Contribution ID: **57** Type: **not specified**

Linking the KM3-230213A Neutrino Event to Dark Matter Decay and Gravitational Waves Signals

Thursday, September 25, 2025 5:30 PM (30 minutes)

The KM3NeT collaboration recently reported the detection of an ultra-high-energy neutrino event, dubbed KM3-230213A. This is the first observed neutrino event with energy of the order of O(100)PeV, the origin of which remains unclear. We interprete this high energy neutrino event as the Dirac fermion dark matter (DM) χ decay through the right-handed (RH) neutrino portal assuming the Type-I seesaw mechanism for neutrino masses and mixings. Furthermore, dark matter χ is assumed to charged under $U(1)$ dark gauge symmetry, which is sponetaneously broken by the vacuum expectation value of the dark Higgs Φ. In this scenario, the DM can decay into a pair of Standard Model (SM) particles for $v_\Phi \gg m_\chi$, which we assume is the case. If the DM mass is around 440 PeV with a lifetime $\sim 5 \times 10^{29}$ sec, it can account for the KM3-230213A event. However, such heavy DM cannot be produced through the thermal freeze-out mechanism due to overproduction and violation of unitarity bounds. We focus on the UV freeze-in production of DM through a dimension-5 operator, which helps in producing the DM dominantly in the early Universe. We have also found a set of allowed parameter values that can correctly account for the DM relic density and decay lifetime required to explain the KM3NeT signal. Moreover, we have generated the neutrino spectra from the two-body decay using the HDMSpectra package, which requires the dark Higgs vacuum expectations value (VEV) to be much larger than the DM mass. Finally, the large value of the dark Higgs field VEV opens up the possibility of generating GW spectra from cosmic strings. We have found a reasonable set of parameter values that can address the KM3NeT signal, yield the correct value of the DM relic density through freeze-in mechanism, and allow for possible detection of GW at future detectors.

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Session Classification: Plenary 14

Track Classification: Plenary