Baryon number violation from confining New Physics

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Abstract. The detection of neutron-antineutron oscillation will be a discovery of fundamental importance in particle physics and cosmology. Models predicting them, usually, assume weak couplings at the scale of the experiment, although Nature has been quite evasive regarding the issue. Acknowledging this, we discuss a new non-perturbative mechanism, generated by confining New Physics in a linear moose, resulting in low-energy baryon number violating effects within the reach of current terrestrial and Neutron Star measurements.

1. Introduction
Nature has eluded all our direct searches for New Physics (NP) so far, but it has bestowed us with a few indirect hints. Most prominent among this is the observed baryon to photon ratio \([1]\) implying a baryon-anti-baryon asymmetry, for which, a crucial ingredient is the violation of baryon number. With the proton decay operator suppressed to very high scales, the discovery of neutron-antineutron \((n - \bar{n})\) oscillation is a clear evidence of New Physics that violate baryon number by two units. This process, in general, is studied \([2]\) through a dimension-9 quark level effective field theory operator \((udd)(udd)\), suppressed by the scale \(M^5\) and is constrained to \(\mathcal{O}(500\text{TeV})\). Though new physics models that lead to this operator are very interesting phenomenologically \([3]\), they are assumed to be non-confining and remain perturbative at energies where the \(n - \bar{n}\) oscillation is measured.

Due to the lack of our understanding regarding the nature of New Physics, it is important to acknowledge confining effects that can influence the low-energy measurements. Such QCD-like theories have been studied \([4]\) in moose notation, in the context of chiral symmetry breaking, compositeness, \('t\) Hooft anomaly matching, etc, and were shown to be very rich, despite the apparent simplicity of the approach. Though complex models can be formulated to study the baryon number violating effects, an uncluttered presentation of the mechanism is possible with a minimal design of the linear moose, where \(U(1)\) global symmetries are linked together by confining non-abelian gauge groups as shown in Fig.1(a). This model at low-energies will result in a lattice with each of the sites supporting a global charge symmetry. One of them is identified with the Standard Model (SM) baryon symmetry \(U(1)_B\) and, for convenience, the rest of the global charges are named mirror baryon \(U(1)_{\bar{B}}\) symmetries \([5]\). The lattice can also have a five-dimensional interpretation \([6]\) with mirror baryons forming higher resonances in the bulk and the SM baryon localised on a brane.

Though this looks like a simple linear moose, the global chiral symmetry group of SM is assumed to be spontaneously broken via QCD condensation at the \(U(1)_B\) lattice site. Similarly, each of the \(U(1)_{\bar{B}}\) lattice site can inherit rich dynamics from their own QCD condensations. Since
In this condensed linear moose model, we describe the mirror and SM matter fields by two
sets of Weyl spinors \((n'_i, n'^+_i)\) and \((n, n')\) respectively located at \(N+2\) sites of the lattice
[7] as shown in Fig. 1(b). Low-energy phenomenology of this lattice is governed by the N+1
\(\Sigma_i\) condensates and \(\Sigma\). The condensate \(\Sigma_i\) is charged \((B, -\bar{B})\) under \([U(1)_B \times U(1)_B]\)
subgroup while \(\Sigma\) is charged \((B, -\bar{B})\) under \([U(1)_B \times U(1)_B]\).

The free neutron Lagrangian density appended with the potential, \(\mathcal{V}_n\), that generates
interactions in the lattice can be written as,

\[
\mathcal{L} = i \bar{n} \gamma^\mu \partial_\mu n - \frac{m_n}{2} [\bar{n}n + \bar{n}^c n^c] + \sum_{i=1}^{N} \left( \bar{n}^c_{(i)} \Sigma_i n'_{i} - m \bar{n}^c_{(i)} n'_{(i)} \right) - y \bar{n} \Sigma n'_{(0)} .
\]

Including an explicit breaking of mirror baryon number localised at the \(N^{th}\) node of the moose
potential and on stabilising $\langle \Sigma \rangle = v$ and $\langle \Sigma_i \rangle = M$, the Lagrangian density of SM neutrons, in the physical basis assuming $m_M \gg y_{\text{eff}}v$, becomes,

$$\mathcal{L} = i\bar{n}\gamma^\mu \partial_\mu n - \frac{m_n}{2} \left[ \bar{n} n + \bar{\nu} \nu^c \right] - \frac{(y_{\text{eff}}v)^2}{m_M} \bar{\nu} n + \mathcal{L}_{\text{int}} + \text{h.c.}. \quad (2)$$

We can see that the strength of neutron-antineutron oscillation as determined in the model becomes,

$$\frac{(y_{\text{eff}}v)^2}{m_M} = y^2 v^2 \left( \frac{m}{M} \right)^2 \frac{1}{m_M}. \quad (3)$$

With Yukawa couplings of $\mathcal{O}(1)$, $\frac{m}{M} \sim 0.1$, and $m_M \sim \mathcal{O}(1 \text{ GeV})$, we get $\epsilon \sim 10^{-34} \text{GeV}$ for $\sim \mathcal{O}(10)$ gears. This result translates to neutron-antineutron oscillation time period of $10^8 s$, which is within the reach of the current and future experiments [8].

### 3. Experimental Constraints

Now, for the lightest mode of the mirror neutron ($n^0$) with $(m_n - m_{n^0}) > \mathcal{O}(100 \text{MeV})$, $B - \bar{B}$ preserving transition of SM neutron to $n^0$ can occur. The $n - n^0$ transition is searched for at experiments looking for the mass difference between the isotopes $(A,Z)$ and $(A - 1,Z)$ but are mostly forbidden due to the binding energy [9], unless $m_n - m_{n^0} < 10^{-12} \text{eV}$ [10]. Though $n \rightarrow n^0 + X$, with $(m_n - m_{n^0}) \sim \mathcal{O}(\text{MeV})$, is kinematically forbidden in a stable nuclei, the availability of higher energies facilitate these transitions in a Neutron Star (NS).

Studying the spin period [11] of a NS, lower limit on the mixing parameter can be computed as $y_{\text{eff}}v \sim 10^{-13} \text{eV}$. Recently, much stronger constraint, which translates to $y_{\text{eff}}v < 10^{-17} \text{eV}$, was reported in [12], by studying the luminosity measurement of cold NS. The derivation assumes elastic SM neutron Nucleon interaction $(\mathcal{N} n \rightarrow \mathcal{N} (n \rightarrow n^0))$, where the SM neutron is converted to $n^0$ in the final leg.

At NS, the luminosity measurement indicating the temperature coming from the heat release due to neutron disappearance in the core, constrains $C_{nN} \nu < 10^{-26} \text{GeV}$ [12]. Which is an $\mathcal{O}(10)$ stronger than the Wilson Coefficient computed in the linear moose model. On the other hand, if the future experiments improve the sensitivity further to constraint the coefficient of oscillation to $C_{nN} \nu < 10^{-28} \text{GeV}$ [12], a detectable $n - \bar{n}$ oscillation signal will constrain the mirror neutron mass.

### 4. Conclusion

Here, we discuss a new mechanism for baryon number violation, generated from a simple linear moose with confining New Physics and baryonic symmetries. At short distances this symmetry suppresses the mirror fermion interaction with SM, thus evading the collider constraints. Precision low-energy experiments, on the other hand, prove to be excellent at probing the confinement effects of the New Physics. The spontaneous breaking of the mirror symmetry via condensation leads to $B - \bar{B}$ conserving interactions. Making baryon number violation measurements such as neutron-antineutron oscillation and Neutron Star luminosity measurements rather sensitive to the effect.

Though at Neutron Stars the effects of the linear moose can directly visible through $n + X_1 \rightarrow n^0 + X_2$ transitions, an explicit mirror symmetry breaking term is required in the mirror sector for $\Delta B = 2$ transitions. Such terms are possible for real fermion representations of the internal chiral group. For heavier mirrors, neutron production by mirror neutron annihilations can lead to a possible low-scale Baryogenesis. This can be very interesting given the scenario accommodates phase transitions in the dark sector.

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