Novel neutron reflectors

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Phase space density and Liouville's theorem

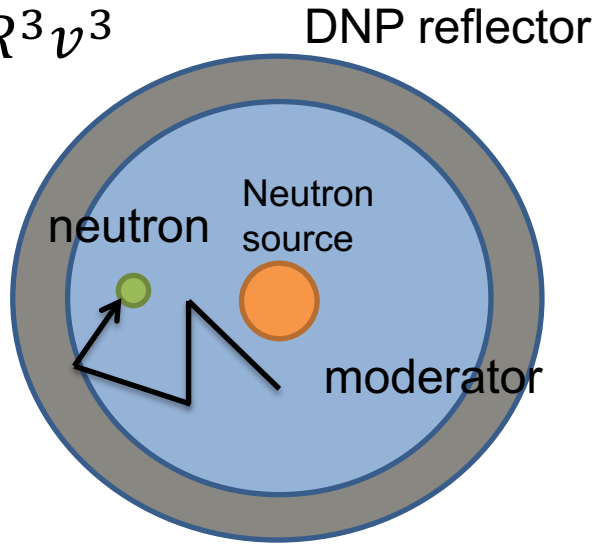
- Phase space density, the density in 6 dimensions:
  - Spatial volume (x, y, and z)
  - Velocity volume (v_x, v_y and v_z)

is the most essential parameter for neutron source because **Conserved force can not change the phase space density** (Liouville's theorem).

$$Phase\ Space\ Density \propto \frac{N}{R^3 v^3}$$

Thus, we need to increase/decrease

- N:Initial Number of particles (Beam power)
- **R^3:Volume (Production in Small volume)**
- **v^3**:Velocity (cooling to low temperature)



Neutron reflectors

Requires

- Large scattering cross section
- Small capture cross section

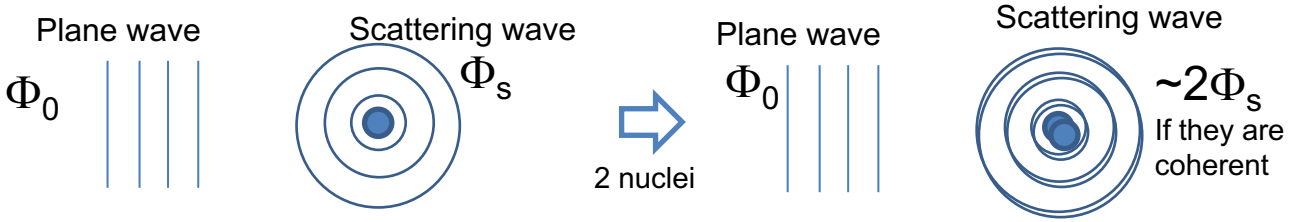
Typically,

- Graphite (reactor grade)
- Be
- Pb

are used for the reflectors of neutron sources.

Large scattering of Diamond Nano Particle (DNP)

Coherent scattering by diamond nano particles is a candidate of the good reflector.



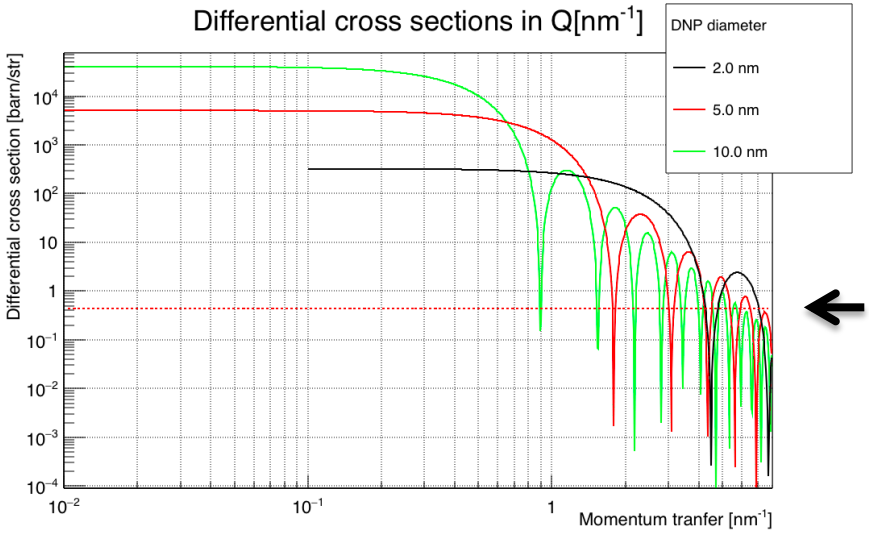
Scattering Cross section
$\sigma \propto |2\Phi_s|^2 = 4|\Phi_s|^2 = 2\sigma_0$

Scattering cross section Low-Q can be described by born Approximation.

$$\Phi(\theta) = -\frac{1}{4\pi}\frac{2m}{\hbar}\int e^{i\boldsymbol{q}\cdot\boldsymbol{r}}V(\boldsymbol{r})d\boldsymbol{r} = -\frac{2m}{\hbar}U_0\mathrm{R}^3\left(\frac{\sin(qR)}{(qr)^3} - \frac{\cos(qR)}{(qr)^2}\right)$$

Diamond nano particle (DNP) is expect to have large coherent scattering

V.V. Nesvizhevsky, arXiv:nucl-th/0510021v2

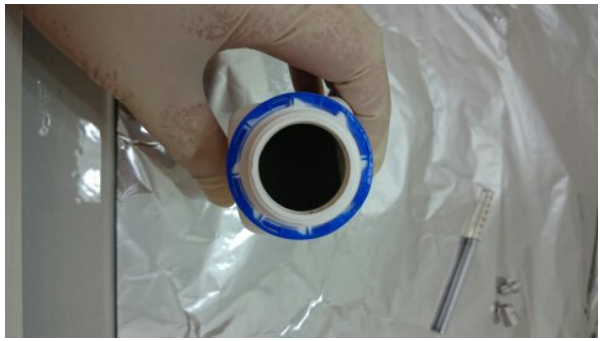


Differential Cross section of single ^{12}C

Cross section gains factor of >1000 for low-q region (<1 nm^{-1}).

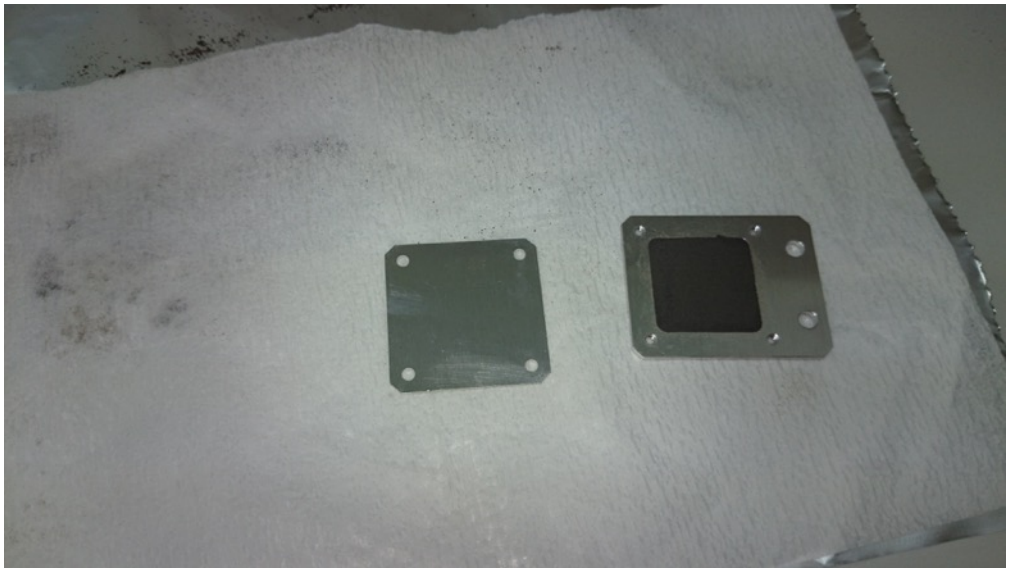
DNP powder

- Air brown: Molto Neuvo®
  - Diameter: 4-6 nm
  - Purity: 97%
  - Water content: 2%
  - Diamond density: 3.1-3.2 g/cm^3
  - Power density: 0.4-0.5 g/cm^3
  - Cost: 1500JPY(11BGP)/g



- Different cross section of the DNP powder was measured at BL21 (NOVA) at J-PARC
  - Appling pressure to increase packing density.
  - Scattering and transmission was measured.

Powder sample



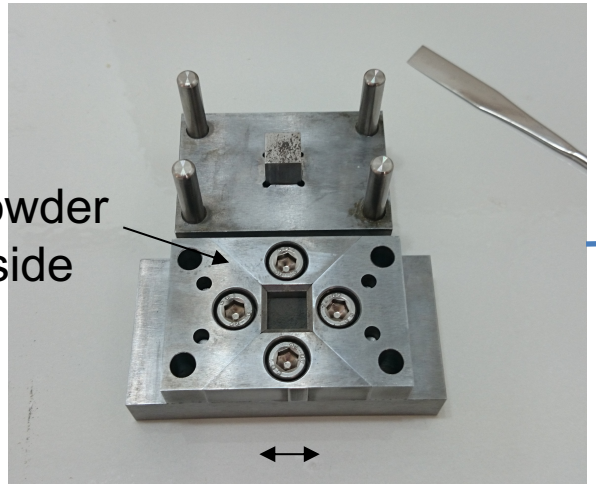
DNP powder was filled in Al cell

- Volume 20 x 20 x 1.0 mm
- Mass 0.1616 g
- Density 0.404 g/cm^3

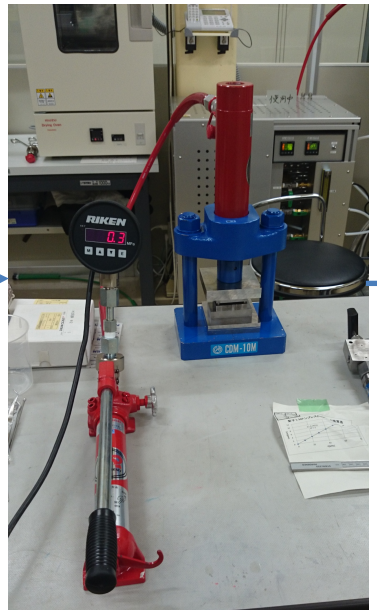
Diamond density 3.1~3.2 g/cm^3 → Filled only 13%.
50% is ideal to obtain largest scattering.

Compression of DNP powder

Pressure cell



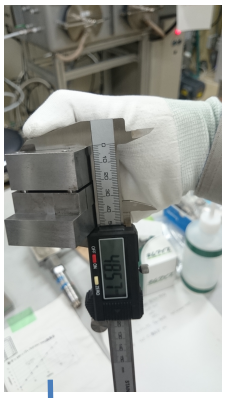
Mini Press

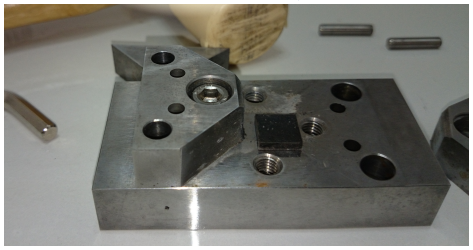


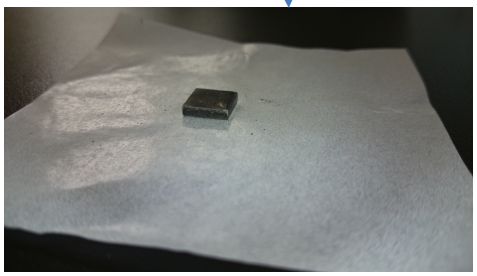
Applied ~150 MPa

Before
6.25mm

After
2.57 mm





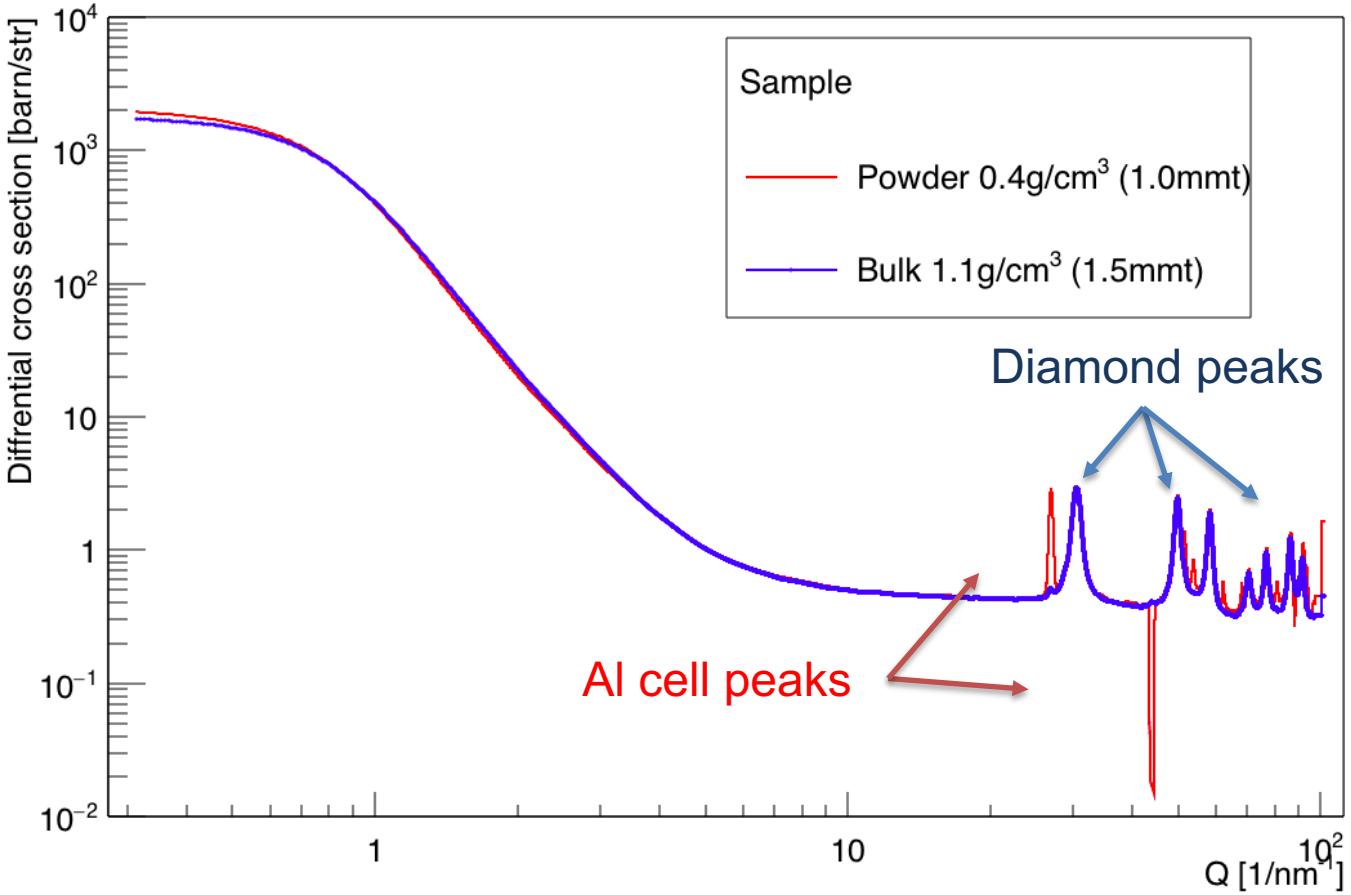


Packing density 1.1 g/cm^3

To increase packing density, pressure was applied on DNP.

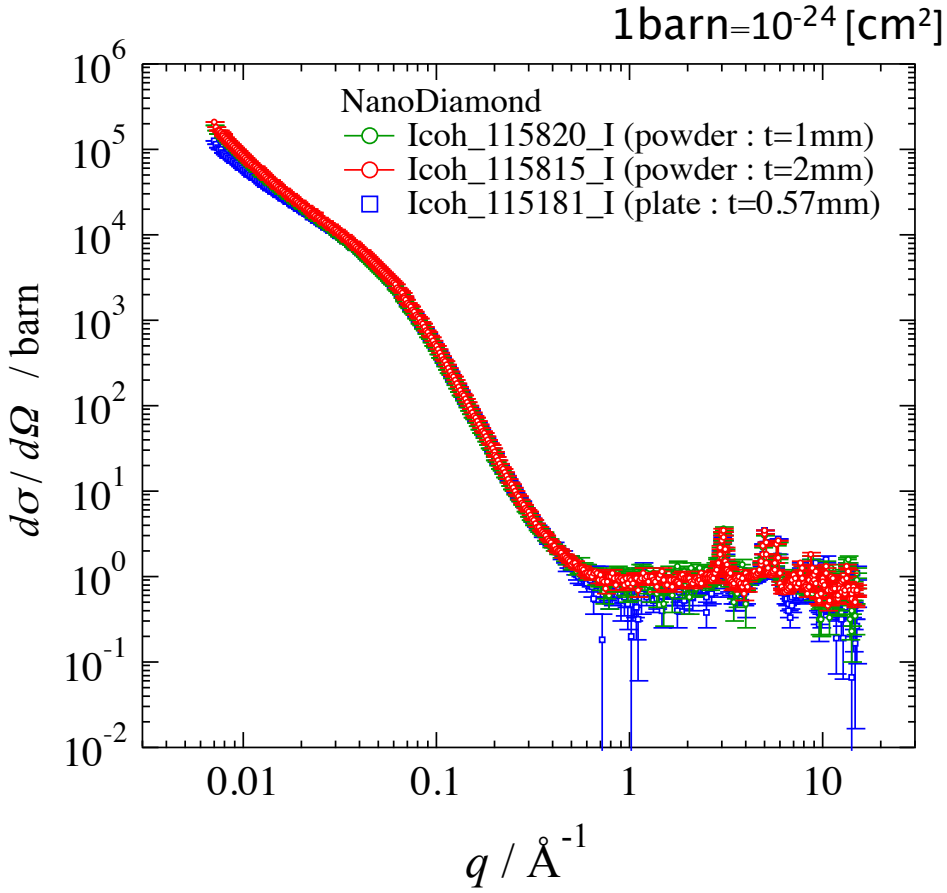
- Diamond density 3.1 g/cm^3
- Powder density 0.4 g/cm^3 (13%)
- Ideal density 1.5 g/cm^3 (50%)
- Compressed sample 1.1 g/cm^3 (35%)

Different cross section



No difference of 2 samples with different densities was observed.

Difference of packing density



Private communication, M.Teshigawara, S. Takata, et al.

The effect of nanodiamond fluorination on quasi-specular reflection of cold neutrons

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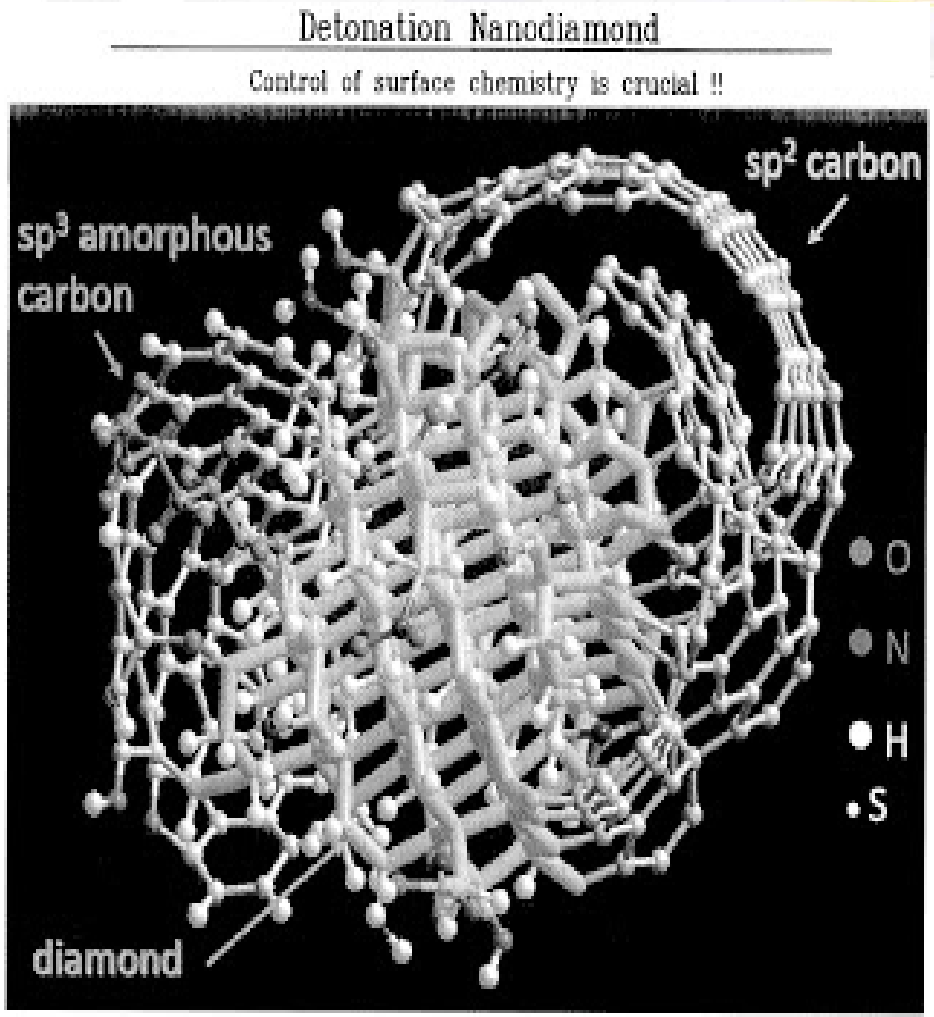
[5] University Clermont - Ferrand, Clermont-Ferrand, France

Nano-diamond Structure



Fluorination process removes

Hydrogen atoms

- sp^2 carbon

P.J. de Carli, J.C. Jameieson, Science 133 (1821) 1961.

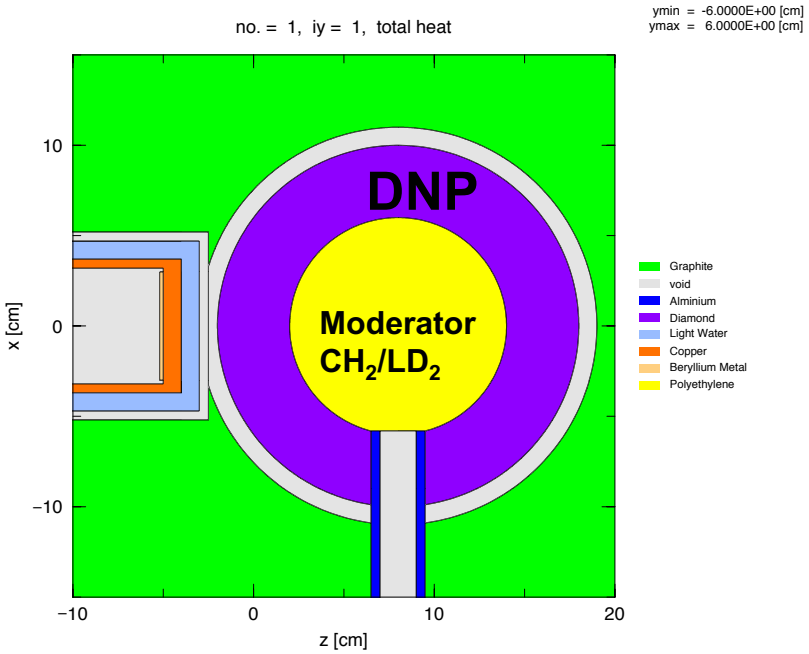
A.E. Aleksenskii, M.V. Baidakova, A.Y. Vul, V.I. Siklitskii, Phys. Solid State 41 (1999) 668

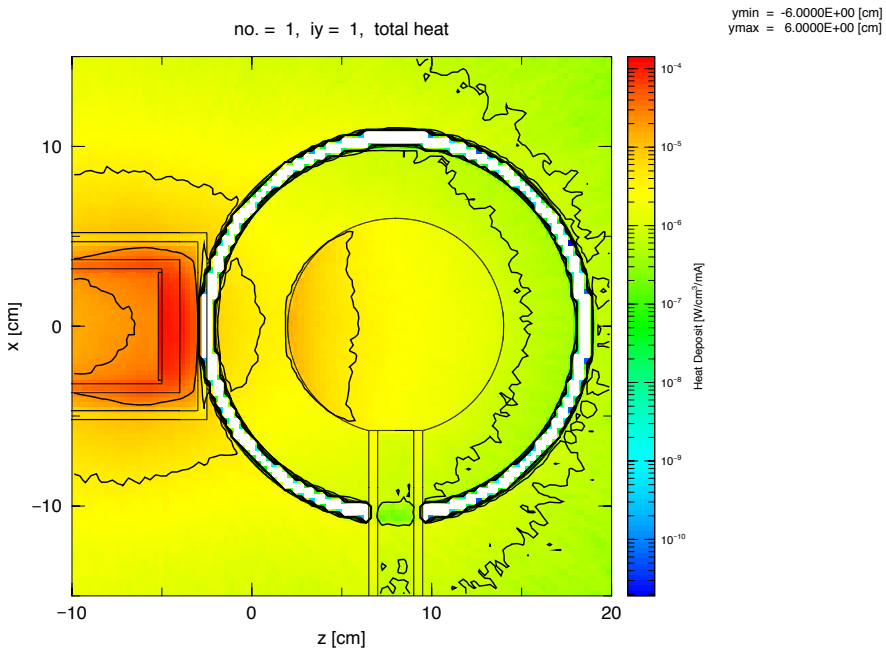
Fluorinated nano-diamonds as Unique Neutron Reflector, V. Nesvizhevsky, U. Koester, M. Dubois, N. Batisse, L. Frezet, A. Bosak, L. Gines, O. Williams, to be submitted

Moderator simulation with DNP

PHITS（Particle and Heavy Ion Transport code System）can use **user defined scattering**.

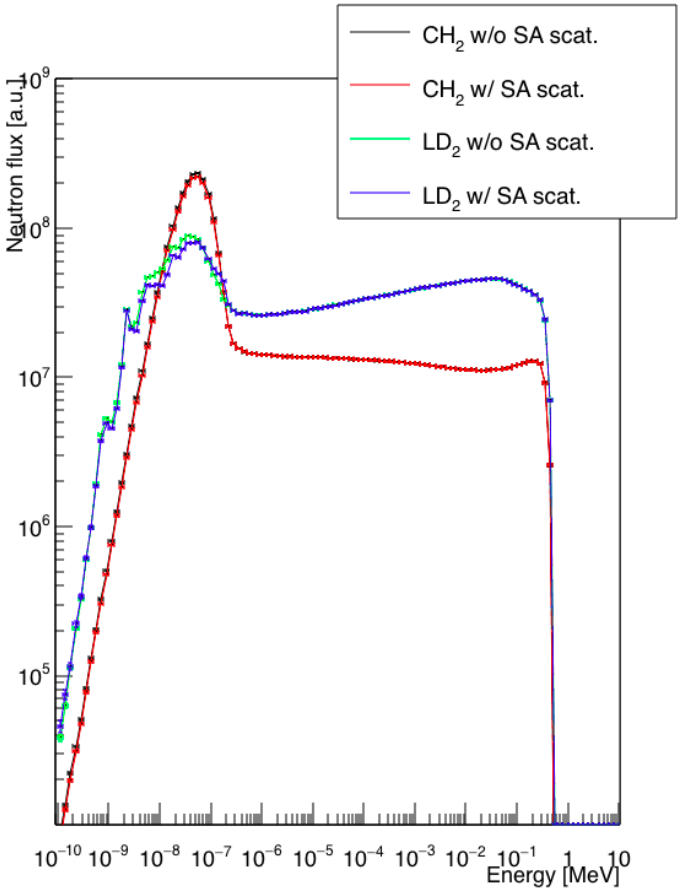
The differential scattering cross section of DNP measured by NOVA was implemented.



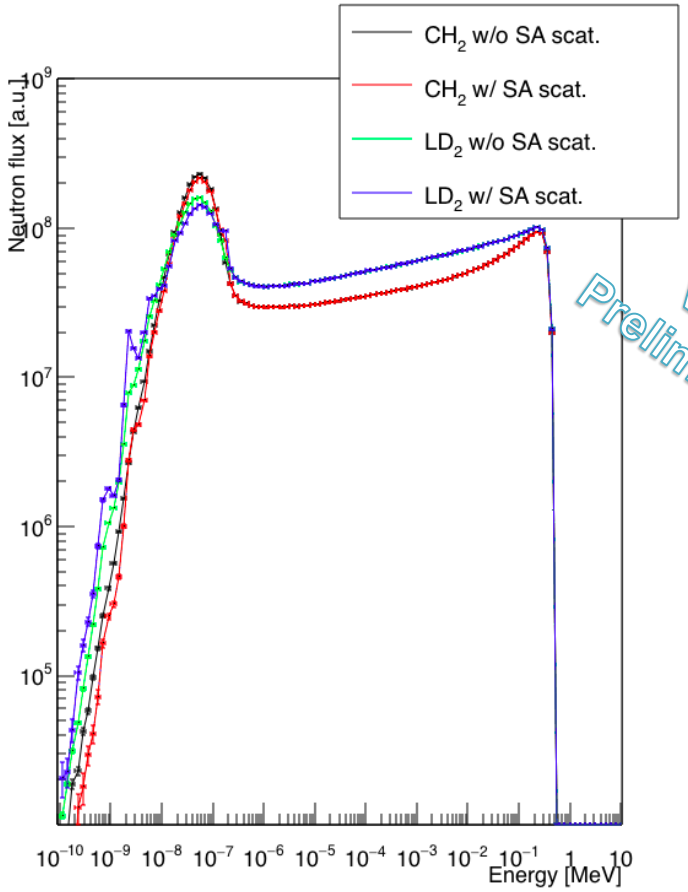


PHITS 2.82 modified

Neutron Flux with and without small angle scattering of DNP

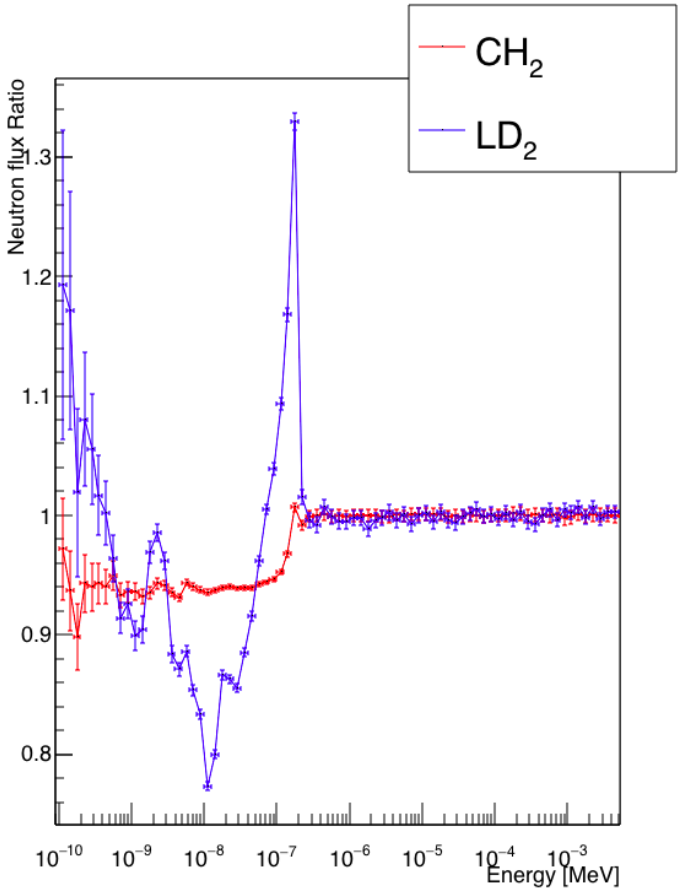


In moderator



In reflector

Neutron flux ratio with/without small angle scattering of DNP



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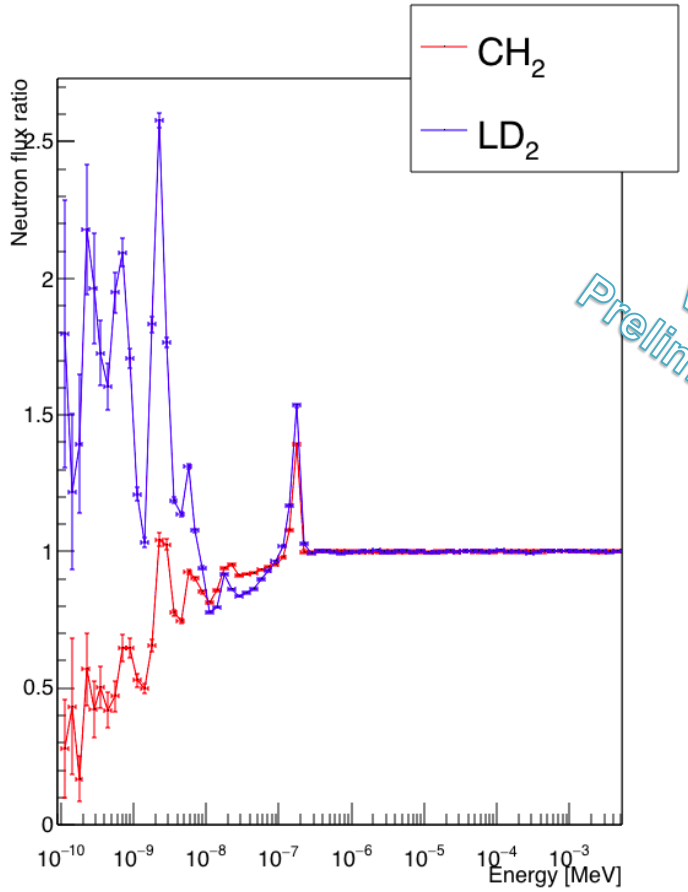

In reflector

How to use in MCNPX

- MCNP requires dynamic structure factor, so called S(q, ω) for low-energy scattering in materials.
- Present calculation only work in Phits.
  - It is not optimized, and takes long time.
- I'm talking how to make ACE file of DNP.
  - Not S(q, ω), but S(q), elastic only.

Summary

- Diamond Nano Particle (DNP) have large scattering cross section for slow neutrons.
- Scattering cross sections were measured.
  - Small density dependence was observed.

- *Phits* code can calculate DNP effect.
- ACE file for MCNP is going to be prepared, hopefully