

The basics of x-ray dosimetry visualized, using Monte Carlo simulations

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15 - 12 - 2022

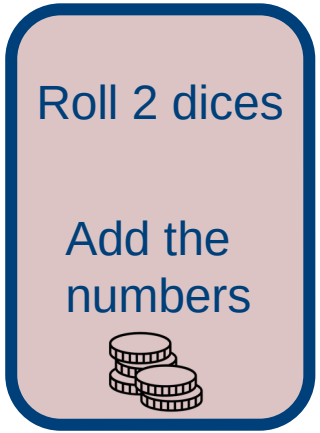
Outline

- **What is a Monte Carlo simulation?**
- **Why is it used in x-ray dosimetry?**
- **Applications**
- **Conclusion**

A problem to solve...

At the beginning of the game, I need to choose a card

Card 1



Card 2



I can play the same card once every round

Which card, on average, gives the highest number of coins?

A problem to solve...

Which card, on average, gives the highest number of coins?

Card 1

Roll 2 dices
Add the numbers



Card 2

Roll 1 dice
Add 3



Card	Game 1	Game 2	Game 3
1	4	7	5
2	6	9	5







A problem to solve...

Which card, on average, gives the highest number of coins?

Card 1

Roll 2 dices
Add the numbers

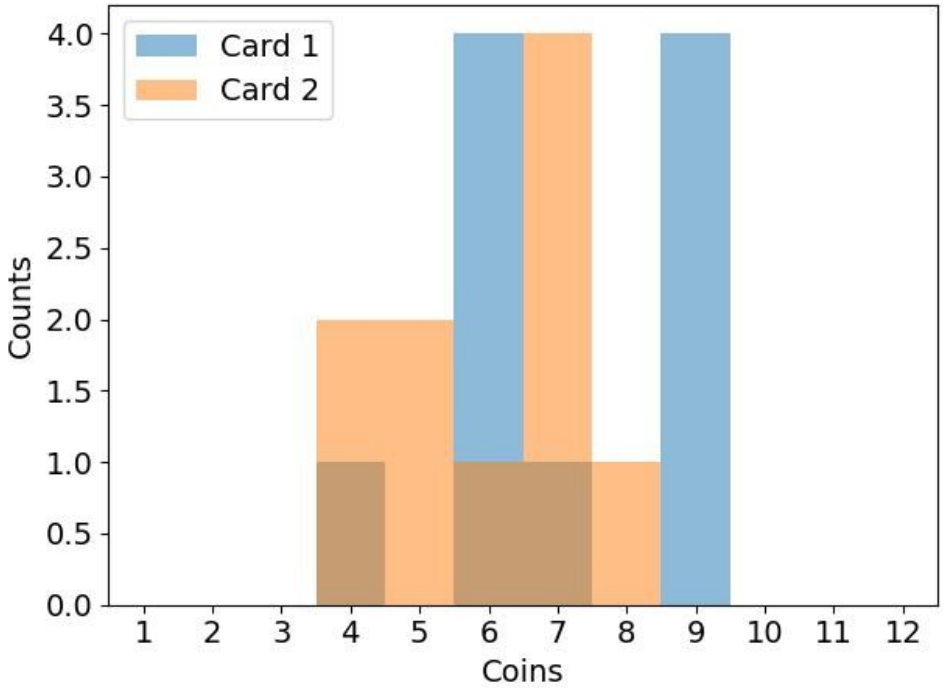
Card 2

Roll 1 dice
Add 3



Mean: 7.1±0.6 Mean: 6.0±0.4

10 rounds



A problem to solve...

Which card, on average, gives the highest number of coins?

Card 1

Roll 2 dices
Add the numbers

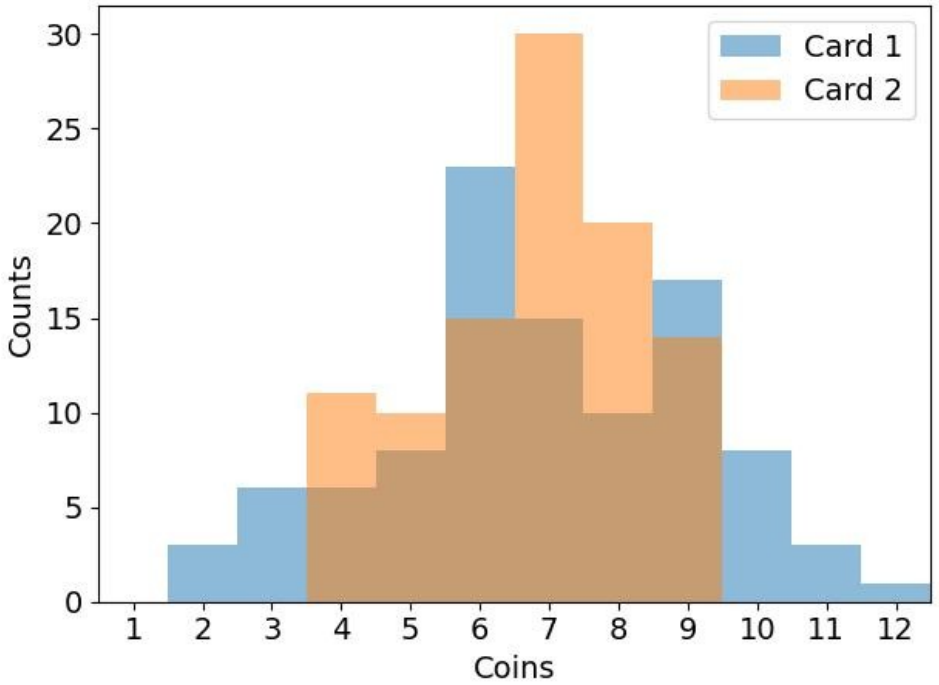
Card 2

Roll 1 dice
Add 3



Mean: 6.9±0.2 Mean: 6.8±0.2

100 rounds



A problem to solve...

Which card, on average, gives the highest number of coins?

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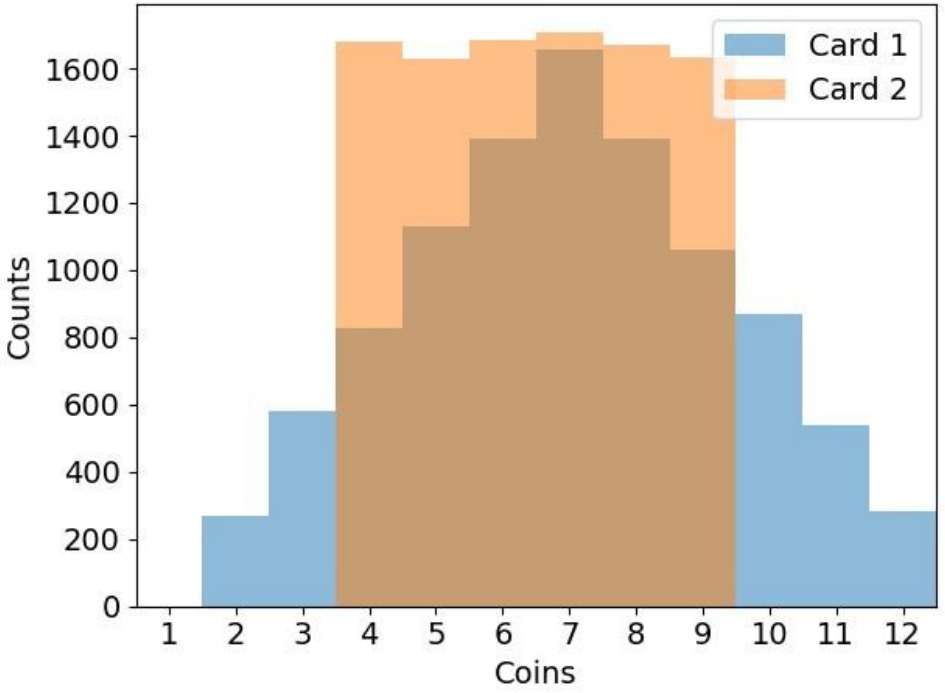
Roll 2 dices
Add the numbers

Card 2

Roll 1 dice
Add 3



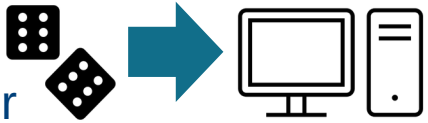


Mean: 7.00±0.02 Mean: 6.50±0.02

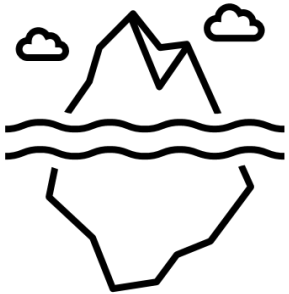
10000 rounds

Card 1

Some ingredients on a Monte Carlo simulation



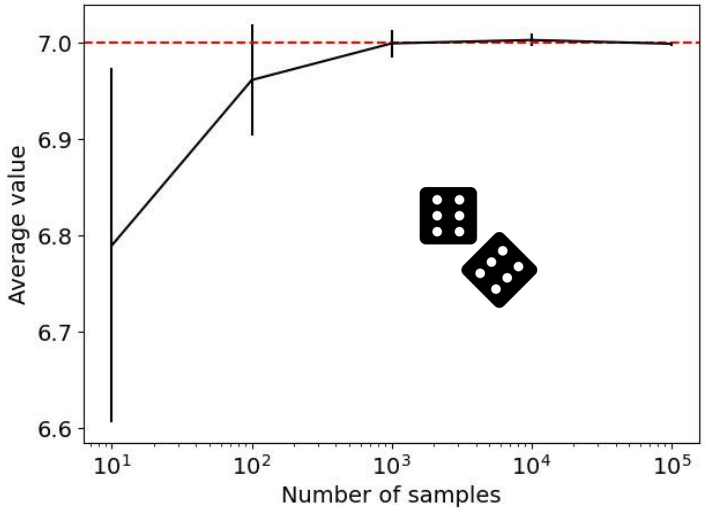
Oversimplification



- (pseudo) random number generator
- Probability density (mass) functions
- Large amount of samples
- Set of "rules"







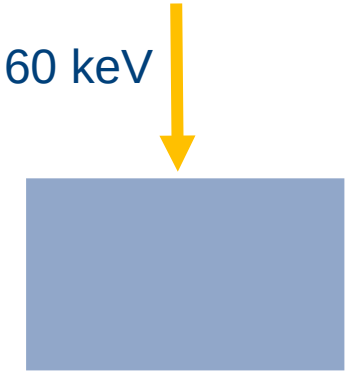
- Expected value or distribution
- Statistical uncertainty – decreases with number of samples

X-ray in diagnostic imaging



Why Monte Carlo simulations?

Distance of photons travelling in water before interacting



What is the average distance?

(a) 1 cm

(b) 5 cm

(c) 10 cm

(d) 20 cm



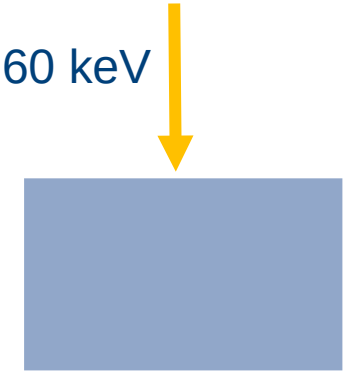
X-ray in diagnostic imaging



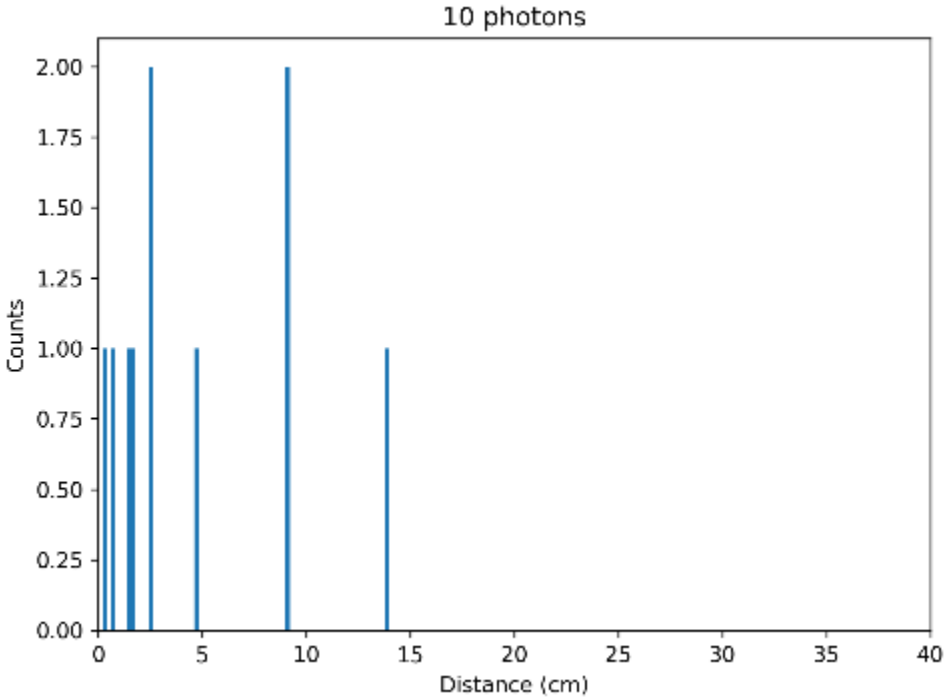
Why Monte Carlo simulations?

Distance of photons travelling in water before interacting

60 keV



Mean: 4±1 cm



X-ray in diagnostic imaging



Why Monte Carlo simulations?

Distance of photons travelling in water before interacting

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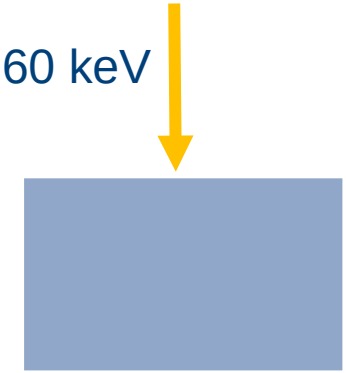
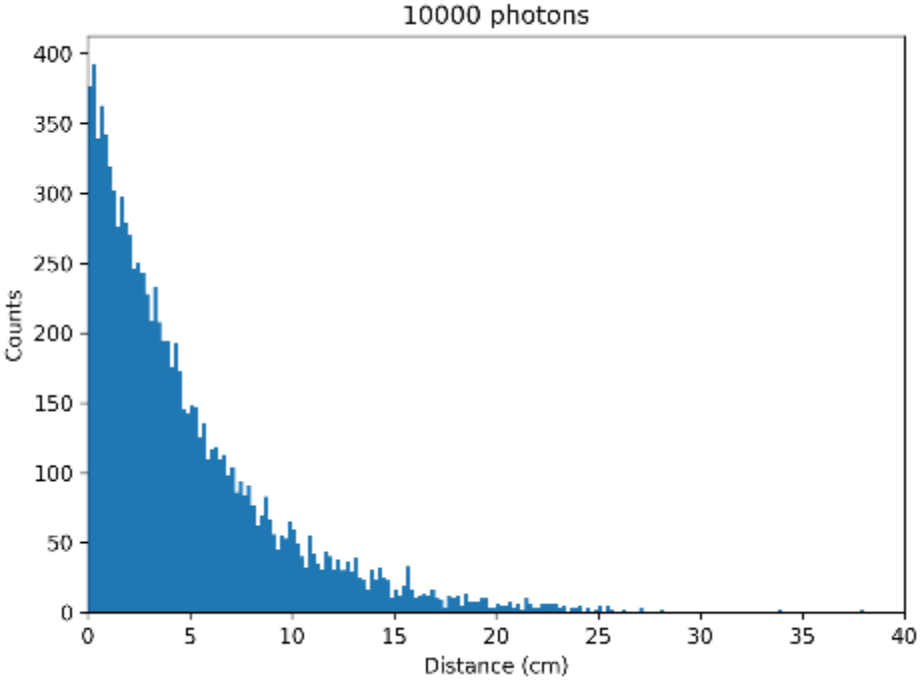


Mean: 4.9±0.1 cm



X-ray in diagnostic imaging



Why Monte Carlo simulations?

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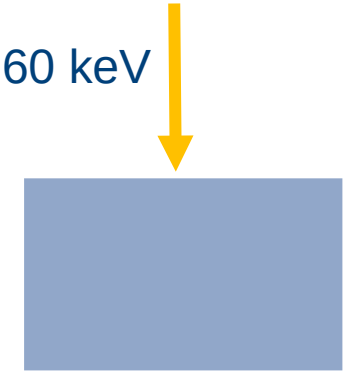
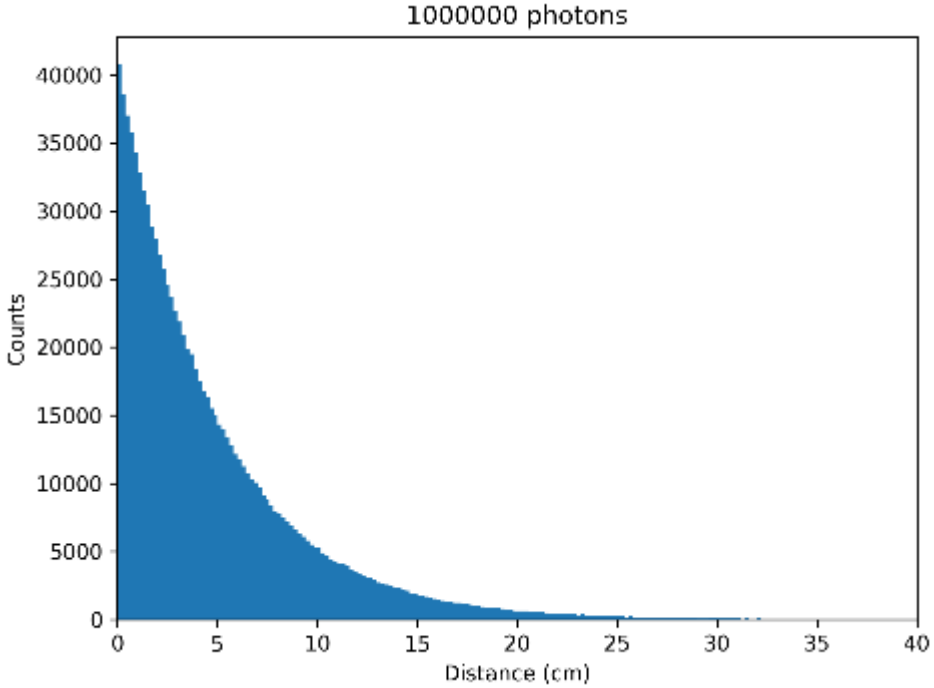


Mean: 4.90±0.05 cm



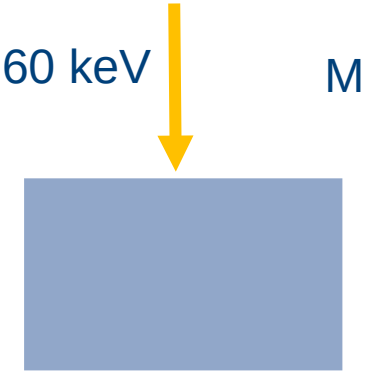
X-ray in diagnostic imaging



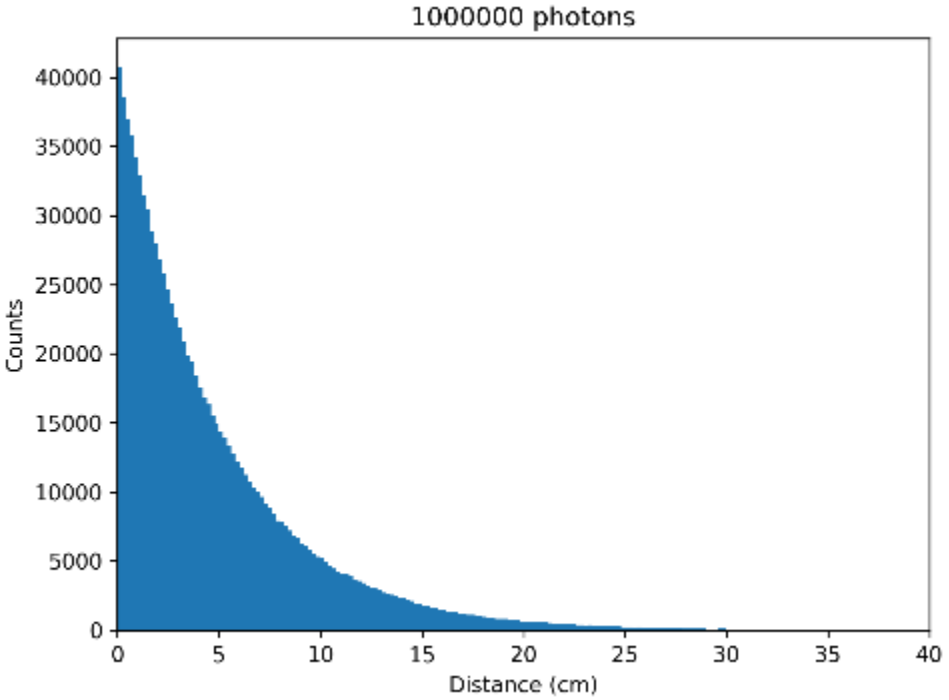
Why Monte Carlo simulations?

Distance of photons travelling in water before interacting

60 keV



Mean: 4.849±0.005 cm





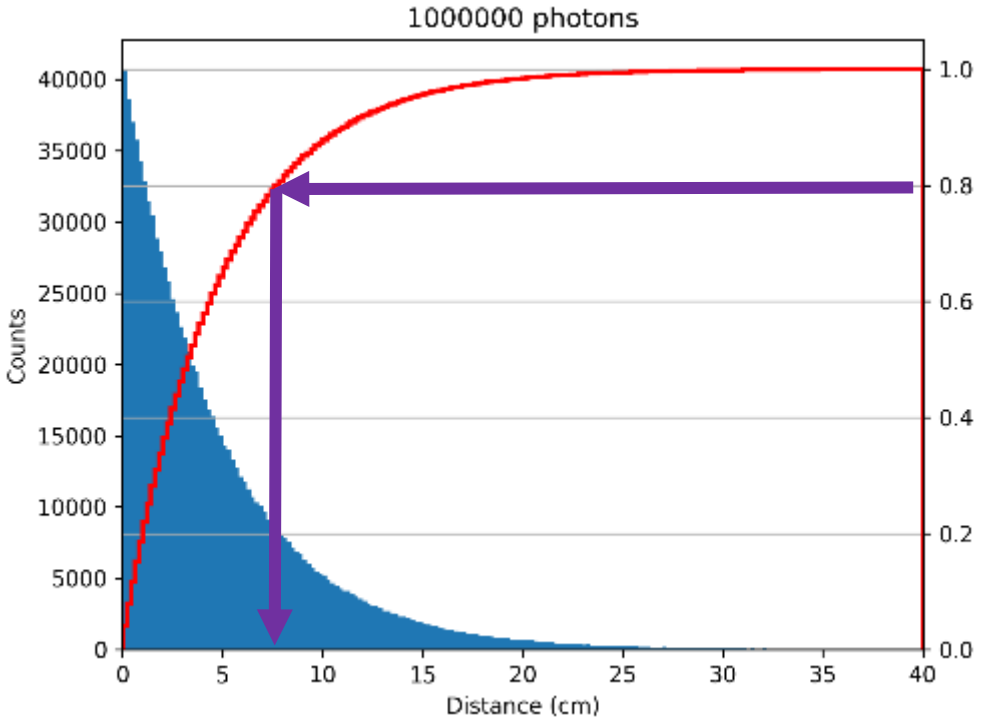
X-ray in diagnostic imaging

Why Monte Carlo simulations?

Distance of photons travelling in water before interacting

60 keV





Correct

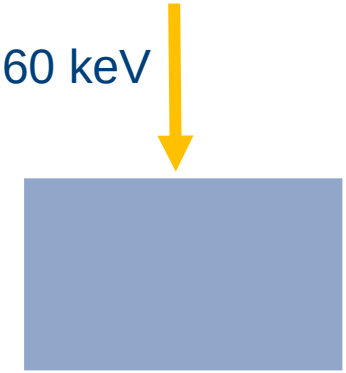
(b) 5 cm

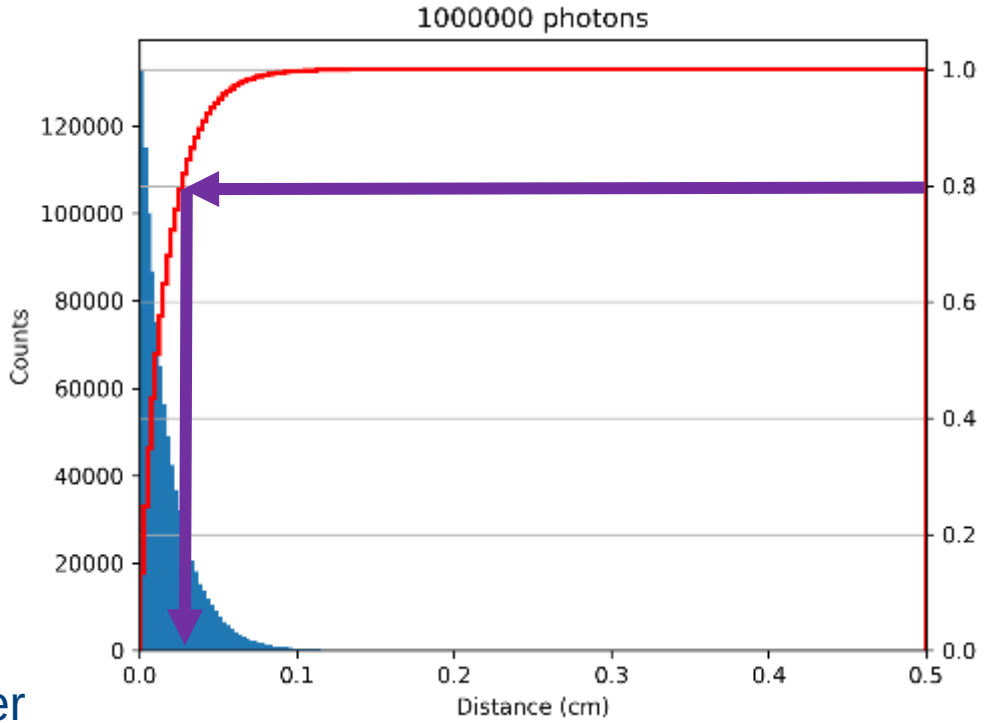
X-ray in diagnostic imaging



Why Monte Carlo simulations?

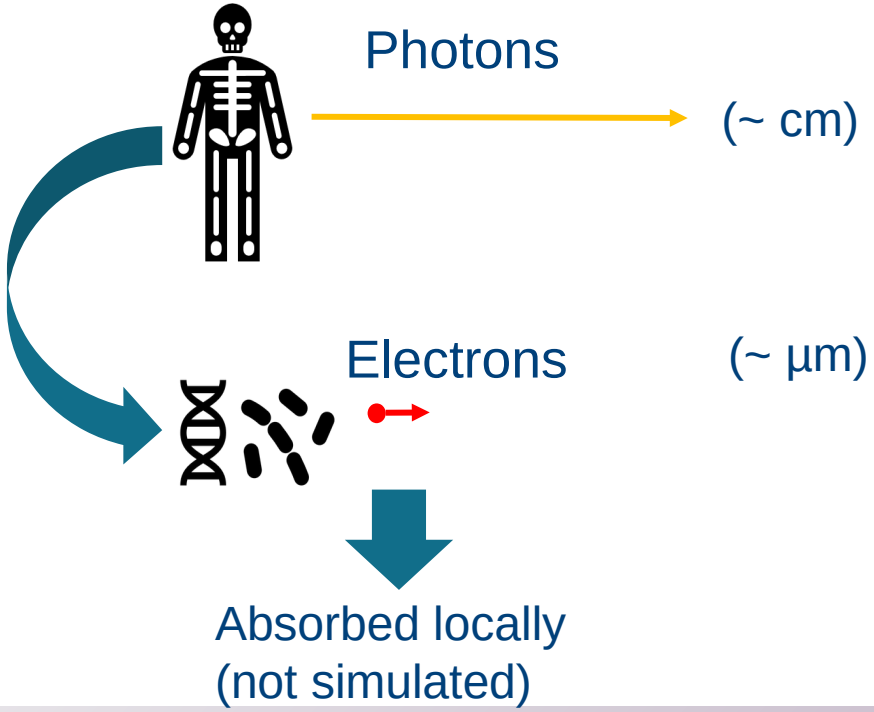
Distance of photons travelling in **lead** before interacting





- ~ 8 cm in water
- ~ 0.3 mm in lead

X-ray in diagnostic imaging

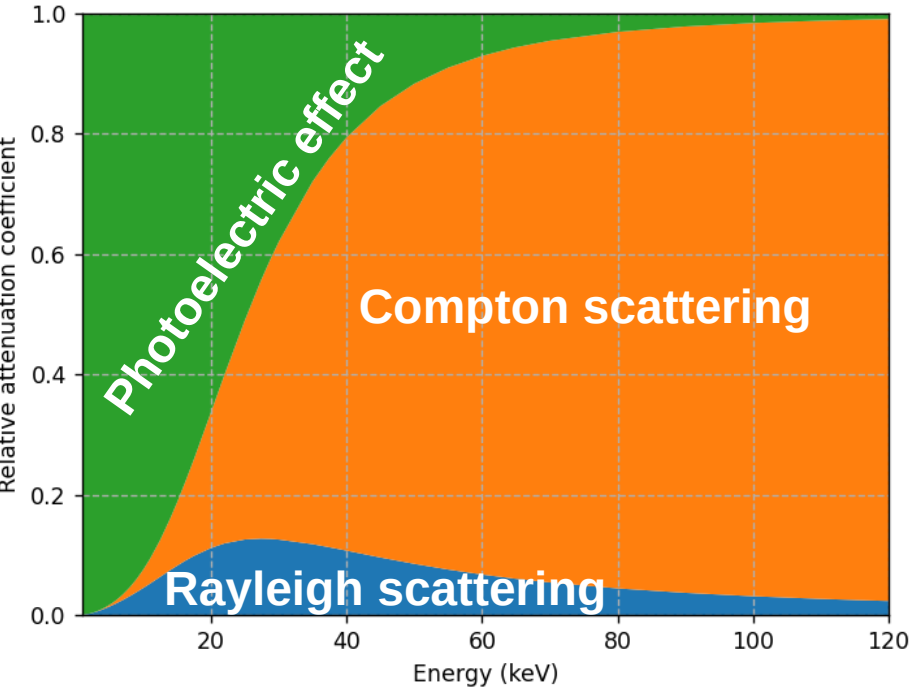


- Rayleigh scattering
- Photoelectric effect
- Compton scattering
- ~~Pair production~~

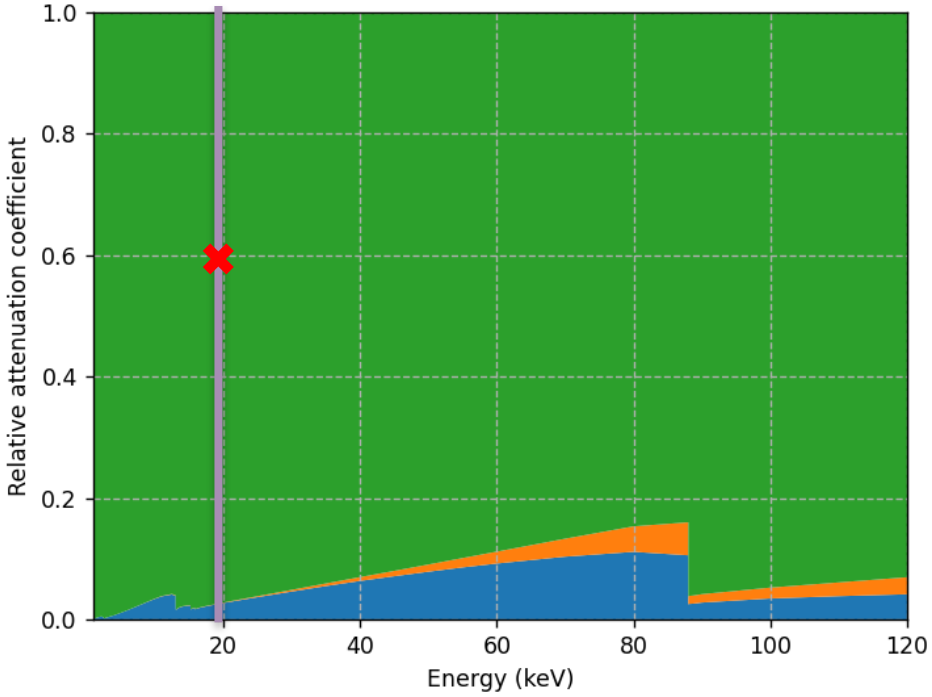
X-ray in diagnostic imaging



Water



Lead



X-ray in diagnostic imaging

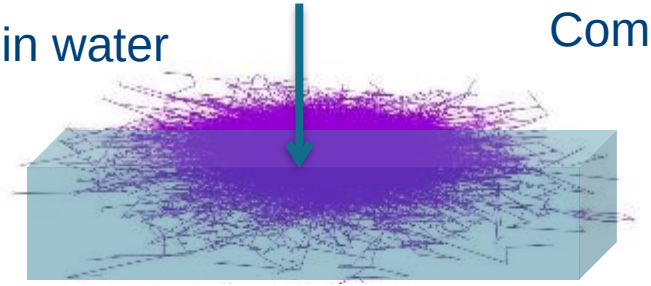
Photon

Stochastic

Travel distance	Type of interaction	Energy deposition Scattering Secondary particles

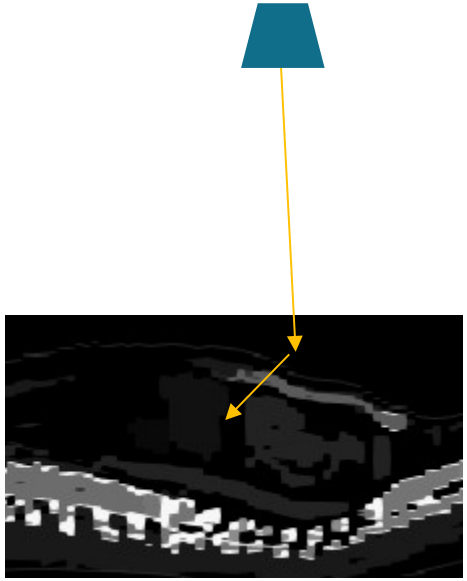
60 keV in water

Complex to solve



Monte Carlo simulation

Monte Carlo simulation and x-rays



Sample distance

Sample interaction

Sample energy deposition and direction

Check if photon is absorbed

Repeat a lot of times

How many photons would be necessary to achieve same dose levels of a real exam?

(a) 1 thousand
(b) 1 million
(c) 1 billion
(d) 1 trillion

Stochastic

~ Deterministic

$$D = \frac{\overline{E}_{depos}}{mass}$$

Bridging between simulation and experiment

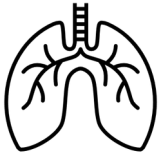
Experimentally measurable quantities

- Air kerma — Ionization chambers, Solid state detectors
- Depth dose — Thermoluminescent dosimeters (TLDs)
- Personal dosimeters

Validation

Quantities estimated from simulations

- Patient dose

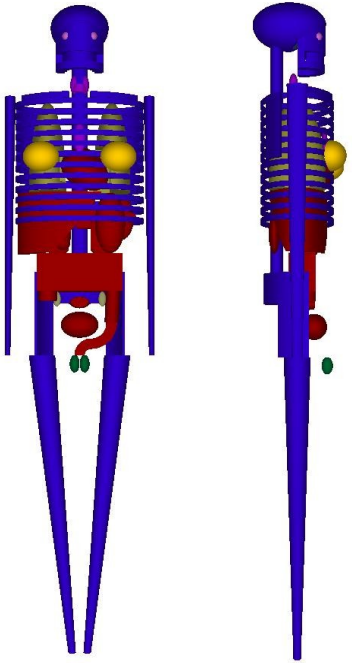


- Operator dose



Anthropomorphic phantoms

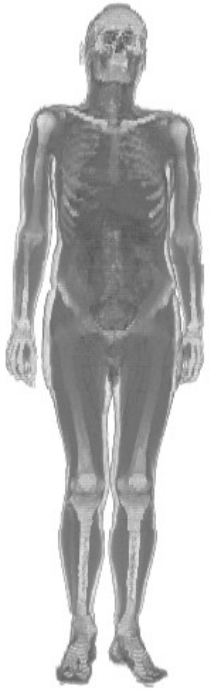
Mathematical phantoms



Modified ORNL anthropomorphic phantom series. Adult. PENGEOM

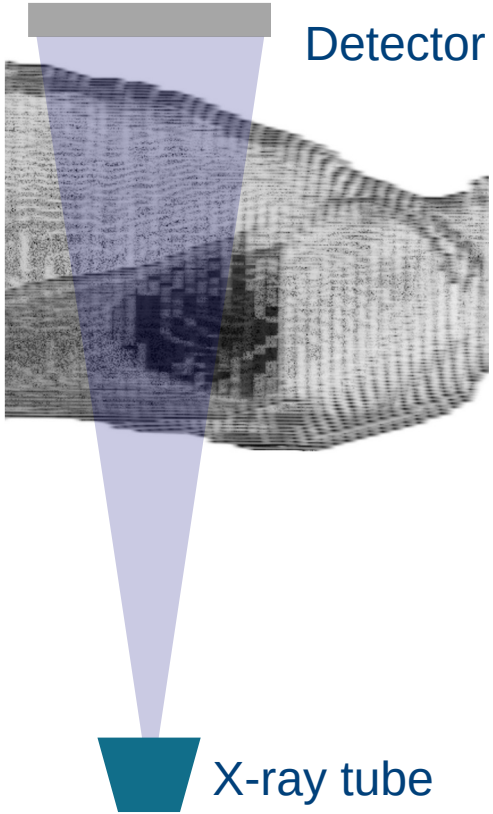
Voxelized phantoms

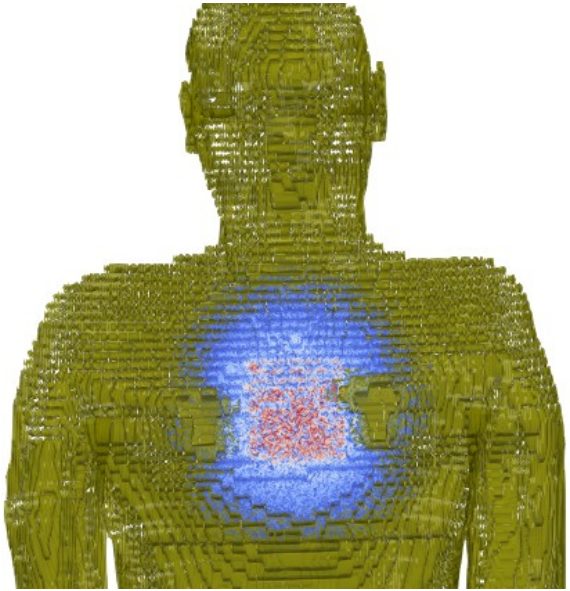
ICRP reference phantoms

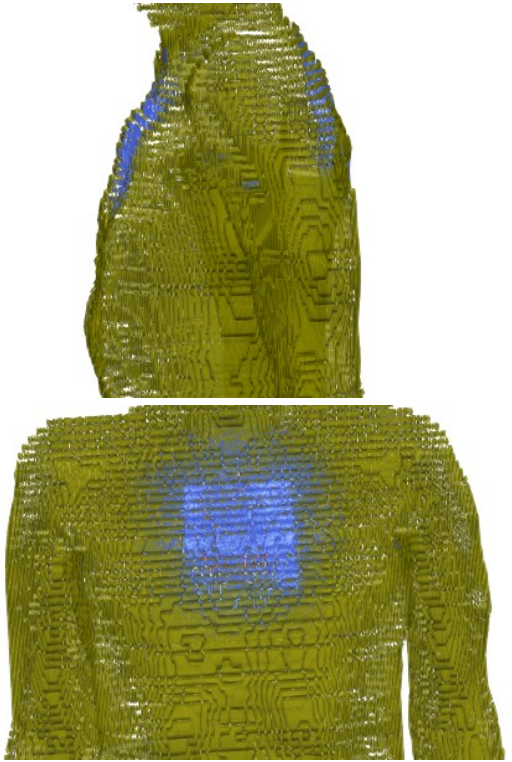


ICRP, 2009. Adult Reference Computational Phantoms. ICRP Publication 110. Ann. ICRP 39 (2).

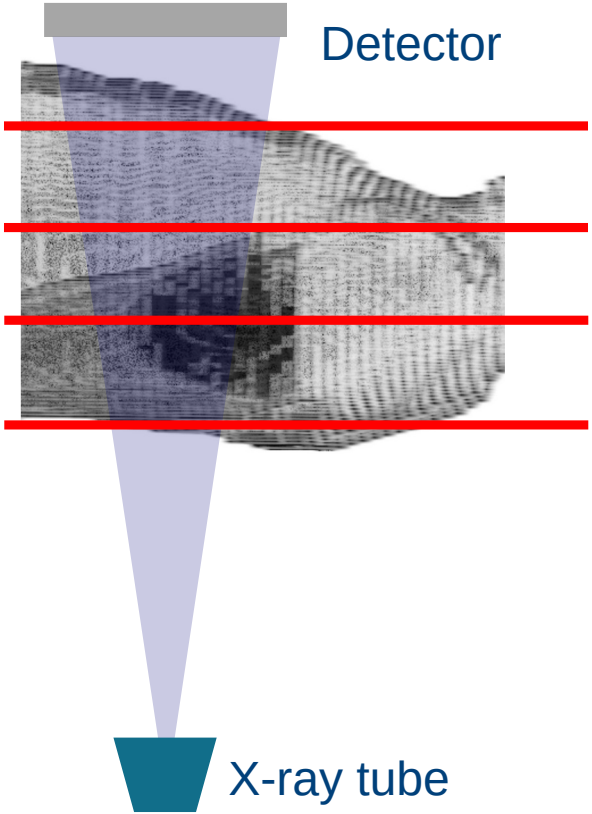
Fluoroscopy - Skin dose

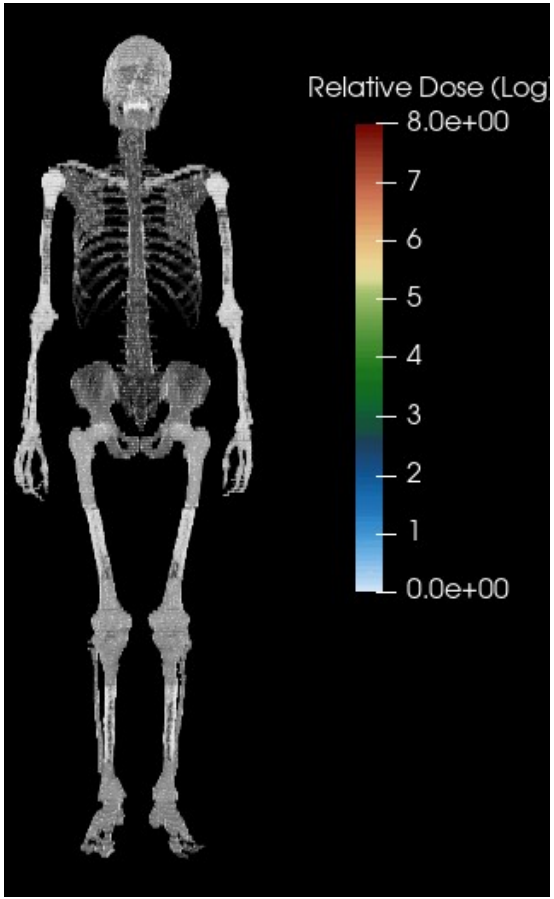




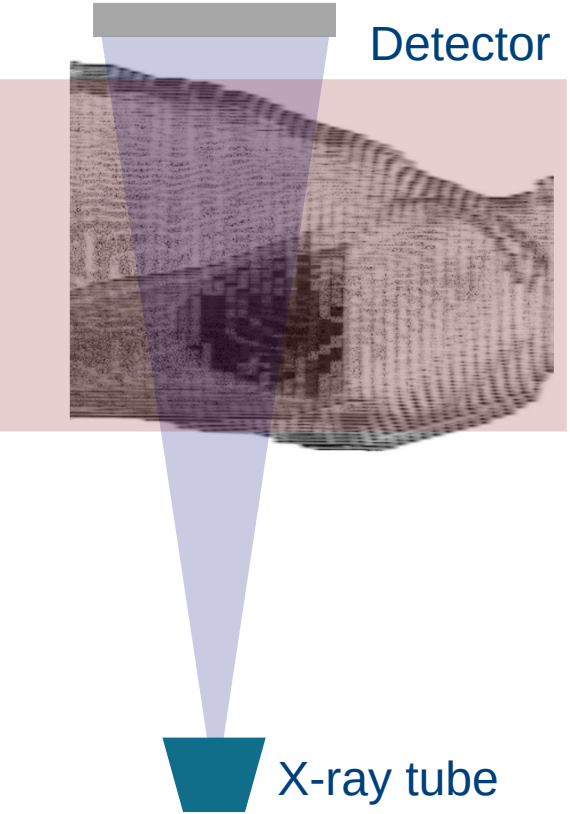


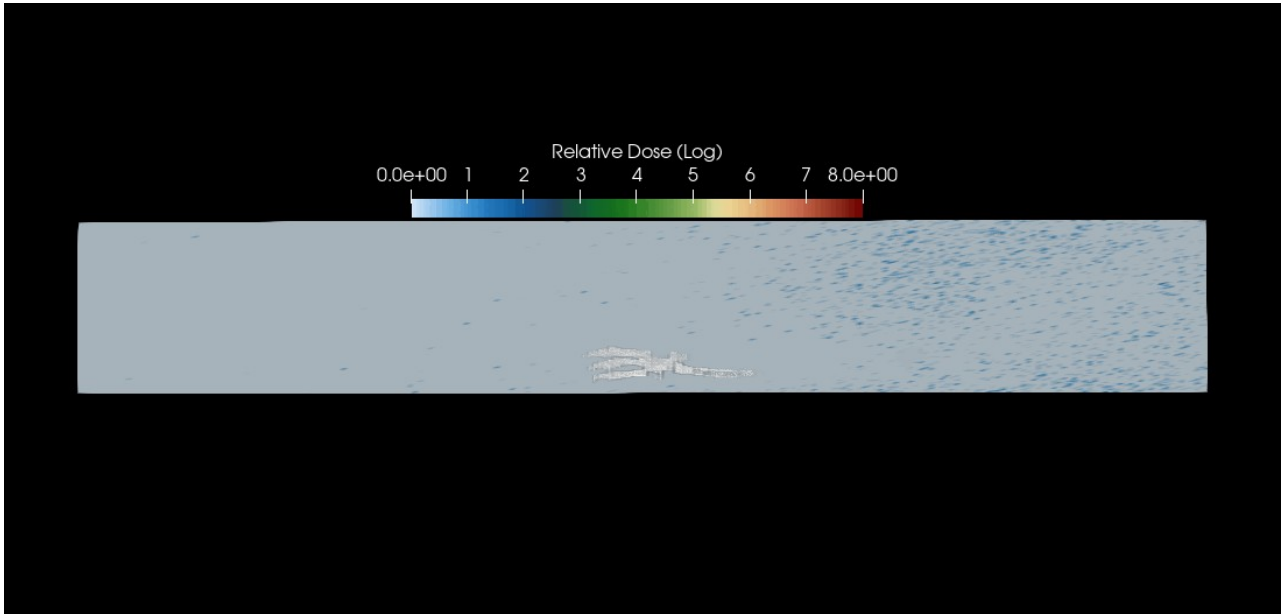
Dose distribution



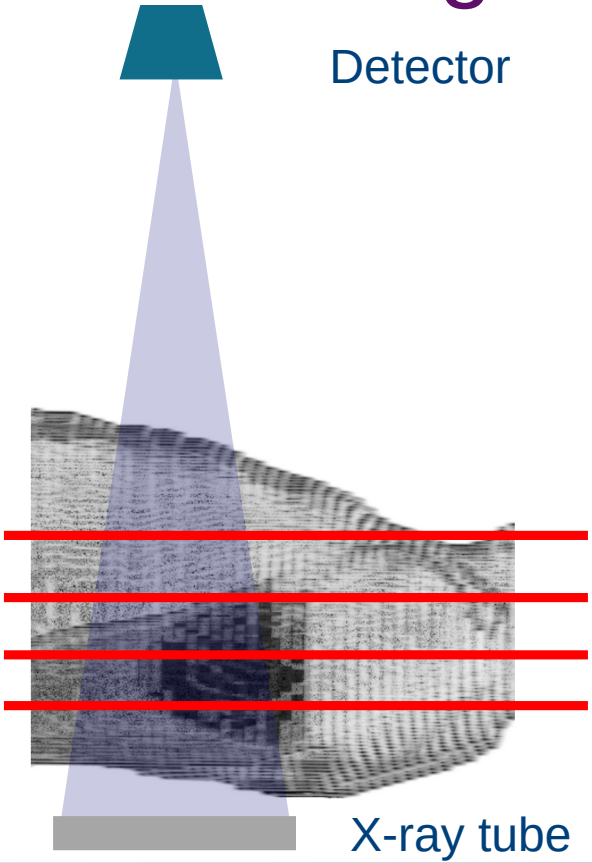


Dose distribution

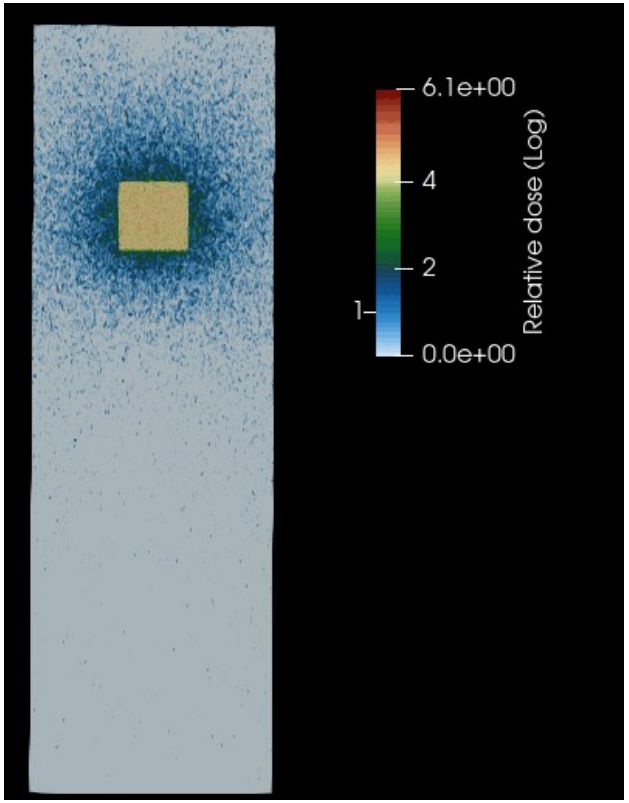




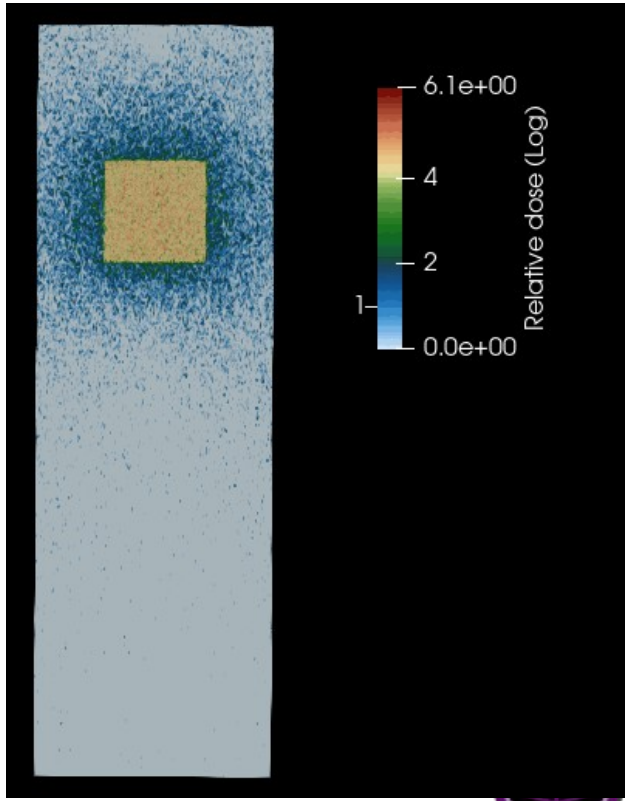
Positioning and field size



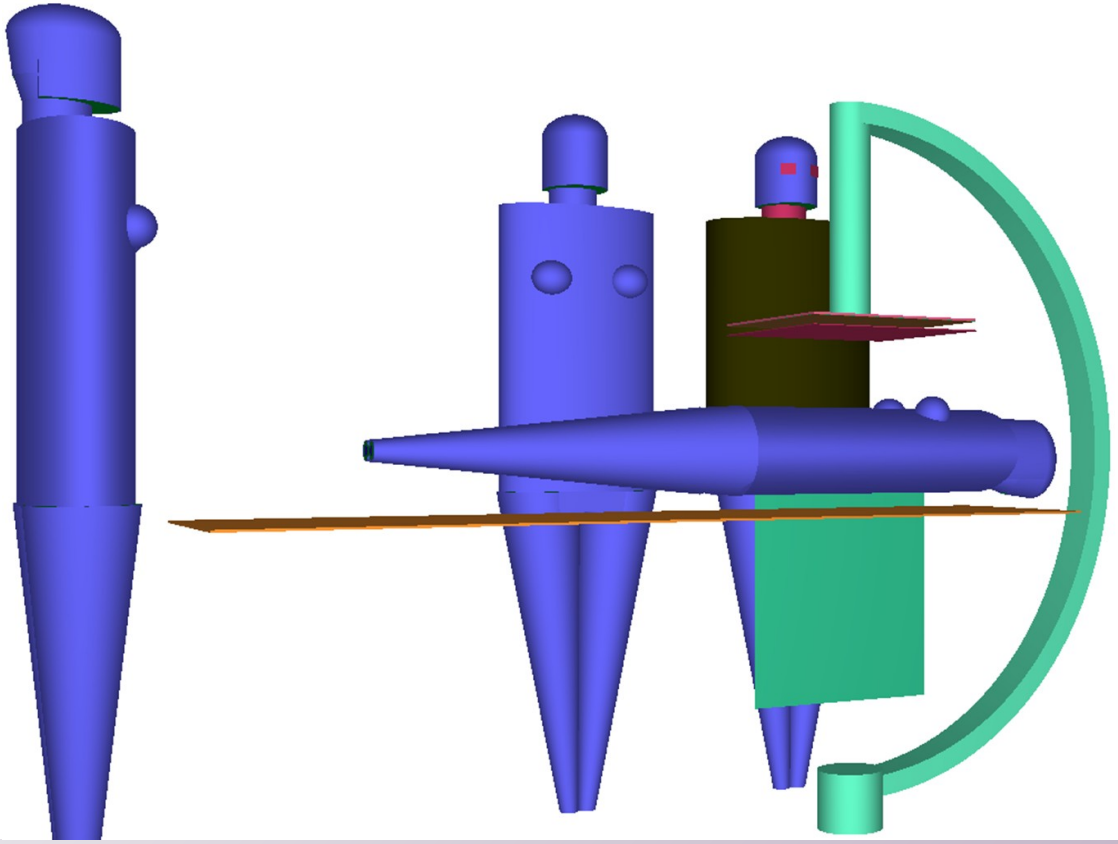
Small field size 71 kV



Large field size 120 kV



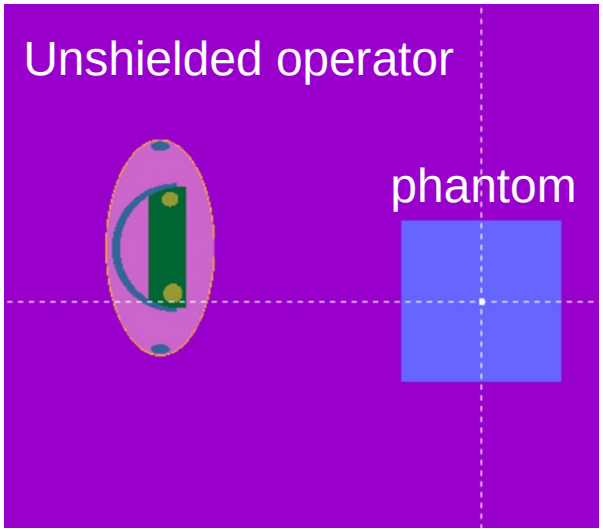
Fluoroscopy - Staff dose

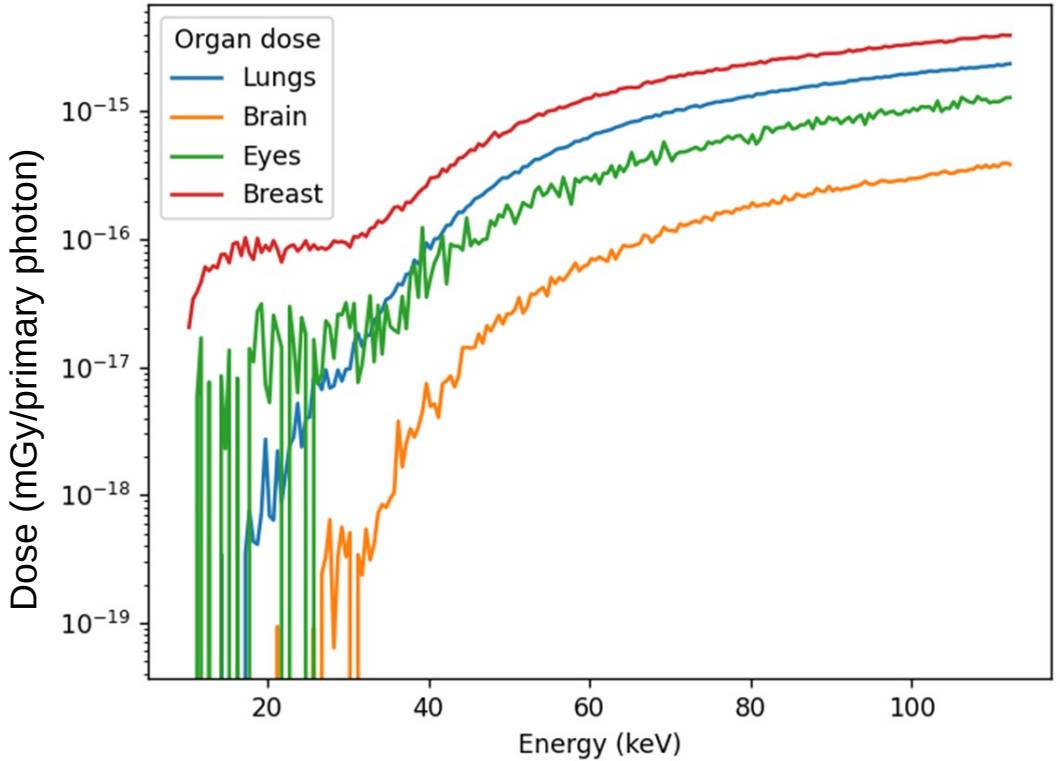


Positioning
Radioprotection equipment

Fluoroscopy - Staff dose

Comparing radioprotection equipment





Optimization tasks



- Dose

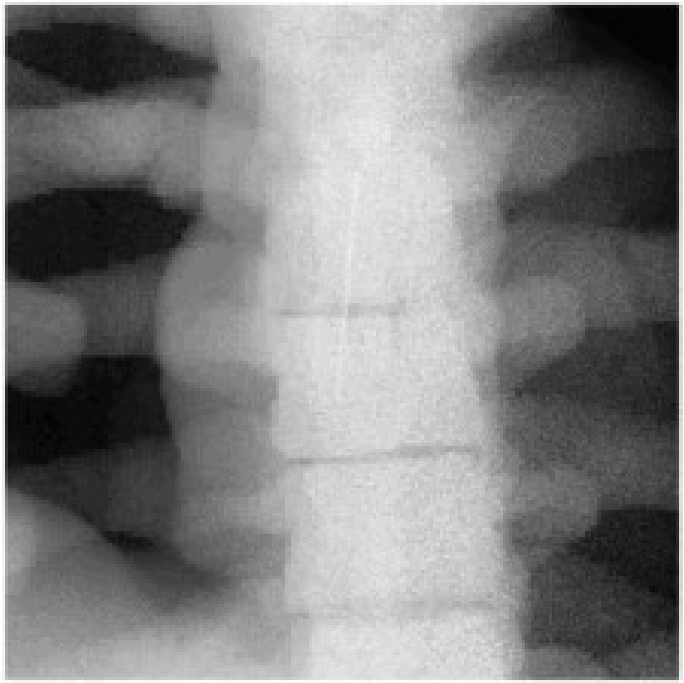


- Image quality

Choose optimal:

- Tube potential
- Additional filtration
- Antiscatter grid

Simulated image



Dose level



Optimization in digital mammography



- Dose → Mean glandular dose

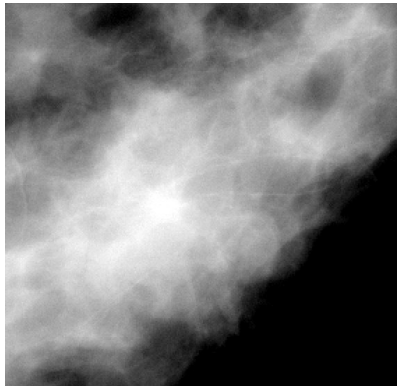
- Image quality

Choose optimal:
- Tube potential
- Spectrum filtration

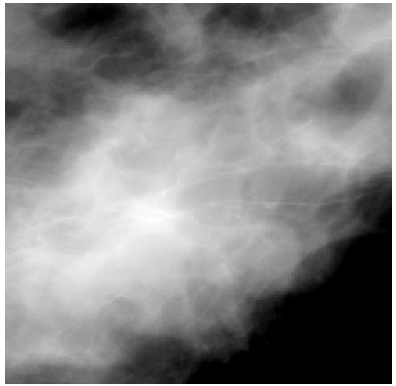
Low dose



Regular dose



High dose



Conclusion

Main points

- Monte Carlo simulations: powerful tool for optimization and radioprotection studies
- Distribution or average values. For example: dose
- Bridge between direct measurable quantities and other quantities
- More complex and realistic simulations (and faster)
- Applications with AI



Thank you

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