Direct search of keV sterile neutrino in tritium beta decay by “Troitsk nu-mass” experiment

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Outline

- Historical remark
- Motivation
- Experimental setup
- Systematics
- Achievable limits
- Plans
- Conclusion
Troitsk $\nu$-mass: experiment on electron neutrino mass is completed

Vladimir Lobashev

Particle Data Group
Why sterile neutrinos?
Motivation from Standard model

**Standard Model**

**Extension with $\nu_R$**

Key question - mass of $\nu_R$
Consider Standard Model with minimal extension to include right handed neutrinos $N_j, j = 1, 2, 3$

After that we can explain:

- **Dark matter, if** $M_1 \gtrsim \text{keV}$  
  *Dodelson & Widrow (94)*

- **Dark matter and Baryon asymmetry, if**  
  $M_1 \gtrsim \text{keV}$ and $M_2, M_3 \sim \text{GeV}$  
  *Akhmedov, Rubakov & Smirnov (98)*  
  *Asaka & Shaposhnikov (05)*

- **Laboratory**
  - $M_1 \lesssim 100 \text{ eV}$: oscillation experiments
  - $10 \text{ eV} \lesssim M_1 \lesssim \text{MeV}$: radioactive decay
  - $\text{MeV} \lesssim M_1 \lesssim \text{GeV}$: leptonic decays of mesons
  - $\text{MeV} \lesssim M_1 \lesssim 100 \text{ GeV}$: decays of sterile neutrino in "beam-dump" experiments.

- **Astrophysical and cosmological**
Motivation from cosmology:
Visible matter only 5%. What is the rest?
Cold or warm Dark Matter?

Heavy particles?  1-10 keV particles?

Simulations favor **Warm** Dark Matter
So, why keV- neutrino?

Candidate for Warm Dark Matter

- LHC results confirm expectations from Standard Model, but
- Neutrino mass, Dark Energy and Dark Matter are well beyond SM
- There is a set of candidates for DM, like WIMPs, they should be heavy and cold – but it contradicts cosmological structures at small scales
- Sterile neutrino with keV-scale mass is a good candidate for Warm Dark Matter.


PS. keV mass range is not available in oscillation experiments
What is the situation now?

Current limits for keV-sterile neutrino
How can we find it?

Move away from the $\beta$-spectrum end point

Measure Tritium $\beta$-spectrum in wide energy range, at least in 13-19 keV

Search for distortion

$|\nu_\alpha > = \sum U_{\alpha i} |\nu_i >$

Then, we have to split spectrum into two parts

$$S(E) = U_{ex}^2 S(E, m_\chi) + (1 - U_{ex}^2) S(E, 0)$$
What is “Troitsk nu-mass” now?

The same Windowless Gaseous Tritium Source

New Spectrometer

Energy range 13-19 keV
Energy resolution about 1.5 eV

+ a lot of upgrades

See also Lett. Of Intent, arxiv:1504.00544
JINST 10 (2015) no.10, T10005
Devil is in details - systematics

- Insufficient accuracy of electron energy loss in gaseous source
- Electron trapping in “magnetic bottle” in the source
- Distortion of spectrometer transmission function
- Detector efficiency and electron scattering at different energy
- Electronics dead time and pile up
- Gas column density fluctuation
- High voltage stability

How to overcome? Calibrations, hardware upgrade, experimental measurements with electron gun, simulations
Problem with electron scattering from detector in MAC-E filter like our spectrometer

Up to 20% electrons scatter back from Si-detector.

*CASINO simulation*

[NIM A832 (2016) 15](http://dx.doi.org/10.1016/j.nima.2016.05.042)  

It changes transmission function and induces non-trivial time correlations
Field configuration in tritium source forms a bottle – magnetic Trap

Trapped electrons can run back and forth up to thousand times passing few kilometers
Trapped electrons distort the actual $\beta$-spectrum

Simulation, for 6e+6 “normal” electrons

Energy dependence

Delta of energy lost for trapped electrons before finally escaping to Spectrometer
Systematic limits on matrix element with the current setup

- Statistics for about 30 days of measurement including trapping error
- Energy loss in the source (current precision)
- Detector dead time and pile-up uncertainty (minor upgrade needed)
- HV instability (current precision)
Demonstration of sterile neutrino search: Oct 2016 measured spectrum versus $U_{sp}$

Recent precision measurements at Troitsk in a wider energy interval
We start data taking: Bounds on sterile neutrino based on October 2016 data

arXiv:1703.10779
Plan for upcoming upgrades which will allow:

- Relative stability of electron gun intensity better than 0.1%
- Calibration of spectrometer transmission function with precisions 0.1%
- Absolute accuracy for gas column density less than 0.001 in units of mean free path
- Increase intensity of tritium source with multichannel detector
- Full signal digitization, pulse shape analysis and simulation
Signal shape plus noise simulation

- With full signal digitization it allows to control pulse overlap
- To increase hit rate by 4-5 times
Test of 7-pixel prototype Si detector (just from last Saturday measurements). German-French-Russian team in Troitsk

Integral Tritium spectrum at Usp=12.5 kV

Differential spectrum
Conclusions

- Measurements are underway
- We get official permission to work with tritium
- A lot of work is going on for calibration, simulation and upgrade
- Experiment is supported by RAS Program in Astroparticle Physics and RFBR grant
- New group within KATRIN collaboration is forming to work on new multichannel detector

Stay tuned!
Thank you for your attention
backup
What else?

- We understand that “inclusive” measurements have serious sensitivity limits, thus we have to find more sophisticated ways:

- To do exclusive measurements reconstructing the whole kinematics including recoil nucleus?

- Use other isotopes? Neutron decay?

- Electron capture? $^7\text{Be}$?

- To set Tritium on Graphane? (similar to PTOLEMY project)

- Do you get good idea?
Comparison of errors for heavy neutrinos between Troitsk and Mainz experiments

Comparison of errors for heavy neutrino mass obtained by the analysis, black symbols connected by solid lines, and approximate estimation $\sigma(U_{e4}^2) = 2.53/m_\nu^2$ based on the result for the electron antineutrino mass V. N. Aseev et. al., Phys. Rev. D84, 112003 (2011), red dashed line.

The blue dotted line corresponds to the estimation $\sigma(U_{e4}^2) = 3.04/m_\nu^2$ for the total error from C. Kraus, et al., Eur. Phys. J. C 40, 447 (2005)

KATRIN. Everything is in place. Cryogenics tested. First shut by electron gun from the rear though the whole setup this month. Then test with Deuterium.