Neutron magnetic storage and neutron lifetime measuring

Victor Ezhov
Petersburg Nuclear Physics Institute NRC KI

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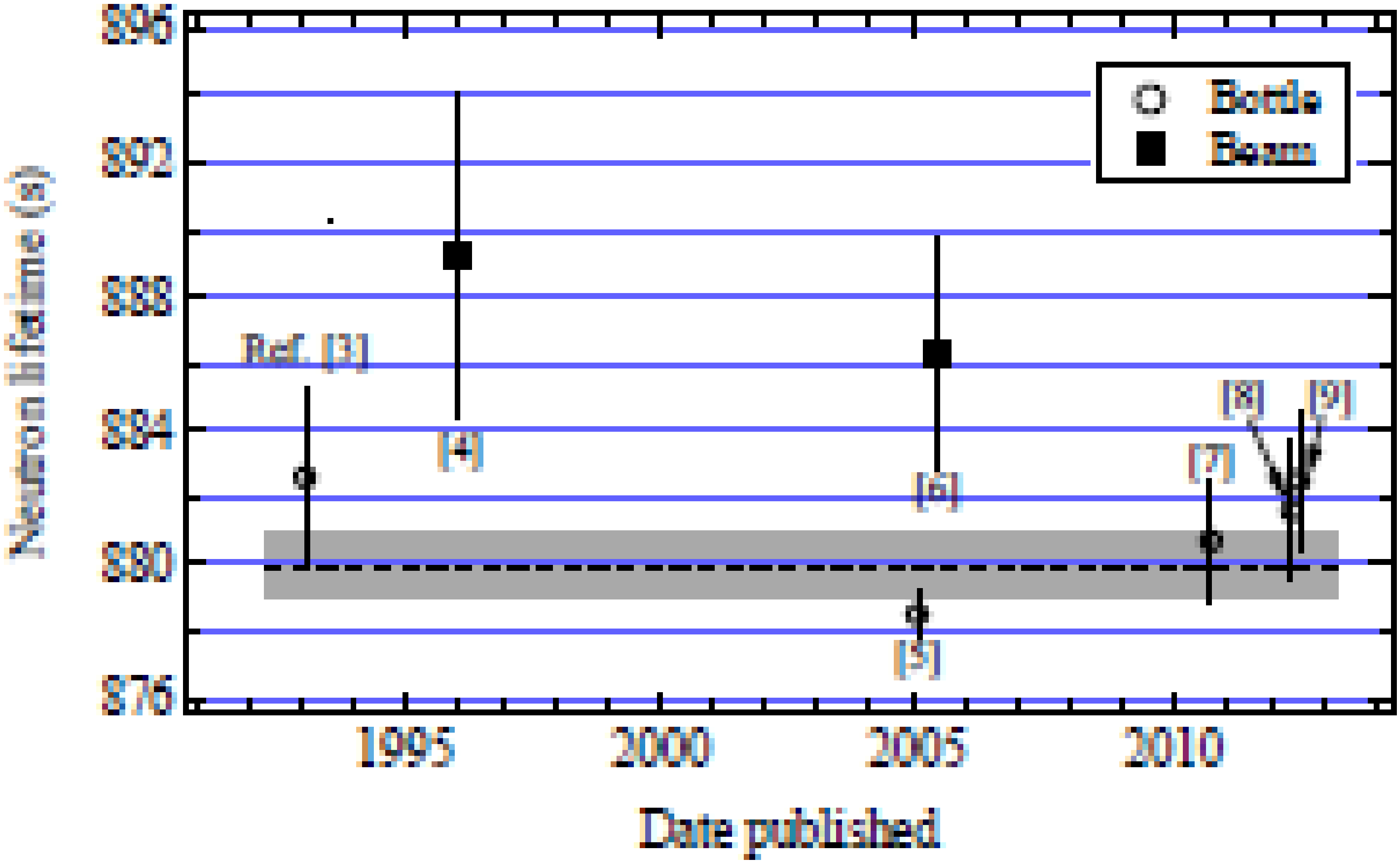


Neutron lifetime (s)
896
892
888
884
880
876
1995
2000
2005
2010
Date published
Bottle
Beam
Ref. [3]
[4]
[5]
[6]
[7]
[8]
[9]

Neutron magnetic storage

Magnetic mirrors, channels and bottles neutrons.
Vladimirskii, V.V. Sov. Phys. JETP 12, 740-746, (1961)

Magnetic potential $U = -\vec{\mu}\cdot\vec{B}$

$$F = -\nabla U = \nabla(\vec{\mu}\cdot\vec{B}) = \pm\mu\nabla\left|\vec{B}\right|$$

\+ for $\vec{\mu}\uparrow\uparrow\vec{B}$ and

– for $\vec{\mu}\uparrow\downarrow\vec{B}$

For magnetic moment of neutron $U = 60neV\cdot T^{-1}$

Nuclear potential of Be $250neV$

Magnetic field 1 T reflects neutrons up to 3.4 m/s, as Al.

Magnetic trap: 1 T for trapping

Main problem: trap configuration

Neutron magnetic storage - (mile stones)

Магнитные зеркала, каналы и бутылки для холодных нейтронов
В.В. Владимирский ЖЭТФ т.39(4), 1062, 1960

Токовые системы

Ю.Ю. Косвинцев, Ю.А. Кушнир, В.И. Морозов, В.А. Плотников Письма ЖЭТФ, т. 27(1), 70, (1978) (НИИАР)

♦=35±10 sec

Ю.Г. Абов, В.В. Васильев, В.В. Владимирский, И.Б. Рожнин Письма ЖЭТФ, т. 44(8), 369, (1986). (ИТЭФ)

τ > 700 sec

Сверхпроводящие

W. Paul, F. Anton, L. Paul, S. Paul, and W. Mampe, Z. f. Physik C 45, 25 (1989). (ИЛЛ + Мюнхен)

τ= 877 ± 10 s

S.N. Dozbosuk et. al., J. Res. Natl. Inst. Stand. Technol. 110, 339, (2005) (Лос Аламос)

$$\tau = 833^{+74}_{-63}\ \mathrm{s}$$

Постоянные магниты

V.F. Ezhov et. al., arXiv:1412.7434 [nucl-ex], (2014) (ПИЯФ + ИЛЛ)

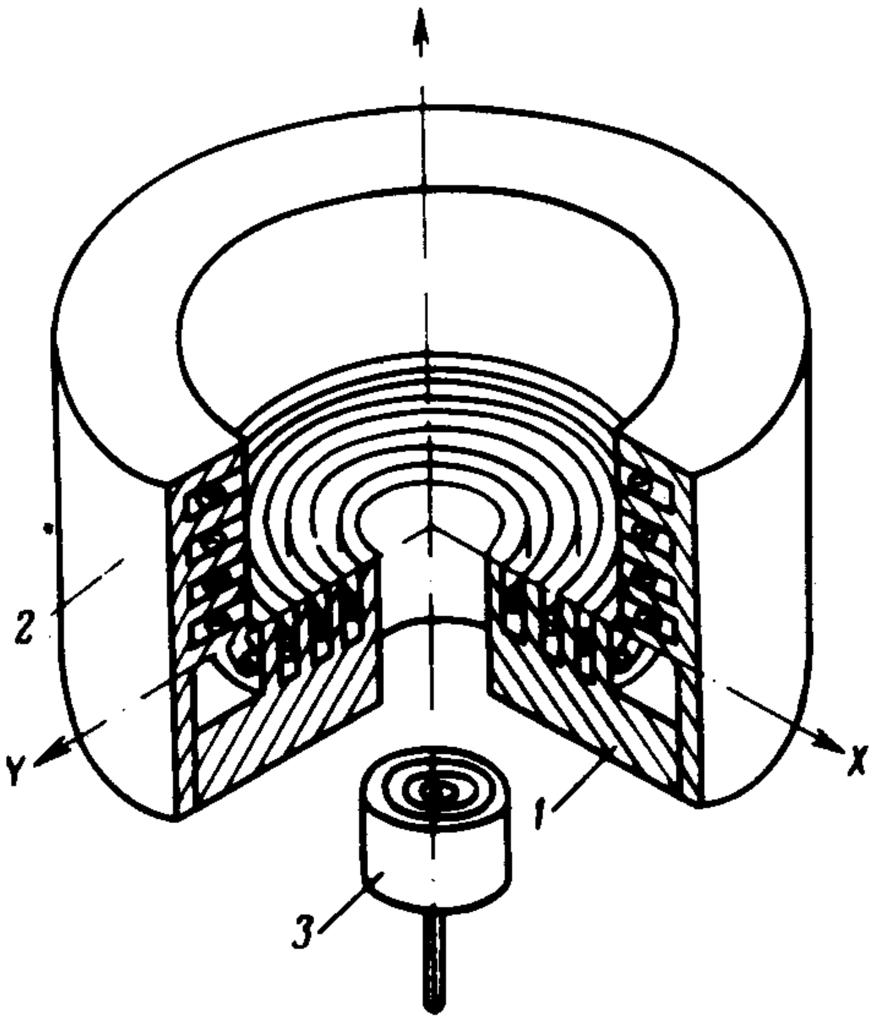
$$\tau_n = 878.2 \pm 1.9\ s$$

First real magnetic trap

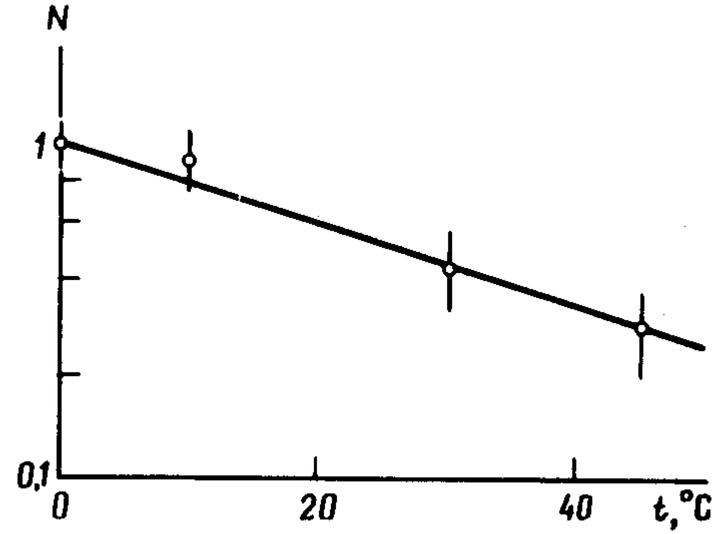
Письма в ЖЭТФ, том 27, вып.1, стр. 70 – 73 5 января 1978 г.

ЭКСПЕРИМЕНТ ПО ХРАНЕНИЮ НЕЙТРОНОВ В МАГНИТНОЙ ЛОВУШКЕ

Ю.Ю.Косвинцев, Ю.А.Кушнир, В.И.Морозов
И.А.Плотников



Reactor CM-2



W=20 kW

Число накопленных в ловушке нейтронов 1,05 ± 0,15, время хранения 35 ± 10 *сек.*

Ioffe-Pritchard trap for neutrons

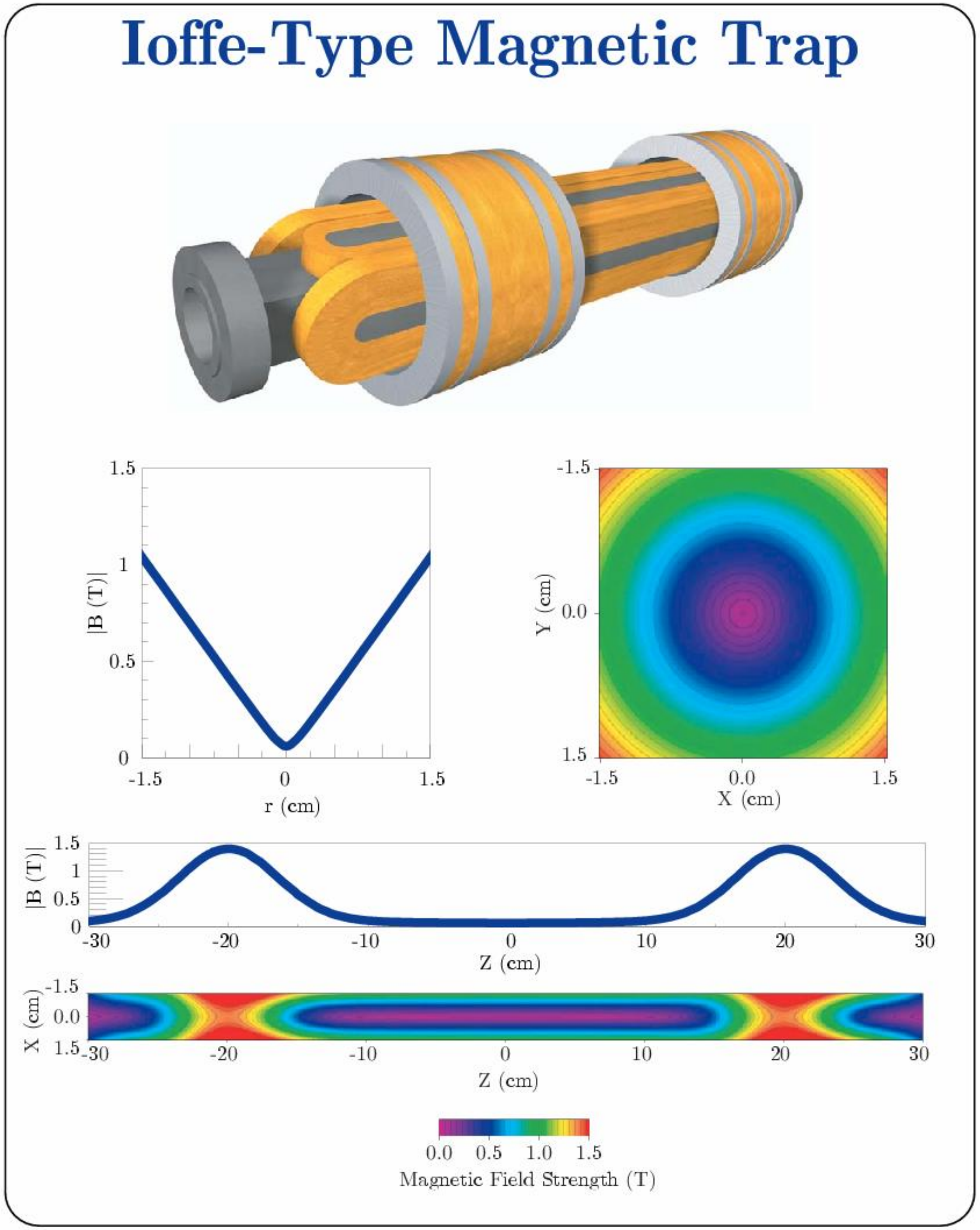
The main problems:

1. **Filling and empting. If one use superconducting system, then he can't switch on field too fast.**
2. **Huge setup and small storage volume**
3. **Field only 1 T**

S.N. Dozhosuk *et al.*, J. Res. Natl. Inst. Stand. Technol. **110**, 339 (2005).

The trapping region is filled with superfluid ^4He, which is used to load neutrons into the trap and as a scintillator to detect their decay. Neutrons have a lifetime in the trap of

$$\tau = 833^{+74}_{-63}\ s$$



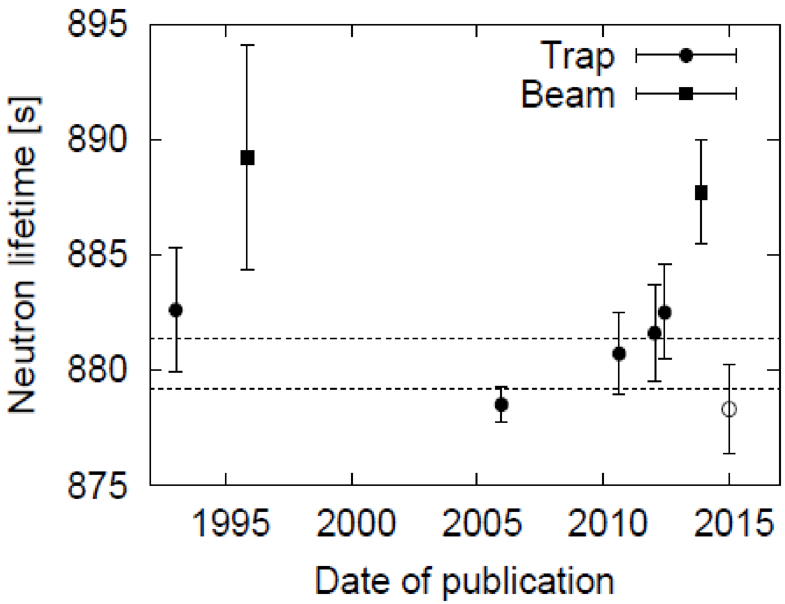
NIST P. R. Huffman

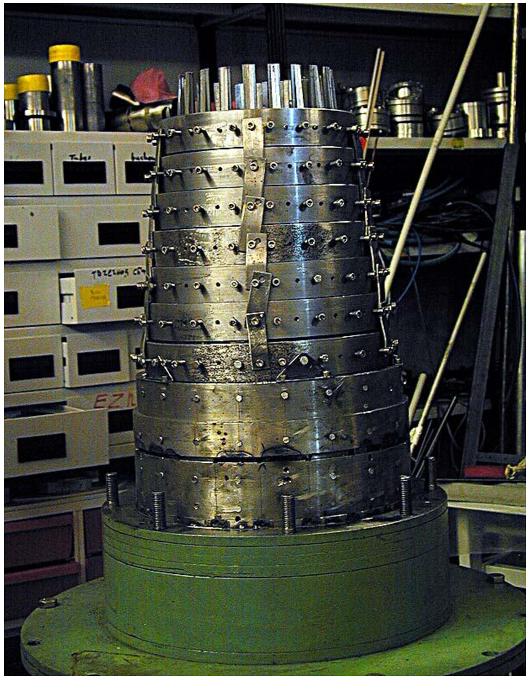
Experimental strategy and main advantages of magnetic storage

- Control of losses (the spin flipped UCN)
- Efficiency losses measuring
- Filling of trap
- Monitor of trap filling

Измерение времени жизни нейтрона в ловушке из постоянных магнитов

**Пучковые данные завышают значение **
**Хранение УХН занижает значение **
Нужен другой тип экспериментов –
Магнитное хранение

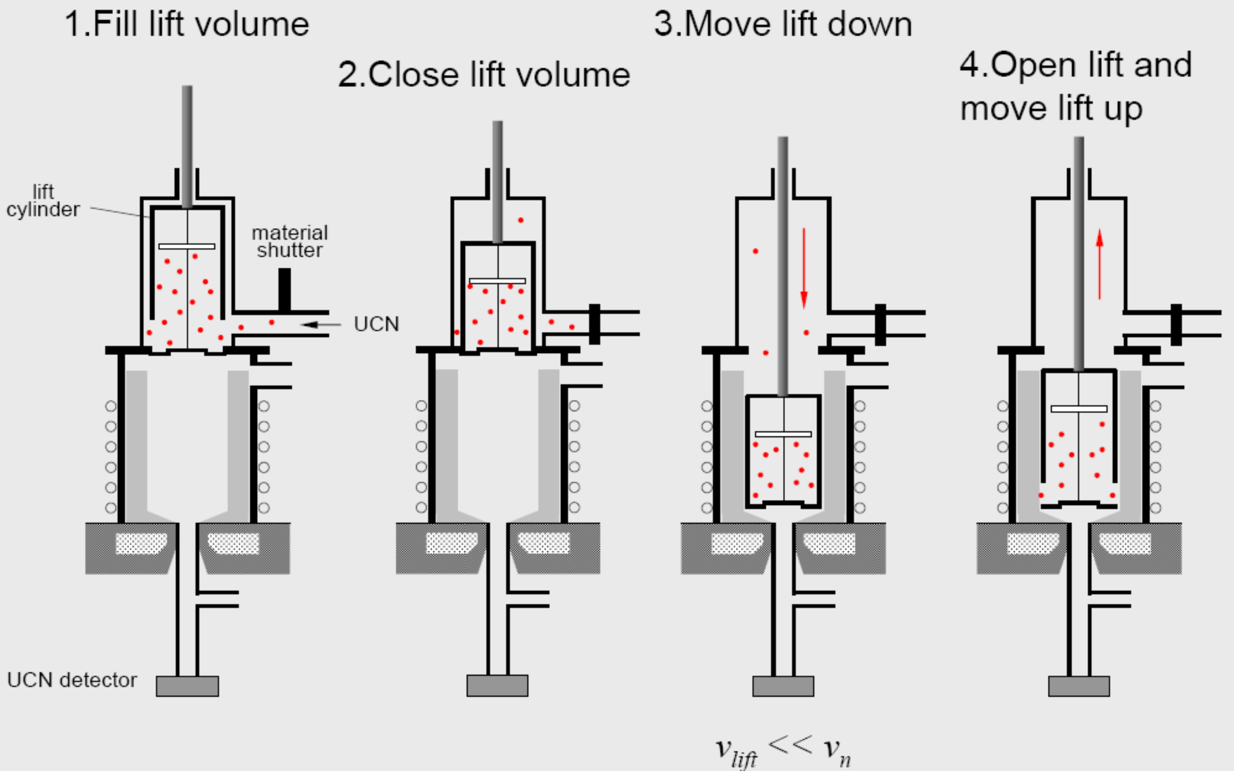


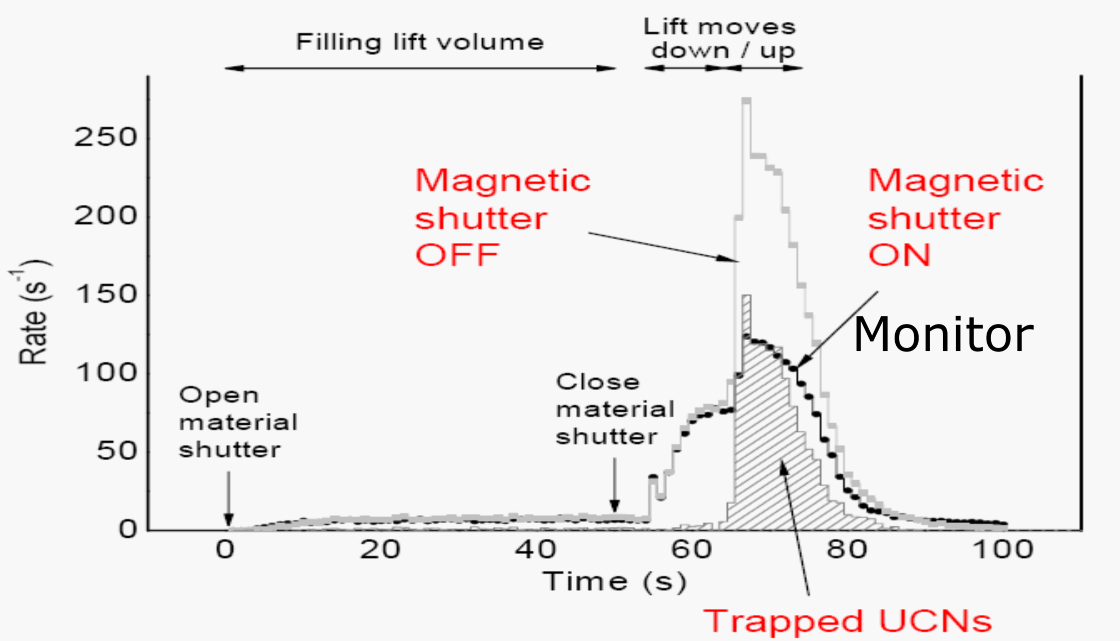


Эксперимент ПИЯФ НИЦ КИ
– контроль потерь во время хранения
-- контроль числа нейтронов в ловушке при каждом наполнении

$$\tau_n = (878.3 \pm 1.9)\ s.$$

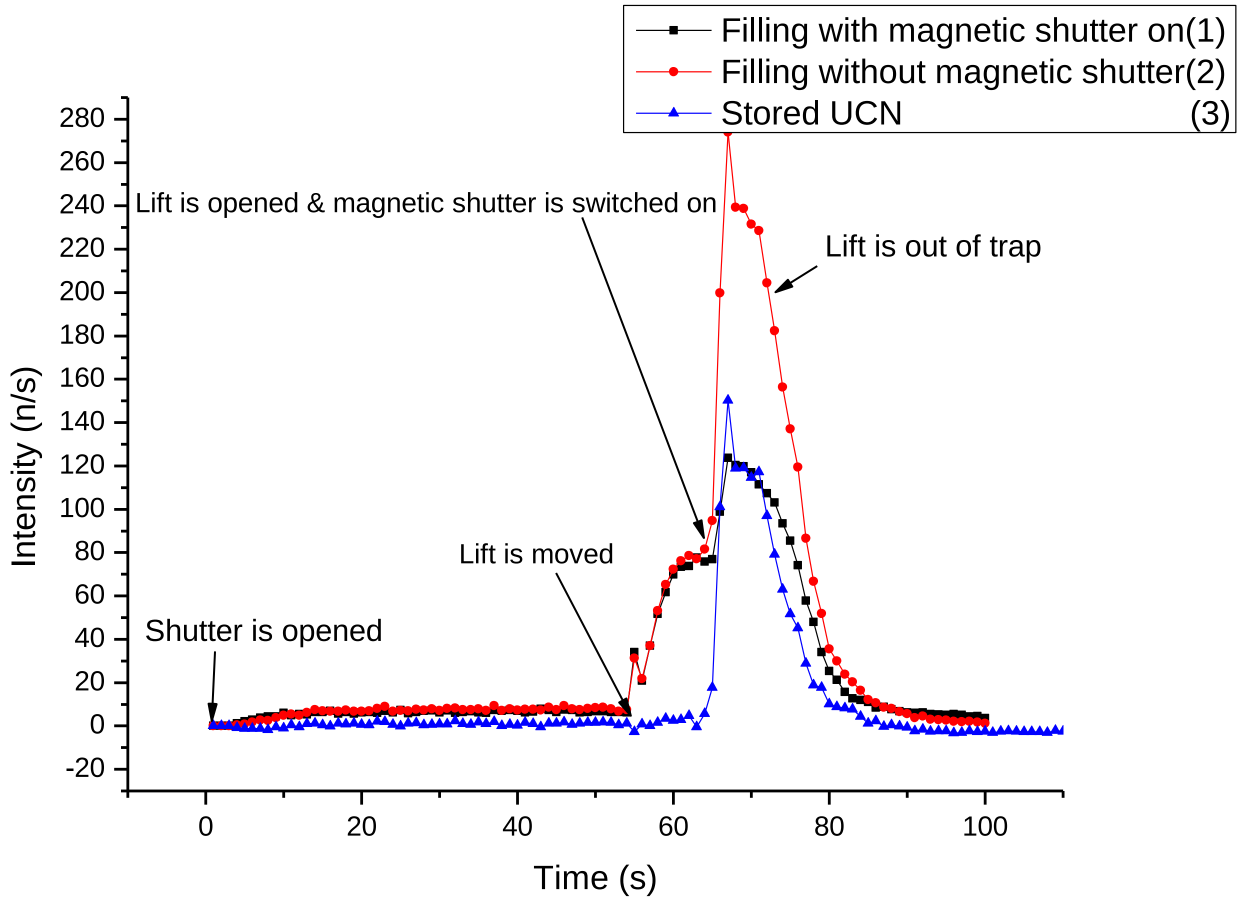
Trap filling





Monitor of trap filling

1. We have used: Trap filling with unpolarized UCN. In this case half of UCN will be detected just during the filling

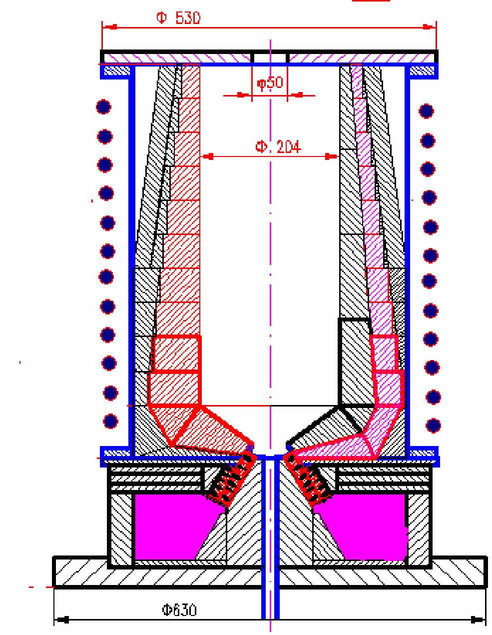


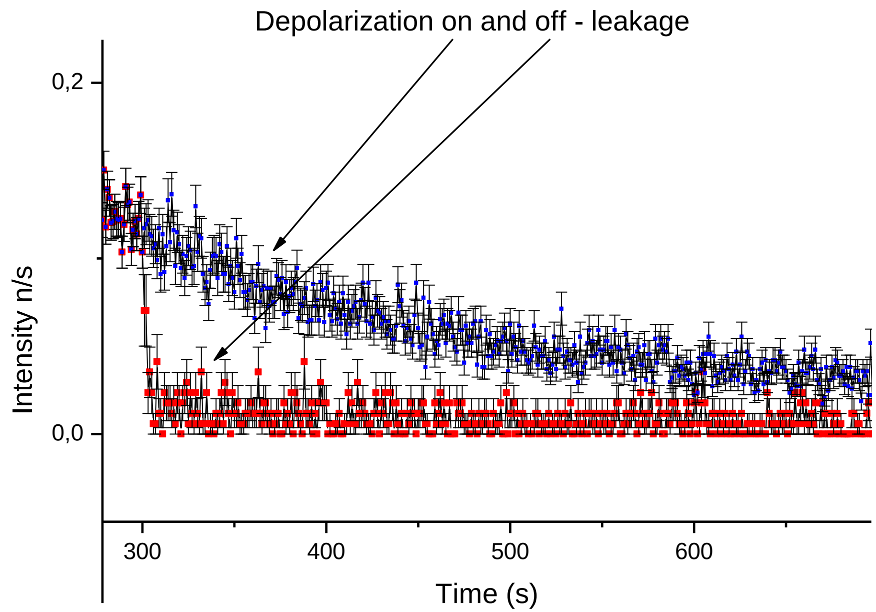
Control of the spin flipped UCN

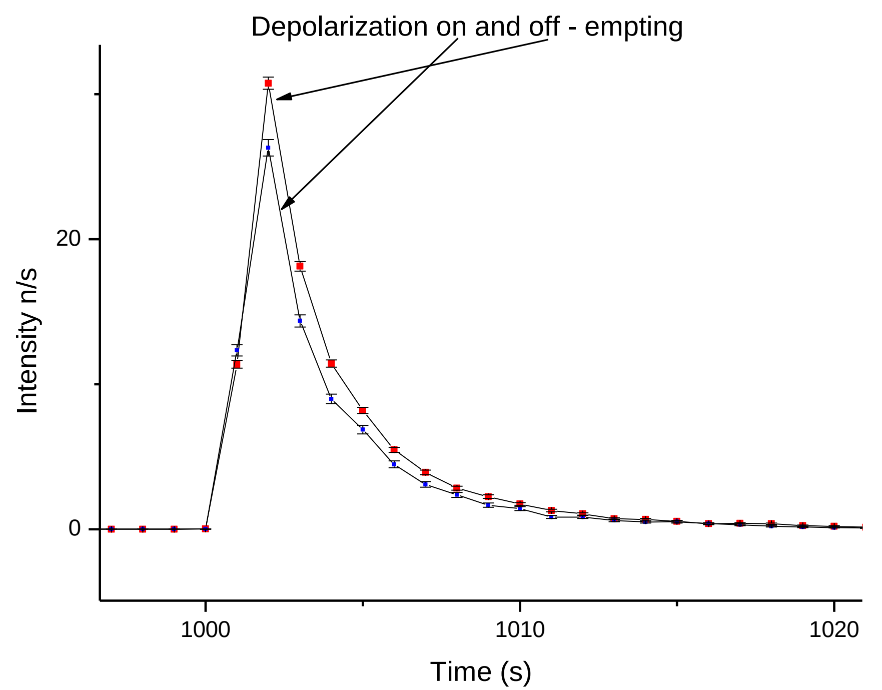
- To control the spin flipped UCN the inner trap walls are covered with thin layer of fomblin that reflects spin flipped UCN. After some collisions (order of some 10-th) the spin flipped UCN penetrate through the magnetic barrier of solenoid and are detected by the UCN detector installed below the solenoid. Hence this intensity may be used as the detector of UCN losses during storage time.

Efficiency of spin flipped neutron collection (direct measuring using artificial depolarization)

$$\varepsilon = \frac{\sum_{t_i=301}^{1000}(N_1(t_i)-N_2(t_i))\cdot e^{\frac{t_i-300.5}{\tau_{decay}}}}{\sum_{t_i=1001}^{1100}(N_2(t_i)-N_1(t_i))\cdot e^{\frac{t_i-300.5}{\tau_{decay}}}}$$







Income of efficiency

In case of constant value of ε

$$\lambda_{decay} = \frac{1}{T} ln\left(\frac{N_{trap}(T)}{N_0}\right)\left(1 - \left(\frac{N_{leak}(T)}{\varepsilon\left(N_0 - N_{trap}(T)\right)}\right)\right)$$

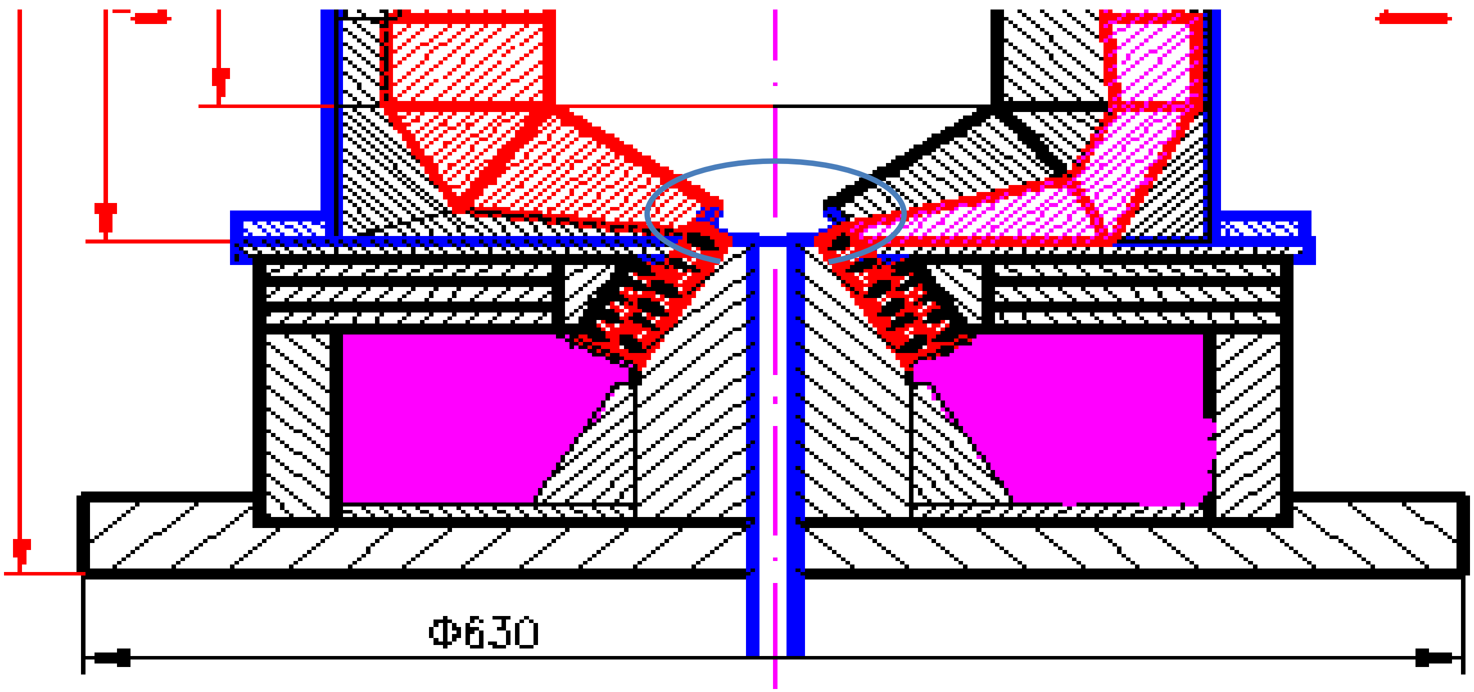
One can see that correction to λ_{decay} provided by efficiency of spinflipped neutron collection has an additional smallness in case of

$$N_{leak}(T) \ll N_0 - N_{trap}(T)$$

Approximation for ε as a constant value is a sufficiently good one for this experiment. Really losses of UCN hitting the wall depend on neutron velocity but spinflipped neutrons (just these neutrons can be lost) are accelerated in magnetic gradient before their hitting a wall. The field near the wall of trap is about 1 T, but the field used in lower magnetic shutter (just this field determines highest energy of stored UCN) is only 0.45 T. It means that velocity interval of UCNs hitting the wall after their acceleration in magnetic field gradient lays in very narrow velocity diapason (between 3.4 and 3.9 m/s). So one can use mean value ε as a constant with a good accuracy.

Unsolved problem of first trap

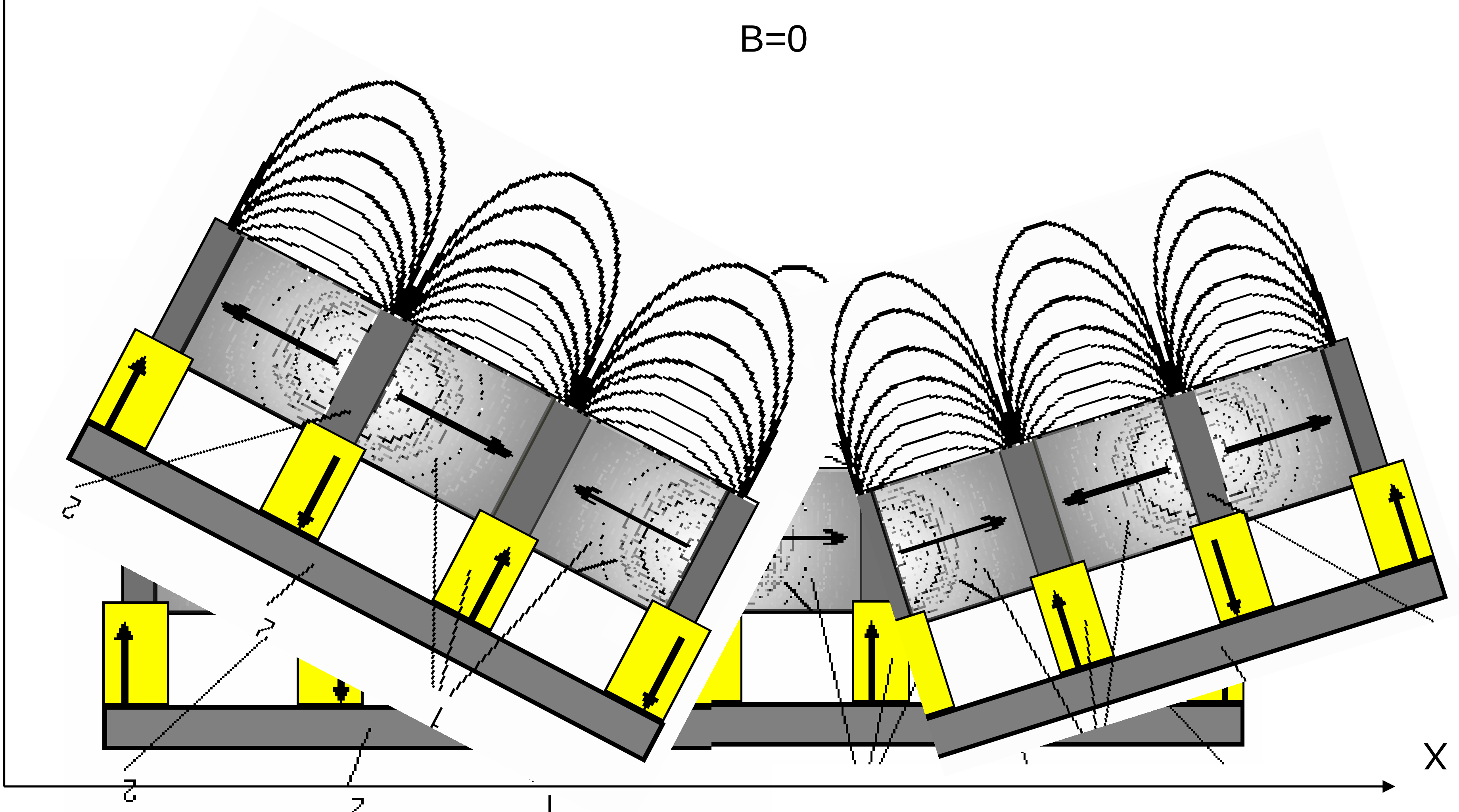
- Interference of shutter and wall magnetic fields
- To exclude it we have to decrease the shutter magnetic field to 2 times (0.45 T instead of 1 T)

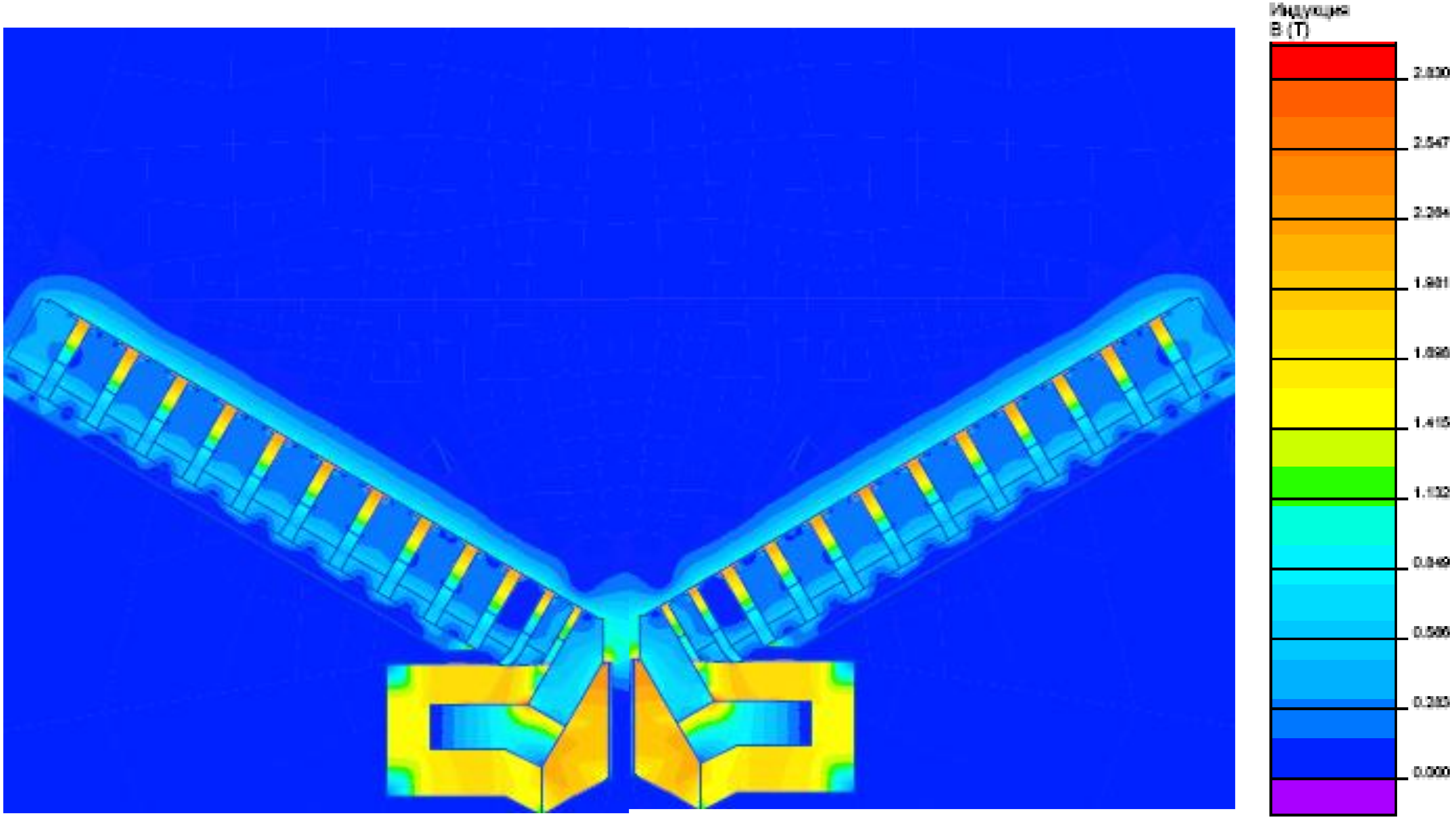


z $\vec{B}_z = \vec{B}_0 e^{-kz}$

Is it possible to create ideal trap?

$k(x)$ **Depend on period of magnetic structure**





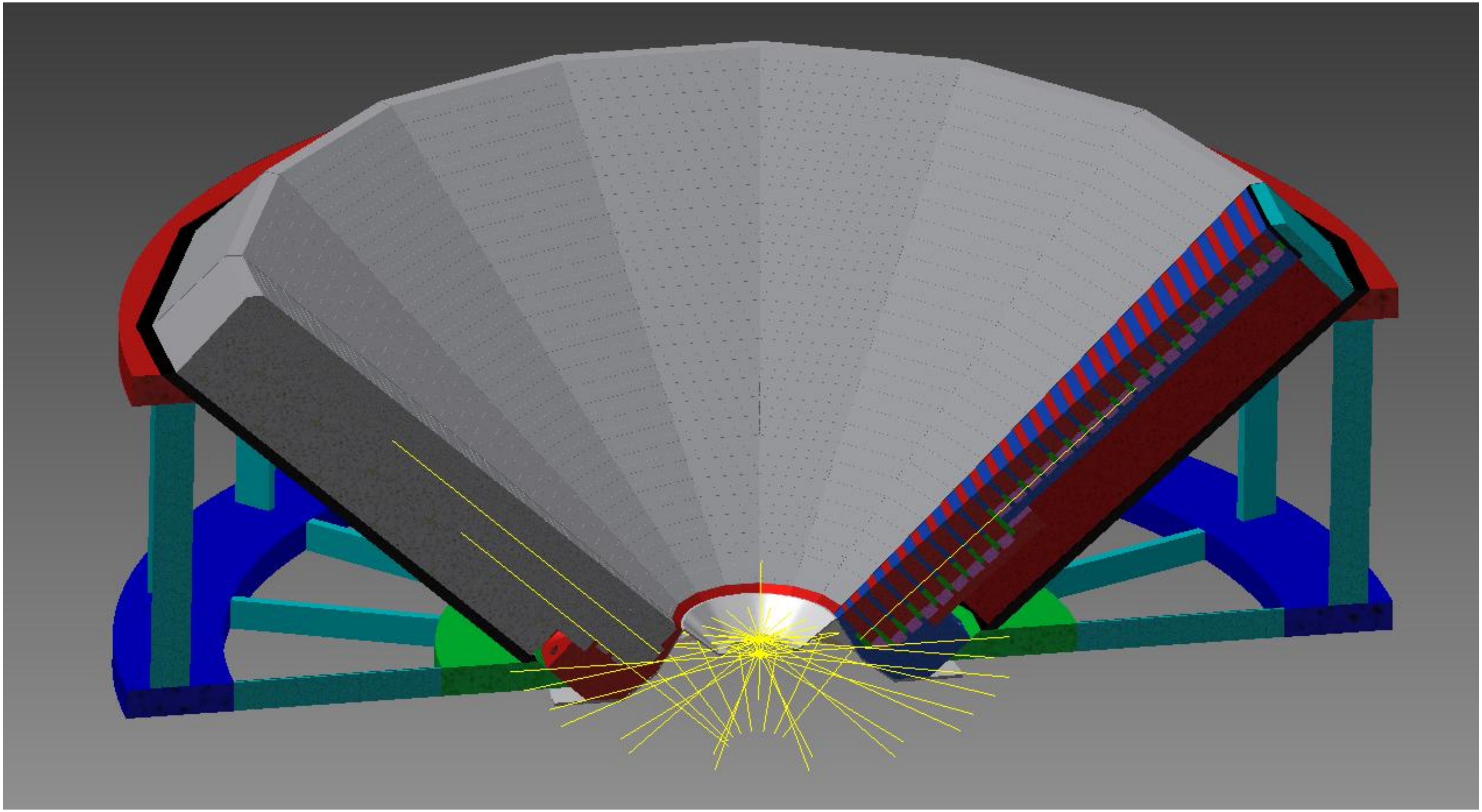
Calculated map of magnetic field for a new trap

Increasing of volume about 15 times

Increasing of stored UCN quantity due to boundary velocity increasing is about 8 times

Our waited accuracy about 0.2-0.3 s.

Trap design



Vacuum chamber and filling system for new trap (ILL, Level D)

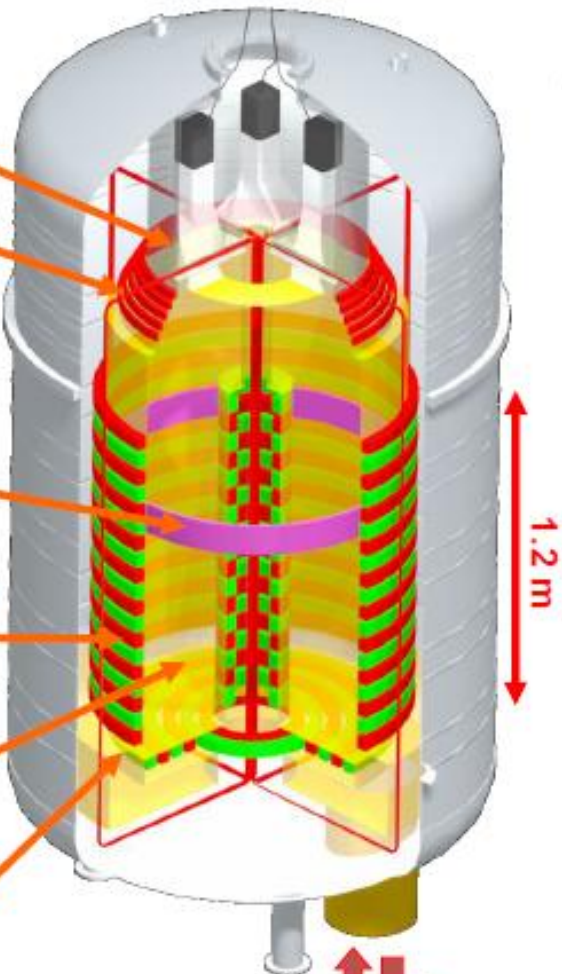
Proposed large volume magnetic storage experiment

$$N(t) = N(t_0)\exp\left(-\frac{t}{\tau_n}\right)$$

PENeLOPE

Magnetic storage of UCN & proton extraction

S. Paul et al.



$\rho_{UCN} = 10^3 - 10^4\ cm^{-3}$ **(PSI /FRM II):**

$N_{stored} = 10^7 - 10^8$

- **Statistical accuracy:**

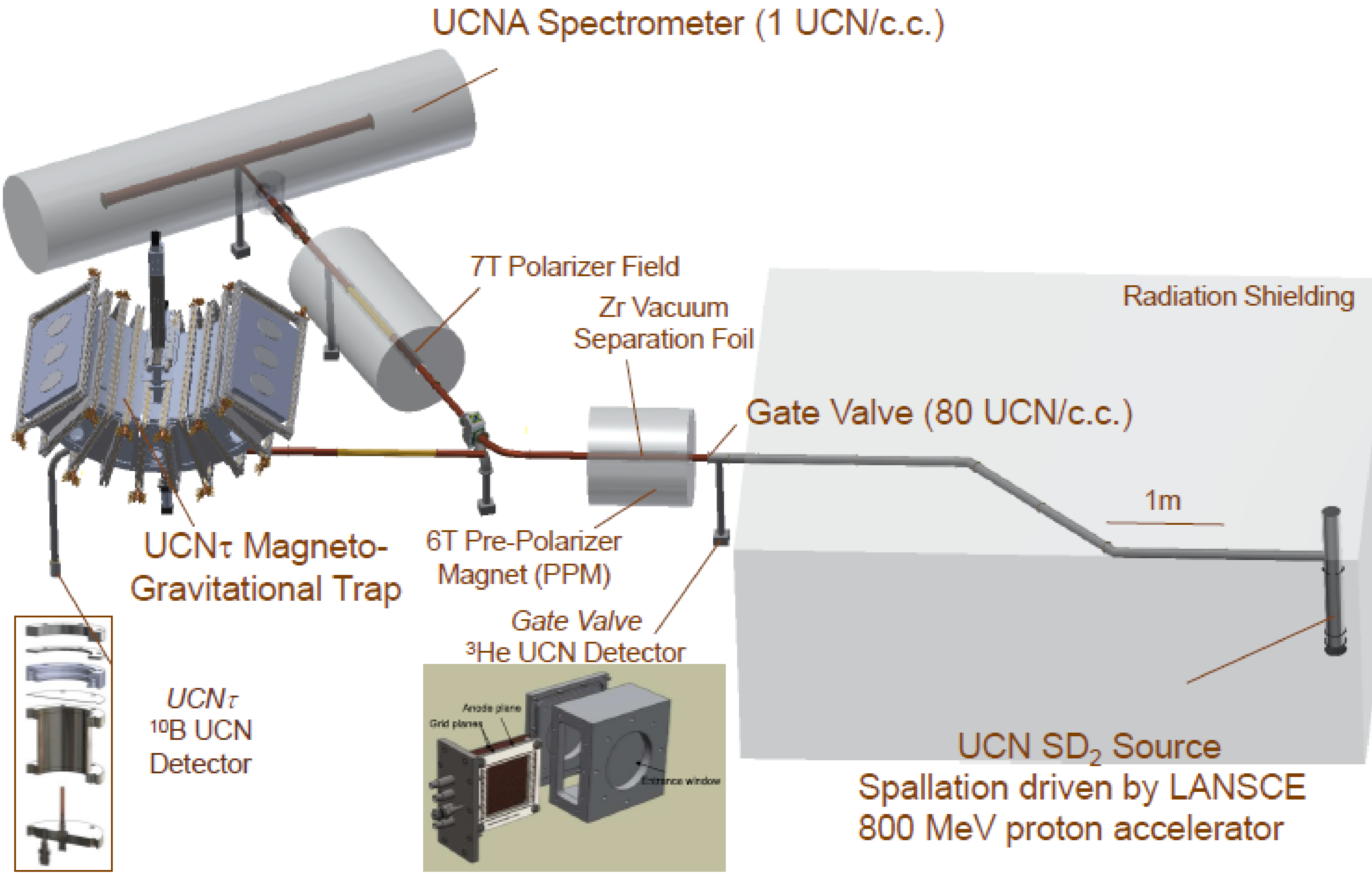
  $\delta\tau_n$ **~ 0.1 s in 2-4 days**

- **Systematics:**
  - **Spin flips negligible (simulation)**
  - **use different values B_{max} to check expected E_{UCN} independence of τ**

R. Picker et al., J. Res. NIST 110 (2005) 357

- Source not yet ready.
- Cryogenic experiment adds challenges.
- Symmetric trap.

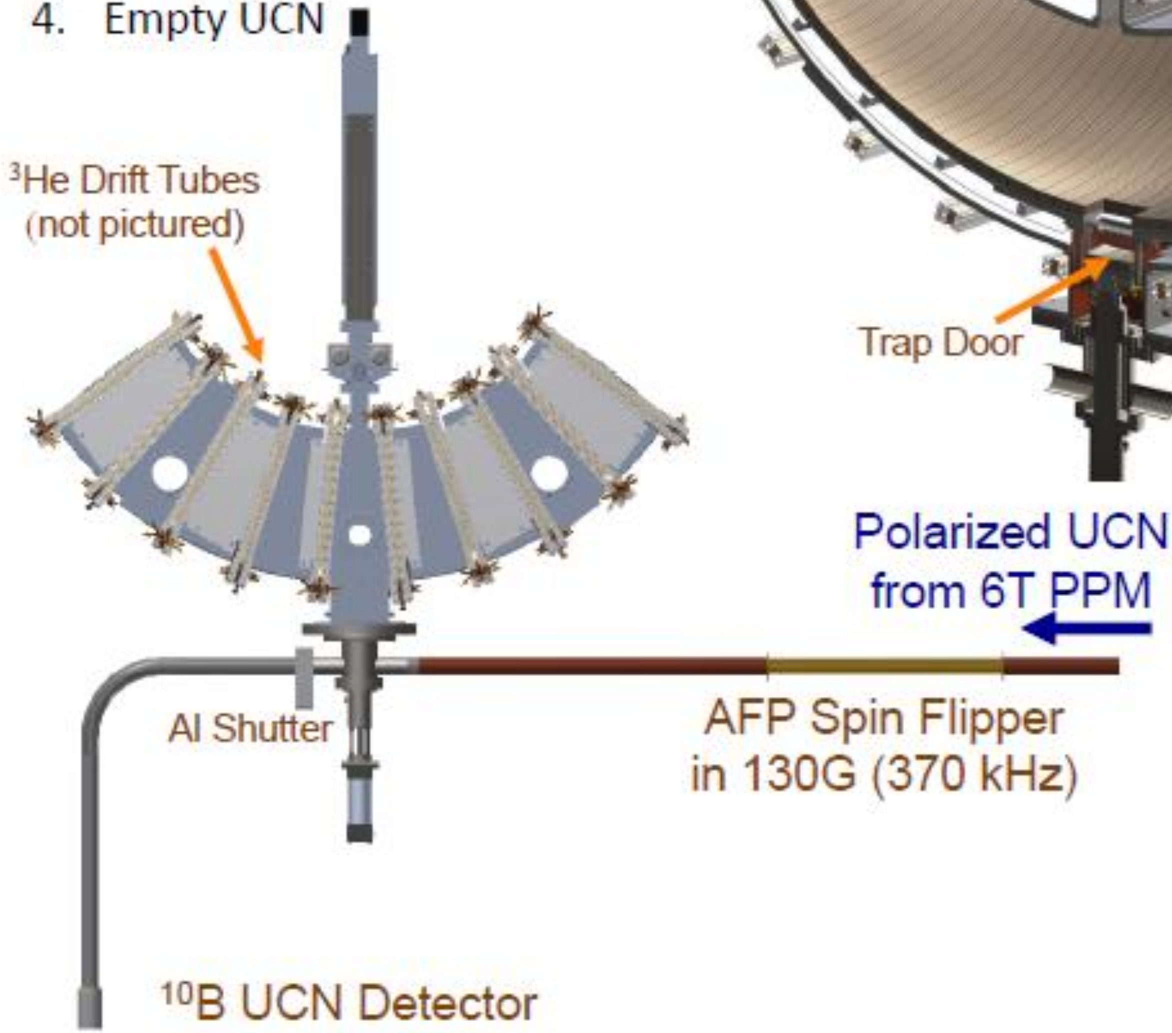
The UCNτ Experiment at LANSCE

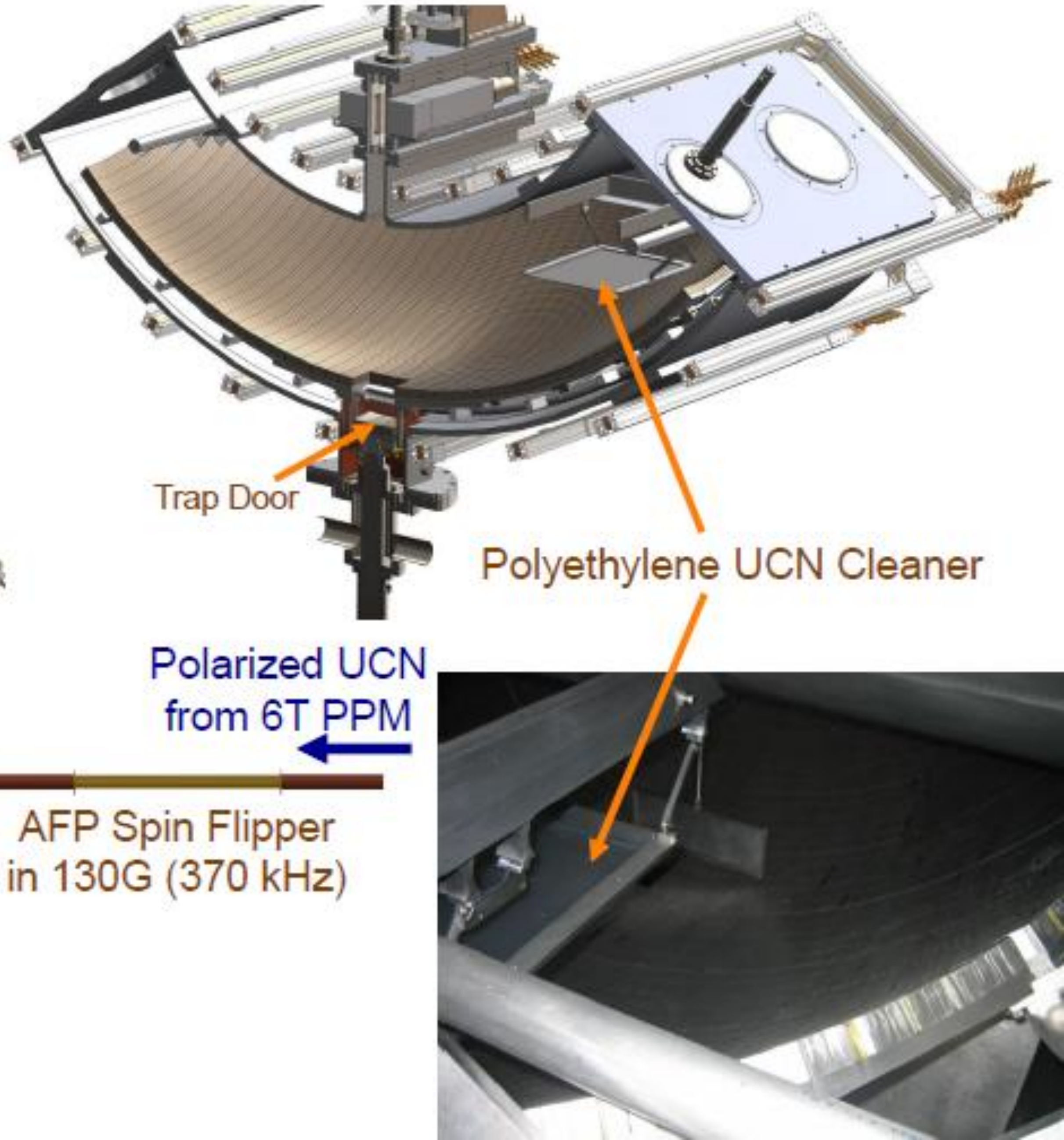


Operation of the UCNτ Experiment

"Fill & Empty" cycle

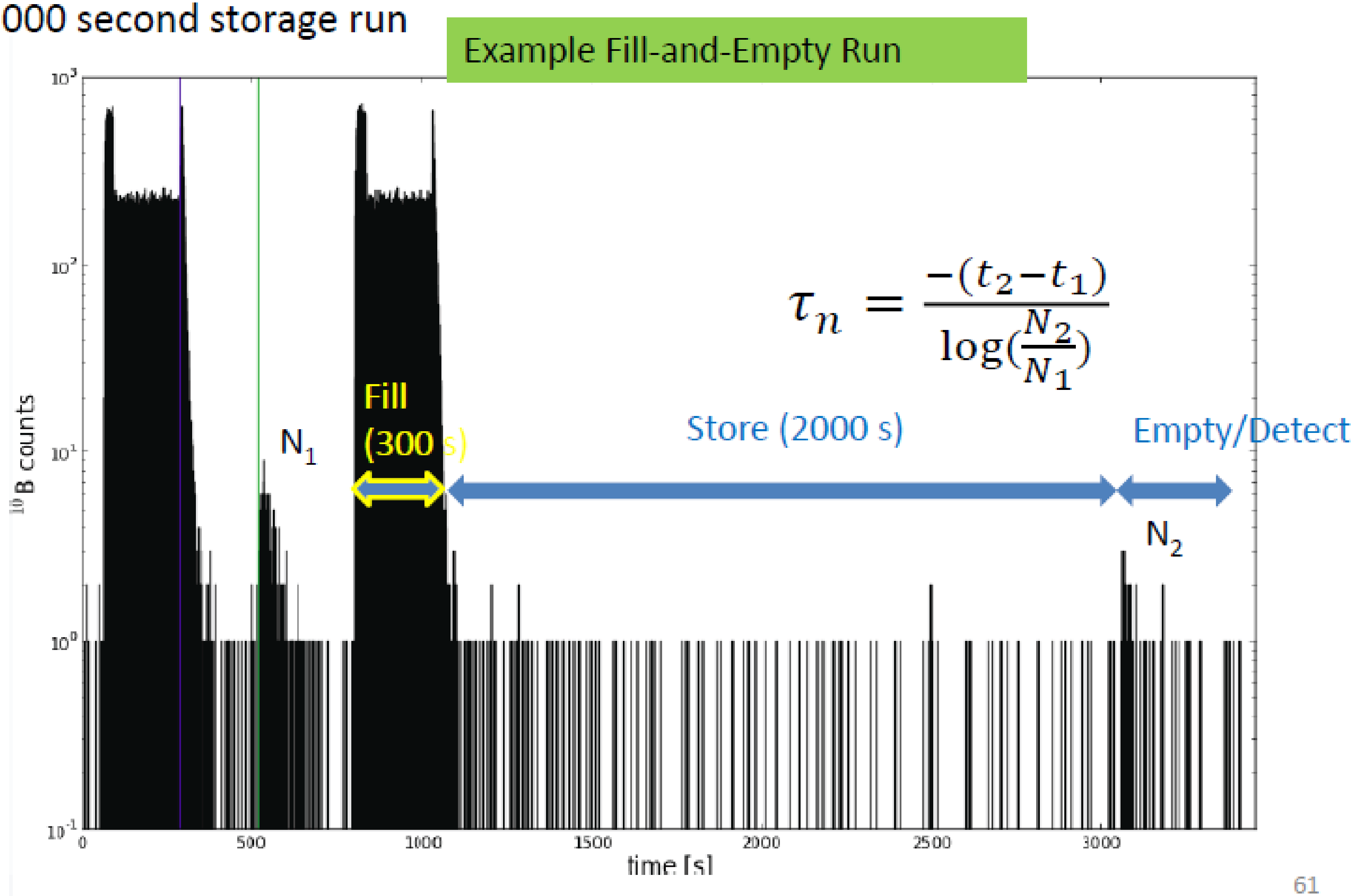
1. fill UCN into the trap
2. Clean the UCN spectrum
3. Store UCN
4. Empty UCN

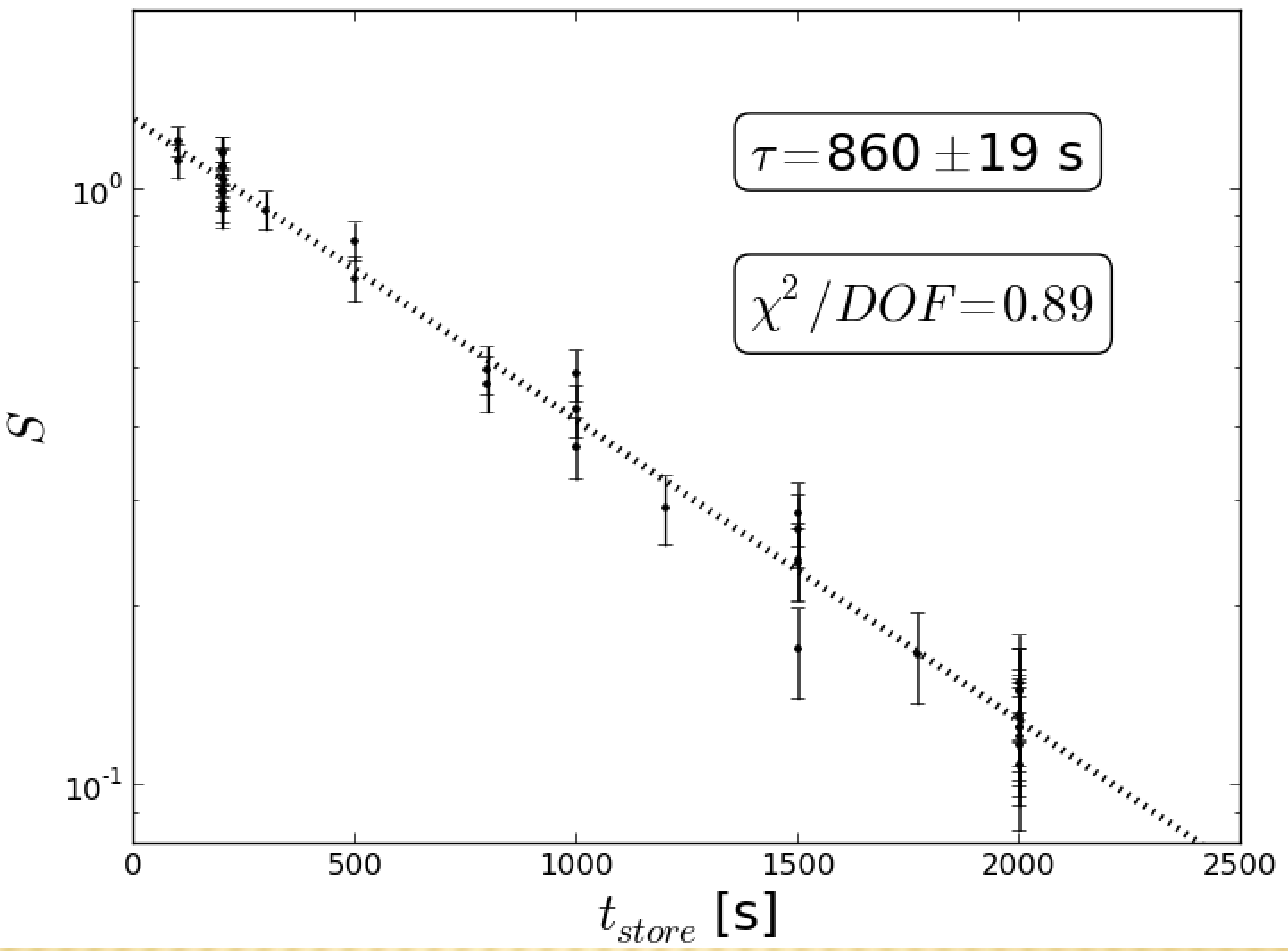




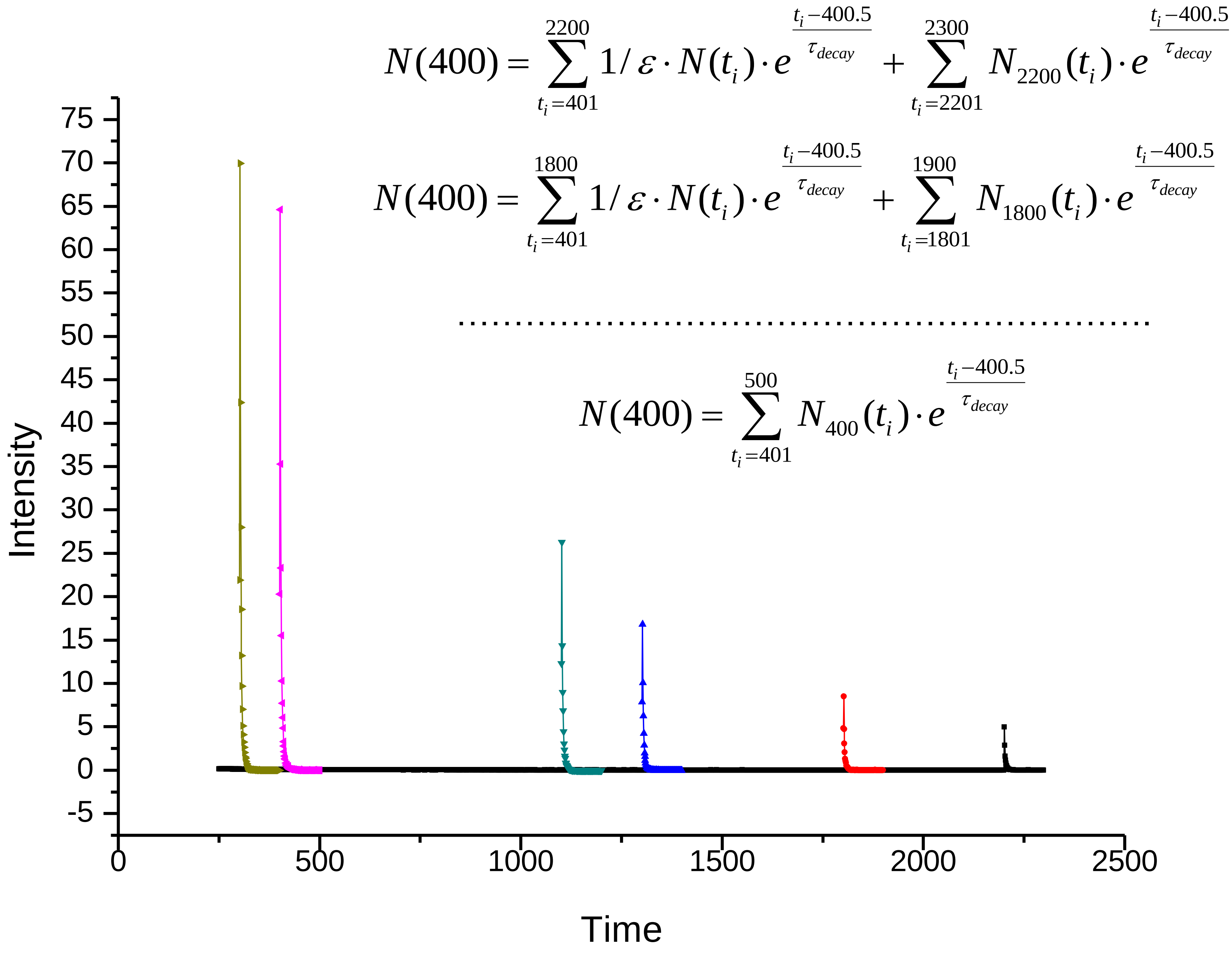
Counts in the dump detector

200 s storage run, followed by a 2000 second storage run



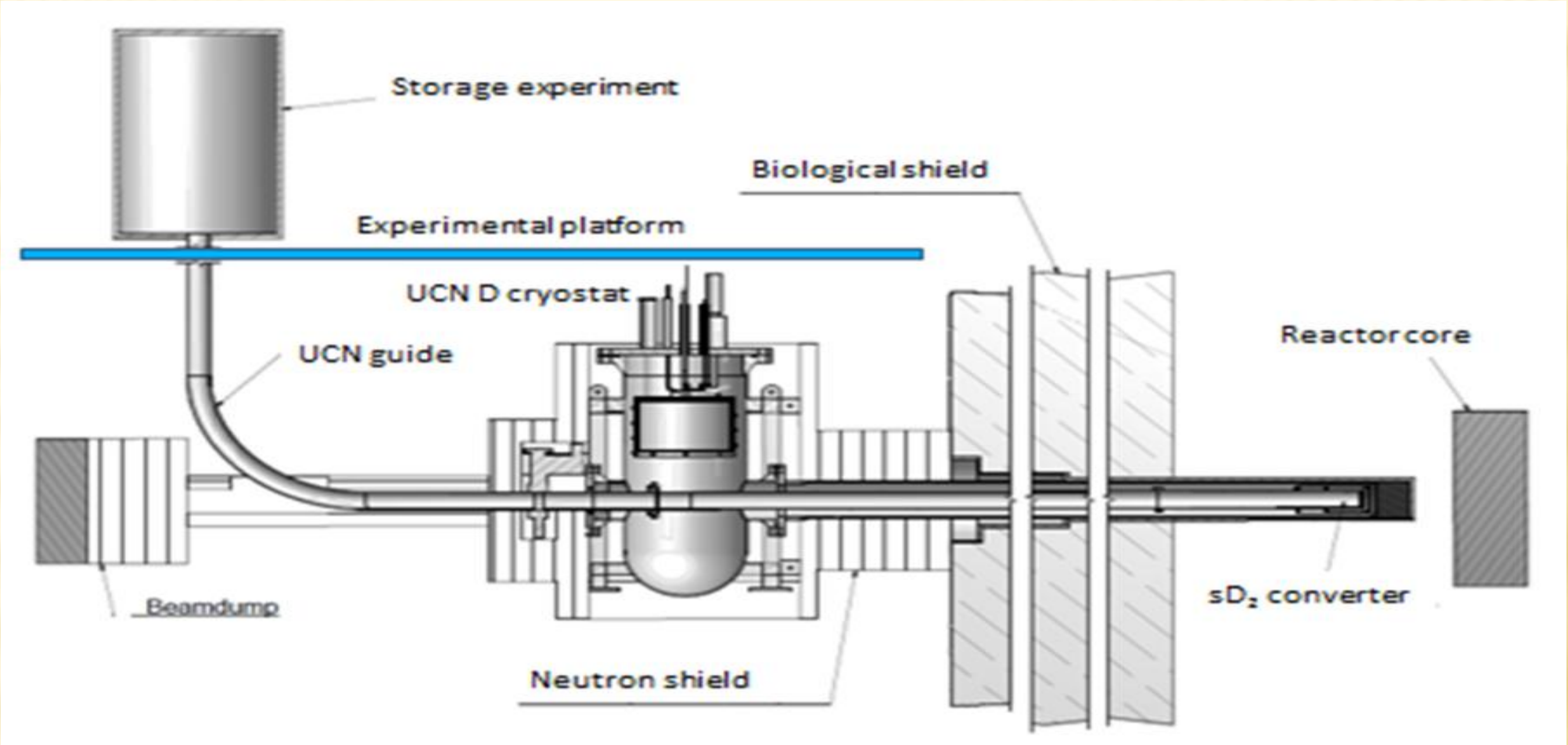


The signal S versus t_{store}. The storage time constant of the trap is given by τ_{store} from the exponential fit (upper). The distribution of residuals of the exponential fit are normalized to their statistical uncertainty (lower



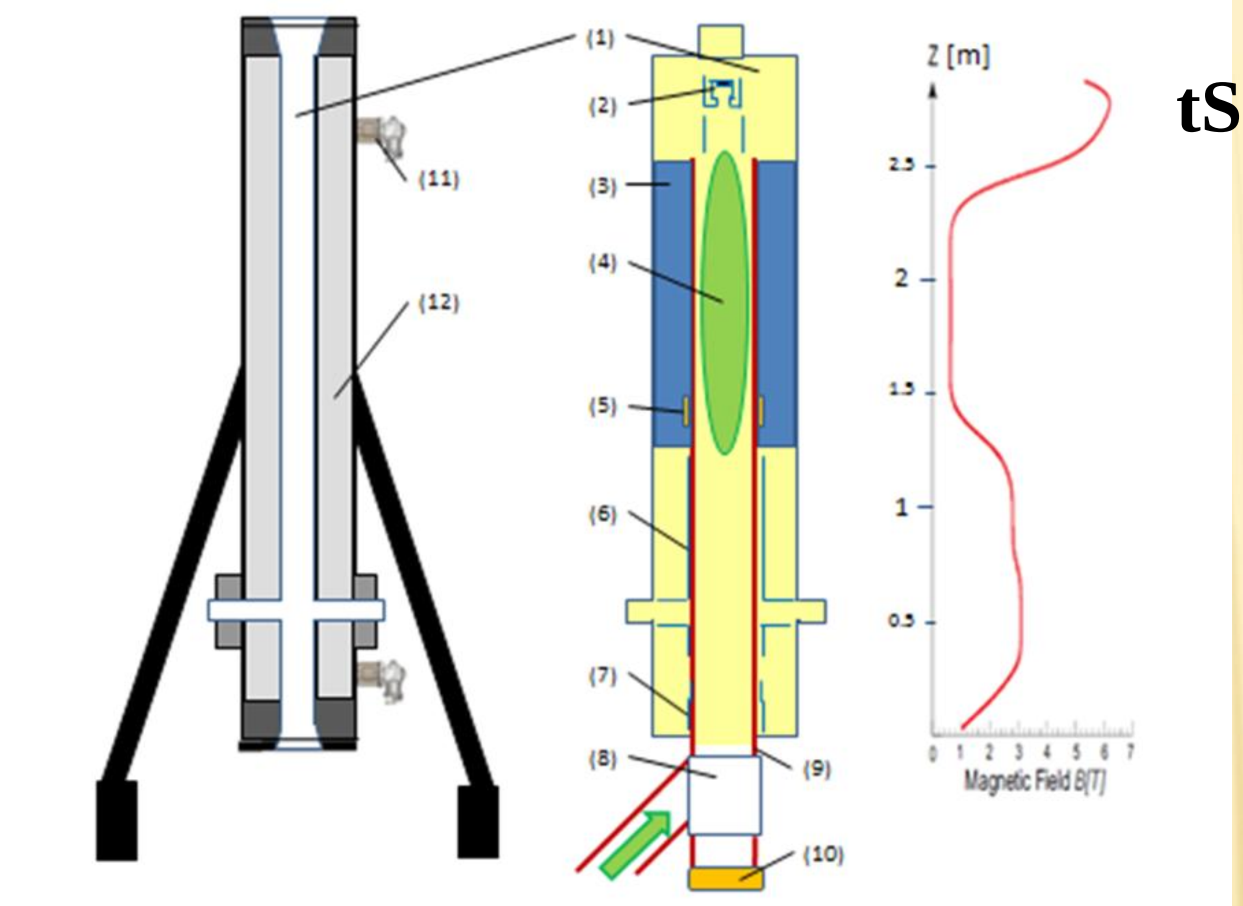
$N(400)=\sum_{t_i=401}^{2200} 1/\varepsilon \cdot N(t_i)\cdot e^{\frac{t_i-400.5}{\tau_{decay}}} + \sum_{t_i=2201}^{2300} N_{2200}(t_i)\cdot e^{\frac{t_i-400.5}{\tau_{decay}}}$
$N(400)=\sum_{t_i=401}^{1800} 1/\varepsilon \cdot N(t_i)\cdot e^{\frac{t_i-400.5}{\tau_{decay}}} + \sum_{t_i=1801}^{1900} N_{1800}(t_i)\cdot e^{\frac{t_i-400.5}{\tau_{decay}}}$
$N(400)=\sum_{t_i=401}^{500} N_{400}(t_i)\cdot e^{\frac{t_i-400.5}{\tau_{decay}}}$
Intensity
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
0
500
1000
1500
2000
2500
Time

UCN Source at the TRIGA Mainz



The newly installed UCN source at beam port D currently delivers UCN densities of 10/cm3 in typical storage volumes of 10 to 20 litres. This number will be further increased by an order of magnitude via the installation of transport tubes coated with 58Ni and the use of solid hydrogen or methane as premoderator.

tSPECT Experiment



(1) inside cold bore tube, (2) proton detector, (3) magnetic multipole for radial trapping, (4) trapped low-field seeking UCN, (5) AFP-spin flip, (6) electrodes, (7) mirror electrode for 4π proton detection, (8) UCN switch, (9) UCN guide, (10) UCN monitor detector to control depolarization, (11) cryo-cooler, (12) isolating vacuum.

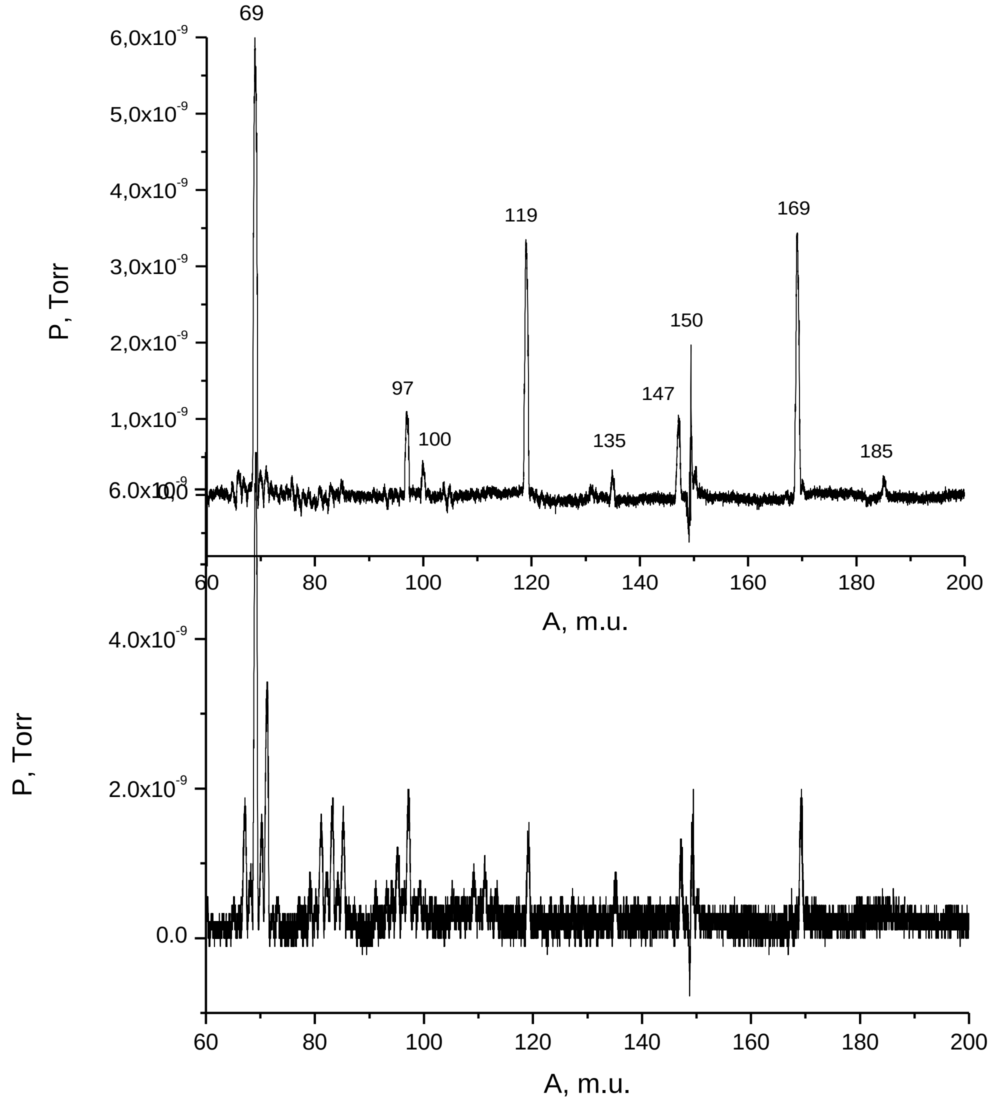
Right hand side: magnetic field long the z-axis of the aSPECT spectrometer. The effective UCN storage volume is V ~ 10 L

Thank you for your attention

Fomblin vapor scattering?

Calibration

Fomblin spectrum under 98 C



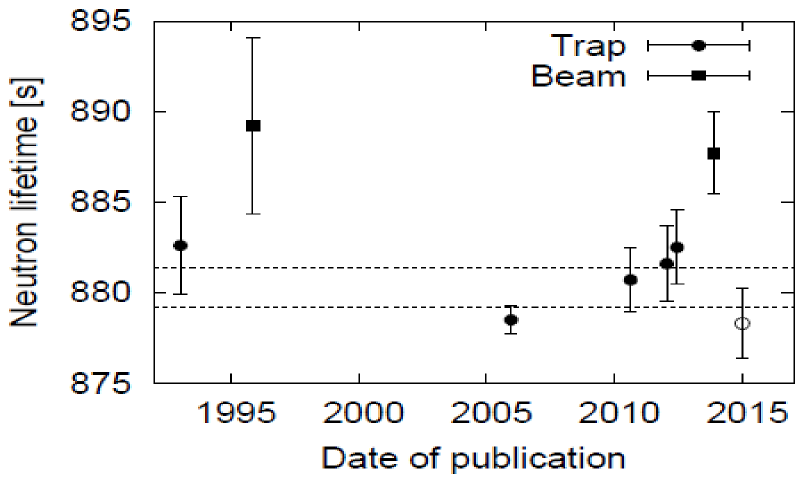
Spectrum of the rest vapor in the trap

Measurement of the neutron lifetime with ultra-cold neutrons stored in a magneto-gravitational trap

V.F. Ezhov, A.Z. Andreev, G. Ban, B.A. Bazarov, P. Geltenbort, A.G. Glushkov, V.A. Knyazkov, N.A. Kovrizhnykh, G.B. Krygin, O. Naviliat-Cuncic, V.L. Ryabov

(Submitted on 23 Dec 2014)

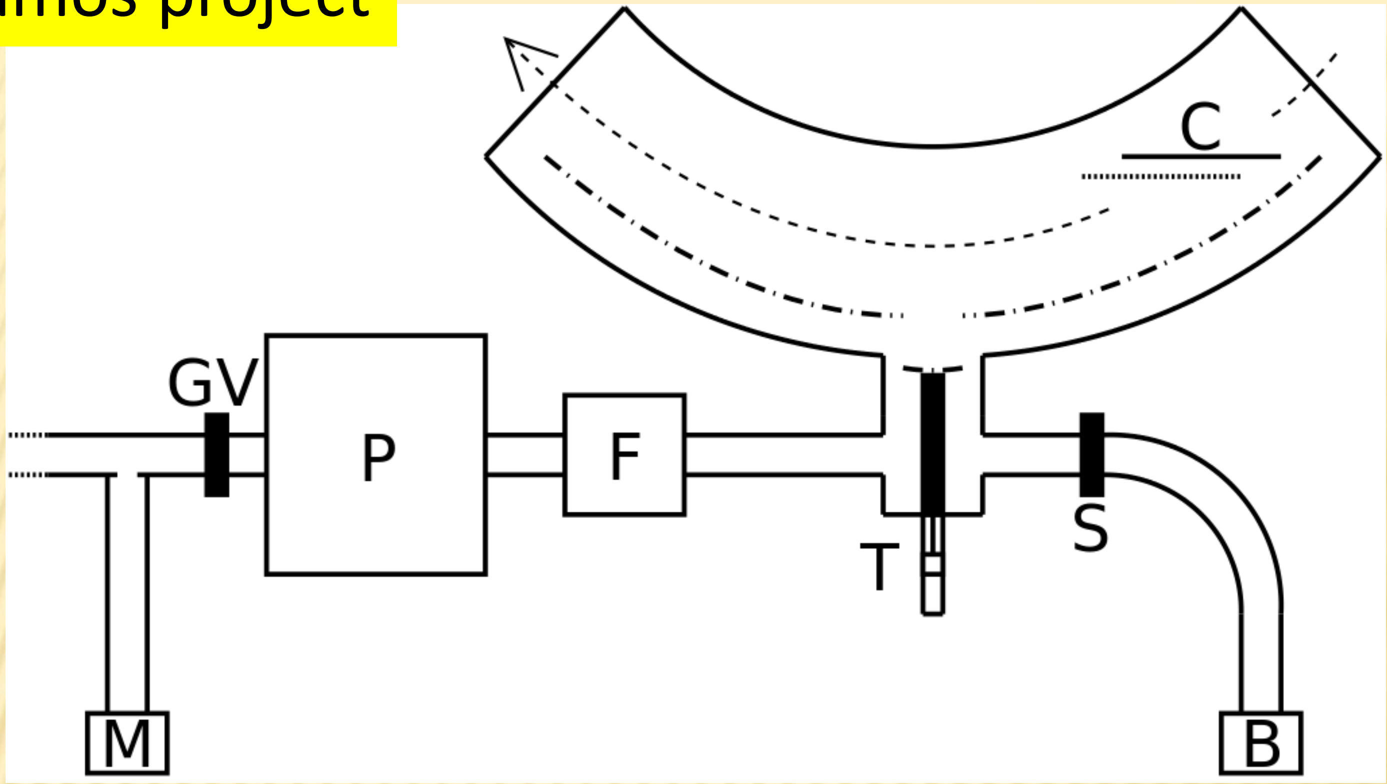
arXiv:1412.7434 [nucl-ex]



$\square_n$=(878.3±1.9) s.

Comparison of the value for the neutron lifetime obtained from this work (open circle) with the values included in the current PDG average (filled squares and circles). The dotted lines indicate the $\pm 1\sigma$ limits of the current average.

Los-Alamos project

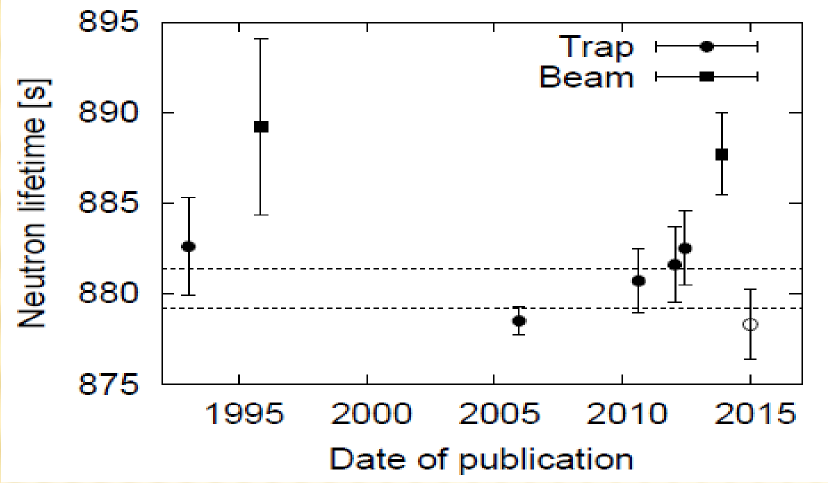


A schematic of the experiment. The UCN source density is monitored through a 1 cm aperture leading to a 3He-based proportional counter (M), or detected further downstream in the 10B counter (B). The apparatus consists of a polarizing magnet (P), a spin flipper (F), and polyethylene cleaner in raised (solid) and lowered (dotted) positions (C). There is an up-stream gate valve (GV) and down-stream aluminum shutter (S), as well as a pneumatic piston-driven magnet plate (T) which opens the bottom of the Halbach array (dash-dot) so that UCN can be loaded. The holding field follows lines parallel to the dashed arrow.

MEASUREMENT OF THE NEUTRON LIFETIME WITH ULTRA-COLD NEUTRONS STORED IN A MAGNETO-GRAVITATIONAL TRAP

V.F. EZHOV, A.Z. ANDREEV, G. BAN, B.A. BAZAROV, P. GELTENBORT, A.G. GLUSHKOV, V.A. KNYAZKOV, N.A. KOVRIZHNYKH, G.B. KRYGIN, O. NAVILIAT-CUNCIC, V.L. RYABOV

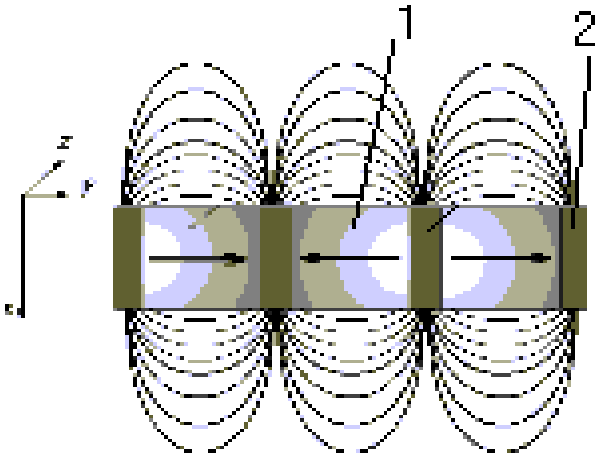
(SUBMITTED ON 23 DEC 2014)
arXiv:1412.7434 [nucl-ex]

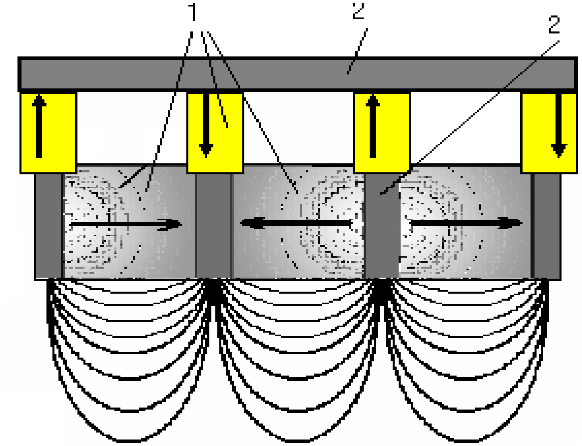


Comparison of the value for the neutron lifetime obtained from this work (open circle) with the values included in the current PDG average (filled squares and circles). The dotted lines indicate the ±1σ limits of the current average.

□$_n$=(878.3±1.9) s.

Magnetic wall for neutrons

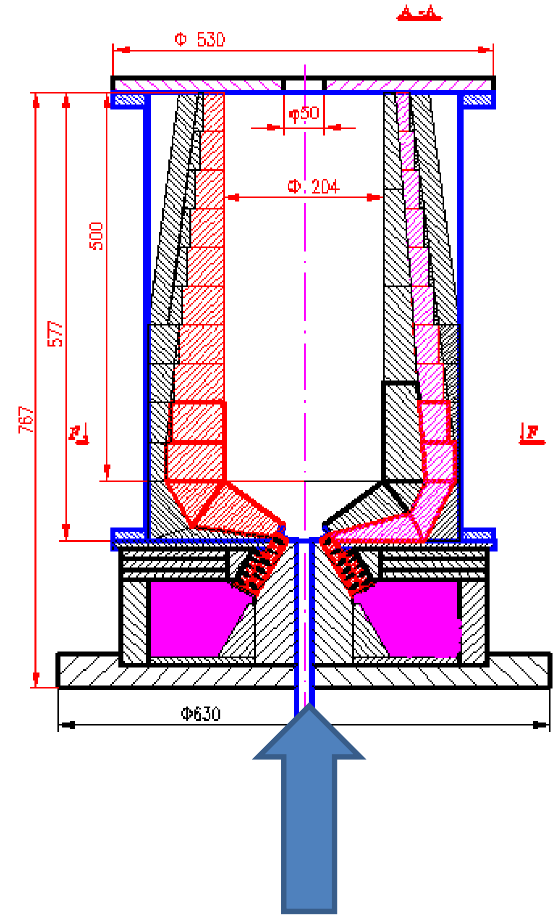




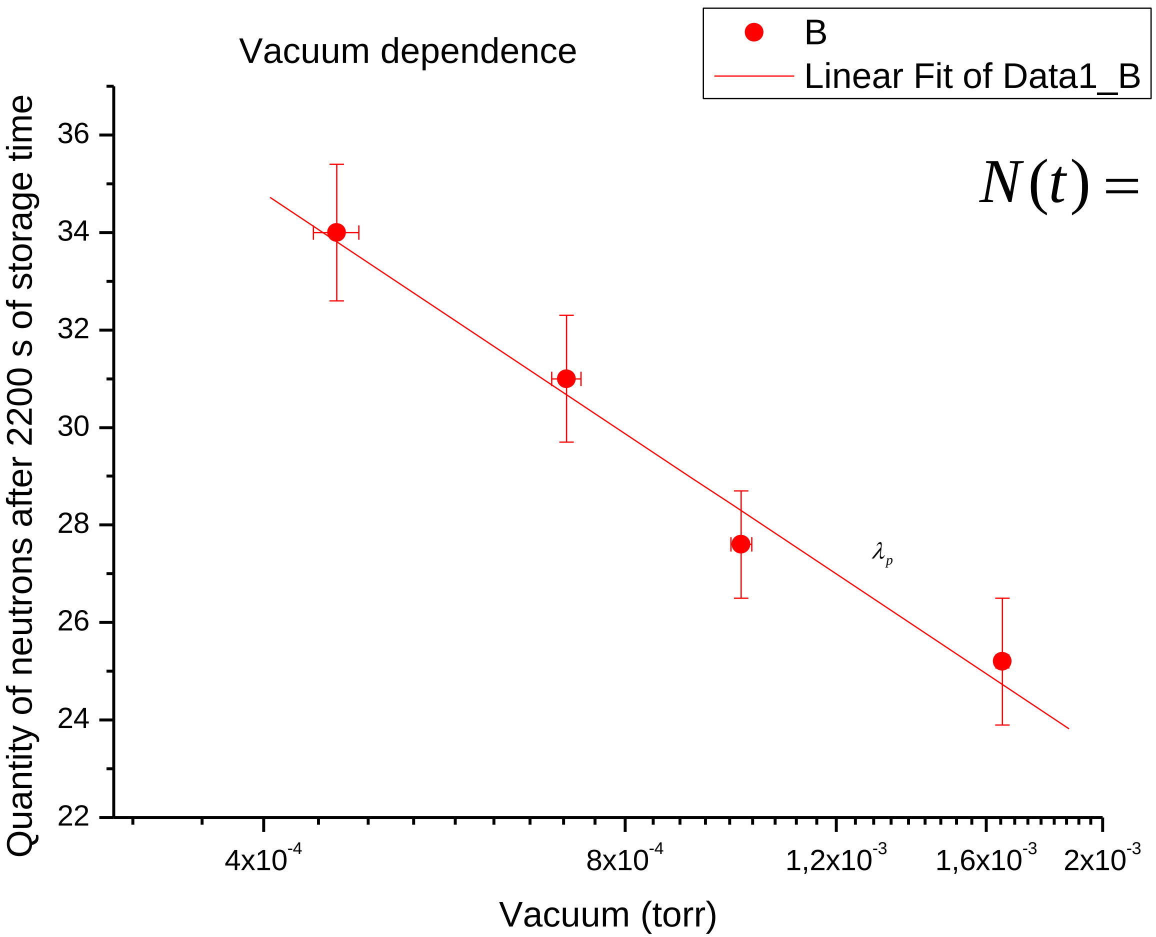
1 – permanent magnet
2 – magnetic field guide

Filling through lower neutron guide

- **Neutrons heating at the moment of magnetic shutter switching on**



Vacuum dependence (rest gases)



$$N(t) = N0\exp((-\lambda_{decay} - \lambda_p p)t)$$

$\square_p p \ll \square_{decay}$

$$\lambda_p = \frac{\ln\left(\frac{N_1(t)}{N0_1}\right) - \ln\left(\frac{N(t)}{N0}\right)}{t(p - p_1)}$$

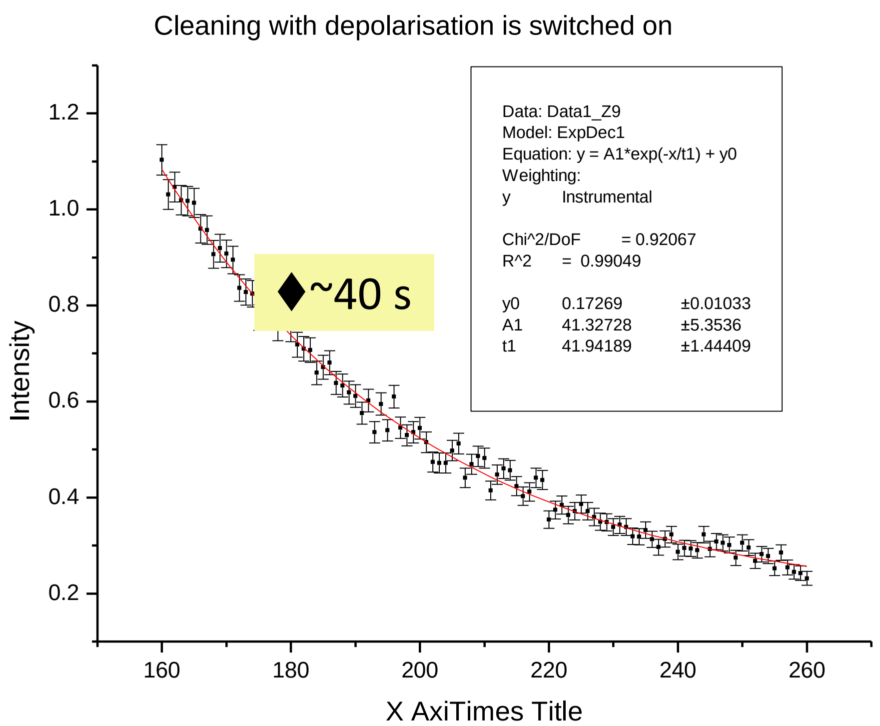
$$\lambda_p = 0.15 \pm 0.04 \ \ {}^{1}\!/_{s \cdot torr}$$

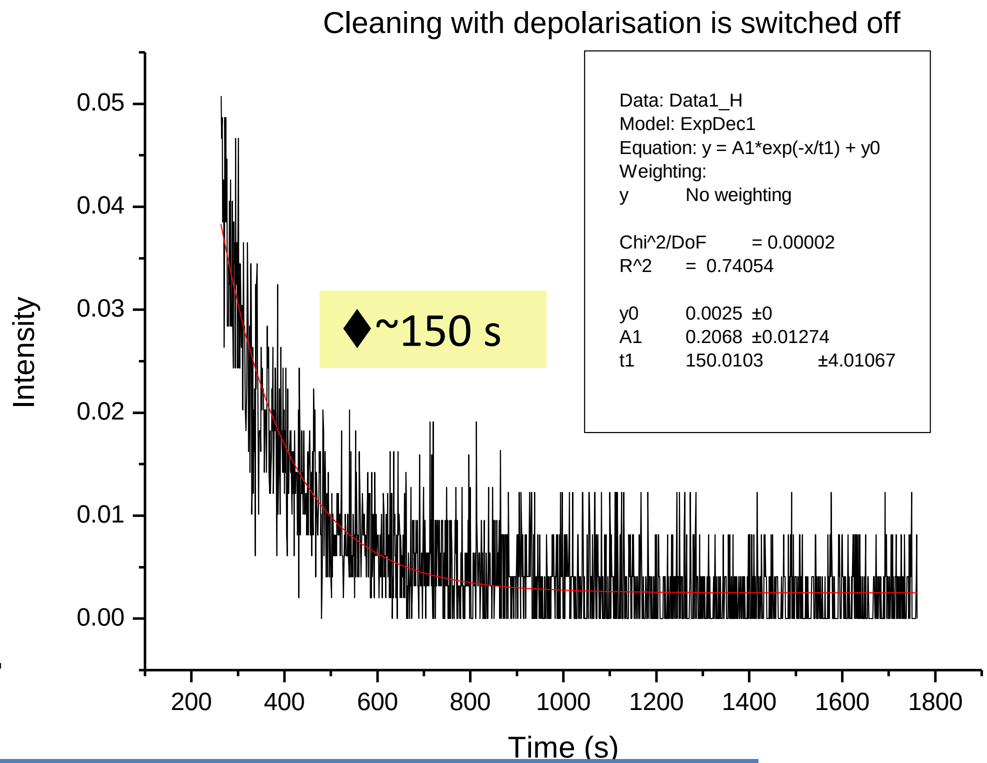
$$\lambda_{decay} = 1/880 = 0.00113 \ 1/\mathrm{s}$$

$$p \Rightarrow 10^{-6} \ \mathrm{torr}$$

Cleaning of the neutron spectrum

Comparing cleaning time with forced spin flip and without (no normalized data)





Depolarization accelerates cleaning time about 3 times

Criterion of sufficient cleaning time – the absence of efficiency changing

LIFETIME MEASURING

RUN A:

- the aperture of the UCN guide inside the magnetic shutter was Ø20 mm and without the forced depolar-ization (two points)
- Storage time

  τ_{st}= 874.6 ± 1.7 s
- After correction using ε =0.903±0.007 from run B

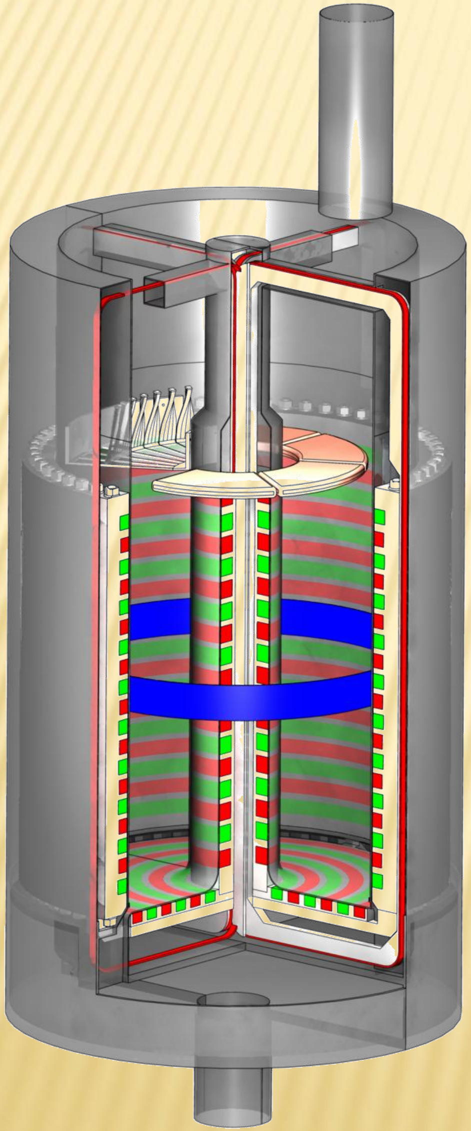
$$\tau_n = 878.3 \pm 1.9\ s$$

RUN B:

- the aperture of the magnetic shutter was enlarged to Ø60 mm and the outer solenoid was used to induce the forced spinflip
- First emptying was done after 400 s and storage times before the second were equal to 600, 900, 1400 and 1800 s.
- ε =0.903±0.007.

$$\tau_n = 878.2 \pm 1.9\ s$$

Munich project



PENeLOPE, a superconducting magneto-gravitational UCN trap for a precise neutron lifetime measurement

I. Altarev, B. Franke , E. Gutsmiedl, F. J. Hartmann, S. Materne, S. Paul, R. Picker,
Physik-Department E18, Technische Universit Munchen, D-85748 Garching

UCN will be trapped in a multipole field of a flux density up to 2 T and will be bound by gravitational force at the top. This makes the extraction and detection of the decay protons possible and allows a direct measurement of neutron decay.

Accuracy of 0.1 s and better demands high storage times and good knowledge of systematic errors, which could result from neutron spin flip and high energetic UCN which leave the storage volume only slowly. Therefore, the neutron spectrum is cleaned by an absorber. The big storage volume of 800 dm3 and the expected high neutron flux of FRMII give more than 10^7 neutrons per filling of the storage volume and meet statistical demands.