A Maximum Likelihood Analysis of Low-Energy CDMS Data

Nicole Fields

University of Chicago

IDM 2012

CDMS

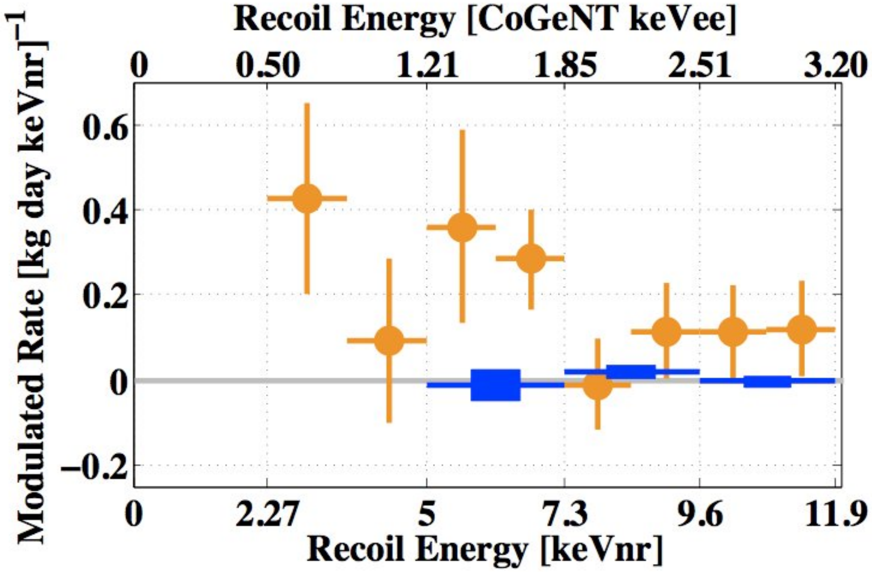
Similarities to CoGeNT

- Target (Ge)
- Exposures
  - CDMS - 240 kg-days (small fraction of total after quality cuts)
  - CoGeNT - 146 kg-days (150 more on the way, continuous data-taking)
- Thresholds
  - CDMS - 2 keVnr (but 5 keVnr in mod. analysis)
  - CoGeNT – 0.5 keVee (~ 2 keVnr)
- Orthogonal bckg. cuts at low E (CDMS NR/ER, CoGeNT Surface/Bulk)
- Location (Soudan Mine)

CDMS Detectors

- Ionization and phonon channels
- Energy resolution ~300 eV (ionization) ~100 eV (phonon). CoGeNT's ~60 eV.
- Good nuclear recoil discrimination, but no surface event discrimination at low-E.
- Ei vs. Er data shown from

  3 to 14 keVnr (arXiv:1203.1309)
- Excludes an annual modulation of 0.06 [keVnr kg day]$^{-1}$ from 5 to 11.9 keVnr

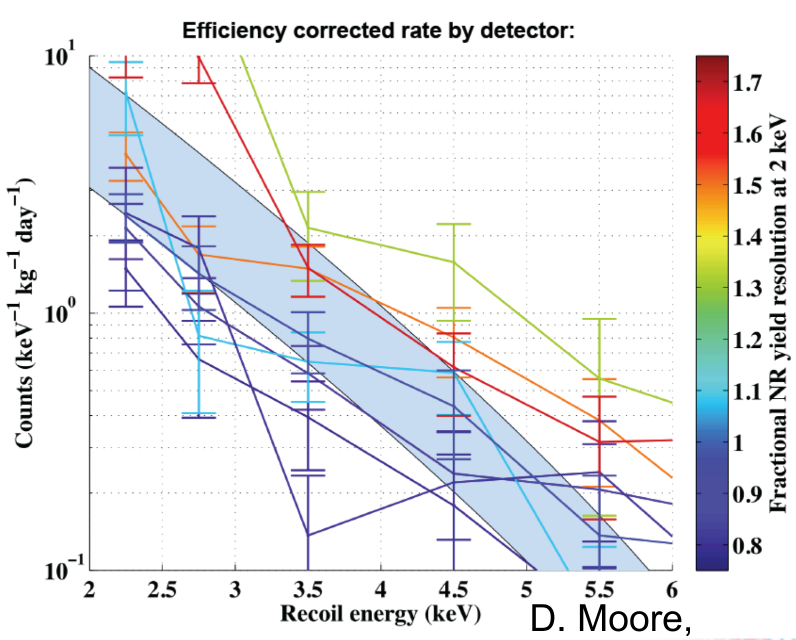


arXiv:1203.1309

CDMS Modulation Analysis

(grievances…)

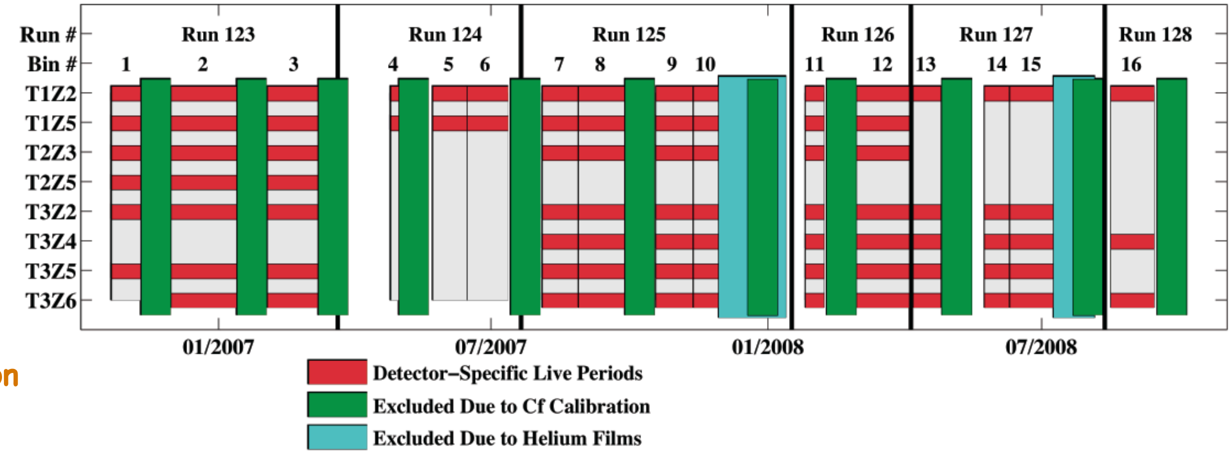
- Analysis stops at 5 keVnr (where CoGeNT excess background starts)
- Eight detectors span an order of magnitude of background rate in signal box
- Detectors with different background levels also have dissimilar live periods (dilutes a modulation)
- Data quality cuts further reduce continuity and total exposure



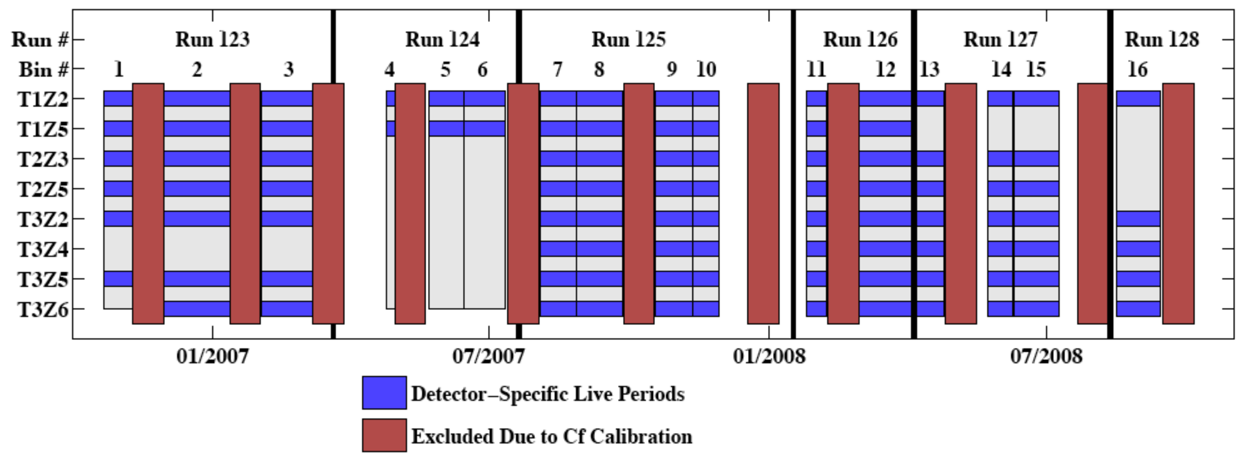
D. Moore, Aspen 2011

CDMS Exposure

UCLA presentation

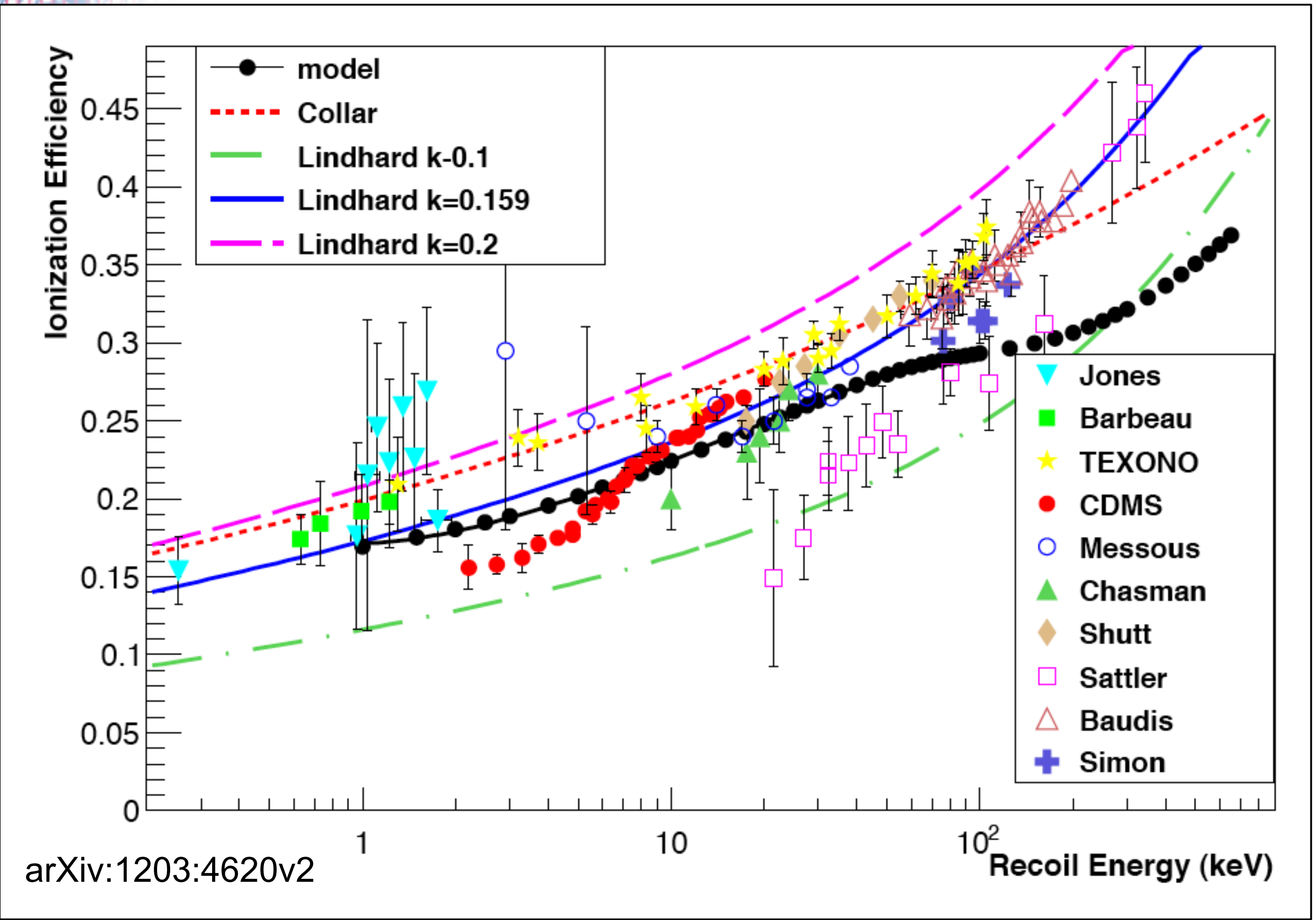


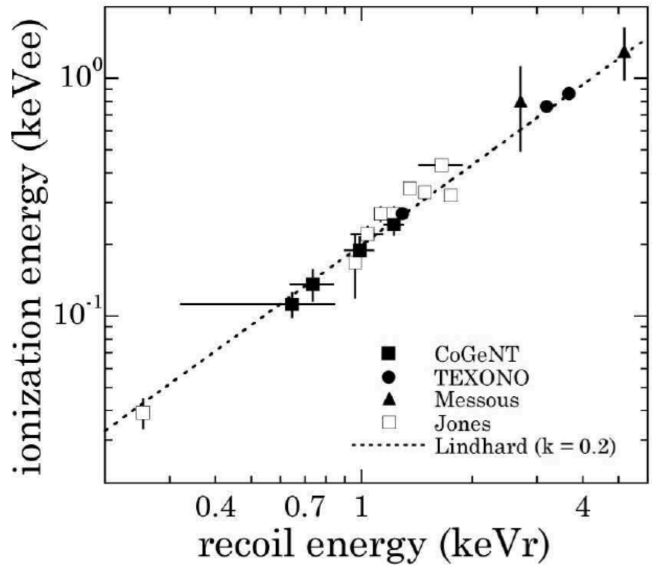
Preprint



- **Always read the fine print: data quality cuts further reduce the individual detector live periods to < 50% of what is shown here (e.g., T3Z2 uses just 10% of the exposure in blue)**

Quenching Factor





All measurements using monochromatic n sources are in tight agreement. CDMS' diverges (uses "best-fit MC" to broad E source, reasons for disagreement remain unknown)

CoGeNT adopts: keVee=(0.19935)*keVnr^(1.1204)

0.2 keV < keVnr < 10 keV

CDMS Background Sources

- Electron recoils (Compton scattering)
- Surface events
  - Mostly betas from ^{210}Pb
- Cosmogenic peaks (neutron activation)
  - $^{68,71}Ge$, ^{65}Zn, ^{55}Fe
- Zero charge events
- Negligible contribution from neutrons
  - <1 event in the 240 kg-day CDMS data

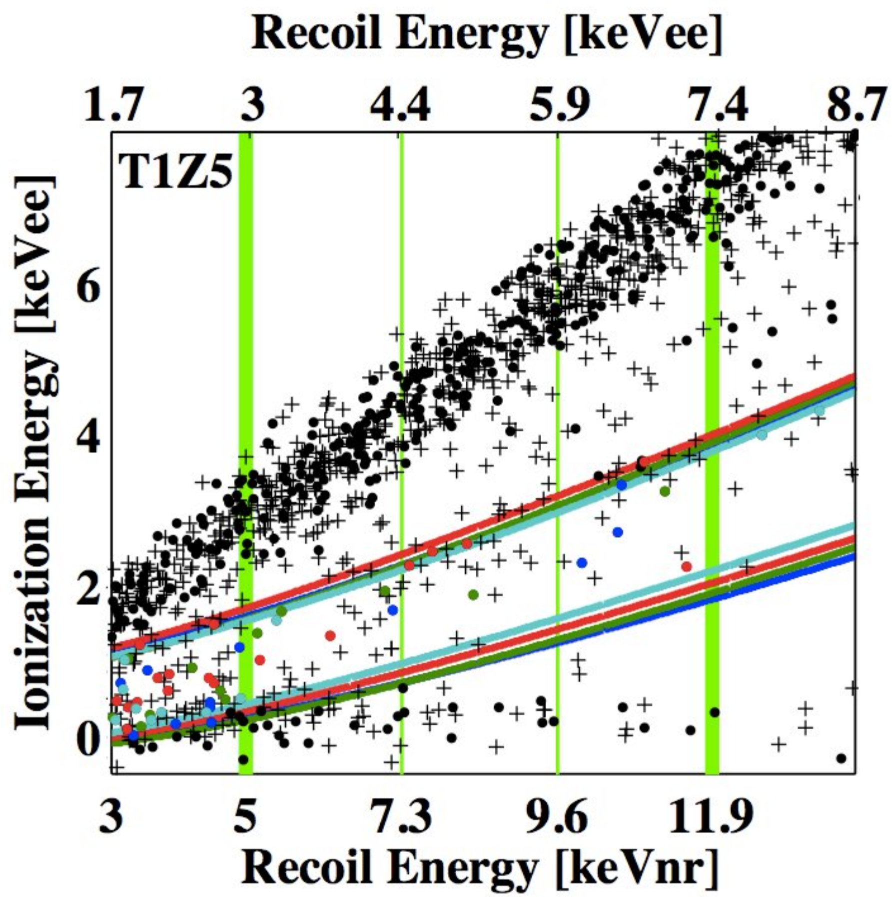
Maximum Likelihood Analysis

(Collar & Fields arXiv:1204.3559)

CDMS data as in arXiv:1203.1309

(CDMS)

- Singles (dots) and multiples (crosses)
- Individual detectors only

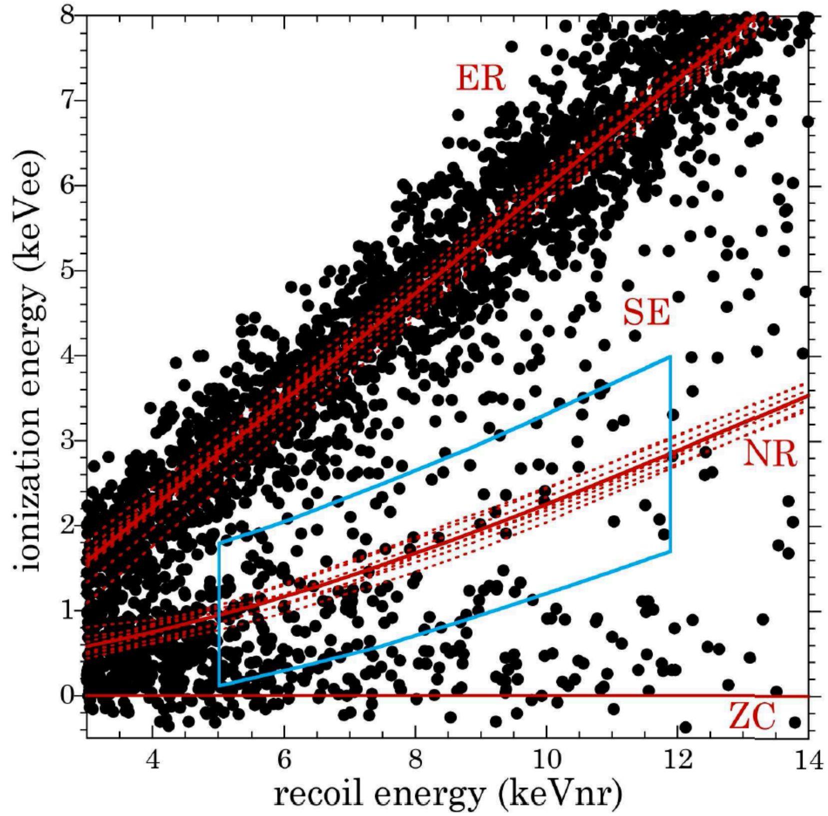


CDMS data as in arXiv:1204.3559

(Collar & Fields)

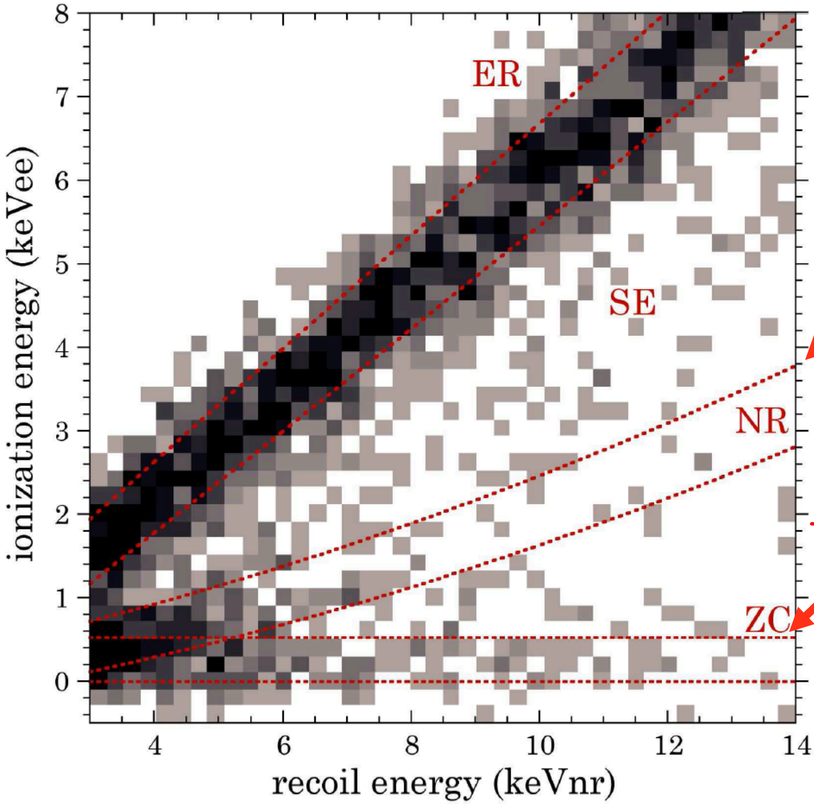
- Digitized with G3DATA
- Summed detectors (singles)
- Any analysis must account for differences between detectors
- Excess readily visible in NR: analysis must quantify this impression

Summed detectors



Why was the possible NR excess not noticed before?

Summed detectors

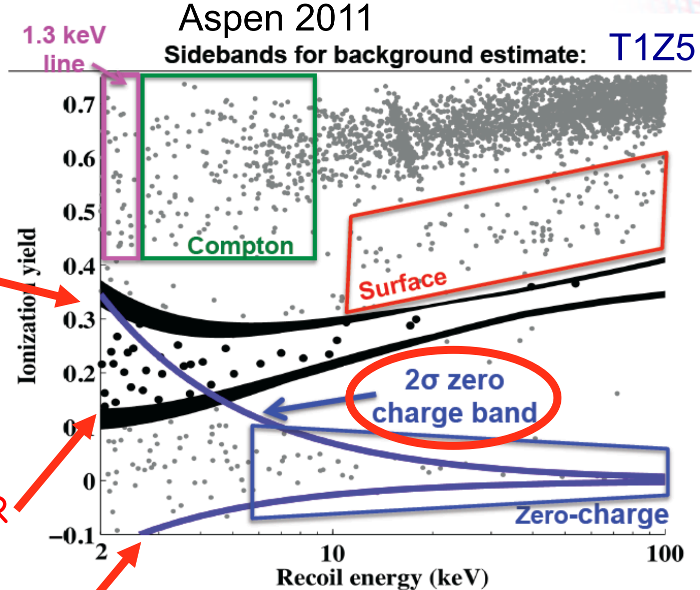


+/-1 σ NR

+/-1 σ ZC

D. Moore,
Aspen 2011

T1Z5



+1.25σ NR

−0.5σ NR

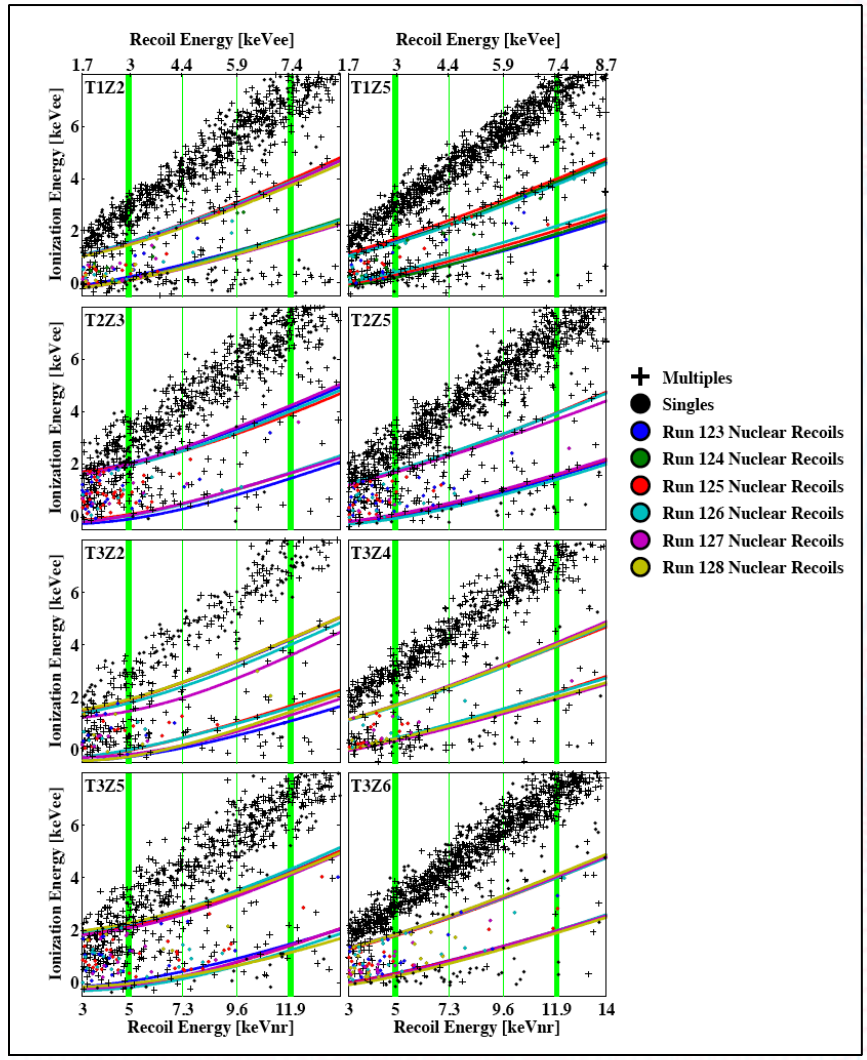
Actually the same ZC behavior as in left figure.
Difference from choice of vertical axis.
(ionization yield = Ei / Er)

CDMS had shown data from one detector only (T1Z5), with less-than-fair comparison between NR and ZC

CDMS data as in arXiv:1203.1309

(CDMS)

- Eight detectors
  - Different electronic noise
  - Different exposures
  - Slightly different ER and NR bands
- Our analysis looks at summed data and individual detectors

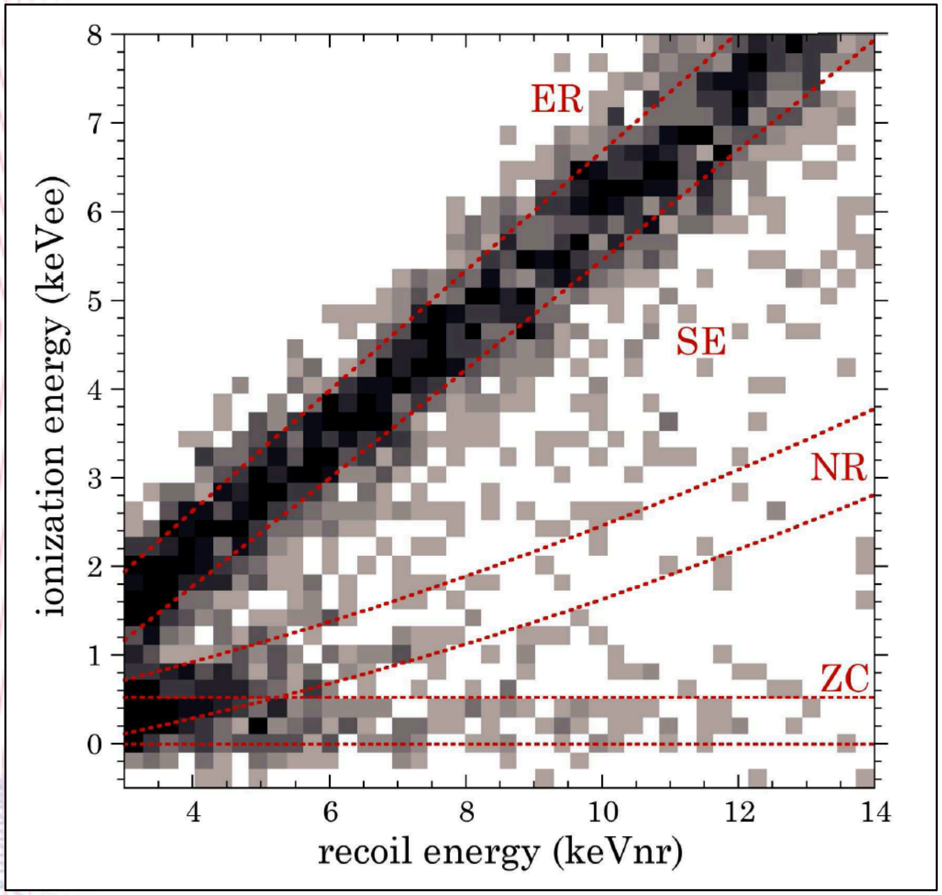


2D Unbinned Maximum Likelihood

- Performed using RooFit, an extension to ROOT
- Two observables, E_i and E_r
- Two (three) Probability Distribution Functions (PDFs) for null (alternative) hypothesis
- In practice, minimize negative log-likelihood using Minuit

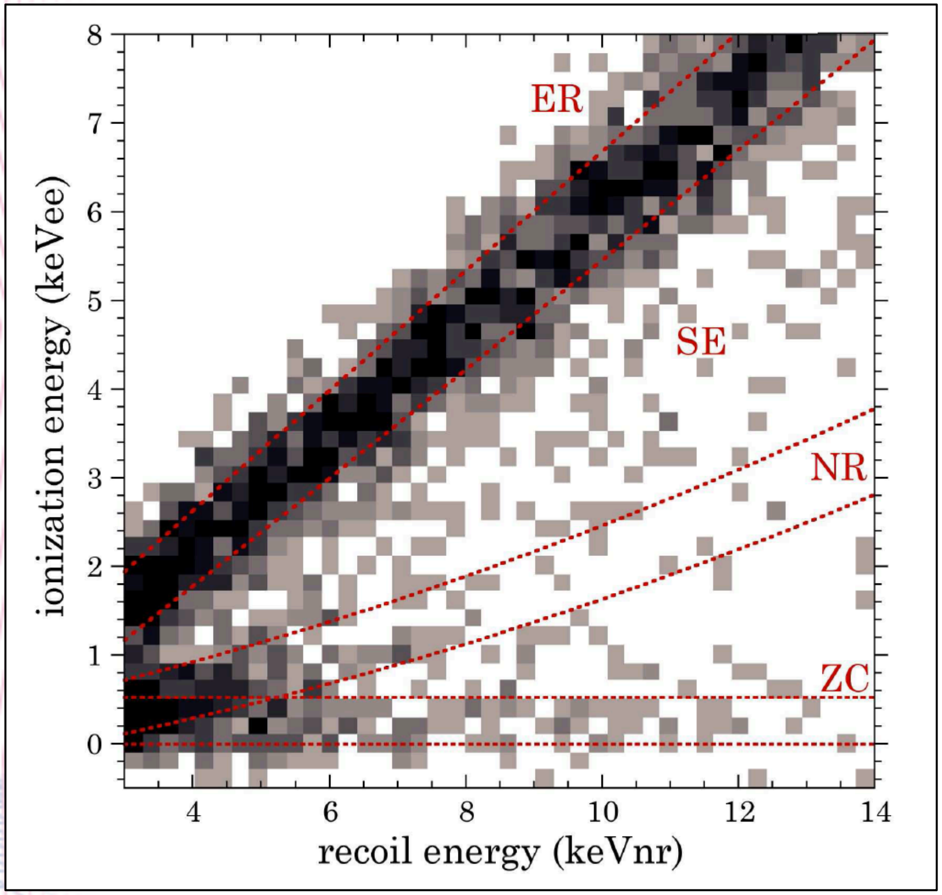
$$-\ln L = -\Sigma \ln f(\vec{x}|\vec{\theta})$$

Electron Recoils (ER) and Surface Events (SE)



- Compton scattering, ^{210}Pb betas (if gamma escapes)
- Surface events leave degraded ionization signals
- Exponential PDF in E_r
- Crystal Ball PDF in E_i
  - Gaussian + Power law tail

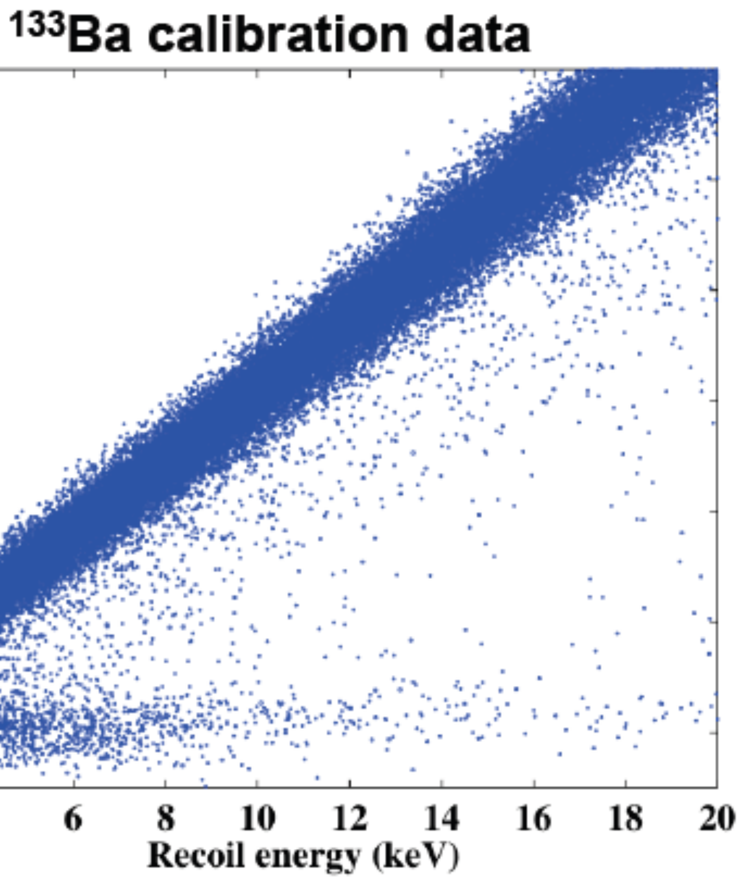
Zero Charge (ZC) Events



- Events that occur in the edges of the detectors
- Leave no ionization signals
- We allow for a small non-zero offset (systematics), just like CDMS, obtaining same ZC band fit as CDMS.
- No distortion in ZC at low-E expected (evidenced in Ba-133 calibrations)
- Exponential PDF in E_r
- Gaussian PDF in E_i

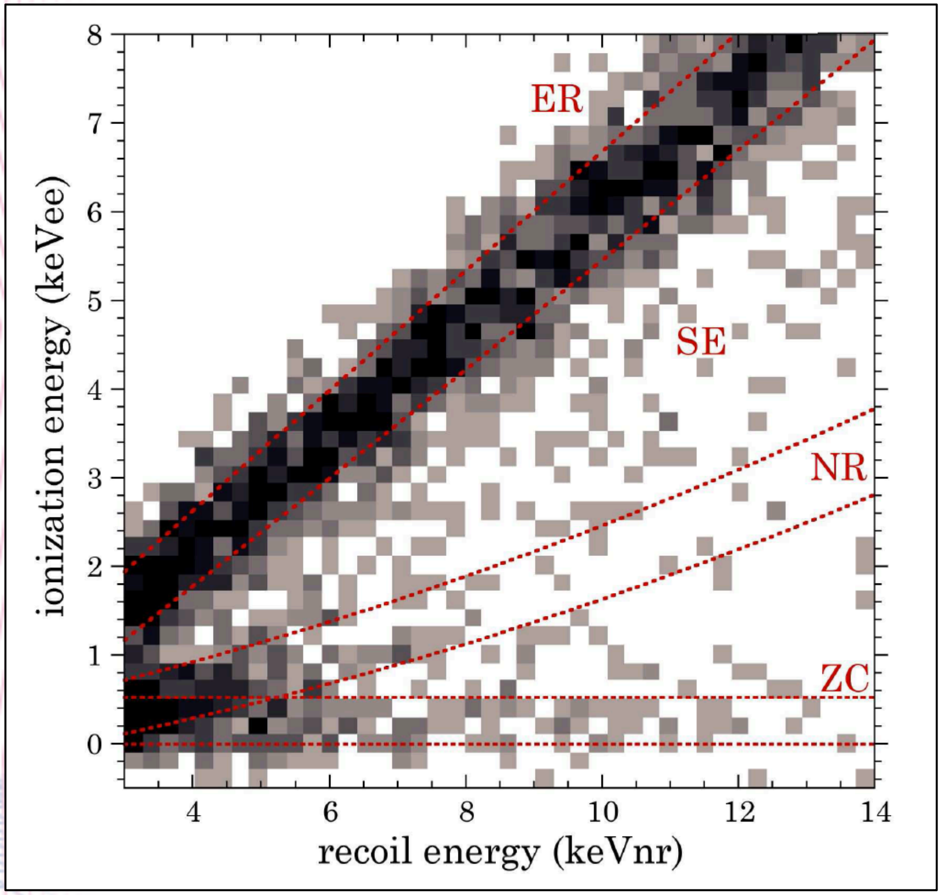
Zero Charge (ZC) Events

D. Moore,
Aspen 2011



- Events that occur in the edges of the detectors
- Leave no ionization signals
- We allow for a small non-zero offset (systematics), just like CDMS, obtaining same ZC band fit as CDMS.
- No distortion in ZC at low-E expected (evidenced in Ba-133 calibrations)
- Exponential PDF in E_r
- Gaussian PDF in E_i

Nuclear Recoil (NR) Events



- Included only in alternative hypothesis
- Initial location of NR band estimated from an average of individual detector bands
- Exponential PDF in E_r
- Gaussian PDF in E_i

Hypotheses

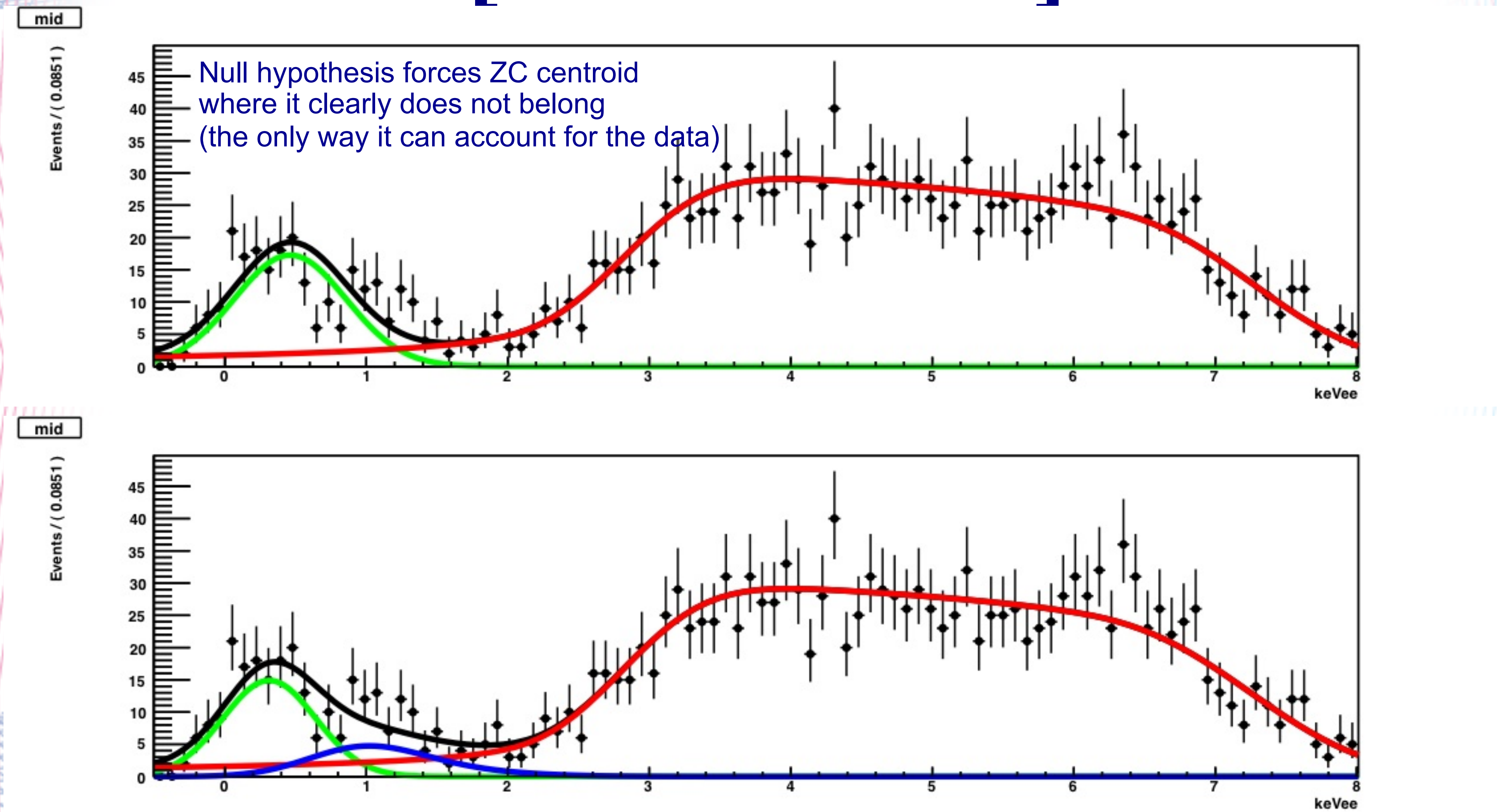
- Null – 11 free parameters
  - 2 common noise parameters, $\sigma^2 = S_1^{\,2} + S_2{}^*C(E_r)$
  - 3 total parameters for the location of the ZC and ER bands (constant, linear) – constrained or fixed
  - 2 exponential slope parameters (ZC, ER)
  - 2 normalization parameters (ZC, ER)
  - 2 power law parameters for SE (n, alpha)
- Alternative – 16 free parameters
  - 3 parameters for the NR band location (quadratic) – constrained or fixed
  - 1 exponential slope parameter, 1 normalization parameter

Results

Detector	Exposure (kg-day)	-2 ln(Λ)/Δd.o.f.	p-value	NR rate > 3 keVnr (c/kg-day)	A_2^{NR} (keVnr^{-1})
all	240.4	35.8 / 5	$1.0 \cdot 10^{-6}$	0.93 ± 0.17	0.650 ± 0.081
all-T3Z5	214.6	47.6 / 5	$4.3 \cdot 10^{-9}$	0.95 ± 0.14	0.701 ± 0.079
T1Z2	43.4	14.2 / 2	$8.3 \cdot 10^{-4}$	0.77 ± 0.20	0.569 ± 0.139
T1Z5	35.0	13.0 / 2	$1.5 \cdot 10^{-3}$	0.50 ± 0.17	0.714 ± 0.299
T2Z3	28.0	9.0 / 2	$1.1 \cdot 10^{-2}$	1.31 ± 0.68	0.659 ± 0.222
T2Z5	34.7	3.4 / 2	$1.8 \cdot 10^{-1}$	0.76 ± 0.41	0.745 ± 0.355
T3Z2	7.8	5.1 / 2	$7.8 \cdot 10^{-2}$	3.38 ± 1.24	0.705 ± 0.215
T3Z4	29.6	12.8 / 2	$1.7 \cdot 10^{-3}$	0.39 ± 0.15	0.636 ± 0.202
T3Z5	25.8	0.26 / 2	$8.8 \cdot 10^{-1}$	0.15 ± 0.38	2.01 ± 2.44
T3Z6	36.1	4.1 / 2	$1.3 \cdot 10^{-1}$	0.61 ± 0.31	0.707 ± 0.361

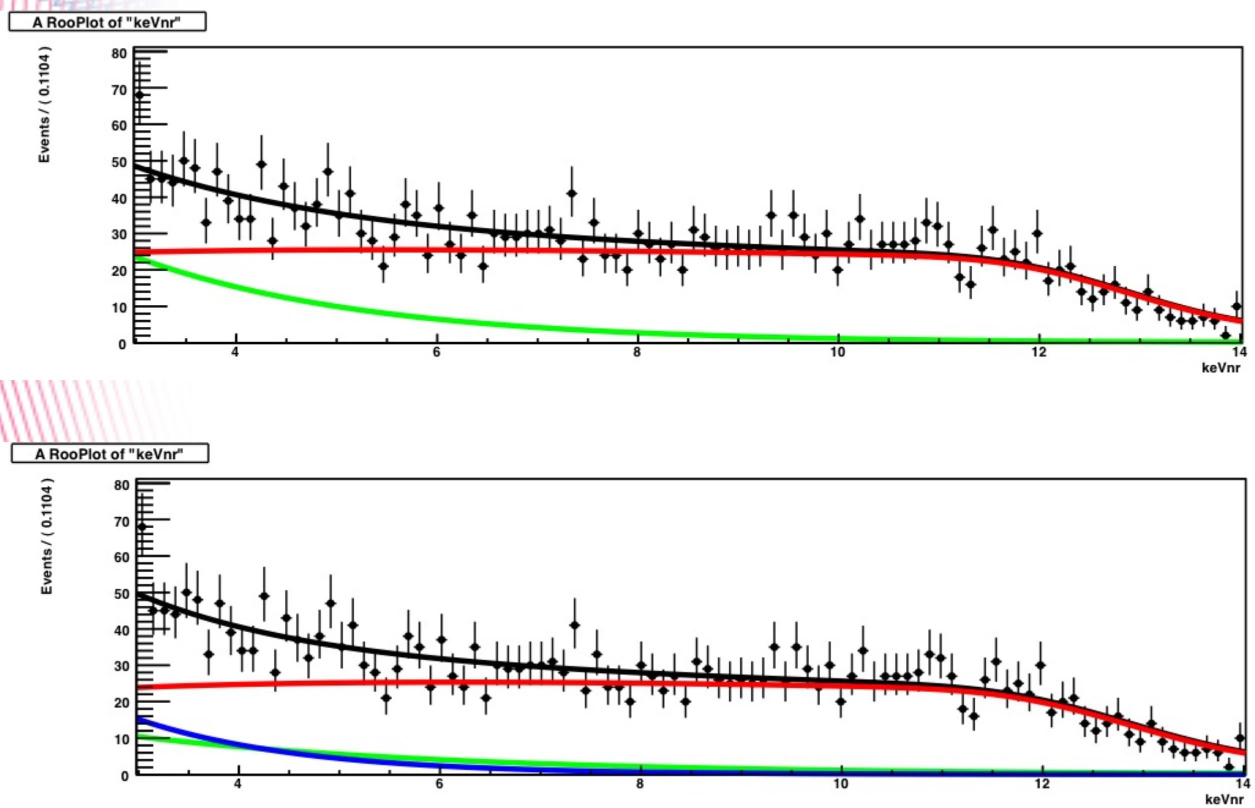
- For individual detectors – ER, NR bands fixed
- ZC offset allowed to float – constrained
- Log likelihoods hand corrected for gaussian constraints – small adjustment in version submitted to journal.
- NR rate and slope parameters consistent across detectors once differences (resolution, exposure) noticed. >5 sigma “evidence” for NR excess on summed data.

Projections (E_i) [5-11.9 keVnr]



– ER – NR – ZC

Projections (E_r)



– ER – NR – ZC

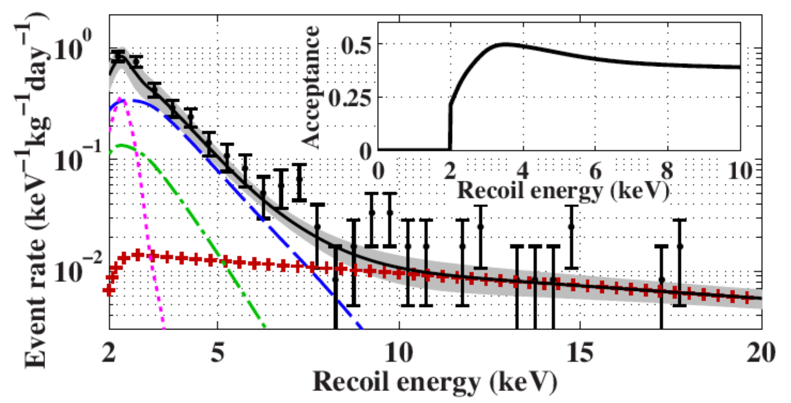
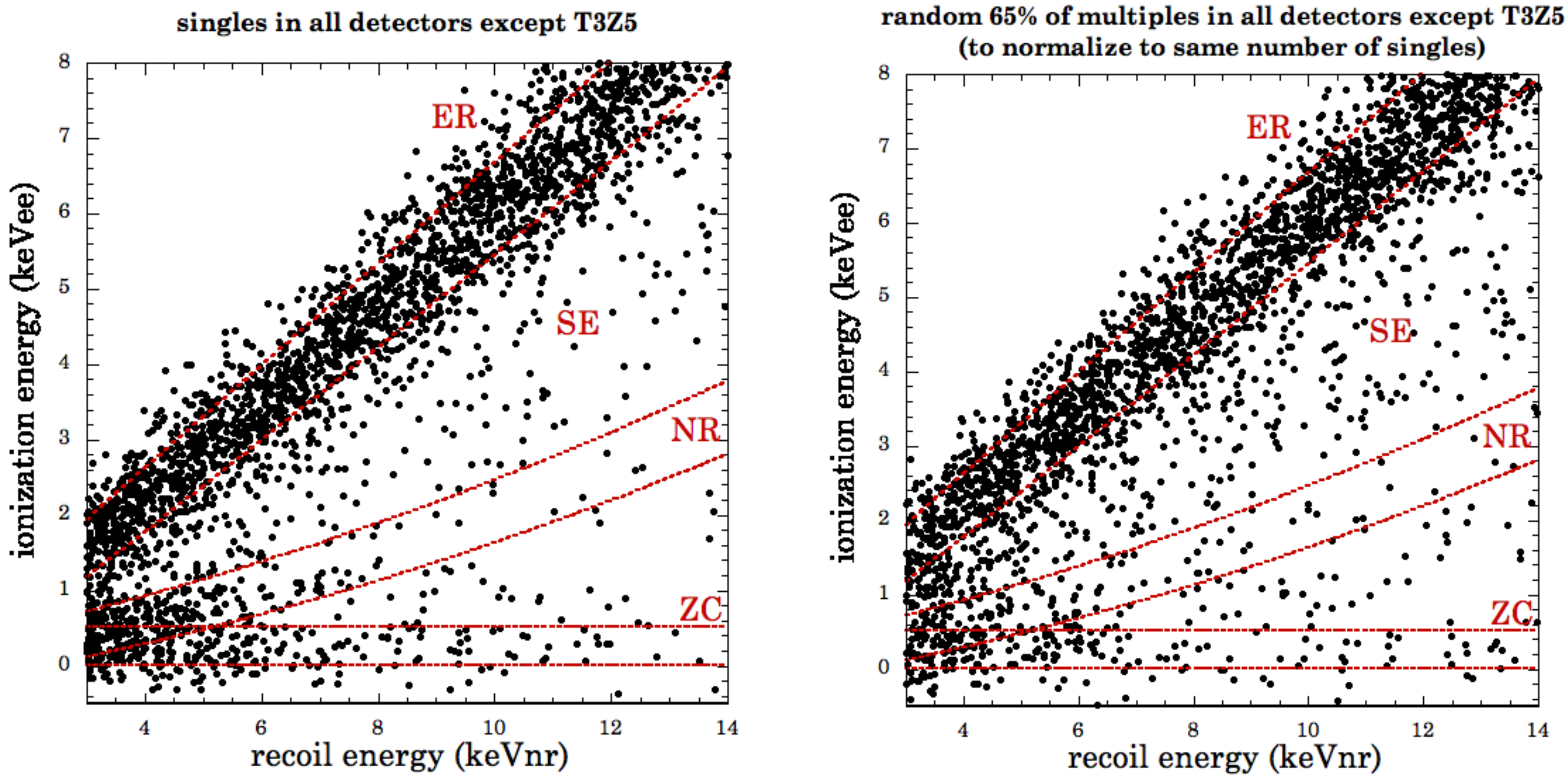


FIG. 1. (color online). Comparison of the energy spectra for the candidate events and background estimates, co-added over the 8 detectors used in this analysis. The observed event rate (error bars) agrees well with the electron-recoil background estimate (solid), which is a sum of the contributions from zero-charge events (dashed), surface events (+), bulk events (dash-dotted), and the 1.3 keV line (dotted). The gray band denotes the 1σ statistical errors on the background estimate. The selection efficiencies have been applied to the background estimates for direct comparison with the observed rate, which does not include a correction for the nuclear-recoil acceptance. The inset shows the measured nuclear-recoil acceptance efficiency, averaged over all detectors.

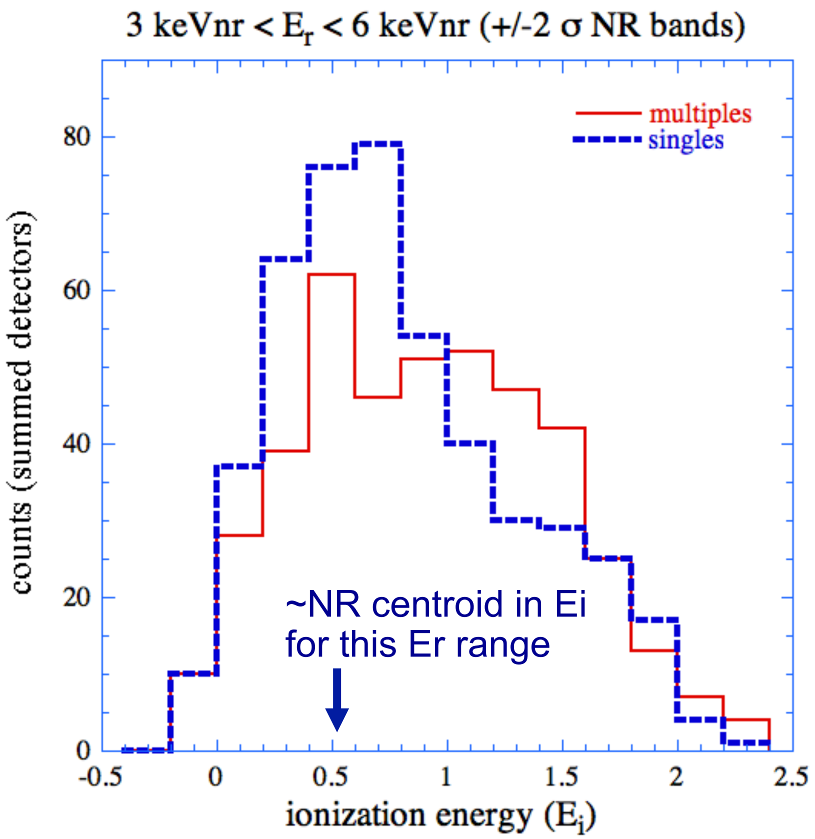
Begs comparison with arbitrary method used in arXiv:1011.2482 to estimate NR and ZC components (see discussion in arXiv:1103.3481). Our conclusions about low-E background composition clash with CDMS': we consider our approach much more refined in this respect.

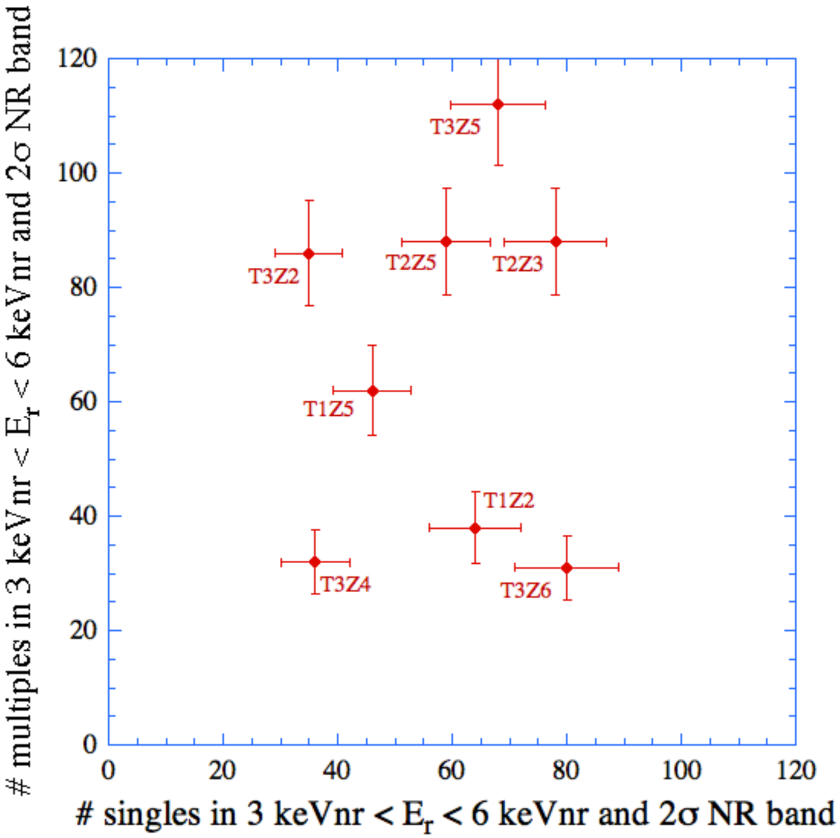
Are these surface events?
(doesn't seem to be the case)



- **Subset of surface activity multiples (e.g., escaping gamma from Pb-210, leaving degraded Ei beta) can lead to singles in NR. However, no obvious accumulation of multiples in NR (right panel) and…**

Are these surface events?
(doesn't seem to be the case)



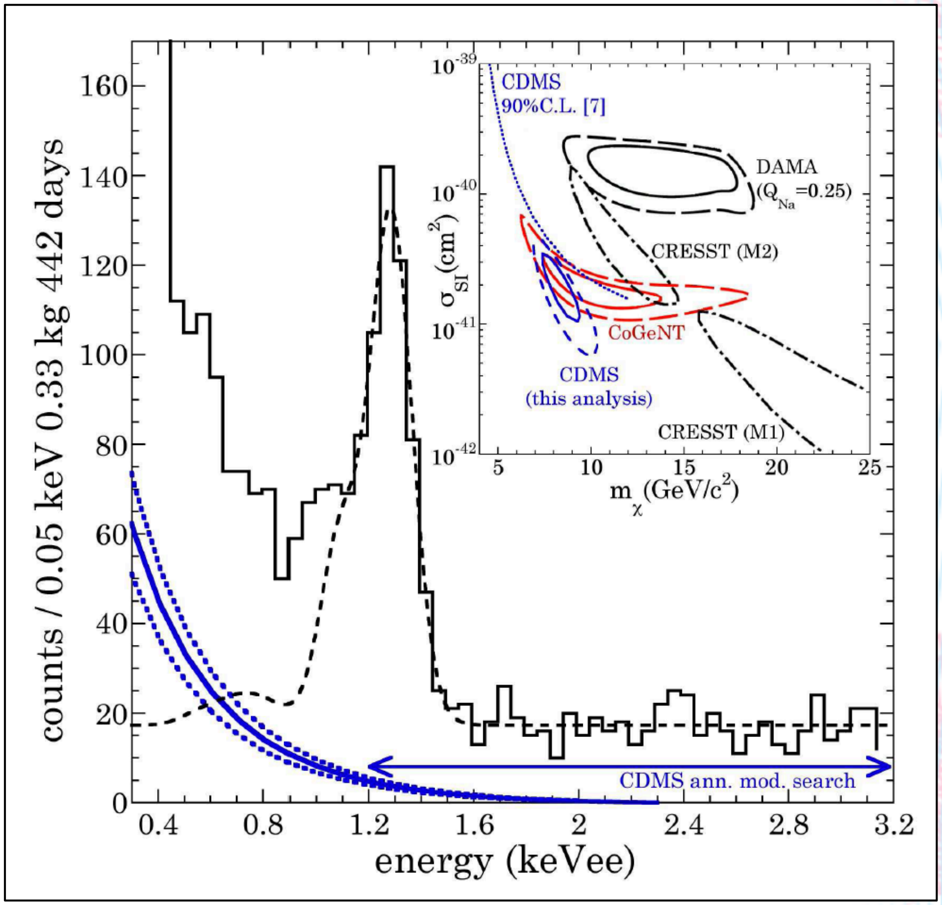


- **Left: singles distribution in ROI is centered around NR, and well-separated from ER. Multiples distribution is on the other hand ~flat across Ei.**

- **Right: complete lack of correlation in single and multiple rates in ROI, pointing at a lack of a common physical origin (overall rates correlate, as they should –external gamma background-). T3Z6 is an endcap detector, but T3 is also the tower lowest in average surface activity, by a factor ~2.5.**

Comparison with CoGeNT

- Does not conflict with previous low energy CDMS limit.
- Right on top of CoGeNT ROI (surface corrected).
- Self-consistency: CDMS ann. mod. analysis cannot exclude this excess due to >5 keVnr choice.
- Unfortunate that data in 2-3 keVnr were not shown (but we know from arXiv: 1011.2482 that CDMS excess continues to trace CoGeNT's there).



Conclusions

- We performed an unbinned maximum likelihood analysis on low energy CDMS data.
- The alternative hypothesis (presence of exponential excess in NR) is preferred over the null hypothesis at 5.7σ. Neutron origin extremely unlikely (< 1 event). Seems present in all detectors.
- The CDMS NR excess seems consistent with the CoGeNT excess following surface BR correction.
- It is also consistent with previous WIMP limits from CDMS.
- An annual modulation analysis reverting to a 2 keVnr threshold (previously sanctioned by CDMS in arXiv:1011.2482) would put the question to rest, but present CDMS technology may not allow for this (stability issues).
- Need for more transparency and openness in access to DM detector data (no, we did not enjoy digitizing all these points). Sadly, CoGeNT remains isolated in this respect.

Thank You!

Questions?