論文の内容の要旨

The search for fermionic thermal relic dark matter at future lepton colliders

(将来レプトン加速器におけるフェルミオン型熱的暗黒物質の探査に関する研究)

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Our current understanding of the universe is based on the standard model (SM) of particle physics. However SM holds some unsolved problems, one of the most important problems is the dark matter (DM) problem. The existence of DM has been confirmed by various astrophysical observations, and physicist have been making large effort to search the identity of DM. Among many candidates of DM, weakly interacting massive particle (WIMP) is considered one of the best candidates of DM. WIMP is a kind of thermal relic dark matter, and they are considered to be in the thermal equilibrium with SM particles at the early hot universe. From this property, WIMP must have some interaction with SM particles, and we can utilize this interaction to detect WIMP at experiments, namely indirect detection experiments, direct detection experiments, and collider experiments. WIMPs are usually contained in the model of new physics beyond SM, and this is also the motivation to consider WIMPs. However, we do not have any signal of new physics at current Large Hadron Collider (LHC) experiments, and in such a situation, we should analyze WIMP by model independent way.

When considering WIMPs model independently, it is effective to classify WIMPs by its gauge representaion of SM, and we focused SM gauge singlet majorana fermionic WIMP. Such WIMP can not have renormalizable interaction with SM particles and we need to introduce mediator particles which connect WIMP and SM particles. If mediators are heavy enough compared to WIMP mass and electroweak scale, we can integrate out mediator fields and get effective field theory which only contains WIMP and SM particles. There are unexplored region still remaining for CP conserving effective field theory, and they are H-funnel region, Z-funnel region and Leptophilic region. Since it is difficult to search these regions by LHC experiments or direct detection experiments, we discussed about the role of future lepton colliders for these regions.

In the thesis, we have presented the expected sensitivity of the Z-portal WIMP at the future lepton colliders. We have adopted the effective operator method where the interaction between the singlet Majorana WIMP (χ) and Z boson is mediated via the dimension-six operator $(\bar{\chi}\gamma_\mu\gamma_5\chi)(H^\dagger iD^\mu H)/2+h.c.$ The final result of our analysis is parametrized by only two parameters, the WIMP mass (m_χ) and the effective WIMP-Z coupling ($g_{\chi\chi Z}$). We discussed the possibility of probing the Z-funnel WIMP mass region (35-55 GeV) using the mono-photon plus missing energy signal at the future lepton colliders. We have done a comprehensive signal-background analysis of the mono-photon searches considering various collider features, such as beam polarization, beam breamsstrahlung, initial-state-radiation and detector effects. While doing this analysis we have taken into account other important constraints on the parameters of this scenario coming from the mono-photon searches, Z-invisible width obtained from the LEP data. This limit is combined with the ones obtained from the Z-invisible width measurement, direct detection and relic abundance of the WIMP. We have done a realistic estimation including the systematic uncertainties for the ILC beam. To do so, we estimate the $\Delta\chi^2$ with 0.1 % and 1 % systematic uncertainties. The collective 90 % C.L. bound for all the cases for a 250 GeV ILC beam with 0.1 % and 1 % systematic uncertainties has also been presented.

In thesis, We also presented the expected sensitivity of Leptophilic WIMP at future lepton colliders. We assumed specific mediators, namely Z_2 odd scalar mediators which couple to WIMP and SM leptons. There are two different type of mediators: left mediators which couple to WIMP and left-handed leptons, and right mediators which couple to WIMP and right-handed leptons. Here we introduced three generations of mediators for left and right mediators, and we imposed lepton flavor universality on the operators.

There are several parameters, which are couplings of the operators, WIMP mass (m_χ), left meiator mass ($m_{\tilde{e}_L}$) and right mediator mass ($m_{\tilde{e}_R}$).

We scanned the parameter region where the perturbativity holds, by considering relic abundance condition and collider experiments. The results are shown in (m_χ,$m_{\tilde{e}_L}$)-plane for left mediator case, and (m_χ,$m_{\tilde{e}_R}$)-plane for right mediator case. There is lower limit and upper limit on WIMP mass from the condition that WIMP gives correct DM abundance observed today, and we found that the bulk region lies on $m_\chi < 500$ GeV and $m_{\tilde{e}_L} < 600$ GeV for left mediator case, and $m_\chi < 400$ GeV and $m_{\tilde{e}_R} < 400$ GeV for right mediator case. When $m_\chi \simeq m_{\tilde{e}_L}$ or $m_\chi \simeq m_{\tilde{e}_R}$ is satisfied, so-called co-annihilation mechanism works, and even higher mass region can explain current DM abundance.

The mediators has been searched in the context of slepton search at LEP or LHC experiments through pair production of sleptons via Drell-Yan process. LHC experiments put constraints on the large area of bulk region, but when WIMP and mediator particle have similar mass, it becomes difficult to search mediator particles. For the lepton colliders, WIMP directly couple with electron and positron, and we can search these WIMPs more effectively. We revealed that WIMP with $m_\chi < 110$GeV can be searched by 250 GeV ILC using mono-photon plus missing energy process.

We also analyzed Leptophilic WIMP introducing left and right mediator simultaneously, and in this case WIMP and mediators cause anomalous muon magnetic moment $(g-2)$ because of the existence of 'A' term. Recent studies report anomaly in muon $(g-2)$ and we find that for the most of bulk region can explain this anomaly with proper 'A' term. Importantly, we have shown that there are detectable parameter regions by ILC which can also explain muon $(g-2)$ anomaly.