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

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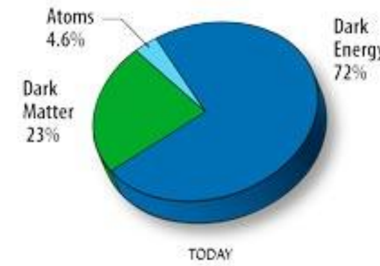
September 23, 2011 – PSS Colloquium

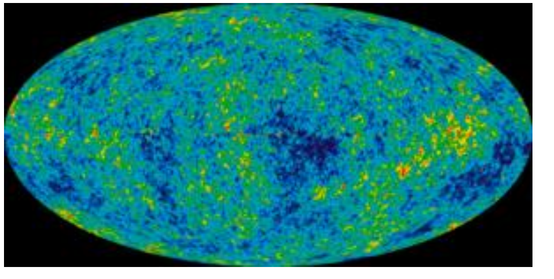
Part 1:

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

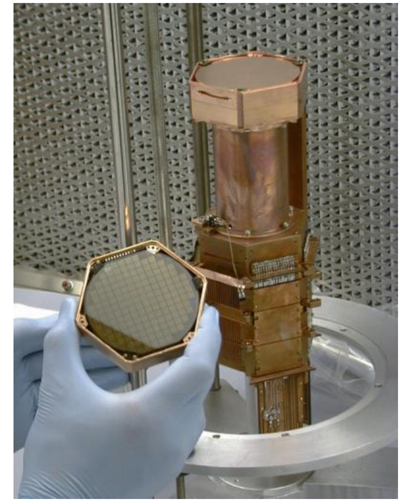
Detection of DM

- 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

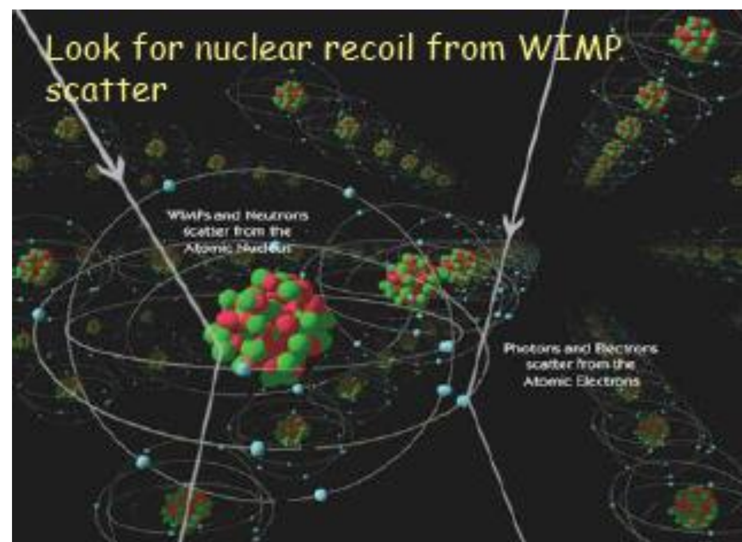
Part 2:

SUPER CRYOGENIC DARK MATTER SEARCH

The Cryogenic Dark Matter Search

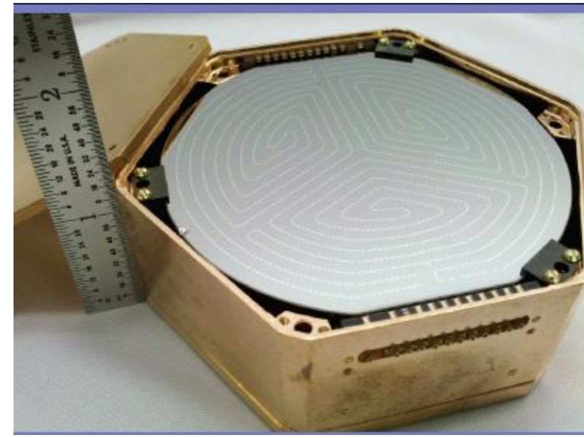


- ZIP Detectors, stacked in towers
  - Si and Ge crystal with sensors attached
  - Detection in the form of phonons and ionization
- Soudan Mine
  - Depth: 780 m, Blocks most cosmic rays
- Expected WIMP flux (Earth orbits inside a dark matter halo!)
  - >1 event/kg/year



DM is a needle in a haystack!

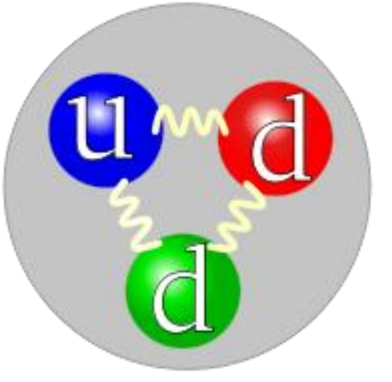
SuperCDMS



- 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

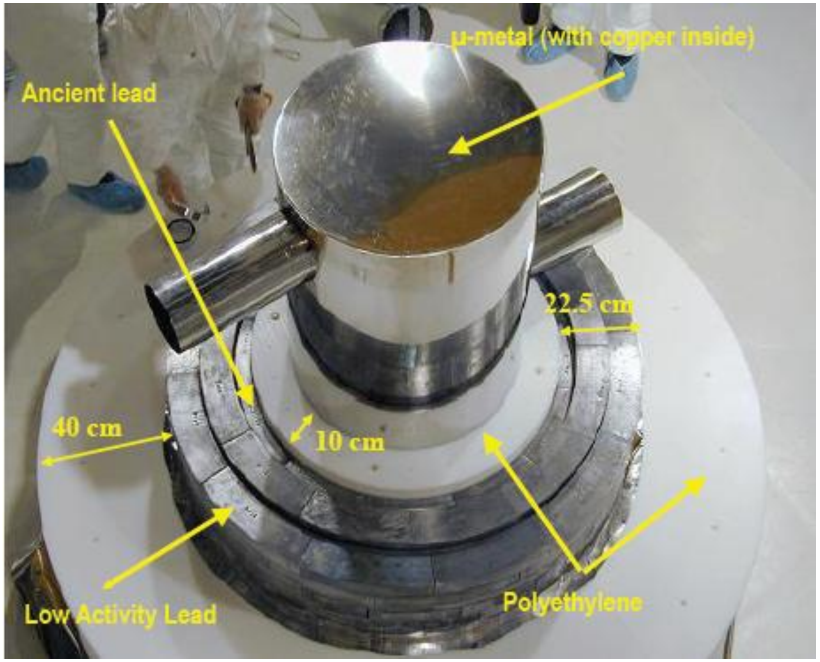
The Haystack: Backgrounds for SuperCDMS

- Gammas:
  - Decay chains of ^{238}U, ^{232}Th, and ^{40}K, as well as natural gammas from (α, n)
- Neutrons:
  - Internal Radiogenic
    - Fission and (α, 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 (α, n) of trace isotopes in the cavern rock
    - Removed with sufficient shielding; negligible contribution
- Muons:
  - Cosmogenically Produced
    - Need active veto



Shielding Options

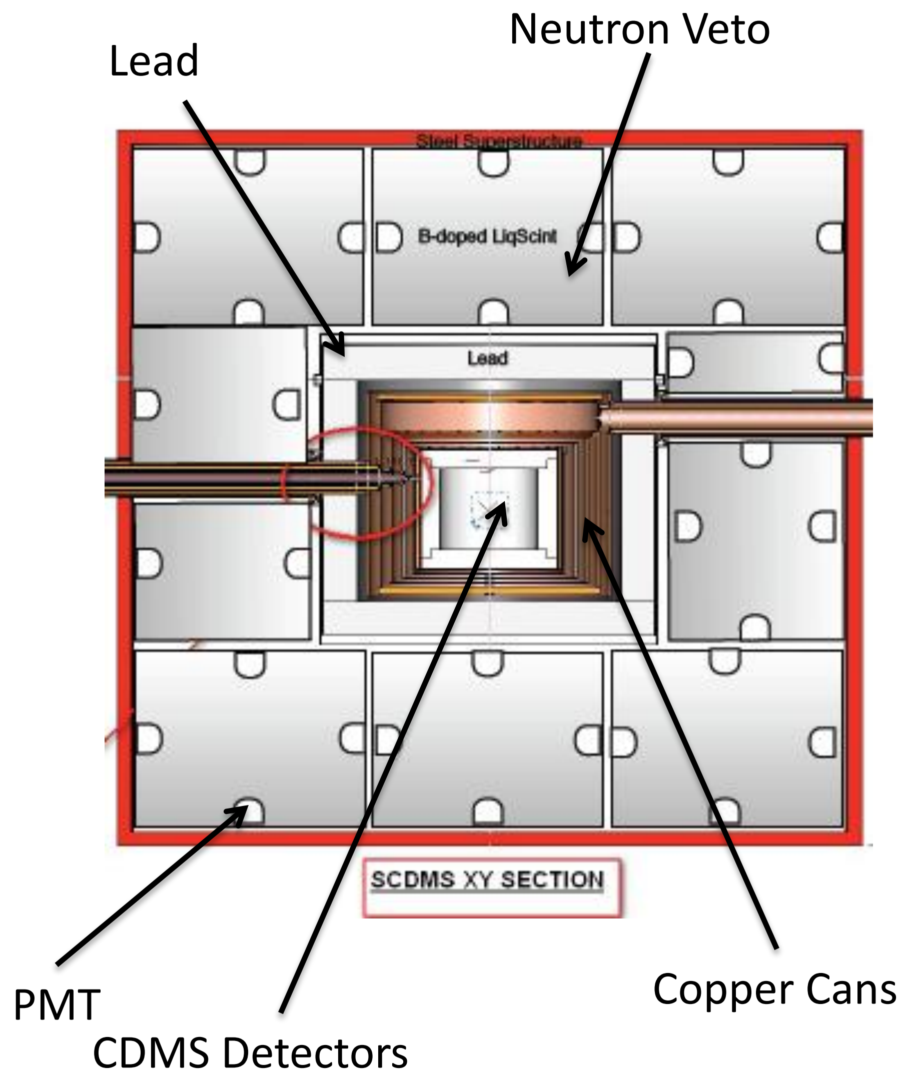
- Gammas: High 'Z'
  - Steel
  - Lead/Ancient Lead
  - Copper
- Neutrons: Low 'Z'
  - Polyethylene (Radio Pure)
  - Scintillator or water (active)
- Muon: High 'Z'
  - Mine Depth
  - Scintillator Paddles
  - Neutron veto doubles for this purpose



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}B

Tag neutrons that cause problems!



Part 3:

SIMULATIONS AND RESULTS

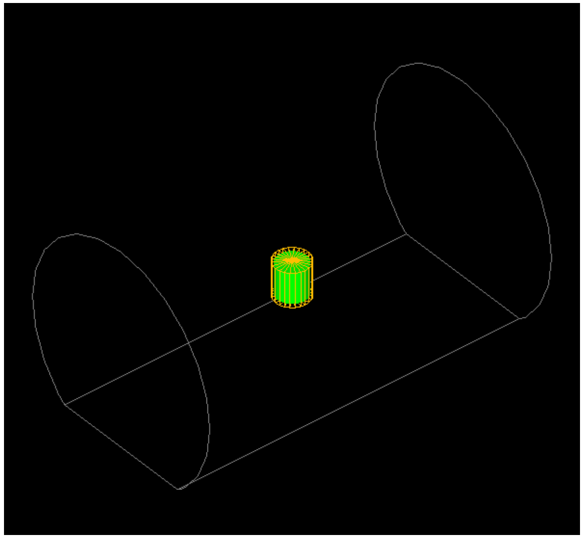
Overview of Studies Performed

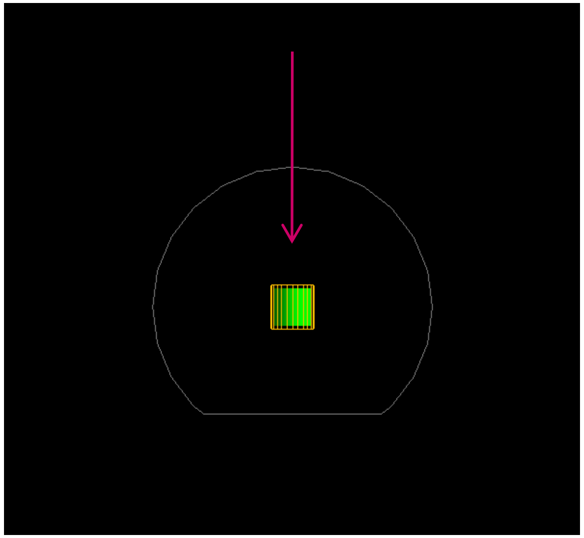
- General
  - Purpose:
    - Study gamma shielding configurations
    - Help improve intuition
    - Validate Geant4 based simulations for neutron veto studies
  - Methods:
    - Modified geometry
      - Simple shielding configurations
    - Analyzed data in ROOT
- Study 1
  - 1D Simulation: Effective Attenuation Length of Materials
- Study 2
  - 3D Simulation: Liquid Scintillator
- Study 3
  - 1D Simulation: Stacked Materials

Definitions

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

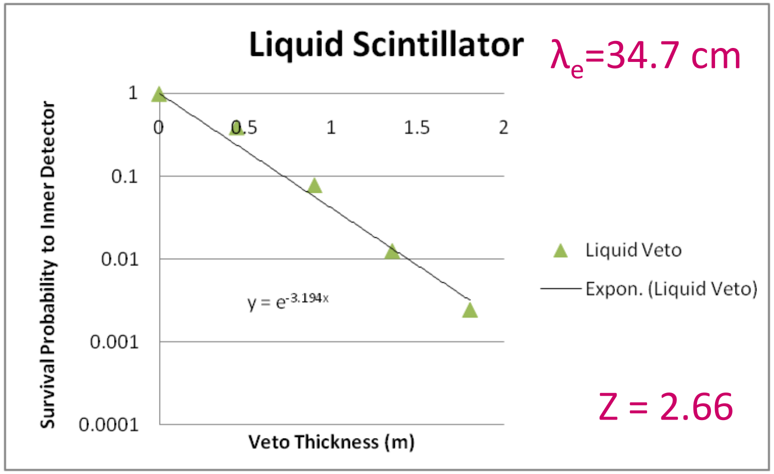


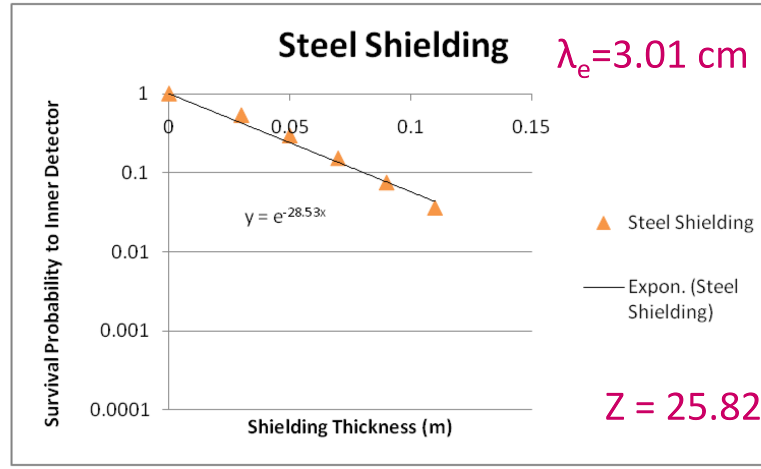


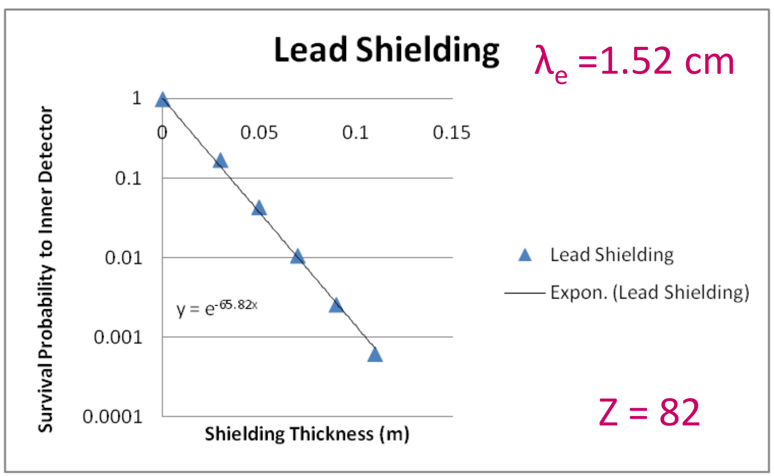
- Purpose:
  - Determine attenuation length of different materials used in shielding for SuperCDMS

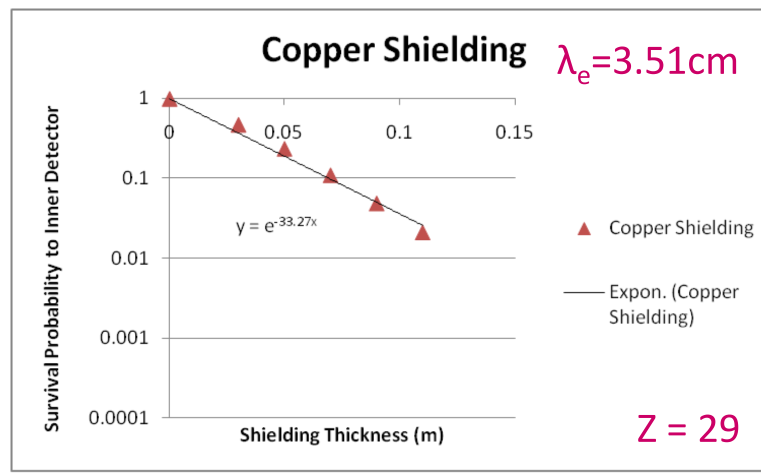
- 1.5 Million events
- Beam of gammas from y-axis
- 1 MeV
- Variables Changed:
  - Various thicknesses of materials
    - Liquid scintillator, lead, copper, steel

Study 1



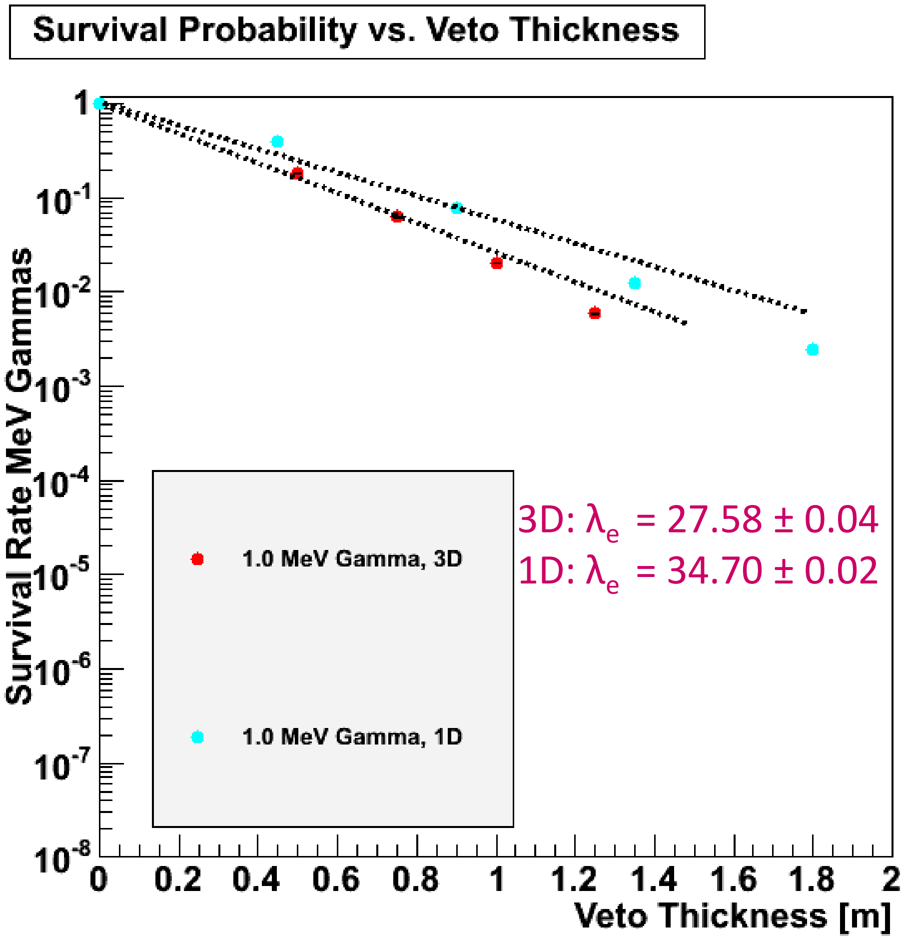






Results: Attenuation length of several materials

Study 2

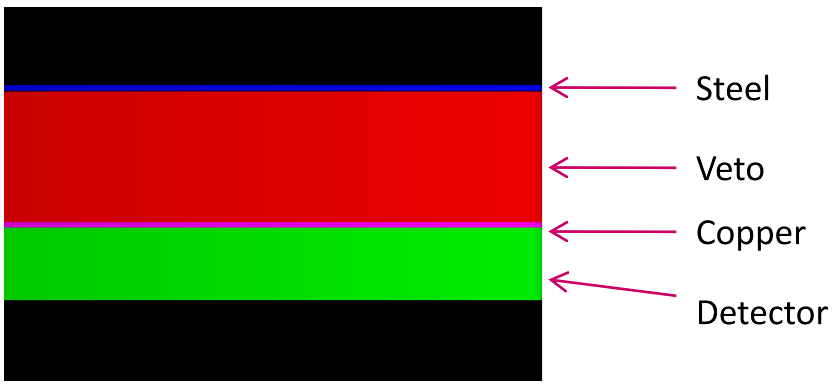


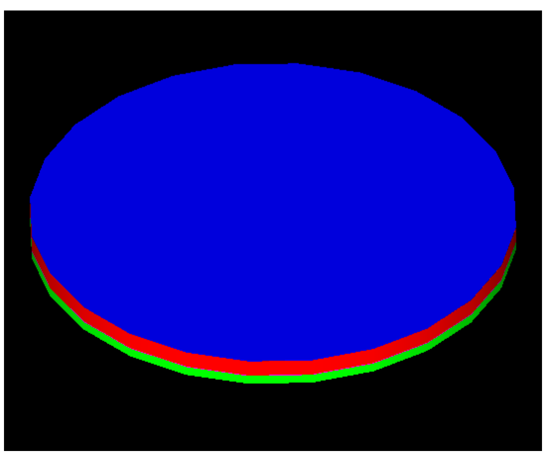
- Purpose:
  - Determine effective attenuation length of liquid scintillator for 3D case; multiple energies
- Results:
  - Comparison viable between 1D and 3D simulations
  - Attenuation length vs. Effective attenuation length

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

Study 3

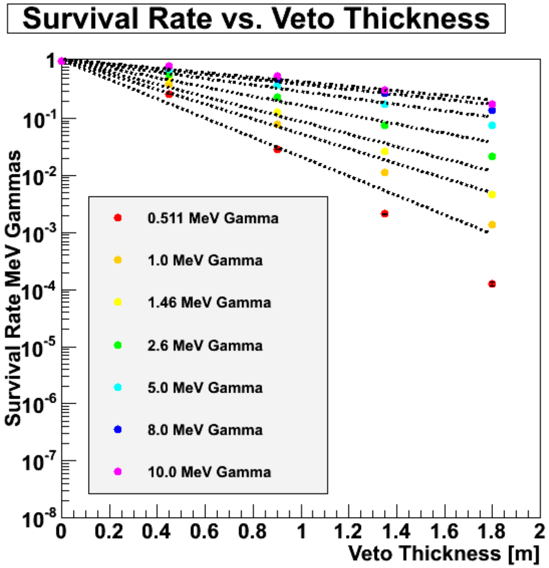
- Purpose:
  - Determine effective attenuation length

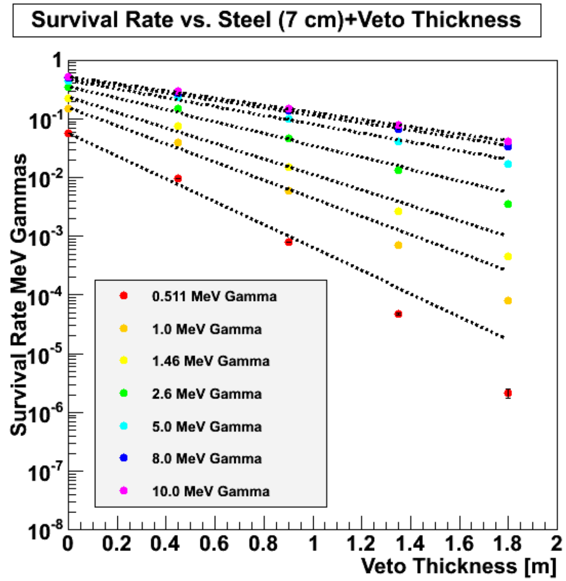


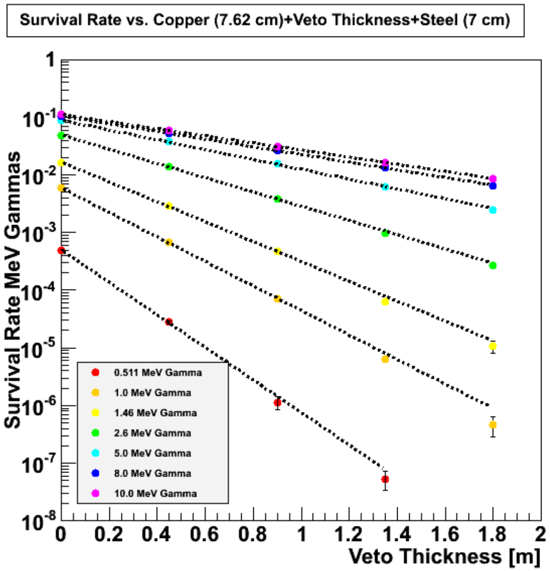


- Variables constant: Copper and Steel
- Variable changing: Veto thickness
- ~1.5 Million events for each energy
- Energies simulated: 0.511, 1, 2.6, 5, 8, 10 MeV

Study 3

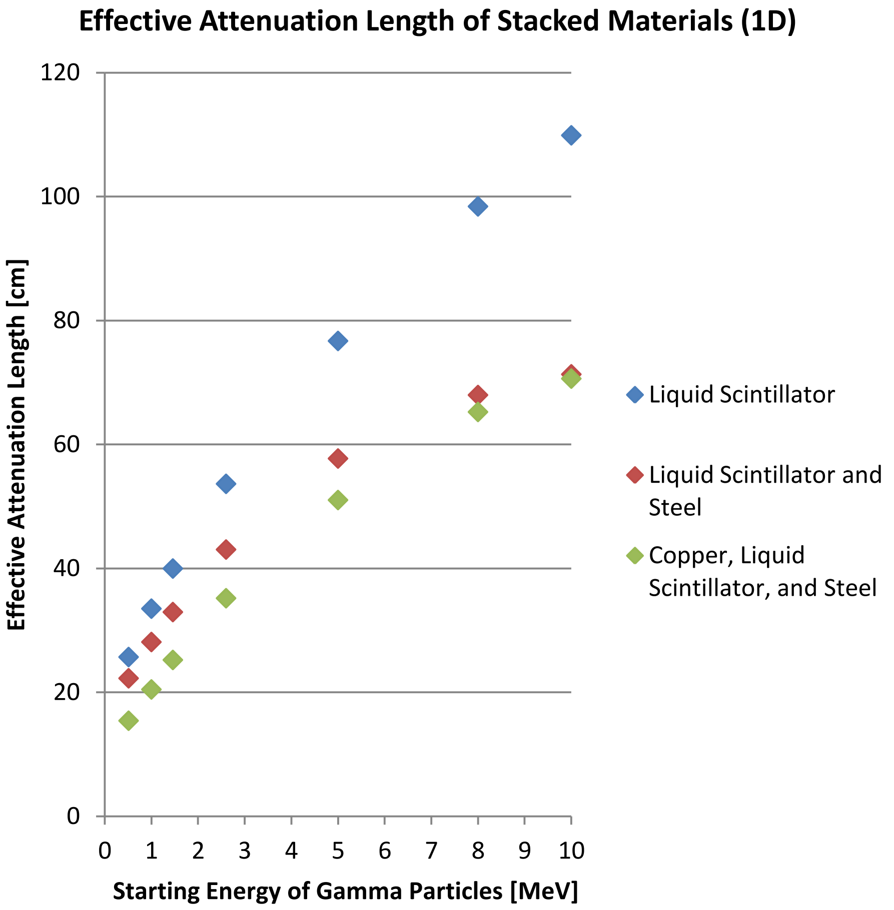

Survival Rate vs. Veto Thickness
Survival Rate MeV Gammas
Veto Thickness [m]
0.511 MeV Gamma
1.0 MeV Gamma
1.46 MeV Gamma
2.6 MeV Gamma
5.0 MeV Gamma
8.0 MeV Gamma
10.0 MeV Gamma


Survival Rate vs. Steel (7 cm)+Veto Thickness
Survival Rate MeV Gammas
Veto Thickness [m]
0.511 MeV Gamma
1.0 MeV Gamma
1.46 MeV Gamma
2.6 MeV Gamma
5.0 MeV Gamma
8.0 MeV Gamma
10.0 MeV Gamma


Survival Rate vs. Copper (7.62 cm)+Veto Thickness+Steel (7 cm)
Survival Rate MeV Gammas
Veto Thickness [m]
0.511 MeV Gamma
1.0 MeV Gamma
1.46 MeV Gamma
2.6 MeV Gamma
5.0 MeV Gamma
8.0 MeV Gamma
10.0 MeV Gamma

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 produces 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 (λ), 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++