
Computational Microelectronics

L22

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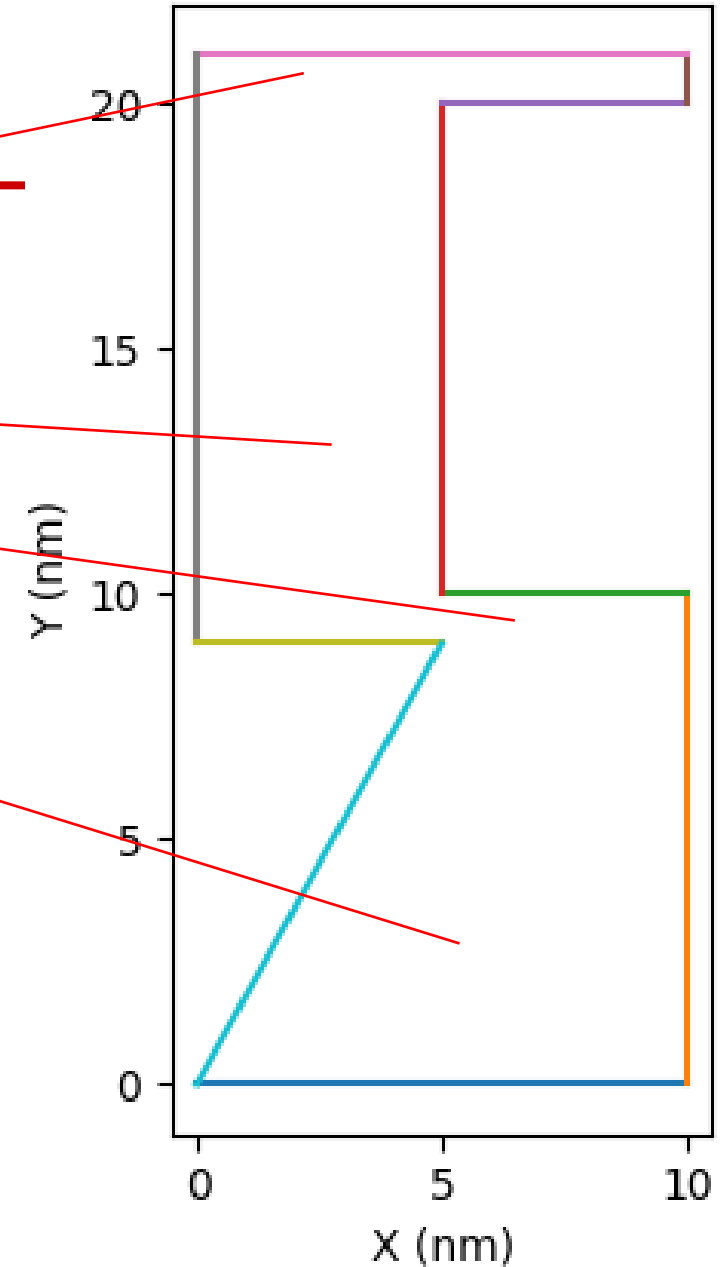
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Monte Carlo

Area of a region

- Of course, we can calculate it.
 - It is $67.5 + 10 + 50 + 10 \text{ nm}^2$.
 - In total, 137.5 nm^2 .
 - However, it is not a general approach.
- Alternative way to calculate the area?
 - Monte Carlo method



Monte Carlo (City)

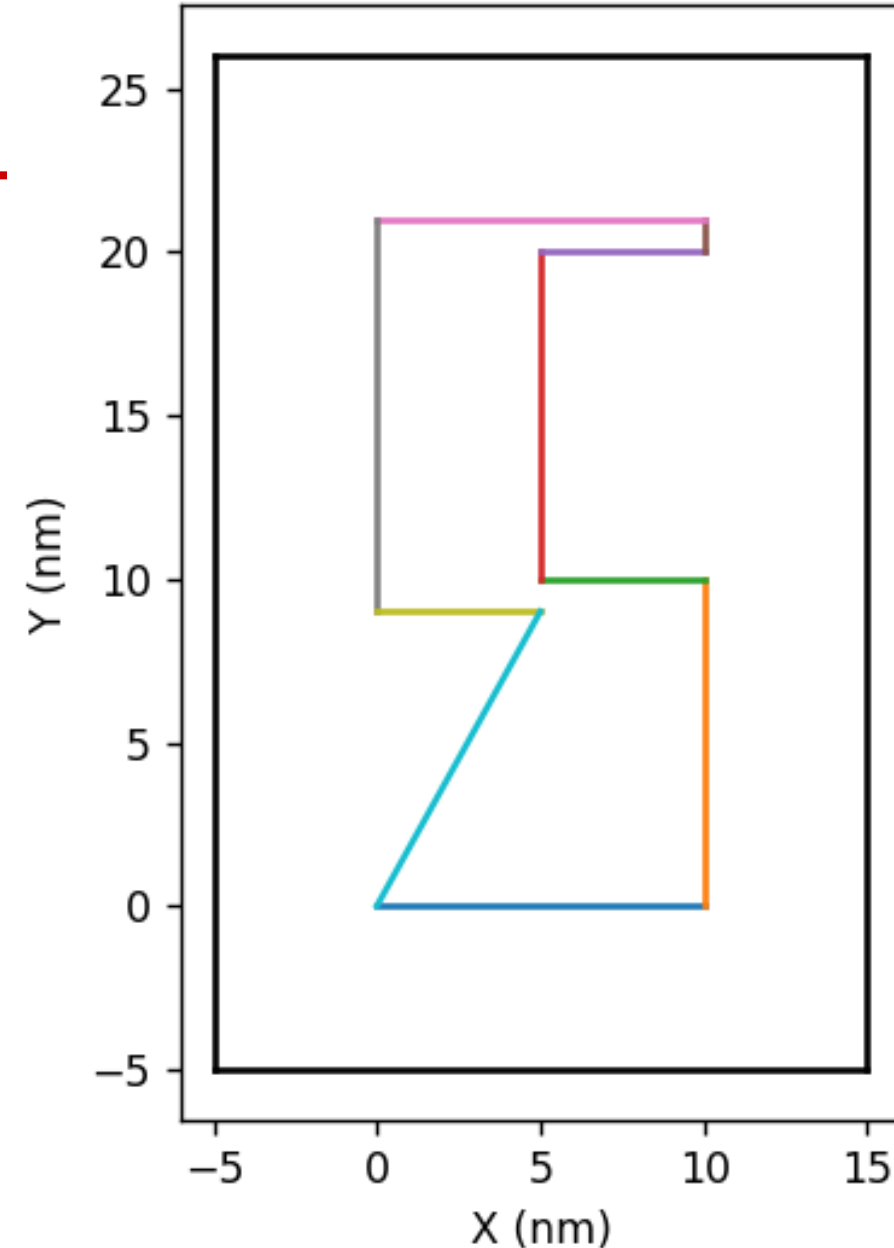
- The Monte Carlo Casino is located there.
 - Gambling is closely related with the random number generation.



Monte Carlo Casino (Wikipedia)

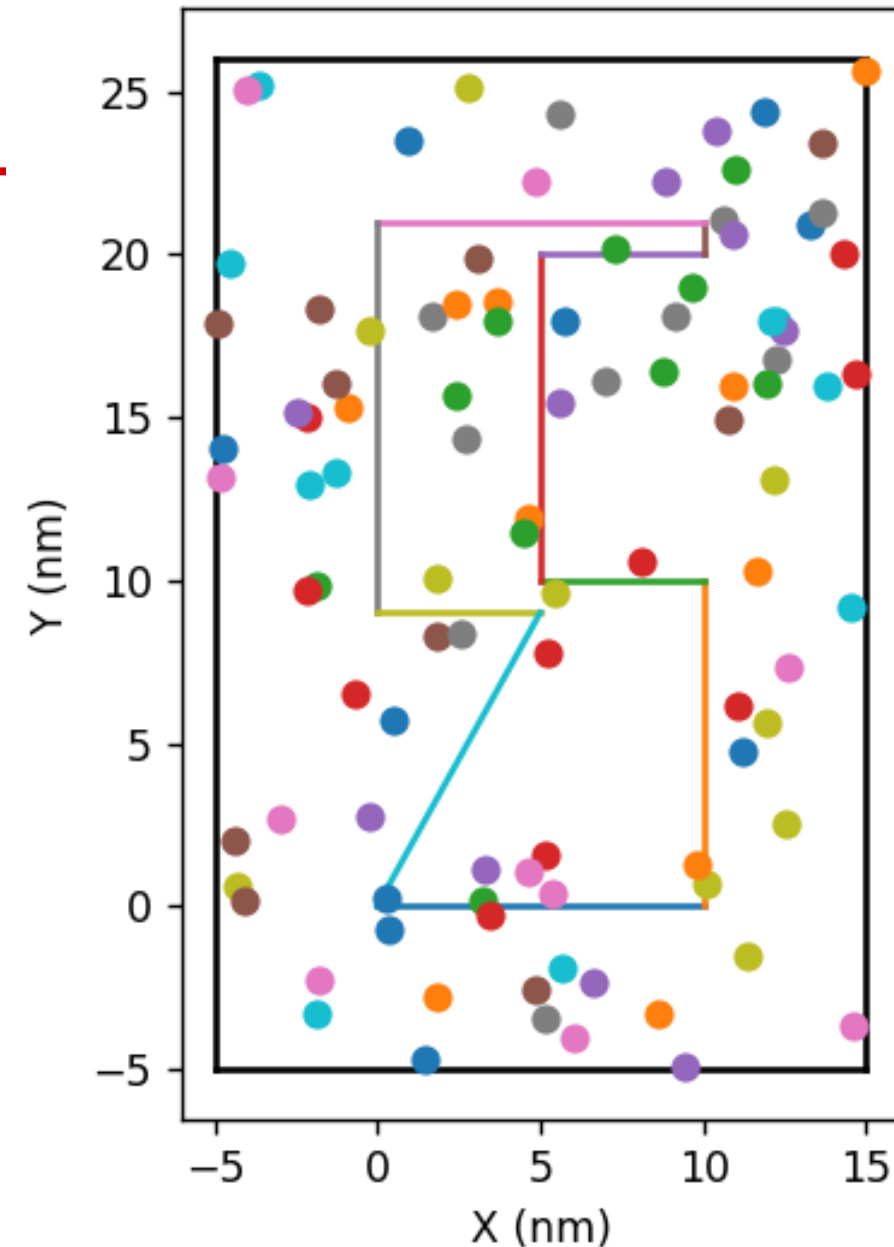
Set a bounding box

- With a sufficient margin
 - In this example, the area of box is 620 nm².
 - When a position is selected randomly,
 $\frac{137.5}{620} = 0.22177$
is the probability to be located inside.
 - Try several points.



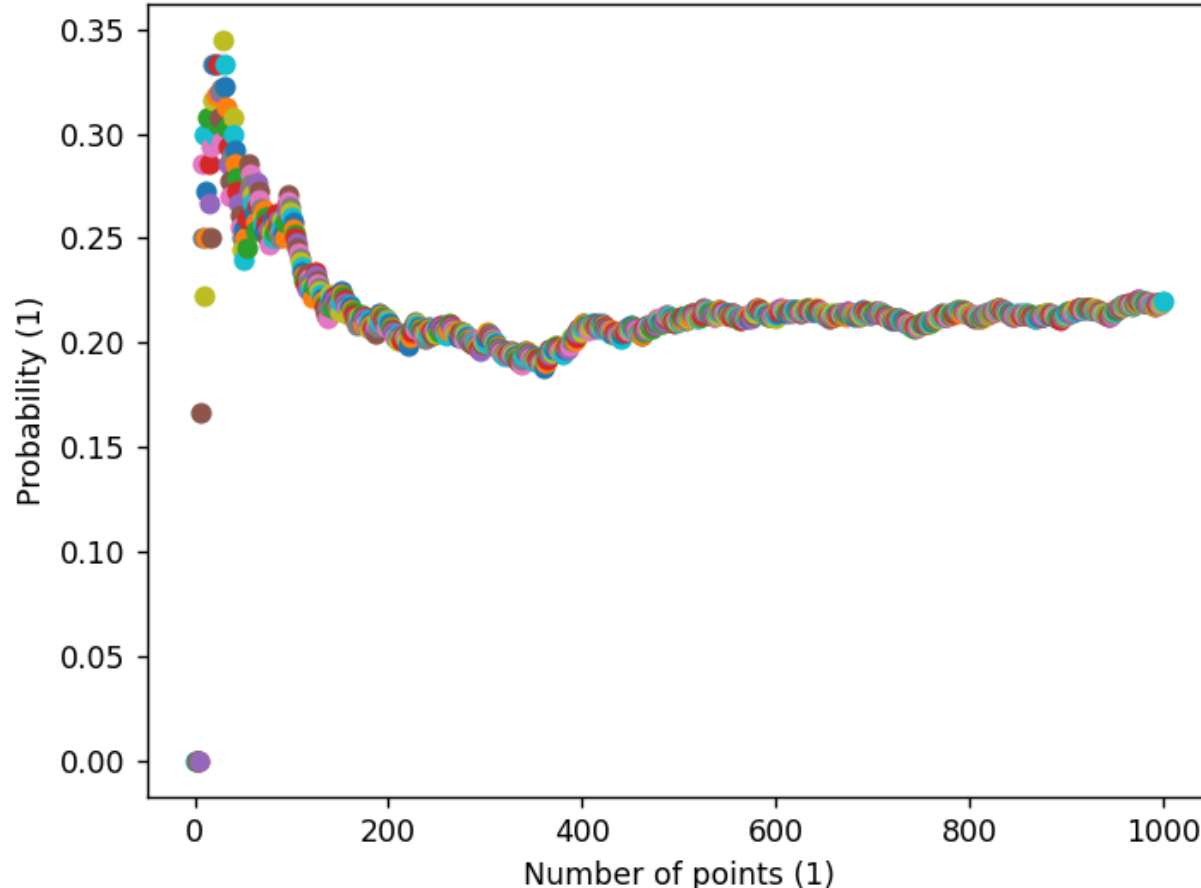
100 random points

- Count the numbers of points inside.
 - Then, we will get an estimated probability.
 - In this particular case, it is 20. (Not bad)



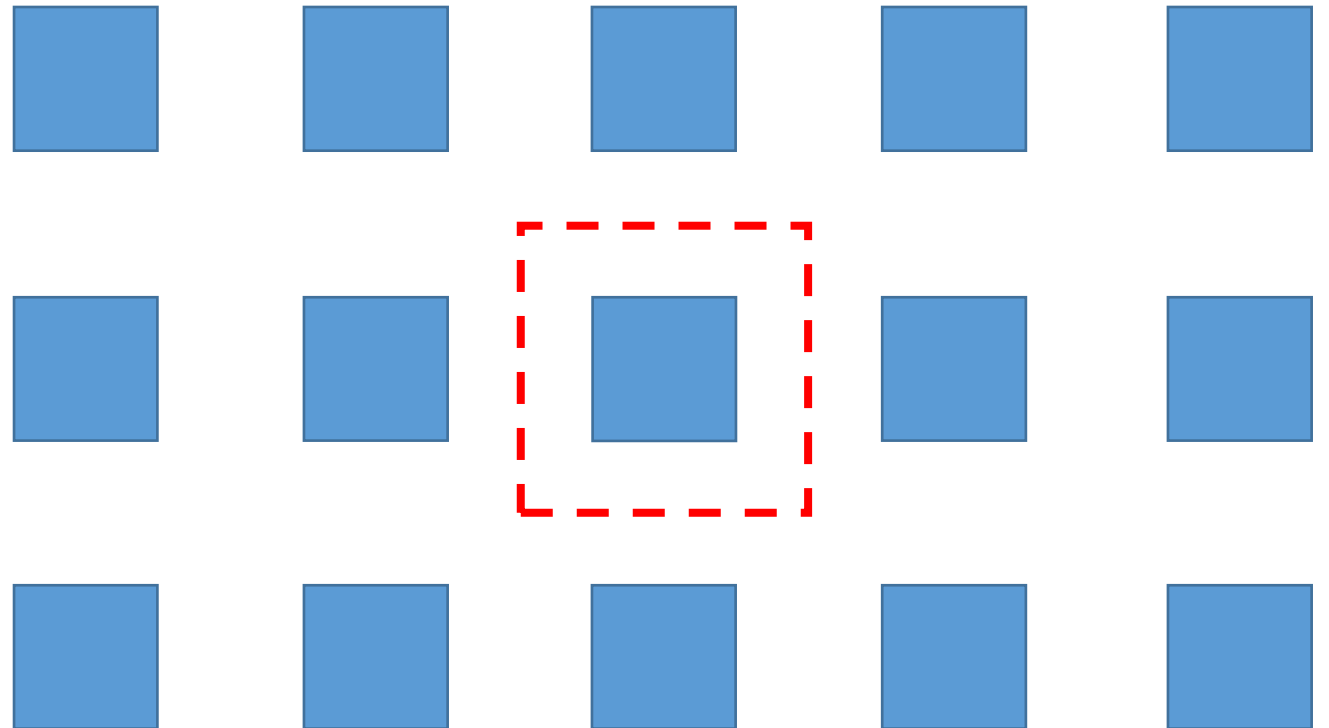
Probability

- Increase the number of points. (Up to 1 k points)
 - The probability approaches to 22 %.



Why do we need random numbers?

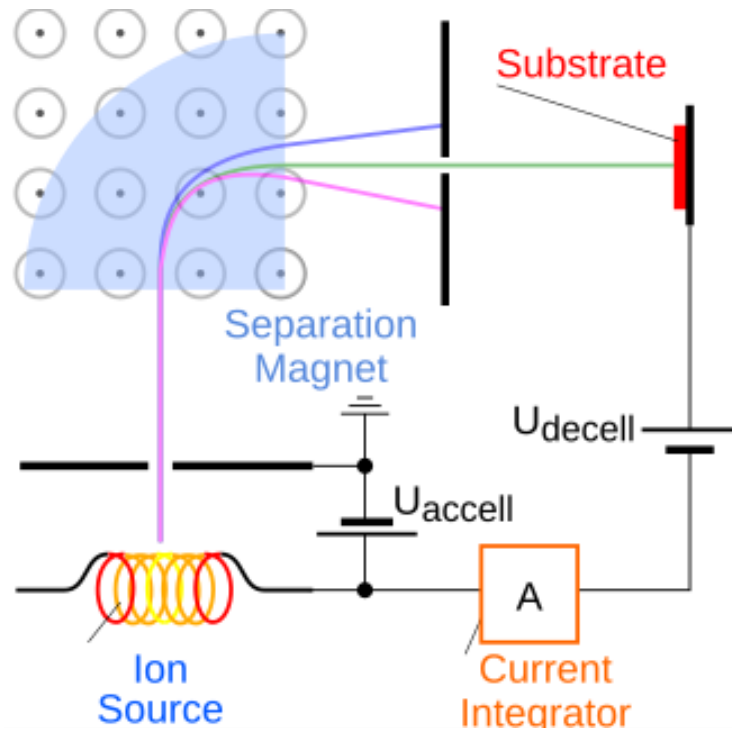
- We are visiting the entire space (the bounding box).
 - The uniform sampling may work.
 - A counter example is shown.
 - Its coverage is $\sim 25\%$.



Ion implantation

Ion implantation

- Accelerated ions ($\sim \text{keV}$)
 - Precise control of energy and dose



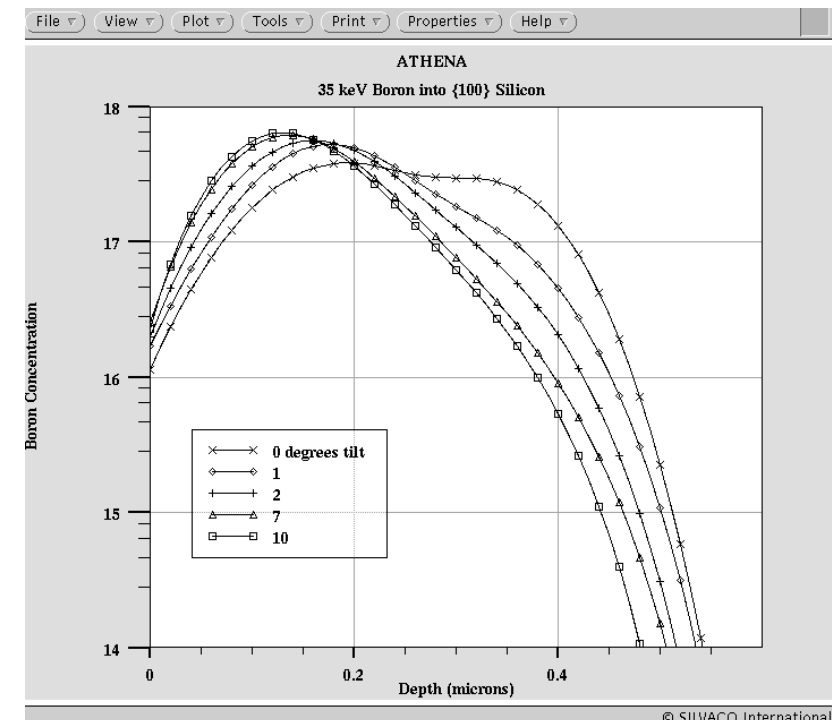
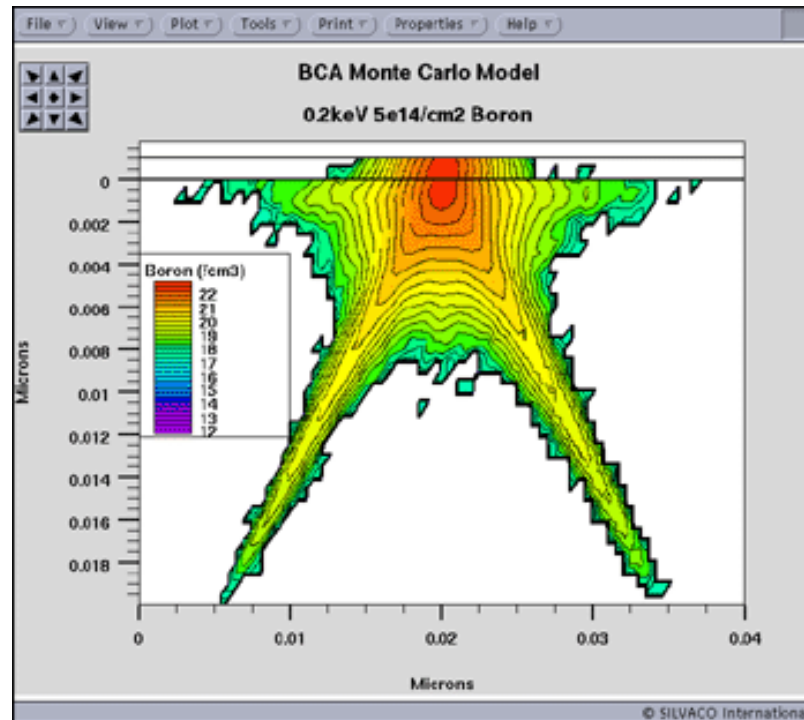
Schematic of ion implanter (Wikipedia)



Ion implanter (isrc.snu.ac.kr)

Doping profile

- Double-Pearson function
 - For a more realistic profile, Monte Carlo simulation is widely used.
 - Energy loss
 - Nuclear scattering
 - Electron scattering

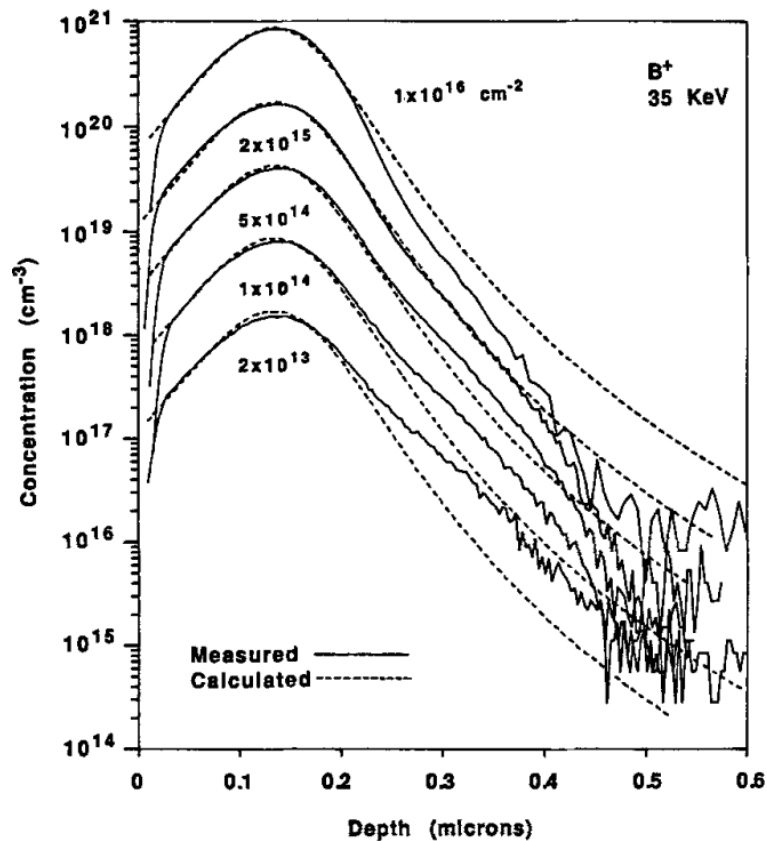


Monte Carlo BCA (binary collision approximation) simulation result and depth profiles (Silvaco)

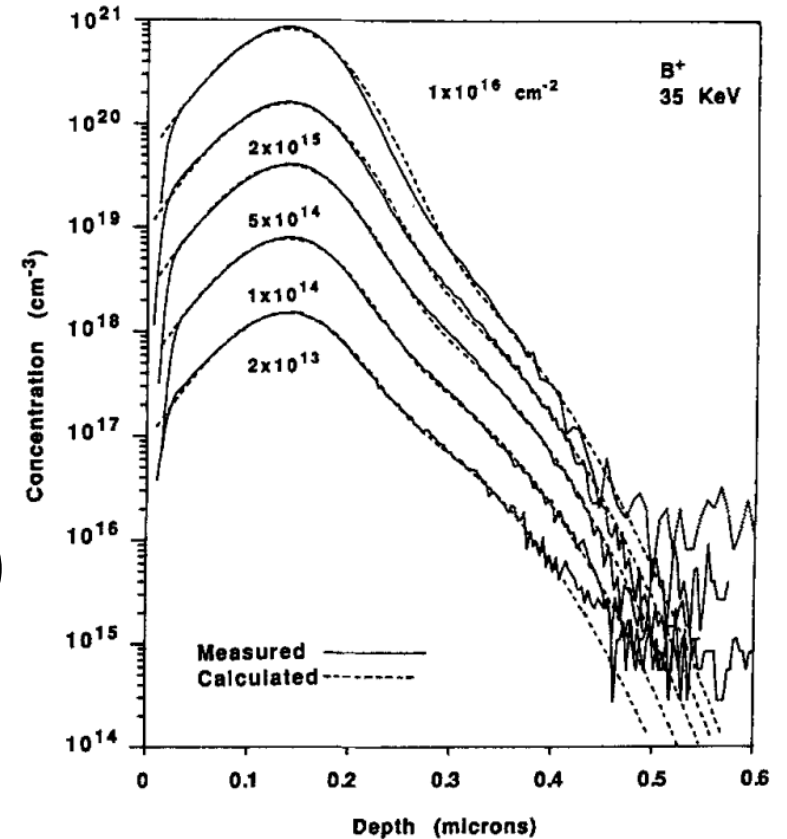
Analytic profile

- Dual-Pearson model

– Head and tail, $f_p(x) = \text{ratio } f_{head}(x) + (1 - \text{ratio}) f_{tail}(x)$



Single- and double-Pearson functions
(A. F. Tasch, JECS, 1989)

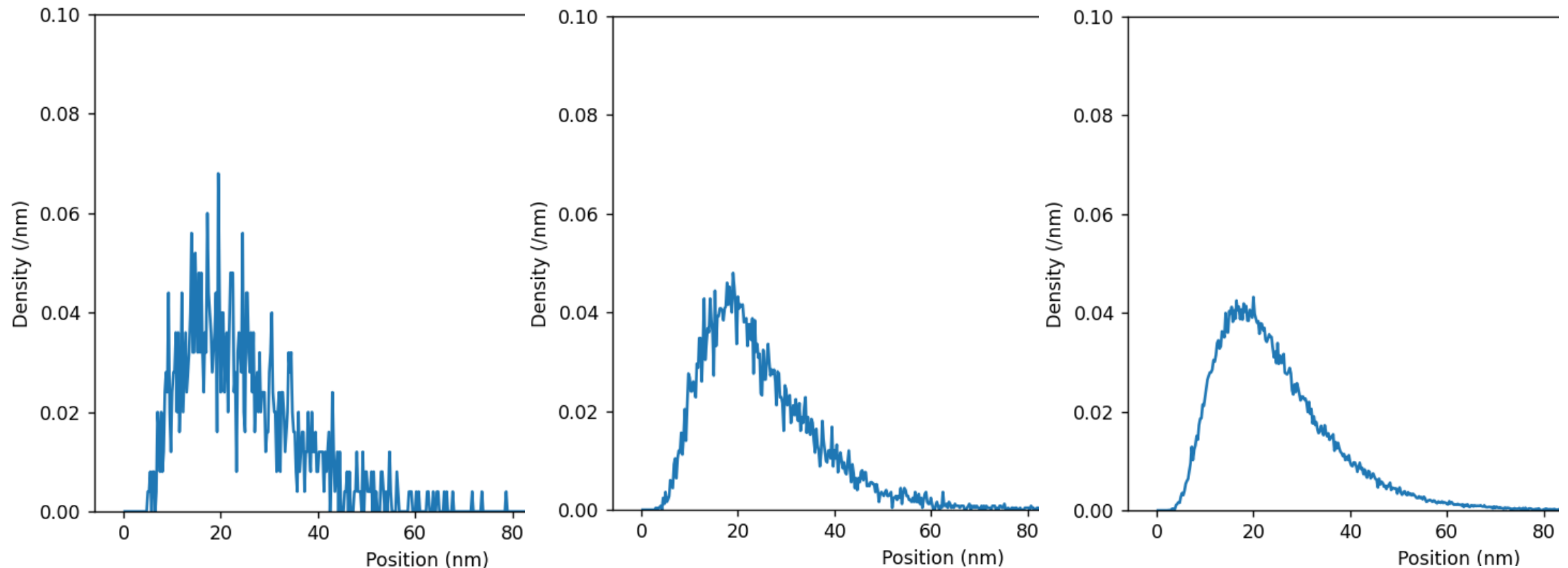


Simple model

- A moving ion and a resting silicon atom
 - 30 keV ion
 - 0.25 nm is the real-space spacing.
 - For every scattering, the impurity ion loses 40 % of its energy.
 - For every step, the scattering probability is calculated:
$$P(E) = \frac{0.75 \text{ keV}}{E}$$
 - When the energy becomes lower than 1 keV, it is assumed that the ion stops.

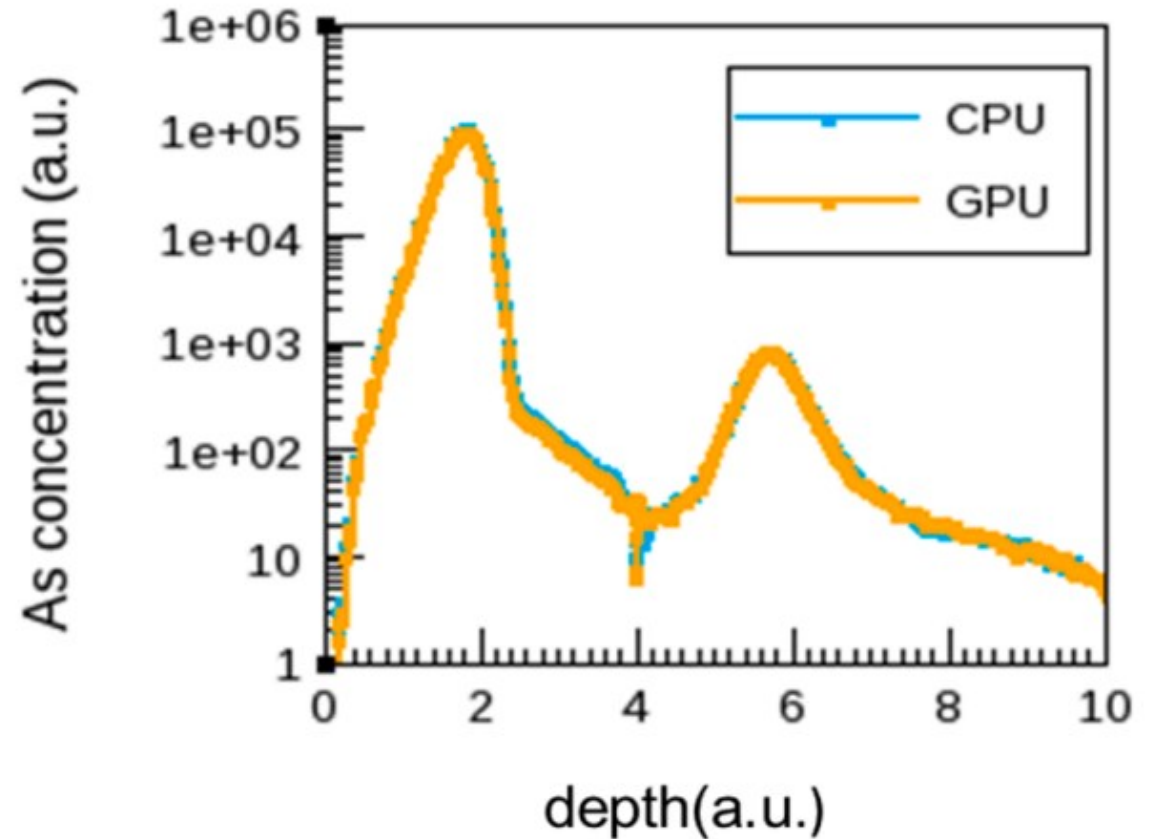
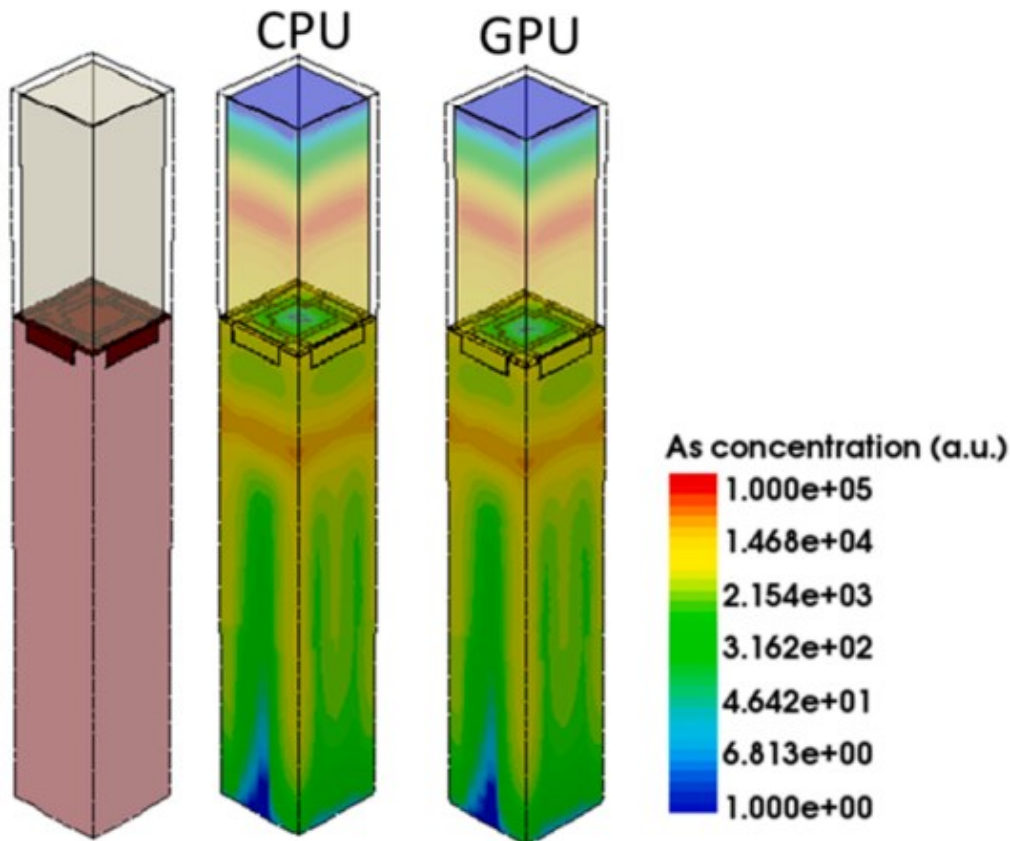
Different sample numbers

- Distribution of a implanted single ion
 - 1 k, 10 k, and 100 k samples



Implementational issue

- GPU implementation for fast simulation



Deep implantation of As into CIS with 3 MeV energy (F. Machida, SSE, 2023)

Homework#22 (The last one)

- Due: AM08:00, December 10 (Next Tuesday)
- Problem#1
 - Write your own code for the ion implantation. Improve its physical model.

Thank you for your attention!