Analysis of experimental data on neutron decay for the possibility of the existence of the right vector boson W_R

A.P. Serebrov

NRC "Kurchatov Institute" Petersburg Institute of Nuclear Physics, Gatchina, Russia

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1. **Precision studies of neutron decay and the search for deviations from the Standard Model**

2. Inconsistencies between experimental results and the $V\!-\!A$ theory of weak interaction

3. The decay of a neutron within the left-right manifest model of mixing left and right vector bosons can be successfully described by W_R with mass ($M_{W_R} = 304^{+28}_{-22}$ GeV, $\zeta = -0.038$)

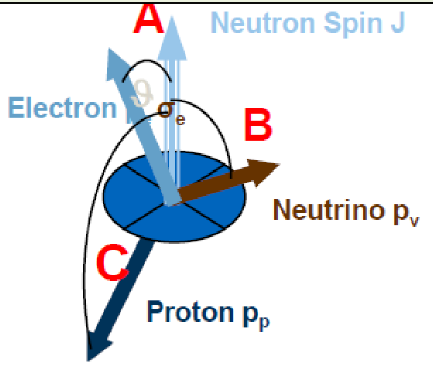
4. Why wasn't W_R(300 GeV , $\zeta = -0.038$) detected at FermiLab and CERN?

5. Prospects for neutron decay experiments

Precision studies of neutron decay and the search for deviations from the Standard Model

$$\frac{d^3\Gamma}{dE_e d\Omega_e d\Omega_\nu} = \frac{1}{2(2\pi)^5} G_F^2 |V_{ud}|^2 \left(1+3|\lambda|^2\right) p_e E_e \left(E_0 - E_e\right)^2$$
$$\times\left[1 + a\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + \frac{\langle\vec{\sigma}_n\rangle}{\vec{\sigma}_n}\cdot\left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e\times\vec{p}_\nu}{E_e E_\nu}\right)\right]$$

Jackson, Treiman, Wyld, Nucl. Phys. 4, 1957



$$A = -2\frac{\lambda^2+\lambda}{1+3\lambda^2}$$ **-0.11958(21) 0.17%**

$$B = 2\frac{\lambda^2-\lambda}{1+3\lambda^2}$$ **0.9807(30) 0.3%**

$\lambda = g_A/g_V$ **-1.2757(5) 0.04%**

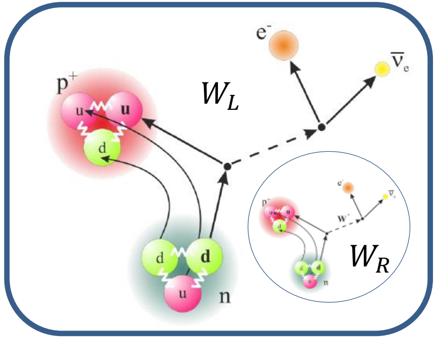
$$a = \frac{(1-\lambda^2)}{(1+3\lambda^2)}$$ **-0.1049(13) 1.3%**

$$D = 2\cdot\frac{\mathrm{Im}(\lambda)}{1+3|\lambda|^2}$$ **-1.2 (2.0)×10^-4^** ($-1.2\,(2.0)\times10^{-4}$)

Neutron lifetime

$$\tau^{-1} = G_F^2 |V_{ud}|^2 (1+3\lambda^2)\frac{f^R m_e^5 c^4}{2\pi^3\hbar^7}$$

877.75 ± 0.35s 0.04%



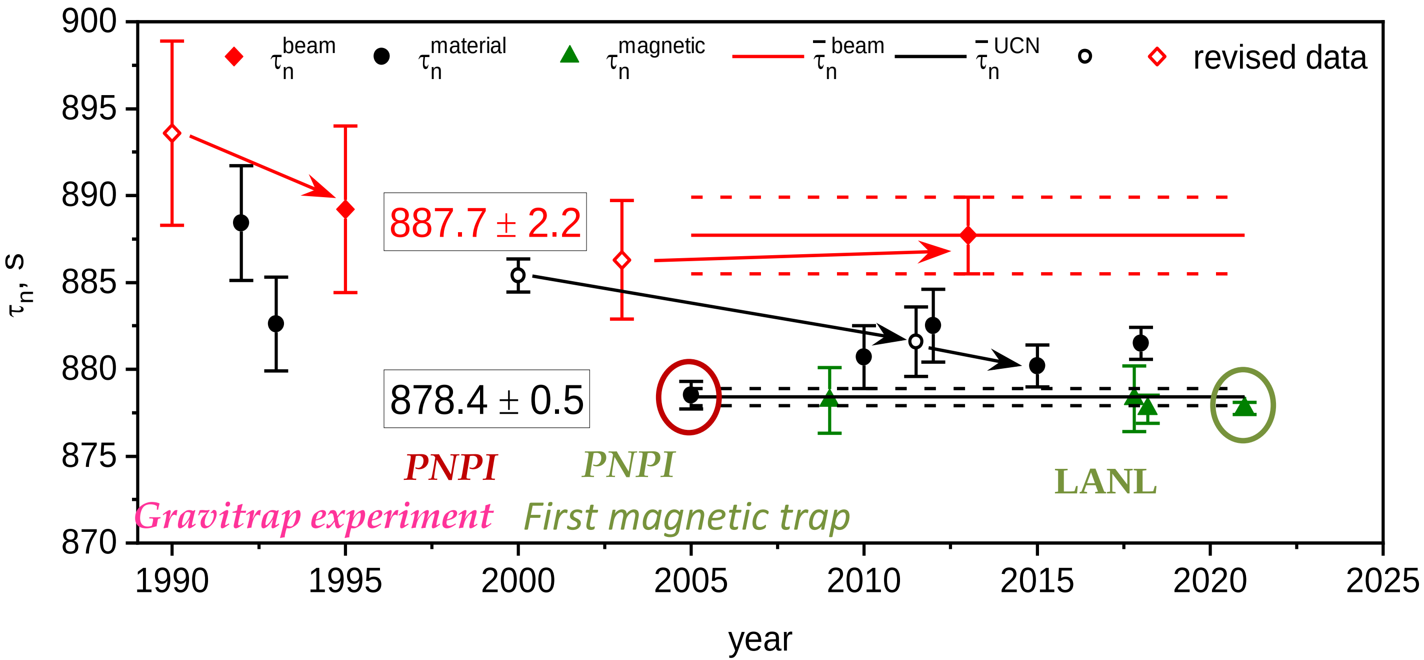
Unitarity CKM

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

$$V_{ud}^{unit} = \sqrt{1 - V_{us}^2 - V_{ub}^2} = 0.97452(18).$$

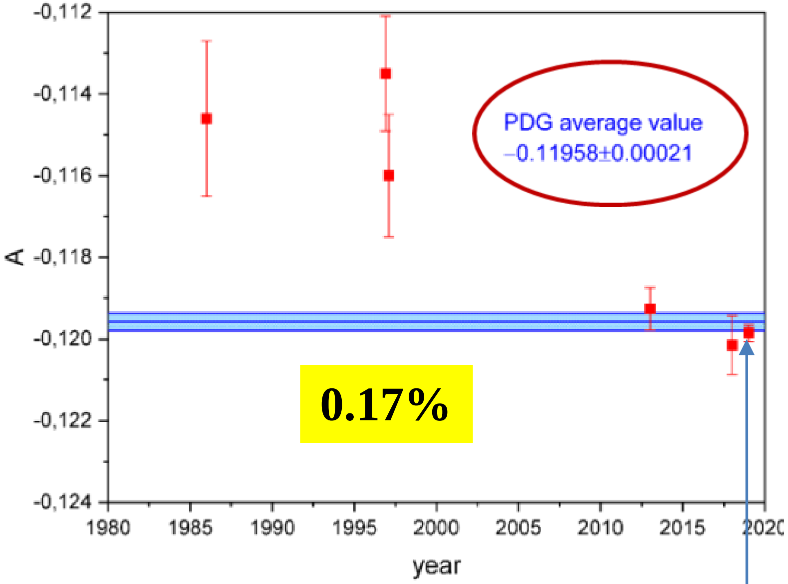
Improving the accuracy of measurements and trends in the neutron lifetime

Neutron lifetime

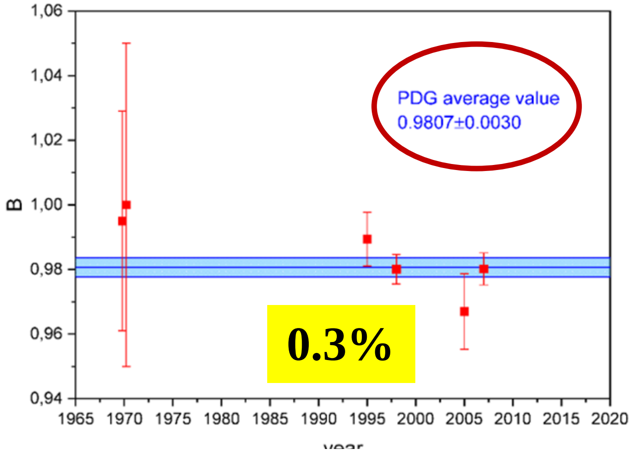


Experimental results on neutron lifetime since 1990 from [8], discrepancy between 2005 data [9] and 2000 data [10], new magnetic trap results (marked in green) which are decisive [11-14].

Measuring neutron decay asymmetries

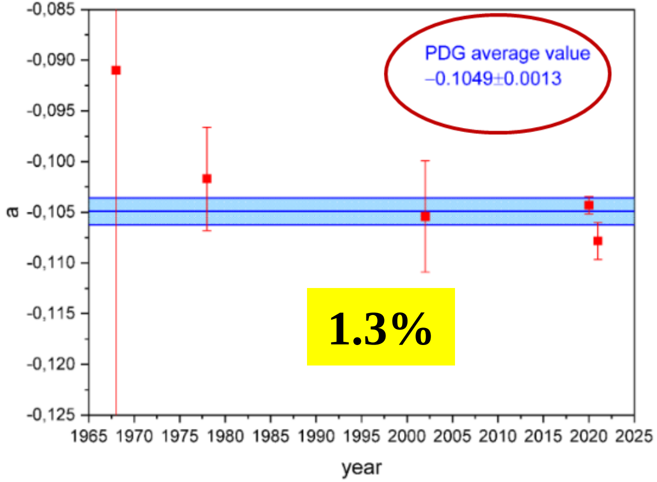


Measurements of the electron asymmetry of neutron decay (A) and the averaged PDG result [18].



Measurements of the neutrino asymmetry of neutron decay (B) and the averaged PDG result [18].

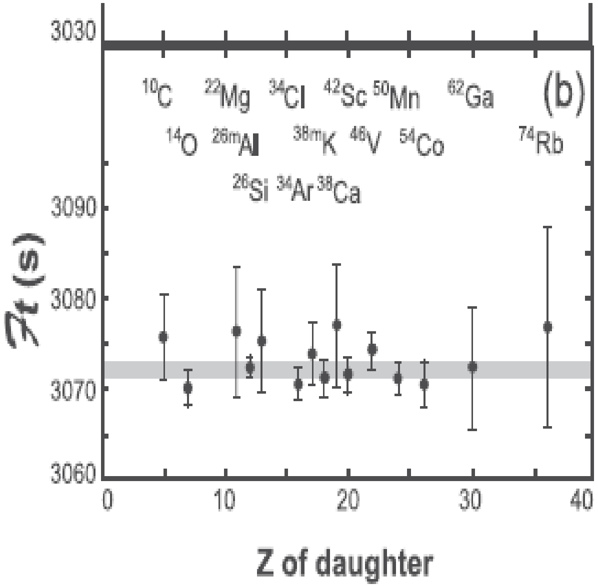
$\lambda = -1.2757(5)$



Measurements of the electron-neutrino asymmetry of neutron decay (a) and the averaged PDG result [18].

Superallowed $0^+ \rightarrow 0^+$ nuclear β decays: 2020 critical survey, with implications for V_{ud} and CKM unitarity

J. C. Hardy* and I. S. Towner
Cyclotron Institute, Texas A&M University, College Station, Texas 77843, USA

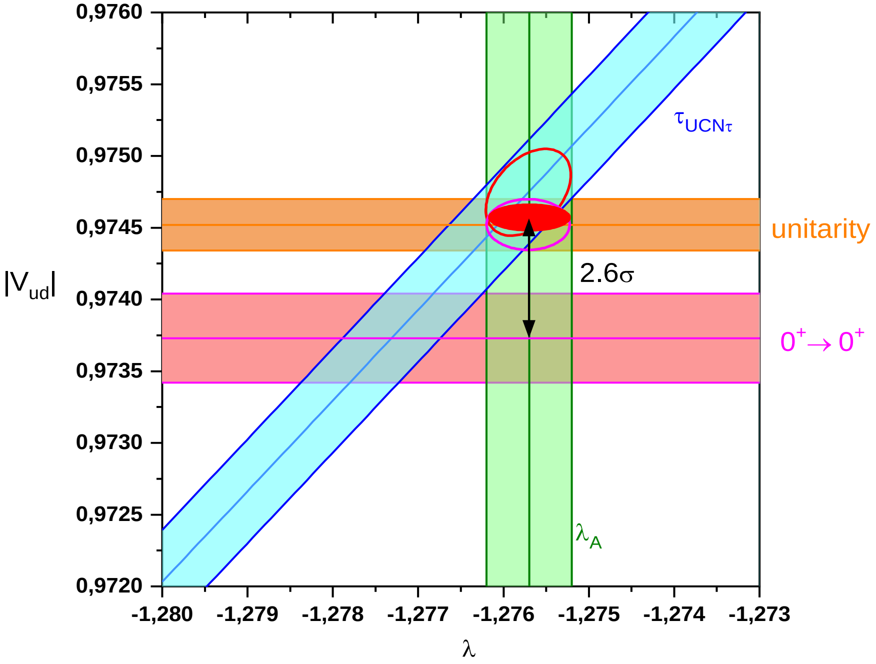


A new critical review of all half-life, decay energy, and branching ratio measurements associated with 23 superallowed 0+ → 0+ is available. Their average Ft combined with the muon lifetime yields the up-down quark mixing element of the Cabibbo-Kobayashi-Maskawa matrix, **Vud = 0.97373 ± 0.00031.** This is one standard deviation lower than our 2015 result, and its uncertainty has increased by 50%. This is not a consequence of any shifts in the experimental data, but of new calculations for the radiative corrections. **The lower Vud now leads to a higher tension in the top-row unitarity test in the CKM Matrix.**

This result is given in the last row of Table XVII:
where the unitarity sum is **|Vu|2 = 0.9985(6),**
indicating **unitarity violation of 2.4σ.**

Inconsistencies between experimental results and the $V\!-\!A$ theory of weak interaction

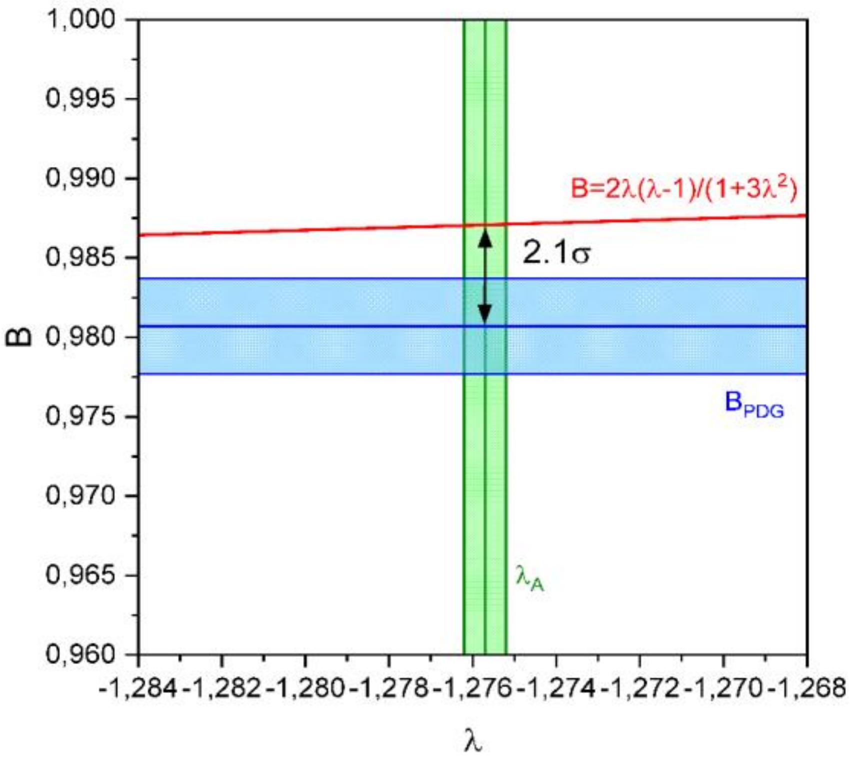
The difference Vud between the matching values and the Vud value from 0+-0+ transitions is 2.6 sigma



Dependence of the quark mixing matrix element Vud on λ , calculated using the SM formulas from neutron decay, from experiments with Fermi superallowed nuclear 0+ - 0+ transitions and from the unitarity of the SM matrix, using Vus measurements [18].

$$\frac{\Delta V_{ud}}{V_{ud}} = 8.6 * 10^{-4}(2.6\,\sigma)$$

There is a discrepancy between the experimental value of neutrino asymmetry and the SM prediction. The difference between these values is 2.1 sigma



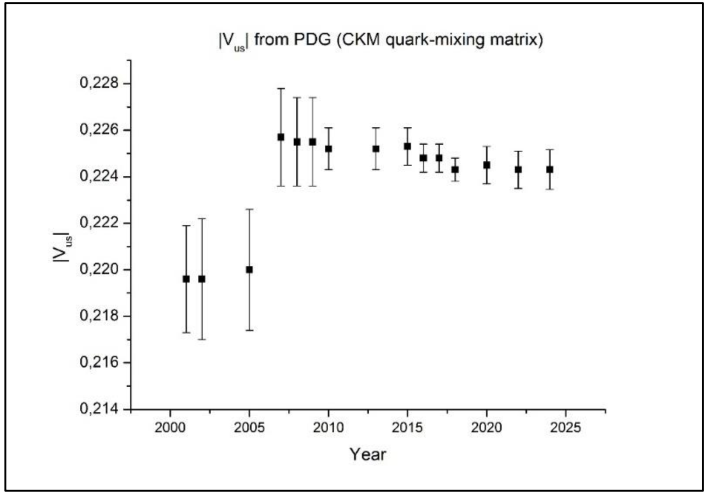
Comparison of the **experimental neutrino asymmetry** of neutron decay and that calculated within the SM framework depending on the ratio of the axial and vector constants of weak interaction λ.

$$\frac{\Delta B}{B} = 6.5 * 10^{-3} (2.1\sigma)$$

$$\frac{\Delta B}{B} = \frac{B_{\exp} - B_{SM}}{B_{SM}} \qquad B_{SM} = \frac{2\lambda_n(\lambda_n - 1)}{(1 + 3\lambda_n^2)}$$

Data |Vus| from PDG

$V_{us} = 0.2243(8)$



The third element of the top row, **|Vub|, is very small** and has almost no effect on the unitarity test. Its value from the Particle Data Group (PDG) evaluation is:

|Vub| = (3.94 ± 0.36) × 10−3

V_{ud}^{unit} from the unitarity of the CKM matrix

$$V_{ud}^{unit} = \sqrt{1 - V_{us}^2 - V_{ub}^2} = 0.97452(18).$$

however, the matrix element V_{ud}^{00} from $0^+ - 0^+$ beta decays is different

$$V_{ud}^{00} = 0.97367(32)$$

$$\frac{V_{ud}^{unit} - V_{ud}^{00}}{V_{ud}^{00}} = 8.6 * 10^{-4} (2.4\,\sigma)$$

The description of experimental results within the framework of the V-A version of the theory turns out to be unsatisfactory, since it cannot be represented by a single value of the parameter $\lambda = G_A / G_V$

$$\tau_{exp} = \frac{4905,7}{V_{ud}^2(1+3\lambda^2)}$$

$$a_{exp} = \frac{(1-\lambda^2)}{(1+3\lambda^2)}$$

$$A_{exp} = -\frac{2\lambda(\lambda+1)}{1+3\lambda^2}$$

$$B_{exp} = \frac{2\lambda(\lambda-1)}{1+3\lambda^2}$$

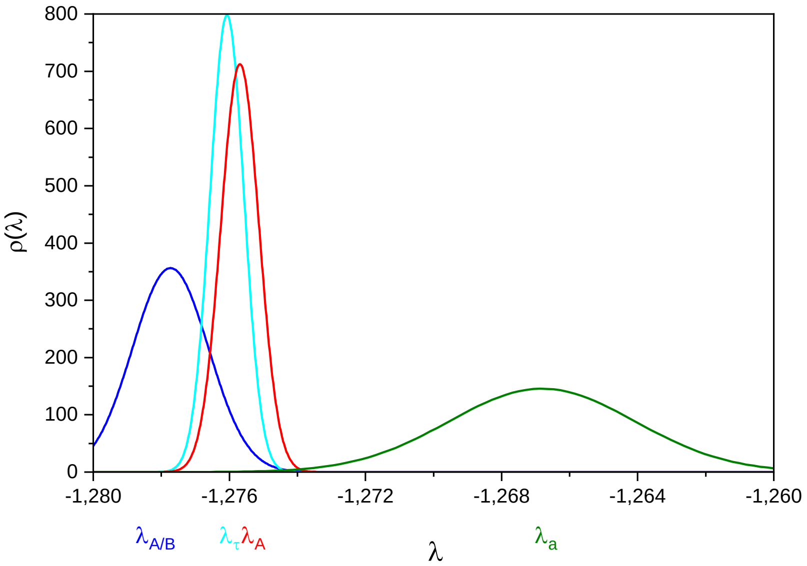
$$\tau_{exp} = 877.75(35)$$

$$a_{exp} = -0.10402(82)$$

$$A_{exp} = -0.11958(21)$$

$$B_{exp} = 0.9807(30)$$

$$V_{ud}^{unit} = 0,97452(18)$$



Results of calculating the parameter value $\lambda = G_A / G_V$ within the V-A version of the weak interaction theory, the experiments for a, A, B and τ cannot be represented by a single value.

The observed discrepancy can be analyzed within the framework of a model taking into account right-handed currents. In the simplest left-right manifesto of the model, mixing of left and right vector bosons is considered, and for current states W_L W_R and mass states W_1 W_2 we can write:

$$W_L = W_1 \cos\zeta + W_2 \sin\zeta$$

$$W_R = e^{-i\omega}(-W_1 \sin\zeta + W_2 \cos\zeta)$$

where ζ is the angle of mixing of current states W_L and W_R, δ – ratio of the squares of the masses of states W_1 and W_2.

ω - CP-violating phase

V-A variant of the theory

$$\tau_{\exp} = \frac{4905,7}{V_{ud}^2(1+3\lambda^2)}$$

$$a_{\exp} = \frac{(1-\lambda^2)}{(1+3\lambda^2)}$$

$$A_{\exp} = -\frac{2\lambda(\lambda+1)}{1+3\lambda^2}$$

$$B_{\exp} = \frac{2\lambda(\lambda-1)}{1+3\lambda^2}$$

left-right manifest model

$$\tau_{\exp} \pm \Delta\tau_{\exp} = \frac{4905,7}{V_{ud}^2[1+x^2+3\lambda^2(1+y^2)]}$$

$$a_{\exp} \pm \Delta a_{\exp} = \frac{(1-\lambda^2)[1+(\delta+\zeta)^2]-4\delta\zeta}{(1+3\lambda^2)[1+(\delta+\zeta)^2]-4\delta\zeta}$$

$$A_{\exp} \pm \Delta A_{\exp} = -\frac{2\lambda[\lambda(1-y^2)+(1-xy)]}{1+x^2+3\lambda^2(1+y^2)}$$

$$B_{\exp} \pm \Delta B_{\exp} = \frac{2\lambda[\lambda(1-y^2)-(1-xy)]}{1+x^2+3\lambda^2(1+y^2)}$$

Where $x = \delta - \zeta, \quad y = \delta + \zeta.$

Expansion in δ and ζ of order no higher than two can be represented by the following expressions

$$\tau_{\exp} \pm \Delta\tau_{\exp} = \frac{4905,7}{V_{ud}^2[1+x^2+3\lambda^2(1+y^2)]}$$

$$a_{\exp} \pm \Delta a_{\exp} = \frac{(1-\lambda^2)[1+(\delta+\zeta)^2]-4\delta\zeta}{(1+3\lambda^2)[1+(\delta+\zeta)^2]-4\delta\zeta}$$

$$A_{\exp} \pm \Delta A_{\exp} = -\frac{2\lambda[\lambda(1-y^2)+(1-xy)]}{1+x^2+3\lambda^2(1+y^2)}$$

$$B_{\exp} \pm \Delta B_{\exp} = \frac{2\lambda[\lambda(1-y^2)-(1-xy)]}{1+x^2+3\lambda^2(1+y^2)}$$

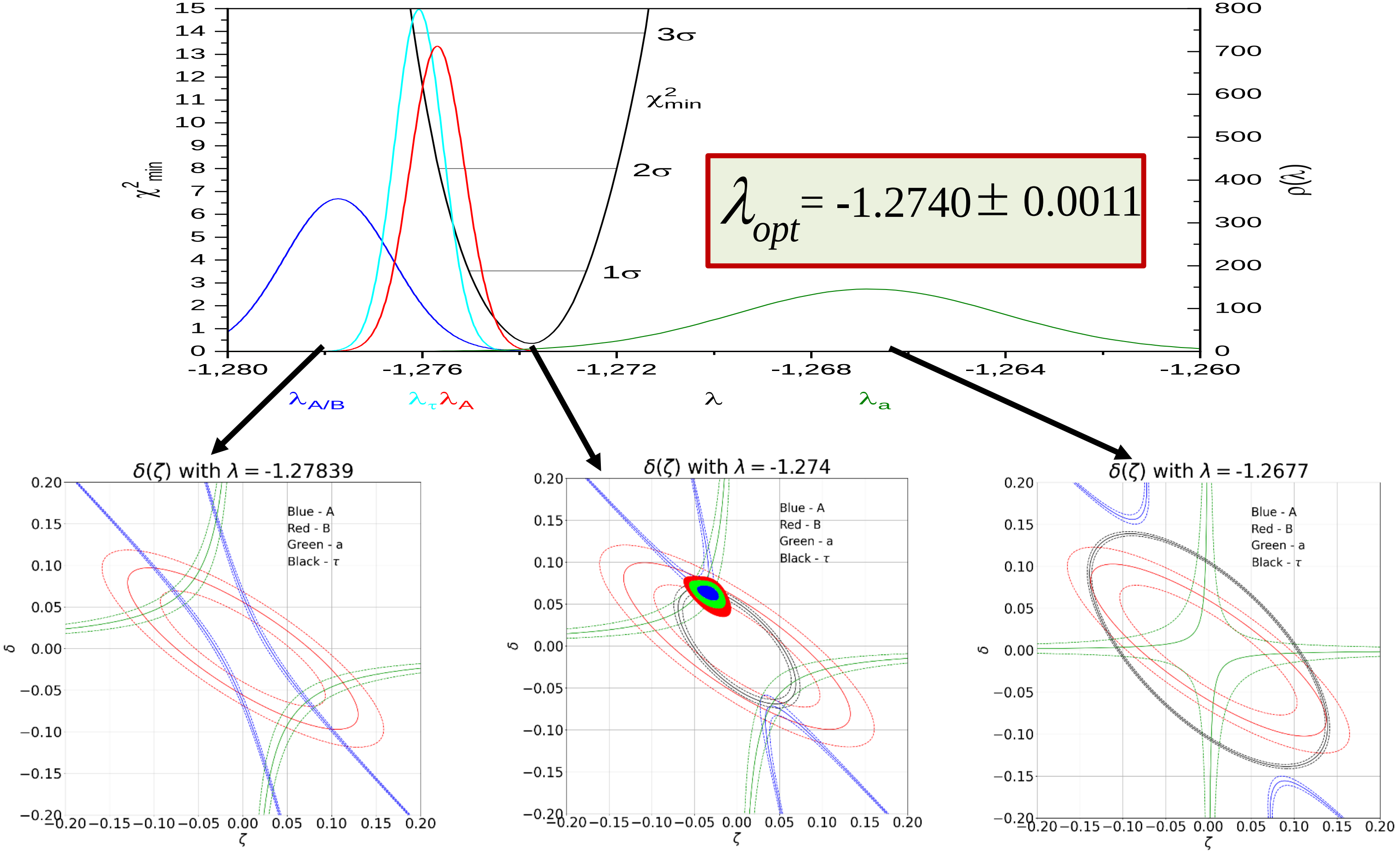
$$\frac{\tau_{\exp} \pm \Delta\tau_{\exp} - \tau_{V-A}}{\tau_{V-A}} \simeq -\left[\delta^2+\zeta^2+2\frac{\left(3\lambda^2-1\right)}{\left(3\lambda^2+1\right)}\delta\zeta\right]$$

$$\frac{a_{\exp} \pm \Delta a_{\exp} - a_{V-A}}{a_{V-A}} \simeq -\frac{16}{\left(1-\lambda^2\right)\left(1+3\lambda^2\right)}\delta\zeta$$

$$\frac{A_{\exp} \pm \Delta A_{\exp} - A_{V-A}}{A_{V-A}} \simeq -2\delta^2-2\delta\zeta\frac{\left[6\lambda^3+3\lambda^2-1\right]}{(\lambda+1)\left(1+3\lambda^2\right)}-2\frac{\lambda}{\lambda+1}\zeta^2$$

$$\frac{B_{\exp} \pm \Delta B_{\exp} - B_{V-A}}{B_{V-A}} \simeq -2\delta^2-2\delta\zeta\frac{\left[6\lambda^3-3\lambda^2+1\right]}{(\lambda-1)\left(1+3\lambda^2\right)}-2\frac{\lambda}{\lambda-1}\zeta^2$$

The search for optimal values was done using the method χ^2



$$\lambda_{opt} = -1.2740 \pm 0.0011$$

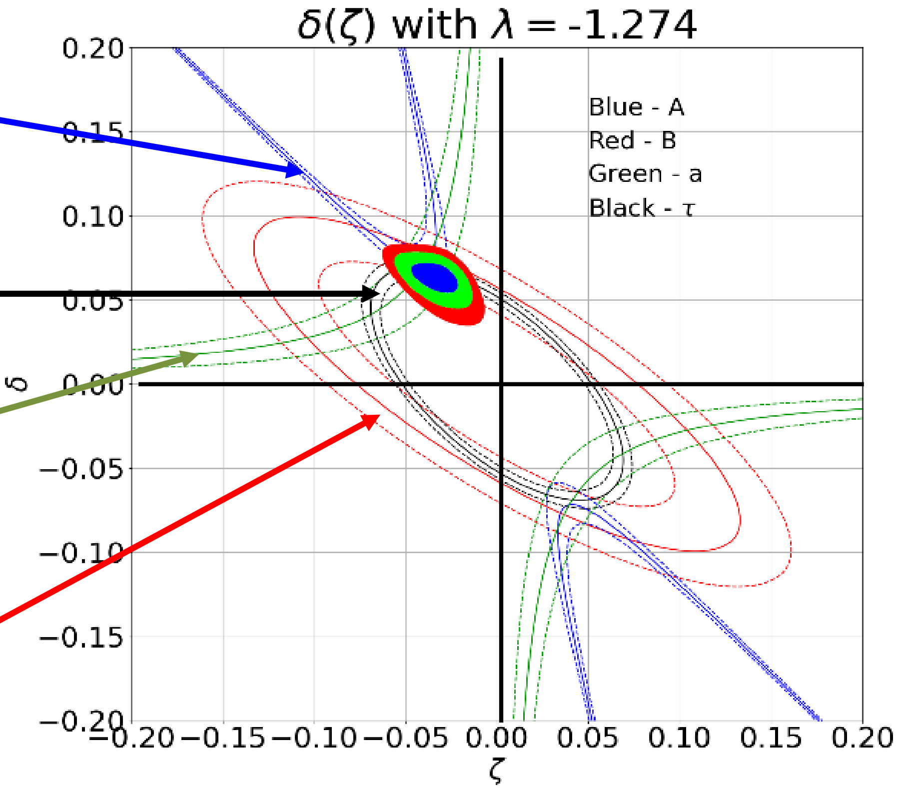
The decay of a neutron within the left-right manifest model of mixing left and right vector bosons can be successfully described

$$\frac{A_{\exp} \pm \Delta A_{\exp} - A_{V-A}}{A_{V-A}} \simeq -2\delta^2 - 2\delta\zeta \frac{\left[6\lambda^3 + 3\lambda^2 - 1\right]}{(\lambda+1)(1+3\lambda^2)} - 2\frac{\lambda}{\lambda+1}\zeta^2$$

$$\frac{\tau_{\exp} \pm \Delta\tau_{\exp} - \tau_{V-A}}{\tau_{V-A}} \simeq -\left[\delta^2 + \zeta^2 + 2\frac{(3\lambda^2 - 1)}{(3\lambda^2 + 1)}\delta\zeta\right]$$

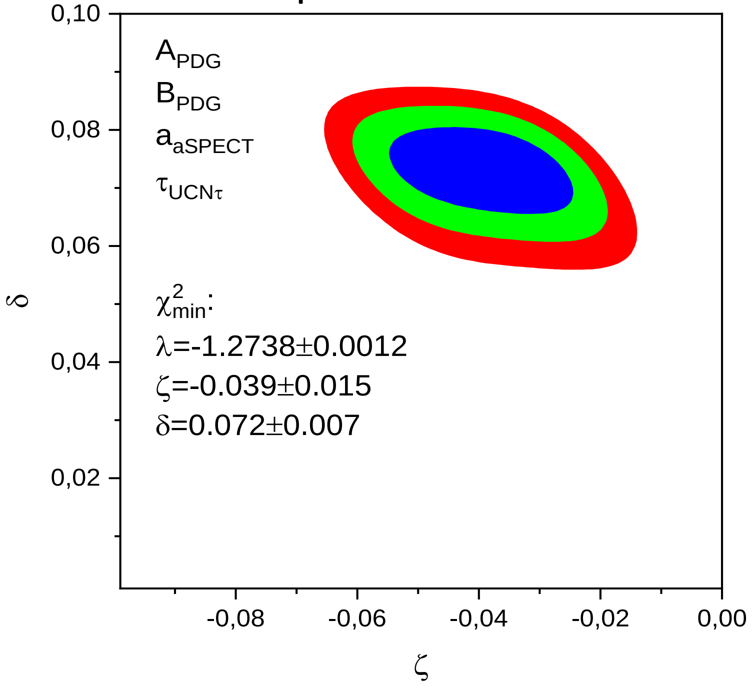
$$\frac{a_{\exp} \pm \Delta a_{\exp} - a_{V-A}}{a_{V-A}} \simeq -\frac{16}{(1-\lambda^2)(1+3\lambda^2)}\delta\zeta$$

$$\frac{B_{\exp} \pm \Delta B_{\exp} - B_{V-A}}{B_{V-A}} \simeq -2\delta^2 - 2\delta\zeta \frac{\left[6\lambda^3 - 3\lambda^2 + 1\right]}{(\lambda-1)(1+3\lambda^2)} - 2\frac{\lambda}{\lambda-1}\zeta^2$$

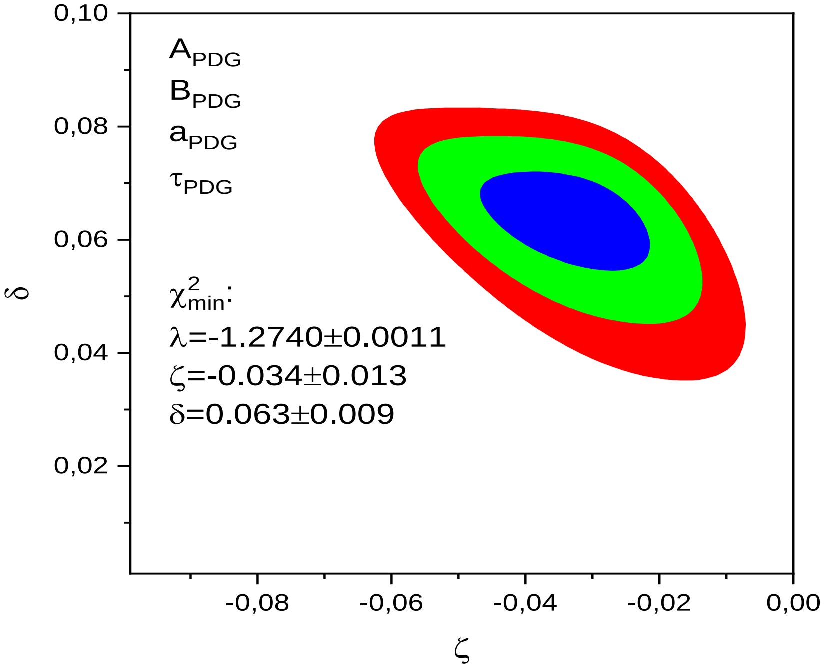


Optimal values of the parameters δ and ζ obtained by the χ2 method using experimental neutron decay data for a, A, B and τ

for the most accurate experimental data



for experimental data PDF

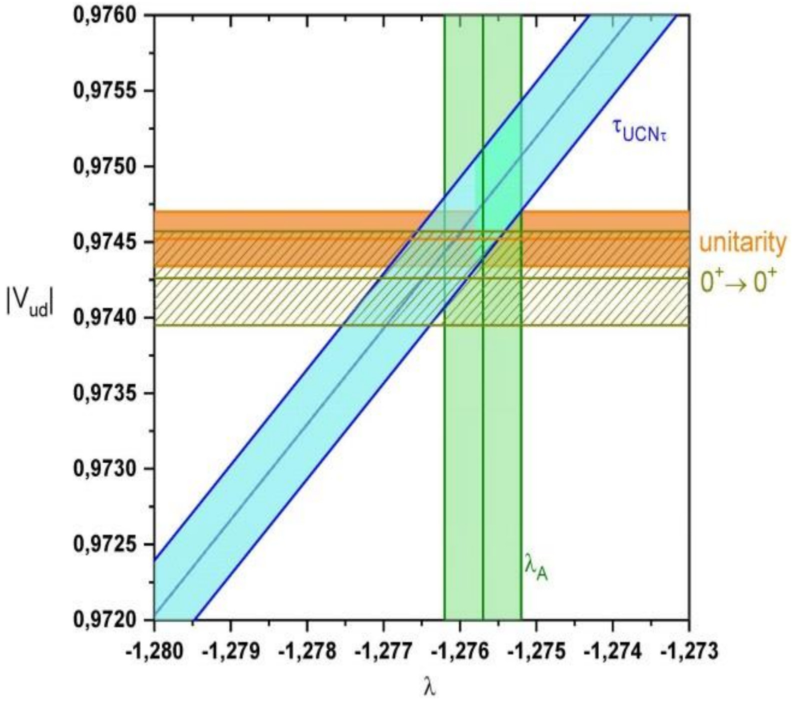


Analysis of Fermi superallowed 0^+–0^+ transitions taking into account the influence of right-handed currents

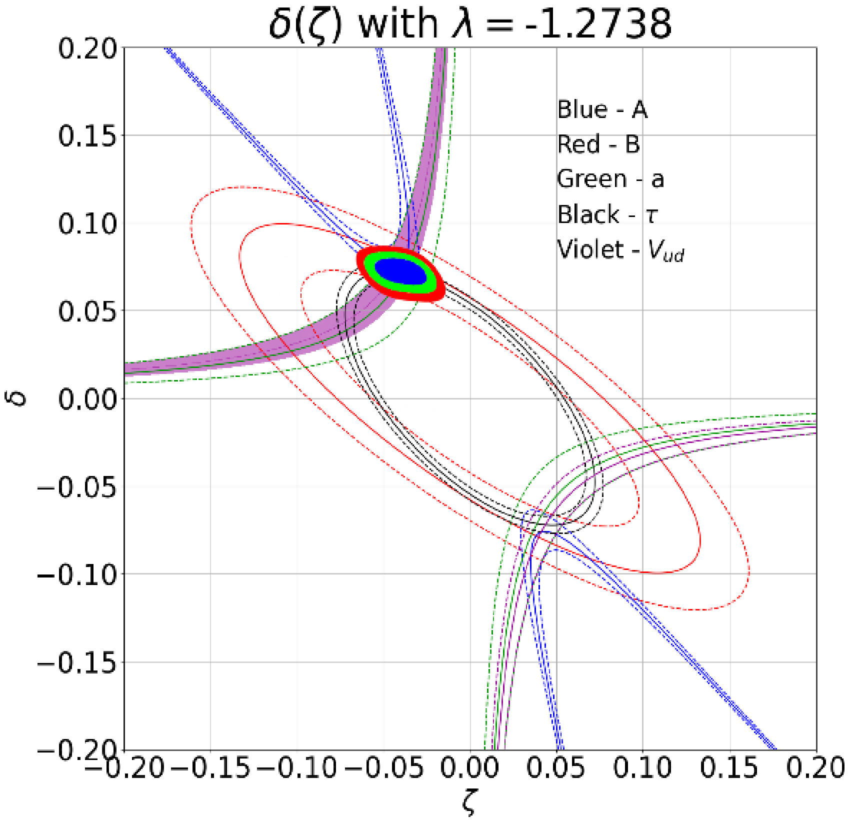
$$(V_{ud}^{00})^2 = (V_{ud,SM}^{00})^2[1+(\delta+\zeta)^2]$$

from neutron decay $V_{ud}^{n} = 0.97477(37)$,
from the unitarity $V_{ud}^{unit} = 0.97452(18)$,
from $0^+ - 0^+$transitions, $V_{ud}^{00} = 0.97426(31)$

Dependence of the quark mixing matrix element *V_ud* on , λ calculated using the SM formulas from neutron decay (blue area). Determination of λ from the electron asymmetry of neutron decay – A (green area). Determination of *V_ud* from the unitarity of the CM matrix, using *V_us* measurements [18] (orange area). **Determination of *V_ud* from experiments with Fermi superresolved nuclear 0+-0+ transitions after introducing a correction for the optimal parameters δ and ζ obtained in the analysis of neutron decay (shaded area).**



It is important to note that the coincidence was obtained when studying different objects - from neutron decay and from nuclear transitions.



It should be additionally noted that the contradiction noted in [22] as a violation of unitarity is eliminated. We explain this discrepancy within the framework of the left-right manifest model.

Dependence of the parameter δ on the parameter ζ from equations (5) for the results of measuring the quantities a, A, B and τ at the value λ_opt=−1.2738 with an additional analysis for 0^+−0^+ transitions from equation (11). Purple lines correspond to this additional analysis.

Taking into account the accuracy of calculation of radiative corrections

$$\frac{1}{\tau_n} = \frac{G_F^2 |V_{ud}|^2}{2\pi^3} m_e^5 (1 + 3\lambda_n^2)(1 + \mathrm{RC}) f$$

$$f = 1.6887(1)$$

Radiative corrections in the form of a multiplier $(1 + \mathrm{RC})$ can be represented as a work $(1 + \mathrm{RC}) = (1 + \delta_R)(1 + \Delta_R)$, where is the contribution

$\boldsymbol{\delta_R = 0.01505}$ arises from the exchange or emission of one photon exclusively, the contribution

$\boldsymbol{\Delta_R = 0.02381}$ – that part of the radiative corrections that is due to the exchange of electroweak boson and QCD corrections [24].

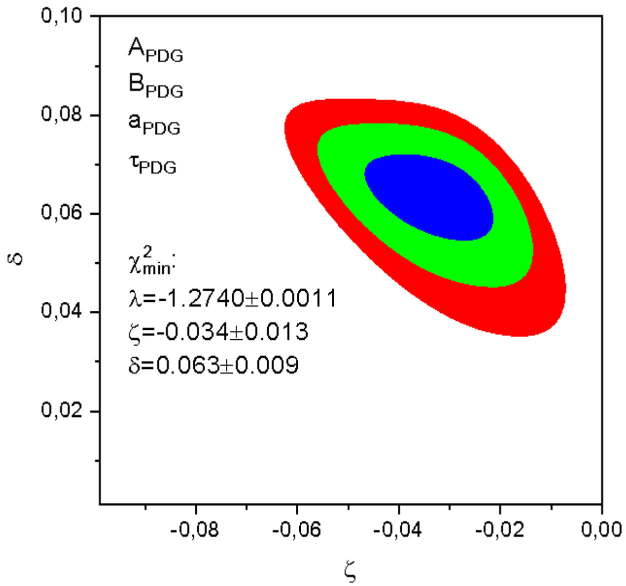
Table of radiative corrections to the neutron lifetime and correlation coefficients of neutron decay asymmetries in percent.

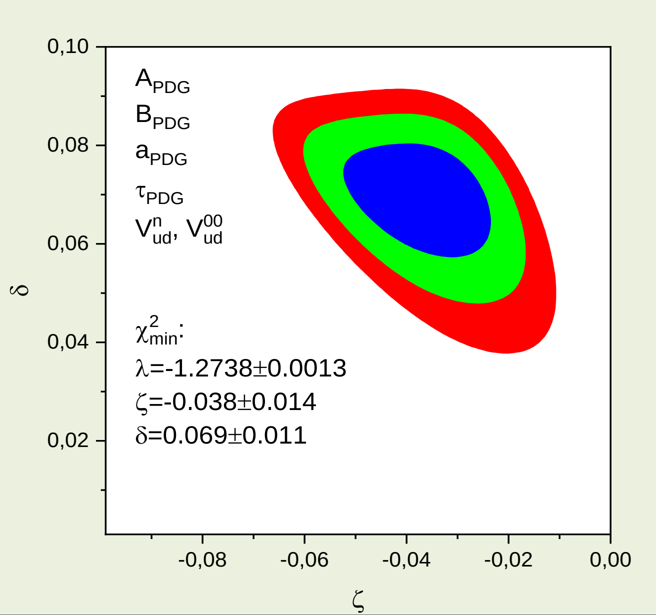
Size	Experimental error %	Correction %	Correction error %	Work
τ_n	0.040	**3.947**	**0.032**	[32]
A	0.176	-0.100	0.01	[16]
a	0.788	0.005	0.005	[35]
B	0.306	<0.1	<0.1	[24]

Taking into account the accuracy of the unitarity condition

The above analysis does not yet take into account the accuracy of determining V_{ud}^{unit} from experiments with strange and charmed mesons $V_{ud}^{unit} = \sqrt{1 - V_{us}^2 - V_{ub}^2} = 0.97452$ **(18).**

Therefore, a final analysis was carried out, taking into account the accuracy of the calculation of radiative corrections for the neutron lifetime and the accuracy of determining V_{ud}^{unit}.





Final result of analysis

Final result of the analysis

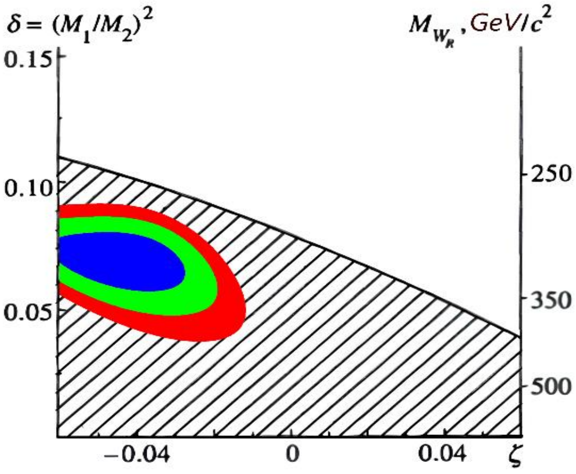
As a result of the analysis, it was found that there are indications of the existence of a right vector boson with mass and mixing angle

$$M_{W_R} = 304^{+28}_{-22}\ \text{GeV}$$

$$\zeta = -0.038 \pm 0.014.$$

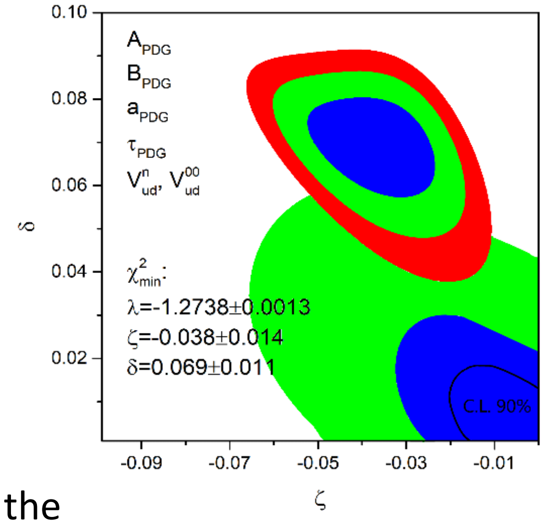
Comparison with the constraints on the mass of W_R and the mixing angle that were obtained earlier - in 1998 in [19] and in 2012 in [36].

Our work 1998 in [19]



Comparison of mass limits W_R and the mixing angle, which were obtained earlier in [19] (shaded area C.L. 90%).

More precise constraints on the W_R mass and mixing angle were obtained in muon decay:



$M_{W_R} > 592$ GeV (90% CL).

$-0.020 < \zeta < +0.017$ (90% CL)

Permitted areas $1\sigma, 2\sigma$ for the masses W_R and mixing angle ζ in the LRS model from [36].

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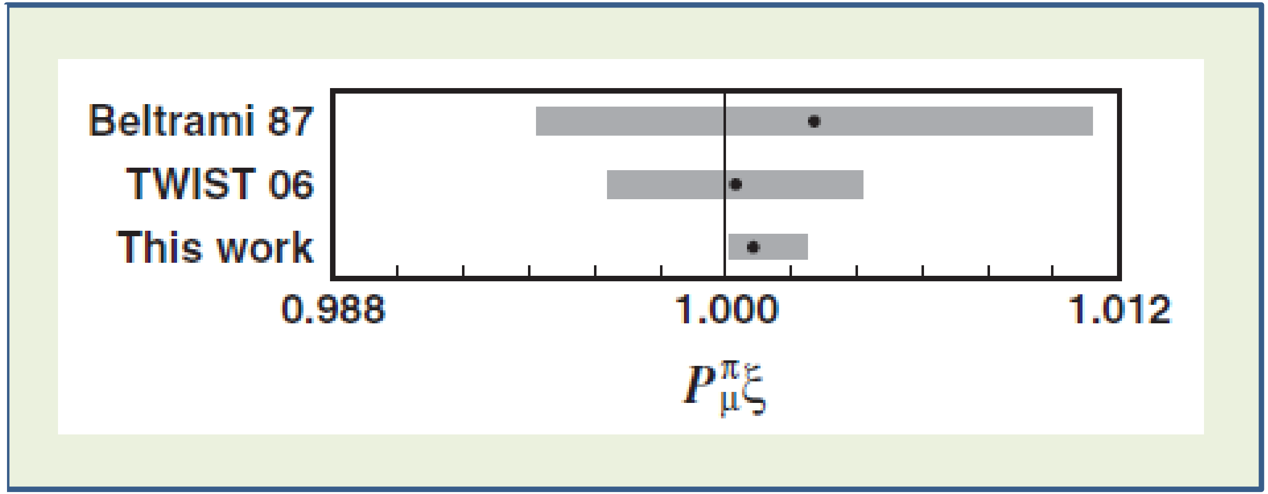
Precise measurement of parity violation in polarized muon decay

J. F. Bueno,[1,*] R. Bayes,[2,†] Yu. I. Davydov,[2,‡] P. Depommier,[3] W. Faszer,[2] C. A. Gagliardi,[4] A. Gaponenko,[5,§] D. R. Gill,[2] A. Grossheim,[2] P. Gumplinger,[2] M. D. Hasinoff,[1] R. S. Henderson,[2] A. Hillairet,[2,‖] J. Hu,[2,¶] D. D. Koetke,[6] R. P. MacDonald,[5] G. M. Marshall,[2] E. L. Mathie,[7] R. E. Mischke,[2] K. Olchanski,[2] A. Olin,[2,**] R. Openshaw,[2] J.-M. Poutissou,[2] R. Poutissou,[2] V. Selivanov,[8] G. Sheffer,[2] B. Shin,[2,††] T. D. S. Stanislaus,[6] R. Tacik,[7] and R. E. Tribble[4]

(TWIST Collaboration)

[1]University of British Columbia, Vancouver, British Columbia, V6T 1Z1, Canada
[2]TRIUMF, Vancouver, British Columbia, V6T 2A3, Canada
[3]University of Montreal, Montreal, Quebec, H3C 3J7, Canada
[4]Texas A&M University, College Station, Texas 77843, USA
[5]University of Alberta, Edmonton, Alberta, T6G 2J1, Canada
[6]Valparaiso University, Valparaiso, Indiana 46383, USA
[7]University of Regina, Regina, Saskatchewan, S4S 0A2, Canada
[8]Kurchatov Institute, Moscow, 123182 Russia



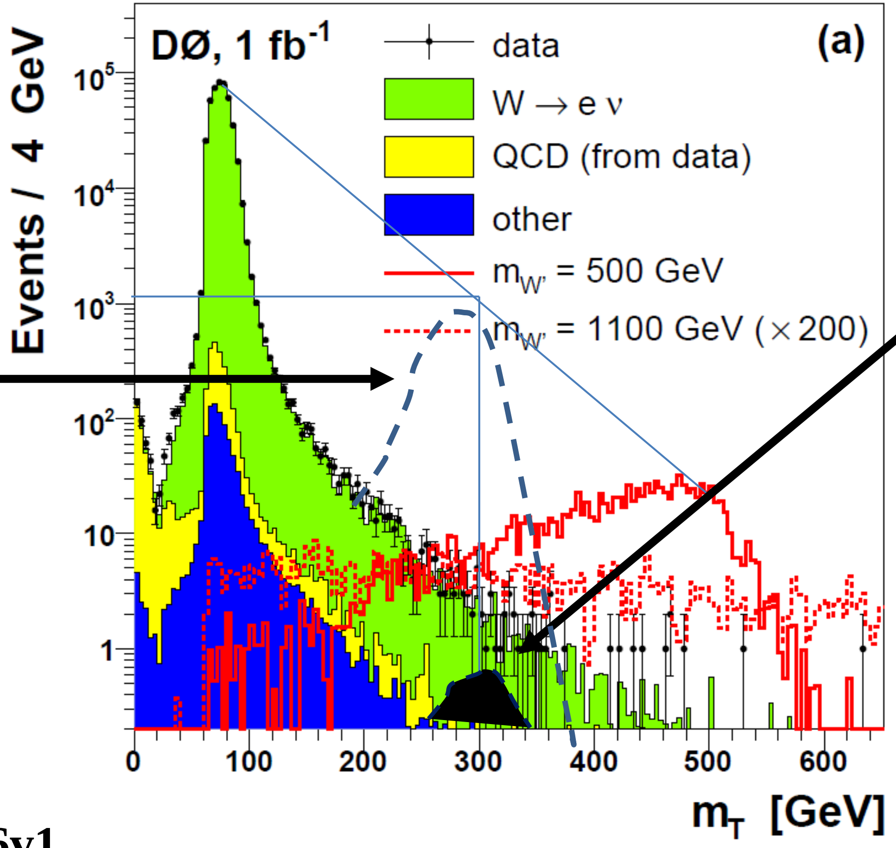
We present a new high precision measurement of parity violation in the weak interaction, using polarized muon decay. The TWIST Collaboration has measured $P^{\pi}_{\mu}\xi$, where P^{π}_{μ} is the polarization of the muon in pion decay and ξ describes the intrinsic asymmetry in muon decay. We find $P^{\pi}_{\mu}\xi = 1.000\,84 \pm 0.000\,29(\text{stat.})^{+0.001\,65}_{-0.000\,63}(\text{syst.})$, in good agreement with the standard model prediction of $P^{\pi}_{\mu} = \xi = 1$. Our result is a factor of 7 more precise than the pre-TWIST value, setting new limits in left-right symmetric electroweak extensions to the standard model.

Why $W_R(300\ \text{GeV}, \zeta = -0.038)$ wasn't detected at FermiLab and CERN?

Why $W_R(300\text{GeV}, \zeta = -0.038)$ wasn't detected at FermiLab?

Expected resonance for

W_R(300 GeV , ζ = 90 *degree*)



Expected statistics for

W_R(300 GeV , $\zeta = -0.038$)

Suppression factor from mixing angle

$\zeta^2 \approx 1.4 \cdot 10^{-3}$

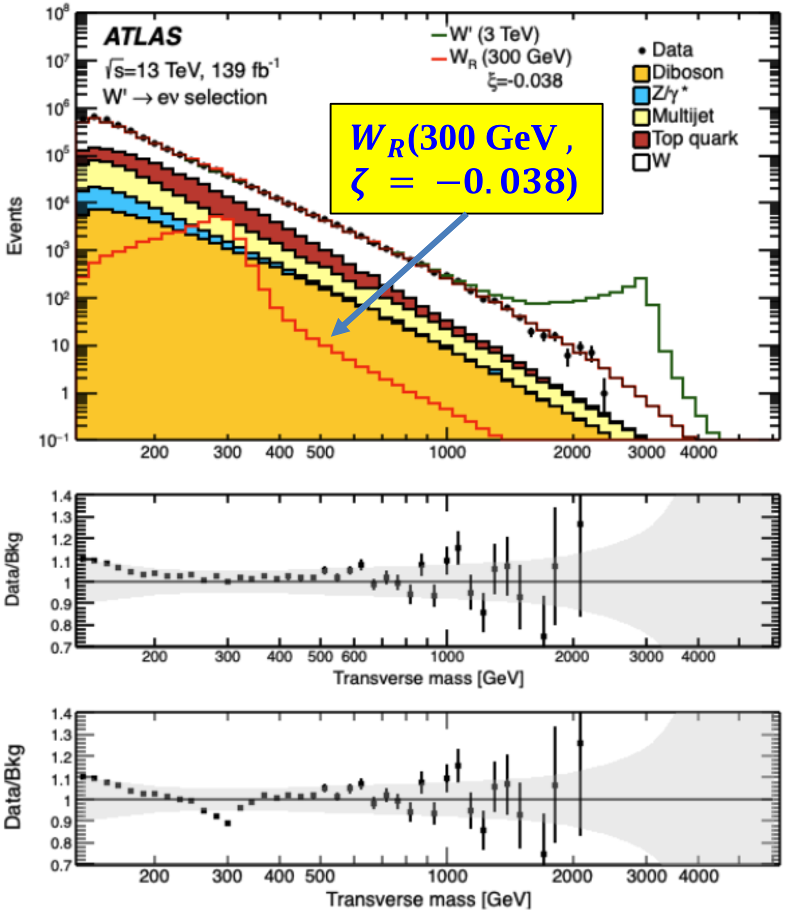
Not enough statistics to detect!

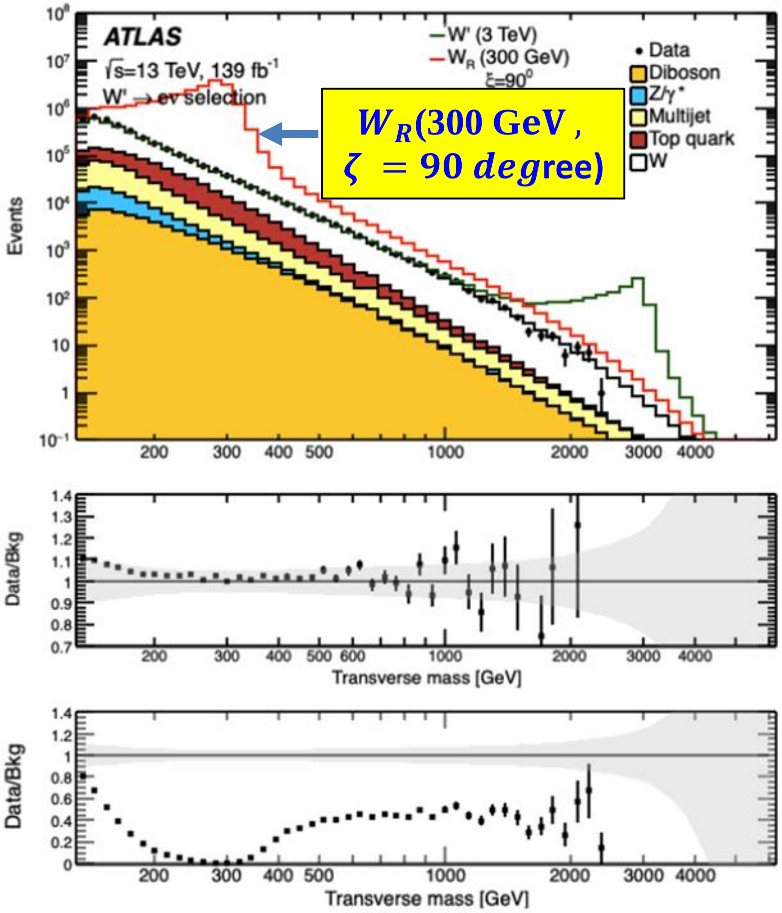
arXiv:0710.2966v1

Search for W' bosons decaying to an electron and a neutrino with the D0 detector

Estimation of the contribution of W_R(300 GeV, $\zeta = -0.038$) to the ATLAS collaboration data

This analysis was done in HEPD of PNPI





The effect of the right boson 304^{+28}_{-22} GeV with a mixing angle of - 0.038 is at the level of systematic calculation errors.

With WR

#	mT	Ratio	Stat.Err.	Syst.Err	N sigma
1	130.00 -- 138.98	1.104	0.006	0.097	1.1
2	138.98 -- 148.59	1.099	0.005	0.090	1.1
3	148.59 -- 158.85	1.080	0.005	0.084	0.9
4	158.85 -- 169.83	1.063	0.005	0.076	0.8
5	169.83 -- 181.56	1.041	0.005	0.070	0.6
6	181.56 -- 194.11	1.025	0.005	0.066	0.4
7	194.11 -- 207.52	1.026	0.005	0.061	0.4
8	207.52 -- 221.86	1.010	0.006	0.056	0.2
9	221.86 -- 237.19	1.002	0.005	0.053	0.0
10	237.19 -- 253.57	0.991	0.006	0.052	0.2
11	253.57 -- 271.10	0.945	0.007	0.051	**1.1**
12	271.10 -- 289.83	0.922	0.006	0.050	**1.6**
13	289.83 -- 309.85	0.891	0.007	0.050	**2.2**
14	309.85 -- 331.26	0.963	0.007	0.051	0.7
15	331.26 -- 354.15	0.988	0.009	0.051	0.2
16	354.15 -- 378.62	1.019	0.010	0.052	0.4
17	378.62 -- 404.78	1.009	0.011	0.053	0.2
18	404.78 -- 432.75	1.020	0.014	0.054	0.4
19	432.75 -- 462.65	1.013	0.014	0.056	0.2
20	462.65 -- 494.62	1.017	0.015	0.057	0.3

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#	mT	Ratio	Stat.Err.	Syst.Err	N sigma
1	130.00 -- 138.98	1.105	0.006	0.097	1.1
2	138.98 -- 148.59	1.099	0.005	0.090	1.1
3	148.59 -- 158.85	1.082	0.005	0.084	1.0
4	158.85 -- 169.83	1.065	0.005	0.076	0.9
5	169.83 -- 181.56	1.045	0.005	0.070	0.6
6	181.56 -- 194.11	1.031	0.005	0.066	0.5
7	194.11 -- 207.52	1.036	0.005	0.061	0.6
8	207.52 -- 221.86	1.027	0.006	0.056	0.5
9	221.86 -- 237.19	1.027	0.006	0.053	0.5
10	237.19 -- 253.57	1.031	0.006	0.052	0.6
11	253.57 -- 271.10	1.006	0.007	0.051	0.1
12	271.10 -- 289. 83	1.024	0.007	0.050	0.5
13	289.83 -- 309.85	1.001	0.008	0.050	0.0
14	309.85 -- 331.26	1.021	0.008	0.051	0.4
15	331.26 -- 354.15	1.010	0.009	0.051	0.2
16	354.15 -- 378.62	1.029	0.010	0.052	0.5
17	378.62 -- 404.78	1.014	0.011	0.053	0.3
18	404.78 -- 432.75	1.023	0.014	0.054	0.4
19	432.75 -- 462.65	1.016	0.014	0.056	0.3
20	462.65 -- 494.62	1.020	0.016	0.057	0.3

Conclusion from the analysis of experiments at colliders

The results of our work

$$M_{W_R} = 304^{+28}_{-22}\ \text{GeV}$$

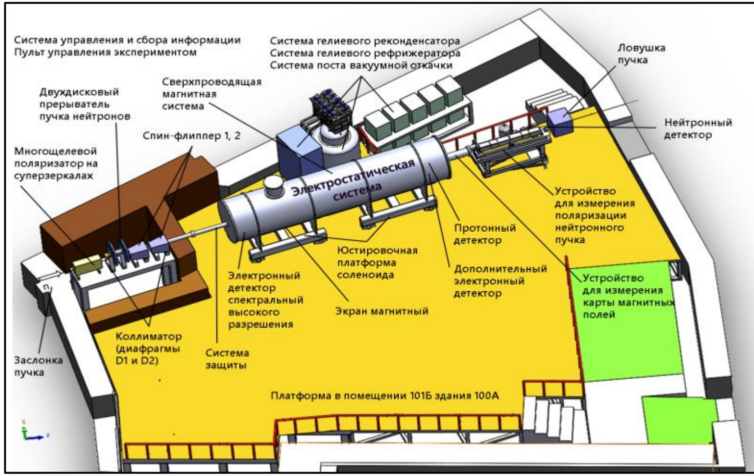
$$\zeta = -\,0.038 \pm 0.014.$$

do not contradict the results of experiments at colliders

Prospects for neutron decay experiments

Project of the installation for measuring neutrino asymmetry at the PIK reactor

There is a possibility of further increasing the accuracy of measurements in neutron decay. For example, the PNPI NRC KI project "Neutron Beta Decay" for the PIK reactor is aimed at this [29-31], in which it is planned to use a superconducting solenoid with a long flight base for neutron decay in order to increase the statistics of decay events and with a magnetic mirror-collimator to isolate the direction of electron emission. It is a development of the PNPI RAS experiment of 1998 [19], in which it is planned to achieve a relative measurement accuracy of 10-3 for neutrino and electron decay asymmetries.

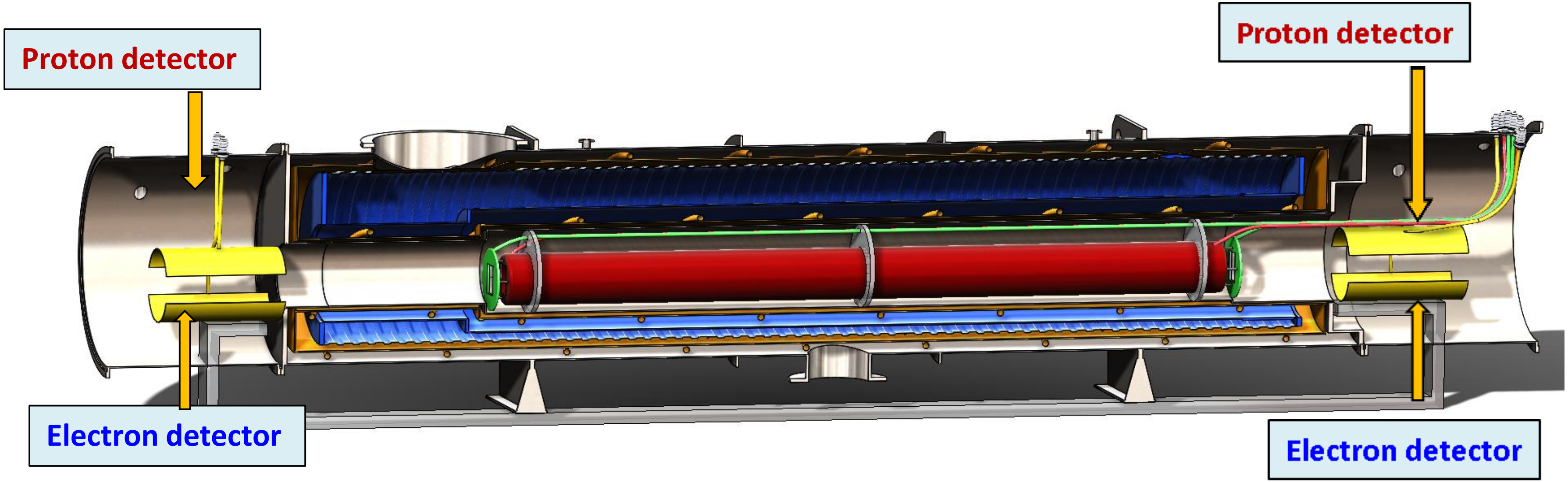


Testing of the installation at NIIEFA 31.05.24.

A current of 1050 A was introduced into the superconducting solenoid.

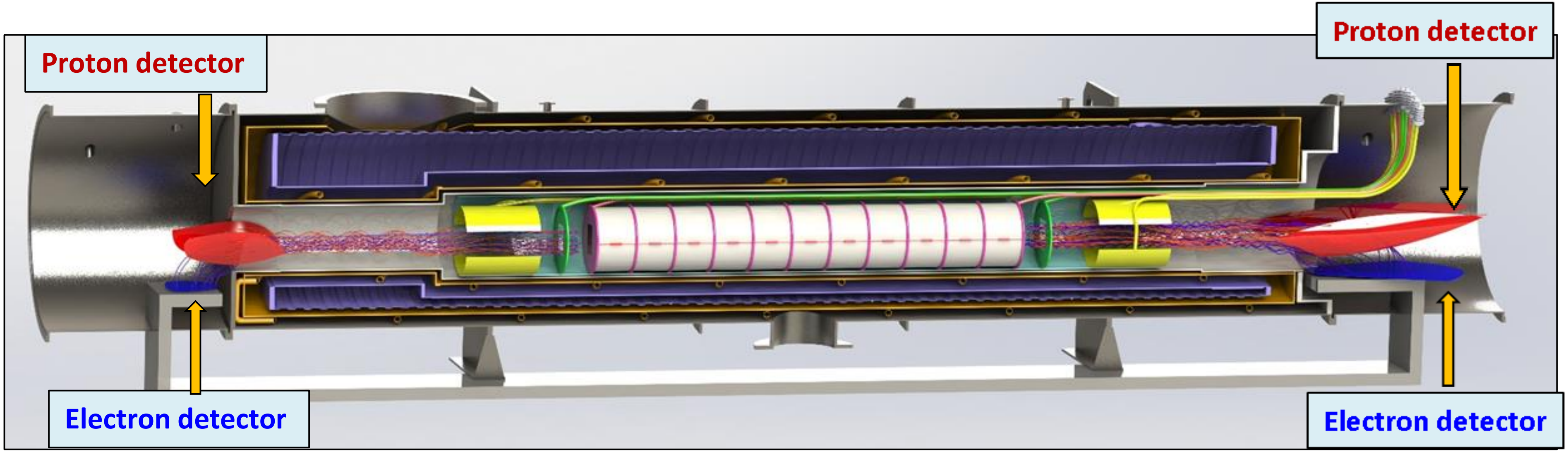
Project of the installation for measuring neutrino asymmetry at the PIK reactor

Relative measurement accuracy of 10^{-3} for neutrino and electron decay asymmetries



Increasing the measurement accuracy by 3 times can already provide an answer to the question posed.

Separate detection of protons and electrons



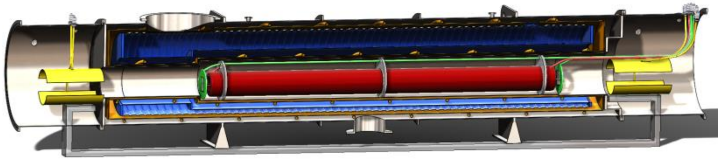
Conclusion

1. As a result of the analysis, it was established that there are indications of the existence of a right vector boson with mass $M_{W_R} = 304^{+28}_{-22}$ GeV and the mixing angle with W_L: $\zeta = -0.038 \pm 0.014$.

2. This result does not contradict experiments at colliders.

3. However, it is necessary to conduct even more precise measurements of neutron decay and its theoretical analysis.

4. Measuring neutrino asymmetry with an accuracy of 10^{-3} is our goal.



SCIENTIFIC RESEARCH PROGRAM
Neutron decay at the reactor PIK