Noise Analysis in the Majorana Dark Matter Detector

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Princeton University

INT REU at the University of Washington, 2010

Outline

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1. Background
   - Dark Matter
   - Germanium Detectors
2. Noise Analysis
   - Overview
   - Find Optimal Filter
3. Results
   - $FWHM^2$ vs Peaking Time
   - Noise Components
   - Simulate Noise

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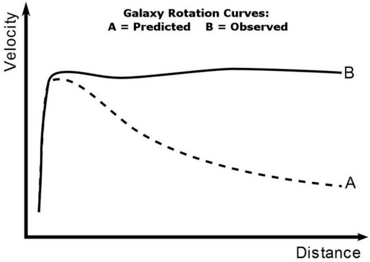
Dark Matter Evidence



- Galactic Rotation Curves
- Gravitational Lensing
- Matter distribution in early universe

Dark Matter Theories

Theories:

- WIMPS - Weakly Interacting Massive Particles
- Axions

How to make detections?

- Nuclear recoil
- Annual modulations from dark matter halo
- Possible DAMA/LIBRE results

Goals of Majorana

- Search for WIMPs in the 1-10 GeV/c^2 mass range
- Resolve energies of < 1KeV
- Achieve ultra low background

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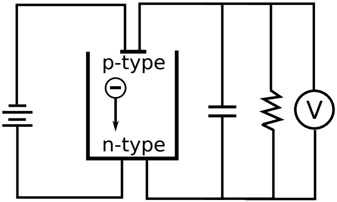
Germanium Detector

High Purity P-type Point Contact (PPC) ^{76}Ge detector:

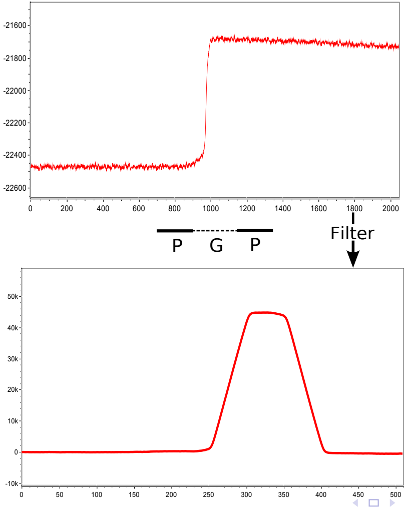
- Reverse biased semi-conductor
- Atomic interactions kick electrons into conduction band
- Charge collected on capacitor
- Signal varies linearly with incident energy
- Reduce leakage current by LN cooling



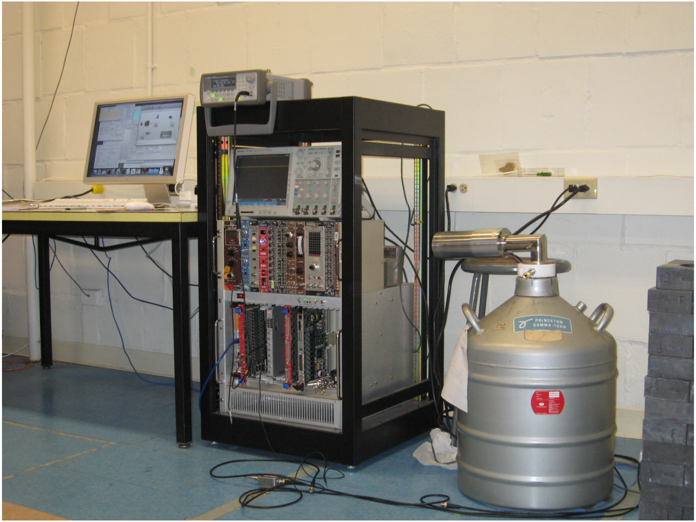
Simplified diagram of Ge detector

Signal Analysis

Measure pulse height (energy) with a trapezoidal filter



CoGeNT Detector in the Majorana Lab



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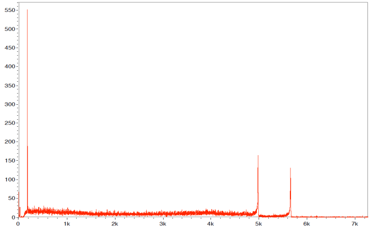
Objective 1

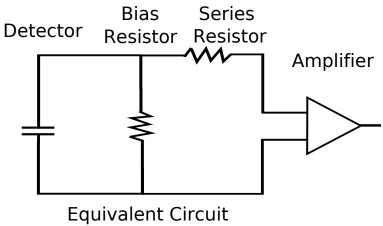
Find peaking time, P, that minimizes electronic noise



- Noise measured by FWHM of energy peak

Objective 2

Understand the components of the noise power spectrum



Three components:

- Parallel: $V(f)^2 = \frac{k_1}{1+k_2 f^2}$
- Series: $V(f)^2 = k_3$
- 1/f: $V(f)^2 = \frac{k_4}{f}$

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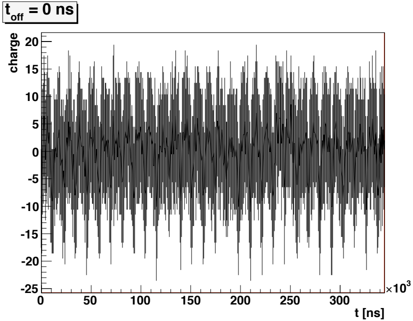
Procedure to Find Optimal Peaking Time

- Obtain raw noise pulses
- Take fourier transform to get power spectrum
- Apply trapezoidal filter to the power spectrum
  - Compute transfer function
- Integrate over spectrum to get RMS, FWHM
- Repeat for various peaking times



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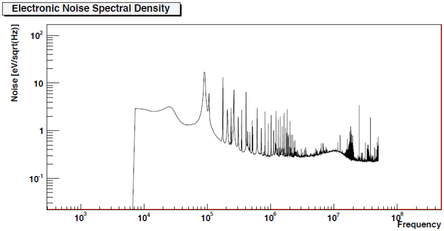

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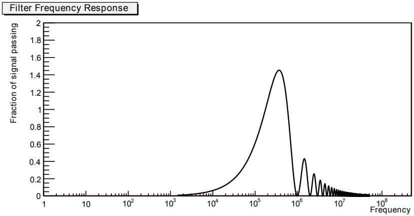
$$H(f) = \frac{2}{\pi f P} sin(\pi f P) sin(\pi f (P + G))$$



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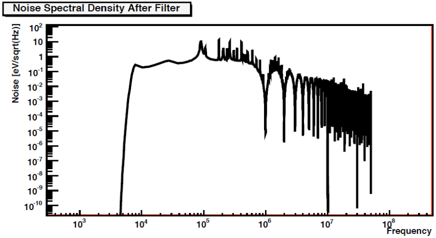

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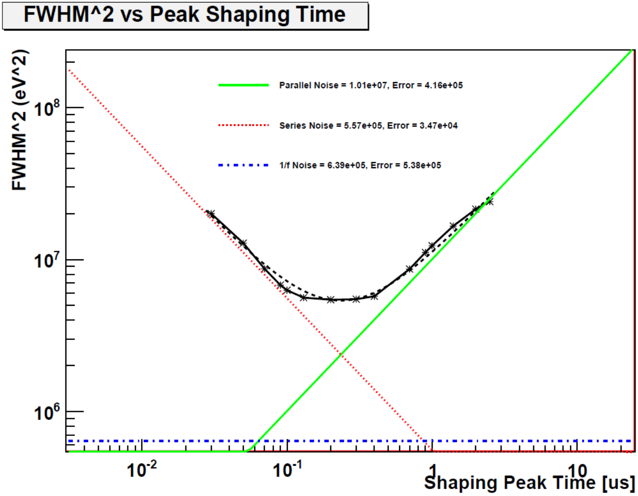
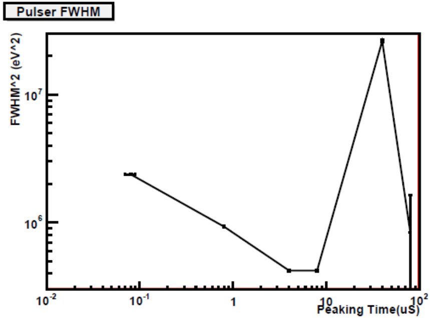
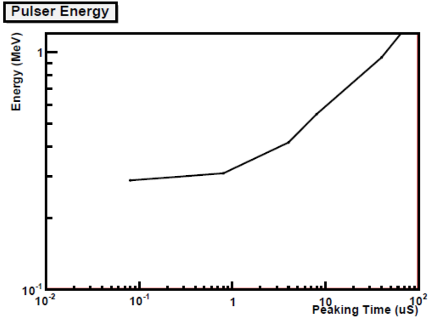
FWHM^2 Curve



$$FWHM^2 = aP + b/P + c$$

FWHM^2 Curve





- Tried to reproduce results by measuring the FWHM directly from an energy spectrum
- More work needs to be done

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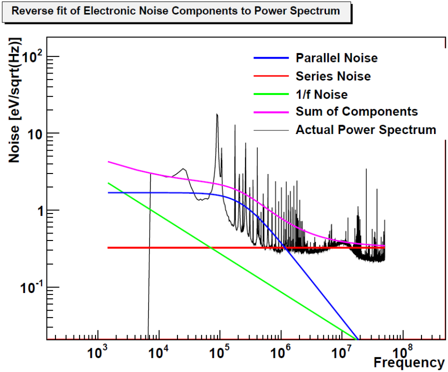
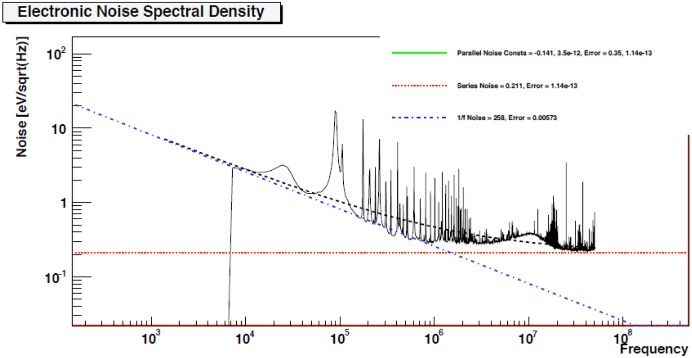
Components of Power Spectrum



Two problems:

- Fit to 1/f noise is highly variable.
- Parallel noise requires two constants. Fit to FWHM vs Peak Time only determines one.

Noise Components



Direct fit to power spectrum does no better.

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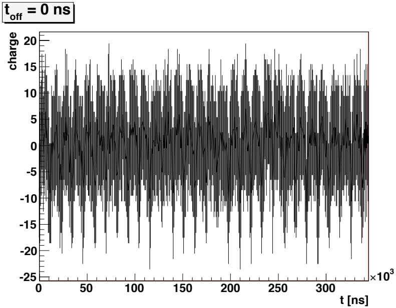
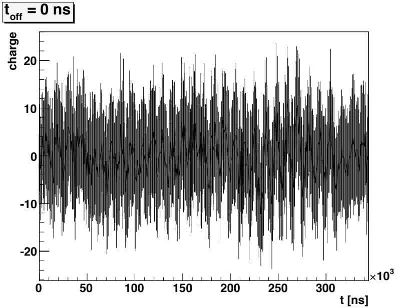
Simulated Noise



Actual noise



Simulated noise

Summary

- Optimal peak time can be determined from raw electronic noise.
- Parallel, series and 1/f noise components can be estimated with some work.
- Overall goal: Minimize noise to increase sensitivity to low energy DM interactions.

- Future Work
  - Calibrate of noise in eV
  - Collect accurate data on FWHM vs peak time directly
  - Understand features of power spectrum better

Acknowledgments:

- Mike Miller
- Mike Marino
- Jonathan Diaz Leon
- Tim Van Wechel
- Entire EWI group
- INT REU

Extra Slides

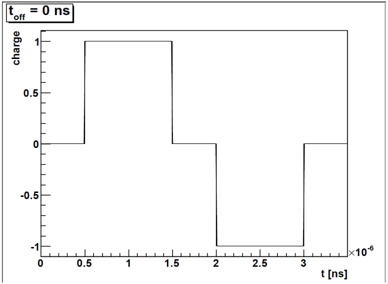
Impulse Function

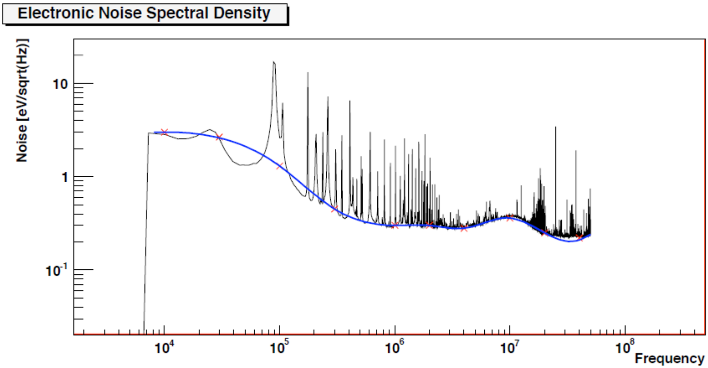
$$F(f(t)) = O(t)$$

$$f(t) \star I(t) = O(t)$$

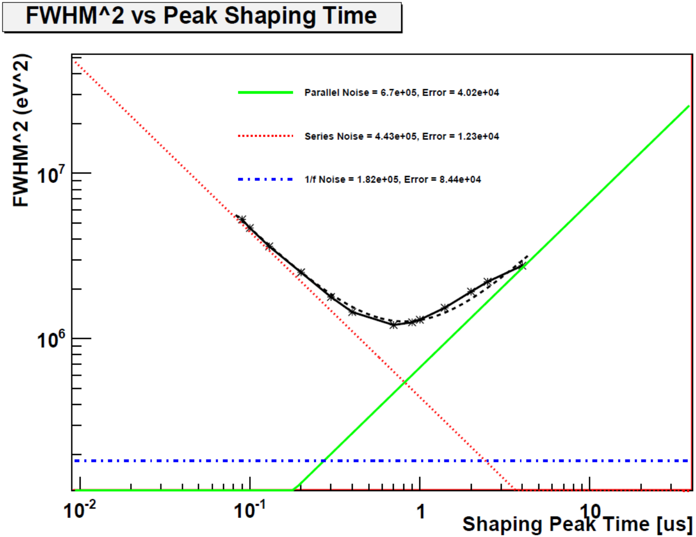
$$\hat{f}(t) \cdot \hat{I}(t) = \hat{O}(t)$$

$$H(f) = \frac{2}{\pi f P} sin(\pi f P) sin(\pi f (P + G))$$

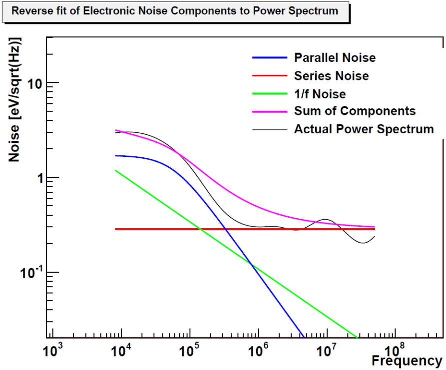



Electronic Noise Spectral Density
Noise [eV/sqrt(Hz)]
10
1
10^{-1}
10^4
10^5
10^6
10^7
10^8
Frequency

FWHM^2 Curve

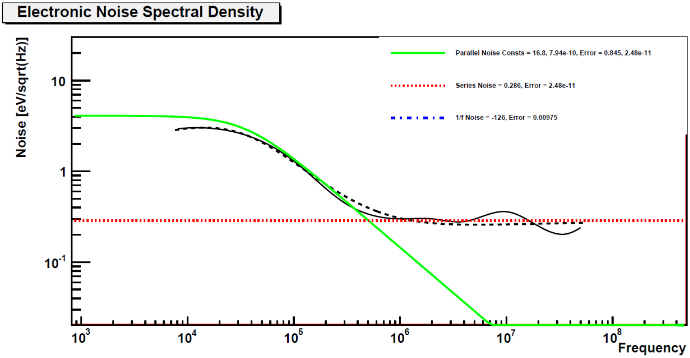

FWHM^2 vs Peak Shaping Time
Parallel Noise = 6.7e+05, Error = 4.02e+04
Series Noise = 4.43e+05, Error = 1.23e+04
1/f Noise = 1.82e+05, Error = 8.44e+04
FWHM^2 (eV^2)
10^7
10^6
10^-2
10^-1
1
10
Shaping Peak Time [us]

Components of Power Spectrum



Two problems still remain:

- Fit to 1/f noise is highly variable.
- Parallel noise requires two constants. Fit to FWHM vs Peak Time only determines one.



Possibly very little 1/f noise?

Independence of Real and Imaginary Fourier Components