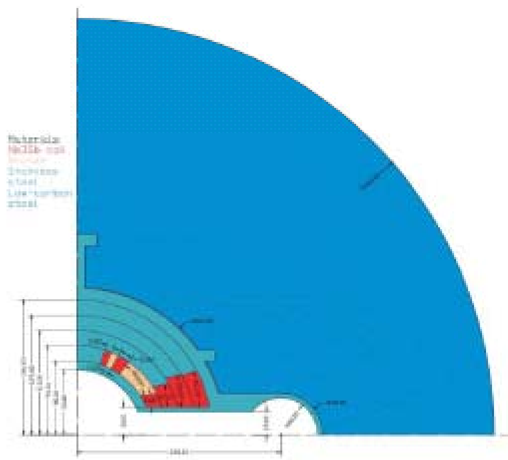


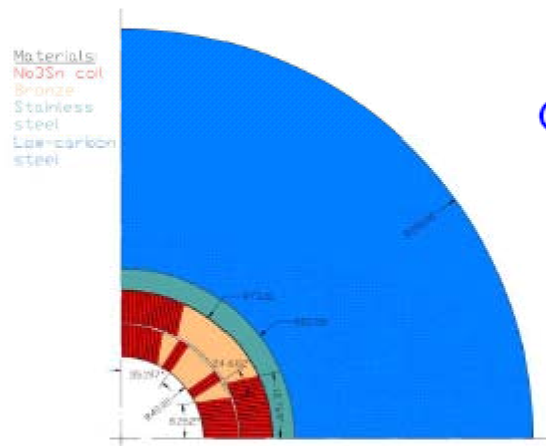
Quad	Units	QLB1	QLB2	QLB3	QLB4	QLB5	QF4
Gradient	T/m	250	187	-131	-131	-89	82
Center Position	m	6.75	8.65	10.85	12.85	15.7	23.9
Radial Aperture	cm	3.5	5	7.5	7.5	7.5	7.5
Quench Gradient at 4.5° ?	T/m	282	209	146	146		

Note the relatively small quench margin

New IR Magnet Design and Implementation in MARS

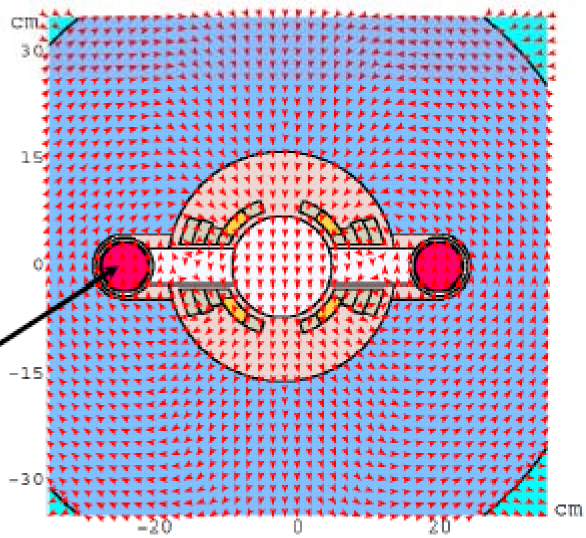
BE1: VK



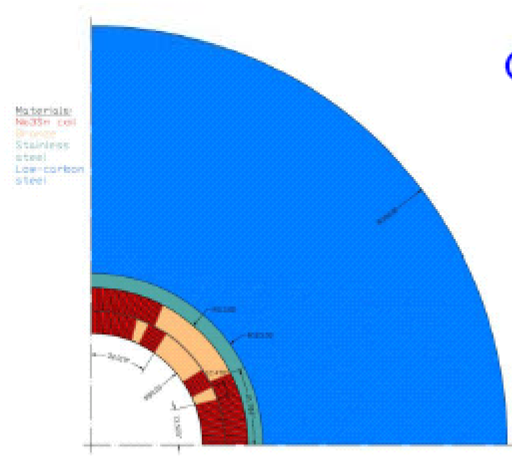


Q1: ID 80mm,
G=250 T/m

BE1: MARS



Tungsten rods
cooled by LN2



Q3: ID 160mm,
G=130 T/m

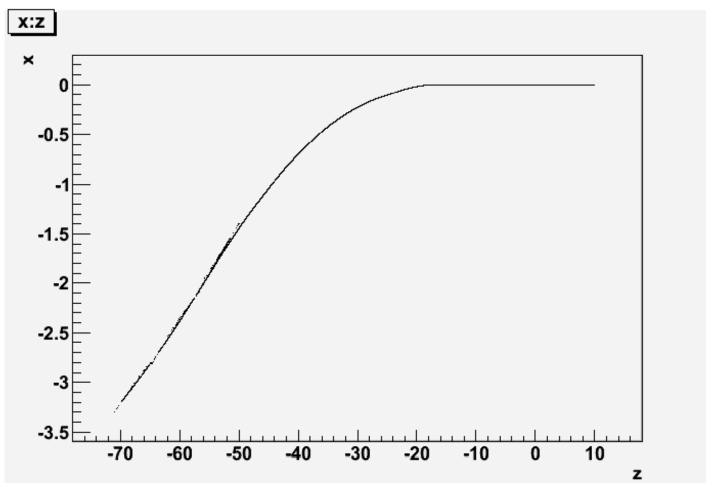
N. Mokhov

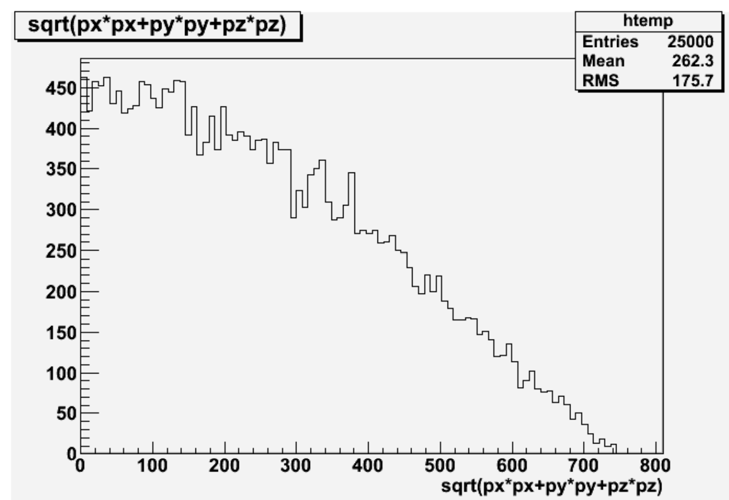
Sources of Muon Collider Backgrounds

- Electrons from muon decays.
  - We expect 4.3×10^5 muon decays per meter for 750 GeV μ^+, μ^- with 10^{12} μ per bunch.
- Synchrotron radiation from decay electrons.
- Photo-nuclear interactions.
  - This is the source of hadron backgrounds. This is largely neutrons.
- Bethe-Heitler muon production: $\gamma A \rightarrow \mu^+\mu^- X$
  - Source is energetic photons on beam line material.
- Incoherent pair production: $\mu^+\mu^- \rightarrow \mu^+\mu^- e^+e^-$
- Beam halo.

BeamMaker– A tool to provide background events to G4beamline

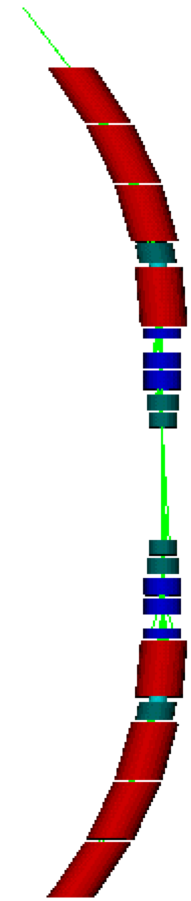
- Decay electrons are fed to G4beamline uniformly along the muon reference orbit.
- Electron energy generated using Michel decay and boosting from muon frame to lab.
- A constant weight factor can be used to normalize background to the number of muons per bunch.
- Other backgrounds can be fed to G4beamline in a similar manner.



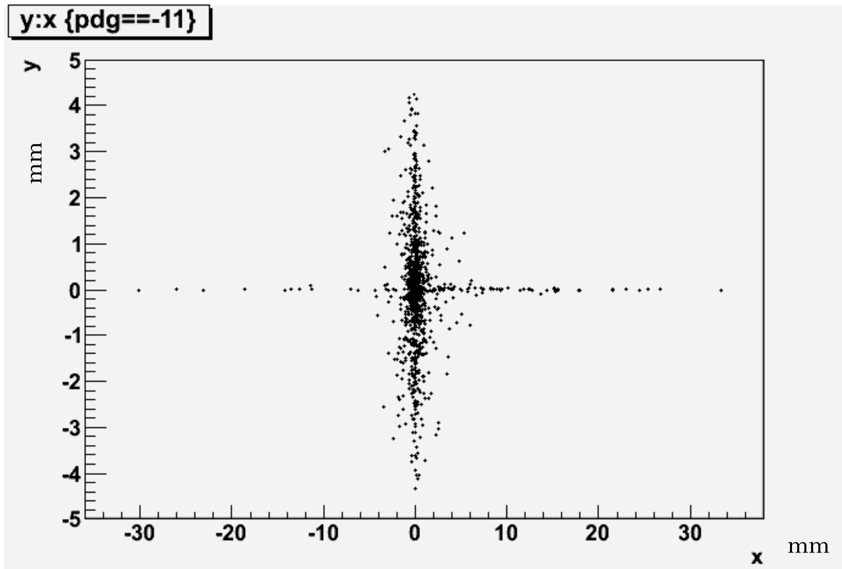


Preliminary G4BL Simulation of Collider Ring IR Magnets

- Using G4BL to simulate the IR region of *Eliana's New Lattice.*
- e^+ from 750 GeVμ^+ decays uniformly along the beam line. Muons decay distributions using Michel description.
- No synchrotron radiation currently included.
  - These are included in Geant4, but have not been able to activate them.
- Fields are generic multipole fields without fringing end fields.
- Preliminary result shows that ~40% of the electron tracks that hit QLB1 hit the magnet face, not the inner aperture.
  - These tracks can be removed collimator shields.

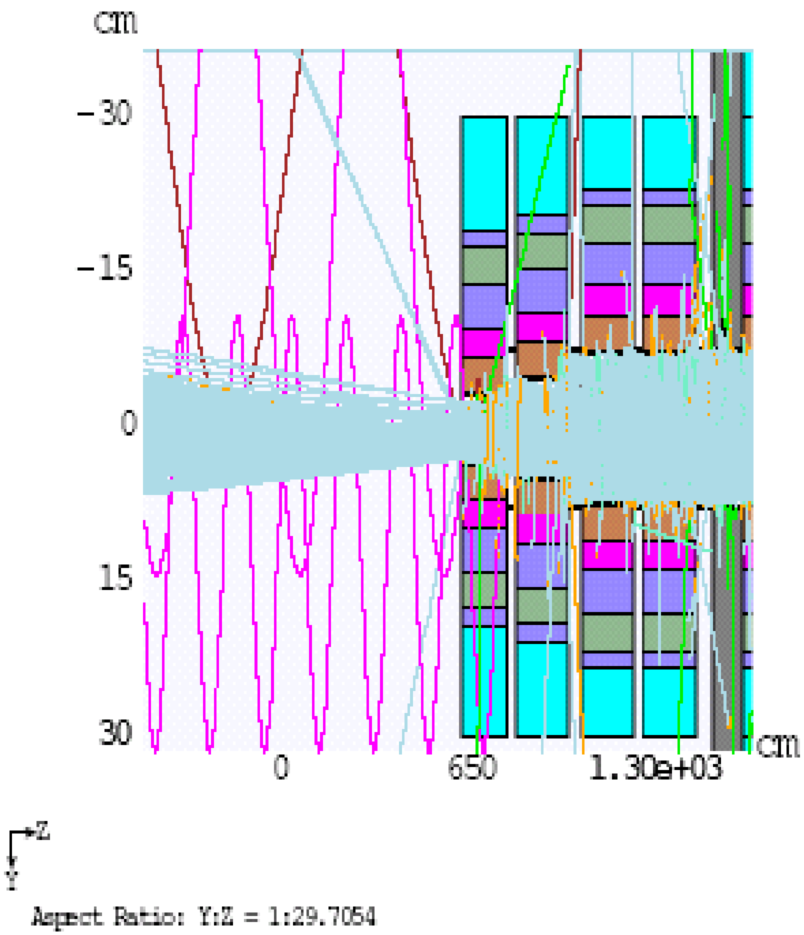


Decay Electrons Tracked to the IP



- The figure shows an x-y plot of e^+ from decays tracked to the IP
  - The figure represents 25000 decays, but only 1600 make it to the IP.
  - Vertical ellipse shows focused beam with $\sigma_{x,y} \approx 2$ mm.
  - Horizontal mid-plane events could be possible background, but they would not make it into the detector.
- It is premature to suggest that this represents results.

Energy Deposition Studies



- Figure shows MARS simulation (by Vadim Alexakhin) of electron tracks in vicinity of IR quads.
  - This should provide the basis of a thermal analysis to determine a temperature profile of these magnets.

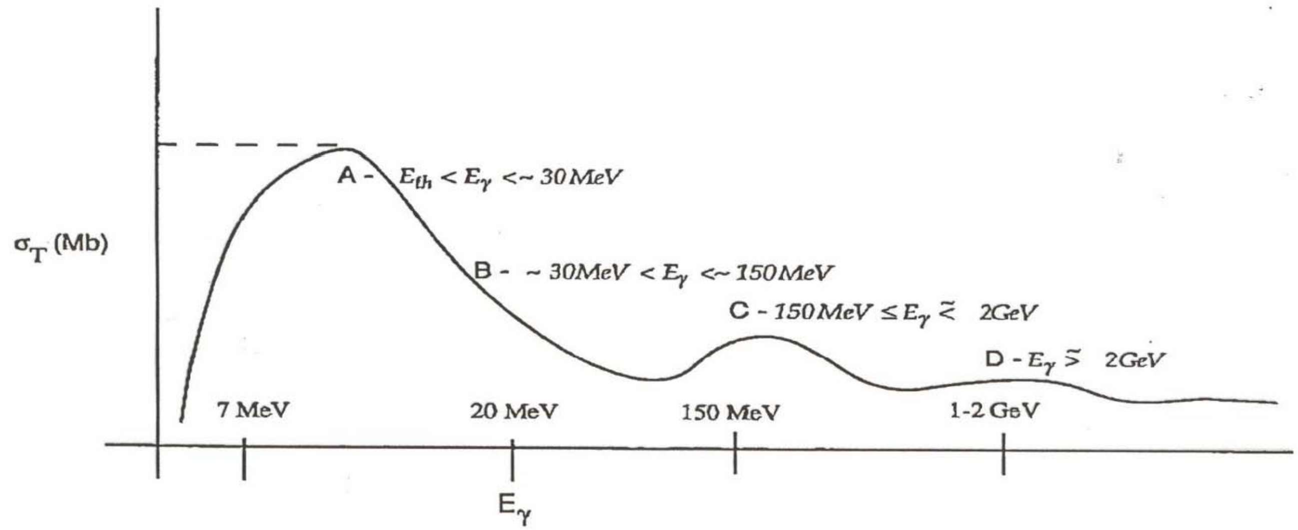
Physics Processes of Interest that are needed in Geant4

- Gamma-nuclear interactions:
  - These are the only mechanisms that can produce hadron backgrounds in the detector.
  - Aaron Morris is looking at the number of hadrons produced in an energetic electron shower.
- Bethe-Heitler muon production.
- Synchrotron radiation
  - Code exists in Geant4, but I am not sure that it is active in G4beamline.
- Neutron thermalization.
  - Borated polyethylene removes neutrons at near thermalized energies.

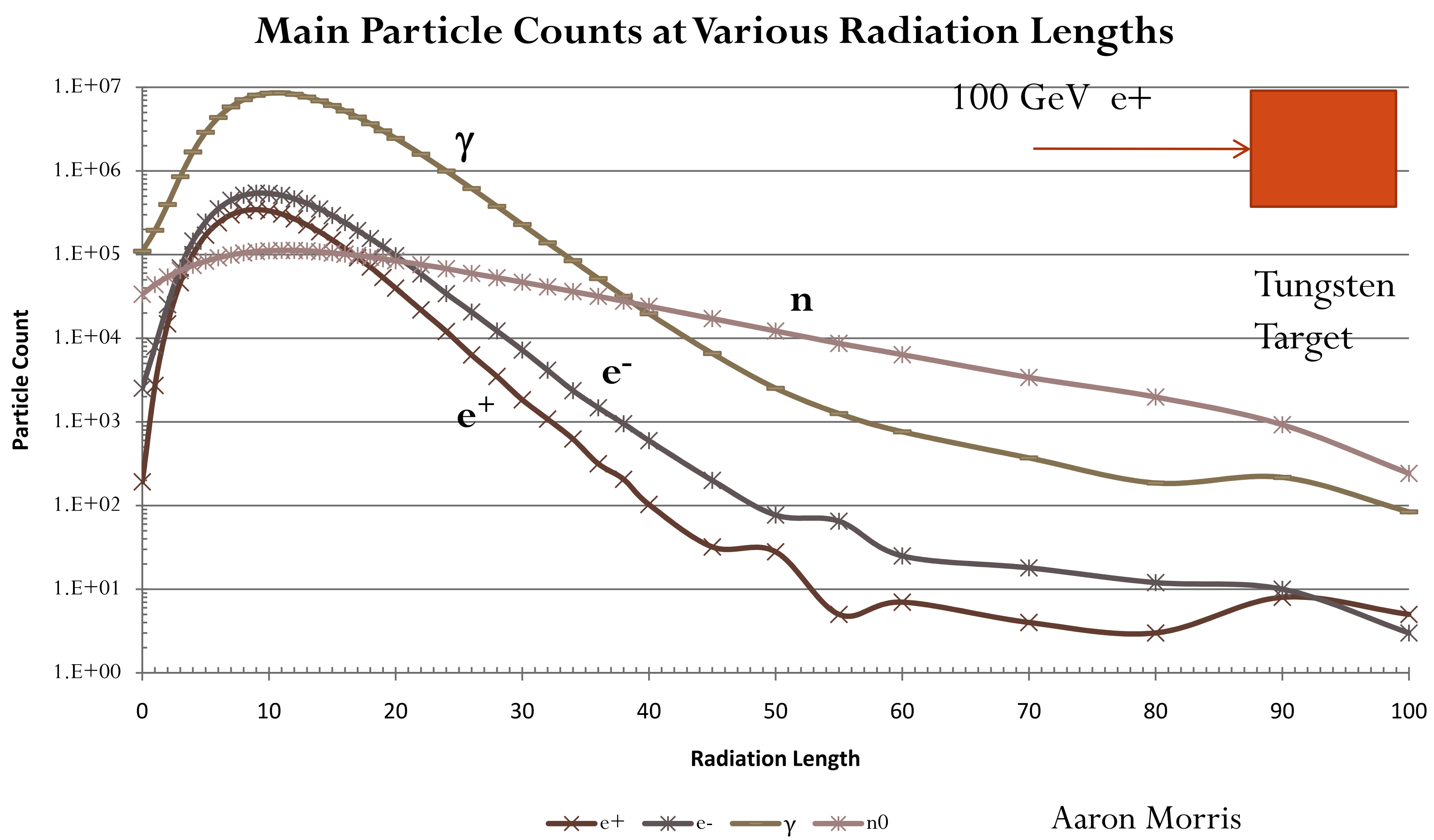
Gamma Nuclear Interaction Models

There are four distinctive energy regions associated with gamma nuclear interactions. There are

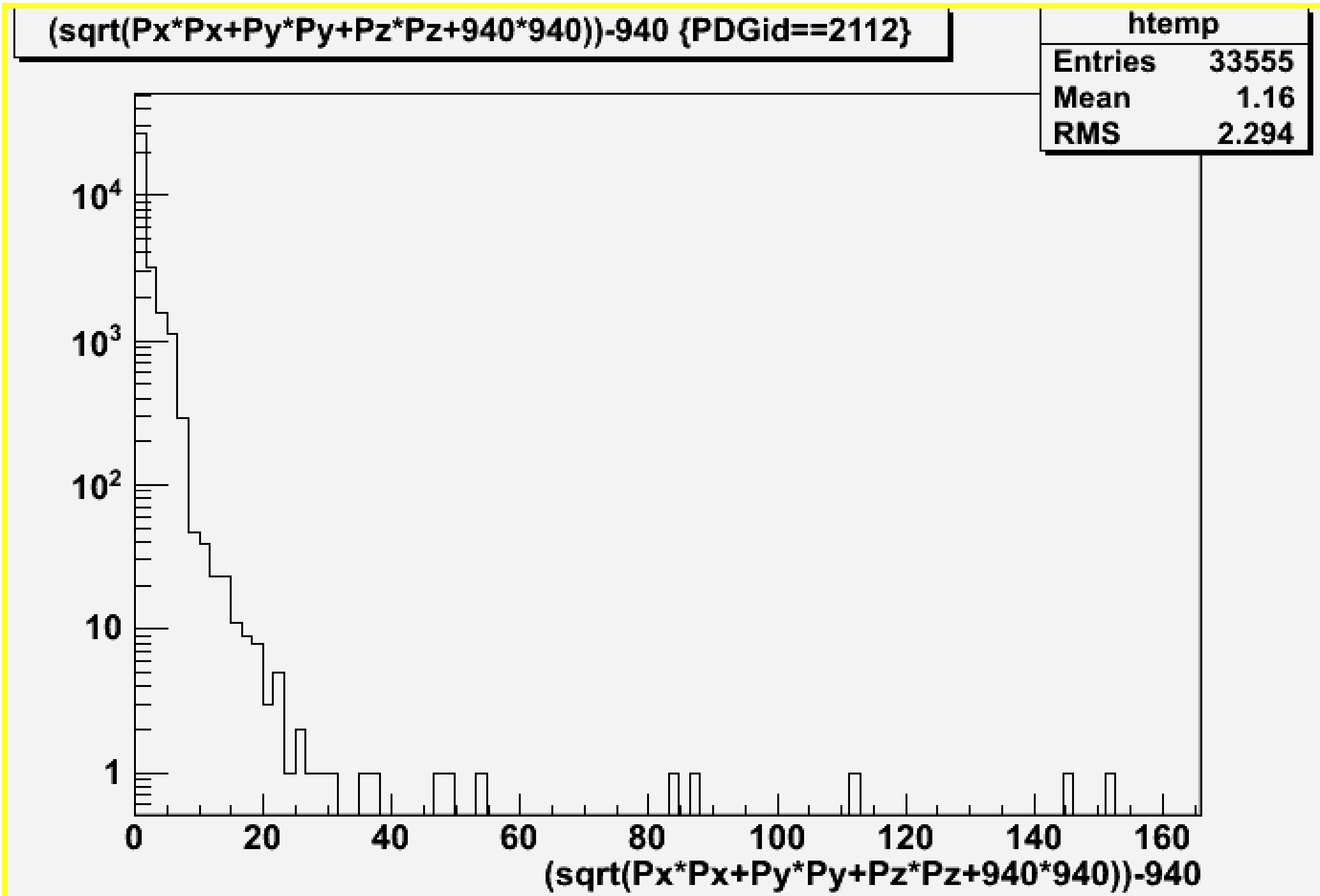
- Giant Dipole Resonance Region — A
- "Quasi-deuteron" Region — B
- Meson Region — C
- Quark Fragmentation Region — D



Particle production for a 100 GeV/c electron beam on a Tungsten target



Neutron Kinetic Energy Spectrum at 1 X_0 from 100 GeV electrons on Tungsten



Aaron Morris

Summary

- We are developing a simulation package for accelerator based backgrounds to a muon collider.
  - The package uses G4beamline and Geant4 for the simulation.
  - Develop facilities in G4beamline for detector background and associated analysis.
- We need to verify the simulation package.
  - Compare results to MARS
  - Verify Geant4 physics processes needed are active.
- We would like to analyze the conical shielding yielding background vs. angle.