Study of particle physics models with implication for dark matter and cosmic ray phenomenology

A thesis submitted in partial fulfillment of
the requirements for the degree of

Doctor of Philosophy

by

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DISCIPLINE OF PHYSICS

INDIAN INSTITUTE OF TECHNOLOGY GANDHINAGAR

2015

To

My Family

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above can cause disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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CERTIFICATE

It is certified that the work contained in the thesis titled **"Study of particle physics models with implication for dark matter and cosmic ray phenomenology"** by **Mr. Gaurav Kumar Tomar** (Roll No. 11330006), has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Acknowledgements

It has been a great prerogative to stay in Physical Research Laboratory for several years, where I got a research as well as homely atmosphere throughout my PhD tenure. It gives me a great pleasure to acknowledge all those who supported me directly or indirectly and made this thesis possible.

First and foremost, I wish to express my sincere gratitude to my supervisor, Prof. Subhendra Mohanty, for giving me guidance, encouragement and support throughout my PhD tenure that lead up to this thesis. It has always been a great pleasure to discuss with him in an open and frank atmosphere created by him. I am very thankful to him for keeping faith in me and giving me encouragement time to time, which was invaluable source of confidence. I am also grateful to him for introducing me to the interesting and challenging problems of the field, which will play an important role in my future research.

I am also thankful to my collaborator Prof. Sandip Pakvasa for his invaluable wisdom and insight.

I take the opportunity to thank Prof. Hiranmaya Mishra, Dr. Namit Mahajan, Prof. S. Goswami, Prof. R. Rangarajan, Prof. Jitesh Bhatt, Dr. B.K.Sahoo, Dr. Partha Konar and Prof. Mohanty for teaching several useful courses at various times during my Ph.D. I also thank the other faculty members of theory group : Prof. Sarkar, Prof. Joshipura, Prof. Rindani, Prof. Dilip Angom and Dr. N. Singh for creating a friendly, interactive atmosphere to work. I am especially thankful to Dr. Namit Mahajan and Dr. Partha Konar for useful discussions from which I learned a lot.

I would especially like to thank my seniors and collaborators Soumya Rao, Tanushree Basak and Ujjal Dey for their enthusiasm and stimulating discussions. The continuous company and support of Tanushree, Gaveshna, Ila, Ujjal, Naveen, and Yashpal has always kept me recharged. A very special thanks to my seniors Arvind Singh, Vimal Don, Vinni, Shashi Prabhakar, Sudip Haldar, and juniors Girish Kumar (aka Keju), Alok Tiwary and Arun Pandey for their continuous support and light moments. I thank all my batch-mates especially Naveen, Yashpal, Wageesh, Arko, Upendra, Gaurav Sharma, Reddy, Monojit, Gulab, Avdesh and Bhavya for cheering with me.

My special thanks to T.N. Soorya sir for his invaluable support, and giving me right-direction at the crucial moment of my life. I am also thankful to my precious friends Sunil Kumra, Hardeep Singh and Tarkeshwar Singh for making my life cheerful by putting ghatiya jokes or roaming around without any purpose. Thank you very much buddies!

I am also grateful to Razaa and Sujata ben for their sincere support and help whenever I asked.

Last, but not the least, I would be nowhere around here without the love and support of my family. Words cannot express my gratitude for my babuji, bhaiyya and didi. I am very thankful to Bhavya for her continuous and unconditional support and being with me whenever I felt alone and weak. I am also thankful to Bhavya's family for their support and faith in me. Finally, I must also acknowledge the love, support and blessings of friends, teachers, relatives and all known and unknown persons whom I met with or interacted with in life.

Gaurav Tomar

Abstract

There are many observations in particle physics and cosmology, which seek physics beyond standard model for their explanation. Some of them are : The excess of positron over cosmic ray background observed by AMS-02 experiment, the 3.6σ discrepancy between muon $(g-2)$ measurement by BNL and its standard model prediction, and the absence of Glashow-resonance in the PeV neutrino events at IceCube. As the thesis title indicates this work is about the study of particle physics models which not only explain the mentioned observations but also give a suitable candidate of dark matter with correct relic density.

In the work presented here we have proposed a gauged horizontal symmetry model for which we introduce a 4th generation of fermions into SM. We then introduce a $\mathrm{SU}(2)_{\mathrm{HV}}$ vector gauge symmetry between the 4th generation leptons and muon families. The 4th generation right-handed neutrino is identified as dark matter which annihilates into leptons final state $(\mu^+\mu^-, \nu_\mu^c\nu_\mu)$ giving rise to correct relic density. In this model, dark matter is lephtophilic in nature, so it can explain AMS-02 positron excess remaining consistent with stringent bounds from antiproton. It is also possible to alleviate the discrepancy in muon $(g-2)$ from 4th generation charge lepton, $\mathrm{SU}(2)_{\mathrm{HV}}$ gauge boson, and from neutral and charged scalars. In this way, both the signals, muon $(g-2)$ and the excess of positron can be explained simultaneously. We have also studied an alternative left-right model called dark left-right model, where it is possible to accommodate a suitable dark matter candidate. The second generation right-handed neutrino is identified as dark matter which dominantly annihilates into leptons final state. So it is possible to explain AMS-02 positron excess and lift the stringent bounds from antiproton. The singly and doubly charged scalars in dark left-right model also contribute to muon $(g-2)$ and so both the signatures can also be related in this model.

Another part of this thesis deals with the absence of Glashow resonance at IceCube PeV neutrino events. The IceCube collaboration has observed neutrino of very high energy which goes upto ~ 3 PeV, but did not see any events at Glashow resonance. The Glashow resonance gives rise to an enhanced cross-section for $\bar{\nu}_e$

at resonance energy 6.3 PeV which increases the detection rate of $\bar{\nu}_e$ by a factor of ~ 10. This implies that at least some of the events should have been observed at Glashow resonance, but none were. We proposed a new mechanism which can explain why neutrinos arising from astrophysical process may be suppressed. We assume a Lorentz violating higher dimensional operator, which modified dispersion relation of neutrinos (antineutrinos). As a result, pion and kaon decay widths get suppressed and we observe a cutoff in the neutrino spectrum which is consistent with IceCube data.

Keywords: Dark Matter, Beyond Standard Model, Relic abundance, Gauge extension, Muon magnetic moment, PeV neutrino events.

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List of Publications

Publications in journals

1. **Gaurav Tomar**, Subhendra Mohanty, and Sandip Pakvasa, *Lorentz Invariance Violation and IceCube Neutrino Events*, JHEP 1511 (2015) 022, doi: 10.1007/JHEP11(2015)022, arXiv:1507.03193.

2. Tanushree Basak, Subhendra Mohanty, and **Gaurav Tomar**, *Explaining AMS-02 positron excess and muon anomalous magnetic moment in dark left-right gauge model*, JHEP 1603 (2016) 062, doi: 10.1007/JHEP03(2016)062, arXiv:1501.06193.

3. **Gaurav Tomar**, and Subhendra Mohanty, *Muon anomalous magnetic moment and positron excess at AMS-02 in a gauged horizontal symmetric model*, JHEP 1411 (2014) 133, doi: 10.1007/JHEP11(2014)133, arXiv:1403.6301.

Conference Papers

1. **Gaurav Tomar**, *Explaining muon magnetic moment and AMS-02 positron excess in a gauged horizontal symmetric model*, XXI DAE-BRNS High Energy Physics Symposium, IIT Guwahati, Assam, India, December 8-12, 2014, Springer Proceedings in Physics, doi: 10.1007/978/3/319/25619/1/66, arXiv:1507.01797.