

KATRIN Experiment: New Constraints on Neutrino Mass

Key Development

- The KATRIN (Karlsruhe Tritium Neutrino) collaboration has published a refined upper limit on neutrino mass using 259 days of measurements.
- The new constraint sets the combined mass of the three known neutrino types to be less than 8.8×10^{-7} times the electron's mass — a twofold improvement over the previous best.
- **Developed by:** Conducted by an international collaboration led by the Karlsruhe Institute of Technology (KIT), Germany.
- **Nations Involved:** Major institutions from Germany, the U.S., and other European countries contribute to the experiment.
- **Objective:** To directly measure the absolute mass of neutrinos—a major unsolved question in particle physics.



Why Neutrino Mass Matters

- Neutrinos are extremely light particles that travel close to the speed of light.
- Their minuscule mass poses challenges in direct detection and measurement.

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- Understanding neutrino mass is crucial to resolving gaps in the Standard Model of particle physics.

Fundamental Mystery

- The reason behind the extremely small mass of neutrinos remains unknown.
- Physicists are unsure whether neutrinos have a **Dirac mass** (like other known particles) or a **Majorana mass** (a particle that is its own antiparticle).

Challenges in Detection

- Neutrinos interact very weakly with matter, making them difficult to detect.
- Most materials are nearly transparent to neutrinos, requiring extremely sensitive and large-scale detectors.

The Epic Journey of the Spectrometer

- The core of the KATRIN experiment — a 200-tonne spectrometer — was constructed in Deggendorf, Germany.
- Transported via a 8,600-km route (mostly by water bodies like the Danube, Mediterranean, Atlantic, and Rhine) to reach Karlsruhe, avoiding risky land transport due to its size and sensitivity.

Why Study Neutrinos?

- Neutrinos are the lightest, most elusive subatomic particles.
- Since their discovery in 1938, they've posed unresolved questions about mass, interaction, and identity.

The KATRIN Breakthrough

- KATRIN determined that the **sum of neutrino masses is less than 8.8×10^{-7} times the electron mass**.
- This is **twice as precise** as previous experimental constraints.
- Based on **259 days** of data and **36 million electrons** analyzed from tritium decay.

The Puzzle of Neutrino Mass

- Oscillation experiments proved neutrinos have mass, but don't reveal the actual values — only mass differences.
- The extreme lightness of neutrinos and their near-light-speed travel make direct measurement highly complex.
- The **Standard Model** doesn't explain their mass, suggesting the need for **new physics**.

Are Neutrinos Their Own Antiparticles?

- Being electrically neutral, they could be their own antiparticles (Majorana particles).
- This requires proving they have a **Majorana mass**, unlike typical particles with **Dirac mass**.
- The key to solving this lies in observing **neutrinoless double beta decay**, an incredibly rare process.

Competing and Complementary Efforts

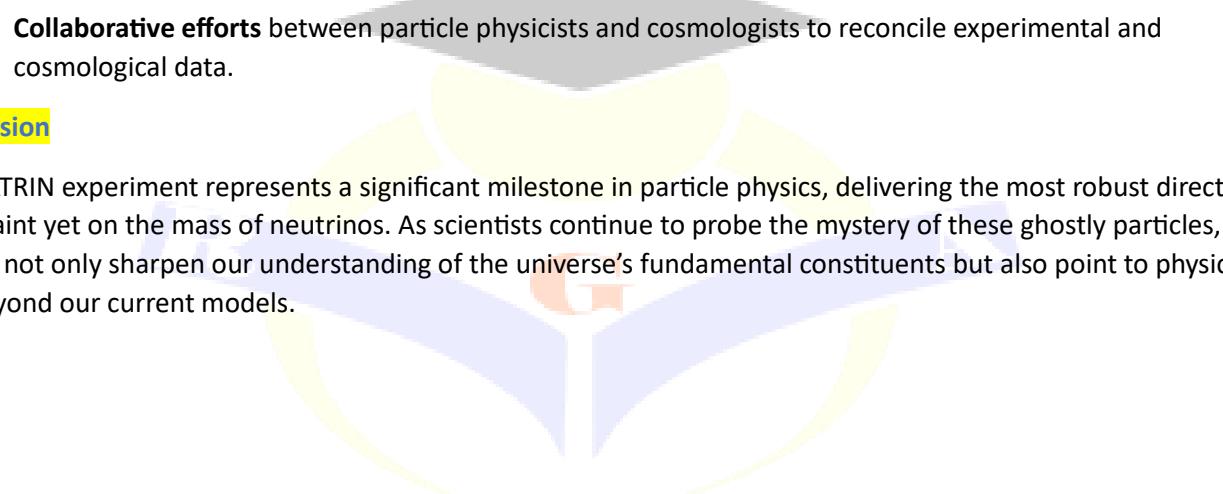
- Cosmological studies suggest even tighter limits on neutrino mass, but rely on assumptions about the early universe.
- Other experiments also aim to detect neutrinoless double beta decay but begin with the assumption that neutrinos are self-conjugate.
- **KATRIN's value lies in its model-independent, assumption-free approach.**

Way Ahead

- **Enhancing detector sensitivity** to refine neutrino mass measurements further.
- **Pursuing evidence of neutrinoless double beta decay** to settle the Majorana vs Dirac debate.
- **Developing theories beyond the Standard Model** to incorporate neutrino masses and interactions.
- **Collaborative efforts** between particle physicists and cosmologists to reconcile experimental and cosmological data.

Conclusion

The KATRIN experiment represents a significant milestone in particle physics, delivering the most robust direct constraint yet on the mass of neutrinos. As scientists continue to probe the mystery of these ghostly particles, such results not only sharpen our understanding of the universe's fundamental constituents but also point to physics that lies beyond our current models.



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