# The Impacts of Cosmic Ray Interactions on Dark Matter Detection

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## Introduction

Dark matter detection is currently being explored using two different methods: direct and indirect detection. A third method, reverse direct detection, is being researched and relies on cosmic rays interacting with dark matter. This collision causes the previously slow dark matter to begin traveling relativistically. Standard direct detection methods can only detect heavier dark matter particles of masses of a GeV or more, travelling at approximately 200 kilometers per second, but with cosmic ray interaction, dark matter particles of smaller masses and higher velocities can be observed through these direct detection methods. This interaction between dark matter and cosmic rays produces an energy dependent cross section, which is used to determine the interaction lengths and energy loss lengths.

By exploring the interaction between cosmic rays and dark matter, more can be learned about these interactions such as their cross sections, interaction lengths, and energy loss lengths for a variety of cosmic ray energies, including extragalactic cosmic rays of energies greater than $10^{15}$ eV. This project will examine the extent of the energy dependence on these characteristics of the interaction, and the impacts of this dependence.

## The Standard Model

A graph of the interaction length, energy loss length, and pair production propagation loss from standard model interactions should be created to allow direct comparisons to be made between this case and dark matter-cosmic ray interactions. The interaction length shows the distance travelled between interactions for photo-pion production on cosmic microwave background photons. Energy loss length shows the distance travelled by a particle before losing its energy for the same interaction. Finally, energy loss length for pair production is calculated.

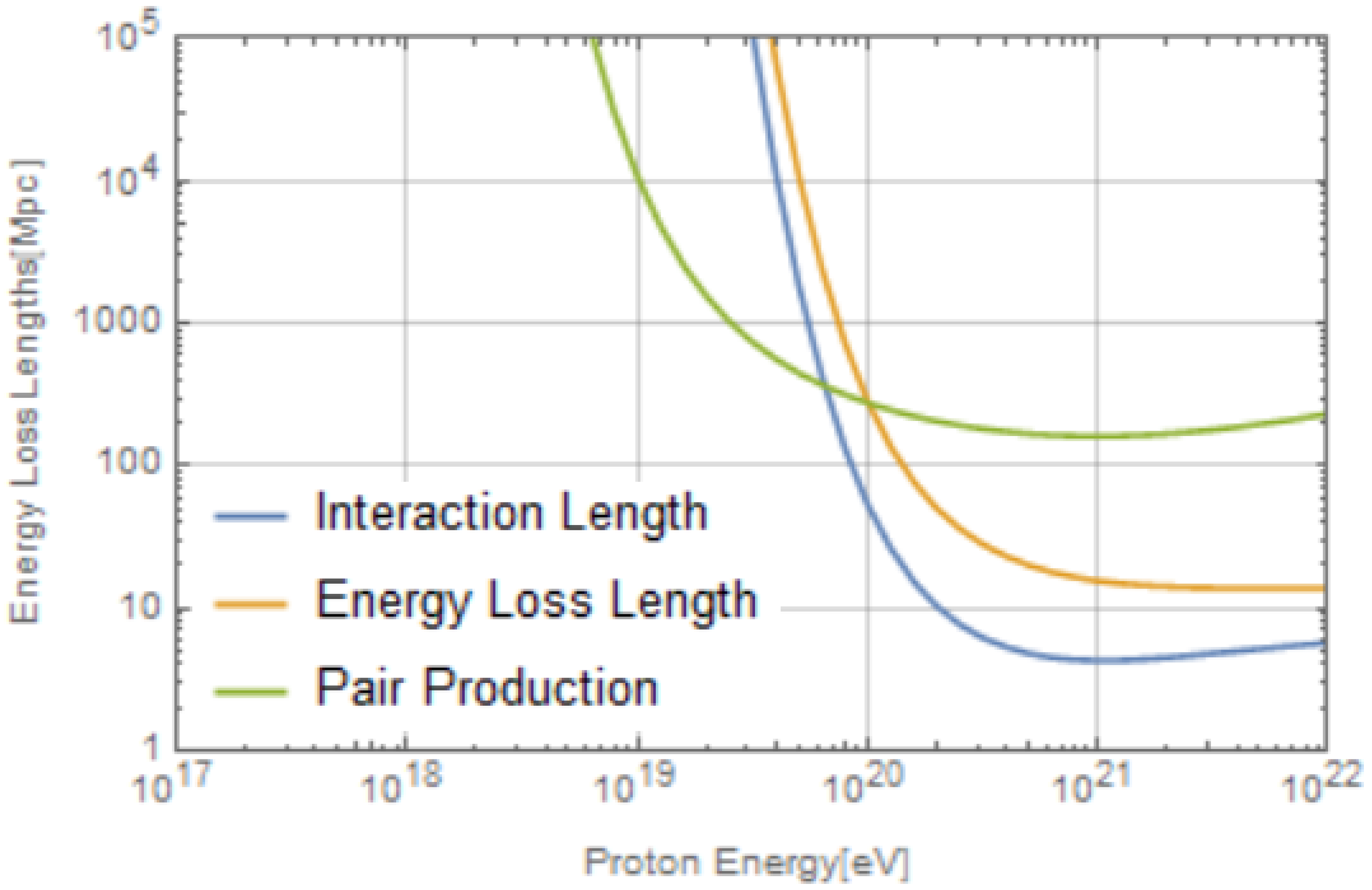


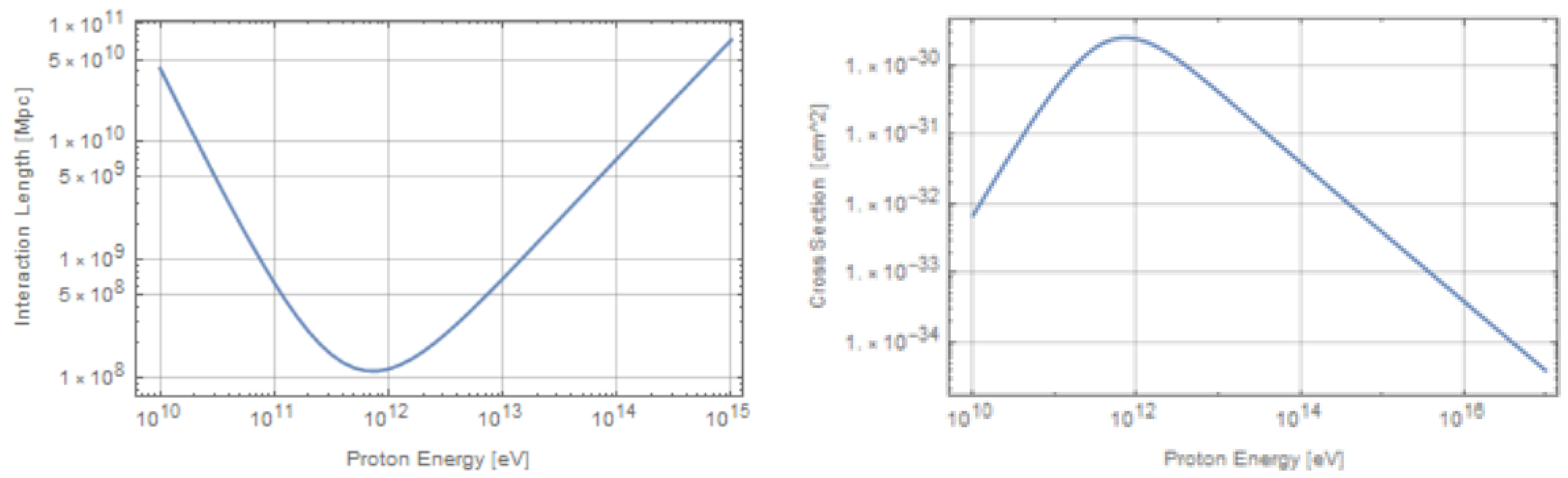

Figure 1: The resulting curves for the standard model interactions between a CMB proton and a photon. The proton energy (x-axis) is in eVs, and the length values (y-axis) are in Mpc.

## Dark Matter Cosmic Ray Energy Dependent Cross Section

When looking at the cosmic ray-dark matter interactions, the cross section is dependent of both the energy of the dark matter and of the cosmic ray. In this case, we assumed a scalar mediator

$$\frac{d\sigma}{dE_\chi}(E_p, E_\chi) = g_{s\chi}^{2} g_{sCR}^{2}\left[\frac{4m_\chi m_p^{2} + 2E_\chi\left(m_\chi^{2} + m_p^{2}\right) + m_\chi E_\chi^{2}}{8\pi\left(2m_\chi E_\chi + m_\phi^{2}\right)^{2}\left(E_p^{2} + 2m_p E_p\right)}\right]$$

The mass of the dark matter particle and the mediator are unknown, so a range of values were tested. For the dark matter mass, keV to MeV values were used. For the mediator mass, keV to GeV values were used. From this differential cross section, the interaction length can be calculated. Dark matter makes up 24% of the universe's energy density, so the number density is $n=.24*\rho_{crit}/m_\chi$.




Figures 2 & 3: The cross section (left) and interaction length (right) of the DM-CR interaction using $m_\chi$=1 MeV, $m_\varphi$=1 GeV. The cross section is in cm²; The interaction length is in Mcp.

## Conclusions

We can see a large difference in length scales between the standard model and the dark matter-cosmic ray interactions. Although the DM-CR interaction length would vary slightly with different dark matter and mediator masses, the length for the extragalactic cosmic rays would be much longer than the results from the standard model. This result leads us to believe that it would be best to constrain our future research to galactic cosmic rays.

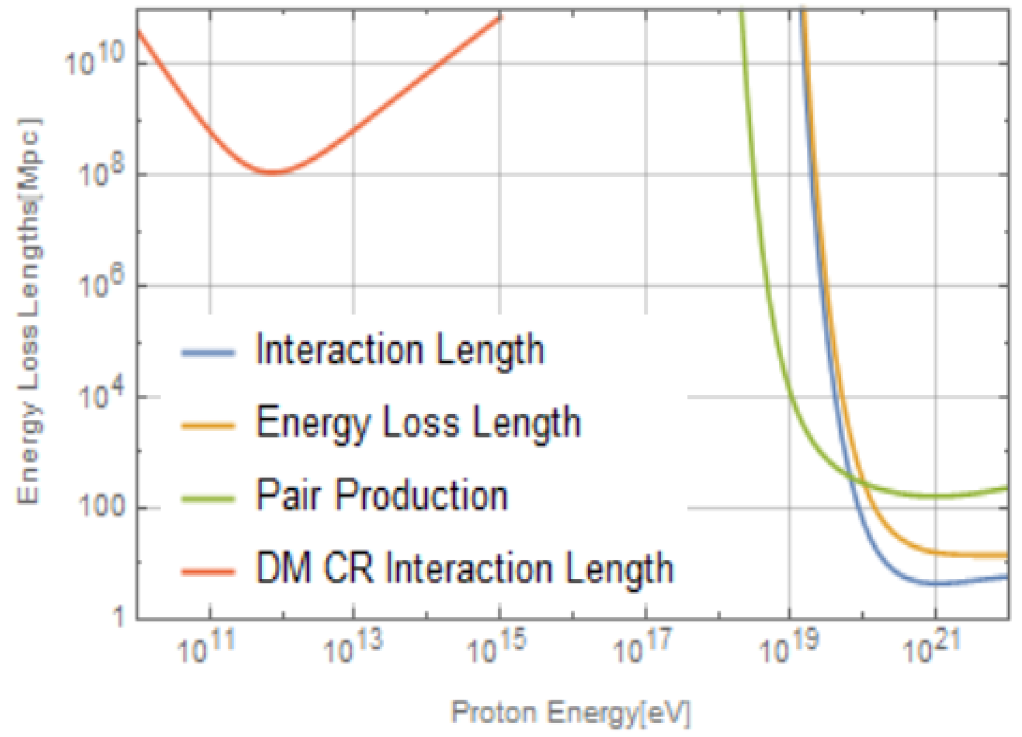



Figure 4: SM curves and the DM-CR interaction length on the same graph (mχ=1 MeV, mφ=1 GeV). The lengths are in Mpc.

**Acknowledgements**

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**References**

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