Principles of CT scan (Item No.: P2550500)

Curricular Relevance

Area of Expertise: ILIAS | **Education Level:** Physik | **Topic:** Hochschule | **Subtopic:** Moderne Physik | **Experiment:** Röntgenphysik

Difficulty

Difficult

Preparation Time

1 Hour

Execution Time

2 Hours

Recommended Group Size

2 Students

Additional Requirements:

- PC
- Sample for CT

Experiment Variations:

Keywords:

Detector calibration, saturation, CT acquisition, CT reconstruction

Overview

Short description

Principle

X-ray computed tomography consists of using X-rays that are converted to a digital signal by a detector and computational algorithms to calculate virtual sections through an object without the need to physically cut them. With this data it is possible to generate 3D representations of the sample under investiga-tion. Both from the external as from the interior of the sample.

Fig. 1: Experimental set-up

Equipment

Position No.	Material	Order No.	Quantity
1	XRE 4.0 X-ray expert set, with tungsten tube	09110-88	1
2	XRCT 4.0 X-ray Computed Tomography upgrade set	09180-88	1

Tasks

1. Perform a CT scan.
2. Define the reconstruction parameters.
3. Investigate the reconstructed volume.

Set-up and Procedure

Set-up

Attach the XRIS to its stage.

Place the Digital X-ray detector XRIS on the rail at position $30\,\mathrm{cm}$. The back side of the XRIS stage corresponds to its position on the rail. This position is called the 'source to detector distance' SDD (mm).

Connect the usb cable between the detector and the computer.

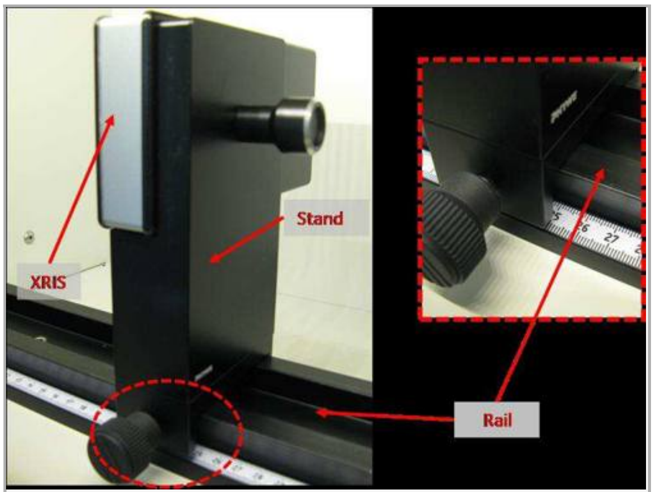

Fig. 2: Set-up of the XRIS

Place the rotation stage XRstage on the rail at position $25\,\mathrm{cm}$. The back side of the XRstage corre-sponds to its position on the rail. This position is called the 'source to object distance' SOD (mm).

Connect the XRstage cable with the 'Motor' connection block in the experiment chamber. Attach the sample table to the XRstage with the fastening screw.

Connect the X-ray unit via USB cable to the USB port of your computer (the correct port of the X-ray unit is marked in Fig. 3).

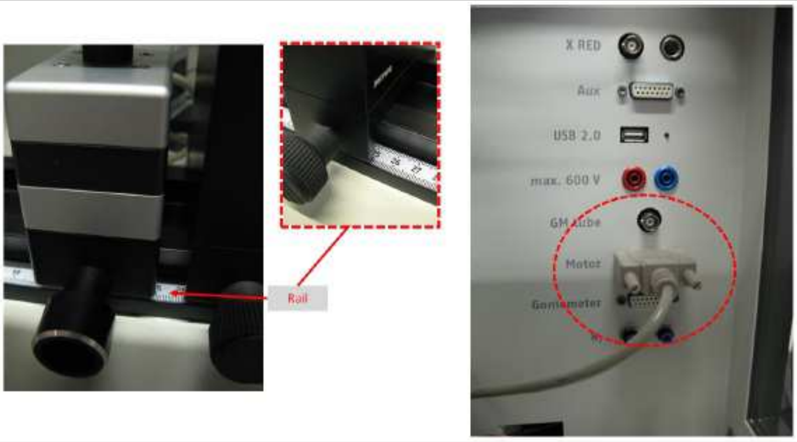

Fig. 3: Set-up of the XRstage

Fig. 4: Connection of the computer

Procedure

- Start the “measureCT” program. A virtual X-ray unit , rotation stage and Detector will be displayed on the screen. The green indication LED on the left of each components indicates that its presence has been de-tected (Fig. 5).
- You can change the High Voltage and current of the X-ray tube in the corresponding input windows or manually on the unit. (Fig. 5).
- When clicking on the unit pictogram additional infor-mation concerning the unit can be retrieved (Fig. 5).
- The status pictogram indicate the status of the unit and can also be used to control the unit such as switching on and off the light or the X-rays (Fig. 5).
- The position of the XRIS and XRstage can be ad-justed to its real position either by moving the XRIS pictogram or by filling in the correct value in the input window. (Fig. 5).
- The settings of the XRIS can be adjusted using the input windows. The exposure time controls the time between two frames are retrieved from the detector, the number of frames defines how many frames are averaged and with the binning mode the charge of neighbouring pixels is averaged to reduce the total amount of pixels in one frame.

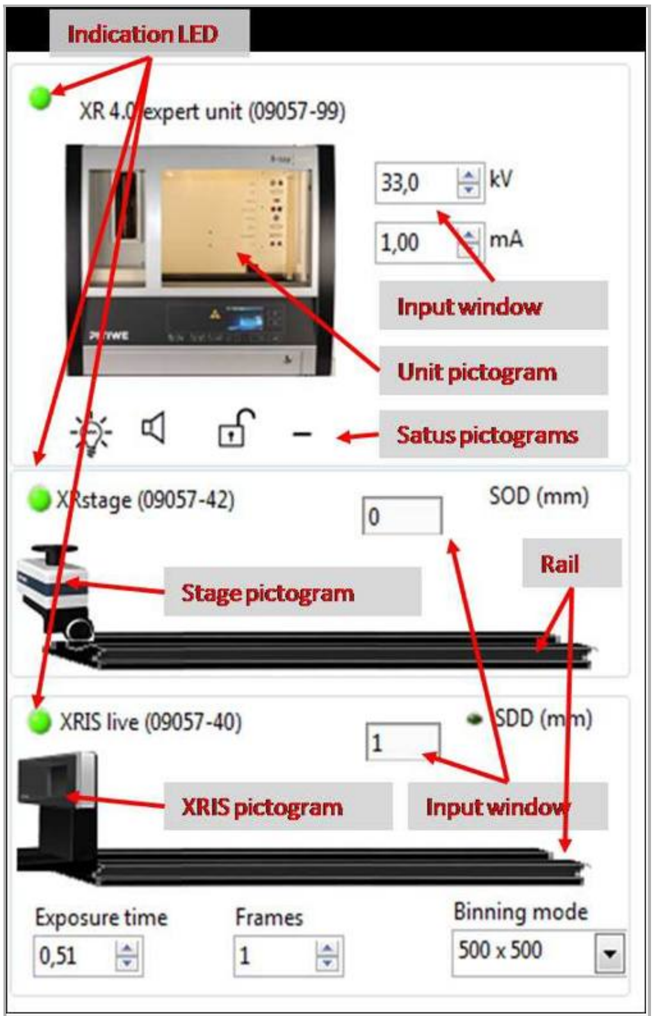

Fig. 5: Part of the user interface of the soft-ware

Experiment execution

1. Perform a CT scan

- Adjust the XRIS settings and X-ray unit settings according to Fig. 6 or load the configuration from the predefined CTO file 'Experiment 5' (see Fig. 6).

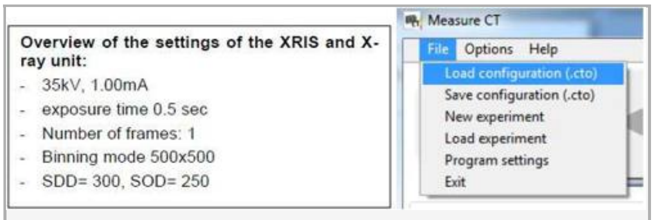

Fig. 6: The settings for this experiment (left panel) and the method load and adjust the settings (right panel)

- Start a new experiment, give it a unique name and fill in your details (Fig. 6). Alternatively it is also possible to load this experiment with pre-recorded images and open this manual. The correct configuration will be loaded automatically as well but the functionalities of the software will be lim-ited to avoid overwriting the existing data.

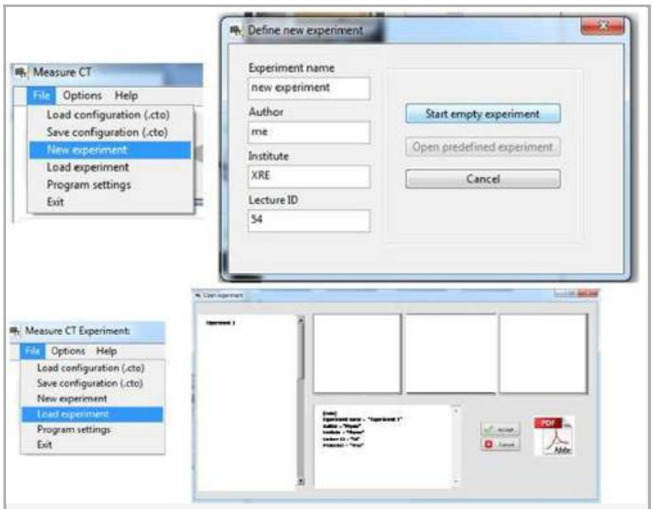

Fig. 7 How to create a new or open an existing experiment

- Switch on the X-rays (Fig. 8.1) and activate the 'Live view' (Fig. 8.2). When the Live view is activated, every new image that is retrieved from the X-ray detector is displayed. The Detector exposure load bar (Fig. 8.3) indicates the average degree of fill for each pixel. **It is very important to remain be-low the maximal fill degree of the detector**. Otherwise the detector will be saturated and won't work properly. If the saturation level is reached, the 'detector exposure' load bar will turn red. (see experiment 1 for more details)
- Calibrate the detector by clicking on "Calibrate'(Fig. 8.4). When the calibration is successfully per-formed, the indication LED (Fig. 8.5) will turn green. The Load bar (Fig. 8.3) will disappear and the Contrast/intensity cursor (Fig. 8.6) will become available. (see experiment 1 for more information)
- Place object XXXX on the sample stage and close the door.
- Adjust SOD (Fig. 8.7) and SDD (Fig. 8.8) in the software according to the actual position.

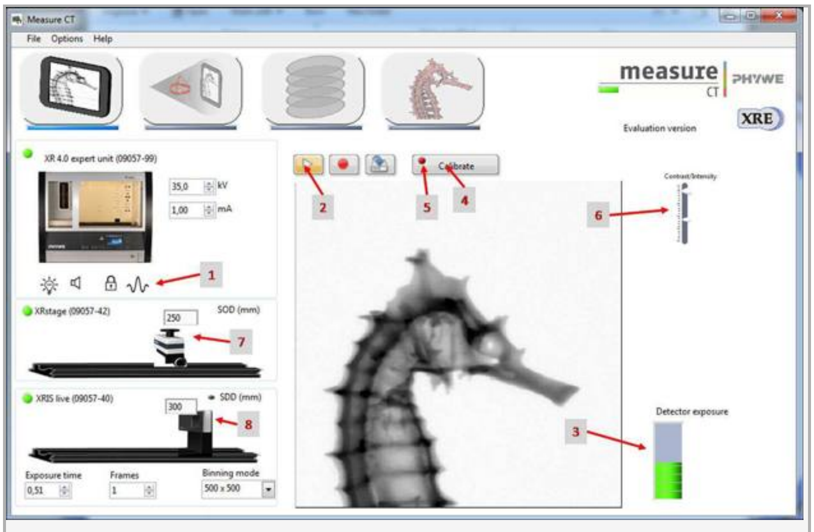

Fig. 8: Settings to set before start of a CT-scan, part 1

- Go from the "Live view page" to the "CT scanning page". The indication pictogram will turn blue when the page is activated.

Fig. 9: CT scanning page

- Start a CT scan (Fig. 10.1). During the CT scan the progress (Fig. 10.2) as well as the remaining time (Fig. 10.3) is displayed. The current image (Fig. 10.4) being recorded is shown and the temporary re-sult (Fig. 10.5) is calculated during the scan. It is also possible to track the position of the rotation (Fig. 10.6). When the scan is finished it is possible to replay the acquisition as a simulation (Fig. 10.7).

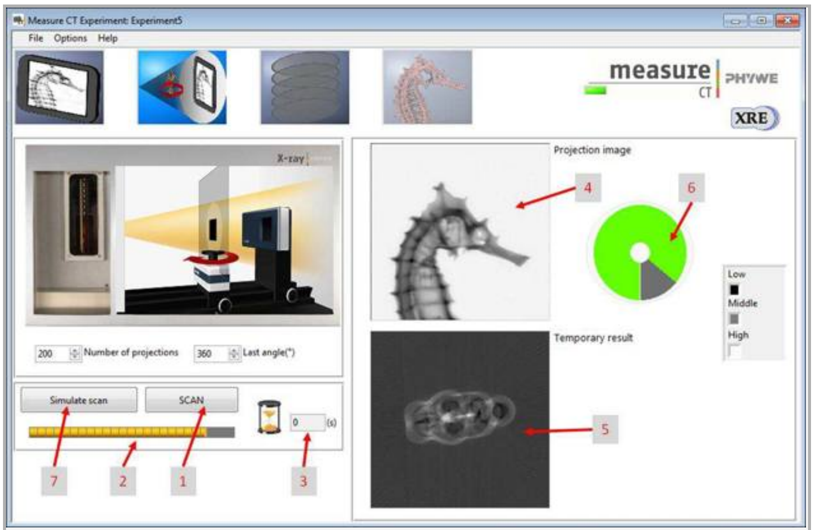

Fig. 10: Start a CT-scan

- When the CT scan is finished it is possible to proceed to the reconstruction. Go from the "CT scanning page" to the "Data reconstruction page". The indication pictogram will turn blue when the page is activated.

Fig. 11: Data reconstruction page

2. Define the reconstruction parameters

Prior to reconstructing the entire volume, it is important to define the correct reconstruction parameters. When the XRstage or the XRIS are moved, slight changes to the parameters will occur. For the best re-constructions it is advisable to test the parameters.

- The effect of the reconstruction parameters can be tested with the test button (Fig. 12.1). The result is displayed (Fig. 12.2) for a certain slice (Fig. 12.3) which corresponds to a certain line of the detector (Fig. 12.4). The SOD and SDD (Fig. 12.5) parameters should not be altered if they correspond to the physical position of the XRstage and XRIS. The most important parameter is the 'Centre of rotation' (Fig. 12.6).

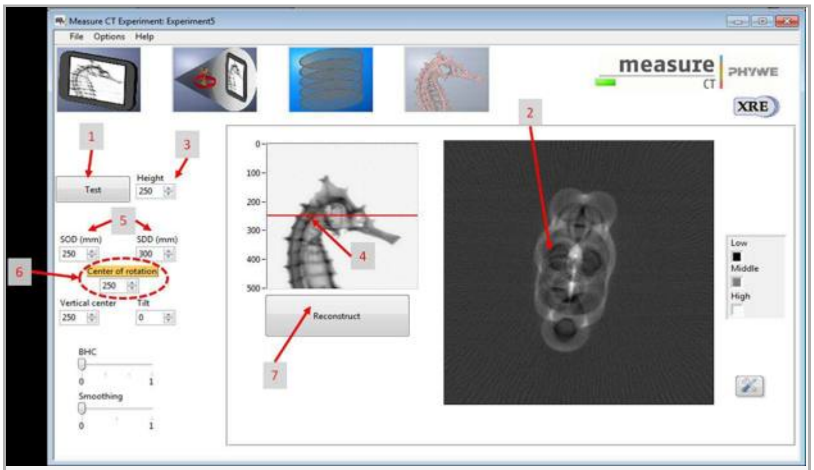

Fig. 12: Data reconstruction page and buttons

- The centre of rotation relates to physical rotation axis. Ideally, this is identical to the central column of pixels (250 for binning 500x500) but it might be different. Modify this value (Fig. 12.6) and click on test (Fig. 12.1), the adjusted result is shown (Fig. 12.2). Change this value until the result looks sharp (Fig.13).

Fig. 13: Optimise the result by changing the Centre of rotation

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- With the remaining parameters it is possible to optimise the quality of the results (see experiment 7). When the result looks satisfying press 'reconstruct' (Fig. 12.7). The software will now reconstruct all slices of the recorded volume from top to bottom. the result are displayed (Fig. 12.2) while it pro-gresses (Fig. 12.3 and Fig. 12.4).

3. Investigate the reconstructed volume

- When the reconstruction is finished it is possible to investigate the reconstructed volume. Go from the "Data reconstruction page" to the "Volume Viewer page". The indication pictogram will turn blue when the page is activated.

Fig. 14: Volume viewer page

- In the volume viewer the 3D dataset is displayed in 4 views. In the 'Axial', 'Saggital' and 'Coronal' view windows (Fig. 15.1), three slices in different directions through the volume are shown according to the slicer indicator (Fig. 15.3). When this indicator is moved around in either one of the three views, the corresponding slice is updated in the two other views. The fourth window (Fig. 15.2) dis-plays a 3D representation of the volume, by moving the 'projection angle' cursors (Fig. 15.6) , views from another direction are calculated. It is also possible to generate more elaborate 3D views with the third party freeware Volview by clicking on the Volview button (Fig. 15.7).

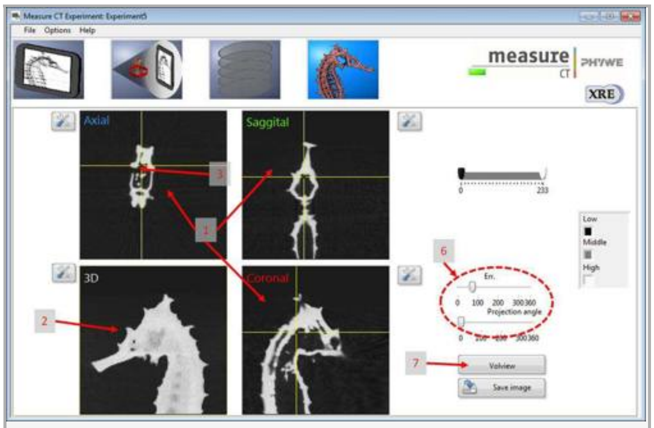


Fig. 15: Volume viewer page and buttons

Theory

Detector saturation

With digital X-ray imaging, X-ray photons that interact with the detector are converted to a digital signal. Such a digital detector is composed of a raster of pixels (picture elements) and each pixel can be con-sidered as bucket. For each interaction of an X-ray photon with the detector, a series of electrons are produced in the pixel corresponding with the location of the photon interaction. These electrons are stored in the pixel, gradually filling up the bucket. After a set time interval, "**exposure time**", the electron content of the pixel is measured by emptying it. For the same intensity of X-ray's, a longer exposure time will results in a larger number of pixels in the bucket.

Each digital detector has a limited bucket size which is called the '**full well capacity**' of the detector. When this level off fill is reached, additional electrons are thrown away because the detector is saturat-ed. A saturated detector will cause inconsistent measurements and has thus to be avoided.

Detector calibration

Each digital detector has a different and variable offset and pixel-specific output. During the calibration these variations will be measured and used in the subsequent imaging.

Even without the X-rays on, the detector will generate a read-out value that is different from 0, called 'dark image'. This has several reasons from which the main reasons are an electronic offset and read-out noise. When determining the beam intensity I_0, it is important to subtract this offset (I_D) from the measured read-out ($I_{0,M}$).

$$I_0 = I_{0,M} - I_D$$

Another issue that exists, is that the sensitivity of every detector pixel is slightly different, resulting in a wide variation of I_0 values for every pixel. During calibration, these variations are recorded.

After calibration, the Transmission value for every pixel (I) is recalculated based on the beam intensity of that pixel at that time (I_M), the beam intensity during calibration($I_{0,M}$) and the dark current intensity (I_D) during calibration.

$$T = \frac{I_M - I_D}{I_{0,M} - I_D}$$

If the calibration was successfully performed, after calibration the images have grey-values between 0 and 1.

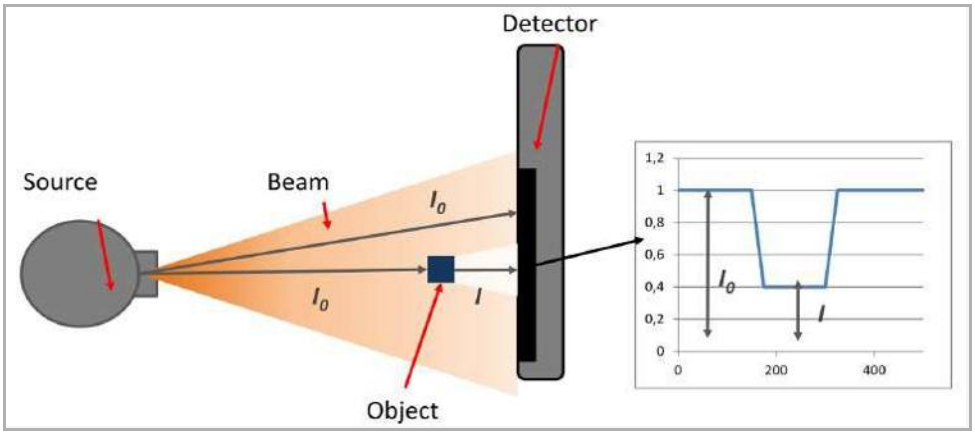
Transmission and Attenuation

In X-ray imaging, the transmission or attenuation of X-rays through a certain object are measured. De-pending on the settings of the source, a beam with a certain intensity I_0 is measured by the detector when no object is placed between the source and the detector. When an object is placed in the path of the beam, this object will attenuate the beam so that the detector measures a smaller intensity I instead of I_0. The remaining intensity I compared to the original I_0 is called transmission (T), which is the opposite of the attenuation (A) of the object.

For a calibrated detector, the beam intensity is rescaled to a value between 1 and 0. With $T = 1$ for the beam without an object in front of the detector (I_0).

$$T_{obj} = \frac{I}{I_0} = 1 - A_{obj}$$

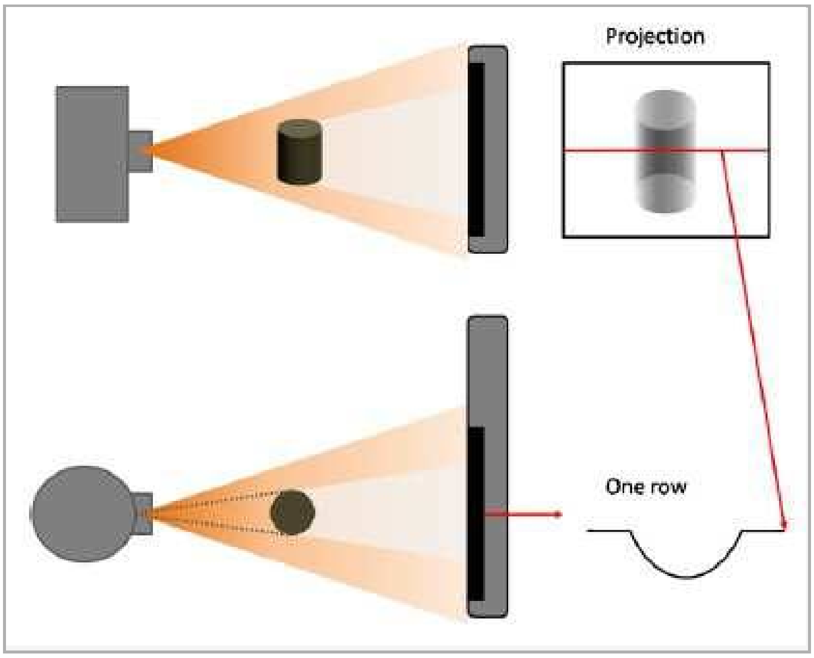
$$A_{obj} = \frac{I_0 - I}{I_0} = 1 - T_{obj}$$



CT scan and reconstruction

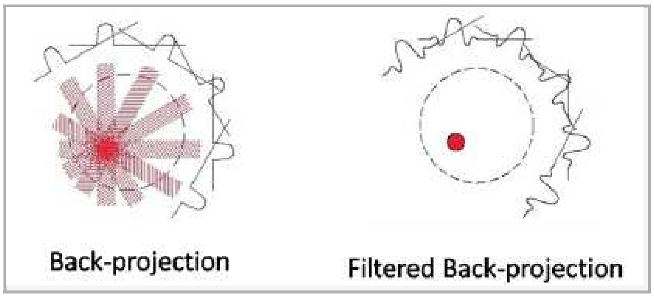
When a CT scan is performed, several radiographies (projections) are recorded at different angles through the sample. By having data about the transmission of the object under different angles it is pos-sible to calculate the µ value at each location in the sample.

If we have for example a cylindrical object, one detector row will have a profile corresponding to picture xxx.



During the reconstruction process, the information of the two images are back-projected in a virtual array and the signal of each of the projections is summed.

The more projections are taken, the more correct the result will be. However, it has been proven that this back-projection and summation is not analytically correct. Therefore the projection data first has to be filtered before being back-projected and summed.



When the reconstruction of one detector row over 360° is successfully performed, the result is one virtual slice through the object. This slice is often saved as a single image and each pixels of the image actually represents one voxel (volume element) of the object. The grey-value of that voxel corresponds to the calculated μ-value of the sample.