Evaluation of neutron lifetime from UCN storage experiments and beam experiments

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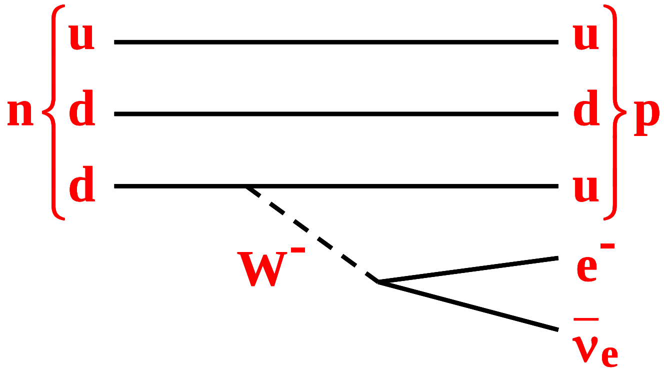
Solvay Workshop on "Beta-Decay Weak Interaction Studies in the Era of the LHC"
(September 3 – 5, 2014)

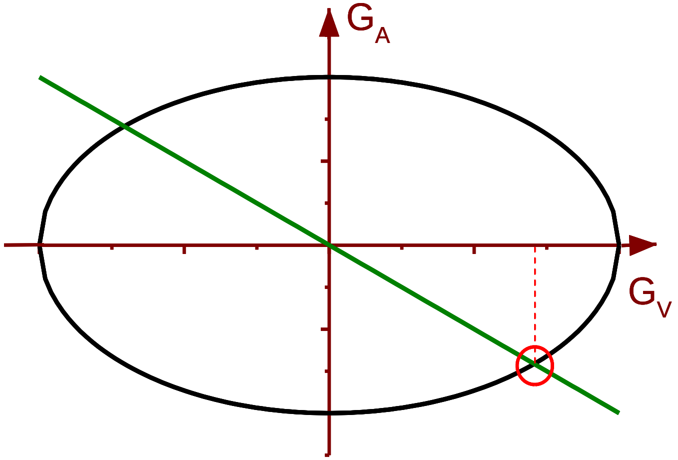
Why neutron lifetime measurements are important?

1. Standard Model (search for possible deviations)

2. Cosmology (Big Bang Model)

Neutron decay and Standard Model





CKM mixing matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$G_V = G_F \cdot V_{ud}$$

$$ft\left(1+\Delta_R\right)\left(1+\delta_R\right) = \frac{k}{\left|V_{ud}\right|^2 G_F^2 \left(1+3\lambda^2\right)}$$

~1.5 % ~2.4 %

$$\lambda = \frac{G_A}{G_V} \qquad A_0 = -2\frac{\lambda\left(\lambda+1\right)}{1+3\lambda^2}$$

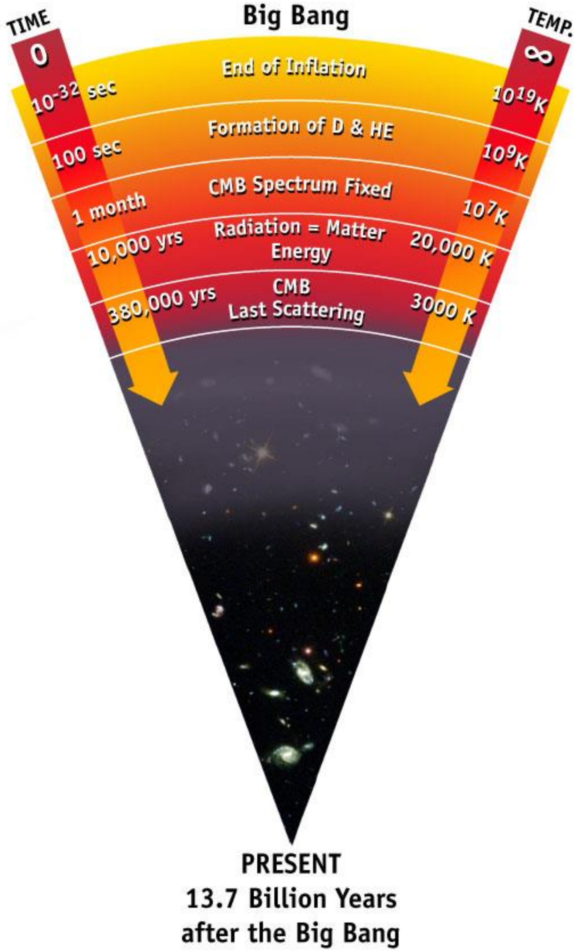
$$\boxed{\left|V_{ud}\right|^2 = \frac{4908.7 \pm 1.9\ \text{s}}{\tau_n\left(1+3\lambda^2\right)}}$$

W.Marciano
A.Sirlin
PRL 96, 032002
(2006)

Required experimental accuracy for τ_n and A has to be about 10^{-3} and better.

Neutron decay and cosmology

G. J. Mathews, T. Kajino, T. Shima, Phys. Rev. D 71, 021302(R) (2005)



$$\left(f\tau_n\right)^{-1}=\frac{G_F^2}{2\pi^3}\left(1+3g_A^2\right)m_e^5$$

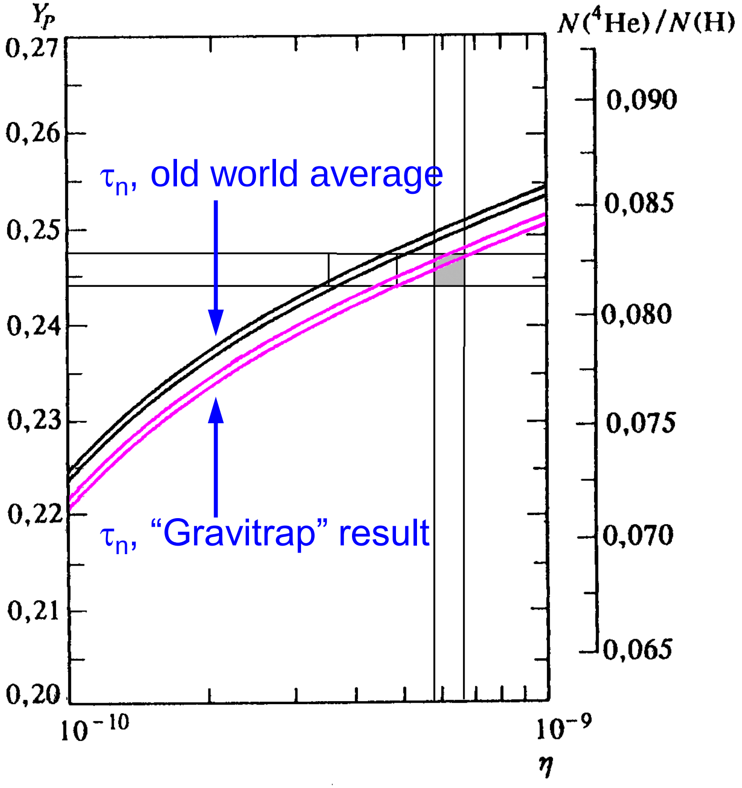
$$\Gamma = (7/60)\pi(1+3g_A^2)G_F^2T^5$$

$$H \approx [(8/3)\pi G\rho_\gamma]^{1/2}$$

$$\rho_\gamma = (\pi^2/30)g_* T^4$$

$$T_f \approx 1\ \mathrm{MeV}$$

$$n/p = \exp\{-\Delta m/T_f\}$$



$$Y_p \approx 2n/(n+p) = 2(n/p)/(n/p+1)$$

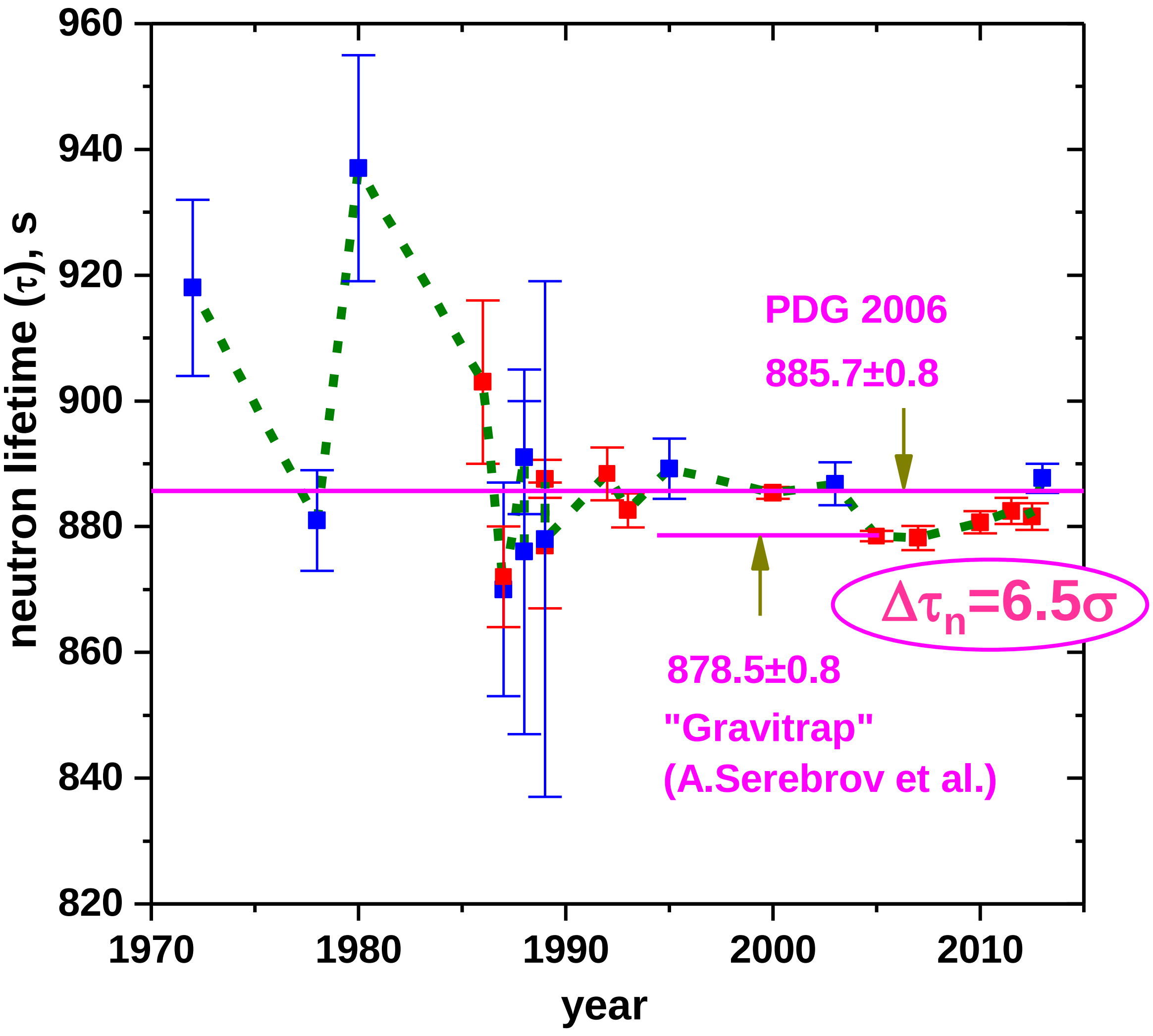
$$\Delta\tau_n = 1\% \quad \rightarrow \quad \Delta Y = 0.75\%\ \left(\pm 0.61\%\right)$$

$$\Delta\tau_n = 1\% \quad \rightarrow \quad \Delta\eta = 17\%\ \left(\pm 3.3\%\right)$$

New τ_n=(878.5±0.8) s confirms n_b/n_γ from CMB.

Neutron lifetime measurements
(history of experimental results)

Lifetime τ[s]	Ref./Year
887.7 ± 2.3	A.T. Yue et al. 2013
881.6 ± 2.1	S. Arzumanov et al. 2012
882.5 ± 2.1	A. Steyerl et al. 2012
880.7 ± 1.8	A. Pichlmaier et al. 2010
878.2 ± 1.9	V. Ezhov et al. 2007
878.5 ± 0.8	A. Serebrov et al. 2004
886.3 ± 3.42	M.S. Dewey et al. 2003
885.4 ± 0.95	S. Arzumanov et al. 2000
889.2 ± 4.8	J. Byrne et al. 1995
882.6 ± 2.7	W. Mampe et al. 1993
888.4 ± 3.1 ± 1.1	V. Nesvizhevski et al. 1992
893.6 ± 3.8 ± 3.7	J. Byrne et al. 1990
887.6 ± 3.0	W. Mampe et al. 1989
872 ± 8	A. Kharitonov et al. 1989
878 ± 27 ± 14	R. Kossakowski et al. 1989
877 ± 10	W. Paul et al. 1989
891 ± 9	P. Spivac et al. 1988
876 ± 10 ± 19	J. Last et al. 1988
870 ± 17	M. Arnold et al. 1987
903 ± 13	Y.Y. Kosvintsev et al. 1986
937 ± 18	J. Byrne et al. 1980
881 ± 8	L. Bondarenko et al. 1978
918 ± 14	C.J. Christensen et al. 1972



PDG 2006

885.7±0.8

$\Delta\tau_n$=6.5σ

878.5±0.8

"Gravitrap"

(A.Serebrov et al.)

Neutron lifetime measurements with traps only (history of experimental results)

Lifetime τ[s]	Ref./Year
881.6 ± 2.1	S. Arzumanov et al. 2012
882.5 ± 2.1	A. Steyerl et al. 2012
880.7 ± 1.8	A. Pichlmaier et al. 2010
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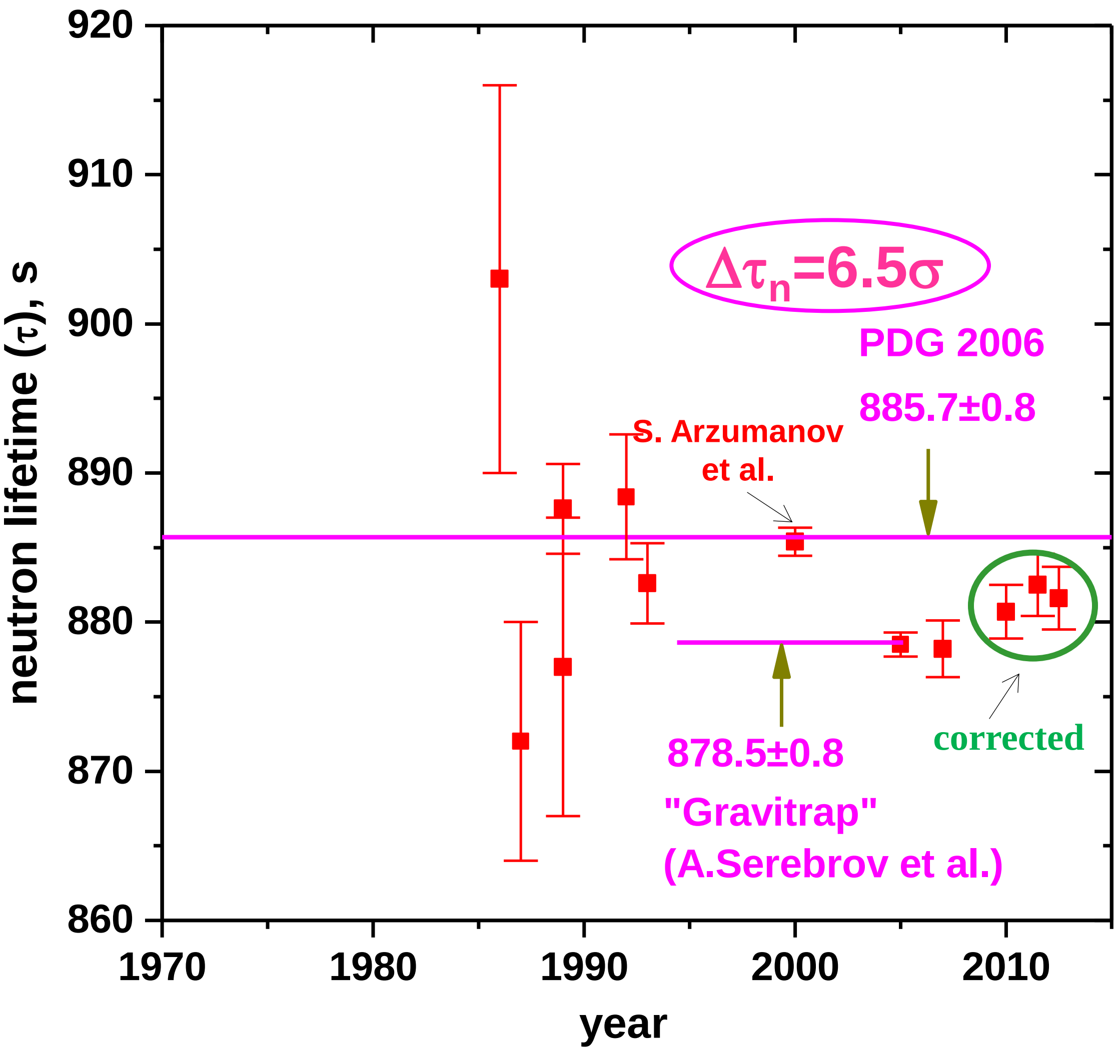
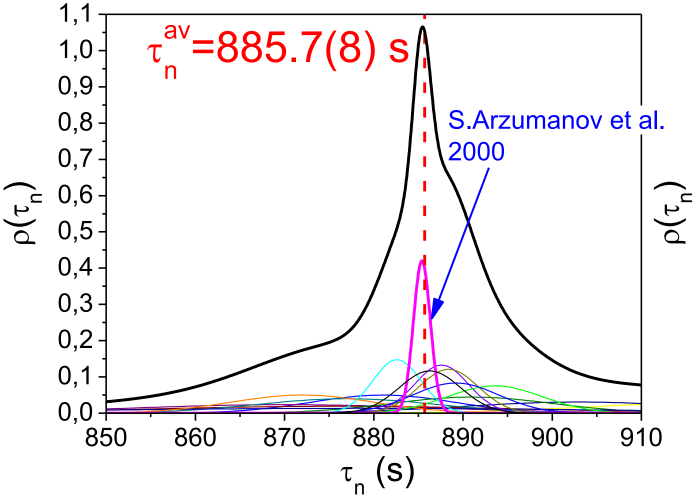
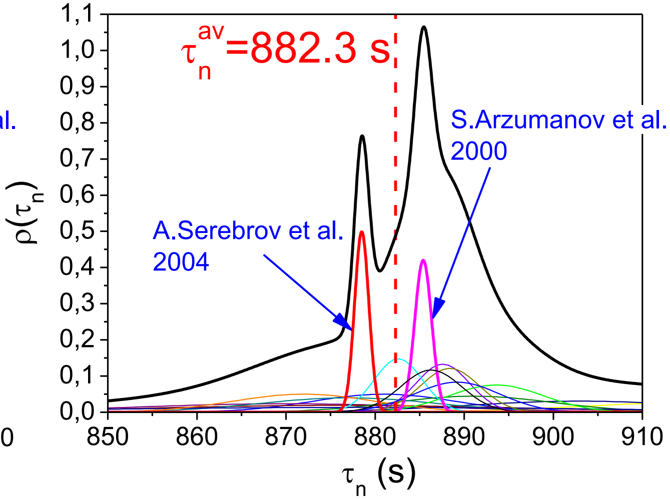


Problem of Neutron lifetime data in 2004 -2007



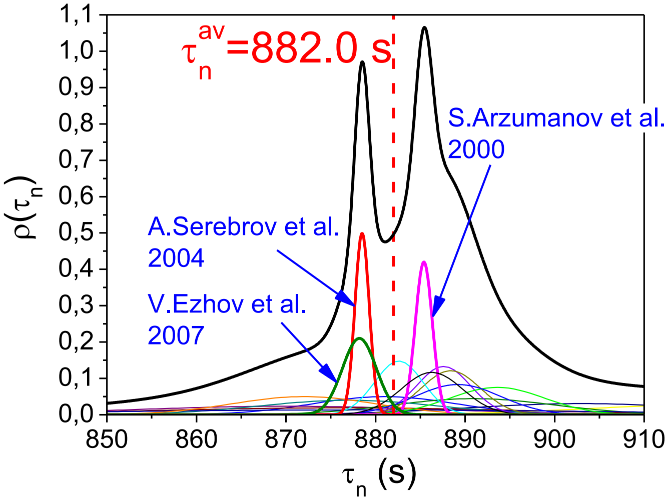
2003

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
886.3 ± 3.42	M.S. Dewey et al. 2003
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What are the reasons of the discrepancy of experimental results?

A.Serebrov et al. 2005: **878.5 ± 0.8**
and S. Arzumanov et al. 2000: **885.4 ± 0.95,** W. Mampe et al. 1989: **887.6 ± 3.0**

1. **First of all it is difference in extrapolation from storage time to neutron lifetime (100 – 200 s instead of 5 – 10 s).**

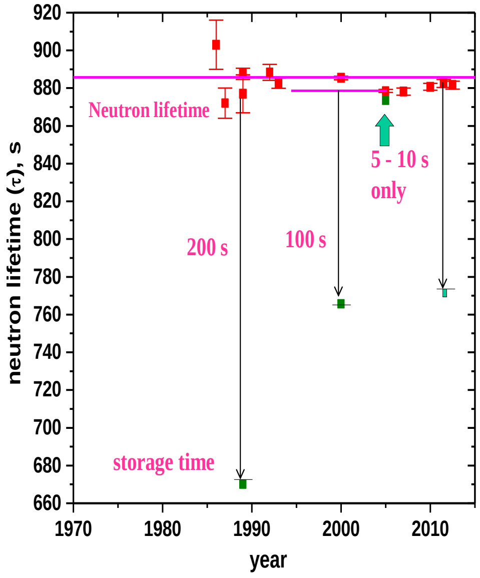
2. The second reason is room temperature and liquid Fomblin, as result:

a) quasielastic scattering - spectral changing during the storage.

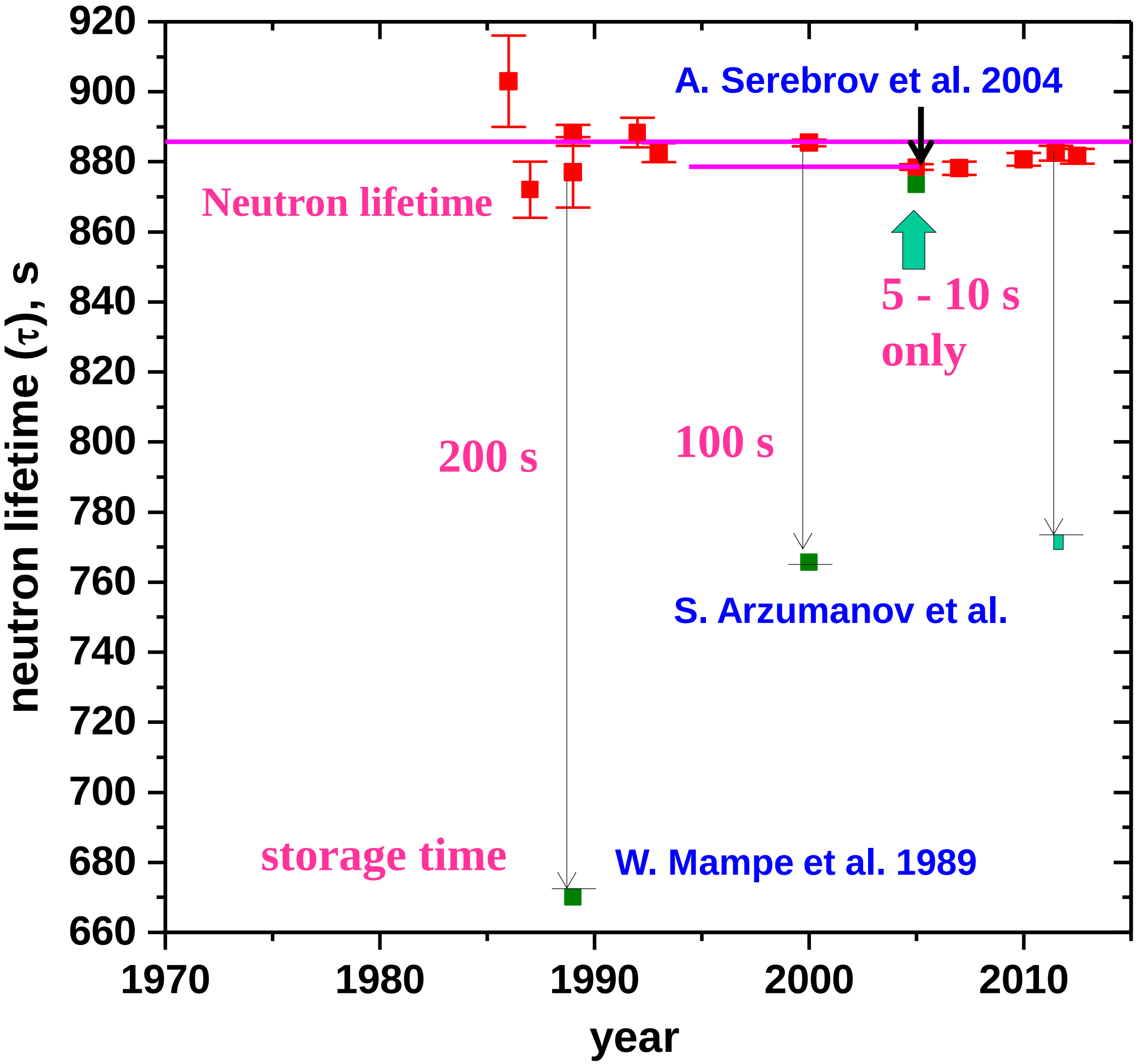
b) mirror reflection - stationary trajectory and storage above barrier neutrons.

But there is no such type problem in our gravitrap experiment because temperature is about 100K and solid Fomblin

Neutron lifetime and storage time in traps



Neutron lifetime and storage time in traps



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

PHYSICAL REVIEW C **78**, 035505 (2008)

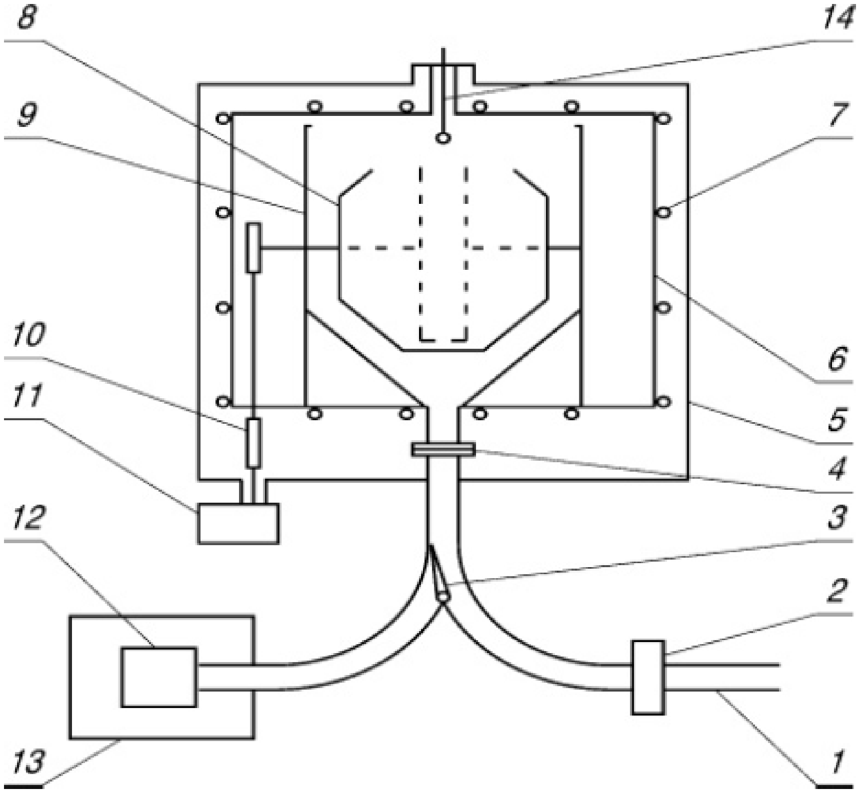


FIG. 1. Schematic of the gravitational UCN storage system: 1—input neutron guide for UCN, 2—inlet valve, 3—selector valve (shown in the position in which the trap is being filled with neutrons), 4—foil unit, 5—vacuum volume, 6—separate vacuum volume of the cryostat, 7—cooling system for the thermal shields, 8—UCN storage trap (with the dashed lines depicting a narrow cylindrical trap), 9—cryostat, 10—trap rotation drive, 11—step motor, 12—UCN detector, 13—detector shield, and 14—vaporizer.

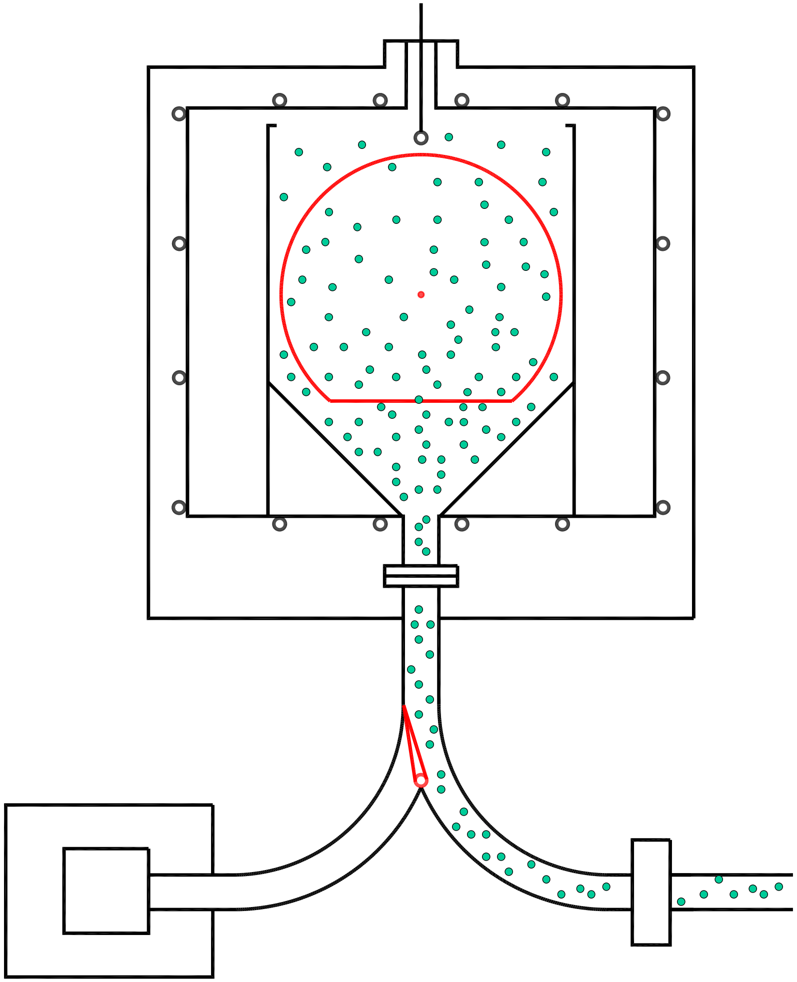
Advantages of this scheme

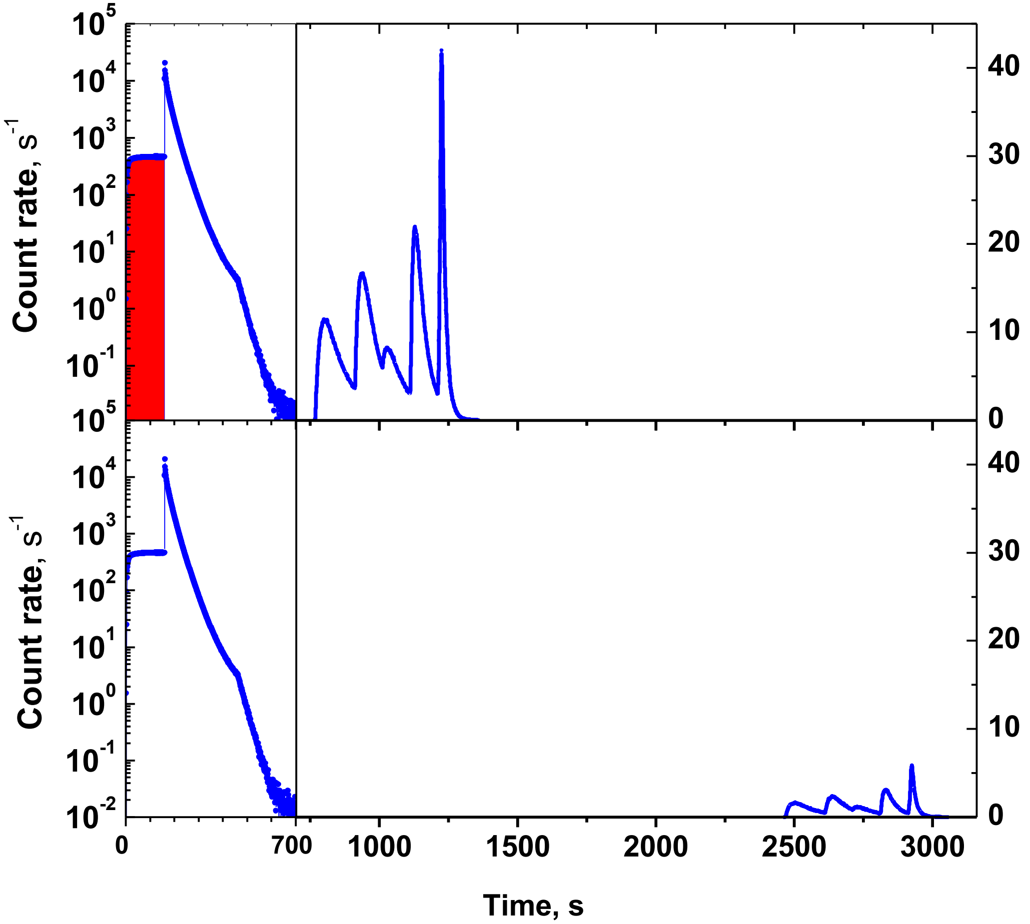
1.Low temperature, solid Fomblin, short extrapolation (5 – 10 s).

2. There is no quasi-elastic scattering and there is control of this process due to gravitational valve.

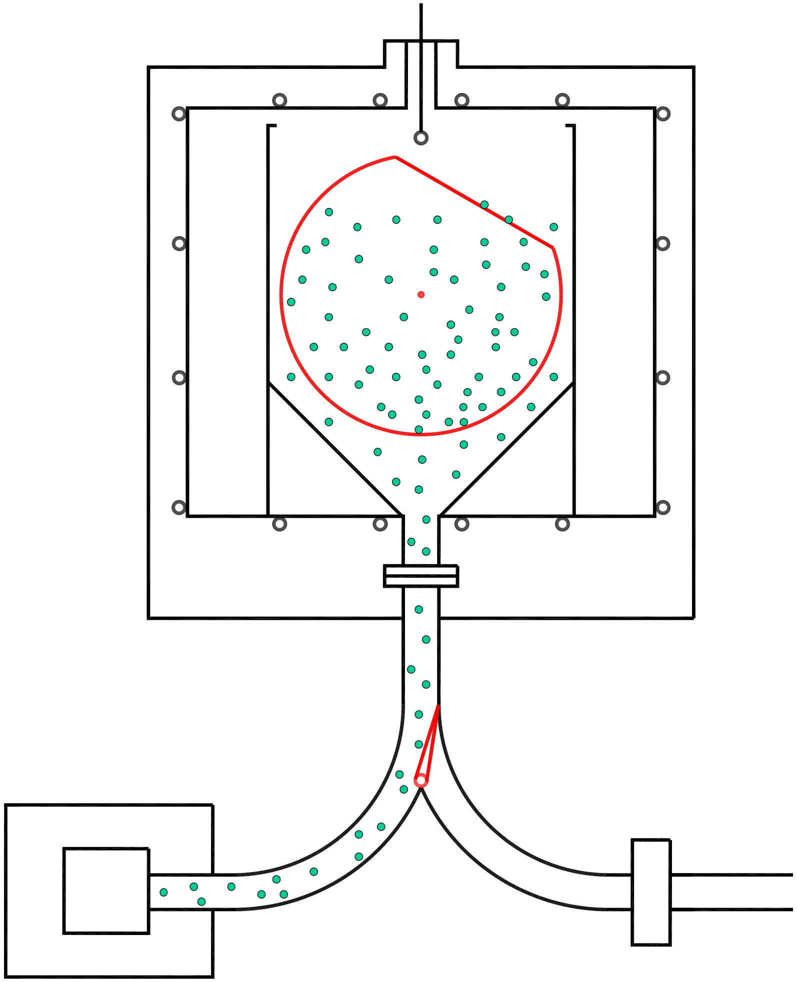
3. Spectrum measurements, control of above-barrier neutrons.

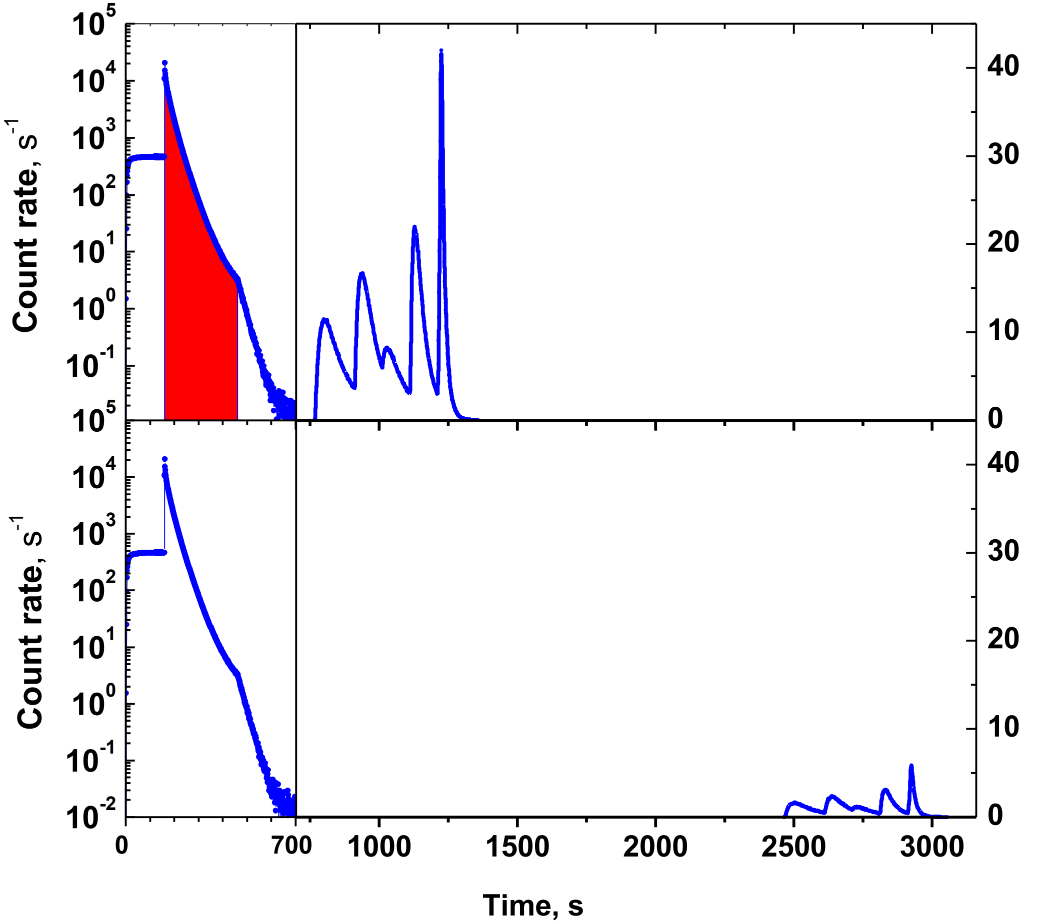
Filling of trap θ=180°



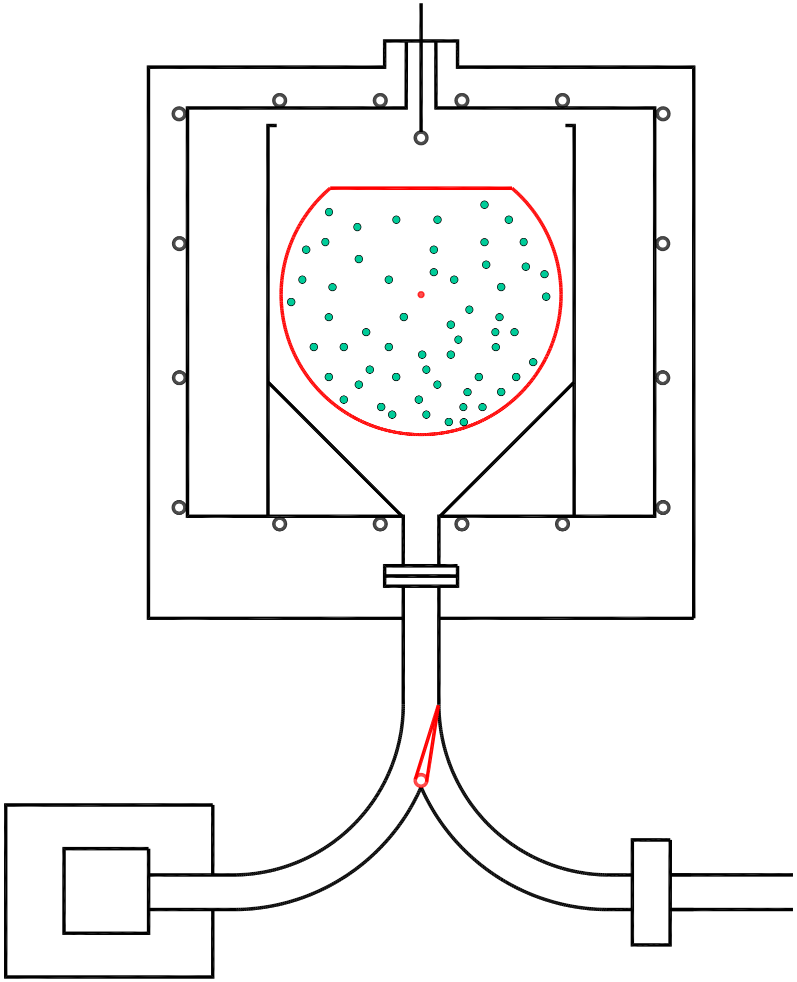


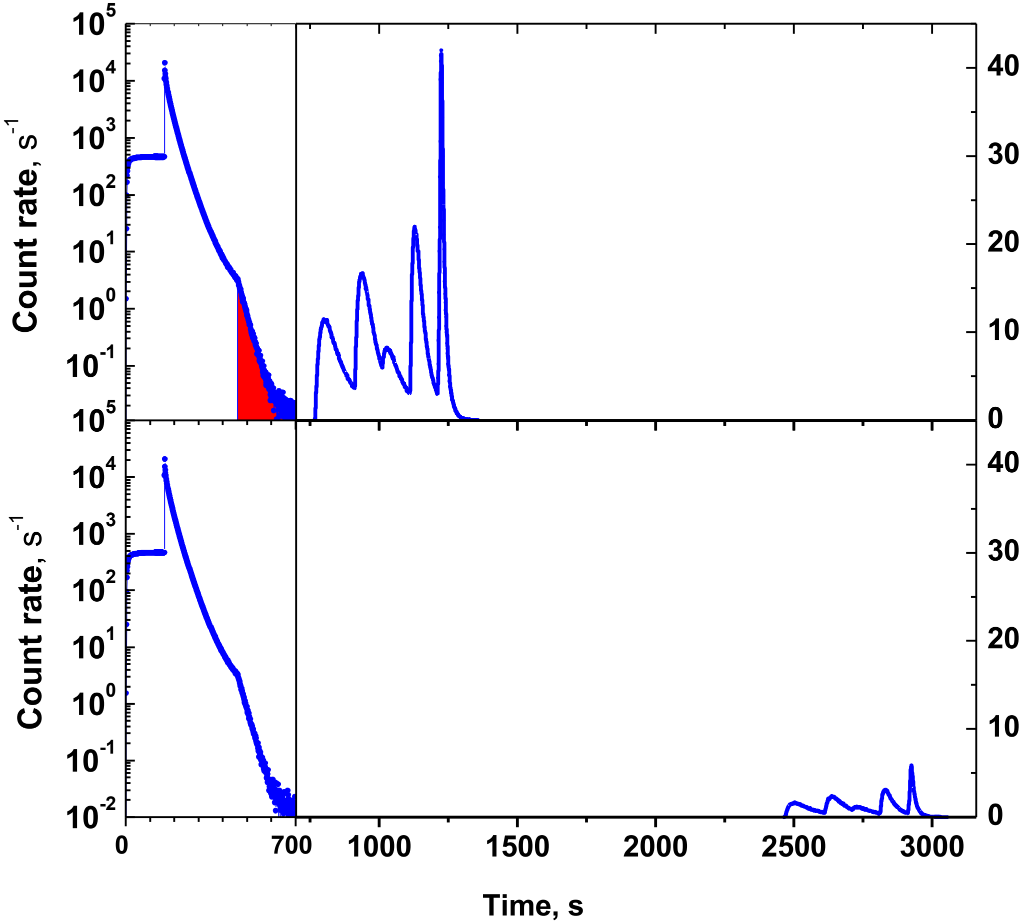
Monitoring θ=30°



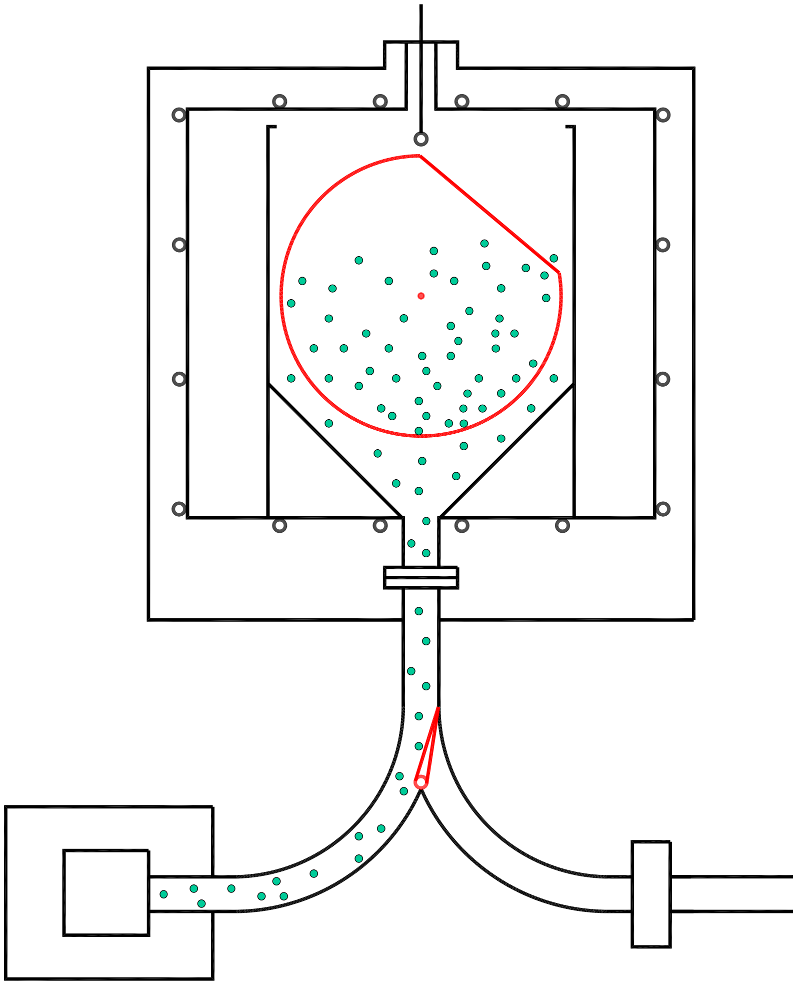


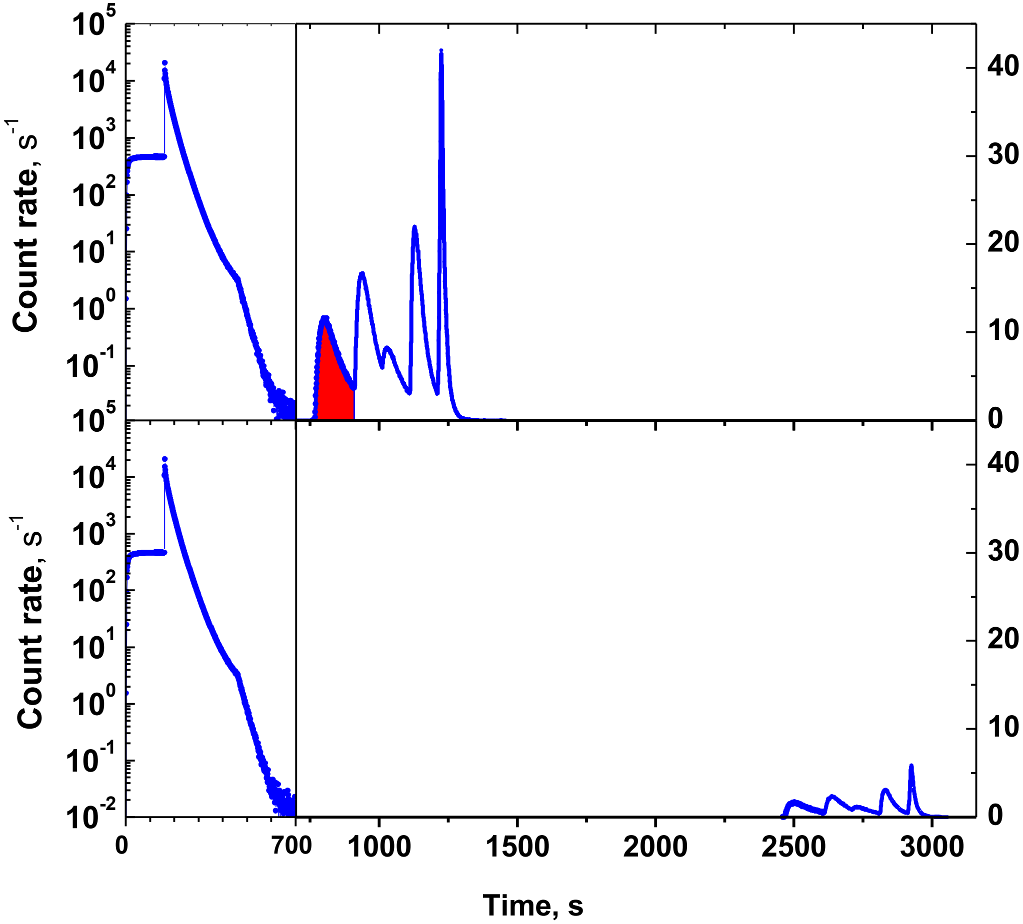
Storage θ=0°



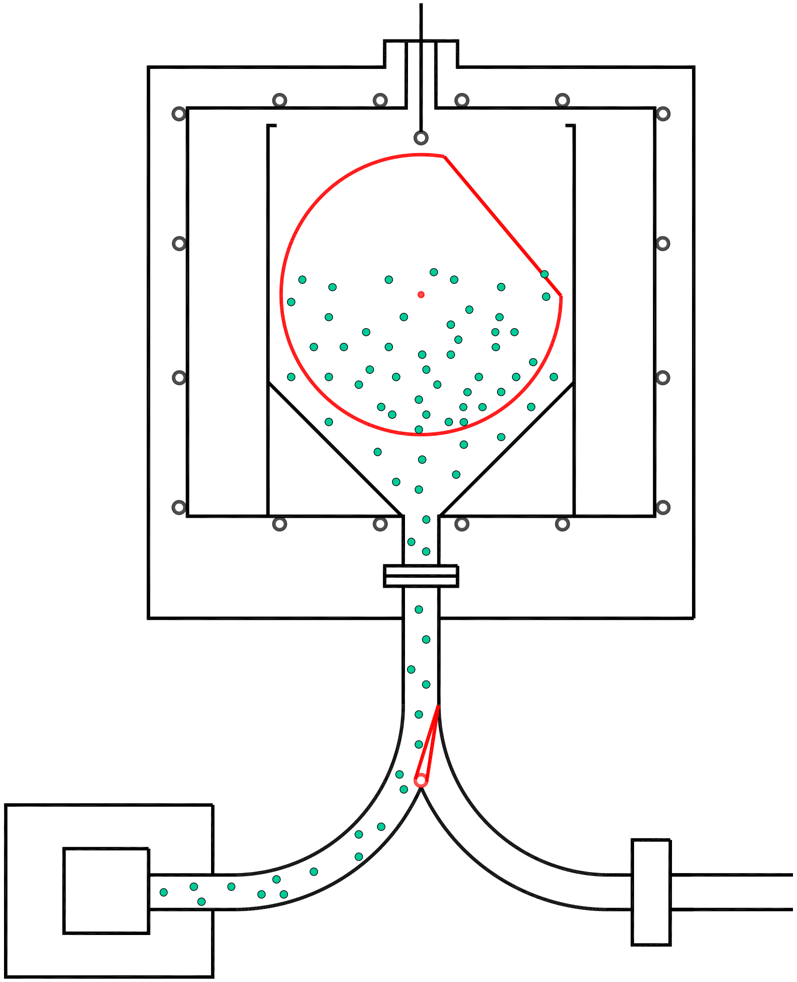

10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
Count rate, s^{-1}
Count rate, s^{-1}
40
30
20
10
0
40
30
20
10
0
0
700
1000
1500
2000
2500
3000
Time, s

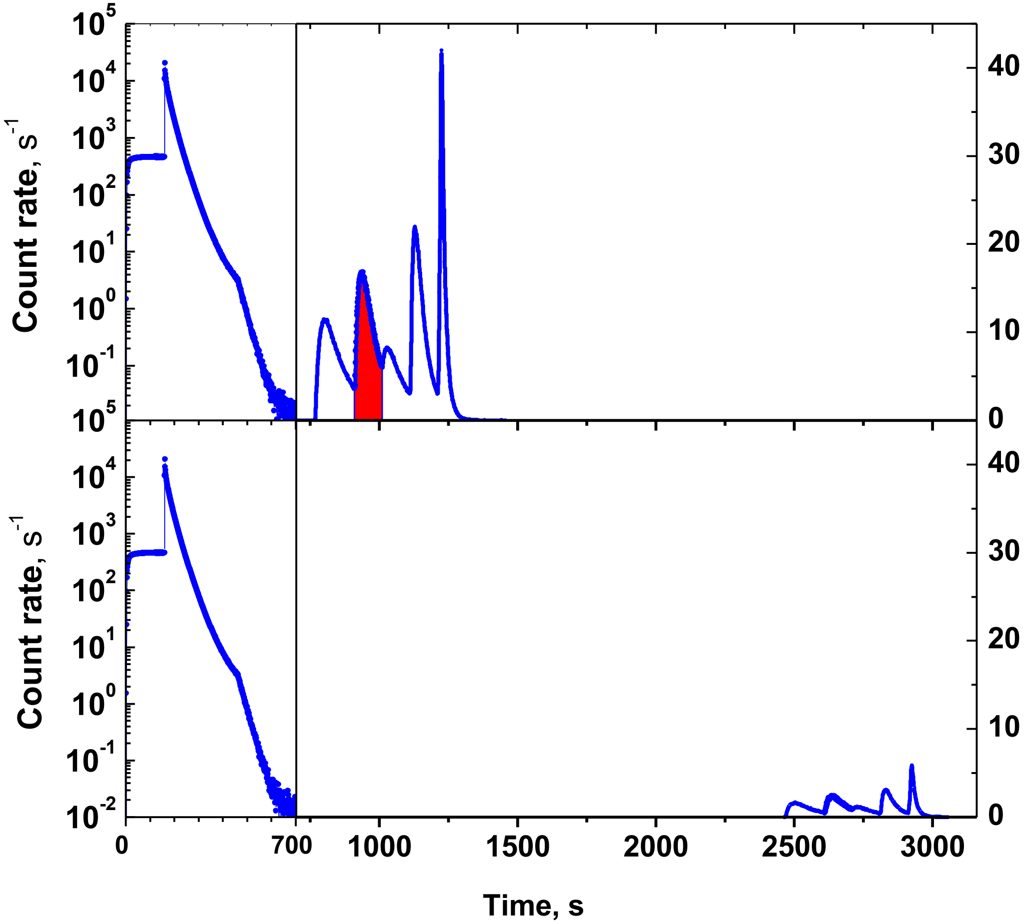
Emptying θ=40°



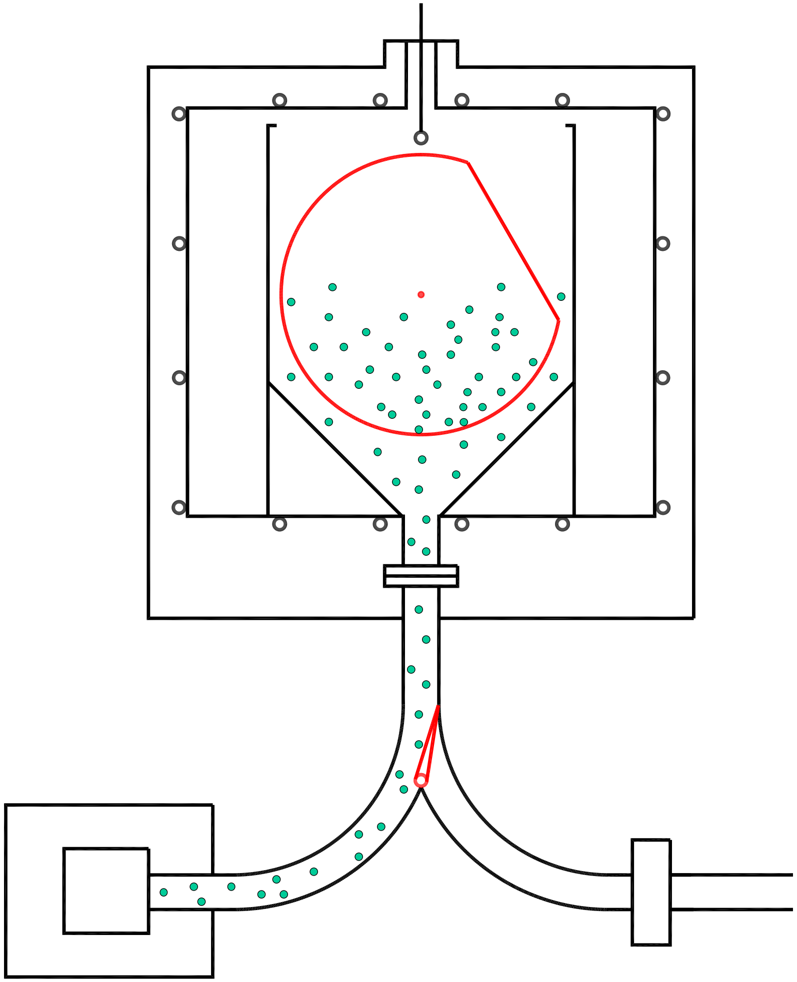


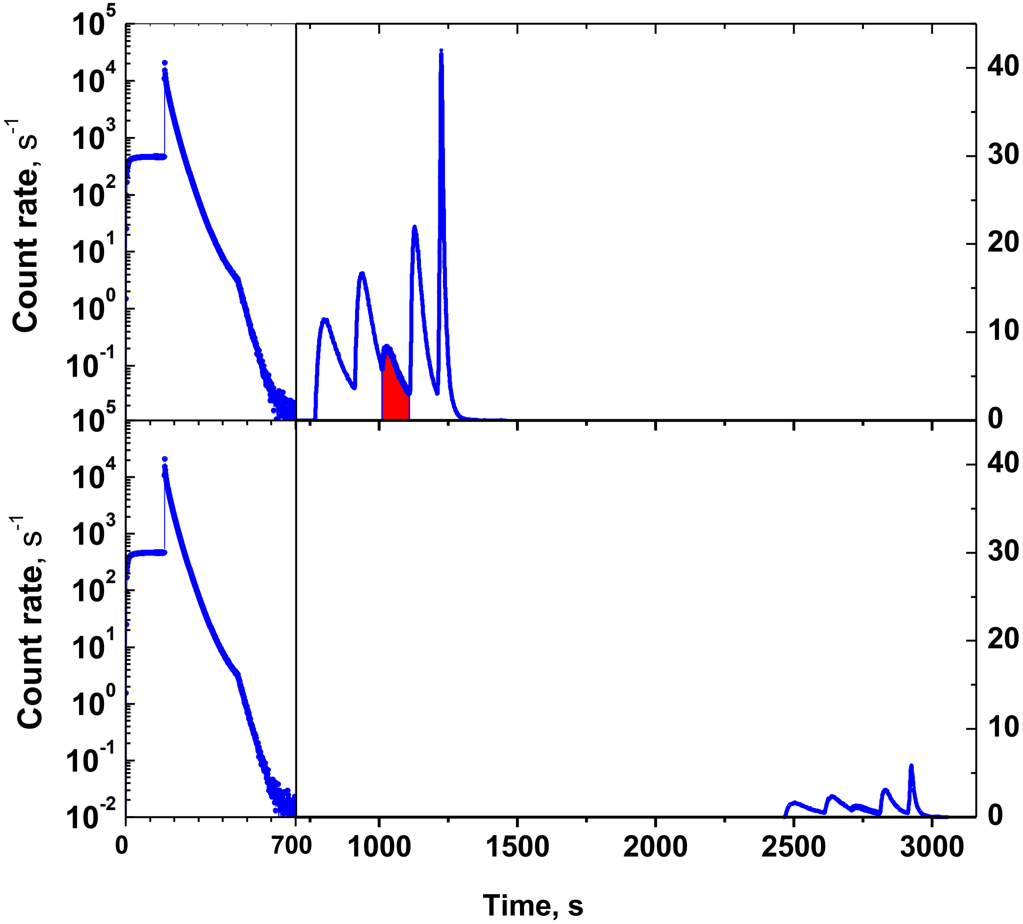
Emptying θ=50°



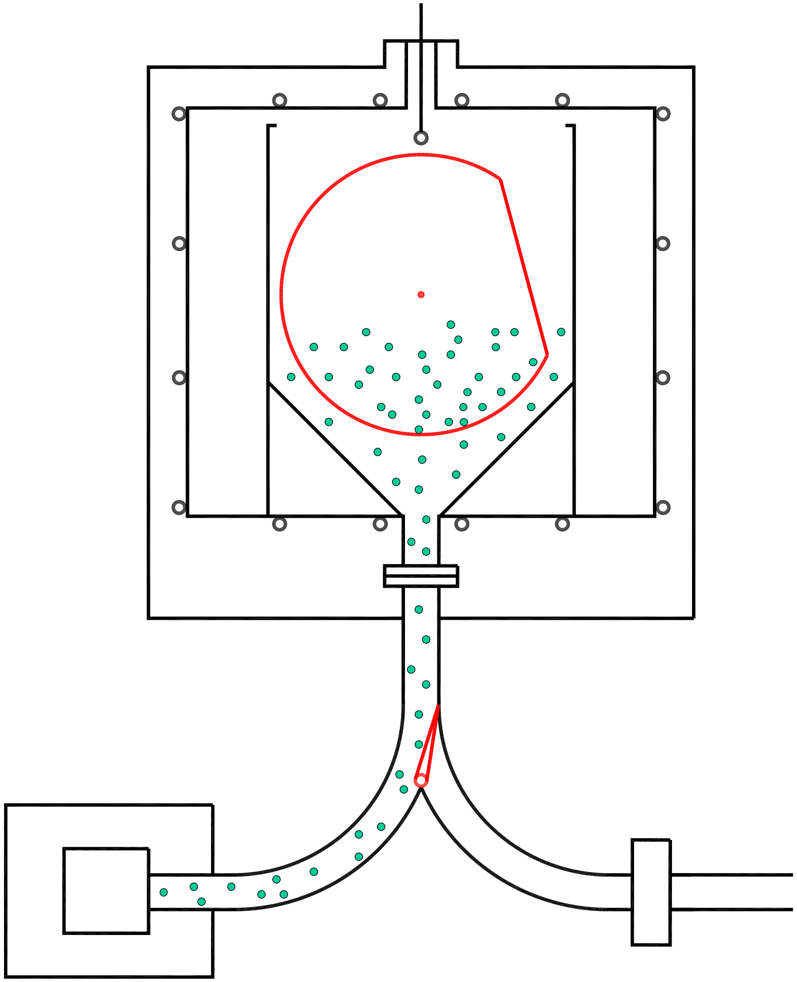


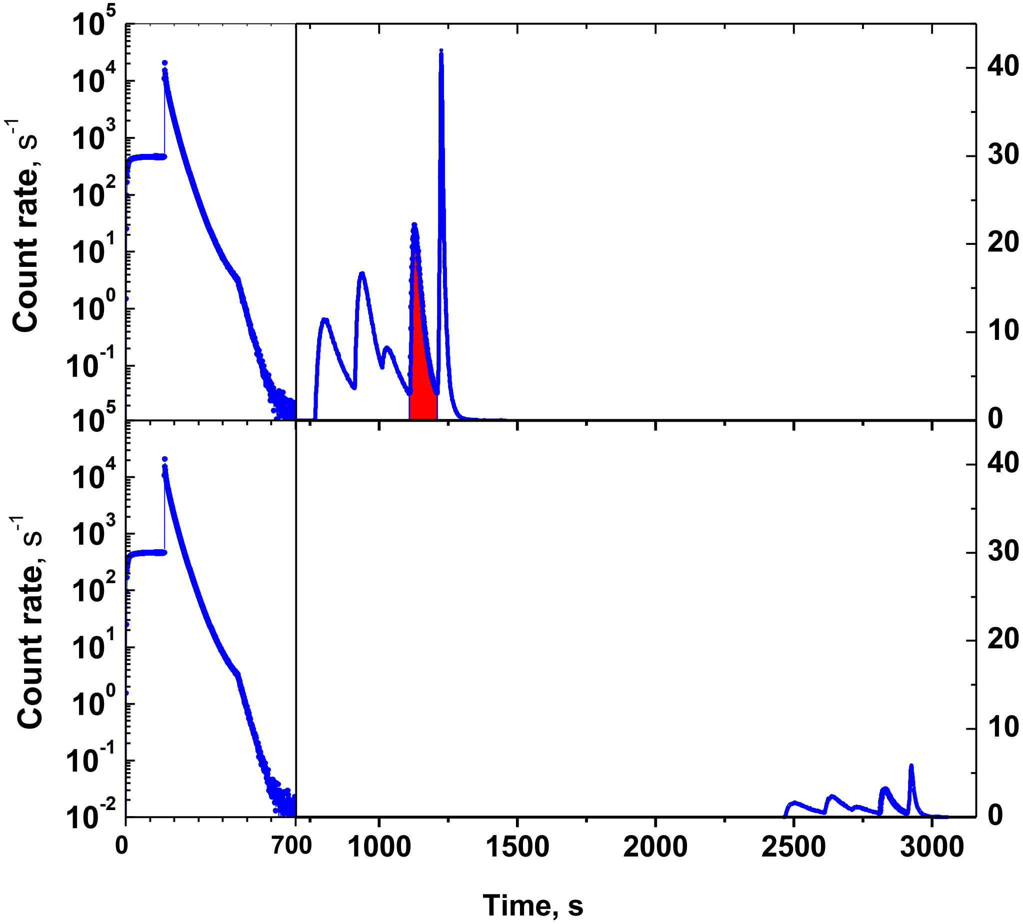
Emptying θ=60°



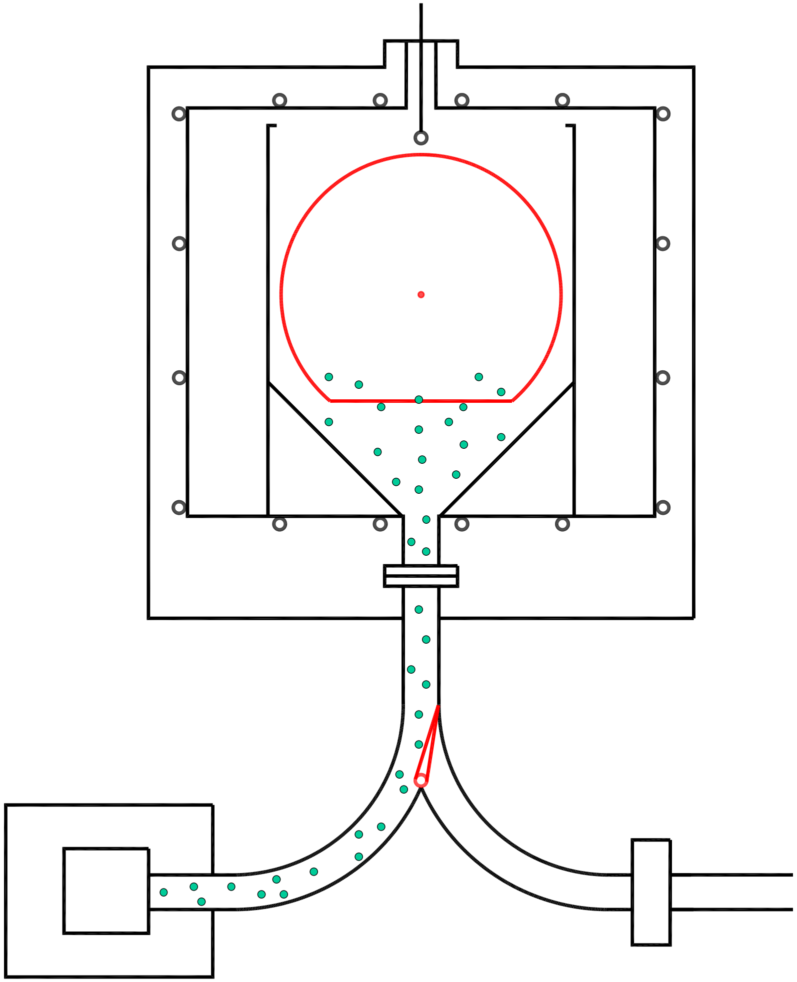


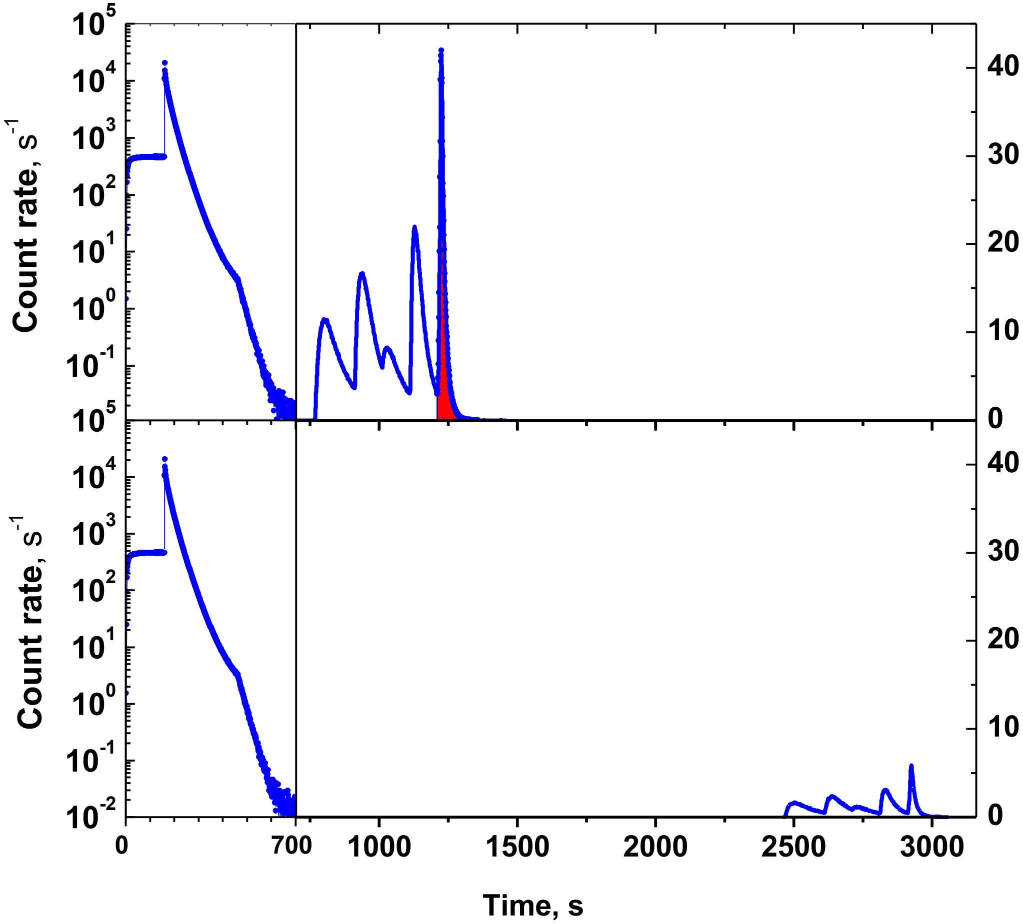
Emptying θ=75°



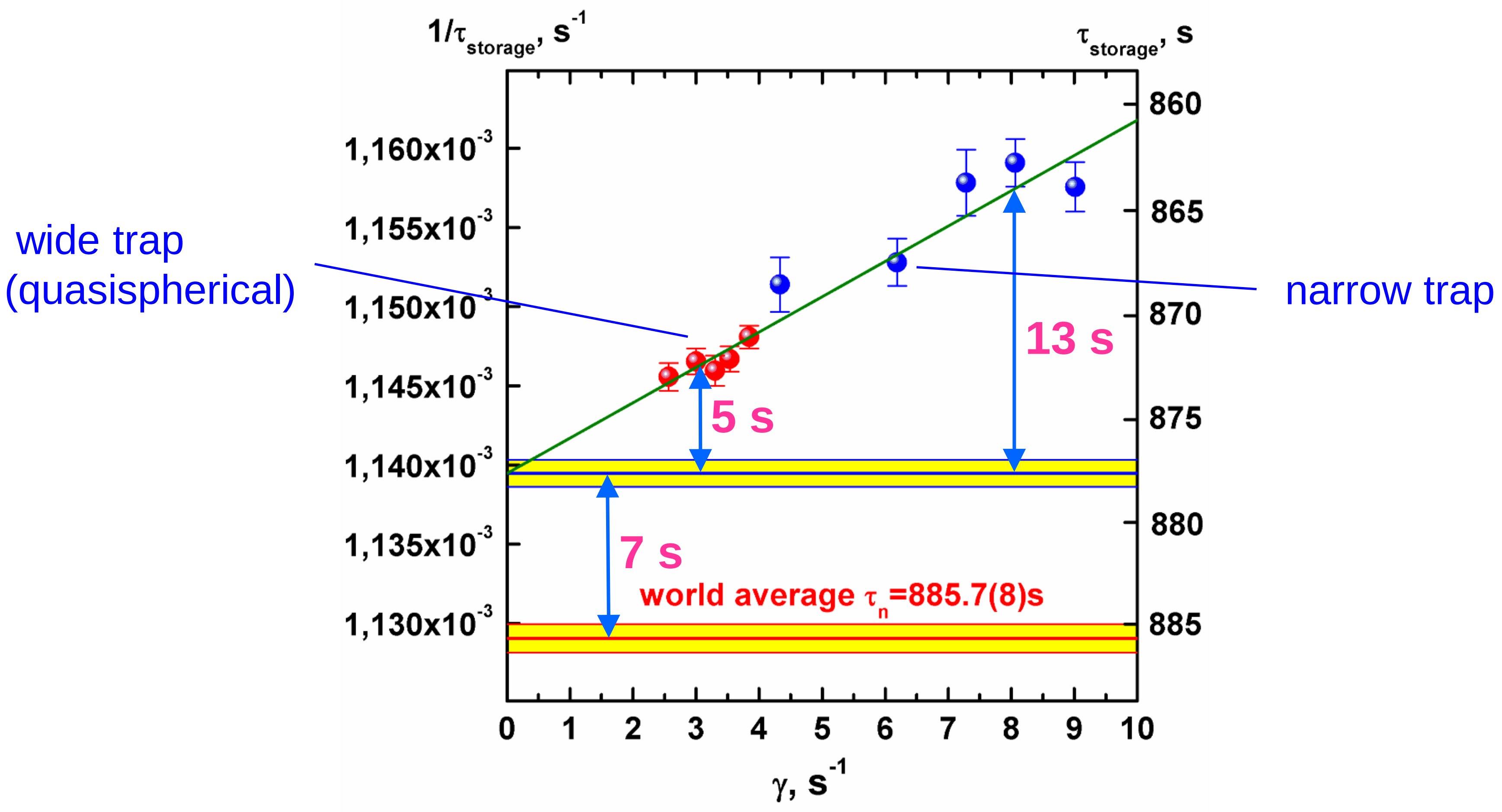


Emptying θ=180°





Extrapolation to n-lifetime



The most close extrapolation to neutron lifetime (5 s only) is reached in this experiment!

Final result and list of systematic corrections and uncertainties

Effect	Magnitude, s	Uncertainty, s
n-lifetime (size extrapolation)	878.07	0.73
Method of calculating γ	0	0.236
Influence of shape of function $\mu(E)$	0	0.144
UCN spectrum uncertainty	0	0.104
Uncertainty of trap dimensions (1 mm)	0	0.058
Residual gas effect	0.4	0.024
Uncertainty in PFPE critical energy (20 neV)	0	0.004
Total systematic correction	**0.4**	**0.3**
Final n-lifetime	**878.5**	**$\pm 0.7_{stat} \pm 0.3_{sys}$**

Our experiment with so close time extrapolation (5- 10 s) from storage time to neutron lifetime is not sensitive to shape of loss function $\mu(y)$

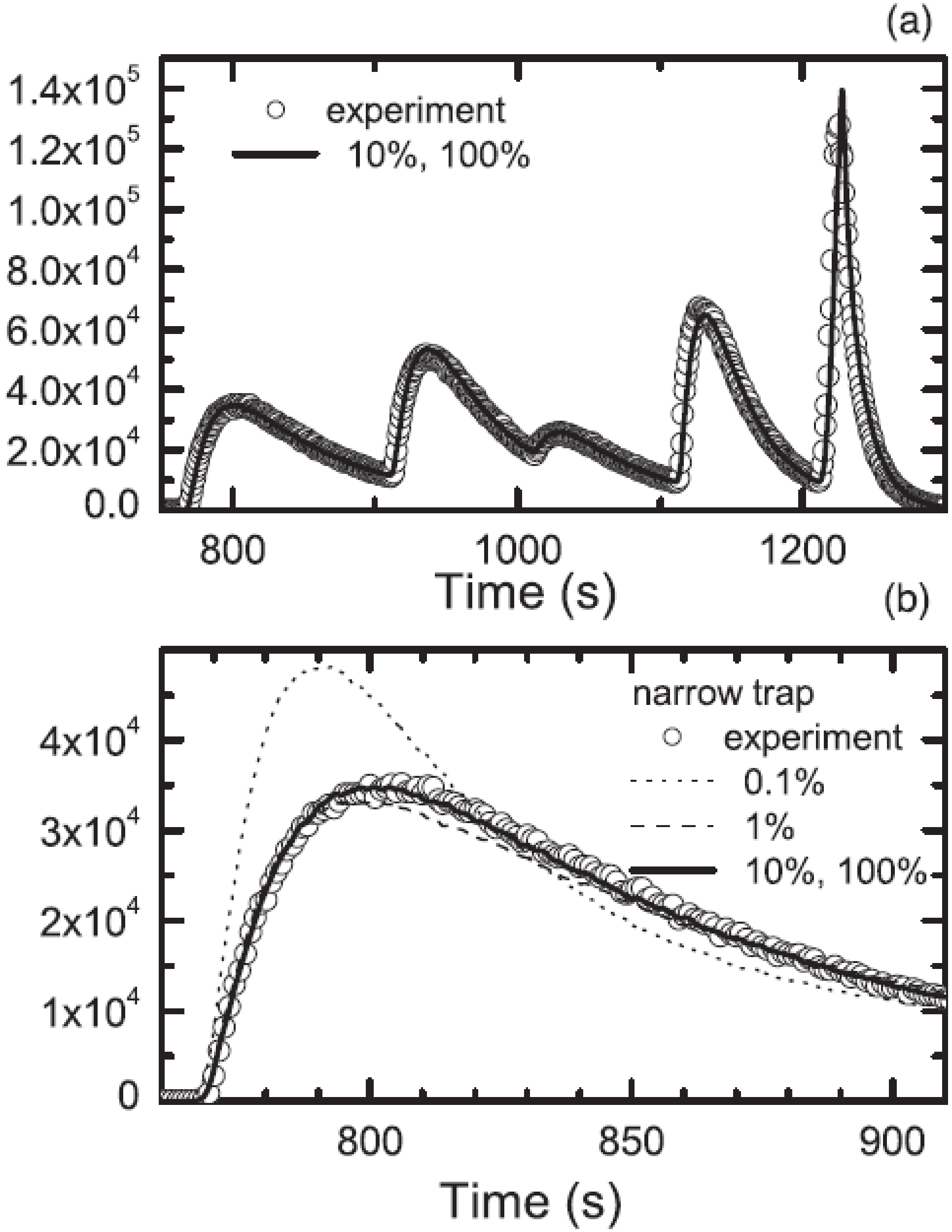
$$\mu(y) = \frac{2\eta}{y^2} \cdot \left(\arcsin y - y\sqrt{1 - y^2}\right) \approx \begin{cases} \pi\eta, & y \to 1, \\ \frac{4}{3}\eta y, & y \ll 1, \end{cases}$$

Even if we used these wrong functions then the systematic errors would still be negligible:

$$\begin{aligned}
&\mu(v) \sim \text{constant}, && -0.158 \text{ s}, \\
&\mu(v) \sim v/v_{\text{lim}}, && -0.022 \text{ s}, \\
&\mu(v) \sim (v/v_{\text{lim}})^2, \text{ and} && +0.1 \text{ s, and} \\
&\mu(v) \sim (v/v_{\text{lim}})^3, && +0.217 \text{ s}.
\end{aligned}$$

It is result of Monte-Carlo simulation.

Monte Carlo simulation of Gravitrap experiment (A.Fomin)

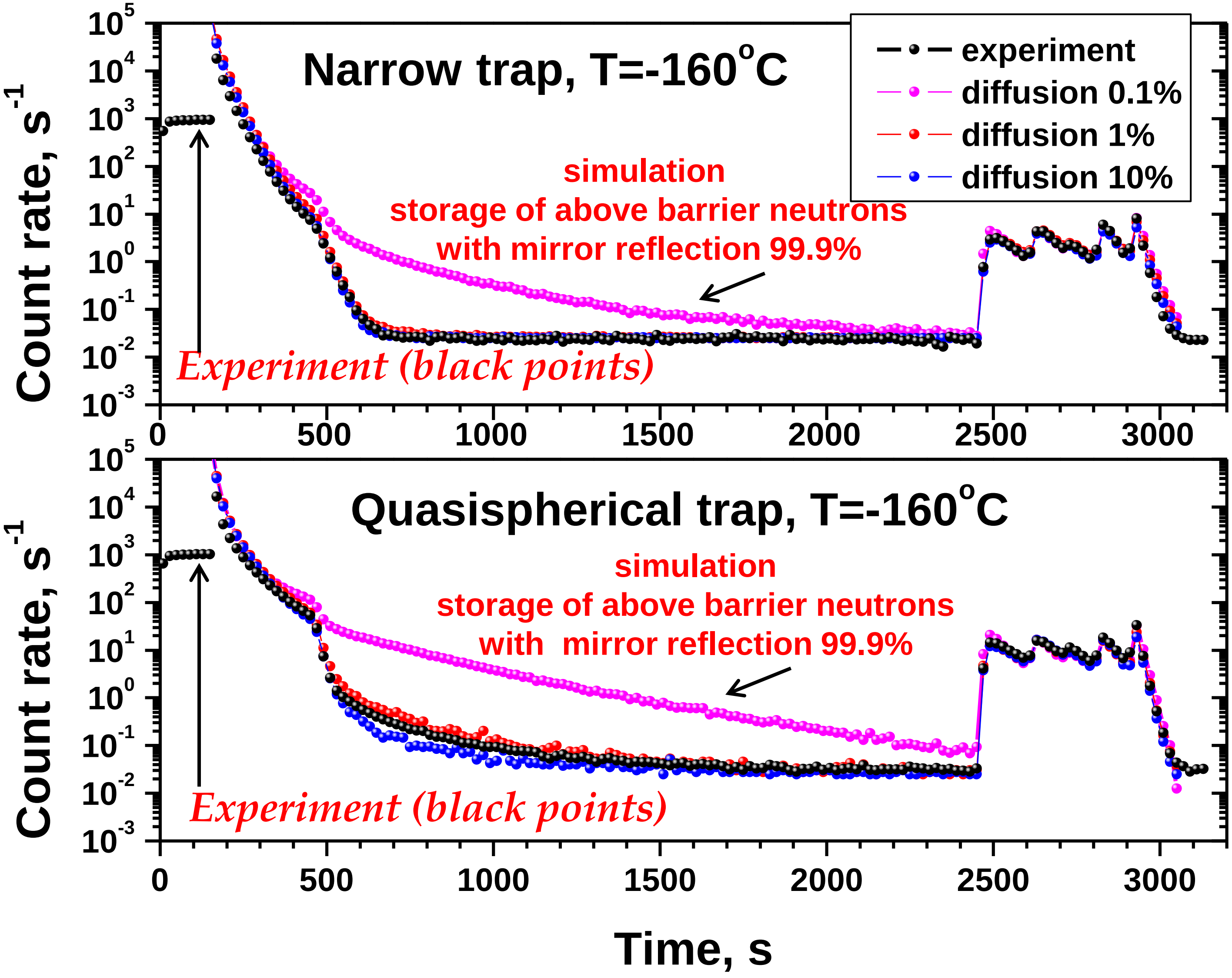


(benchmark)

FIG. 14. Simulation of an experiment by the Monte Carlo method, consisting in simulating the neutron discharge from a narrow cylindrical trap. The dotted curve corresponds to the results of calculations with a 0.1% diffuse reflection probability; the dashed curve corresponds to a 1% diffuse reflection probability, and the solid curve to 10% and 100%.

Monte Carlo simulation of Gravitrap experiment

Evidence that there are no stationary trajectory and storage of above barrier neutrons.



Narrow trap, T=-160°C

simulation
storage of above barrier neutrons
with mirror reflection 99.9%

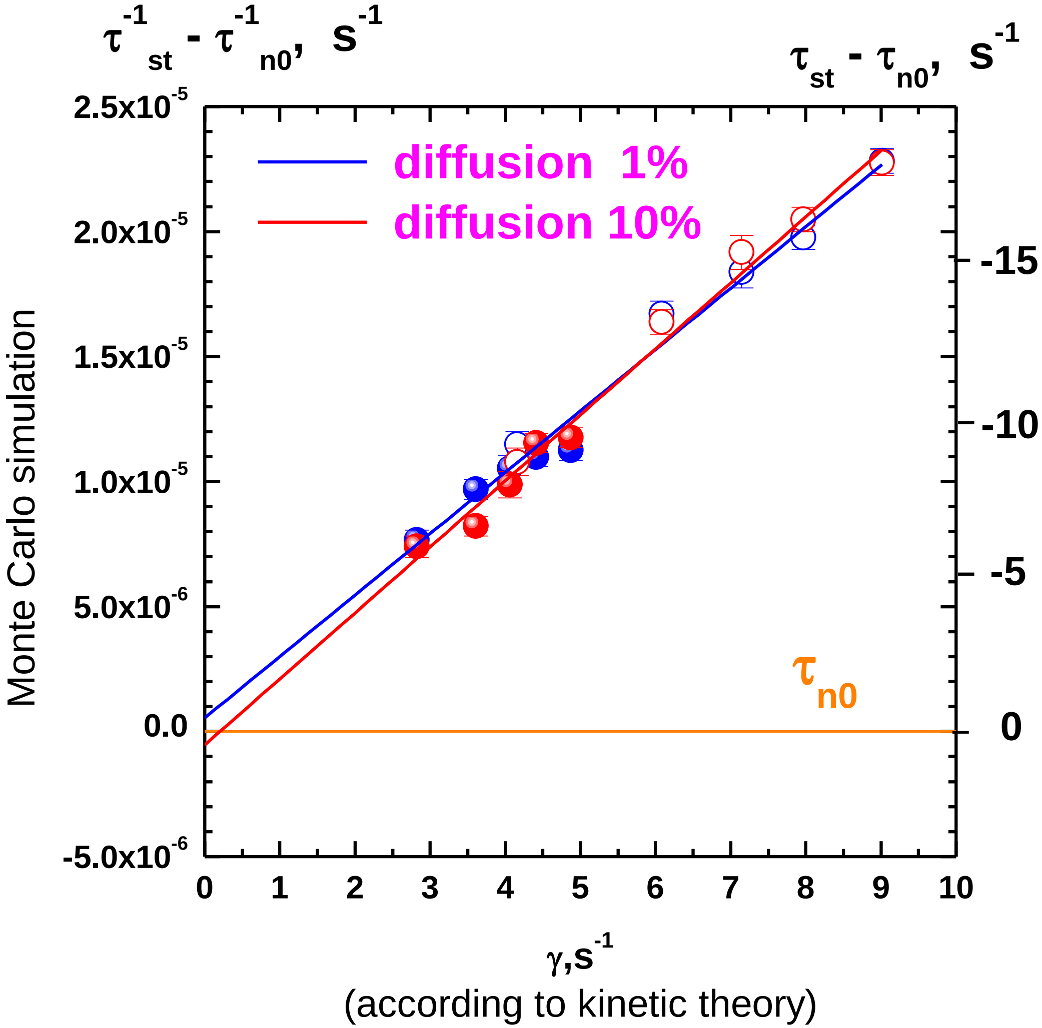
Experiment (black points)

Quasispherical trap, T=-160°C

simulation
storage of above barrier neutrons
with mirror reflection 99.9%

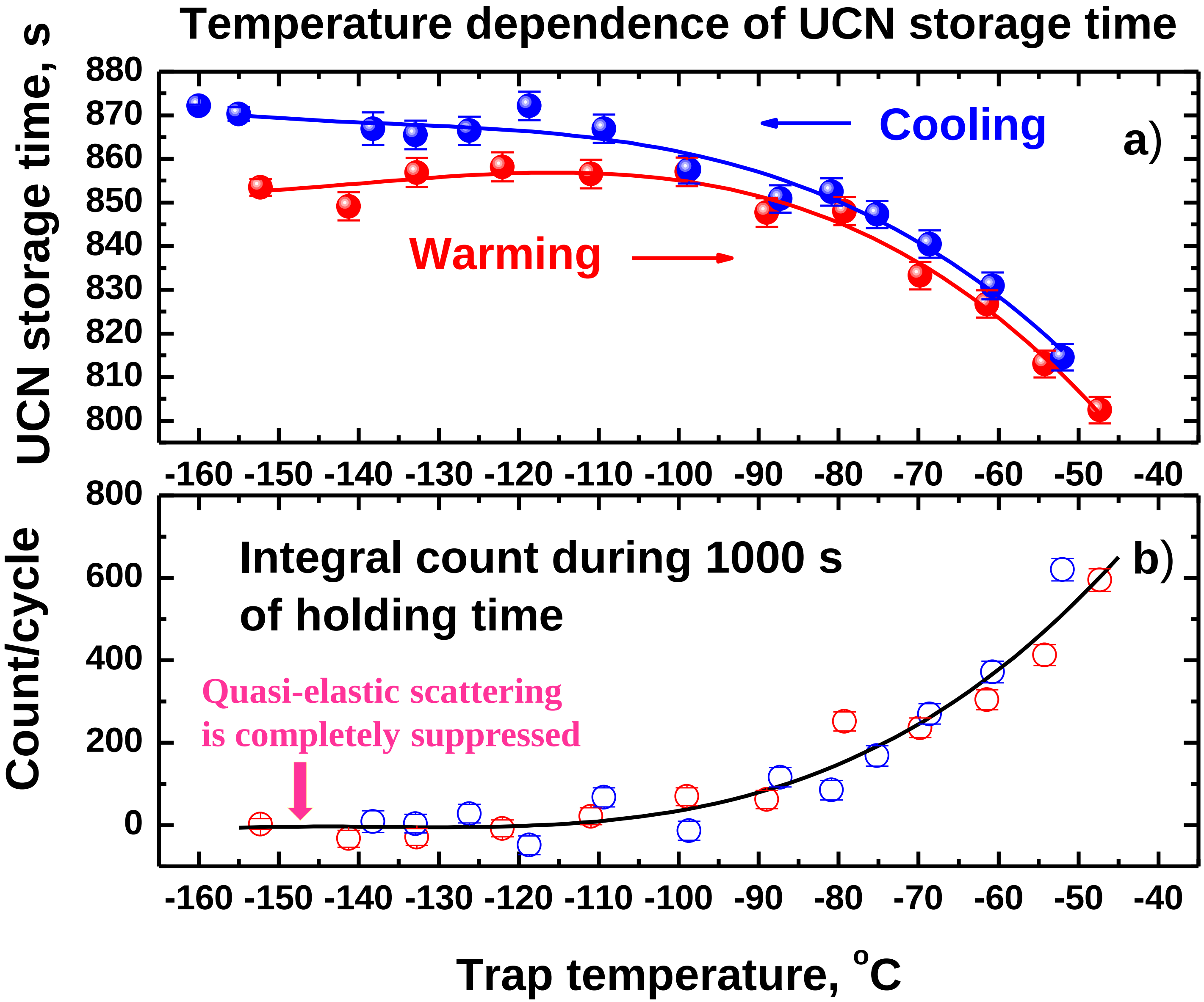
Experiment (black points)

Specular reflections and extrapolation



Systematic error of gamma calculation method is 0.017 ± 0.236 s

Temperature dependence of quasi-elastic scattering



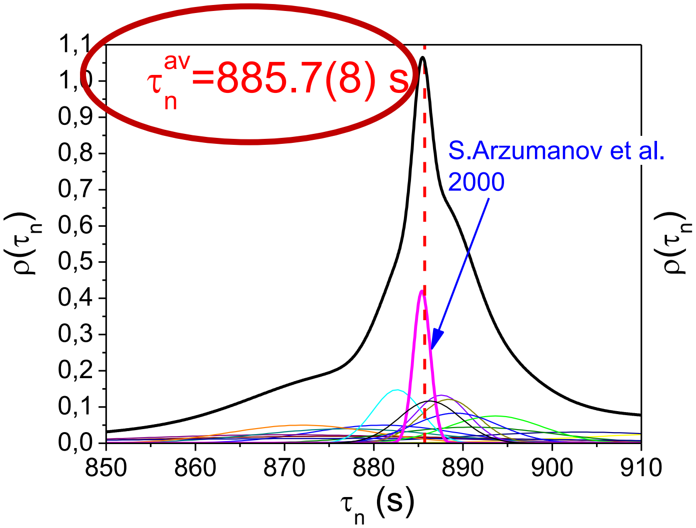
Conclusion for gravitrap experiment

- The storage time in the experiment is the most close to neutron lifetime. The **probability of losses is about 1%** of probability of neutron lifetime.
- The extrapolated time is only 6 s from the best storage time, while the **accuracy of extrapolation ±0.7$_{stat}$ s and ±0.3$_{sys}$ s.** It means that relative accuracy of taking into account the losses in storage process is about 10% only.
- **The process of quasi-elastic scattering is completely suppressed.** Upper limit for corrections of such type process is 0.03 s.
- **There is no effect of stationary trajectory.**
- The coating properties of PFPE are completely perfect. **Uncovered part of surface has to be less than 10^{-6} (experimental result with Ti coating).** It gives the guarantee of the same loss factor for the different traps with beryllium substrate.
- **The stability and reproducibility of PFPE coating was demonstrated in course of experiment.**

All mentioned advantages of experiment allow to obtain the most precise result of neutron lifetime measurement: 878.5±0.8 s.

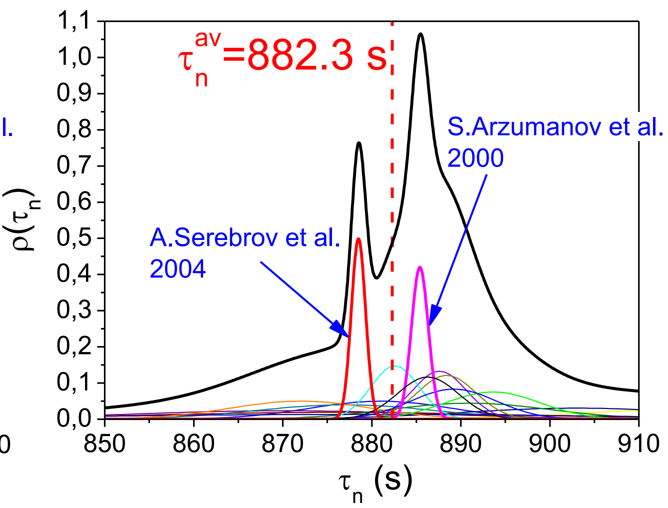
Problem of Neutron lifetime data in 2010

and analysis of possible systematics in previous experiments (Serebrov, Fomin PRC 82, 035501(2010)



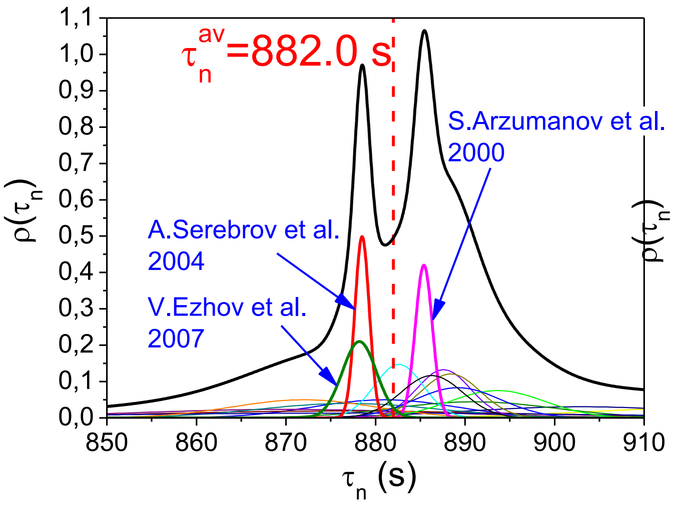
2003

before Gravitrap measurement



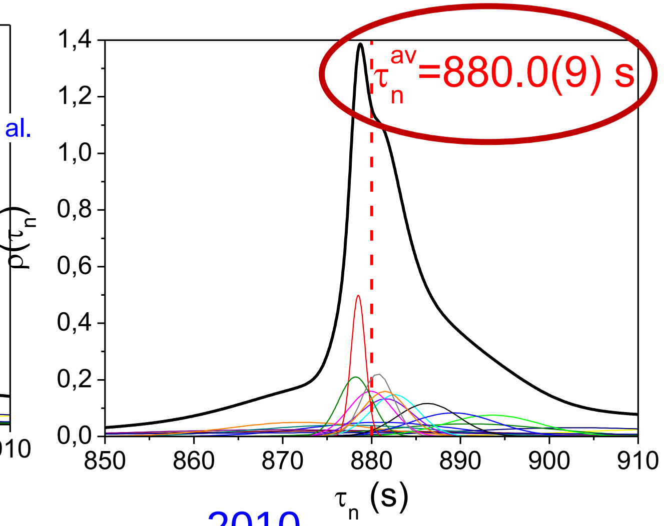
2004

after Gravitrap measurement



2007

after magnetic trap measurement



2010

new analysis

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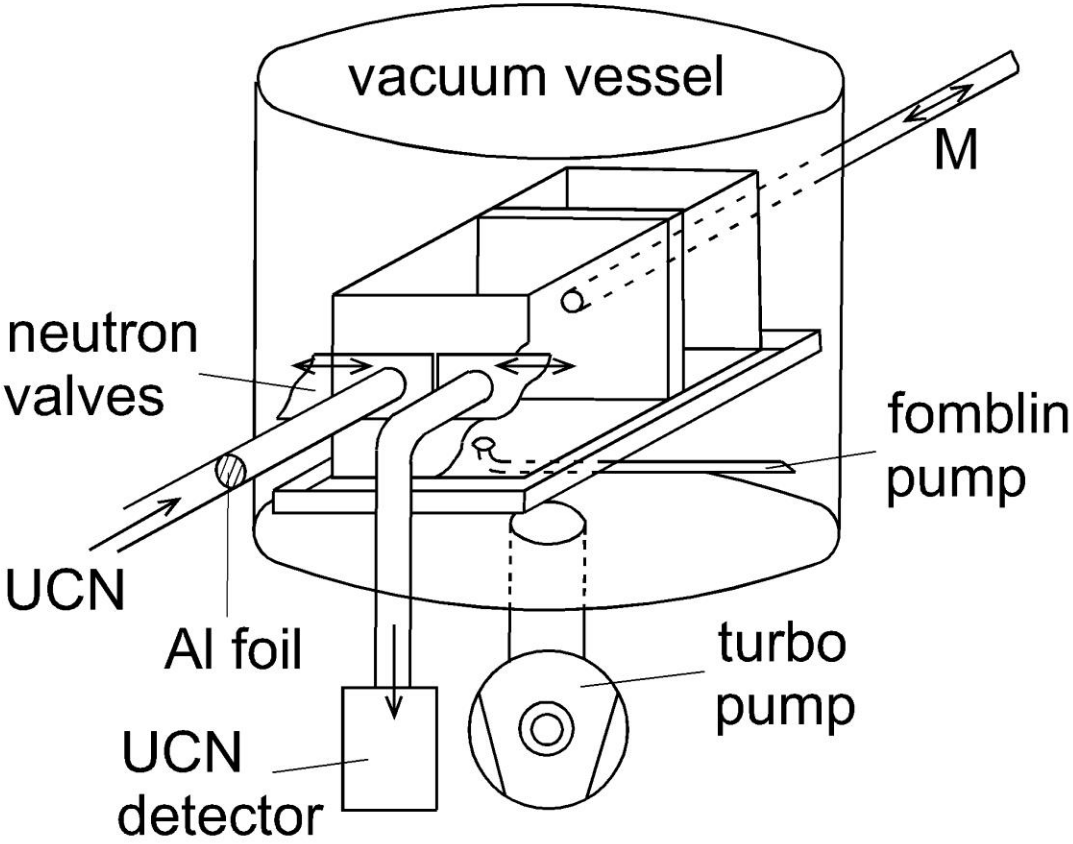
(Serebrov, Fomin PRC 82, 035501(2010)

Experiment MAMBO I [W.Mampe et al. PRL 63 (1989) 593]

Sketch of the apparatus MAMBO I



Comparison of loss factors in PNPI experiment and in experiment MAMBO I [W.Mampe et al. PRL 63 (1989) 593]

Green box is the field of PNPI data

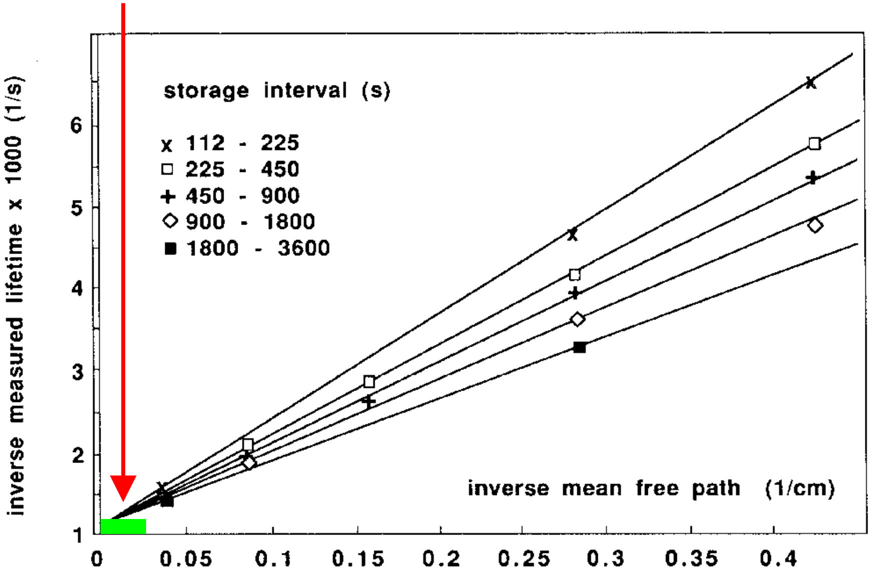


FIG. 2. Measured inverse bottle lifetimes as a function of the bottle inverse mean free path and for different storage intervals, from a 10-d run. The error bars are smaller than the data points.

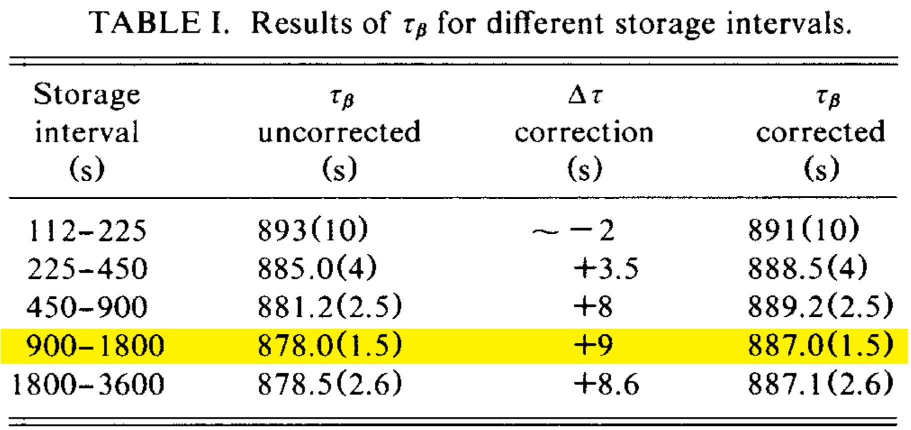
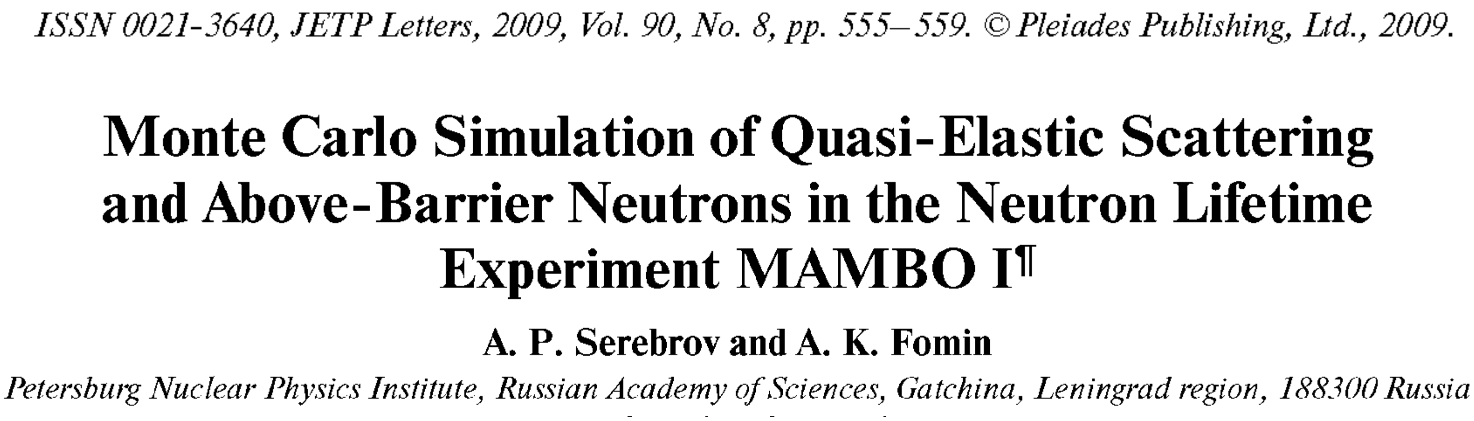


TABLE I. Results of τ_β for different storage intervals.

Storage interval (s)	τ_β uncorrected (s)	$\Delta\tau$ correction (s)	τ_β corrected (s)
112–225	893(10)	∼ −2	891(10)
225–450	885.0(4)	+3.5	888.5(4)
450–900	881.2(2.5)	+8	889.2(2.5)
900–1800	878.0(1.5)	+9	887.0(1.5)
1800–3600	878.5(2.6)	+8.6	887.1(2.6)

887.6 ± 3.0 s

Monte Carlo simulation of the experiment MAMBO I and possible correction of neutron lifetime result



ISSN 0021-3640, JETP Letters, 2009, Vol. 90, No. 8, pp. 555–559. © Pleiades Publishing, Ltd., 2009.

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

A. P. Serebrov and A. K. Fomin

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

PHYSICAL REVIEW C **82, 035501 (2010)**

Neutron lifetime from a new evaluation of ultracold neutron storage experiments

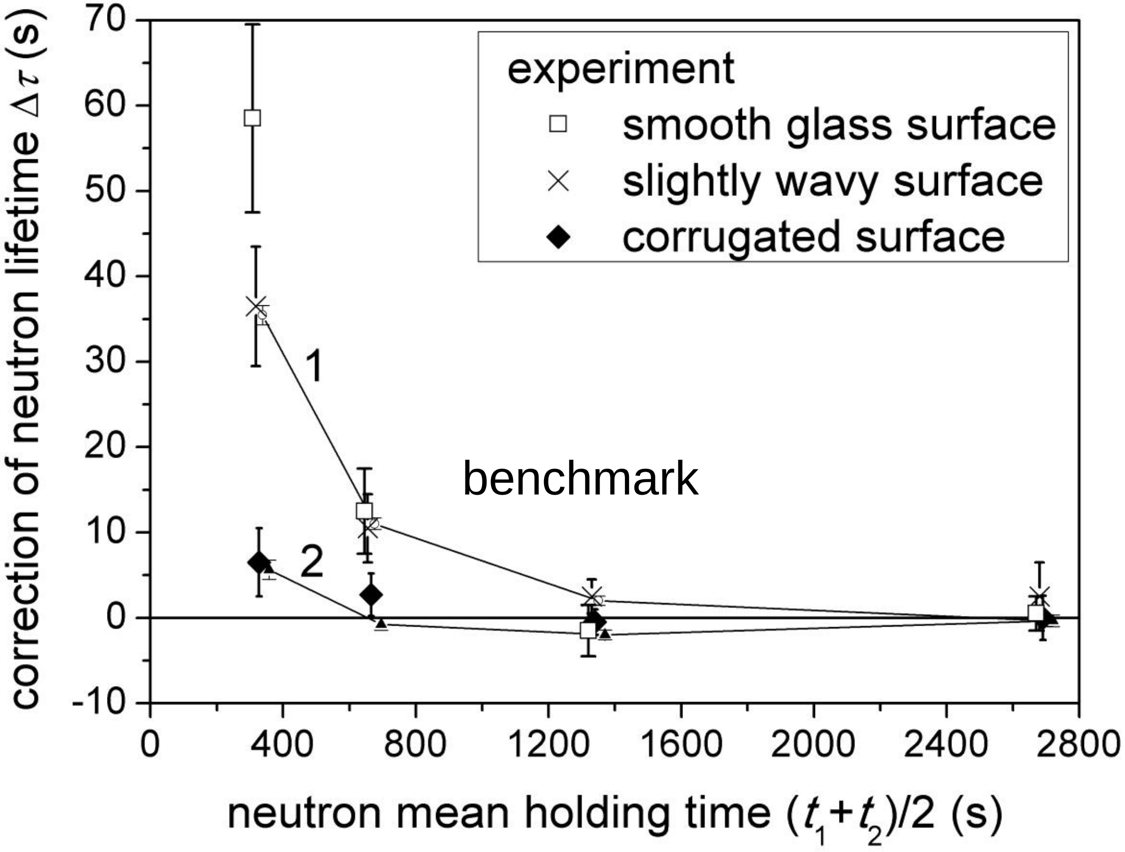
A. P. Serebrov* and A. K. Fomin

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.

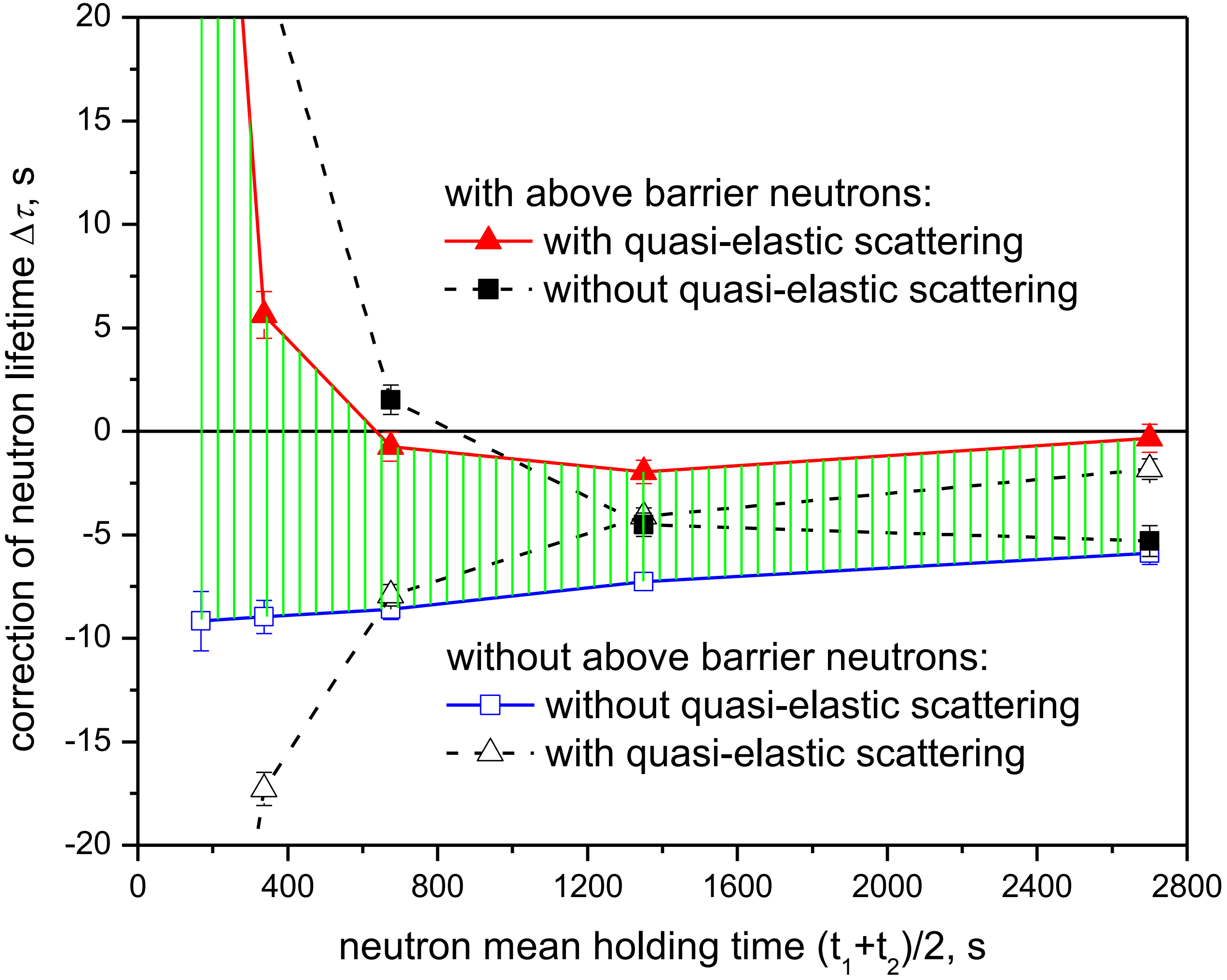
It shows that the result of this experiment can be corrected and instead of the previous result 887.6 ± 3 s the new result 881.6 ± 3 s could be claimed.

Comparison of MC simulation and experimental data (benchmark)



Dependence of the uncorrected experimental neutron lifetime on the holding time intervals for different bottle surface structures in comparison with results of the simulations with different probability of specular reflections from the walls. (1) with 99% specular and 1 % diffuse reflections, (2) with 50% specular and 50 % diffuse reflections.

Monte Carlo simulation of the experiment MAMBO I



It was shown 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.

PHYSICAL REVIEW C **85, 065503 (2012)**

Quasielastic scattering in the interaction of ultracold neutrons with a liquid wall and application in a reanalysis of the Mambo I neutron-lifetime experiment

A. Steyerl,1,* J. M. Pendlebury,2 C. Kaufman,1 S. S. Malik,1 and A. M. Desai1

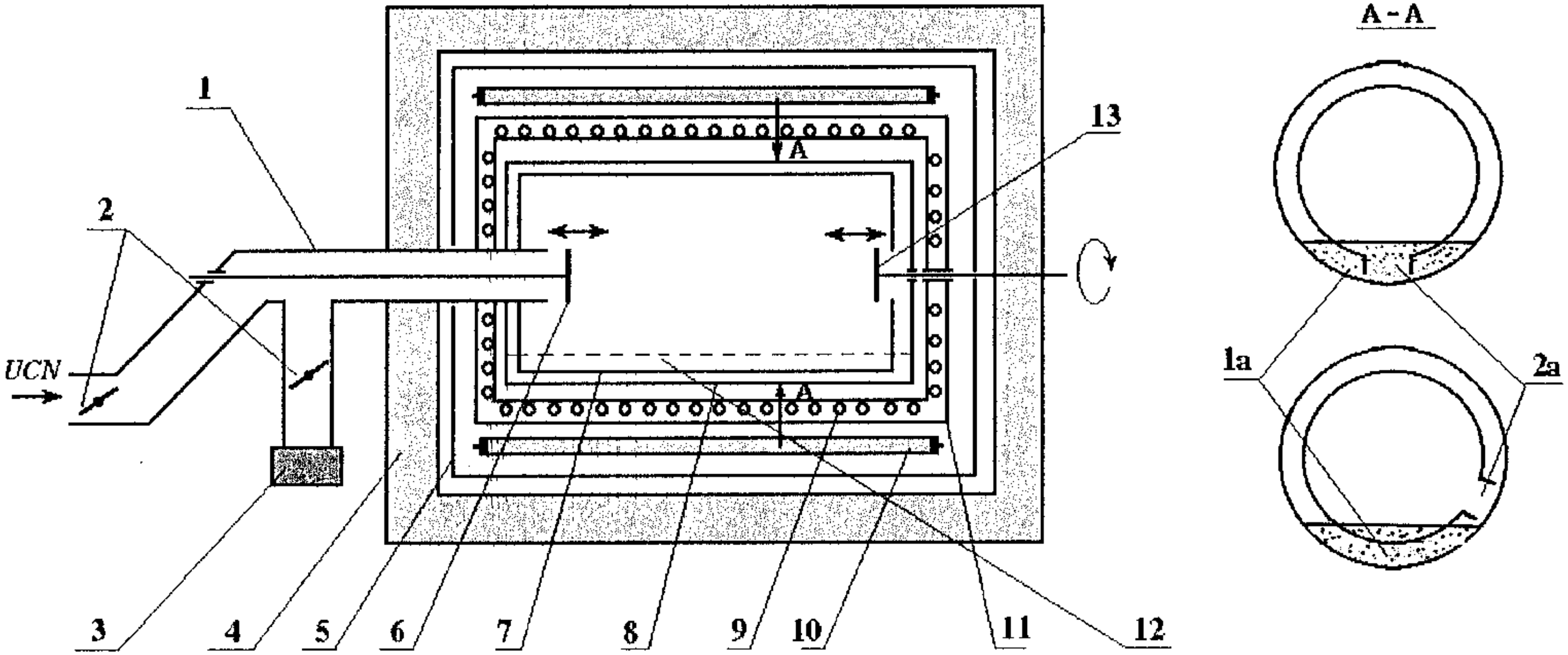
Abstract

We develop a theory of ultracold and very cold neutron scattering on viscoelastic surface waves up to second-order perturbation theory. The results are applied to reanalyze the 1989 neutron-lifetime experiment using ultracold neutron storage in a Fomblin-coated vessel by Mampe *et al. [Phys. Rev. Lett.* ***63, 593 (1989)].*** Inclusion of this theory of the quasielastic scattering process in the data analysis shifts the neutron lifetime value from

887.6 ± 3 to 882.5 ± 2.1 s.

S. Arzumanov et al. 2000 Physics Letters B 483 (2000) 15–22

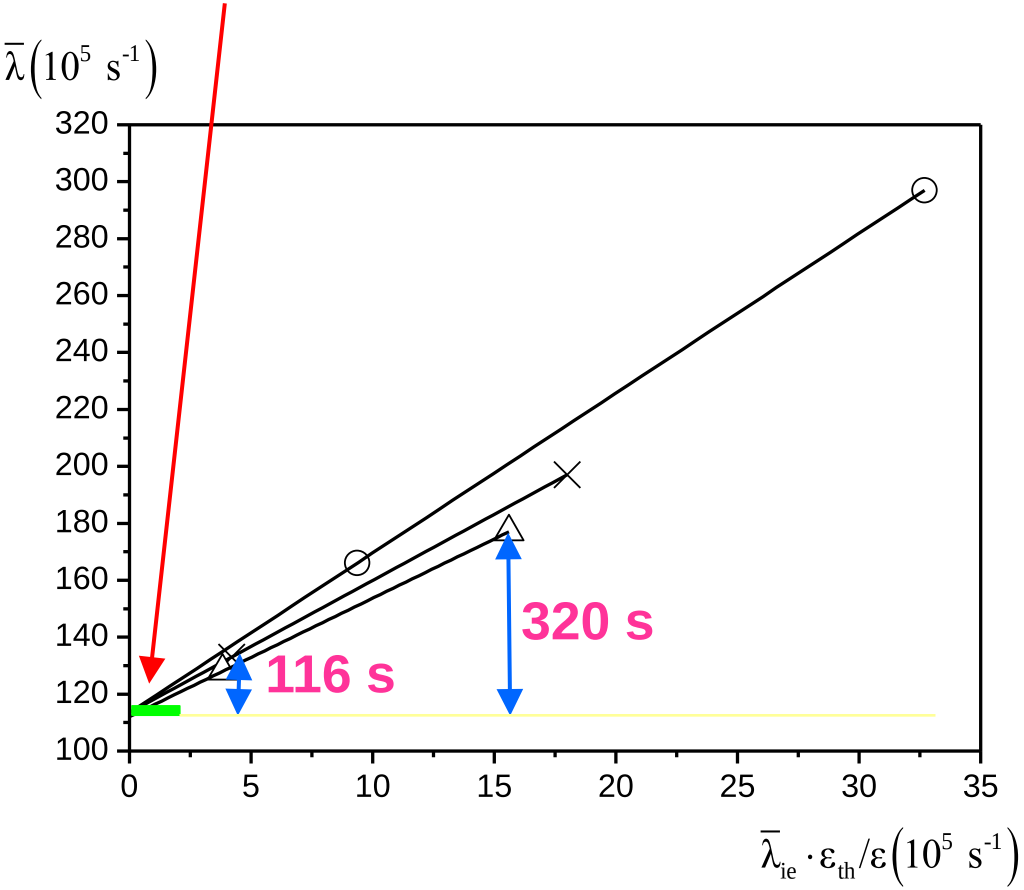
Experimental setup



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.

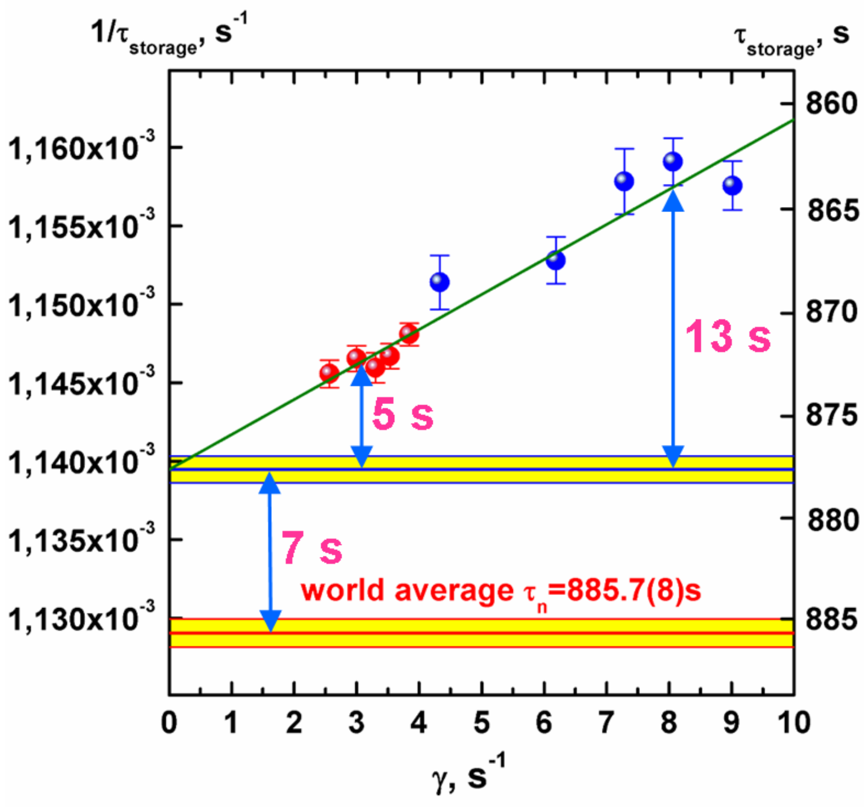
Comparison of loss factors in experiments of PNPI and KIAE

Green box is the field of PNPI data

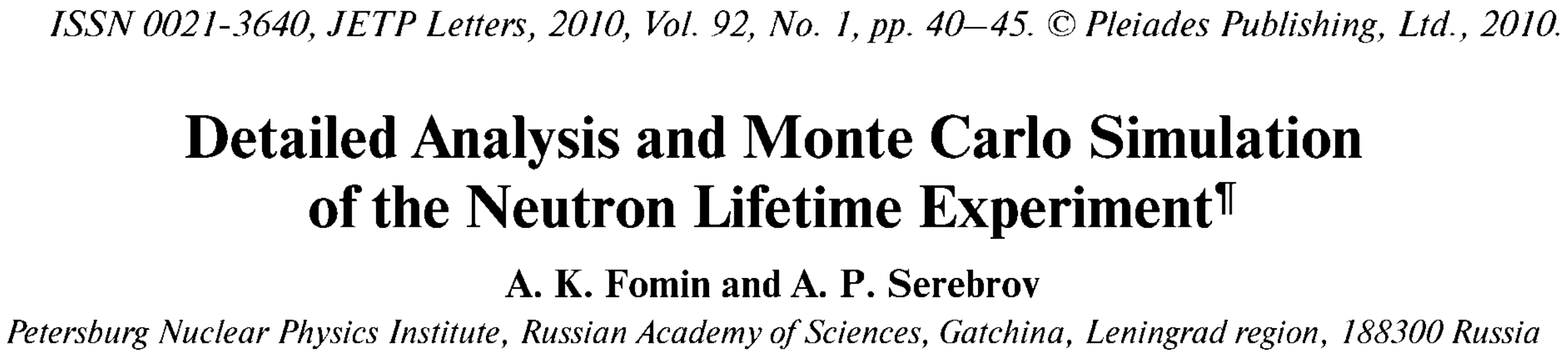


885.4 ± 0.9 ± 0.4 s

Loss factor in KIAE experiment is 25 times bigger than in PNPI experiment



878.5 ± 0.7 ± 0.3 s



ISSN 0021-3640, JETP Letters, 2010, Vol. 92, No. 1, pp. 40–45. © Pleiades Publishing, Ltd., 2010.

Detailed Analysis and Monte Carlo Simulation of the Neutron Lifetime Experiment¶

A. K. Fomin and A. P. Serebrov

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

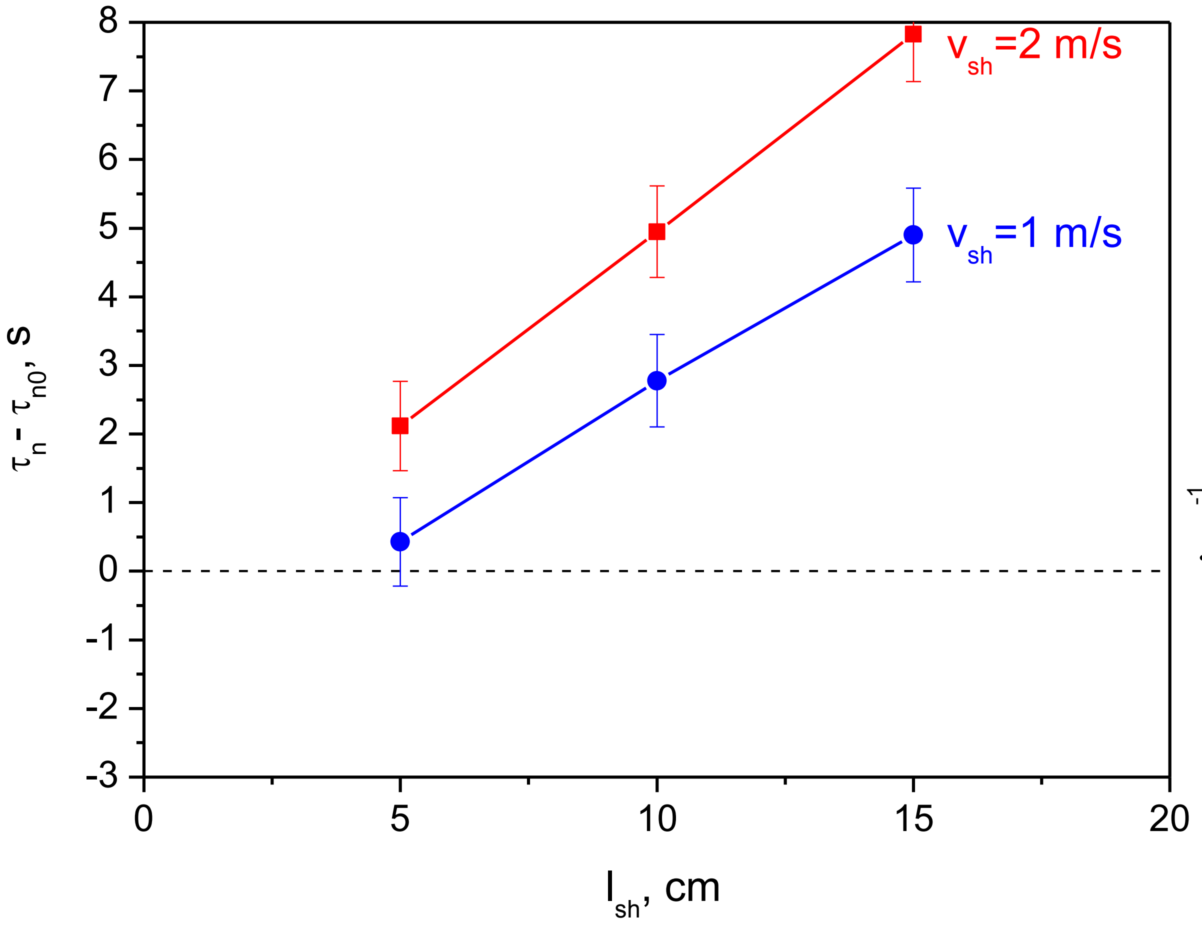
PHYSICAL REVIEW C **82, 035501 (2010)**

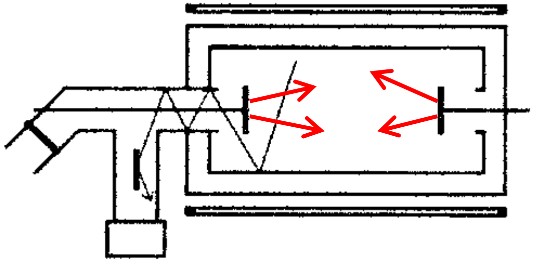
Neutron lifetime from a new evaluation of ultracold neutron storage experiments

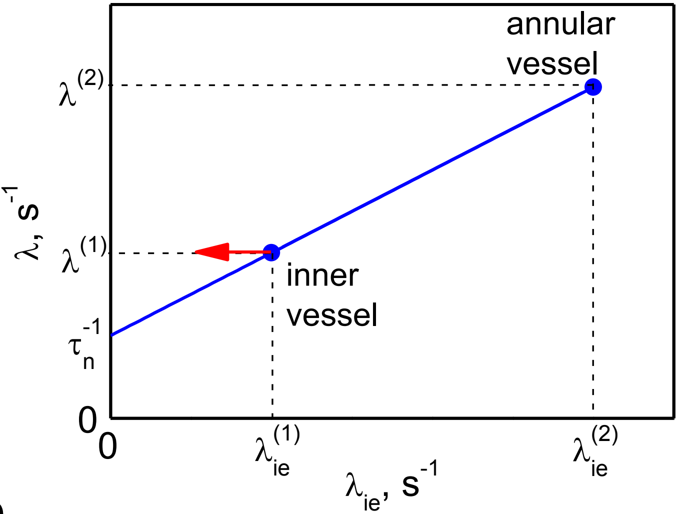
A. P. Serebrov* and A. K. Fomin

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 ± 0.9_{stat} ± 0.4_{syst} s after correction is 879.9 ± 2.5 s.

Effect of heating of neutrons by the shutters







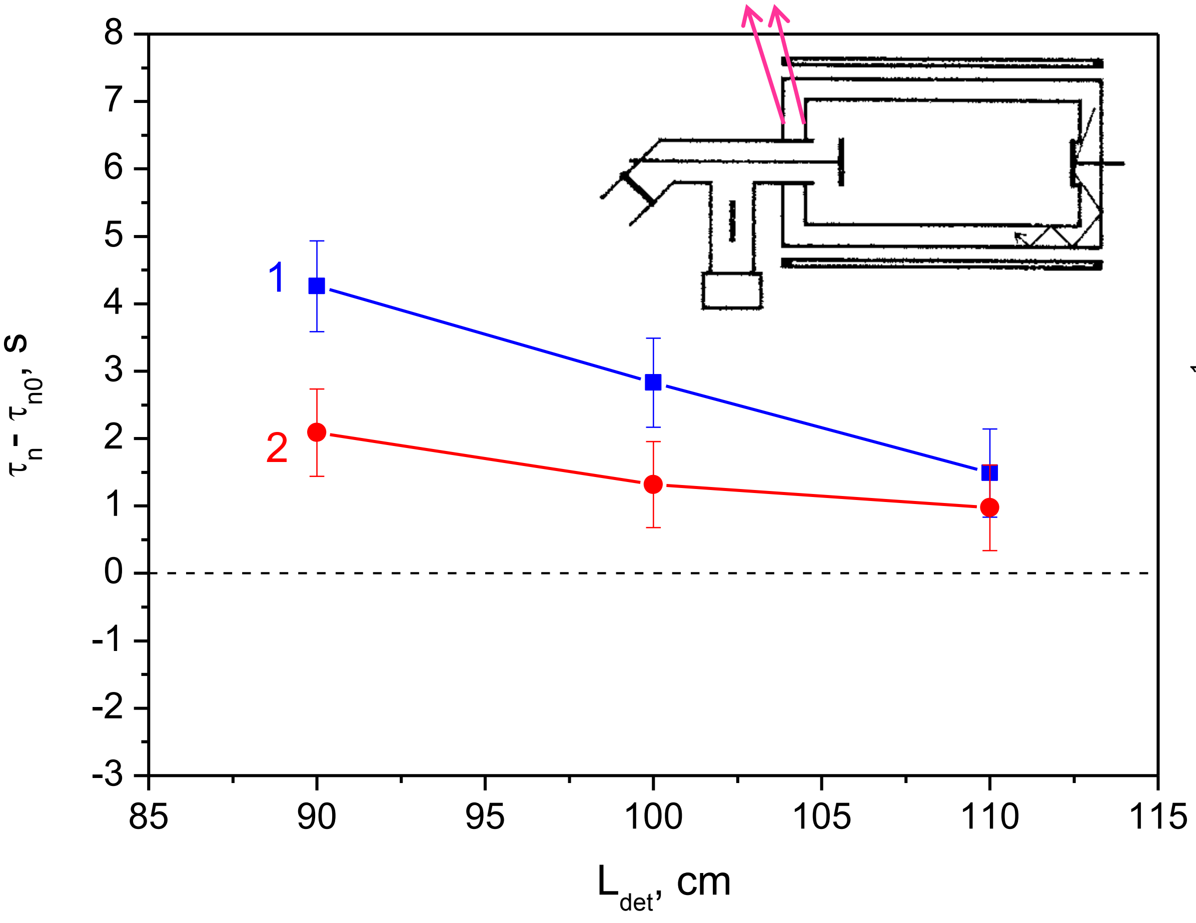
$$\lambda = \frac{1}{T}\ln(N_i / N_f)$$

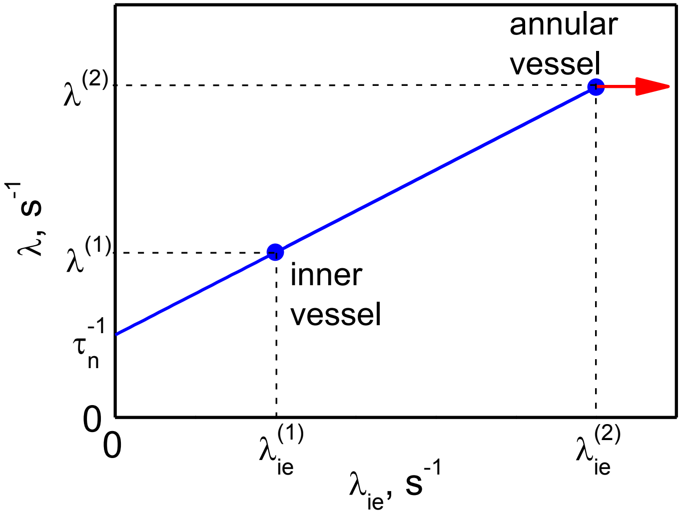
$$\lambda_{ie} = \frac{J\lambda}{N_i - N_f}\frac{\varepsilon}{\varepsilon_{th}}$$

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





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

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

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

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.

MC correction to the neutron lifetime result of the experiment

	correction, s	uncertainty of the result, s
effect of heating of neutrons by the shutters	-2.8	2
effect of not equal thermal neutron detection efficiencies for different vessels	-2.1	1
effect of not equal thermal neutron detection efficiencies for different vessels (correction in the experiment +0.6 s)	-0.6	
total	-5.5	2.2

The result of the experiment for neutron lifetime $885.4 \pm 0.9_{\text{stat}} \pm 0.4_{\text{syst}}$ s after correction is 879.9 ± 2.5 s.

JETP Letters, 2012, Vol. 95, No. 5, pp. 224–228.

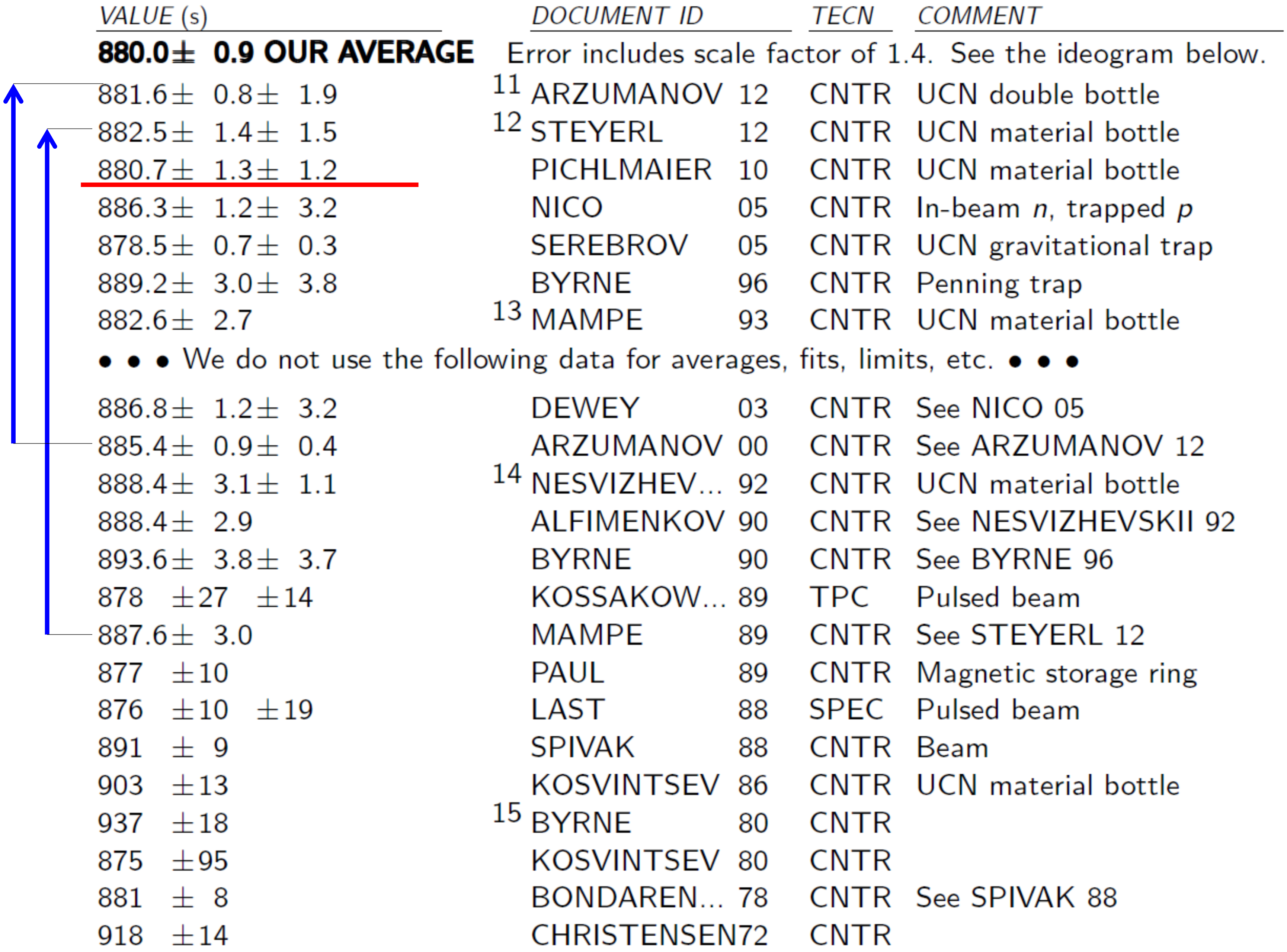
Analysis and Correction of the Measurement of the Neutron Lifetime

S. S. Arzumanov, L. N. Bondarenko, V. I. Morozov, Yu. N. Panin, and S. M. Chernyavsky

Abstract

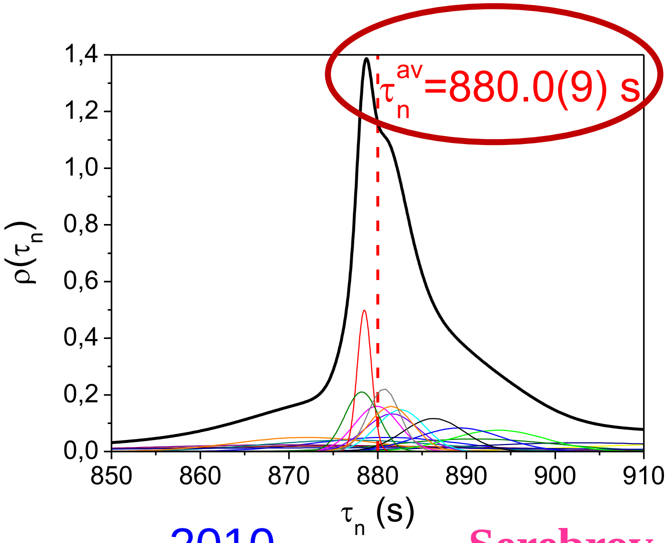
Corrections have been introduced into the result **885.4 ± 0.9stat ± 0.4syst s** of our measurements of the neutron lifetime. The corrected value is **881.6 ± 0.8stat ± 1.9syst s.**

PDG 2013



VALUE (s)	DOCUMENT ID		TECN	COMMENT
880.0± 0.9 OUR AVERAGE	Error includes scale factor of 1.4. See the ideogram below.			
881.6± 0.8± 1.9	[11] ARZUMANOV	12	CNTR	UCN double bottle
882.5± 1.4± 1.5	[12] STEYERL	12	CNTR	UCN material bottle
880.7± 1.3± 1.2	PICHLMAIER	10	CNTR	UCN material bottle
886.3± 1.2± 3.2	NICO	05	CNTR	In-beam *n*, trapped *p*
878.5± 0.7± 0.3	SEREBROV	05	CNTR	UCN gravitational trap
889.2± 3.0± 3.8	BYRNE	96	CNTR	Penning trap
882.6± 2.7	[13] MAMPE	93	CNTR	UCN material bottle
• • • We do not use the following data for averages, fits, limits, etc. • • •				
886.8± 1.2± 3.2	DEWEY	03	CNTR	See NICO 05
885.4± 0.9± 0.4	ARZUMANOV	00	CNTR	See ARZUMANOV 12
888.4± 3.1± 1.1	[14] NESVIZHEV...	92	CNTR	UCN material bottle
888.4± 2.9	ALFIMENKOV	90	CNTR	See NESVIZHEVSKII 92
893.6± 3.8± 3.7	BYRNE	90	CNTR	See BYRNE 96
878 ±27 ±14	KOSSAKOW...	89	TPC	Pulsed beam
887.6± 3.0	MAMPE	89	CNTR	See STEYERL 12
877 ±10	PAUL	89	CNTR	Magnetic storage ring
876 ±10 ±19	LAST	88	SPEC	Pulsed beam
891 ± 9	SPIVAK	88	CNTR	Beam
903 ±13	KOSVINTSEV	86	CNTR	UCN material bottle
937 ±18	[15] BYRNE	80	CNTR	
875 ±95	KOSVINTSEV	80	CNTR	
881 ± 8	BONDAREN...	78	CNTR	See SPIVAK 88
918 ±14	CHRISTENSEN	72	CNTR	

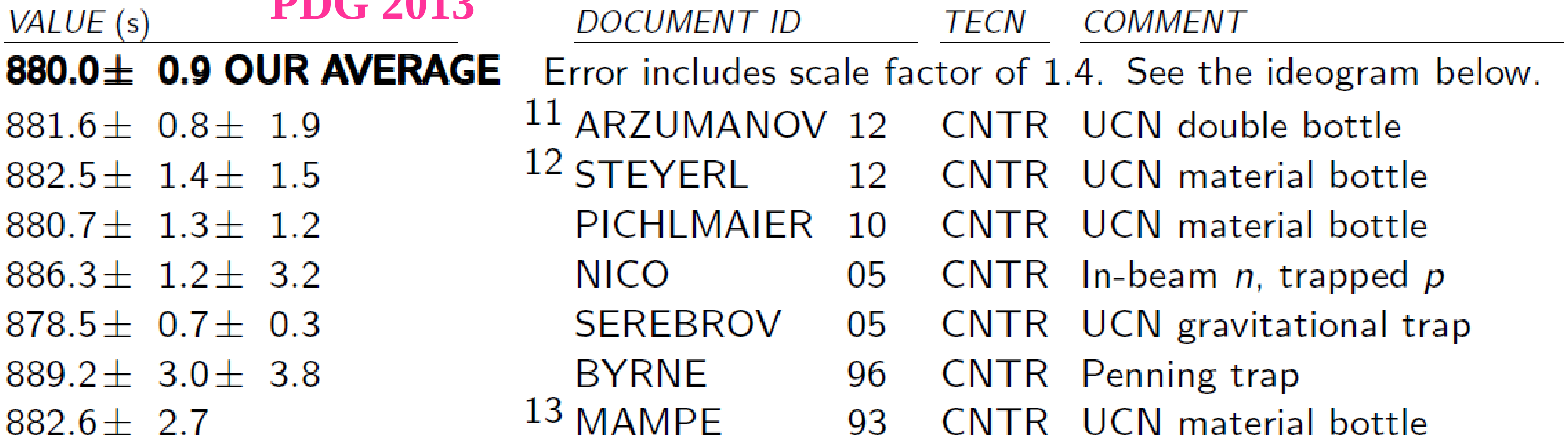
Neutron lifetime data after author corrections of experimental results



2010
new analysis

Serebrov, Fomin
PRC 82, 035501(2010)

PDG 2013



VALUE (s)	*DOCUMENT ID*	*TECN*	*COMMENT*
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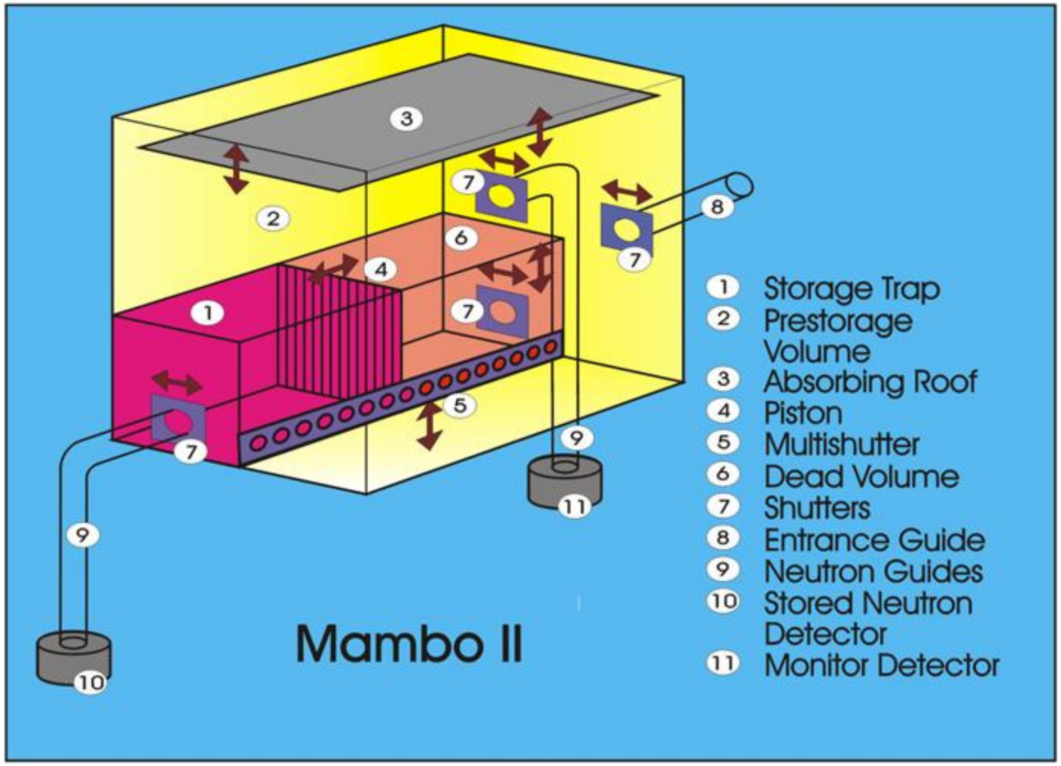
880.7± 1.3± 1.2	PICHLMAIER 10	CNTR	UCN material bottle
886.3± 1.2± 3.2	NICO 05	CNTR	In-beam *n*, trapped *p*
878.5± 0.7± 0.3	SEREBROV 05	CNTR	UCN gravitational trap
889.2± 3.0± 3.8	BYRNE 96	CNTR	Penning trap
882.6± 2.7	[13] MAMPE 93	CNTR	UCN material bottle

Physics Letters B 693 (2010) 221–226

Neutron lifetime measurement with the UCN trap-in-trap MAMBO II

A. Pichlmaier a,*1, V. Varlamov b, K. Schreckenbach a,c,⁎, P. Geltenbortd*



neutron lifetime *τ = (880.7 ± 1.3 ± 1.2)* s.

It was the first experimental conformation of would average value880.0(9)s.

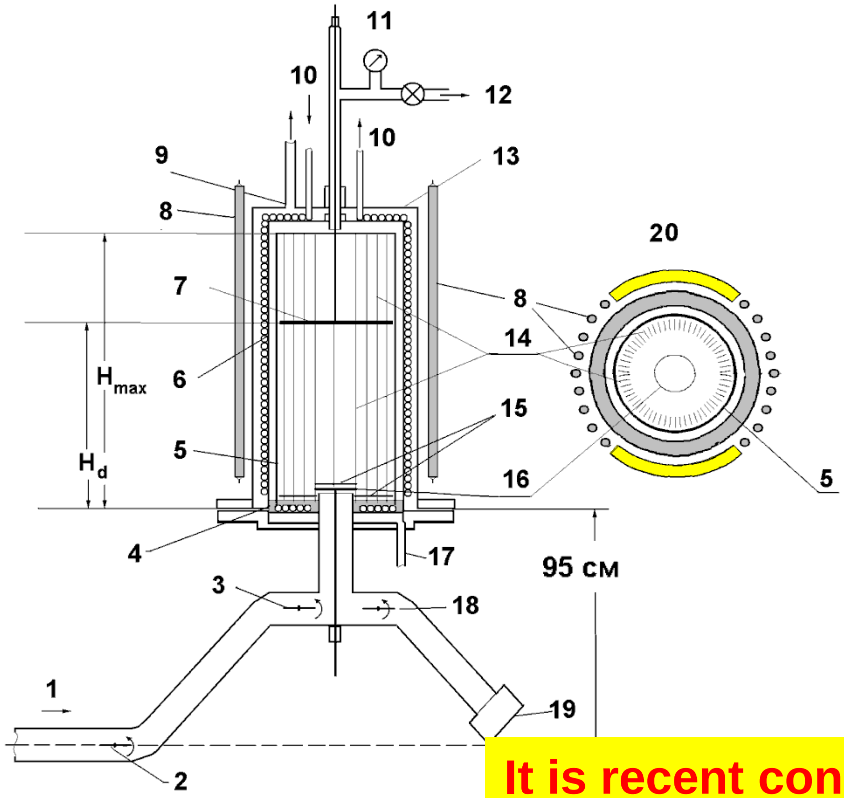
A MEASUREMENT OF THE NEUTRON LIFETIME USING THE METHOD OF STORAGE OF ULTRACOLD NEUTRONs AND DETECTION OF INELASTICALLY UP-SCATTERED NEUTRONS

S. Arzumanov [a], L. Bondarenko[a], S. Chernyavsky[a], P. Geltenbort[b], V. Morozov[a], V.V. Nesvizhevsky[b], Yu. Panin[a], A. Strepetov[a]
[a]NRC "Kurchatov Institute", 1, Akademika Kurchatova sqr., Moscow, Russia, R-123182
[b]ILL, 71 av. Martyrs, Grenoble, France, F-38000

ISINN 2014 (Dubna)

Abstract

We present estimations and results of experimental studies of systematic effects in our neutron lifetime experiment carried out in 2008-2010 at ILL. Taking into account these systematic corrections, we reduce the data of three independent sets of measurements performed with different energy spectra of ultracold neutrons at different temperatures of UCN traps to the averaged neutron lifetime value equal to **880.2(1.2) s.**



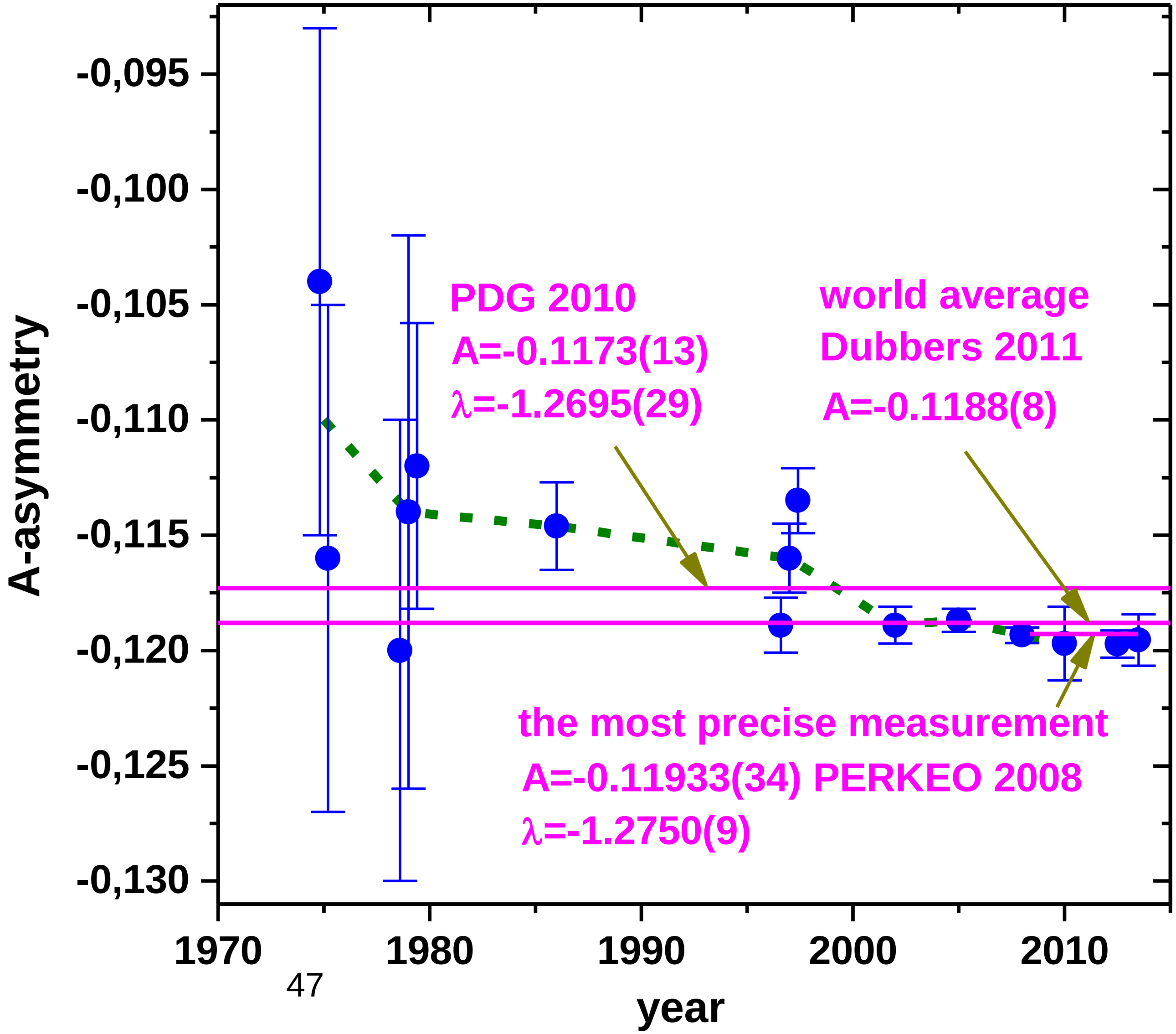
It is recent conformation of would average value 880.0(9)s.

A scheme of the experimental set-up for the neutron lifetime measurement. 1 – the entrance neutron guide, 2 – the UCN source shutter, 3 – the input shutter, 4 – fluid fluorine polymer, 5 – the copper cylinder, 6 – the cooling coil, 7 – the polyethylene disk, 8 – thermal neutron counters, 9 – the pumping tube, 10 – the cooler tube, 11 – the valve of the He filling line, 12 – the tube of the high-vacuum line, 13 – the vacuum set-up chamber, 14 – copper stripes, 15 – the additional surface above the trap bottom and the entrance shutter, 16 – the entrance plane shutter, 17 – the pumping tube for the chamber bottom, 18 – the detector shutter, 19 – the UCN detector, 20 – a horizontal cross section of the set-up with blocks of polyethylene reflector for thermal neutrons.

At present time all neutron lifetime experiments with UCN storage are in good agreement but after corrections and due to new measurements.

A-asymmetry measurements (history of experimental results)

A-asymmetry	Ref./Year
-0.11954± 0.00112	Mendenhall et al. 2013
$-0.11972\,(^{+53}_{-65})$	Mund et al. 2013
-0.1197 ± 0.0016	Liu et al. 2010
-0.11933 ± 0.00034	Abele et al. 2008
-0.1187 ± 0.0005	Mund et al. 2005
-0.1189 ± 0.0008	Abele et al. 2002
-0.1135 ± 0.0014	Yerozolimsky et al. 1997
-0.1160 ± 0.0015	Liaud et al. 1997
-0.1189 ± 0.0012	Abele et al. 1997
-0.1146 ± 0.0019	Bopp et al. 1986
-0.1120 ± 0.0062	Erozolimskii et al. 1979
-0.1140 ± 0.0120	Erozolimskii et al. 1979
-0.1200 ± 0.0100	Erozolimskii et al. 1979
-0.1160 ± 0.0110	Krohn and Ringo 1975
-0.1040 ± 0.0110	Krohn and Ringo 1975



PDG 2010
A=-0.1173(13)
λ=-1.2695(29)

world average
Dubbers 2011
A=-0.1188(8)

the most precise measurement
A=-0.11933(34) PERKEO 2008
λ=-1.2750(9)

All is OK for Standard Model with new world average value of neutron lifetime

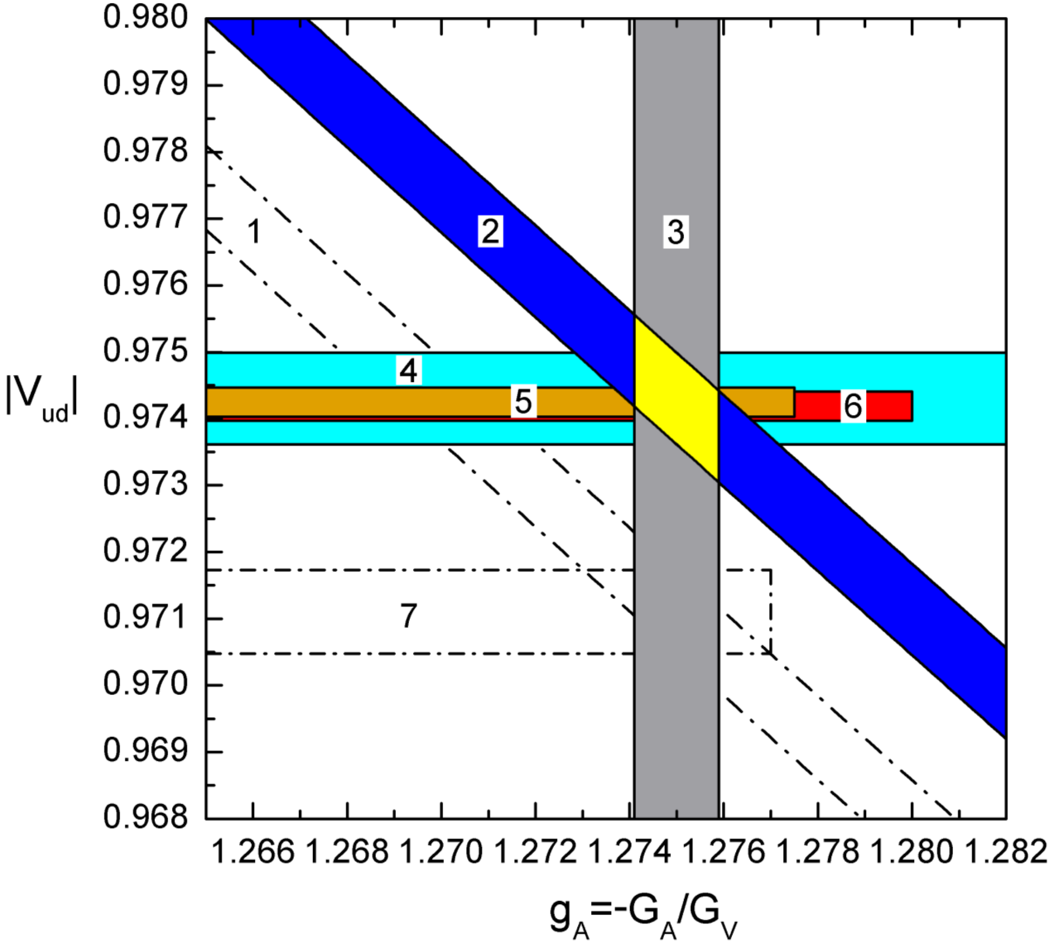
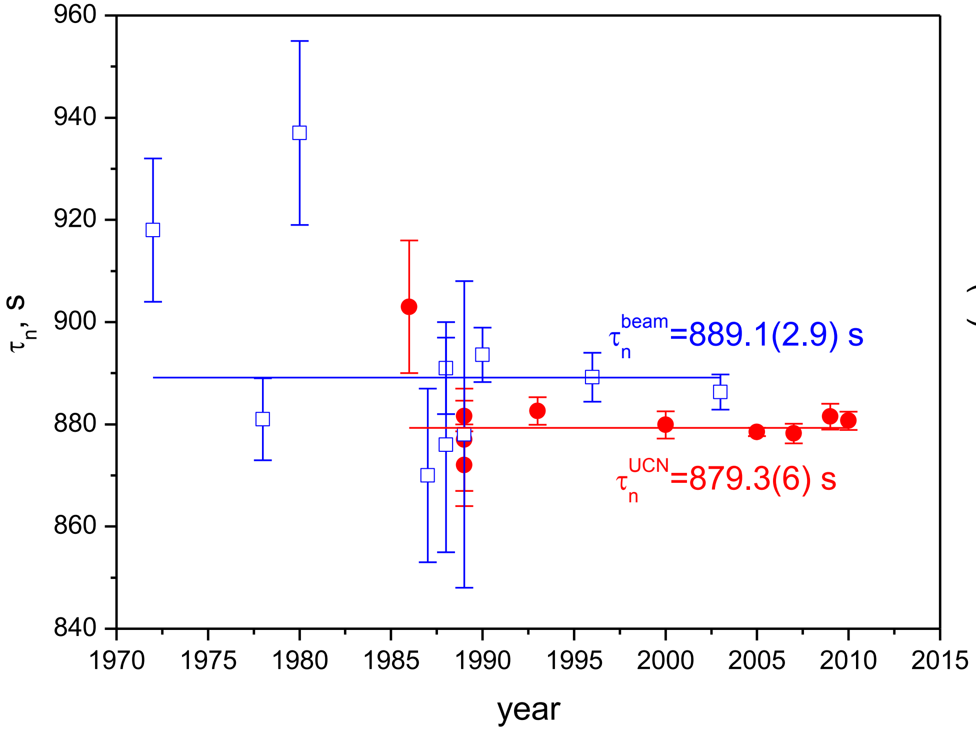
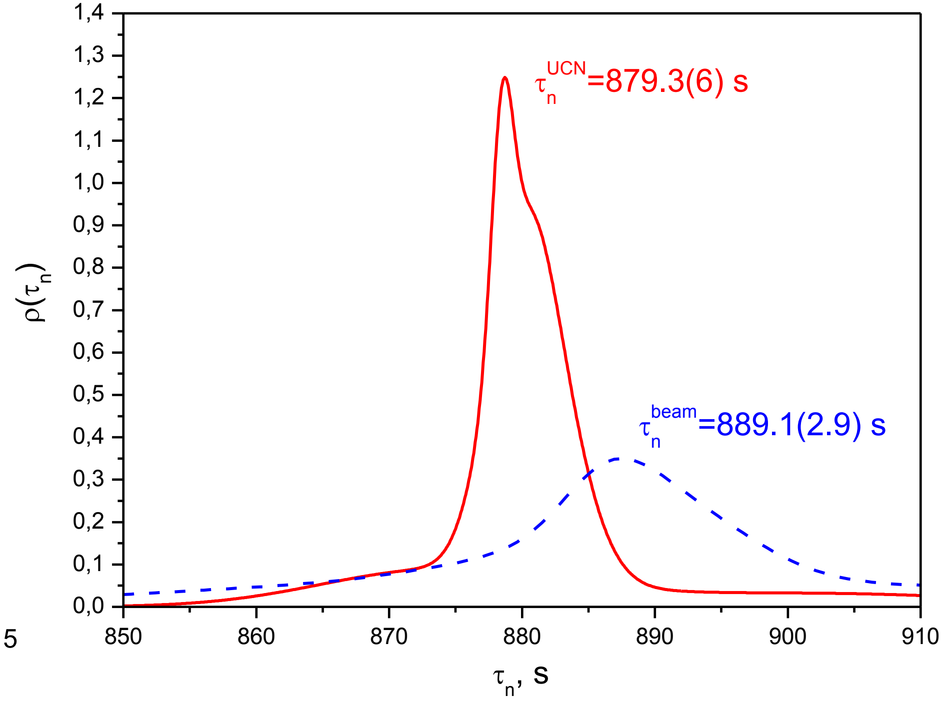


FIG. 13. Dependence of the CKM matrix element $|V_{ud}|$ on the values of the neutron lifetime and the axial coupling constant g_A. (1) Neutron lifetime (PDG 2006); (2) neutron lifetime (this article); (3) neutron β asymmetry (Perkeo 2007); (4) neutron β decay (this article + Perkeo 2007); (5) unitarity; (6) $0^+ \to 0^+$ nuclear transitions; (7) neutron β decay (PDG 2006 + Perkeo 2007).

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)

Neutron lifetime from beam experiment is in contradiction:

1. **with UCN storage experiments, as minimum – 3 experiment**
2. **with A-asymmetry experiment because of Standard Model**

Contradiction with two type of experiment or contradiction with Standard Model.

Before discuss any problem with Standard Model it is necessary to obtain confirmation from experiments, first of all from beam experiment but as well as fromUCN storage experiment also.

Concerning beam experiment :

1. **It is necessary to demonstrate efficiency of proton detector.**
2. **It is necessary to demonstrate the storage time of proton trap.**

Concerning UCN storage experiment :

1. **It is possible to increase the accuracy of measurements.**
2. **It is possible to check some ideas about influence of physical vacuum.**

Some experiments are realized:

Experimental search for neutron–mirror neutron oscillations using storage of ultracold neutrons

A.P. Serebrov et al. Physics Letters B 663 (2008) 181–185

Trap with Ultracold Neutrons As a Detector of Dark Matter Particles with Long-Range Forces

A. P. Serebrov* and O. M. Zherebtsov

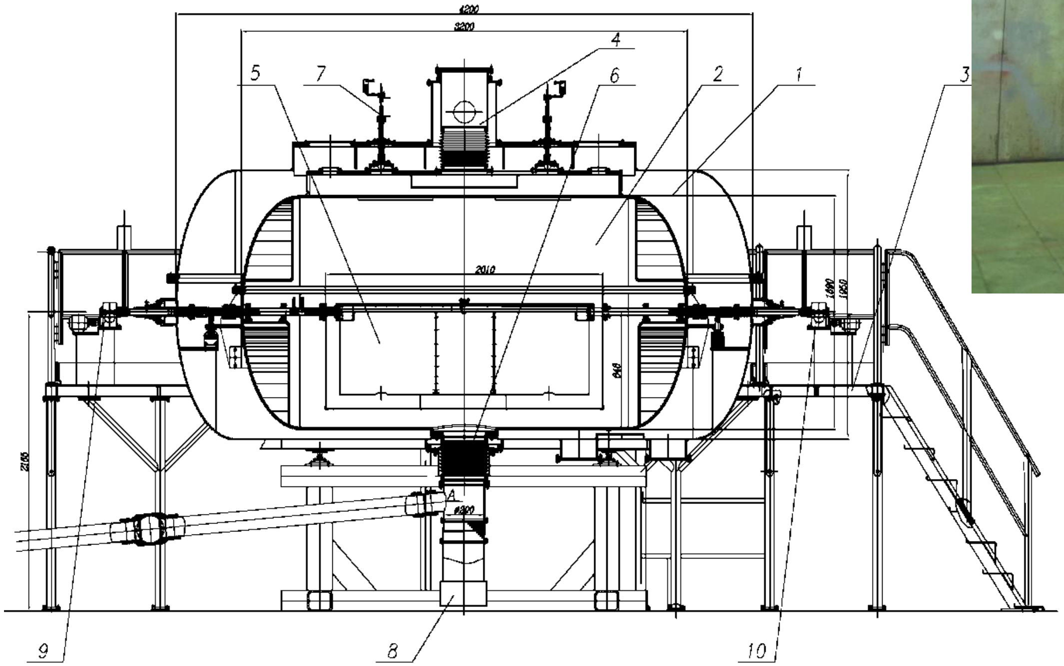
Ultracold-neutron trap as a tool to search for dark matter interacting with long-range forces

A. P. Serebrov,* O. M. Zherebtsov, A. K. Fomin, and M. S. Onegin

Future neutron lifetime experiments with UCN storage in material traps

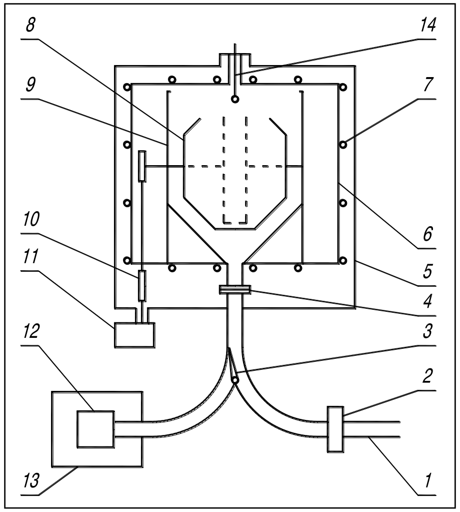
UCN gravitational spectrometer "Big Gravitrap" for neutron lifetime measurement with accuracy 0.2 s

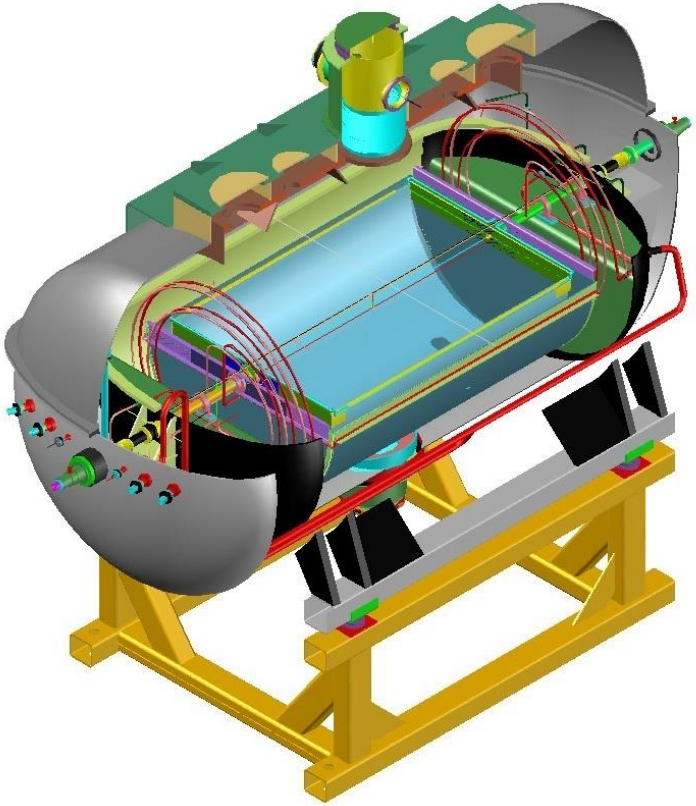
Scheme of setup



External view of setup with platforms for service, Preparation at PNPI

Gravitrap → Big Gravitrap





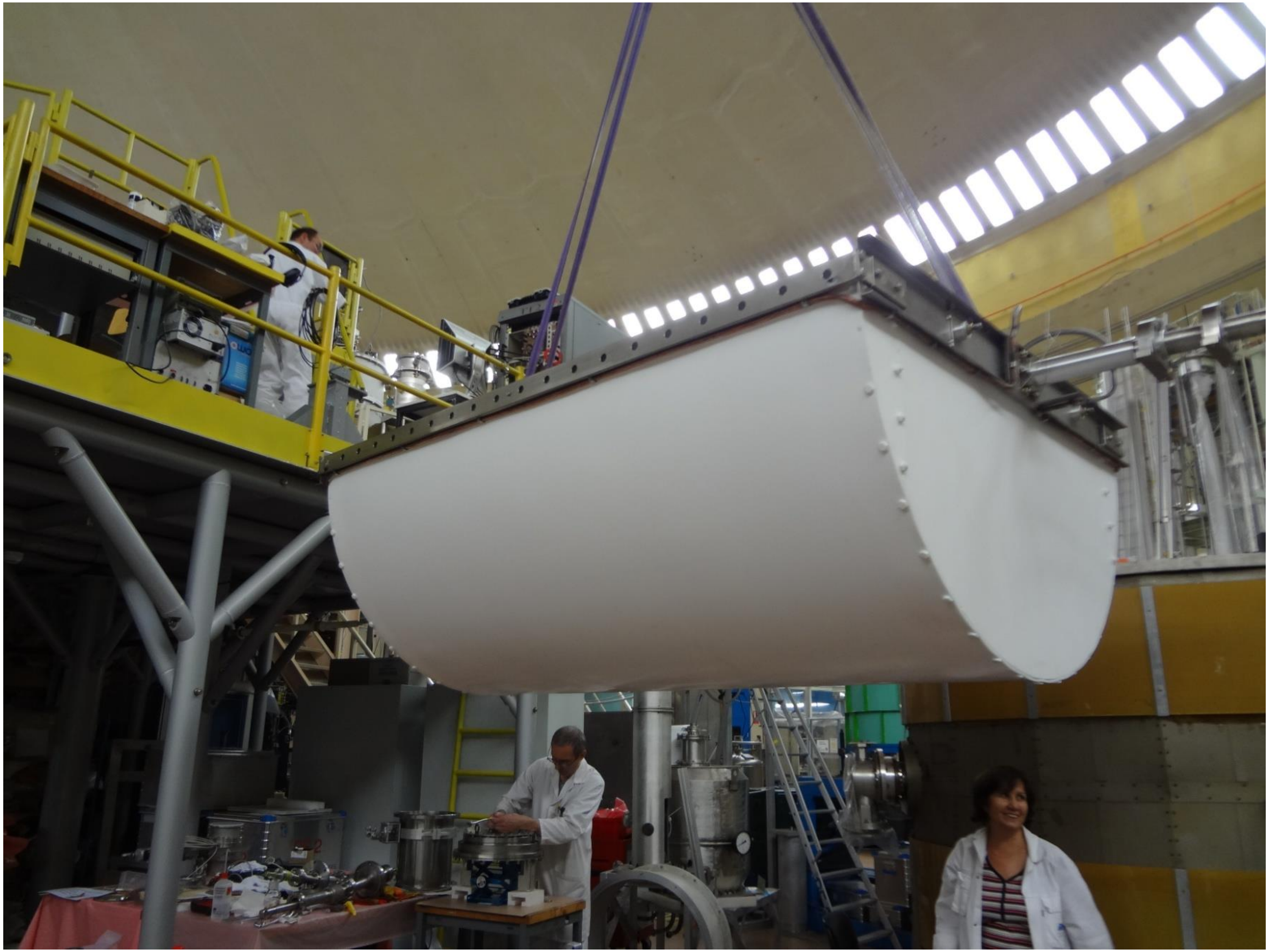
Increasing of “wide” trap volume is 5.3.
Increasing of “narrow” trap volume is 18.

1. Statistical accuracy 0.7 s → 0.2 s;
2. Vacuum correction 0.4 s → 0.04 s;
3. Measurement in two positions without disassembling;
4. Improvement of loss factor ? $2\cdot10^{-6} \rightarrow 10^{-6}$?
5. Expected accuracy: statistical ~ 0.2 s
   systematical < 0.1 s

Installation of Big Gravitrap on ILL reactor (August 2014)

Installation of Big Gravitrap on ILL reactor

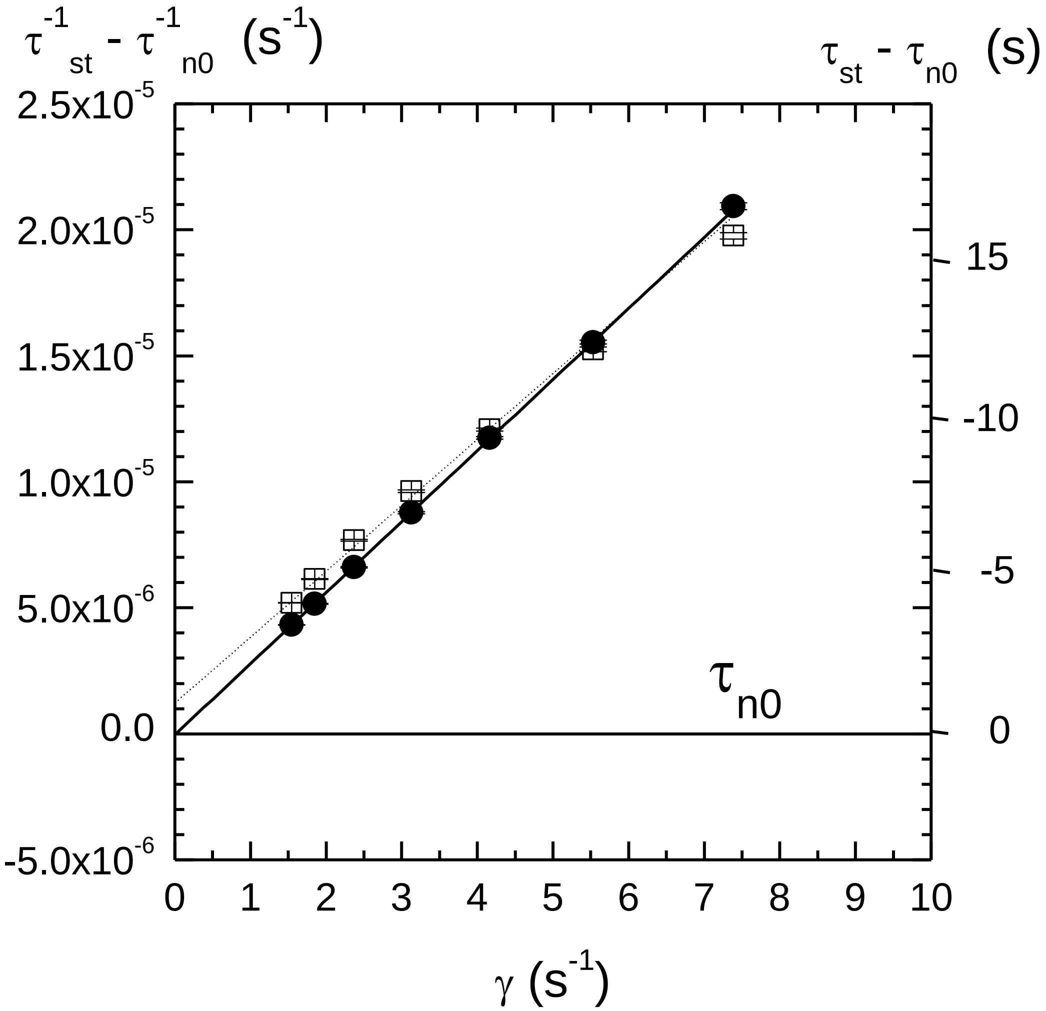
UCN trap made from teflon



UCN trap made from teflon

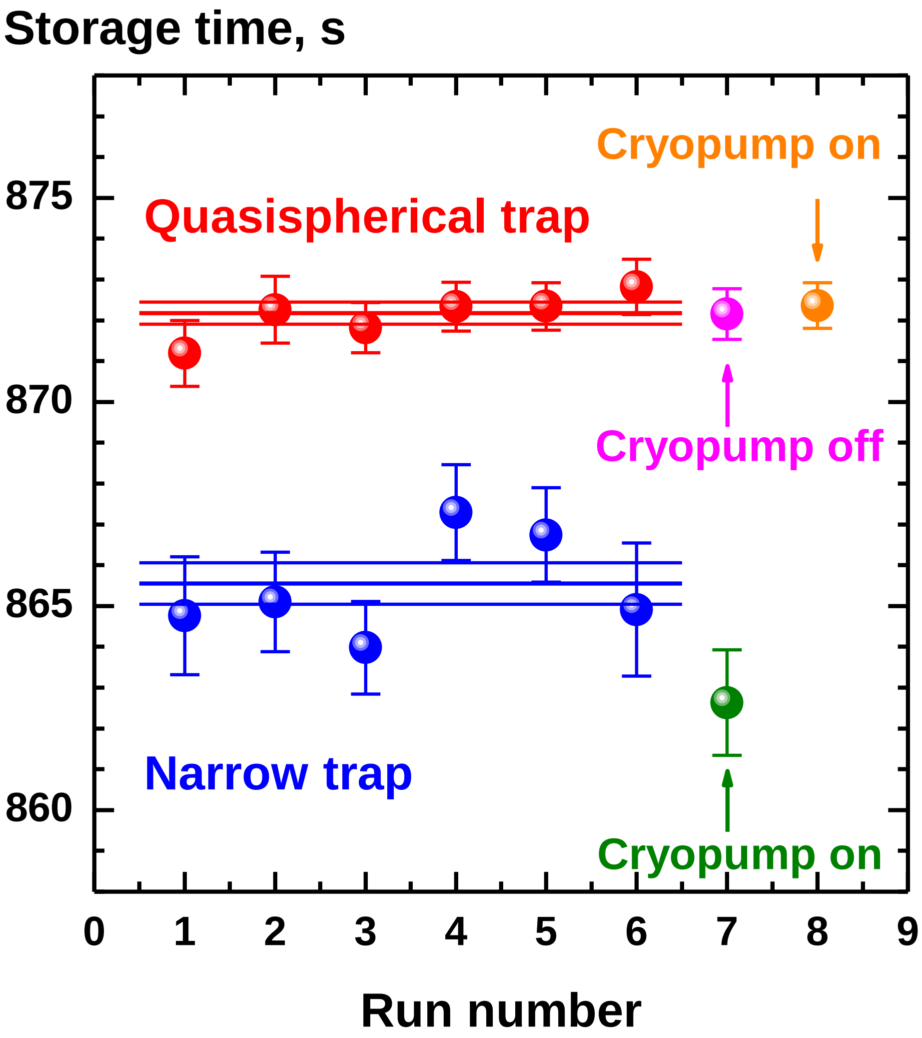
Thank you for your attention

MC simulation of “Gravitrap” experiment to check importance of reflection law



Monte Carlo experiment with different reflectivity models of diffuse scattering involving simulation of an extrapolation to the neutron lifetime. The filled circles represent the results of simulation when the model of diffuse scattering is described by the law of Lambert (correct simulation). The open squares the results of simulation when diffuse scattering uniformly distributed over solid angle (wrong simulation).

Measurement of UCN storage times



Results:

quasispherical trap

$$\tau_{st} = 872.2 \pm 0.3\, s$$

narrow trap

$$\tau_{st} = 865.6 \pm 0.6\, s$$