Characterization of a gamma shield for the K100 Cryostat, S.C.D.M.S.

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Motivation

Super Cryogenic Dark Matter Search collaboration

S34, Tate Labs is a Research and Development Laboratory supporting cold hardware and detector design assessment and quality control
Motivation

Larger volume detectors are more susceptible to the gamma background which require larger exposure time or a shield [1].

S34 Gamma Background, no people, 18 hours
We collect ejected electrons by applying an electric field across the detector, this is our ionization signal but a baryon interaction with the nucleus can also eject an outer shell electron through nuclear recoil. [2]
Theory

How do we absorb/minimize the gamma background? [3]

\[ I = I_0 e^{-n \sigma x} \]

N = Z density, \( \sigma \) = energy dependent cross section, x = distance traveled in the material
Gamma Shield Structure

Surrounds the Polyethylene Neutron Shield

Mounted on 2 cart system which can support up to 8000 pounds safely
Gamma Shield Structure

Current total weight: \(~6000\) pounds, including neutron shield and carts

Frame Structure and components are made of Al, the shield is composed of \(1/8\)” lead sheets cut to a variety of sizes
Gamma Shield Structure

- Outer top shield
- Bottom shield assembly
Gamma Shield Structure

Inner top shield
Cold hardware

K100 Cryostat Diagram[4]
Detector

Interlaced Z-sensitive Ionization Phonon Ge detectors [5]

Current design: r=50mm, h=30mm
Analysis

We apply a bias voltage which creates an electric field in order to collect our ionization signal.

We need to isolate Bulk events, i.e. Qi dominant

$R(Q_i) = 44\text{mm}$ and $R(Q_o) = 50\text{mm}$
Analysis

We need to select events in the main $X^2$ distribution

Large $X^2$ is characteristic of an event pile-up signature which happens if residual phonon energy is not dissipated before a new trigger [6] Rise time is 1µs and the attenuation time is 40µs
Analysis Goals

Create a charge spectrum for known source in order to verify the effectiveness of our algorithms ✓

Finalize and code an algorithm to define an efficiency parameter for the shield as a function of unit volume of the detector
Analysis Example

As a test of our algorithm, we analyzed Run 32 data with the shield installed.

Source was an internal Am-241 source mounted on side 2. Am-241 has a characteristic 60 keV energy line and we expect to see it in our charge spectrum.

60 keV has a penetrating depth of approximately 1 mm in the Ge detectors.

We expect to see the 60 keV spike on side 2 but not on side 1.

Total data set consists of a total 108342 events in 21 data series.
Analysis Example

In order to isolate Qi dominant events we define

$$Q_{\text{partition}} = \frac{Q_i - Q_0}{Q_i + Q_o}$$

thus for $0.9 < Q_{\text{partition}} < 1$ we will have Qi dominant events.

The $Q_i, Q_o$ values are scalars related to voltage changes and the energy deposited across each side.
\( Q_{\text{partition}} \) histograms for zip1 and zip2, top and bottom of detector
After first cut we are down to 43872 events

We can fit a second order polynomial to the $X^2$ distribution of $Q_{sum}$ which we can use as a first step towards our cut

$$Q_{sum} = Q_i + Q_o$$
Analysis Example

The fit lines are of the form

\[ y(x) = a + bx + cx^2 \] with \( \sigma a, \sigma b \) and \( \sigma c \).
Analysis Example

Now we can define an individual cut for each side of the form

\[ y(x) = a + (b + \beta \sigma b)x + (c + \tau \sigma c)x^2 \]

Because we are looking for a known signal we can define a best fit line. It will be important to keep the same \( \beta, \tau \) fit parameters for the same configuration with/without the shield in our final analysis.
Analysis Example

Final cut on $Q_{sum}$ vs $Q_{i-chi-square}$ for both distributions
Analysis Example

Final data set, 27162 points.
After implementing each cut we can create a charge spectrum after creating a 1d histogram of the $Q_{sum}$ distribution.
Analysis Example

Spectrum as observed by zip 1
Analysis Example

Spectrum as observed by zip 2
Energy spectrum as observed by source side
Analysis

So far so good

Further work is necessary in developing a likelihood of source event parameter as a function of detector unit volume.
We don’t control the refrigerator schedule but we can fit in 2 runs.

Once we have our first data set, we can finalize our algorithm to define an efficiency parameter for the shield as a function of unit volume of the detector.

Sources to be used: Ba-133, Am-241
Schedule

Typical Run Schedule:

- 2 days: warm-up and de-installation of tower structure

- 3 days: install new tower setup, install shield and get to 77k if no leaks are detected

- 1/2 days: get to 50mk, fingers crossed!

- 10/14 days: take data, try to stay at temperature

REPEAT
Conclusion

We aim to characterize the efficiency of a gamma shield for the K100 Cryostat in order to anticipate the quality of data using a 150mm crystal. Currently, we are effective with a 100mm crystal.

If the gamma shield is found to be ineffective, a new solution has to be found.

The S34, Tate Labs R&D Lab is a crucial component in the design of the upcoming SNOLab facility.

Moving from a 10kg detector at Soudan to 200kg detector at SNOLab

Soudan: 15 individual detectors

SNOLab: 200 individual detectors
References