Physics of background discrimination in liquid xenon-based dark matter detectors

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Princeton / Case Western

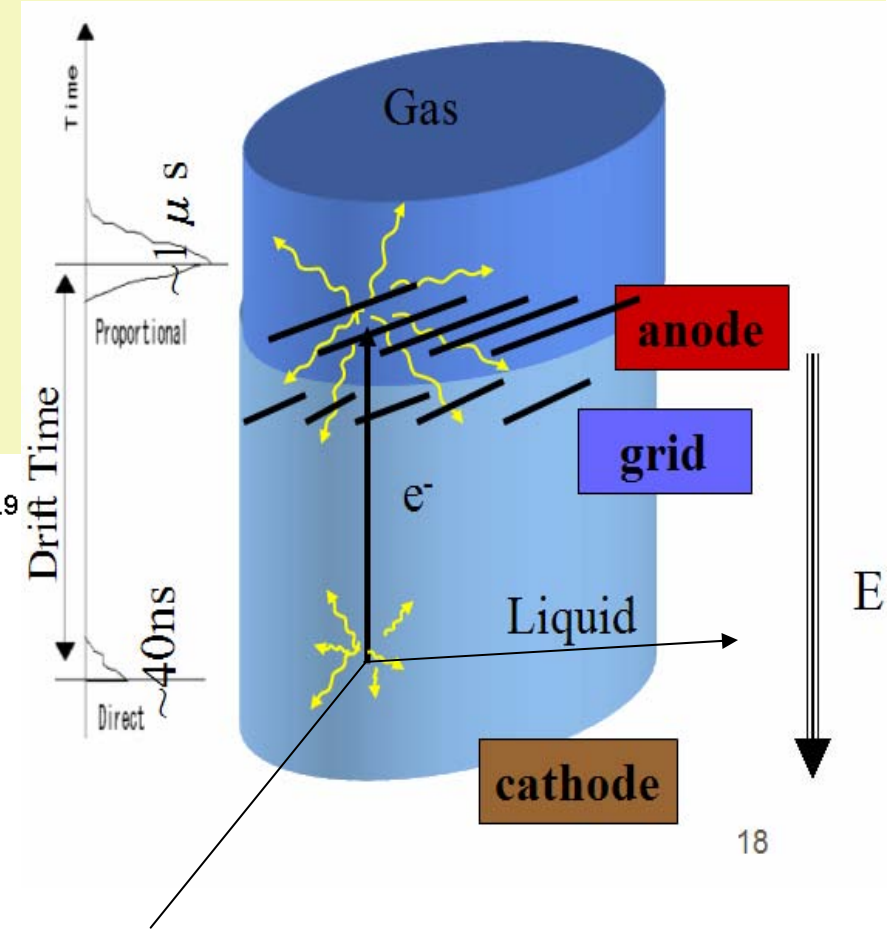
Xenon Collaboration

Outline

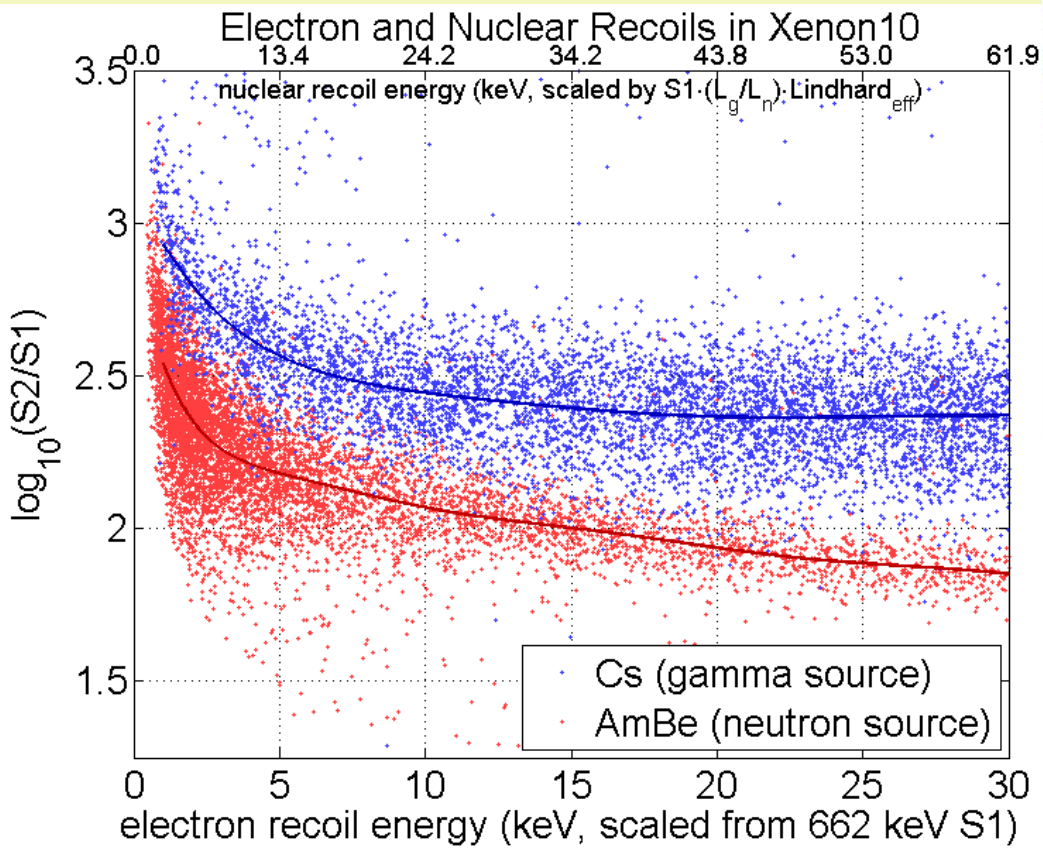
- Intro / Xenon discrimination review
- Observed Discrimination
  - Determined by what?
- Measuring recombination fluctuations
- Discrimination with…
  - Improved light collection
  - Higher drift field

Signal Production in ℓXe

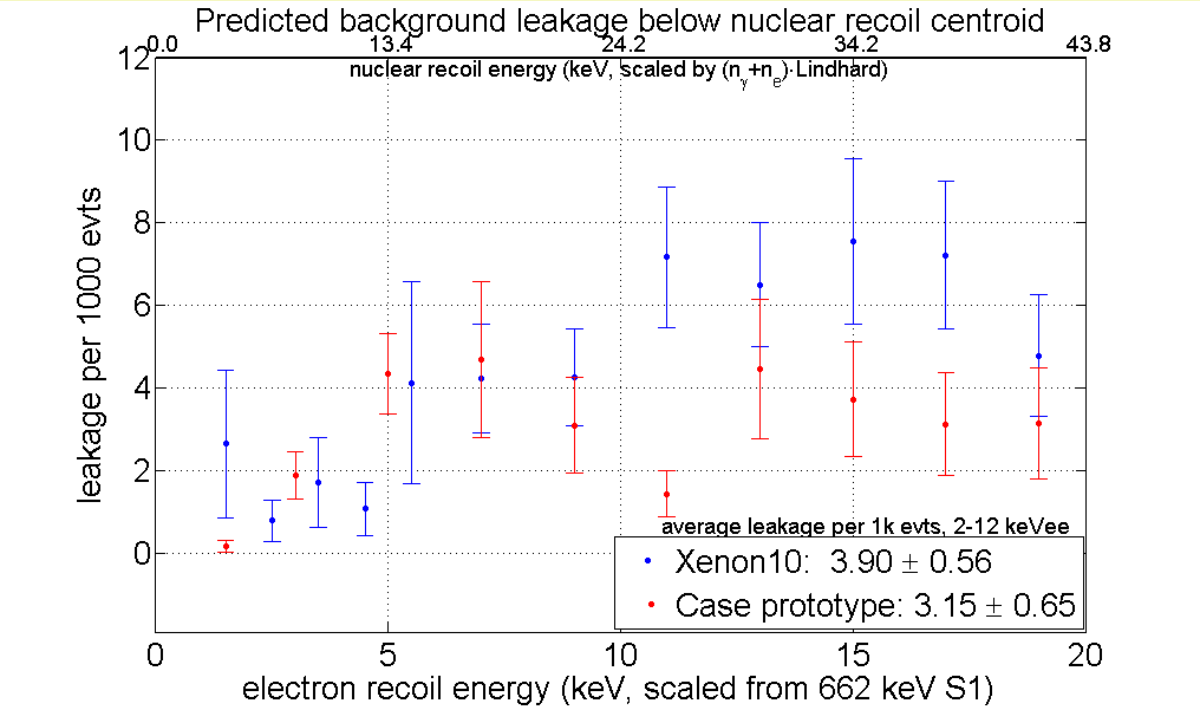
- Scintillation and charge measured per event
- Background discrimination from charge/light ratio.



γ, n / WIMP

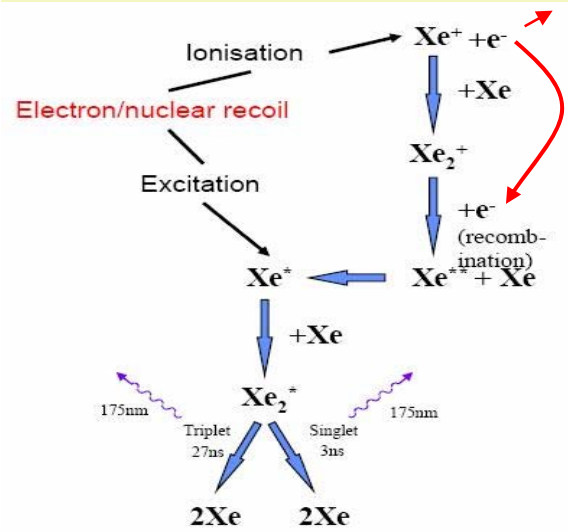


Discrimination



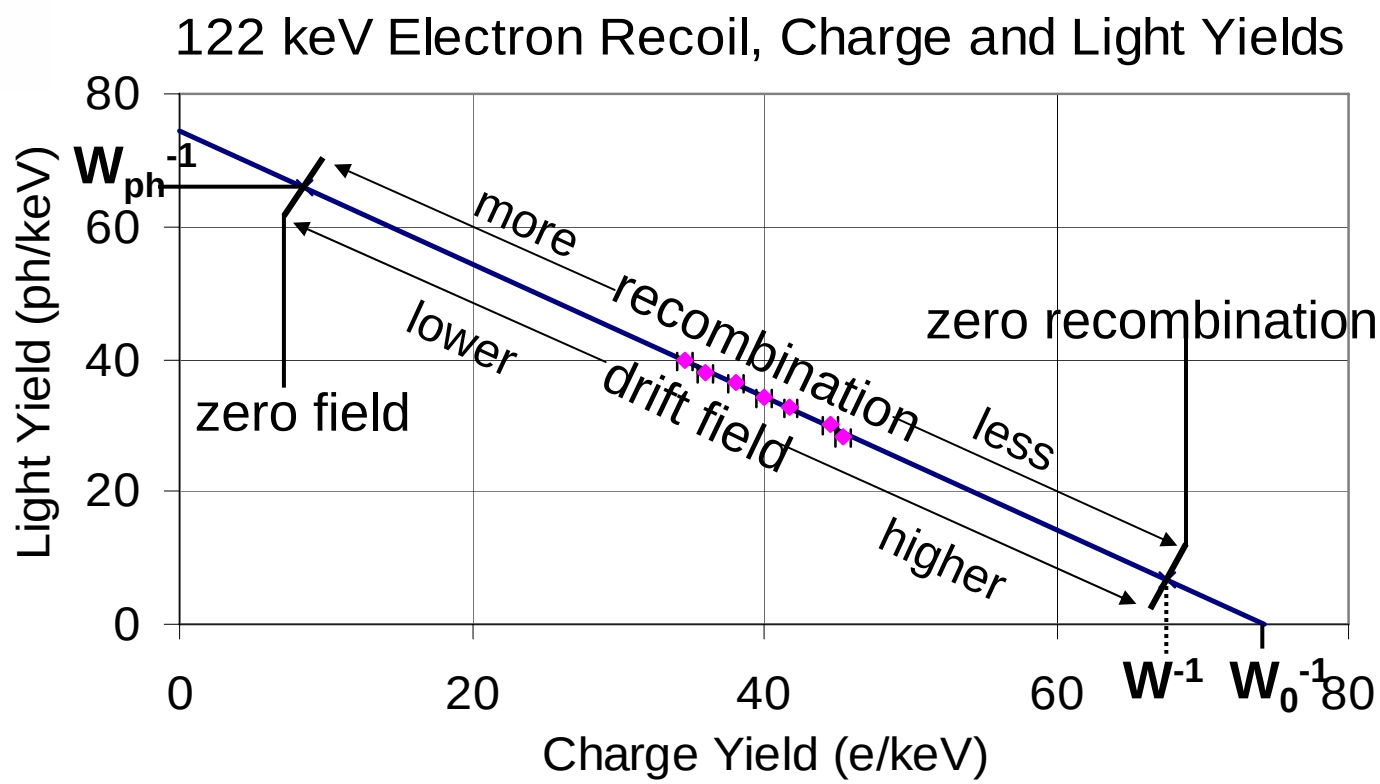
- What determines discrimination?
  - Band separation (given)
  - Band widths
    - a) Statistical fluctuations (Poisson/binomial)
    - b) Instrumental fluctuations in signal gain (Position dependence, *etc.*)
    - c) Recombination fluctuations
- How can we tell b) from c) ?

Recombination → Charge-light anti-correlation



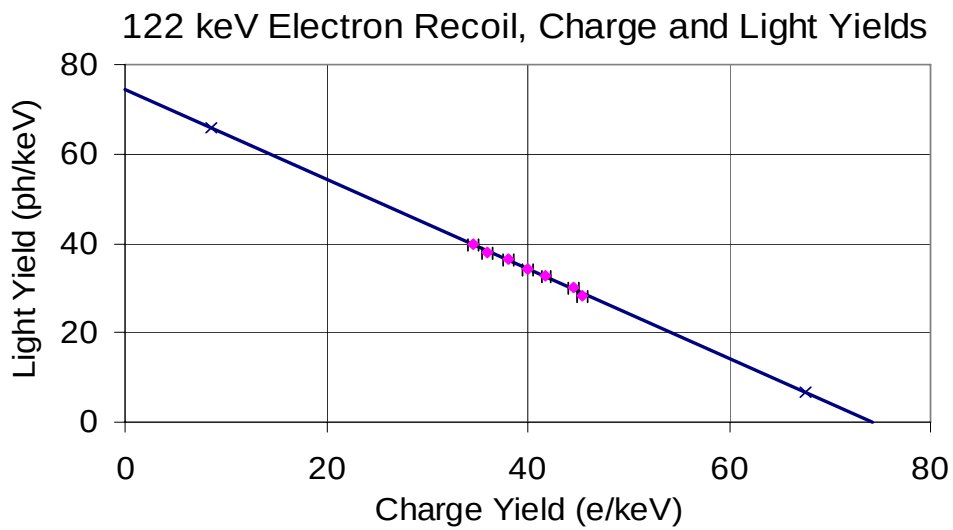
Nigel Smith, RAL

- Need to calibrate anti-correlation
  - Measure peak at different fields



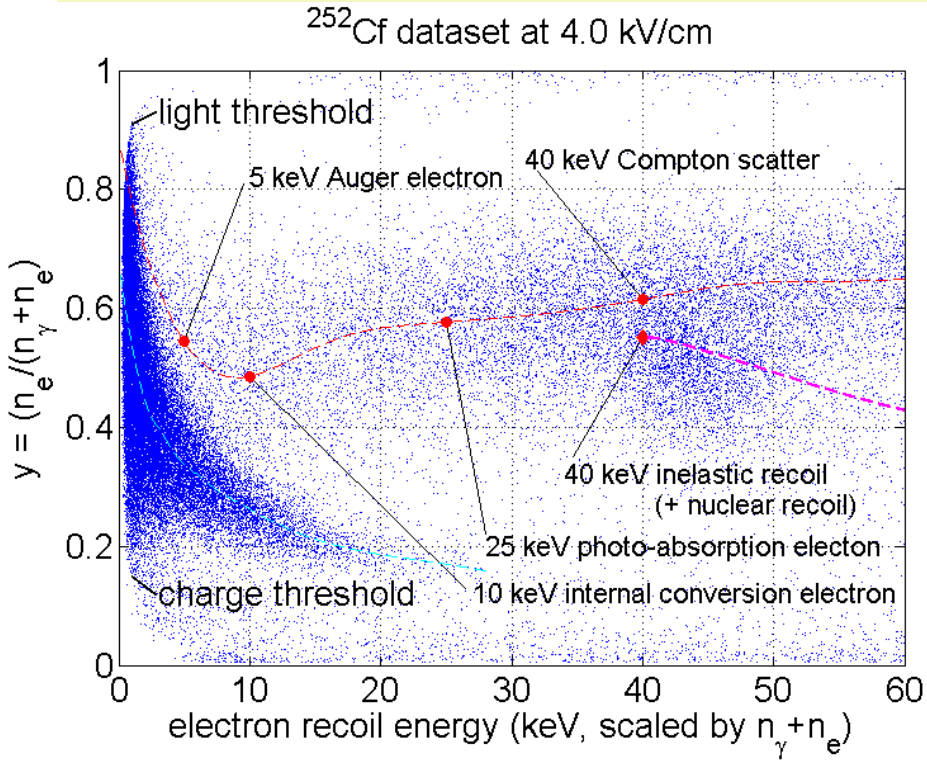
C. Dahl, APS April 2007

Recombination → Charge-light anti-correlation

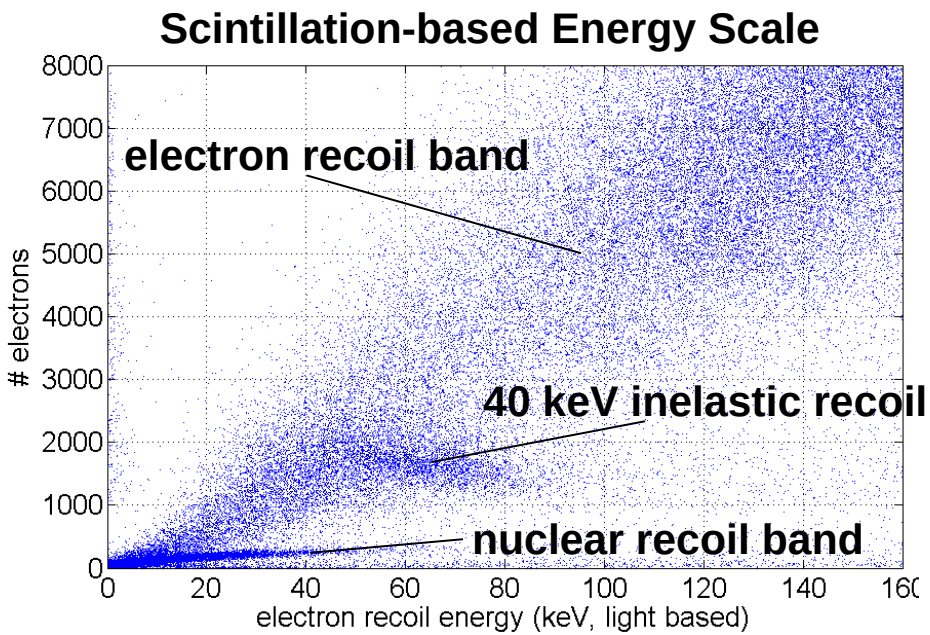


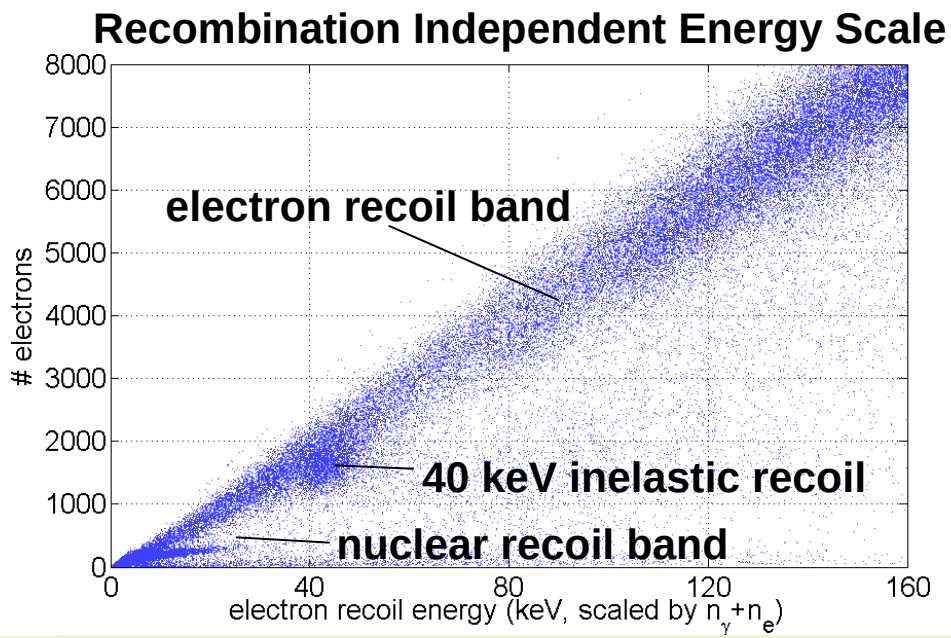
- Need to calibrate anti-correlation
  - Measure peak at different fields

- Construct recombination independent sum
  - Check positions of other peaks
  - Reconstruct complex events



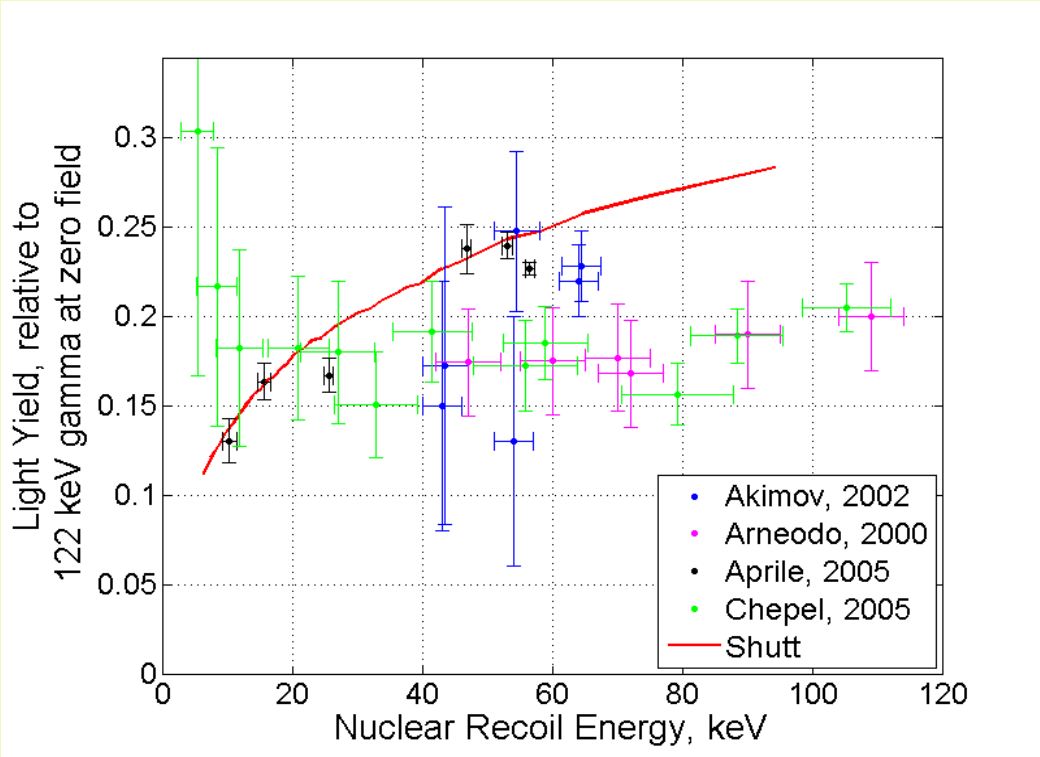
Recombination, Cont'd





- Recombination flucts also anti-correlated
  - More on this later-

Recombination, Cont'd

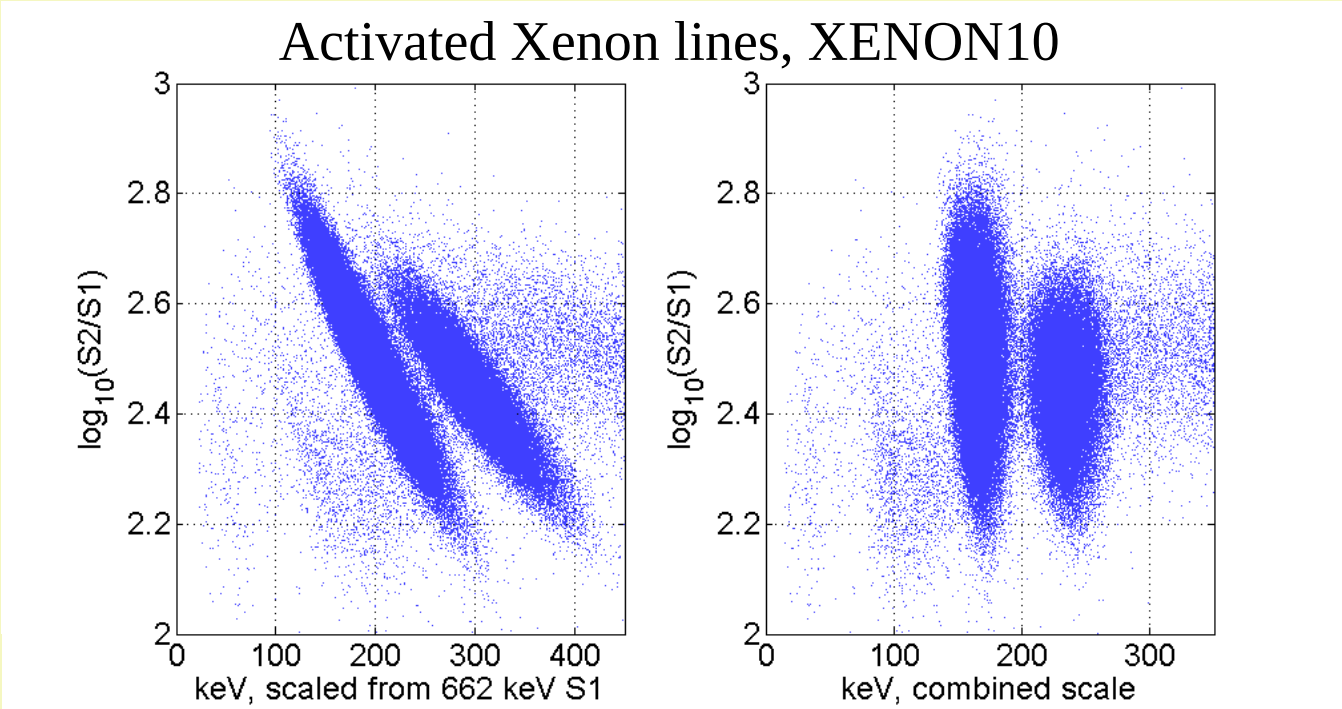


- keVr combined scale
  - Lindhard applies to total electronic excitation

Good agreement at WIMP recoil energies

(Light yield alone loses escaped electrons)

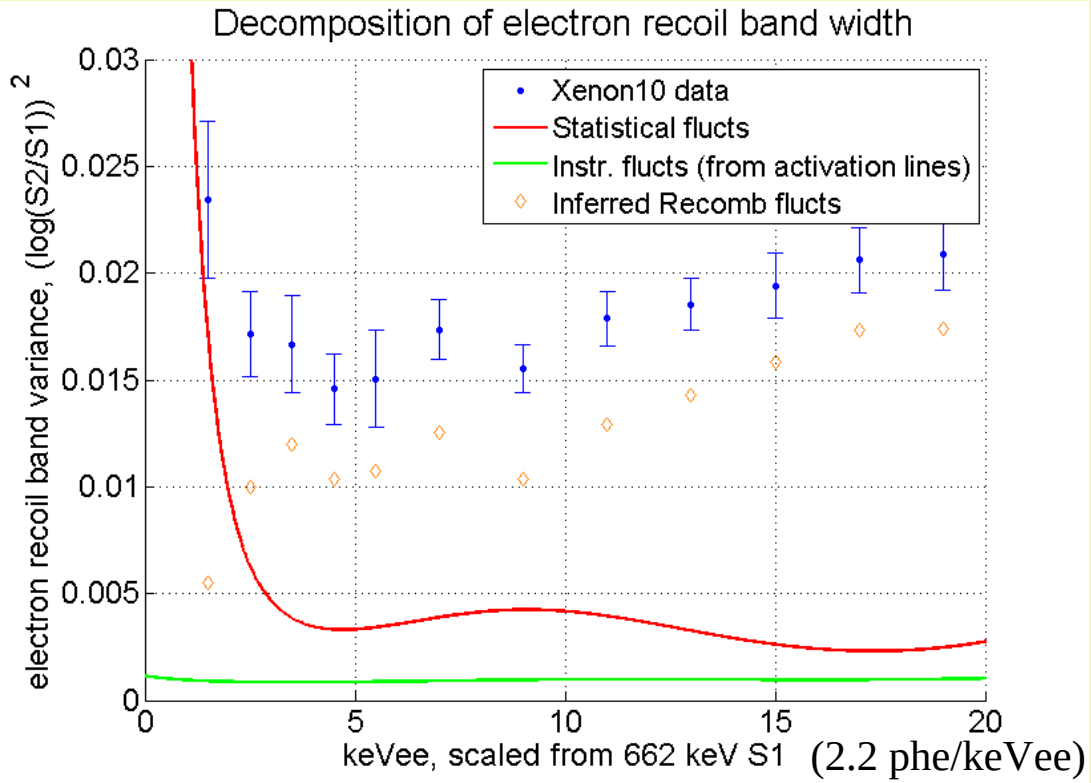
Recombination fluctuations also anti-correlated



- Improved resolution with combined energy scale
- $\sigma^2_{S1} + \sigma^2_{S2} - \sigma^2_{S1+S2} = 2\,\sigma^2_{recomb}$
  - Equivalent to off-diagonal element of covariance matrix
  - Large systematic involved – instrumental flucts can also be correlated

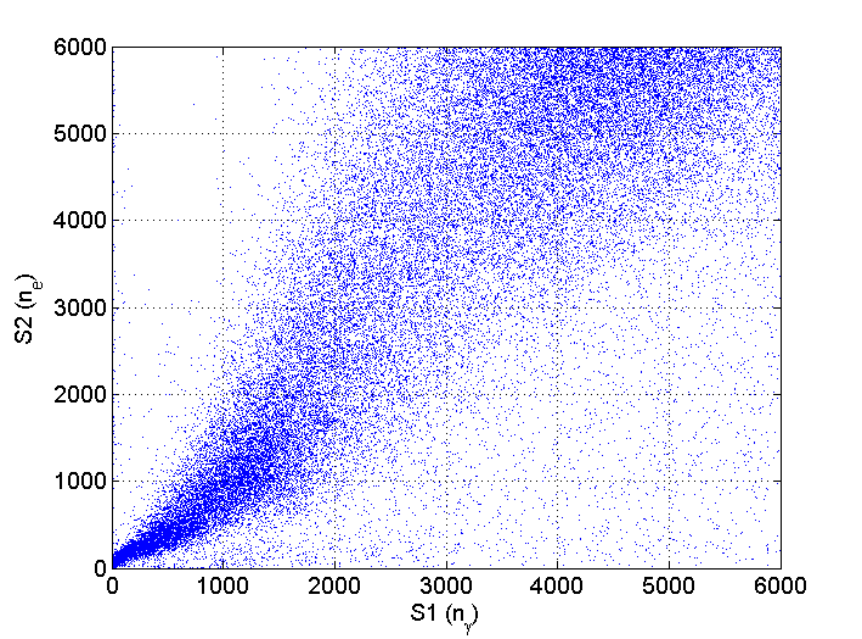
Limits to Discrimination

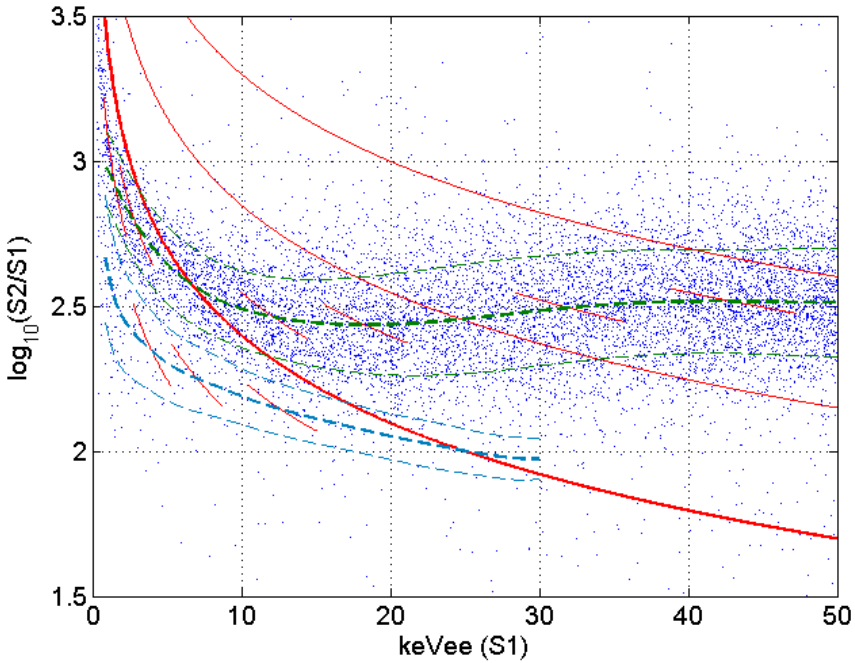
- Extrapolate from activation peaks to WIMP range
  - Instrumental flucts scale with signal size
  - 25% fewer predicted leakage events without instrumental flucts
  - Recombination fluctuations: hard limit of 99.9% rejection at 50% acceptance

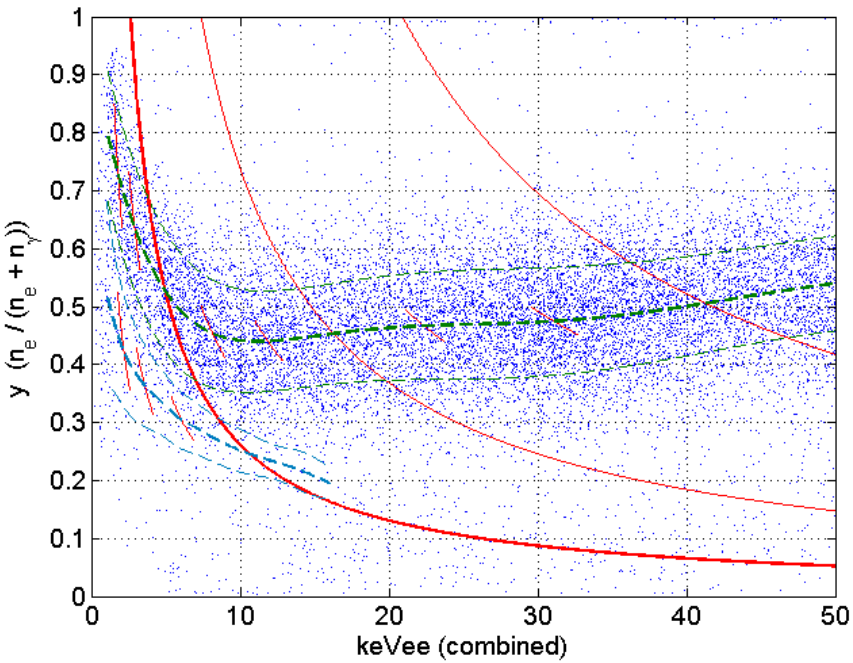


(2.2 phe/keVee)

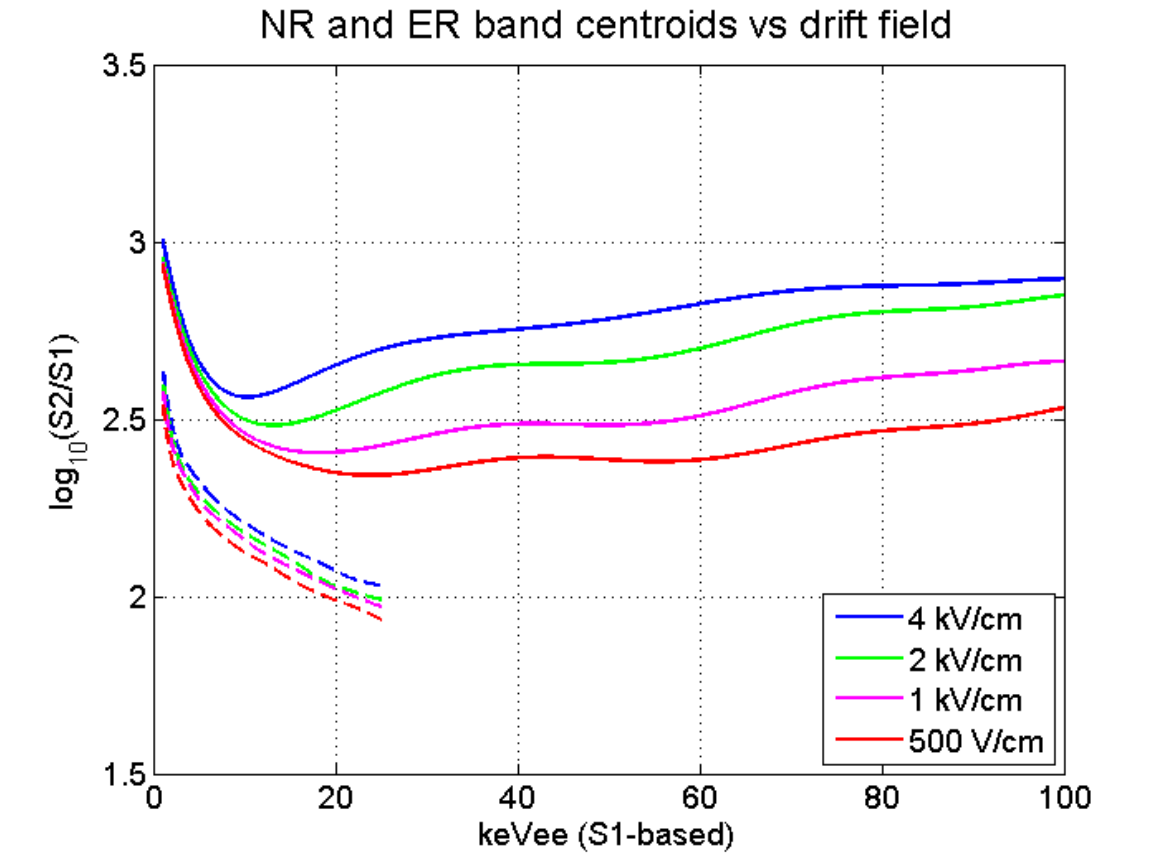
Second look: S1 fluctuations



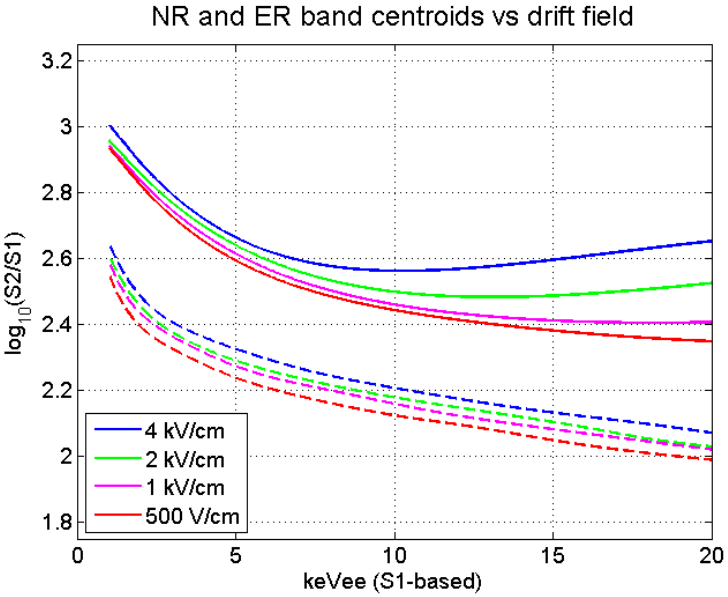




Field Dependence



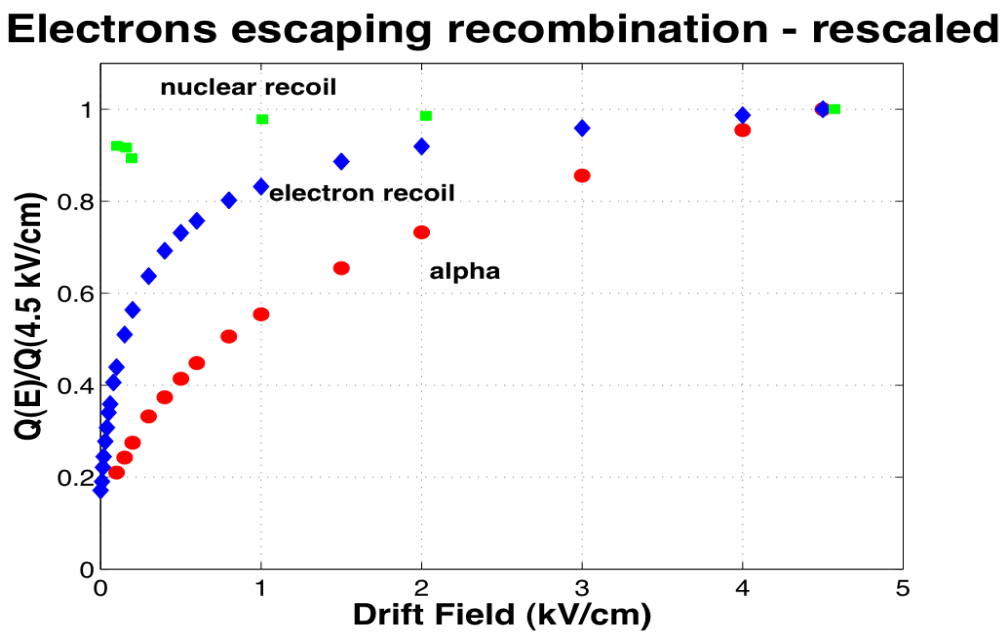
- Electron recoils are field dependent
- Nuclear recoils are not, very

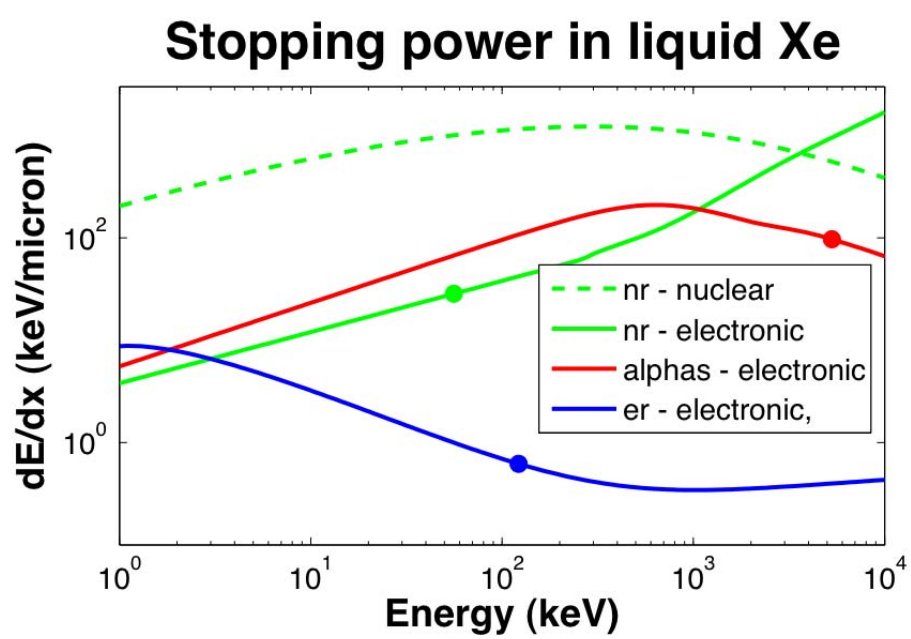


- But… ER field dependence disappears in WIMP range

Yield vs Field behavioral disorders

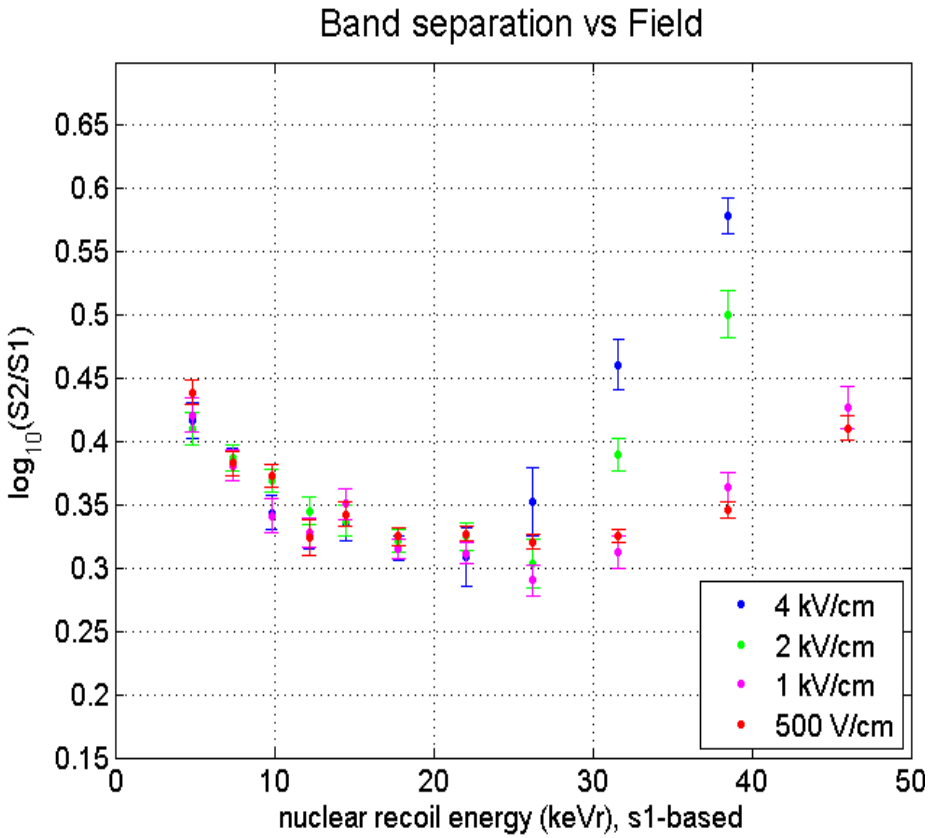
- What's happening to the charge yield vs field?
  - Yield should anti-correlate to $dE_{electronic}/dx$
  - BUT low energy electron recoils have HIGHER yield
  - Similar behavior in nuclear recoils
  - This is also where field independence kicks in

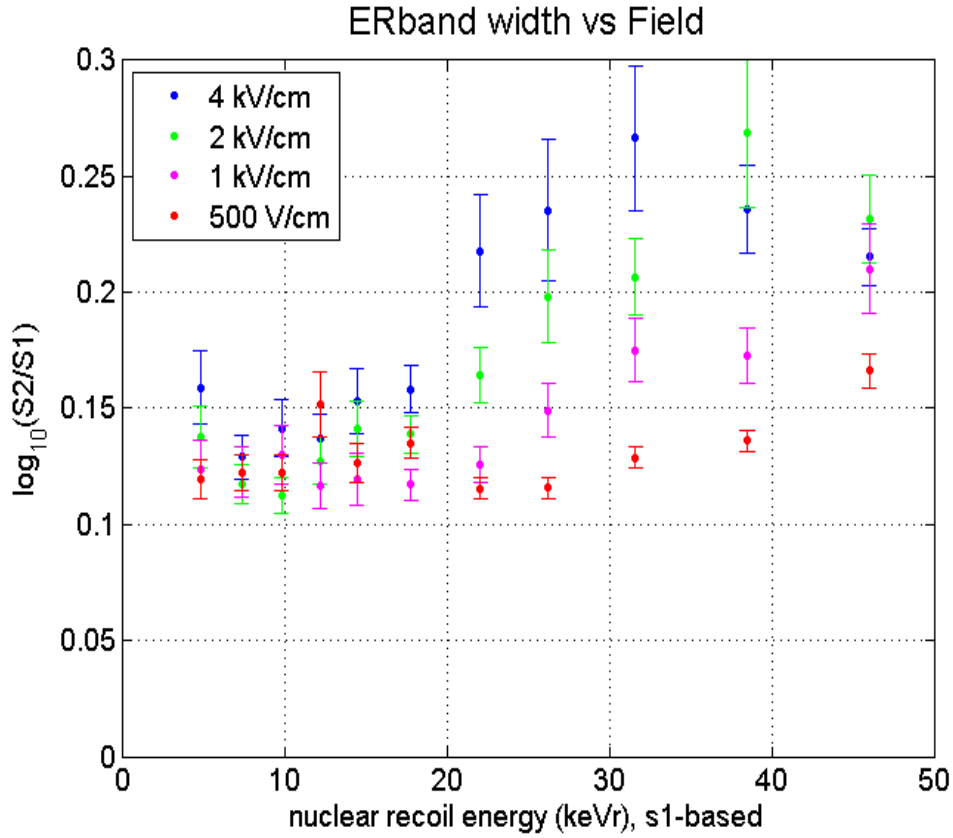




Field Dependence, cont

- Band separation and width field independent under 25 keVr





– Tails could change at higher field

Conclusions

- Observed and Calibrated recombination anti-correlation
- Separated instrumental/recombination fluctuations at activation lines
- Scale instrumental flucts to WIMP energies
  - 25% fewer leakage evts w/o instrumental flucts
  - Hard limit of 99.9% discrimination, 2-12 keVee
- No field dependence < 25 keVr