

Correction for pile-up effect based on pixel-by-pixel calibration for tomography with Medipix3RX detector

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Summary

1 – Context

Dead time dispersion in transmission tomography
Medipix

2 – Dead time measurement

Reference Method
New method

3 – Pile up correction

Method
Results

Conclusion

1.1 – Dead time dispersion in transmission Tomography

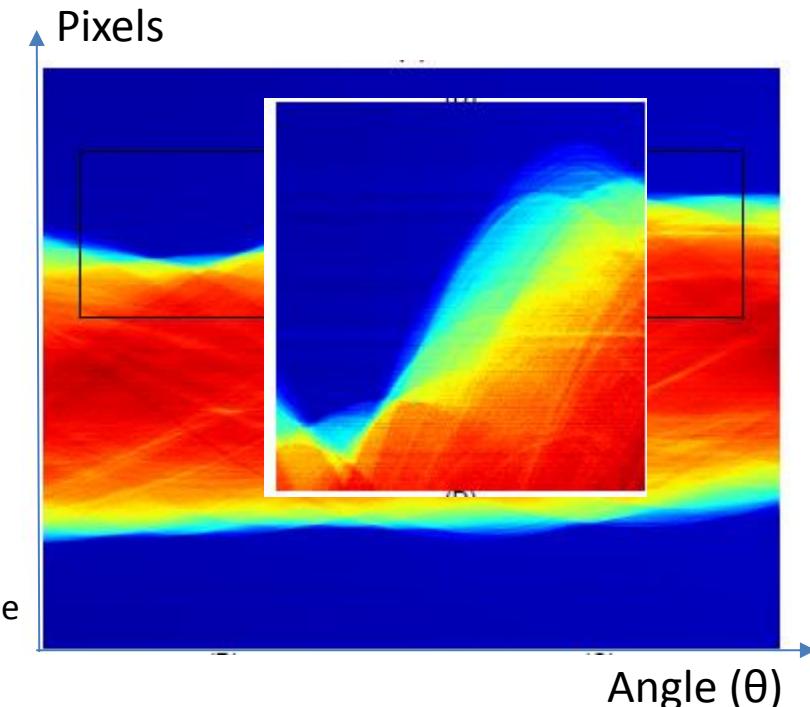
Dead time dispersion:

- non linear dispersion
- responsible for strips in the sinogram and ring artefacts in the reconstructed image

Classical approaches (ref 1,2) : the model of sinogram corruption assumes that the deviation does not depend on the angle (independent of the sample).

$$Sino(pixel, \theta) = Att(pixel, \theta) + \varepsilon(pixel)$$

Limit of the model for dead time dispersion



$$Att(pixel, \theta) = -\log \left(\frac{M}{M_0} \right)$$

Measurement with the sample

Flat field

$$Sino(pixel, \theta) = -\log \left(\frac{N}{N_0} \right)$$

Measurement with the sample with dead time correction

Flat field with dead time correction

→ $\varepsilon = \log \left(\frac{M_0}{N_0} \right) + \log \left(\frac{N}{M} \right)$

≠ 0 for high fluxes (low attenuating objects)

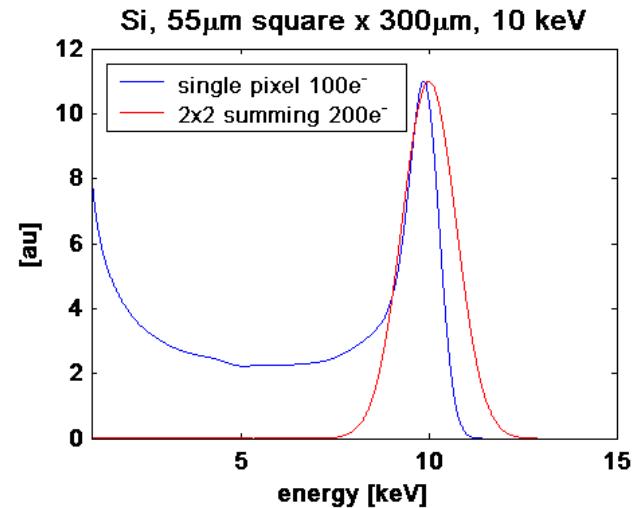
1) E.X. Miqueles et al, *Generalized Titarenko's Algorithm for Ring Artefacts Reduction* (submitted paper)

2) Titarenko S, Withers PJ & Yagola A, 2010, *An analytical formula for ring artefact suppression in X-ray tomography*, Applied Math. Letter, vol.23, pp.1489-1495.

1.2 – Medipix - description

Medipix 3RX

- CMOS pixel detector readout chip designed to be connected to a segmented semiconductor sensor
- Developed by an international collaboration, hosted by CERN
- Different modes of operation:
 - Single pixel mode : 55 microns pixel, 2×12 bits energy thresholds
 - Charge summing mode
 - Spectrometric mode / Color mode (110 microns pixels – 8 energy thresholds)



In blue is the spectrum observed by a 55 mm square silicon pixel detector which is uniformly exposed to 10 keV photons. In red is the spectrum seen by a pixel operating in charge summing mode where the output of 4 pixels are added. Other material and energies have also been simulated.

<http://medipix.web.cern.ch/medipix/pages/medipix3.php>

These experiments

- Medipix3RX ASIC bump bonded to 300 microns Silicon sensor
- Readout: Fitpix USB interface and Pixelman software (Czech Technical University).
- Single Pixel Mode configured with single 24 bit counters
- High gain mode
- Threshold equalization using the noise level

1.2 – Medipix - dead time vs energy resolution

Basic characterization: performance function of the pulse shape

Main parameter to modify the pulse shape:

Ikrum: current within the pre amplifier

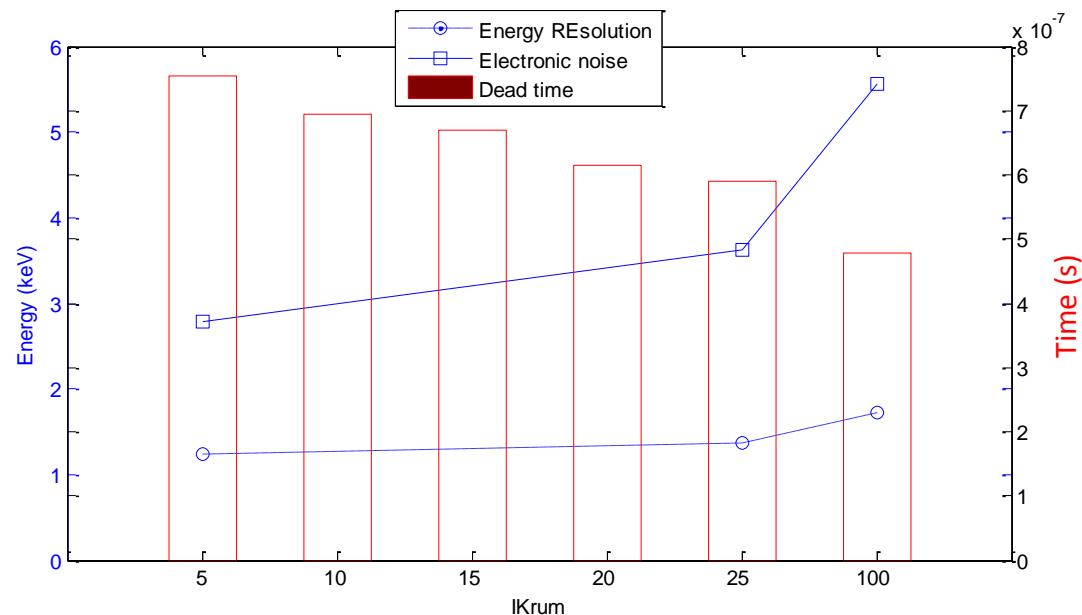
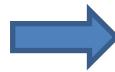
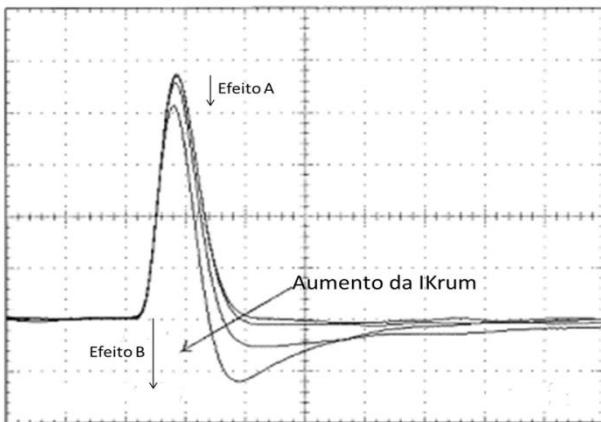


Illustration of the effect of Ikrum current on the pulse - source: O'Connor, P. et. al., "Ultra Low Noise CMOS preamplifier-shaper for X-ray Spectroscopy". Nuclear Instruments and Methods in Physics Research, vol. 409, 1998

Trade off between low pulse shaping time and high energy resolution and low noise

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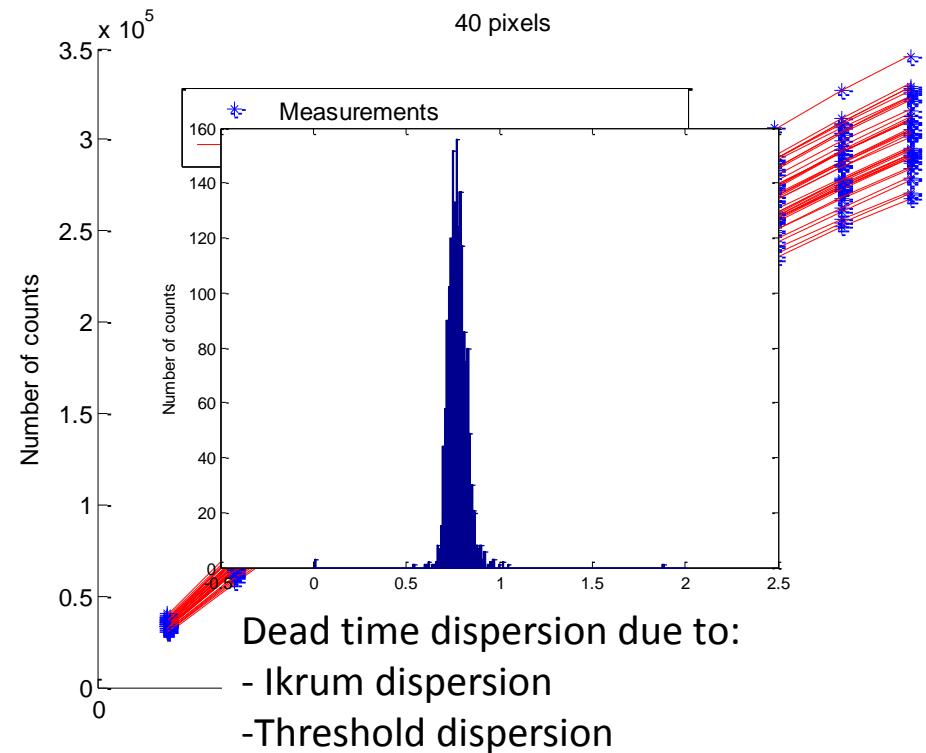
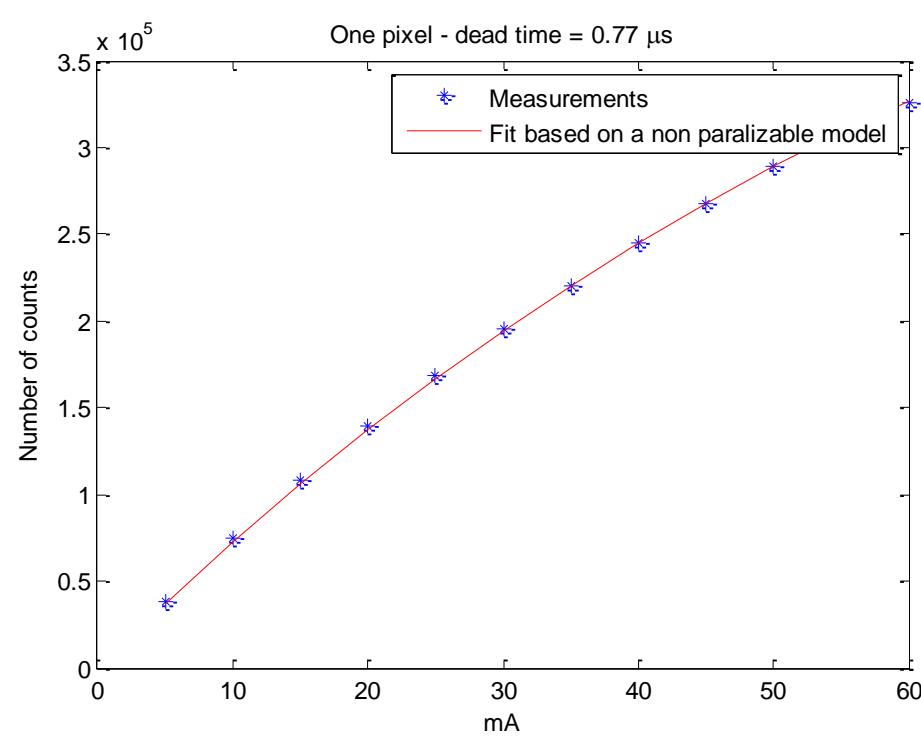
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2.1 – Reference method

Basic steps

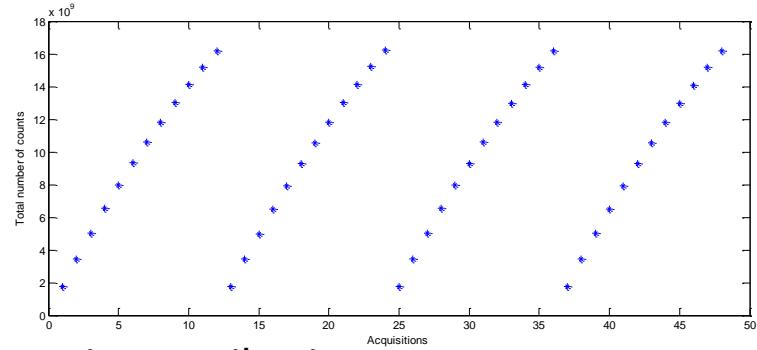
- Images with different currents of the X-ray generator
- Hypothesis that the lowest flux image is not affected by pile up
- Calculation of the corrected fluxes
- Fit with paralysable or non-paralysable model



2.1 – Reference method

We repeat the experiments 4 times

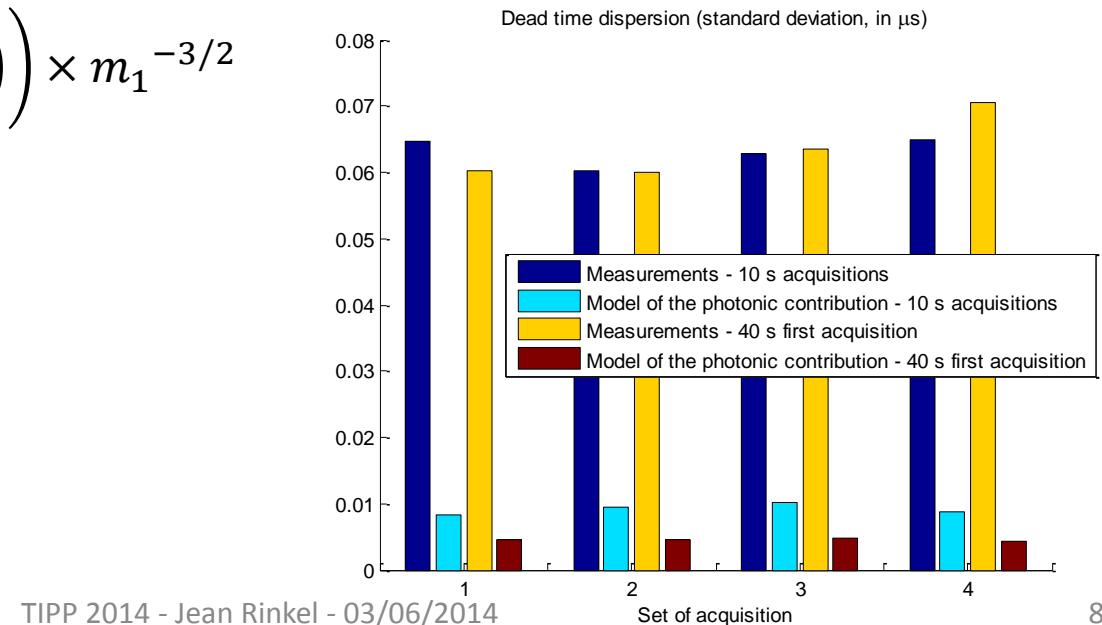
Dead time dispersion study



4 dead time distributions

1) Comparison to the model of the photonic contribution

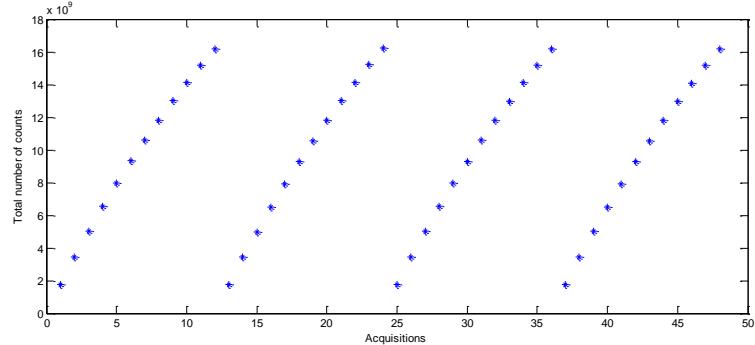
$$\sigma_{phot} = \frac{1}{N} \times \left(1 - \log \left(\frac{N \times m_1}{m_N} \right) \right) \times m_1^{-3/2}$$



2.1 – Reference method

We repeat the experiments 4 times

Dead time dispersion study



4 dead time distributions

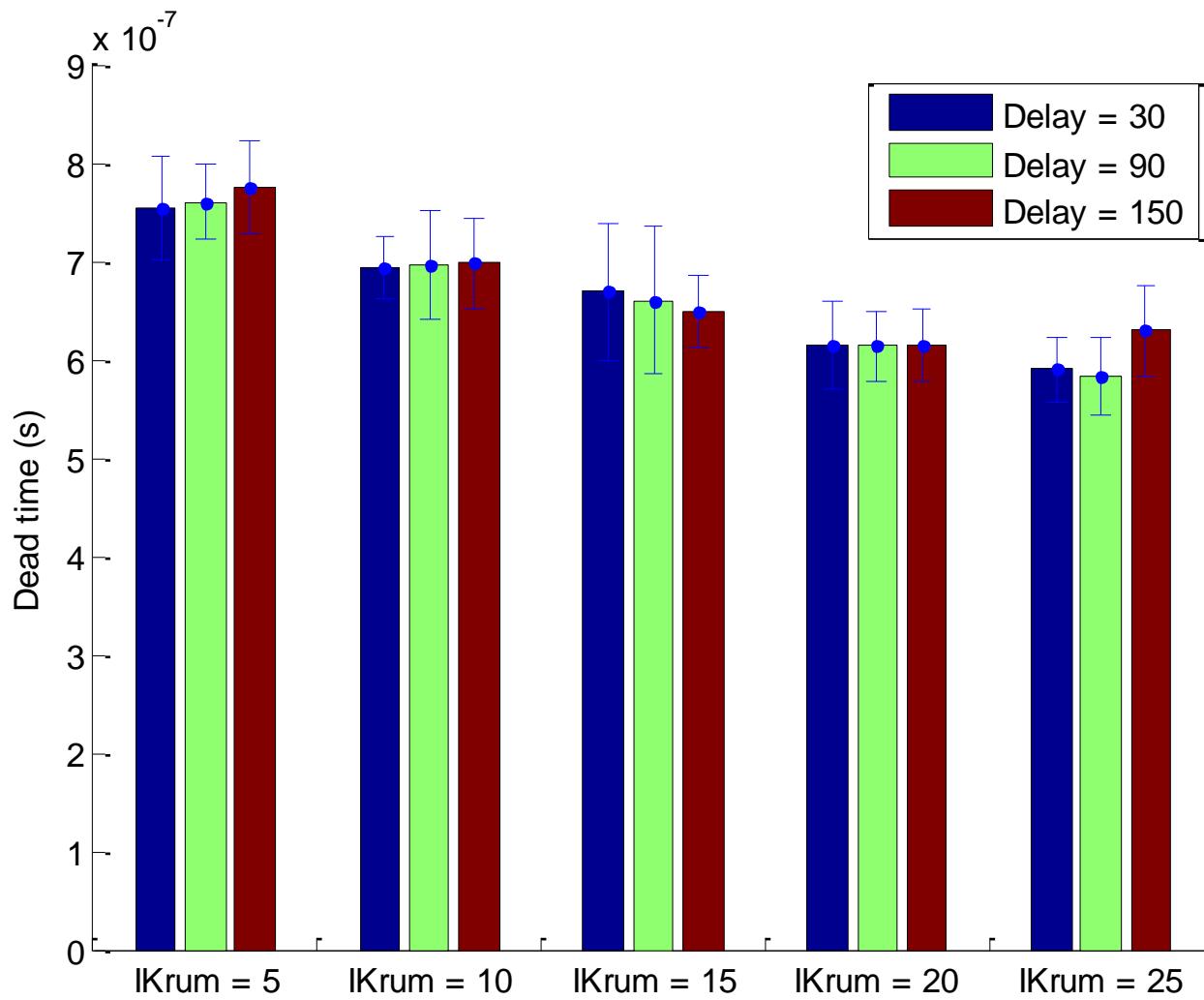
- 1) Comparison to the model of the photonic contribution
- 2) Correlation analysis between the dead times of the 4 sets

Linear Correlation Coefficient R =

	Set 1	Set 2	Set 3	Set 4
Set 1	1.0000	0.7983	0.8030	0.7673
Set 2	0.7983	1.0000	0.8537	0.8073
Set 3	0.8030	0.8537	1.0000	0.8292
Set 4	0.7673	0.8073	0.8292	1.0000

Conclusion: our measured dispersion is mainly due to the pixel dispersion (sensor + electronics)

2.1 – Reference method



2.2 – New method

Context

- Synchrotron experiments: flux adjusted by filters, difficult to know exactly the transmission of the filters, especially for polychromatic beams
- Dead time calibration has to be done for each threshold equalization procedure



Need for a fast procedure

Method

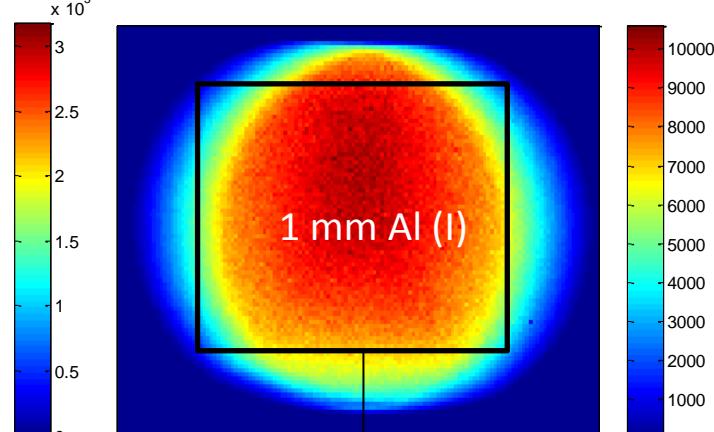
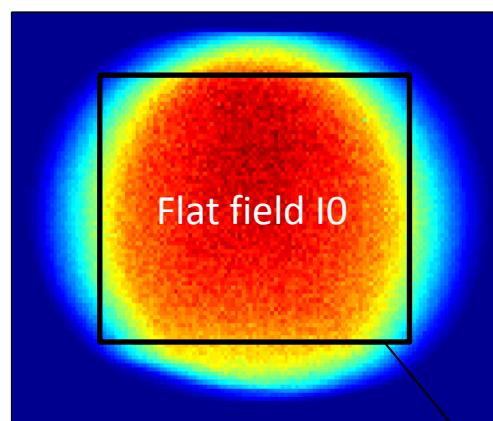
- Acquisition with flat field (I_0)
- Acquisition with a filter (I)
- Calculation of mean transmission
- Calculation of dead time variation

$$\delta\tau = \frac{TR - TRmean}{\frac{\partial TR}{\partial \tau}}$$

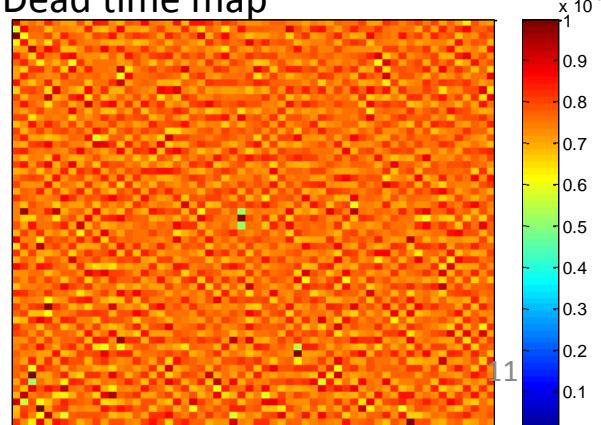
- With a paralizable dead time model:

$$\frac{\partial TR}{\partial \tau} \approx I_0 \times TR \quad \rightarrow \quad \delta\tau = \frac{TR - TRmean}{I_0 \times TR}$$

- Calculation of the dead time value using a priori knowledge the mean dead time value $tmean$: $\tau = tmean + \delta\tau$

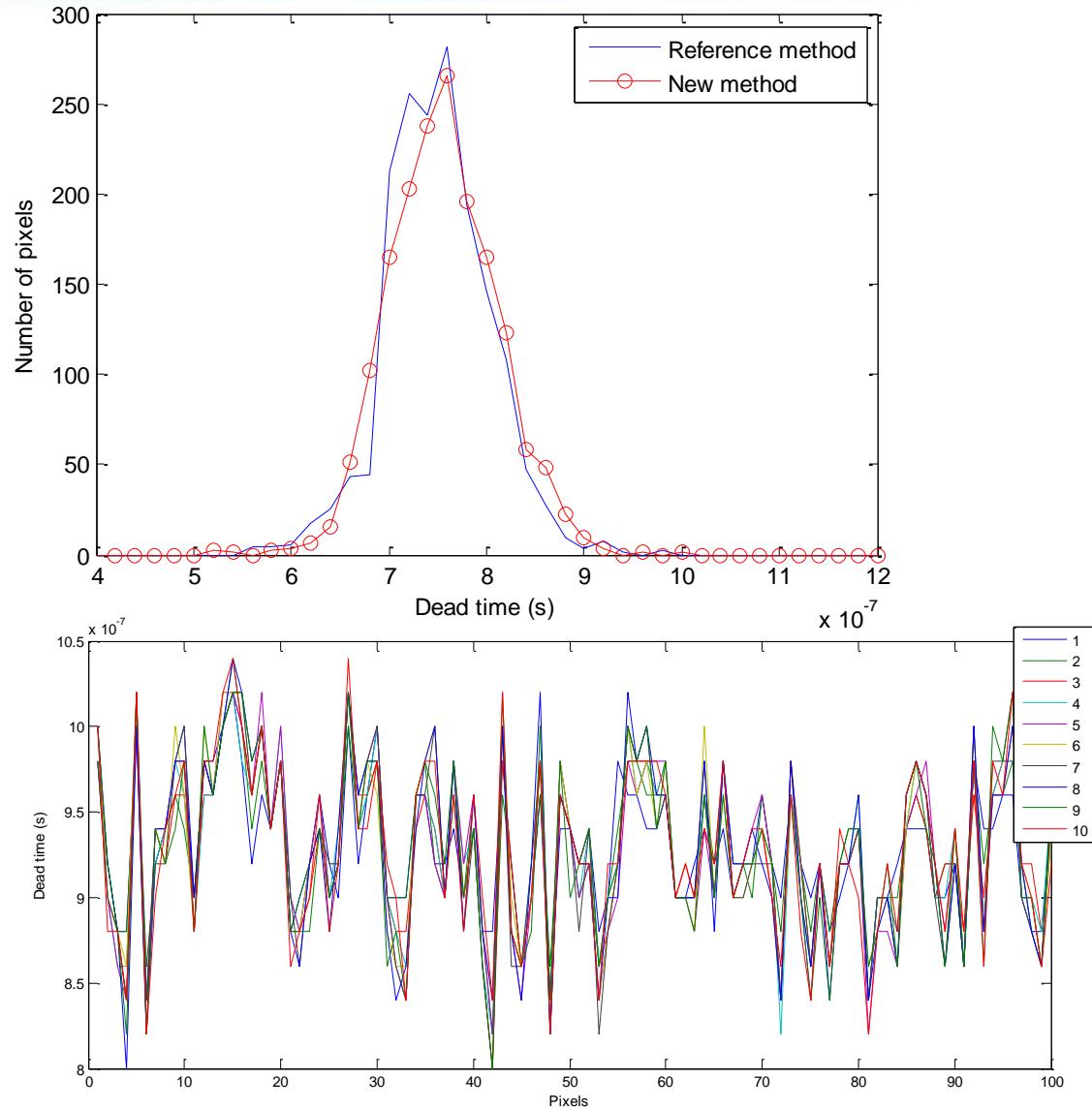


Dead time map



2.2 – New method - Experimental validation

- Comparison with the reference method on dead time histograms



- Robustness assessment

Calibrated dead time values on a central ROI (100 pixels) using different calibration filters (1: 100 microns Al, 2: 200 microns Al,..., 10: 1 mm Al)

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3.1 – Pile up correction - method

Method based on pixel-to-pixel dead time calibration

Non-paralyzable model: $M = \frac{N}{1 - N \times \tau} \quad \rightarrow \quad N = \frac{M}{1 + M \times \tau}$

Paralyzable model: $M = Ne^{-N \times t} \quad \rightarrow \quad$ Iterative correction (local inversion)

N(i): estimate of the corrected pixel value at the ith iteration

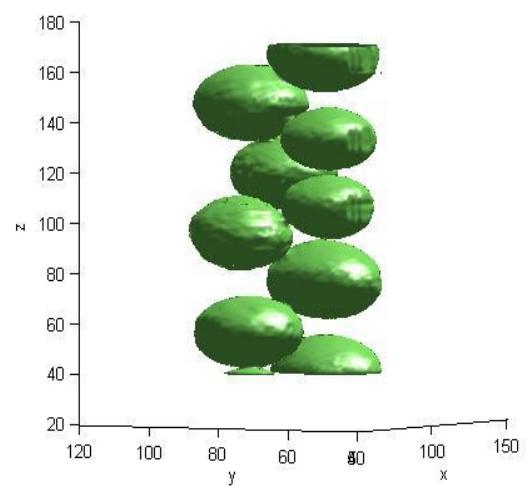
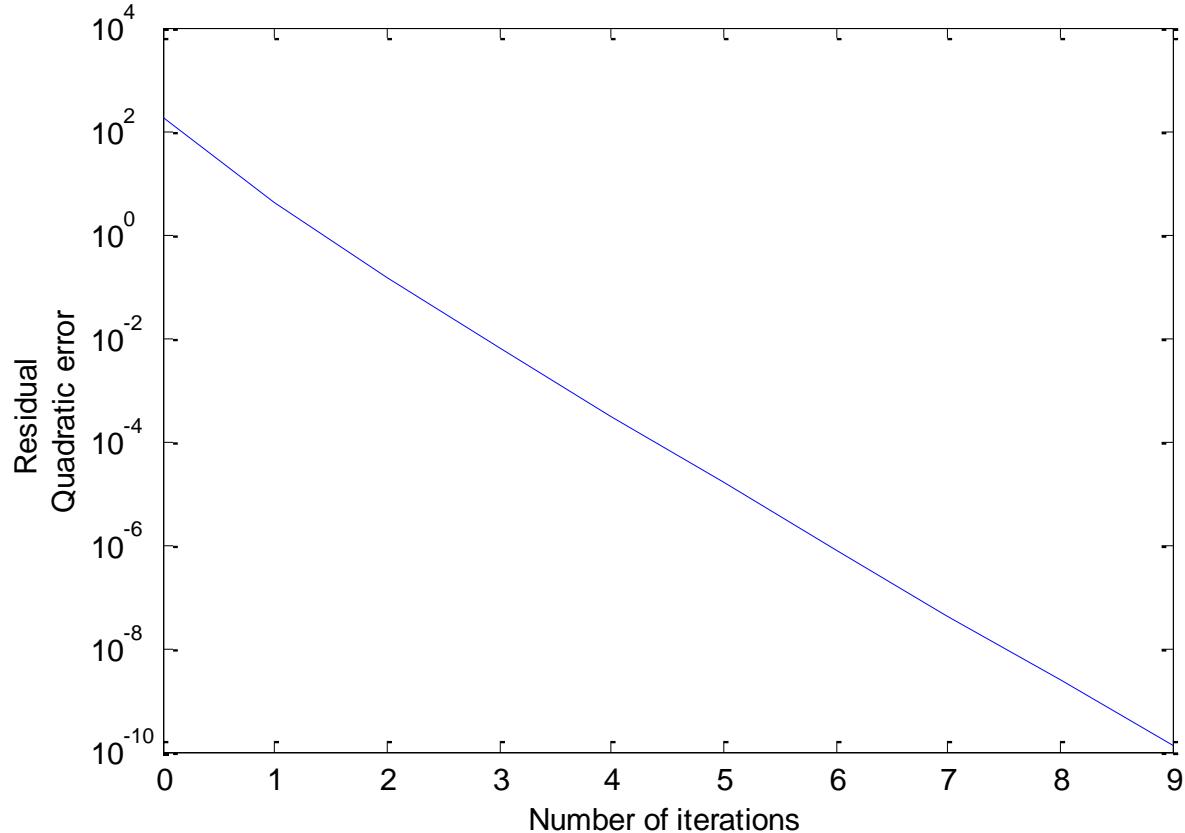
Initial guess N(0) = M

for i = 1:Niter

N(i) = N(i - 1) + M - N(i - 1)e^{-N(i-1) × τ}
end

Siemens X-ray generator – Cu anode, 20kV

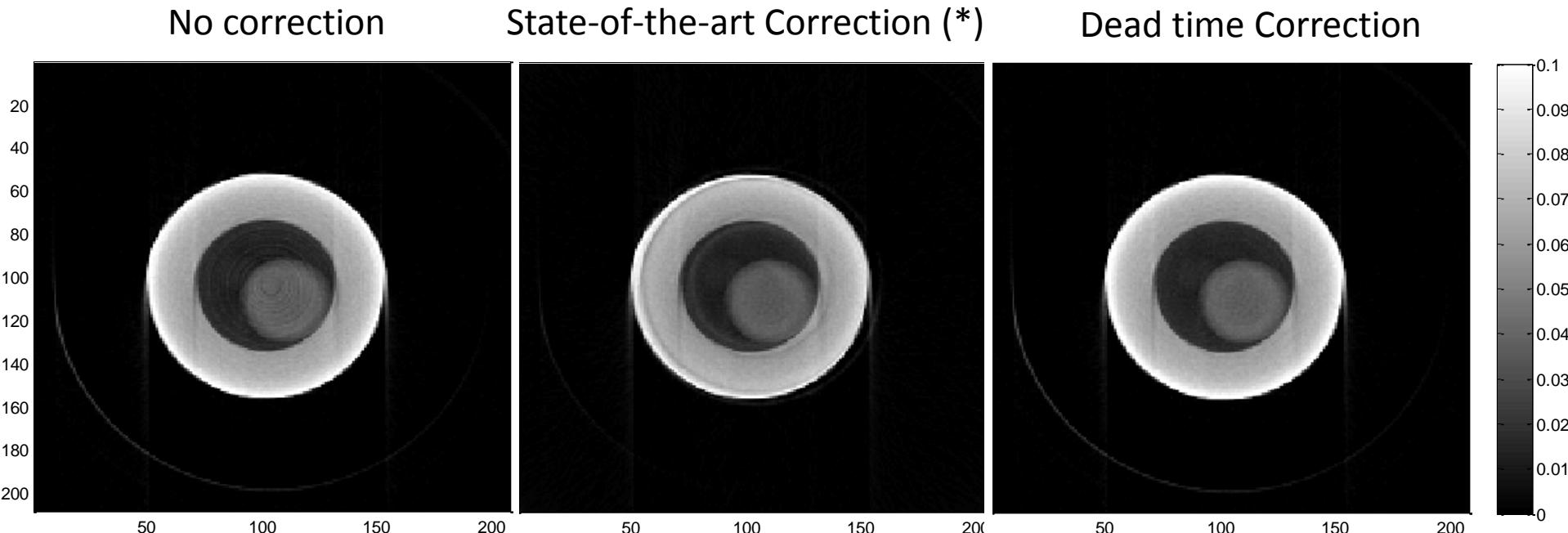
Sample: glass tube (5 mm diameter) with polystyrene balls inside



3.2 – Pile up correction - results

Siemens X-ray generator – Cu anode, 20kV

Sample: glass tube (5 mm diameter) with polystyrene balls inside

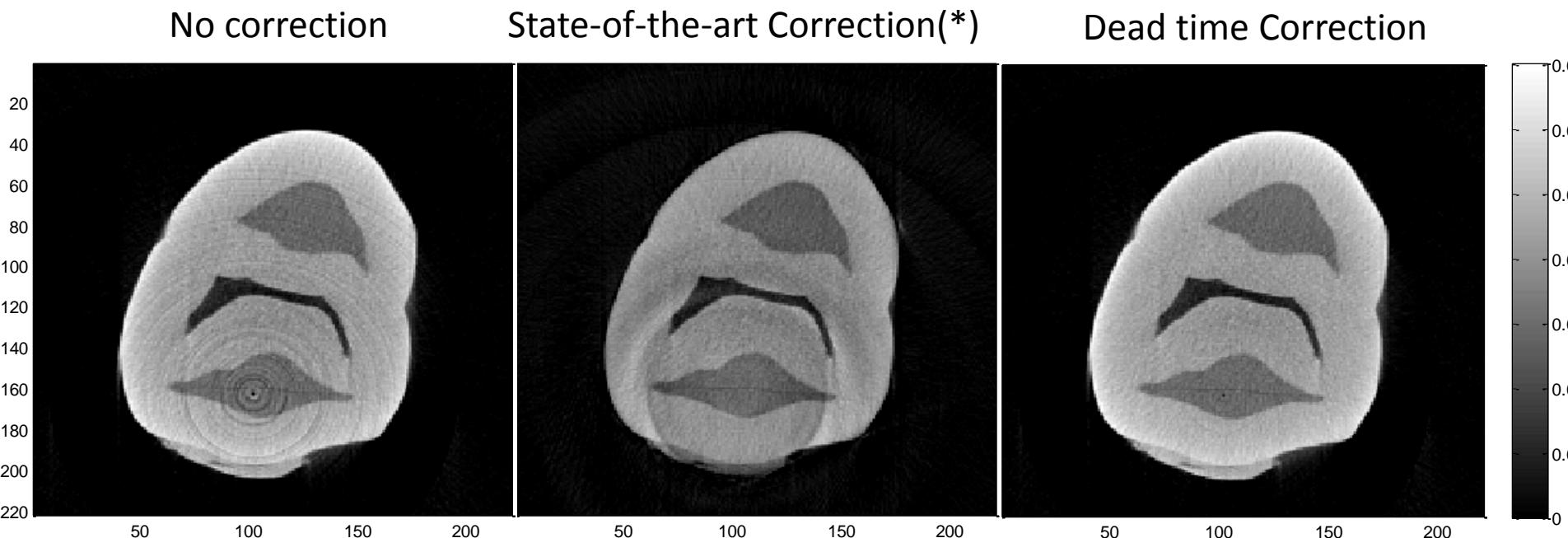


* E.X. Miqueles et al, *Generalized Titarenko's Algorithm for Ring Artefacts Reduction*
(paper submitted to Journal of Synchrotron Radiation)

3.2 – Pile up correction - results

IMX beamline at LNLS synchrotron (polychromatic beam)

Sample: molar tooth



* E.X. Miqueles et al, *Generalized Titarenko's Algorithm for Ring Artefacts Reduction*
(paper submitted to Journal of Synchrotron Radiation)

Conclusion

- Fast method developed for dead time calibration and correction
 - Dead time calibration method validated by comparing with a standard method
 - Robustness assessed by modifying the filter
 - Dead time correction validated on reconstructed images and compared to a mathematical approach.
- This method enables
 - Good artefact reduction
 - Quantification of the reconstructed attenuation coefficients
- Future
 - Monochromatic measurements
 - Other modalities: phase contrast tomography, small angle scattering ...

Thank you for your attention!