Analytical Method for First Order Rayleigh Scattering in CBCT Application

PHYS 4250 Project report

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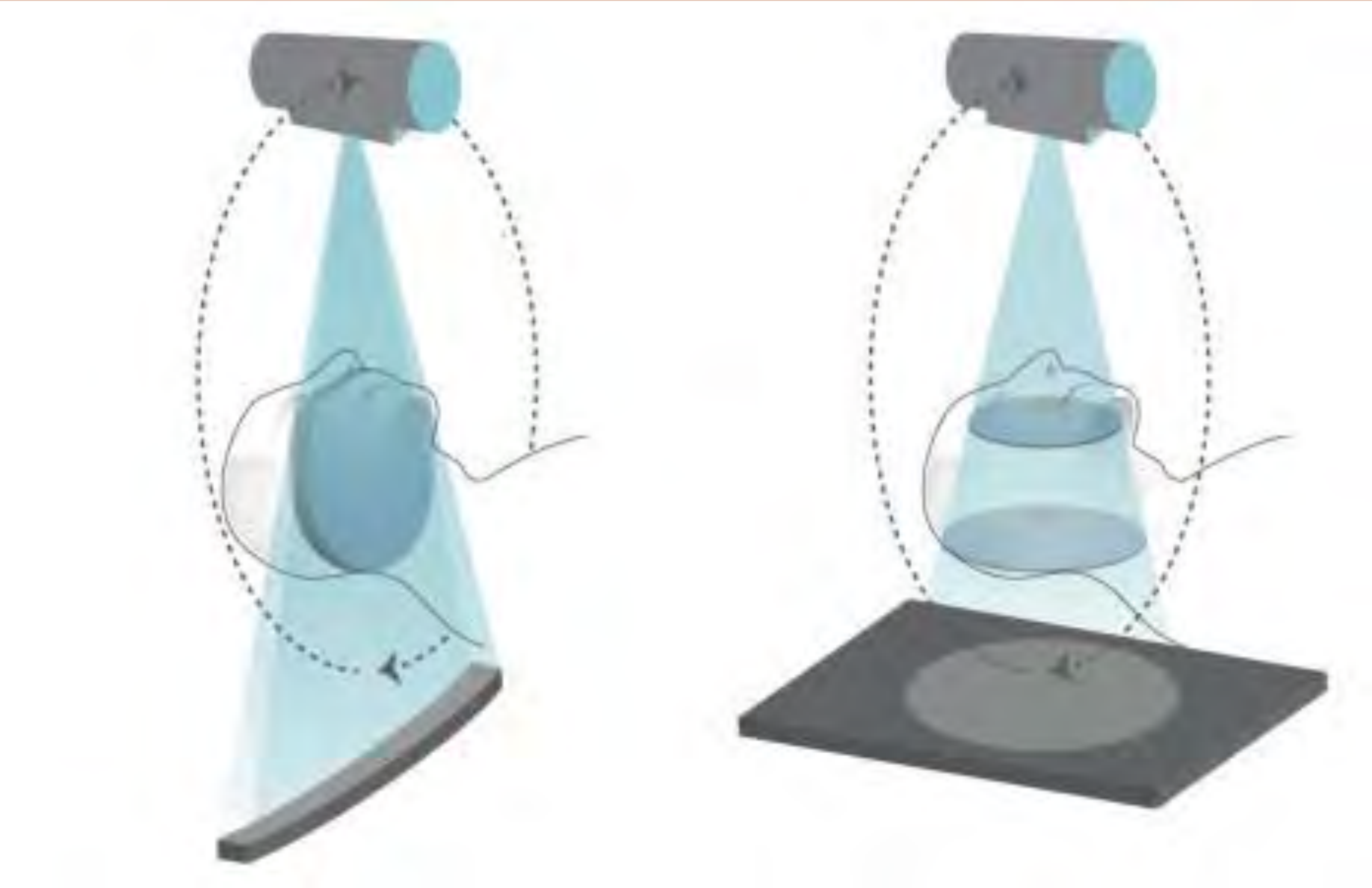
Computed Tomography (CT) & Cone beam CT (CBCT)



CT: 2-D Picture   CBCT:3-D Structure

Medical Imaging System

- Application:

  Image Guided Radiotherapy (figure)

  Tumor & Trauma Diagnosis

  Nondestructive testing

Motivation

- Scatter correction in CBCT provide better anatomical image quality.

Current problem

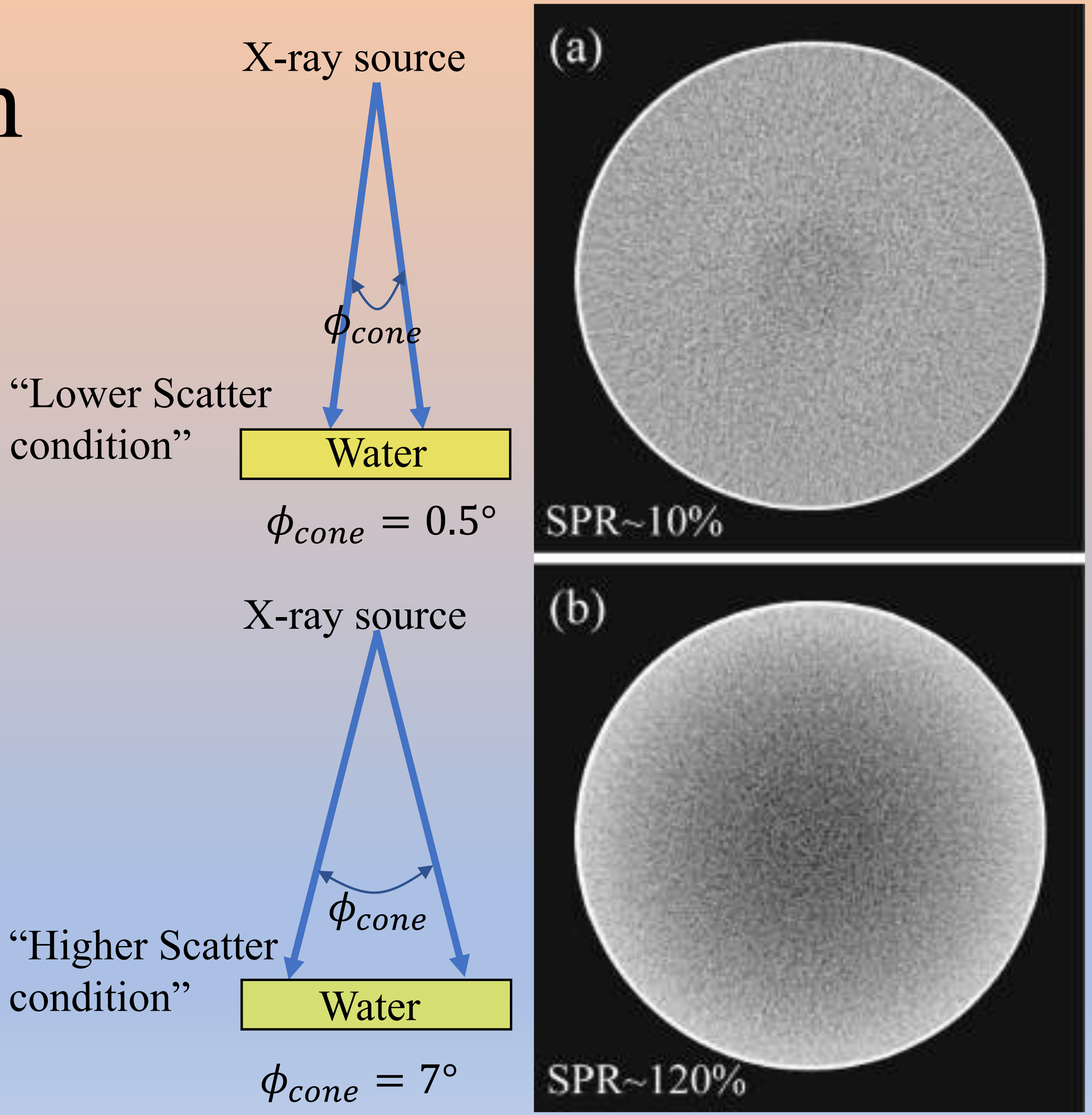
- Scattering induced noise[1]

Campton scattering

(solved)

Rayleigh scattering

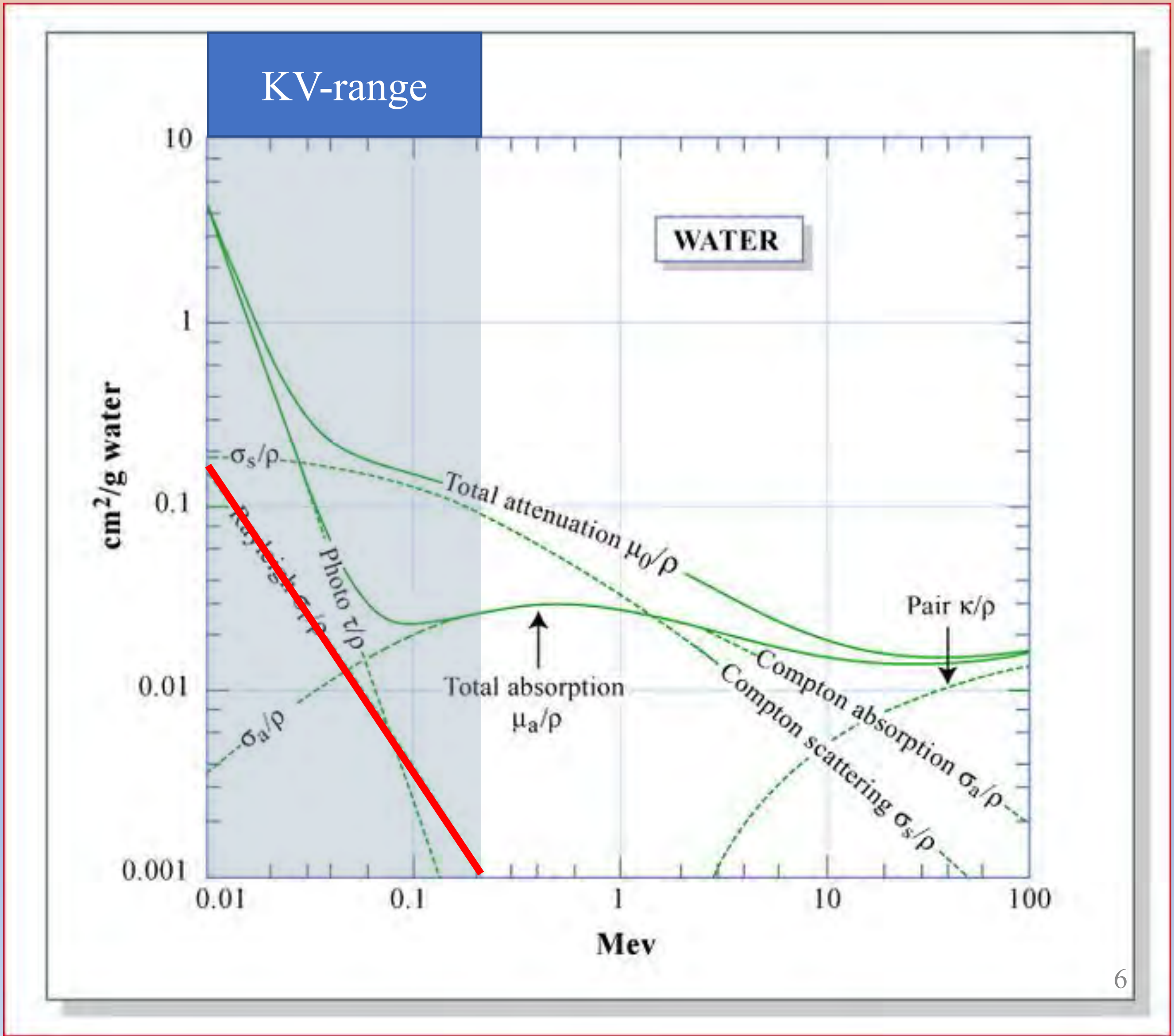
(remain to be solved)



Radiation Interaction

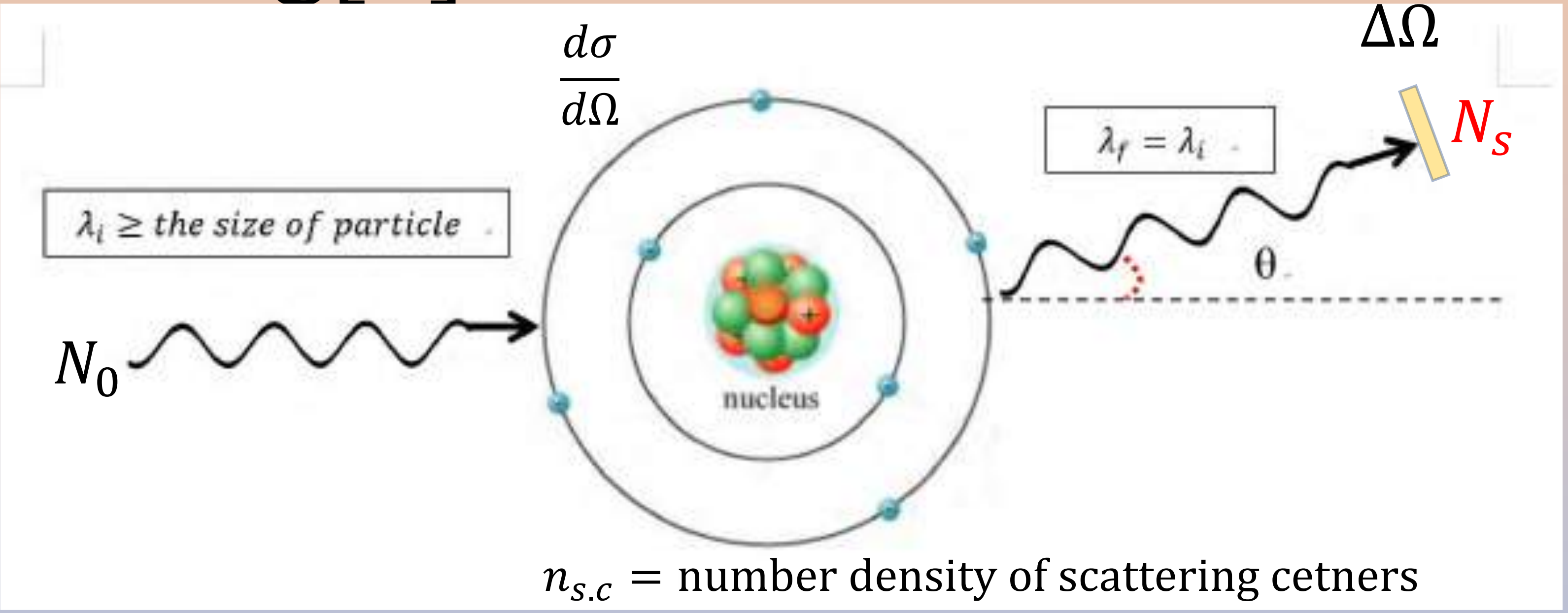
- Rayleigh scattering

  Energy range



Rayleigh Scattering[2]

- Scattering theory:



$$N_s(\theta, E) = N_0 n_{s.c} \frac{d\sigma}{d\Omega}(\theta, E)\Delta\Omega$$

Detected Signal

X-ray Intensity

Differential Cross section

Solid angle of detector

Differential Cross Section

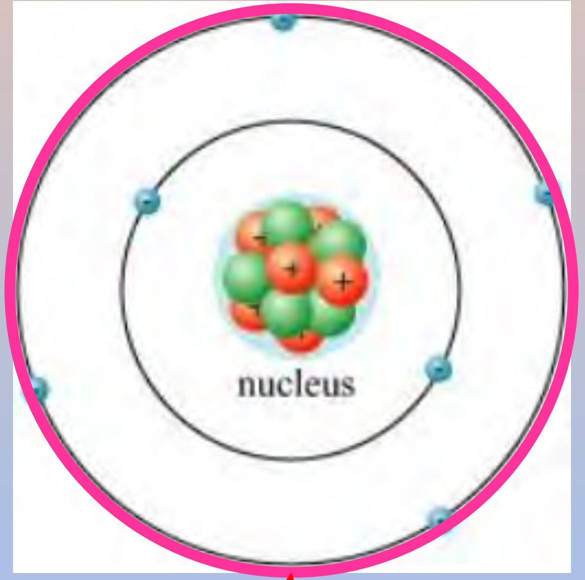
$$\frac{d\sigma}{d\Omega} = \frac{r_0^2}{2}(1 + \cos^2\theta)F_M^2(x)$$

Transfered momentum: (in unit Å)

$$x(E,\theta) = \frac{E}{m_0 c^2}\sin\left(\frac{\theta}{2}\right)$$

Constant

Material Form Factors[2]

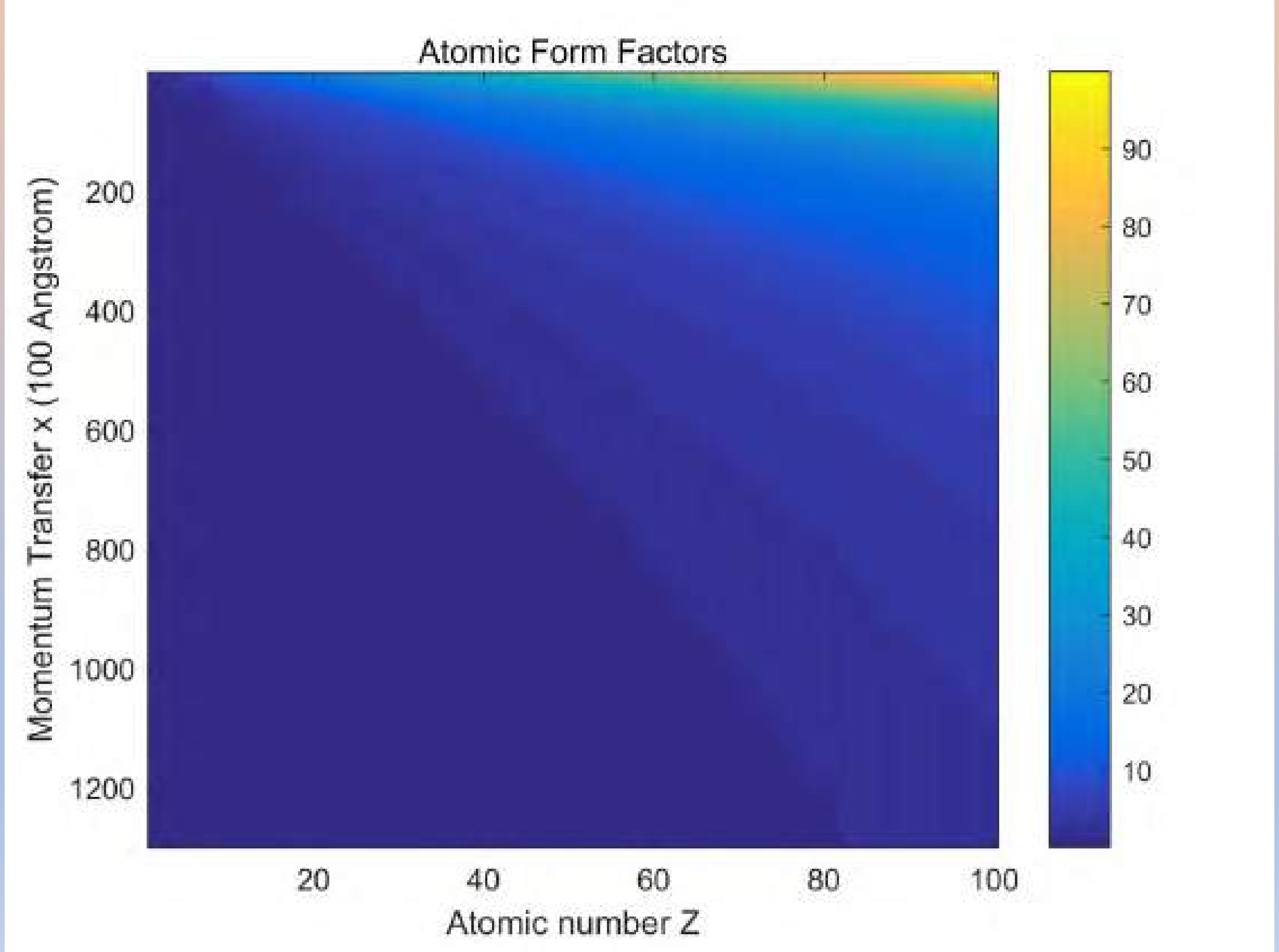


$$F_M^2(x) = \boxed{W \times \sum \frac{\omega_i}{M_i}}\boxed{F^2(x, Z_i)}$$

Chemical composite

Atomic Form Factors [3]

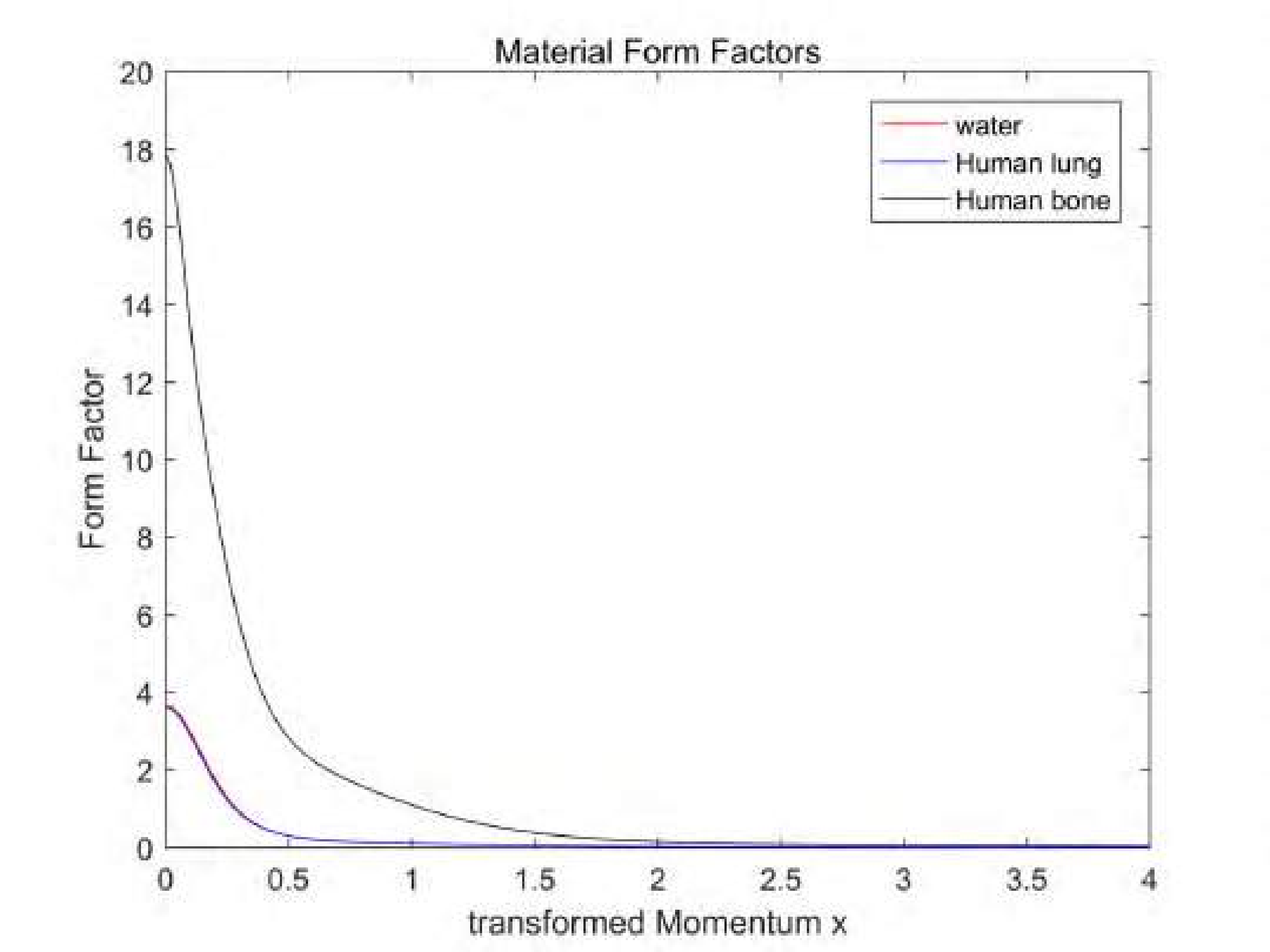
Atomic Form Factors



Material Chemical Formulas (EGS data)

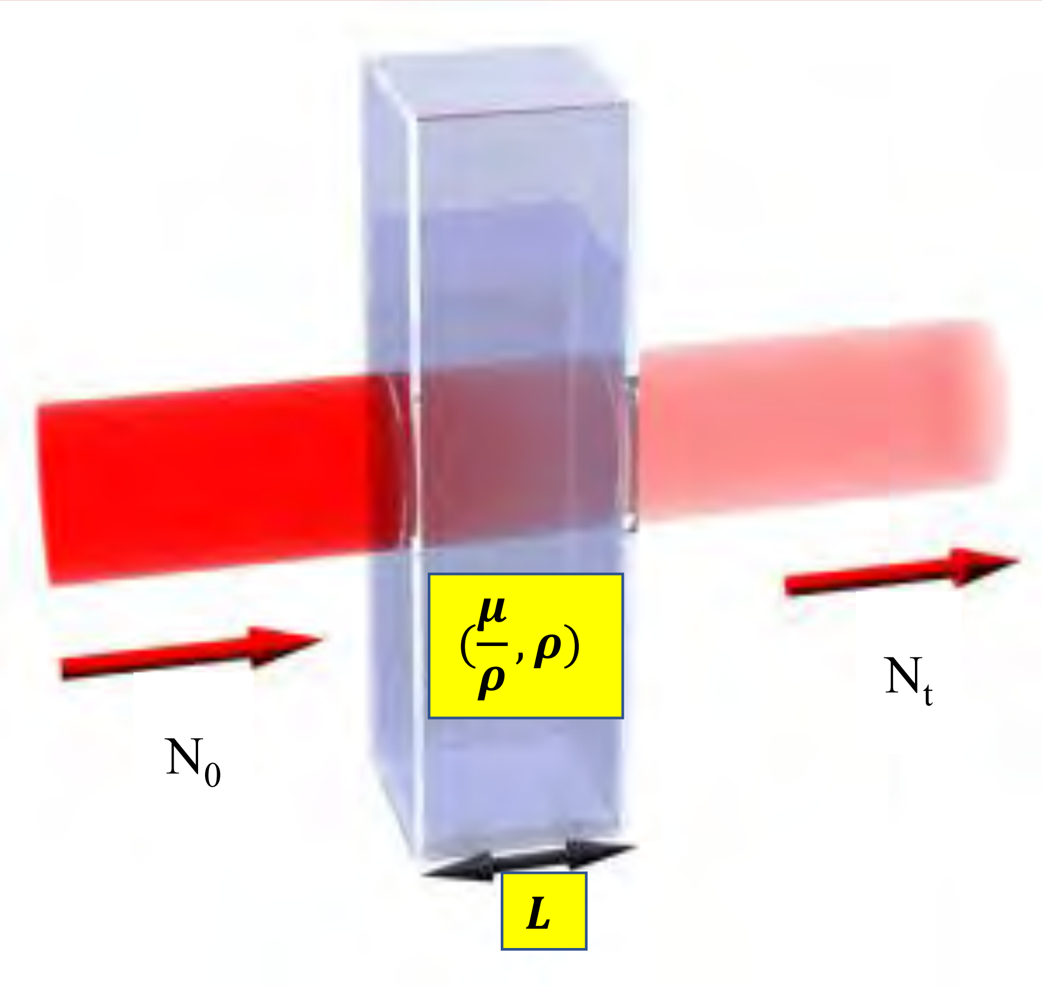
Human tissue/(mass fraction)		Water	Human Lung	Human Bone
Elements	Density$(g \cdot cm^{-3})$	1.0	0.26	1.85
H		0.112	0.103	0.063984
C		-----	0.105	0.278
N		-----	0.031	0.027
O		0.888	0.749	0.410016
Na		-----	0.002	-----
Mg		-----	-----	0.002
P		-----	0.002	0.07
S		-----	0.003	0.002
Cl		-----	0.003	-----
K		-----	0.002	-----
Ca		-----	------	0.147

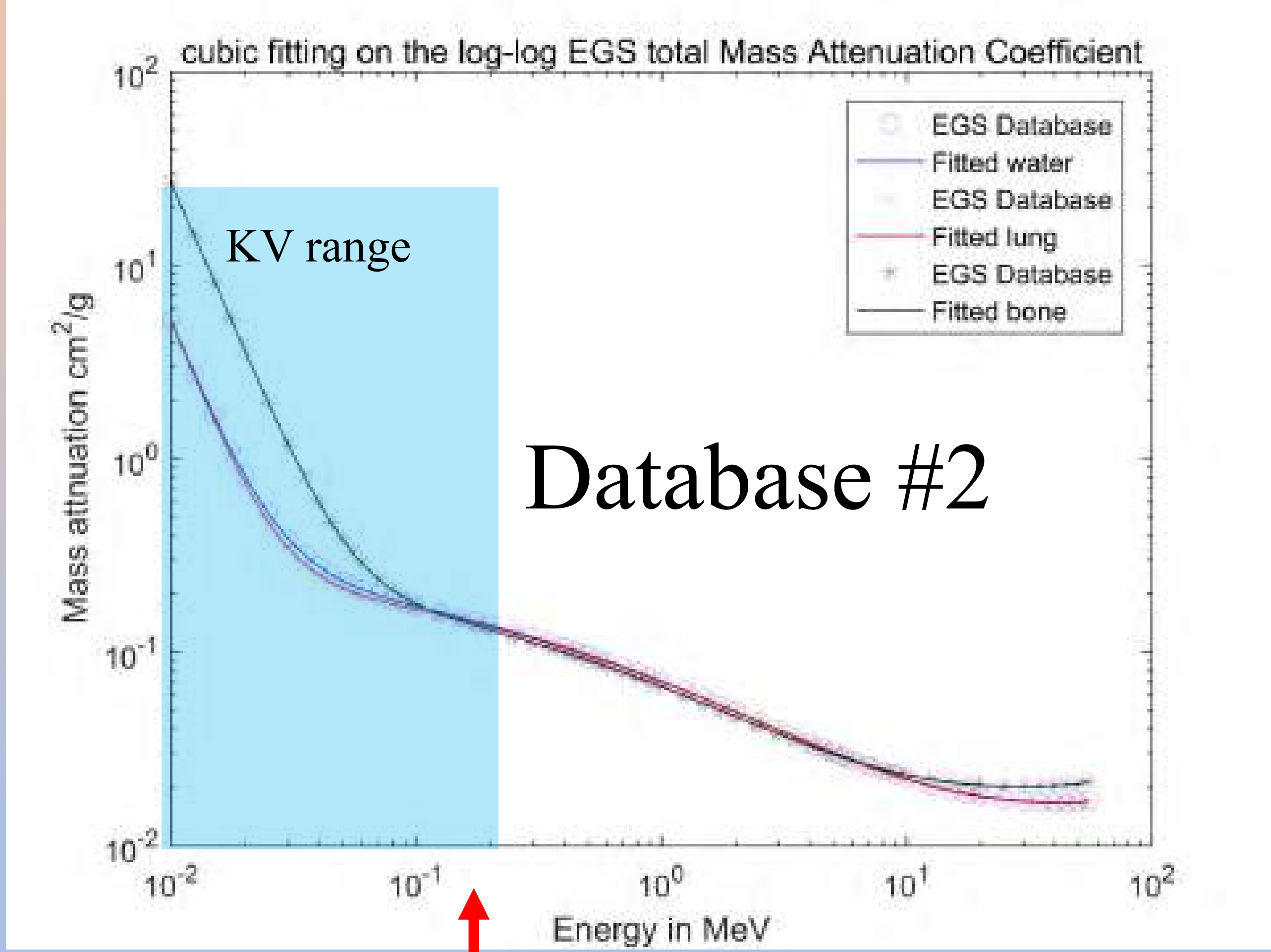
Form Factor interpolation



Database #1

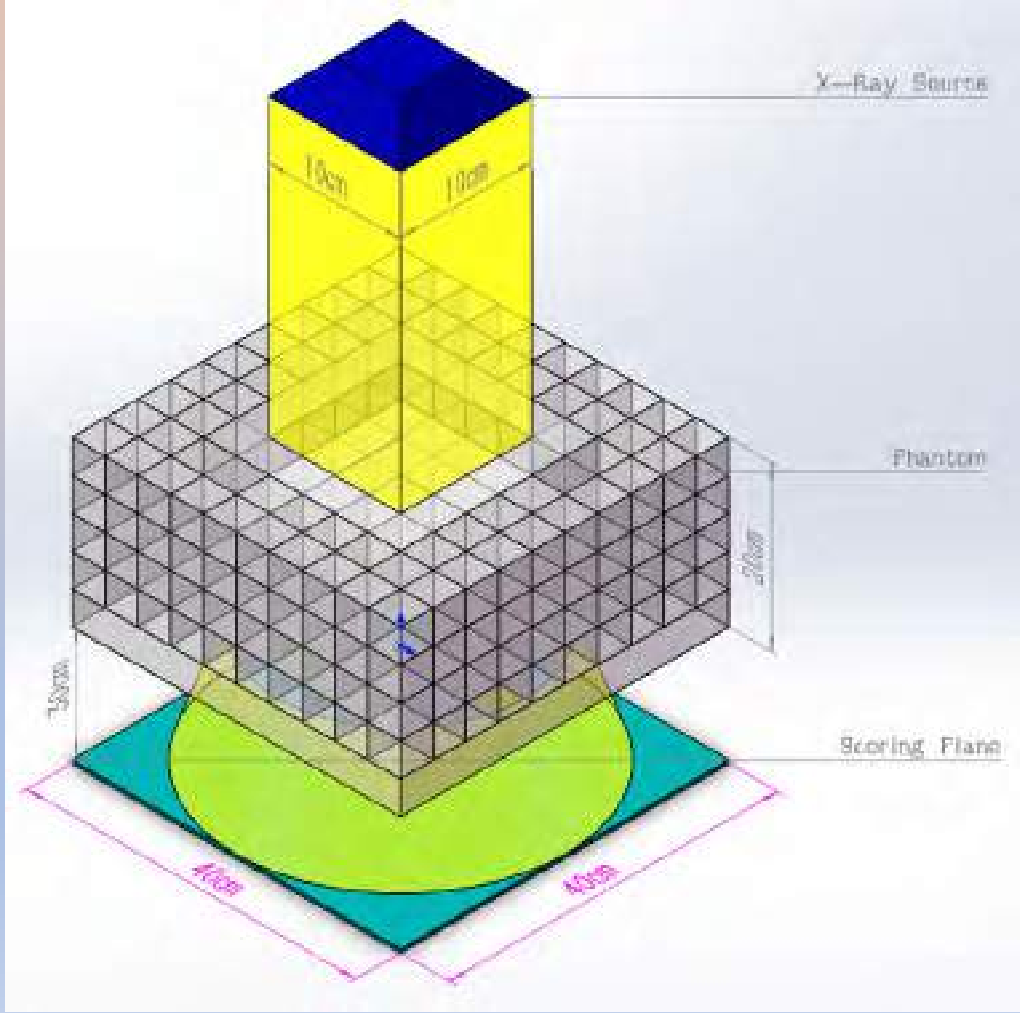
Mass attenuation coefficients and interpolation

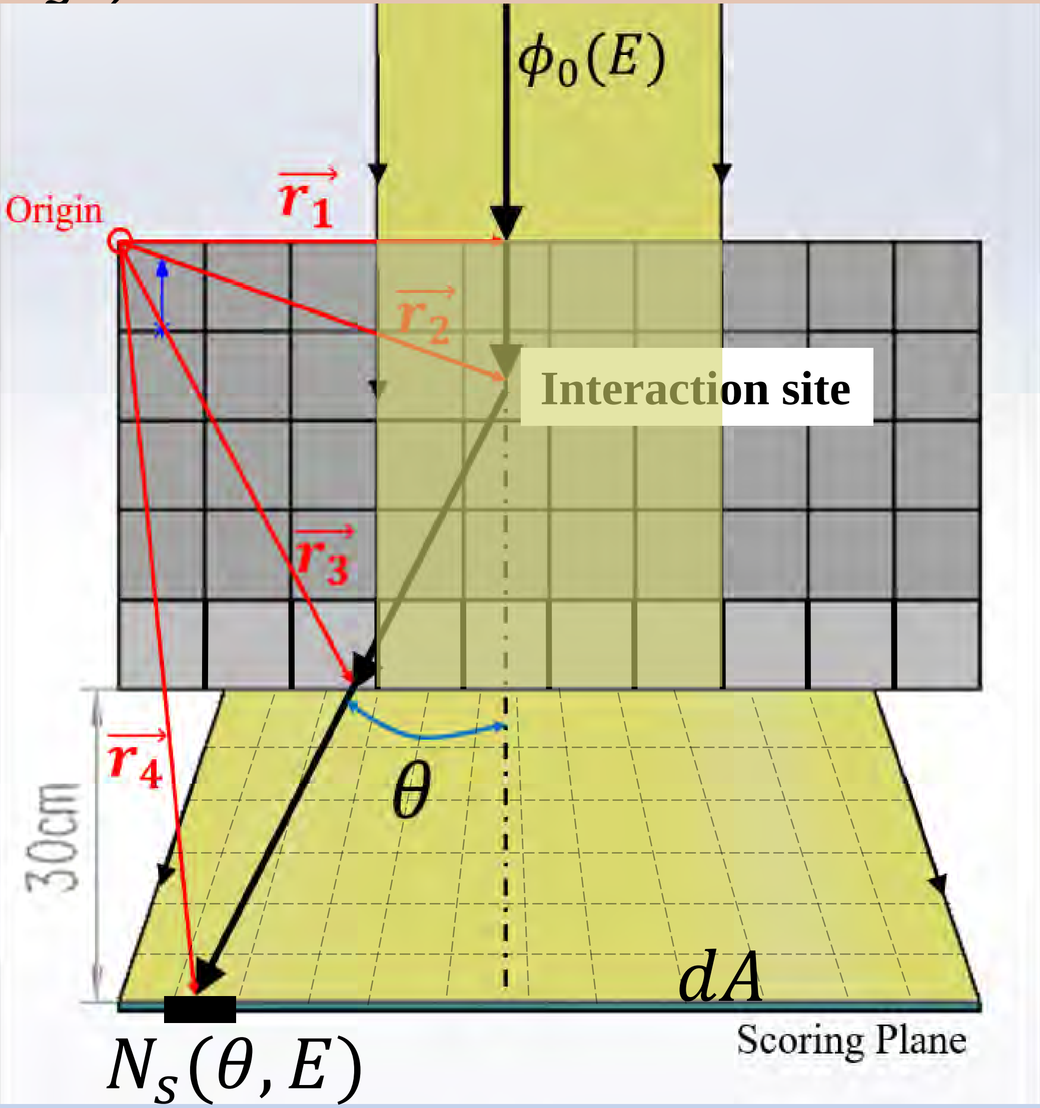




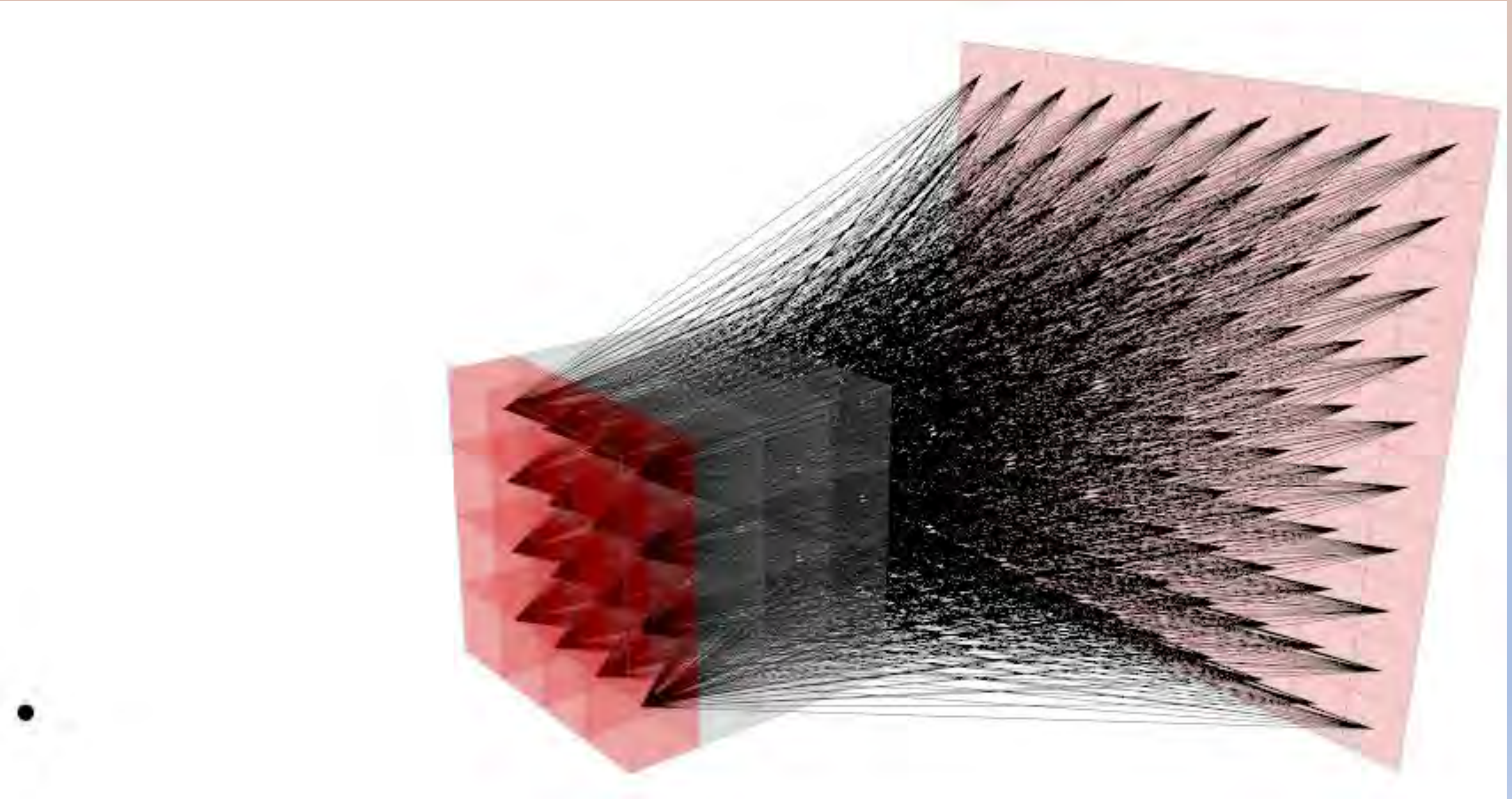
$$I_e = I_0 e^{\int \left(-\frac{\mu}{\rho}(E)\right) \rho(l) dl}$$

Simulation Setup
(Parallel beam Geometry)



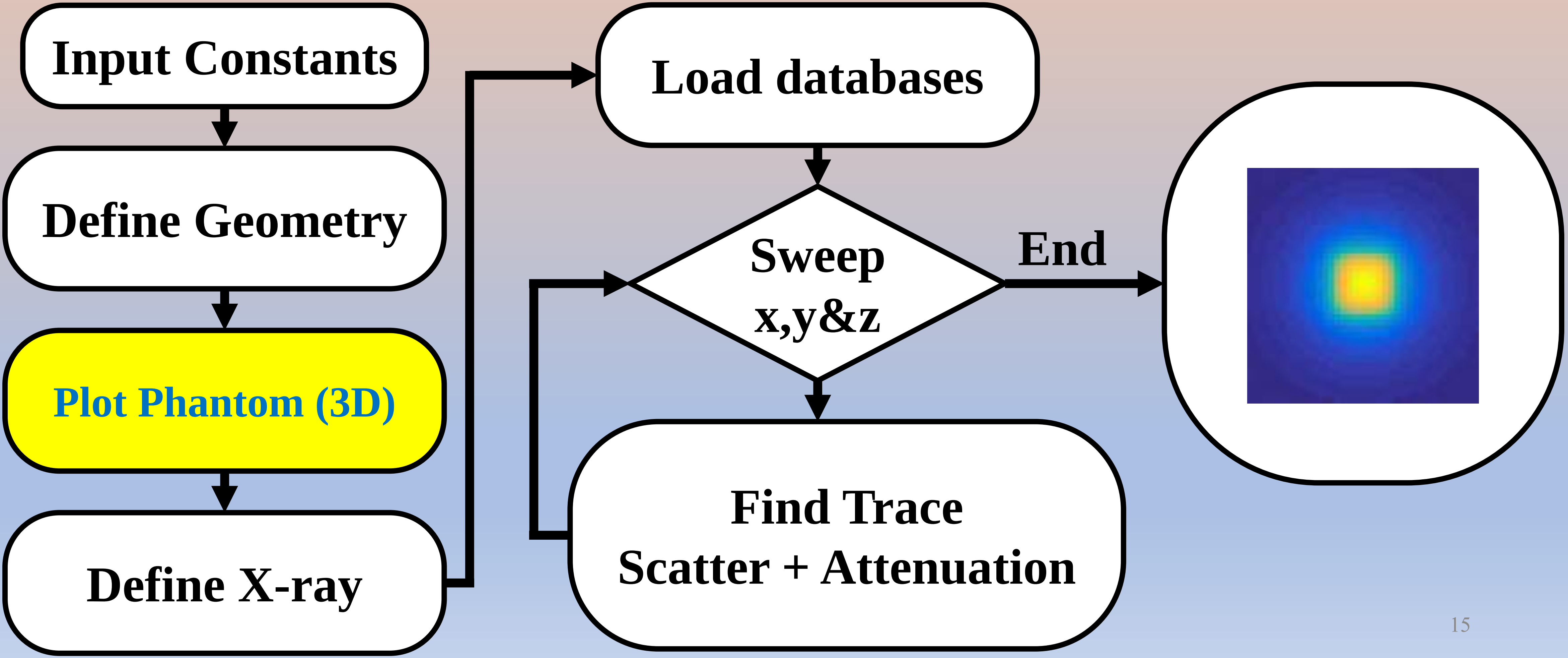


Simulation setup



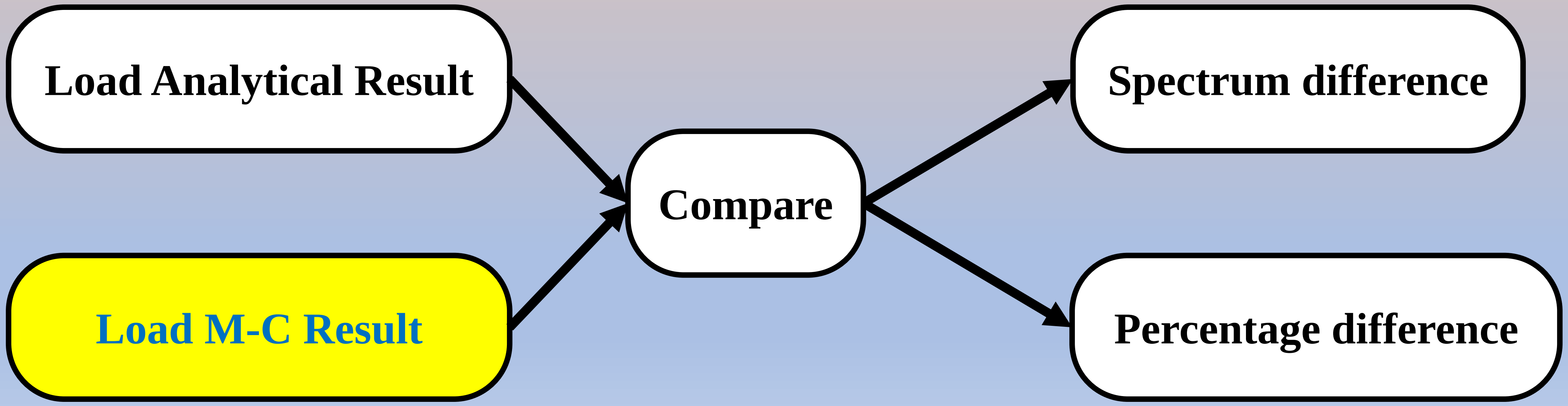
MATLAB code

- main_r_1stScatteredFluence.m

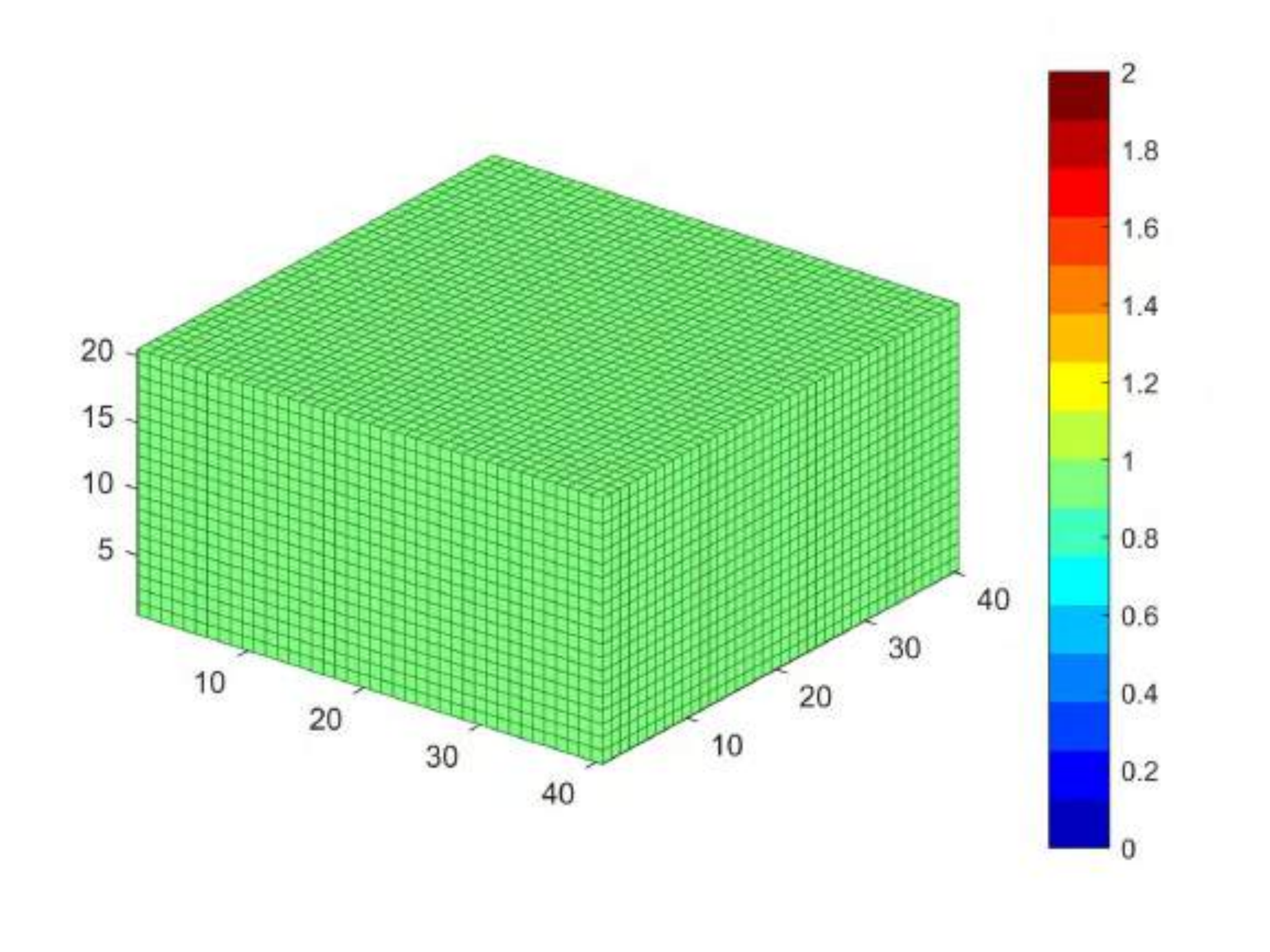


Verification using Monte-Carlo method

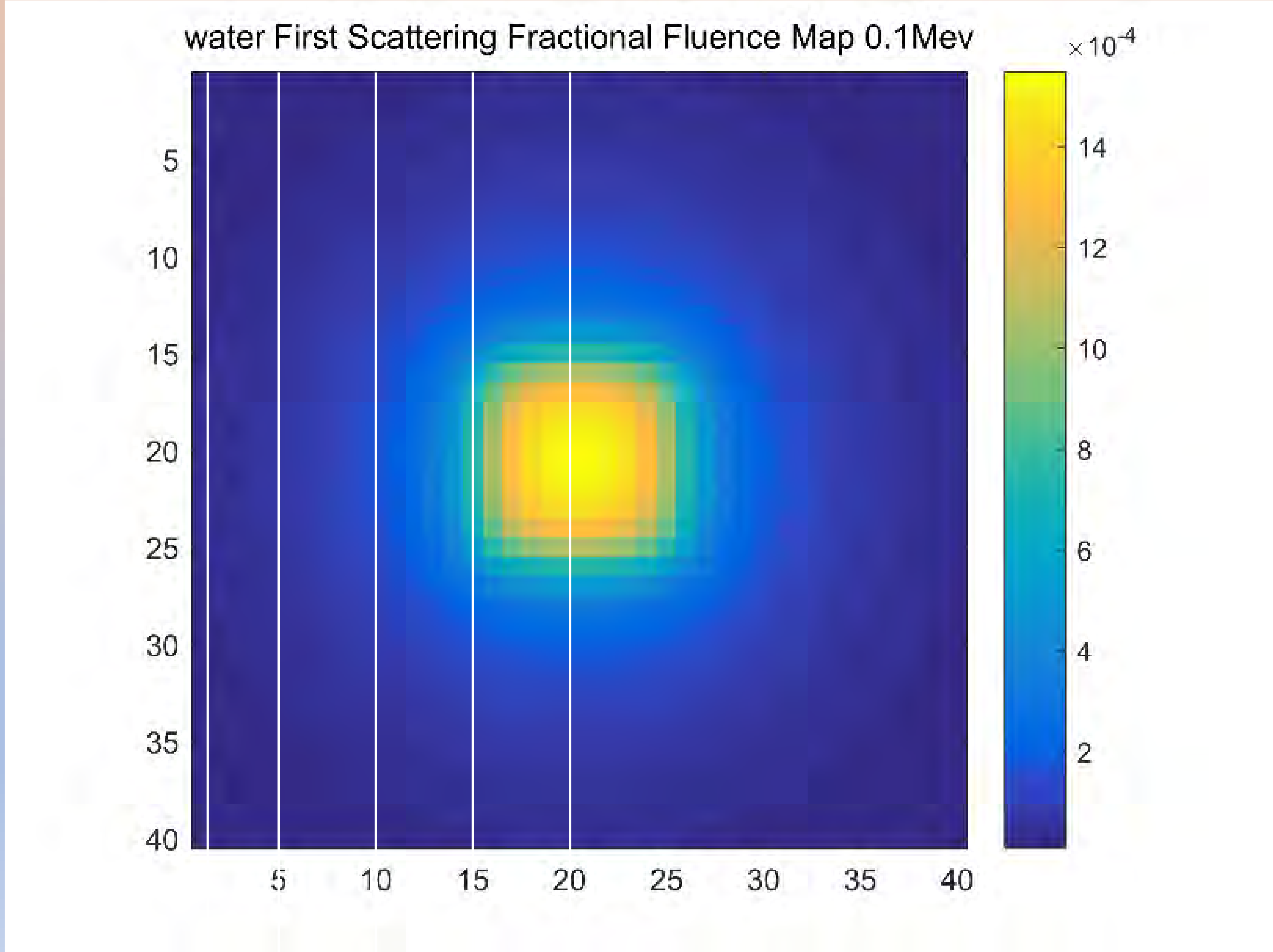
- AMCcomparison.m
- Monte Carlo simulation
  - Modified Dosxyznrc user code (EGSnrc package)



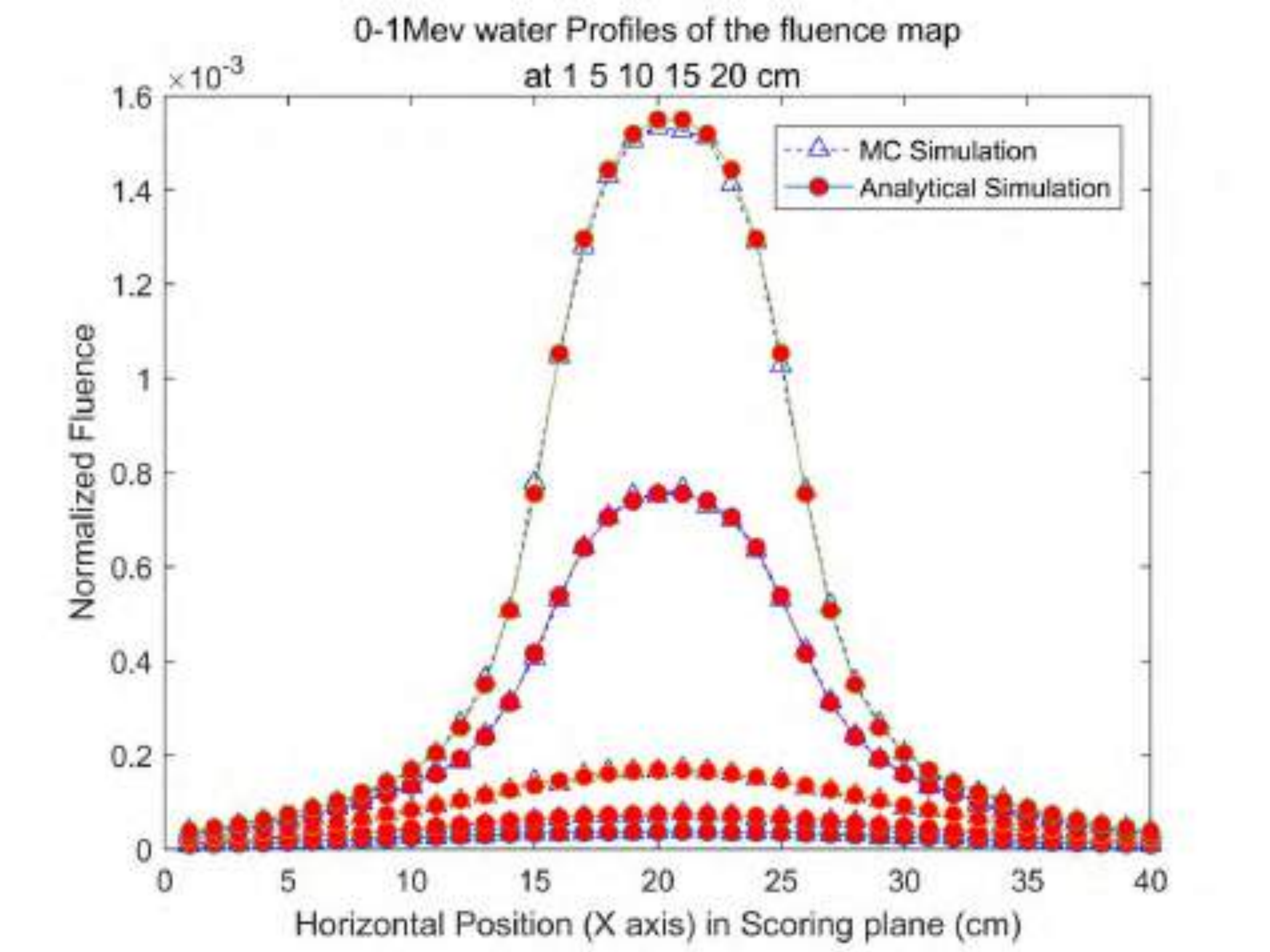
Simulation phantom (Water)

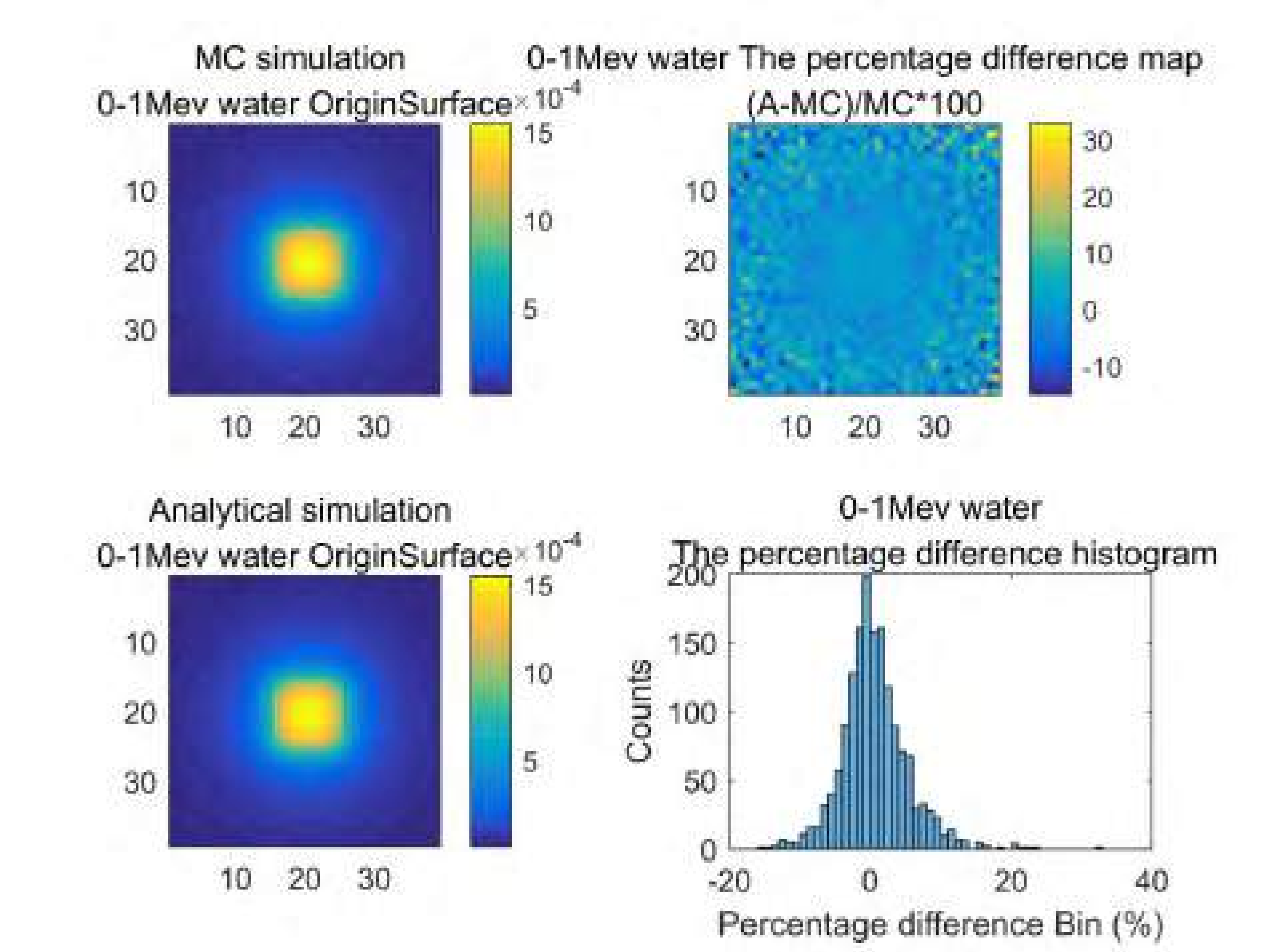


Simulation Results (Water)

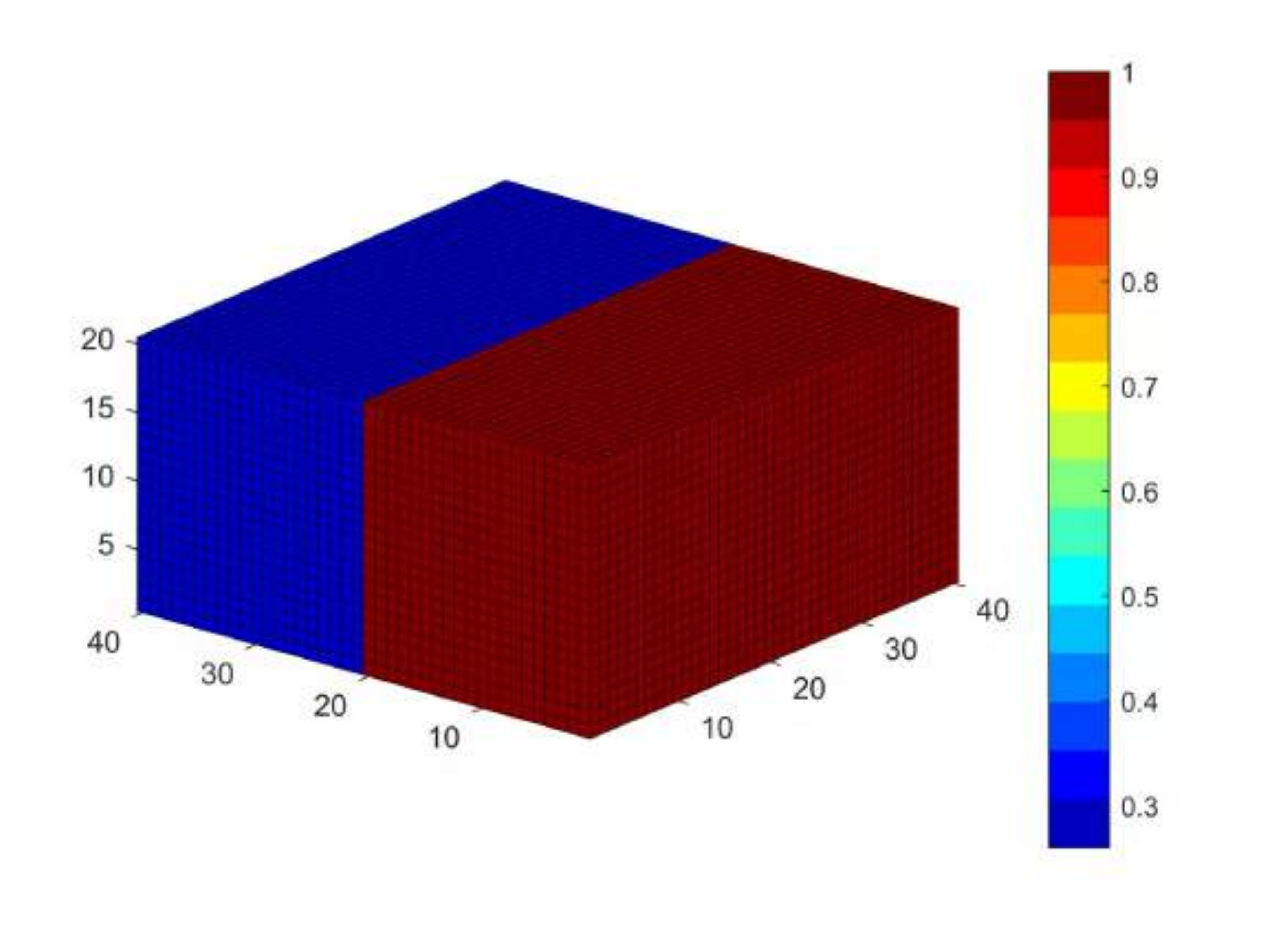


Compare with Monte-Carlo Method

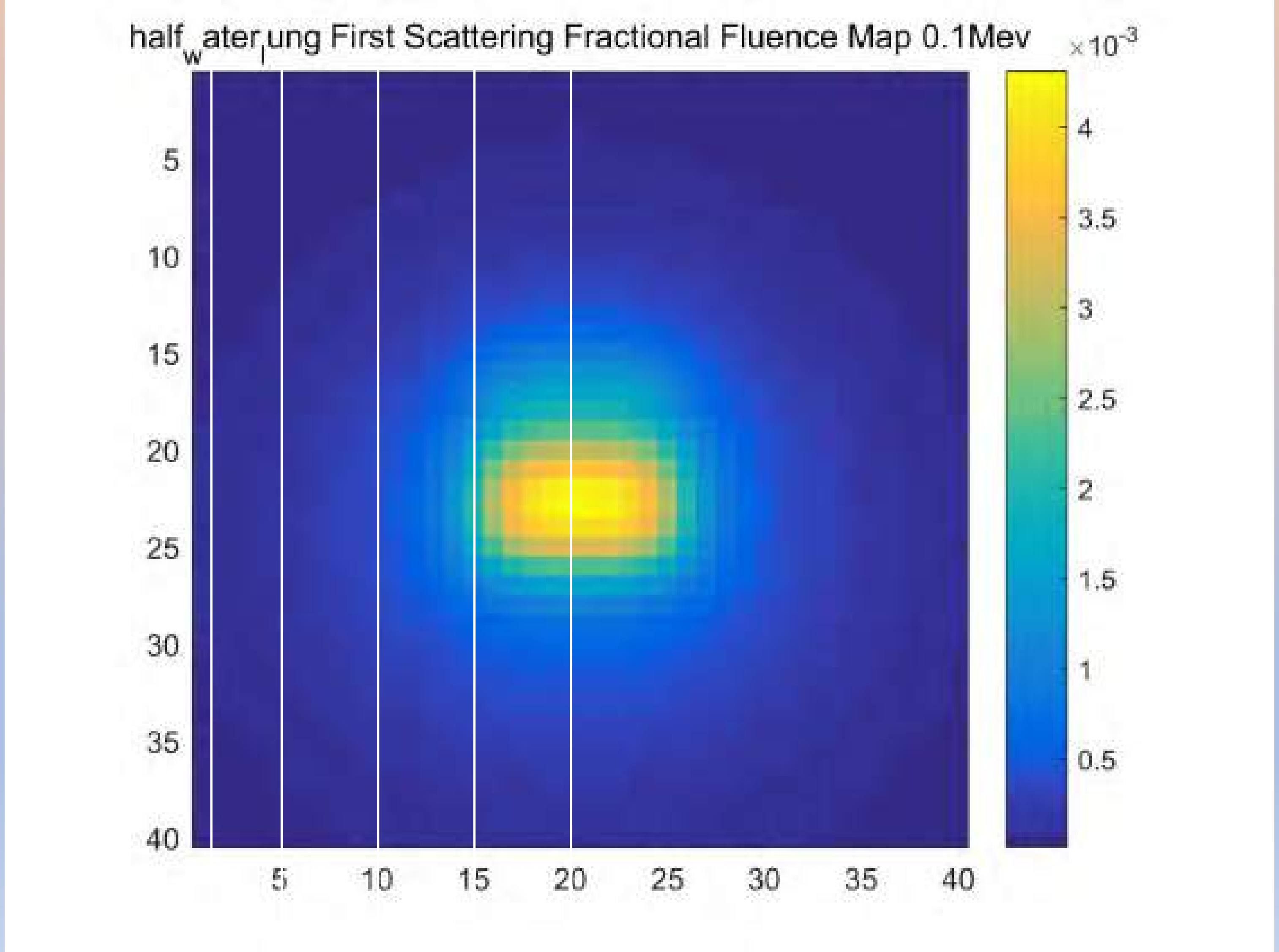




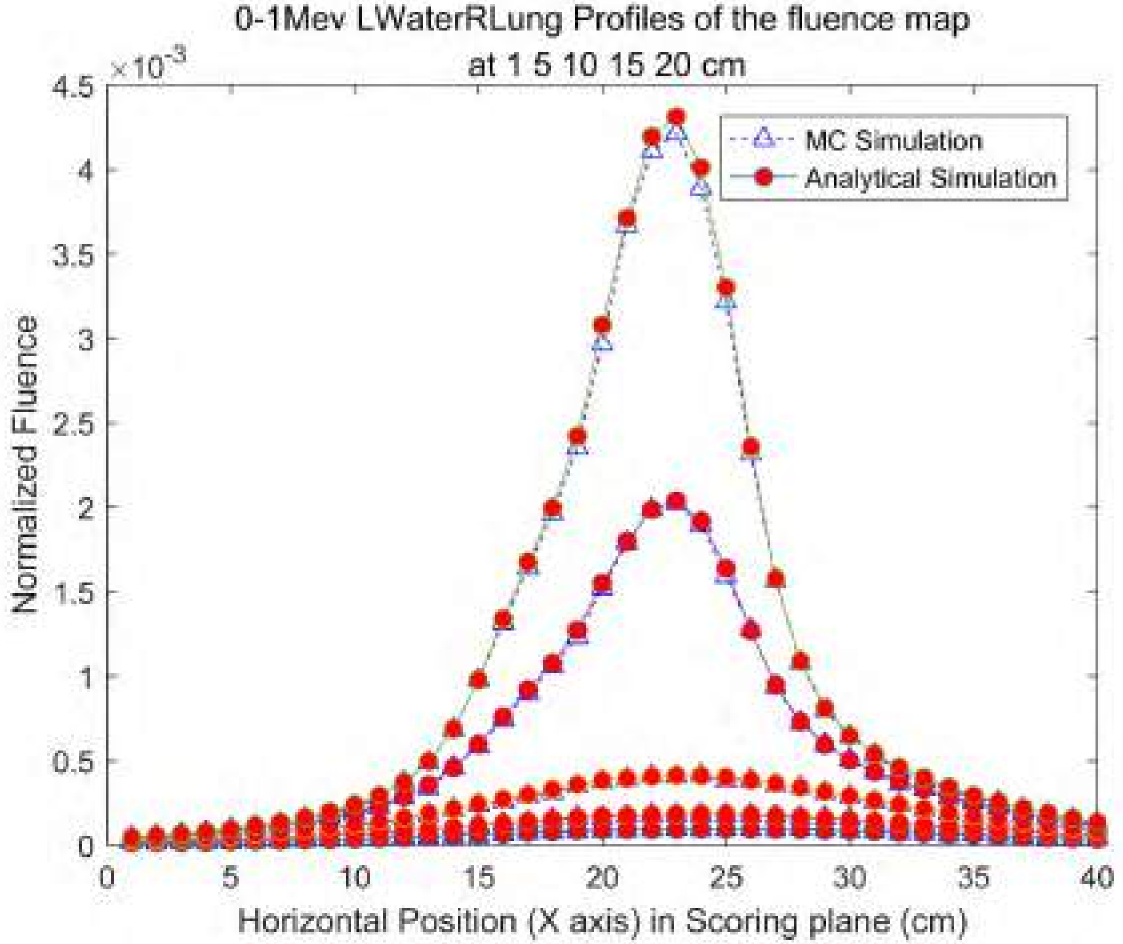
Simulation phantom (half water half lung)

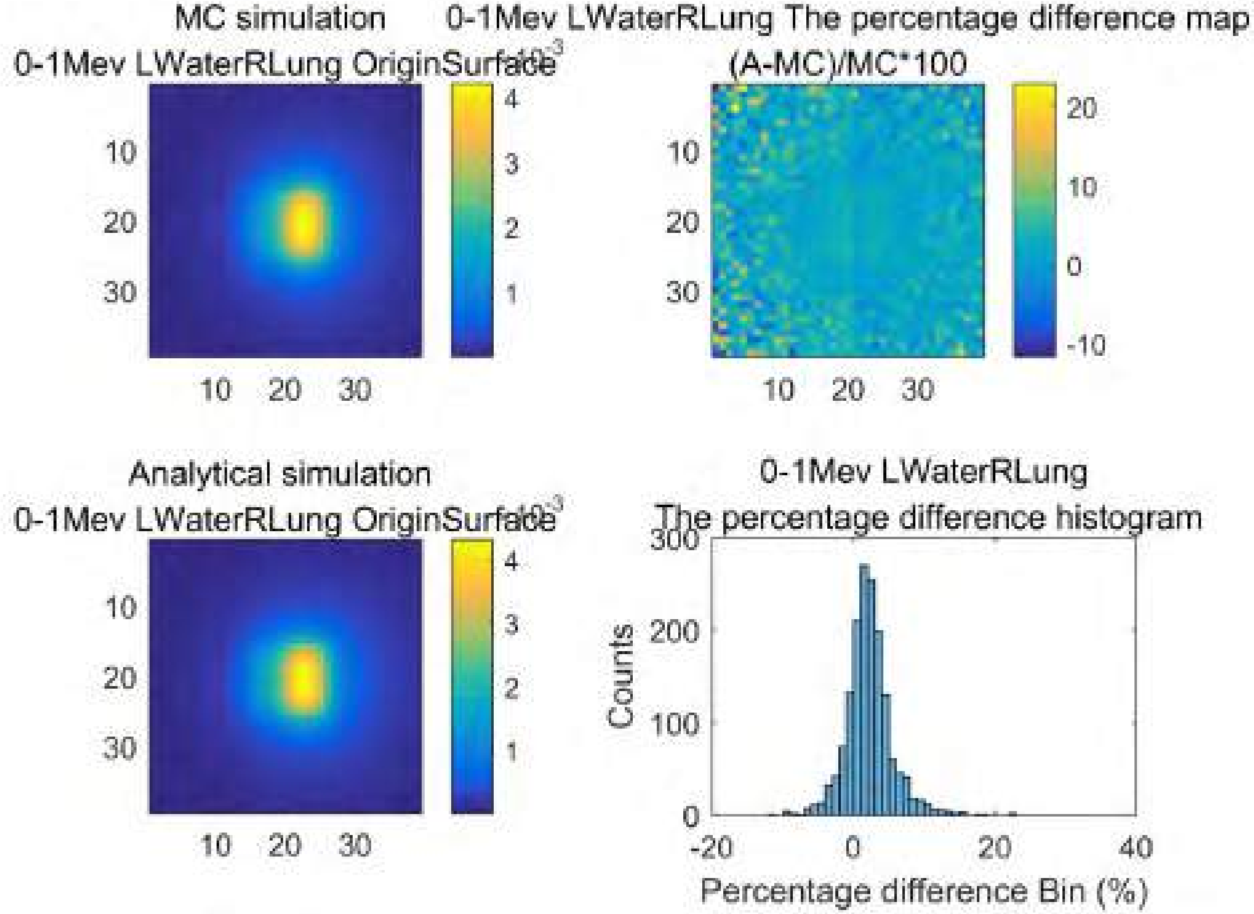


Simulation Results



Compare with Monte-Carlo Method





Discussion

- Limit 1: We do not have experiment data to validate our results.
- Limit 2: The X-ray is parallel. We need to generalize to divergent beam.
- Limit 3: Only apply to singly scatter.

Conclusion

- 1. A reliable analytical method for Rayleigh scattering has been build under parallel beam geometry.
- 2. Time-saving by utilizing pre-calculations (3.6s compare to 7 hours)
- 3. Combining with Compton scattering method, the total singly scattered fluence pattern can be obtained.
- 4. Beneficial to first order scatter correction in CBCT reconstruction

Thank you!

Questions?

Reference

[1] J. H. Siewerdsen and D. A. Jaffray, " Cone-beam computed tomography with a at-panel imager: Magnitude and effects of x-ray scatter," *Medical physics*, vol. 28, no. 2, pp. 220-231, 2001.

[2]. H. Ingleby, J. Lippuner, D. W. Rickey, Y. Li, and I. Elbakri, "Fast analytical scatter estimation using graphics processing units," *Journal of X-ray science and technology*, vol. 23, no. 2, pp. 119-133, 2015.

[3]. Hubbell, J. H., Veigele, W. J., Briggs, E. A., Brown, R. T., Cromer, D. T., & Howerton, R. J. "Atomic form factors, incoherent scattering functions, and photon scattering cross sections." *Journal of physical and chemical reference data* vol.4, no.3 pp.471-538,1975.