Searches for Lepton and Baryon Number Voilation

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Introduction

The conservation of leptonic L and baryonic B quantum numbers does not emerge from any particular symmetry of the standard model. In fact, the standard model has an anomalous leptonic of baryonic currents. Indicating a theoretical need to suppose that only $L - B$ is conserved and anomaly-free.
Moreover, the creation of matter, by the baryogenesis requires B violation. As this is the -only known- way to explain why there was matter more than anti-matter i the early universe. All new physics (NP) beyond the standard model requires a form of B or L violation. In this project, we explore the current status os experimental searches for such processes

Objectives

- Study the conservation of Leptonic and Baryonic numbers in the Standard Model and their limitations
- Identify the main phenomena for Leptonic and Baryonic numbers violation beyond the standard model and
- Summarize the current limits on the conservation or L and B numbers based on the modern experimental data.

Overview of the Standard Model

Our current understanding of particle physics can be gathered in the Standard Model which contains three main categories

- Fermions : matter particles
- Gauge bosons : force mediators (photon, gluons, W's and Z)
- The Higgs Boson

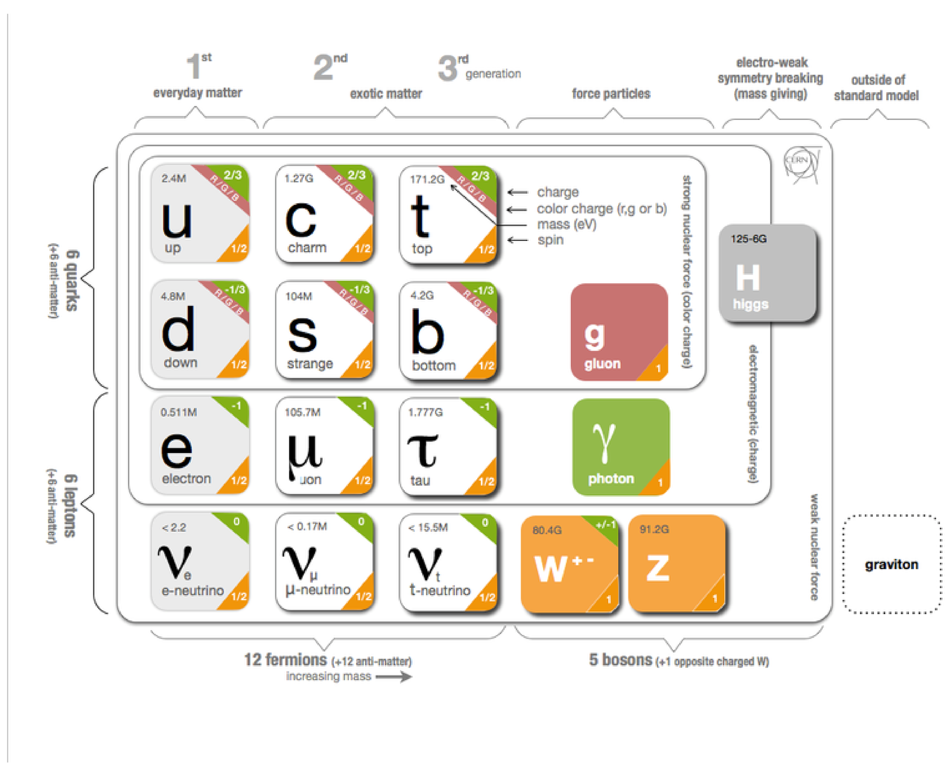

FIGURE 1: *The Standard Model*

There are two types of elementary matter particles, characterized by 2 quantum numbers : Quarks, having a Baryonic number $B = 1/3$ and Leptons having leptonic family number and a general leptonic number. The anti-particles have opposite sign quantum numbers.
Quarks cannot exist free in nature due to the strong interaction. Hence they bind in two ways to from hadrons Mesons and Baryons

Baryonic and Leptonic numbers

In the standard model, B , L and L_f are conserved. But not from a symmetry law. The true symmetry of the SM gives conservation of $B - L$ .Due to the existence of anomalies in leptonic and baryonic weak currents

$$\partial_\mu j^\mu_L = N_L \frac{g^2}{16\pi^2} F^{\mu\nu}_i F^i_{\mu\nu} \neq 0 \tag{1}$$

Violation of B , L and L_f conservation is an essential phenomena for the new physics (NP). This violation – when observed – will indicate a new symmetry between quarks and leptons. B- number violation is needed to explain baryogenesis

Searches for L_f Violation

Lepton flavor changing currents violating Lf have to be neutral current. Which is suppressed in the SM by leptonic version of the GIM-mechanism. Neutrino oscillations observed at the super Kamio-Kande experiment gives a slight hint for L_f violation

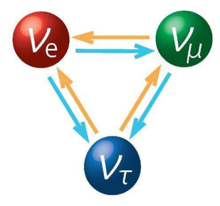

FIGURE 2: *Neutrino flavor oscillation*

It was confirmed that neutrinos oscillate between flavors, indicating that they have a mass. However, their mass is very low $m_\nu < 0.001$. eV In order to confirm the Violation of L_f , observation of charged lepton flavor change via the process of muon decay, the dynamics of this Violation is governed by the neutrino mixing angle

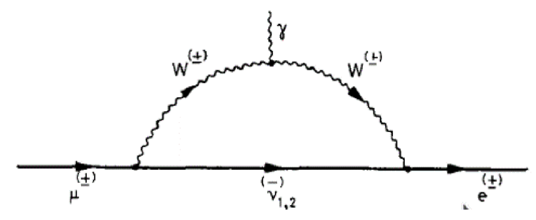

FIGURE 3: *Diagram for the radiative process $\mu \to e\gamma$ Which have a Branching ratio compared to the process $\mu \to e\nu_\mu\bar{\mu}_e$ of $\mathcal{B} = \frac{\alpha}{\pi}\Delta m^2/m_W \sin^2 2\theta$*

The mixing angle is related to the ν masses in the relation

$$\sin 2\theta = \frac{2m_{\nu_e}}{\sqrt{(m_{\nu_\tau} - m_{\nu_\mu} - m_{\nu_e})^2 + 4m^2_{\nu_e}}} \tag{2}$$

Since neutrinos have mass, the previous process should occur, yet there is no recording observation of it, up to sensitivity up to $\mathcal{B} < 10^{-12}$.

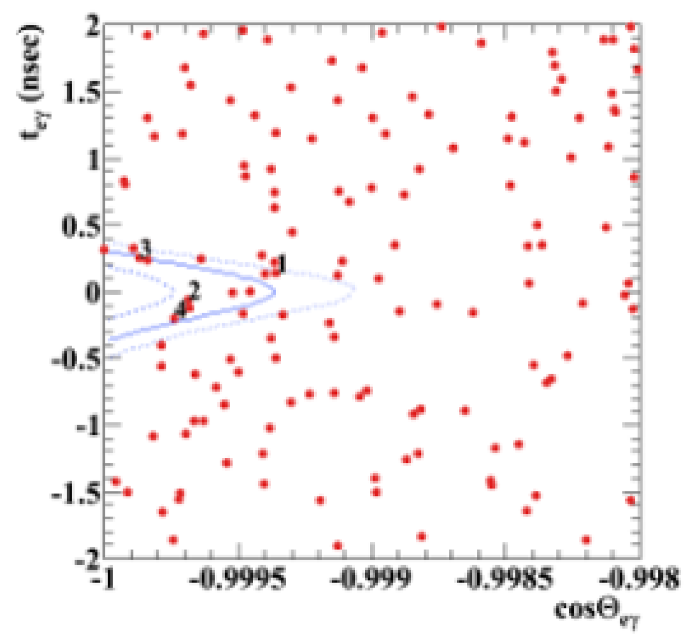

FIGURE 4: *Measurement of the neutrino mixing angle from observation of the decay of 10^{14} muon in the PSI-R-99-05 in Japan 2010-2012. Setting the current limit of the Branching ration of the muon decay $\mathcal{B} < 2.4 \times 10^{-12}$*

Searches for L Violation

Lepton number can be violated by different processes. The most significant one from experimental point of view is the neutrinoless double β decay i.e. $0\nu\beta\beta$.
Detection of $0\nu\beta\beta$. decay would imply that neutrinos are Majorana particles, that acquire their mass by oscillating between matter and anti matter.

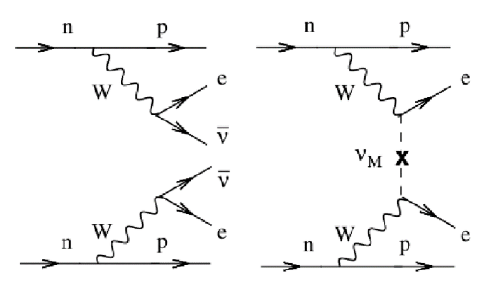

FIGURE 5: *Types of double beta decay*

The experimental limit on half-life for $0\nu\beta\beta$ decay for any element of interest is $> 2.1 \times 10^{15}$ years, as many experiments has shown (COURE, GERDA, EXO and others..)

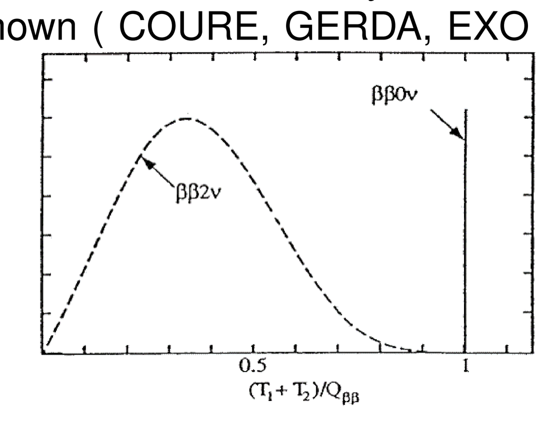

FIGURE 6: *: Expected spectrum of the electrons for $\beta\beta$ decay . In the case of ν-emission we observe a bell-shaped distribution of electron-energy In the 0ν production, we expect to observe a well-defined energy line*

LHCb experiment (CERN,2016) search for L-violating modes of the τ-decay. Set the following limit on the branching ratios (BR) (L-violating mode/ L-conserving mode)

$$\mathcal{B}(\tau \to \mu^-\mu^-\mu^+) < 8.0 \times 10^{-8}$$
$$\mathcal{B}(\tau \to \bar{p}\mu^-\mu^+) < 3.3 \times 10^{-7}$$
$$\mathcal{B}(\tau \to \mu^-\mu^- p) < 4.4 \times 10^{-7}$$

BNL-E781 Collaboration, (USA) has set a limit on the L violating decay BR for the kaon decay KL , $B < 4.7 \times 10^{-12}$.

Searches for B Violation

One of the most important events beyond the SM, many (almost all NP theories predict its decay)

Theory	Proton half life in years (τ_p)
Quantum gravity in D=4	$\sim 10^{45}$
Quantum gravity in $D > 4$	$\sim 10^{33} 10^{64} (\frac{M_{qq}}{\Lambda})^4$
Georgi-Glashow SU(5)	$\sim 10^{30} - 10^{31}$
Mimimal SUSY SU(5)	$\sim 10^{28} - 10^{32}$
SUSY (MSSM) SU(5)	$\sim 10^{34}$
SUSY (D=5) SU(5)	$\sim 10^{35}$
SO(10) GUT	$\lesssim 10^{35}$
Mimimal SUSY (MSSM) SO(10)	$\sim 10^{34}$
SUSY SO(10)	$\sim 10^{32} - 10^{35}$
Supergravity (SUGRA) SU(5)	$\sim 10^{32} - 10^{34}$
Superstring (Flipped SU(5))	$\sim 10^{35} - 10^{36}$

FIGURE 7: *Proton lifetime in several models*

Experimental searches for the proton decay had set a limit for the proton half-life of about $\tau_p > 10^{34}y$

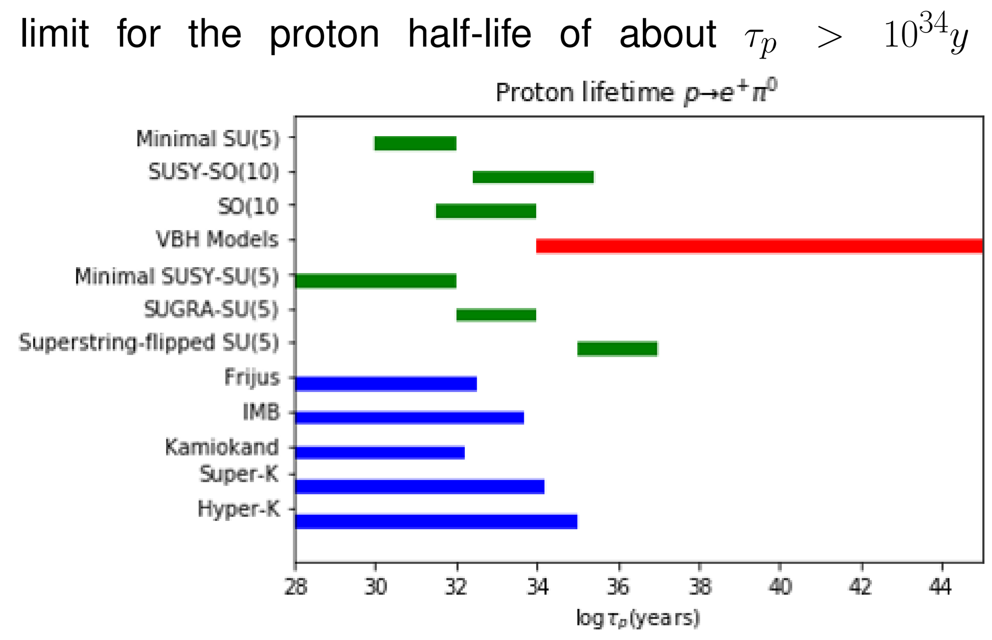

FIGURE 8: *Proton lifetime searches*

LHCb , 2017 searches for Ξ^0_b matter anti-matter oscillation, they have set a limit on frequency of oscillation $\omega < 0.08$ psec. Moreover, the LHCb has searches for B voilating decay modes of the Λ_b and Ξ^0_b and found

$$\mathcal{B}(\Lambda_b \to K^-\mu^+) < 3.6 \times 10^-9$$
$$\mathcal{B}(\Xi^0_b \to K^-\mu^+) < 1.8 \times 10^-8 \tag{3}$$

CMS collaboration (CERN, 2014) searched for a potential decay for the top quark that violates B.The Results set an upper limit of the BR of $\mathcal{B} < 0.0016$

Conclusion

- So far, the only potential evidence for B and L Violation is the neutrino osculations.
- At the run 1 of LHC, more experimental limits on the conservation of leptonic and baryonic numbers.
- The new data from the run 2 of the LHC and the new experiments could bring us closer to finding L and B violating events.

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