Computed tomography using the Medipix1 chip

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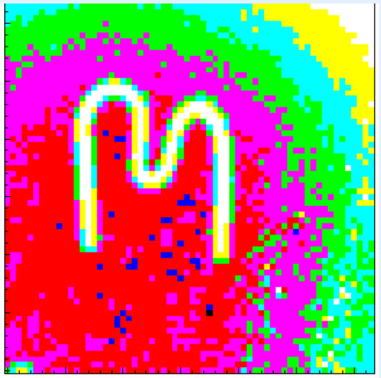


Outline

- Detection system
- Principles of Computed Tomography (CT)
- Conventional CT images
- CT using the energy threshold of the Medipix1
  - Effects on contrast
  - Similar non-CT measurements and simulations
- CT with a large virtual detector
- Conclusion and Outlook

Medipix1 – our detector

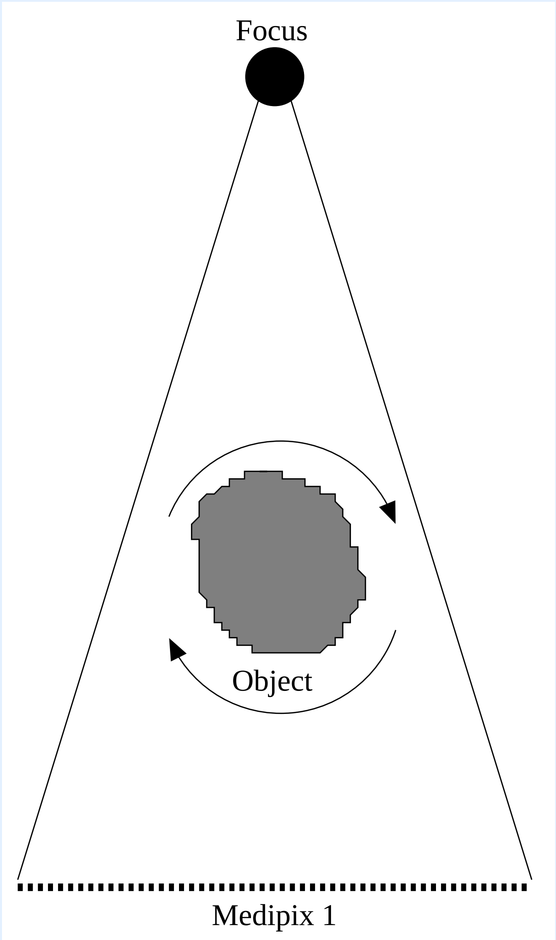
- The Medipix1-system was developed by the Medipix-Collaboration mainly at CERN
- It is a hybrid pixel detector; we use $300\,\mu\mathrm{m}$ Si as conversion material
- Characteristic properties:
  64×64 pixels each of size $(170\,\mu\mathrm{m})^2$ with a 15bit counter
- Single photon counting device
- Energy sensitive due to a threshold discriminator
- Threshold discriminator can be fine-tuned via a 3bit-DAC

Data acquisition system

- X-ray tube with Mo anode, tube voltage: $20 - 40\,\mathrm{kV}$, focal spot $\approx 0.4\,\mathrm{x}\,0.6\,\mathrm{mm}^2$
- Medipix1 is controlled via MUROS and `Medisoft`
- Translation and rotation stages are required for CT measurements
- Because we do hundreds of measurements we have an automation system which controls tube, `MediSoft` and the stages

Principles of Computed Tomography (CT)

- In contrast to medical CT we rotate the object
- For a complete CT dataset projections of the object in an angular range of at least $180\,^\circ$ are necessary
- Measured value in each detector element:
  $I = I_0 \exp\left[-\int_{\mathrm{ray}} \mu(x,y,E_{\mathrm{eff}})\,\mathrm{d}s\right]$
- Input for reconstruction (filtered back-projection): $$\int_{\mathrm{ray}} \mu(x,y,E_{\mathrm{eff}})\,\mathrm{d}s$$



- The reconstructed variable is $\mu(x,y,E_{\mathrm{eff}}) = \mu_{\mathrm{eff}}(x,y)$

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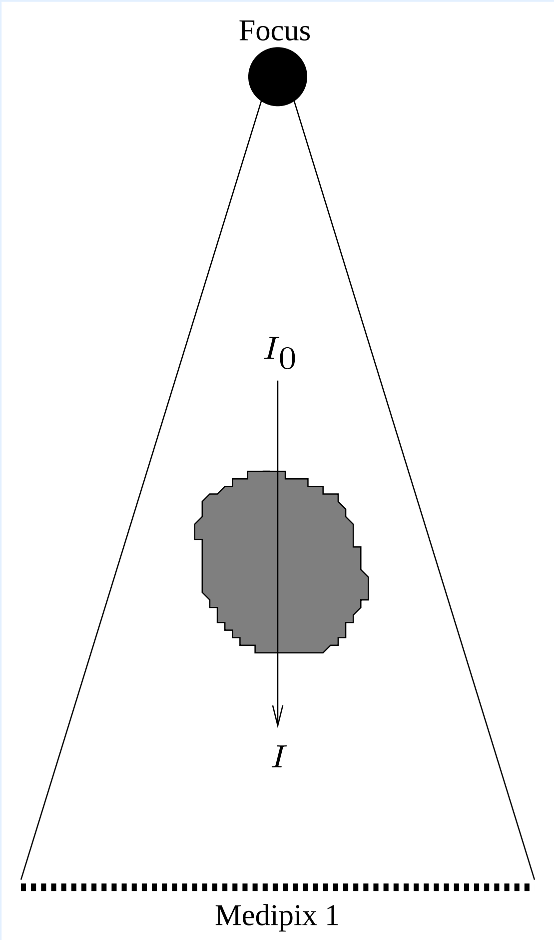

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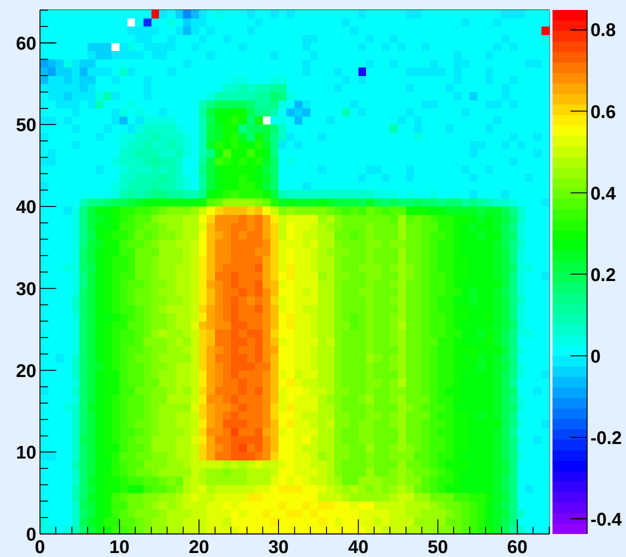

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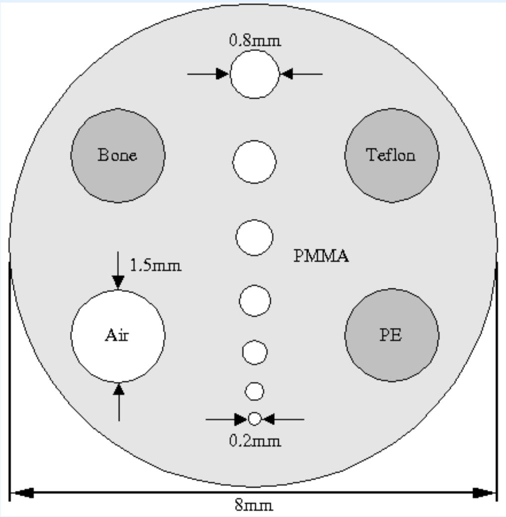
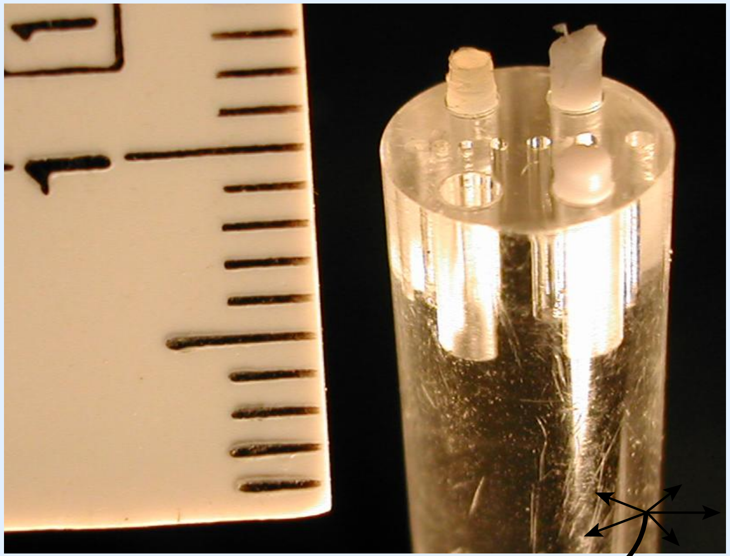
Conventional CT images

- Object is made out of an $8\,\mathrm{mm}$ PMMA rod; the $1.5\,\mathrm{mm}$ holes are filled with bone, PA, Teflon, and air
- Measurement was done with minimal threshold $\Rightarrow$ all photons are used
- Differences in attenuation between materials clearly visible
- $0.2\,\mathrm{mm}$-hole can be resolved
- Beam hardening artefacts produced by bone





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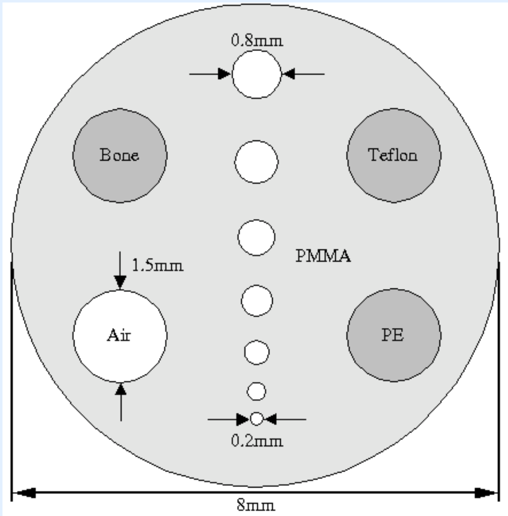
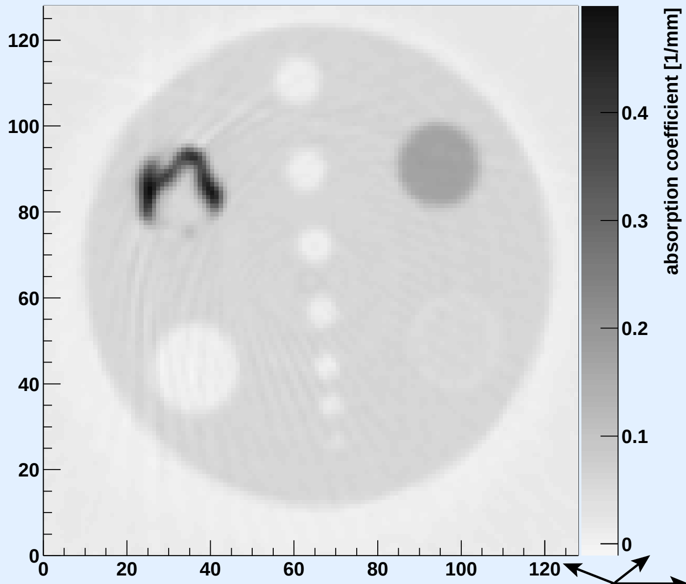
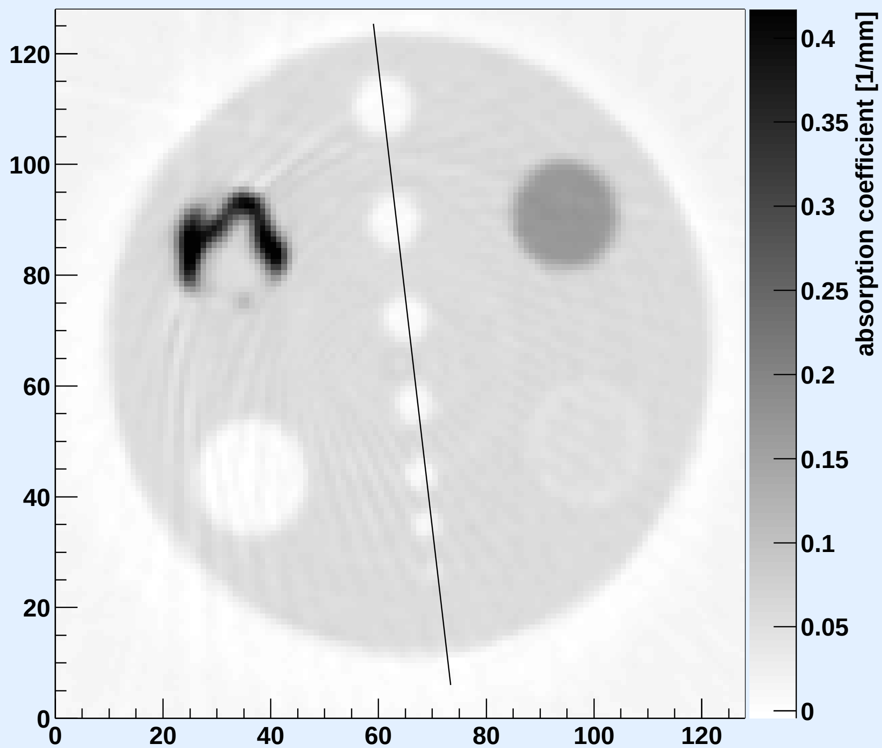
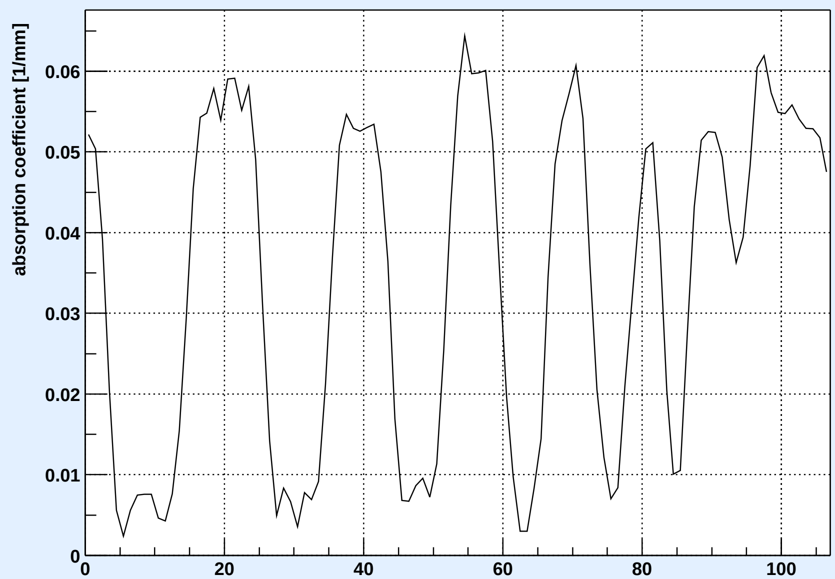




Evaluation via linescan

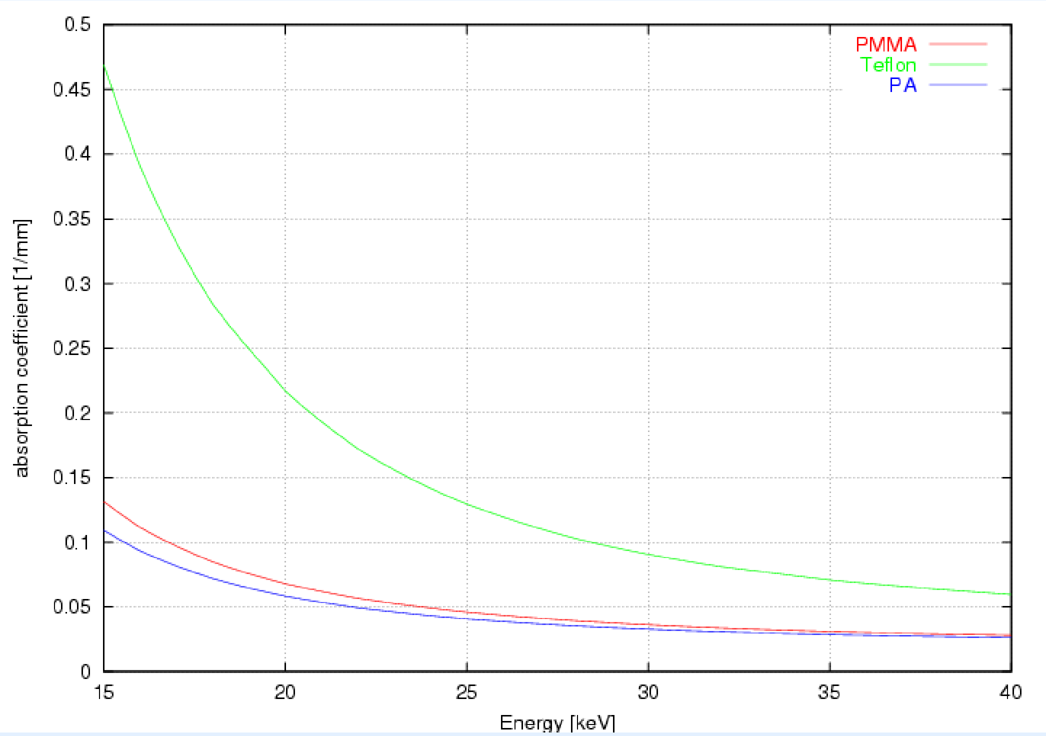




Linescan shows that contrast diminishes with diameter of holes

How can we use the energy threshold?

- μ changes with photon-energy
- Use Medipix1 to measure μ with respect to energy, which is *not* possible with integrating detectors

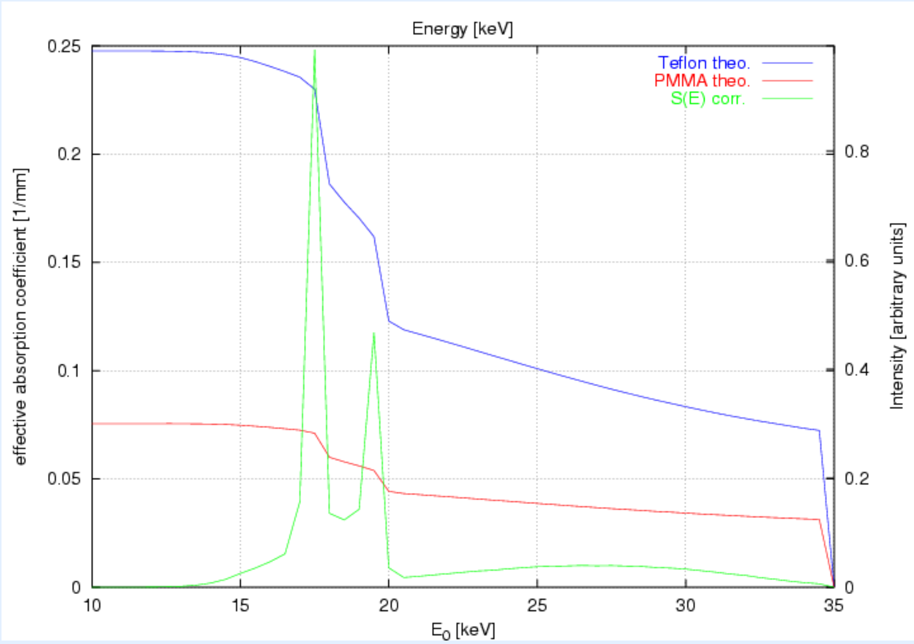


Dependency of μ_{eff} on energy threshold

- The measured μ_{eff} depends on the used spectrum $S(E)$ and the energy range of the photons:

$$\mu_{\mathrm{eff}} = \frac{\int_{E_0}^{\infty} S(E)\, \mu(E)\, \mathrm{d}E}{\int_{E_0}^{\infty} S(E)\, \mathrm{d}E}$$

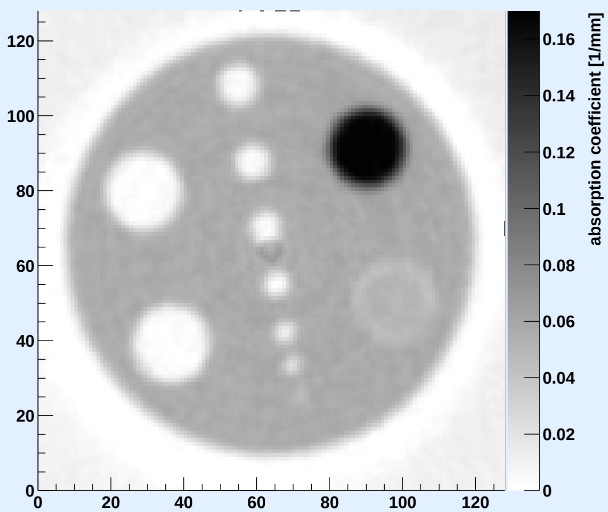
- E_0 can be varied when using the Medipix1



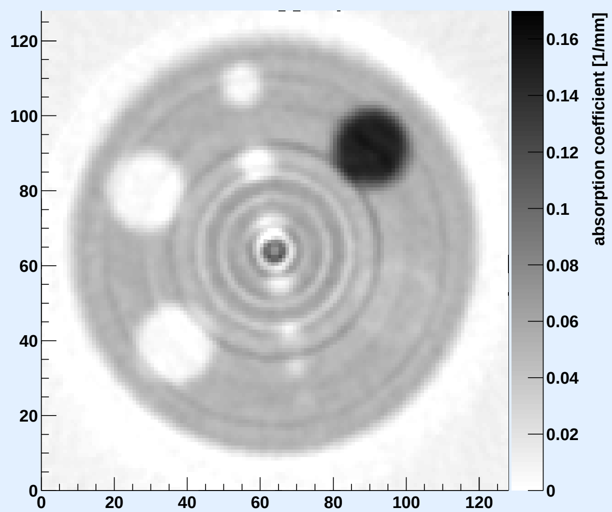
- μ_{eff} is shown for Teflon (blue) and PMMA (red) for the corrected and simulated spectrum of Mo at $35\,\mathrm{keV}$ ($2\,\mathrm{mm}$ Al and $0.3\,\mathrm{mm}$ Mo as filter)

CT measurements with E_0 variation

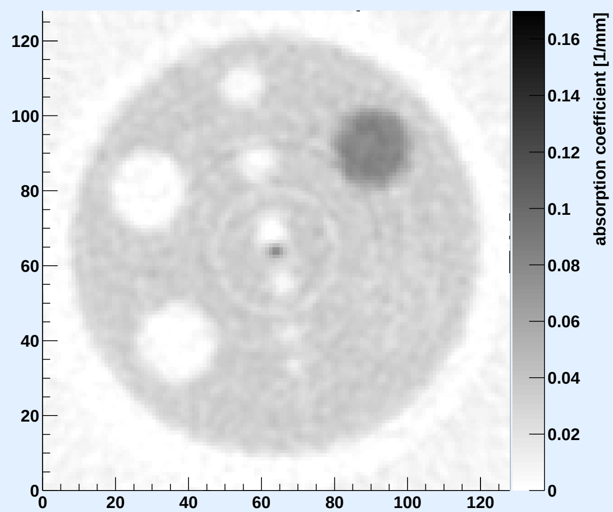
- We did CT-measurements at 3 different cut-off energies E_0 with the object described earlier (at $35\,\mathrm{kV}$ with $2\,\mathrm{mm}$ Al, $0.3\,\mathrm{mm}$ Mo)
- Images where evaluated for contrast changes and for the absolute value of $\mu_{\mathrm{eff}}(E_0)$



E_0= 11.5 keV



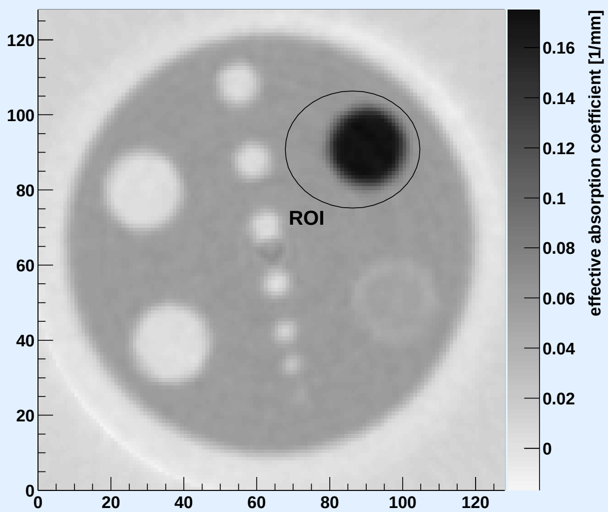
E_0= 16.5 keV

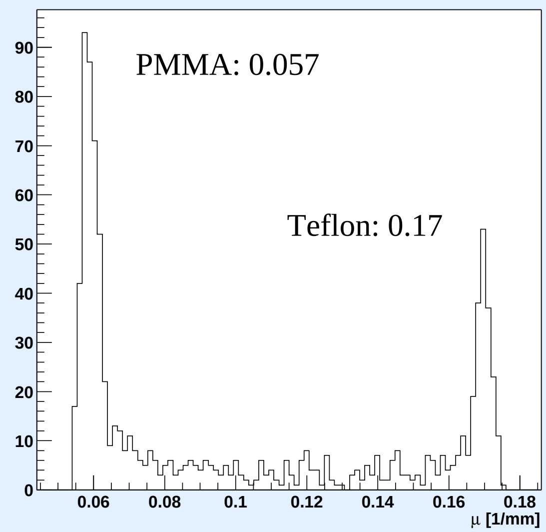


E_0= 23.6 keV

Effects on contrast

- Contrast between an object with absorption μ and its background (μ_{bg}) is defined by: $C = \frac{\mu - \mu_{\mathrm{bg}}}{\mu_{\mathrm{bg}}}$
- The contrast of Teflon to PMMA changes from 2.0 to 1.47





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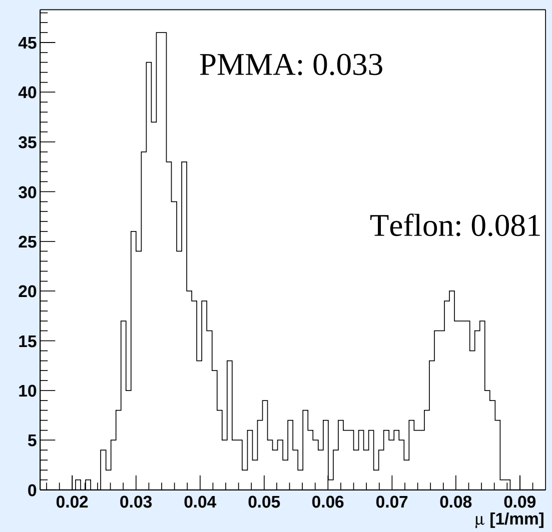

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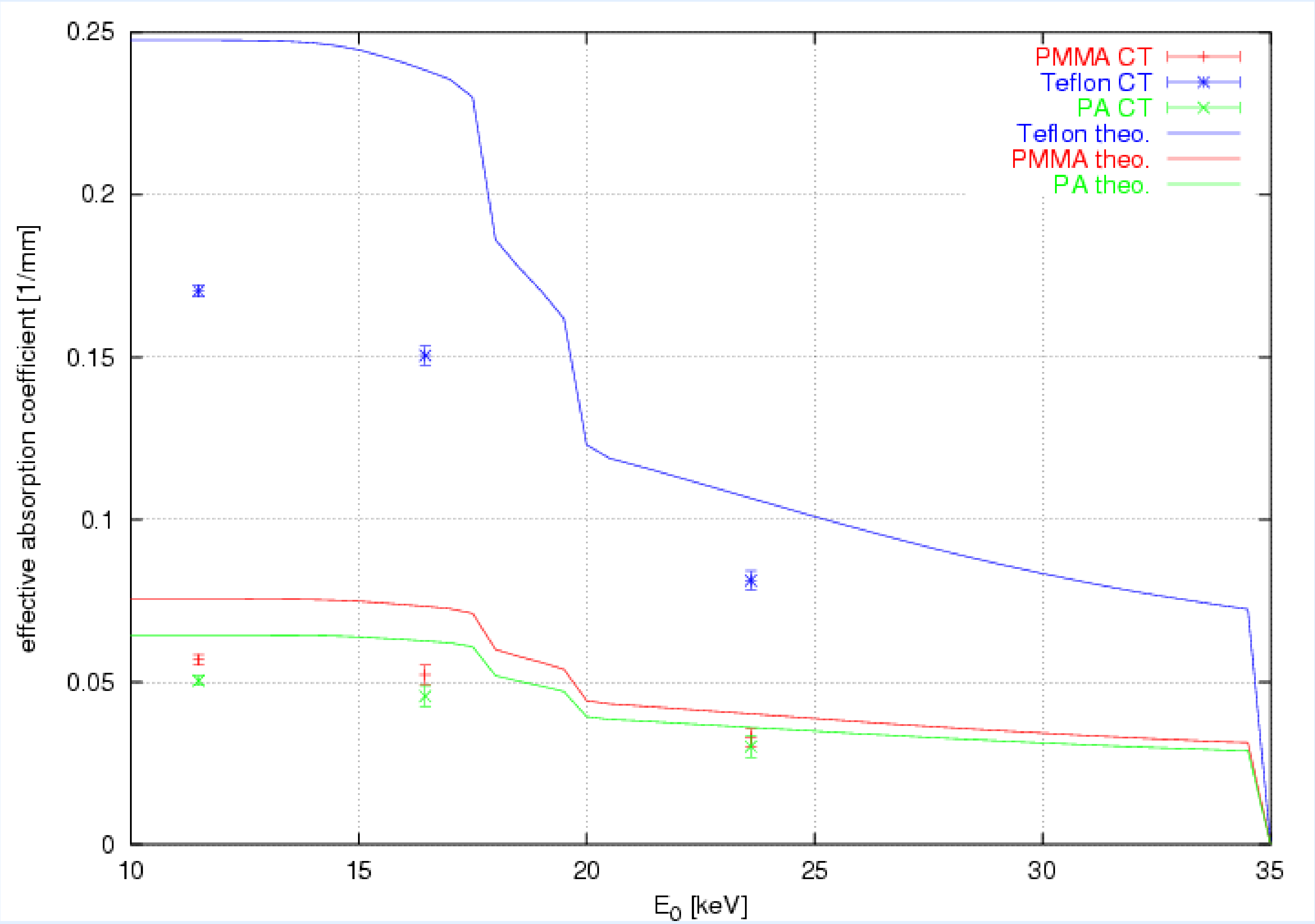
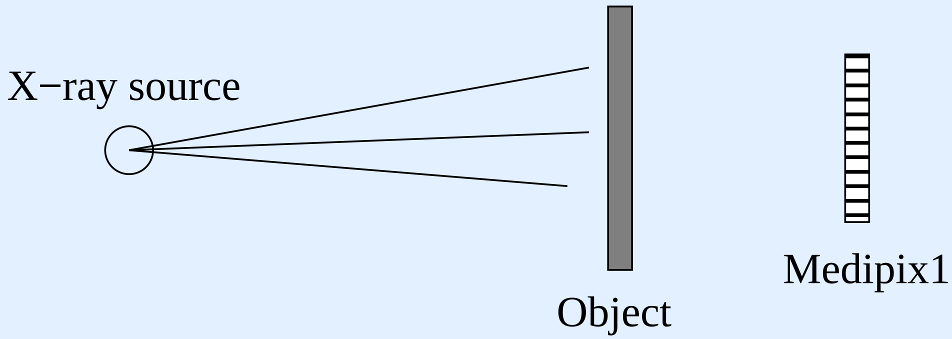
Comparison of measured $\mu_{\mathrm{eff}}(E_0)$ with theory



Similar non-CT measurements of $\mu_{\text{eff}}(E_0)$

- Simple non-CT measurements were done to reproduce theoretical $\mu_{\text{eff}}(E_0)$
- Differences are smaller compared to the CT values



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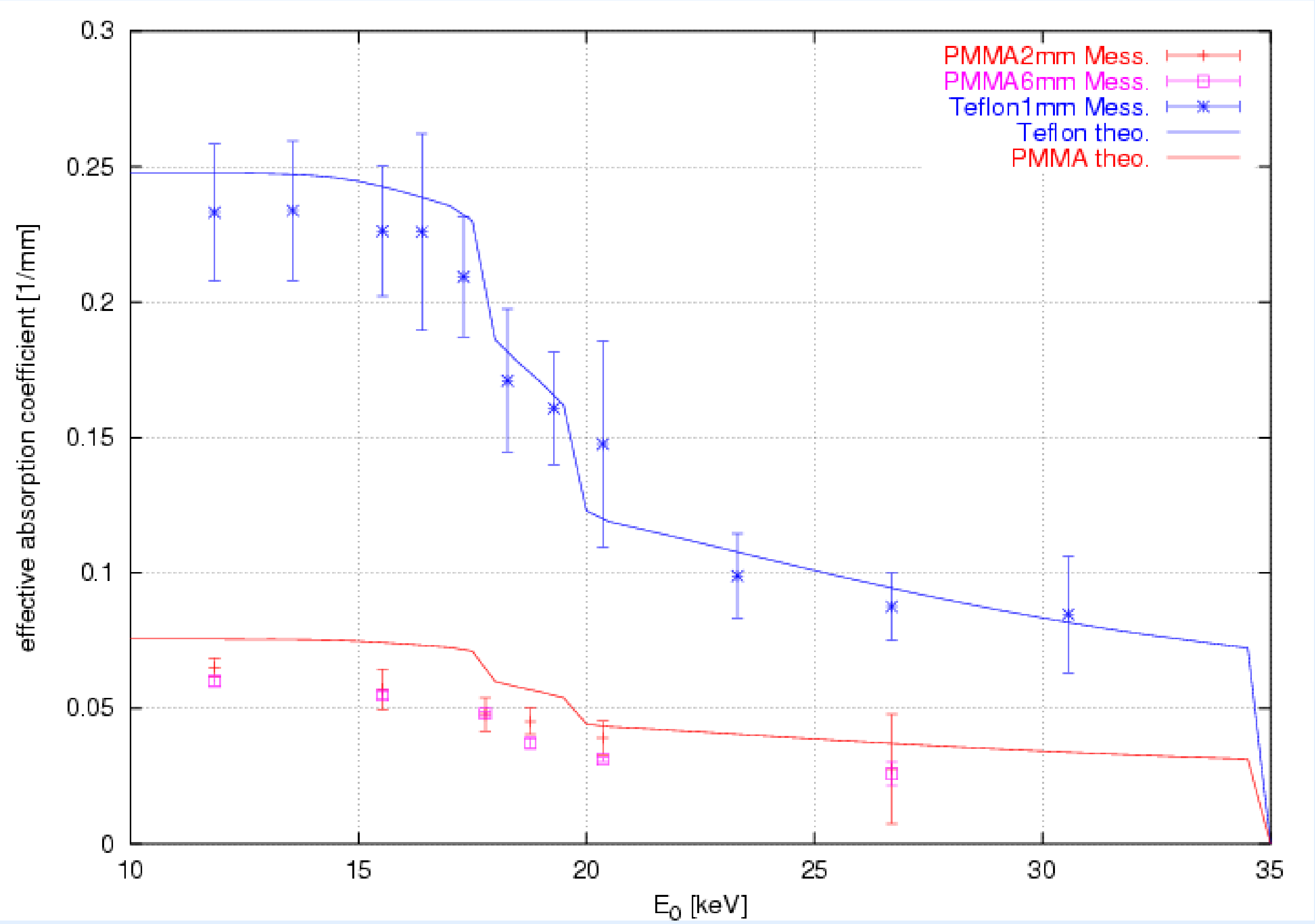
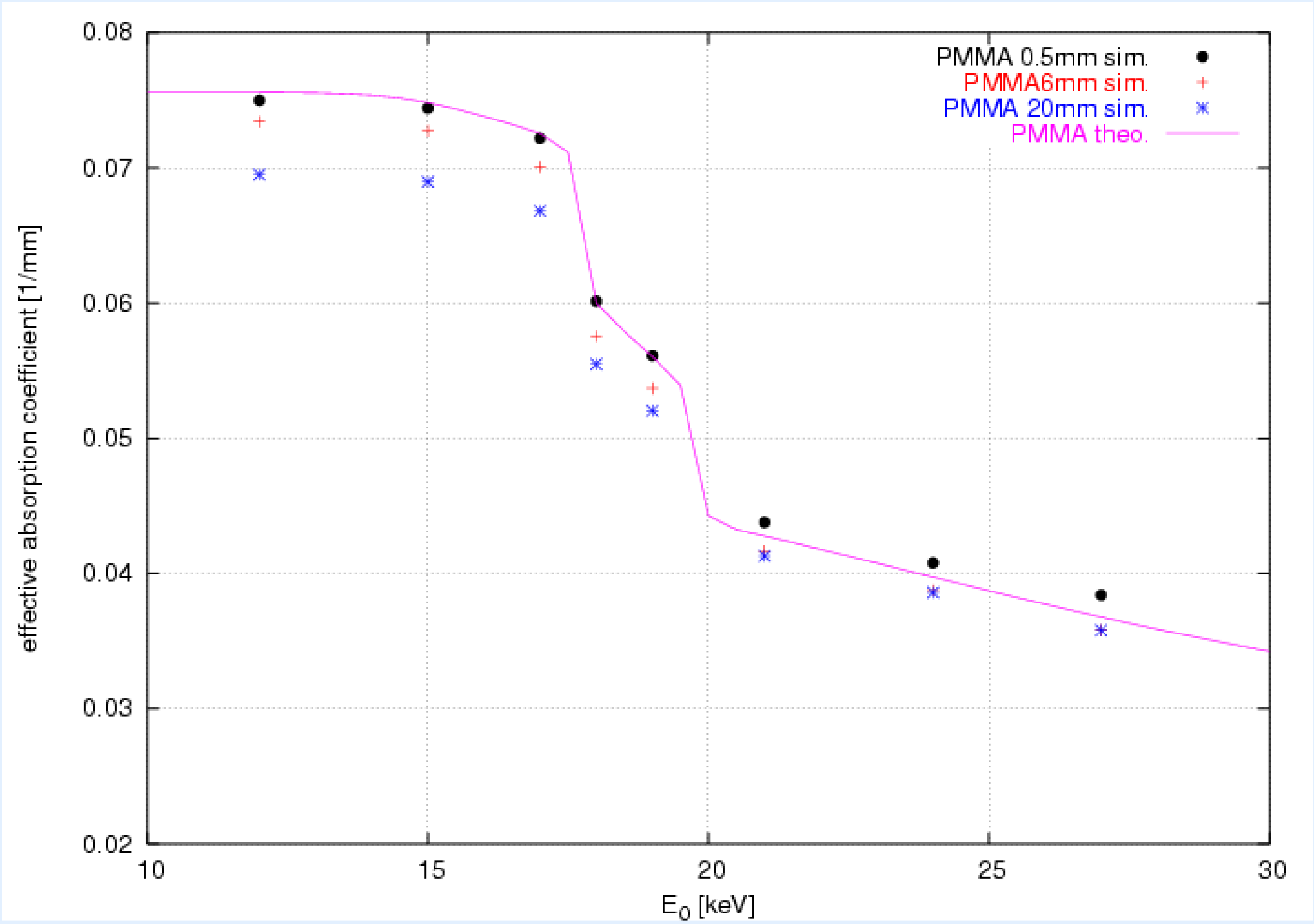


Simulation results

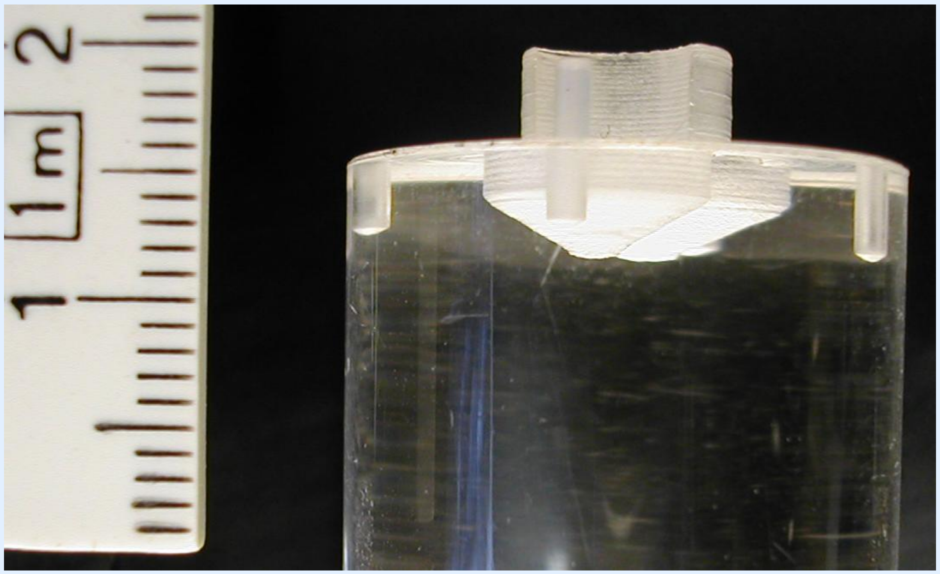
- Simple measurement was simulated for different material thicknesses (ROSI)

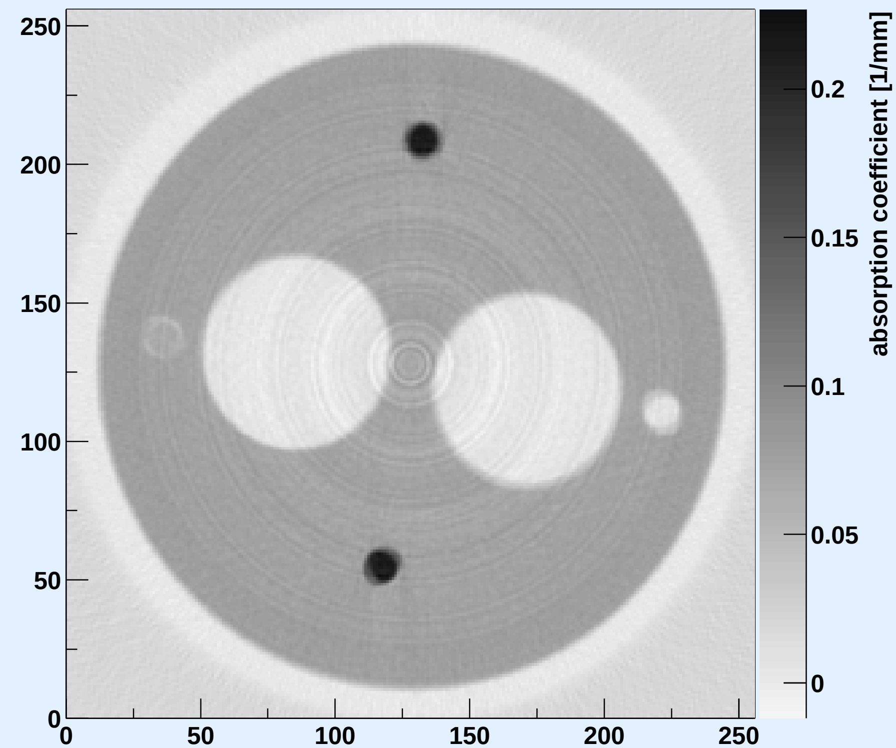


Evaluation of measurements and simulation

- In both measurements were differences between the measured data and the theoretical curve
- Possible reason could be the photon spectrum $S(E)$ because it isn't measured but obtained from a simulation
- One reason for the differences is beam hardening:
  - The low-energy-photons of the spectrum have a shorter absorption length
  - Resulting beam is more penetrating $\Rightarrow \mu_{\text{eff}}$ is smaller
  - Effect increases with increasing object thickness
  - A high E_0 causes a decrease of the impact of beam hardening

CT with a large virtual detector





Medipix1 was moved to 3 adjacent positions at each angle to imitate a larger detector (1110 measurements)

Conclusion and outlook

- Small scale CT is possible with the Medipix1
- Even with simple techniques quite good results can be obtained
- Energy threshold can be used to measure $\mu_{\mathrm{eff}}(E_0)$
- Higher photon energies combined with different conversion materials will be used in future measurements
- Looking forward to Medipix2 (two thresholds, larger sensitive area, smaller and more pixels)

Thanks to . . .

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