Nuclear physics at a new Dubna neutron source

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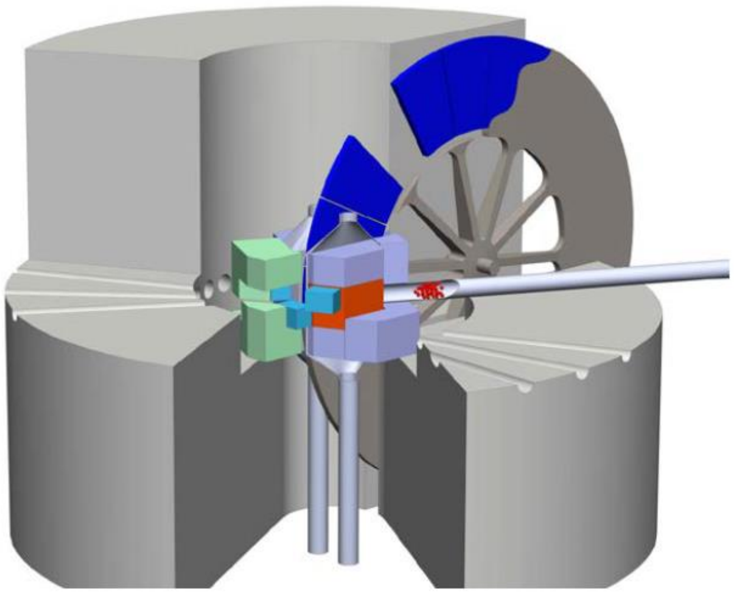
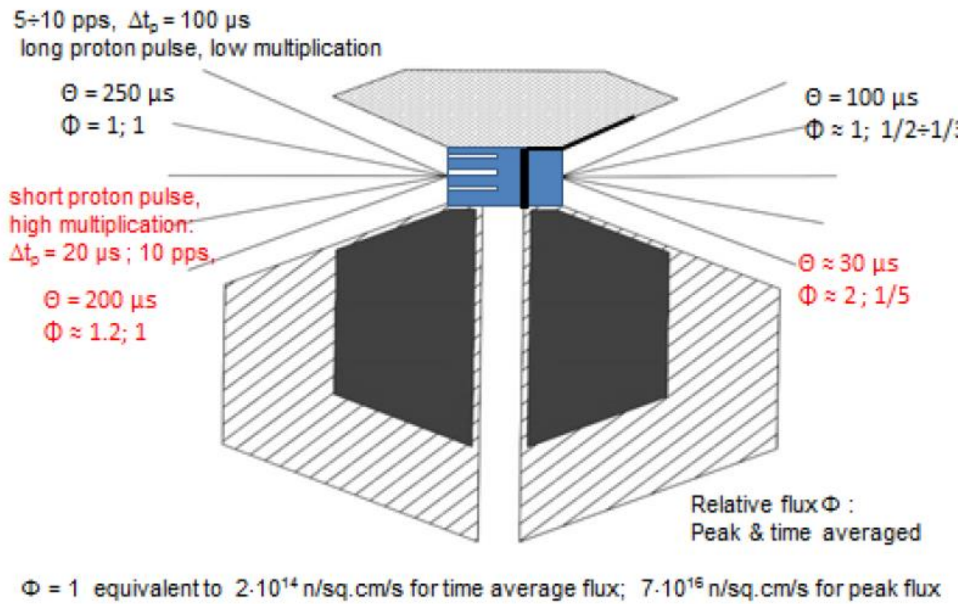
Reasons to discuss NUCLEAR PHYSICS PROGRAM at PAC for CONDENSED MATTER PHYSICS:

1. The new source has been discussed here several times.
2. To show that the nuclear researchers will need several neutron beams at a new source.
3. We hope that we are all interested in a very cold neutron source and we have to unite our efforts.

Possible scheme of a new source:





The other scheme was presented in the previous report by Prof. Yu.N.Pepelyshev

Principal features of the source

- based on the linear proton accelerator
- subcritical target with multiplication

Main parameters of the source

- Average thermal neutron flux density Φ_n not less than 10^{14} n/(cm^2·s)
- Instantaneous flux in pulse $\Phi > 10^{16}$ cm^{-2}·s^{-1}
- Pulse width 200 ÷ 300 μs and 20 ÷ 30 μs
- Repetition rate 10-30 Hz

List of nuclear physics experiments/fields discussed by Local Nuclear Physics Work Group depending on the pulse width and intensity:

1-100 ns …
100-400 ns …
The need additional target and other proton beam structure

20 ÷ 30 μs

- search for the new and known investigations of T-odd effects in neutron-nuclear resonances;
- measurements of parity-violating effects in the lowest neutron resonances;
- precise measurements of neutron cross sections in low-lying resonances;

200 ÷ 300 μs

- measuring of neutron-neutron scattering cross section;
- measuring of neutron life-time;
- UCN physics at high density source (separate long list);
- research using VCN (will be shown below);

Does not need the pulse structure

- UCN physics at an intense source (long list);
- search for symmetry breaking in fission and reactions with light nuclei;
- Investigations of exotic neutron rich nuclei;

VCN is the instrument to get new quality of measurements

UCN → **VCN** → CN

are widely used in precision particle physics experiments

extremely broad applications in various domains: solid state, soft matter, surface physics, magnetism, chemistry, biology, precision studies of the neutron decay and in studies of fundamental symmetries

neutrons (v=8÷200 m/s) are very attractive for:

- **search for extra-short-range interactions at neutron scattering;**
- **experiments with neutrons in a whispering gallery;**
- **beam experiment to measure the neutron life-time;**
- **search for neutron-antineutron oscillations;**
- **…**
- **spin-echo technique;**
- **reflectometry;**
- **high-resolution inelastic scattering;**
- **small angle scattering;**
- **diffraction;**
- **…**

Advantages of VCN:

- long time observation;
- large angles of reflections from mirrors;
- larger phase shift and as result more sensitive to contrast variation;
- large capture cross-section and big contrast at transmission;
- large wavelength;
- …

VCN would give new quality of measurements

Disadvantage of VCN:

Small flux intensity (as for UCN it is only a part of spectrum)

There are a lot of papers concerning the VCN applications and perspectives:

- R.Golub "The production of very cold neutrons" **Physics Letters A** Volume 38, Issue 3, 31 January **1972**, Pages 177-178
- V. V.Golikov, V.I.Lushchikov, and F.L.Shapiro "Production of very cold neutrons" Zh. Eksp. Teor.Fiz.64, 73-81(January **1973**)
- Roland Gähler, Anton Zeilinger "Wave-optical experiments with very cold neutrons" American Journal of Physics **59**, 316 (**1991**)
- E. M. Rasel, K. Eder, J. Felber, R. Gähler, R. Golub, W. Mampe, A. Zeilinger (**1994**) "Interferometry with very Cold Neutrons". In: van der Merwe A., Garuccio A. (eds) Waves and Particles in Light and Matter. Springer, Boston, MA
- van der Zouw G., Weber M., Felber J., Gahler Roland, Geltenbort P., Zeilinger A. (**2000**). "Aharonov–Bohm and gravity experiments with the very-cold-neutron interferometer." NIM A: 440. 568-574
- R. Georgii , N. Arend , P. Böni , D. Lamago , S. Mühlbauer & C. Pfleiderer "Scientific Review: MIRA: Very Cold Neutrons for New Methods" **Neutron News** Volume 18, **2007 - Issue 2 ,** Pages 25-28
- V.V. Nesvizhevsky "Reflectors for VCN and applications of VCN" REVISTA MEXICANA DE F´ISICA S **57** (1) 1–5 (**2011**)

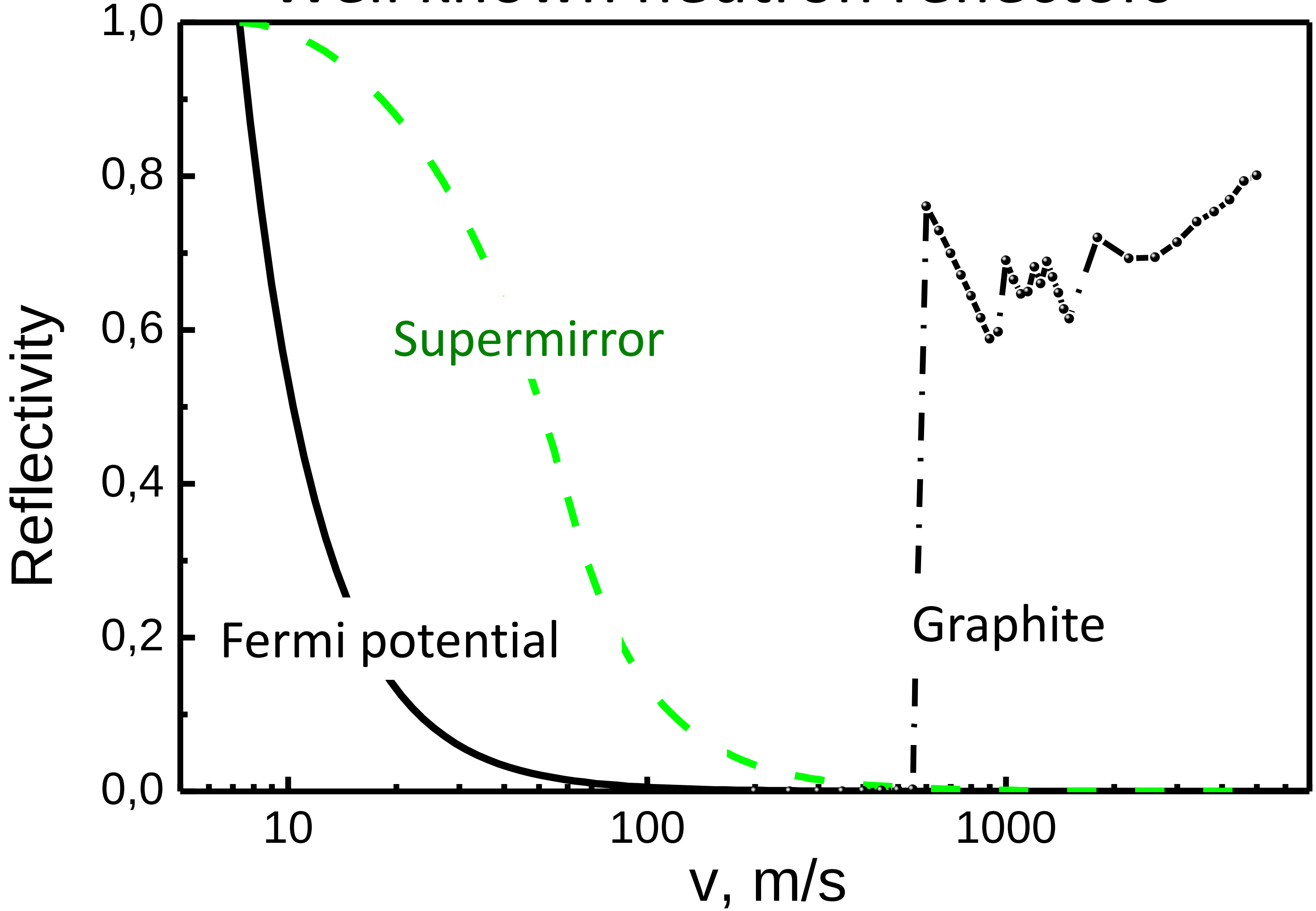
Dedicated workshops:

- **«Workshop on Applications of the Very Cold Neutron Source»**
- 21-24 August 2005 at IPNS-ANL
- **«Present Status and Future of Very Cold Neutron Applications»**
- 13-14 February 2006 Paul Scherrer Institute - Switzerland
- **«Very Cold Neutron Source for the Second Target Station Workshop»**
  27-28 April 2016 Oak Ridge National Laboratory, SNS Building 8600

Developing of new technology: reflectors for very cold neutrons. It allows one to increase the intensity of VCN

- V.V. Nesvizhevsky, E.V.Lychagin, A.Yu.Musychka, A.V.Strelkov, G. Pignol, K.V. Protasov "The reflection of very cold neutrons from diamond powder nanoparticles" // NIM A **595**, (2008) 631-636
- Lychagin E.V., Muzychka A.Yu., Nekhaev G.V., Nesvizhevsky V.V., Pignol G., Protasov K.V., Strelkov A.V. "Storage of very cold neutrons in a trap with nano-structured walls" Physics Letters B 679 (2009) 186–190
- R. Cubitt, E.V. Lychagin, A.Yu. Muzychka, G.V. Nekhaev, V.V. Nesvizhevsky, G. Pignol, K.V. Protasov, and A.V. Strelkov (2010). "Quasi-specular reflection of cold neutrons from nano-dispersed media at above-critical angles." NIM A 622: 182-185.
- A. R. Krylov, E. V. Lychagin, A. Yu. Muzychka, V. V. Nesvizhevsky, G. V. Nekhaev, A. V. Strelkov, and A. S. Ivanov "Study of Bound Hydrogen in Powders of Diamond Nanoparticles" // Crystallography Reports, 2011, Vol. 56, No. 7, pp. 102–107
- V. V. Nesvizhevsky, M. Dubois, Ph. Gutfreund, E. V. Lychagin, A. Yu. Nezvanov, and K. N. Zhernenkov, " Effect of nanodiamond fluorination on the efficiency of quasispecular reflection of cold neutrons", Phys. Rev. A 97, 023629

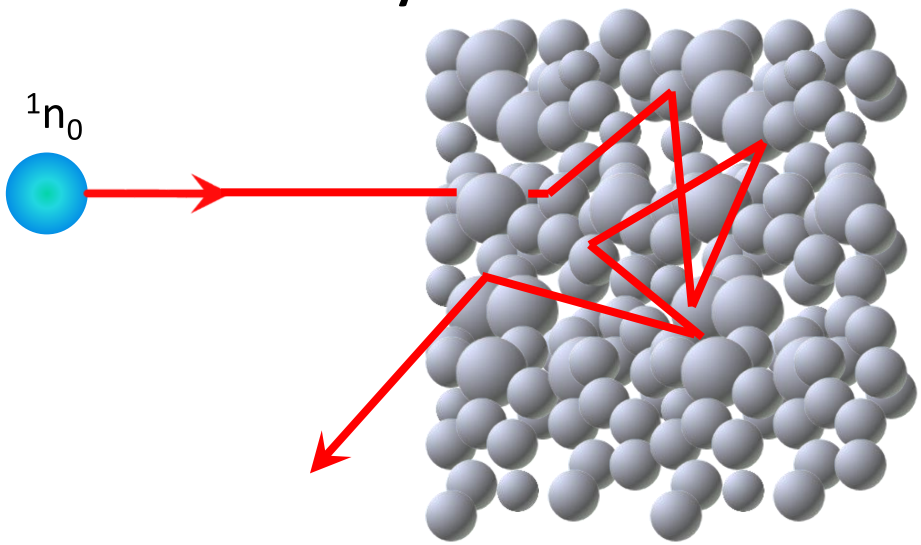
Well known neutron reflectors



Elastic reflectivity for isotropic neutron flux

Diamond nanoparticles as neutron reflectors

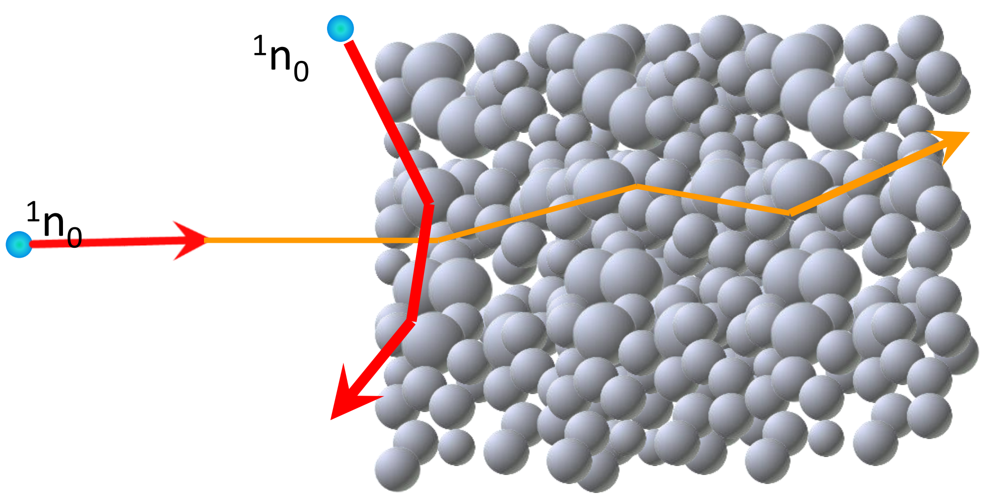
Very cold neutron reflector ($E<10^{-4}$ eV)



- Large scattering probability
- Large scattering angle
- Small penetration

Possible to have an efficient reflector at any incident angle

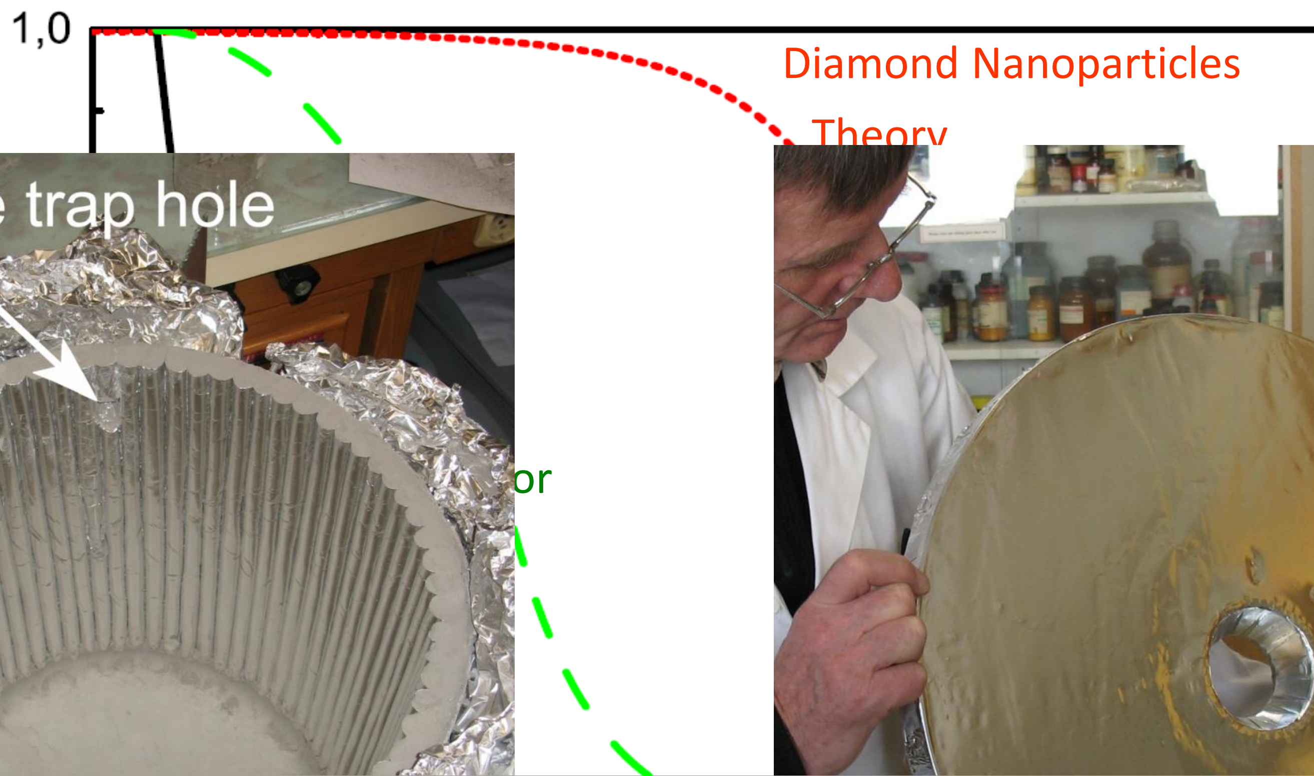
Cold neutron reflector ($E<5\cdot10^{-3}$ eV)

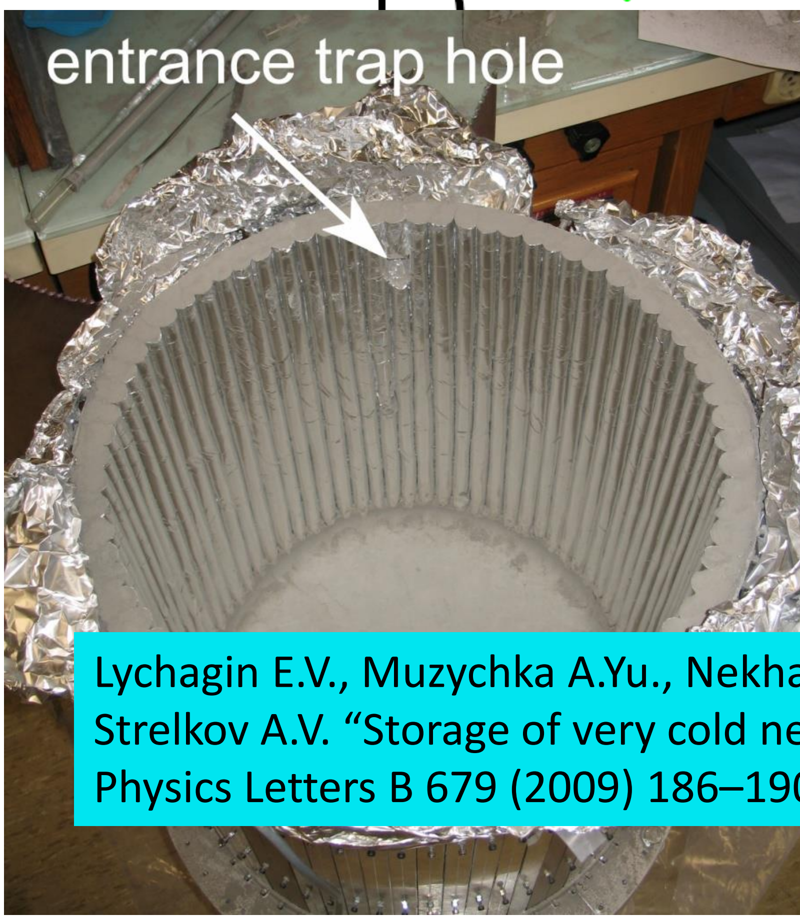


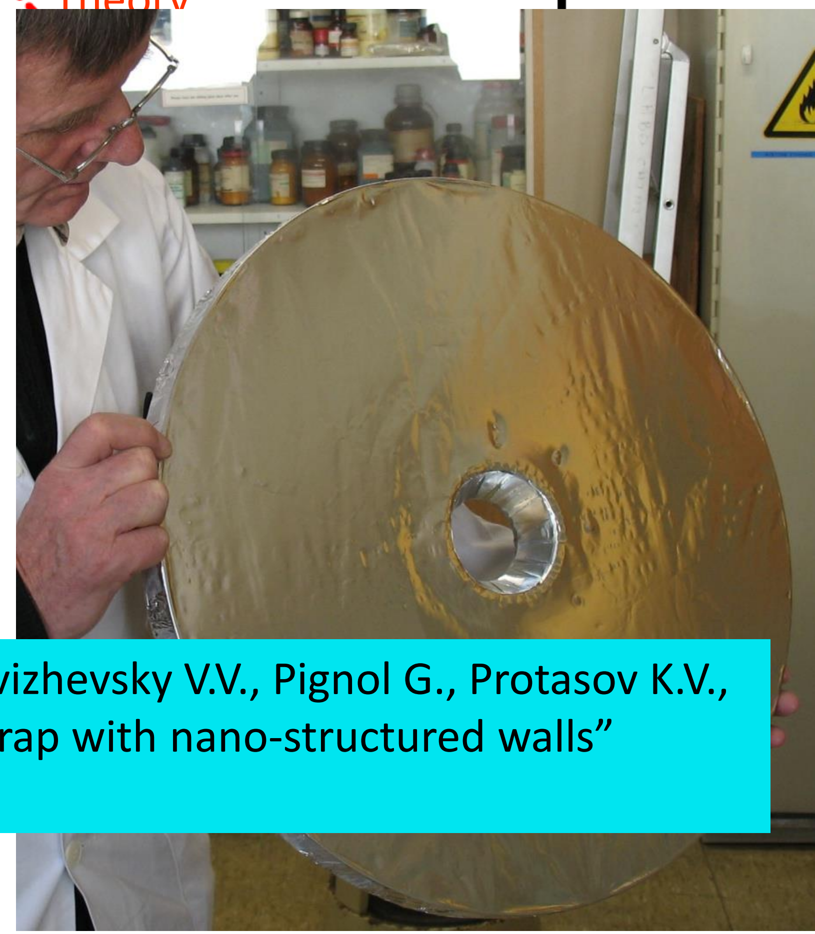
- Small scattering probability
- Small scattering angle
- Deep penetration

Possible to have an efficient reflector only at gliding angle of neutron incidence

Measurement of VCN storage in a diamond nanopowder trap
Neutron reflection probability via neutron velocity:







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Diamonds of detonation synthesis (Nanodiamond) is the best choice

Advantages: big "contrast", small size of particles, low neutron capture

Disadvantages: - hydrogen admixture: ~10% of nuclei
- admixture of metal impurities and activation in neutron fields as the result

Fluorination is a method to clean particles from hydrogen

Non-degased sample $C_{7.4\pm0.15}H$

Degased sample $C_{12.4\pm0.2}H$

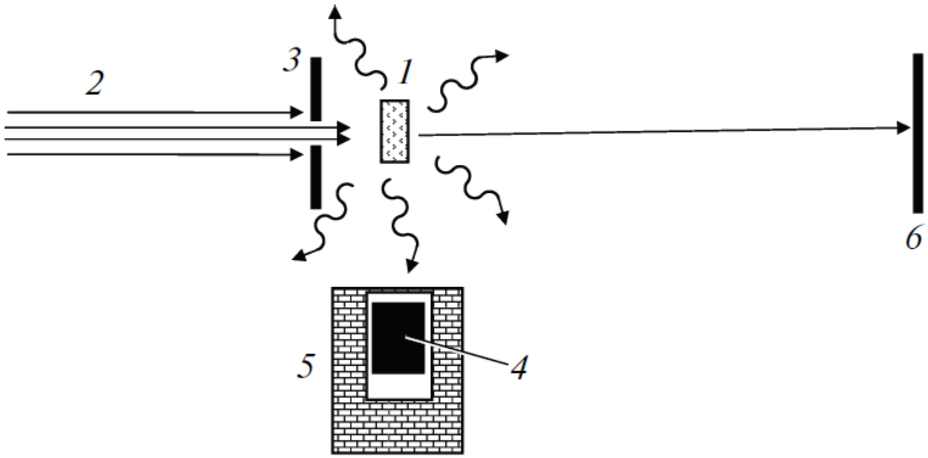


Fig. 1. A scheme of the measurement of a fraction of hydrogen in powder. 1—sample; 2—neutron beam; 3—collimator; 4—γ-detector; 5—detector shielding; 6—neutron detector.

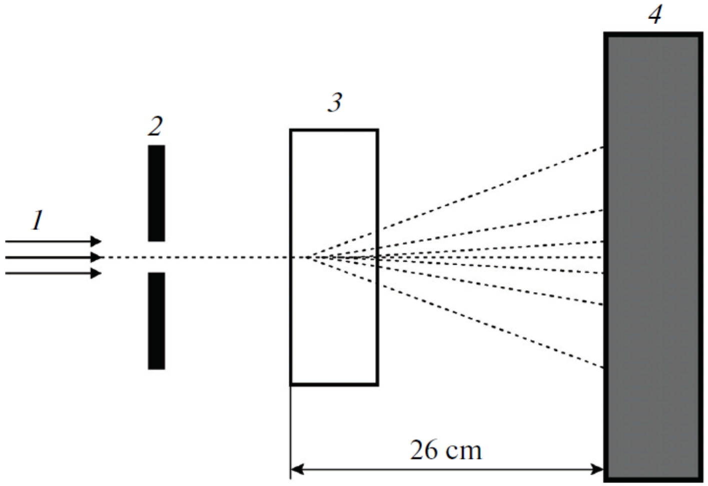
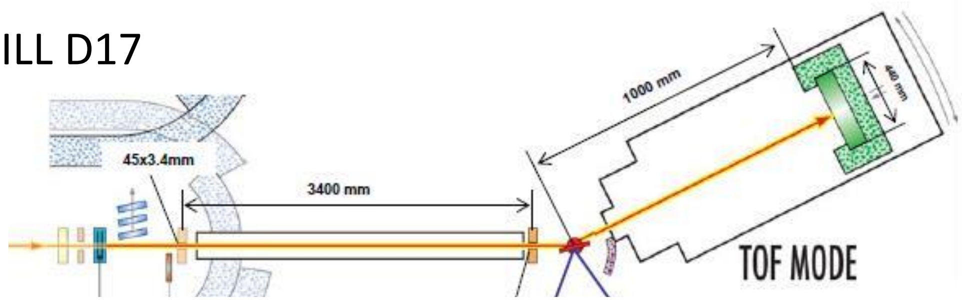


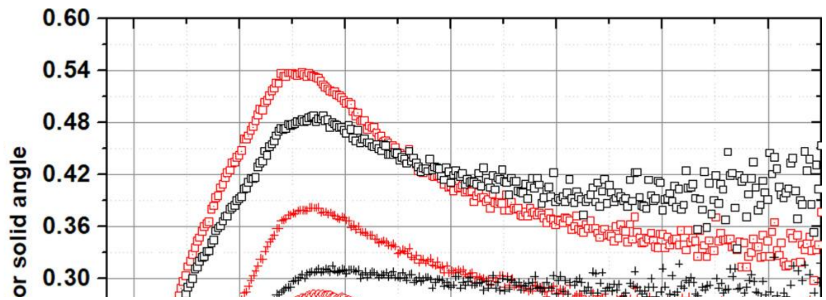
Fig. 3. A scheme of the measurement of the total cross-section of neutron scattering. 1—neutron beam; 2—diaphragm; 3—sample; 4—position-sensitive neutron detector.

Fluorinated sample $C_{430\pm30}H$

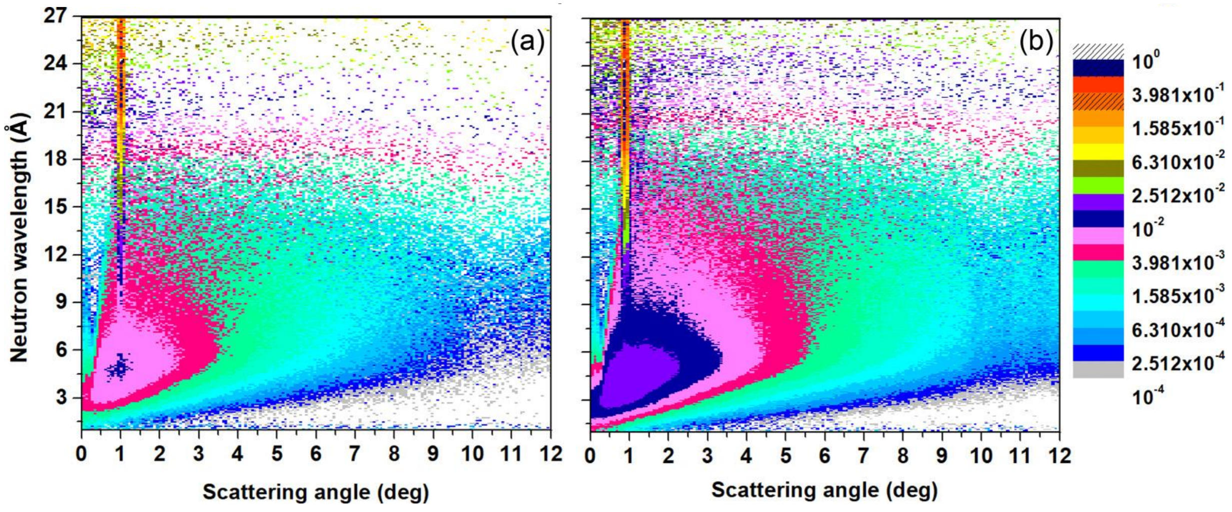
Improvement for CN after fluorination

ILL D17





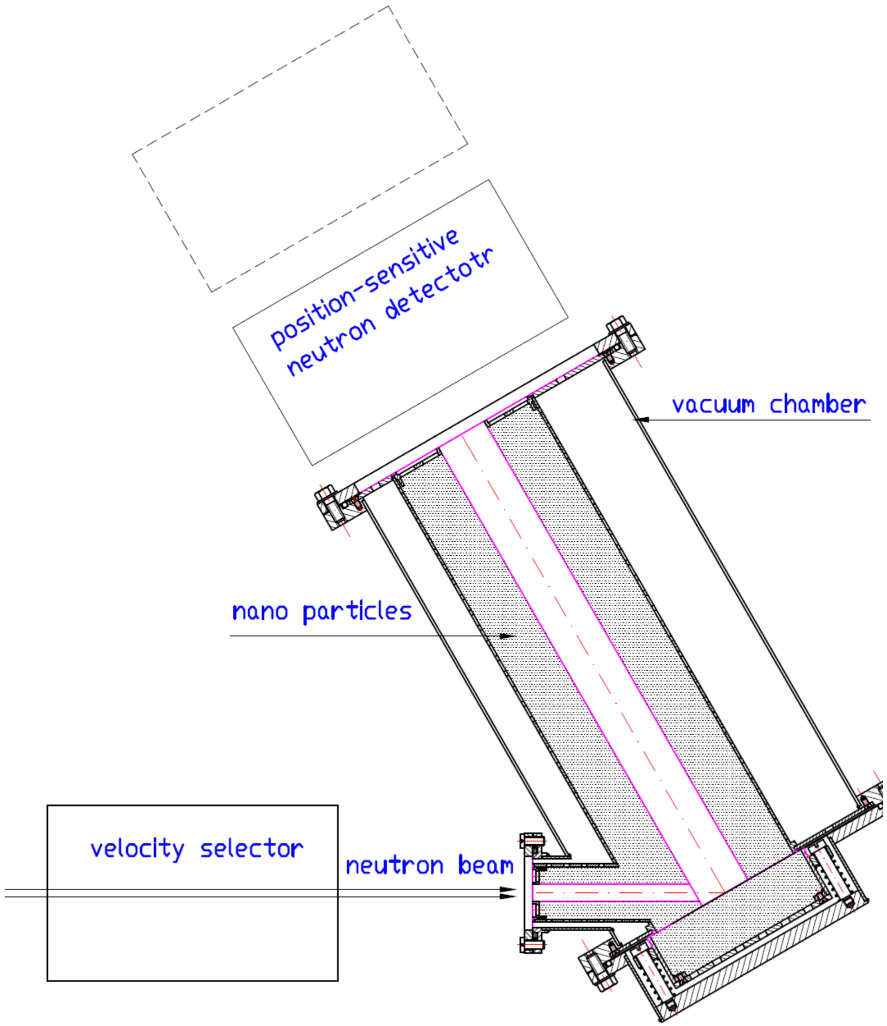
The result was reported at ISINN-25 by K.Zhernenkov and published
V.V. Nesvizhevsky, M. Dubois, Ph. Gutfreund, E.V. Lychagin, A.Yu. Nezvanov, and K.N. Zhernenkov
Physical Review A **97** 023629 (2018)

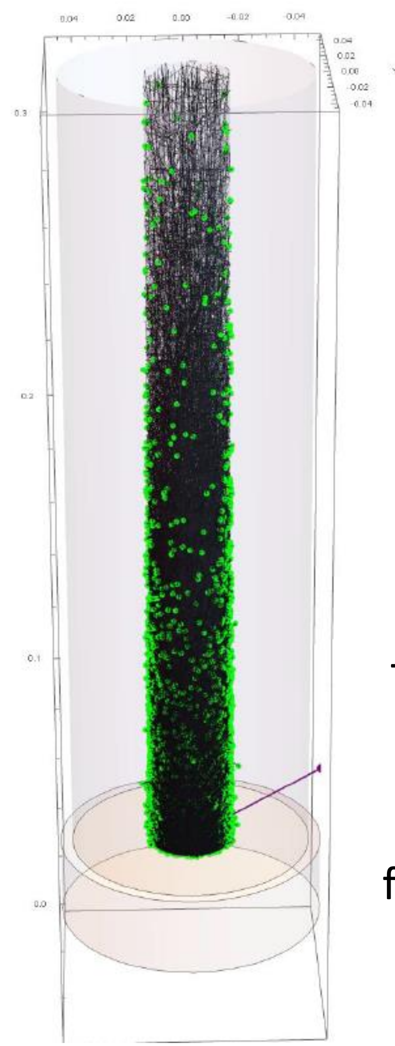


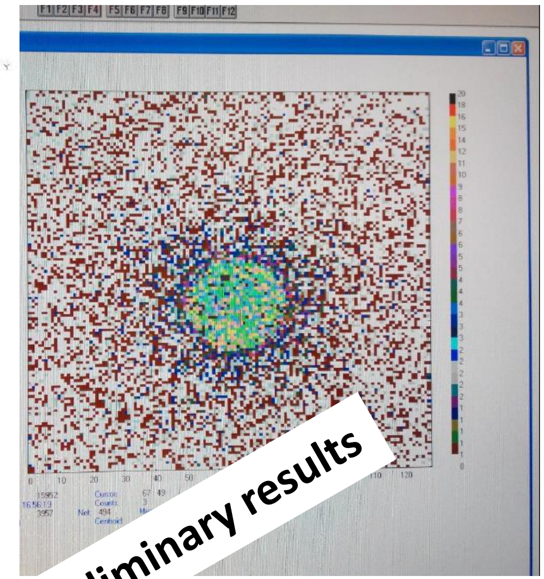
Neutron wavelength (Å)

The general probability of neutron scattering (within the angular acceptance of the D17 position-sensitive detector) as a function of the neutron wavelength, for the incidence angles of 1deg., 2deg., 3deg.

Experimental VCN extractions from the model source







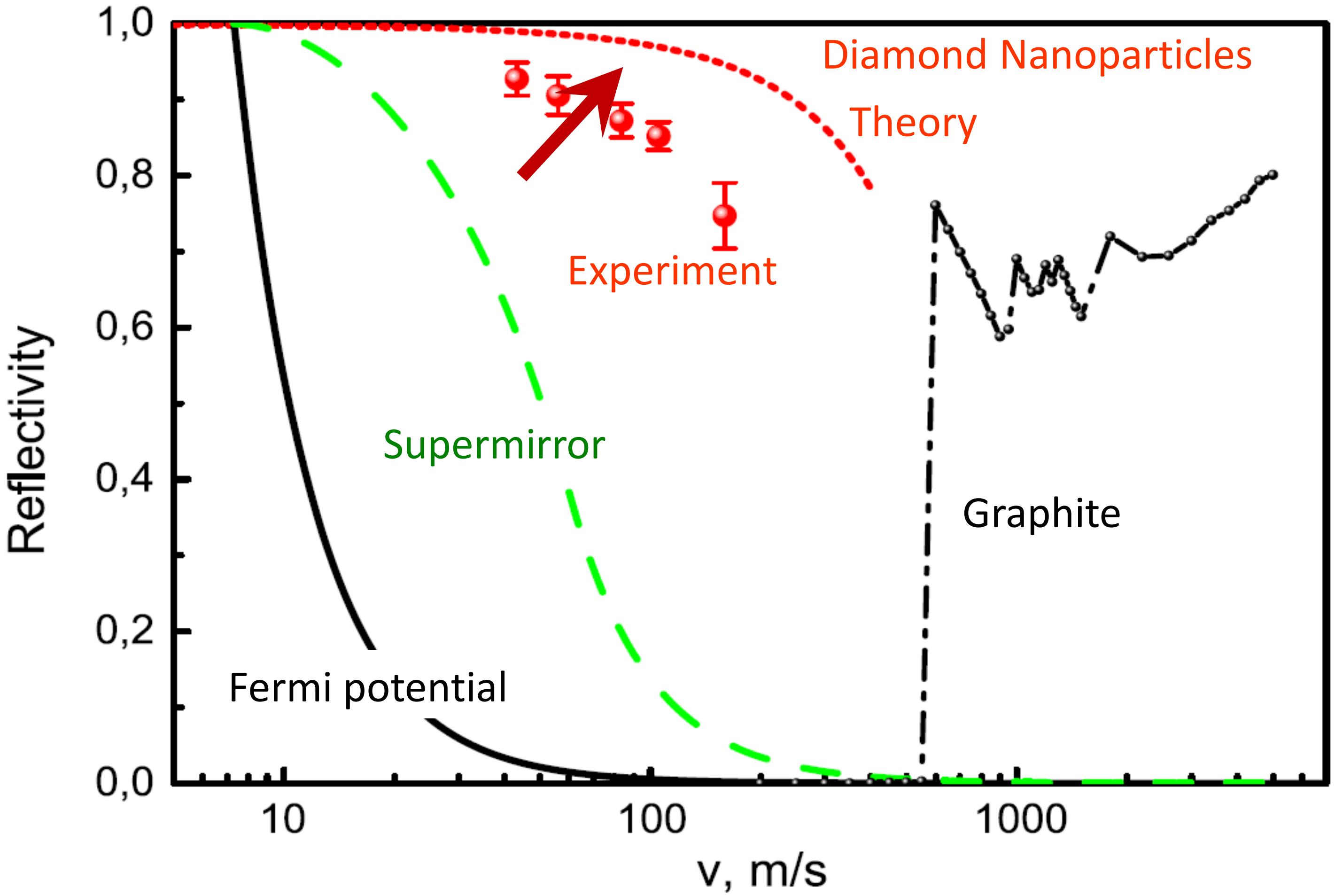
Preliminary results

The gain factor is about

10 times

It can be improved by further powder cleaning against impurities

With fluorinated powder we are somewhere near the tip of the arrow



Further improvement is related with deagglomeration, cleaning against nitrogen and metal impurities

Conclusions

1. Nuclear physics has a wide research program for a new neutron source and will require neutron beams.
2. We definitely would like to have an intensive UCN source.
3. Very cold neutrons are a very promising tool for research in the field of solid state physics as well as in particle physics.
4. Diamond powder could be used as efficient reflector for VCN (at any angles) and for CN (at gliding angles).
5. It has been demonstrated that there are new reflectors for efficient VCN extraction from the source.
6. It is needed to include UCN and VCN sources to the list of new neutron source tools. New developments for VCN reflectors should be taken into account to construct the VCN source.

Thank you for your attention