

# Searches for Light Dark Matter and Evidence of Coherent Elastic Neutrino-Nucleus Scattering of Solar Neutrinos with the LUX-ZEPLIN (LZ) Experiment

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We present searches for light dark matter (DM) with masses 3–9 GeV/ $c^2$  in the presence of coherent elastic neutrino-nucleus scattering (CE $\nu$ NS) from  $^8\text{B}$  solar neutrinos with the LUX-ZEPLIN experiment. This analysis uses a 5.7 tonne-yr exposure with data collected between March 2023 and April 2025. In an energy range spanning 1–6 keV, we report no significant excess of events attributable to dark matter nuclear recoils, but we observe a significant signal from  $^8\text{B}$  CE $\nu$ NS interactions that is consistent with expectation. We set world-leading limits on spin-independent and spin-dependent-neutron DM-nucleon interactions for masses down to 5 GeV/ $c^2$ . In the no-dark-matter scenario, we observe a signal consistent with  $^8\text{B}$  CE $\nu$ NS events, corresponding to a  $4.5\sigma$  statistical significance. This is the most significant evidence of  $^8\text{B}$  CE $\nu$ NS interactions and is enabled by robust background modeling and mitigation techniques. This demonstrates LZ’s ability to detect rare signals at keV-scale energies.

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**Introduction**—Weakly interacting massive particles (WIMPs) remain a highly motivated dark matter (DM) candidate in the GeV/ $c^2$ –TeV/ $c^2$  mass range [1,2]. The LUX-ZEPLIN (LZ) experiment currently sets the strongest constraints on DM-nucleon scattering cross sections for masses greater than 9 GeV/ $c^2$  [3]. Light DM candidates with masses less than 9 GeV/ $c^2$  are well motivated [4,5], but present significant analysis challenges as they produce lower energy recoils. Additionally, at the increasingly

smaller cross sections probed by current generation xenon DM experiments, the sensitivity to light DM is limited by solar neutrinos undergoing coherent elastic neutrino-nucleus scattering (CE $\nu$ NS) which form an irreducible “neutrino-fog” background [1,6–8]. Neutrinos from  $^8\text{B}$  decays in the Sun [9] produce CE $\nu$ NS interactions, resulting in a nuclear recoil spectrum in xenon that closely resembles that of a 5.5 GeV/ $c^2$  DM candidate. Previous results from the PandaX-4T and XENONnT experiments have revealed indications of solar  $^8\text{B}$  CE $\nu$ NS interactions at significances lower than  $3\sigma$  [10,11], and have set limits on light DM nucleon cross sections in this regime [12,13]. In this Letter we present the first nuclear recoil DM search from LZ for DM of masses 3–9 GeV/ $c^2$  and the first evidence of solar neutrino CE $\nu$ NS interactions on xenon, using a 5.7 tonne-yr exposure.

**Experiment**—The LZ experiment [14,15] operates underground in the Sanford Underground Research Facility (SURF) in Lead, South Dakota, USA, with a

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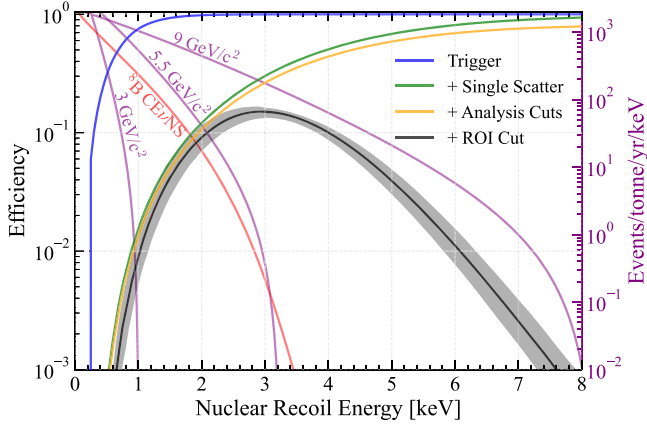


FIG. 1. Detection efficiency as a function of NR energy, after applying the S2 trigger (blue),  $\geq 3$ -fold SS reconstruction (green), analysis selections (orange), and region-of-interest (black) in sequence. The uncertainty band (gray) includes the uncertainties associated with the yields and fluctuations in the NR response model and the efficiency of single-scatter reconstruction and analysis selections. Also shown are the DM recoil spectra (purple) for masses of 3 GeV/ $c^2$ , 5.5 GeV/ $c^2$ , and 9 GeV/ $c^2$ , assuming a cross section of  $10^{-44}$  cm $^2$ , before the application of detection efficiency. The predicted  $^8\text{B}$  CEvNS recoil spectrum (red) is similar to that of a DM particle with mass 5.5 GeV/ $c^2$ .

4300 meter water-equivalent overburden to shield from cosmic radiation. At the center of the experiment is a dual-phase time projection chamber (TPC) containing seven tonnes of active liquid xenon. The TPC is surrounded by two subsystems, the liquid xenon Skin and the Outer Detector (OD), which serve as active vetoes to reject  $\gamma$ -ray and neutron backgrounds. The entire apparatus is immersed in 230 tonnes of ultrapure water, which passively shields from radioactivity in the underground cavern.

Particle interactions in the liquid xenon target typically produce either electron recoils (ERs) or nuclear recoils (NRs), generating prompt vacuum ultraviolet scintillation (S1) and ionization. Ionization electrons drift upward under the influence of an electric field. They are extracted into a thin layer of gaseous xenon above the liquid surface, where they produce a delayed electroluminescence signal (S2). The S1 and S2 photons are observed by photomultiplier tube arrays above and below the active liquid xenon volume. The time interval between the S1 and the S2 pulses measures the drift time of the ionization, which is proportional to the interaction depth ( $z$ ), while the transverse position ( $x, y$ ) is reconstructed from the hit pattern of the S2 light in the top PMT array.

**Dataset**—The dataset for this analysis (WS2025) includes 546 live days collected between March 2023 and April 2025, extending the WS2024 dataset used in our previous dark matter search [3]. Dedicated americium-beryllium (AmBe) and deuterium-deuterium (DD) neutron calibrations were performed during this period. The TPC drift field was established at 97 V/cm and the extraction field in the liquid phase was 3.4 kV/cm.

We collect data using the data acquisition system described in Ref. [16], with a trigger efficiency of  $95 \pm 1\%$  for S2 sizes corresponding to four extracted electrons. An event reconstruction algorithm identifies single scatter (SS) events with one prominent S1 and S2, with the efficiency shown in Fig. 1. The loss in efficiency at low energy is driven by requiring that the S1 is observed in at least three PMTs. We quantify these inefficiencies with waveform simulations and calibration datasets: beta decays from an injected tritiated methane ( $\text{CH}_3\text{T}$ ) source and AmBe neutron calibrations. Pulse shape variations from photon arrival times and electron drift diffusion result in additional losses, and are accounted for in the detector response modeling.

The calibration program of the TPC [17] allows for monitoring of detector spatial and temporal uniformity. The ( $x, y, z$ ) position- and time-dependent responses of the S1 and S2 signals are corrected using  $^{222}\text{Rn}$  and  $^{218}\text{Po}$   $\alpha$ -decay events present throughout the detector as in [3], allowing the definition of corrected quantities S1c and S2c in units of photons detected (phd). The scintillation and ionization gains for quanta produced in the liquid xenon are  $g_1 = 0.112 \pm 0.002$  phd/photon and  $g_2 = 34.0 \pm 0.9$  phd/electron [3].

The region-of-interest (ROI) is restricted to SS events where the S1 is observed in at least three PMTs with the S1c size that lies between 2 and 15 phd. The search parameter space spans an S2 range of 3.5–14.5 electrons (44.5 phd per extracted electron), disjointed from the ROI of [3]. The ROI approximately corresponds to nuclear recoil energies from 1–6 keV.

**Selections**—This ROI is contaminated by events from delayed charge and light emission after large energy depositions. After such events, we reject data for a period that scales with the size of the energy deposition, incurring a 16% loss of exposure. The median vetoing pulse area is  $10^{5.8}$  phd, and the mean vetoed time is 44 ms. After removing periods of unstable detector conditions and elevated photon or electron rates, 417 live days remain.

A fiducial volume (FV) is defined to reject particle interactions occurring in proximity to the stainless steel high voltage grids and TPC wall. S2s in this analysis suffer from worsened ( $x, y$ ) position resolution [18], compared to the larger S2s used in Ref. [3]. This motivates a stricter radial FV boundary, on average 5.4 cm from the wall and 15 cm from the PTFE-embedded high voltage resistors. We require  $< 0.01$  total events originating from the wall which sets the definition of the radial FV boundaries as a function of depth and azimuth. The vertical limits are unchanged from [3]. This results in a FV mass of  $5.09 \pm 0.15$  tonnes compared to  $5.5 \pm 0.2$  in [3], which is determined using tritium events. Events with S2s consistent with localized grid emission [19] are also removed through time and S2 ( $x, y$ ) position-based selections using a computer vision algorithm [20], resulting in an additional 1% loss of

exposure. The remaining  $5.7 \pm 0.2$  tonne-yr of exposure is used in this analysis.

Veto coincidence requirements reject external backgrounds such as radiogenic neutrons from spontaneous fission or ( $\alpha$ , n) reactions [3]. Prompt coincidences of TPC events with pulses in the OD ( $\leq 300$  ns) or Skin ( $\leq 250$  ns) reject neutron scatters. Delayed coincidences (using a  $\leq 600$   $\mu$ s time window following the main S1) target neutrons which thermalize, capture in the gadolinium-loaded liquid scintillator, and produce cascades of  $\gamma$  rays following nuclear de-excitation. AmBe data taken during this period allowed for measuring a delayed neutron tagging efficiency in good agreement with measurements from americium-lithium (AmLi) data in [3]. Corresponding neutron simulations, corrected using AmBe and AmLi calibration data, predict the delayed (delayed + prompt) tagging efficiency of radiogenic neutrons to be  $87 \pm 2\%$  ( $92 \pm 4\%$ ) [3].

Finally, a series of selection criteria remove events inconsistent with xenon recoil signals in the fiducial volume. These criteria exploit the expected S1 and S2 spatial pattern and pulse shapes of genuine events. Each selection was initially defined to maintain high acceptance of signals from calibration data. Selections with simple functional forms were then refined utilizing a covariance matrix adaptation evolution strategy (CMA-ES) [21] which simultaneously optimizes the signal-to-background ratio across multiple dimensions and outputs selections defined in the observables provided to the algorithm. The efficiency loss from these selections is shown in Fig. 1.

*Bias mitigation*—To reduce analyzer bias, we fabricate and insert artificial signal-like events into the raw dataset [22] by combining real S1 and S2 pulses from sequestered CH<sub>3</sub>T and AmLi calibration data, respectively. We create two types of events: high mass DM-like scatters, following an exponential plus flat energy spectrum, described in Ref. [3]; and, for the latter 59% of this dataset, we additionally inject  $^8\text{B}$  CE $\nu$ NS-like scatters. The former type is designed for the  $\geq 9$  GeV/ $c^2$  DM search and has a small expected contribution in this ROI. The artificial scatters consist of detectable S1 and S2 pulses, with the injected number of events after all selection criteria drawn from a Poisson distribution of mean 1.75. The true number and type of artificial events inserted into the dataset was hidden from data analyzers until after the analysis was finalized. Subsequently, it was revealed that only one artificial single event was injected into the data within our ROI and fiducial volume selection. This event also passed all our data selection criteria. While prior bias mitigation efforts using similar techniques injected substantially more events [22–24], the goal of this injection is not to mask the presence of  $^8\text{B}$  interactions, but to mask their rate. The mean injection rate was intended to be comparable to  $1\sigma$  fluctuations on the expected  $^8\text{B}$  signal in the latter 59% of this dataset. Additionally, the expected rate of  $^8\text{B}$  CE $\nu$ NS events for injection was calculated prior

to the results from a new dedicated low-energy calibration campaign and finalization of cuts and efficiencies; this means the mean of the Poisson distribution (1.75) was smaller than the square-root of the final expected rate reported here. See Supplemental Material for more information on bias mitigation [25].

*Response modeling*—The detector response model used to predict the response of xenon nuclear recoils is based on NEST 2.4.5 beta [26,27] and tuned using a dedicated DD neutron dataset. The LZ DD generator provides a well-characterized source of nearly monoenergetic 2.45 MeV neutrons producing NRs from the smallest detectable signals to the endpoint recoil, 1–74 keV [28,29].

We constrain the NEST model describing the charge and light yields ( $Q_y$  and  $L_y$ , respectively) and their fluctuations as a function of energy using a Markov chain Monte Carlo-based fitting method implemented with the EMCEE package [30]. Neutron recoils out to the DD endpoint are included in this fit to constrain the NEST model parameters across a large energy range, including higher energies outside of the ROI of this analysis. The DD dataset has limited ability to constrain the low-energy-specific yield parameters ( $\lesssim 2.5$  keV), motivating our choice to enforce NEST priors derived from other existing measurements [28,29,31] for these parameters.

We include two important modifications to the NEST model described in Ref. [27]. First, fluctuations in S1 and S2 sizes are allowed to vary via the Fano-like factors  $F_{ex}$  and  $F_i$ , which control the variances of excitons and ions, respectively. We model  $F_{ex}$  as a linear function of exciton number where the slope and intercept are allowed to float freely. We find that  $F_i$  can be modeled as a constant. Second, we introduce an additional parameter to allow recombination fluctuations, or the fluctuations governing the trade-off between  $Q_y$  and  $L_y$ , to be either sub- or suprabinoimial. Both modifications are needed to achieve a good fit across the DD energy spectrum. Further details of this fitting procedure, including best fit parameters and corresponding yields models, are discussed in Supplemental Material and an upcoming publication [25].

*Backgrounds*—Accidental coincidence events and neutrons are background components in the search for  $^8\text{B}$  CE $\nu$ NS interactions. Events caused by electrons and  $\gamma$ -ray backgrounds produce S2 signals above the ROI of this analysis and are thus negligible. For the dark matter search,  $^8\text{B}$  CE $\nu$ NS is considered a background and is discussed in the following section.

Accidental coincidence events are comprised of S1–S2 pairs where the pulses do not originate from a common energy deposition. Instrumental effects, such as PMT dark counts [41] and spurious electron emission from the high voltage electrodes [19], produce isolated S1 and S2 pulses which can pile up within an event window. These events are modeled using a data-driven technique in which isolated pulses are combined at the waveform level to form

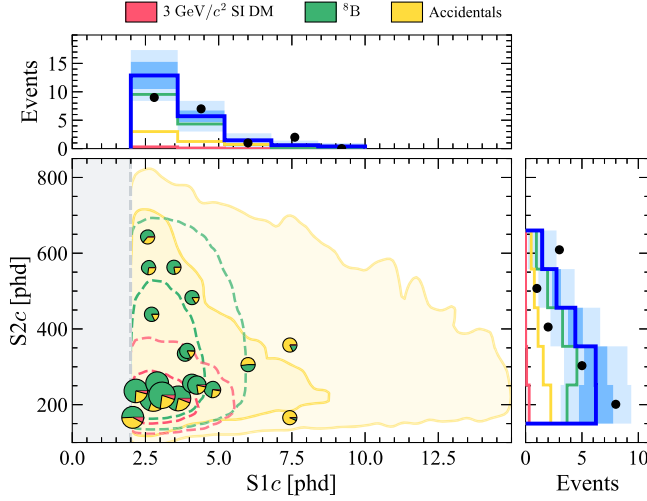


FIG. 2. The 19 events comprising the final dataset passing all selections are shown as individual pie charts in the observable space  $\{S1c, S2c\}$ . Each pie chart depicts the relative fit contributions from the accidental coincidences (yellow) and  $^8\text{B}$  CEzNS (green) background components along with a  $3 \text{ GeV}/c^2$  DM candidate (pink). The relative size of each pie chart is proportional to its contribution to  $3 \text{ GeV}/c^2$  DM events. Contours enclose  $1\sigma$  and  $2\sigma$  model distributions. The data (black points) and best-fit model (solid blue line) in  $S1c$  and  $S2c$  projections are also shown. Shaded light blue (dark blue) bands depict the total (systematic-only) model uncertainty. The detector neutron component is subdominant and therefore not shown.

synthetic SS events. In this ROI, the spectra of isolated S1 and S2 pulses are sensitive to variations in electron and photon rates occurring on millisecond timescales. Thus we perform an environment-matched pairing procedure where we pair isolated S1 and S2 pulses according to the ambient

electron and photon rates. The result is a high-fidelity description of real accidental events.

A pure population of accidental coincidences can be found by searching for events with unphysical drift times (UDT), where the apparent drift time exceeds that of events originating at the cathode ( $\gtrsim 1 \text{ ms}$ ). This population provides a data-driven constraint on the accidental coincidence rate and is used to determine the normalization for the accidental model. The model is extensively validated with several ancillary datasets which probe a range of environments: UDT events, events with elevated photon and electron rates, AmLi calibration data, and events that fail the S1 and S2 pulse-based selections. The resulting goodness-of-fit tests [42] comparing the data and model prediction in binned  $S1c$ ,  $S2c$ , and  $\{S1c, S2c\}$  distributions in these ancillary datasets all pass at a significance level of 0.05. More details are discussed in Supplemental Material and an upcoming publication [25].

After all selection criteria, the predicted number of accidental coincidences is  $6.6 \pm 0.3$  events in the ROI for the 5.7 tonne-yr exposure. The uncertainty is driven by both the number of UDT events at the point of normalization and the number of unique S1 and S2 pulses used in the accidental model. Additional systematic uncertainties are deemed unnecessary based on the good data-model agreement observed across the ancillary datasets. These datasets validate the normalization procedure and confirm the ability to accurately model populations with varying underlying accidental coincidence sources.

*Dark matter search*—After the application of all data selection criteria and the removal of the one artificial event, 19 events remain in the ROI (see Fig. 2). The search for dark matter is conducted with a two-sided unbinned profile likelihood ratio test statistic defined in the observable space  $\{S1c, S2c\}$  [43,44].

TABLE I. Expected and best-fit counts for each background and/or signal component in various fit scenarios to the 19 observed events, as well as the value of the Gaussian-constrained nuisance parameter  $\sigma_{\text{eff}}$ . The second column shows the predicted counts and  $\sigma_{\text{eff}}$  value, the latter of which is  $0 \pm 1$  by construction. The next three columns show fits where the  $^8\text{B}$  signal is incorporated as a background component following the expectation in the first column; results from a background-only fit, where the  $^8\text{B}$  signal is constrained, and signal-plus-background fits assuming a spin-independent dark matter particle with mass  $3 \text{ GeV}/c^2$  and  $9 \text{ GeV}/c^2$ , are shown. The last column shows the fit with the  $^8\text{B}$  rate unconstrained in the no-dark-matter hypothesis. The spin-independent (SI) DM, neutron, and  $^8\text{B}$  CEzNS uncertainties include systematics associated with the NR response modeling, the detection uncertainties, and the flux uncertainty ( $^8\text{B}$  CEzNS only). The fitted values of  $\sigma_{\text{eff}}$  represent the shifts in the fitted component rates with respect to their predicted values due to the combined NR response modeling and detection efficiency uncertainties, in units of standard deviations.

| Components            | Expectation            | Background-only fit     | $3 \text{ GeV}/c^2$ fit | $9 \text{ GeV}/c^2$ fit | $^8\text{B}$ CEzNS unconstrained fit |
|-----------------------|------------------------|-------------------------|-------------------------|-------------------------|--------------------------------------|
| SI DM                 | ...                    | ...                     | $0.4^{+5.4}_{-0.4}$     | $0.0^{+4.0}_{-0.0}$     | ...                                  |
| $^8\text{B}$ CEzNS    | $20.6^{+8.9}_{-6.8}$   | $15.0^{+4.0}_{-3.4}$    | $14.7^{+4.2}_{-3.9}$    | $15.0^{+3.9}_{-3.4}$    | $12.3^{+7.0}_{-5.4}$                 |
| Accidental coinc.     | $6.6 \pm 0.3$          | $6.5 \pm 0.3$           | $6.5 \pm 0.3$           | $6.5 \pm 0.3$           | $6.6 \pm 0.3$                        |
| Detector neutrons     | $0.04^{+0.25}_{-0.04}$ | $0.1^{+0.2}_{-0.1}$     | $0.1^{+0.2}_{-0.1}$     | $0.1^{+0.2}_{-0.1}$     | $0.1^{+0.2}_{-0.1}$                  |
| Total                 | $27.2^{+10.1}_{-7.3}$  | $21.6^{+4.7}_{-3.8}$    | $21.7^{+6.2}_{-2.8}$    | $21.6^{+5.0}_{-2.5}$    | $18.9^{+7.0}_{-5.5}$                 |
| $\sigma_{\text{eff}}$ | $0 \pm 1$              | $-0.81^{+0.59}_{-0.60}$ | $-0.86^{+0.63}_{-0.71}$ | $-0.81^{+0.58}_{-0.60}$ | $0 \pm 1$                            |

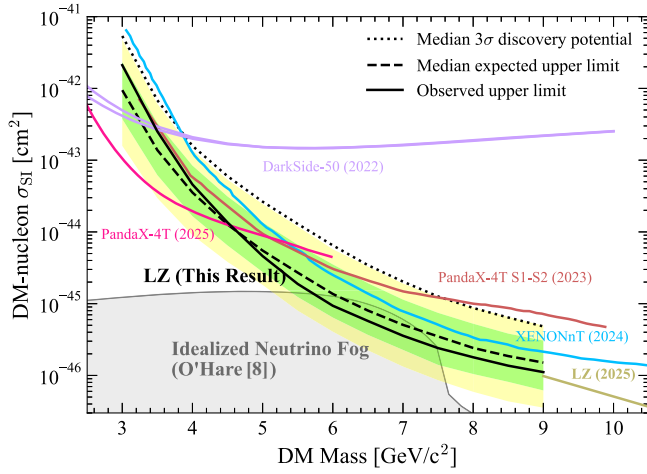


FIG. 3. Upper limits (90% CL) on the spin-independent DM-nucleon cross section as a function of DM mass using the 5.7 tonne-yr dataset are shown in the solid black line. The range of expected upper limits from background-only experiments are shown as green and yellow regions for 68% and 95% of experiments, respectively. The dashed black line shows the median expected upper limit, while the dotted black line shows the median  $3\sigma$  discovery potential, using the post-fit model. The onset of the neutrino fog, as defined in [8], is shown as the shaded gray region. Other experimental limits are also shown [12,13,46,47].

The components of the likelihood describing particle interactions—detector neutrons,  $^8\text{B}$  CE $\nu$ NS, and the dark matter signal—are constructed with the xenon response model described above and an event simulation framework [45]. We account for the systematic uncertainty on the light and charge yields, the quanta fluctuations, and the detector efficiency in the likelihood. This is incorporated through a single Gaussian constraint with nuisance parameter  $\sigma_{\text{eff}}$  controlling the combined rate uncertainty, the scale of which depends on the individual recoil spectra. The change in rate due to a  $+1$  ( $-1$ ) standard deviation shift in  $\sigma_{\text{eff}}$  varies as a function of DM mass, from  $+81\%$  ( $-60\%$ ) at  $3 \text{ GeV}/c^2$  to  $+21\%$  ( $-20\%$ ) at  $9 \text{ GeV}/c^2$ .

We constrain the detector neutron rate *in situ* by including an additional dataset in the likelihood which requires events to pass all data selection criteria but fail the delayed coincidence veto. There is one event in this dataset. The best-fit number of neutron events in this sideband dataset is  $0.3^{+1.7}_{-0.3}$ , which is consistent with predictions from simulations. The neutron veto efficiency, incorporated as a Gaussian constraint, relates this sideband dataset to the main science dataset, while the other background components are related via the false veto probability from random coincidences (3%).

The expected number of events in the main science dataset from  $^8\text{B}$  CE $\nu$ NS interactions, accidental coincidences, and detector neutrons is shown in Table I. The uncertainties are incorporated in the likelihood as

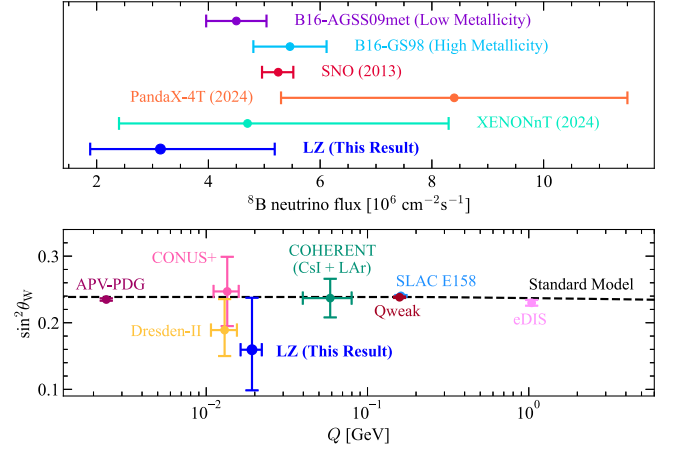


FIG. 4. Top: measurement of  $^8\text{B}$  solar neutrino flux assuming the SM-predicted CE $\nu$ NS cross section and weak mixing angle. Predictions from low- and high-metallicity solar models are shown [58] alongside other experimental measurements [10,11,56]. Bottom: measurement of  $^8\text{B}$  solar- $\nu$  flux and SM CE $\nu$ NS cross section is shown. The median and  $\pm 1\sigma$  values are depicted in both the top and bottom plots. Also shown are other experimental results [59–66] and the SM prediction [67].

constraints on their respective rates. The accidental rate is Gaussian-constrained. The  $^8\text{B}$  CE $\nu$ NS rate has an additional 4% flux uncertainty imposed as a Gaussian constraint [44].

The best-fit model and data in the  $\{S1c, S2c\}$  analysis space and its projections are also shown in Fig. 2. The background-only model is evaluated using binned goodness-of-fit tests, with p-values of 0.51, 0.44, and 0.53 in  $S1c$ ,  $S2c$ , and  $\{S1c, S2c\}$  spaces, respectively. All data-model comparisons show good agreement.

The 90% confidence level upper limit on the spin-independent DM-nucleon cross section as a function of mass is shown in Fig. 3. The observed upper limit spans from  $2.1 \times 10^{-42} \text{ cm}^2$  at  $3 \text{ GeV}/c^2$  to  $1.1 \times 10^{-46} \text{ cm}^2$  at  $9 \text{ GeV}/c^2$ . Results for the spin-dependent DM-nucleon coupling scenario are shown in the Appendix.

**Boron-8 CE $\nu$ NS measurement**—We also perform a measurement of the  $^8\text{B}$  CE $\nu$ NS process on xenon nuclei with the same dataset assuming zero dark matter events. Using the  $q_0$  test statistic [43], we reject the hypothesis of zero  $^8\text{B}$  CE $\nu$ NS events with a statistical significance of  $4.5\sigma$ . This significance is driven by our observation of 19 events, which represents a substantial deviation from the total expected backgrounds from accidental coincidences and neutrons ( $6.6 \pm 0.3$ ). The median expected significance is  $6.7^{+2.4}_{-2.2}\sigma$ . The best-fit value of  $^8\text{B}$  CE $\nu$ NS counts of  $12.3^{+7.0}_{-5.4}$  is shown in the last column of Table I and is consistent with the prediction of  $20.6^{+8.9}_{-6.8}$ .

The detection of the  $^8\text{B}$  solar neutrino CE $\nu$ NS process enables measurements of various quantities of physical

interest (Fig. 4) within the standard model (SM). The  $^8\text{B}$  CE $\nu$ NS event rate is dependent on the CE $\nu$ NS differential cross section [48,49] and the  $^8\text{B}$  solar neutrino flux [44]. We also include electroweak radiative corrections to the tree-level CE $\nu$ NS cross section following Refs. [50–52]. Similar calculations are also discussed in Ref. [53]. In deriving our  $^8\text{B}$  CE $\nu$ NS signal, we assume the neutrino energy spectrum from Ref. [54]. Employing an alternative  $^8\text{B}$  neutrino spectra from Ref. [55] shifts the predicted  $^8\text{B}$  counts by less than 6%, which is subdominant to our systematic uncertainty. If we assume the SNO measured  $^8\text{B}$  neutrino flux [56], we can directly probe average CE $\nu$ NS cross section on xenon and specifically the weak-mixing angle [57]. The  $^8\text{B}$  solar neutrino flux is found to be  $3.1^{+2.1}_{-1.3} \times 10^6 \text{ cm}^{-2} \text{ s}^{-1}$ , in good agreement with Ref. [58]. The flux-weighted CE $\nu$ NS cross section on xenon is found to be  $7.4^{+4.8}_{-3.0} \times 10^{-40} \text{ cm}^2$ . The SM weak mixing angle at an average momentum transfer of  $19.2 \pm 2.9 \text{ MeV}/c$  is found to be  $\sin^2\theta_W = 0.16^{+0.08}_{-0.06}$ . We compute the momentum transfer as  $Q = \sqrt{2m_{\text{Xe}}E_r}$ , averaging over the natural isotopic abundances of xenon to calculate the xenon nuclear mass  $m_{\text{Xe}}$ , and using the mean  $^8\text{B}$  CE $\nu$ NS nuclear recoil energy  $E_r$  predicted by our simulation including detection efficiencies ( $1.51 \pm 0.46 \text{ keV}$ ). All of these measurements are consistent with SM expectations and previous measurements.

**Conclusions**—LZ has achieved limits on SI DM-nucleon interactions that are world leading above  $5 \text{ GeV}/c^2$ . The sensitivity and robustness of this analysis is enabled by careful calibration of the detector nuclear recoil response, with a comprehensive treatment of light and charge yields as well as their fluctuations, and excellent mitigation and modeling of accidental coincidences down to S2s of 3.5 electrons that would otherwise impede DM searches with masses less than  $9 \text{ GeV}/c^2$ . We present the strongest evidence to date for CE $\nu$ NS on xenon from solar neutrinos at a significance of  $4.5\sigma$ , which demonstrates LZ’s ability to detect nuclear recoil signals of astrophysical origin. Using the detected  $^8\text{B}$  CE $\nu$ NS interactions, we present measurements of the weak mixing angle and CE $\nu$ NS cross section on xenon. The measured  $^8\text{B}$  neutrino flux is found to be consistent with that measured by the SNO collaboration. The LZ experiment continues to take data towards a target 1000-day exposure that will allow for further dark matter searches into the neutrino fog and enable improved measurements of the CE $\nu$ NS process.

*Note added*—After this result was released, the XENONnT collaboration released similar results [77].

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*Data availability*—The data that support the findings of this article are openly available [70].

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## End Matter

*Appendix: Spin-dependent DM results*—The treatment of spin-dependent models follows the procedure in Refs. [3,71]. References [72–74] describe the neutron-only and proton-only nuclear structure functions, with the structure functions from [72] treated as the nominal model. These structure functions are used as inputs to model DM scattering on  $^{129}\text{Xe}$  and  $^{131}\text{Xe}$ .

Upper limits (90% confidence level) on the spin-dependent cross section as a function of DM mass are

shown in Fig. 5 in both the DM-neutron and DM-proton coupling scenarios with the nuclear structure function uncertainty depicted as the gray band. The dotted black line depicts the  $3\sigma$  discovery potential. The strongest limit is set for a DM mass of 9  $\text{GeV}/c^2$  at a cross section of  $\sigma_{\text{SD}}^n = 1.6 \times 10^{-41} \text{ cm}^2$  in the DM-neutron scenario, and at 9  $\text{GeV}/c^2$  at a cross section of  $\sigma_{\text{SD}}^p = 5.2 \times 10^{-40} \text{ cm}^2$  in the DM-proton scenario.

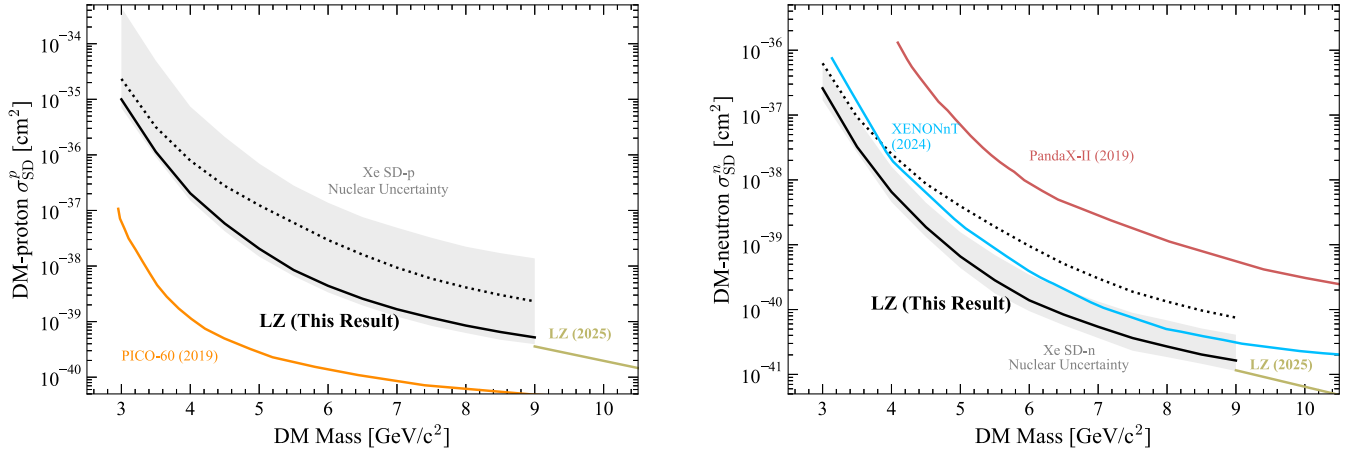


FIG. 5. Upper limits (90% CL) from the 5.7 tonne-yr analysis on the spin-dependent DM-proton (left) and DM-neutron (right) cross section as a function of DM mass are shown with a solid black line. The observed limit uses the mean of the nuclear structure functions from [72], with the gray band depicting the uncertainty from nuclear modeling in the models described in [72–74]. The median  $3\sigma$  discovery potential using the post-fit model is shown as the dotted black line. Other experimental limits for spin-dependent DM-proton [3,75] and DM-neutron [3,76] scattering are also shown.