Charge and Light Yields

^{127}Xe Inner-Shell Electron Captures

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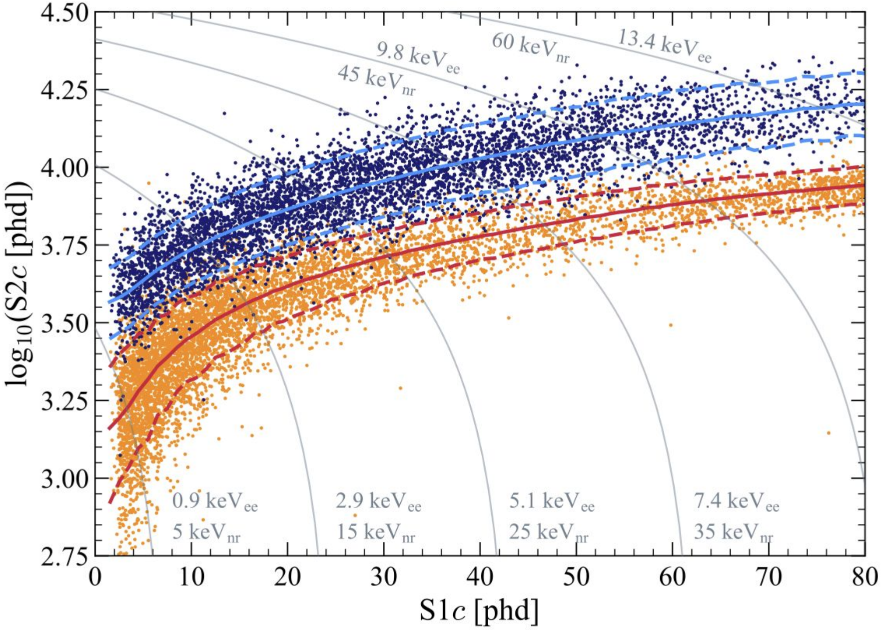
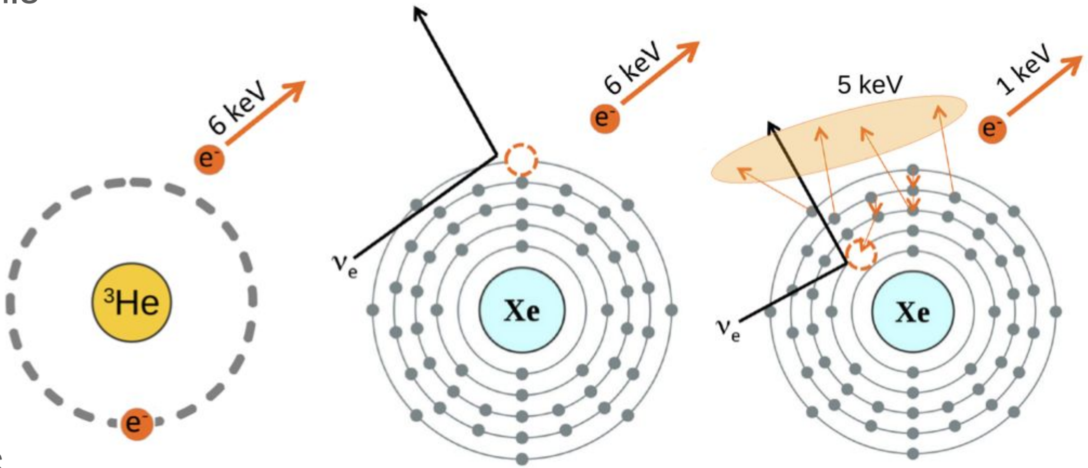
ER/NR discrimination

- LXe-TPCs measure both light (S1) and charge (S2) signals
- Ratio of S2 to S1 signals allows discrimination between electron-recoils and nuclear-recoils
- Electron-recoil response calibrated with ^{3}H β-decays
- Nuclear-recoil response calibrated with DD-neutrons



But what about neutrino ER events?

- Unlike beta decays, neutrino recoils often produce inner-shell electron vacancies.
  - Inner-shell vacancies
  - higher ionization density
  - higher recombination
  - more "NR-like" signal
- L-shell ν-ER events fall within WS ROI
  - Expect 4 L-shell ν-ER events in SR1WS, ~70 events over 1000 livedays

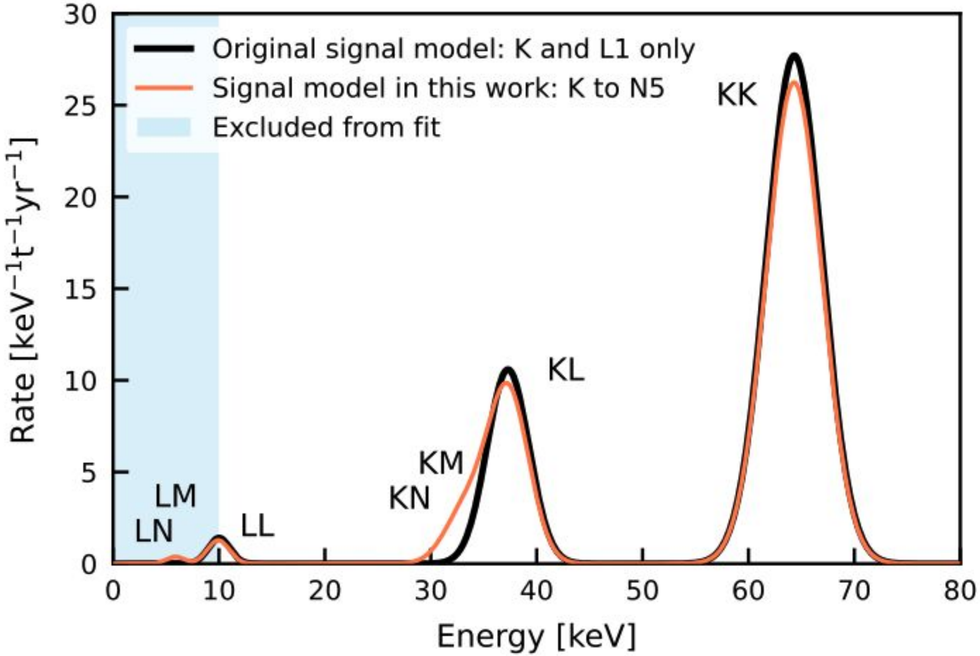


Phys. Rev. D 104, 112001 (2021)

Xe124 ECEC

- Double-electron-capture decay direct to nuclear ground state
- Longest half-life ever directly measured, ~10^{22} years!
- Interesting signal, but the LL peak falls within WS ROI
- 5 expected events in SR1WS, ~80 events expected over 1000 livedays

XENON 1T



Phys. Rev. C 106, 024328 (2022)

Migdal Effect

- Migdal effect - nuclear recoils are predicted to ionize the recoiling atom ($\mathcal{O}(10^{-5})$ probability), which can leave an inner-shell vacancy
- The atomic de-excitation provides an “ER-like” component to the interaction
    - Could boost sub-threshold nuclear recoils above threshold!
- But this “ER-like” component is less ER-like than we originally thought - searches might expect less separation between Migdal events and NR backgrounds

Accounting for this could help relieve tension between predicted Migdal rate and the non-observation by Xu et. al.

LLNL-JRNL-850170 (2023)

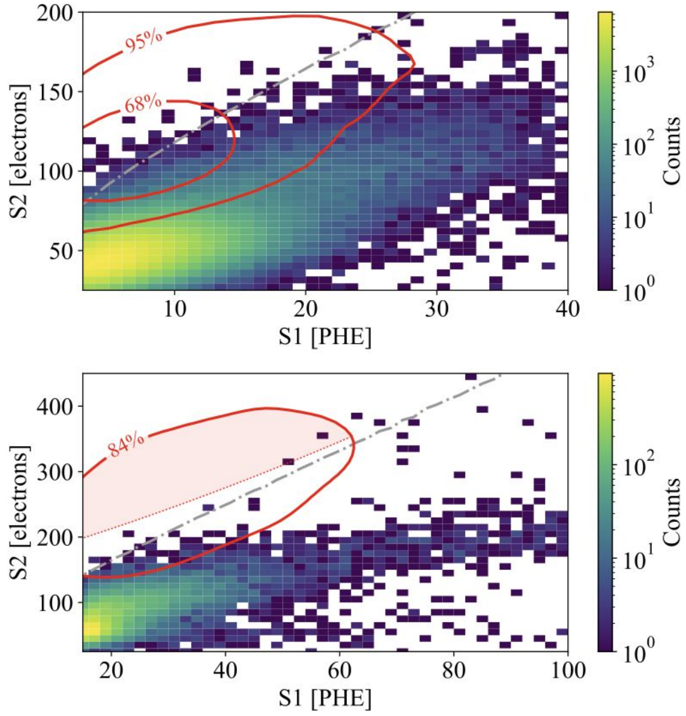
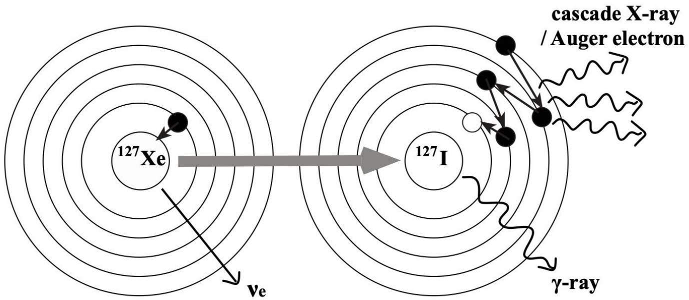


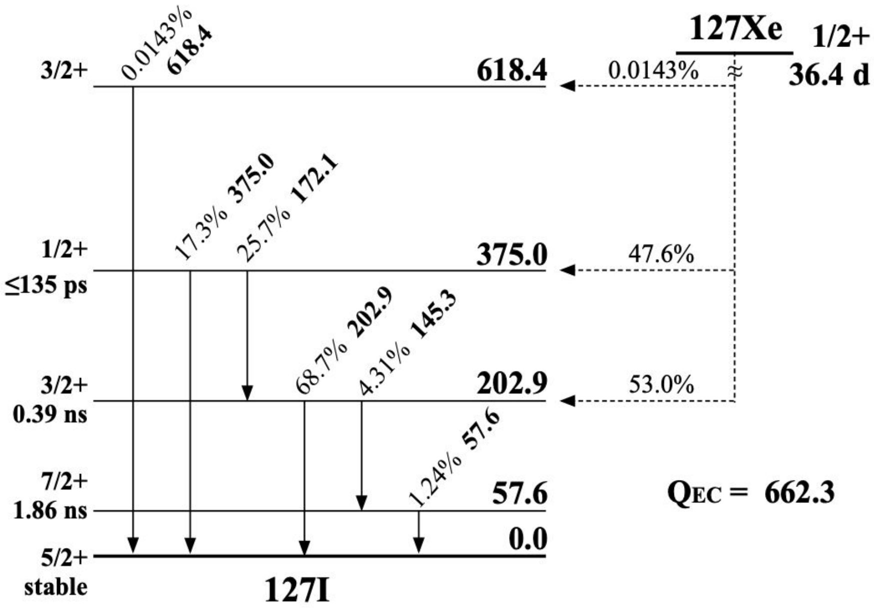
FIG. 2. The S2 vs S1 distributions for the data used in the M-shell (top) and L-shell (bottom) Migdal signal searches. In both figures, signal contours (solid red) and the ER distribution median (dot-dashed grey) are also plotted. The shaded region in the bottom illustrates the analysis ROI for the L-shell Migdal search.

^{127}Xe Electron Capture



Phys. Rev. D 96, 112011 (2017)

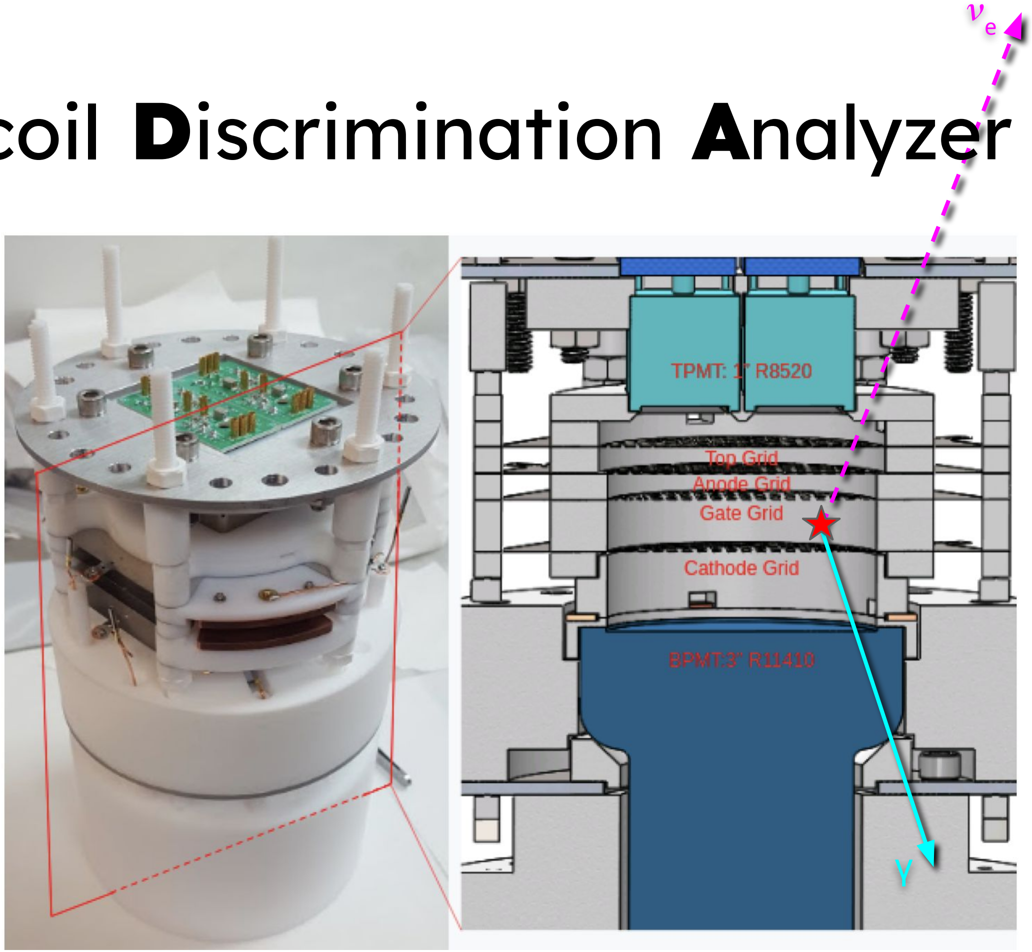
Shell	Energy	Branching Fraction
K	33.2 keV	0.834
L	5.2 keV	0.131
M	1.1 keV	0.029
N	0.186 keV	0.007



A. Hashizume, Nuclear Data Sheets 112, 1647 (2011)

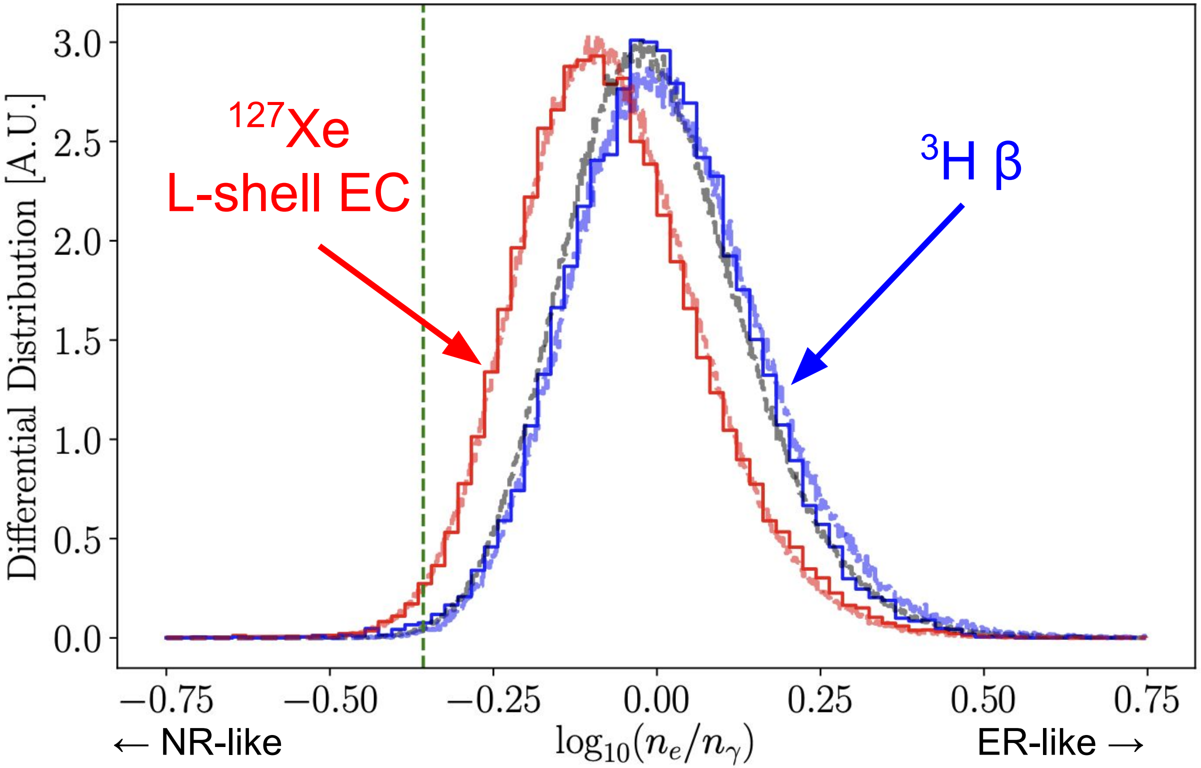
XEnon **L**-shell **R**ecoil **D**iscrimination **A**nalyzer

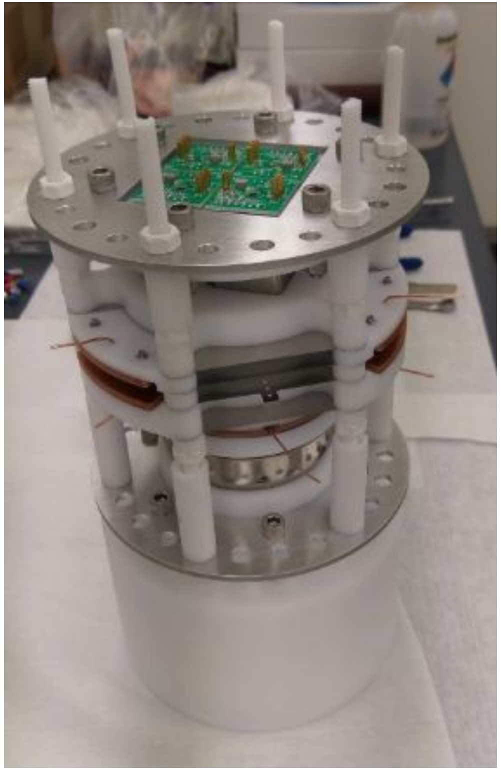
- AKA **"XELDA"**
- Small LXe-TPC, formerly at Fermilab
- Active volume:
  - 177g xenon
  - 1.27cm tall x 6.33cm
- Gammas escape active volume, leaving only the atomic de-excitation



Phys. Rev. D 104, 112001 (2021)

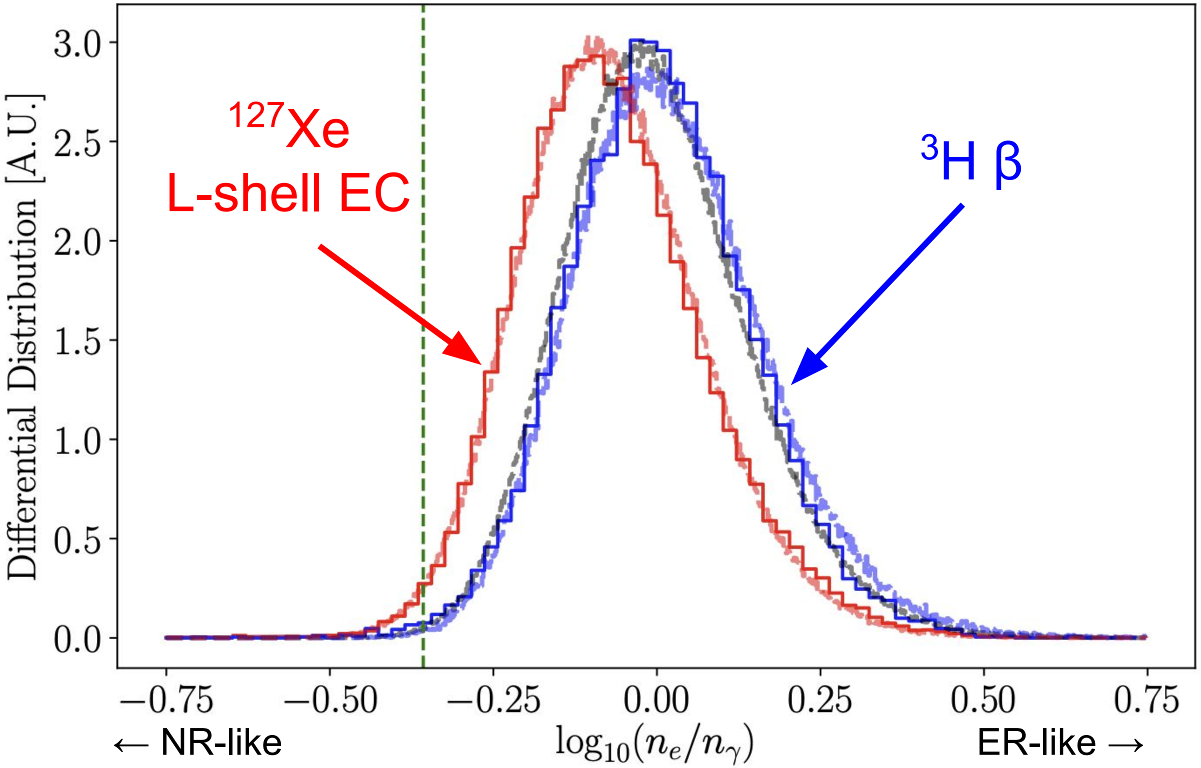
XELDA Results





Phys. Rev. D 104, 112001 (2021)

XELDA Results



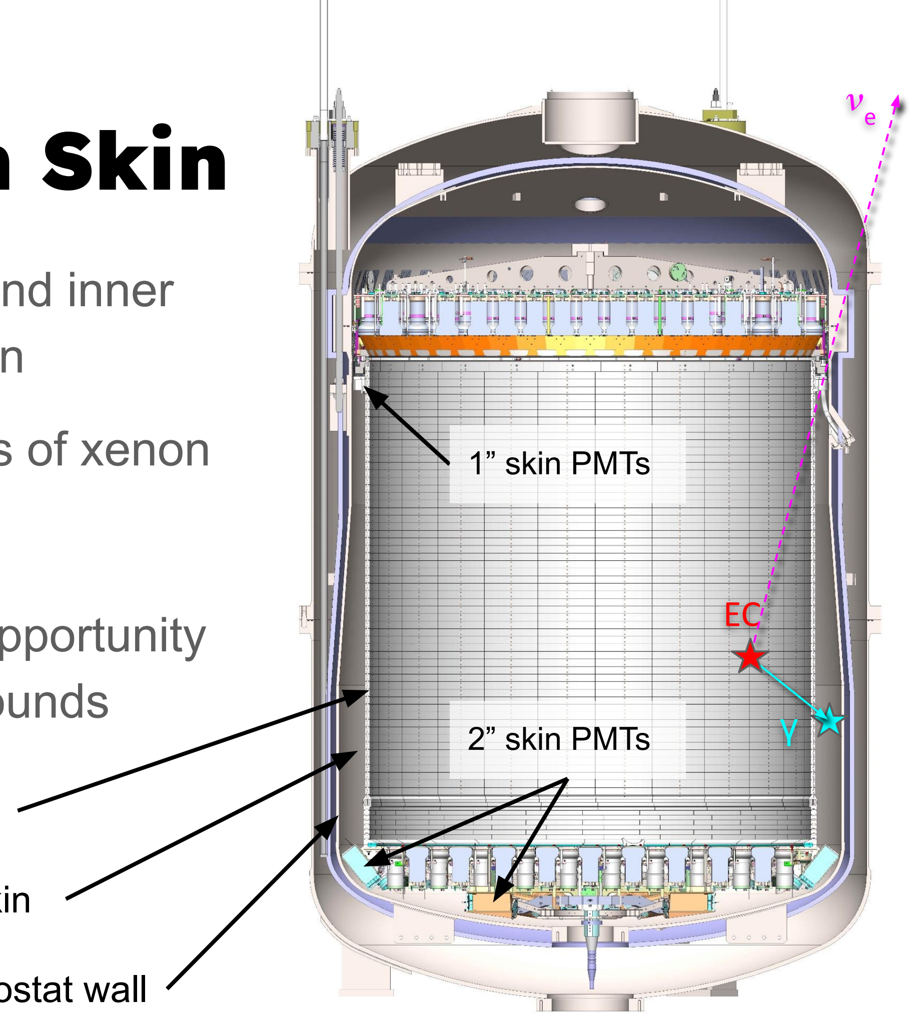
Phys. Rev. D 104, 112001 (2021)

- XELDA data was taken at 363V/cm *(shown)* and 258V/cm drift fields
- Incorporated into NEST as “weighted-ER” model - a weighted average of NEST’s beta and gamma responses
- But today’s large LXe - TPCs, LZ and nT, are operated at 193 V/cm and 23 V/cm
- Is it safe to extrapolate down to these low fields?

LUX-ZEPLIN

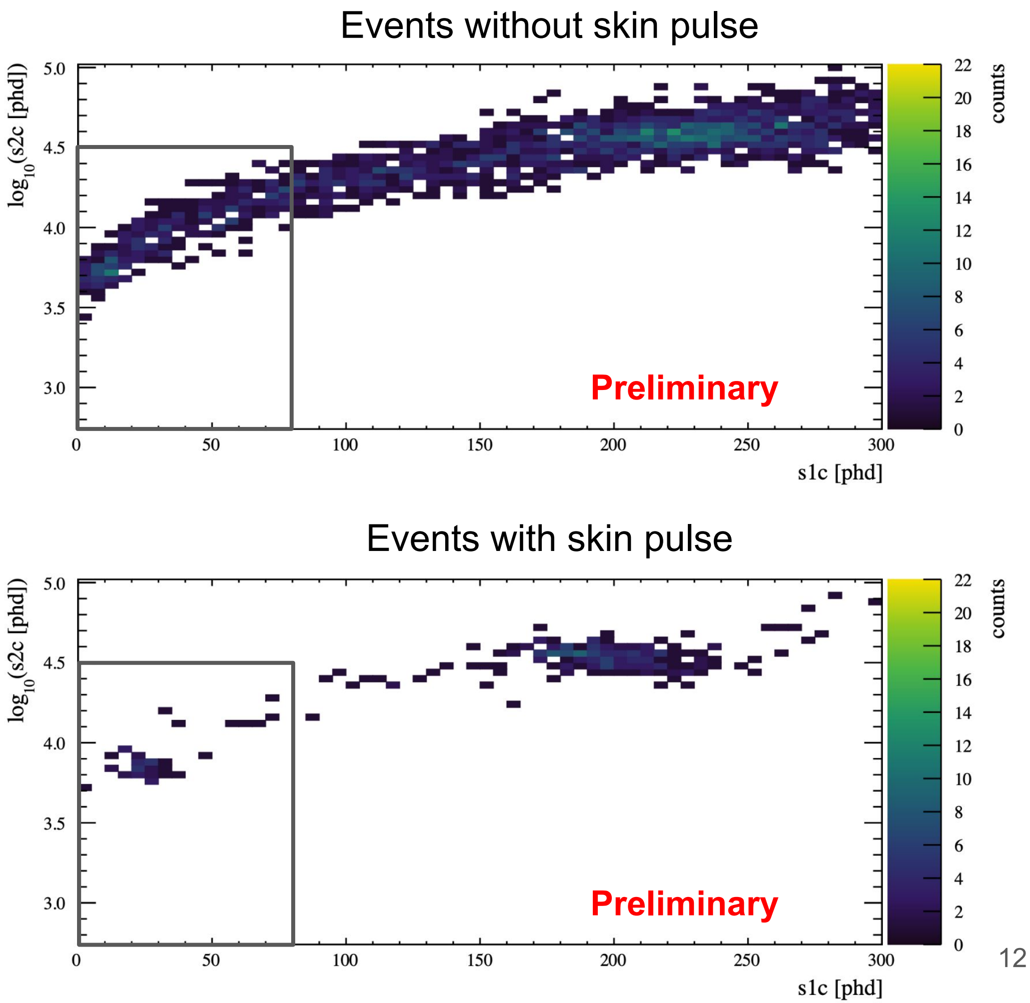
LUX-ZEPLIN Xenon Skin

- The region between the TPC wall and inner cryostat wall is called the xenon skin
- LZ's skin containing a total of 2 tons of xenon
- Instrumented with 131 PMTs
- Serves as a gamma veto, and an opportunity to further characterize LZ's backgrounds



Skin-tagged ^{127}Xe

- Select events with significant energy deposits in the skin detector
- This gives a high-purity sample of ^{127}Xe events where the nuclear gamma exits the TPC
- Few other processes in this ROI also deposit energy in the skin



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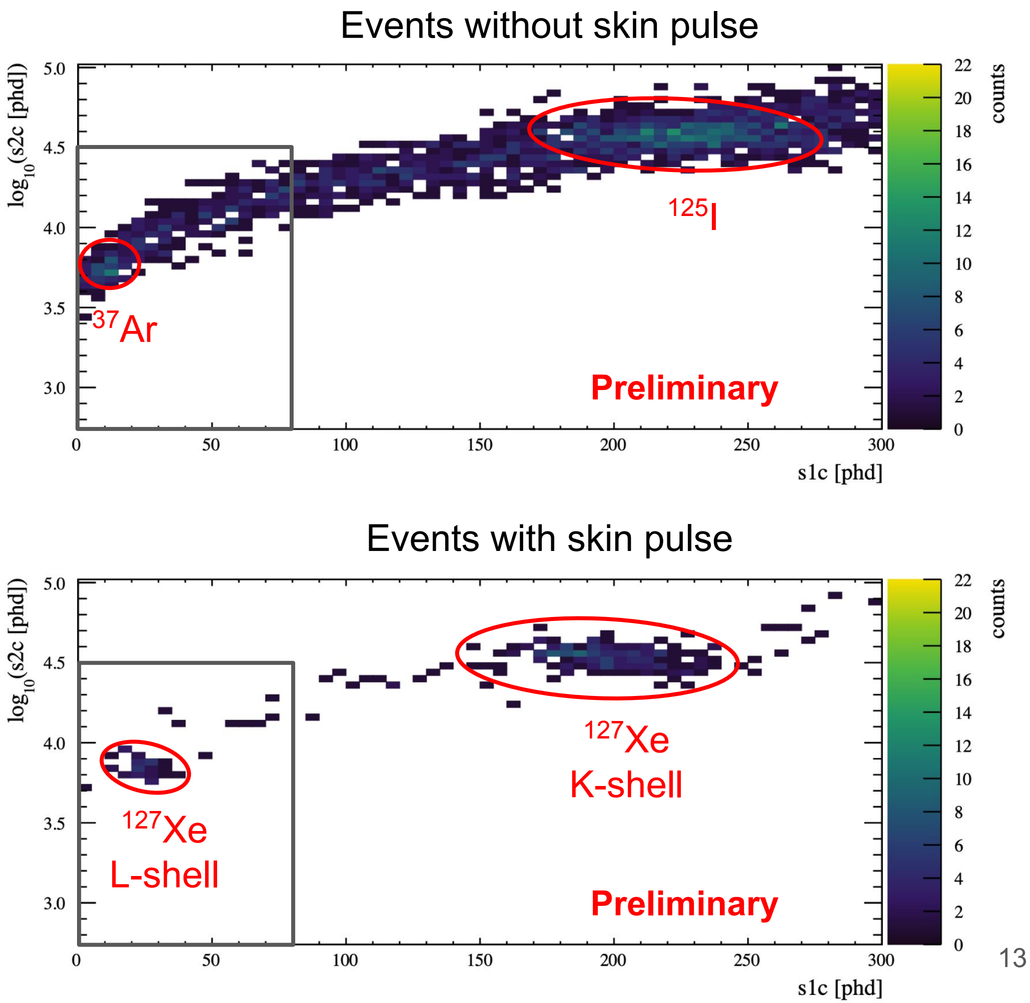
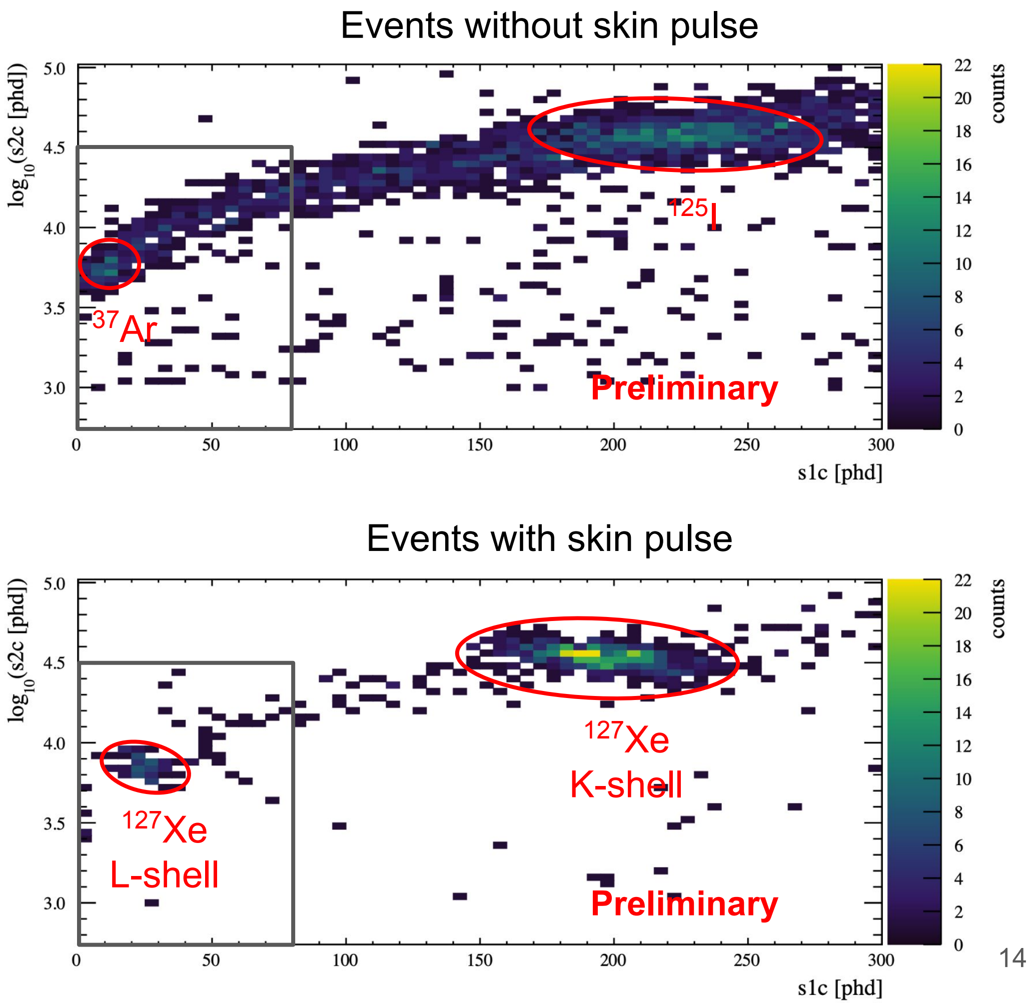
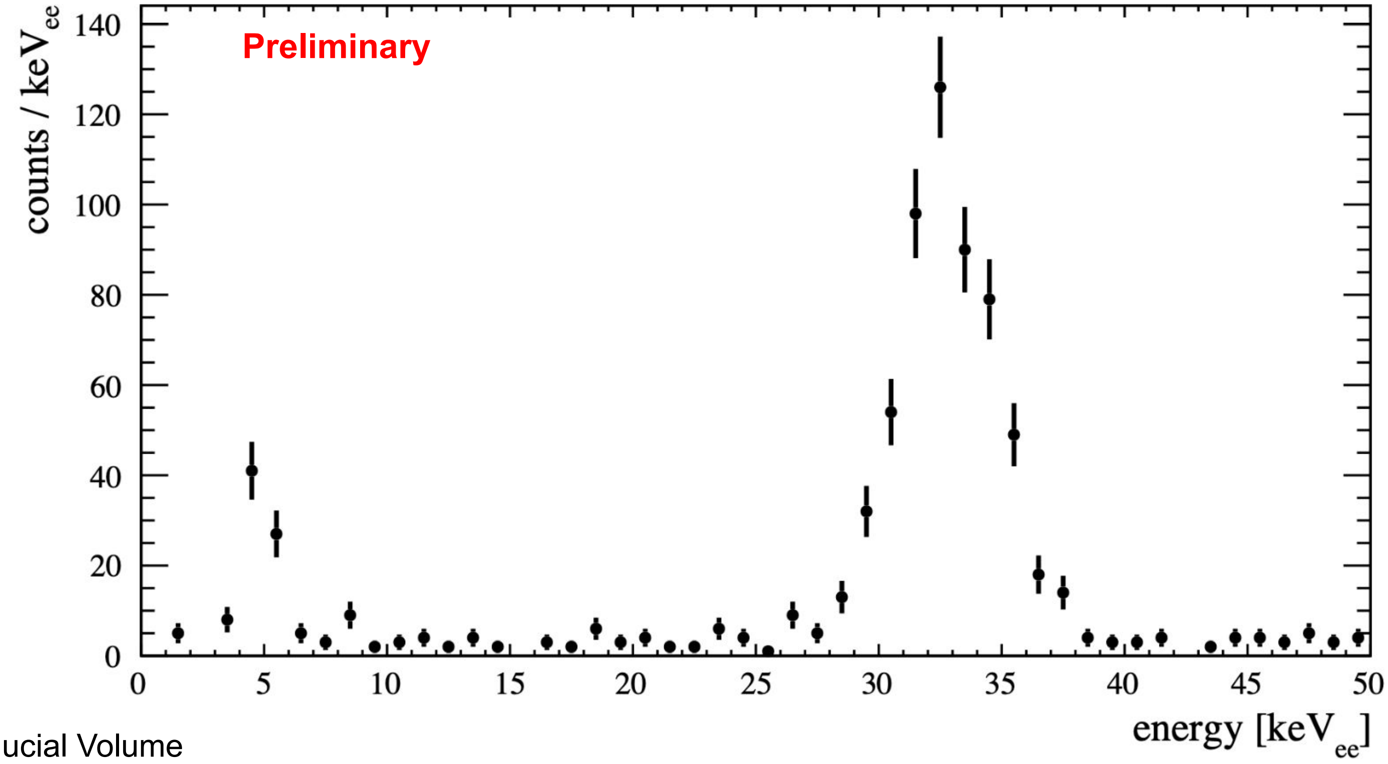


Extend FV

- Select events with significant energy deposited in the skin detector
- This gives a high-purity sample of ^{127}Xe events where the nuclear gamma exits the TPC
- Few other processes in this ROI also deposit energy in the skin
- Expanding the fiducial volume gives improved L-shell stats

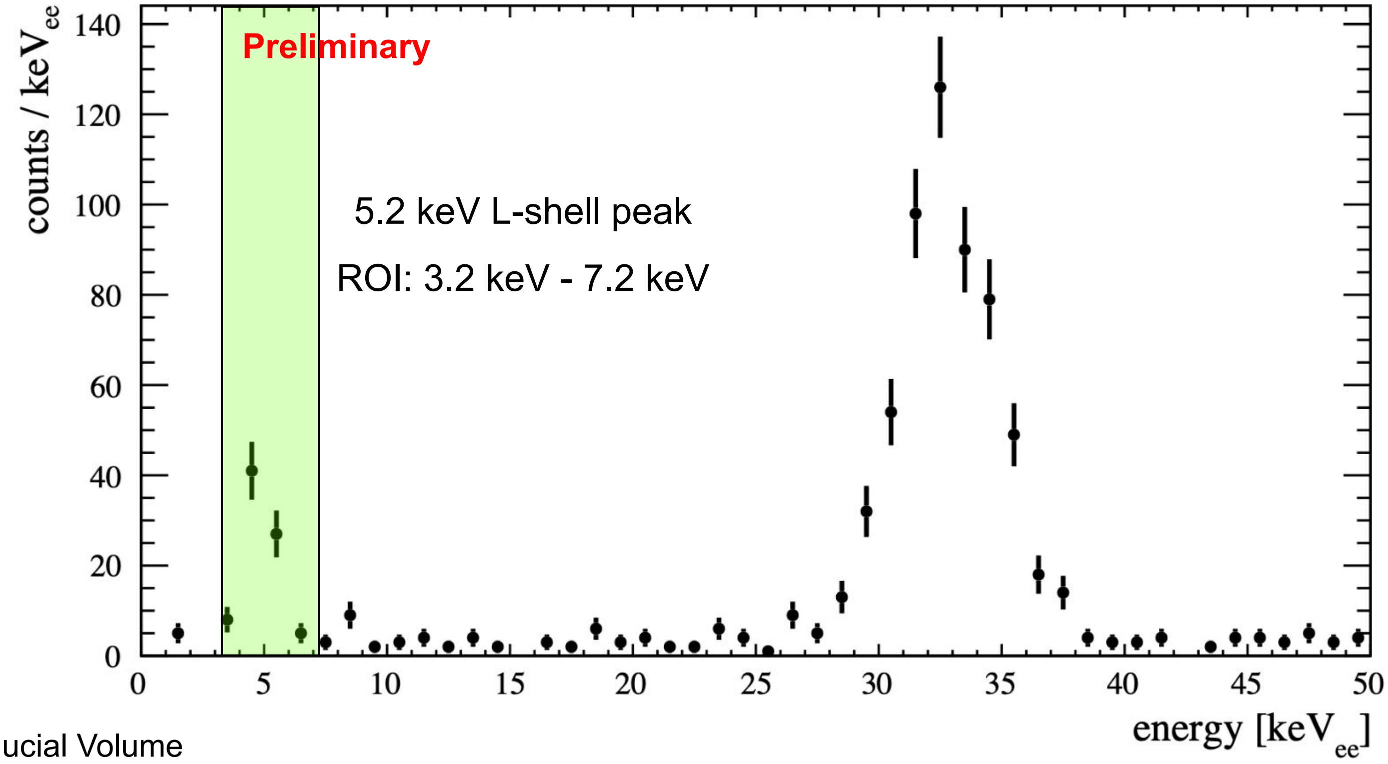


Skin-tagged Energy Spectrum



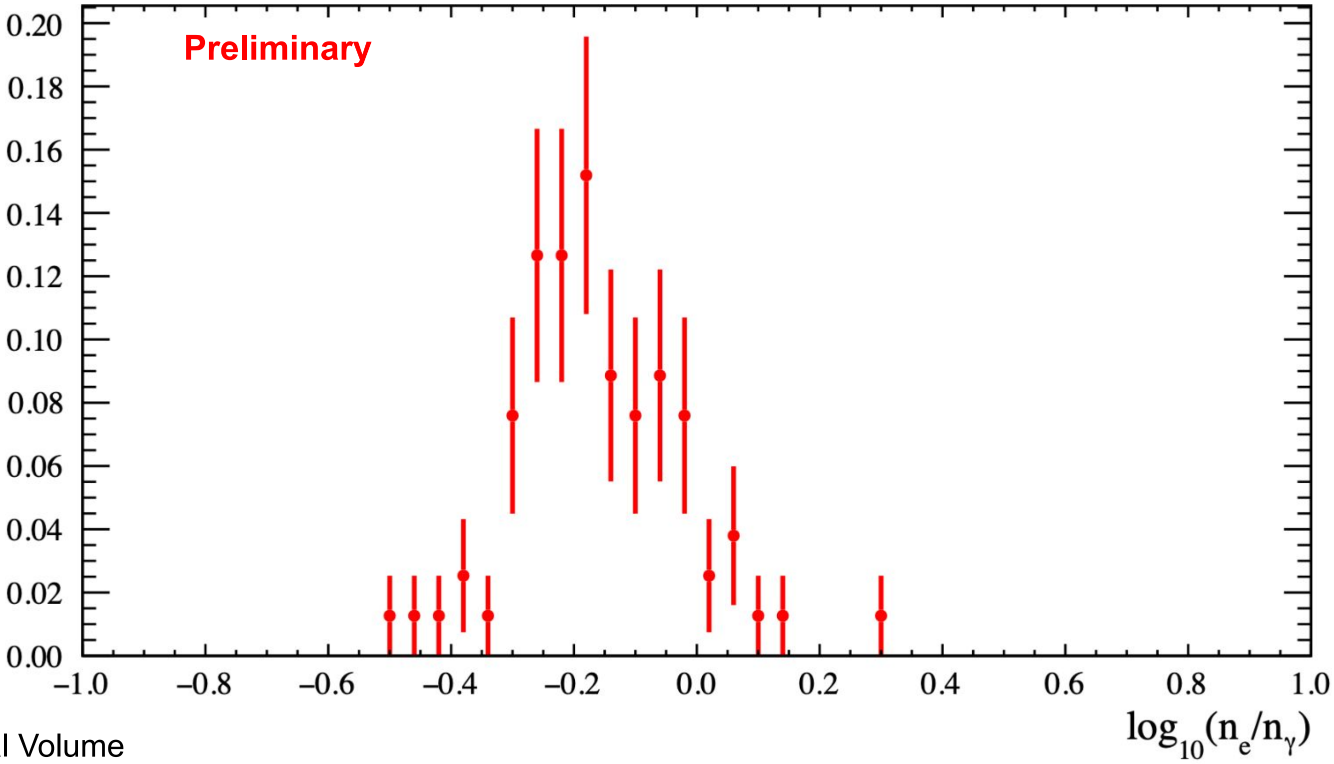
Extended Fiducial Volume

Skin-tagged Energy Spectrum



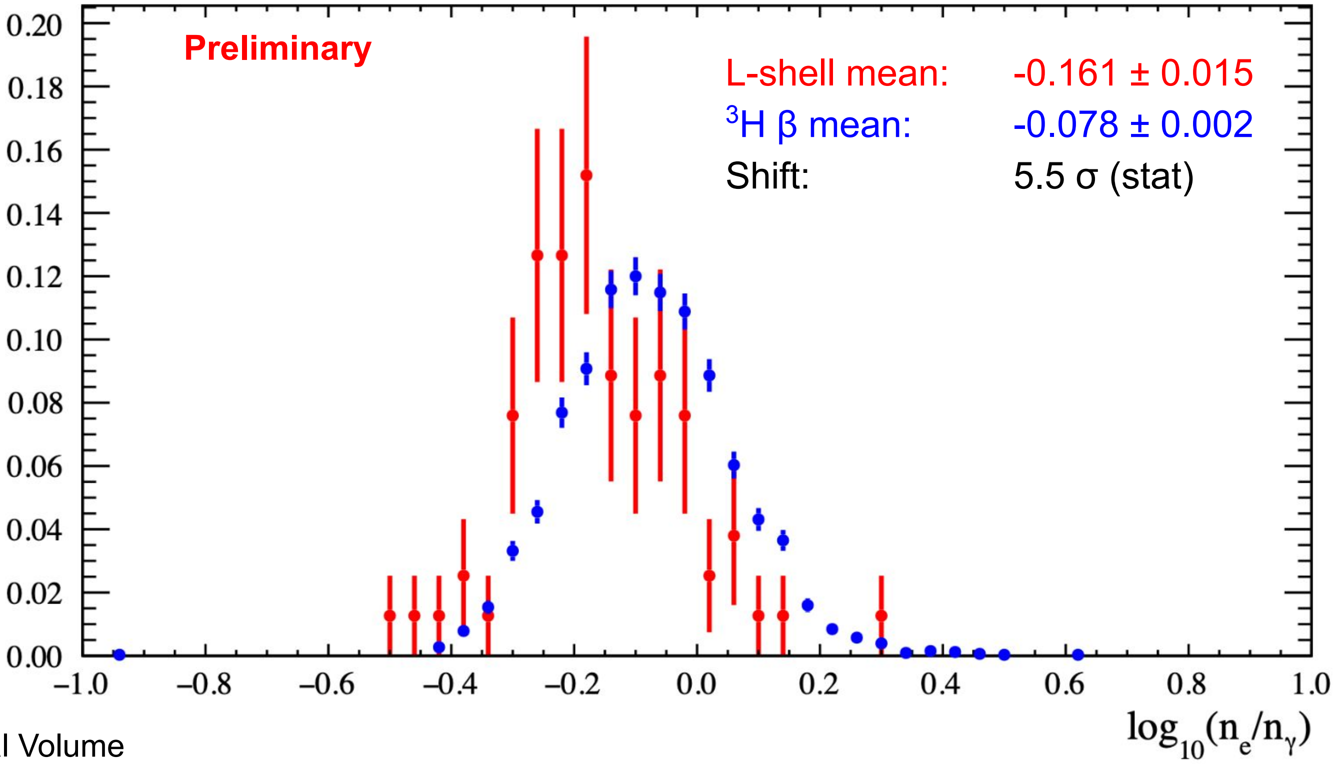
Extended Fiducial Volume

L-shell Events



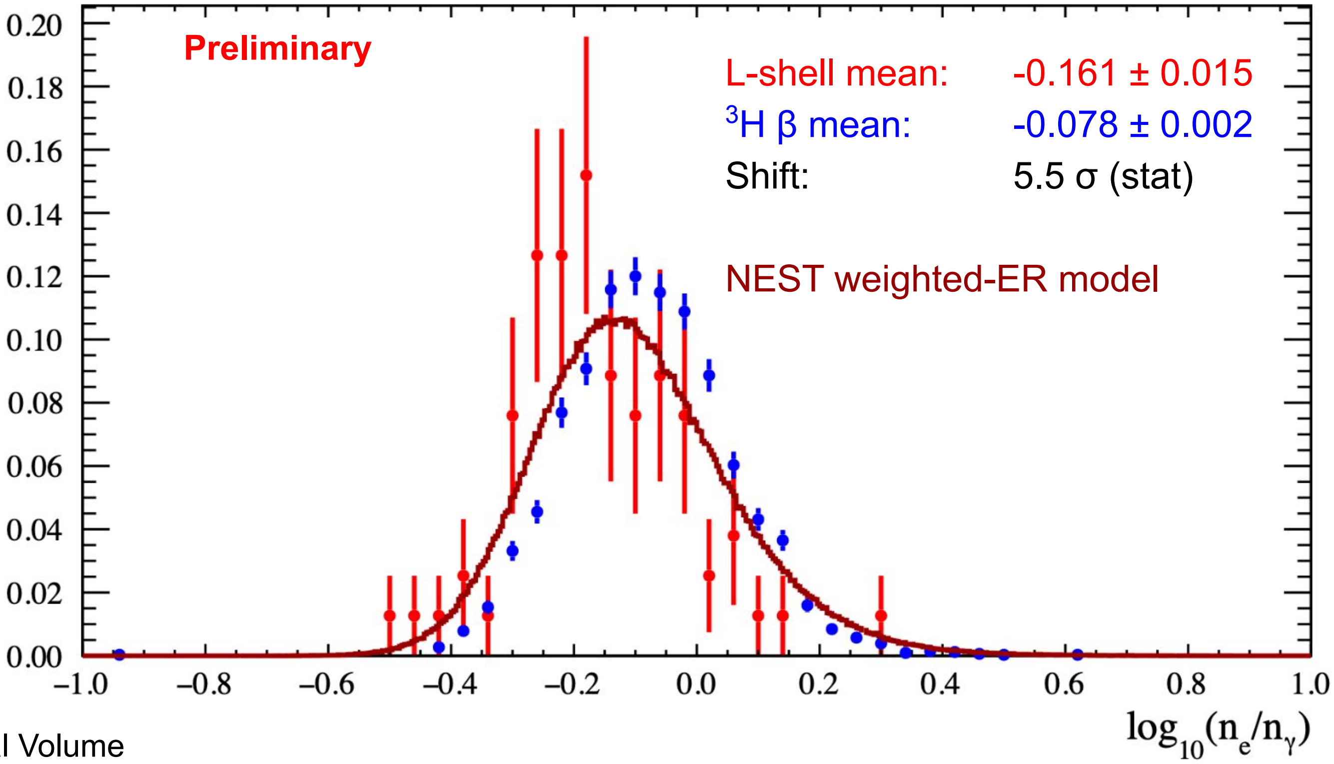
Extended Fiducial Volume

L-shell + ^3H β Events



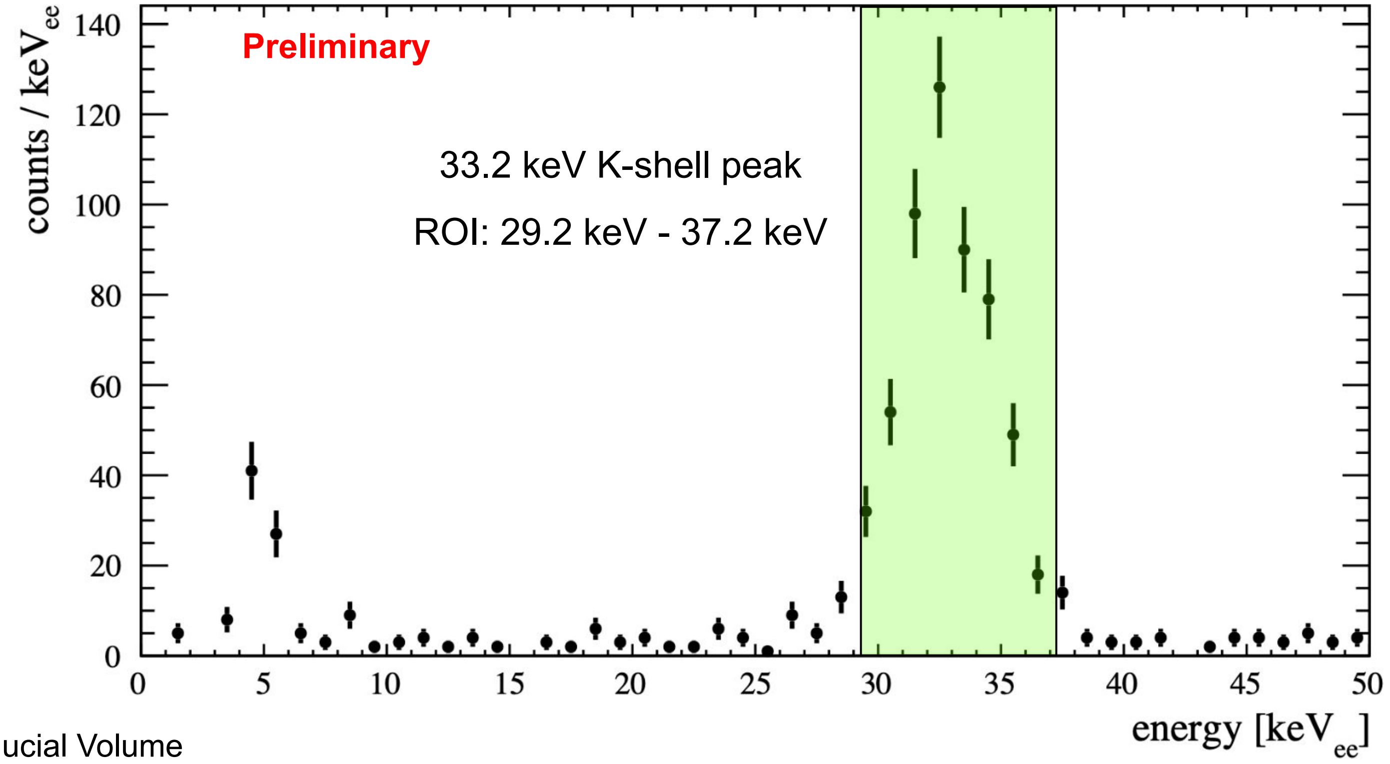
Extended Fiducial Volume

L-shell + ^{3}H β Events



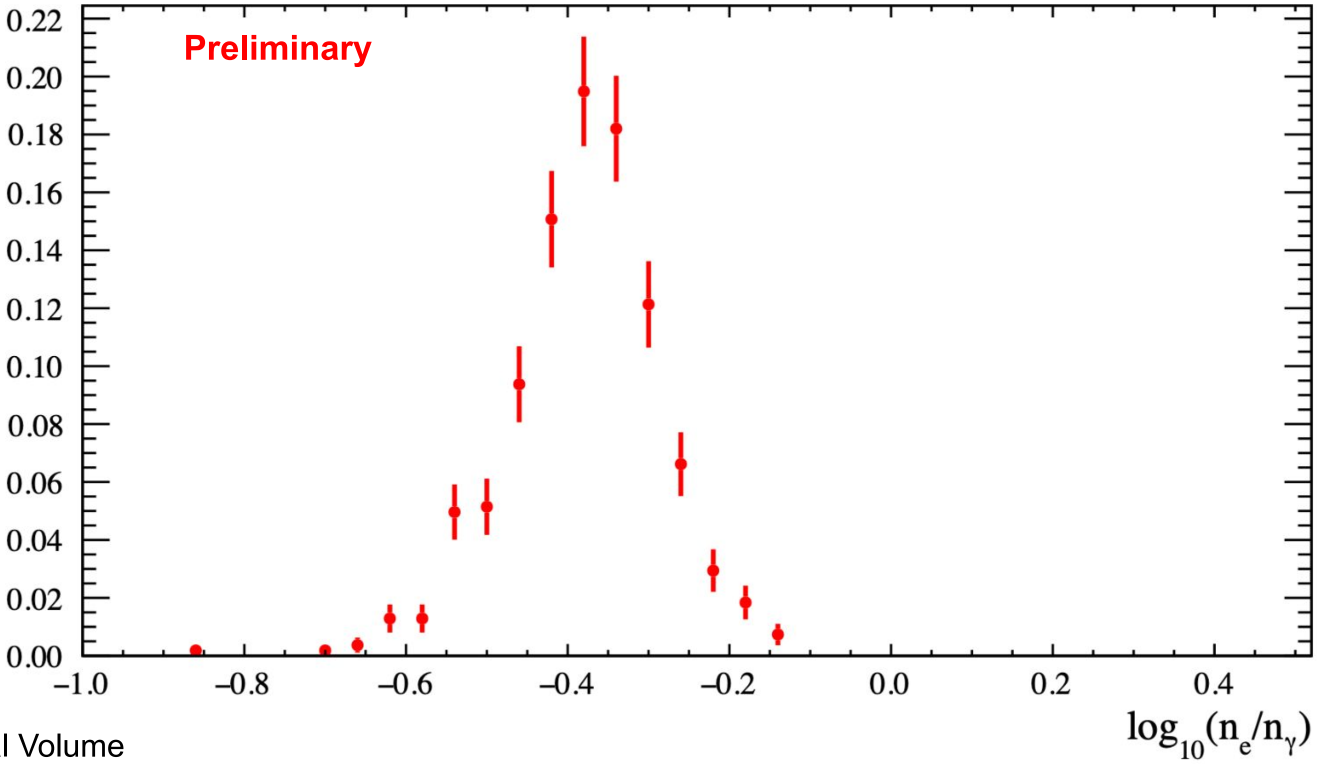
Extended Fiducial Volume

Skin-tagged Energy Spectrum



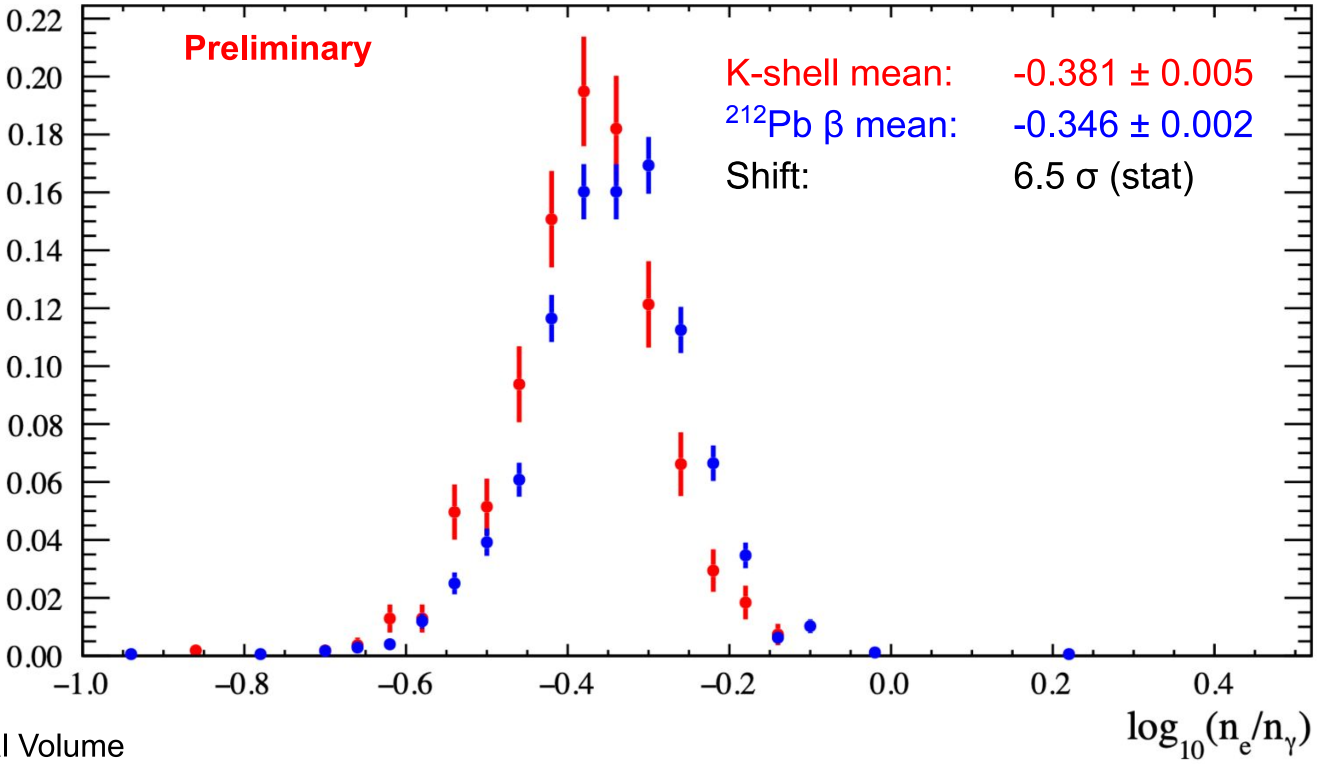
Extended Fiducial Volume

K-shell Events



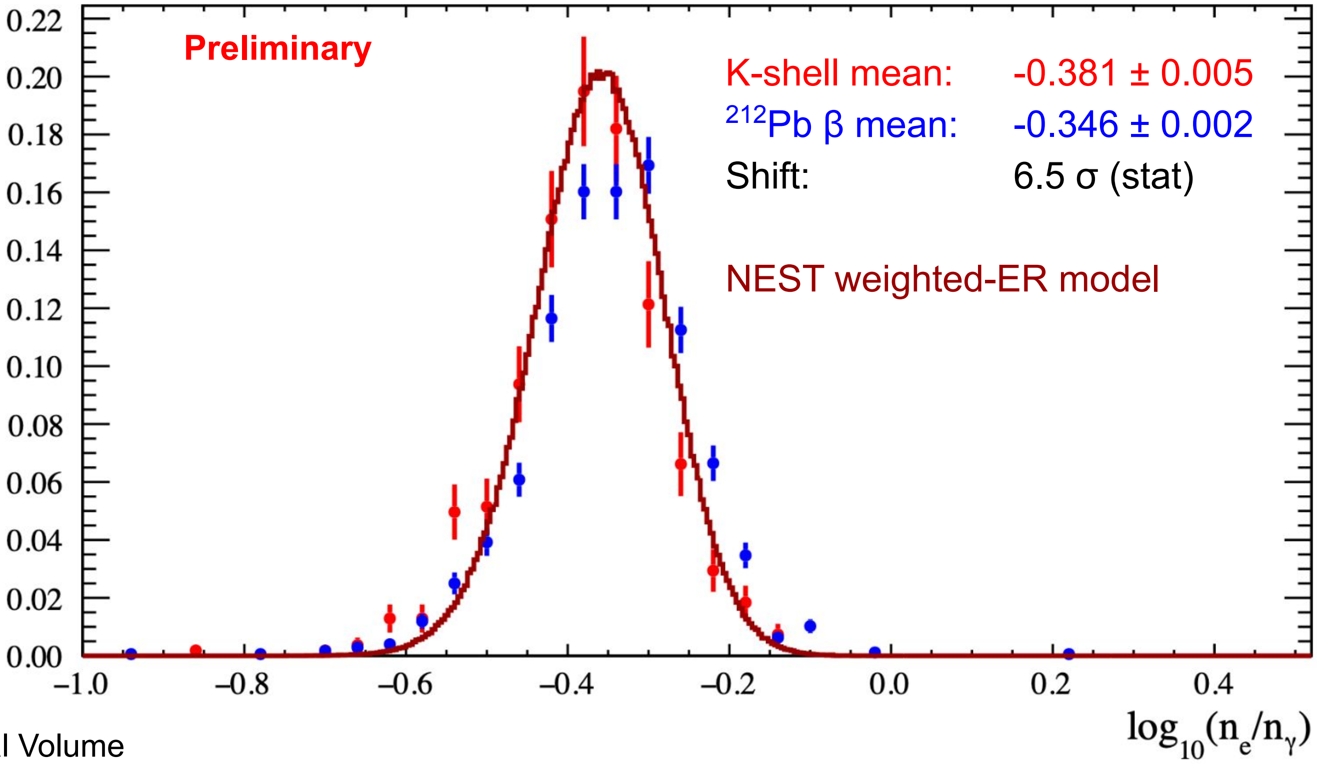
Extended Fiducial Volume

K-shell + ^{212}Pb β Events



Extended Fiducial Volume

K-shell + ^{212}Pb β Events



Extended Fiducial Volume

In Conclusion

- Processes with inner-shell electron vacancies have a different charge and light yields than the β-decays we traditionally calibrate with
- As large LXe-TPCs push towards higher and higher exposure, we will need to model this effect
- We can use ^{127}Xe, from either cosmogenic or artificial activation, to directly measure this effect
- An instrumented skin allows LZ (and potentially future LXe-TPCs) to measure this effect *in-situ*, with identical drift field and detector conditions to their science searches

LZ (LUX-ZEPLIN) Collaboration, 37 Institutions

@lzdarkmatter

250 scientists, engineers, and technical staff

https://lz.lbl.gov/

- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King's College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- Northwestern University
- Pennsylvania State University
- Royal Holloway University of London
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
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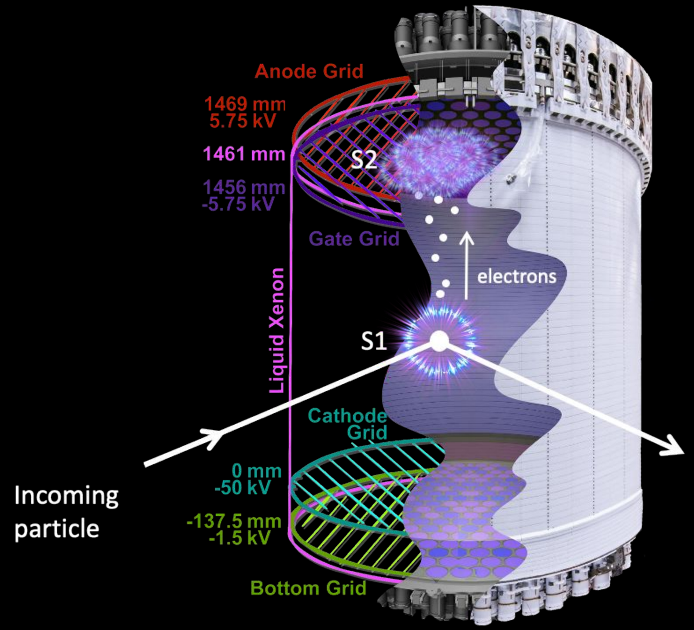
Thank you!



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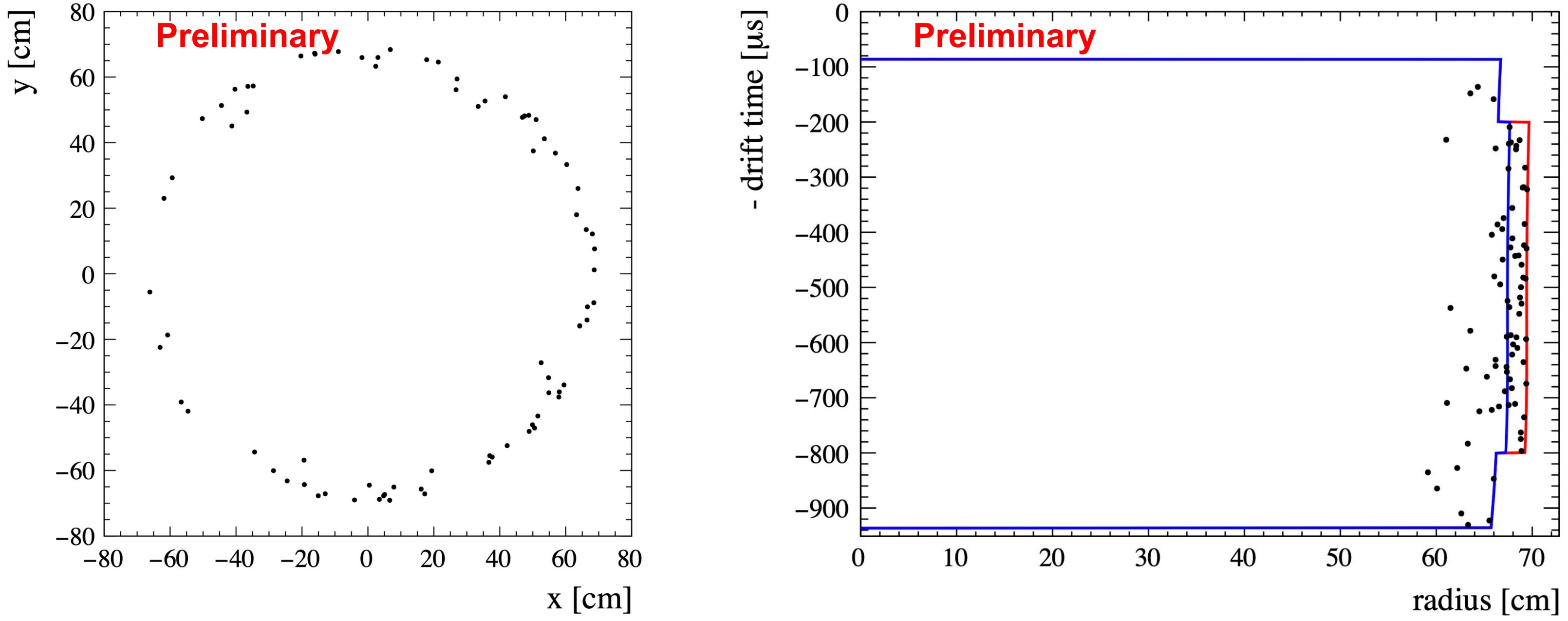
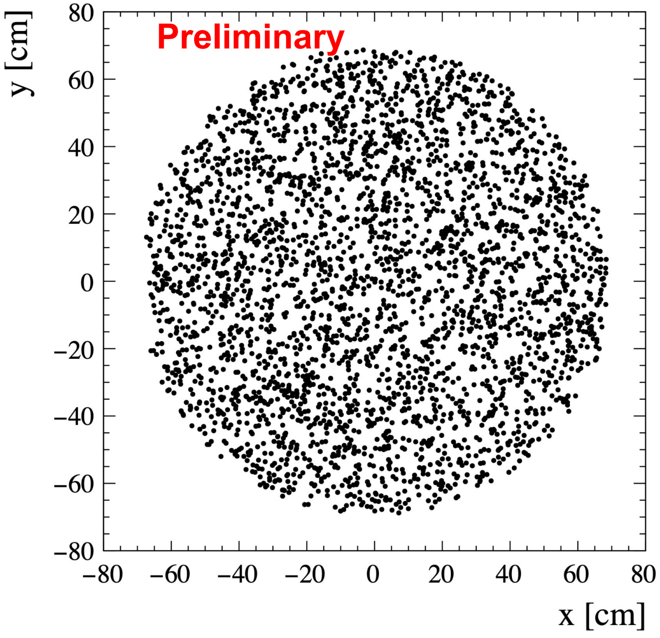
Additional Slides

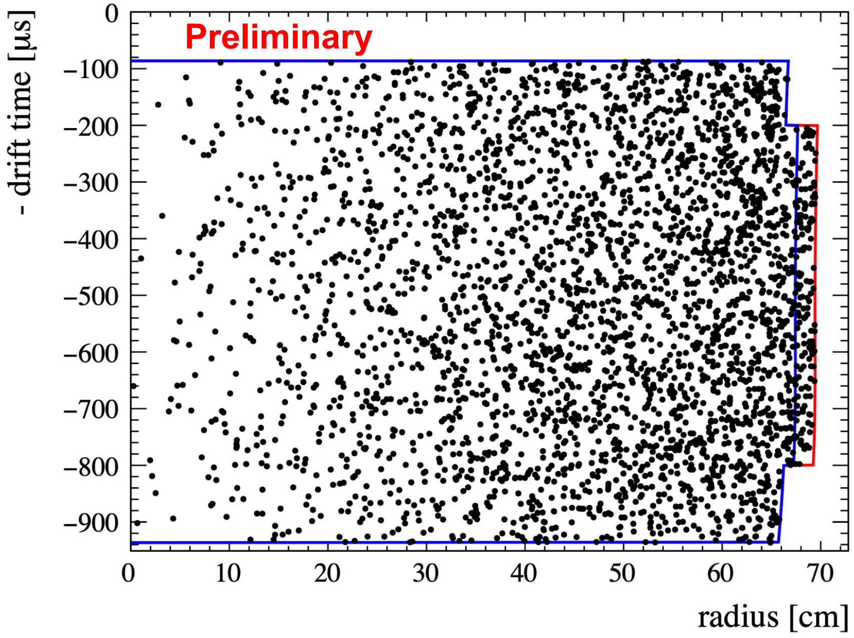
^{127}Xe L-shell EC position distribution



Extended Fiducial Volume

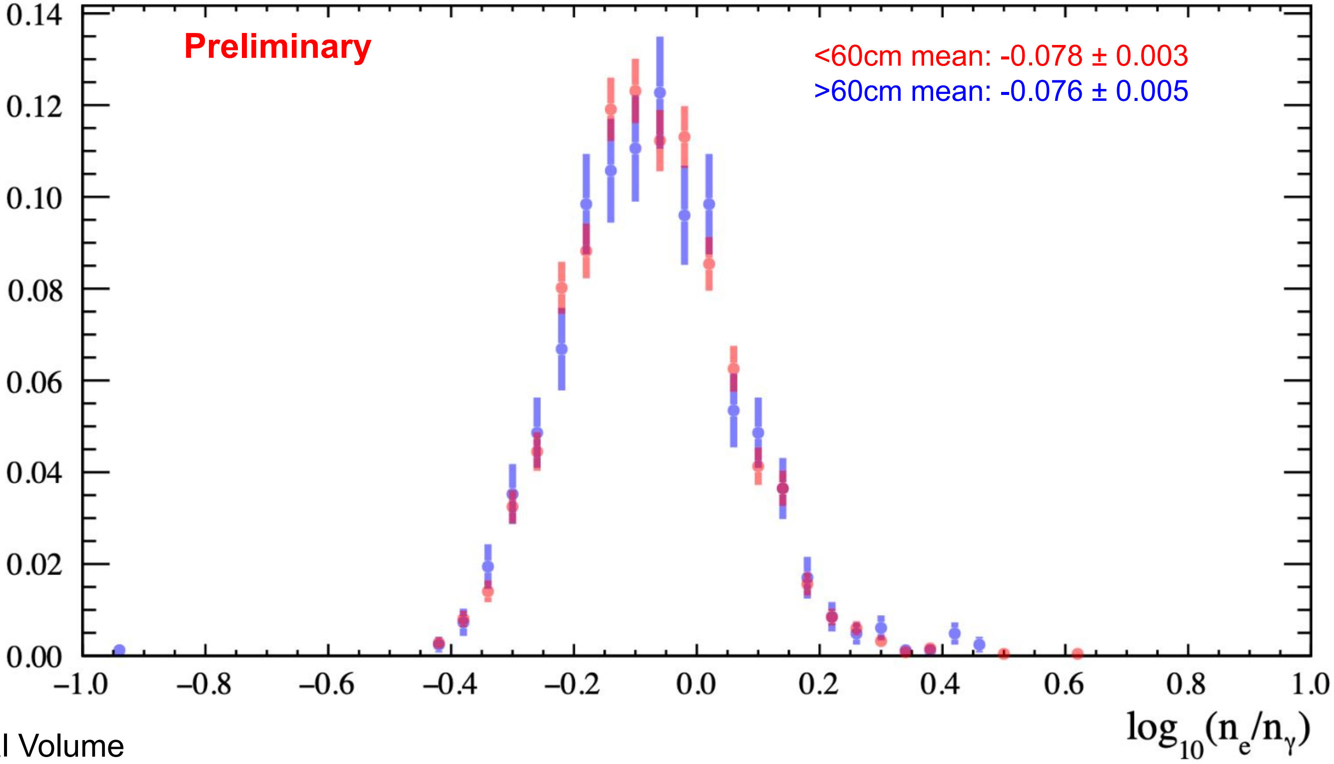
^3H β position distribution





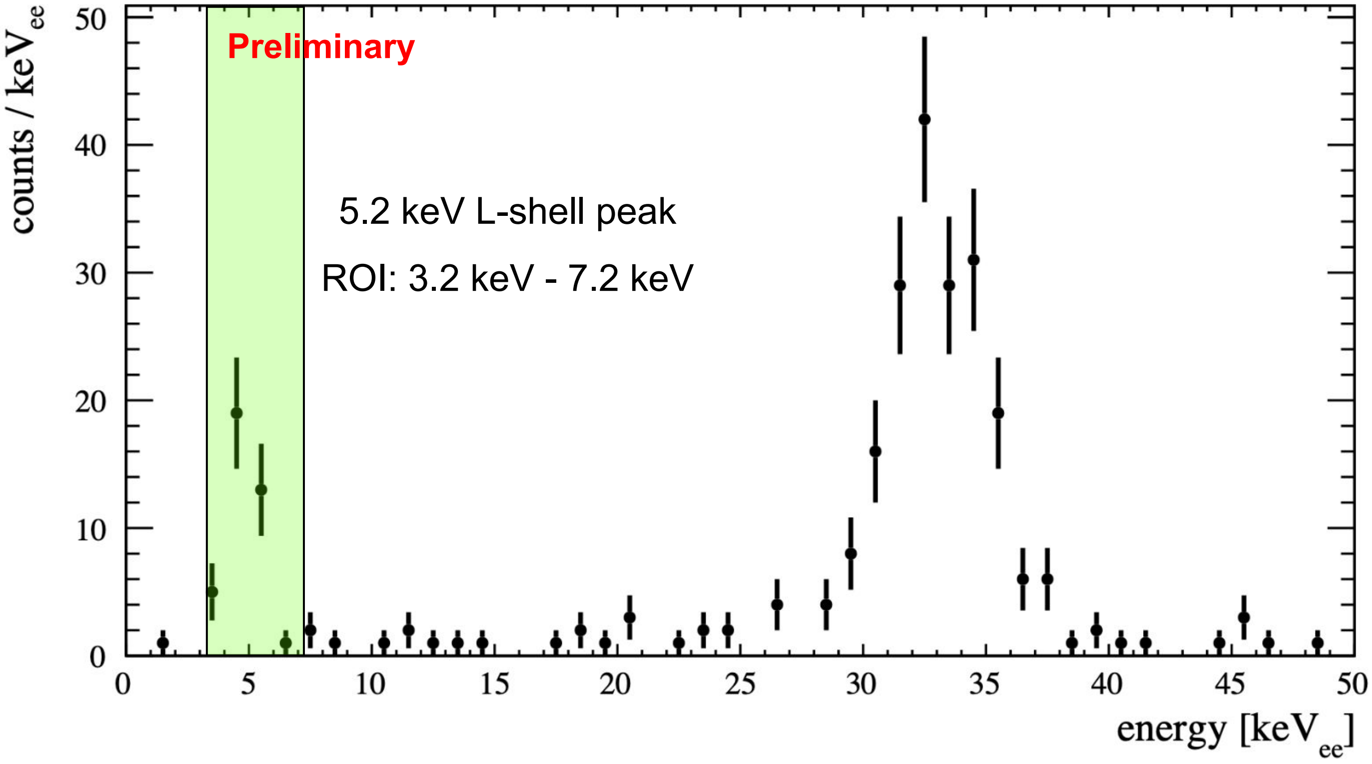
Extended Fiducial Volume

^3H β, inner vs outer volume

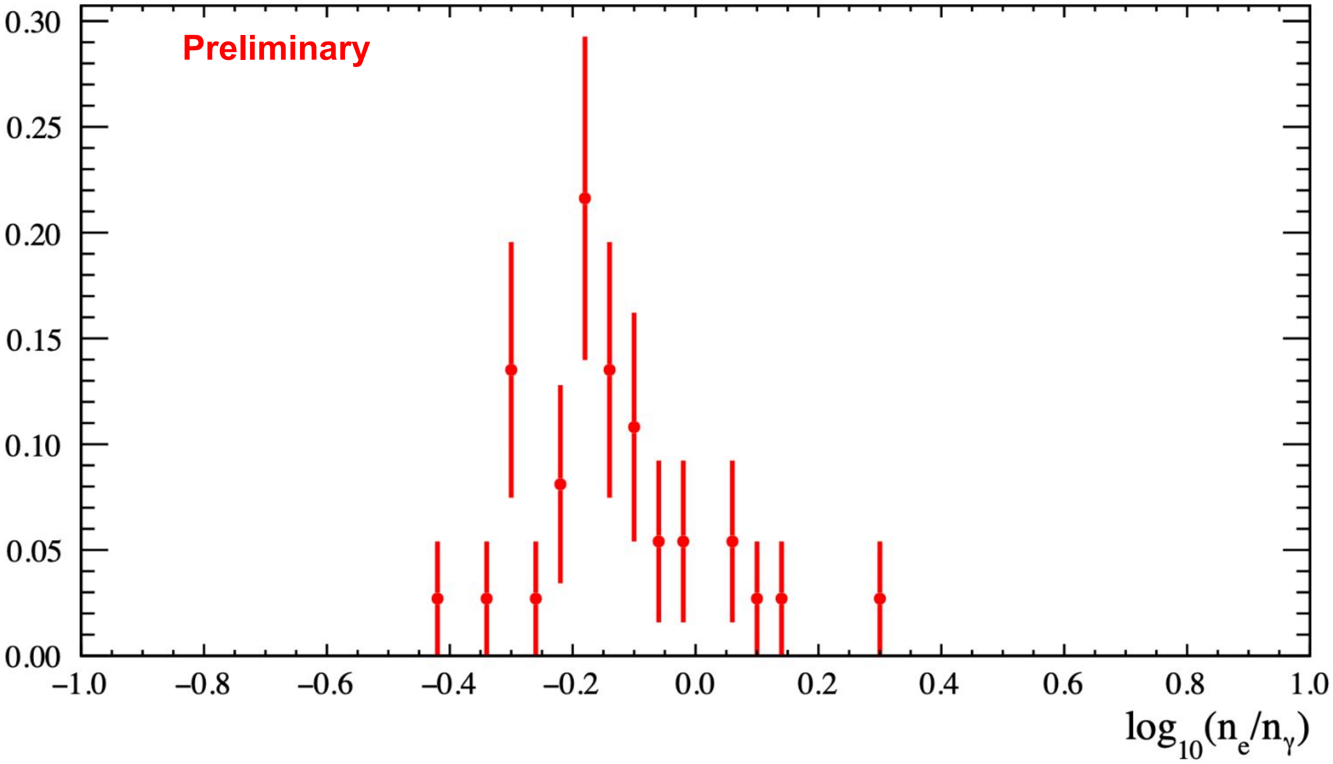


Extended Fiducial Volume

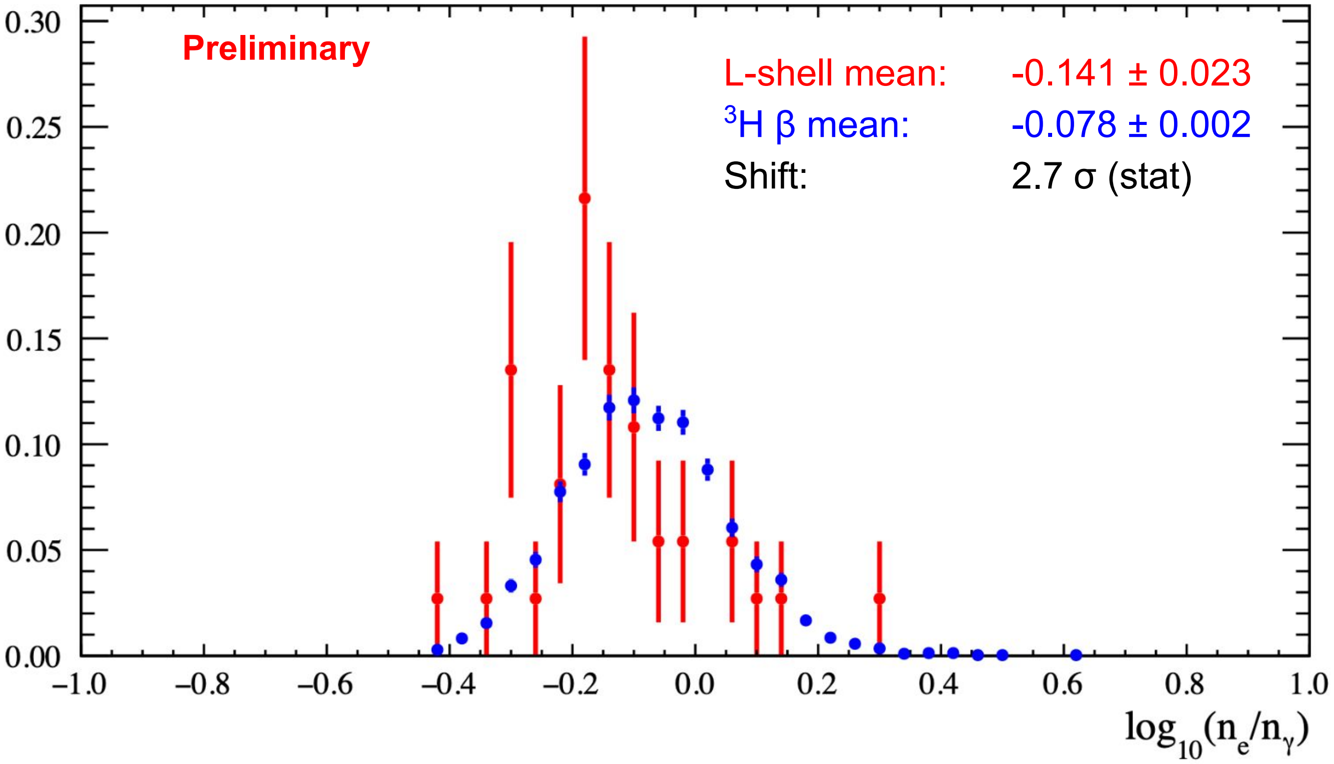
Skin-tagged Energy Spectrum



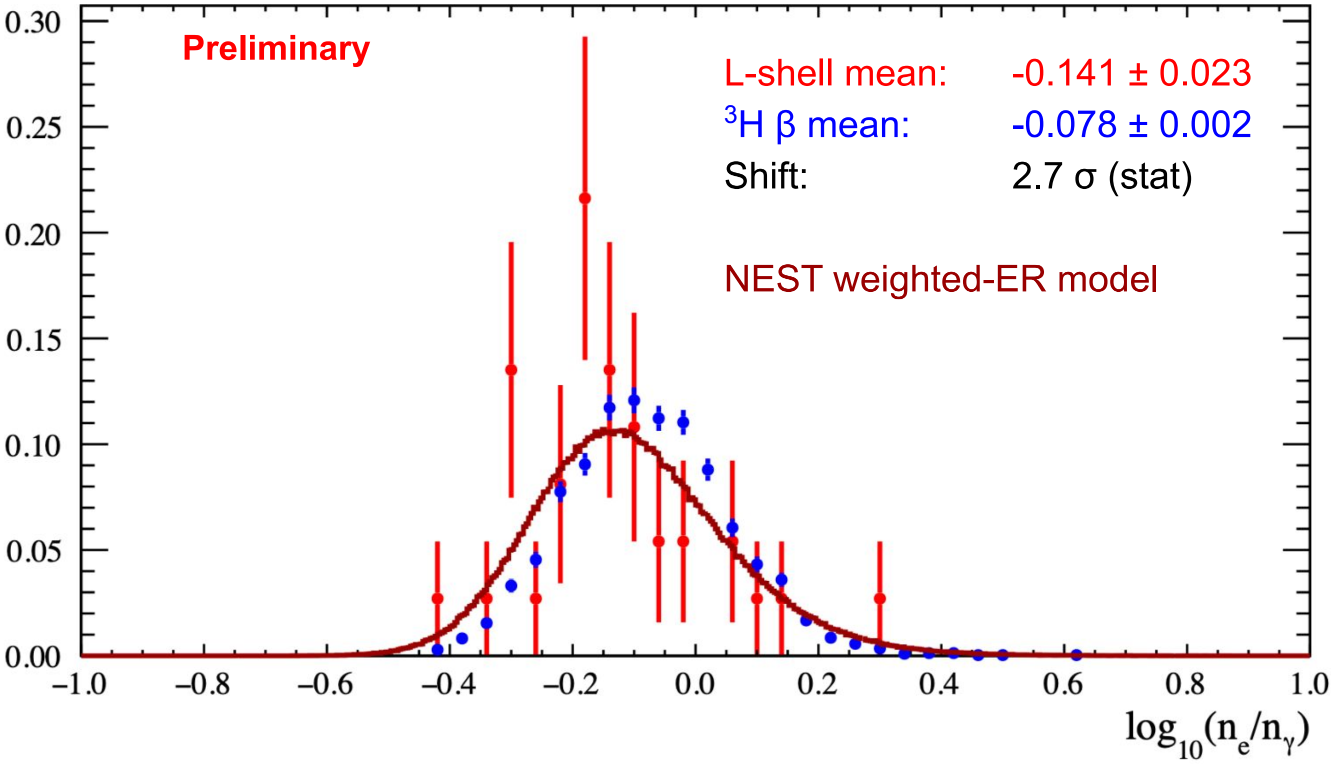
L-shell Events



L-shell + ^{3}H β Events



L-shell + ^{3}H β Events



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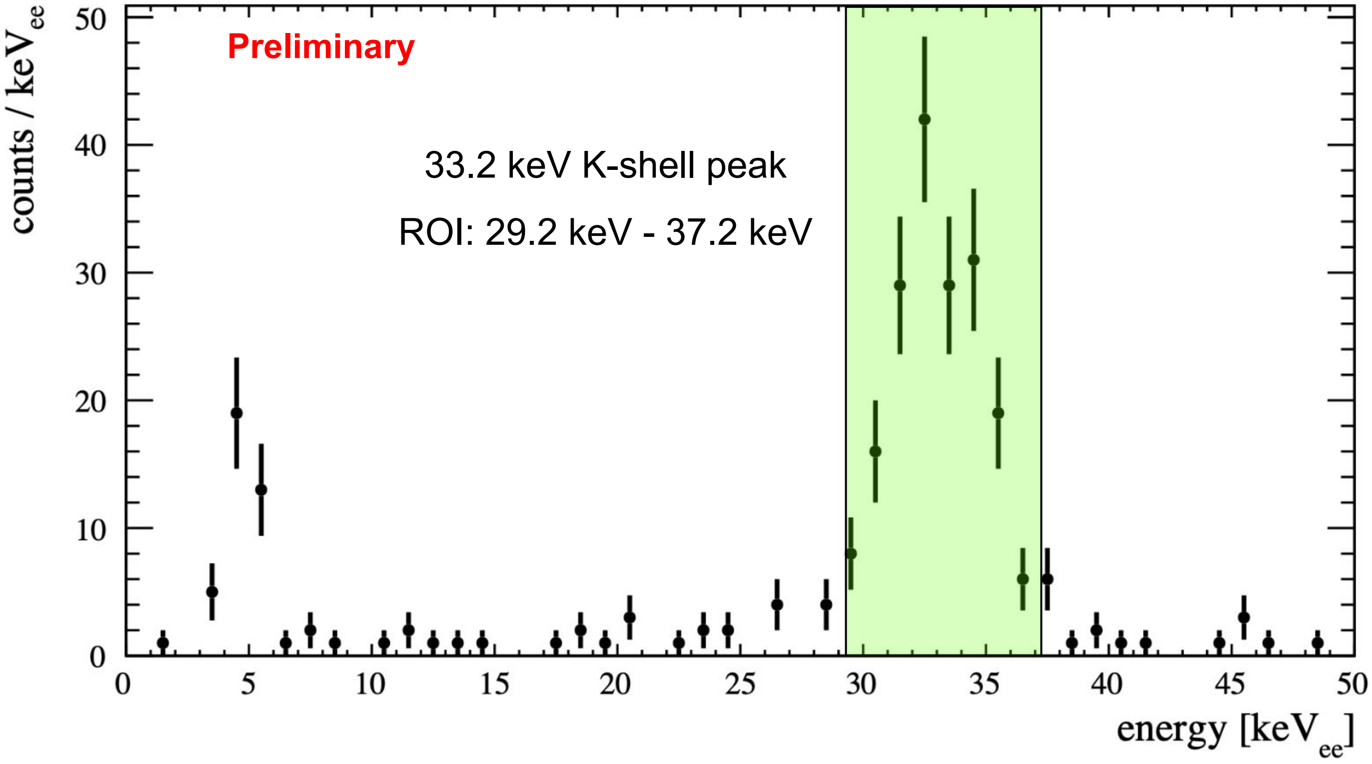
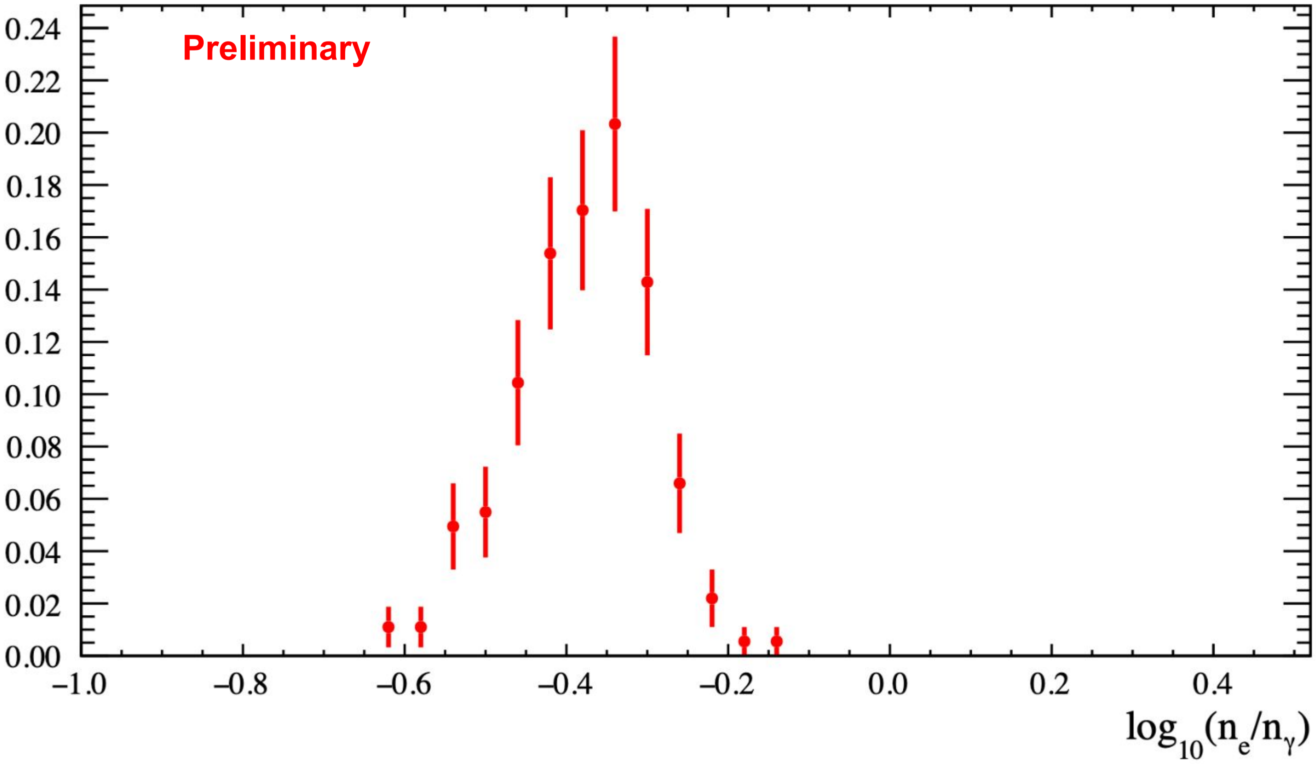
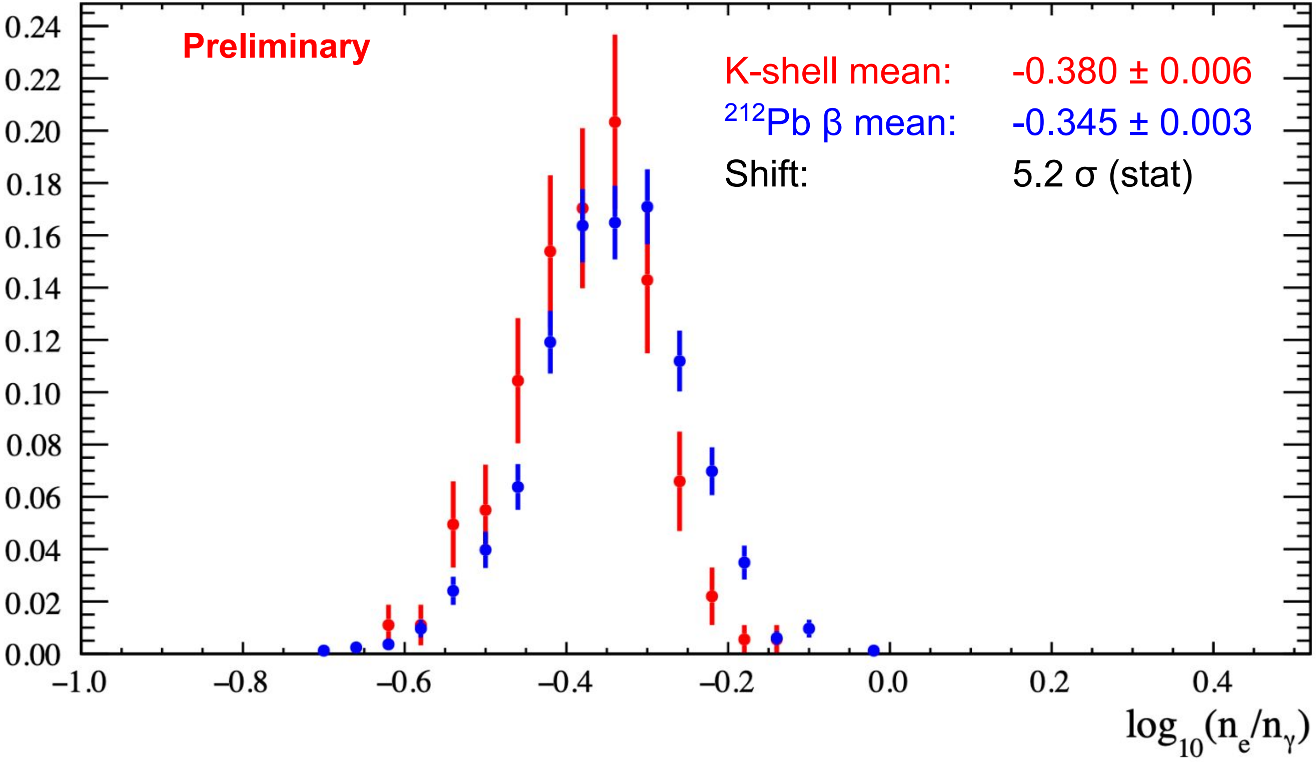


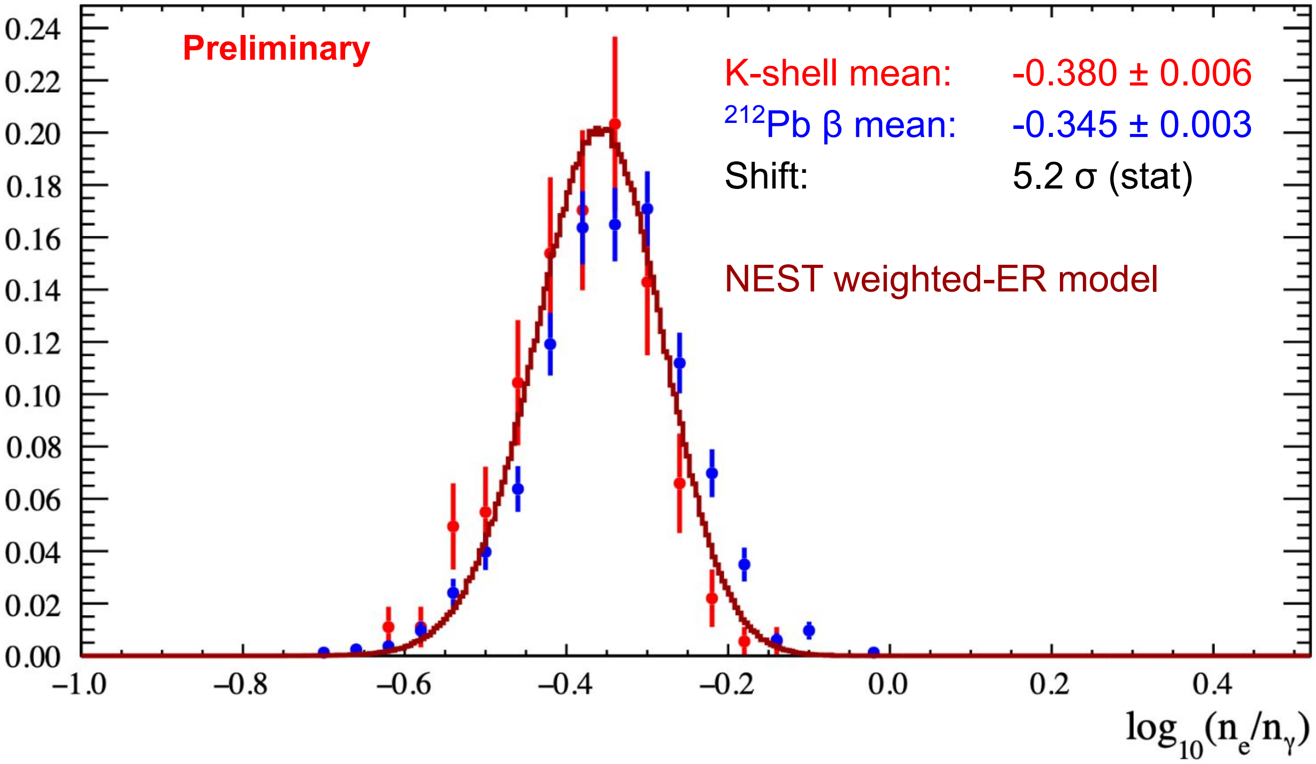
K-shell Events



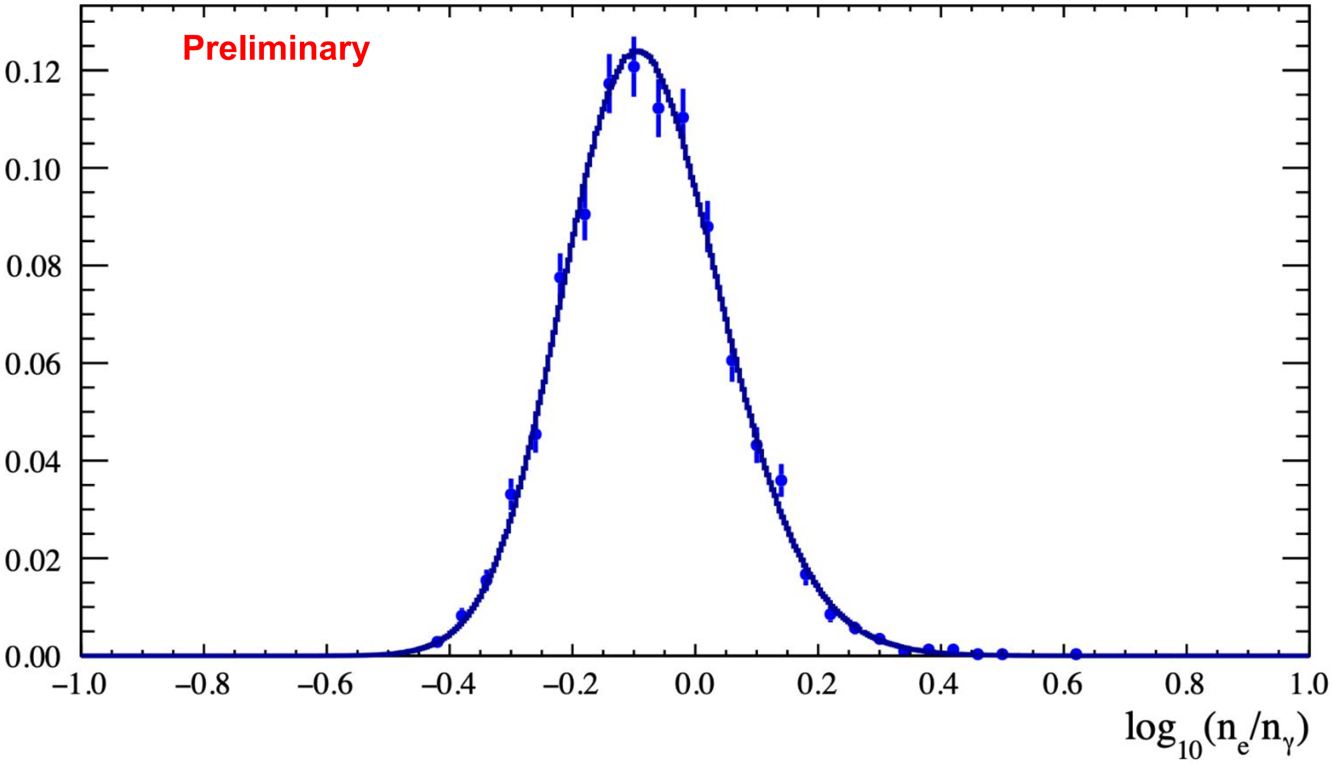
K-shell + ^{212}Pb β Events



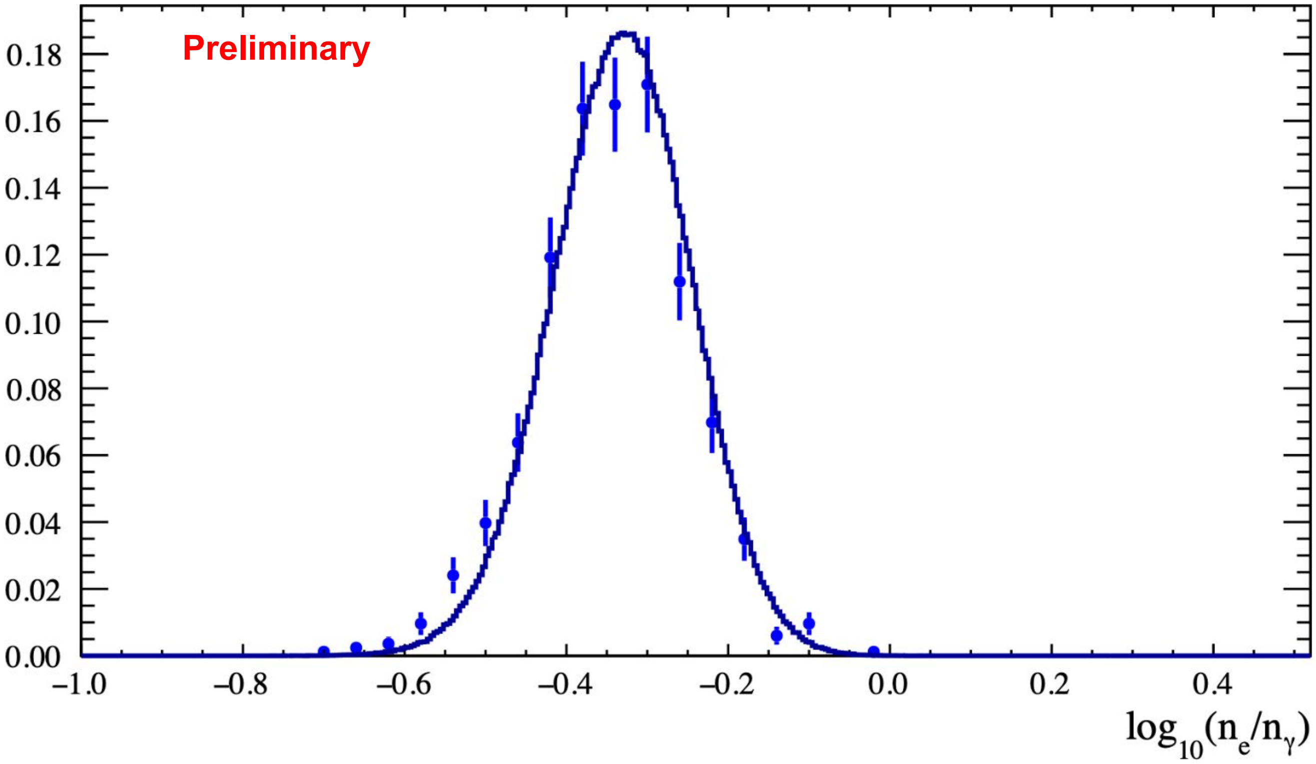
K-shell + ^{212}Pb β Events



^3H β, data vs sims



^{212}Pb β, data vs sims



Data Compared

	L-shell ROI (events in extended FV)	K-shell ROI (events in FV, in extended FV)
WS data, without skin pulse (primarily ^{214}Pb)	(178) ^{37}Ar, untagged L-shell backgrounds must be well-modeled, low stats	(624) ^{125}I, ^{124}Xe, untagged K-shell backgrounds must be well-modeled, low stats
^{3}H calibrations	(3317) ✅	(NA) Above ^{3}H endpoint
^{212}Pb calibrations	(1966) Lower stats than ^{3}H	(1760) ✅