

Long Beam Neutrino Facility and Neutrino Mixing

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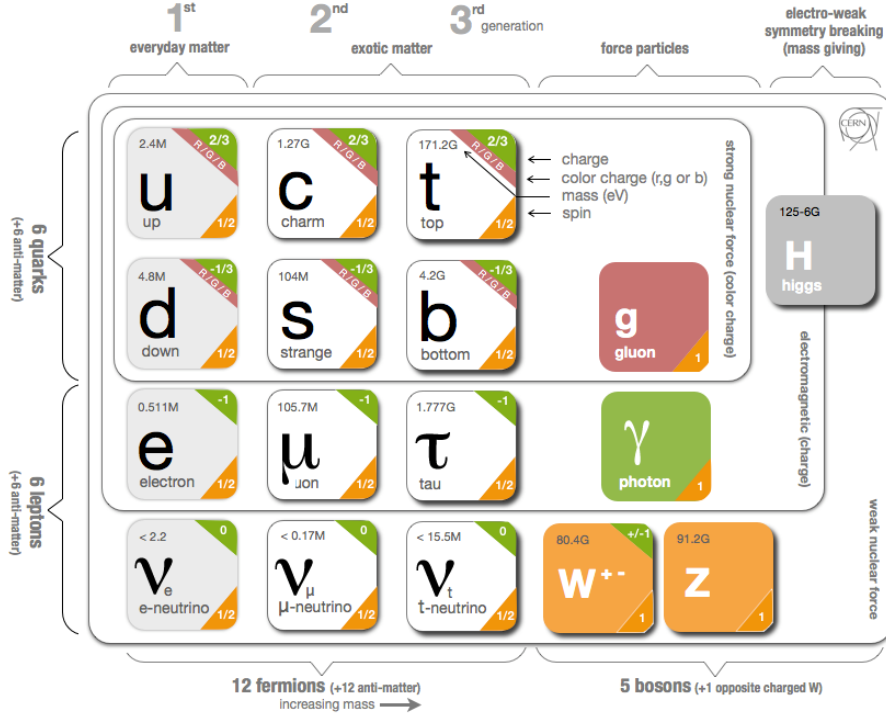
Abstract

Paper for the Comprehensive Exam.

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Figure 1: Fundamental particles and interactions



Three generations of fundamental particles and interaction mediators. Charged leptons and quarks are subjects to electromagnetic interactions (through photons). Quarks can also interact strongly (through gluons). All leptons and quarks can interact weakly (through W^\pm and Z^0 bosons). All the particles shown are discovered at the moment and no other fundamental particle is discovered. [3]

1 Introduction

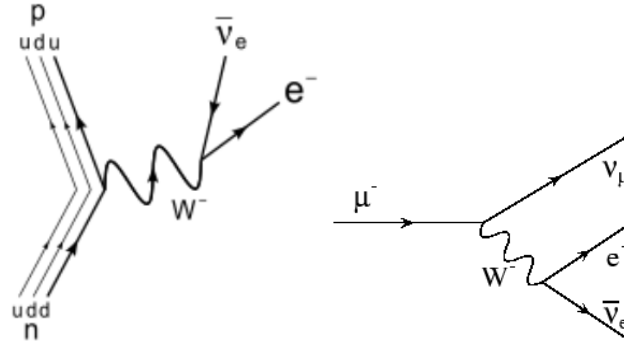
The Standard Model includes three charged leptons, three neutrinos and six quarks and their antiparticles which are splitted into three generations and can interact through gauge bosons (see 1). The neutrinos. neutrinos are fundamental particles of the Standard Model?? Figure with Standard Model particles and interations.

How many neutrinos pass through the cm^2 per second (flux), check PDG.

Two very common and well known interactions which includes neutrinos are neutron beta decay and muon decay. The Feynmann diagrams of these processes are shown at ??.

Mean lifetime of free neutron is 15 minutes and $> 99.9\%$ of those which decay will do it though the beta decay: $n \rightarrow p + e^- + \bar{\nu}_e$ [1]. At the level of fundamental particles, neutron consists of two d-quarks and one u-quark and in the beta decay one of the d-quarks transfers to u-quark though the weak interaction mediated by W^- boson. Thus, the proton, which consists of two u-quark and one d-quark, is being produced. When this happens, the electron and electron antineutrino are emitted to preserve the charge and the lepton Flavor number conserved. The examples of the neutron beta decay in nature include $^{49}_{19}K \rightarrow ^{40}_{20}Ca$, $^{64}_{29}Cu \rightarrow ^{64}_{30}Zn$, $^3_1H \rightarrow ^3_2He$ [2] (the positive beta decay, $p \rightarrow n + e^+ + \nu_e$, is not possible for free proton but it can happen when the proton is the part of the nuclei). As for the muon, it's mean lifetime is $2\mu s$ and 99% of muons which decay would do that to electron, muon neutrino and electron antineutrino as $\mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e$ though the the W boson. This process is also common in nature, in cosmic rays: muon are produced in the upper layers of the Earth atmosphere from the interaction of the particles coming from cosmic with the atmosphere substances though the reaction [WHICH

Figure 2: Feynmann diagrams of neutron and muon decays



Feynmann diagrams of left: neutron beta decay [5](d-quark of transfers to u-quark through the W-boson with emission of electron and antineutrino), right: muon decay [4](muon decays to electron, neutrino and antineutrino through W-boson).

REACTION ?] and then some number of muons decay while traveling through the atmosphere to the ground.

There are three flavors of neutrino, one for each generation: electron neutrino, muon neutrino, tau neutrino. And in the processes described above (neutron beta decay and muon decay) the lepton flavor numbers L_e , L_μ and L_τ are conserved. The table 1 shows the value of this number for all leptons and antileptons.

Table 1: Lepton Flavor Number

particles	L_e	L_μ	L_τ
e^-, ν_e	+1	0	0
$e^+, \bar{\nu}_e$	-1	0	0
μ^-, ν_μ	0	+1	0
$\mu^+, \bar{\nu}_\mu$	0	-1	0
τ^-, ν_τ	0	0	+1
$\tau^+, \bar{\nu}_\tau$	0	0	-1

2 Theory of Neutrino Oscillations

2.1 Two Neutrinos Case

Here the P() of nu mu -> nu e should be derived. Write formulas to start with but skip most of the algebra. Do not assume p1=p2

2.2 Mixing Matrix

Consider three neutrino case and put matrix and common notations here

3 Experimentantal Measurements and Open Questions

3.1 Experiment

read through PDG carefully

3.2 Long Baseline Experiments

read through PDG carefully

3.3 Open Questions

list from PDG

4 Long Baseline Neutrino Facility

4.1 What questions it's going to answer

4.2 How it's going to answer these questions and how it's better than other experiments

4.3 What questions it's not going to answer

References

[1] Particle Data Group

[2] Griffiths

[3] website: <http://www.isgtw.org/spotlight/go-particle-quest-first-cern-hackfest>

[4] website: <http://www.hep.ucl.ac.uk/jpc/all/ulthesis/node9.html>

[5] website: <http://en.wikipedia.org/wiki/Neutron>

[6] LBNF website: <http://lbnf.fnal.gov/>