Simulator for the interaction between γ-rays and scintillator

Kai ISHIZUKA

HEP lab B4, Saga Univ

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Yonsei-Saga partnership program, Yonsei Univ, Korea

Outline

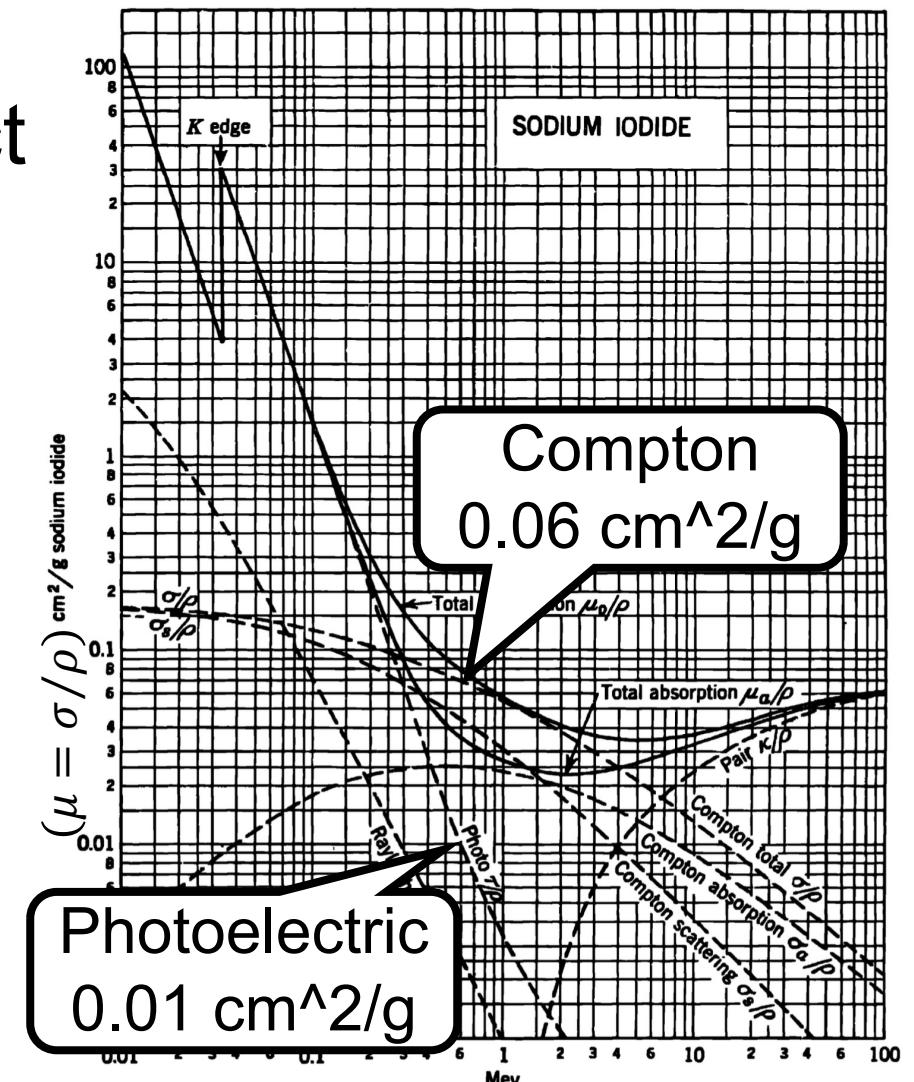# 1.1 Motivation

Compton scattering : Photoelectric effect

Figure data ~6:1
MCA data ~1.9:1
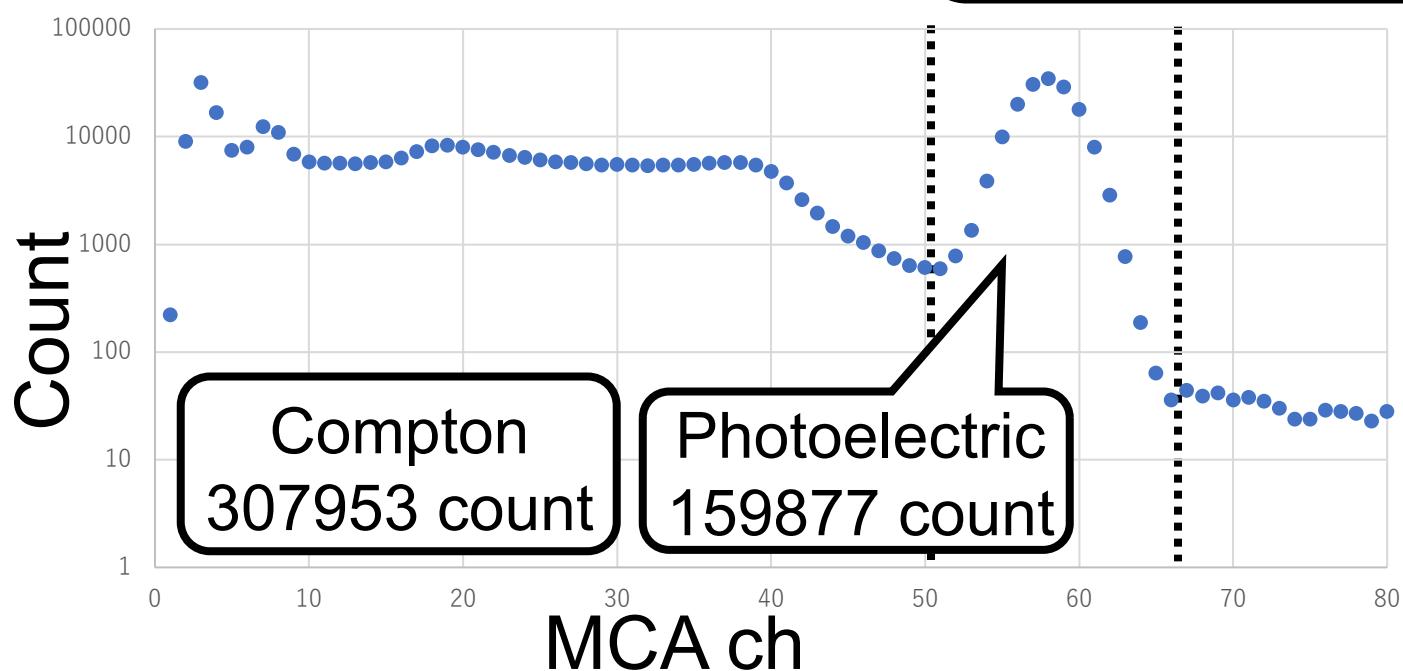
Effects of secondary and later reactions?

Compton 0.06 cm^2/g

Photoelectric 0.01 cm^2/g

Compton 307953 count
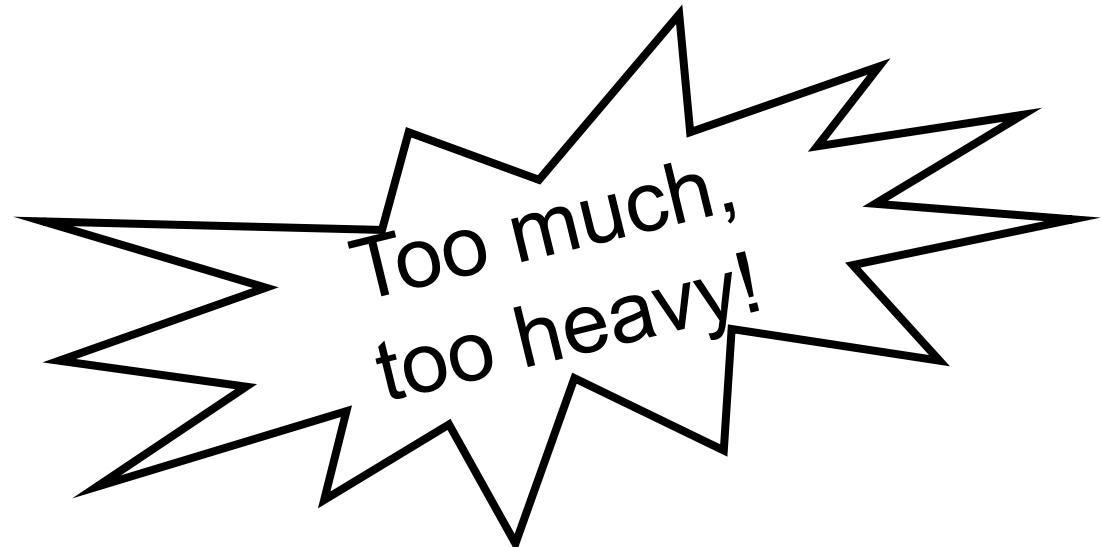
Photoelectric 159877 count

Count

MCA ch

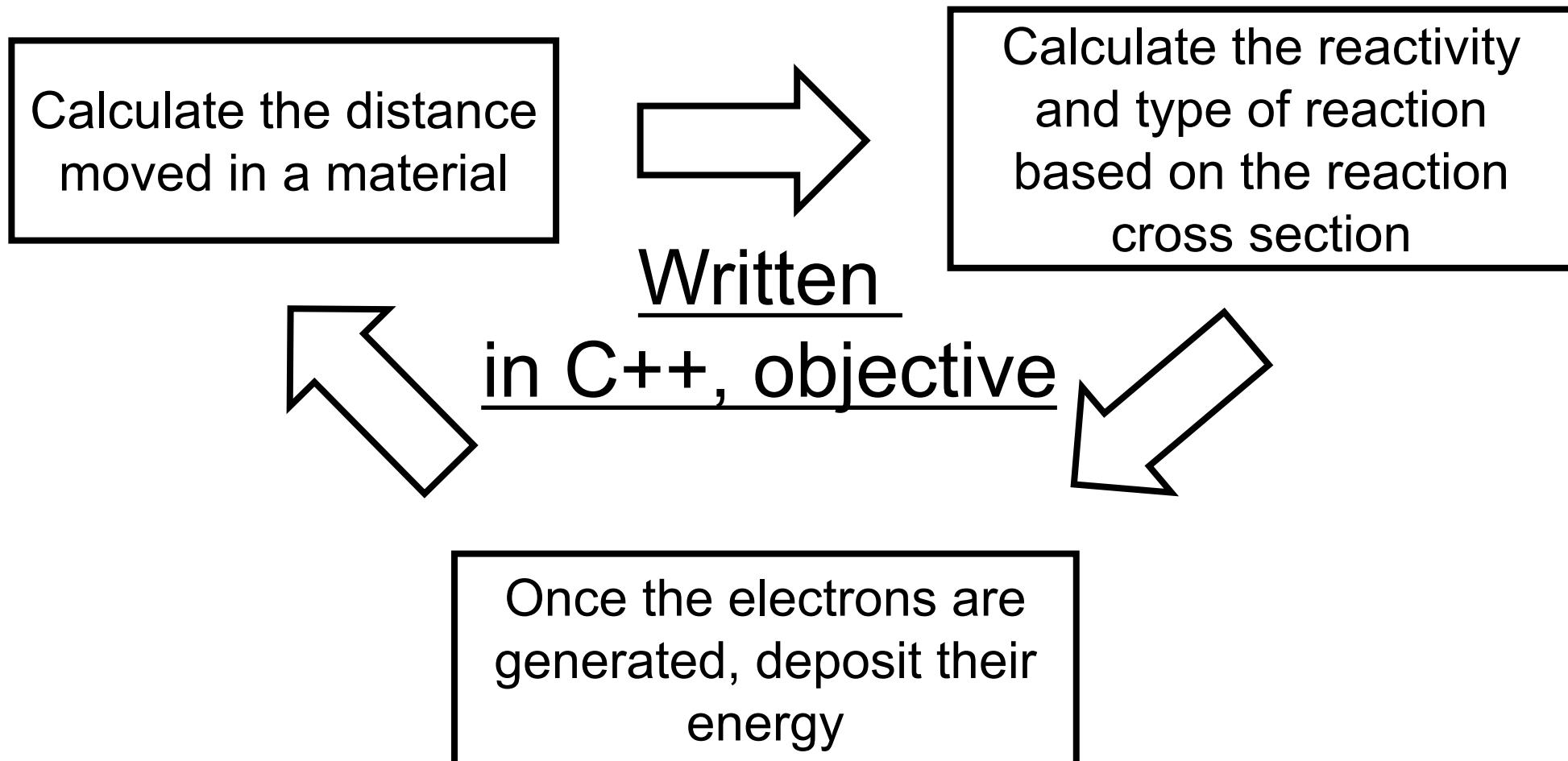RD Evans, *THE ATOMIC NUCLEUS*, p.717, Fig. 1.6

1.2 Existing simulators

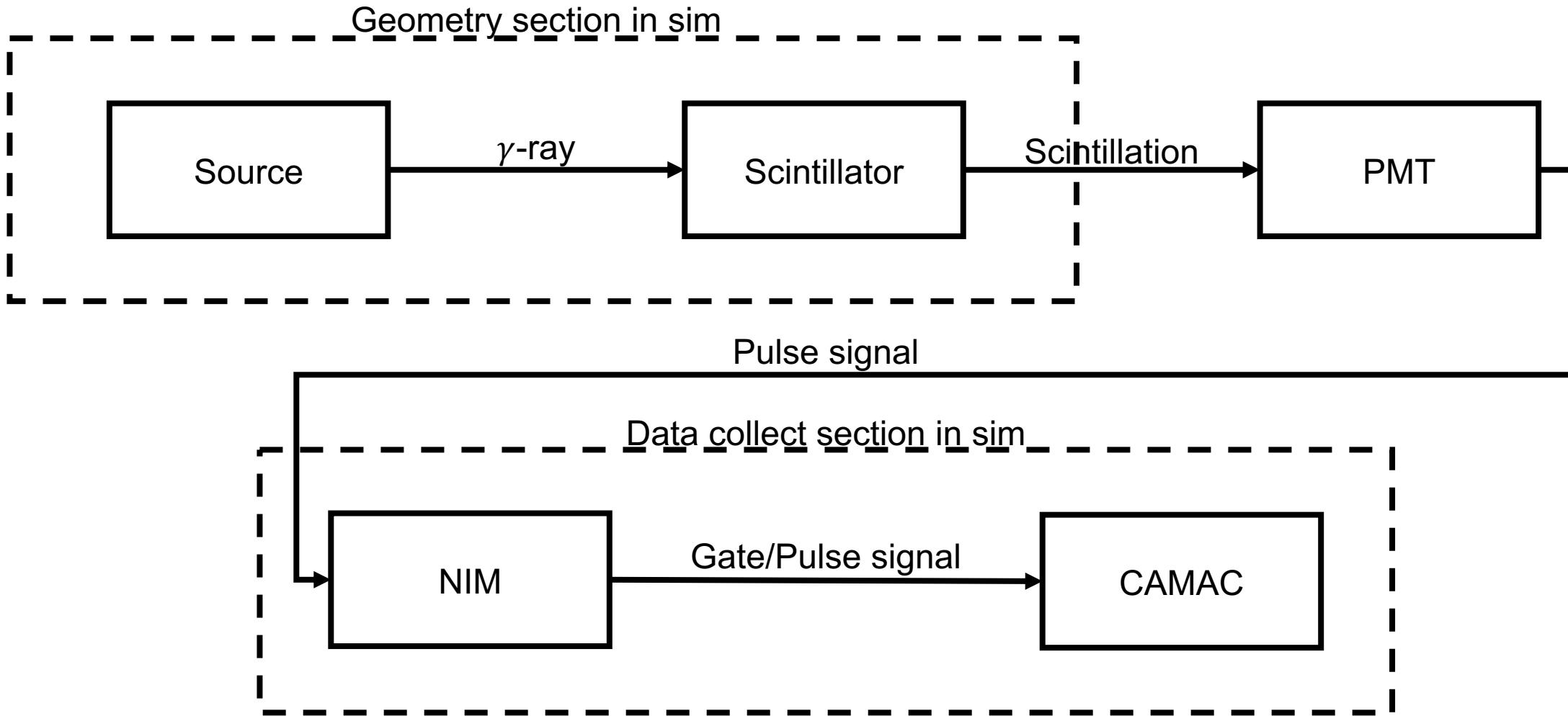**Required functions: calculation of electromagnetic interactions and geometry**

- GEANT4
  - Developed at CERN
  - Written by C++
- EGS5
  - Developed at SLAC→KEK
  - Written by Fortran

Too much, too heavy!

2. Monte-Carlo method

Calculate the distance moved in a material

Calculate the reactivity and type of reaction based on the reaction cross section

<u>Written</u> <u>in C++, objective</u>

Once the electrons are generated, deposit their energy

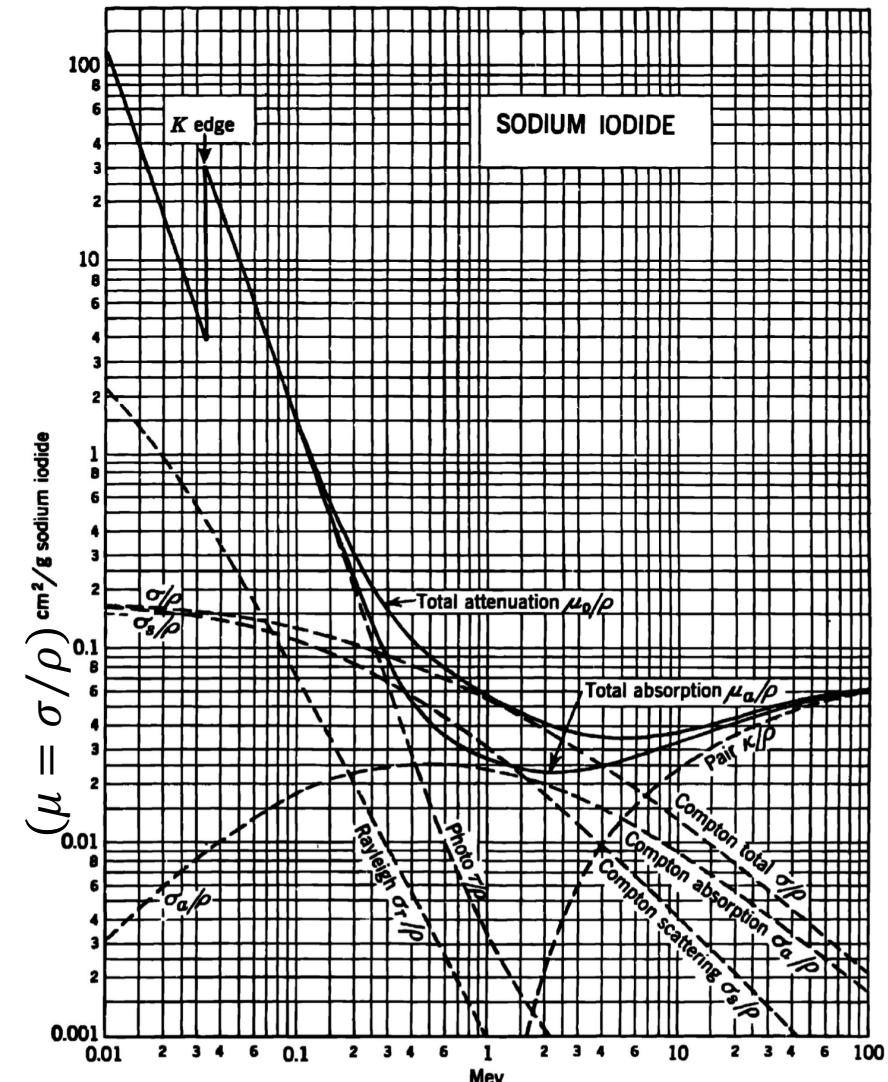# 2. Applicable parts of the simulator

2.1 About reaction cross-section table

- Write down the values visually and linearly complete between data.

- The absorption mean free path is determined using the inverse function method.

Mean free path: $L = -\dfrac{1}{\mu\rho}\log(1-a)$

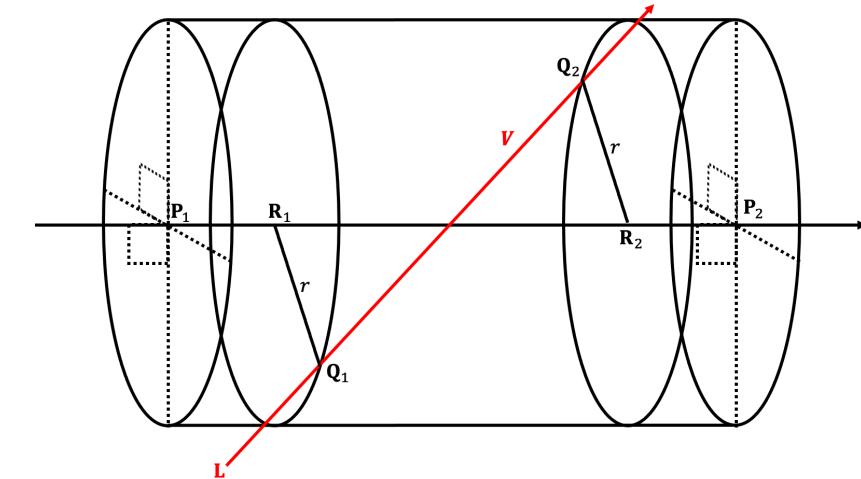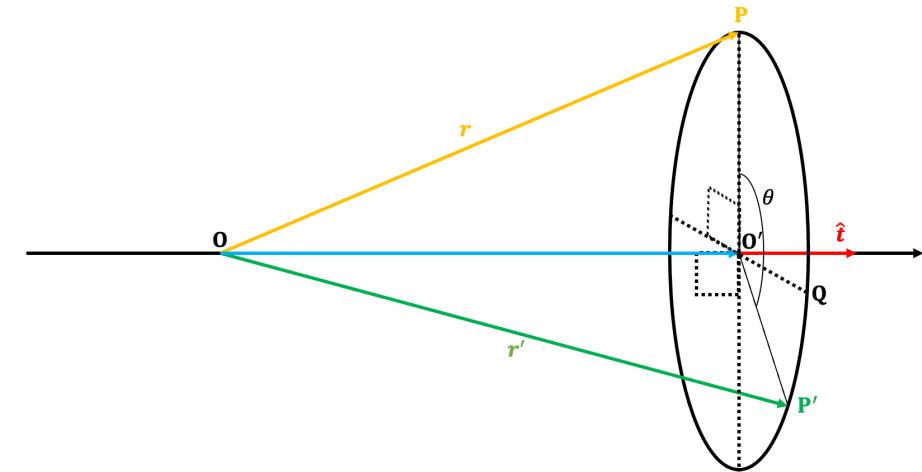Where a represents a uniform real random number between 0 and 1.

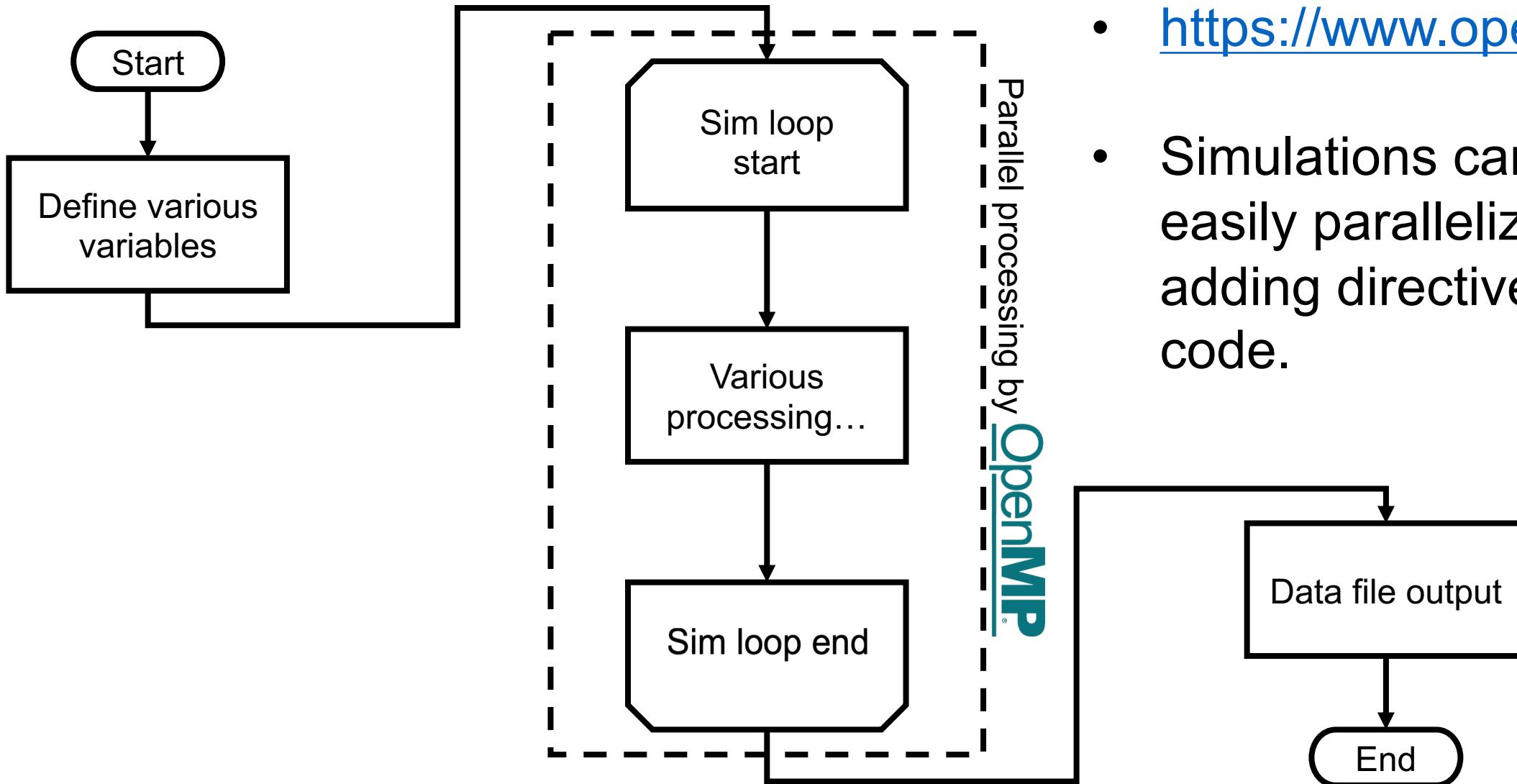RD Evans, *THE ATOMIC NUCLEUS*, p.717, Fig. 1.6

2.2 Geometrical calculation

Implemented calculations

- Movement of particles
  - Straight
  - Turn
- Intersection with an object
  - Planes
  - Curved surface of a cylinder
- Powered by Eigen
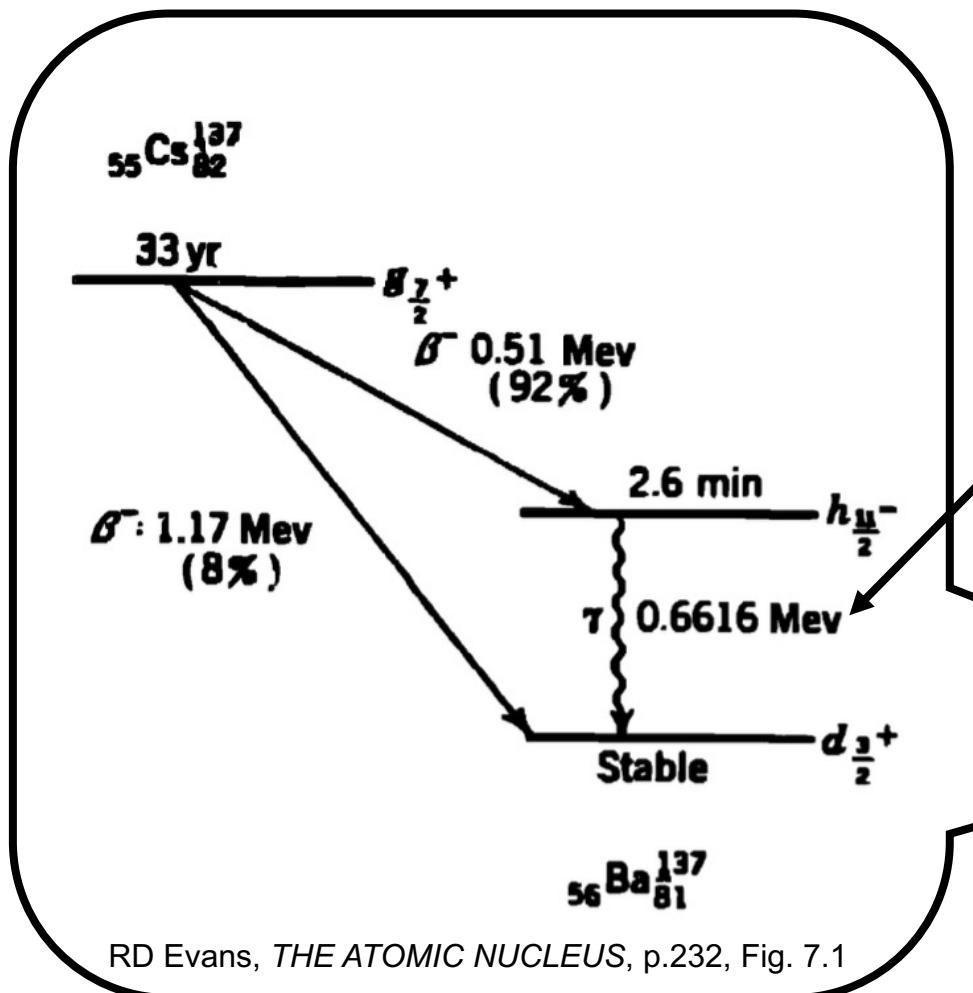 - C++ Library for linear algebra
  - https://eigen.tuxfamily.org

2.3 Parallel processing by OpenMP

Start

Define various variables

Sim loop start

Various processing…

Sim loop end

Parallel processing by OpenMP
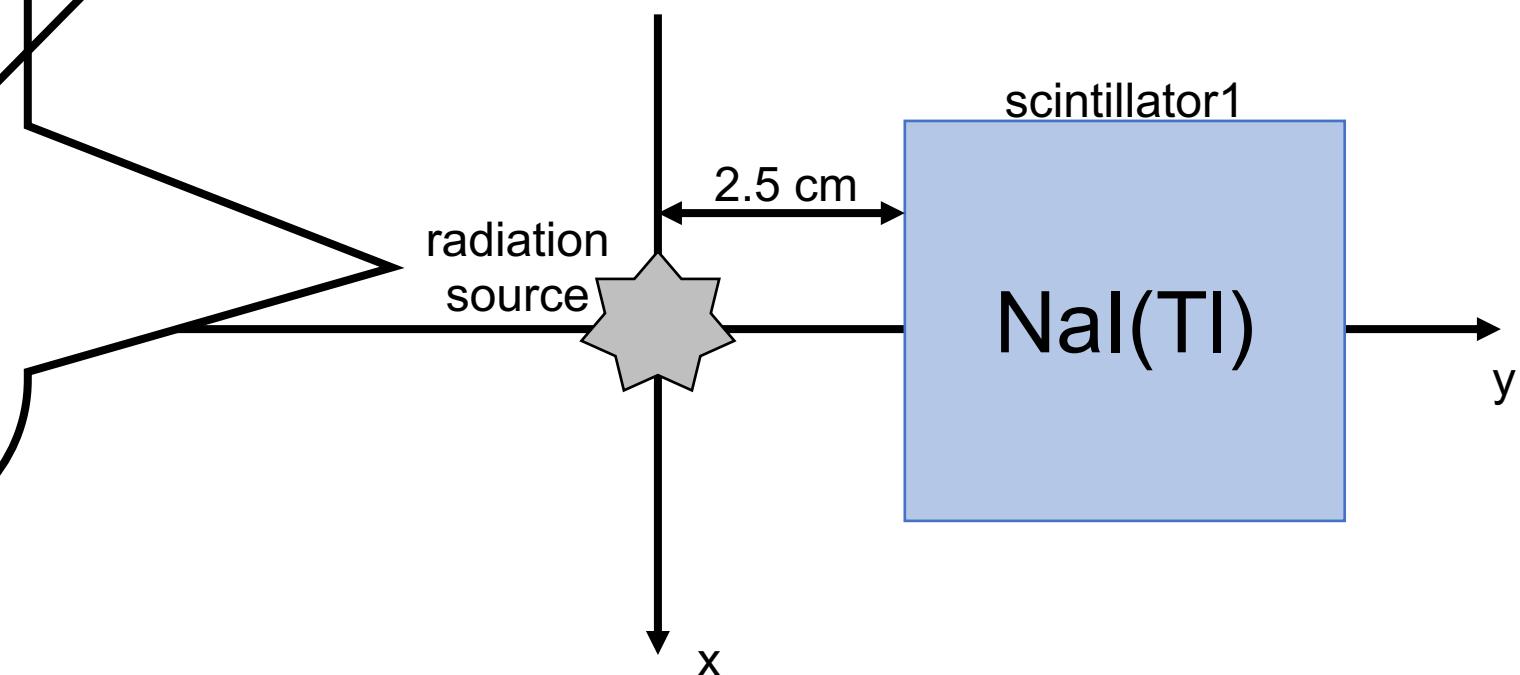
Data file output

End

- https://www.openmp.org

- Simulations can be easily parallelized by adding directives to the code.

3.1 γ-ray observation

Cs^{137} emits γ rays of 661.6 keV

$_{55}Cs^{137}_{82}$

33 yr

$g_{\frac{7}{2}}^{+}$

β^{-} 0.51 Mev (92%)

2.6 min $h_{\frac{11}{2}}^{-}$

β^{-}: 1.17 Mev (8%)

γ 0.6616 Mev

Stable $d_{\frac{3}{2}}^{+}$

$_{56}Ba^{137}_{81}$

RD Evans, *THE ATOMIC NUCLEUS*, p.232, Fig. 7.1

radiation source

2.5 cm

scintillator1

NaI(Tl)

x

y

3.1 γ-ray observation (Sim result)

477 keV $(\theta = \pi, 662 - h\nu')$

662 keV

$$h\nu' = \frac{h\nu}{1 + \left(\frac{h\nu}{m_e c^2}\right)(1 - \cos\theta)}$$

Compton scattering

Photoelectric effect
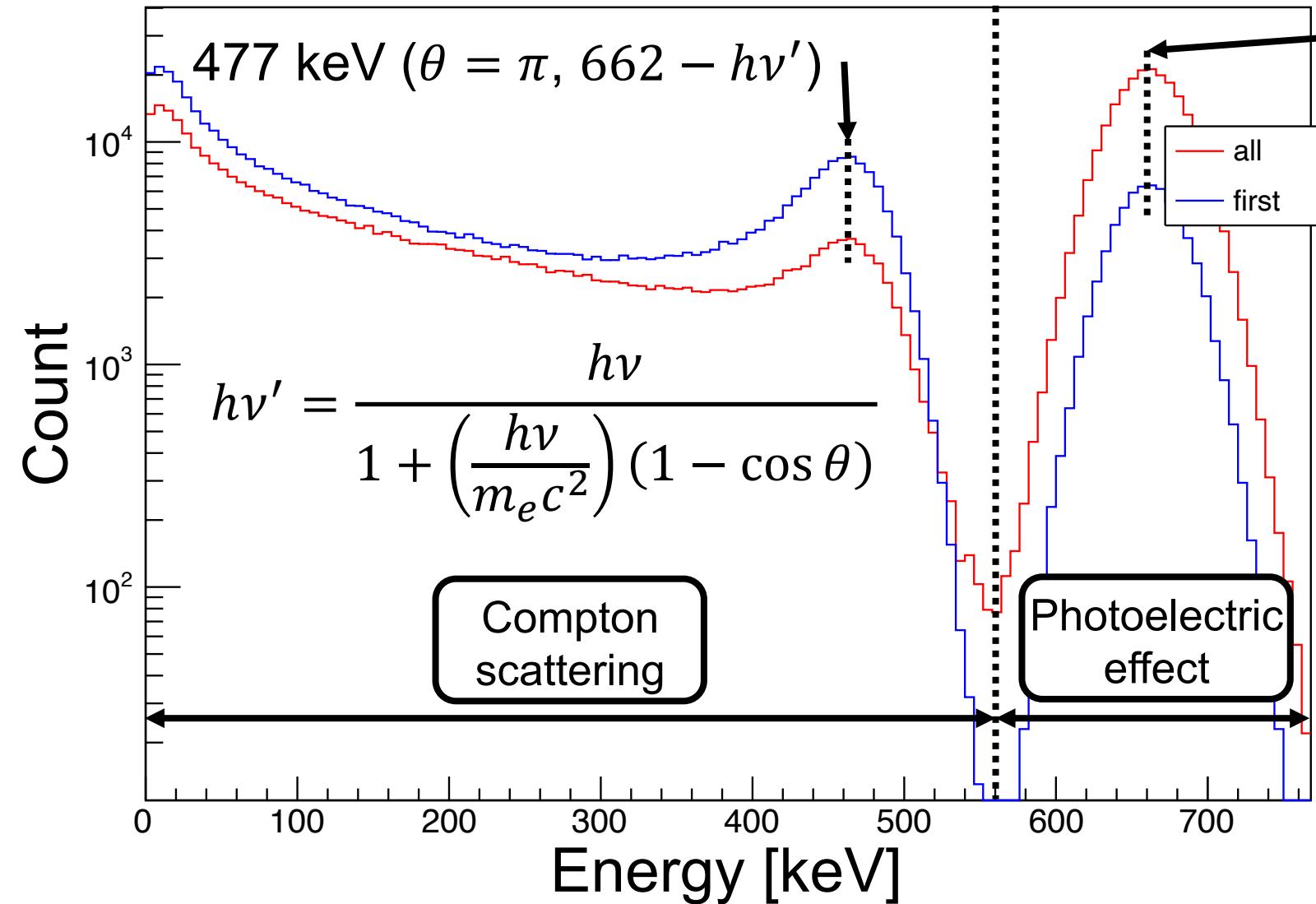
- all(red-line) ~1.5:1
  - include secondary and later reactions
- first(blue-line) ~7.7:1
  - primary interaction only

Resolution is reproduced using the Gaussian distribution of the C++ STL, including energy dependence.

3.1 γ-ray observation (Sim result)

→Photons that have lost their energy
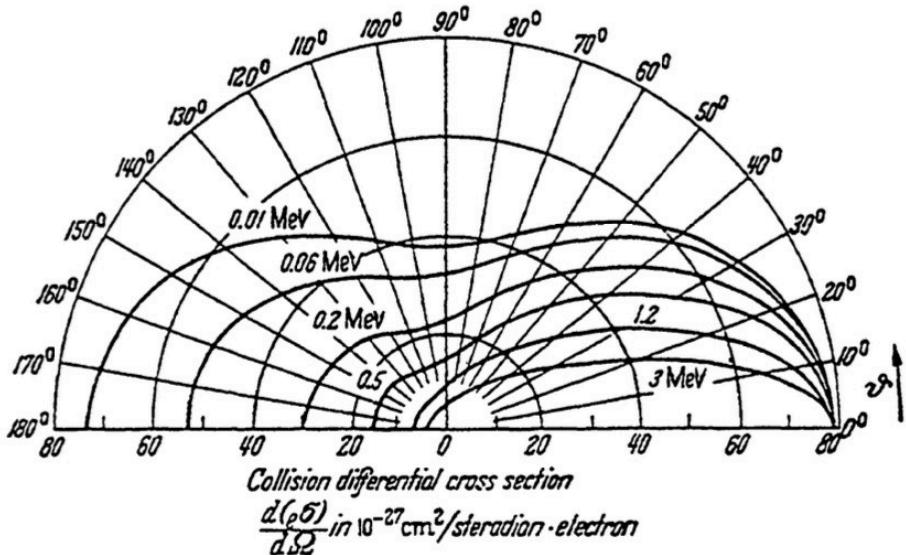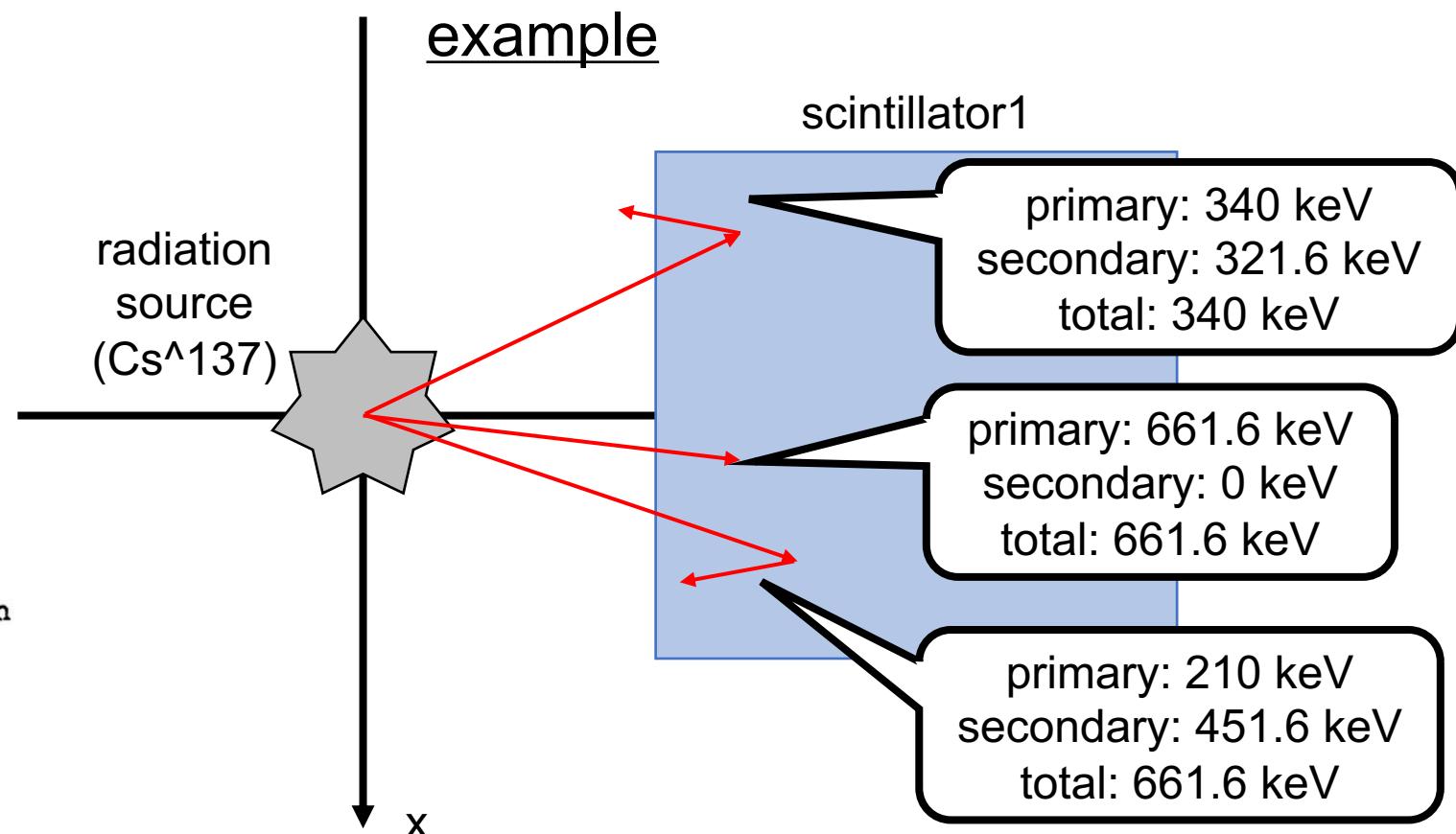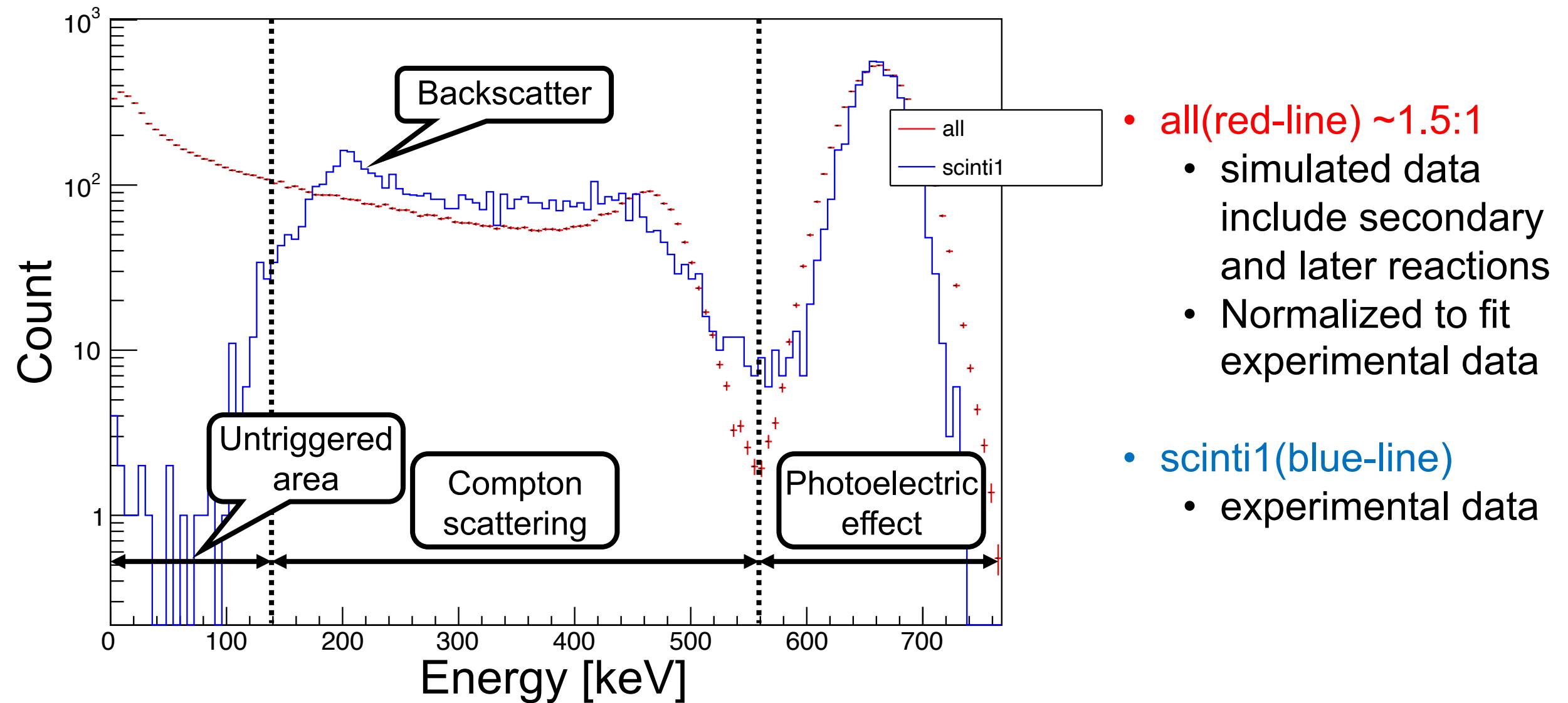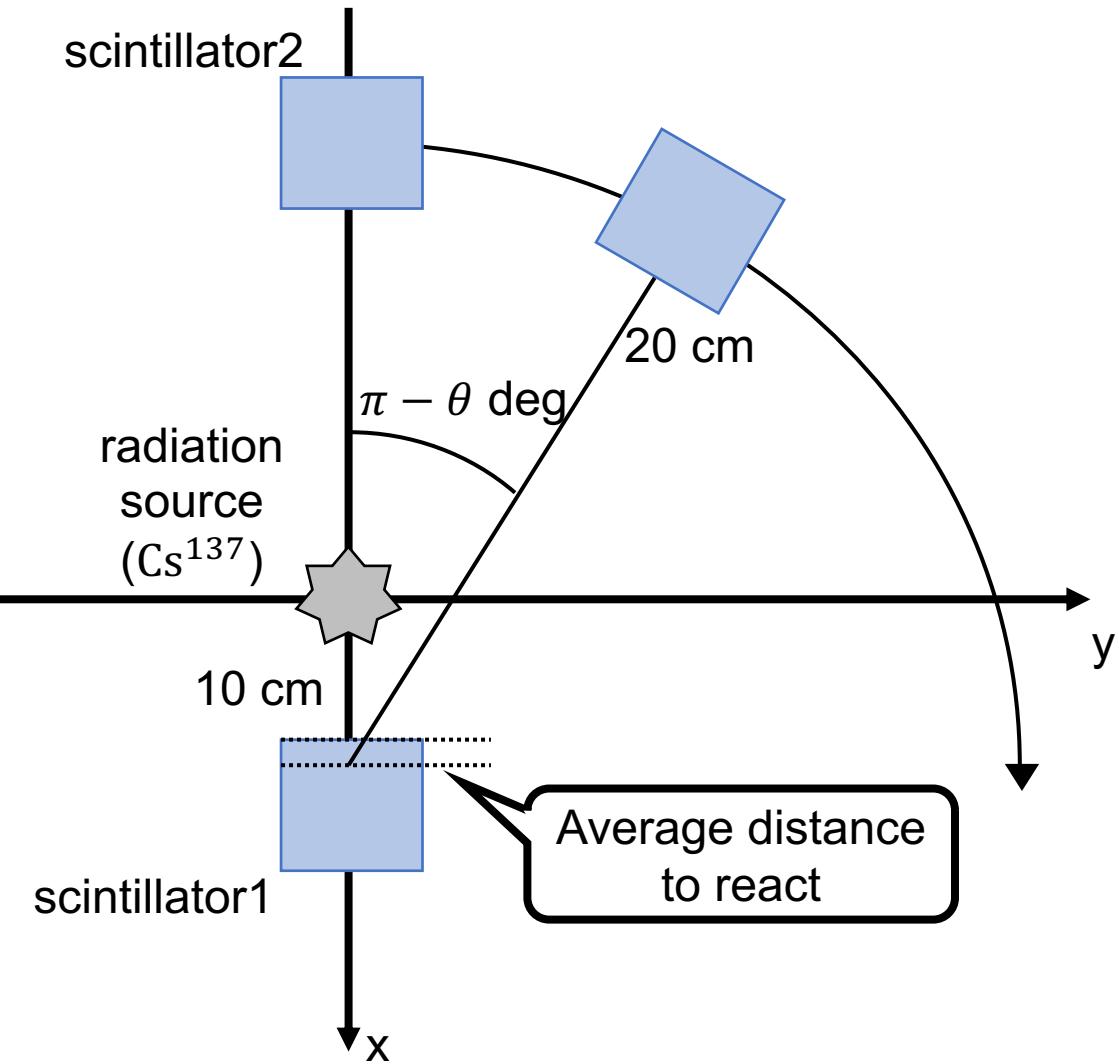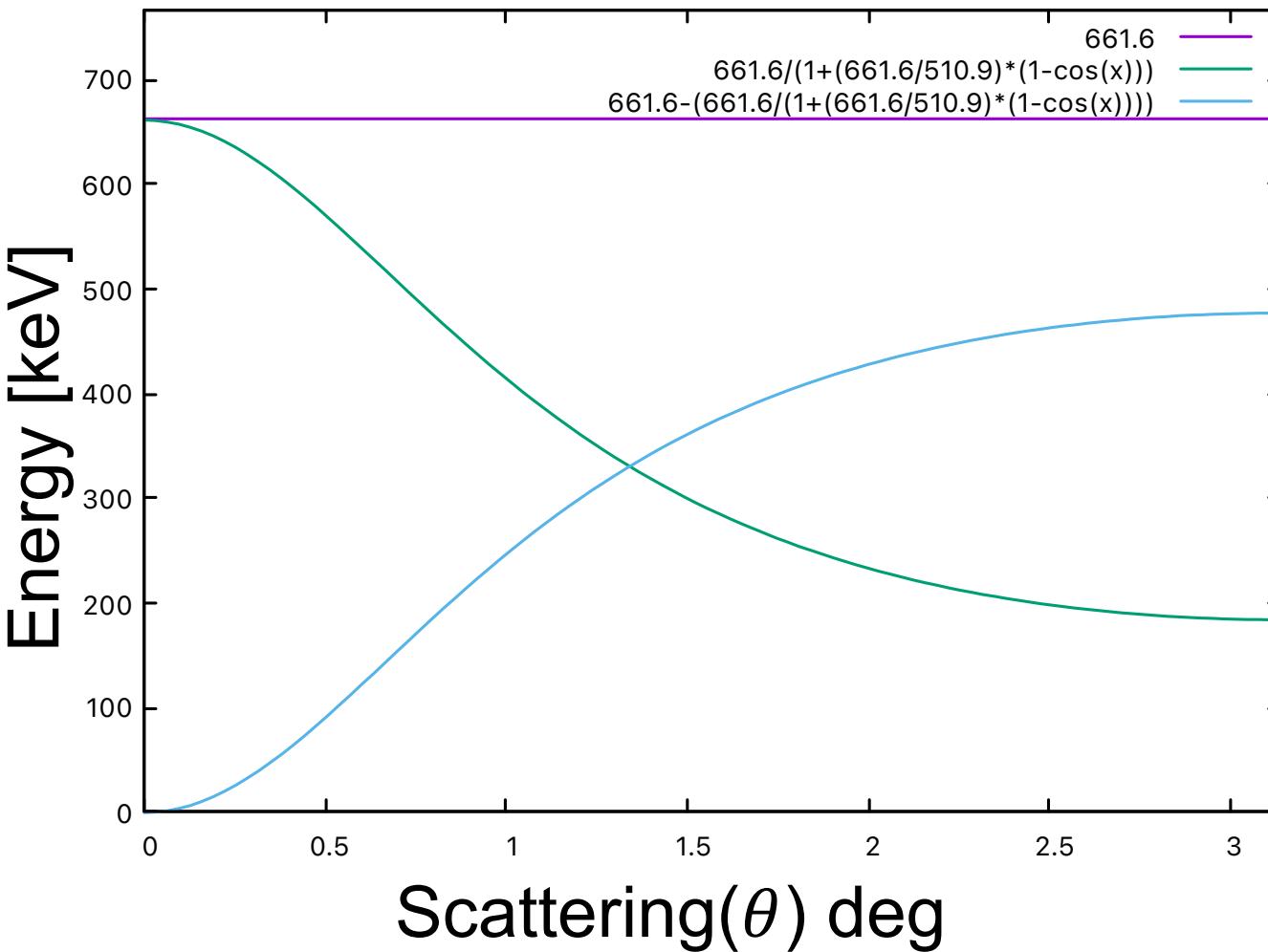can have large scattering angles.

Fig. 17   Polar plot of the Compton cross-section
as a function of the photon scattering
angle θ, for several incident photon
energies[16]

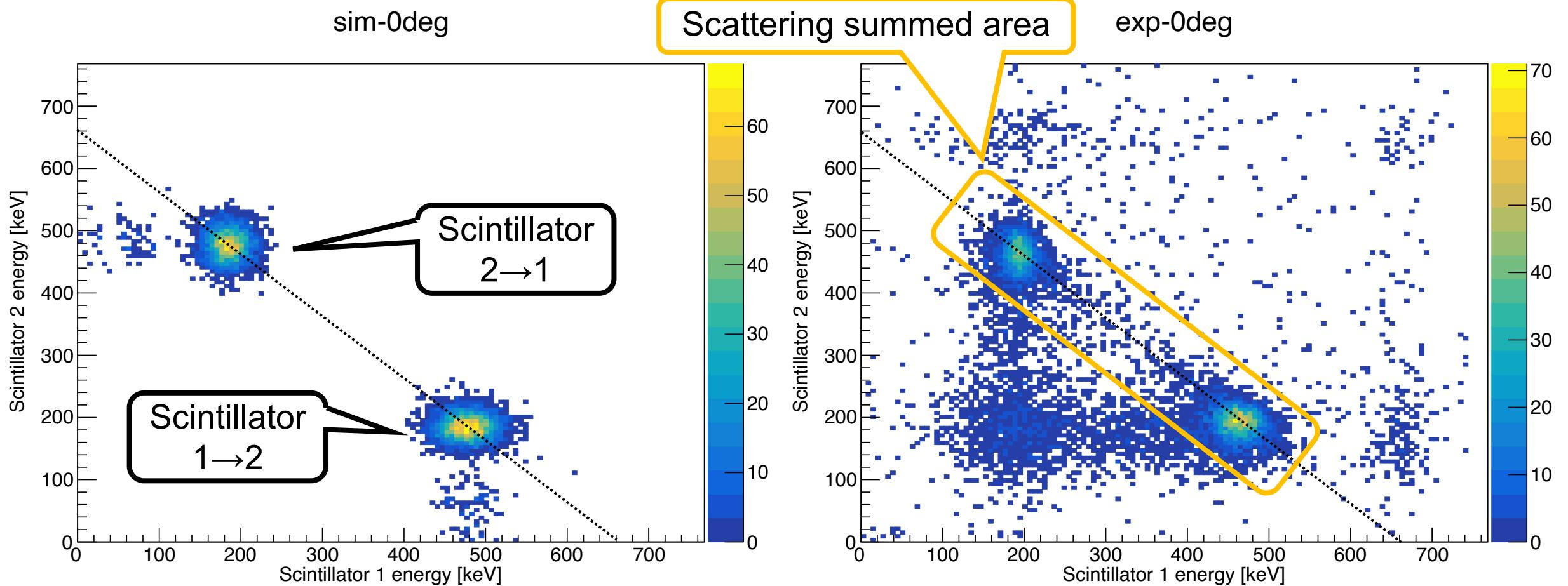F. Sauli, *PRINCIPLES OF OPERATION OF MULTIWIRE
PROPORTIONAL AND DRIFT CHAMBERS*, p.17

example

scintillator1

radiation
source
(Cs^137)

x

primary: 340 keV
secondary: 321.6 keV
total: 340 keV

primary: 661.6 keV
secondary: 0 keV
total: 661.6 keV

primary: 210 keV
secondary: 451.6 keV
total: 661.6 keV

3.1 γ-ray observation (Sim&Exp result)

- **all(red-line) ~1.5:1**
  - simulated data include secondary and later reactions
  - Normalized to fit experimental data
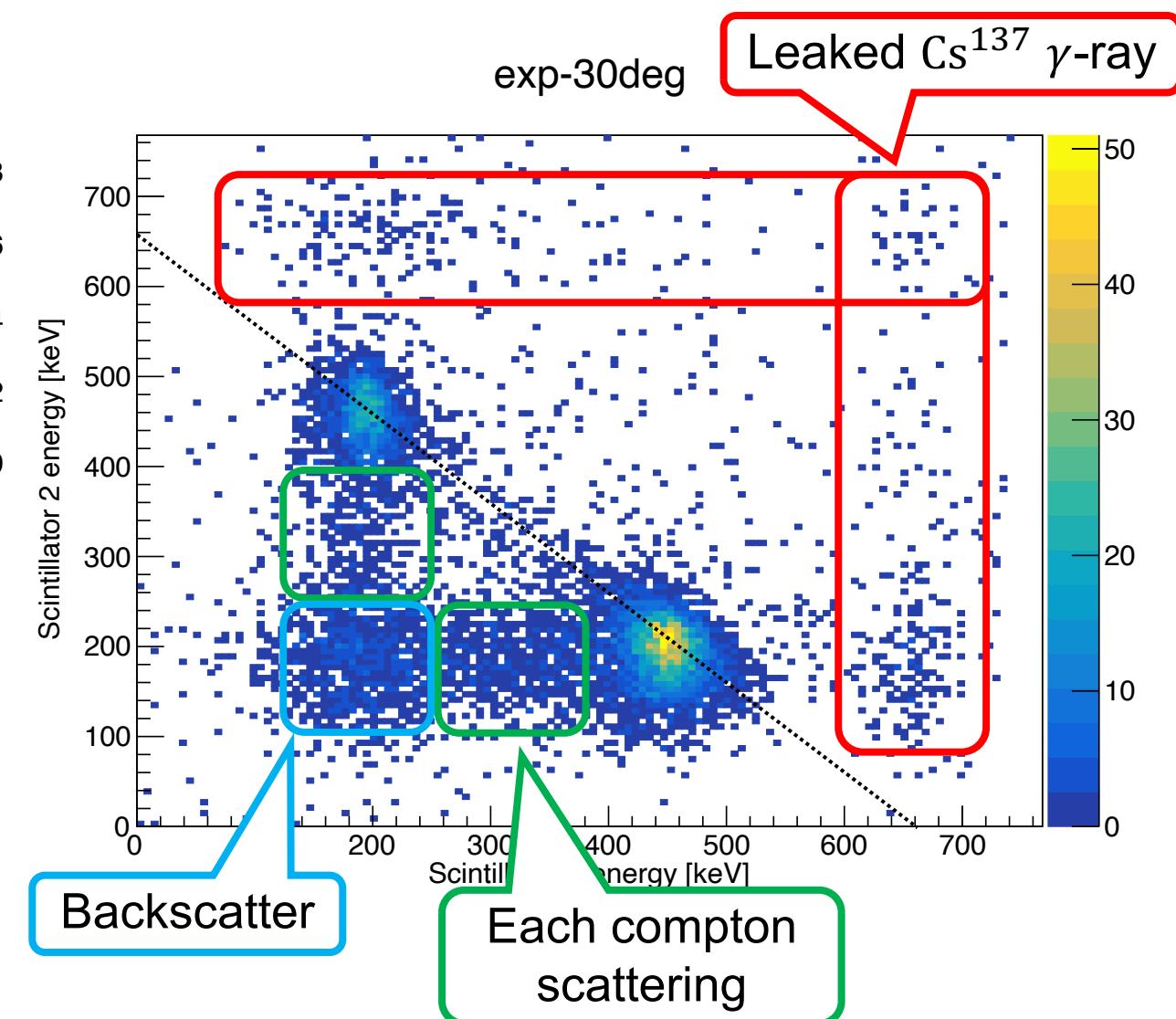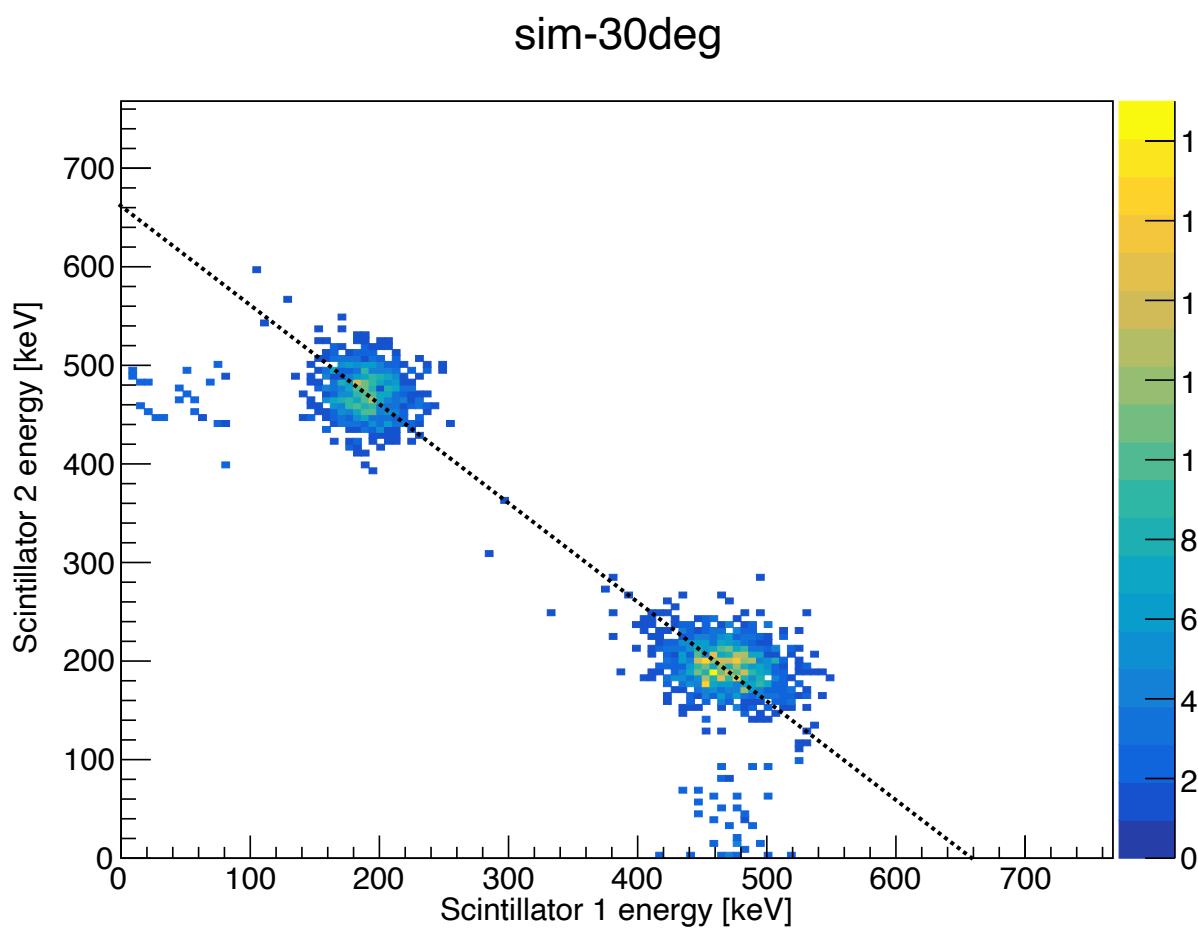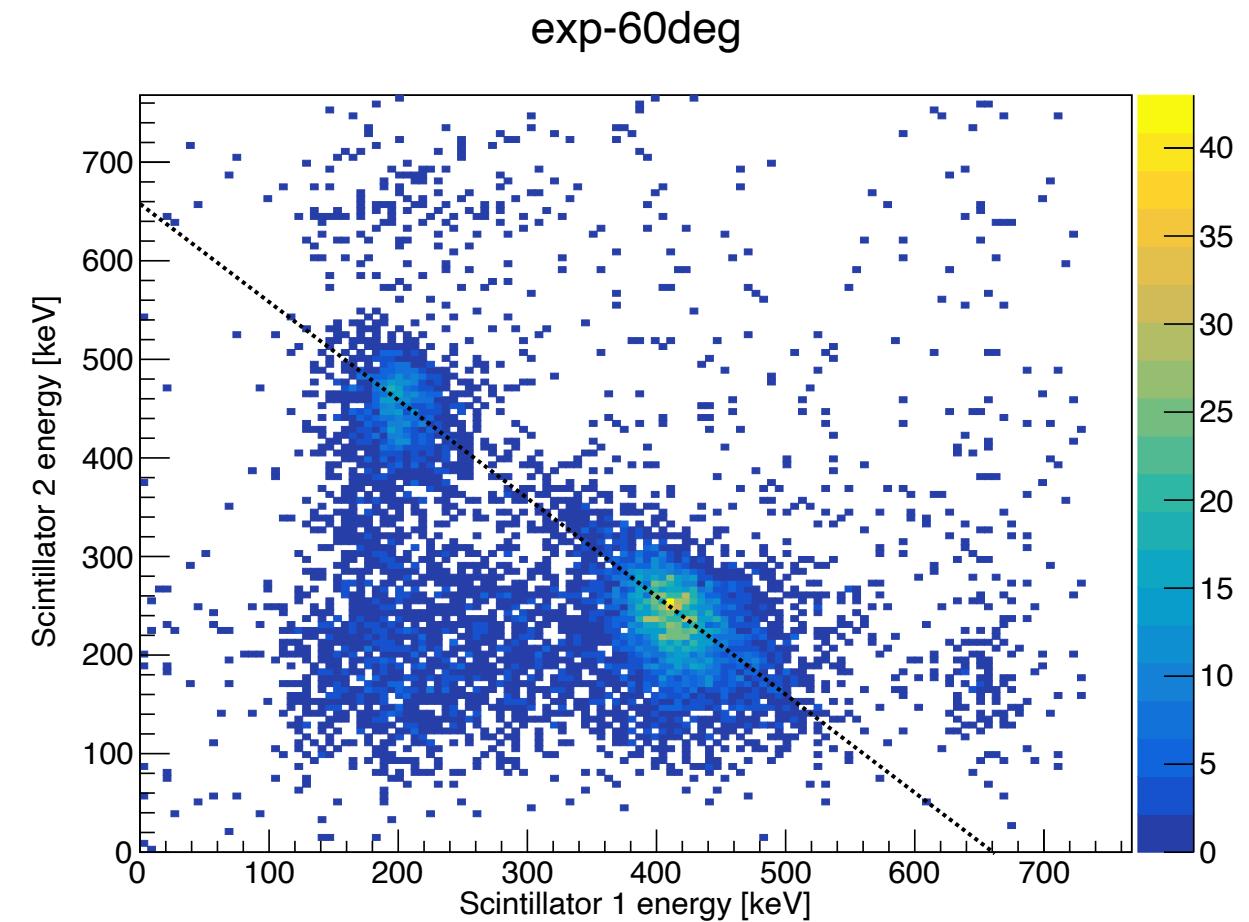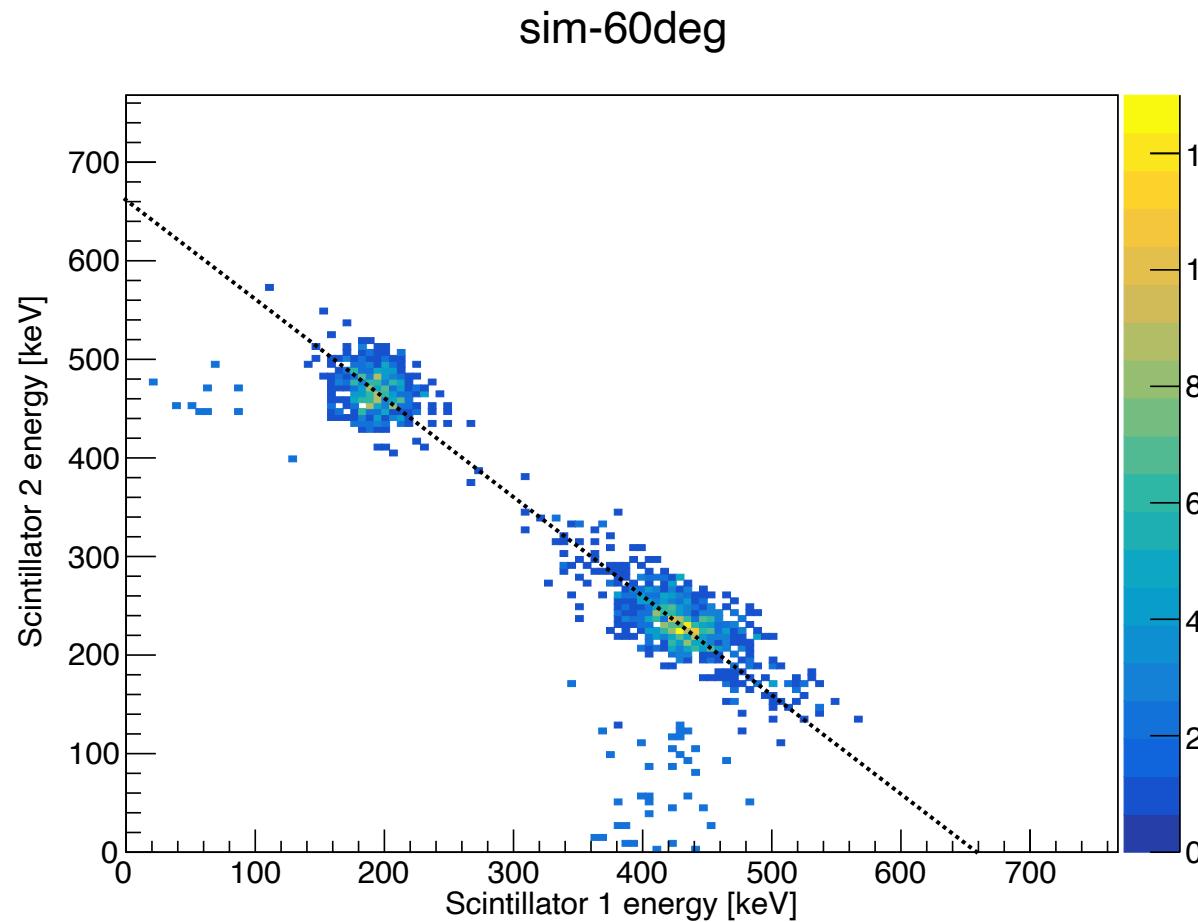
- **scinti1(blue-line)**
  - experimental data

3.2 Observation of Compton-scattering
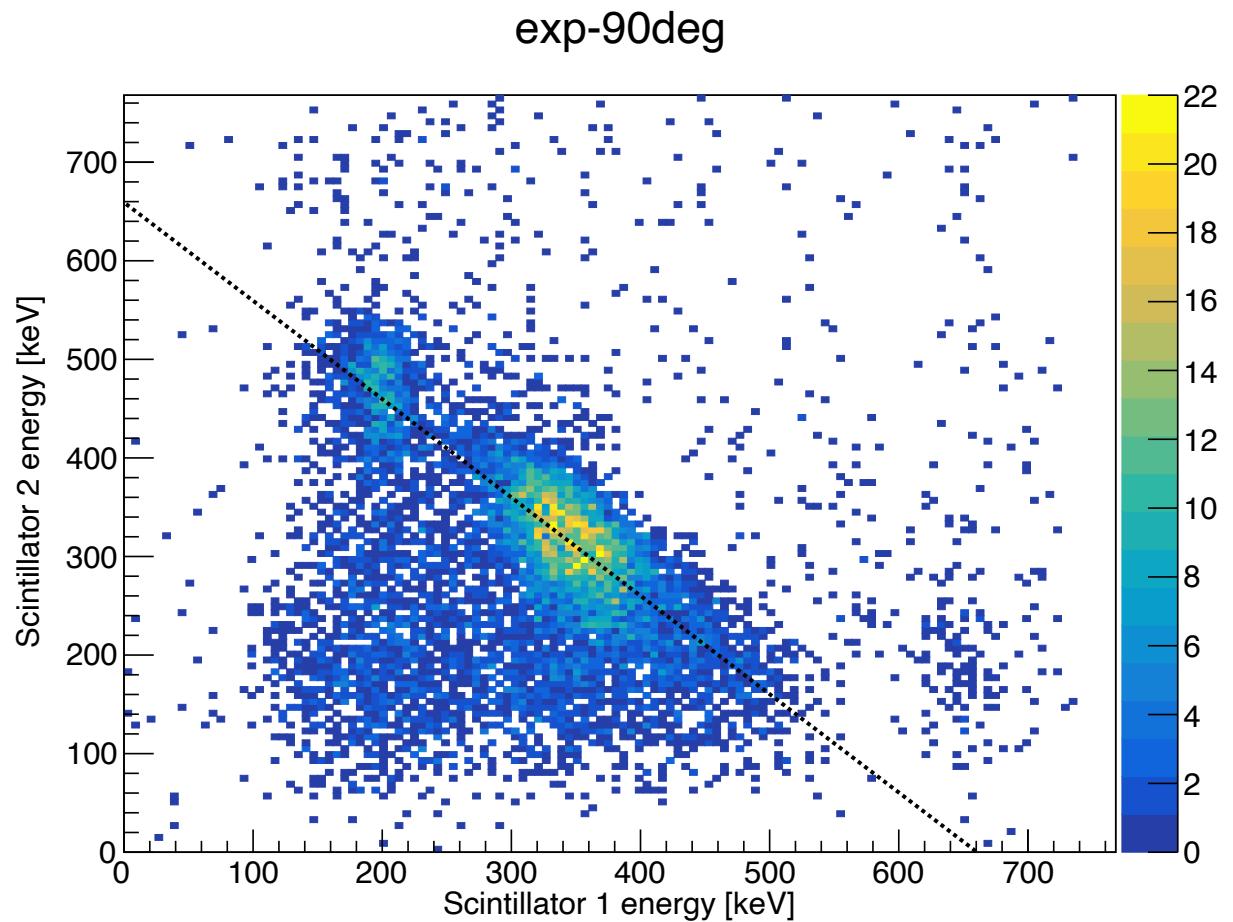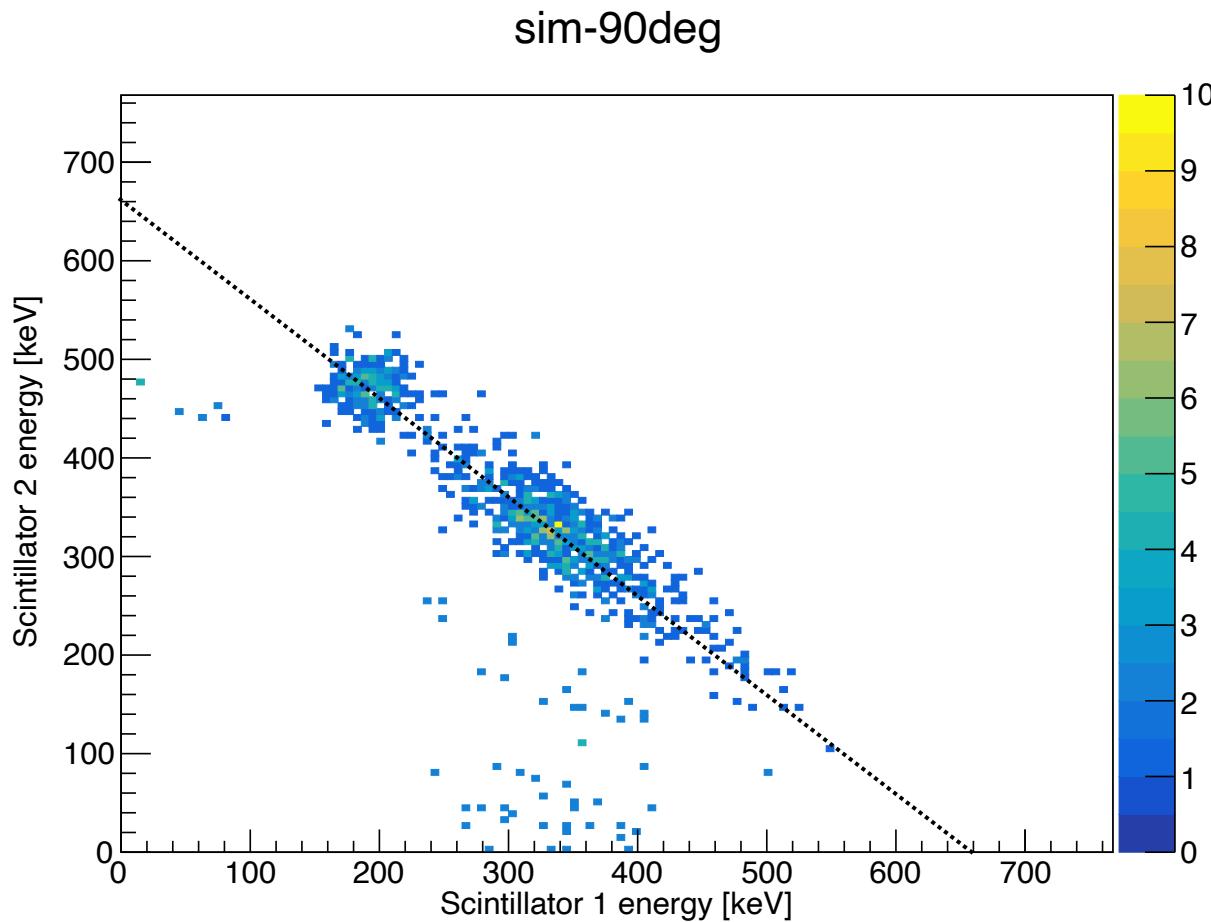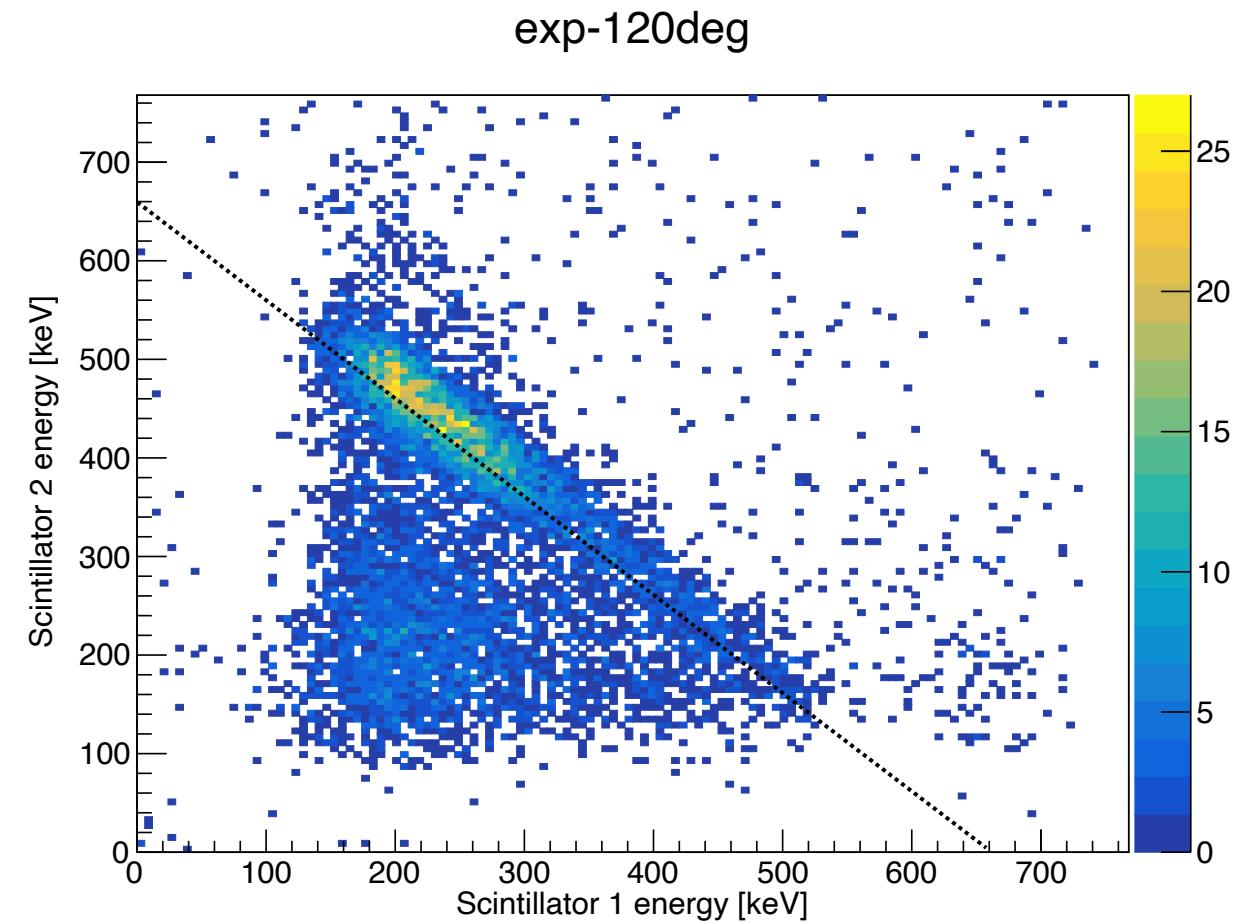
3.2 Observation of Compton-scattering

sim-0deg

exp-0deg

Scattering summed area

Scintillator 2→1

Scintillator 1→2

3.2 Observation of Compton-scattering

sim-30deg

exp-30deg

Leaked Cs^{137} γ-ray

Backscatter

Each compton scattering

3.2 Observation of Compton-scattering

sim-60deg

exp-60deg

3.2 Observation of Compton-scattering

3.2 Observation of Compton-scattering
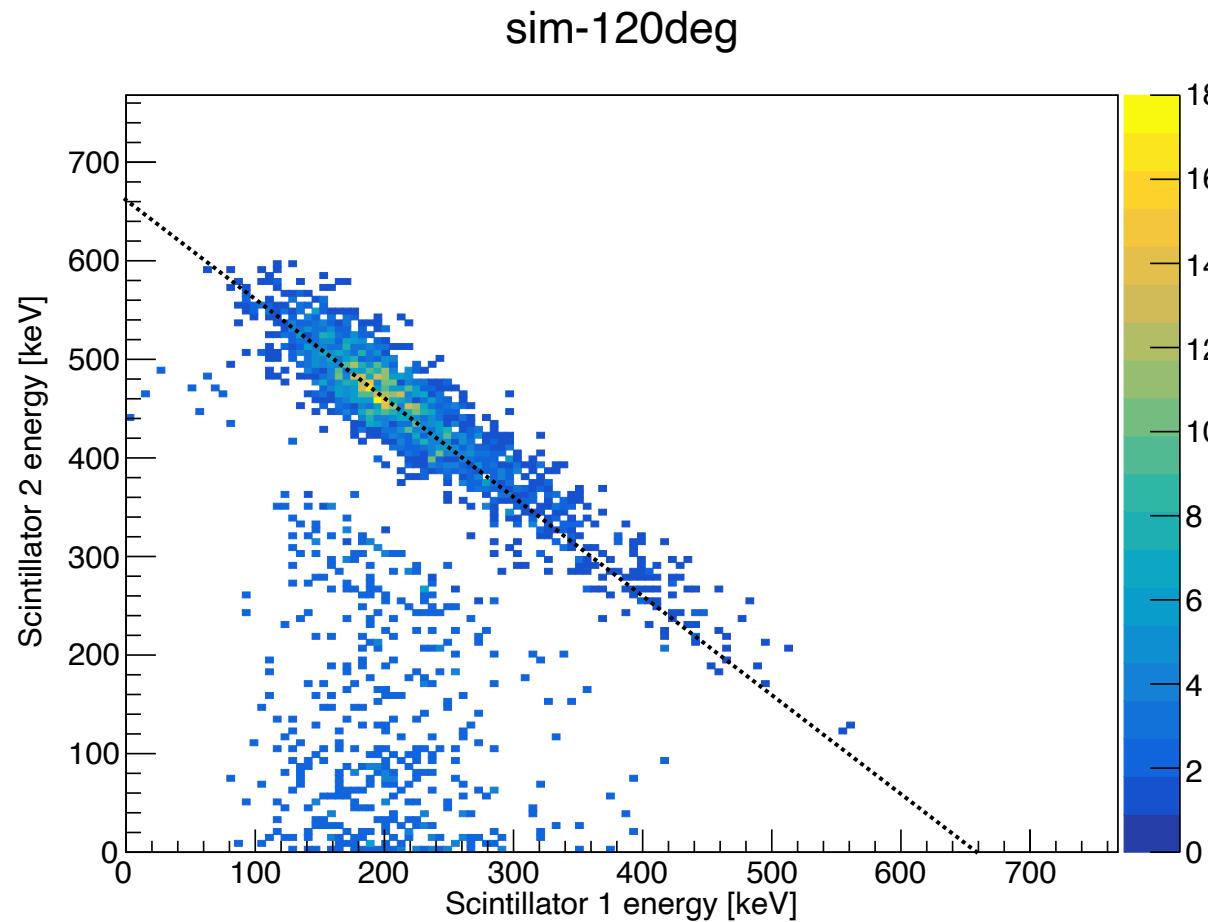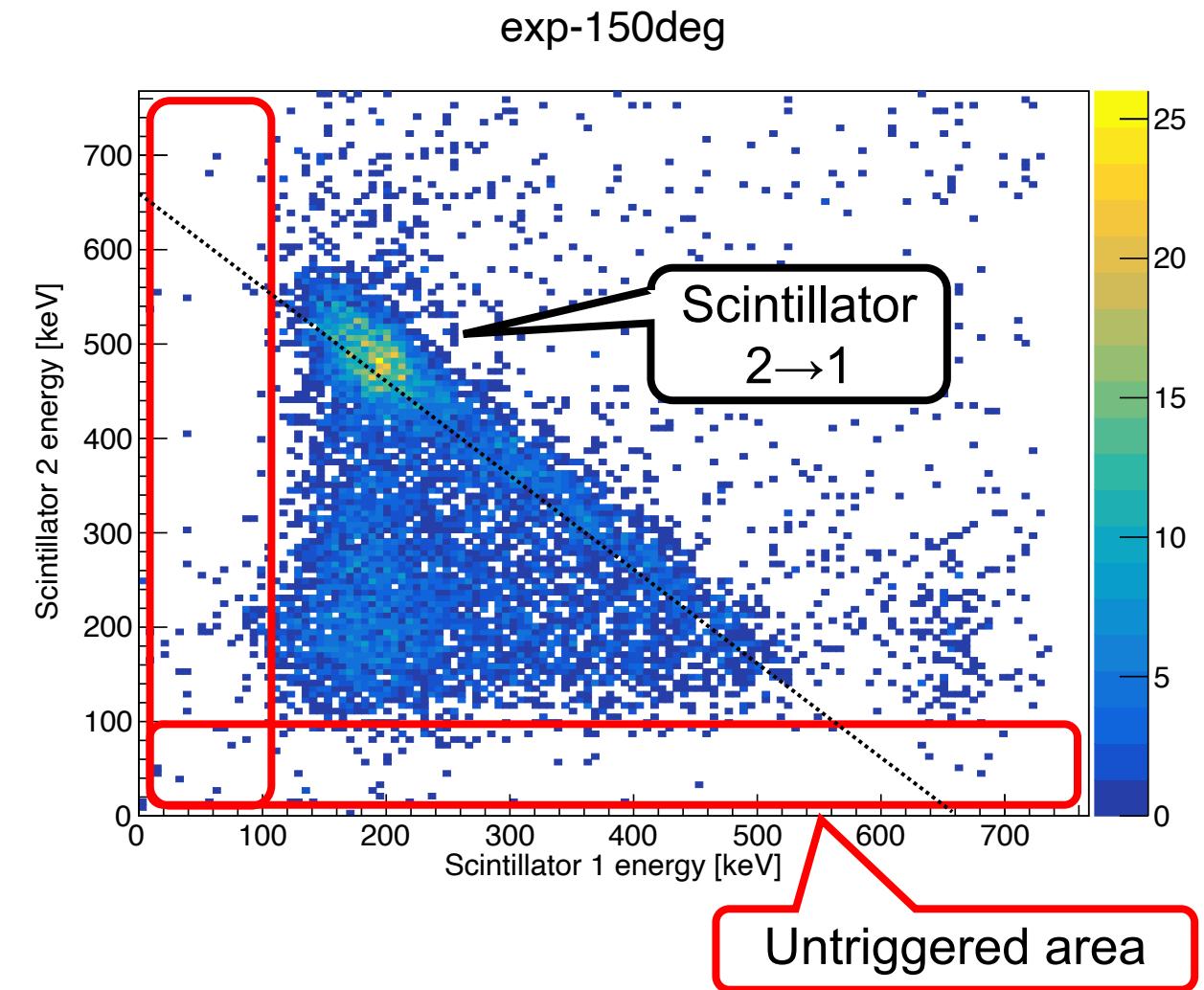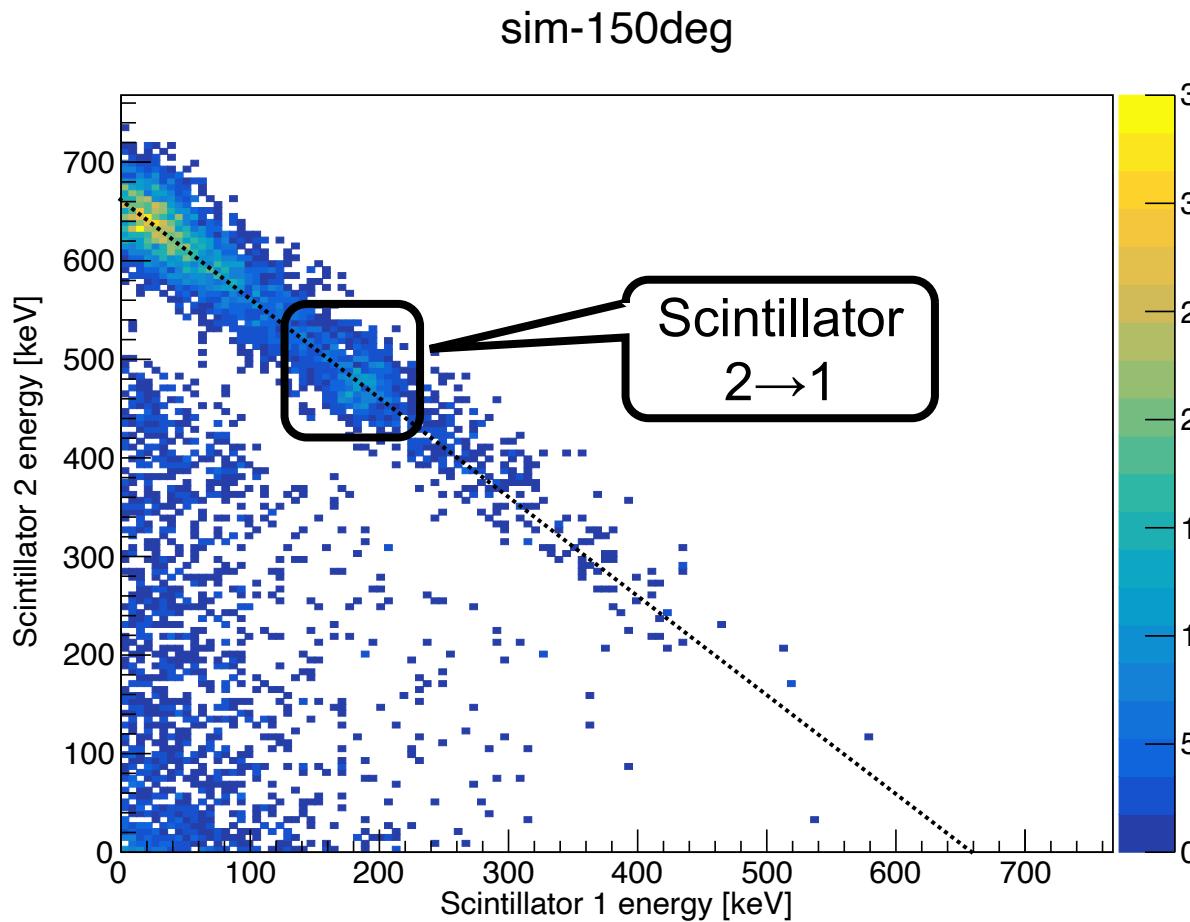
3.2 Observation of Compton-scattering

4　Conclusion & Issues

- Although the phenomenon is limited, I have developed a simulator that can reproduce the reaction process.

- The more generalized the functionality and setup, the more difficult it becomes to use.

- Insufficient quantitative verification of simulator output results.