Methods to Search for New Physics in proton-proton collisions at the LHC – Same Sign dimuon Final State for Lepton Number Violation Process

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Motivation
- The Lepton Number (L) is conserved at the perturbative level in the (beautiful but not completely) Standard Model.
- Neutrino oscillations have been observed, indicating the lepton flavor changes, for example, electron flavor (\(e_L\)) to muon flavor (\(\mu_L\)). But, the Lepton Number Violation (LNV) has not been observed.
- Some theoretical models predict LNV, e.g., Majorana neutrinos (N) may be their own antiparticles. Lepton Number (L) is not conserved

Standard Model (SM) of Particle Physics
- The Standard Model (SM) explains how the basic building blocks of matter interact. Governed by four fundamental forces and classifies all the subatomic particles known. Because of its success in explaining a wide variety of experimental results, the Standard Model (SM) is sometimes regarded as "a theory of almost everything".

Large Hadron Collider (LHC)
- The Large Hadron Collider (LHC) is a successon of machines with increasingly higher energies.
- Each machine injects the beam into the next one, which takes over to bring the beam to an even higher energy, and so on.
- In the LHC the last element of this chain each particle beam is accelerated up to the record energy of 6.5 TeV.

Lepton Number (L)
- All leptons have assigned a value of \(\pm 1\), anti-leptons -1 and non-leptonic particles 0.

Lepton Number Conservation
- The Conservation of Lepton Number means, that whenever a lepton of a certain generation is created or destroyed, the same generation must be created or destroyed.
- The Lepton Number (L) is conserved in the SM

Lepton Number Violation (LNV)
- Two processes of LNV have been focussed.
  1. \(\mu^- + \mu^- + \text{jets} + \text{noMET}, (\Delta L = +2)\)
  2. \(\mu^+ + \mu^- + \text{jets} + \text{noMET}, (\Delta L = -2)\)

The CMS Detector
- The Compact Muon Solenoid (CMS) detector is a large technologically advanced detector comprising many layers, each designed to perform a specific task. Together these layers allow CMS scientists to identify and precisely measure the energies and momenta of all particles produced in collisions at CERN’s Large Hadron Collider (LHC).

Experimental Tools
- Two same-sign dimuons are produced in all decay processes. In most cases, one muon is coming from W or Z decay processes and the other muon will decay from b or c quarks, tau lepton, top quark and finally from Unknown Sources (Fake muons), which would probably be from charged pions and kaons decay in-flight.

Data & Monte Carlo Samples
1. Data Sample
   - MET dataset is one for dark matter searches in CMS (TTU) and contains high pt muon events. We use the 2016 MET dataset at \(\sqrt{s} = 13\) TeV with CMS detector at LHC, which corresponds to 35.9 fb\(^{-1}\), and study the potential of Lepton Number Violation (LNV) searches in double muon events.

2. Monte Carlo Sample
   - (1) Z(\ell\ell) + jets (2) W(\ell\nu) + jets (3) Z(\ell\ell) + jets (Drell-Yan)
   - (4) T(Tt) (5) Single Top (6) Diboson (WW, WZ, and ZZ)
   - (7) QCD
   - (8) \(\gamma + \) jets

Event Selection
1. Basic Cuts
   1. Require number of muons \(> 1\)
   2. Require muon \(p_T > 20\) GeV (10 GeV) \& \(|\eta| < 2.4\)
   3. Require same sign two muons: \((\mu^+ + \mu^-)\) & \((\mu^- + \mu^+)\)
   4. Require the 4\# leading jet: \(p_T > 100\) GeV \& \(|\eta| < 2.5\)
   5. \(\Delta p_T (\ell, \text{MET}) > 0.5\) in order to reject the QCD events
   6. Recoil Energy cut: \(-2p_T (\text{hadron}) = p_T (\mu^-) + p_T (\mu^+) > 250\) GeV

2. Additional Cut
   - Muon mass cut: \(\text{Max}(p_T, m_T) > 200\) GeV

Analysis
- The cross-sections are measured for the signal region in data and Monte Carlo simulation with two different cuts (“basic cuts” and “additional cut”). Red points are Data, blue points are Monte Carlo prediction.

- The cross-sections (\(\sigma\)) (Data and Monte Carlo) of this process based on the events calculated as:

\[
\text{Cross-section (fb)} = \frac{\text{Number of events}}{\text{Number of fb}} = 35.9 \pm 0.1
\]

Conclusions
- We performed the analysis for the search for new Physics in proton-proton collisions at the LHC same sign dimuon final state for Lepton Number Violation (LNV) process.
- The data collected by the CMS experiment for proton-proton collision at 13 TeV with (2016 MET dataset) was used. (2.5 \(\times 10^7\) proton-proton interactions) "Surprise!"
- We studied the potential of CMS experiment to search Lepton Number Violation (LNV) process in dimuon \(-\) no MET channel (\(\mu^+ - \mu^-\) & \(\mu^- + \mu^+)\). We found the cross-sections of Data (3.9 fb for the “basic cuts” and 0.5 fb for the “additional cut”) are consistent with the estimated background from Monte Carlo. No excess signal is observed in those channels.