Noise Analysis in the Majorana Dark Matter Detector

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Outline

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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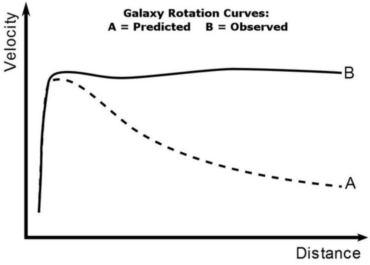
Dark Matter Evidence



- 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 Majoranna

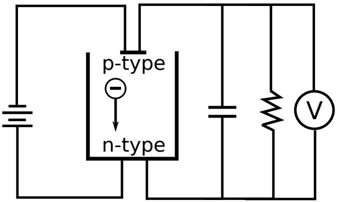
- Search for WIMPs in the 1-10 GeV/c^2 mass range
- Resolve energies of < 1KeV
- Achieve ultra low background

Outline

Germanium Detector

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

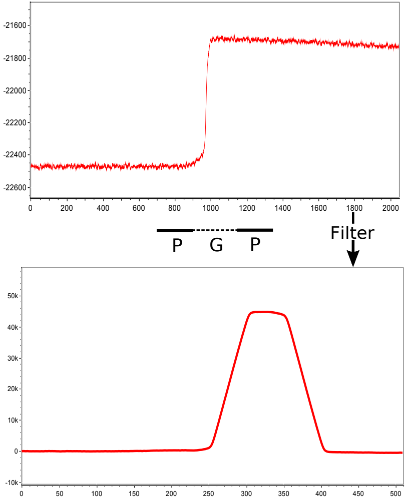
- Reverse biased semi-conductor
- Atomic interactions kick electrons into conduction band
- Charge collected on capacitor
- Signal varies linearly with incident energy
- Reduce leakage current by LN cooling



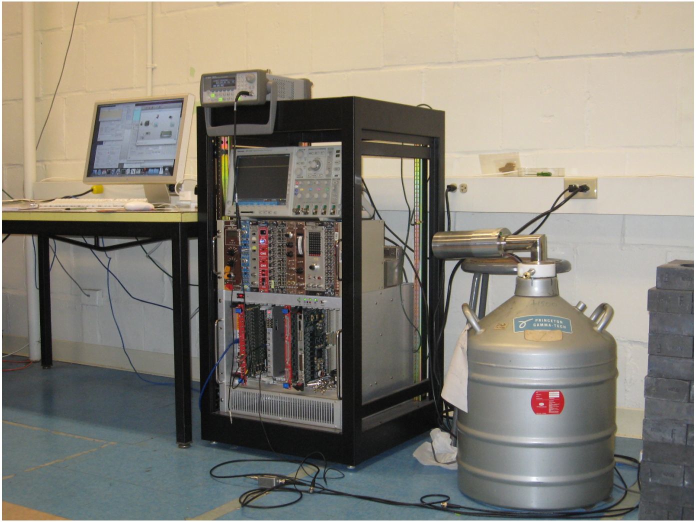
Simplified diagram of Ge detector

Signal Analysis

Measure pulse height (energy) with a trapezoidal filter



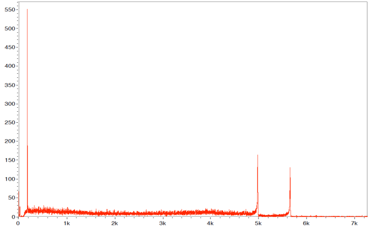
CoGeNT Detector in the Majorana Lab



Outline

Objective 1

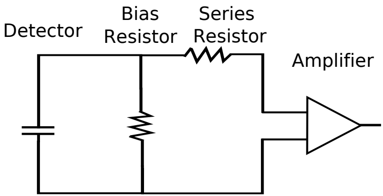
Find peaking time, P, that minimizes electronic noise



- Noise measured by FWHM of energy peak

Objective 2

Understand the components of the noise power spectrum



Equivalent Circuit

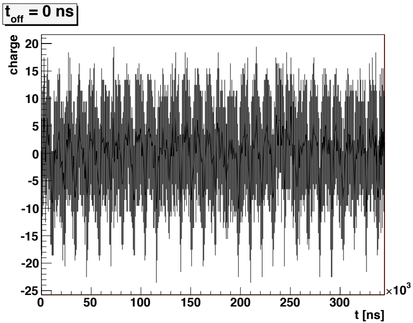
Three components:

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

Outline

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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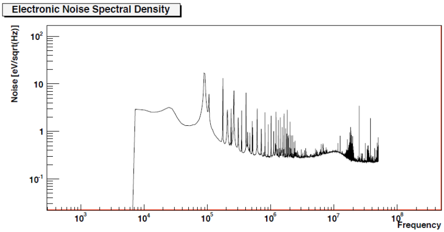

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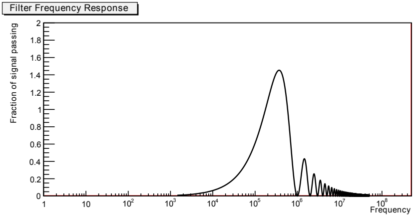
$$H(f) = \frac{2}{\pi f P} sin(\pi f P) sin(\pi f (P+G))$$



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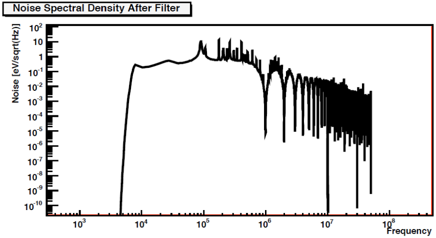

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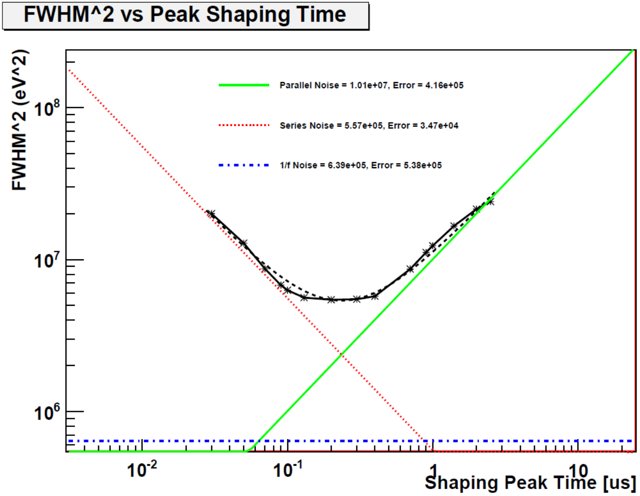
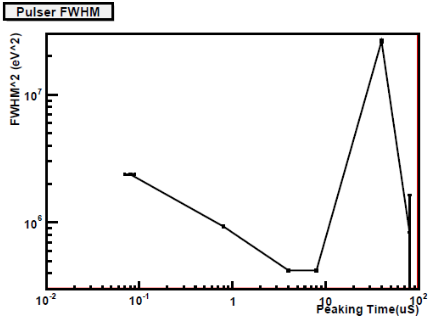
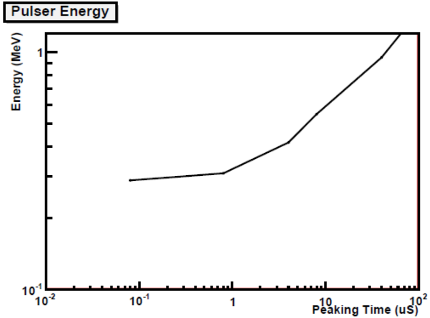
FWHM^2 Curve



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

FWHM^2 Curve

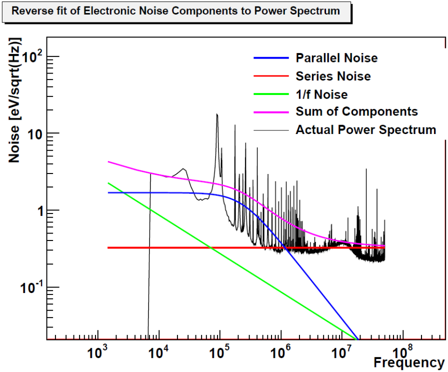




- Tried to reproduce results by measuring the FWHM directly from an energy spectrum
- More work needs to be done

Outline

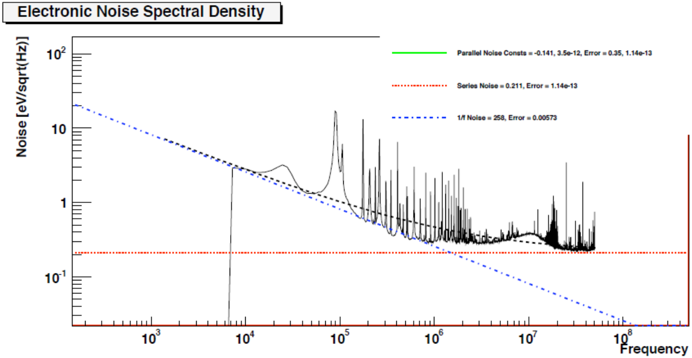
Components of Power Spectrum



Two problems:

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

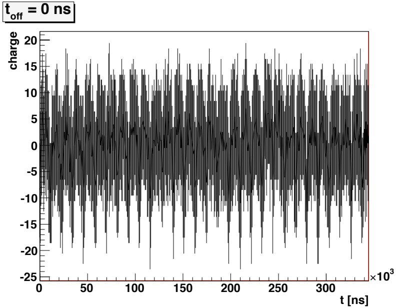
Noise Components



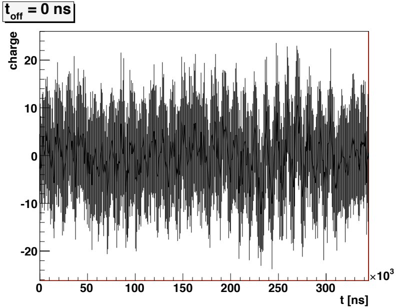
Direct fit to power spectrum does no better.

Outline

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

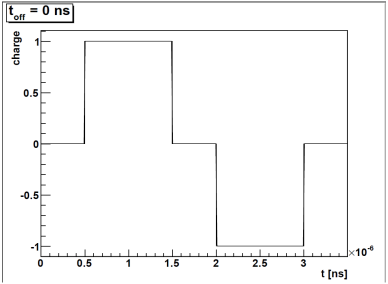
Acknowledgments:

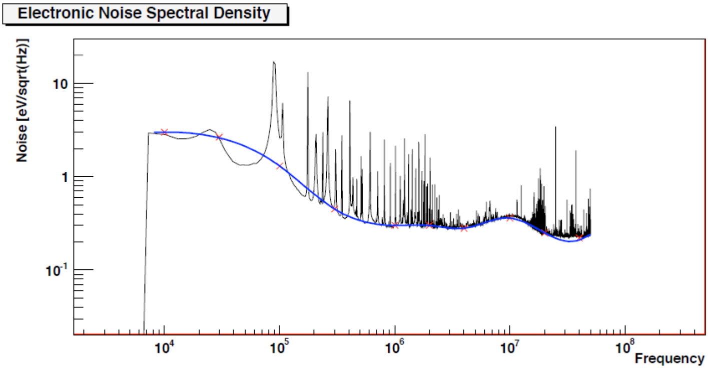
- Mike Miller
- Mike Marino
- Jonathan Diaz Leon
- Tim Van Wechel
- Entire EWI group
- INT REU

Extra Slides

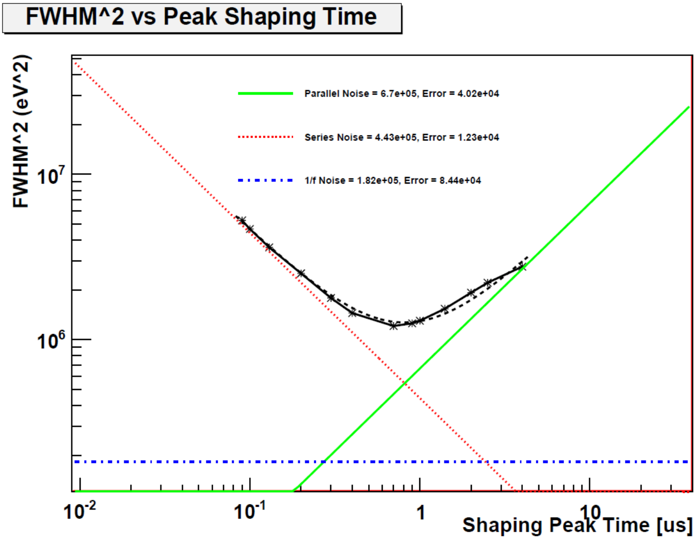
Impulse Function

$$F(f(t)) = O(t)$$
$$f(t) \star I(t) = O(t)$$
$$\hat{f}(t) \cdot \hat{I}(t) = \hat{O}(t)$$
$$H(f) = \frac{2}{\pi f P} sin(\pi f P) sin(\pi f (P + G))$$



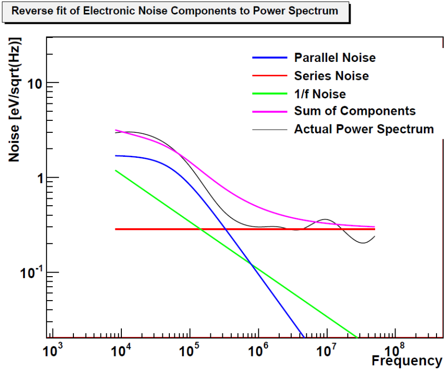

Electronic Noise Spectral Density
Noise [eV/sqrt(Hz)]
10
1
10^{-1}
10^4
10^5
10^6
10^7
10^8
Frequency

FWHM^2 Curve



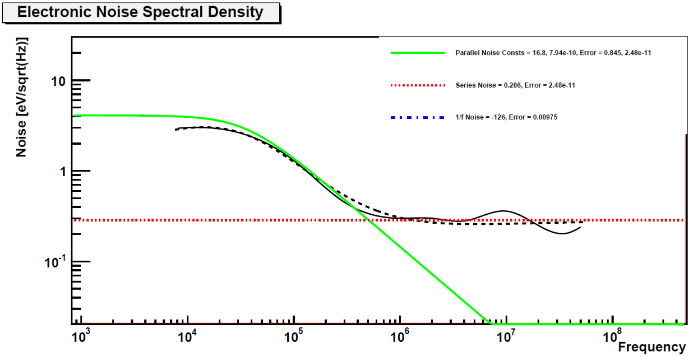
FWHM^2 vs Peak Shaping Time
Parallel Noise = 6.7e+05, Error = 4.02e+04
Series Noise = 4.43e+05, Error = 1.23e+04
1/f Noise = 1.82e+05, Error = 8.44e+04
FWHM^2 (eV^2)
10^7
10^6
10^-2
10^-1
1
10
Shaping Peak Time [us]

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