Overview and New Results from the LUX Experiment

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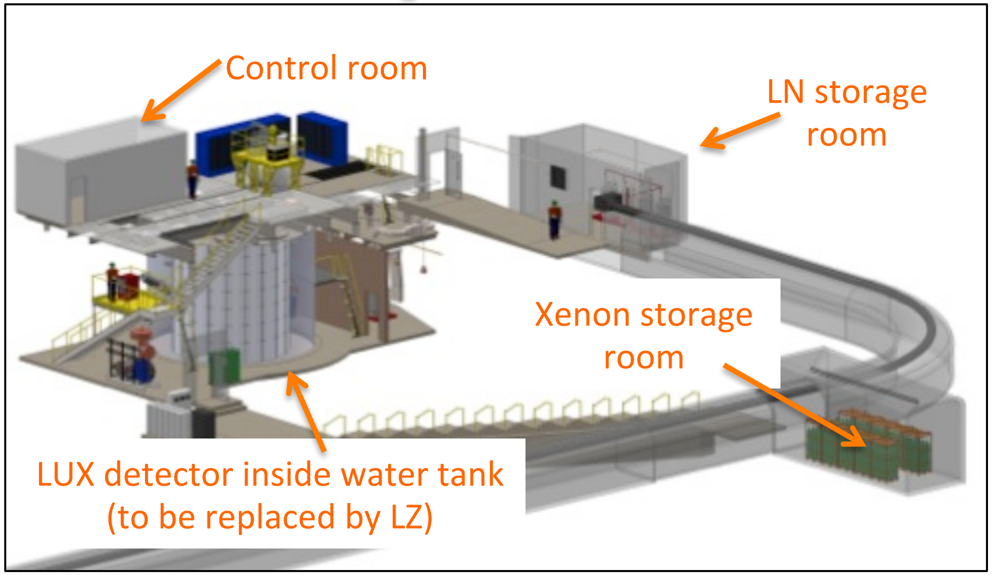
UCLA Dark Matter

February 23rd, 2018

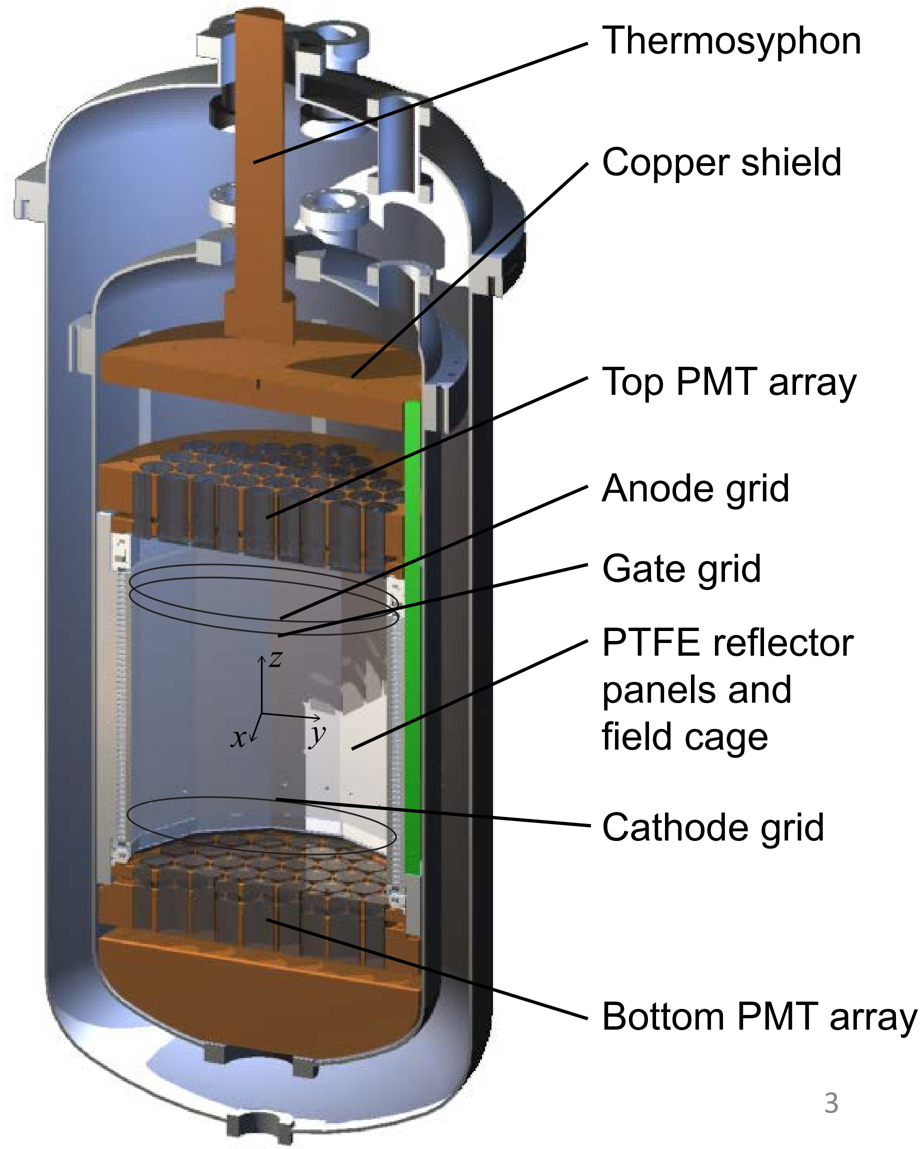
Sanford Underground Research Facility

Davis Cavern 1480 m
(4300 m water equivalent)
Lead, South Dakota



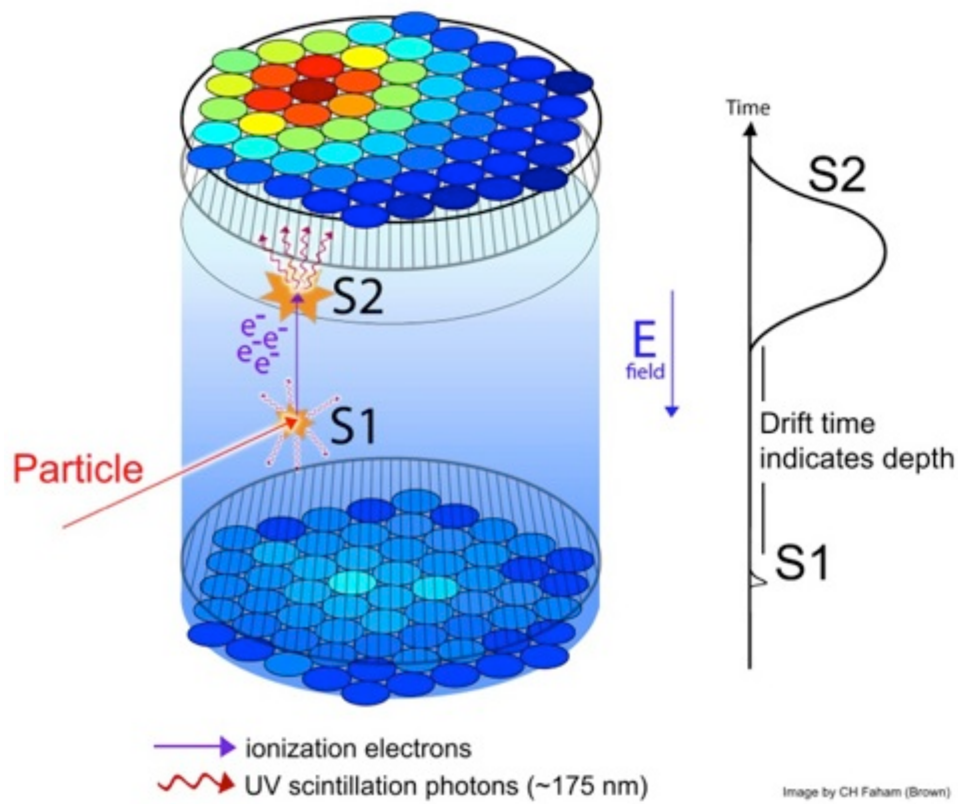
The LUX Detector

- Dual-phase Xe TPC
- Active volume: 250 kg
- Dimensions: 59 cm height by 49 cm diameter
- 122 PMTs split between top and bottom arrays
- Surrounded by 7.6 m diameter water tank



Events in Dual-phase Xe TPCs

- Two scintillation signals for each event.
  - S1: de-excitation of short-lived xenon dimers
  - S2: electrons liberated at the event site extracted into the gas phase.
- Time difference between S1 and S2 gives depth
- S2 hit pattern gives lateral position information



Comprehensive analysis paper: arXiv:1712.05696
Electric field modeling: JINST 12 P11022 (2017)

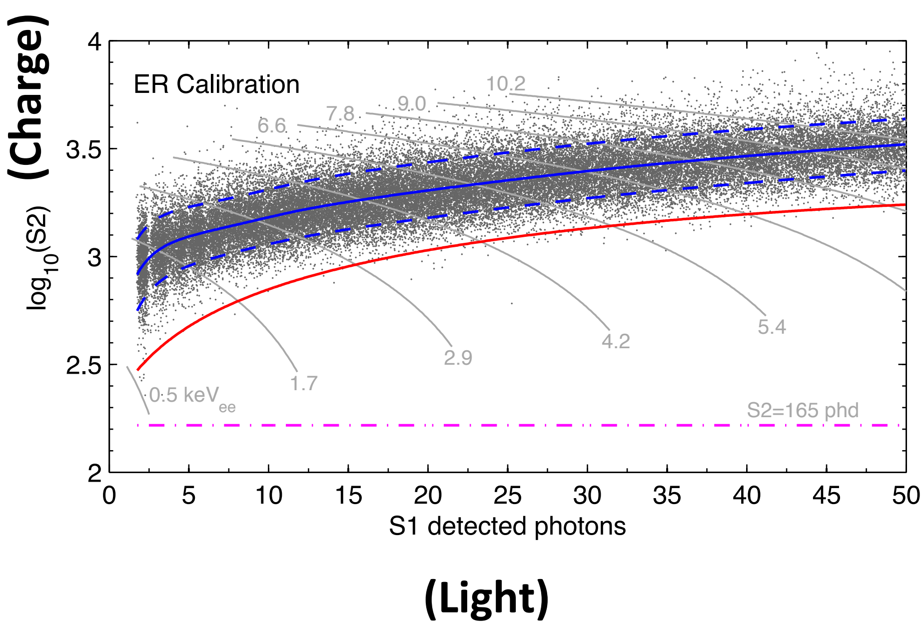
Background and Signal Calibrations

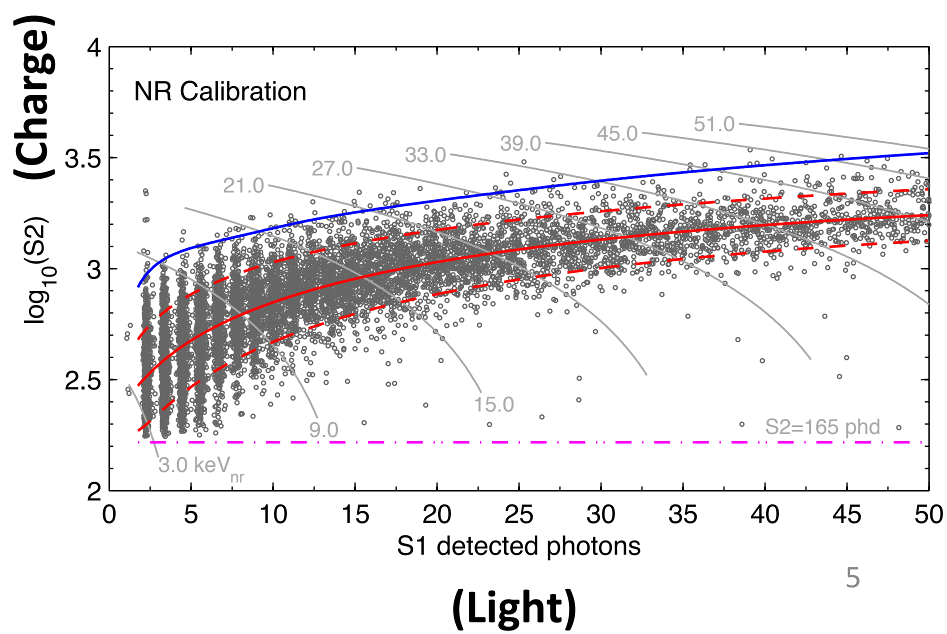
Background Events

- Electron Recoil (ER)
- Higher charge-to-light ratio
- Calibrate using high-statistics tritium dataset (165,863 events)
- Phys. Rev. D 93, 072009

Signal Events (WIMP-like)

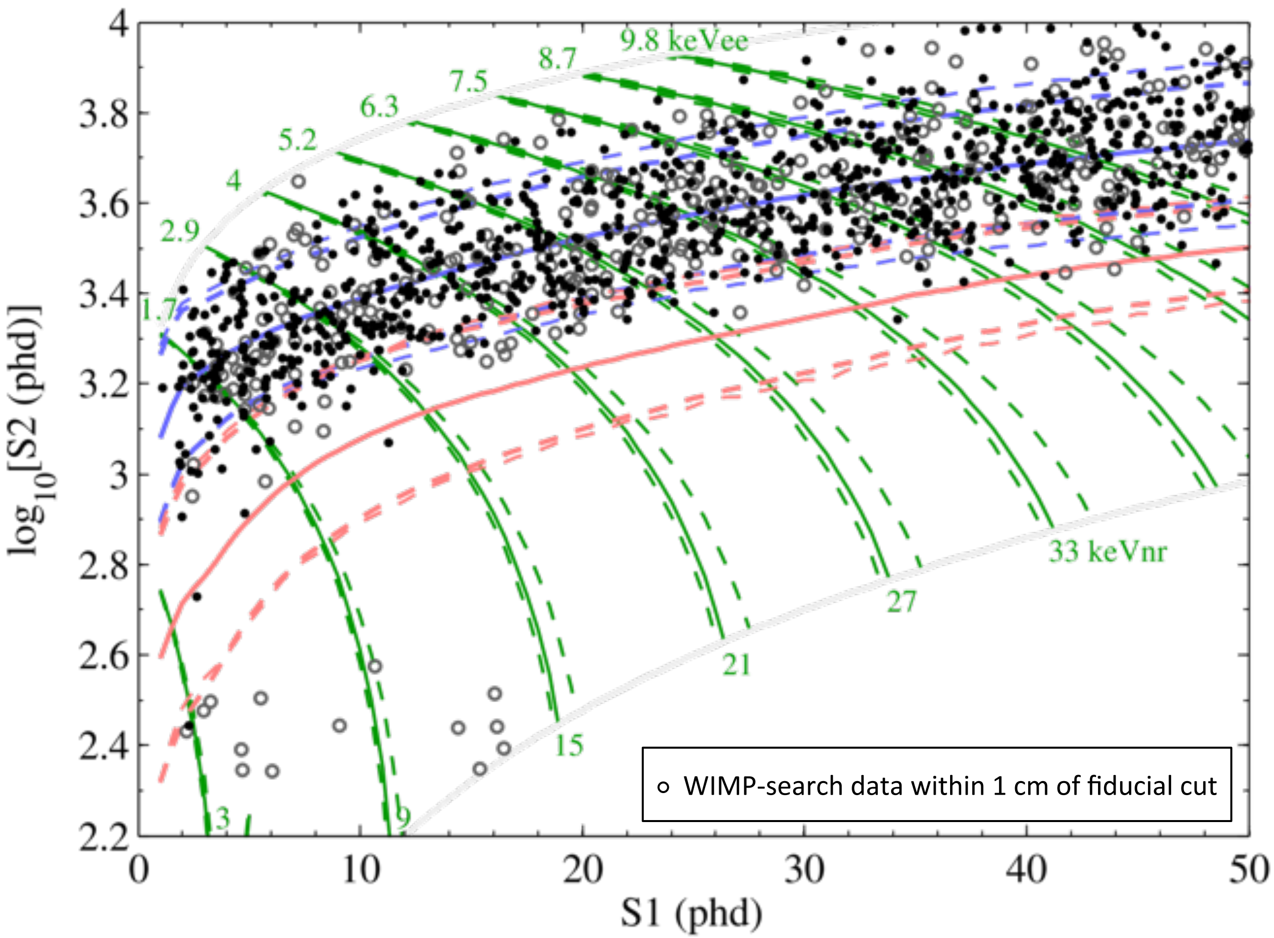
- Nuclear Recoils (NR)
- Lower charge-to-light ratio
- Energy lost to atomic motion (quenching)
- Calibrate using D-D neutrons
  - *In-situ* nuclear recoil (NR) calibration
- arXiv:1608.05381





WIMP Search data

Second science run: 2014-2016 (332 live-days)

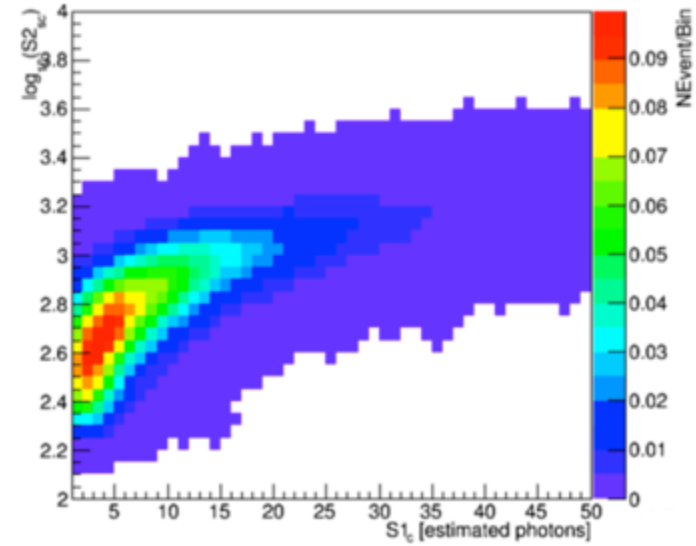


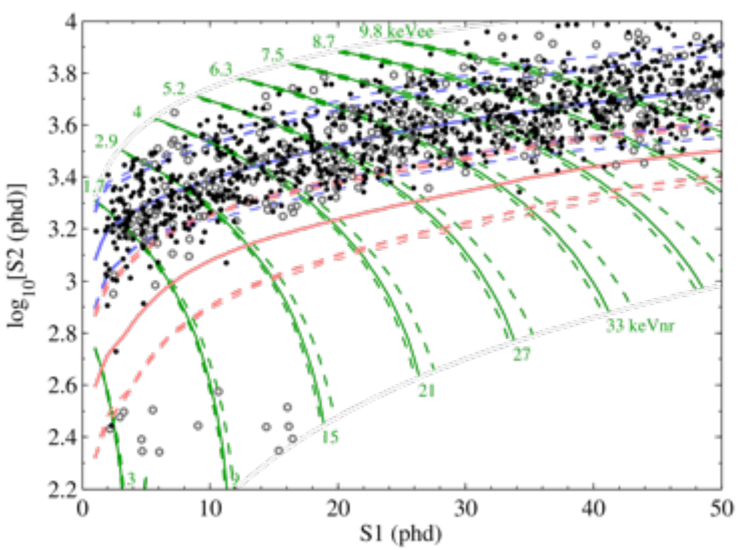
Phys. Rev. Lett. 118, 021303

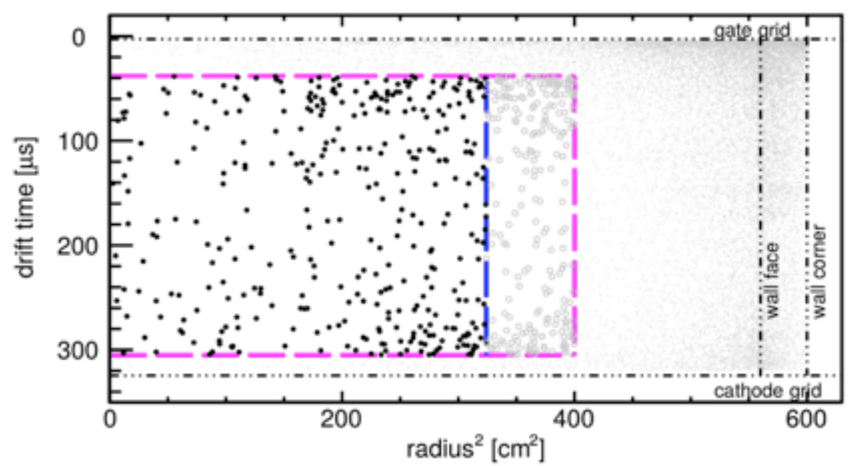
Profile Likelihood Ratio (PLR)

- Compares data to background distribution and signal distributions for different mass models
- Function of S1, S2, radius, depth and azimuthal angle
- Fit for systematic parameters (derived from DD data)

i.e. Expected signal distribution for a 33 GeV WIMP

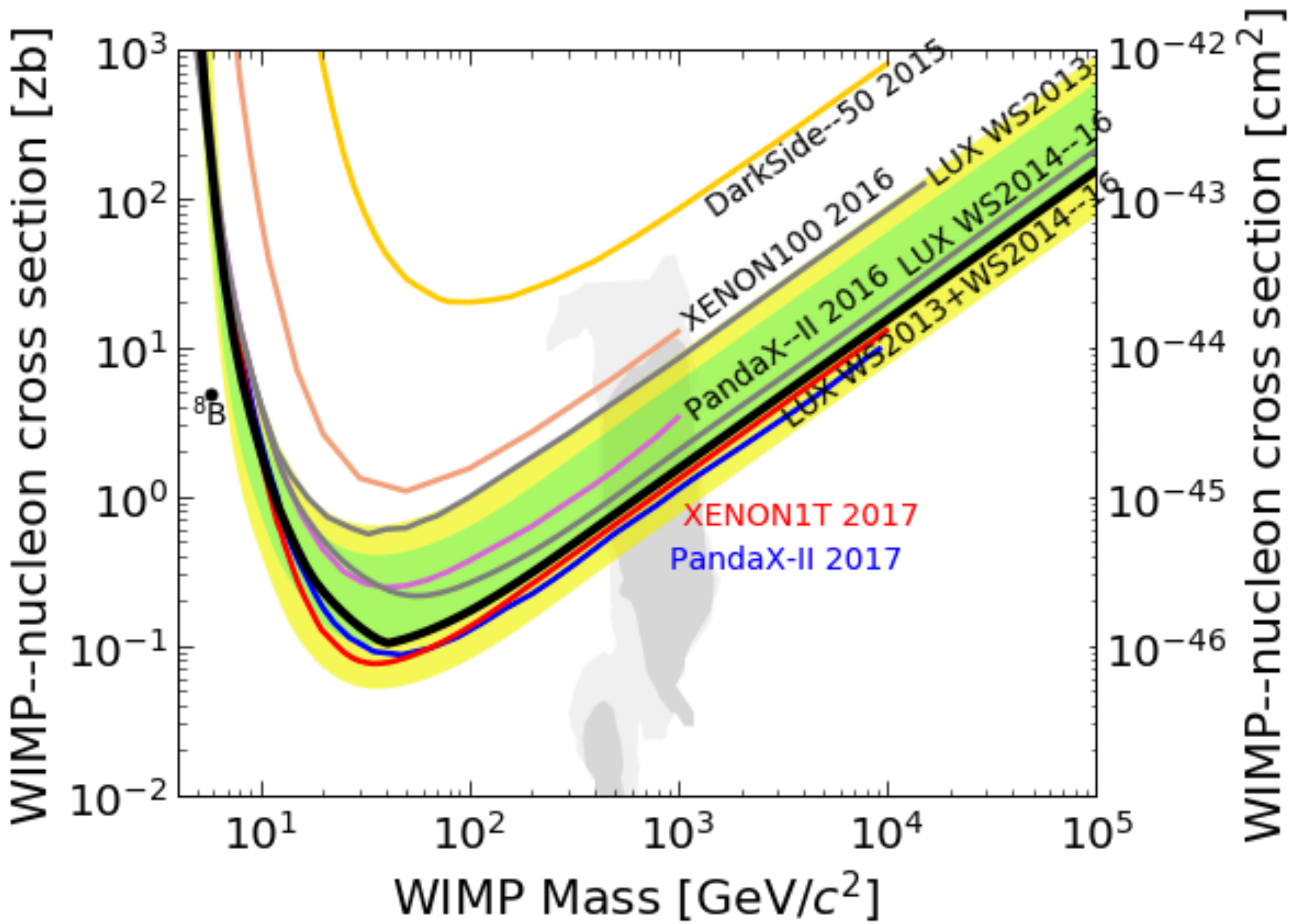






Spin independent limit

from full LUX exposure



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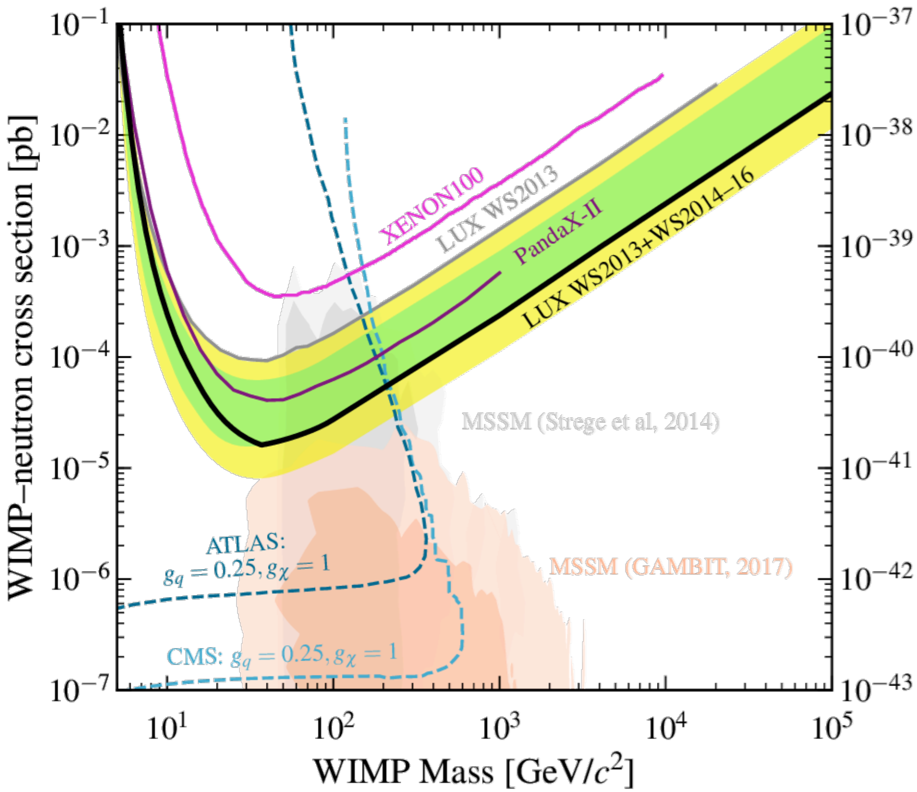
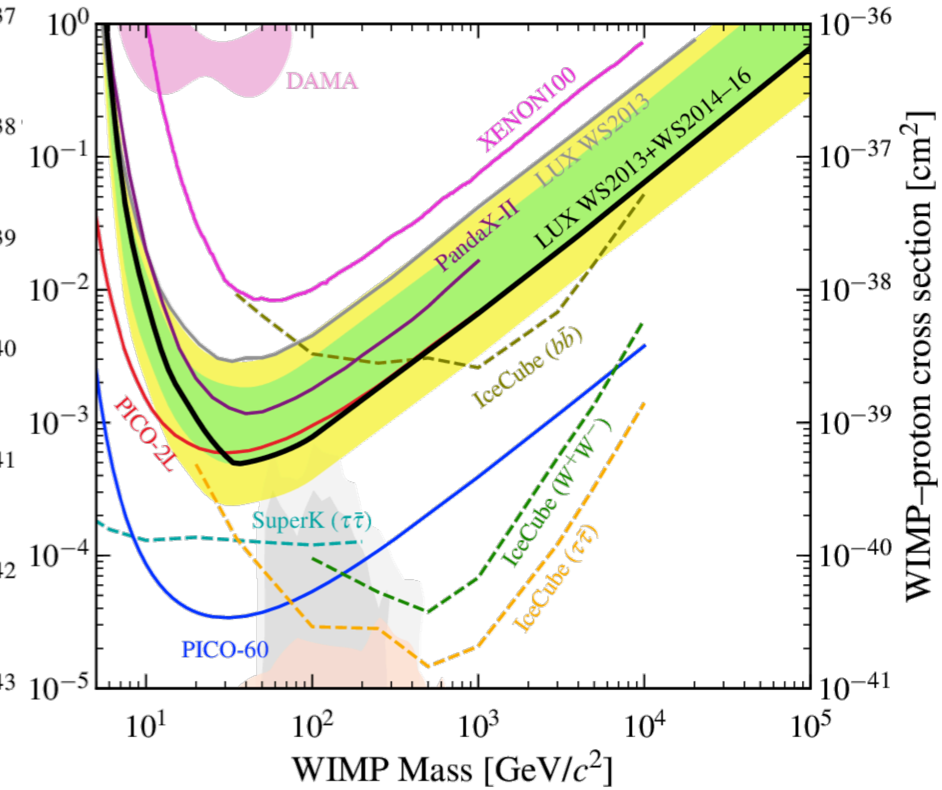
Spin Dependent Limit

from full LUX exposure

WIMP-neutron



WIMP-proton



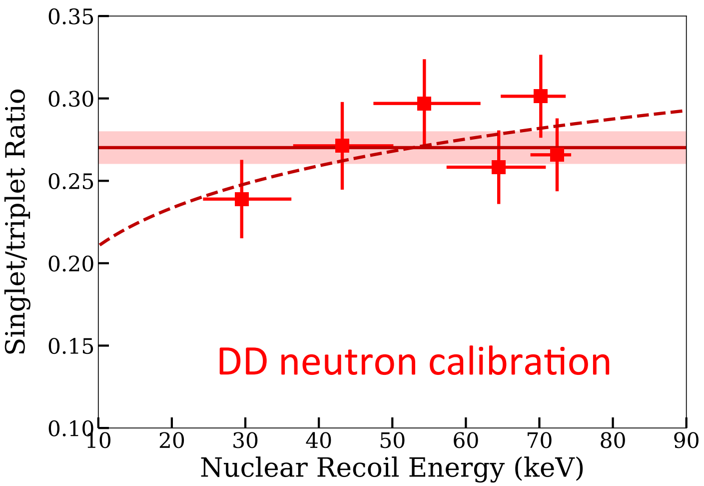
Phys. Rev. Lett. 118, 251302

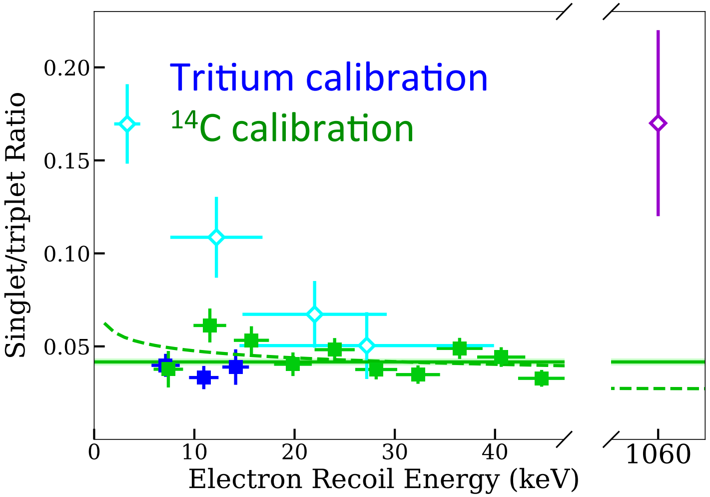
Pulse shape Discrimination Studies

- Xenon can get excited into two states with different lifetimes:
  - Singlet= 3 ns
  - Triplet= 24 ns
- Singlet to triplet ratio different for NR vs ER events
- Discriminate on prompt fraction:

$$PF = \frac{\int_{t0}^{t1} \mathrm{S1}(t)dt}{\int_{t2}^{t3} \mathrm{S1}(t)dt} = \frac{\sum \text{Prompt Photons}}{\sum \text{Total Photons}}$$

- Characteristic times optimized with calibration data
  - Prompt Photon Window: -8 to 32 ns
  - Total Photon Window: -14 to 134 ns

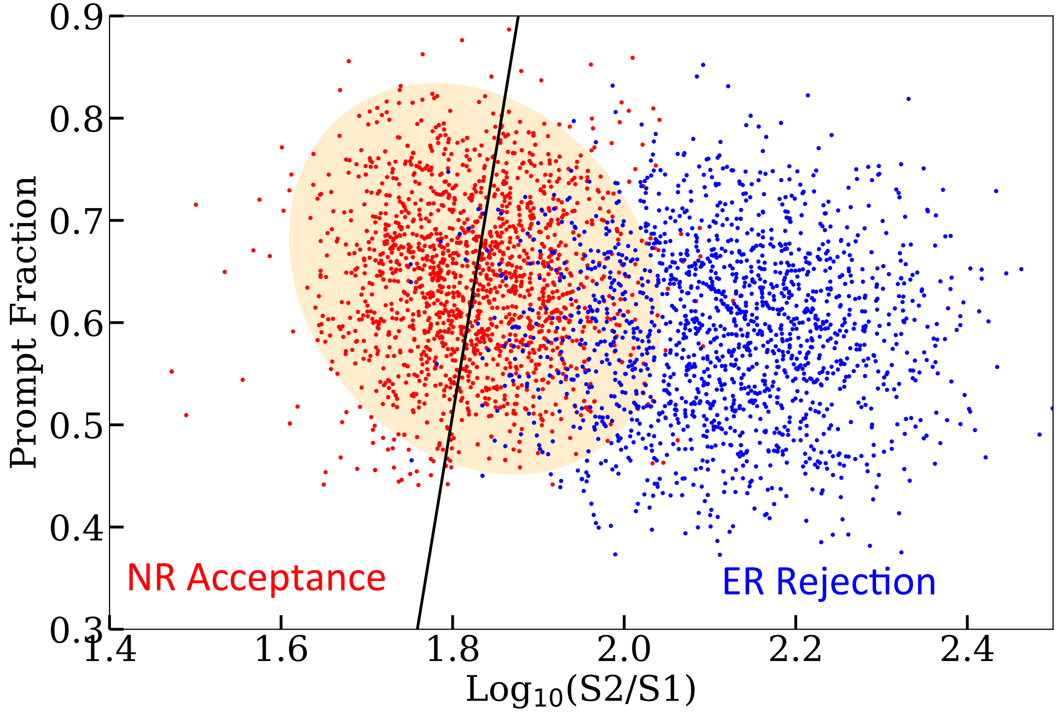




arXiv:1802.06162

Pulse shape Discrimination Studies

- Use this discrimination in conjunction with standard charge-to-light ratio to improve overall discrimination power
- Result: Decreases ER events in NR acceptance region by factor of 2



arXiv:1802.06162

Effective Field Theory

- More general Lagrangian for WIMP-nucleus interactions
  - Nuclear responses which may depend on new parameters like angular momentum, spin orbit coupling, etc

$$
\begin{aligned}
\mathcal{L}_{\text{int}} &= \sum_i c_i \mathcal{O}_i \\
&= c_1 + ic_3 \vec{S}_N \cdot (\vec{q} \times \vec{v}^{\perp}) + c_4 \vec{S}_\chi \cdot \vec{S}_N \\
&+ ic_5 \vec{S}_\chi \cdot (\vec{q} \times \vec{v}^{\perp}) + c_6 (\vec{S}_\chi \cdot \vec{q})(\vec{S}_N \cdot \vec{q}) \\
&+ c_7 \vec{S}_N \cdot \vec{v}^{\perp} + c_8 \vec{S}_\chi \cdot \vec{v}^{\perp} + ic_9 \vec{S}_\chi \cdot (\vec{S}_N \times \vec{q}) \\
&+ ic_{10} \vec{S}_N \cdot \vec{q} + ic_{11} \vec{S}_\chi \cdot \vec{q} + c_{12} \vec{S}_\chi \cdot (\vec{S}_N \times \vec{v}^{\perp}) \\
&+ ic_{13} (\vec{S}_\chi \cdot \vec{v}^{\perp})(\vec{S}_N \cdot \vec{q}) + ic_{14} (\vec{S}_\chi \cdot \vec{q})(\vec{S}_N \cdot \vec{v}^{\perp}) \\
&+ -c_{15} (\vec{S}_\chi \cdot \vec{q})((\vec{S}_N \times \vec{v}^{\perp}) \cdot \vec{q})
\end{aligned}
$$

Formulation: Fitzpatrick et al. arXiv:1203.3542
Package for computing nuclear responses: arXiv:1308.6288
Original paper applying EFT to DM arXiv:1008.1591

Effective field theory analyses in LUX

- First science run (85 live days)
  - Follows initial LUX analysis (Phys. Rev. Lett. 112, 091303)
  - Nicole Larson, thesis
- Full science run (427 live days)
  - Follows Phys. Rev. Lett. 118, 021303

Effective field theory analyses in LUX

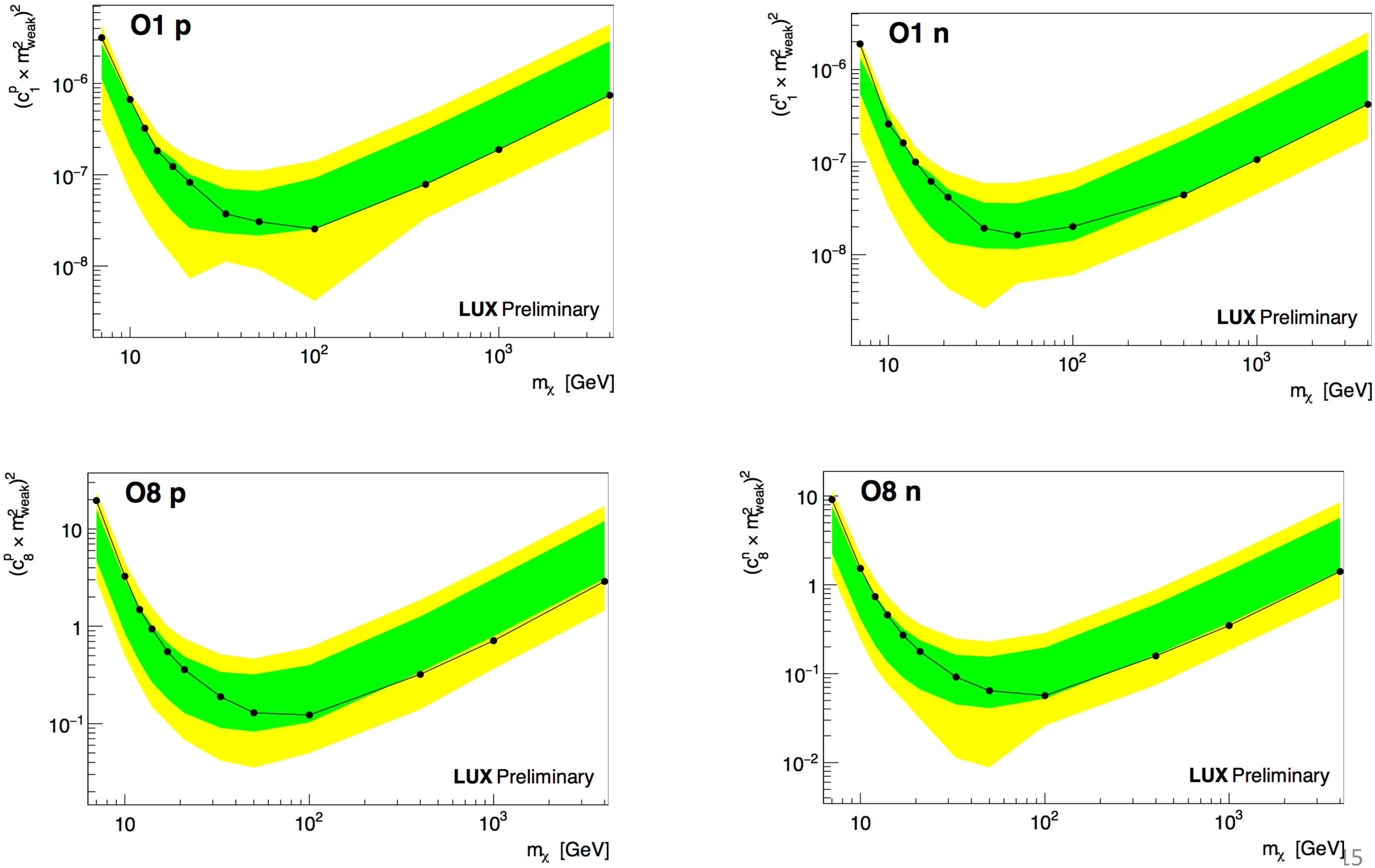
- Generate new signal model in PLR for the nuclear response expected for each operator at each test mass
  - Consider operators and WIMP-proton and WIMP-neutron couplings individually
- Expanding energy window of analysis
  - Still studying pulse and event classification efficiency at the higher energies
  - See Kelsey's talk later this afternoon
  - Today will show O1 and O8

$$
\begin{aligned}
\mathcal{L}_{\text{int}} &= \sum_i c_i \mathcal{O}_i \\
&= c_1 + ic_3 \vec{S}_N \cdot (\vec{q} \times \vec{v}^{\perp}) + c_4 \vec{S}_\chi \cdot \vec{S}_N \\
&+ ic_5 \vec{S}_\chi \cdot (\vec{q} \times \vec{v}^{\perp}) + c_6 (\vec{S}_\chi \cdot \vec{q})(\vec{S}_N \cdot \vec{q}) \\
&+ c_7 \vec{S}_N \cdot \vec{v}^{\perp} + c_8 \vec{S}_\chi \cdot \vec{v}^{\perp} + ic_9 \vec{S}_\chi \cdot (\vec{S}_N \times \vec{q}) \\
&+ ic_{10} \vec{S}_N \cdot \vec{q} + ic_{11} \vec{S}_\chi \cdot \vec{q} + c_{12} \vec{S}_\chi \cdot (\vec{S}_N \times \vec{v}^{\perp}) \\
&+ ic_{13} (\vec{S}_\chi \cdot \vec{v}^{\perp})(\vec{S}_N \cdot \vec{q}) + ic_{14} (\vec{S}_\chi \cdot \vec{q})(\vec{S}_N \cdot \vec{v}^{\perp}) \\
&+ -c_{15} (\vec{S}_\chi \cdot \vec{q})((\vec{S}_N \times \vec{v}^{\perp}) \cdot \vec{q})
\end{aligned}
$$

Operator	50-GeV WIMP $E^{50\%}_{max}$ (keV$_{\text{nr}}$)	50-GeV WIMP $E^{90\%}_{max}$ (keV$_{\text{nr}}$)	500-GeV WIMP $E^{50\%}_{max}$ (keV$_{\text{nr}}$)	500-GeV WIMP $E^{90\%}_{max}$ (keV$_{\text{nr}}$)
SI	10.8	27.3	16.6	44.7
$\mathcal{O}_1$	6.8	21.7	11.8	43.8
$\mathcal{O}_3$	26.4	49.1	148.1	344.4
SD	8.6	21.6	11.9	37.5
$\mathcal{O}_4$	7.0	24.0	32.8	299.6
$\mathcal{O}_5$	16.2	38.6	65.5	328.9
$\mathcal{O}_6$	33.6	64.0	267.3	433.7
$\mathcal{O}_7$	5.0	16.2	25.2	279.9
$\mathcal{O}_8$	6.8	22.2	14.5	64.8
$\mathcal{O}_9$	13.7	37.2	276.7	464.7
$\mathcal{O}_{10}$	21.7	48.6	112.6	340.4
$\mathcal{O}_{11}$	15.5	34.4	39.0	279.9
$\mathcal{O}_{12}$	17.4	38.1	34.8	176.5
$\mathcal{O}_{13}$	28.2	53.2	54.5	219.7
$\mathcal{O}_{14}$	11.9	27.9	240.9	400.0
$\mathcal{O}_{15}$	34.3	59.1	261.2	433.7

Nicole Larson, Thesis

Observed limits for O1 and O8



Summary

- Two science runs: 2013 (85 live days) & 2014-2016 (332 live days)
  - Phys. Rev. Lett. 118, 021303 combines these data using updated calibrations and analysis tools
- Demonstrated PSD, which improve discrimination potential
- Applying new analysis tools to EFT analysis
  - Still working on some higher energy pulse classification studies
- More new results:
  - Annual/Diurnal rate modulation
    - See Jingke Xu's talk following this one
  - Updated background analyses
    - See Kelsey Oliver-Mallory's talk later this afternoon