Progress Report

Long term project MD 78

Beam line ID 17

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First period Spring 2004, beam time March 12, 8:00 to March 17, 8:00

Title: ***"Di-chromatic angiography and fluorescence imaging, a new non-invasive diagnostic method and first application for dynamic measurements of cardiac function***

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1. Scientific program

In this first exploratory phase two main subjects are investigated, both related to new detectors and methods:
a) Improvement of precision for coronary angiography using gadolinium based contrast agent. Although the higher available flux at the imaging detector (multi-cell Ge detector) allows higher precision of the absorption measurement, the remaining beam fluctuations – for the iodine measurements still tolerable – become a major limitation of the method. These fluctuations are due to floor vibrations that couple into the bent Laue monochromator system. Interferometric vibration measurements have shown a strong amplification in the crystal support structure with strong low frequency components ranging from 20Hz – 100Hz. Moreover, rotational modes in the monochromator crystal produce inhomogeneous angular variations along the horizontal beam profile. The accompanied intensity fluctuations increase with energy. A time dependent flux measurement at the entrance of the object is necessary. It could be shown, that the beam profile is well described with a polynomial of 8^{th} order. Therefore a new ion chamber for monitoring the beam intensity with 2 x 8 segments (for both energies separately) has been installed and tested and new correction software has been developed. Test measurements with a phantom have been carried out.

b) Investigation of the method of florescence tomography. The method relies essentially on the separation of the fluorescence radiation emanating from Gd from the background, mainly from elastic scattering and fluorescence of other material. Measurements with a Xe proportional counter for the spectra have been carried out. A newly developed collimator has been tested.

c) A prototype of a multiwire chamber (16 wires) with a sensitive area of 50 x 500 mm^2 for imaging has been tested at the beam. Since the detector is operated with Xe at elevated pressure a closed gas system has been tested including an evacuation and filling procedure. Safety aspects have been observed and it could be shown that a non-inflammable gas mixture (Xe/CO_2) can be used.

2. Set up for measurements.

a) Multi-cell ion chamber with test phantom

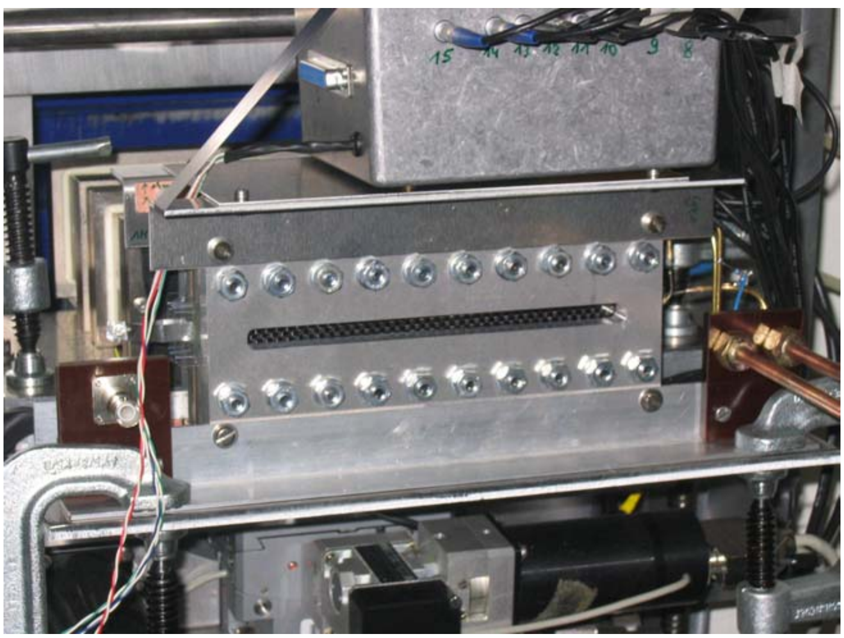


Fig. 1. Multicell ion chamber (2 x 8 channels) mounted at beam entrance to experimental area

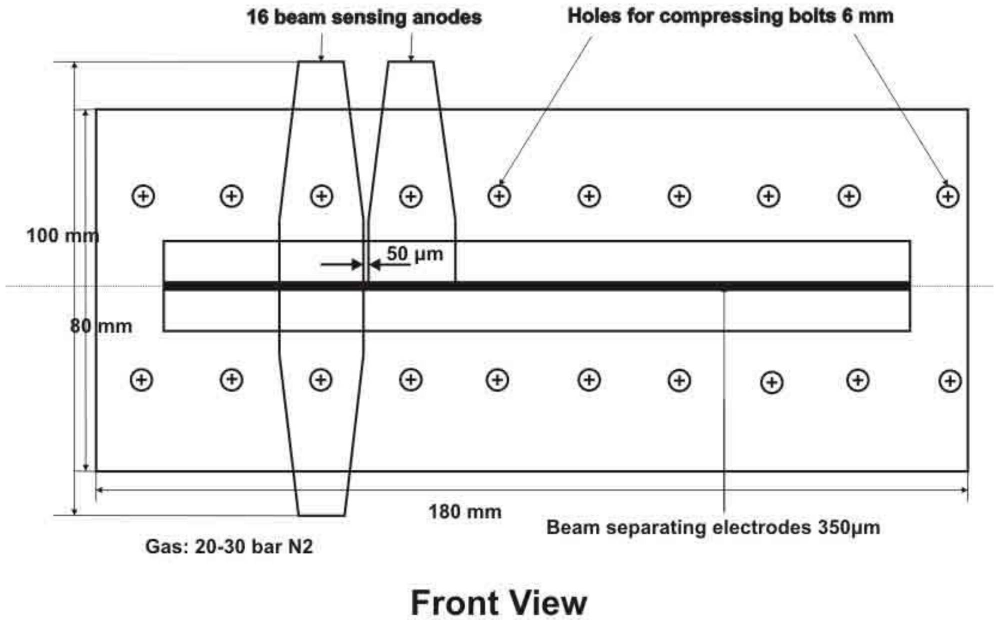


Fig. 2. Principle of multi-cell ion chamber.

Fig. 3. Phantom for Gd-contrast measurement. A staircase structure filled with contrast medium (optically enhanced by coloring) represents the ventricle filling, tubes

the arteries (diameters from 2 mm to 8 mm) and a water reservoir the absorption in the body.

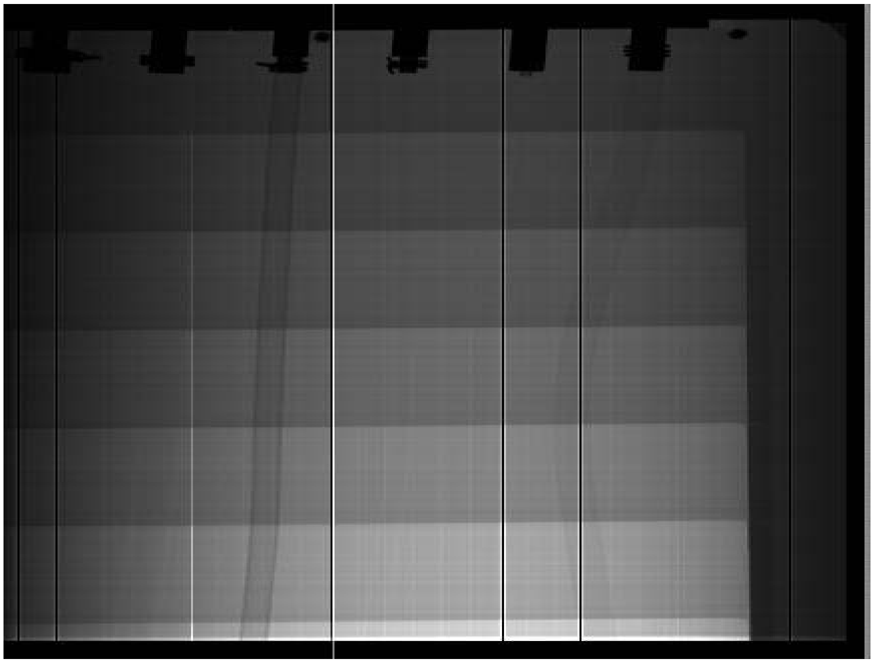


Fig. 4. X-ray image of phantom of fig. 3

b) Set-up for Xe proportional counter spectral measurements and projection imaging.

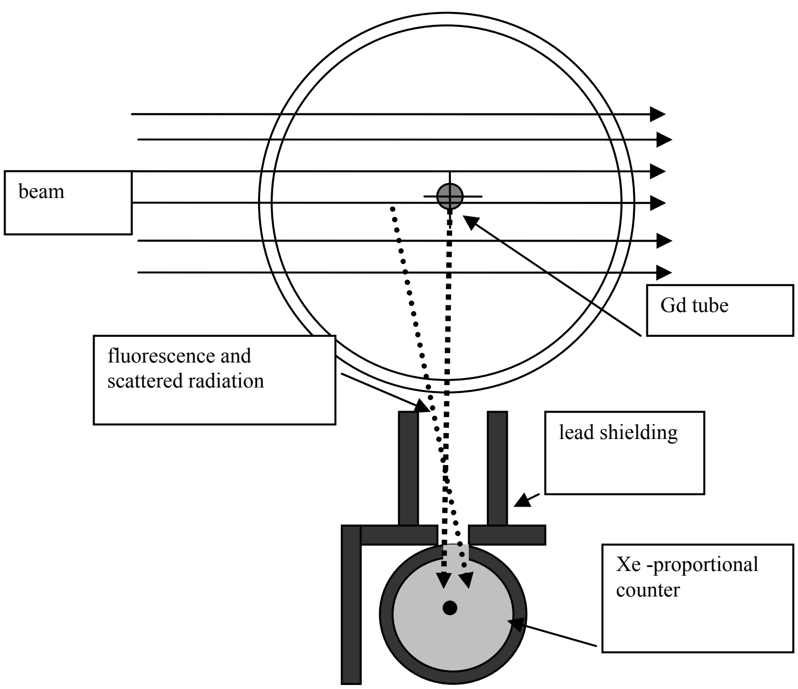


Fig. 5 Set-up for measurements of Gd-fluorescence in air. No collimator.

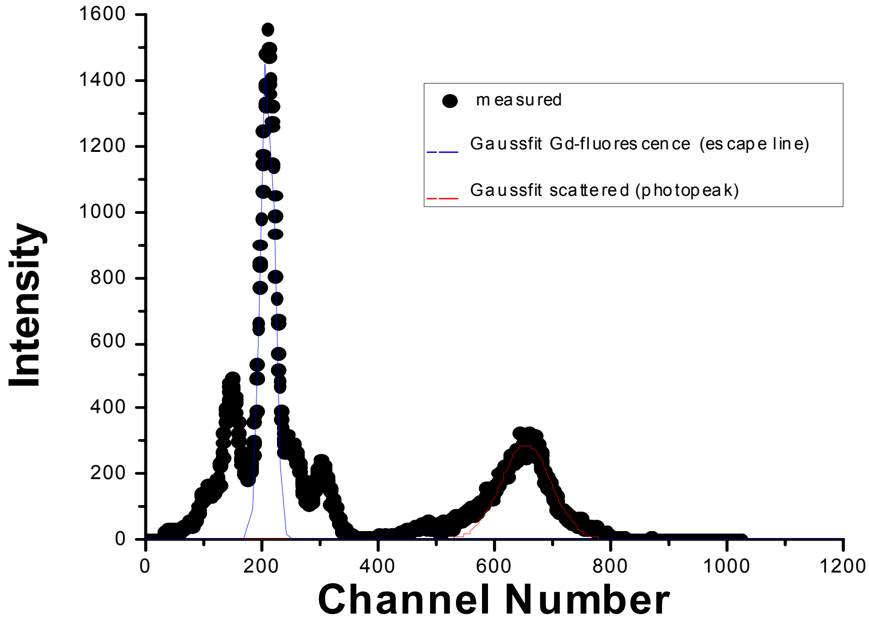


Fig. 6. Spectrum recorded with set-up of fig.1. Photopeak of scattered radiation (red) and escape peak of Gd-fluorescence (red). Other peaks see text.

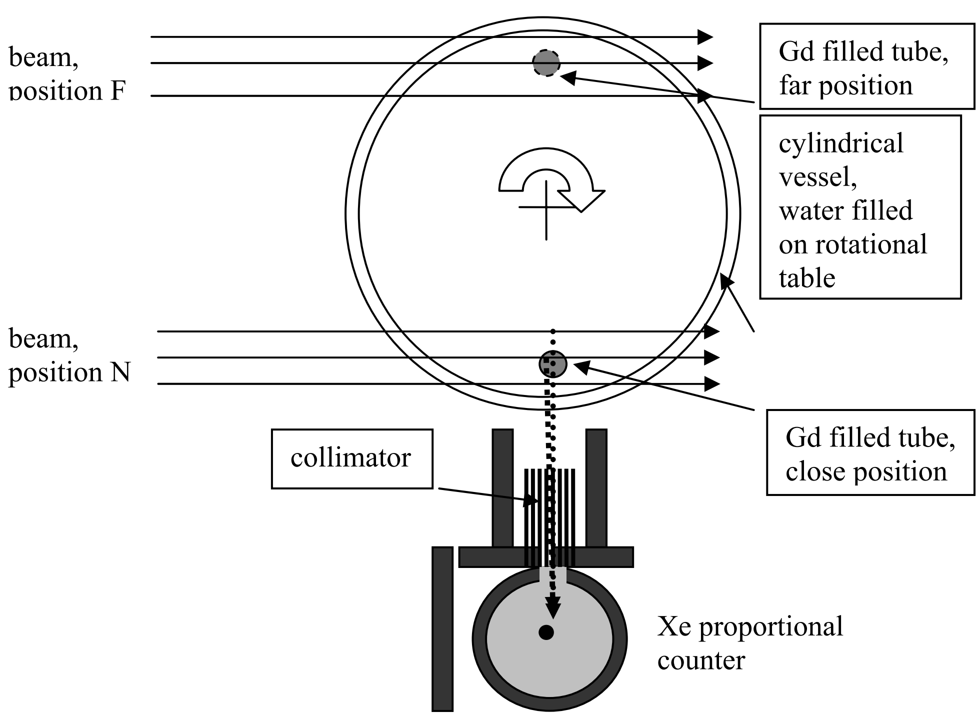


Fig. 7 Set-up for measurements of Gd-fluorescence in water using collimator. Rotation of the cylindrical vessel shows position resolution.

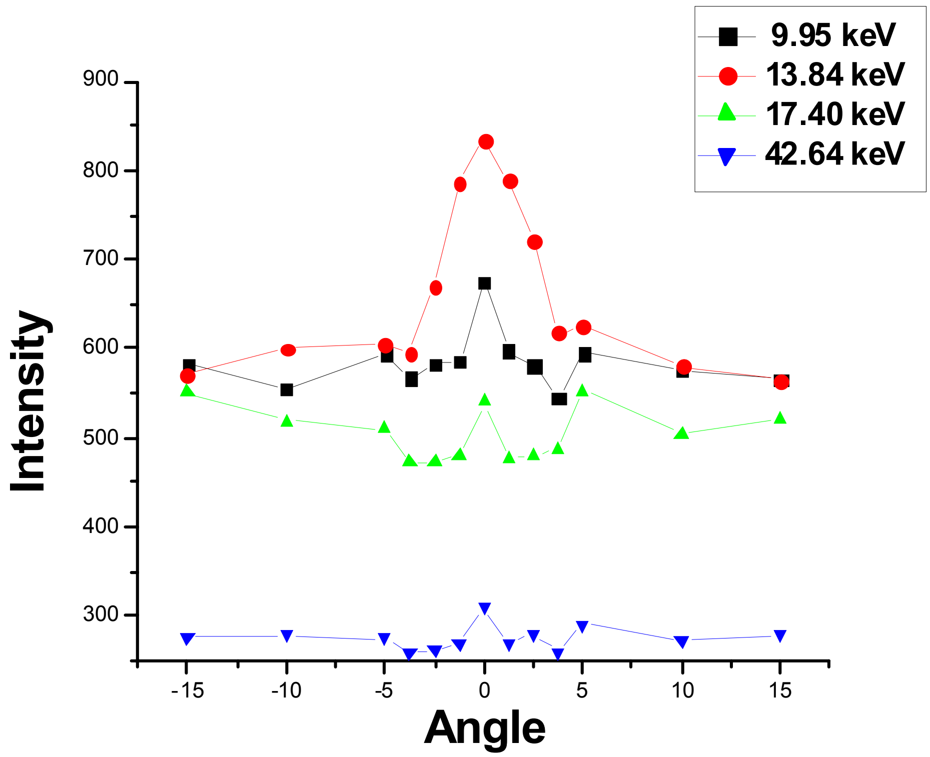


Fig. 8. Intensity recorded for Gd-sample 5 mm diam. as function of rotation angle.

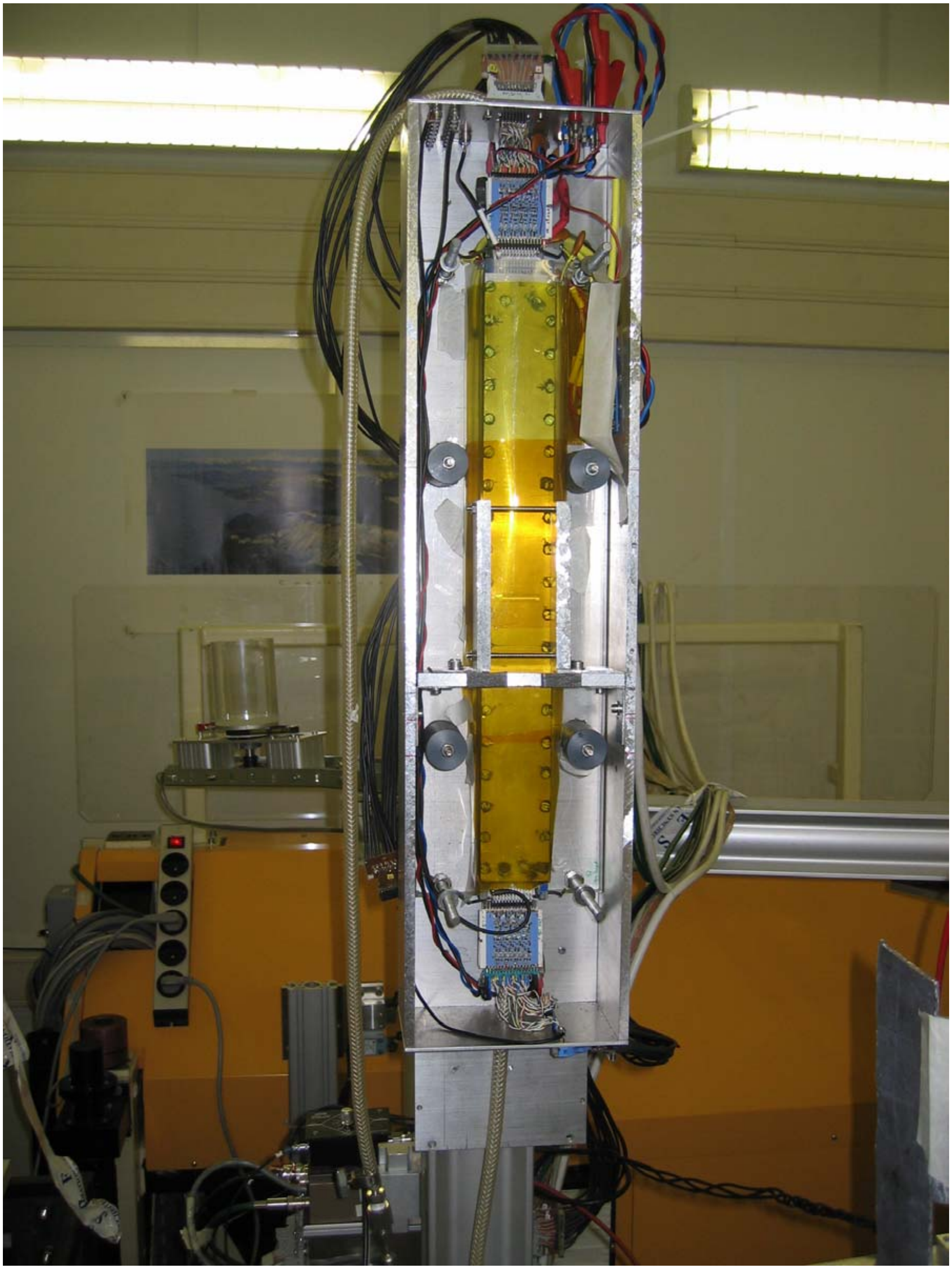


Fig. 9. 16 – channel detector for fluorescence imaging installed at beam line.

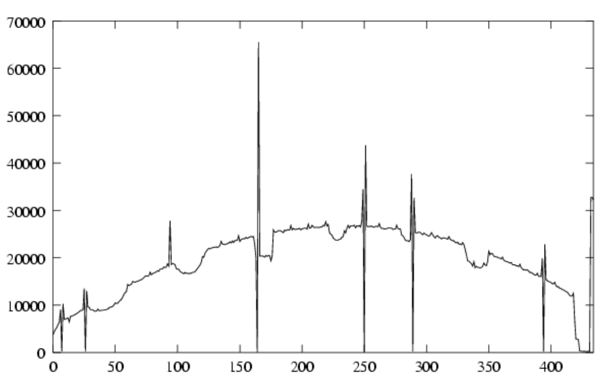
3. Discussion of results.

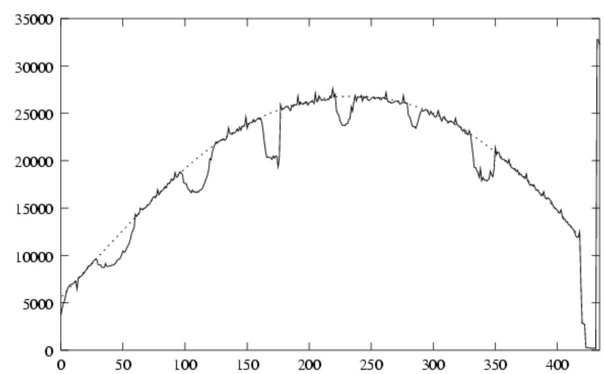
Ion chamber beam monitoring

The ion chamber has been successfully installed and tested. The required precision could be achieved with an analogue read out electronics close to the detector. For the digitization and the on-line recording difficulties have been encountered due to a large rf-pick-up. The effect has been studied in detail and the solution will be the installation of the digitization electronics near the detector and the transmission of the data via optical fiber links.

Recovery of Defective Pixels

To record absorption images a high purity germanium pixel-detector was used. However some of the pixels are defective resulting in a large systematic error with respect to the expected intensity value. To detect defective pixels a simple gradient search was performed on each intensity profile. If the gradient exceeds a given threshold the pixel is considered to be defect. Defective pixels are replaced by cubic spline interpolation. The approach is flexible enough to detect and recover adjacent measurement errors, c.f. figure 10.





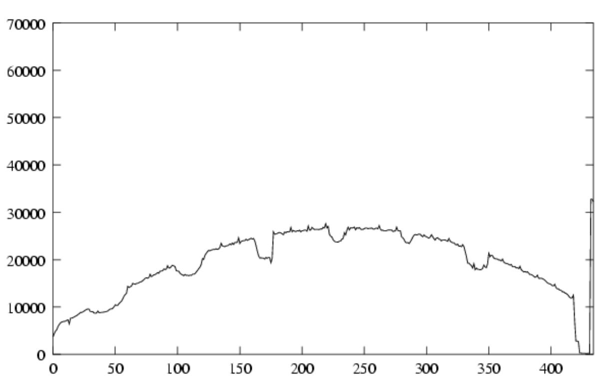


Fig. 10. Upper Left: Intensity profile of row 75 of absorption image test417_10_sc33_1.UP. Defective pixels are readily detectable.
Lower Left: Corrected intensity profile using cubic spline interpolation. Only defective pixels are corrected. Smooth intensity drop-offs are caused by absorption of contrast agent intentionally placed in the beam
Fig. 11(Right). Solid line: Corrected intensity values. Dotted Line: Approximated intensity values. A polynomial of degree 8 was fitted. r was set to 4. Intensity drop-offs were detected automatically and excluded from the fit.

Automatic Background Estimation Using Orthogonal Polynomials

At ESRF beamline ID17 it is required to obtain an exact analytical representation of the intensity profile. Due to a rapidly oscillating number of photons in the beam (see chapter 1a) the intensity profile cannot be measured separately. Moreover the cross section of the intensity profile may diverge from its parabolic shape. In our case absorption images are used to approximate the intensity profile by a linear combination of orthogonal polynomials. The weights of the least squares fitting routine are iteratively adjusted so that channels not belonging to the intensity profile are excluded from the fit. The method can readily implemented on a computer and needs little or no user supervision with respect to input and control parameters. The intensity profile is described by a set of orthogonal polynomials p_j with degree m:

(3.1) $$f(x_i) = \sum_{j=0}^{m} c_j p_j(x_i)$$

with coefficients

(3.2) $$c_j = \sum_{i=1}^{n} \frac{w_i y_i p_j(x_i)}{\kappa_j}$$

Here y_i denotes the content of channel x_i. w_i represents the corresponding weight. κ_j is a normalization constant dependent on p_j. Since the polynomial terms p_j are orthogonal no matrix inversion is required. Moreover polynomials with much higher degree can be fitted to the experimental data without running into problems with ill-conditioned normal equations and oscillating terms. The goal of the method is to fit the experimental data by a polynomial of degree m to data points belonging to the intensity profile and to interpolate under superimposed structures. This can be done by a careful manual selection of data points belonging to the intensity profile. Instead all channels are included in the fit although one has to make sure that only the intensity profile contribution is emphasized (fig. 11).

Detection of fluorescence radiation for imaging

Fig. 6 shows the spectrum recorded with the Xe-proportional counter in the arrangement of fig. 5. The expected detected x-ray lines are the 50.3 keV primary beam (elastic scattering, about channel 743), the Compton scattering (90 deg. geometry), centered around 46 keV (about channel 680), fluorescence from Gd (43 keV, channel 638) and fluorescence from other material (mostly lead, L-lines around 10.5 keV, channel 155). The lines around 50 keV are accumulating in the photopeak E_{ph} and cannot be separated. However, the escape of the Xe-fluorescence (29.779 keV) shift the whole spectrum by about this amount to lower energies producing the escape peaks with E_{escape}. Now the peaks are separated since the relative resolution has improved by a factor k = $\sqrt{E_{escape}/E_{ph}}$ such that the elastic peak (channel 303) the Gd K_α fluorescence (channel 200) and even the Compton scattering shows on the upper shoulder of the Gd –peak (channel 250). The L – lead fluorescence is unaffected and well separated.

Projection measurements have been performed with the set-up of fig. 7 discriminating on the Gd-fluorescence. A Gd-filled tube (5mm diam) has been moved in front of the imaging collimator (angular resolution 1.1 deg). As expected, the Gd-fluorescence line (13.4 keV) shows the strongest variation and reproduces with a width of 4.7 deg. (fwhm) the convolution of the resolution and the tube width. This is an important result confirming the expectation that the spatial resolution of the order of 1..2 mm will be achieved in later applications. Other lines show small variations which may be due to the simple data analysis (only the peak values instead of the integral of Gaussian fitting curves) was used. A more detailed analysis under different scattering angels will be necessary.

The prototype of a position sensitive detector (fig.9) was successfully installed and data have been taken. Although rf-pick-up was observed (there seems to be an important rf-current flowing between different parts of the measurement hutch) the differential read out allowed first measurements. At the moment the data are still analyzed since extensive calibration of the 16 channels has to be applied.

4. Experimental program in the next run (June 16 – 21)

a) The higher resolution of the transmission measurement with Gd contrast agent will be demonstrated with a fully equipped monitoring ion chamber and the correction of beam fluctuations. The resulting precision will be used for a quantitative study of the measurement of the degree of occlusion in the coronary arteries of a test animal (2 pigs) in transmission geometry using the Ge- detector. In particular the arteries of the left CA (LAD and CX) will be investigated. First time resolved measurements of the myocard perfusion will be obtained using optimized projections and optimizing the temporal separation between images. The data will be compared to conventional, selective coronarography that will be performed on the fluoroscopy unit at ID17.

b) The spectral response of the Gd-fluorescence as compared to scattered radiation (elastically and Compton scattering) will be investigated using the Xe-proportional counter in a mounting allowing an angular scan.
The position sensitive detector with a test collimator of full length (400 mm) will be installed and simple phantoms containing Gd contrast agent will be imaged.