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Calculation and Simulation of Scattering Intensity Distribution in Neutron Pinhole Image in the Presence of Air

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Introduction

In the existing literature, the scattering intensity distribution in neutron pinhole image is considered as a uniform background, and the neutrons attenuation and scattering in air are ignored.

In this paper we propose a novel program for calculating the scattering intensity distribution on the incident plane of BC408 scintillation, which takes into account the presence of air. Simulation work is also carried out in Geant4, and the calculation results are compared with the simulation results, which shows that the two methods are consistent.

Materials and Methods

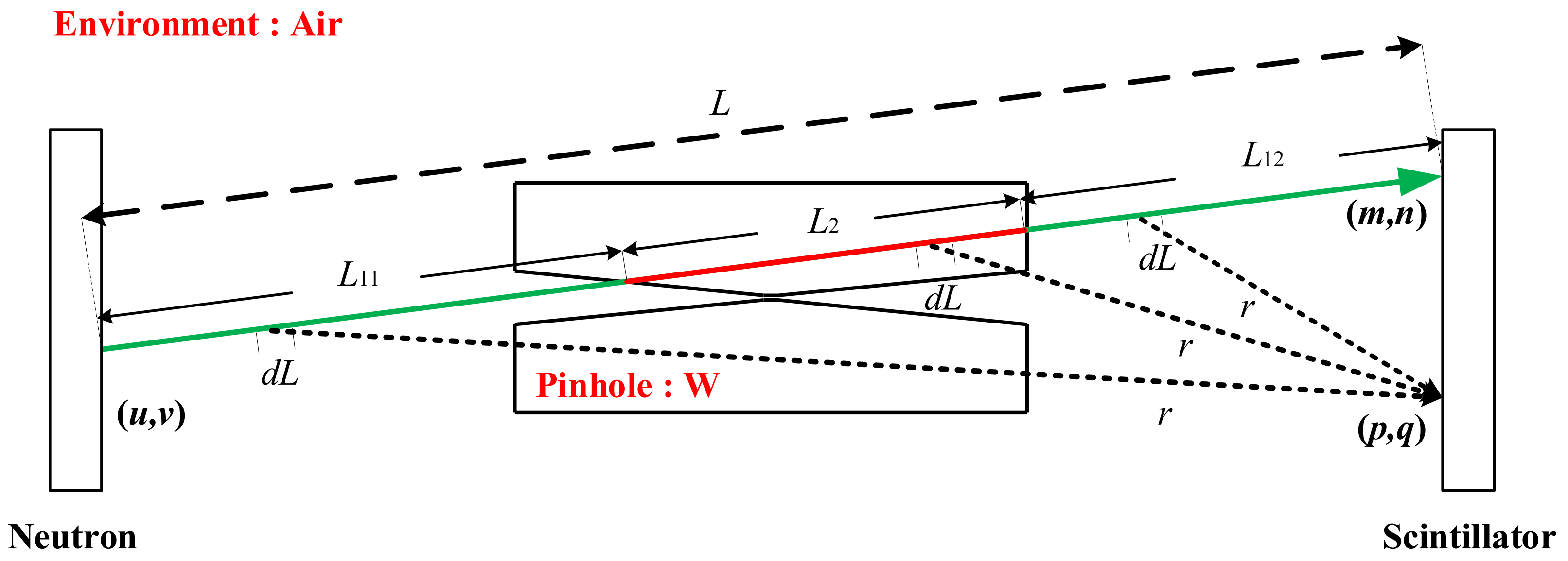
Materials

Neutron source: 14 MeV neutrons produced in nuclear fusion and fission
Thick pinhole: Tungsten 184
Air: composed of 70% N-14 and 30% O-16, density ρ= 1.29mg /cm3

MATLAB Calculation Program

The intensity distribution of the neutron source is discretized into a point source matrix *f*(*u,v*), and the area of each discretized pixel is *dS*. The neutron intensity distribution on the incident plane of scintillation is expressed as a discrete matrix M=M1+M2, where M1 denotes the intensity distribution of the penetrating ray and M2 denotes the intensity distribution of the scattered ray. The calculation program consists of **five steps**.

Environment : Air



1. Calculate the intensity of penetrating rays contributed by object plane pixel (*u,v*) to image plane pixel (*m,n*)

$$M_1(m,n,u,v)=f(u,v)\frac{dS}{4\pi L^2}\cos\theta\cdot e^{-(\mu_1L_{11}+\mu_2L_2+\mu_1L_{12})}$$

2. Calculate the number of neutron rays interacting with the substance in each *dL* step

$$\alpha(u,v,m,n,k)=f(u,v)\frac{dS}{4\pi L^2}\cos\theta\cdot$$
$$\begin{cases} e^{-\mu_1(k\text{-}1)dL}(1-\mathrm{e}^{-\mu_1 dL}) & ,\ Scat\in L_{11}\ ,\ 1\le k\le L_{11}/dL \\ e^{-\mu_1L_{11}}e^{-\mu_2(k\text{-}1)dL}(1-\mathrm{e}^{-\mu_2 dL}) & ,\ Scat\in L_2\ ,\ 1\le k\le L_2/dL \\ e^{-\mu_1L_{11}}e^{-\mu_2L_2}e^{-\mu_1(k\text{-}1)dL}(1-\mathrm{e}^{-\mu_1 dL}) & ,\ Scat\in L_{12}\ ,\ 1\le k\le L_{12}/dL \end{cases}$$

3. Calculate the number proportion of neutron rays from each scattering point in the solid angle of pixel point (*p,q*) on the image plane

$$\beta(u,v,m,n,k,p,q)=\frac{\sum_i\left[\int_{\Omega^*}\frac{d\sigma_i}{d\Omega}d\Omega\right]}{\sigma_{total}}\quad,\quad \Omega^*\approx\frac{dS}{r^2}\cos\theta$$

4. Calculate the attenuation coefficient of the scattered neutron rays transmitted along a straight line to the pixel point (*p,q*)

$$\eta(u,v,m,n,k,p,q)=\begin{cases} e^{-\mu_1(r-L_2')}e^{-\mu_2L_2'} & ,\ Scat\in L_{11} \\ e^{-\mu_1(r-L_2'')}e^{-\mu_2L_2''} & ,\ Scat\in L_2 \\ e^{-\mu_1 r} & ,\ Scat\in L_{12} \end{cases}$$

5. Traversing the pixel (*u,v*), pixel (*m,n*) and scattering point *k*

$$M_1(m,n)=\sum_{u,v}f(u,v)\frac{dS}{4\pi L^2}\cos\theta\cdot e^{-(\mu_1L_{11}+\mu_2L_2+\mu_1L_{12})}$$

$$M_2(p,q)=\sum_{u,v}\left[\sum_{m,n}\left(\sum_k f(u,v)\frac{dS}{4\pi L^2}\cos\theta\cdot\alpha(k)\beta(k)\eta(k)\right)\right]$$

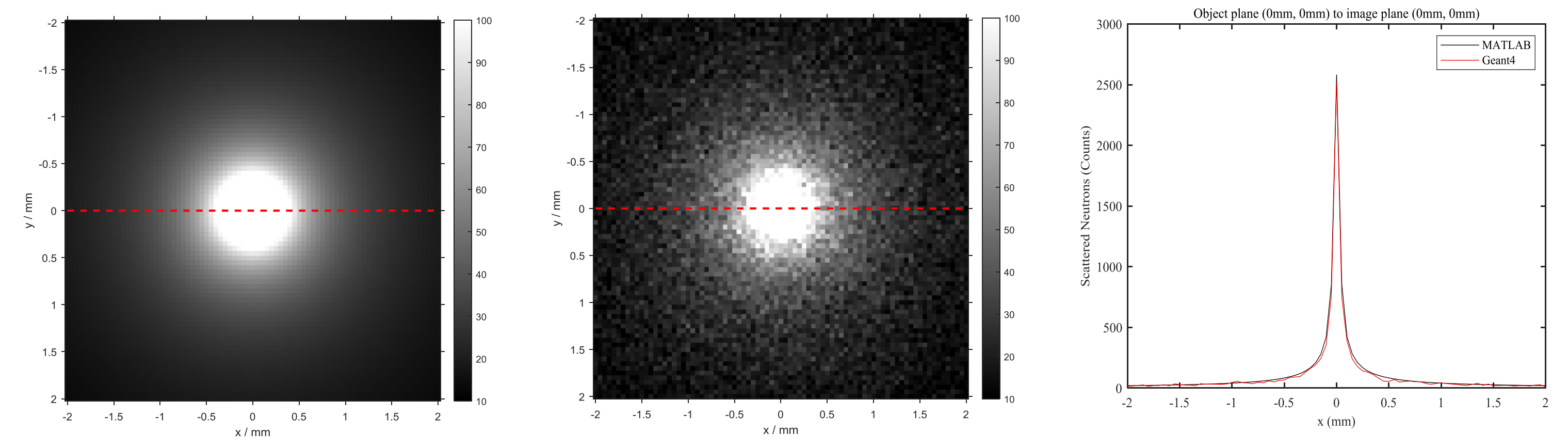
Genat4 (version 10.06.p02) Simulation

In this paper, the QGSP_BIC_HP physical model of Geant4 is selected, which uses the ENDF/B-VIII.0 neutron database.

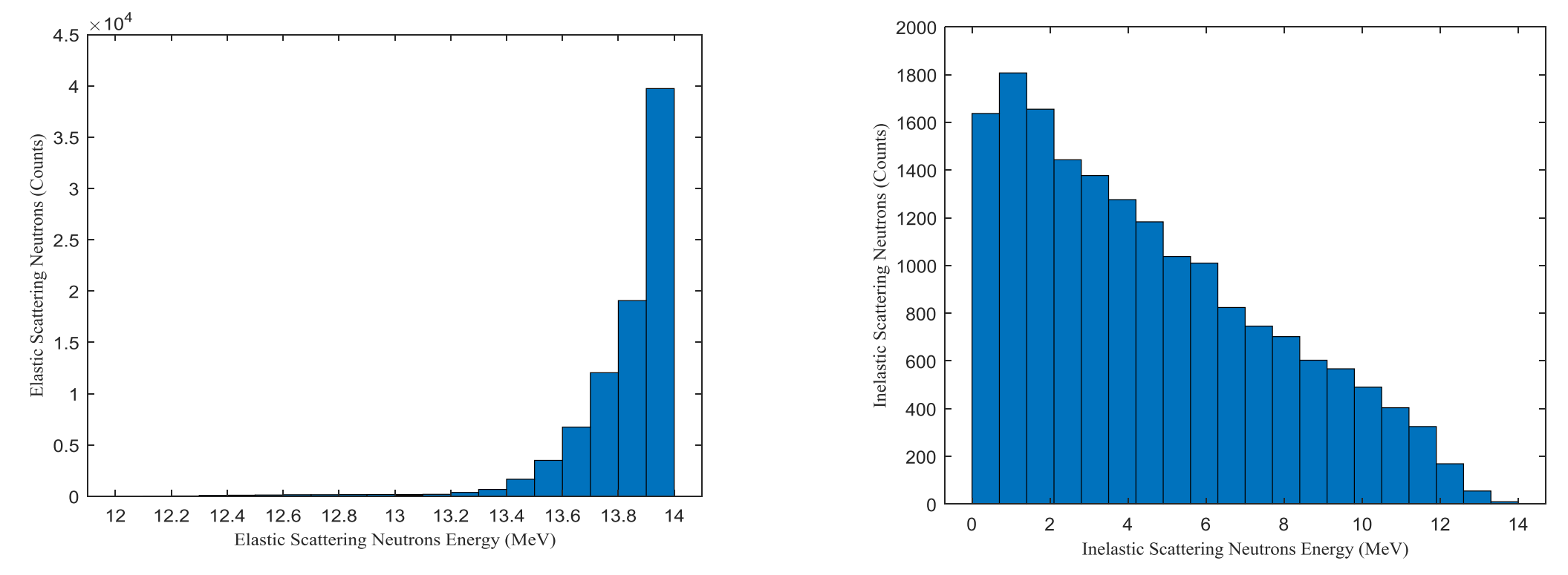
Results and Discussion

Single Penetration Path

1. A particle emitter is placed at the object surface (0mm,0mm), and 10^9 14MeV neutrons are emitted towards the image surface (0mm,0mm)

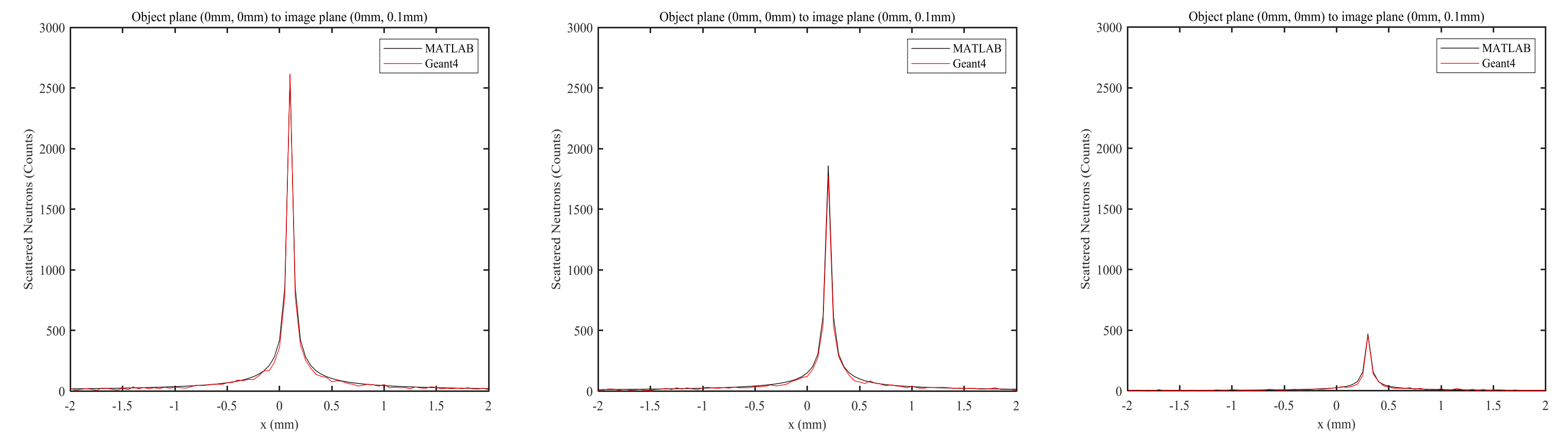


The calculated results agree well with the simulation results.
The intensity distribution of scattered neutrons is not uniform.



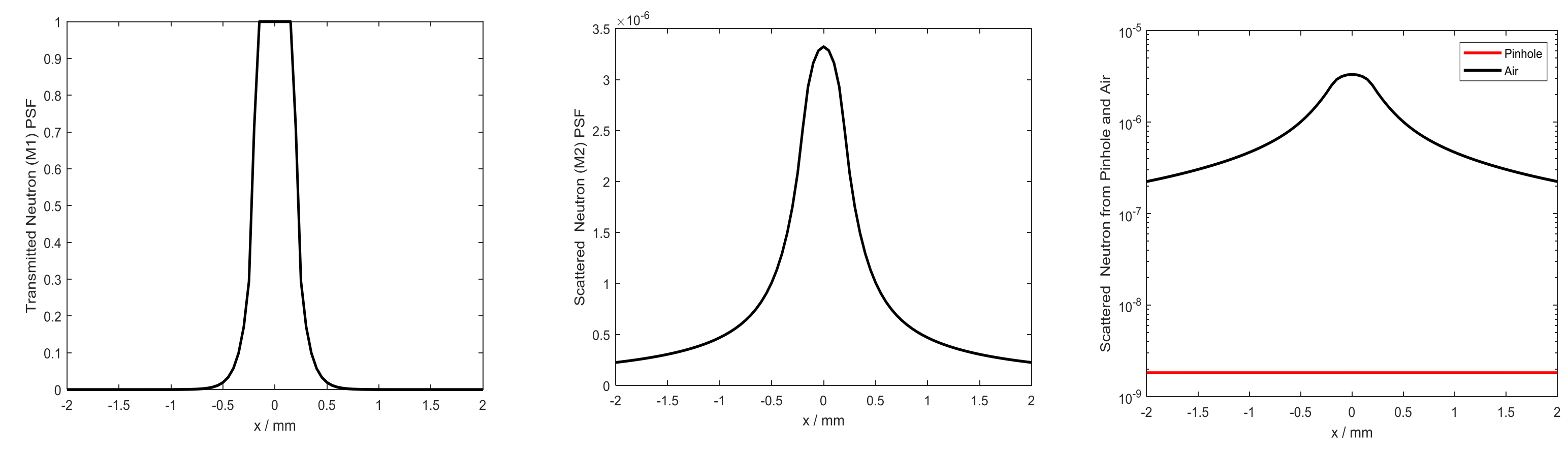
The average energy of scattered neutrons from elastic scattering is 13.8322MeV, while that of scattered neutrons from inelastic scattering is 4.5457 MeV. The number of inelastic scattering is only 20.24% of elastic scattering.

2. A particle emitter is placed at the object surface (0mm,0mm), and 10^9 14MeV neutrons are emitted towards the image surface (0mm,0.1mm), (0mm,0.2mm), (0mm,0.3mm) respectively



Single Point Source

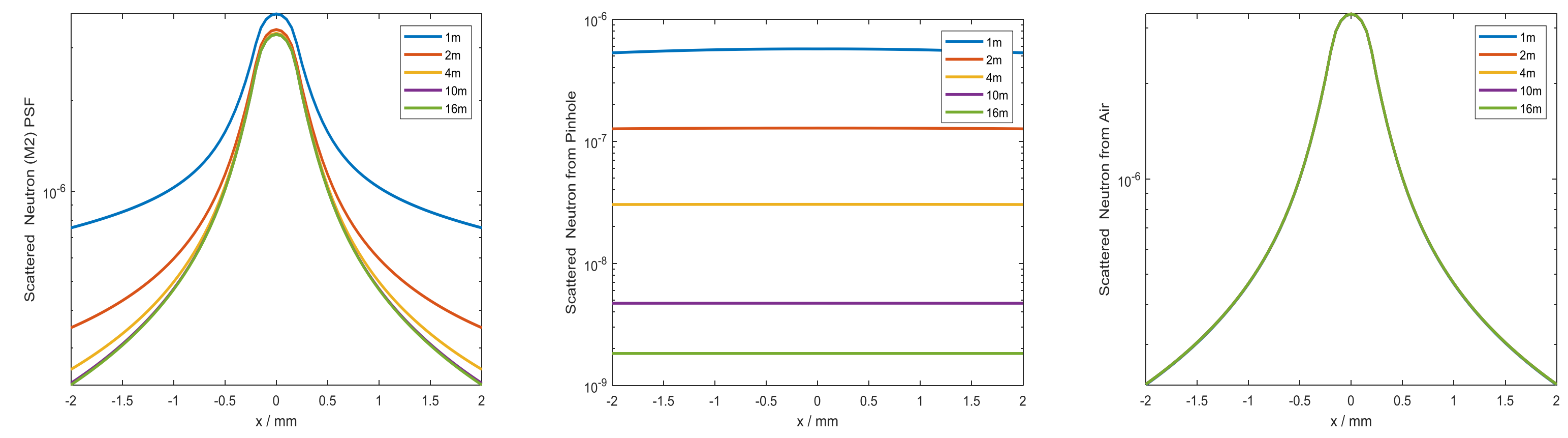
Neutron point source at object surface (0mm,0mm)



For a neutron point source, the intensity distribution of scattered neutrons is not uniform, and the shape of the scattered neutrons depends on the apparent aperture.

Change Distance

The object distance and image distance of pinhole are 1m, 2m, 4m, 10m and 16m respectively



The relative scattering intensity caused by pinhole was inversely proportional to the square of the image distance, while the relative scattering intensity caused by air does not change with the image distance.

Conclusion

For a neutron pinhole image, when air is taken into account, the scattering intensity distribution is no longer uniform, and its shape is related to the apparent aperture.

References

[1] C. R. Christensen et al (submitted). Reconstructions of Pinhole Images in the Presence of Noise, with Application to Inertial Confinement Fusion Product Neutrons.
[2] C. R. Christensen, Cris W. Barnes, G. L. Morgan, M. Wilke, D. C. Wilson; First results of pinhole neutron imaging for inertial confinement fusion. Rev Sci Instrum 1 May 2003; 74 (5): 2690–2694.