Mirror Dark Matter Search in the LUX Experiment

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Mirror Dark Matter Model

- Dark matter in a hidden sector isomorphic to standard model [1]
- Mirror partners of Standard model particles with same masses, lifetimes and self interactions
- Multi component plasma halo

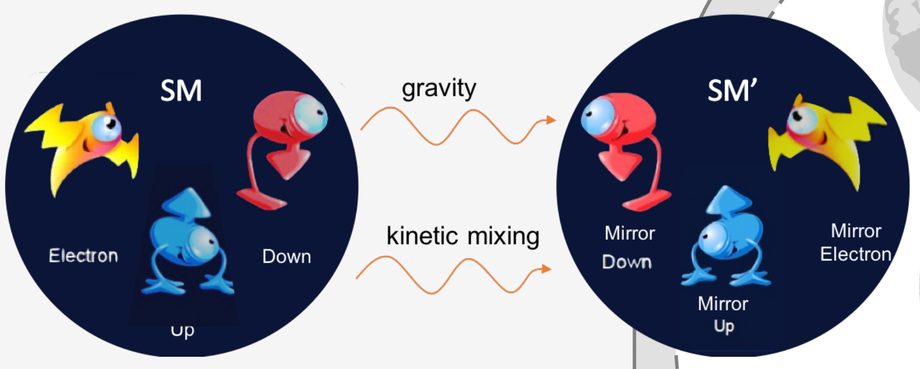
Interactions:

$$\mathcal{L} = \mathcal{L}_{SM}(e,u,d,\gamma,W,Z\ldots) + \mathcal{L}_{SM'}(e',u',d',\gamma',W',Z'\ldots) + \mathcal{L}_{mix}$$

SM Lagrangian | Mirror Lagrangian | Mixing term: contains non-gravitational interactions

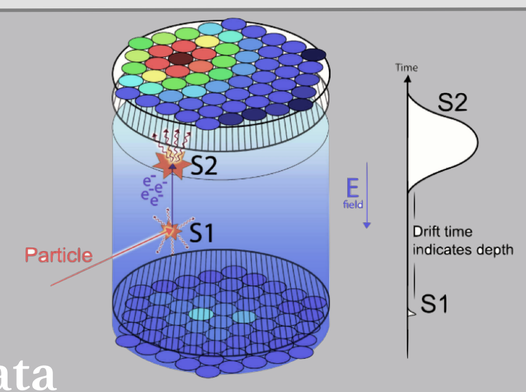
$$\mathcal{L}_{mix} = \frac{\varepsilon}{2} F^{\mu\nu} F_{\mu\nu} + \Lambda \phi^{\dagger}\phi\, \phi'^{\dagger}\phi'$$

Kinetic mixing term | Higgs – mirror Higgs coupling



LUX Experiment

- Dual phase xenon time projection chamber with 250kg active mass
- Ran from 2013-2016
- Detector located 1458 m underground at Sanford Underground Research Facility, USA
- Main aim was WIMP search – spin independent nuclear recoil interaction

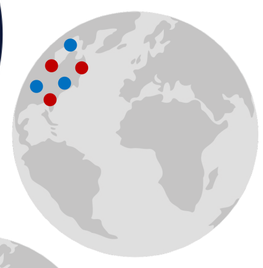


LUX Data

- Particle interaction with Xe atom produces scintillation light (S1) and ionization electrons
- Electrons drifted vertically by electric field and extracted to gas phase where they produce an electroluminescence signal (S2)
- Spatial coordinates (x,y) from S2 and z from drift time between S1 and S2

Dark Matter Shielding

1. Mirror dark matter energy loss from kinetic mixing interaction with ordinary matter leads to capture.



2. Mirror dark matter thermalizes with ordinary matter, forming an extended distribution in the Earth.

3. Self interactions between captured distribution and incoming mirror dark matter cause collisional shielding.

Shielding modifies flux and velocity distribution of incoming mirror dark matter.

Theory to Detection

Kinetic mixing interaction allows incoming mirror electron to scatter of an atomic electron in Xe. This is different to the nuclear recoil signal used for the conventional WIMP search. Interaction rate depends on local mirror electron temperature, T, and kinetic mixing parameter, ϵ.

Differential scattering rate [3]:

Shielding effects
$n^0_{e'}$: mirror electron number density
v^0_c: velocity distribution

Target
N_T: atoms per kg

Kinetic mixing interaction:
$\lambda = \frac{2\pi\varepsilon^2\alpha^2}{m_e^2}$

$$\frac{dR}{dE_R} = g_T N_T n^0_{e'} \frac{\lambda}{v_c^0 E_R^2}\left[1 + A_v cos\omega(t-t_0) + A_\theta(\theta-\bar{\theta})\right]$$

Atomic effects
g_T: number of electrons with binding energy < E_R

Modulation terms

Analysis

Simulations

- Noble Element Simulation Technique [4] used to simulate detector observables (r, z, S1, S2) from signal and background energy spectra
- Background normalised using detector component screening and direct measurements and xenon sampling during data taking

Data

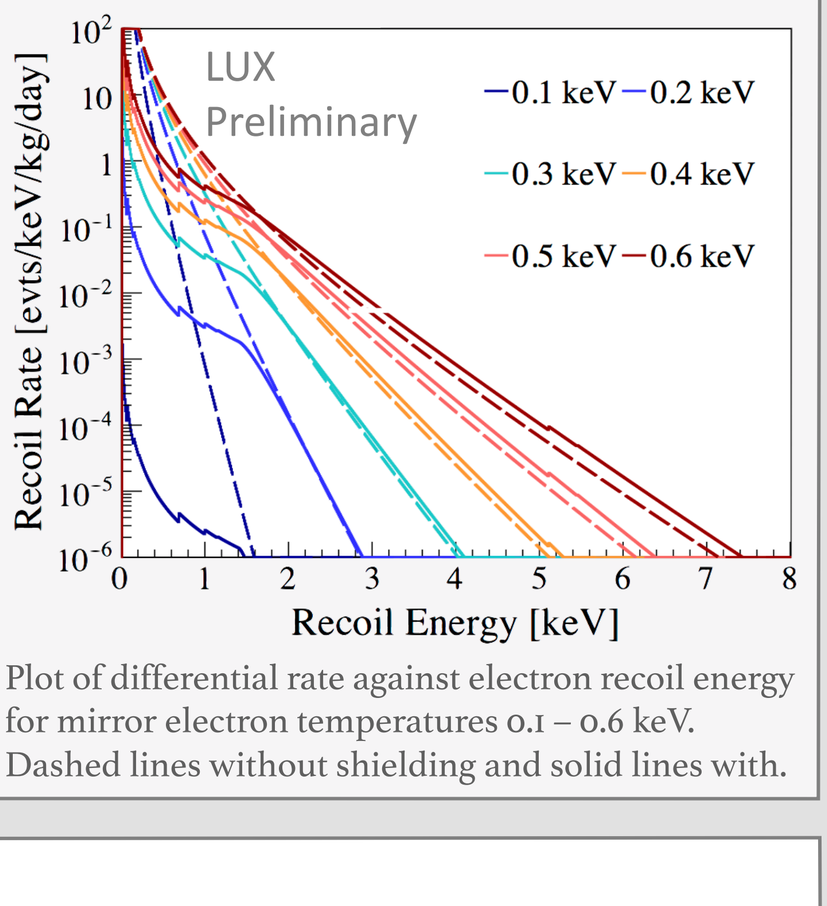
- WIMP search data taken April-September 2013, 118 kg × 95 days exposure
- Fiducial radius 18 cm, z range 8.5 – 48.6 cm and 0 < S1 < 80

Profile Likelihood Ratio Test

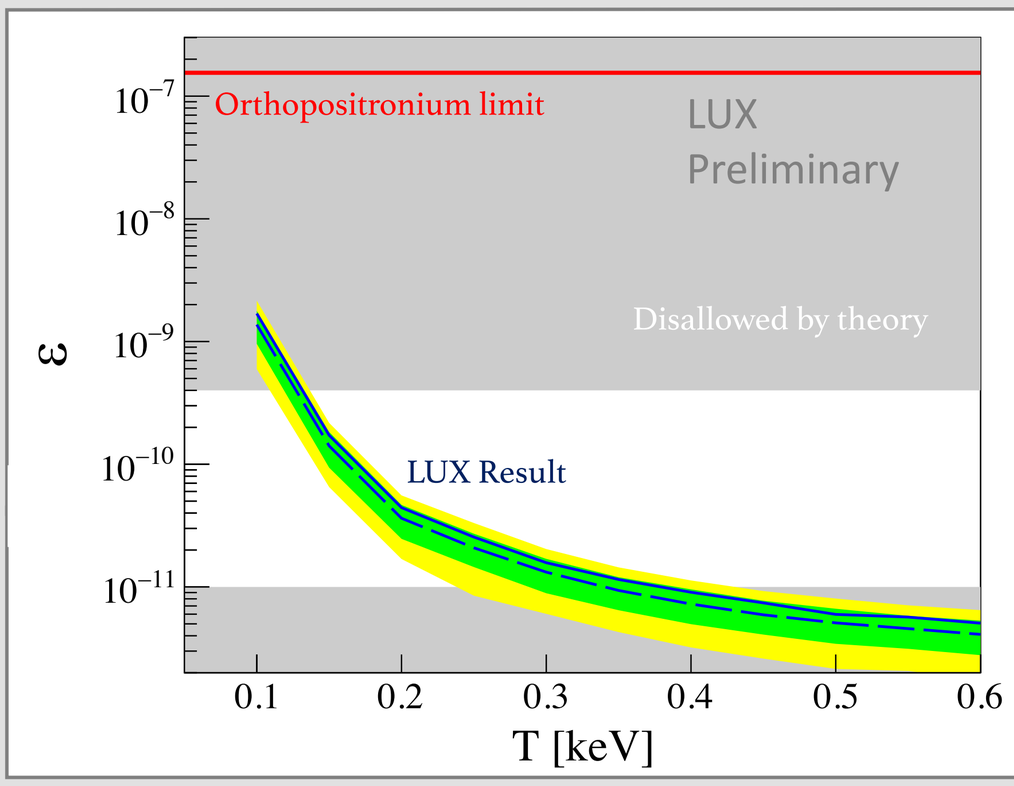
Find 90% confidence limit on number of signal events, for a range of mirror electron temperatures. Uncertainties on background rates used as nuisance parameters and number of signal events is the parameter of interest.

Limit Setting

Scale limit on number of signal events to find 90% confidence limit on kinetic mixing parameter ε.



Plot of differential rate against electron recoil energy for mirror electron temperatures 0.1 – 0.6 keV. Dashed lines without shielding and solid lines with.



Results

- First direct detection search for mirror dark matter
- Ruled out local electron temperatures above 0.3 keV (for this model) and constrained kinetic mixing below this
- Previous experimental constraint from search for invisible decays of orthopositronium in vacuum [5]
- Theory constraint on kinetic mixing [1]: $10^{-11} \leq \varepsilon \leq 4\times10^{-10}$ lower limit from halo dynamics, upper limit from structure formation

References

[1] R.Foot, Mirror dark matter: Cosmology, galaxy structure and direct detection, Int. J. Mod. Phys. A, 29, 1430013 (2014)
[2] D. Akerib et al. (LUX Collaboration) First results from the LUX dark matter experiment at the Sanford underground research facility, Phys. Rev. Lett., 112, 091393 (2014)
[3] R.Foot, Shielding of a direct detection experiment and implications for the DAMA annual modulation signal, Phys. Lett. B., 789, 592-597 (2019)
[4] M.Szydagis et al., NESTv2.0, 10.5281/zenodo.1314669,https://doi.org/10.5281/zenodo.1314669 (2018)
[5] C.Vigo et al., First search for invisible decays of orthopositronium confined in a vacuum cavity, Phys. Rev. D, 97, 092008 (2018)