Accelerator Backgrounds in a Muon Collider

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Outline

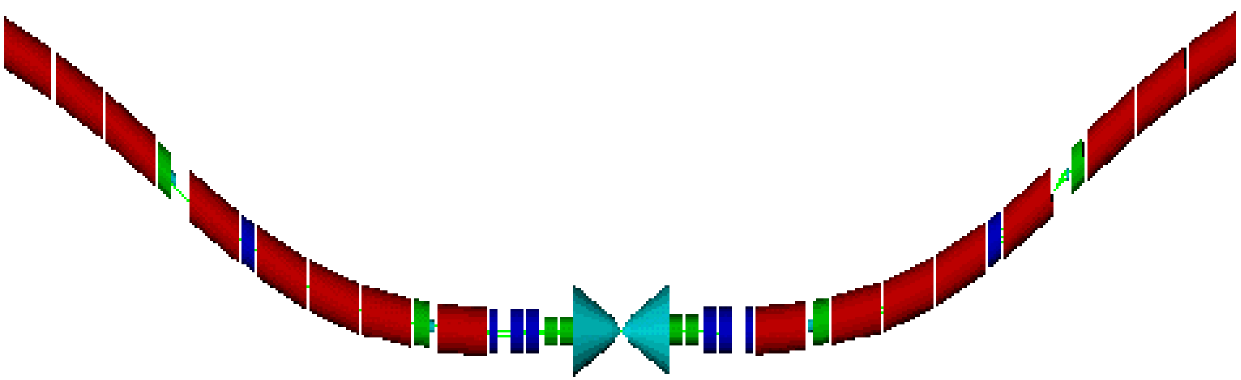
- Introduction
- Description of our simulation
- G4BL simulations
- Mars simulations
- Comparisons and comments.
- Our Future Direction
- Conclusions

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 been awarded (in June 2010) a Phase I grant in collaboration with Northern Illinois University to simulate accelerator backgrounds for a Muon Collider. Awaiting Phase II.
  - This is a new project for us consequently we are preliminary in results at this point. We are describing our plan of action.
  - Our team include
    - Steve Kahn, Mary Anne Cummings, Kevin Beard, Tom Roberts, Muons, Inc.
    - Dave Hedin, Aaron Morris, NIU
    - Joe Kosminski, Lewis University
- As part of my (S. Kahn) 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 in our SBIR?

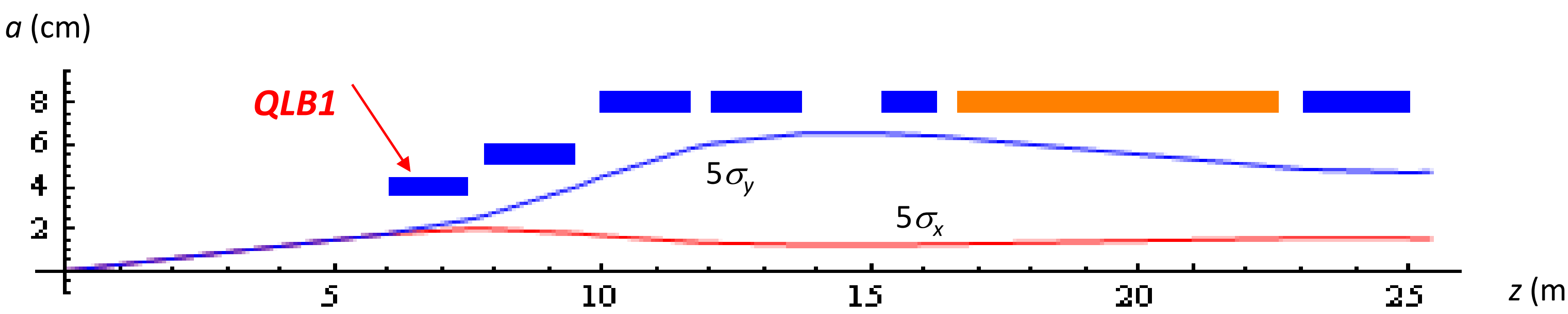
- The development of a Monte Carlo package to simulate muon accelerator backgrounds.
  - The package should be able to accept a MAD lattice description.
  - Provide particle fluxes and detector occupancy rates.
  - Output a file of background events for use with the physics analysis.
- Verification of 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.
- In particular, particle occupancy rates for electrons, gammas, neutrons into detectors to optimize detector design.



The Simulation Package

- Simulate accelerator based backgrounds in the muon collider intersection region.
- This package will use G4beamline (GEANT4 interface)
  - Also we plan to interface to MARS for verification.
- 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.

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



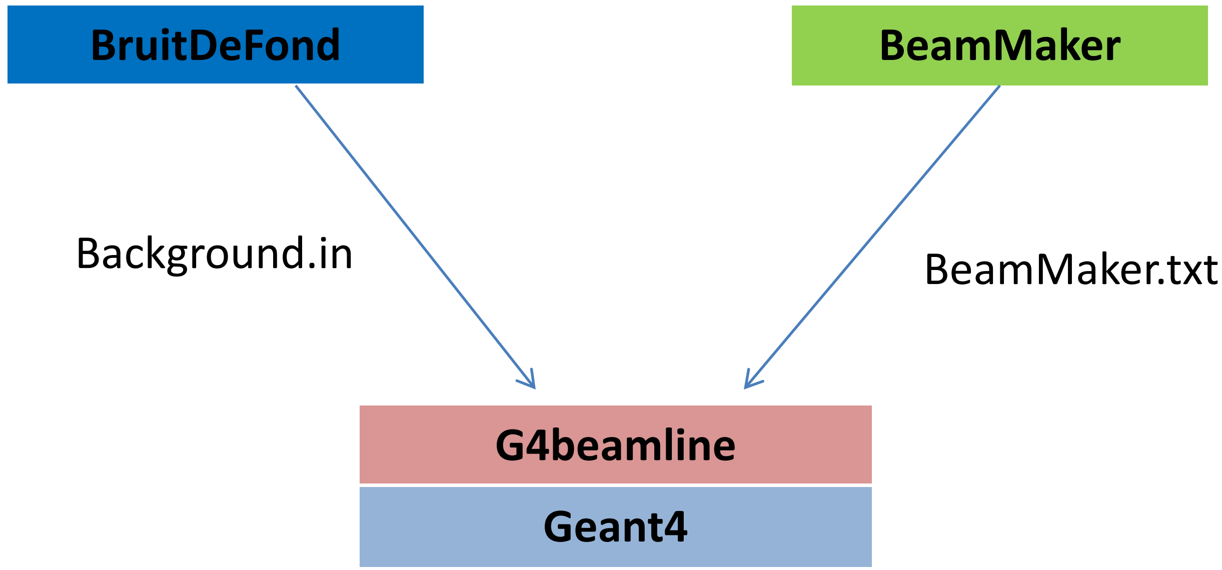
Quad	*Units*	*QLB1*	*QLB2*	*QLB3*	*QLB4*	*QLB5*	*QF4*
Gradient	T/m	250	187	-131	-131	-89	82
Center Position	m	6.75	8.65	10.85	12.85	15.7	23.9
Radial Aperture	cm	3.5	5	7.5	7.5	7.5	7.5
Quench Gradient at 4.5° ?	T/m	282	209	146	146		

Note the relatively small quench margin

Sources of Muon Collider Backgrounds

- Electrons from muon decays.
  - We expect 8.6×10^5 muon decays per meter for both 750 GeV μ^+, μ^- with 2×10^{12} μ per bunch.
  - These electrons are off momentum and could hit magnets, etc.
- 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 and shielding material.
- Incoherent pair production: $\mu^+\mu^- \rightarrow \mu^+\mu^- e^+ e^-$
  - $\sim 3\times10^4$ pairs expected per beam crossing.
  - Detector magnetic field should trap most of these.
- Beam halo.

What exists to produce G4beamline input



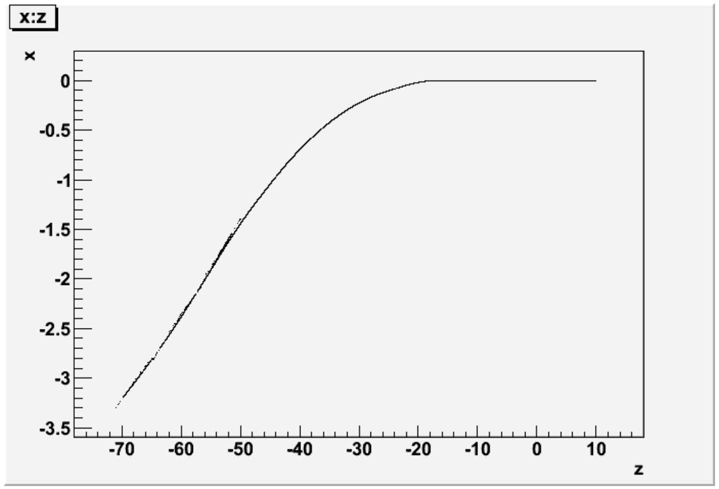
•*BruitDeFond* produces an ASCII file of G4beamline commands that describe the ±75 m of muon collider interface region
•*BeamMaker* produces a *BLTrackFile* that can be read by *beam* input card. This file contains e^+ and e^- thrown with the Michel decay distribution.

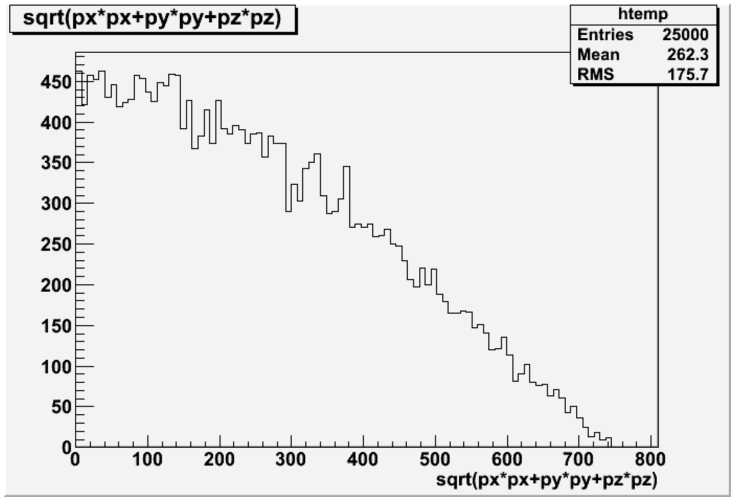
The *BruitDeFond* Program

- 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. (expanding to ±200)
  - 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.
  - 5T solenoid field over the detector.
- We have described the Tungsten conical shielding configuration with a scaling algorithm that allows conical angle studies.

BeamMaker– A tool to provide background events to G4beamline

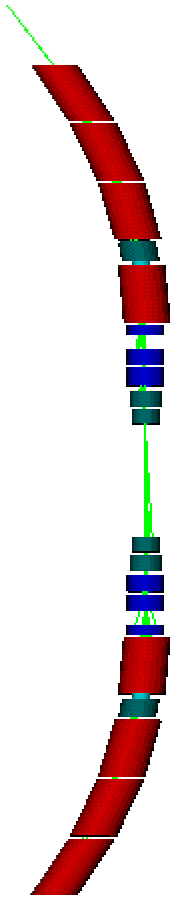
- Decay electrons are fed to G4beamline uniformly along the muon reference orbit.
- Electron energy generated using Michel decay and boosting from muon frame to lab.
- A constant weight factor can be used to normalize background to the number of muons per bunch.



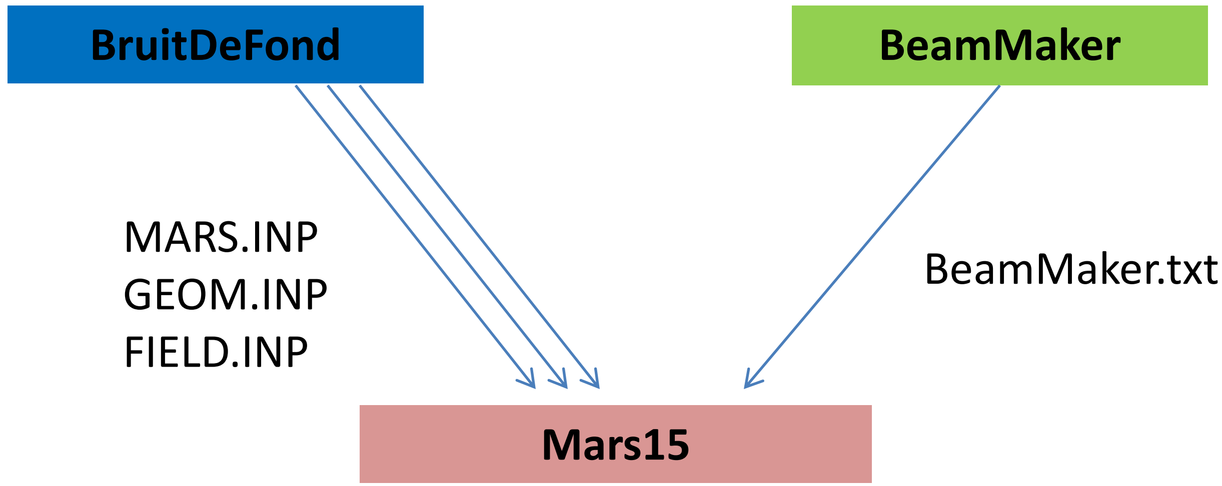


Preliminary G4BL Simulation of Collider Ring IR Magnets

- 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. (new version will have it)
  - These are included in Geant4, but have not been able to activate them.
- Fields are generic multipole fields without fringing end fields. No field in magnet iron.

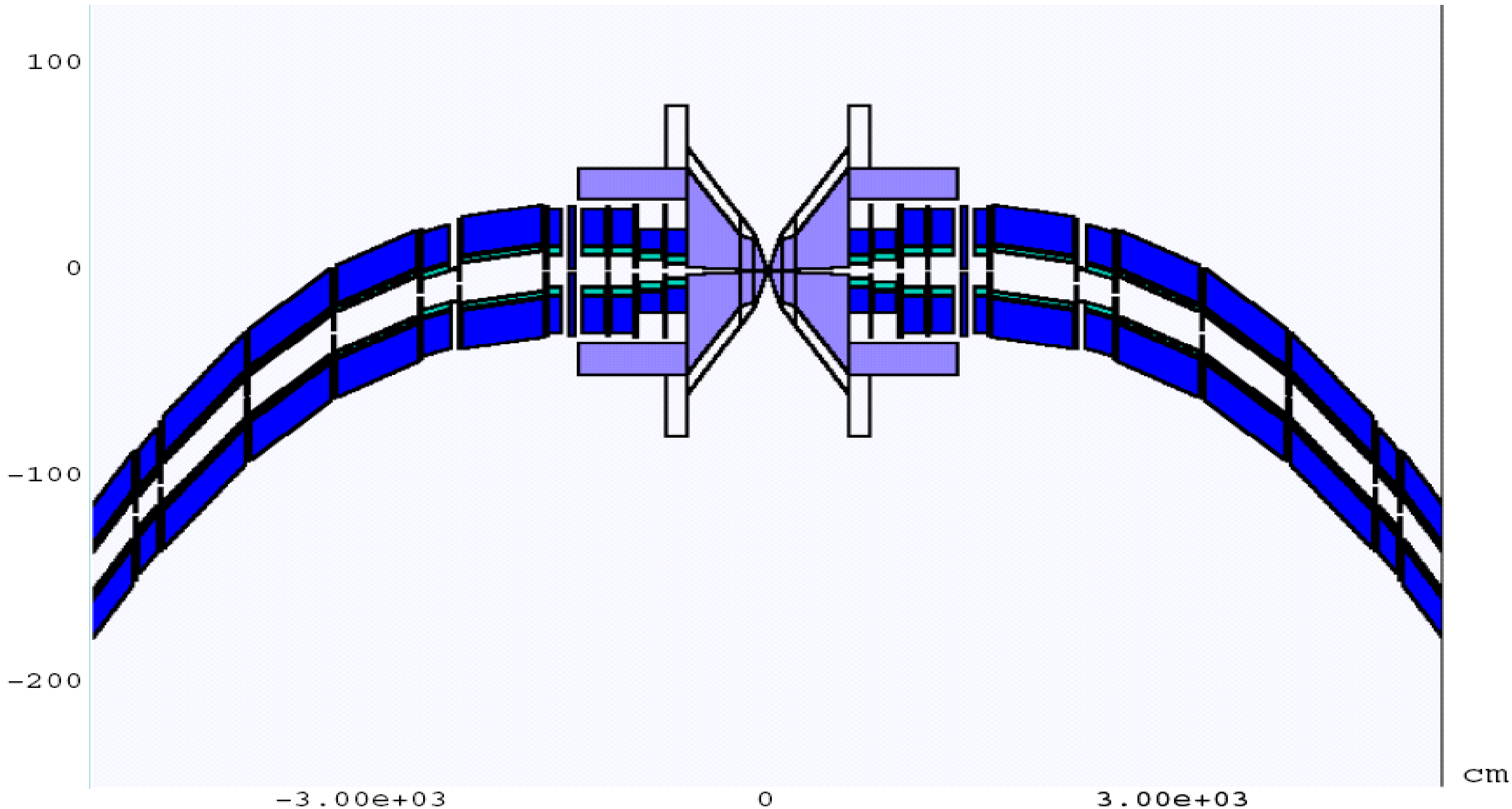


We can also use this program to produce MARS input for Verification



- *BruitDeFond* can generate MARS.INP and GEOM.INP files.
- The *extended* geometry is description is used.
- The field is described by the FIELD.INP file which is read by the MARS user subroutine “field” that we wrote.
- We use the same BeamMaker.txt file for the MARS input.

Mars Geometry Generated by *BruitDeFond* Package



Data Samples

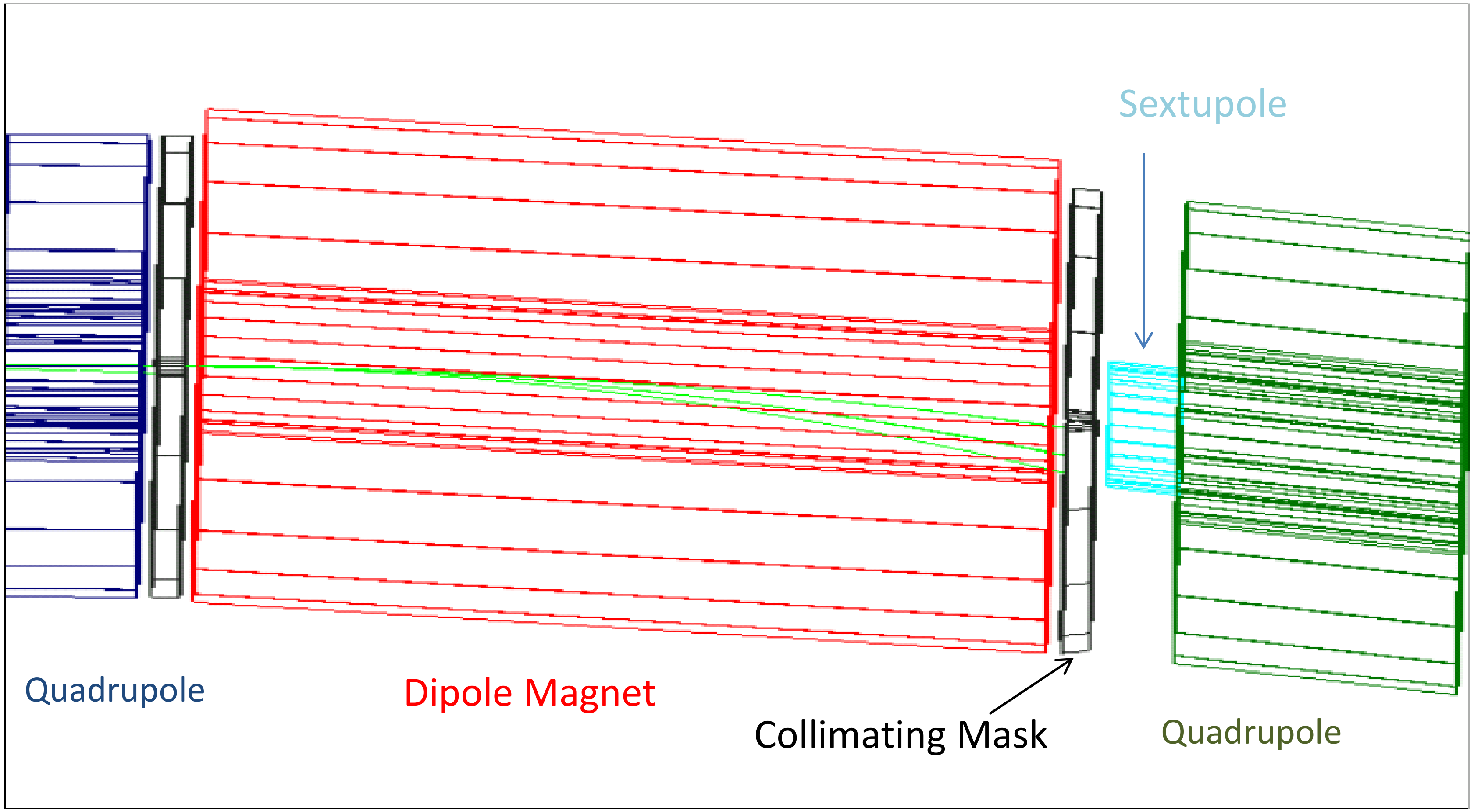
Sample	Number of Events	Description	
G4BL	$10000e^{+} + 10000e^{-}$	QGSP_BERT	Original runs
G4BL	$5000\ e^{+} + 5000\ e^{-}$	QGSP_BERT_HP	New runs
MARS 1507	$400K\ e^{+} + 400K\ e^{-}$	Weighted, no mcnp	Orig. runs, pt tgt
MARS 1510	$2000\ e^{+} + 2000\ e^{-}$	Not weighted, no mcnp	New runs, not pt tgt

- All samples are normalized to 2×10^{12} muons/bunch.
- We impose a cut requiring KE>200 keV.
- All runs are with a 10° cone.

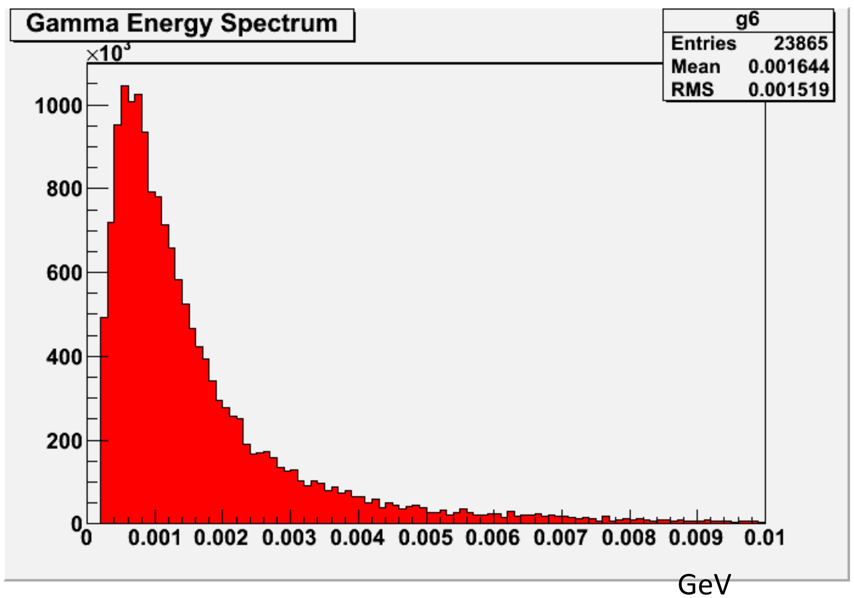
G4beamline Studies

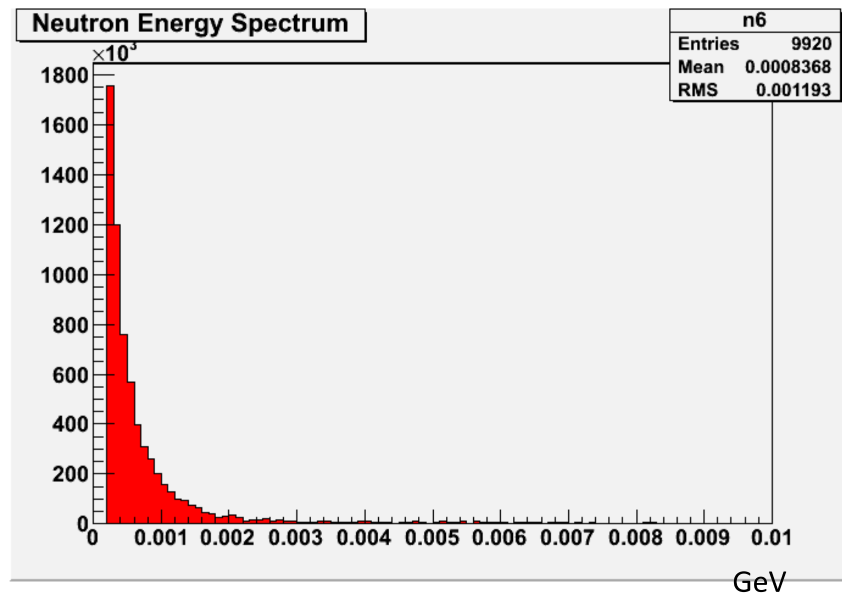
- Collider configuration as described.
- Use 10° shielding cone.
- 10 K event samples with minimum KE set to 200 keV.
  - This requires 3 days on NICADD cluster.
- Events carry a constant weight to normalize to 2×10^{12} muons/bunch.
- Detector planes positioned at SiD locations.
  - Vertex and tracker detector plane have equivalent SiD material description. Particles are scored as they pass through planes.
  - Calorimeter material present, but no particle scoring.

Figure Shows Typical Off-Momentum Decay Positrons in a Dipole Magnet



Energy Spectra of γ and n

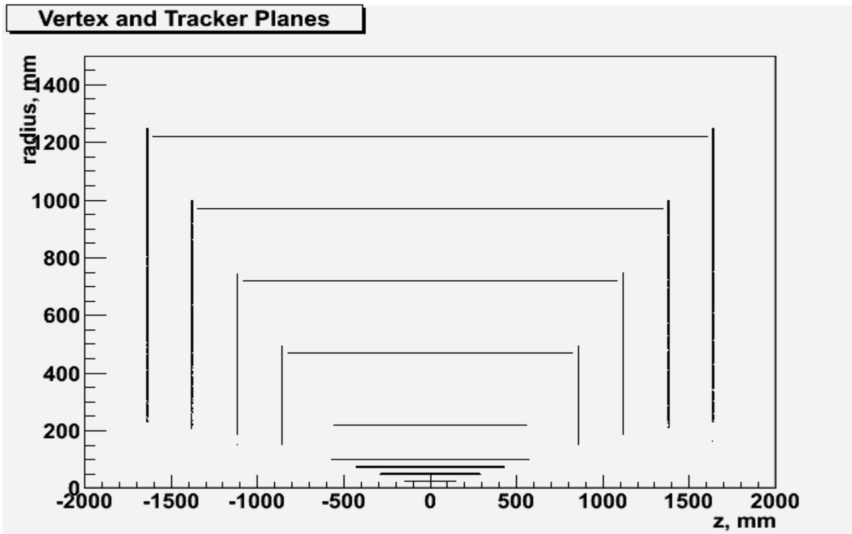


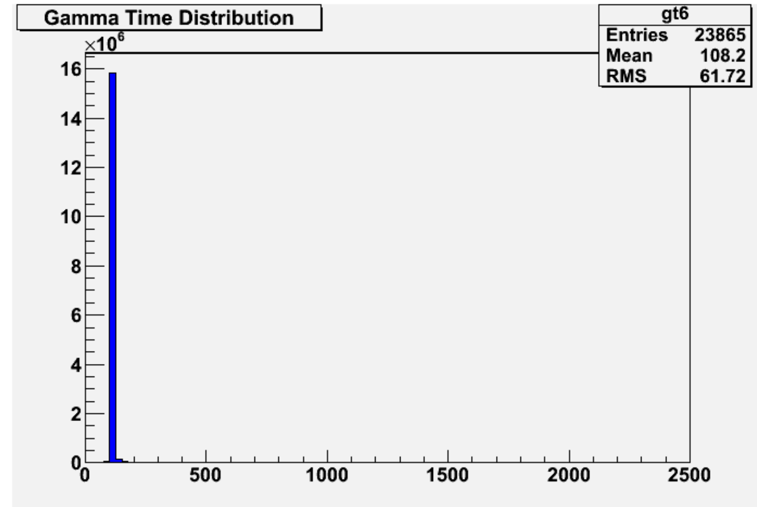


Particle spectra at R=47 cm. There is a 200 keV minimum KE threshold.

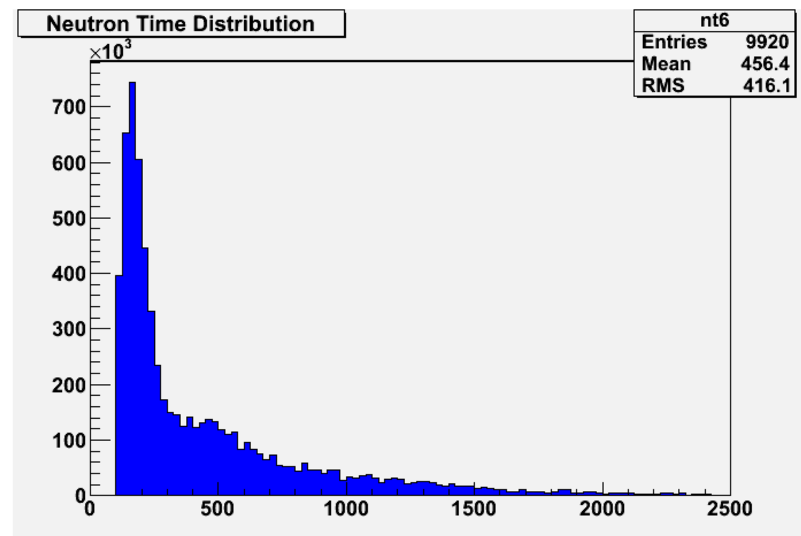
Time Distribution of γ and neutrons

Plots from a plane at R=47 cm





ns

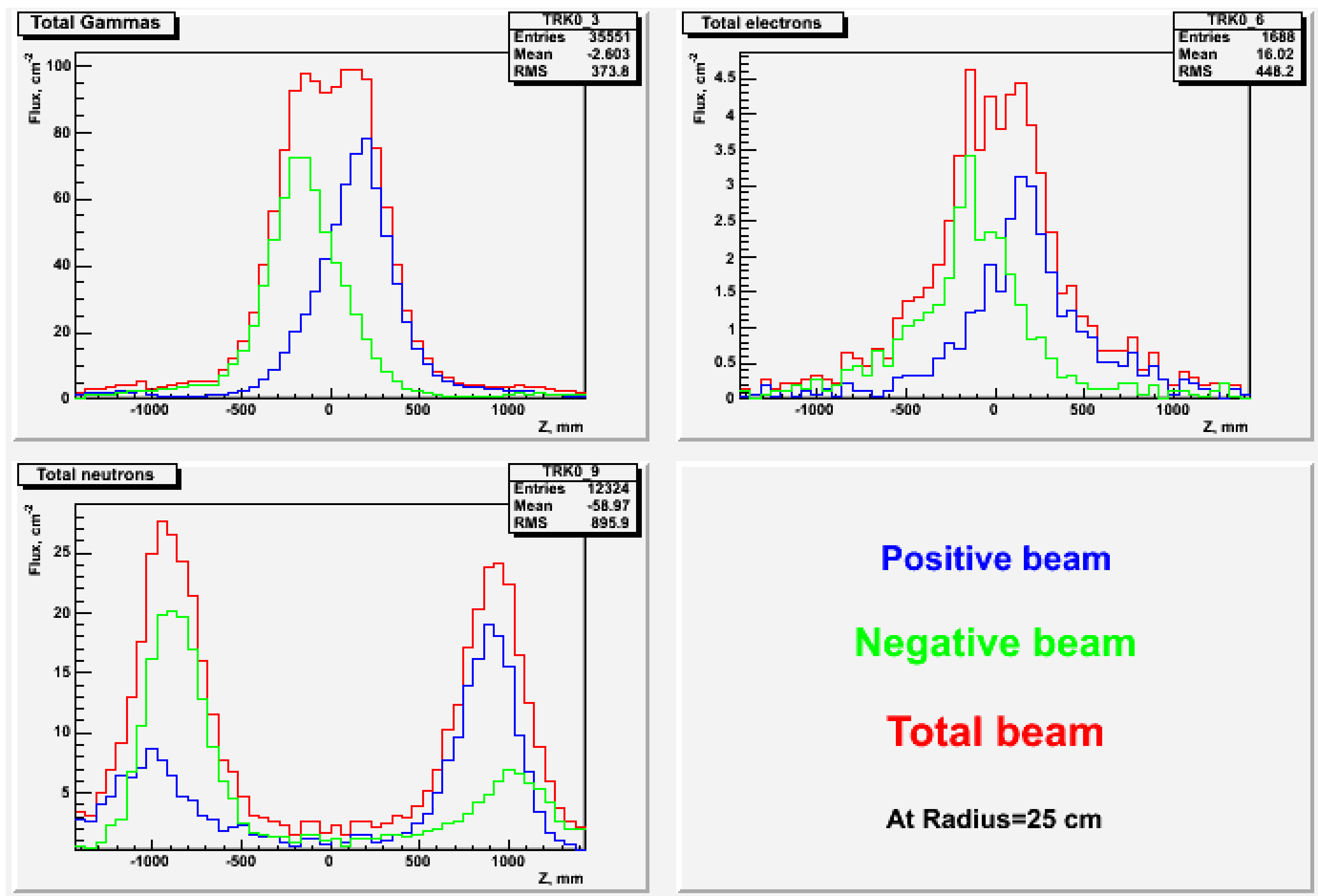


ns

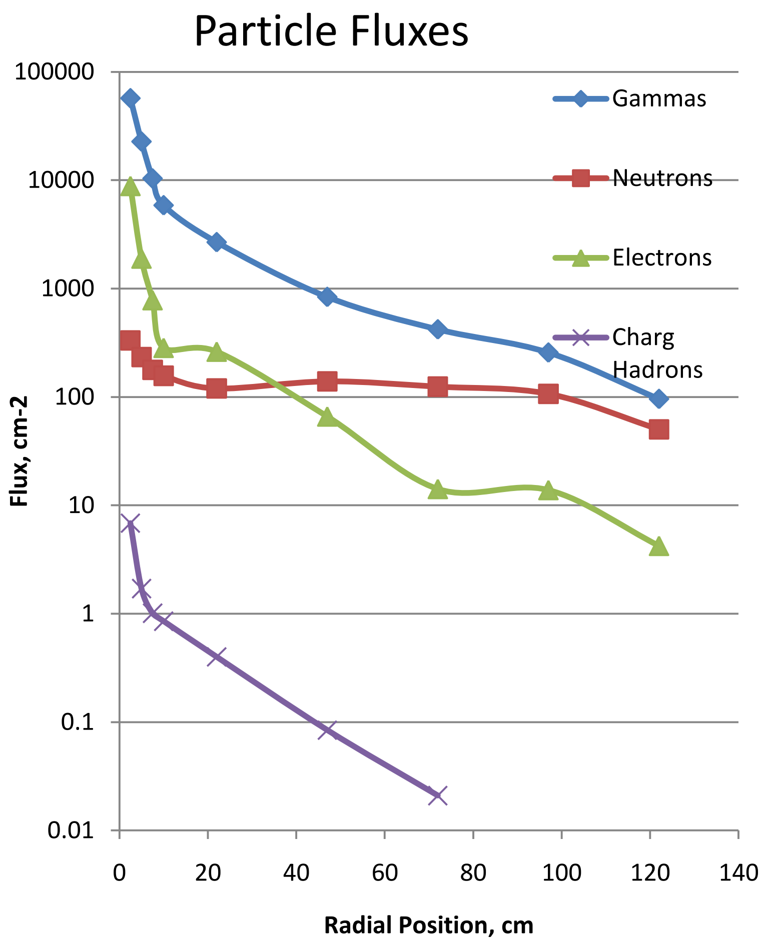
Can cut neutron time tale with electronic gate, and timing instrumentation.

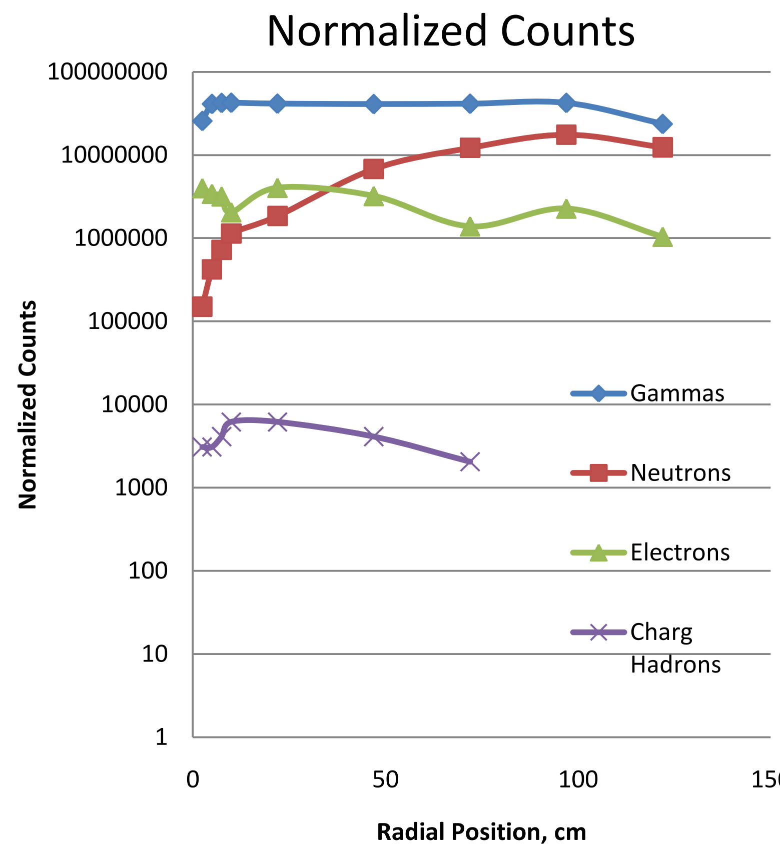
Particle Fluxes at r=25 cm

Neutrons come from the conical shields

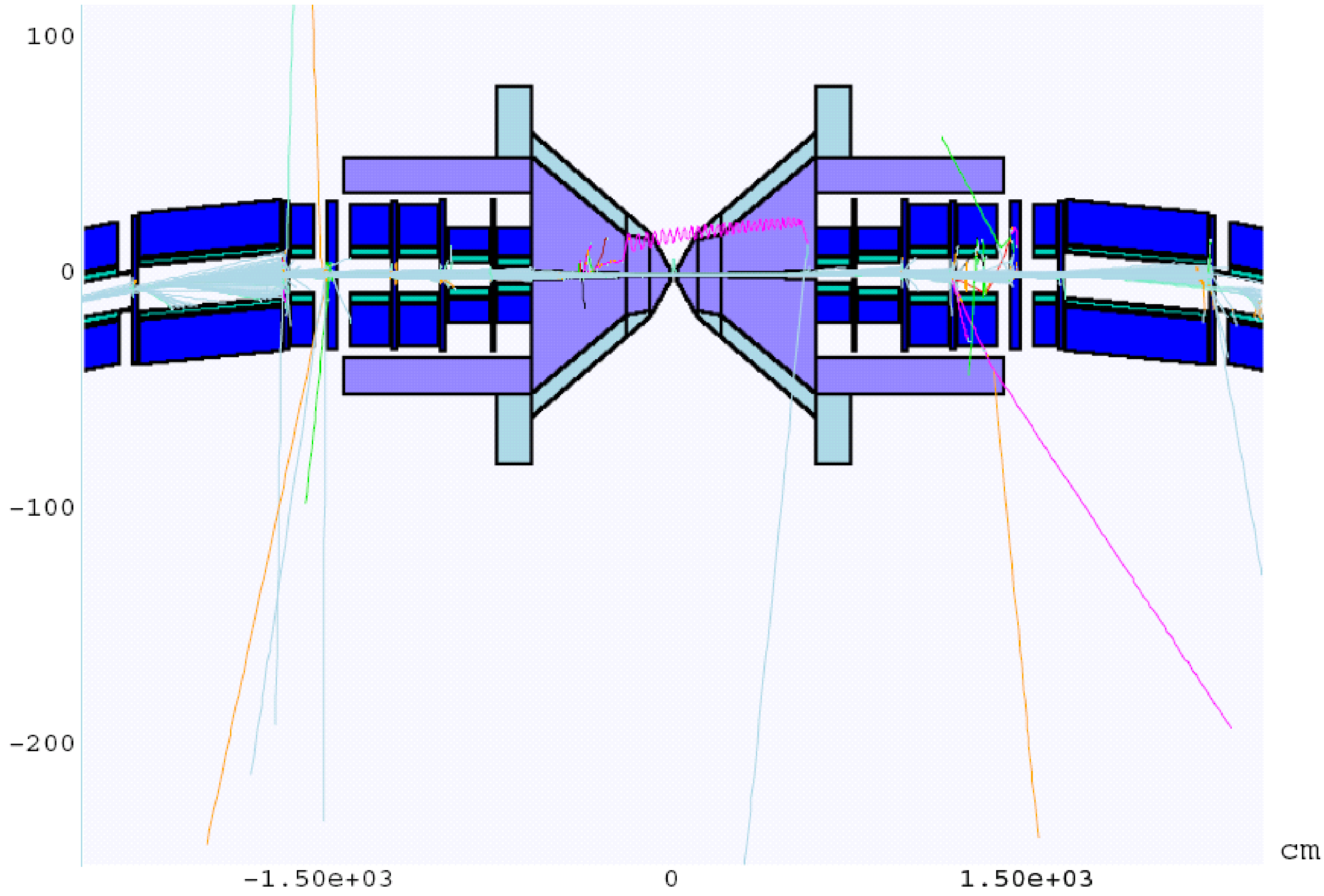


G4BL: Fluxes at Radial Positions for 10° Cone

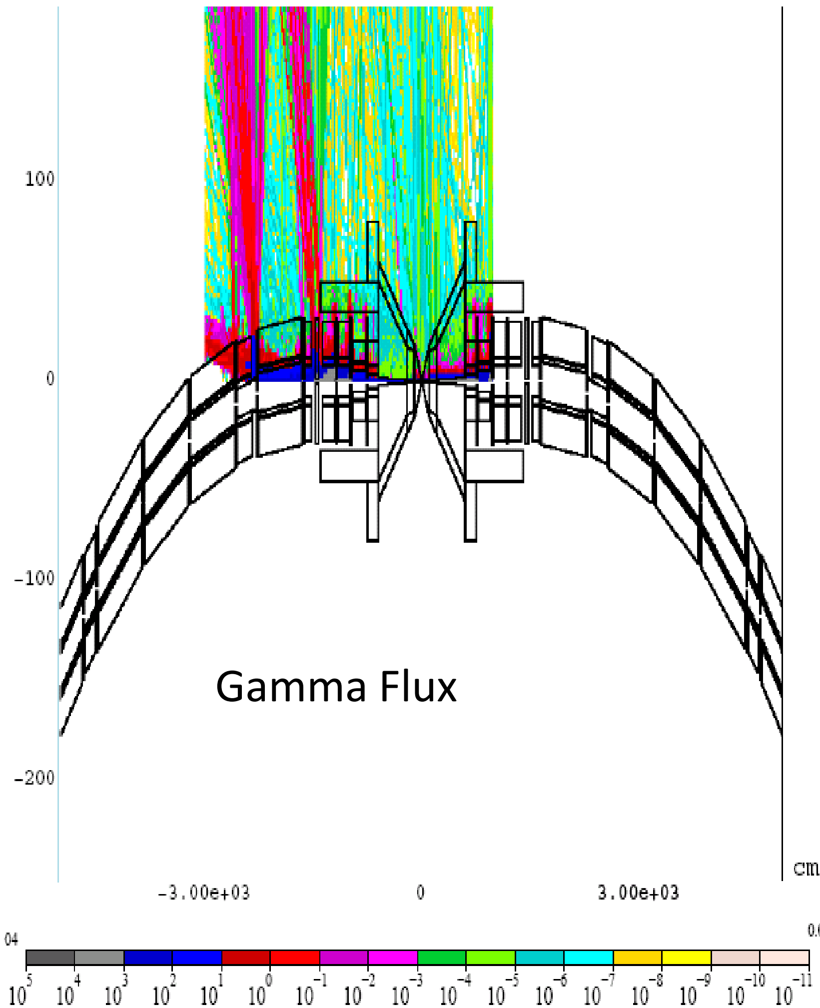


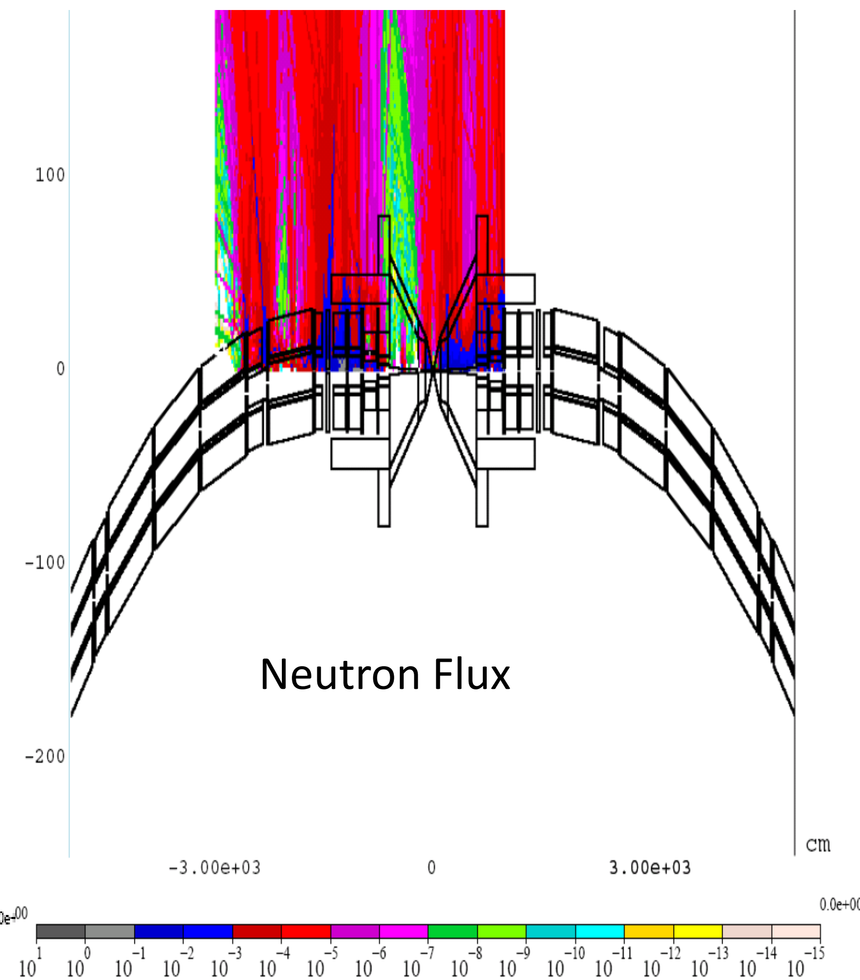


Mars: Run of ~20 Decay Muons

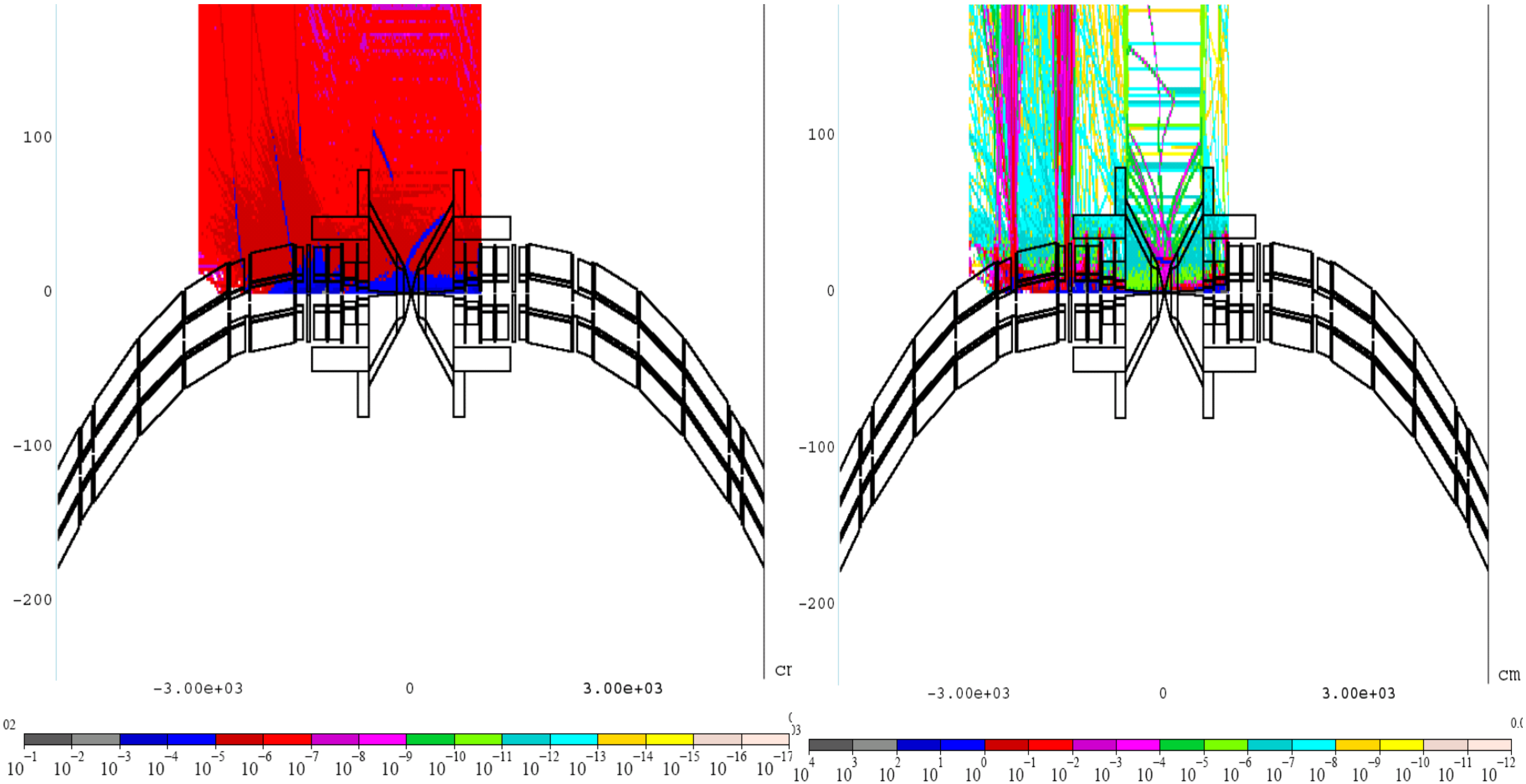


Gamma and Neutron Fluxes from Mars



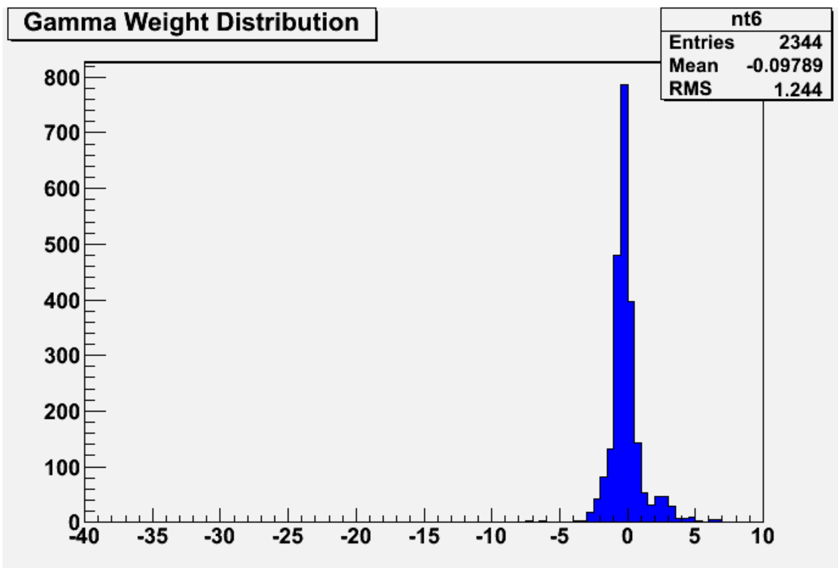


Mars: Muon and Electron Fluxes

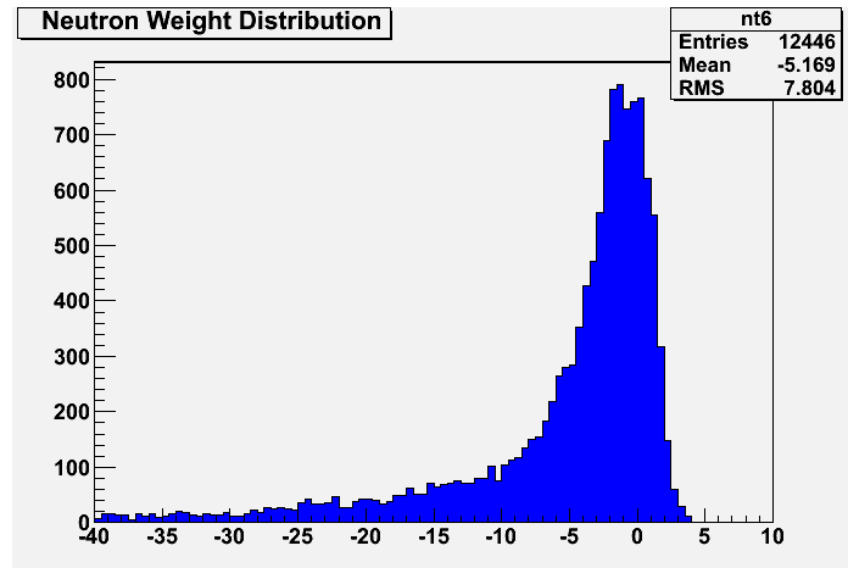


Mars: Weight Distributions of Particle Hits

- The distributions show the distribution of weights for gammas and neutrons
- Neutron weights vary over 40 orders of magnitude.

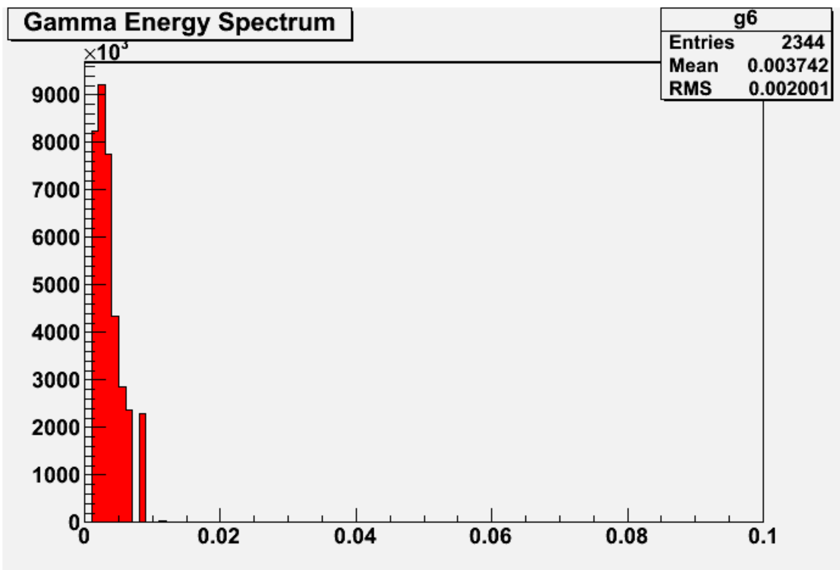


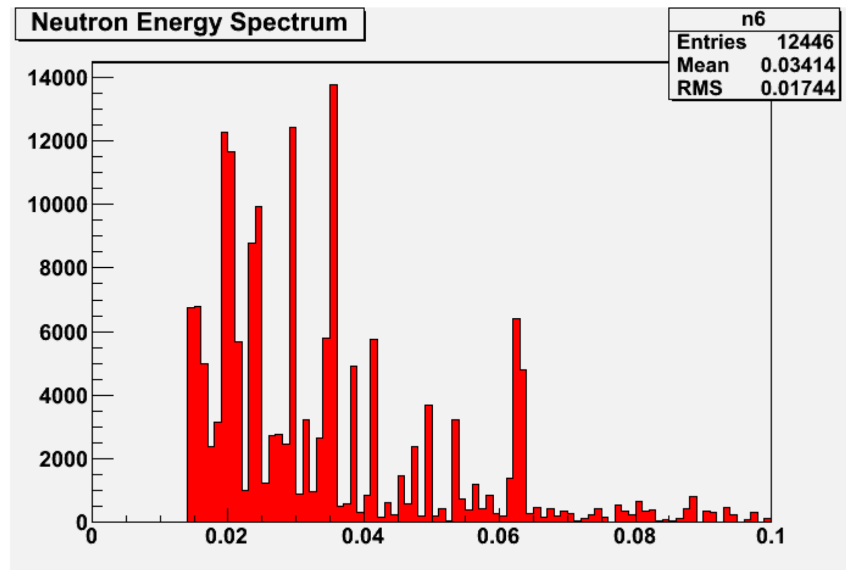
$Log_{10}(wt)$



$Log_{10}(wt)$

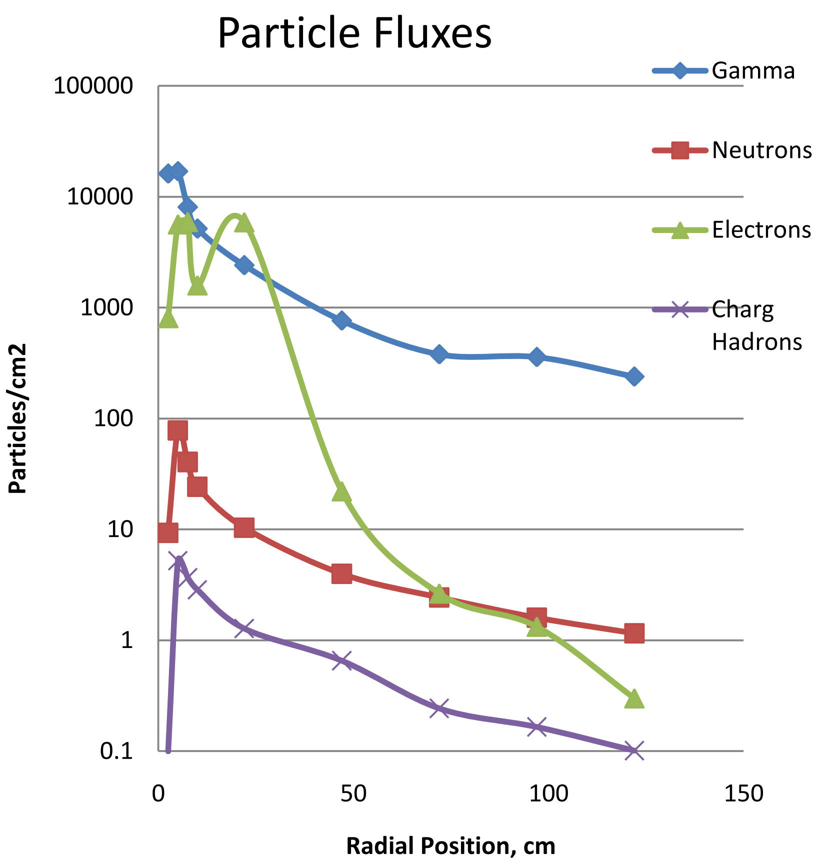
Mars: Energy Spectra of γ and n

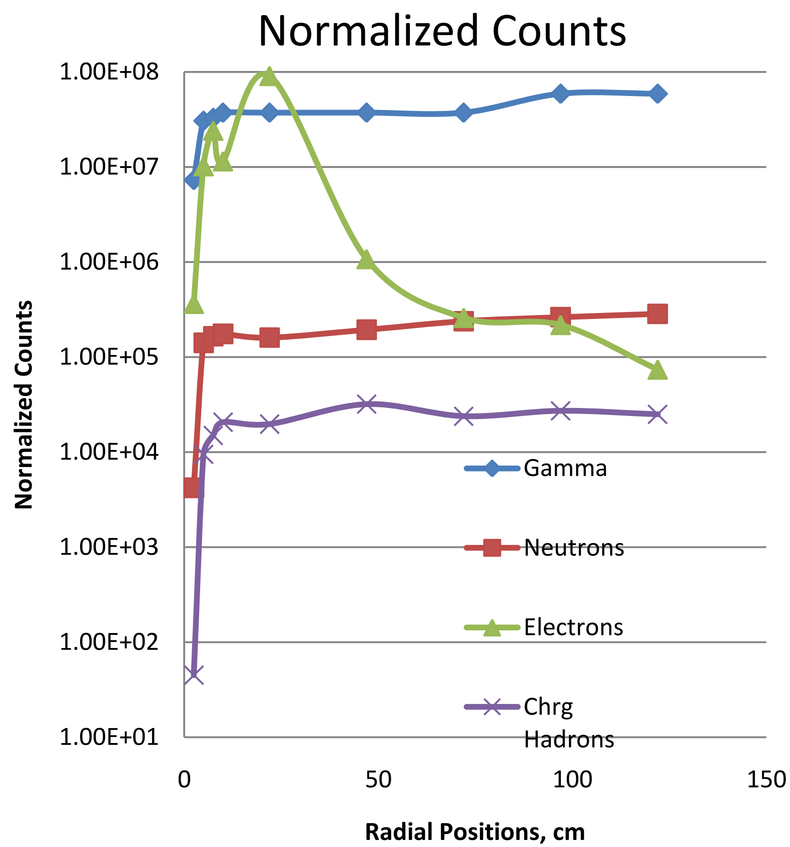




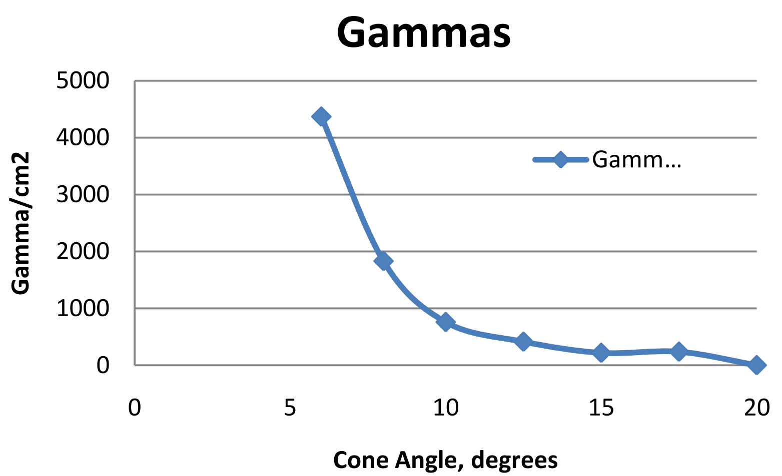
Mars without MCNP seems to cut neutrons below 14 MeV, even if one requests a lower cutoff.

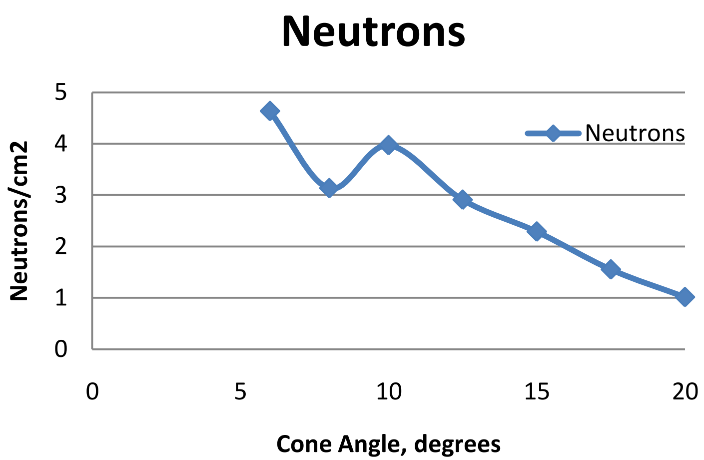
Mars: Fluxes at Radial Positions for a 10° Cone

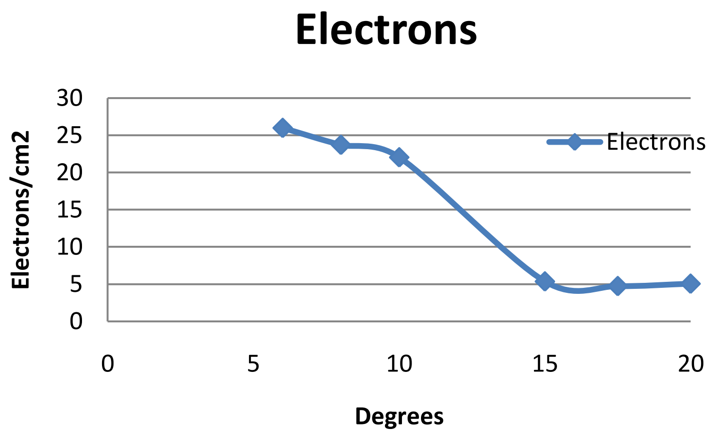




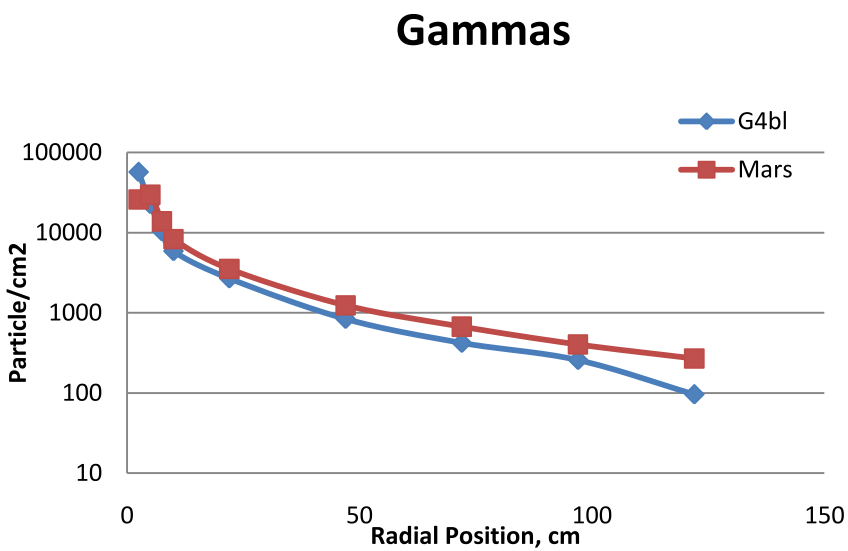
Mars Fluxes as a Function of Cone Angle

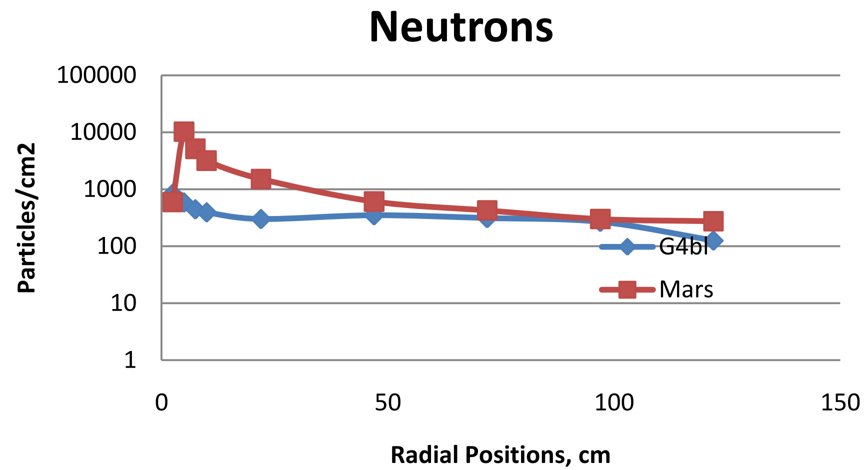


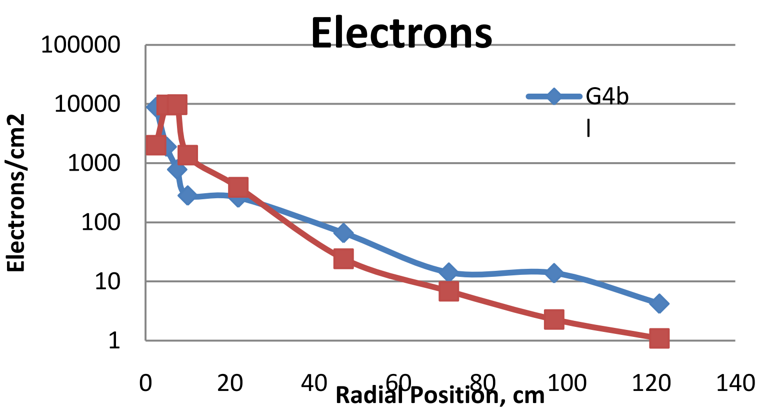




Comparison of G4BL and Mars Fluxes







G4BL and Mars γ fluxes fall on top of each other.

This implies that the relative normalization is OK.

The G4BL neutron flux is ~10-100 times larger than the Mars flux.

- The Mars sample only includes neutrons with KE>14.7 MeV.
- The G4BL sample is largely below 2 MeV
- Most neutrons are expected to be generated by the nuclear dipole resonance at ~10-20 MeV. This would yield lower energy neutrons.
- We need to run Mars with the MCNP option to obtain the low energy neutrons.

Future Plans for Phase II

- Clean up items that may not have been finished in Phase I:
  - Boron issues.
  - Other enhancements to improve the background package and G4beamline for background analysis.
- Package *BruitDeFond* for use by others.
  - Enter into a CVS repository. Current it exists on laptops.
  - Instruction manual
- Bethe-Heitler muon study.
  - Aaron Morris is looking at Bethe-Heitler issues in our study.
  - Muons can penetrate magnets and shielding and enter into detector region.
  - We need a large sample of Bethe-Heitler muons, however the cross-section is not large.
    - We may need to enhance the cross-section and weight those events
  - A small number of high energy muons undergoing a catastrophic interaction can deposit isolated energy into a single calorimeter cell.
  - Can fast time-of-flight or shower shape analysis distinguish Bethe-Heitler muons? We think so…

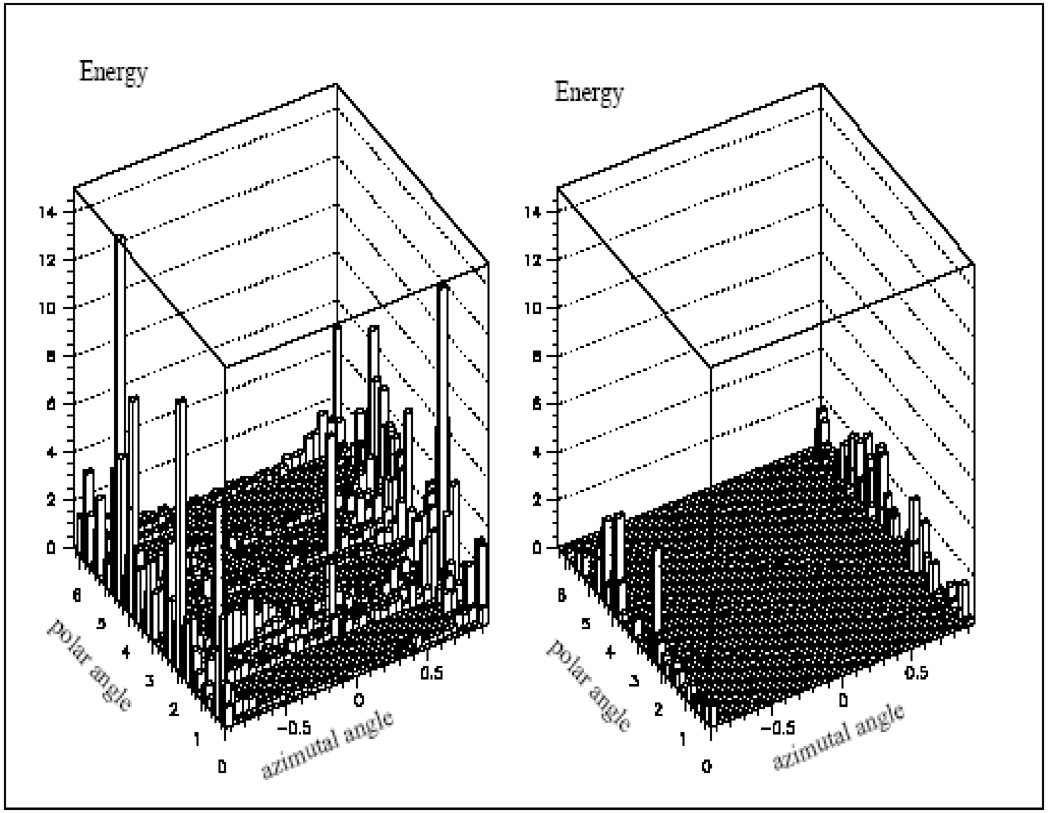


FIG. 69. The left-hand plot shows the energy deposition from Bethe-Heitler muons vs the cosine of the polar angle and azimuthal angle in the calorimeter for a 4 TeV COM collider. The right-hand plot shows the same distributions with a 1 ns timing cut.

Future Plans (Cont.)

- Perform a physics analysis by superimposing beam backgrounds onto physics events.
  - The superposition should be done at the digitization level
  - Use reconstruction techniques to see if backgrounds can be removed without corrupting.
  - Evaluate the effect of beam backgrounds on specific physics channels.
  - University grad student or post doc to do these studies. (pending award of Phase II)
- Perform optimization of shielding to reduce backgrounds.
  - The next slide shows shield shaping that was performed in the original study.
- Optimize magnets to reduce energy deposition
- Use shielding instrumentation to reduce cone angle.
  - Analysis to demonstrate that it works.

Accomplishments Continued

- We have calculated particle fluxes at various locations in the detector region.
- We have looked at the particle fluxes as a function of cone angle (next talk)
  - This slide may indicate that the “10°” cone may not be the ideal shielding. This is a Phase II task.

Conclusions

- We have developed a simulation tool to investigate muon collider detector backgrounds.
- Background particle fluxes from muon beam decays are calculated using G4BL.
  - Comparison with Mars shows agreement for γ fluxes. Differences of neutron fluxes are understood.
- The amount of background in the detector region is dependent on the conical shielding angle.
  - Choosing the optimum angle is a trade-off between the size of the physics signal relative to the size of the background. Increasing the 10° cone angle to 15°(20°) reduces the background by a factor of ~2 (~4).