A Study of Background Particles for the Implementation of a Neutron Veto into SuperCDMS

Johanna-Laina Fischer

Mentor: Dr. Lauren Hsu [FNAL, CDMS]

September 23, 2011 – PSS Colloquium
Part 1:

BRIEF EXPLANATION OF DARK MATTER
Missing Mass?

• Jan Oort and Fritz Zwicky
  – Used Virial theorem to find an observed gravitational mass of astronomical systems and found luminous mass
    • 400x more gravitational mass
• Vera Rubin
  – Used rotation curves to same conclusion as Zwicky
• CMB
  – Anisotropies
• Gravitational Lensing
  – Light distortions by unknown massive object
DM Candidates (some examples)

• WIMPs (Weakly Interacting Massive Particles)
  – Non baryonic matter
  – Hypothetical particle (predicted by SUSY)
  – Large mass compared to other particles
  – Interact gravitational force

• MACHOs (Massive Compact Halo Objects)
  – Made of baryonic matter
  – Emits little or no radiation
    • Black hole, neutron star, brown dwarf
  – Gravitational Lensing
Detection of DM

• Accelerator Creation
  – Detection of decay products of WIMPS created from hadron collision
    • Early Universe, ATLAS, CMS, LHC

• Indirect
  – Search for products via annihilation of relic DM
    • GLAST, ICEcube

• Direct
  – Interactions with ordinary matter
    • CDMS, COUPP, DRIFT, SuperCDMS
Part 2:

SUPER CRYOGENIC DARK MATTER SEARCH
The Cryogenic Dark Matter Search

- ZIP Detectors, stacked in towers
  - Si and Ge crystal with sensors attached
  - Detection in the form of phonons and ionization
- Soudan Mine
  - Depth: 780 m, Blocks most cosmic rays
- Expected WIMP flux (Earth orbits inside a dark matter halo!)
  - >1 event/kg/year

DM is a needle in a haystack!
SuperCDMS

• Improved detectors
  – New iZIP detectors (SNOLAB)
    • Larger, 100 kg (vs. 4 kg for CDMS)
    • Each side can collect both phonon and ionization energy to better reject surface events

• Better shielding
  – Deeper site (SNOLAB): 2 km
    • Lower cosmic ray-induced neutron background
  – Proposed neutron veto
  – Implement more radio-pure material for shielding
The Haystack: Backgrounds for SuperCDMS

• Gammas:
  – Decay chains of $^{238}\text{U}$, $^{232}\text{Th}$, and $^{40}\text{K}$, as well as natural gammas from ($\alpha$, n)

• Neutrons:
  – Internal Radiogenic
    • Fission and ($\alpha$, n) of non-negligible contributions from trace isotopes (primarily U) in material surrounding CDMS detectors
  – Cosmogenically Produced
    • Spallation from cavern rock and the experimental apparatus
    • Small contribution from neutrons from cavern rock
  – Radiogenic Rock
    • Fission and ($\alpha$, n) of trace isotopes in the cavern rock
    • Removed with sufficient shielding; negligible contribution

• Muons:
  – Cosmogenically Produced
    • Need active veto
Shielding Options

- **Gammas: High ‘Z’**
  - Steel
  - Lead/Ancient Lead
  - Copper

- **Neutrons: Low ‘Z’**
  - Polyethylene (Radio Pure)
  - Scintillator or water (active)

- **Muon: High ‘Z’**
  - Mine Depth
  - Scintillator Paddles
  - Neutron veto doubles for this purpose
Neutron Veto

• The Problem
  – Both WIMPs and neutrons are neutral
  – Both WIMPs and neutrons are very weakly interacting
  – Both will scatter off a Ge nucleus and provide a nuclear-recoil
  – “False Positive”

• The Solution
  – Neutron Veto
    • Modular tanks of liquid scintillator (mineral oil) doped with 10-20% $^{10}\text{B}$

Tag neutrons that cause problems!
Part 3: SIMULATIONS AND RESULTS
Overview of Studies Performed

• General
  – Purpose:
    • Study gamma shielding configurations
    • Help improve intuition
    • Validate Geant4 based simulations for neutron veto studies
  – Methods:
    • Modified geometry
      – Simple shielding configurations
    • Analyzed data in ROOT

• Study 1
  – 1D Simulation: Effective Attenuation Length of Materials

• Study 2
  – 3D Simulation: Liquid Scintillator

• Study 3
  – 1D Simulation: Stacked Materials
Definitions

• Attenuation length ($\lambda$)
  – $P(x) = e^{-(x/\lambda)}$
  – Survival probability, $P(x)$: Probability that a particle will enter a detector with K.E. equal to its original K.E.

• Effective Attenuation length ($\lambda_e$)
  – $P(x)$: Probability that a particle will enter a detector with K.E. > 0
  – Approximate exponential curve

• Stopping power
  – The average energy loss of a particle per unit path length ($dE/dx$)
Study 1

- Purpose:
  - Determine attenuation length of different materials used in shielding for SuperCDMS

- 1.5 Million events
- Beam of gammas from y-axis
- 1 MeV
- Variables Changed:
  - Various thicknesses of materials
    - Liquid scintillator, lead, copper, steel
Results: Attenuation length of several materials
Purpose:
- Determine effective attenuation length of liquid scintillator for 3D case; multiple energies

Results:
- Comparison viable between 1D and 3D simulations
- Attenuation length vs. Effective attenuation length

10 M events
- 1, 2.6, 5, 8, 10 MeV
- Gammas from cavern
Study 3

- **Purpose:**
  - Determine effective attenuation length

- **Variables constant:** Copper and Steel
- **Variable changing:** Veto thickness
- **~1.5 Million events for each energy**
- **Energies simulated:** 0.511, 1, 2.6, 5, 8, 10 MeV
Study 3
Study 3

• Results:
  – Changed geometry for study
    • Original geometry did not hold
  – Effective attenuation length found for liquid scintillator
Summary

• Background events problematic
  – Gamma particles
    • Greater stopping by high Z materials
    • Greater the gamma energy, greater the attenuation length needed
  – Neutrons cause “false positive” for DM

• Simulations of effective attenuation lengths of different materials
  – Geant4 viable for neutron veto studies
  – How much shielding needed
    • Effective attenuation lengths of liquid scintillator (multiple energies)
      – Alone
      – Stacked with steel
      – Stacked with copper and steel
    • Can use 1D simulations
Backup Slides

BACK-UP!
Shielding and Veto

- **Shielding**
  - Passive, just blocks particles
  - Steel, Lead, Copper
- **Veto**
  - Shields from gamma particles and neutrons
  - Detects neutrons produced from radioactive decay in internal shielding
  - Active, takes information from particles that it blocks
  - Mineral Oil
- **Rate of blocking particles**
  - Need $10^4$ reduction in background gammas
  - Attenuation lengths ($\lambda$), Beer-Lambert Law
    - $P(x) = e^{-x/\lambda}$
  - Effective attenuation length
Geant4

• GEometry ANd Tracking
• Simulates particles through matter
  – MC
    • Geometry
    • Tracking
    • Detector Response
    • Run management
• Object oriented programming in C++