LUX-Zeplin (LZ) Projected Sensitivity to Neutrino Electromagnetic Properties

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UMassAmherst

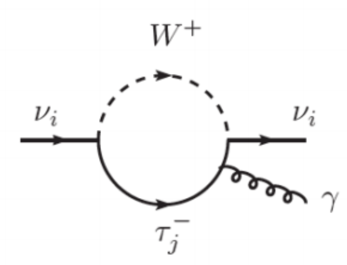
Amherst Center for Fundamental Interactions

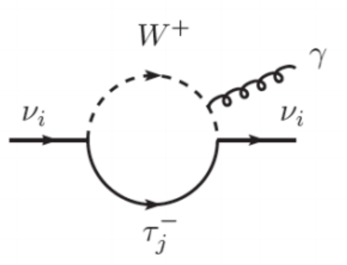
Physics at the interface: Energy, Intensity, and Cosmic frontiers

University of Massachusetts Amherst

Big Picture Motivation

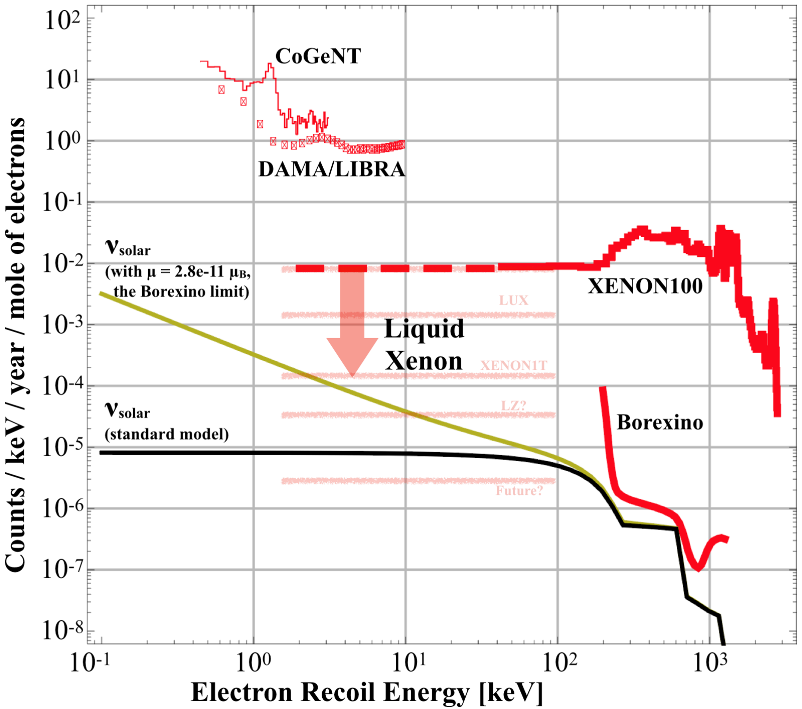
- Neutrino physics: Discovery of neutrino oscillations implies that neutrinos have non-zero mass, which implies non-zero E&M properties
- The E&M properties probe:
  - Whether neutrinos are Dirac vs Majorana in nature [4,5]
  - If there are unknown particles via loop diagrams





Big Picture Motivation: low threshold helps

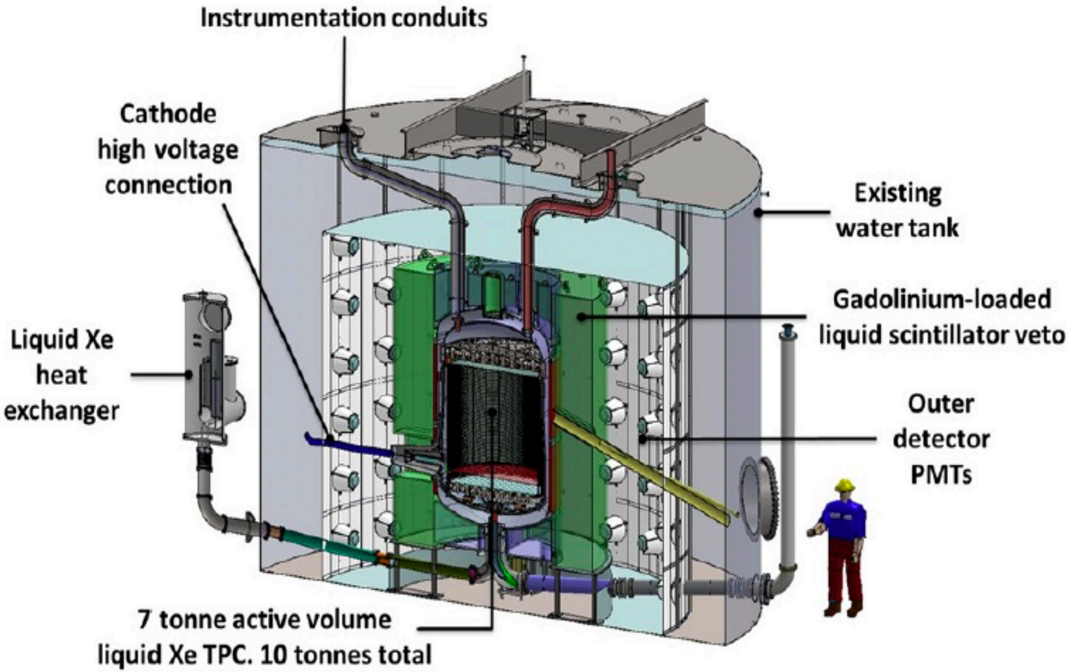
- EM properties lead to an enhancement in solar neutrino electron scattering
- Borexino (order ~100keV regime): current leader
- LXe (order ~1keV regime) competitive given background reduction
- This study: How well will LZ specifically do?



[2] arXiv:1303.6073

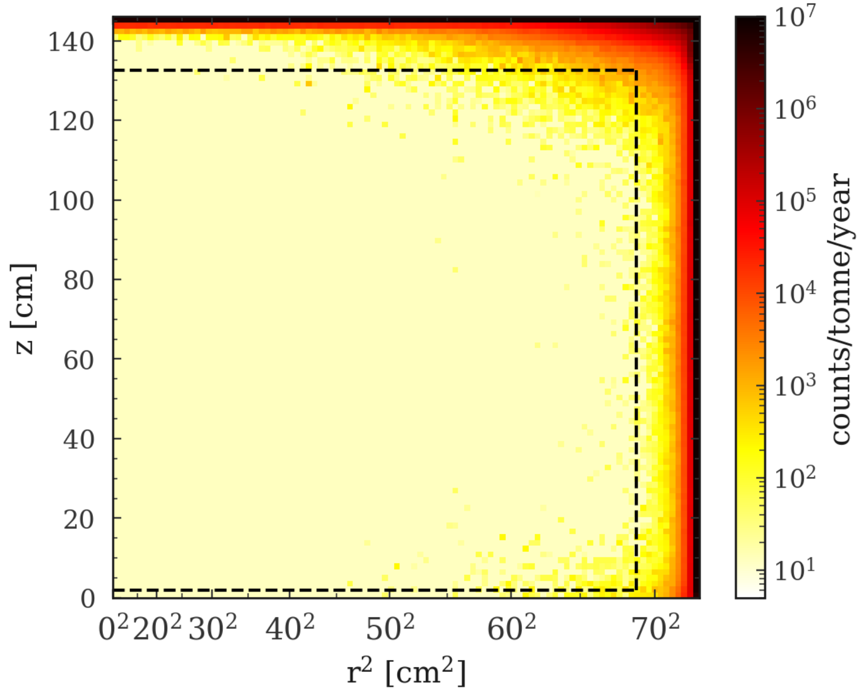
LZ Overall Physical Design

- LZ is primarily a WIMP dark matter experiment
- Located in Lead, South Dakota~200 person collaboration
  - See LZ overview talk from C. Carmona (Saturday session C13)



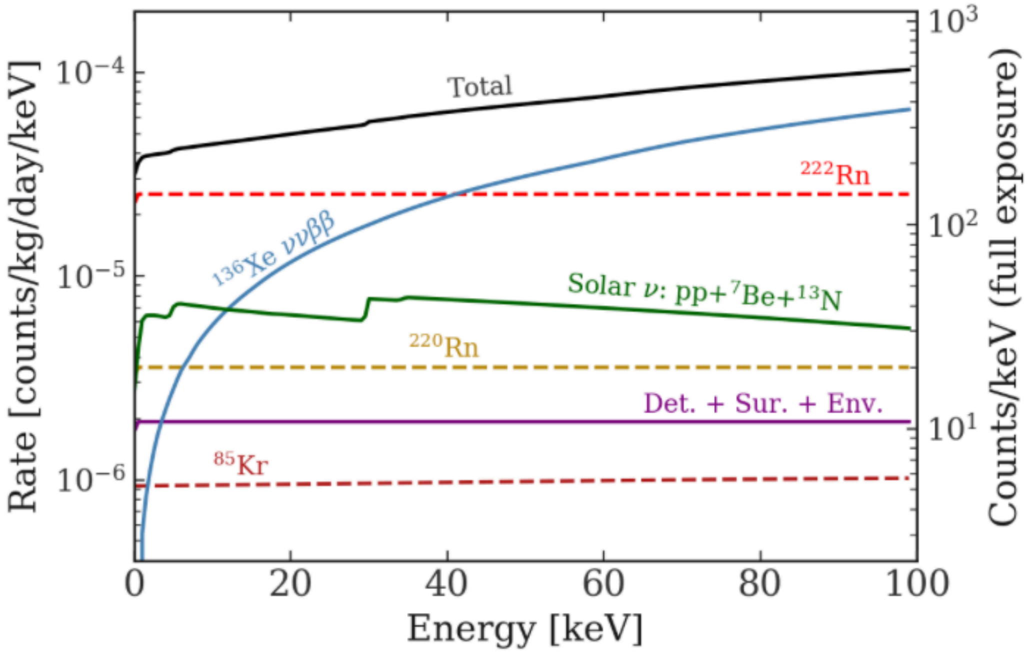
LZ Backgrounds, after vetoing

- LXe self-shielding reduces backgrounds
- Fiducial mass: 5.6 tonnes (within black-dashed line)
- Plotting background rate for a window of the lowest 100 keV



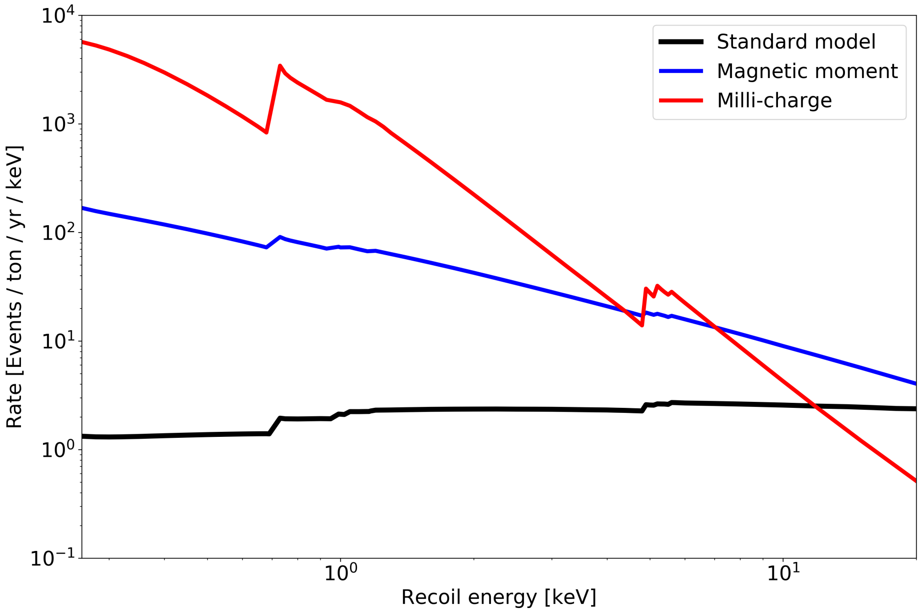
LZ Background major components

- Within FV, we expect to be dominated by 222 Rn daughters
- Xe136 double beta decay also relevant

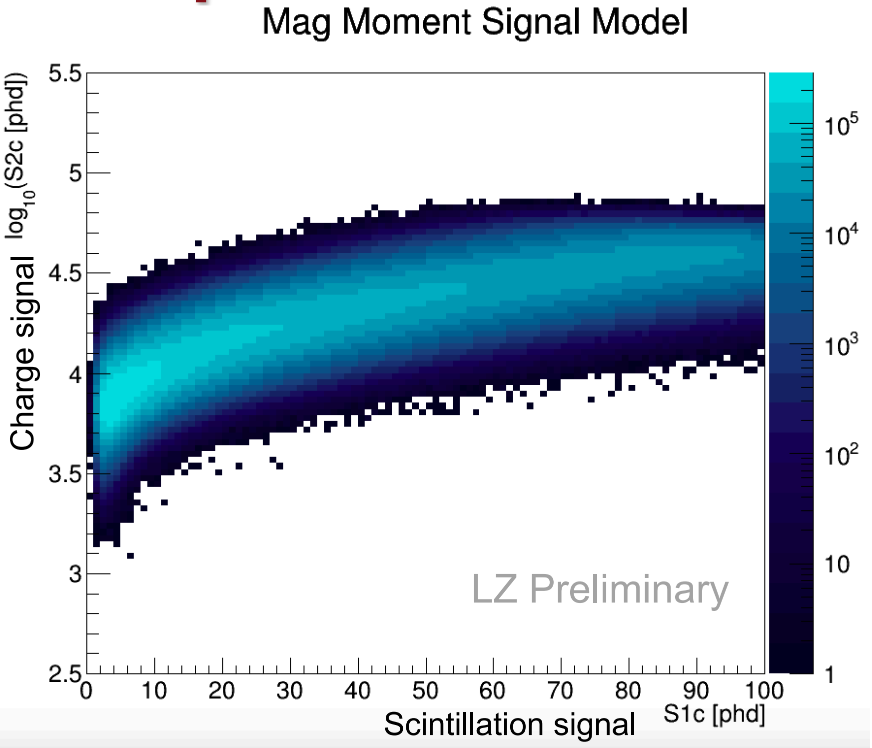


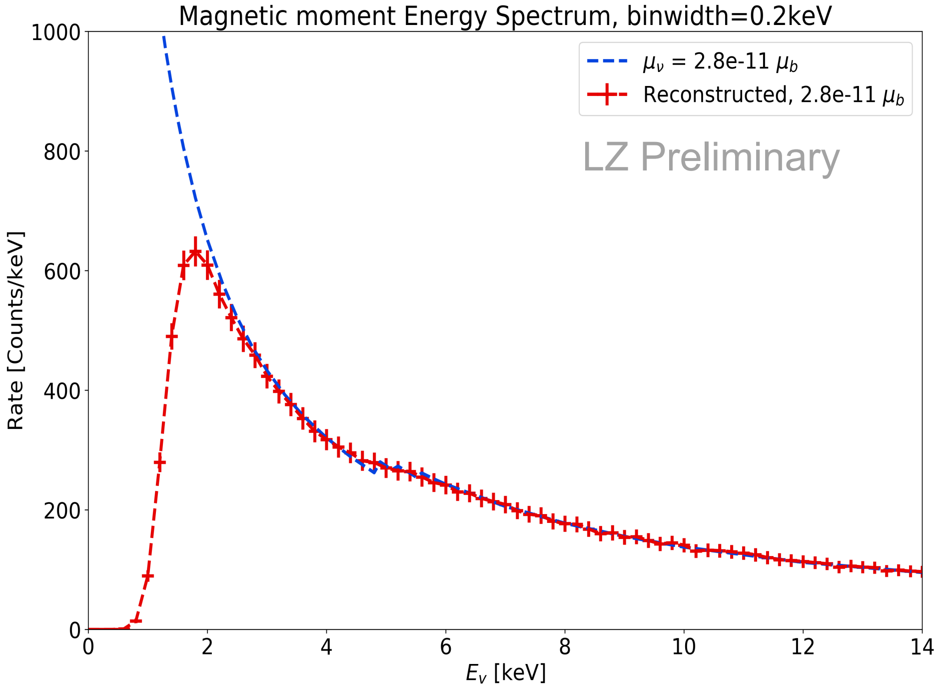
Complication I: Electrons are bound

- At low energies, electron binding energies become relevant
- Using results Hsieh et al., using relativistic calculations from arXiv:1903.06085v1 [1]



Complication II: NEST reconstruction; threshold





Profile Likelihood Ratio (PLR) Method

- We project only single-sided 90% CL upper limits (we do not consider discovery sensitivities)
- We assume a 5.6 ton x 1000 day exposure
  - ~4 years of operation
- Background rate uncertainties are included as nuisance parameters
  - Nuclear recoil backgrounds were found to have negligible effect, thus not included

PLR Method (cont.)

$$L(\sigma, \boldsymbol{\nu}|\mathfrak{D}) = \left[\mathrm{Pois}(n_0|\mu) * \prod_{e=1}^{n_0} \frac{1}{\mu} \left(\mu_s(\sigma) f_s(\boldsymbol{x_e}|m_{\mathrm{WIMP}}) + \sum_{b=1}^{N_b} \mu_b f_b(\boldsymbol{x_e}|\boldsymbol{\nu}) \right) \right] * \prod_{p=1}^{N_p} f_p(\boldsymbol{g_p}|\nu_p)$$

Extended term: $\mathrm{Pois}(n_0|\mu)$

Event probability model: $\prod_{e=1}^{n_0} \frac{1}{\mu} \left(\mu_s(\sigma) f_s(\boldsymbol{x_e}|m_{\mathrm{WIMP}}) + \sum_{b=1}^{N_b} \mu_b f_b(\boldsymbol{x_e}|\boldsymbol{\nu}) \right)$

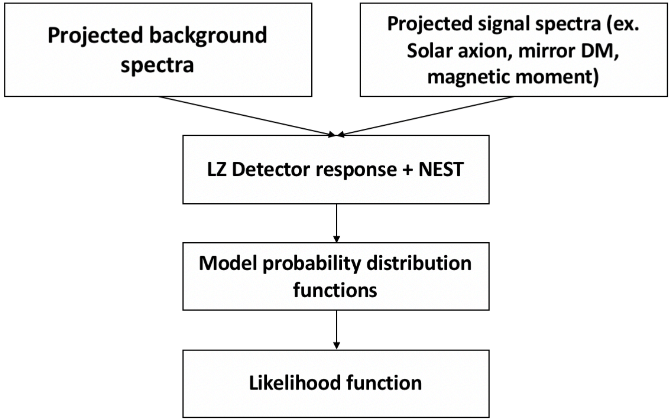
Constraint term: $\prod_{p=1}^{N_p} f_p(\boldsymbol{g_p}|\nu_p)$

- Observables: $\boldsymbol{x} = \{S1, S2\}$
- Parameter of interest: $\sigma_{\mathrm{WIMP}-N}$
- Nuisance parameters:

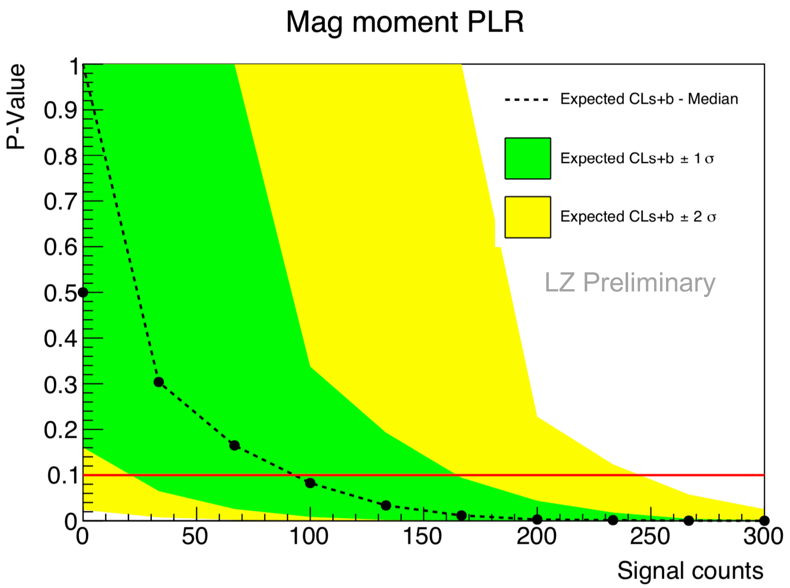
$$\boldsymbol{\nu} = \{\mu_b\}_{b=1}^{b=N_b}$$

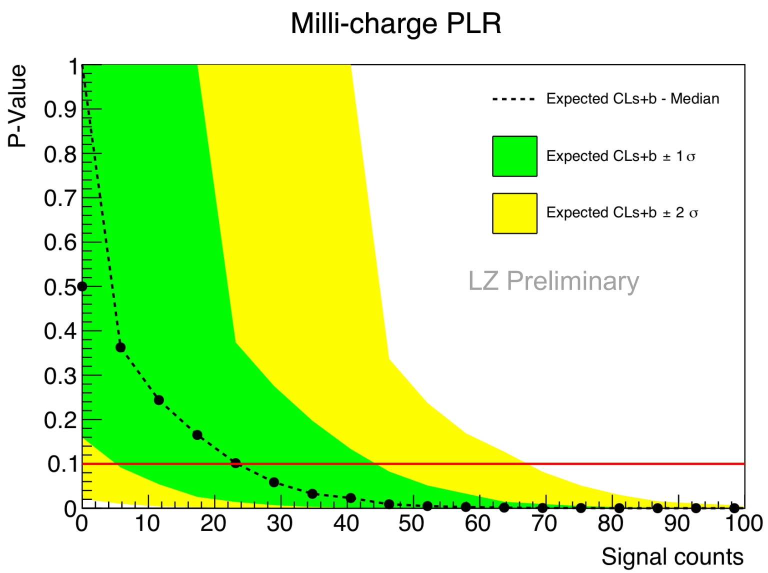
- Global observables:

$$\mathbf{g} = \{a_b\}_{b=1}^{b=N_b}$$



PLR Results





Neutrino magnetic moment:
97 signal counts

Effective milli-charge:
22 signal counts

PLR results (cont.)

- How does this translate to projected LZ sensitivities?
  - Neutrino magnetic moment: 93^{+95}_{-68} signal counts
    - This translates to $4.9^{+2.0}_{-2.4} \times 10^{-12} \mu_B$
    - (~ 5x improvement over Borexino [3])
  - Effective milli-charge: 22^{+23}_{-17} signal counts
    - This translates to $1.13^{+0.42}_{-0.60} \times 10^{-13}\ e_0$
    - (~10x improvement over GEMMA [6])

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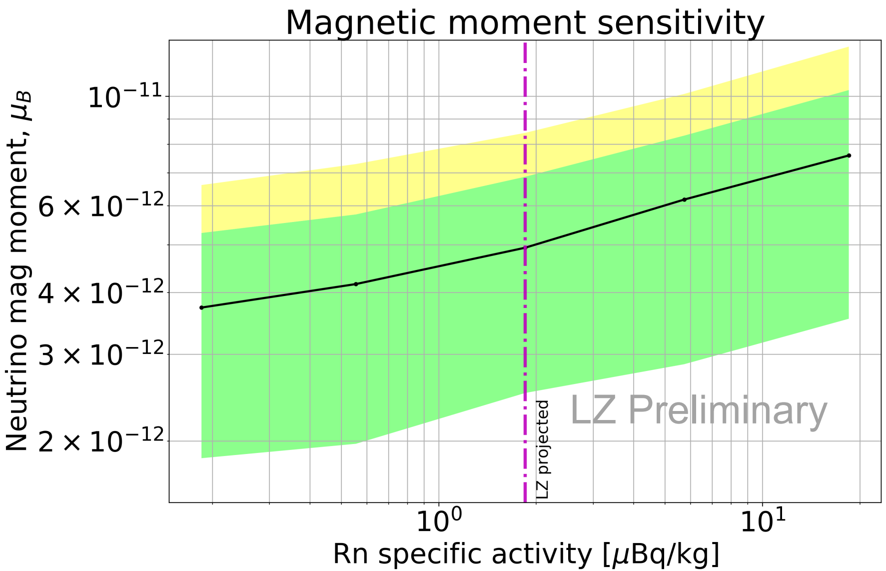
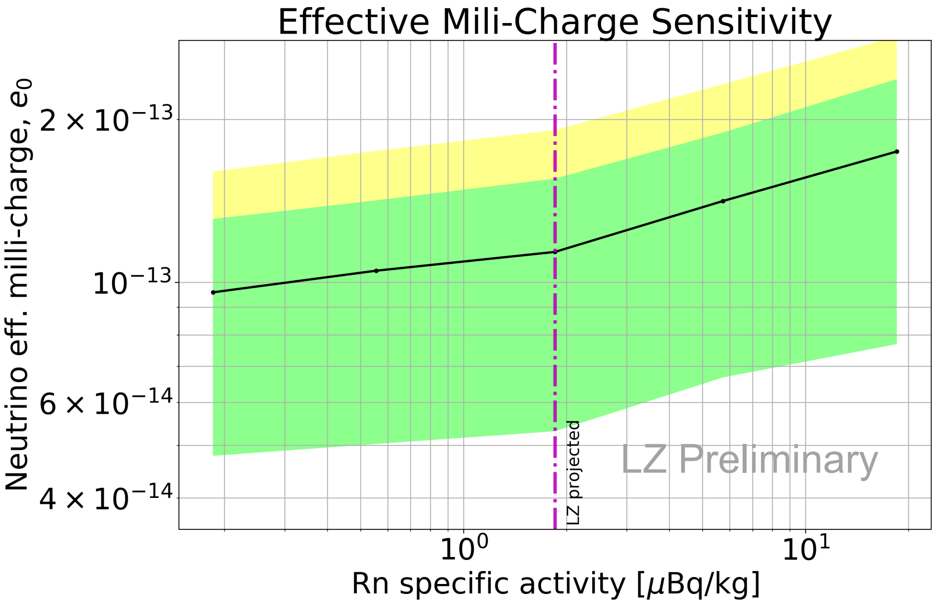
Background Sensitivity studies





- Some uncertainty in what 222Rn concentration we will see
- We vary 222Rn activity to quantify the (small) effect on sensitivity

Conclusion

- LZ expects to have sensitivities (compared to current limits):
  - Magnetic moment: $4.9^{+2.0}_{-2.4} \times 10^{-12} \mu_B$ (~ 5x lower limit than Borexino [3])
  - Milli-charge: $1.13^{+0.42}_{-0.60} \times 10^{-13}\ e_0$ (~10x lower limit than GEMMA [6])
- LZ looking forward to starting operations soon!

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Extra: References

1. "Discovery potential of multi-ton xenon detectors in neutrino electromagnetic properties", https://arxiv.org/abs/1903.06085
2. "Exploring nu signals in dark matter detectors", https://arxiv.org/abs/1202.6073
3. "Limiting neutrino magnetic moments with Borexino Phase-II solar neutrino data", https://arxiv.org/abs/1707.09355
4. "Model Independent Bounds on Magnetic Moments of Majorana Neutrinos", https://arxiv.org/abs/hep-ph/0606248
5. "Neutrino Magnetic Moment", https://arxiv.org/abs/hep-ph/0601113
6. "New bounds on neutrino electric millicharge from GEMMA experiment on neutrino magnetic moment", https://arxiv.org/abs/1411.2279

Extra: Equations

$$\mu_\nu = \frac{3m_e G_F}{4\pi^2\sqrt{2}} m_\nu \mu_B \approx 3.2 \times 10^{-19} \left(\frac{m_\nu}{1eV}\right) \mu_B,$$

$$\mu_\nu^q = \frac{q_\nu}{2m_\nu}$$