User guide

NM/PET-CT Quality Control
— **LIFEx** —

C. Nioche, M. Soret, and C. Comtat

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Part I NM/PET QC

Part I

NM/PET QC

Chapter 1

NM/PET calibration and uniformity QC

1.1 Goal

This Quality Control (QC) protocol allows for the assessment of the quantification accuracy and the uniformity of a cylindrical phantom filled with an uniform activity concentration. It follows the guidelines of the PET working group of the French Society of Medical Physics (SFPM).

1.2 Requirements

The QC NM/PET protocol requires that the NM/PET image is quantified in Bq per ml and contains all the information needed for the computation of the SUV: body mass, radionuclide total dose, radiopharmaceutical start time and radionuclide half-life.

The image shall contain only the uniform cylindrical phantom, oriented along the longitudinal axis (see Figure 1.1). If several images (series) are loaded, the assessed image shall be the reference image.

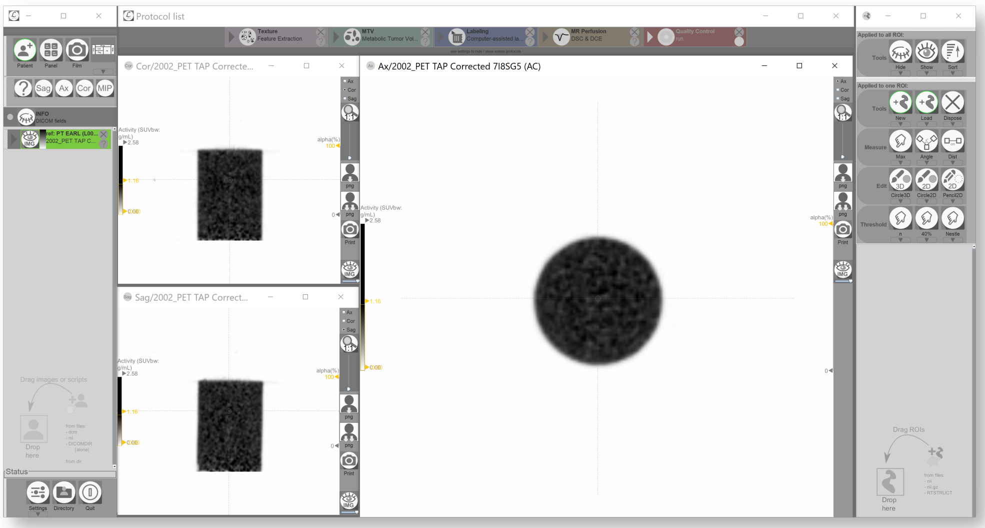

Figure 1.1: Cylindrical phantom in GUI

1.3 Image processing

The NM/PET Calibration and Uniformity QC contains two part (see Figure 1.2):

1. Axial: Calibration and axial uniformity test
2. Transverse: Transverse uniformity test

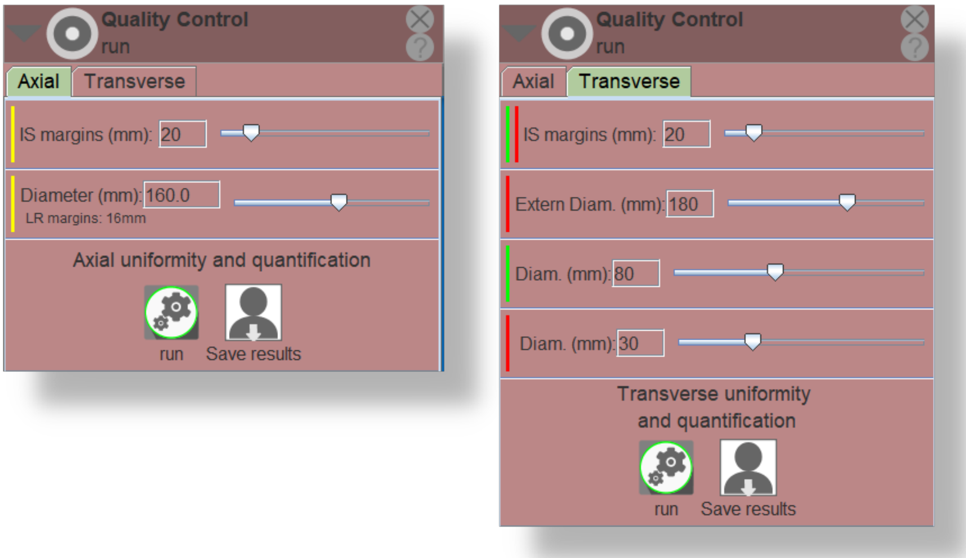

Figure 1.2: Axial and Transverse QC in GUI

1.3.1 Calibration and axial uniformity test

A centered circular ROI is automatically drawn in yellow in each slice of the cylinder (see Figure 1.3).

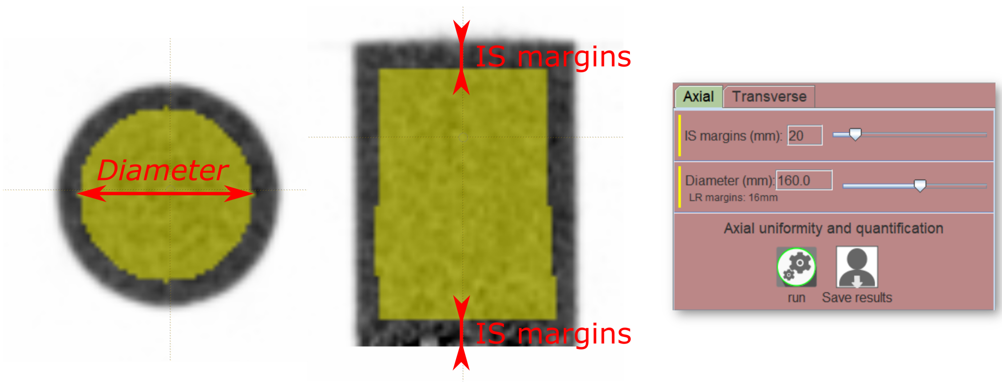

Figure 1.3: Definition of the ROIs for the calibration and axial uniformity test

The diameter of the ROI is specified in mm: $Diameter(mm)$. A typical value is 80 % of the cylinder diameter.

The extreme slices of the cylinder are excluded. The superior and inferior margins are specified in mm: $ISmargins(mm)$. A typical value is 20 mm.

The ROI mean value is automatically computed for each slice z: $ROI_{\text{axial}}(z)$. From these values, the following quantities are calculated with the *run* command (see Figure 1.4):

- the average: $\overline{ROI}_{\text{axial}} = Mean\{ROI_{\text{axial}}(z)\}$;
- the standard deviation: $\sigma(ROI_{\text{axial}}) = Standard\ deviation\{ROI_{\text{axial}}(z)\}$;
- the coefficient of variation: $c_V(ROI_{\text{axial}}) = \frac{\sigma(ROI_{\text{axial}})}{\overline{ROI}_{\text{axial}}}$;
- if the units are SUV body weight, the volumic bias: $\frac{\overline{ROI}_{\text{axial}}-1}{1}$;
- the minimum value: $min(ROI_{\text{axial}}) = Minimum\{ROI_{\text{axial}}(z)\}$;
- the maximum value: $max(ROI_{\text{axial}}) = Maximum\{ROI_{\text{axial}}(z)\}$;
- the axial integral uniformity: $IU_{\text{axail}} = \frac{max(ROI_{\text{axial}})-min(ROI_{\text{axial}})}{\overline{ROI}_{\text{axial}}}$.

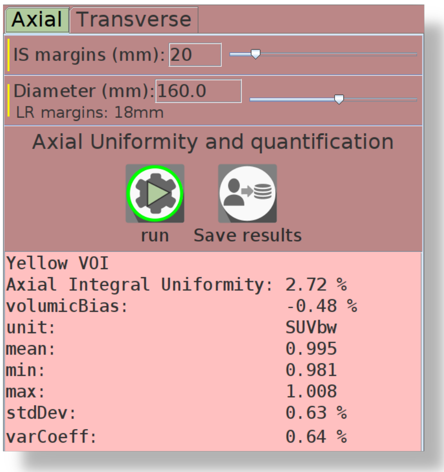

Figure 1.4: Results of the calibration and axial uniformity test

The results can be exported as a CSV ASCII file with the *Save_results* command.

1.3.2 Transverse uniformity test

A centered circular ROI in green and four peripheral circular ROIs in red are automatically drawn in each slice of the cylinder (see Figure 1.5).

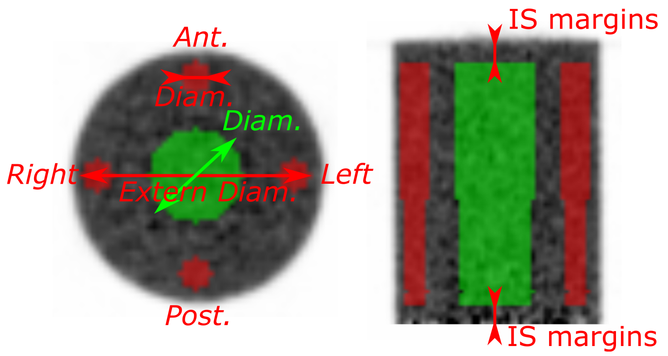

Figure 1.5: Definition of the ROIs for the transverse uniformity test

Green ROI. The diameter of the green ROI, respectively the red ROIS, is specified in mm: $Diam.(mm)$. A typical value is 40 % of the cylinder diameter for the green ROI

Red ROI. The diameter of the four red ROIs is 15 % of the cylinder diameter for the four red ROIs. The location of the red ROIs is specified by the diameter of the circumscribed circle specified in mm : $ExternDiam.(mm)$. A typical value is 90 % of the cylinder diameter.

The extreme slices of the cylinder are excluded. The superior and inferior margins are specified in mm: $ISmargins(mm)$. A typical value is 20 mm.

The ROI mean values are computed for each slice z:
$ROI_{\text{center}}(z)$, $ROI_{\text{right}}(z)$, $ROI_{\text{left}}(z)$, $ROI_{\text{ant}}(z)$ and $ROI_{\text{post}}(z)$.

From these values, the transverse integral uniformity is automatically computed for each slice as:

$$IU_{transverse}(z) = \frac{max_{transverse}(z) - min_{transverse}(z)}{mean_{transverse}(z)} \tag{1.1}$$

where

$$min_{transverse}(z) =$$
$$Minimum\{ROI_{center}(z); ROI_{right}(z); ROI_{left}(z); ROI_{ant}(z); ROI_{post}(z)\}$$

$$max_{transverse}(z) =$$
$$Maximum\{ROI_{center}(z); ROI_{right}(z); ROI_{left}(z); ROI_{ant}(z); ROI_{post}(z)\}$$

$$mean_{transverse}(z) =$$
$$Mean\{ROI_{center}(z); ROI_{right}(z); ROI_{left}(z); ROI_{ant}(z); ROI_{post}(z)\}$$

From the transverse integral uniformities, the following quantities are calculated with the *run* command (see Figure 1.6):

- the average: $\overline{IU}_{transverse} = Mean\{IU_{transverse}(z)\}$;
- the central value: $IU_{transverse}(z_c)$ on the central slice z_c;
- the minimum value: $min(IU_{transverse}) = Minimum\{IU_{transverse}(z)\}$;
- the maximum value: $max(IU_{transverse}) = Maximum\{IU_{transverse}(z)\}$;
- the global value, estimated on the volumic ROIs.

The results can be exported as a CSV ASCII file with the *Save_results* command.

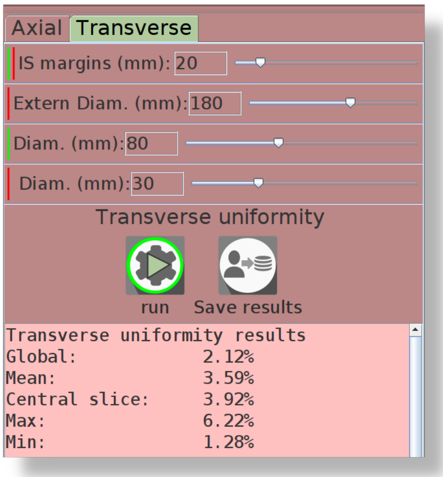

Figure 1.6: Results of the transverse uniformity test

Chapter 2
NM/PET image quality QC

2.1 Goal

NM/PET image quality QC

This test allows for the evaluation of the PET system image quality in a standardized situation representative of a typical clinical condition. It is a global measure that includes data acquisition and image reconstruction and quantification steps. It follows the guidelines of the PET working group of the French Society of Medical Physics (SFPM).

2.2 Requirements

The test requires the NEMA IEC NM/PET Body Phantom Set™. It consists of a body phantom, a lung insert of known internal diameter and an insert with six fillable spheres of increasing inner diameter: 10 mm, 13 mm, 17 mm, 22 mm, 28 mm, and 37 mm.

The body is filled with a uniform background activity concentration $a_{\text{background}}$ and the six spheres are filled with a constant activity concentration a_{sphere} with $a_{\text{sphere}} > a_{\text{background}}$. The ratio between the spheres and the background activity concentrations is known precisely:

$$\text{nominal ratio value} = \frac{a_{\text{sphere}}}{a_{\text{background}}}, \tag{2.1}$$

and has to be strictly superior to 1. There is no activity in the lung insert: $a_{\text{lung}} = 0$.

All corrections needed to get a quantitative image expressed in becquerel per milliliter [Bq/mL] shall be applied during reconstruction.

2.3 Data loading and preparation

The quantitative reconstructed image of the NEMA IEC NM/PET Body Phantom Set™ expressed in Bq/mL shall be loaded. The units can be changed from SUV to kBq/ml in the colour scale.

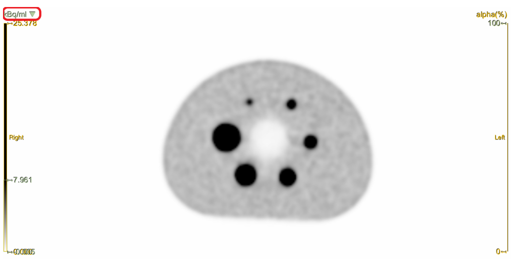

Figure 2.1: Axial slice of the NEMA IEC NM/PET Body Phantom Set™. Red rectangle: data units.

Select the Phantom IQ tab in the Quality control protocol and specify the three required parameters:

- Resampling [mm]: the value of the desired isotropic voxel size in millimeters after image resampling for the regions of interest computations. If you enter 0, no resampling will be performed and the voxel size will remain identical to that of the series loaded. Note that the mean value of the regions of interest can vary by a few percent when modifying the resampling value. For longitudinal studies, it is recommended to use the same value.

- Lung internal dia. [mm]: the internal diameter in millimeters of the cylindrical lung insert.
- Nominal ratio value : $\frac{a_{\text{sphere}}}{a_{\text{background}}}$. There is no default value; it has to be strictly higher than 1.

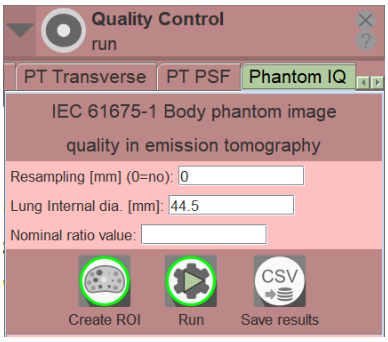

Figure 2.2: Phantom IQ in GUI.

Warning. Resampling modifies the image data (Quintic Lagrangian interpolation) displayed as a result. This new series replaces the original one. If you want to repeat the procedure, it is recommended that you unload the reference (modified) series and start loading the original series again.

2.4 Image processing

The processing is run in two steps. When selecting the "Create ROI" button, thirteen spherical volume of interests (VOI) are automatically drawn from the axial slice in which the smallest of the spheres is best seen : six VOIs in the body background, six VOIs centred on the spheres and one VOI centred on the lung insert. The location of the VOIs

Figure 2.3: The thirteen VOIs drawn in the NEMA IEC NM/PET Body Phantom Set™.

can be manually adjusted, using the tools of the "REGION OF INTEREST" panel. Once the thirteen VOIs have been drawn, the computation of the contrast recovery coefficients (2.2) and the lung error (2.3) are performed by selecting the "Run" button.

2.4.1 Body background

Six spherical VOIs with a diameter of 37 mm are automatically drawn in the background. The mean and standard-deviation of the activity concentration in each background VOI I are reported: BGSphere$I$_Mean and BGSphere$I$_Dev. The averaged activity concentration across the six VOIs is also reported: BGSpheres_Mean.

2.4.2 Contrast spheres

A spherical VOI is automatically drawn for each of the six contrast sphere, with a diameter equal to the nominal internal diameter D of the sphere. Its theoretical volume $\frac{4}{3}\pi\left(\frac{D}{2}\right)^3$ and effective volume, depending on the voxel sampling, are reported.

The mean and standard-deviation of the activity concentration in the contrast spheres VOI of diameter D are reported: Sphere$D$_Mean and Sphere$D$_Dev.

The measured activity concentration ratios between the contrast spheres D and the body background are reported: Sphere$D$_RatioWithBGSM $= \frac{\text{Sphere}D\text{\_Mean}}{\text{BGSpheres\_Mean}}$.

The Contrast Recovery Coefficient (CRC) of each sphere D is then calculated as follows:

$$\text{Sphere}D\text{\_CRC} = \frac{\text{Sphere}D\text{\_RatioWithBGSM} - 1}{\text{Sphere}D\text{\_NominalRatio} - 1}, \tag{2.2}$$

where Sphere$D$_NominalRatio is the nominal ratio value.

2.4.3 Lung insert

A spherical VOI is automatically drawn on the cylindrical lung insert, with a diameter equal to the internal diameter of the insert.

The mean and standard-deviation of the activity concentration in the contrast lung VOI are reported: LungInsert_Mean and LungInsert_Dev.

The lung error is calculated as:

$$\text{LungError} = \frac{\text{LungInsert\_Mean}}{\text{BGSpheres\_Mean}}. \tag{2.3}$$

2.4.4 Results

All numerical results can be saved in a comma-separated values (CSV) text file by selecting the "Save results" button.

Chapter 3

Point Spread Function – spatial resolution

3.1 Goal

This Quality Control (QC) protocol allows for the measurement of the spatial resolution under the conditions of a clinical oncological examination, that is to say in an attenuating and scattering medium.

3.2 Requirements

Point Spread Function - spatial resolution

The QC NM/PET protocol requires that the NM/PET image is quantified in Bq per ml. The image shall contain only the uniform cylindrical phantom, oriented along the longitudinal axis and tilted slightly along the z axis (see Figure 3.1). The image should cover up to 5cm beyond the edges of the phantom.

3.3 Image processing

The software expects the uniform phantom data to be acquired on a slight incline. It analyzes the images to determine the 3 central planes of the cylinder. Given this information, two ROIs are automatically drawn in blue and magenta in a central sagittal slice of the cylinder (see Figure 3.1, p.18). The blue ROI is used to measure the spatial resolution in the radial direction and the magenta ROI in the axial direction.

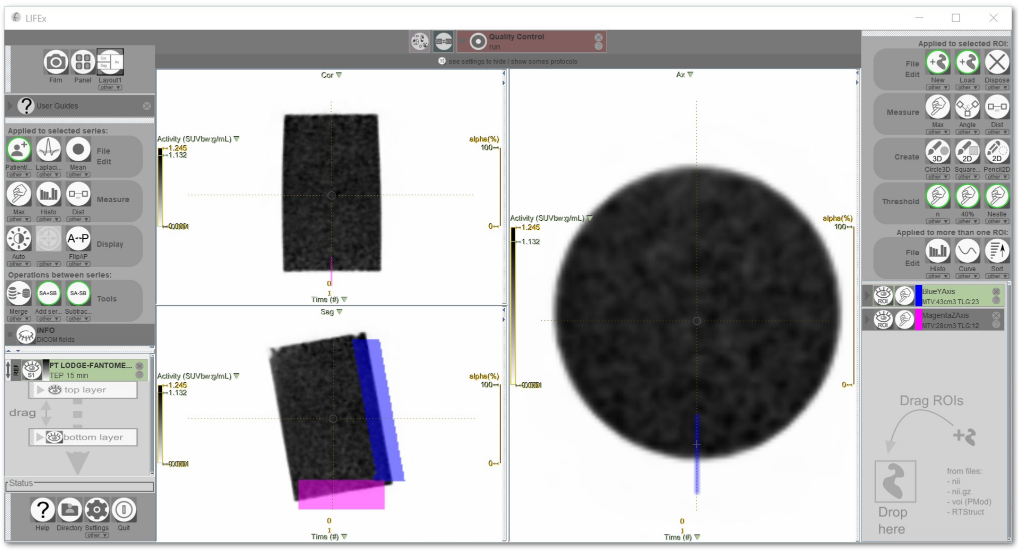

Figure 3.1: Blue and magenta ROIs in the central sagittal slice of the cylinder

The two ROI can be edited by hand. If the walls of the phantom have internal indentations, it is recommended to redraw the ROIs to avoid them.

Two measurements are made without requiring user interaction:

- Spatial Resolution in the Axial Direction: An edge profile is drawn on the central axial slice, and on several slices in front and several slices behind (see Figure 3.2, p.20). By appropriately displacing and then combining line profiles from different slices, the edge response function ESF(s) can be measured with a sampling interval much finer than the pixel spacing of the original images. From these composite-edge profiles ESF(s), the spatial resolution of the system can be determined by fitting an analytic function erf() and measuring the full width at half maximum (FWHM) (see Figure 3.3, p.21).

$$ESF(s) = \int_{-\infty}^{S} PSF(S')ds' \tag{3.1}$$

Point Spread Function - spatial resolution

$$PSF(s) = \frac{A}{\sigma\sqrt{2\pi}} e^{-(s-\mu)^2/2\sigma^2} \tag{3.2}$$

$$ESF(s) = \frac{A}{2}\left(1 + erf\left(\frac{s-\mu}{\sigma\sqrt{2}}\right)\right) \tag{3.3}$$

$$FWHM = \sqrt{8\ln 2\sigma} \tag{3.4}$$

Where $ESF(s)$ is the edge function, $PSF(s)$ is the point spread function of the signal, A is a scaling factor which takes into account the magnitude of the data, μ is the center of the Gaussian function, and σ is the standard deviation of the Gaussian function.

- Spatial Resolution in the Radial Direction: An edge profile is drawn on the central coronal slice and on several slices to the left and right. In a manner similar to the previous step, the spatial resolution is obtained.

The results can be exported as a CSV ASCII file with the Save_resultscommand (see Figure 3.3, p.21).

Point Spread Function - spatial resolution

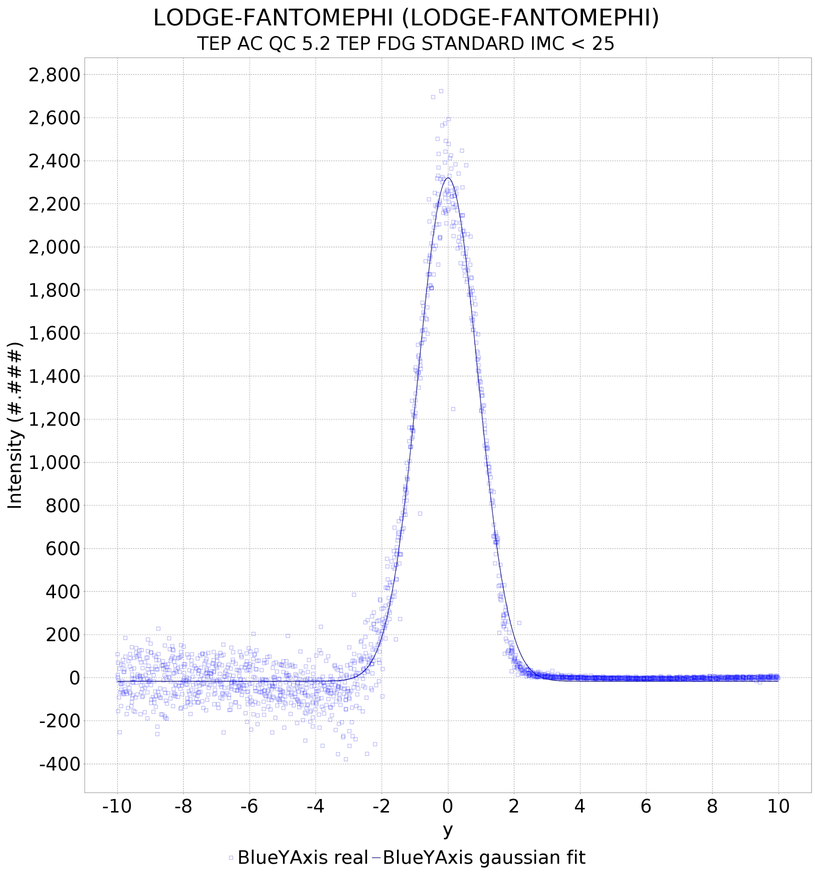

Figure 3.2: Spatial resolution in the axial direction. The blue dots indicate the data and the black curve indicate the Gaussian function fit from which the resolution measure is derived

Point Spread Function - spatial resolution

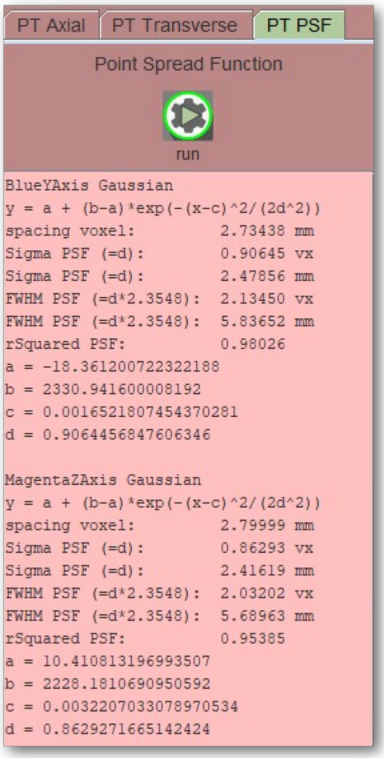

Figure 3.3: Results of the spatial resolution in the axial and radial direction