Characterization of Non-Gaussian beam profiles of polycapillary lenses

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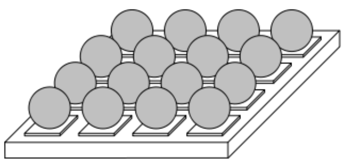
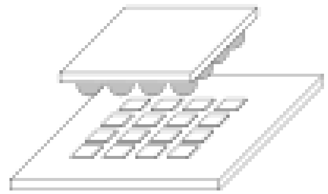
Outline

- Introduction
  - µ-EDXRF of Arrayed microstructures
  - Energy dependence spot size of polycapillary x-ray optics
  - Halo effect
- Characterization of non Gaussian beam profiles
  - Experimental Characterization method „Knife-edge“
  - Beam profile modeling approach
  - 2D Beam Profile with Radon transformation
  - Halo effect contribution to microstructure analysis
- Summary

Arrayed Microstructures
Example „Copper Pillars“

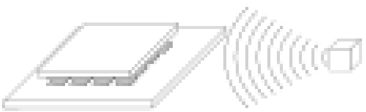


1. Metallization Solder

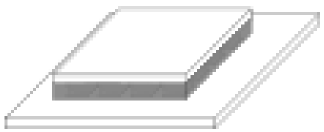


2. „Flipping“

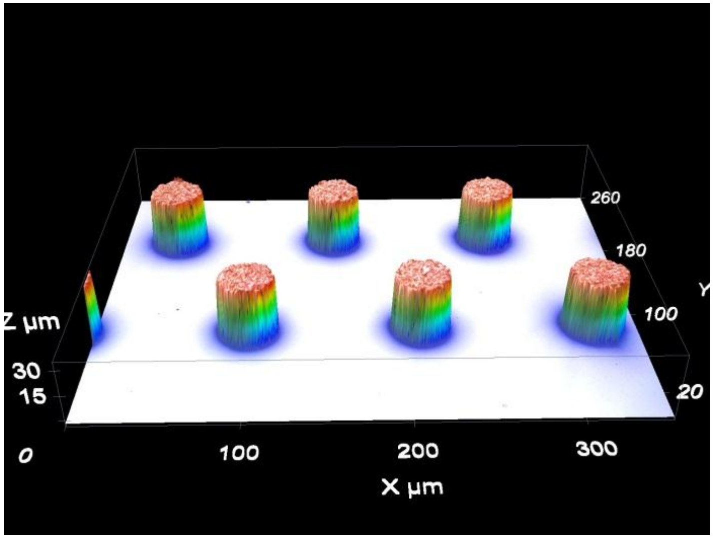
Source: Wikipedia



3. Soldering

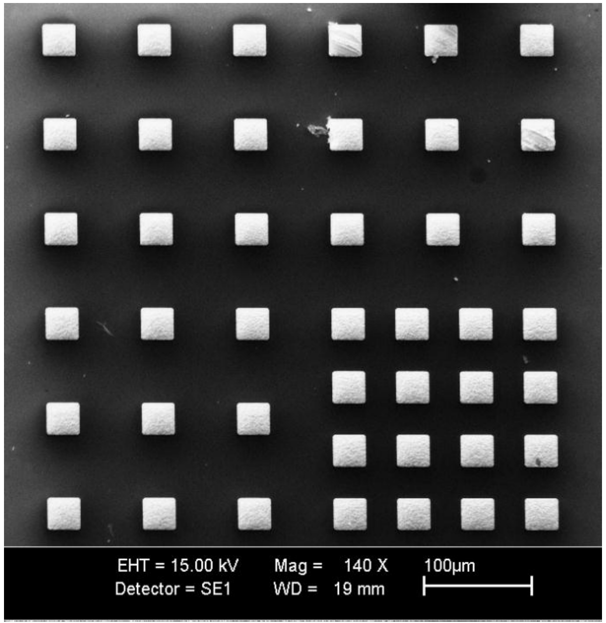


4. „Under filling“

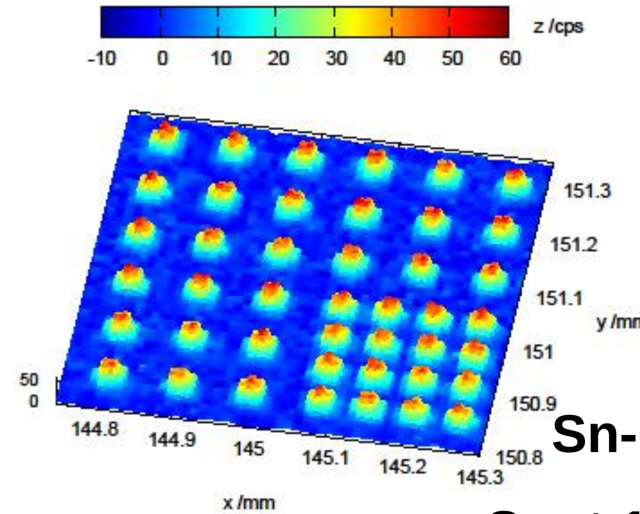


- Solder junctions for electronic components
- Metallic layers Sn on Cu
- µ-EDXRF thickness and elemental composition for individual structures
- Size of microstructures comparable to Spot size, small pitch size
- **Knowledge of the beam profile is mandatory for quantification**

Size measuring spot

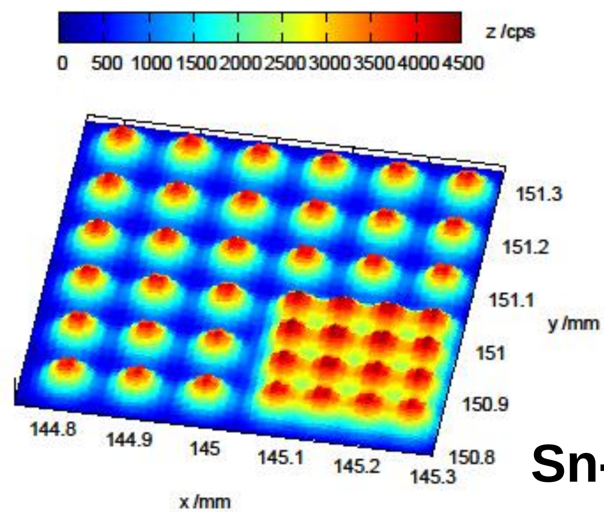


- **Energy dependence of measuring spot!**
- Mapping Sn structure on Si wafer
- Fluorescence for Sn-L and Sn-Ka
- 500 µm x 500 µm (50 x 50)
- Size 60 µm, pitch size 30 µm



Sn-Ka

Spot 18 µm



Sn-L

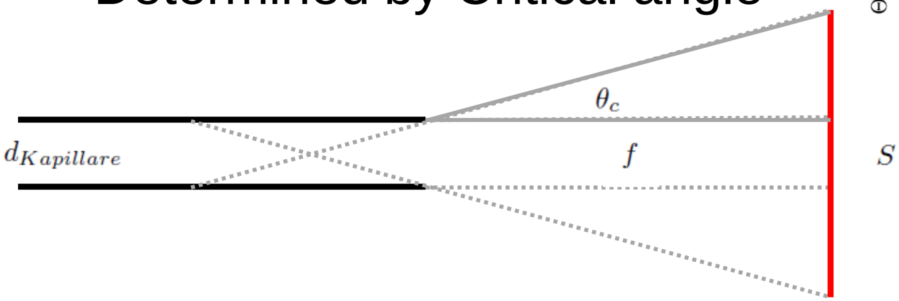
Spot 36 µm

Spot-size Polycapillary

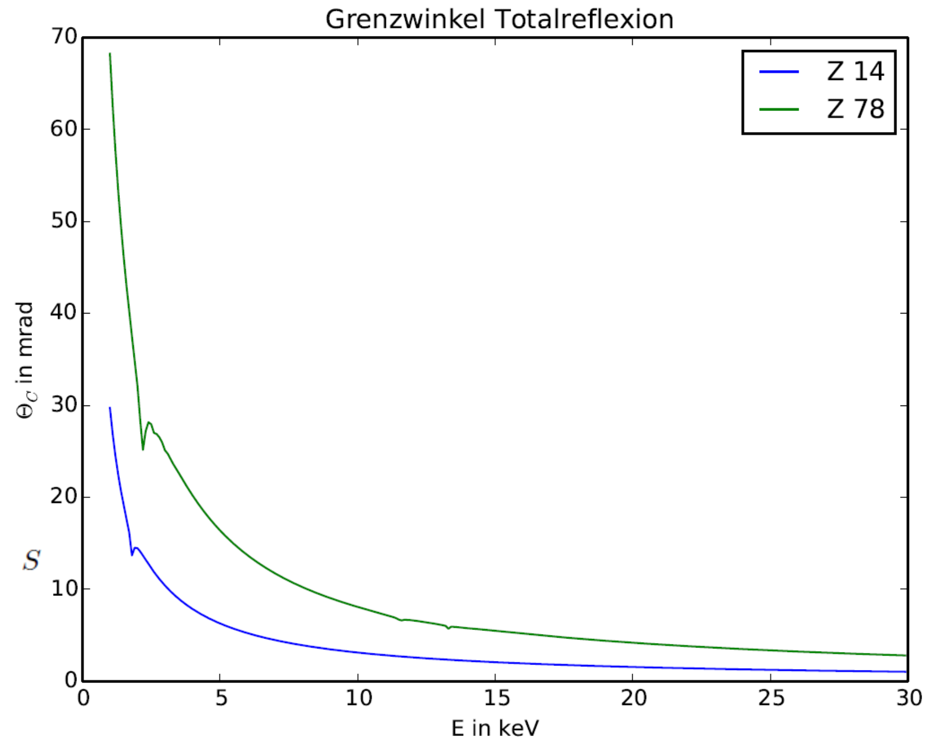
- Spot size is energy dependent

$$S(\mu m) \approx \frac{60 \cdot f(mm)}{E(keV)}$$

- Determined by Critical angle



$$S = 2 \cdot tan\ \theta_c \cdot f + d_{Kapillare}$$



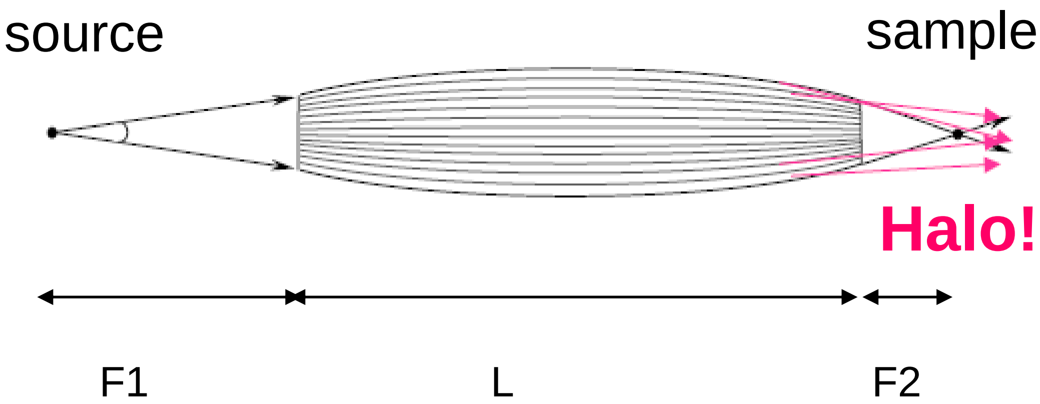
- Energy dependence by Critical angle ~1/E
- Gain factor: intensity ratio with and without optic

$$gain \propto \left(\frac{2 \cdot \Theta_C \cdot R}{d_{Kapillare}}\right)^2$$

- Optimization problem: gain vs. spot size
- Glass as fabrication material of choice

T. Schoonjans er Al., The xraylib library for x-ray matter interactions. recent developments, Spectrochimica Acta Part B: Atomic Spectroscopy 66 (1112) (2011)

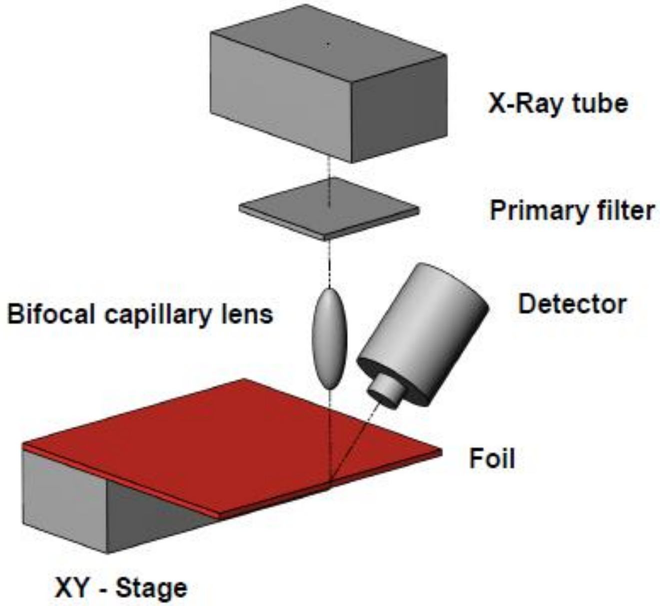
Halo effect

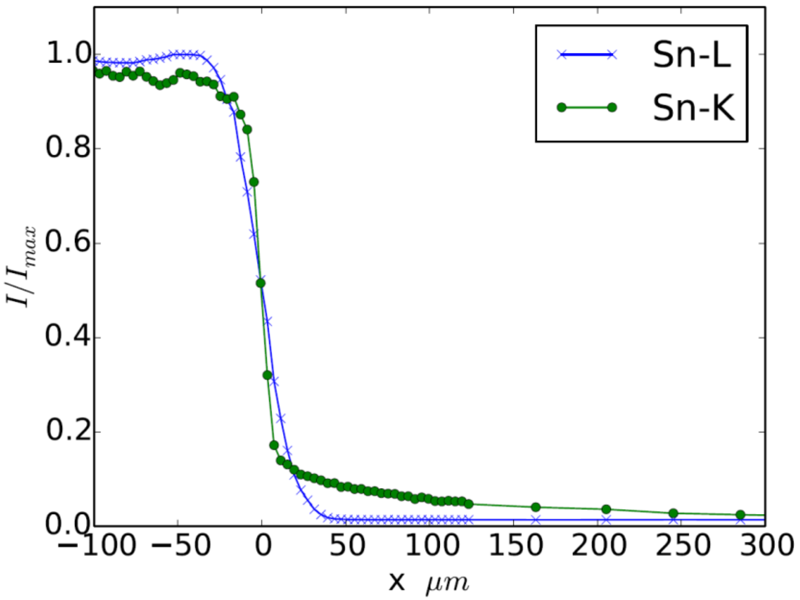


- Monocapillary acts as conductor for x-ray photons by total reflections
- High energetic photons with $\theta > \theta_C$ can penetrate into the glass
- Insufficient Absorption → Escaping from the optic
- **Diffuse background radiation**

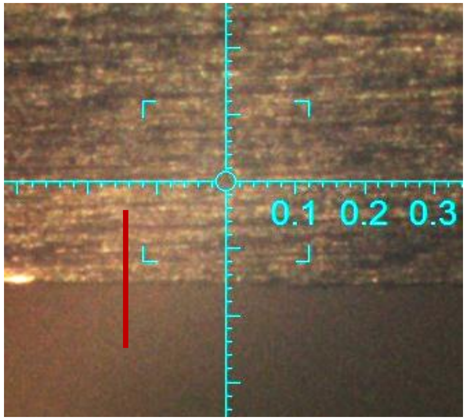
Analogy
Halo effect of the moon in the atmosphere !

Characterization beam profile via „Knife-edge“

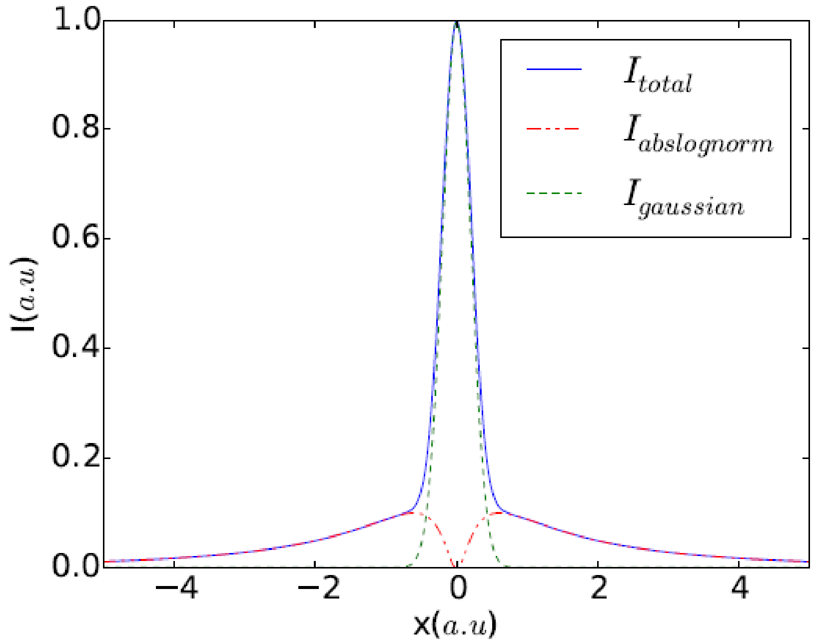




- Pure element foil edge as 2D intensity integrator
- Common tabletop µ-EDXRF setup
- Advantages
  - Suitable for **in Situ characterization**
  - Suitable for **high energies**
- Scan by movement of the edge though focal plan



Modeling of the beam profile



- 1D beam profile model

$$\boxed{I_{total} = I_{gaussian} + I_{abslognorm}}$$

- 6 Parameters for various beam shapes
- 2 Parameters for Halo Characterization
  - r measure for deviation from pure gaussian

$$r = \frac{I_2}{I_1 + I_2}$$

  - R measure for the strength of halo

$$R = \frac{\int_{-3\sigma_1}^{3\sigma_1} I(x)dx}{I_1 + I_2}$$

R→1 for halo free Polycapillaries

$$I_{gaussian} = \frac{I_1}{\sigma_1\sqrt{2\pi}} \cdot exp\left(-\frac{1}{2}\left(\frac{x-\mu_1}{\sigma_1}\right)^2\right)$$

$$I_{abslognorm} = \frac{I_2}{2|x|\sigma_2\sqrt{2\pi}} \cdot exp\left(-\frac{1}{2}\left(\frac{log|x|-\mu_2}{\sigma_2}\right)^2\right)$$

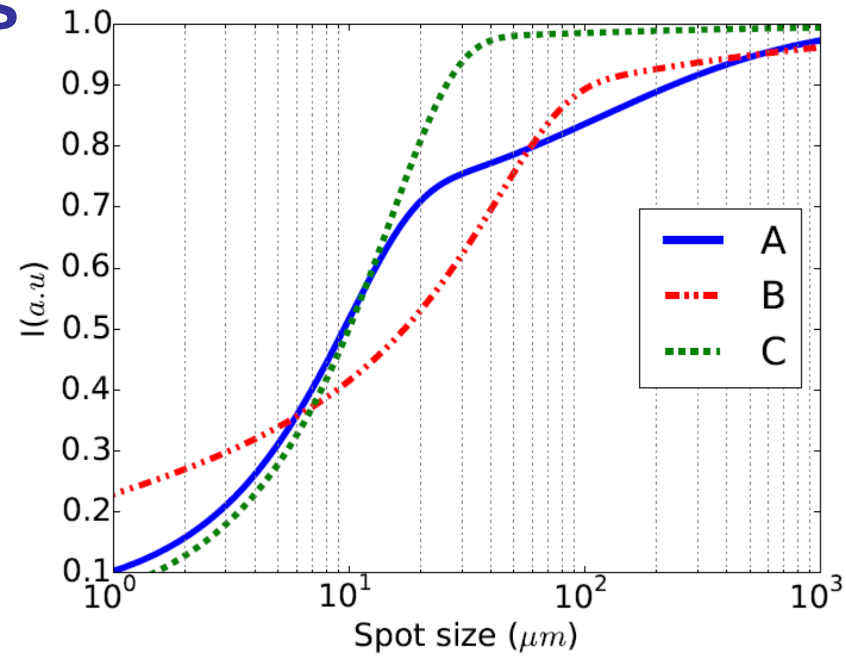
Comparison Polycapillaries

- Integrated beam profile for Sn-Ka
  → fitted to edge scan for Cap. A,B,C

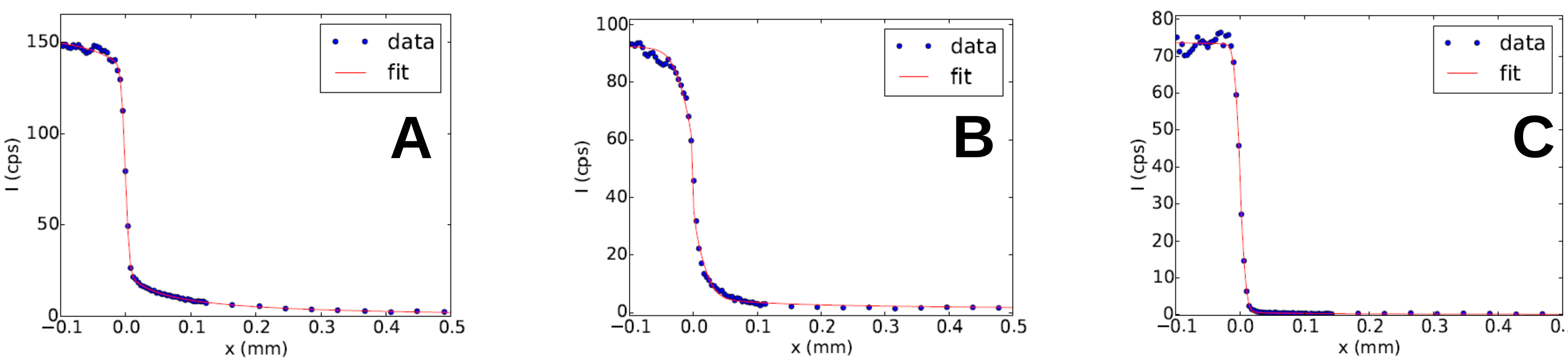
$$I_i(x) = \frac{I_1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{x-\mu_1}{\sqrt{2}\cdot\sigma_1}\right)\right) + \operatorname{sgn}(x) \cdot \frac{I_2}{4} \cdot \left(1 + \operatorname{erf}\left(\frac{\log|x|-\mu_2}{\sqrt{2}\cdot\sigma_2}\right)\right) \frac{I_2}{2}$$

- Integrated Spot intensity

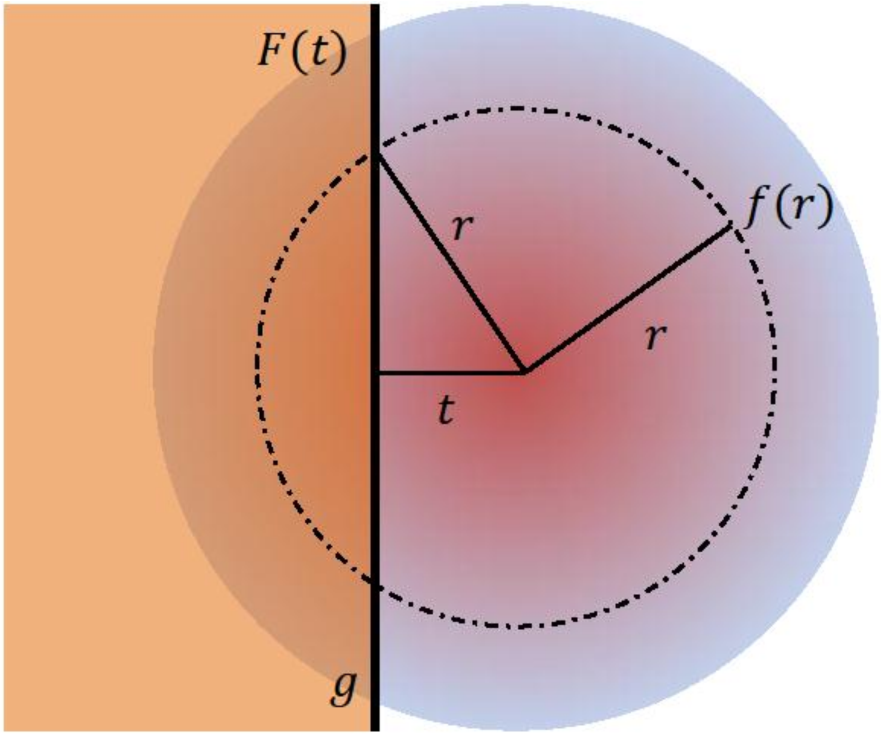
$$d = 2 \cdot x \qquad I_{spot}(x) = 1 - 2 \cdot \frac{I_i(x)}{I_1 + I_2}$$



- Different Characteristics for Cap. A und B, Cap. C halo free!



Radon Transformation



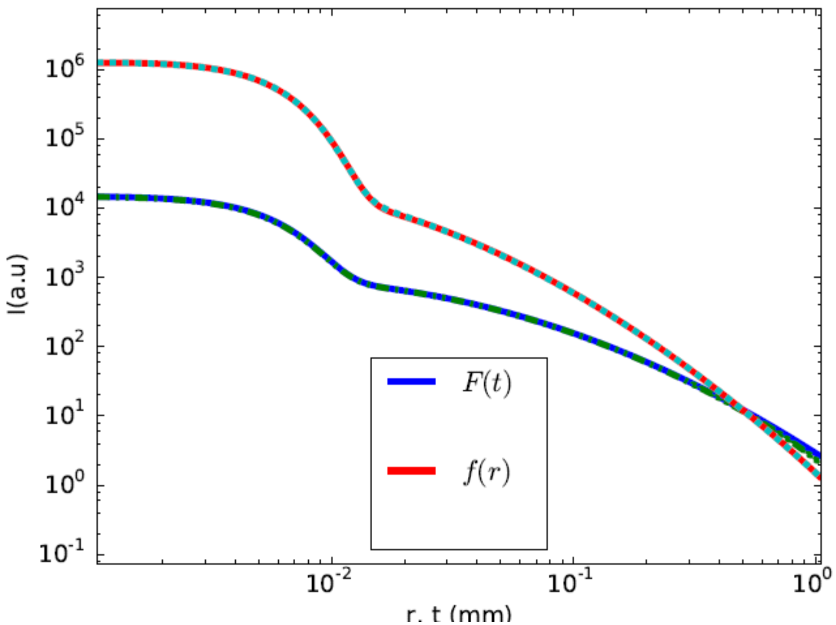
- 1D description not sufficient
- 2D Radial beam profile by Inverse Radon Transformation

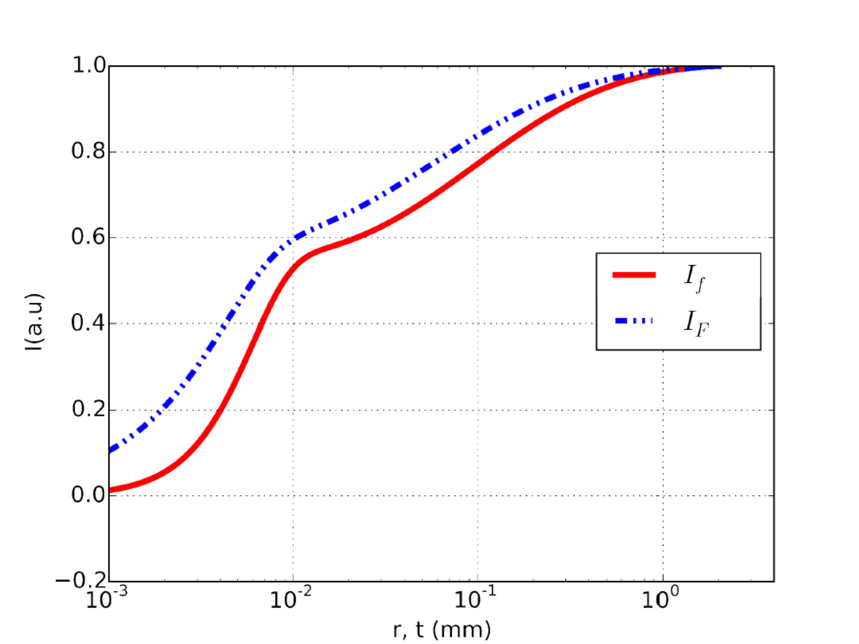
$$f(r) = -\frac{1}{\pi}\int_r^{\infty} \frac{F'(t)}{\sqrt{t^2 - r^2}}dt$$

- $F'(t)$ derivative of $F(t)$
- $F(t)$ 1D beam profile from edge scan
- Radon Transformation for Back transformation

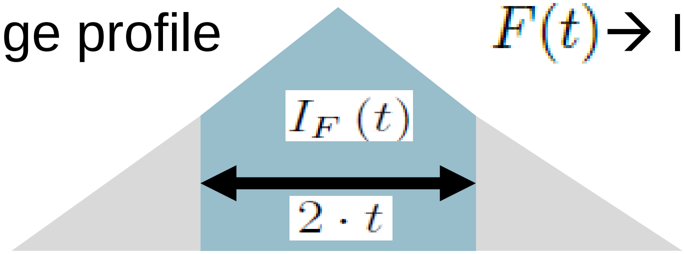
$$F(t) = \int_g f(r) = 2\int_t^{\infty} \frac{r}{\sqrt{r^2 - t^2}} f(r)dr$$

Numerical Results



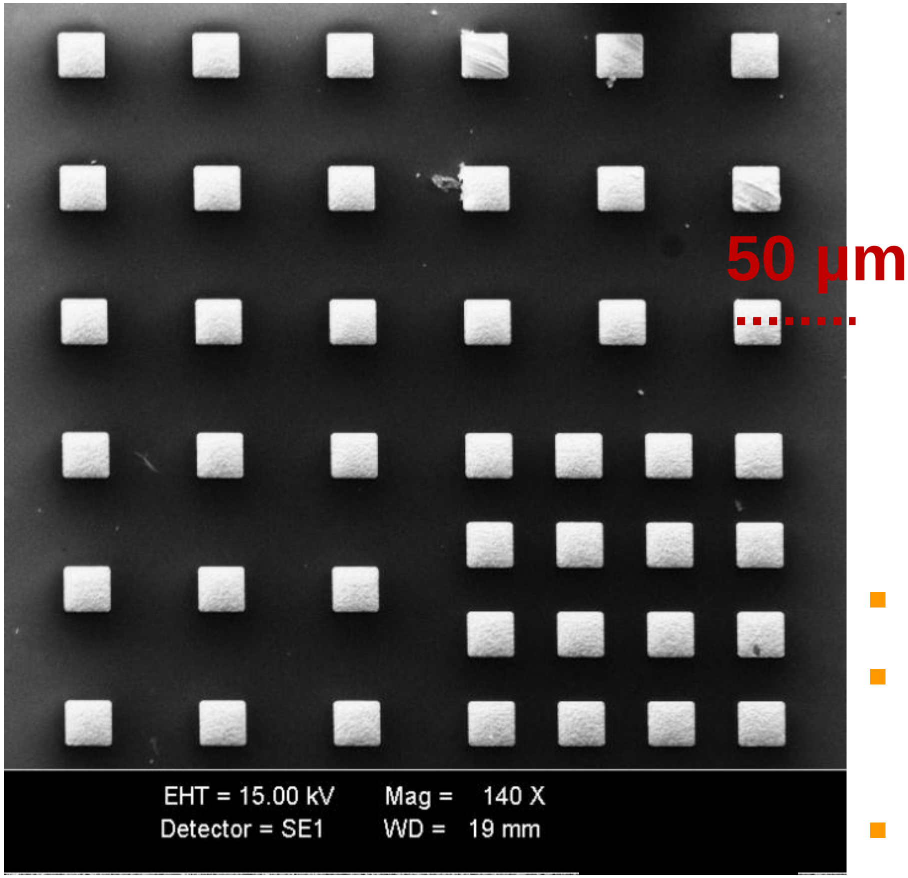


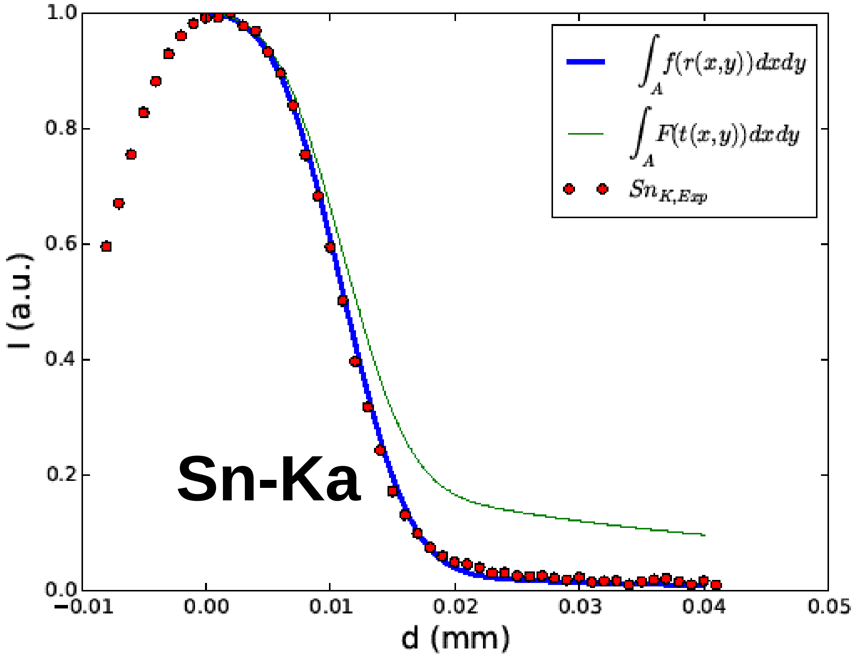
- Inverse Radon Transformation $f(r)$ red, Edge scan model $F(t)$ blue
- Integrated Spot intensities
  - 2D Radial Beam profile $f(r)$ → Intensity on a disk with radius r I_f
  - 1D Edge profile $F(t)$ → Intensity on 1D Spot with d=2t I_F



$$I_F\ (t) = 1 - 2 \cdot \frac{I_i\ (t)}{I_1 + I_2}$$

Modeling Halo effect





- 50 µm Scan on microstructure
- Size of the microstructure 22 µm

- 2D Numerical Integration of $f(r)$ in agreement with experimental data
- 2D integration for $F(t)$ unsuitable

Summary

- A Quantitative Halo Characterization method was developed
- Parameters for comparison of different polycapillaries were proposed
- Calculation method to estimate the influence of halo contribution to different measurement situations were presented
- This work has supported the development of halo free polycapillaries

Thank you for your attention!