Universität Zürich UZH

# Recent Results from XENONnT

## Searching for Dark Matter and Neutrinos

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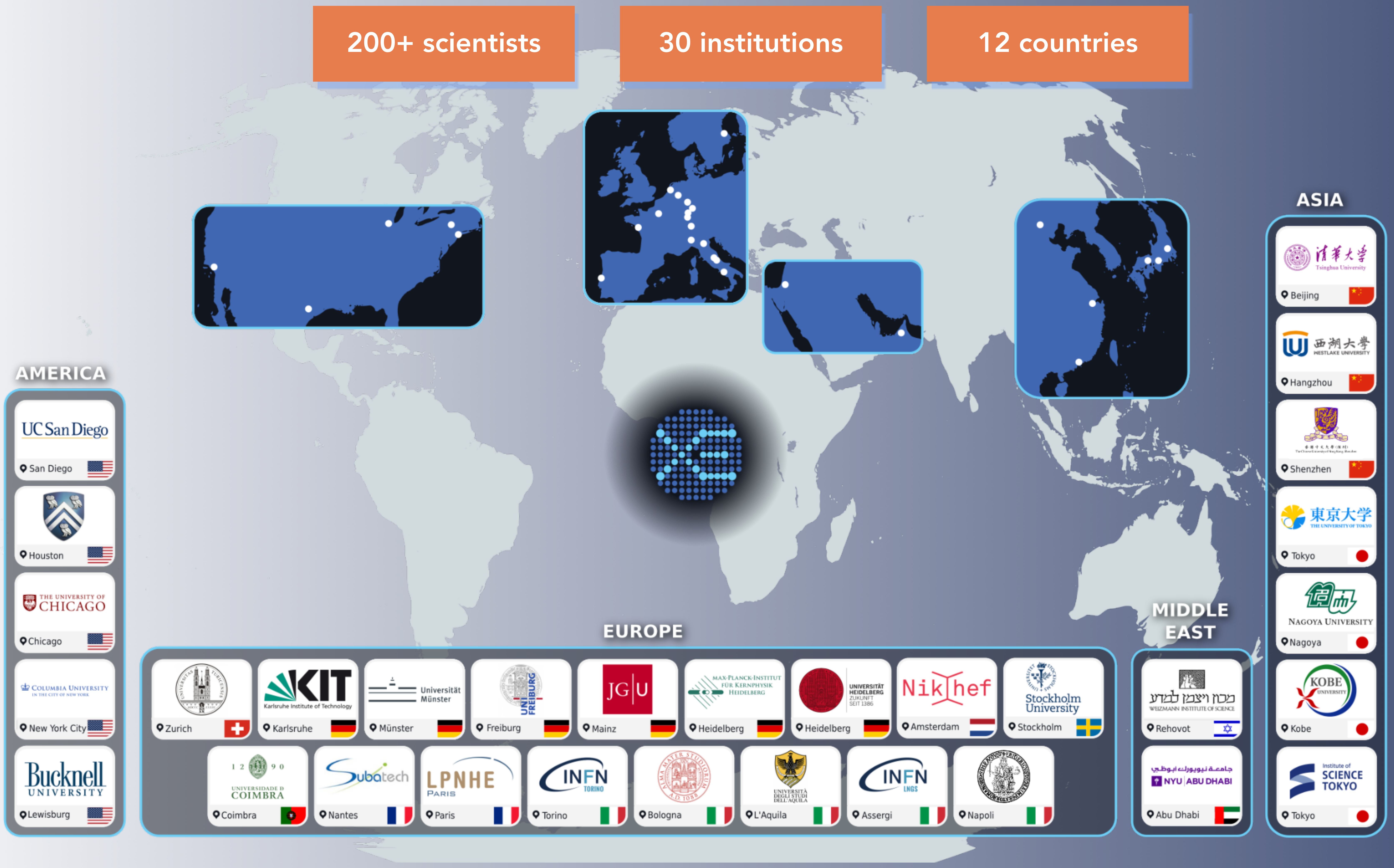
XENONnT

Target mass



# The XENON program
## Nested detectors

1 **Cherenkov muon veto (MV)** *JINST* ***9**, P11006 (2014)*

- 10 m x 10 m
- 84 PMTs

**700 tonnes Gd-loaded water tank**

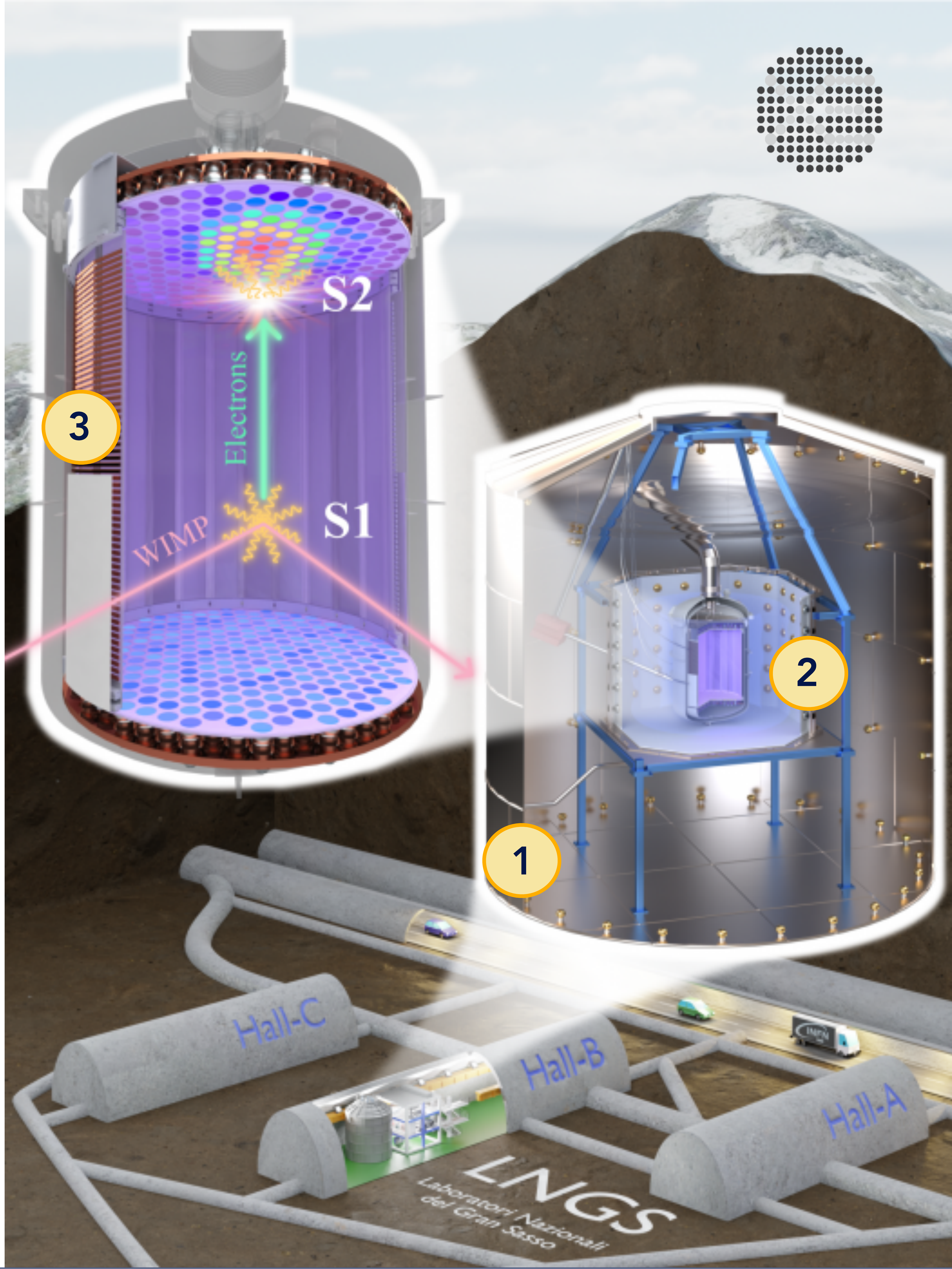
2 **Cherenkov neutron veto (NV)** *Eur. Phy. J. C* ***85** (2025) 695*

- Optically separated from MV
- 120 PMTs
- Neutron capture times: ~75 μs vs ~200 μs in pure water capture

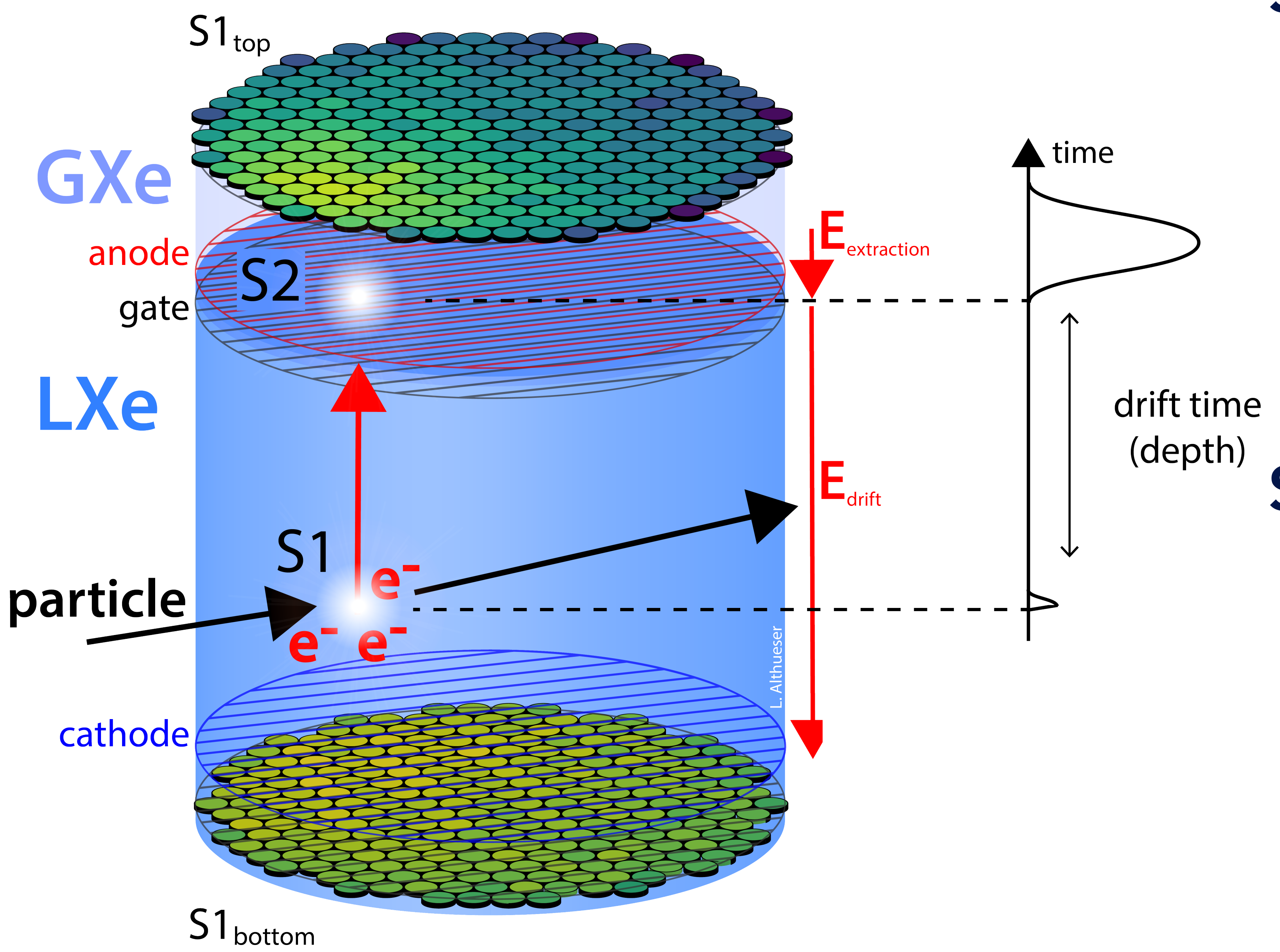
3 **Liquid Xenon (LXe) time projection chamber (TPC)** *Eur. Phys. J. C* ***84**, 784 (2024)*

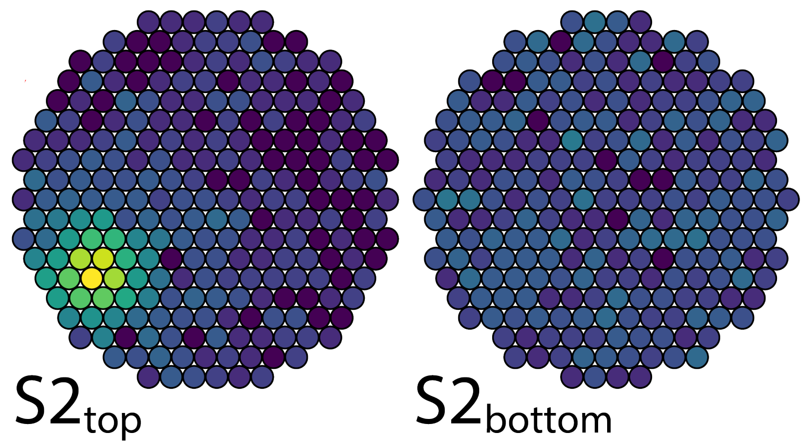
- 5.9 tonnes active LXe mass (8.5 tonnes in total)
- 494 PMTs
- 1.5 m x 1.3 m (drift length x diameter)
- 23 V/cm operating drift field

*From PRX **15**, 031079 (2025)*



# The dual-phase TPC




## Signal detection

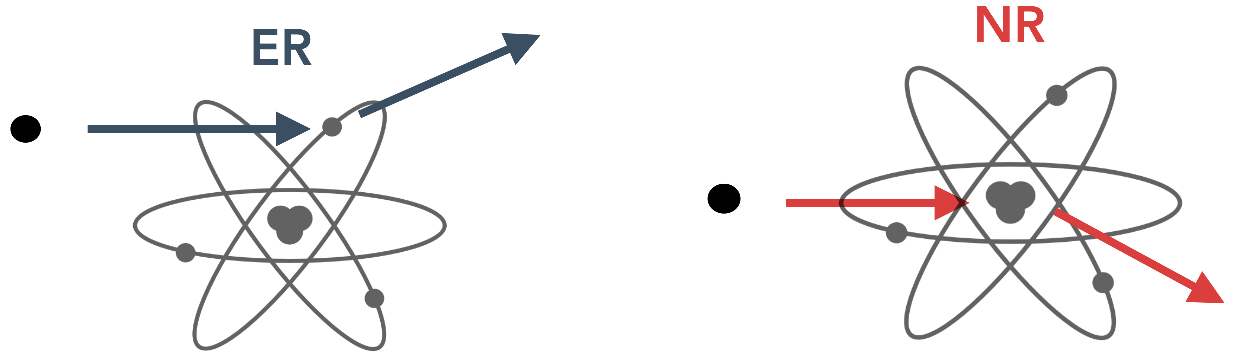
- S1 from prompt scintillation light in LXe
- S2 from ionization electrons in gas xenon (GXe)

## Signal and energy reconstruction

- $x - y$ from S2 hit pattern
- $z$ from S1-S2 delay time
- Energy from combined S1 and S2 signals: $E \propto \left(\frac{S_1}{g_1} + \frac{S_2}{g_2}\right)$

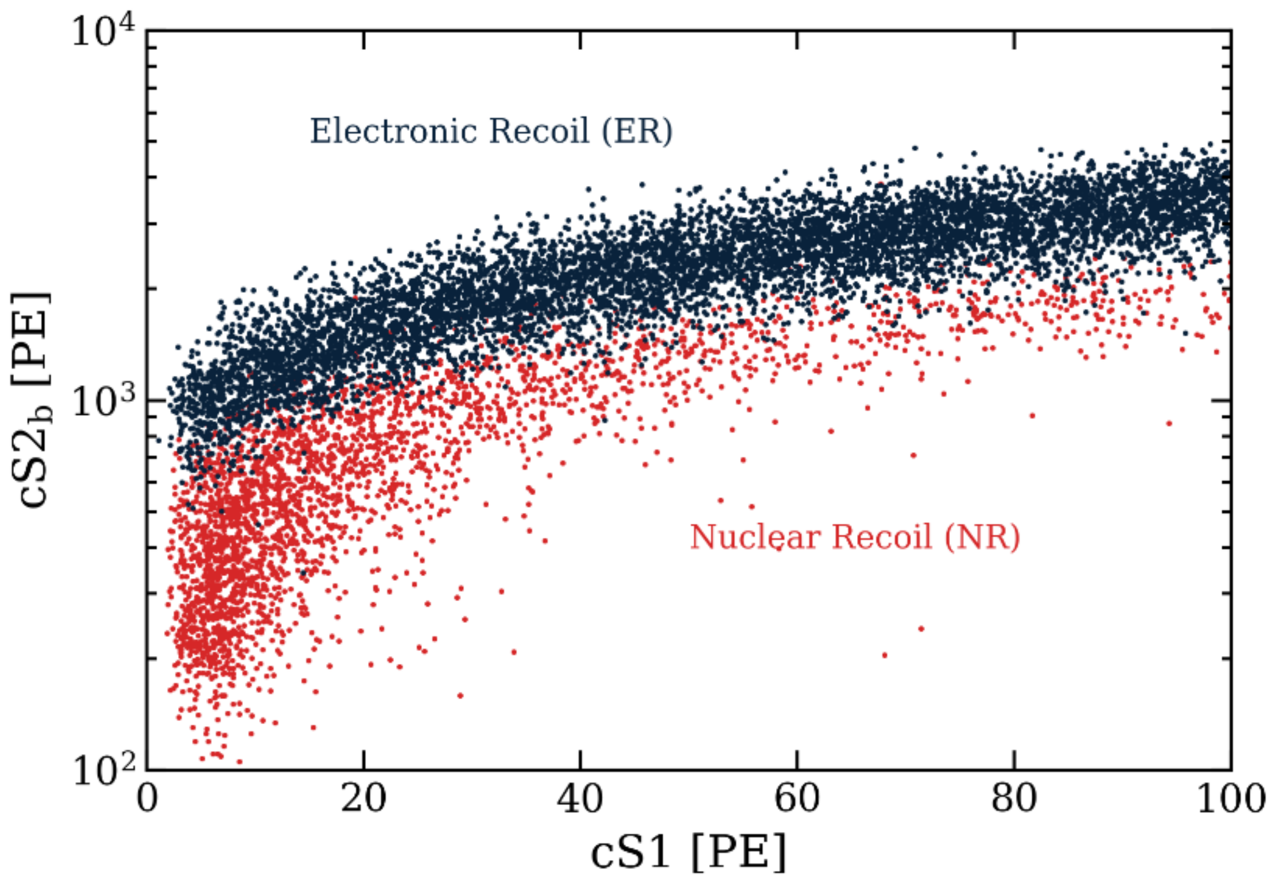
## Signal discrimination

- Ratio S2/S1 to discriminate between nuclear recoils (NR) and electronic recoils (ER)

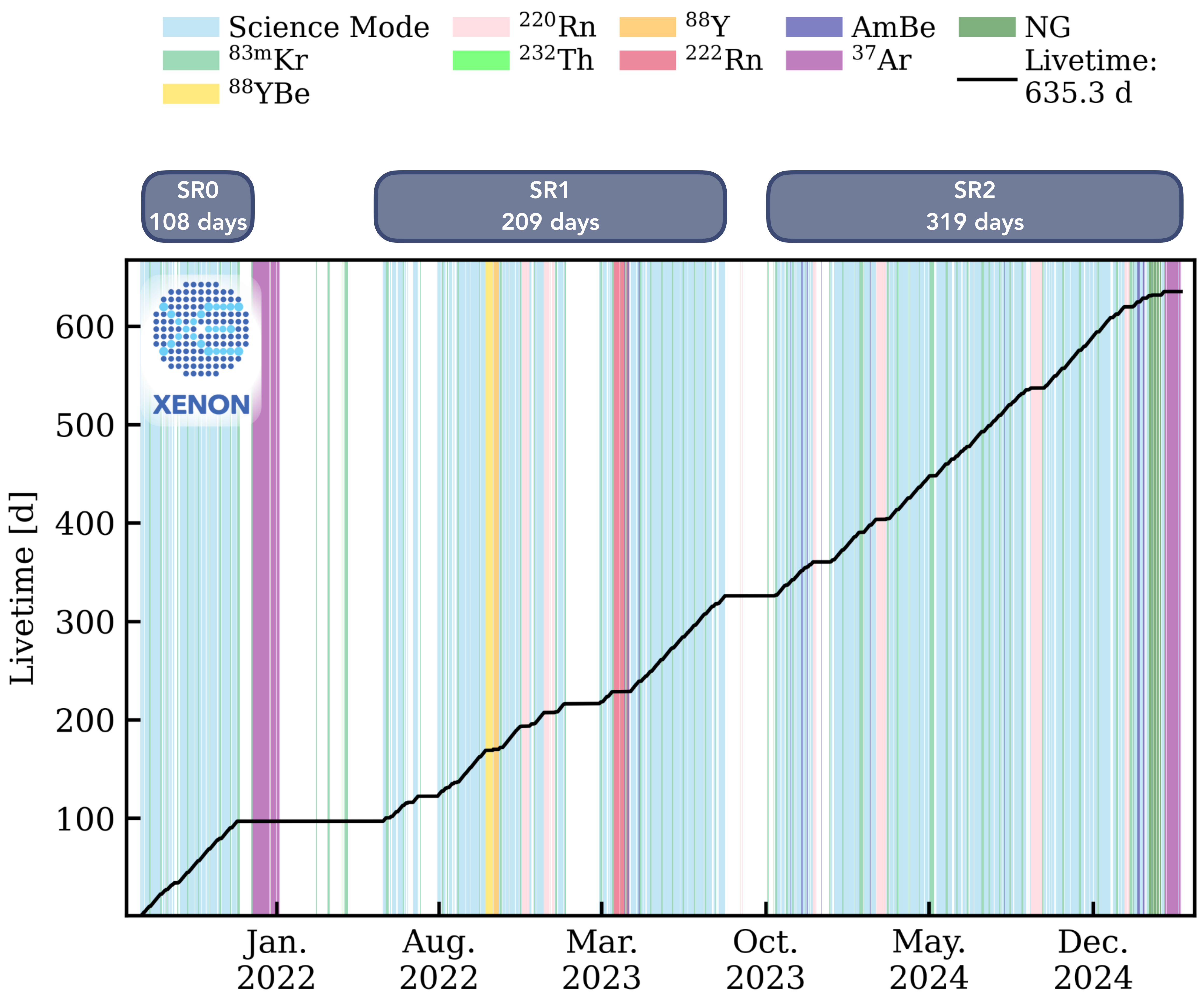



- Gamma and Beta
- Double-weak decays
- Neutrino elastic scattering
- Solar axions, ALPs

- Neutrons
- Neutrinos (CE$\nu$NS)
- WIMPs



# XENONnT science data




**Fiducial mass**
**~4 tonnes**

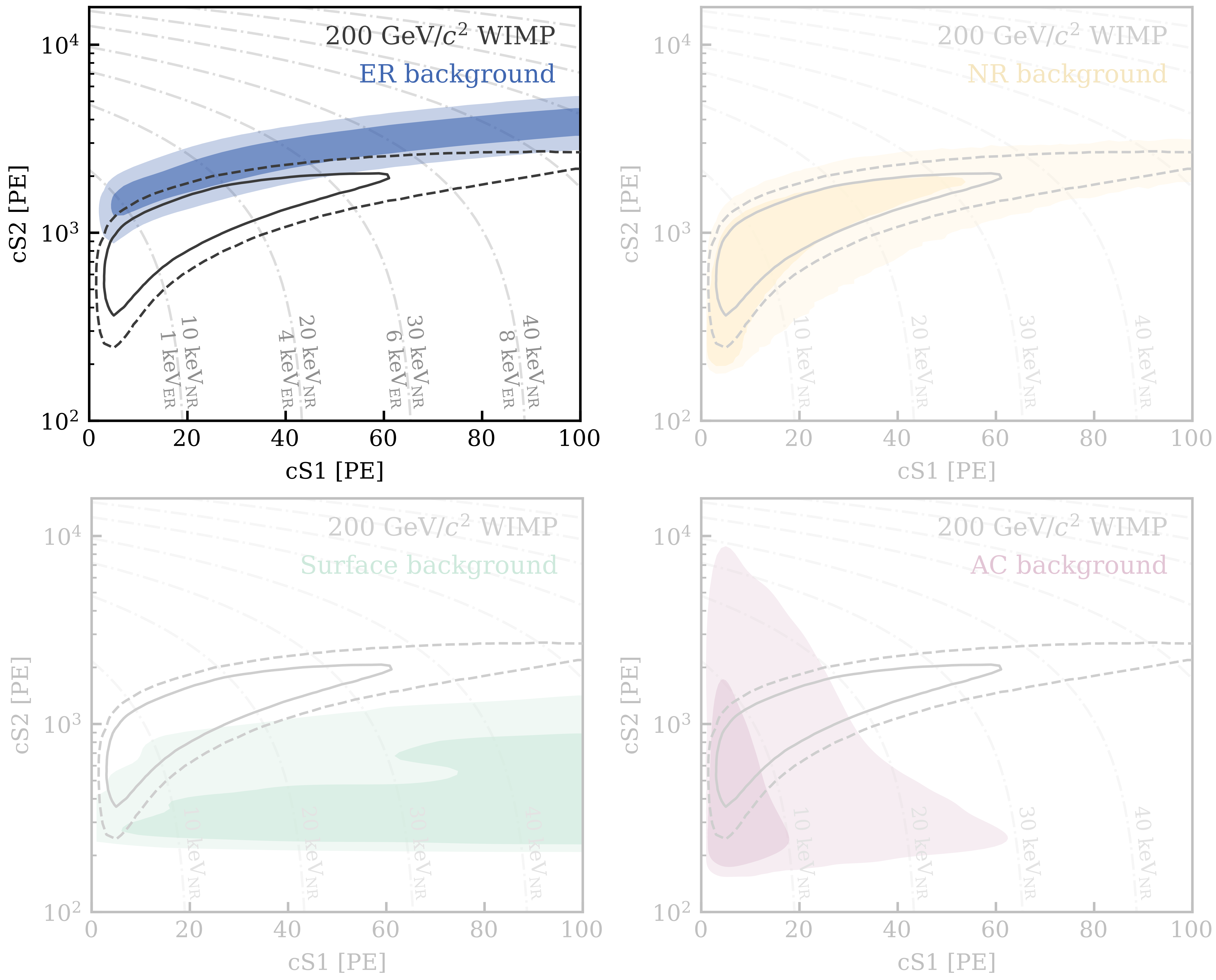
**Exposure**
**~ 6.7 tonnes · year**

## DM and neutrino search results so far

- SR0
  - Searches of new physics in ER
  - WIMP search in NR
- SR0 + SR1
  - First indication of solar $^8$B neutrinos
  - First search of light DM in neutrino fog
  - WIMP search
- SR0+ SR1 + SR2
  - Measurement of solar $^8$B neutrinos
  - Light DM search

# WIMP search

# Background model




**Electronic recoil (ER)**

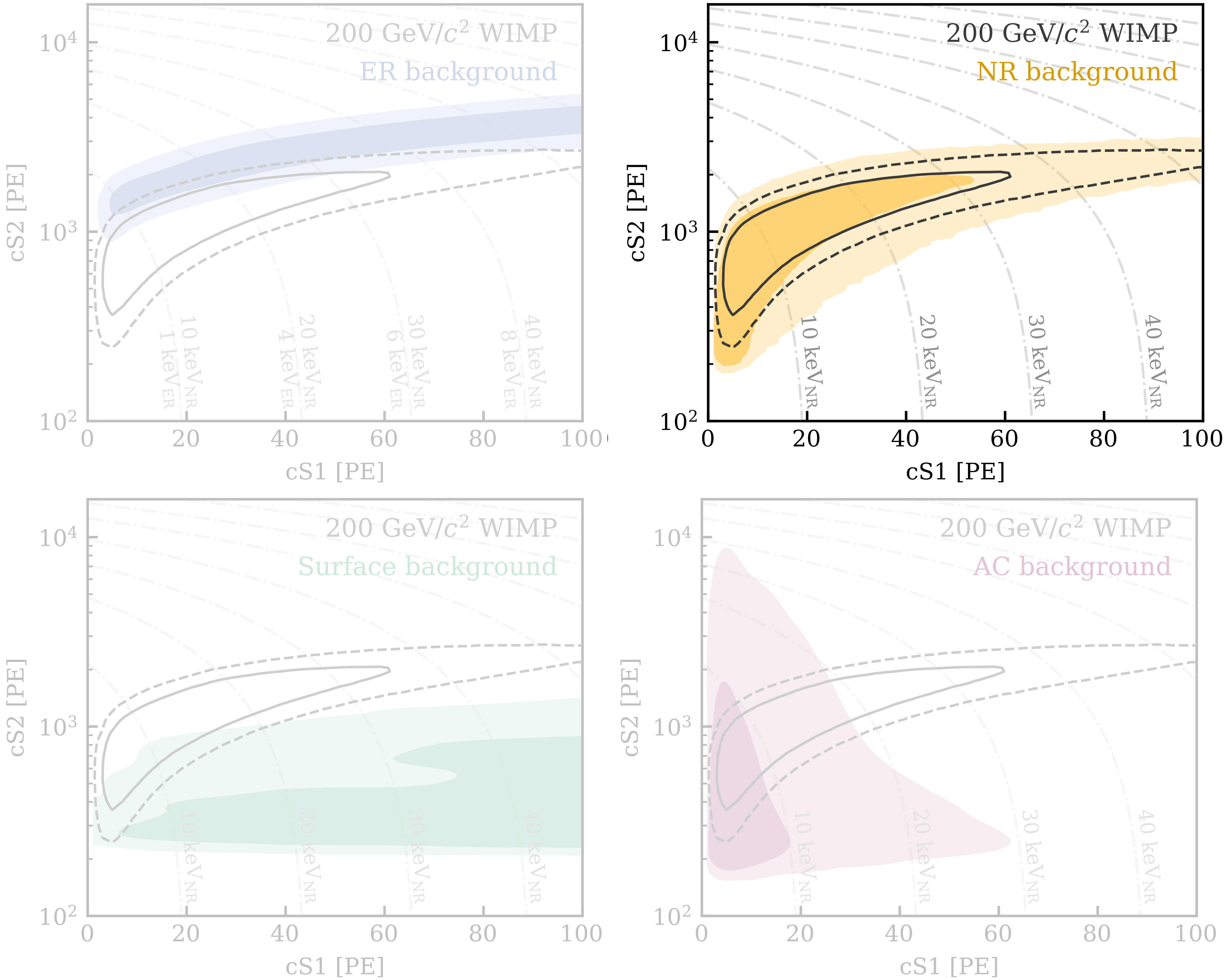
- Continuous $\beta$-spectrum of $^{214}$Pb at low energies
- $^{85}$Kr β-decays
- Solar $\nu$-e scattering
- Double-weak decays of xenon isotopes

**Shape constrained by $^{220}$Rn calibration data**

*"c" before S1/S2 stands for "corrected"

*Analysis paper: PRD **111**, 062006 (2025)*

# Background model



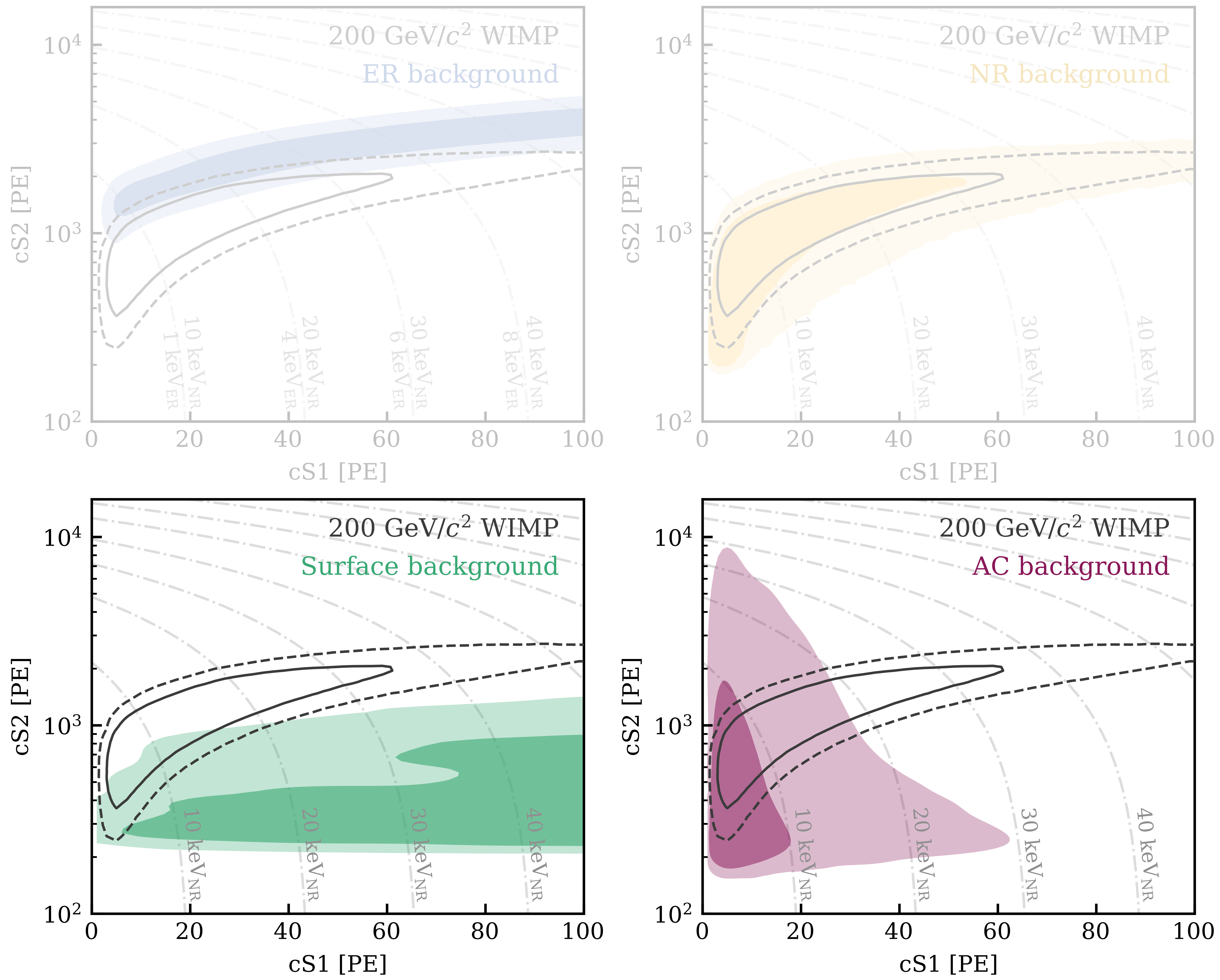

**Nuclear recoil (NR)**

- Radiogenic neutrons from detector materials
- CE$\nu$NS events in region of interest (ROI)

**Constrained by sideband of multi-scatter events and single-scatter events tagged by n-Veto**

*Analysis paper: PRD **111**, 062006 (2025)*

# Background model




**Surface events**

- $^{214}$Pb rate from PTFE walls

**Reduced by volume fiducialization**

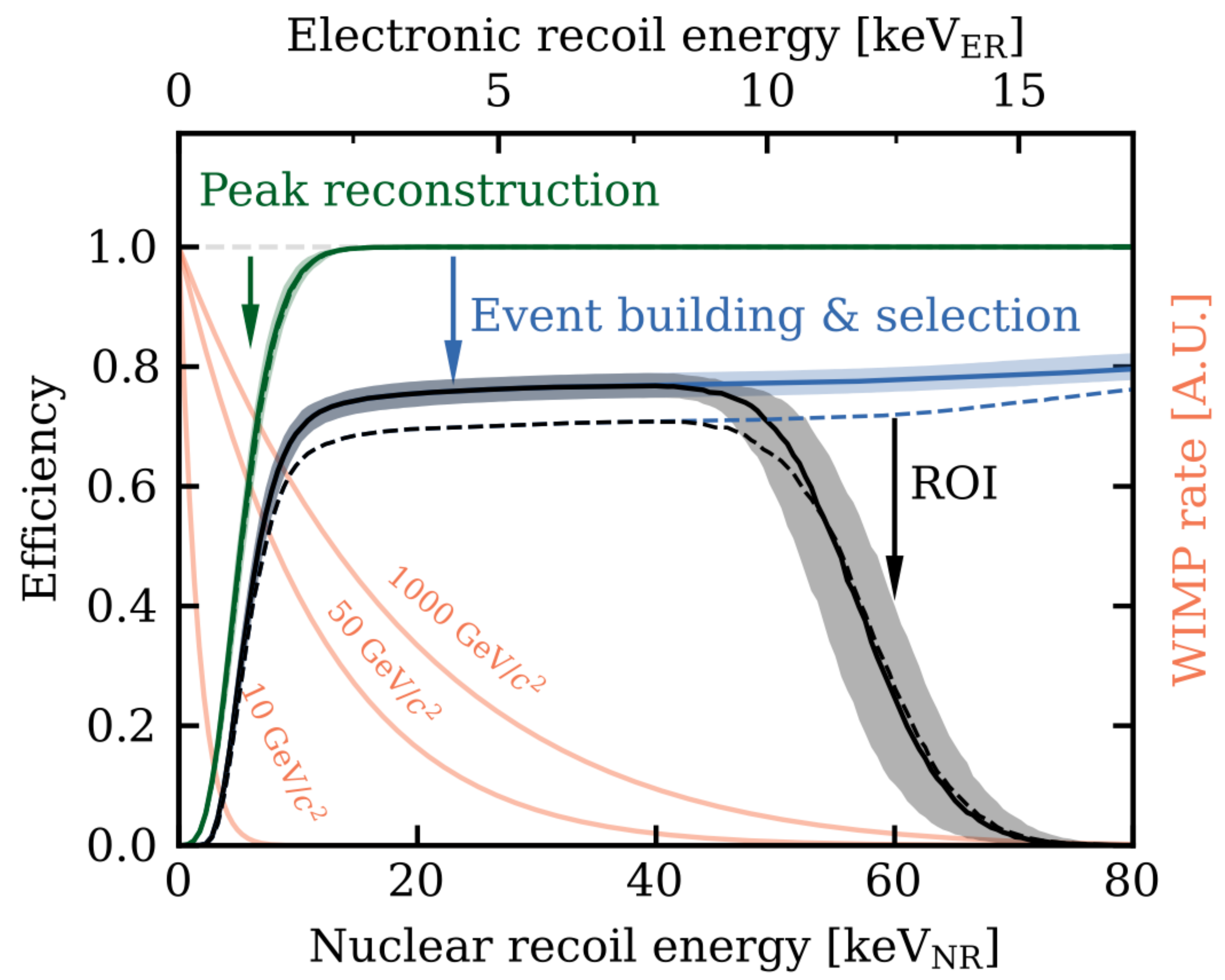
**Accidental coincidences (AC)**

- Incorrectly paired S1 and S2 signals
- Modeled using data-driven methods

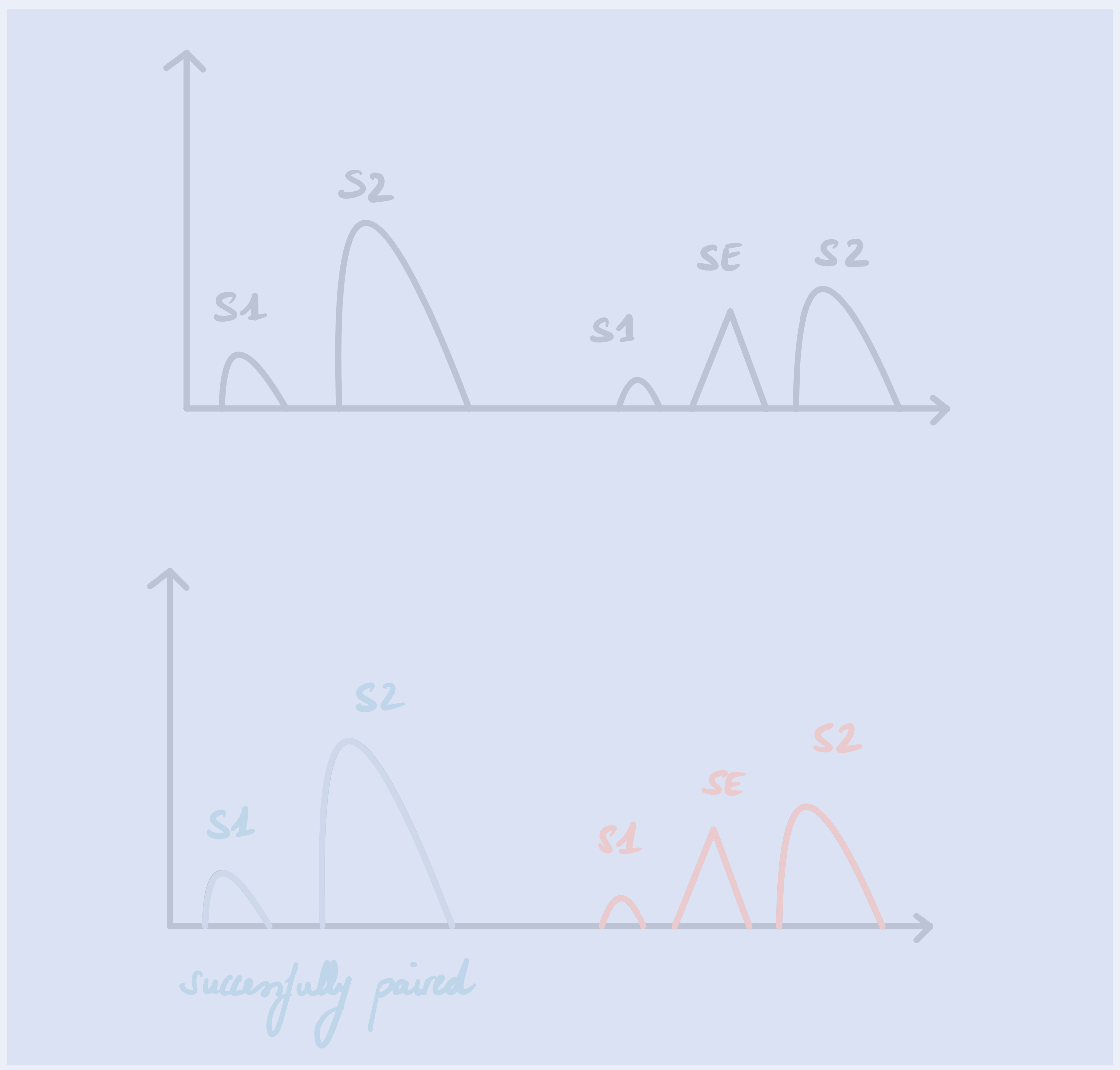
**Suppressed by ML-based data selection**

*Analysis paper: PRD **111**, 062006 (2025)*

# Signal reconstruction

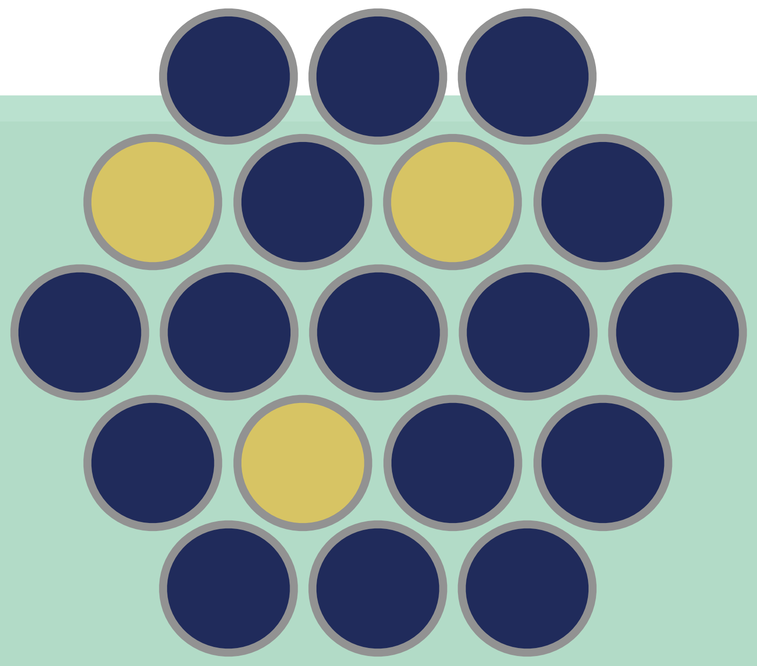



*Efficiency vs recoil energy for SR1a (dashed) and SR1b (solid); orange curves show example WIMP spectra*




**Event building and selection**

Build S1+S2 pairs; reject AC via GBDT; apply quality cuts



**Peak reconstruction**

S1 threshold: 3-PMT coincidence

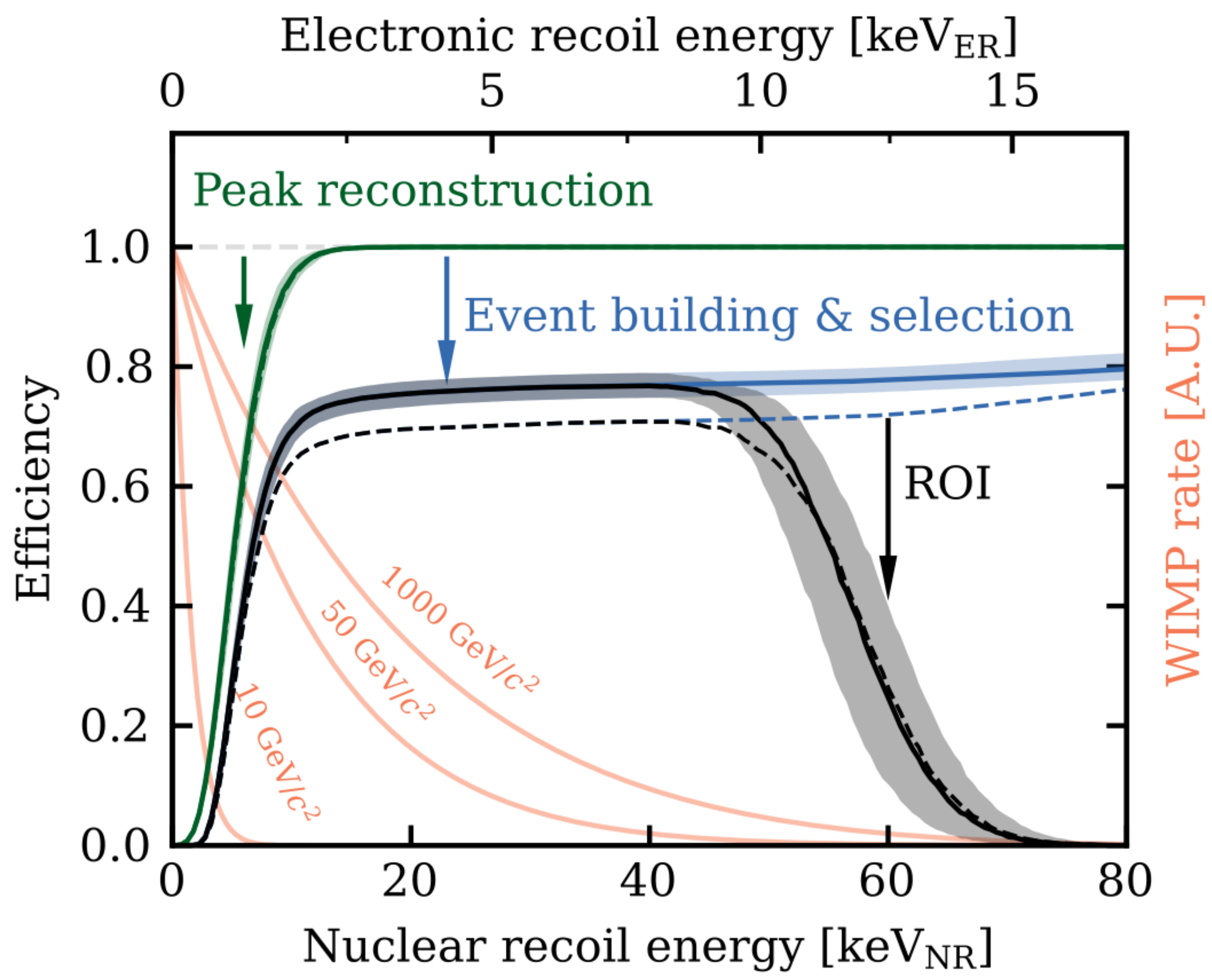
**ROI**

$cS1 < 100$ PE

$cS2 \in [10^{2.1}, 10^{4.1}]$ PE

*WIMP search paper: PRL **135**, 221003*

# Signal reconstruction

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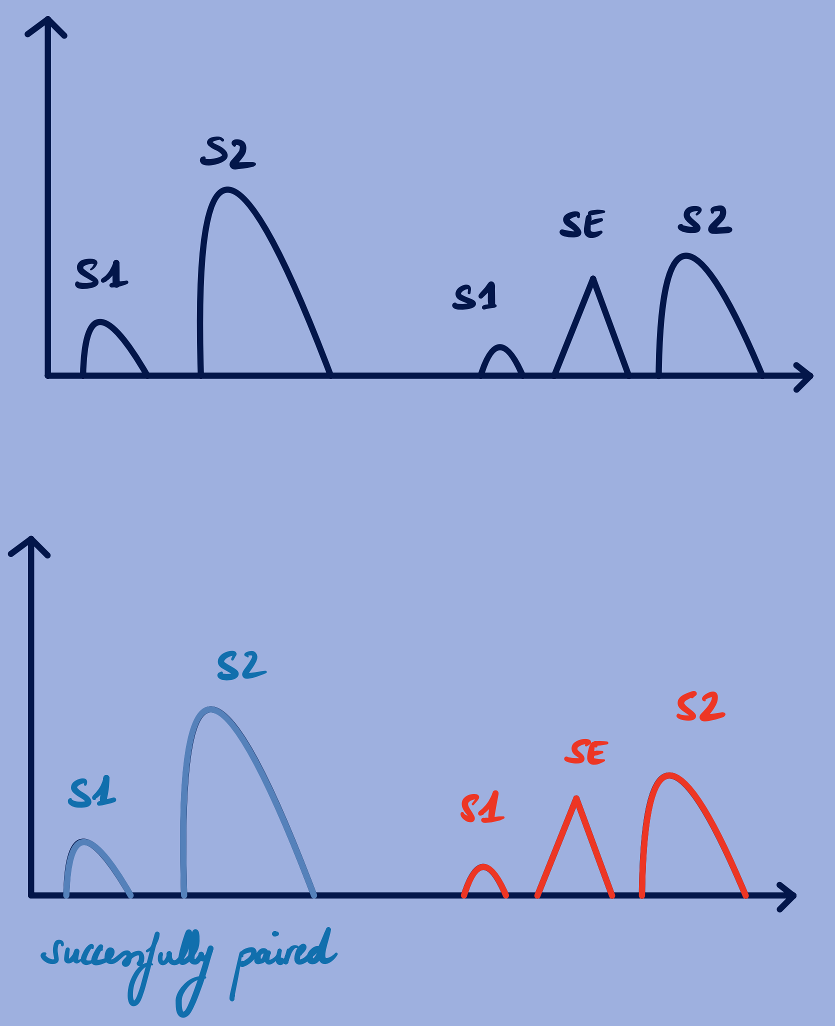


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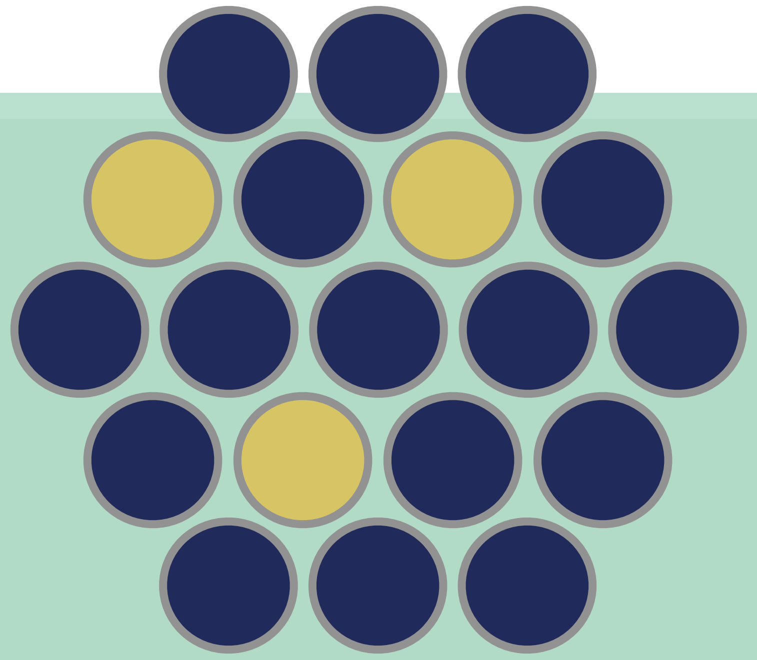

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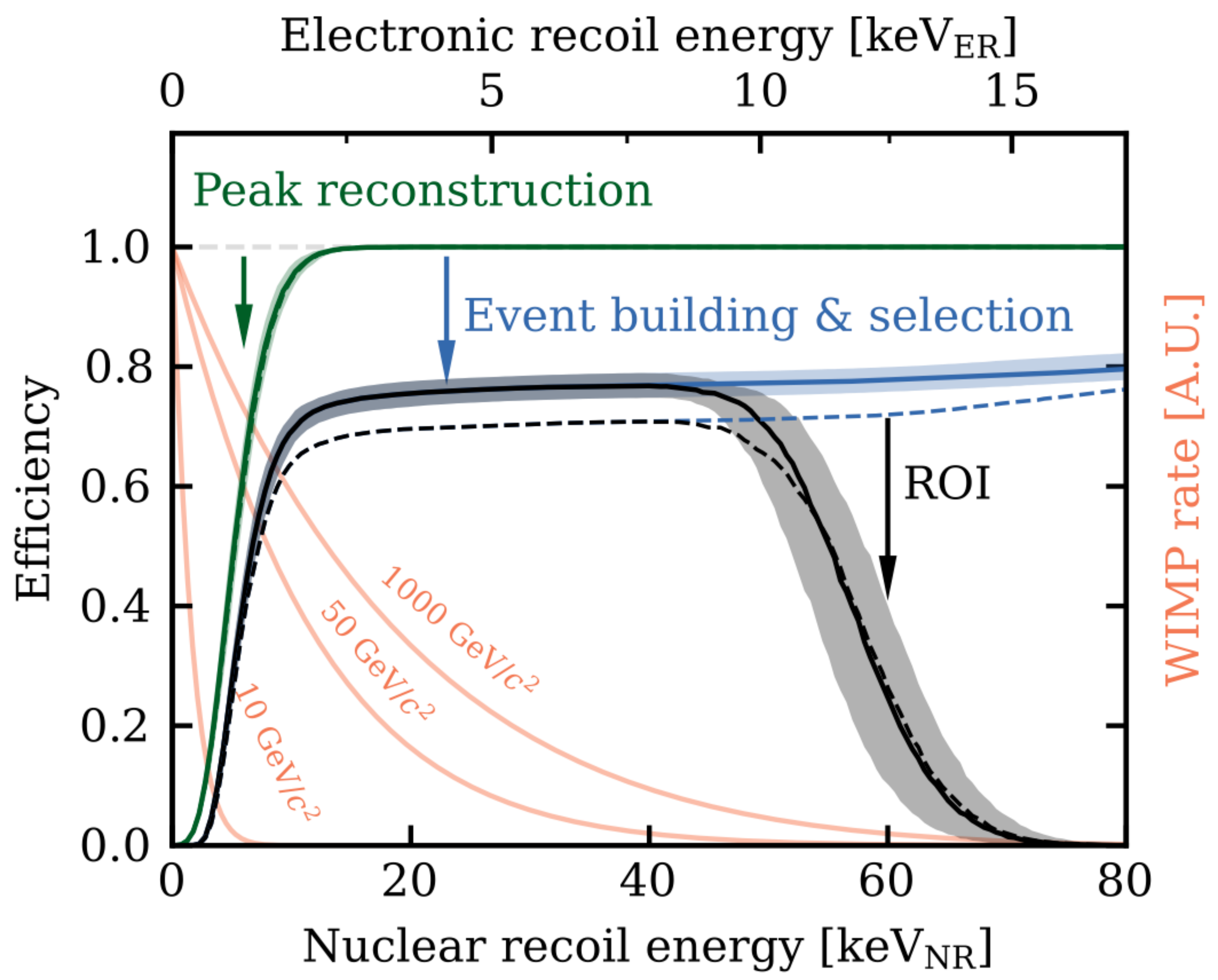


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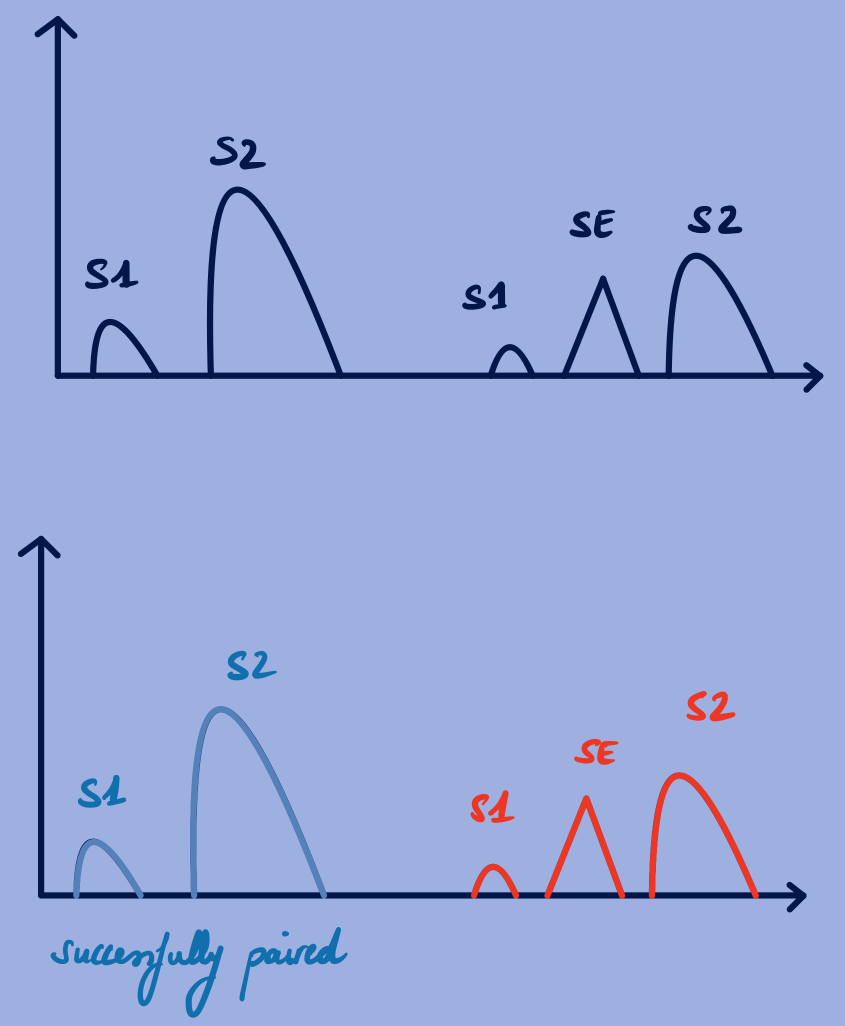


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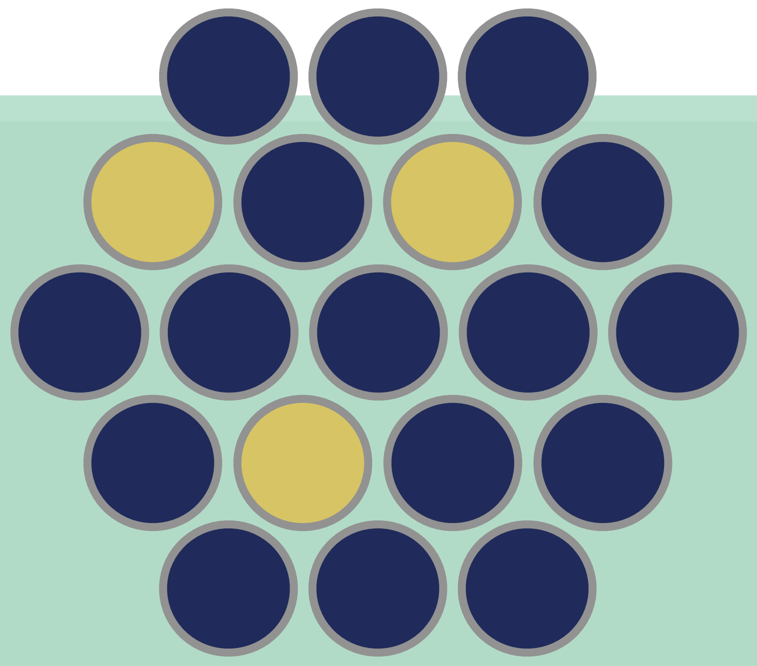

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*WIMP search paper: PRL **135**, 221003*

# WIMP results

**Total exposure**

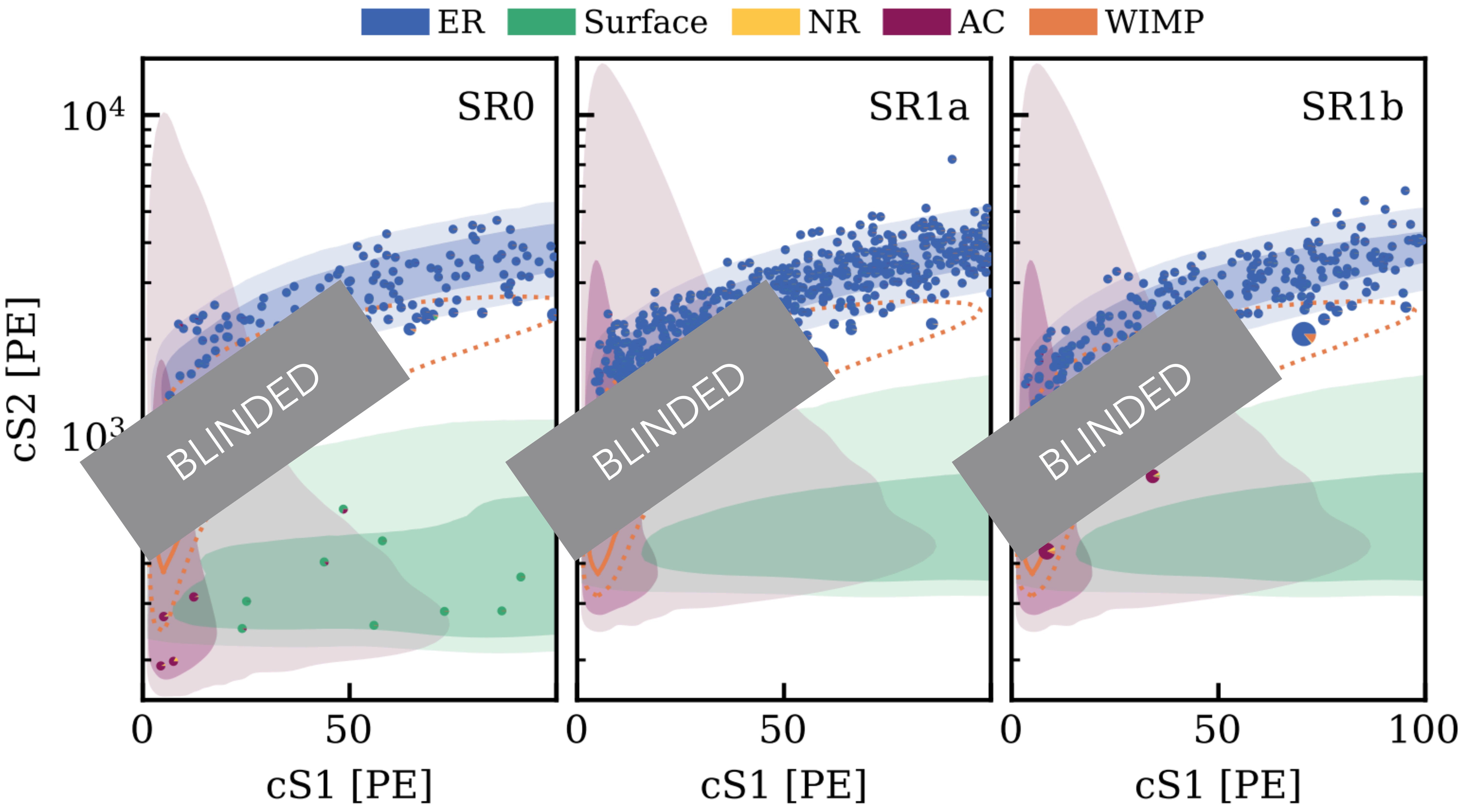
3.1 tonnes · year

**Science data**

- SR0 : re-analyzed
  - Updated background model
  - Unblinded data kept untouched
- SR1 :
  - Blind analysis in WIMP ROI

**66.6 days**
- High rates of $^{85}Kr$ and $^{37}Ar$
- $^{3}H$ background

**119.9 days**
- ER rate back to SR0 level
- $^{3}H$ component remains




*WIMP search paper: PRL **135**, 221003*

# WIMP results

### Total exposure

3.1 tonnes · year

### Science data

- SR0 : re-analyzed
  - Updated background model
  - Unblinded data kept untouched
- SR1 :
  - Blind analysis in WIMP ROI

**Observed events**

45 events in the blinded region

No significant excess over background

[PRL **135**, 221003](PRL 135, 221003)

**66.6 days**
- High rates of $^{85}Kr$ and $^{37}Ar$
- $^{3}H$ background

**119.9 days**
- ER rare back to SR0 level
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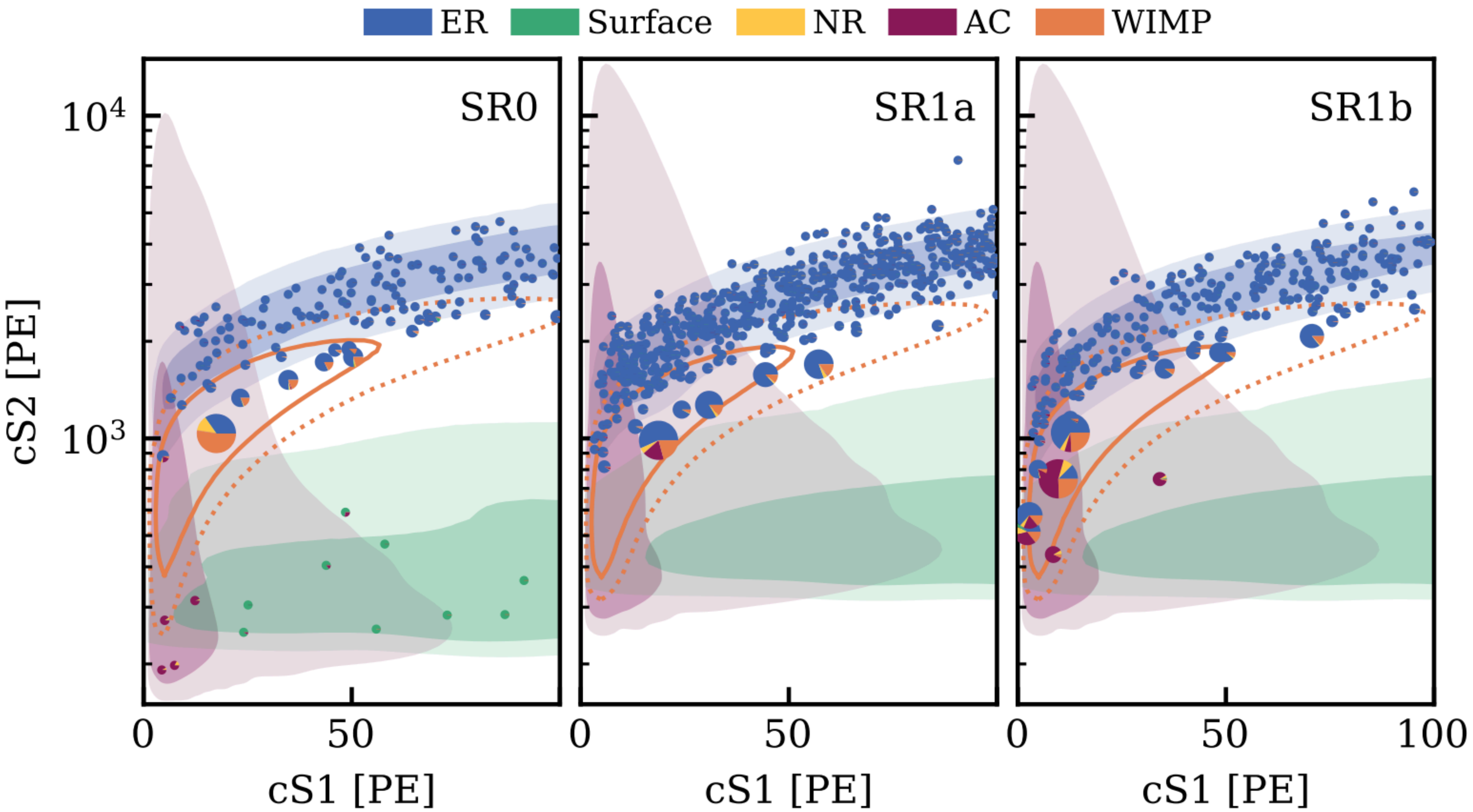


*The pie charts represent a fraction of the best-fit model w/ 200 GeV/c² WIMP evaluated at the position of the event*

# WIMP results

**Total exposure**

3.1 tonnes · year

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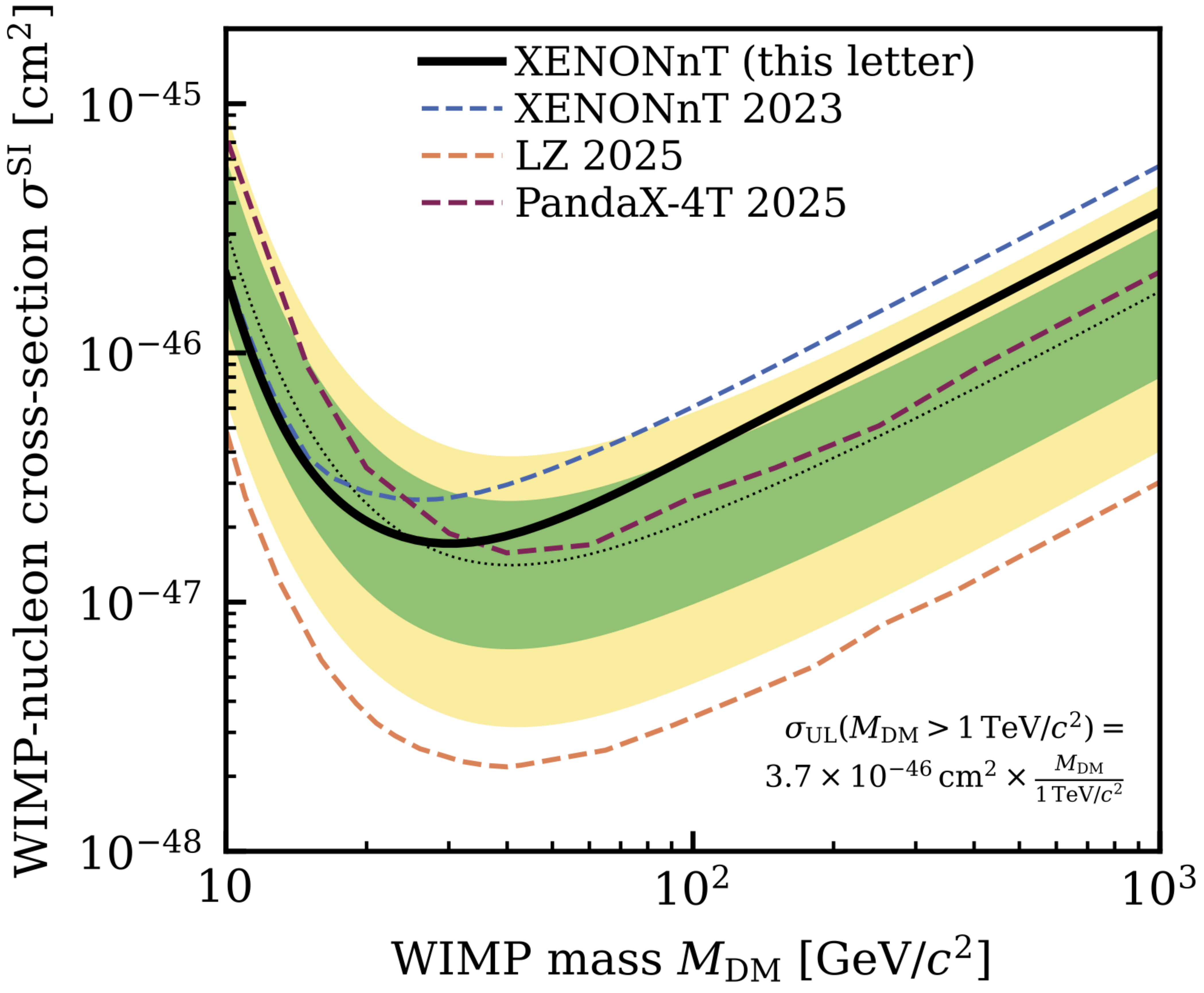
- SR0 : re-analyzed
  - Updated background model
  - Unblinded data kept untouched
- SR1 :
  - Blind analysis in WIMP ROI

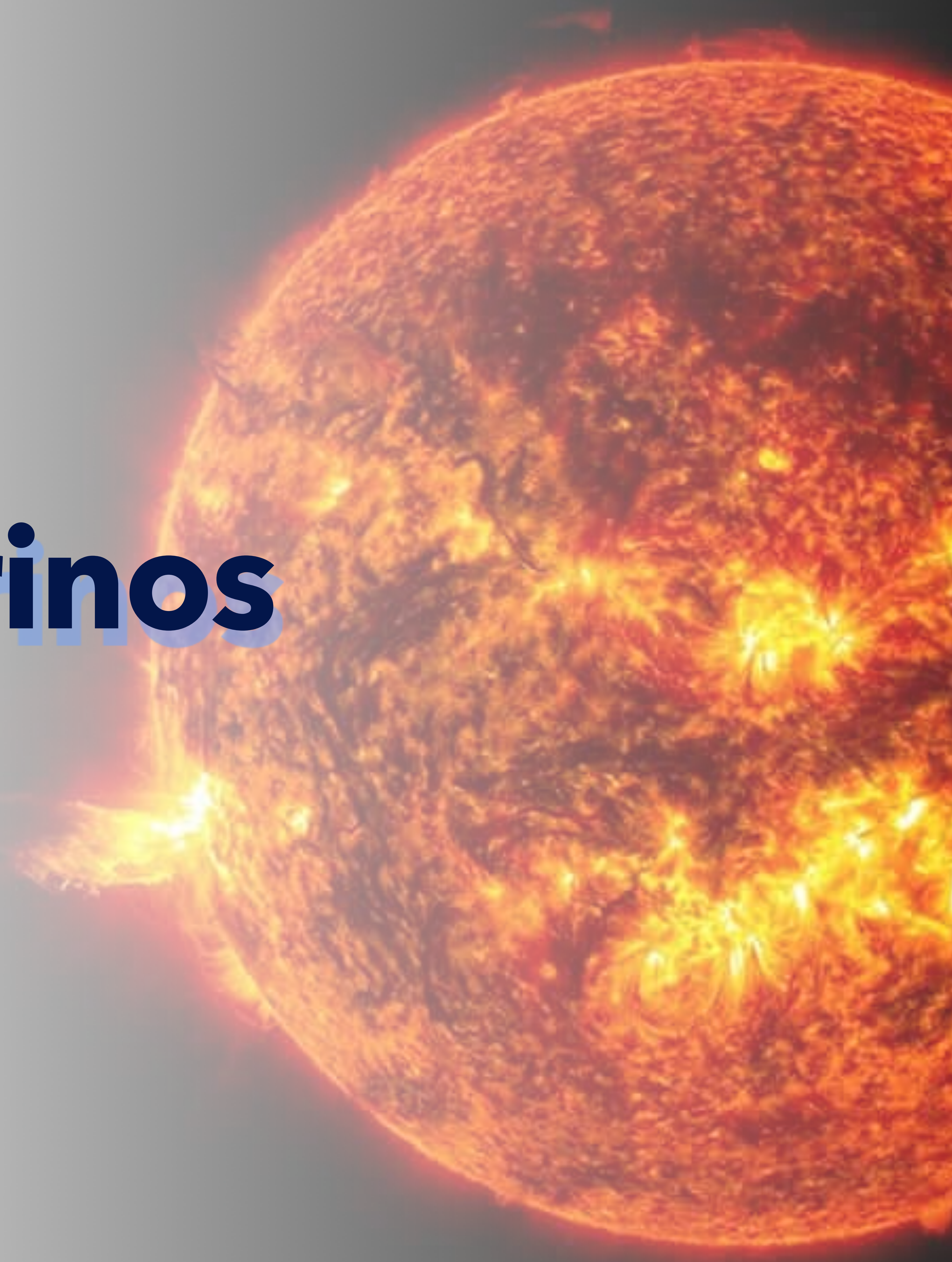
**New exclusion limit on WIMP-nucleon SI cross-section at**

$1.7 \cdot 10^{-47}$ cm$^2$ for $m_\chi = 30$ GeV/c$^2$

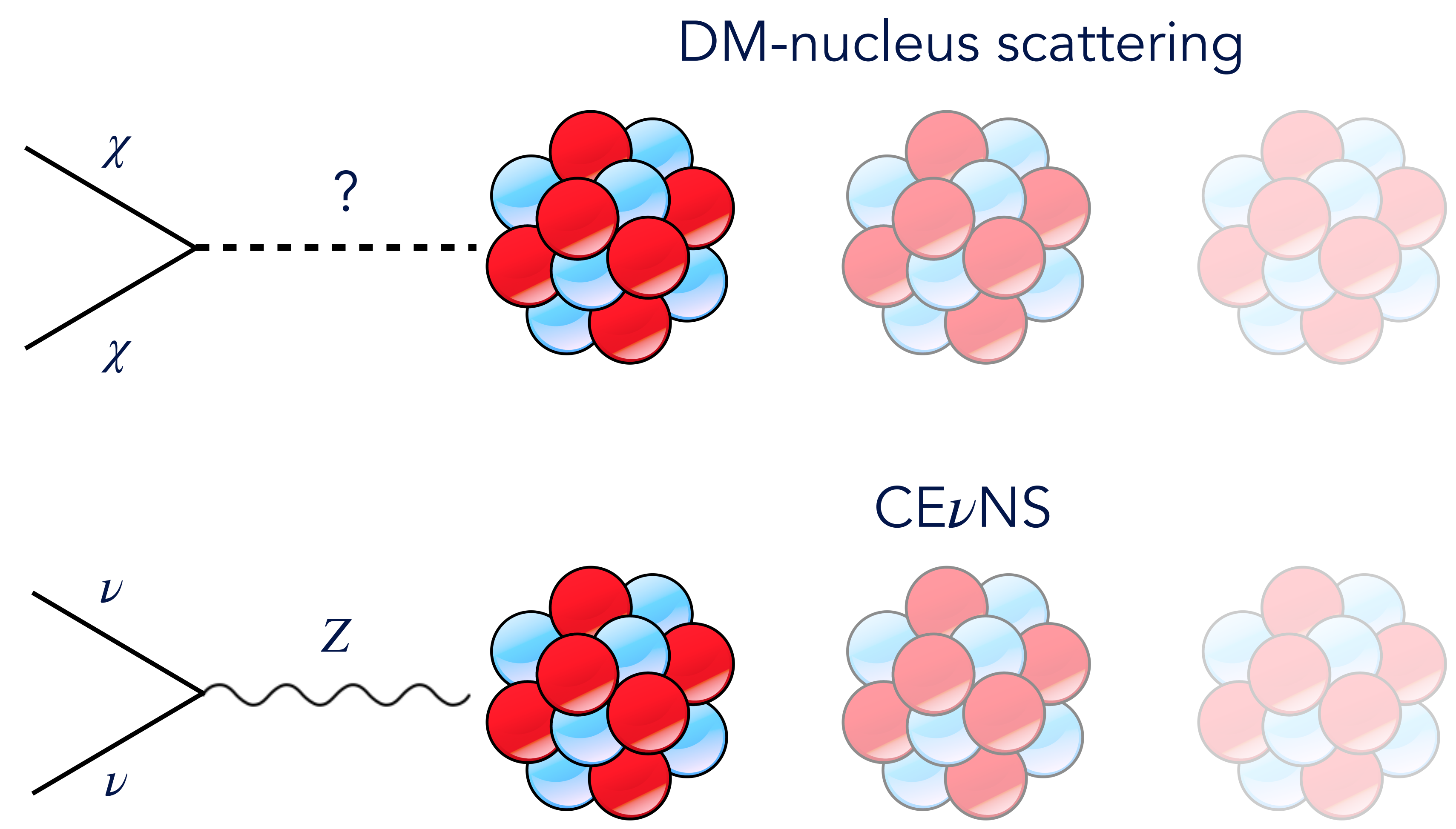
*PRL **135**, 221003*



# $^{8}$B solar neutrinos



# Stepping into the neutrino fog

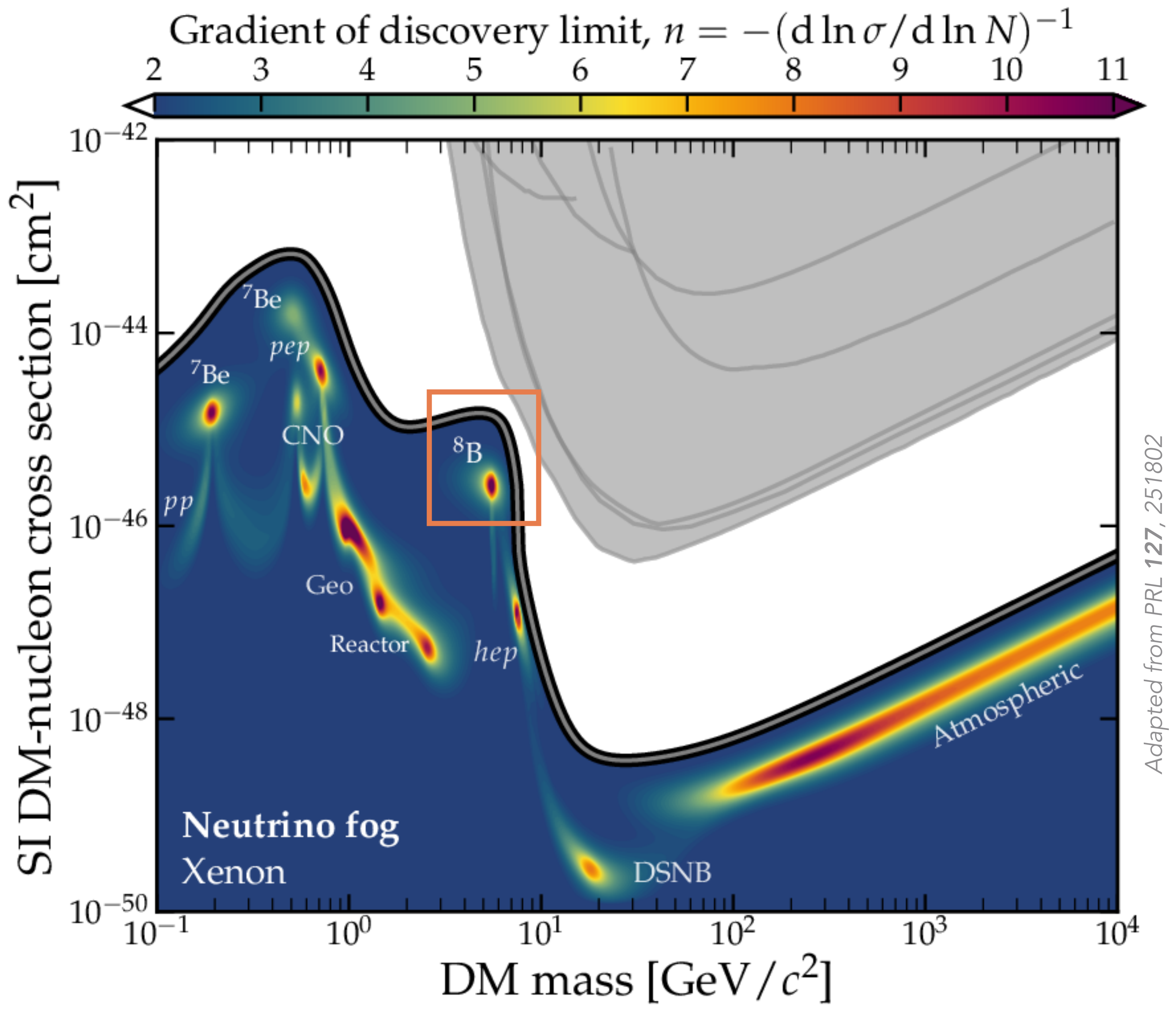



## CE$\nu$NS signal

**C**oherent **E**lastic Neutrino-**N**ucleus **S**cattering

- SM process: predicted in 1974, observed by COHERENT in 2017
- Coherent enhancement gives $\sigma \propto N^2$, but only at low momentum transfer → $^8$B CE$\nu$NS typical recoil energy < 1.5 keV
- Produces single-scatter nuclear recoils that **mimic a WIMP signal**

→ **irreducible "neutrino fog"**




*Color shows how much the fog slows sensitivity gains with exposure*

# Stepping into the neutrino fog

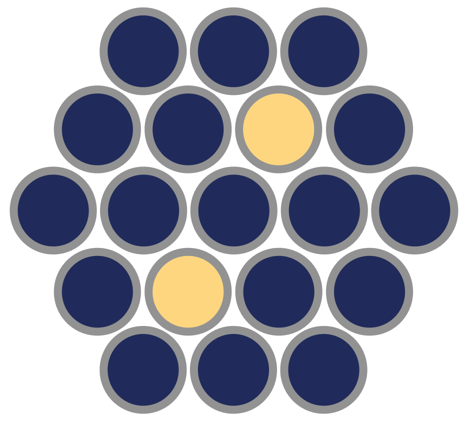
## Datasets

- SR0 + SR1 + SR2 - total livetime of 603 days
- Total exposure: 6.77 tonnes · year
- SR0 and SR1 unchanged; SR2 combined with same drift field and stable conditions

## Lowering the threshold

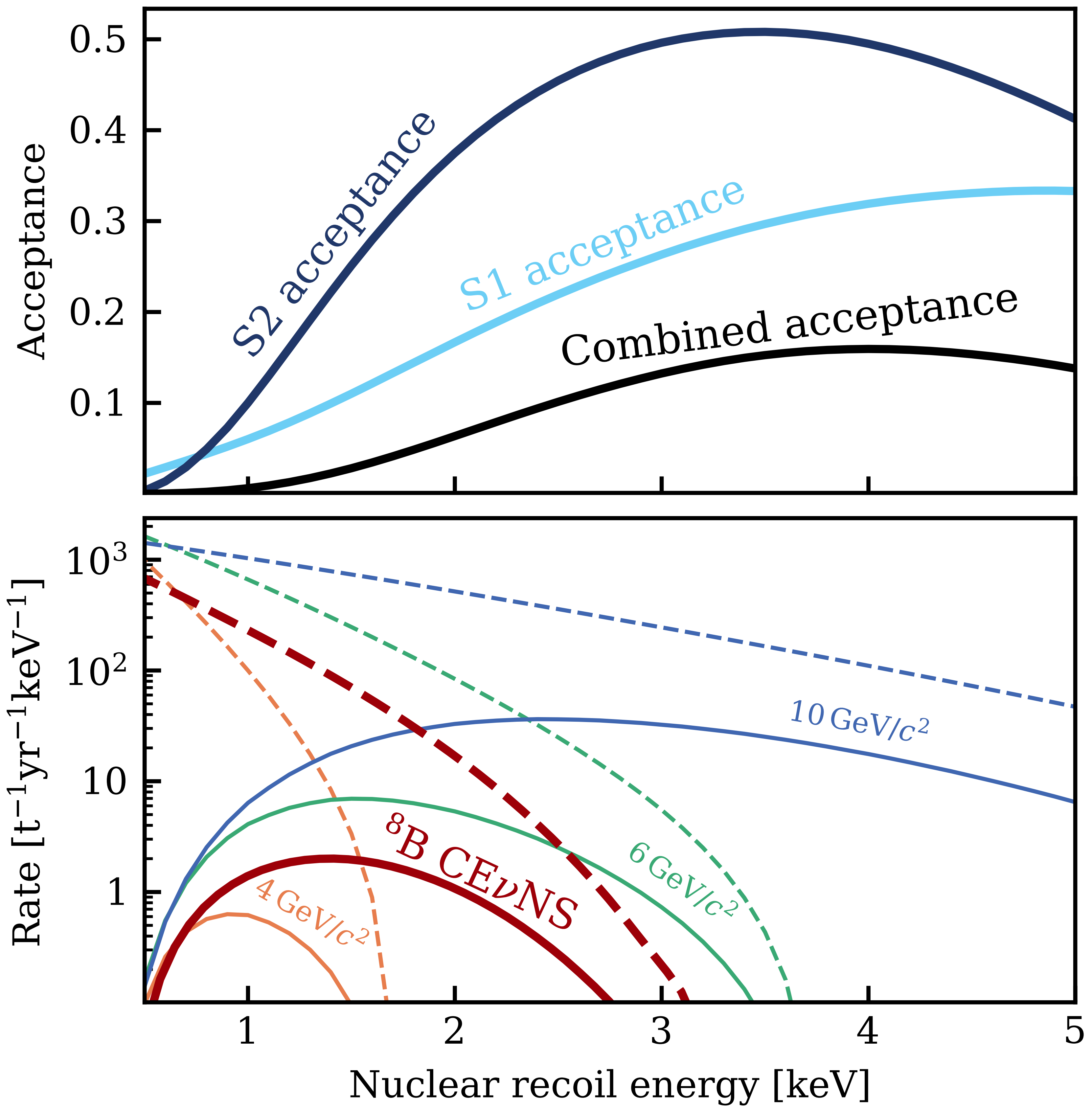
2-fold instead of 3-fold detection

→ lower energy ROI



**Precisely model**

Low energy NRs + AC background




***Top:*** *Low-energy NR acceptance, exposure-weighted over the three SRs.* ***Bottom:*** *Expected $^8$B CEvNS and SI WIMP spectra, with (solid) and without (dashed) acceptance.*

*CE$\nu$NS search paper: arXiv:2604.06002*

# Measurement of solar $^8$B CE$\nu$NS

## Signal and background predictions

| Component | Expectation |
|---|---|
| AC (SR0) | $7.5 \pm 0.7$ |
| AC (SR1) | $17.8 \pm 1.0$ |
| AC (SR2) | $14.9 \pm 0.7$ |
| ER | $1.2 \pm 1.2$ |
| Neutron | $0.8^{+0.4}_{-0.5}$ |
| Total background | $42.1^{+1.9}_{-1.7}$ |
| $^8$B (SR0) | $3.2^{+1.0}_{-0.9}$ |
| $^8$B (SR1) | $5.9^{+1.9}_{-1.6}$ |
| $^8$B (SR2) | $7.2^{+2.3}_{-1.9}$ |
| Total $^8$B | $16^{+5}_{-4}$ |
| Total observed | |

## How we test it

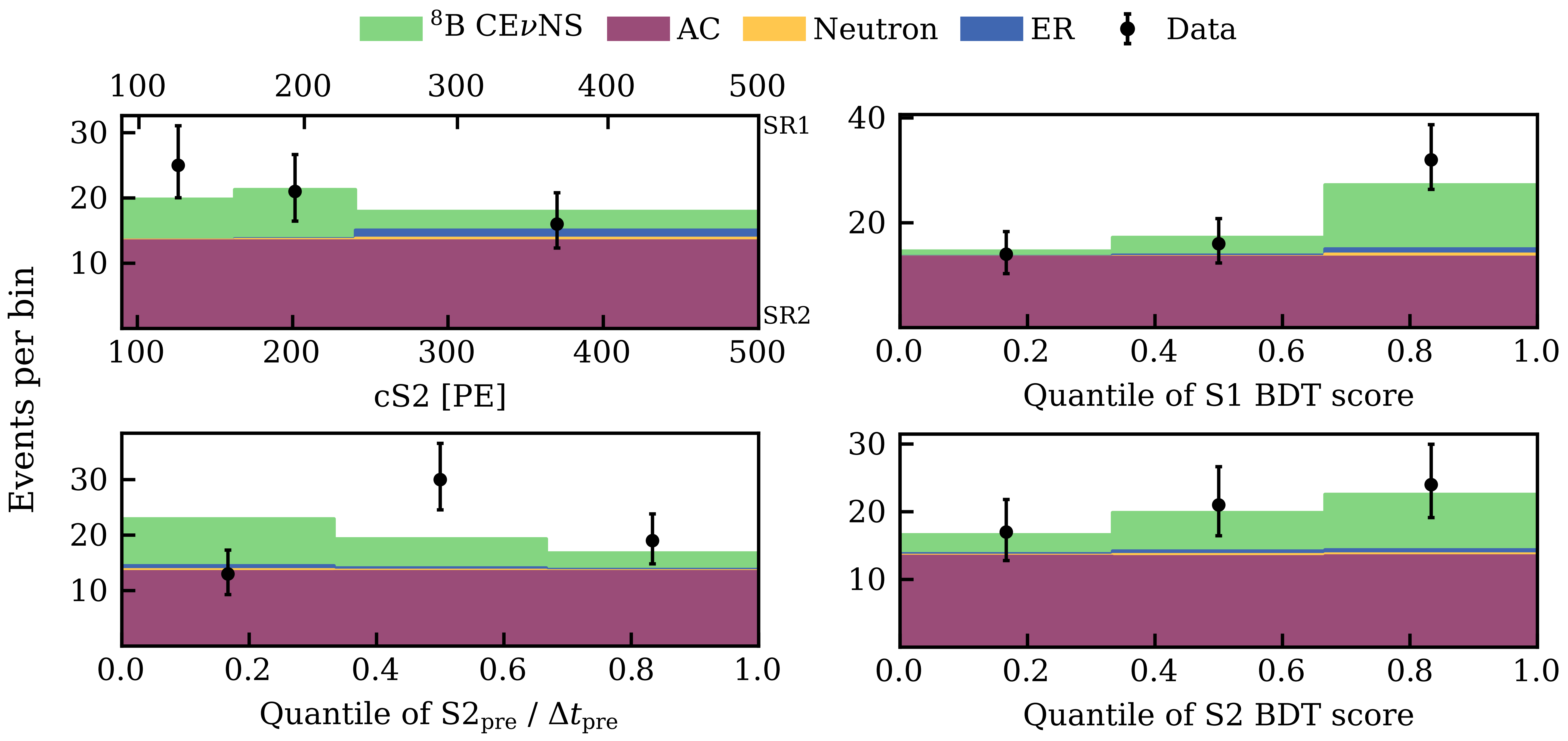
- 4 observables: cS2, $S2_{pre}/\Delta t_{pre}$, S1 BDT, S2 BDT
- 3 bins each → 81-bin extended likelihood fit, AC-flat binning
- Blinded ROI
- Goodness-of fit tests fixed before unblinding

*CE$\nu$NS search paper: arXiv:2604.06002*

# Measurement of solar $^{8}$B CE$\nu$NS

## Signal and background predictions

| Component | Expectation | Best-fit |
|---|---|---|
| AC (SR0) | $7.5 \pm 0.7$ | $7.4 \pm 0.7$ |
| AC (SR1) | $17.8 \pm 1.0$ | $17.9 \pm 1.0$ |
| AC (SR2) | $14.9 \pm 0.7$ | $14.9 \pm 0.7$ |
| ER | $1.2 \pm 1.2$ | $1.4 \pm 1.1$ |
| Neutron | $0.8^{+0.4}_{-0.5}$ | $0.8 \pm 0.4$ |
| Total background | $42.1^{+1.9}_{-1.7}$ | $42.4 \pm 1.9$ |
| $^{8}$B (SR0) | $3.2^{+1.0}_{-0.9}$ | $3.3 \pm 1.0$ |
| $^{8}$B (SR1) | $5.9^{+1.9}_{-1.6}$ | $6.1^{+1.7}_{-1.9}$ |
| $^{8}$B (SR2) | $7.2^{+2.3}_{-1.9}$ | $7.3^{+2.1}_{-2.3}$ |
| Total $^{8}$B | $16^{+5}_{-4}$ | $17 \pm 5$ |
| Total observed: $9\,(SR0) + 28\,(SR1) + 25\,(SR2) = 62$ | | |




arXiv:2604.06002

3.3 σ observation of solar $^{8}$B CE$\nu$NS, with a measured $^{8}$B neutrino flux of $(5^{+3}_{-2}) \times 10^{6}$ cm$^{-2}$ s$^{-1}$

# Conclusion and outlook

## Results

- **WIMPs:** no excess over background, new exclusion limit at $1.7 \cdot 10^{-47}$ cm$^2$ for $m_\chi = 30$ GeV/c$^2$
- **$^8$B CE$\nu$NS:** first multi-SR measurement at 3.3 $\sigma$ rejection of background-only hypothesis
- The neutrino fog is now signal, not just background

## Outlook

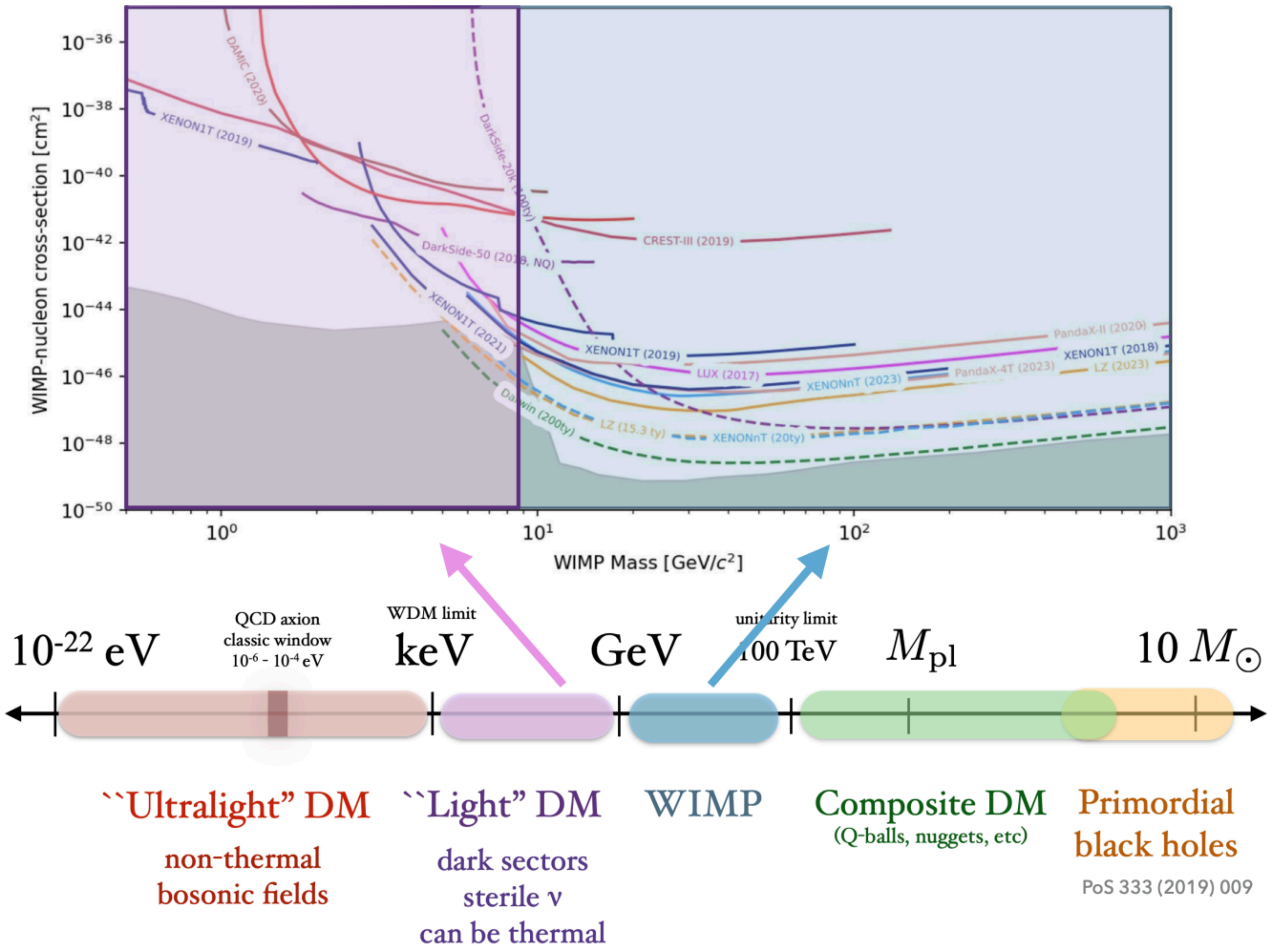
- XENONnT recommissioned after **electrode upgrade** → higher fields, better background suppression
- Ongoing: SR0+1+2 WIMP search
- **XLZD:** next-generation LXe TPC, target mass up to ~60 t

xenonexperiment.org

@xenon_experiment

# Backup slides

# Regions of interest



# WIMP results

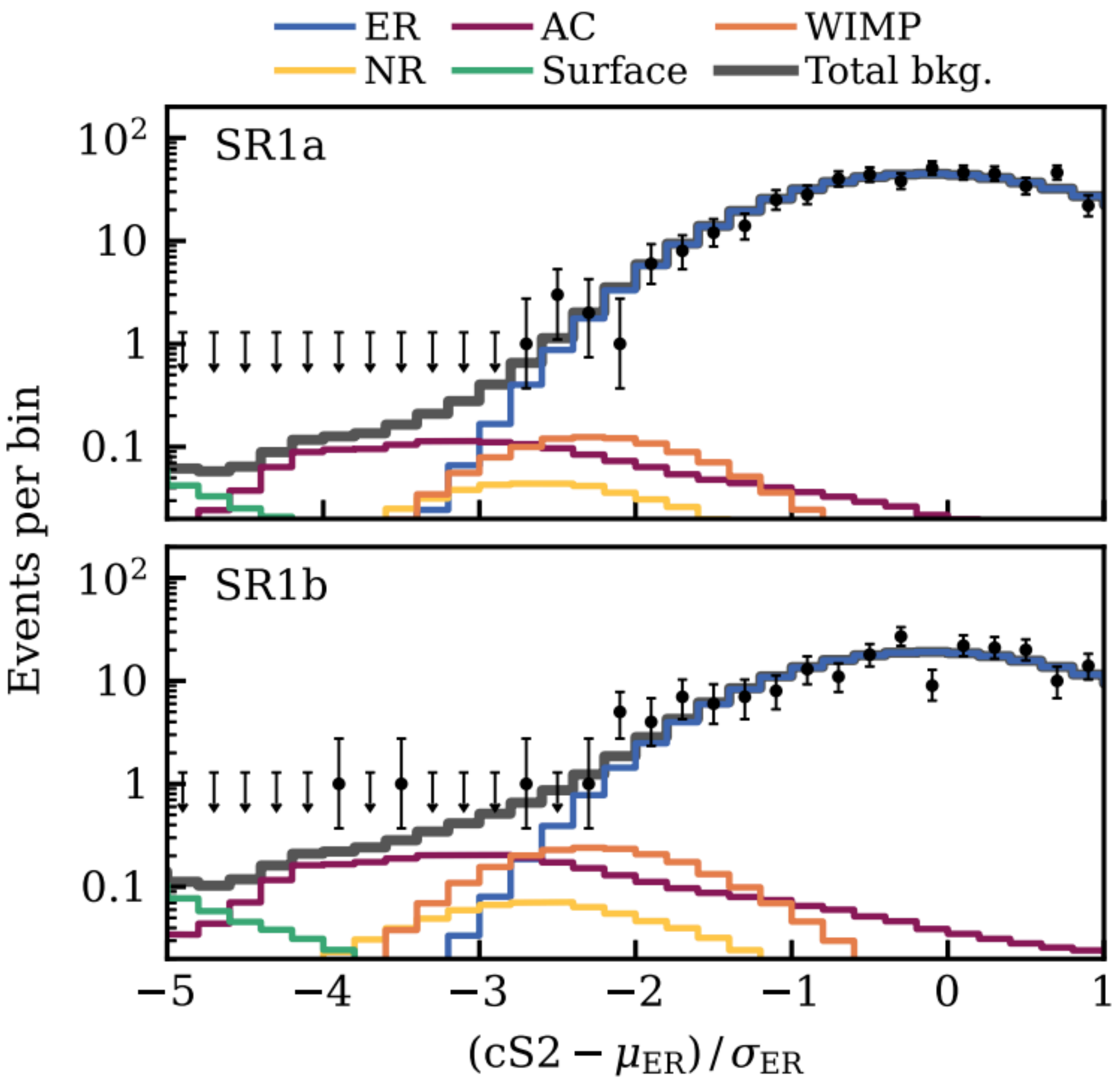



FIG. 3. Distribution in cS2 of the observed data and the best-fit model including an unconstrained 200 GeV/$c^2$ SI WIMP component in SR1a (top) and SR1b (bottom). The cS2 is normalized by subtracting the median $\mu_{ER}$ and dividing by the standard deviation $\sigma_{ER}$ of the ER distribution along cS1. The gray histogram represents the total background expectation. Black dots represent observed event counts, while triangles mark bins with zero events, both with Poisson confidence intervals.

*PRL* ***135**, 221003*

# CEvNS Background

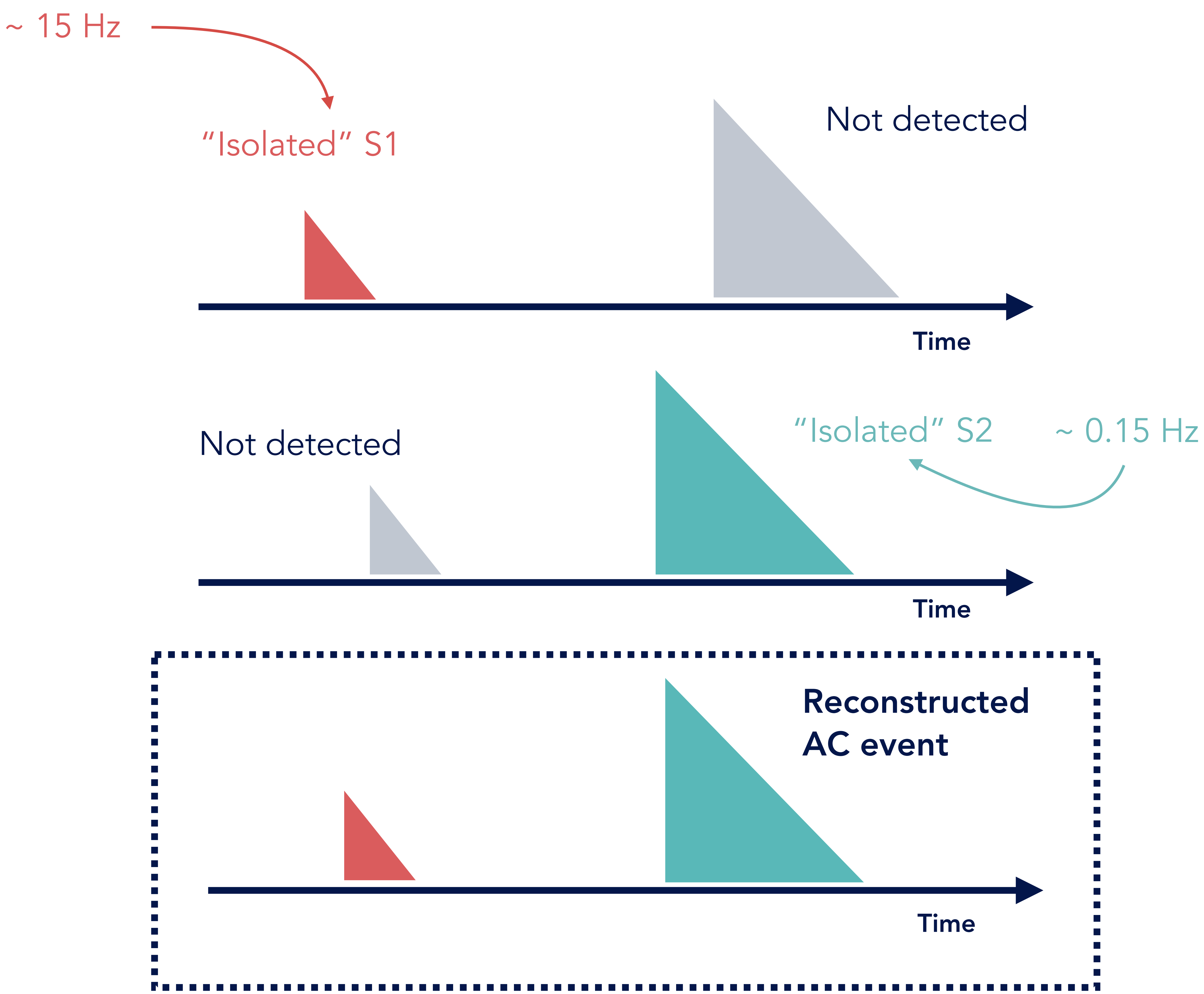
### AC background

- AC dominate the background at low thresholds
- Isolated signals are mostly delayed S1s/S2s following high-energy interactions (material radioactivity γ's)

### Suppression

- **S2 Time Shadow :** veto signals correlated with a preceding high-energy event
- **S1 & S2 BDTs** : waveform ML separating CEvNS from AC

  → AC rates: **430 → ~15**
- Residual AC handled in the likelihood fit

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