Towards high-energy phase contrast imaging

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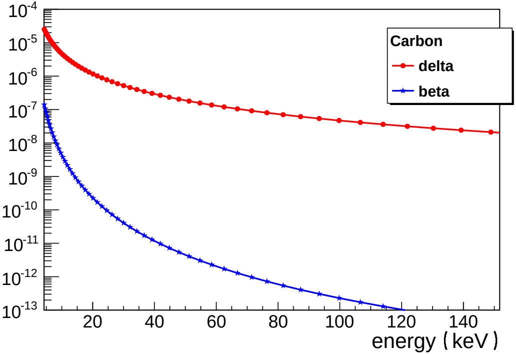
Why high energy?

$$n = 1 - \delta - i\beta$$



$$\delta \sim \mathcal{E}^{-2}$$

$$\beta \sim \mathcal{E}^{-4}$$

good phase contrast with reduced dose.

What energy is *high* energy?

Three mean energies

- 60 keV
- 100 keV
- 120 keV

conventional tube $\rightarrow$ large bandwidth $\sim$ 25 keV

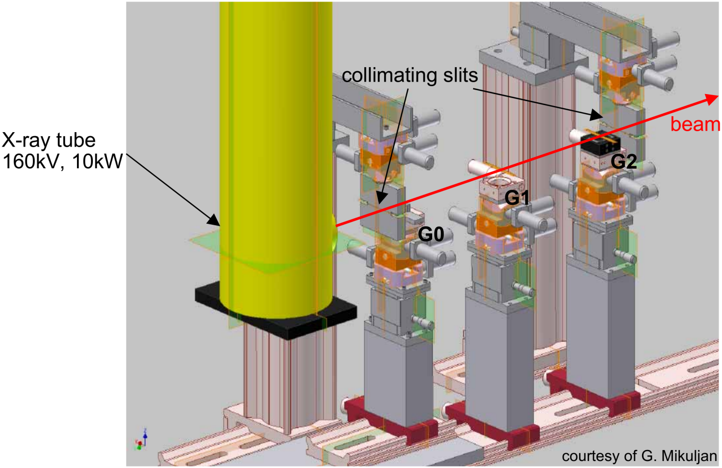
Seven different geometries

calculations and design: Thomas©

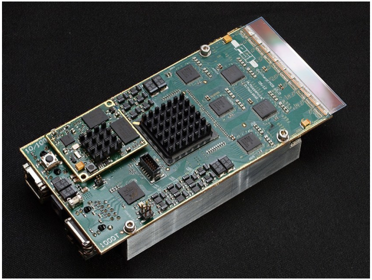
energy (keV)	total length (cm)	talbot order
60	28	1
60	66	3
60	123	5
100	40	1
100	60	1
100	123	3
120	66	1

talbot $= p^2/8\lambda$

The experimental setup



The Gotthard detector



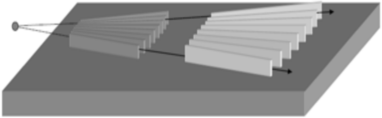
- silicon strips
- photon counting
- pitch 50 µm
- depth 8 mm
- thickness 320 µm
- linearity (energy) $< 0.5\,\%$

The gratings

The biggest challenge:

- fan geometry $\rightarrow$ bent gratings
- pitch $= 2.8\,\mu m$
- thickness $= 800\,\mu m$

Very high aspect ratio $\rightarrow$ edge-on illumination



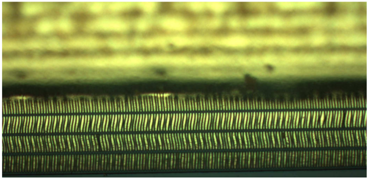
(EP10167569 by M. Stampanoni and C. David)

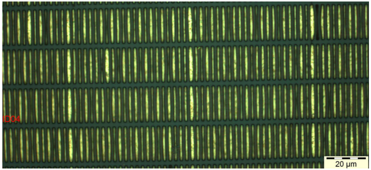
Edge-on illumination

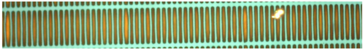
- arbitrary aspect ratio is possible
- difficult alignment (no Moiré pattern)
- 1D projections
- 2D with tomographic scans
- sample on a rotation stage

The gratings: electron microscope pictures

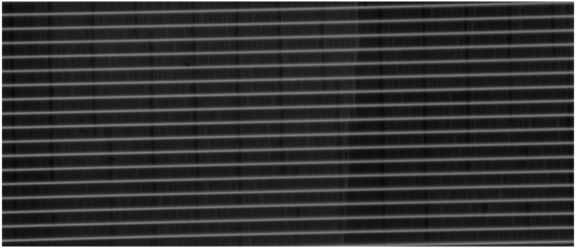
delivered on 10th December from MICROWORKS PRECISION STRUCTURES

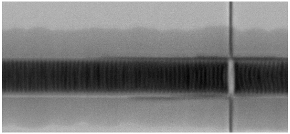


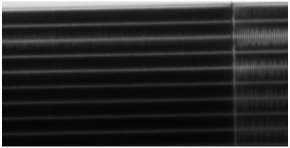




The gratings: TOMCAT images





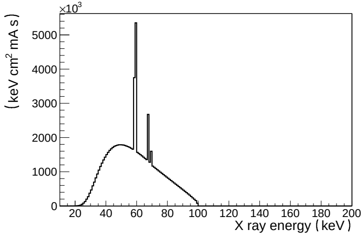


Grating defects

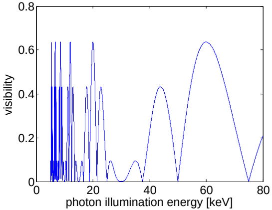
- overgrowth
- nonparallel and distorted grooves
- secondary structures

X-ray filters

example: at 60 keV useful window 50 keV to 75 keV



tube spectrum



Single-layer filters

transmission $e^{-\mu(\mathcal{E})d}$
try different materials.

Multi-layer filters

“Playing” with the edges.
Many elements $\longrightarrow$ genetic algorithm

natural selection	X-ray filters
organism	multi-layer filter
gene	thickness of each layer
fitness	flux in the energy window

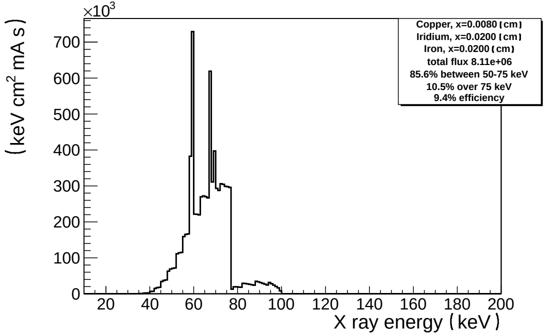
The genetic algorithm

At each step (generation), on a population of 50 filters.
running time < 1 s per generation.

1. evaluate the fitness
2. the five fittest survive and reproduce
3. small random mutations occur

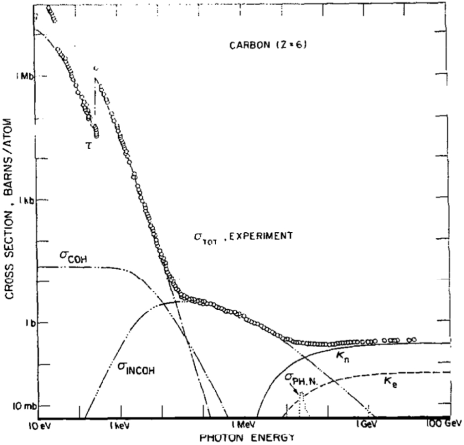
Results of the genetic algorithm

- fast convergence ($\sim$ 200 generations)
- explore many possibilities at once



Compton scattering

cross section increase $\longrightarrow$ noise from large-angle scattering



Compton scattering

- estimate with Monte Carlo (Silvia©)
- energy selection as a possible improvement

High-energy photons scattered at large angles lose a greater fraction of their energy with respect to low-energy photons.

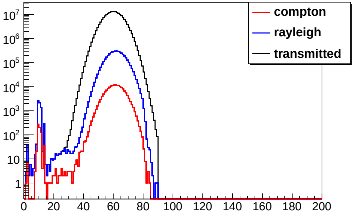
$$\Delta\lambda \sim \lambda_{\text{Compton}} = \frac{h}{m_e c} = 2.4\,\text{pm}$$

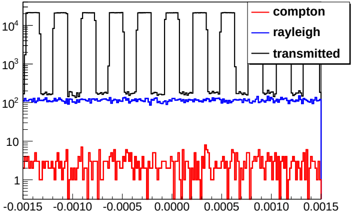
$$\lambda(100\,\text{keV}) = 12.4\,\text{pm}$$

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta\mathcal{E}}{\mathcal{E}} \sim 20\,\%$$

Silvia's Monte Carlo estimate

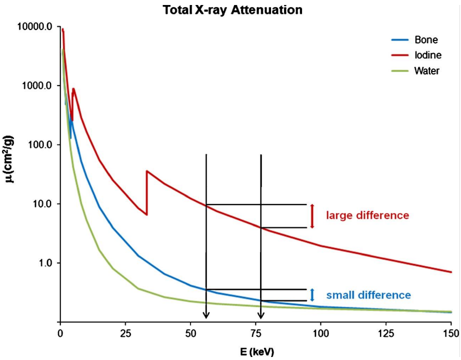
@60 keV $<1\,‰$





Further ideas for the spectral data

- absorption and refraction curves
- enhanced material classification
- student project with Eiger detector (A. Bergamaschi)



Dual- and multi-energy CT: approach to functional imaging, Insights Imaging. 2011 April; 2(2): 149159

Thanks Thomas for all the support!

And thanks Silvia for the MC simulations!

Thanks you for your attention!

Questions? Comments?