Kr85 Measurements and Estimates for DarkSide-50

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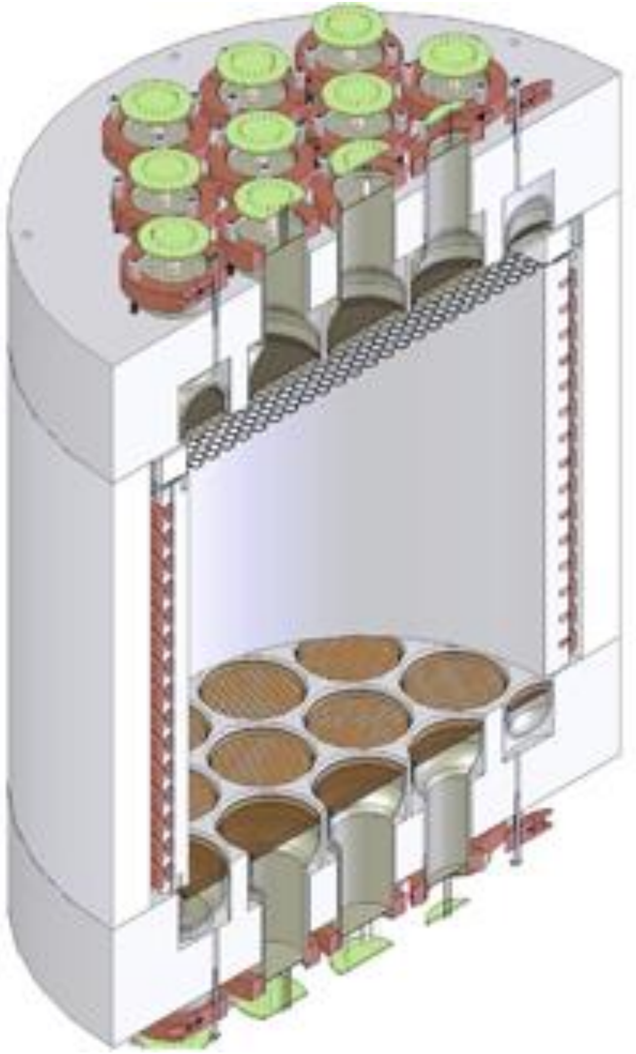
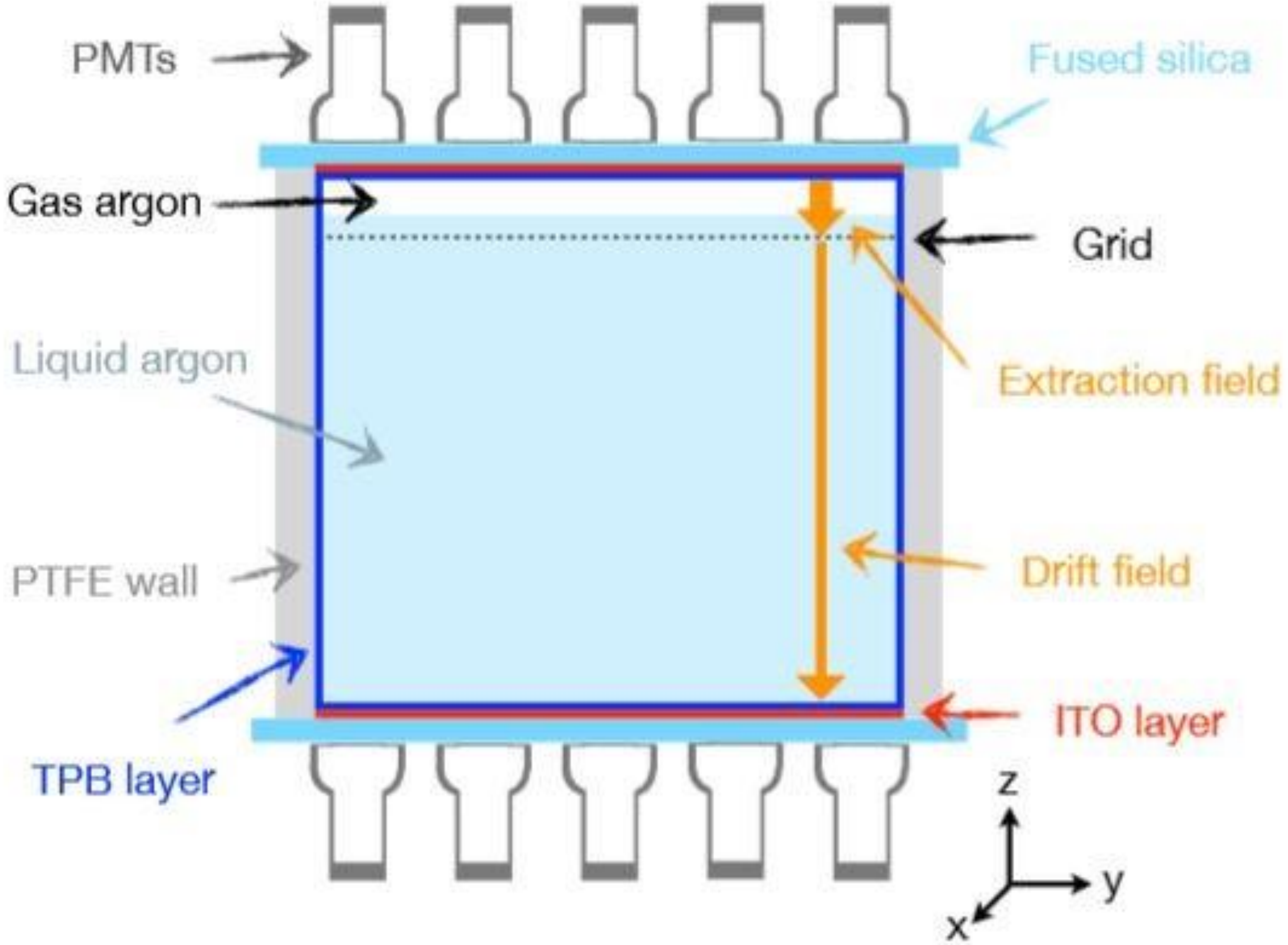
DMSS 2018

Goals

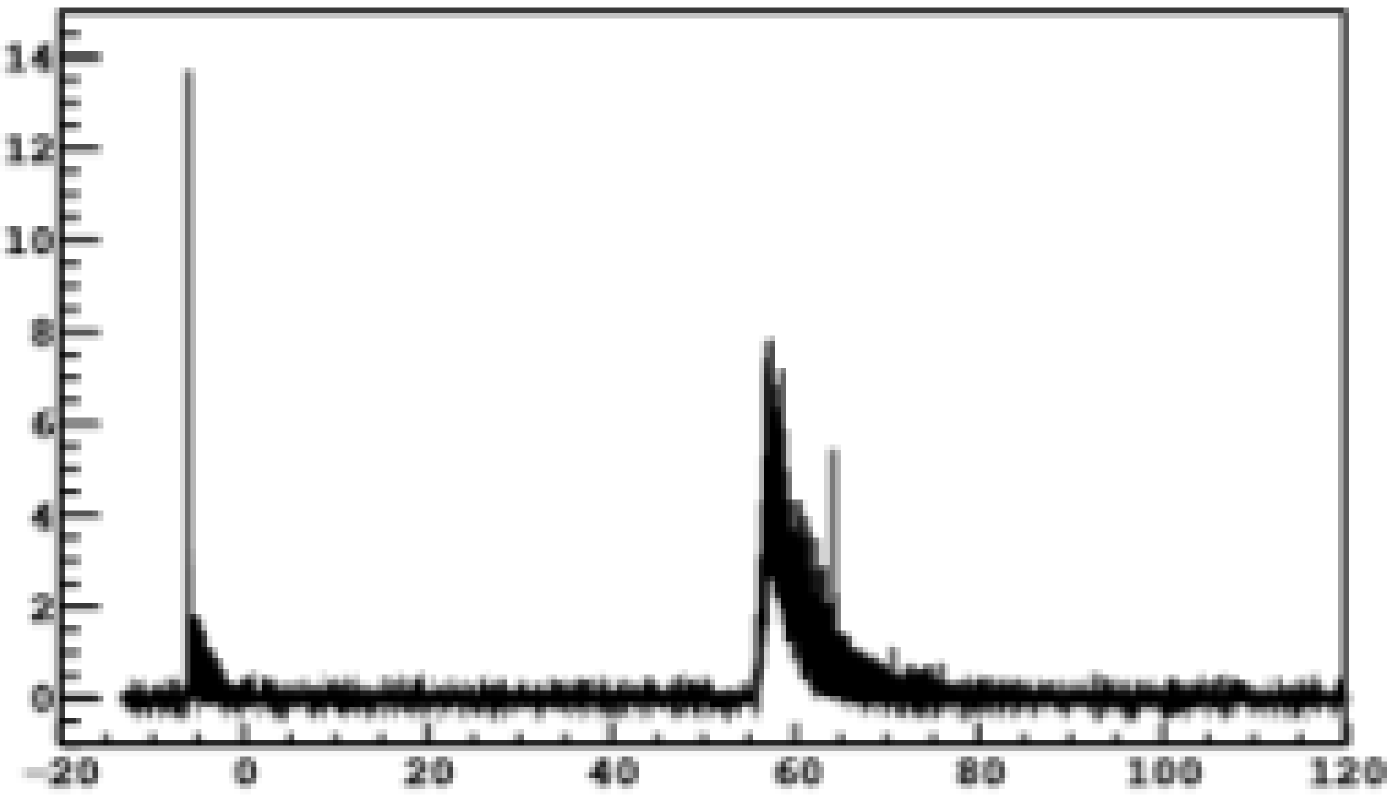
- Investigate the presence of Kr85 in our detector
- Replicate previous work on the 70d data to develop methods and familiarize with data structure
- Predict the number of events we should see over the 532d data
- Test predictions through measurements

DarkSide-50

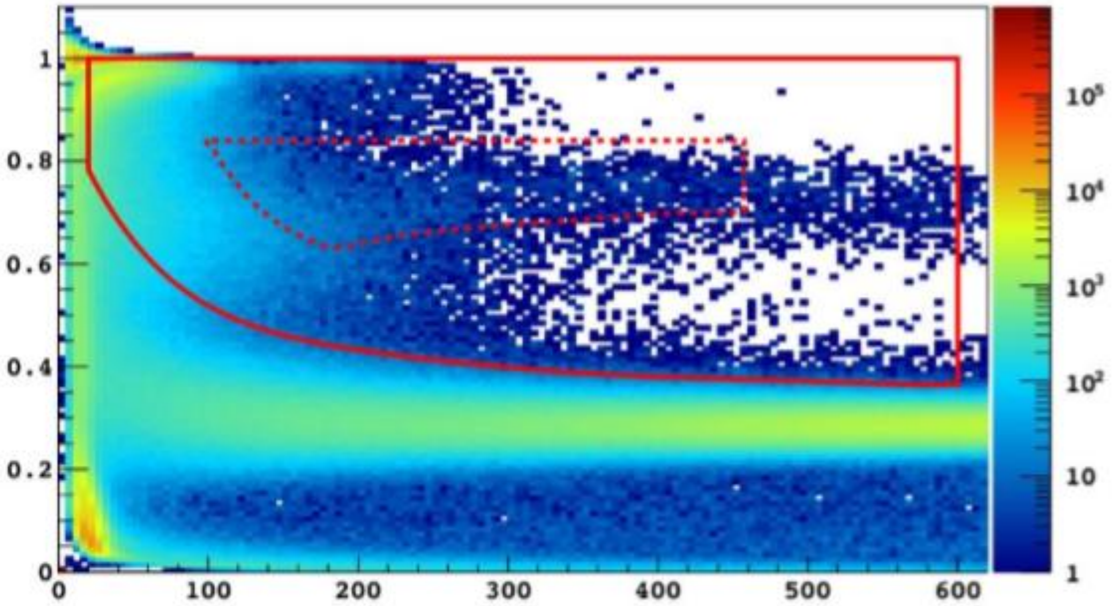


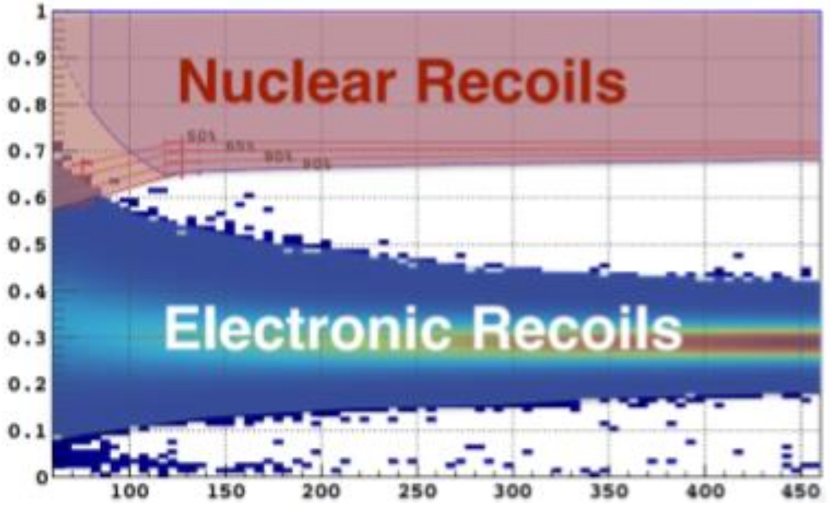

PMTs
Fused silica
Gas argon
Grid
Liquid argon
Extraction field
PTFE wall
Drift field
ITO layer
TPB layer
z
y
x

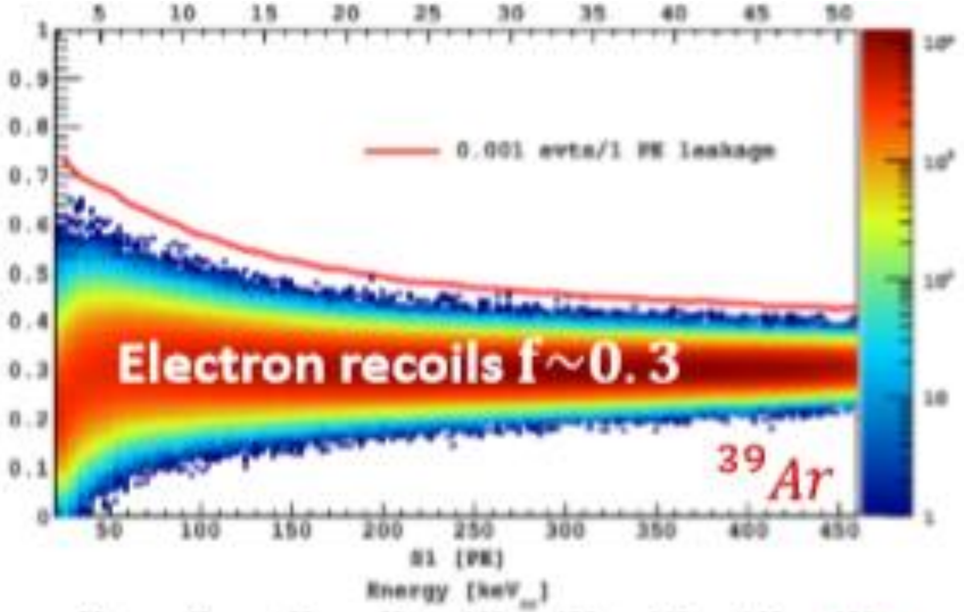
S1s and S2s

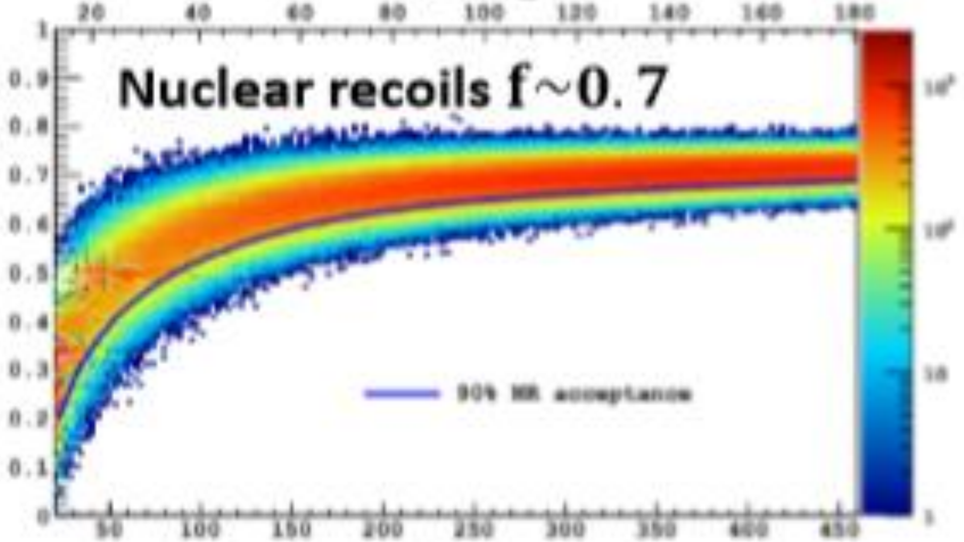


NR vs ER



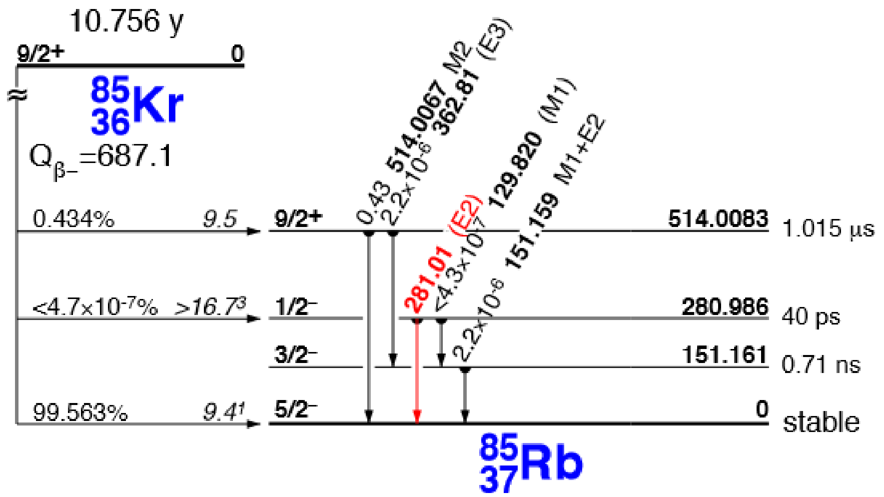

Nuclear Recoils
Electronic Recoils


0.001 evts/1 PE leakage
Electron recoils f~0.3
^{39}Ar
S1 [PE]


Nuclear recoils f~0.7
90% NR acceptance

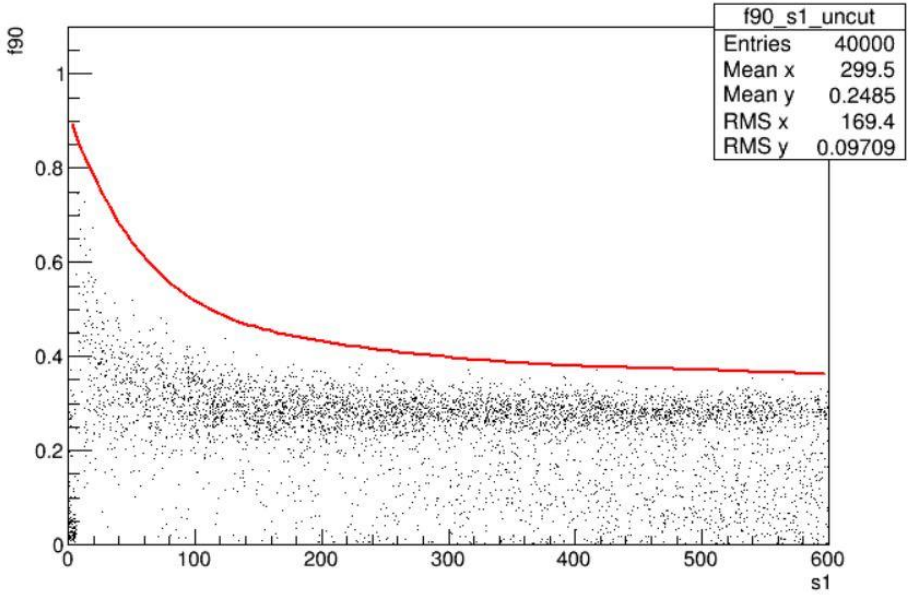
Kr85 Decay Scheme

- Kr85 mostly undergoes beta decay to stable rb85
- It can also decay to the metastable state rb85m, with a branching ratio of 0.43%
- Metastable rb85m has a half-life of 1.015 µs, and de-excites by emitting a γ-ray
- This produces a delayed coincidence signature, a pair of S1s



Monte Carlo Simulation

- A clean sample of 40k kr85 beta + gamma events were simulated using g4ds
- The blinding box was superimposed over a plot of f90 vs S1 for the events in order to check if we should expect to see any kr85 events in that region
  - f90 is the ratio of the integral of the first 90 ns to the integral of the first 7 μs of the S1 pulse, assumed to be the first pulse in an event
- No events were shown to be present within the blinded region
- Kr85 should NOT be a background for high-mass WIMPs (low-mass is another story)

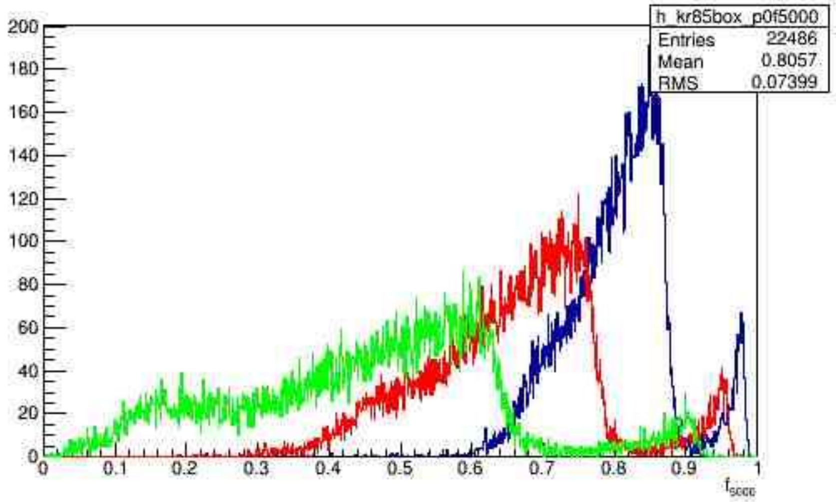


Solving the Recombination Issue

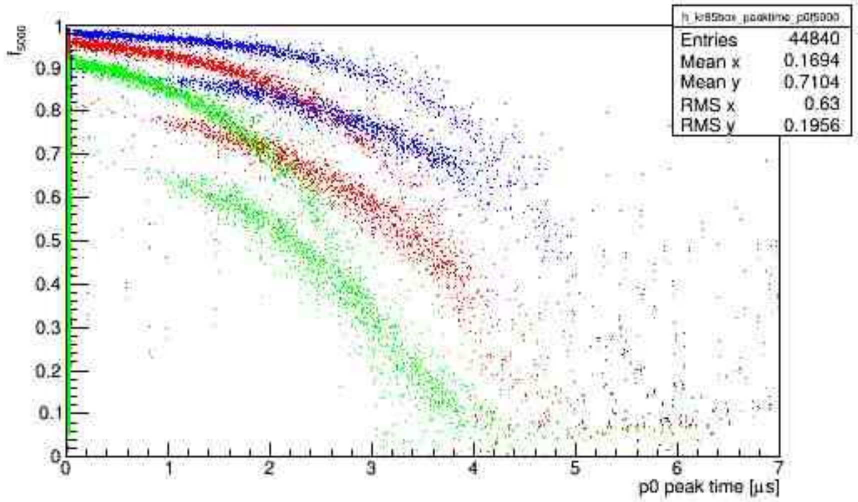
- The two S1s in the decay are often recombined as one pulse
- Define a new cut: f5000
  - Defined the integral of the first 5μs of the events divided by the integral of the first 7μs of the event
- The f5000 cut is discriminating between kr85 events, which have two S1s (beta + gamma), and other events that have an S1 immediately followed by an S2
- It is almost guaranteed that the beta and gamma from kr85 coincidence events will be within 5 μs of each other
  - Kr85 beta decays to rb85m, which decays by emitting a gamma ray with a half-life of 1.015 μs
  - This means that there is a 96.37% chance that the rb85m will decay within 5 μs of the beta decay
  - f5000 for those events will be very large
- Meanwhile, for S1+S2 events with a drift time between 0 and 5μs, an S2 pulse will have a long tail that extends beyond 5 μs, and so the value of f5000 will be much lower
- This results in two distinct populations of events, even when the S1s are reconstructed into one pulse, allowing us to isolate the kr85 events in the detector

f5000 in 70d Data

- In a previous analysis it was determined that the f5000 cut was the best integral-based cut to use to identify the kr85 candidate population
- Acceptance and rejection is based on the plots shown below
  - In the left plot, the second, smaller peak is the kr85 population
  - In the right plot, the upper band is the kr85 population
  - The cut was mostly set using the right plot; an f5000 value was chosen that was as low as possible to catch as much of top band as possible without dipping into the lower band. Anything in the left plot above that value is considered as belonging to the kr85 peak
- I analyzed all of the possible integral-based cuts on the 70d data (f1000, f2000, f3000, f4000, f5000, and f6000) and determined that the f5000 cut was indeed the best one to use based on number of kr85 events accepted and other events discriminated

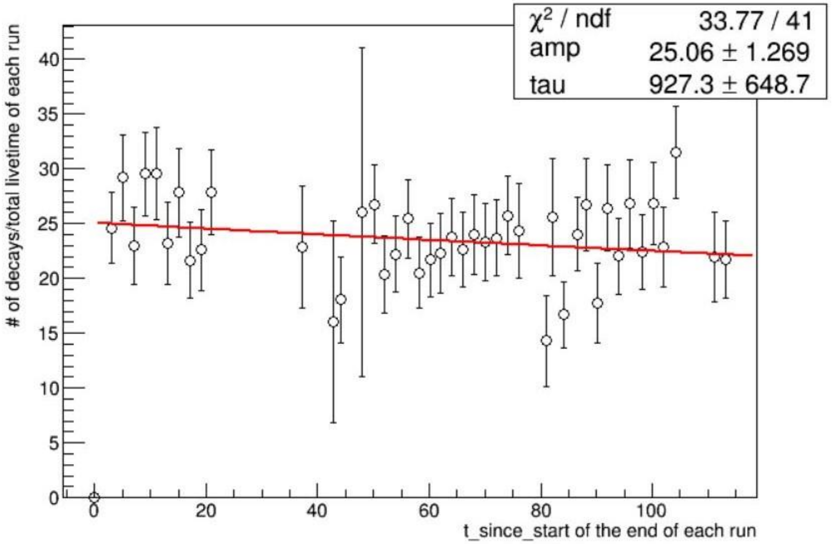


- f3000
- f4000
- f5000



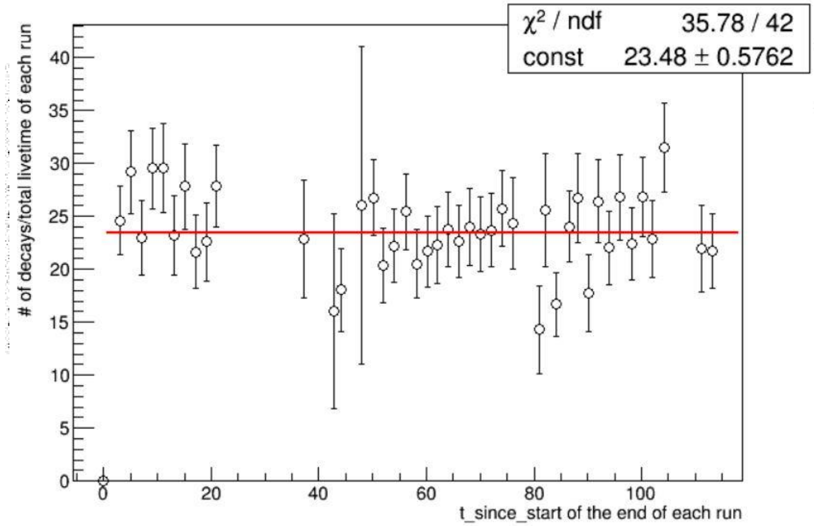
Decay Rate Measurement and Estimation

- Previous measurements found a global detection efficiency of 75.9% in the detector, and so all the rates found must be adjusted because of this
- This analysis also conducted a spectral fit that gave a decay rate of (35.3 ± 2.2) decays per day – this results in (26.8 ± 1.7) detections per day
- Dividing the number of events detected in the 70d data by the number of days gave a decay rate of (31.9 ± 0.8) decays per day, or (24.2 ± 0.6) detections per day
- I plotted the number of decays as a function of real time and fit it with a flat line, giving me a decay rate of (30.9 ± 0.8) decays per day, or (23.5 ± 0.6) detections per day, which agrees with previous analysis
- A flat line fit can be used here because the length of time being looked at is much shorter than the accepted tau for kr85, and so the decay rate is essentially constant
- I also fit an exponential to the data, giving a value for tau of (927±649)d, which is much faster than the accepted value of 5655d



← Exponential fit

Flat fit →

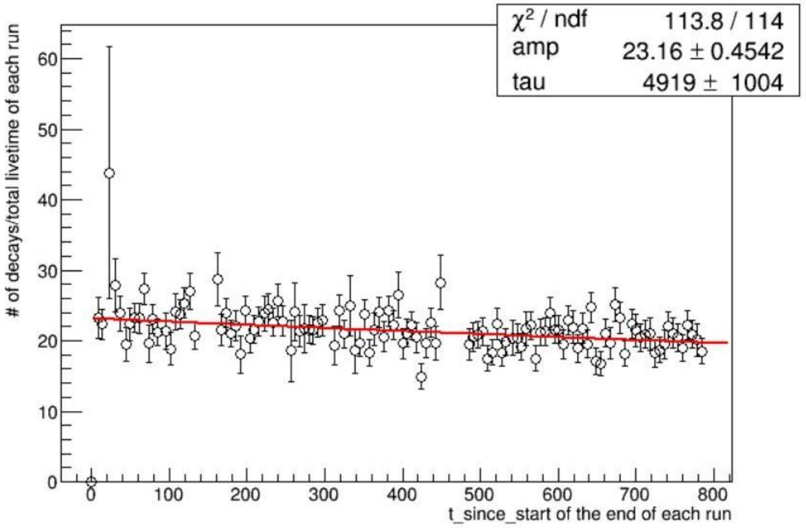


Predicting the Events in the 500d Dataset

- For the predictions, I know that the 532d data starts immediately following the 70d data, has a real time of ~800d, and neglect any calibration campaigns
- I also use the known value of tau, 5655d (15.5 yrs)
- From the flat fit of the 70d data, we know that the average decay rate over the 70d was (23.5 ± 0.6) detected decays per day
- Using the equation $\frac{dN}{dt} = -\lambda * N_0 \ * \ e^{-\lambda t}$, we can find N_0 using the values from the 70d, and then plug this in to find $\frac{dN}{dt}$ for the 532d
- This results in a decay rate of (29.8 ± 0.8) decays per day, or (22.6 ± 0.6) detections per day

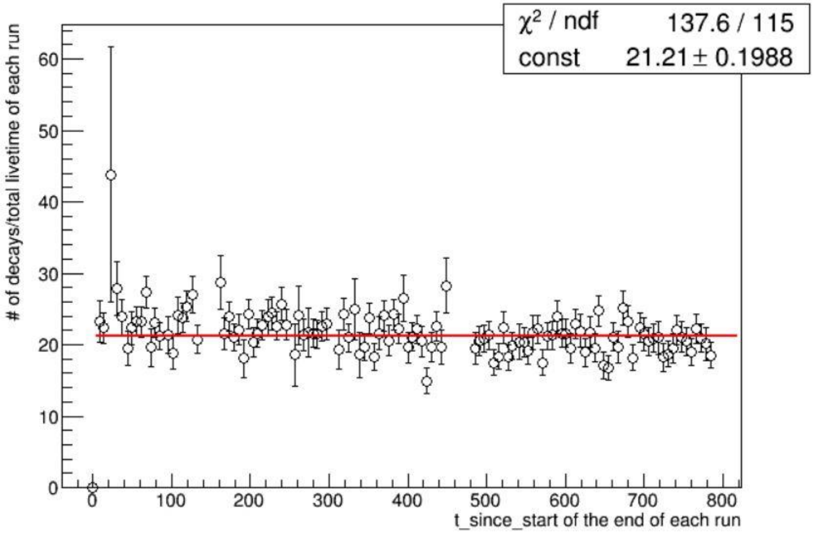
Results

- Kr85 has an accepted value for tau of 5655d
- In the 532d data, 11699 events were observed, giving an average decay rate of (21.21 ± 0.2) detected decays per day from the linear fit, which agrees with the number estimated
- I also applied an exponential fit to the data, which gave a value for tau of τ = (4919 ± 1004)d



← Exponential fit

Flat fit →



Conclusions

- Based on Monte Carlo simulations, we do not expect to find any kr85 events within the blinding box for the 532d data
- The decay constant given by the exponential fit results in a τ that agrees within uncertainties with the known value of τ for kr85
    - Kr85 has $\tau \approx 5655$d – the exponential fit gives $\tau = (4919 \pm 1004)$d
- Precise measurements of kr85 levels in the DarkSide-50 detector were made, increasing our knowledge of backgrounds for low-mass WIMPs and of the sensitivity of the detector

Backup Slides

How kr85 Events are Selected

- Quality cuts
  - All channels found
  - Baseline found
  - Livetime longer than 400 ms

- Timing cuts
  - S1 start time
  - Event peak time

How kr85 Events are Selected

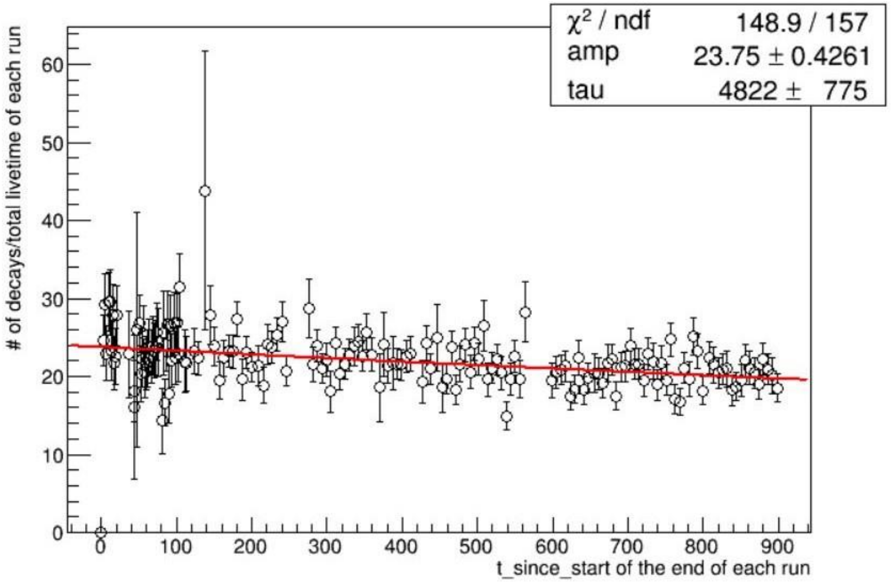
- Pulse shape cuts
  - At least 2 pulses in event
  - 1 pulse or 2 pulse
  - f5000
  - Check kr85box, the region we look for ^{85}Kr events in (cuts on S1 max energy)
  - Check for not an S2 (cuts on S1 max fraction & top-bottom asymmetry)

Predicting the Events in the 500d Dataset (Alternate)

- For the predictions, I know that the 532d data starts immediately following the 70d data, has a livetime of 455d, and I neglect any calibration campaigns
- I also use the known value of tau, 5655d (15.5 yrs)
- I used the numbers from the 70d data to predict the number of decays in the 532d data, resulting in a total of (13582 $\pm$ 4358) kr85 -> rb85m decays in the 532d data
- We expect the detection efficiency of 75.9% found to be constant across data sets considered, since it is dependent on characteristics of the detector that are unchanged over time
- Accounting for this, there should be (10308 ± 3308) decays detected over 532d
- This results in a decay rate of (22.6 ± 7.3) detected decays per day

Combined Data

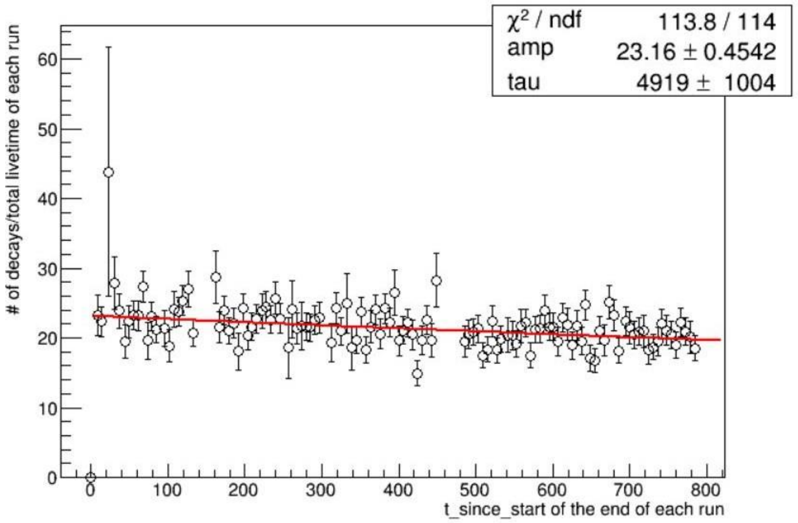
- Combining both the 70d and 532d data and applying an exponential fit gives τ = (4822 ± 775) days
  - This is still fast, but is slightly improved over just the 532d data
  - The combined length of the datasets, around 925 days, is still far below the known value for tau for kr85, and so is not expected to be consistent



Fixing Tau

- I applied an exponential fit to each of the data sets with tau fixed to the expected value
  - For each of the datasets, the Chi-Squared value varies by a small amount, but not significantly
    - For 70d, Chi2/ndf goes from 0.824 (tau not fixed) to 0.838 (tau fixed)
    - For 500d, Chi2/ndf goes from 0.998 (tau not fixed) to 0.993 (tau fixed)
    - In the combined data, Chi2/ndf goes from 0.948 (tau not fixed) to 0.947 (tau fixed)
  - Since the fit is not much improved or worsened by forcing tau to be the known value, all of the data can be said to follow the correct distribution

500d (tau not fixed)



500d (tau fixed)