Simulation of CT-images: from X-ray spectrum to CT-numbers

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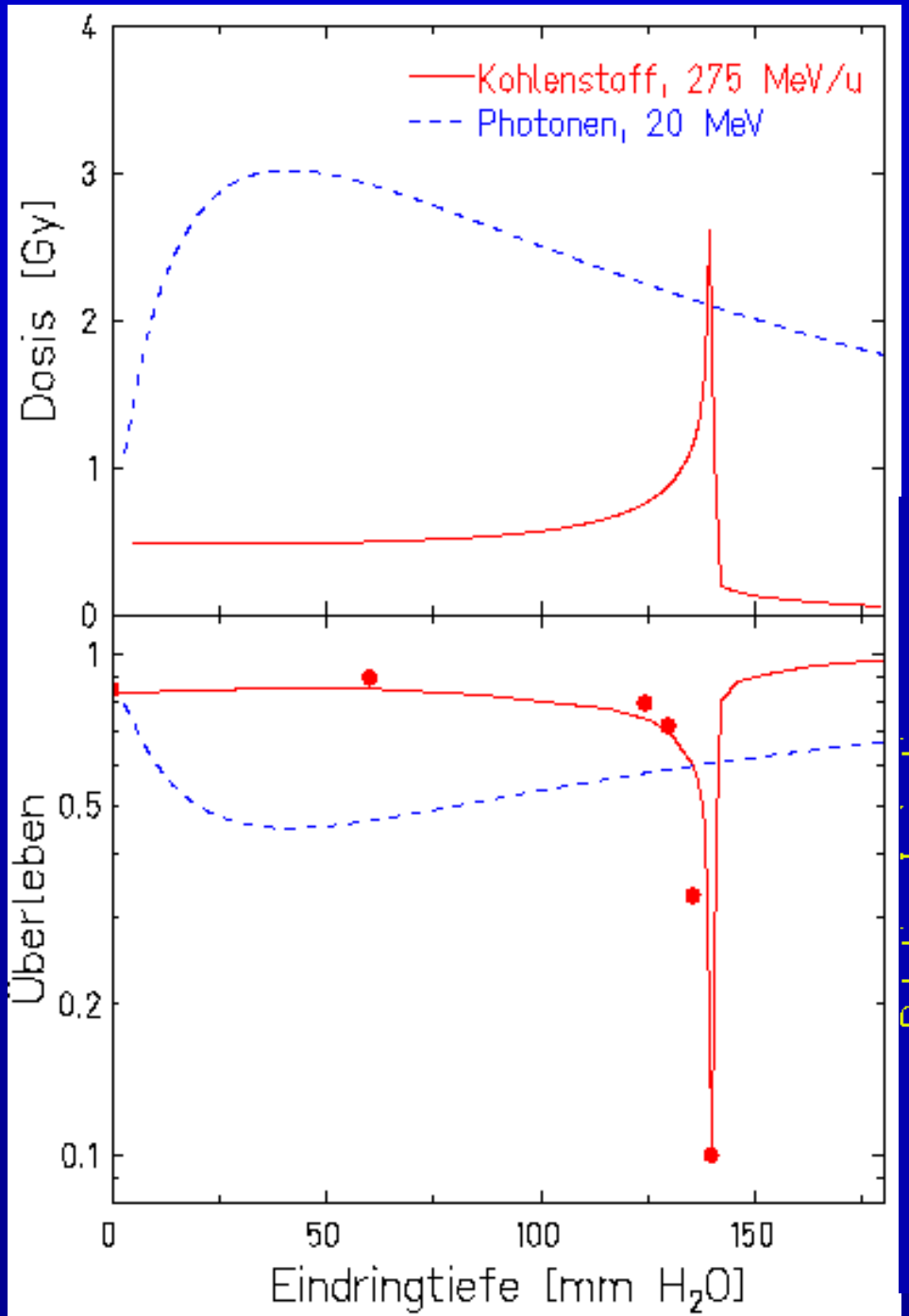
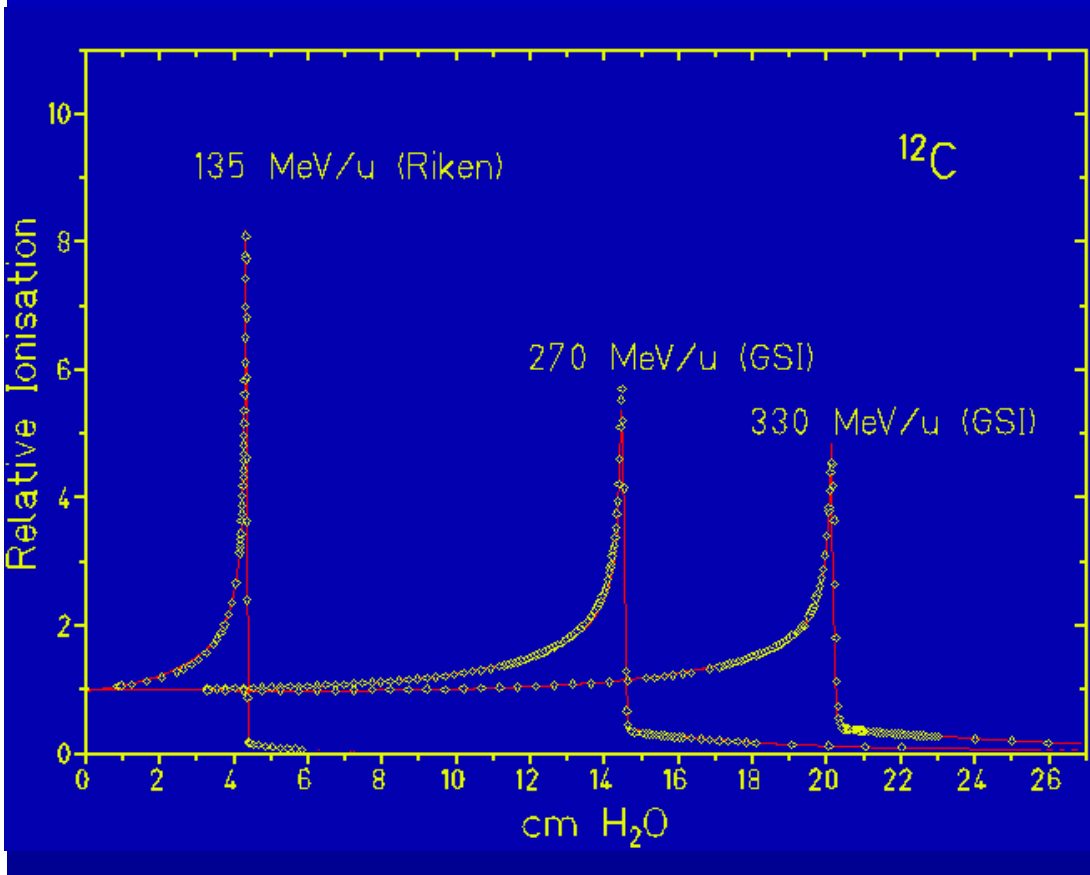
Ion therapy vs. Photon radiotherapy



Bragg-peaks for different Carbon ion energies



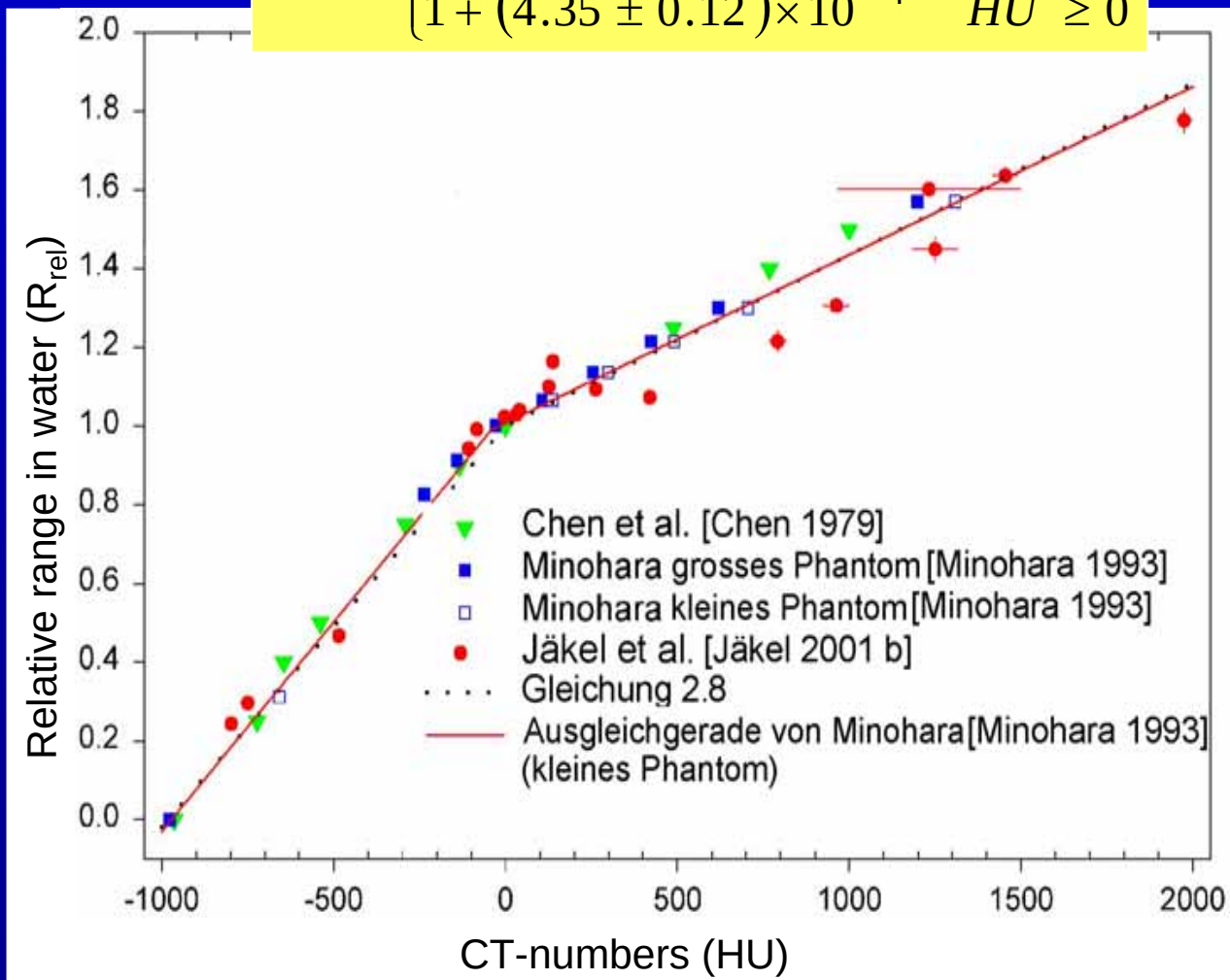
Introduction (CT-calibration)

$$\mu(E,Z) = \sigma(E,Z) \bullet \rho_e$$

$$\text{CT} - \text{number} = 1000 \cdot \left(\frac{\mu}{\mu_w} - 1\right)$$

$$R_{rel} = \Delta Range_{water} / d_{medium}$$

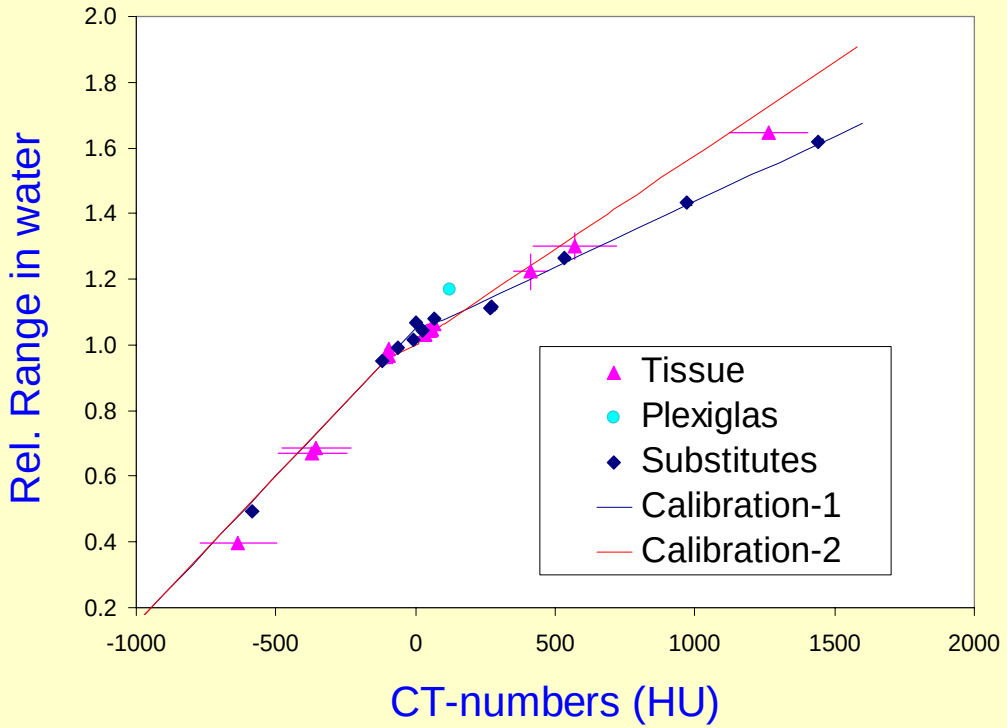
$$R_{rel} = \begin{cases} 1 + (9.41 \pm 0.08) \times 10^{-4} & HU < 0 \\ 1 + (4.35 \pm 0.12) \times 10^{-4} & HU \geq 0 \end{cases}$$

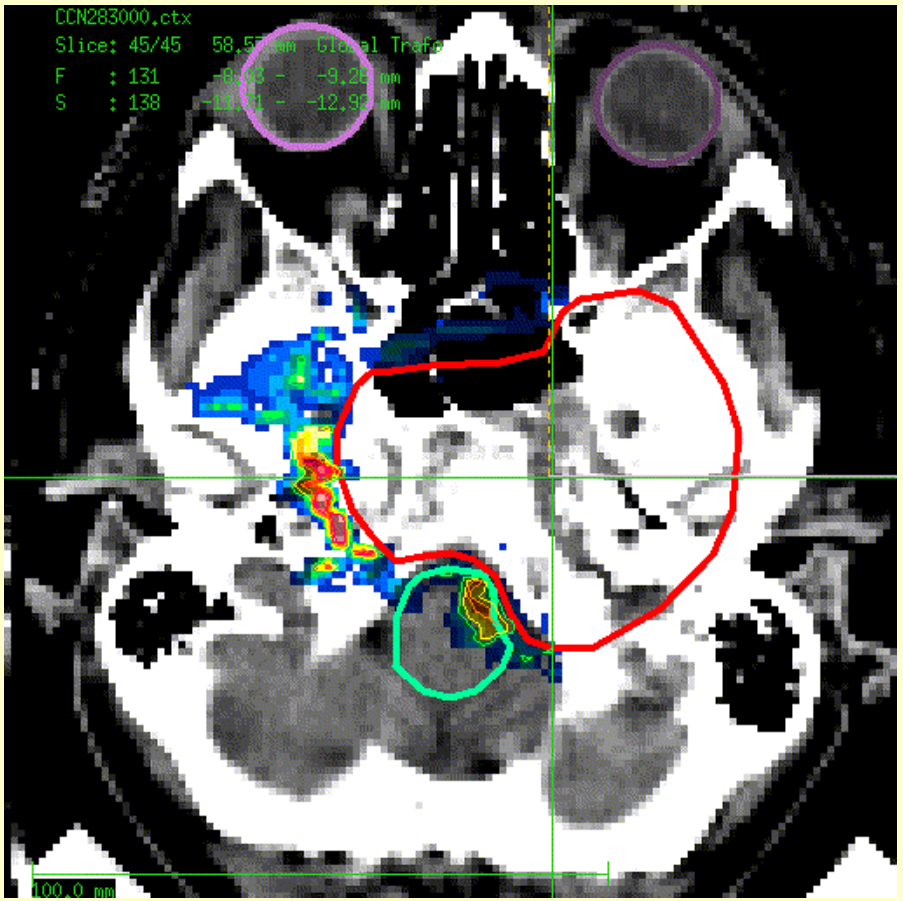


Uncertainty of calibration curve 2% -3% ;

Range uncertainty
2-3 mm at 10 cm

Uncertainties of CT-numbers can be up to 300 HU for bone-like materials. This can lead to uncertainties in the range of ions (position of Bragg-peak)





Changes of the CT-numbers of bone-like materials affect the calibration curve and cause up to 6 mm change in the range of Carbon ions. Up to 80% of the dose is allocated to the critical organs.

What influences CT-numbers ?

- Design parameters of the CT-scanner (filters, collimators, generation)
- Voltage of the X-ray tube
- Size of Field of view (FOV)
- Reconstruction algorithms
- Parameters of the scanned object (material of phantom, size, geometry, homogenity, position in the FOV, movement)
- Artefacts, especially metal artefacts

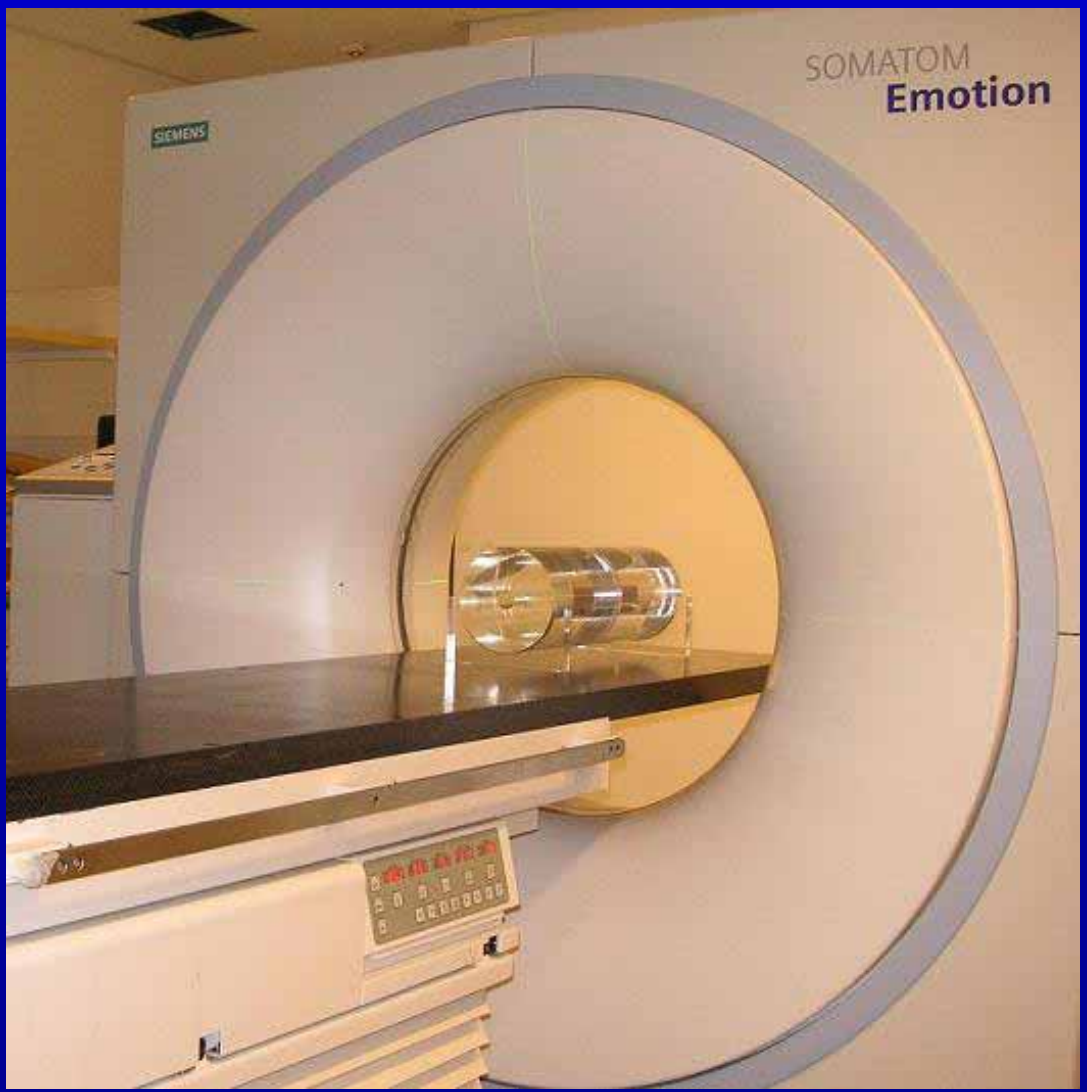
The dependance of CT-numbers on the above parameters is only known emprically.

Aim ...

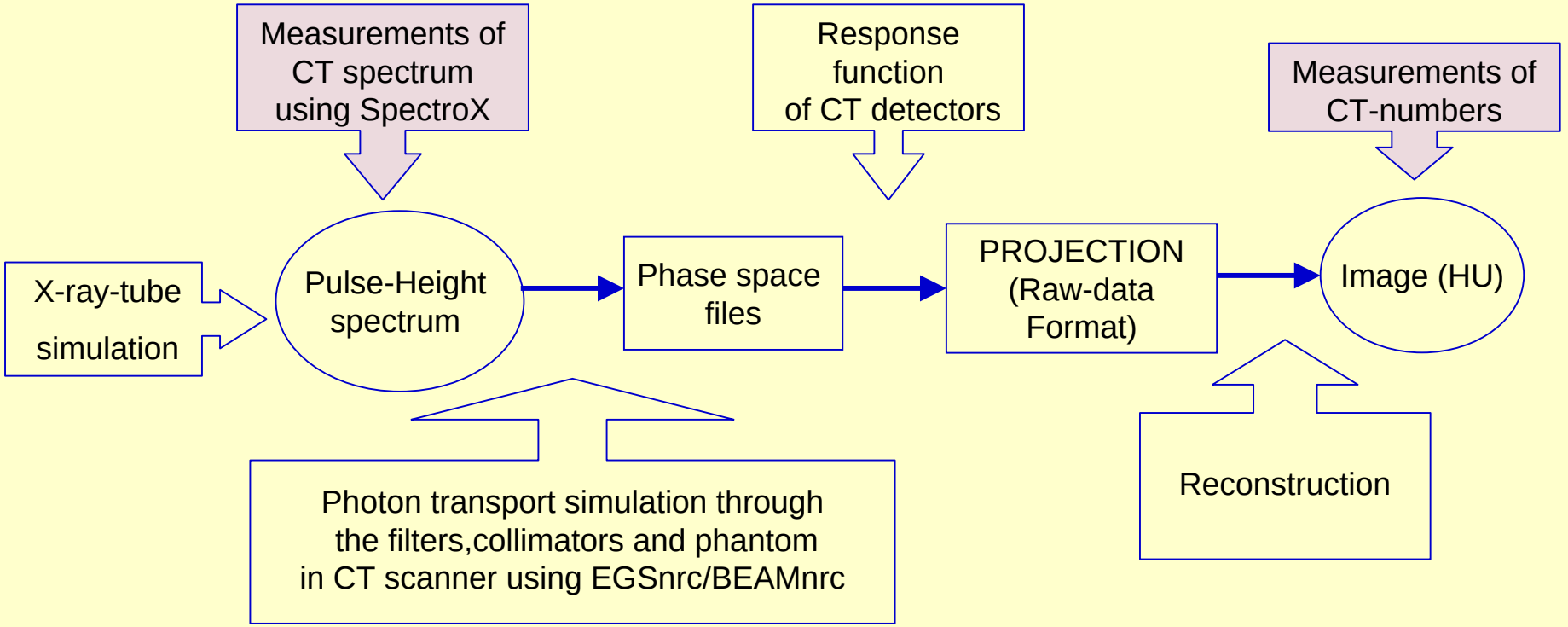
- Develop a method to calculate CT-numbers under different conditions.
- Analyze the effects of measurement conditions on calculated CT-numbers.
- Estimate range uncertainties due to different measurement conditions of CT-numbers.

Cylindrical phantom from PMMA (16 cm diameter) and Gammex-RMI substitutes (Middletown, WI).

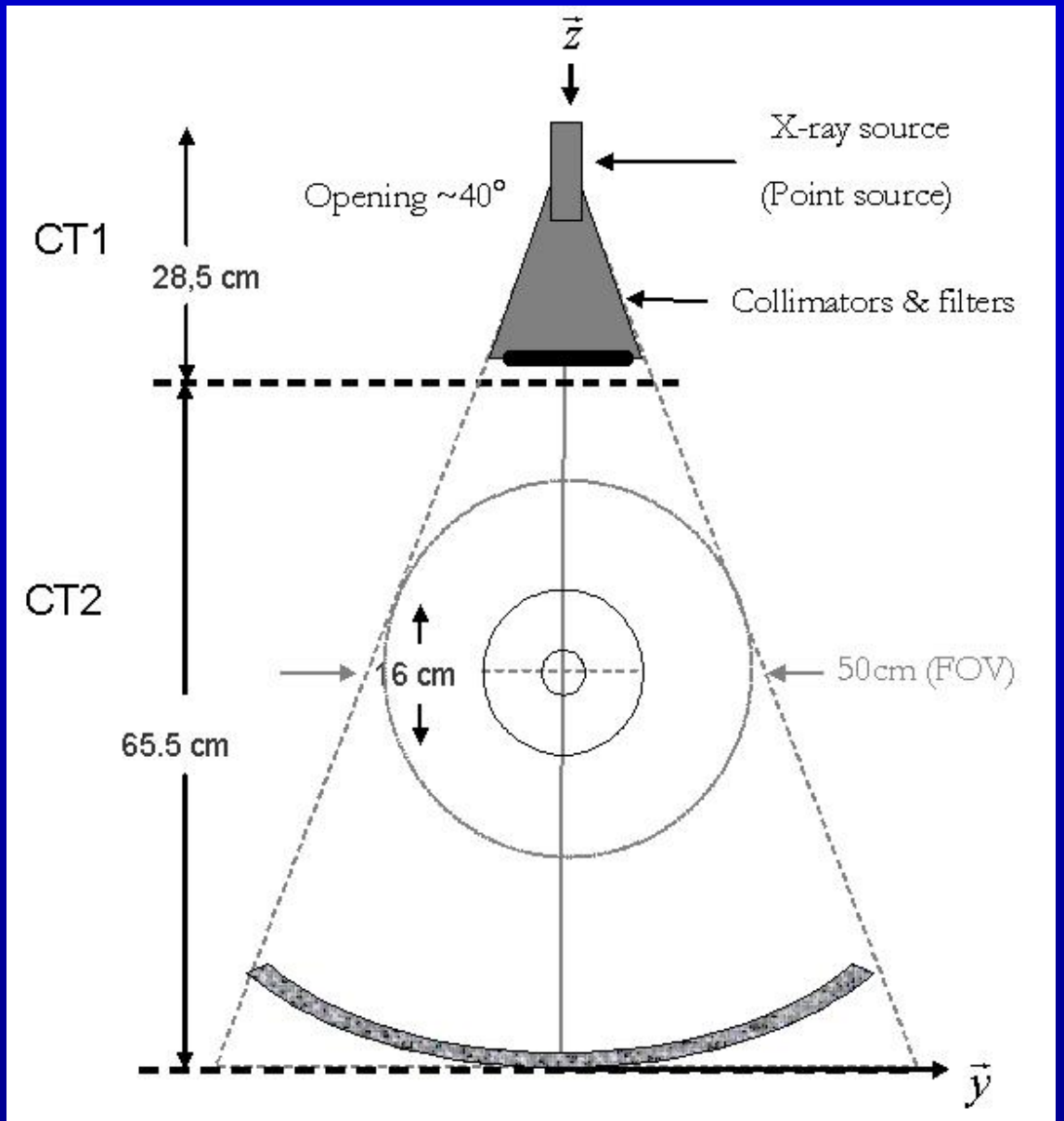
Siemens Emotion CT equipped with a DURA352 X-ray tube.



CT-numbers calculation chain



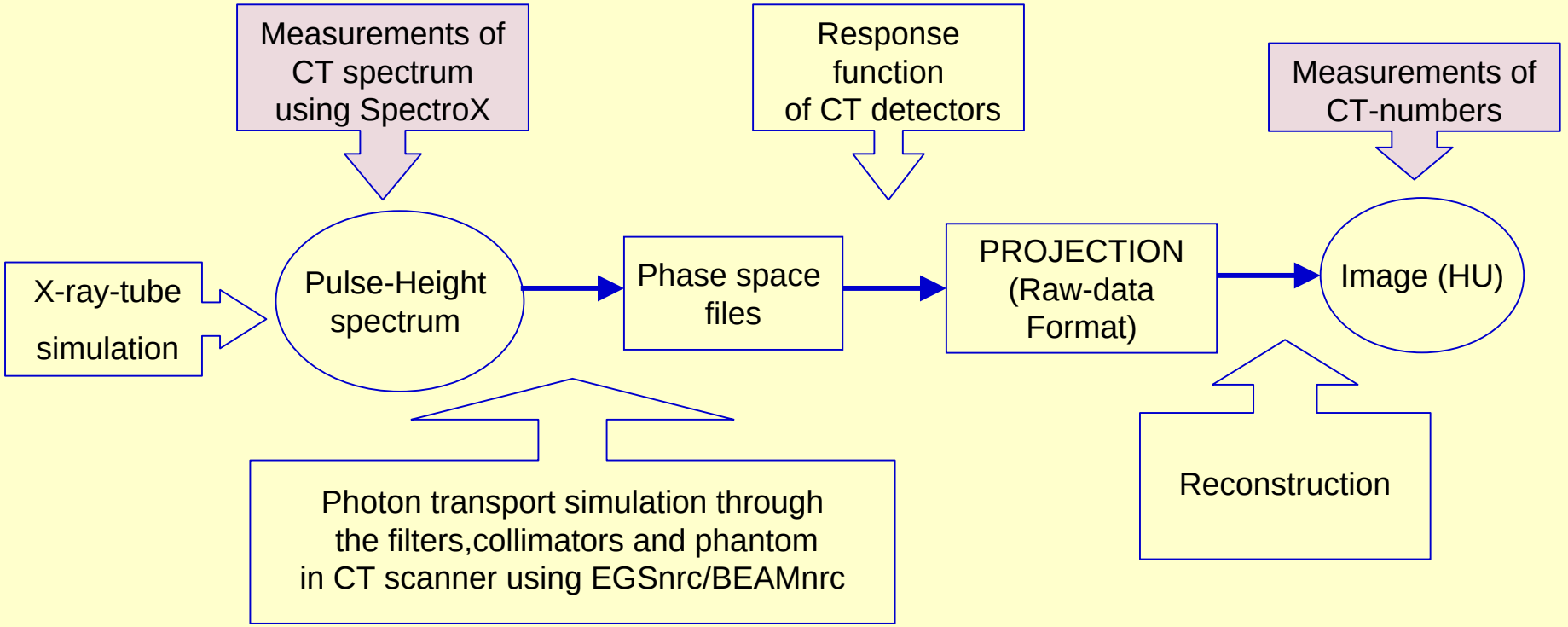
Scheme of CT-scanner and phantom



1) CT1-part was used to simulate X-ray source, filters and collimators. 10^{10} photons with a given energy spectrum. 1 week of CPU time.

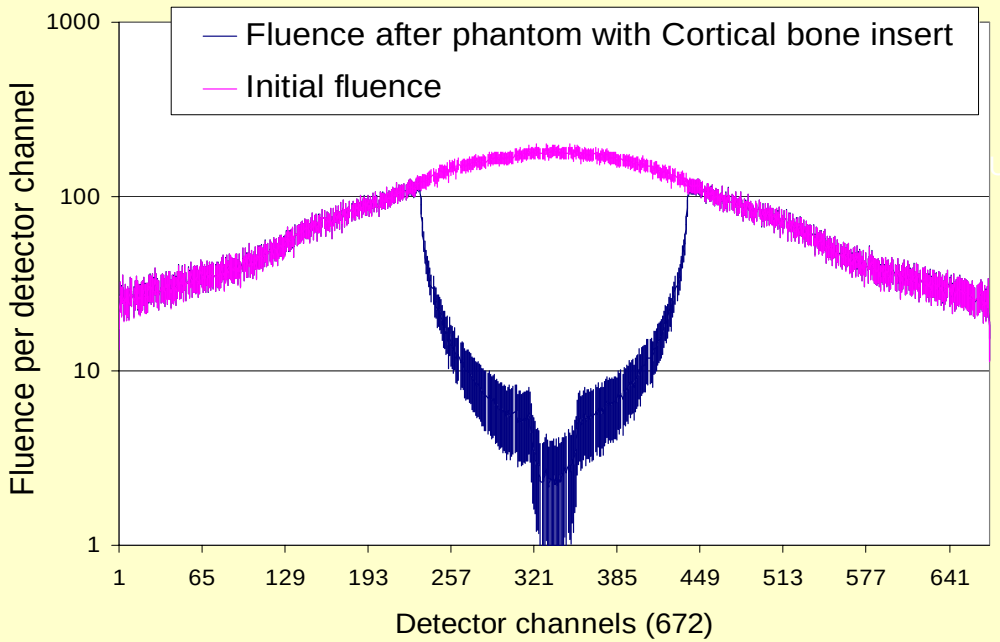
2) CT2-part was used to simulate phantom and inserts. $5x10^{8}$ photons. Input is PHSP from CT1. 1-3 hrs of CPU time.

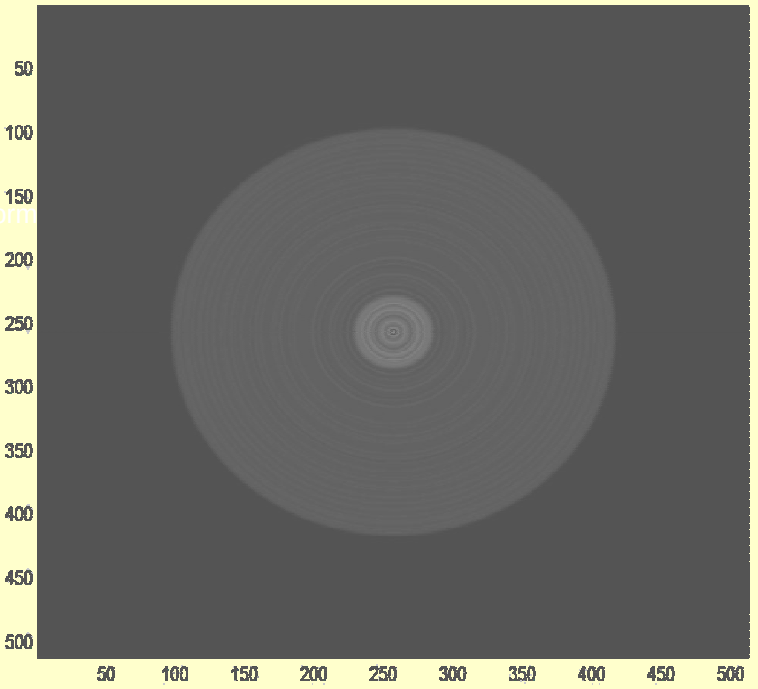
CT-numbers calculation chain



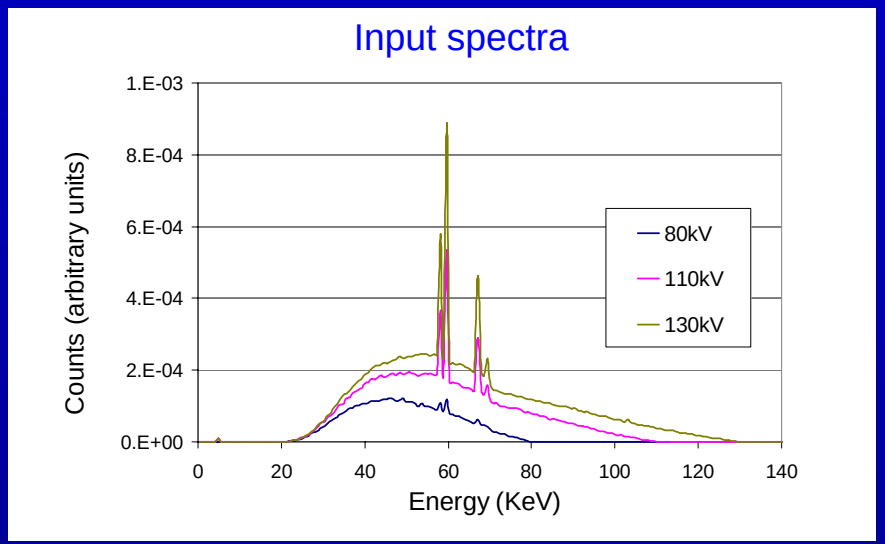
Projections and images

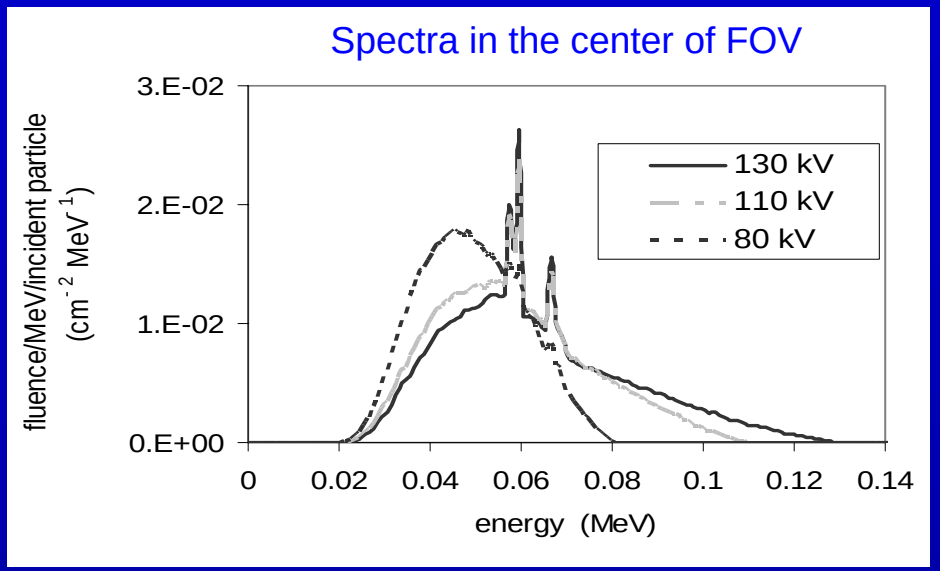
Single projection → Matrix – image

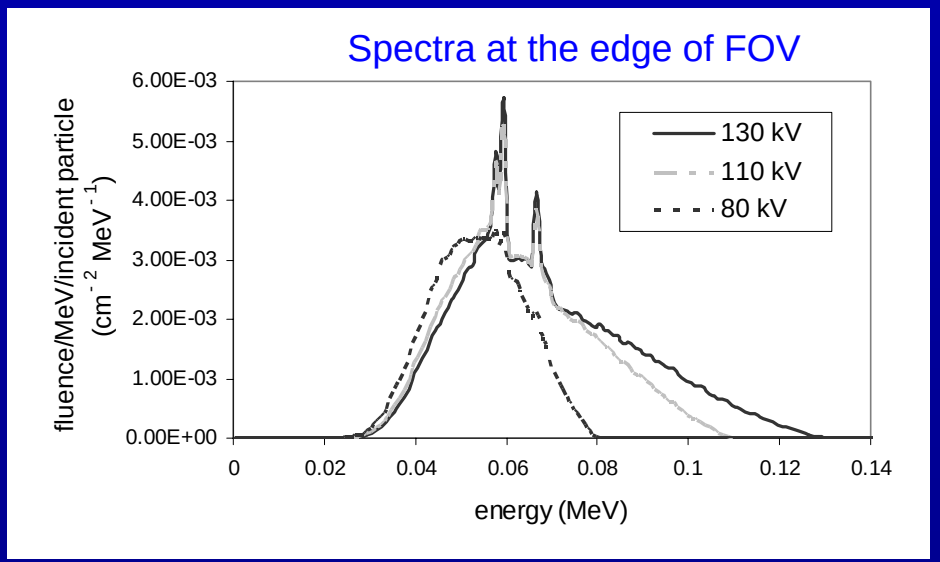




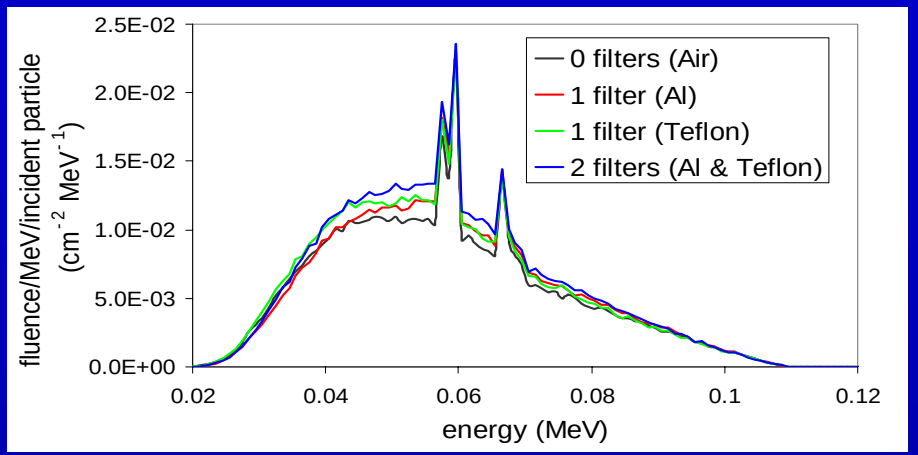
Input CT-spectra calculated for the Emotion CT-scanner with DURA352 X-ray tube for 80, 110 and 130 kV

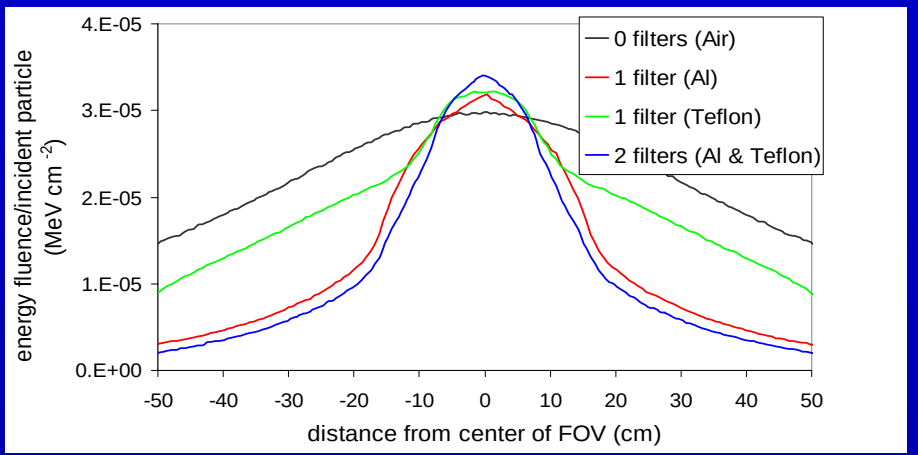


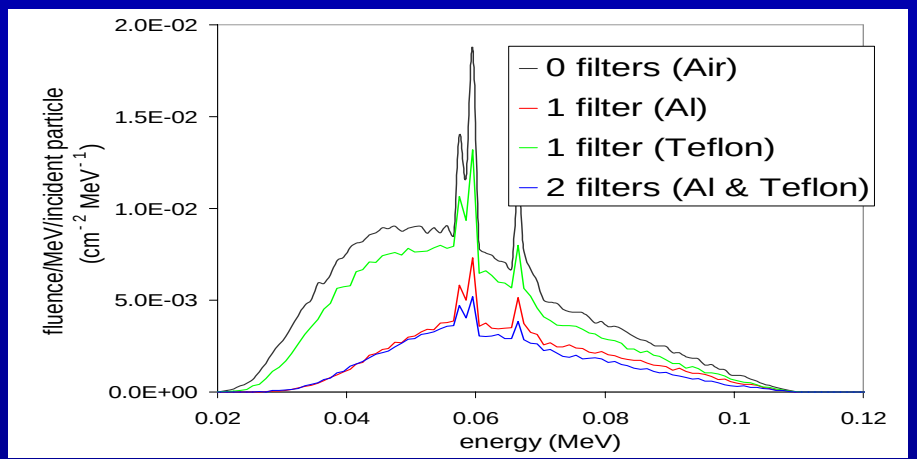


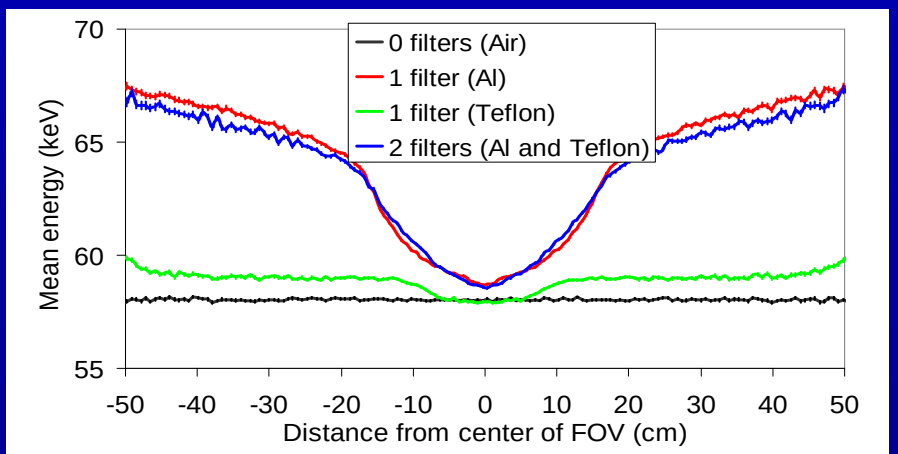


The effect of filters (Aluminium and Teflon) on the fluence and mean energy of the spectrum were investigated using 110 kV spectrum



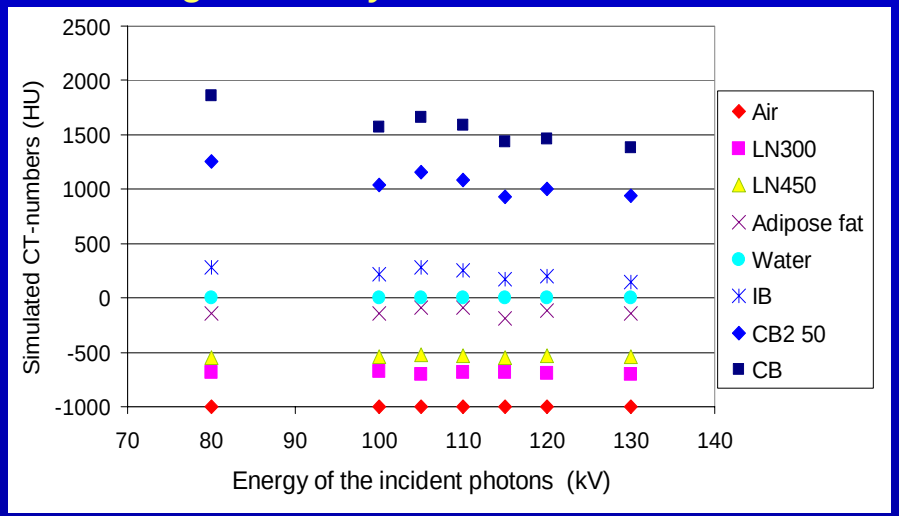




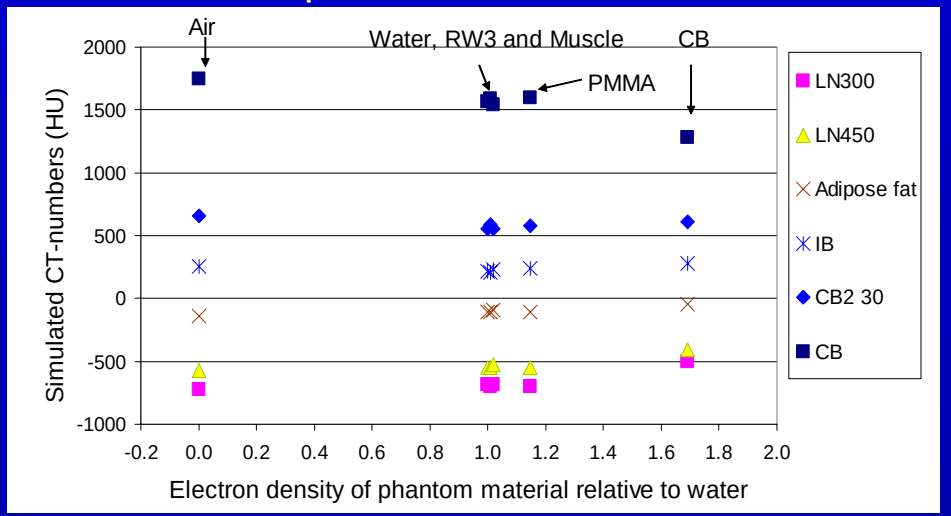


Simulated effects

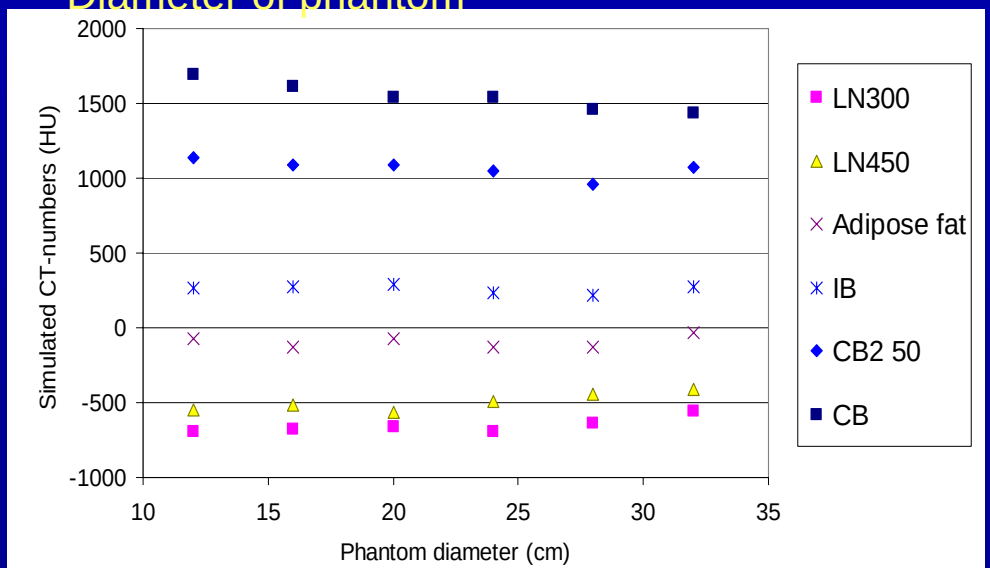
Voltage of X-ray tube



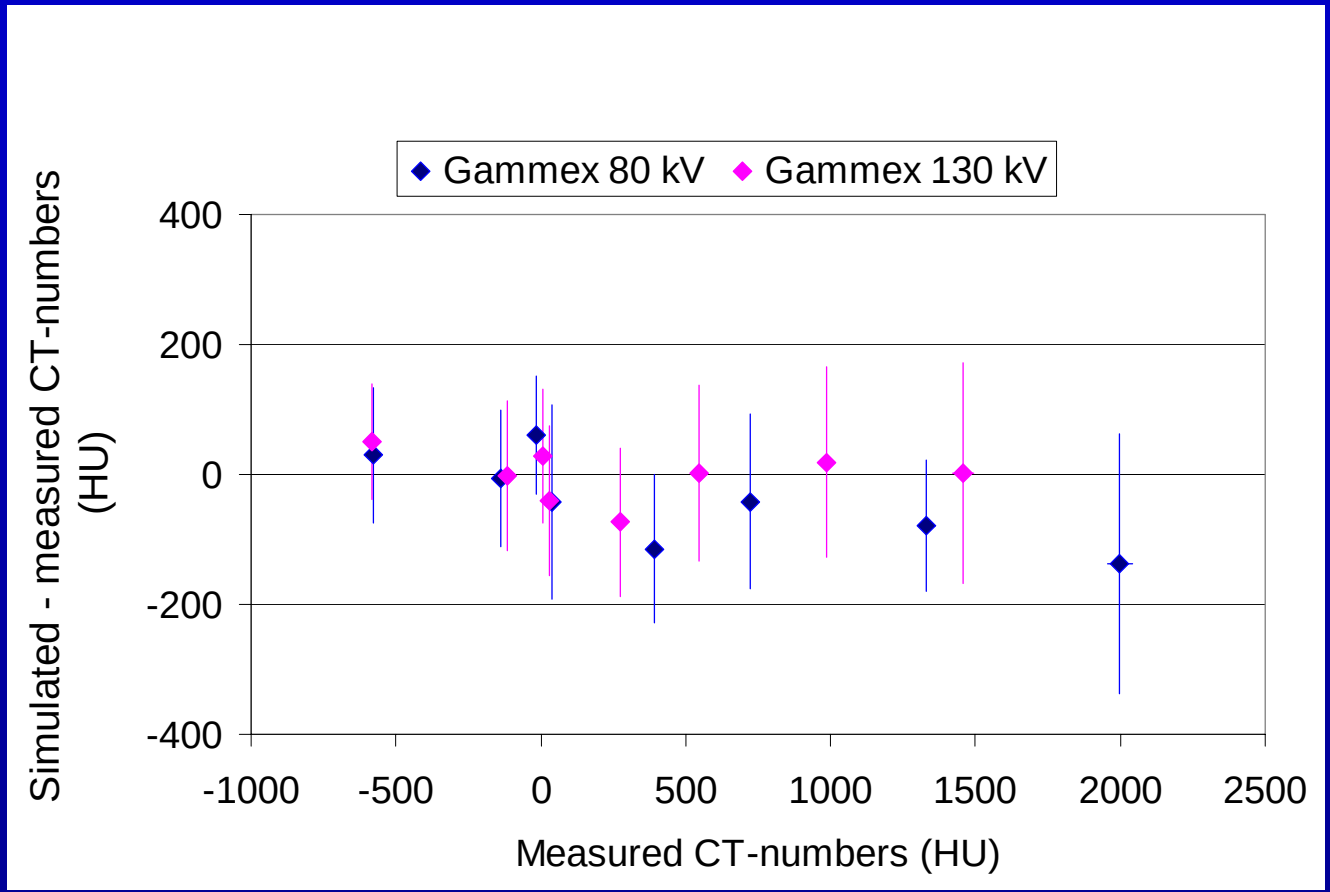
Material of phantom



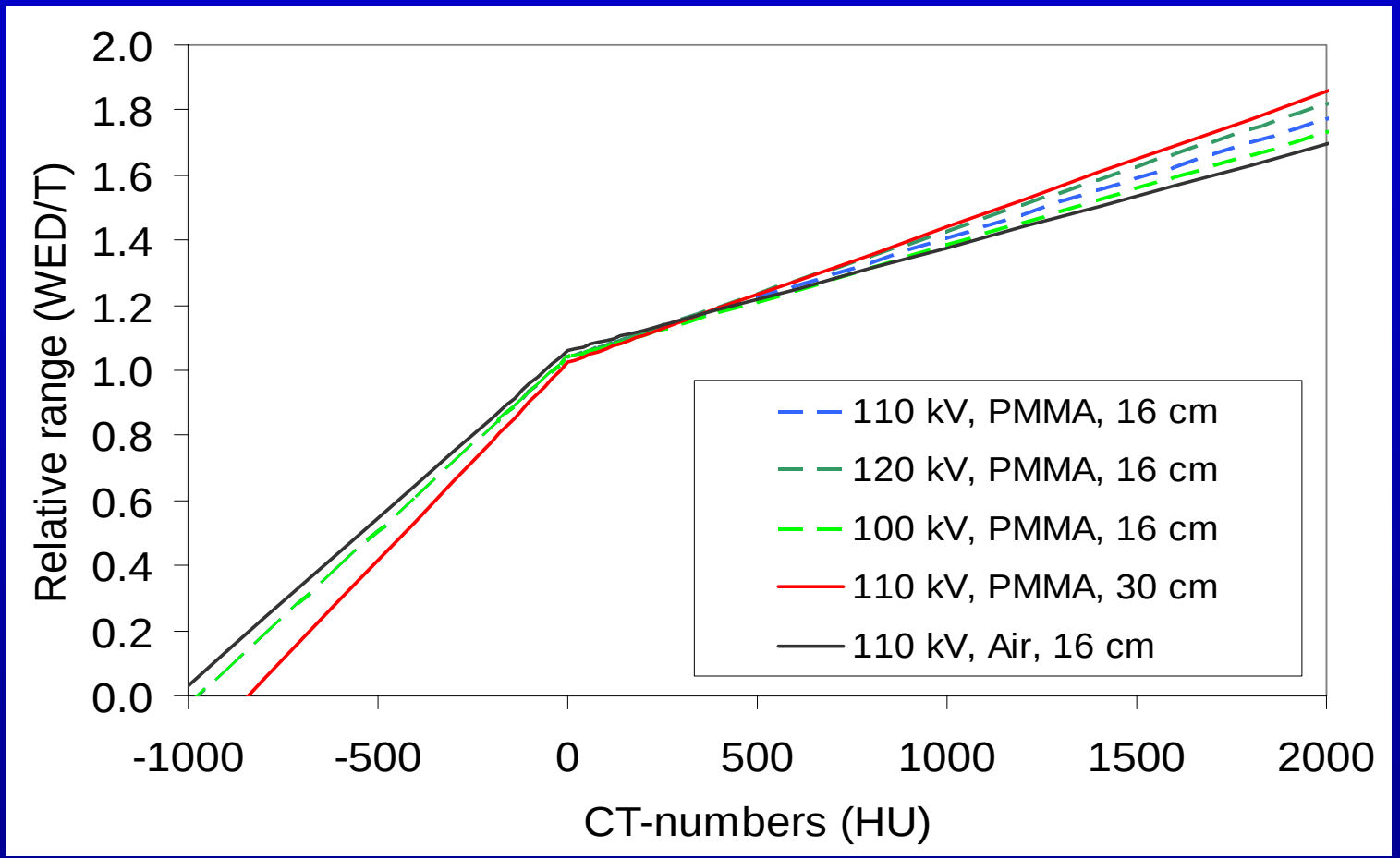
Diameter of phantom



Comparison of simulated and measured CT-numbers



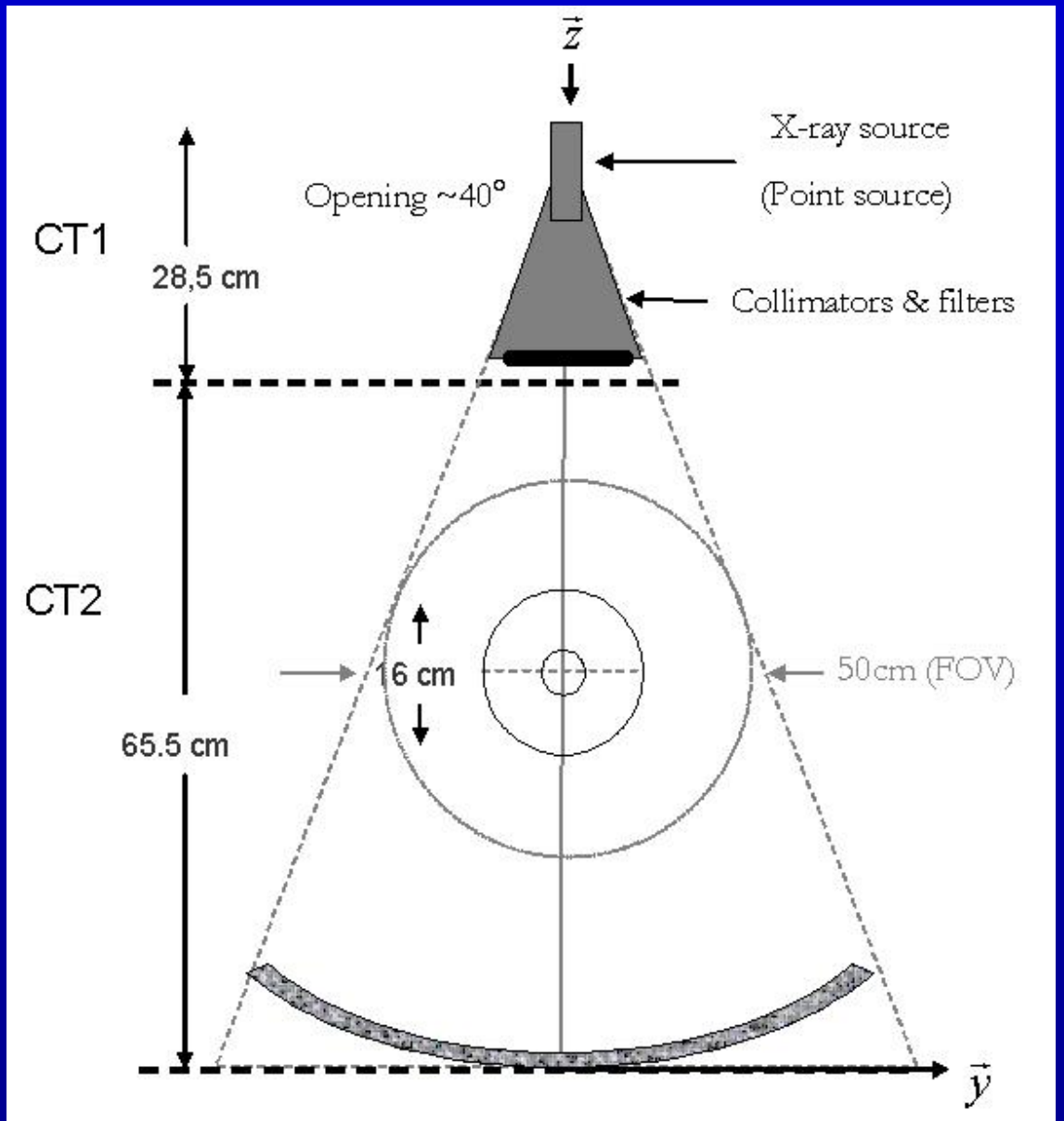
Effect of voltage, phantom size and phantom material on Carbon range



Conclusions

- It is POSSIBLE to calculate CT-numbers from MC simulation
- The presented method was used to calculate the effects of different measurement parameters on CT-numbers and Carbon range
- It is necessary to improve the effeciency of the MC simulation to use more than one projection for reconstruction (time needed for each projection is 1-3 hrs of CPU time) to decrease the uncertainties of calculted CT-numbers
- The simulation can not be used to calculate CT-numbers of irregular or off-center objects

Scheme of CT-scanner and phantom



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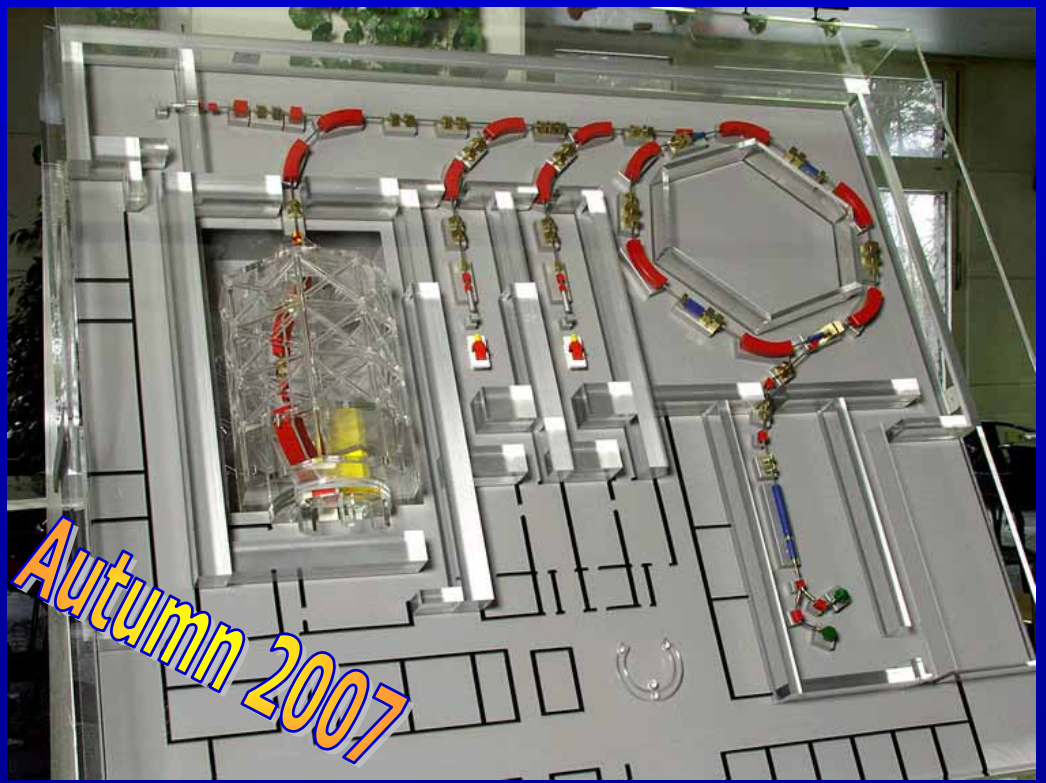
Thank you for your attention

Clinical Ion Therapy facility in Heidelberg (HIT)
University Heidelberg / GSI / DKFZ
1000 patients / year
p, He, C, O



Questions ???