Probing the Intrinsic Electron Recoil Rejection Power in Liquid Xenon for Dark Matter Searches

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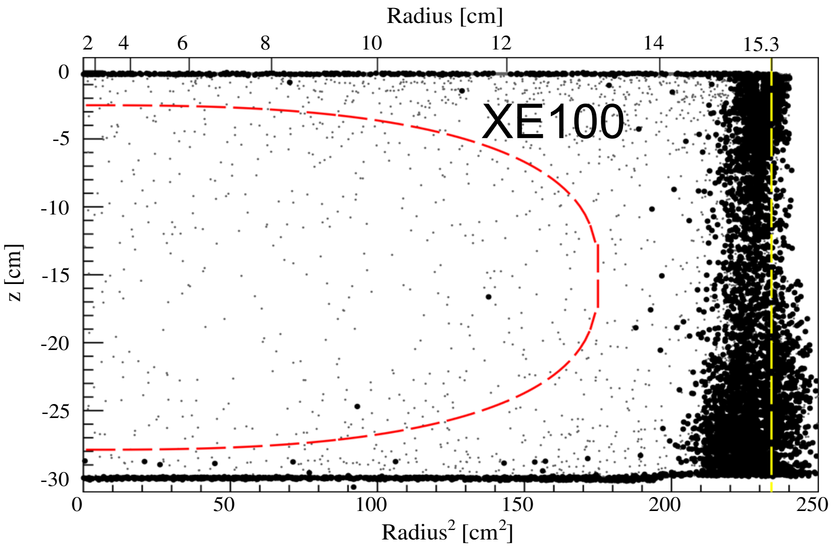
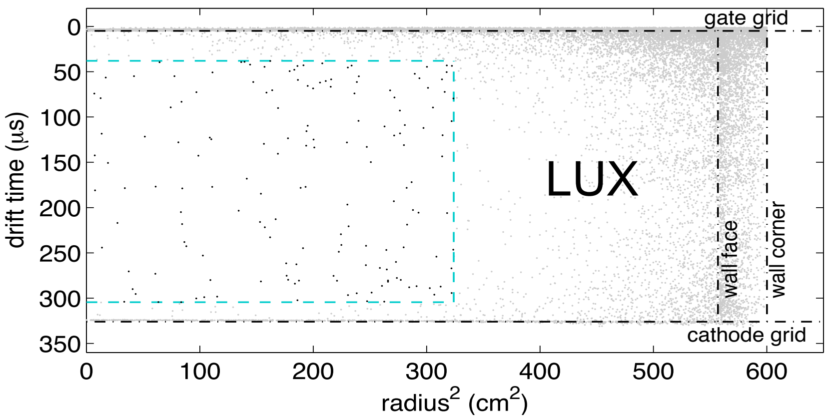
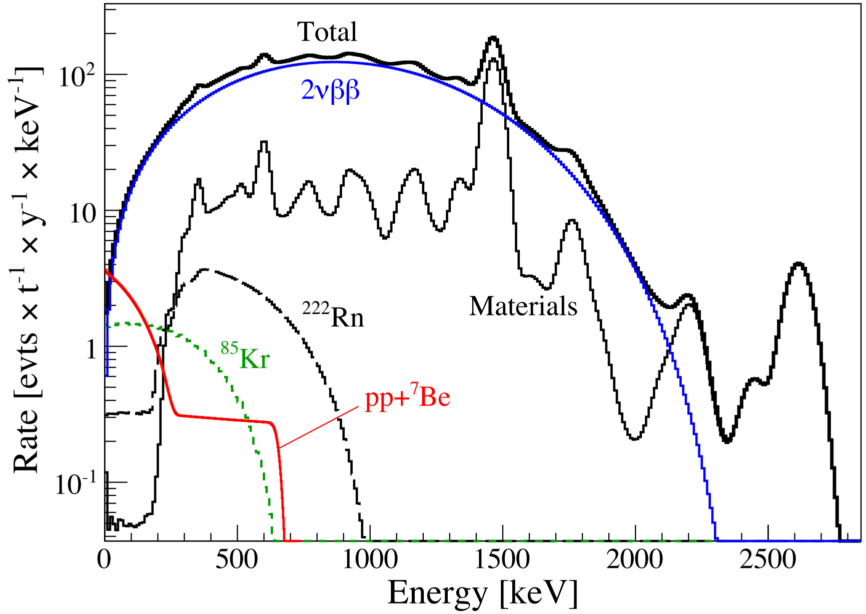
Until now, the dominant background for liquid xenon DM experiments are electron recoils (ERs).



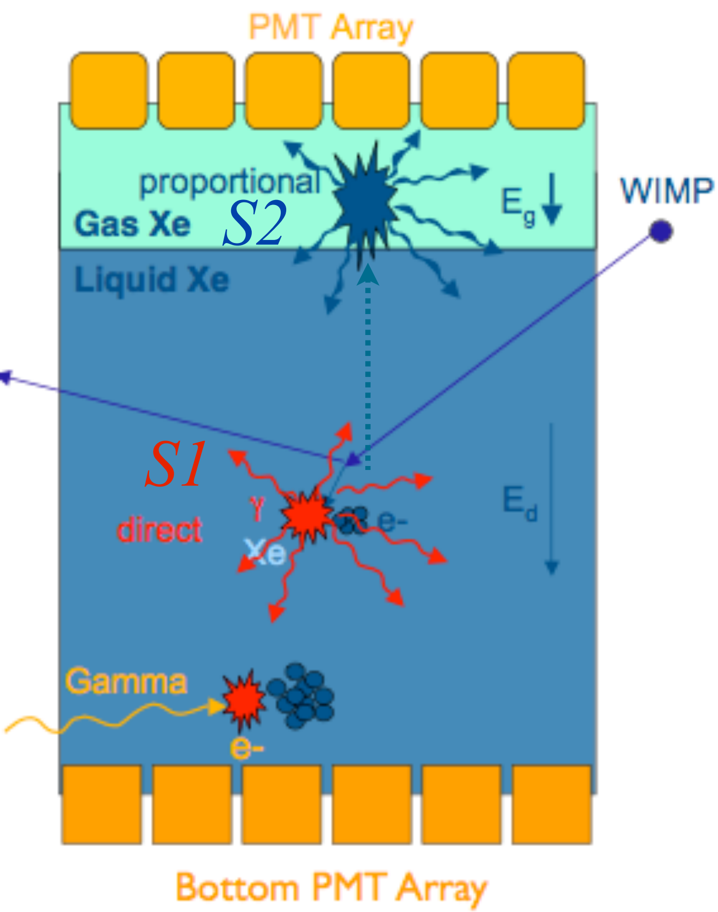


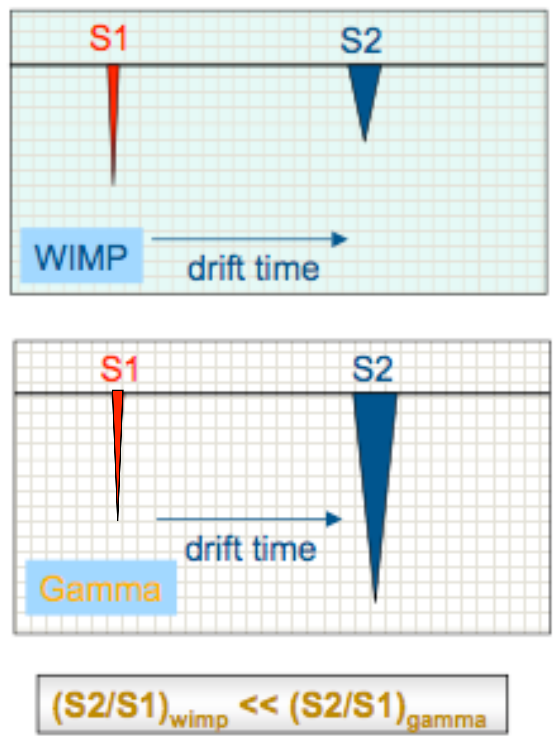
Baudis et al., arXiv:1309.7024

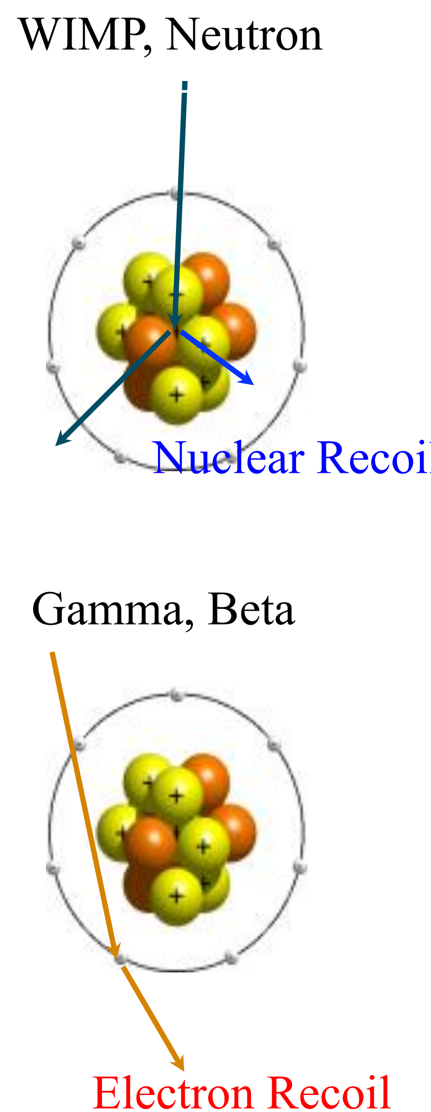


For future multi-ton Xe experiments, ER backgrounds from Xe136 2v2b and solar neutrinos will be dominant (before reaching the neutrino coherent scattering background)

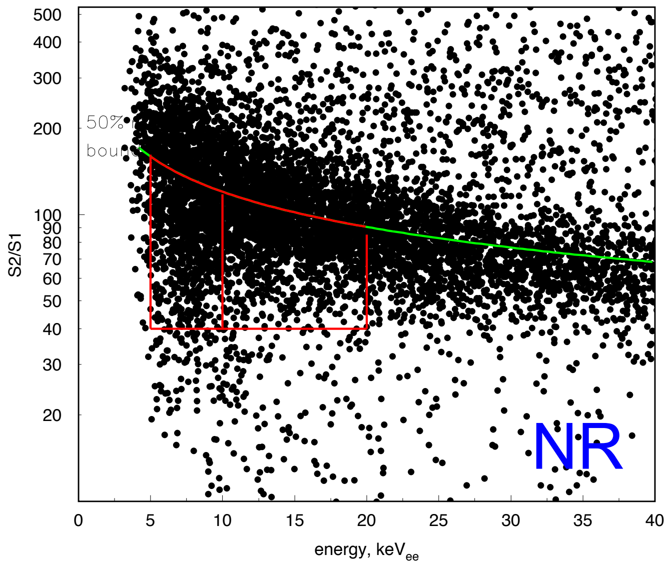
The two-phase xenon detectors use S2/S1 ratio to reject electron recoil background in the fiducial volume.

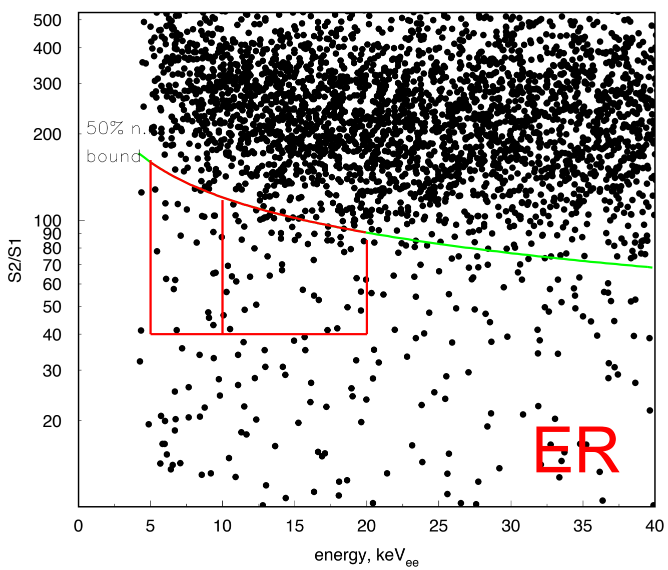






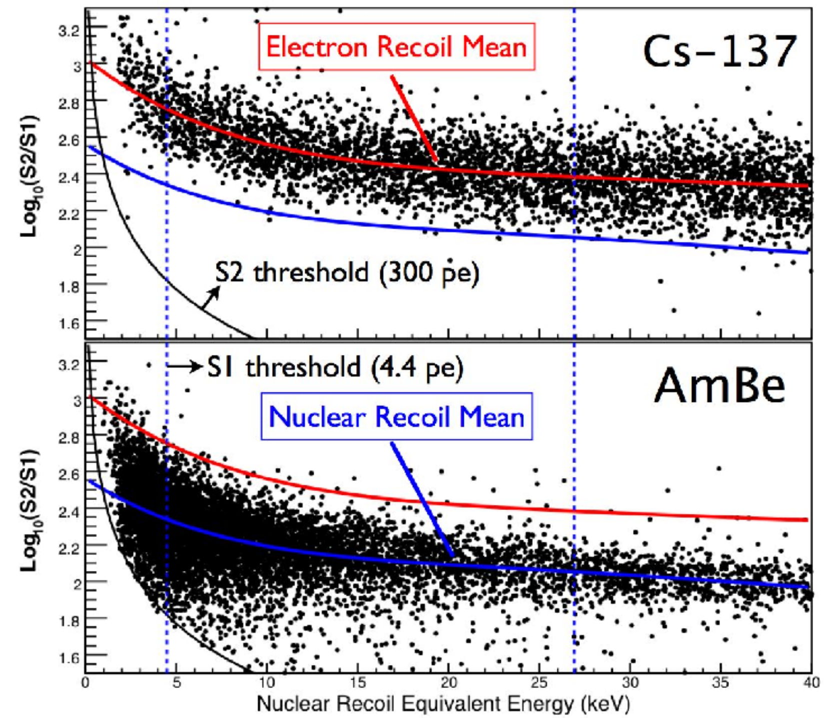
ZEPLIN-II, arXiv:0701858





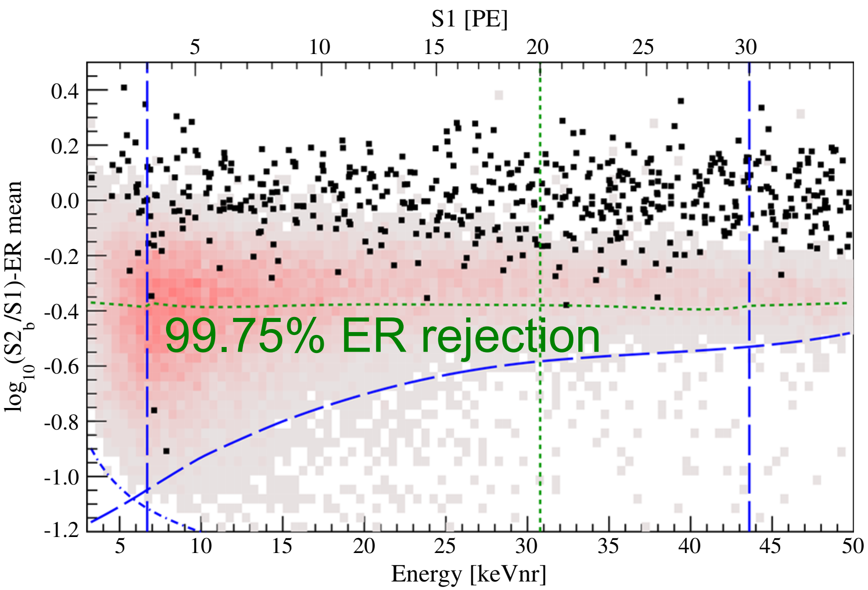
98.5% ER rejection for
~50% NR acceptance

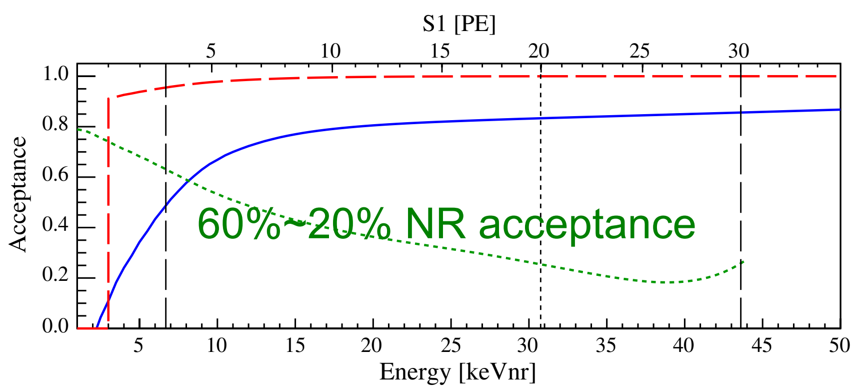
XENON10, PRL 2008



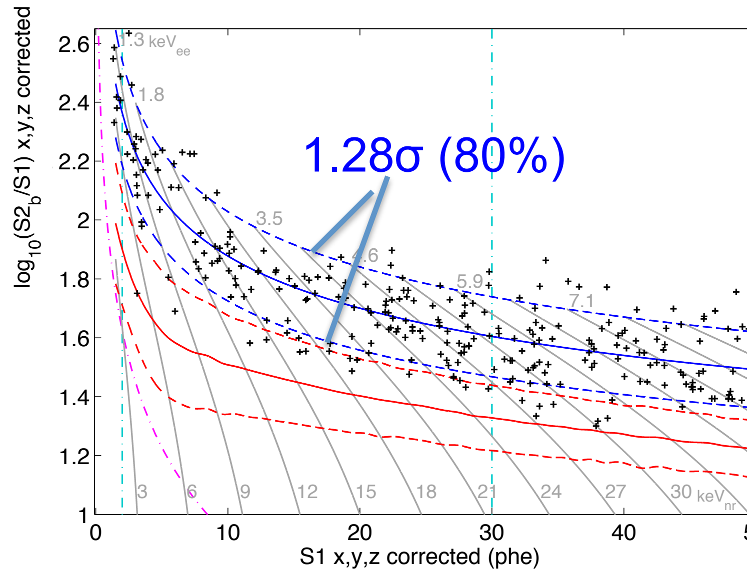
E_{nr} (keV)	ε_c	A_{nr}	$1 - R_{er}$ (10^{-3})	
4.5–6.7	0.94	0.45	$0.8^{+0.7}_{-0.4}$	99.9%
6.7–9.0	0.90	0.46	$1.7^{+1.6}_{-0.9}$	
9.0–11.2	0.89	0.46	$1.1^{+0.9}_{-0.5}$	
11.2–13.4	0.85	0.44	$4.1^{+3.6}_{-2.0}$	
13.4–17.9	0.83	0.49	$4.2^{+1.8}_{-1.3}$	
17.9–22.4	0.80	0.47	$4.3^{+1.7}_{-1.2}$	
22.4–26.9	0.77	0.45	$7.2^{+2.4}_{-1.9}$	99.3%

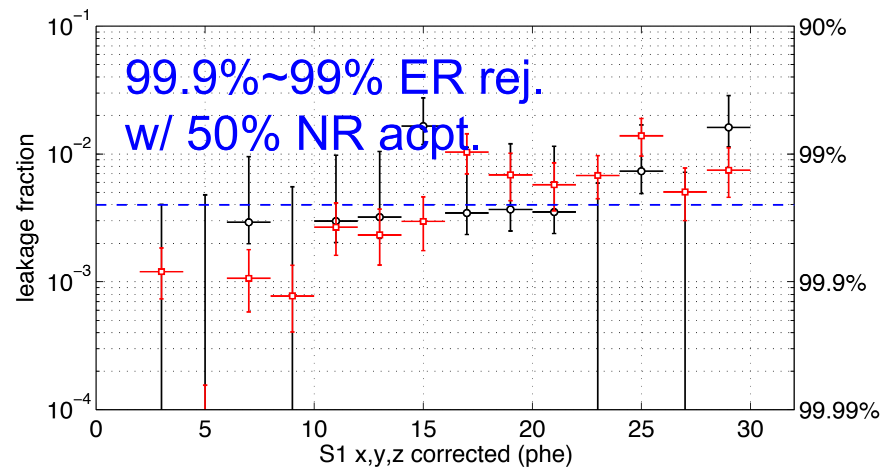
XENON100, PRL 2012





LUX, PRL 2014

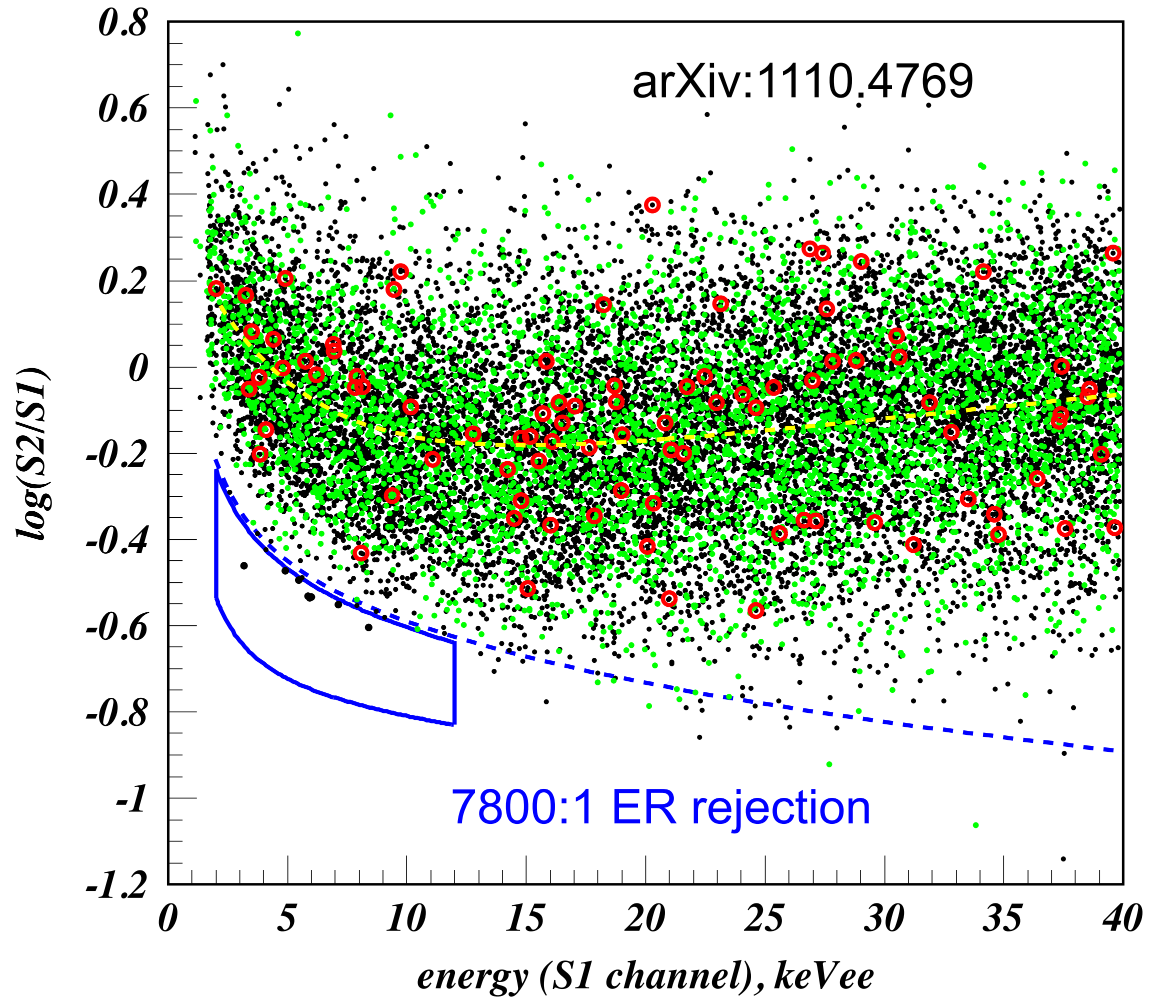




The Question:

Is 99.9% ER rejection (50% NR acceptance) the fundamental limit for liquid xenon?

ZEPLIN III: achieved 99.987% ER rejection power, the best reported for LXe DM detectors.



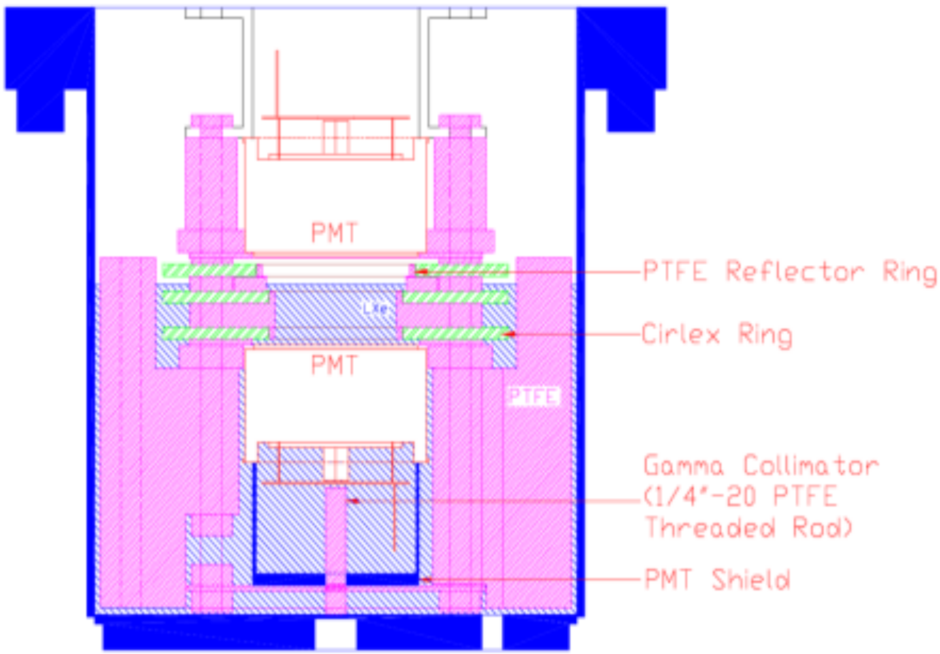
	Field (kV/cm)	Light yield (pe/keVee, for 122 keV at zero field)	Energy ROI (keVnr)	NR acceptance	ER rejection power
ZEPLIN-II	1.0	1.1	14-58	50%	98.5%
XENON10	0.73	5.4	4.5~26.9	45%~49%	99.9~99.3%
ZEPLIN-III	3.4	3.1-4.2	7-35	~50%	99.987%
XENON100	0.53	3.8	6.6-43.3	60%~20%	99.75%
LUX	0.18	8.8	3-27	50%	99.9~99%

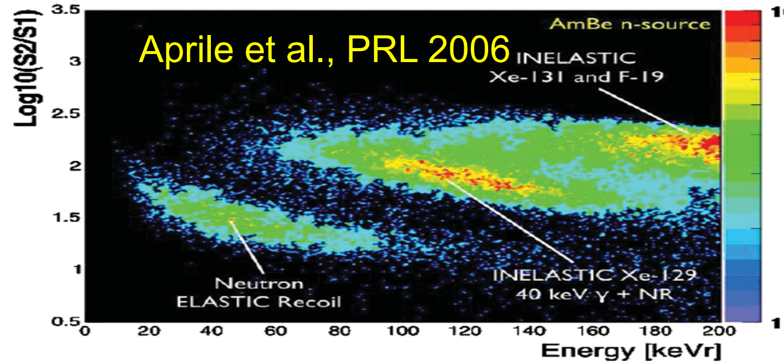
What is the key factor that determines the ER rejection power?

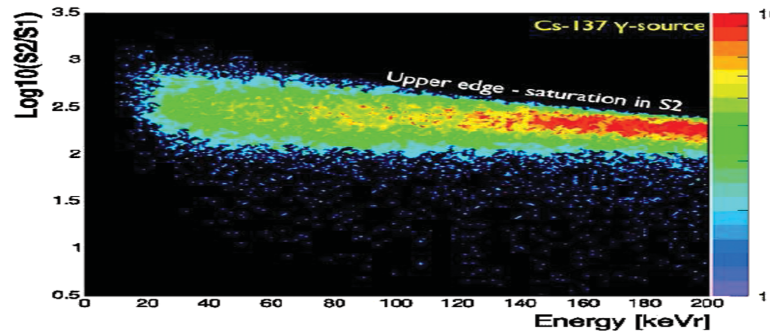
- Stronger field?
- Higher light yield?
- Something else?

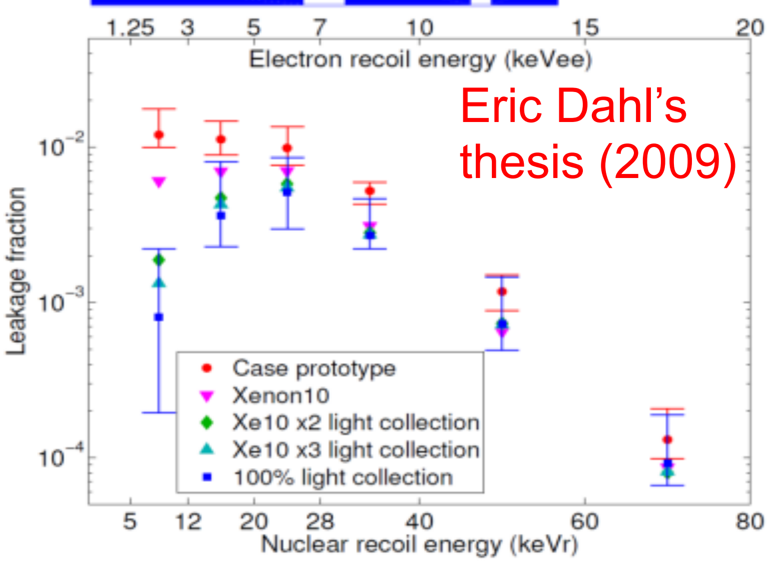
Unfortunately it’s difficult to answer these questions with the large Xe dark matter detectors.

Some earlier studies performed at small LXe prototypes (with no 3D sensitivity)



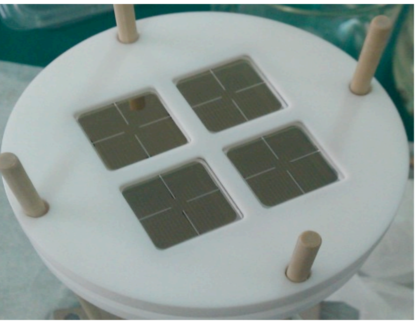


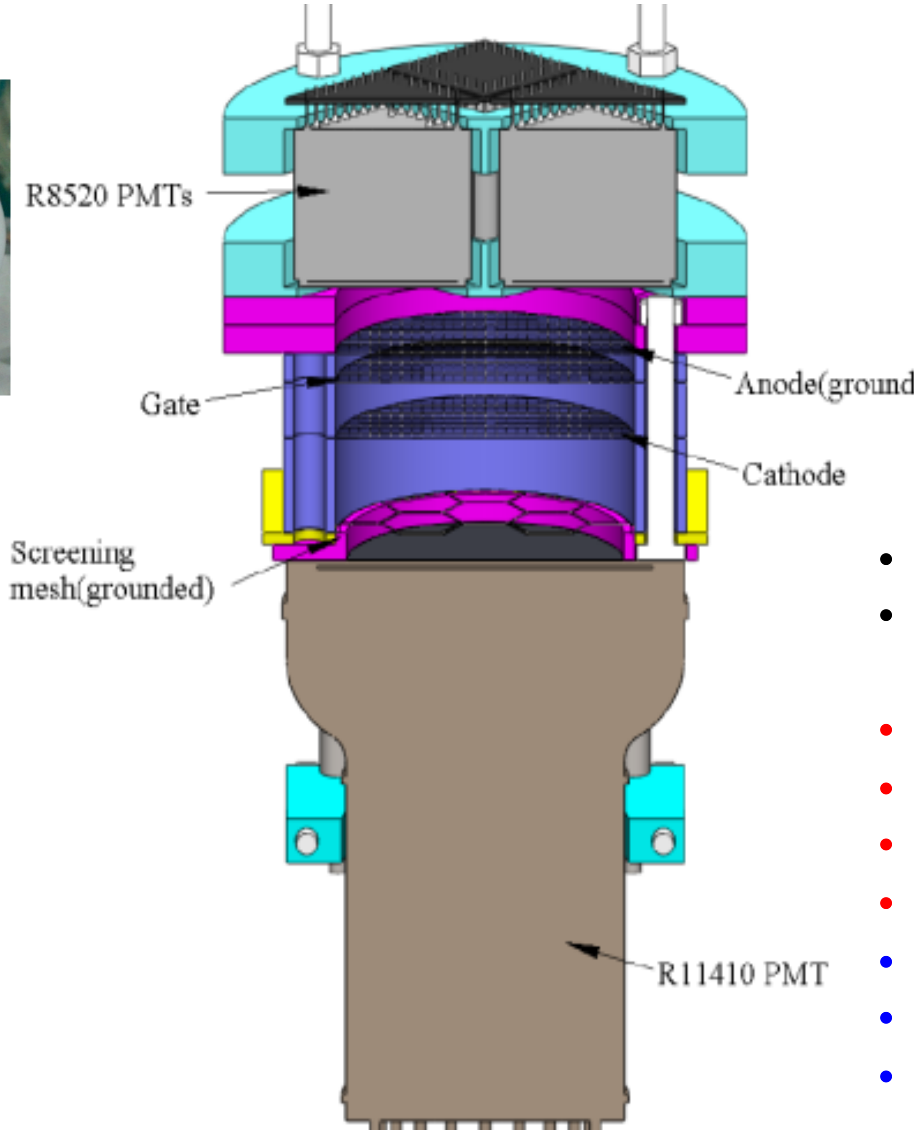


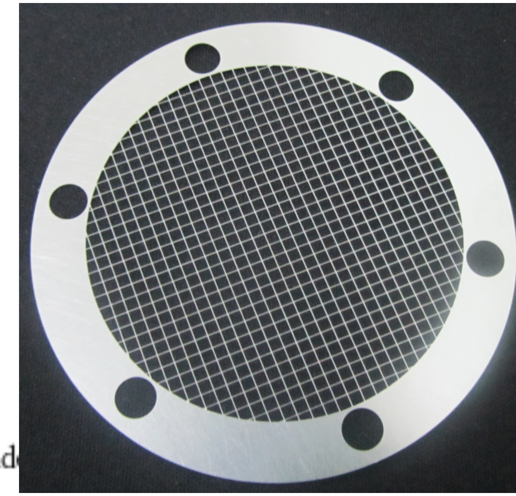


Both studies obtained ~99% ER rejection (50% NR acceptance), suffered from edge effect.

A 3D sensitive two-phase xenon TPC used for this study

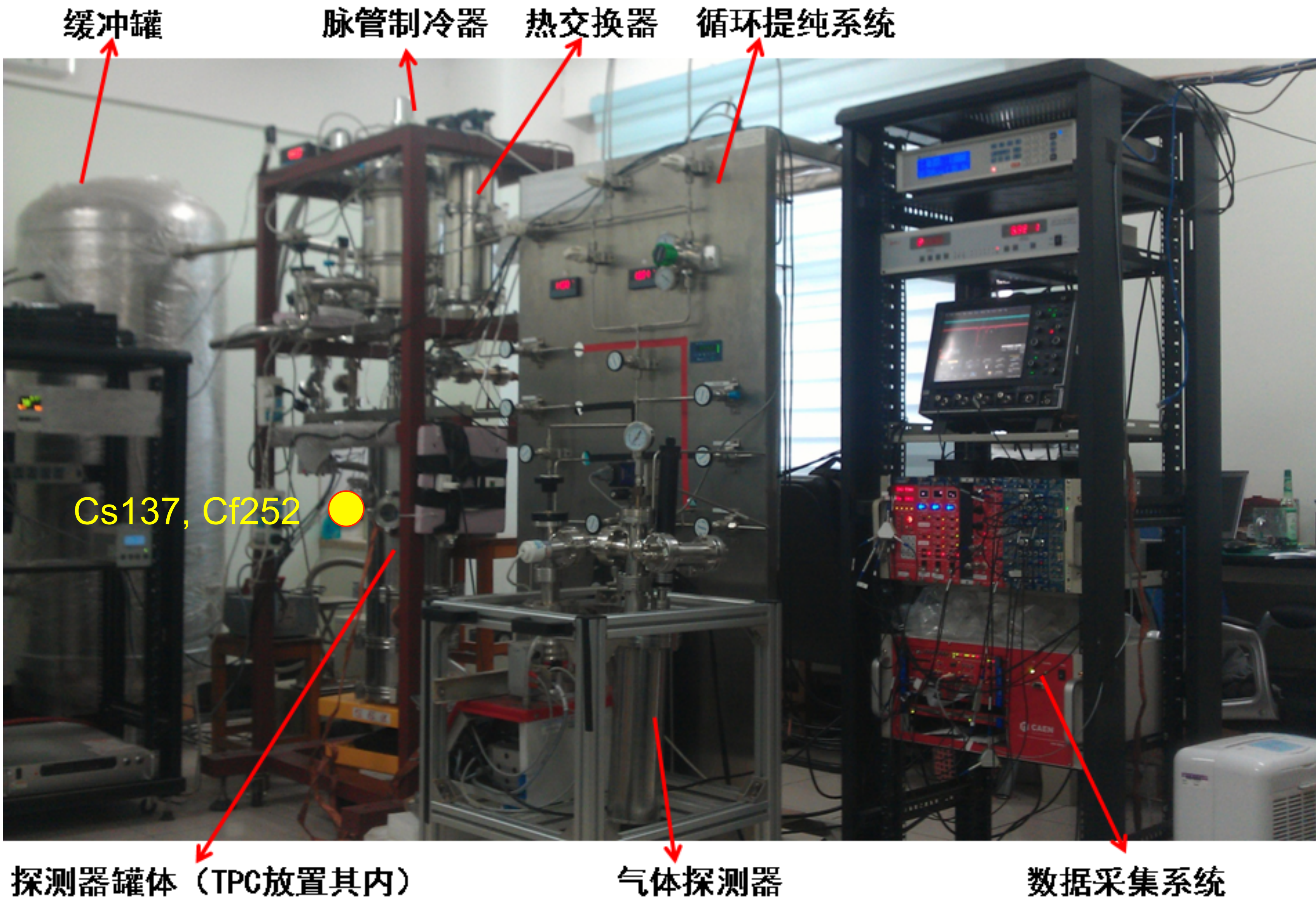




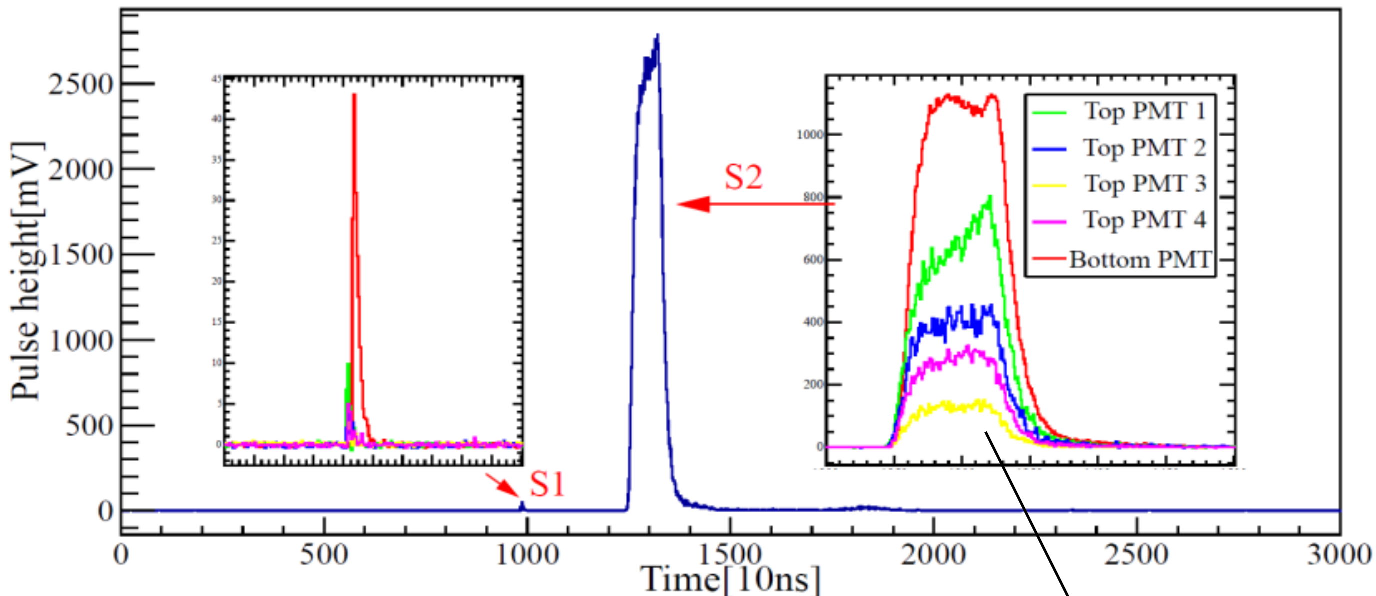


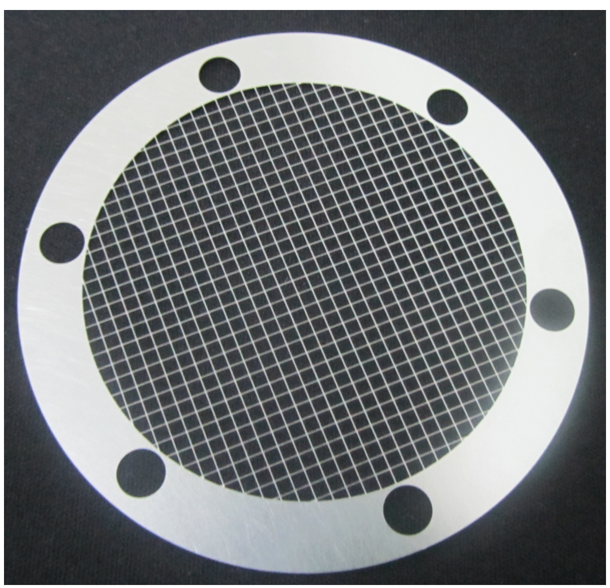
- Active diameter: 58 mm
- Meshes: 2 mm pitch with 100 um crossing bars
- Anode-Gate grid: 5 mm
- Liquid level: ~2.5 mm
- Gate grid V: -4 kV
- Gas field: >10 kV/cm
- Drift length: 1 cm
- Cathode: -(4.2~6) kV
- Drift field: 0.2-2 kV/cm

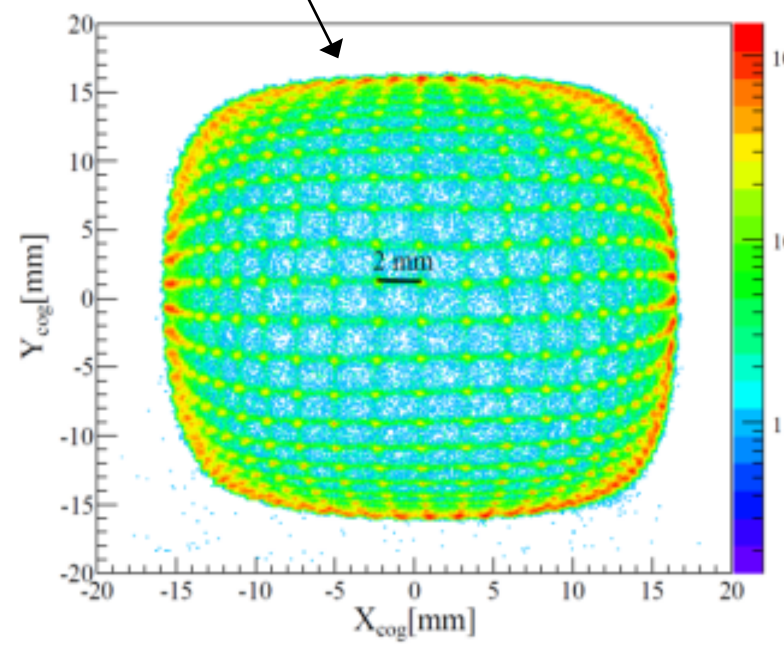
External sources (Cs137, Cf252) are used for electron recoils (ERs) and nuclear recoils (NRs) discrimination studies.

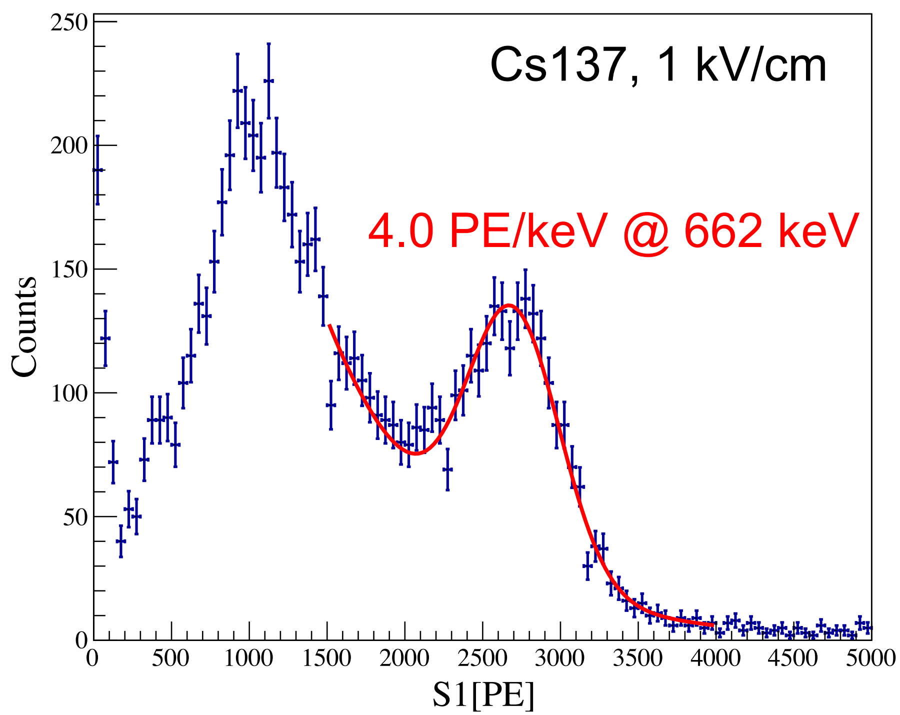


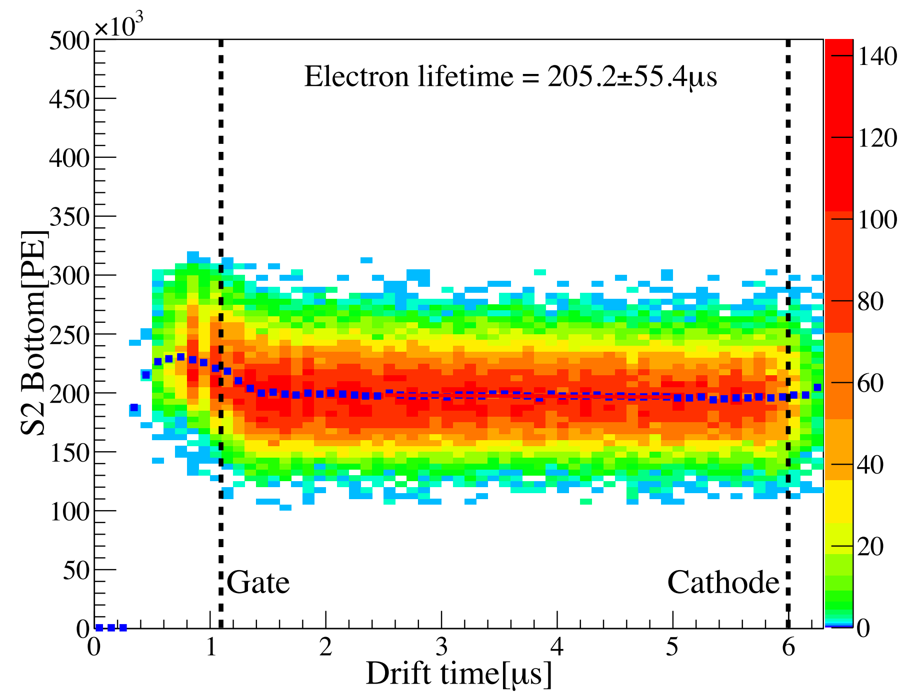
Typical signals from the TPC









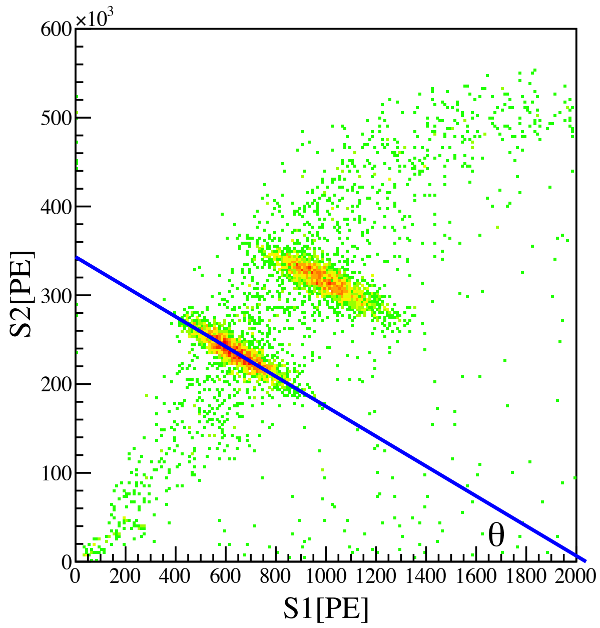


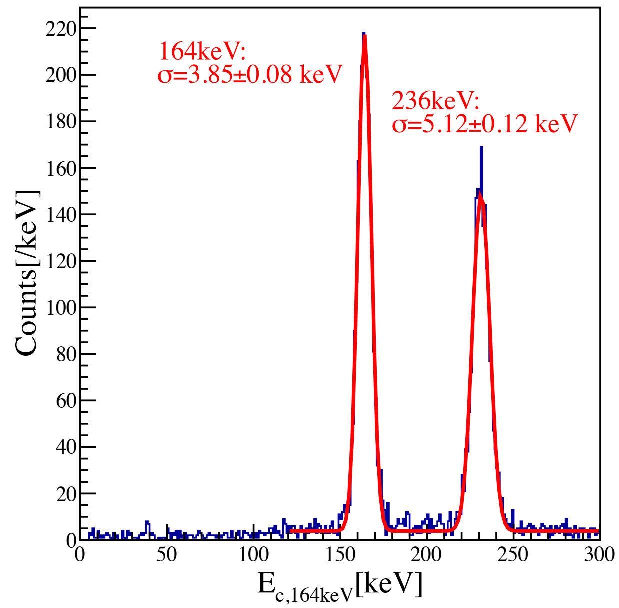
Light yield: equivalent to 10.0 PE/keV for 122 keV at zero field

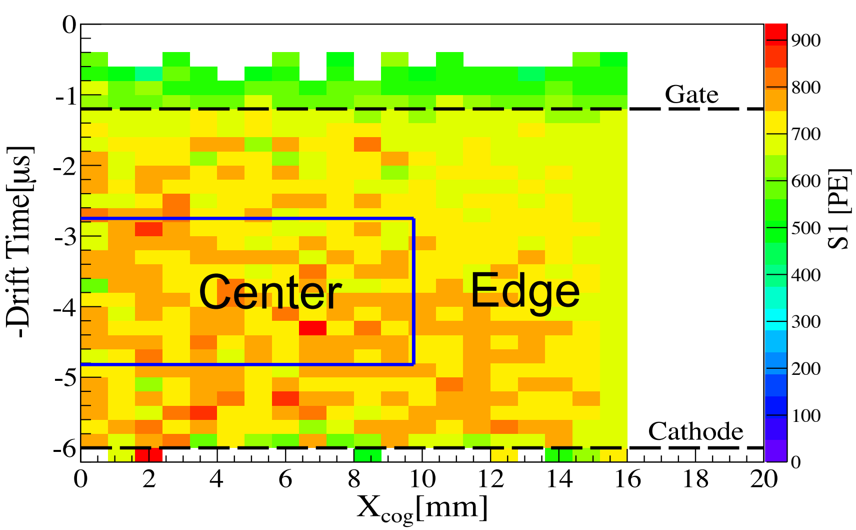
Electron lifetime: ~200 us (or 40 cm attenuation length)

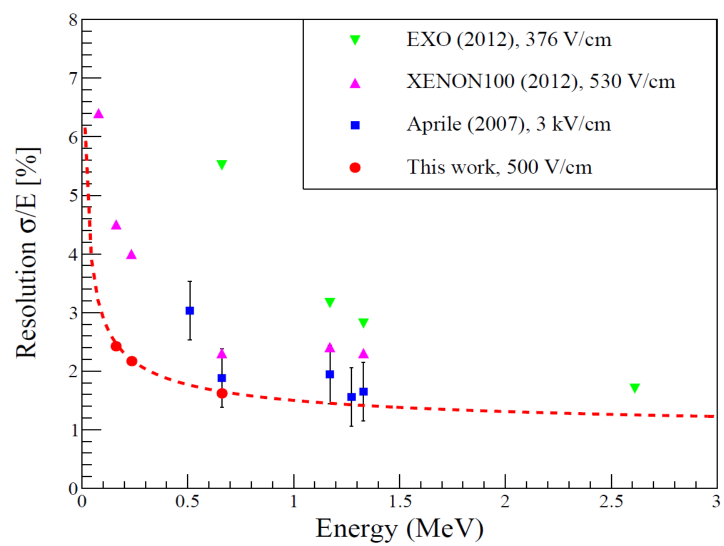
This TPC obtained excellent energy resolution for gamma rays.

Q. Lin, et al., 2014 JINST 9 P04014 (arXiv:1309.5562)

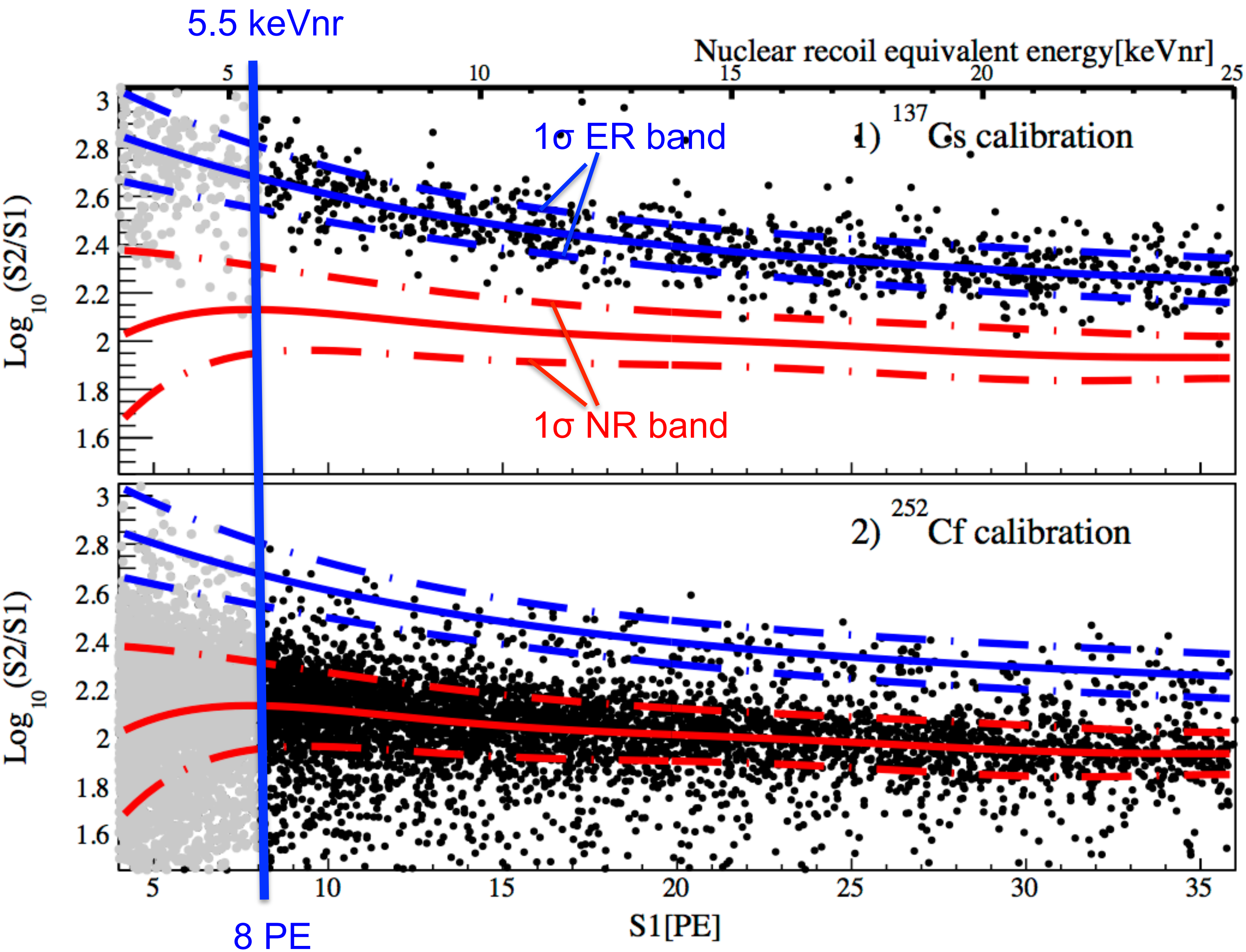




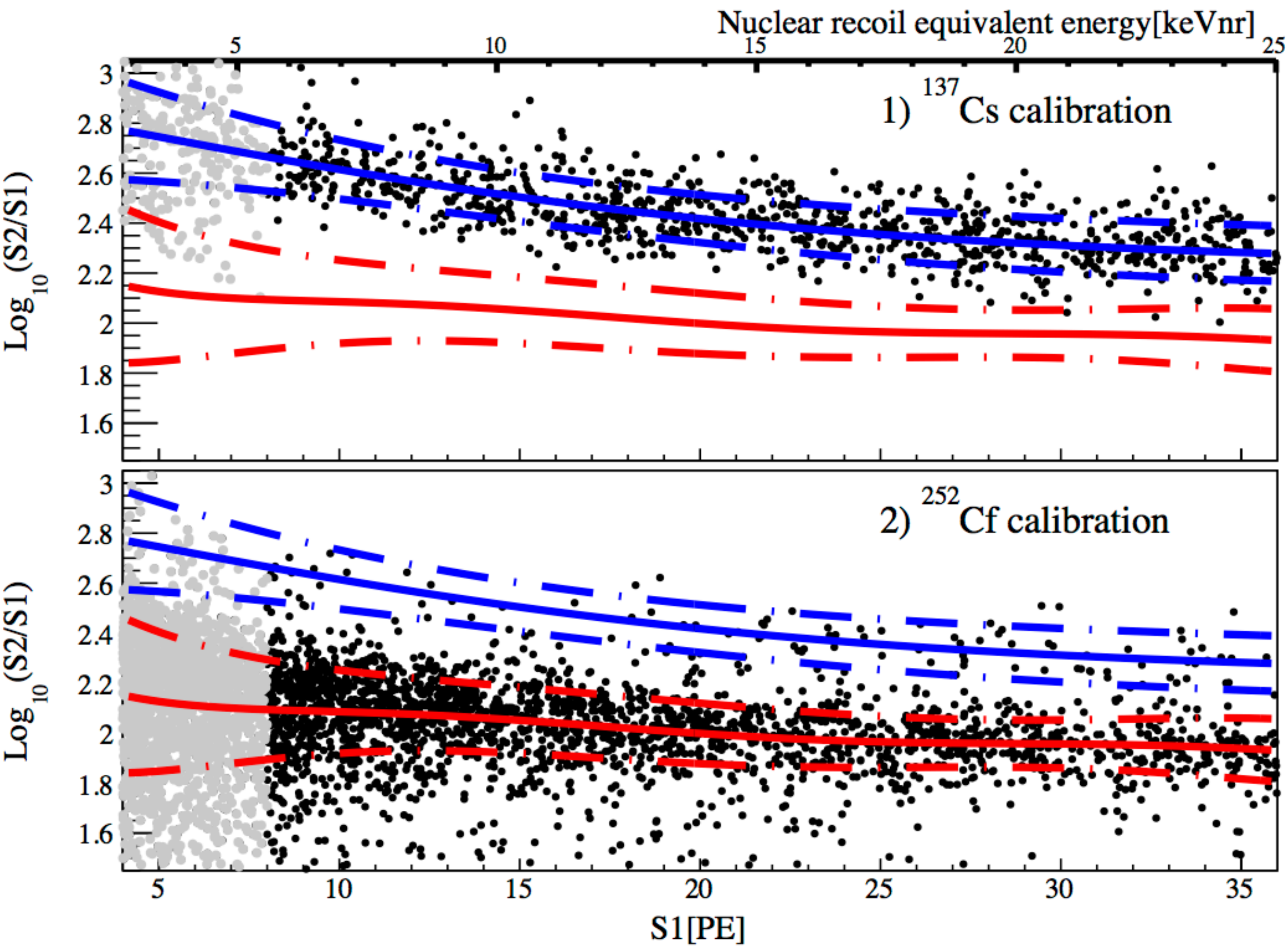




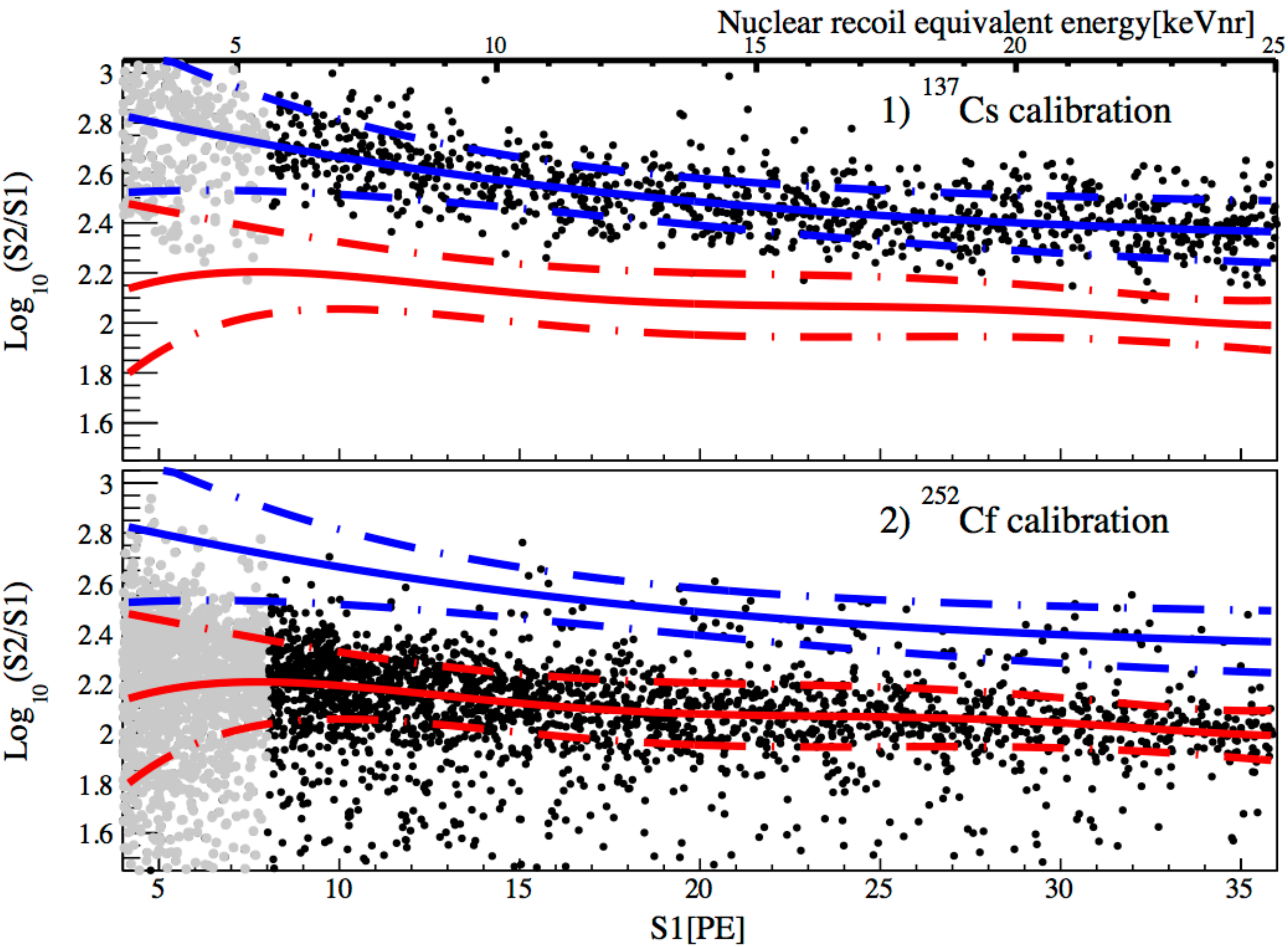
ER and NR bands obtained at 200 V/cm



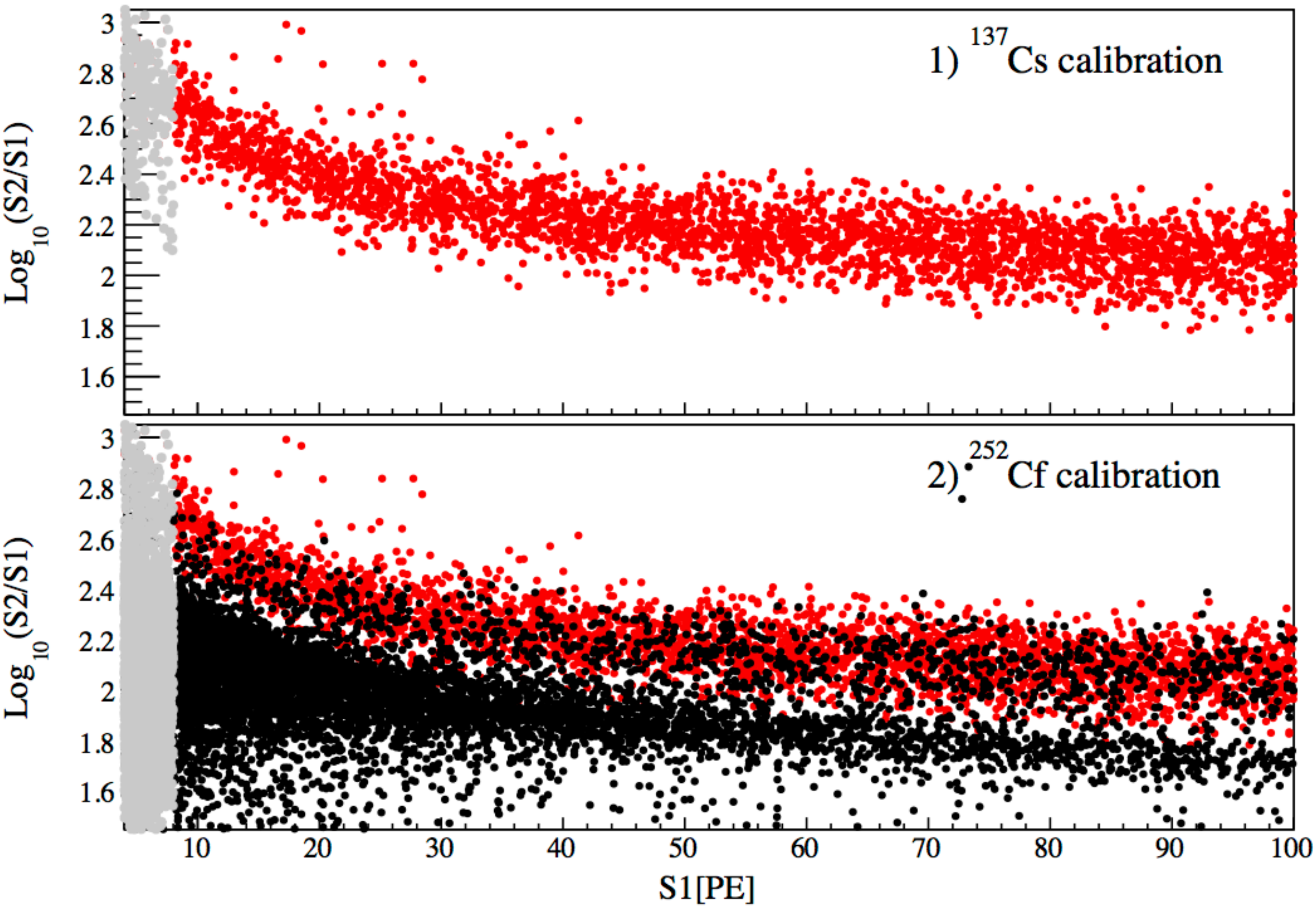
ER and NR bands obtained at 700 V/cm



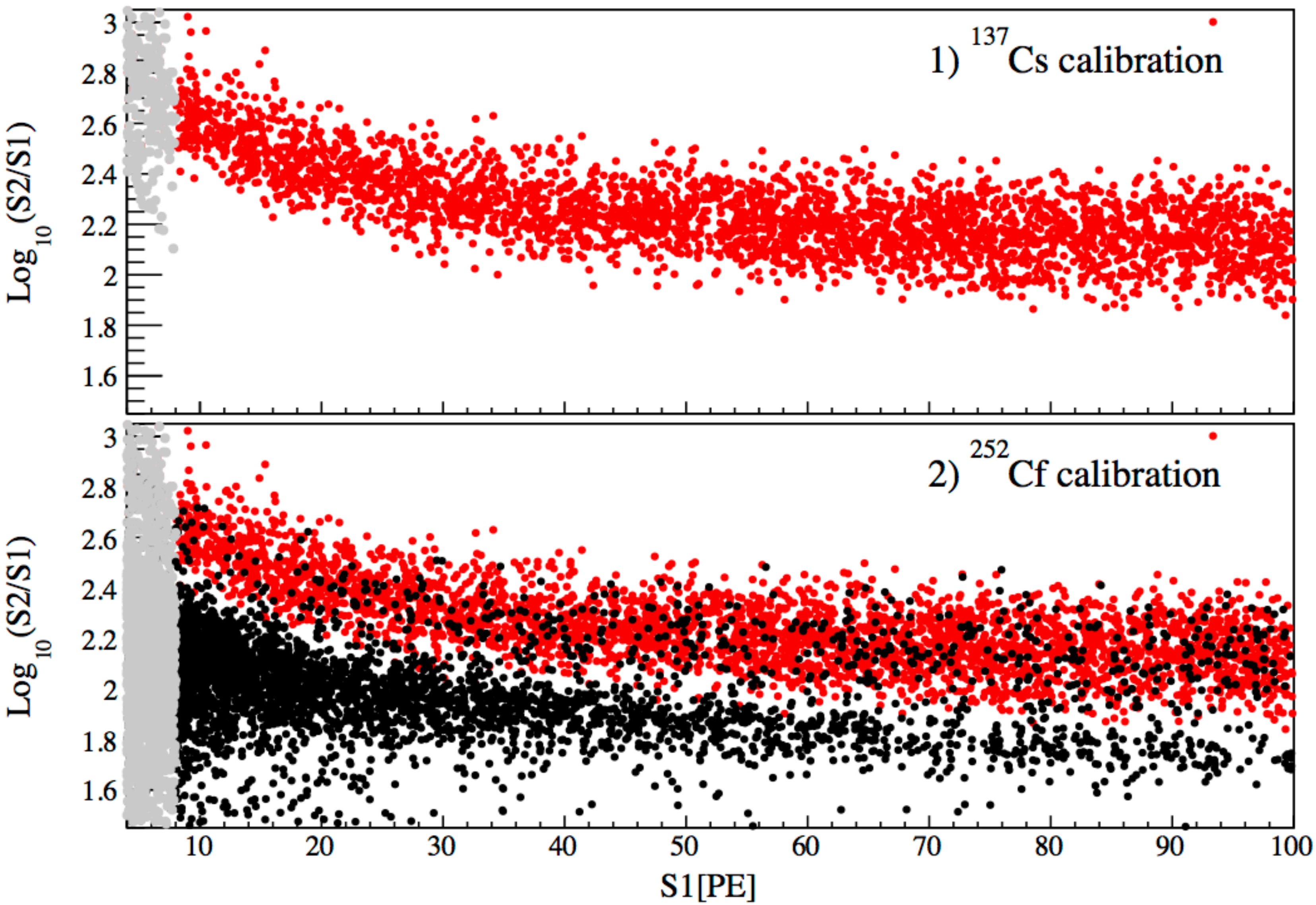
ER and NR bands obtained at 1000 V/cm



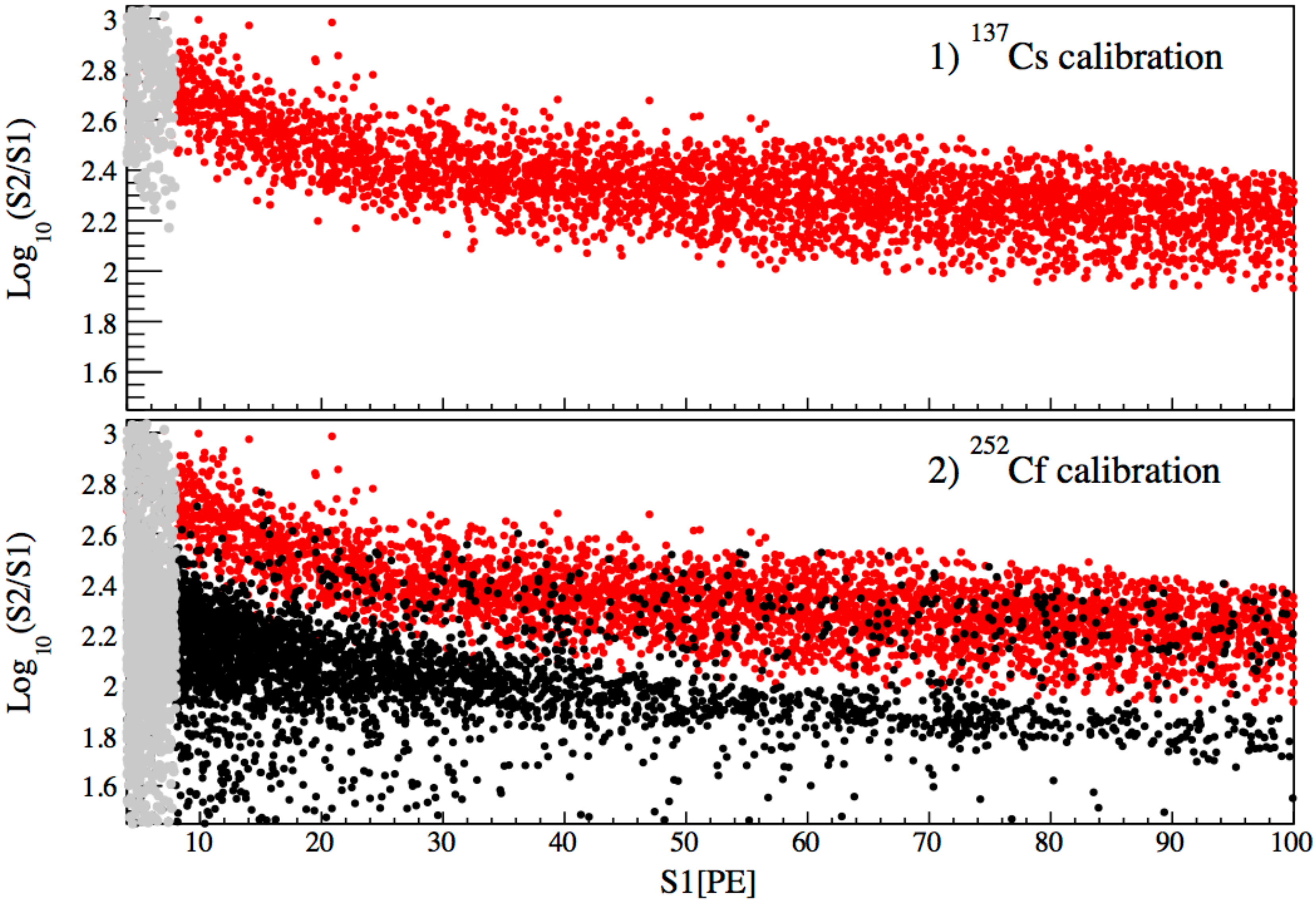
ER/NR calibration bands overlapped, 200 V/cm



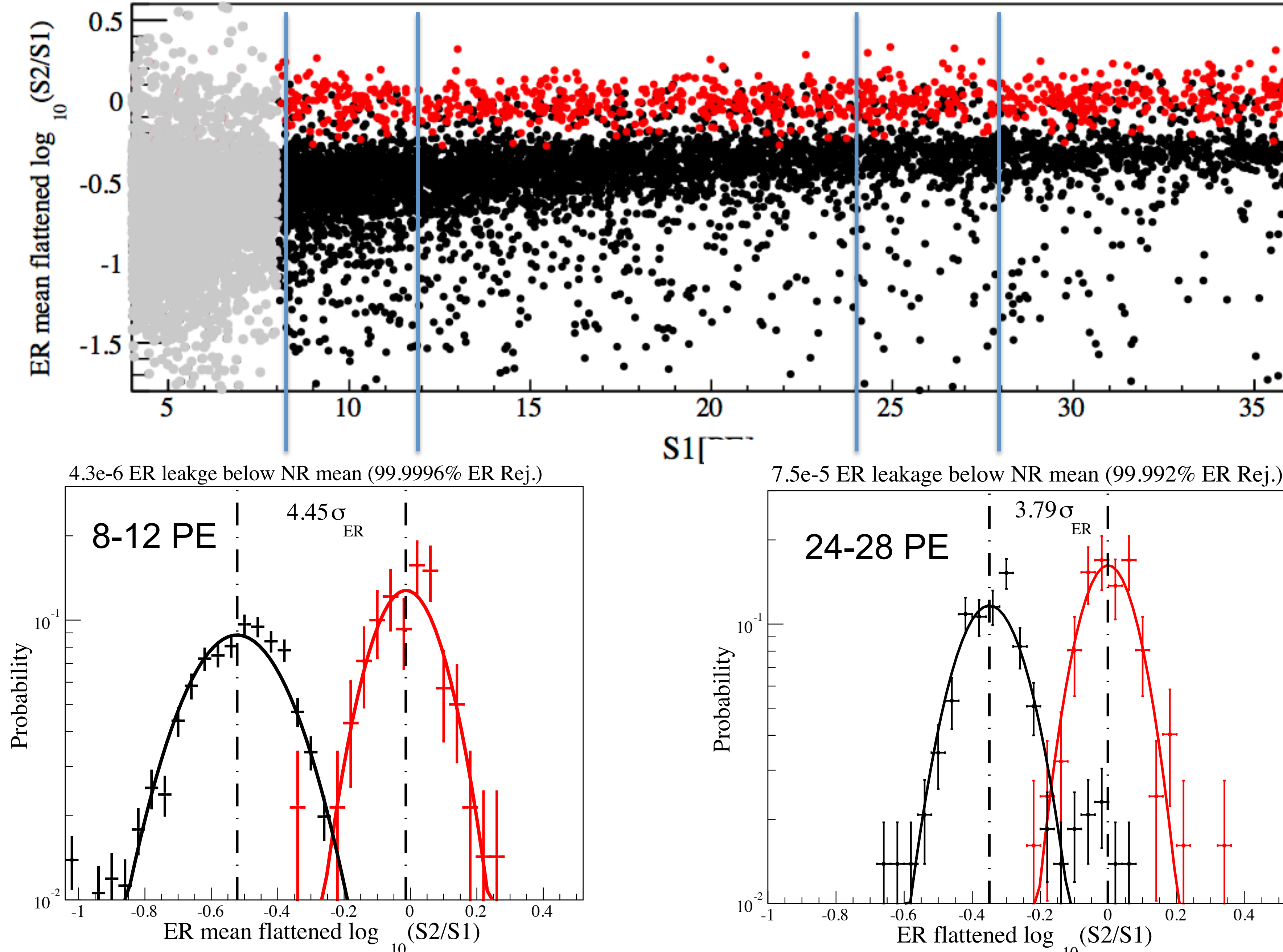
ER/NR calibration bands overlapped, 700 V/cm



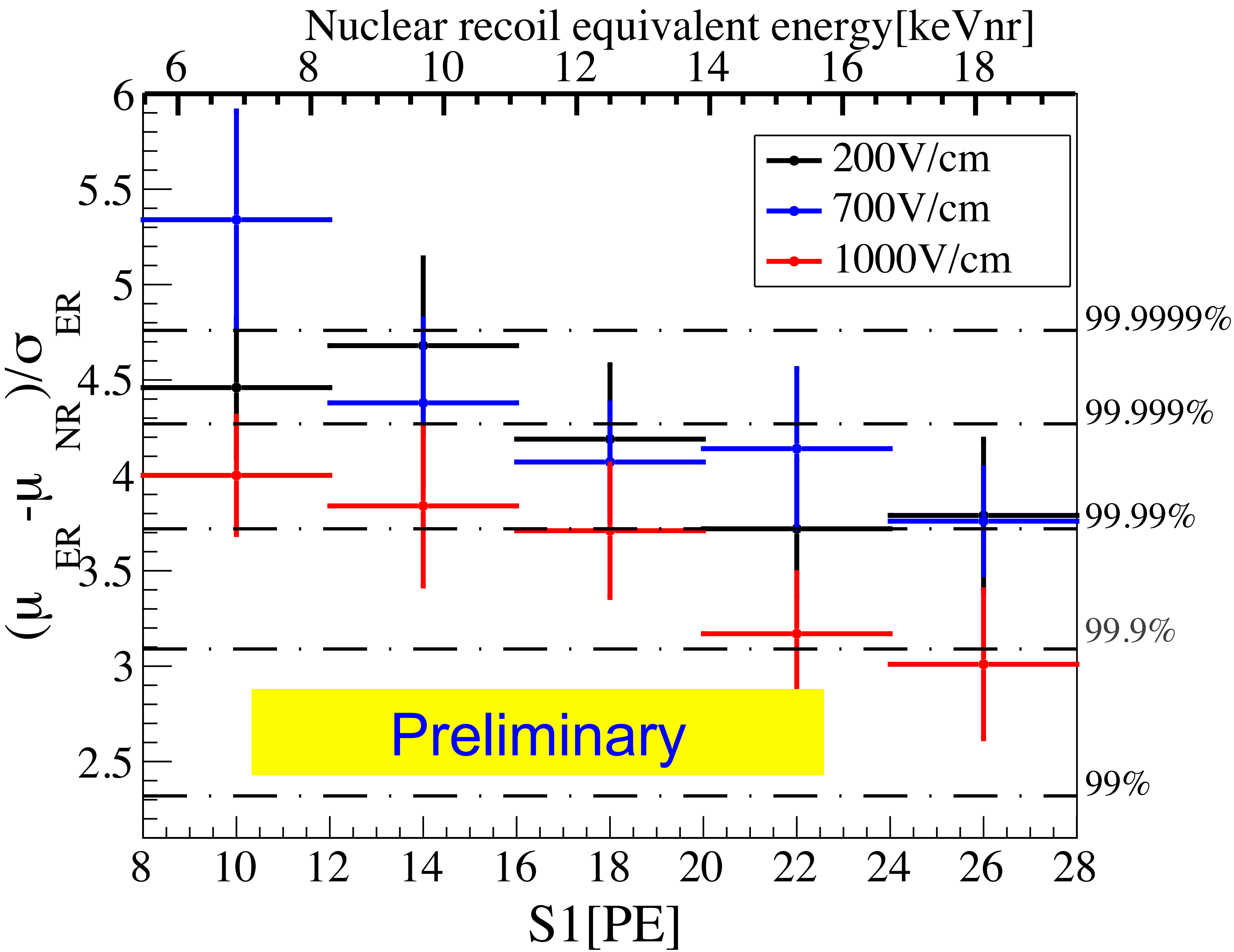
ER/NR calibration bands overlapped, 1000 V/cm



Calculating the ER "Gaussian leakage fraction":



ER rejection power at different drift fields (central events)



Main Observations

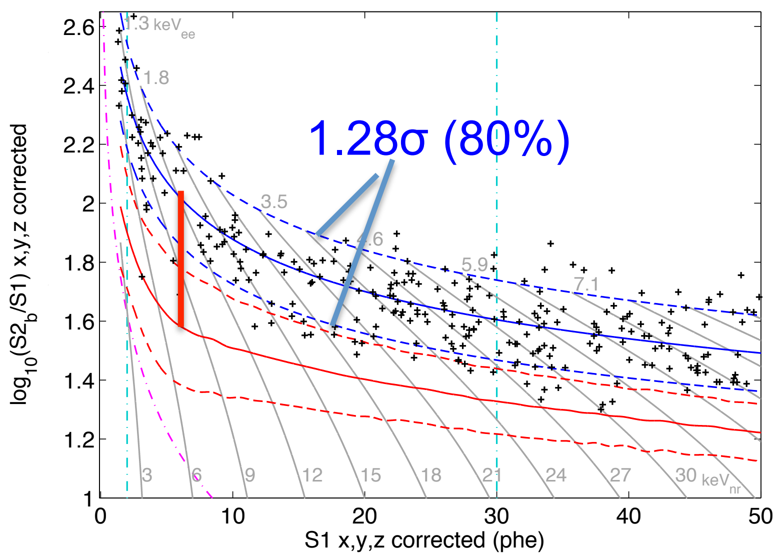
- ER rejection power above 10^5 is observed (50% NR acceptance, 5.5~11 keVnr)
  - two orders of magnitude better than previous results
- No strong drift field dependence
  - observed $>10^5$ ER rejection at 200 V/cm drift field
  - If confirmed, HV will not be a concern for future multi-ton two-phase Xe detectors (low field operation)
- ER rejection power gets better at lower energy
  - Xe is ideal for WIMP detection!

But why?

- ER/NR band separation
- ER band variance

Energy Bin (200 V/cm)	ΔLog10(S2/S1)	σ ER
8-12 PE	0.491±0.011	0.110±0.009
12-16 PE	0.423±0.010	0.090±0.009
16-20 PE	0.377±0.011	0.090±0.008
20-24 PE	0.349±0.011	0.094±0.009
24-28 PE	0.330±0.010	0.087±0.009

LUX, PRL 2014



Implications for the future

- Key factors to achieve a high ER background rejection (with high NR acceptance)
  - S1 light collection
  - S2 threshold
  - Field uniformity (NOT strength)

This result is very encouraging for a background-free operation of multi-ton two-phase Xe detectors towards a WIMP detection.