Searches for low-mass WIMPs using the CDMS II Ge detectors

Robert Nelson *
Caltech
For the CDMS II collaboration

* affiliated with The Aerospace Corporation

TAUP 2013

Outline

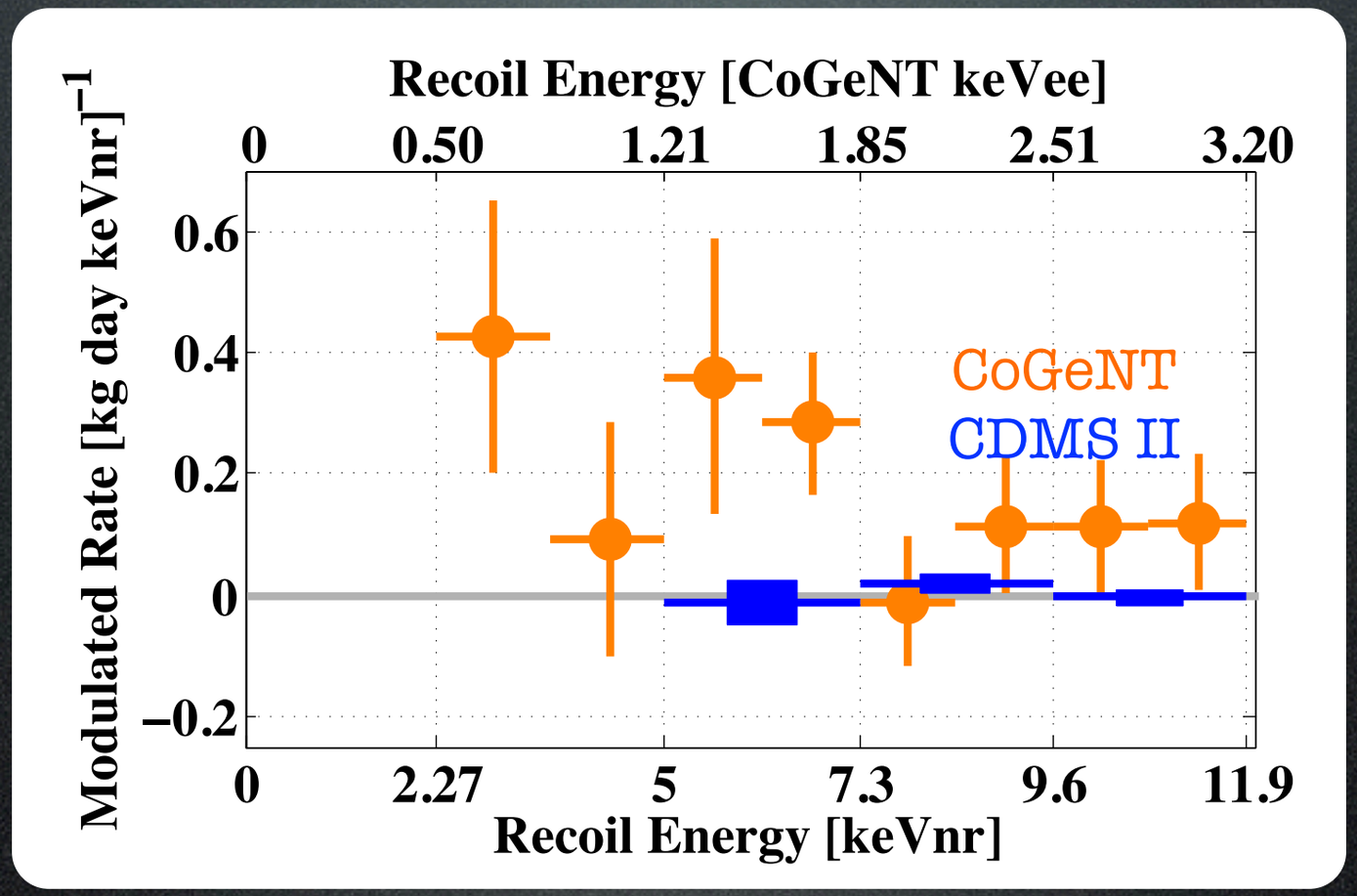
- Motivation
- Annual modulation results
- Collar and Fields' analysis
- Reproduction of Collar and Fields' now for singles and multiple scatters
- Towards a better background model

Motivation

- Collar and Fields' analysis was the main motivation for this work.
  - arXiv:1204.3559
- Low-mass WIMPs are of strong theoretical interest, also because of the CoGeNT result.
  - Phys. Rev. Lett. 107 (2011) 141301
- CDMS has searched for low-mass WIMPs by lowering energy thresholds.
  - Phys. Rev. Lett. 106 131302 (2011)
  - This implies the leakage of backgrounds into the signal region.
  - Prime for max-likelihood methods and annual modulation searches!

Annual modulation result

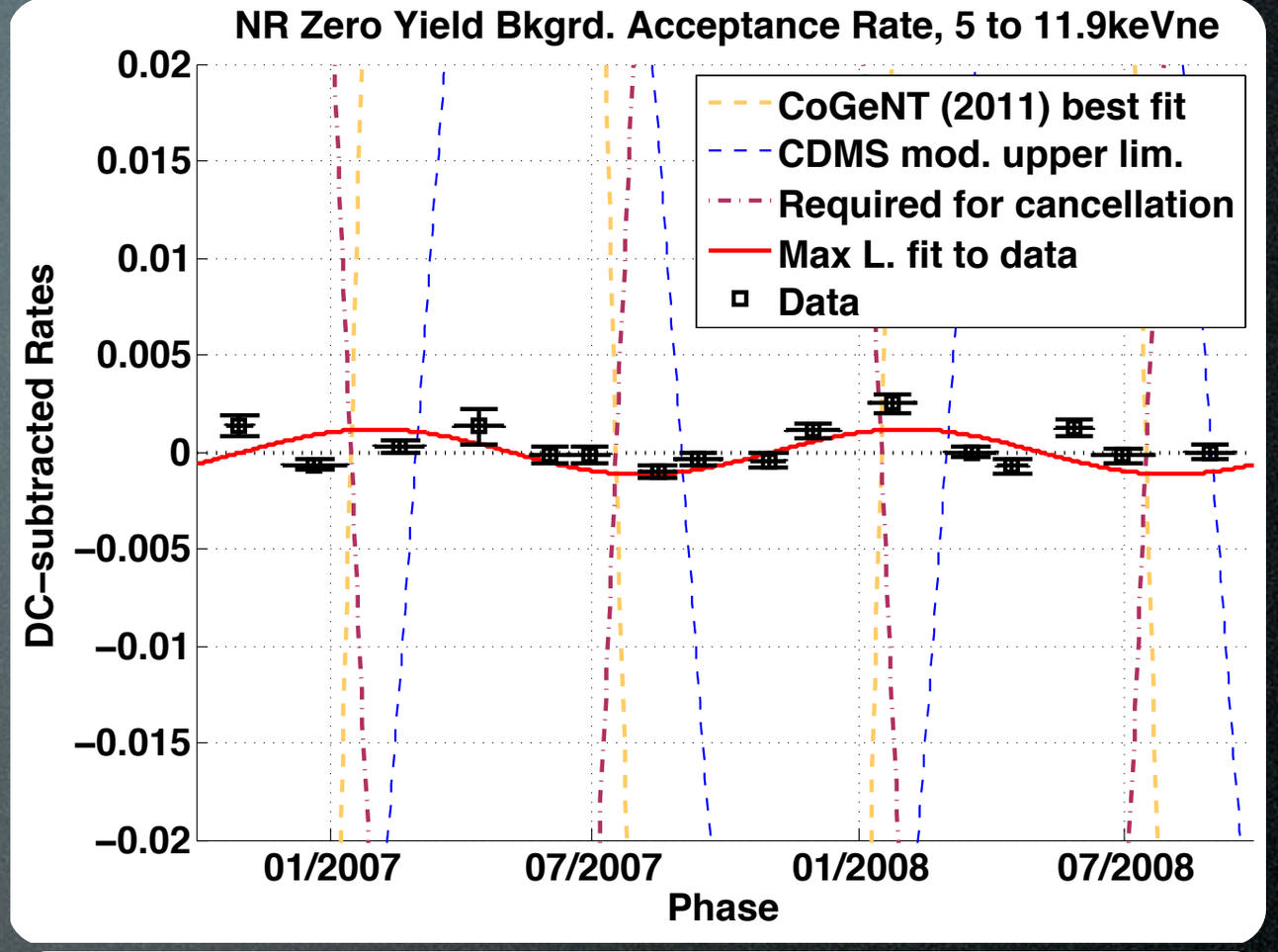
- CDMS II saw no evidence of annual modulations above 5 keVnr.

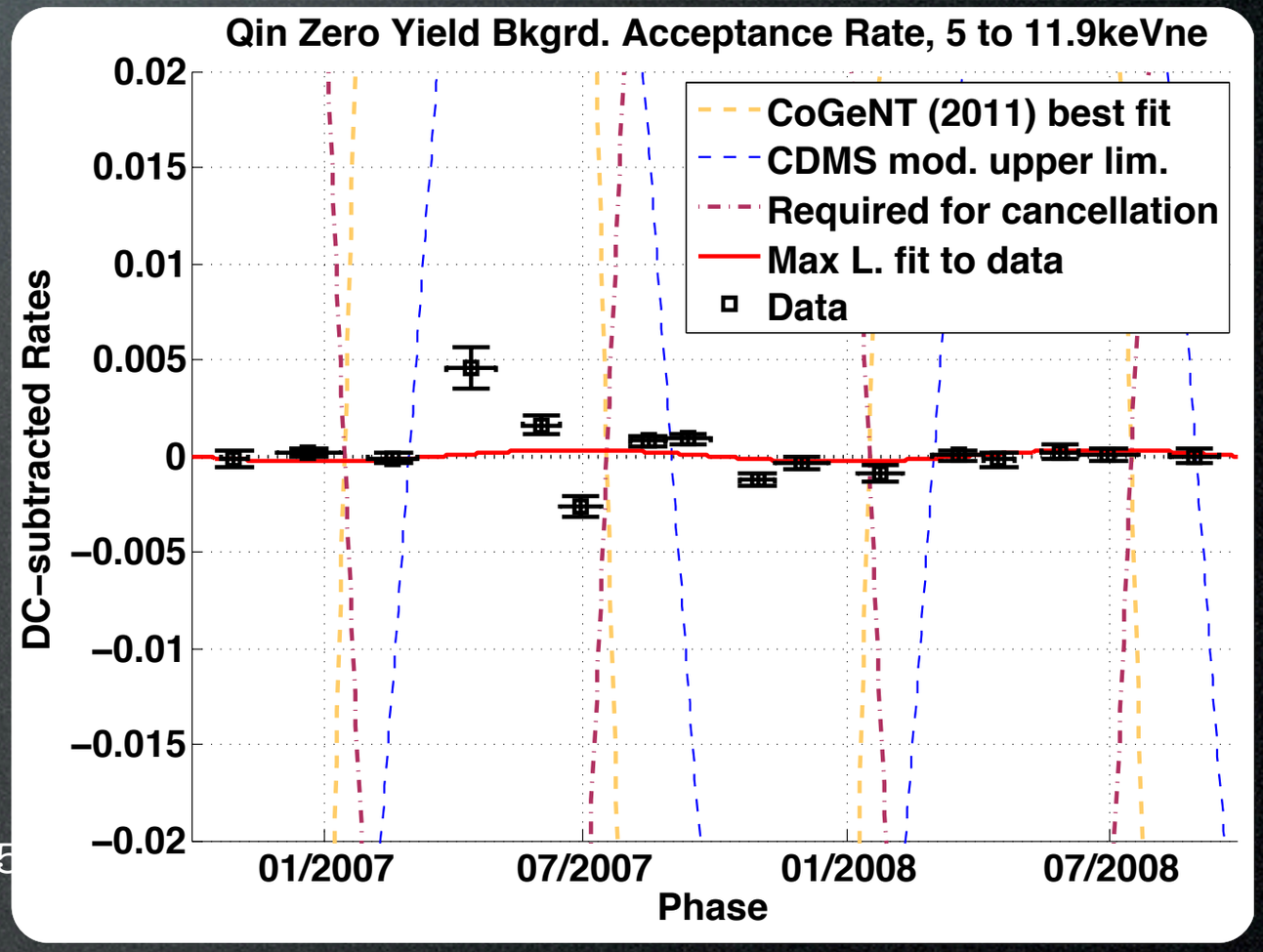


- arXiv:1203.1309

Annual-modulation systematics

- Best-fit amplitudes for modulations introduced by these cuts are 0.001 and 0.003 [keV kg day]$^{-1}$ for the NR and fiducial volume cuts, respectively.
- 20x less than our annual modulation upper limit.

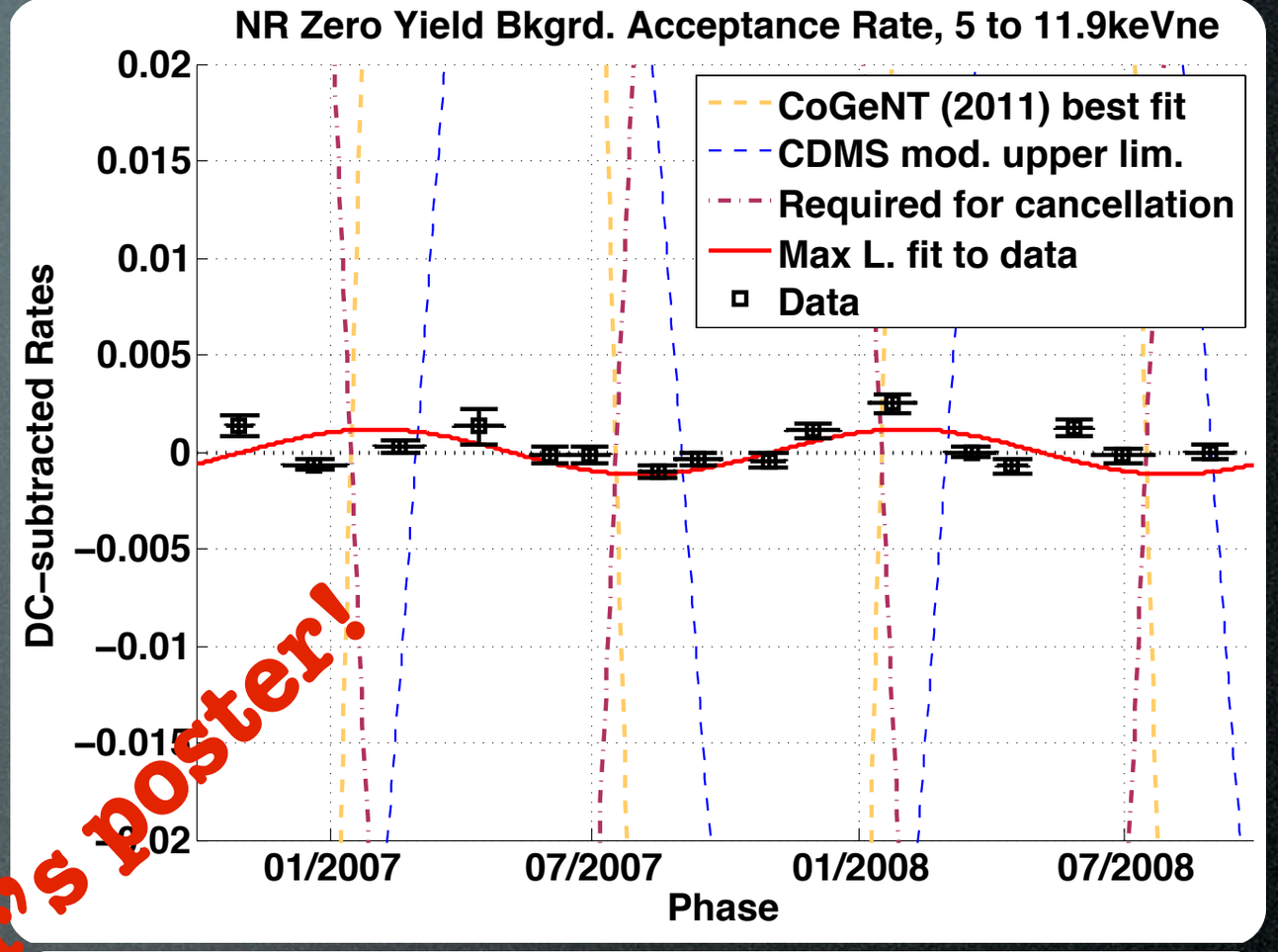


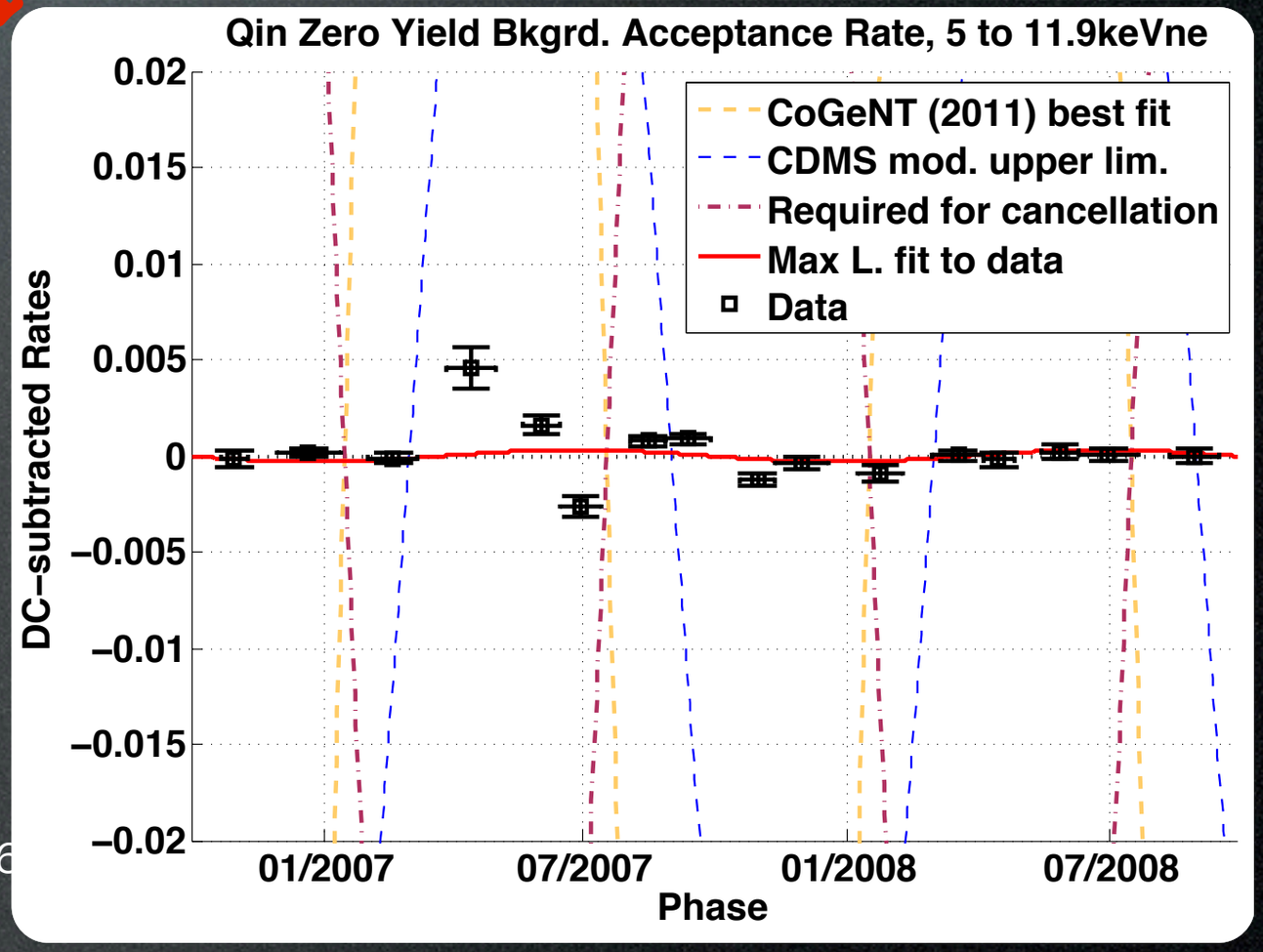


Annual-modulation systematics

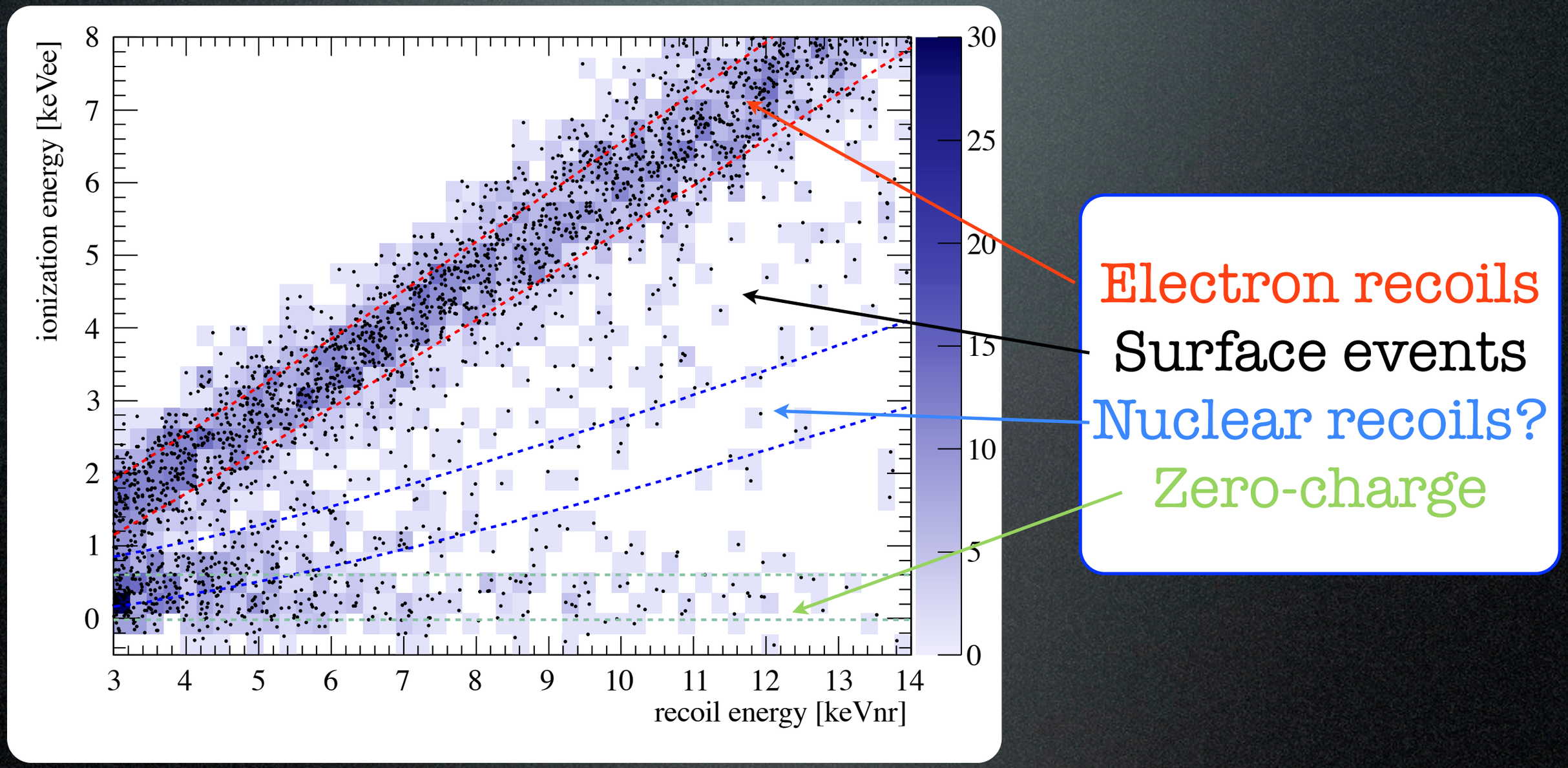
- Best-fit amplitudes for modulations introduced by these cuts are 0.001 and 0.003 [keV kg day]$^{-1}$ for the NR and fiducial volume cuts, respectively.
- 20x less than our annual modulation upper limit.

See D. Speller's poster!





Data summed over the 8 low-threshold detectors

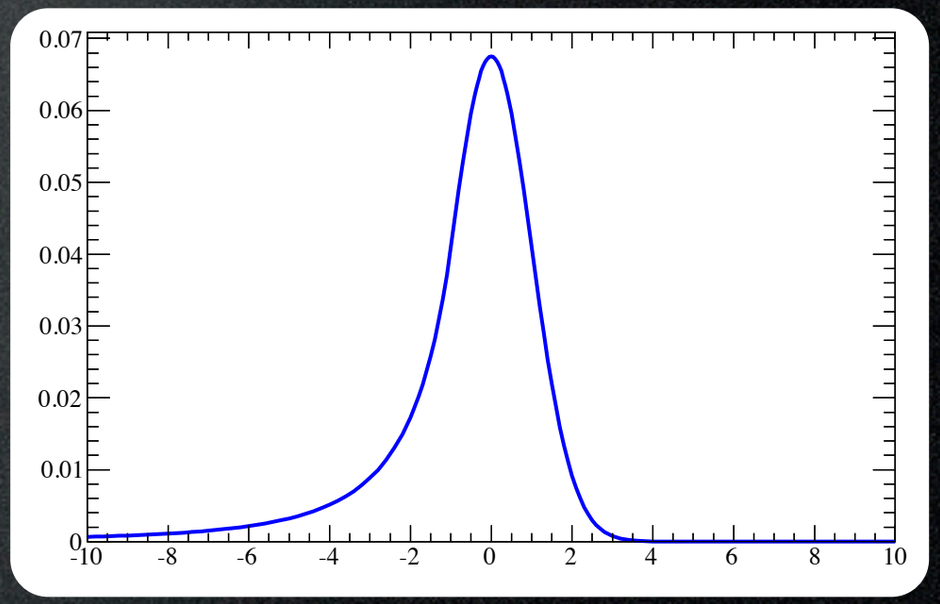


- Collar and Fields had a good idea to fit our data in ionization and recoil energy to a model.
- arXiv:1204.3559

Collar and Fields' model

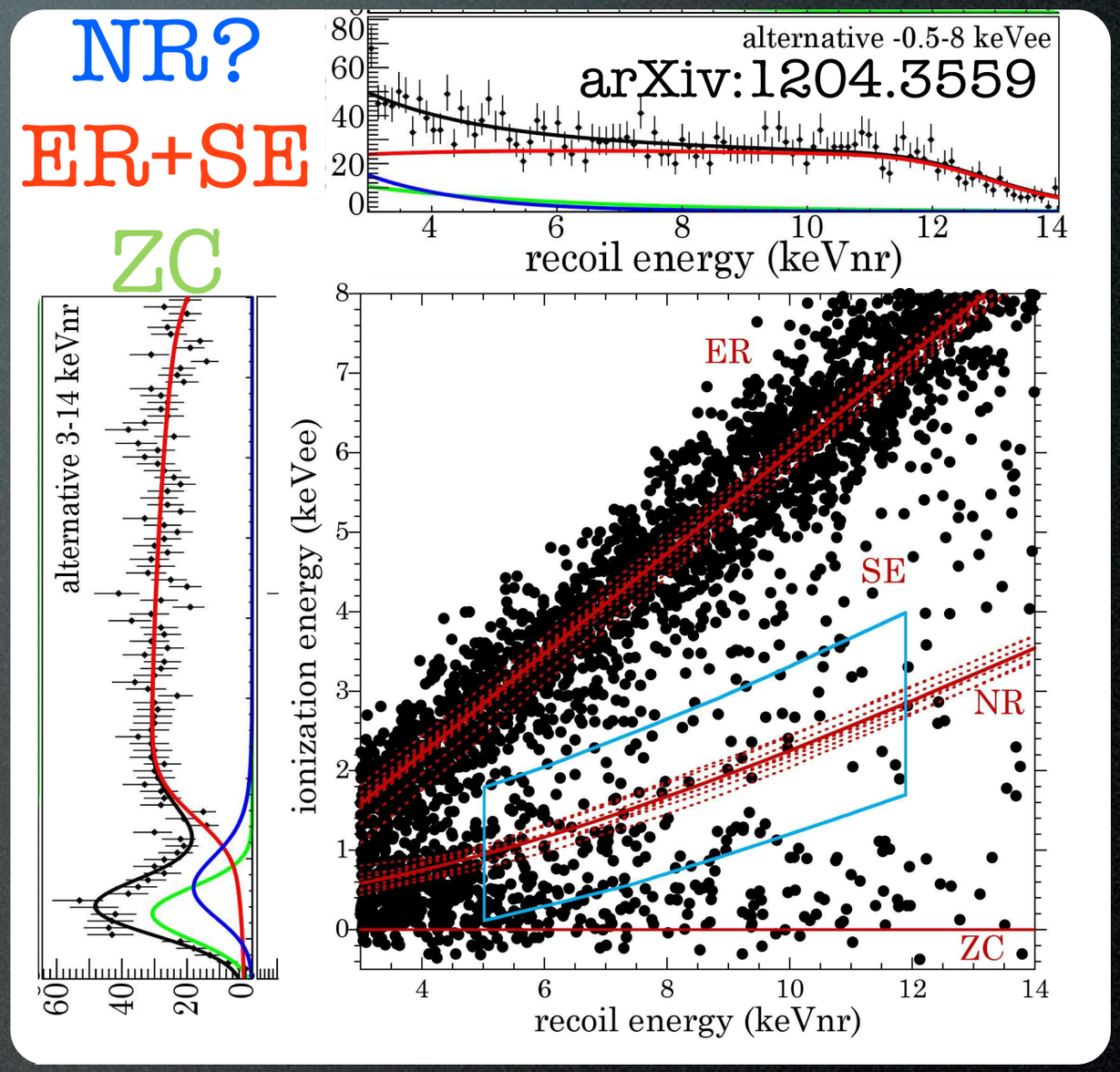
- Collar and Fields digitized figures of the CDMSII data (accurately I might add!)
- Defined a PDF with:
  - Exponentials in recoil energy.
  - Gaussians in ionization.
  - Crystal-ball PDF to describe surface events.
    - Gaussian with power law

- arXiv:1204.3559



Collar and Fields'

- For their assumed background pdf shape, the authors found a 5.7σ NR excess.

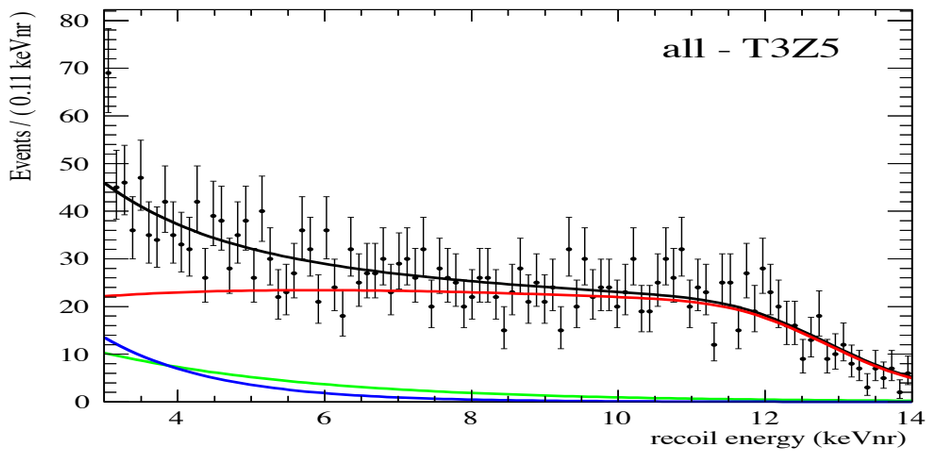


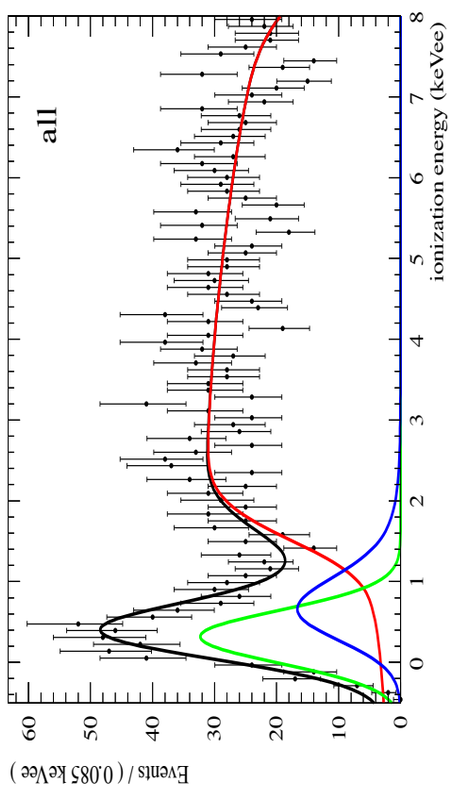
Our reproduction

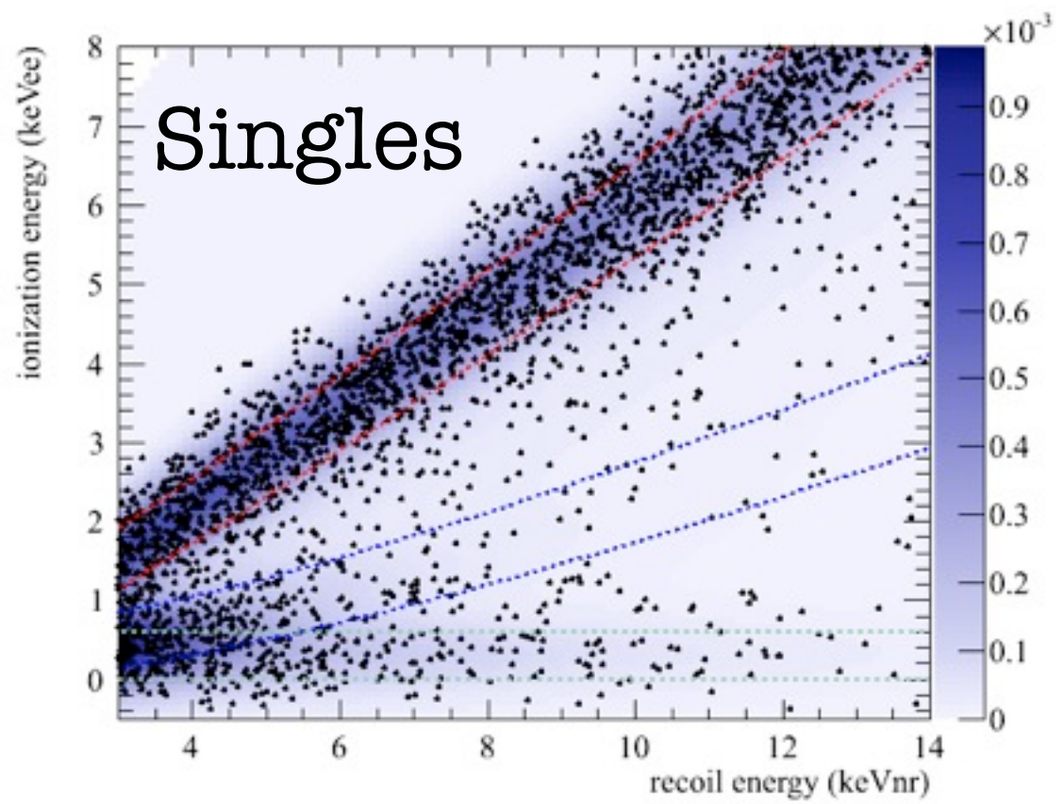
NR

ER+SE

ZC







Parameter	no NR	with NR
$-2\ln\Lambda/\Delta d.o.f.$	22.74 / 5	
p-value	3.8×10^{-4}	
σ	3.6	
S_1 [keVee]	0.373±0.020	0.304±0.028
S_2 [keVee^2/keVnr]	0.035±0.005	0.047±0.005
$C_0^{\rm ER}$ [keVee]	-0.409±0.016	-0.409±0.026
$C_1^{\rm ER}$ [keVee/keVnr]	0.646±0.002	0.646±0.002
$A_2^{\rm ER}$ [keVnr^{-1}]	0.058±0.009	0.067±0.009
α	1.621±0.152	1.746±0.123
n	1.035±0.286	0.917±0.233
$C_0^{\rm ZC}$ [keVee]	0.459±0.024	0.318±0.040
$A_2^{\rm ZC}$ [keVnr^{-1}]	0.438±0.030	0.327±0.038
$C_0^{\rm NR}$ [keVee]		-0.088±0.101
$C_1^{\rm NR}$ [keVee/keVnr]		0.170±0.021
$C_2^{\rm NR}$ [keVee/keVnr^2]		0.004±0.001
$A_2^{\rm NR}$ [keVnr^{-1}]		0.693±0.089
$f^{\rm ER}$	0.819±0.009	0.811±0.009
$f^{\rm ZC}$	0.181±0.009	0.112±0.015
$f^{\rm NR}$		0.076±0.012
NR rate > 3 keVnr [c/kg-day]		0.87±0.14

Standard χ^2

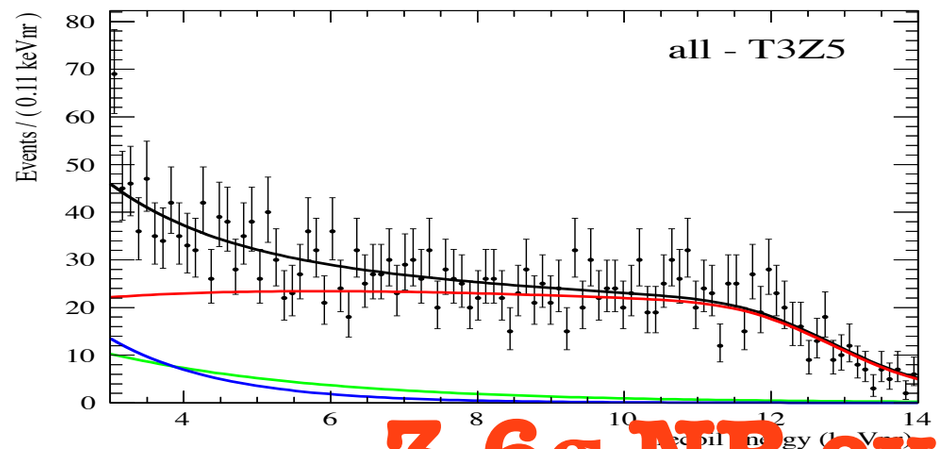
CDMS reproduction of Collar and Fields'

Our reproduction

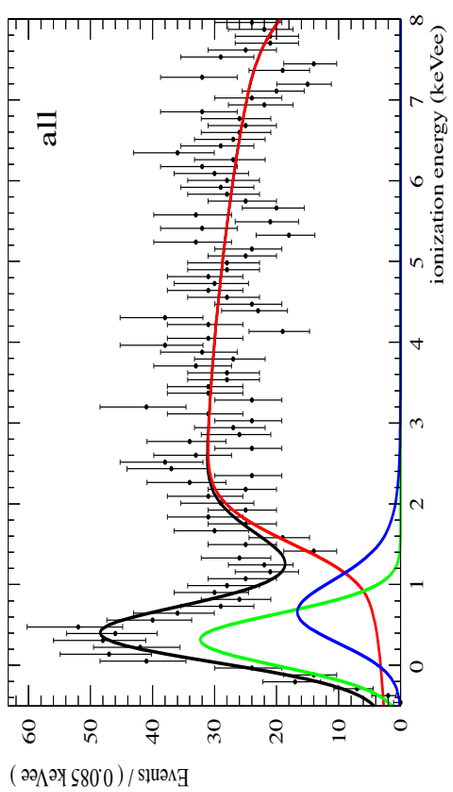
NR

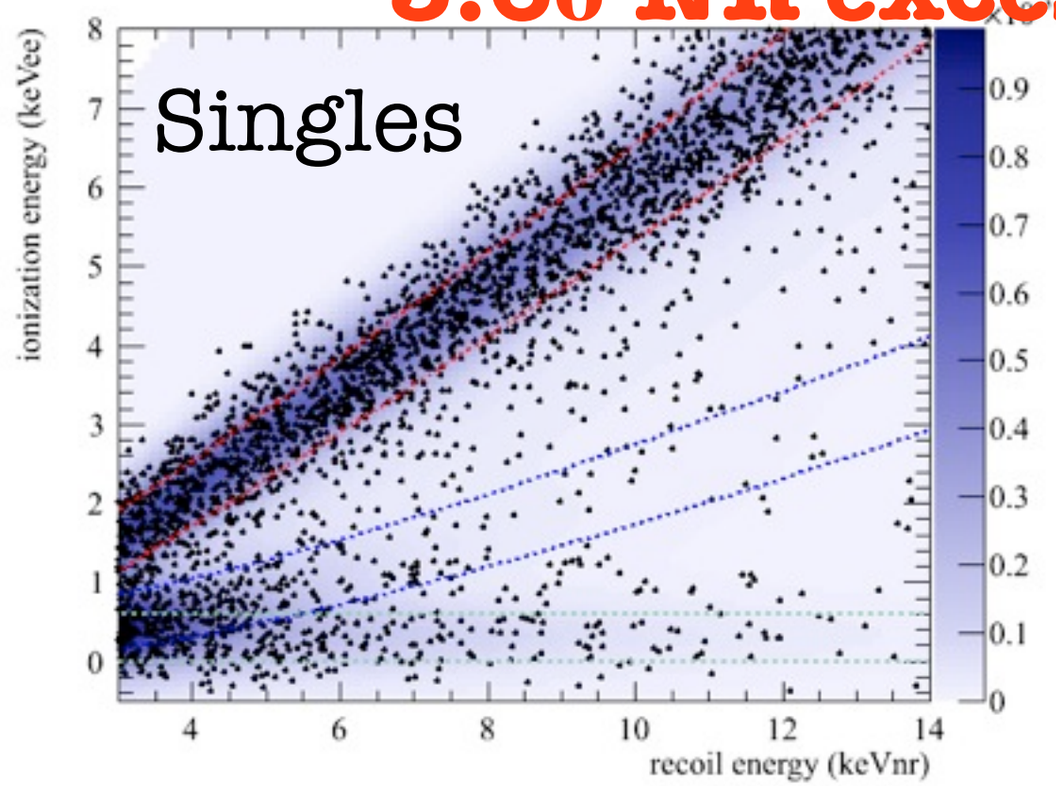
ER+SE

ZC



3.6σ NR excess





Parameter	no NR	with NR
$-2\ln\Lambda/\Delta d.o.f.$	22.74 / 5	
p-value	3.8×10^{-4}	
σ	3.6	
S_1 [keVee]	0.373±0.020	0.304±0.028
S_2 [keVee^2/keVnr]	0.035±0.005	0.047±0.005
C_0^{ER} [keVee]	-0.409±0.016	-0.409±0.026
C_1^{ER} [keVee/keVnr]	0.646±0.002	0.646±0.002
A_2^{ER} [keVnr^{-1}]	0.058±0.009	0.067±0.009
α	1.621±0.152	1.746±0.123
n	1.035±0.286	0.917±0.233
C_0^{ZC} [keVee]	0.459±0.024	0.318±0.040
A_2^{ZC} [keVnr^{-1}]	0.438±0.030	0.327±0.038
C_0^{NR} [keVee]		-0.088±0.101
C_1^{NR} [keVee/keVnr]		0.170±0.021
C_2^{NR} [keVee/keVnr^2]		0.004±0.001
A_2^{NR} [keVnr^{-1}]		0.693±0.089
f^{ER}	0.819±0.009	0.811±0.009
f^{ZC}	0.181±0.009	0.112±0.015
f^{NR}		0.076±0.012
NR rate > 3 keVnr [c/kg-day]		0.87±0.14

Standard χ^2

Hmmm, that's interesting

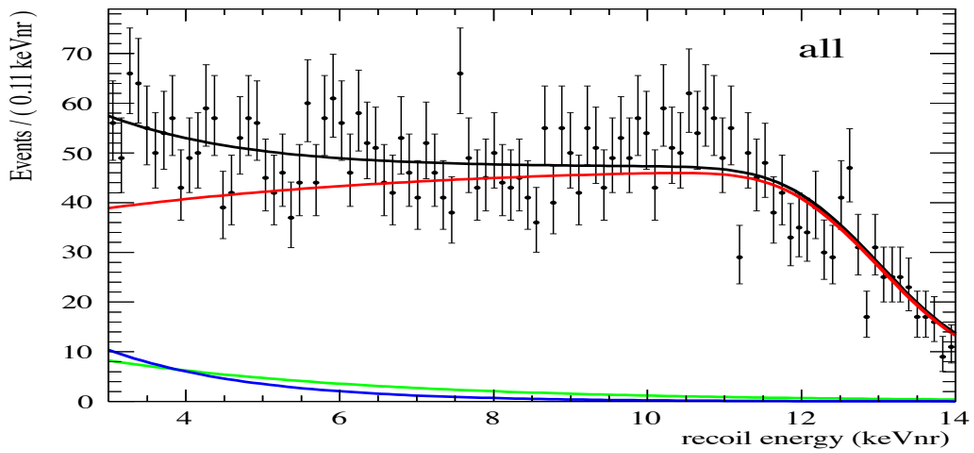
- But what about the multiple-scatter events you say???

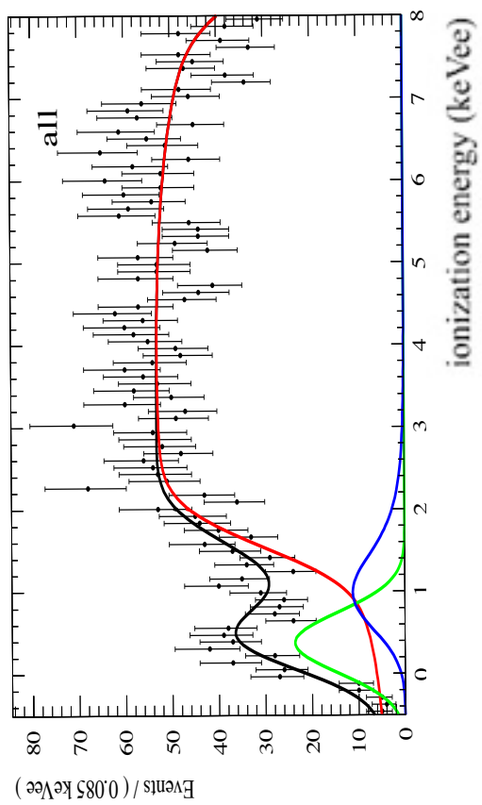
Maximum-likelihood fit

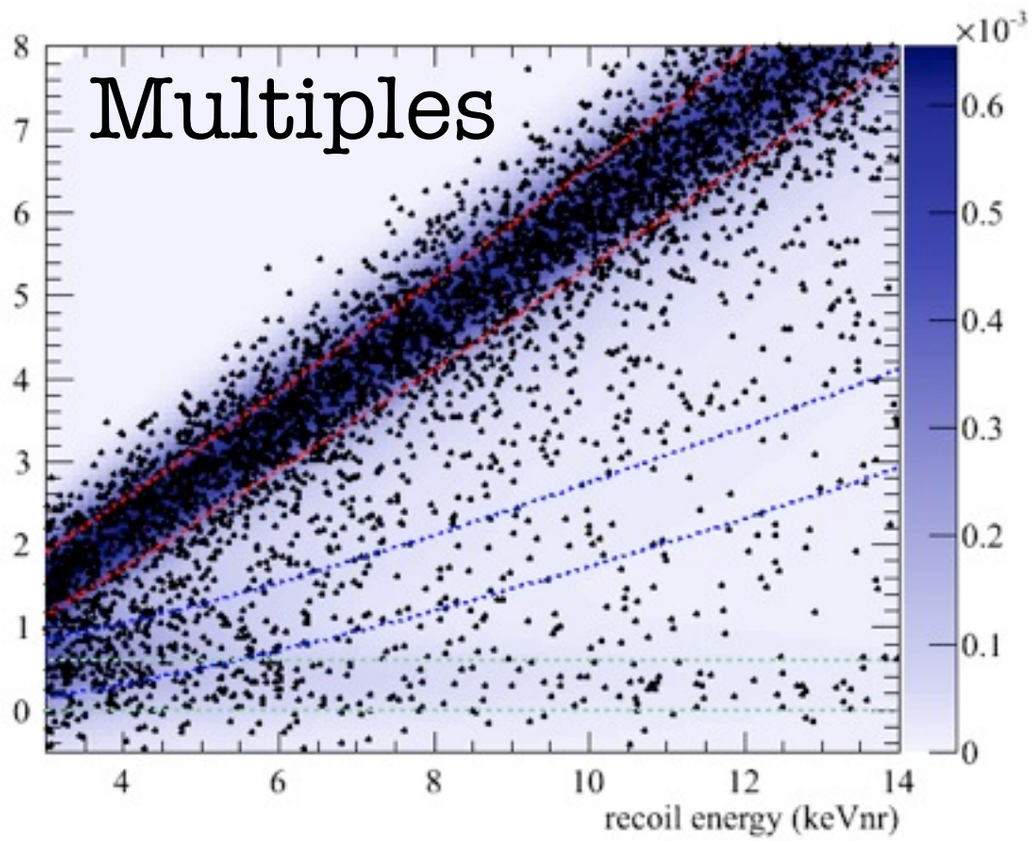
NR?

ER+SE

ZC







Parameter	no NR	with NR
$-2\ln\Lambda/\Delta d.o.f.$	22.8 / 5	
p-value	3.7×10^{-4}	
σ	3.56	
S_1 [keVee]	0.416±0.022	0.353±0.028
S_2 [keVee^2/keVnr]	0.025±0.005	0.036±0.005
$C_0^{\rm ER}$ [keVee]	-0.388±0.017	-0.380±0.011
$C_1^{\rm ER}$ [keVee/keVnr]	0.642±0.008	0.642±0.001
$A_2^{\rm ER}$ [keVnr^{-1}]	0.025±0.007	0.300±0.007
α	1.551±0.091	1.599±0.088
n	1.019±0.170	1.058±0.164
$C_0^{\rm ZC}$ [keVee]	0.551±0.038	0.379±0.043
$A_2^{\rm ZC}$ [keVnr^{-1}]	0.411±0.051	0.277±0.041
$C_0^{\rm NR}$ [keVee]		0.064±0.094
$C_1^{\rm NR}$ [keVee/keVnr]		0.202±0.005
$C_2^{\rm NR}$ [keVee/keVnr^2]		0.005±0.000
$A_2^{\rm NR}$ [keVnr^{-1}]		0.567±0.101
$f^{\rm ER}$	0.921±0.006	0.904±0.007
$f^{\rm ZC}$	0.079±0.006	0.057±0.010
$f^{\rm NR}$		0.039±0.007
NR rate > 3 keVnr [c/kg-day]		0.72±0.13

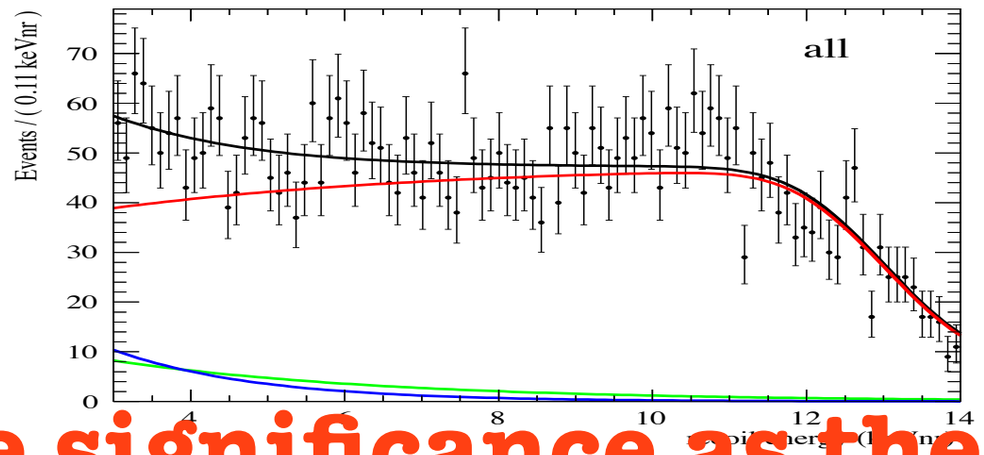
Standard χ^2

Maximum-likelihood fit

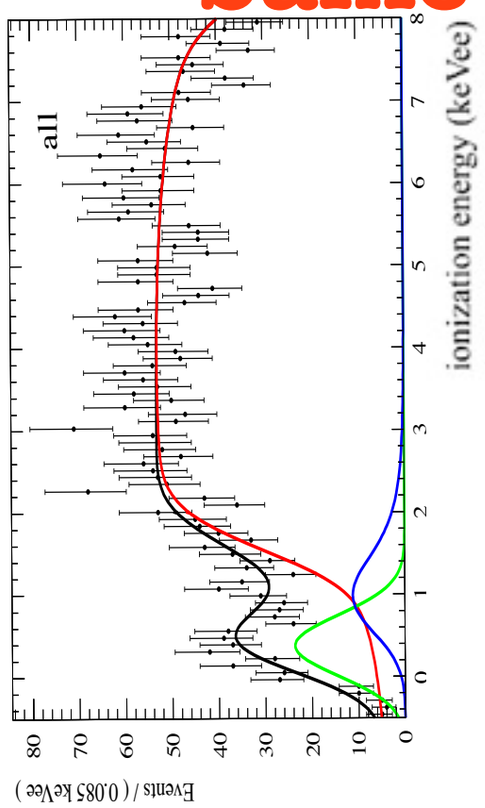
NR?

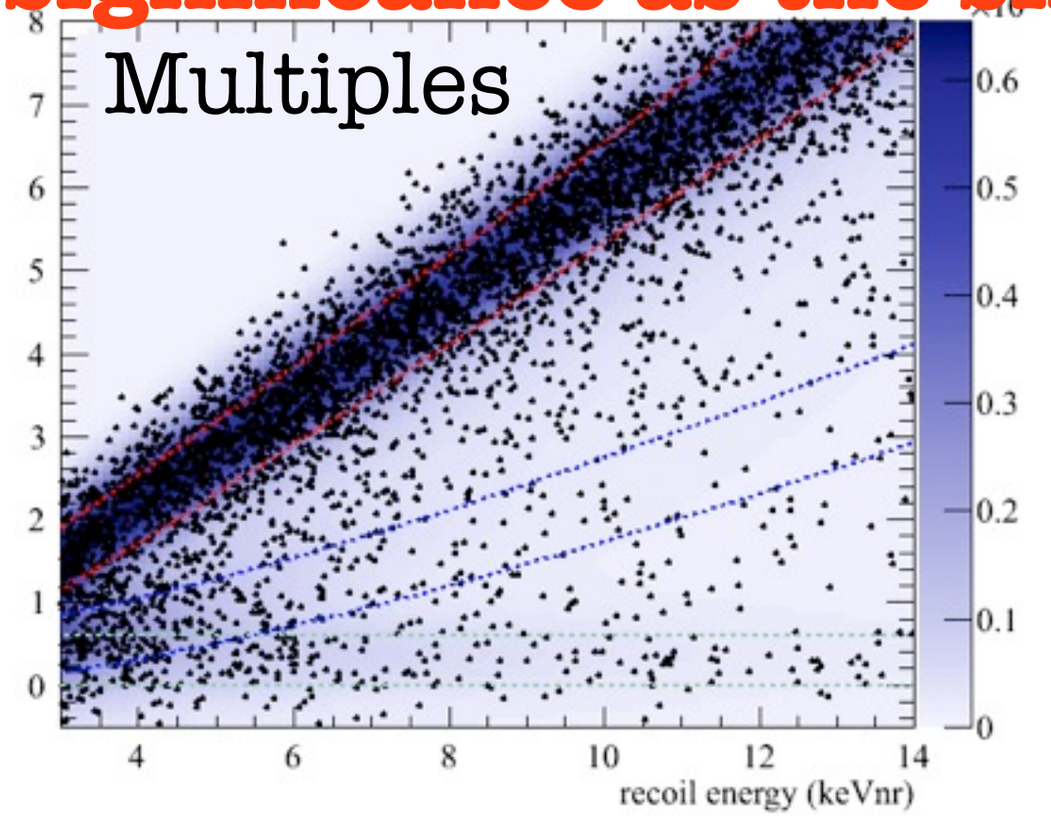
ER+SE

ZC



Same significance as the singles!!





Parameter	no NR	with NR
$-2\ln\Lambda/\Delta d.o.f.$	22.8 / 5	
p-value	3.7×10^{-4}	
σ	3.56	
S_1 [keVee]	0.416±0.022	0.353±0.028
S_2 [keVee^2/keVnr]	0.025±0.005	0.036±0.005
C_0^{ER} [keVee]	-0.388±0.017	-0.380±0.011
C_1^{ER} [keVee/keVnr]	0.642±0.008	0.642±0.001
A_2^{ER} [keVnr^{-1}]	0.025±0.007	0.300±0.007
α	1.551±0.091	1.599±0.088
n	1.019±0.170	1.058±0.164
C_0^{ZC} [keVee]	0.551±0.038	0.379±0.043
A_2^{ZC} [keVnr^{-1}]	0.411±0.051	0.277±0.041
C_0^{NR} [keVee]		0.064±0.094
C_1^{NR} [keVee/keVnr]		0.202±0.005
C_2^{NR} [keVee/keVnr^2]		0.005±0.000
A_2^{NR} [keVnr^{-1}]		0.567±0.101
f^{ER}	0.921±0.006	0.904±0.007
f^{ZC}	0.079±0.006	0.057±0.010
f^{NR}		0.039±0.007
NR rate > 3 keVnr [c/kg-day]		0.72±0.13

Standard χ^2

Hold on a second!!

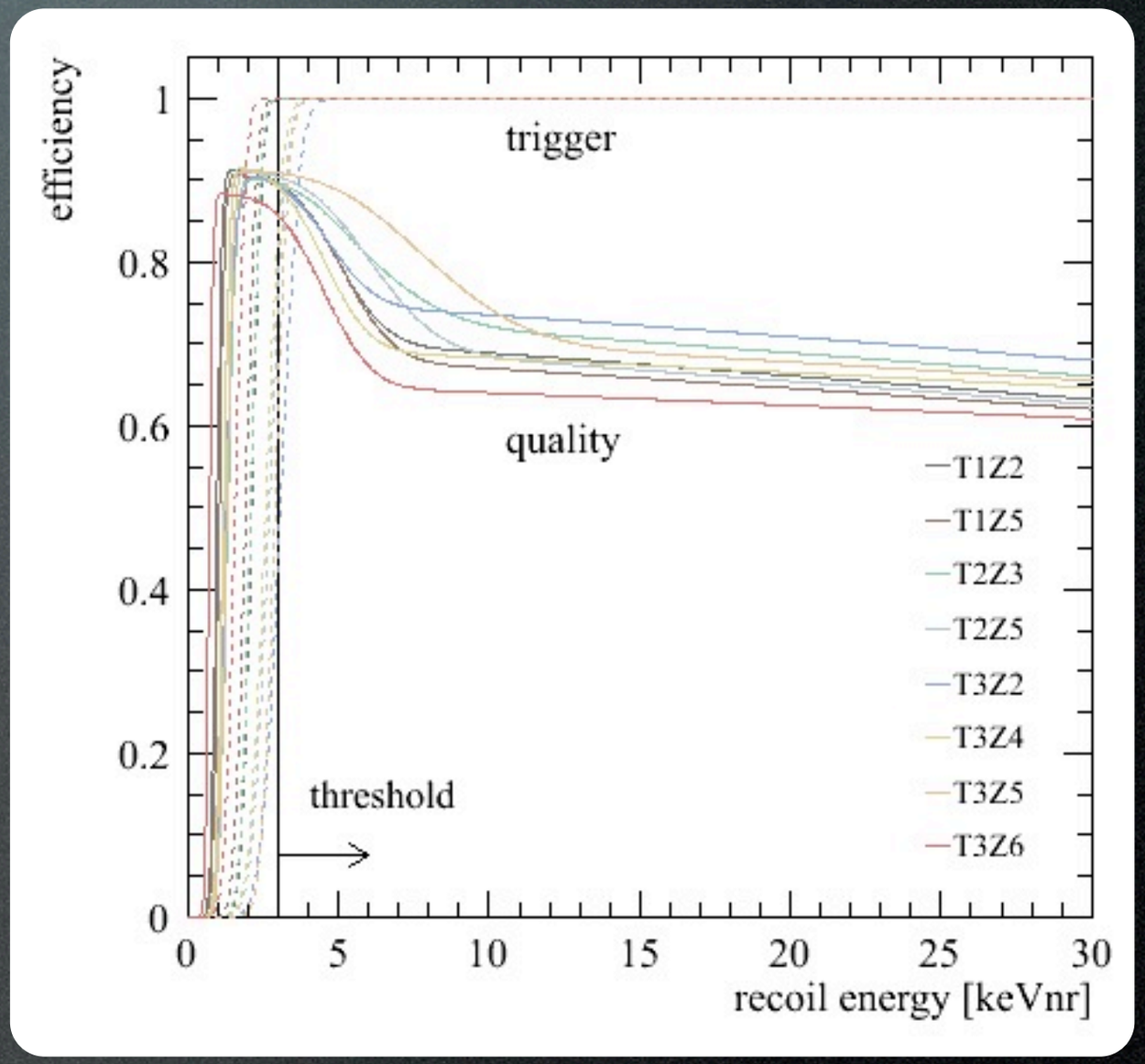
- Any background model that needs significant NRs in the multiple scatters cannot be accurate enough to be trustworthy.

Work in progress

- Include cut efficiencies.
- Developing complete models of important backgrounds using custom GEANT4 and detector Monte Carlo simulations and datasets to determine background distributions in recoil energy and ionization yield, before and after fiducial-volume cuts.
- Use multiple scatters to check model accuracy.

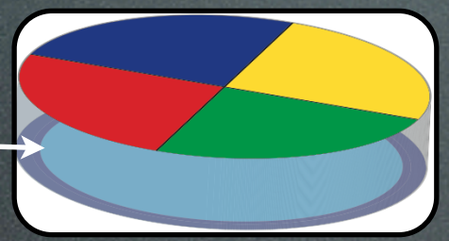
Efficiency correction

- Cut efficiency corrections near threshold are important.

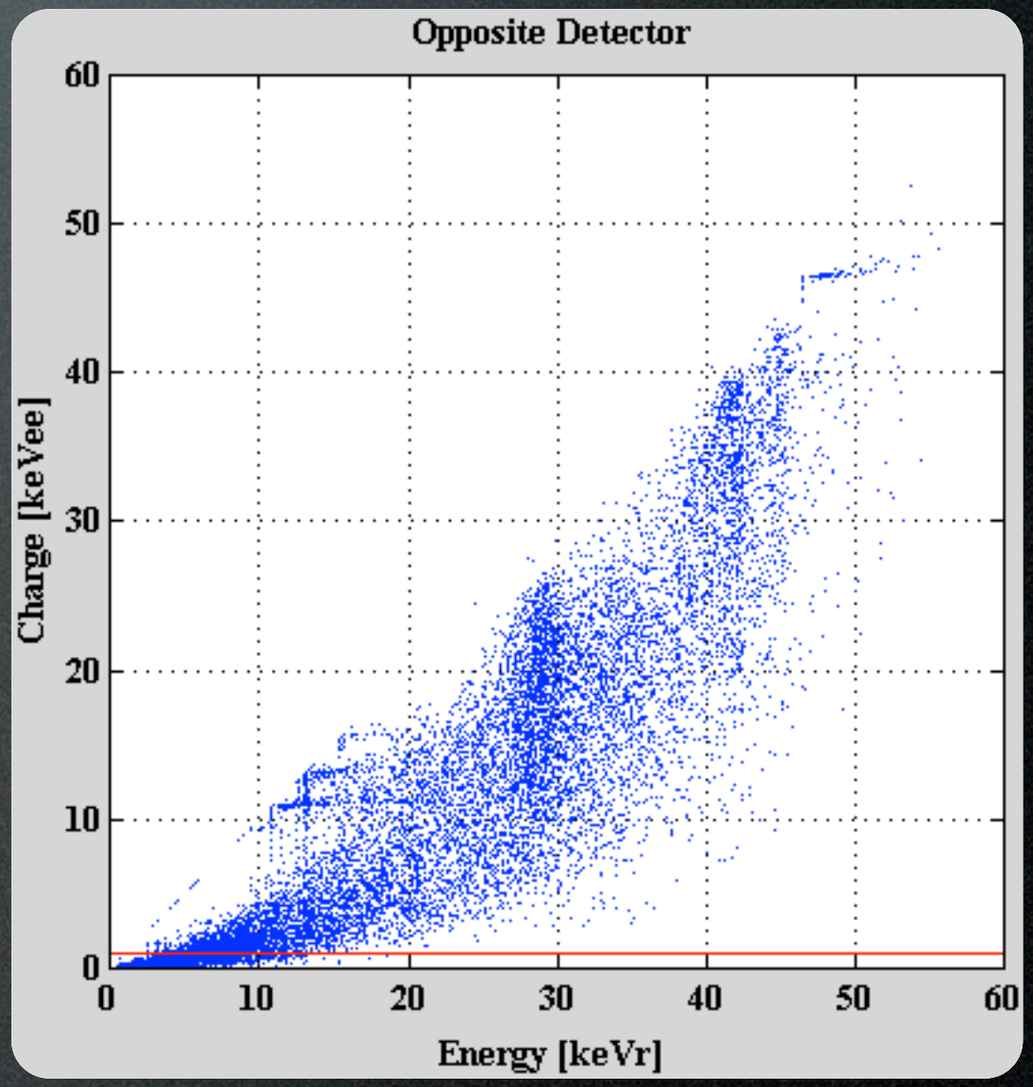


^{210}Pb contamination

- As ZC events are a significant background to this type of analysis, we're working hard to understand their source.
  - Typically high radius.



  - ^{210}Pb decays in the detector housing can hit a detector with a beta.
    - Population is in the NR and ZC bands!



Conclusions

- CDMS sees no evidence of annual modulations above 5 keVnr. Still working to understand the systematics below 5 keVnr.
- Maximum-likelihood methods are powerful tools for analyzing low-threshold dark-matter-search data in the presence of backgrounds.
- While we qualitatively recreate the Collar and Fields analysis, any analysis that finds an excess in the multiples questions a WIMP hypothesis.
- ^{210}Pb decays are an important background, that contribute to the ZC and NR events and we are working hard to understand their impact.