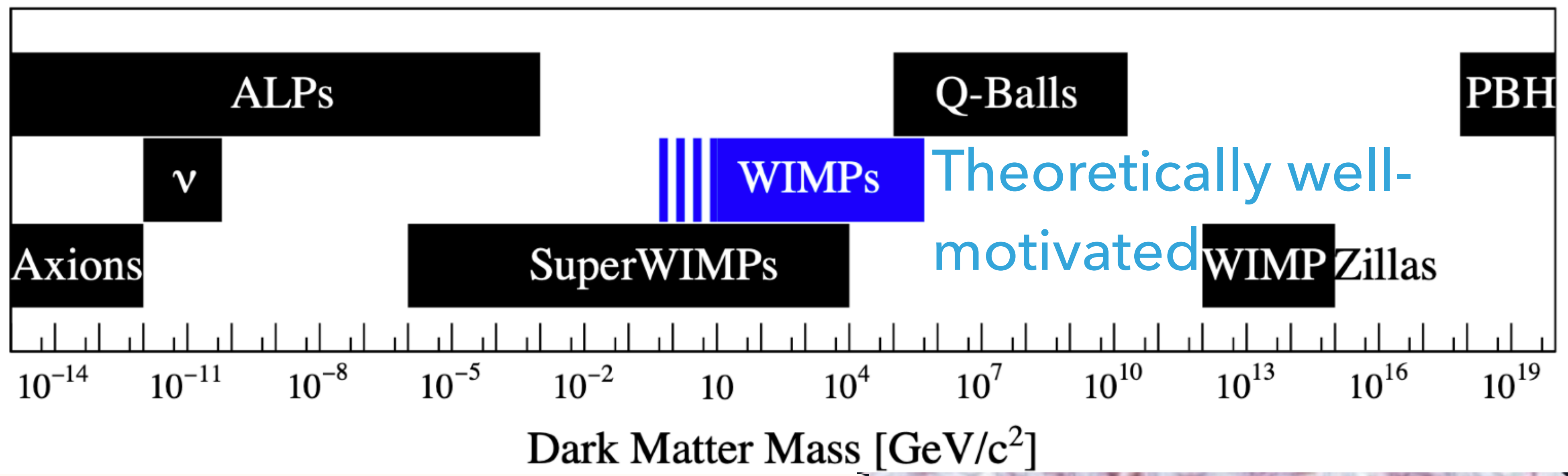
## WIMP SEARCH AND BEYOND

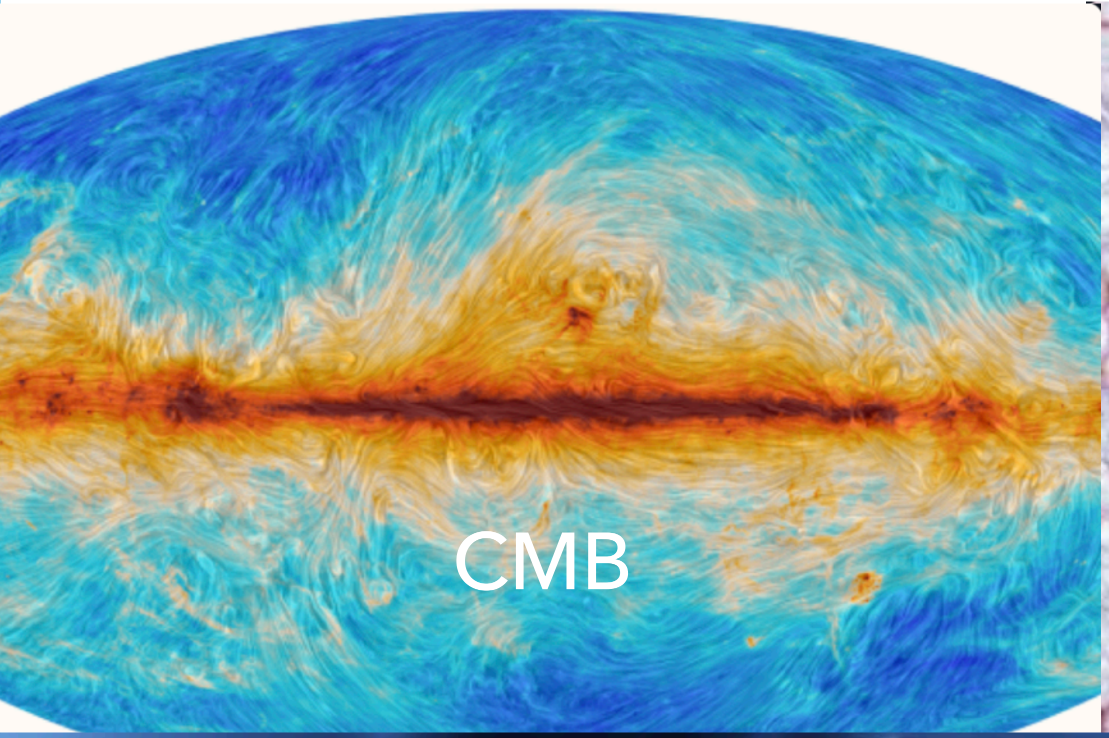
# THE XENONnT EXPERIMENT

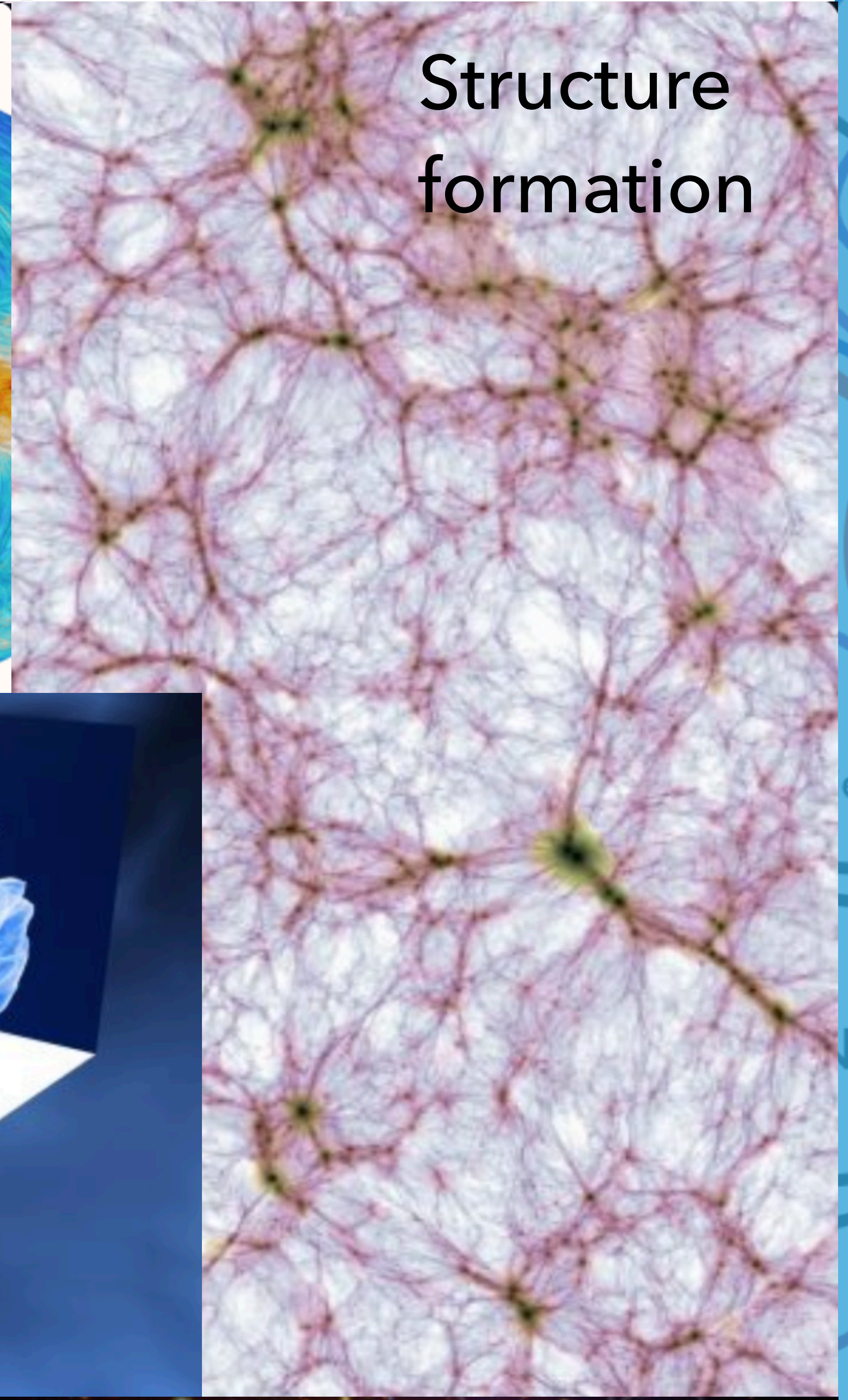
Lanqing Yuan (UChicago), on behalf of XENON collaboration

Jan 12 2024, Institute of High Energy Physics

XENON

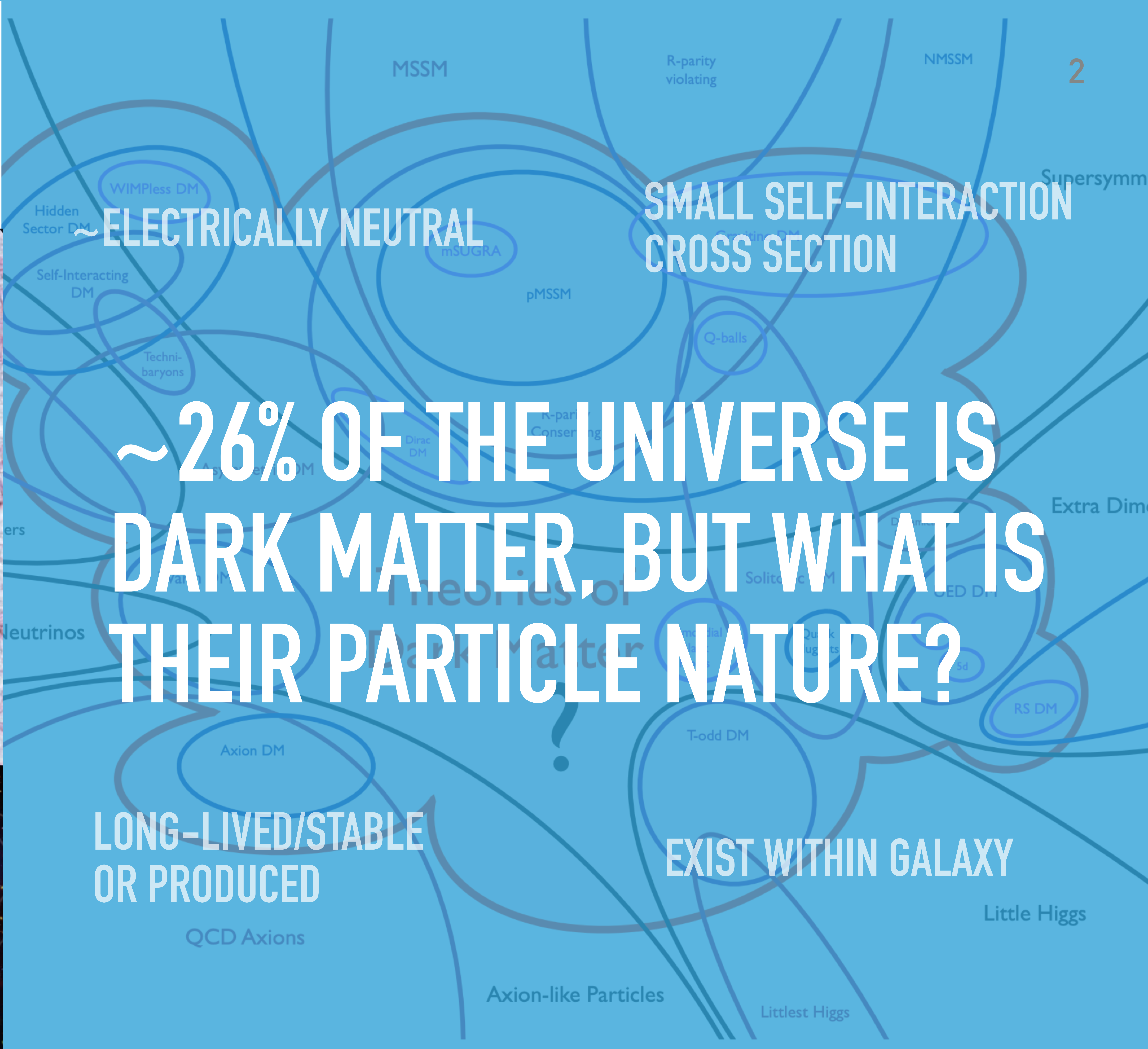








~ELECTRICALLY NEUTRAL

SMALL SELF-INTERACTION CROSS SECTION

# ~26% OF THE UNIVERSE IS DARK MATTER, BUT WHAT IS THEIR PARTICLE NATURE?

LONG-LIVED/STABLE OR PRODUCED

EXIST WITHIN GALAXY

# ROADMAP

- **Dark Matter Direct Detection**
- The XENONnT Detector
- Detector Calibration
- First Low Energy Electronic Recoil Search Result
- First Nuclear Recoil Search Result
- Search in Other Channels

# DIRECT DETECTABILITY OF DARK MATTER

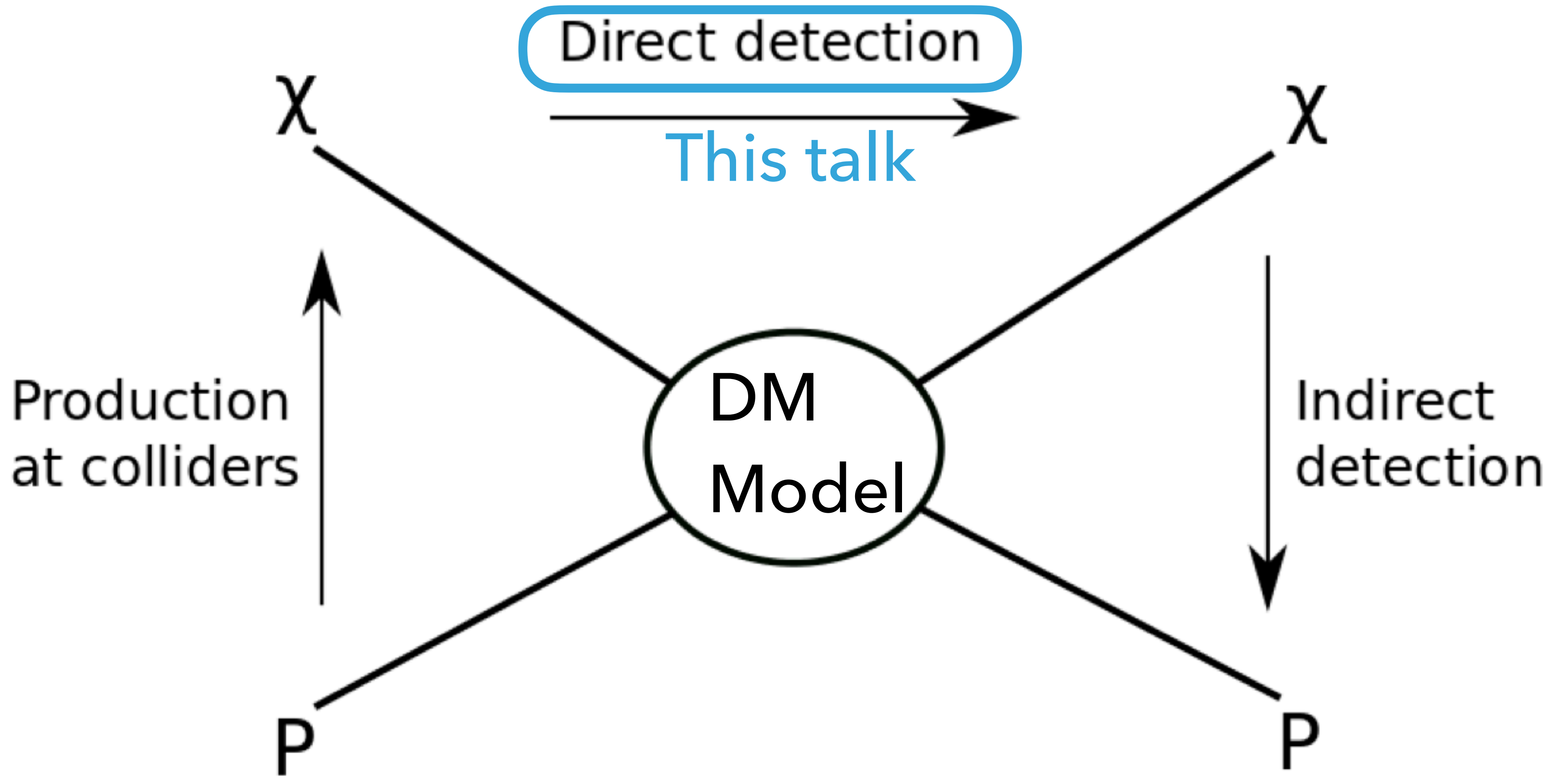
- Direct Detection: record the rare occasions that particle DM scatters off a target material

PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

**Detectability of certain dark-matter candidates**

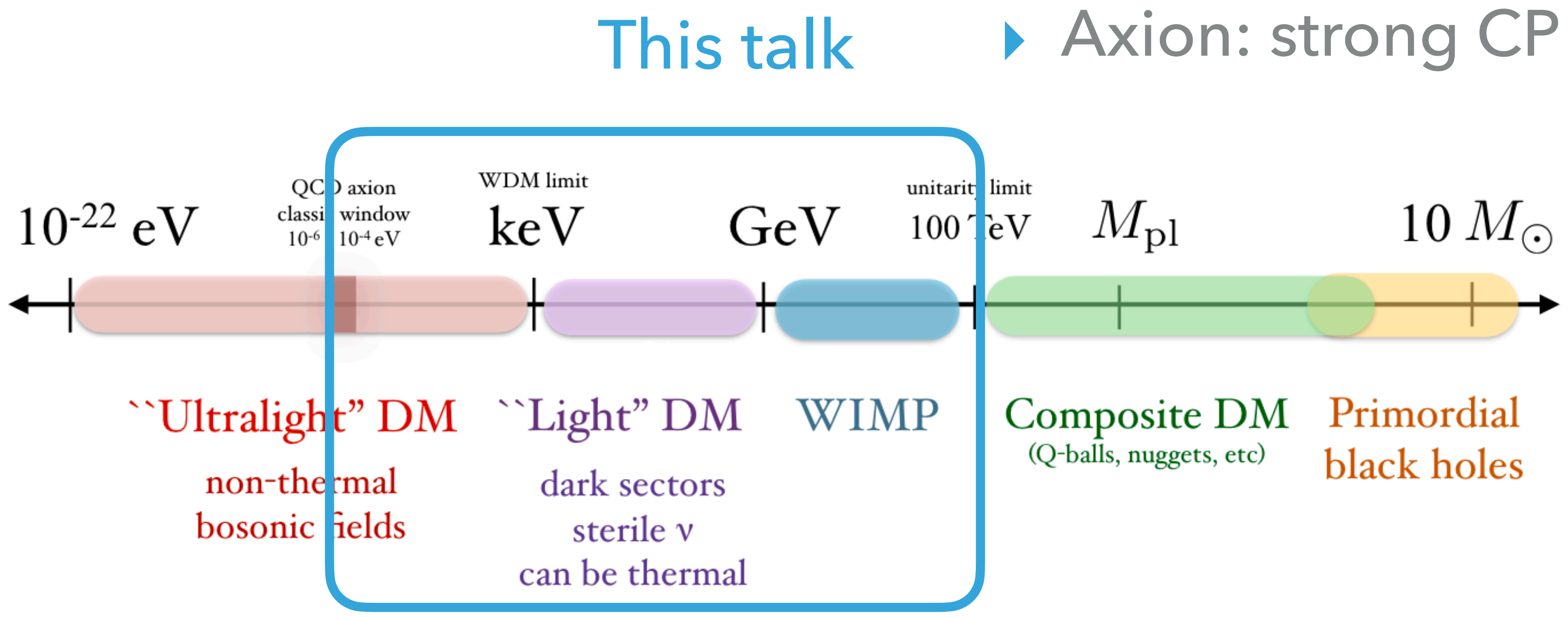
Mark W. Goodman and Edward Witten
*Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544*
(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.



# DIRECT DETECTABILITY OF DARK MATTER

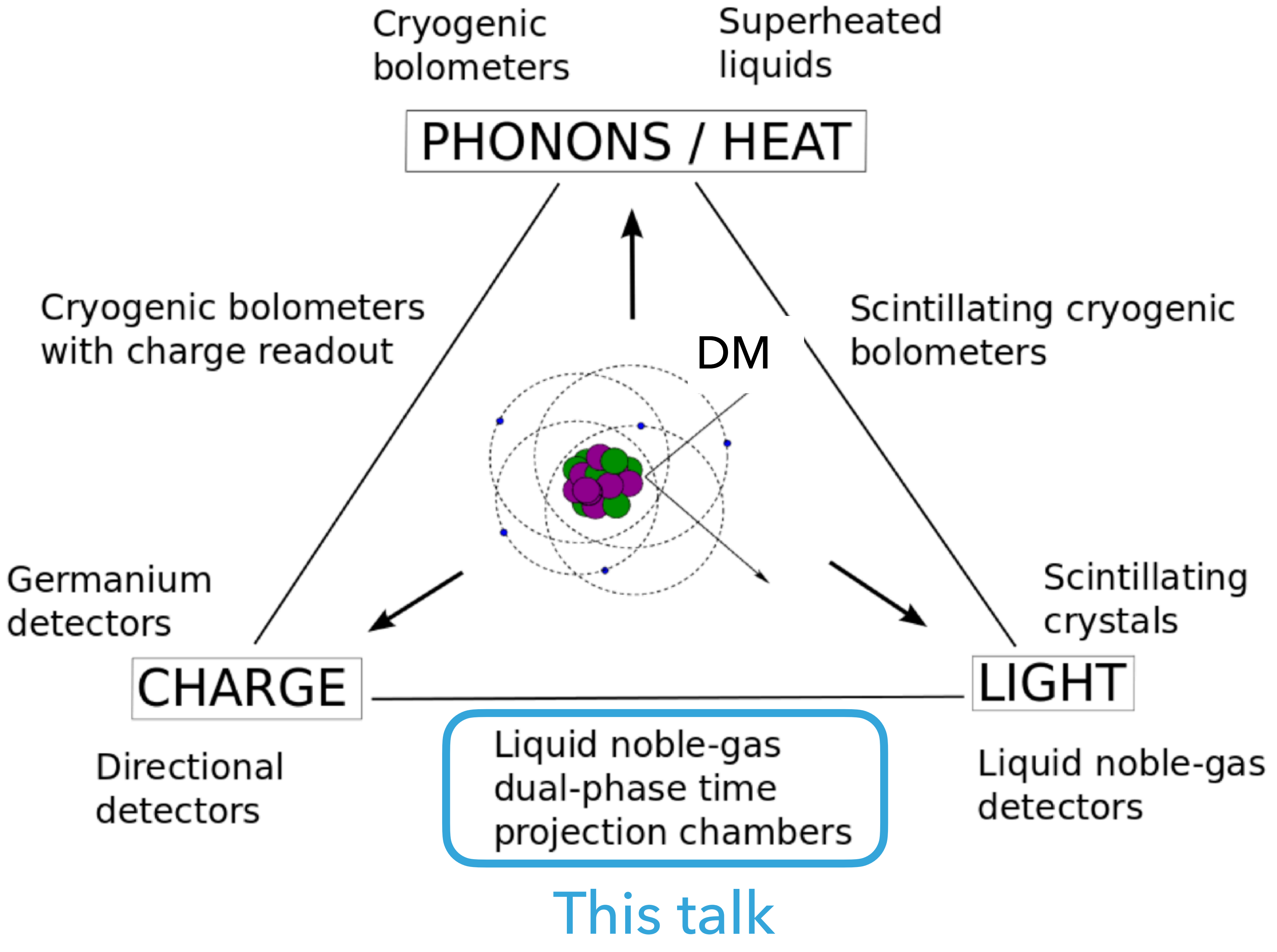
- WIMP: Supersymmetry
- Axion: strong CP problem




- Direct Detection: record the rare occasions that particle DM scatters off a target material
- Differential rate per unit target mass:

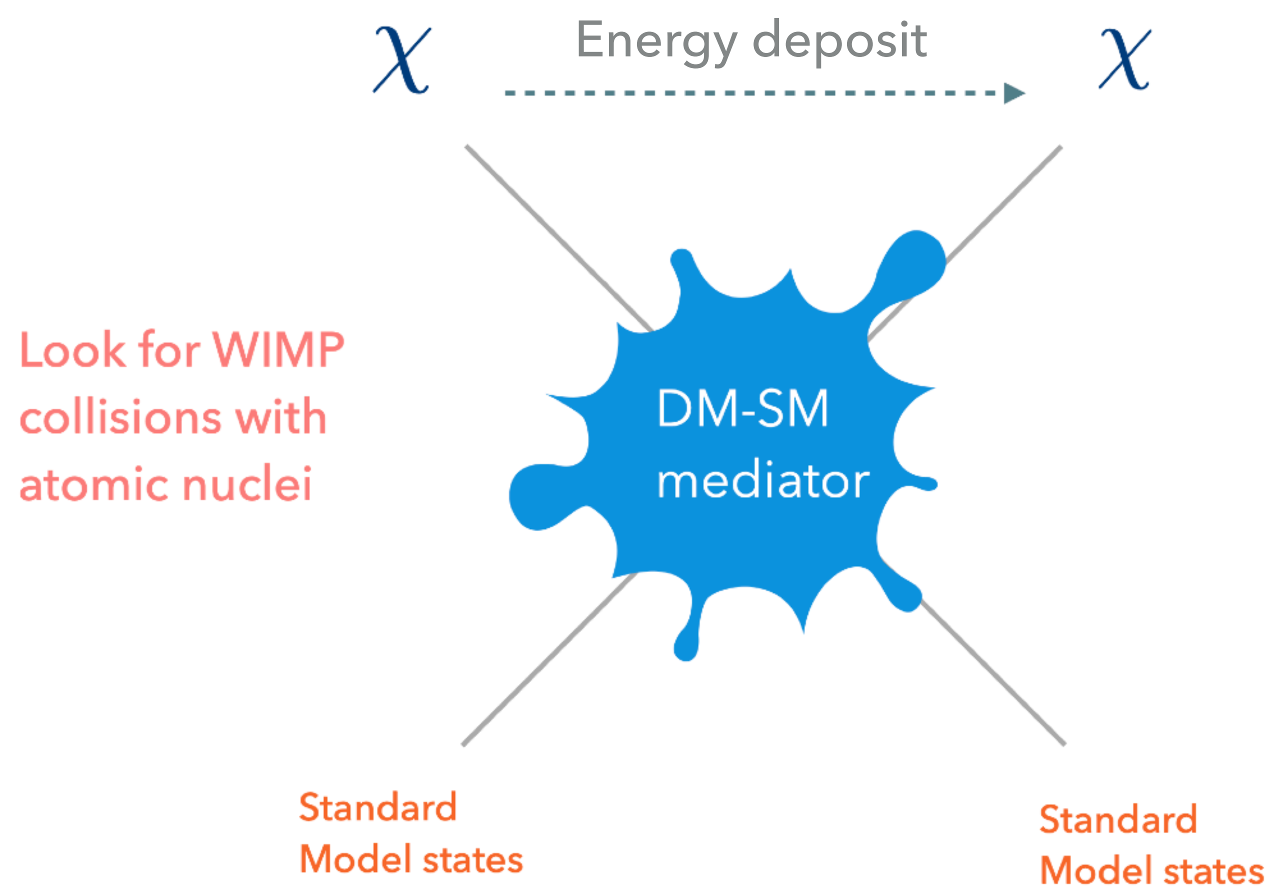
$$\frac{dR}{dE_R} = N_T n_\chi \int \frac{d\sigma}{dE_R} v f(\mathbf{v})\, d^3\mathbf{v}$$

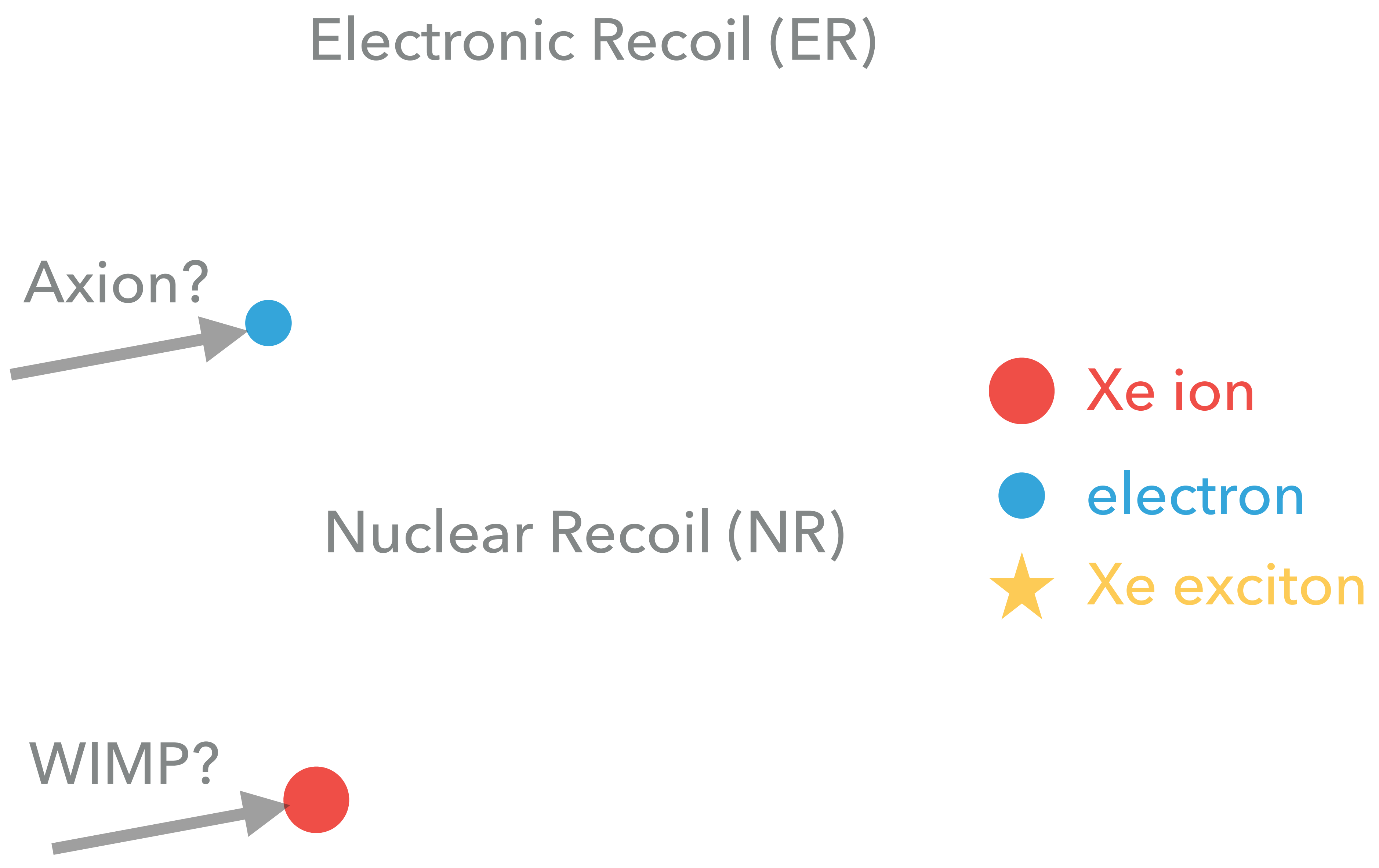
Recoil energy spectrum ($\frac{dR}{dE_R}$); number of target per unit target mass ($N_T$); DM number density ($n_\chi$); DM-SM scattering cross section ($\frac{d\sigma}{dE_R}$) — Want to measure this!; DM velocity distribution ($f(\mathbf{v})$)



# EXAMPLE DETECTOR: OBSERVABLE SIGNALS IN XENON

- **Incident particles (including DM) deposit energy via some mediator into xenon atom**



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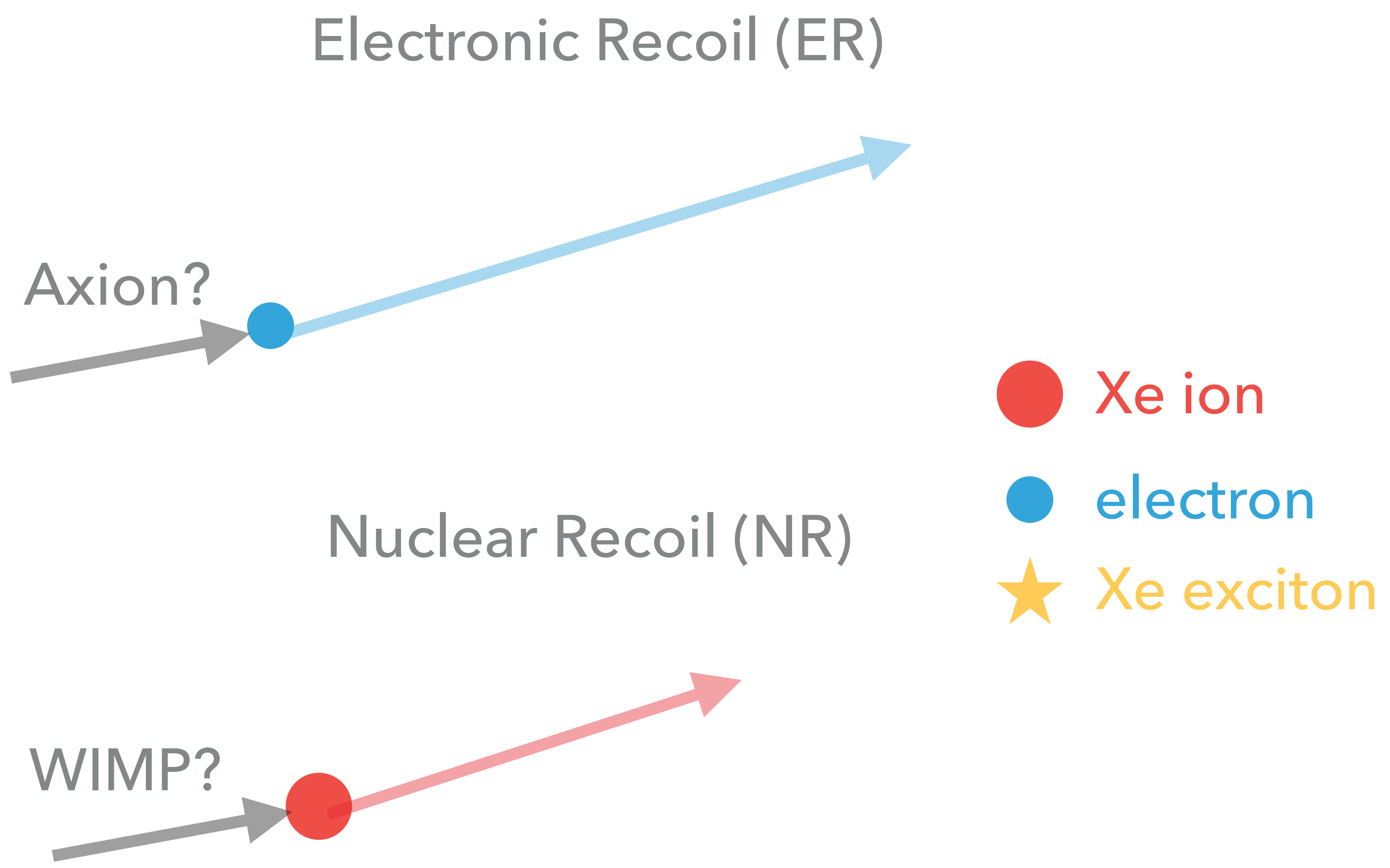
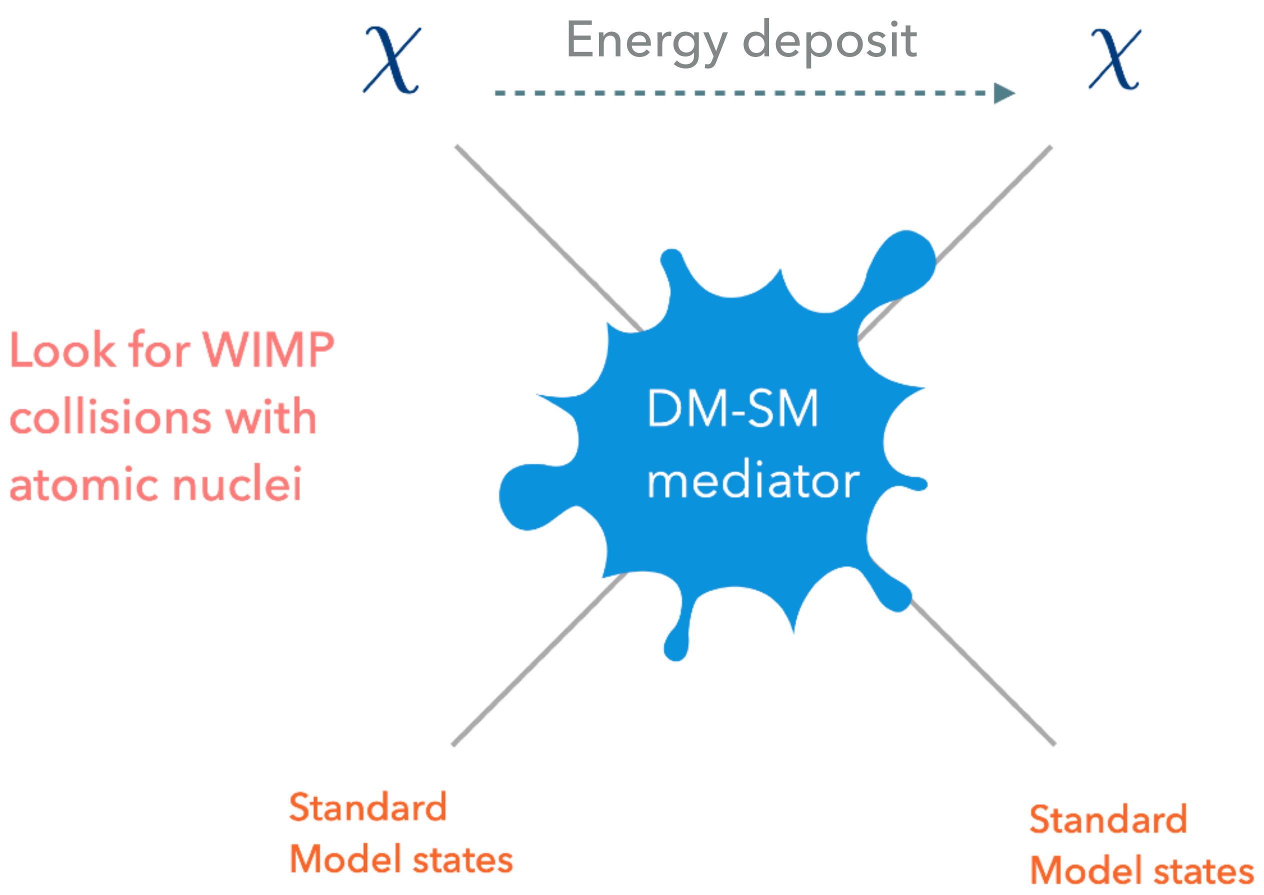
- **Initial interaction leads to either recoiled xenon ion or electron**



# EXAMPLE DETECTOR: OBSERVABLE SIGNALS IN XENON

- Incident particles (including DM) deposit energy via some mediator into xenon atom
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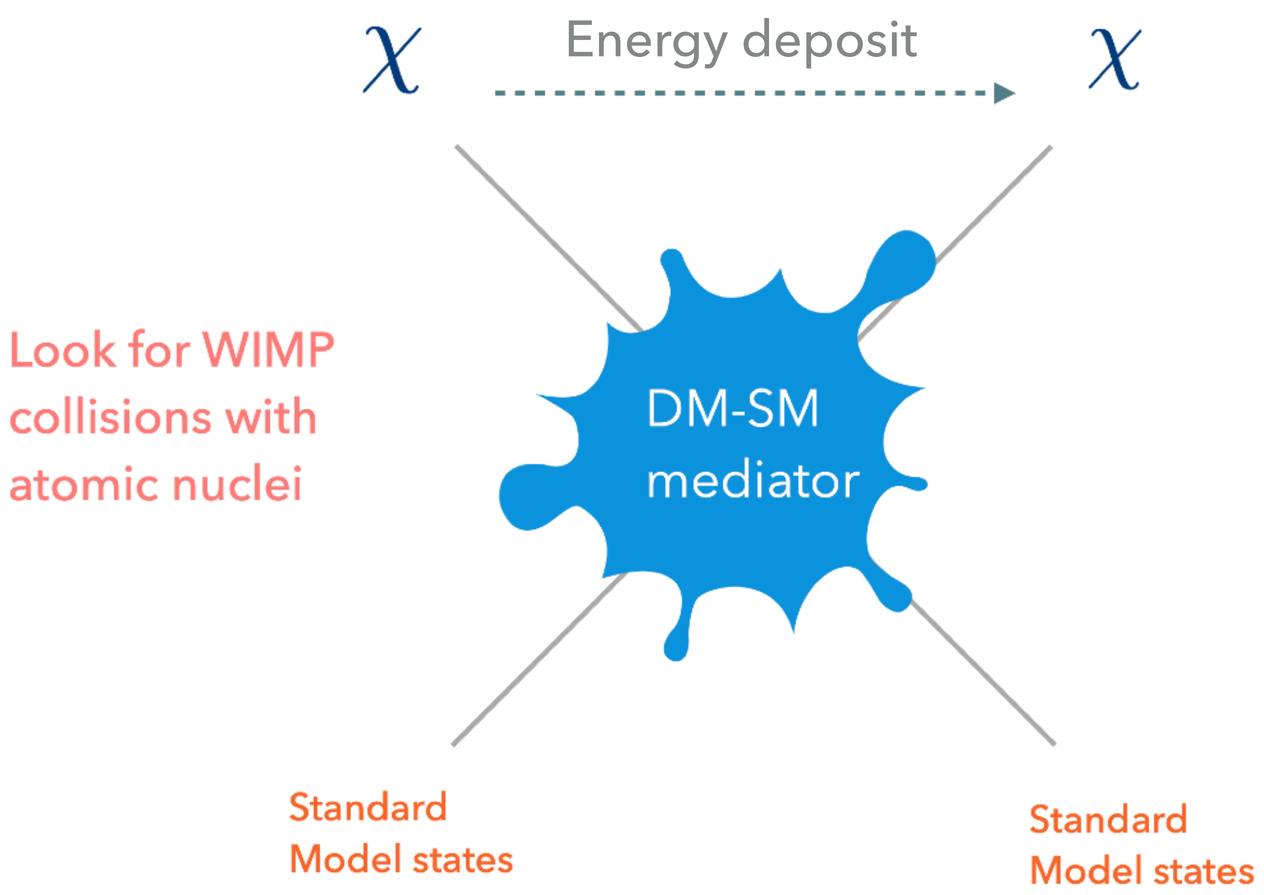
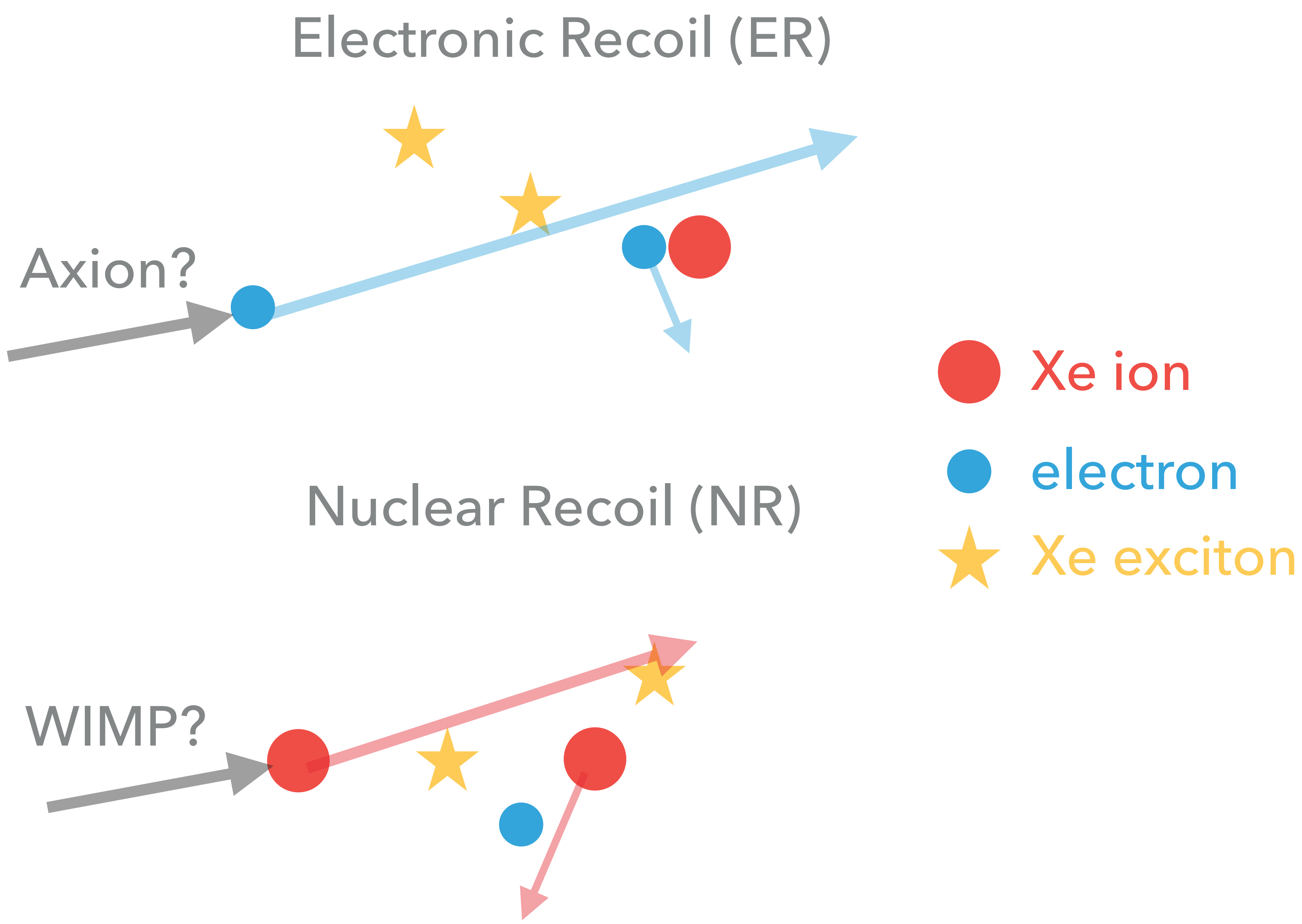
- **The recoiled ion/electron scatter intensely with other xenon atoms, leading to either ionization or excitation**



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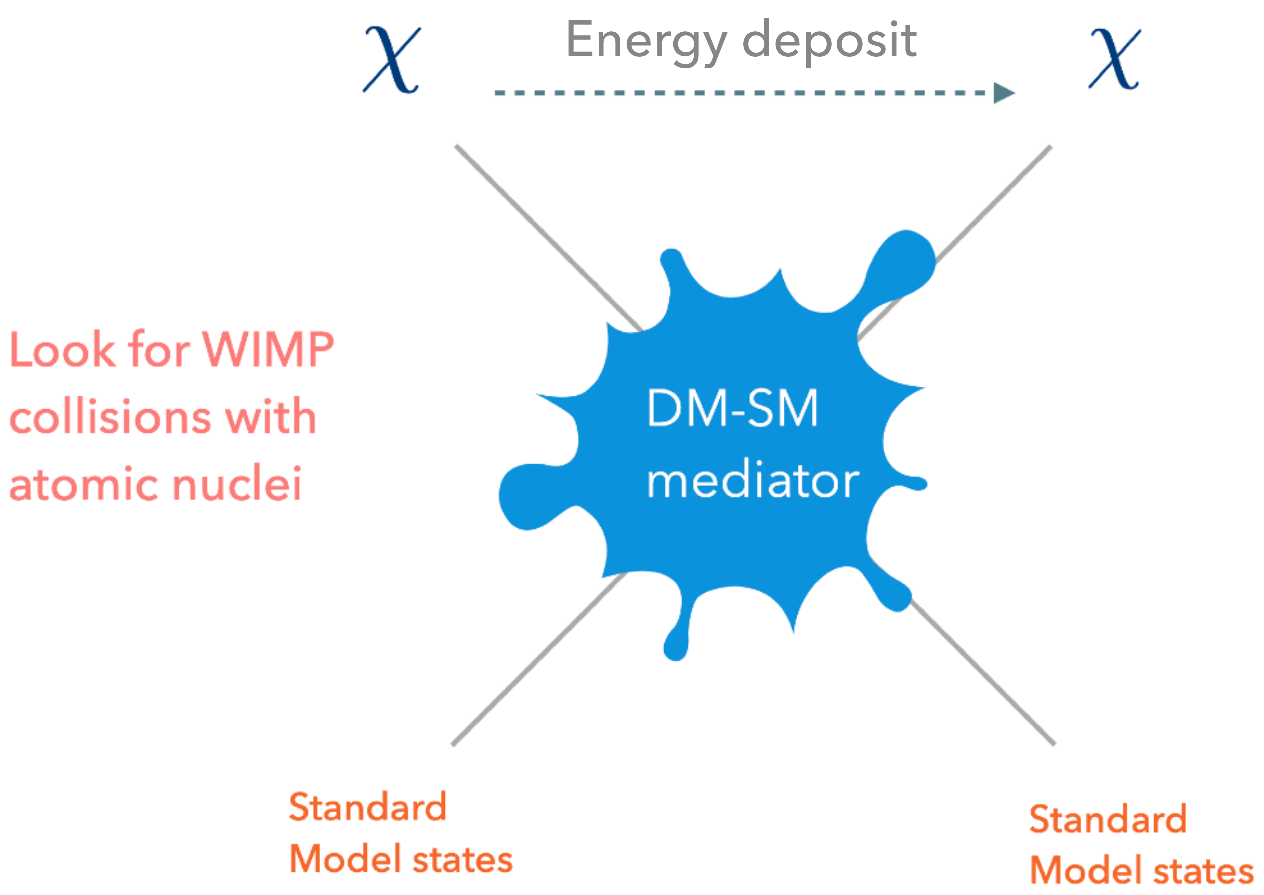
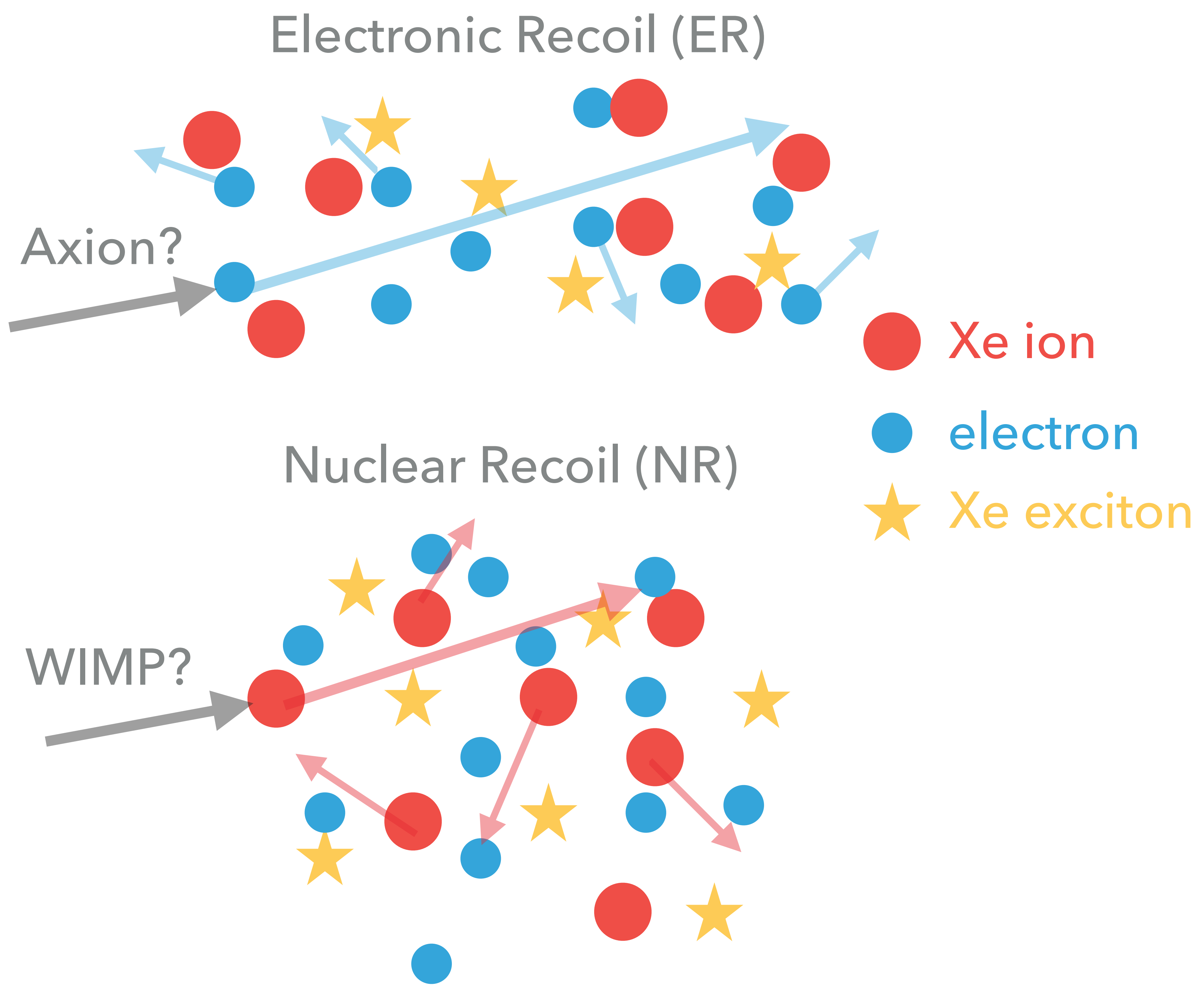
- **Iterate processes above with incident particle replaced by secondary particles (either electron or xenon ion)**




Different ratio of excitation/ion in NR/ER & density/shape of tracks thus recombination ratio → Discrimination power for NR/ER

# ROADMAP

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- **The XENONnT Detector** ~The hardware efforts to reduce background
- Detector Calibration
- First Low Energy Electronic Recoil Search Result
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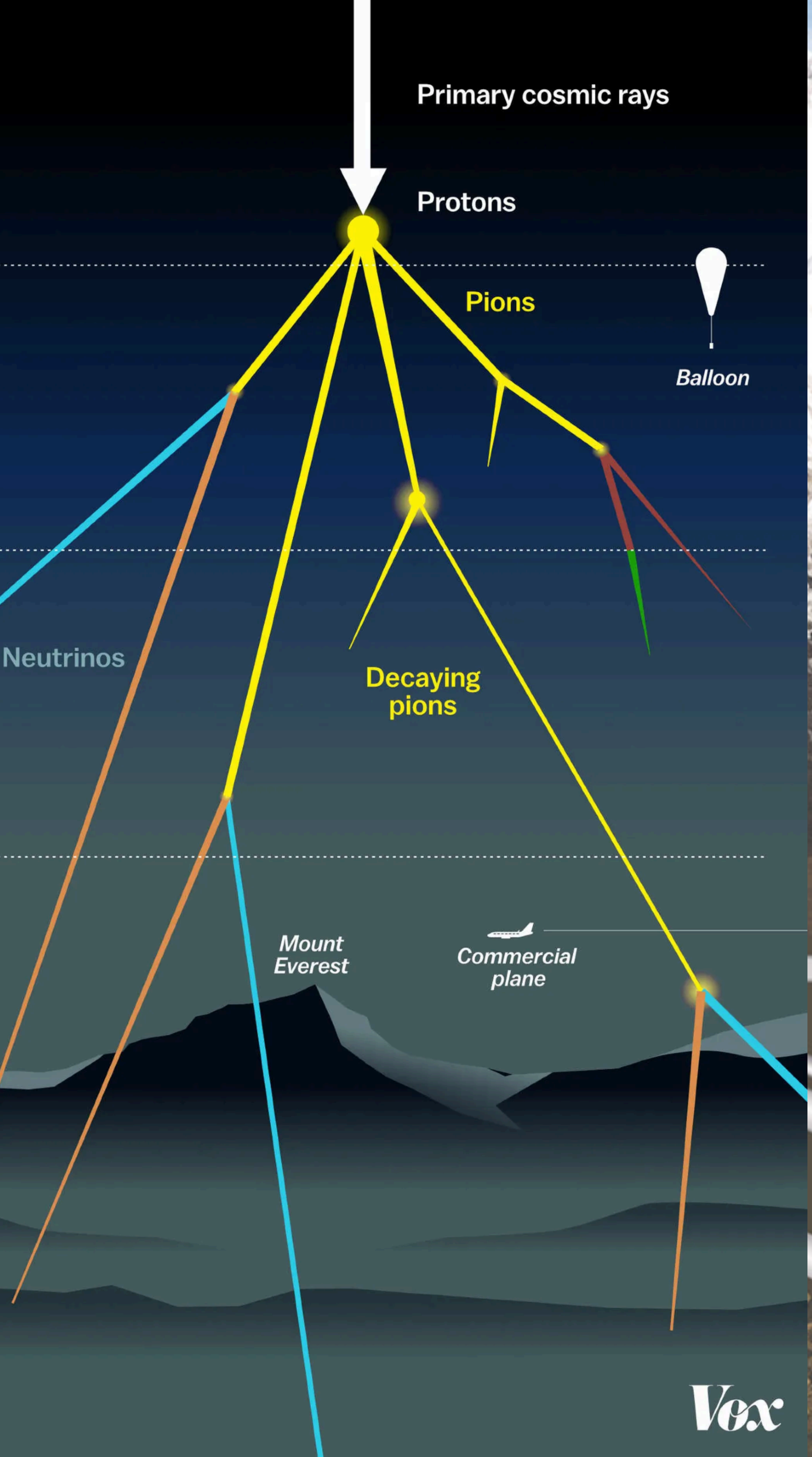
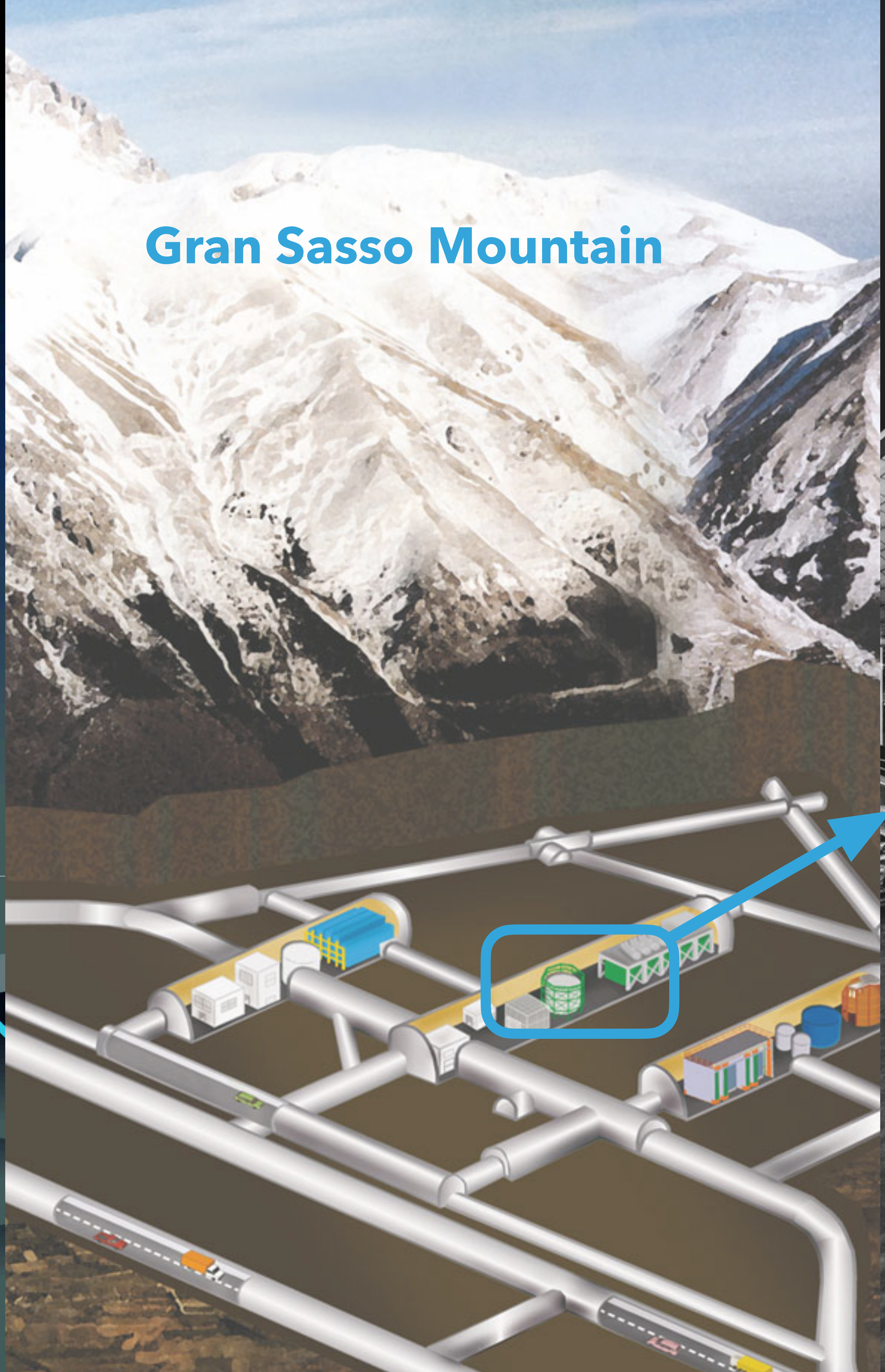

Primary cosmic rays
Protons
Pions
Balloon
Neutrinos
Decaying pions
Mount Everest
Commercial plane
Vox


Gran Sasso Mountain

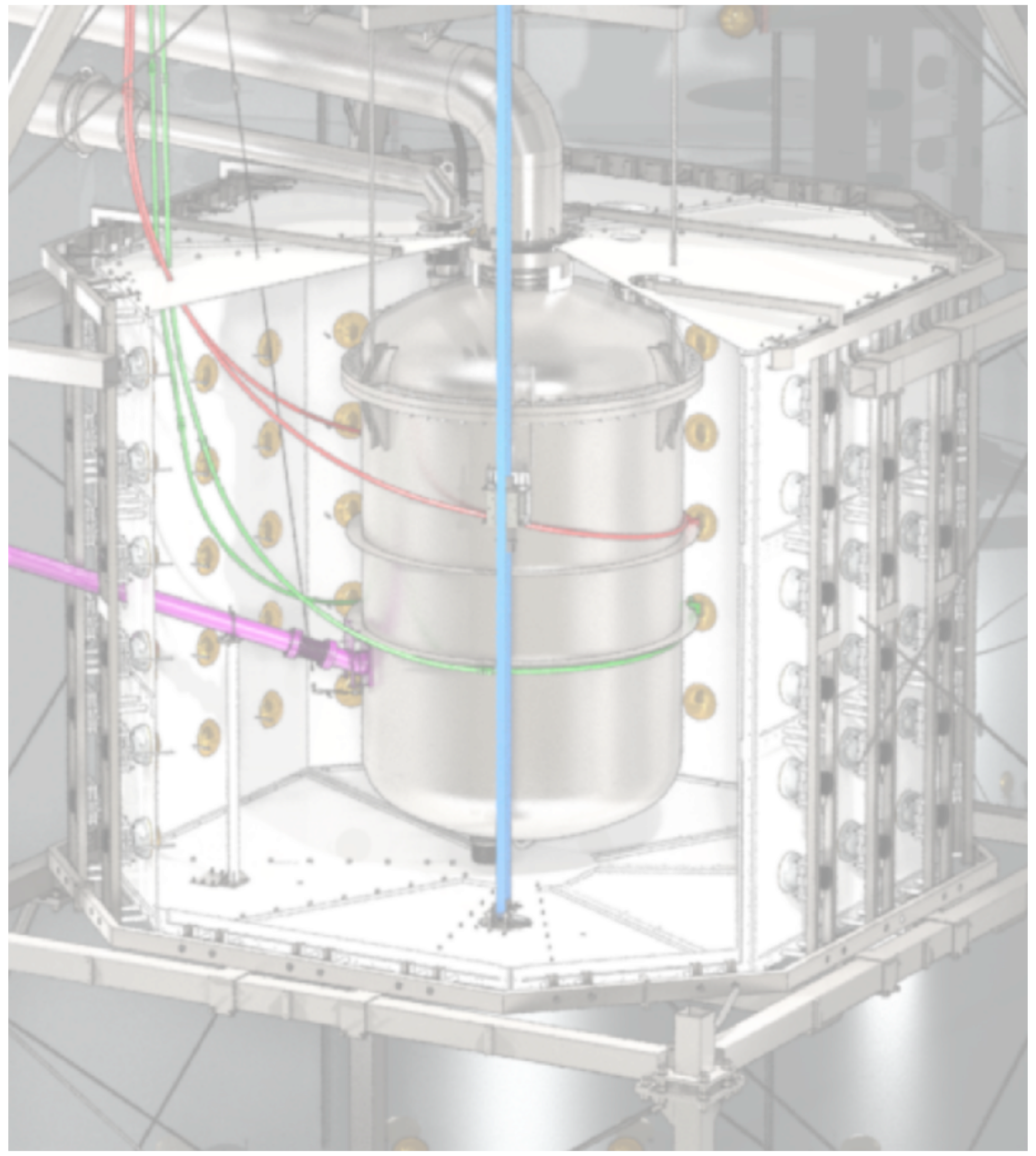

Infrastructures
Detectors

# 3 NESTED DETECTORS: TPC/NV/MV SHARING SAME DAQ

**LXe Time Projection Chamber (TPC)**

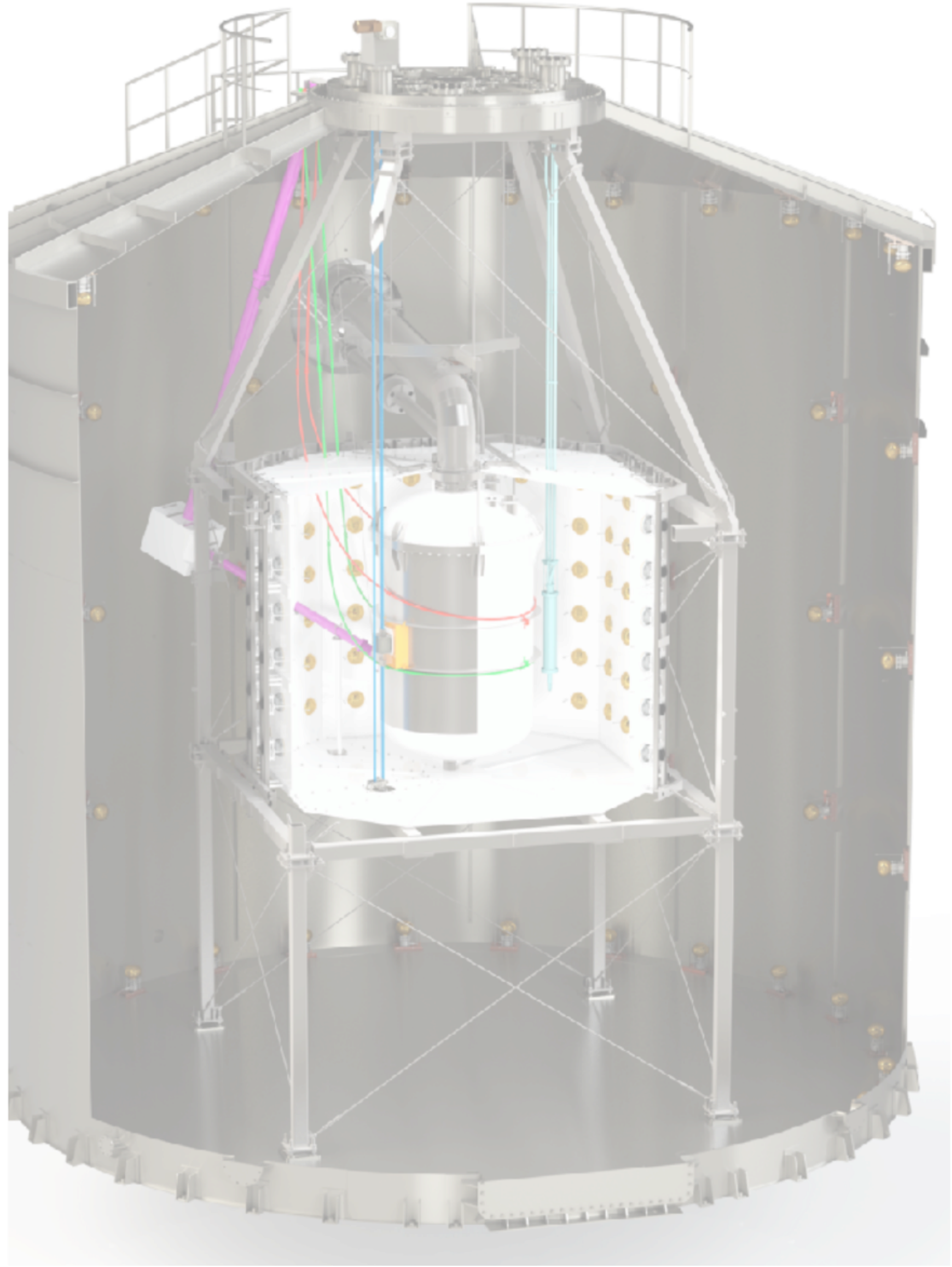
- 5.9T active target mass
- including ~8.9% $^{136}Xe$ by natural abundance
- 1.3m/1.5m active target diameter/height
- 493 Hamamatsu 3″ PMTs

**Gd-salted water-based neutron Cherenkov Detector Neutron Veto (NV)**



- (Pure water for published results so far)
- 120 8″ high QE PMT
- 33 $m^3$ volume
- Use neutron capture to tag neutron events at the efficiency of **65%** in pure water
- High reflectivity expanded PTFE

**Water-based muon Cherenkov Detector Muon Veto (MV)**



- Diameter/Height 9.6m/10.2m, 700T water
- High reflectivity inner coating
- 84 Hamamatsu 8″ PMTs
- Actively veto cosmogenic neutrons
- Passively vetoing neutron and gamma-induced background

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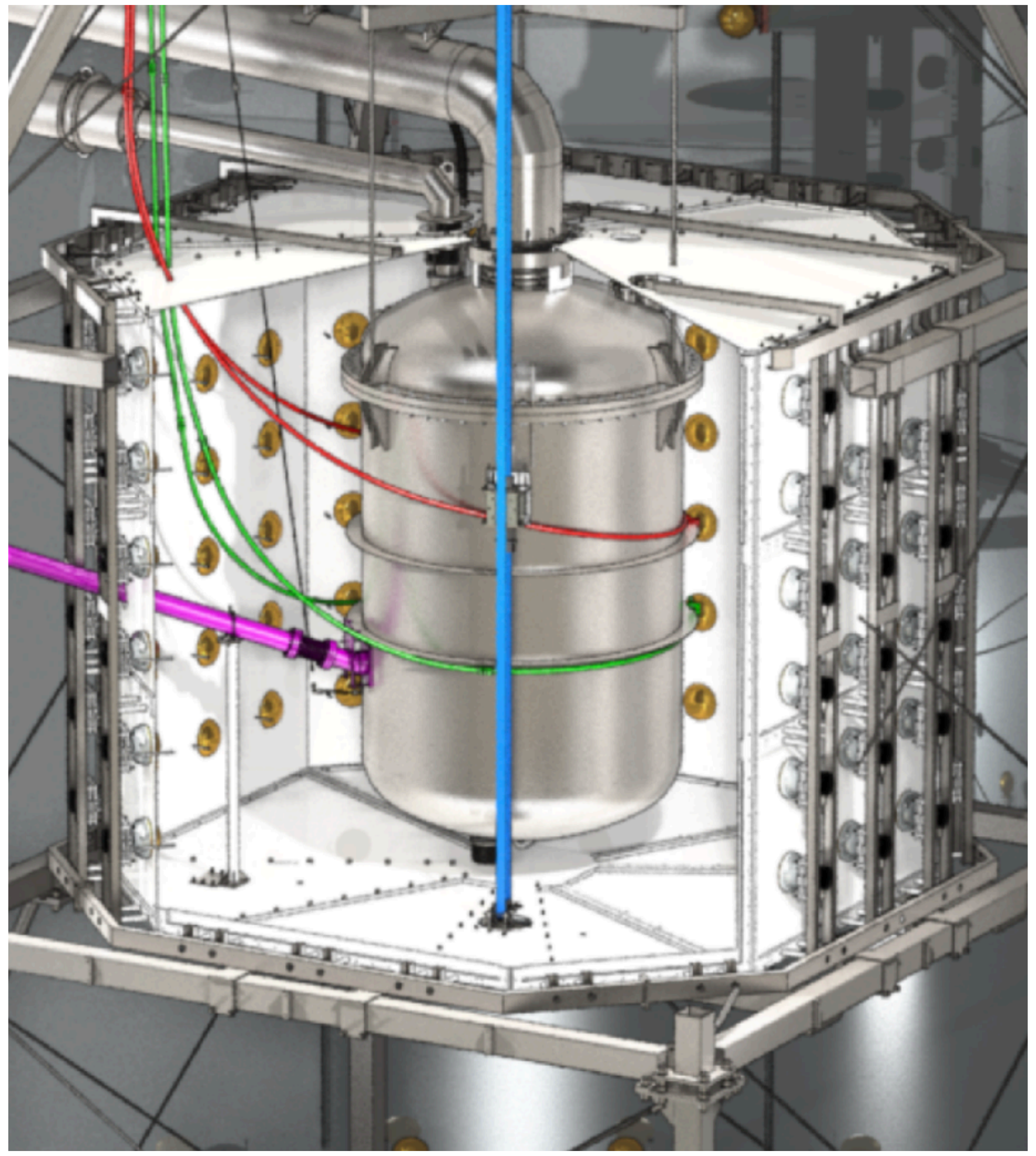

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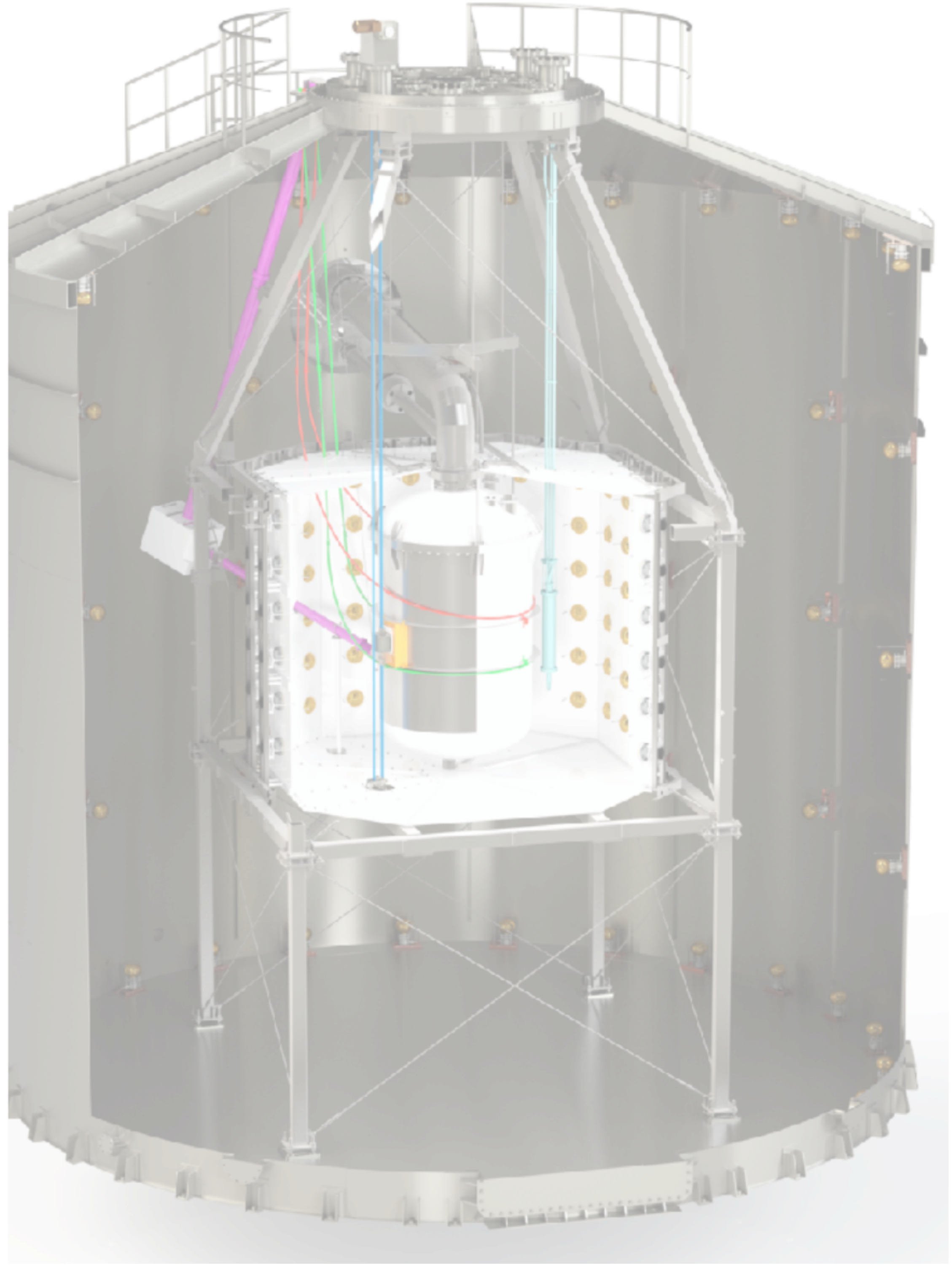

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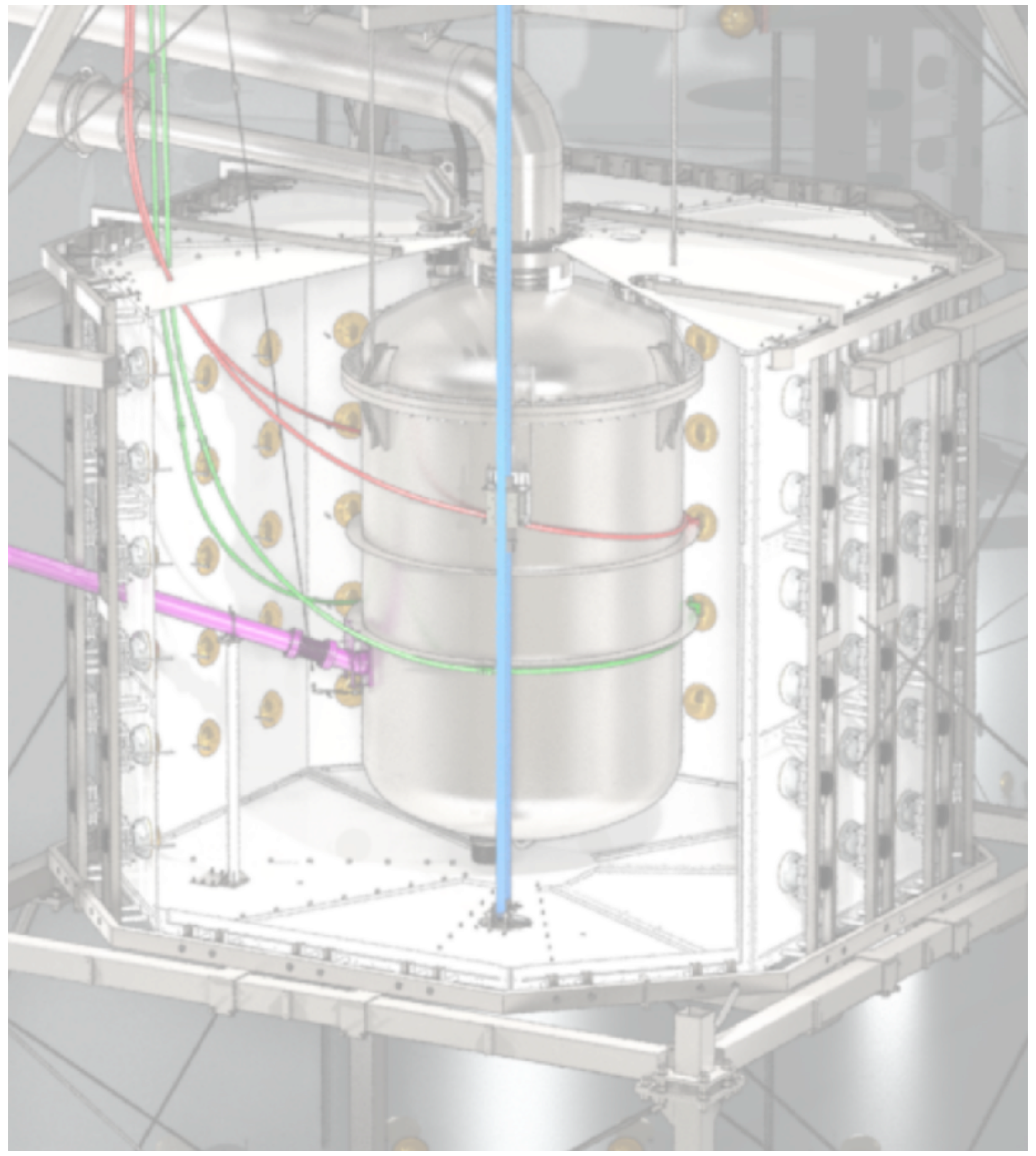

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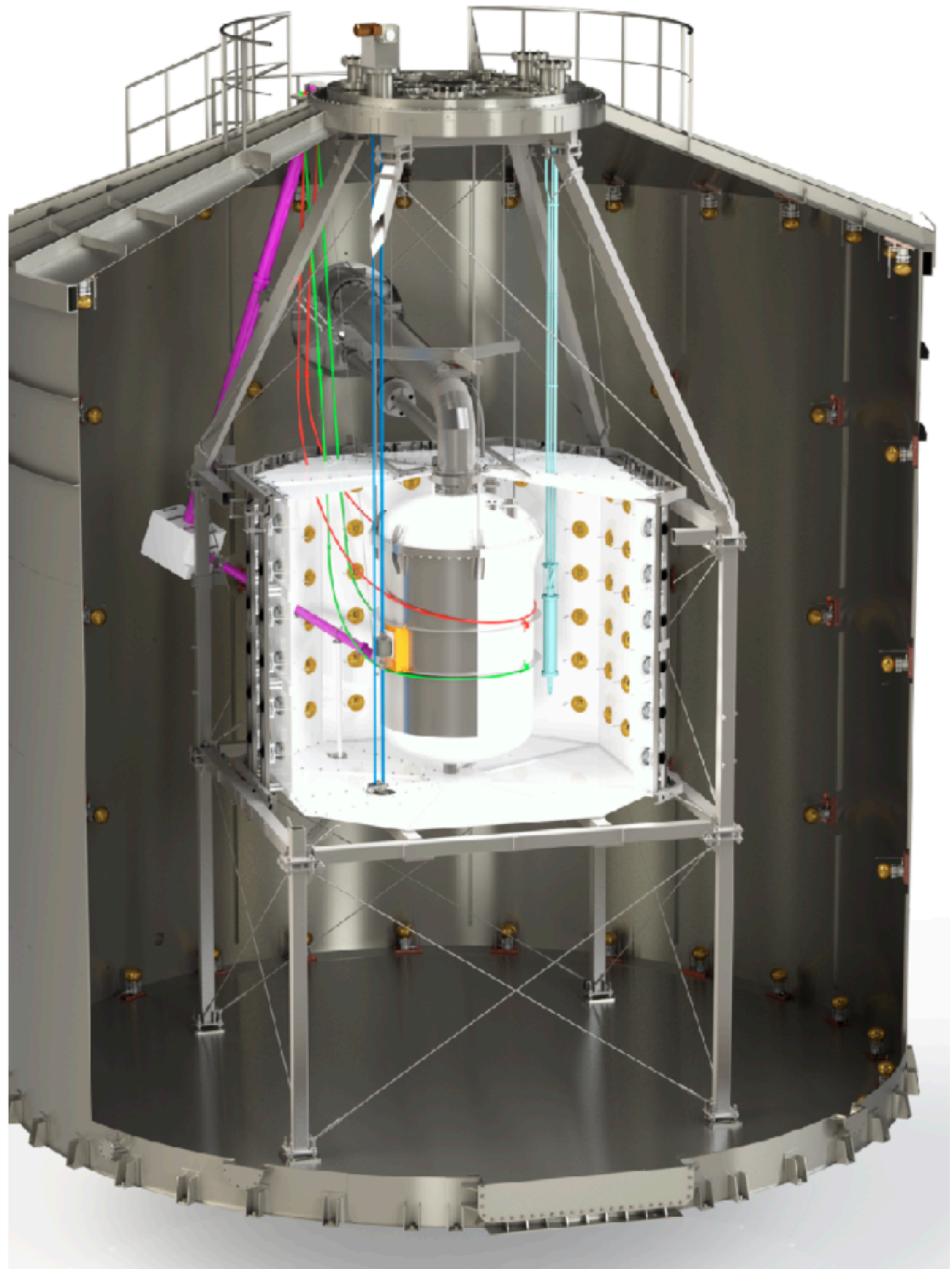

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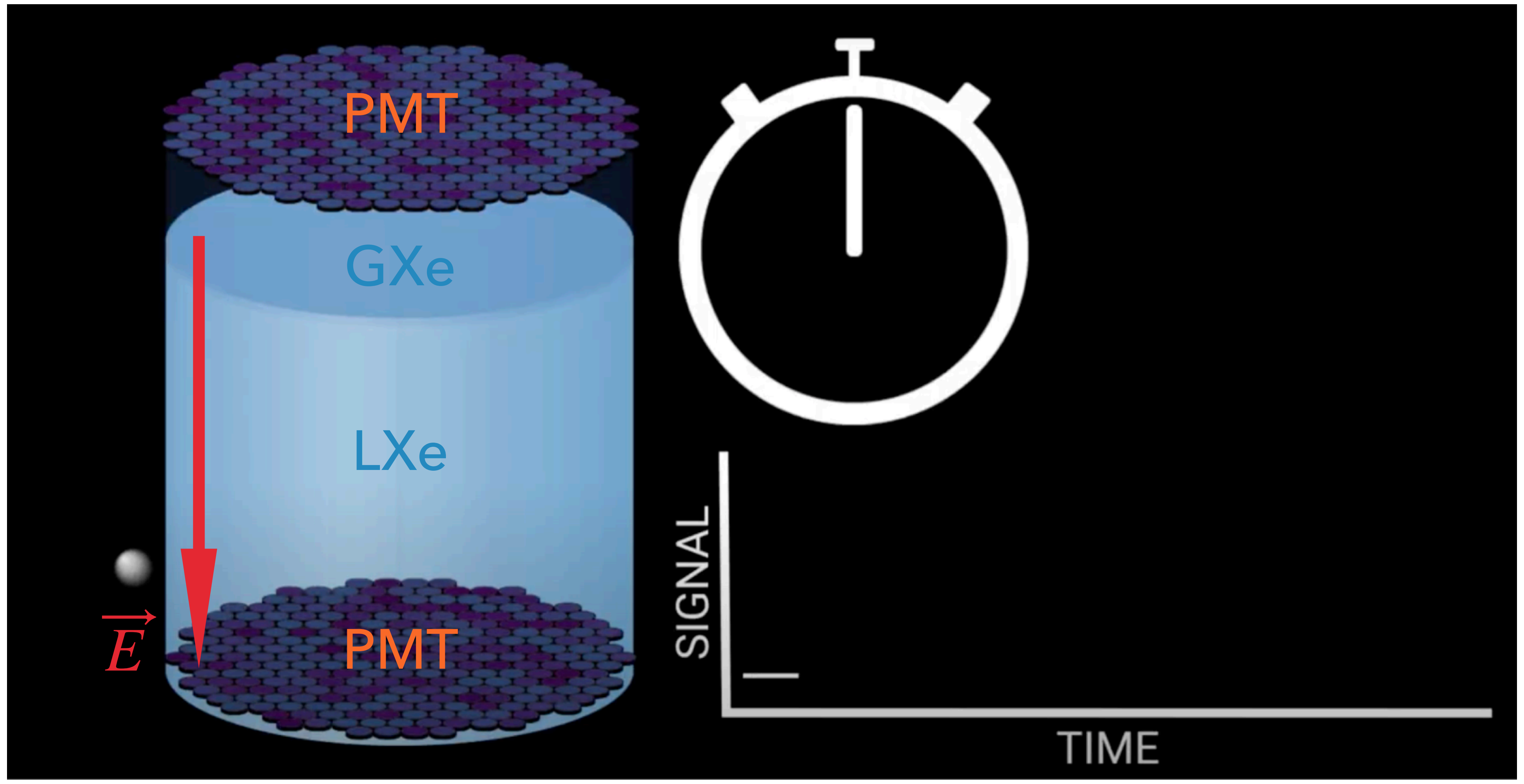
# TPC WORKING PRINCIPLE

- **Dual Phase Xenon Time Projection Chamber**



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- Dual Phase Xenon Time Projection Chamber
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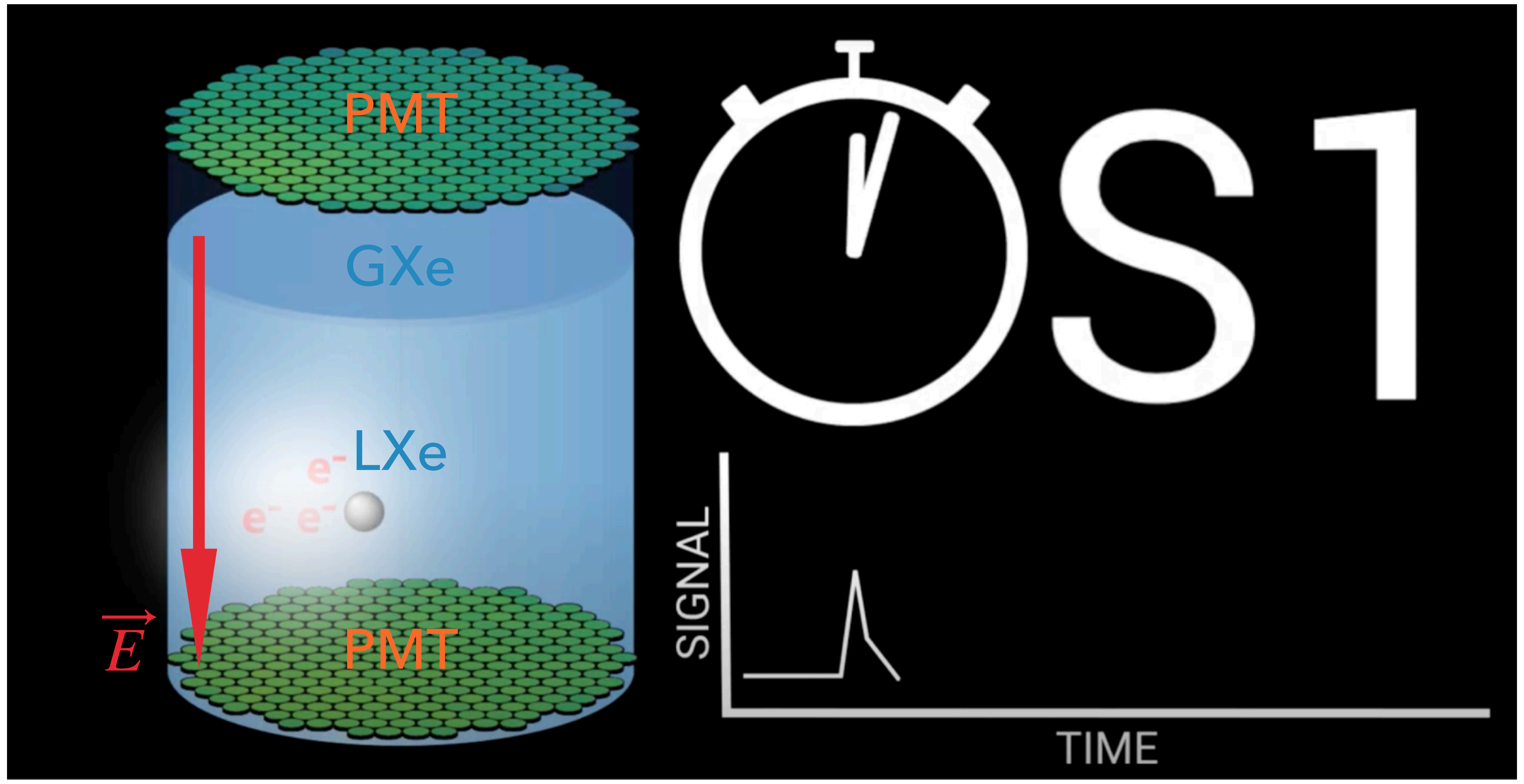


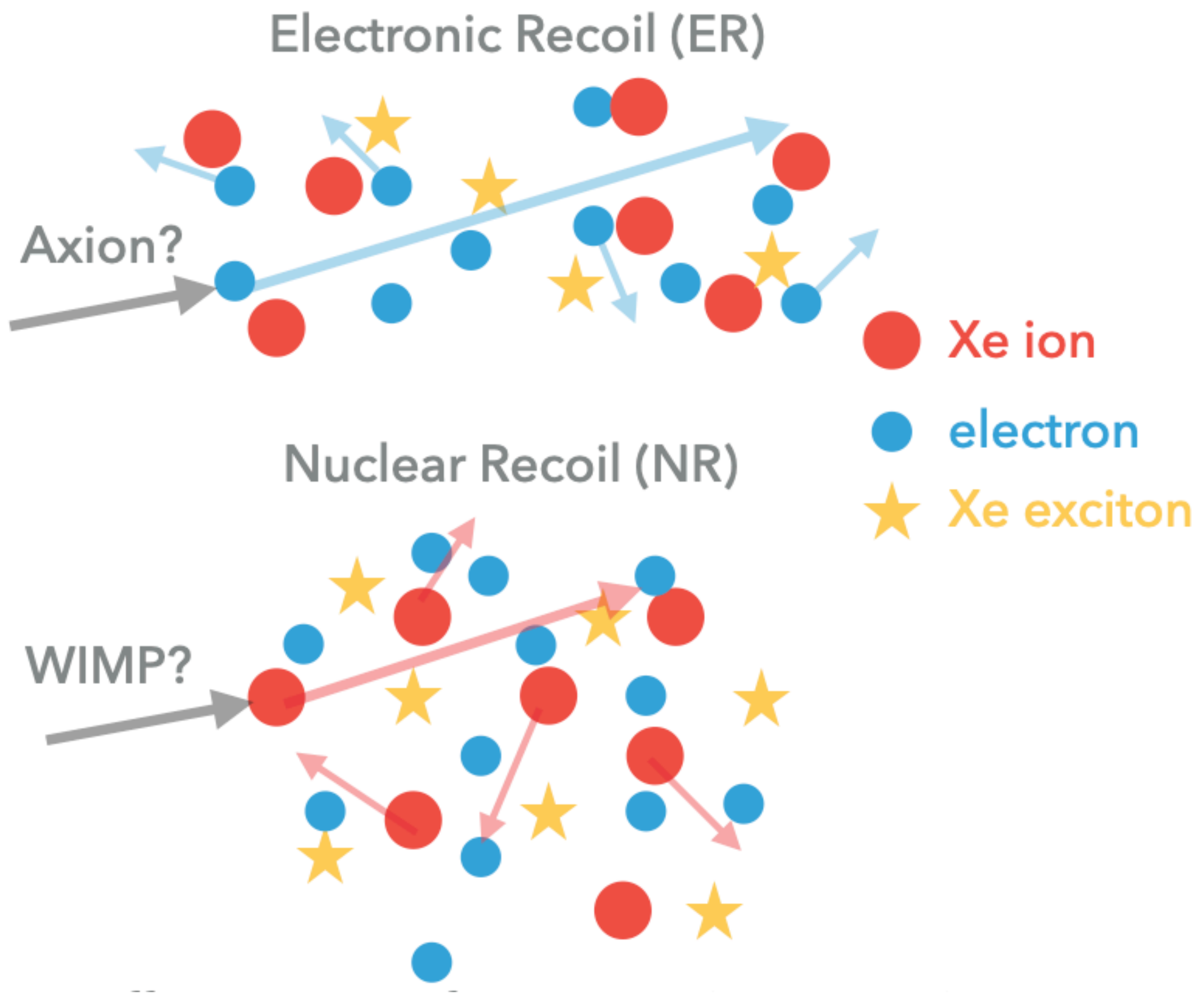

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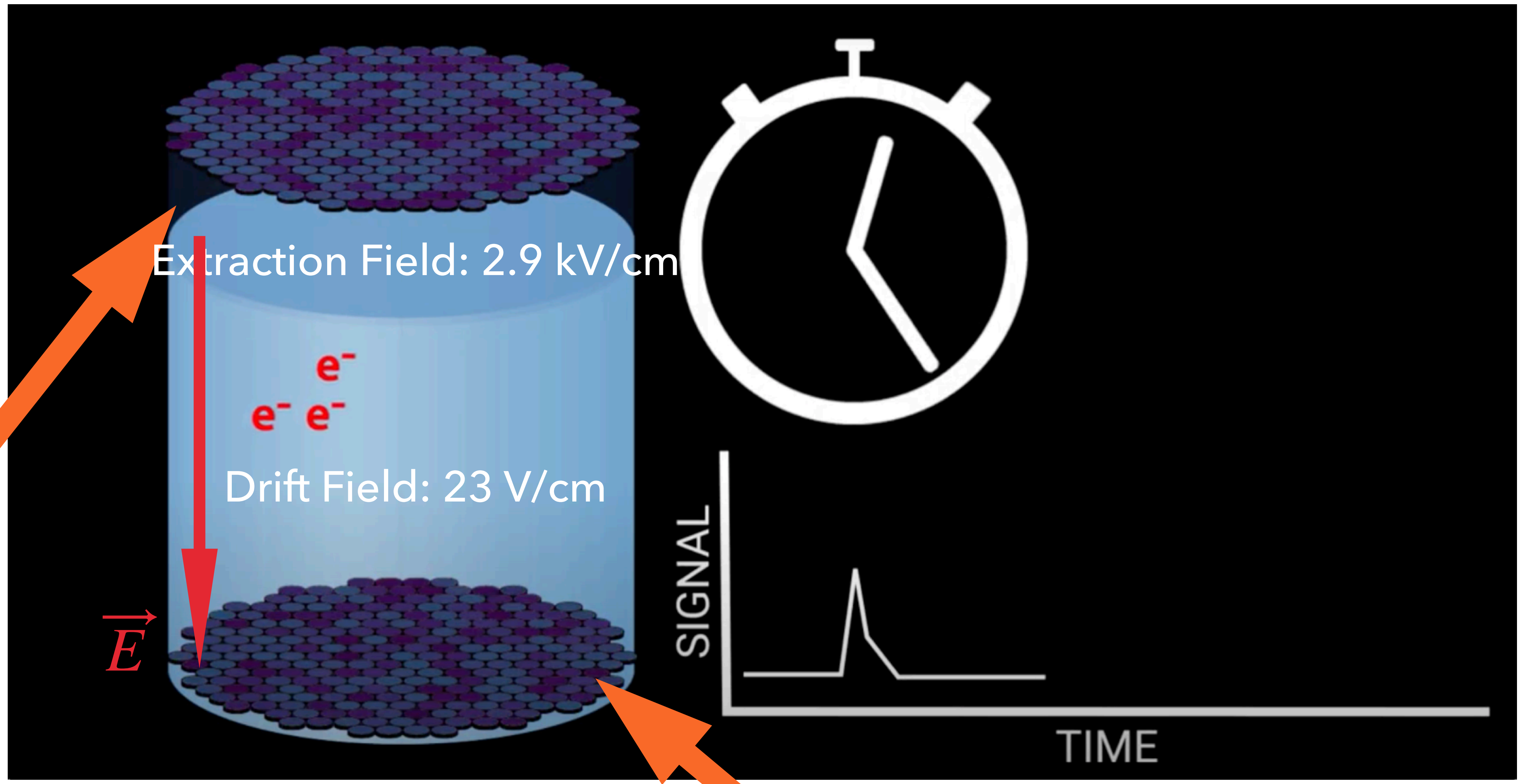
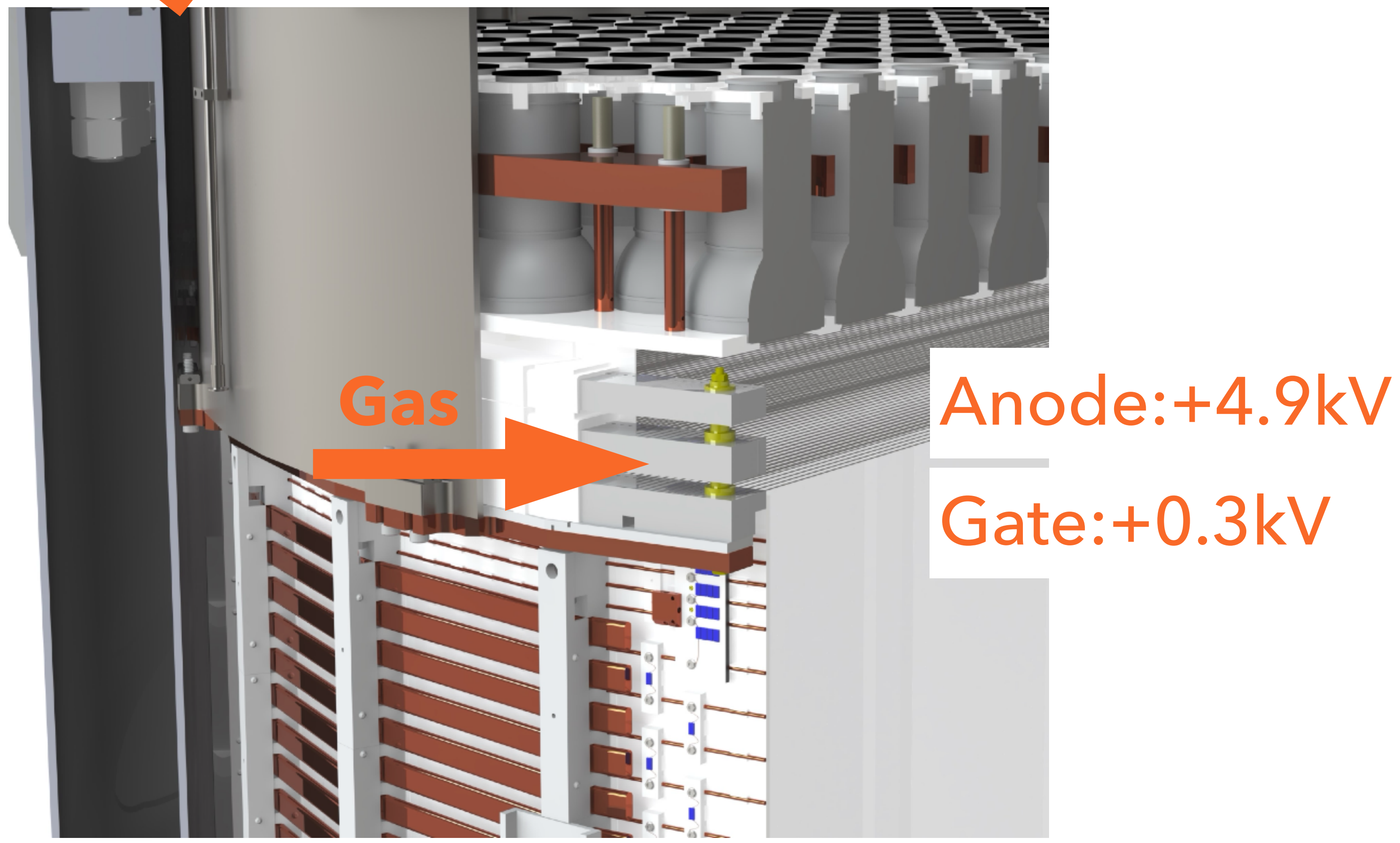
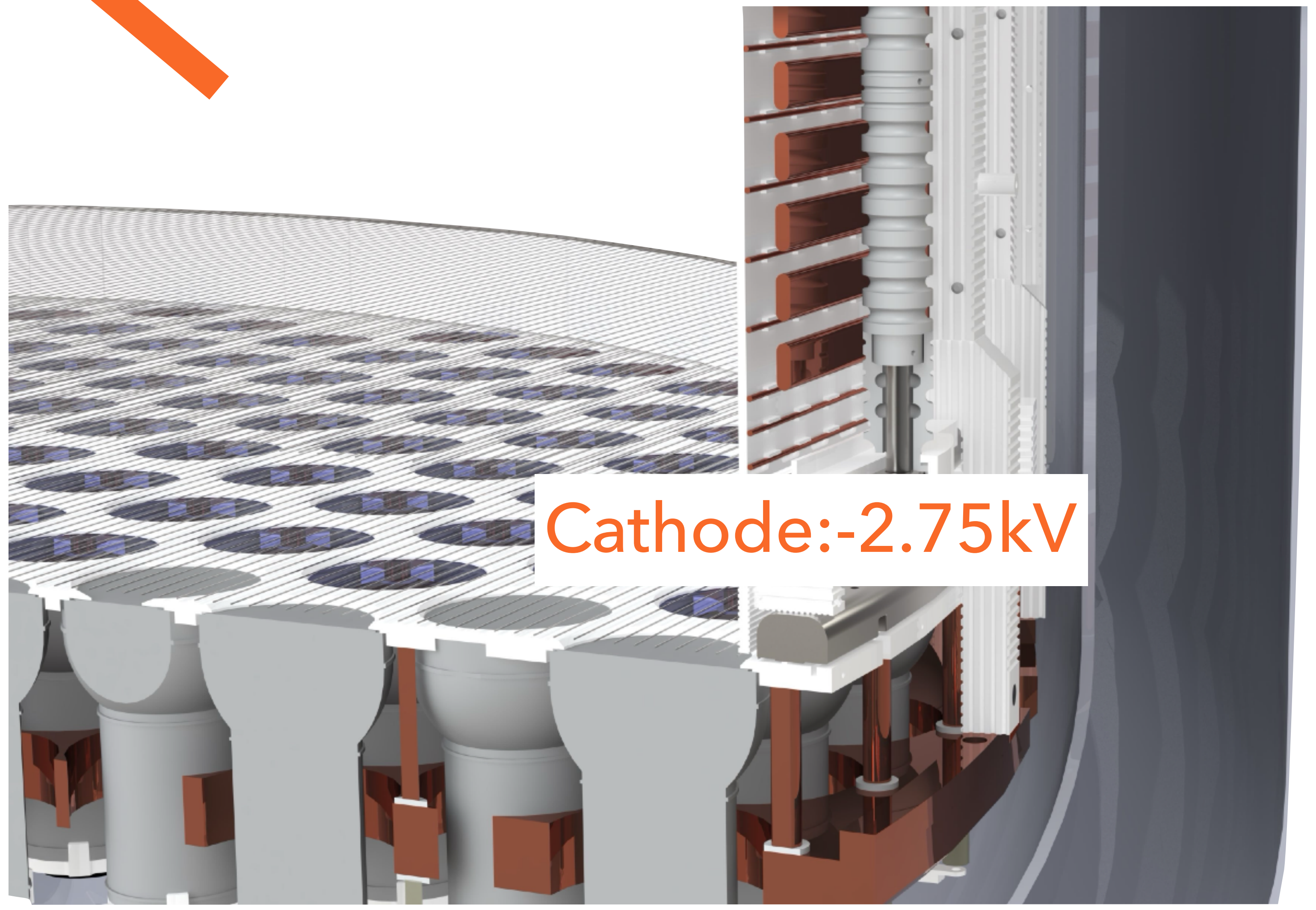
  - **Escaped electrons drift up.**



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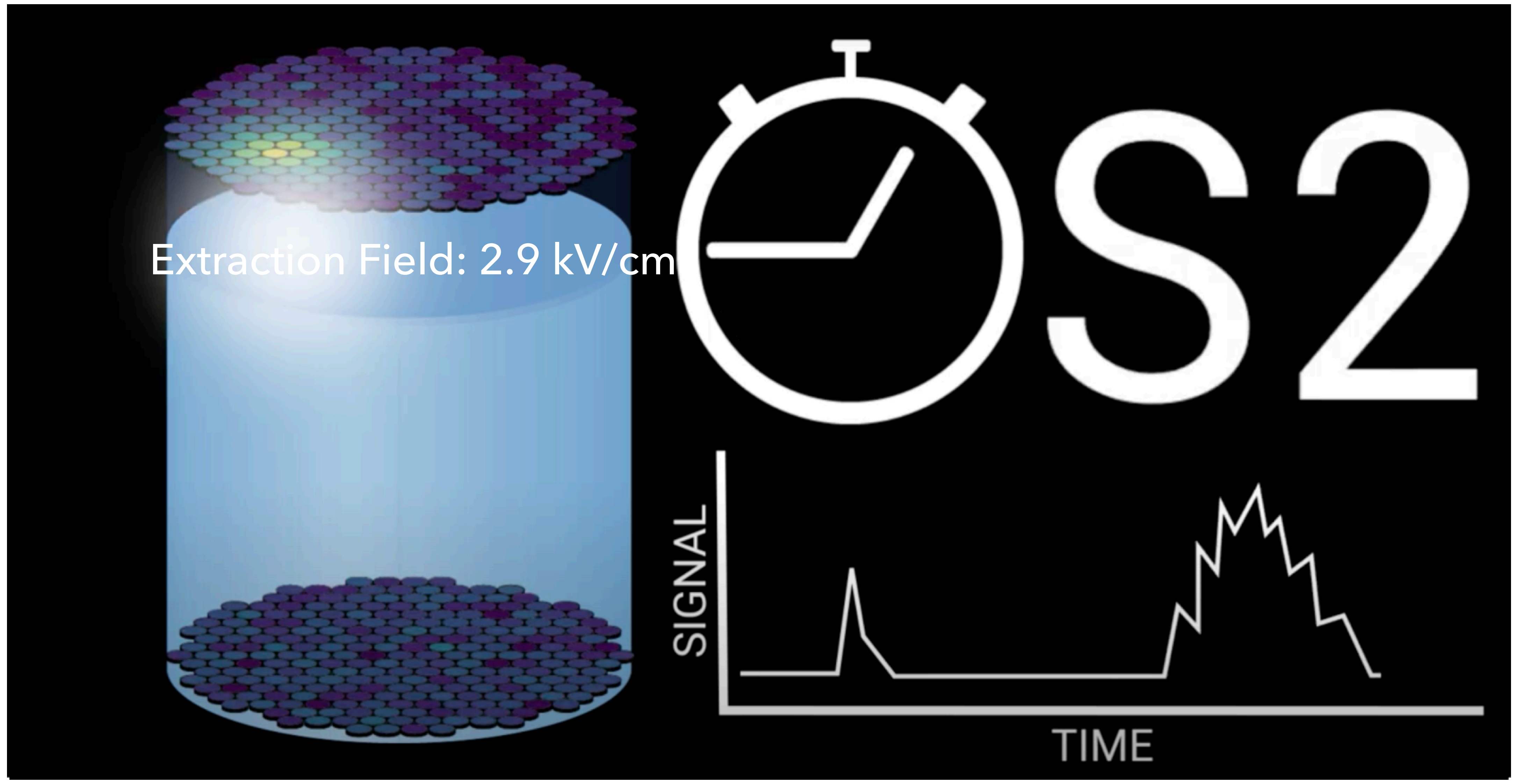

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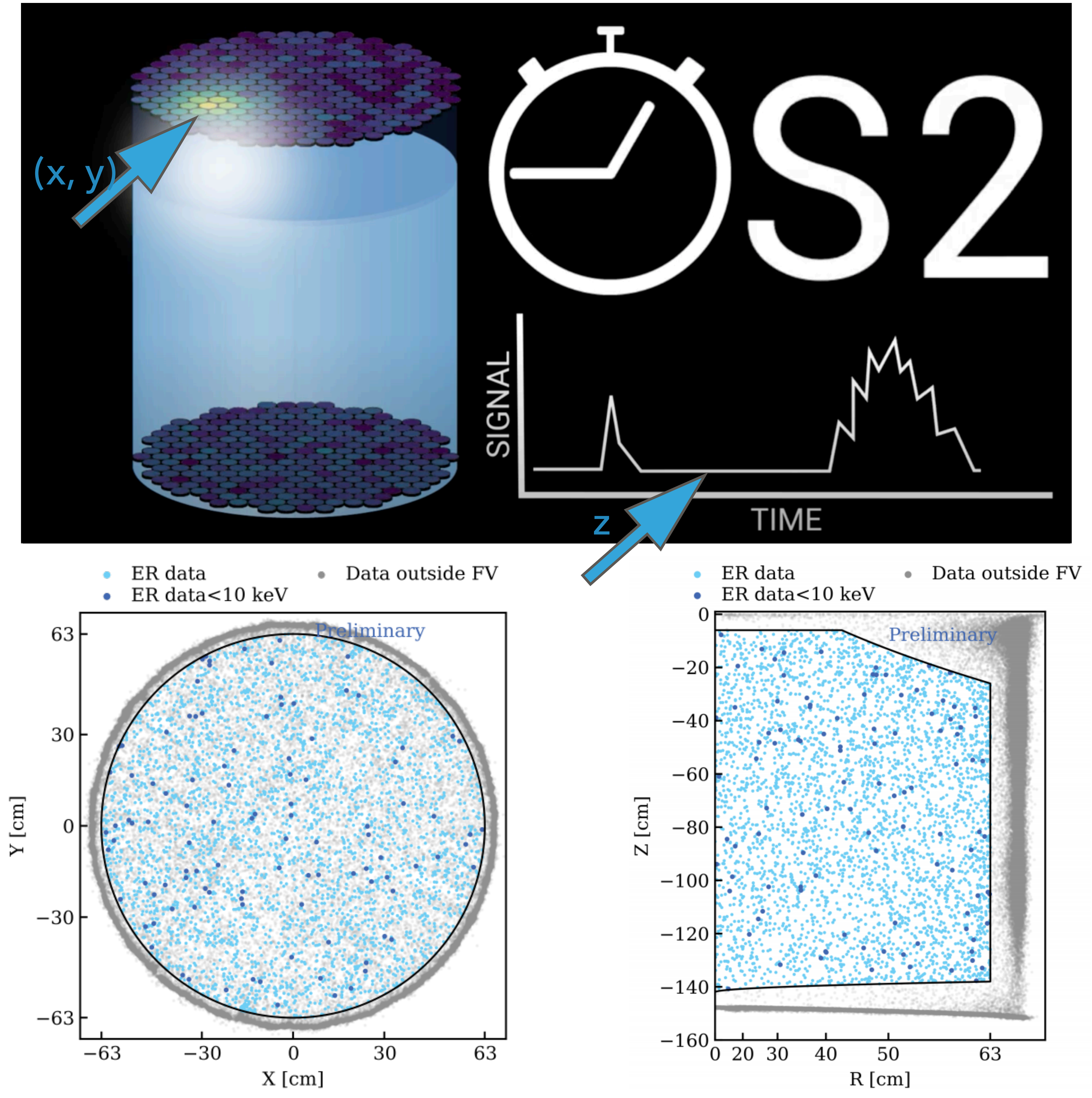
- **3D position reconstruction→Fiducial Volume**




XENONnT SR0 ER background events

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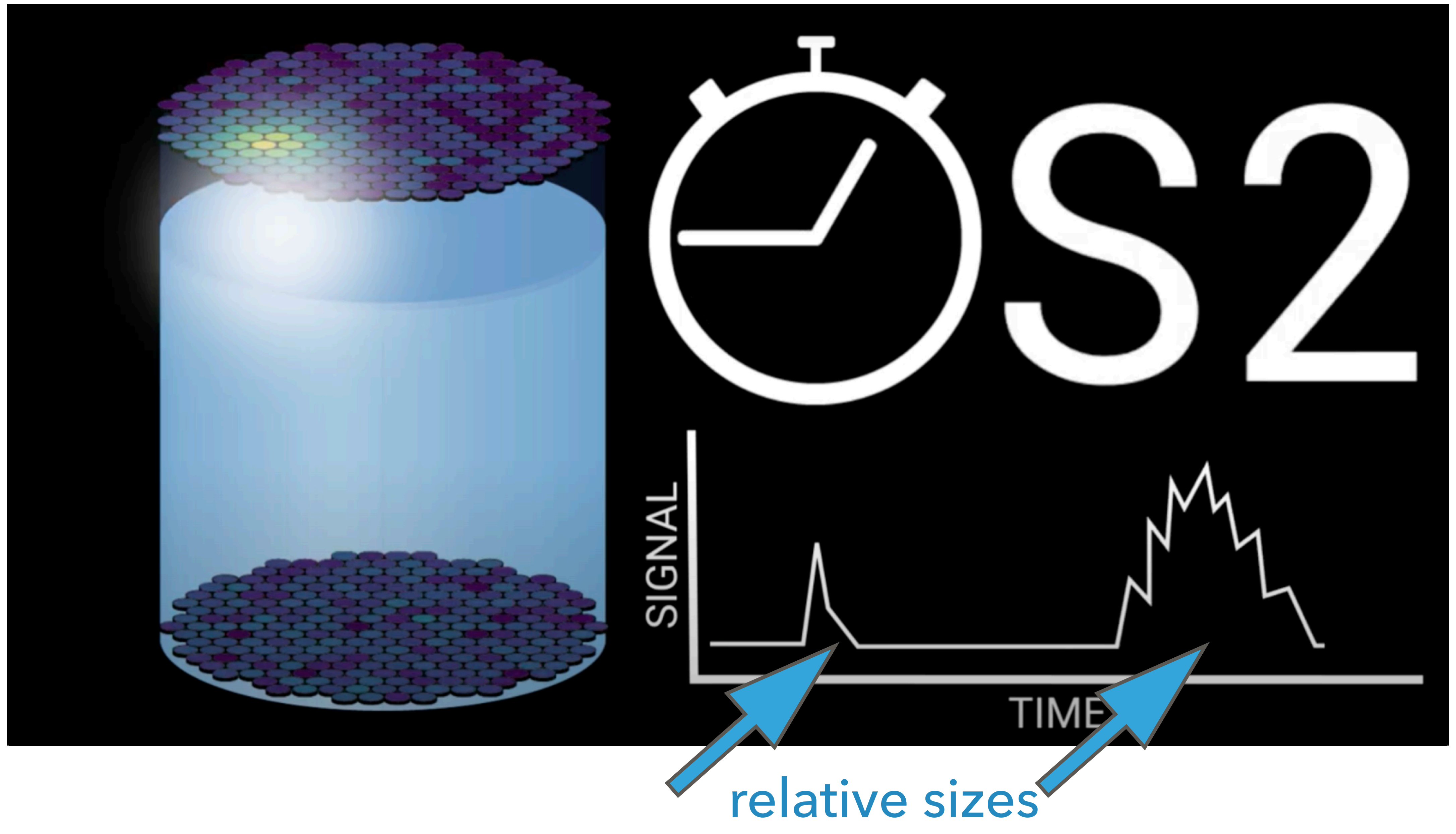
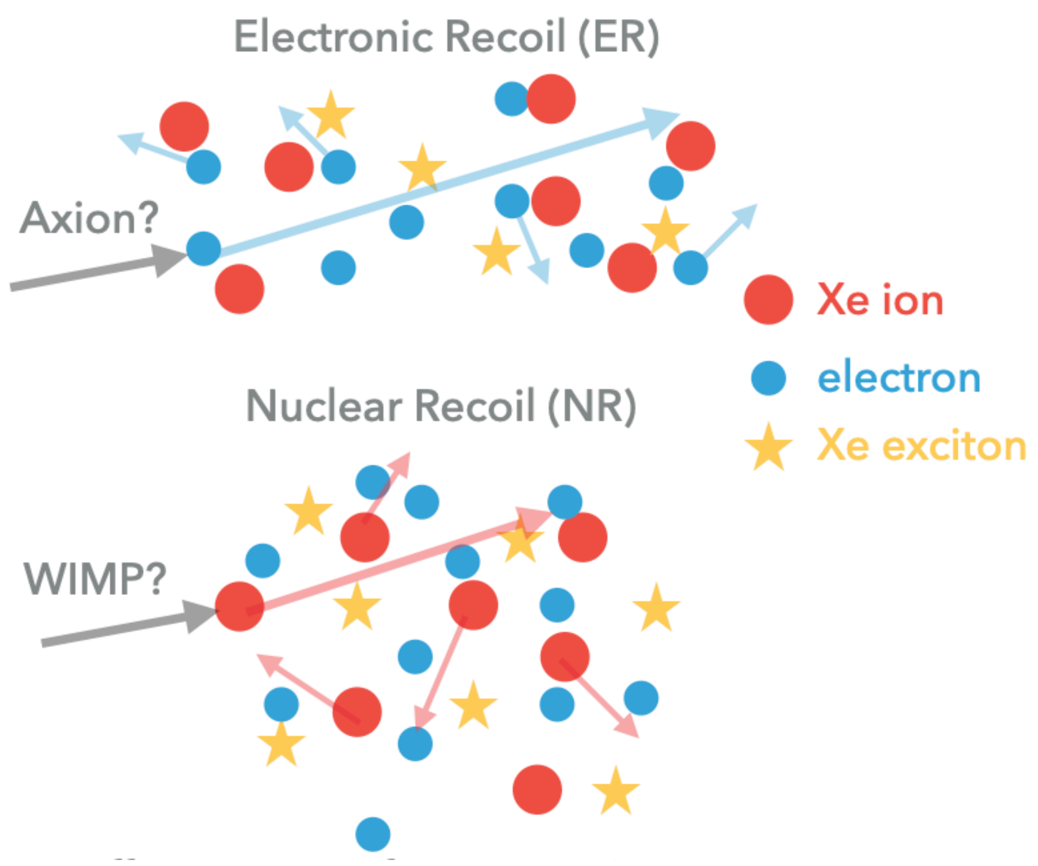
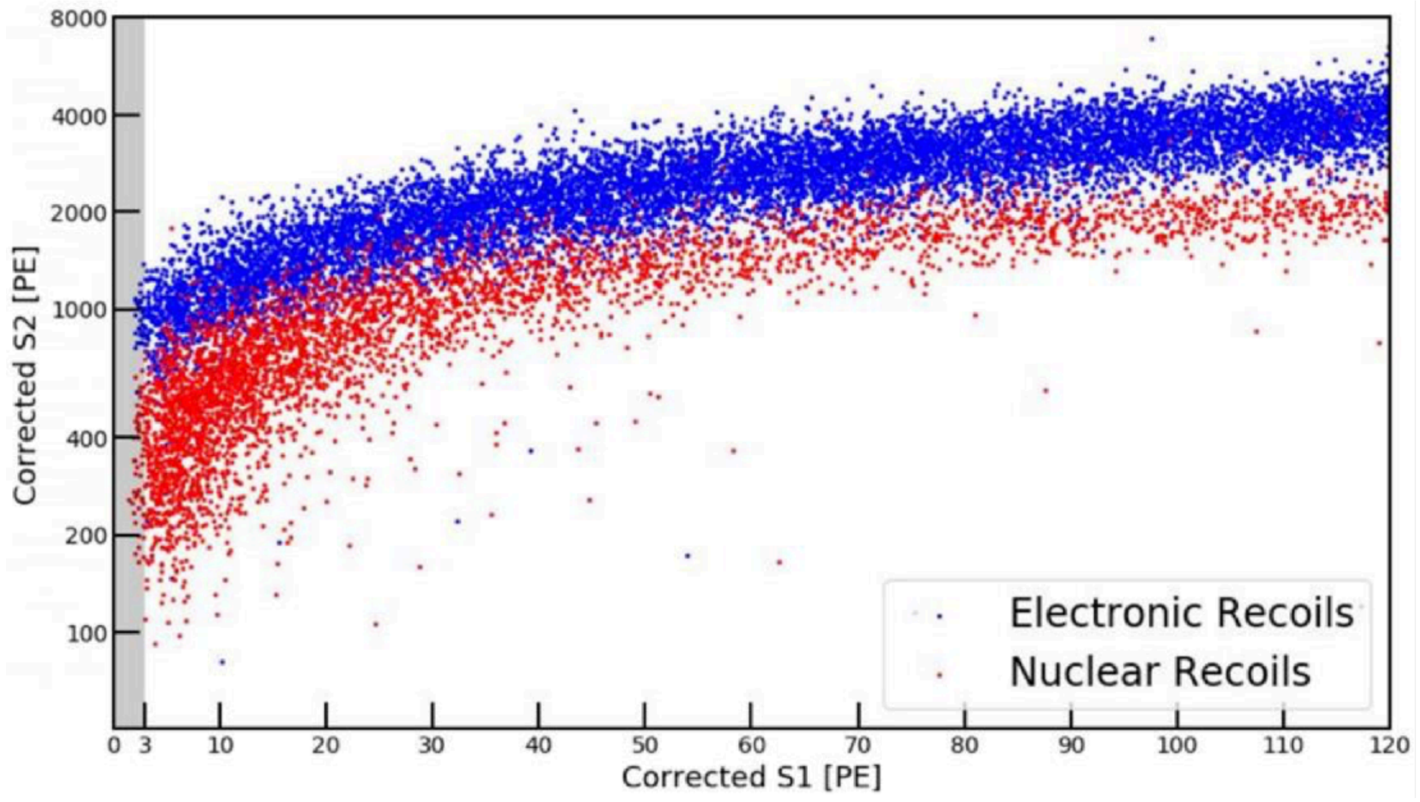
- 3D position reconstruction→Fiducial Volume
- **ER/NR discrimination**




Example NR/ER band a previous generation XENON detector

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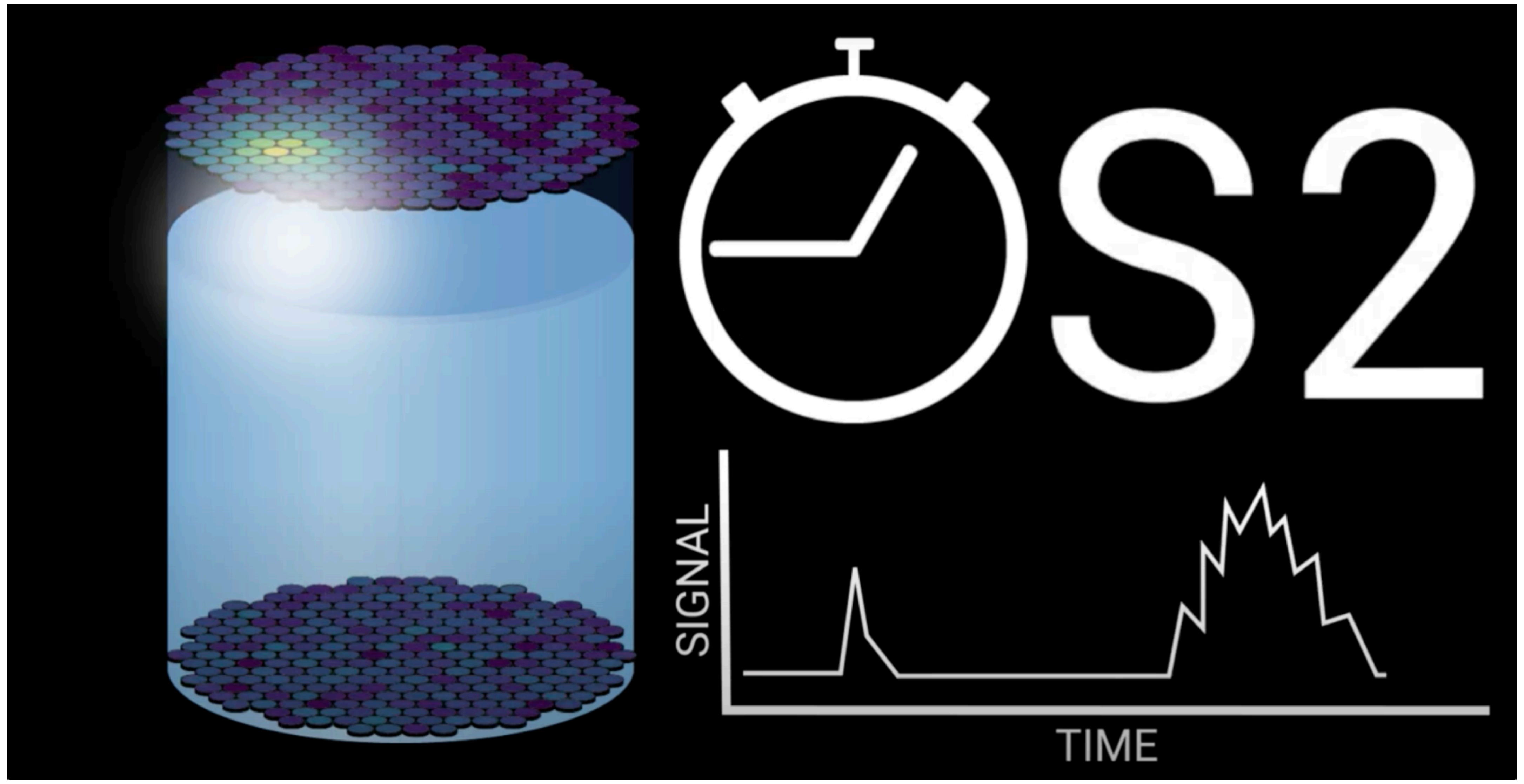
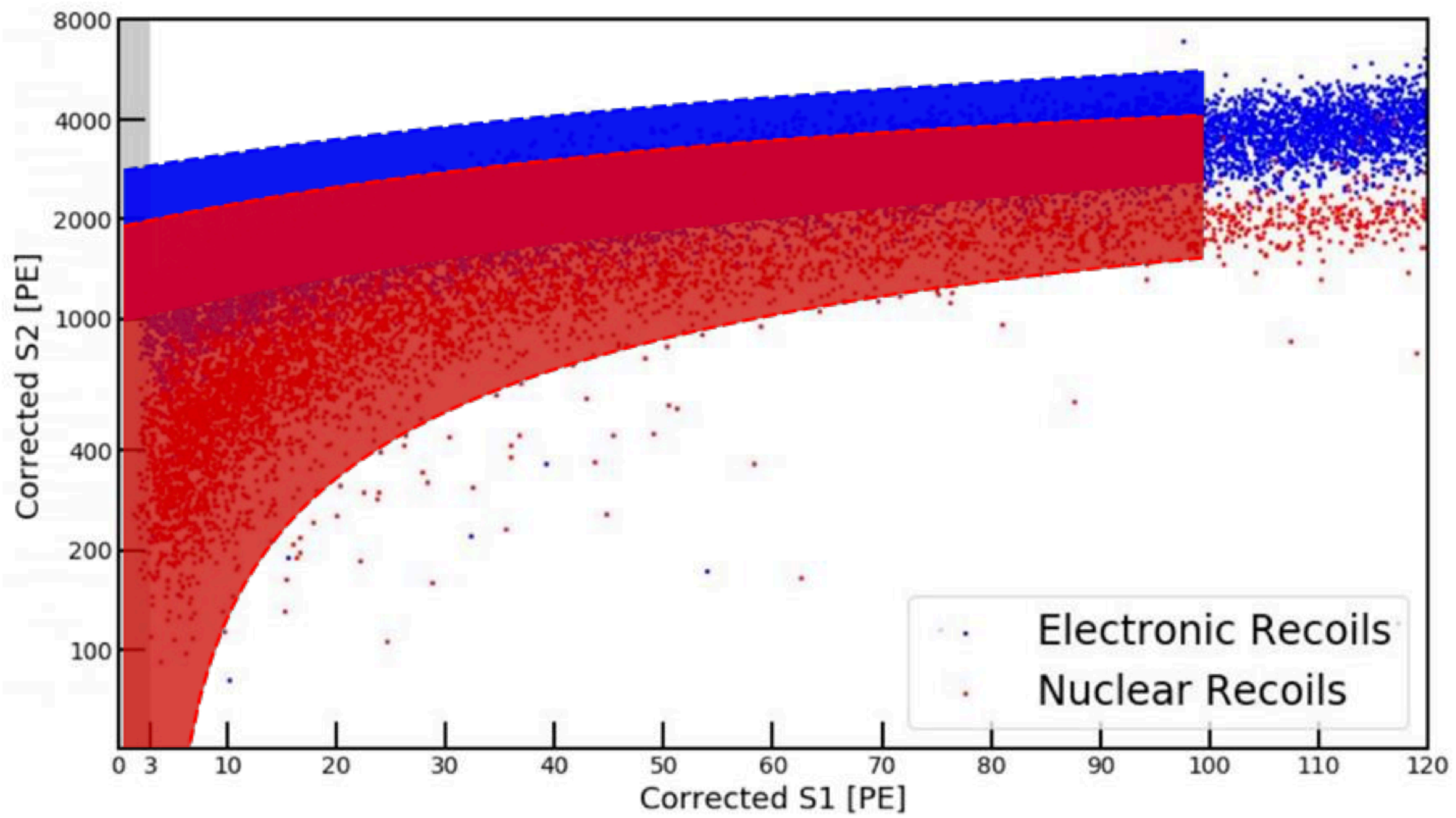
- 3D position reconstruction→Fiducial Volume
- ER/NR discrimination
- **Blind analysis inside FV for <10keV!**

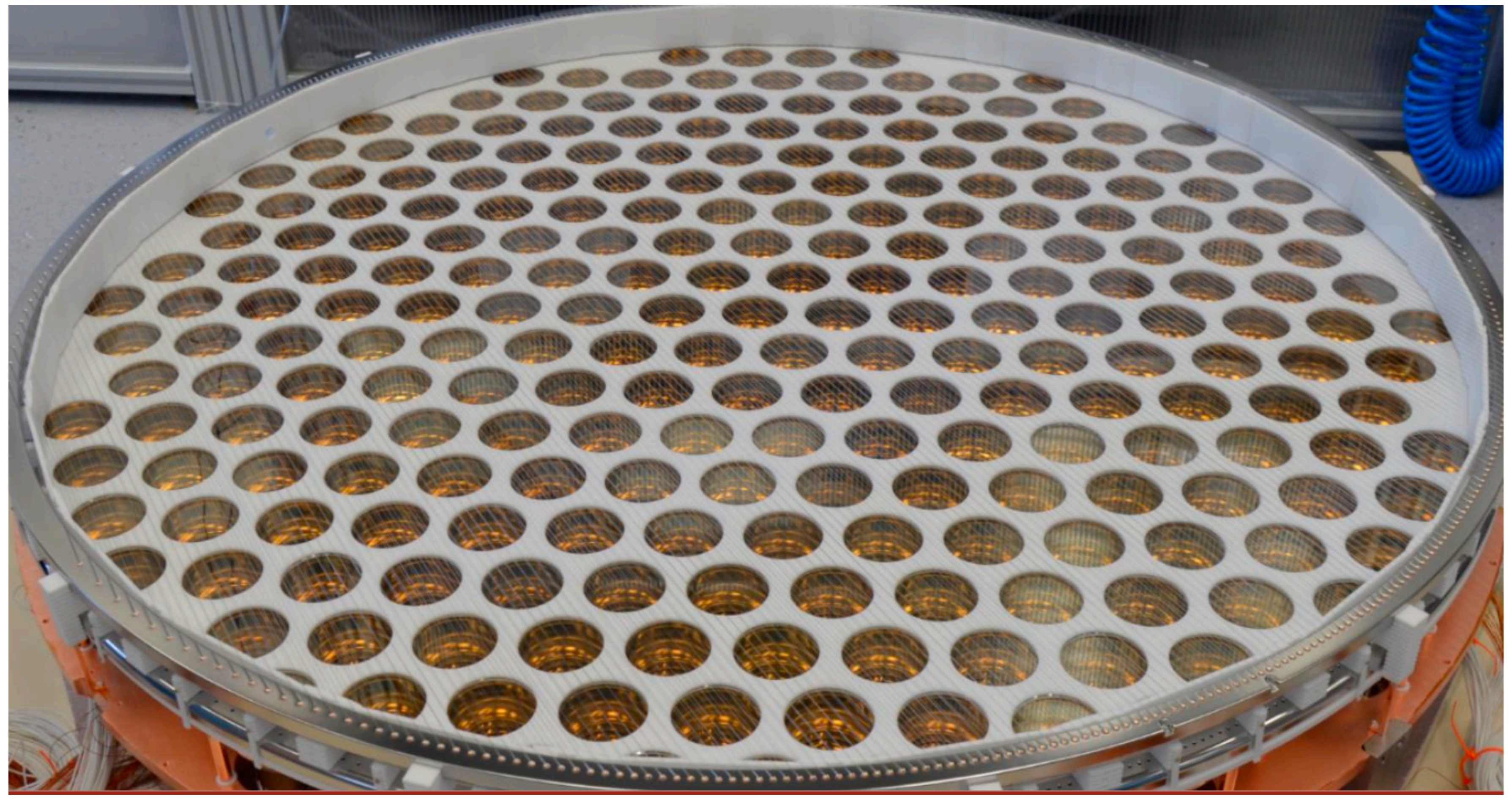



Example NR/ER band a previous generation XENON detector

# XENONnT VS XENON1T

- **X3 Larger target mass (x4 fiducial mass) → lower material background & more exposure**



248→494 3″ Hamamatsu PMTs

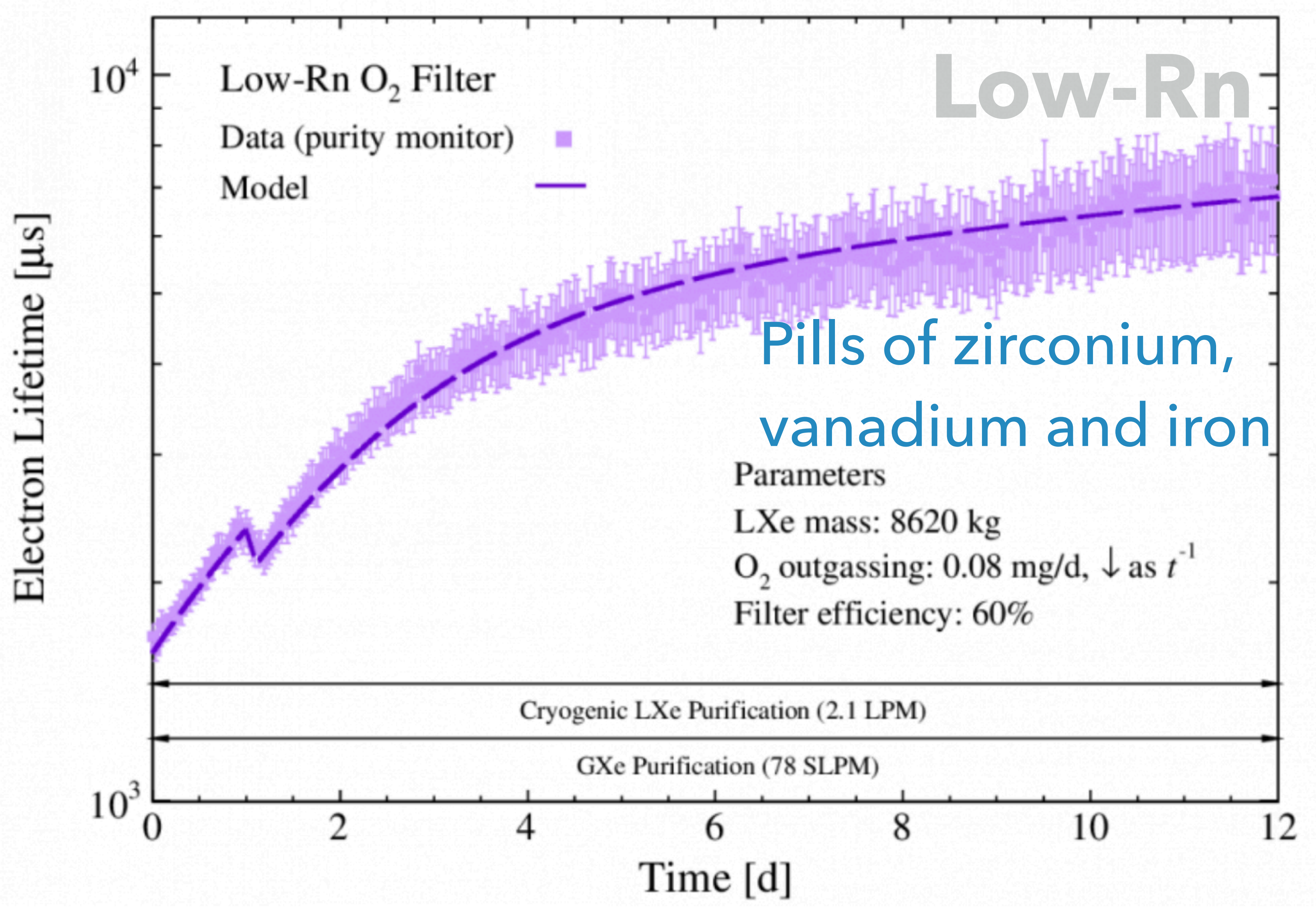

XENON1T

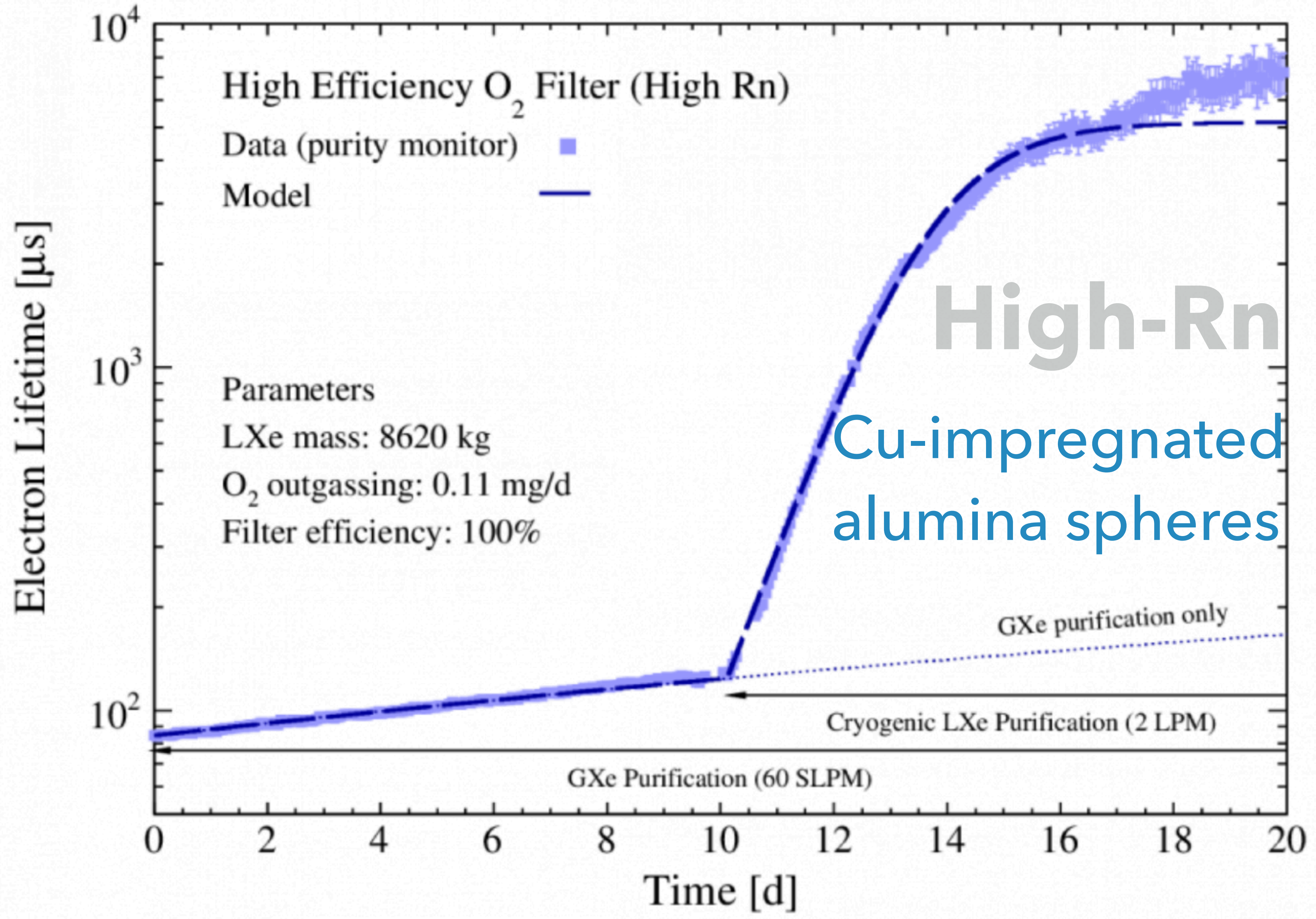
XENONnT

# XENONnT VS XENON1T

- X3 Larger target mass (x4 fiducial mass) → lower material background & more exposure
- **Added LXe purification: e-lifetime 0.65ms → >10ms**
  - Removing electronegative impurities ($H_2O$ and $O_2$)
  - LXePUR: Up to 16 ton/day
    - Low-Rn filter: 60% removal efficiency
    - High-Rn filter: 100% removal efficiency
  - Gas/Liquid purification running simultaneously

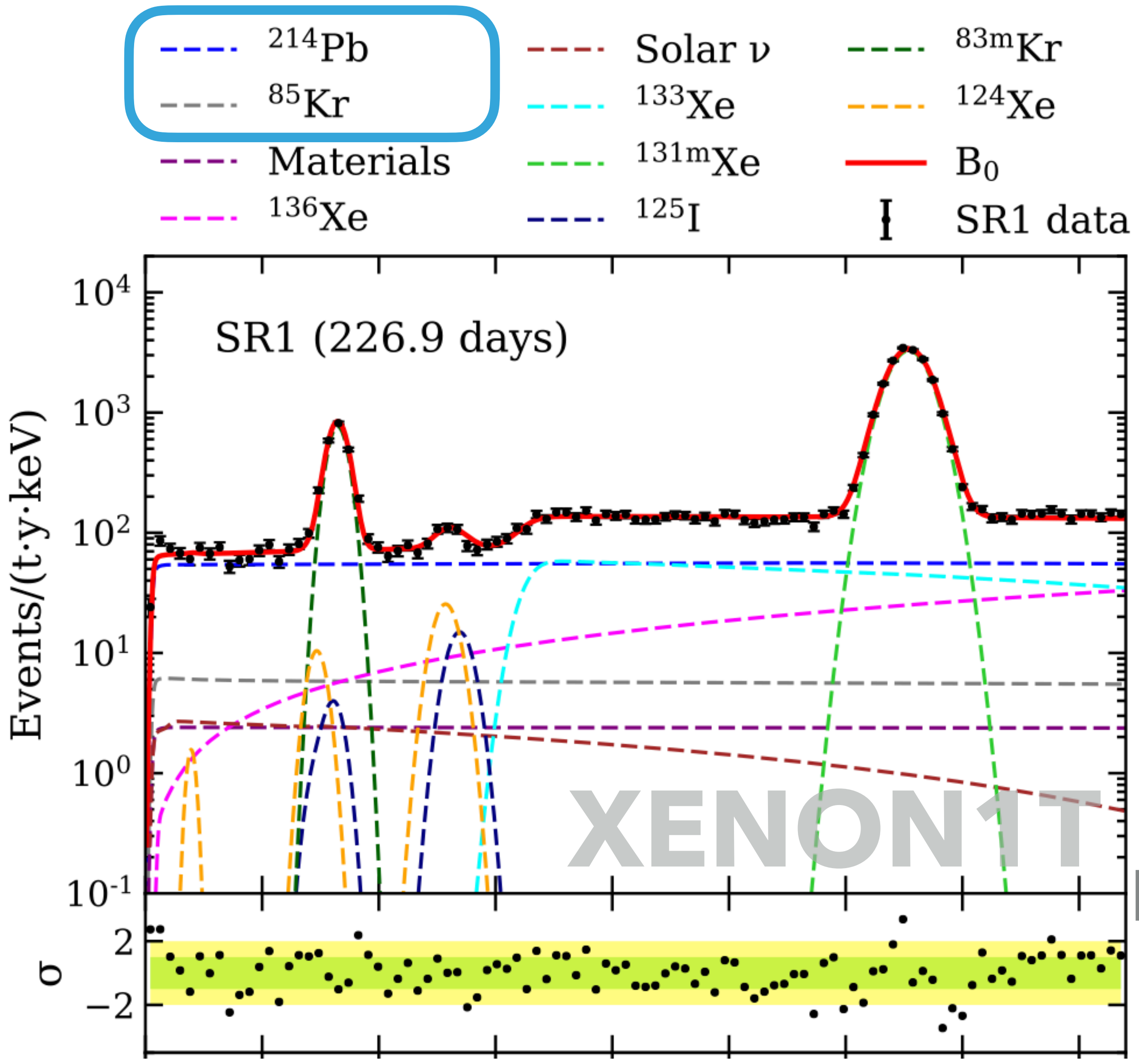
| | Full drift time: | Electron lifetime: | Electron survival (@full drift length): |
|---|---|---|---|
| 1T | 0.67 ms | 0.65 ms | 30 % |
| nT | 2.2 ms | **~15 ms** | **86 % @ 15 ms** |



# XENONnT VS XENON1T

- X3 Larger target mass (x4 fiducial mass) → lower material background & more exposure
- Added LXe purification: e-lifetime 0.65ms → >10ms
- **Radon Distillation: $^{222}$Rn suppressed to ~0.8 mBq/t**

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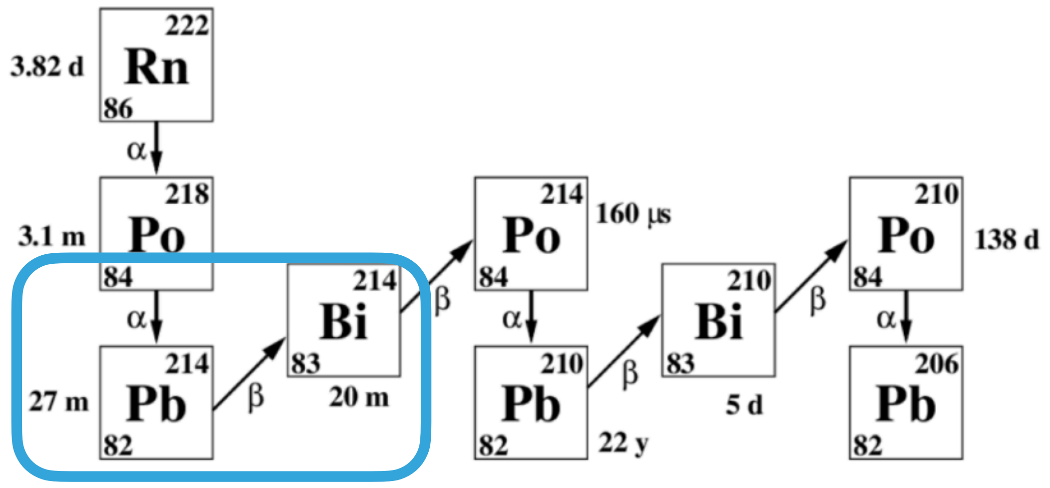
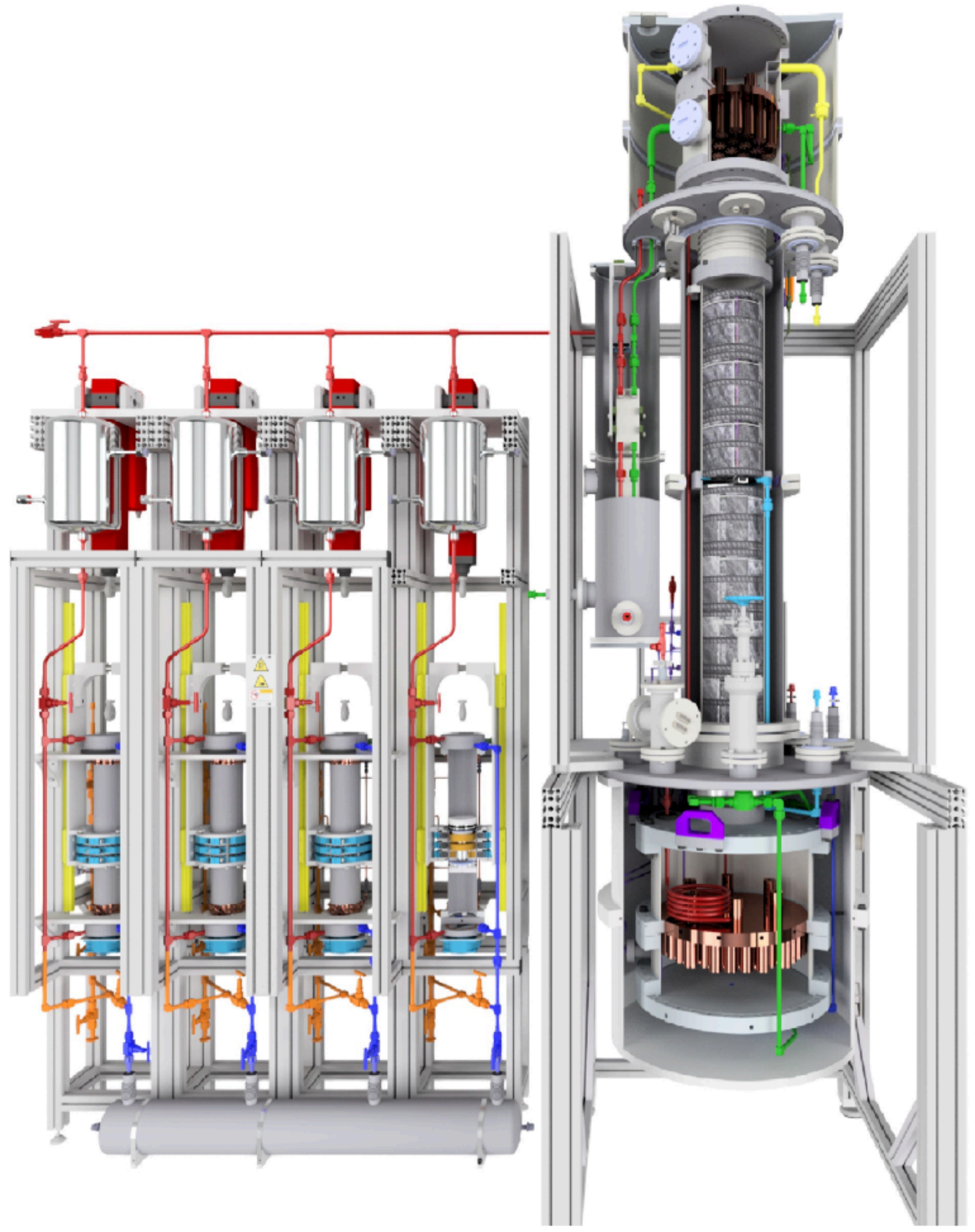
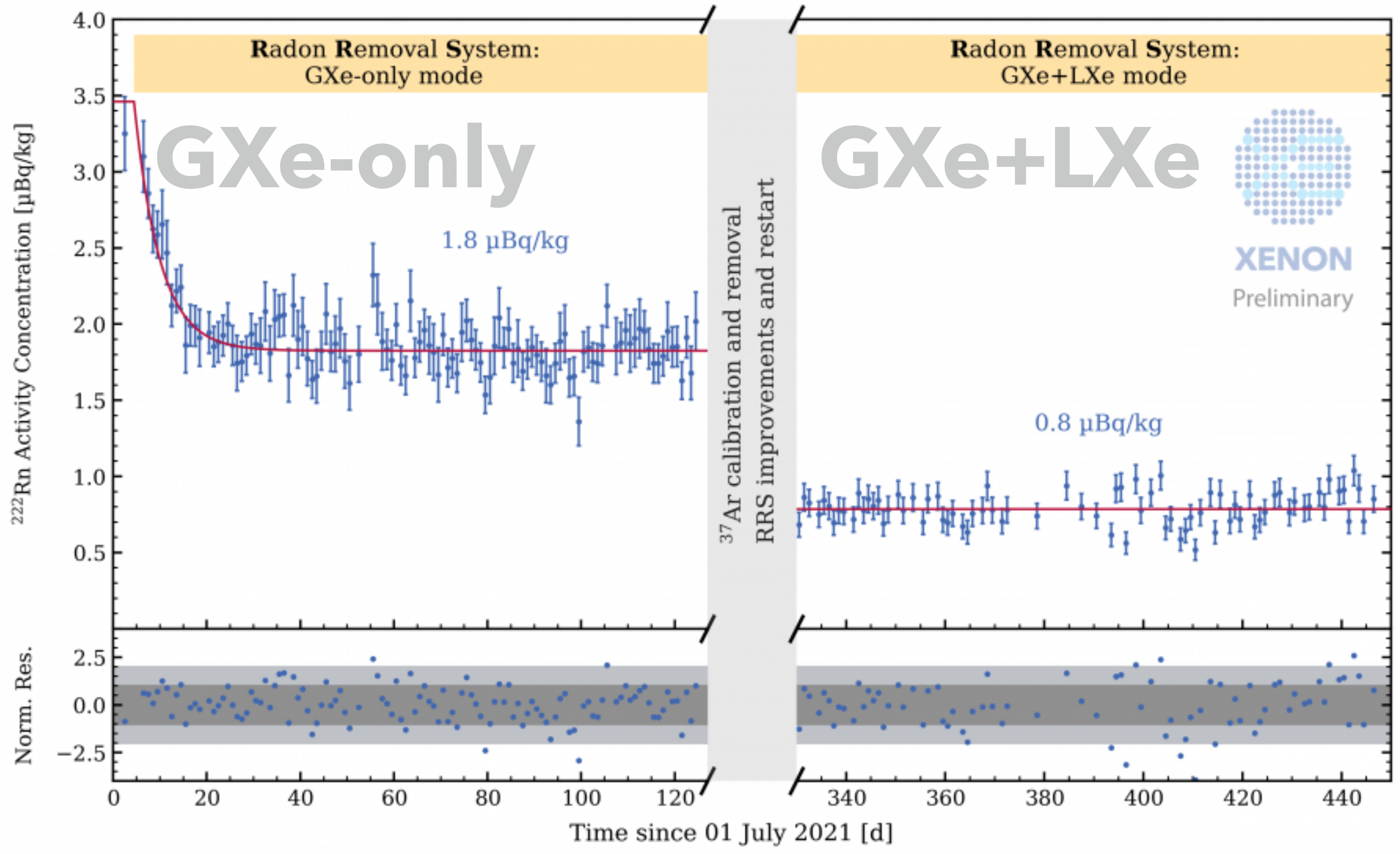



$^{214}$Pb has been the major background for ER in XENON1T

- $^{222}$Rn mostly from pipes, cables & cryogenic system
- Continuous distillation at ~91kg/h
- GXe+LXe extraction mode
- Initial $^{222}$Rn concentration: 4.3mBq/ton → 0.8mBq/ton



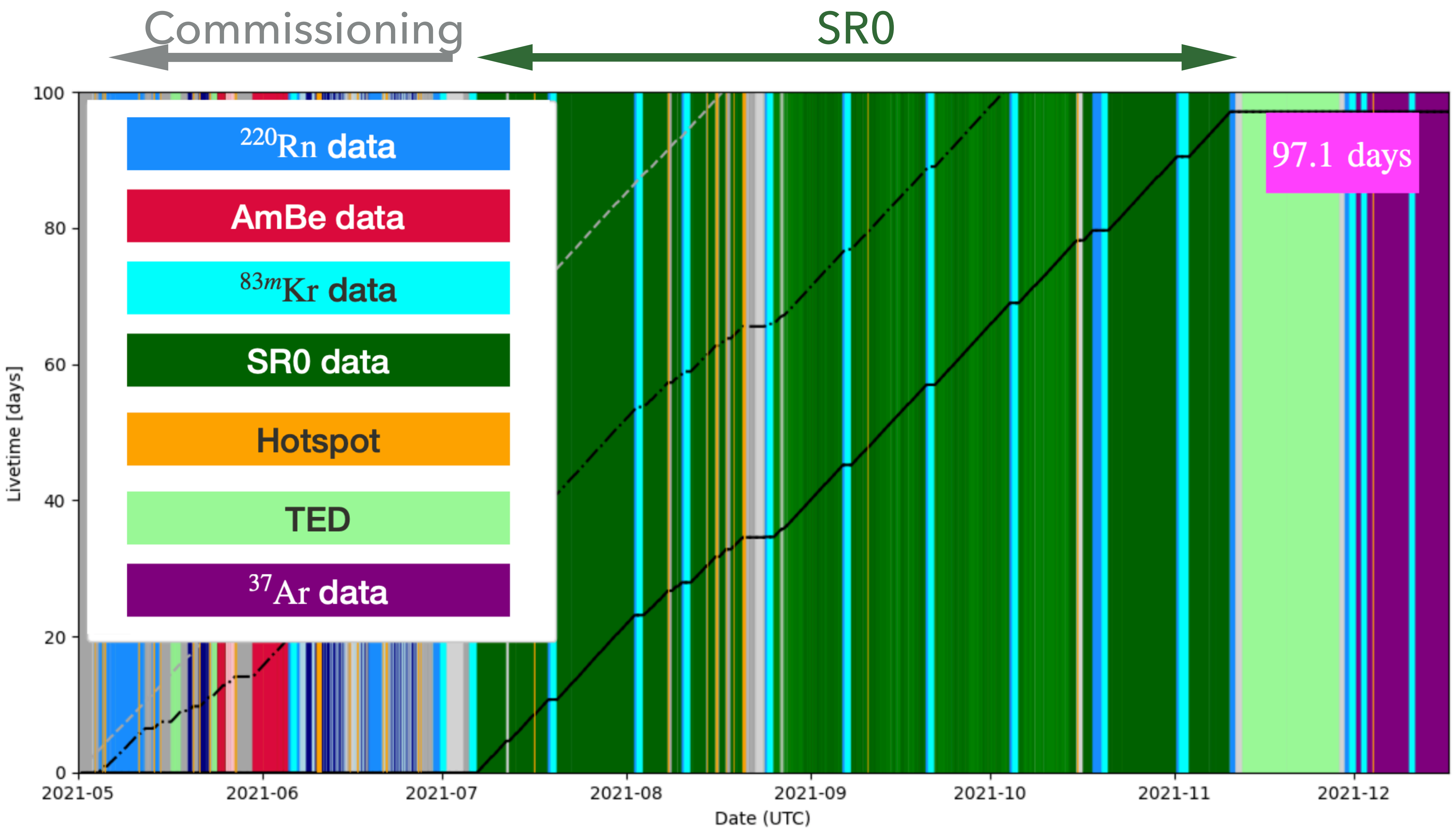


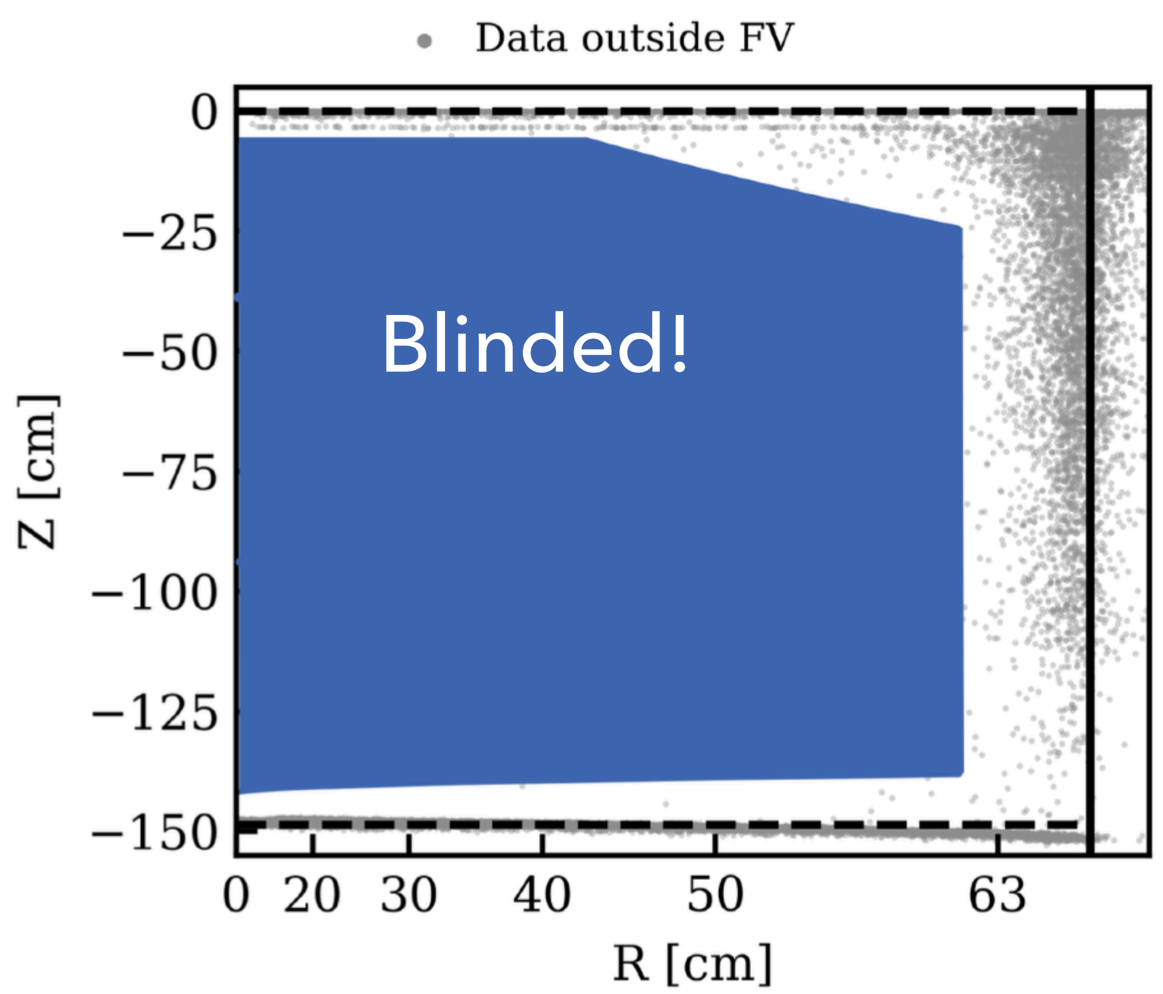
# ROADMAP

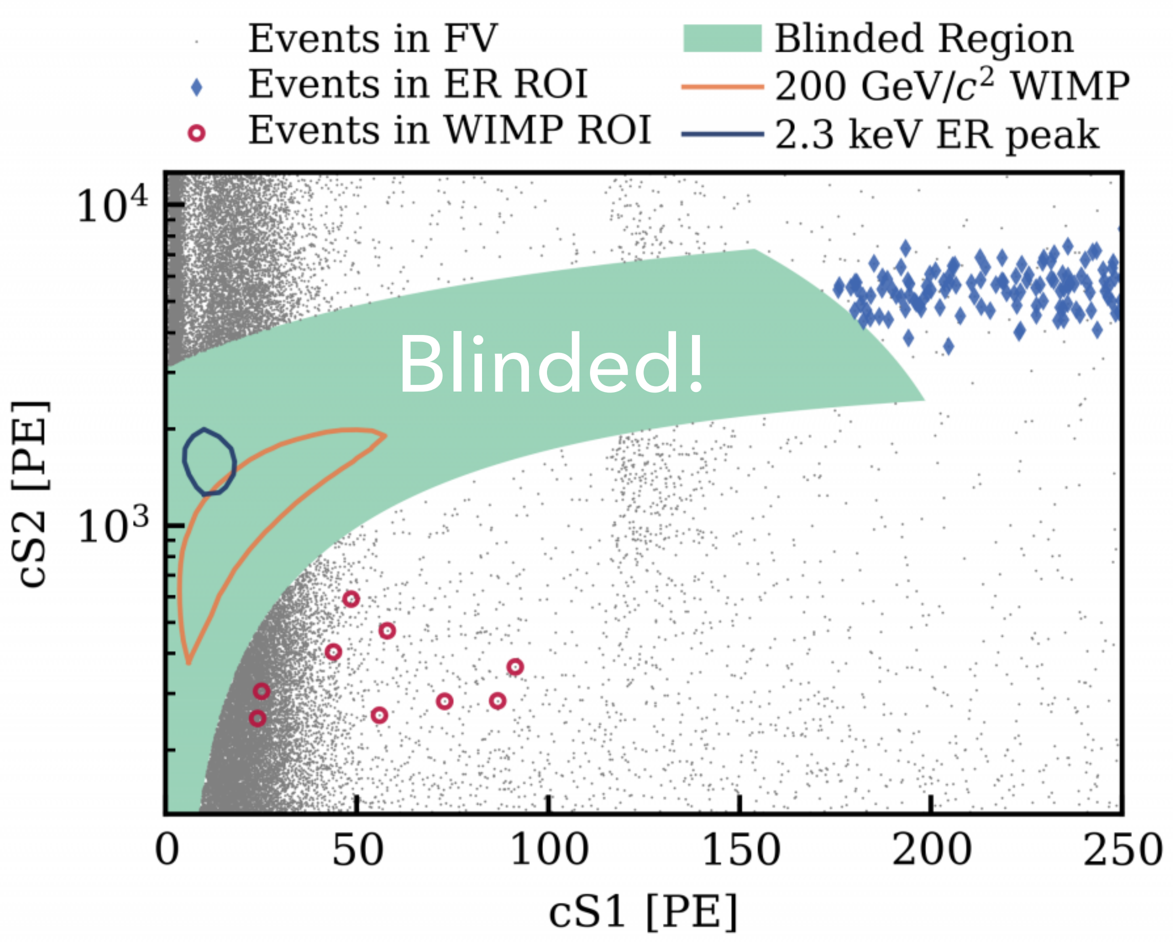
- Dark Matter Direct Detection
- The XENONnT Detector
- **Detector Calibration** ~How a signal/background event should look like?
- First Low Energy Electronic Recoil Search Result
- First Nuclear Recoil Search Result
- Search in Other Channels

# FIRST SCIENCE RUN: SR0

- 4.18±0.13/4.37±0.14 ton fiducial volume for NR/ER search & 97.1 days of exposure → ~**1.1 ton·year exposure**



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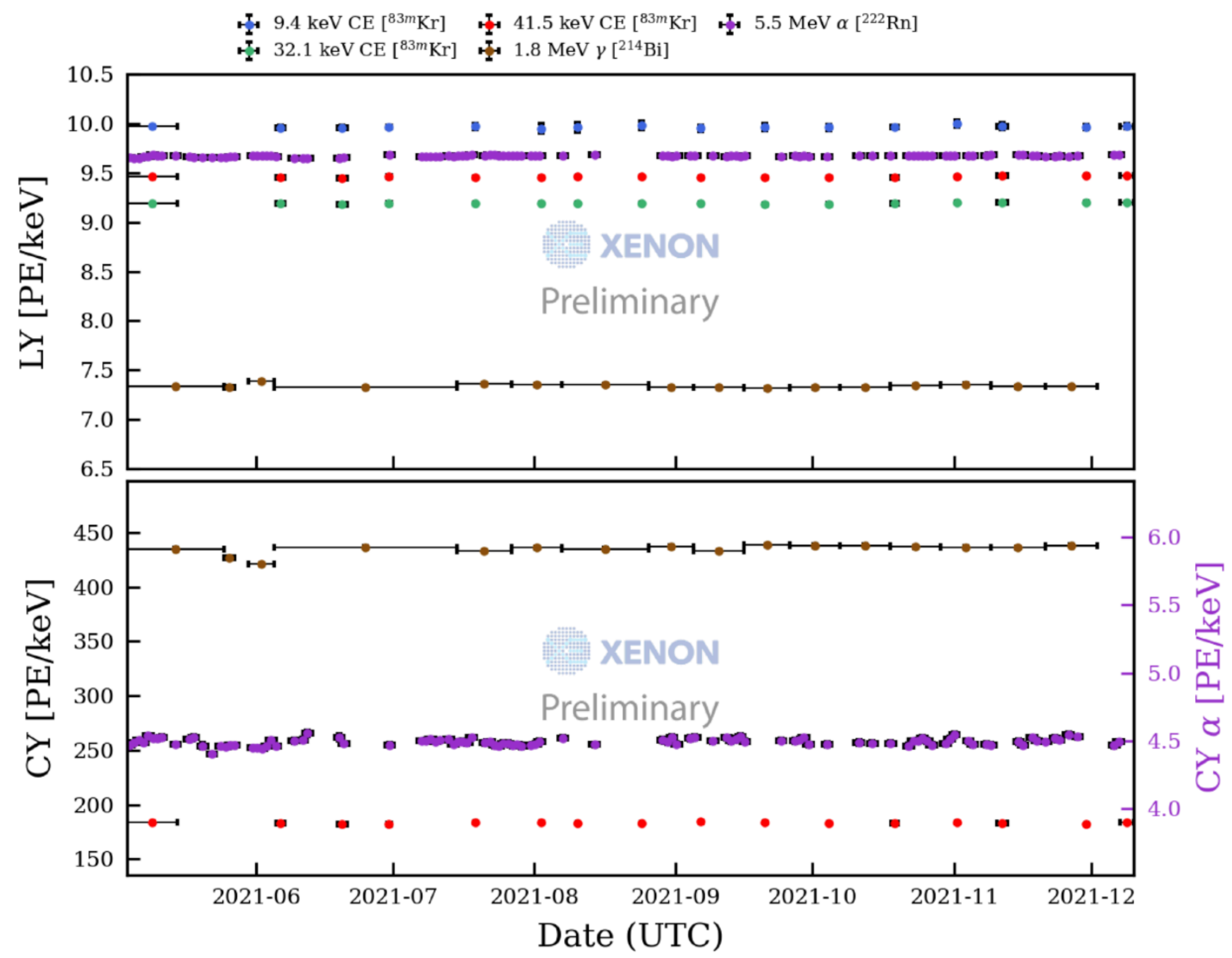
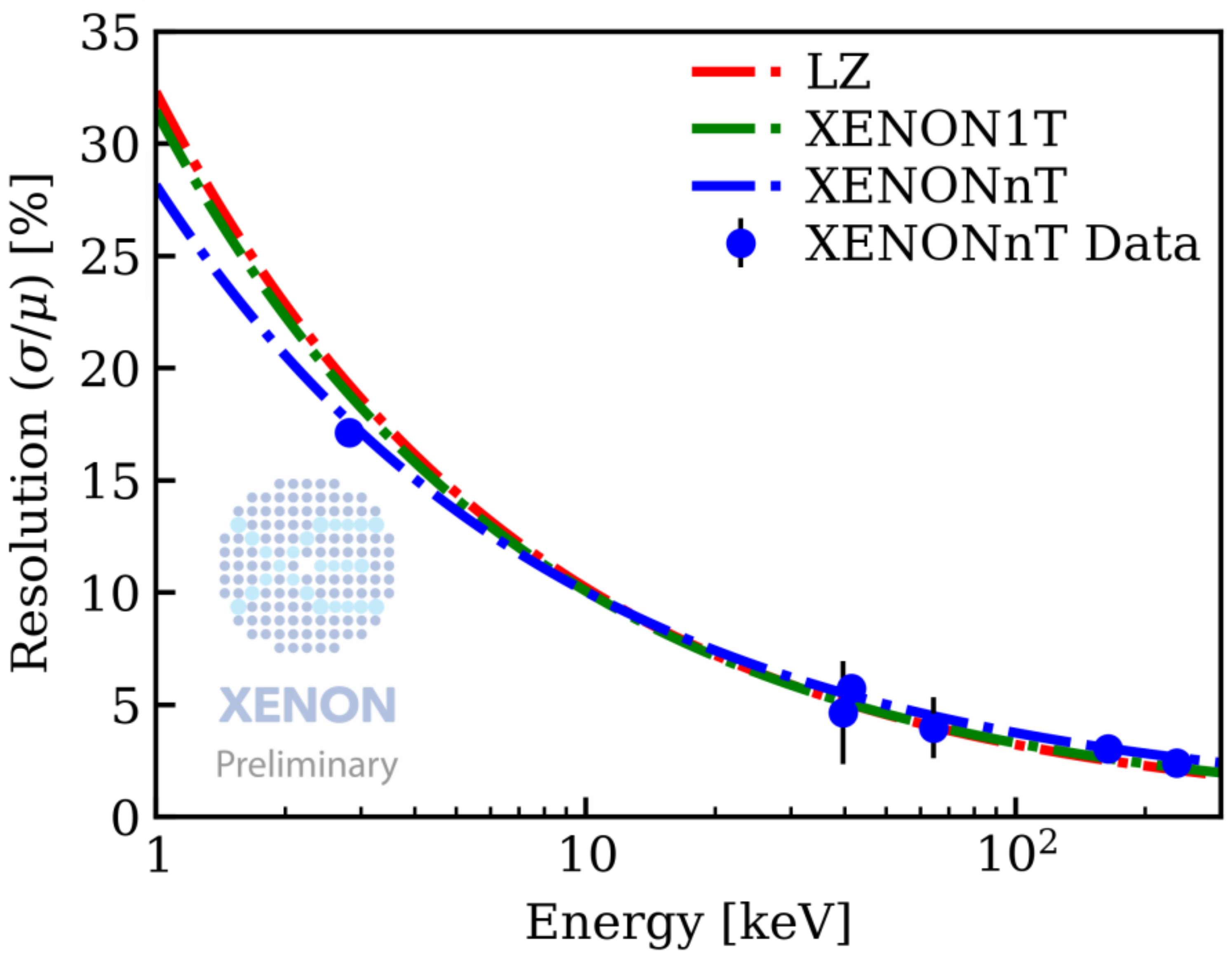
- **Calibrations:**

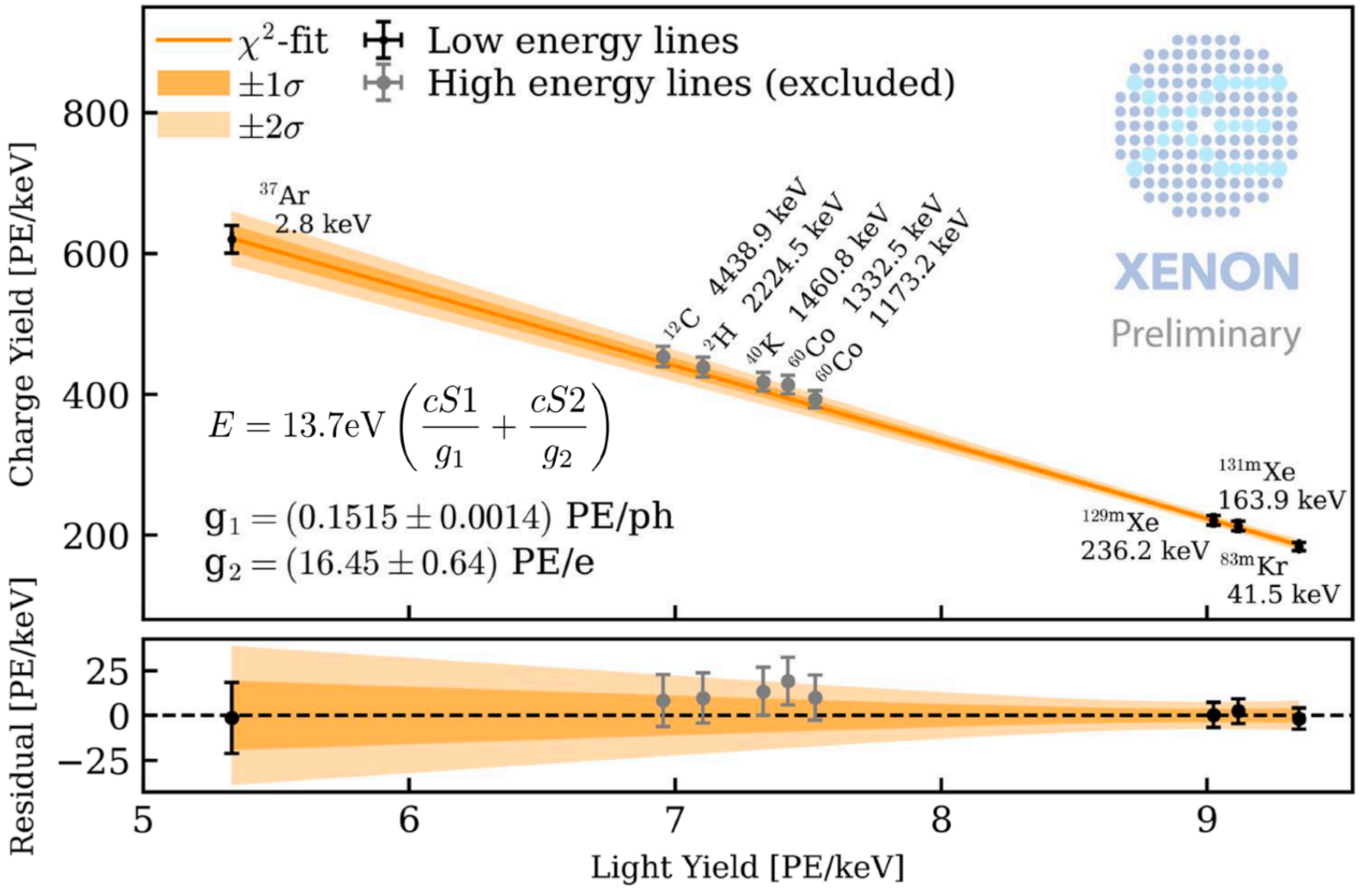
Extremely stable detector response: <~1% LY/CY fluctuation over SR0




$$E = W(n_{ph} + n_e)$$

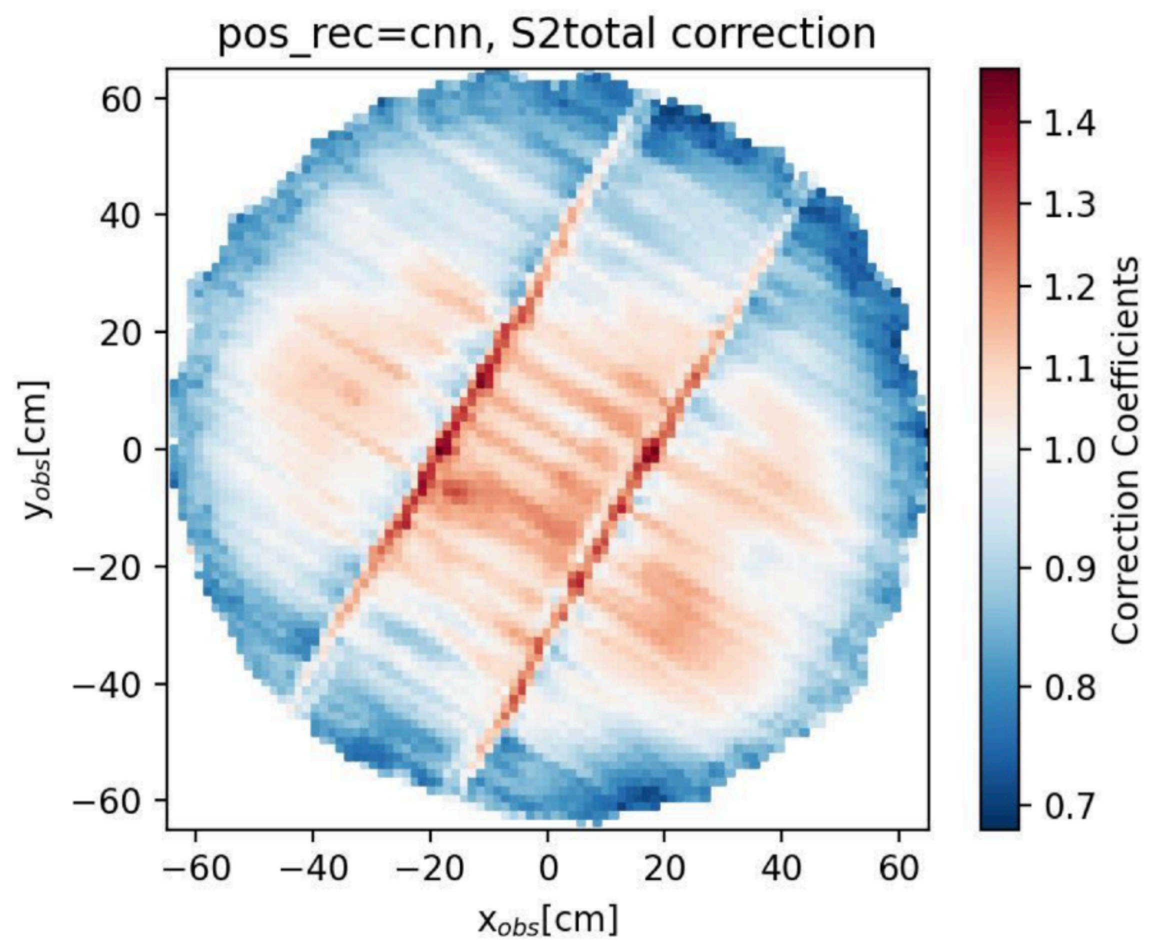
$$E = W\left(\frac{S1}{g_1} + \frac{S2}{g_2}\right)$$



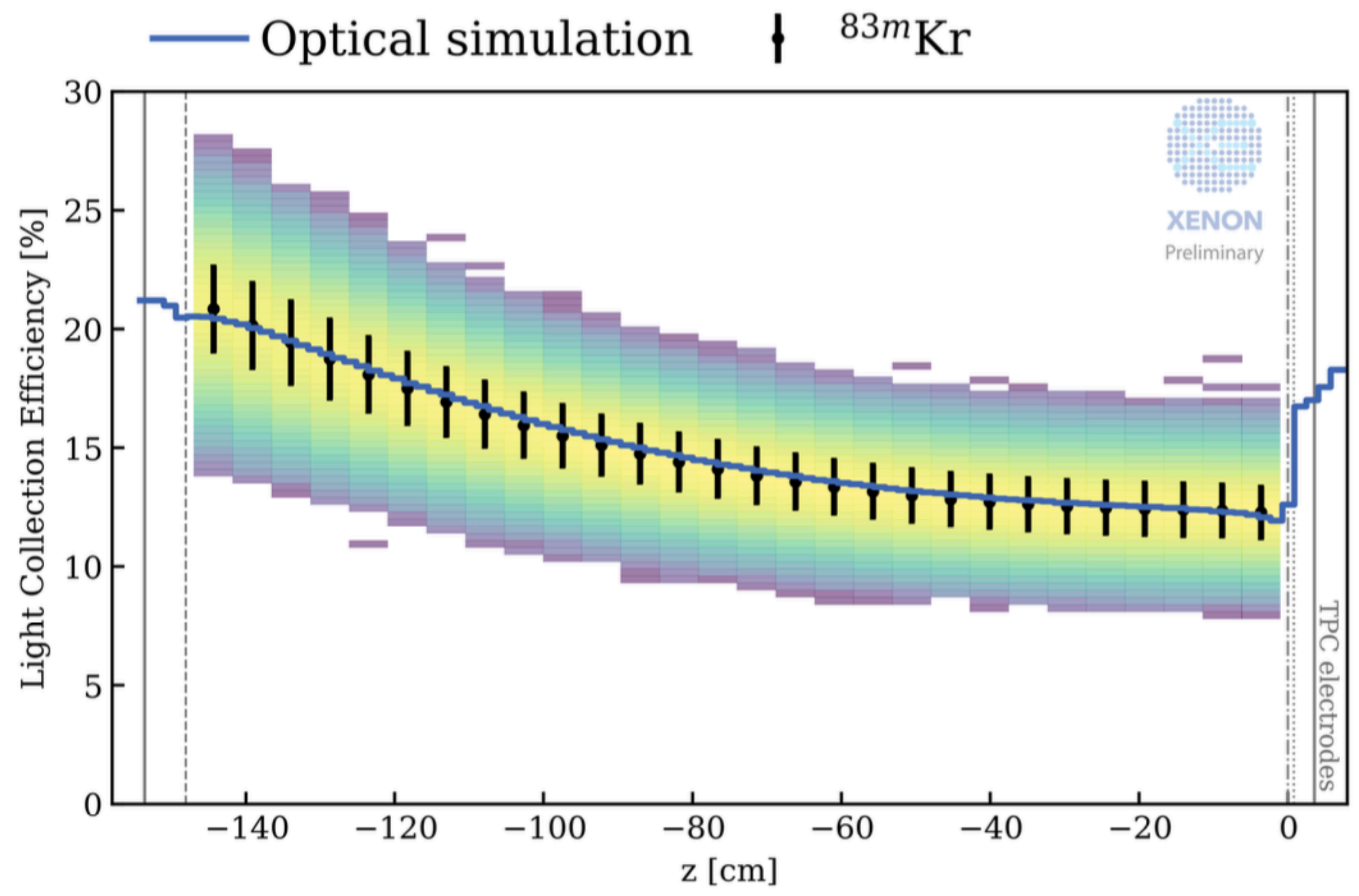
# FIRST SCIENCE RUN: SR0

- 4.18±0.13/4.37±0.14 ton fiducial volume for NR/ER search & 97.1 days of exposure → ~1.1 ton·year exposure
- Calibrations:
  - **$^{83m}$Kr: Uniformly distributed gamma events**

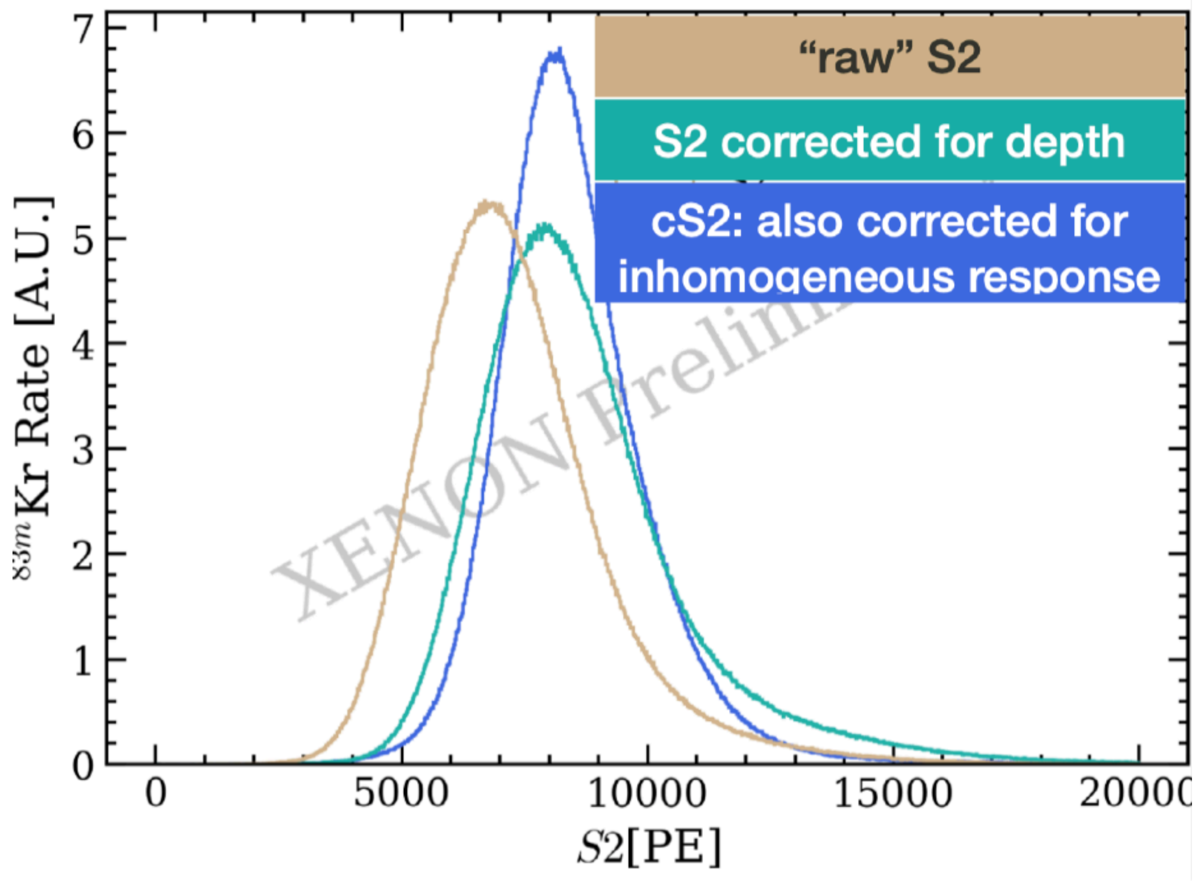
Relative size correction for S2s in x-y plane

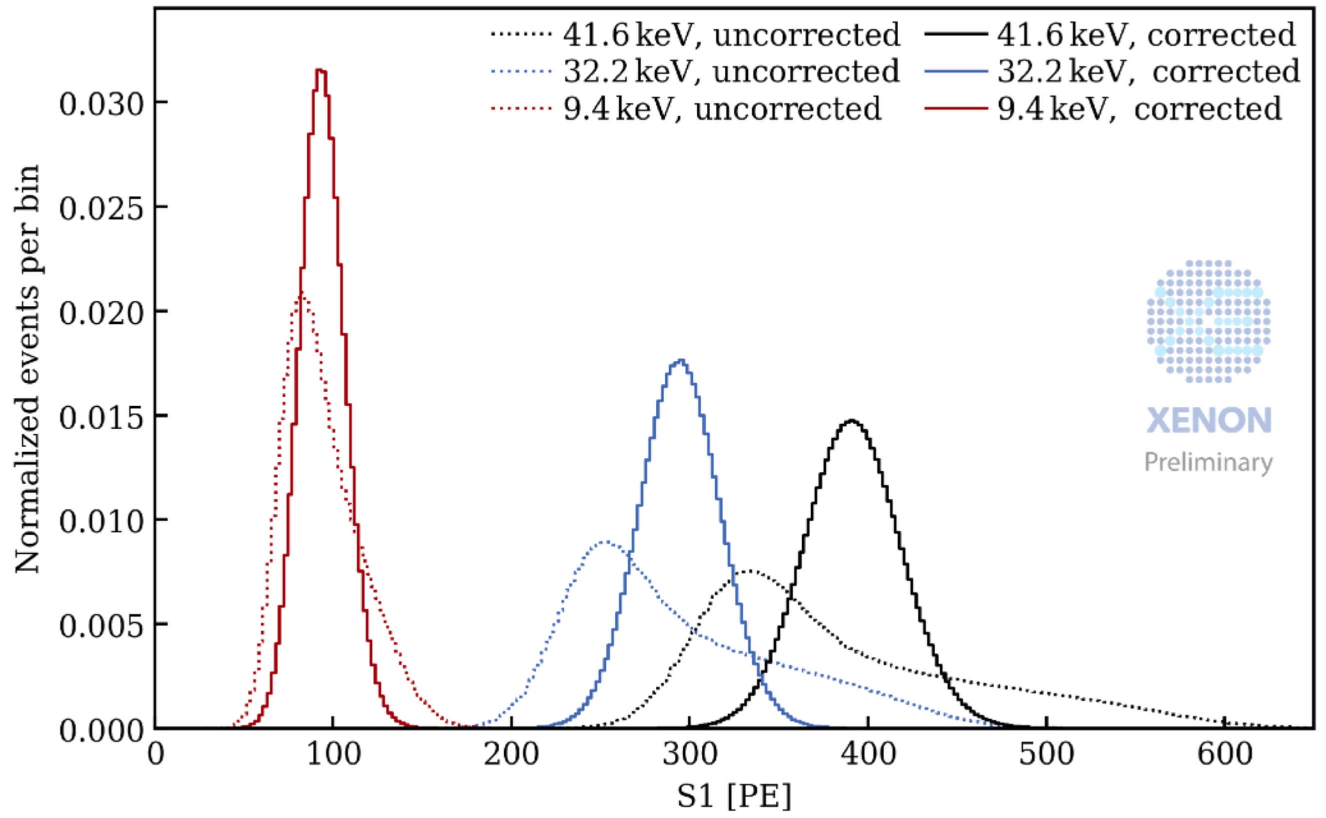



Tuned MC to match photon propagation attenuation along z




Useful for reconstruction uniformity correction and detector response monitoring.



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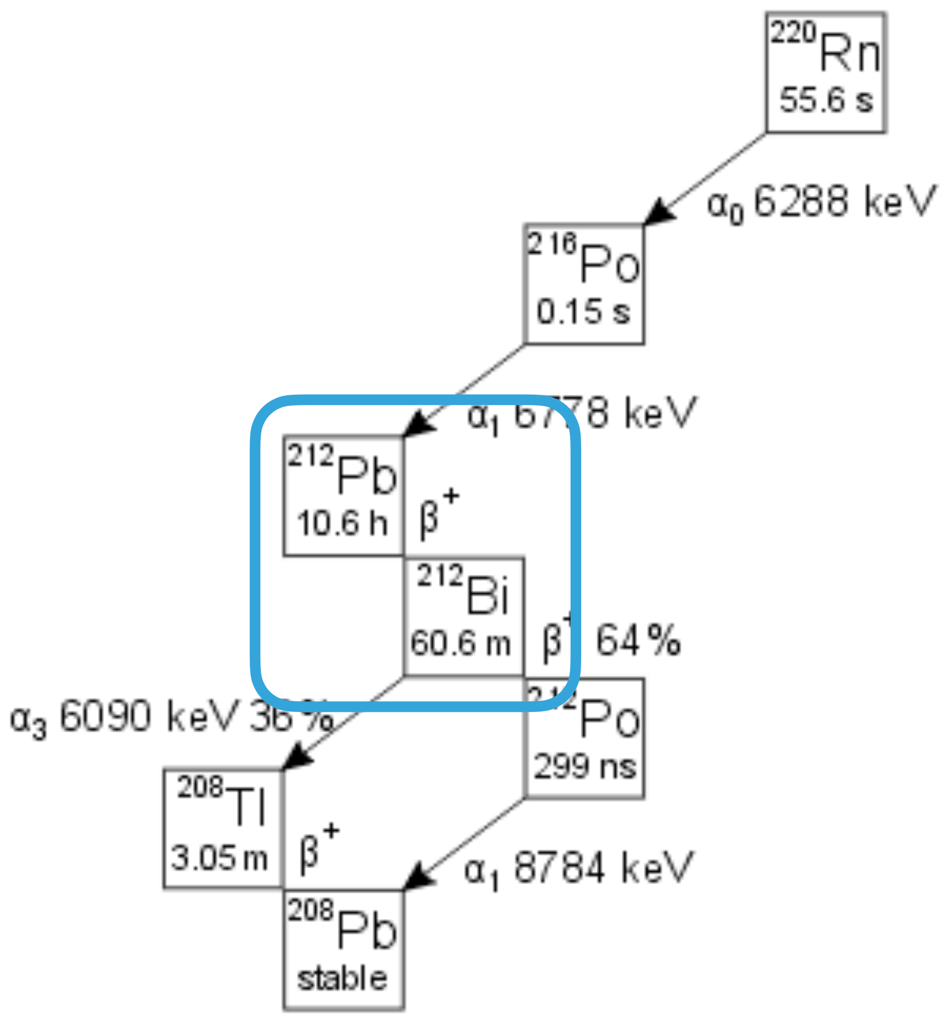
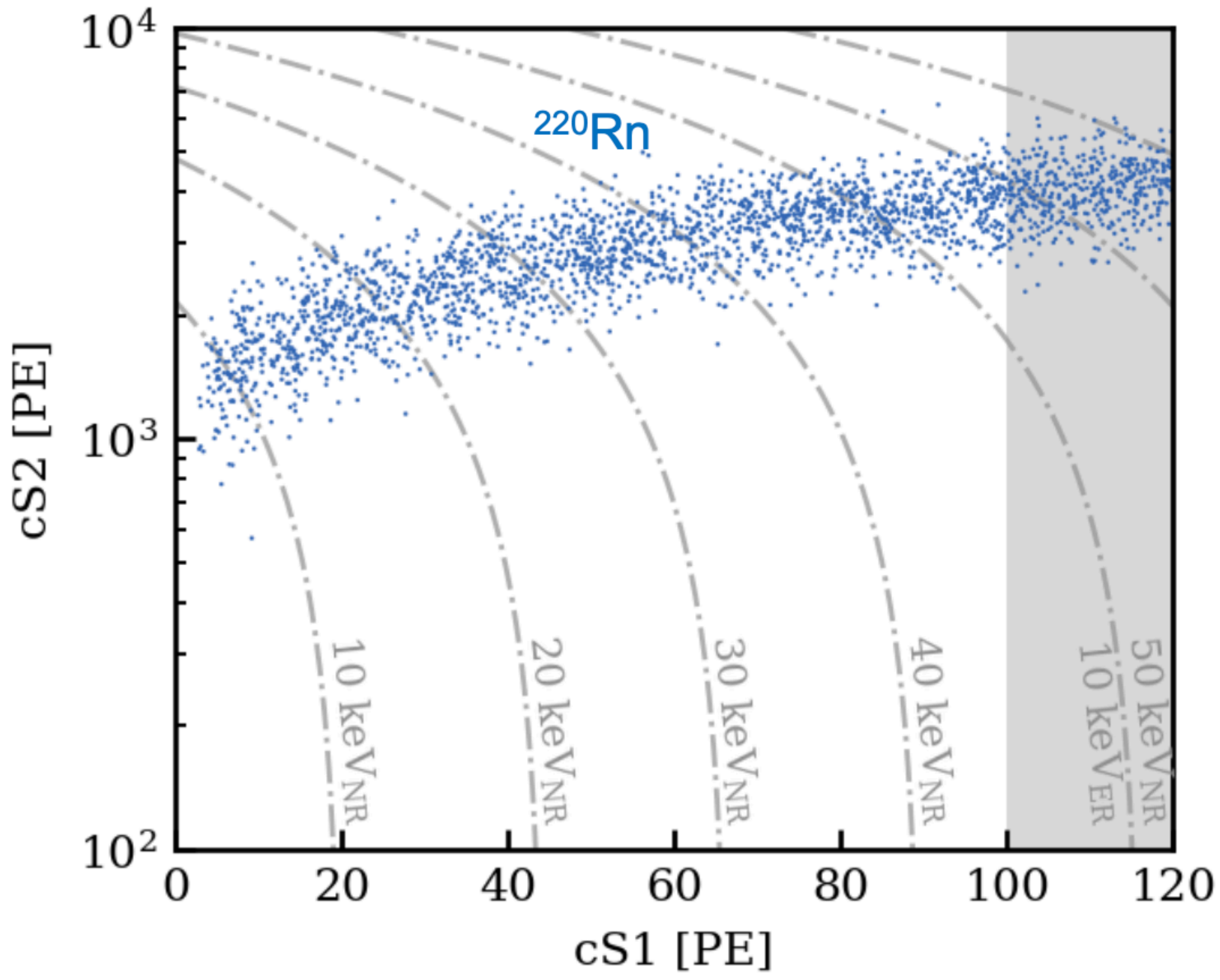
  - **$^{220}$Rn: ER band**



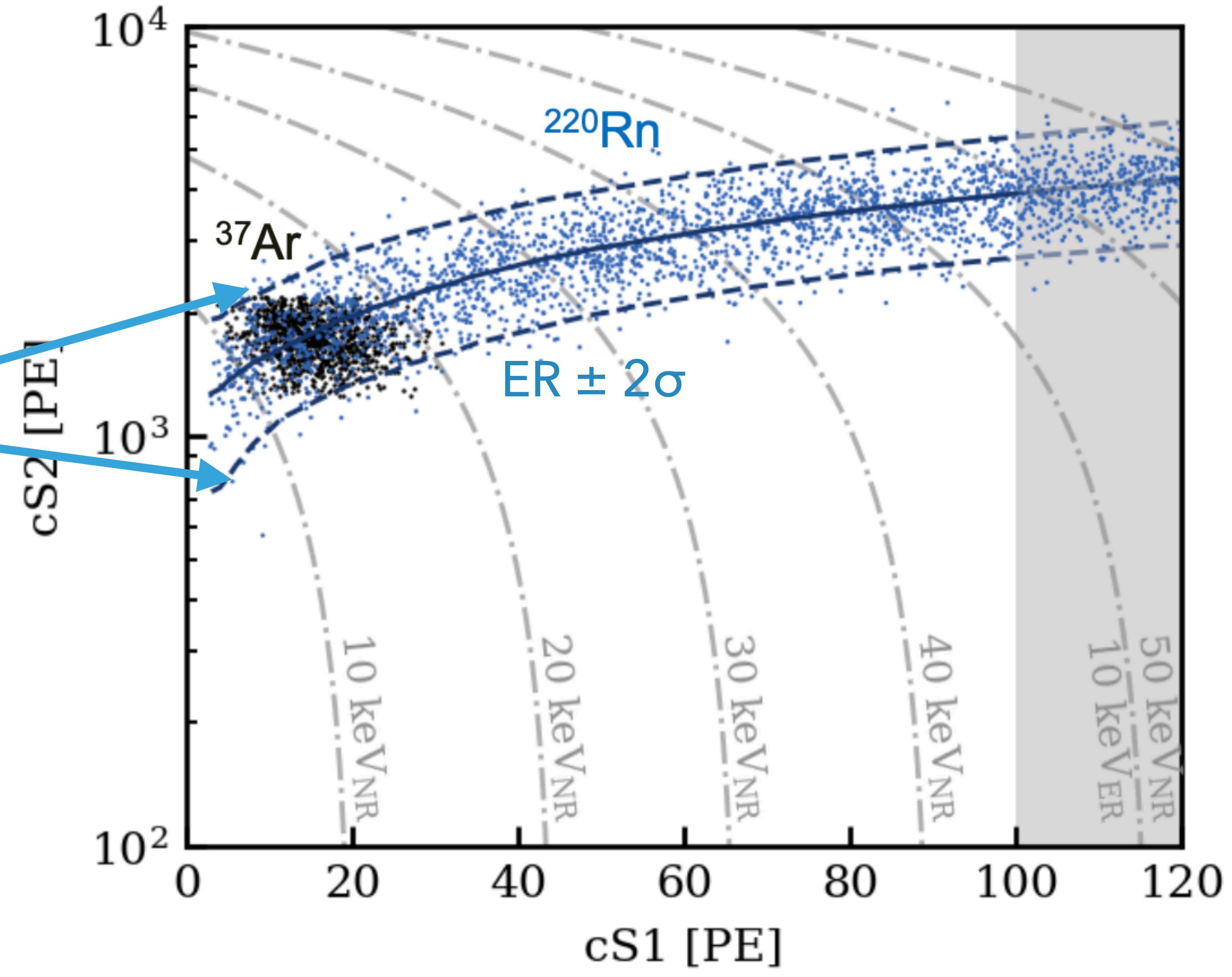




- Uniformly distributed in TPC
- Flat β spectrum in low energy
  - Fitted with microphysics+detector response model for ER
  - Useful for cut acceptance validation

# FIRST SCIENCE RUN: SR0

- 4.18±0.13/4.37±0.14 ton fiducial volume for NR/ER search & 97.1 days of exposure → ~1.1 ton·year exposure
- Calibrations:
  - $^{83m}$Kr: Uniformly distributed gamma events
  - $^{220}$Rn: ER band
  - **$^{37}$Ar: Uniformly distributed 2.8 keV Electron Capture events**

ER search blind region

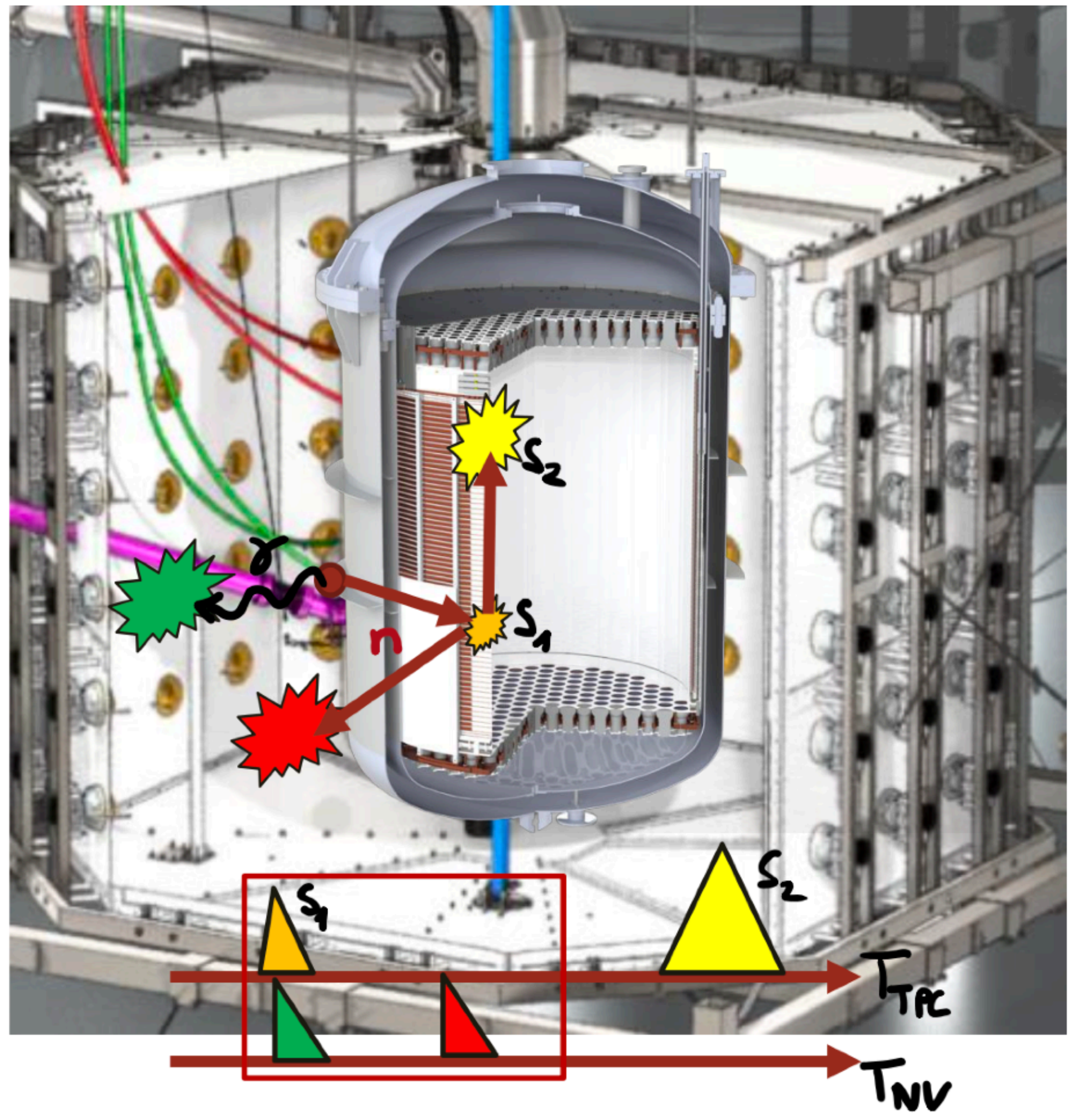



- Uniformly distributed in TPC
- Mono-energetic line at 2.8 keV
- Useful to study detector response/data selection of ER near energy threshold
- Combined with $^{220}$Rn to fit microphysics+detector response model

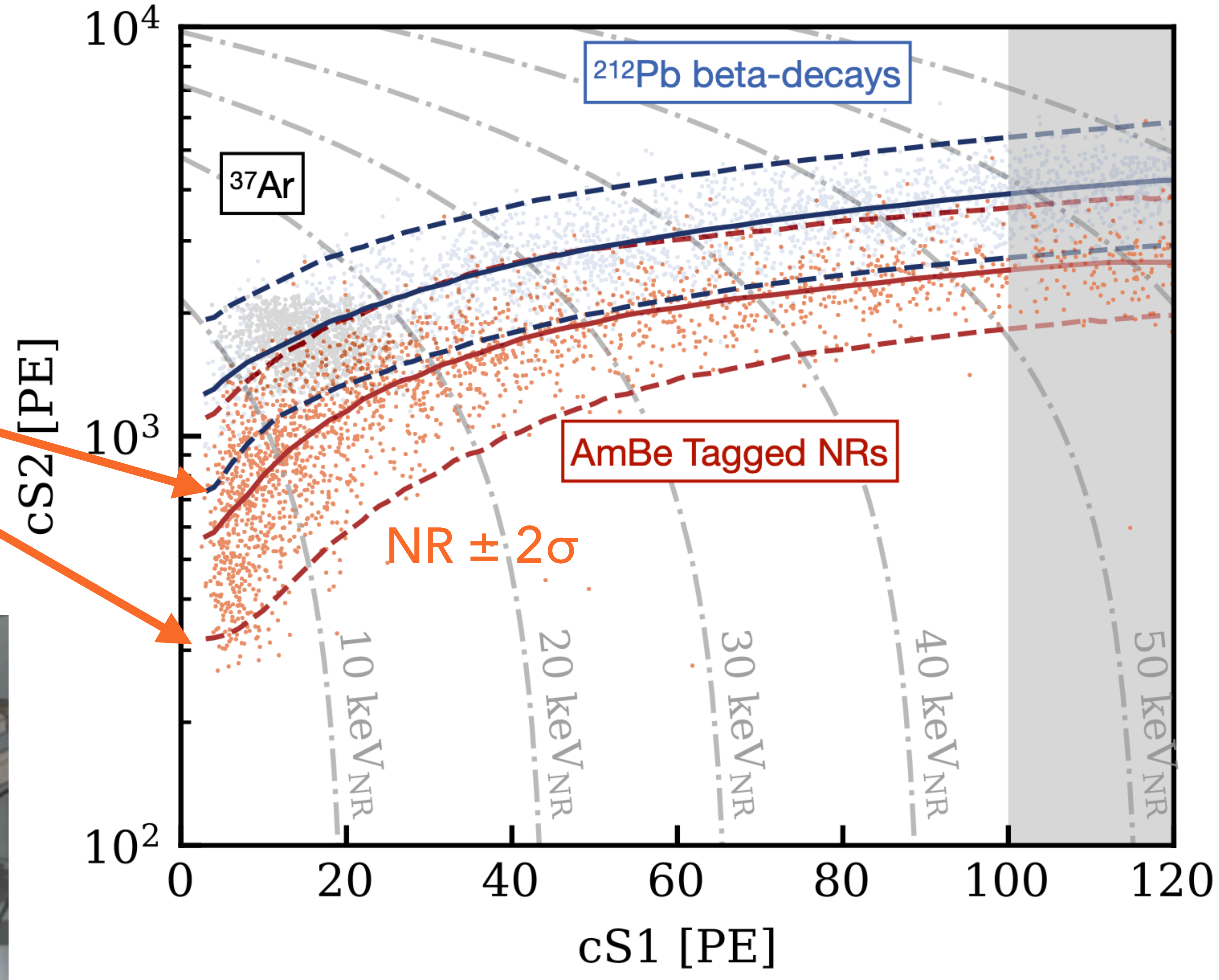
# FIRST SCIENCE RUN: SR0

- 4.18±0.13/4.37±0.14 ton fiducial volume for NR/ER search & 97.1 days of exposure → ~1.1 ton·year exposure
- Calibrations:
  - $^{83m}$Kr: Uniformly distributed gamma events
  - $^{220}$Rn: ER band
  - $^{37}$Ar: Uniformly distributed 2.8 keV Electron Capture events
  - **AmBe: NR band**

Central calibrations in low energy search!




NR search blind region



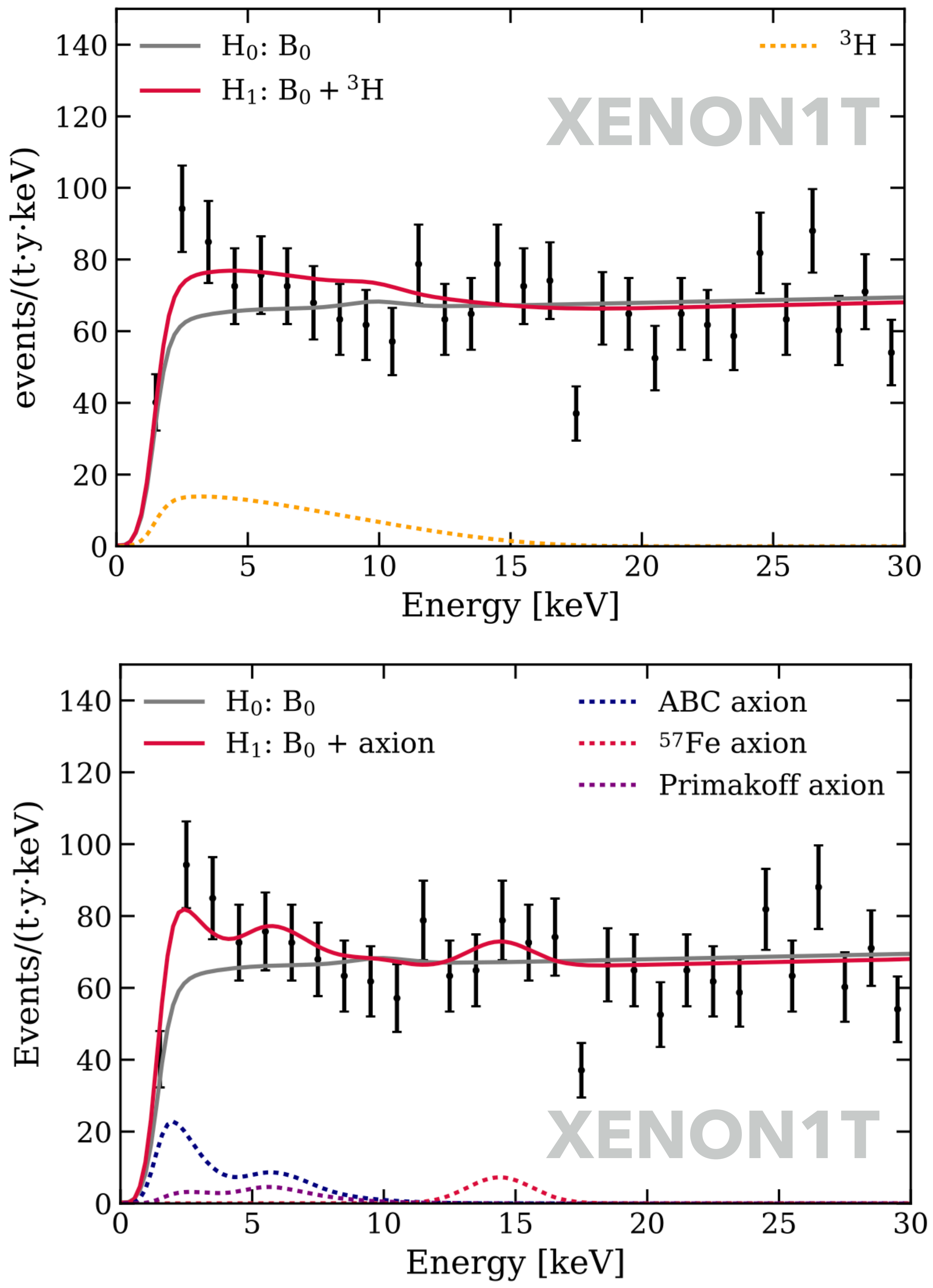

- Neutrons mostly from $^9$Be capturing $^{241}$Am's α-decay
- Pure neutron events tagged by NV in a 400 ns wide coincidence window
- Fitted with microphysics+detector response model for NR

# ROADMAP

- Dark Matter Direct Detection
- The XENONnT Detector
- Detector Calibration
- **First Low Energy Electronic Recoil Search Result**
- First Nuclear Recoil Search Result
- Search in Other Channels

# XENON1T LOW ER EXCESS

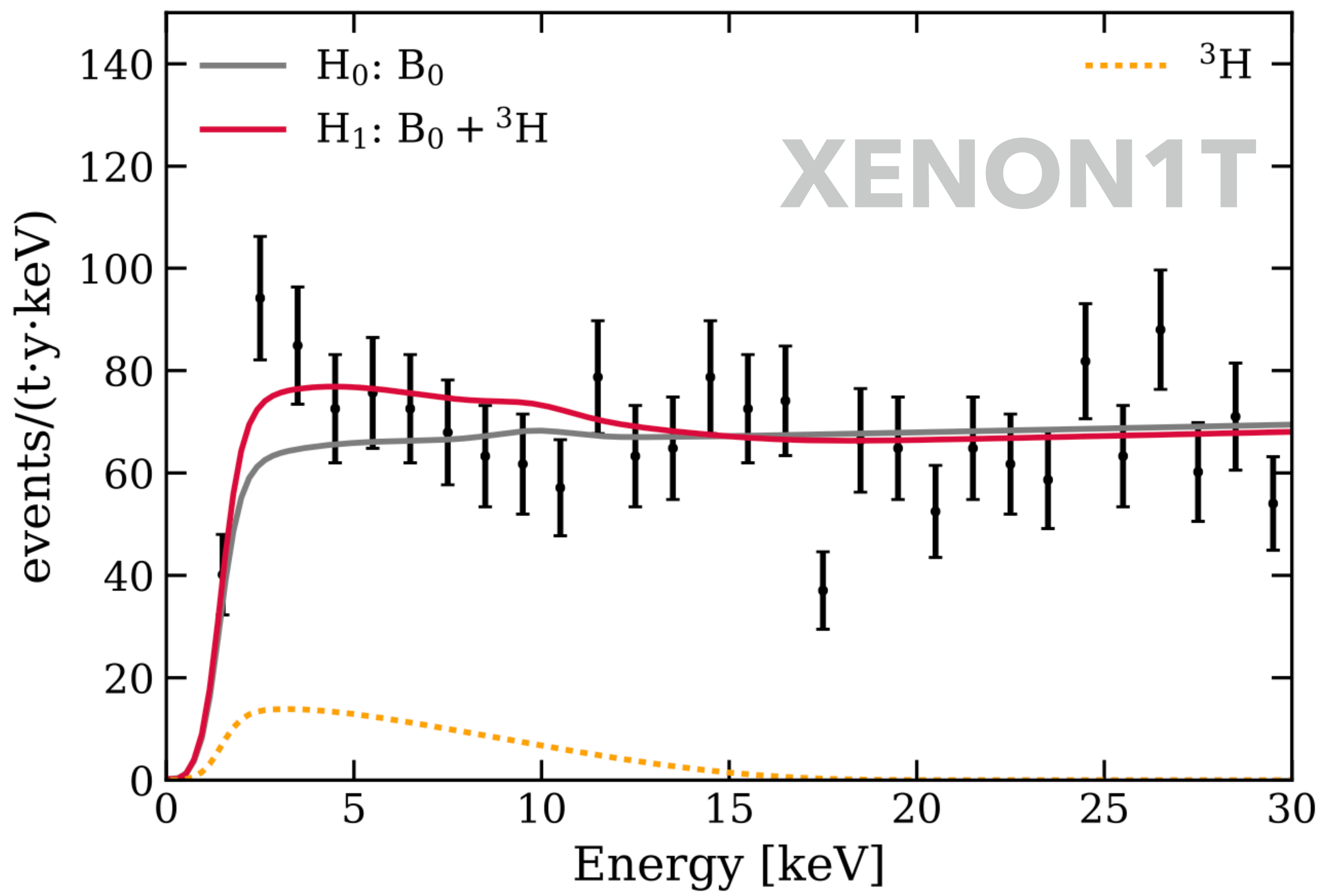
- In 2020, XENON1T observed an excess in electronic recoil energy spectrum, above expected background
  - Could be tritium traces, which cannot be confirmed or excluded by XENON1T
  - If not tritium, then could be new physics like solar axions (3.4σ), neutrino magnetic moment (3.2σ) etc.
- **XENONnT top priority: Confirm or exclude this excess**

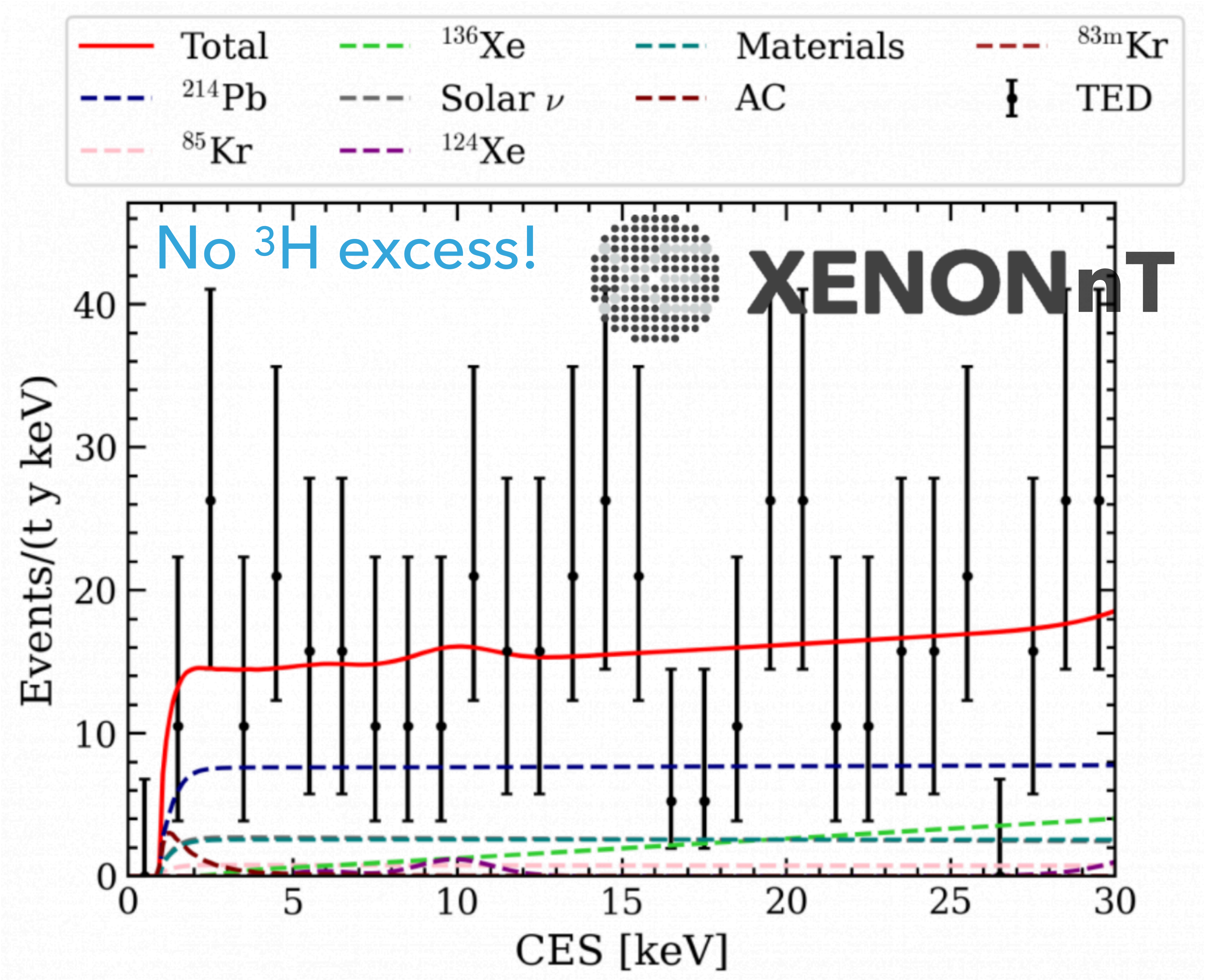



Based on axis-electric effect

# DECOUPLING TRITIUM

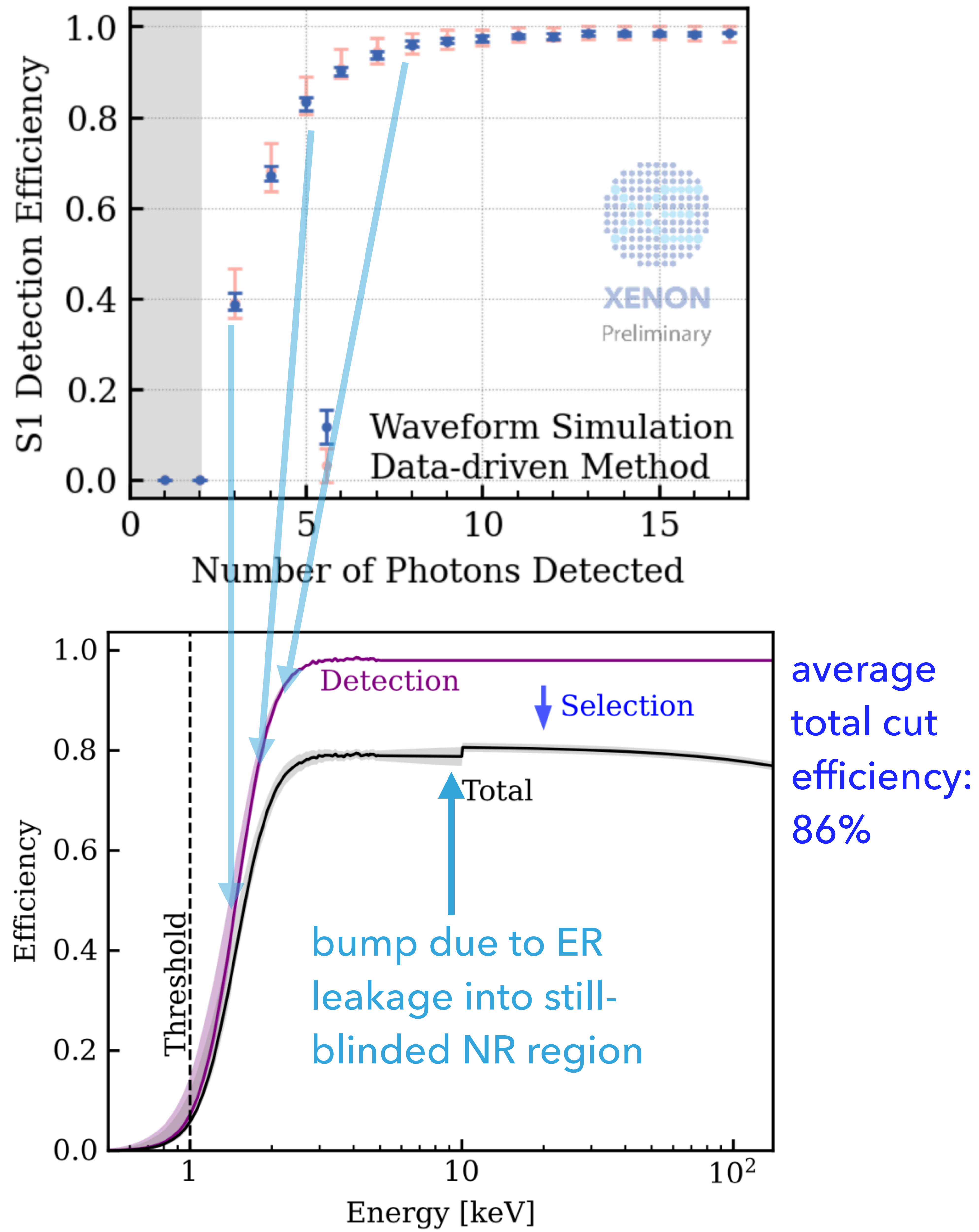
- Better tritium reduction in XENONnT
  - Two months of outgassing, and purification of gaseous xenon with Zr getters and 3 weeks of gaseous xenon cleaning reduces possible hydrogen contamination…
- Tritium Enhanced Data
  - Bypassing getters in the purification loop would increase the equilibrium hydrogen concentration in the detector at least 10 times higher.
  - Taken data for 14.3 days after main SR0 for blind analysis, enough to conclude **tritium is NOT a significant background in XENONnT**.



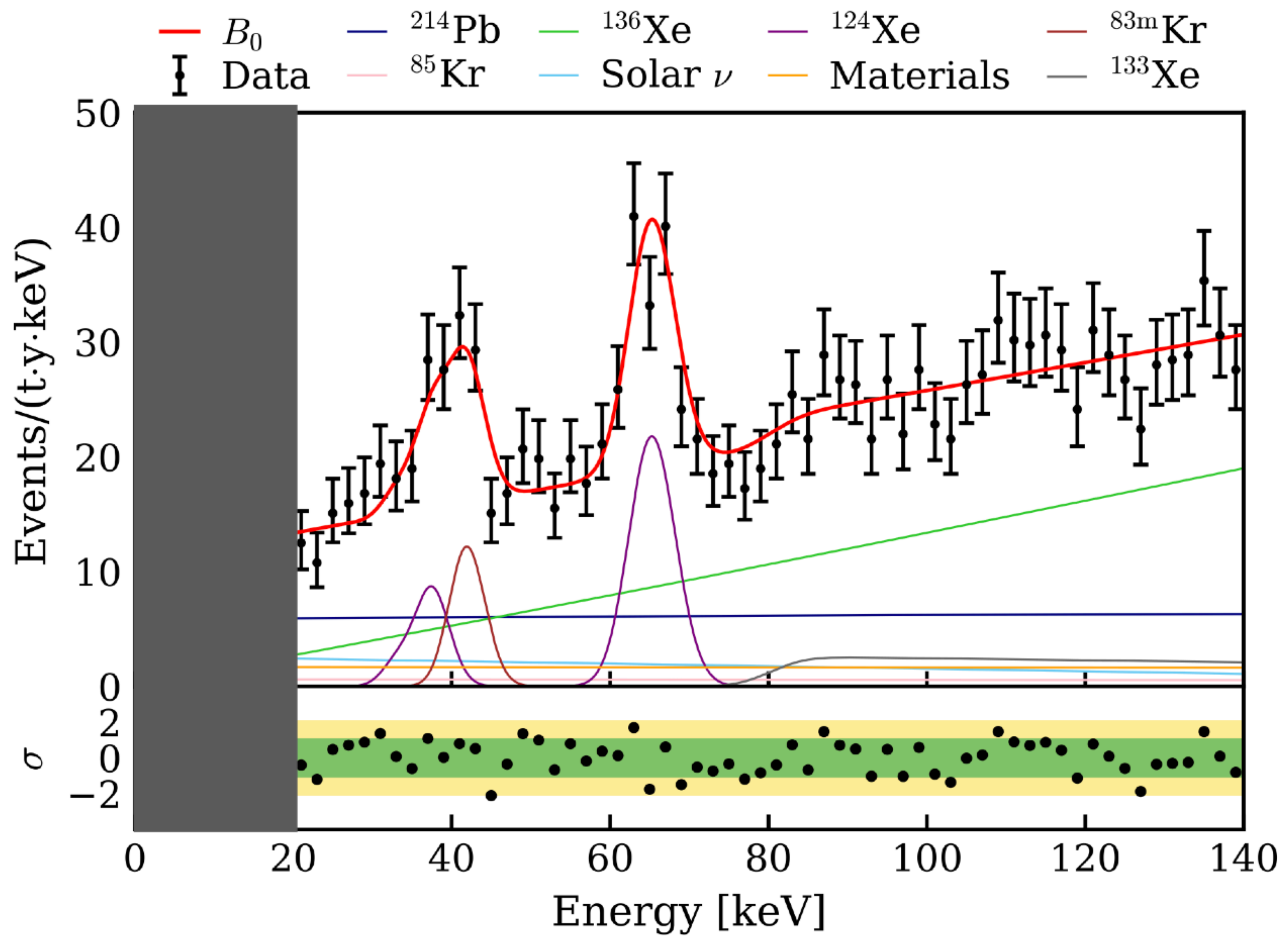
# EFFICIENCIES

- Low energy (<~2keV ER) efficiency dominated by S1 3-fold tight-coincidence requirement
  - Estimated with detail-modeled waveform simulation (WFSim), and verified by a data-driven approach
  - Good agreement
- Higher energy (> ~2keV ER) efficiency dominated by data selection cuts
  - S2 over 500 PE
  - Nothing in veto time coincidence <300 ns
  - S1/S2 peak quality cuts
  - Fiducial Volume: 4.37 ± 0.14 ton



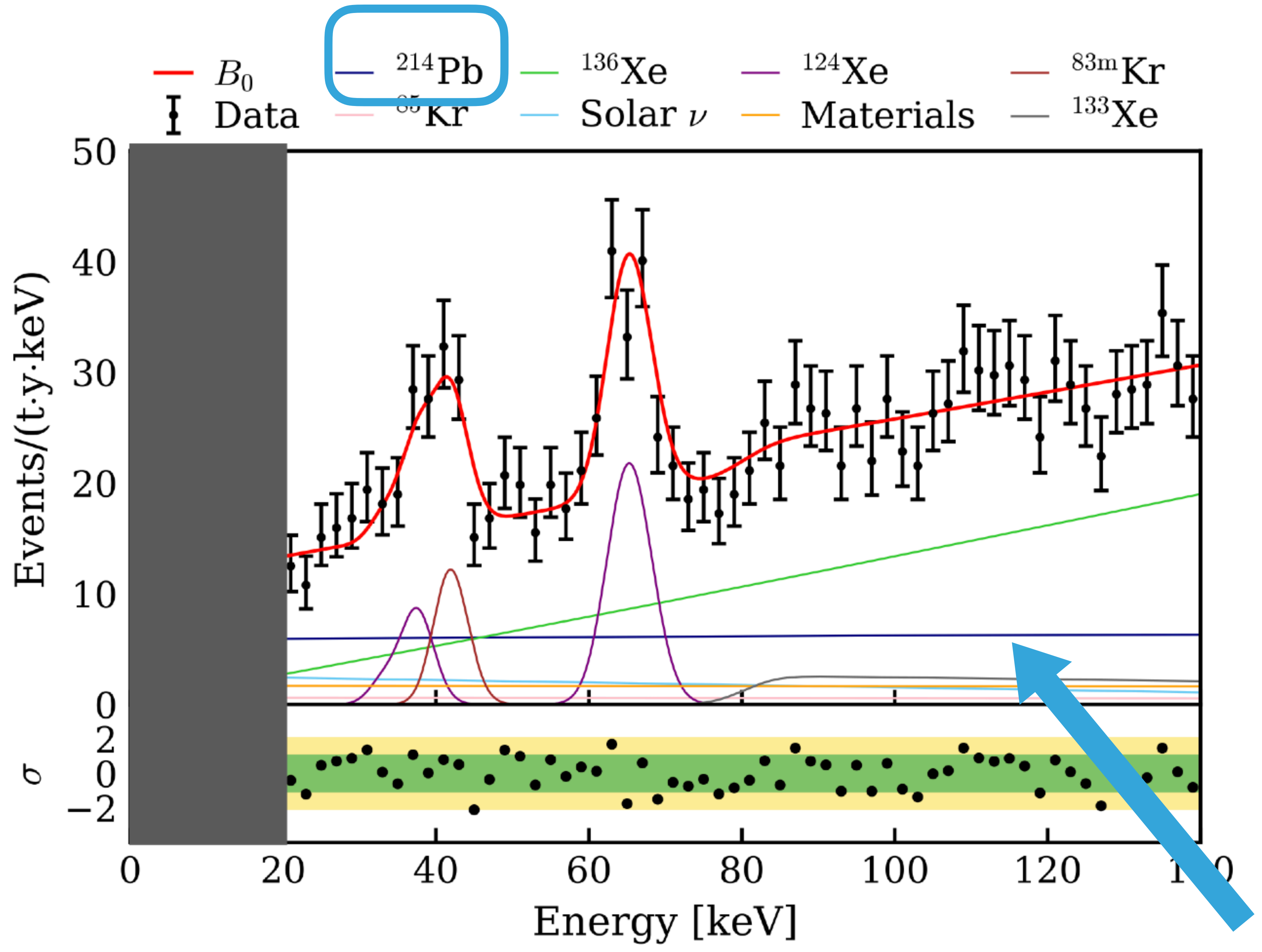
# UNBLINDING LOW ER SEARCH

- **ER background built on lowER ROI sideband**



# UNBLINDING LOW ER SEARCH

- ER background built on lowER ROI sideband
  - **Dominated by Flat beta spectrum from $^{222}$Rn daughter: ~1/7 of XENON1T thanks to Radon Distillation**



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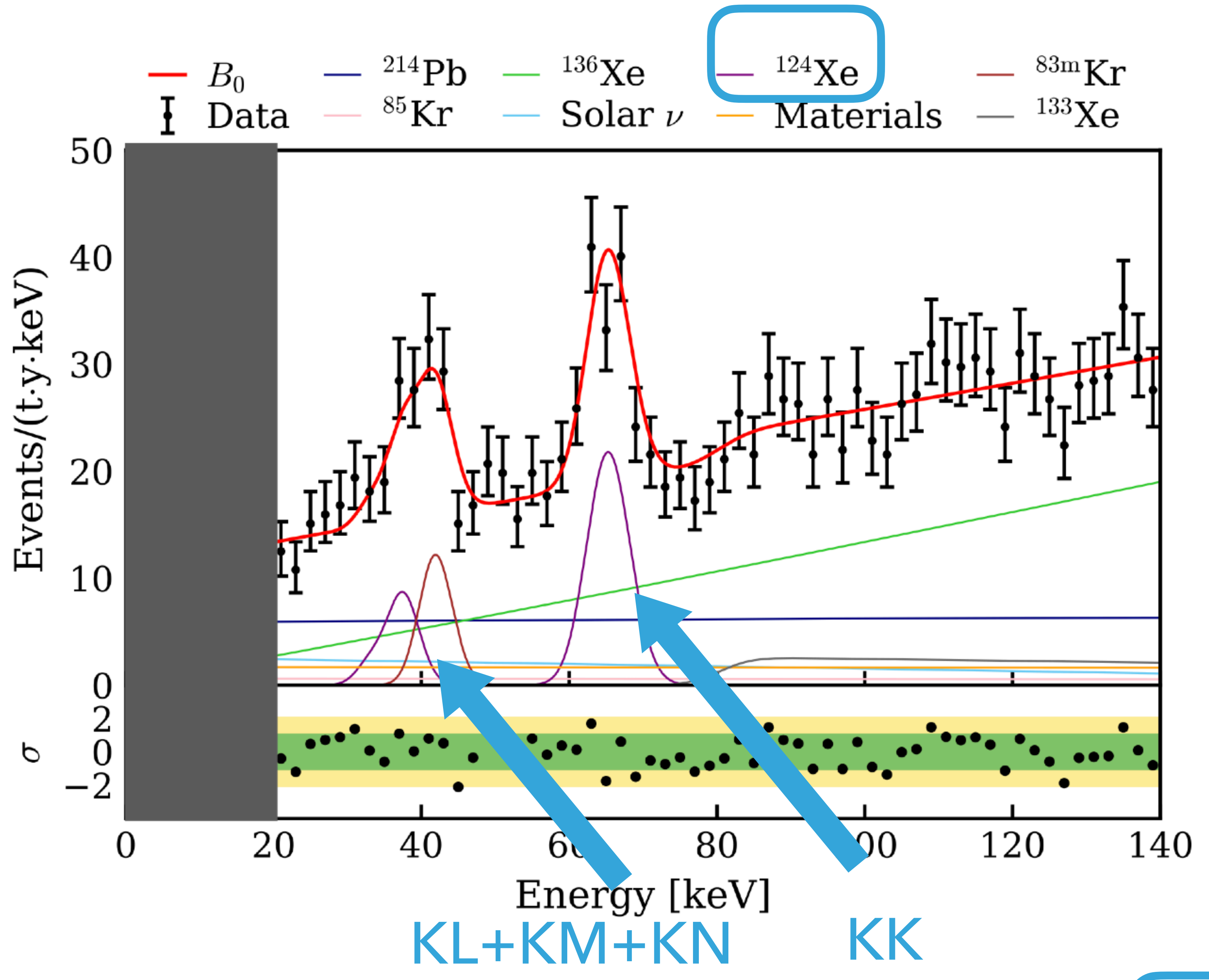
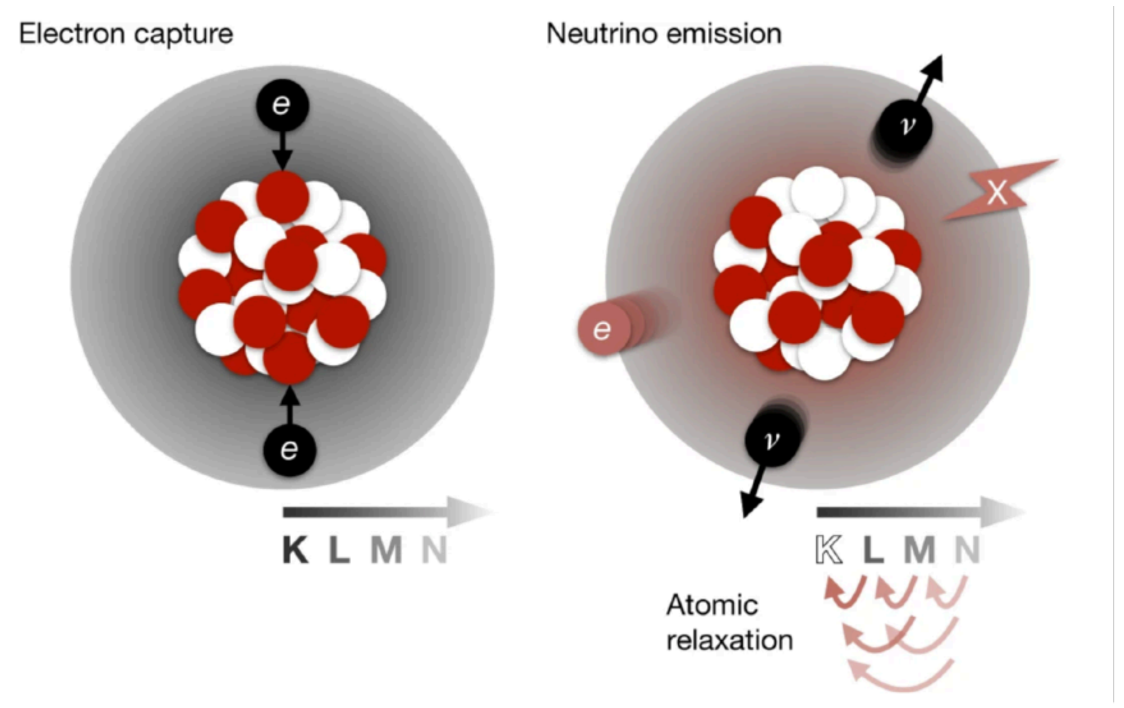
  - Dominated by Flat beta spectrum from $^{222}$Rn daughter: ~1/7 of XENON1T thanks to Radon Distillation
  - **Can clearly see double electron capture, and used them to fit g1/g2**




$$T_{1/2}^{2\nu ECEC} = (1.15 \pm 0.13_{stat} \pm 0.14_{sys}) \times 10^{22} yr$$

Was rarest process ever observed!



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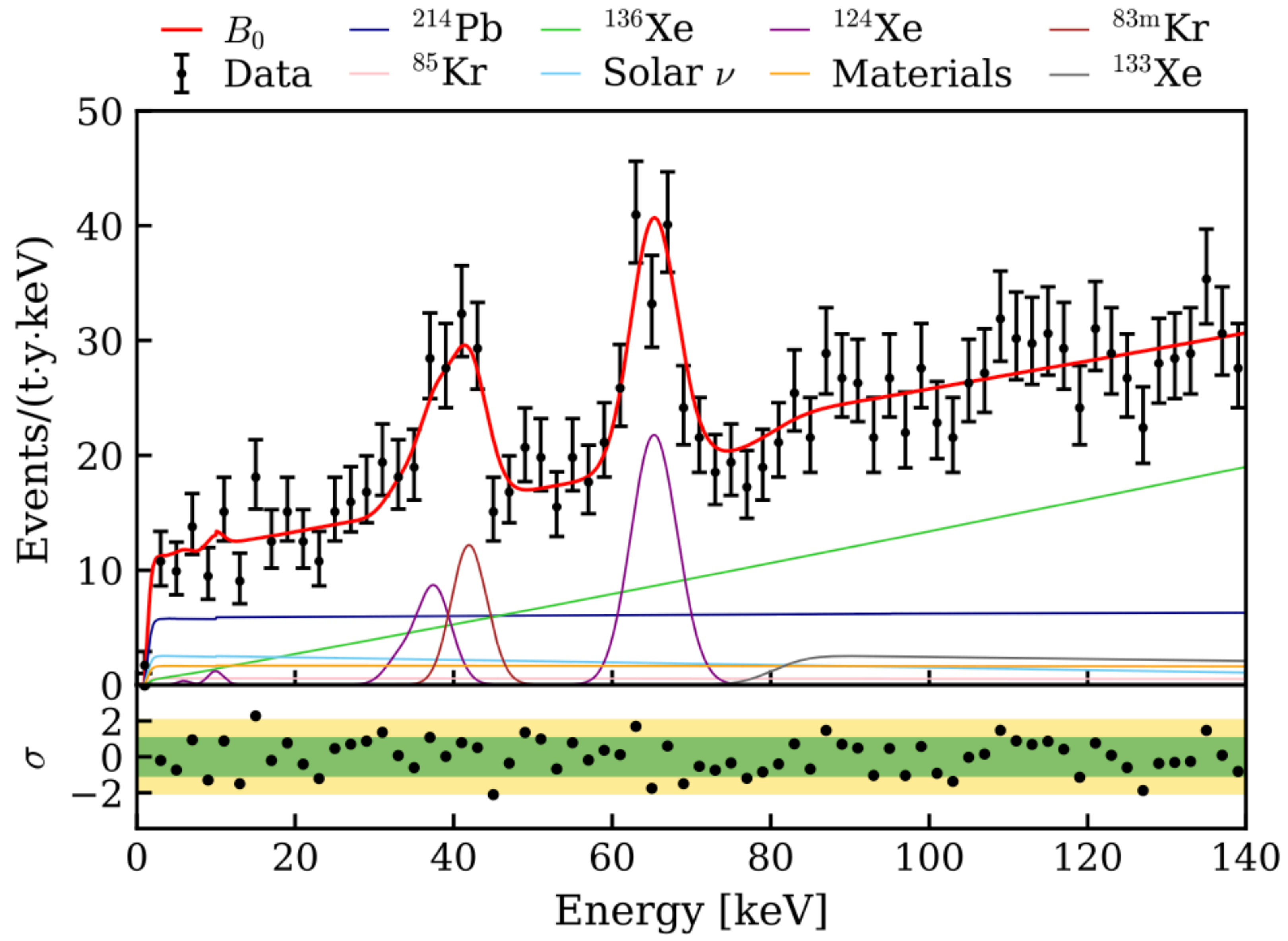
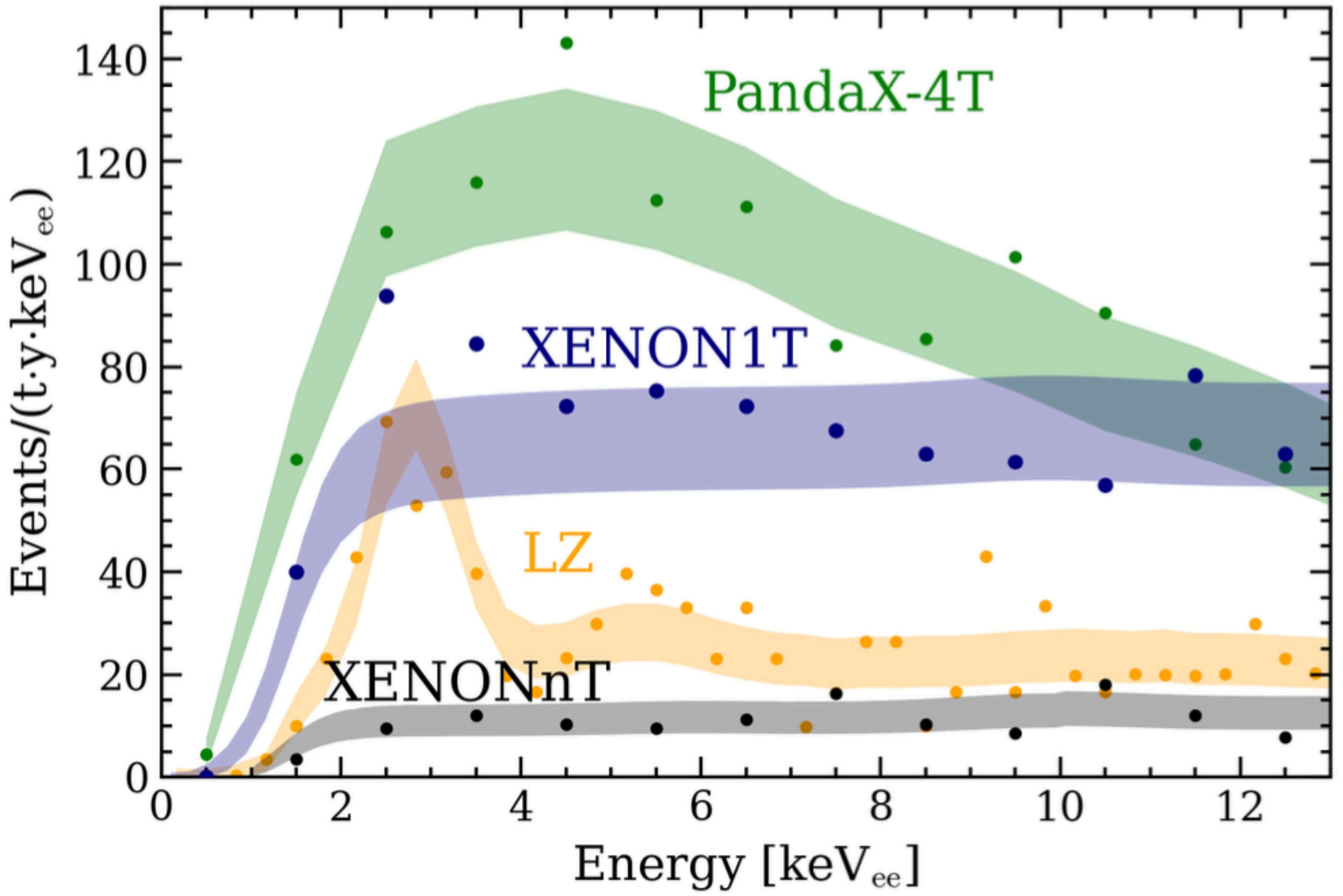
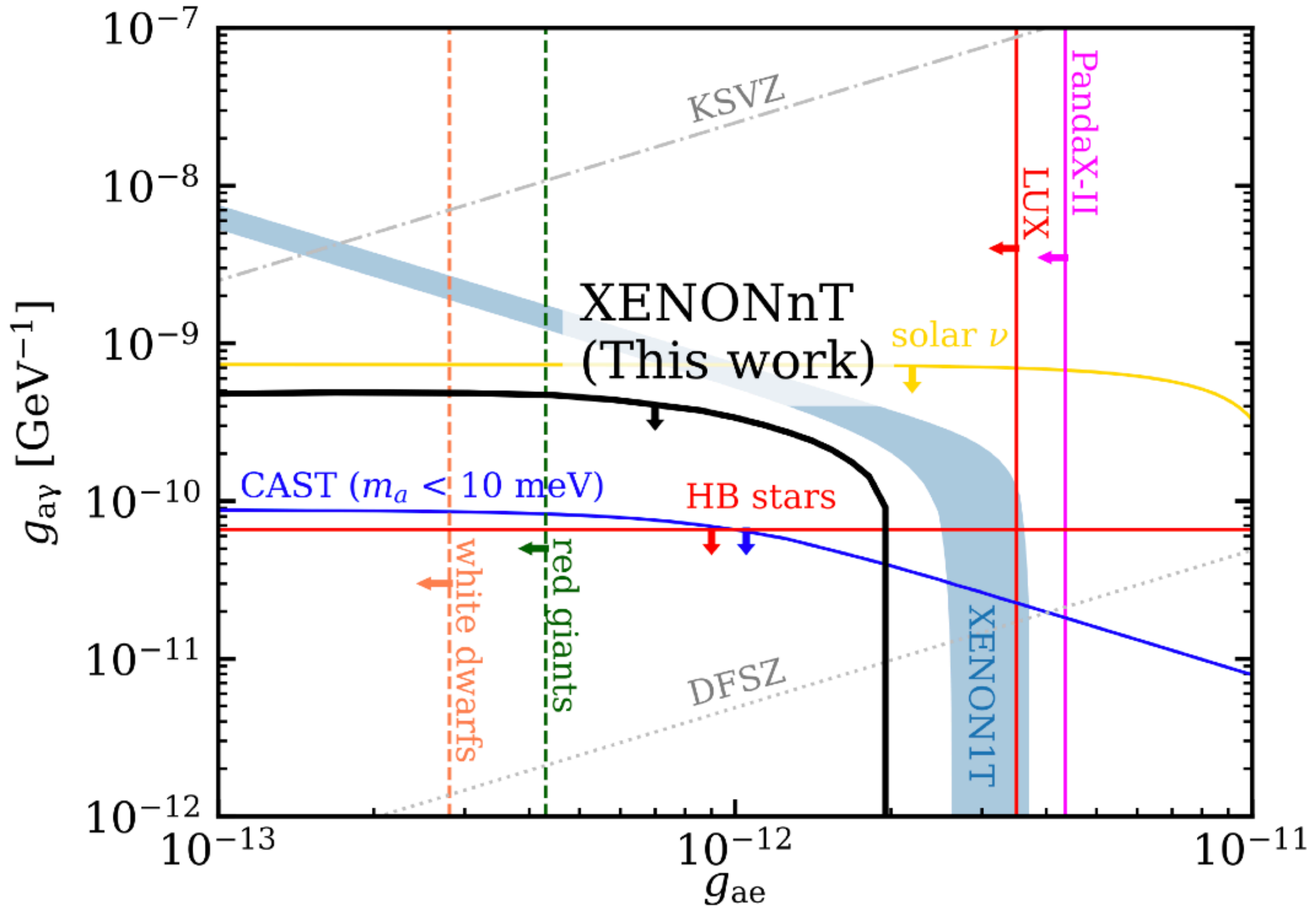
- ER background built on lowER ROI sideband
  - Dominated by Flat beta spectrum from $^{222}$Rn daughter: ~1/7 of XENON1T thanks to Radon Distillation
  - Can clearly see double electron capture, and used them to fit g1/g2
- **Unblinding result**
  - **Unprecedented low background**
  - **XENON1T excess was most likely tritium**

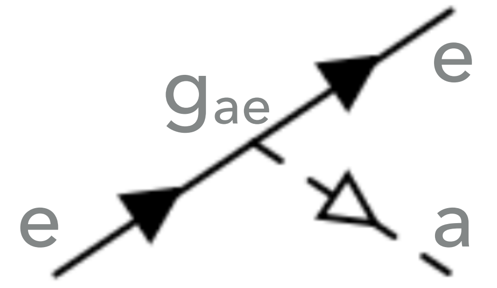


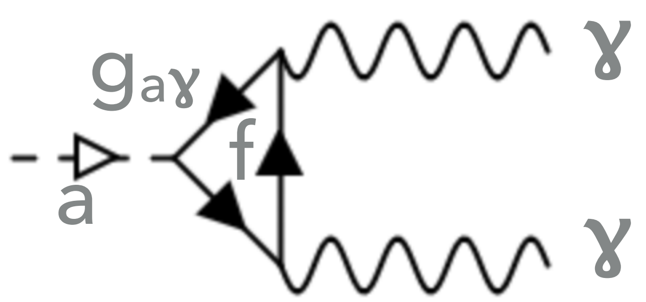



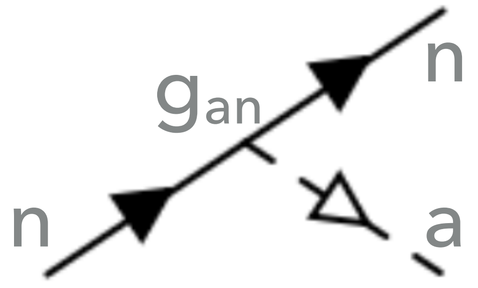
# LIMITS ON BSM PHYSICS: LEADING IN EARTH-BASED DETECTOR

- **Solar axions**
  - Inference done in ($g_{ae}$, $g_{a\gamma}$, $g_{an}$) but projected in 2D



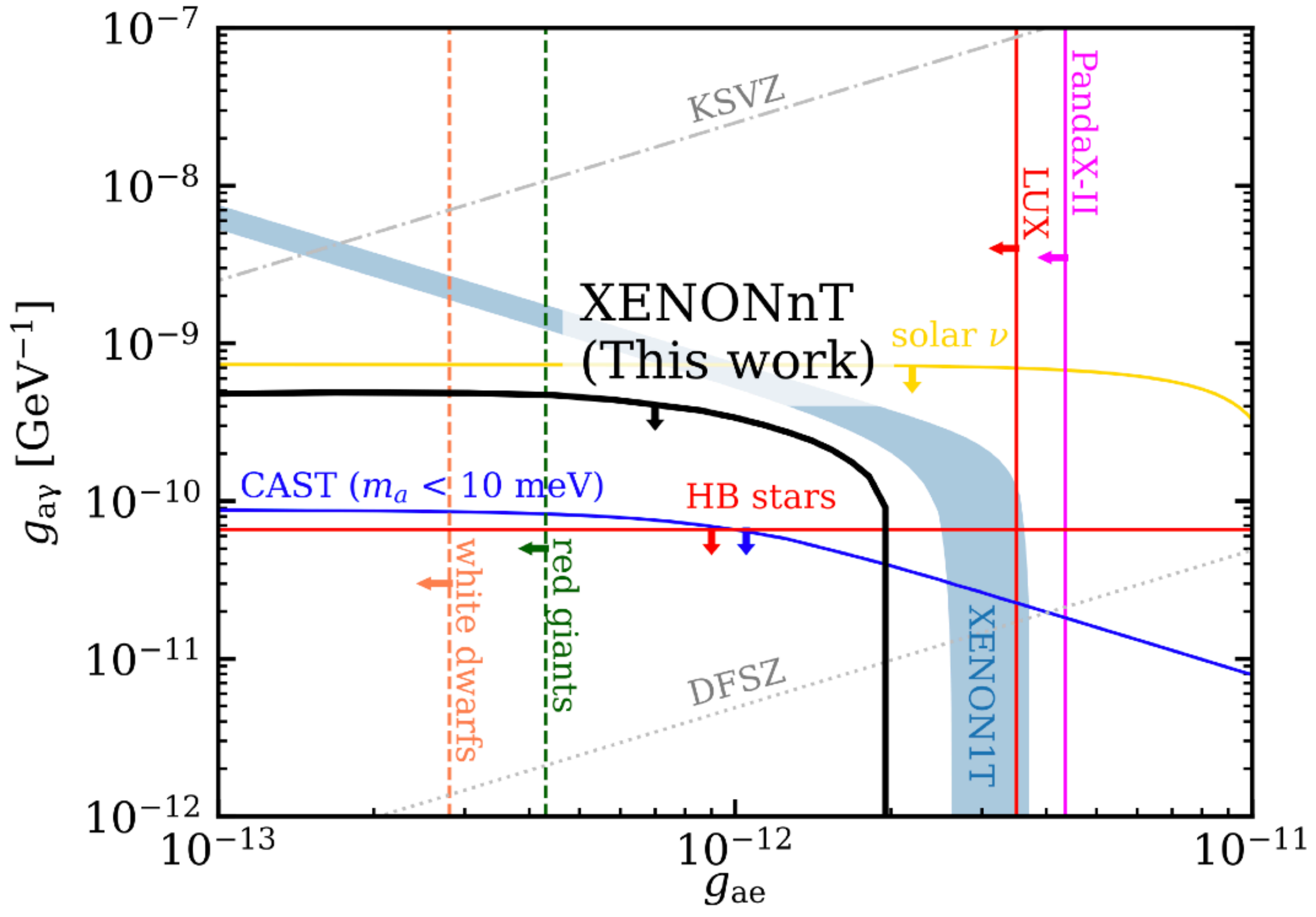



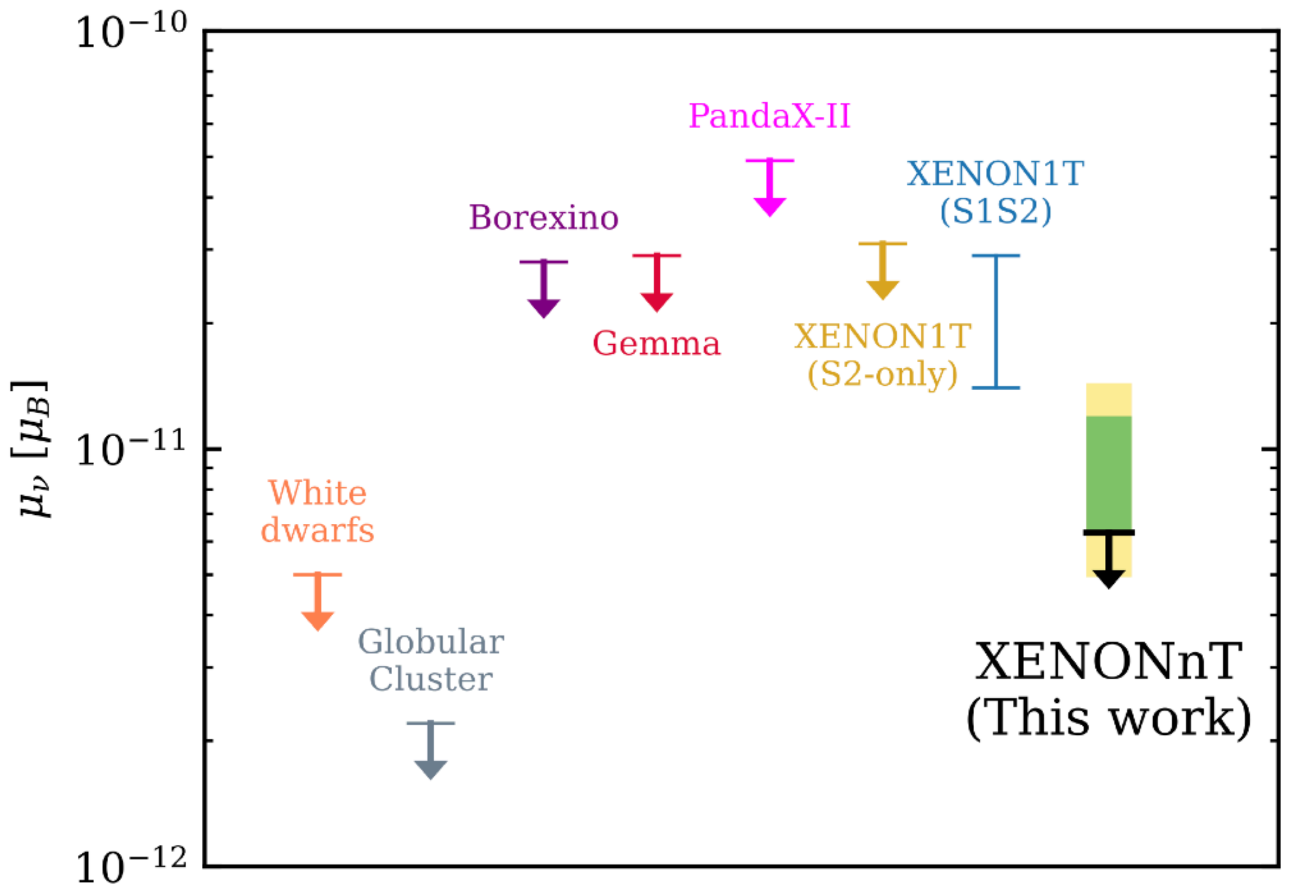



# LIMITS ON BSM PHYSICS: LEADING IN EARTH-BASED DETECTOR

- Solar axions
  - Inference done in ($g_{ae}$, $g_{a\gamma}$, $g_{an}$) but projected in 2D
- **Neutrino magnetic moment**
  - Using solar neutrinos



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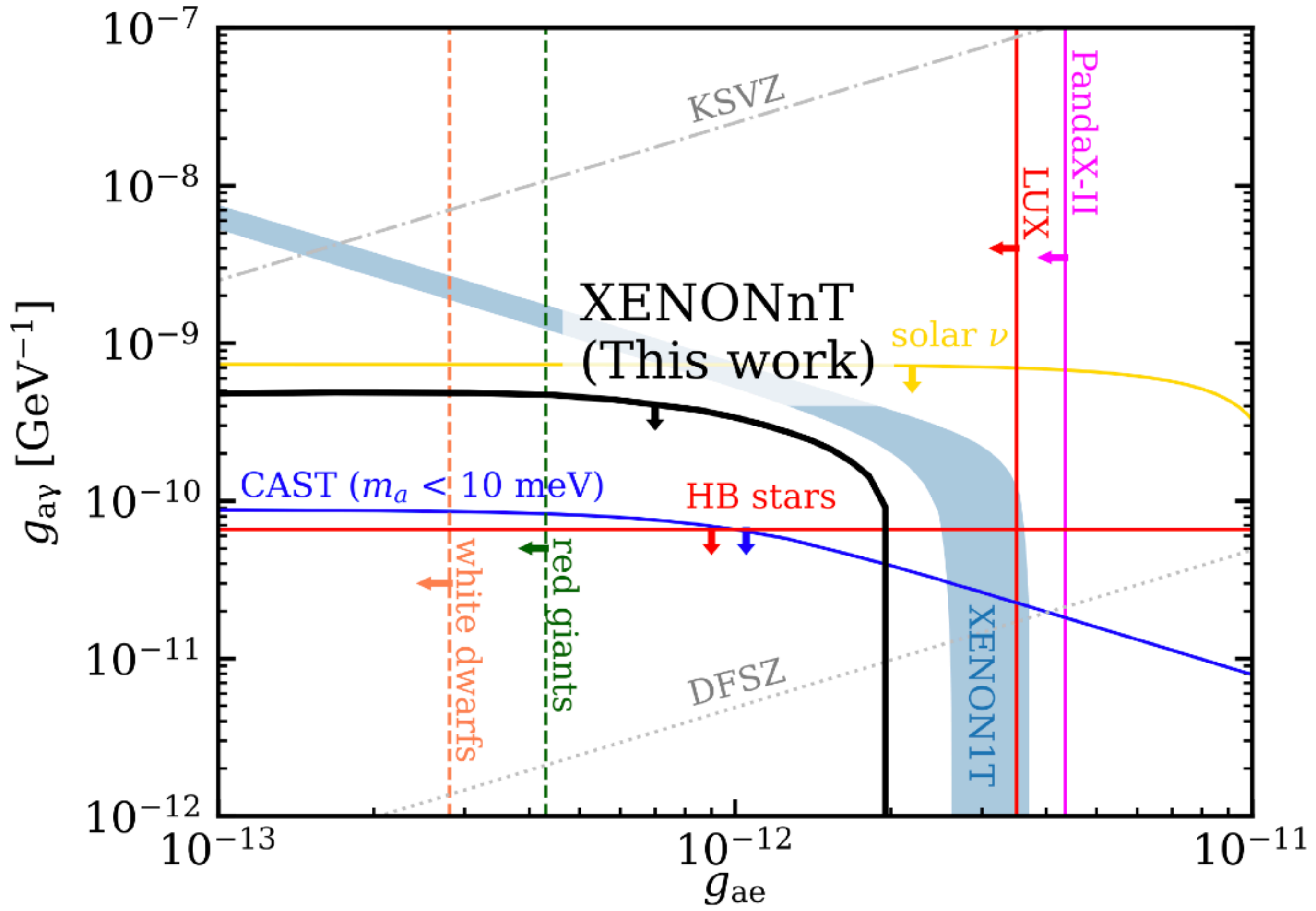
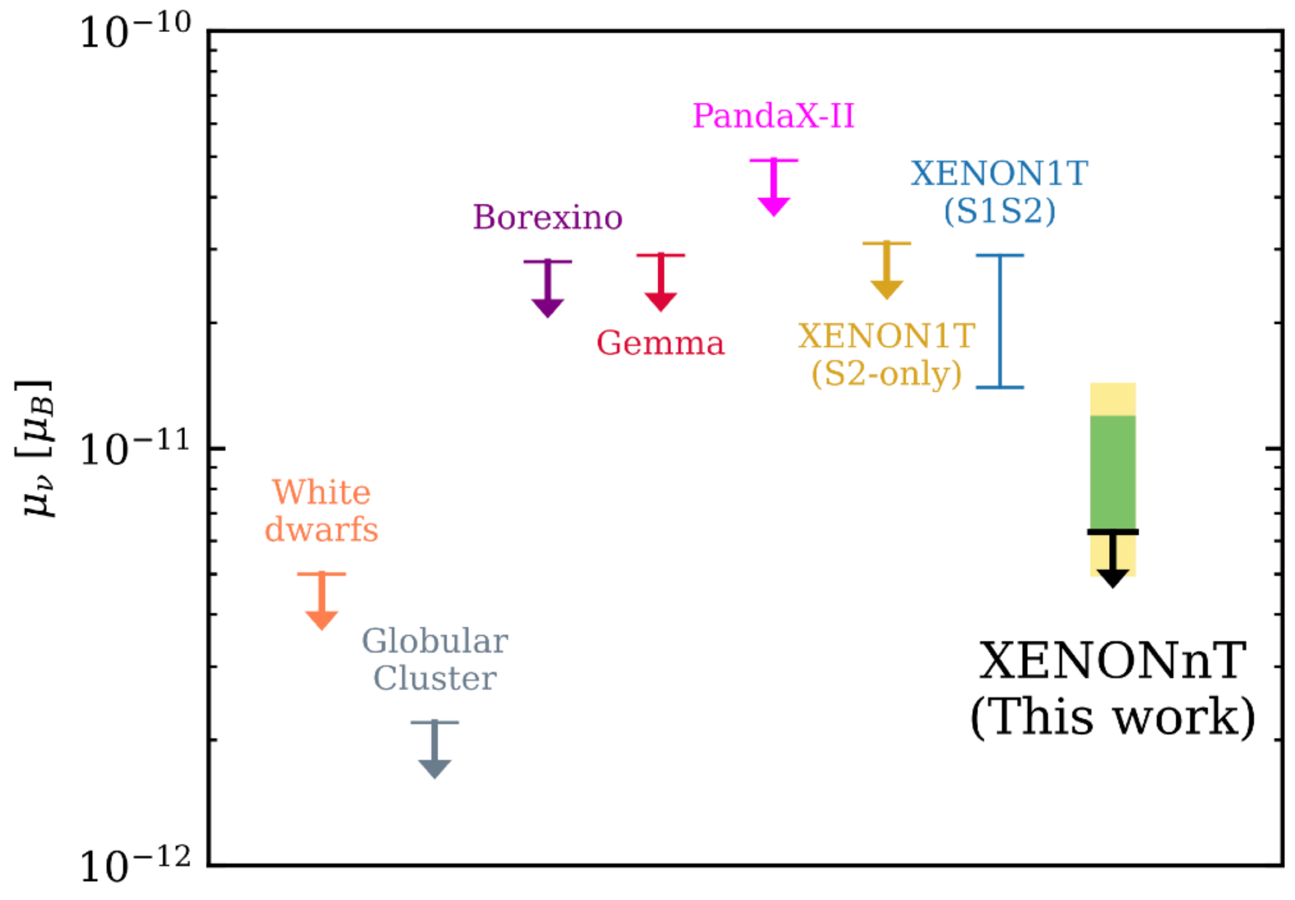
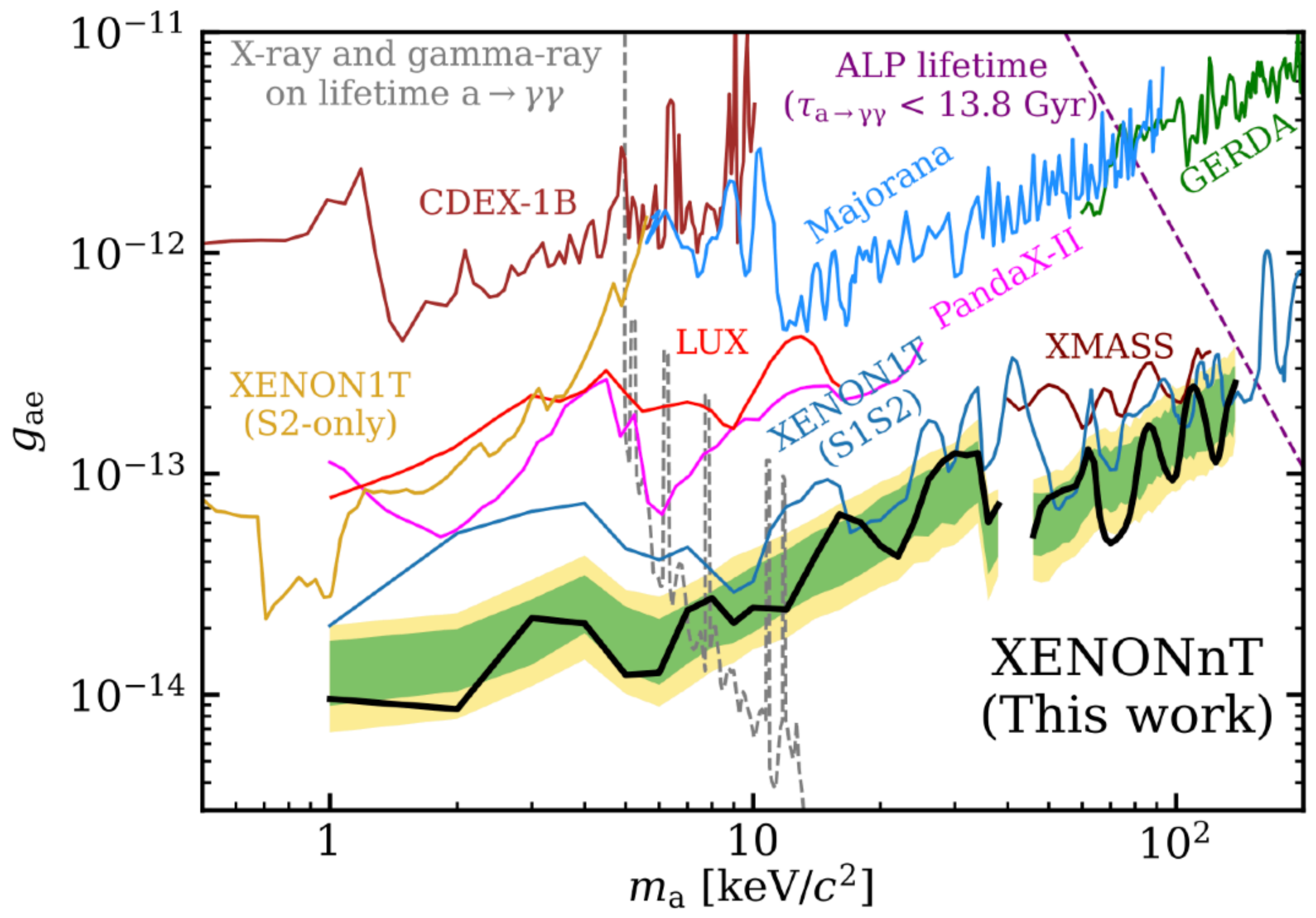
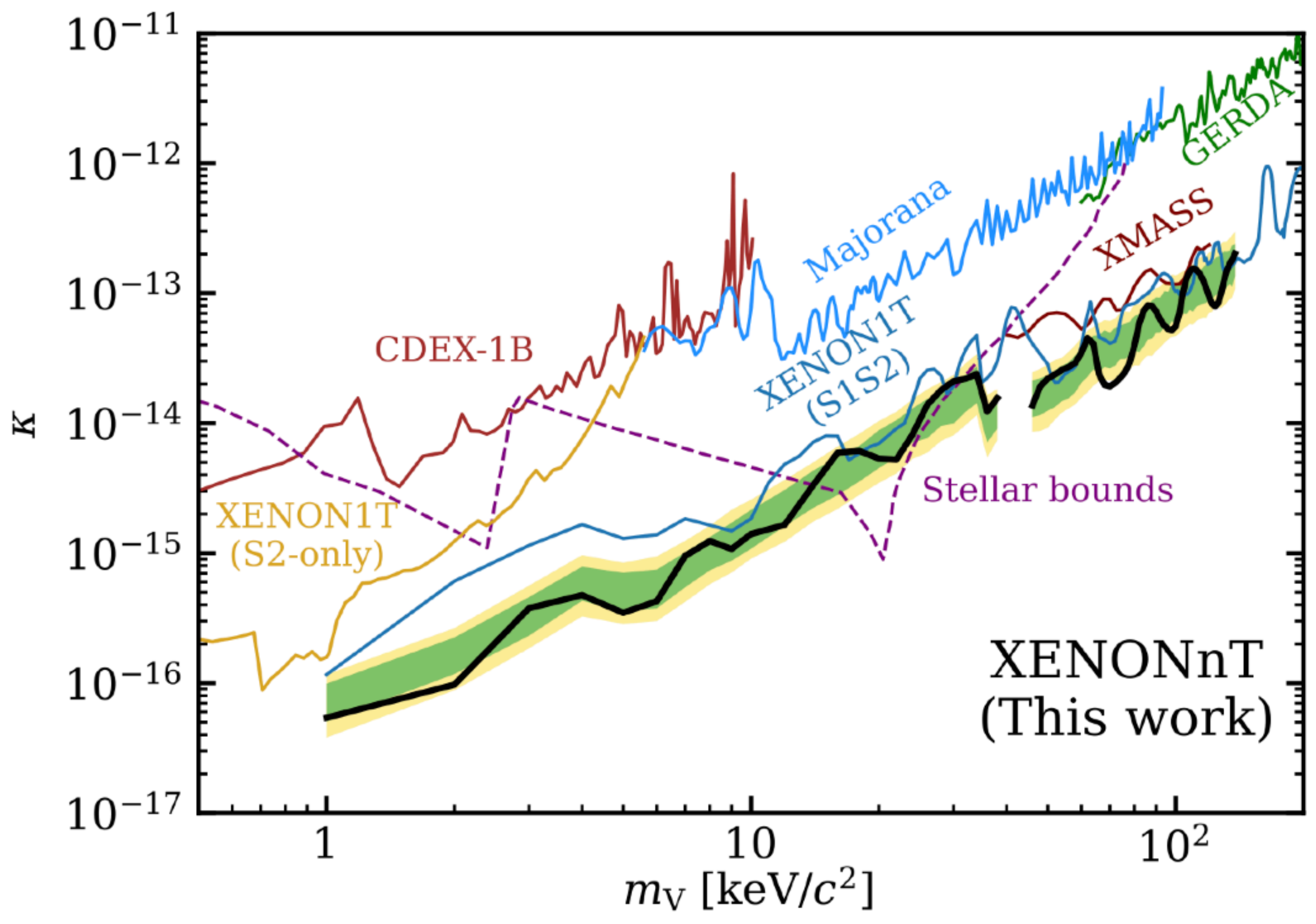
- Solar axions
  - Inference done in ($g_{ae}$, $g_{a\gamma}$, $g_{an}$) but projected in 2D
- Neutrino magnetic moment
  - Using solar neutrinos
- **Bosonic DM**
  - ALPs and dark photons




ALPs




Dark photons

# ROADMAP

- Dark Matter Direct Detection
- The XENONnT Detector
- Detector Calibration
- First Low Energy Electronic Recoil Search Result
- **First Nuclear Recoil Search Result**
- Search in Other Channels

# WIMP SEARCH IN XENON DETECTOR

- Predicted by Supersymmetry
  - Cold DM, mass in ~(GeV, TeV)
- Follow Standard Halo Model (isothermal) →Capped Maxwell velocity distribution
- DM-SM scattering (NR) rate by astrophysical inputs, particle physics (goal!) and detector physics

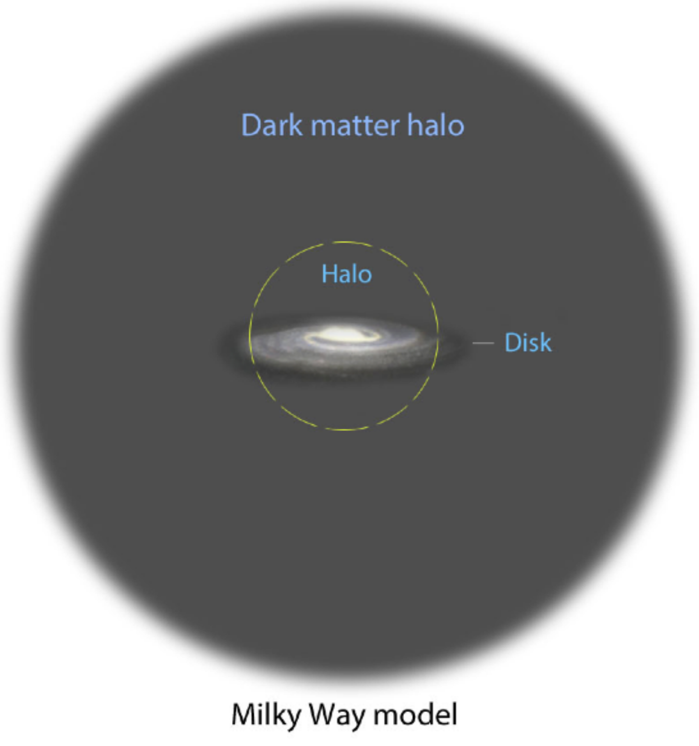
Measured rate / DM energy density / DM escape velocity / DM velocity distribution

$$\frac{dR}{dE_R} = \frac{\rho}{m_\chi}\frac{1}{m_N}\int_{v_{min}}^{v_{esc}} dv\, f(v) v \frac{d\sigma}{dE_R}(v)$$

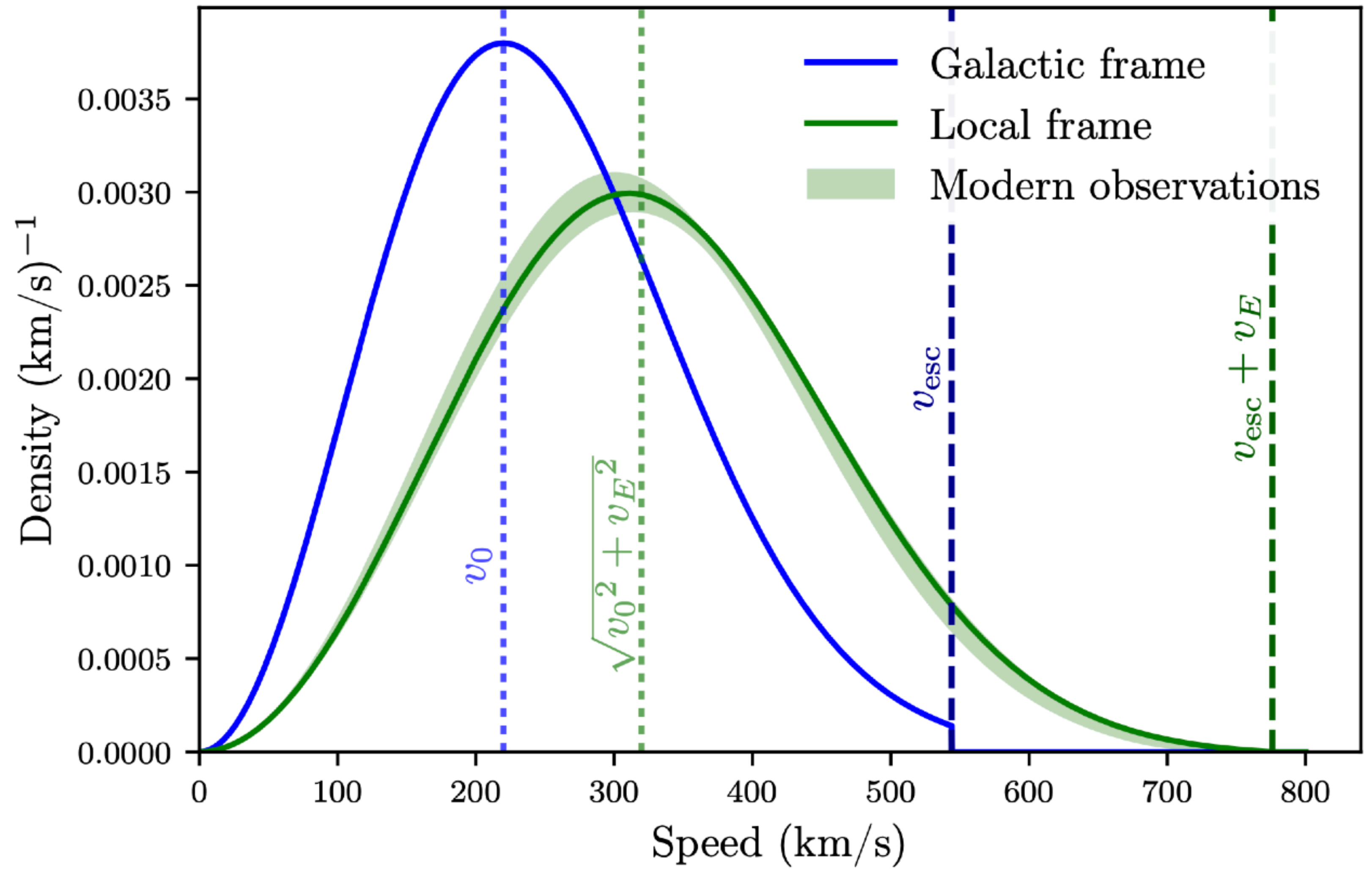
Recoil energy / DM mass to infer / Xenon atom mass / detector energy threshold / DM-SM scattering cross section

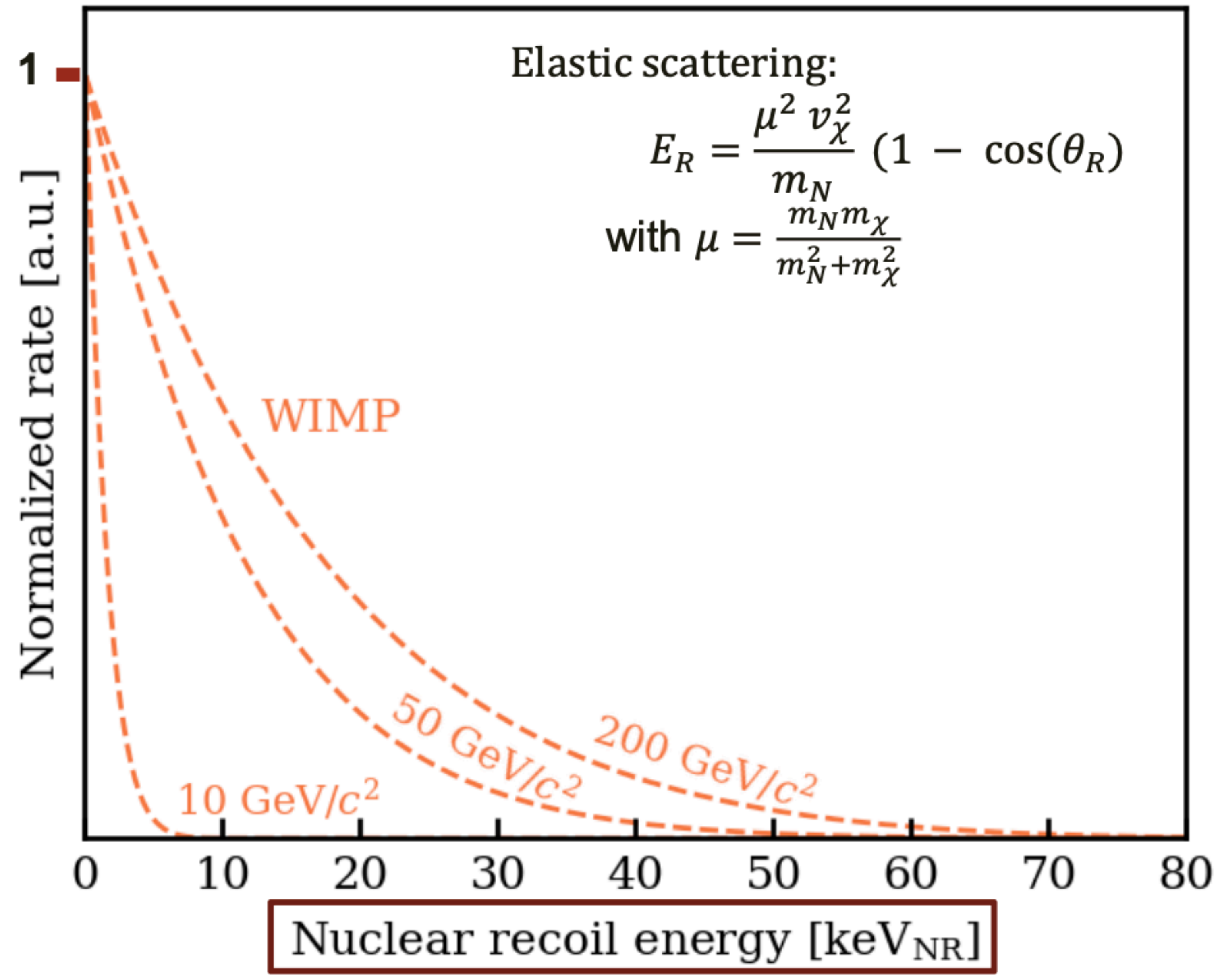
$$\frac{\mathrm{d}\sigma}{\mathrm{d}E_R} = \left[\left(\frac{\mathrm{d}\sigma}{\mathrm{d}E_R}\right)_{\mathrm{SI}} + \left(\frac{\mathrm{d}\sigma}{\mathrm{d}E_R}\right)_{\mathrm{SD}}\right]$$

$\propto A^2$ $\quad \propto j, S_n, S_p$



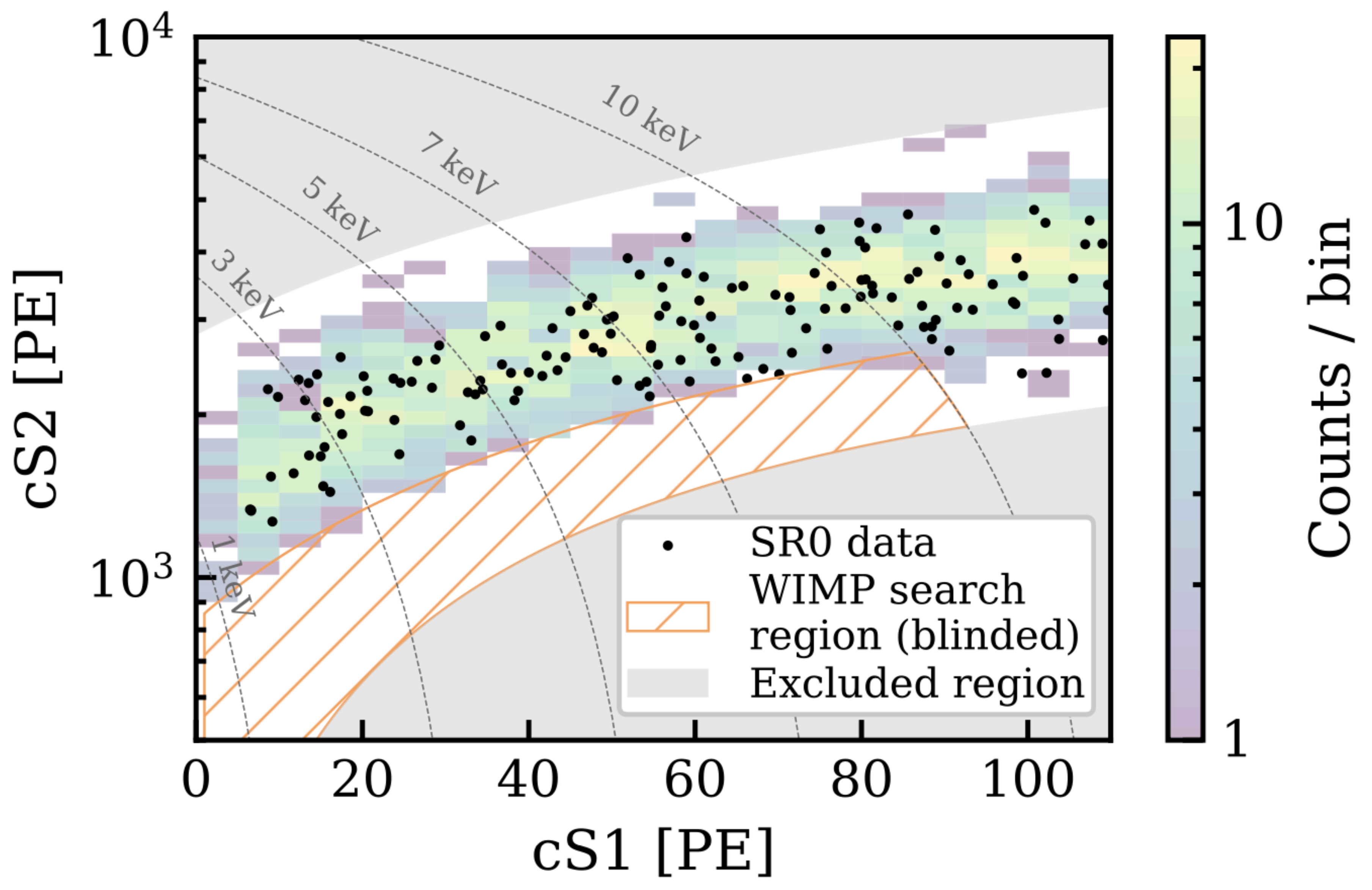
Milky Way model

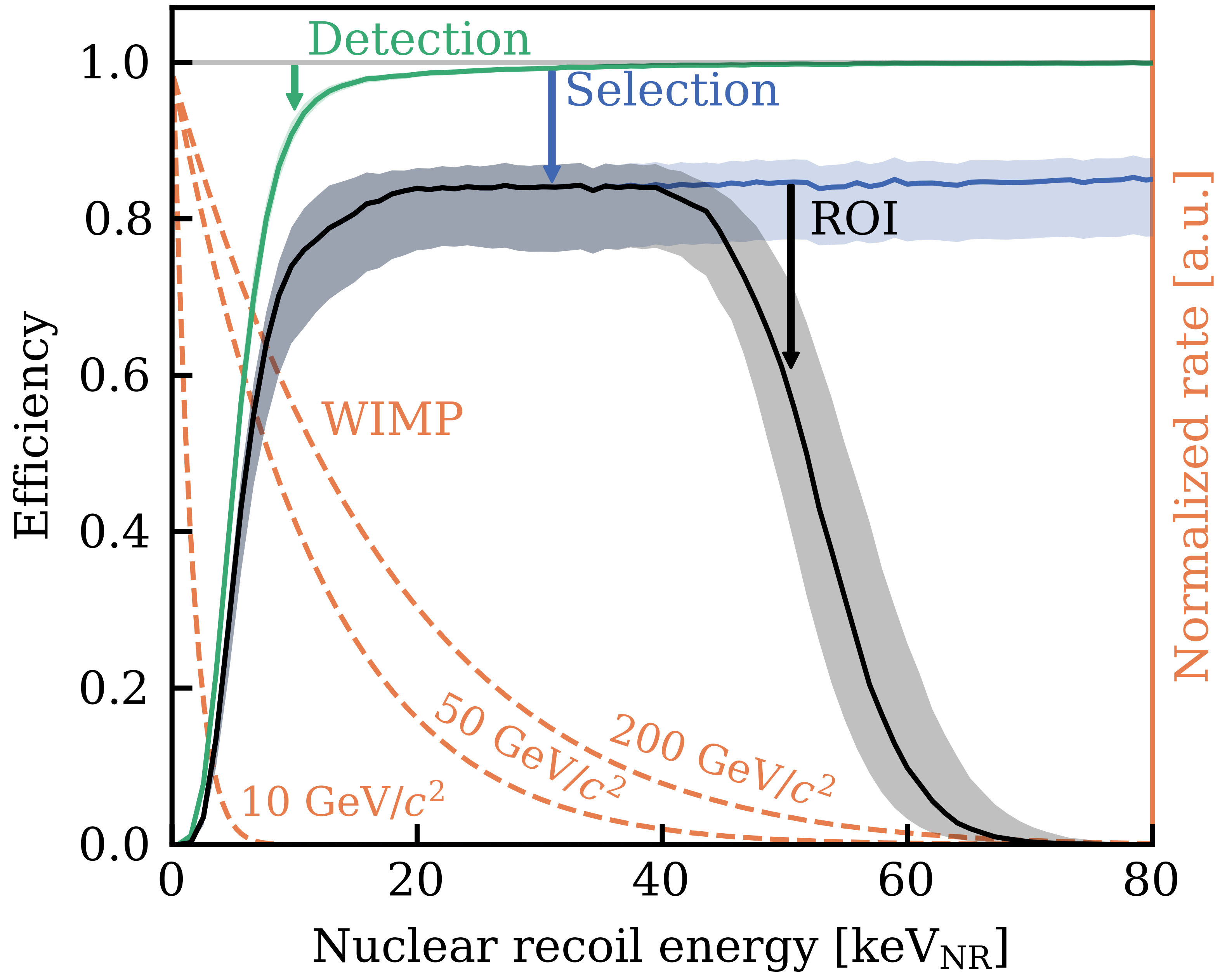


# EFFICIENCIES

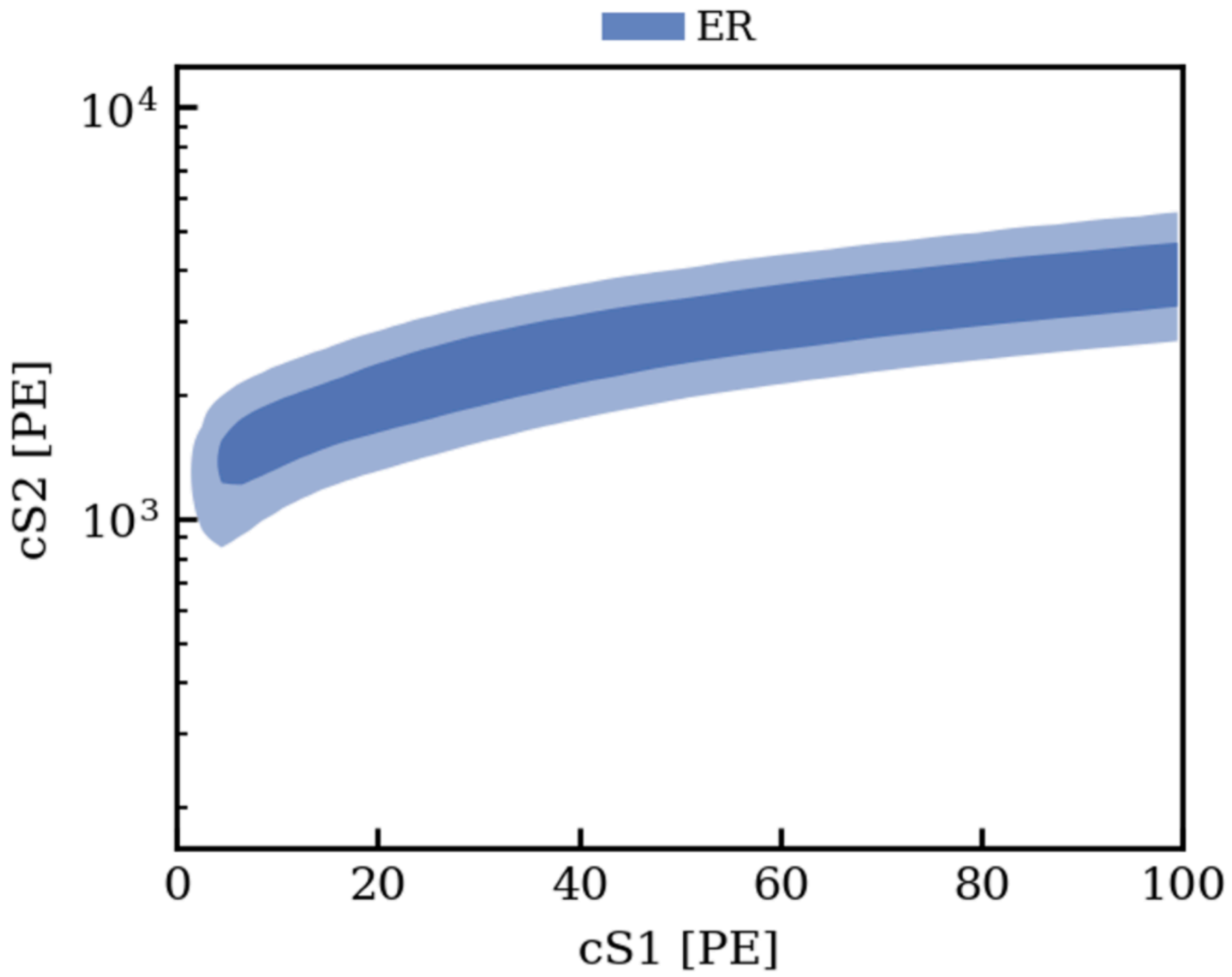
- Search in cS1-cS2 space
- Adopted same detection efficiency as a function of photons detected as in low ER search
- Almost the same S1/S2 peak quality data selection as in low ER search

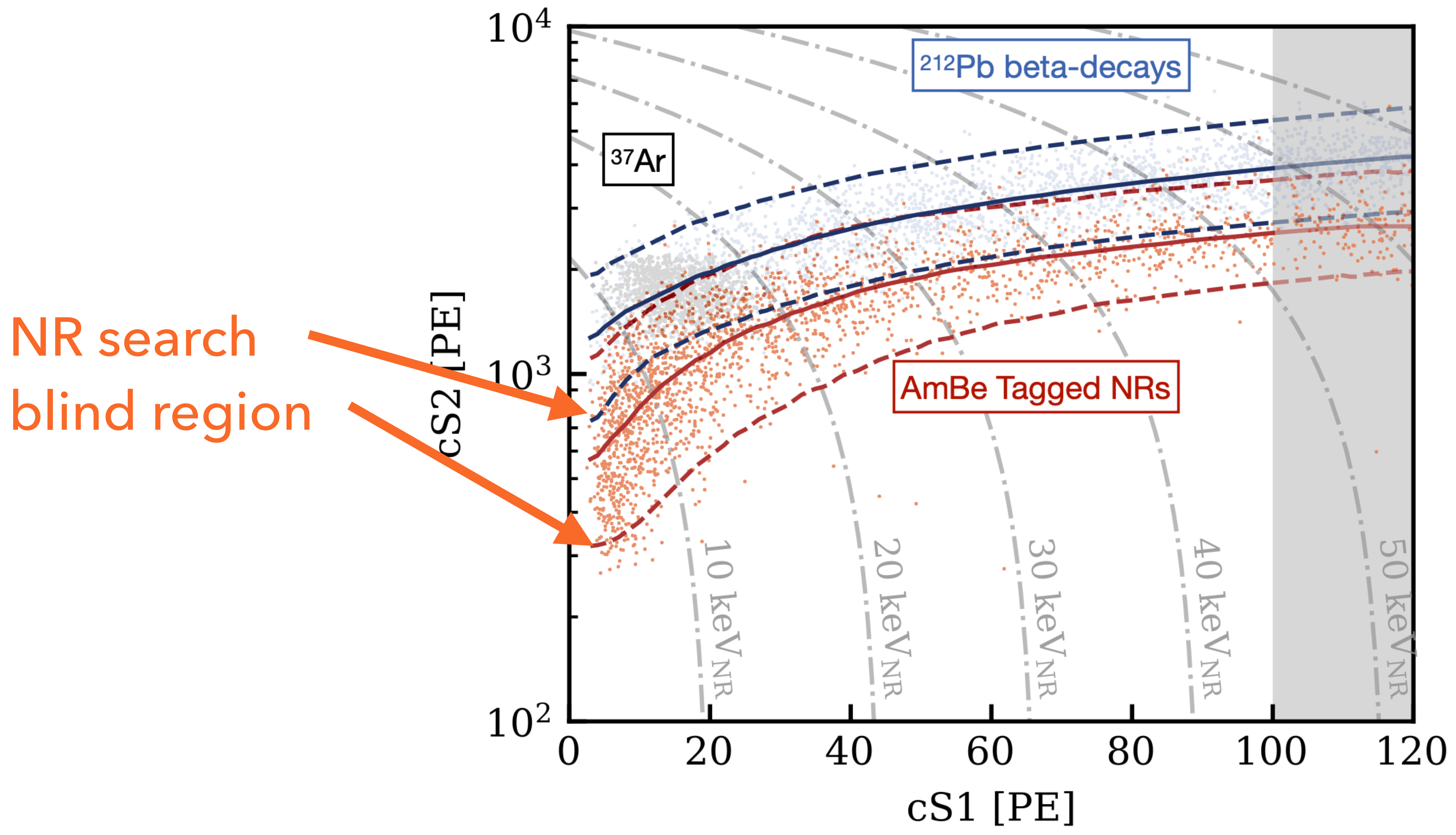


# BACKGROUNDS

- **Low ER leakage into WIMP ROI**
  - **Dominated by beta decays from $^{214}Pb$ a daughter of $^{222}Rn$**
  - **Prior to unblinding, 134 events are found in the ER band of the ROI.**
  - **Estimated Fraction events below NR band median: 1.1%**



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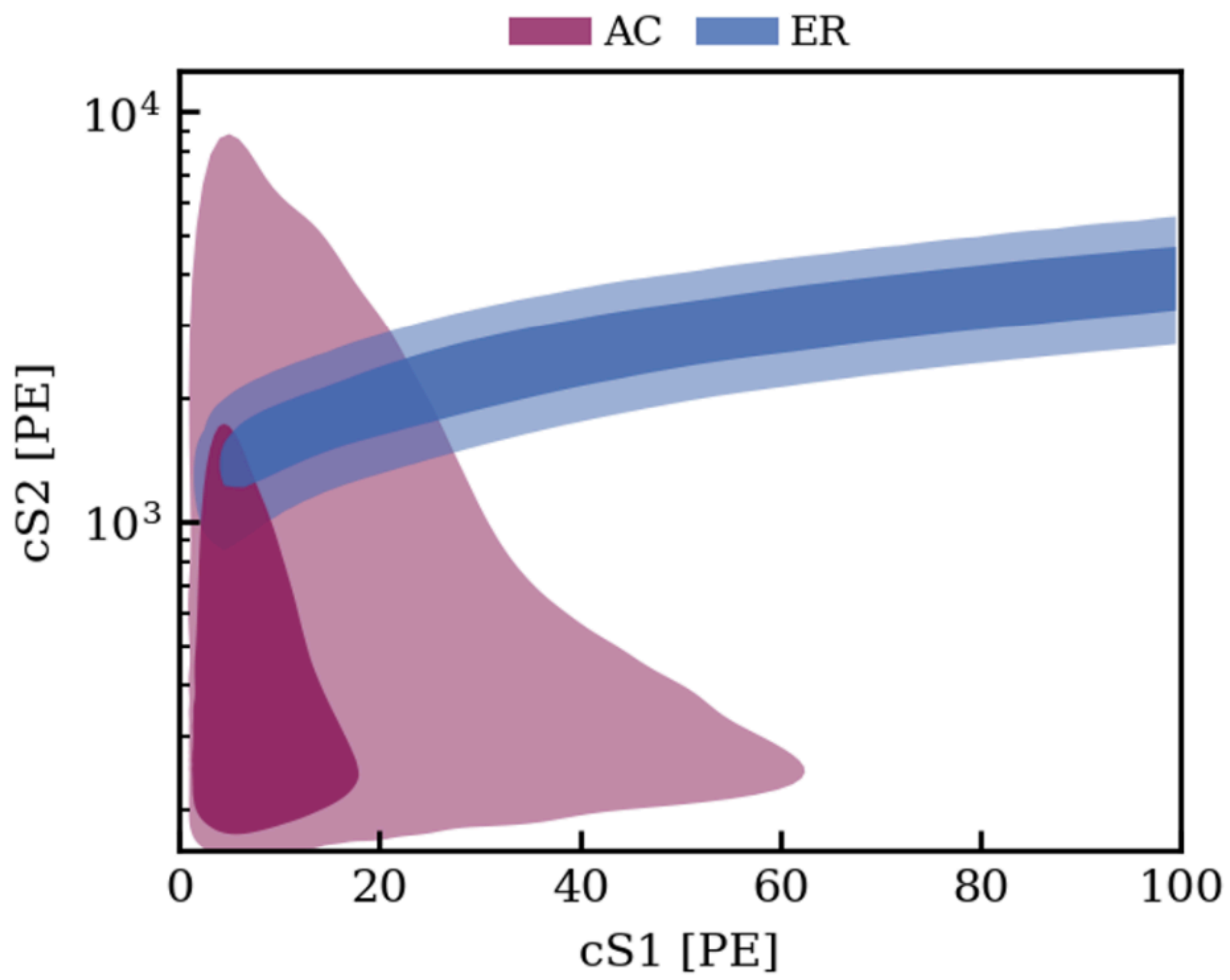
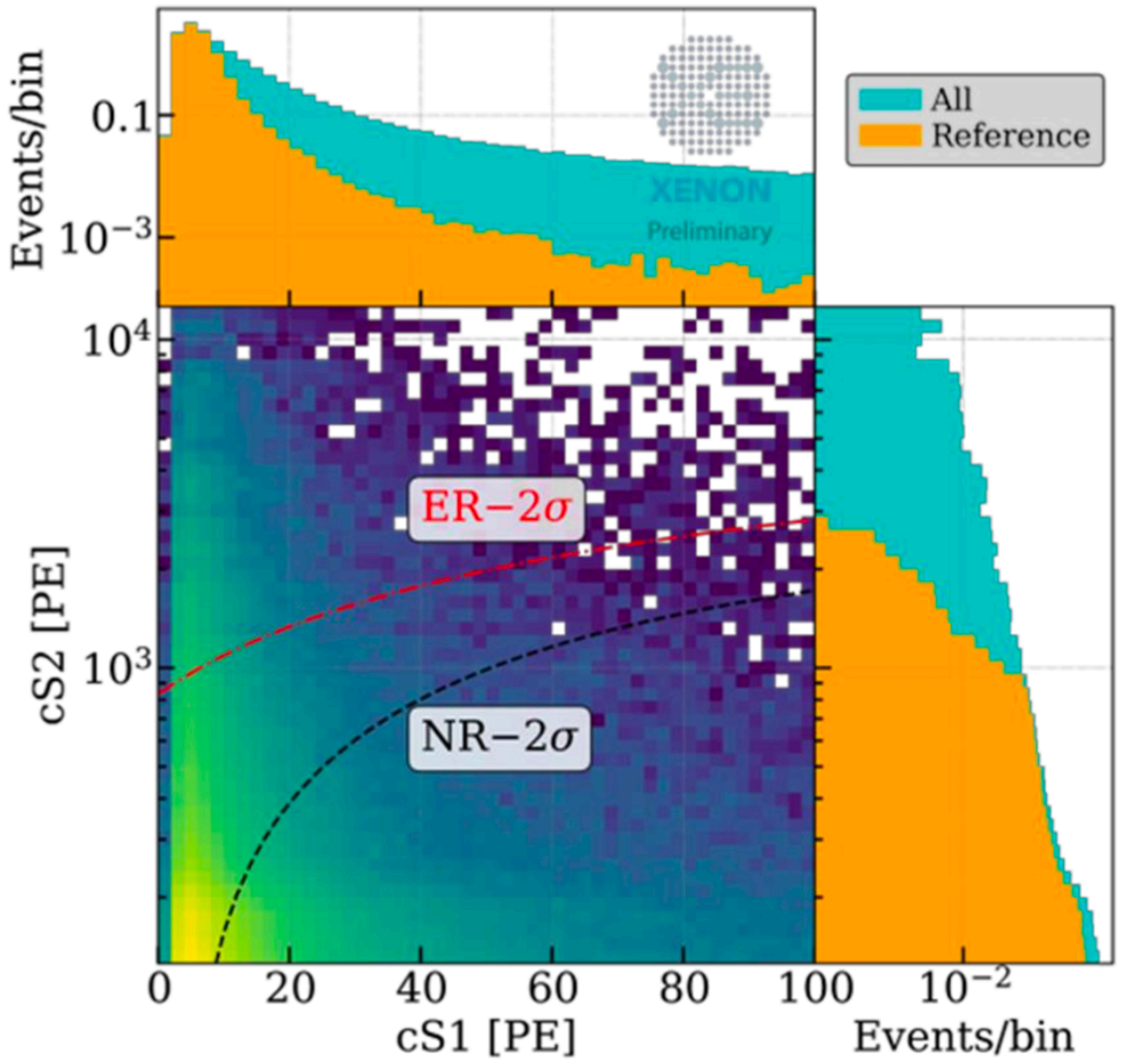
- **Accidental coincidences**
  - **Random unphysical pairing of S1 and S2 signals**
  - **Strongly suppressed based on a gradient boosted decision tree, using S2 shape, are and Z information**




Template generated by pairing isolated S1/S2 and their ambience

validated on sidebands (all cuts but not S2 width+S2 BDT) and low energy calibrations



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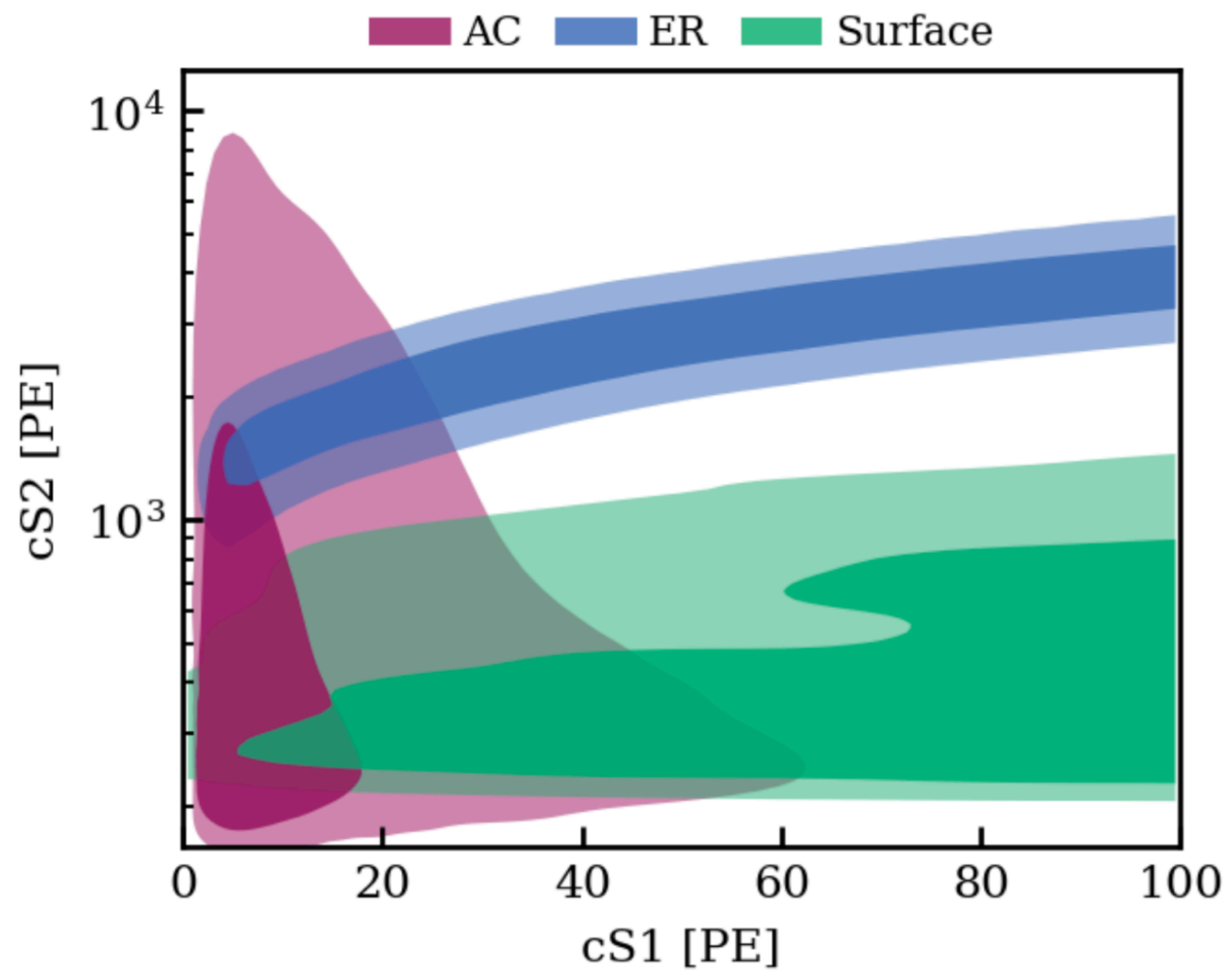
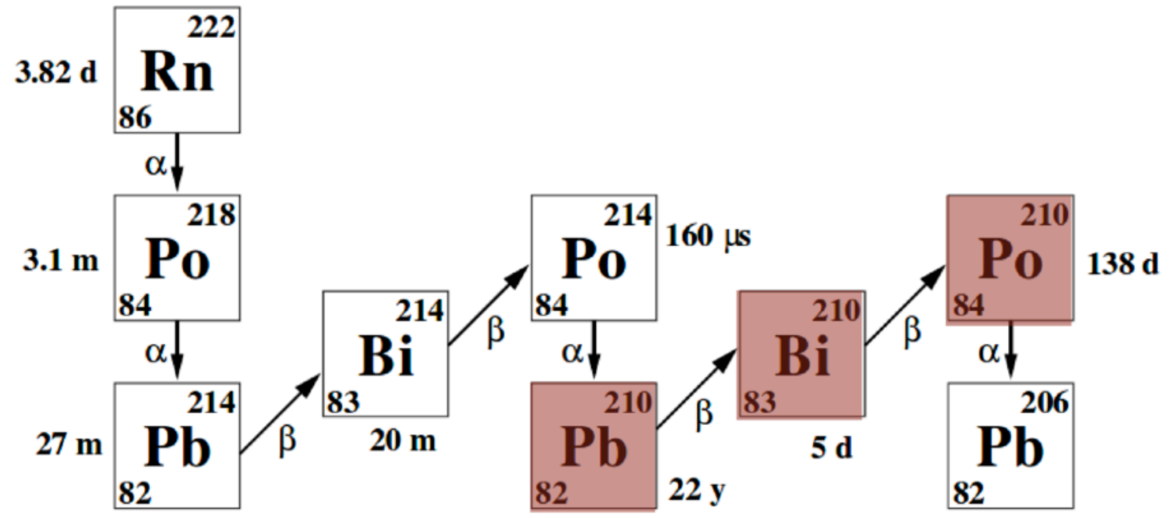
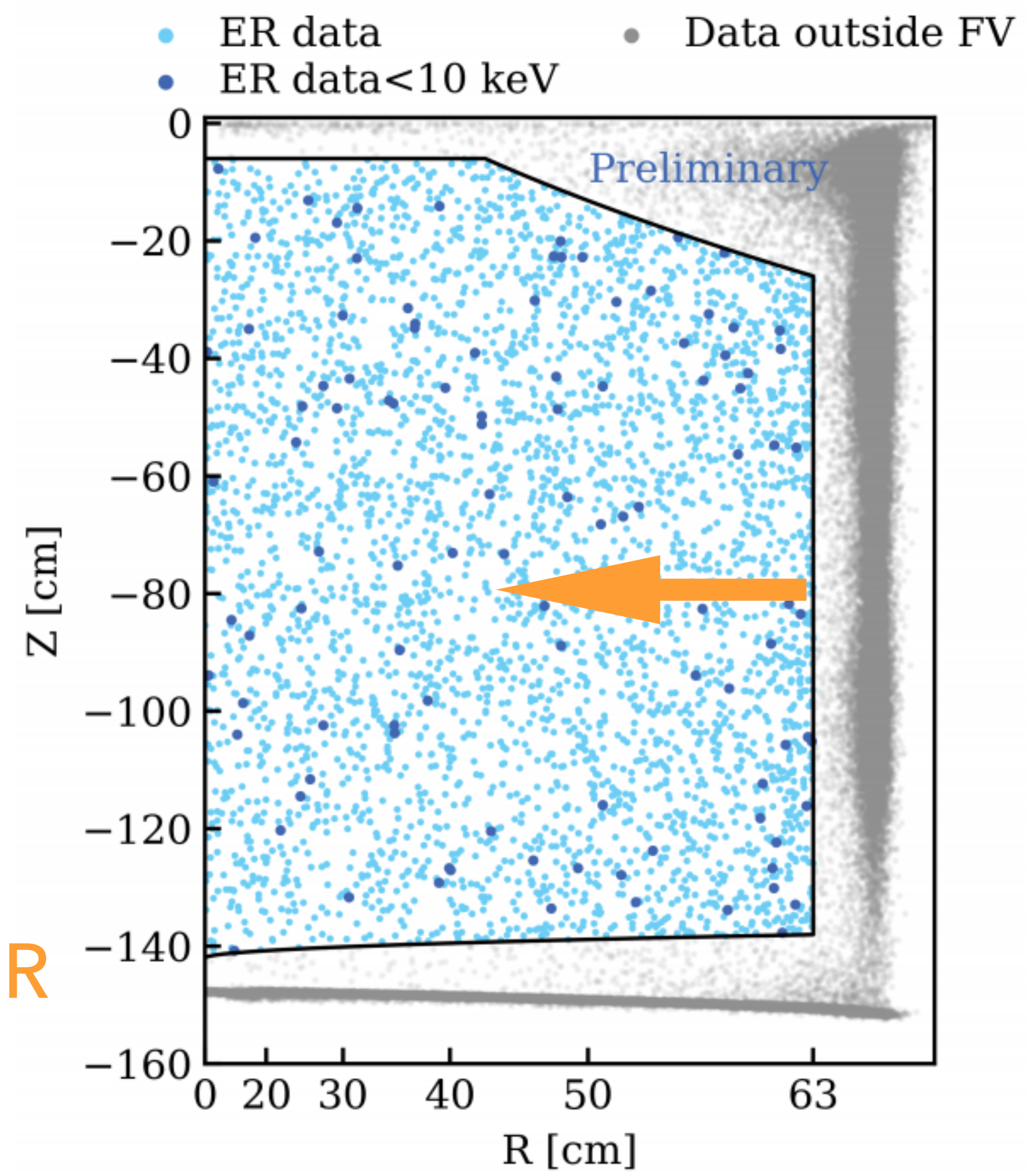
- **Surface background model**
  - **“Surface” events due to ERs from $^{210}$Pb plate out at detector walls (with charge loss)**
  - **Use events reconstructed outside the fiducial volume and a KDE to create a smooth template for ROI**
  - **Fine-tuned fiducial volume radius to suppress**




FV is more stringent than ER



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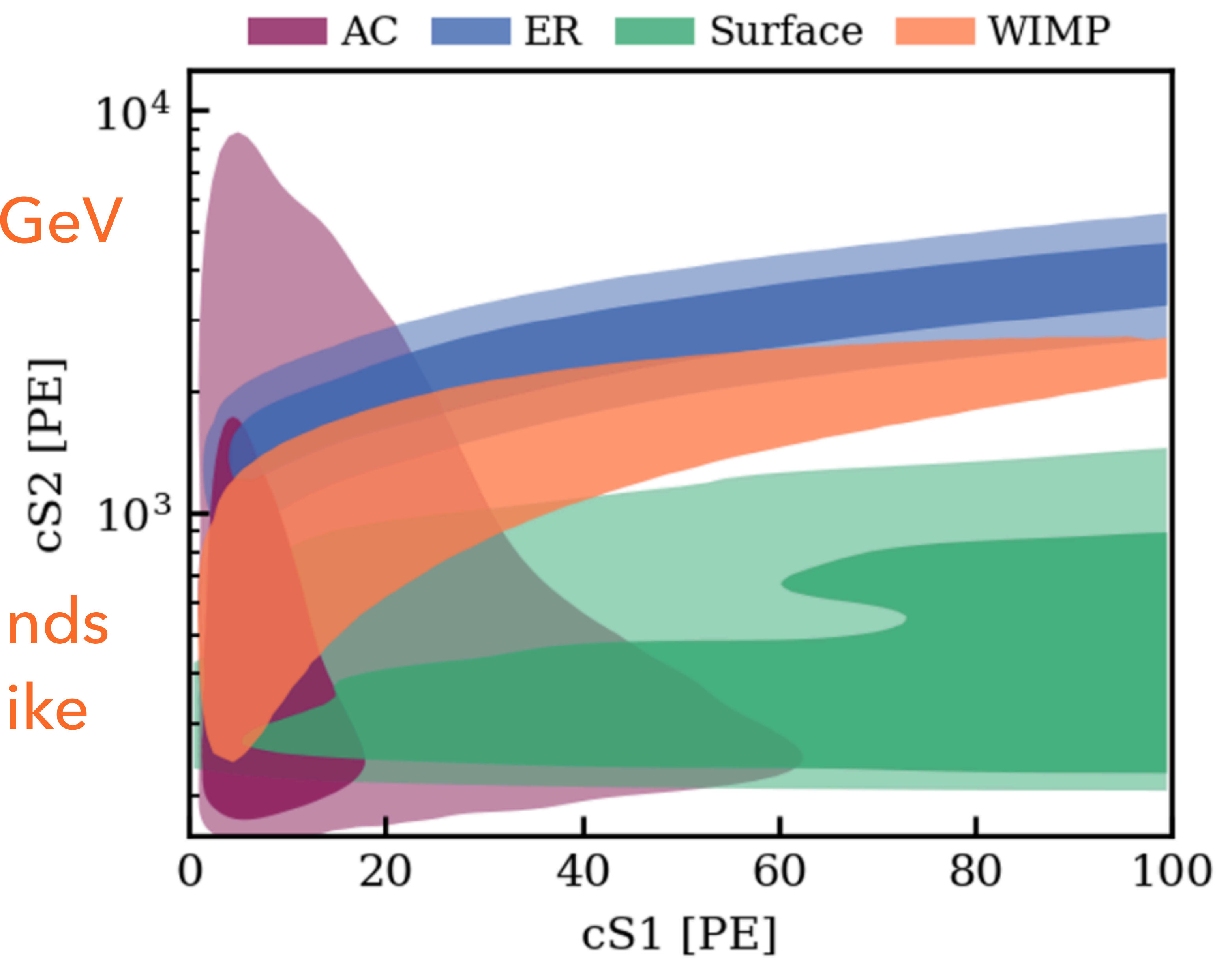
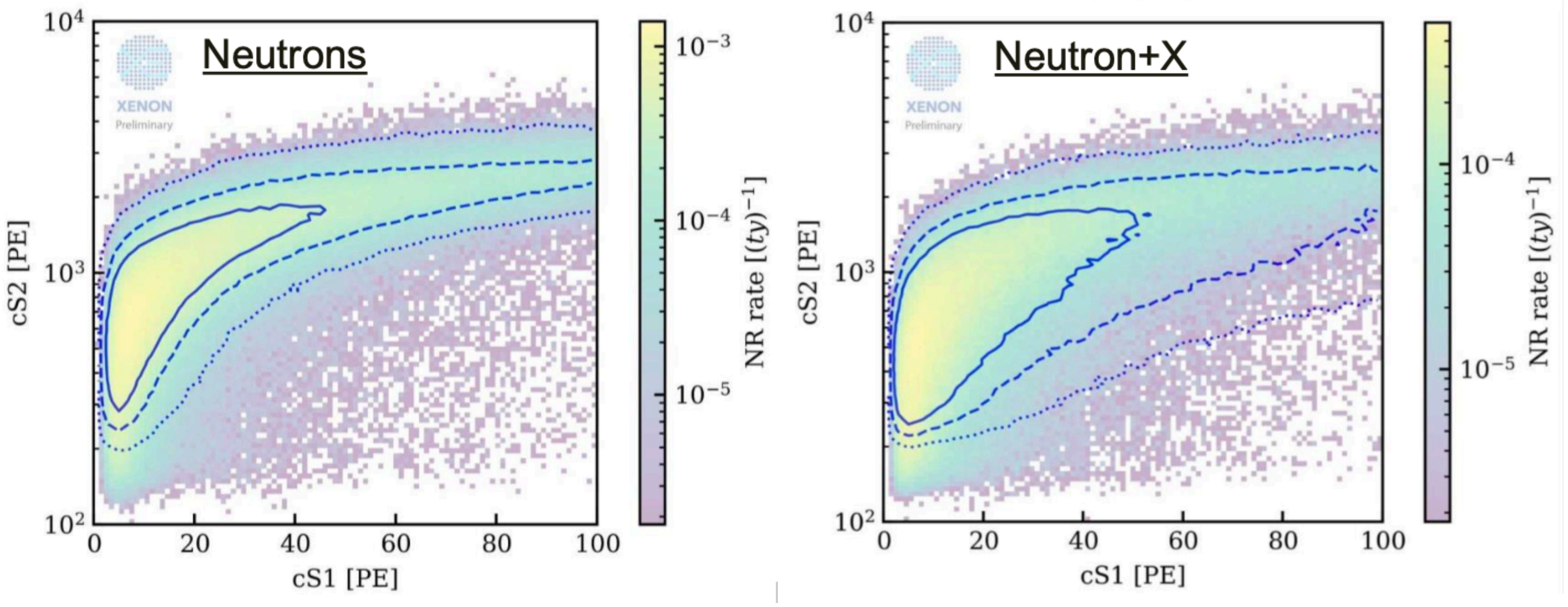
  - "Surface" events due to ERs from $^{210}Pb$ plate out at detector walls (with charge loss)
  - Use events reconstructed outside the fiducial volume and a KDE to create a smooth template for ROI
  - Fine-tuned fiducial volume radius to suppress
- **NR background**
  - **Neutron events from spontaneous fission and (α,n) reactions**
  - **CEVNS (negligible)**

2σ contour of 200GeV WIMP template

Neutron backgrounds looks very similar like WIMP!

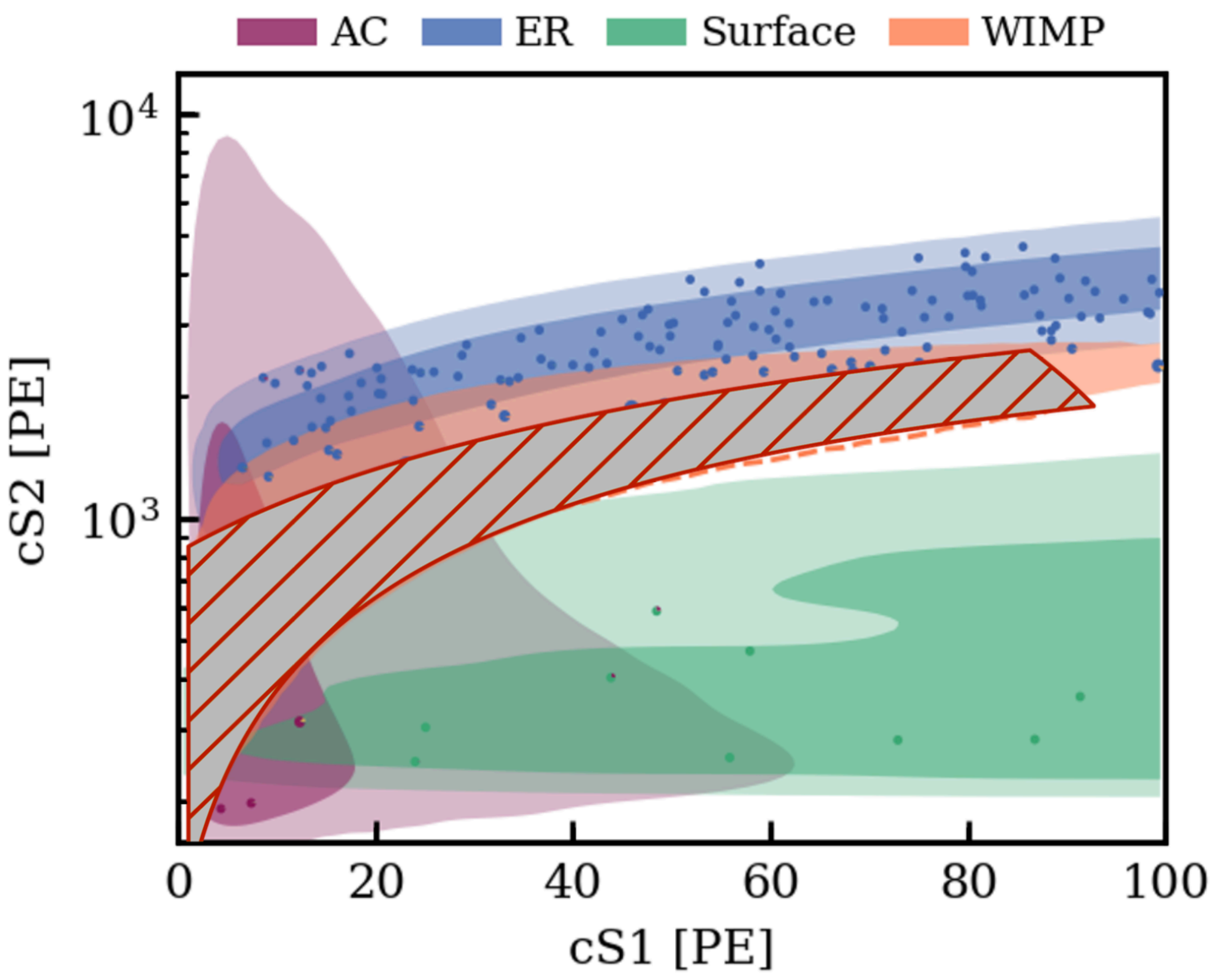



Background templates generated via full-scale Neutrons waveform simulations + analysis chain

# UNBLINDING

| | Nominal | Best Fit | |
|---|---|---|---|
| | ROI | | Signal-like |
| ER | 134 | | |
| Neutrons | $1.1^{+0.6}_{-0.5}$ | | |
| CE$\nu$NS | $0.23 \pm 0.06$ | | |
| AC | $4.3 \pm 0.9$ | | |
| Surface | $14 \pm 3$ | | |
| Total Background | 154 | | |
| WIMP | - | | |
| Observed | - | | |

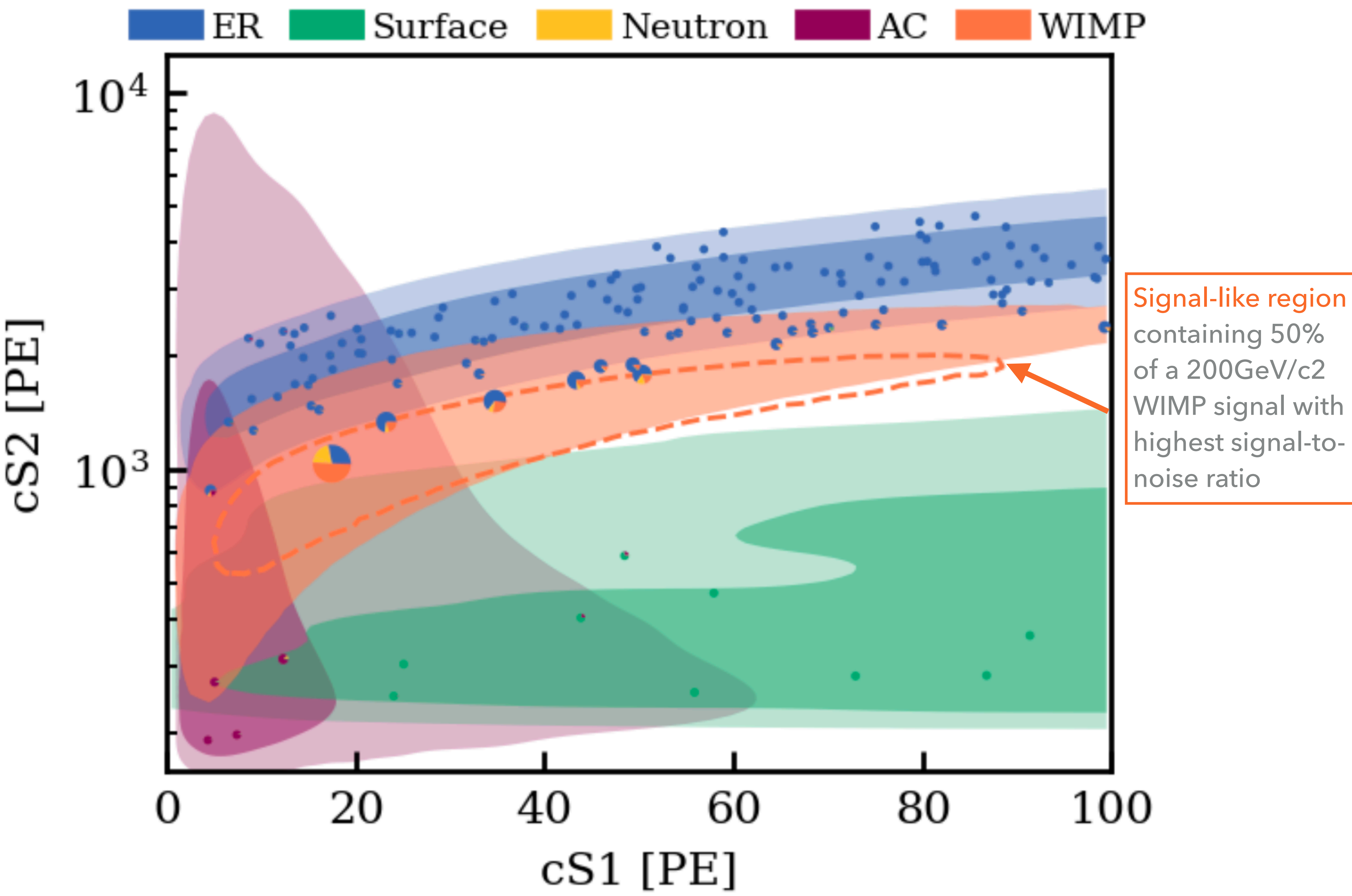


# UNBLINDING

- **No significant excess**

| | Nominal | Best Fit | |
|---|---|---|---|
| | ROI | | Signal-like |
| ER | 134 | $135^{+12}_{-11}$ | $0.92 \pm 0.08$ |
| Neutrons | $1.1^{+0.6}_{-0.5}$ | $1.1 \pm 0.4$ | $0.42 \pm 0.16$ |
| CE$\nu$NS | $0.23 \pm 0.06$ | $0.23 \pm 0.06$ | $0.022 \pm 0.006$ |
| AC | $4.3 \pm 0.9$ | $4.4^{+0.9}_{-0.8}$ | $0.32 \pm 0.06$ |
| Surface | $14 \pm 3$ | $12 \pm 2$ | $0.35 \pm 0.07$ |
| Total Background | 154 | $152 \pm 12$ | $2.03^{+0.17}_{-0.15}$ |
| WIMP | - | 2.6 | 1.3 |
| Observed | - | 152 | 3 |

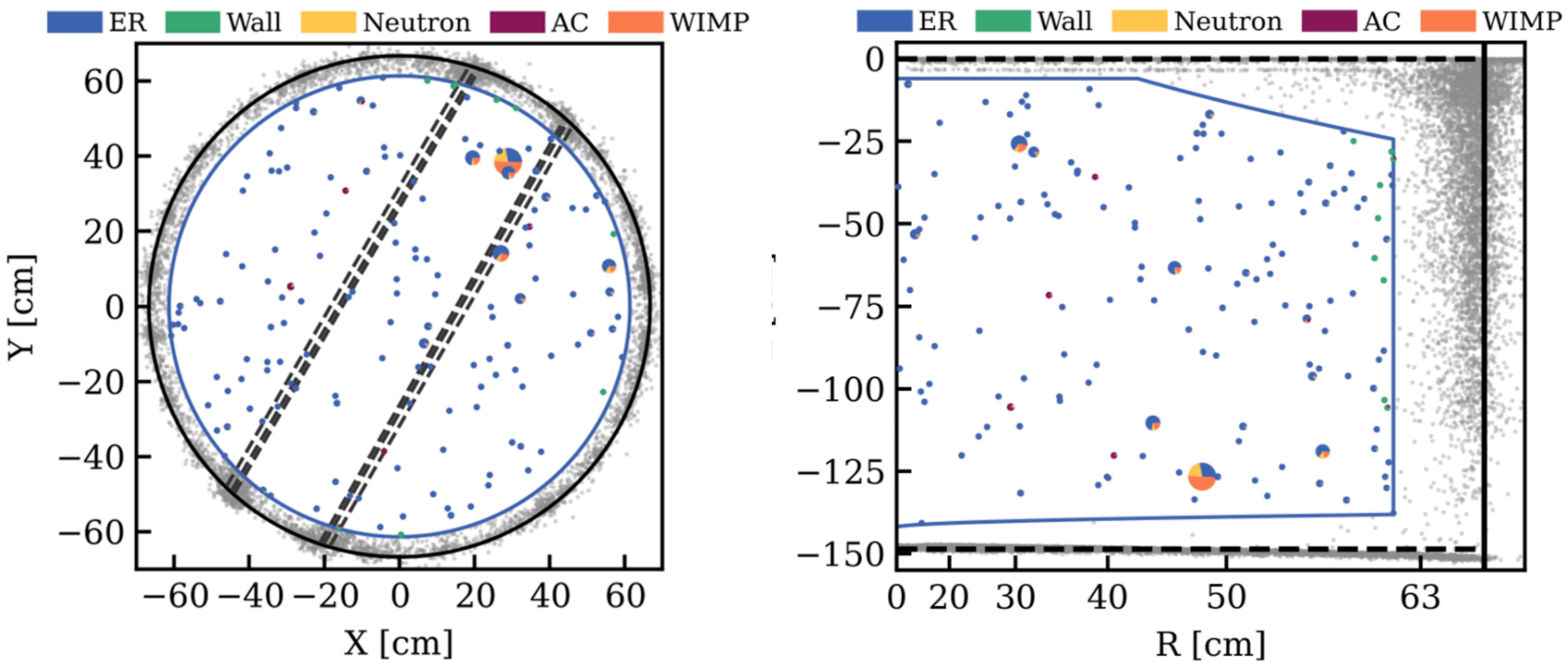
152 events in ROI, 16 in NR blinded region




**(Assuming there is WIMP!)** Event represented with pie-chart showing the fraction of the best-fit PDF for a 200 GeV/c2 mass WIMP

# UNBLINDING

- **Asymmetric event spatial distribution??**
- Checked x-y distribution of the following and found no spatial preference
  - Data selection cuts
  - Detector effect correction
  - Unblinded events in ER band
- No significant angular preference in materials
- No significant angular preference in unblinded ER events near NR band

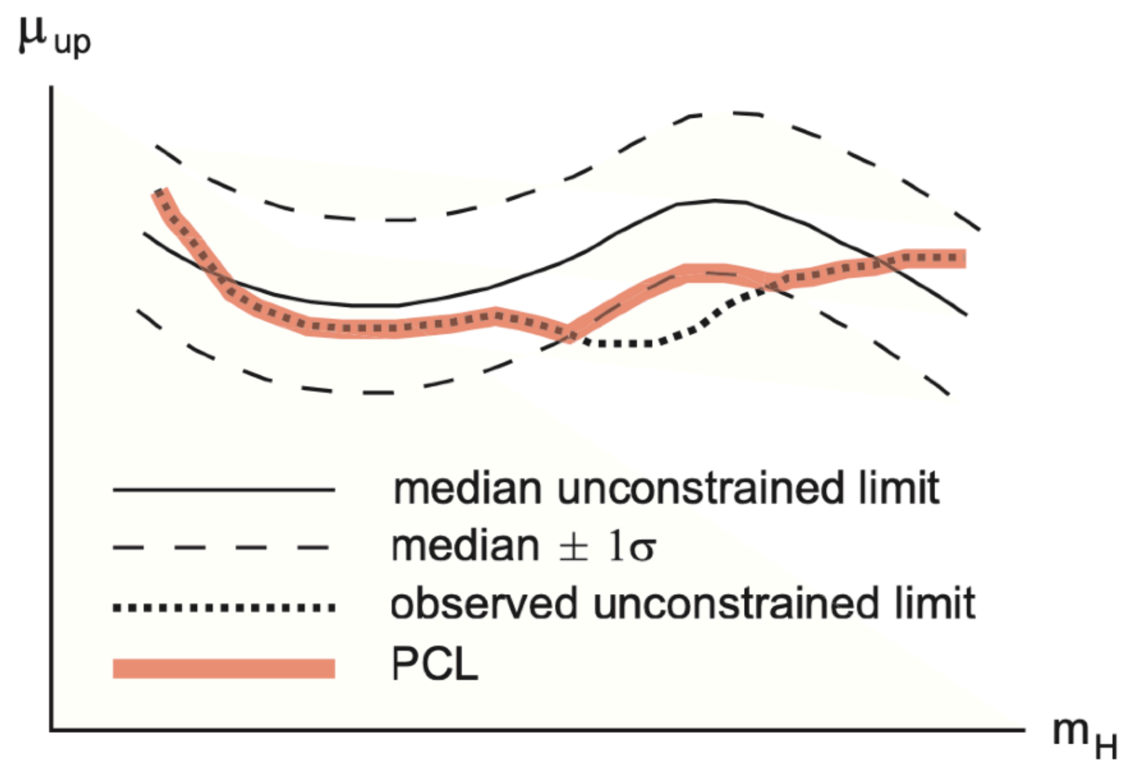


# LIMITS ON WIMP SI INTERACTION WITH NUCLEONS

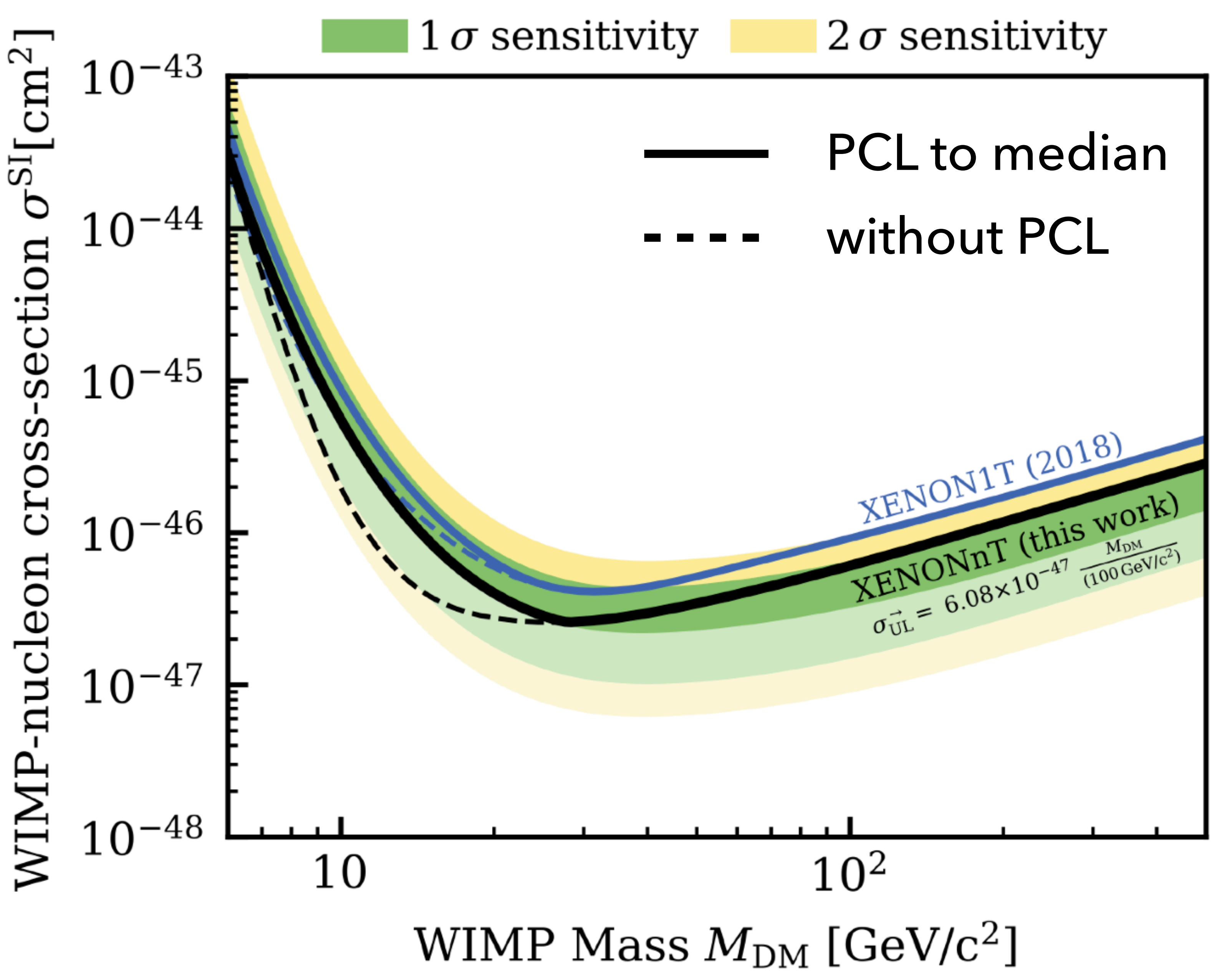
- Median upper limit @ 90% confidence (Feldman-Cousin construction obtained by MC) for Log-Profiled-Likelihood-ratio

$$q(\sigma) = -2\log\frac{L(\sigma,\hat{\hat{\theta}})}{L(\hat{\sigma},\hat{\theta})}$$

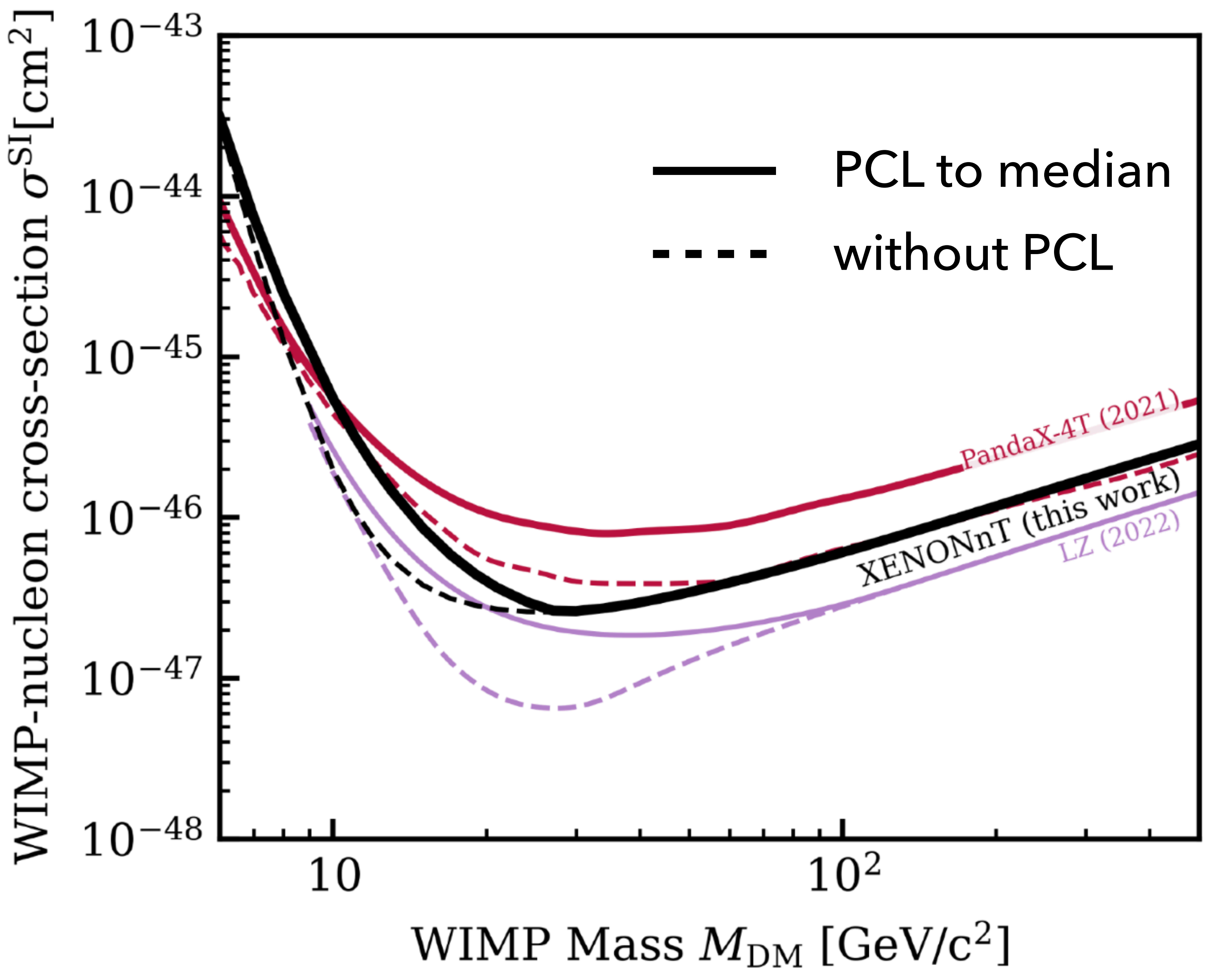
- **Blinded WIMP dark matter search with 1.1 tonne-year exposure**




Power constraint limits (PCL) to avoid problematic spurious exclusion




Comparison to other **blinded** analysis




Comparison to other **unblinded** analysis

# LIMITS ON WIMP SD INTERACTION WITH NUCLEONS

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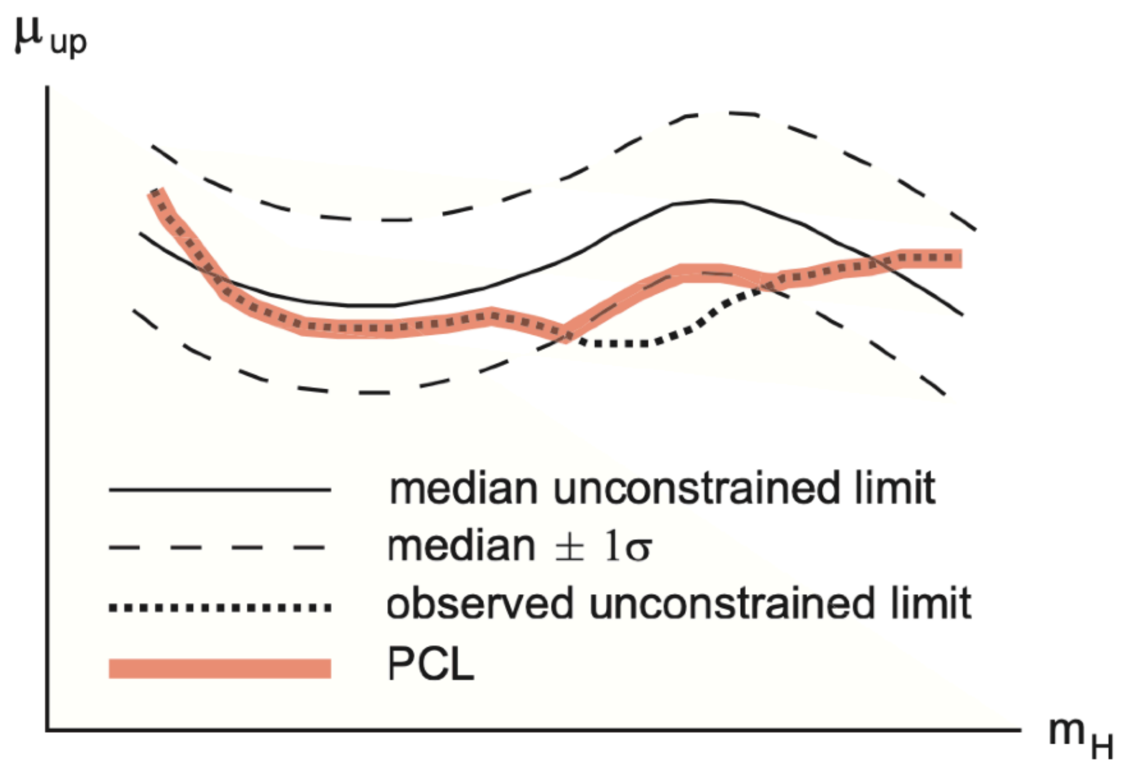


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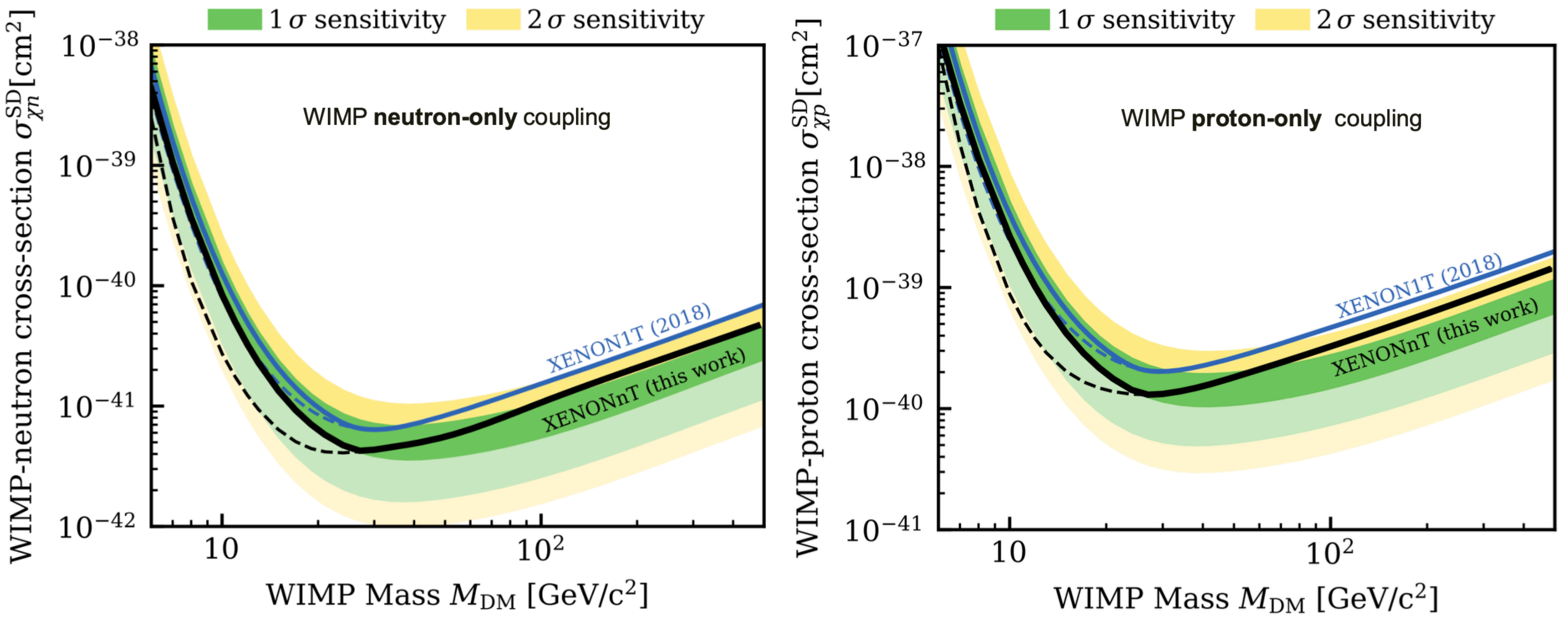


Sensitive in $^{129}$Xe and $^{131}$Xe only

# ROADMAP

- Dark Matter Direct Detection
- The XENONnT Detector
- Detector Calibration
- First Low Energy Electronic Recoil Search Result
- First Nuclear Recoil Search Result
- **Search in Other Channels**

# $^8$B COHERENT ELASTIC NEUTRINO-NUCLEUS SCATTERING (CEVNS)

- CEvNS: a long-wavelength (low momentum transfer) Z boson can probe the entire nucleus, and interact with it as a whole
- **"neutrino fog" from solar $^8$B neutrinos, with ~1keV$_{NR}$ NR signature in NR**
- **Same analysis searches for light dark matter**
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- Major background: Accidental Coincidence
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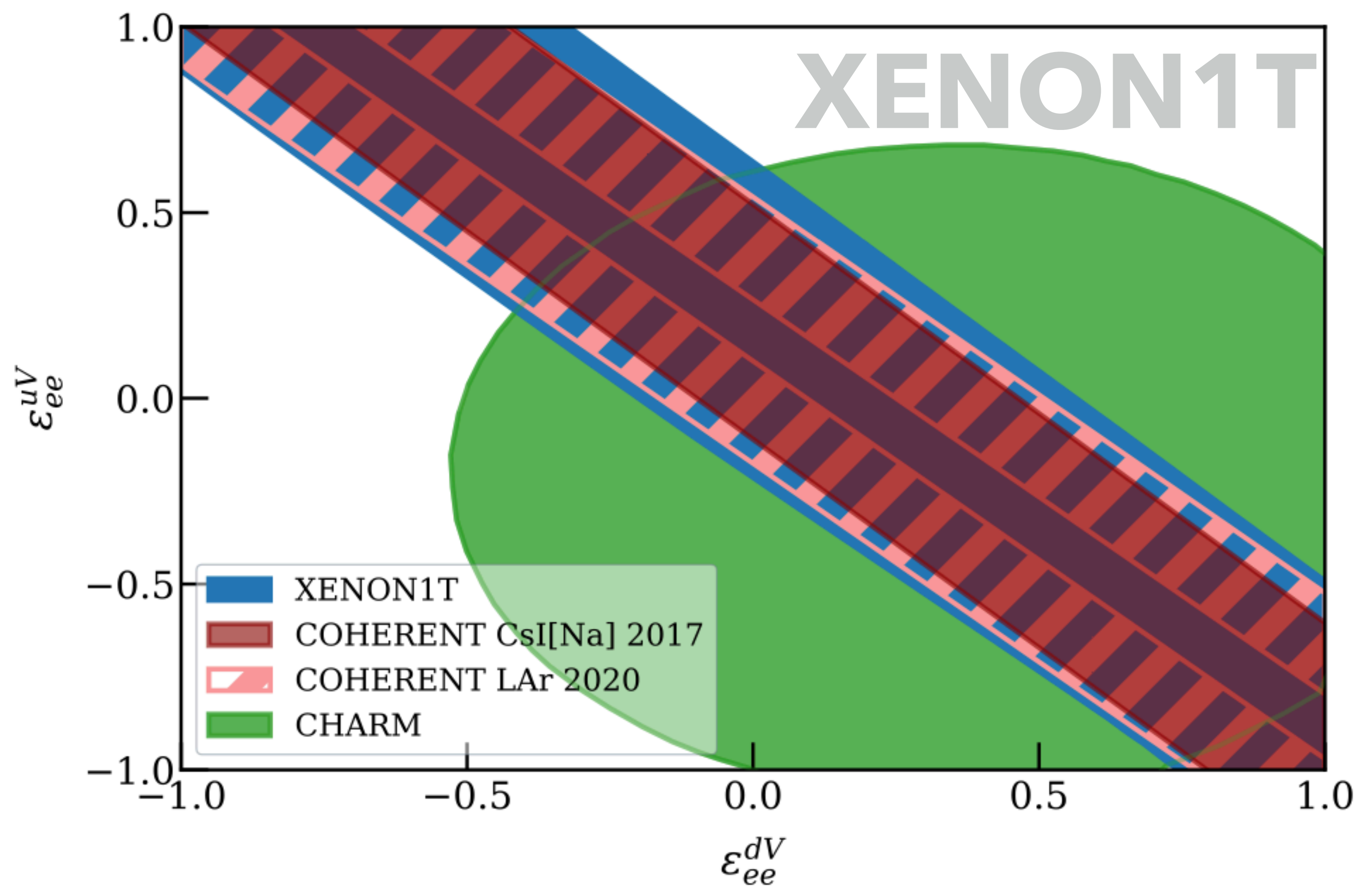
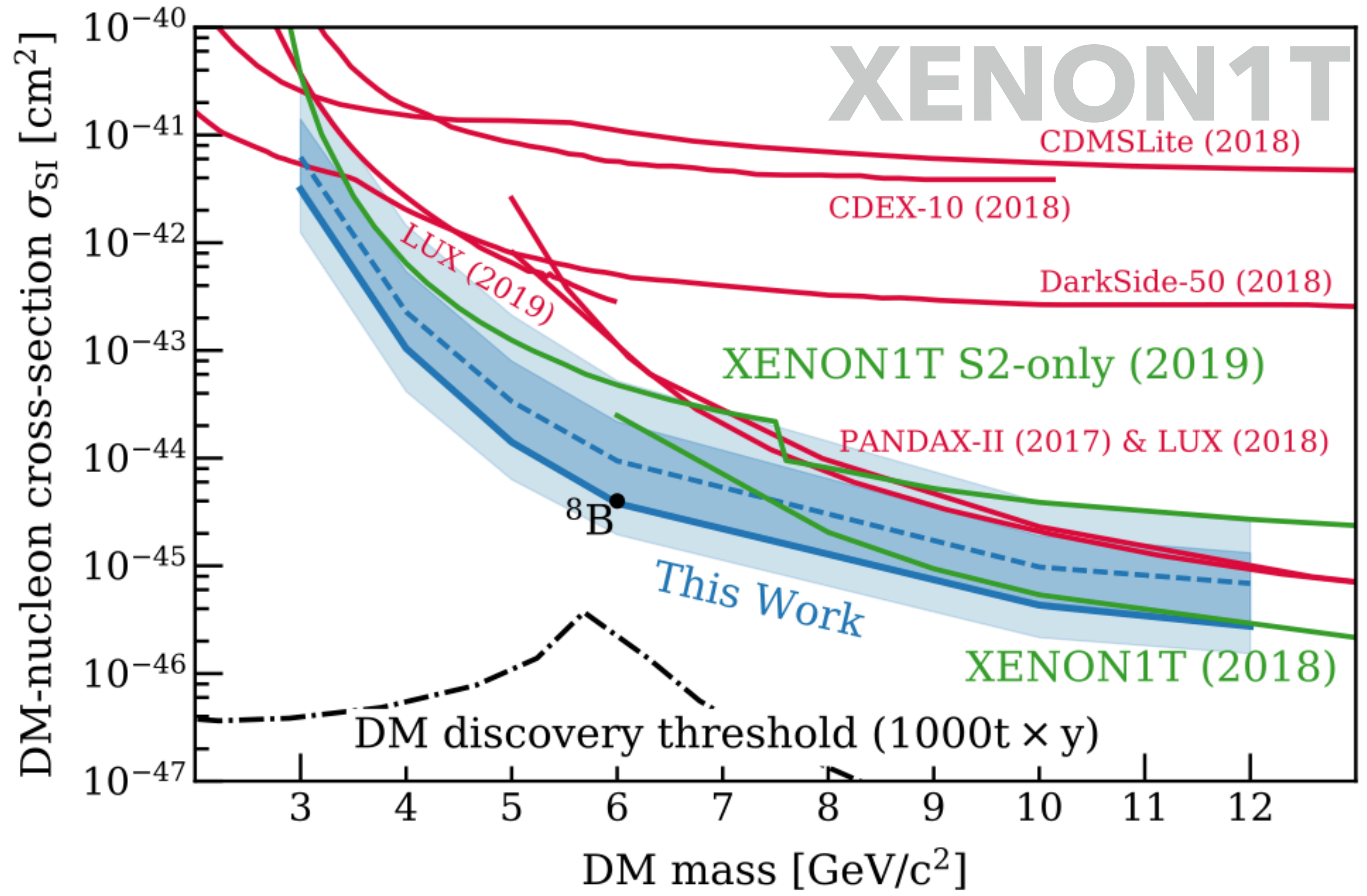



Constraints on non-standard vector couplings between the electron neutrino and quarks

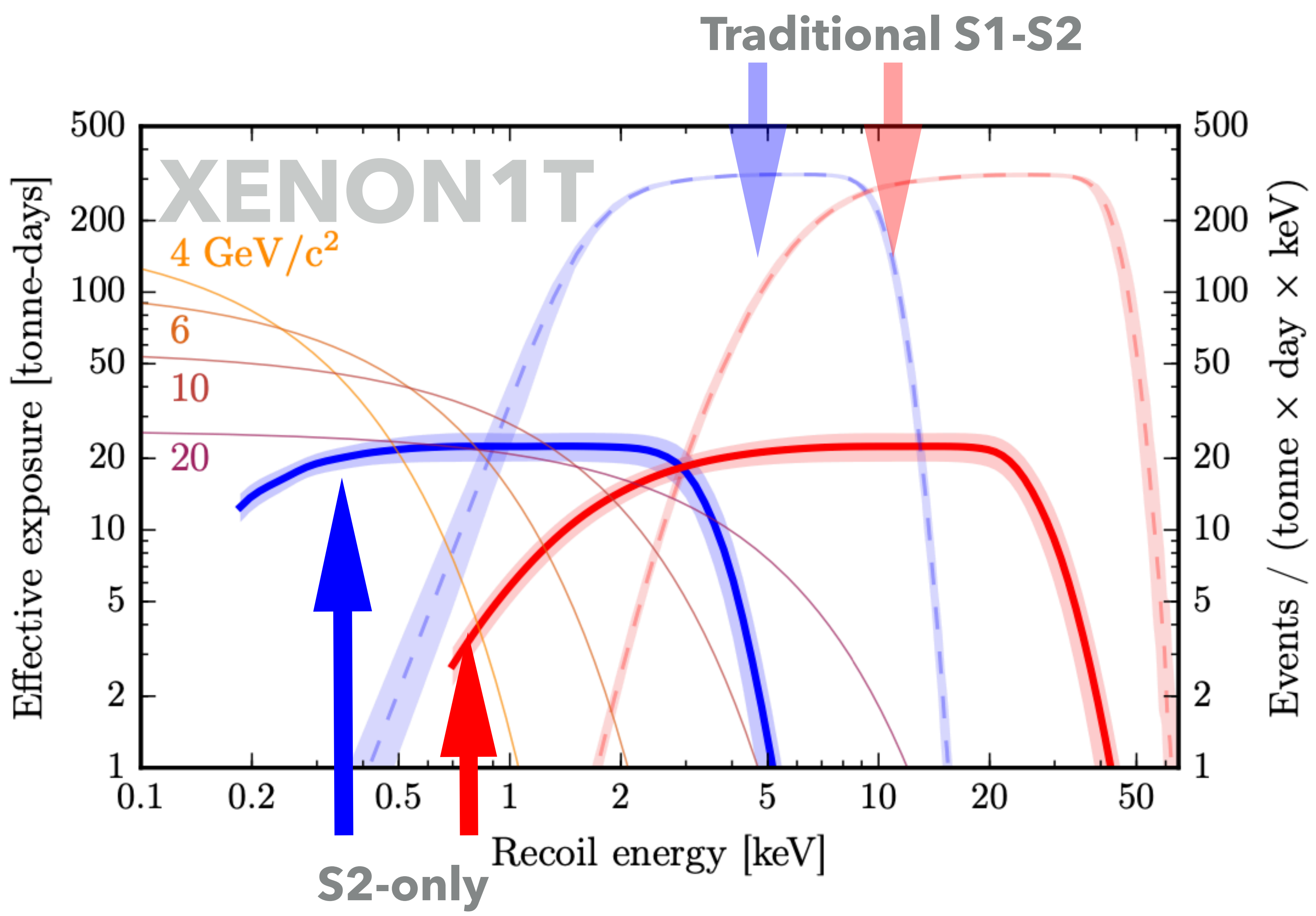
XENON1T $^8$B CEvNS: 2 events

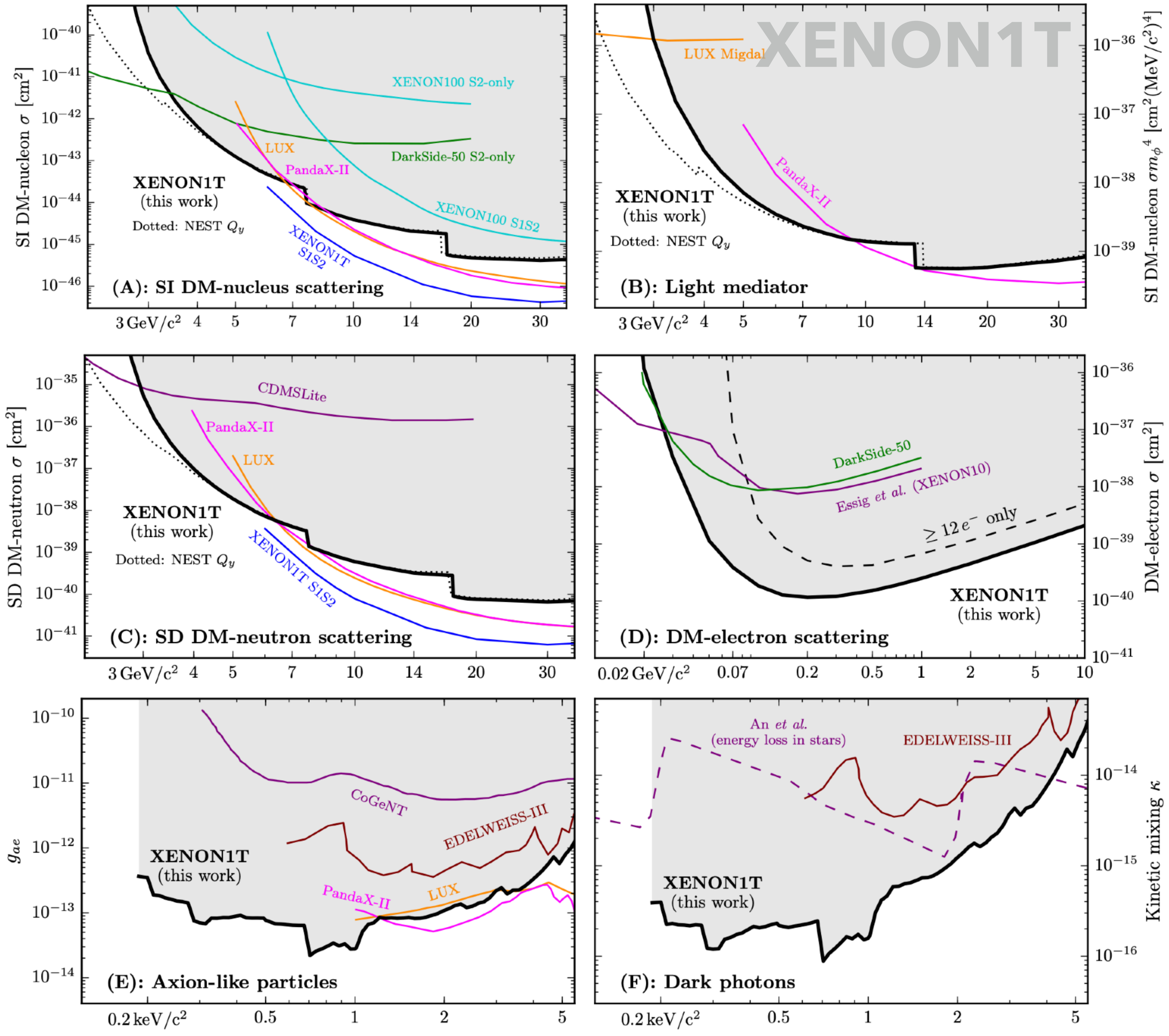



Low mass spin-independent DM-nucleon cross section

# S2-ONLY SEARCH FOR LIGHT DARK MATTER

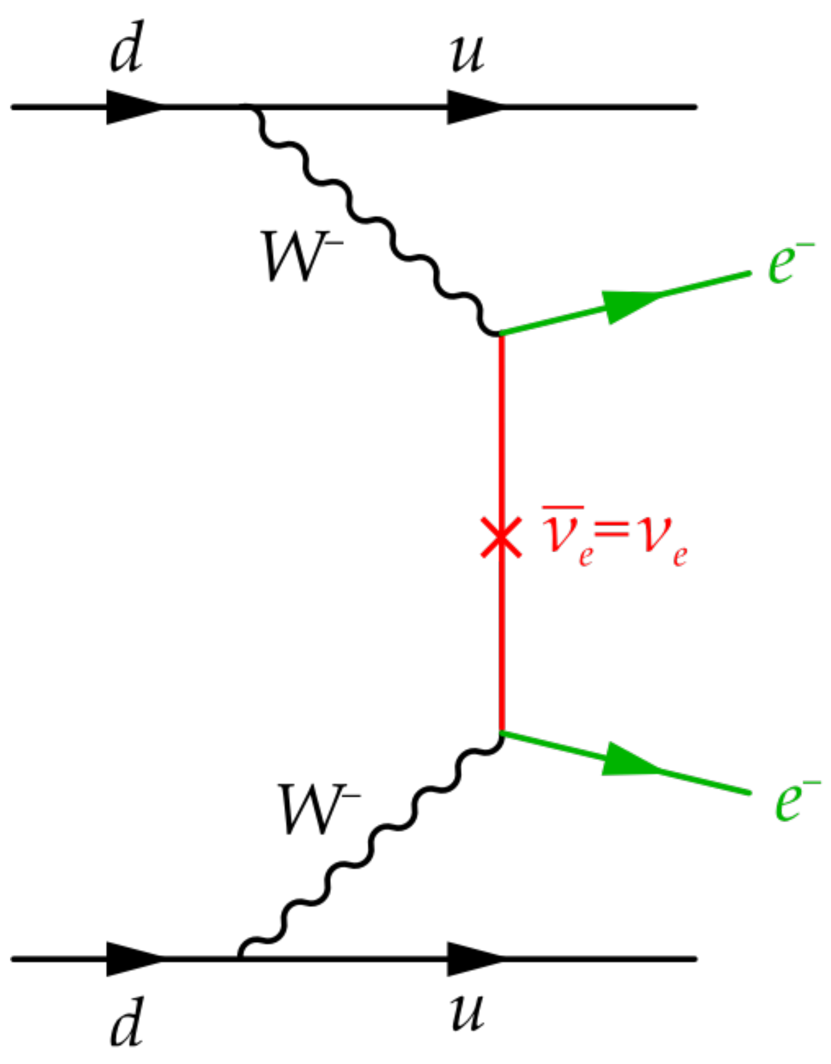
- Can extend search (without discovery power) to S2-only signals for DM with low recoil energy
- With better S2-only background modeling, larger exposure with triggerless DAQ, and very high electron lifetime, **XENONnT will give much stringent constraints soon**

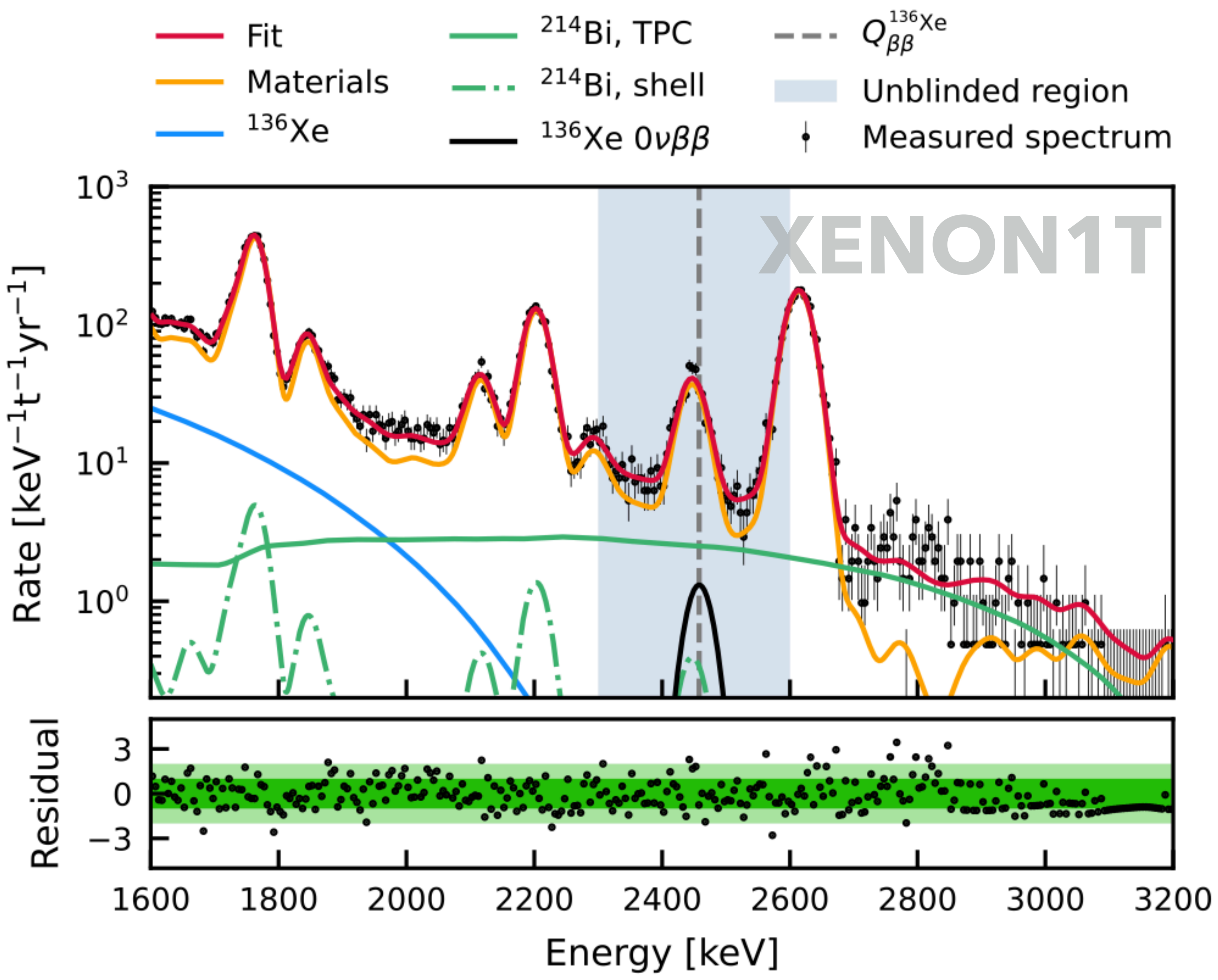


# SEARCH FOR NEUTRINO-LESS DOUBLE BETA DECAY

- **XENON1T demonstrated feasibility of 0$\nu$bb search in future LXeTPC DM experiments**



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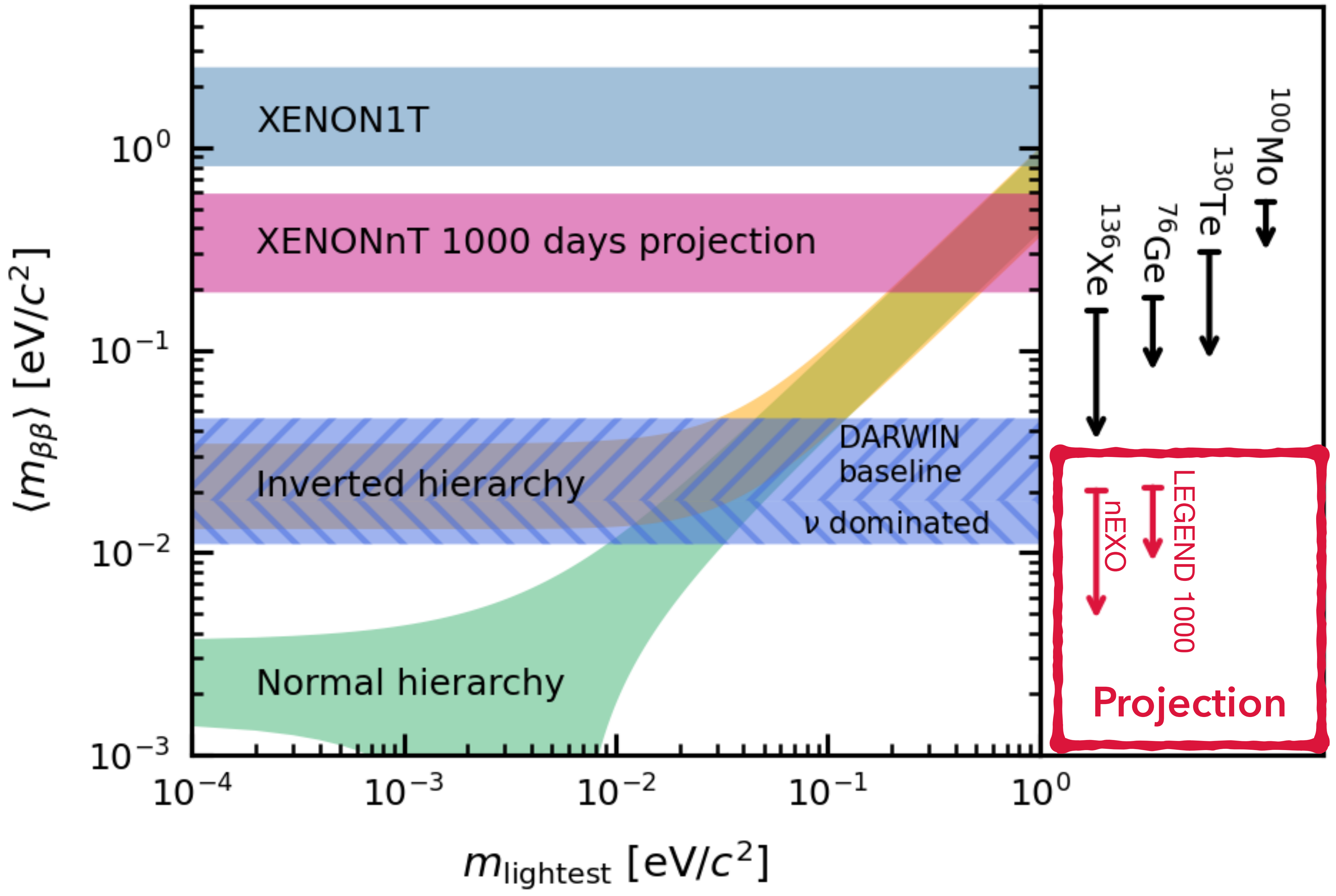
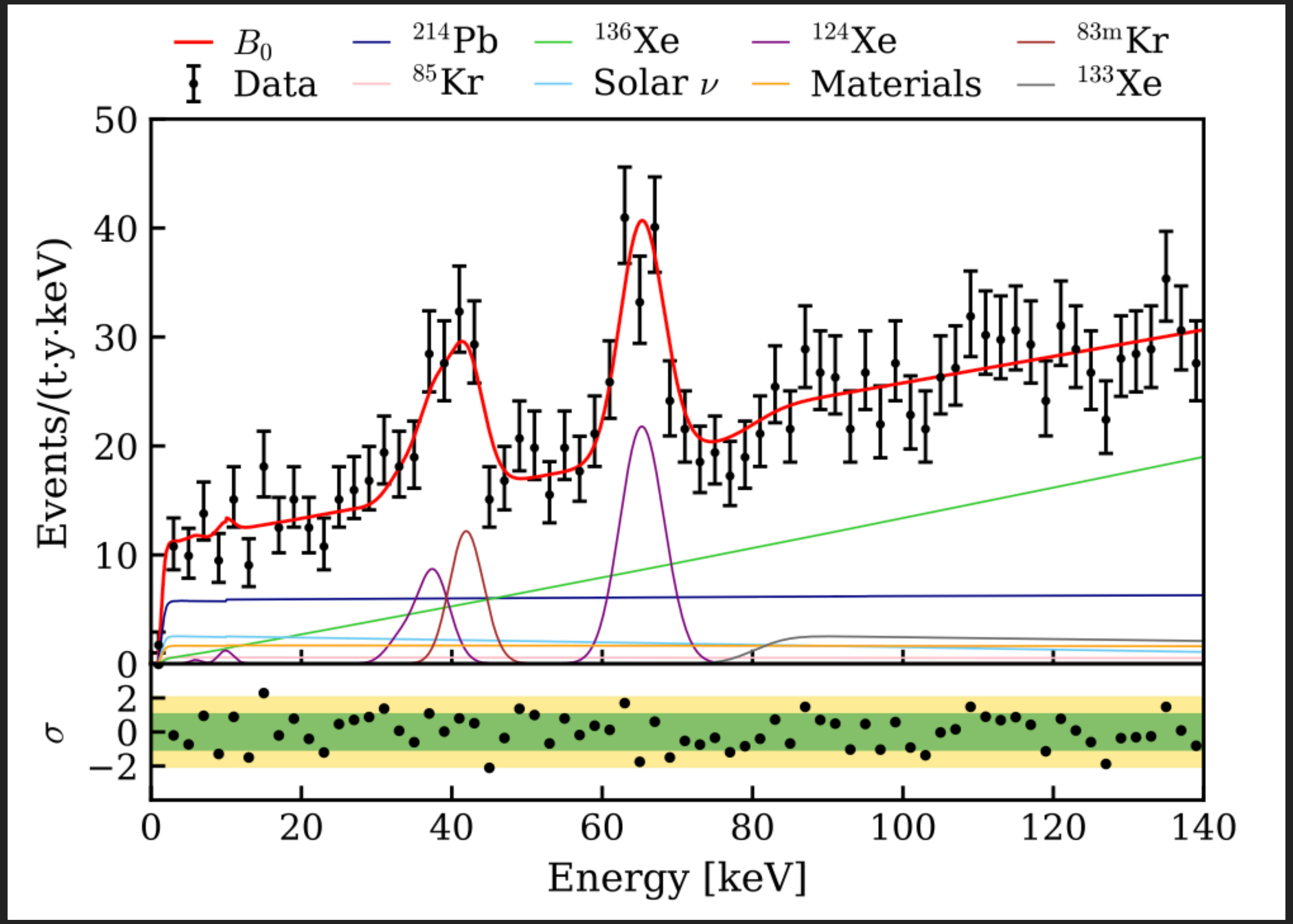
- XENON1T demonstrated feasibility of $0\nu bb$ search in future LXeTPC DM experiments
- Not competitive with dedicated experiments due to
  - Non-enriched target
  - Background optimization for DM search (SS Cryostat)
- Additional analysis work needed to push further the sensitivity to be competitive
- **XLZD approaches sensitivities of future tonne-scale $0\nu\beta\beta$ experiments while being dedicated to DM search**



# CONCLUSIONS AND OUTLOOK

- Blinded analysis of ER data with 1.1 tonne-year exposure
  - Excluded XENON1T excess
  - Unprecedented low ER background (15.8±1.3) events/(t·y·keV)
- Blinded WIMP dark matter search with same data in SR0
  - Best limit for SI at $2.6 \cdot 10^{-47}$cm$^2$ at 28GeV
- SR1 data taking ongoing for many months
  - Further reduction of 222Rn content due to GXe + LXe radon distillation
  - Lower neutron background powered by Gd-loading NV
- Searches in other channels ongoing…



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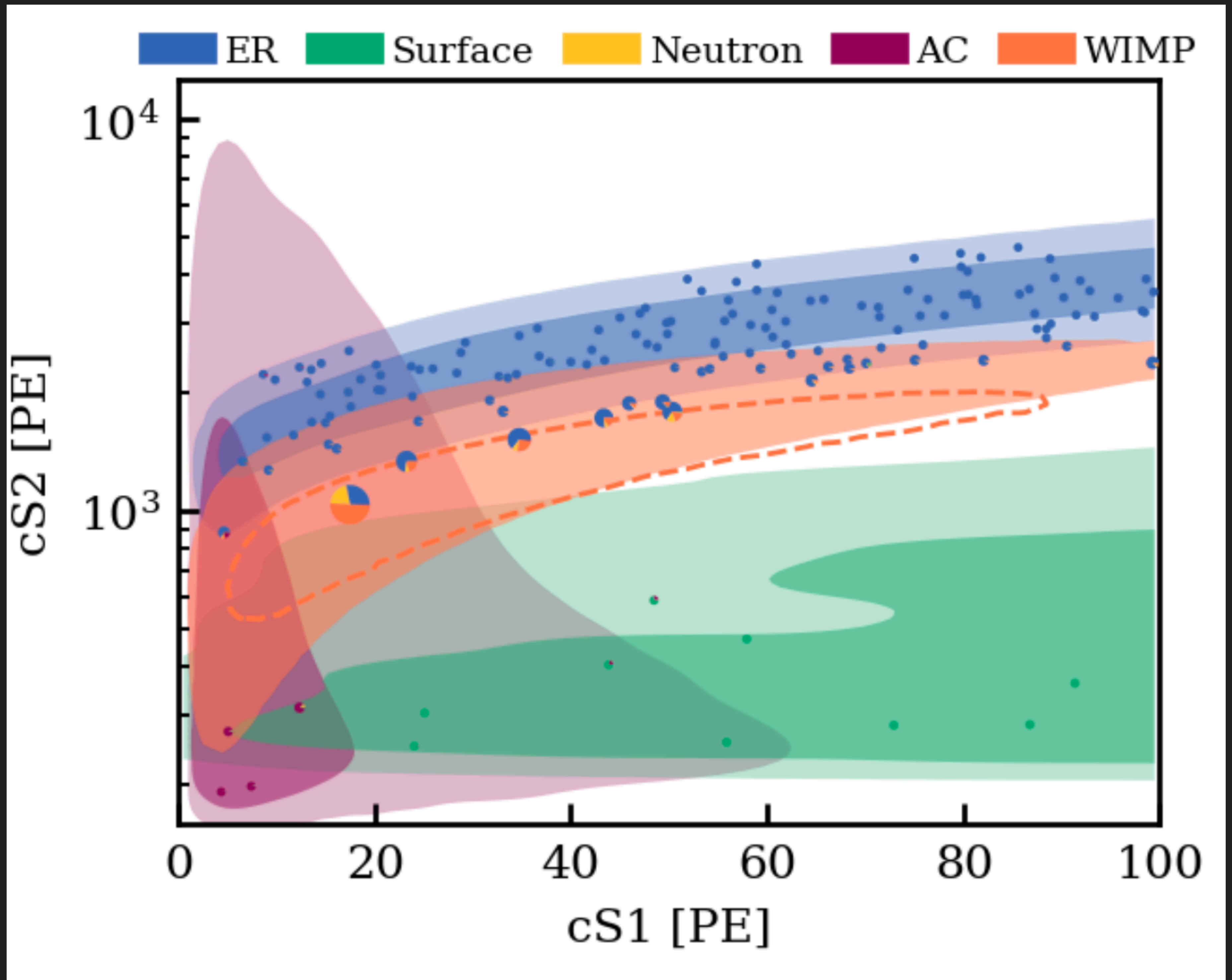

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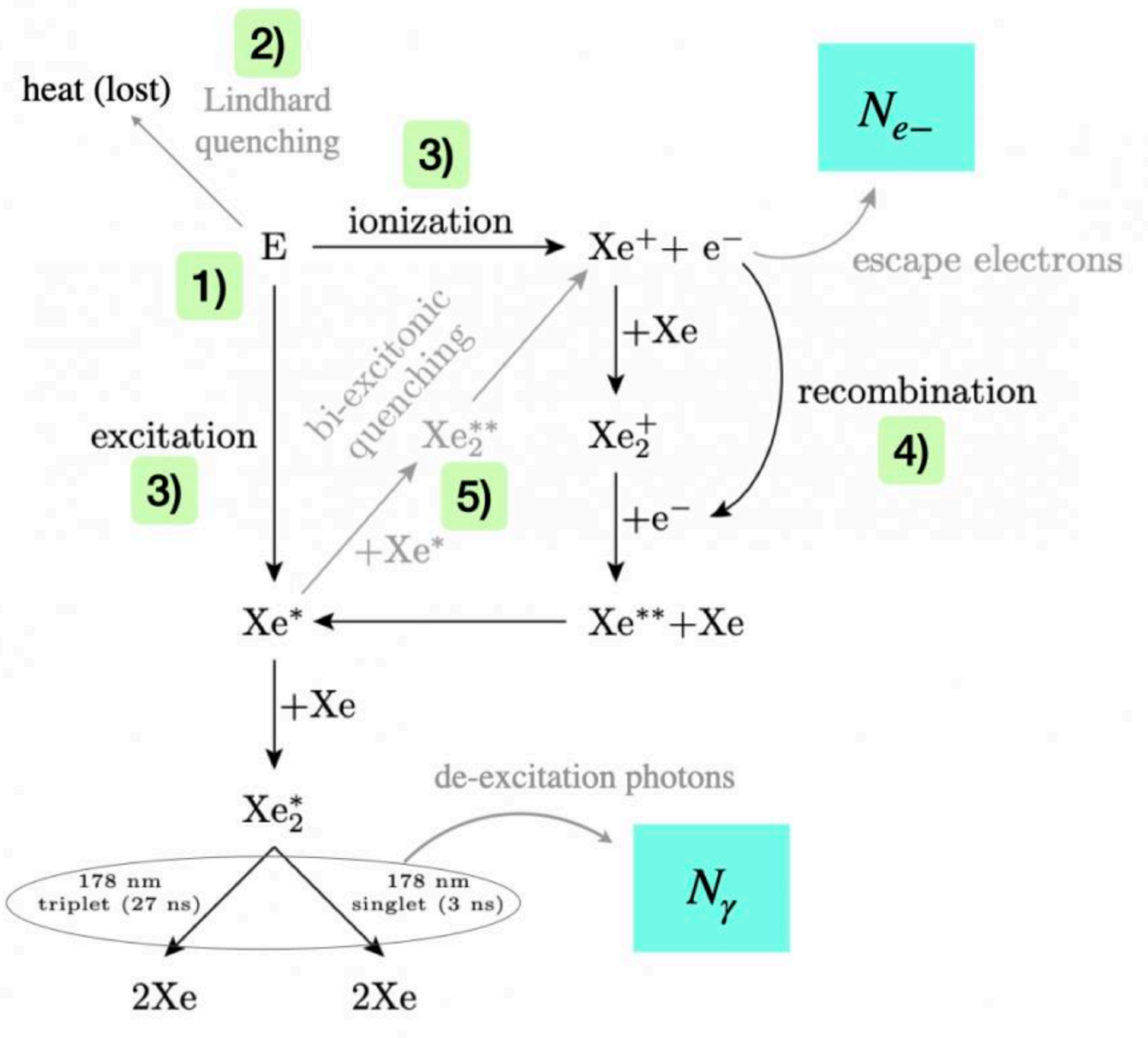
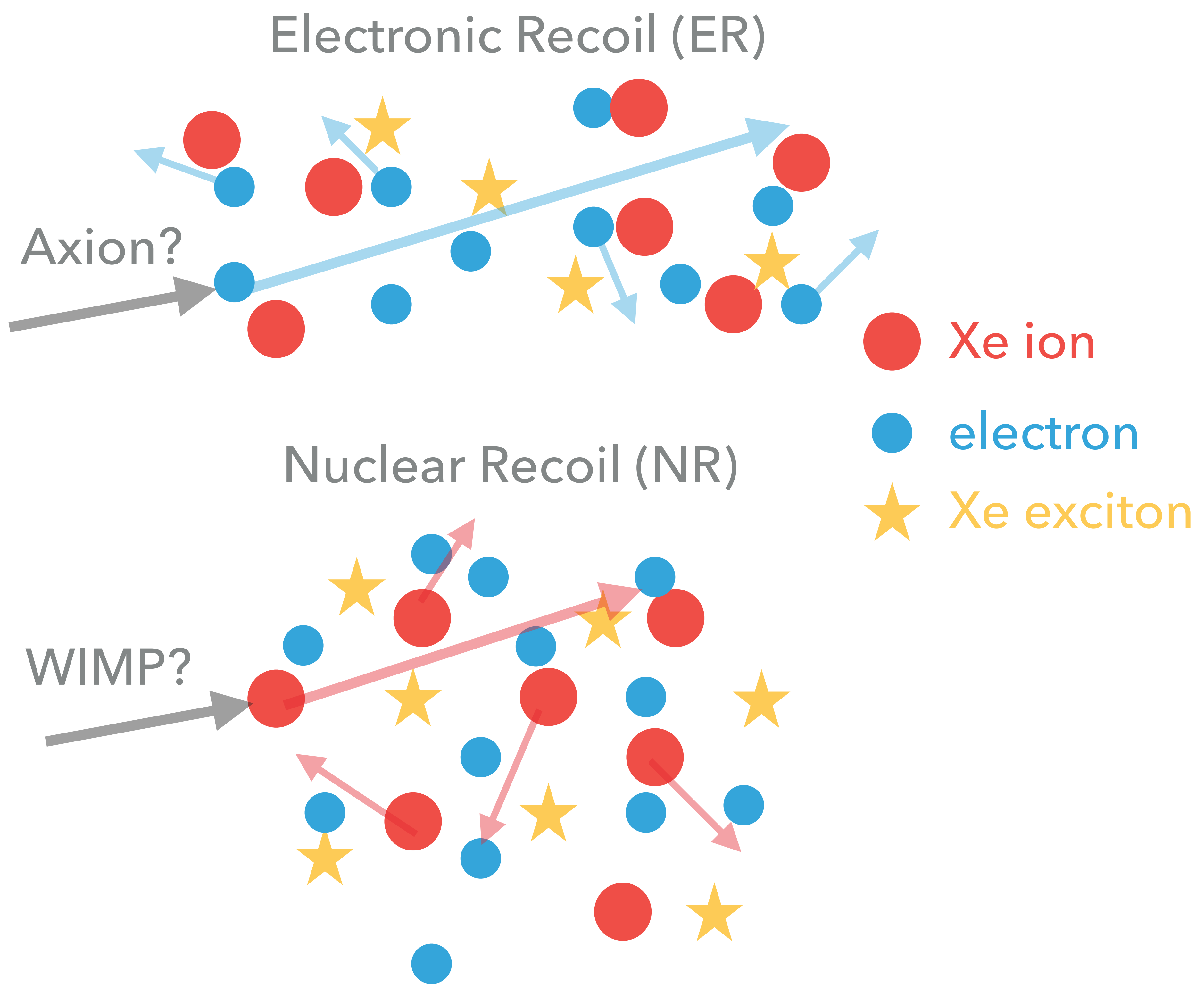
# QUESTIONS?

Politics is unfortunately above my pay grade so ask physics please : )

# BACKUP

# EXAMPLE DETECTOR: OBSERVABLE SIGNALS IN XENON

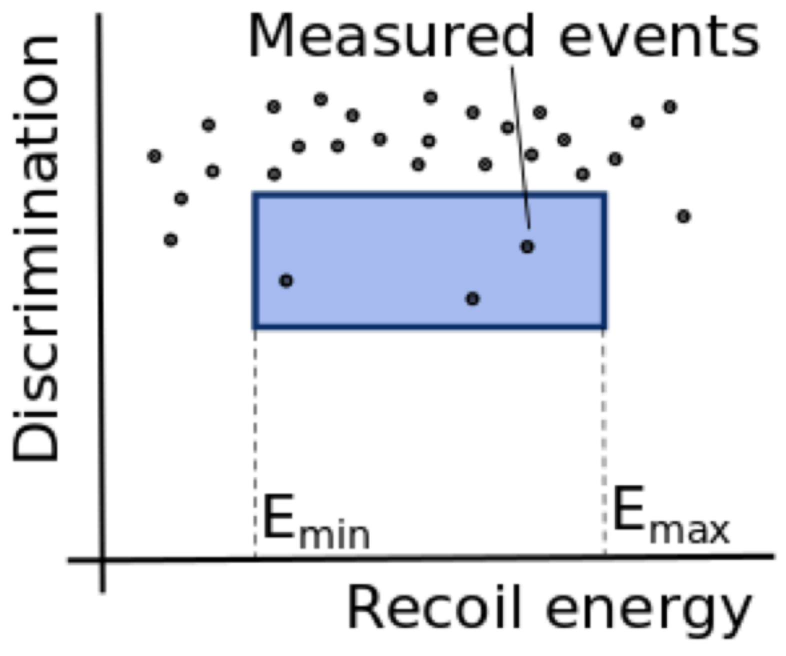


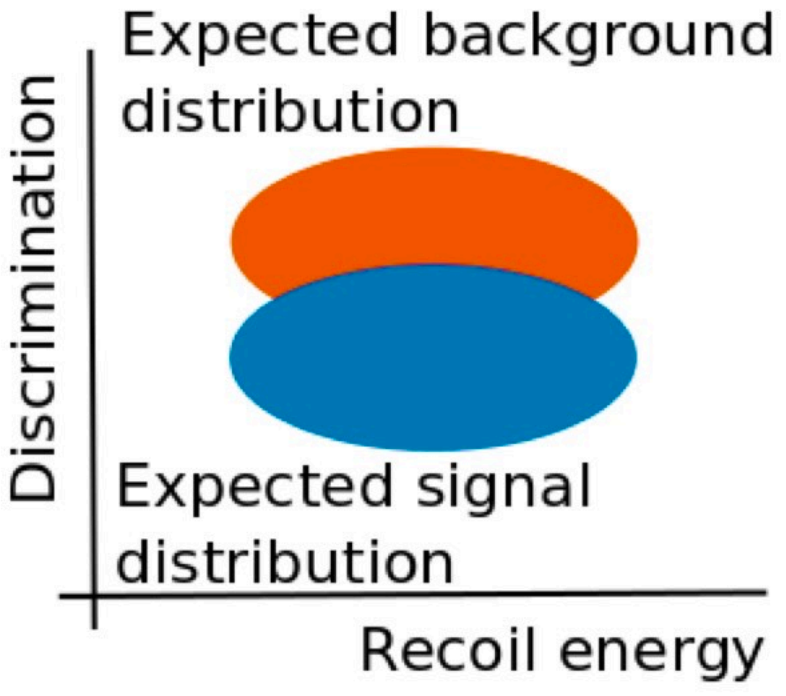




Different ratio of excitation/ion in NR/ER & density/shape of tracks thus recombination ratio → Discrimination power for NR/ER

# RESULT OF A DIRECT DETECTION EXPERIMENT (WITH DISCOVERY POWER)

- **"Counting experiment"**
  - **Select a signal region where the ratio of signal to expected background is high**
  - **Estimate the background in search space**



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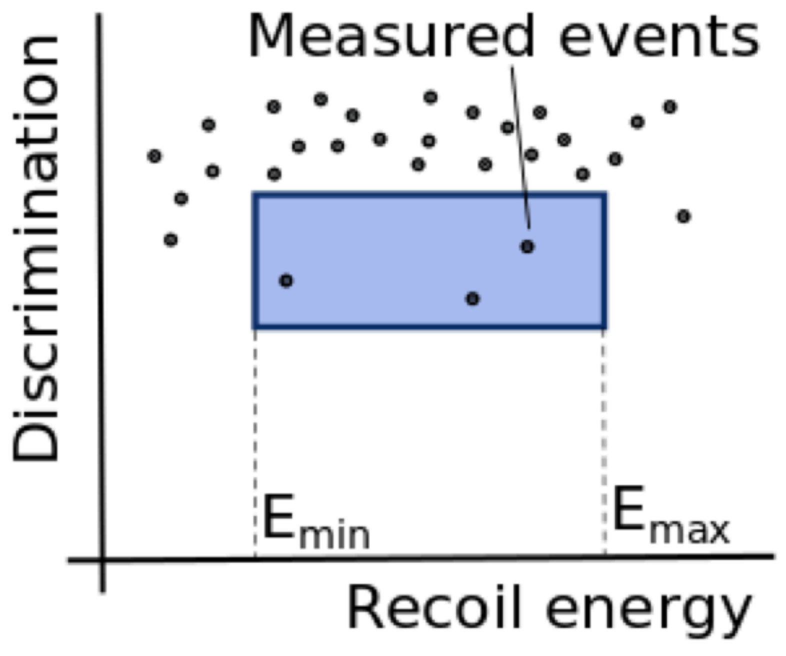
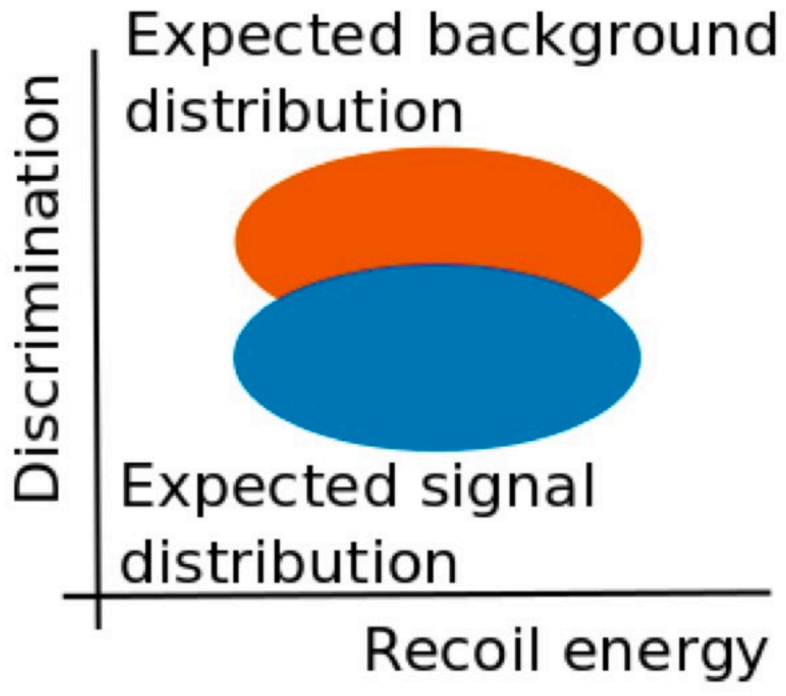
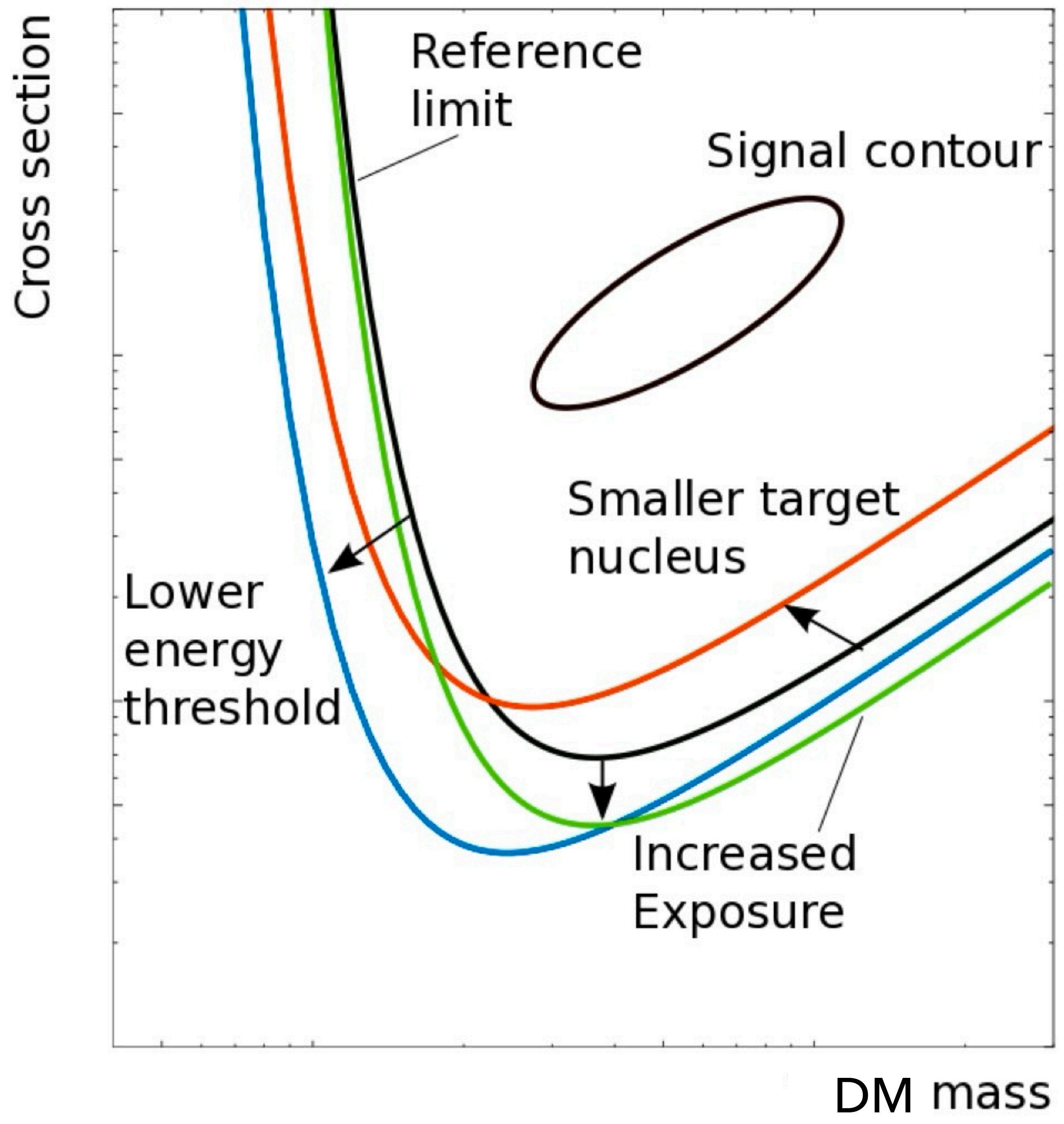
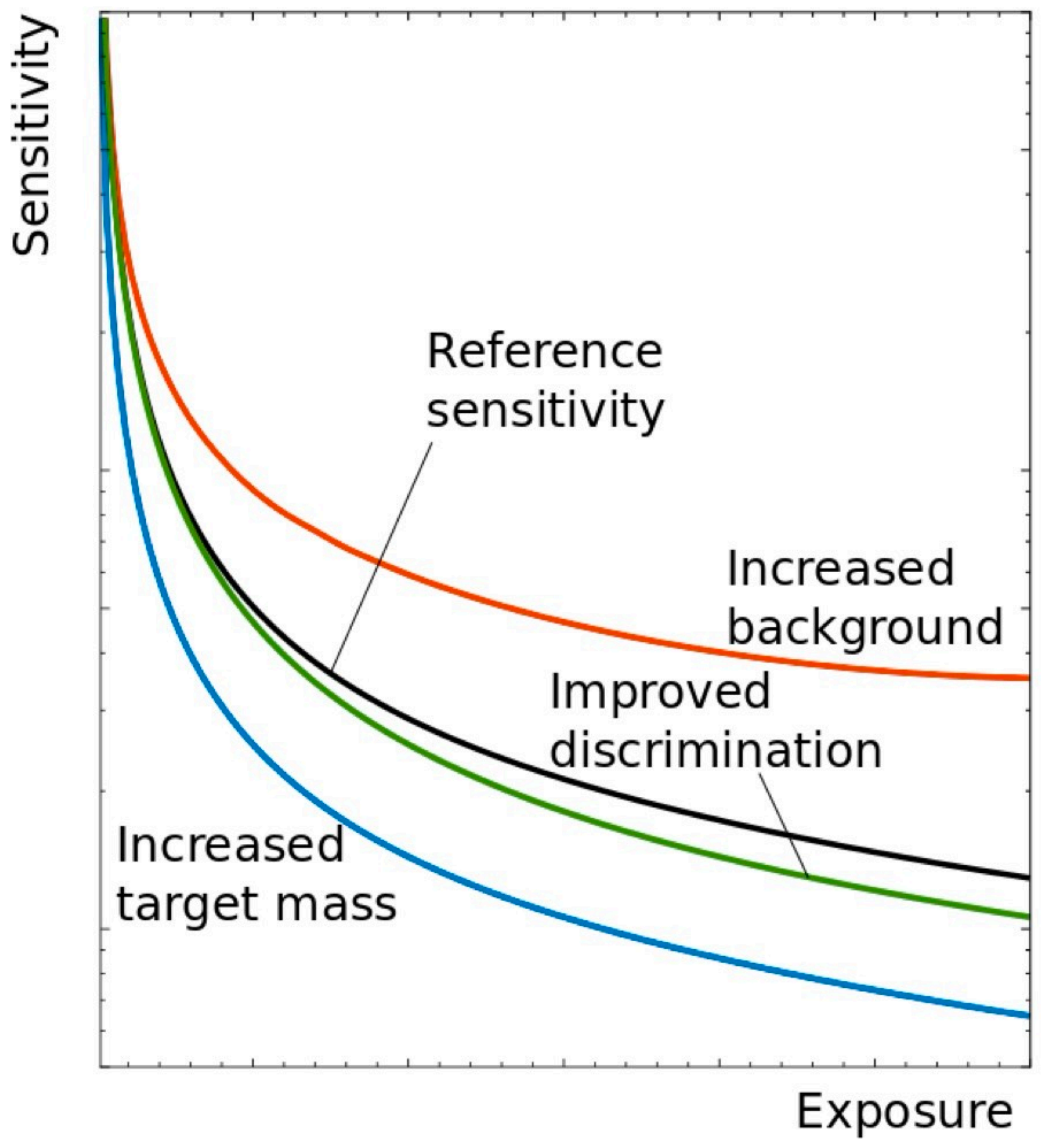
- "Counting experiment"
  - Select a signal region where the ratio of signal to expected background is high
  - Estimate the background in search space
- **Two most important tasks**
  - **Understand how signals and background look like**
  - **Reduce background events in search region**

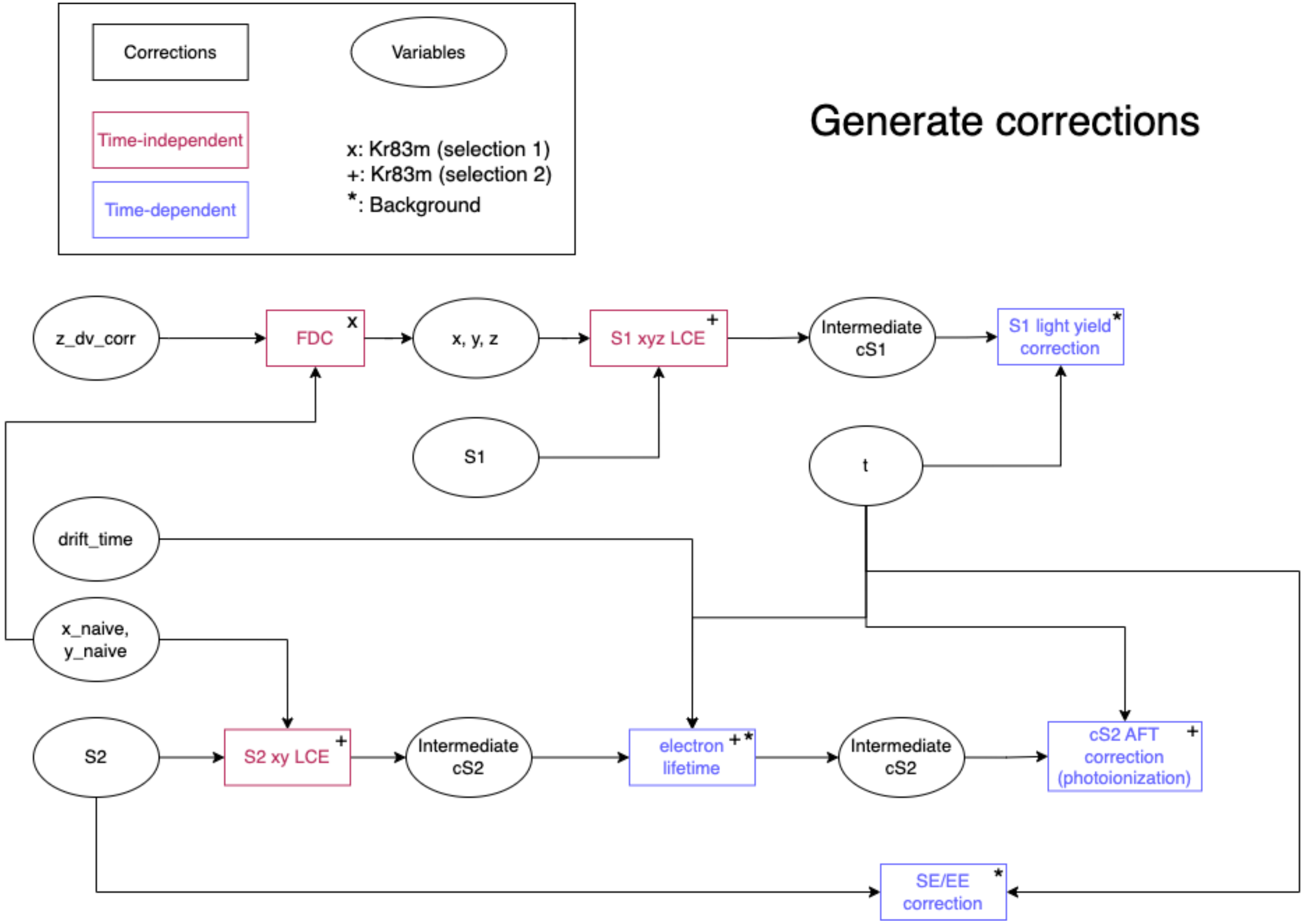


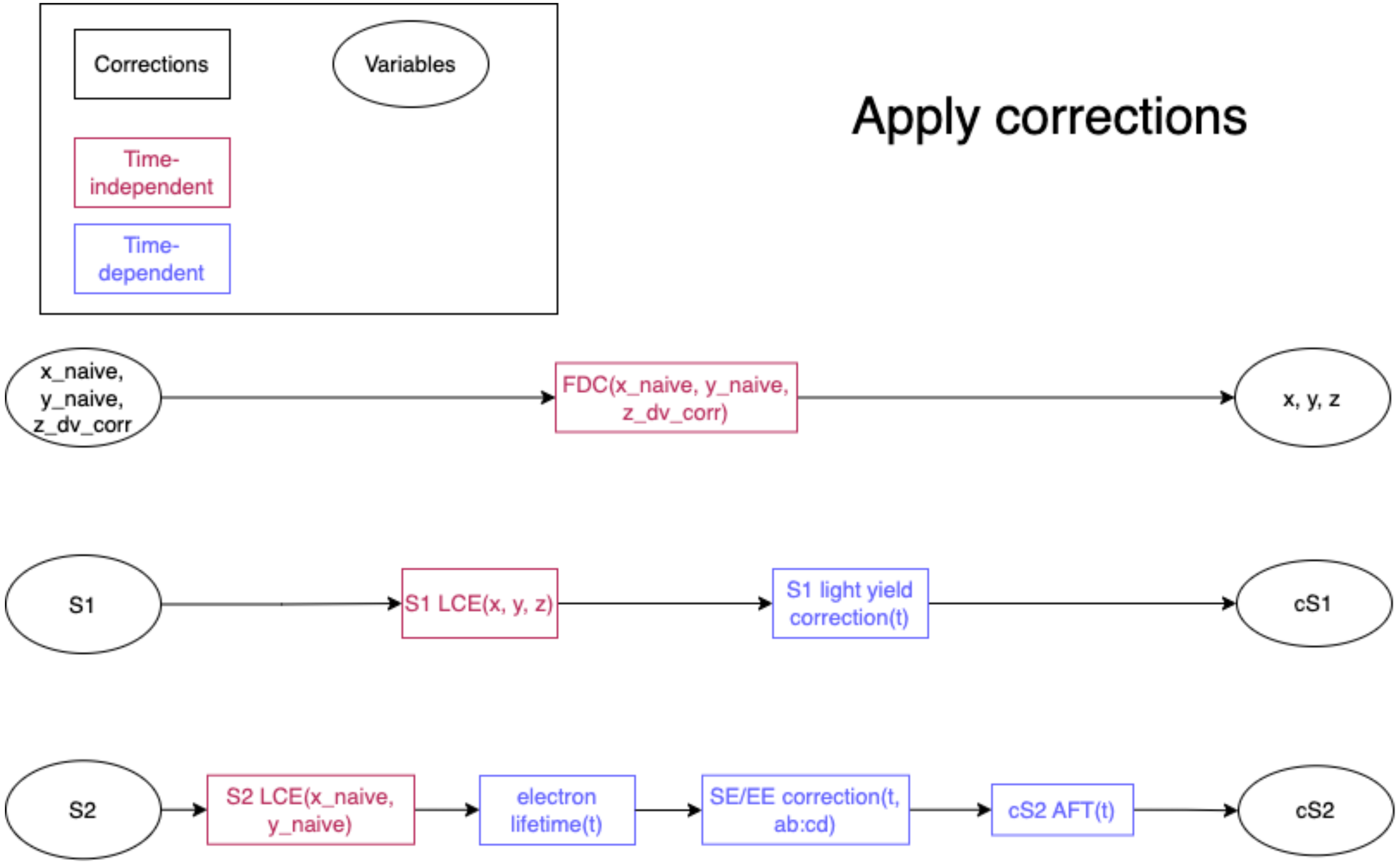



# DETECTOR CORRECTION GENERATION

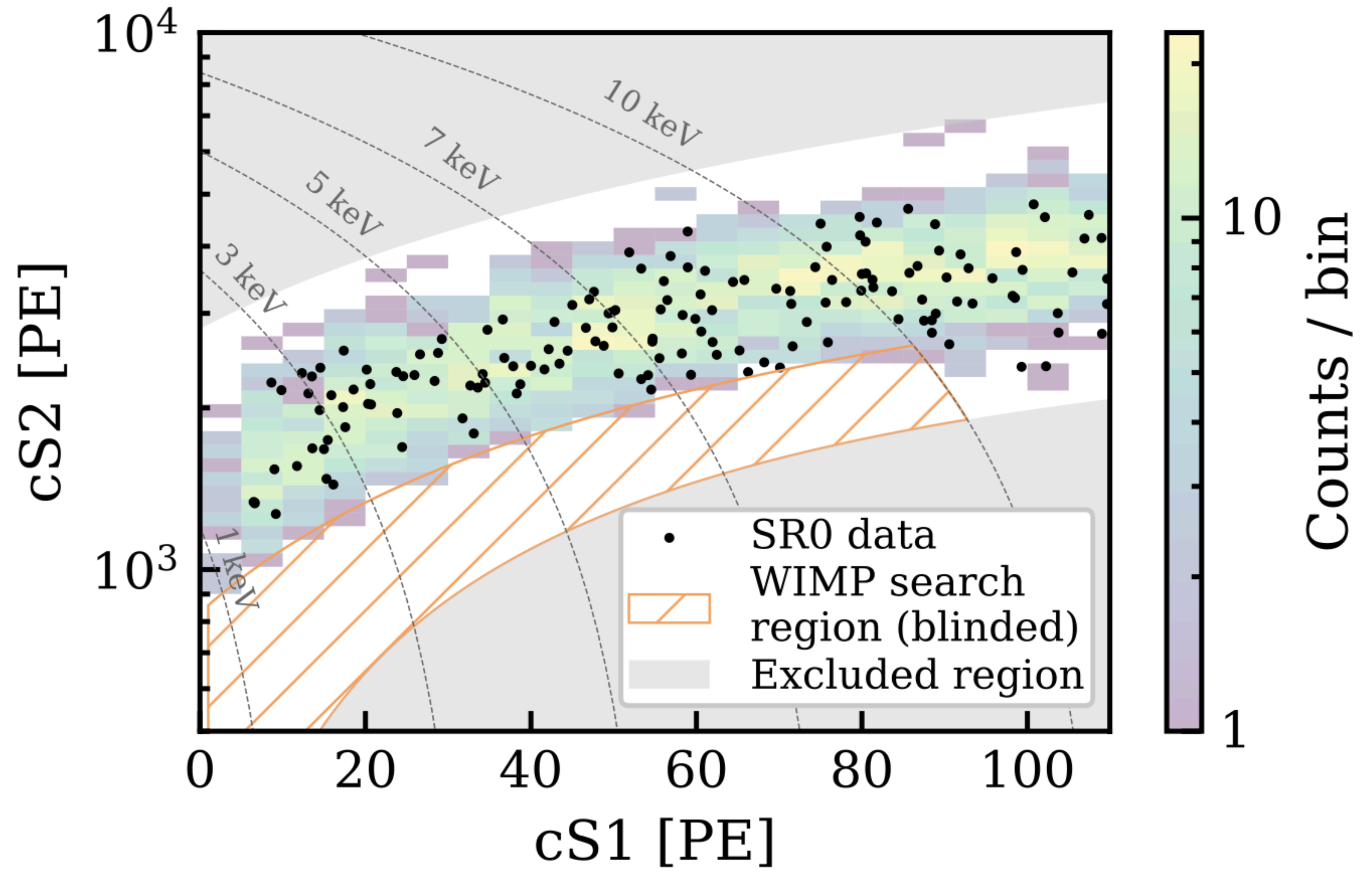


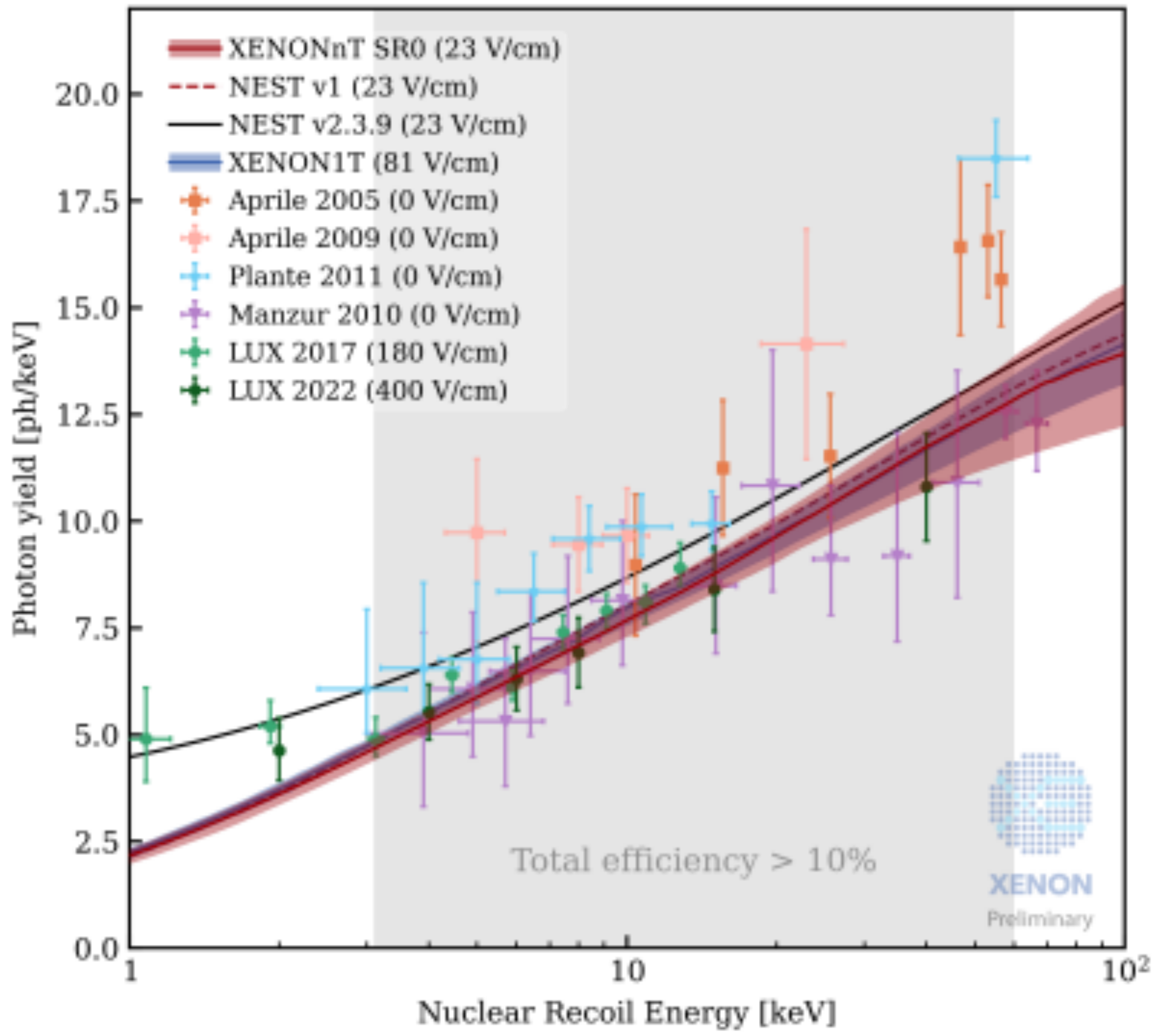
# DETECTOR CORRECTION APPLICATION

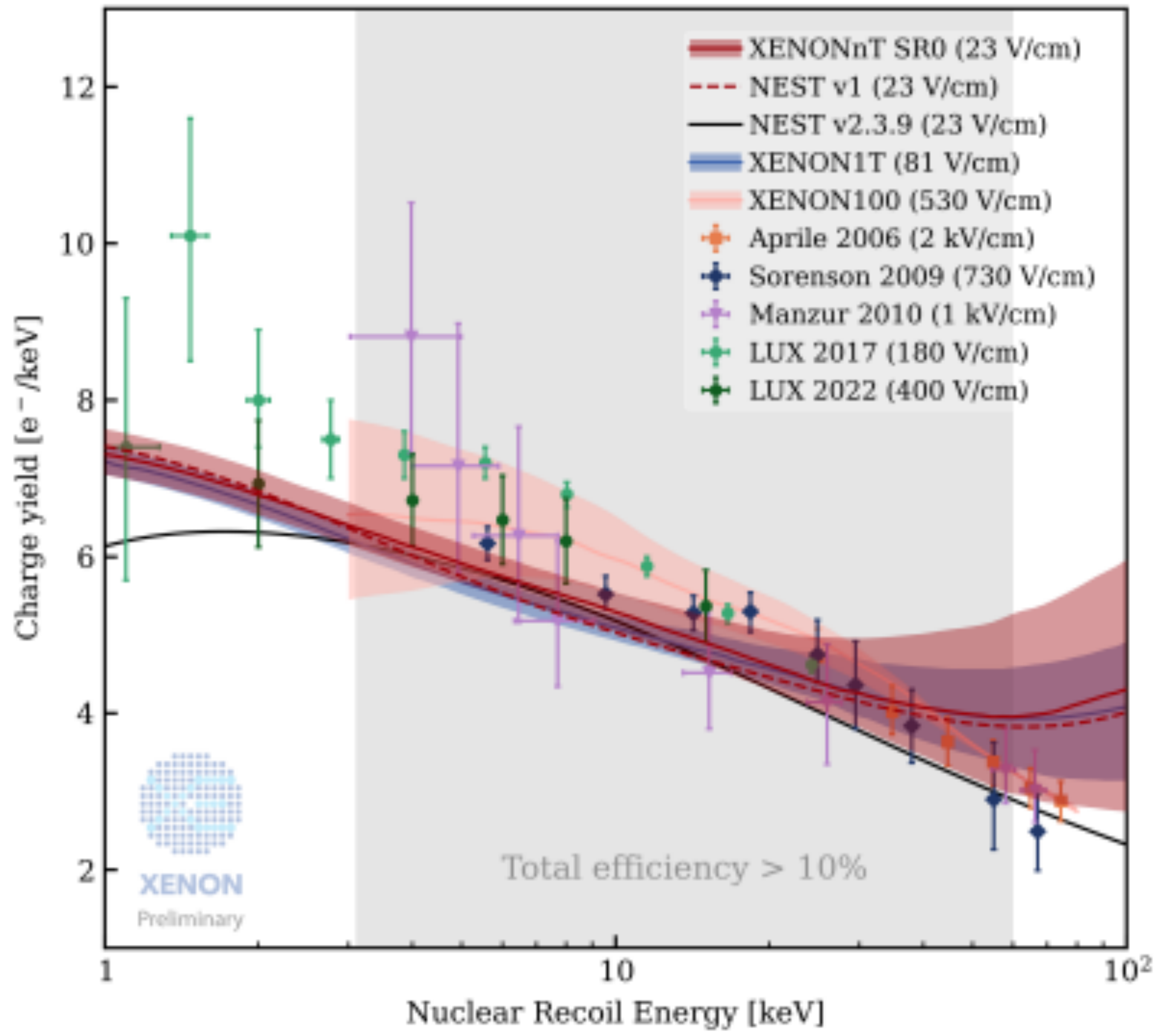


# EFFICIENCIES

- Fitted AmBe neutron calibrations to microphysics+detector model
- Search in cS1-cS2 space

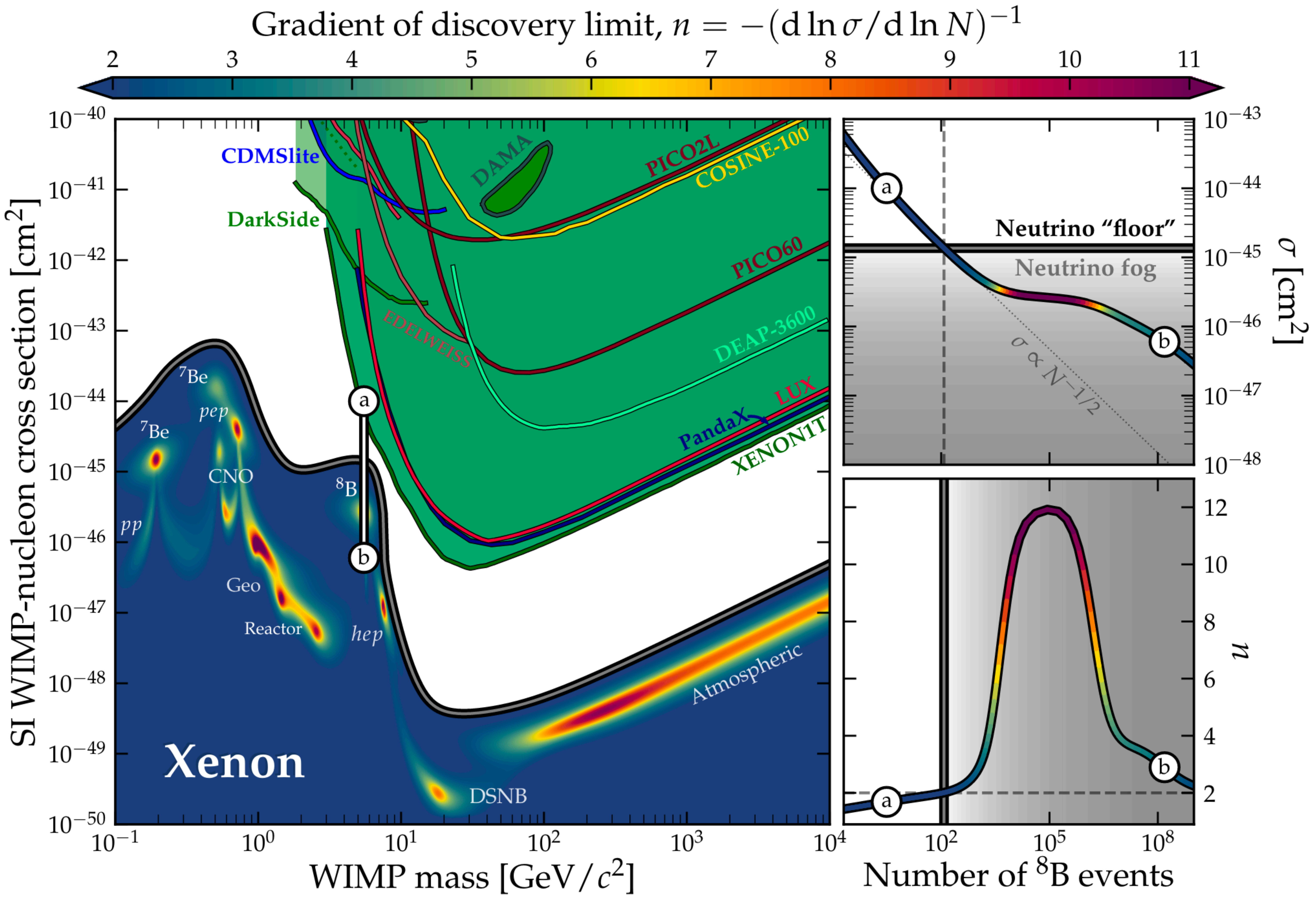


# NEUTRINO FOG LANDSCAPE

- Motivation of neutrino fog rather than floor
  - **Severity of neutrino background is highly dependent on uncertainty of neutrino flux**
    - Uncertainty improves over time
  - **The DM and neutrino signals are never perfect matches.**
    - The spectrum discrimination will help regain sensitivity for DM



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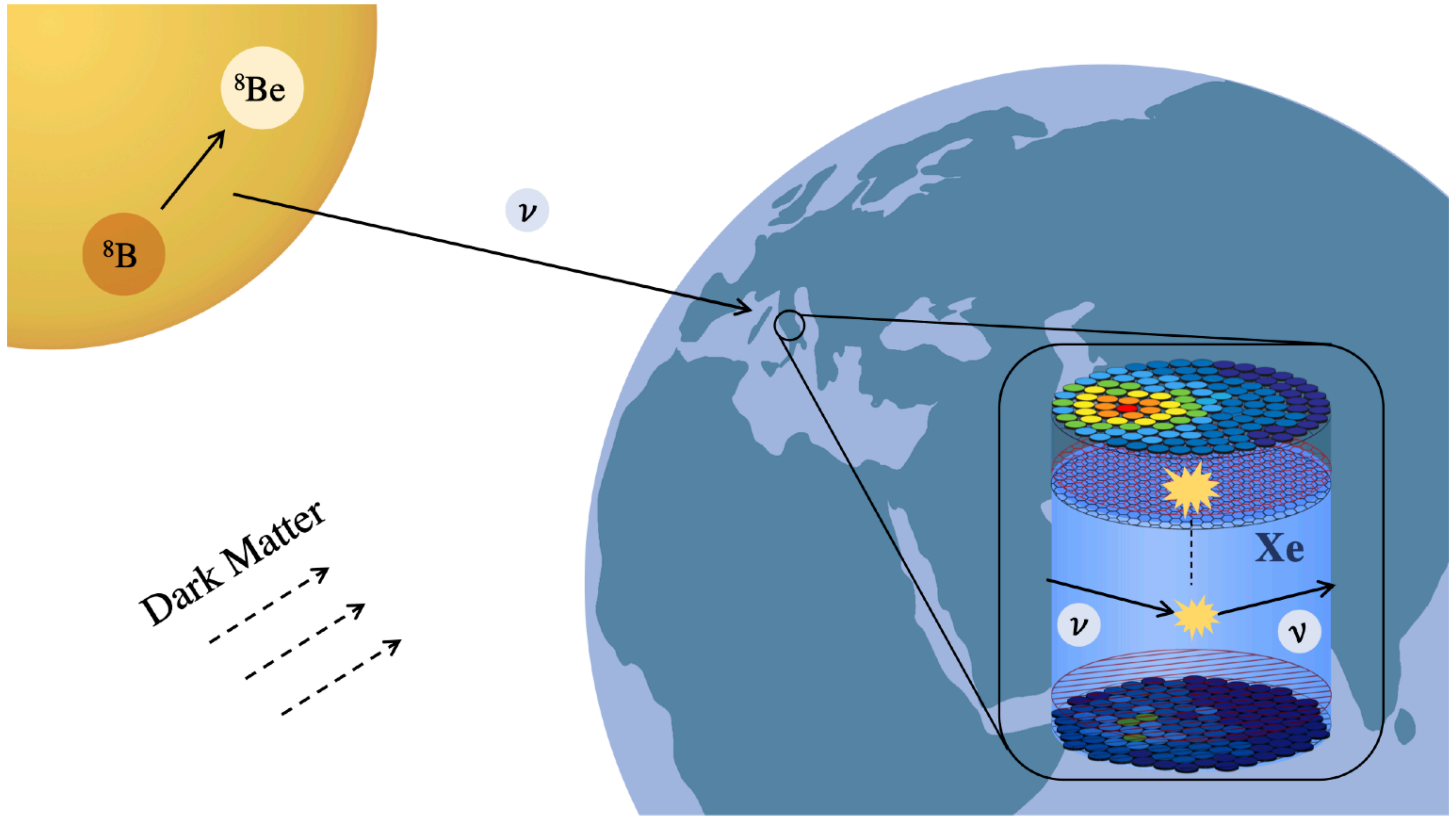


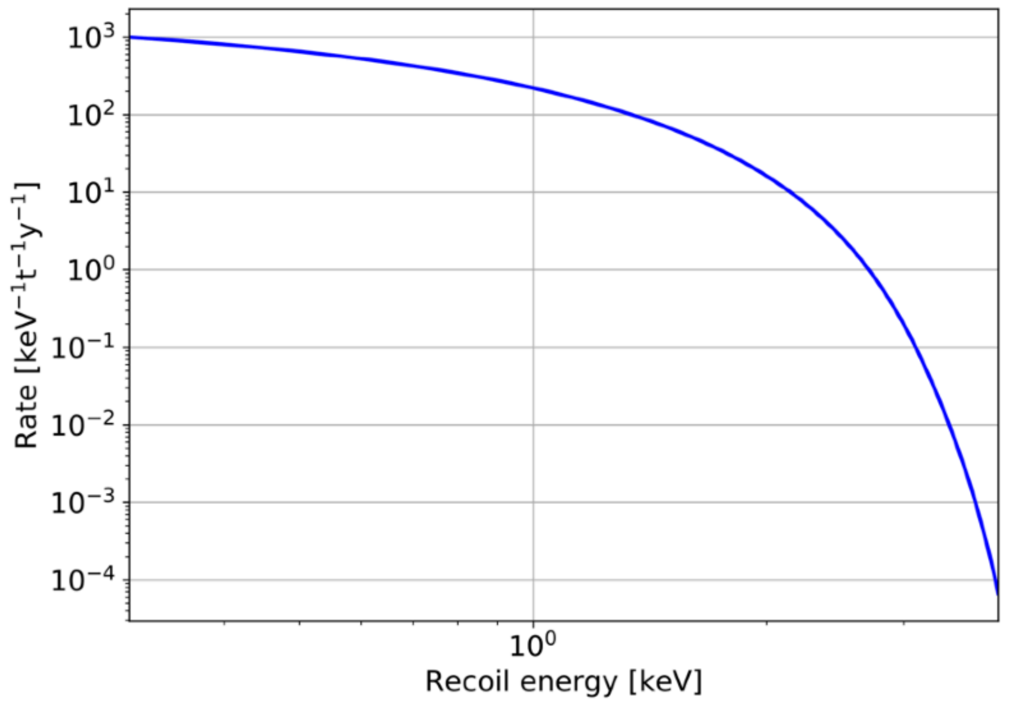


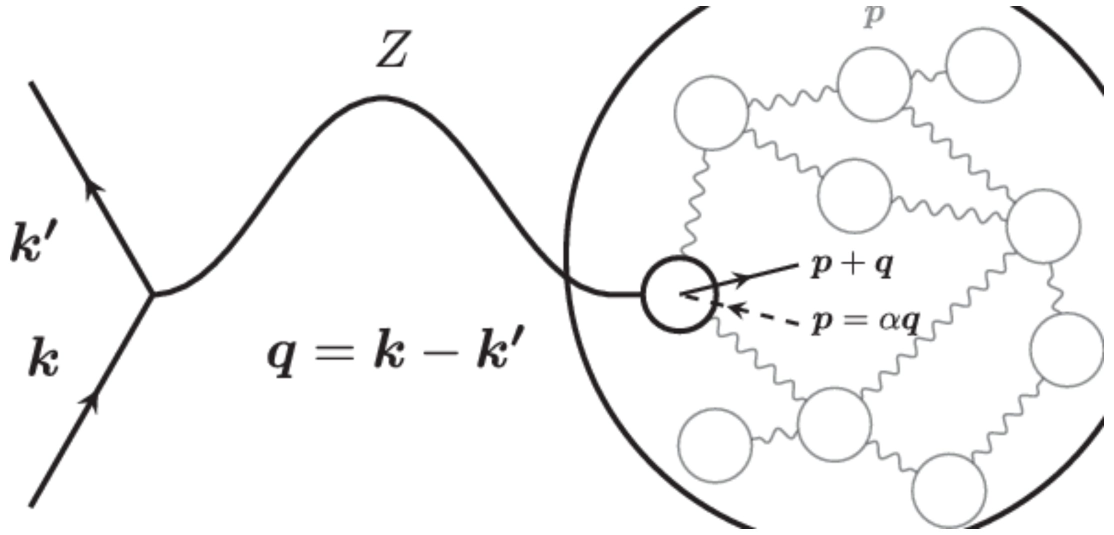

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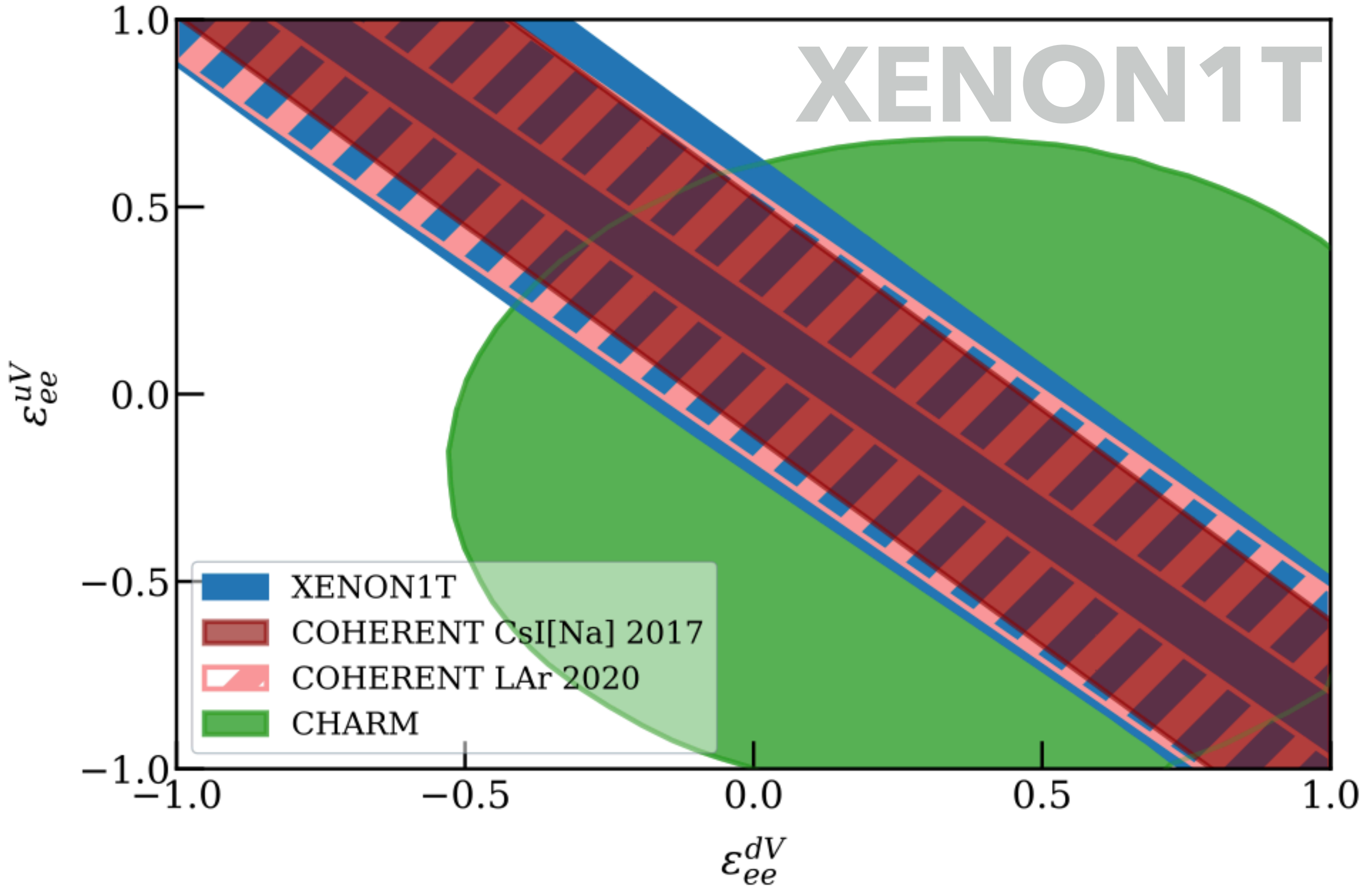
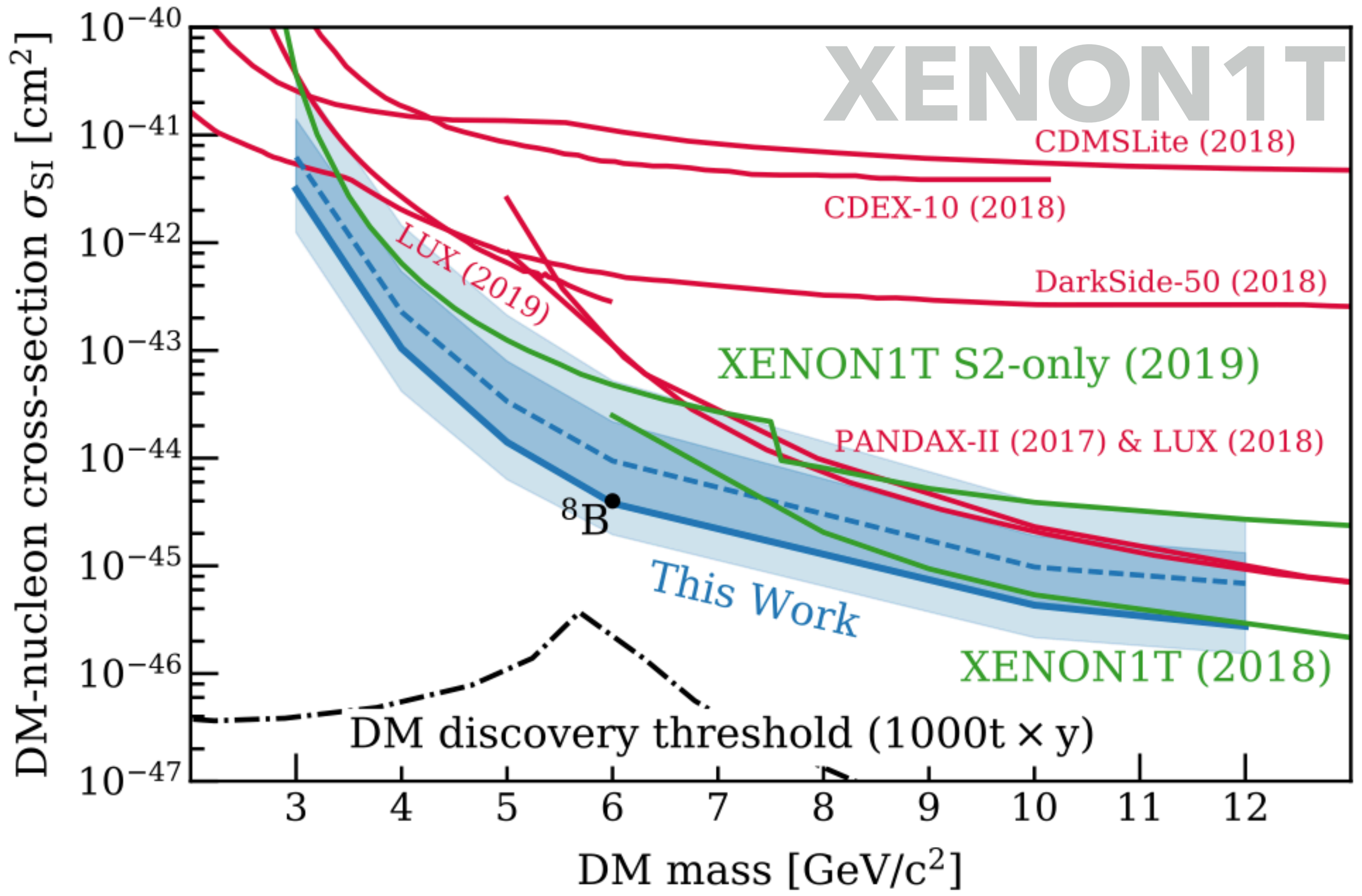



Constraints on non-standard vector couplings between the electron neutrino and quarks

XENON1T $^{8}$B CEvNS: 2 events

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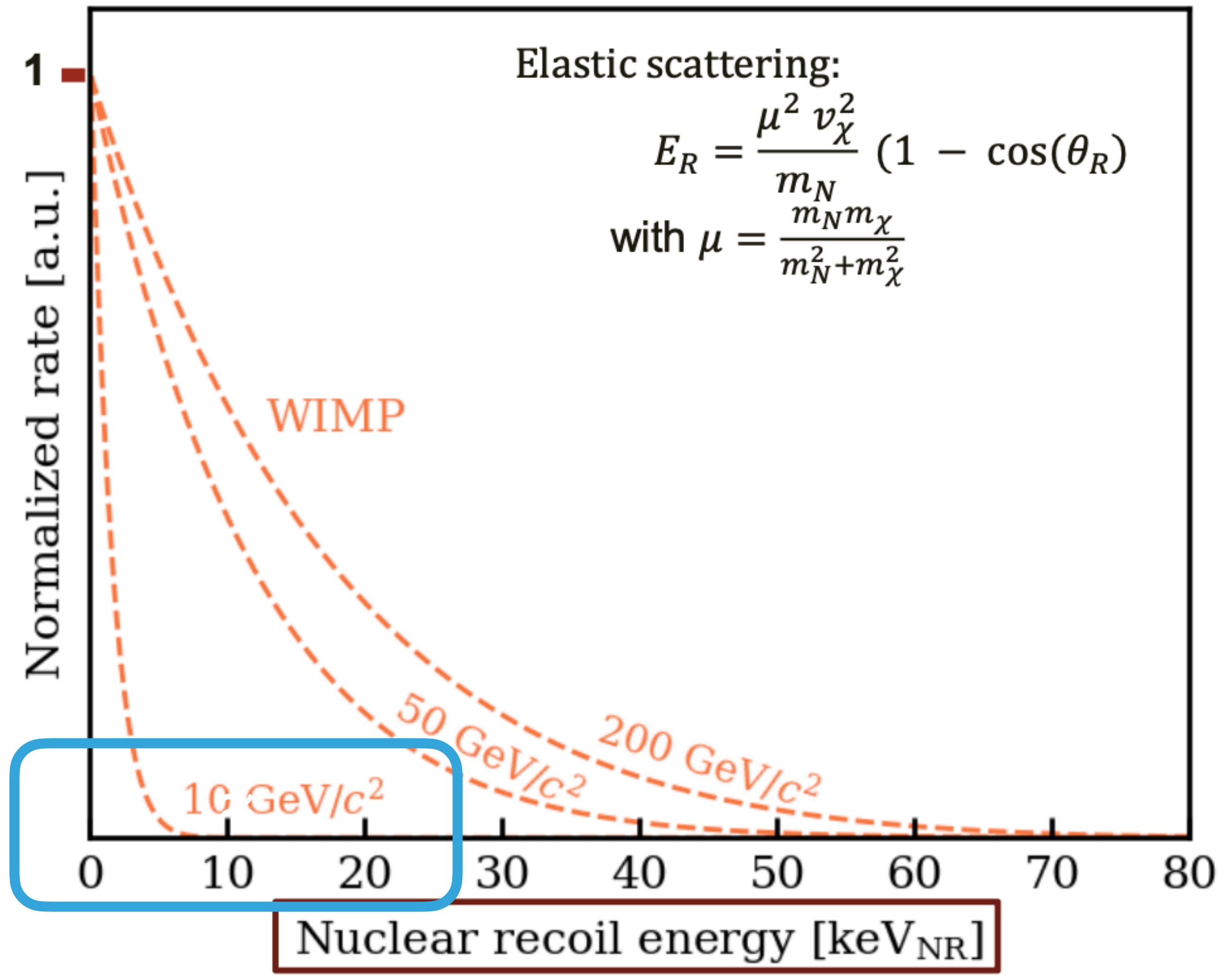
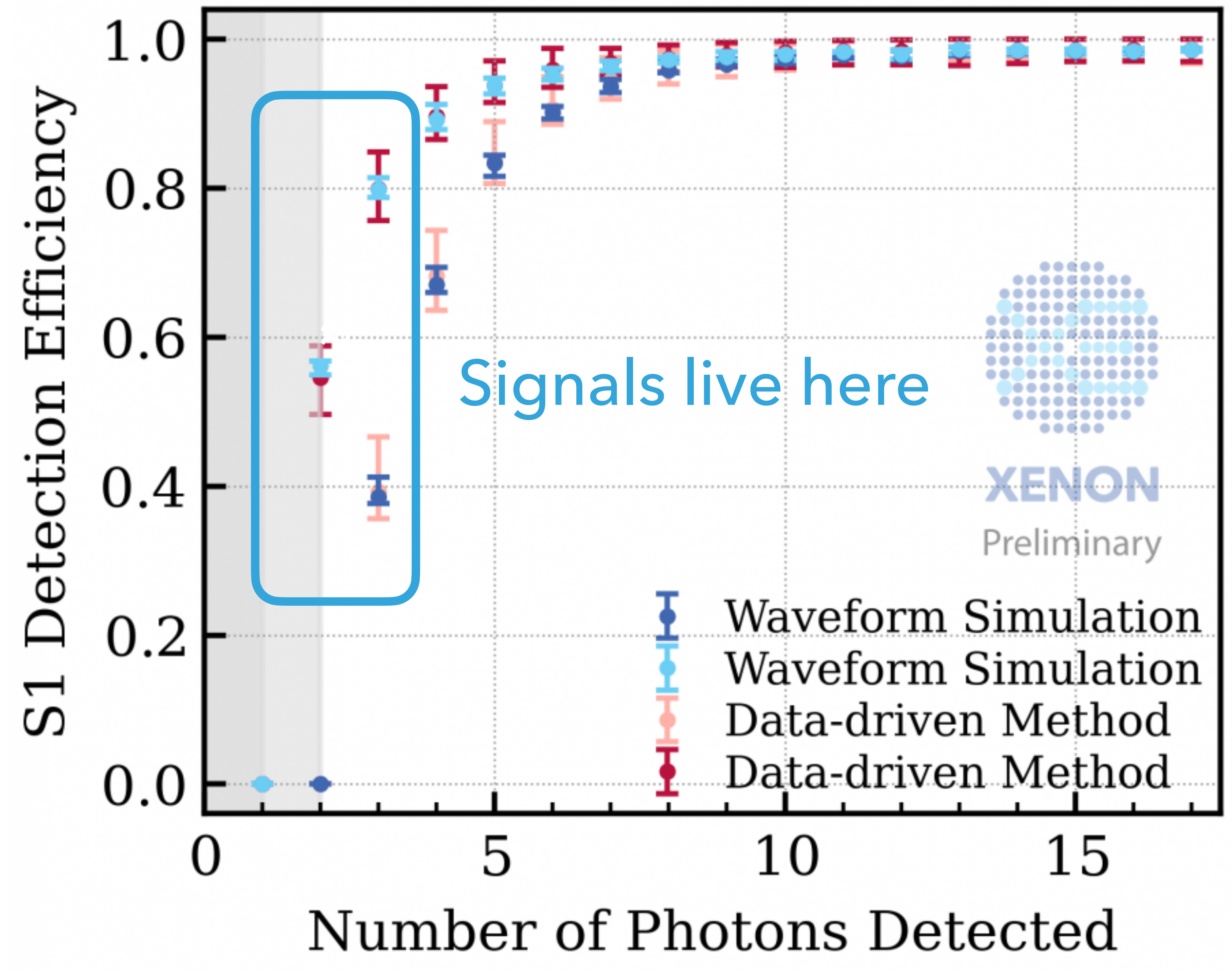



Signals live here



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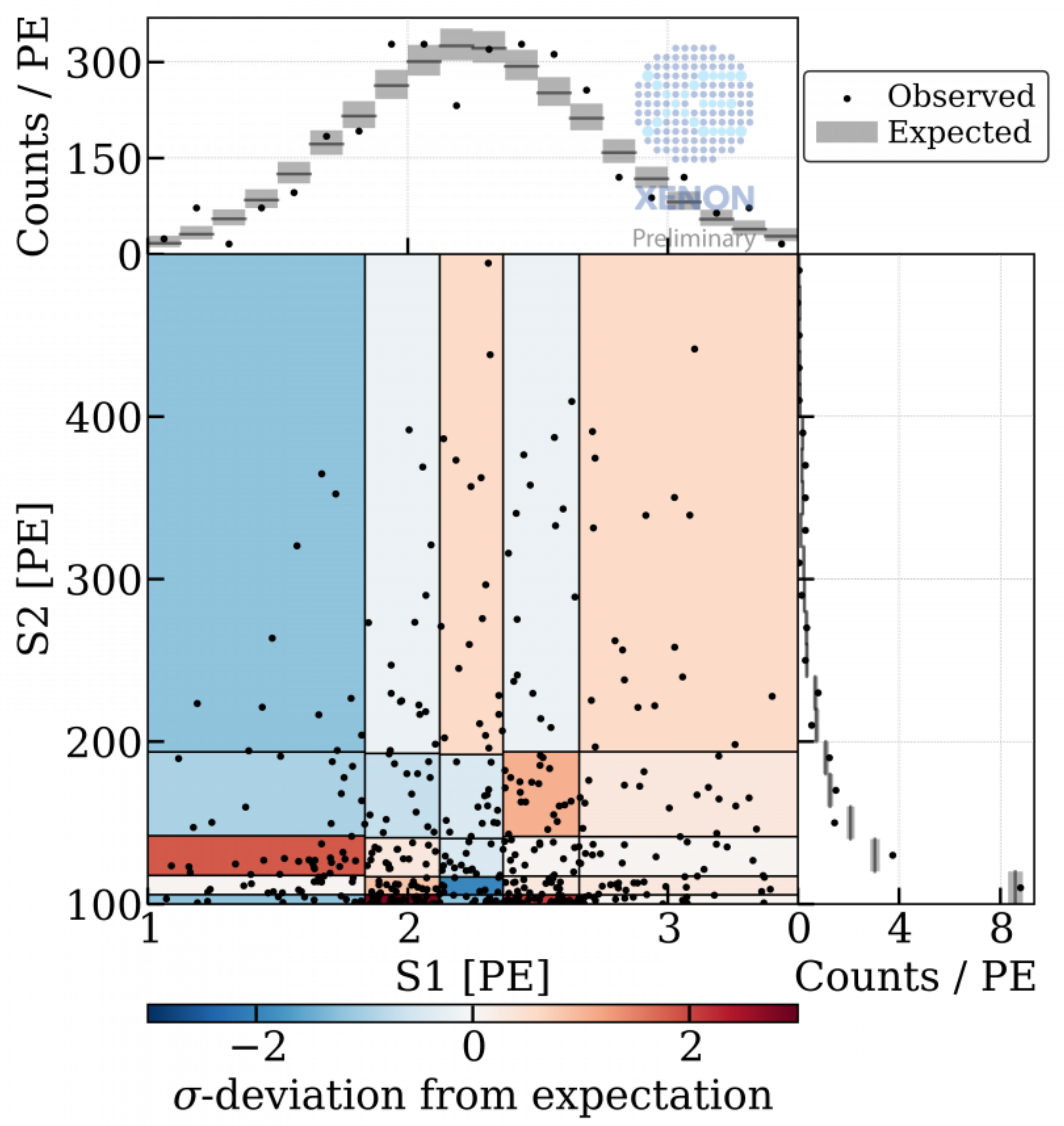


AC model validation in $^{220}$Rn calibration 2-fold data: AC has been modeled and validated to 5% precision!

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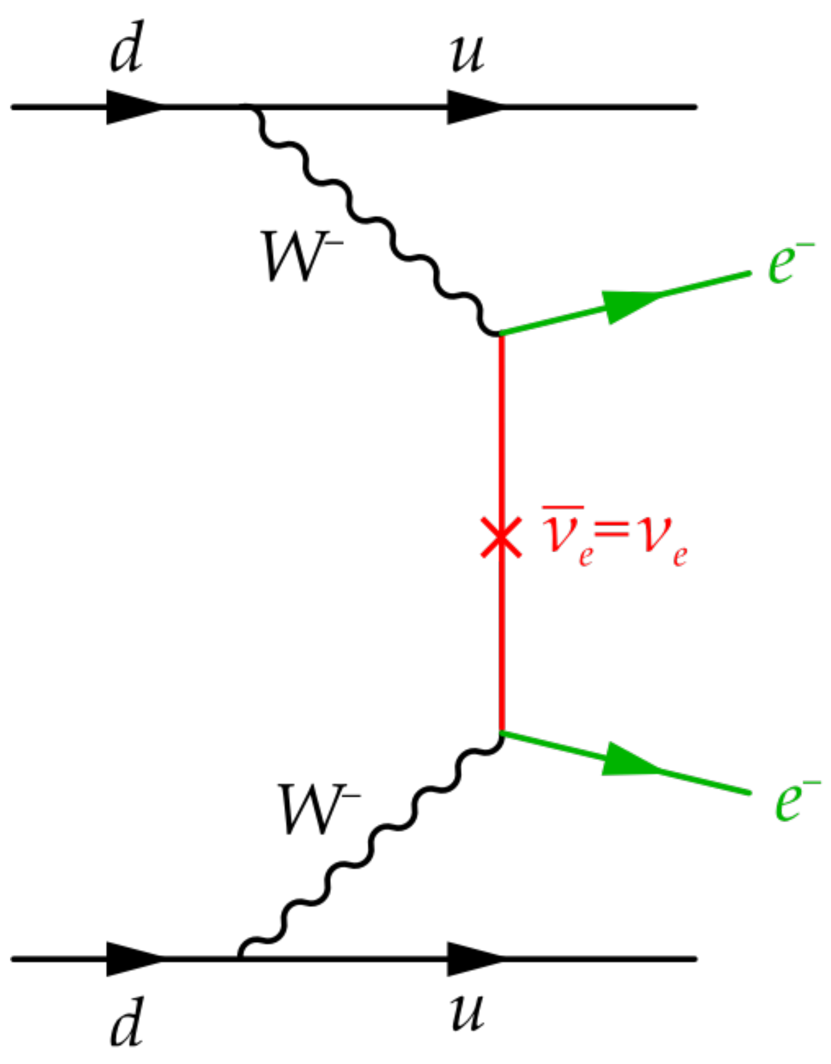
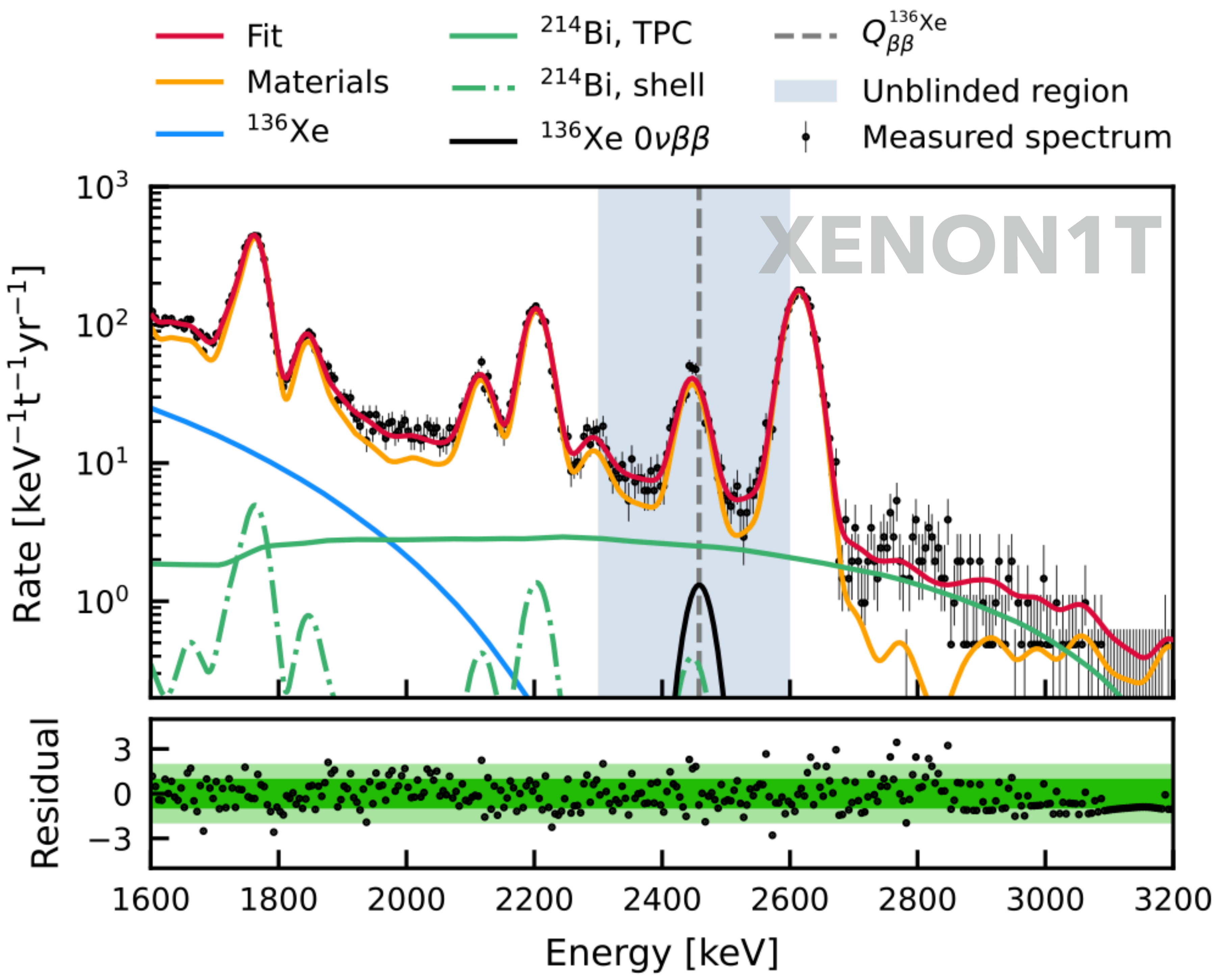
- **XENON1T demonstrated feasibility of 0$\nu$bb search in future LXeTPC DM experiments**



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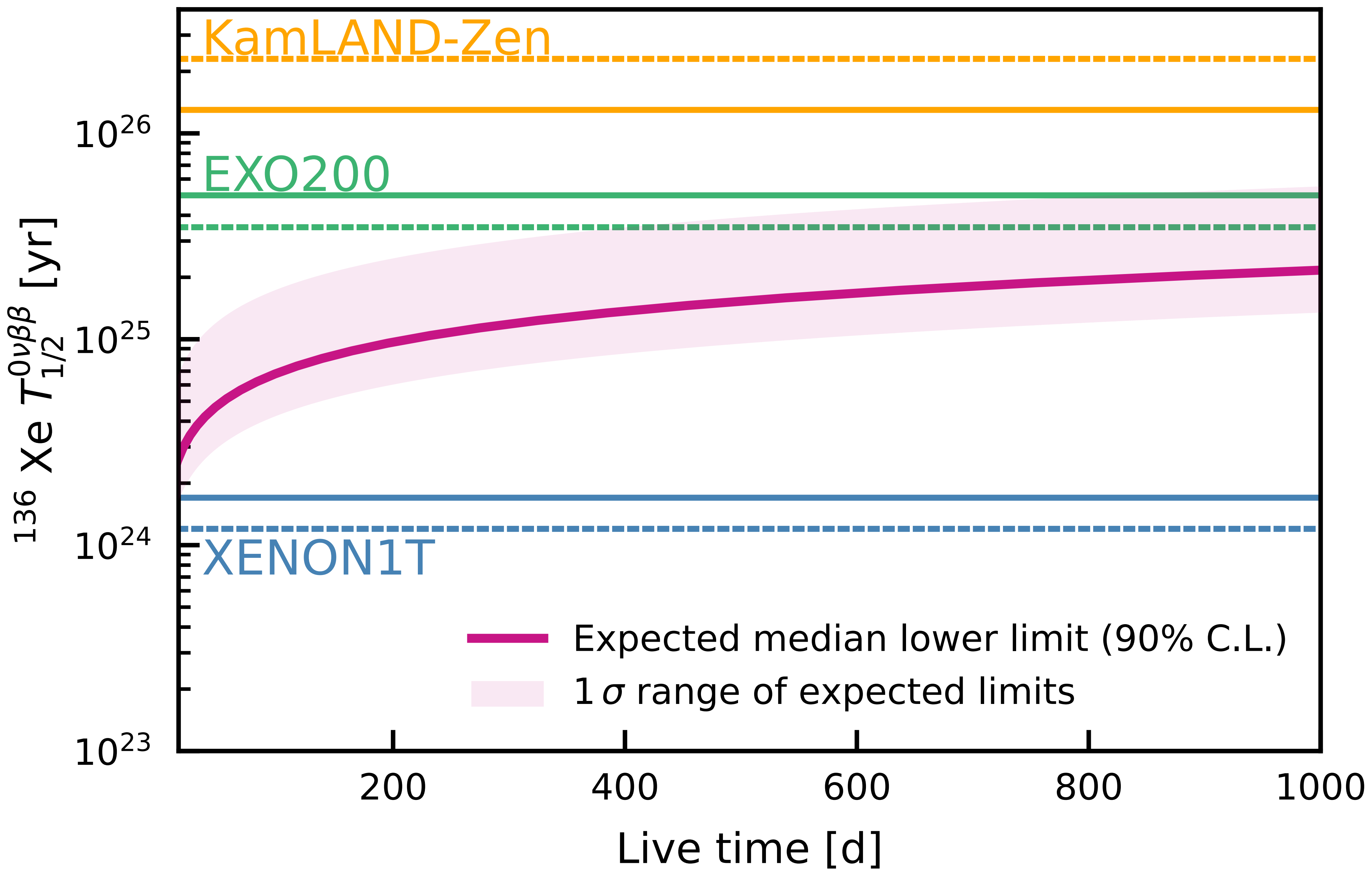

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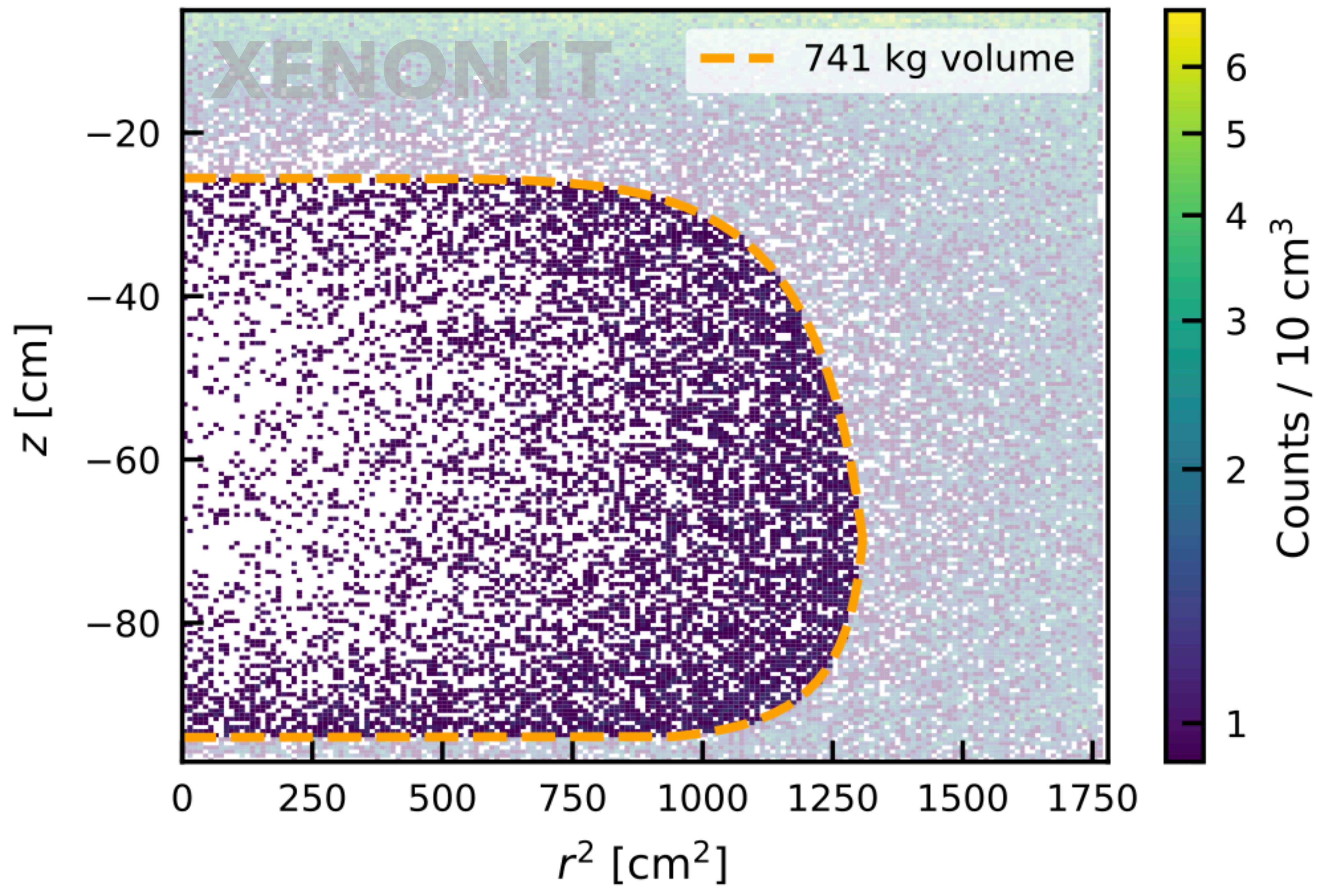
  - **Non-enriched target**
  - **Background optimization for DM search (SS Cryostat)**
- Additional analysis work needed to push further the sensitivity to be competitive

XENON1T: 741kg in optimized FV →~66kg $^{136}$Xe




Have to reduce FV to escape from material gamma

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