Monte Carlo simulation of the neutron lifetime experiment by storing ultracold neutrons with detection of inelastically scattered neutrons

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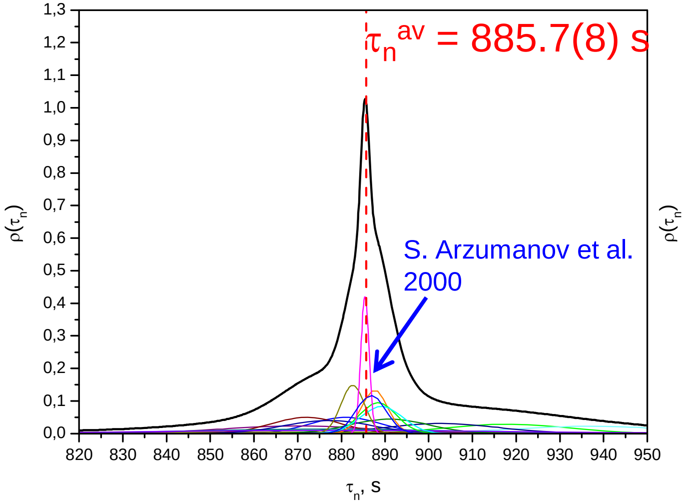
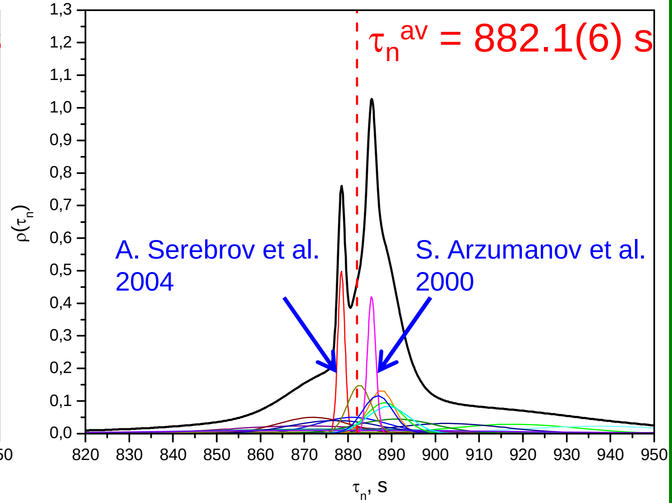
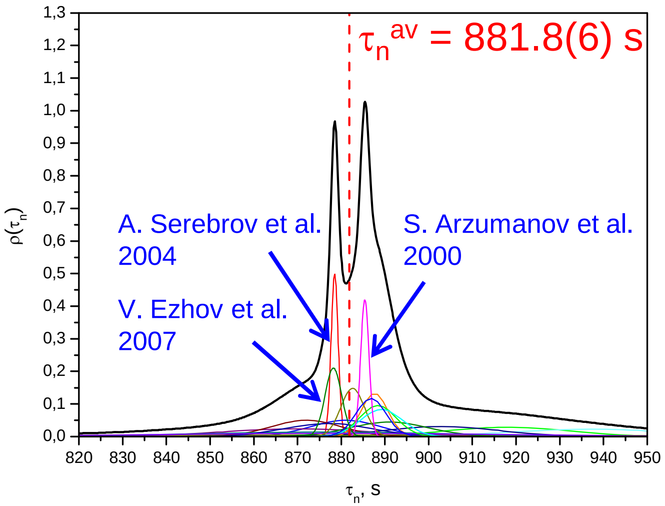
Motivation



2003
before Gravitrap measurement



2004
after Gravitrap measurement



2007
after magnetic trap measurement

Lifetime τ[s]	Ref./Year
878.2 ± 1.9	V. Ezhov et al. 2007
878.5 ± 0.8	A. Serebrov et al. 2004
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918 ± 14	C.J. Christensen et al. 1972

Precision MC simulations

MC simulation was performed at the following computing clusters:
1. PNPI ITAD cluster (photo)
2. PNPI PC Farm

The experiment

1)

Physics Letters B 483 (2000) 15–22

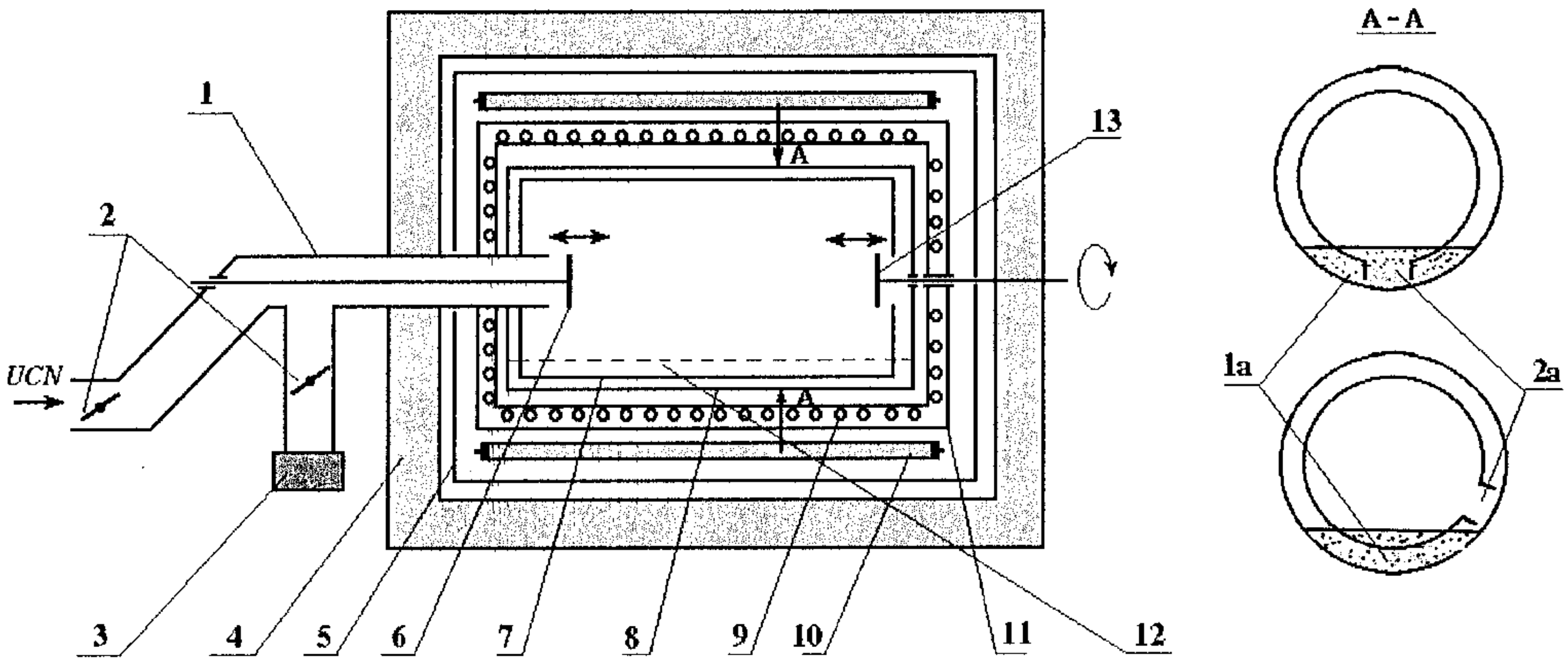
Neutron life time value measured by storing ultracold neutrons with detection of inelastically scattered neutrons

S. Arzumanov [a], L. Bondarenko [a], S. Chernyavsky [a], W. Drexel [b], A. Fomin [a], P. Geltenbort [b], V. Morozov [a], Yu. Panin [a], J. Pendlebury [c], K. Schreckenbach [d]

[a] *RRC Kurchatov Institute, 123182, Moscow, Russia*
[b] *Institute Laue Langevin, BP 156, F-38042 Grenoble Cedex 9, France*
[c] *University of Sussex, Brighton BN1 9QH, Sussex. UK*
[d] *Technical University of Munich, D-85747 Garching, Germany*

2) A. Fomin PhD Thesis
"Neutron lifetime value measured by storing ultracold neutrons with detection of inelastically scattered neutrons"
Kurchatov Institute, Moscow, 2000

Experimental setup

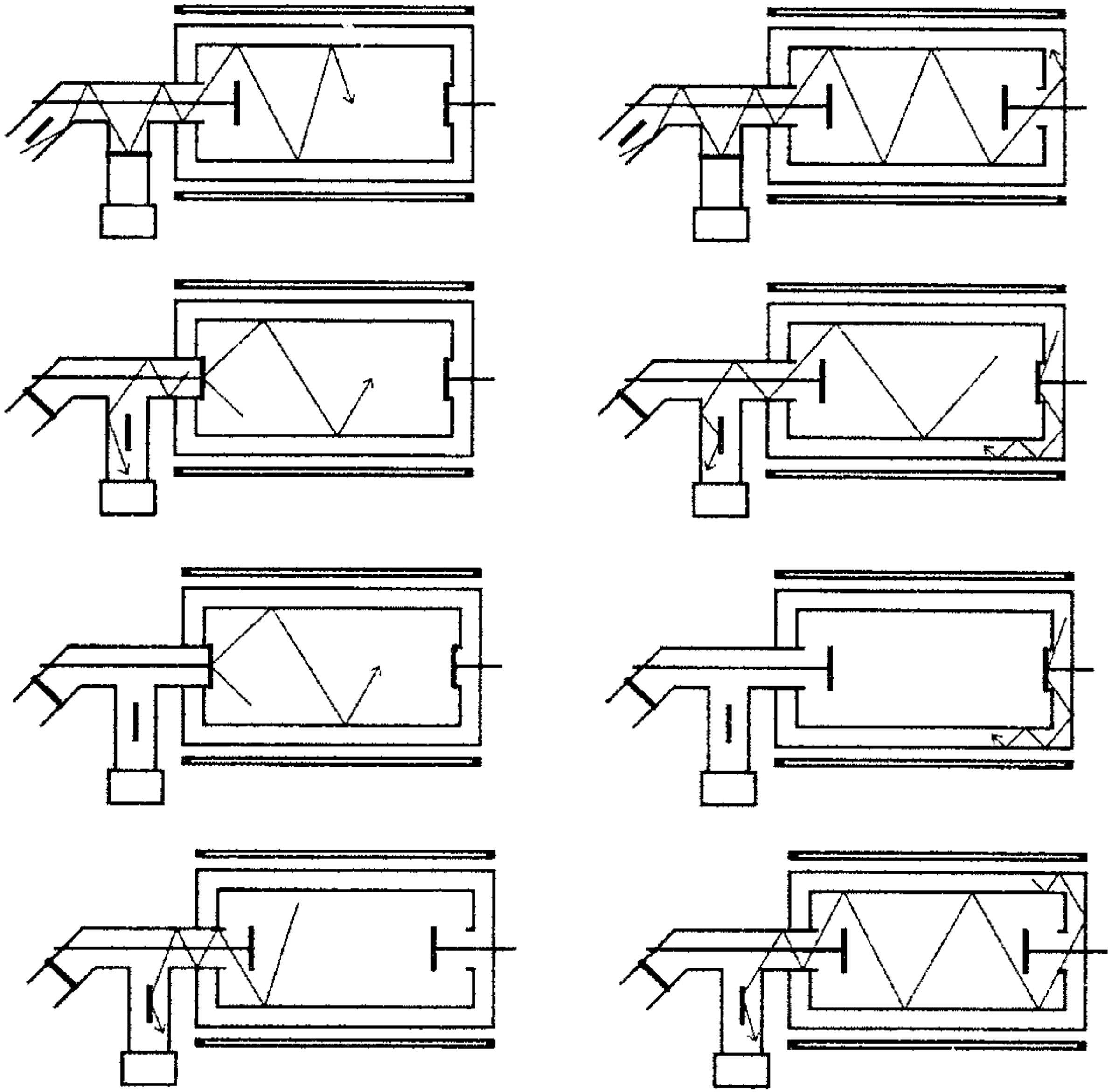


1 - UCN guide, 2 - shutters, 3 - UCN detector, 4 - polyethylene shielding, 5 - cadmium housing, 6 - entrance shutter of the inner vessel, 7 - inner storage vessel, 8 - outer storage vessel, 9 - cooling coil, 10 - thermal neutron detector, 11- vacuum housing, 12 - oil puddle, 13 - entrance shutter of the gap vessel, 1a - oil puddle, 2a - slit.

The procedure of the experiment

measurement with the inner vessel

measurement with the annular vessel



filling

cleaning — N_i

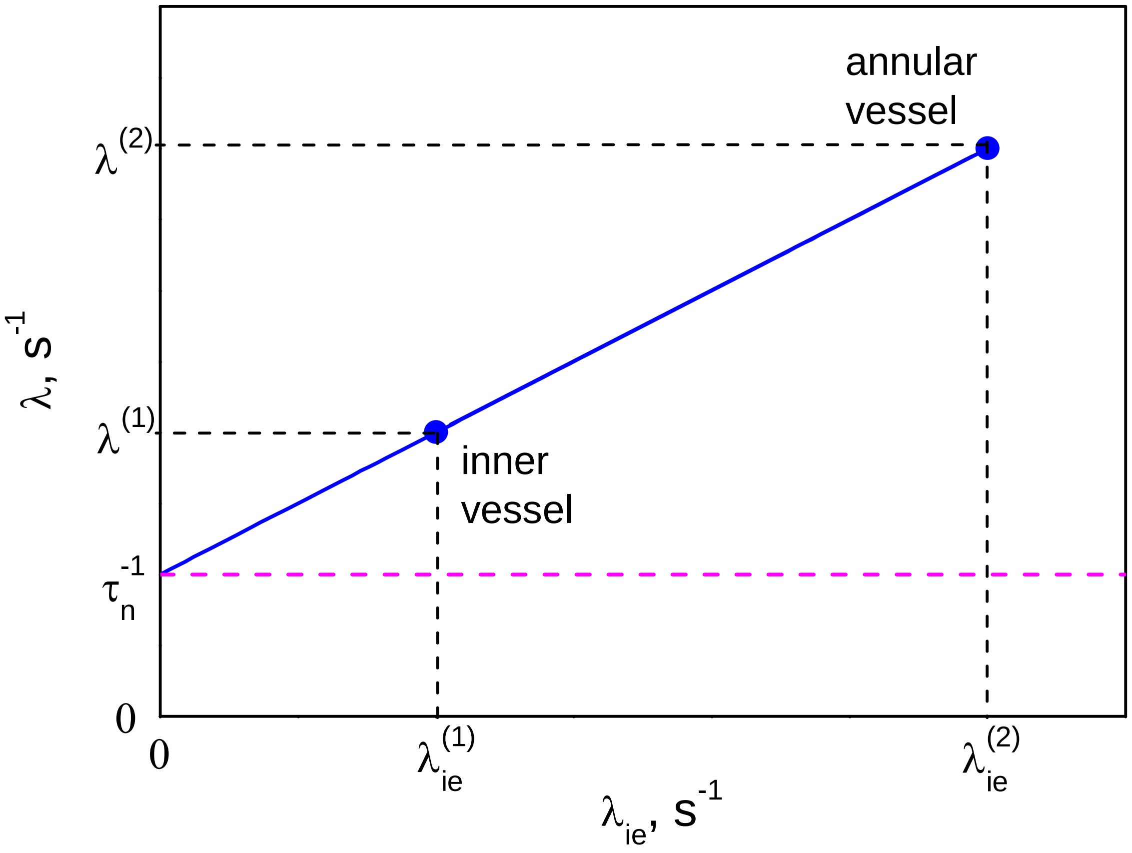
holding — J

emptying — N_f

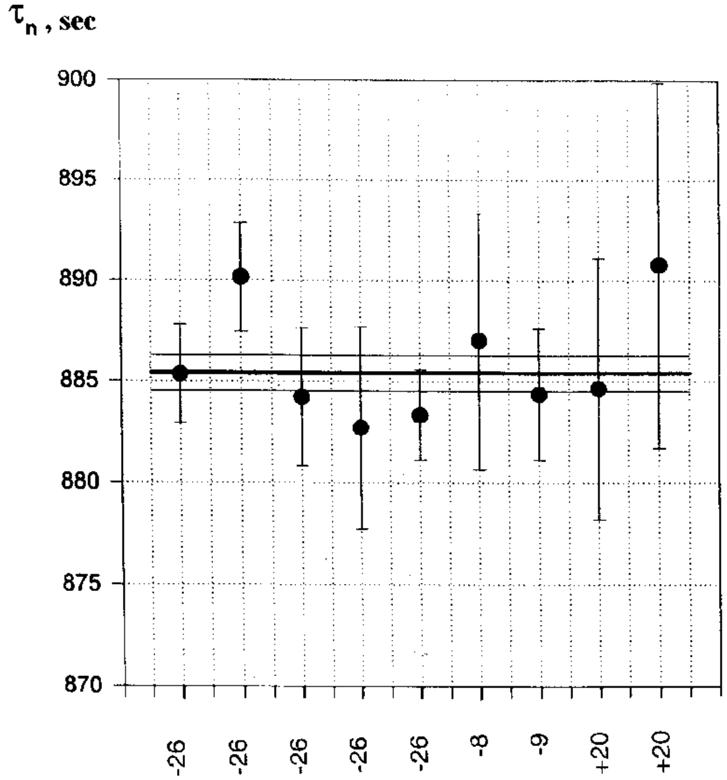
Experimental method

$$\lambda = \lambda_n + \lambda_{loss} = \lambda_n + \lambda_{ie} + \lambda_{cap} = \lambda_n + a\lambda_{ie} \qquad a = \lambda_{loss} / \lambda_{ie} = 1 + \sigma_{cap} / \sigma_{ie}$$

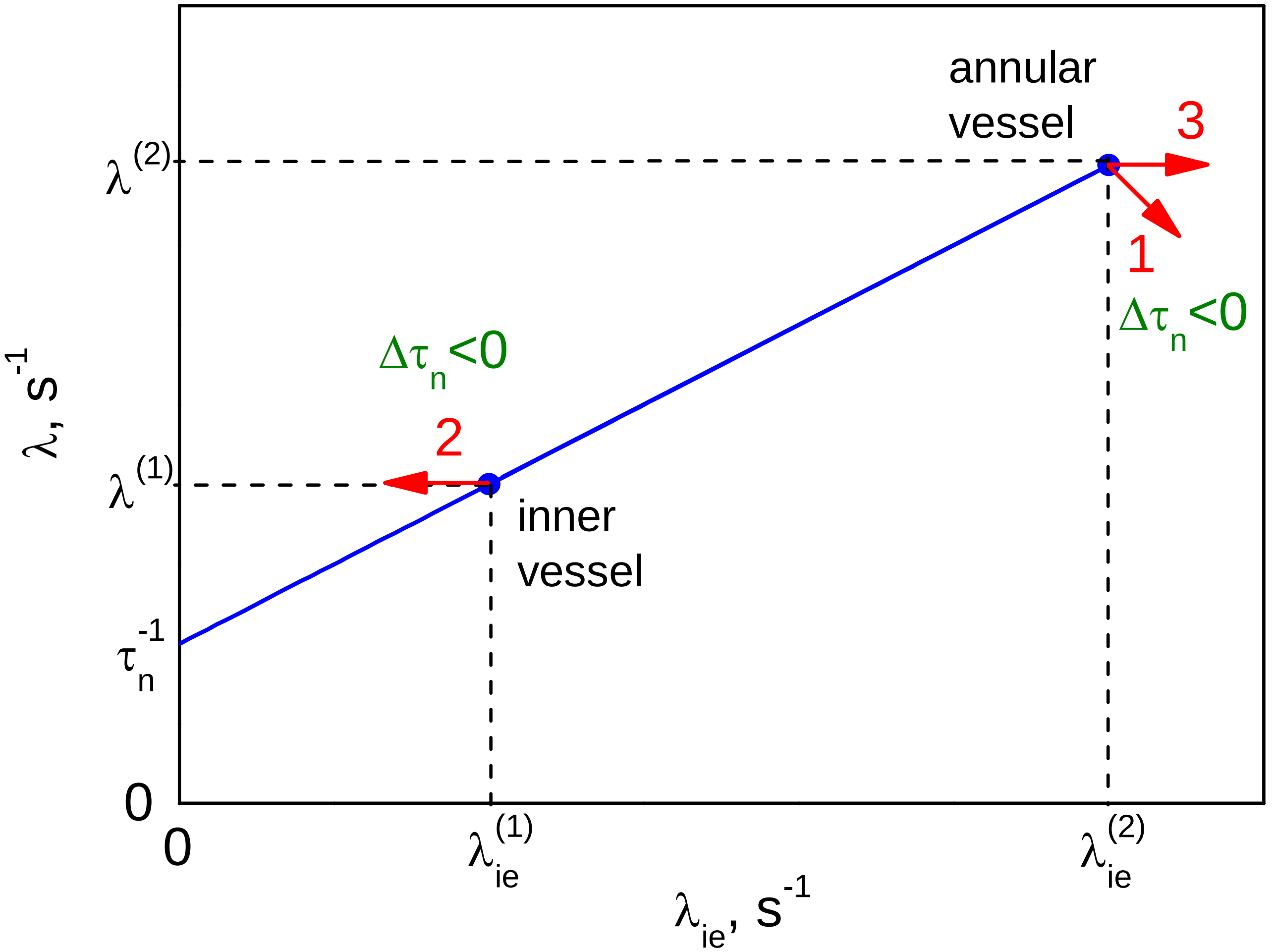
$$\lambda = \frac{1}{T}\ln(N_i / N_f) \qquad \lambda_{ie} = \frac{J\lambda}{N_i - N_f}\frac{\varepsilon}{\varepsilon_{th}}$$



$\tau_n = 885.4 \pm 0.9_{stat} \pm 0.4_{syst}$



Influence of various effects for measured value of neutron lifetime

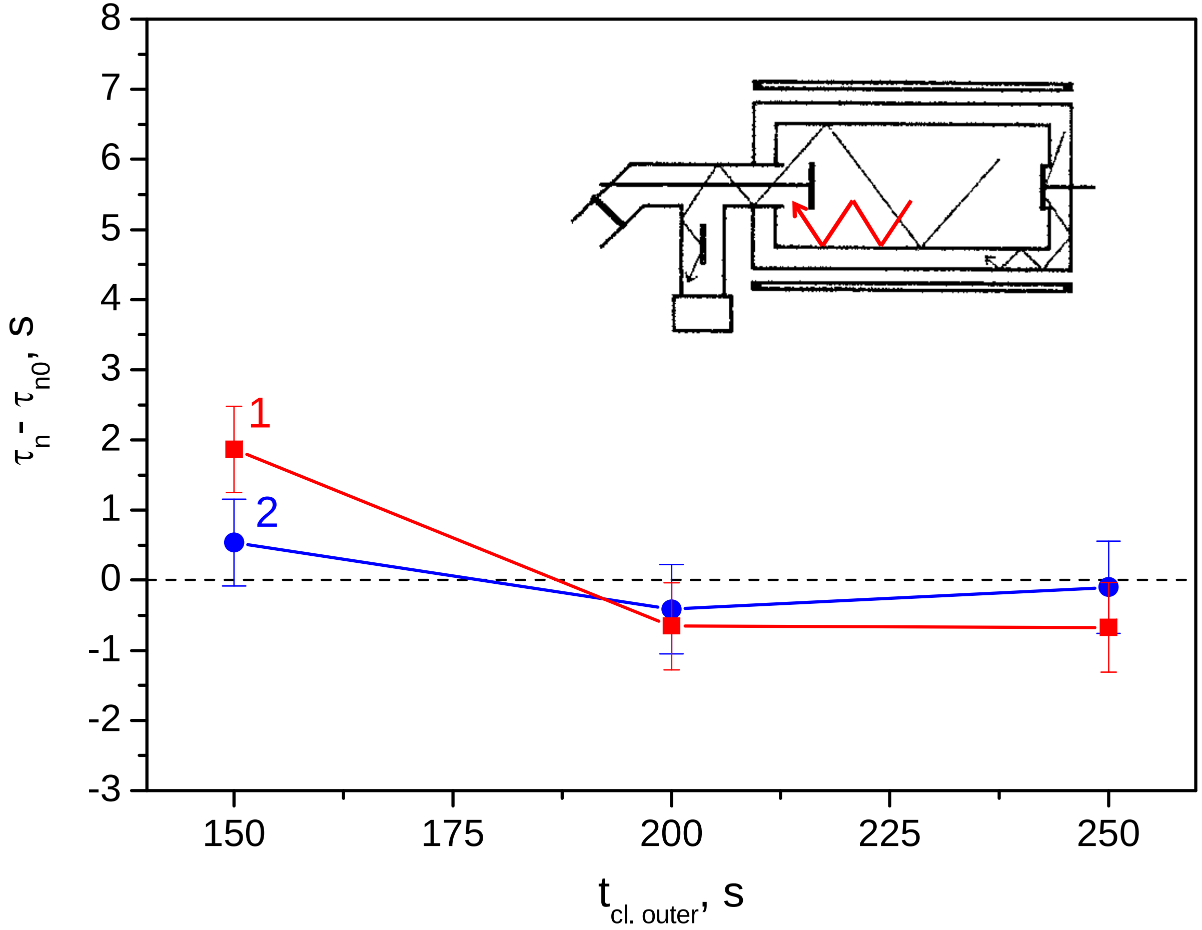


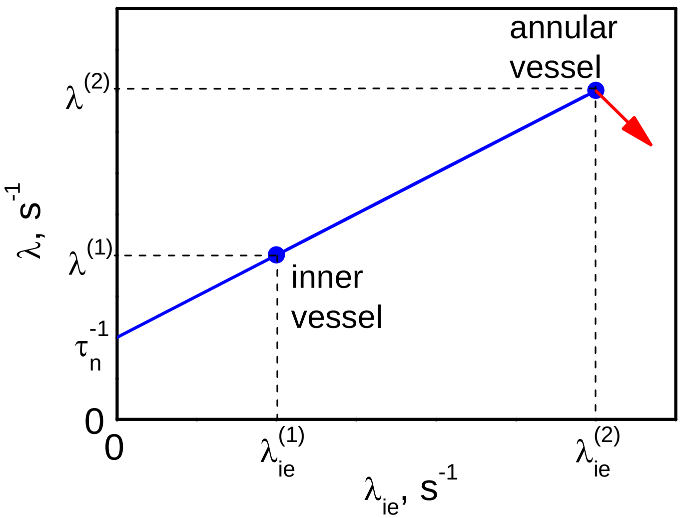
1 - effect of not full emptying of the inner vessel during cleaning while working with the annular vessel

2 - effect of heating of neutrons by the shutters

3 - effect of not equal thermal neutron detection efficiencies for different vessels

Effect of not full emptying of the inner vessel during cleaning while working with the annular vessel





$$\lambda = \frac{1}{T}\ln(N_i / N_f)$$

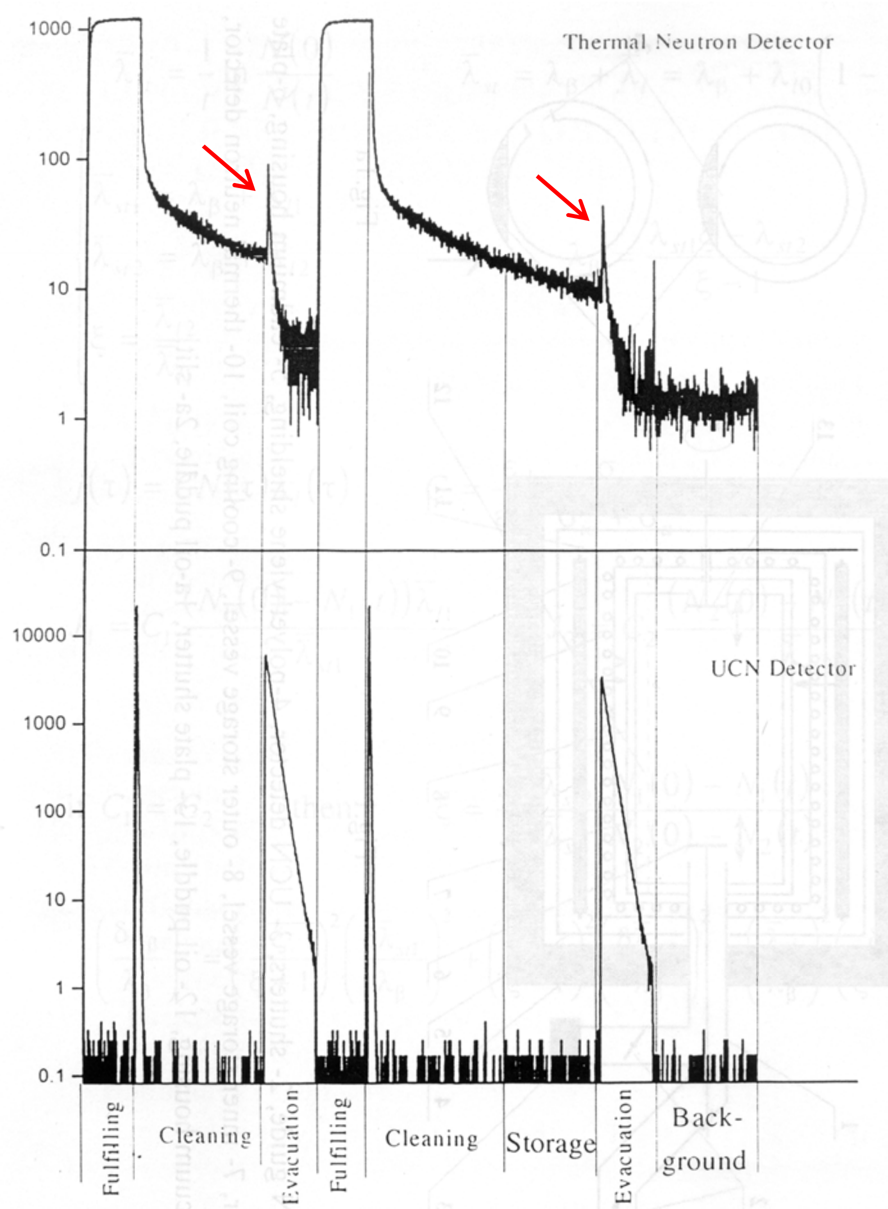
$$\lambda_{ie} = \frac{J\lambda}{N_i - N_f}\frac{\varepsilon}{\varepsilon_{th}}$$

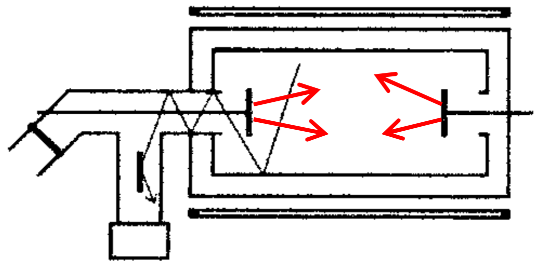
1 – 0.8 m neutron guide to UCN detector
2 – 1 m neutron guide to UCN detector

There is no correction for cleaning times more than 200 s.

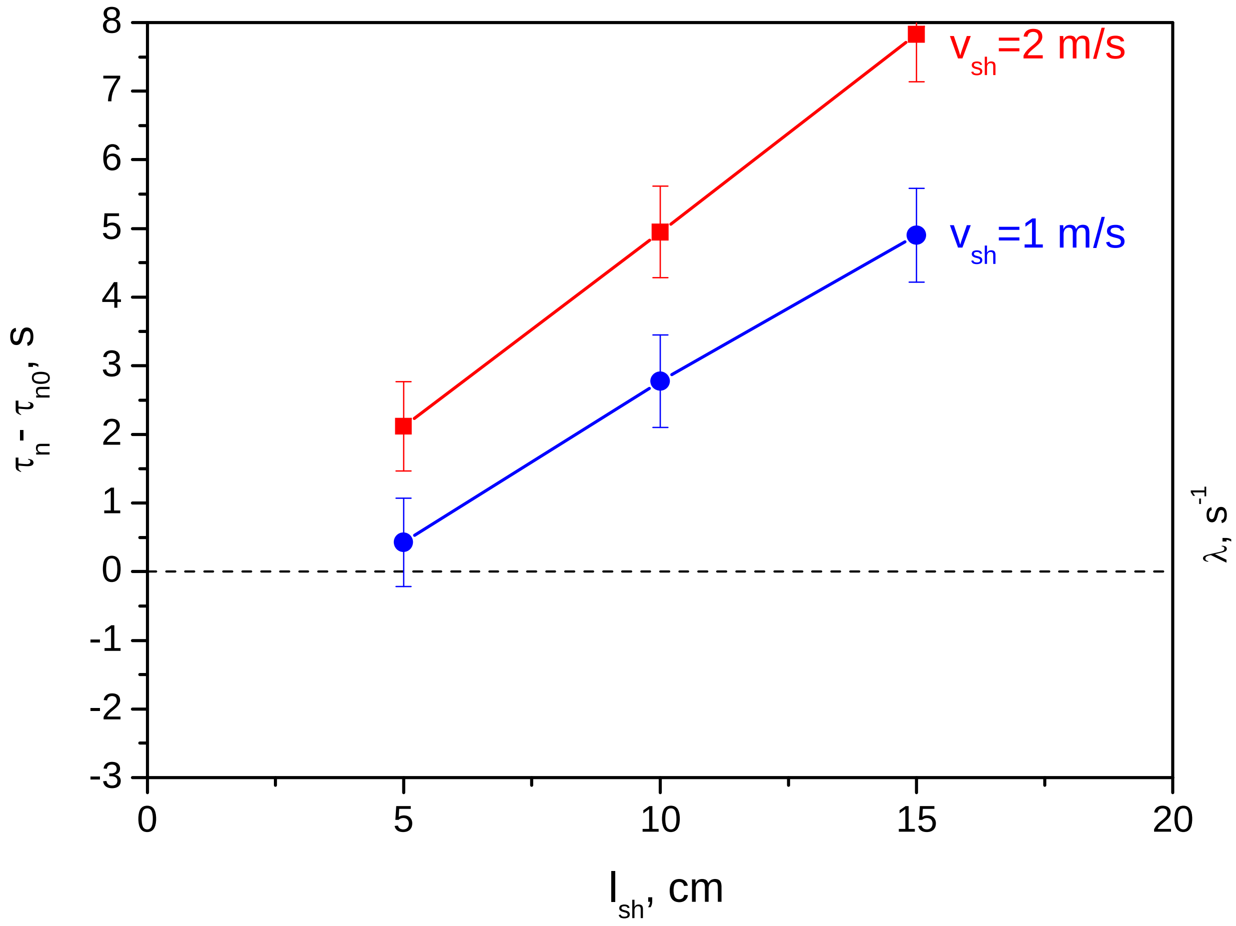
Effect of heating of neutrons by the shutters

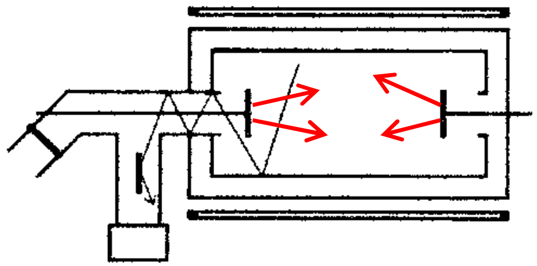
The First UCN Workshop, Pushkin, Russia, 1998

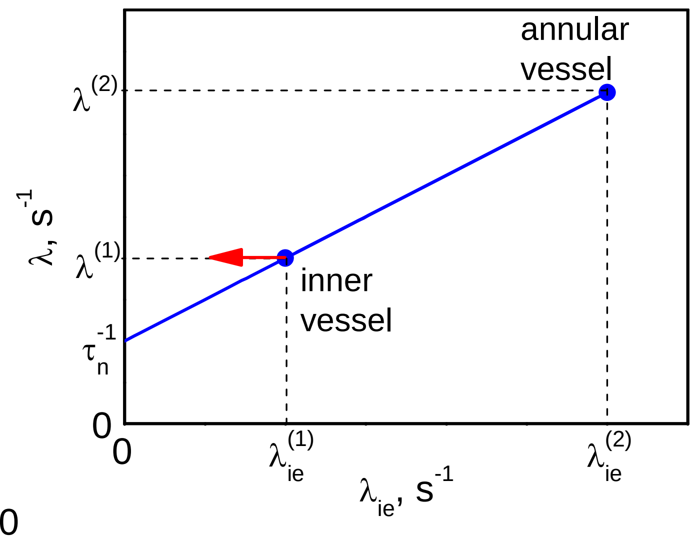




Effect of heating of neutrons by the shutters







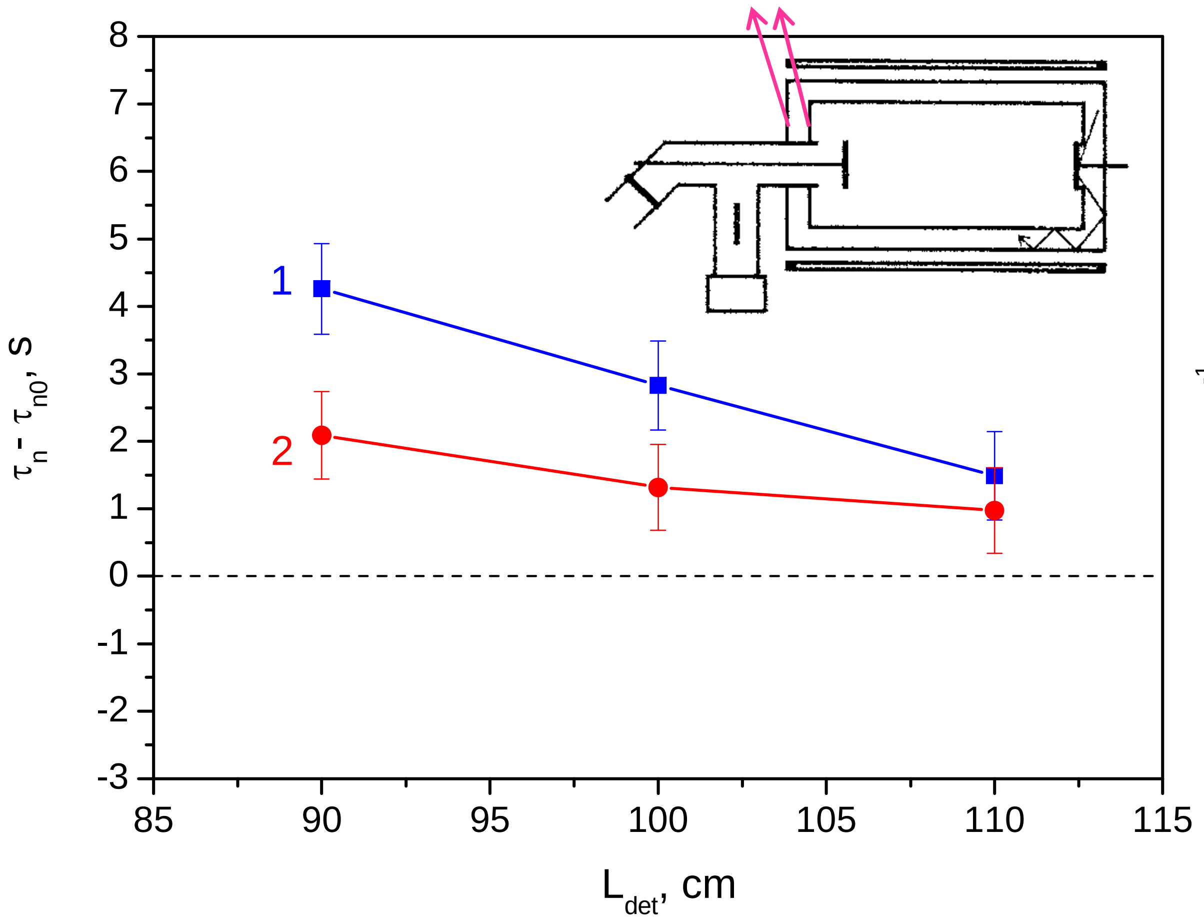
$$\lambda = \frac{1}{T}\ln(N_i / N_f)$$

$$\lambda_{ie} = \frac{J\lambda}{N_i - N_f}\frac{\varepsilon}{\varepsilon_{th}}$$

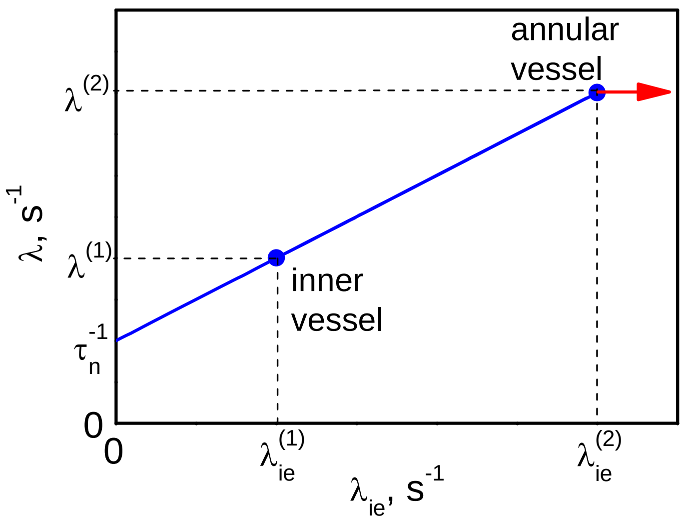
The calculations were done with the shutter velocity of 1 and 2 m/s and the shutter course of 5, 10 and 15 cm.

The correction is -2.9 s for the shutter velocity of 1 m/s and the shutter course of 10 cm. Uncertainty of the result of the experiment due to this effect is about 2 s.

Effect of not equal thermal neutron detection efficiencies for different vessels



1 – without absorption and scattering
2 – with absorption and scattering

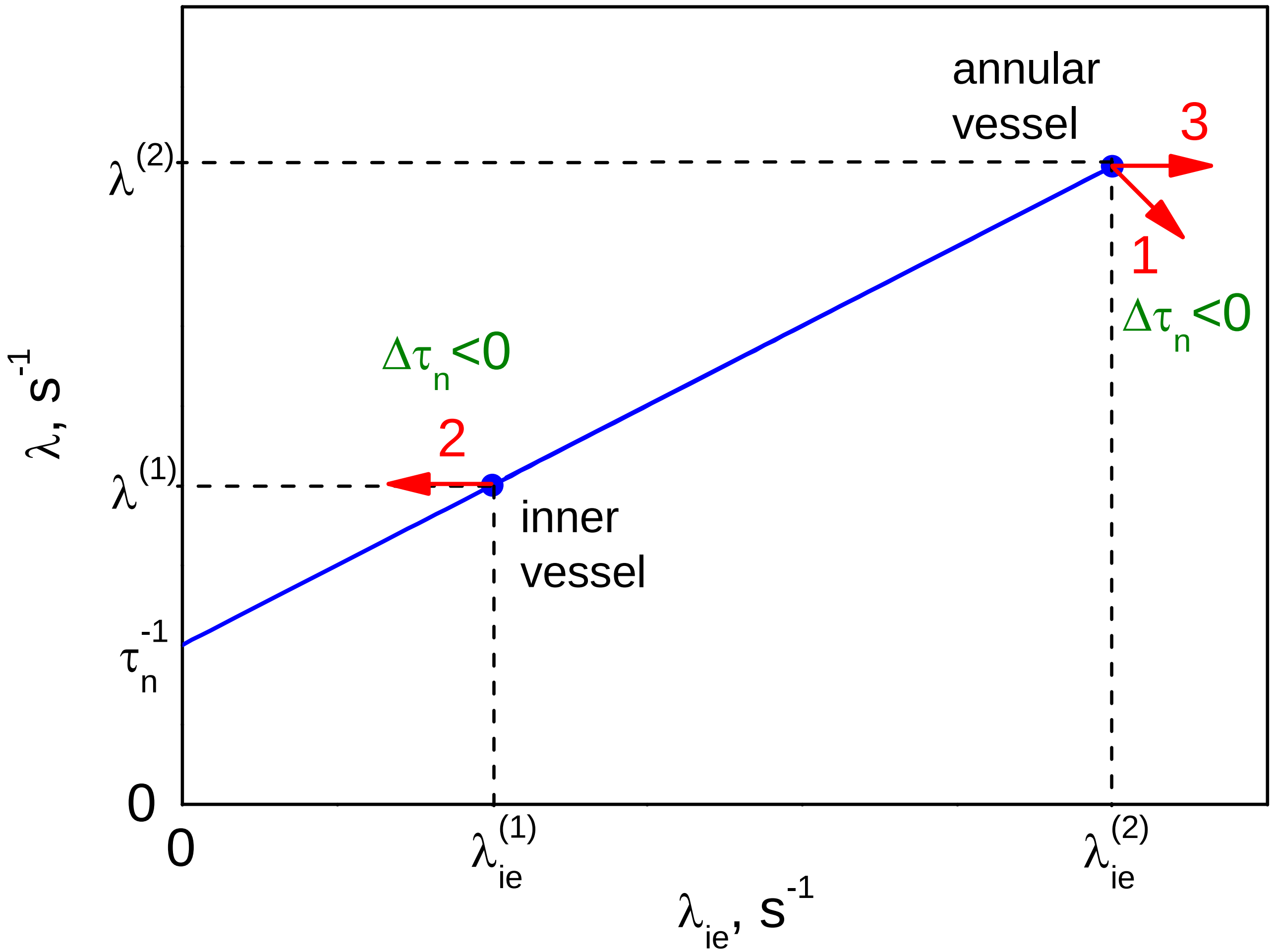


$$\lambda = \frac{1}{T}\ln(N_i / N_f)$$

$$\lambda_{ie} = \frac{J\lambda}{N_i - N_f}\frac{\varepsilon}{\varepsilon_{th}}$$

The correction is -2.1 s for the thermal neutron detector length of 90 cm.
Uncertainty of the result of the experiment due to this effect is about 1 s.

Influence of various effects for the measured value of the neutron lifetime

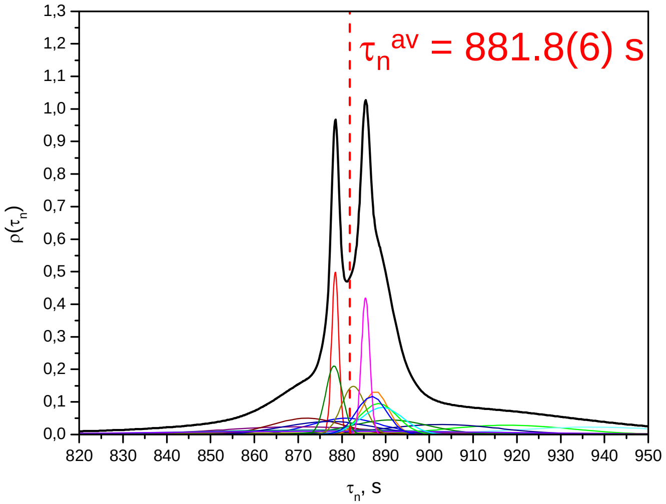


All effects give a negative correction to the measured value of the neutron lifetime.

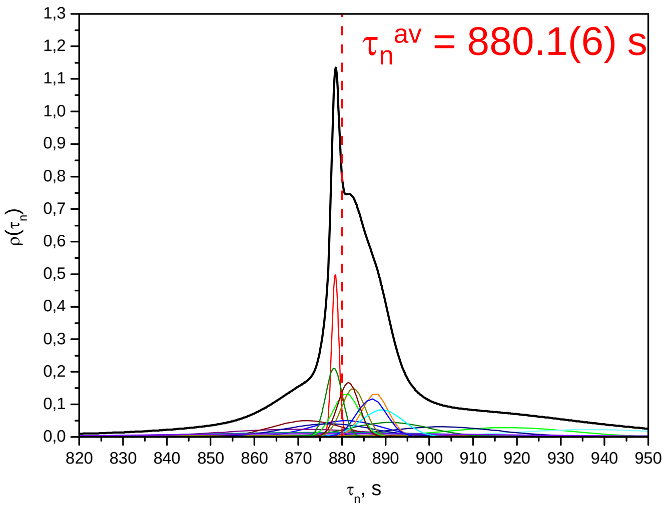
MC correction to the neutron lifetime result of the experiment

<table>
<tr><th></th><th>correction, s</th><th>uncertainty of the result, s</th></tr>
<tr><td>not full emptying of the inner vessel during cleaning while working with the annular vessel</td><td>0</td><td>0</td></tr>
<tr><td>effect of heating of neutrons by the shutters</td><td>-2.8</td><td>2</td></tr>
<tr><td>effect of not equal thermal neutron detection efficiencies for different vessels</td><td>-2.1</td><td rowspan="2">1</td></tr>
<tr><td>effect of not equal thermal neutron detection efficiencies for different vessels (correction in the experiment +0.6 s)</td><td>-0.6</td></tr>
<tr><td>total</td><td>-5.5</td><td>2.2</td></tr>
</table>

Analysis with new experimental data 2009



2007
after magnetic trap measurement



2009
new analysis

Lifetime τ[s]	Ref./Year
878.2 ± 1.9	V. Ezhov et al. 2007
878.5 ± 0.8	A. Serebrov et al. 2004
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Lifetime τ[s]	Ref./Year
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Monte Carlo simulation of the experiment MAMBO I and possible correction of neutron lifetime result

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Monte Carlo Simulation of Quasi-Elastic Scattering and Above-Barrier Neutrons in the Neutron Lifetime Experiment MAMBO I¶

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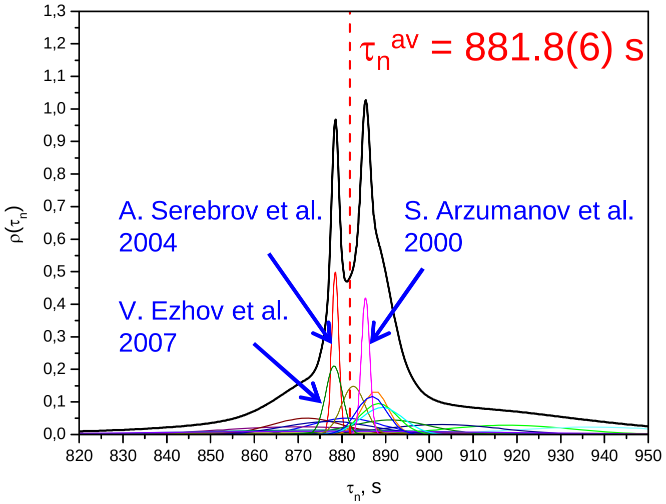
Petersburg Nuclear Physics Institute, Russian Academy of Sciences, Gatchina, Leningrad region, 188300 Russia

The Monte Carlo simulation included:

1) quasielastic neutron scattering on the surface of liquid fomblin oil wall coatings of the UCN storage vessel,
2) abovebarrier neutrons.

It shows that the result of this experiment can be corrected and instead of the previous result 887.6 ± 3 s the new result 881.6 ± 3 s could be claimed.

Analysis with new experimental data and MC corrections 2010



2007
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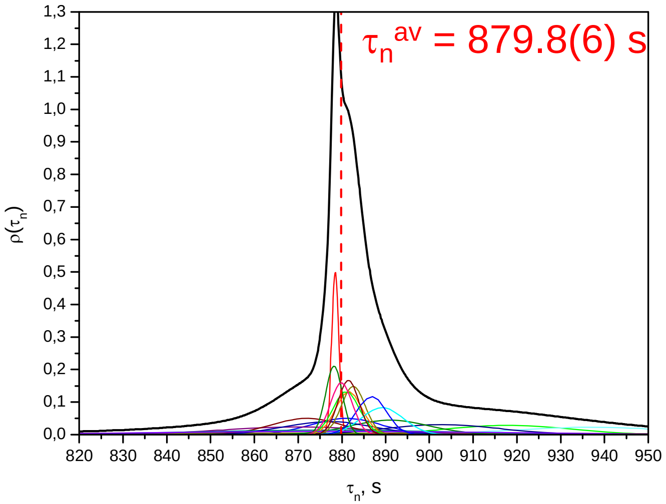

2010
new analysis

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Conclusion

The Monte Carlo simulation of the neutron lifetime experiment by storing ultracold neutrons with detection of inelastically scattered neutrons [S. Arzumanov et al., Phys. Lett. B 483 (2000) 15] found a negative correction of 5.5 s. The result of the experiment for neutron lifetime $885.4 \pm 0.9_{stat} \pm 0.4_{syst}$ s after correction is 879.9 ± 2.5 s.

The new analysis gives the world average value of 879.8 ± 0.6 s.