International Conference on Monte Carlo Techniques for Medical Applications (MCMA2017)

Evaluation of the clinical translation of an optimized Compton Camera during Boron Neutron Capture Therapy for melanoma patients

Chunhui Gong (Diyun Shu)

gongchunhui@nuaa.edu.cn

Department of Nuclear science and engineering

Nanjing University of Aeronautics and Astronautics

China

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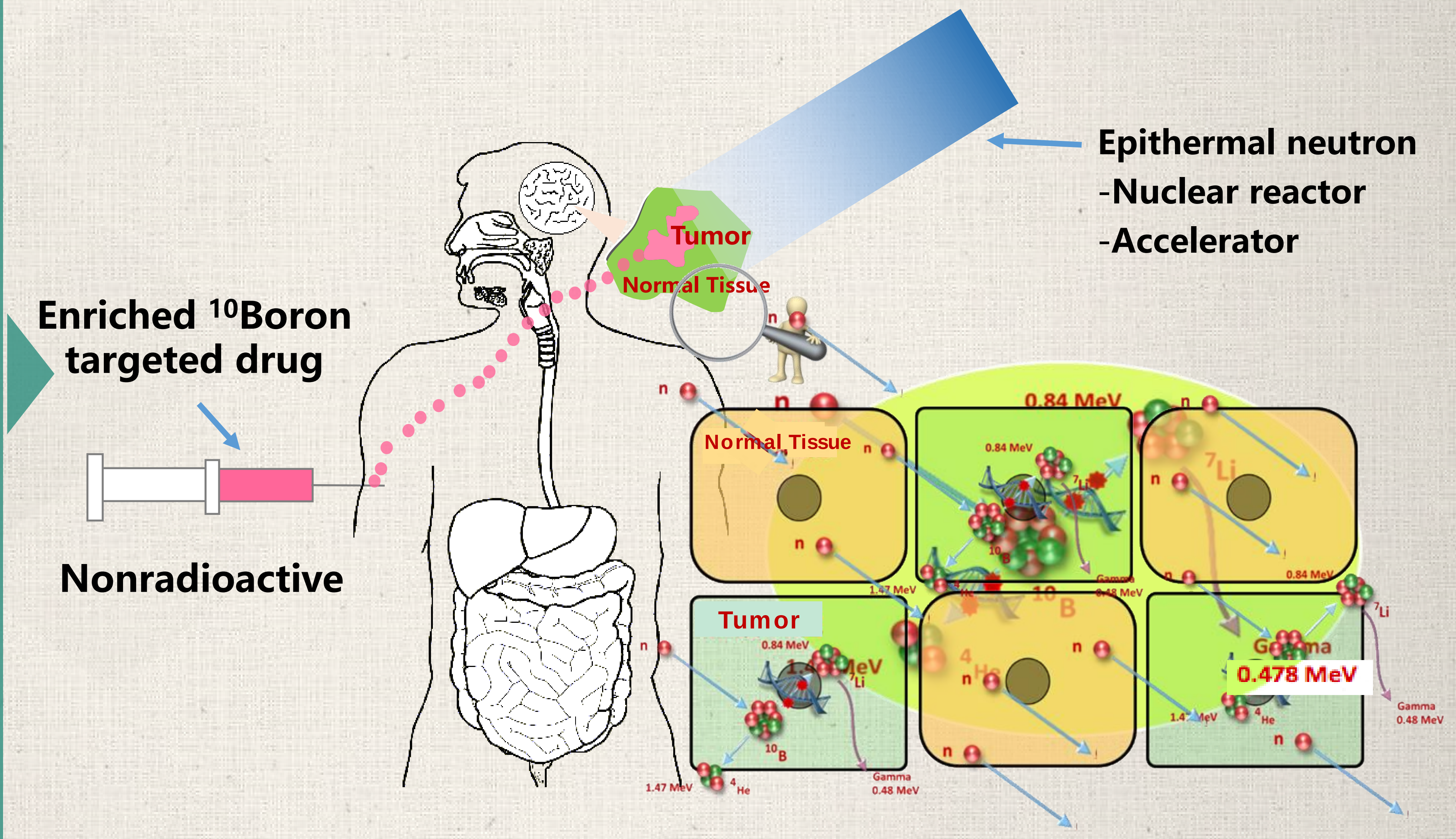
1 Introduction

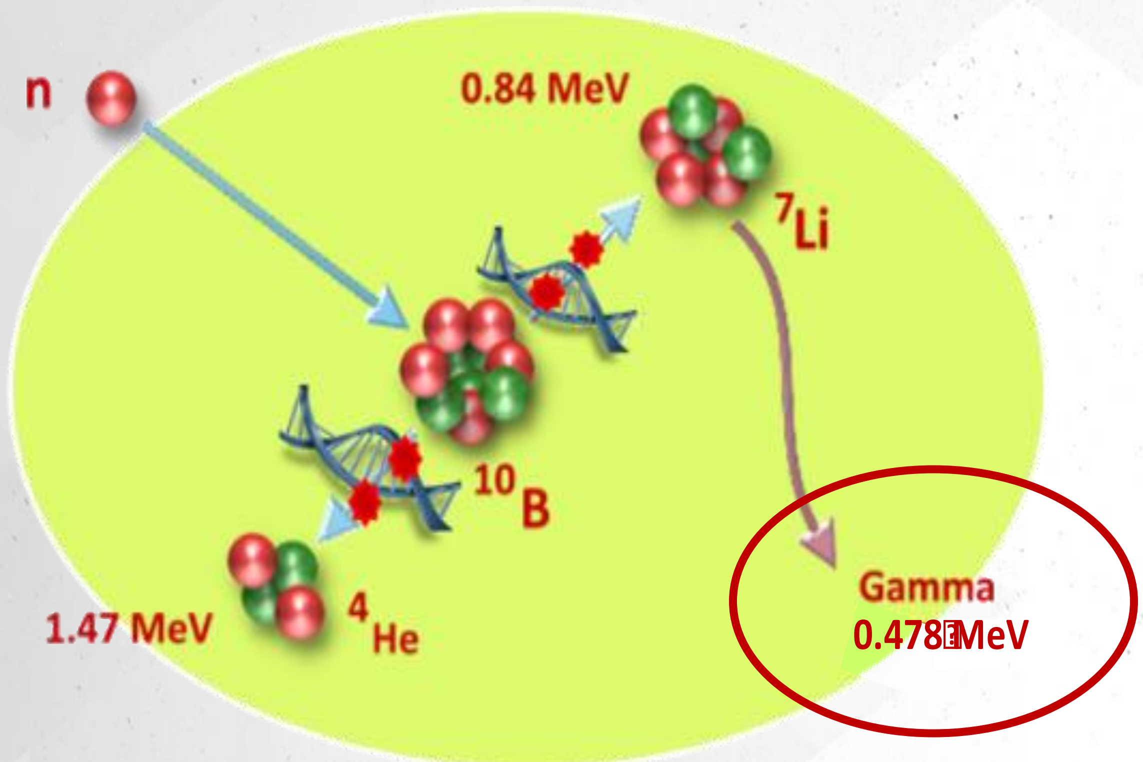
- Boron Neutron Capture Therapy (BNCT)
- Compton camera (CC)

Boron Neutron Capture Therapy

BNCT is a binary form of radiation therapy using high propensity of the nonradioactive nuclide ^{10}B to capture thermal neutrons resulting in the prompt nuclear reaction $^{10}B(n,\alpha)^{7}Li$. The products of this reaction have high LET, whose path lengths in tissues are in the range of 4.5-10μm (about a cell diameter).



1.1 Boron Neutron Capture Therapy (BNCT)

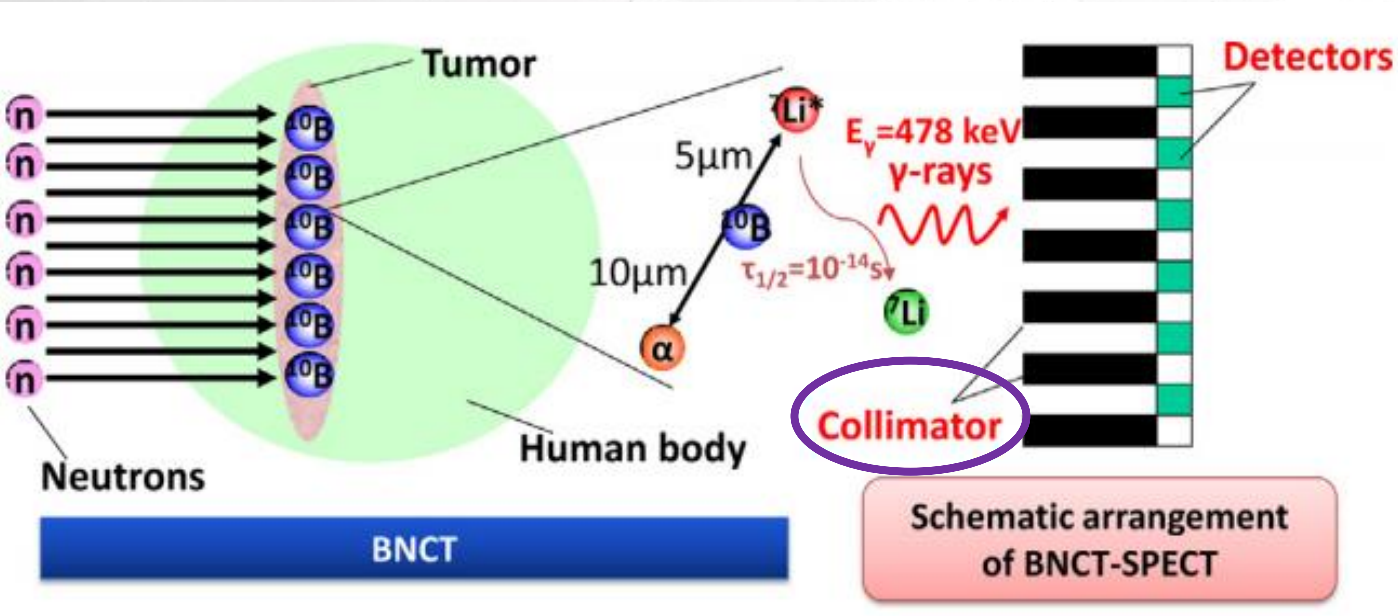


- **One of key issues in BNCT:**
  - **- Boron concentration within patient/sample**
- **Experiment approach:**
  - **- in-vitro measurement**
  - **- pretreatment PET to predict the distribution in-vivo**
  - **- Imaging via prompt γ emission from $^{10}B(n,\alpha)^{7}Li$ reaction**

If the position and intensity of the gamma-ray emission is measured, it is equivalent to the reaction rate (concentration) distribution of $^{10}B(n,\alpha)^{7}Li$ reaction.

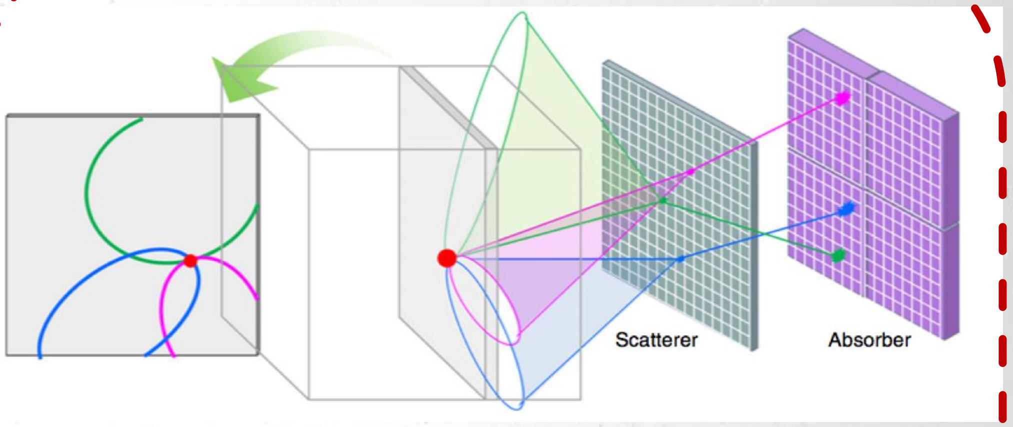
1.1 Boron Neutron Capture Therapy (BNCT)

Conventional SPECT



- ***Localization of the photon source*: mechanical collimation**
- ***Drawback:* intrinsic limitations in <u>sensitivity and spatial resolution due to the collimator</u>.**

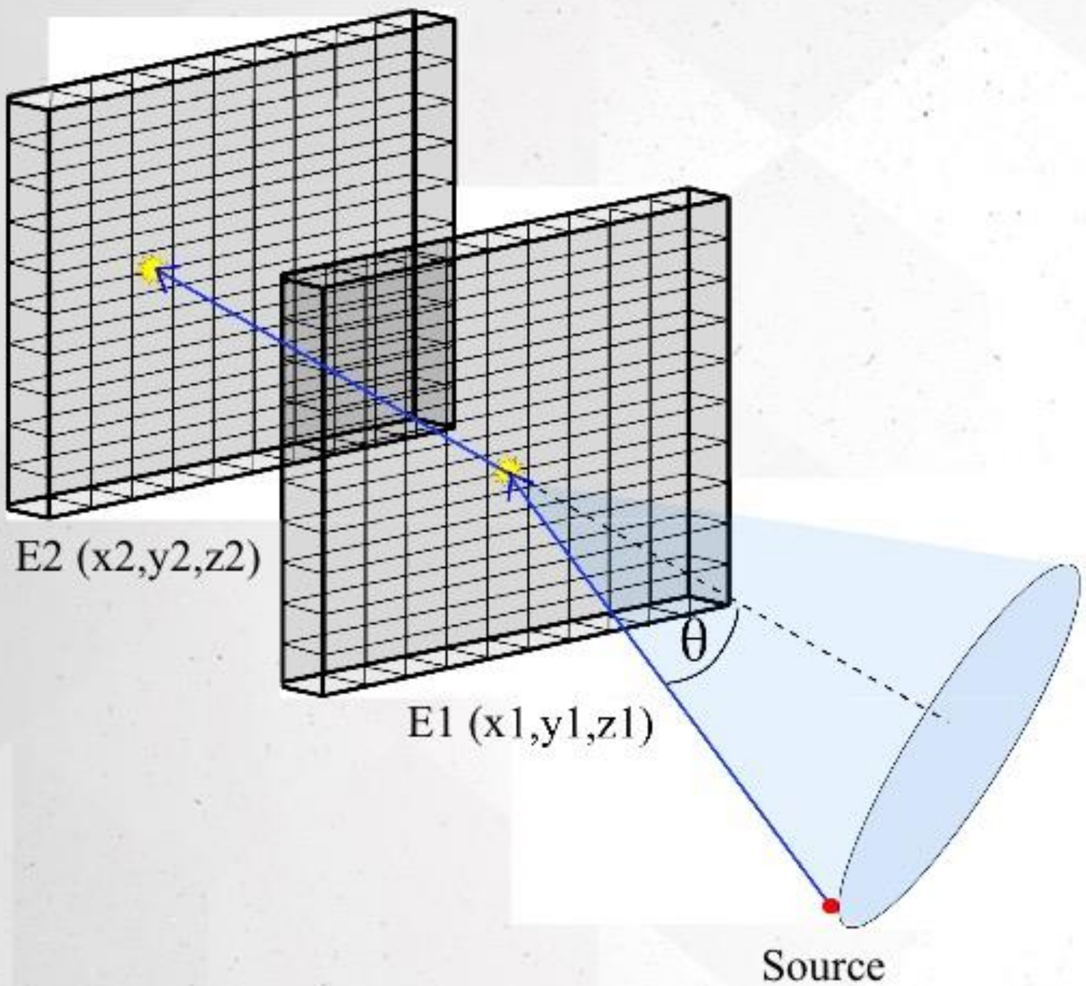
Compton camera (CC)



- ***Localize the radioactive source:* kinematics of Compton scattering**
- ***Advantages over SPECT camera*: <u>higher sensitivity, larger field of view</u> and <u>larger energy range</u>.**

Limitation of mechanical collimator → So people try the electronical collimator: Compton Camera

1.2 Compton camera (CC)

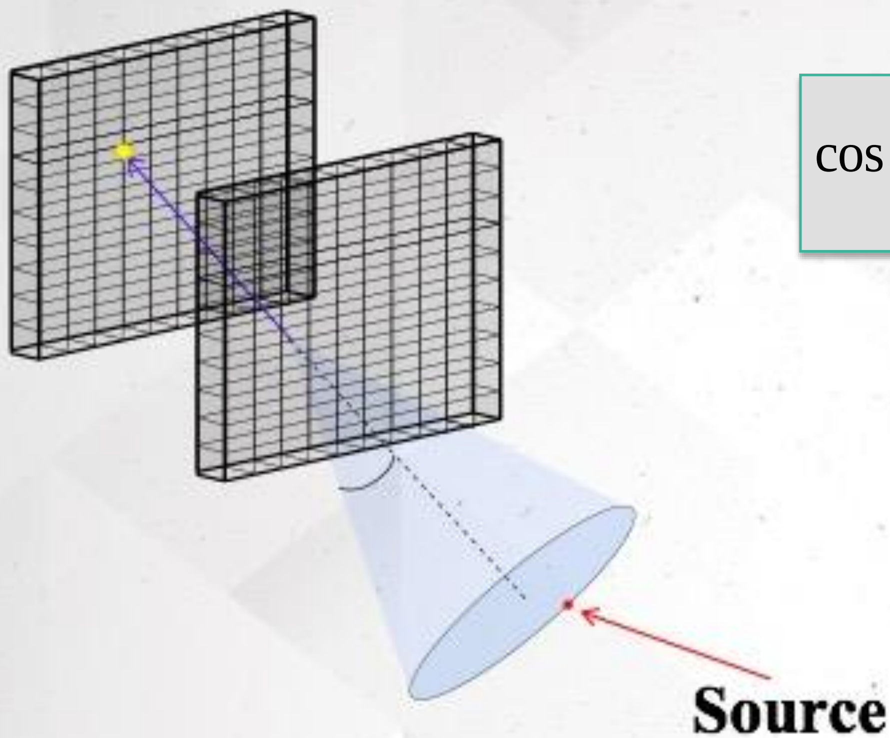


- The Compton camera (CC) principle relies on projecting ***Cones of Response*** into imaging space.
- Gamma-ray energy will be deposited in a detector through Compton scattering and then absorbed in a second detector via the photoelectric effect.
- Cones are projected using **the Compton scattering equation.**

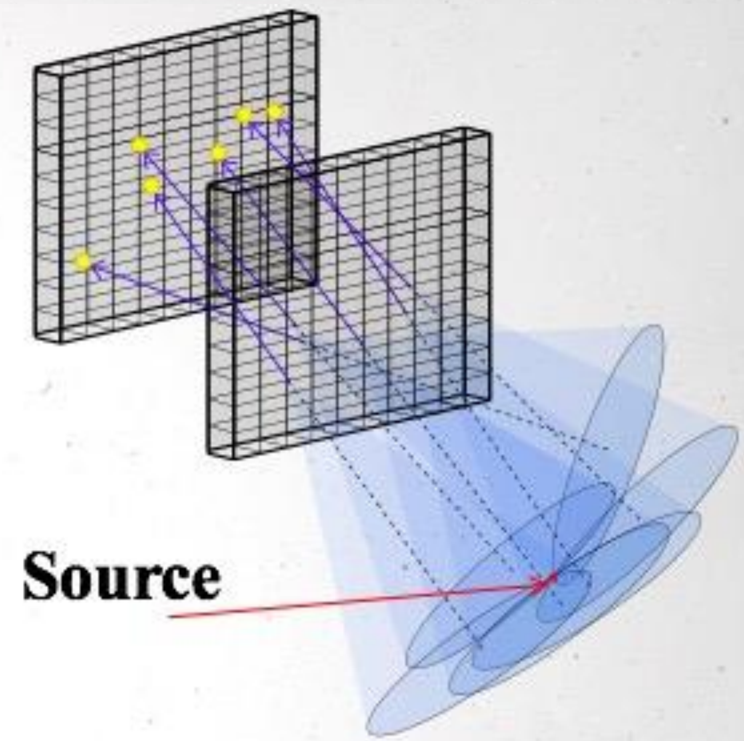
$$\cos\theta = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2} \right)$$

- Require a knowledge of **energy, position.**

1.2 Compton camera (CC)



$$\cos\theta = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2} \right)$$

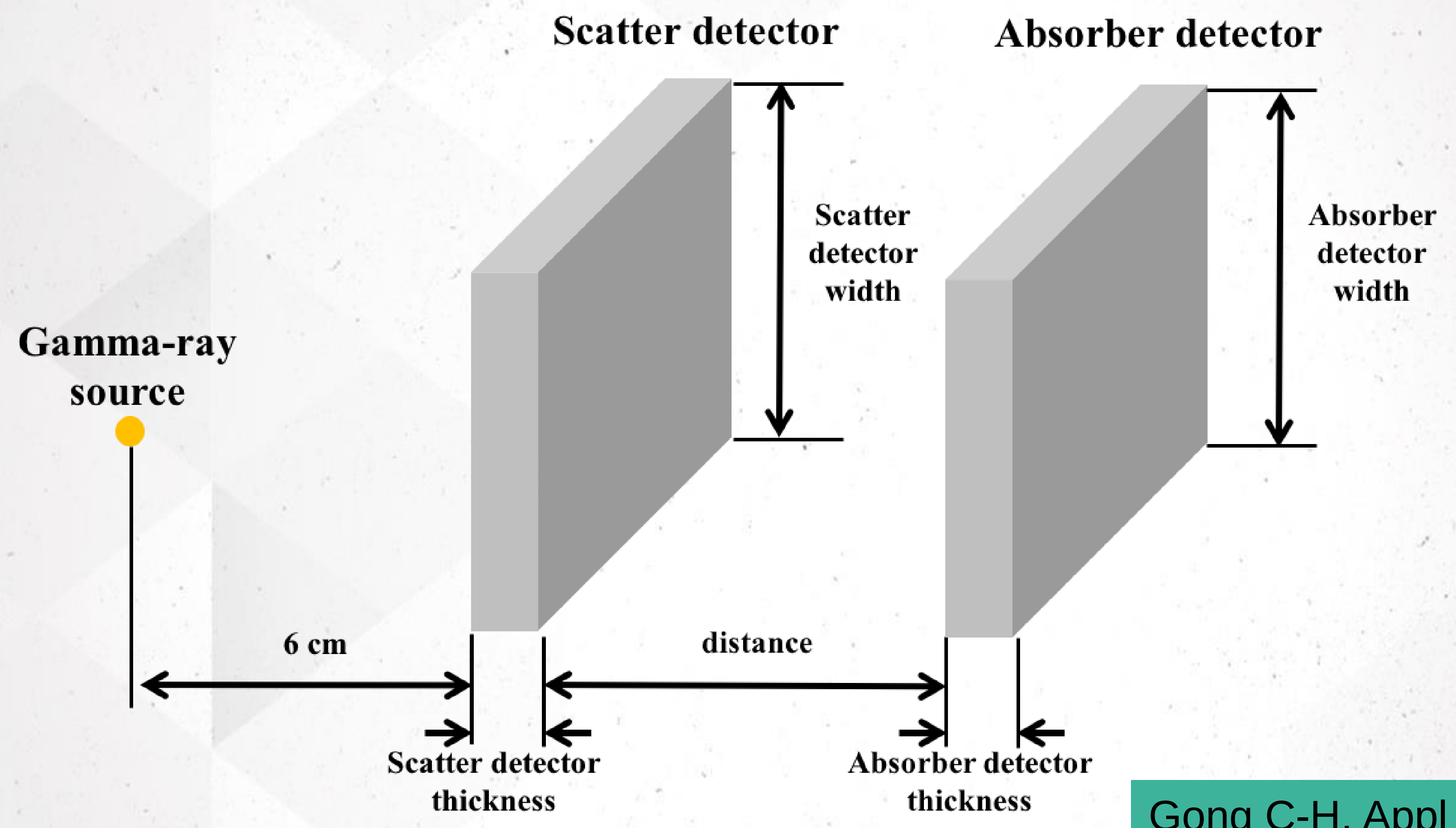


- ❖ The cone axis is determined through the interaction positions in the scatter and absorber detectors.
- ❖ The energy deposited determines θ.
- ❖ From these parameters a cone is reconstructed.

From the overlap of multiple cones, the **source location** can be found.

Compton camera (CC)

A CC composed of a 10 × 10 × 3 cm^3 silicon layer (scatter detector) and a 10 × 10 × 10 cm^3 germanium layer (absorber detector) 1-cm away from the silicon layer, was used in this work.



Gong C-H, Appl Radiat Isot 2017;124:62–7.

This study focuses on the evaluation of the clinical translation of the CC for Melanoma patients.

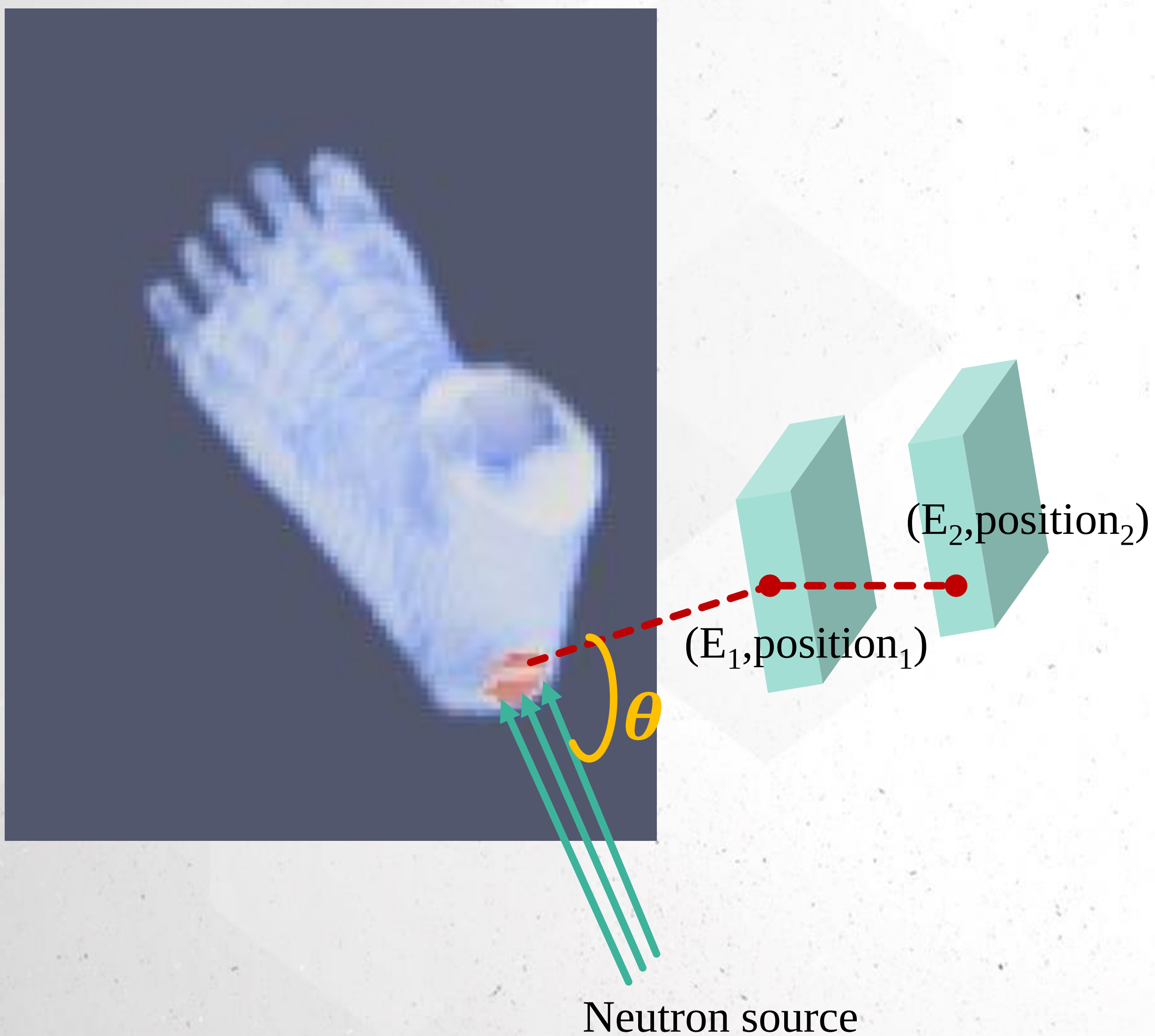
2 Materials and methods

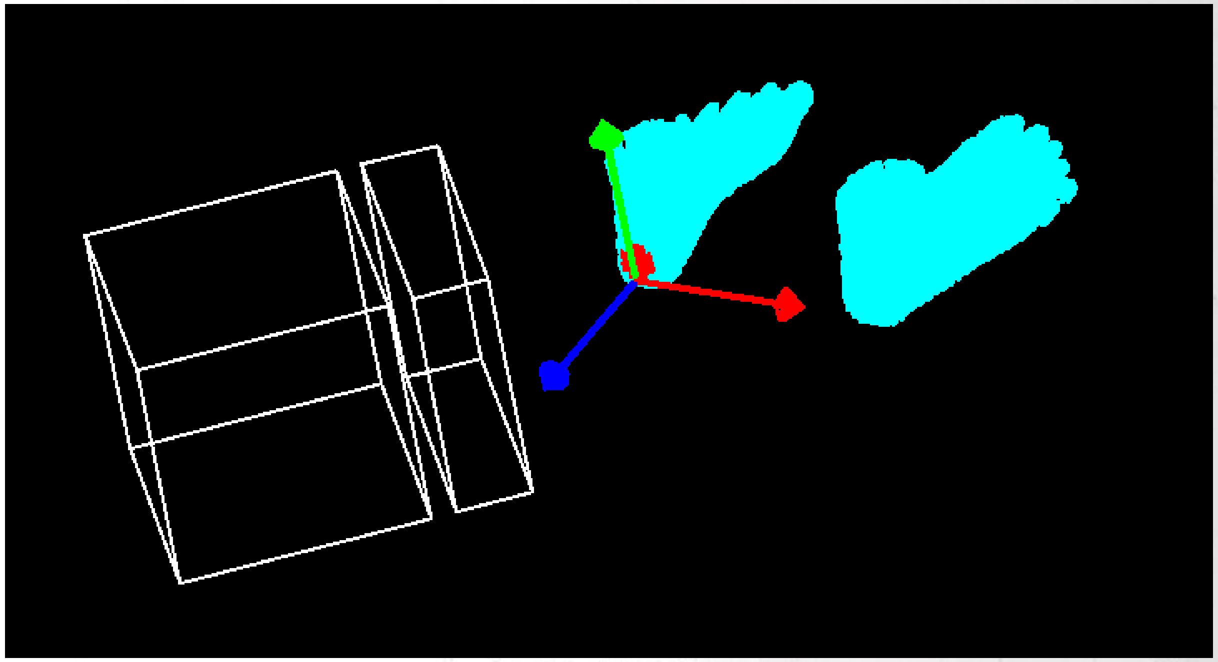
- System configuration
- Image Reconstruction algorithms
- Monte Carlo method

2.1 System configuration

System configuration in simulation includes:

- ❑ **Neutron source**
- ❑ **Melanoma lesion built in Chinese hybrid male phantom (CHMP)**
- ❑ **Compton camera (CC)**





To detect the prompt gamma rays emitted by the nuclear reaction $^{10}B(n,\alpha)^{7}Li$, the Compton Camera should be positioned to prevent direct interaction with neutron source. Here, the angle between the neutron source and Compton camera was set as 30°, 50°, 70° and 90°.

❑ Melanoma lesion built in Chinese hybrid male phantom (CHMP)

❖ **CHMP:**

- was established based on the mesh modeling method with the great flexibility and reality;
- can be adjusted with various characteristics such as gender, age, weight, height, and volumes of organs.

❖ **Melanoma lesion built in CHMP:**

- The melanoma lesion was modeled on the skin of the CHMP, it was on the heel;
- The lesion diameter was set as 1 cm;
- The boron concentration was set as from 30 to 100 ppm in lesion, while 10 ppm in normal tissue.

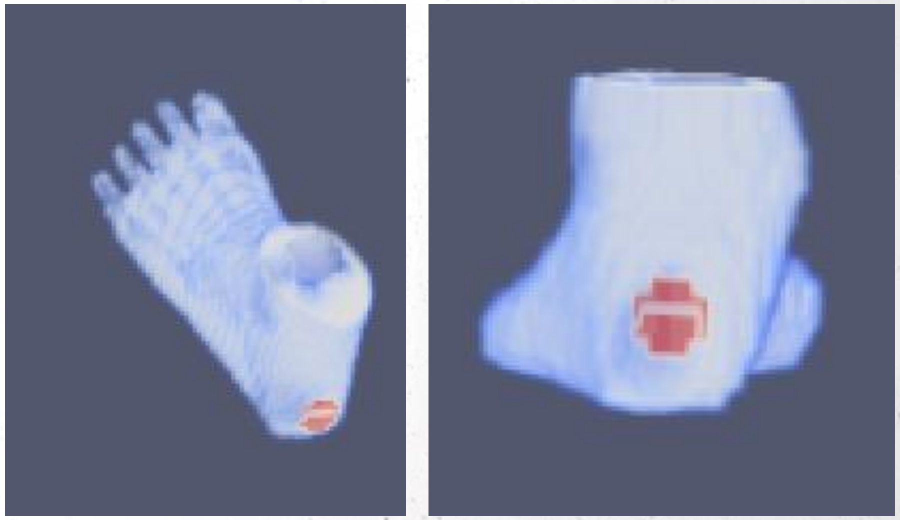


Image Reconstruction algorithms

Analytical algorithms

based on only a single reconstruction

Back projection

characteristics： fast but with artifacts

Iterative algorithms

use multiple repetitions in which the current solution converges towards a better solution

OSEM

MLEM

characteristics： As a consequence, the computational demands are much higher

LM-MLEM
(List mode Maximum Likelihood Estimation Method)

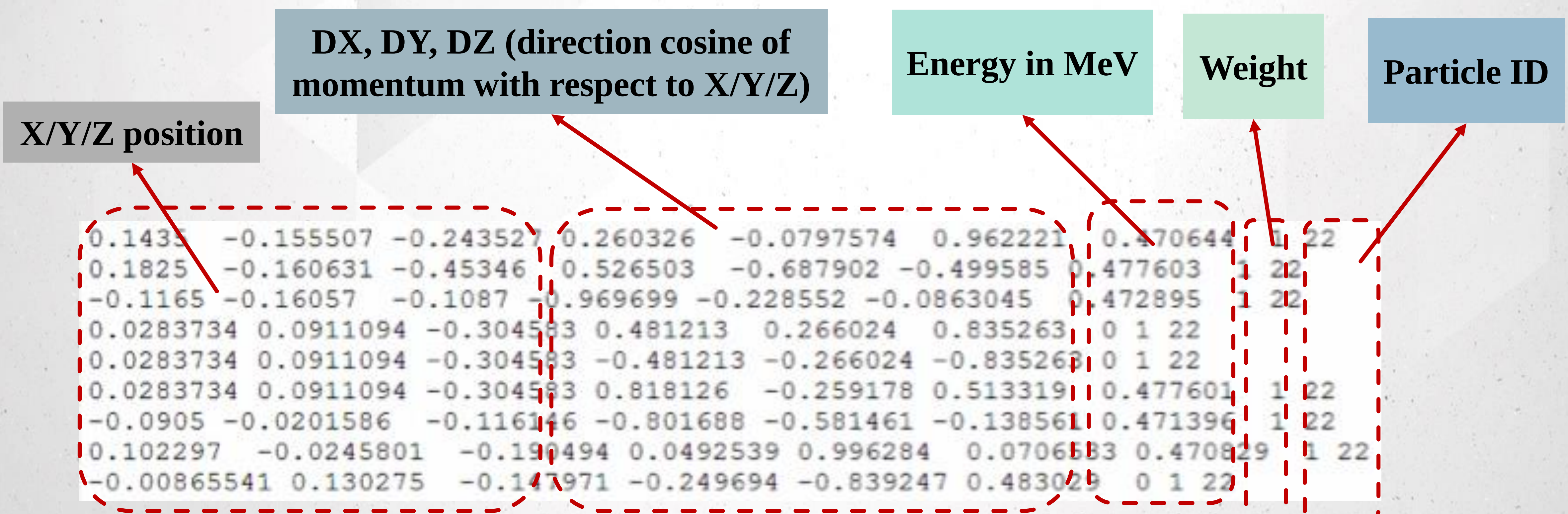
Monte Carlo method

Geant4

- To evaluate the clinical translation of the CC for Melanoma patients in BNCT, the Monte Carlo simulation toolkit Geant4 was used in this study.

Phase space file

- To increase the calculation efficiency and decrease the calculation error, **Phase space file** in geant4 was used in this work. It is a collection of properties for interested particles.
- Here, the property of gamma which is generated in the Chinese hybrid male phantom was recorded in Phase space file. After the records, the phase space file was loaded and continued to perform the simulation.



3 Simulation results

- Image reconstruction selection
- FBP vs LM-MLEM
- Results

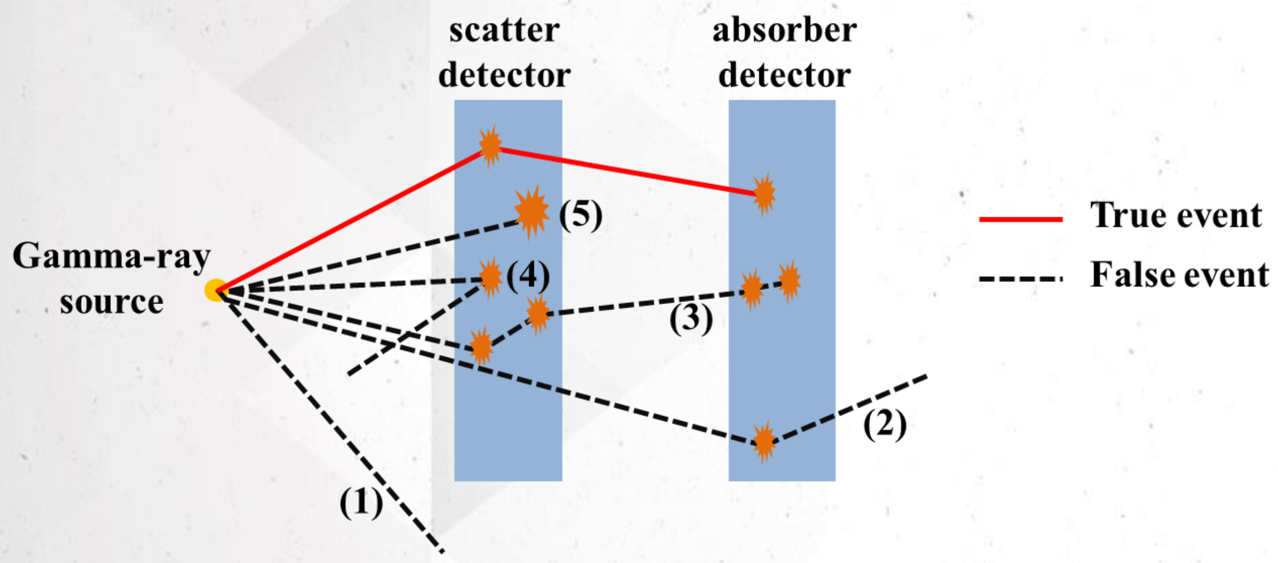
Image reconstruction selection

Step 1: Geant4 simulation and record the next information：

(1) (x_1, y_1, z_1) and E_1 in scatter;

(2) (x_2, y_2, z_2) and E_2 in absorber.

Step 2: Choose the **True Events** from all the recorded events. Conditions：single/single & $E_1 + E_2 = E_0 = 478$ keV.

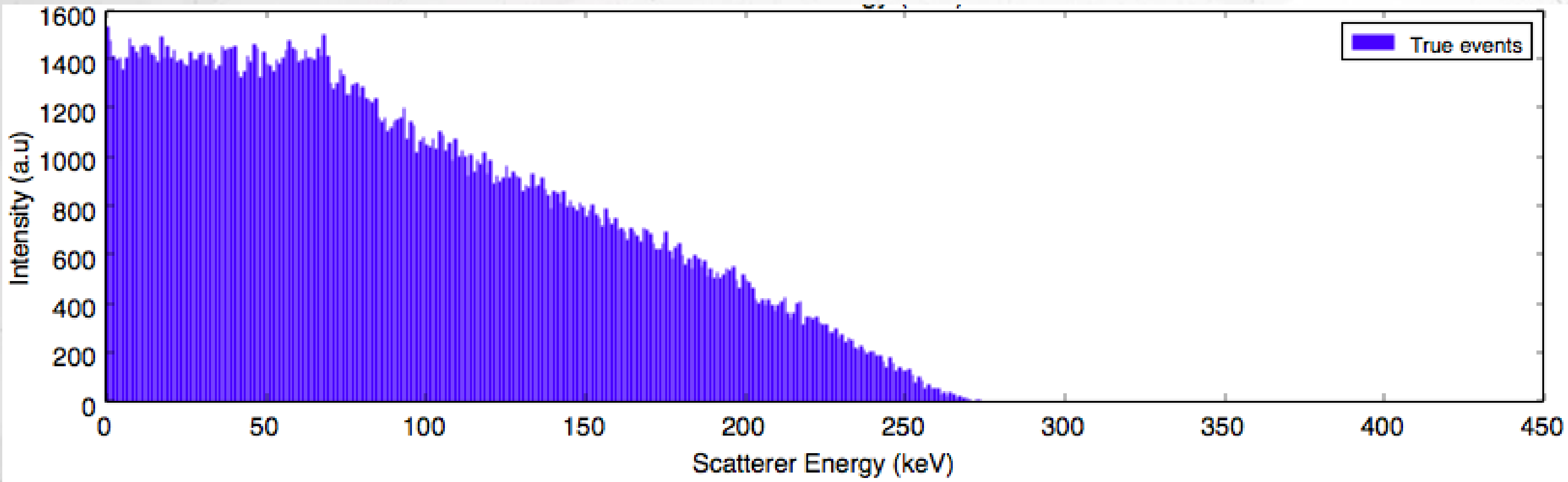


Step 3: Analysis the **True Events** and reconstruct the images with **True Events.**

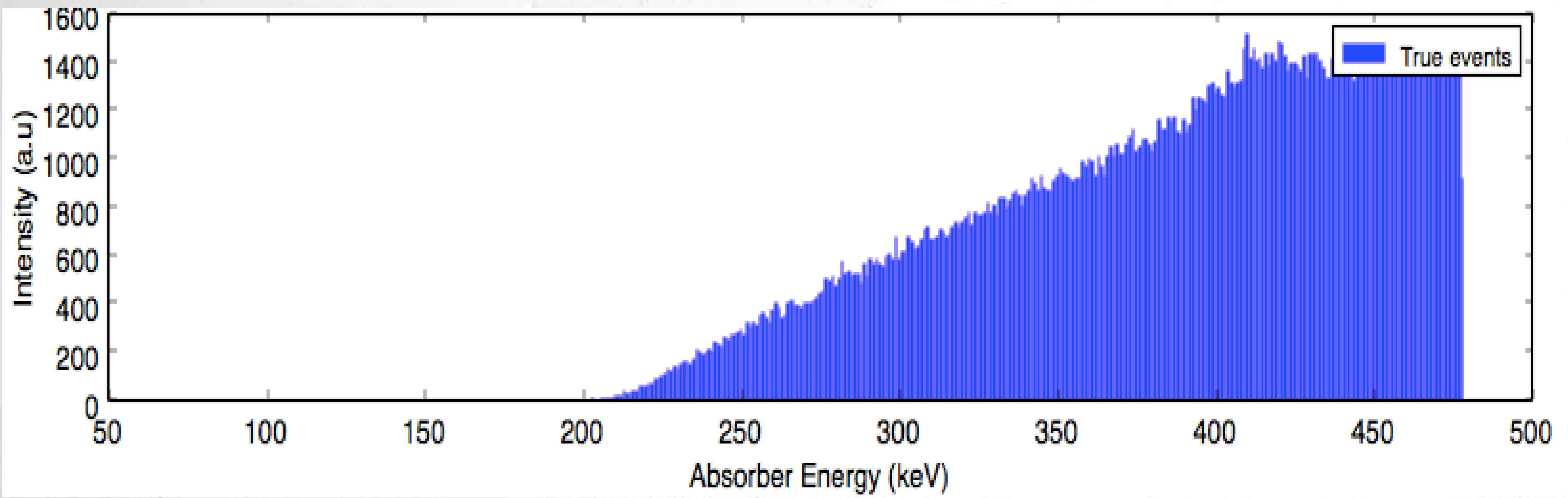
Image reconstruction selection

1) the deposited energies in the two detectors of the Ture events;

2) the Compton scatter angle distribution of the True events.



deposited energies in scatter detector

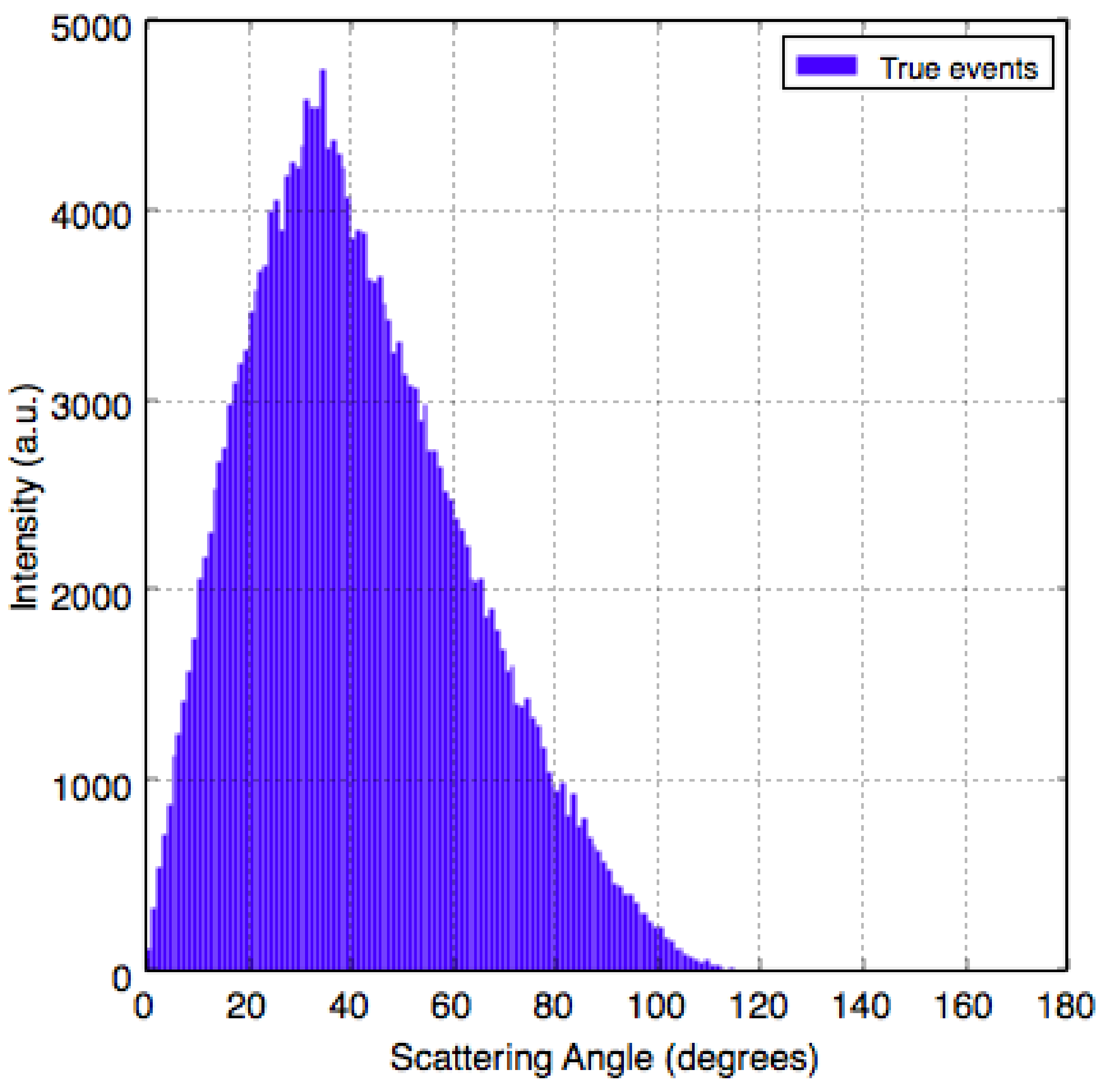


deposited energies in absorber detector

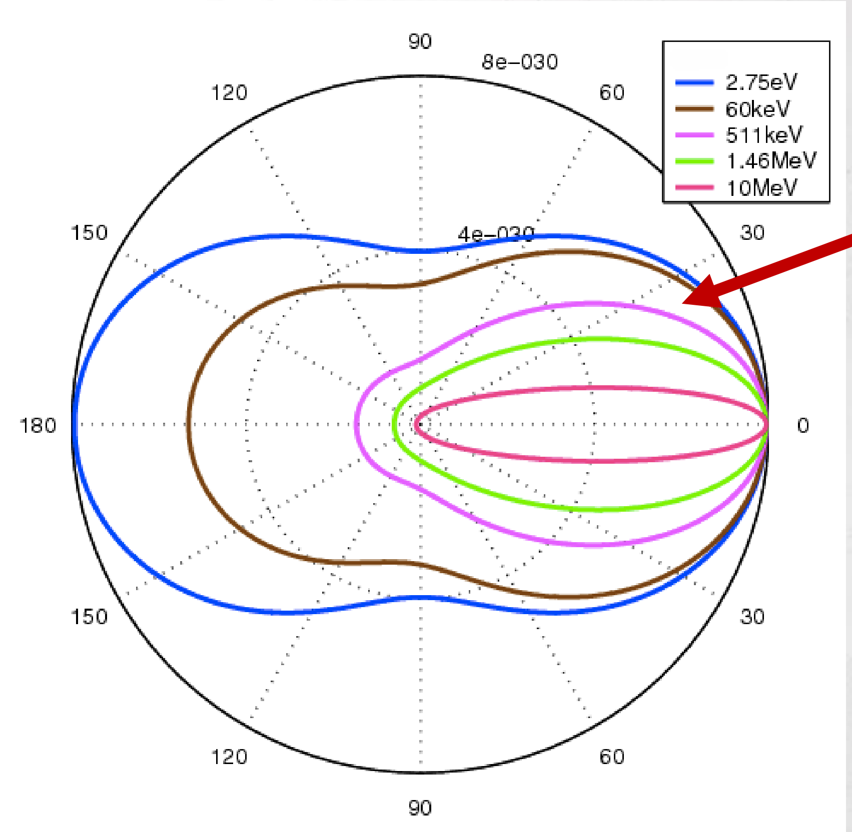
Image reconstruction selection

1) the deposited energies in the two detectors of the Ture events;

2) the Compton scatter angle distribution of the True events.



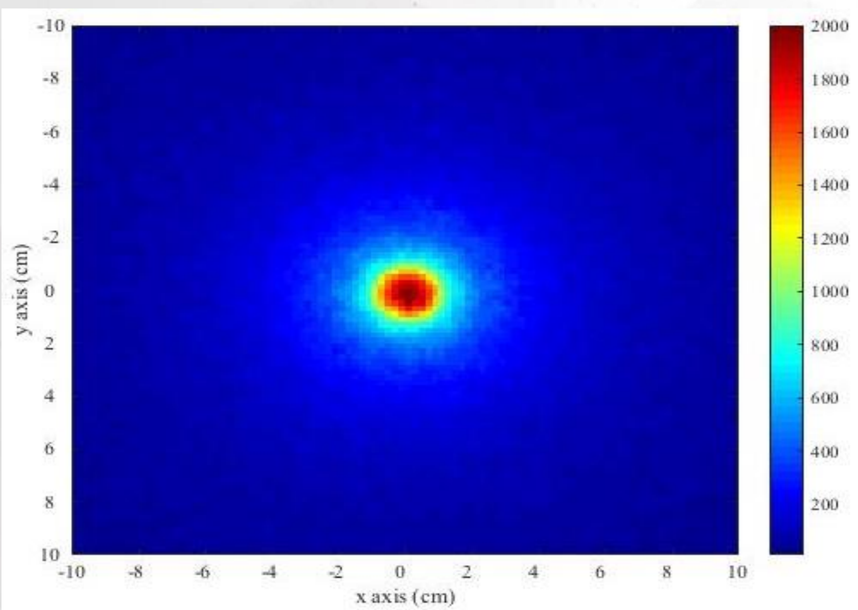
Compton scatter angle distribution of the True events

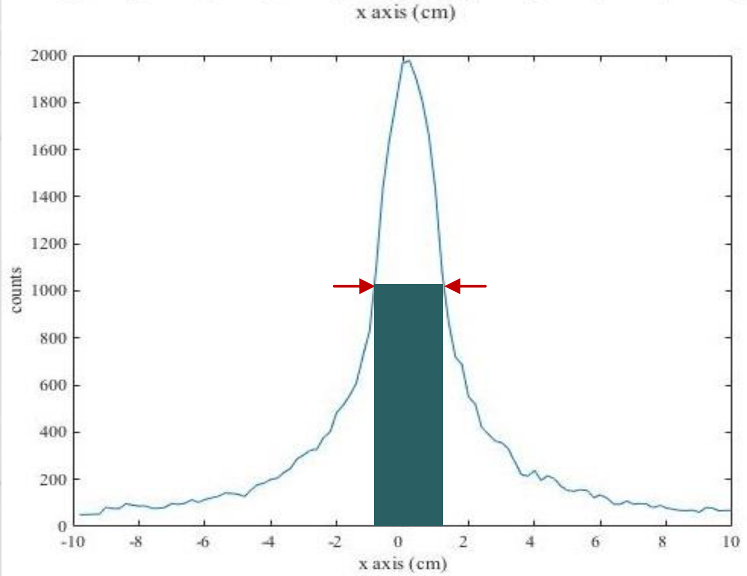


3.2 FBP vs LM-MLEM

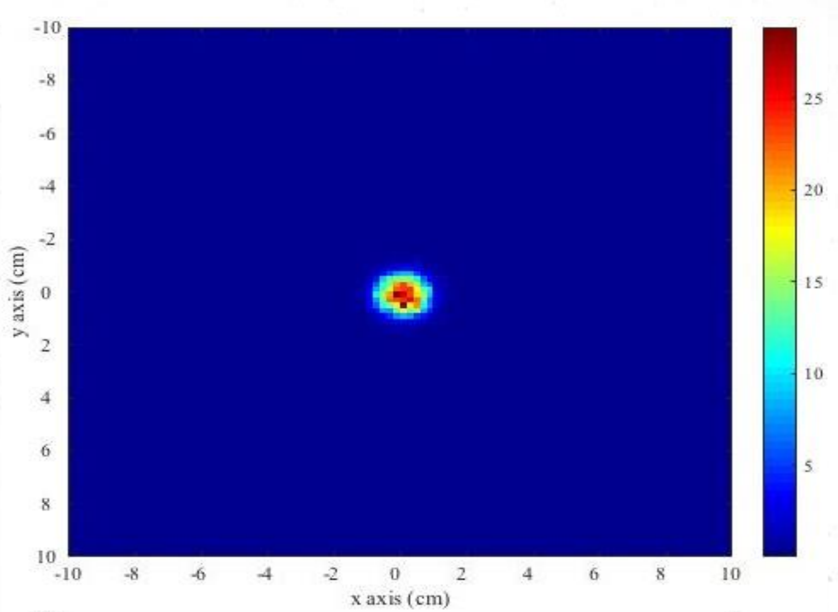
Volumetric sphere source，pos: (0, 0, -6 cm), radius = 1 cm

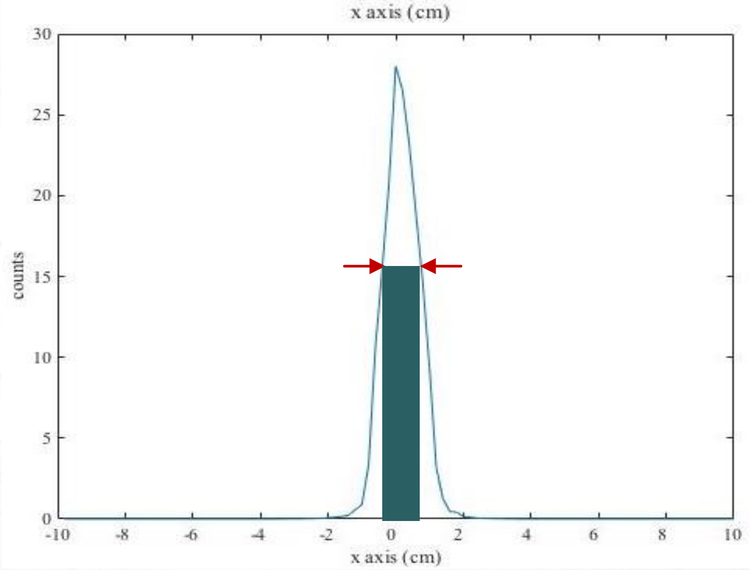
Reconstruction result by SBP





Reconstruction result by LM-MLEM (iteration=4)

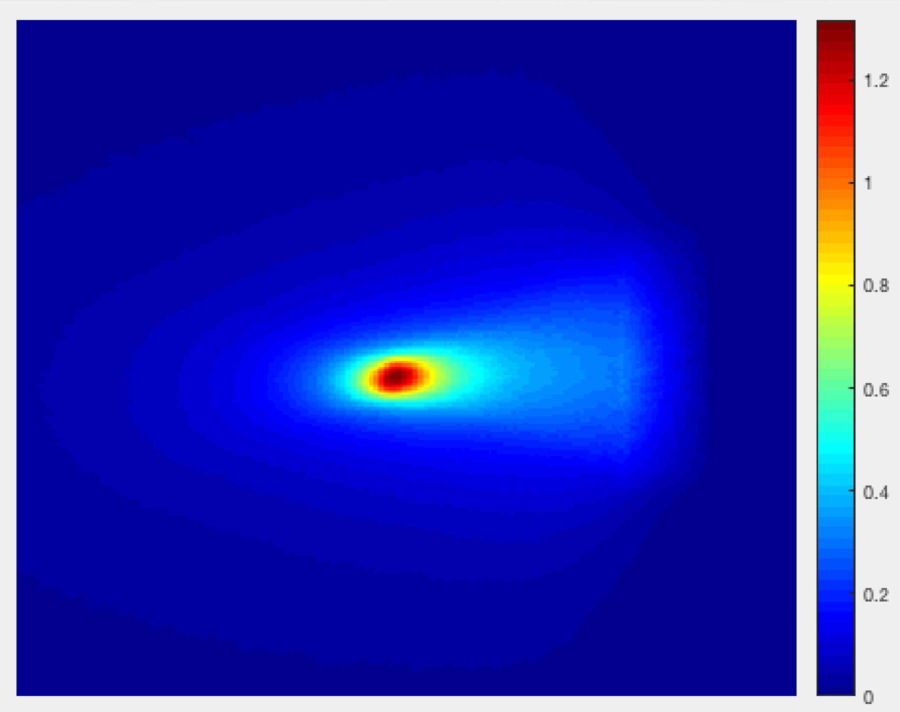




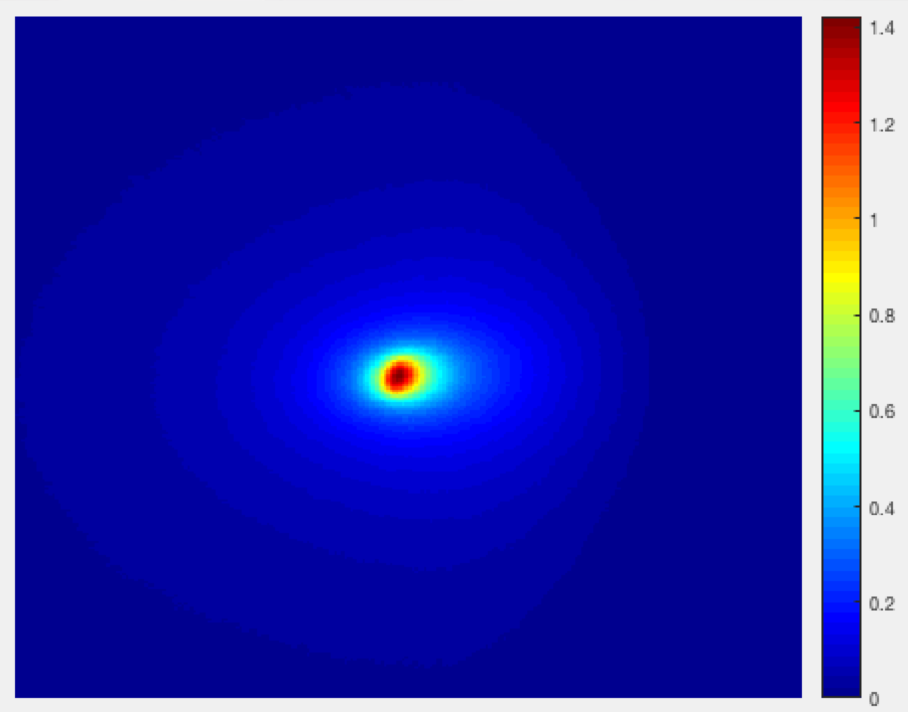
To compare the difference between the SBP and LM-MLEM, a volumetric sphere source with 1-cm radius was used to detect by Compton camera.

Compared to the reconstruction results by LM-MLEM, the reconstructed images by SBP have this big artifact due to the limitation of simple back projection.

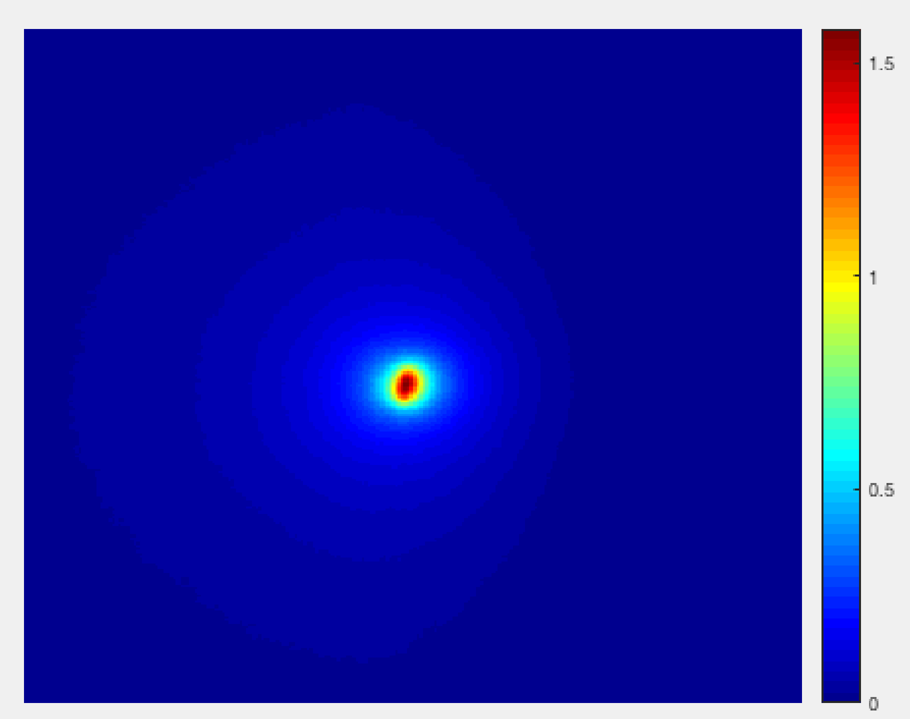
Results



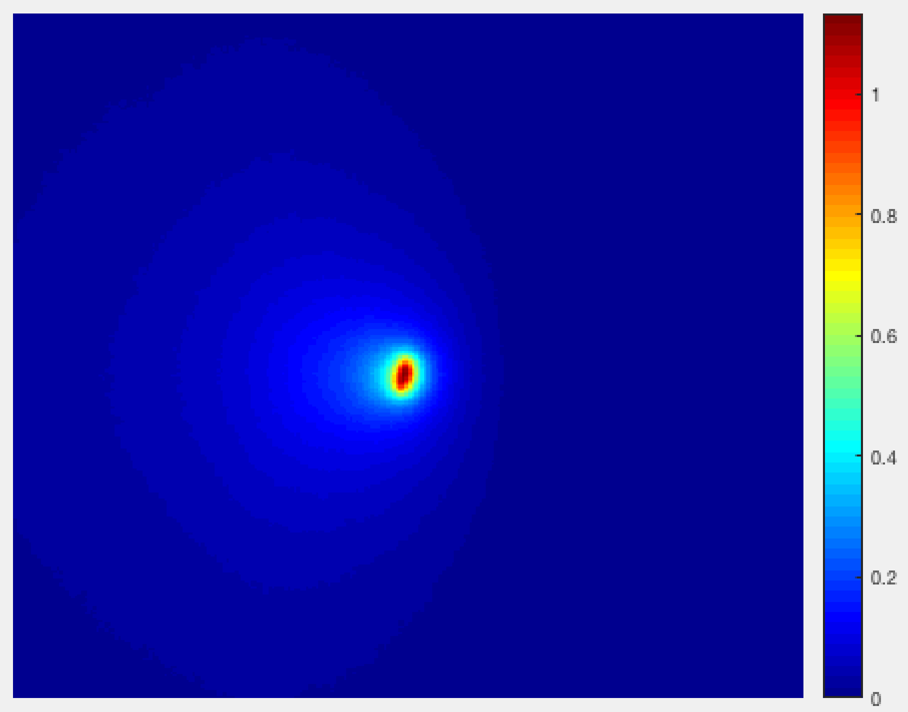
30 degree



50 degree



70 degree



90 degree

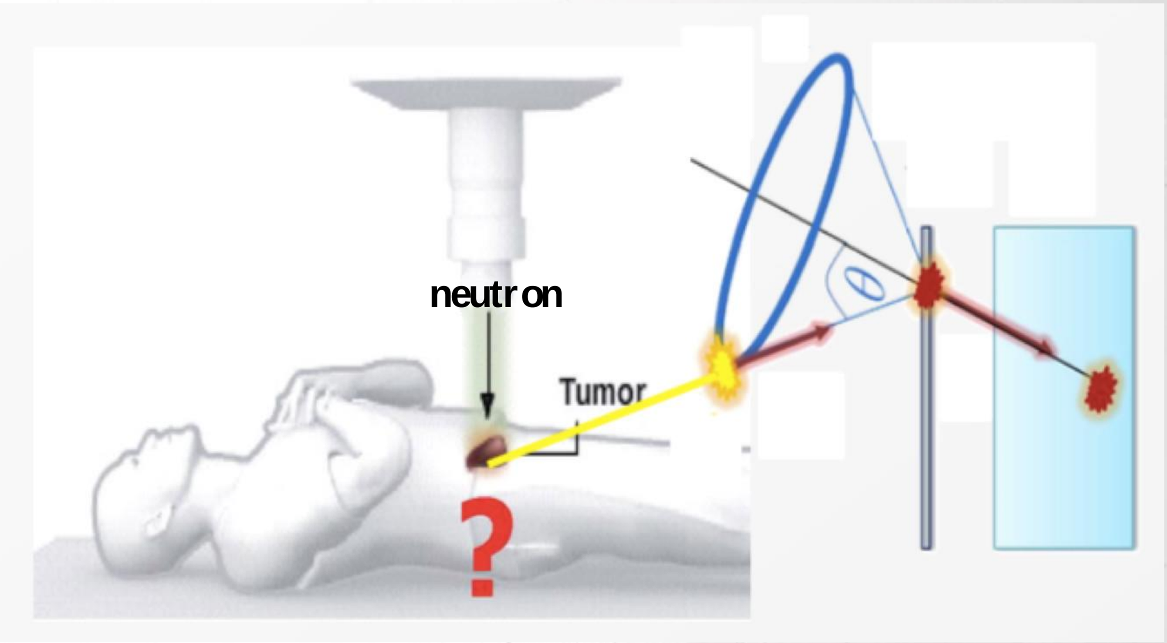
The four figures presented the reconstructed images from different degrees by LM-MLEM.

4 Conclusion

4 Conclusion

1. Completed the implementation of the SBP and LM-MLEM algorithm of CC for BNCT. LM-MLEM shows better performance than SBP methods.

2. This study shows that CC can be used to reconstruct the location of the capture reaction, which can be further used for the dose calculation in BNCT. LM-MLEM is an efficient algorithm to perform the reconstruction for this application. The results provide the fundamental basis for further clinical translation of the CC during BNCT.



Thanks !!!

Email address：gongchunhui@nuaa.edu.cn