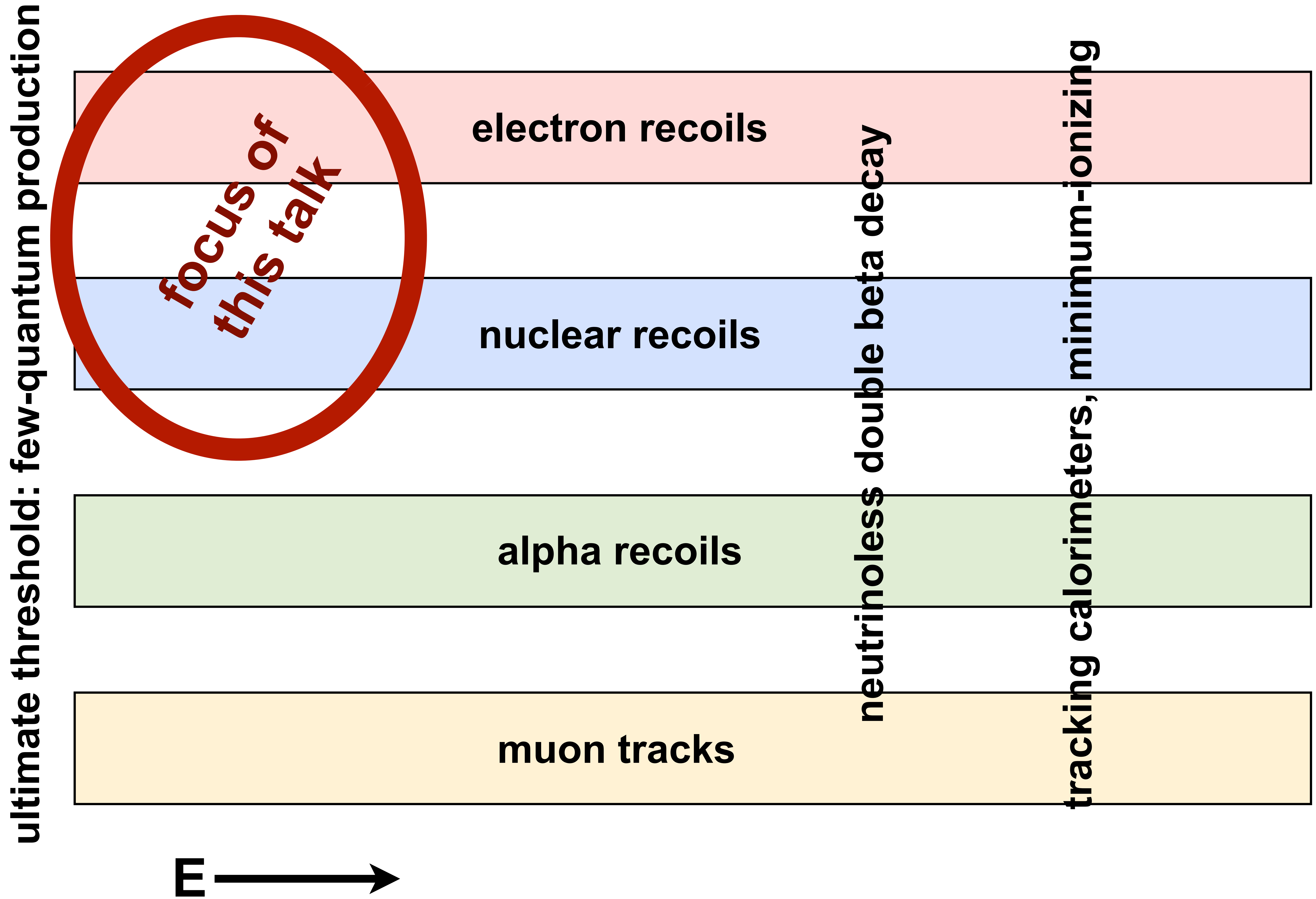
Calibration of Noble Liquid Detectors

Scott Hertel - U. Massachusetts Amherst
CPAD2017 U. New Mexico

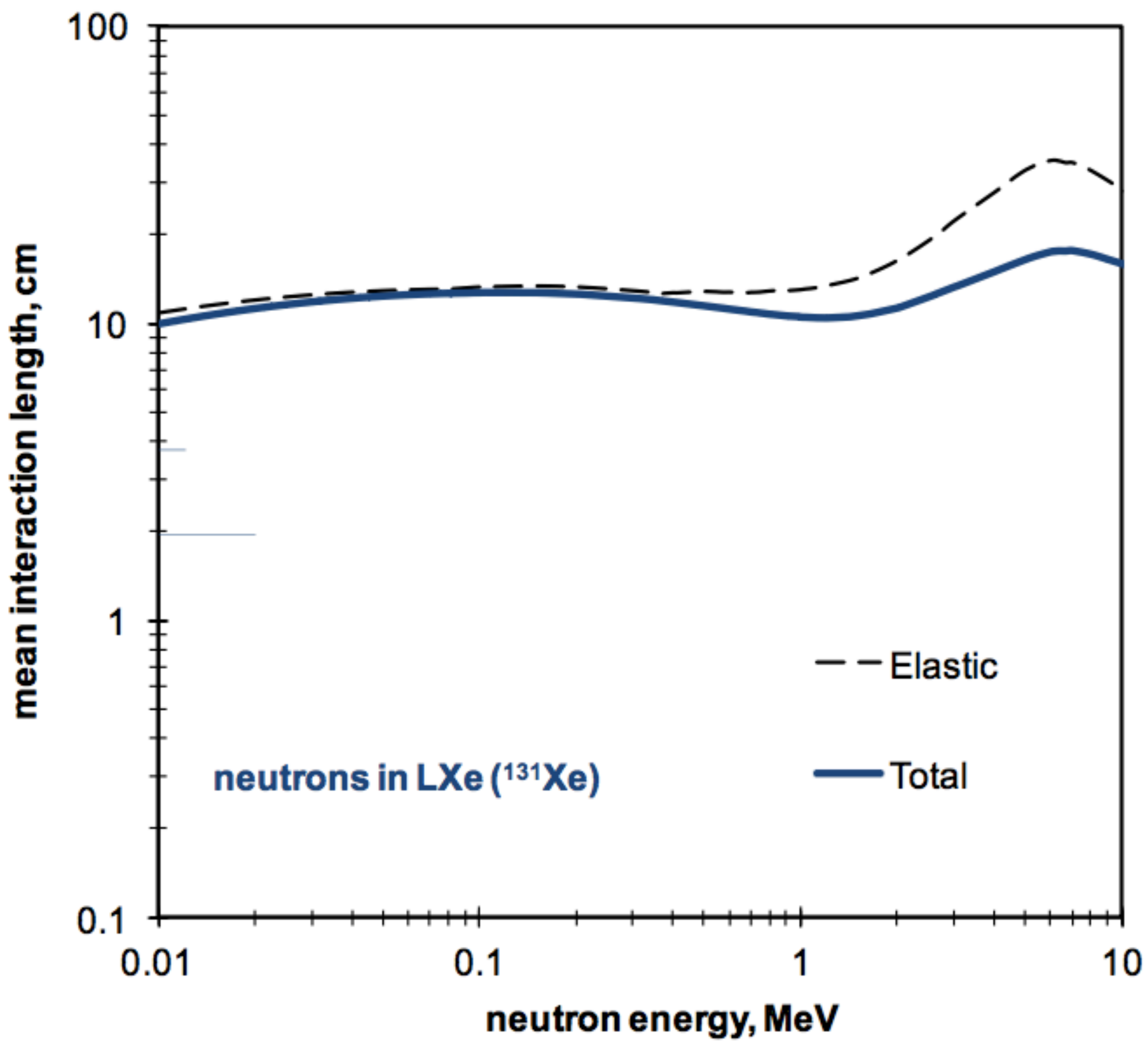
disclaimer : I am a dark matter person.

sorry! I don’t know much about the MeV scale...

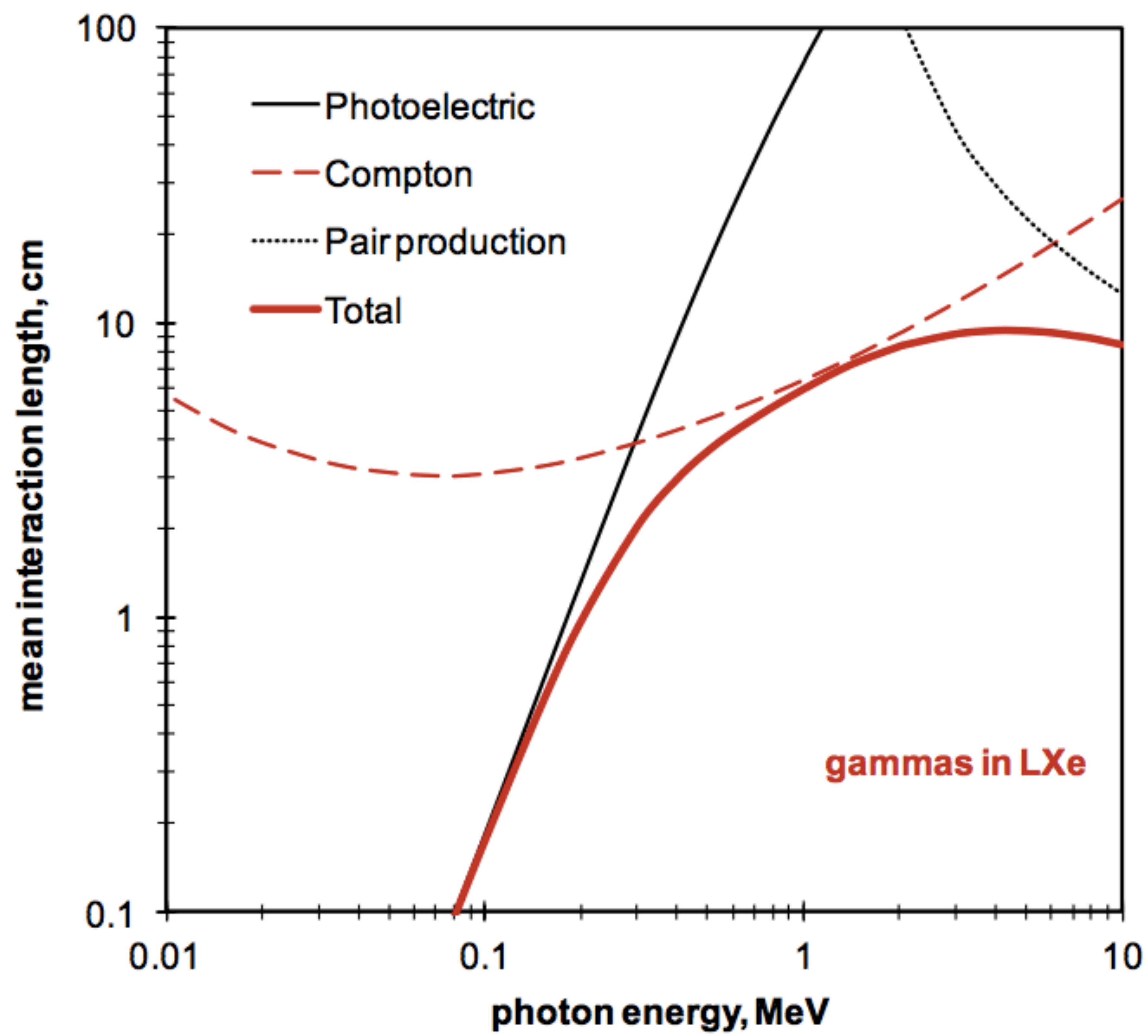


self shielding of external radiation

neutrons in LXe: ~10cm

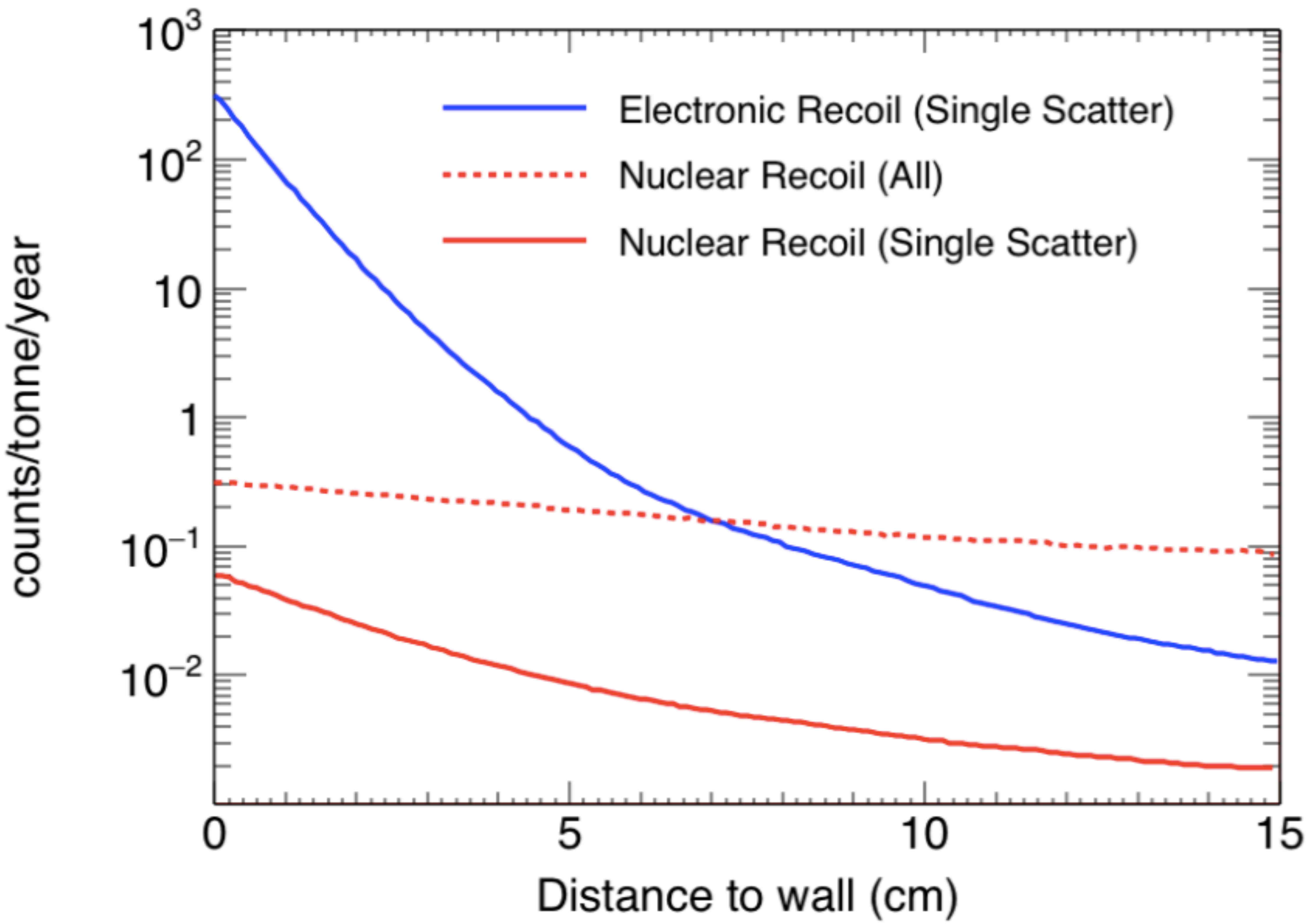


gammas in LXe: <10cm

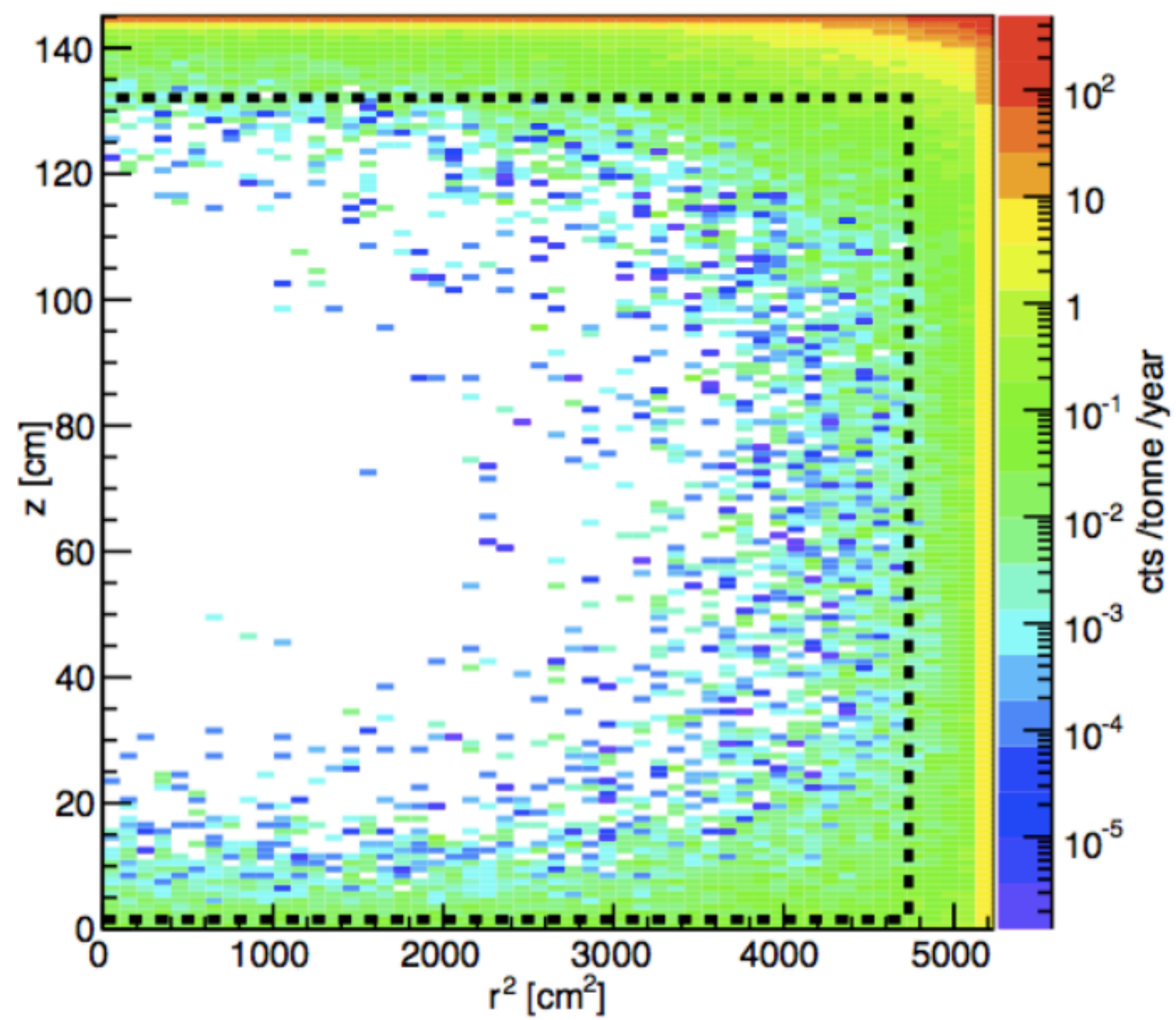


self shielding of external radiation

LXe



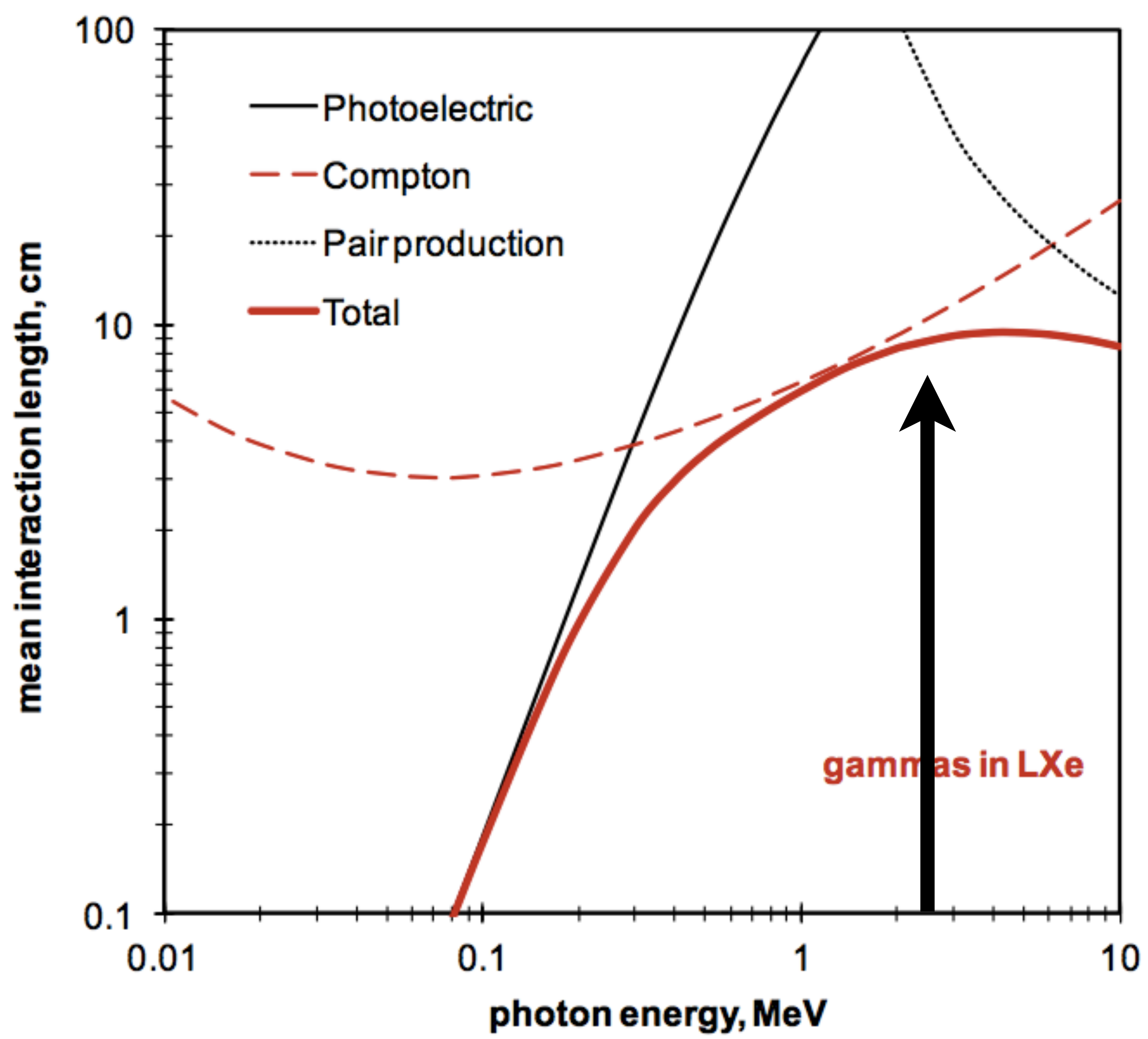
LZ simulation of
low-E single-scatter electron recoils



gamma sources

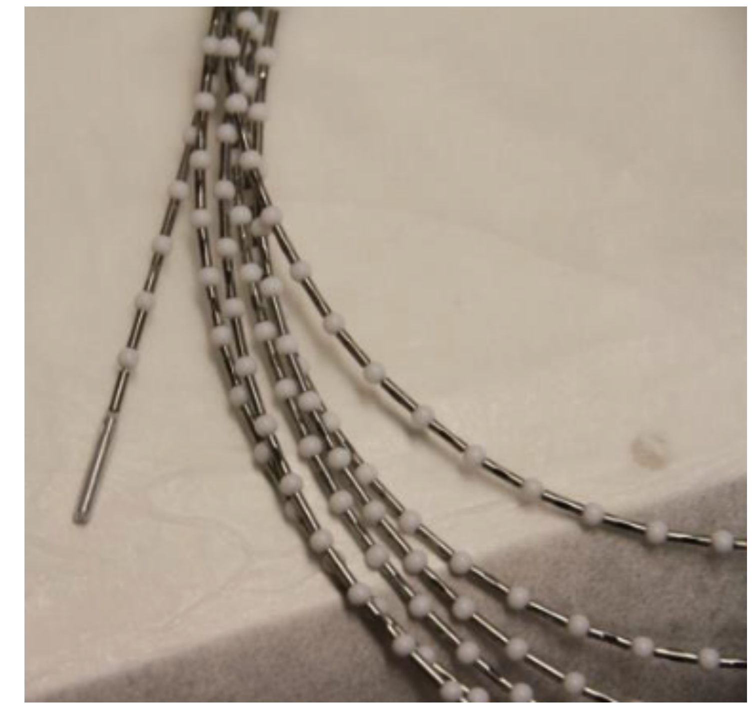
the EXO-200 example:
“easy”. self-shielding not severe

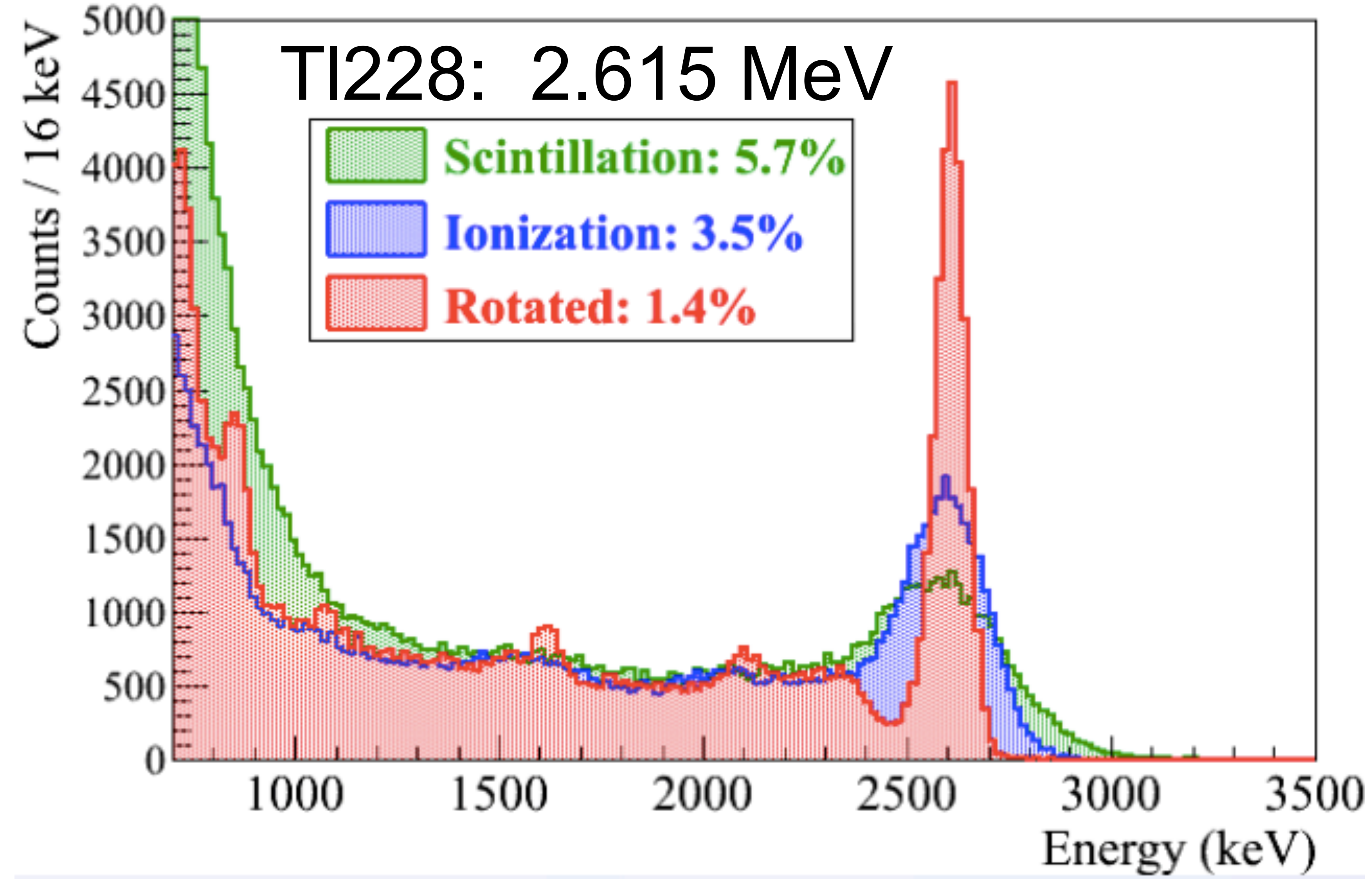
high-energy window of interest (2.458 MeV)
medium-scale TPC



sources

strings



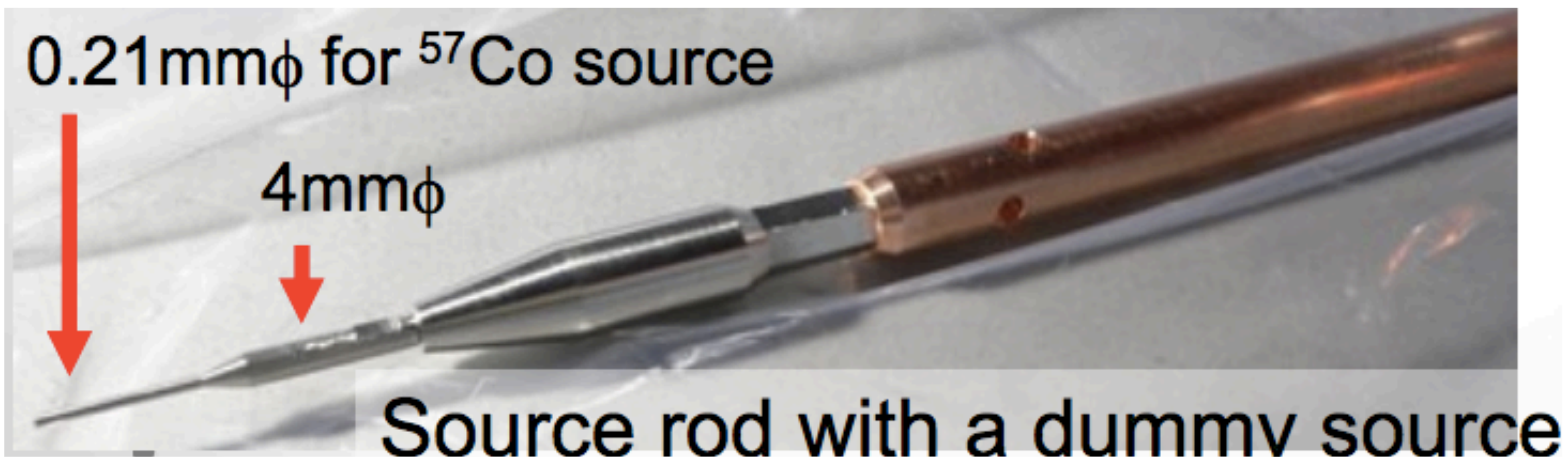


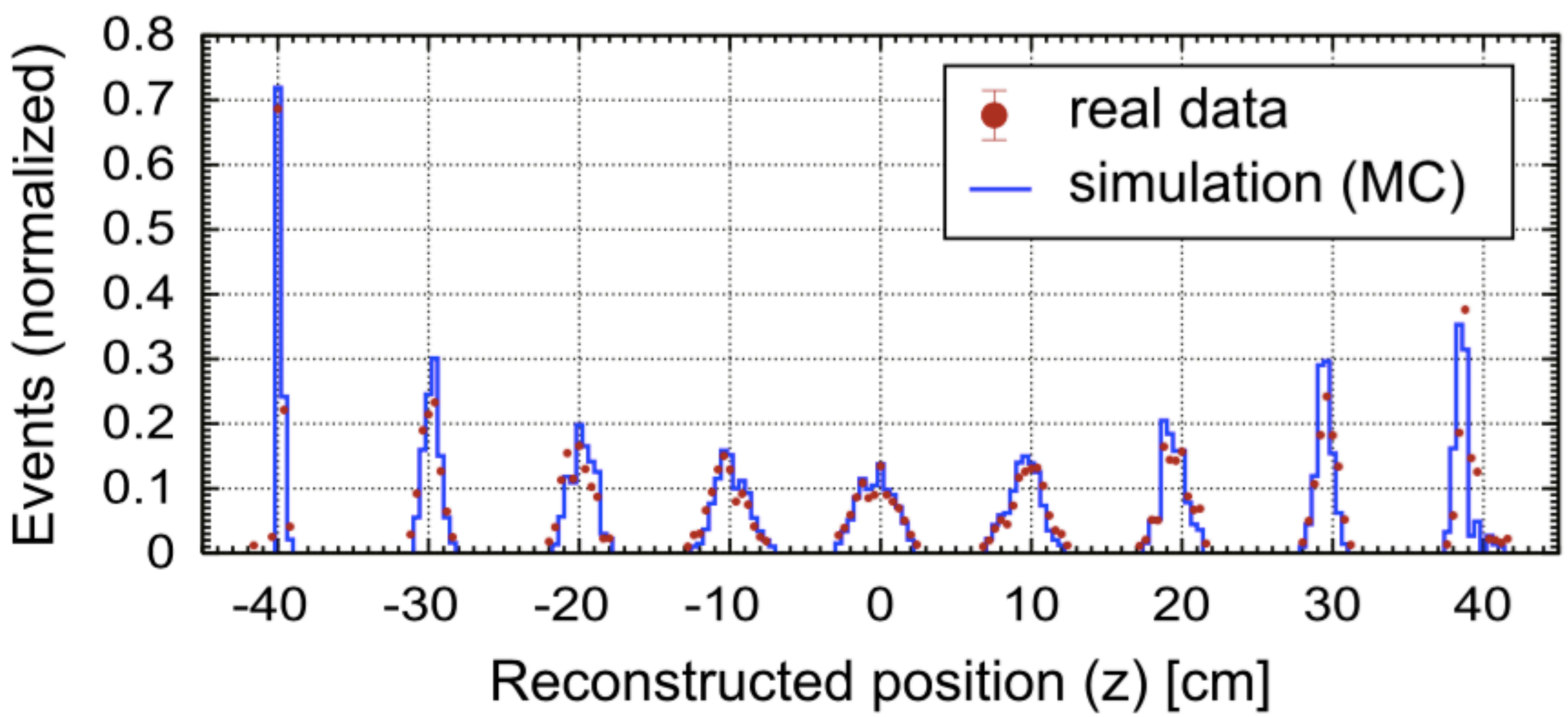
gamma sources

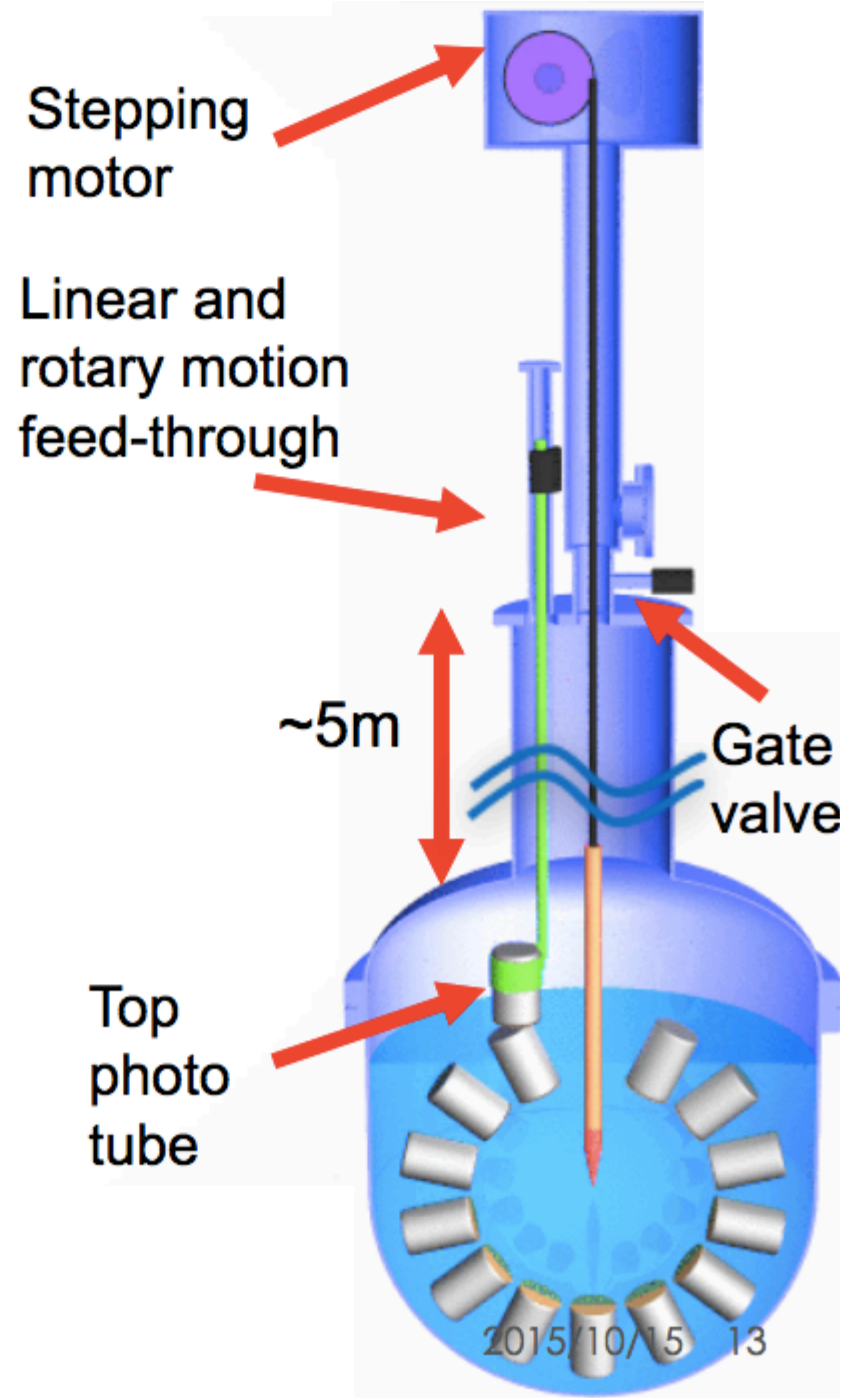
Larger detectors also ok if zero-field (can inserting source into liquid)

example: XMASS

long thin tip to avoid shadowing
57Co, 241Am, 109Cd, 55Fe, 137Cs...

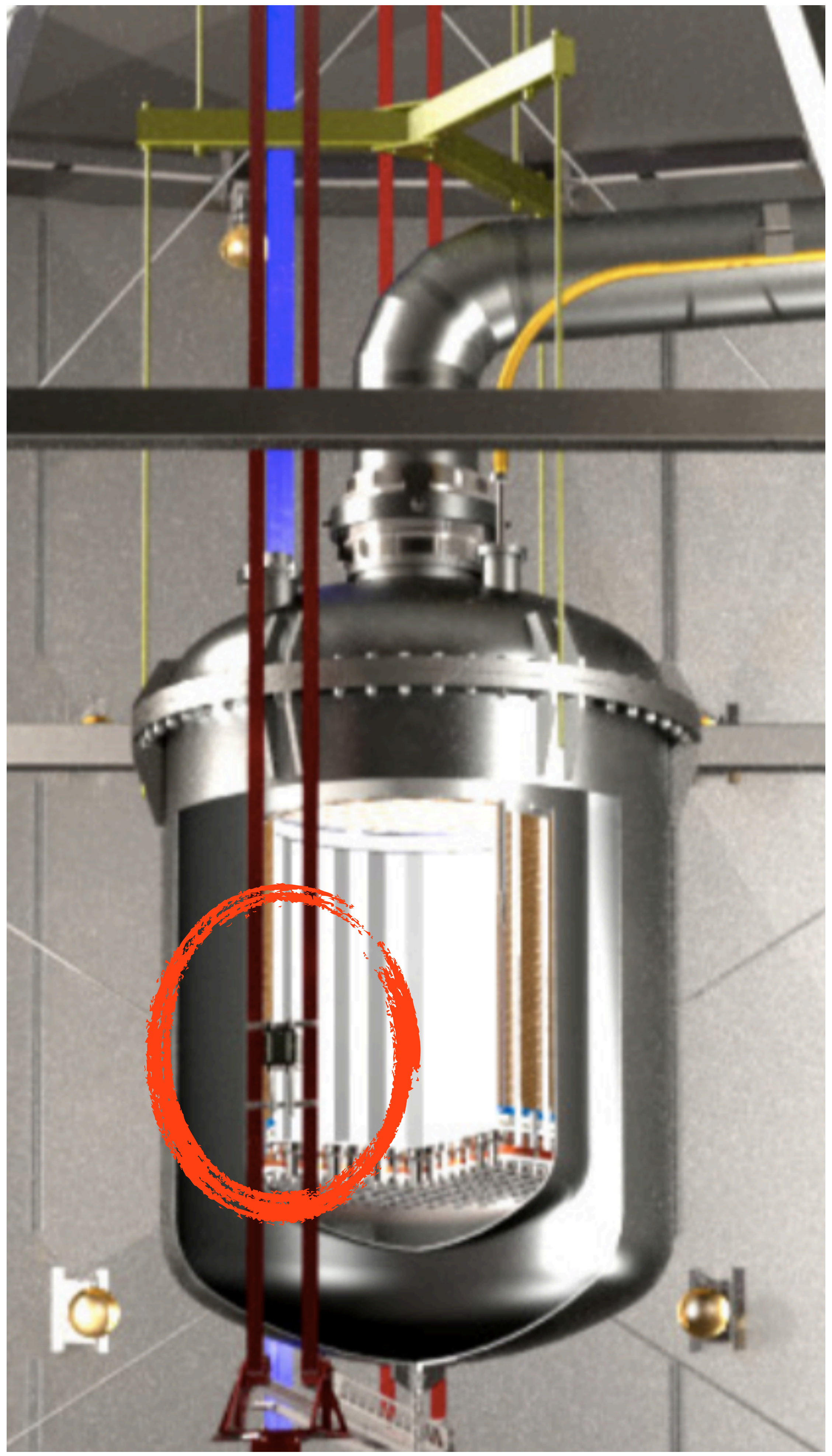


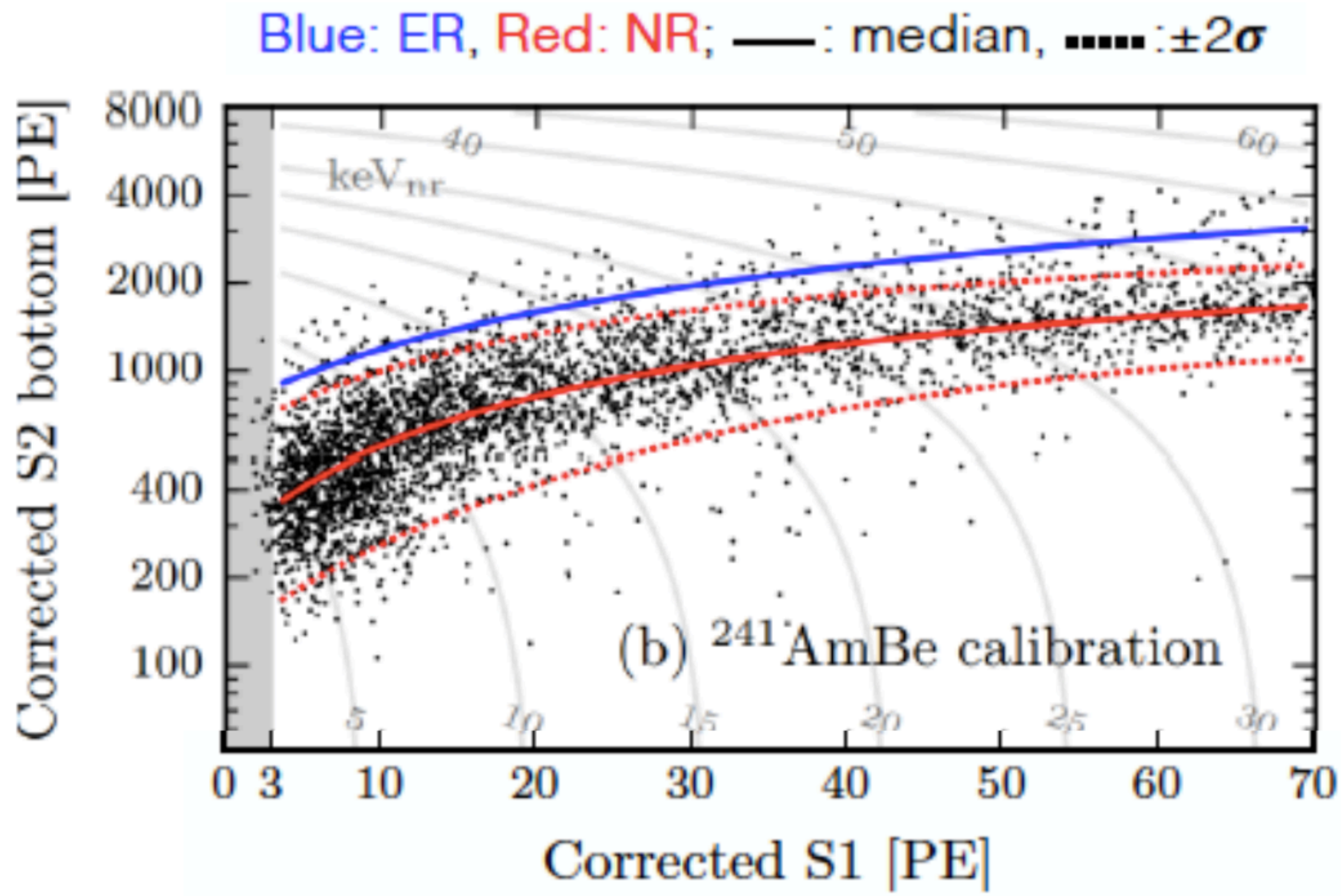




neutron sources

example: AmBe in XENON1T





Great for band mean.
outliers: misidentified multiple scatters and gammas

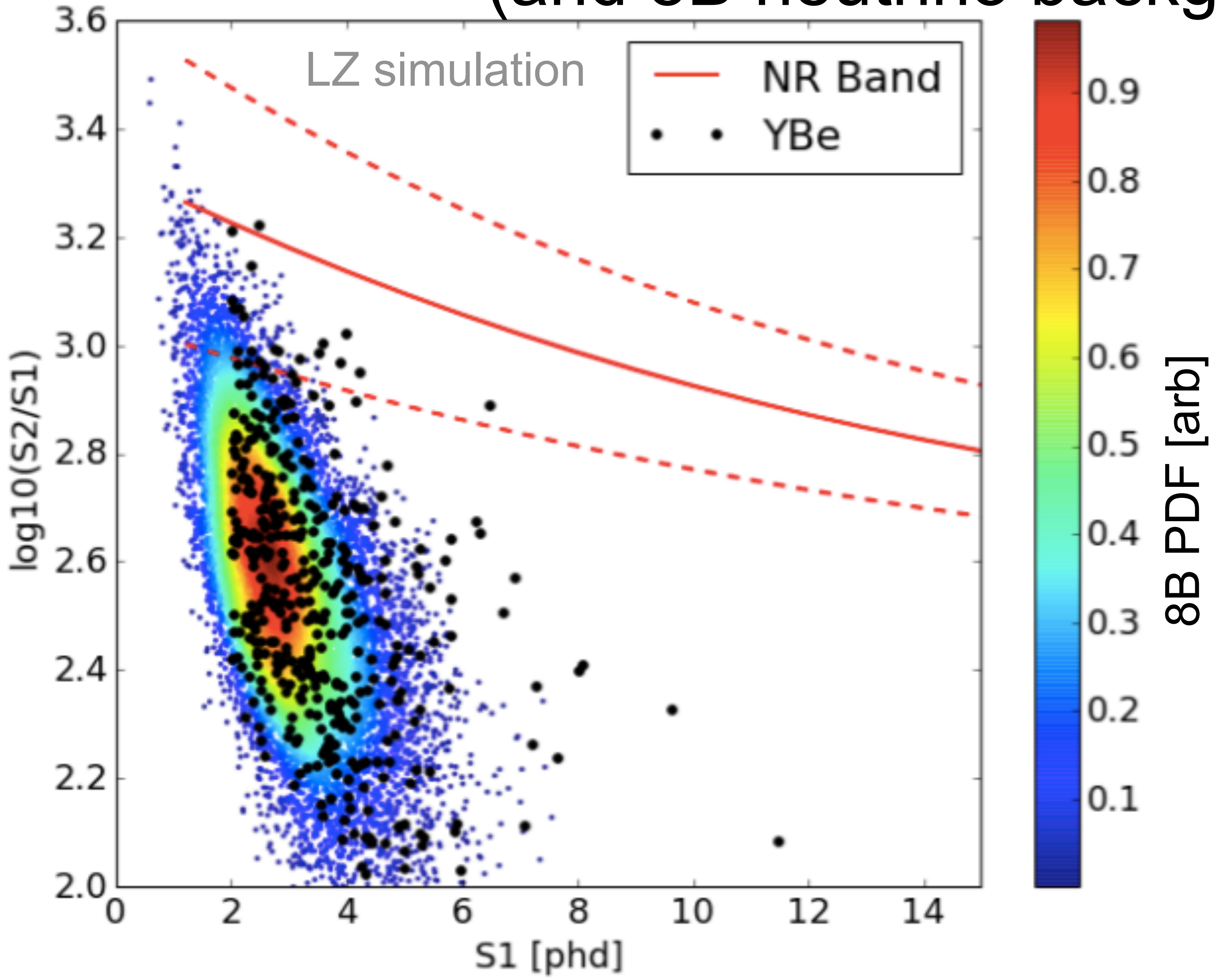
Spectrum gives some limited energy information.
(endpoint is only point that is really pinned down)

neutron sources

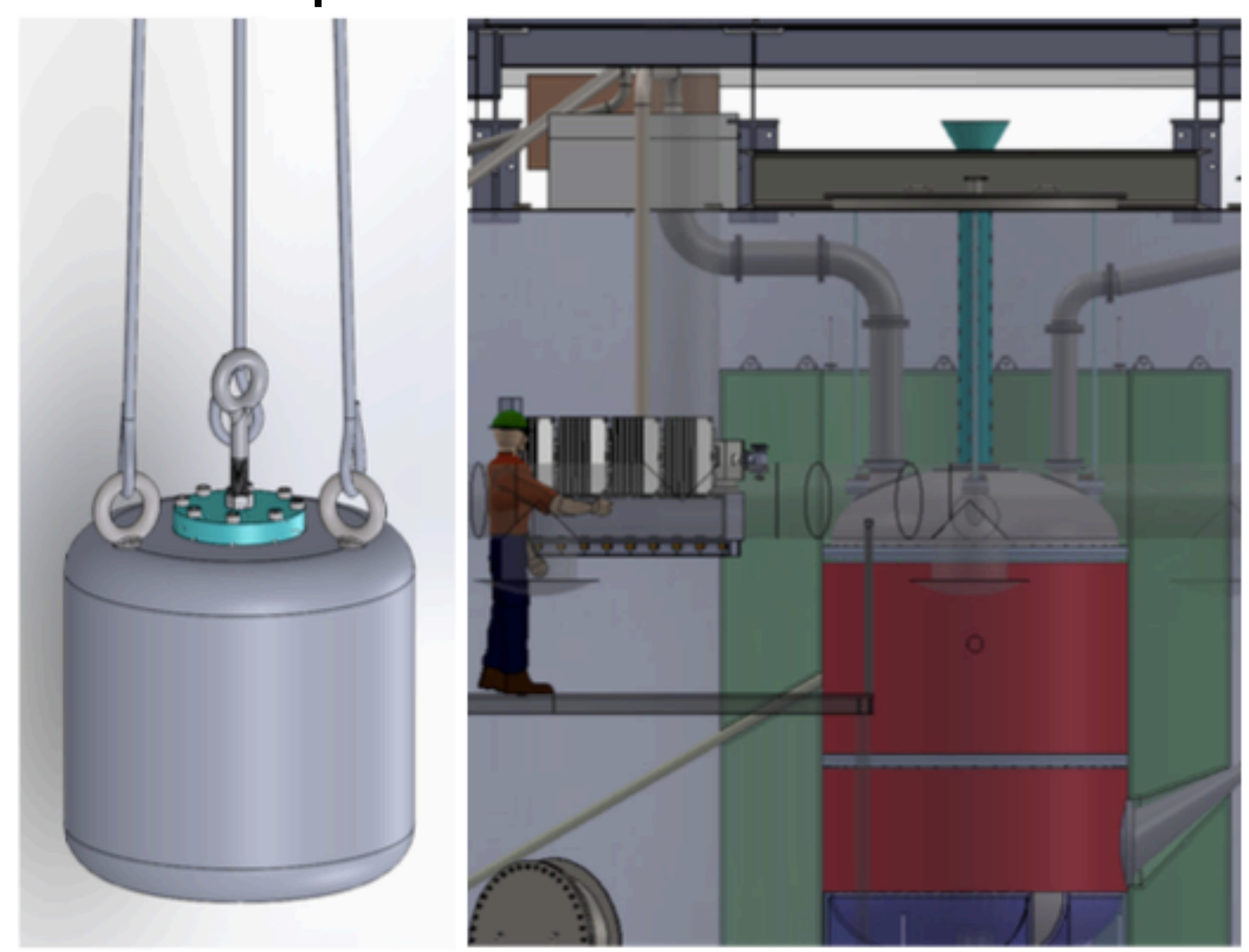
gamma-n sources (low-E monoenergetic neutrons)
endpoint-centric analysis aims

	neutron Energy	endpoint in Xe	endpoint in Ar
88Y : Be	152 keV	4.6 keV	14.6 keV
205Bi : Be	88.5 keV	2.7 keV	8.4 keV

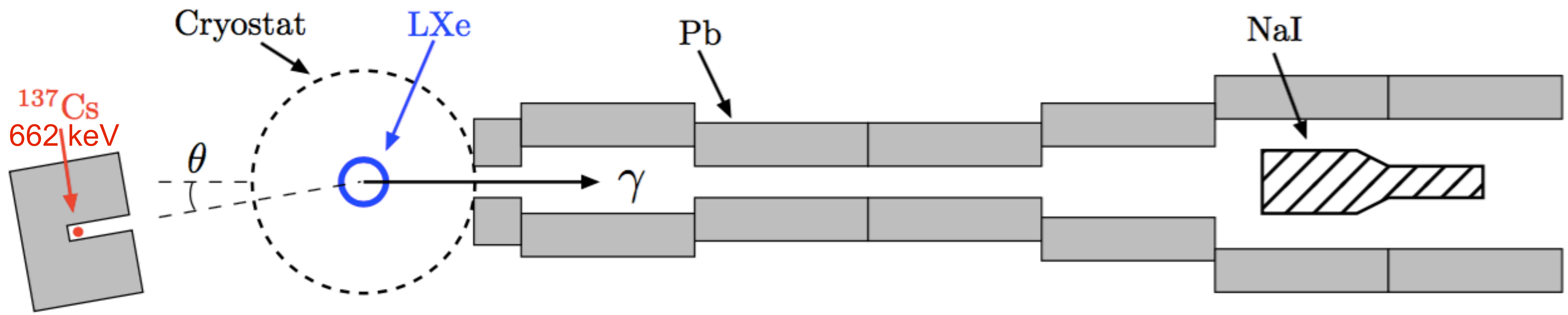
near-threshold, similar to few-GeV WIMP (and 8B neutrino background)



significant gamma shielding required
LZ example:

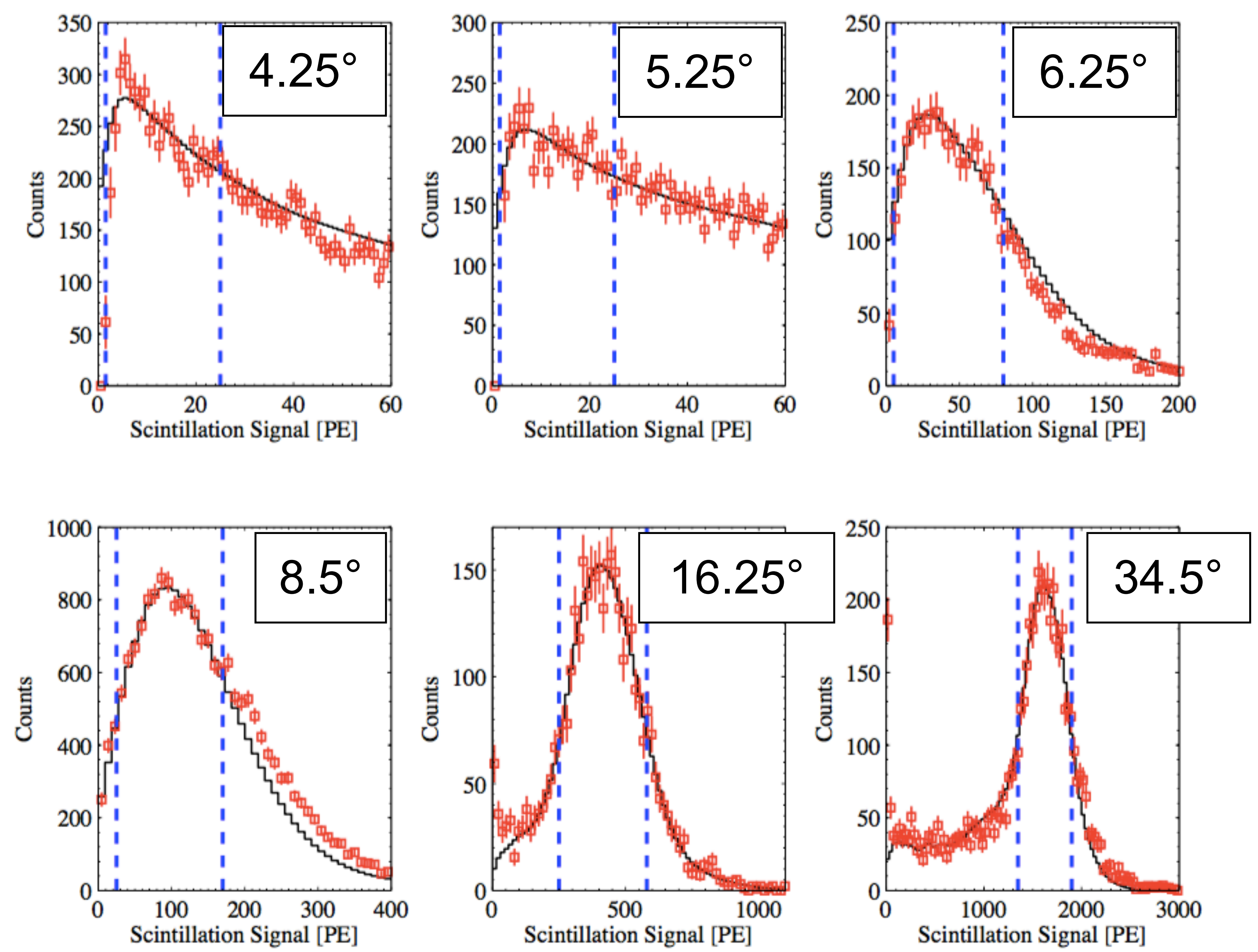


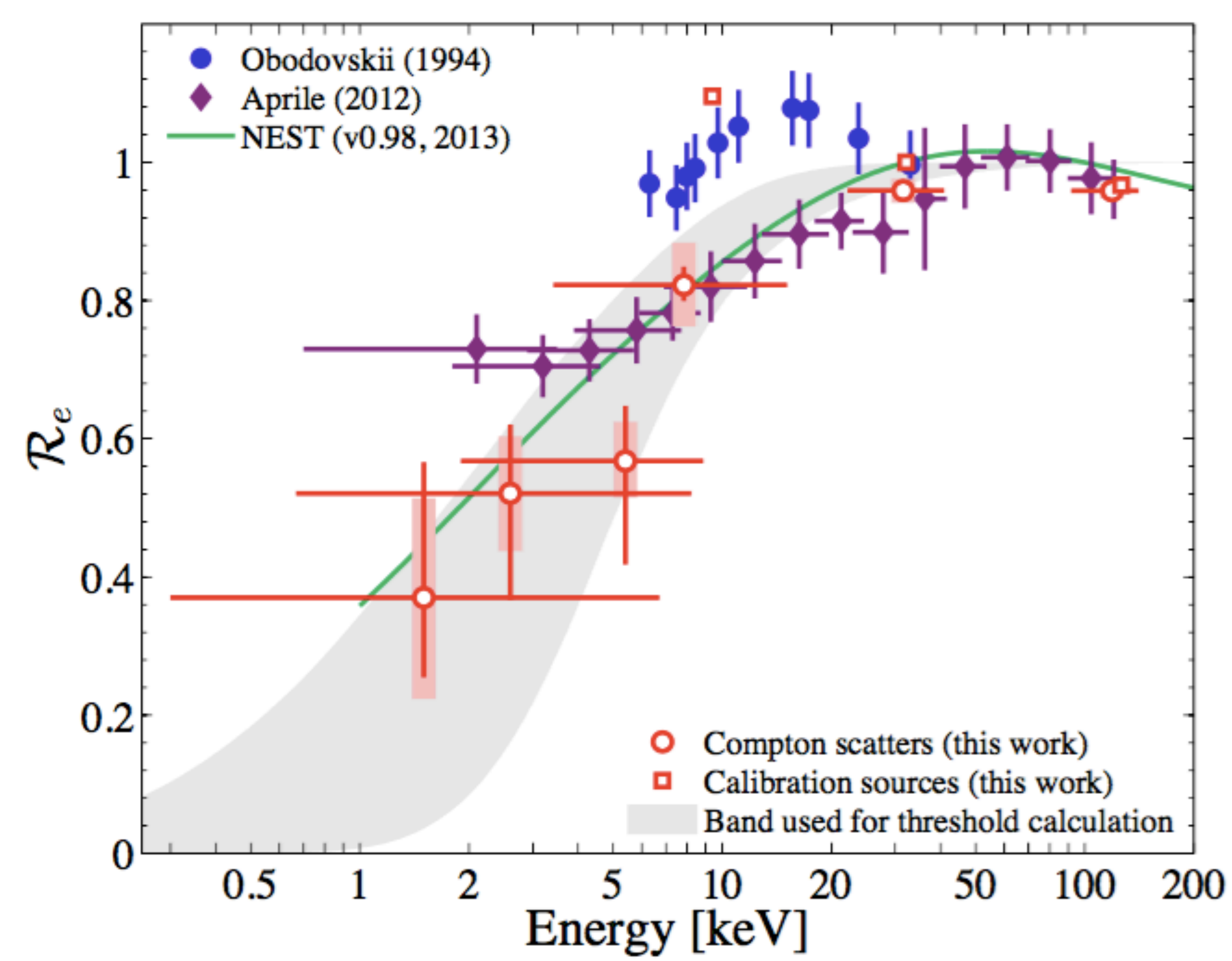
monoenergetic gamma with recoil angle measurement



example from Baudis group

powerful technique, but only possible in smaller detectors





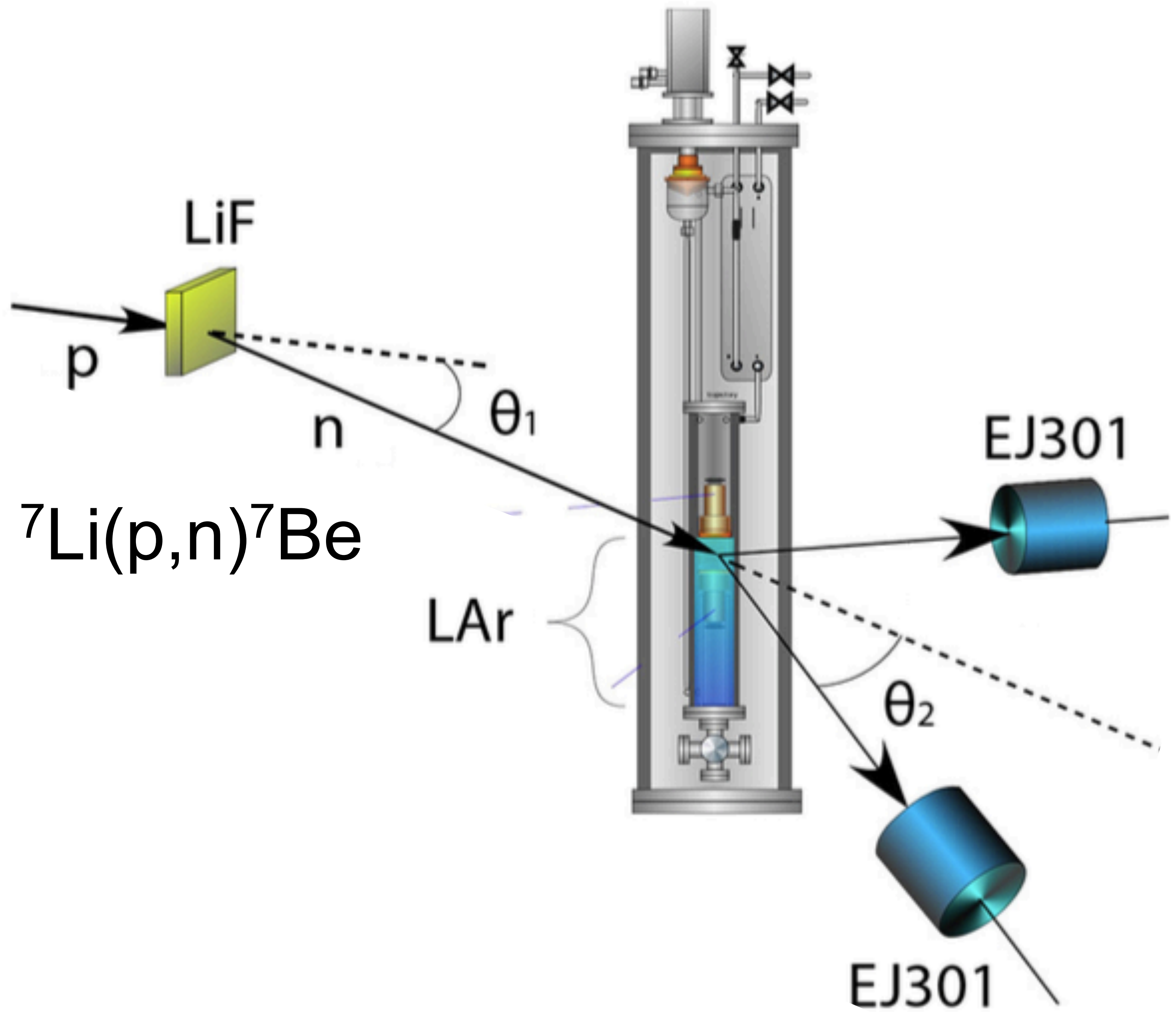
https://arxiv.org/abs/1303.6891

monoenergetic neutron with recoil angle measurement

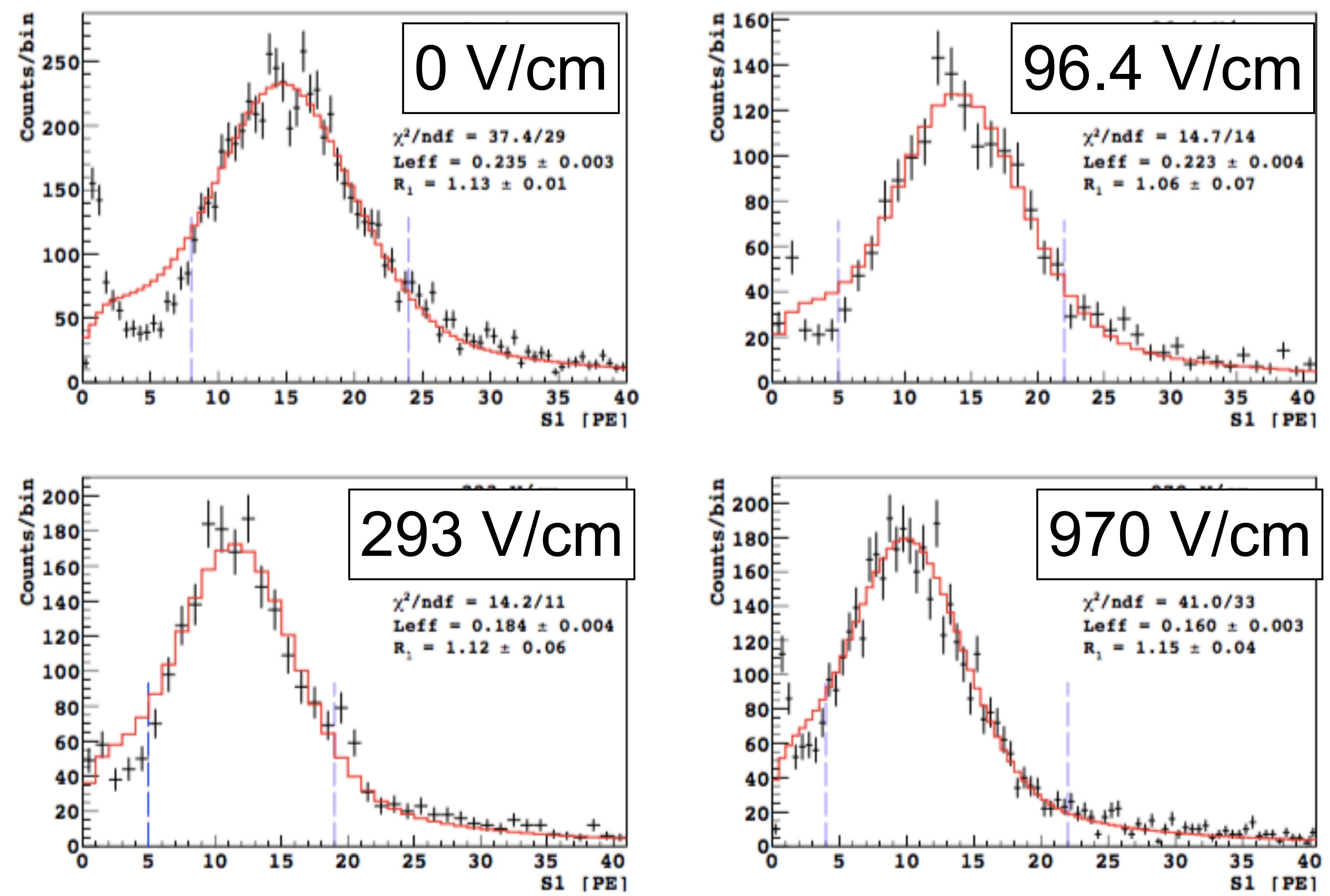
small-scale detector with external angle measurement

example: SCENE collaboration

again: powerful technique, again limited in detector scale



all plots : 10.3 keV nuclear recoils

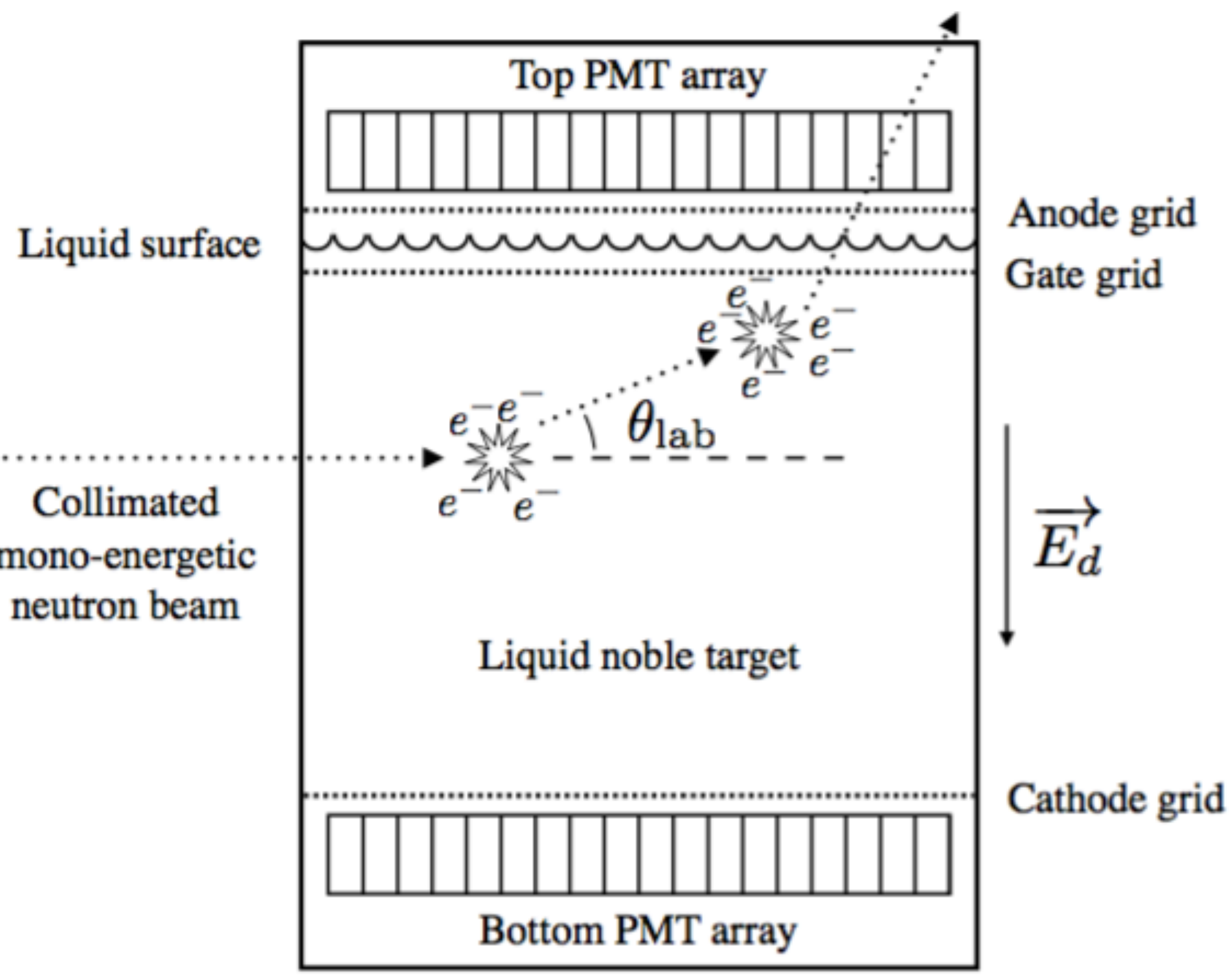


arXiv:1406.4825

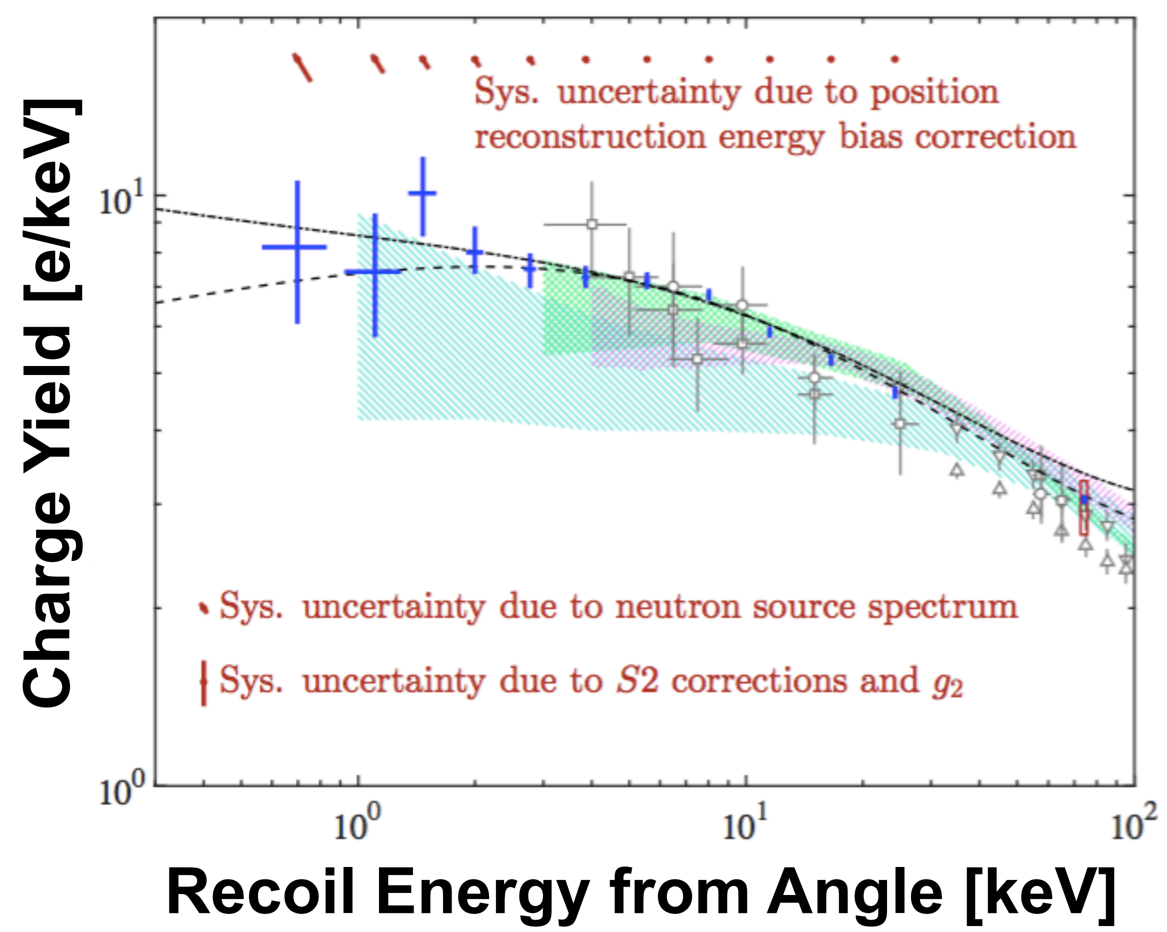
monoenergetic neutron with recoil angle measurement

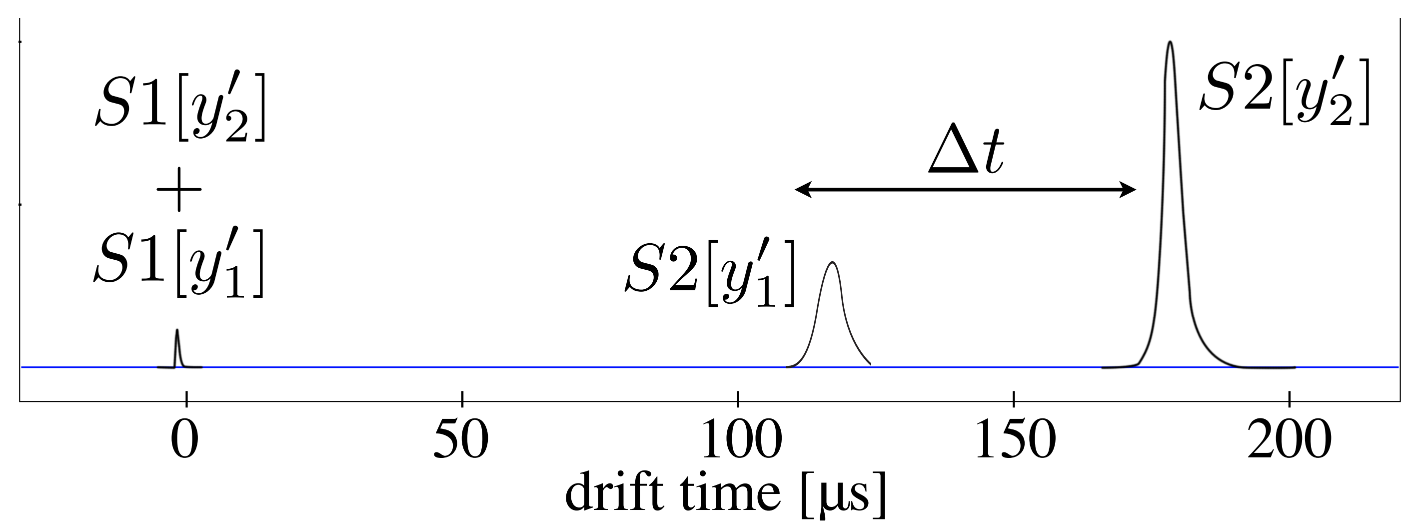
large-scale detector with internal angle measurement

in LUX

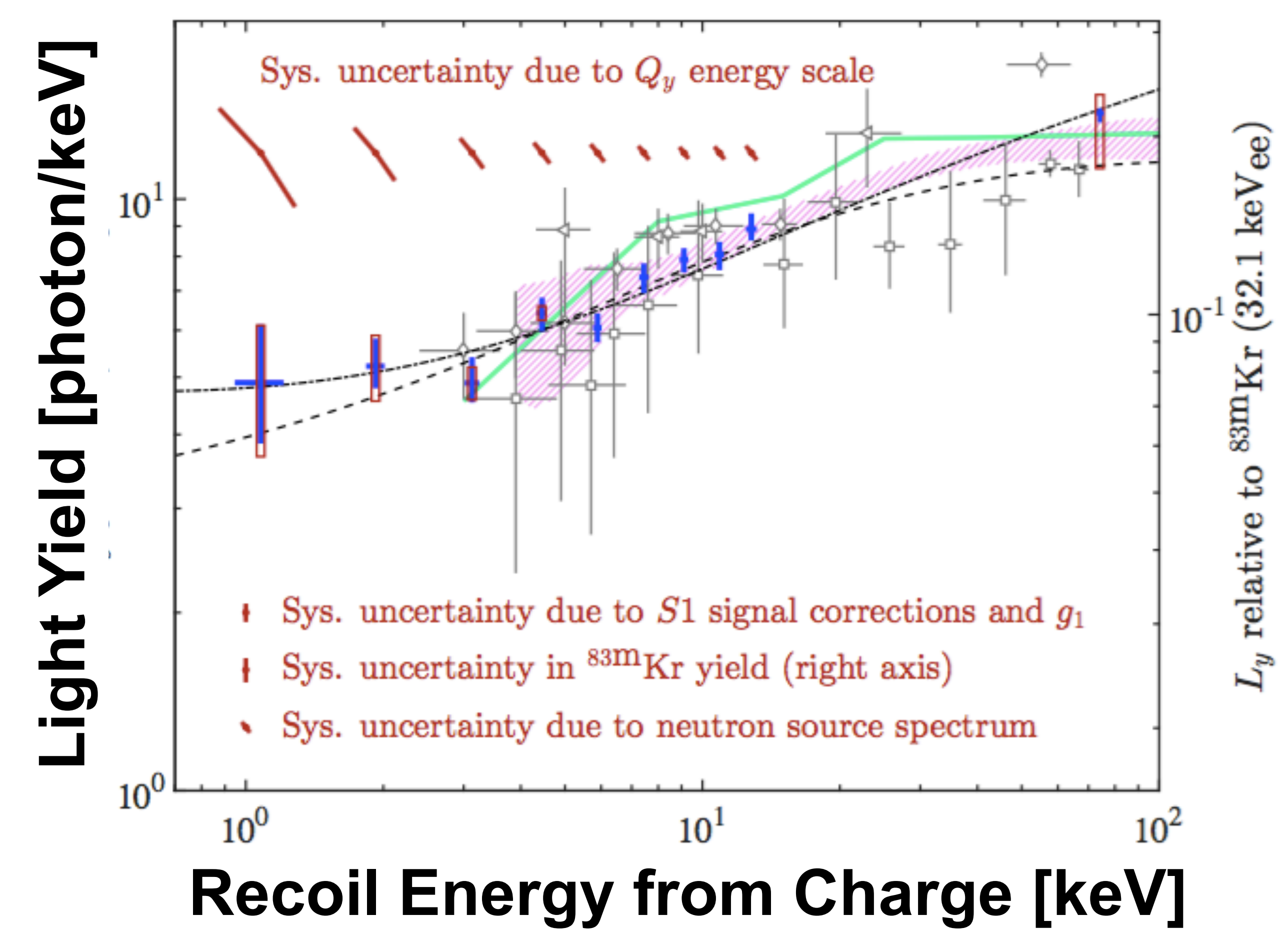


Step 1: Charge Yield
Uses double-scatter selection
(one S1, two S2)
E1 is known (angle)





Step 2: Light Yield
Uses single-scatter selection
(one S1, one S2)
E comes from Charge Yield (step 1)

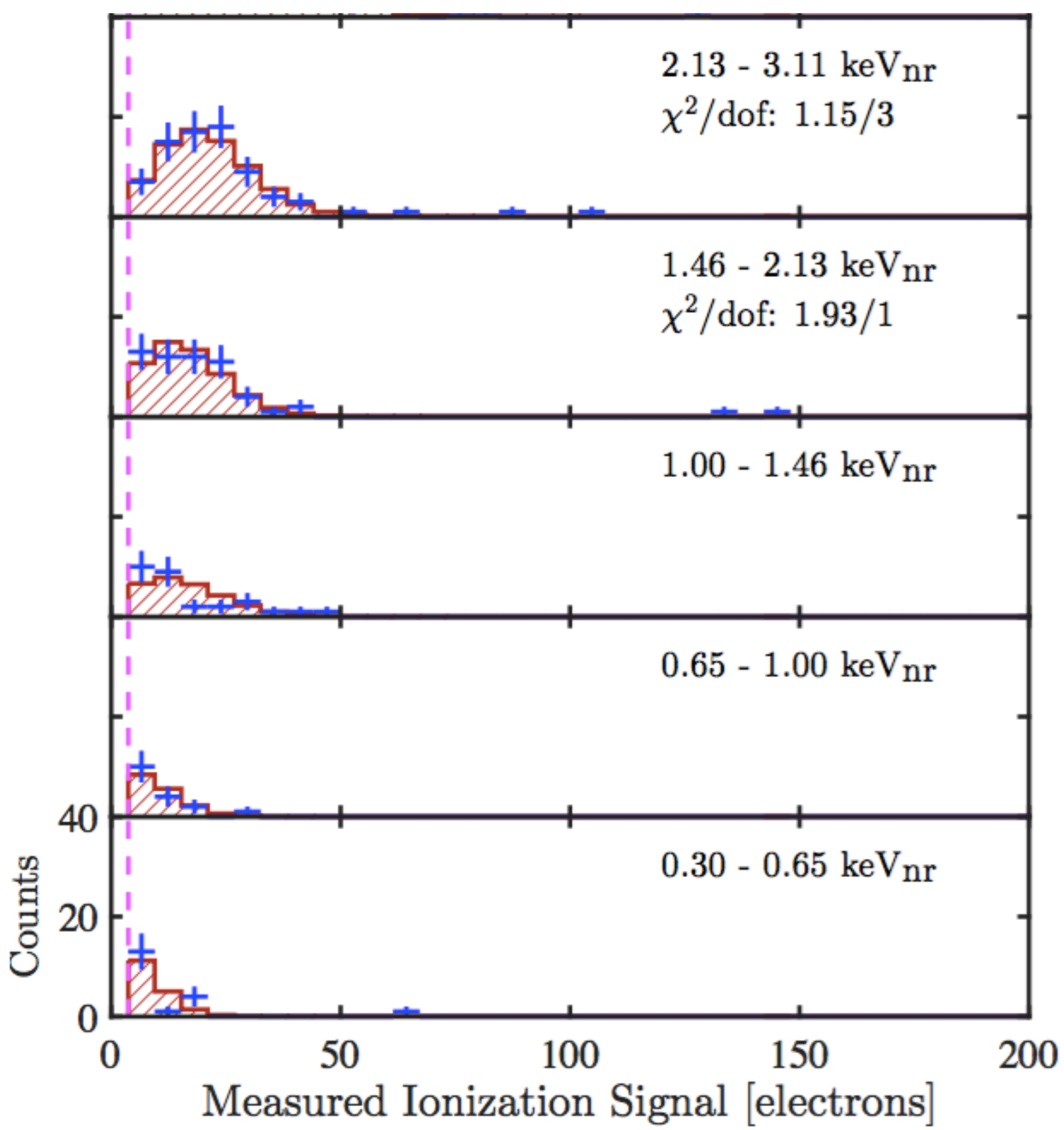


https://arxiv.org/abs/1608.05381

monoenergetic neutron with recoil angle measurement

large-scale detector with internal angle measurement

https://arxiv.org/pdf/1608.05309



Threshold limitation: small angles
Strategy: increase angle for a given energy, by using a lower-energy n beam

DD neutron : 2.45 MeV
DD neutron + 180° reflection on D : 272 keV
very hot gamma-n sources of even lower energies

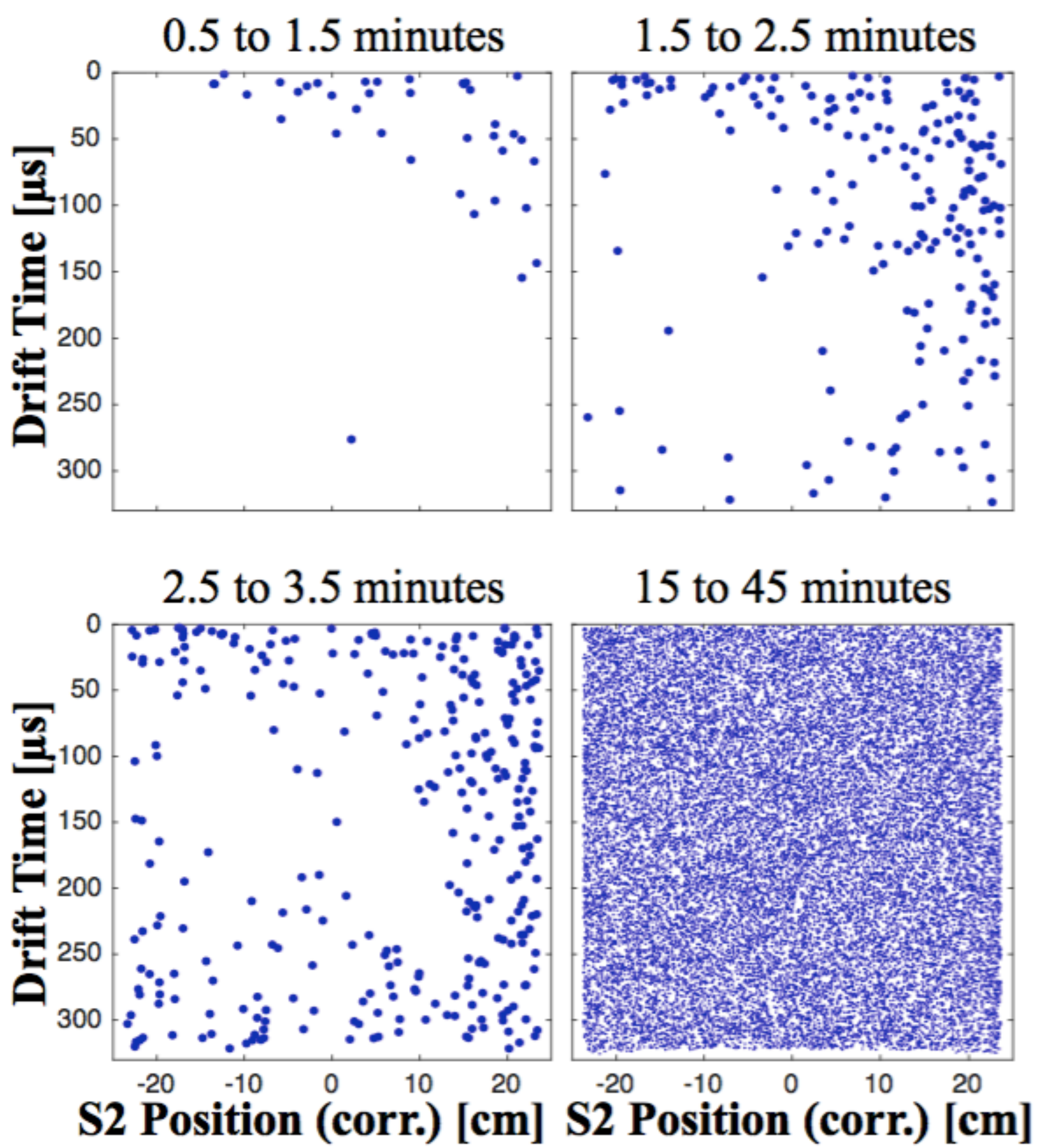
Threshold limitation: Charge measurement still requires S1 observation (for dark count rejection and drift time measurement)

Strategy: use beam timing to set t0 for S1-free recoils

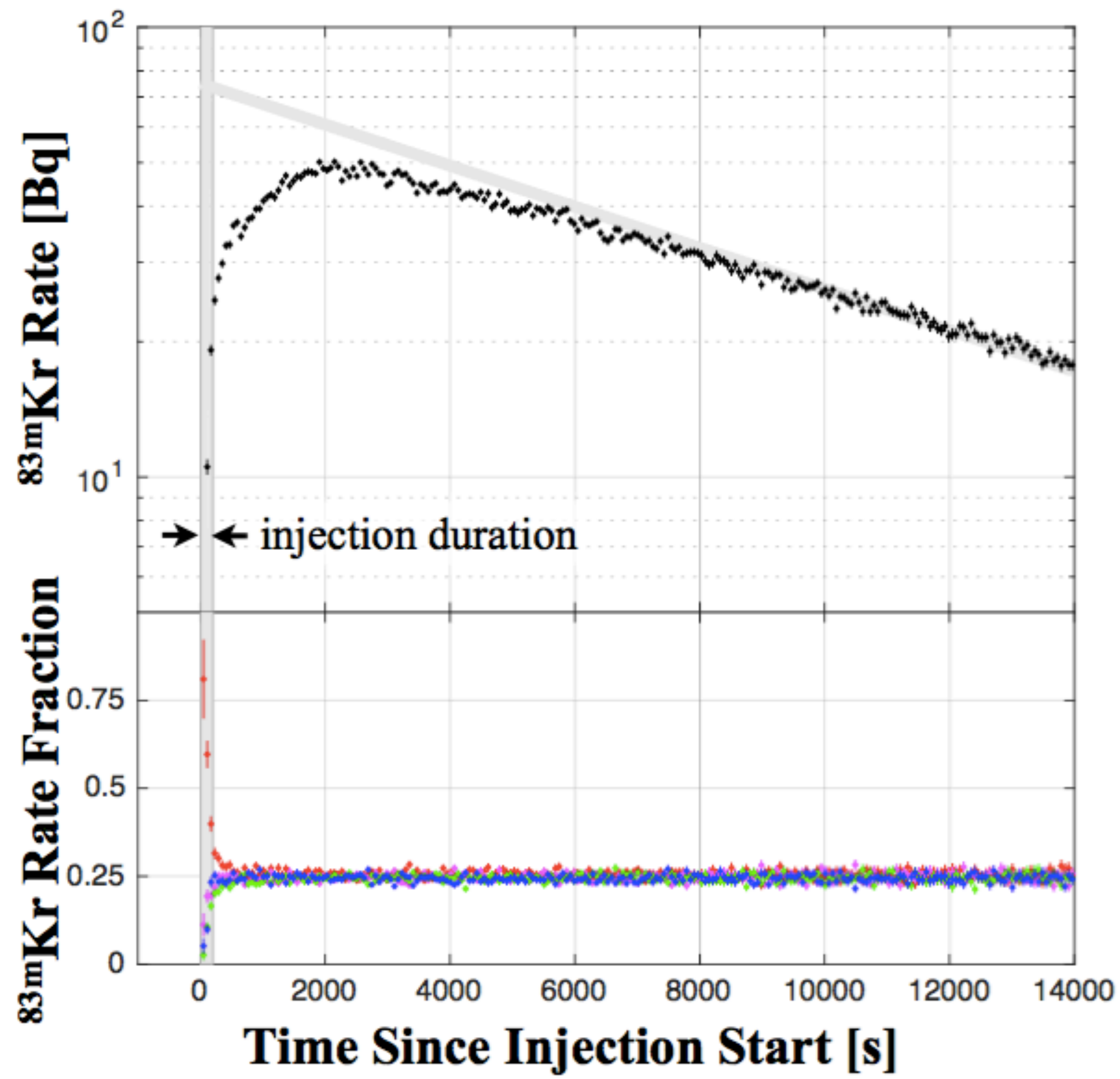
internal sources

(LUX Kr83m example)

Step1: mixing into the target liquid



Step2: return to background
(either passive decay or active purification)



internal sources

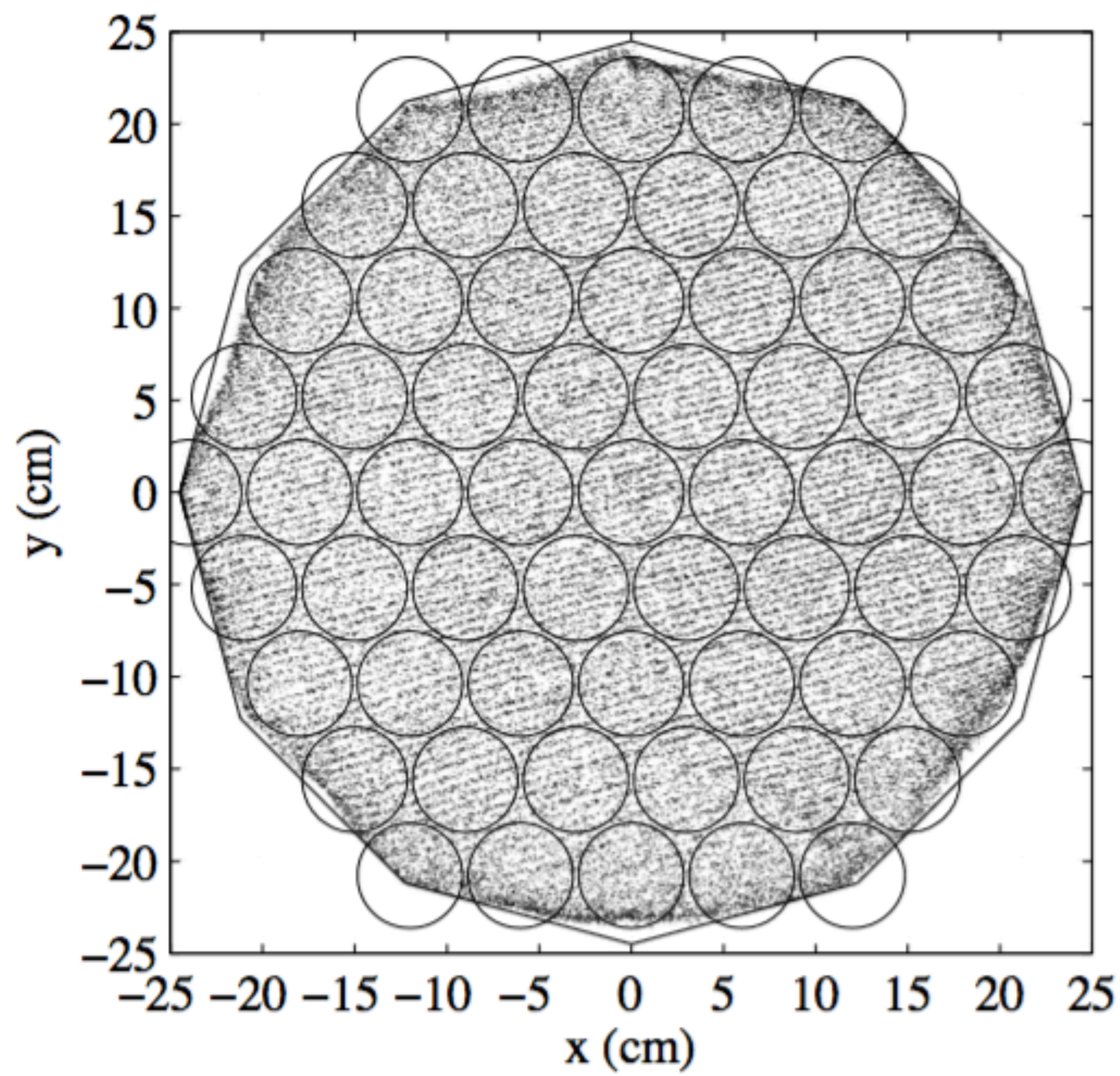
(LUX Kr83m example)

general to any volume-filling source:

-> aids measurement of fiducial mass
(just passage fraction)

-> aids tuning of position reconstruction algorithms

low energy beneficial to limit systematics

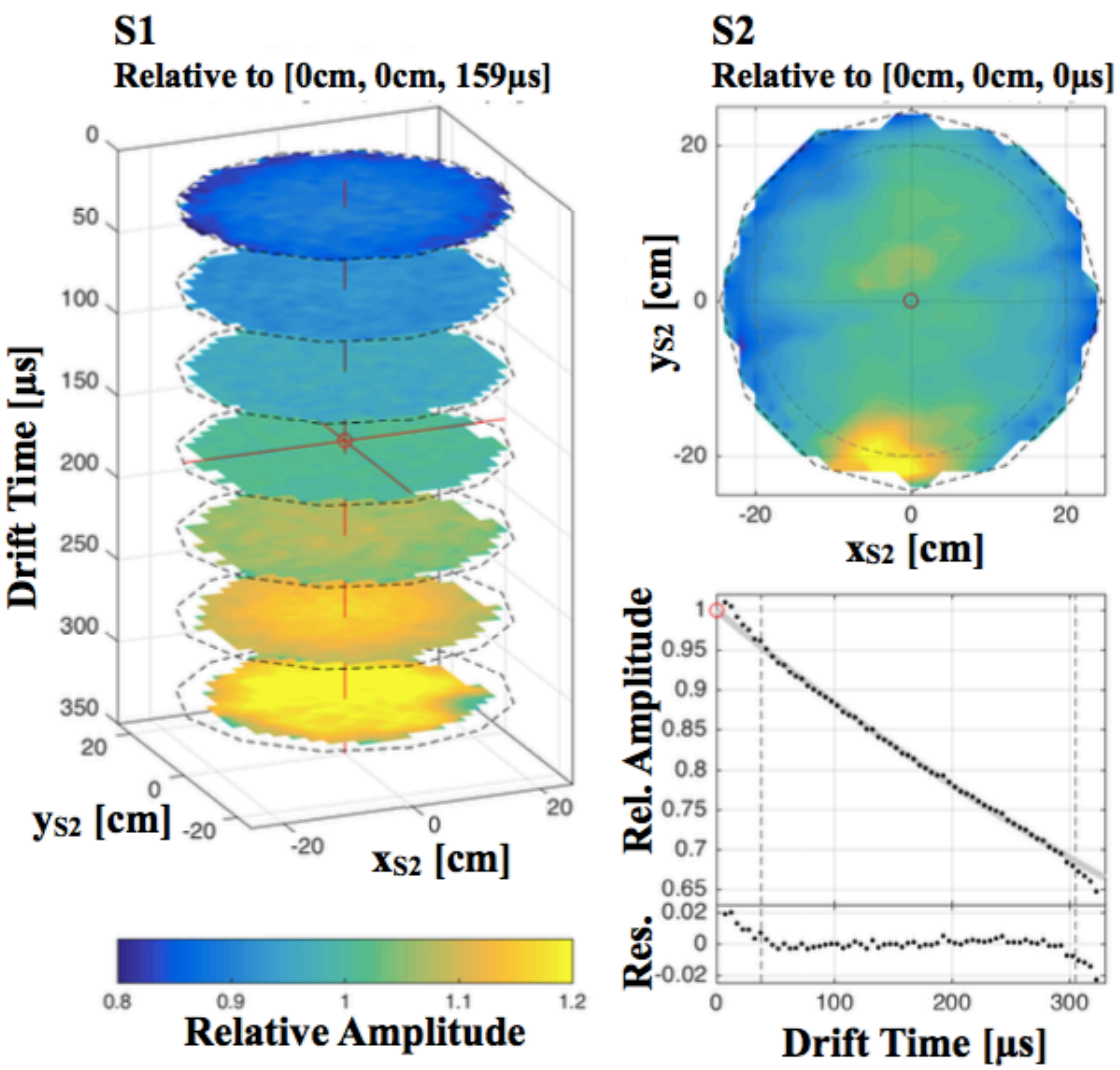


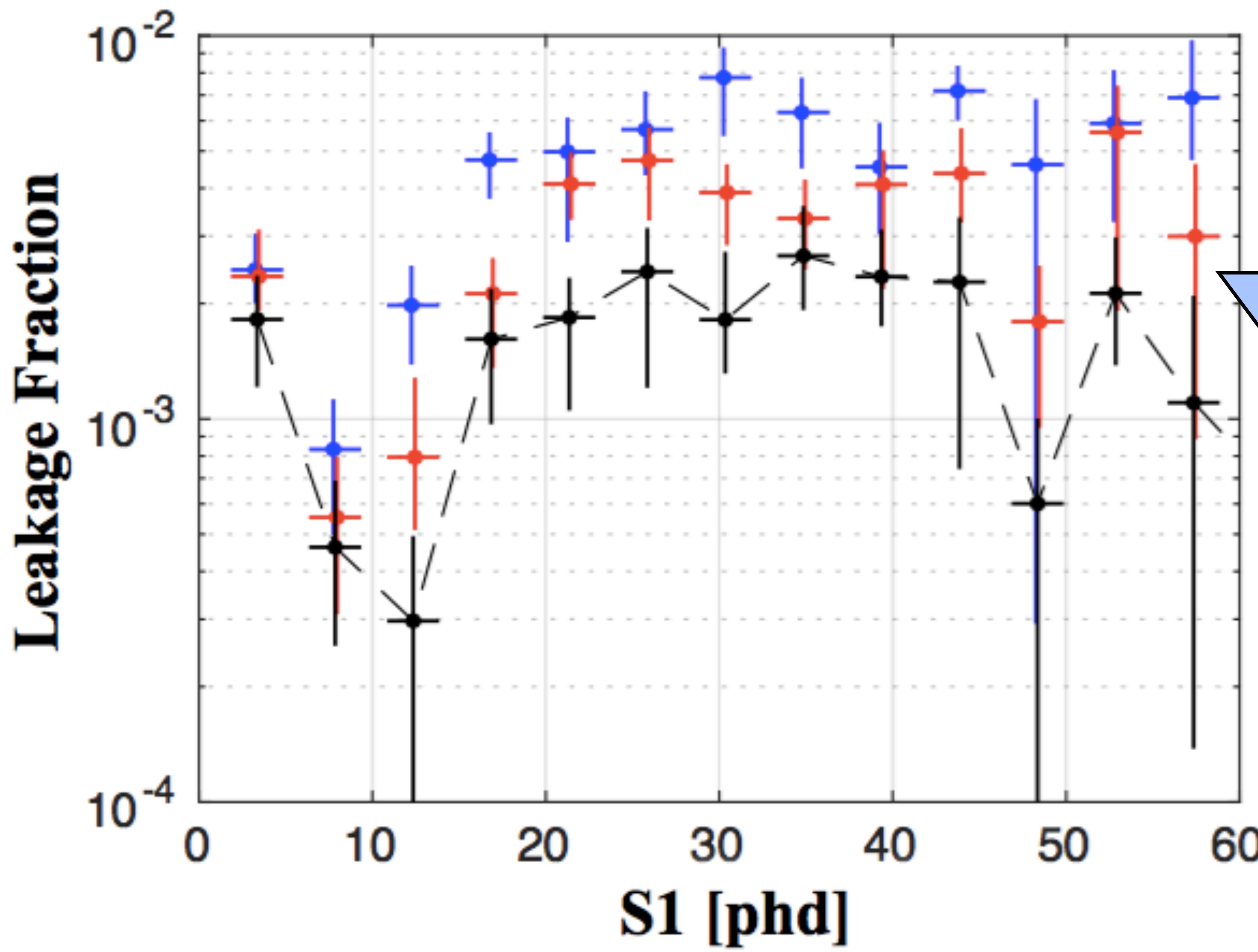
internal sources

(LUX Kr83m example)

general to any peaked distributed source:

easy 3D mapping of efficiencies & gains
-> very important to improving resolution





improved resolution
is improved background rejection

internal sources: 37Ar

Electron Capture
K-shell: 2.8 keV
L-shell: 270 eV (!)

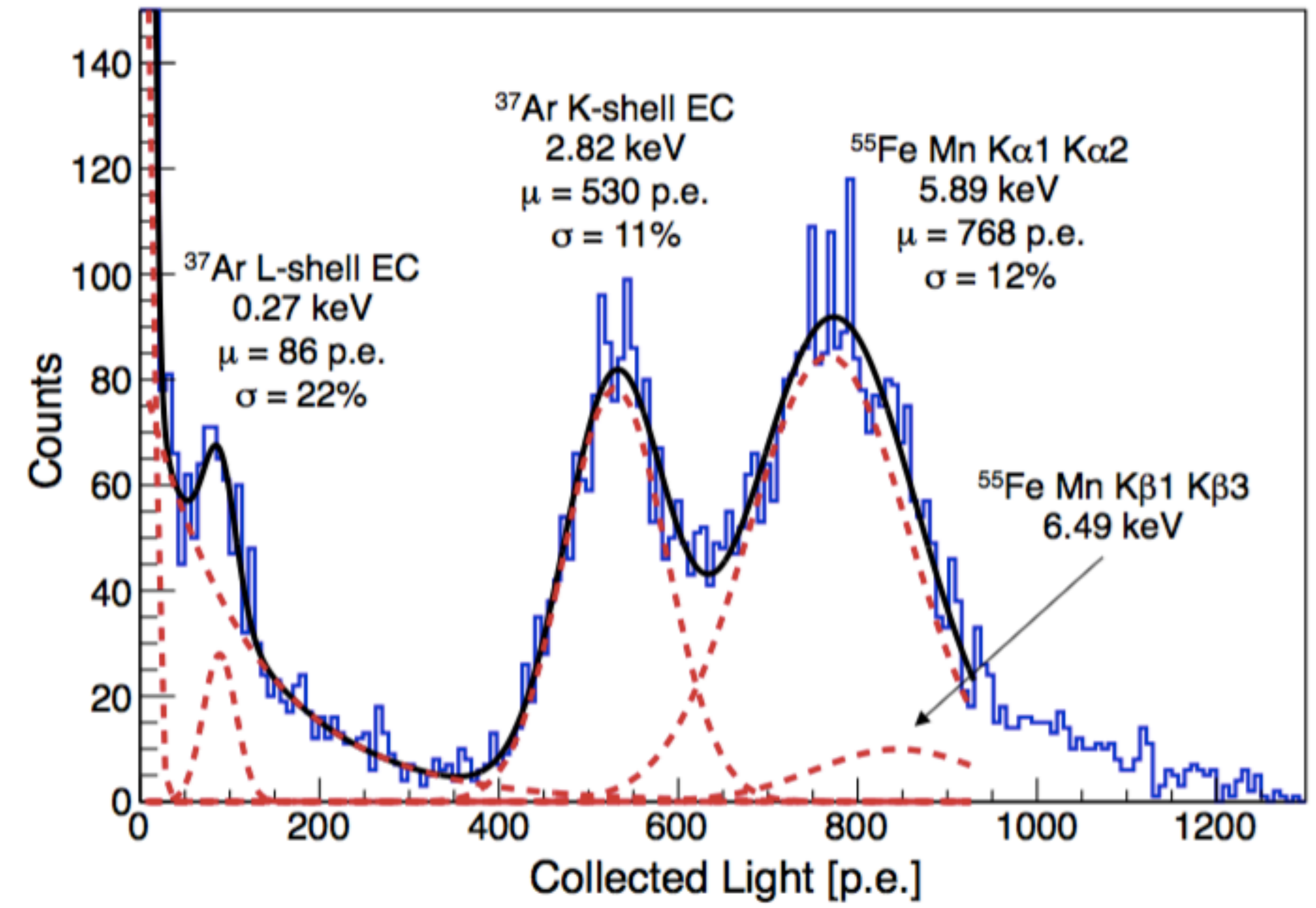
halflife: 35d

injected in end-of-run LUX injection

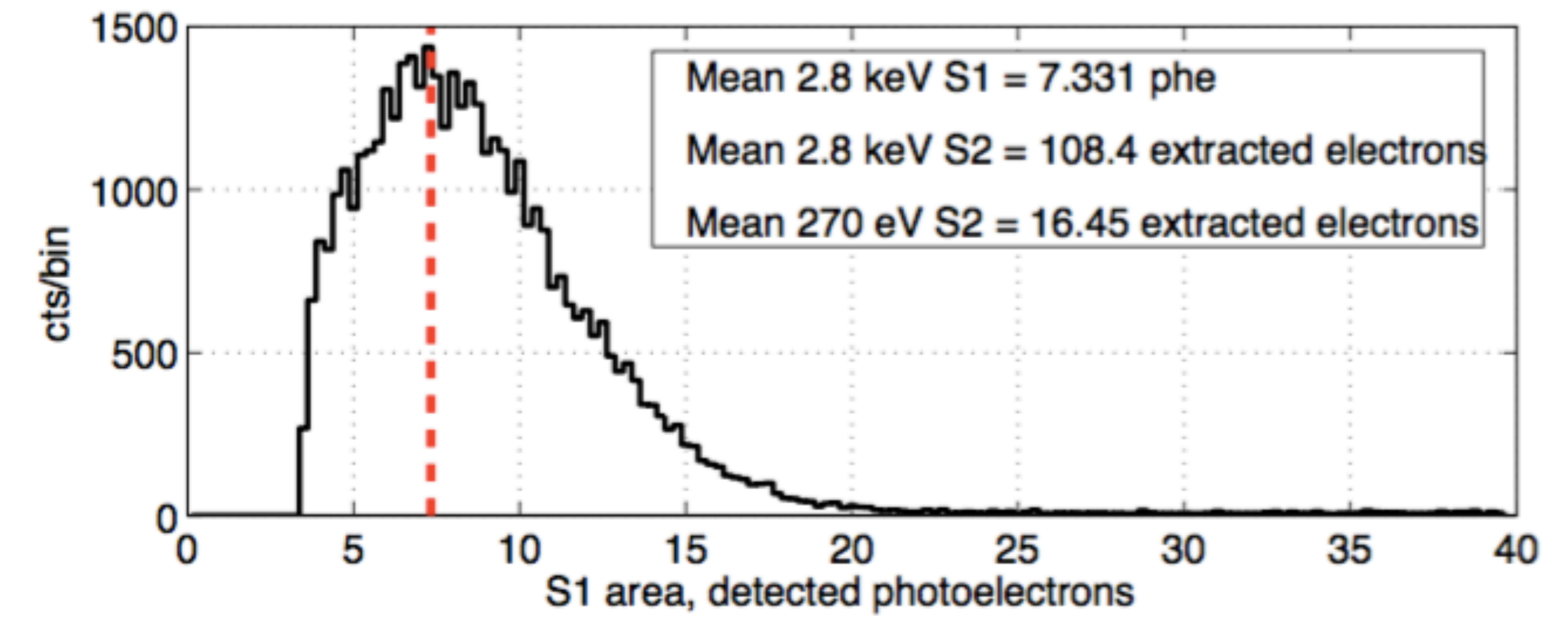
'for free' calibration in early DarkSide-50 exposure

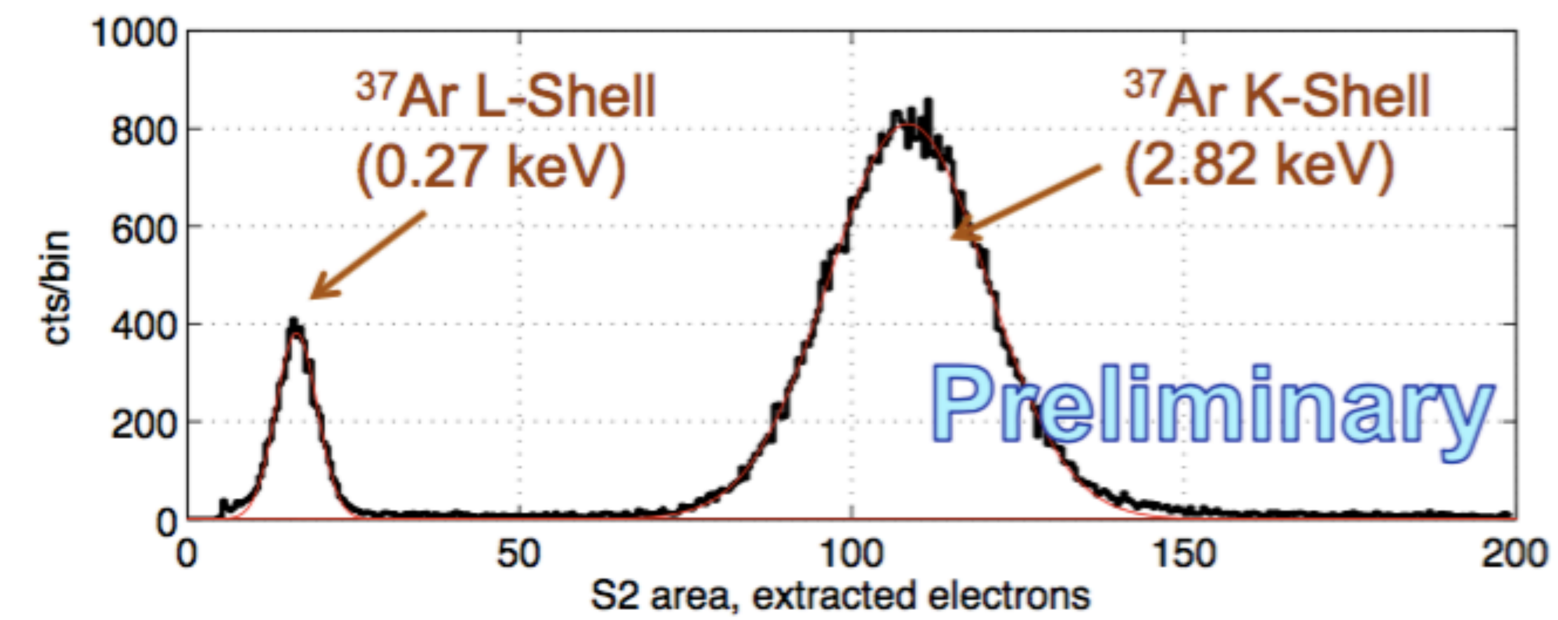
35d is prohibitive...
but possible at end-of-experiment (LUX data in hand)
or in experiments with in-situ isotope separation (xenon1t?)

LAr: https://arxiv.org/abs/1301.4290



LXe: https://arxiv.org/abs/1705.08958



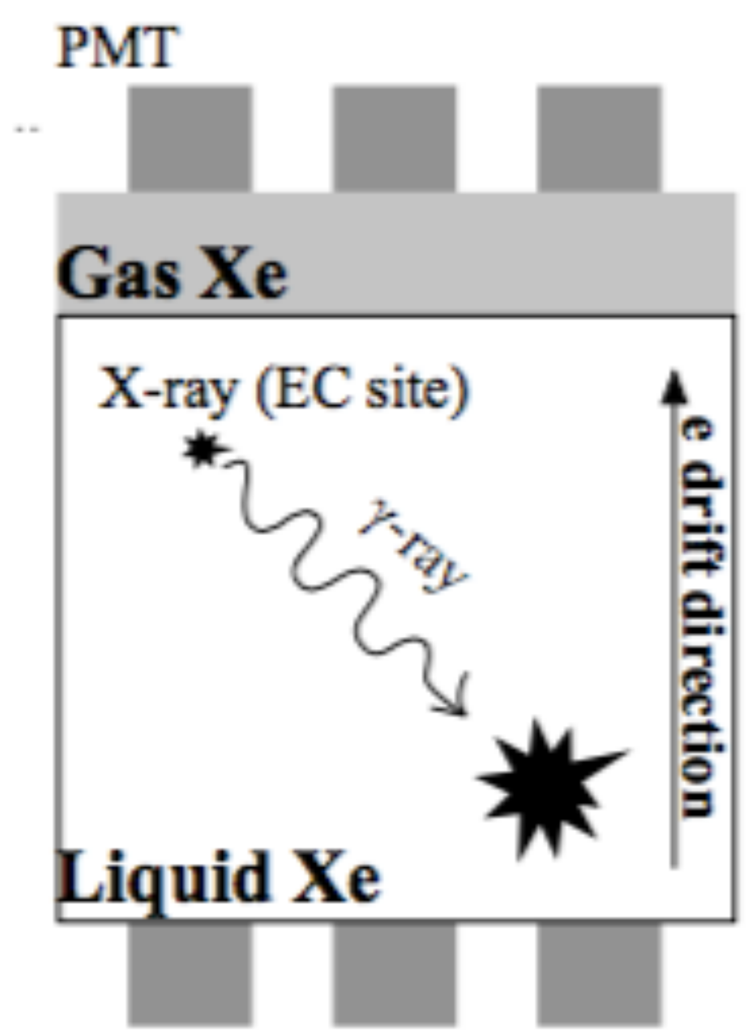


internal sources: 127Xe

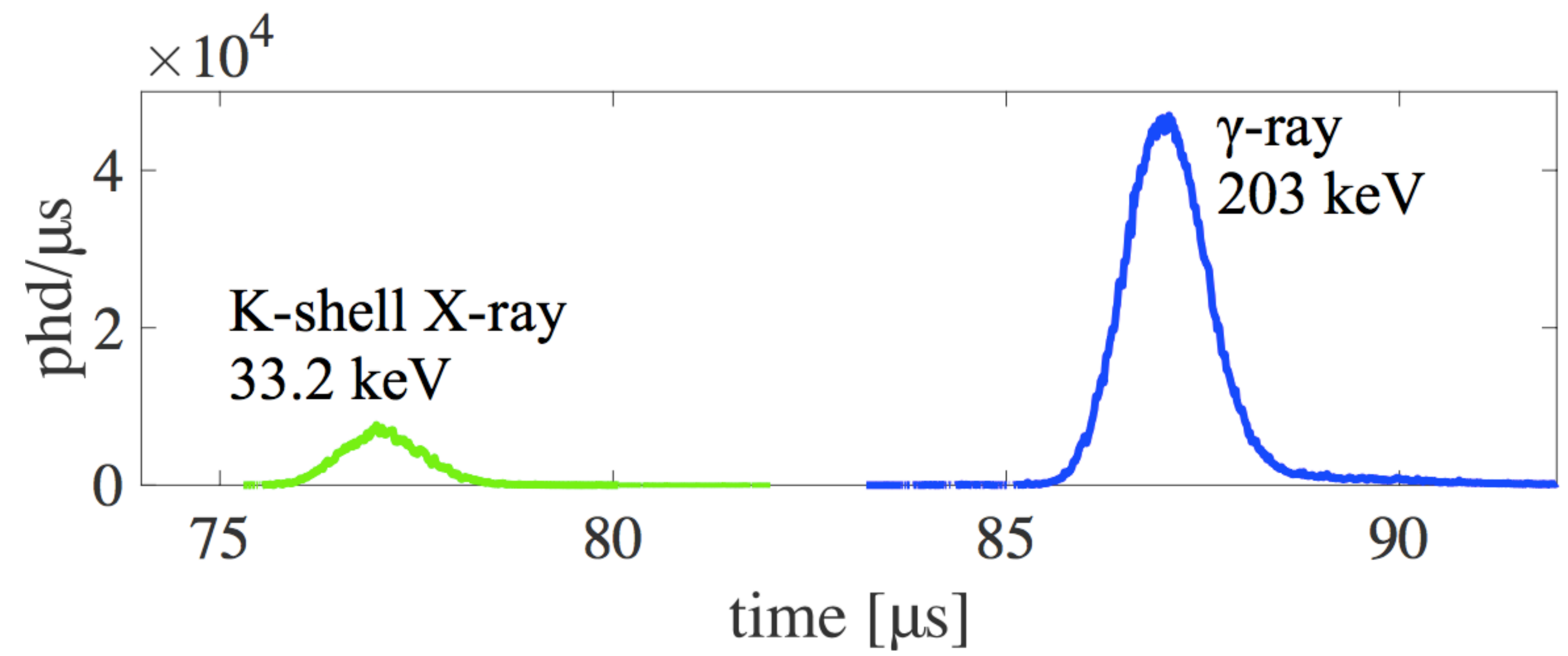
Electron Capture
- K-shell: 33.2 keV
- L-shell: 5.2 keV
- M-shell: 1.1 keV
- N-shell: 190 eV (!)

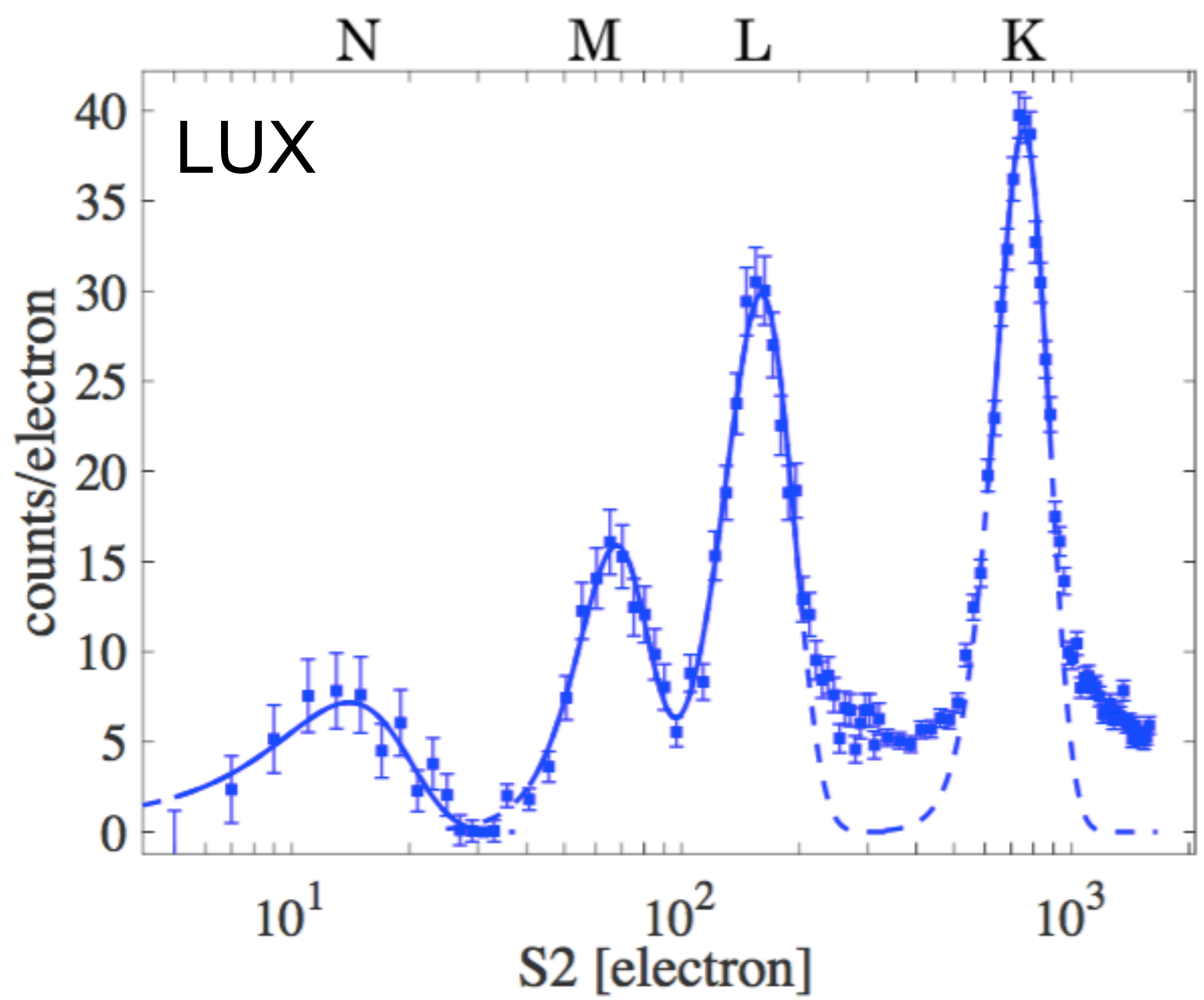
halflife: 36d

downside: coincident gamma
(in TPC, charge-only still very possible)

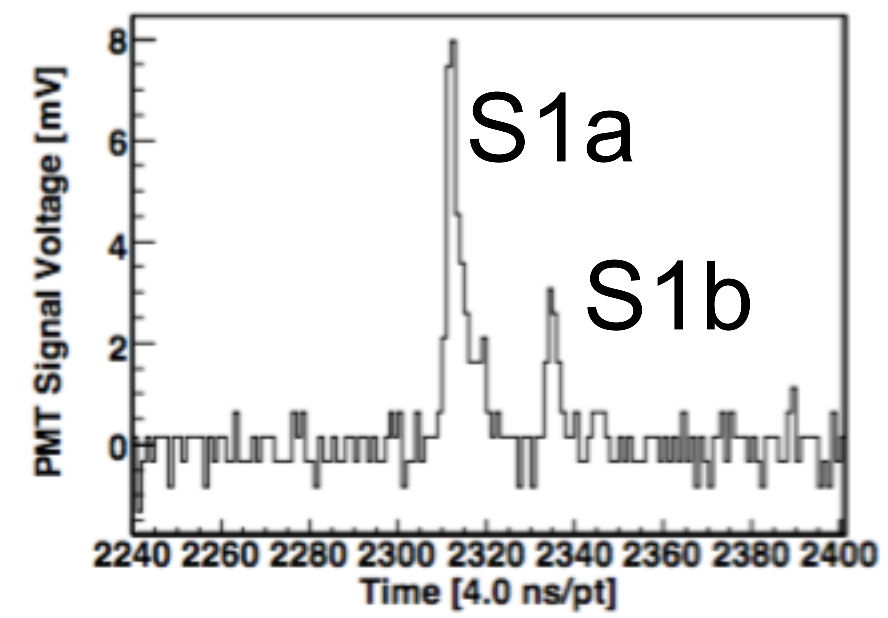


https://arxiv.org/abs/1709.00800





internal sources: Kr83m



workhorse calibration peak

1. convenient production (Rb83 with 86d halflife)
2. convenient half life (1.8h)
   (convenient assuming few-hour liquid mixing)

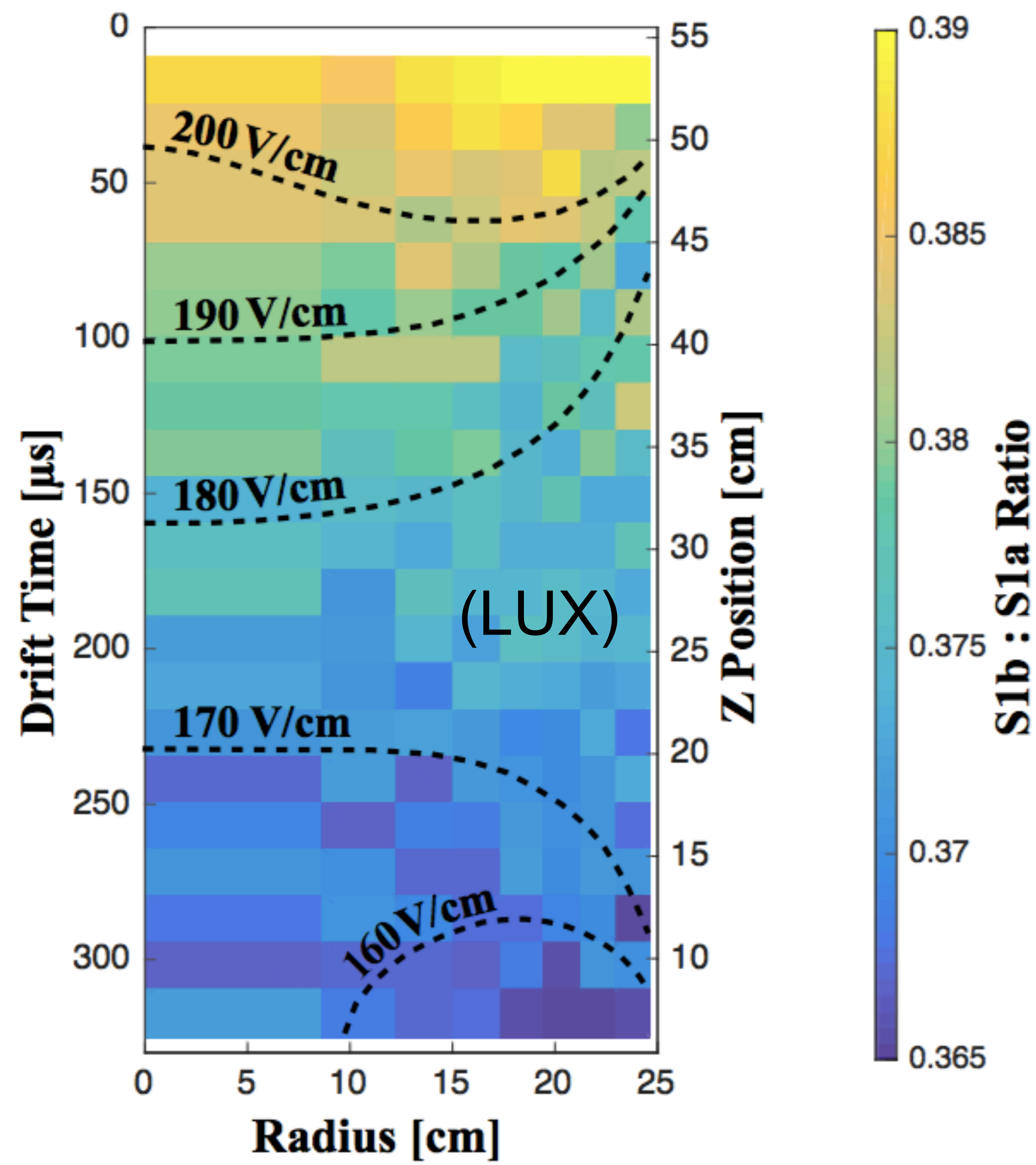
some complexity: two-step decay of 32.1 + 9.4 keV (154ns)

standard mode: use as a merged 43 keV peak

novel two-S1 mode: compare 32.1 + 9.4 keV S1 amplitudes

ratio shows you recombination variation

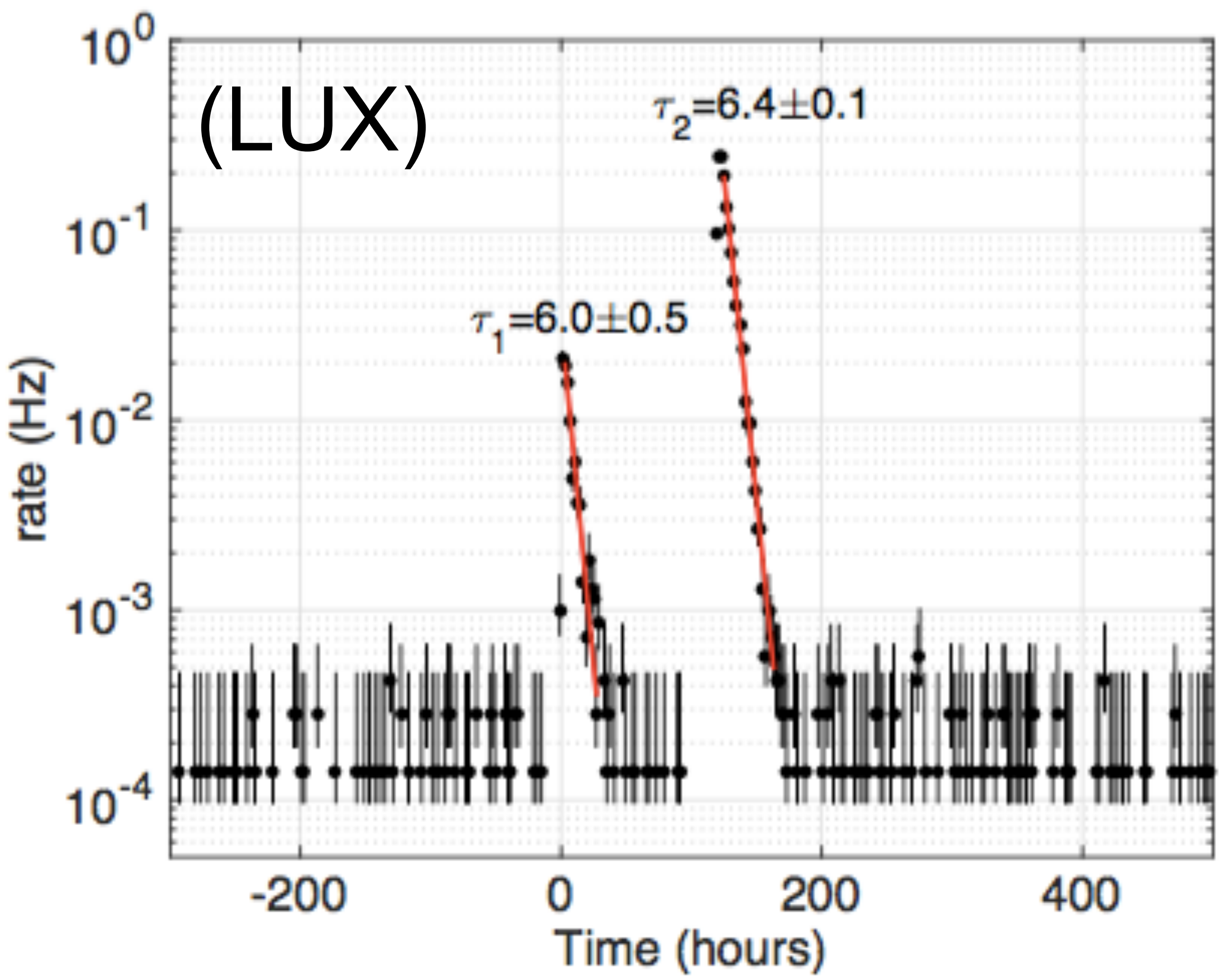
maps 1-to-1 with E-field amplitude

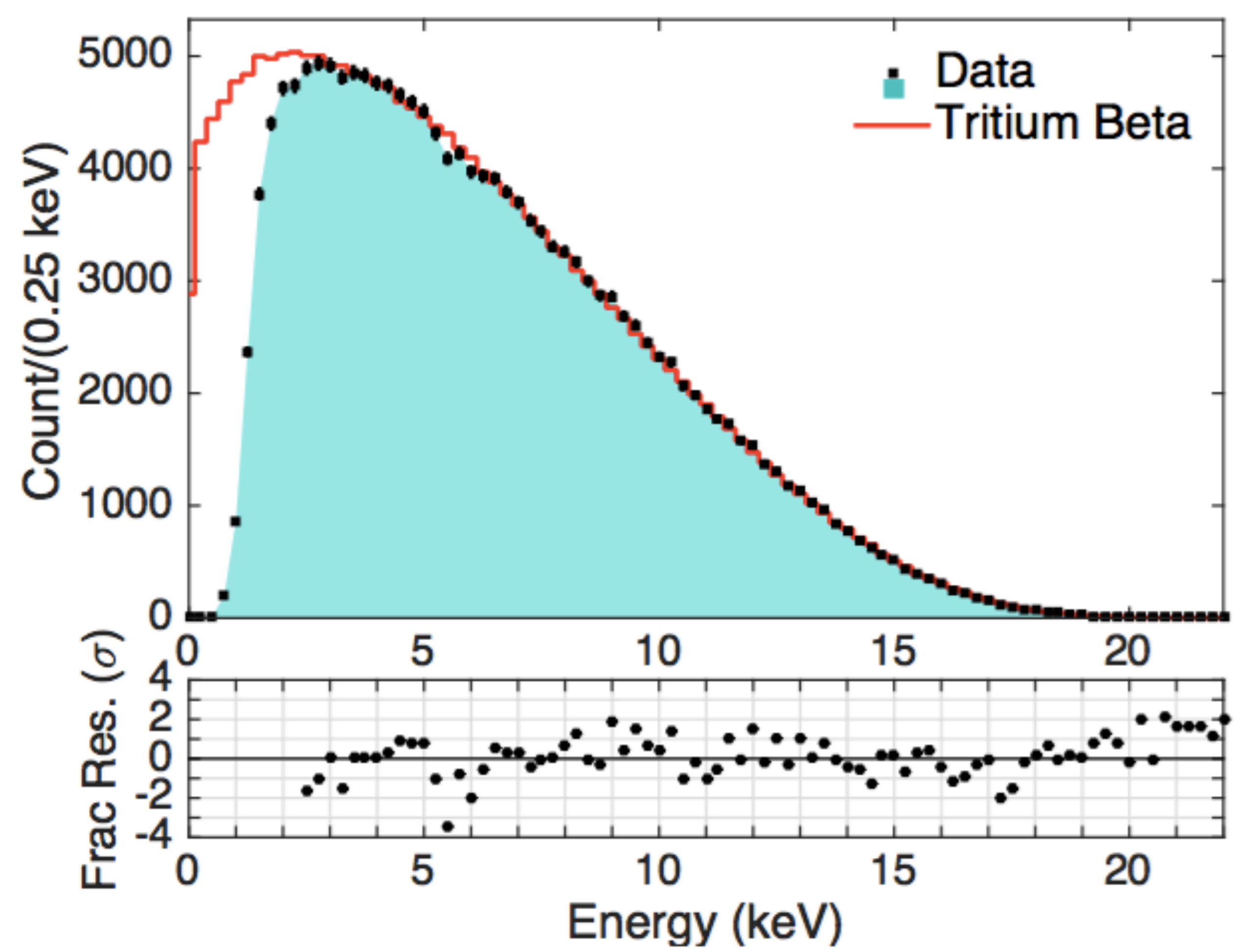


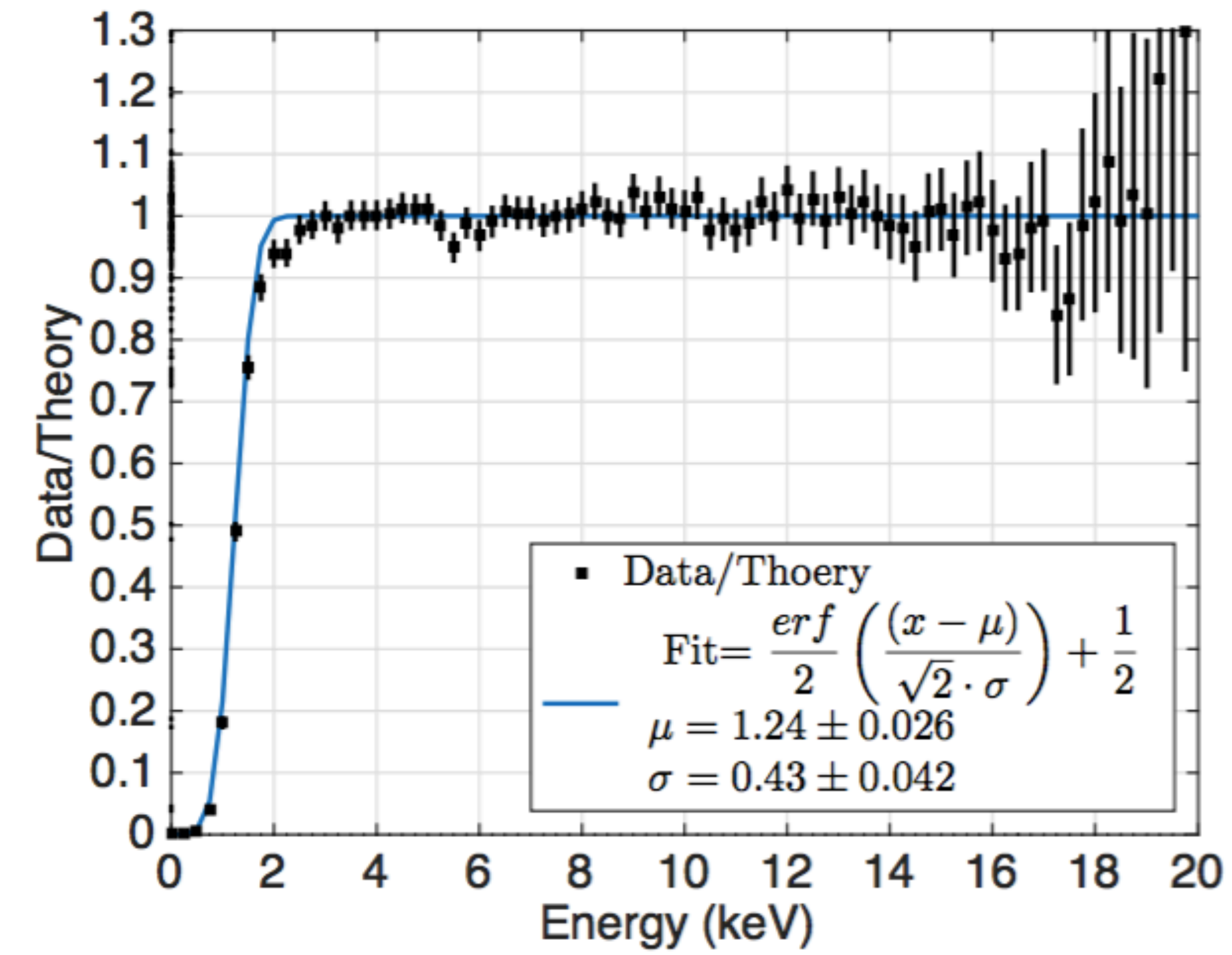
internal sources: long-lived beta sources in CH_4

Long-lived sources: naively would ruin the detector

Trick: inject source as source-labeled easy-to-remove molecule
opens up long-lived betas (tritium, C14, etc.) for electron recoil continuum calibrations







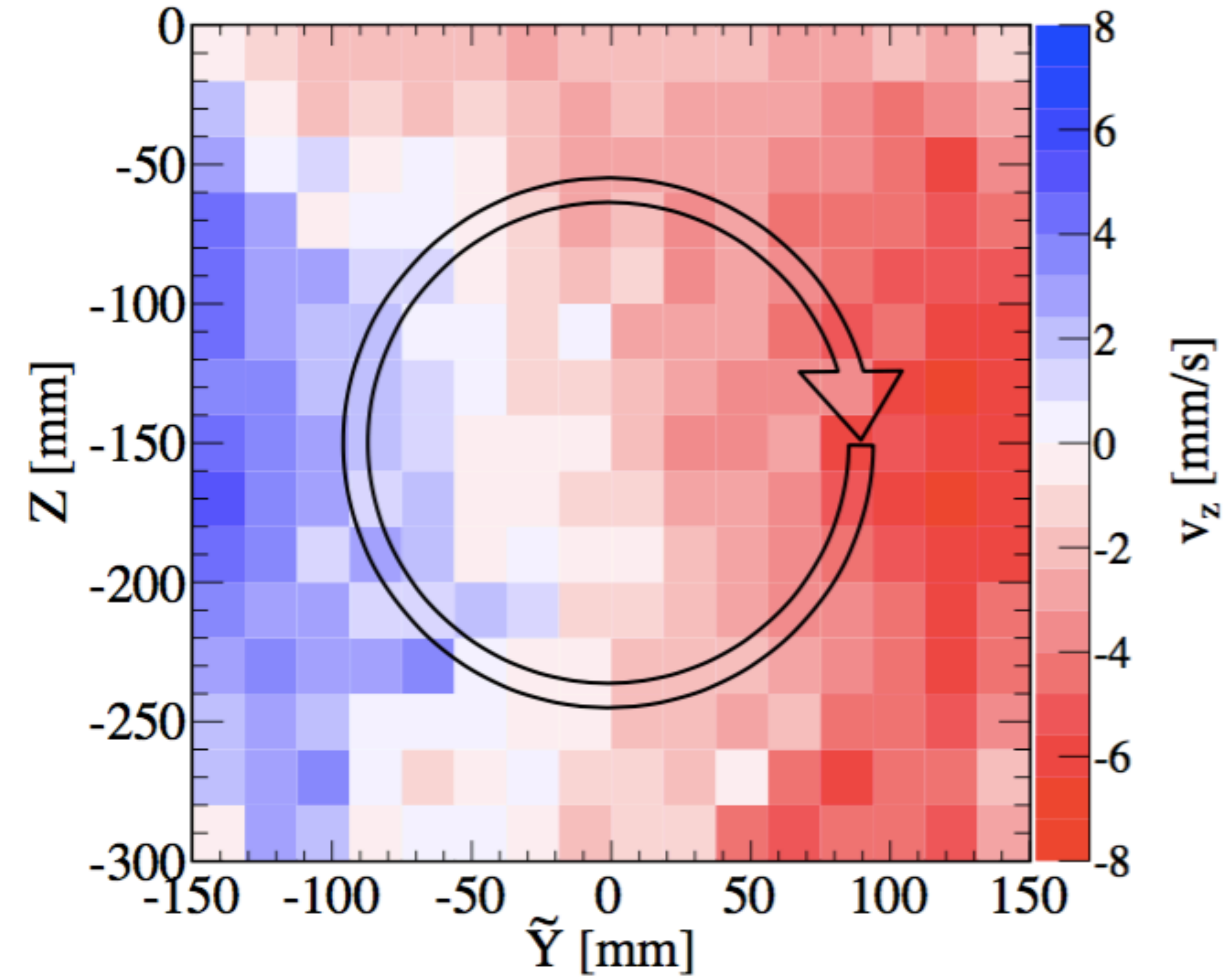
tritium: https://arxiv.org/abs/1512.03133

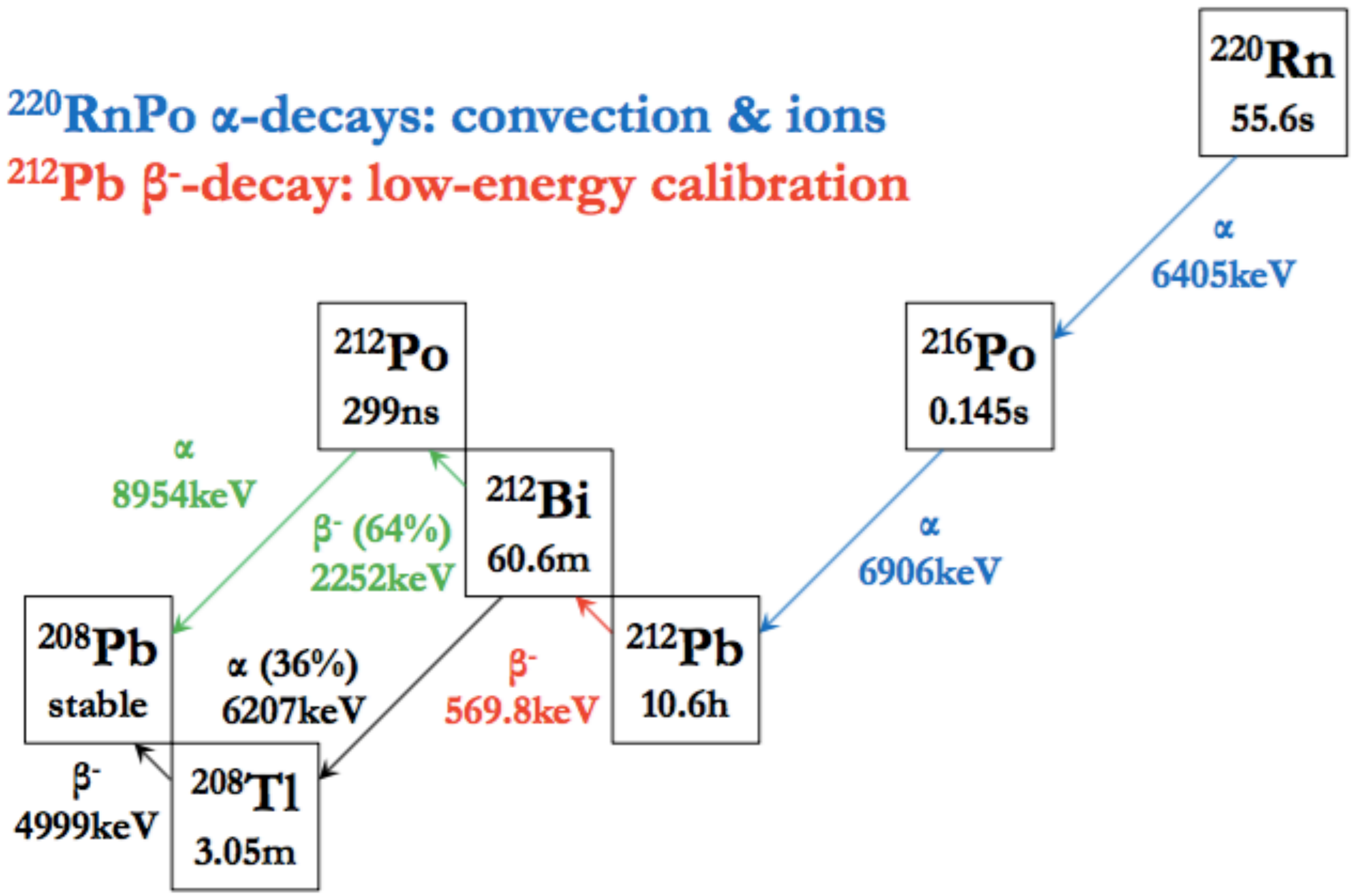
internal sources: Rn220

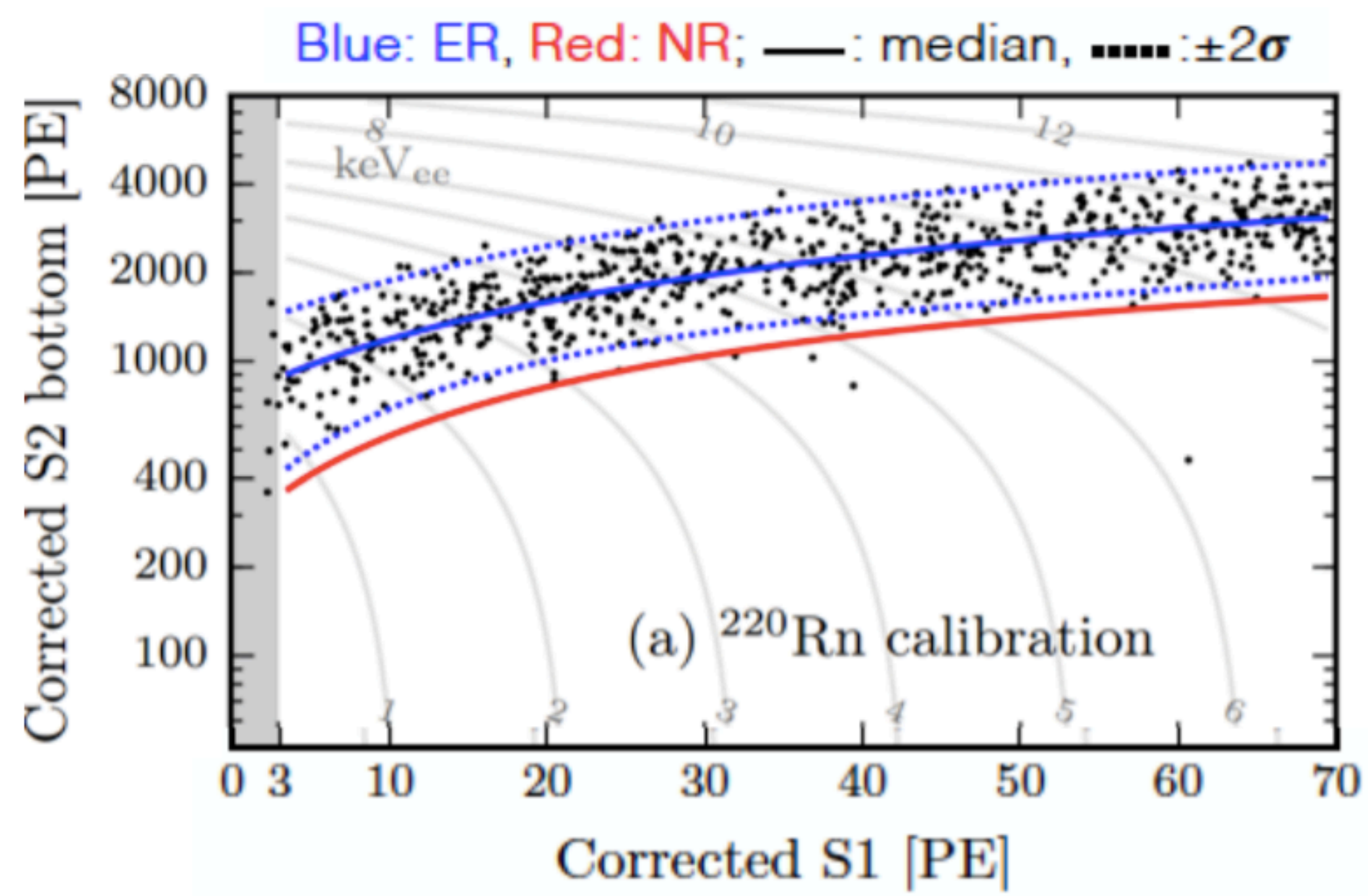
(XENON100 & XENON1T)
https://arxiv.org/abs/1611.03585

Th228 parent

Rich information from series of daughter decays
- -alphas give bright-scintillation peaks
- -delayed coincidences allow flow mapping (0.145s and 3min)
- -imitates collection/removal/sticking of Rn222 daughters
- -Pb212 proves a beta-decay band (w/ relatively low statistics)







summary points

External: limited by self-shielding
exponentially less useful as detector scale grows
neutrons not so bad, gamma-n sources promising at low energies

Beams: angle selection selects recoil energy
small-scale test detectors with external angle measurement
large-scale ‘real’ detectors can use internal angle measurement

Internal: low-energy electron recoils in the bulk
distributed monoenergetic peak for ‘flat-fielding’ resolution enhancement
electron capture peaks at very low energies
betas for broad energy range including threshold
Rn220 with rich daughter chain