Measurement of the neutrino magnetic moment at the NOvA experiment

Technical note

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Abstract

This is the abstract

Contents

1 Introduction

(TO DO: *Describe the main motivations for the analysis. Briefly mention that there was a previous study by Biao, what were the results there and what limitations (or maybe talk about this in the Experimental overview?)*)

2 Experimental overview

(TO DO: *Create a story for the experimental overview. Point out what is the hole in the current knowledge that NOvA can fill up*)

2.1 Direct muon (anti)neutrino magnetic moment measurements

2.1.1 NOvA (Biao's thesis)

- ν_μ only
- Only comparing total event counts - 25 events observed and 23.78 expected
- Put an upper limit (90% C.L.) of $\mu_{\nu_\mu} < 1.58 \times 10^{-9} \mu_B$ with 10.9% systematic uncertainty on the standard model background
- Used 3.62×10^{20} POT of data (6.74×10^{23} POT for MC) with $T\theta^2 < 0.003\mathrm{GeV} \times \mathrm{Rad}^2$, $0.3 < T < 0.9\mathrm{GeV}$

2.1.2 MiniBooNE

- ν_μ only
- Observed excess of events (seems a bit too high)

2.1.3 E734 at the Alternating Gradient Synchrotron (AGS) of the Brookhaven National Laboratory

- **Both ν_μ and $\overline{\nu}_\mu$**
- $\mu_{\nu_\mu} < 8.5 \times 10^{-10} \mu_B$

2.1.4 LSND

2.2 Direct electron (anti)neutrino magnetic moment measurements

2.3 Solar neutrino magnetic moment measurements

2.3.1 XENONnT

First results published in arXiv:2207.11330[**?**] on 22 July 2022.

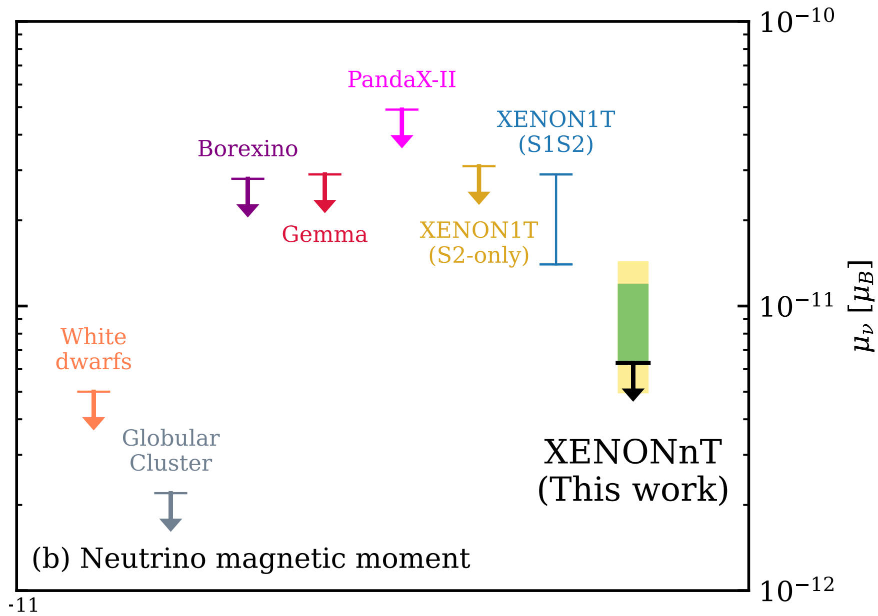

Figure 1: 90% C.L. upper limit on solar neutrinos with an enhanced magnetic moment.

- 5.9 tonne dual-phase liquid xenon TPC dark matter detector
- Region Of Interest is (1,140) keV
- Very low background (5 times lower than XENON1T)
- Tritium excluded as the potential background (also in XENON1T)
- No excess found - XENON1T excess excluded with 4σ
- The 90% C.L. upper limit on solar neutrinos with an "enhanced" magnetic moment is $\mu_{\nu_{sol}} < 6.3\times 10^{-12}\mu_B$, the strongest non-astronomical limit so far (see fig.**??**)

Amir Khan used[**?**] XENONnT's results and derived limits on electromagnetic properties for the three SM neutrino flavours (see fig.**??**). For ν_μ they

2.3.2 XENON1T

2.3.3 BOREXINO

Should be $\mu_{\nu_e} < 2.8\times 10^{-11}\mu_B$ [BorexinoLimit2017.pdf]

2.3.4 GEMMA

Should be $\mu_{\nu\ Eff} < 2.9\times 10^{-11}\mu_B$. [GemmaLimits2013.pdf]

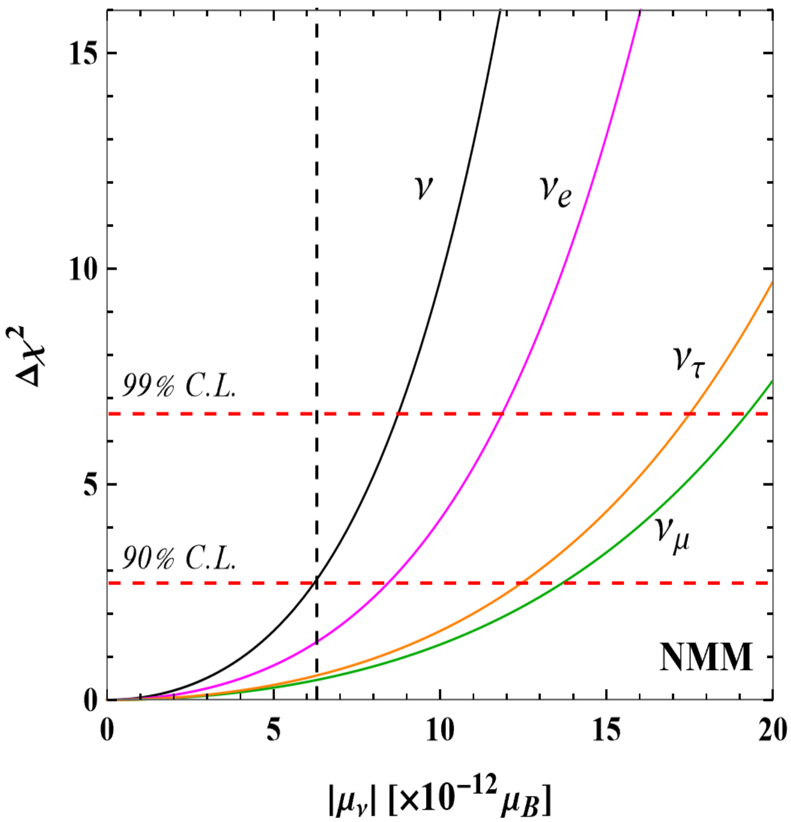

Figure 2: One-dimensional $\Delta\chi^2$ distribution with 90% and 99% C.L. boundaries of neutrino magnetic moments. The distribution in black corresponds to the effective flavor independent magnetic moment

2.4 Other

2.4.1 LHC Forward Physics Facilities

Preliminary sensitivity studies for future experiments (namely for FLArE and FASERν2)

- LHC's Forward Physics Facilities study high energy (TeV) neutrinos of all flavours from the ATLAS interaction point.
- Large opportunity to study tau neutrinos in more detail

2.5 Astrophysics

[NuMMBasicsAndAstro_2022.pdf] Neutrino electromagnetic processes that could be studied/observed in astrophysics

- Neutrino radiative decay
  - Decay of heavier neutrino flavour into a lighter neutrino and a photon
  - "The neutrino radiative decay has been constrained from the absence of decay photons in studies of the solar, supernova and reactor (anti)neutrino fluxes, as well as of the spectral distortions of the cosmic microwave background radiation."
  - Less stringent than the plasmon decay into a nu-antinu pairs
- Plasmon decay to neutrino-antineutrino pair
  - "For constraining neutrino electromagnetic properties, and obtaining upper bounds on neutrino magnetic moments in particular, the most interesting process is the plasmon decay into a neutrino-antineutrino pair [11]"
  - Plasmon decay frees the energy from the stars plasma in form of neutrinos that escape and therefore speeds up the star cooling
  - "observed properties of globular cluster stars provides new upper bounds on the effective neutrino magnetic moment $\mu_{ef} \leq (1.2-2.6)\times 10^{-12}\mu_B$ that is valid for both cases of Dirac and Majorana neutrinos."
- Transition of neutrino helicities $\nu_L \to \nu_R$ from active to sterile neutrinos
  - Supernovas would cool much faster - not observed for 1987A by Kamioka II and IMB, constraining Dirac neutrino mag. moment

3 Conclusion

(TO DO: *Report the limit with its uncertainty*)

(TO DO: *Very briefly discuss differences with current world limit and how the techniques differ*)

(TO DO: *Very briefly summarise expectations for future measurements.*)

References

[1] Carlo Giunti, Julieta Gruszko, Benjamin Jones, Lisa Kaufman, Diana Parno, and Andrea Pocar. Report of the Topical Group on Neutrino Properties for Snowmass 2021. 9 2022. arXiv: 2209.03340.

[2] Carlo Giunti and Alexander Studenikin. Neutrino electromagnetic interactions: A window to new physics. *Rev. Mod. Phys.*, 87:531–591, Jun 2015. URL: https://link.aps.org/doi/10.1103/RevModPhys.87.531, doi:10.1103/RevModPhys.87.531.

[3] Nicole F. Bell, Mikhail Gorchtein, Michael J. Ramsey-Musolf, Petr Vogel, and Peng Wang. Model independent bounds on magnetic moments of Majorana neutrinos. *Phys. Lett. B*, 642:377–383, 2006. arXiv:hep-ph/0606248, doi:10.1016/j.physletb.2006.09.055.

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