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

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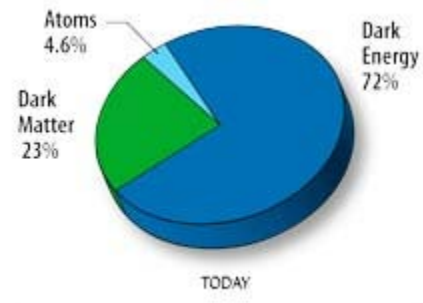
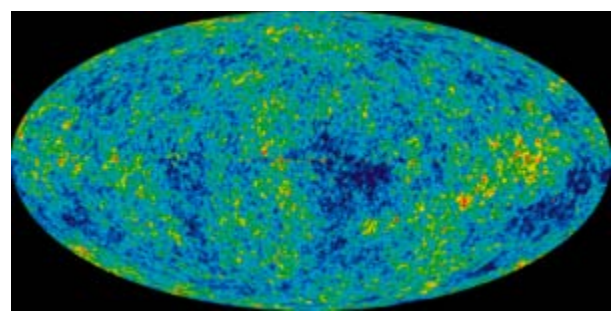
Part 1:

BRIEF EXPLANATION OF DARK MATTER

Missing Mass?



- Jan Oort and Fritz Zwicky
  - Used virial theorem to find an observed gravitational mass of the system and then the luminous mass.
    - Two methods did not add up; 400x more gravitational mass
- Vera Rubin
  - Used rotation curves to same conclusion as Zwicky.
- CMB
  - Anisotropies
- Gravitational Lensing



DM Candidates (some examples)

- WIMPs (Weakly Interacting Massive Particles)
  - Non-baryonic matter
  - Hypothetical particle (predicted by SUSY)
    - LSP/neutralinos?
  - Large mass compared to other particles
  - Interact only with weak and gravitational
- MACHOs (Massive Compact Halo Objects)
  - Made of baryonic matter
  - Emits little or no radiation
    - Black hole, neutron star, brown dwarf
  - Gravitational Lensing

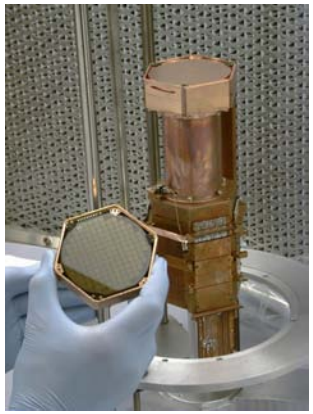
Part 2:

DARK MATTER DETECTION

Detection of DM

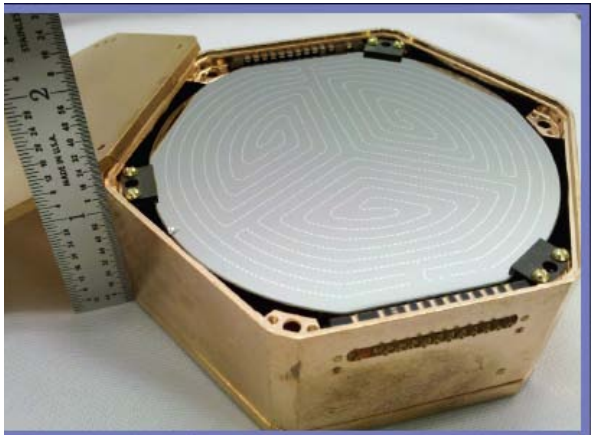
- Accelerator Creation
  - Detection of decay products of WIMPS created from hadron collision
    - Early universe, ATLAS, CMS, LHC
- Indirect
  - Search for products via annihilation
    - GLAST, IceCube
- Direct
  - Interactions with ordinary matter
    - CDMS, COUPP, DRIFT, SuperCDMS

CDMS



- ZIP detectors, stacked in copper towers
  - Si and Ge crystal with sensors attached
    - Crystal receives energy from incoming particles; sensors collect information.
  - **Detection in the form of phonons (nuclear recoils) and ionization (electron recoils)**
    - One side of the detector collects phonons; one side collects ionization.
- Shielding
- Soudan Mine
  - Depth: 2090 mwe, blocks most cosmic rays
- **Expected WIMP flux (Does not change; Earth orbits inside a dark matter halo!)**
  - 0.1 event/kg/day
- Expected background flux
  - 0.9 event/kg/day, after veto
- **Needle-in-a-haystack comparison**

SuperCDMS



- Improved Detectors
  - New iZIP detectors
    - **Larger, 100 kg (vs. 4 kg for CDMS)**
    - Greater phonon sensitivity
    - Each side can collect both phonon and electron recoils to collect signals.
- Better Shielding
  - Deeper site (SNOLAB): 6060 mwe
    - Lower cosmic ray-induced neutron background
  - Proposed neutron veto
  - Implement more radio-pure material for shielding.

Part 3:

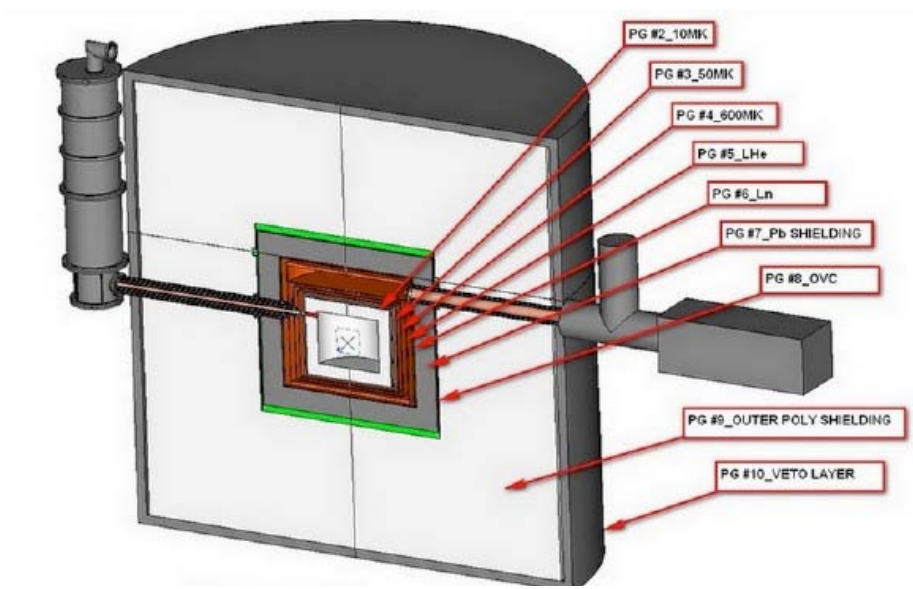
BACKGROUND AND SETUP

Background Particles

- Gammas
  - Decay chains of ^{238}U, ^{232}Th, and ^{40}K
- Neutrons
  - Internal Radiogenic
    - Fission and (α, n) of non-negligible contributions from trace isotopes (primarily U) in material surrounding CDMS detectors
      - U/Th in the copper cans from cryostat1
      - the Pb shielding (via fission of U) and poly shielding (via [alpha, n])
  - Cosmogenically Produced
    - Spallation from cavern rock and the experimental apparatus
    - Muon veto significantly removes from 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

SuperCDMS Shielding

- Gammas:
  - Steel
  - Lead/Ancient Lead
    - shielding from gammas resulting from radioactivity
  - Copper
    - shielding from gammas
- Neutrons:
  - Polyethylene (radio pure), past
    - Moderate neutrons produced from fission decays and from (α,n) interactions resulting from U/Th decays
  - Instrumented (active)
    - Scintillator or water
- Muon:
  - Mine depth
  - Scintillator Paddles, past
  - Neutron veto functions for this purpose



Neutron Veto

- The Problem
  - Both WIMPs and neutrons are neutral.
  - Both WIMPs and neutrons are very weakly interacting.
  - Have about the same de Broglie wavelength.
  - Both will scatter off a Ge nucleus and provide a nuclear recoil.
  - "False Positive"
- Basic Design
  - Modular tanks of liquid scintillator doped with 10-20% ^{10}B, mineral oil

Shielding and Veto

- Shielding
  - Passive, just blocks particles
  - Steel, Lead, Copper
- Veto
  - Active, takes information from particles that it blocks
  - Mineral Oil
- Rate of Blocking Particles
  - Need 10^4 reduction in background.
  - Attenuation lengths (λ), Beer-Lambert Law
    - $P(x) = e^{-(x/\lambda)}$
  - Attenuation factor

Understanding Background Particles

- MC Simulations of Gamma Particles
  - From decay chains
    - ^{238}U + ^{232}Th, lower energy gammas
    - ^{40}K
    - (α,n)
  - Greater stopping by high Z materials
  - Greater the gamma energy, greater the attenuation length needed
- Neutrons
  - Greater stopping by low Z materials (mineral oil)
  - Greater the neutron energy, greater the attenuation length needed

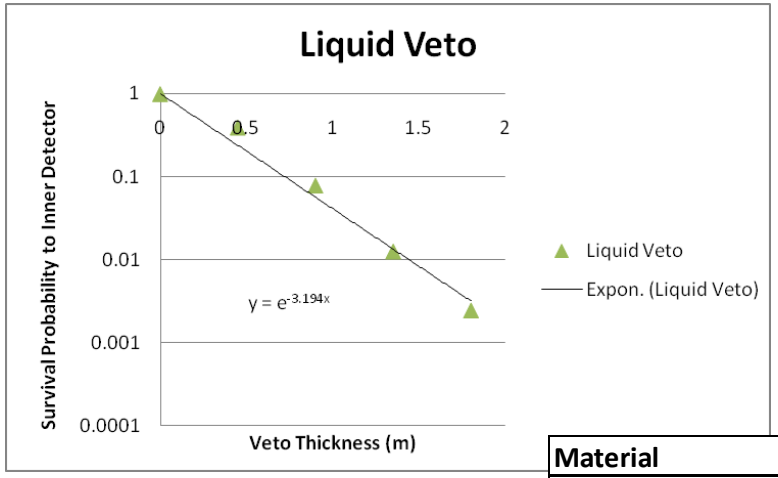
MC Setup

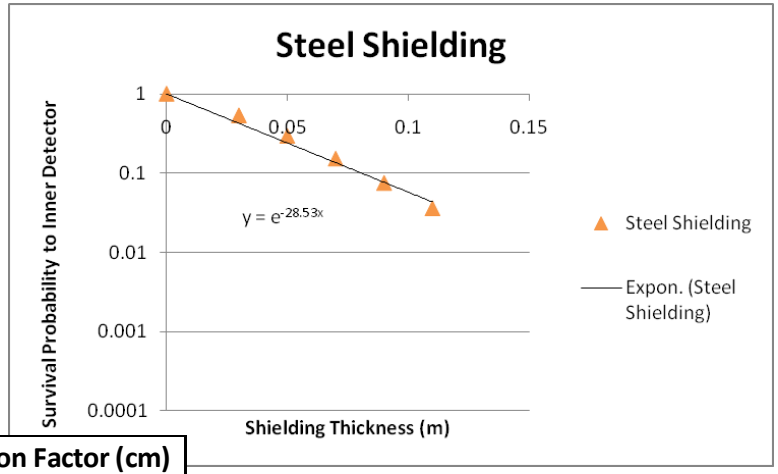
- 1D Simulations
  - Attenuation length of gammas at different energies, for different thicknesses of materials
    - 0.511, 1, 1.46, 2.6, 5, 8, 10??? (Explain why those energies.)
    - Geant4 to create "slabs" of materials
      - Vacuum, essential infinite plane, mineral oil
      - Effective attenuation length for combination
        - » Copper, mineral oil, steel
- 3D Simulations
  - Effective attenuation length of gammas but for the realistic case
    - Cavern, air, true dimensions of material

Part 4:

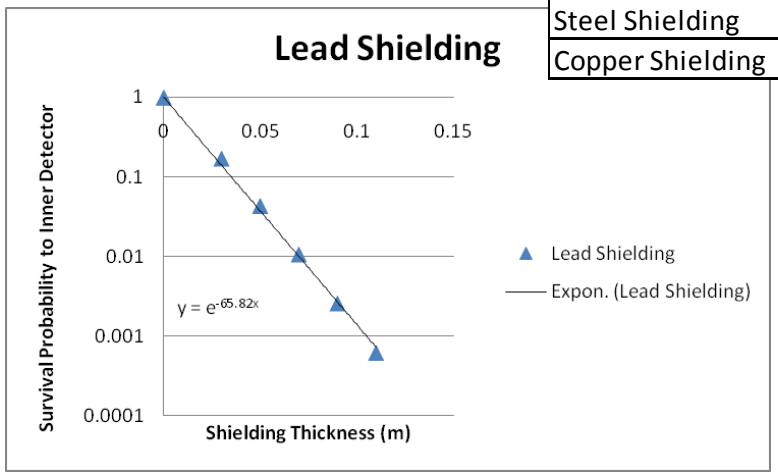
DATA AND RESULTS

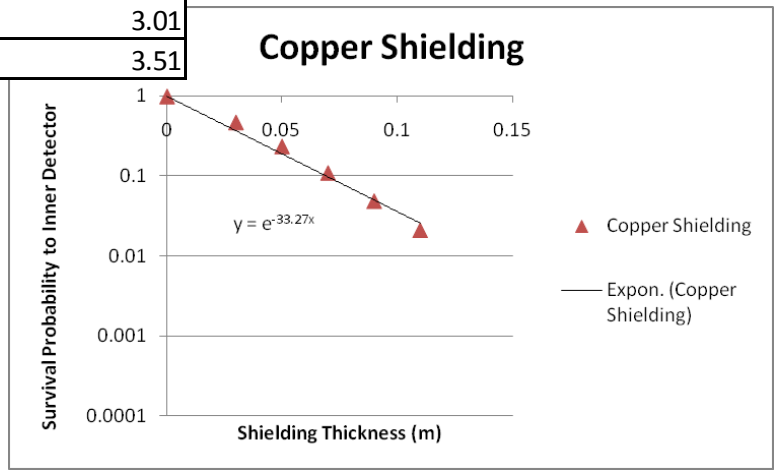
1D Simulation: Attenuation Factor of Materials





Material	Attenuation Factor (cm)
Liquid Scintillator	31.3
Lead Shielding	1.52
Steel Shielding	3.01
Copper Shielding	3.51





3D Simulation

- Attenuation
- Survival Probability
- Plot currently running

Conclusions

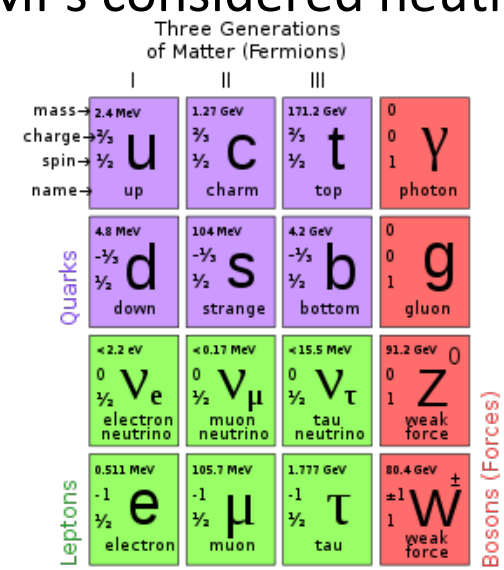
- Not all plots available yet; plot currently running; data not yet fully analyzed

The End!

QUESTIONS?

Backup Slides

BACK-UP!

Baryonic vs. Non-Baryonic

- Baryonic: composed of normal matter, atoms
- Dark matter considered to be non-baryonic matter (not composed of atoms)
  - Small fraction baryonic?
    - weak or no electromagnetic radiation
- Beyond the Standard Model particles
  - Due to no electromagnetic or strong interactions
- Interacts gravitationally and weakly
  - General class of particles: Weakly Interacting Massive Particles (WIMPs)
    - Mass of atomic nucleus
    - Scatter off atomic nucleus
- WIMPs considered neutral