

SuperCDMS - Low Threshold Limits with Run 133 data

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Replicating R133-LT cuts (efficiency)

1. Obtain cdmstools directory -
http://mitchcomp.physics.tamu.edu/cdms/advanced/cdmstools_guide.php
2. Configure FCCS tree in matlab
3. Load R133-Cf data
4. Apply cuts on next slide to find “prebdt” cuts
5. Apply BDT cuts
6. Efficiency = (# events passing BDT cuts and preBDT cuts) / (# events passing preBDT cuts)
7. Multiply efficiency by trigger/analysis efficiencies with combined_threshold_eff.m
8. Calculate WIMP phonon spectrum from recoil energy spectrum.
9. Convolve spectrum with efficiency = Spectrum Averaged Efficiency (SAE)
10. Divide by SAE(efficiency =1) to get Spectrum Averaged Exposure (SAEx)

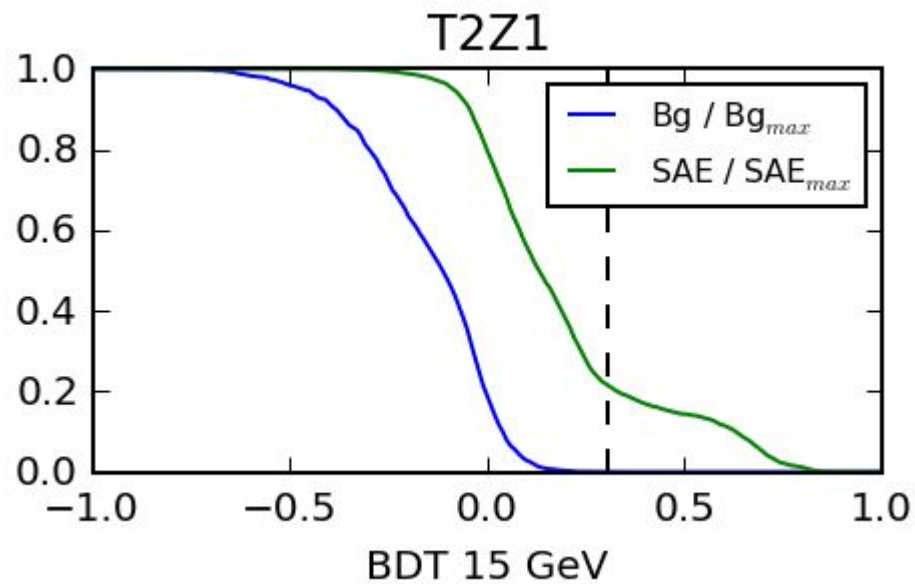
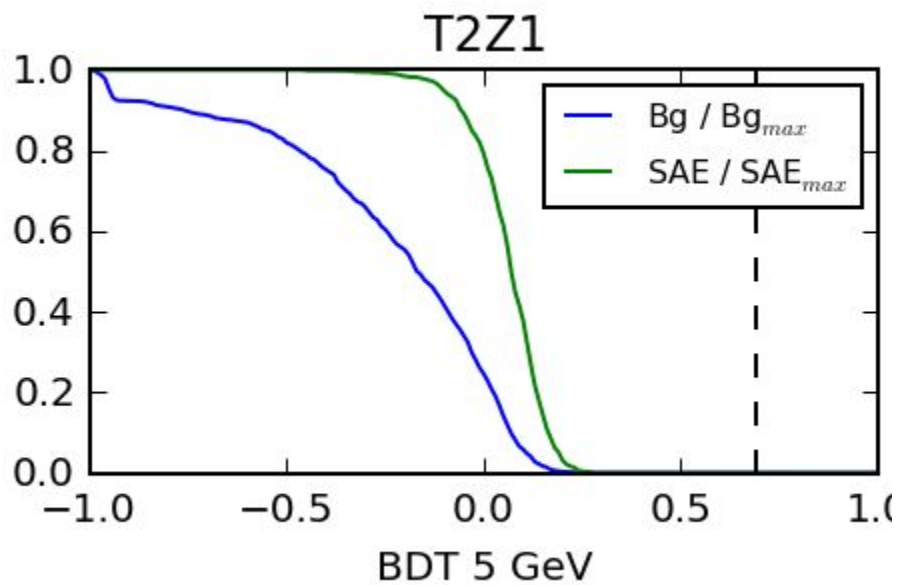
Cuts

- ~cRandom_133
- cBiasPM_133(detnum)
- cTriggeredEvent_133_LT
- cStableTrigThresh_133_LT
- ~cSquarePulse_v53
- ~cTrigBurst_133
- ~cNuMI_133
- ~cRTrig_Soudan
- ~cPsat_133
- ~cQsat_133
- cGoodEv_v53;
- cQin1_v53_LT
- cQin2_v53_LT
- cQisym_v53_LT
- cNR_qimean_3sig_v53_LT
- SeriesNumber(detnum, 0) < 1.130601e10
- **SeriesNumber(1115, 0) < 1.1212121650e10** (this is for distinguishing the before and after short time periods)

Replicating R133-LT Data (background)

1. Obtain background monte carlo data.
2. Sum the weights for each event (be careful with the shorted detector - the two time periods are labelled 1116 and 1117).
3. Scale the weights with these scale factors for each detector:
 - a. [1.98068, 1.99015, 1.9122, 1.93953, 1.97736, 2.00543, 1.98764, 2.02094]
 - b. Not entirely sure what these are, I got these from Kristi's code, I believe that these are the reciprocal fractions of events which went to test/training data.
4. Sum the weights due to events with $BDT < \text{threshold}$. (Advised to sort by BDT and use `np.cumsum`).

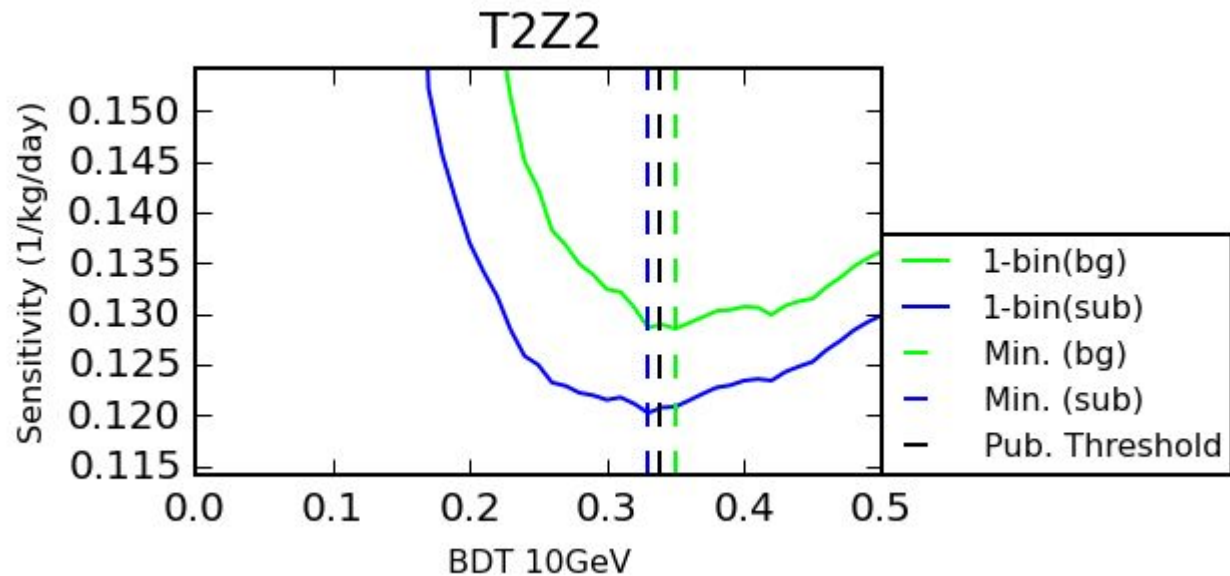
Representative Detector



Replicating R133 - Expected Limits

1. Using Poisson distribution for background, sample background realizations.
2. What was done in 2013: Sum all background expectation values. Sum all SAE. Treat the experiment as one large detector.
3. For each realization, compute a 90% upper limit on number of signal and divide by SAE to find cross section, or SAEx to find “sensitivity parameter”
 - a. In all cases, the number of events is sampled from background pdf. If doing **background subtraction**(not done in published result), the limit knows about this expectation and subtracts it off (actual math is slightly more complicated than subtraction).
 - b. CDMS uses Bayesian limits, which are asymptotically identical to Frequentist limits in counting experiments except for low event numbers. Bayesian limits asymptote to ~ 2.3 while Frequentist limits can go negative, leading to interpretational problems.
4. Several ways to get “expected” limit from these realizations. Either average them (sometimes called Toy MC) or just take the most likely realization, at the # realized events = # expected background events.

Sensitivities



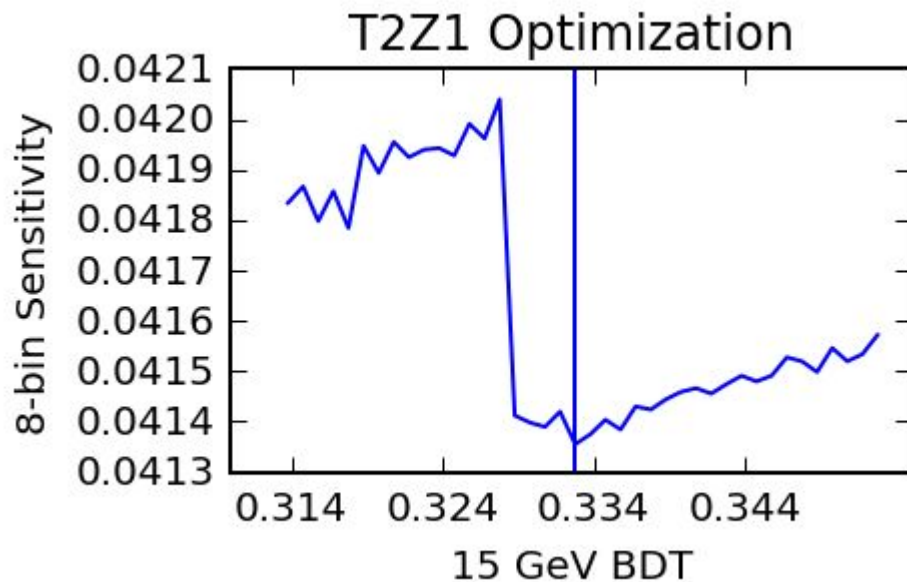
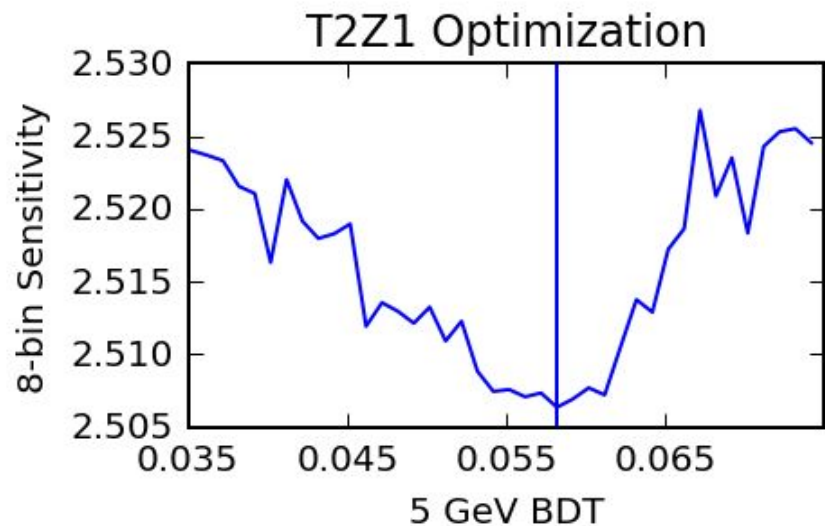
My analysis: Markov-Chain Monte Carlo “8-bin”

- Idea: don't pool background and efficiencies. Sample event numbers independently.
- To extract expected limit I constructed a model with the WIMP-nucleon cross section as a parameter.
- Using MCMC, the space of possible cross sections was sampled, and the 90% percentile value was selected as the upper limit.
- Automatically performs background subtraction.
- Can parallelize the background distribution to find average limit, or simply evaluate the upper limit at fractional event values using the Gamma function (analytic continuation) to obtain the expected limit.

BDT Threshold Optimization

- In the single bin case, I showed that the published BDT thresholds do minimize the expected upper limit, relatively insensitive to the BDT thresholds chosen (at the scale of 0.01-0.05).
- In the 8-bin case, using the Brazos cluster I parallelized the work of finding the minimum.
 - Each step, 7 of 8 thresholds were kept fixed and one was varied in the vicinity of its current value. Expected limits were calculated at each value.
 - This was repeated for each threshold value.
 - The thresholds were moved in the direction of their minima.
 - Above process was repeated until it converged on a solution.
- These “reoptimized” thresholds with the new method gave an additional

Representative detector



BDT Thresholds

Detector	<i>SAEx</i> (PRL) 1/kg/days	<i>SAEx</i> (optimized) 1/kg/days	Background (PRL)	Background (optimized)	PRL BDT threshold	Optimized BDT threshold
T1Z1	1.662	2.397	0.012	0.065	0.268	0.194
T2Z1	3.611	3.658	0.112	0.150	0.240	0.239
T2Z2	6.802	8.558	0.148	0.331	0.339	0.277
T4Z2	3.312	3.391	0.031	0.031	0.303	0.288
T4Z3	4.273	6.216	0.046	0.254	0.279	0.222
T5Z2	4.523	4.919	0.142	0.157	0.294	0.281
T5Z3-BS	0.398	0.718	0.002	0.030	0.328	0.242
T5Z3-AS	1.205	3.208	0.000	0.244	0.368	0.227

Table 3.3: The analysis parameters before and after 8-bin optimization for a WIMP mass of $10 \text{ GeV}/c^2$. The “PRL” thresholds are those used in the 2014 PRL result and the optimized thresholds are those chosen by gradient descent on the 8-channel Markov-Chain Monte Carlo (MCMC) method. Note that the *SAEx* is evaluated in units of $\sigma = 10^{-42} \text{ cm}^2$. Also note that in all cases the same or more background events are allowed as the BDT threshold is lowered. Allowing more background allows more signal acceptance, and this analysis indicates that this increases acceptance outweighs the increase in expected background events.

Expected Limits

M_{WIMP} (GeV/c ²)	$\langle \xi^{90} \rangle$ (bg unsubtracted) (PRL BDT thresholds) (1/kg/days)	$\langle \xi^{90} \rangle$ (bg subtracted) (PRL BDT thresholds) (1/kg/days)	$\langle \xi^{90} \rangle_{8\text{-bin}}$ (PRL BDT thresholds) (1/kg/days)	$\langle \xi^{90} \rangle_{8\text{-bin}}$ (Reopti- mized BDT thresh- olds) (1/kg/days)
5	5.692	3.484	3.453	2.191
7	.824	.578	0.569	0.427
10	.121	.111	0.110	0.103
15	.045	.044	0.044	0.041

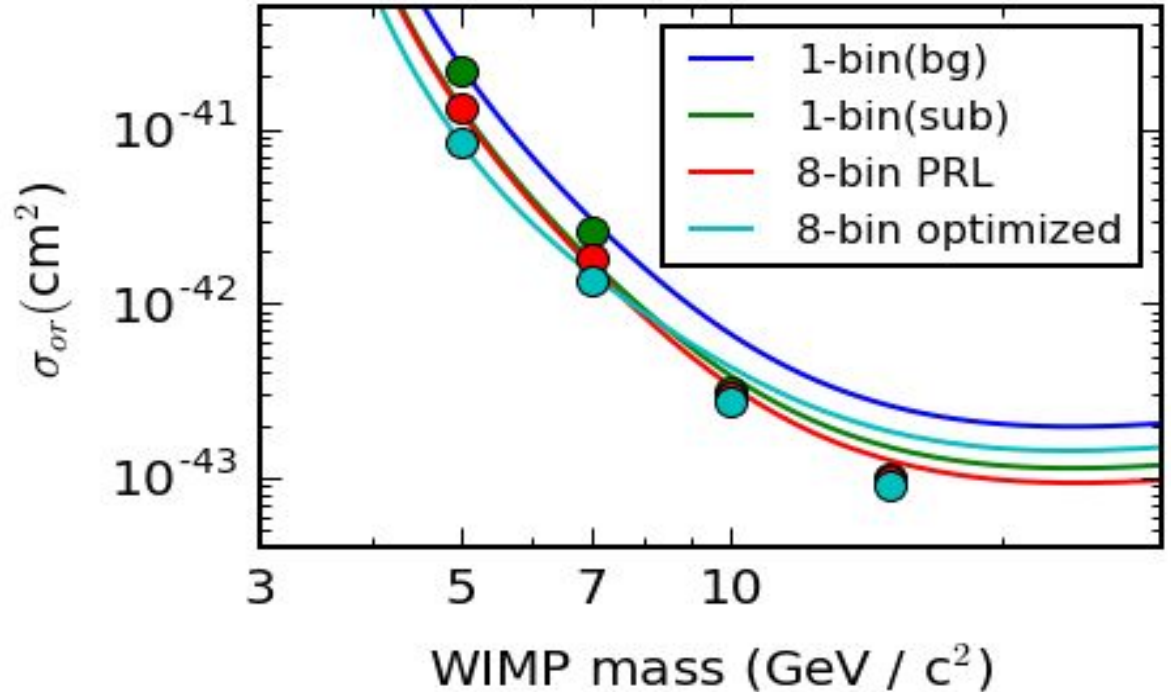
Table 3.2: The 8-bin expected sensitivity parameters $\langle \xi^{90} \rangle$ before and after reoptimization.

The logical or of masses

- The idea back when I was doing this was that there was going to be a global event list, i.e. a definitive number of candidate events that didn't depend on WIMP mass.
- As a result, the BDT cuts, which were optimized at four **specific** masses, had to be combined.
- This was done by taking the logical .OR. in other words, if an event passed **any** cut, it was counted.
- The above procedures have to be amended in order to accommodate for this. The code for the background expectation changed considerably.
- I could not find a good way to optimize for the .OR., so I just reported using the individually (mass, not detector) optimized thresholds.

.OR. result

The dots were calculated at the individual masses, whereas the lines used the .OR. cuts. The mass dependence in the .OR. appears only in the spectrum calculation, and nowhere else.



Summary

- A lot of the confusion in the documentation has been ironed out.
- The actual limit setting procedure is different than the optimization method, which is fine.
- The 8-bin limit setting gains SCDMS some sensitivity, and is one motivation a thorough understanding of background sources.
- Other procedures take into account detector differences in a slightly different way. The information is still accounted for in optimal interval, I believe.