Material Reconstruction with Spectroscopic Pixel X-Ray Detectors

J. Giersch, M. Firsching, D. Niederlöhner,
G. Anton

Physikalisches Institut 4,
Universität Erlangen-Nürnberg,
Germany

6th IWORID 2004

Outline

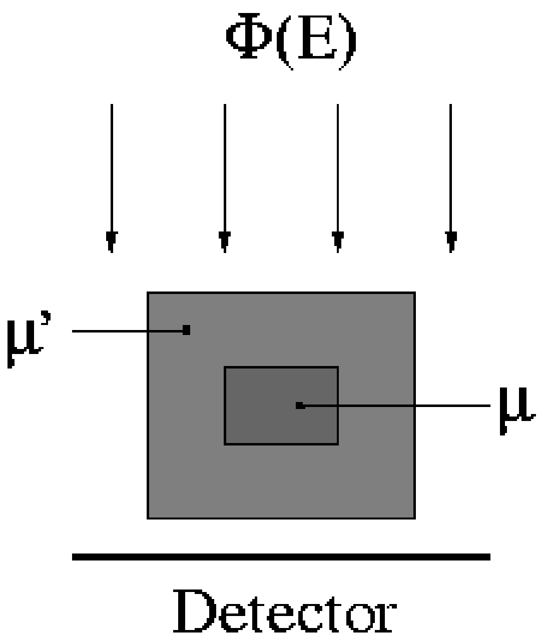
- Trend towards energy resolution
- Approach for material reconstruction
- Simulation study
- Noise consideration

Trends in X-Ray Pixel Detectors

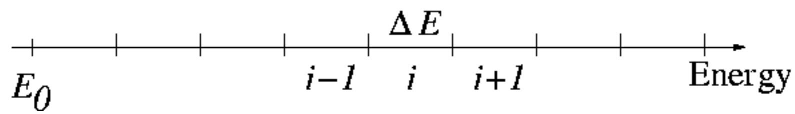
- **One energy threshold in each pixel**
  Readout for a 64 x 64 pixel matrix with 15-bit single photon counting, M.Campbell, E.H.M.Heijne, G.Meddeler, E.Pernigotti, W.Snoeys, IEEE Trans.Nucl.Sci. 45 (3), June **1998** 751-753
- **Two energy thresholds in each pixel**
  Medipix2, a 64k pixel readout chip with 55 µm square elements working in single photon counting mode, X.Llopart, M.Campbell, R.Dinapoli, D.SanSegundo, E.Pernigotti, Proc. of the IEEE Nuclear Science Symposium and Medical Imaging Conference, San Diego, California, November 4-10, **2001**, M7-4, accepted for publication in IEEE Trans.Nucl.Sci.
- **An ADC in each pixel**
  Towards a single-photon energy-sensitive pixel readout chip: pixel level ADCs and digital readout circuitry, David San Segundo Bello, Bram Nauta and Jan Visschers, Proceedings of the 13th ProRISC workshop, Veldhoven, the Netherlands, November 28 and 29, **2002**, pp.444-448

What can be done with energy information?

Weighting Technique



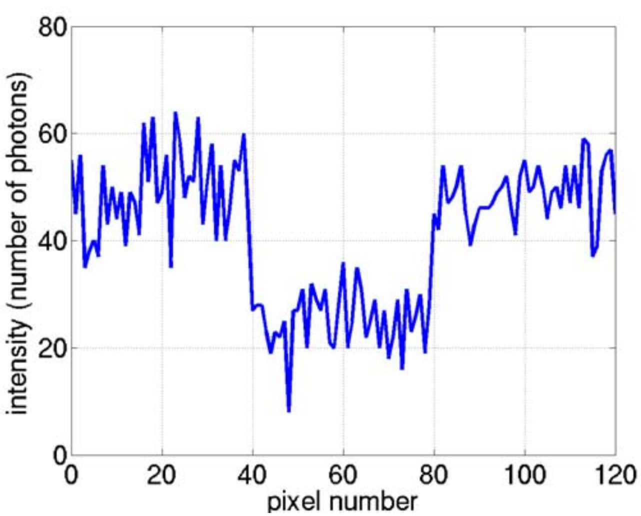
$$S = \left\langle I' \right\rangle - \langle I \rangle$$



$$E = E_0 + i\Delta E$$

$$S_i = \left\langle I_i' \right\rangle - \langle I_i \rangle$$

$$\tilde{S} = \sum_i S_i \cdot w_i$$



$$SNR = \frac{\tilde{S}}{\sigma_{\tilde{S}}}$$

$$w_i = \frac{T_i - T_i'}{T_i + T_i'}$$

$w_i =$ weighting function

$T_i =$ transmittance in energy channel i

Material Information

Object

input spectrum
$n_0(E)$
(known)

→ Transmittance $T(E)$ →

output spectrum
$n(E)$
(measured for each pixel)

$$T(E) = \exp(-\sum \mu'_j(E) \cdot \varrho_j d_j)$$

$$\mu'(E) := \frac{\mu(E)}{\varrho}$$

$$a_j := \varrho_j d_j$$

a_j: material concentration

j: material index

Likelihood approach

μ'_i
T_i
$T_i = n(i)/n_0(i)$

→ Reconstruction for each pixel →

$a_1(x,y)$,
$a_2(x,y)$,
...

i: energy index

$$L(\underline{a}) = f(T_1|\underline{a}) \cdot f(T_2|\underline{a}) \cdot \; \ldots \; \cdot f(T_n|\underline{a})$$

best estimation $\underline{a} = \underline{\hat{a}}$

$$L(\underline{\hat{a}}) \stackrel{!}{=} \text{maximum}$$

Least Square Fit

$$-\log T_i = \sum_{j=1}^{p} \mu'_j(E) \cdot a_j$$
$$y_i := -\log T_i$$

- *New measure value y* is linear in material concentration *a*
- Gaussian distribution are a good approximation for photon numbers
  ⇨ Transmittance *T* is Gaussian distributed
- With sufficient statistics *log(T)* can be linearised
  ⇨ New measure value *y* is Gaussian distributed

⇨ Likelihood approach is equivalent to Least Square Fit

Reconstruction

Matrix notation:

$$\underline{y} = M \cdot \underline{a}$$

Example of *μ'*-matrix *M*:

$$M := \begin{pmatrix} \mu'_{E_1,\mathrm{H}} & \mu'_{E_1,\mathrm{O}} & \mu'_{E_1,\mathrm{I}} \\ \mu'_{E_2,\mathrm{H}} & \mu'_{E_2,\mathrm{O}} & \mu'_{E_2,\mathrm{I}} \\ \mu'_{E_3,\mathrm{H}} & \mu'_{E_3,\mathrm{O}} & \mu'_{E_3,\mathrm{I}} \\ \mu'_{E_4,\mathrm{H}} & \mu'_{E_4,\mathrm{O}} & \mu'_{E_4,\mathrm{I}} \end{pmatrix}$$

Reconstruction is „matrix inversion“:

$$M^{-1} = (M^T M)^{-1} M^T$$

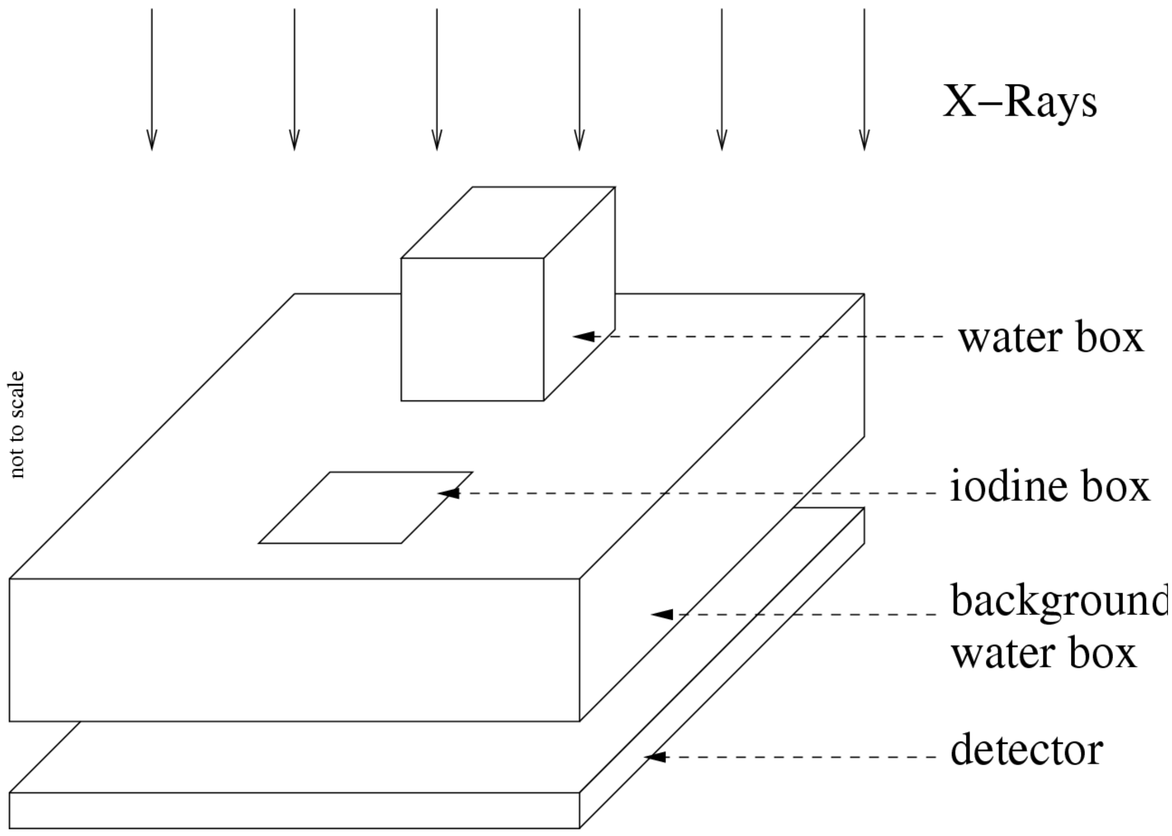
$$M^{-1} \quad : \quad \text{pseudoinverse}$$

$$\underline{\hat{a}} = M^{-1} \underline{y}$$

Simulation Case 1

All simulation done with EGS4 based Monte Carlo Simulation ROSI

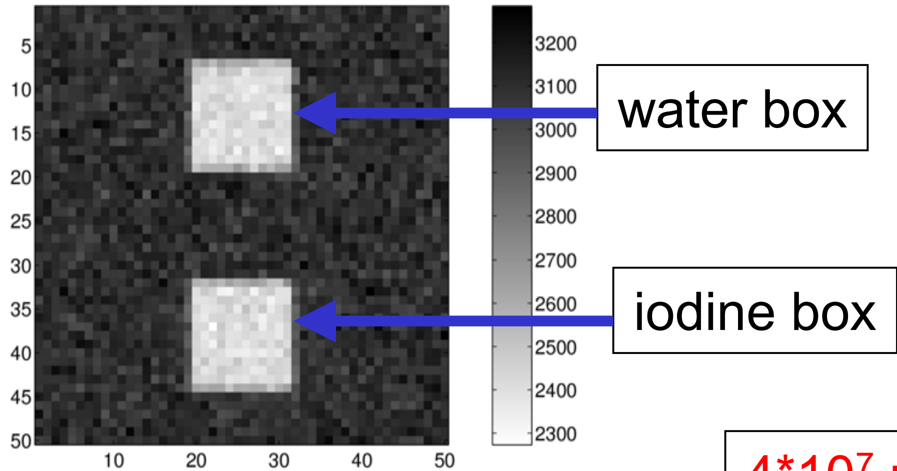
www.pi4.physik.uni-erlangen.de/Giersch/ROSI/



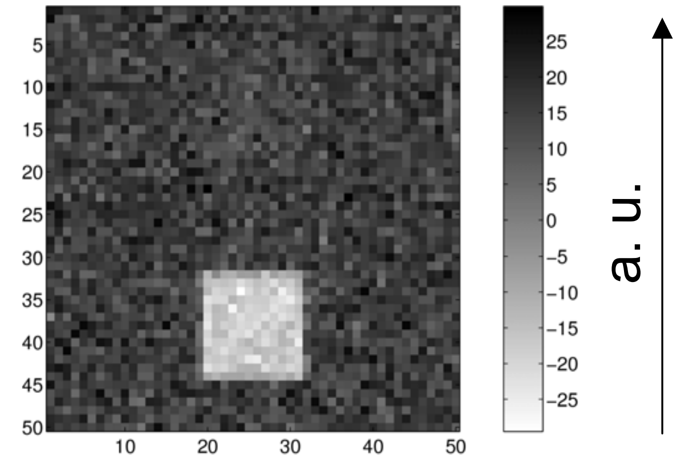
- Water background:
  2 cm x 2 cm, 1 cm thick
- Water box:
  0.5 cm x 0.5 cm, 1 cm thick
- Iodine box:
  0.5 cm x 0.5 cm, 52 μm thick
  (25.6 mg/cm^2)
- Ideal energy resolving detector
- Ideal anti-scatter grid
- X-ray source with four lines
  (30 keV, 40 keV, 60 keV, 80 keV)
  and homogenous intensity

Results of Simulation Case 1

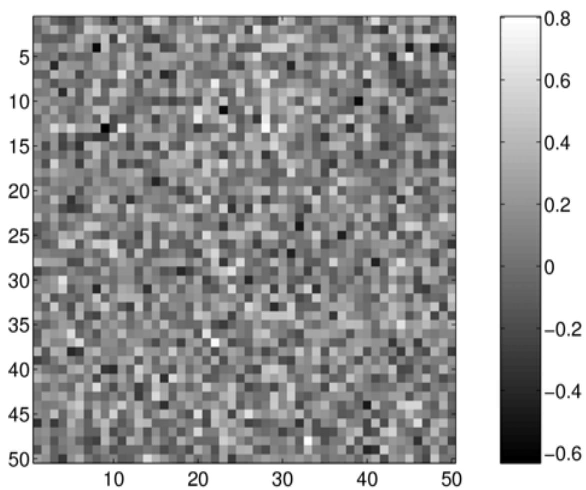
Counting image



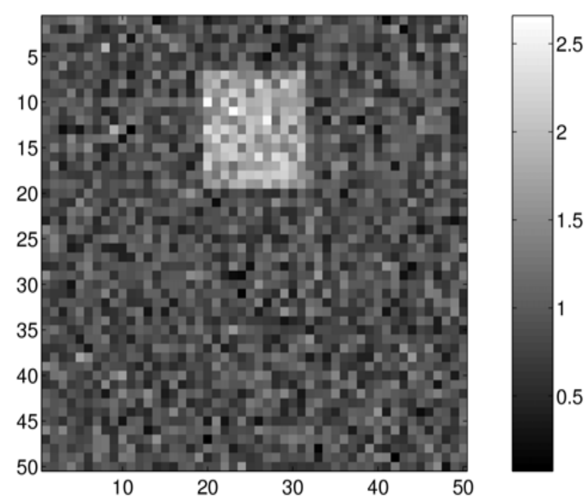
Weighting image
(optimised for water-iodine contrast)



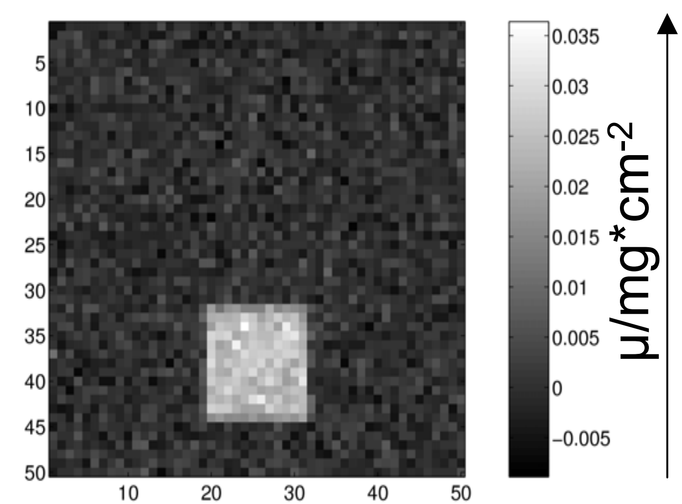
$4*10^7$ photons



Hydrogen concentration

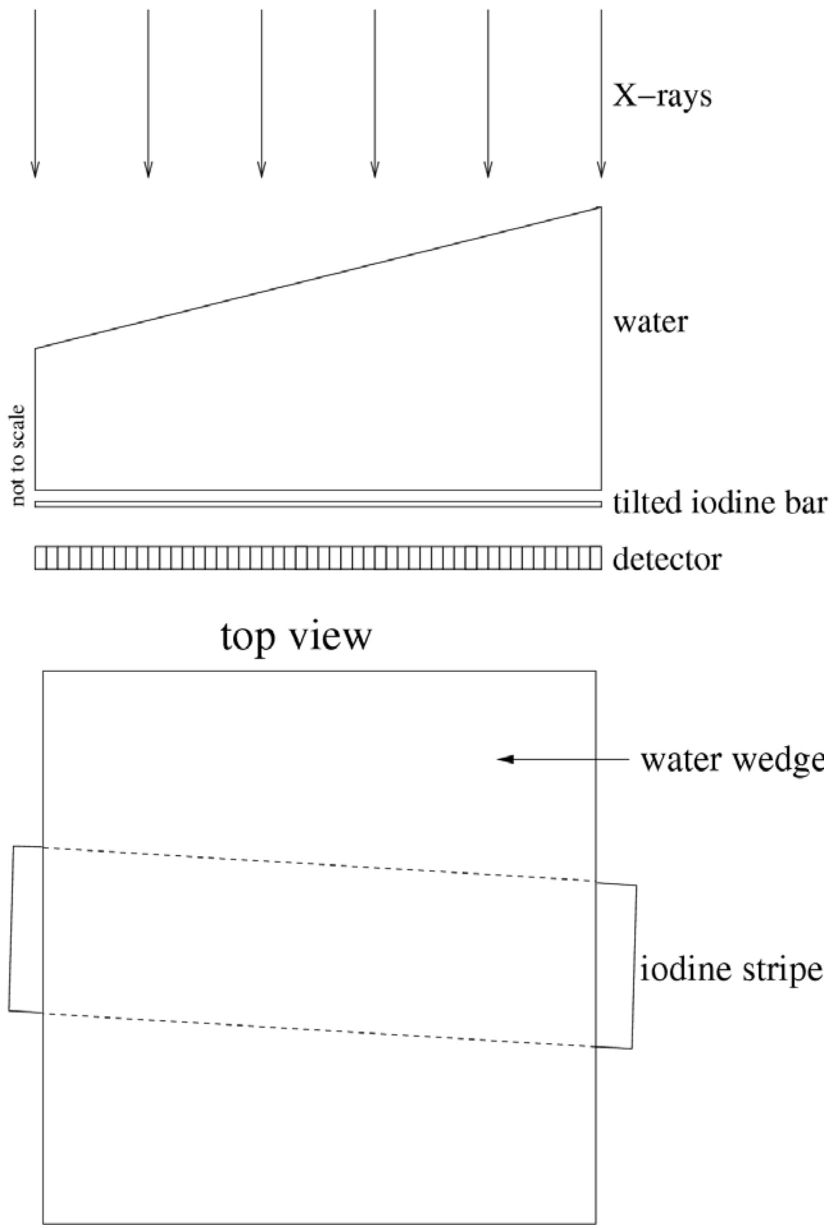


Oxygen concentration



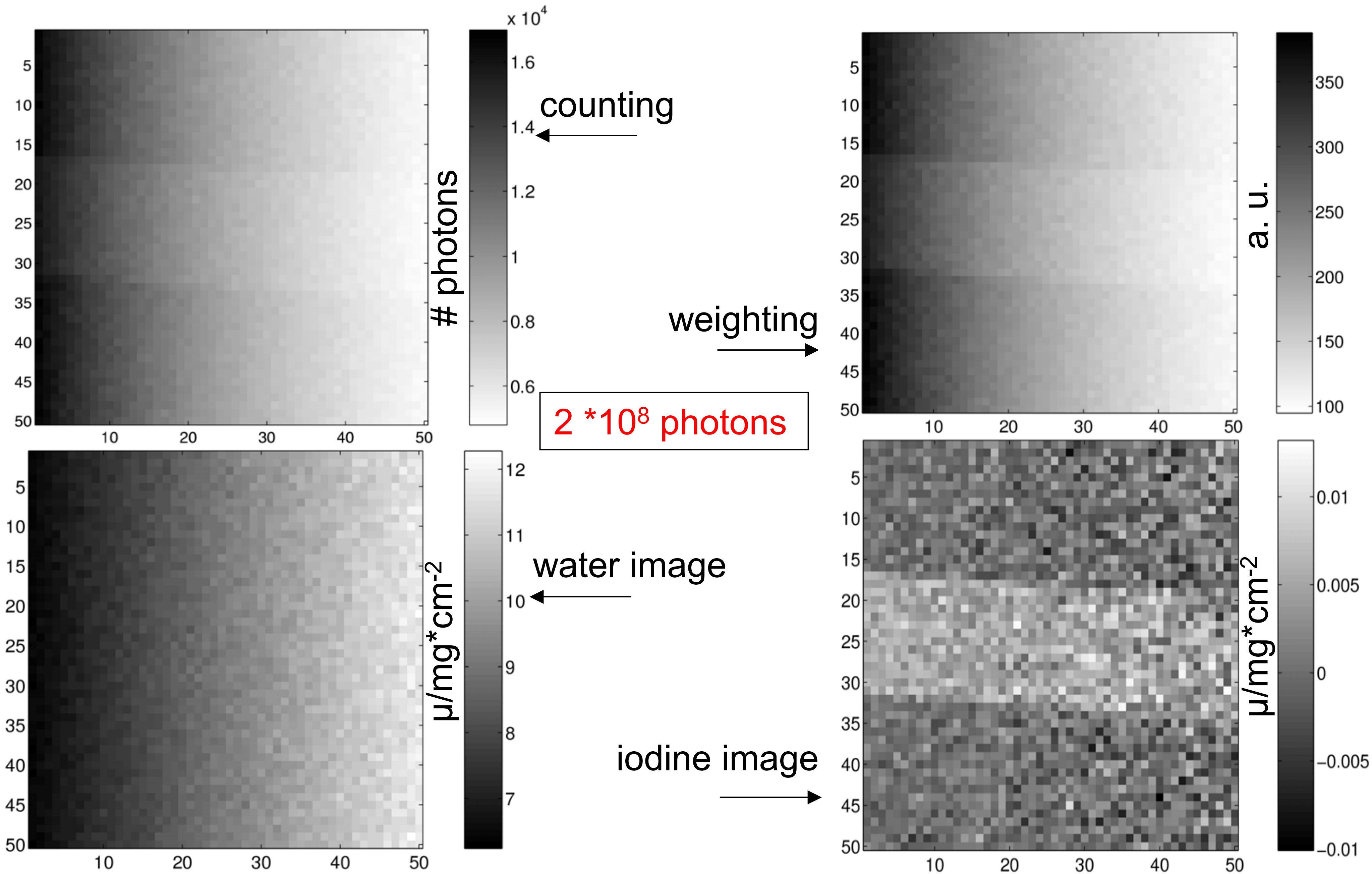
Iodine concentration

Simulation Case 2



- Water wedge:
  10 cm x 10 cm,
  Thickness: 6 cm ... 12 cm
- Iodine bar:
  3 cm x 11 cm, 10 µm thick
  (4.93 mg/cm^2)
- Ideal energy resolving detector
- Ideal anti-scatter grid
- X-ray source with four lines
  (30 keV, 40 keV, 60 keV, 80 keV)
  and homogenous intensity

Results of Simulation Case 2



SNR Consideration

SNR_C: signal-to-noise ratio of counting image

SNR_M: signal-to-noise Ratio of material image

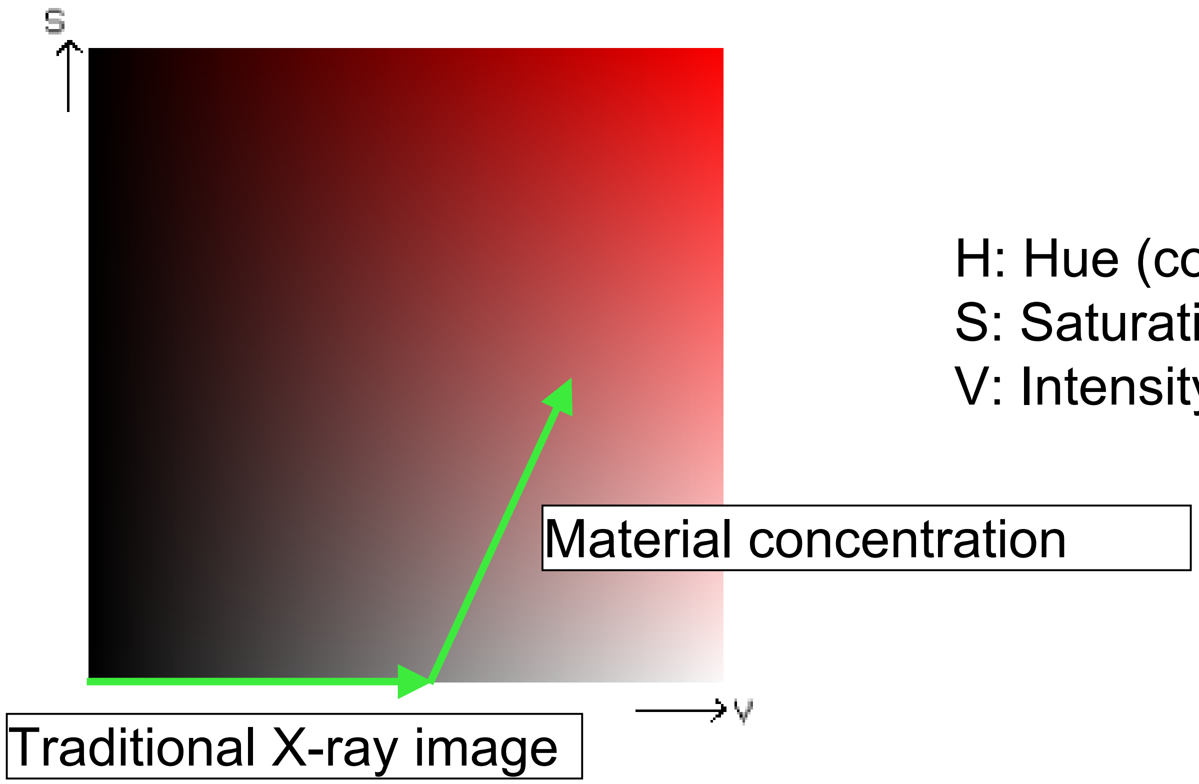
Water	SNR_C	SNR_M	SNR_C/SNR_M
6 cm	4.34	2.84	1.52
9 cm	2.89	1.86	1.55
12 cm	1.95	1.20	1.62

Image of material concentration uses not all information

Proposal: Image Fusion

Goal: Combination of

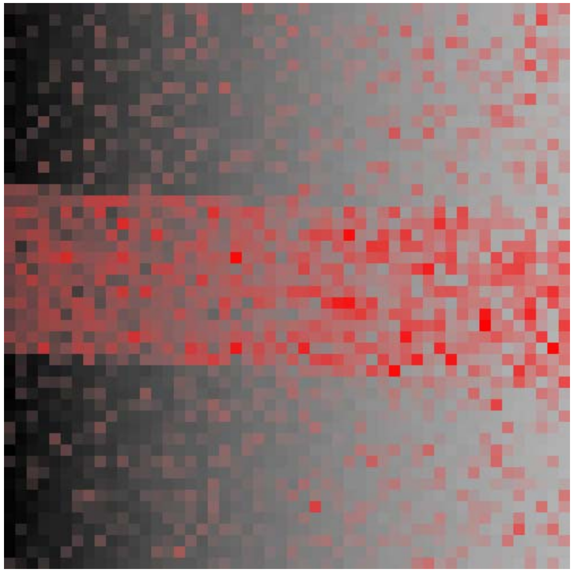
- good SNR of intensity of traditional X-ray image and
- additional information of material reconstruction



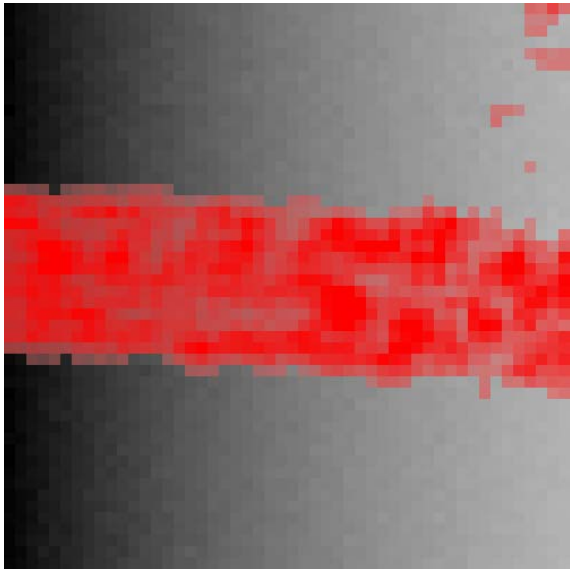
H: Hue (colour)
S: Saturation of colour
V: Intensity value

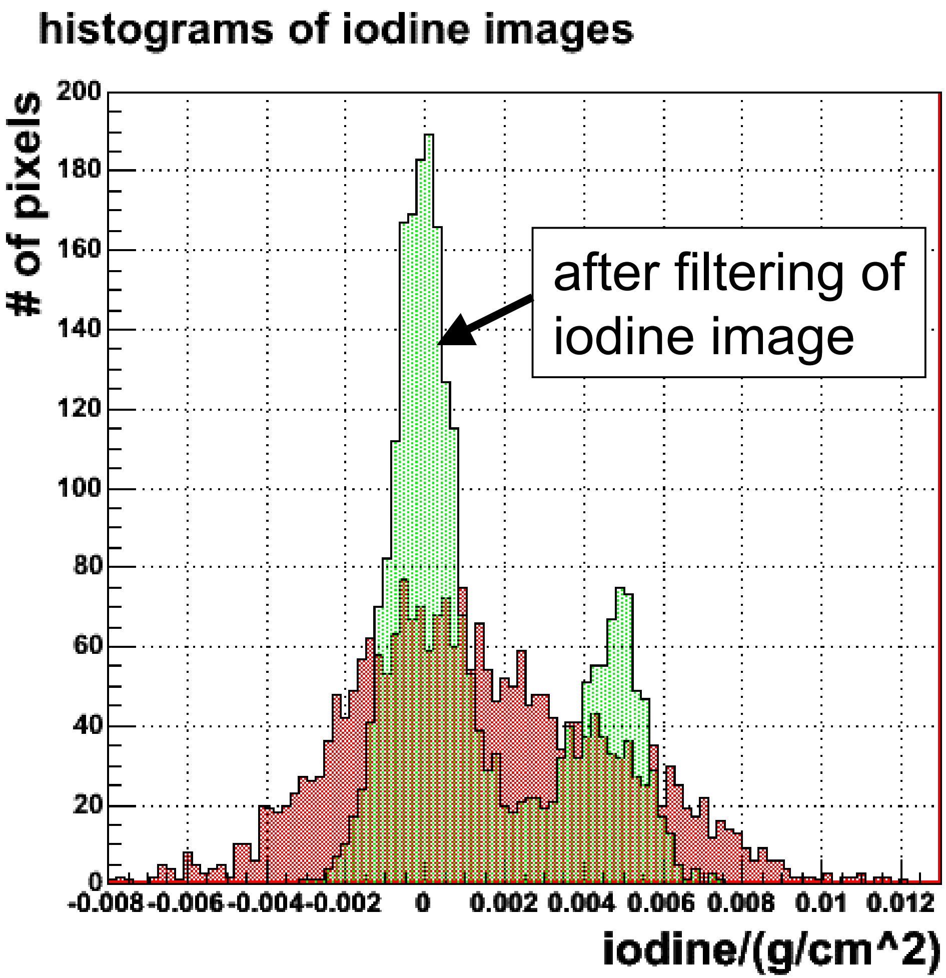
Iodine concentration → saturation of colour red

Results of Image Fusion



Filtering of iodine image:
sliding average 3 x 3 pixels, ”windowed”





Conclusion

- Spectroscopic pixel detectors can be used for reconstructing material concentration
- Image fusion allows to add material information to traditional X-ray images
- Detectors with material reconstruction capabilities can lead to new applications