

Search for $NN\bar{b}$ with UCN

A. Fomin

**A. Serebrov, M. Chaikovskii, O. Zherebtsov,
A. Murashkin, E. Golubeva (INR RAS)**

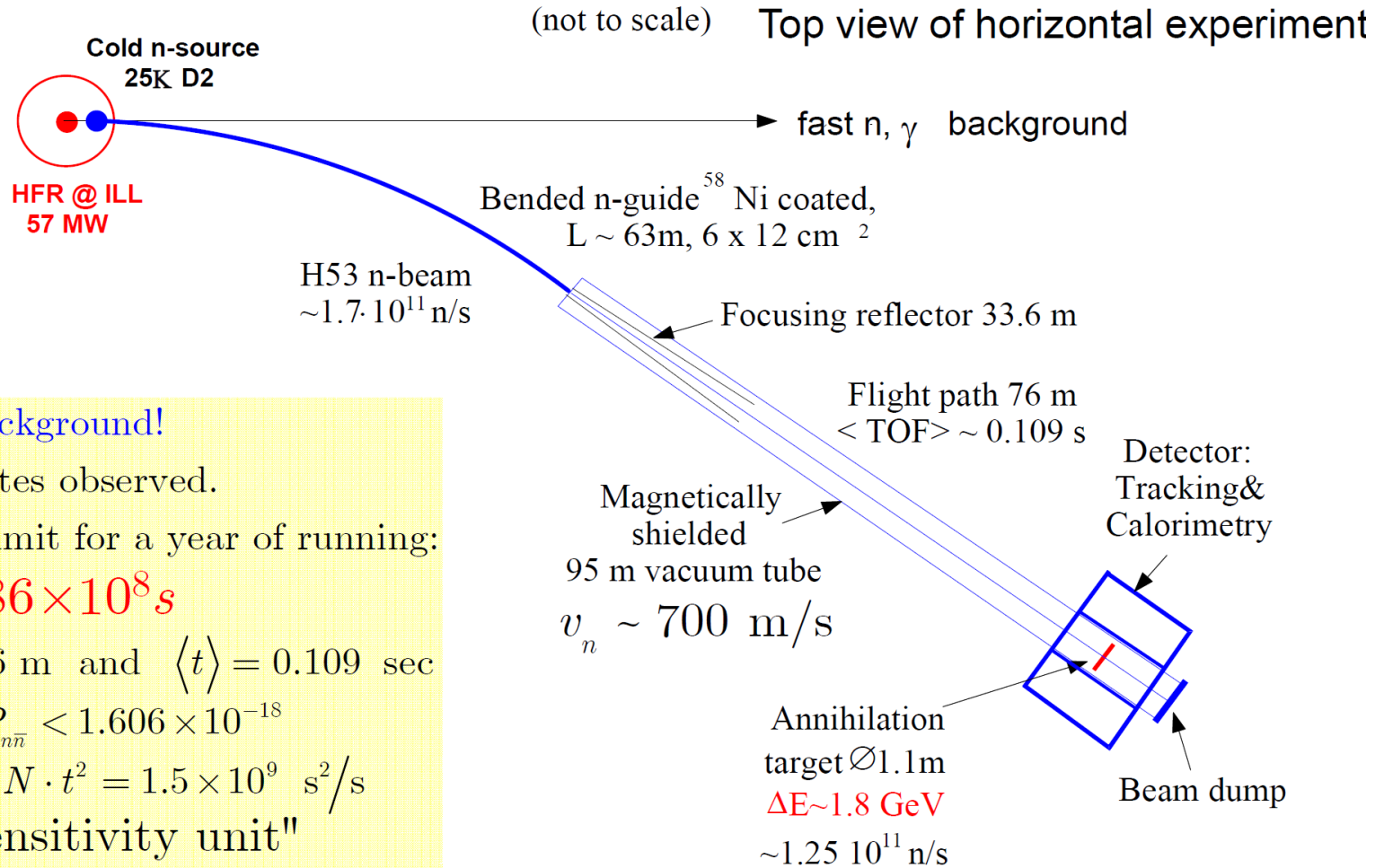
NRC «Kurchatov Institute» - PNPI, Russia, Gatchina

Theoretical Innovations for Future Experiments Regarding Baryon Number Violation, Part 1
ACFI, 3-6 August 2020

Beam experiment at ILL

At ILL/Grenoble reactor in 89-91 by Heidelberg-ILL-Padova-Pavia Collaboration

M. Baldo-Ceolin et al., Z. Phys., C63 (1994) 409



No GeV background!

No candidates observed.

Measured limit for a year of running:

$$\tau_{n\bar{n}} > 0.86 \times 10^8 \text{ s}$$

with L ~ 76 m and $\langle t \rangle = 0.109$ sec

measured $P_{n\bar{n}} < 1.606 \times 10^{-18}$

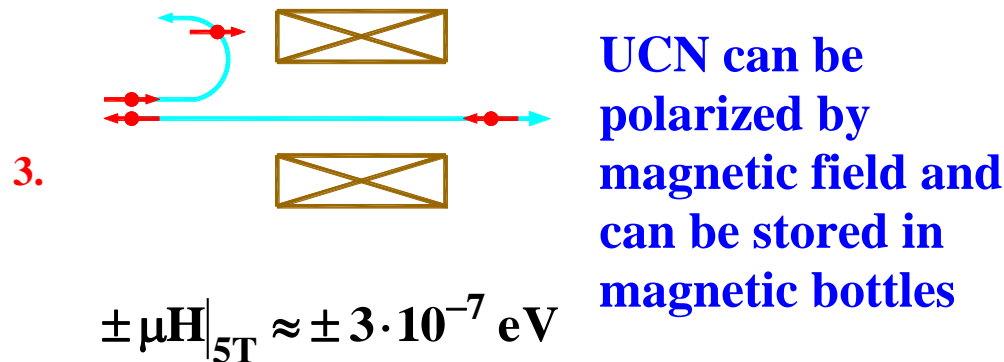
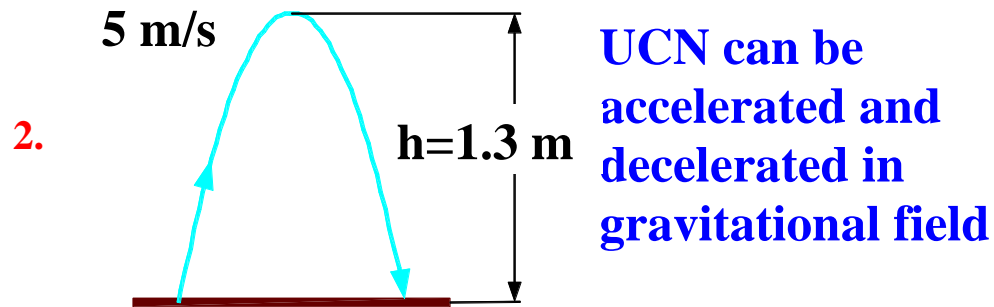
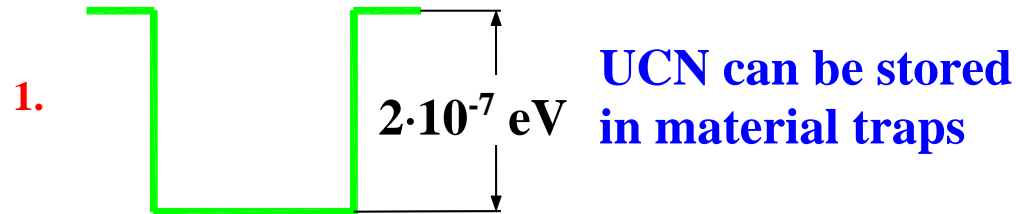
sensitivity: $N \cdot t^2 = 1.5 \times 10^9 \text{ s}^2/\text{s}$

\doteq "ILL sensitivity unit"

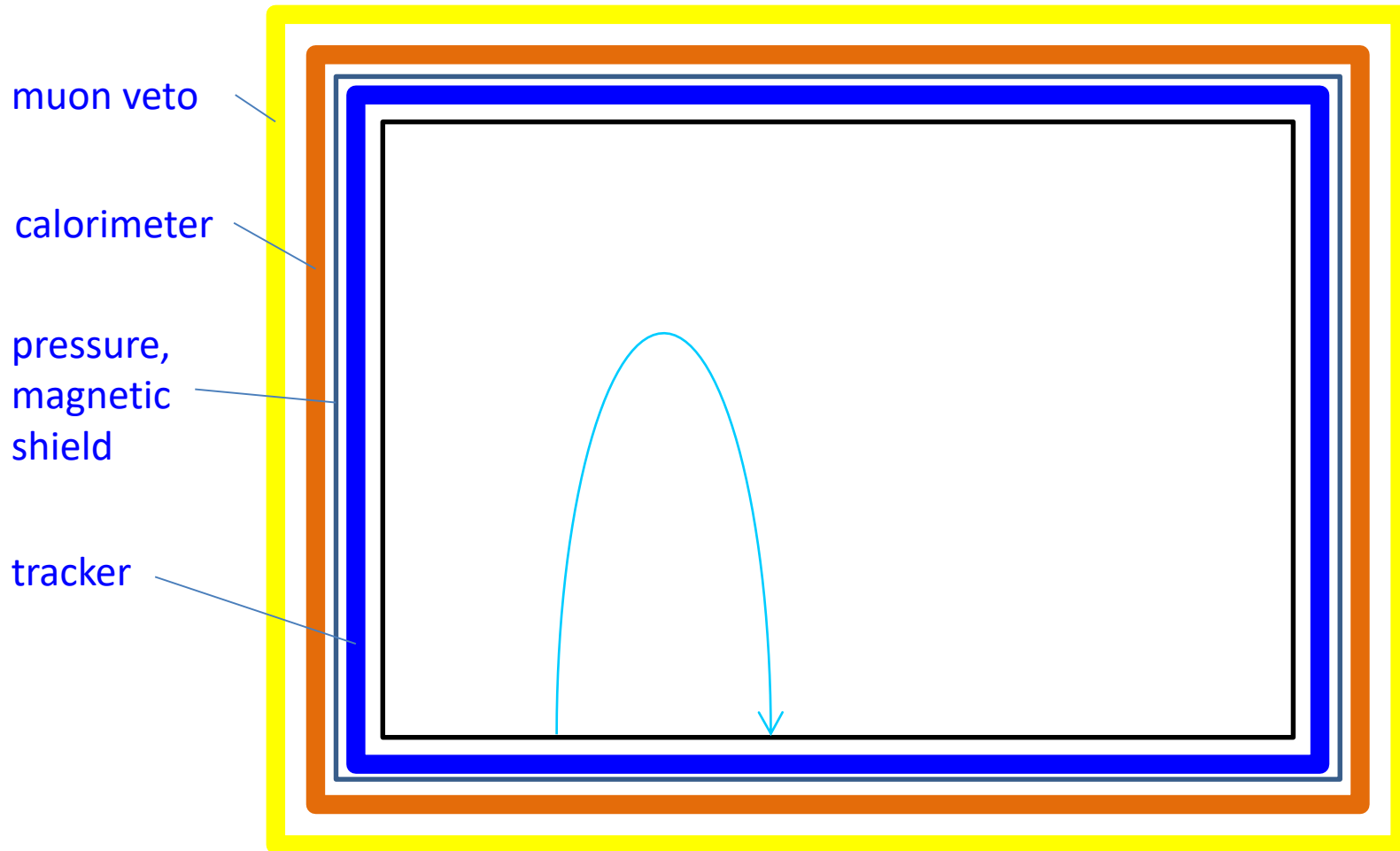
Ultracold neutrons

$\lambda \approx 800 \text{ \AA}$, $v \approx 5 \text{ m/s}$, $T \approx 1.5 \cdot 10^{-3} \text{ K}$, $E \approx 1.3 \cdot 10^{-7} \text{ eV}$

Firs observation of UCN in 1968.



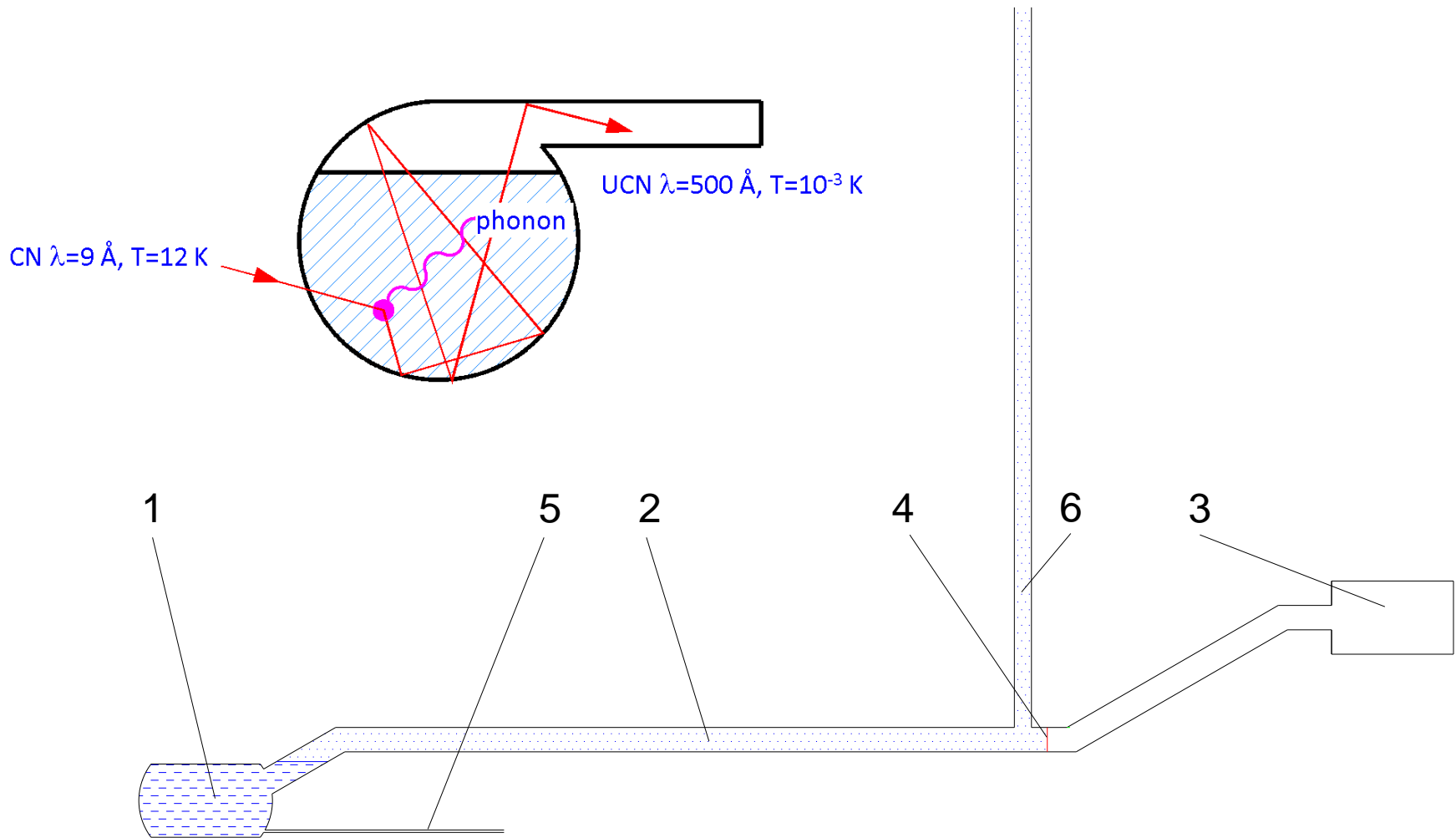
NNbar via UCN



$N \cdot t^2$ – discovery potential

M.V. Kazarnovskii et al., JETP Lett. 34 (1), 47 (1981)

MC model of UCN source with superfluid helium



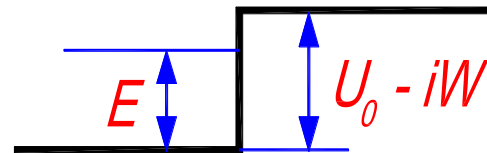
(1) source chamber; (2) neutron guide; (3) UCN trap; (4) membrane in front of the inlet to the UCN trap; (5) pipe for filling the chamber; (6) pipeline for evacuation of the chamber (UCN gravitational shutter)

What is the probability for UCÑ to be reflected?

$$\tilde{R} = \left| \frac{k_1 - k_2}{k_1 + k_2} \right|^2 \quad k_1^2 = \frac{2m\tilde{E}_\perp}{\hbar^2} \quad k_2^2 = \frac{2m}{\hbar^2} (\tilde{E}_\perp - \tilde{U})$$

$$\tilde{U} = \tilde{U}_0 - i\tilde{W} \quad \tilde{\eta} = \frac{\tilde{W}}{\tilde{U}_0}$$

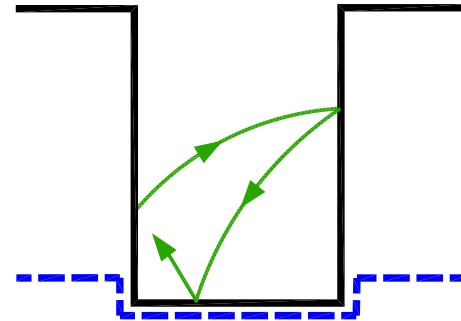
$$\tilde{R} = \left| \frac{1 - \sqrt{1 - \frac{\tilde{U}_0}{\tilde{E}_\perp} (1 - i\tilde{\eta})}}{1 + \sqrt{1 - \frac{\tilde{U}_0}{\tilde{E}_\perp} (1 - i\tilde{\eta})}} \right|^2$$



We can consider two cases:

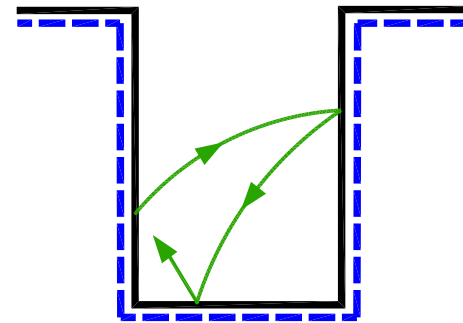
1. $\tilde{R} = 0$

(pessimistic case)



2. $\tilde{R} = \tilde{R} (\eta = 0.2) \approx 0.8$

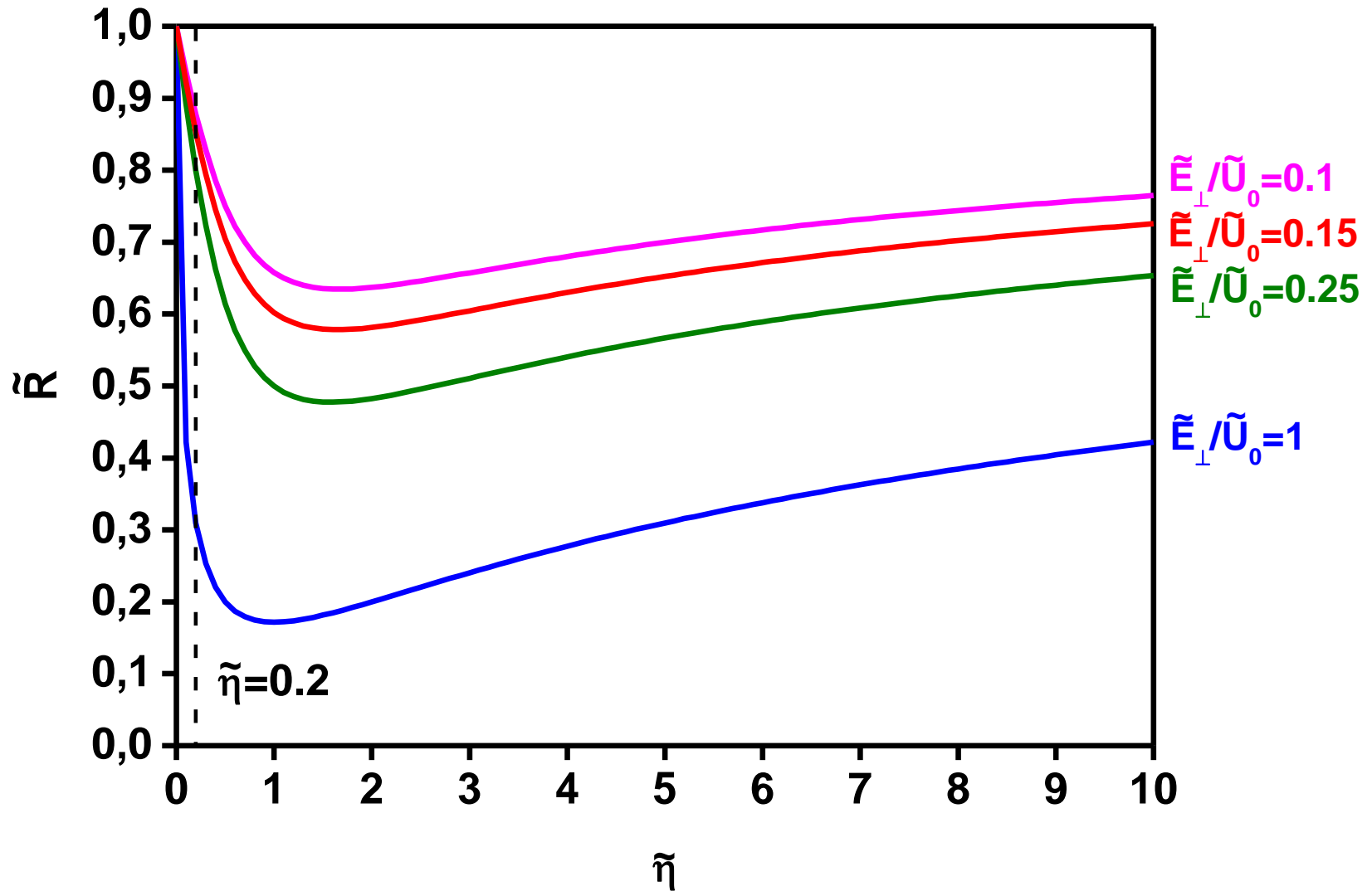
(optimistic case)



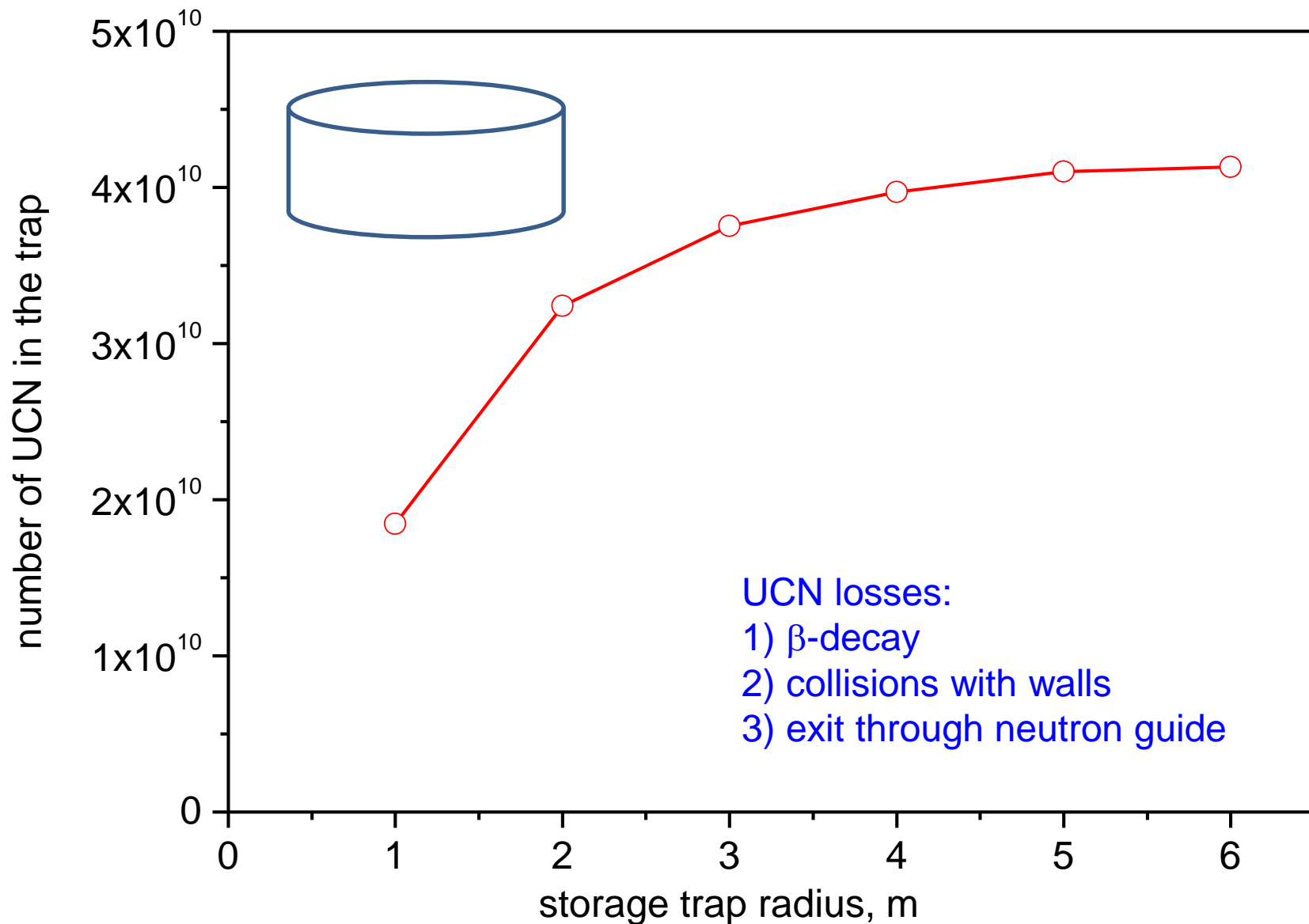
$U_0 - iW$ for n ———

$\tilde{U}_0 - i\tilde{W}$ for \tilde{n} - - -

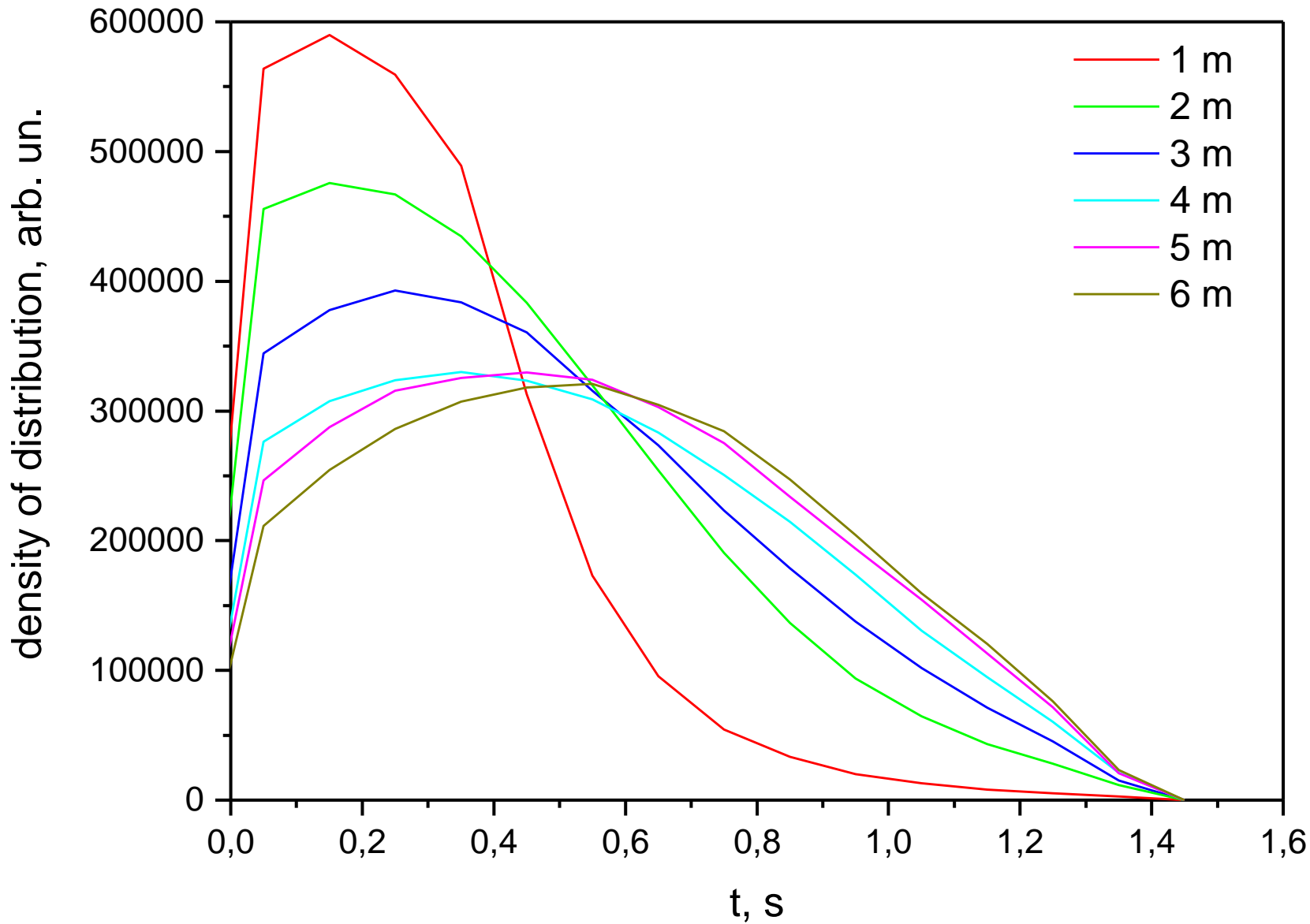
Reflection coefficient for UCN



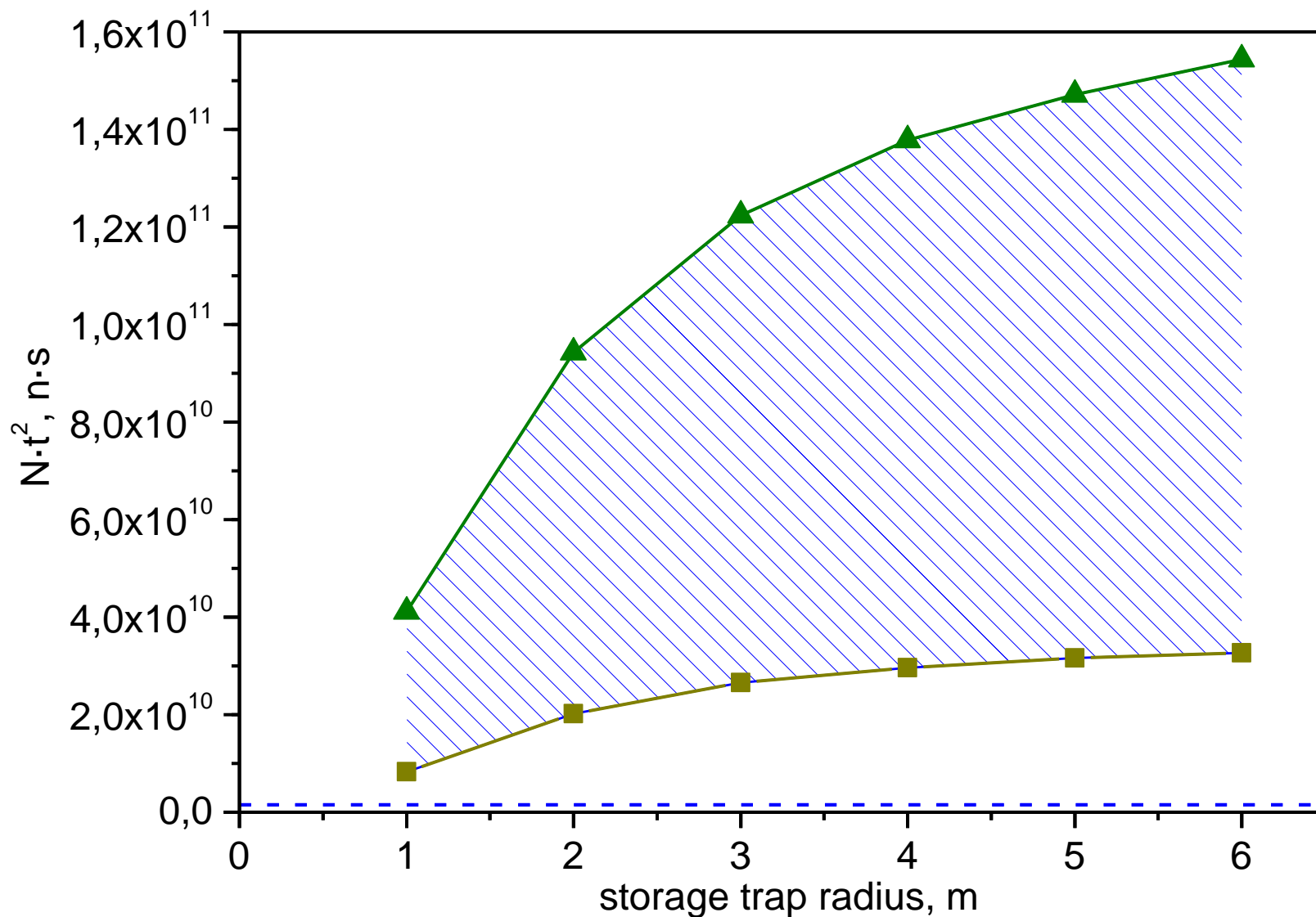
UCN number in the trap for different storage trap radius



UCN time of flight for different storage trap radius

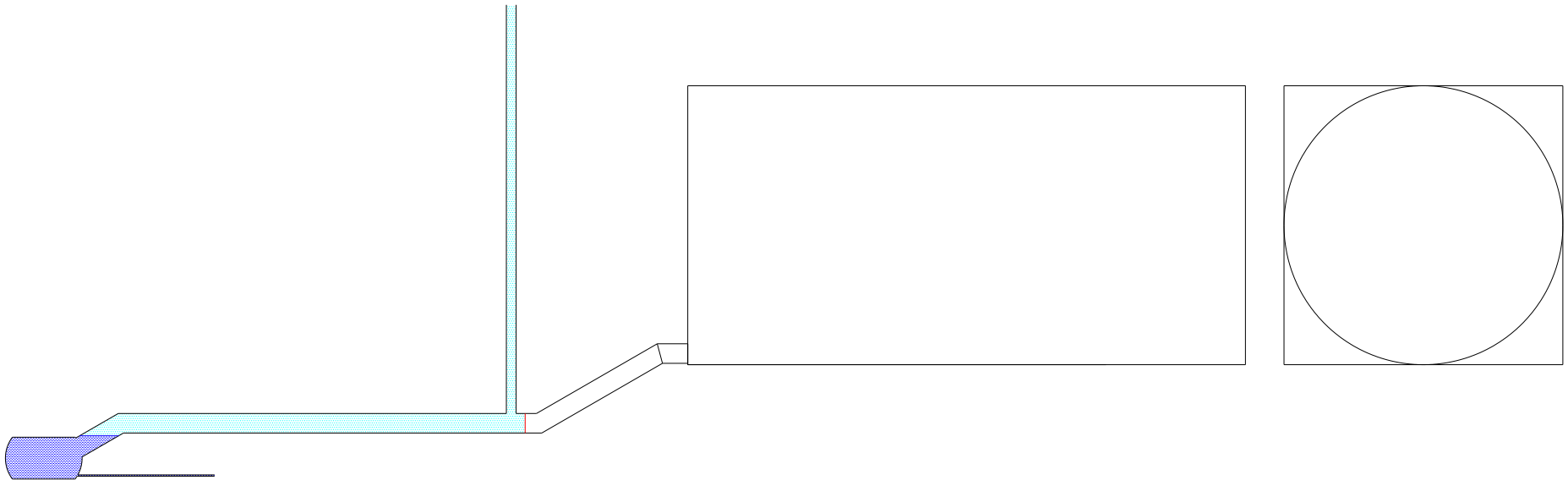


$N \cdot t^2$ for different storage trap radius

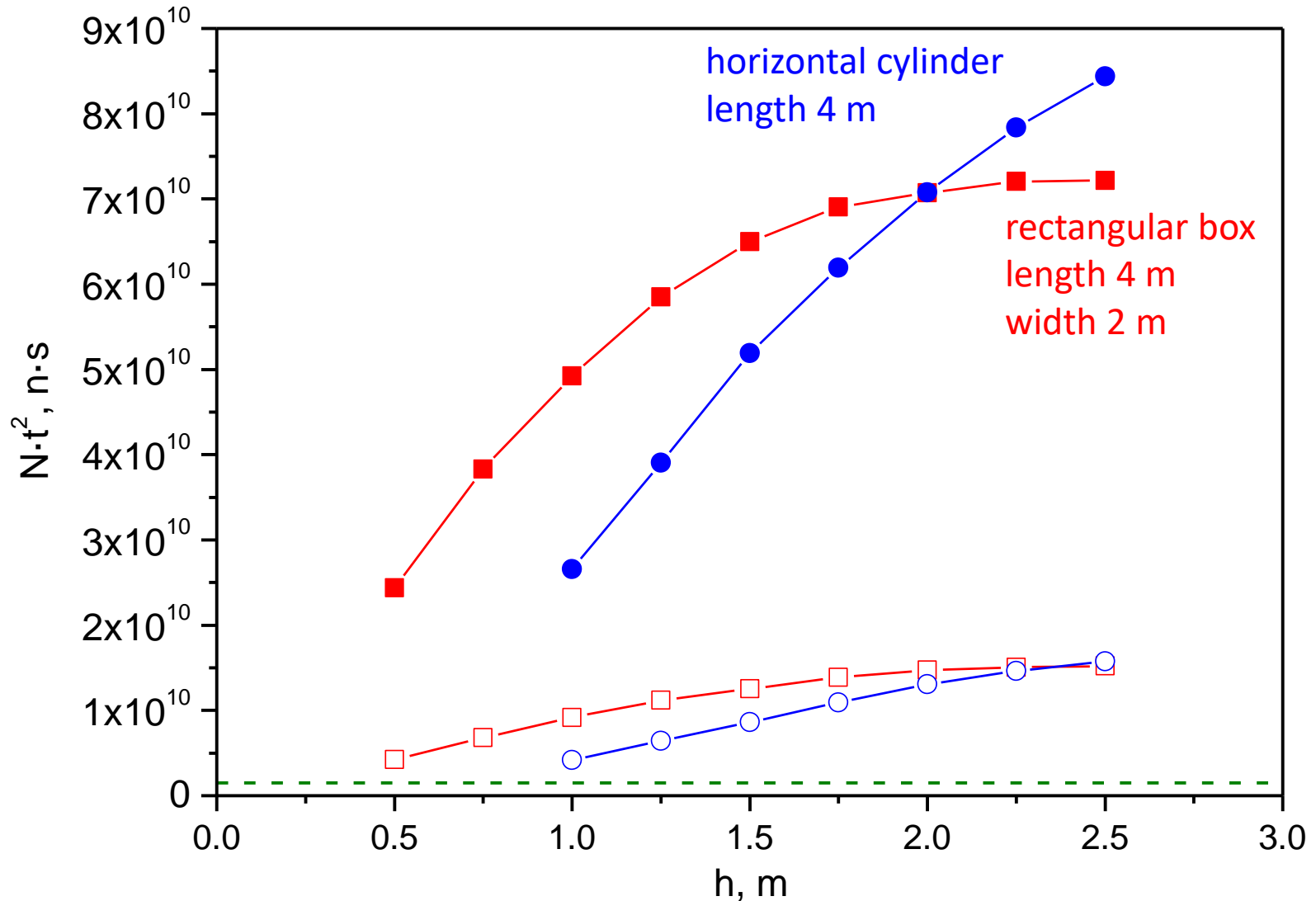


Production of the source 10^8 UCN/s.

Form of the storage trap



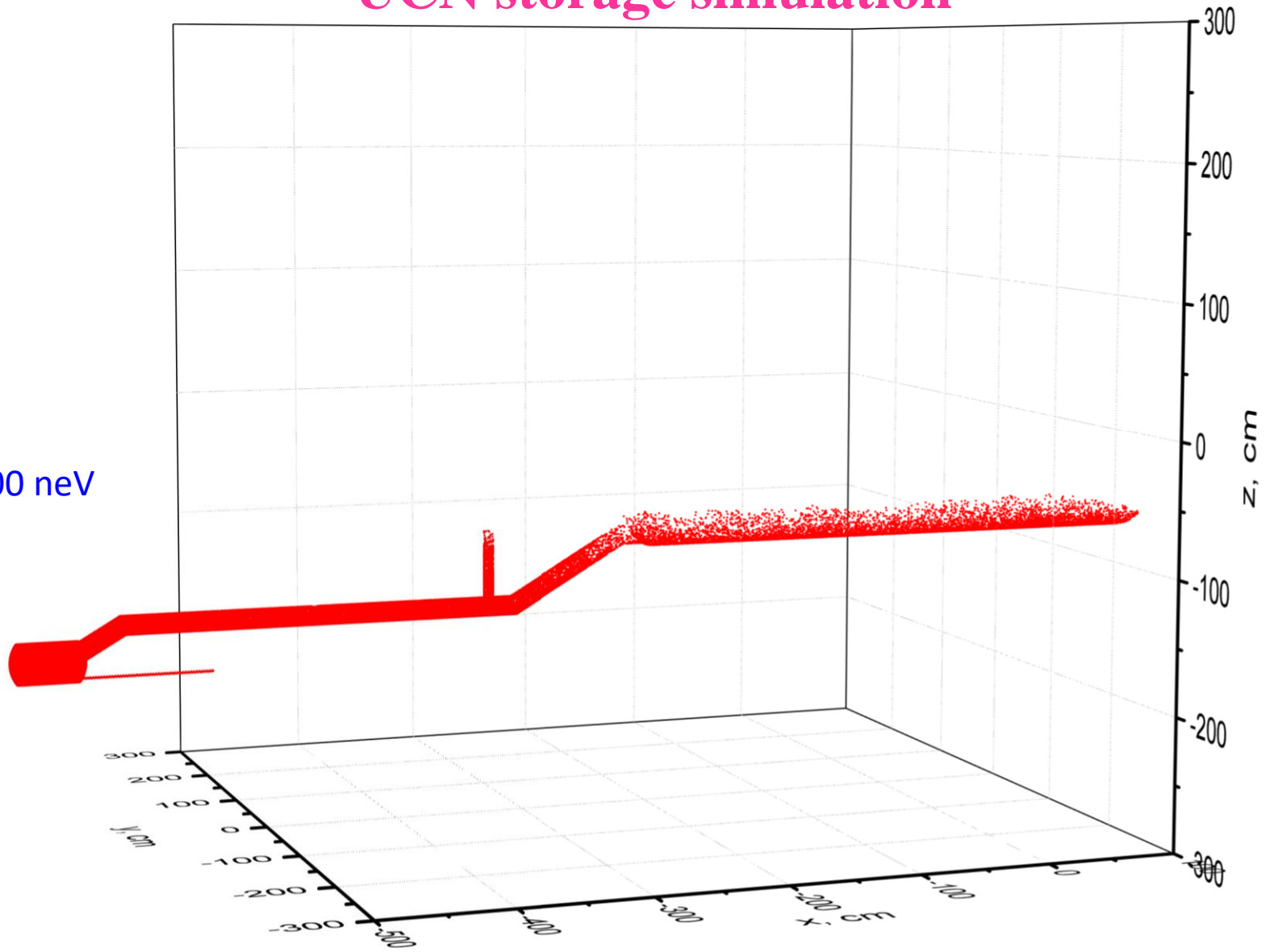
$N \cdot t^2$ for different storage trap height



Production of the source 10^8 UCN/s.

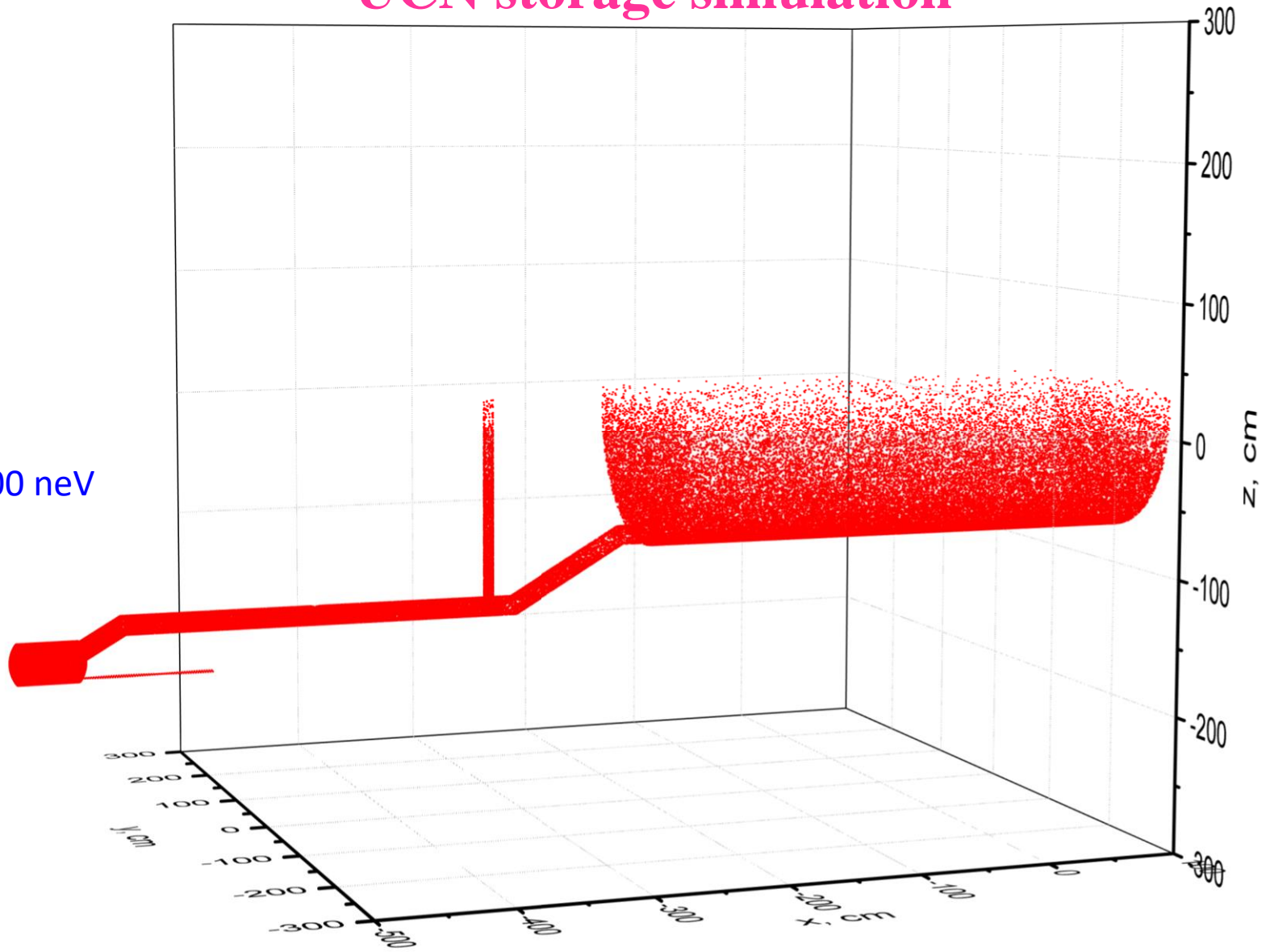
UCN storage simulation

E=100 neV



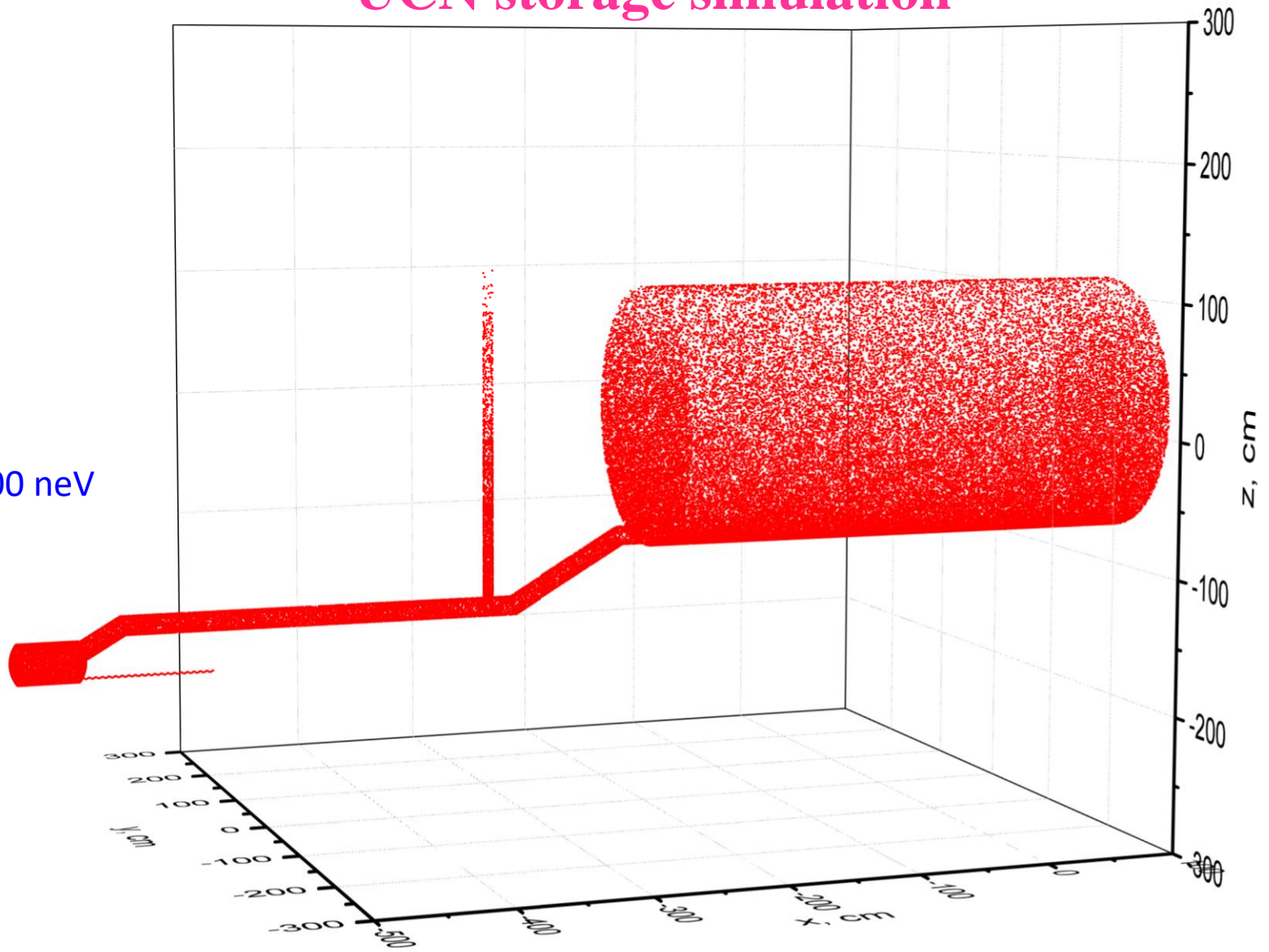
UCN storage simulation

E=200 neV



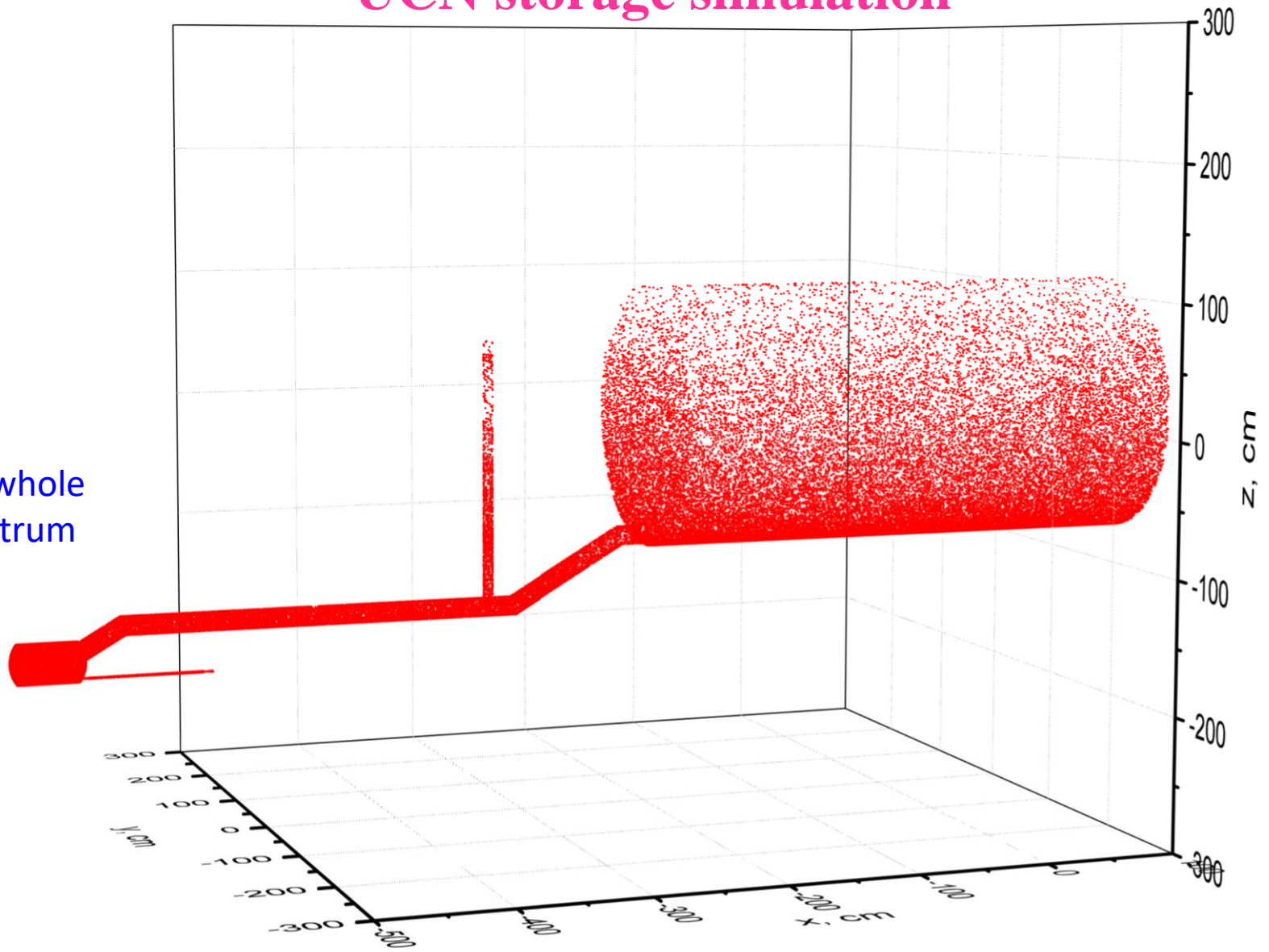
UCN storage simulation

E=300 neV

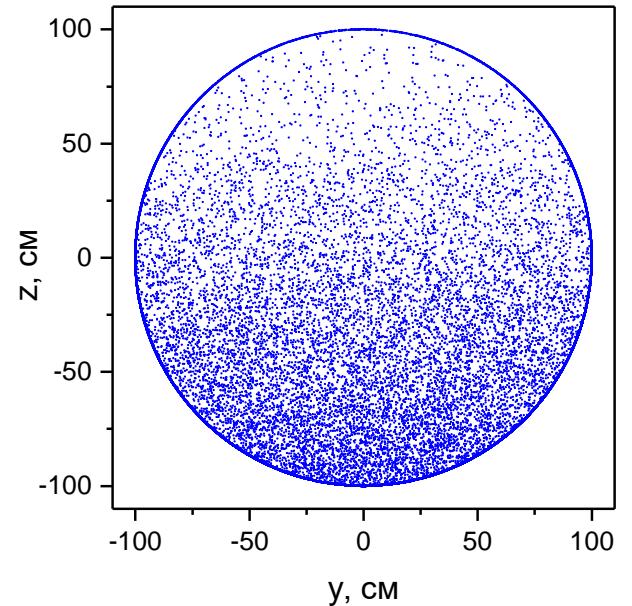
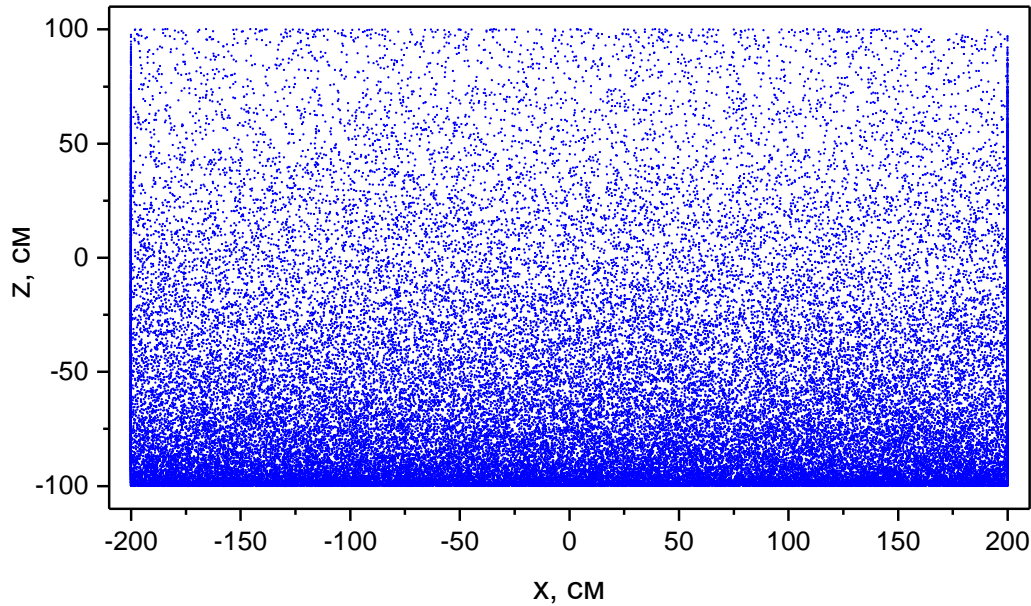
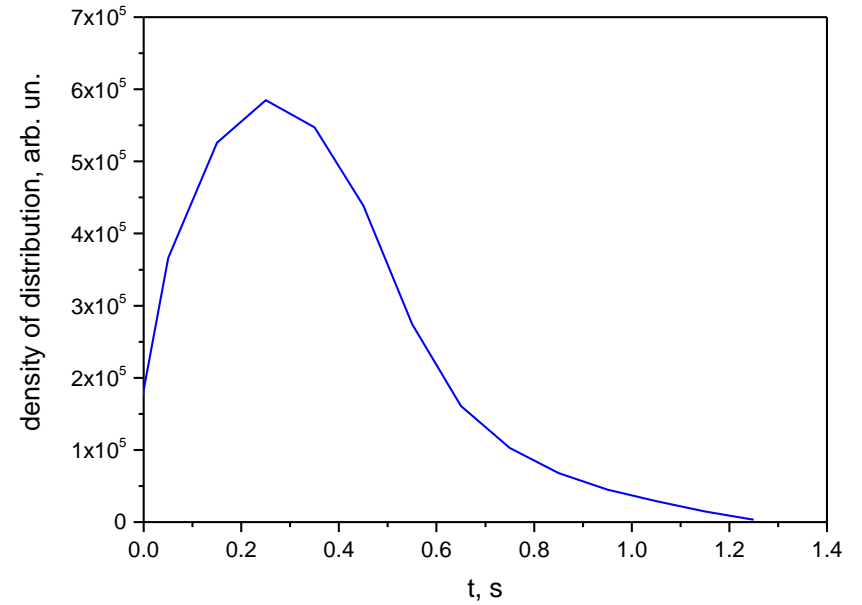
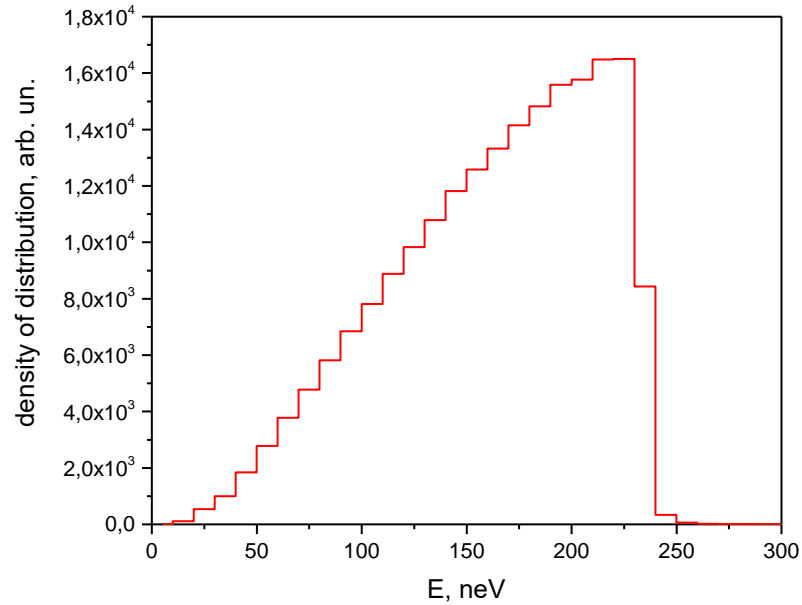


UCN storage simulation

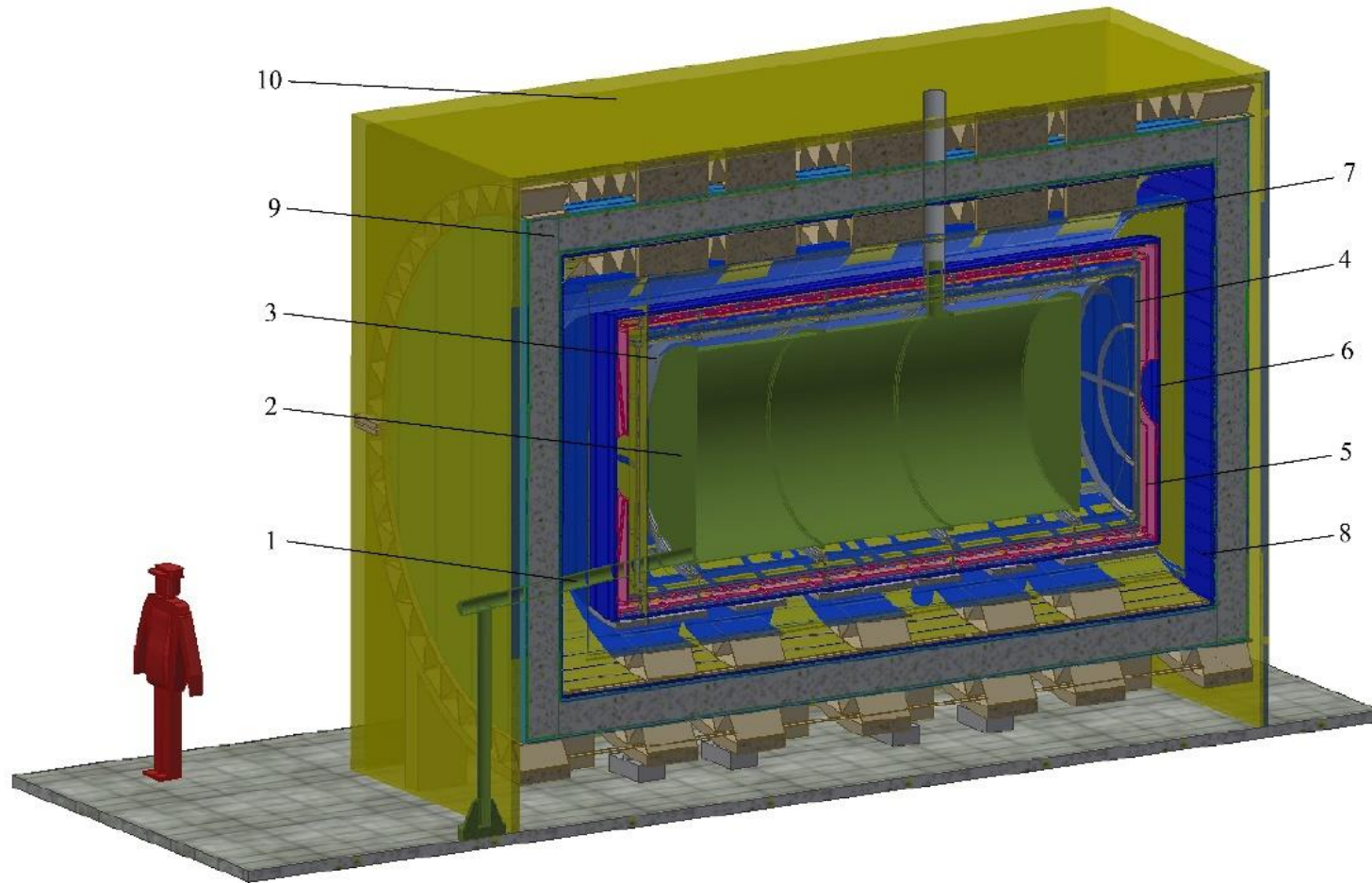
the whole spectrum



UCN storage simulation

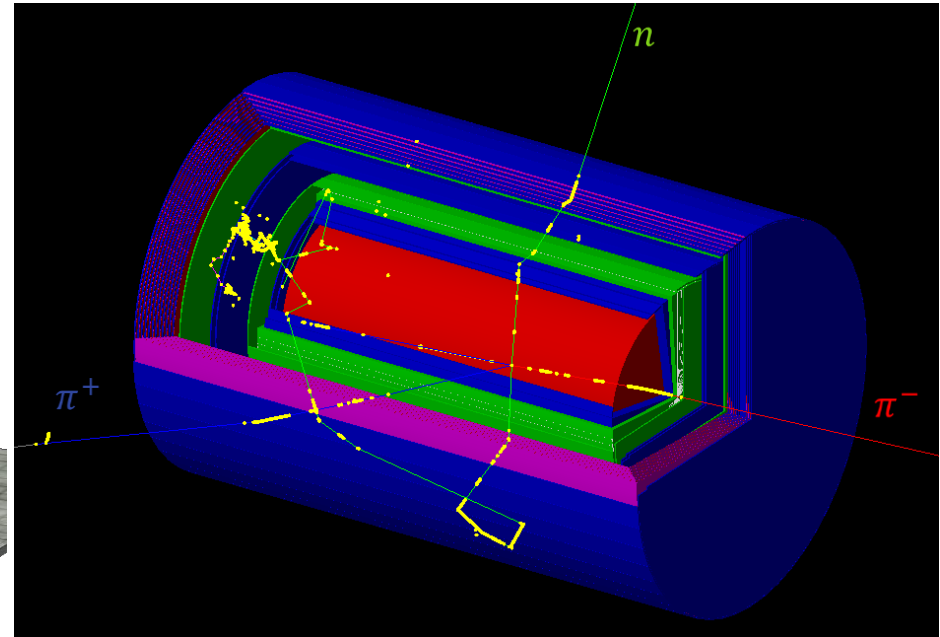
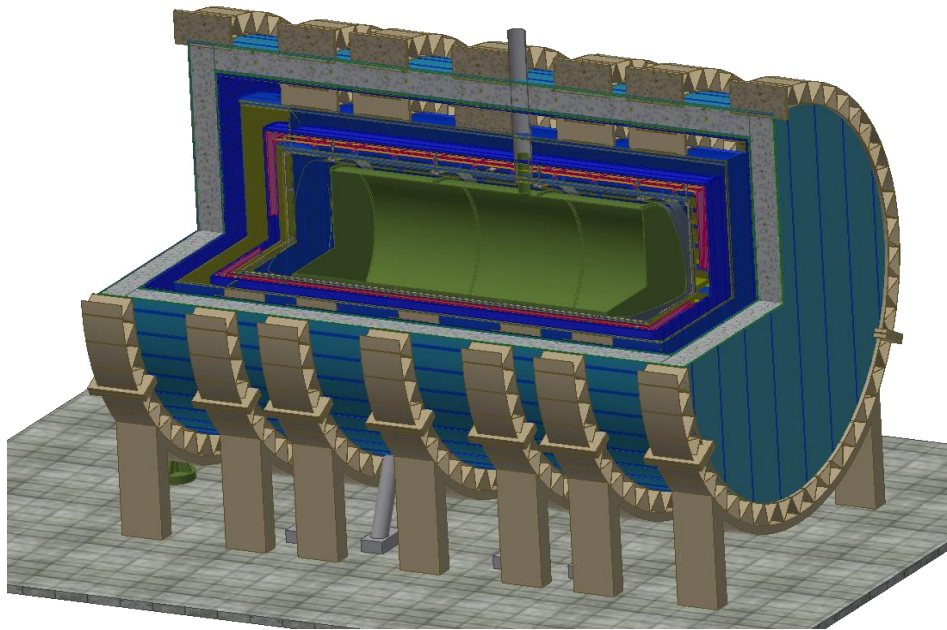


Design of the setup



1 – neutron guide, 2 - UCN trap, 3 - vacuum chamber, 4 – track detector (inner part), 5 - magnetic shield, 6 - hodoscope (internal part), 7 - track detector (middle part), 8 - hodoscope (external part), 9 - calorimeter, 10 – active shielding

GEANT4 simulation

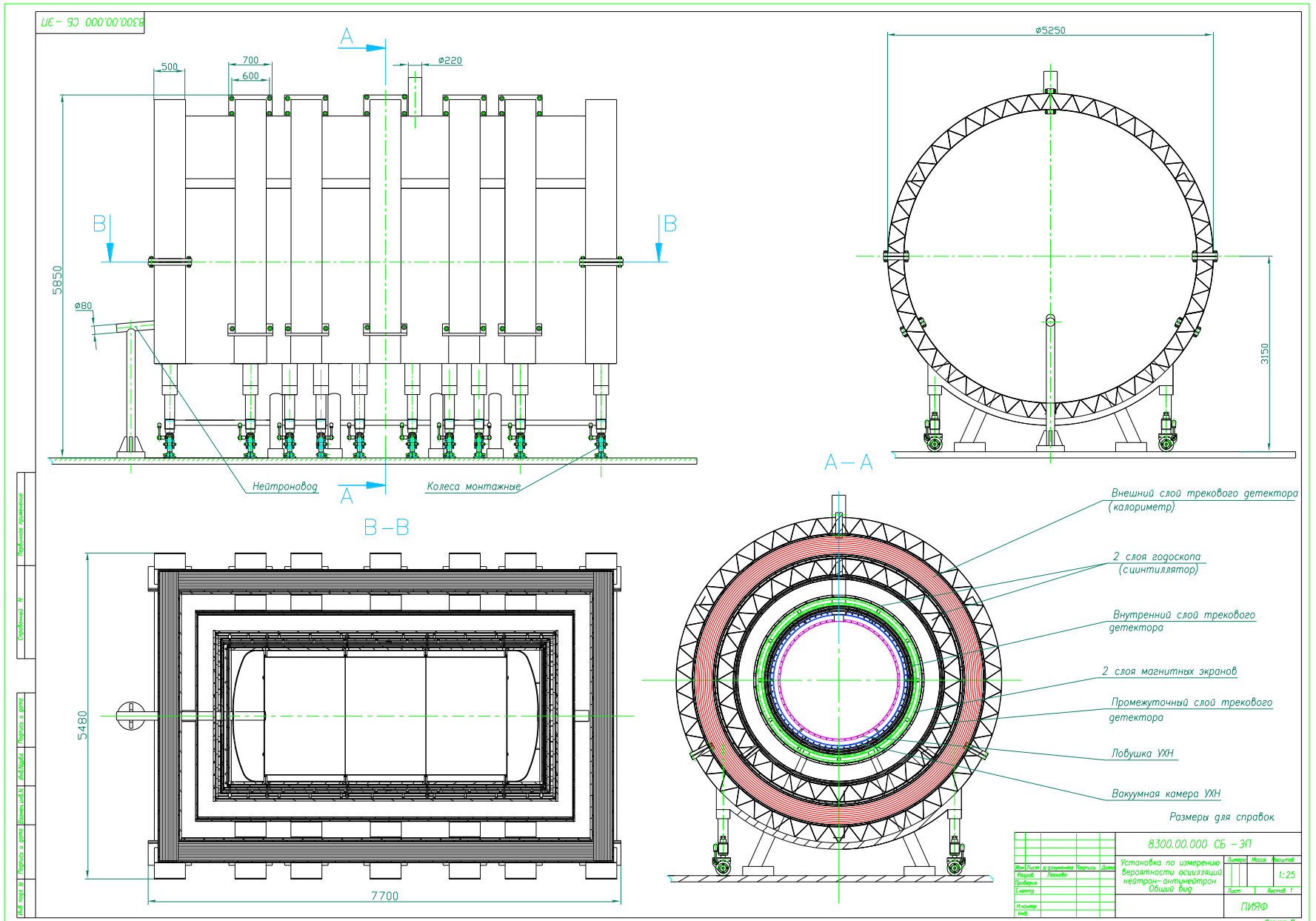


The detector efficiency is calculated to be $(68 \pm 2)\%$



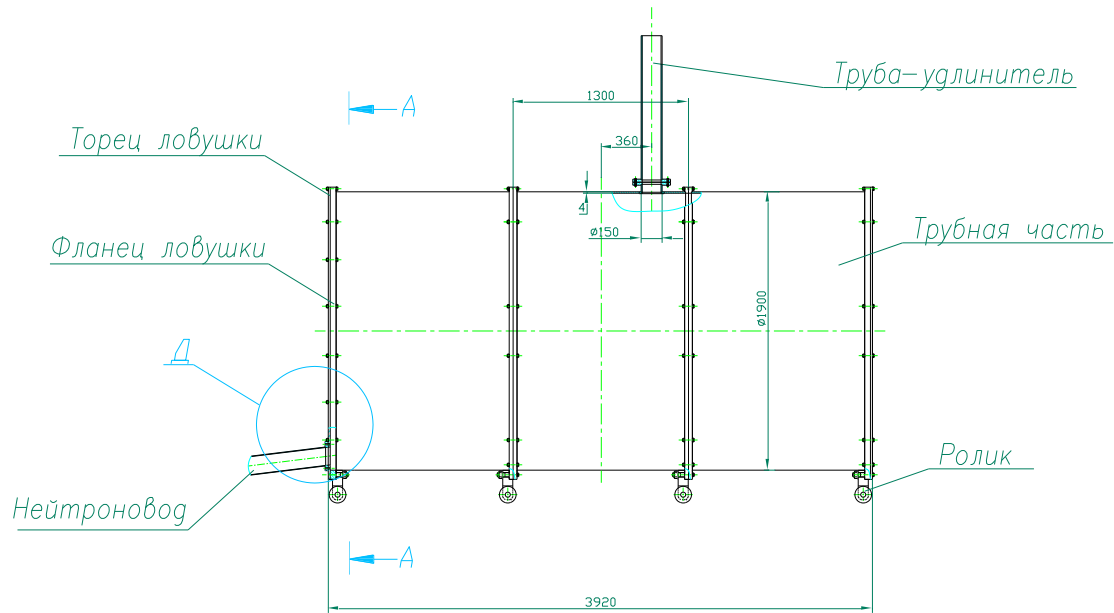
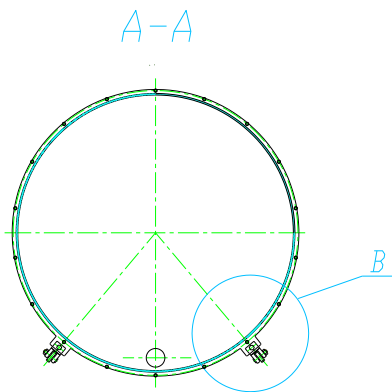
E.S. Golubeva, J.L. Barrow, C.G. Ladd, Phys. Rev. D 99 (2019) 035002

Design of the setup

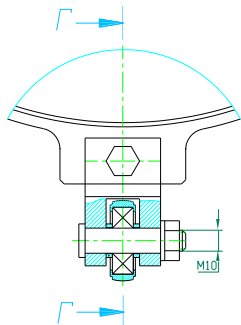


UCN trap

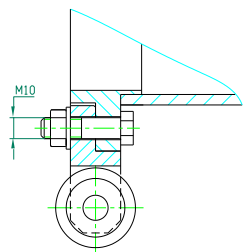
8300.02.000 СБ - ЭП



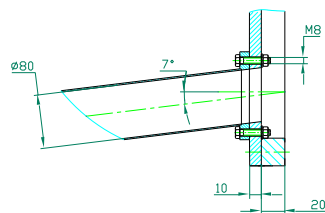
B(1:1) Ⓞ



Г-Г(1:1)



Д(1:2)

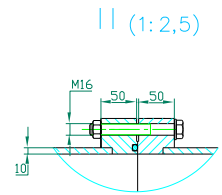
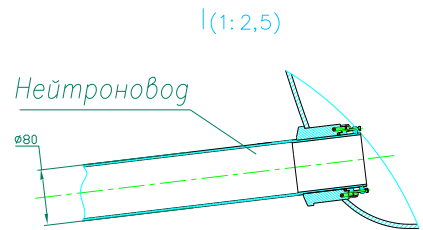
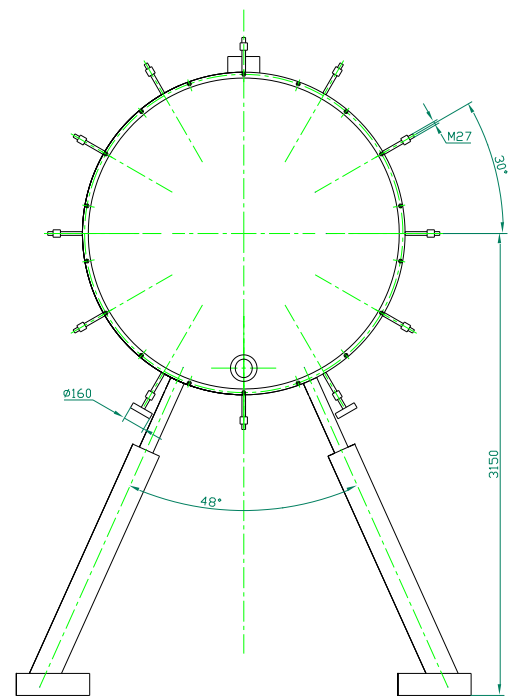
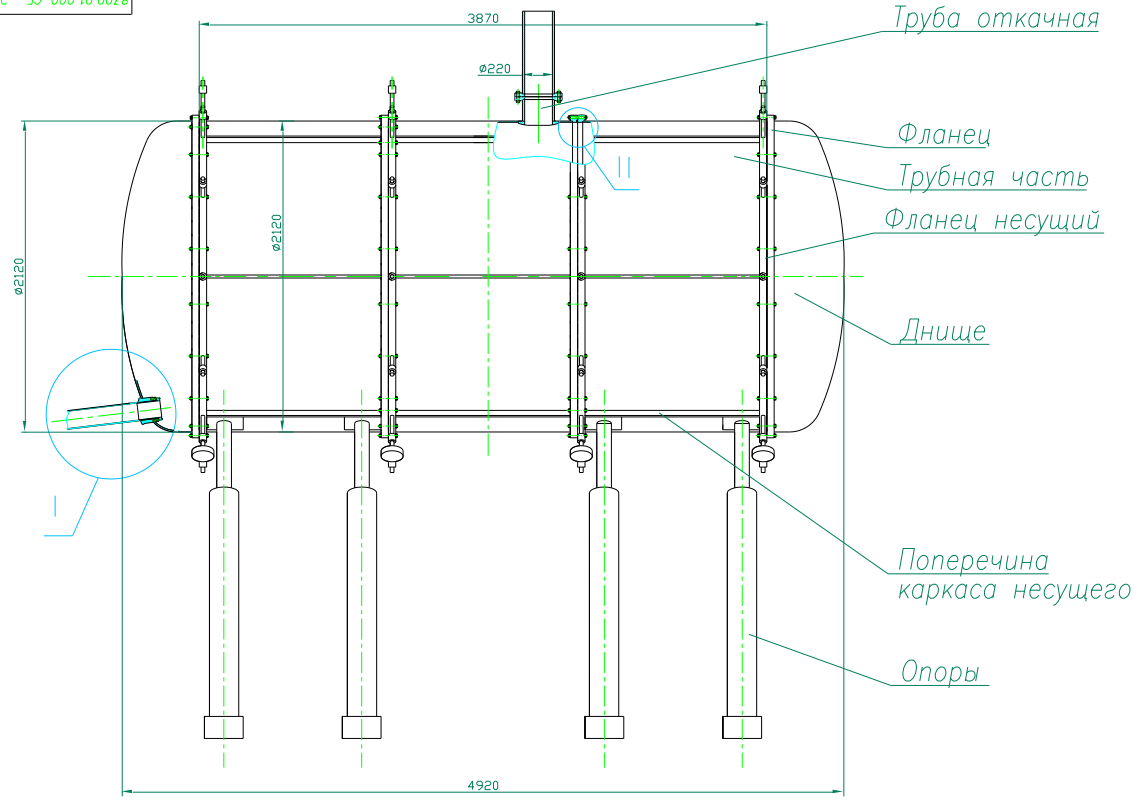


1. Размеры для справок

				8300.02.000 СБ - ЭП		
Исполн.	Д. Романов	С. Родина	Л. Давыд	Ловушка УХН	Листов	Масса
Разработ.	Л. Романов			Общий вид	Листов	1:15
Утвержден						
Инженер						
Удобр.						
				ПНДФ		

Vacuum chamber

И6 - 90 000100058

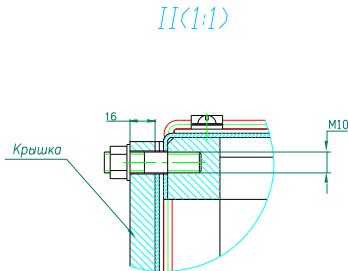
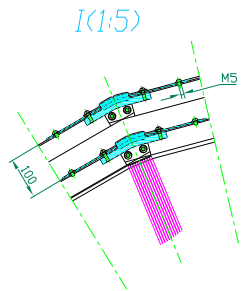
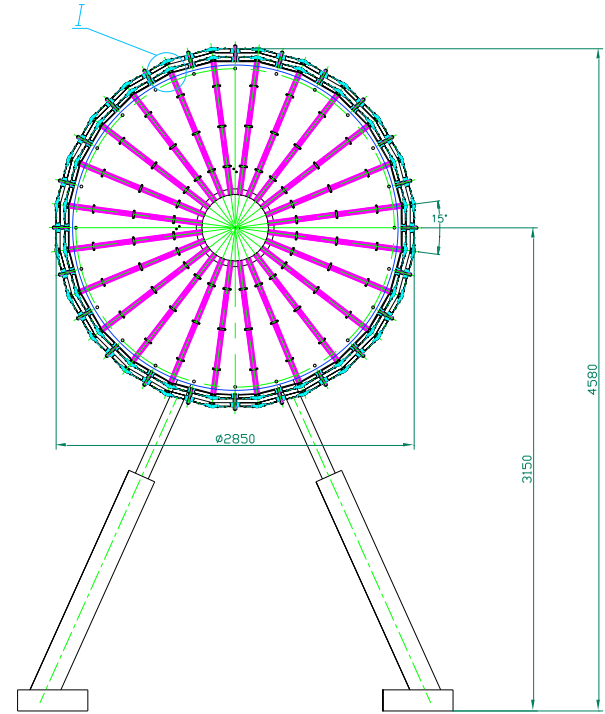
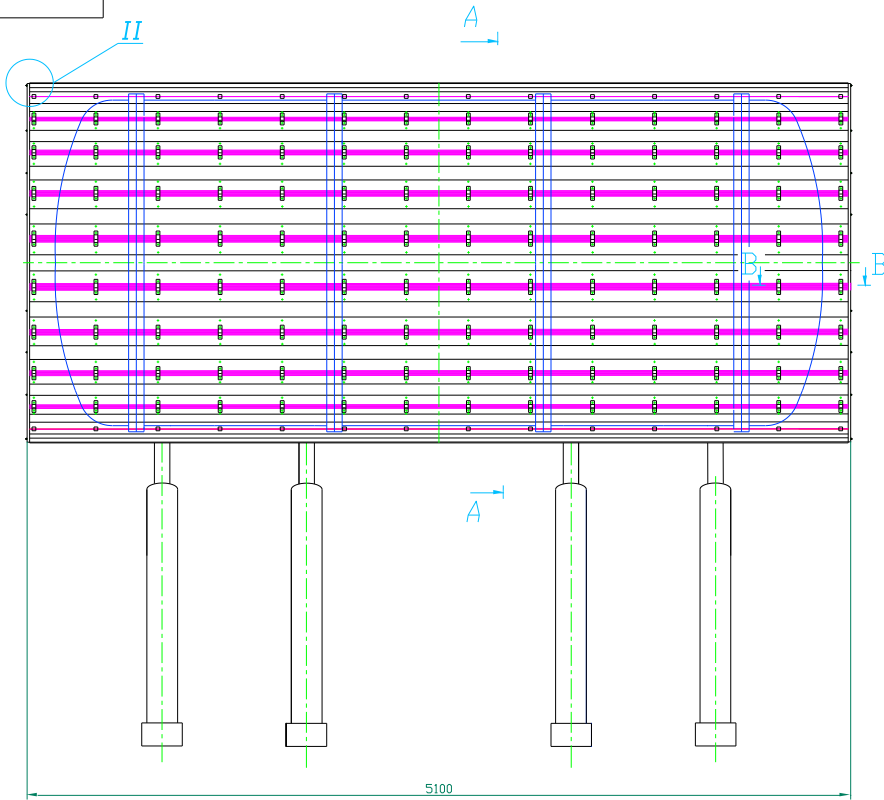


Размеры для справок

				8300.01.000 СБ - ЭП			
Изм	Лист	№ документа	Рабочая	Дата	Литера	Масса	Кол-во
Разработчик	Проверен	Утвержден	Составитель				
Вакуумная камера УХР				1:15			
Общий вид				Лист 1			
П.И.ЯФ				Литера			
Табл				Формат А1			

И6 - 90 000100058
 Спроектировал: М.
 Проверил: М.
 Утвердил: М.
 Дата: 10.01.2010

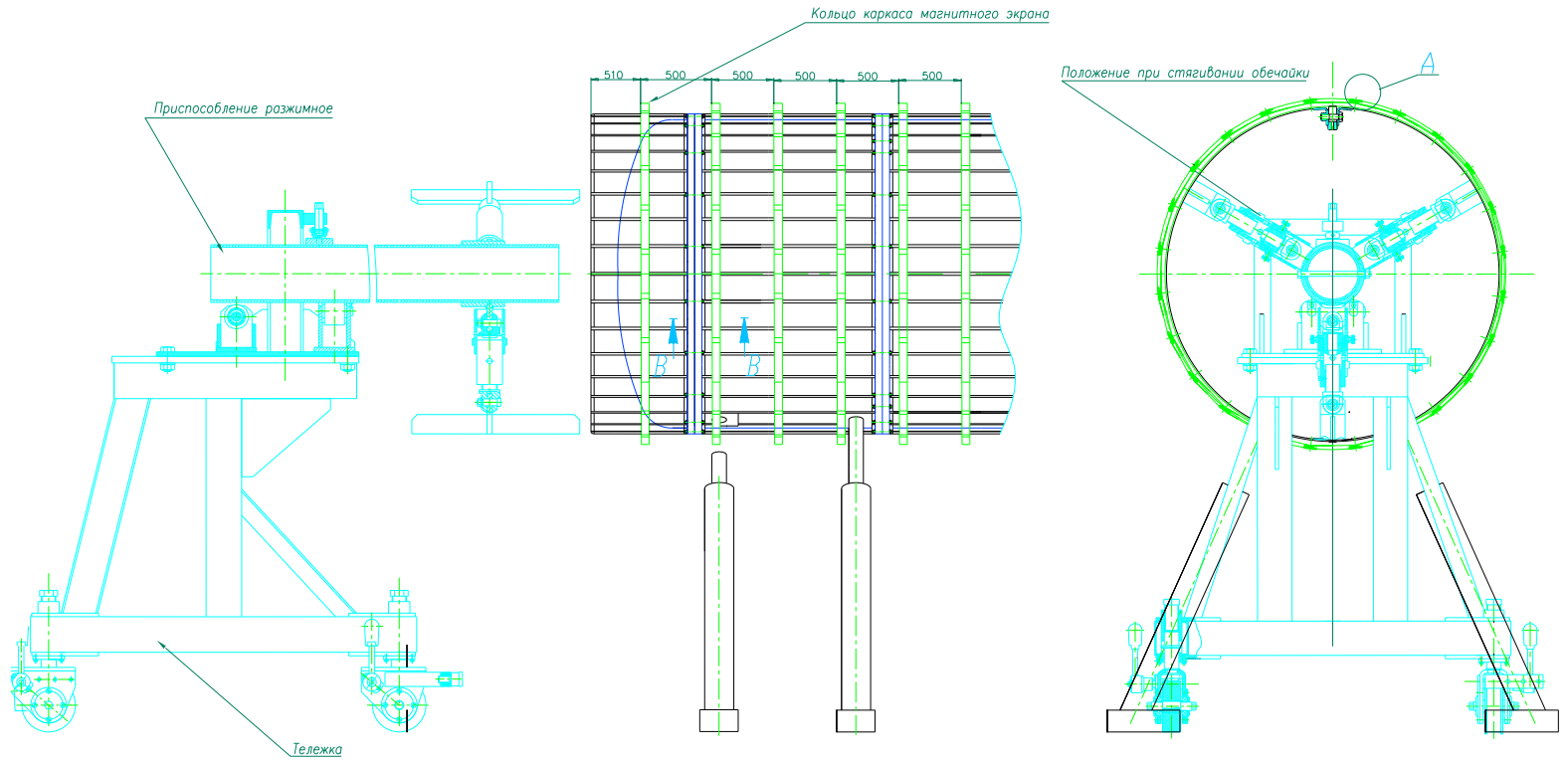
Magnetic shielding



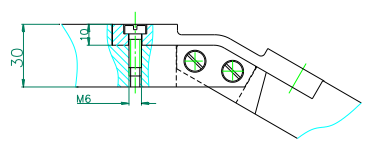
№	Лист	И.разработчик	Разреш.	Дата	Литера	Масса	Фасетов
		Лесина					1:15
Схема сборки магнитных экранов					Лист	Листов 1	
					ПН/ЯФ		

Magnetic shielding

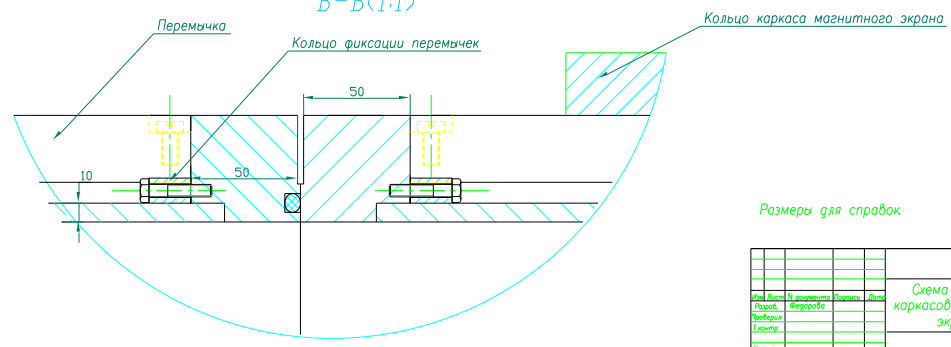
8300.12.000.СВ - 3М



A(1:1)



B-B(1:1)



Размеры для справок

№	Деталь	Материал	Объем	Вес	Деталь	Масса	Материал
1	Кольцо каркаса магнитного экрана	Сталь			1		
2	Перемычка	Сталь			2		
3	Кольцо фиксации перемычек	Сталь			2		
4	Болт	Сталь			4		
5	Гайка	Сталь			4		
6	Шайба	Сталь			4		
7	Пружина	Сталь			2		
8	Шпилька	Сталь			2		
9	Гайка	Сталь			2		
10	Шайба	Сталь			2		
11	Болт	Сталь			2		
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98	Болт	Сталь			2		
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100	Шайба	Сталь			2		

Схема сборки каркасов магнитных экранов

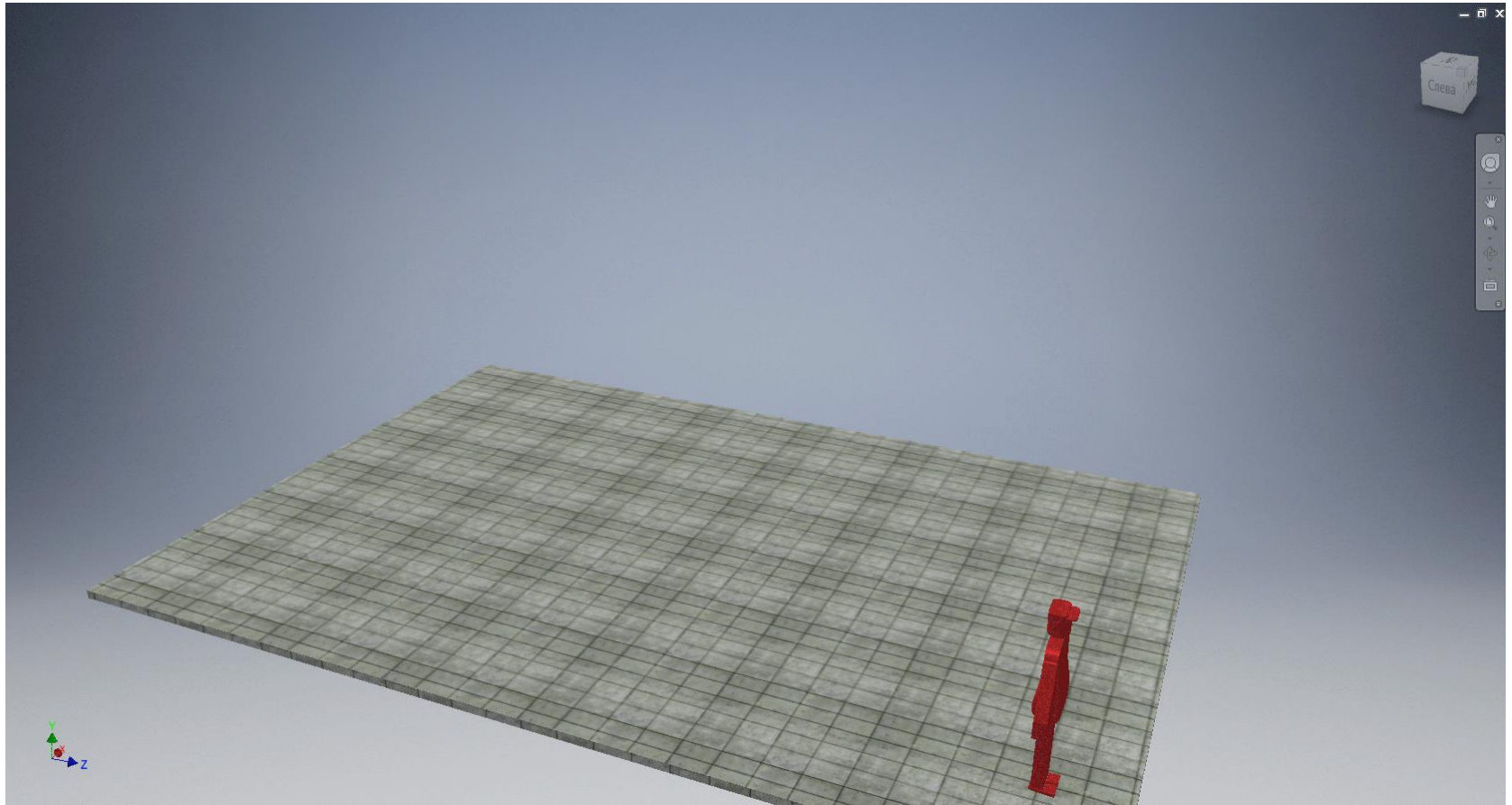
1:15

Лист 1 Листов 2

П.И.ЯФ

Формат А1

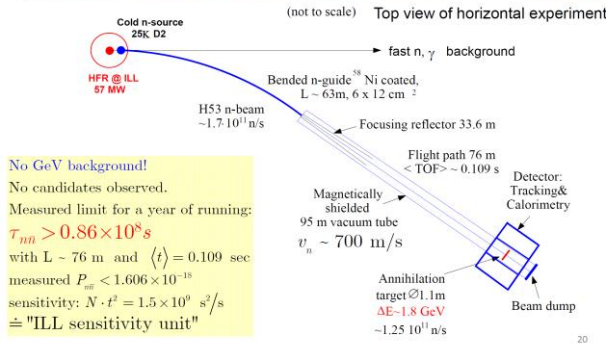
Design of the setup



Size matters

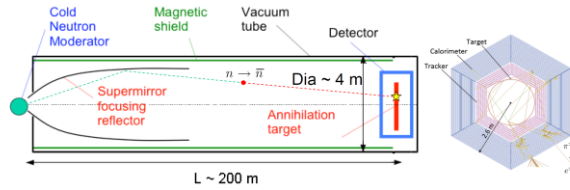
ILL

At ILL/Grenoble reactor in 89-91 by Heidelberg-ILL-Padova-Pavia Collaboration
 M. Baldo-Ceolin et al., Z. Phys., C63 (1994) 409

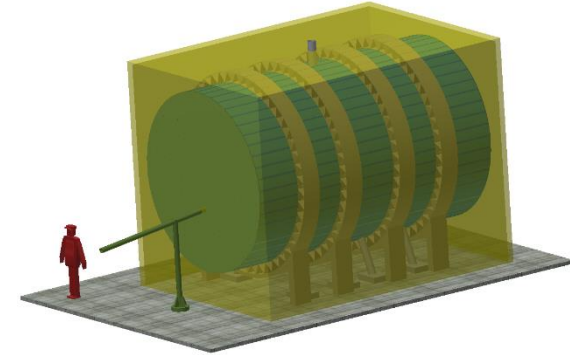


ESS

Scheme of Horizontal N-Nbar experiment for ESS Neutron Source



UCN



ESS



ILL



UCN

Schemes of UCN sources to compare the projects for WWR-M reactor and PIK reactor

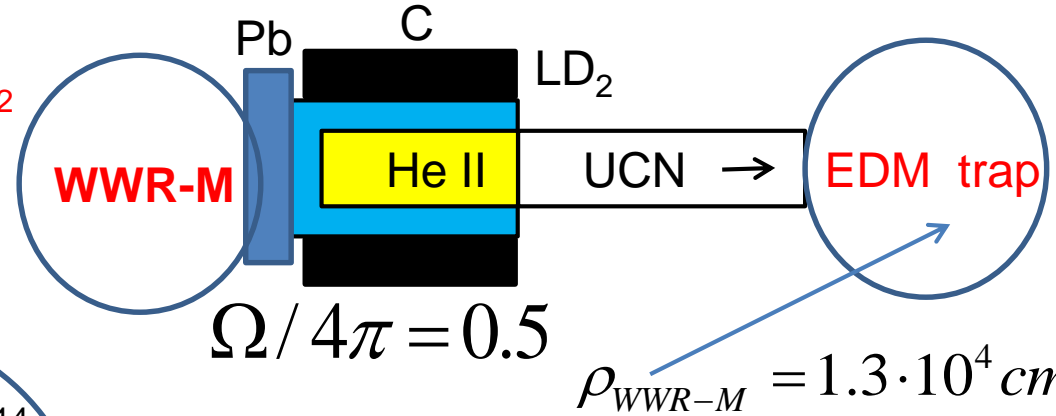
WWR-M

He II inside thermal column

$$\Phi = 3.2 \cdot 10^{12} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$$

$$d\Phi/d\lambda (9 \text{ A}) = 3.2 \cdot 10^{10} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{A}^{-1}$$

$$\Phi = 3.2 \cdot 10^{12} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$$



$$\rho_{WWR-M} = 1.3 \cdot 10^4 \text{ cm}^{-3}$$

PIK

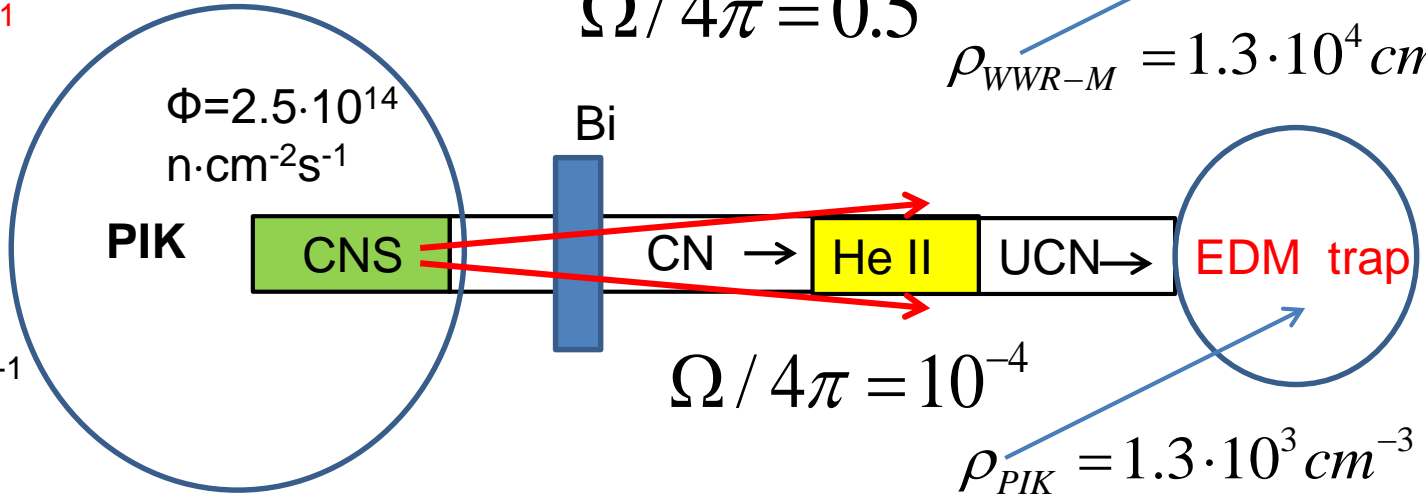
GEK 4-4'

He II on the beam

$$\Phi = 2.5 \cdot 10^{14} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$$

$$d\Phi/d\lambda (9 \text{ A}) = 10^9 \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{A}^{-1}$$

$$\Phi = 2.5 \cdot 10^{14} \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$$

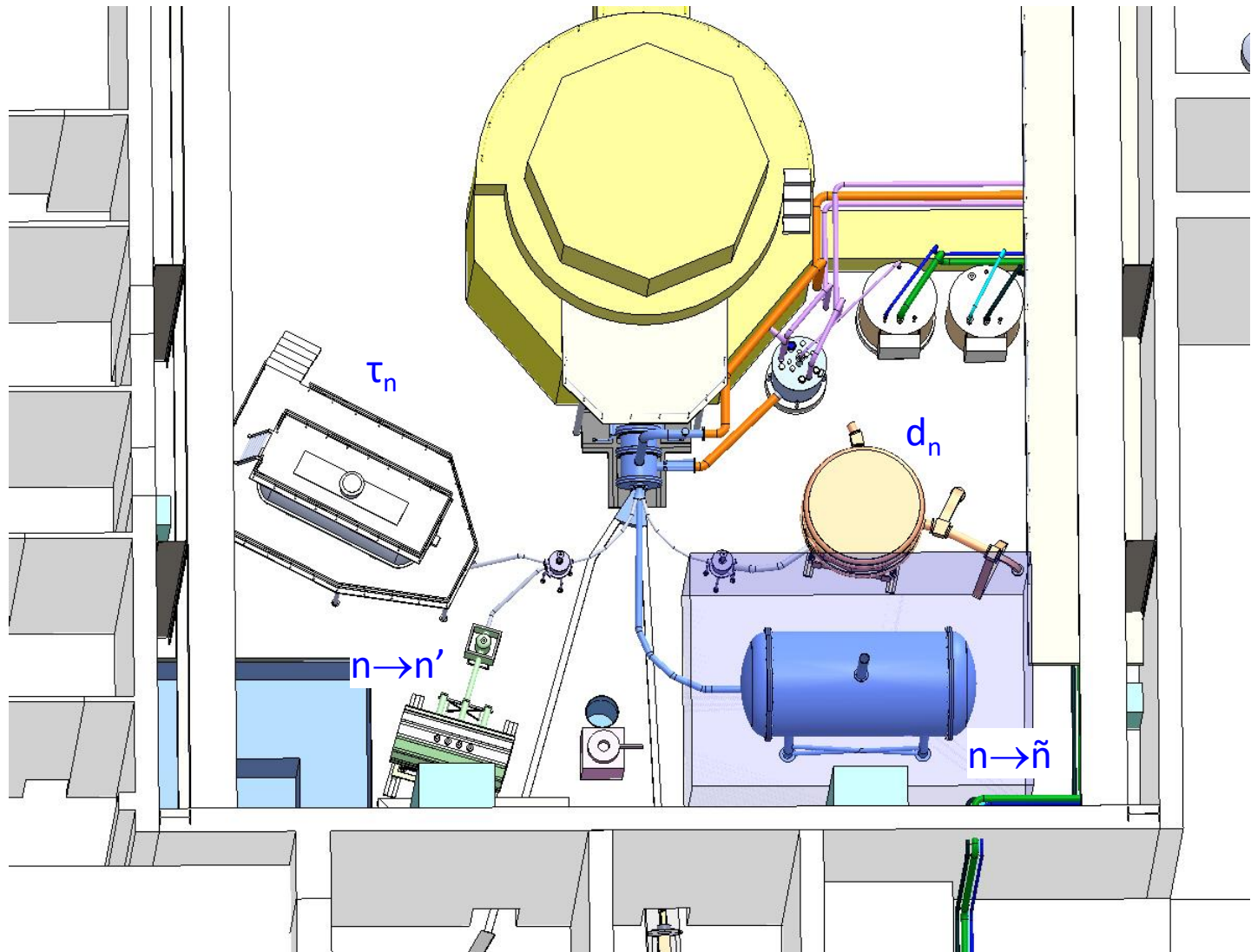


$$\rho_{PIK} = 1.3 \cdot 10^3 \text{ cm}^{-3}$$

$$\Phi_{WWR-M} \cdot \Omega_{WWR-M} / \Phi_{PIK} \cdot \Omega_{PIK} = 50$$

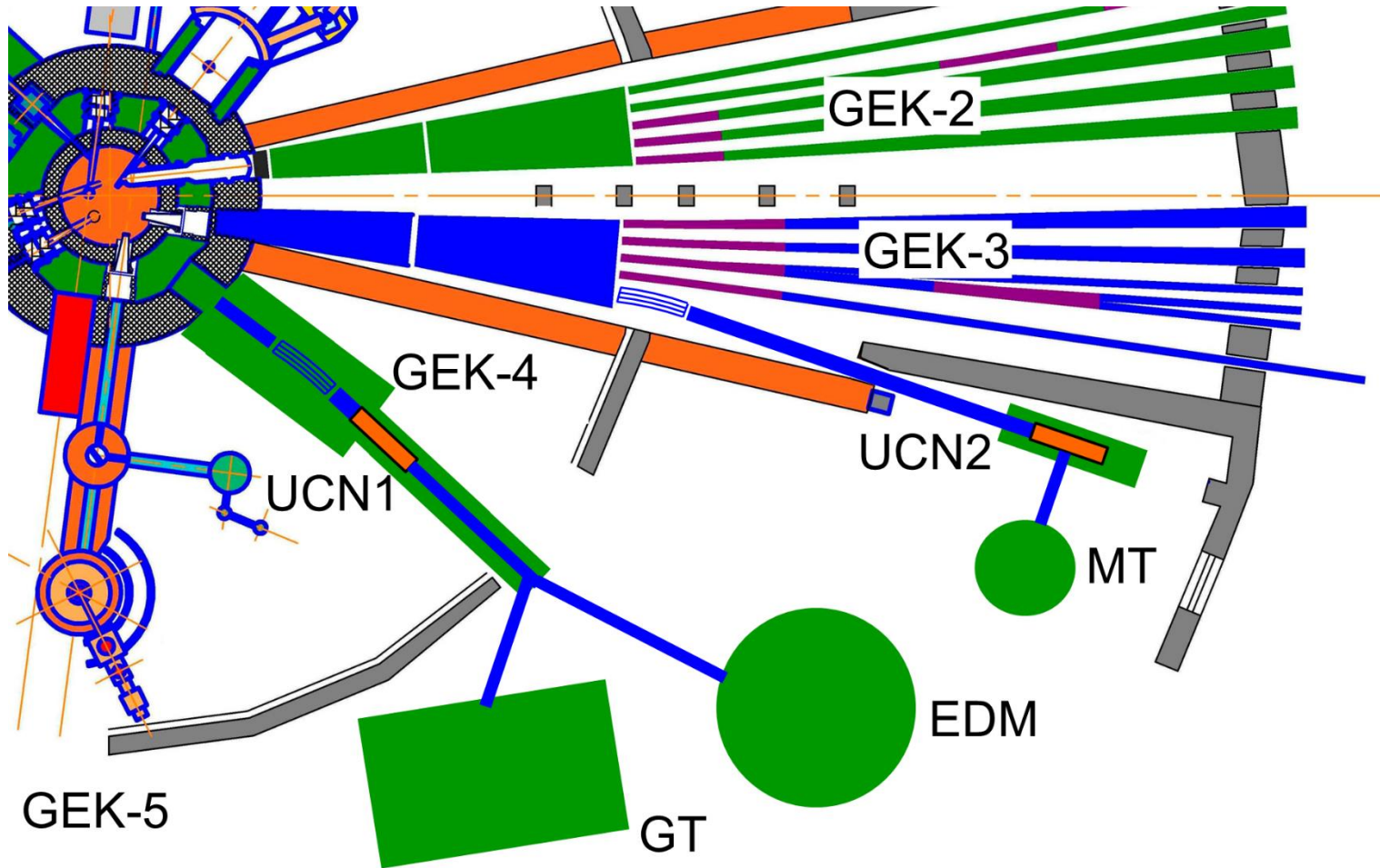
$$\rho_{WWR-M} / \rho_{PIK} = 10$$

UCN facilities at reactor WWR-M



The reactor is in the regime of long-term shutdown.

UCN facilities at reactor PIK



There is no place for large facilities in the reactor hall.

NNbar via UCN

source	$\Phi(\lambda=9 \text{ \AA}),$ $\text{cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$	sensitivity, ILL units	comment
WWR-M	$3 \cdot 10^{10}$	10-40	The reactor is in the regime of long-term shutdown.
PIK	10^9	1-4	There is no place for large facilities in the reactor hall.
ESS	?	?	The possibility of NNbar with UCN should be considered.

Conclusion

1. Designed storage trap for NNbar oscillation experiment:
horizontal cylinder with diameter 2 m, length 4 m.
2. Increase of the experiment sensitivity is about $10 \div 40$ times to ILL level at UCN source production 10^8 n/s.
3. Oscillation period for 3 years:
 $\tau_{n\bar{n}} \geq (0.6 \div 1.2) \cdot 10^9$ s (90% CL)

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