PNPI–ILL–PTI collaboration on nEDM

at the ILL reactor in Grenoble

and

at the WWR–M reactor in Gatchina

(second part)

Present status

and

Future Prospects

of the

"Gatchina double chamber EDM spectrometer"

at the

Gatchina UCN Supersource at PNPI's reactor WWM-R

Serebrov A.P.

for Oak Ridge nEDM workshop 13 October 2012

Presented by Peter Geltenbort

Project

for an

ultracold and cold neutron source with superfluid helium

at the WWR-M reactor in PNPI, Gatchina

Sensitivity

$$s_d = \frac{\hbar}{2aET\sqrt{N}}$$

~ 0.65

20 kV/cm

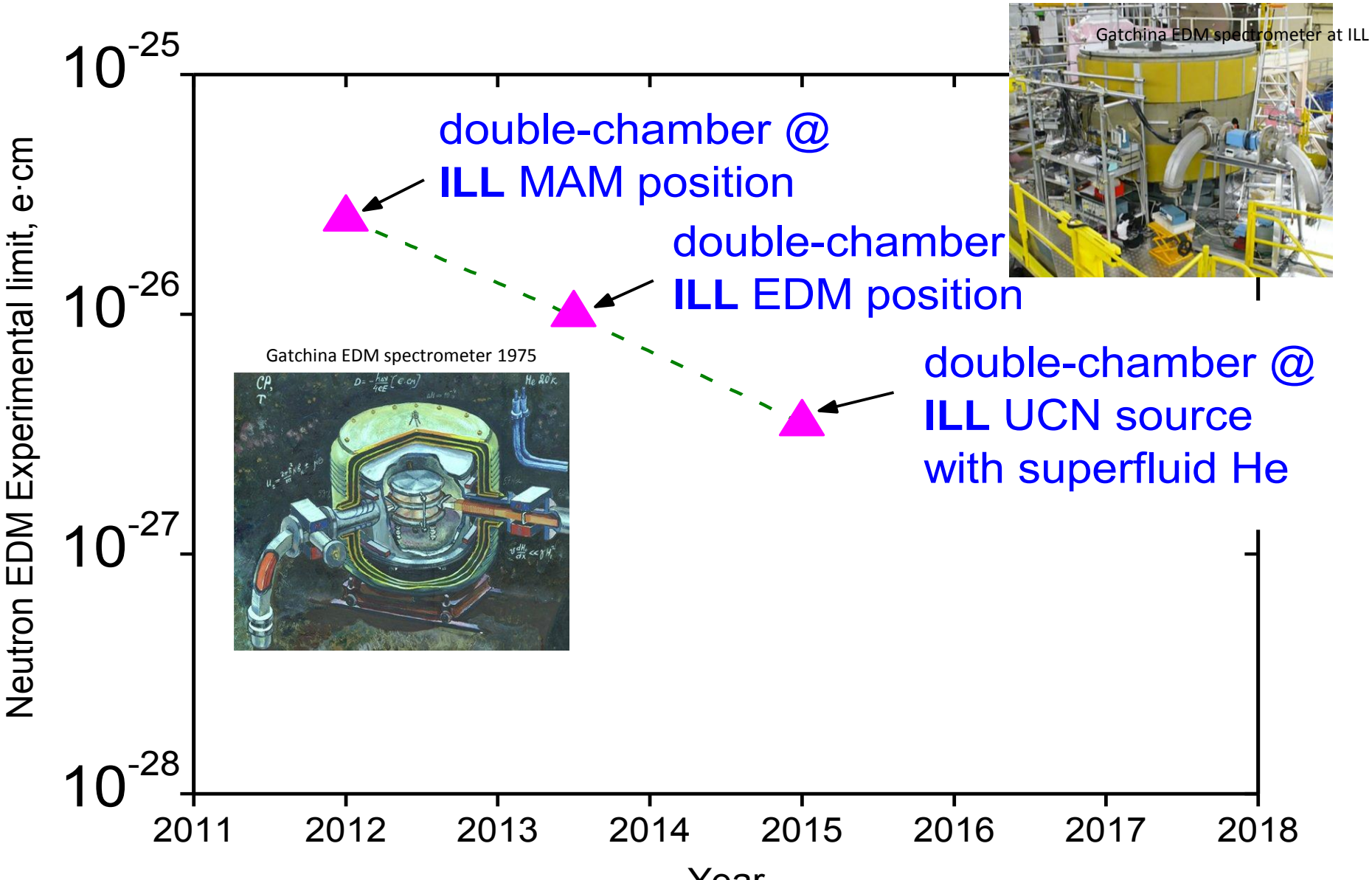
65 s

Increased at each position
From ~4 to ~200 UCN/cc at the entrance

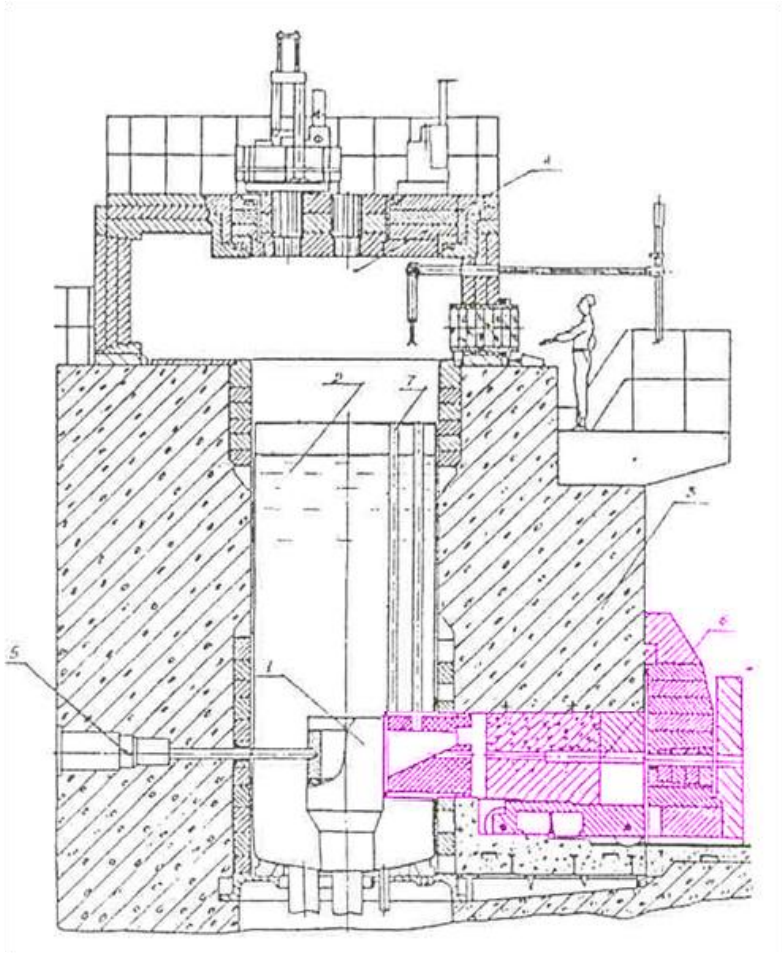
Courtesy of P. Harris (adapted to PNPI's existing nEDM spectrometer at the ILL)

PNPI-ILL-PTI collaboration

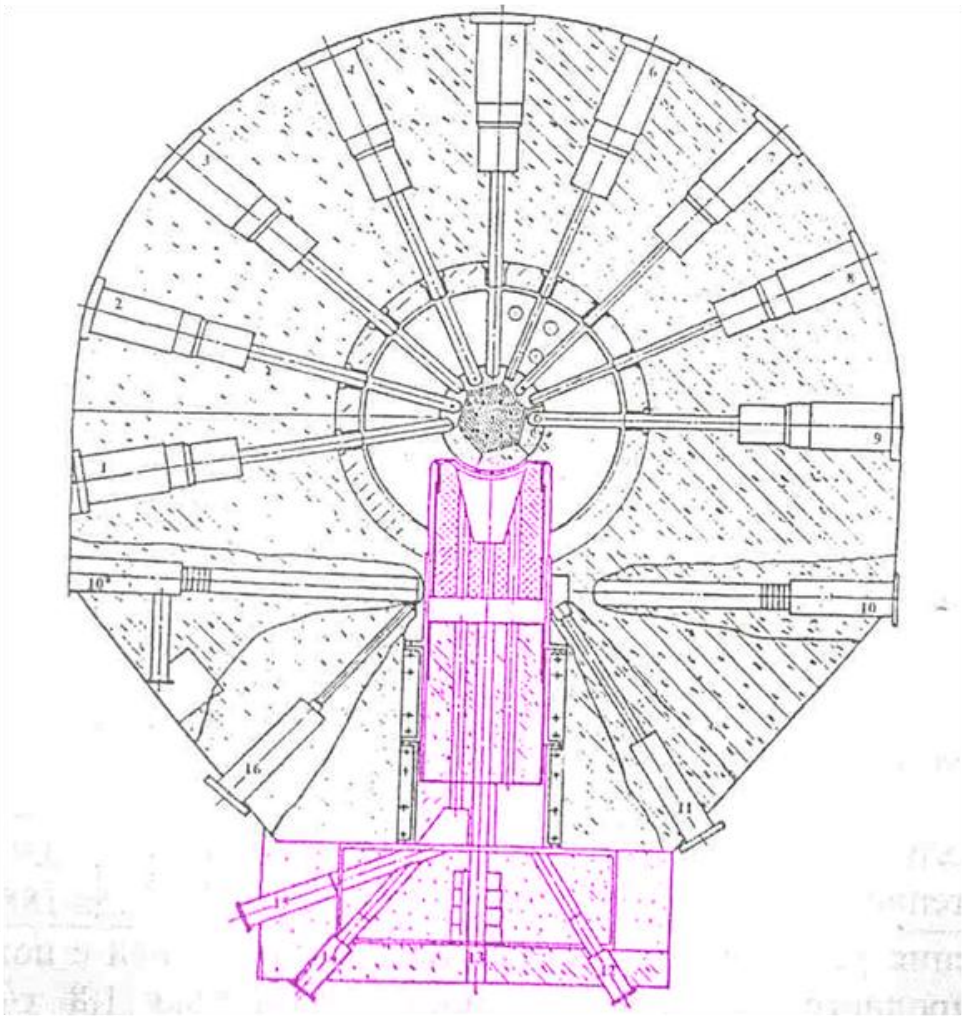
Prospects to increase sensitivity of EDM measurements at the ILL



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 energizes 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.

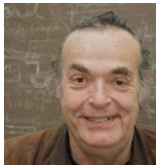
Neutron scattering in liquid helium

I.Ya. Pomeranchuk "Selected works"

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

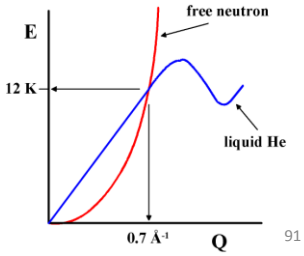
The scattering of slow neutron in He-II is considered. It is shown that the scattering is a negligible small at the temperature below than temperature of critical point.

* 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



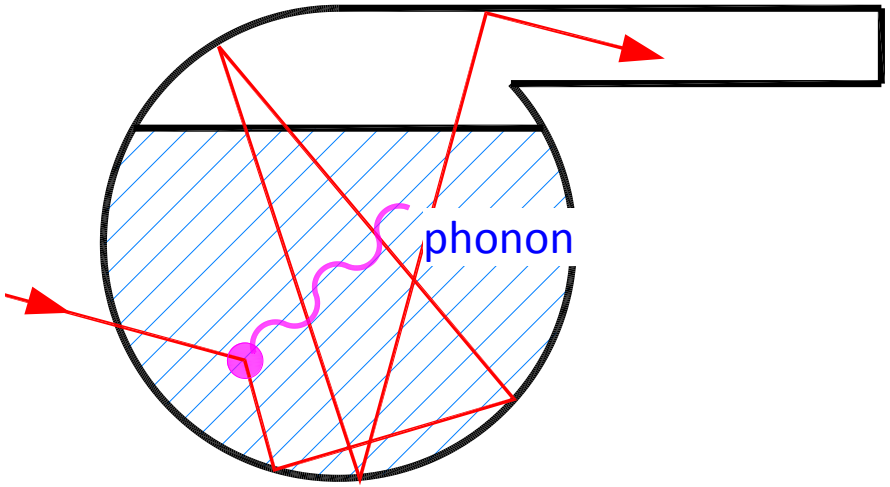
E_{beg}=12 K → E_{UCN}≈10^{-3} K

↓

λ=9 Å

91

UCN λ=500 Å, T=10^{-3} K



CN λ=9 Å, T=12 K

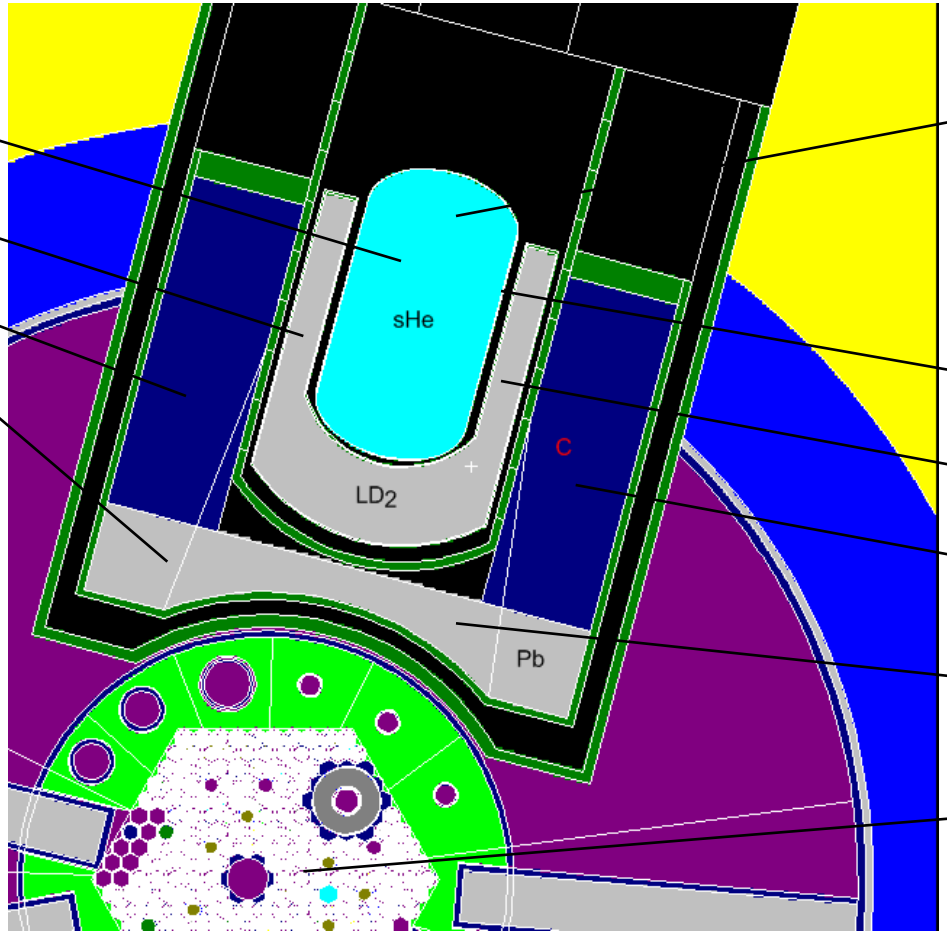
MCNP neutron flux calculation results and heat generation in thermal column of WWR-M reactor at 15 MW

He T=1.2 K

LD_2 T=20 K

C T=300 K

Pb T=300 K



$\rho_{ucn}=10^4$ cm^{-3} (τ=10 s)

$\Phi=4.5\cdot10^{12}$ n/(cm^{2}s)

$\Phi(\lambda=9\ A)=3\cdot10^{10}$ n/(cm^{2}sA)

Q_{He}=6 W

19 W

Al, Q_{Al}=13 W

LD_2, Q_{LD2+Al}=100 W

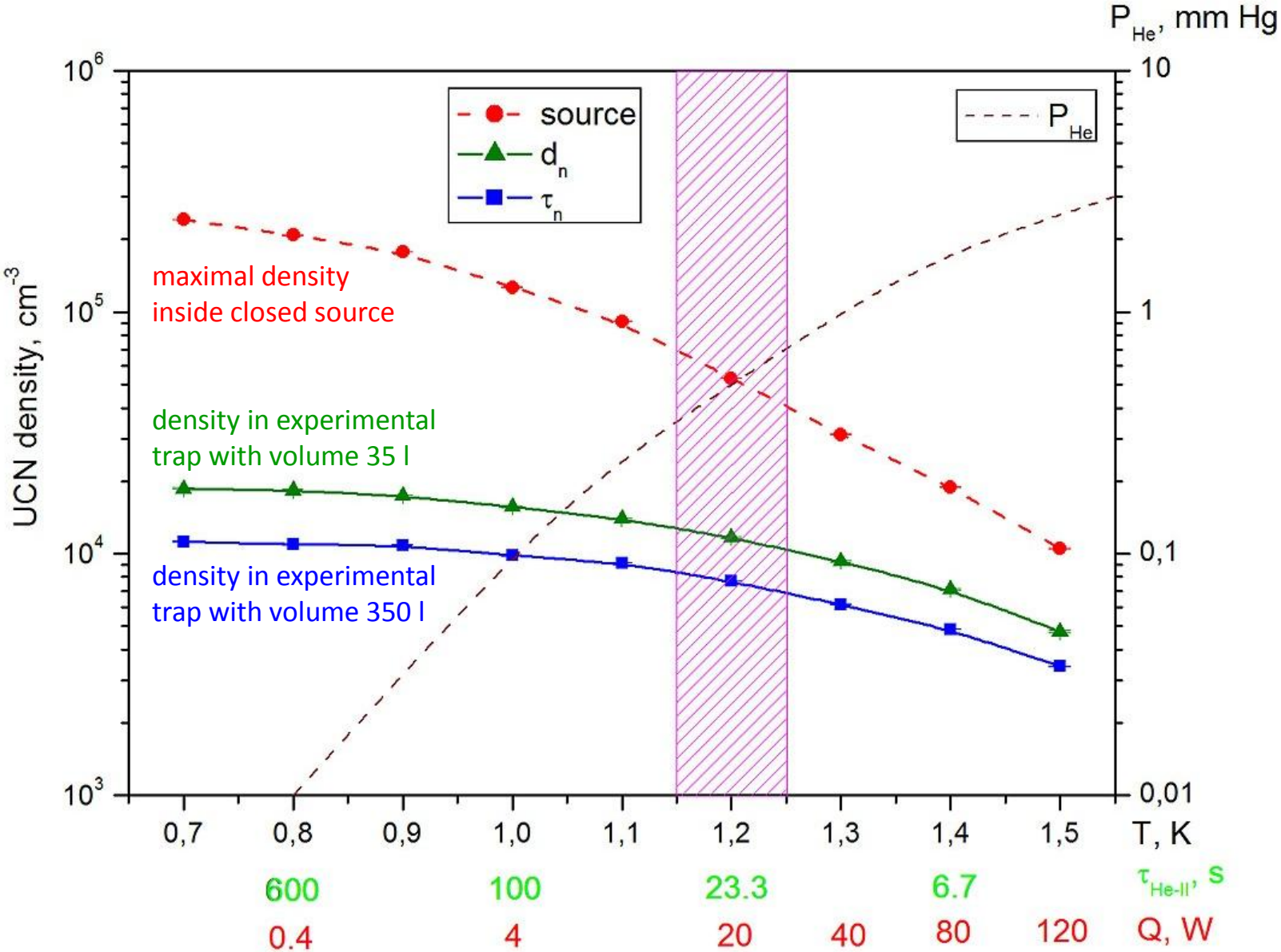
C, Q_C=700 W

Pb, Q_{Pb}=15 кW

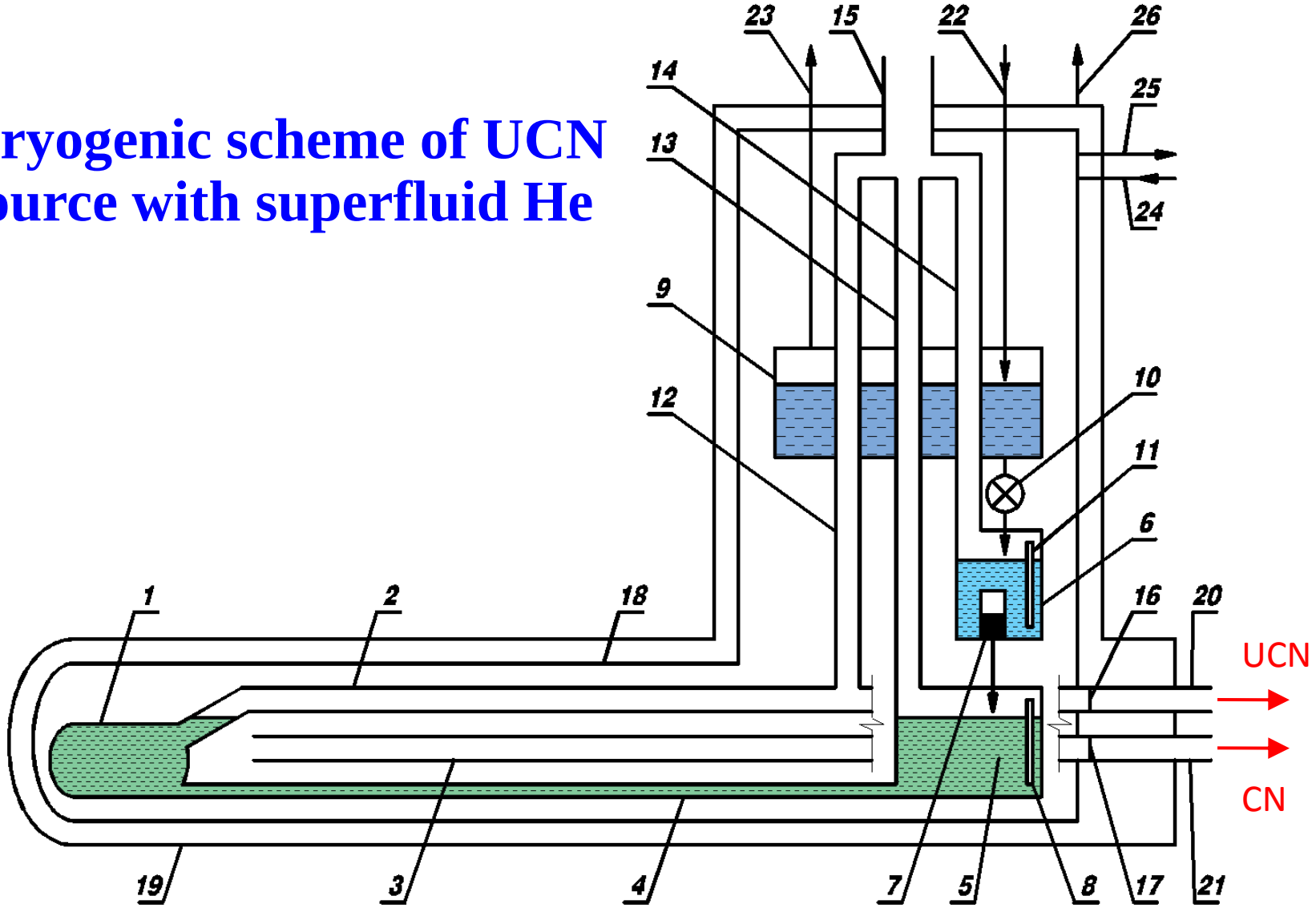
$\Phi=10^{14}$ n/(cm^{2}s)

Q=15 MW

UCN density

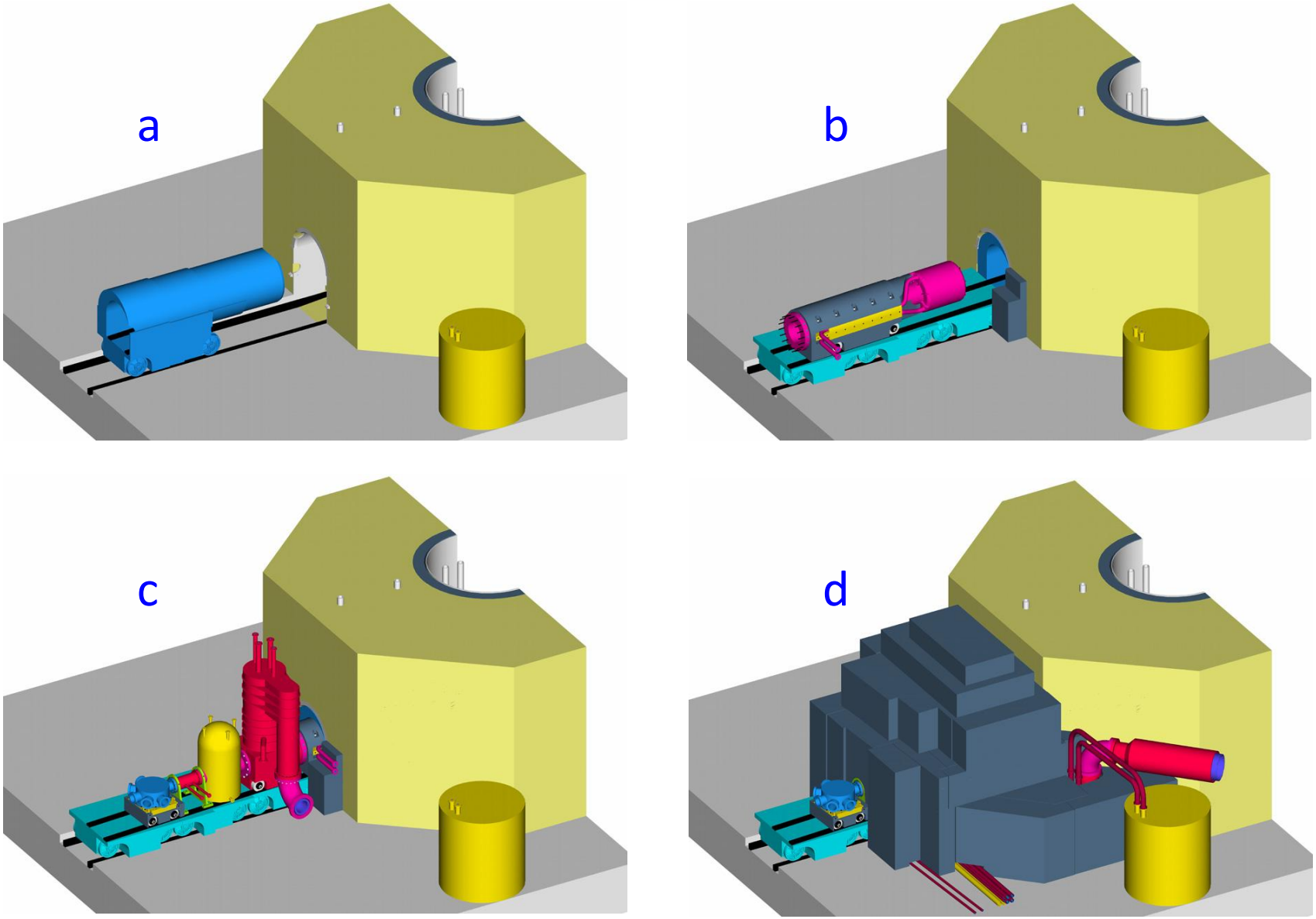

P He, mm Hg
10
1
0,1
0,01
10^6
10^5
10^4
10^3
UCN density, cm^-3
source
d n
τ n
P He
maximal density
inside closed source
density in experimental
trap with volume 35 l
density in experimental
trap with volume 350 l
0,7
0,8
0,9
1,0
1,1
1,2
1,3
1,4
1,5
T, K
600
100
23.3
6.7
τ He-II, s
0.4
4
20
40
80
120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

Cryogenic scheme of UCN source with superfluid He



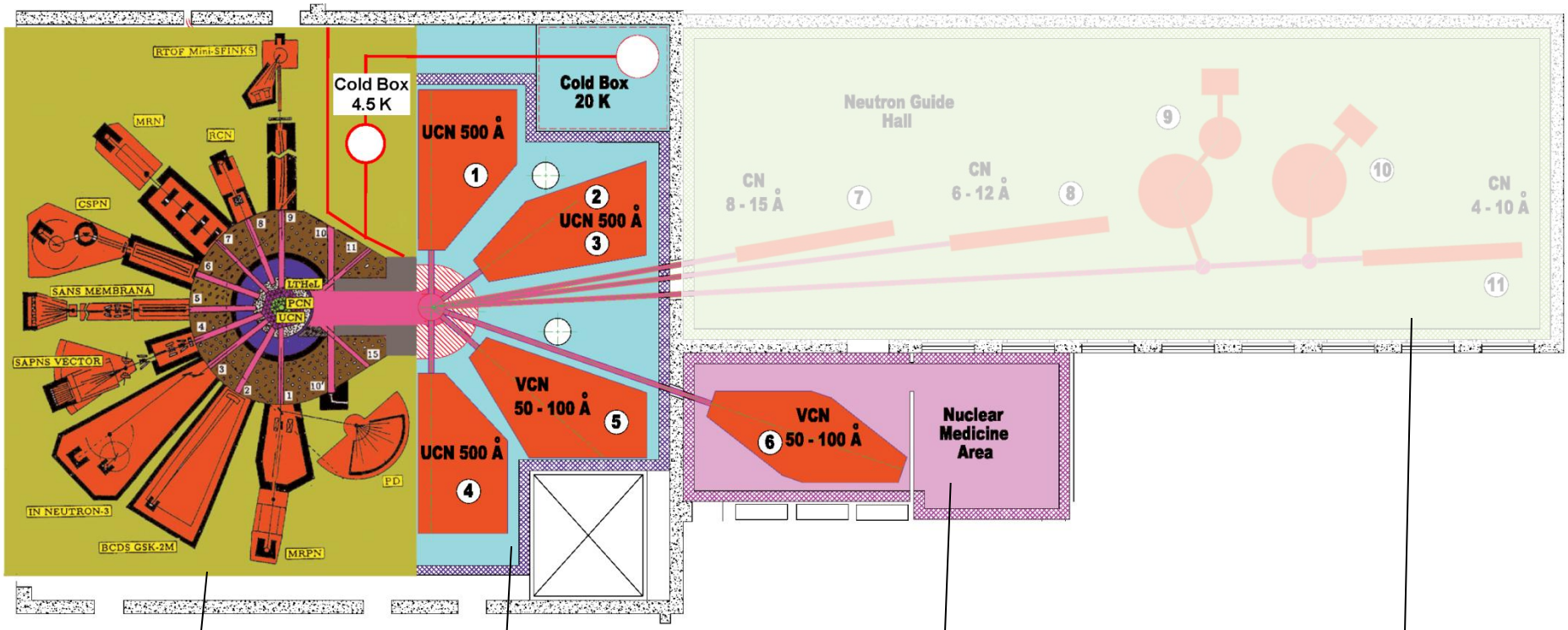
1 – He II cell; 2 – UCN neutron guide, 3 – CN neutron guide, 4 – He II supply pipe, 5 – lower bath @ 1.2 K, 6 – intermediate bath @ 1.2 K, 7 – ^{3}He filter, 8 – level sensor, 9 – upper bath @ 4.2 K, 10 – helium supply valve, 11 – level sensor, 12 – vacuum pipe (gravitation trap for UCN), 13 – vacuum 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.

Scheme of 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.

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

Demounting of old equipments

Demounting of old equipments is finished

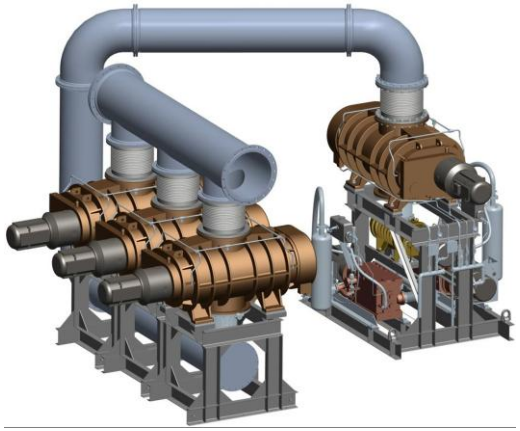
General view with new equipment

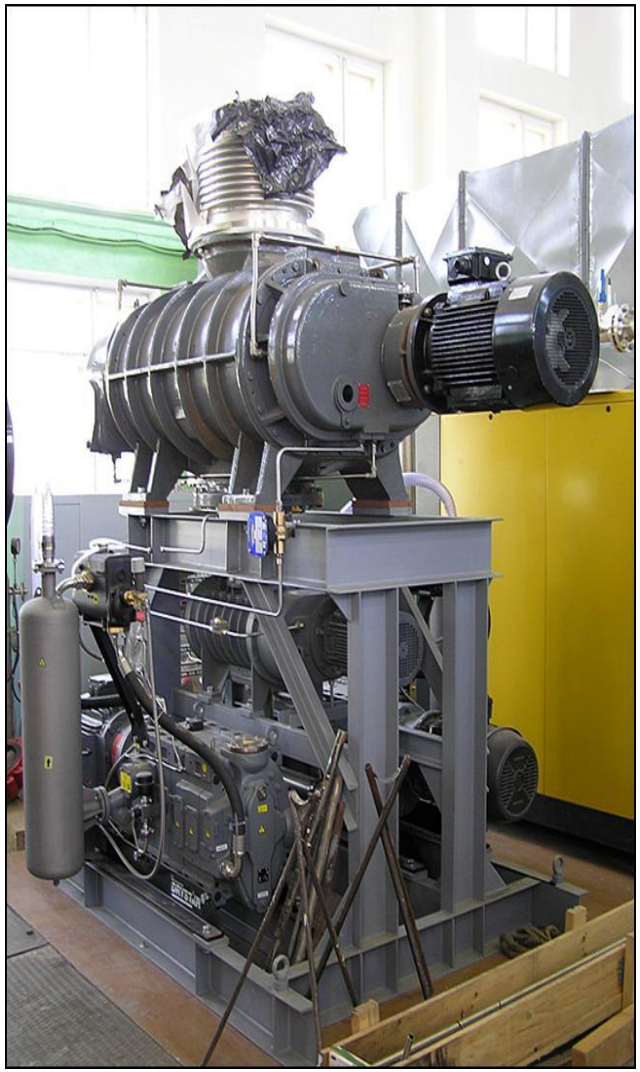
Helium refrigerator
15 K, 3000 Watts

Helium liquefier
50 l/h

Gas system

Pumping system of helium





High pressure compressors

Water cooling system

Gas Storage System

Preparation of non-standard equipment

Vacuum test of full-scale model of UCN source

Cryogenic test of full-scale model of UCN source

Manufacturing of cryostat for superfluid helium at 1.2 K

Manufacturing of cryostat for superfluid helium at 1.2 K

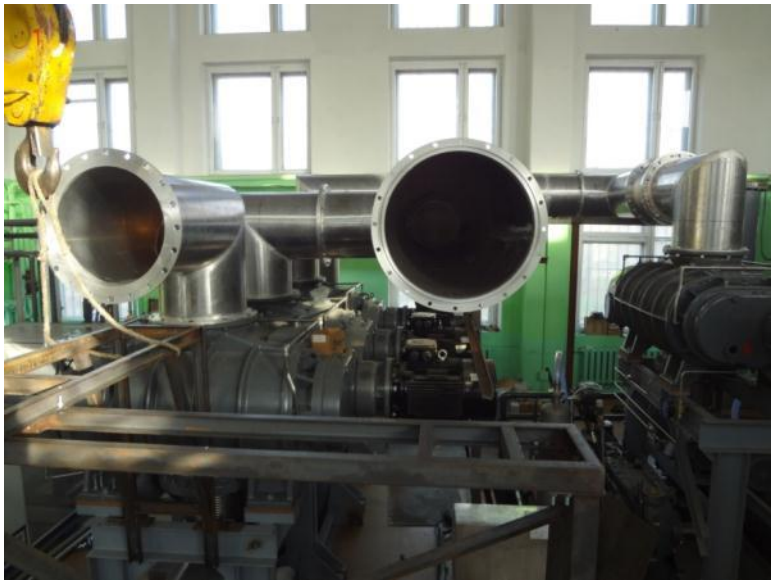
Manufacturing of He heating system

Vacuum test of He heater

Manufacturing of He pumping tubes

Vacuum test of pumping tubes

Installation of He pumping tubes



New facilities at PNPI, UCN source with superfluid He.

2016. New facilities at PNPI, UCN source with superfluid He. **Factor in UCN density is about 60 times with respect to H172B ILL facility.**

$\rho_{ucn\ at\ entrace}$ ~ 12000 ucn/cm^3, δD_{edm} ~ $5 \cdot 10^{-27}$ e·cm/day

Upper limit of sensitivity : $5 \cdot 10^{-28}$ e·cm/100 day

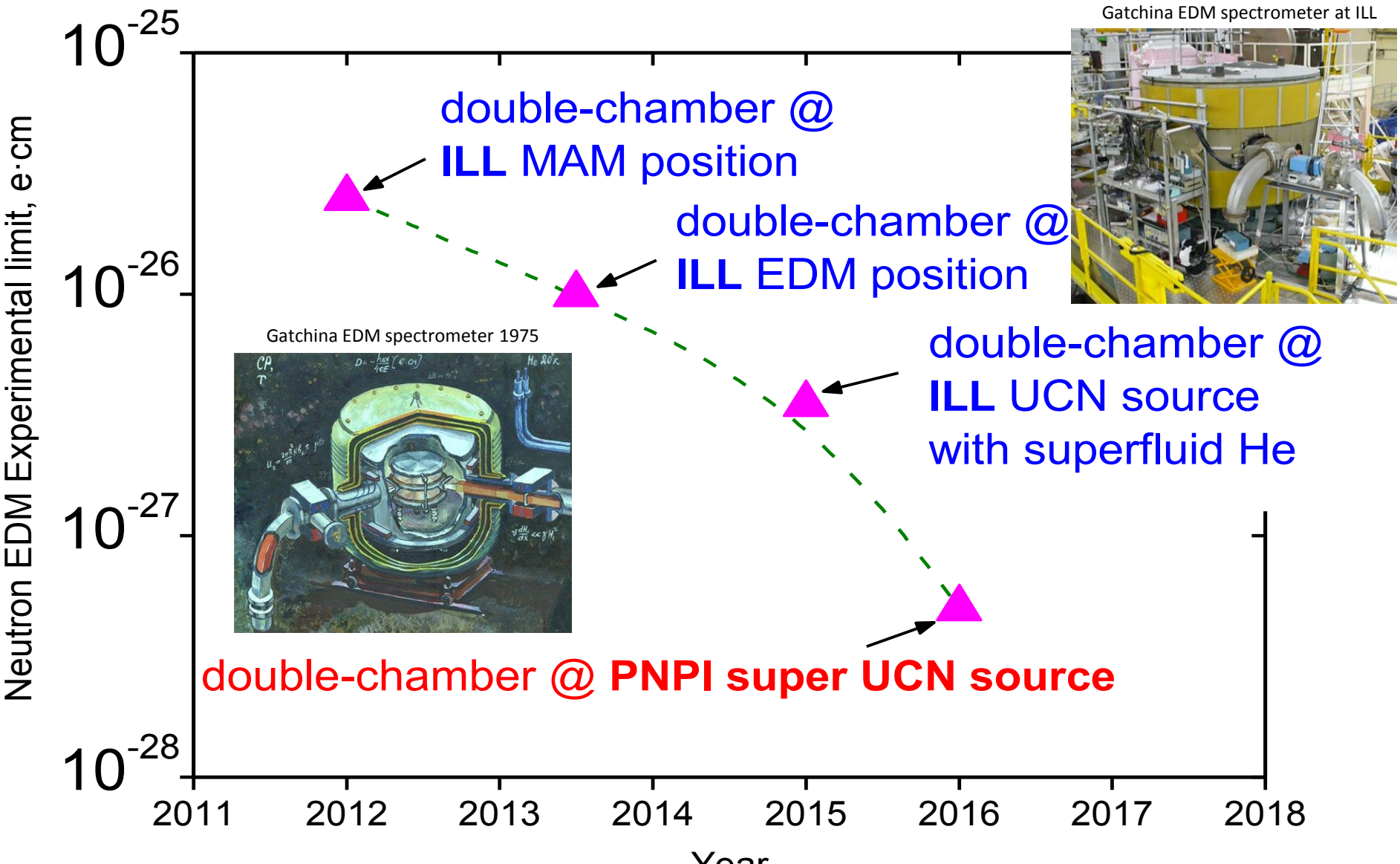
2017 -2018. New facilities at PNPI, UCN source with superfluid He. Multichamber EDM spectrometer.

$\rho_{ucn\ at\ entrace}$ ~ 12000 ucn/cm^3, δD_{edm} ~ $3 \cdot 10^{-27}$ e·cm/day

Upper limit of sensitivity : $3 \cdot 10^{-28}$ e·cm/100 day

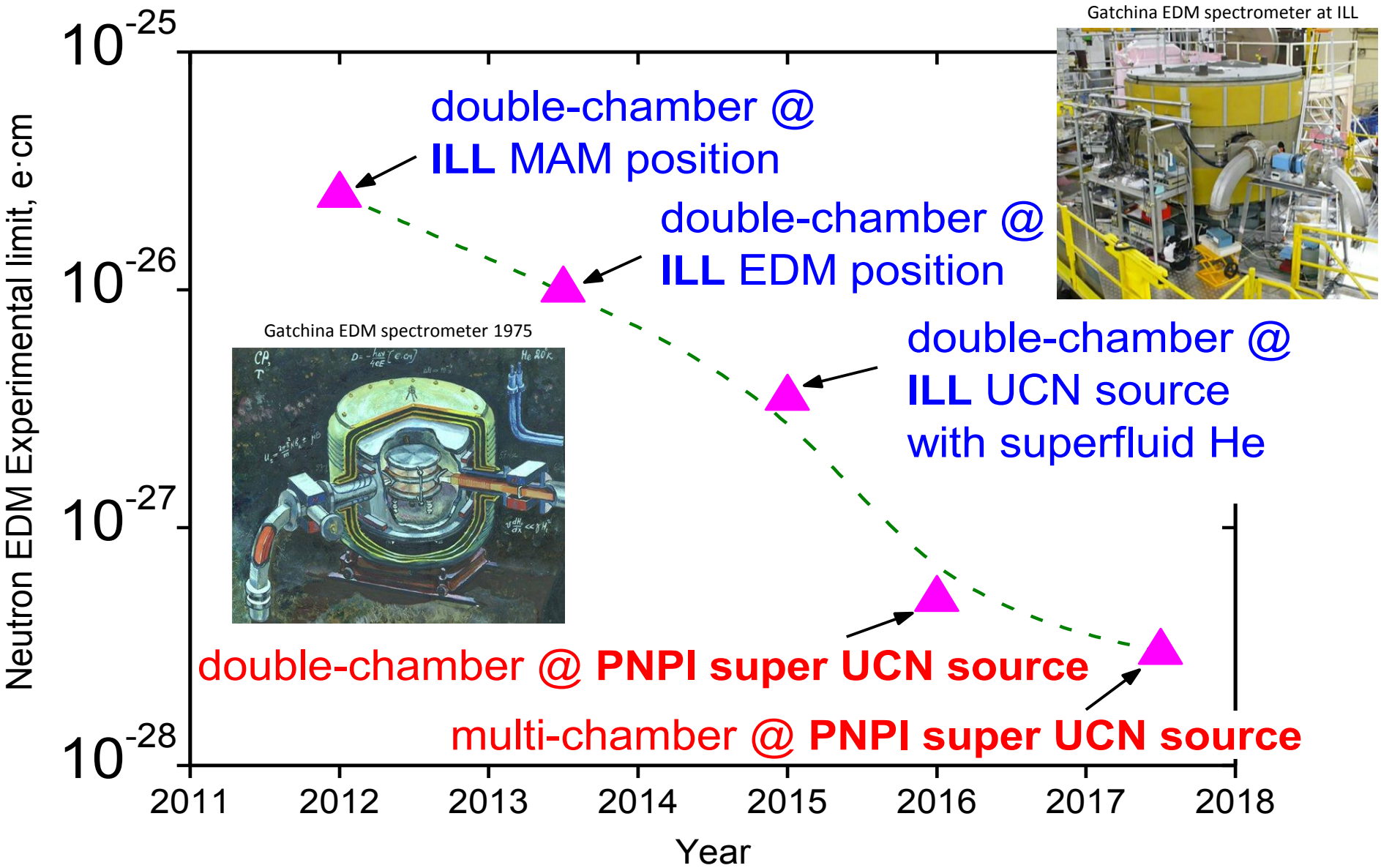
PNPI-ILL-PTI collaboration

Prospects to increase sensitivity of EDM measurements



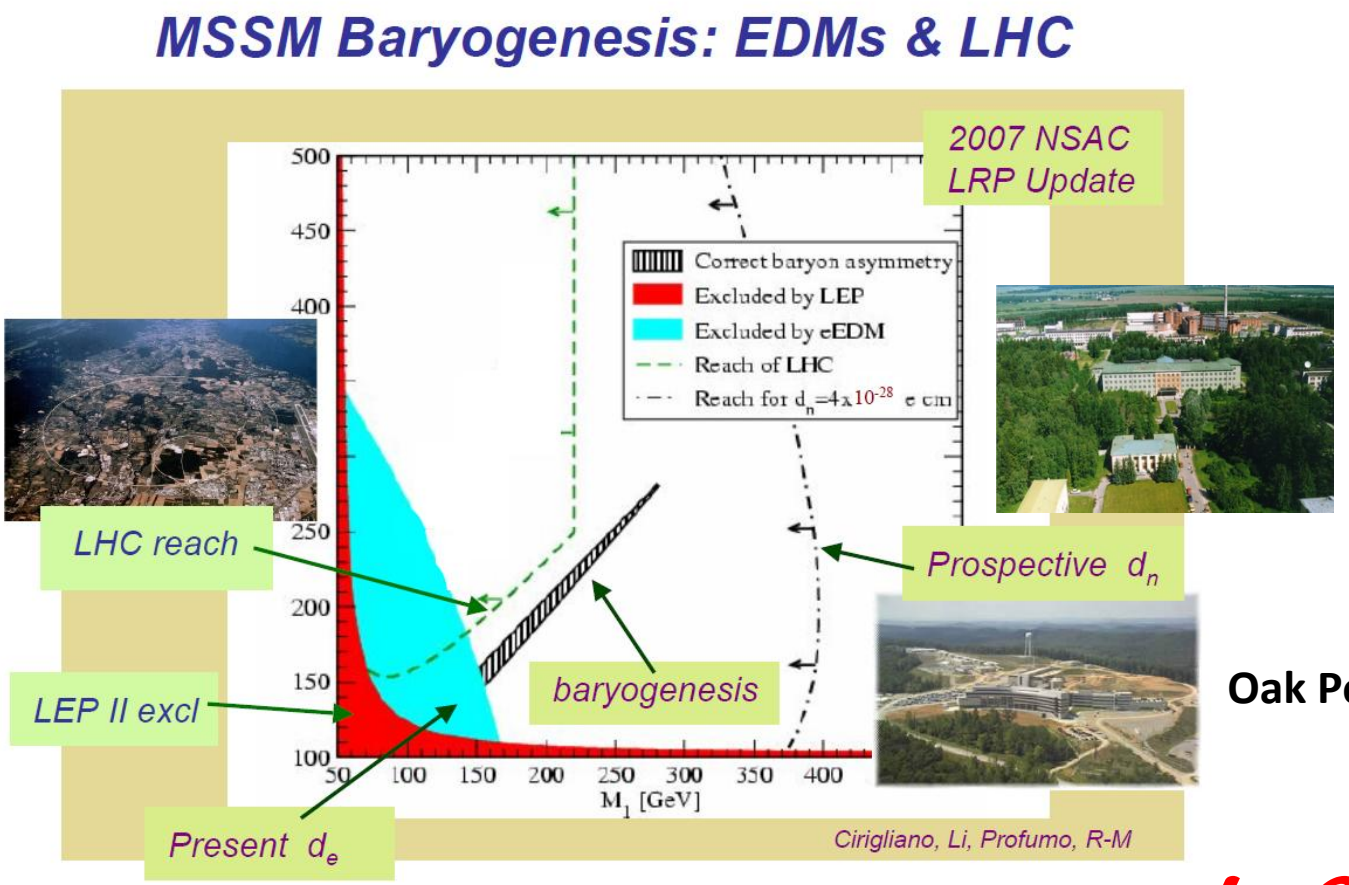
PNPI-ILL-PTI collaboration

Prospects to increase sensitivity of EDM measurements



Friendly Competition: GATCHINA - OAK RIDGE (Orlova Роща – Oak Роща)

Роща (roscha)
it means
in russian
a small forest



Orlova Роща

Oak Роща

Best regards from Russia

Anatolii Serebrov

... to complete the "nEDM landscape"

Besides the 6 experiments presented at this workshop

cryoEDM at ILL
PNPI-EDM at ILL
OILL-EDM at PSI
EDM at TUM
EDM at RCNP (and later at TRIUMF)
EDM at SNS

there is also a nEDM project for J-PARC

as well as a crystalEDM project lead by PNPI at ILL

J-PARC P33

"Measurement of Neutron Electric Dipole Moment at J-PARC"

Hirohiko M. SHIMIZU	Neutron Science Division, KEK
Takashi INO	Neutron Science Division, KEK
Suguru MUTO	Neutron Science Division, KEK
Tamaki YOSHIOKA	Neutron Science Division, KEK
Kenji MISHIMA	Neutron Science Division, KEK
Yasushi ARIMOTO	Neutron Science Division, KEK
Kaoru TAKETANI	Neutron Science Division, KEK
Hiroshi IWASE	Radiation Science Center, KEK
Toru OGITSU	Cryogenics Science Center, KEK
Nobuhiro KIMURA	Cryogenics Science Center, KEK
Sachio KOMAMIYA	Dept. Phys., Univ. Tokyo
Satoru YAMASHITA	ICEPP, Univ. Tokyo
Yoshio KAMIYA	ICEPP, Univ. Tokyo
Yuichi MORITA	Dept. Phys., Univ. Tokyo
Hidetoshi OTONO	Dept. Phys., Univ. Tokyo
Hideyuki OIDE	Dept. Phys., Univ. Tokyo
Yoshihisa IWASHITA	Inst. Chem. Res., Kyoto Univ.
Masahiro HINO	Research Reactor Institute, Kyoto Univ.
Masaaki KITAGUCHI	Research Reactor Institute, Kyoto Univ.
Hiroyuki FUJIOKA	Dept. Phys., Kyoto Univ.
Masako YAMADA	Dept. Phys., Kyoto Univ.
Sohei IMAJO	Dept. Phys., Kyoto Univ.
Haruhiko FUNAHASHI	Inst. Promotion of Excellence in Higher Education, Kyoto Univ.
Tatsushi SHIMA	Research Center for Nuclear Physics, Osaka Univ.
Masahiko UTSURO	Research Center for Nuclear Physics, Osaka Univ.
Kenji SAKAI	J-PARC Center, Japan Atomic Energy Agency
Koichiro ASAHI	Tokyo Inst. Tech.
Takeshi INOUE	Tokyo Inst. Tech.
Masato TSUCHIYA	Tokyo Inst. Tech.
Tsubasa NANAO	Tokyo Inst. Tech.
Akihiro YOSHIMI	RIKEN
Yoshiaki KIYANAGI	Fac. Engineering, Hokkaido Univ.
Takeshi KAWAI	Xi'an Jiaotong Univ.

nEDM proposal for J-PARC (p33)

J-PARC proton beam from LINAC

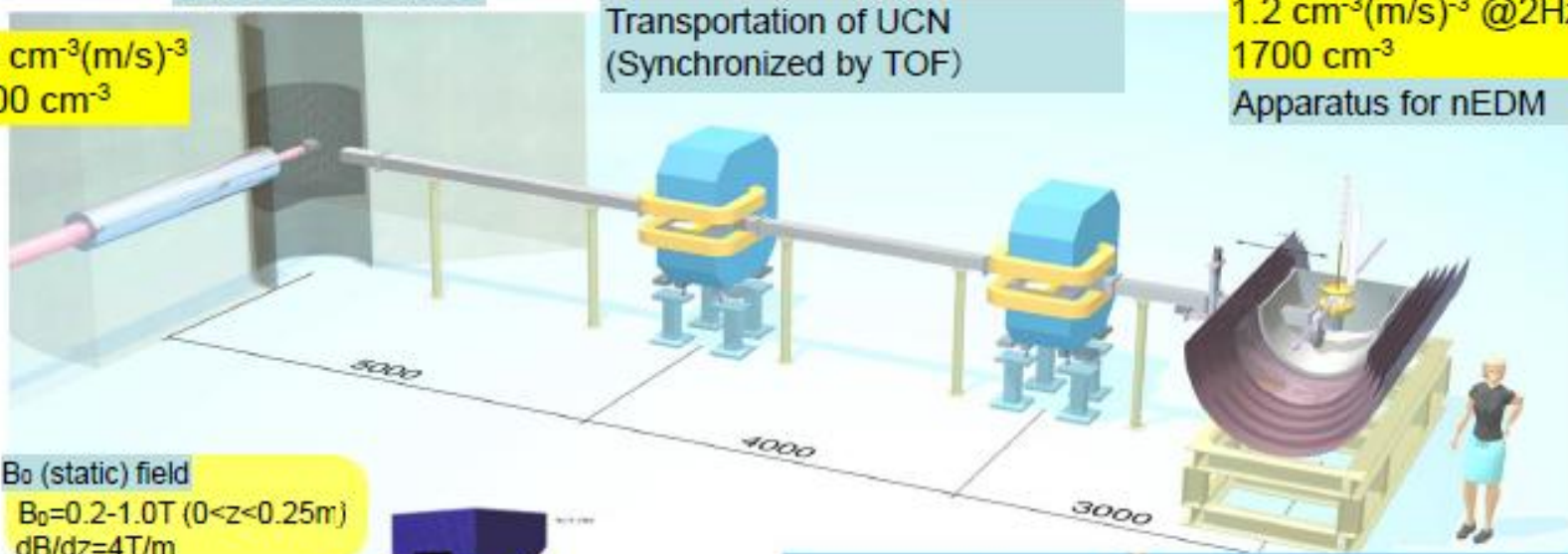
Pulse UCN source

4.3 $cm^{-3}(m/s)^{-3}$
6200 cm^{-3}

Transportation of UCN
(Synchronized by TOF)

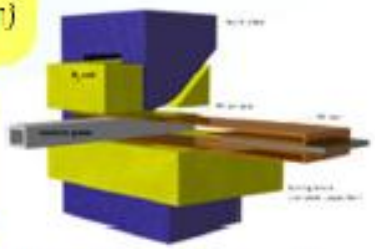
0.22 $cm^{-3}(m/s)^{-3}$ @2Hz
× 10 times injection
1.2 $cm^{-3}(m/s)^{-3}$ @2Hz
1700 cm^{-3}

Apparatus for nEDM



B_0 (static) field
B_0=0.2-1.0T (0<z<0.25m)
dB/dz=4T/m

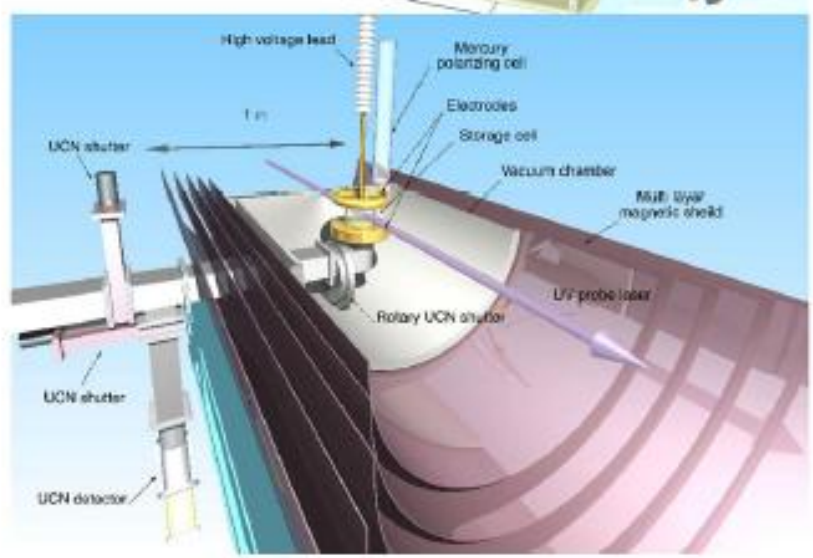
B_1 (RF) field
$\omega/2\pi$=6-30MHz
B_1=1mT
L=200nH
C=0.14-3.5nF



$d_n=(+0.2\pm1.5(stat)\pm0.7(syst))\times10^{-26}$ e cm

Transport the peak density of UCN

10^{-27} e cm (5000h)



8

Advantages of diffraction method of the nEDM search

- Strong electric field (**up to10^9 V/cm**), acts on neutron moving close to diffraction condition in a crystal without center of symmetry. It leads to spin rotation effects.

  (In lab only field ~**10^4 V/cm is available)**

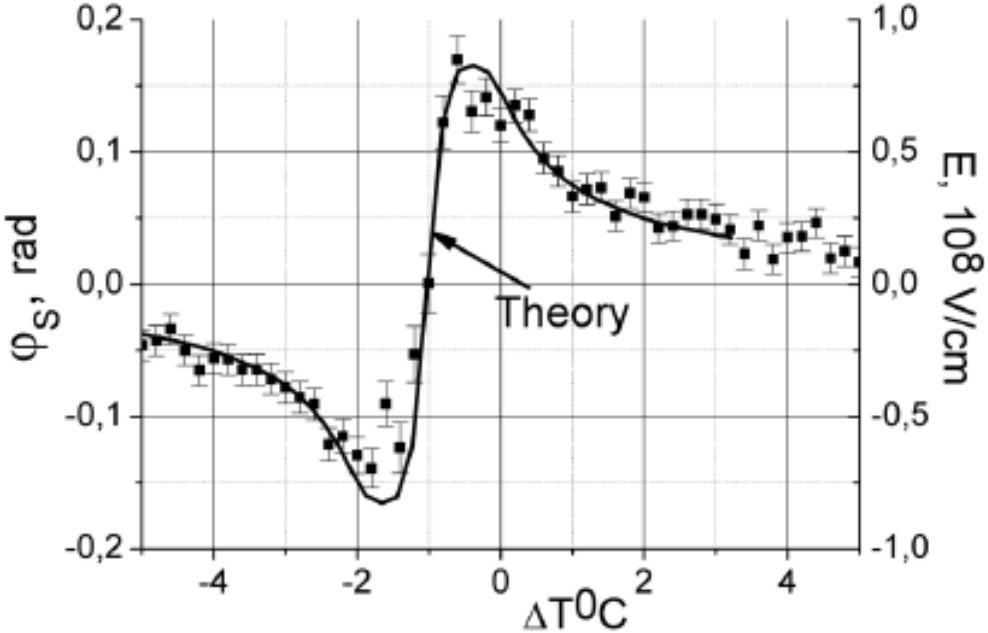
- Direction of this field is perpendicular to crystallographic plane

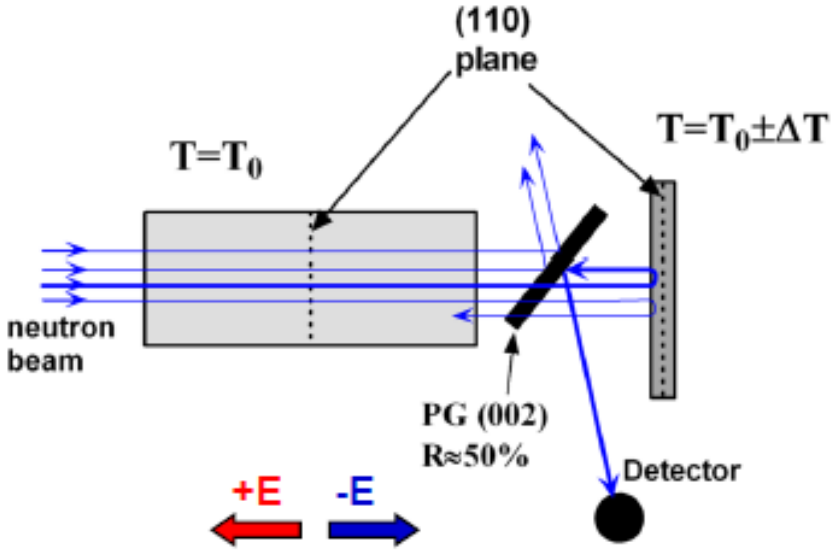
- Feasibility of controlled changing the **sign and the value** of the electric field acting on neutron in crystal.

- A few ways to eliminate the false Schwinger effect

- The feasibility to use the assembling of a few different crystals to increase the interaction time

Experiment

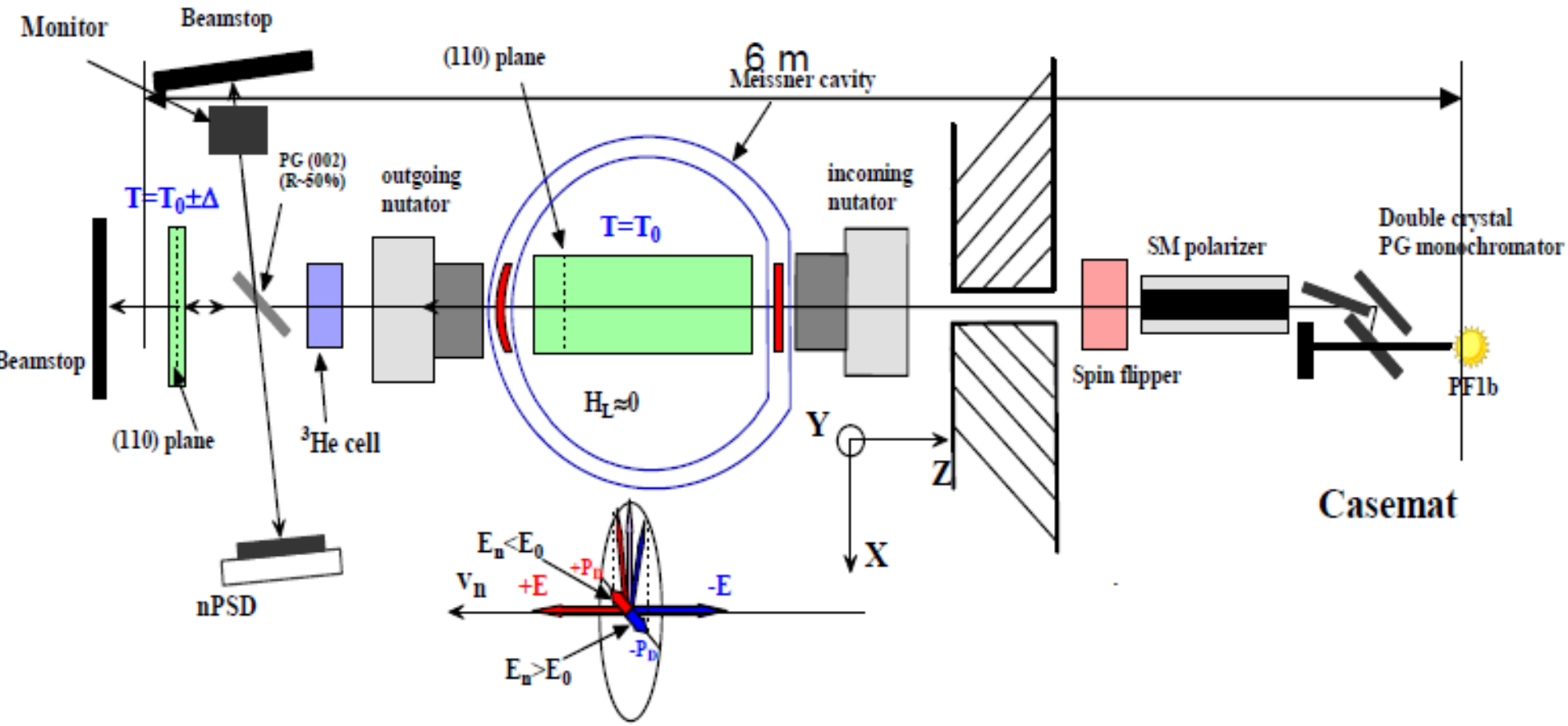




Dependence of interplanar electric field, acting on neutron, on the temperature difference of two crystals

From the test experiment it follows that the sensitivity to measure the EDM is ~ 2 · 10^{-25} e·cm/day (3 times more than in ILL UCN experment)

Scheme of the experiment



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Summary of the experimental scheme

- Possibility to reverse of the electric field.
- "Zero" Schwinger effect.
- Possibility to control and suppress the systematic.
- Low influence of crystal quality. (For $\omega_m \gg \Delta\theta$ the effects ~ $\Delta\theta / \omega_m$. Intensity ~ ω_m). ➡ New kinds of NSC crystals
- One can increase the effect by using a series of crystals

For quartz crystal,

for thickness L_c=50 cm

100 day

➡ $\sigma_d \sim 1.3 \cdot 10^{-26}\ e \cdot cm$

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Summary of the systematic

Residual magnetic field	
Value	$\mathbf{H}_r \sim 10^{-4}\,Gs$
Time stability	$\Delta\mathbf{H}_r \sim 10^{-5}\,Gs/hour$
3D analysis of polarization	$\delta_y \sim 10^{-3}\,rad$
The crystals alignment	$\sim 0.02^0$
The ΔT^0 control	$\sim 0.01^0 C$

$\sigma_d < 6\ 10^{-27}$ e cm

16 June 2011

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