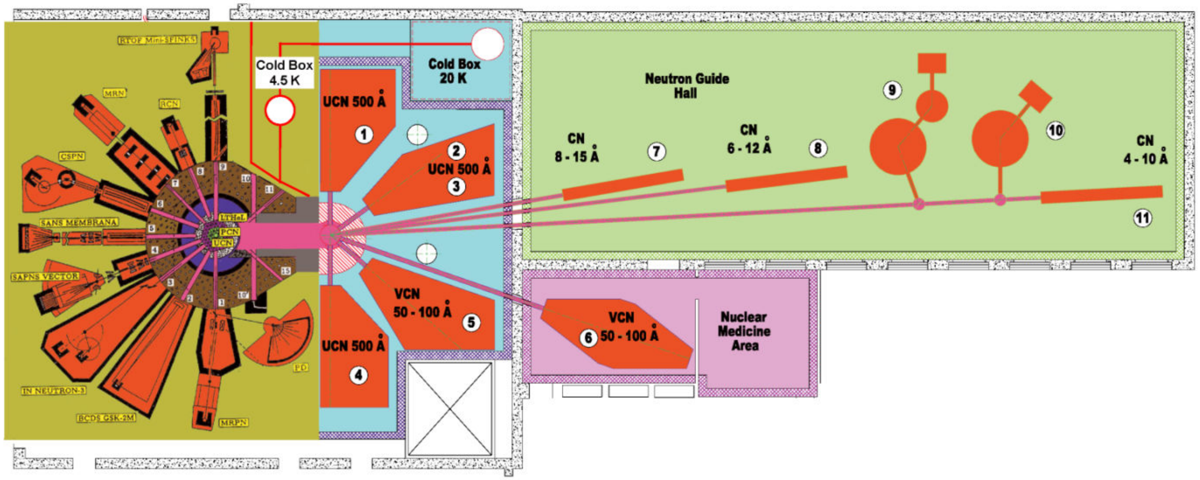
Project of ultracold neutron source with superfluid helium at WWR-M reactor (PNPI, Gatchina) and scientific research program

A.P. Serebrov

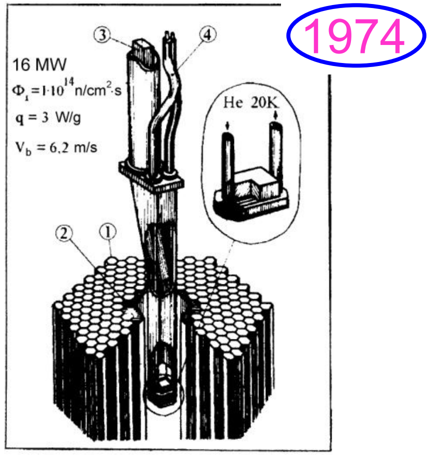


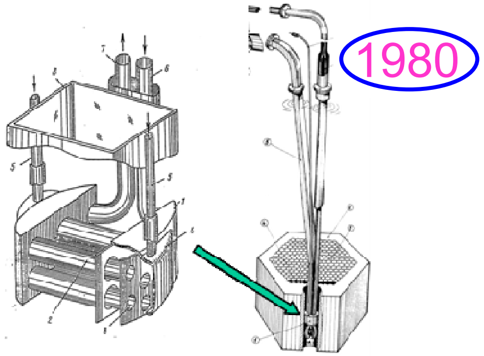
UCN2010
International Workshop on UCN and Fundamental Neutron Physics
RCNP, Japan
April 8 - 9, 2010

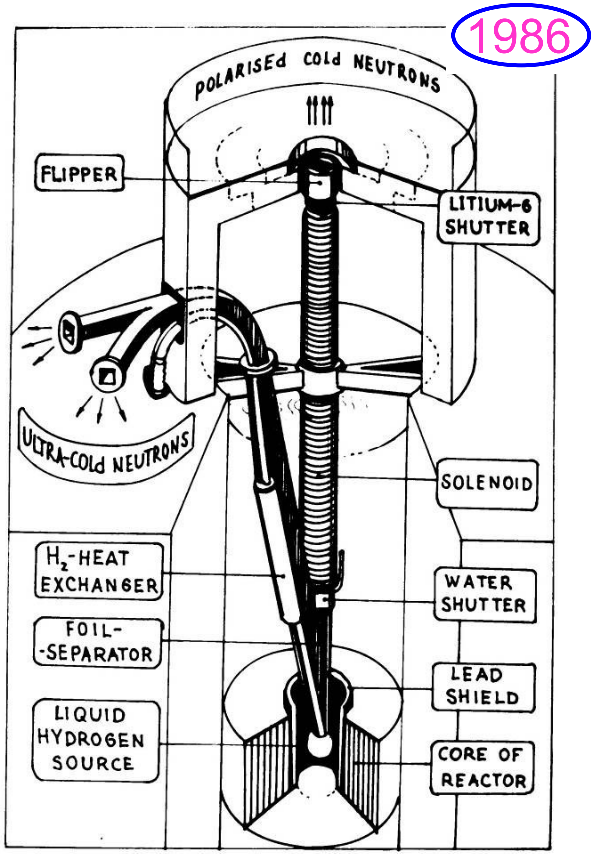
Content

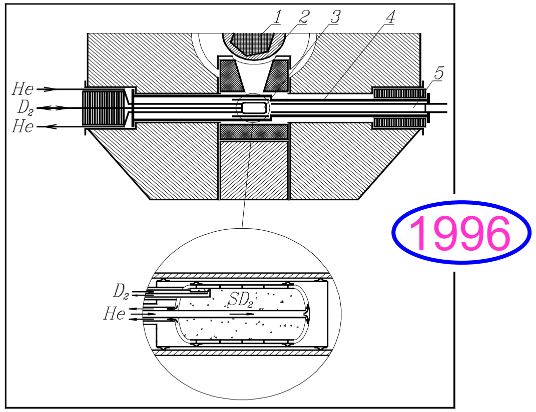
1. UCN sources at PNPI
2. Ultracold neutron source with superfluid helium
3. New facilities of WWR-M reactor
4. Scientific research program
5. Movie "How it will be"

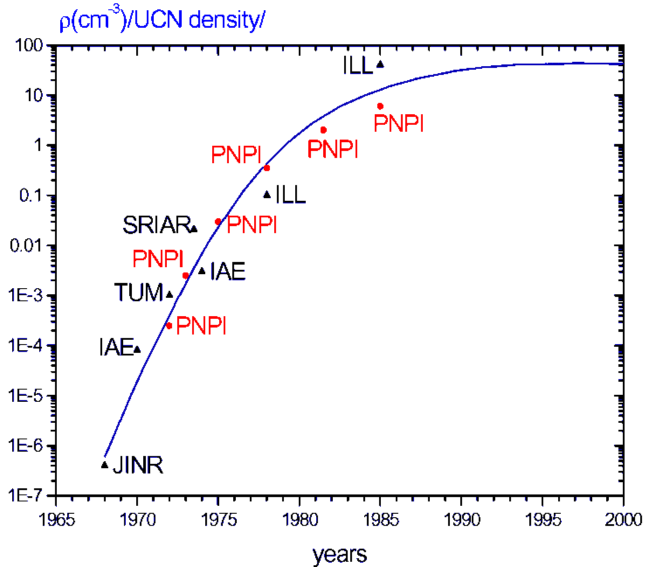
UCN sources produced by PNPI

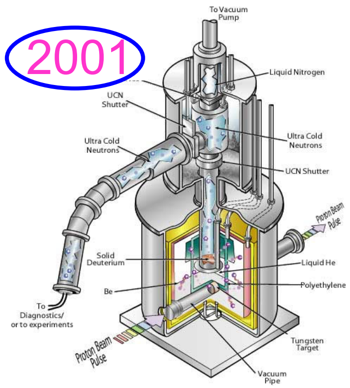


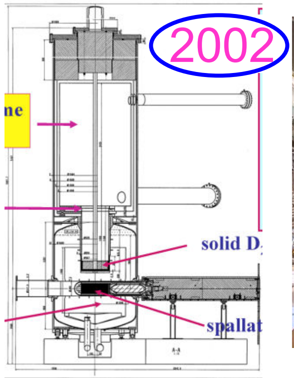


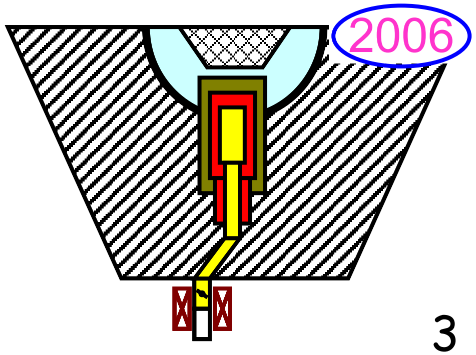




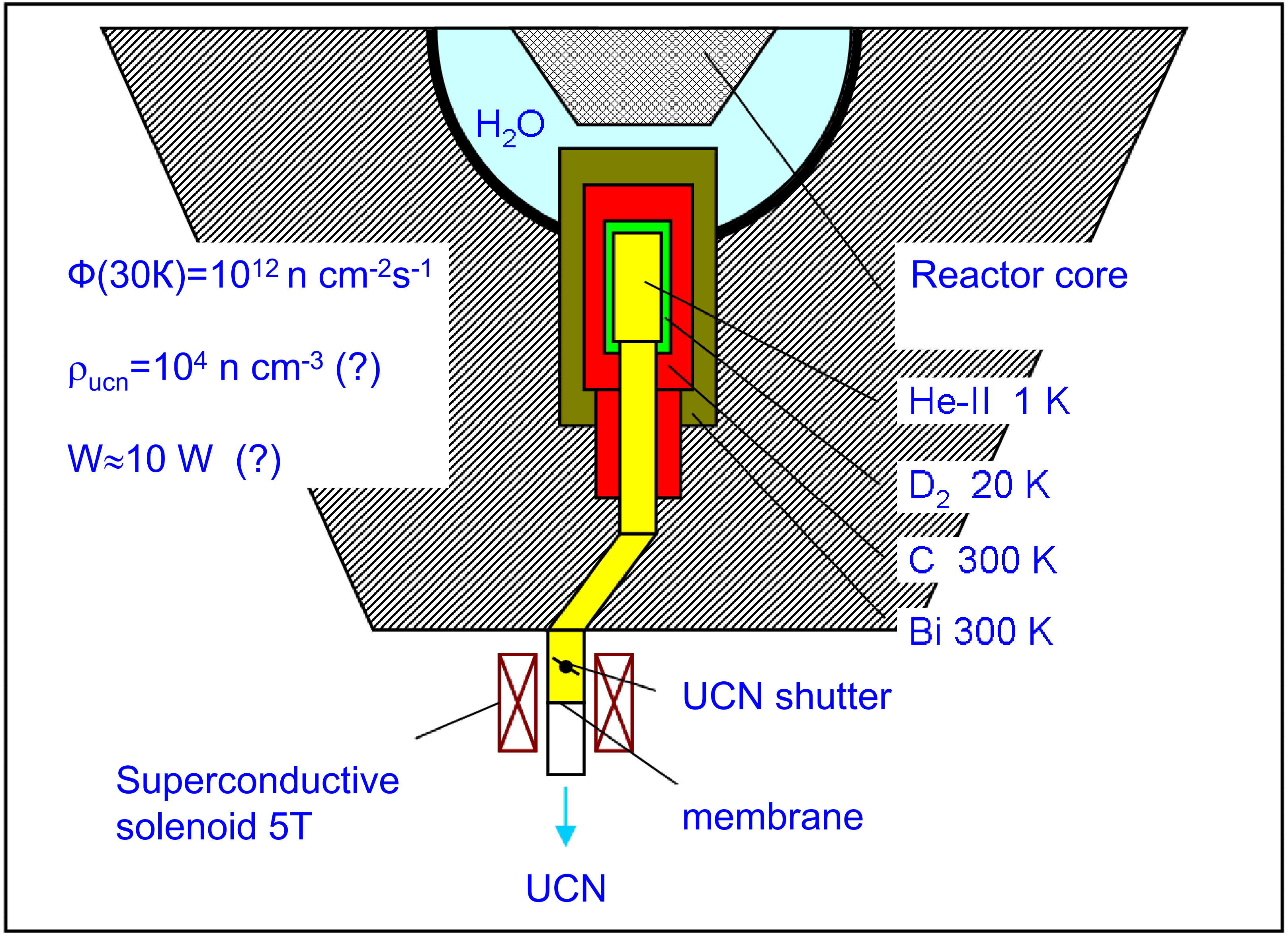








Conceptual idea of UCN source at WWR-M reactor



Project of ultracold and cold neutron source with superfluid helium at WWR-M reactor

Neutron scattering in liquid helium

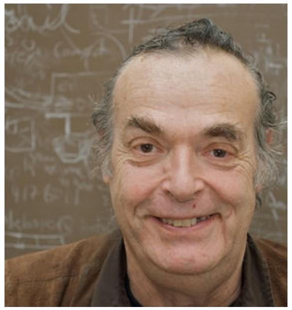
I.Ya. Pomeranchuk “Selected works”

About neutron scattering with energy a few degree in fluid Helium II

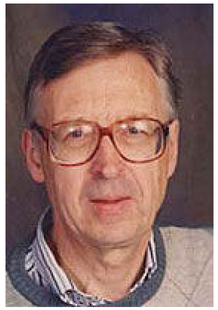
The scattering of slow neutron in He-II is considered. It is shown that the scattering is a negligible small at the temperature below than temperature of critical point.

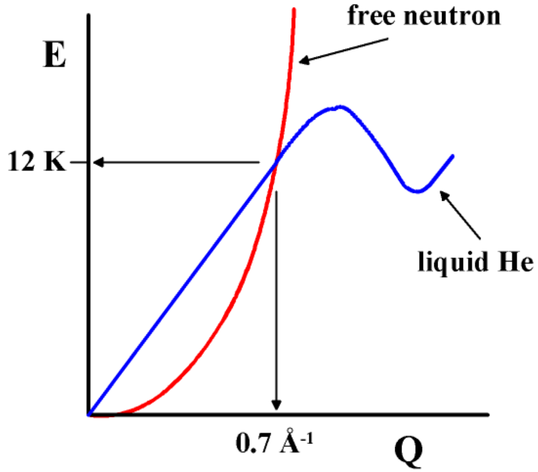
* ЖЭТФ, 1946, 16, 391; J. Phys. USSR, 1945, 9, 461.

UCN source based on superfluid He-II



R. Golub, J.M. Pendlebury, Phys. Lett. A 62 (1977) 337





E_{beg}=12 K → $E_{UCN}\approx 10^{-3}$ K

λ=9 Å

Storage time of UCN in He-II (results of experiment)

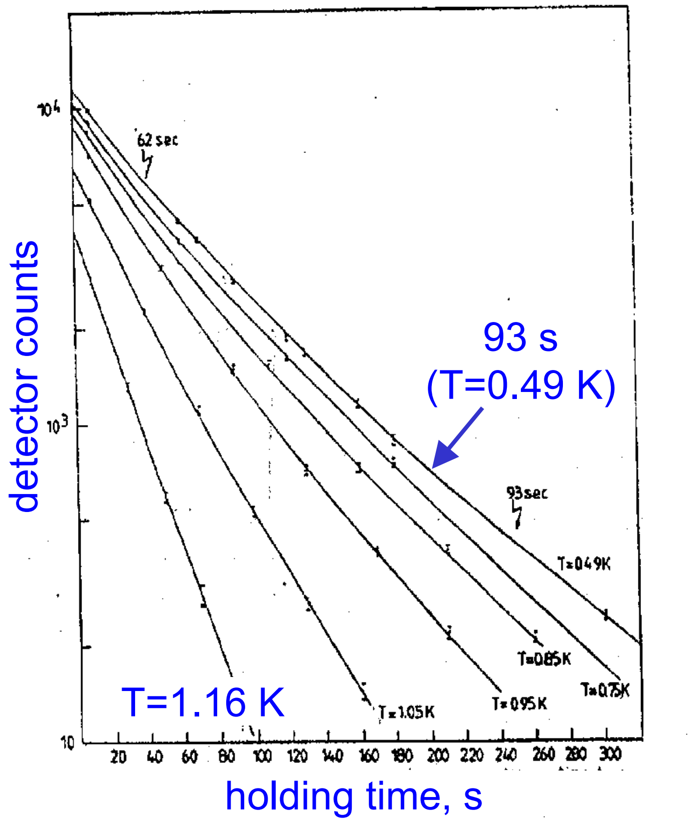


Fig. 2. Storage of UCN in a liquid Helium filled vessel. $N(t_s)$ - number of observed detector counts after a storage time t_s

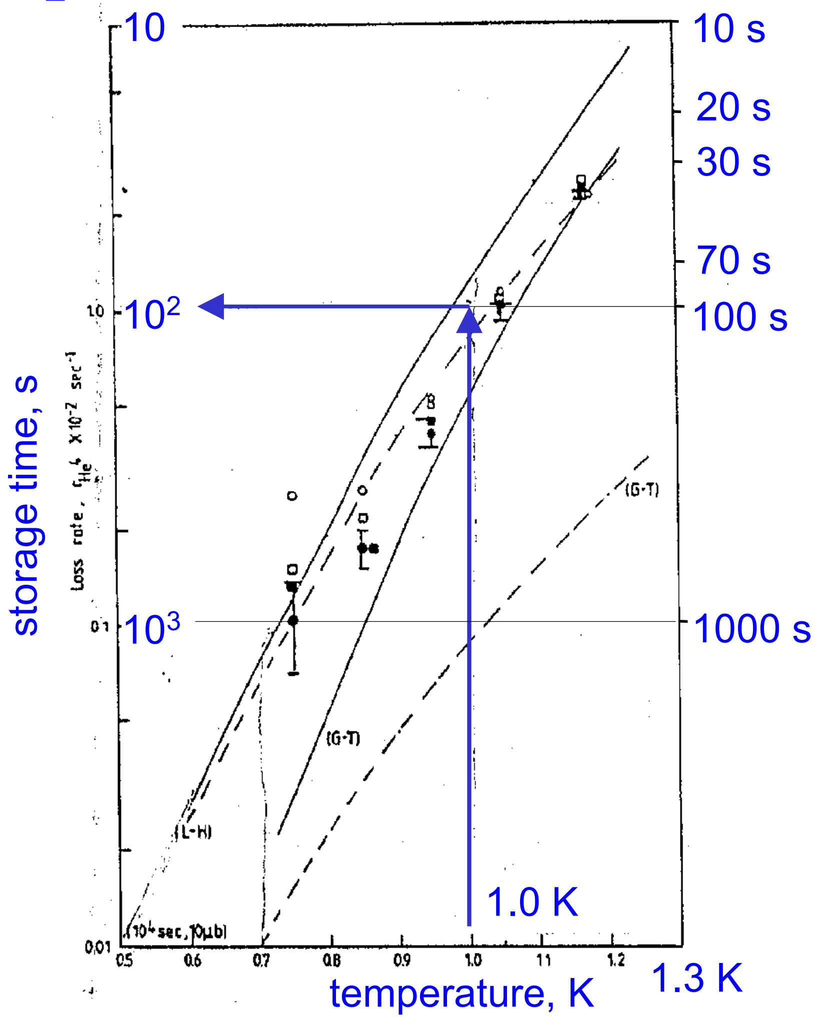


Fig. 3. Loss rate due to the interaction of UCN with superfluid Helium[4] as a function of temperature. The numbers in brackets on the vertical scale give the corresponding storage times and total cross section (for 4.6 m/s UCN), respectively. ● Method A, ■ Method B, ○ Method A (corrected), □ Method B (corrected), see text. Dashed lines show the results for the two phonon scattering process calculated using Landau's Hamiltonian [4] (L-H) and by Griffin and Talbot [6], (G-T). Solid lines show the total loss rate using these two approaches

H.Yoshiki experiment at ILL

Phys. Lett. A 308 (2003) 67-74

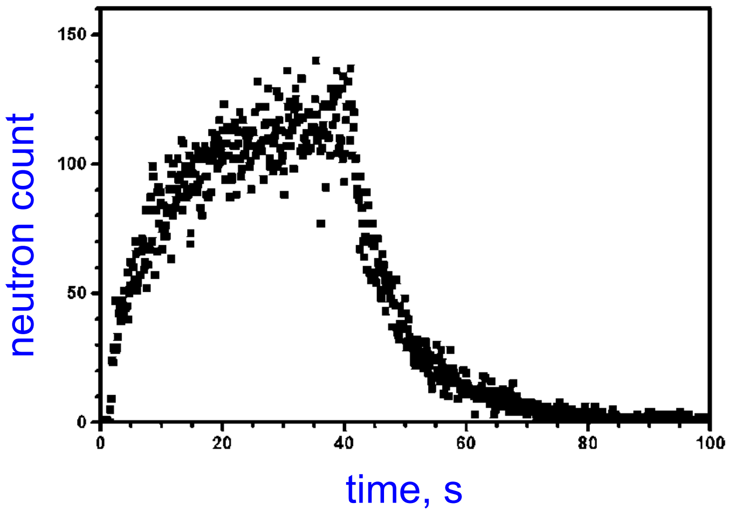


Fig. 5. The UCN detector counts as a function of time, with the velocity selector set to 9 Å.

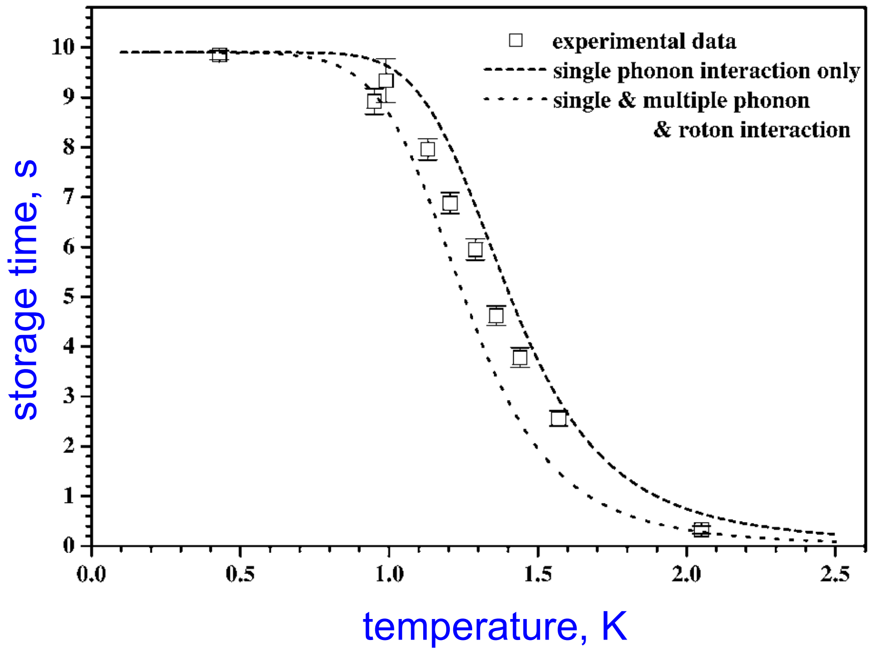


Fig. 4. Experimental measurement of the temperature dependence of UCN storage lifetime, together with the theoretical expectations [6] from two models of phonon and roton interactions.

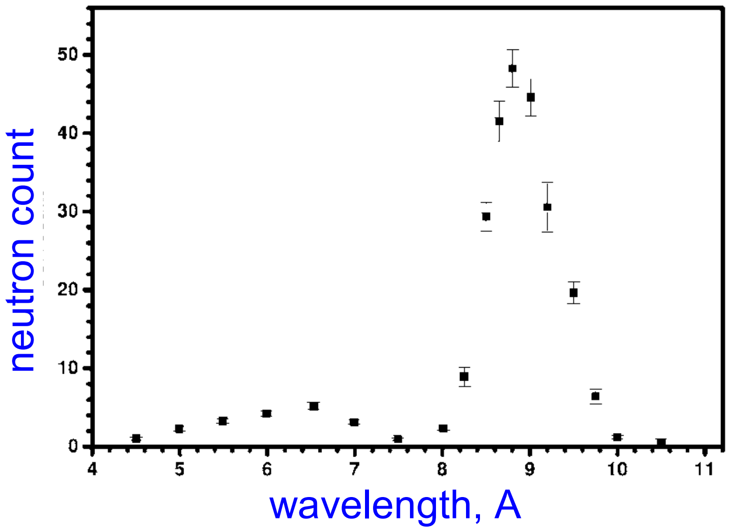


Fig. 6. The UCN count rate recorded at wavelengths between 4 Å and 11 Å.

UCN density in the source $\rho = C\tau$

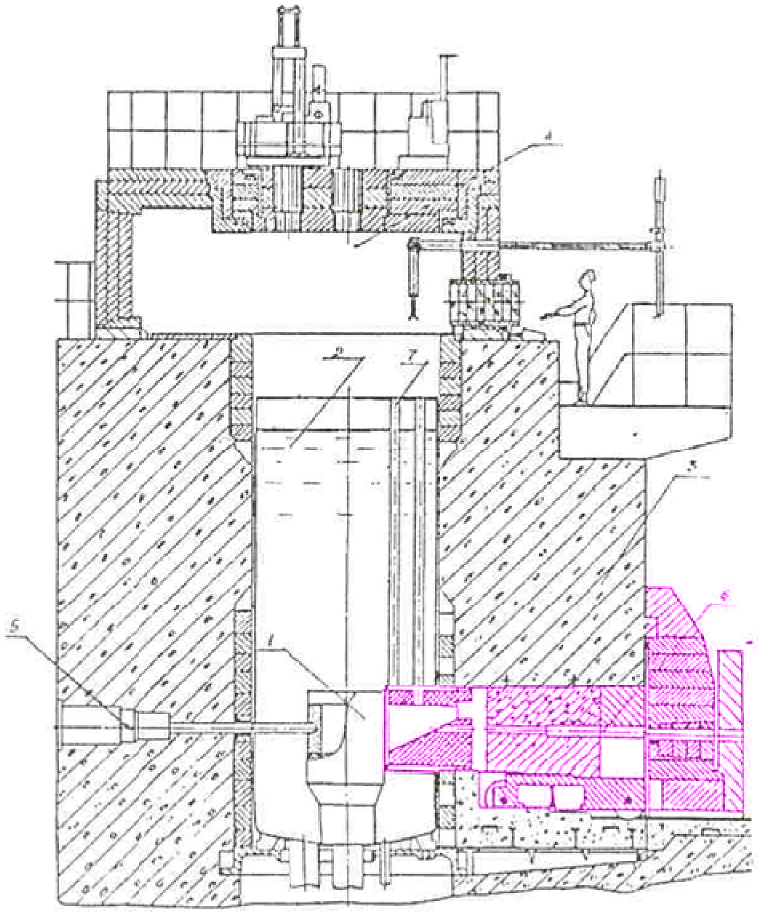
$\Phi(\lambda = 9\text{Å}) = 2.7 \cdot 10^7$ n/(cm^2·s·A)

C – UCN generation (0.9±0.1) n/(cm^{3}s)

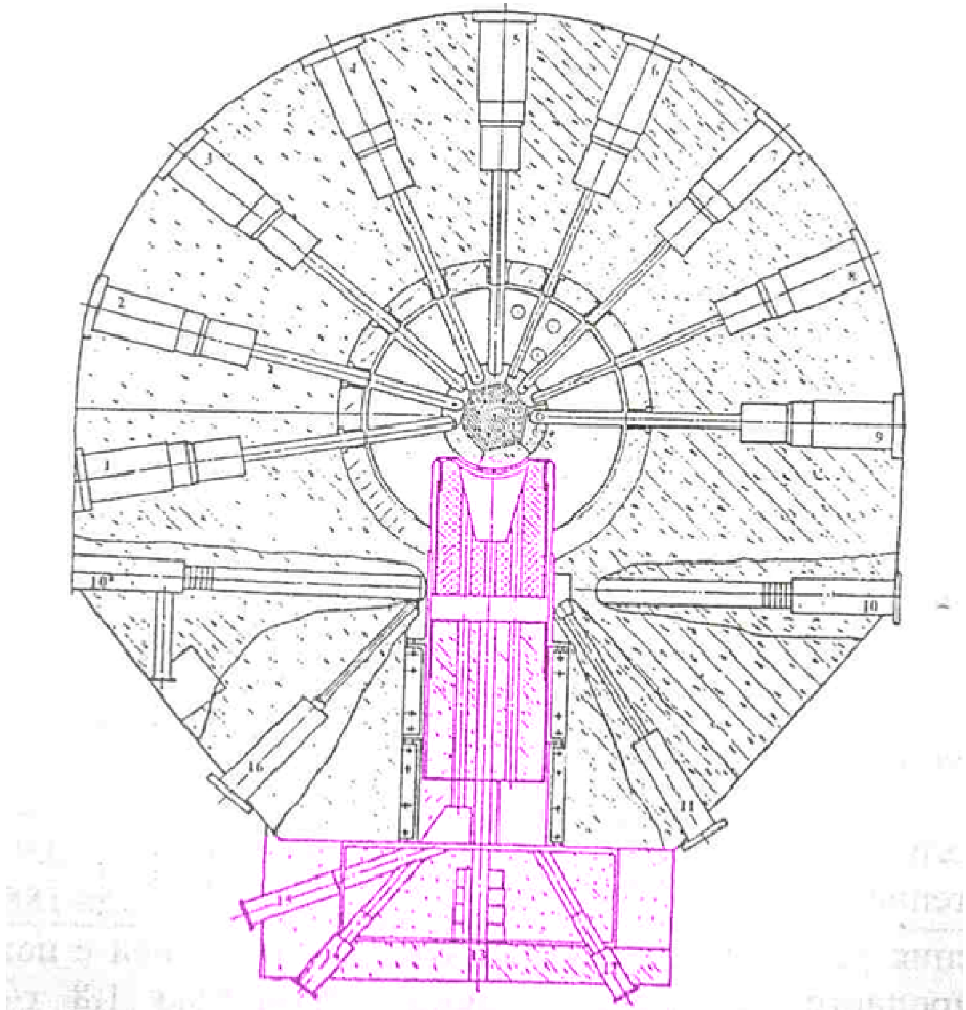
τ- storage time in the source

$\rho \approx 10$ cm^{-3}

Thermal column of WWR-M reactor



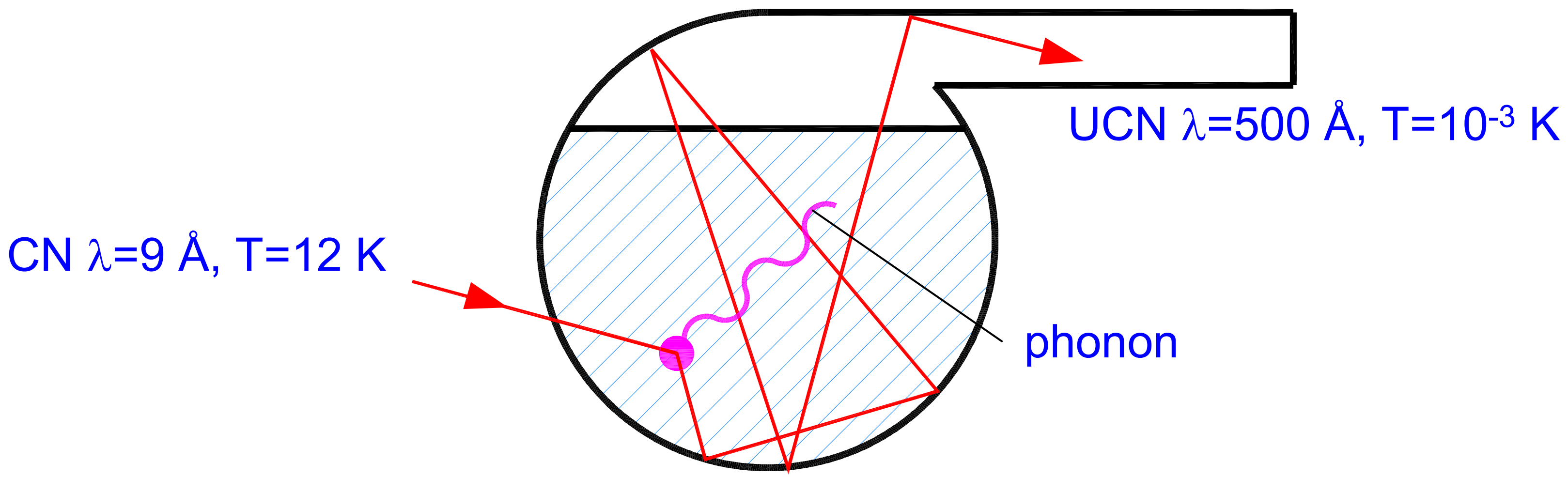
Vertical cross section of WWR-M reactor.
1 – reactor core, 2 – reactor tank, 3 – concrete protection, 4 – chamber above the reactor, 5 – horizontal channel, 6 – thermal column, 7 – vertical channel.



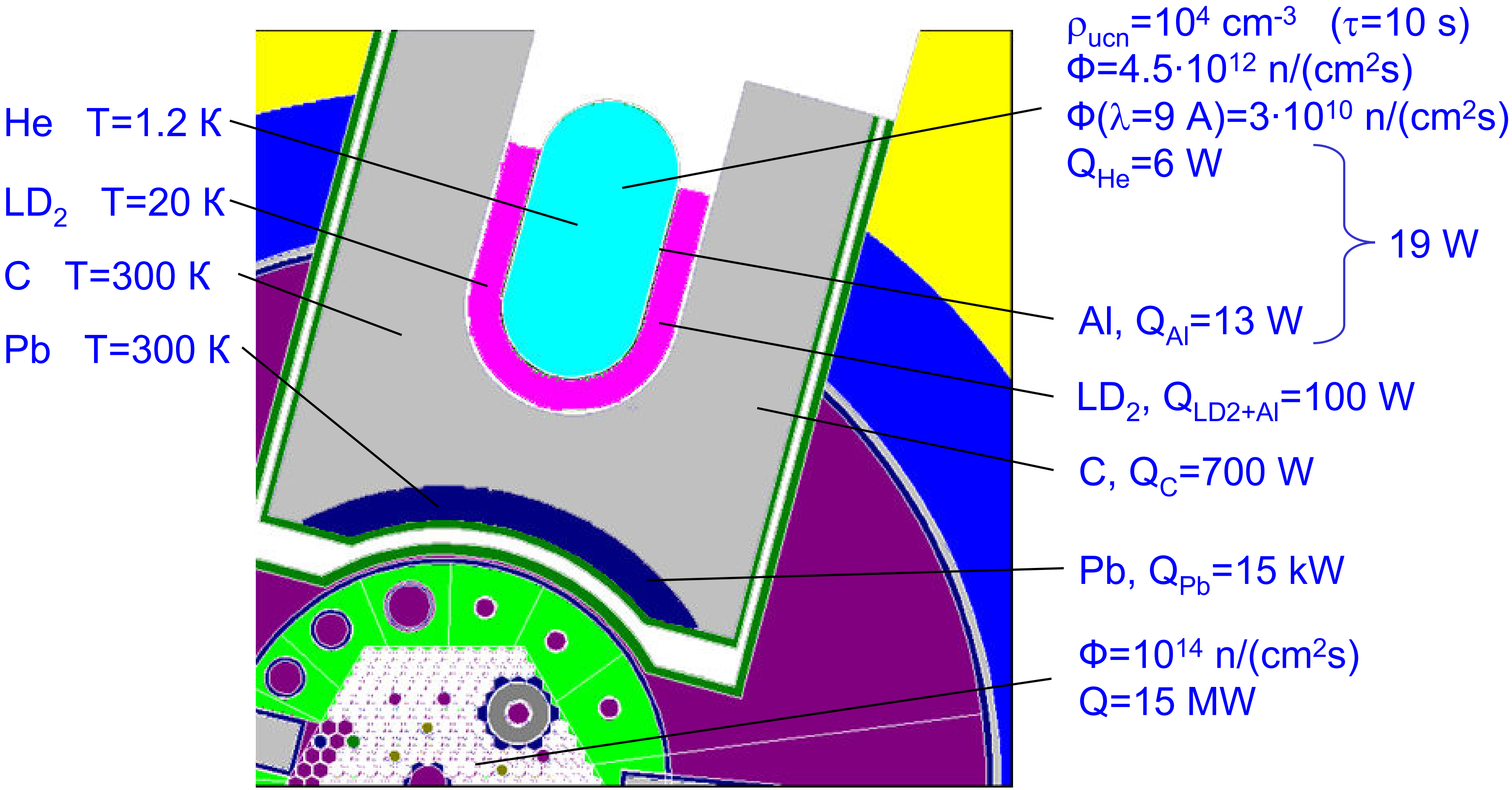
Cross section of WWR-M reactor

Idea

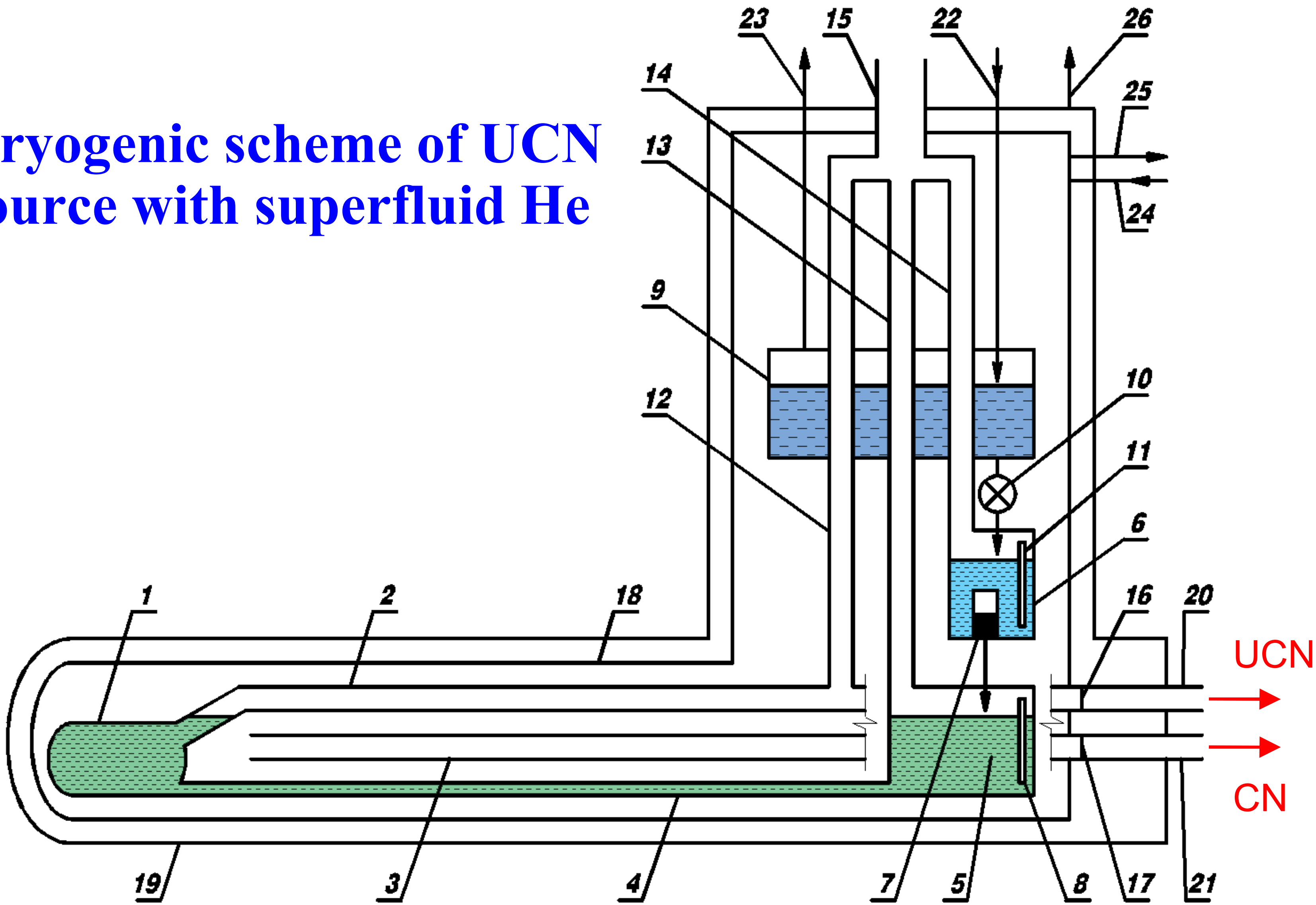
UCNs are generated in helium from cold neutrons of 9Å wavelength (12 K energy). It is correspond with phonon energy: cold neutron enegizes phonon, practically stops and becomes an ultracold one. UCN can “lives” in superfluid helium for tens or hundreds of seconds until a phonon be captured.
Cold neutrons (9Å) penetrate through the wall of a trap, but ultracold neutrons (500Å) are reflected, that is why UCN can be accumulated up to the density defined by the time of storage in the trap filled with superfluid helium.



MCNP neutron flux calculation results and heat generation in thermal column of WWR-M reactor at 15 MW

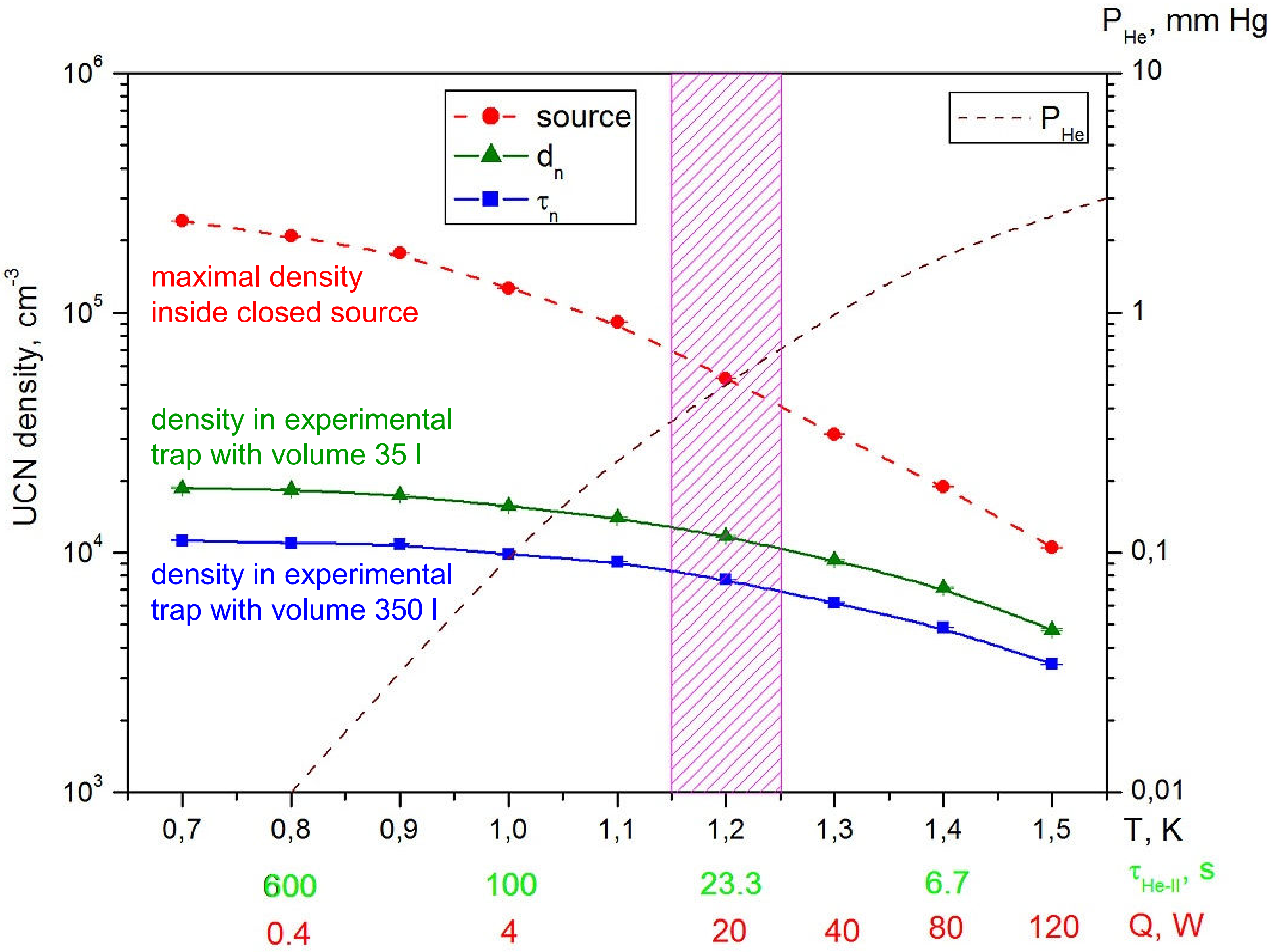


Cryogenic scheme of UCN source with superfluid He



1 – He II cell; 2 – UCN neutron guide, 3 – CN neutron guide, 4 – He II supply pipe, 5 – lower bath @ 1.2 K, 6 – intermediate bath @ 1.2 K, 7 – ^{3}He filter, 8 – level sensor, 9 – upper bath @ 4.2 K, 10 – helium supply valve, 11 – level sensor, 12 – vacuum pipe (gravitation trap for UCN), 13 – vacuum pipe for lower bath, 14 – vacuum pipe for intermediate bath, 15 – main vacuum manifold, 16 – UCN neutron guide membrane, 17 – CN neutron guide membrane, 18 – thermal shield @ 20 K, 19 – vacuum jacket, 20 – UCN outer neutron guide, 21 – CN outer neutron guide, 22 –helium supply at temperature of 4.2 K, 23 – pipe for helium vapour removal, 24 – helium supply for thermal shield 18, 25 – helium removal from thermal shield 18, 26 – pumping of vacuum jacket.

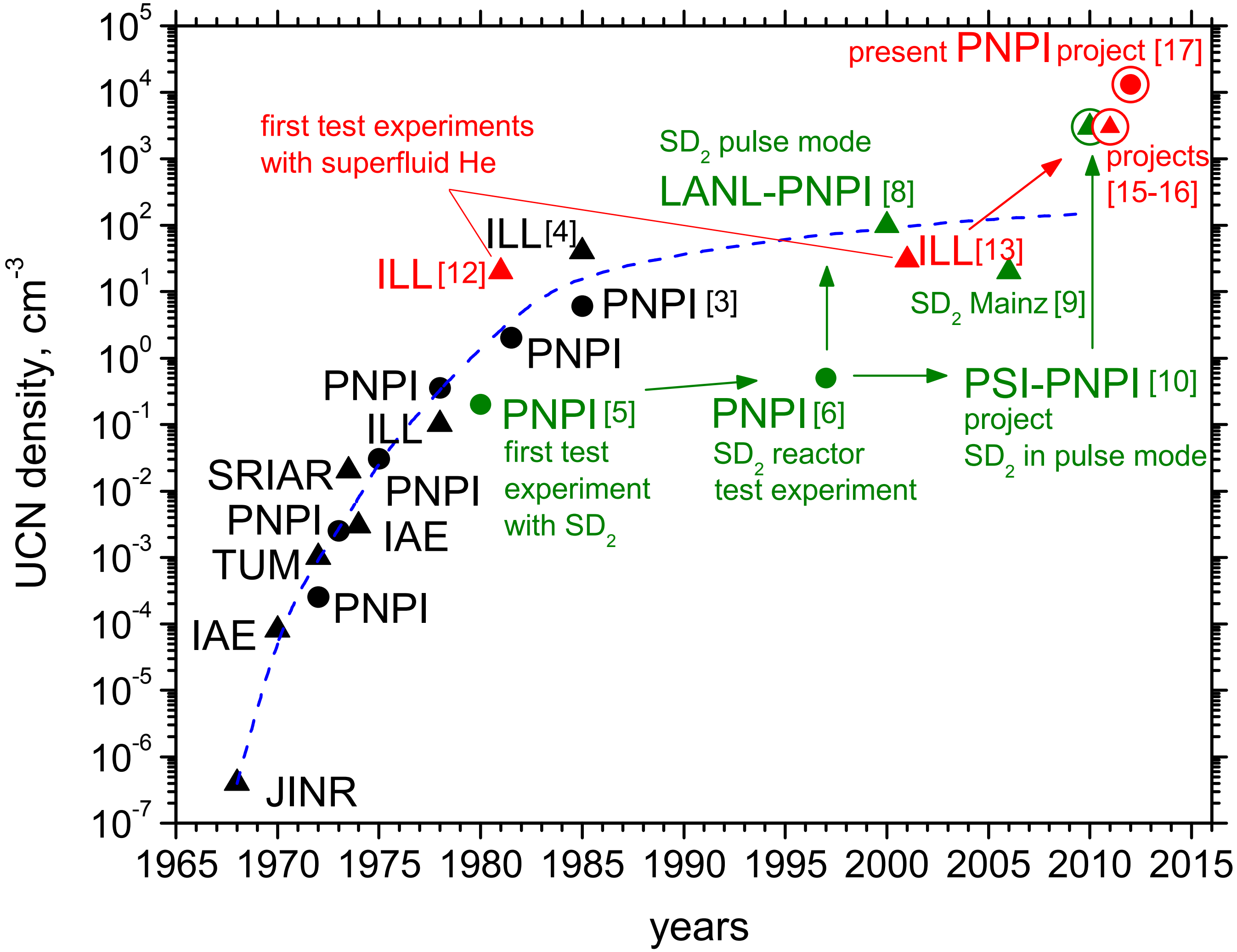
UCN density



P_{He}, mm Hg
10^6
10^5
10^4
10^3
10
1
0,1
0,01
UCN density, cm^{-3}
source
d_n
τ_n
P_{He}
maximal density
inside closed source
density in experimental
trap with volume 35 l
density in experimental
trap with volume 350 l
0,7
0,8
0,9
1,0
1,1
1,2
1,3
1,4
1,5
T, K
600
100
23.3
6.7
τ_{He-II}, s
0.4
4
20
40
80
120
Q, W

Comparison of expected UCN density with UCN density of present sources

	UCN density (cm^{-3})	Gain factor
Present project	10^4	
ILL (turbine source)	10	10^3



Cryogenic and vacuum equipment

At present there are some equipment for UCN source at WWR-M reactor :

- Helium refrigerator TCF 50 (3000 W @ 15 K, Linde Kryotechnik AG)
- Helium liquefier L280 (80 l/h, Linde Kryotechnik AG)
- Vacuum pump station (BOC Edwards)

Helium refrigerator

Gas management systems

Helium liquefier

Helium tank

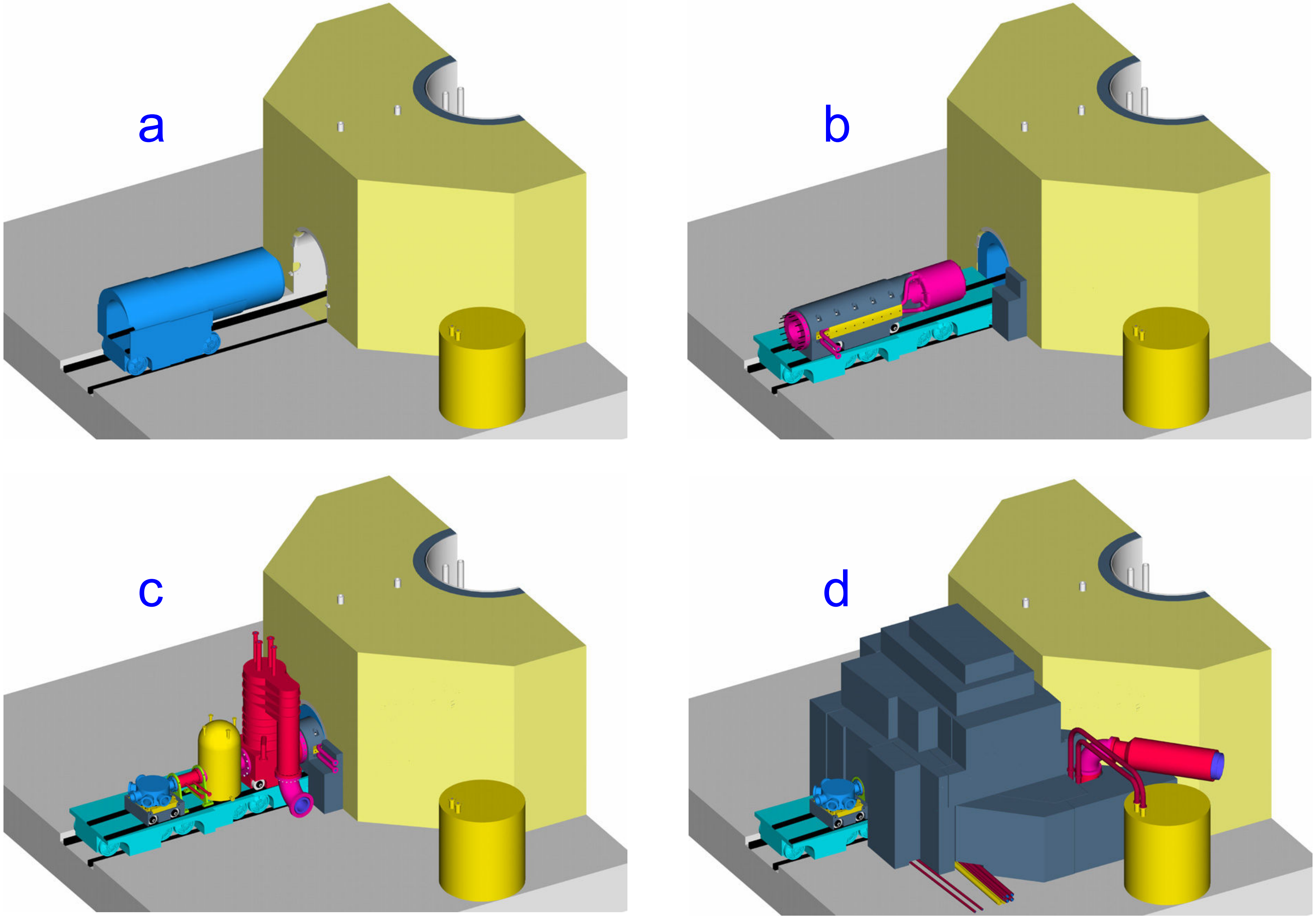
Vacuum equipment

General view

General view

General design

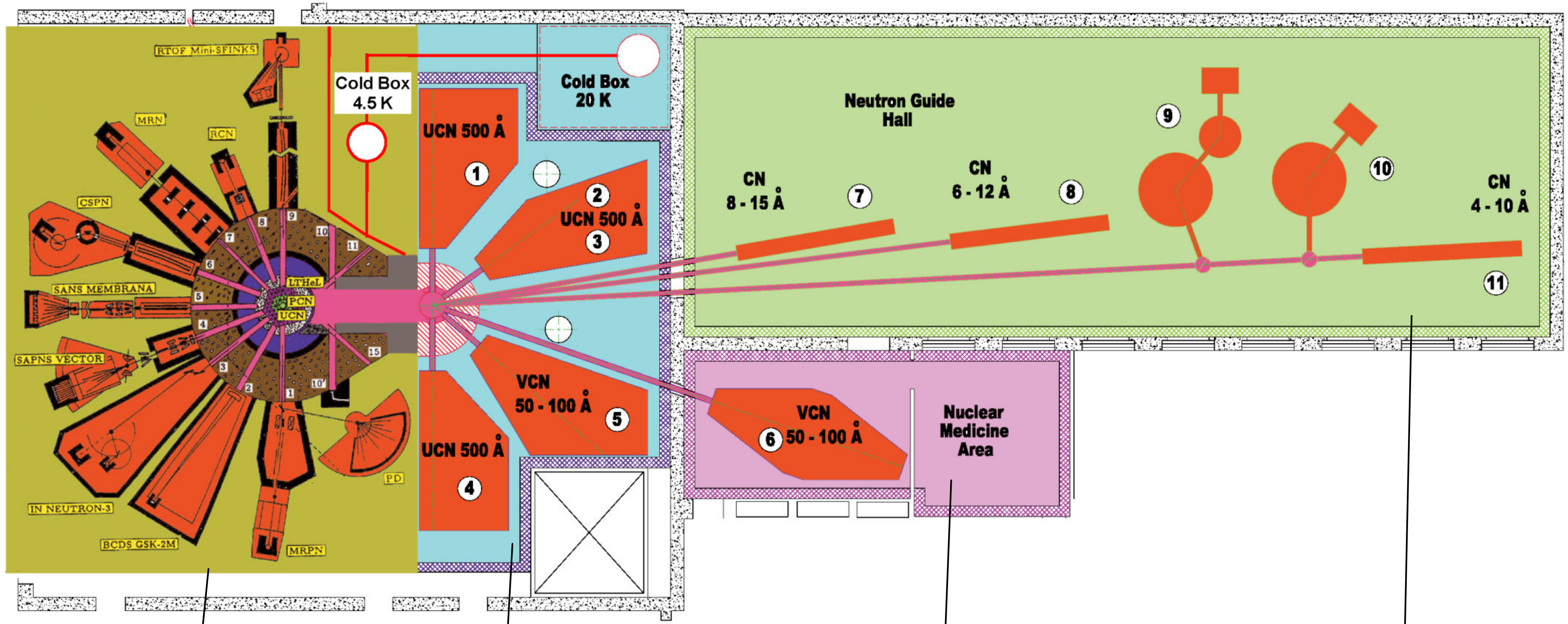
Installation of UCN source on WWR-M reactor



a – Pb shielding mounting; b – graphite block mounting; c – mounting of cryostat, UCN superconductive polarizer and UCN switchboard; d – mounting of biological shielding.

New facilities of WWR-M reactor

Ultracold and cold neutron source at WWR-M reactor with neutron guide halls



hall of thermal neutrons

hall of ultracold neutrons

hall of very cold neutrons

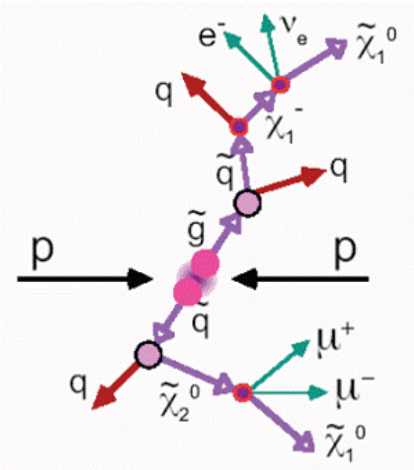
hall of cold neutrons

Program of fundamental research with ultracold neutrons

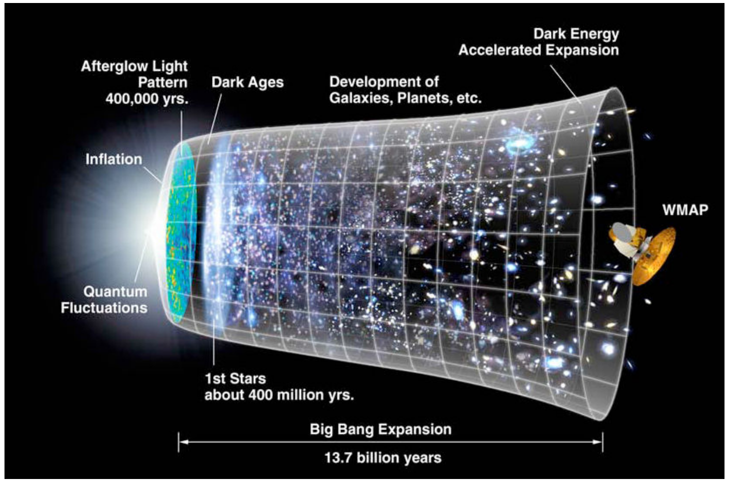
1. Neutron EDM and problem of CP-violation
2. Precise measurements of neutron β-decay and search for deviations from Standard Model
3. Search for neutron-antineutron oscillations

Fundamental interaction of elementary particles. Methods of research

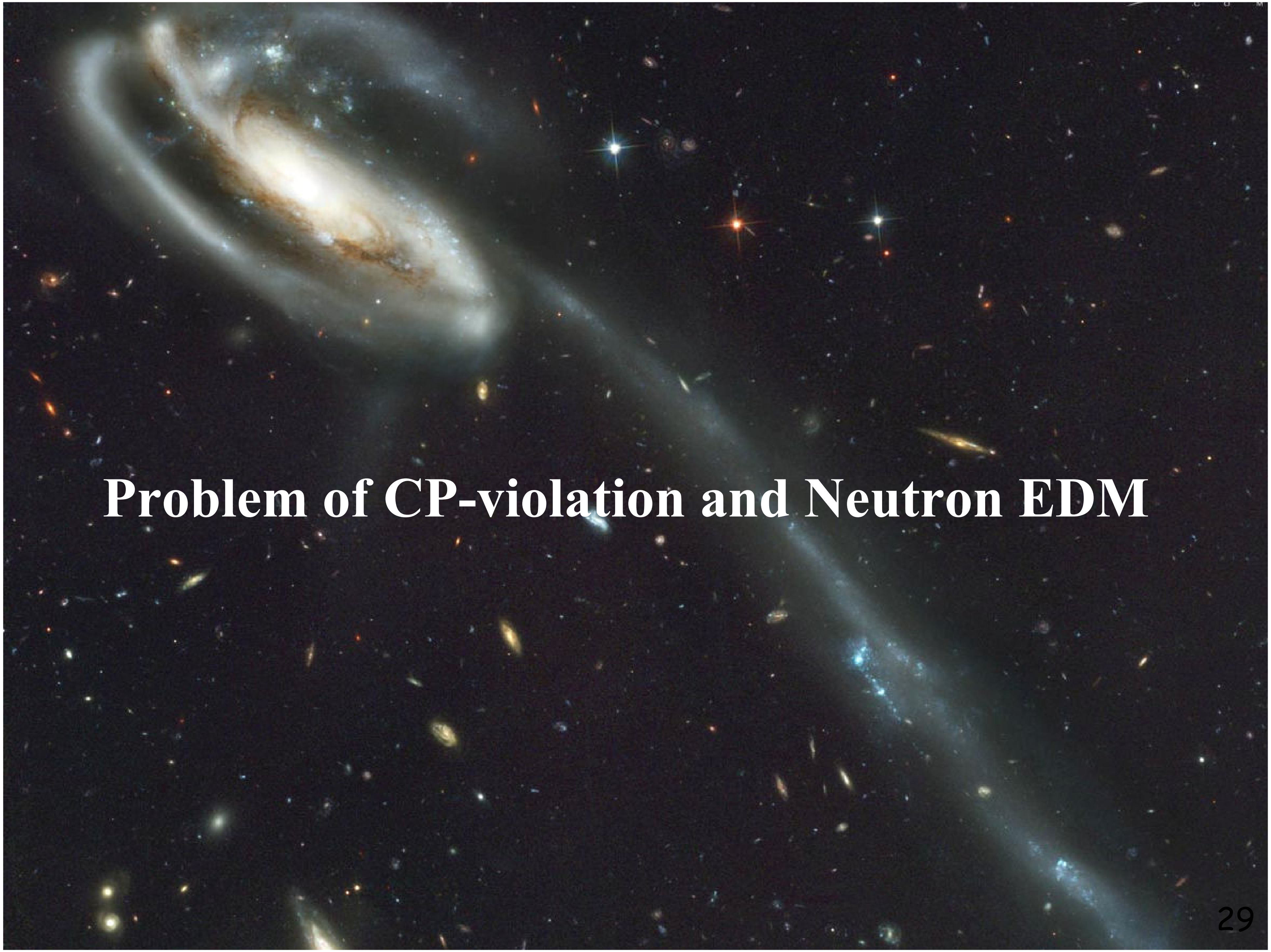
1. High-energy physics E<10^{13} eV.



2. Cosmology, astrophysics, cosmic rays, neutrino physics.

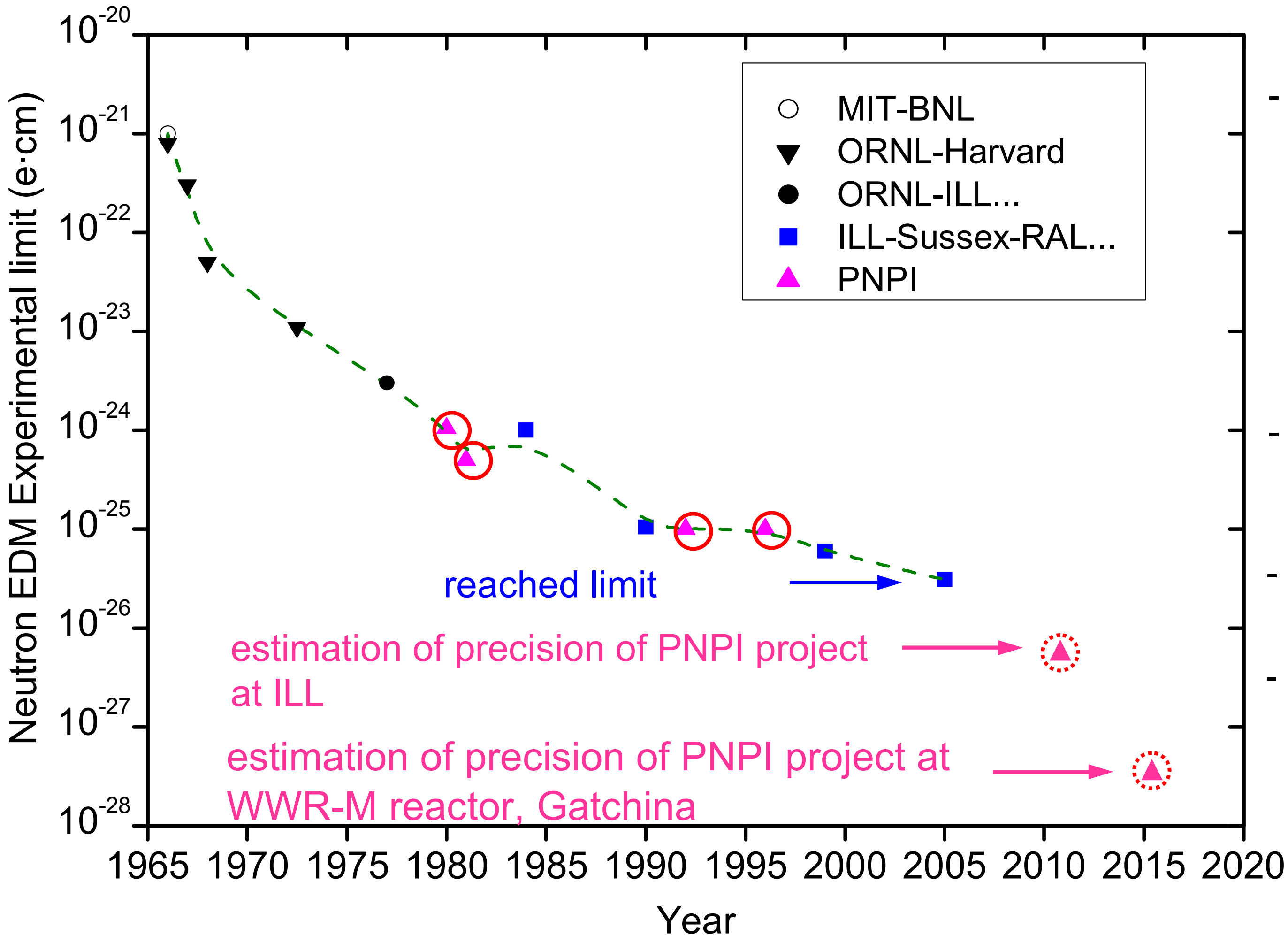


3. Precise investigations, search of small deviations to Standard law of physics. One of a way is the investigation with UCN of 10^{-7} eV



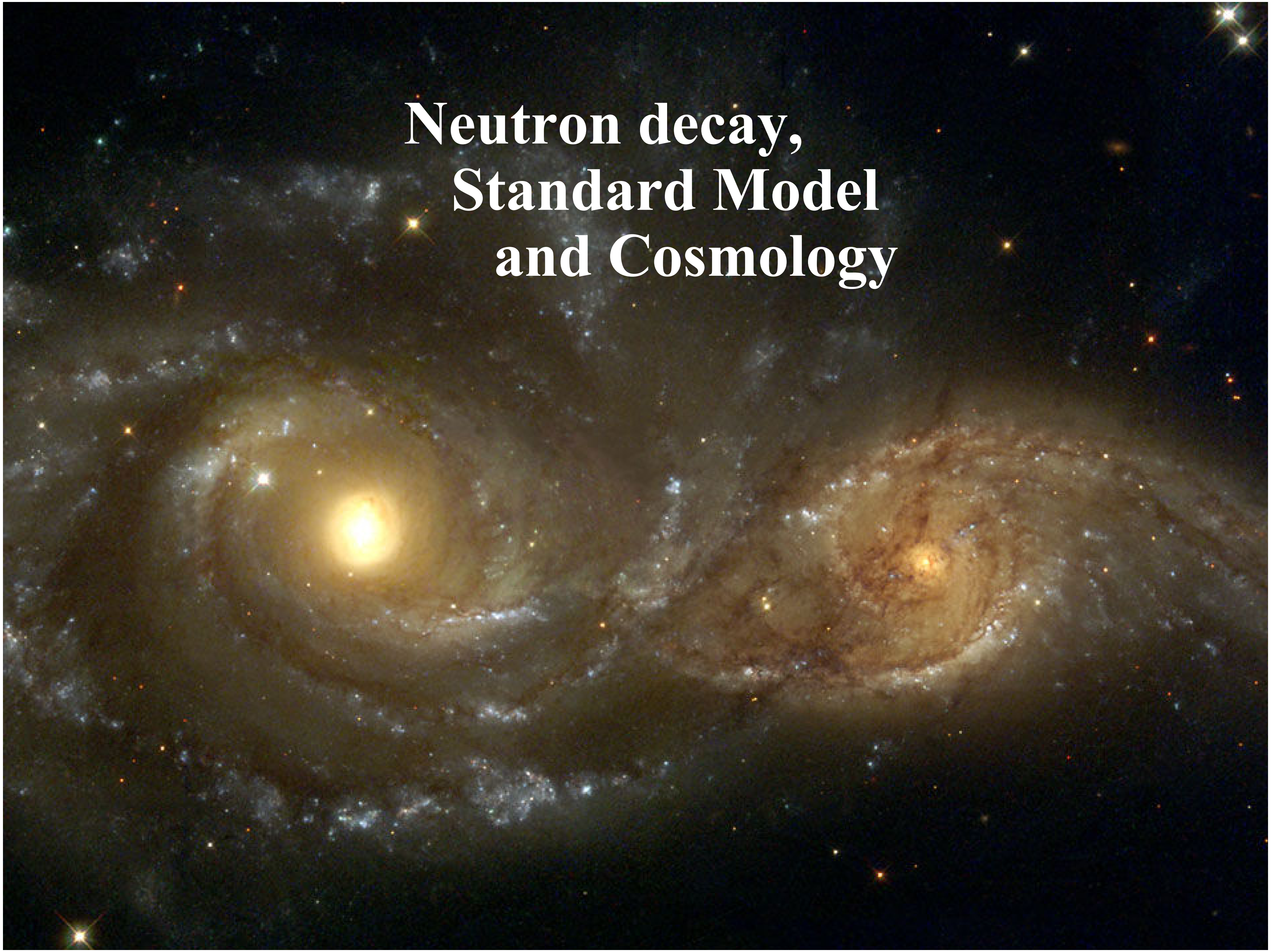
Problem of CP-violation and Neutron EDM

Neutron EDM and problem of CP-violation



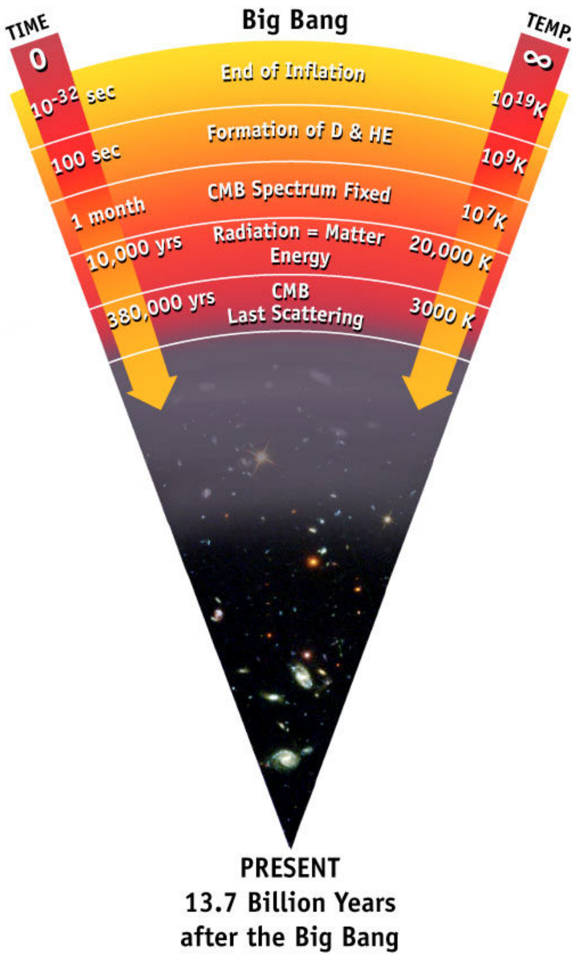
Theoretical Prediction:

- Electromagnetic
- Weinberg Multi-Higgs
- Minimal SUSY Cosmology
- Left-Right Symm.


Neutron decay,
Standard Model
and Cosmology

Neutron decay and cosmology

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



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

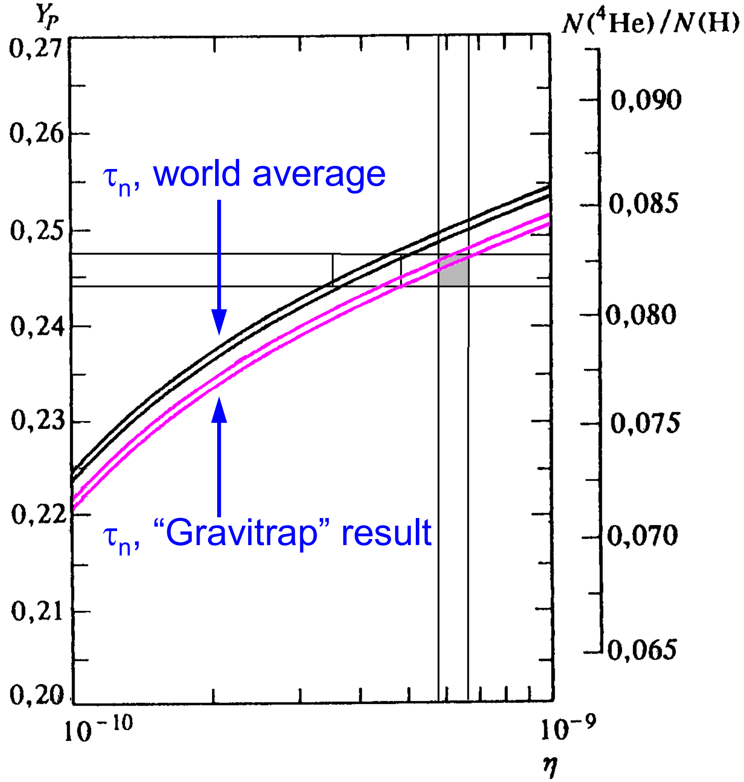
$$\Gamma = (7/60)\pi(1 + 3g_A^2)G_F^2T^5$$

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

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

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

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



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

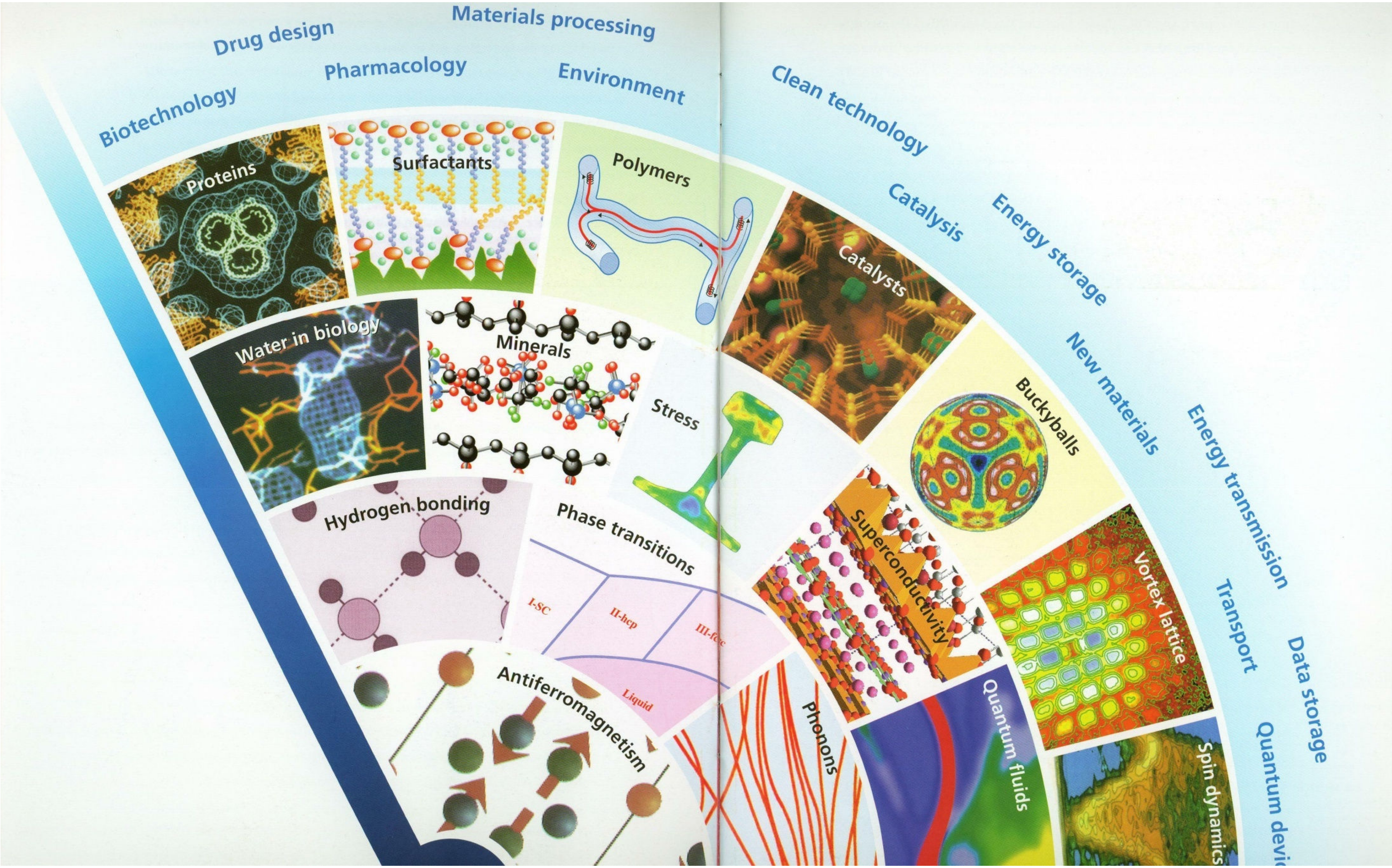
$$\Delta\tau_n = 1\% \quad \rightarrow \quad \Delta Y = 0.75\% \ (\pm 0.61\%)$$

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

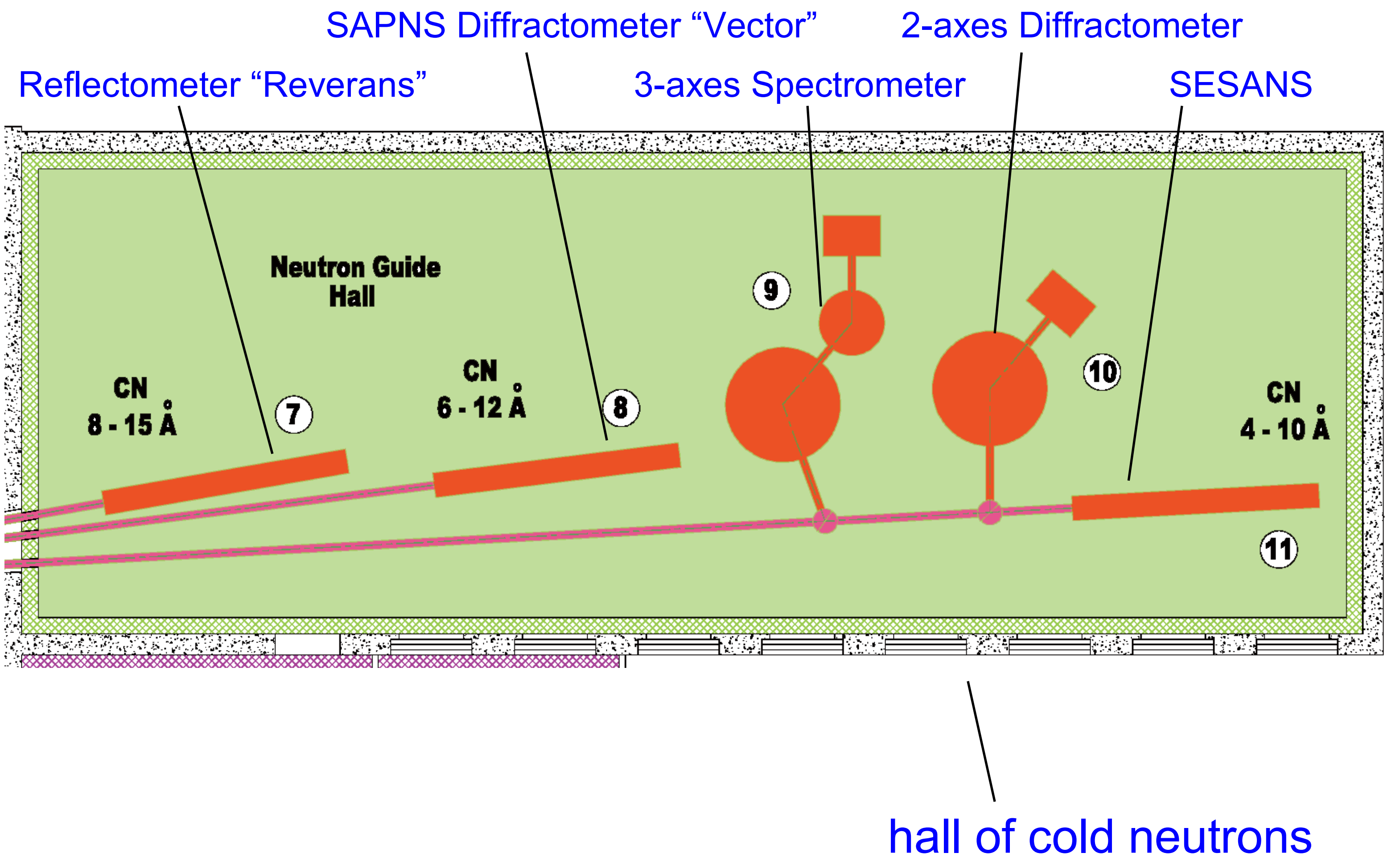
New τ_n=(878.5±0.8) s confirms n_b/n_γ from CMB.

Studies of the structure and dynamics of nanostructures by means of cold and very cold neutrons

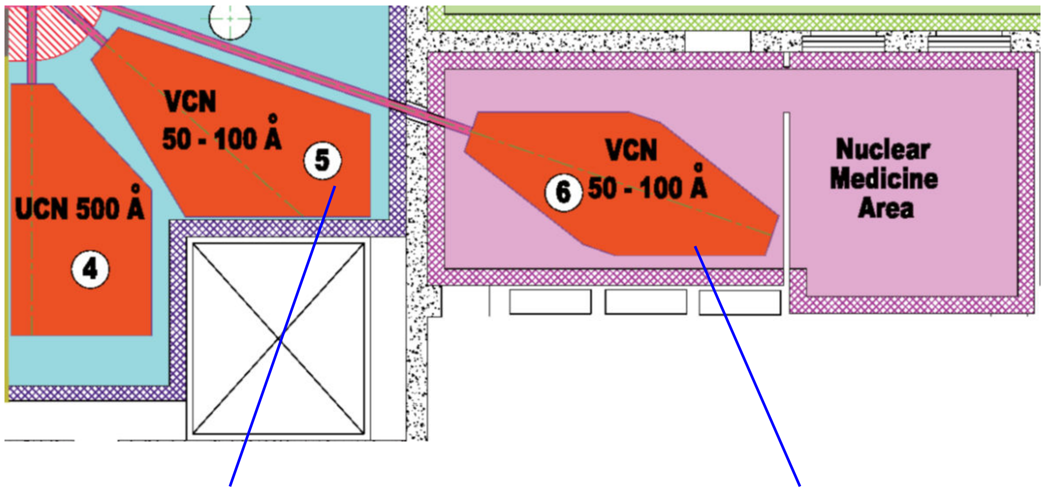
Studies of the structure and dynamics of solid state



Studies of nanostructures by means of cold neutrons

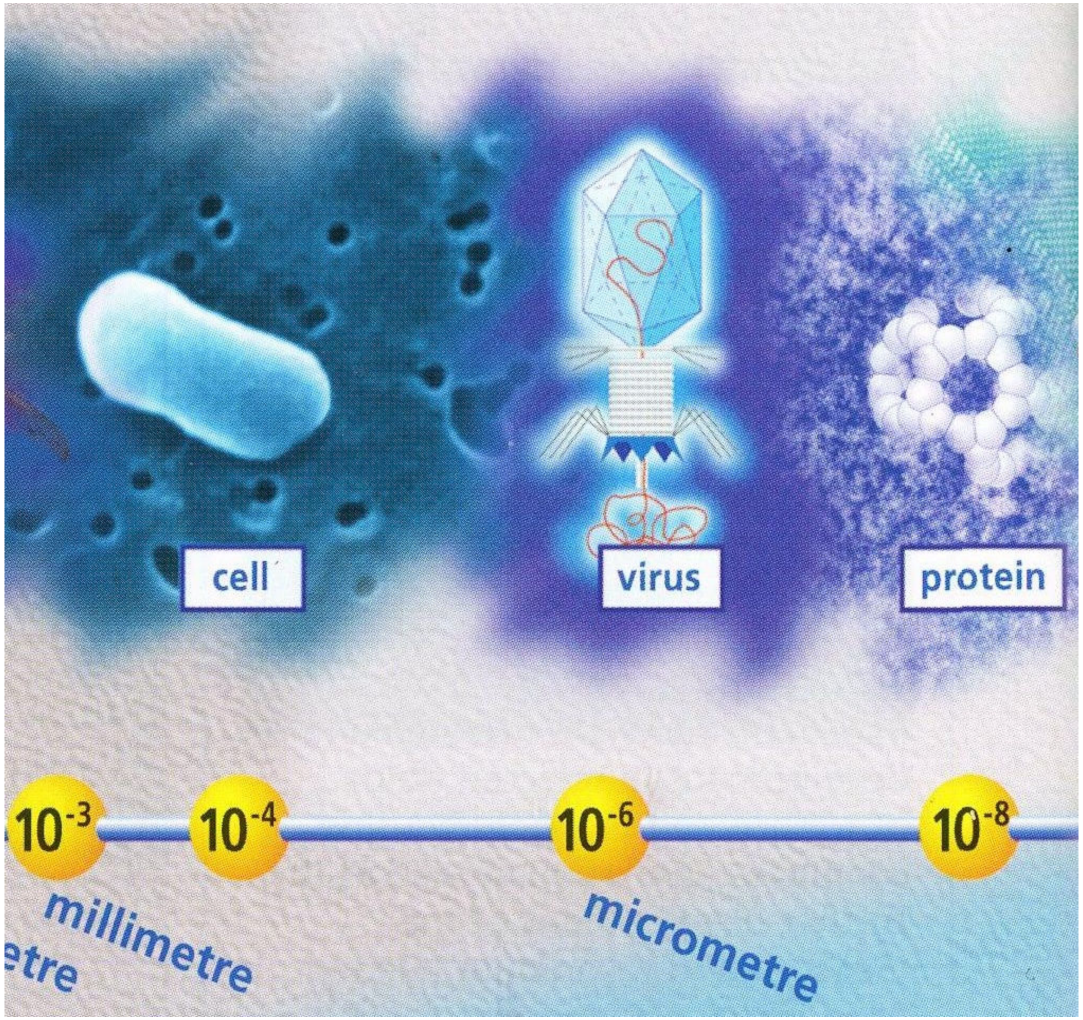


Studies of nanostructures by means of very cold neutrons 30 Å - 100 Å



Diffractometer with very cold neutrons

Spin-echo spectrometer with very cold neutrons



Biological micro-molecules and structures:

DNA,

Proteins,

Ferments,

Cell membranes.

Current state of UCN source project at PNPI

✓ **1. Cryogenic and vacuum equipment**

✓ **2. Design**

? **3. Budget**

Movie
“How it will be”