Backgrounds in the νBDX-DRIFT Experiment at Fermilab

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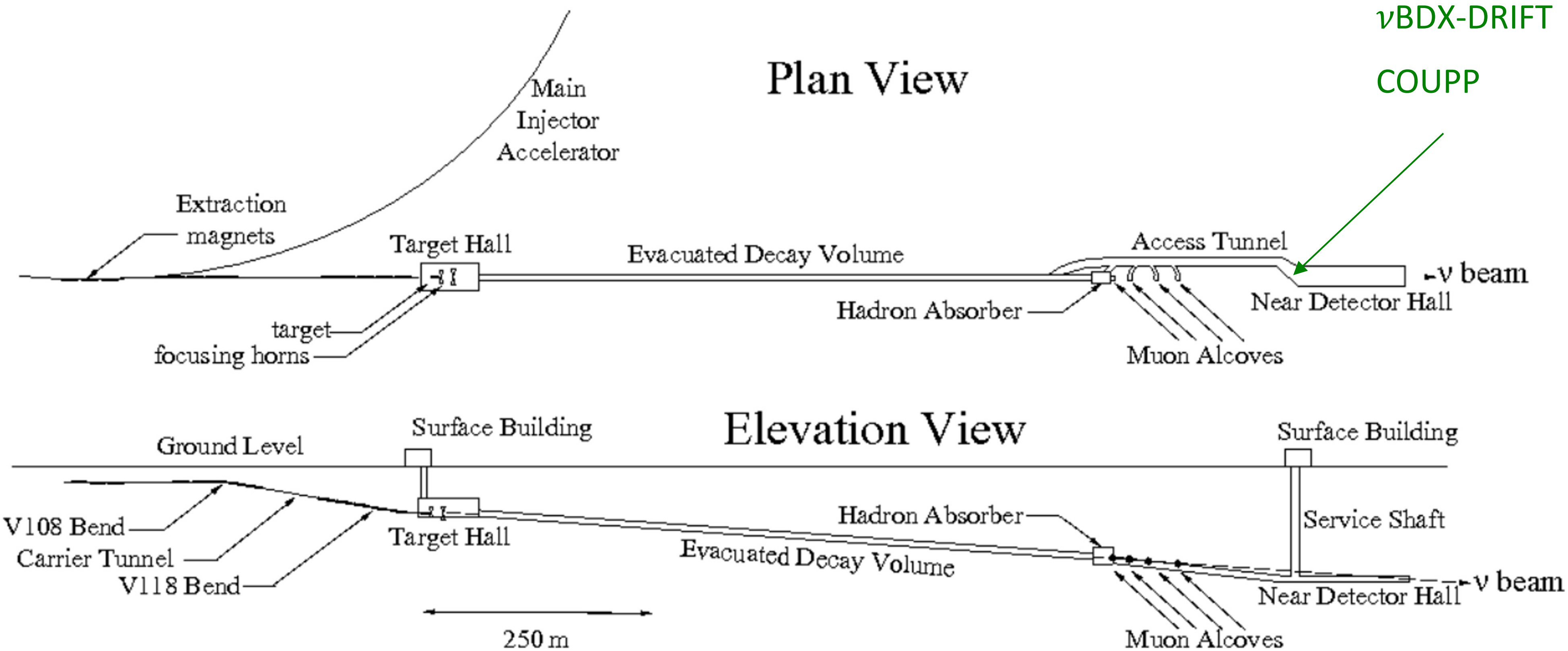
General Considerations

- We want to know background levels for low-energy nuclear recoils in a neutrino beam at Fermilab
- These backgrounds arise, predominantly, from “rock-neutrons” generated by neutrino interactions in the rock around underground detectors at Fermilab
- In the near term our plan is to run in the NuMI beam

νBDX-DRIFT at NuMI

νBDX-DRIFT

COUPP



COUPP at NuMI

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Improved Limits on Spin-Dependent WIMP-Proton Interactions from a Two Liter CF_3I Bubble Chamber

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(COUPP Collaboration)

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Data from the operation of a bubble chamber filled with 3.5 kg of CF_3I in a shallow underground site are reported. An analysis of ultrasound signals accompanying bubble nucleations confirms that alpha decays generate a significantly louder acoustic emission than single nuclear recoils, leading to an efficient background discrimination. Three dark matter candidate events were observed during an effective exposure of 28.1 kg day, consistent with a neutron background. This observation provides strong direct detection constraints on weakly interacting massive particle (WIMP)-proton spin-dependent scattering for WIMP masses >20 GeV/c^2.

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There is abundant evidence that $\sim$85% of the matter in the Universe is cold, dark, and nonbaryonic [1]. Together, dark matter and dark energy are pillars in modern cosmology which form a simple framework to understand the detailed observations of baryonic structure, the Hubble diagram, the cosmic microwave background, and the abundances of light elements. However, present knowledge of the nature of these essential ingredients of cosmology is limited. A new weak-scale symmetry, such as the preservation of *R* parity in supersymmetry, would predict a massive particle with properties that conform with the current knowledge of dark matter [2]. If these weakly interacting massive particles (WIMPs) are the dark matter, then they may scatter off nuclei with enough energy, and at alpha-decay identification based on the acoustic emission from bubbles [6]. This Letter confirms the observation of alpha discrimination and utilizes this technique to set limits on spin-dependent WIMP-proton scattering.

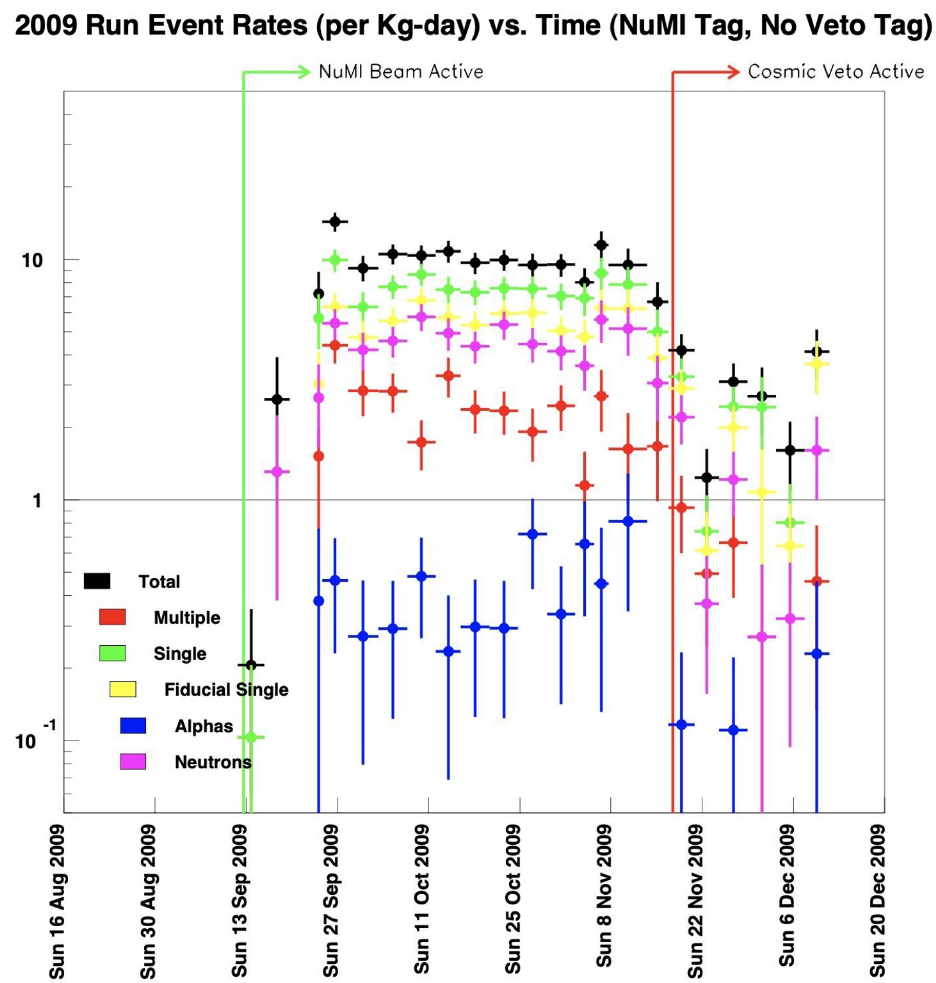
This Letter reports results from a 3.5 kg CF_3I bubble chamber operated from August 19 to December 18, 2009, in the MINOS near detector tunnel [7] at the Fermi National Accelerator Laboratory. The bubble chamber was located 3 m off the axis of the NuMI neutrino beam [7], which operated with 10 μs pulses, typically every 2.5 s. The short duty factor allowed for a calibration source of efficiently tagged, beam-induced, fast neutrons. Additional calibration was provided using a switchable americium-beryllium neutron source (sAmBe) [5].

Backgrounds - Benchmarking

- Use COUPP 2009 nuclear recoil data to benchmark the simulation
- Need data from when the beam was on
- COUPP (unpublished) measured

  4.42 +/- 0.19 events/kg/day

  after subtracting coincidentals
- 3.25 kg CF_3I



Backgrounds - Inputs

- Dolomite composition from Fermilab

> I updated the ND rock using information in MINOS-doc-1083 and 2777, particularly the quoted water content in doc-2777, and Wikipedia's composition for shale. I also assumed that we've drained half the water out since the water content was measured. The result was:
>
> <D value="2.33" unit="g/cm3"/>
> <fraction n="0.0147547" ref="Hydrogen"/>
> <fraction n="0.0114328" ref="Carbon" />
> <fraction n="0.5637993" ref="Oxygen" />
> <fraction n="0.0431255" ref="Calcium" />
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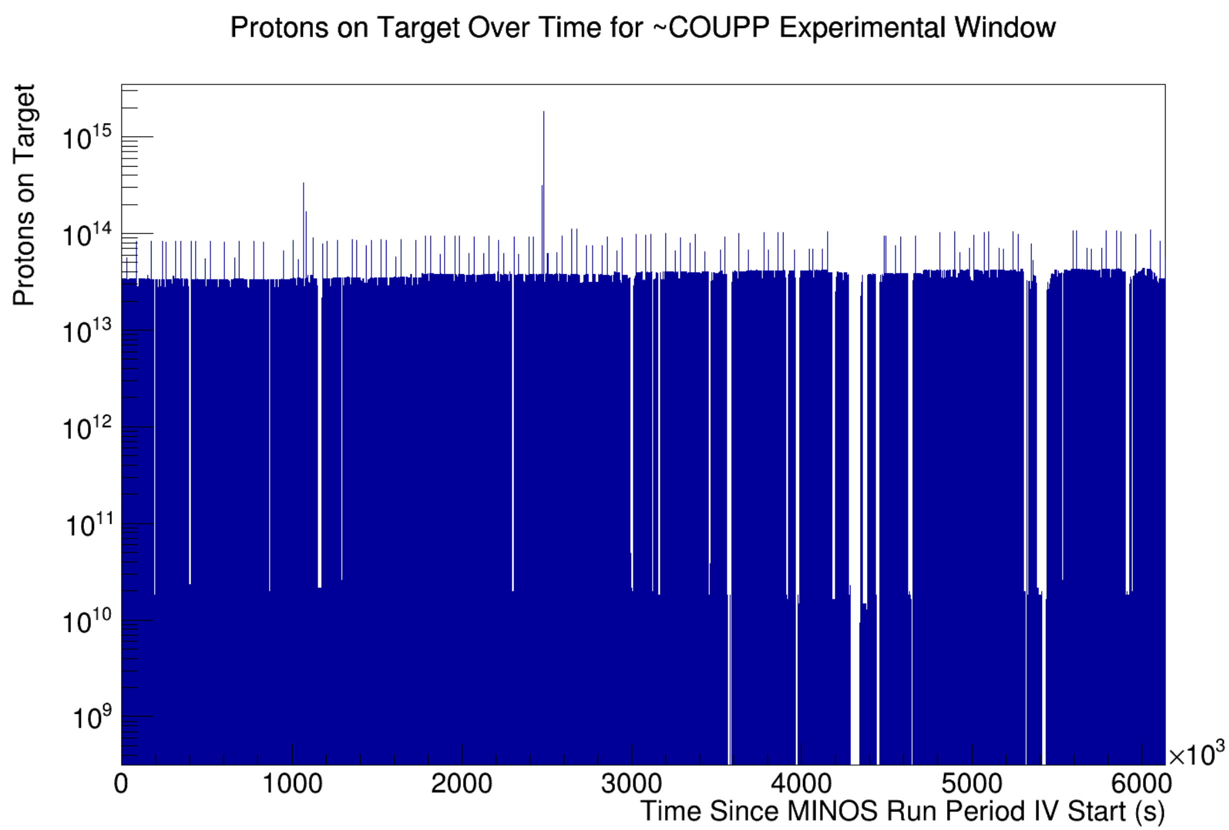
> <fraction n="0.0179492" ref="Iron" />
> <fraction n="0.2420140" ref="Silicon" />
> <fraction n="0.0093778" ref="Potassium"/>
>

Backgrounds - Inputs

- Dolomite composition from Fermilab
- POT per pulse
- Time between pulses



Backgrounds - Inputs

- Dolomite composition from Fermilab
- POT per pulse
- Time between pulses
- NuMI neutrino flux
- LE mode

The NuMI Beam at FNAL and its Use for Neutrino Cross Section Measurements

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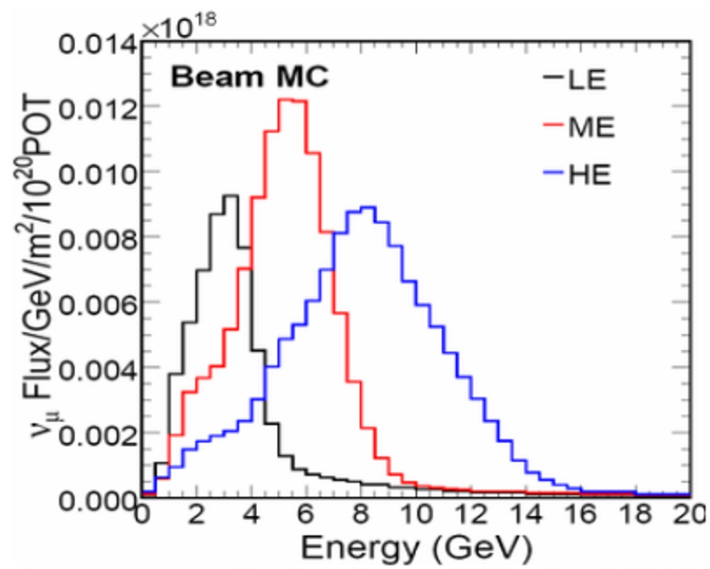

FIGURE 2. Neutrino energy spectra achieved at a distance of 1040 m from the NuMI target with the horns separated by 10 m and the target inside the first horn (LE), or retracted 1 m (ME) or 2.5 m (HE).

Backgrounds - Code

- Dolomite composition from Fermilab
- POT per pulse
- Time between pulses
- NuMI neutrino flux
- LE mode
- Used Genie to generate end-state particles coming from ν - nuclei interactions

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- Used GEANT to generate recoils

Backgrounds – COUPP Efficiency Model

- Dolomite composition from Fermilab
- POT per pulse
- Time between pulses
- NuMI neutrino flux
- LE mode
- Used Genie to generate end-state particles coming from ν - nuclei interactions
- Used GEANT to generate recoils
- COUPP Efficiency Model

Bubble Formation Model

$$\epsilon(E) = 1 - \exp(-\alpha[(E - E_T)/\ E_T])$$

where for $E_T = 16.8^{+0.8}_{-1.1}$ keV

$$\alpha_{C,F} = 0.15$$

$$\alpha_I = 2.8^{+1.6}_{-0.8}$$

PRD, 88, 2013

Backgrounds - Benchmarking

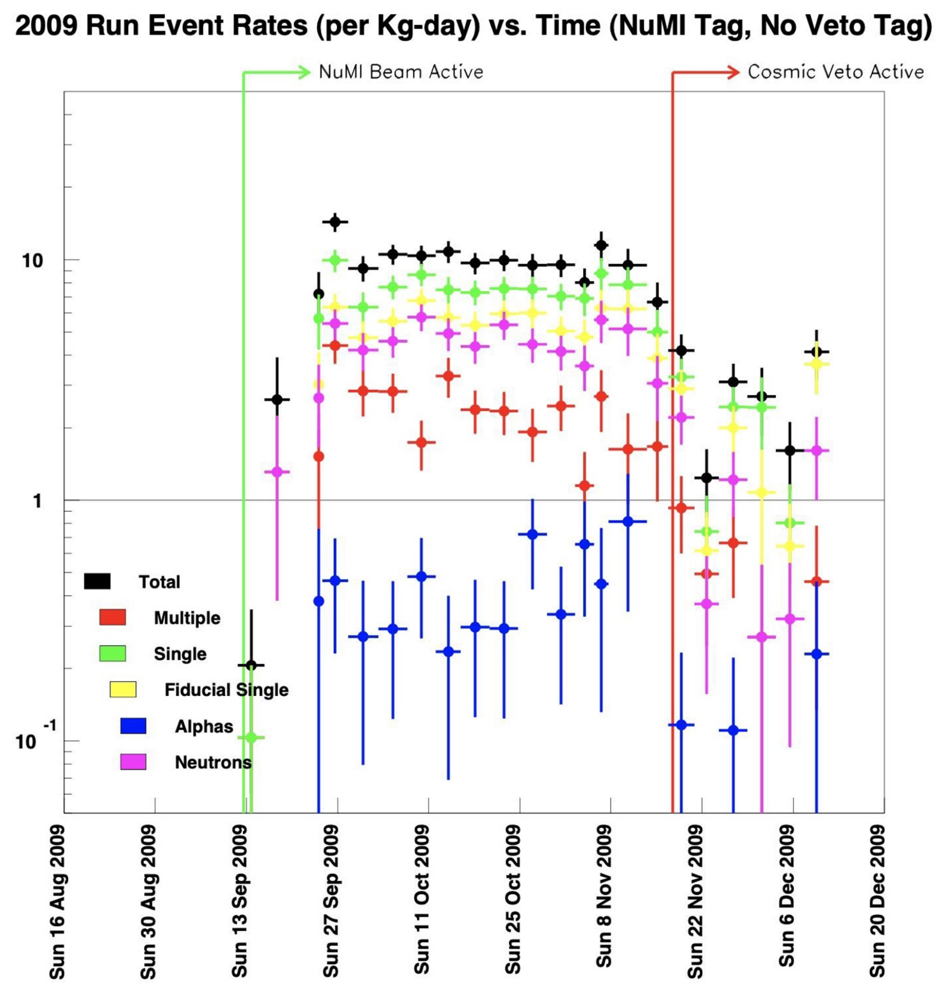
- Use COUPP 2009 nuclear recoil data to benchmark the simulation
- COUPP (unpublished) measured

  4.42 +/- 0.19 events/kg/day

  after subtracting coincidentals
- Genie/Geant prediction

  hA => 4.00 +/- 0.16 events/kg/day

  hN => 4.15 +/- 0.19 events/kg/day
- Up to 0.35 events/kg/day needs to be added to this due to inelastic collisions inside the CF_3I

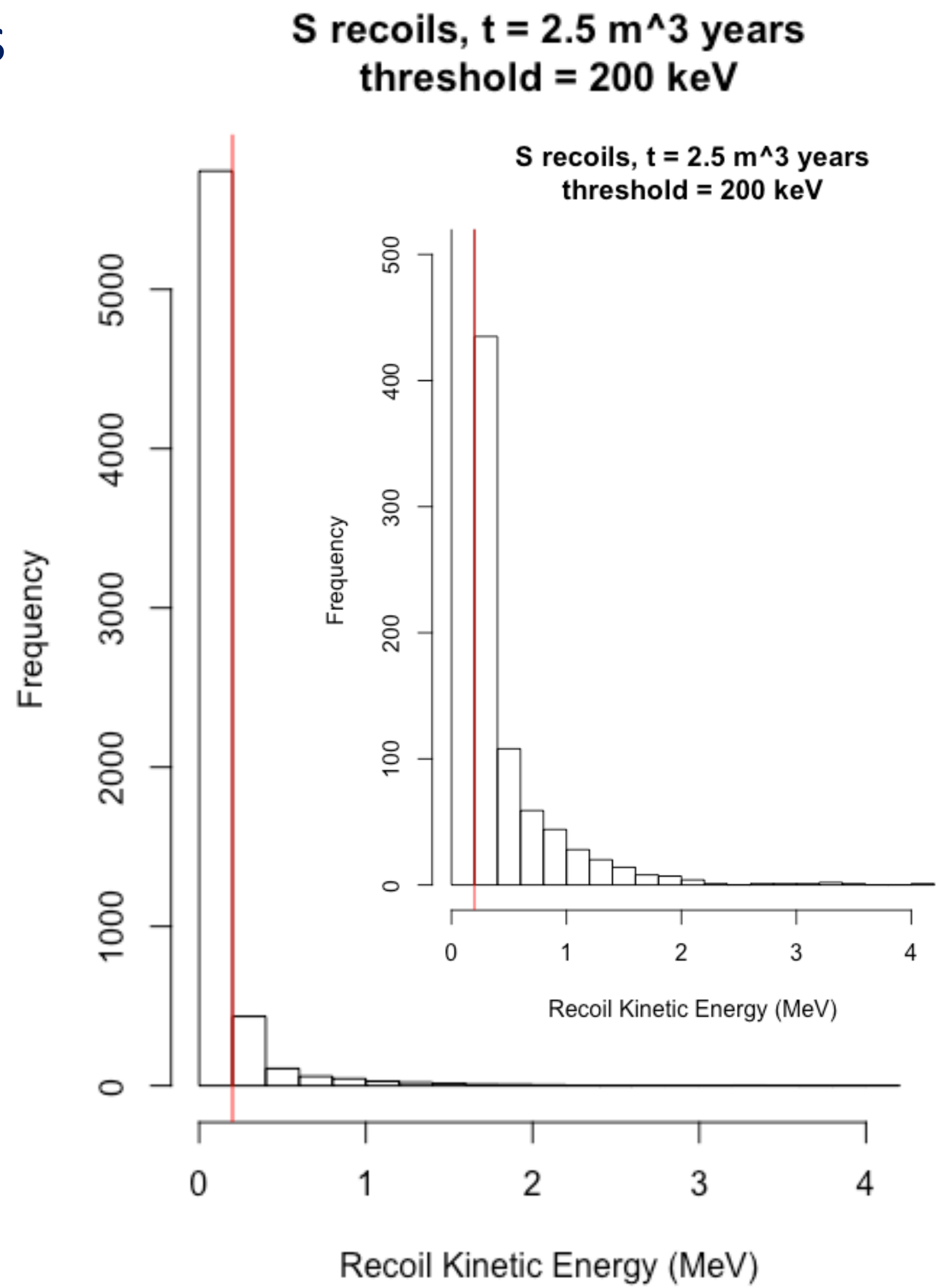


Background Prediction for νBDX-DRIFT

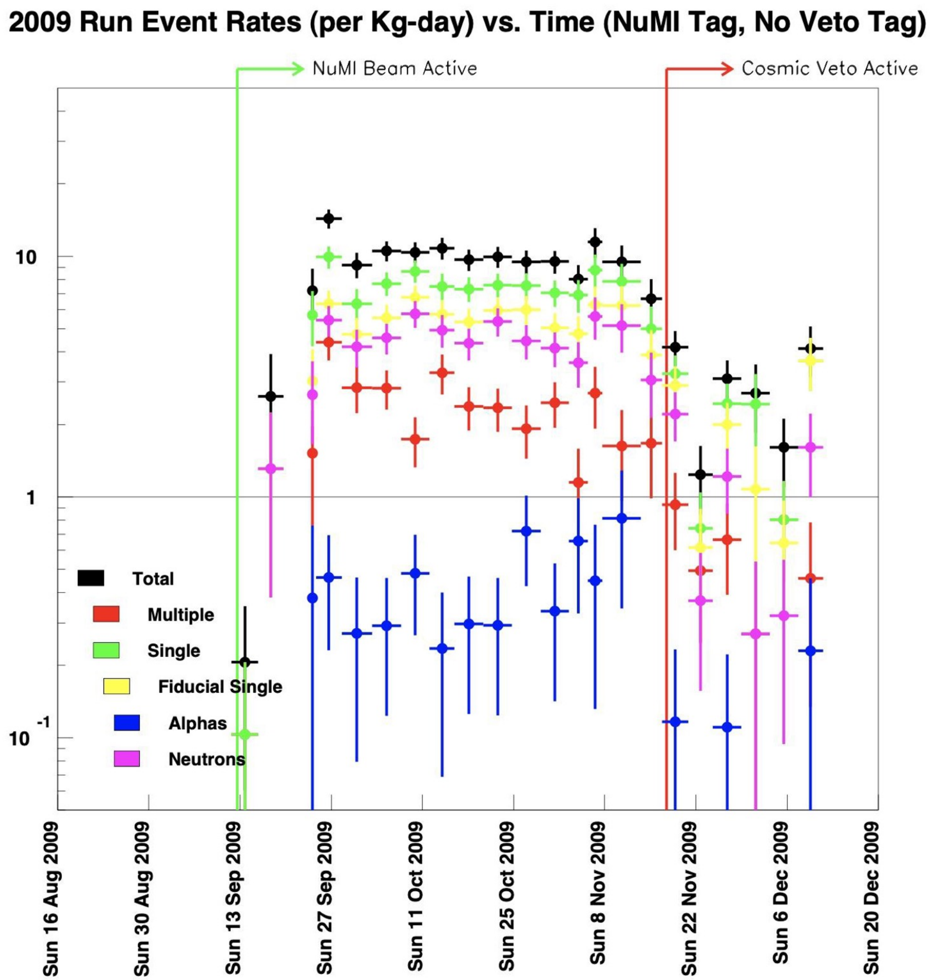
- Changed 3.25 kg CF_3I to 400 Torr CS_2
- Re-ran Genie and recorded neutrons exiting the walls
- Smoothed those neutrons and restarted at walls (2 stage simulation)
- Recorded interactions in the detector including elastic nuclear recoils

Backgrounds - Predictions

- 1 m^3 νBDX-DRIFT detector filled with 400 Torr CS2
- 1.66 kg CS_2
- 733 S recoil and 1122 C recoil events bigger than threshold
- 2.03 events/kg/day, similar to the COUPP result
- This rate can be significantly reduced by adding a scintillator around the νBDX-DRIFT detector, as was done with COUPP



COUPP Veto



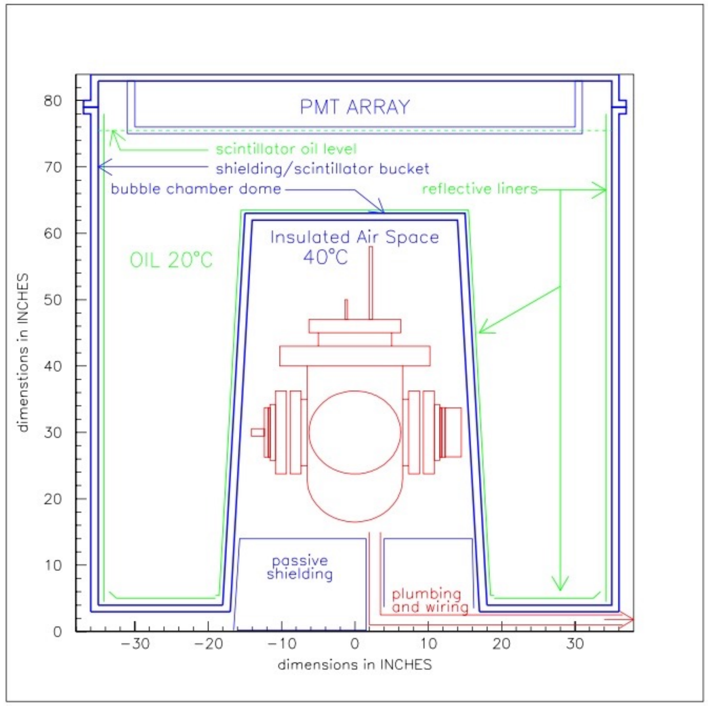
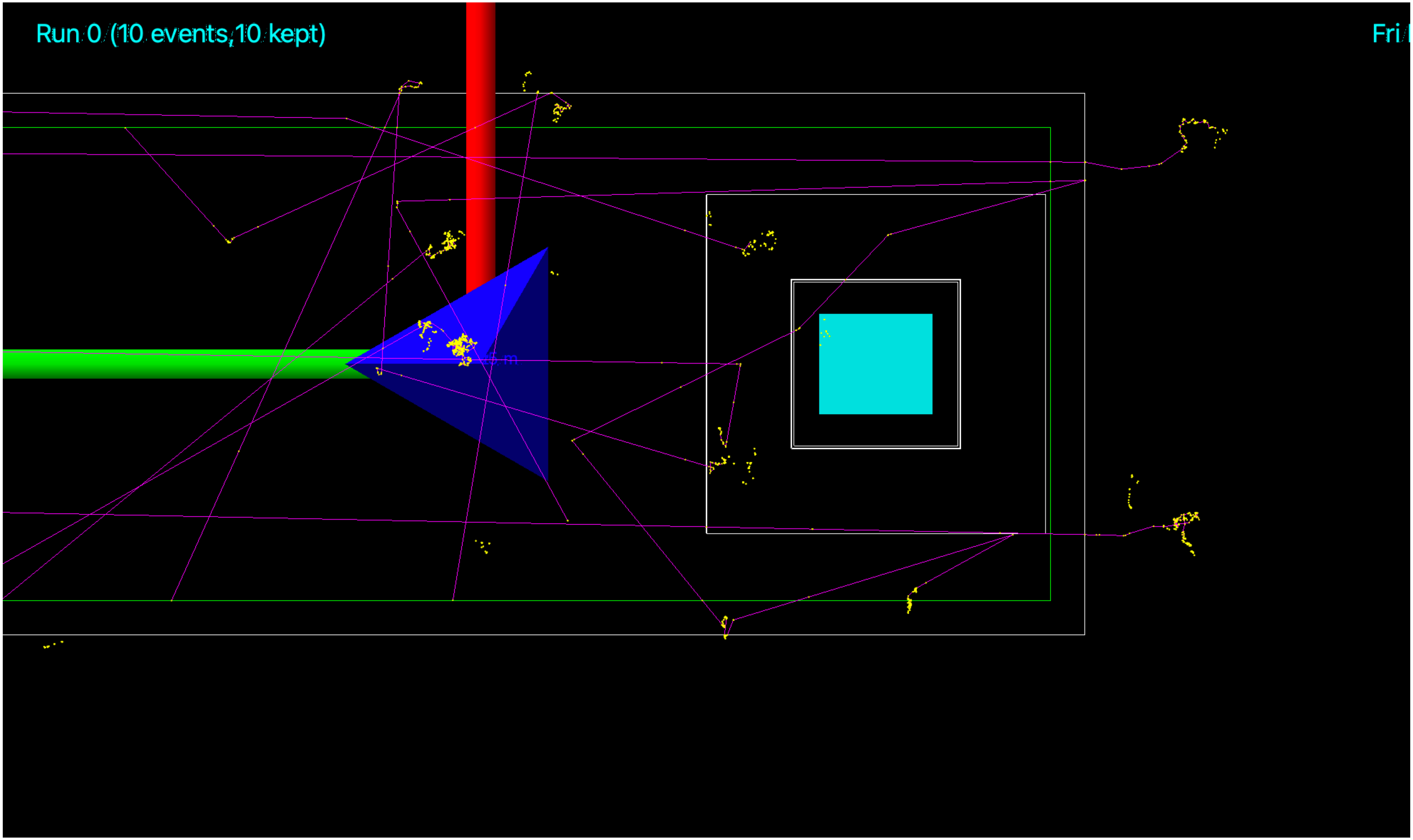


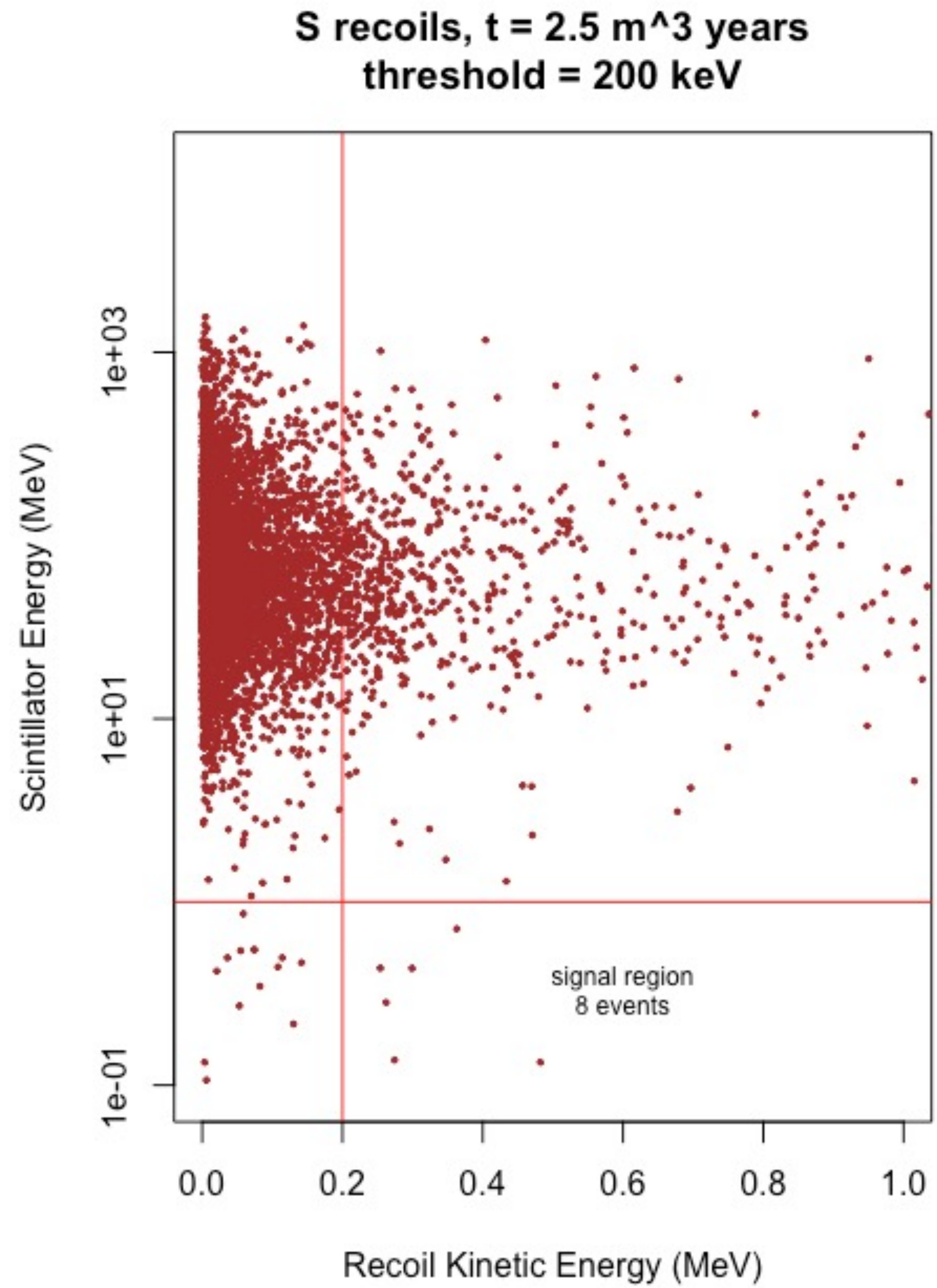
Figure 10 A diagram of the shielding for the 2009 run. Bicron 517L scintillating oil filled the "bundt cake" shaped veto tank around the pressure vessel. The shielding below the pressure vessel is passive neutron moderator. 19 photomultipliers are housed at the top of the veto tank and view the active liquid through acrylic windows. The thinnest portion of the active veto is the 15" thick portion directly above the pressure vessel.

νBDX-DRIFT Veto



Backgrounds - Predictions

- 1 m^3 νBDX-DRIFT detector filled with 400 Torr CS_2
- 0.75 m scintillator surrounding vacuum vessel, similar to the COUPP veto
- Neutrino or BSM events will not interact in the scintillator. Reject those that do



Backgrounds - Predictions

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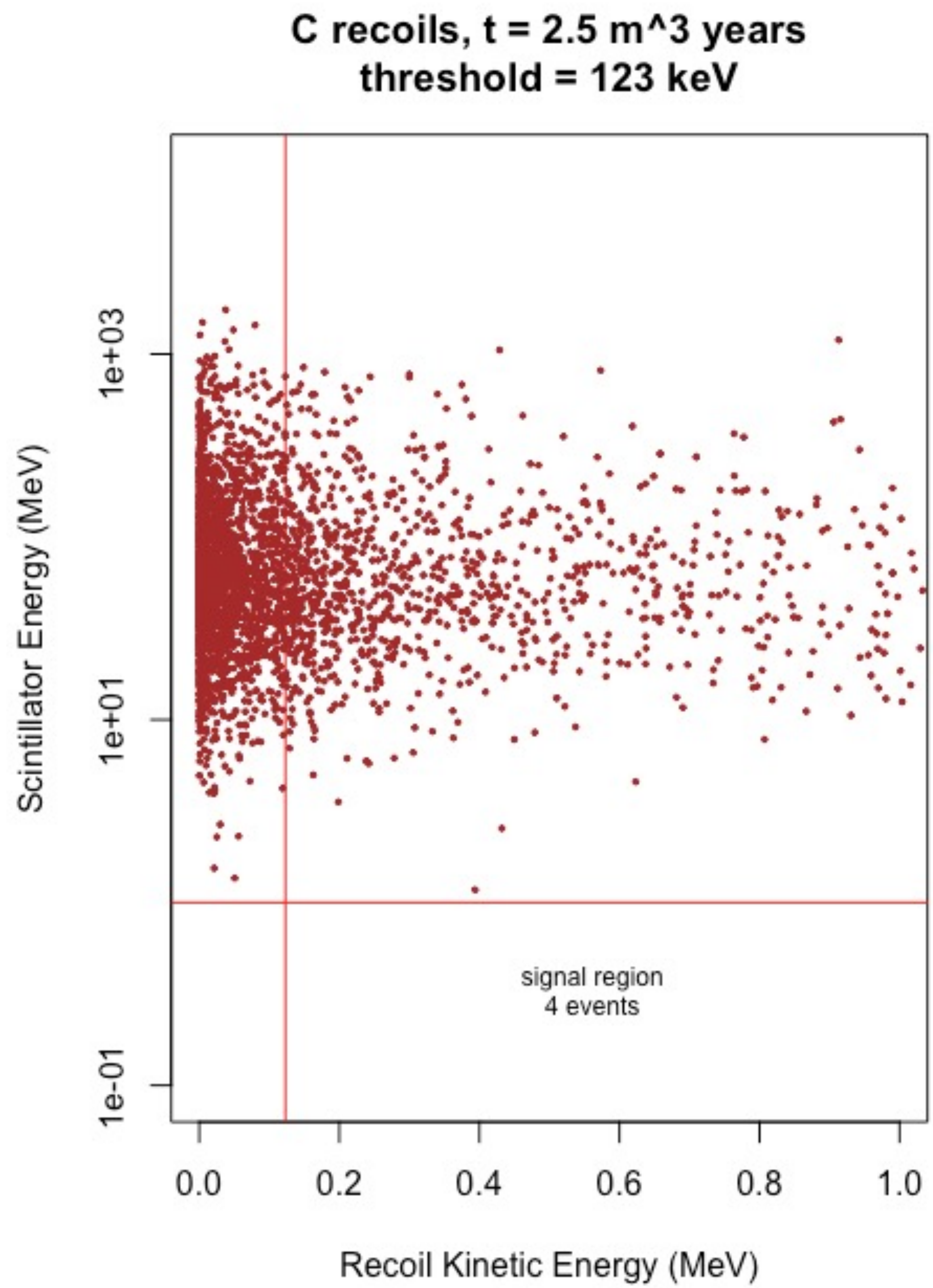
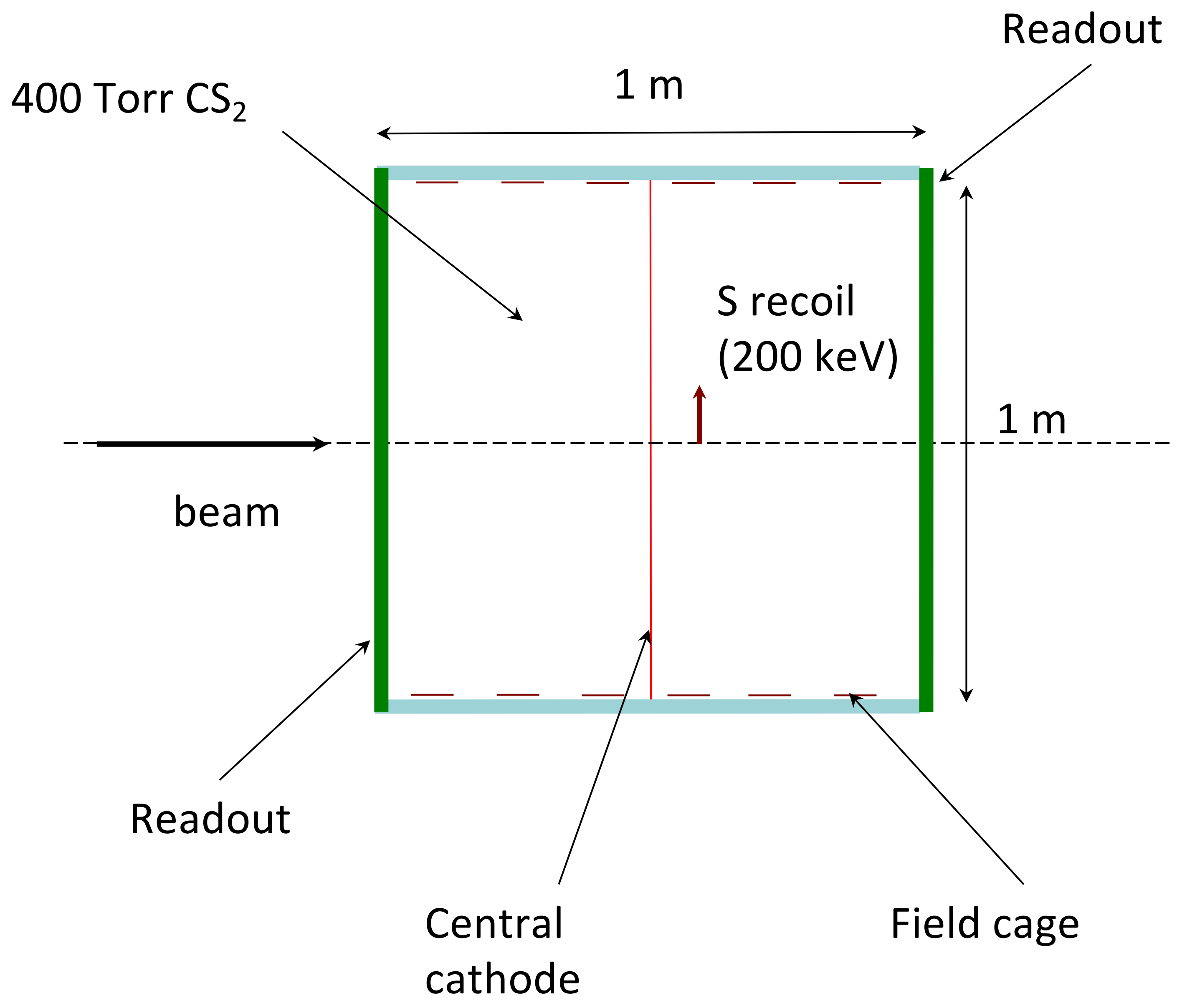
- 0.75 m scintillator surrounding vacuum vessel, similar to the COUPP veto
- Neutrino or BSM events will not interact in the scintillator. Reject those that do
- => few events per kg per YEAR



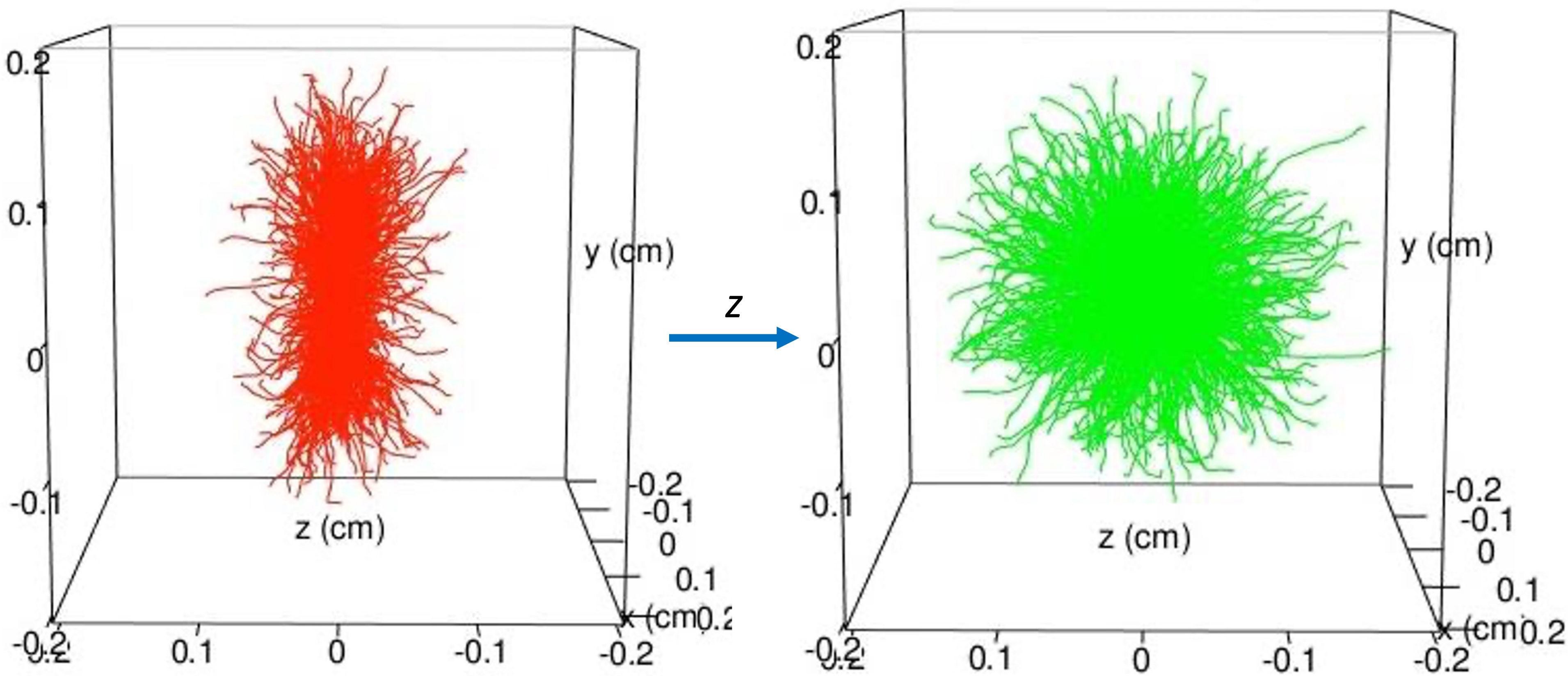
Directionality



Directional Signal and Background

1,000 50 keV
signal events

1,000 50 keV
background events



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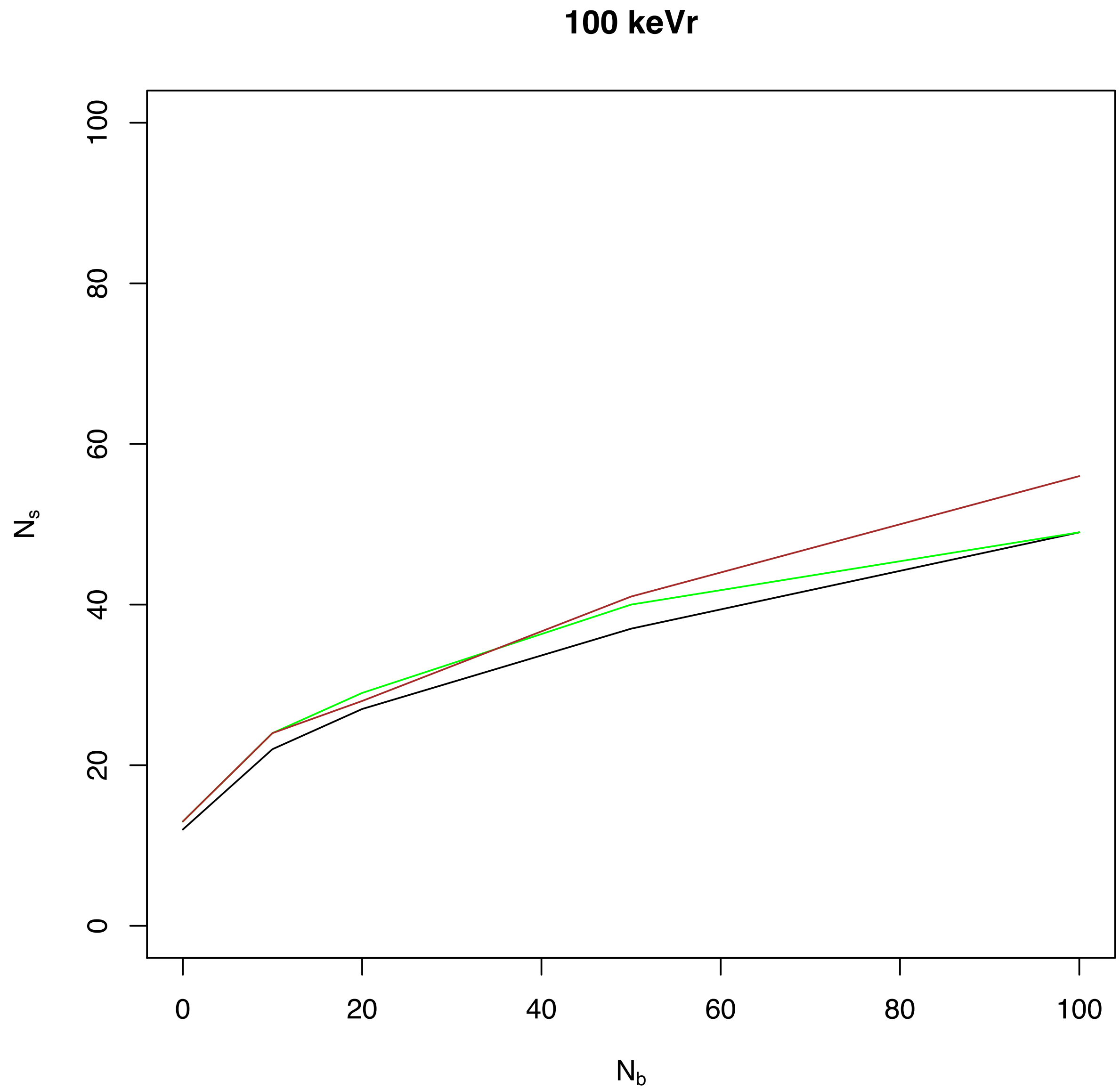
Directional Signal and Background



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Conclusion

- A Geant and Genie based model was implemented to predict event rates in the 2009 COUPP run in the NuMI beam
- Good agreement was obtained
- With the benchmarked model rates were predicted for the νBDX-DRIFT detector in the NuMI beam
- With a scintillator veto, backgrounds at several events per kg per year are possible
- An optimized veto could reduce cost and increase efficiency

The End