NF03 Subtopical Group Report 3

Baryon Number Violation Whitepaper

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Thanks to all the contributors

Searches for Baryon Number Violation in Neutrino Experiments: A White Paper

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Overview

- This paper will summarize the experimental and theoretical aspects of baryon number violation searches performed in neutrino detectors.
- ~40 pages so far
- Topic overlap with RF04: Baryon and Lepton Number Violating Processes
    - Our understanding is that their whitepaper does not focus on experimental prospects

Contents

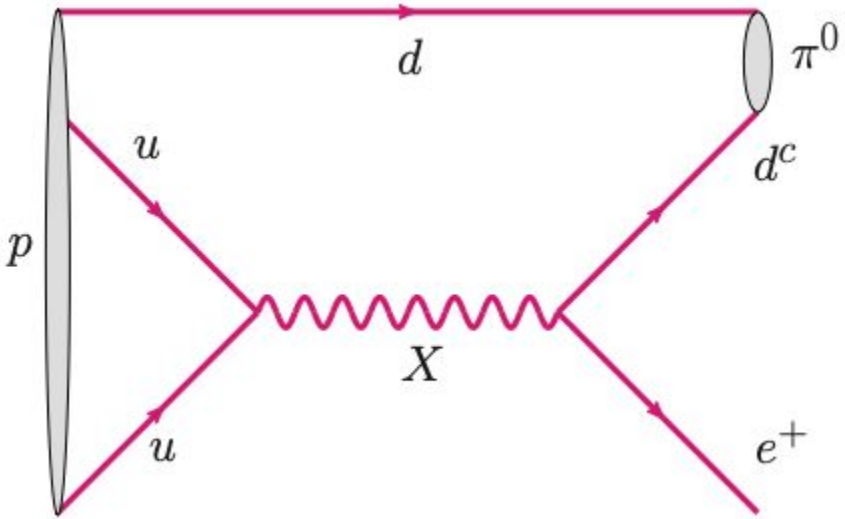
Theoretical Motivation

- Baryon number is an accidental symmetry of the SM.
- Expected to be violated in many well-motivated BSM scenarios with quark-lepton symmetry, such as Pati-Salam, SU(5) and SO(10) GUTs.
- GUT scale is too high to be directly probed in the lab.
- But there is a smoking gun signal: **proton decay**.

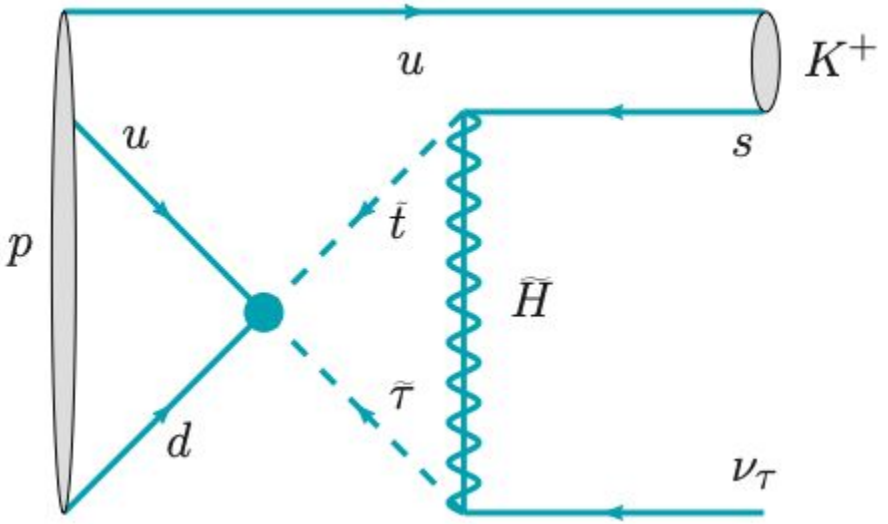
- Historical context: Kamioka Nucleon Decay Experiment (Kamiokande).
- Kamiokande-II (SN1987A, solar neutrino deficit)
- Super-Kamiokande (neutrino oscillation)
- The most stringent bounds on proton decay also come from Super-K.

- Goal of the whitepaper: **Illustrate the importance of experiments *simultaneously* searching for BNV and studying neutrino properties.**

Proton Decay in GUTs



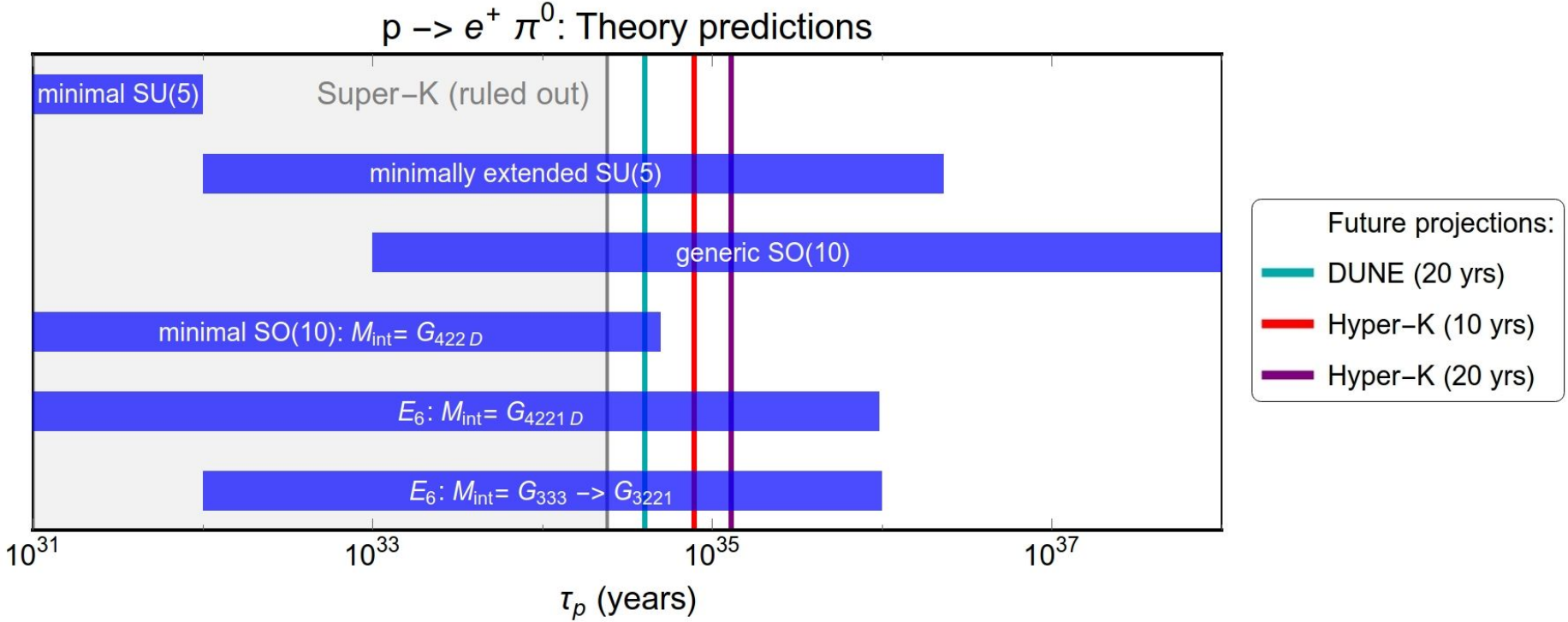
Non-SUSY: dimension-6 operator



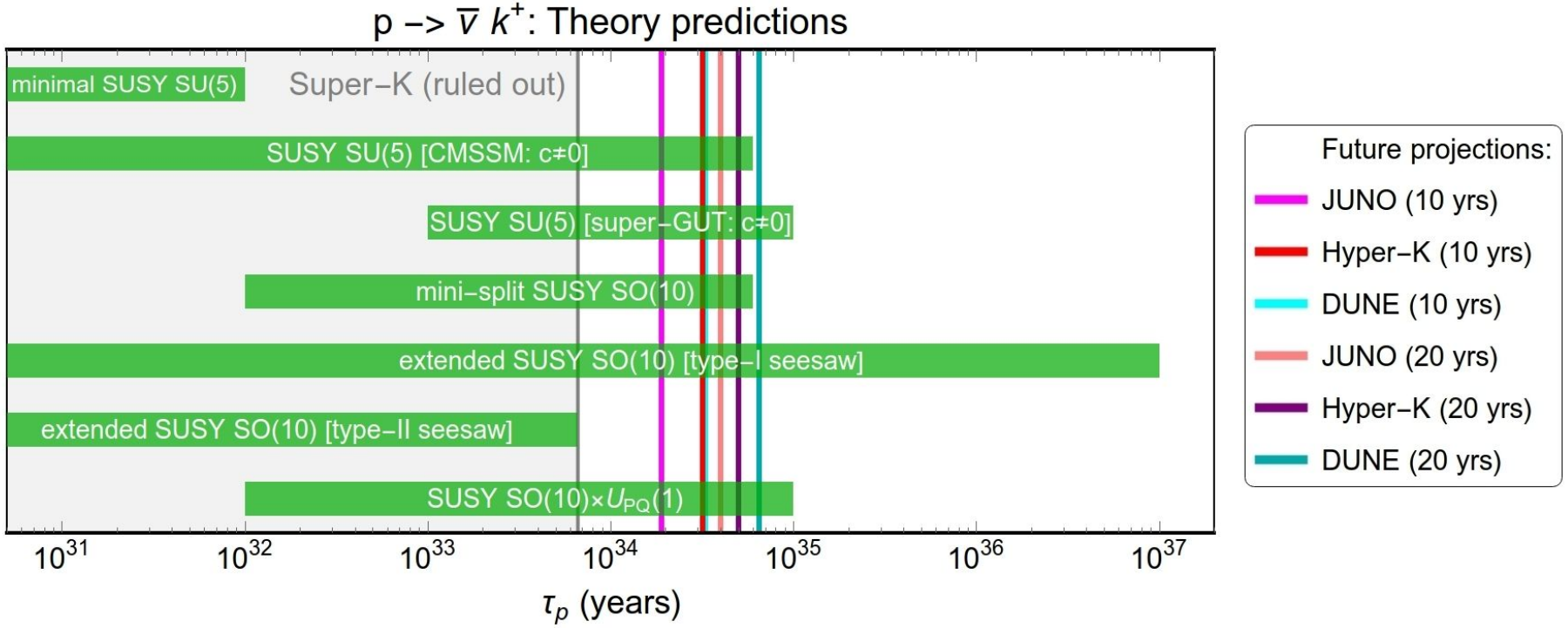
SUSY: dimension-5 operator

Georgi, Glashow ‘74; Sakai, Yanagida ‘82; Weinberg ‘82; Babu, Mohapatra ‘93; Bajc, Senjanovic ‘06; Dev, Mohapatra ‘10; Dev, Dutta, Mohapatra, Severson ‘12; Dutta, Mimura, Mohapatra ‘13; Babu, Khan ‘15; Perez, Murgui ‘16; Ellis et al ‘19; Dorsner, Saad ‘20; … Recent review by Hisano, 2202.01404

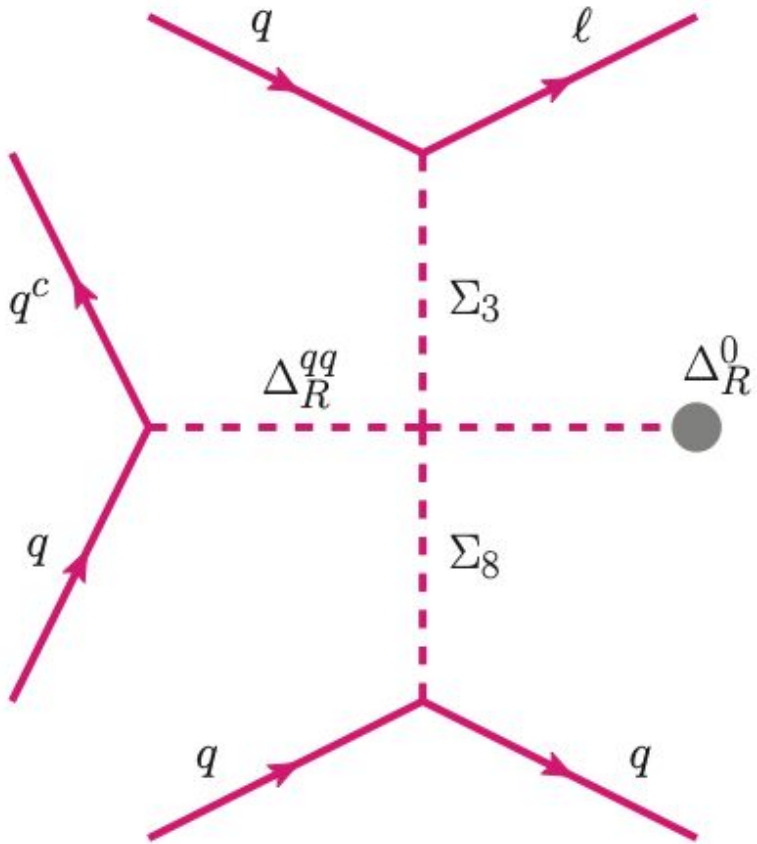
Non-SUSY GUTs

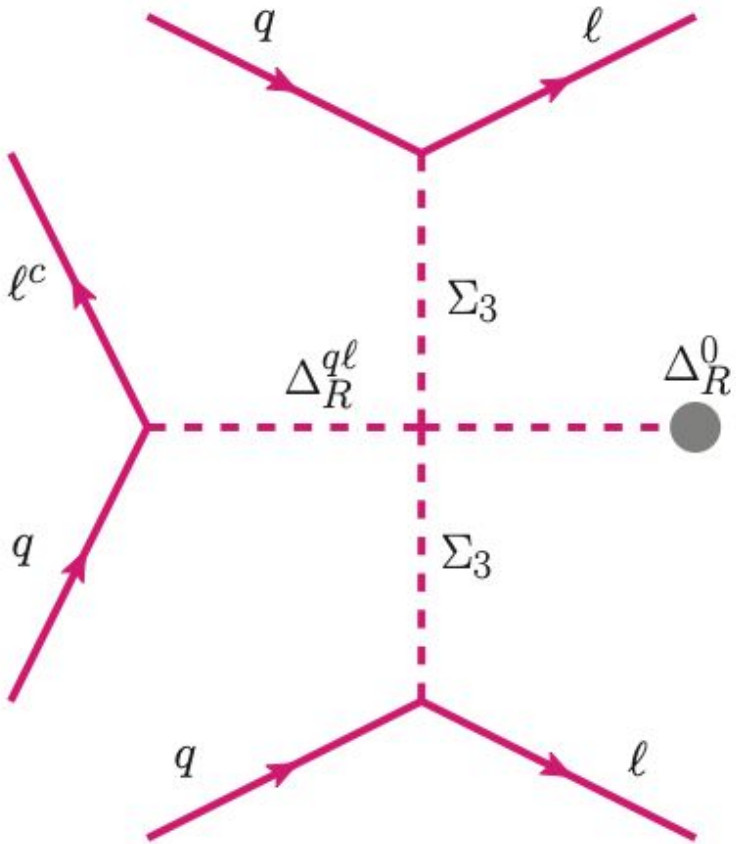


SUSY GUTs


p –> $\overline{\nu}$ k^+: Theory predictions
minimal SUSY SU(5)
Super−K (ruled out)
SUSY SU(5) [CMSSM: c≠0]
SUSY SU(5) [super−GUT: c≠0]
mini−split SUSY SO(10)
extended SUSY SO(10) [type−I seesaw]
extended SUSY SO(10) [type−II seesaw]
SUSY SO(10)×U_{PQ}(1)
10^{31}
10^{32}
10^{33}
10^{34}
10^{35}
10^{36}
10^{37}
τ_p (years)
Future projections:
JUNO (10 yrs)
Hyper−K (10 yrs)
DUNE (10 yrs)
JUNO (20 yrs)
Hyper−K (20 yrs)
DUNE (20 yrs)

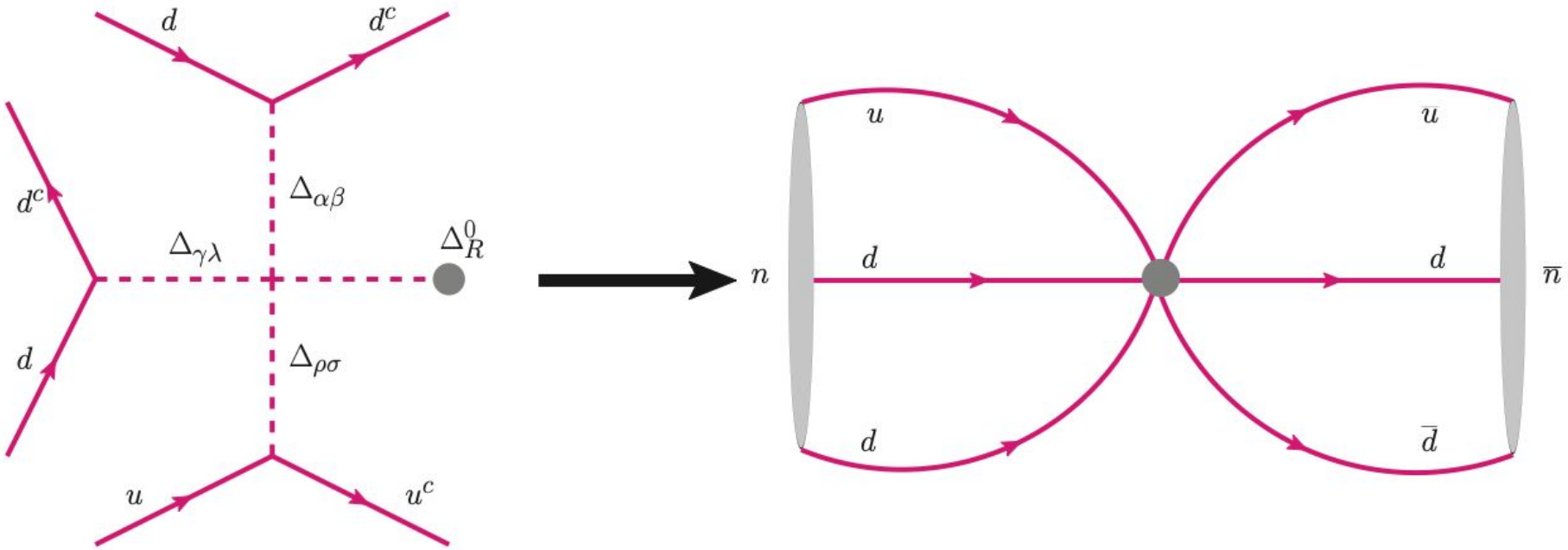
Other BNV Processes





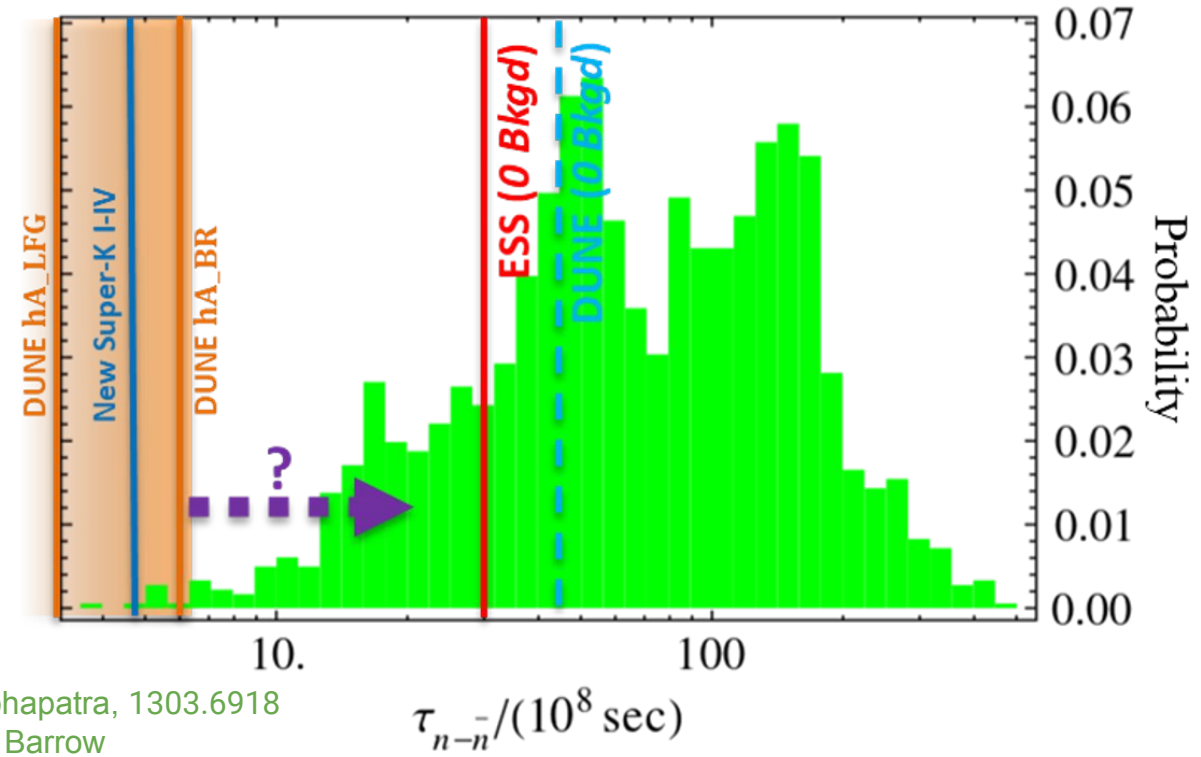
Mohapatra, Marshak (PRL ‘80); Pati, Salam, Sarkar (PLB ‘83)

Neutron-Antineutron Oscillation



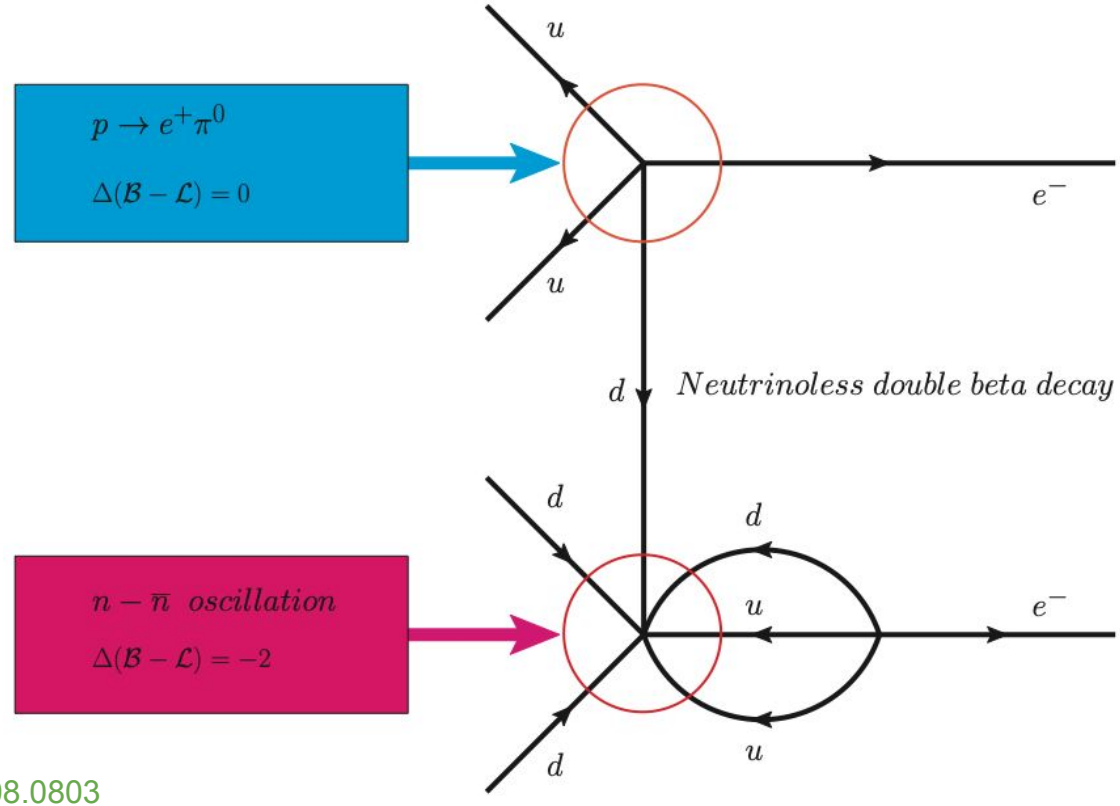
Mohapatra, Marshak (PRL ‘80)

Upper Limit on n-nbar



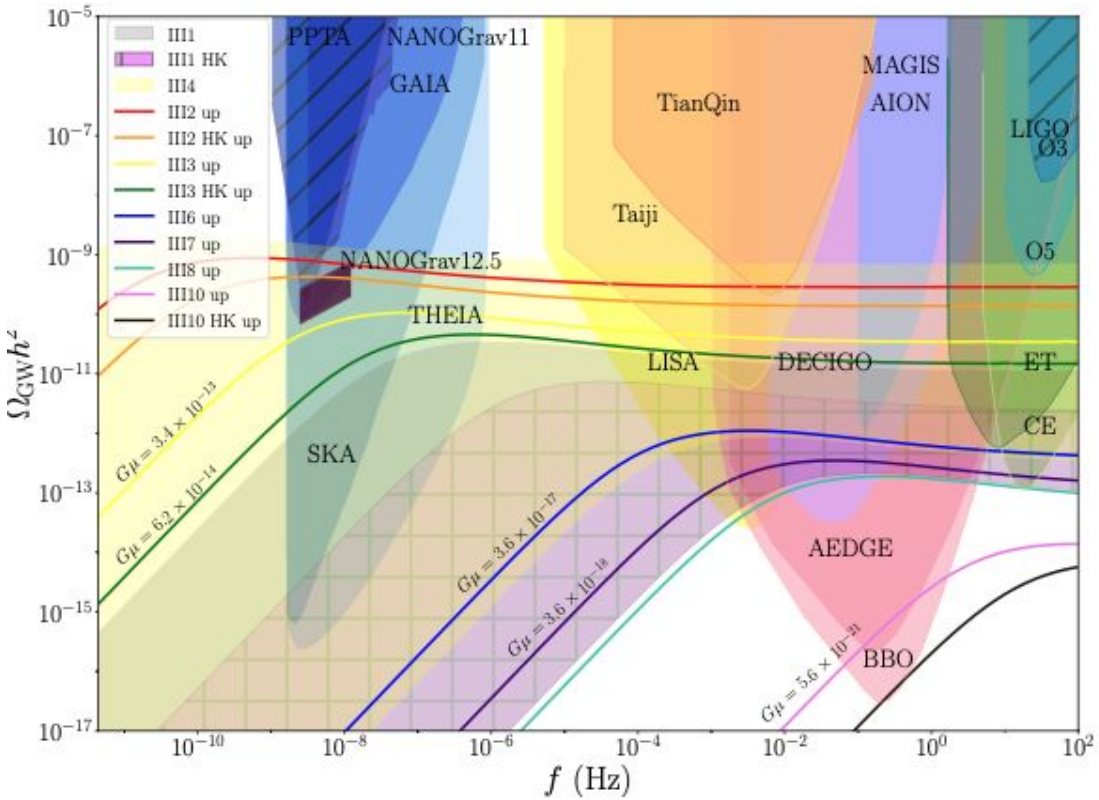
Babu, Dev, Fortes, Mohapatra, 1303.6918
Expt lines drawn by J. Barrow

Connection to Other BSM Physics: Majorana Neutrinos



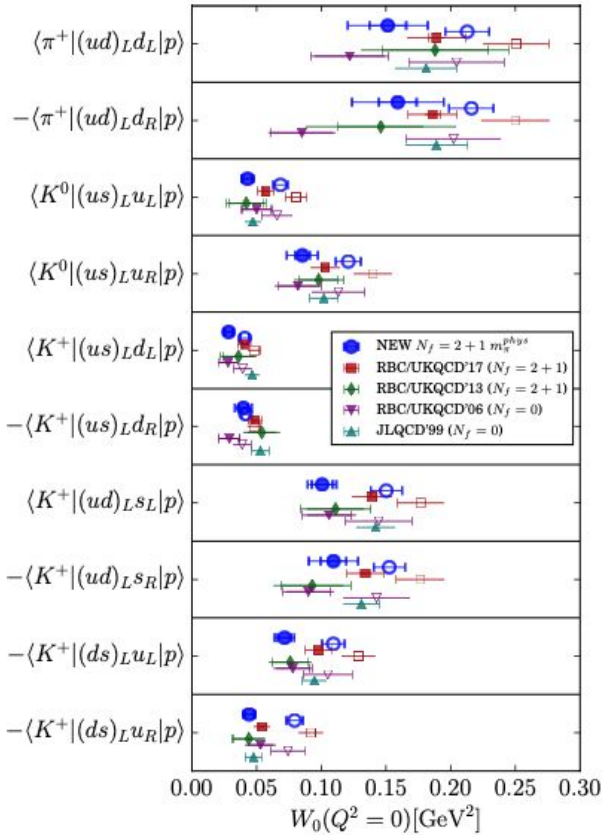
Babu, Mohapatra, 1408.0803

Connection to Gravitational Waves



King, Pascoli, Turner, Zhou, 2106.15634

Lattice Developments



Yoo *et al*, 2111.01608

For n-nbar matrix elements,

Operator	$\mathcal{M}_I^{\overline{\mathrm{MS}}}(2\ \mathrm{GeV})$,	$\mathcal{M}_I^{\overline{\mathrm{MS}}}(700\ \mathrm{TeV})$,	$\frac{\mathcal{M}_I^{\overline{\mathrm{MS}}}(2\ \mathrm{GeV})}{\text{MIT bag A}}$	$\frac{\mathcal{M}_I^{\overline{\mathrm{MS}}}(2\ \mathrm{GeV})}{\text{MIT bag B}}$
Q_1	$-46(13) \times 10^{-5}\ \mathrm{GeV}^6$	$-26(7) \times 10^{-5}\ \mathrm{GeV}^6$	4.2	5.2
Q_2	$95(17) \times 10^{-5}\ \mathrm{GeV}^6$	$144(26) \times 10^{-5}\ \mathrm{GeV}^6$	7.5	8.7
Q_3	$-50(12) \times 10^{-5}\ \mathrm{GeV}^6$	$-47(11) \times 10^{-5}\ \mathrm{GeV}^6$	5.1	6.1
Q_5	$-1.06(48) \times 10^{-5}\ \mathrm{GeV}^6$	$-0.23(10) \times 10^{-5}\ \mathrm{GeV}^6$	-0.84	1.6

Rinaldi *et al*, 1901.07519

Theory Summary

- Observation of BNV will be a clear signal of BSM physics.
- Synopsis of the expected nucleon lifetimes in a wide class of GUT models.
- Comparison with experimental projections.
- Importance of other BNV processes like n-nbar oscillation.
- Connection to other BSM physics: neutrino mass, baryogenesis, dark matter, gravitational waves, flavor physics.
- Lattice developments in the calculation of the hadronic form factors.
- To-do list:
  - Include lattice update for n-nbar
  - Comment on other nucleon decay and di-nucleon decay modes
  - Anything else missing?

Current and Future Experiments

Currently running experiments:

- Super-K: A bit on history, brief summary of published limits nucleon decay limits as well as neutron-antineutron transformation limit
- NOvA: Summary of NOvA analysis for neutron-antineutron transformation search

Planned and proposed detectors:

- Hyper-K: contribution expected soon
- DUNE: Brief summary of published sensitivities for nucleon decay ($p \to \bar{\nu} K$ and $n \to e^- K^+$) and neutron-antineutron transformations
- JUNO: Brief summary of $p \to \bar{\nu} K$ sensitivity analysis
- THEIA: Comparisons of sensitivities for Theia, Hyper-K, JUNO, DUNE, DUNE+Theia ($p \to \bar{\nu} K$ and $p \to e^+ \pi^0$)

*Sections are in no particular order.

Other Experimental Considerations (both DUNE-adjacent)

Effect of Different Nuclear Model Configurations on Sensitivity to Intranuclear Neutron-Antineutron Transformations

- Highlights the impact of nuclear model choices on calculated sensitivities
- Specific examples for DUNE, but generally relevant

LArTPC

- Considering the impact of the detection of nuclear de-excitation gammas and precise timing from photon detectors on nucleon decay sensitivities in LArTPCs

Experimental Summary

Anything missing? Ideas on what to emphasize? What is important to communicate to people outside the neutrino community on this topic?