Neutron lifetime: experimental problem or anomaly?

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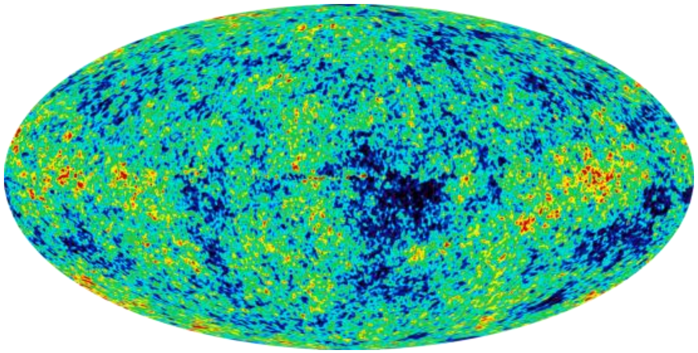
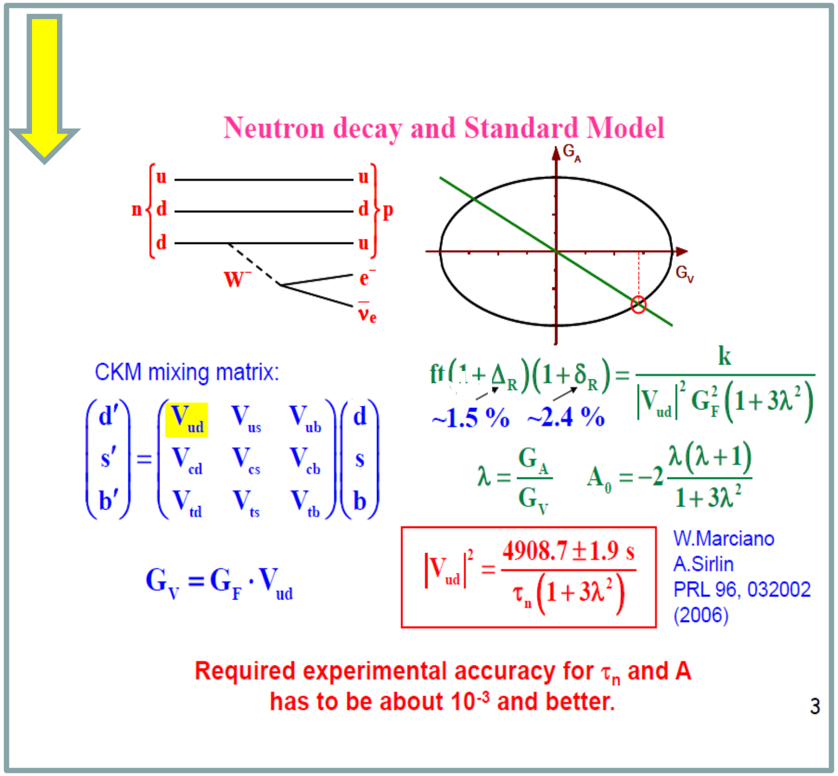
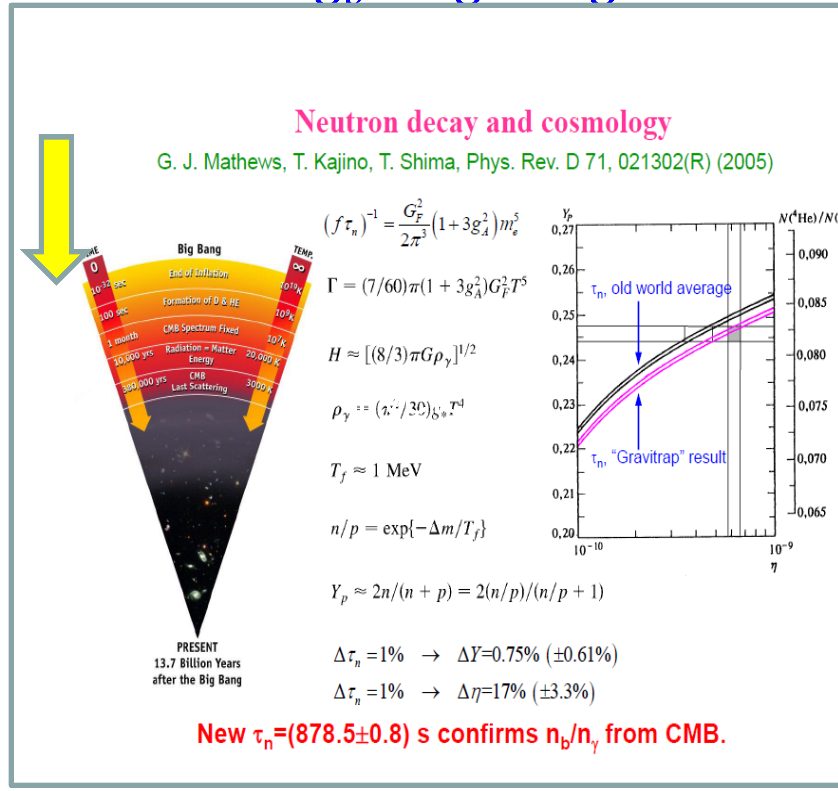


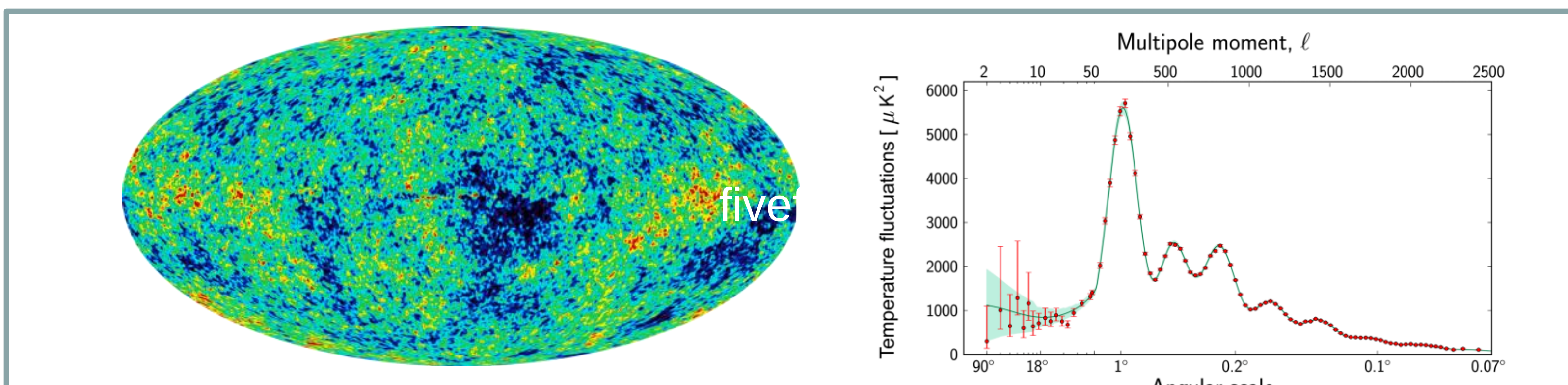
NORDITA workshop on 10-14 December 2018, Stockholm

1. Standard Model (search for possible deviations)

2. Cosmology (Big Bang Model)

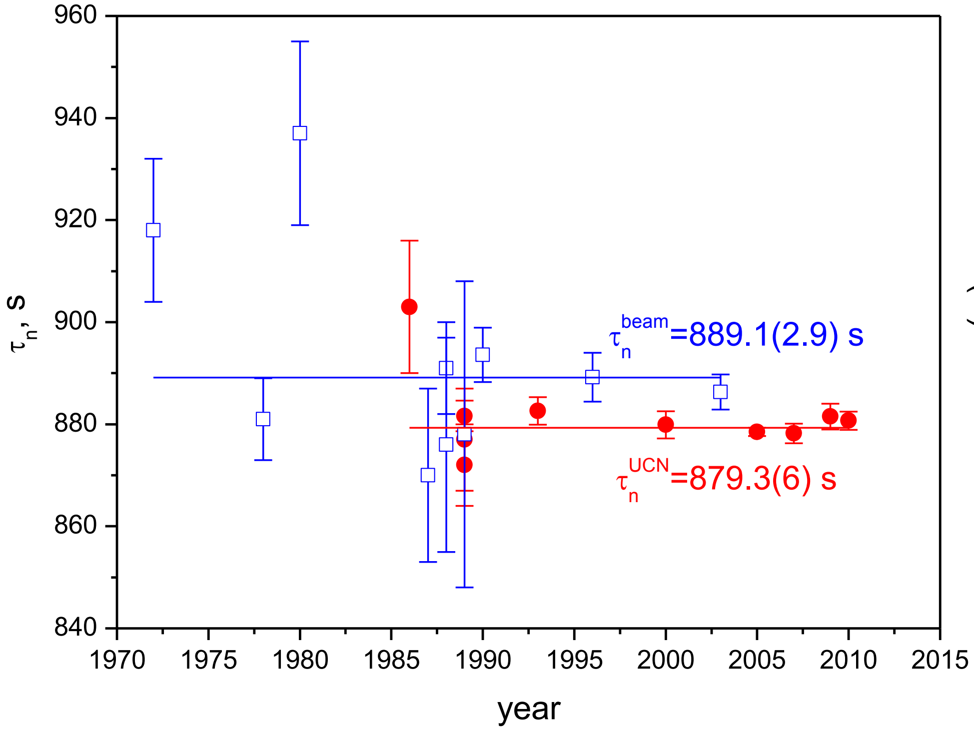


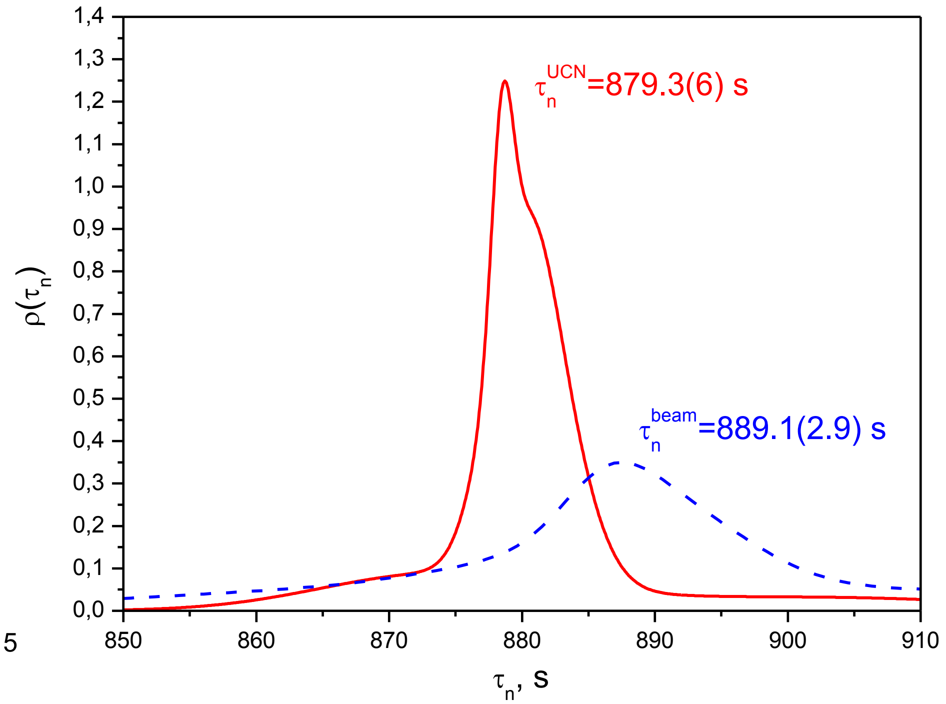




Neutron lifetime from
UCN storage experiments and beam experiments

A.P. Serebrov and A.K. Fomin / Physics Procedia 17 (2011) 199–205





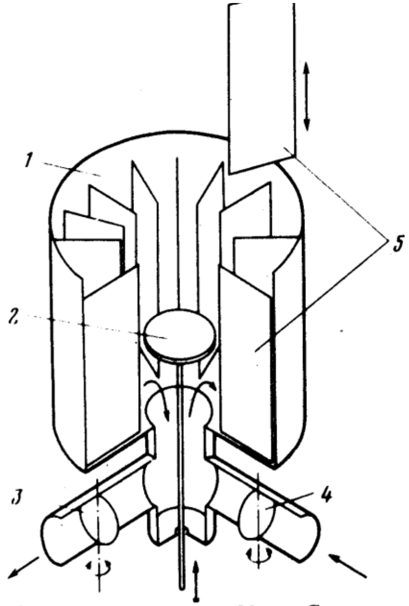
$\Delta\tau_n$=9.8(2.96) s (3.3σ)

$\Delta\tau_n$=8.4(2.2) s (3.8σ) PRL 111, 222501 (2013)

The first neutron lifetime experiment with UCN

(V.I. Morozov's group at SM-2 reactor Dimitrovgrad, Russia)

Pis'ma Zh. Eksp. Teor. Fiz. **31**, No. 4, 257–261 (20 February 1980)



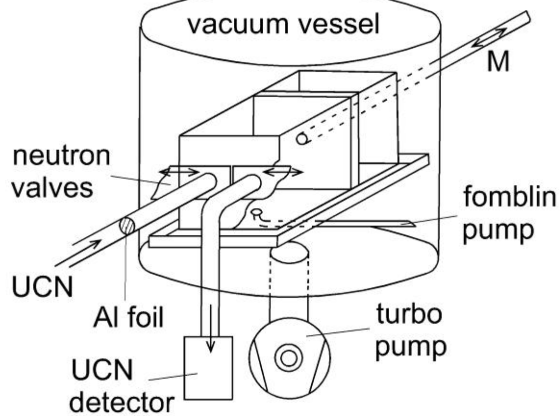
885.4 ± 0.95 s	S. Arzumanov et al. 2000

Experiment MAMBO I

W.Mampe et al. PRL 63 (1989)

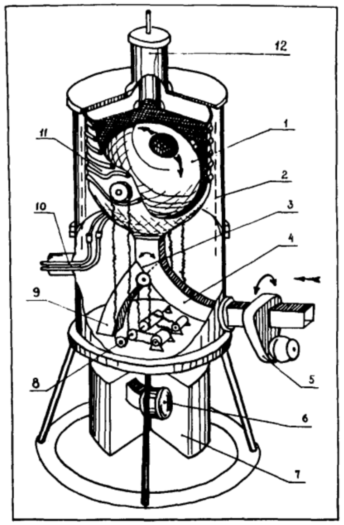
with fomblim oil

ILL reactor, Grenoble

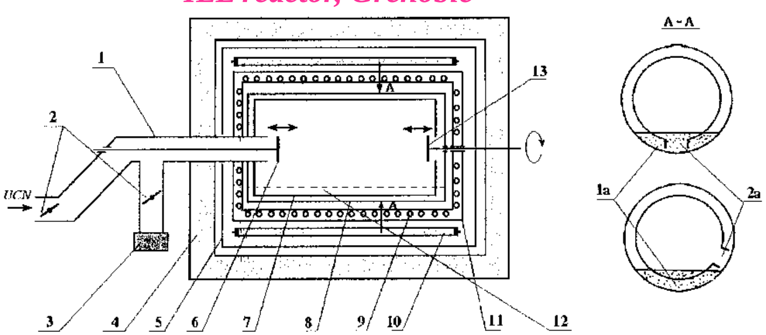


ILL reactor, Grenoble

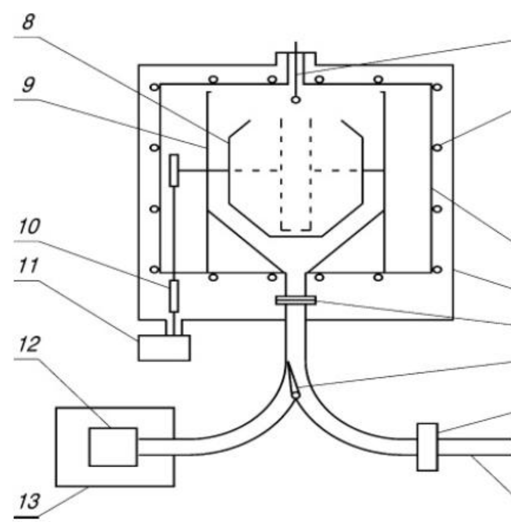
Experiment with Gravitational trap for UCN (PNPI,Gatchina)



ILL reactor, Grenoble



ILL reactor, Grenoble



Gravitrap experiment

A.Serebrov et al. Phys Lett B 605, (2005) 72-78

878.5 ± 0.8 s

2002-2004 (PNPI-JINR-ILL), ILL reactor, Grenoble

Gravitrap I

First trap of permanent magnets **2001**

V. F. Ezhov Technical Physics Letters. 2001. T. 27. C. 1055.

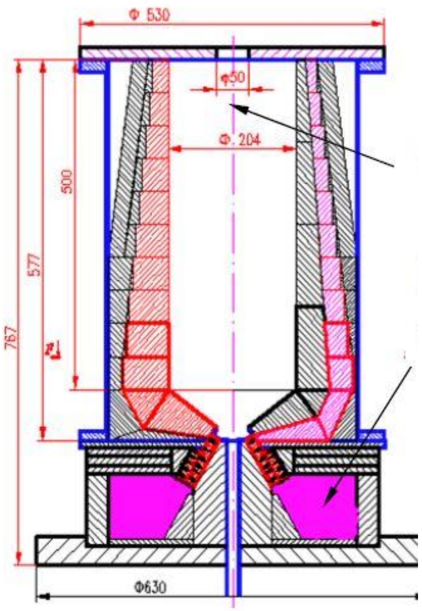
τ_n **=(878.3±1.9) s**

arXiv:**1412**.7434 [nucl-ex]
2014

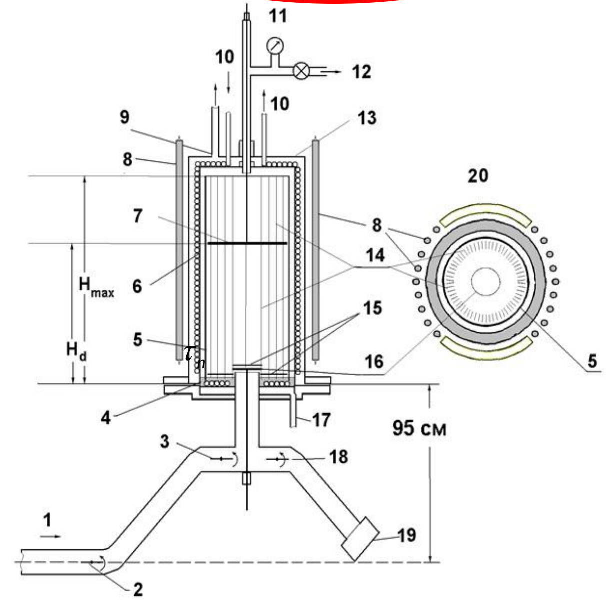
JETP 107 (11)
2018

2003

ILL reactor, Grenoble



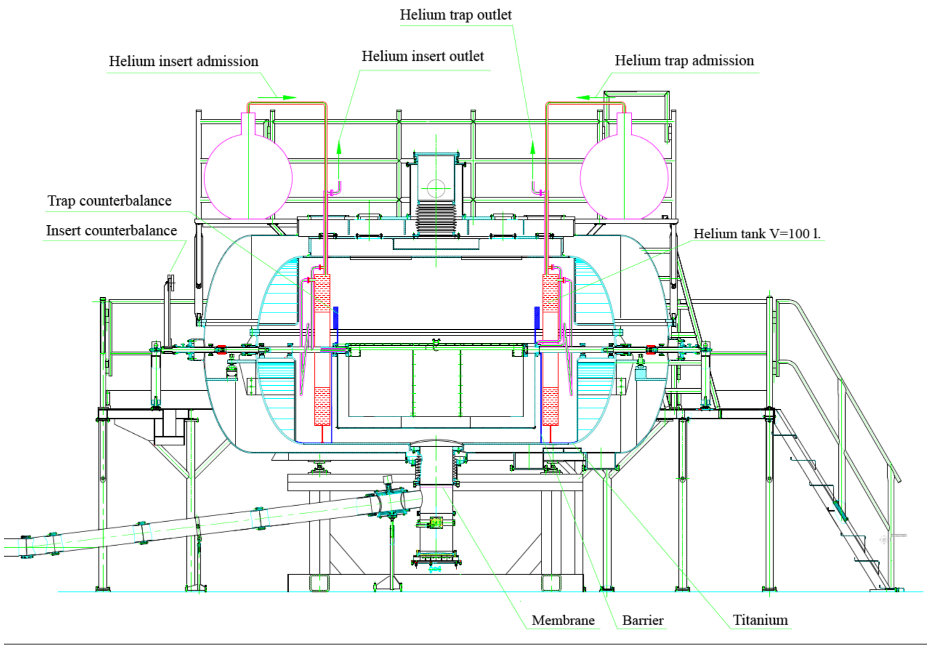
The result of experiment:
$\tau = (880.2 \pm 1.2)$ s
Phys. Lett. B. 745 (2015) 79-89
V.I. Morozov 2015



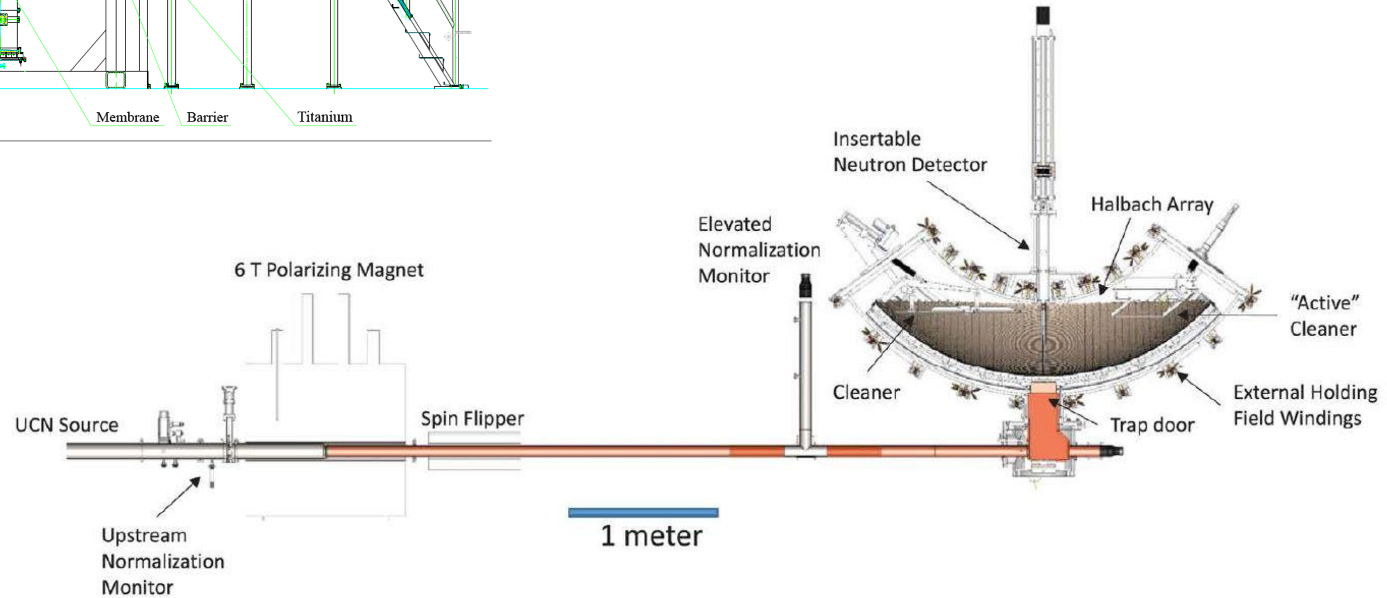
ILL reactor, Grenoble

Recent new neutron lifetime results

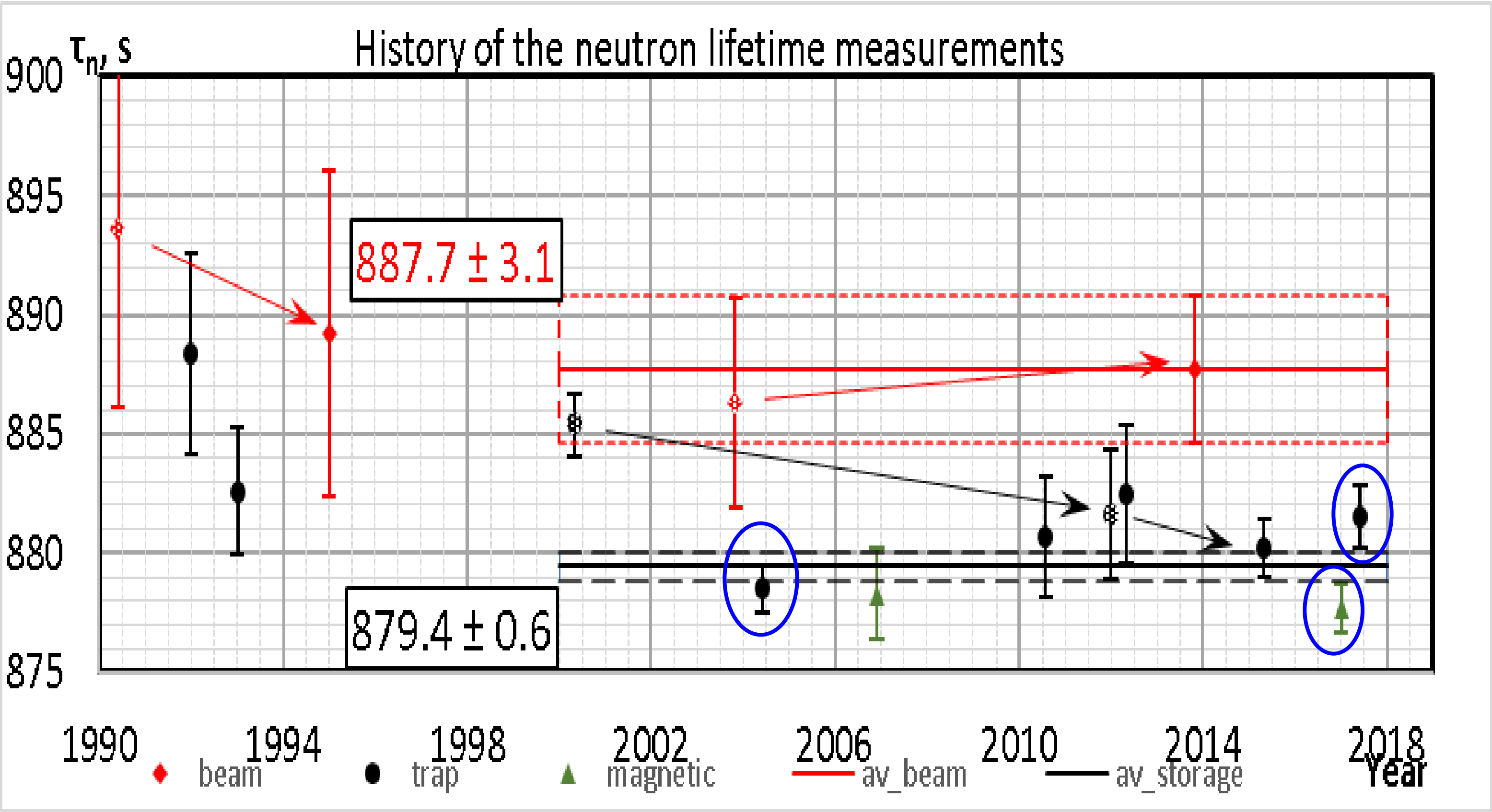
$$\tau_n = 881.5 \pm 0.7_{stat} \pm 0.6_{syst}\ s$$



As a result of this approach and the use of an in situ neutron detector, the lifetime reported here [**877.7 ± 0.7 (stat) +0.4/–0.2 (sys) seconds**] does not require corrections larger than the quoted uncertainties.

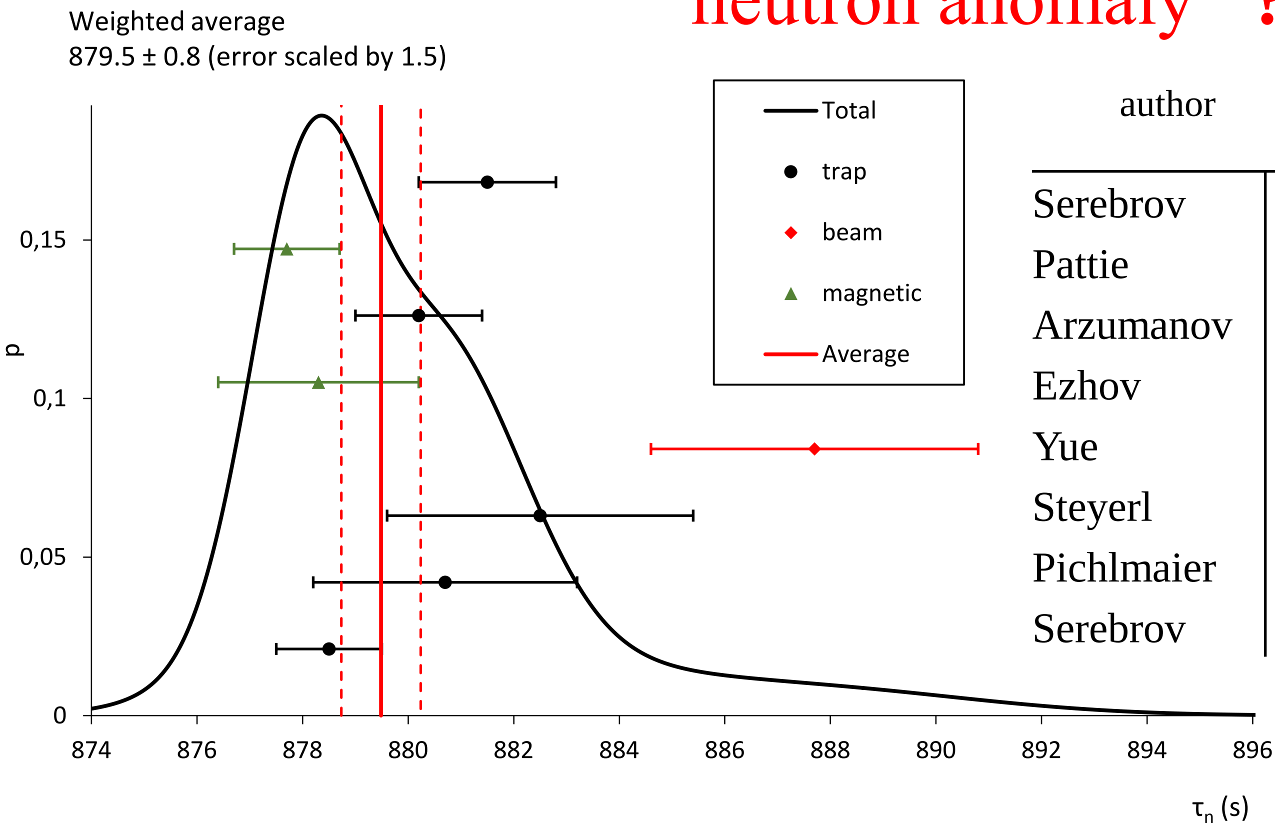


Latest measurements with gravitational trap (PNPI , Russia) and magnetic trap (LANL, USA) confirmed the result obtained by PNPI group in 2005.



The results of measurements performed using UCN storing method are in good agreement, however there is a significant discrepancy at 3.5σ (1% of decay probability) level with beam method experiment. That discrepancy is mentioned in scientific literature as "neutron anomaly". The possible sources of the discrepancy are discussed.

“neutron anomaly” ?



author	year	value	error stat	error sys	error Σ	χ^2
Serebrov	2017	881.5	0.7	0.6	**1.3**	2.4
Pattie	2017	877.7	0.7	0.3	**1.0**	3.2
Arzumanov	2015	880.2	1.2		**1.2**	0.4
Ezhov	2014	878.3	1.9		**1.9**	0.4
Yue	2013	887.7	1.2	1.9	**3.1**	7.0
Steyerl	2012	882.5	1.4	1.5	**2.9**	1.1
Pichlmaier	2010	880.7	1.3	1.2	**2.5**	0.2
Serebrov	2004	878.5	0.7	0.3	**1.0**	1.0

The discrepancy between beam and UCN storing experiments is 3.5σ if we use quadratic addition and 2.6σ is we use linear addition. In any case it is a noticeable discrepancy and it is sometimes called "neutron anomaly". It would be very interesting to have the results of repeated experiment with neutron beam and proton trap, and also an independent experiment with neutron beam and registration of both protons and electrons from neutron decay.

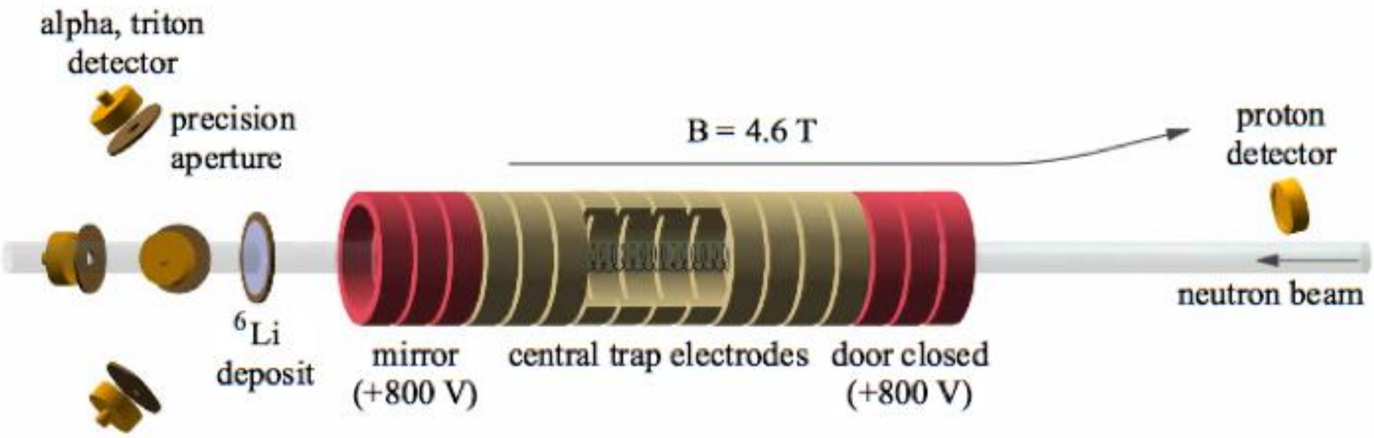
The repeating of the experiment with proton trap is planned as well as a new experiment at neutron beam. It may clarify the neutron anomaly problem or will lead to more certain proofs of its existence.

Neutron Lifetime with a Cold Beam

Apparatus Mounted on NG-6 at NCNR

New NIST beam proposal there they hope to reach systematic uncertainty at the level of 0.2 sec was accepted. (information from Geoff Greene)
They are given initial money to start design of the new modification.

Experimental Method



Collaboration: Gettysburg, Indiana, Michigan, TU Munich, NIST, ORNL, Tennessee, and Tulane

Support: NIST, DoE, NSF

Analysis of the discrepancy between beam and UCN storing measurement methods

The beam experiment is constructed on the basis of the following ratio (1):

$$\Delta N_p = \lambda N_n \Delta t$$

ΔN_p — number of the registered products of neutron decay (protons or electrons) when passing a neutron bunch through installation,

N_n — number of the neutrons which have passed through installation,

Δt — time of flight of neutrons through installation,

$\lambda = 1/\tau_n$ — probability of neutron decay,

τ_n — neutron lifetime.

At the same time the only channel of the neutron decay on p, e, $\tilde{\nu}$ is supposed. The probability of disintegration of a neutron in atom of hydrogen is negligible and is estimated in $3.9 \cdot 10^{-4}\%$.

The main difficulty of the beam experiment — absolute measurements of values in the ratio (1) and also efficiency of registration of protons.

UCN storing measurement method

The experiment with storage of ultracold neutrons is based on measurement of the following dependence on time:

$$N_n(t) = N_n(0)e^{-t/\tau_{storage}}$$

Where $N_n(t)$ — number of neutrons in the trap which can be measured by means of the neutron detector through certain intervals of time, $\tau^{-1}_{storage}$ — probability of storage of UCN in the trap:

$$\tau^{-1}_{storage} = \tau^{-1}_{n} + \tau^{-1}_{loss}$$

The main difficulty of an experiment with UCN is an exact measurement of probability of losses of UCN in the trap τ^{-1}_{loss}. Losses in the trap depend on the frequency of collisions with trap walls and interaction of UCN with residual gas in a trap:

$$\tau^{-1}_{losses} = \eta \cdot \gamma(E) + \tau^{-1}_{vac}$$

Where η — the factor of losses which isn't depending on energy of UCN,
γ(E) — the effective frequency of collisions depending on energy of UCN and the sizes of a trap,
τ^{-1}_{vac} — probability of loss of UCN at interaction with molecules of residual gas.

Some comments

Beam experiment is the one most accurate of beam experiments, its accuracy override previous beam experiments. The descrepancy between one beam experiments and the series of UCN storing experiments should not be called "neutron anomaly" yet, at least, one have to repeat the experiment and carry out independent beam experiments.

Naturally, in current situation of searching for "new physics" the interest to that problem is totally understandable. Any discrepancy at 3σ level becomes a matter of discussion. So we would like to look through and list here the ideas discussed before and under discussion now, which aims to explain the measurement discrepancy.

“Small heating" at storage of UCN in traps.

• One of the most popular hypotheses is so-called "small heating" at storage of UCN in traps. Recently work [1] in which even influence of rotation of Earth on storage of UCN in traps is considered has been published. Really, because of rotation of a trap and because of interaction of UCN to walls of a trap there will be a slow broadening of a range of the stored neutrons (a warming up and cooling). Because of increase in energy the neutron can leave a trap. In work [1] it is offered to consider this effect in experiments on storage of UCN, so far as concerns accuracy 1% is better. Due to these it should be noted that in an experiment with a big gravitational trap effect of "heating" UCN in the course of storage in a trap is controlled. "Heated" neutrons would jump out of a trap and would be found by the detector to currents of a long interval of storage of 1600 s. Experimental assessment on the top limit of such effect is less than one second. Besides, this effect is compensated at extrapolation to the zero frequency of impacts, i.e. at extrapolation by neutron life time.

[1] S. K. Lamoreaux. arXiv:1804.01087, 2018.

Assumptions about neutron –mirror neutron oscillations

Z Berezhiani.

When in 2005 the result 878.5±0.7±0.3s with a deviation 6.5s from data of PDG has appeared, in one of the assumptions were discussed neutron – mirror neutron oscillations.

1. The matter is that $n \to n'$ oscillations (if they exist) considerably are suppressed already in magnetic field of Earth.
2. Besides, the effect of leakage of UCN because of mirror components is proportional to number of collisions in a trap and is excluded at extrapolation to the zero frequency of impacts.

Thus, the idea of $n \to n'$ oscillations can't explain a divergence of two methods of measurements (with understating of result as UCN losses in the method of storage).

[2] A. P. Serebrov, E. B. Aleksandrov, N.A. Dovator et. al. // Nucl. Instr. Meth. A, Vol. 611, No. 2-3, 2009. pp. 137-140.

Dark matter particles with mass close to neutron mass

Recently an interesting explanation of the neutron decay anomaly was published in work [3]. It is based on introducing additional decay channel into dark matter in final state. Assuming those particles are stable in final state then they can be the dark matter particles with mass close to neutron mass.

That experimental test [4] was performed almost right after the publication [3] At 4σ confidence level monochromatic γ-quanta were not observed.

[3] B. Fornal, B. Grinstein. arXiv:1801.01124, 2018.

[4] Z. Tang, M. Blatnik, L. J. Broussard et. al. arXiv:1802.01595, 2018.

Mirror dark matter again

[5] Z Berezhiani. arXiv:1807.07906, 2018.

In the recent publication [5] the scheme of mirror dark matter when

$$m_n - m_{n'} \approx 10^{-7} \text{ eV}$$

is considered. Further it is supposed that when the neutron flies by through magnetic field of the solenoid, there is compensation of a difference of mass thanks to energy in magnetic field due to the magnetic moment of a neutron. Transitions of n→n' amplify, and the share of standard decay decreases by 1%. Such assumption can be investigated in an experiment [6], varying magnetic field and also in a new beam experiment [7] with magnetic field by 5 times smaller which prepares now.

A. Serebrov et.el. arXiv:1802.06277, 2018.

The result of the analysis is the conclusion that for mirror neutrons the region of the mass difference $m_n - m_{n'} \geq 3$ MeV is closed. The region of the mass difference $m_n - m_{n'} \leq 2$ MeV turned out to be not closed, because there are practically no nuclides with neutron binding energies below 2 MeV.

[6] A. T. Yue, M. S. Dewey, D. M. Gilliam et al. // Phys. Rev. Lett., Vol. 111, No. 22, 2013. P. 222501.

[7], N. Sumi, H. Otono, T. Yoshioka et.al. arXiv:1712.01831, 2017.

Measurements of neutron decay asymmetry and Standard Model test

We can consider in more detail a research of the neutron decay including measurement of asymmetry decay and the test of Standard Model. As it is well known, the matrix V_{ud} element of a matrix of CKM can be defined from decay of a neutron thanks to measurements of lifetime and asymmetry of decay. We can be compared to other methods of definition V_{ud}.

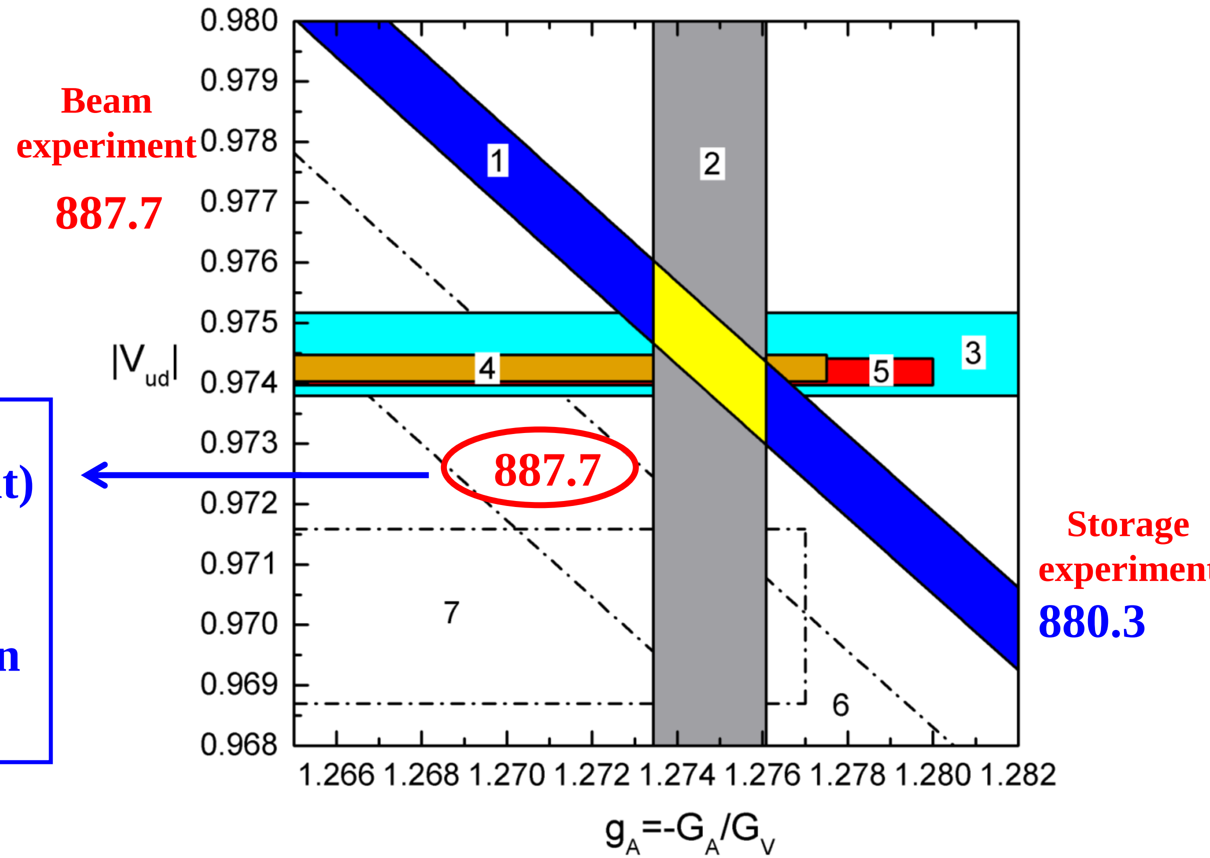
It is possible to see that the test for Standard Model is carried out successfully only in a case of use of data of neutron lifetime from experiments with storage of UCN and sharing of the most exact data of asymmetry of decay.

D. Mund, B. Märkisch, M. Deissenroth et. al. // Phys. Rev. Lett., Vol. 110, 2013. P. 172502.

Analysis of neutron lifetime (887.7± 2.2 s from beam experiment) for Standard Model

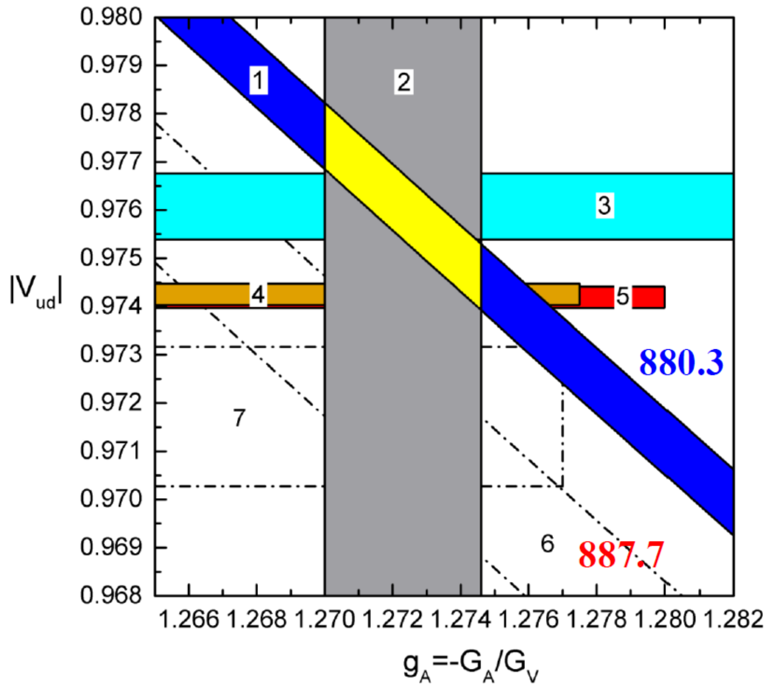
The best accuracy data

The result of neutron lifetime (887.7 s from beam experiment) is in contradiction with best measurements of asymmetry of β-decay because of analysis in frame of Standard Model



Dependence of the CKM matrix element $|V_{ud}|$ on the values of the neutron lifetime and the axial coupling constant g_A. (1) neutron lifetime, PDG 2015 (w/o Yue 2013); (2) neutron β-asymmetry, PERKEO II; (3) neutron β-decay, PDG 2015 (w/o Yue 2013) + PERKEO II; (4) unitarity; (5) $0^+ \rightarrow 0^+$ nuclear transitions; (6) neutron lifetime, Yue 2013; (7) neutron β-decay, Yue 2013 + PERKEO II.

PDG data



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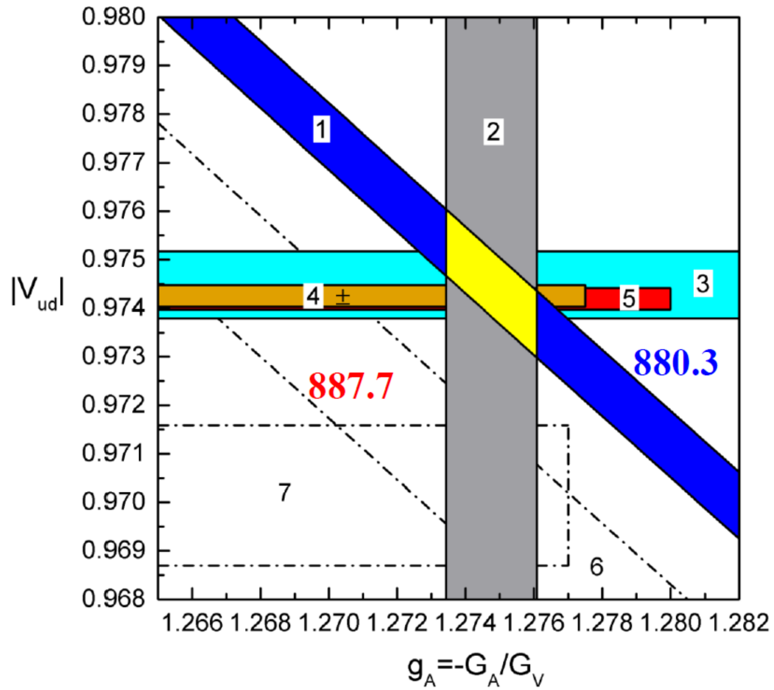

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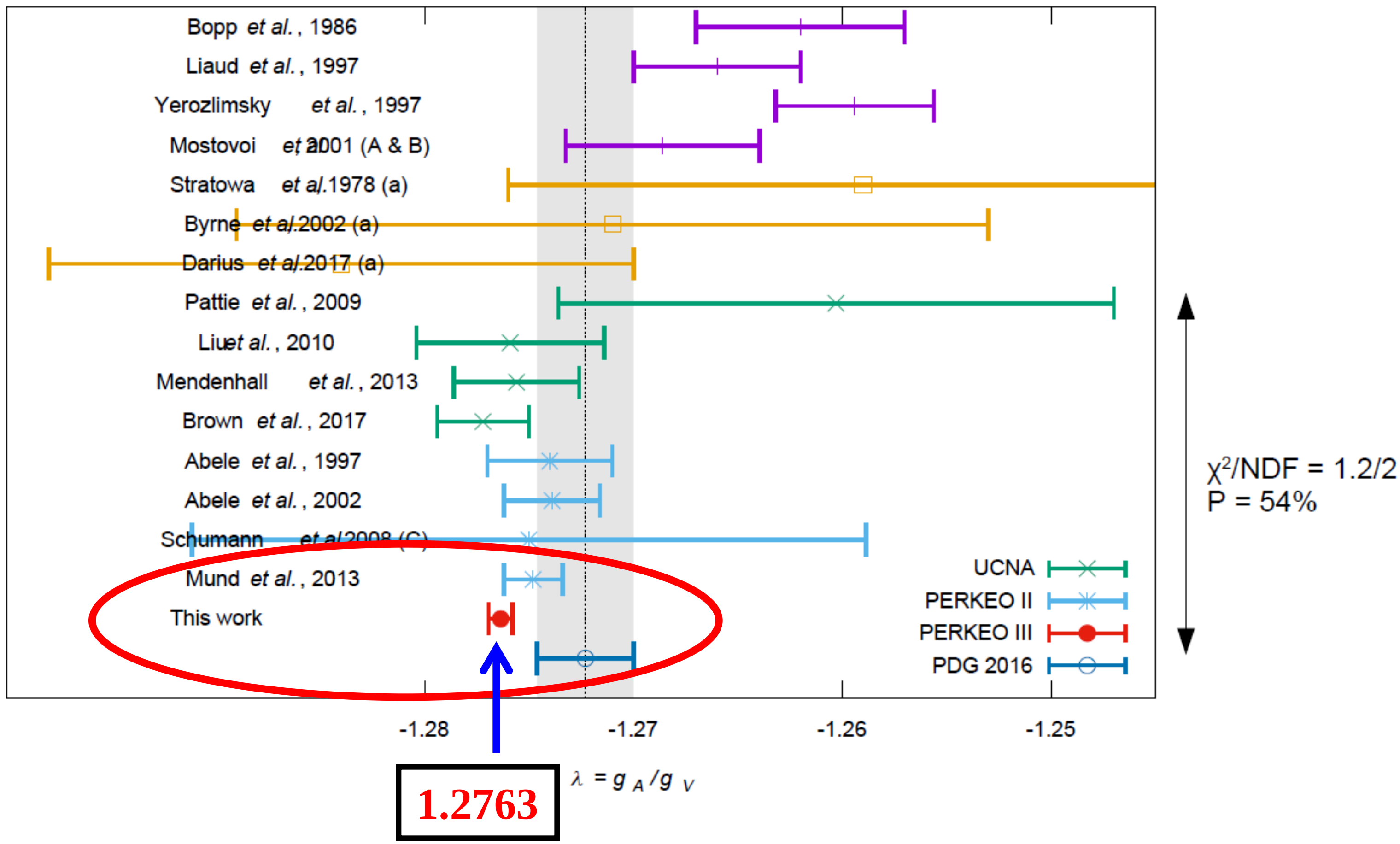
In this situation, we have to conclude that it is necessary to carry out new experiments for measuring $\lambda=G_A/G_V$ from β-decay to confirm the most precise result.

Status of g_A

AXIAL VECTOR- TO VECTOR COUPLING CONSTANT



Heiko Saul | Physik Department ENE, TUM | PPNS 2018, ILL Grenoble | May 24th 19

Analysis of neutron lifetime (887.7± 2.2 s from beam experiment) for Standard Model

The result of neutron lifetime (887.7 s from beam experiment) is in contradiction with best measurements of asymmetry of β-decay because of analysis in frame of Standard Model

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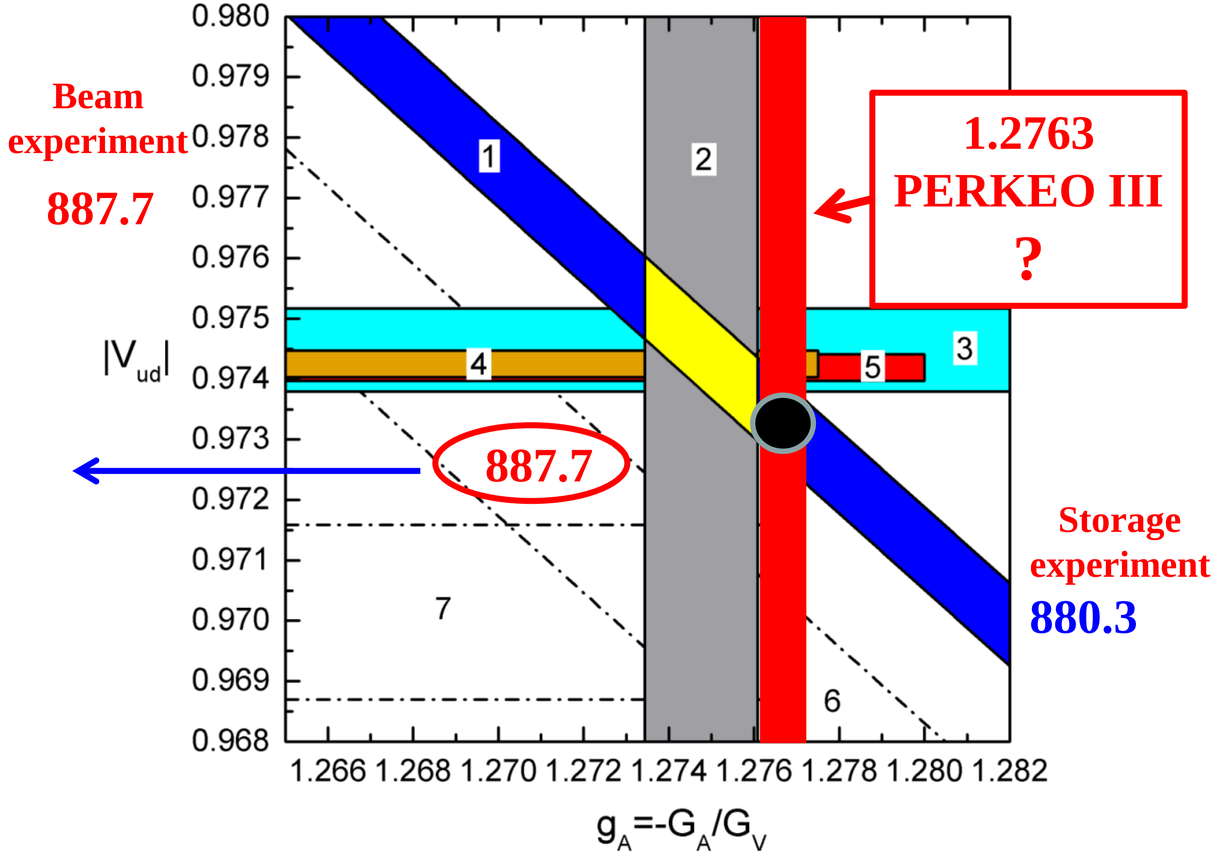

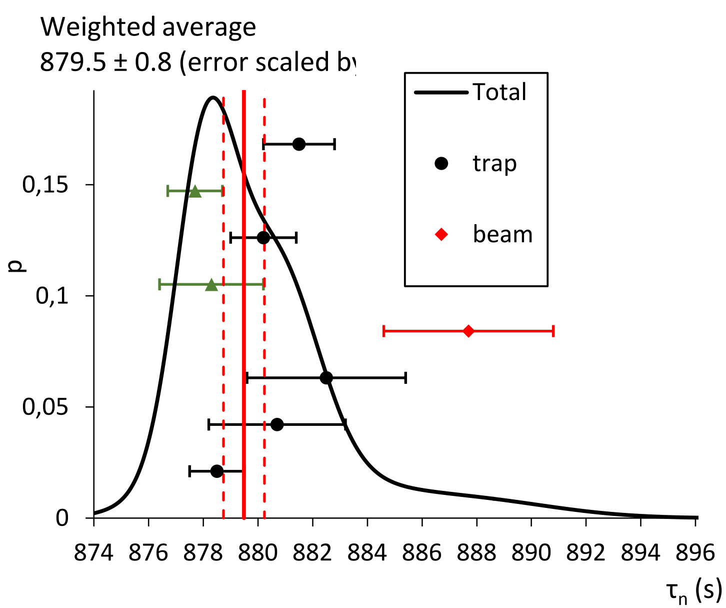

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Conclusion

1. New NIST beam proposal with systematic uncertainty at the level of 0.2 sec was accepted (information from Geoff Greene).

2. It will be crucial experiment because it will be very important restriction (or) for any additional decay channel besides well know.

It is possible that they would solve the problem of neutron anomaly or confirm the existence of the problem.

3. But for today, in problems of physics of elementary particles, astrophysics, cosmology and neutrino physics it is preferable to use value from experiments with UCN.

$$879.3 \pm 0.6s$$

Thank you for attention