Recent Science from LUX

Alex M

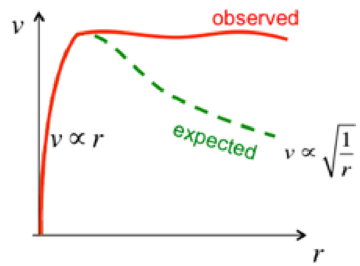
Dark Matter

Rotation Curves

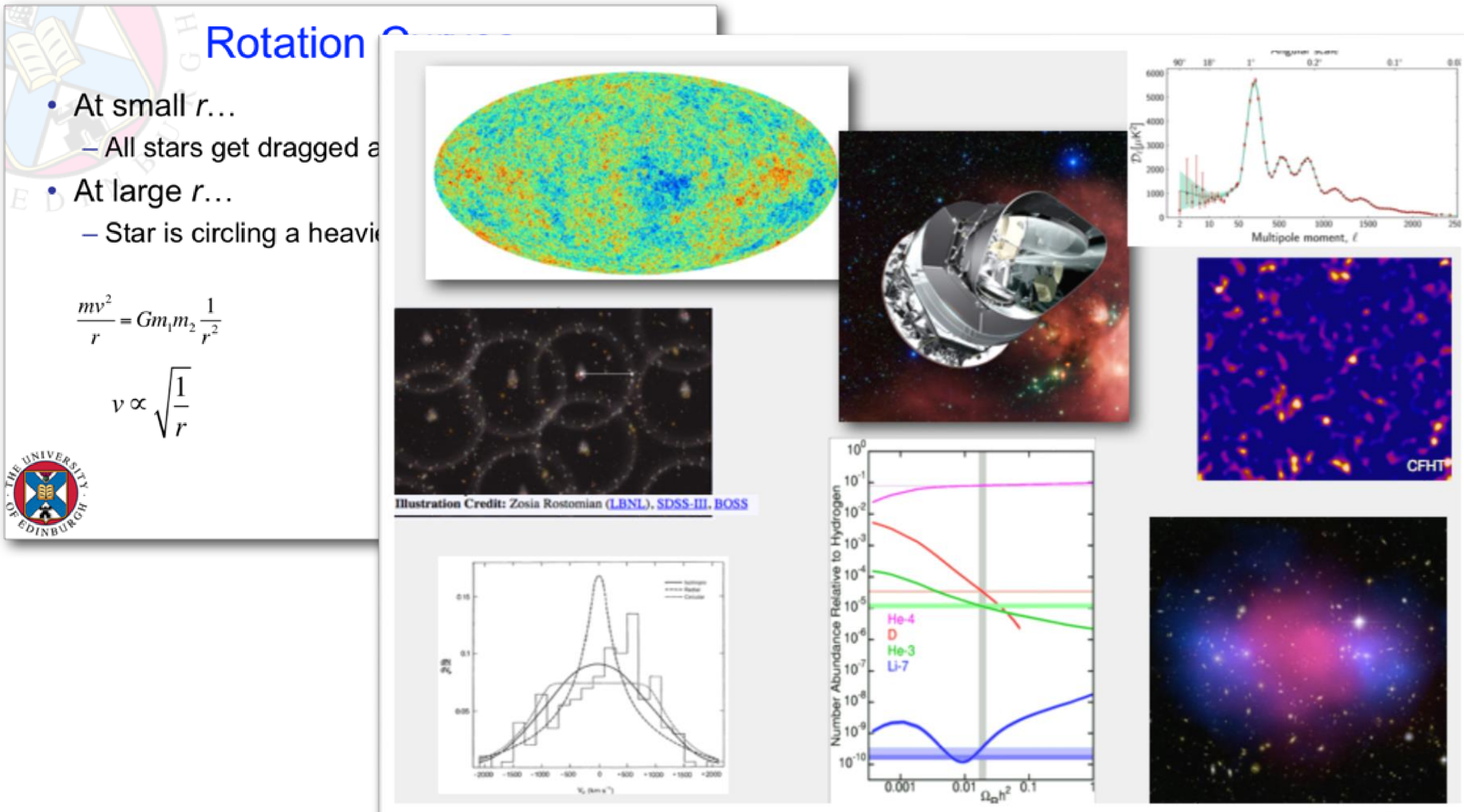
- At small *r*…
  - All stars get dragged around together: $v \propto r$
- At large *r*…
  - Star is circling a heavier mass:

$$\frac{mv^2}{r} = Gm_1m_2\frac{1}{r^2}$$

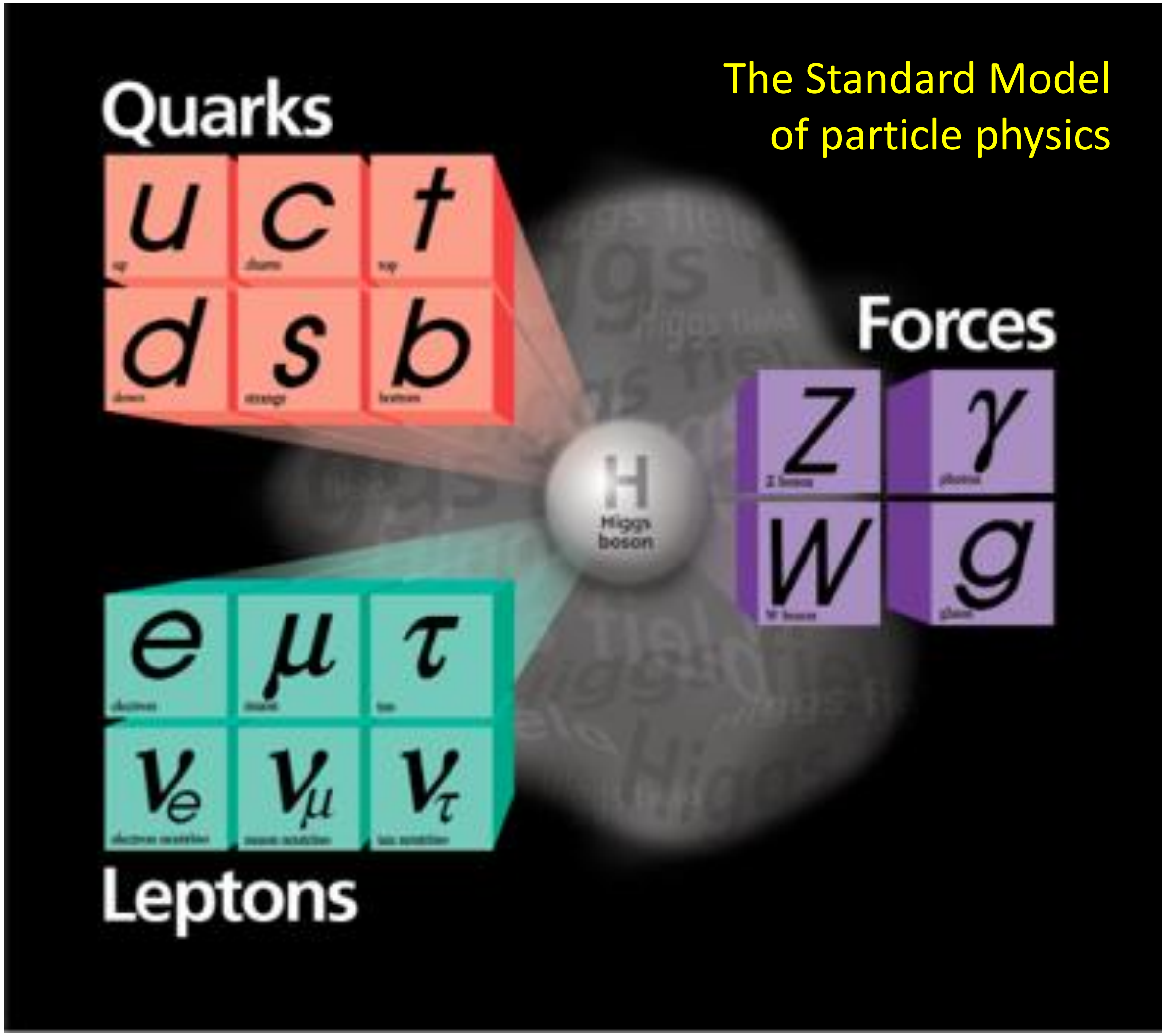
$$v \propto \sqrt{\frac{1}{r}}$$

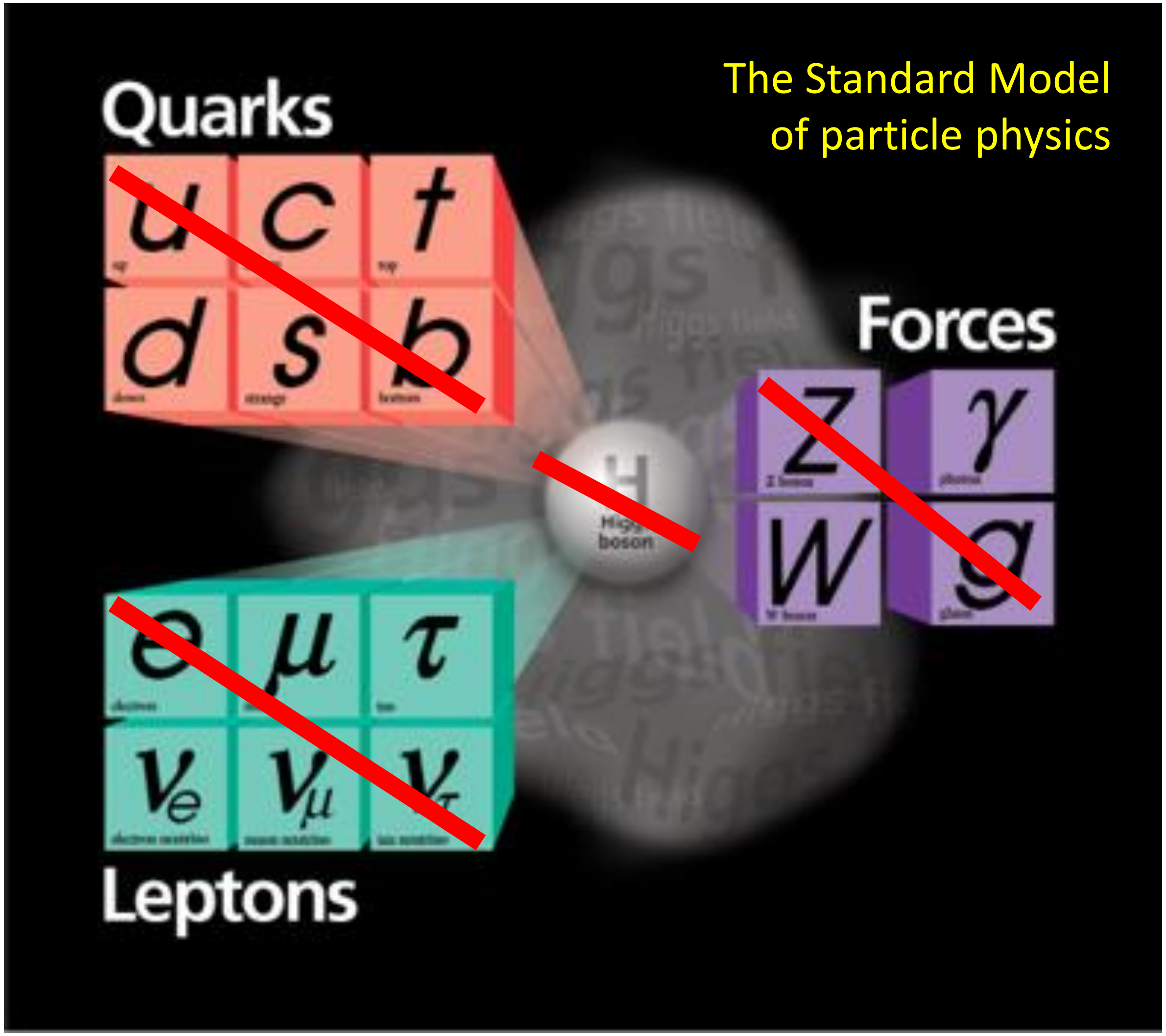


Dark Matter



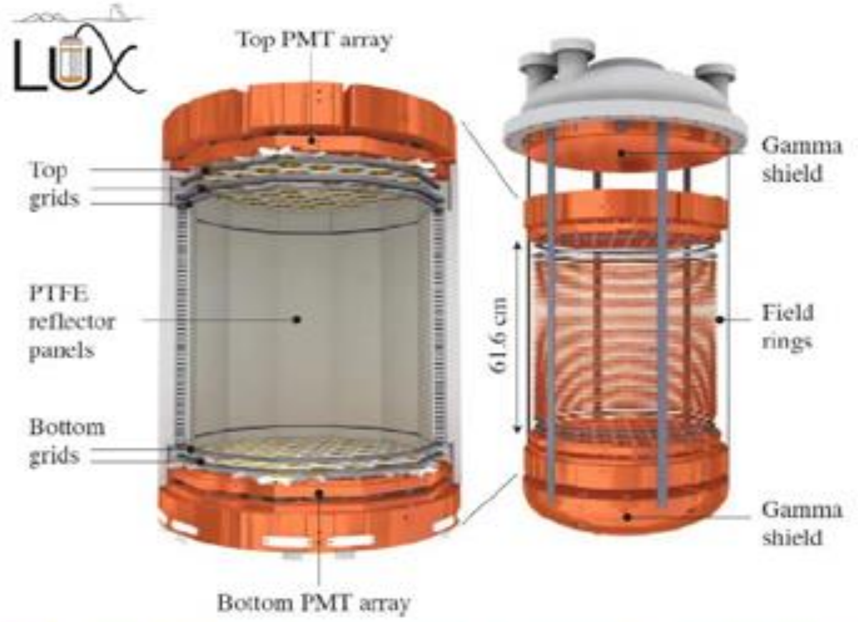
Rotation
At small r…
All stars get dragged a
At large r…
Star is circling a heavi
Illustration Credit: Zosia Rostomian (LBNL), SDSS-III, BOSS
Multipole moment, ℓ
Number Abundance Relative to Hydrogen
He-4
D
He-3
Li-7
CFHT

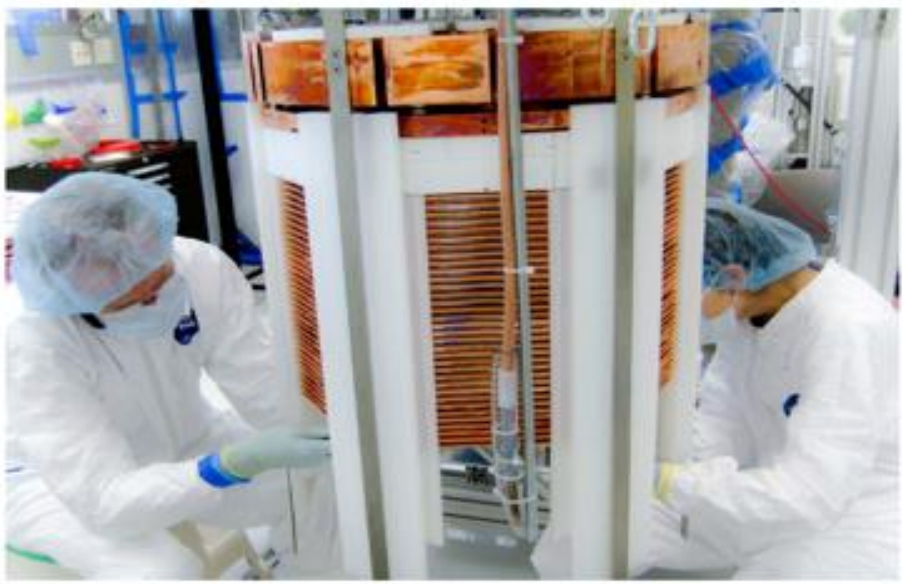

The Standard Model
of particle physics
Quarks
u c t
d s b
Forces
Z γ
W g
H
Higgs
boson
e μ τ
ν_e ν_μ ν_τ
Leptons

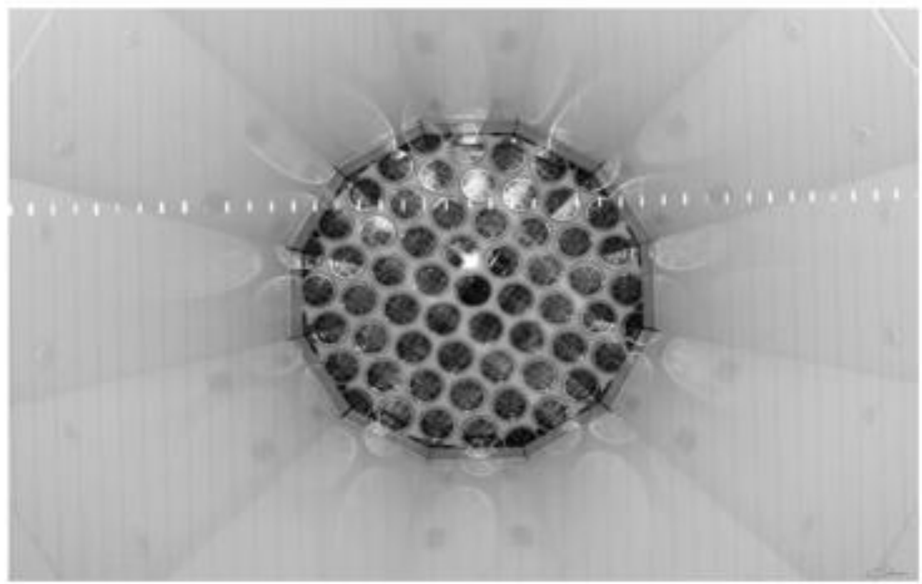


- No electromagnetic interaction
- No strong interaction
- Stable
- Neutrinos are too light

The existence of Dark Matter implies Physics Beyond the Standard Model


LUX
Top PMT array
Top grids
PTFE reflector panels
Bottom grids
Bottom PMT array
61.6 cm
Gamma shield
Field rings
Gamma shield





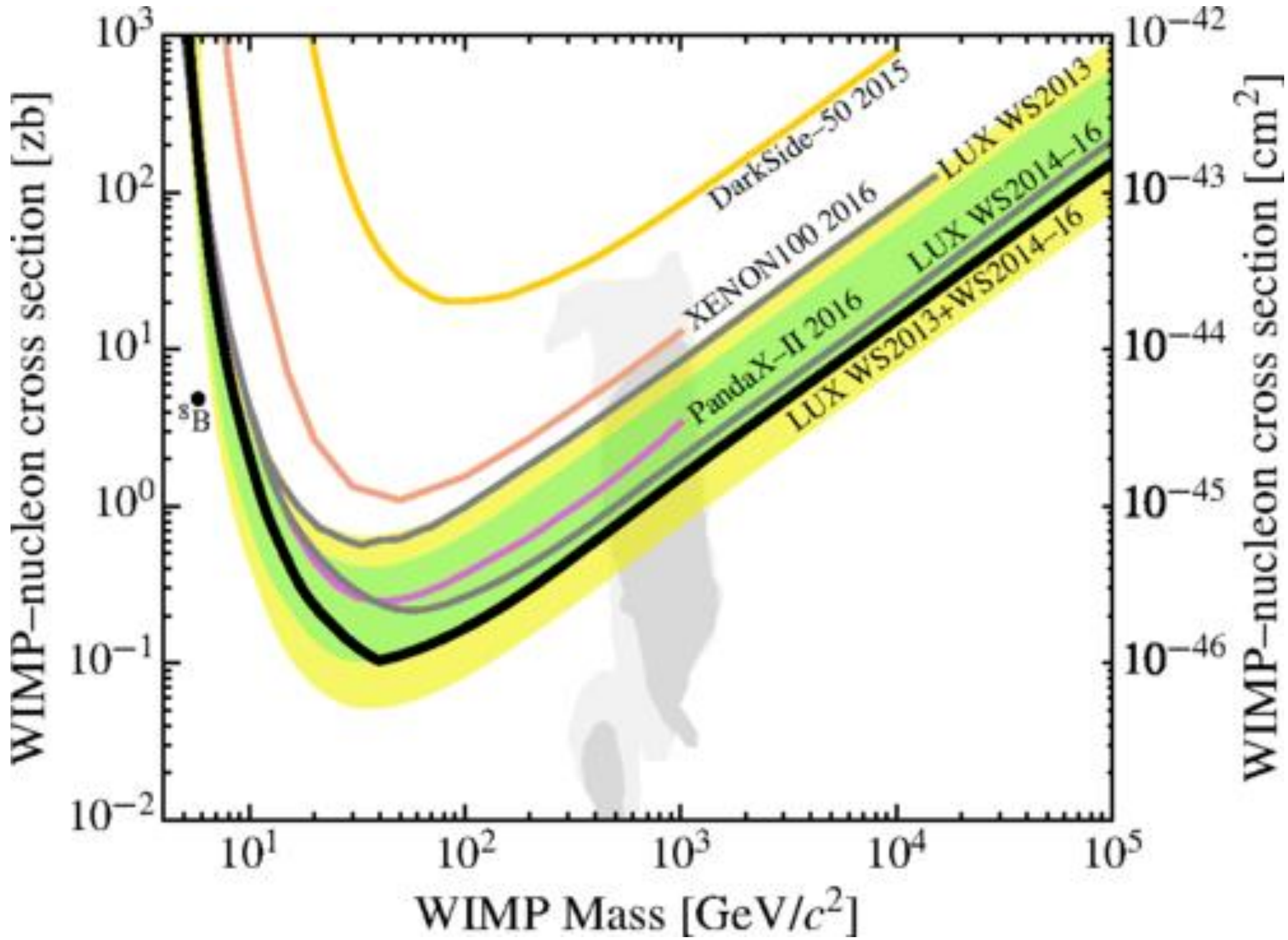
Topics

- WIMPs, SI, SD, EFTs
- Axions & axion like particles
- Two neutrino double electron capture
- Other…

WIMPs (Published)

- First results from the LUX dark matter experiment at the Sanford Underground Research Facility Physical Review Letters 112 (2014) 091303
- Improved limits on scattering of weakly interacting massive particles from reanalysis of 2013 LUX data Physical Review Letters 116 (2016) 161301
- Results on the spin-dependent scattering of weakly interacting massive particles on nucleons from the Run 3 data of the LUX experiment Physical Review Letters 116 (2016) 161302
- Results from a search for dark matter in the complete LUX exposure Physical Review Letters 118 (2017) 021303

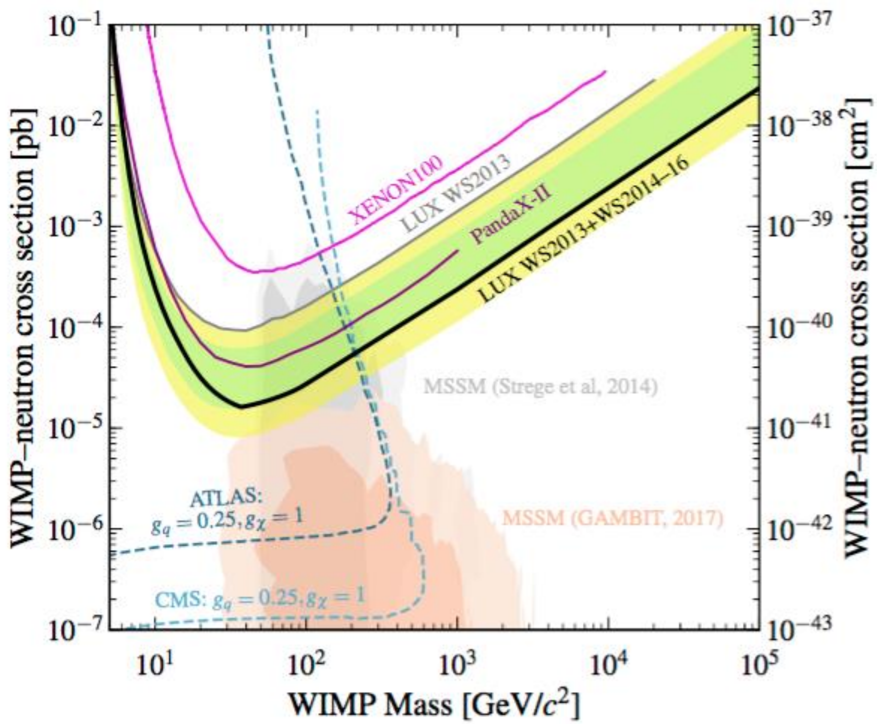
WIMPs (SI, published)



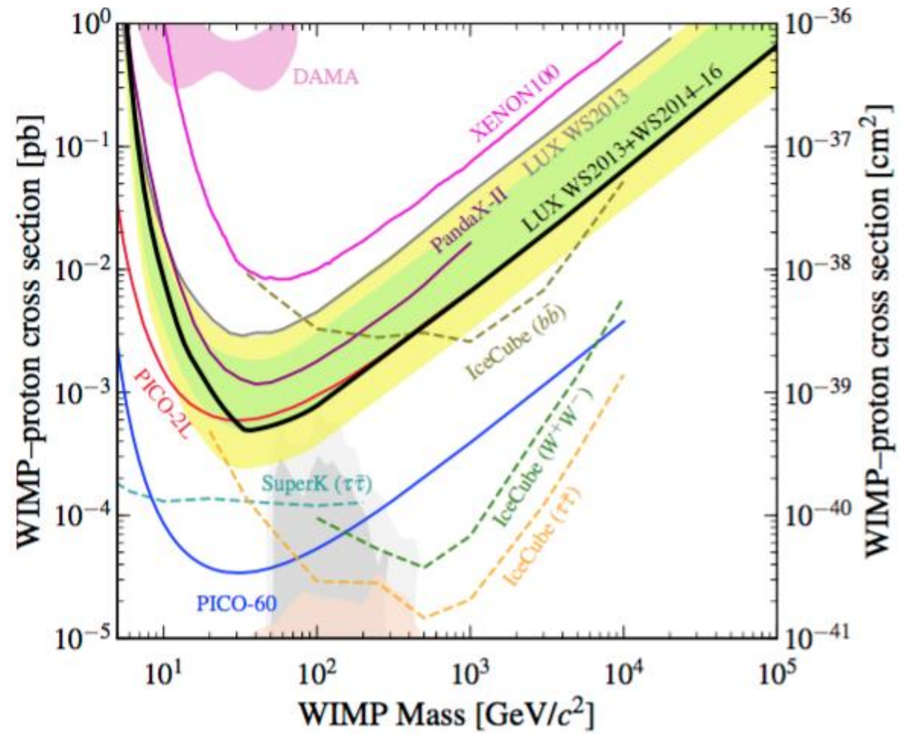
WIMPs (SD, under review)

- Run 3 + Run 4 SD limits
    - (arXiv; Submitted to PRL)

SD n

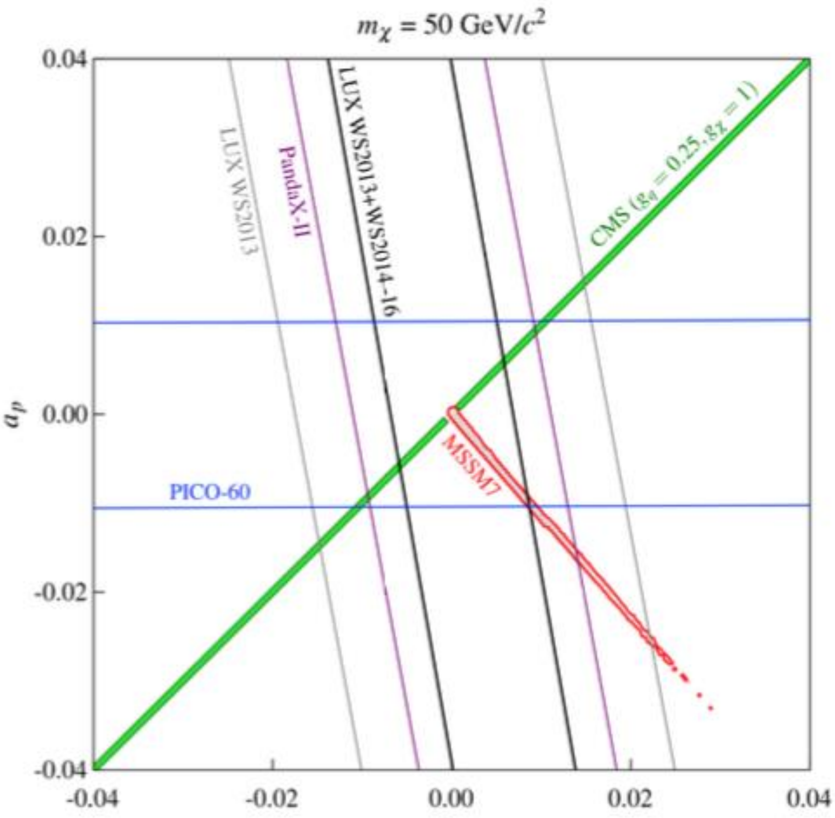


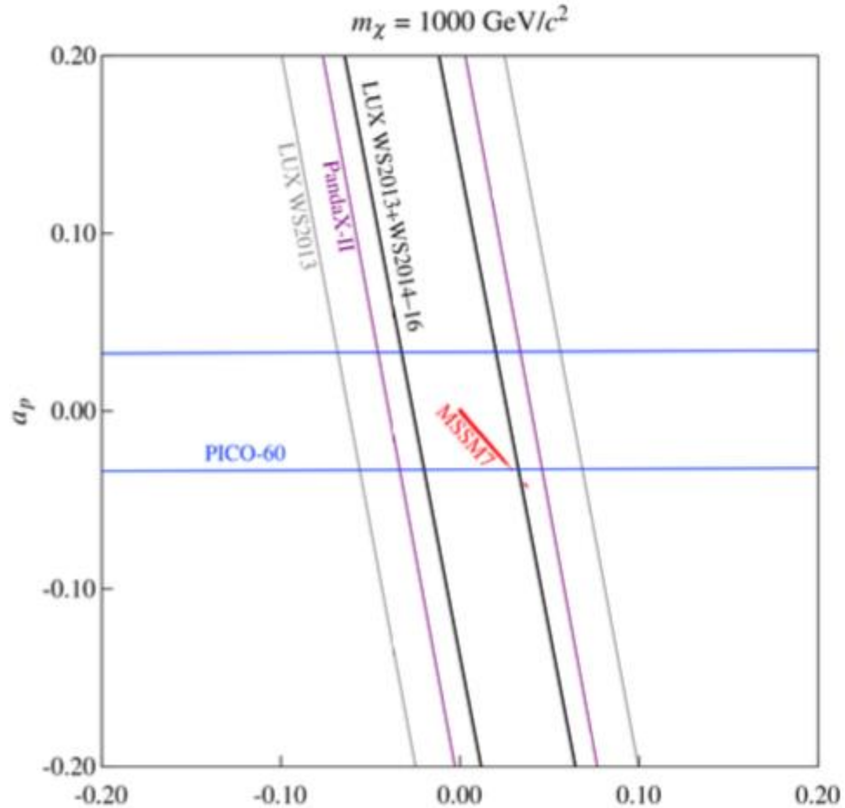
SD p



WIMPs (SD, under review)

- Run 3 + Run 4 SD limits: $a_n - a_p$ Plane Exclusions





Effective field theories

- **Close to submission to PRD(?)**
- SI, SD interactions are the only interactions that do not vanish in the zero-momentum-transfer limit.
- But there are several momentum- and velocity-dependent interactions also allowed by basic symmetry considerations.
  - The usual SI and SD interactions could be suppressed…
  - Momentum transfer is not necessarily small on a parton scale...
  - Novel nuclear responses such as angular-momentum-dependent (LD) and angular-momentum/spin-dependent (LSD) responses are allowed…
  - These LD and LSD responses can interfere with the SI and SD responses…

References:

Fitzpatrick et al. arXiv:1203.3542 and arXiv:1211.2818

Anand et al. arXiv: 1308.6288 and arXiv:1405.6690

Cirelli et al. arXiv:1307.5955

Effective field theories

Nuclear response operator (formed from linear combinations of the interaction operators)

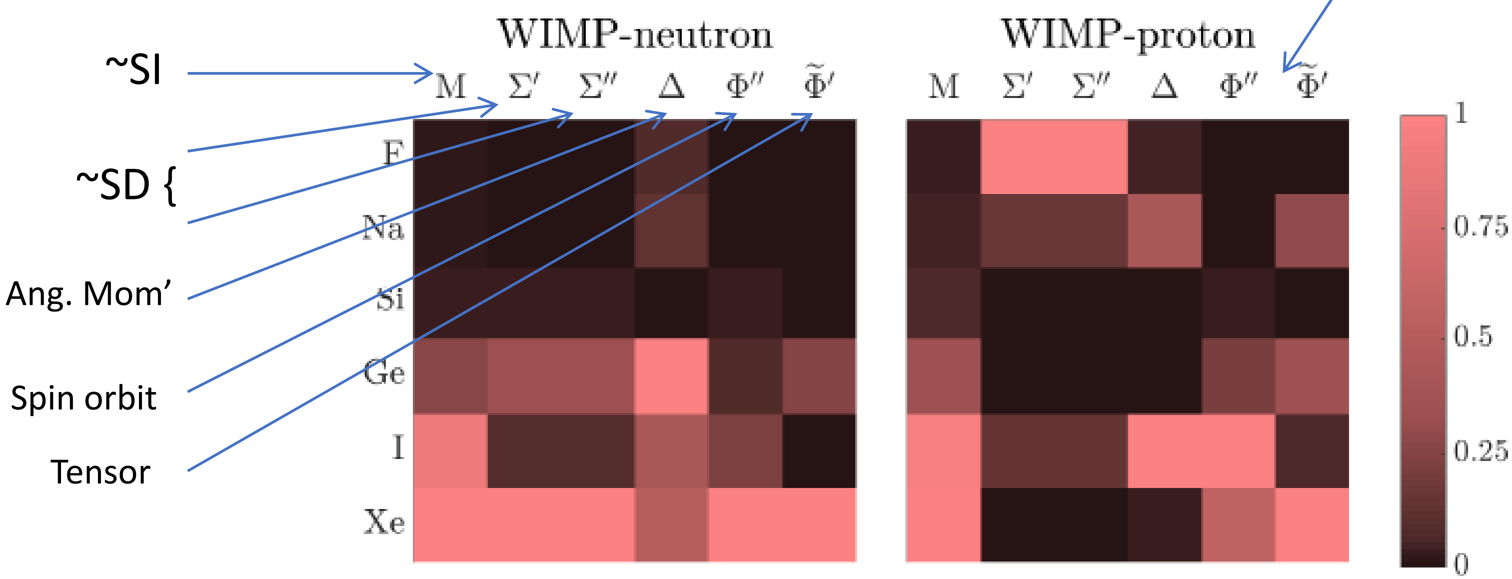
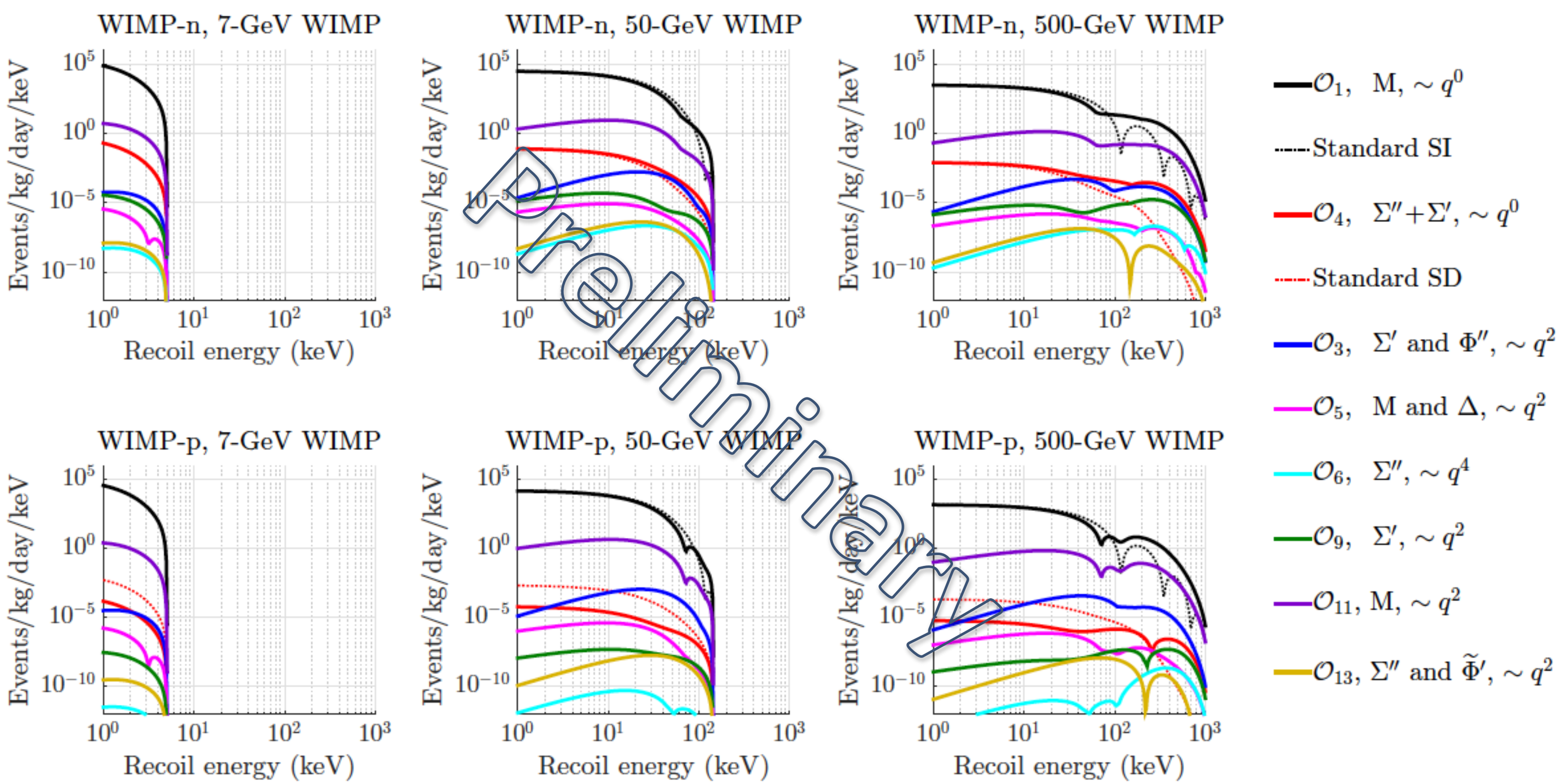


FIG. 1. The relative size of integrated nuclear form factors $\int_0^{100\ \mathrm{MeV}} \frac{1}{2} q dq F_k(q^2)$ by target for $k = \mathrm{M}, \Sigma'', \Sigma', \Delta, \Phi''$, and $\tilde{\Phi}'$, adapted and expanded from Fig. 1 of [22]. The contribution of each isotope is weighted by natural abundance. Each value is normalized by that of the element with the maximum integrated form factor.

Effective field theories



Axions and ALPs

- arXiv, Submitted PRL, referees comments received
- 'Natural' solution to strong CP problem.
  - $U(1)_{PQ}$ spontaneously broken at high energy scale
- Solar Axions
  - Solar production of QCD axions
- Galactic ALPs
  - keV scale ALPs that could be dark matter
- Coupling via Primakoff effect; g_{Ae}

Axions and ALPs

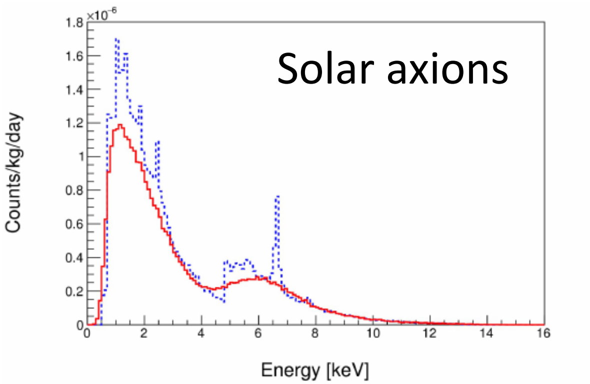


FIG. 1: Dashed blue distribution: expected energy spectrum from a massless solar axion, assuming a coupling $g_{Ae} = 10^{-12}$. The shape arises from the combination of a continuous contribution to the axion flux due to Bremsstrahlung and Compton scattering, together with features associated with atomic recombination and deexcitation effects. Solid red distribution: The expected LUX experimental solar axion energy spectrum, as modelled with NEST [33–35].

Profile likelihood search
- Solar axions
- ALP (0-16 keV in steps)

- r, z, S1, S2 observables
- Activities nuisance par's

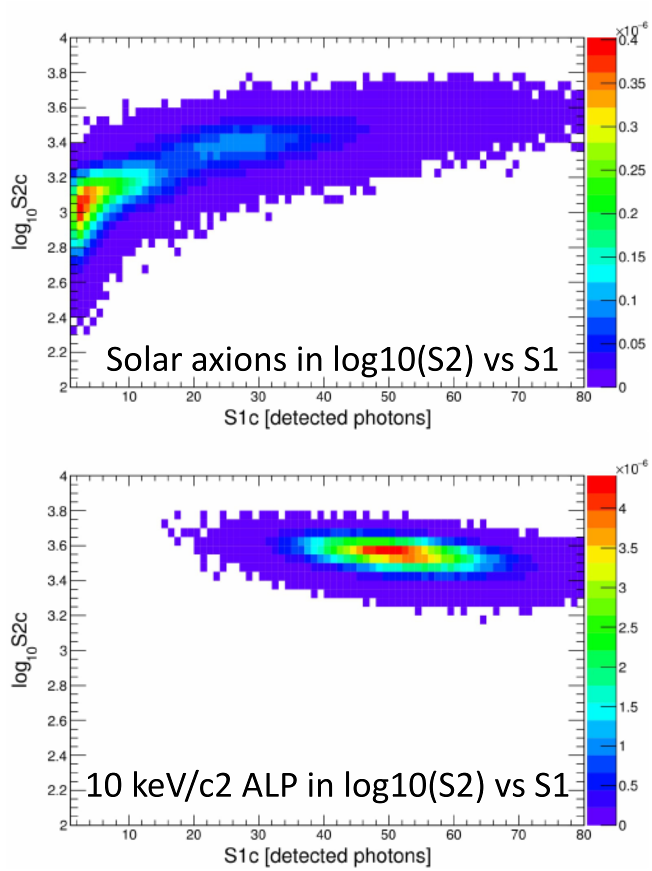


FIG. 4: Signal models projected on the two dimensional space of $\log_{10} S2_c$ as a function of $S1_c$, for massless solar axions (top) and 10 keV/c^2 mass galactic ALPs (bottom).

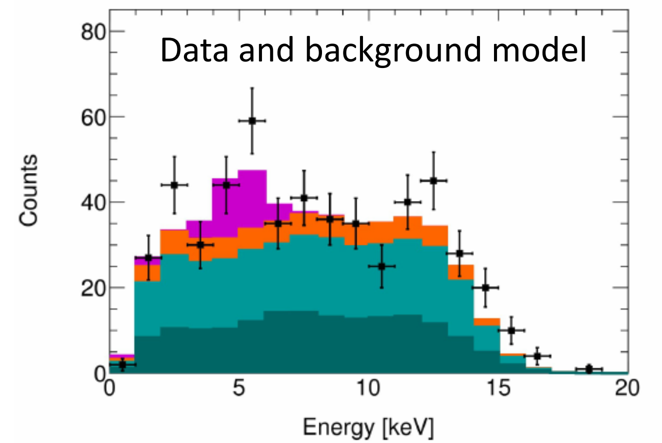


FIG. 3: Energy spectrum of the LUX 2013 electron recoil background. Data are filled black squares with error bars; the individual contributions to the background model are the stacked colored histograms: low-z-origin γ rays (dark green), other γ rays (light green), ^{85}Kr or Rn-daughter contaminants in the liquid xenon undergoing β decay (orange), x-rays due to ^{127}Xe (purple). The number of counts in each background component is based on independent assay results and background estimates, with no additional scaling. The cut off at higher energies is due to the requirement on S1 signal size.

Axions and ALPs

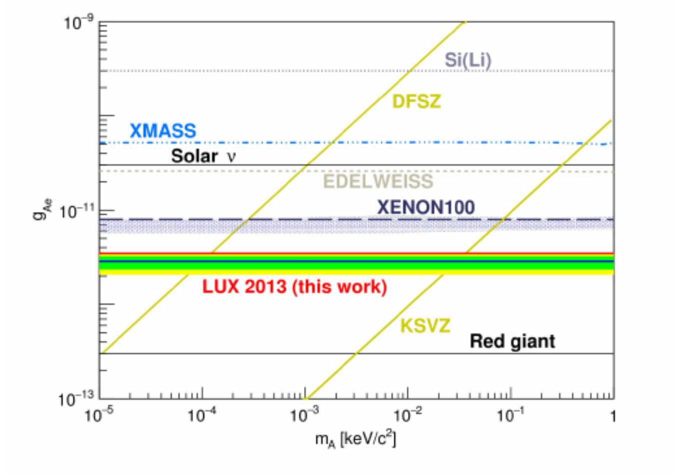


FIG. 6: Red curve: LUX 2013 data 90% C.L. limit on the coupling between solar axions and electrons. Blue curve: 90% C.L. sensitivity, ± 1 σ (green band) and ± 2 σ (yellow band).

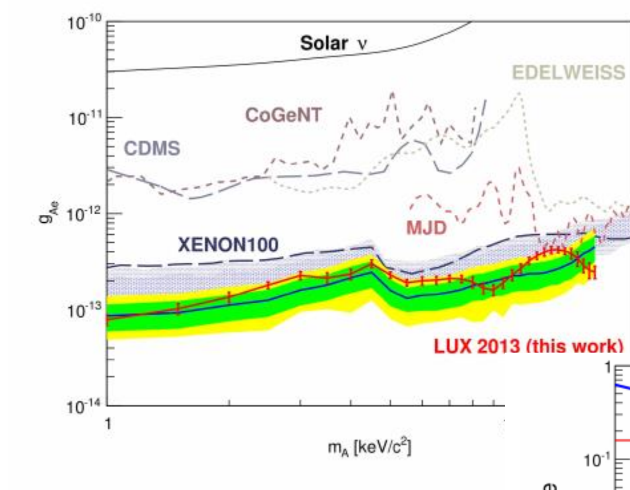


FIG. 7: Red curve: LUX 2013 data 90% coupling between galactic axion-like partic Blue curve: 90% C.L. sensitivity, ± 1 σ (g 2 σ (yellow band).

Including look elsewhere effect, discovery is excluded at 1.6 σ

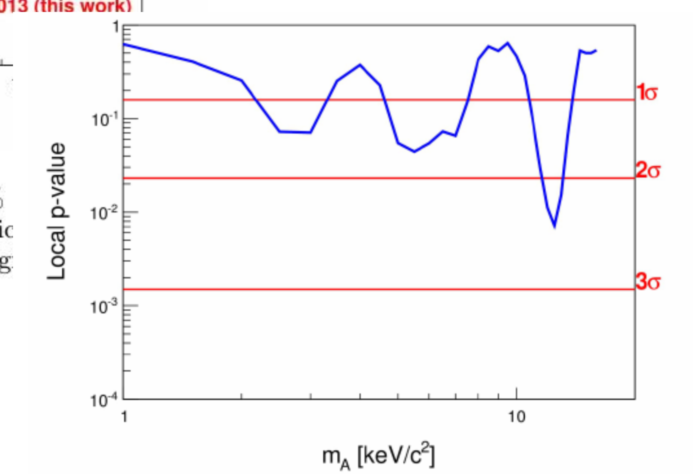


FIG. 5: Local p-value as a function of the ALP mass. The minimum is reached at 12.5 keV/c^2, where the local p-value is 7.2×10^{-3}, corresponding to a 2.4σ local deviation.

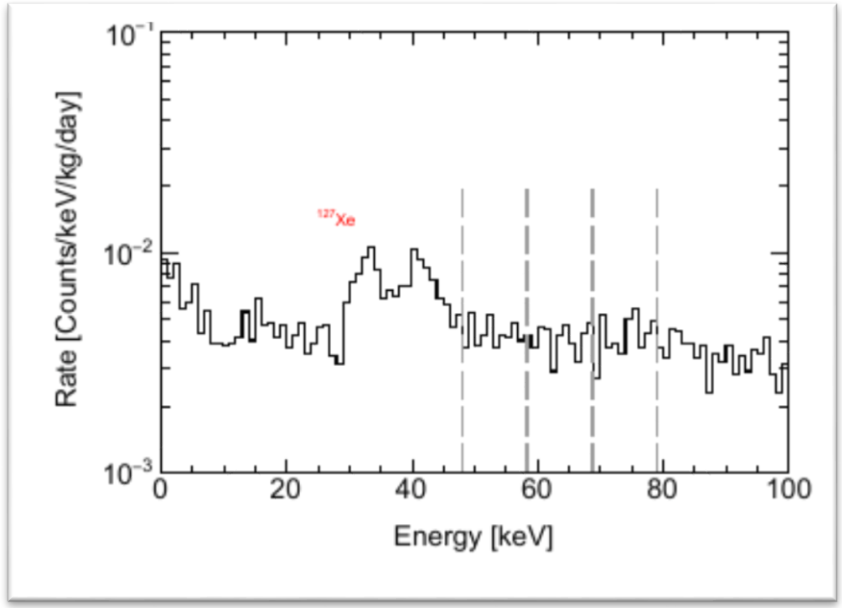
Two Neutrino Double Electron Capture

- An allowed SM process, observed in ^{78}Kr and ^{130}Ba (only)
- Provides benchmarking of matrix element calculations (for 0νBB, 0νDEC, which are BSM)
- Expectation $\tau_{2\nu DEC}$ ~ few x 10^{21} yr
- XMASS result: ^{124}Xe: > 4.7 x 10^{21} yr

- Predicted signal: cascade of x-rays and/or Auger electrons with total energy of 63.6 keV

Two Neutrino Double Electron Capture

- Construct Kr-free data set
- Estimate energy resolution at 63.6 keV
- Explore whether multiple vs. single energy deposition alter width (no)
- Consider acceptance, efficiencies and systematics
- Define ROI & side bands
- Use Rolke statistics
- Derive limit



$(2.87 \pm 0.22(stat.) \pm 0.15(syst.)) \times 10^{21}$ years, at a 90% confidence level.

Other (physics, in the works)

- Daily/Annual modulation searches
- Solar neutrino magnetic moment and solar sterile neutrinos
- Inelastic dark matter (EFT approach)
- ^{134}Xe $0\nu\beta\beta$
- Leptophillic dark matter
- Lightly ionising particles
- Mirror dark matter
- Plasma dark matter
- Dark photon / dark sector mediator searches
- Halo model independent limits
- Run 4 versions of run 3 result: EFT, axions, DEC, etc
- …

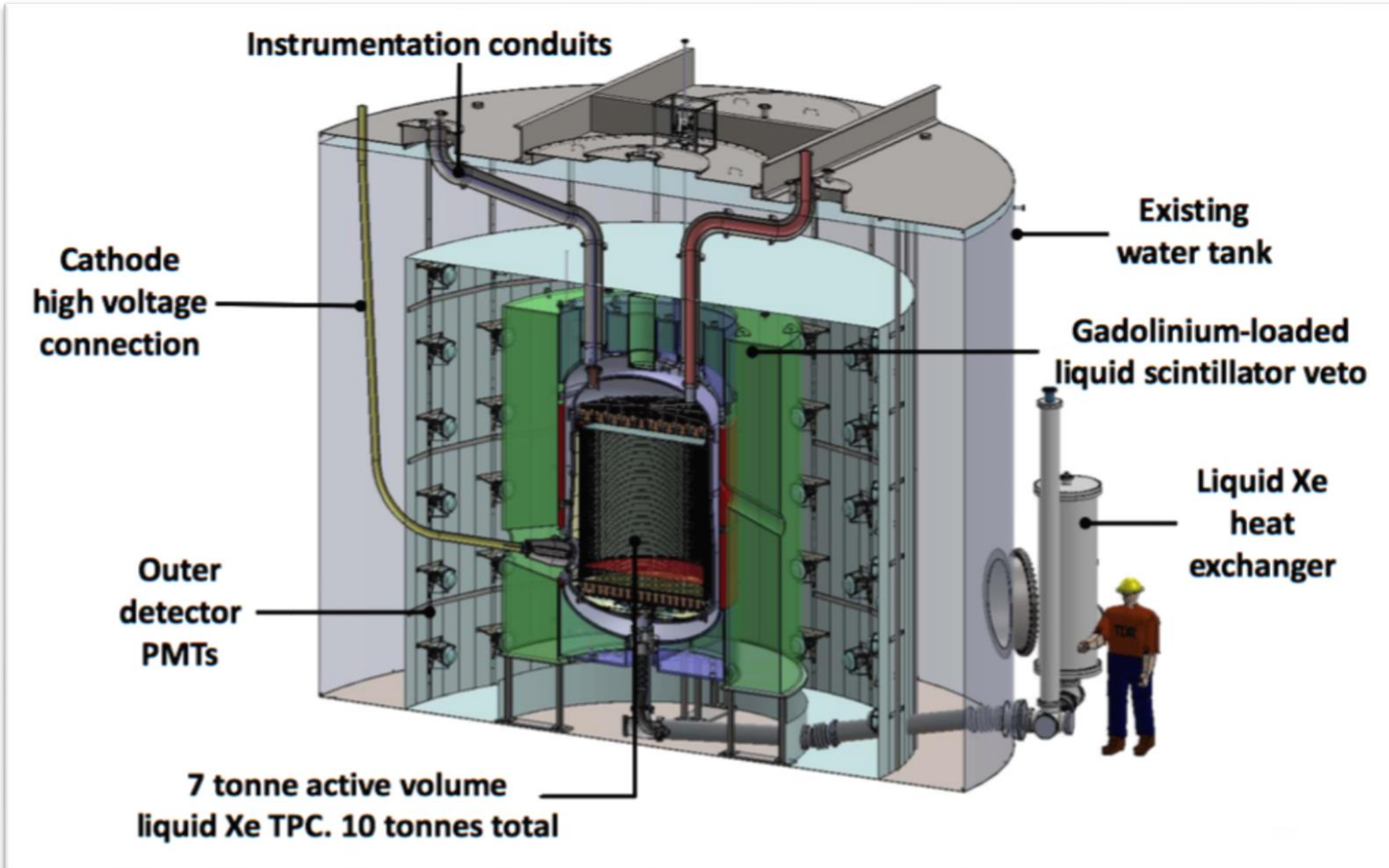
Other (non-physics, published)

- Radiogenic and muon-induced backgrounds in the LUX dark matter detector Astroparticle Physics 62 2015 33-46
- Tritium calibration of the LUX dark matter experiment Physical Review D 93 2016 072009
- FPGA-based trigger system for the LUX dark matter experiment Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 818 2016 57-67
- Signal yields, energy resolution, and recombination fluctuations in liquid xenon Phys. Rev. D 95, 012008 95 2017 012008

Other (non-physics, in the works)

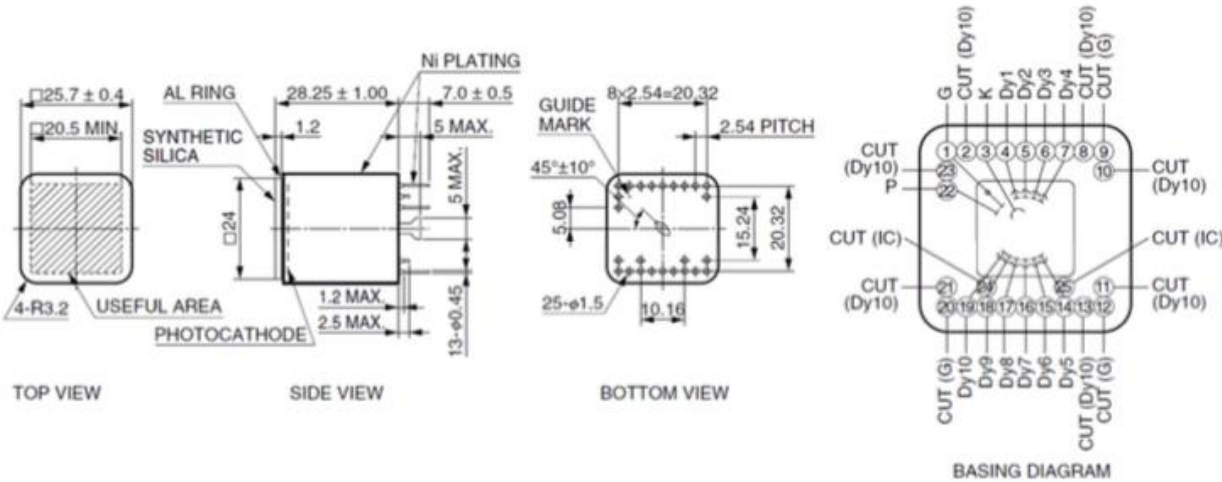
- "Calibration, event reconstruction, data analysis and limits calculation for the LUX dark matter experiment" (PRD to support 300 d PRL)
- "3D Modeling of Electric Fields in the LUX Detector "
- "Position-dependent calibration of the LUX dark matter experiment using ^{83m}Kr"
- "Low-energy (0.7–74 keV) nuclear recoil calibration of the LUX dark matter experiment using D-D neutron scattering kinematics"
- ^{127}Xe (ultra) low energy ER calibration
- S2-only analysis
- "Ultra-Low Energy Calibration of LUX Detector using ^{127}Xe Electron Capture"
- "Position Reconstruction in LUX"
- Trigger Efficiency
- S1 pulse shape discrimination
- Run 4 ER/NR S1/S2 field corrections
- Run 4 backgrounds
- Machine learning analysis
- …

LUX-ZEPLIN



Instrumentation conduits
Existing water tank
Cathode high voltage connection
Gadolinium-loaded liquid scintillator veto
Liquid Xe heat exchanger
Outer detector PMTs
7 tonne active volume liquid Xe TPC. 10 tonnes total

R8520-406



[R8520-406 Specification]

Skin PMT studies

Functional tests

- Single photoelectron response & resolution, Dark Count, Linearity, After-pulsing, *Gain*
- *RTP, and Vaccum & cold*

- Pressure tests
  - 5 bar (gauge)

Astronomy Technology Centre Detector Lab – Option 2 (preferred)

- Cleaner
- Direct access to (or within) cleanroom
- Less spacious
- Similarly capable test chambers