Finding new physics, phenomenological, experimental and astrophysical predictions

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Despite being the most successful theory of particle physics to date, the Standard Model of particle physics is not perfect.

Gossip in the corridor

- Although neutrinos are among the most abundant particles in the Universe, many of their basic properties are still unknown!

- Neutrinos may have tipped the balance in favour of matter over anti-matter in the Universe!

Standard Model is one of the most successful stories in particle physics

- Are neutrino experiments just tests for Standard Model?

... is that it?

No!

- **Now, neutrino physics has entered an era of precision measurements.**

We need absolute scale of the neutrino masses Σm_ν

- Neutrino oscillation experiments can measure two of the neutrino-mass splittings, and are getting very close to a determination of the neutrino-mass ordering also CP violation among neutrinos including θ_{23} octant!
- However, neutrino oscillation experiments have no information about the absolute scale of the neutrino masses, Σm_ν.
- Cosmology, on the other hand, is a promising avenue for the determination of Σm_ν.

- Massive neutrinos leave unique imprints on cosmological observables throughout the history of our universe.

Next-generation cosmological test for Σm_ν

- Current cosmological observations already provide the tightest bounds on the sum of the neutrino masses, although they are unable to go beyond a very tight upper limit.
- As next-generation surveys approach, their improved sensitivity will help reach a guaranteed target for physics beyond the SM.
- Cosmology is likely to be the first experimental avenue to move from a tight upper limit to a clear detection of Σm_ν.

Comparision of tests for $\Sum m_\nu$

- Note that cosmological observables are not the only probes of the absolute neutrino mass scale.
- Complementary information can be provided by laboratory searches such as kinematic measurements in β-decay experiments and neutrino-less double-β decay ($0\nu2\beta$) searches.
- A detection of the absolute neutrino mass scale with cosmology would be crucial to test the consistency between different probes.
- In fact, an inconsistent picture would be an interesting indication of new physics in the neutrino sector.

- Experimental efforts are also being devoted to a first direct detection of the cosmic neutrino background (e.g. the PTOLEMY experiment), which represents a very challenging task.

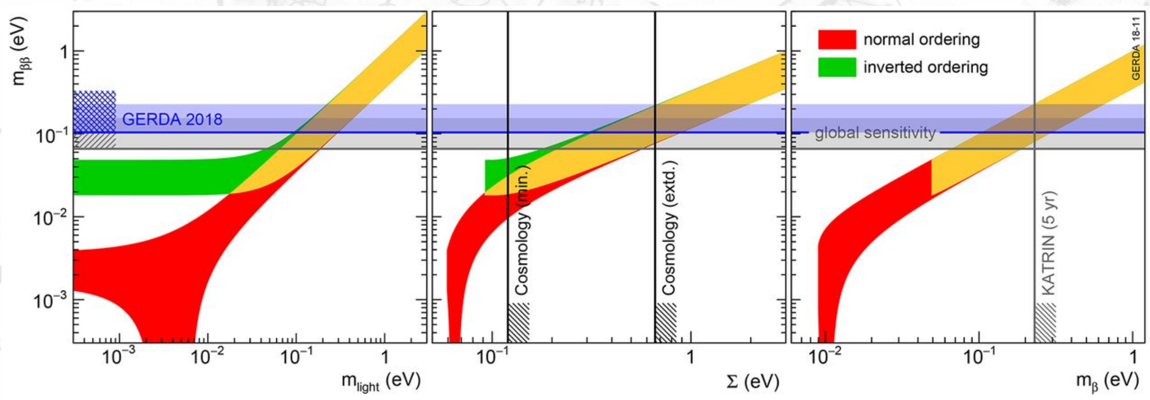
Best cosmological probes

- CMB Lensing: In the large-scale structure (LSS), the effect of massive neutrinos is a reduction of the lensing power at intermediate and small scales.
- Next-generation CMB experiments will provide extended catalogs of clusters detected through the thermal and kinetic Sunyaev-Zel'dovich (tSZ and kSZ) signal along with amplitude of scalar fluctuations from galaxy clusterings. These signals are independent avenues to tight constraints on Σm_ν.
- Neither CMB nor LSS observables can alone provide a significant detection of neutrino masses, but together they will guarantee detection of the sum of neutrino masses.

Cosmological probes for Σm_ν and dark matter & energy properties

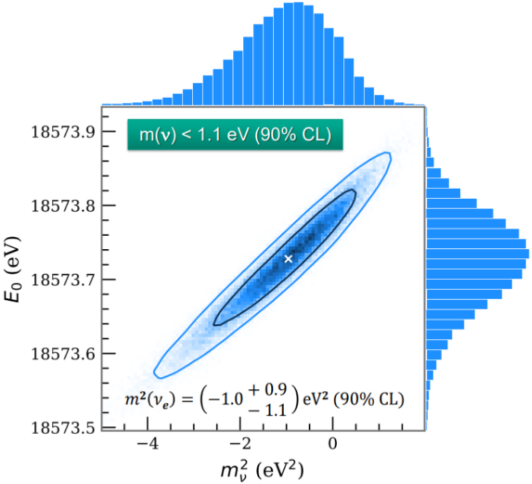
- Cosmic voids, Sunyaev-Zel'dovich cluster abundances, Kinetic Sunyaev-Zel'dovich, Optical lensing, Lyman-α forest, Galaxy clustering, CMB lensing, Galaxy-lensing cross-correlation etc.

Important laboratory result



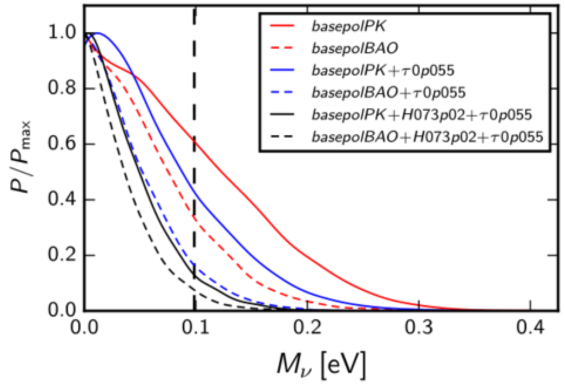
If the neutrino is Majorana, an upper limit to the mass of the neutrino of 0.07 - 0.16 eV. GERDA has obtained this result after not observing any signal in its germanium-76 detector after an exposure time of 82.4 kg-year.

Important laboratory result



The most relevant thing about the new result is that KATRIN seems to be working perfectly.

Important cosmological result



Posterior distributions on the neutrino mass sum from combinations of various state-of-the-art cosmological datasets as of early 2017, including measurements of the power spectrum of BOSS DR12 galaxies and CMB measurements from the Planck 2015 data release.

Recent cosmological values

$$\Sigma m_\nu < 0.18\ eV\ (NH,\ Planck + FS)$$

$$\Sigma m_\nu < 0.21\ eV\ (IH,\ Planck + FS)$$

and

$$\Sigma m_\nu < 0.15\ eV\ (NH,\ Planck + BAO)$$

$$\Sigma m_\nu < 0.18\ eV\ (IH,\ Planck + BAO)$$

- **With LSS and future CMB (tSZ & kSZ), situation will change!**

Next-generation CMB experiments are necessary