Research Statement

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Before starting my PhD studies, I had been interested in neutrinos about their oscillations and mass generation mechanism. Since there was an opportunity to work on searches for heavy Majorana neutrinos at the LHC, I joined the CMS group at the Seoul National University (SNU-CMS). I summarize my research achievements during my PhD period and future plan.

1 Origin of the Neutrino Mass

During my PhD studies, I have done three different physics analyses, all searching for heavy Majorana neutrinos at the LHC using the CMS detector. The primary purpose of the analyses is to investigate mass generation mechanism of neutrinos.

1.1 Searches for heavy Majorana neutrinos based on the type-I seesaw mechanism

Two of the analyses were on searches for direct production of heavy Majorana neutrinos at dilepton channel from $q\bar{q}$ annihilation process in proton-proton collisions. The dominant background from the Drell–Yan and top pair productions were significantly reduced by requiring same-sign dilepton signature utilized Majorana nature of heavy neutrinos. As a result, the leading background contains fake leptons produced from jets. My major contribution was to estimate the fake lepton background which requires full understanding of detector response and property of jets. To understand and reduce fake lepton background, I investigated which process gives dominant fake lepton contribution. I found out through MC/Data studies that $W^{\pm}$ + jets and top pair production processes are main sources. Former source is mainly pion and kaon induced fake leptons while semi-leptonic decays of B mesons are dominant mechanism for latter one. Based on these results, I introduced three different cuts, which resulted in significant reduction of fake lepton background contribution. First, the missing transverse momentum cut is firstly applied to reduce irreducible Standard Model (SM) backgrounds. And tight cut on impact parameter of leptons and vetoing b-tagged jets are introduced. Thanks to these cuts, the first analysis used 8 TeV data achieved the world best limit for heavy Majorana neutrino masses above 200 GeV. The result was published to the JHEP [1] and I presented it at ICHEP 2016. The second analysis used 13 TeV data also obtained the world best limit for heavy Majorana neutrino masses above 430 GeV. The result was also published to the JHEP [2] and highlighted in ICHEP 2018 and NuFact 2019 plenary talks.

1.2 Searches for heavy Majorana neutrinos based on the left-right symmetric model

The major topic of my thesis was search for pair production of heavy neutrinos based on the left-right symmetric extension of the SM (LRSM). In the signal, the extra neutral gauge boson (Z') is produced from $q\bar{q}$ annihilation process in proton-proton collisions at $\sqrt{s} = 13$ TeV. Then, the Z' decays into two heavy Majorana neutrinos (N), and each N decays into a lepton plus two jets. The signal has very different kinematic signatures depending on the ratio of Z' and N masses. When the mass of N is much lighter than that of Z', two heavy Majorana neutrinos are highly boosted and their decay products are clustered within small relative distances. It is an exotic signature which has not been explored by the CMS collaboration yet. I have developed an algorithm to search for Z' which considers all different event topologies at one time. This analysis is very complicated and challenging. I also developed analysis framework to measure all scale factors of physical objects as well as generating all signal MC samples as the main analyzer and contact person of this analysis. As a result, the sensitivity of this analysis reaches up to Z' mass of 4.2 TeV while the previous analysis performed by the ATLAS could reach up to 2.2 TeV. The result will be submitted to JHEP 2021.

2 Development of the Silicon Pixel Trigger at Level 1 Trigger system

Trigger system is the most important element of hadron collider experiments. At the LHC, proton beams collide every 25 ns and the size of an event is few MB. Therefore, data taking rate should be reduced to 1 kHz so the storage system can handle the data. The level 1 pixel trigger aims to achieve better purity and same efficiency on electrons even with an order of higher luminosity. I developed a level 1 pixel trigger algorithm which showed that the transverse energy threshold of electrons can be reduced to 20 GeV from 35 GeV by using pixel tracker hit information at the High Luminosity (HL) LHC phase which will start in 2027. It means that the CMS can take data with same trigger thresholds even with an order of higher luminosity compared to LHC Run1.

3 Gas Electron Multiplier (GEM) Chamber

The GEM chamber is a part of the muon detector upgrade at the CMS for the HL-LHC. Since GEM chambers have very high rate capability and fast timing response, they are ideal for the muon system at the endcap region under the HL-LHC. I participated in the QC (quality control) tests for GEM foils and GEM chambers for one year at CERN. The QC tests are the official procedures before installation of the GEM chambers. I achieved good experience in the QC tests which consist of gas leakage test, impedance check, gain measurement and the uniformity test of the chambers. Additionally, I performed an R&D project on GEM foils produced by MECARO company at South Korea. Using the small size of GEM foils (10 cm $\times$ 10 cm), I measured rate capability and discharge probabilities. Then, I assembled a full size of GEM chamber using MECARO foils and performed all QC tests which proved that all foils satisfied the spec required by the CMS experiment. As a result, Korea-CMS team made an MOU with CERN to provide the MECARO GEM foils for the CMS muon upgrade.

4 Generic Detectors

During my PhD period, I have been trying to be more familiar with hardwares used in the particle physics experiments. I volunteered to be a supervisor of spark chamber restoration club of undergraduate students. There were chances to learn electronic modules such as discriminators and logic units, and to set up cosmic muon trigger system. I taught students about how to optimize working voltage of PMTs depending on thresholds of discriminators, principle of protection resistor, and gas mixtures for gaseous detectors. Using experience from the spark chamber activity, I set up cosmic ray trigger system and multi-wire drift chamber for the cosmic ray test stand at the Seoul National University. I analyzed two weeks of cosmic muon data and achieved about 500 μm position resolution using 64 channels.

5 Future Research

I have been working on neutrino mass generation mechanism at hadron collider, and searching for TeV scale heavy Majorana neutrinos. The upper and the lower bound of the three SM neutrino mass sum provided by direct measurement (KATRIN experiment) and Δm^2_{13} are almost in same order, so there could be the first direct measurement of neutrino mass. If various lepton flavor violation experiments such as $\mu \to e\gamma$ and $\mu \to eee$ observe the signals, the ratio of two branching ratios will provide a good guideline on the generation mechanism of neutrino masses beyond the SM (BSM). To find the BSM signature, properties of neutrinos need to be very precisely studied: leptonic CP phase, mass ordering of neutrinos, and Dirac vs Majorana nature of neutrinos. The DUNE is expected to have bigger than 5 σ significance for mass ordering with 6 years of operation and for 75% of CP phase values with 15 years of operation. The short baseline neutrino (SBN) program of the Fermi Lab. is testing clue of sterile neutrinos from the LSND and the MiniBooNE using several LArTPC detectors. I am looking forward to contribute to development of these projects, and highly interested in data analysis which I can utilize my skills that I have learned during my PhD studies. I co-developed the analysis framework which is used in the SNU-CMS group [3]. This experience will be benefit for development of analysis tool for (proto)DUNE and SBND experiments. I find the Neutrino Division of the Fermi National Accelerator Laboratory is a leading place of neutrino physics. I would like to develop my research carrer in this leading institution and make many valuable contributions. I look forward to working with your group.

References

[1] V. Khachatryan et al. "Search for heavy Majorana neutrinos in ee + jets and eμ + jets events in proton-proton collisions at $\sqrt{s} = 8$ TeV". In: *JHEP* 04 (2016), p. 169. ISSN: 1029-8479. DOI: `10.1007/JHEP04(2016)169`.

[2] V. Khachatryan et al. "Search for heavy Majorana neutrinos in same-sign dilepton channels in proton-proton collisions at $\sqrt{s} = 13$ TeV". In: *JHEP* 2019 (2019), p. 122. ISSN: 1029-8479. DOI: `10.1007/JHEP01(2019)122`.

[3] Sungbin Oh et al. *SNU analysis framework*. URL: `https://github.com/CMSSNU/SKFlatAnalyzer`.