Ant colony algorithm for driving variance reduction techniques in Monte Carlo simulations of radiation transport

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Outline

- Introduction
- Implementation of the ant colony algorithm: LINAC
- Some applications
- Conclusions

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large calculation CPU times!!

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- splitting
- interaction forcing
- directional bremsstrahlung splitting
- range rejection

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how to do it?

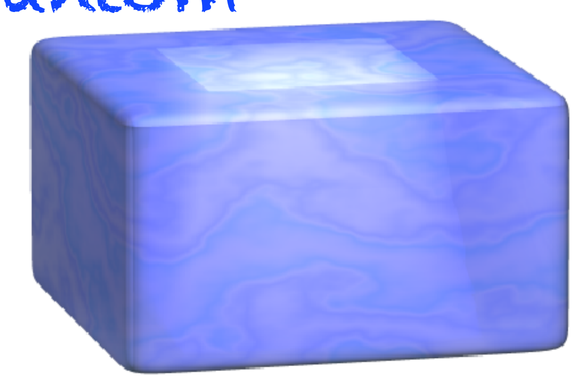
Implementation of the ant colony algorithm: LINAC

LINAC geometry (Siemens Mevatron KDS)

head

jaws

phantom



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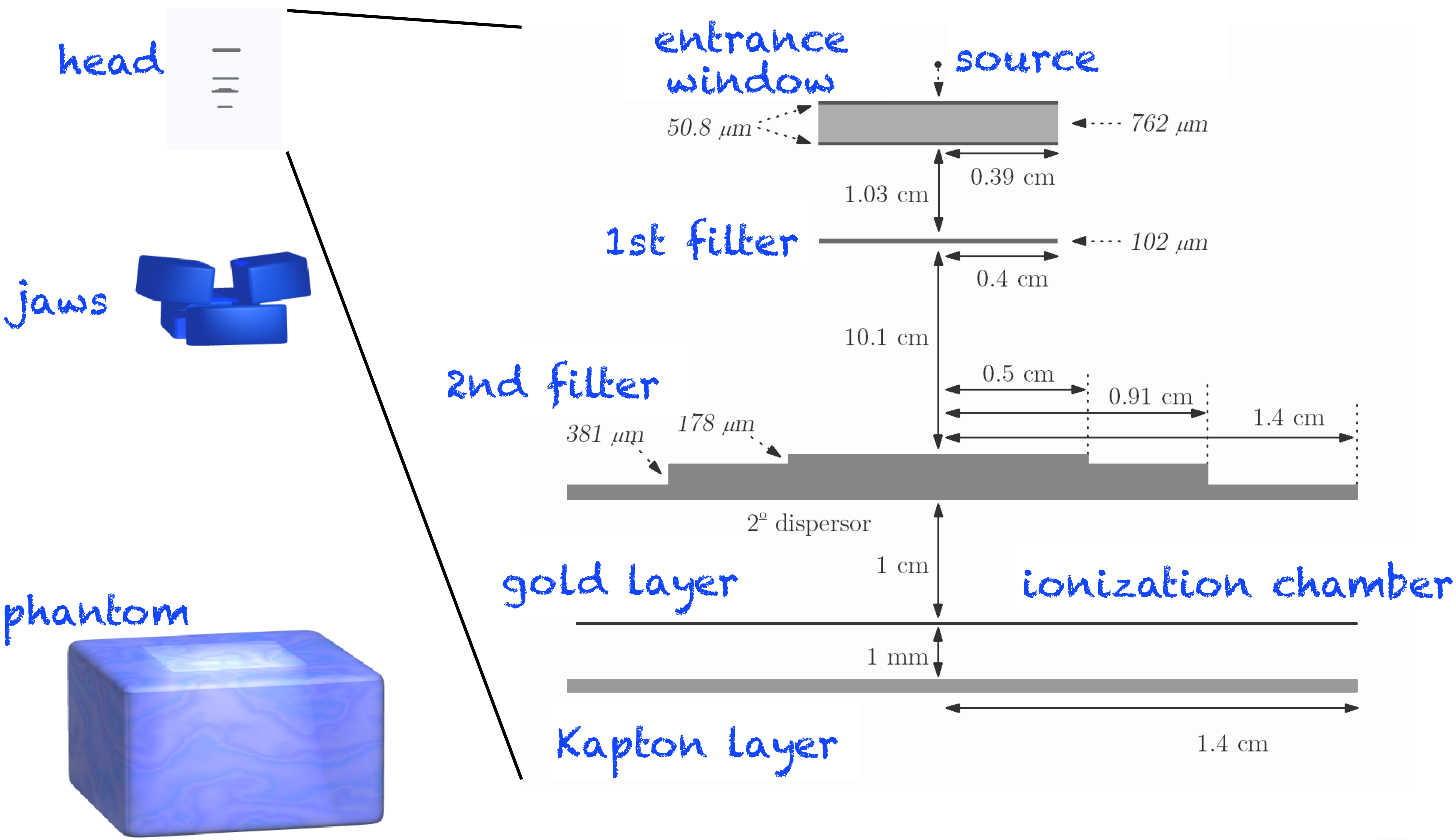

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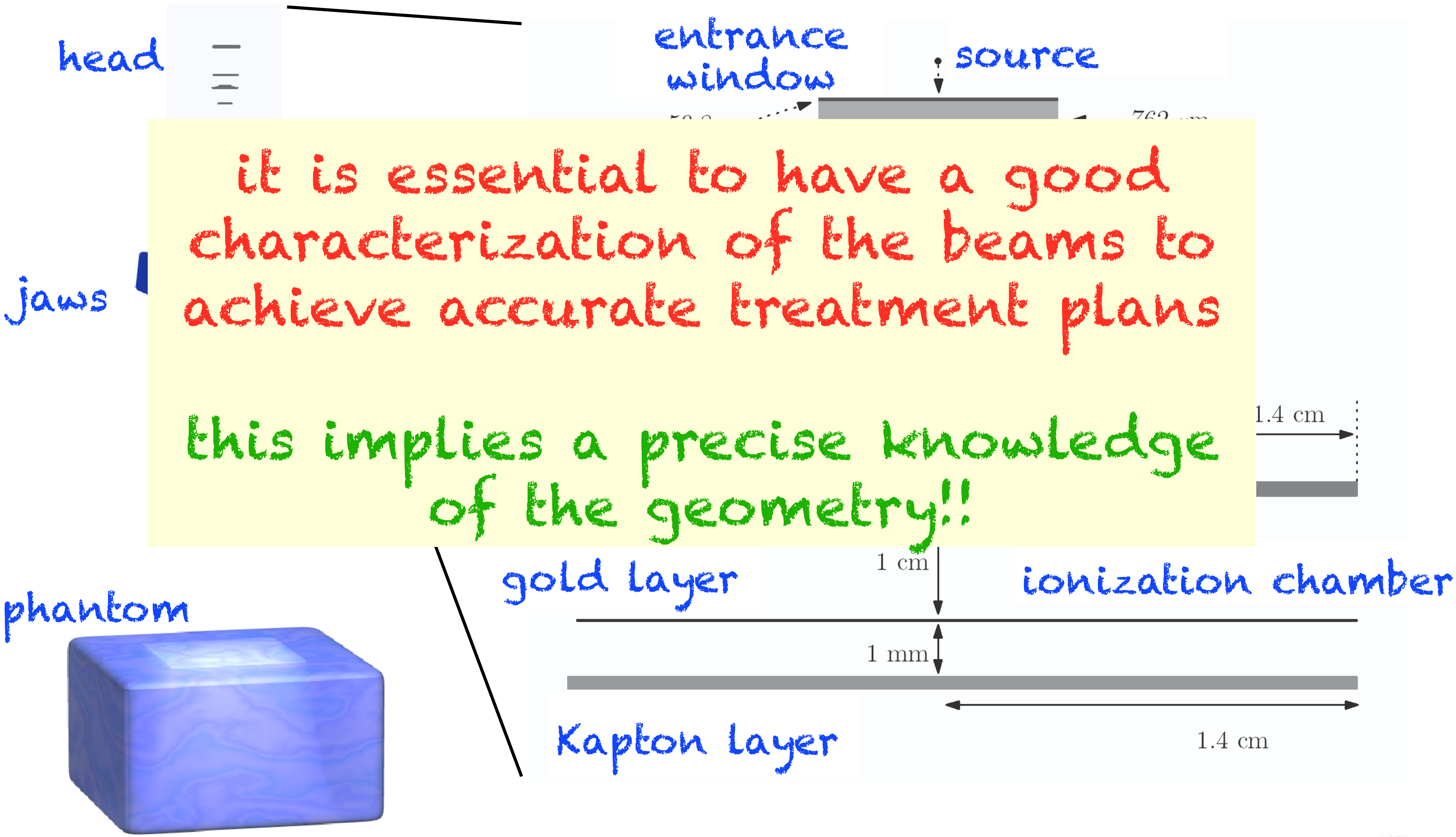
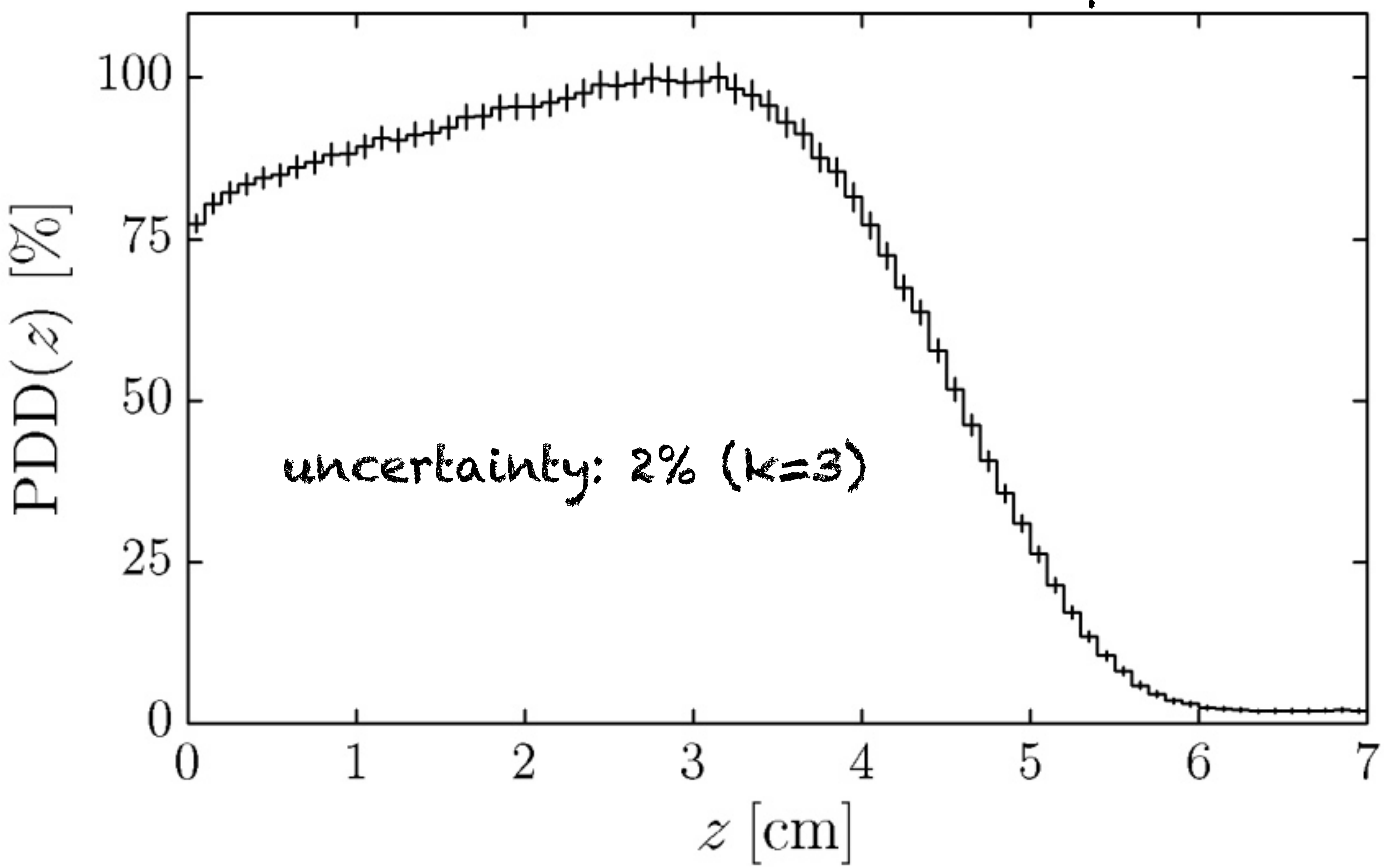


it is essential to have a good characterization of the beams to achieve accurate treatment plans

this implies a precise knowledge of the geometry!!

Implementation of the ant colony algorithm: LINAC

12 MeV electron beam / water phantom



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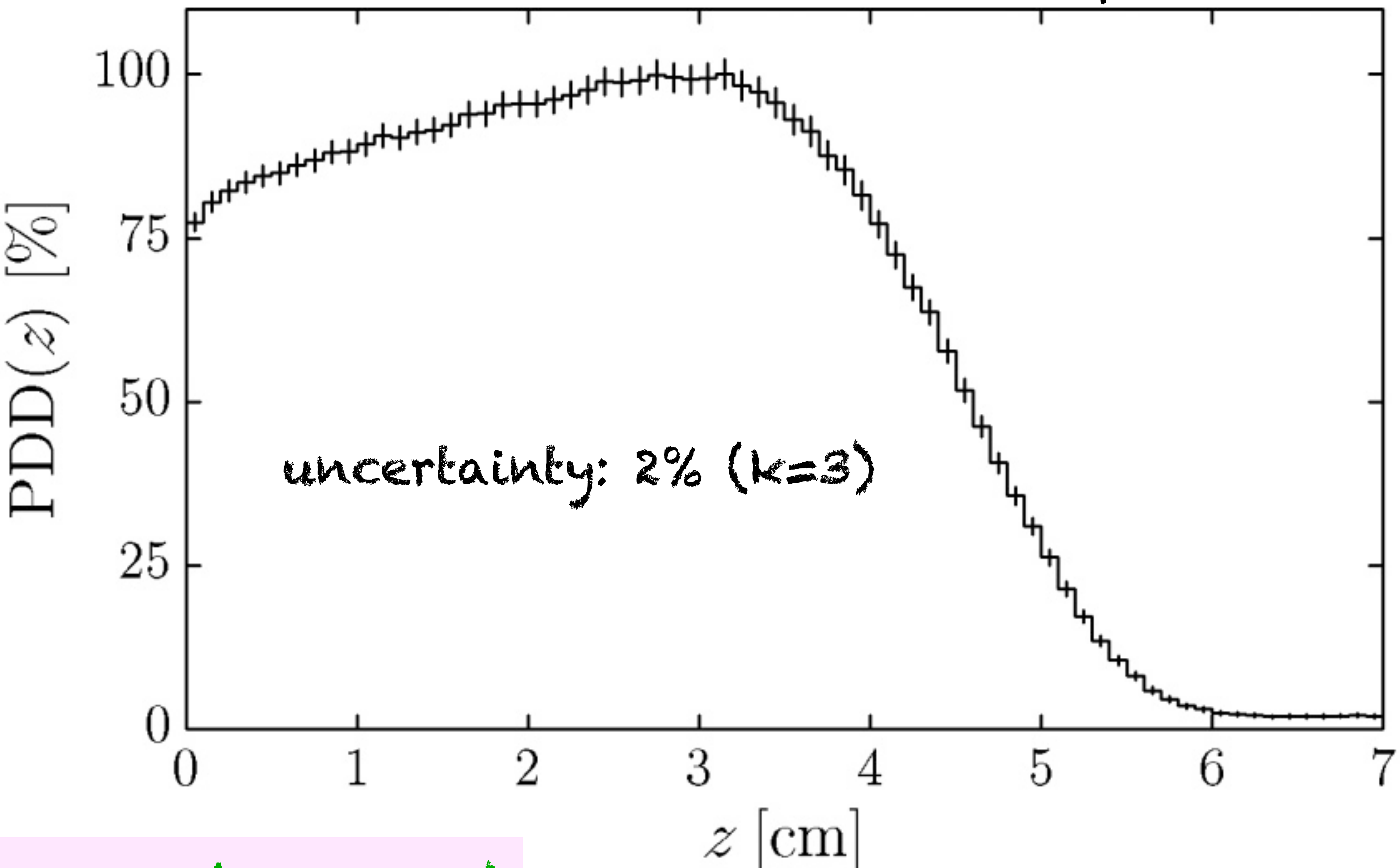

PC Pentium4 (1.6 GHz)

CPU time: 220 h

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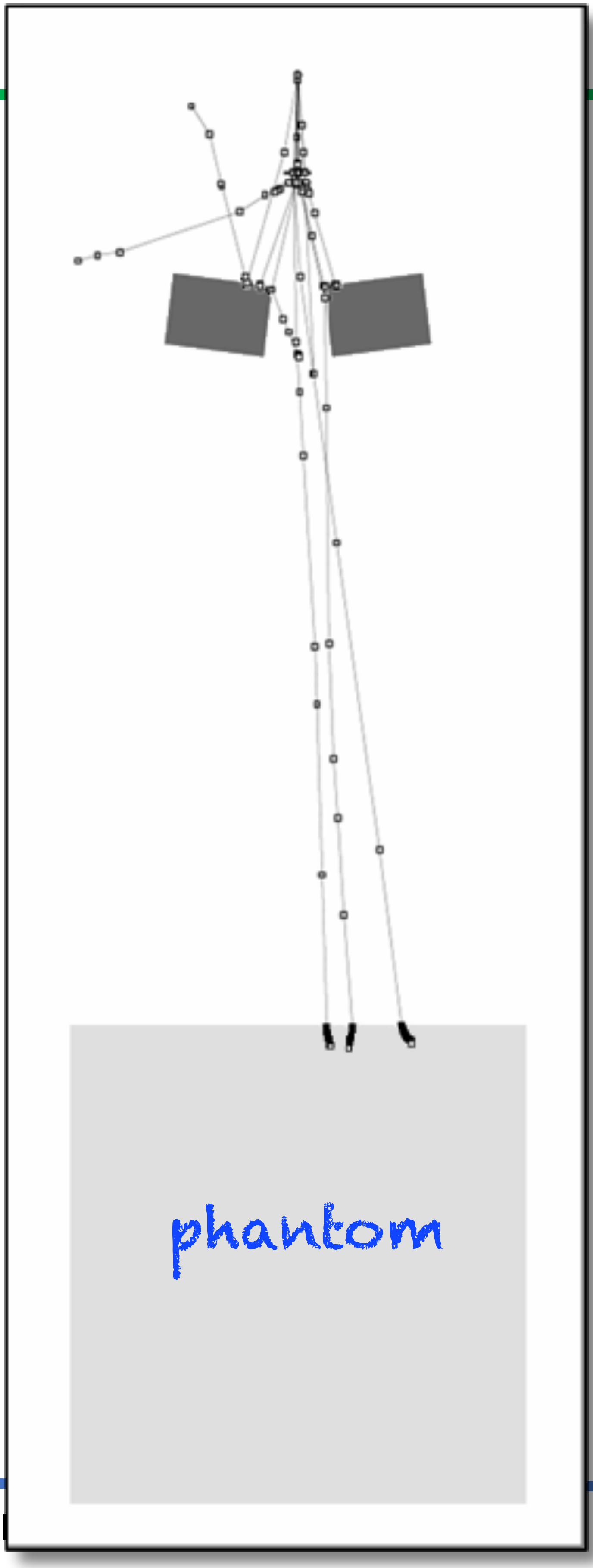

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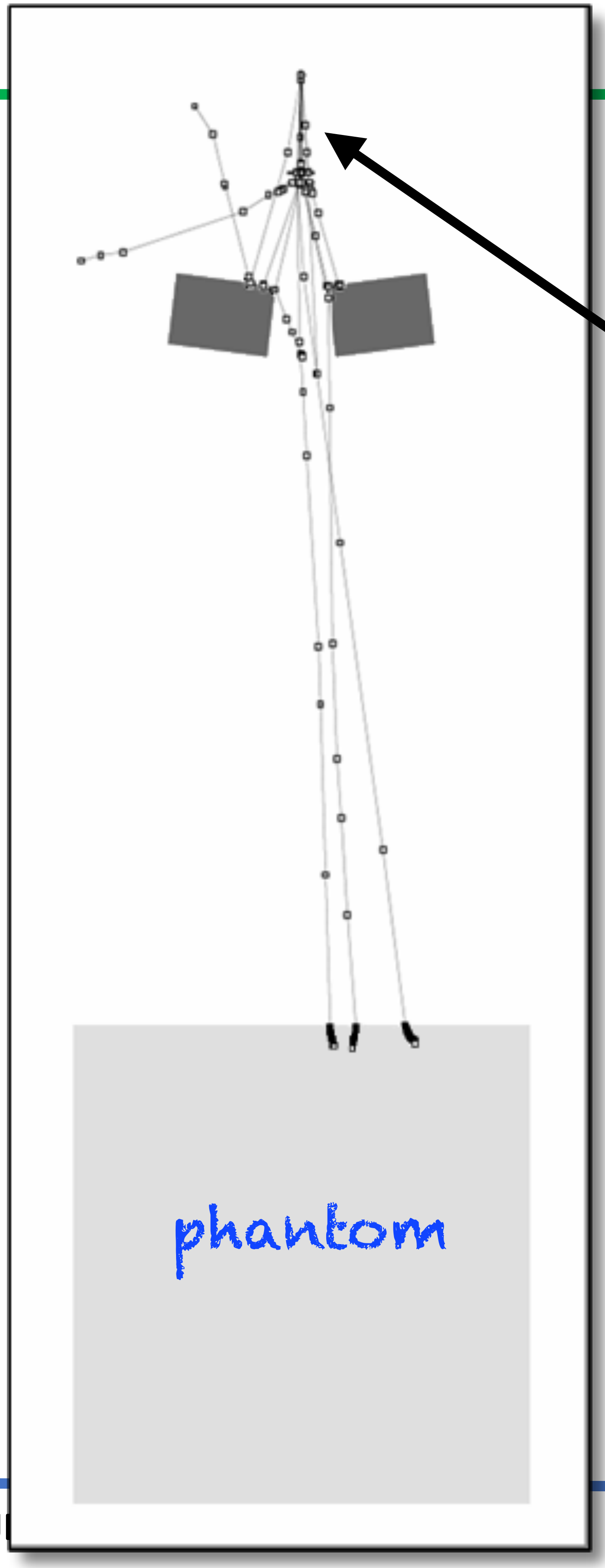

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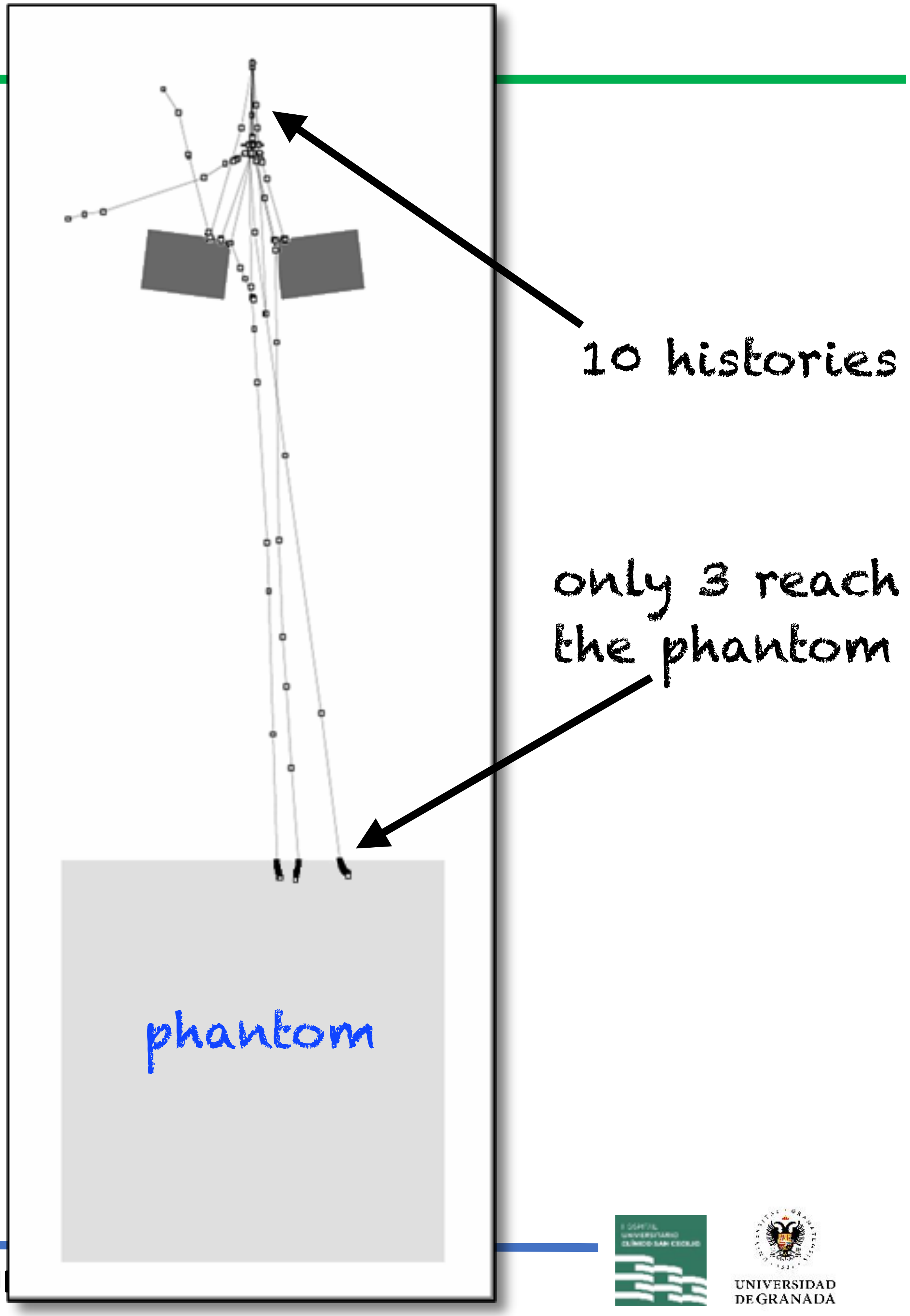

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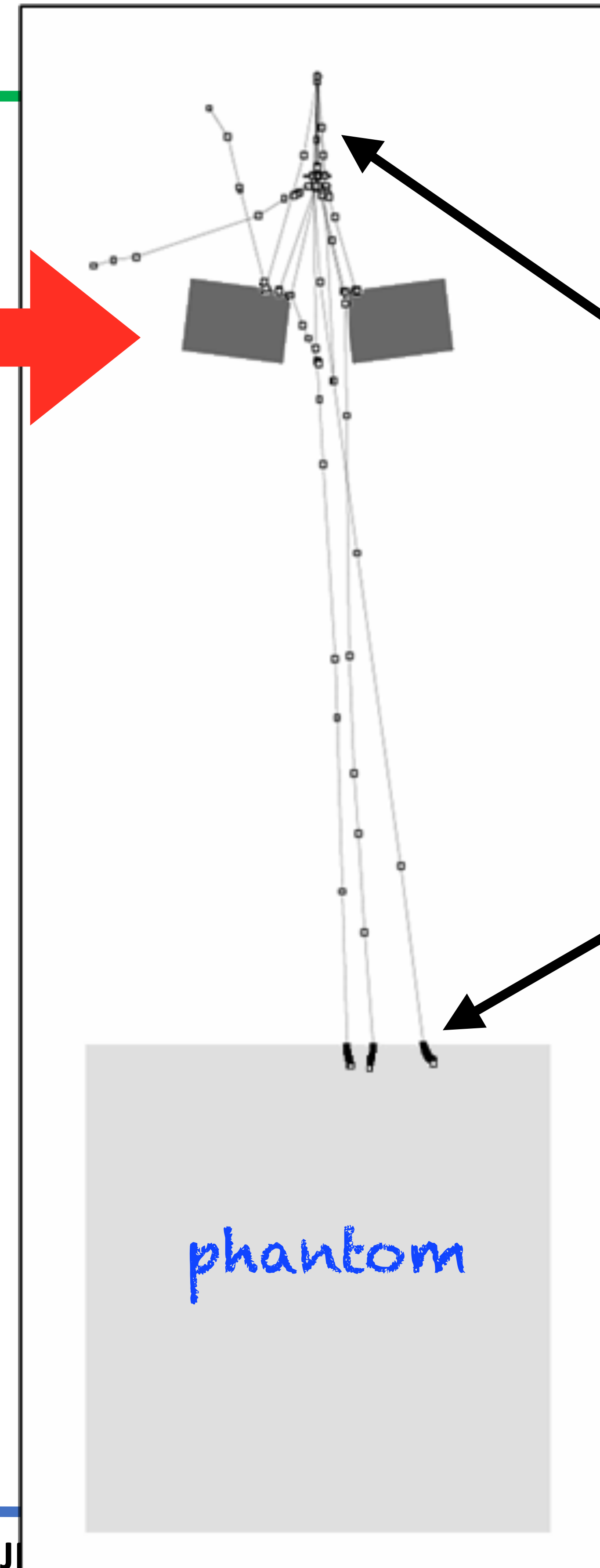
most of the time spent in simulating particles absorbed or backscattered in the jaws



10 histories

only 3 reach the phantom

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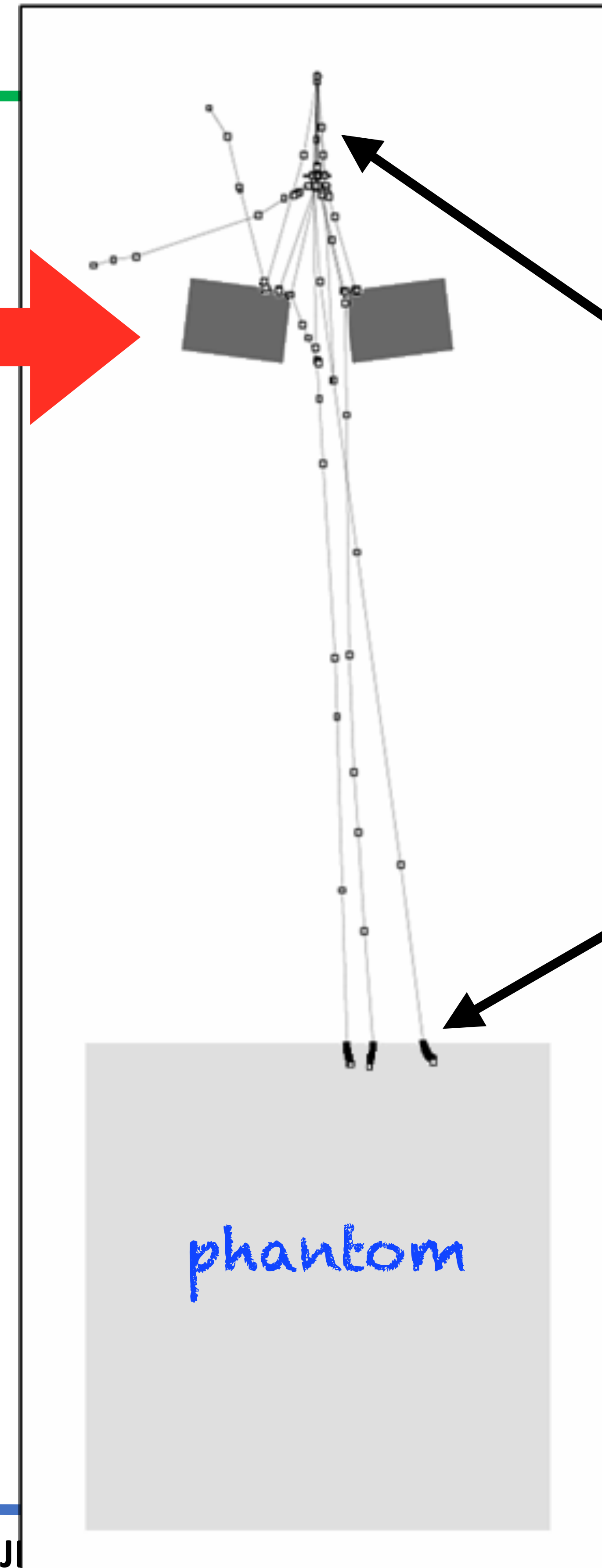

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VRT:

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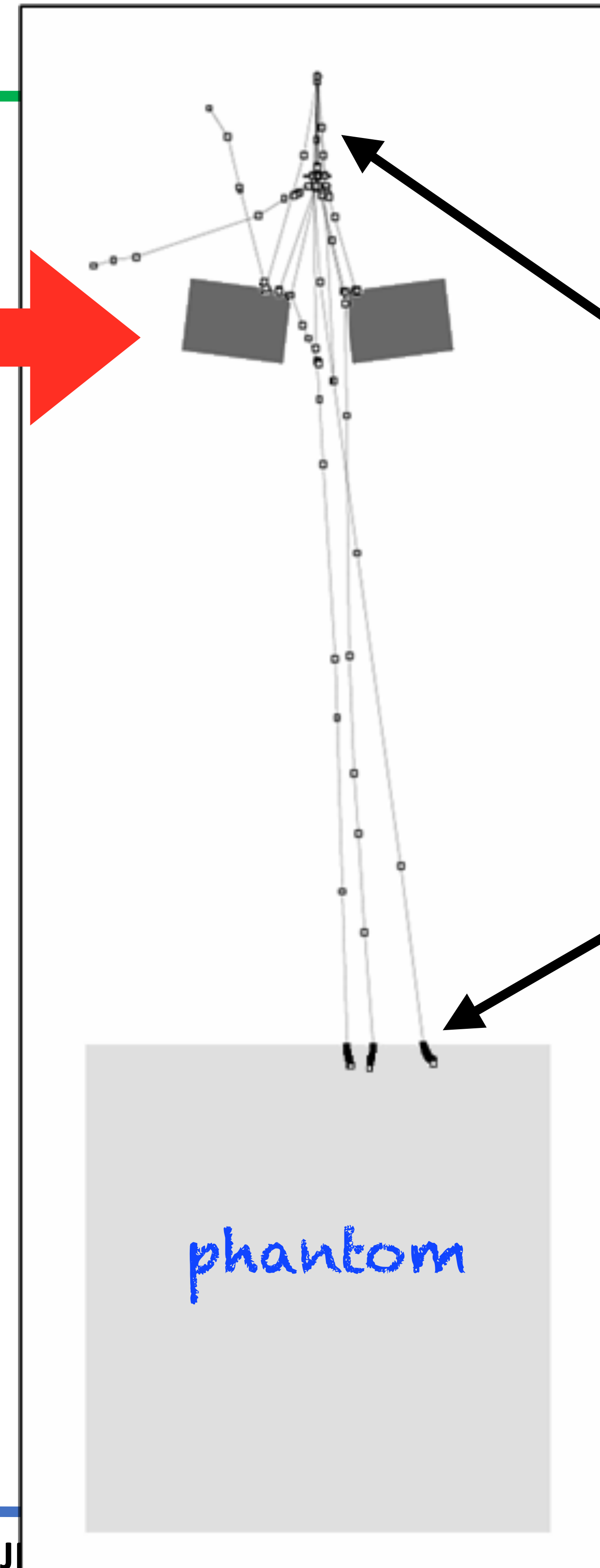

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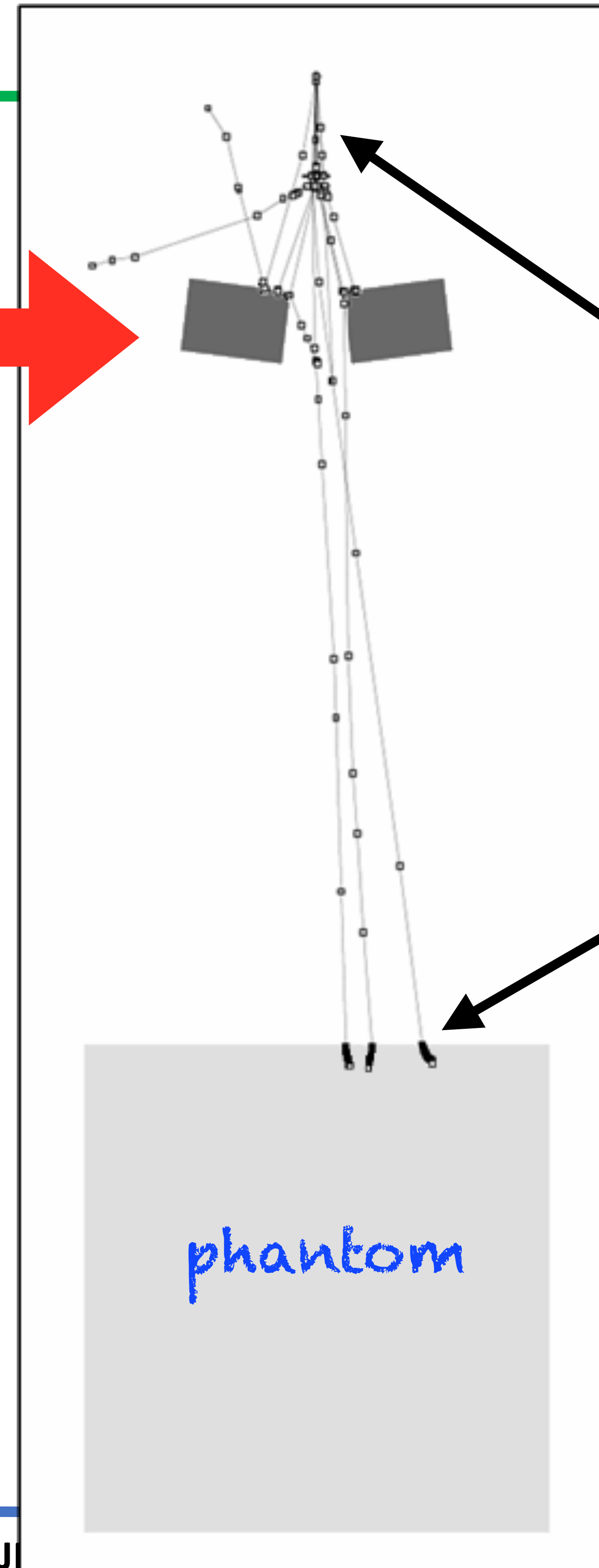
where to apply Rr / sp?

ant colony algorithm



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-ants tend to follow paths with a certain level of pheromone
-the level of pheromone increases in the optimal paths between nest and food

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-each cell is characterized by an importance value

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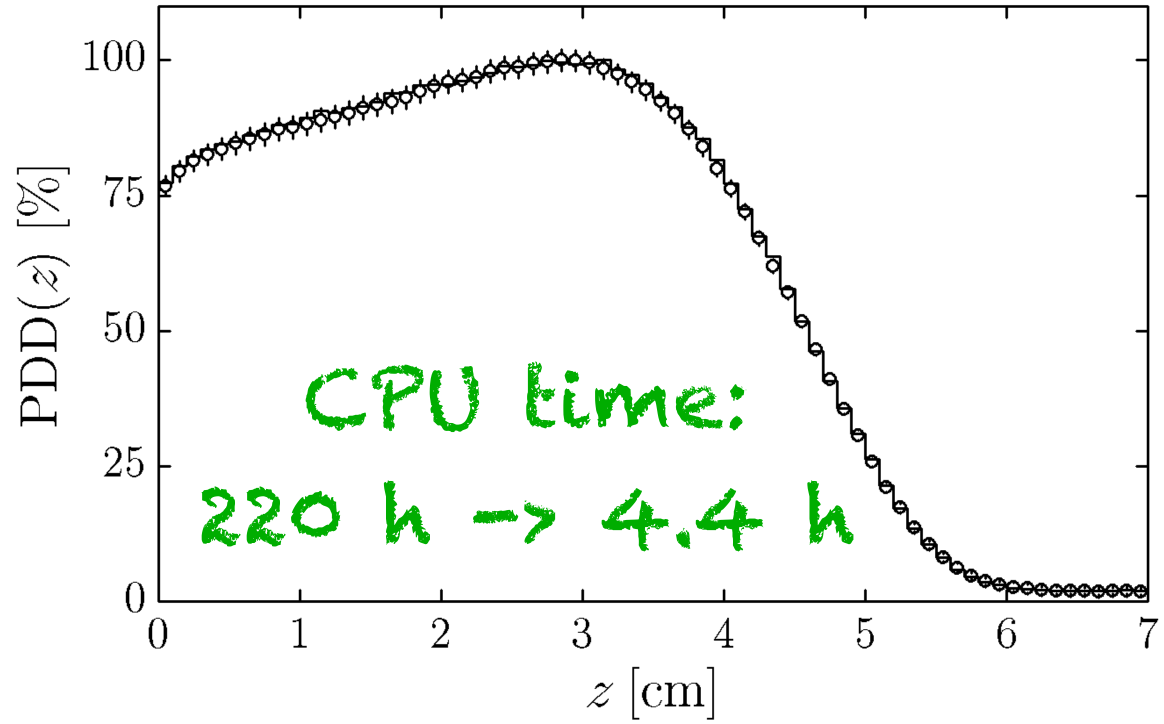

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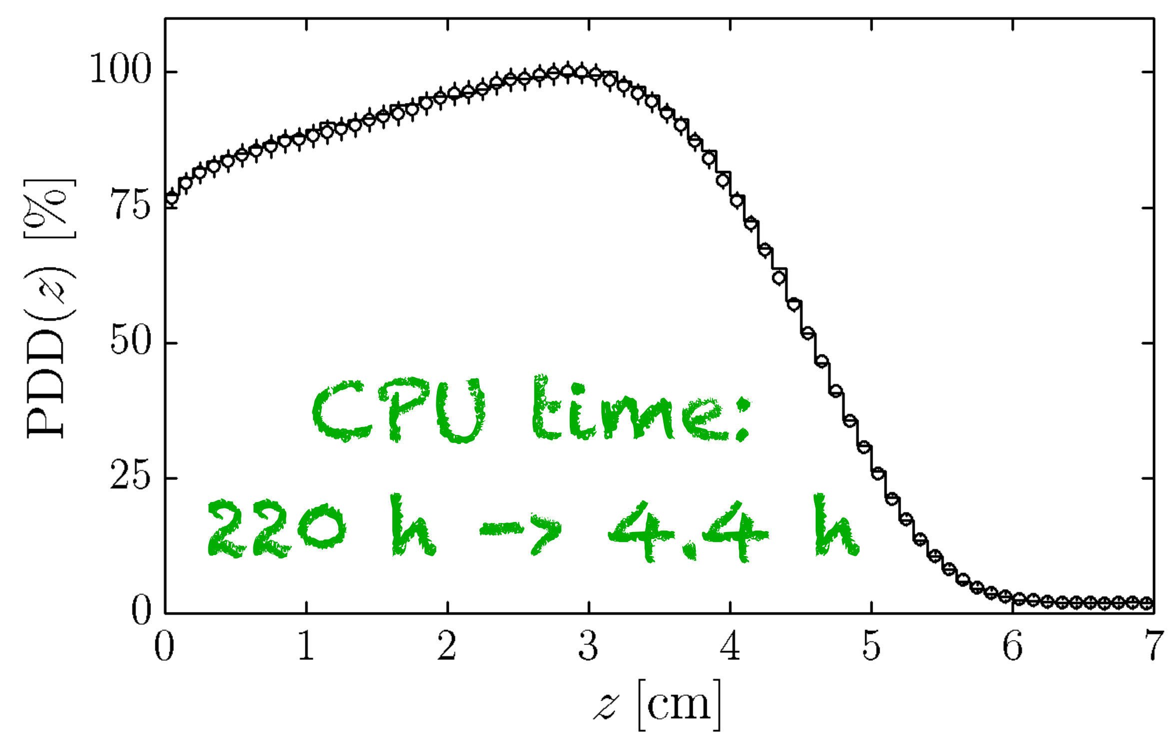
$$I = 2^k$$

$$k = \begin{cases} \left[5\dfrac{P(i)}{P(0)} - 5\right], & \text{if } P(i) \le P(0)\,, \\ \left[7\dfrac{P(i) - P(0)}{1 - P(0)}\right], & \text{if } P(i) > P(0)\,. \end{cases}$$

$$P(i) = \frac{N_{\mathrm{f}}(i)}{N_0(i)}$$

$N_0(i)$: number of particles entering i-cell

$N_0(i)$: number of particles entering i-cell and reaching ROI



importance maps

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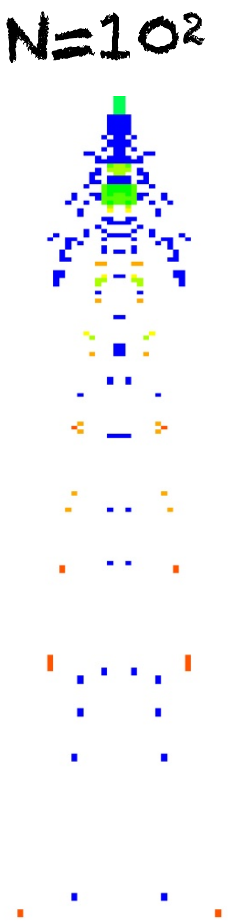
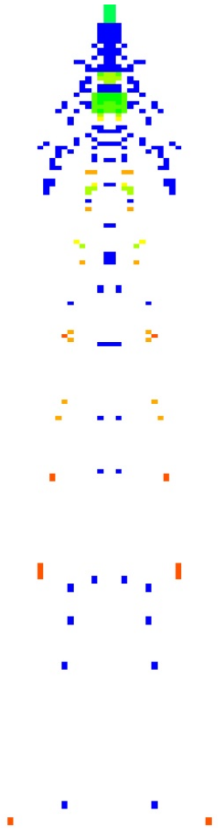
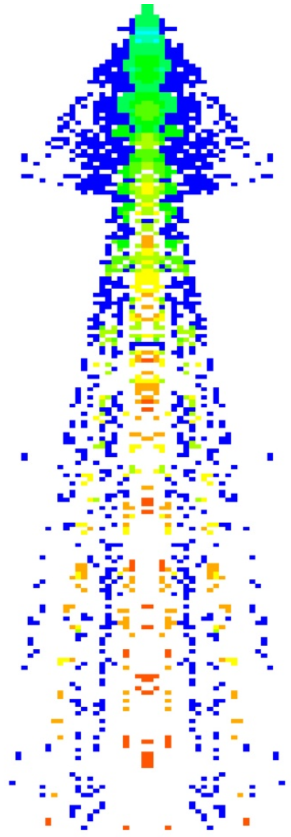


importance maps

$N=10^2$



$N=10^3$



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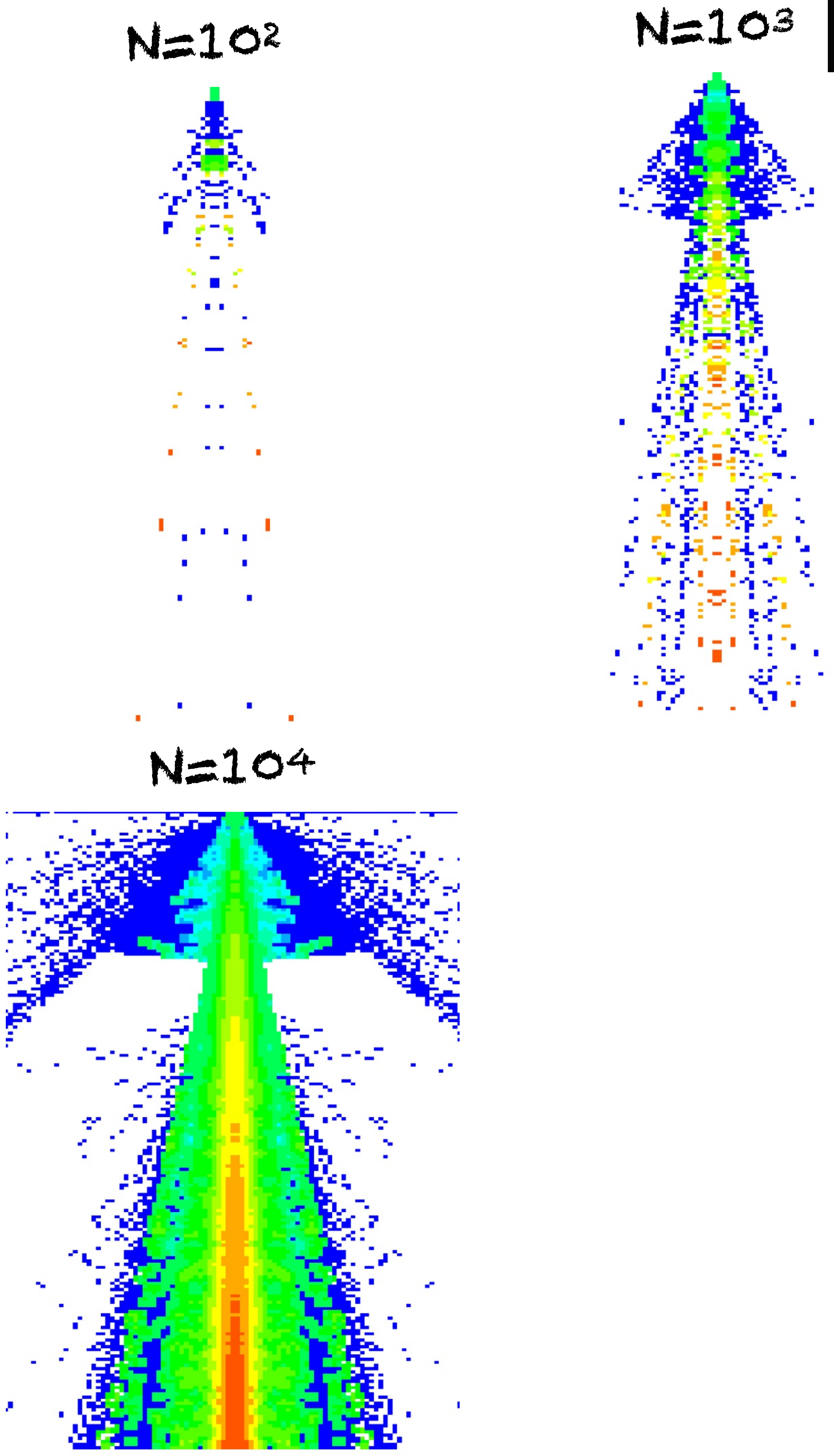

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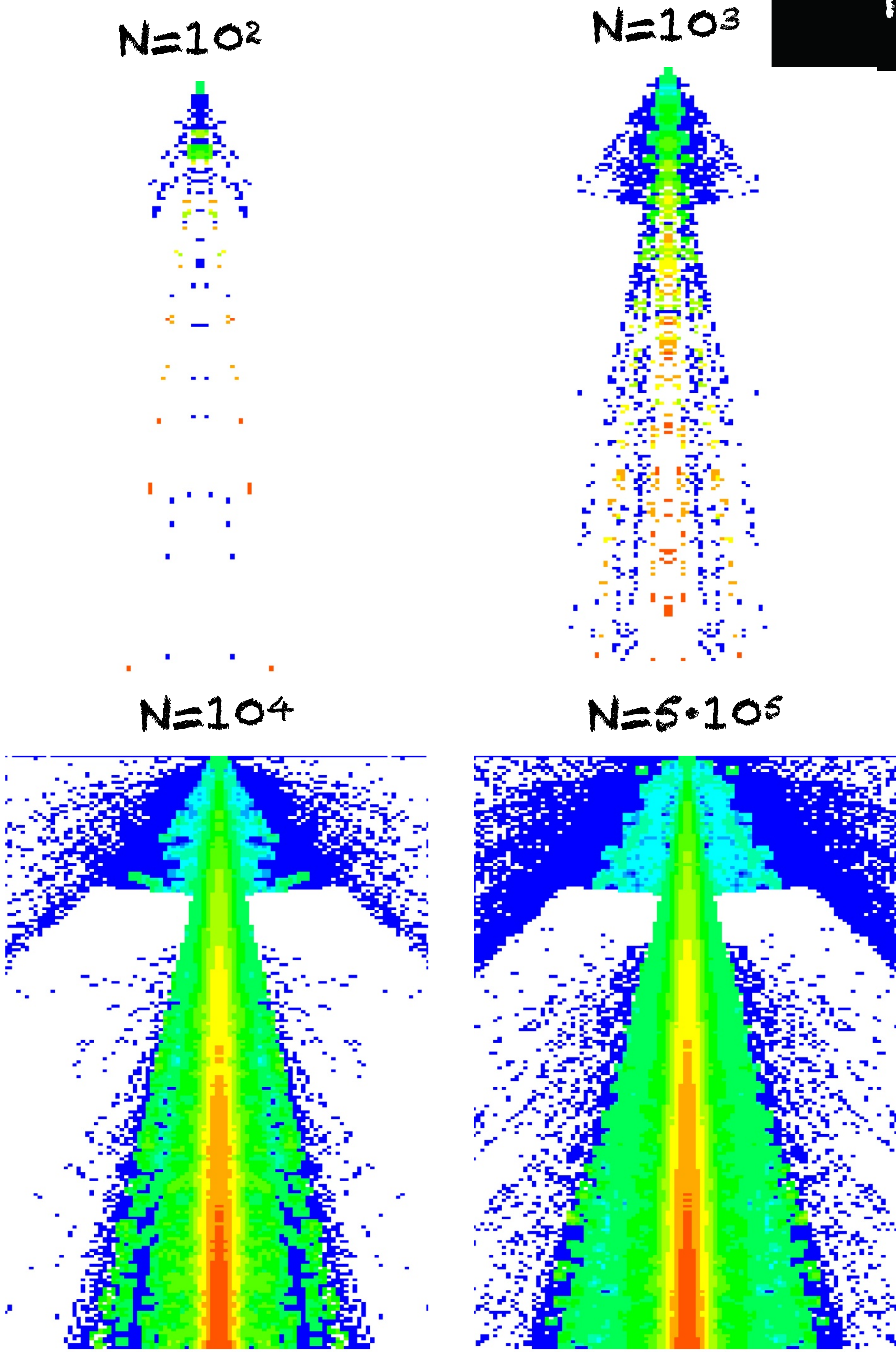

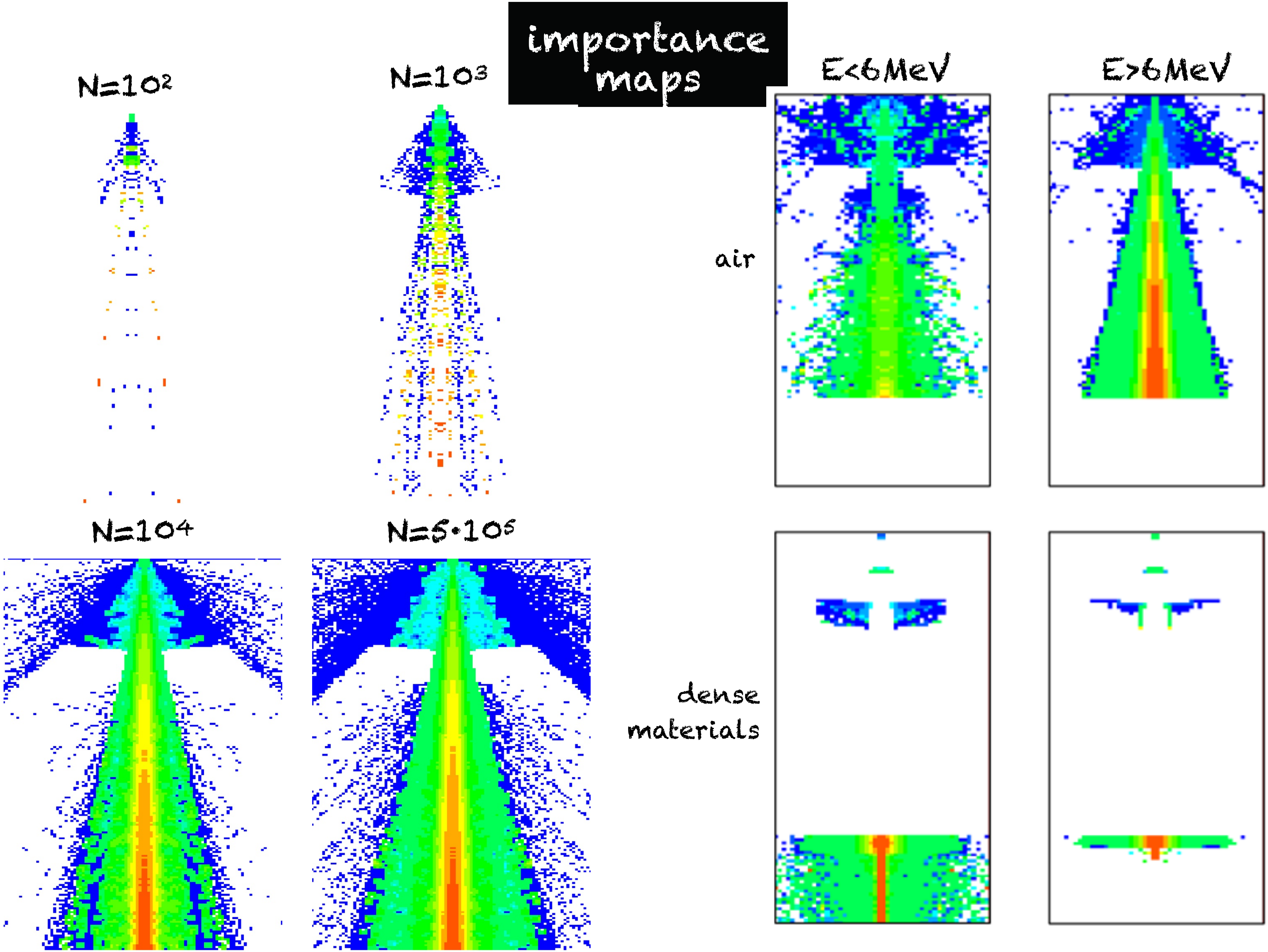
importance maps
N=10²
N=10³
N=10⁴
N=5•10⁵
E<6MeV
E>6MeV
air
dense materials

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  handled automatically!!!

- based on the scoring of the importance map

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- is it general enough?
- which are the main characteristics to be care of?

Some applications

MOSFET used as dosimeters

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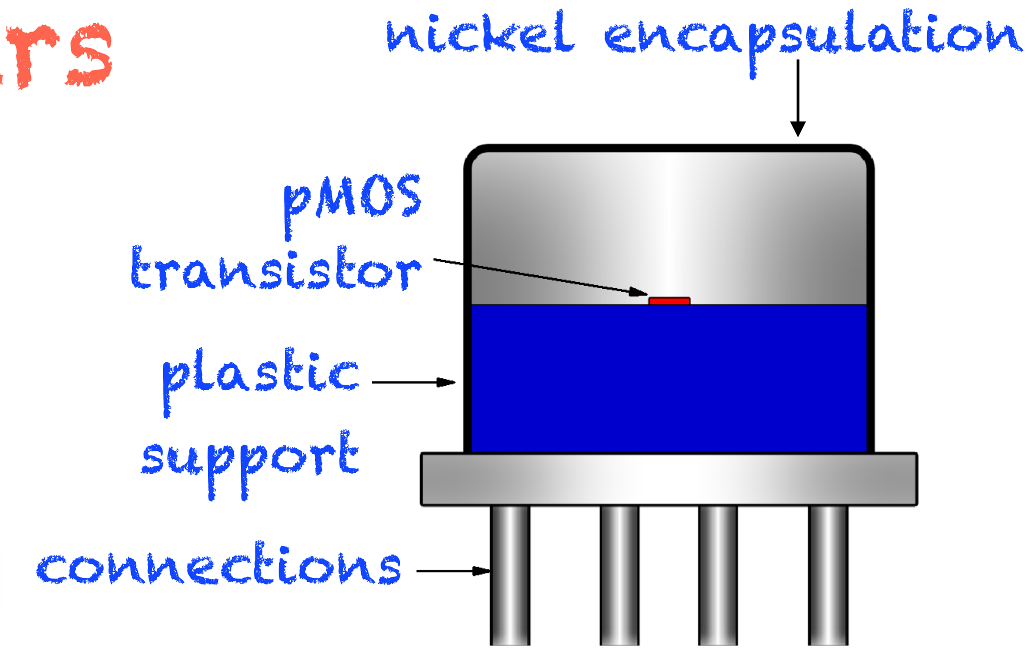

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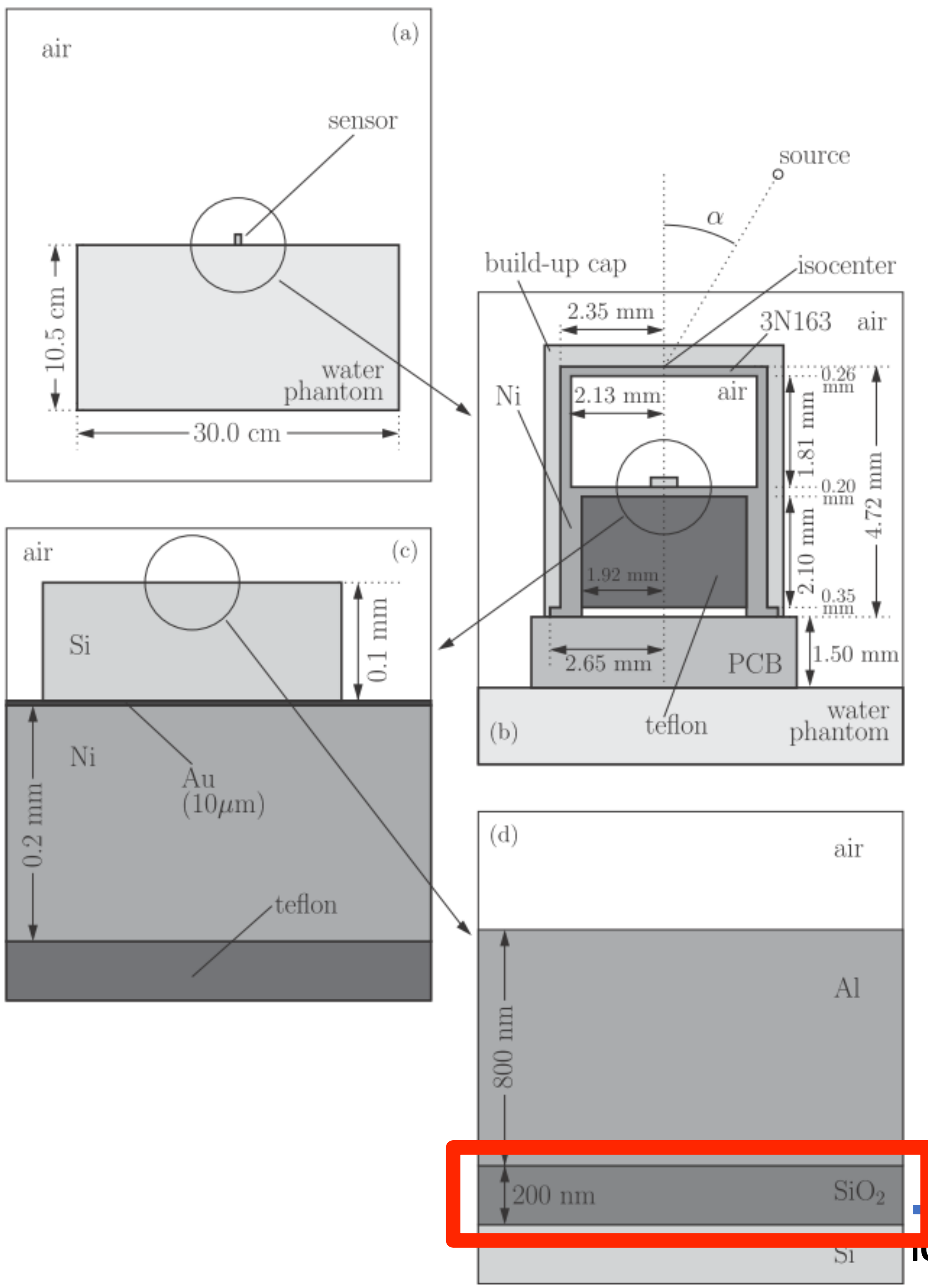

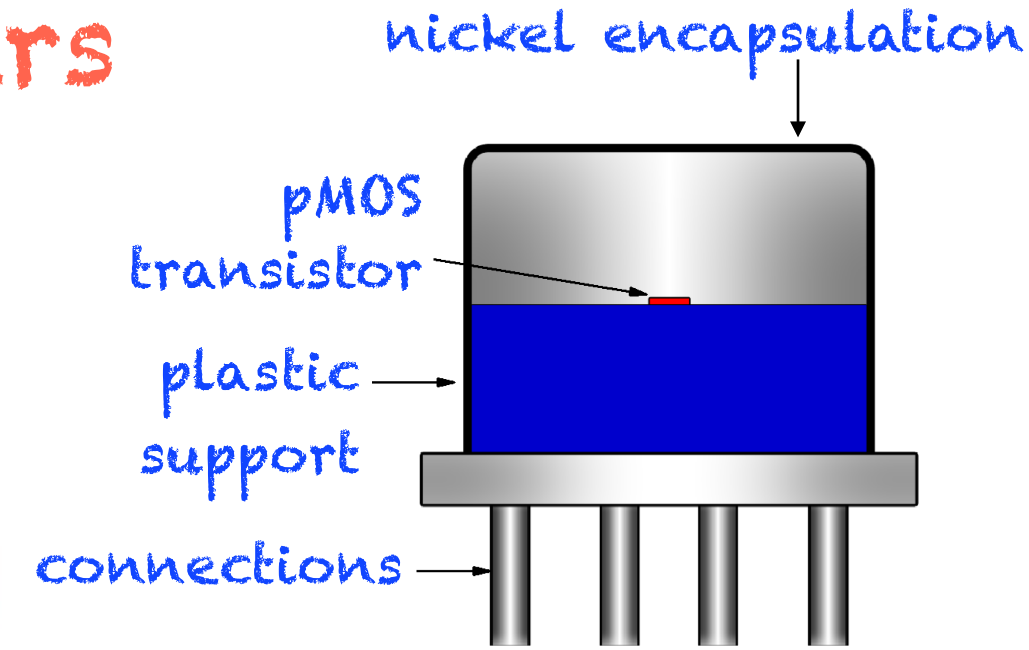

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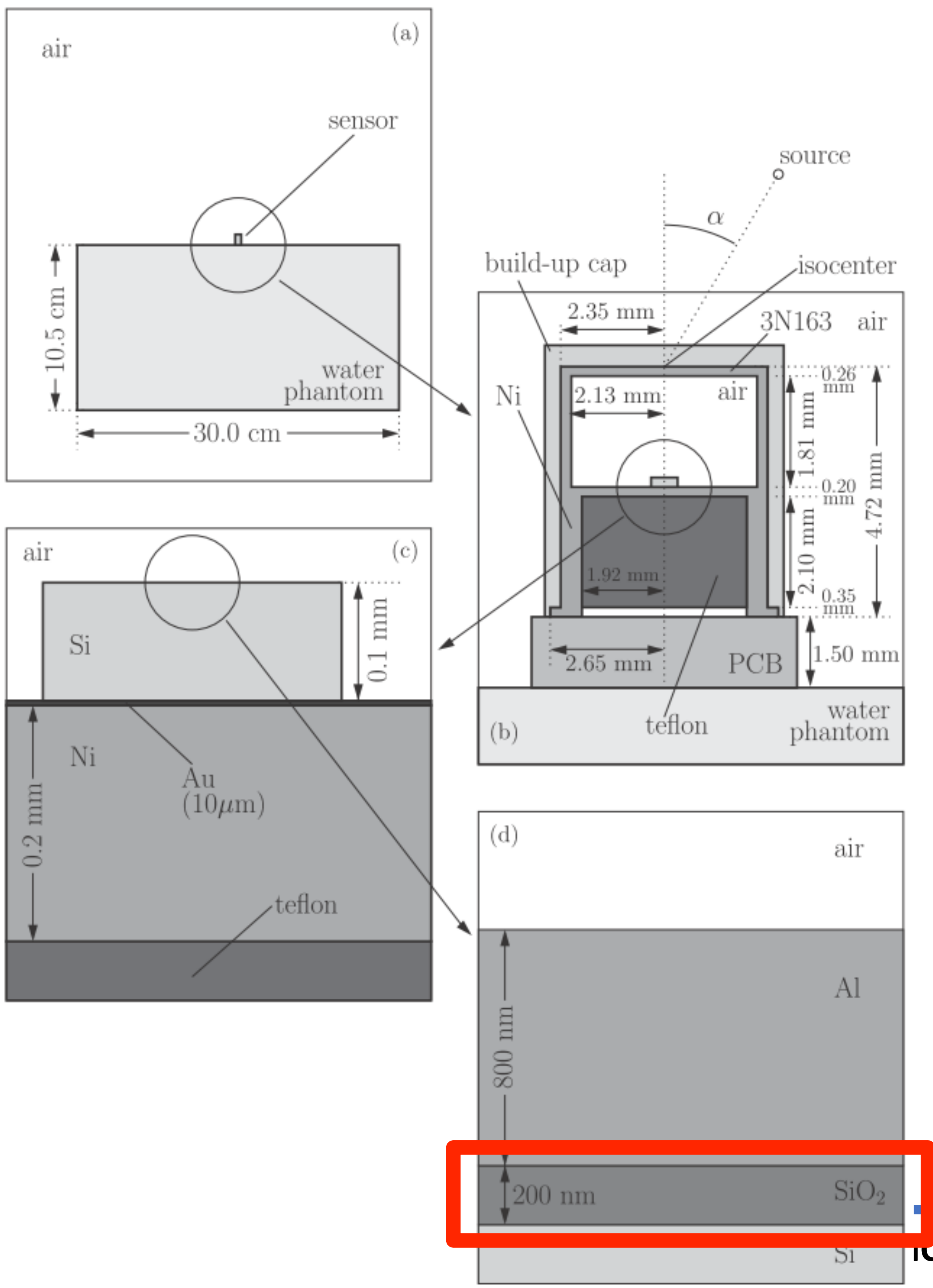

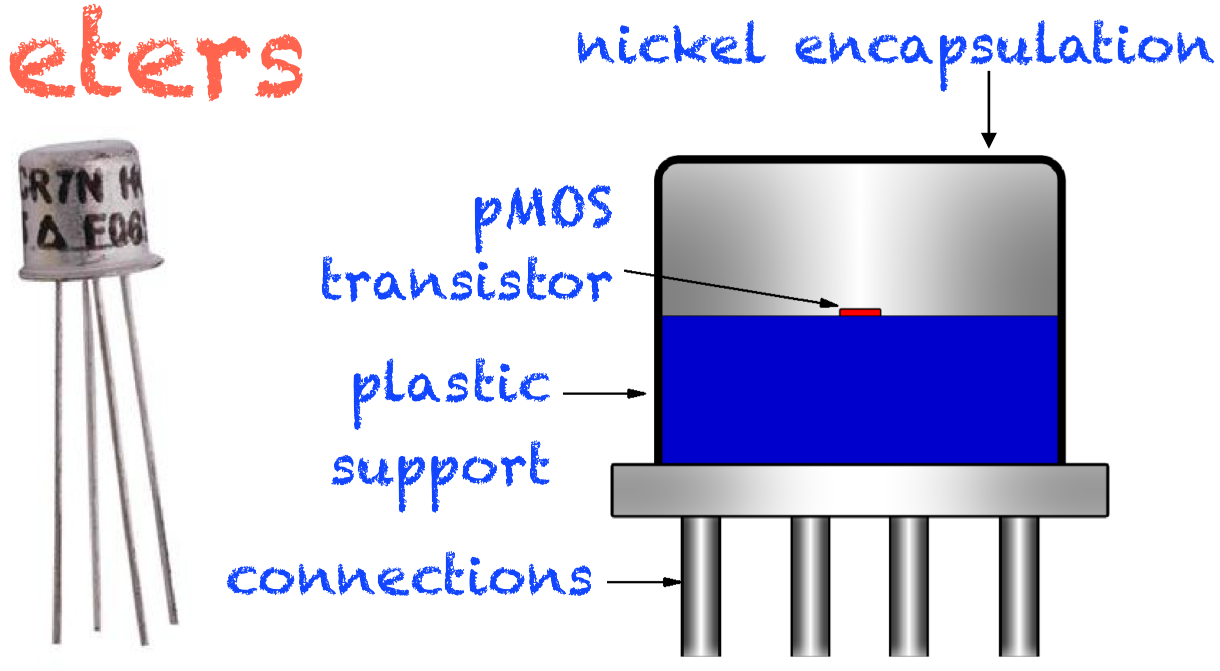

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- detailed simulation within MOSFET
- very low statistic: 30 days for an uncertainty of 10% (k=3)

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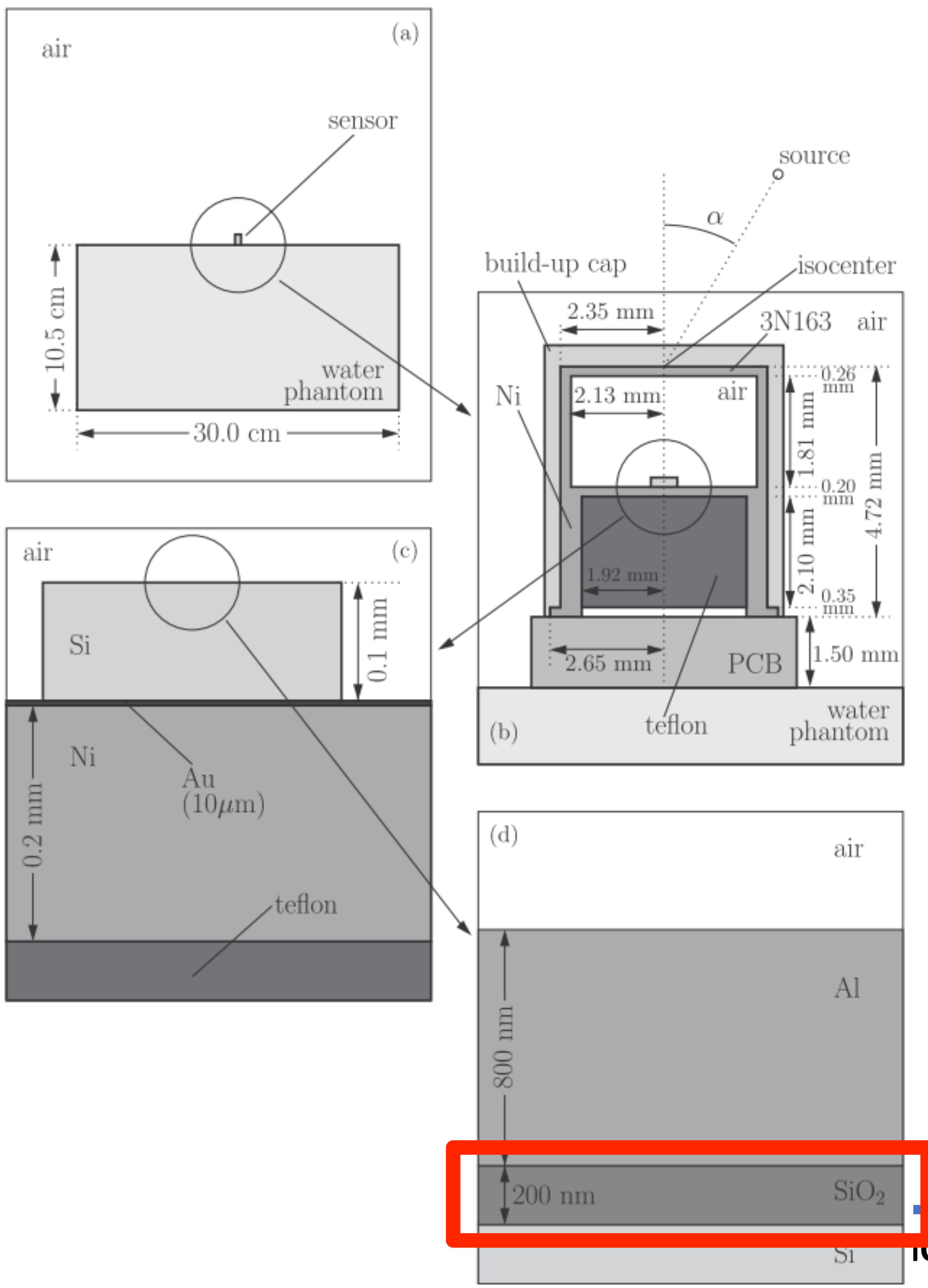

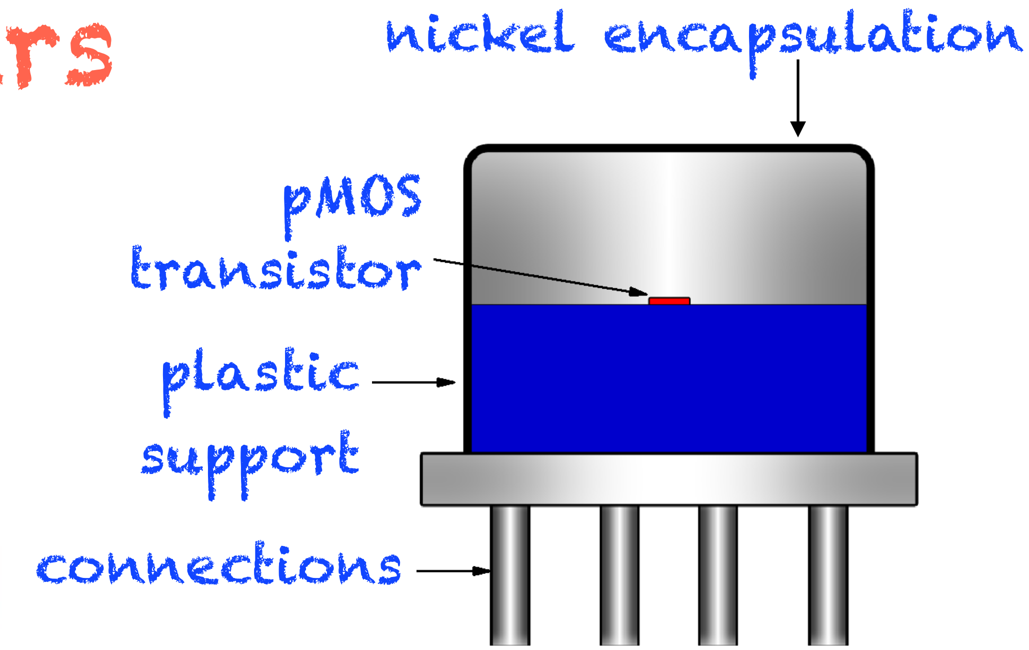

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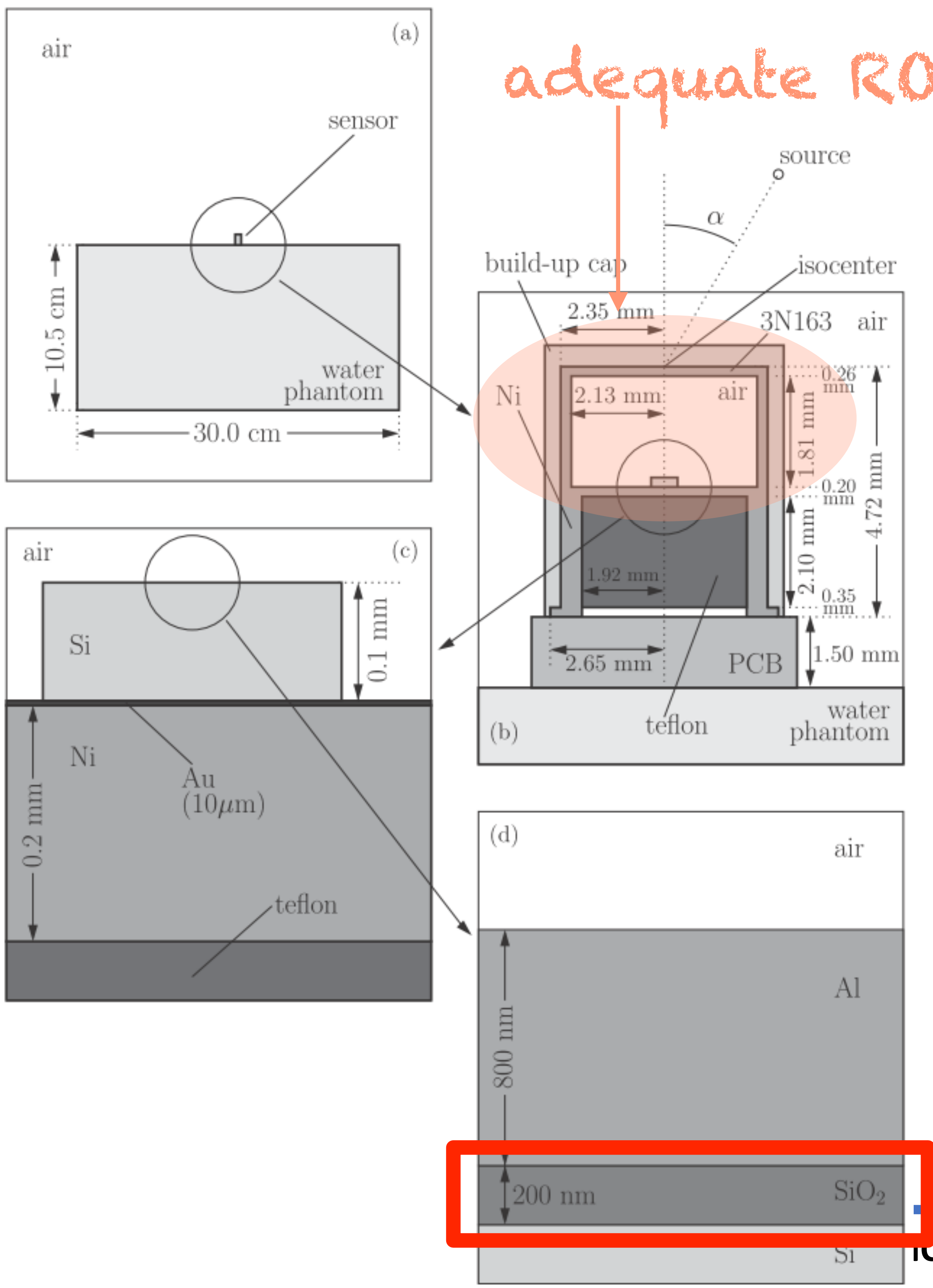

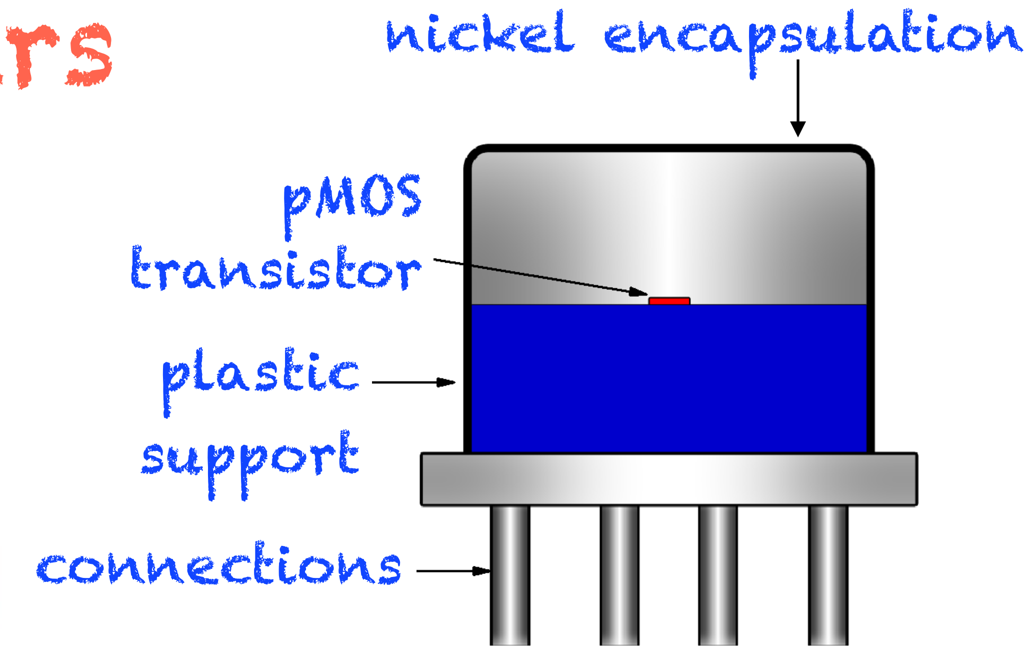

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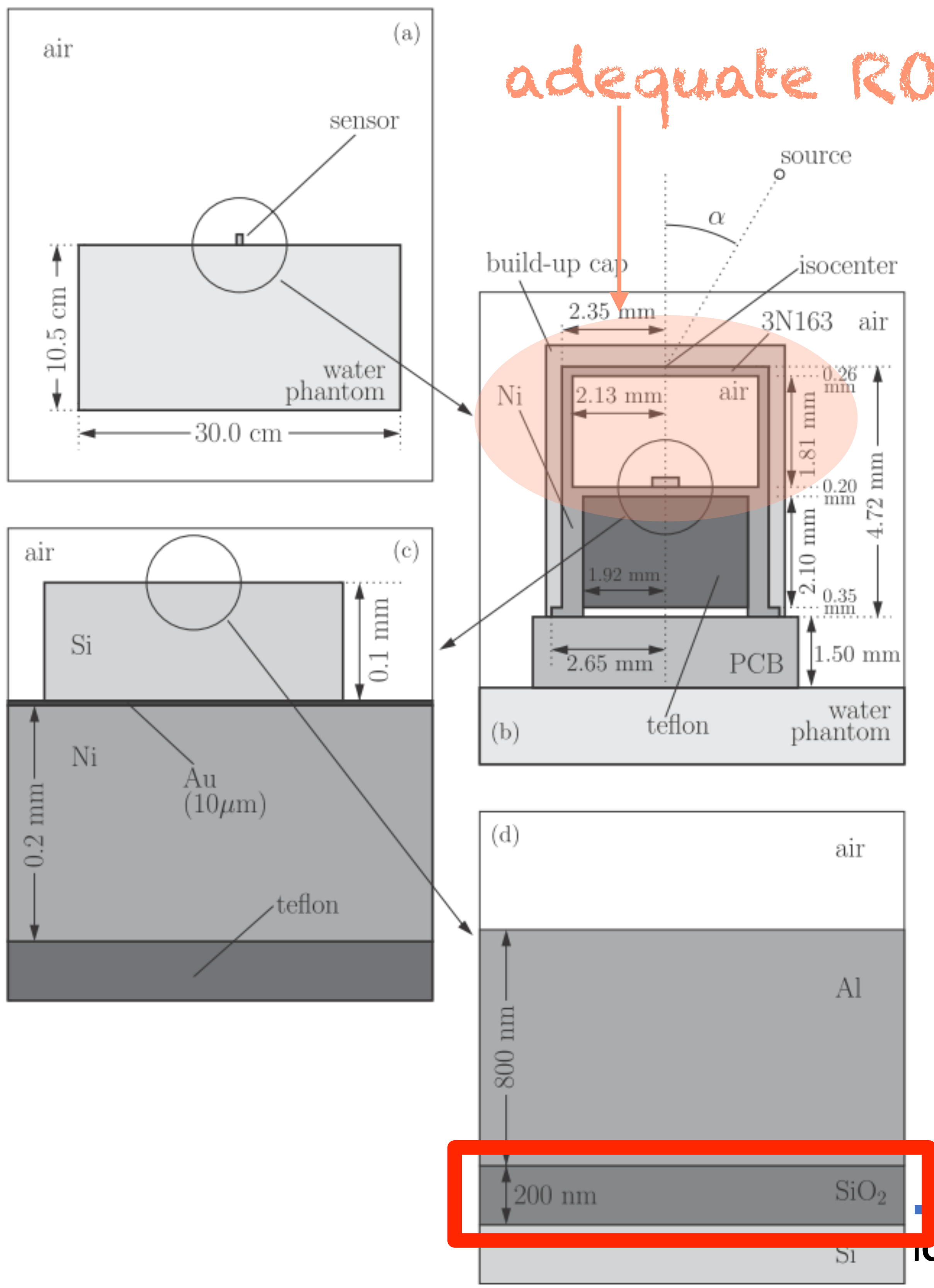

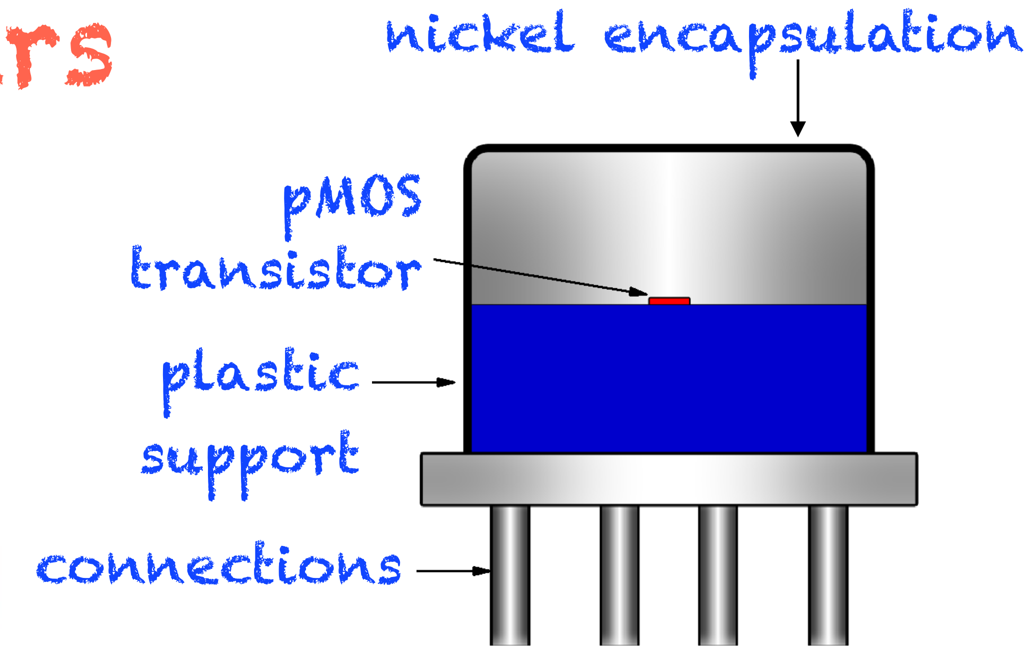

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- factor 20 reduction in CPU

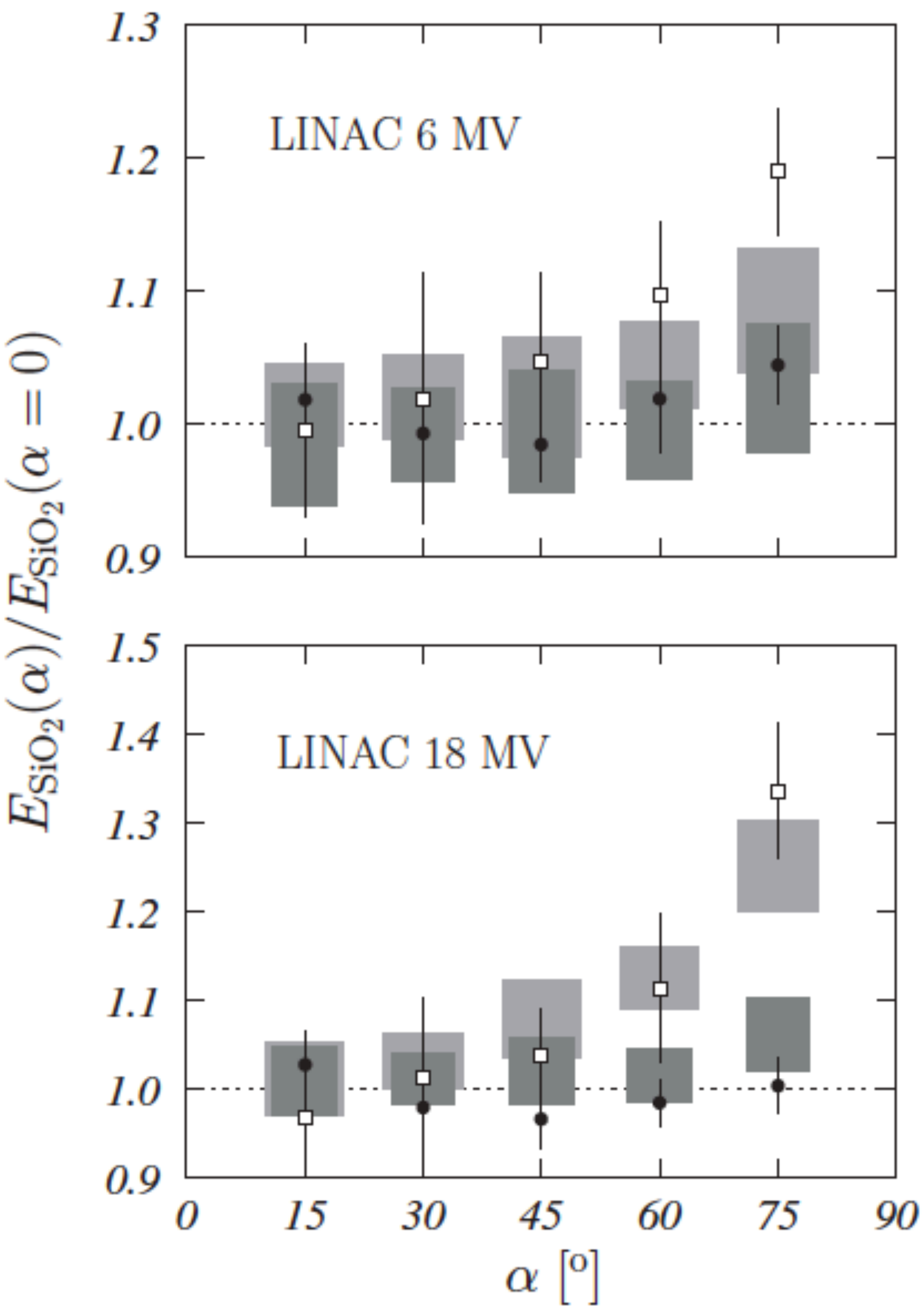

Figure 4. Effect of the additional brass encapsulation of the MOSFET. The experimental results (black dots) and the results of the corresponding simulations (darker gray bands) are compared to the results in the absence of the brass encapsulation shown in figure 3. In the case of the 6 (18) MV beam, the thickness of the brass casing is 0.3 (0.5) mm. Uncertainties correspond to 3σ.

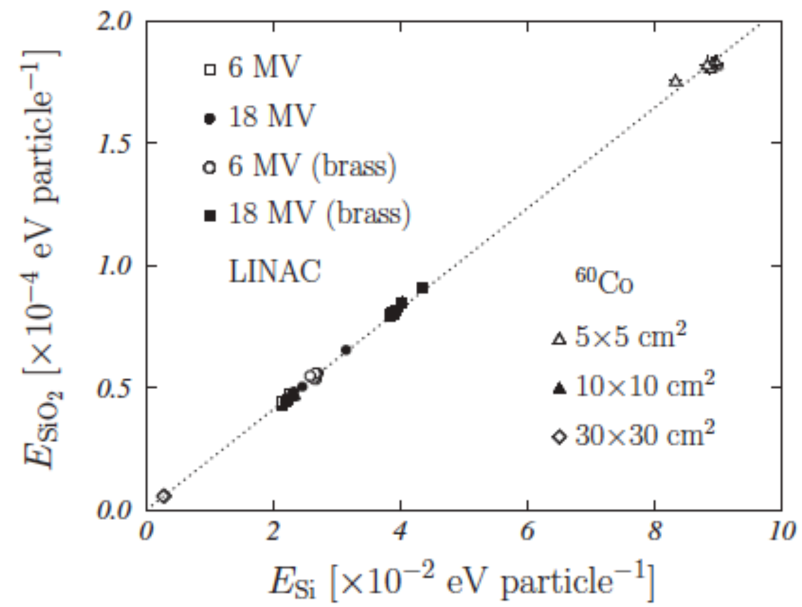

Figure 5. Energy deposited in the SiO_2 versus that deposited in the Si bulk. The corresponding values obtained in all our simulations are included. The straight line gives the linear regression of the data with a slope of 2.06×10^{-3}. Uncertainties in the data correspond to 1σ.

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-very narrow beams used for treatment of small lesions nearby healthy tissues that have to be preserved
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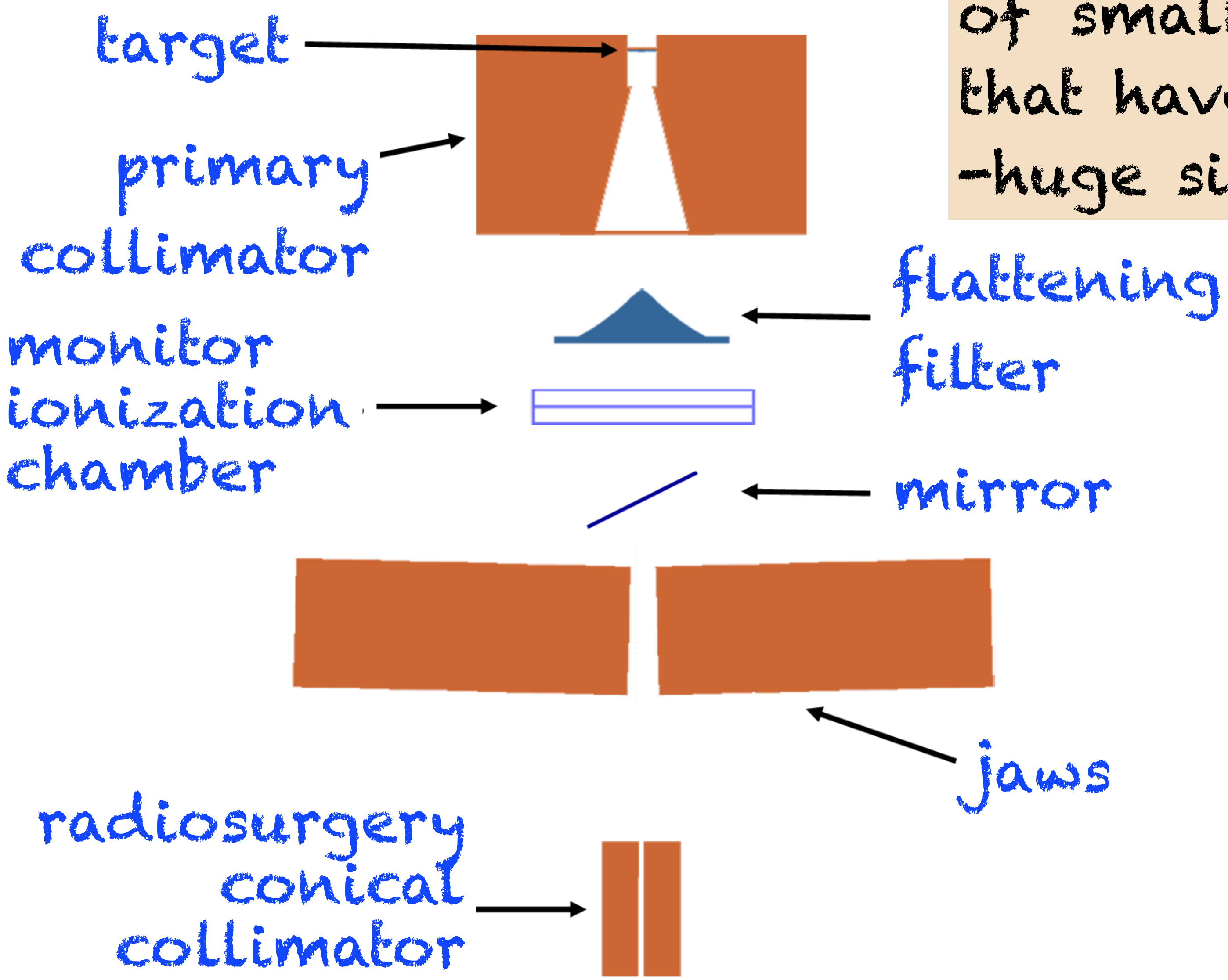

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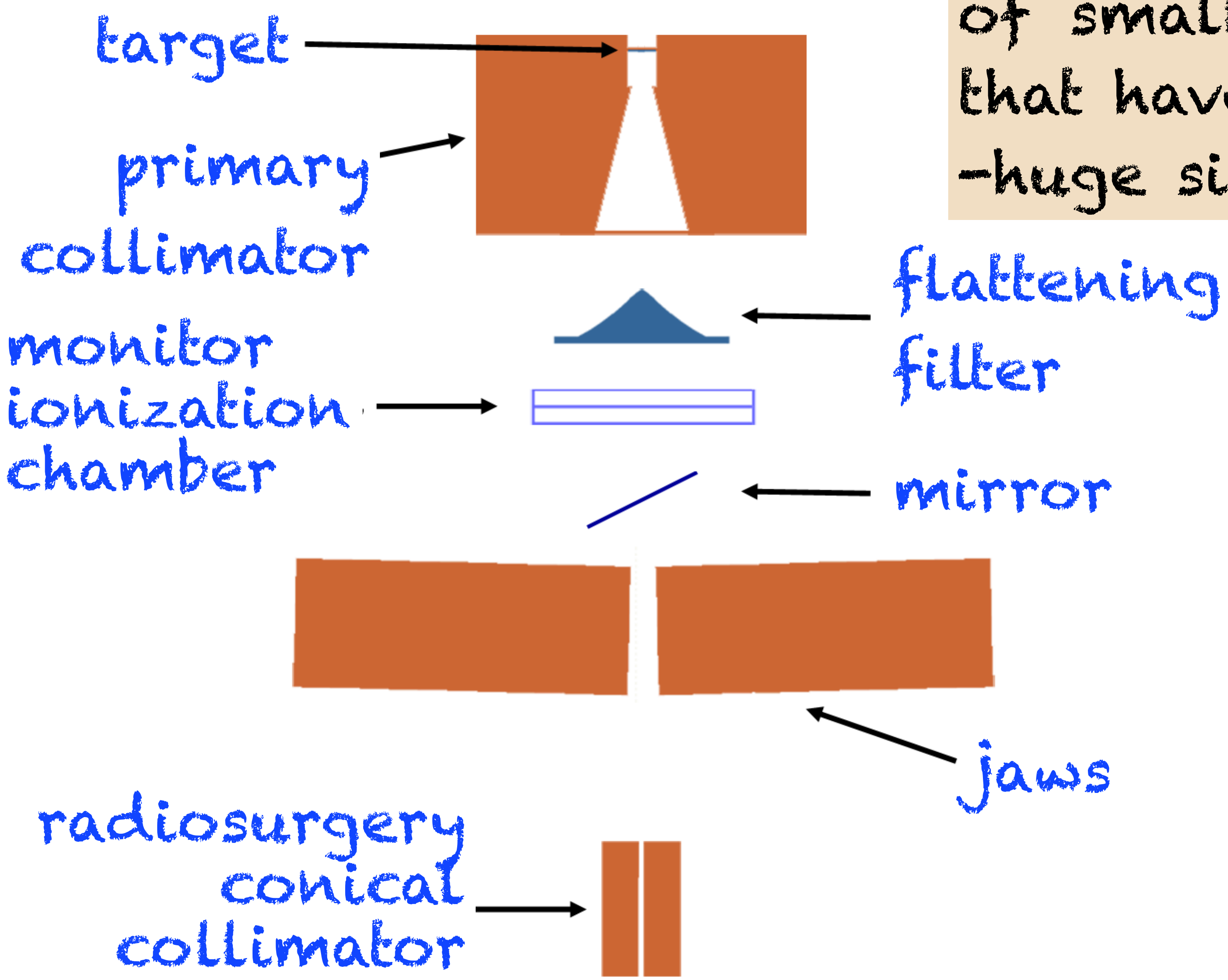

-very narrow beams used for treatment of small lesions nearby healthy tissues that have to be preserved

-huge simulation CPU times!!

-VRT applied to both electrons and photons

$I_1 = I(x, y, z, E, M)$ for electrons.

$I_2 = I(x, y, z, E, M, \theta, \phi)$ for photons.

Some applications

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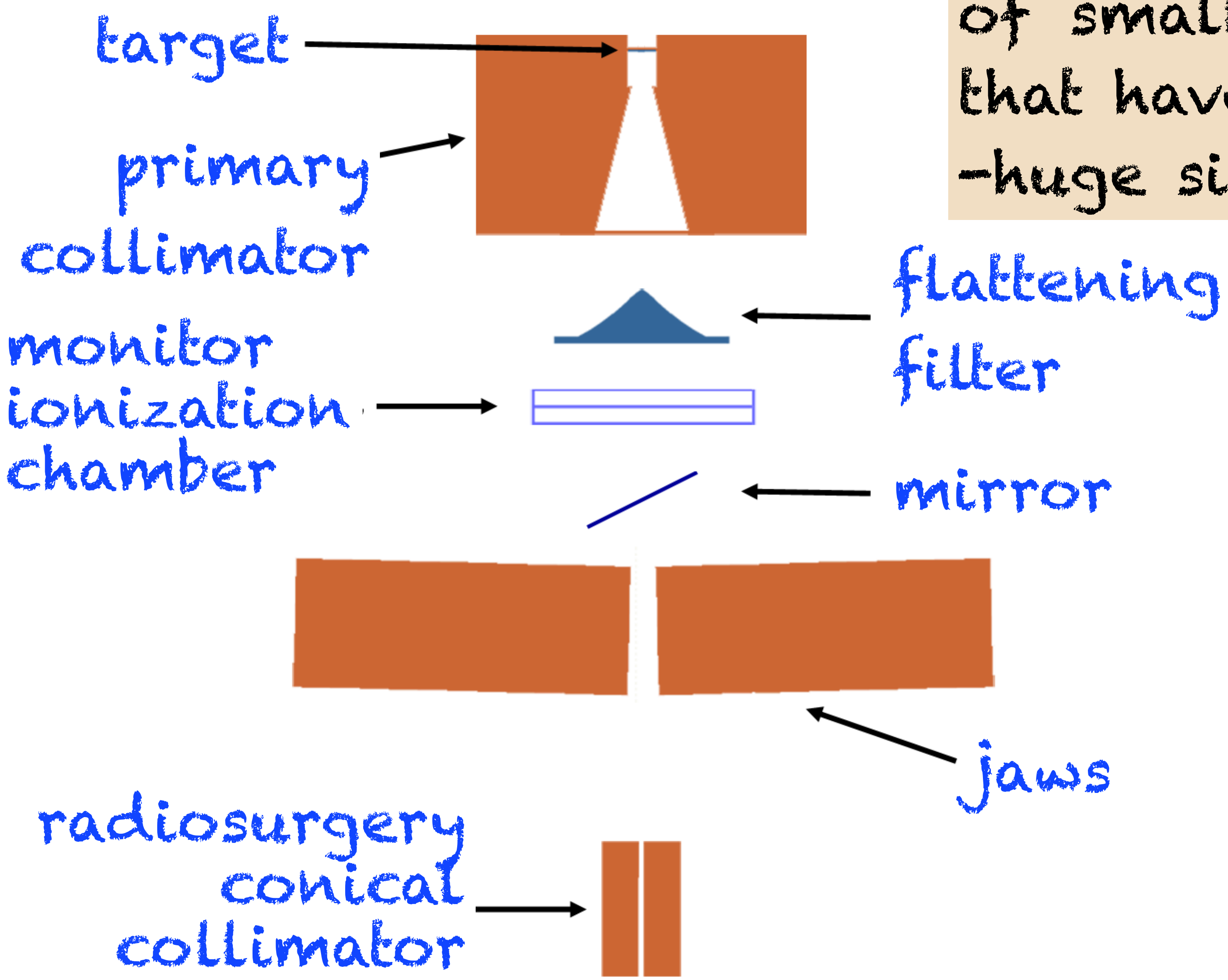

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- directional Bremsstrahlung splitting is needed
  -applied throughout the whole geometry

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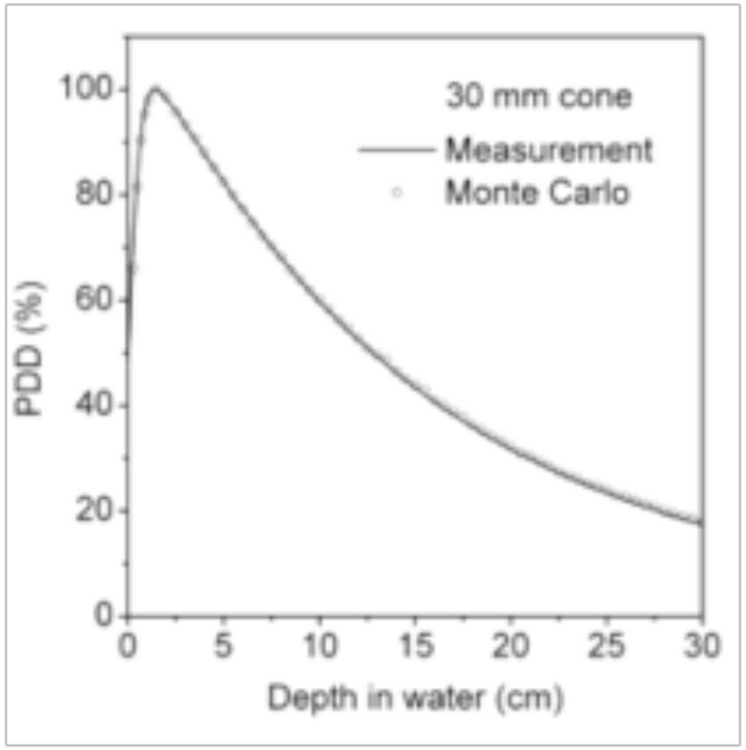

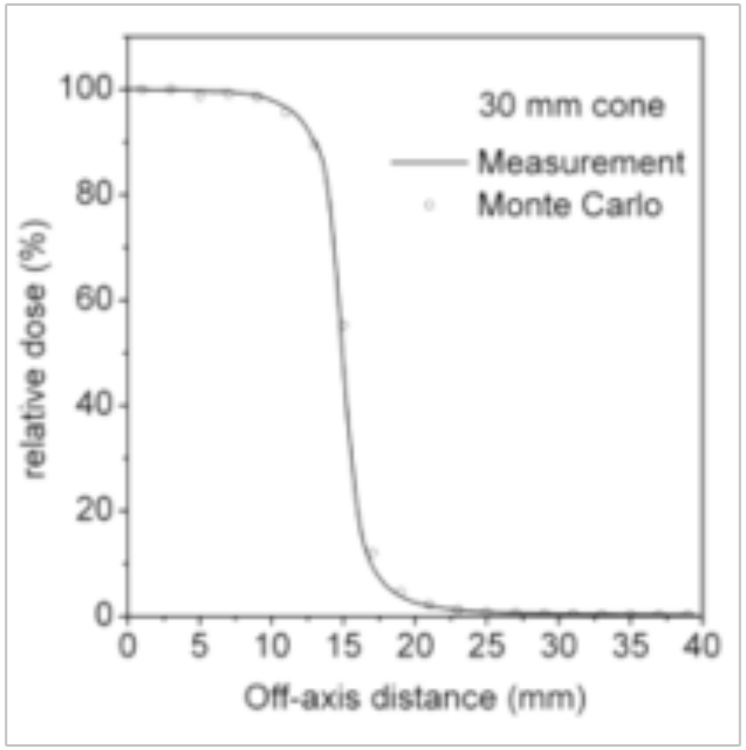

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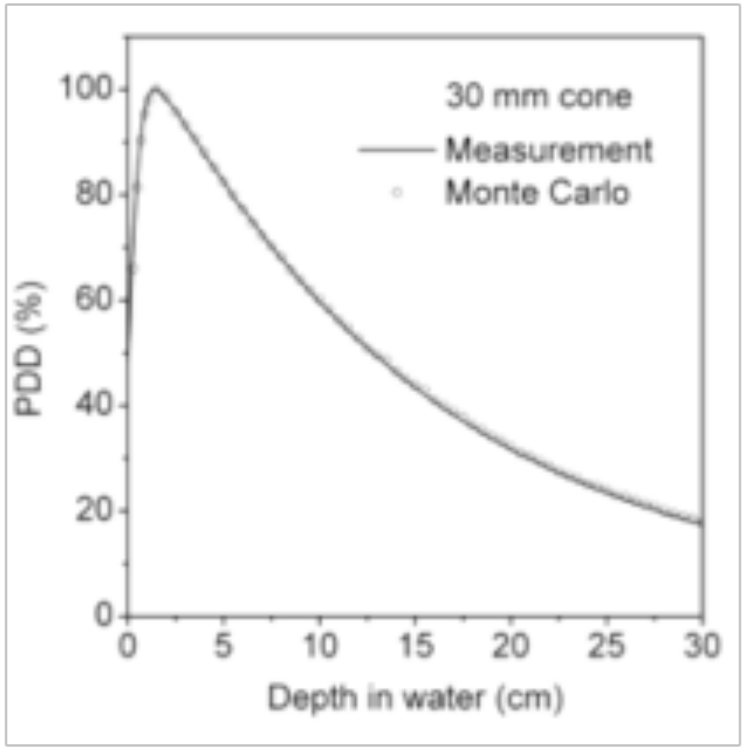

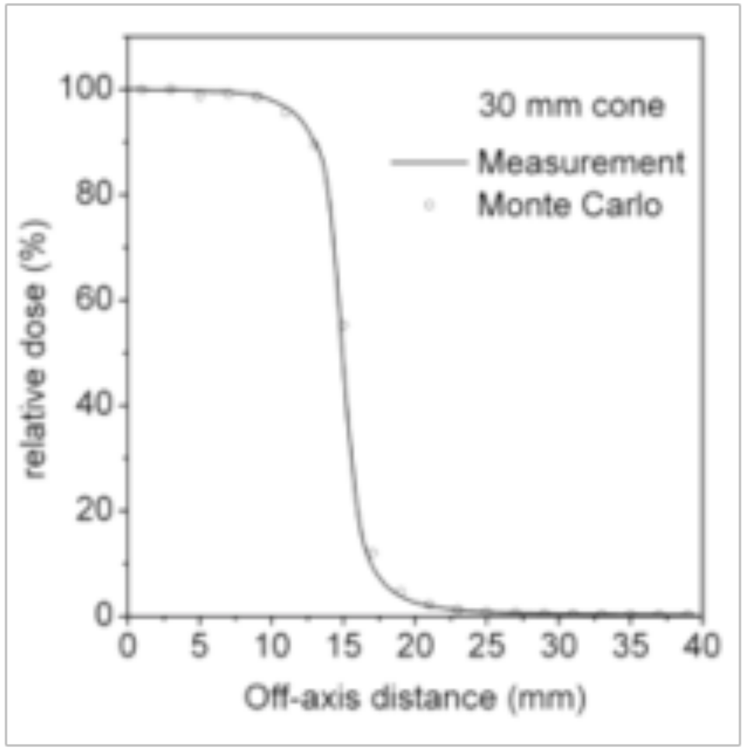

CPU times:
9 h (10 mm) to 0.9 h (30 mm)

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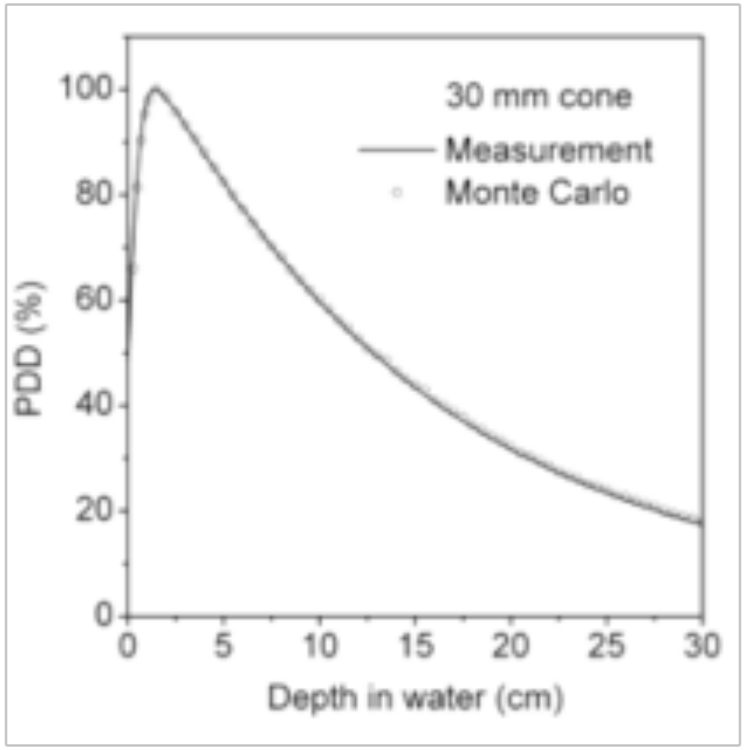
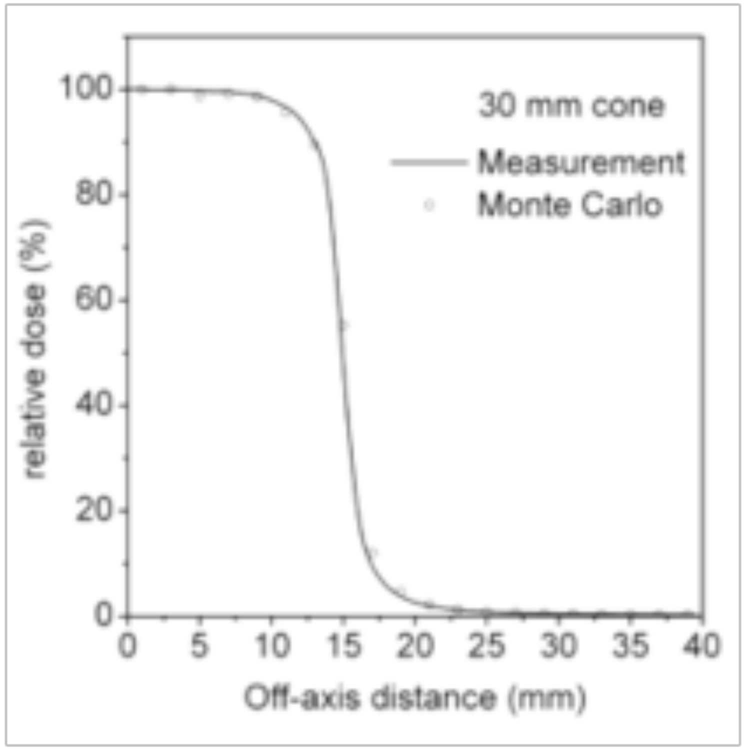
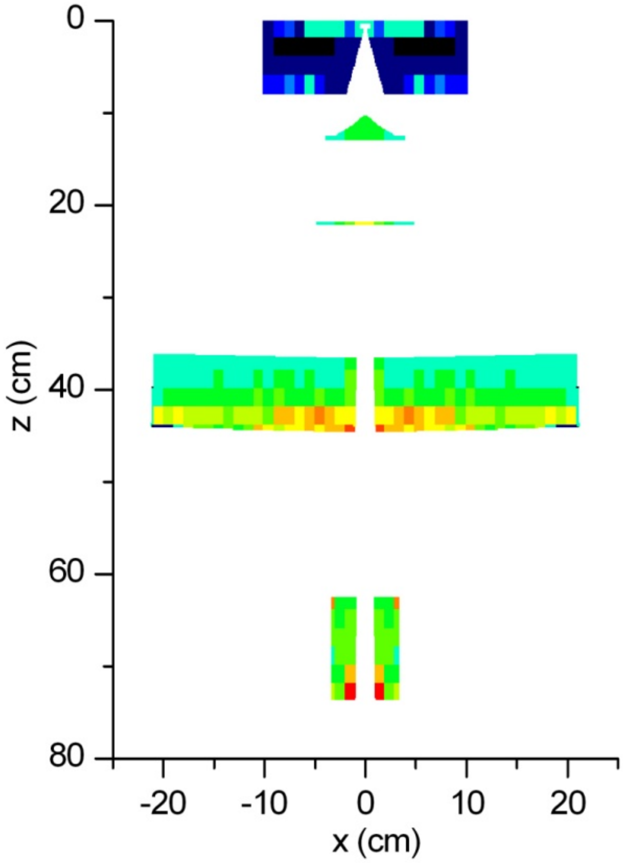
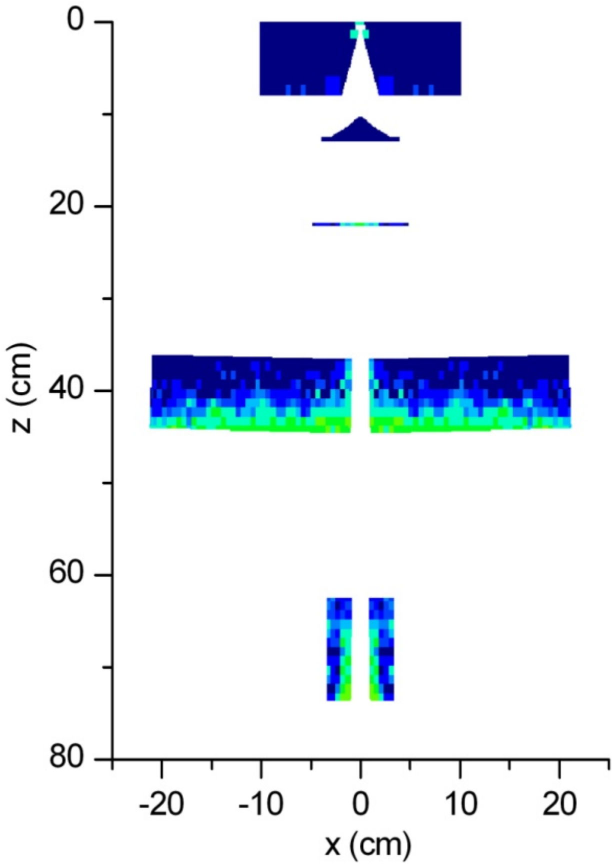




high energy photons

high energy electrons





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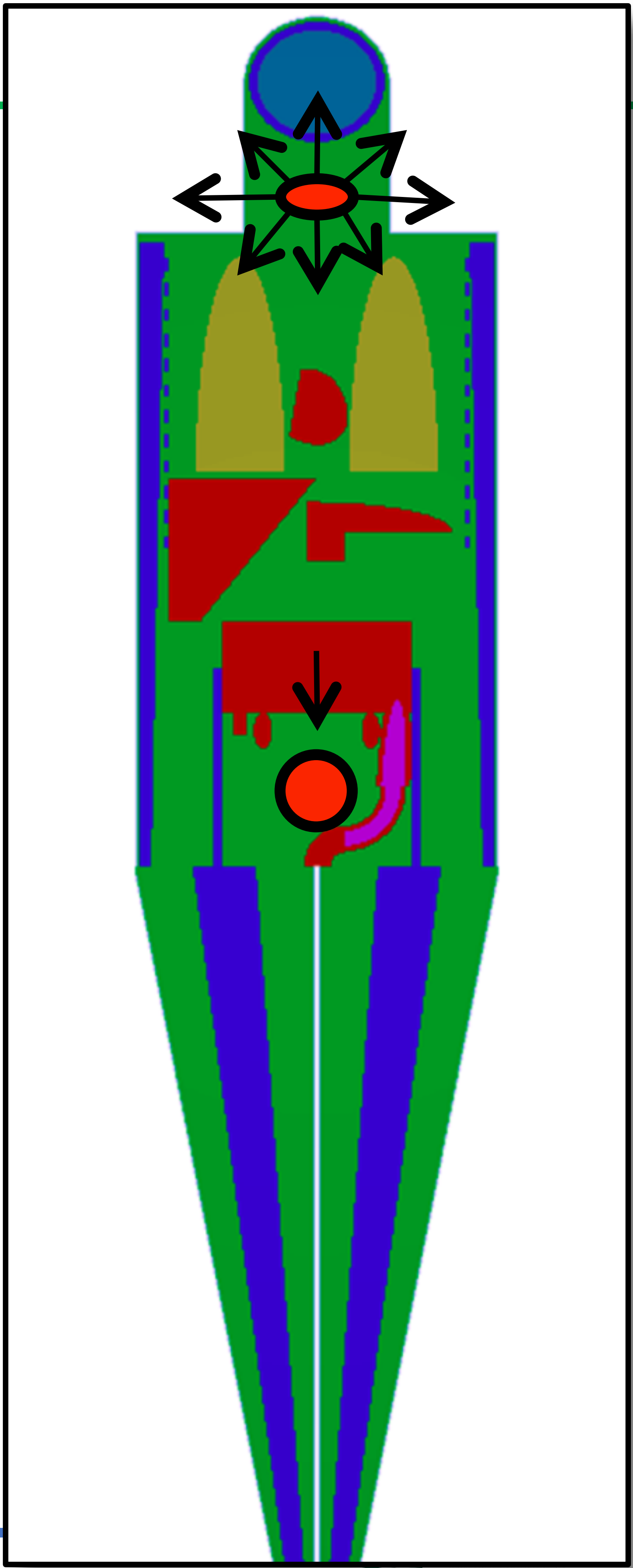
-inform about organ/tissue irradiation due to diagnostic or therapy of other organ

-interest in Nuclear Medicine



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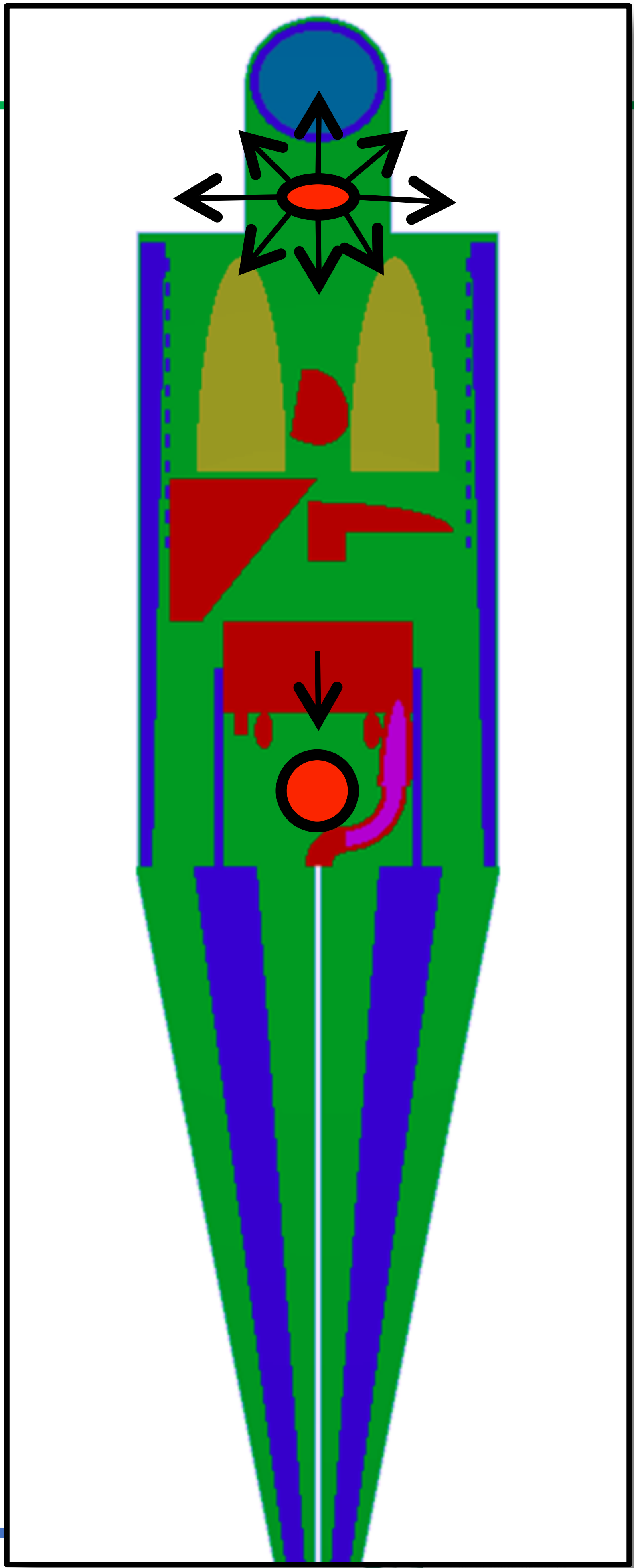

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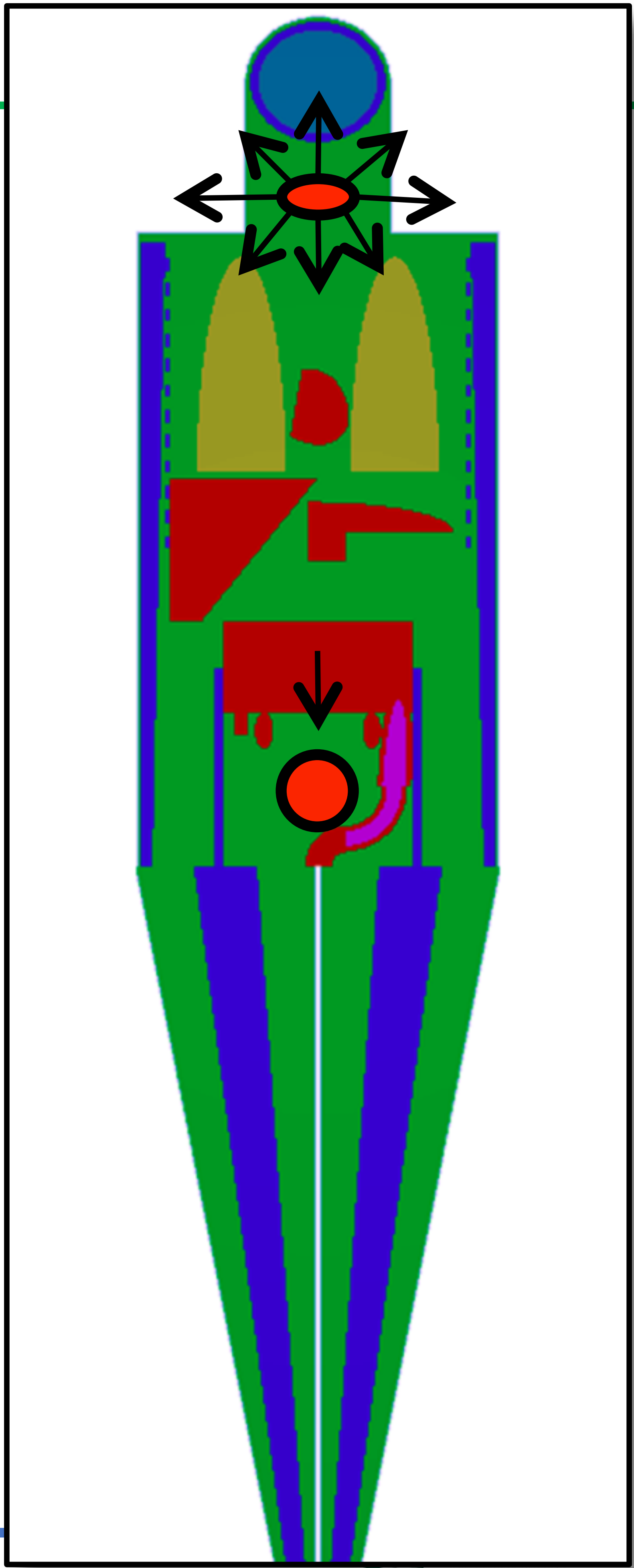

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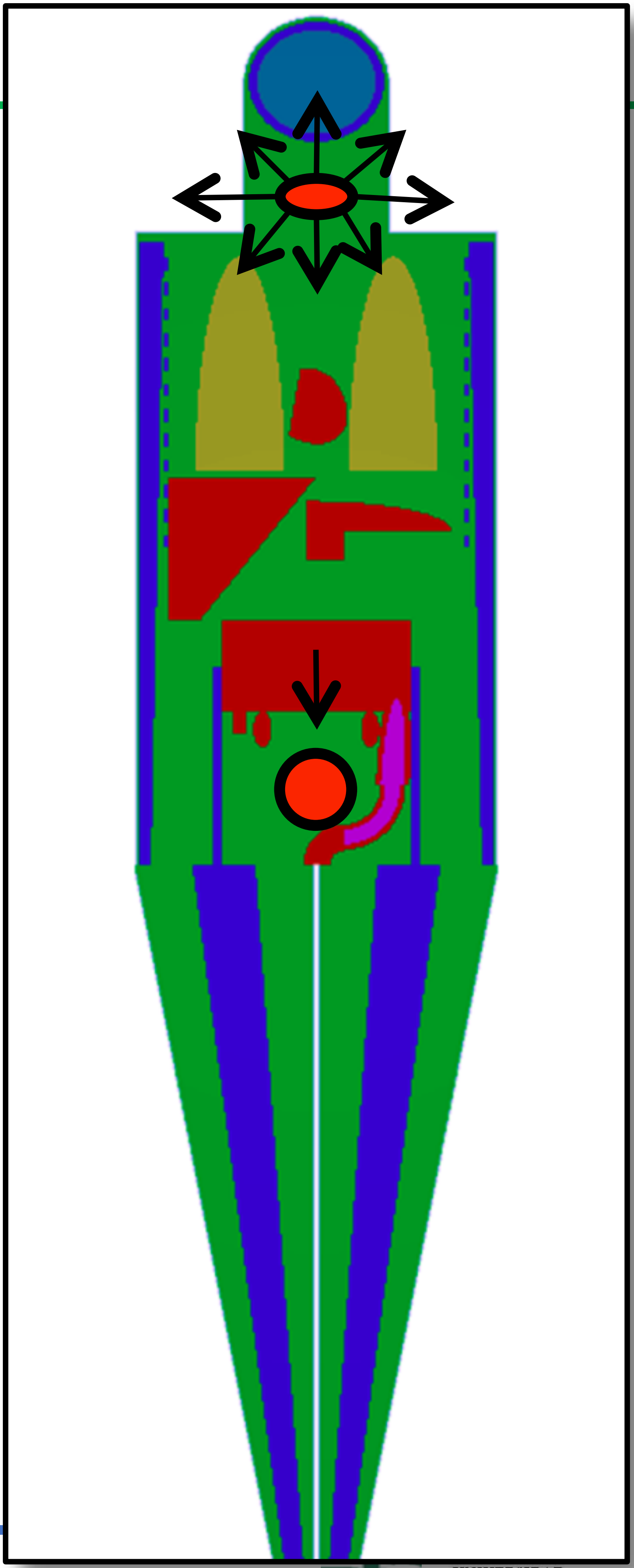

Correction factors of micro-chambers

Some applications

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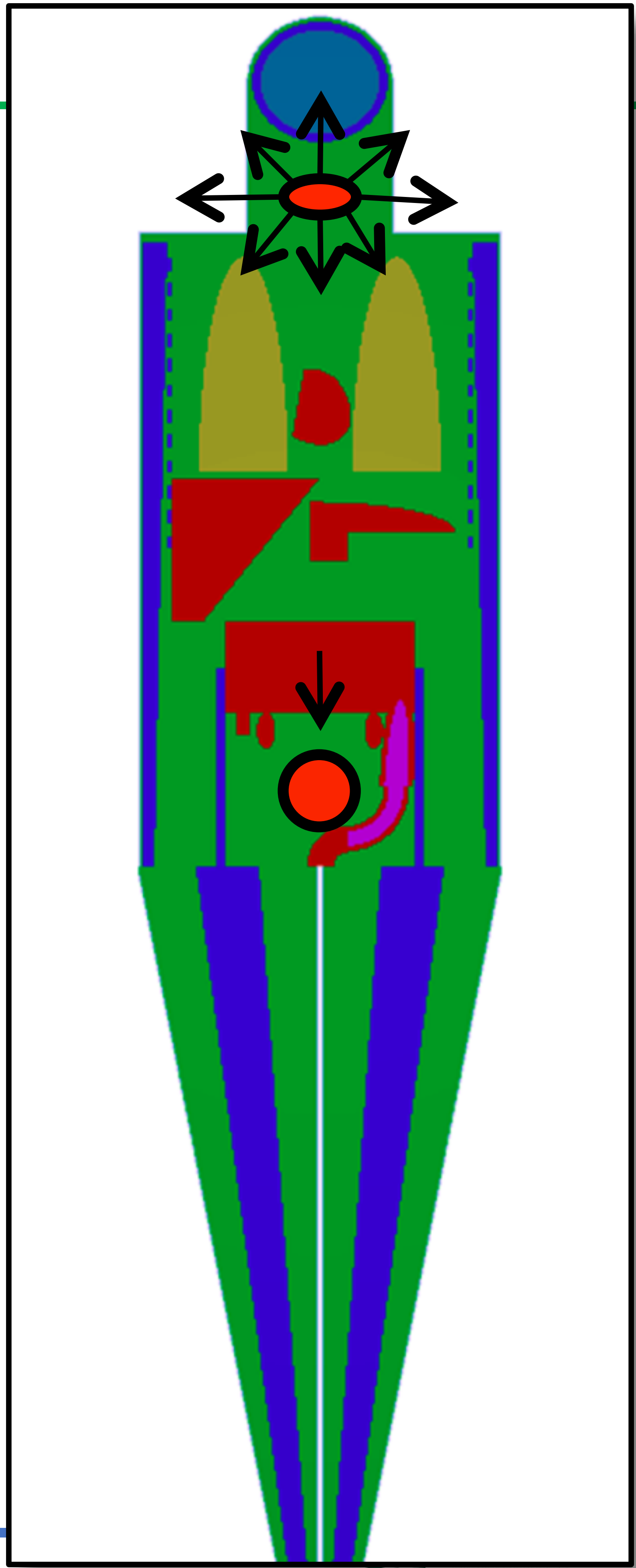

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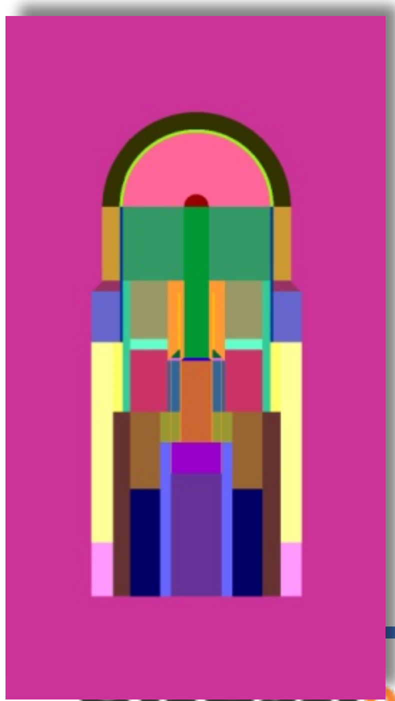

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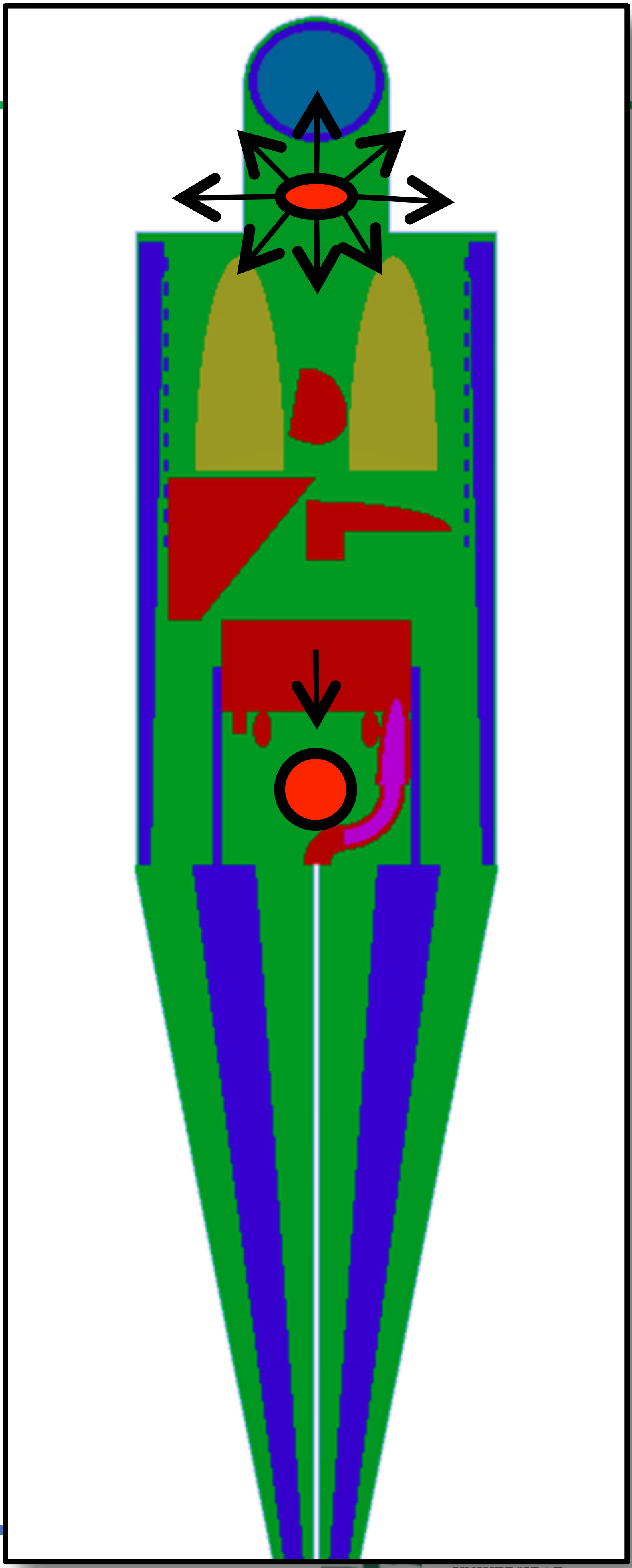

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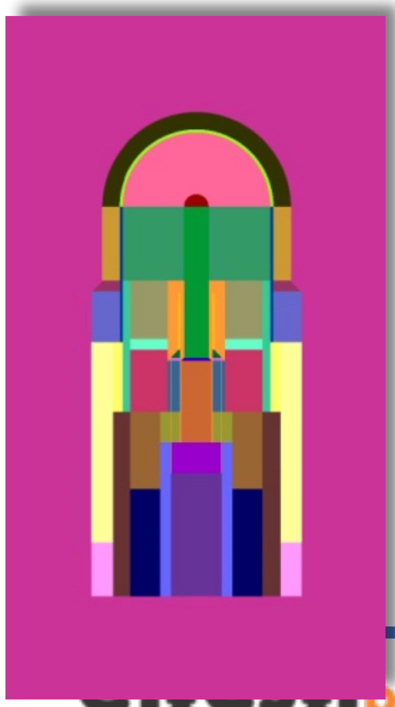

-efficiency increases by a factor 100!!

Conclusions

- An optimization algorithm based on 'ant colony behavior' has been developed
- It allows the efficient implementation of variance reduction techniques
- It uses the information scored on importance maps
- Minimum intervention by the user is required … but details are relevant

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Ant colony algorithm for driving variance reduction techniques in Monte Carlo simulations of radiation transport

A. M. Lallena

Thanks for your attention