Sterile neutrinos: from cosmology to the LHC

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Abstract: Sterile neutrinos arise in several extensions of the Standard Model to accommodate massive neutrinos. In particular the recently proposed νMSM predicts 3 right-handed neutrinos which could explain the dark matter puzzle and the baryon asymmetry of the Universe. A summary of present limits and possible improvements are summarized.

Keywords: heavy neutrinos, cosmology, accelerator beam

The νMSM model (1)

Singlet (sterile) neutrino states arise in models which try to implement massive (light) neutrinos in extensions of the Standard Model. In particular the recently developed νMSM model considers 3 singlet states N_1, N_2 and N_3 associated with the 3 active neutrinos.

N_1 having a mass of 10 keV has a lifetime very long compared to the age of the Universe. Because of its small mass, it is essentially stable on cosmological times. It could account of for the missing mass in the form of Warm Dark Matter. Its search can only be thought in astrophysical measurements. Limits exist from searches of monochromatic gamma-rays coming from distant galaxies.

The other two states, N_2 and N_3, if they are almost degenerate could solve the problem of the disappearance of antimatter in the Universe. Their masses is expected to be in the range 100 MeV-few GeV. N_2 and N_3 can be searched for in the laboratory through their mixing with light neutrinos. Limits exist.

Production of sterile neutrinos

If heavy neutrinos exist, they mix with active neutrinos through a unitary transformation. Any neutrino beam will contain a fraction of heavy neutrinos at the level U_{Nl}^2 where U denotes the mixing matrix element between the heavy state N and l being either e or μ or τ.

At accelerators, neutrinos are emitted in pion and kaon decays. At higher energies, charm, beauty and W contribute. Kinematically the mass range allowed for a heavy N depends on the emission process. In πμ decays, sterile neutrinos can reach a mass of 30 MeV. In πe, the range is increased to 130 MeV. Kaons allow larger potential masses of up to 450 MeV.

The flux of N's accompanies the flux of known neutrinos at the level of U_{Nl}^2. Corrections to this straightforward result come from helicity conservation which applies differently. For massless neutrinos, it suppresses πe decays relative to πμ decays. This is not true anymore for $\pi \rightarrow eN$.

Decays of sterile neutrinos

N's will decay through weak interactions. The decay modes depend on the N mass. The first channel to open is N→ eeν, as soon as the mass is greater than 1 MeV. With increasing masses, new modes open and one can obtain eμν, πe, μμν, πμ…

The lifetime is given by the formula applying to weak decays, apart from a suppression factor coming again from the mixing U_{Nl}^2. Phase space factors are also changed.

Previous results

The search consists in looking for a decay signature, typically two charged tracks reconstructing a vertex in an empty volume arising in a neutrino beam.

This has been attempted by the low energy experiment PS191 (2) with 5 10^{18} protons of 19 GeV on target. The figure shows the present situation with limits from above coming from this experiment, together with limits from below coming from astrophysics arguments. Between these two kinds of limits there remains a small window of existence. Soon-to-run experiments could improve these results and close the window.

The MiniBoone result (3) can be interpreted as coming from a heavy neutrino of mass around 200 MeV, with mixing in the presently allowed region. This is a good reason to try to improve on the old results.

Future

The present result can easily be improved with the use of modern beams. For example, the NuMI beam at Fermilab offers 100 times more neutrinos than the old PS191 measurement. The proton beam is 120 GeV. Thus the beam has a fair component of neutrinos from charm decays. This has the advantage to open the search of N's up to a mass of 1.3 GeV.

A calorimeter having a good energy and direction resolution is being built: this is the Minerva detector. With a 10m decay volume in front, it is possible to test the MiniBoone excess and close a good part of the remaining window.

Other possibilities exist at the LHC. First the LHCb will accumulate a huge number of B decays and this allows the search of N's up to 5 GeV masses. Furthermore the Atlas and CMS detectors will accumulate a large number of W decays which can also be used to search for the existence of N's up to 50 GeV masses.

Conclusion

The νMSM model is a natural and attractive extension of the Standard Model. It predicts new states which can be searched for in coming experiments. The fascinating possibility of the existence of sterile neutrinos in a reachable domain should be tested in the coming future.

References

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