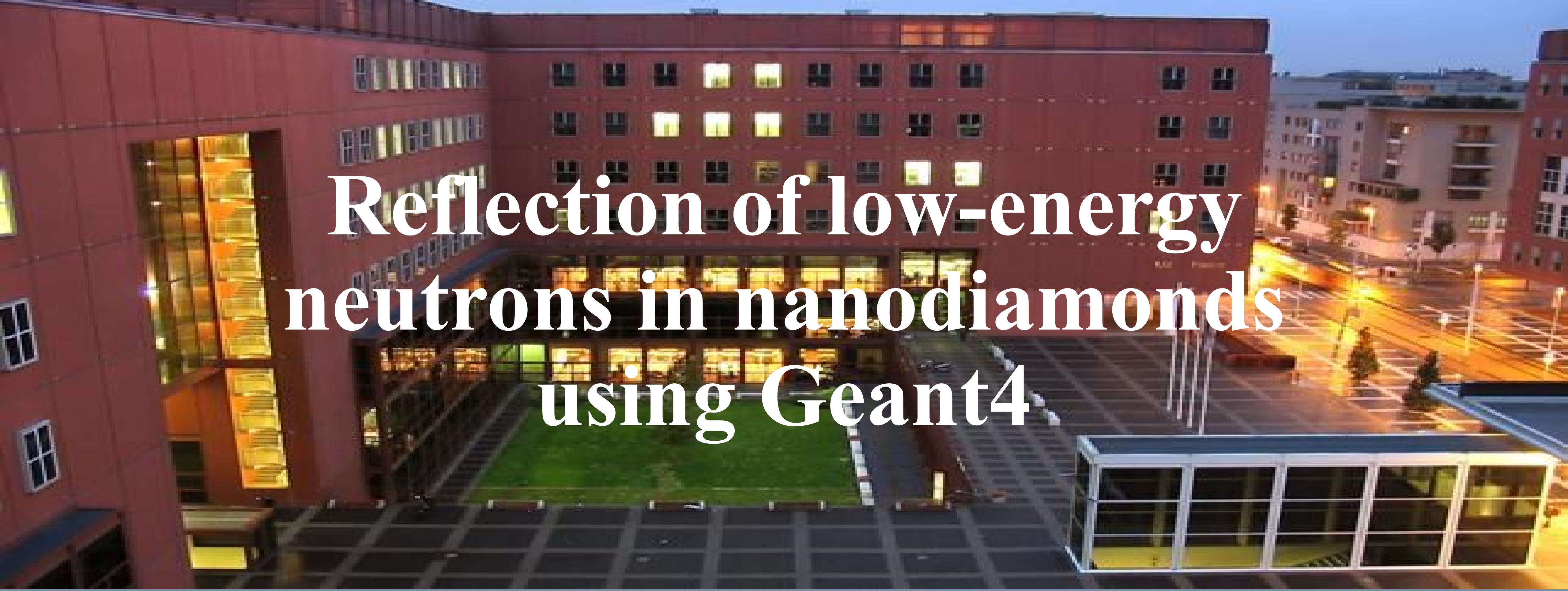


# Reflection of low-energy neutrons in nanodiamonds using Geant4

Mostafa Jamalipour[1], Luca Zanini[2]

[1]University of Milano-Bicocca

[2]European Spallation Source (ESS)

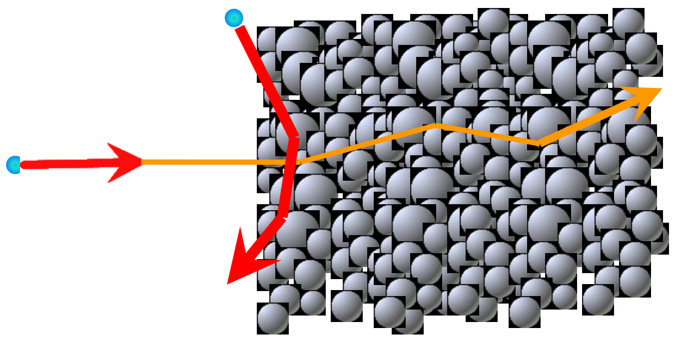
ENSAR2 workshop: GEANT4 in nuclear physics

# Outline

- Nanodiamonds for neutron reflection
- Nanodiamond cross sections
- Nanodiamond scattering in Geant4
- Benchmark with Exp. Data
- Application
- Conclusion
- Open Issues

# Nanodiamonds for neutron reflection

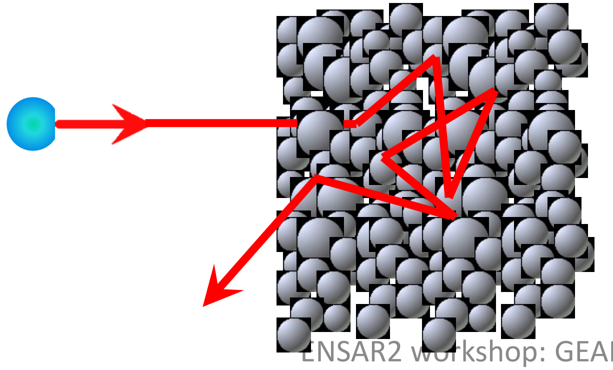
**Cold neutron reflector** ($E<5\cdot10^{-3}$ eV)



- Small scattering probability
- Small scattering angle
- Deep penetration

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

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



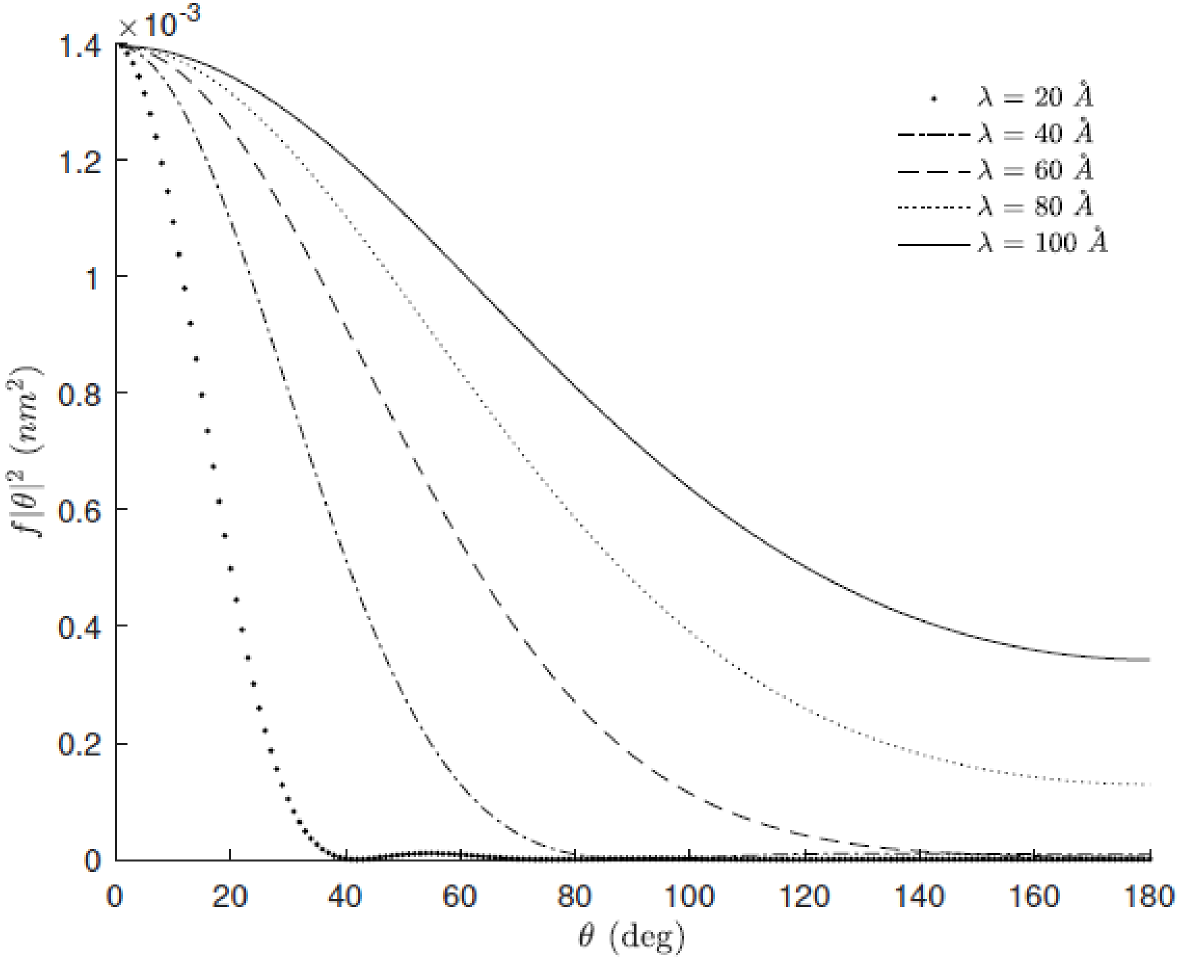
- Large scattering probability
- Large scattering angle
- Small penetration

**Possible to have an efficient reflector at any incident angle**

# Nanodiamond cross sections

From Born approx.

- Scattering amplitude
- $f(\theta) = -\frac{2m}{\hbar^2} V_0 R^3 \left(\frac{\sin(qR)}{(qR)^3} - \frac{\cos(qR)}{(qR)^2}\right)$


Nesvizhevsky, V. V., G. Pignol, and K. V. Protasov. "Nanoparticles as a possible moderator for an ultracold neutron source. 2007

# Nanodiamond cross sections

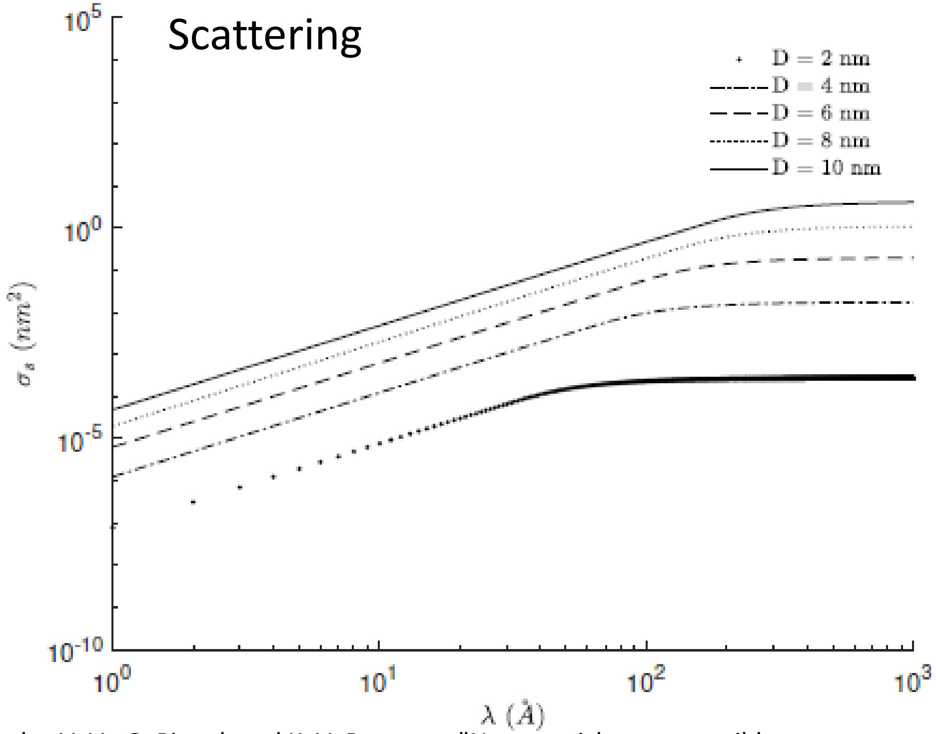
- Elastic scattering

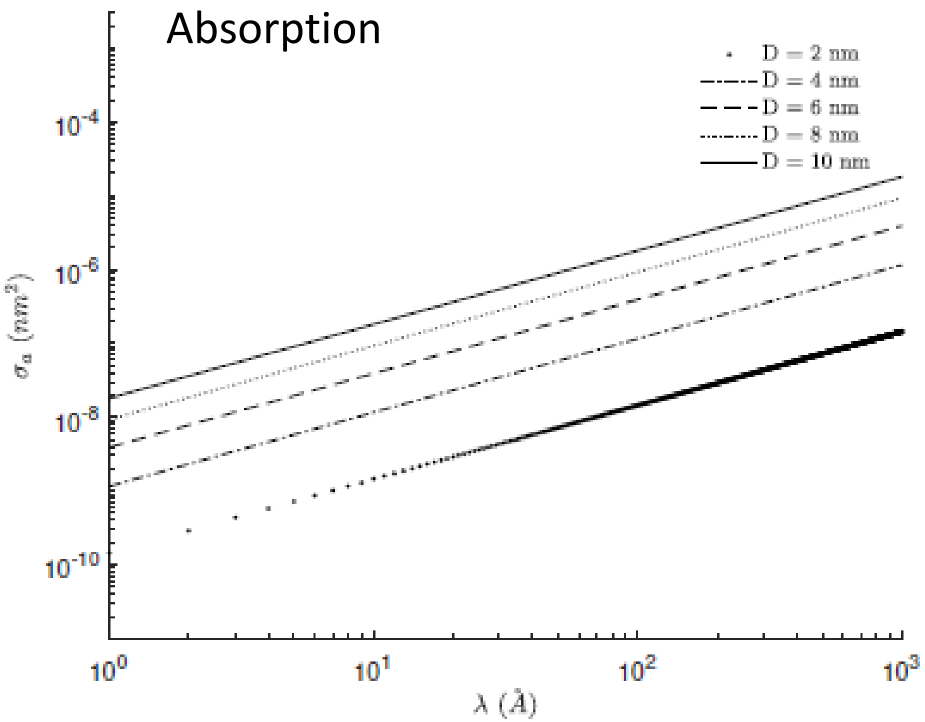
$$\sigma_s = \int |f|^2 d\Omega = 2\pi \left|\frac{2m}{\hbar^2} V\right|^2 R^6 \frac{1}{(kR)^2} I(kR), I(kR) = \frac{1}{4}\left(1 - \frac{1}{(2kR)^2} + \frac{\sin(4kR)}{(2kR)^3} - \frac{\sin^2(2kR)}{(2kR)^4}\right)$$

- Absorption

$$\sigma_a = \frac{4\pi}{3} \frac{2m}{\hbar^2} V_1 R^4 \frac{1}{kR}$$

$$\sigma_s \gg \sigma_a$$



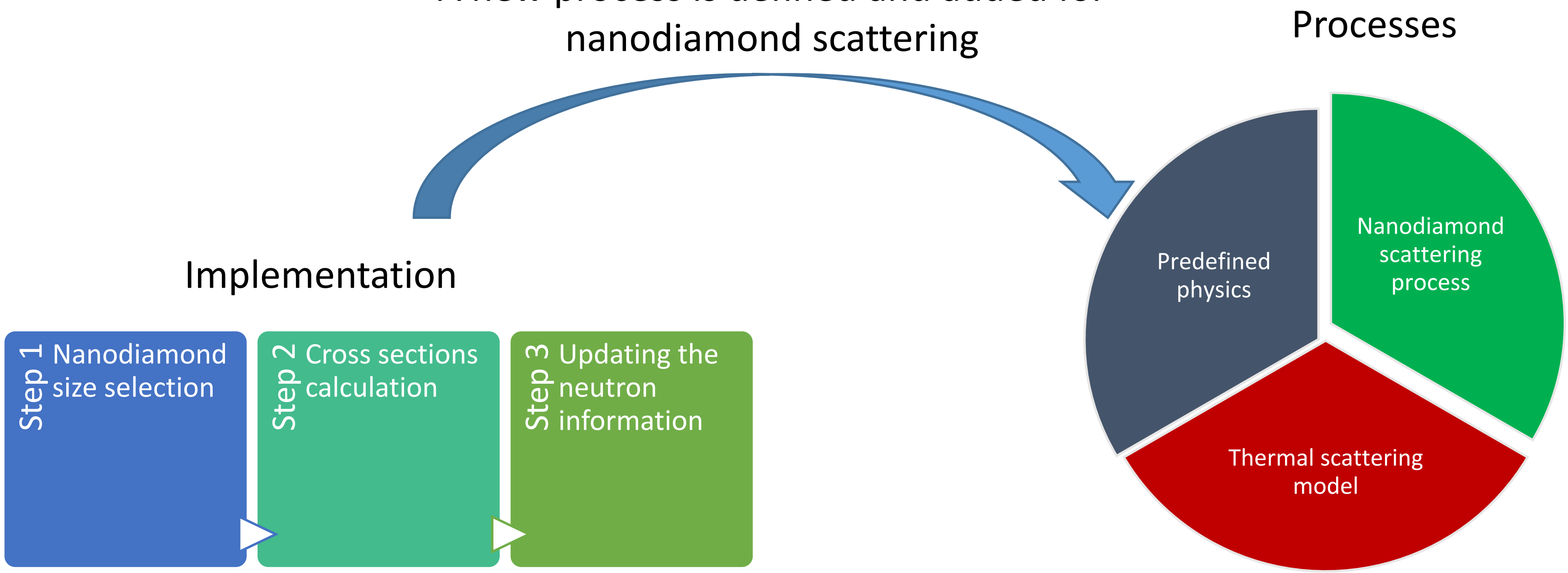

Nesvizhevsky, V. V., G. Pignol, and K. V. Protasov. "Nanoparticles as a possible moderator for an ultracold neutron source. 2007

# Nanodiamond scattering in Geant4

A new process is defined and added for nanodiamond scattering

Nanodiamond information prepared in a new class:

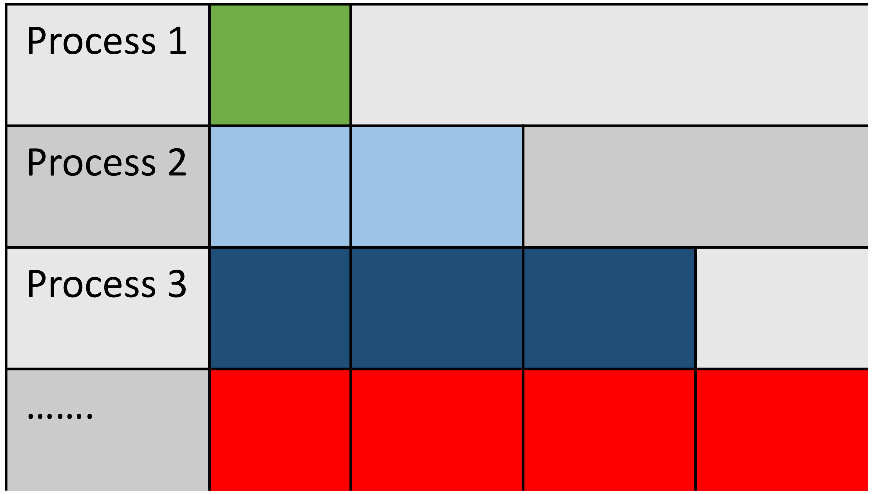
- ❖ Particle size
- ❖ Mean free path
- ❖ Scattering angle




Geant version 4.10

# Nanodiamond scattering in Geant4

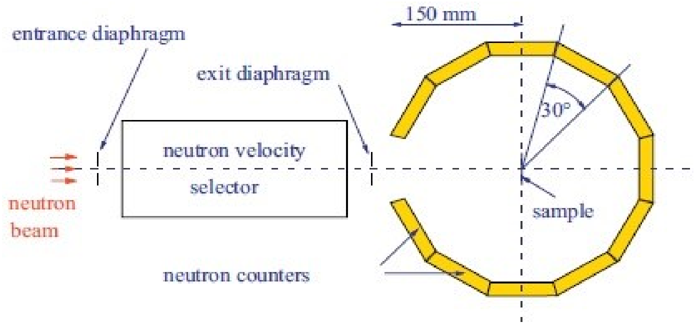
- Impurites were defined for the nanodiamond. Geant4 Decides based on the mean free path value.
- It will make its random decision based on the mean free path it receives from the process and the values from the predefined model in itself.

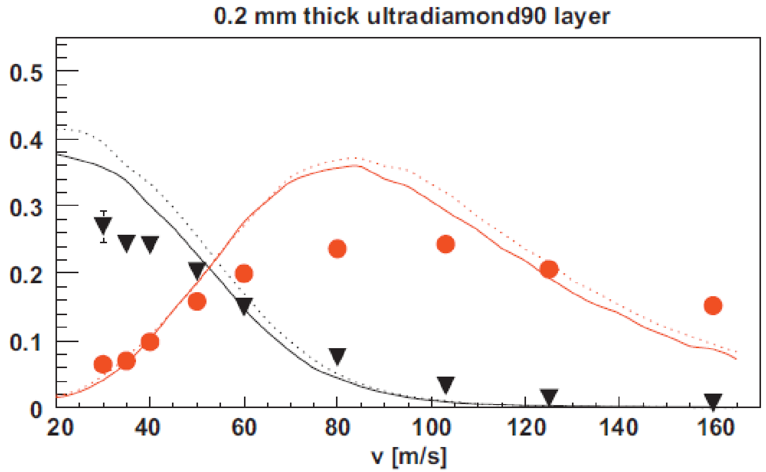



- ➢ Hydrogen has a large cross section. The lower its percentage, the larger the mean free path it produces. Therefore, the higher the probability of Nanodiamond scattering.

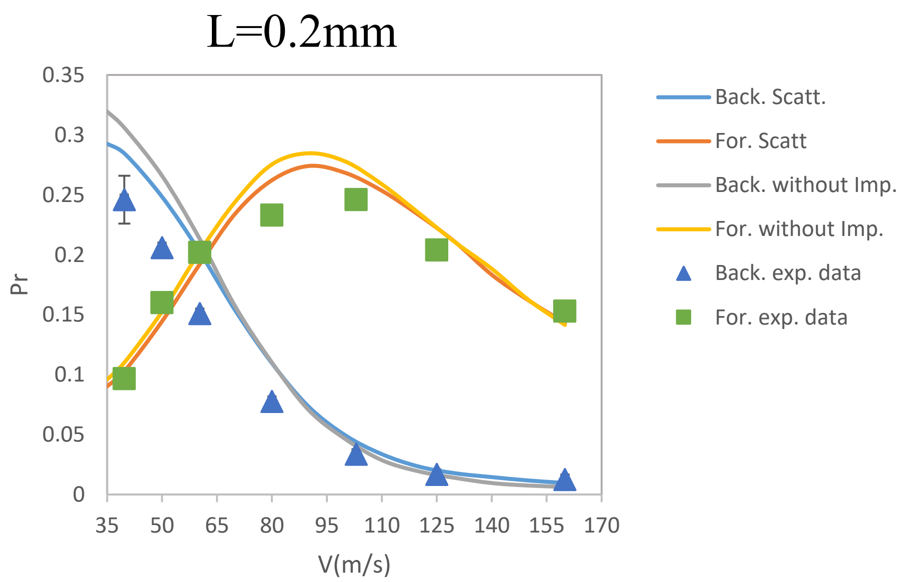
# Benchmark with Exp. Data I

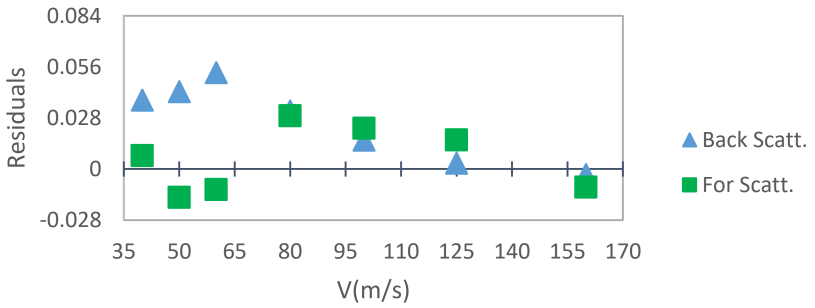
Experiment carried out at ILL, 2008



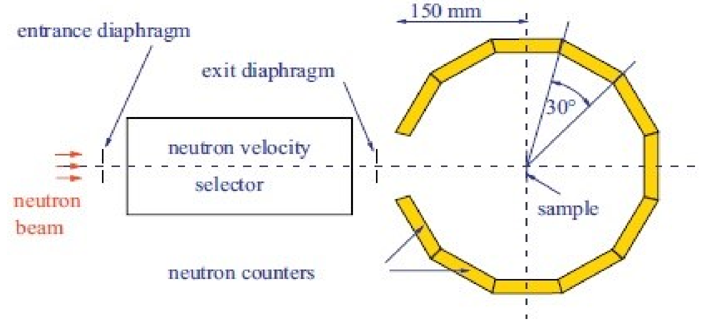

Nesvizhevsky, V. V., et al. "The reflection of very cold neutrons from diamond powder nanoparticles. 2008

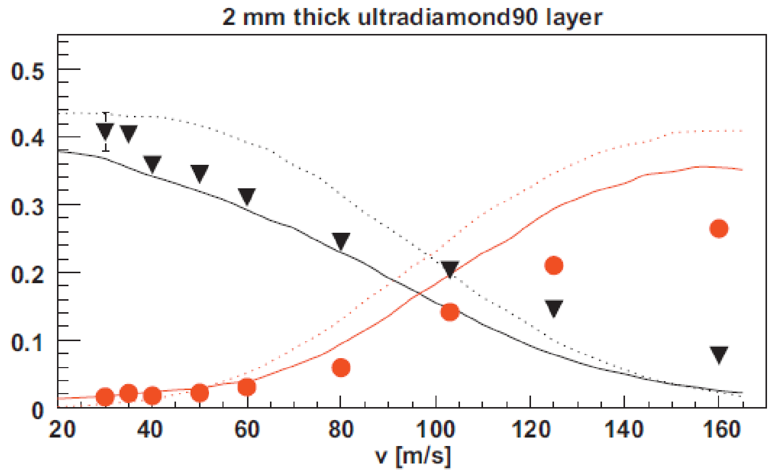


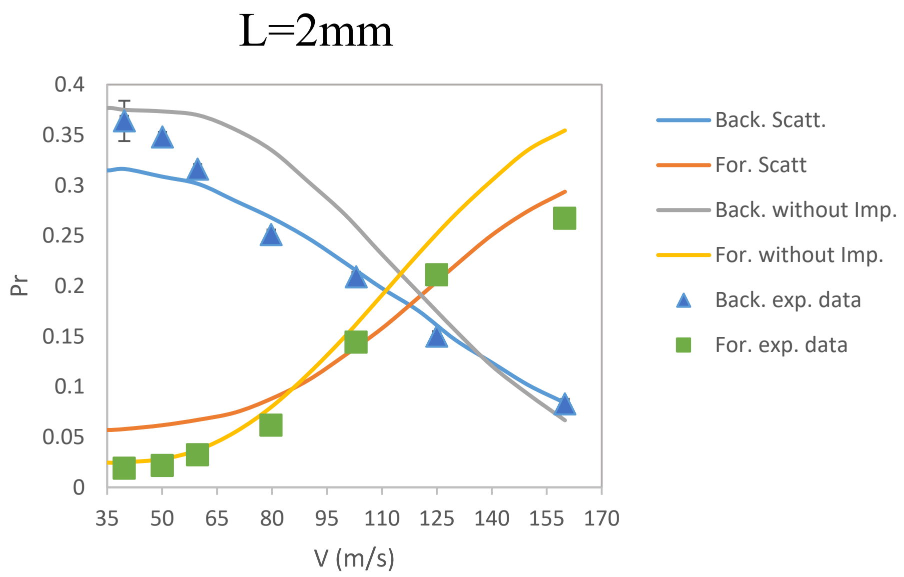
# Benchmark with Exp. Data I

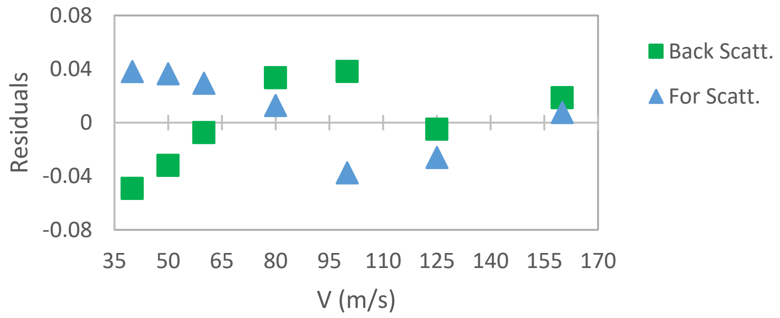
Experiment carried out at ILL, 2008



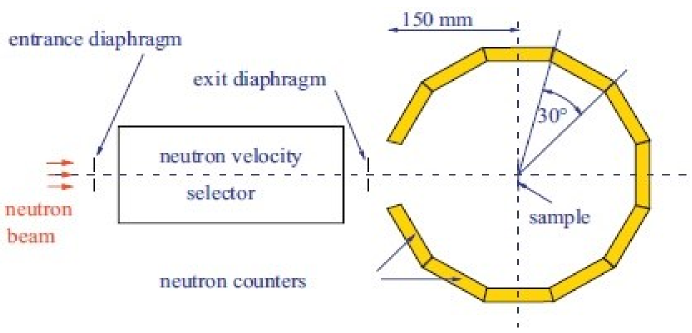

Nesvizhevsky, V. V., et al. "The reflection of very cold neutrons from diamond powder nanoparticles. 2008

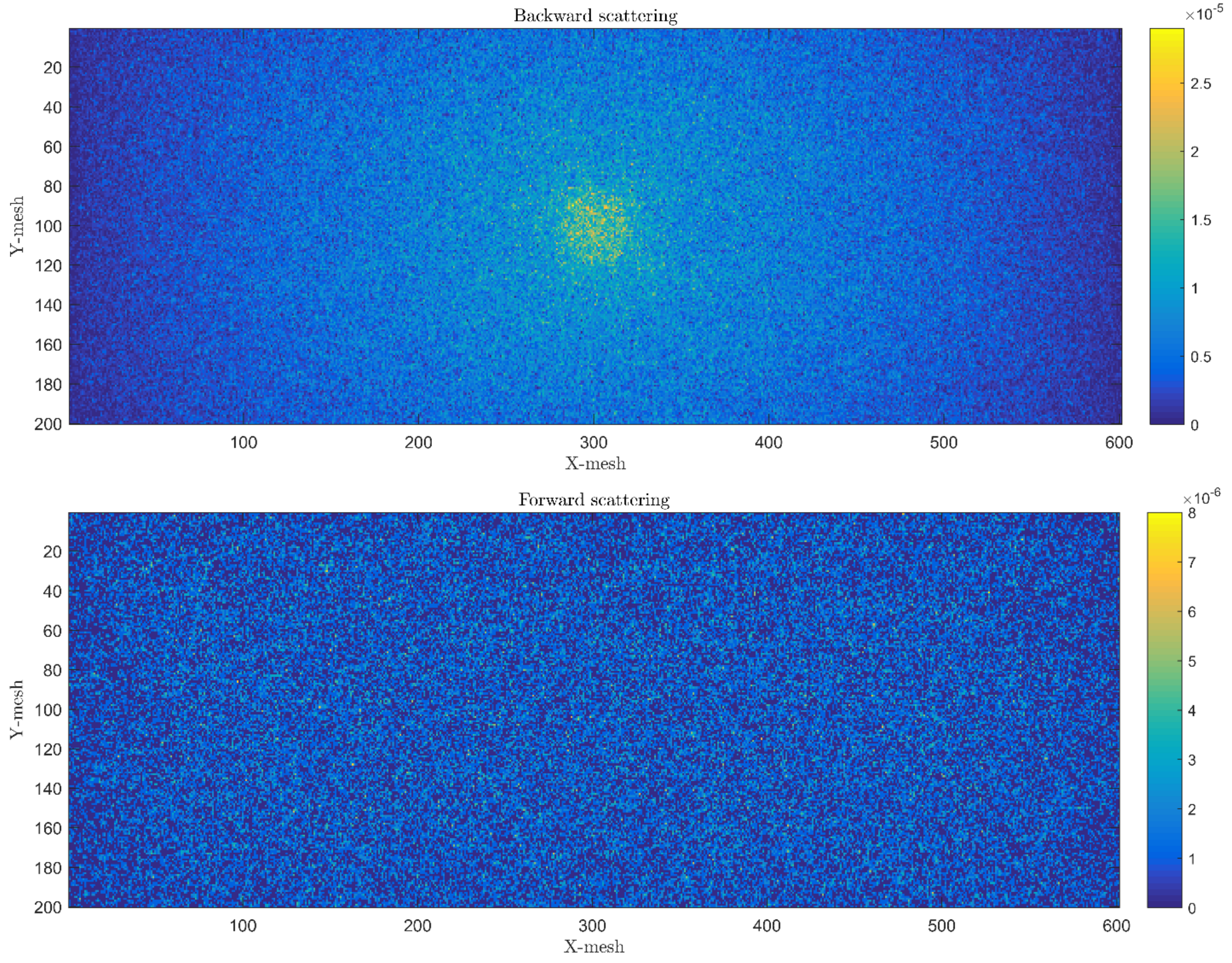


# Normalized number of neutrons in detectors

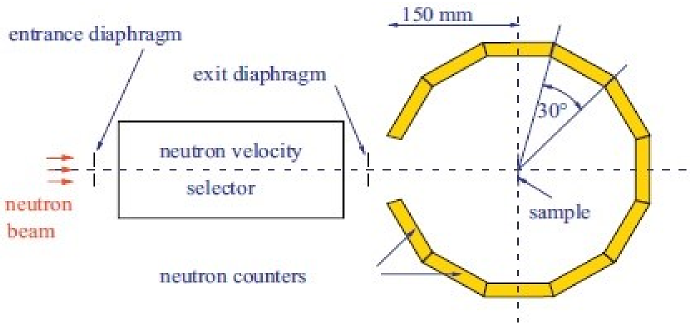
L=2 mm
V=30 m/s

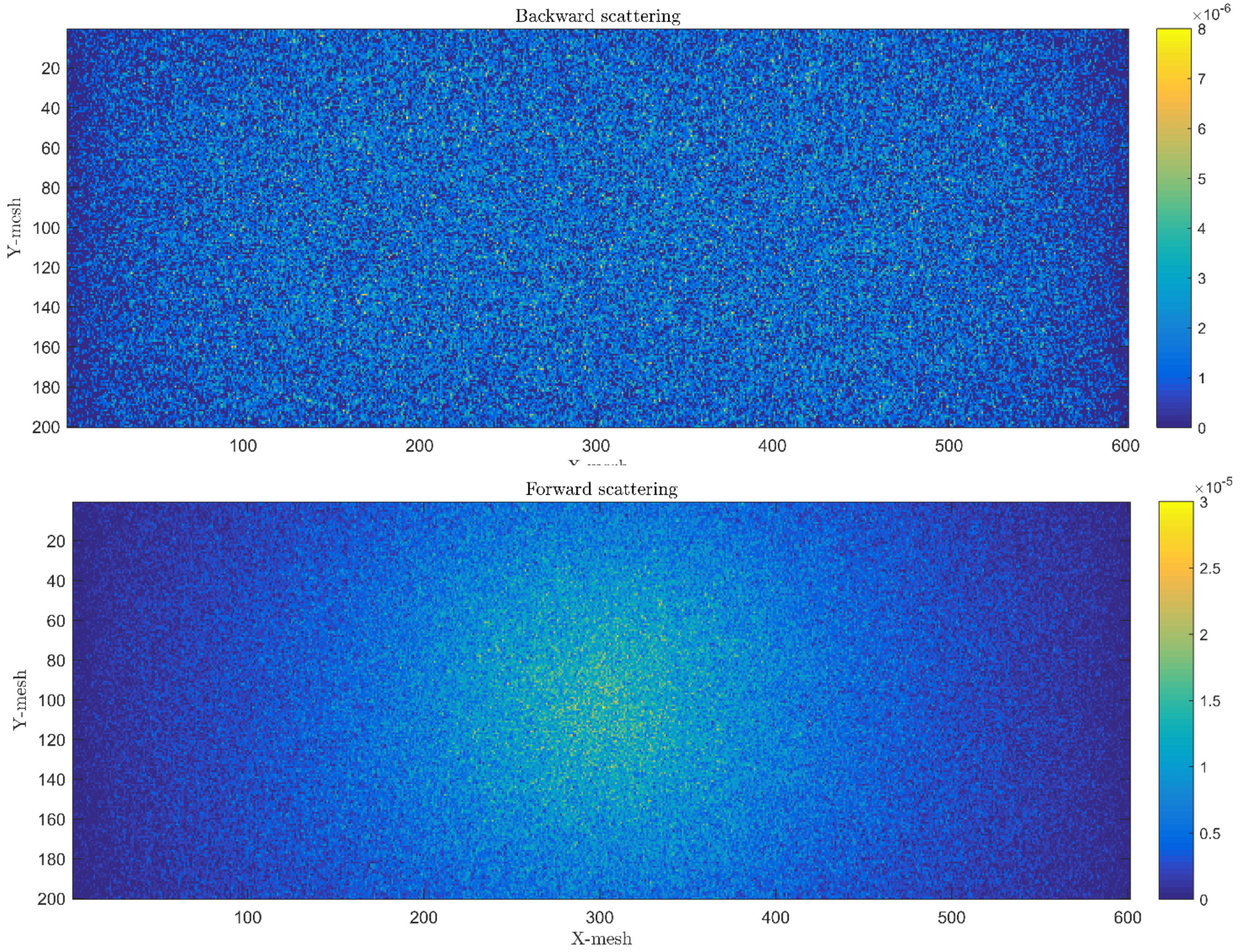


# Normalized number of neutrons in detectors

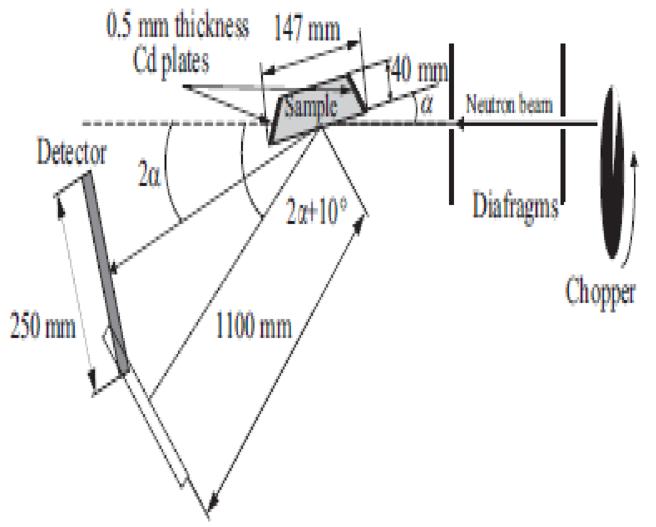
L=2 mm
V=160 m/s



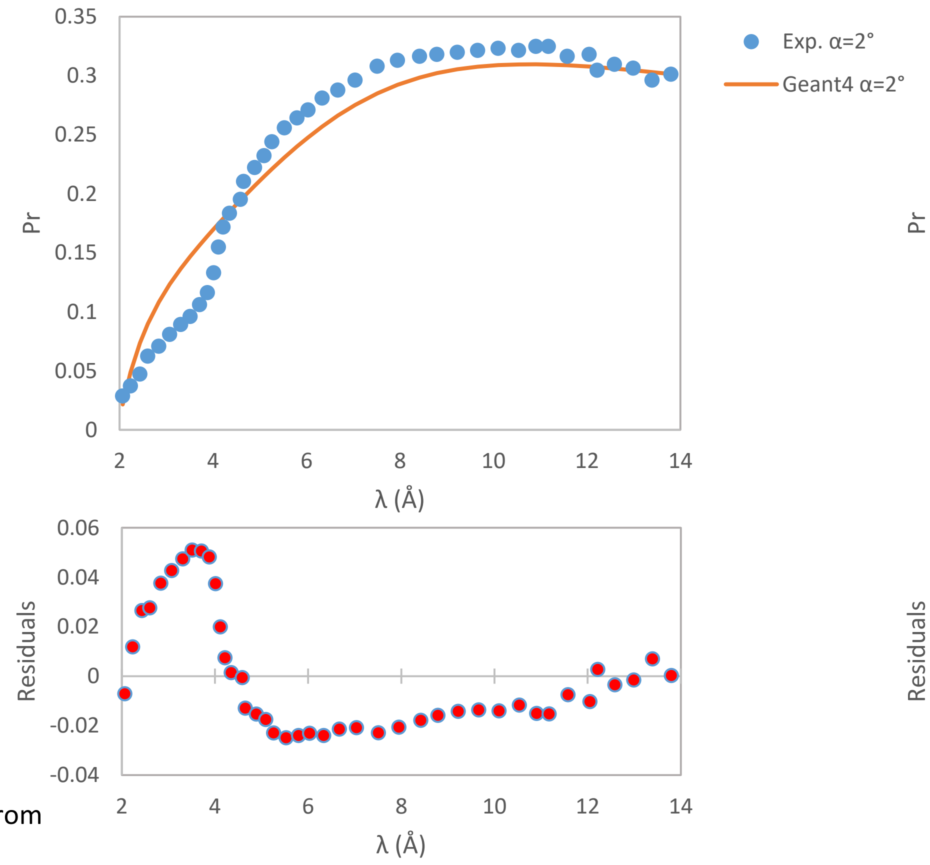



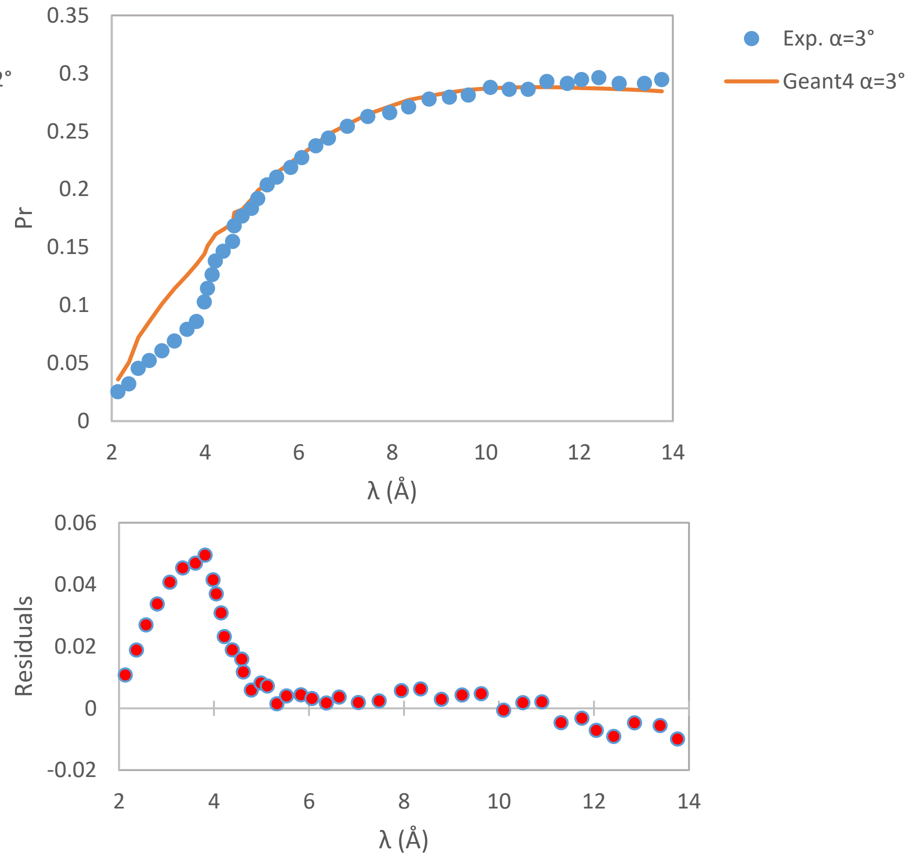
# Benchmark with Exp. Data II

Experiment carried out at ILL, 2010




Cubitt, R., et al. "Quasi-specular reflection of cold neutrons from nano-dispersed media at above-critical angles, 2010



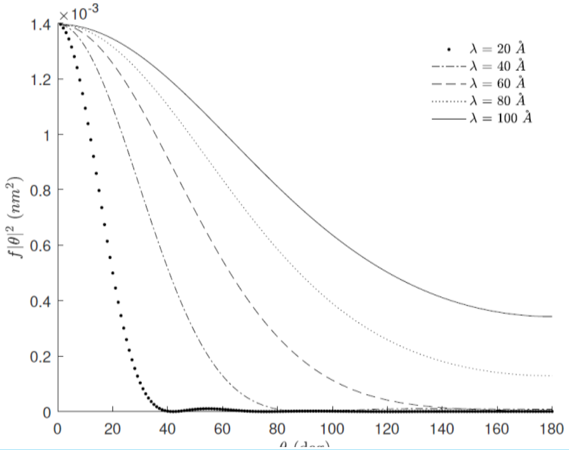



# Application

## First

Around the source
for Very Cold Neutrons

D=4nm

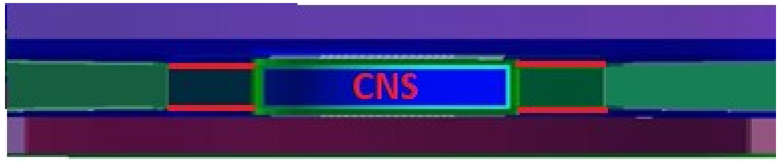



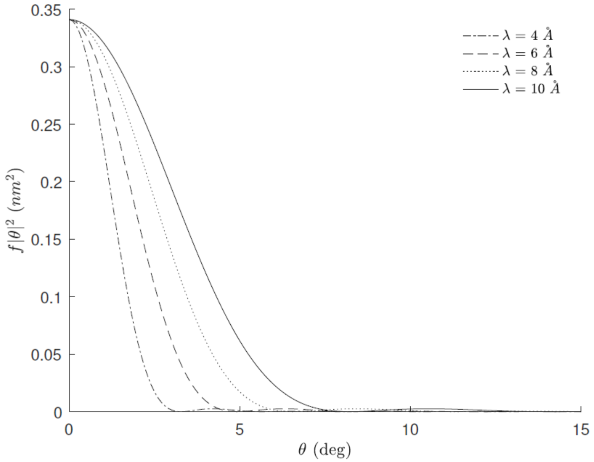

Reflector candidate for ESS VCNS

## Second

Around the beam extraction
for Cold Neutrons

D=10nm




Refector candidate for CNS

# Conclusion

- The new process can help calculate the neutron reflection with a good approximation.
- The problems related to impurities can almost be handelled in Geant4 although their structure is not well-defined.

# Open Issues

- Bragg's scattering on crystal structure of nanodiamond core needs to be implemented.
- Unavailability of libraries for materials producing VCN.
- We have the Solid deuterium for MCNP but we also need to test it in Geant4.
- We have received Tatsumi's ENDF2G4NDL code (Thanks A. Ribon). We will look at it and see if we can make it work. Help or collaboration is welcome.
- We plan to measure scattering kernels for candidate materials for VCN.
- Evaluated cross sections should eventually be tested in Geant4.