Positron microscope

- fast positrons emitted by a β^+ radioisotope
- spatial resolution ≈ 100 μm (positron stopping depth)
- non-destructive mapping of spatial distribution of defects

Positron microscope

- mapping of spatial distribution of defects
- microhardness HV
- dislocations (work hardening)

$$HV \approx \sqrt{\rho_D}$$

- grain boundaries (Hall-Petch)

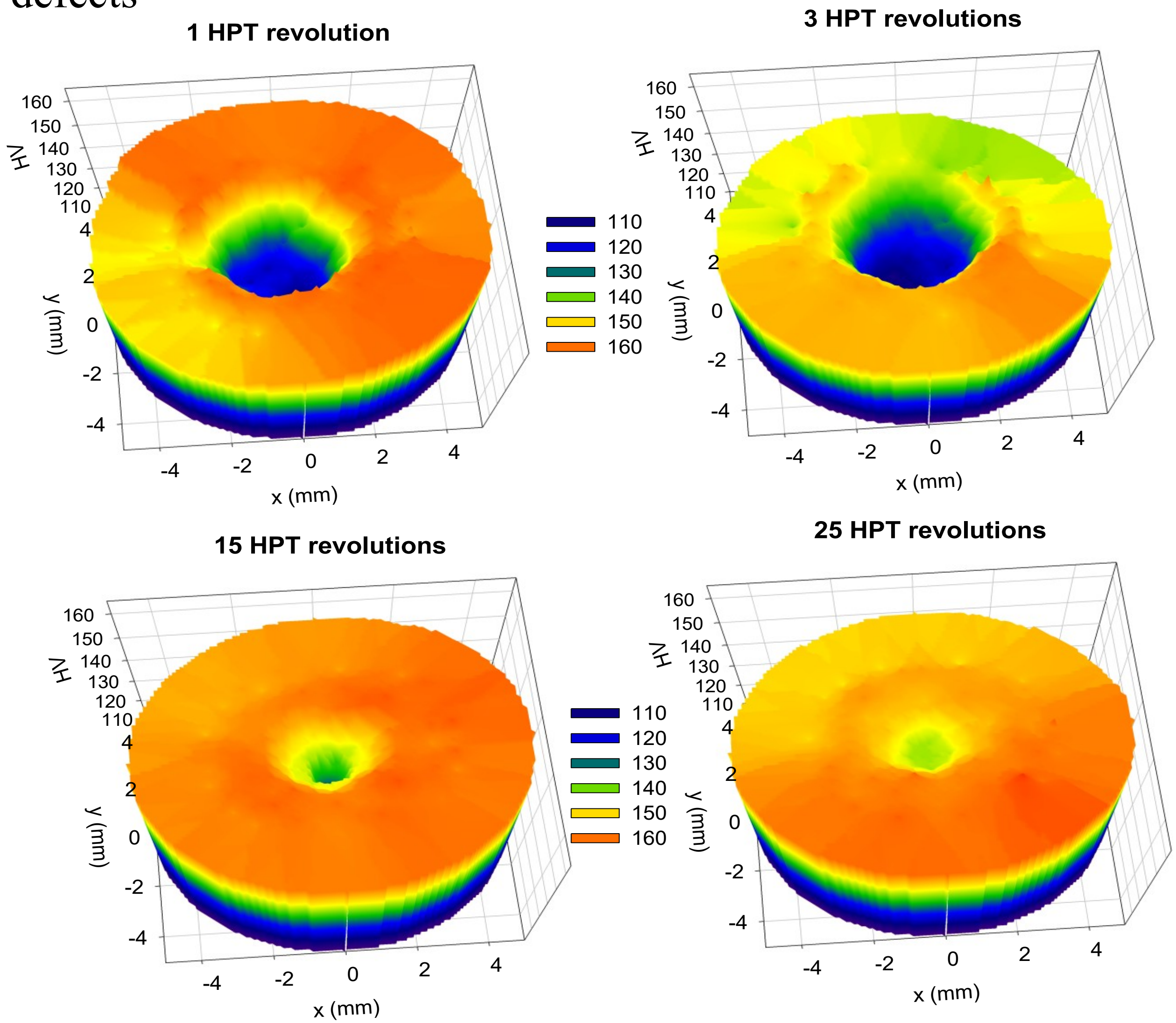
$$HV \approx 1/\sqrt{d}$$

- torsion straining

$$e = \ln\left(\vartheta r / l\right)$$

  - e – von Misses equiv. strain
  - ϑ - rotation angle
  - r – radial distance
  - l – sample thickness

Ultra fine grained Cu HPT (p = 6 GPa)



Positron microscope

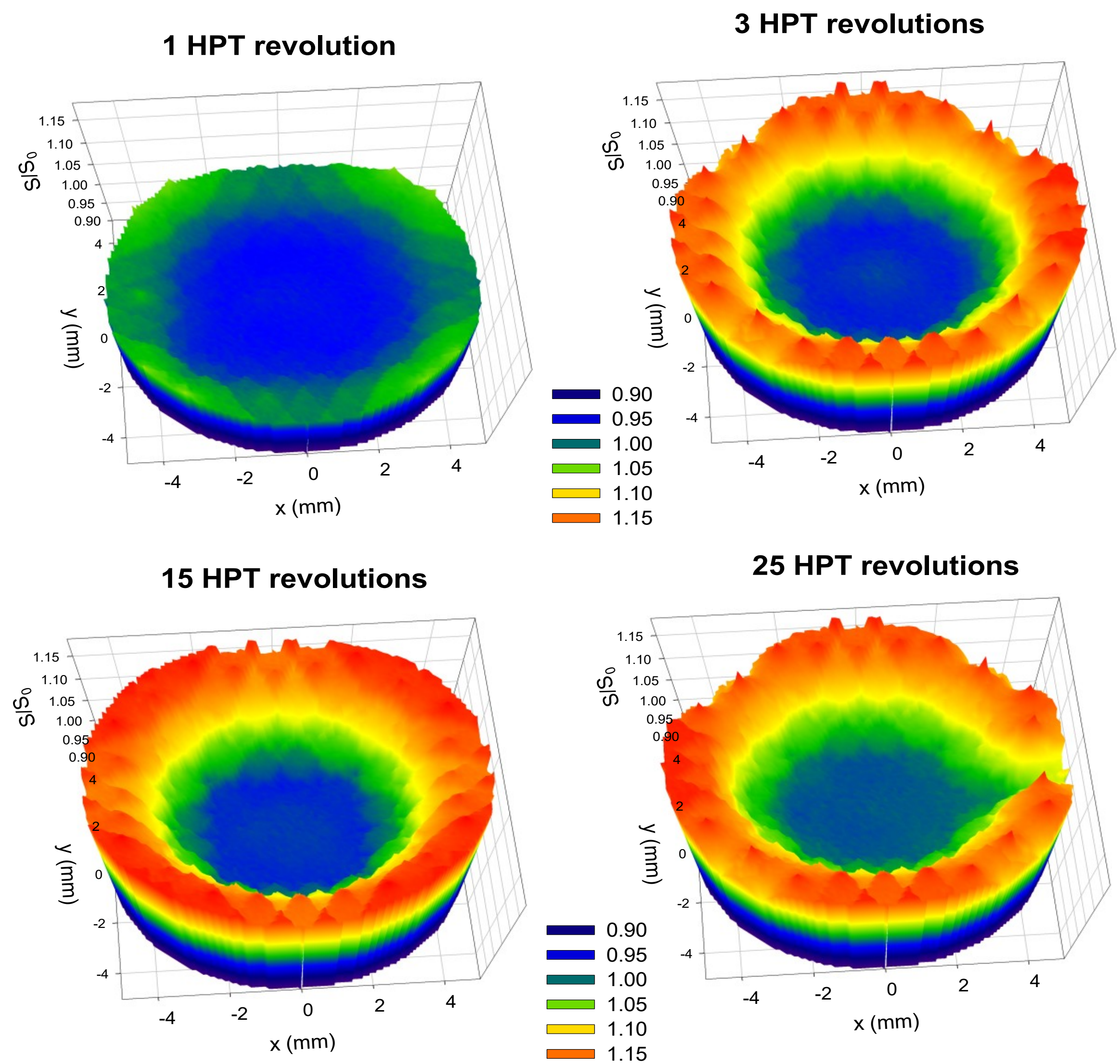
- mapping of spatial distribution of defects
- measurement of Doppler broadening
- *S*-parameter mapping
- dislocations
- grain boundaries
- deformation-induced vacancies

- torsion straining

$$e = \ln(\vartheta r / l)$$

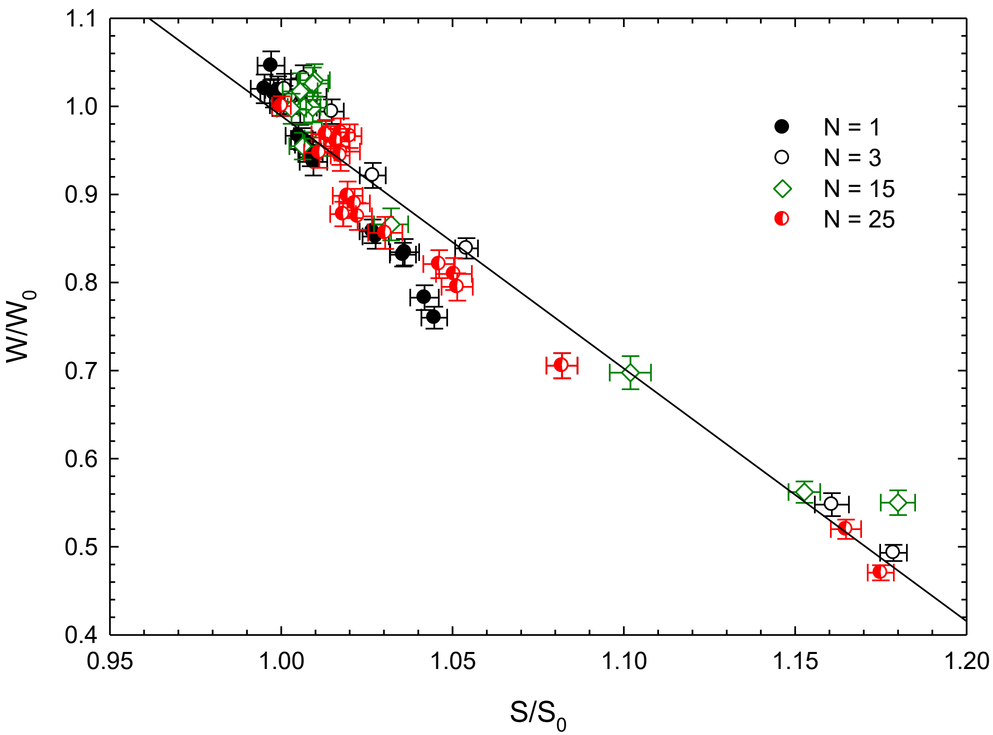
  - e – von Misses equiv. strain
  - ϑ - rotation angle
  - r – radial distance
  - l – sample thickness

Ultra fine grained Cu HPT (p = 6 GPa)

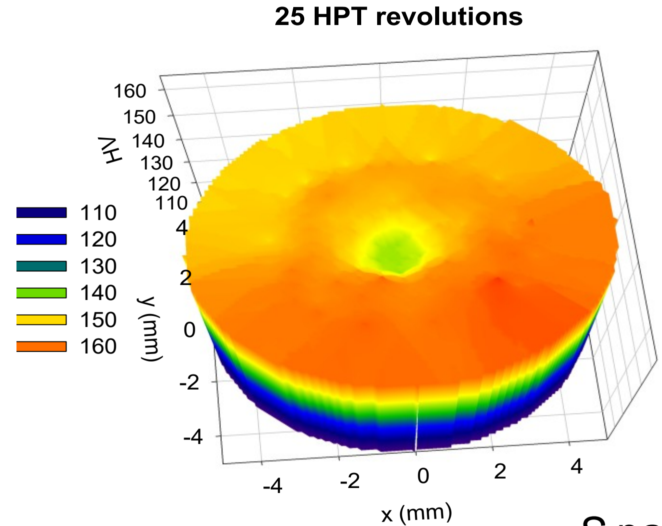


Positron microscope

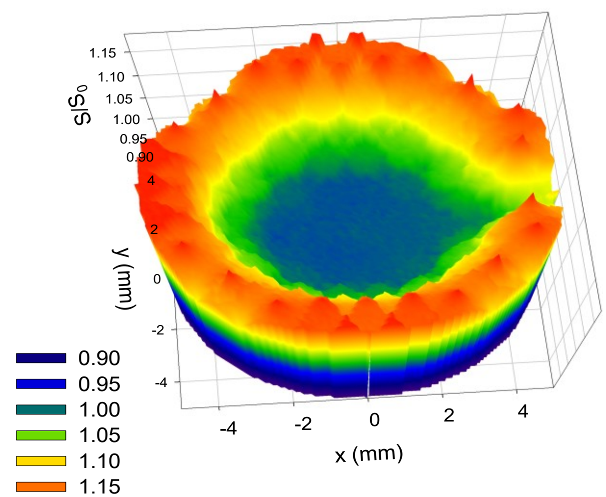
- **Ultra fine grained Cu HPT (p = 6 GPa)**
- *S*-*W* plot



microhardness



S parameter



Positron microscope

- slow positrons moderated in a slow positron beam
- the mean implantation depth of $E \approx 1$ keV positrons is $z_{mean} \approx 10$ nm
- spatial resolution is limited by positron diffusion length $L_+ \approx 100$ nm
- mapping of lateral distribution of defects + depth profile of defects
- non-destructive 3D mapping of defect distribution

Positron microscope

• **brightness of positron beam**

$$B = \frac{I}{\Omega_x \, \Omega_y}$$

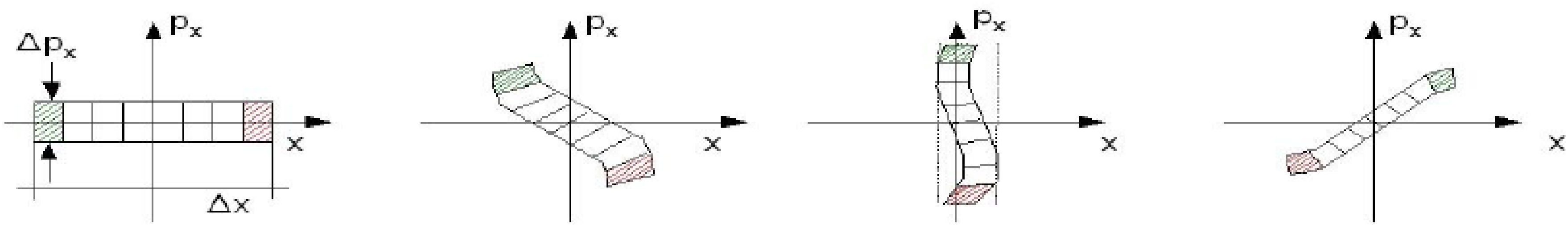
I – intensity

• brightness of commercially available e^+ sources is $10^{-19} - 10^{-16}$ the brightness of typical e^- sources!

• Liouvill theorem

$$\Delta x \, \Delta p_x = \Omega_x = \text{konst}$$

$$\Delta y \, \Delta p_y = \Omega_y = \text{konst}$$



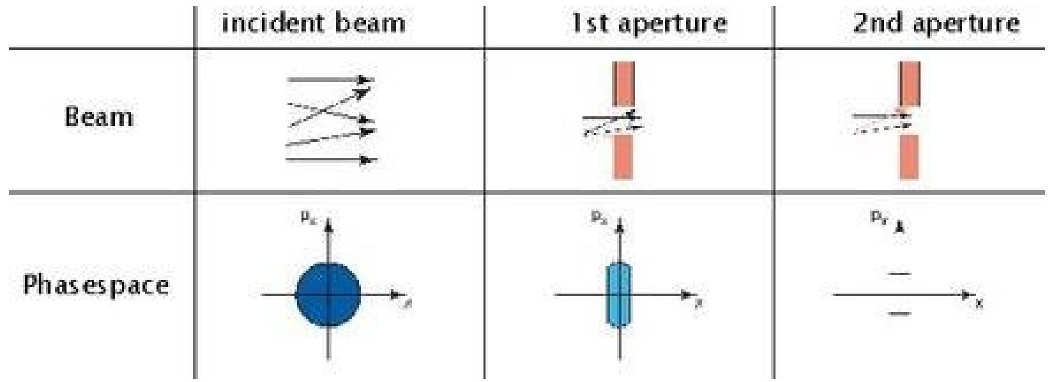
Kögel, EPOS meeting 2002

Positron microscope

• **remoderation**

$$B = \frac{I}{\Omega_x \Omega_y}$$

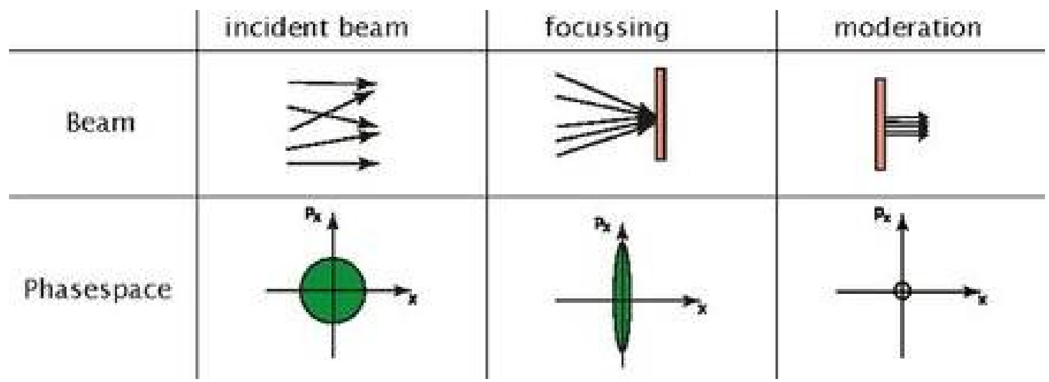
I – intensity



• brightness enhancement

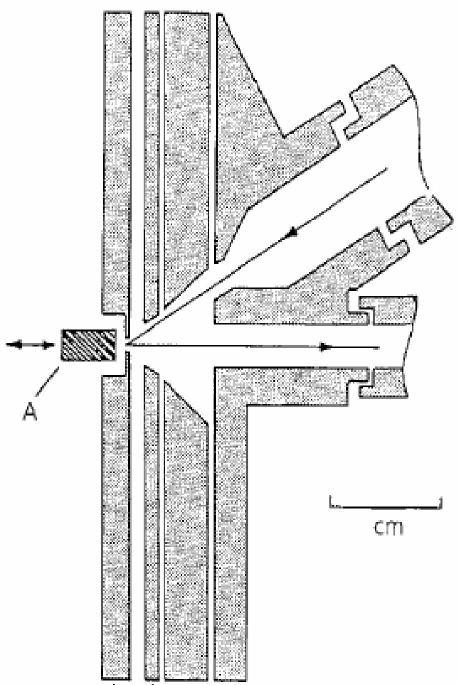
• i.e. reduction of beam volume in the phase space

• inevitable reduction of intensity

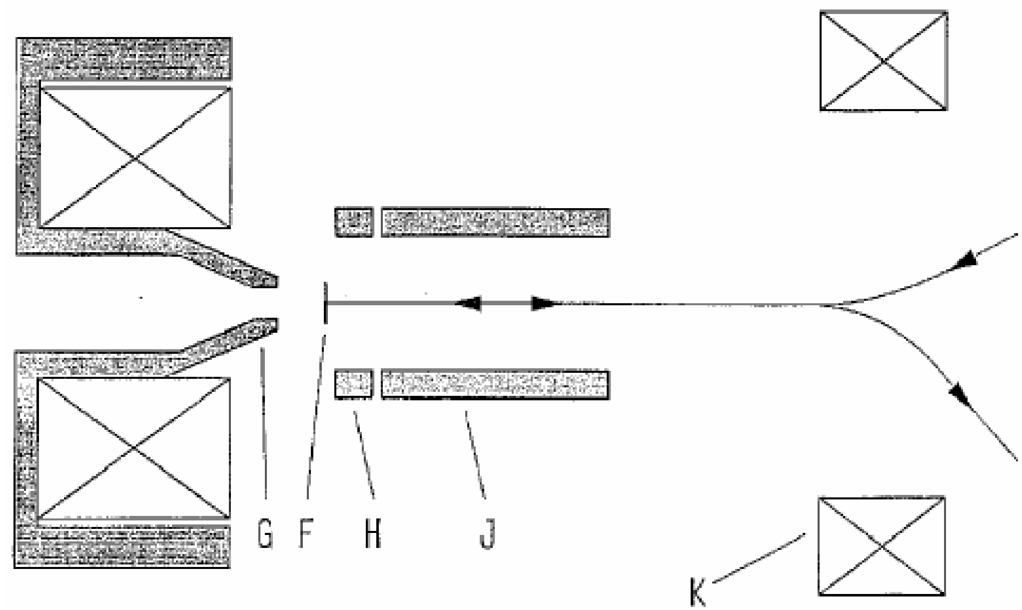


Positron microscope

- **remoderation**
  - electrostatic remoderator
  - reduction of beam spot size ≈ 10 ×



- remoderator with magnetic lens
- magnetic separation of primary beam and remoderated e^+
- reduction of beam spot size ≈ 100 ×



Kögel, EPOS meeting 2002

Positron microscope

- **remoderation**
  - electrostatic remoderator
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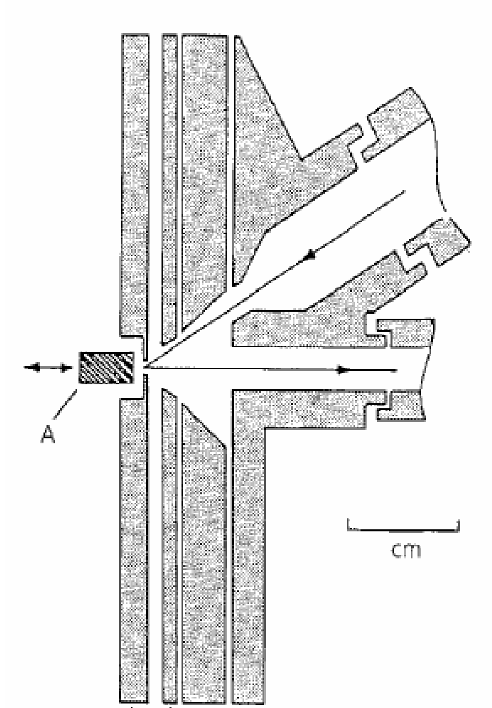
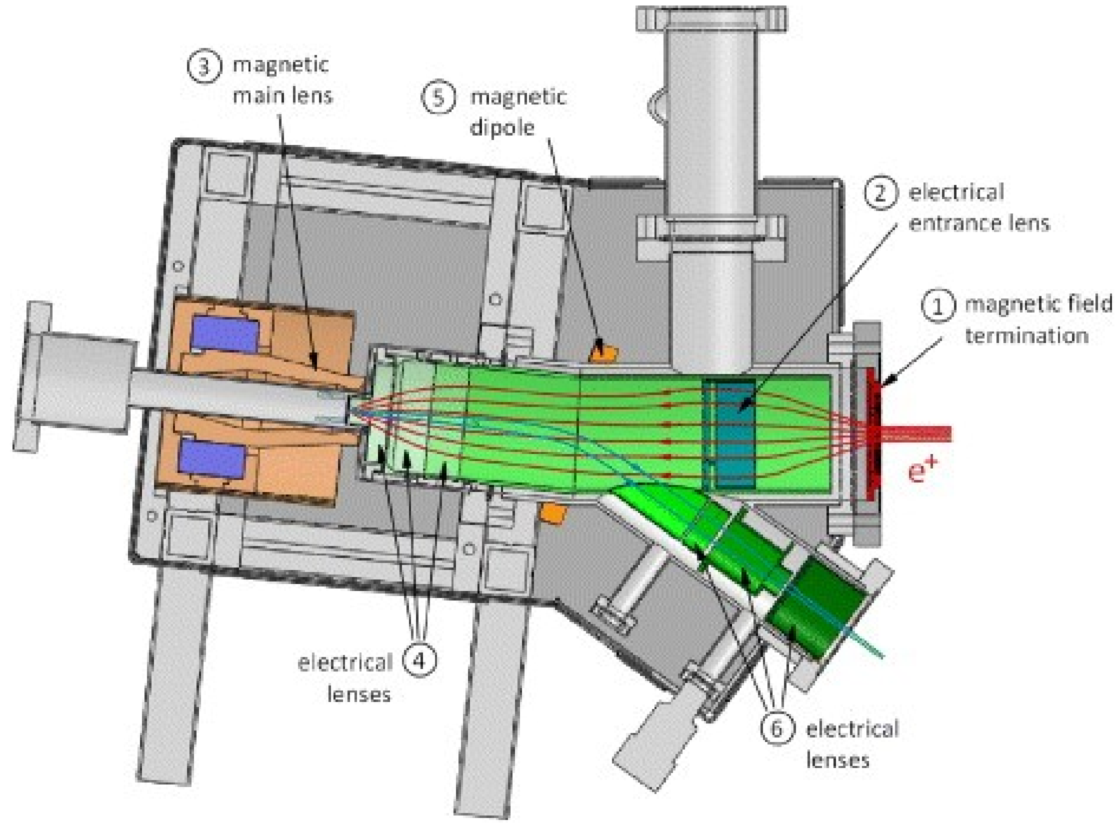


Kögel, EPOS meeting 2002

- remoderator with magnetic lens
- magnetic separation of primary beam and remoderated e^+
- reduction of beam spot size ≈ 100 ×



Positron microscope

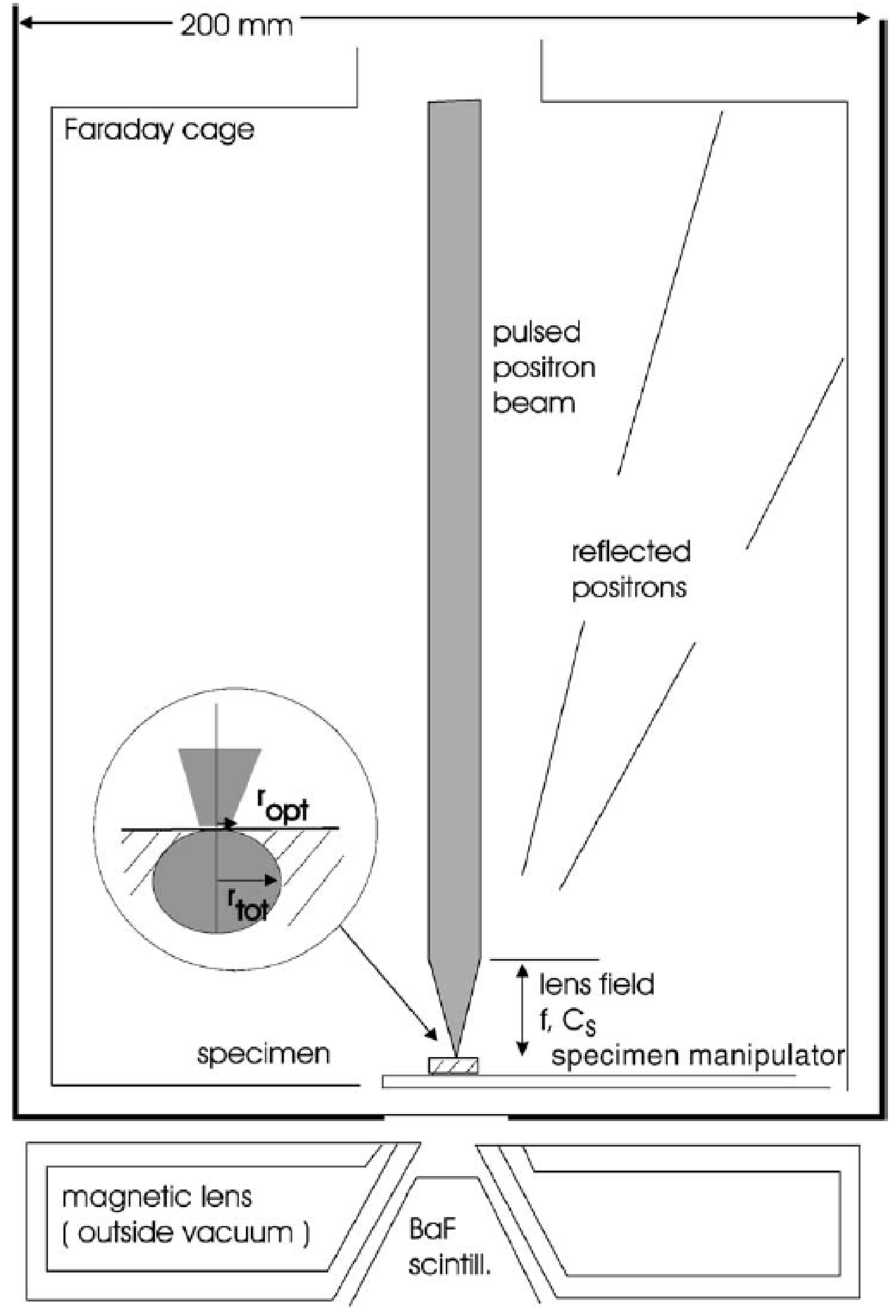
- **scanning positron microscope**
- TU Munich
- focused pulsed slow e^+ beam

- spot size of focused beam ≈ 2 μm

$$r_{opt} = \sqrt{\frac{f^2 \Delta E}{E} + \frac{C_S^2 R^6}{16 f^6}}$$

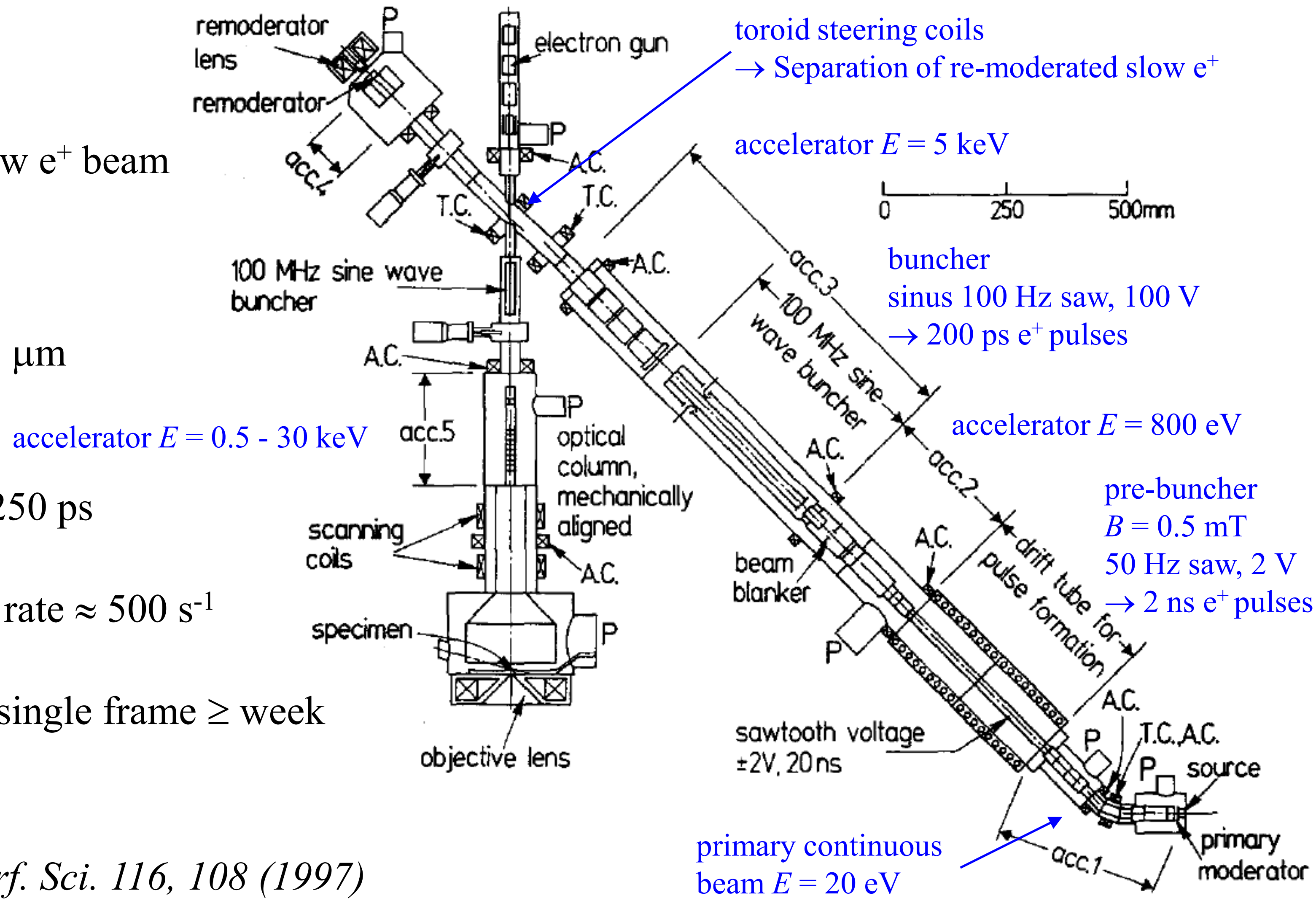
- ΔE – dispersion of transversal e^+ energy
- f – focused length of electrostatic lens
- C_S – spherical aberation
- R – beam radius

Kögel et al. Appl. Surf. Sci. 116, 108 (1997)



Positron microscope

- **scanning positron microscope**
- TU Munich
- focused pulsed slow e^+ beam
- beam spot size ≈ 2 μm
- time resolution ≈ 250 ps
- coincidence count rate ≈ 500 s^{-1}
- collection time of single frame ≥ week

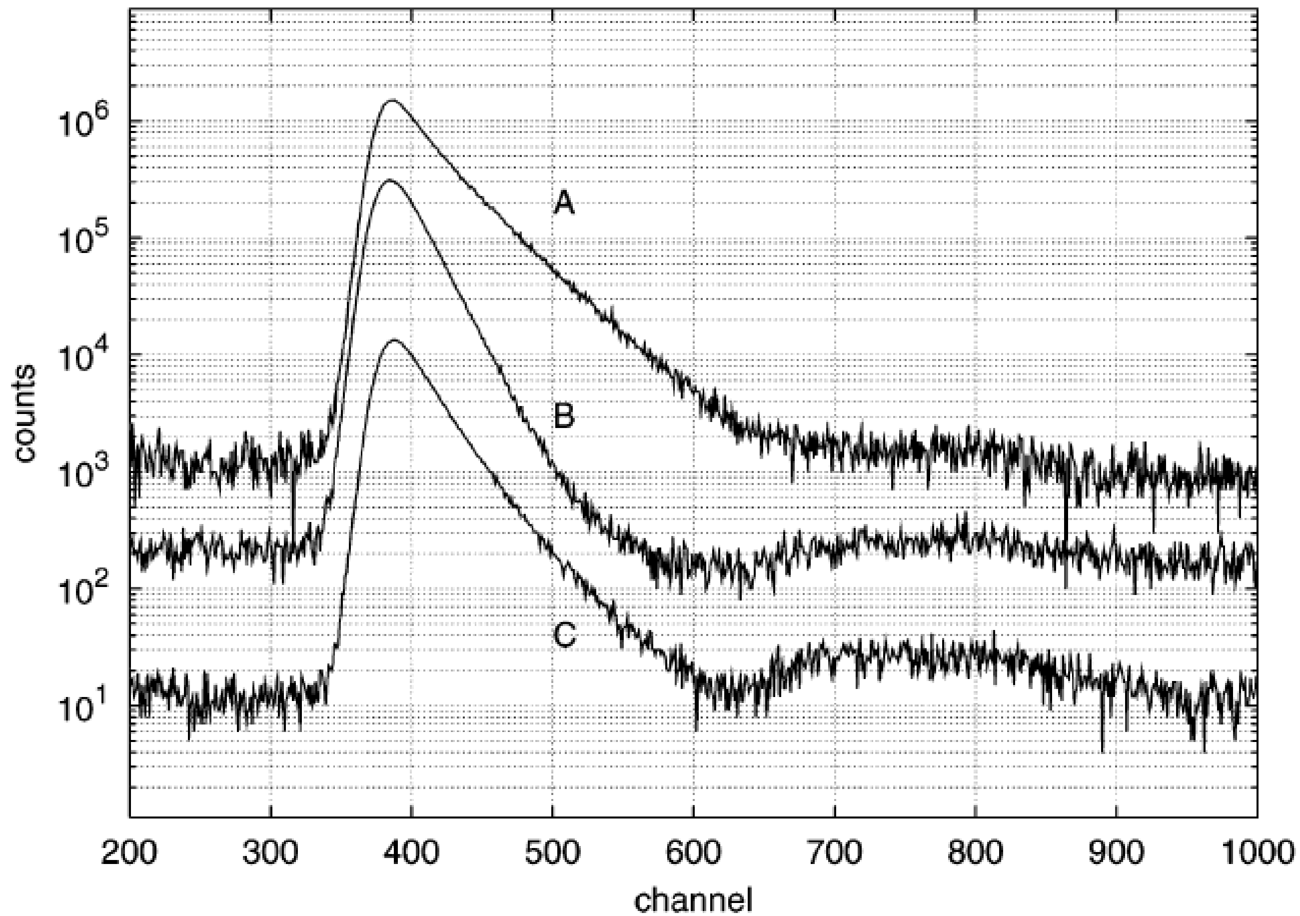


Kögel et al. Appl. Surf. Sci. 116, 108 (1997)

Positron microscope

- **scanning positron microscope**
- TU Munich
- focused pulsed slow e^+ beam
- time resolution ≈ 250 ps

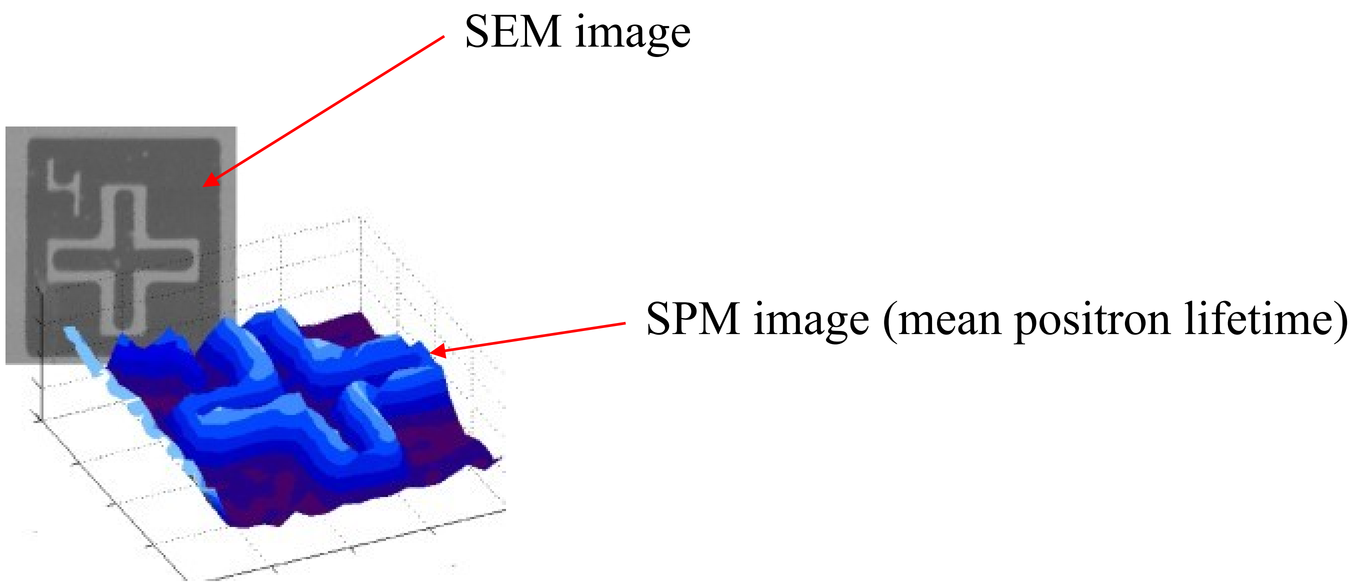
example of positron lifetime spectra measured on SPM, E = 8 keV



Kögel et al. Appl. Surf. Sci. 116, 108 (1997)

Positron mikroskope

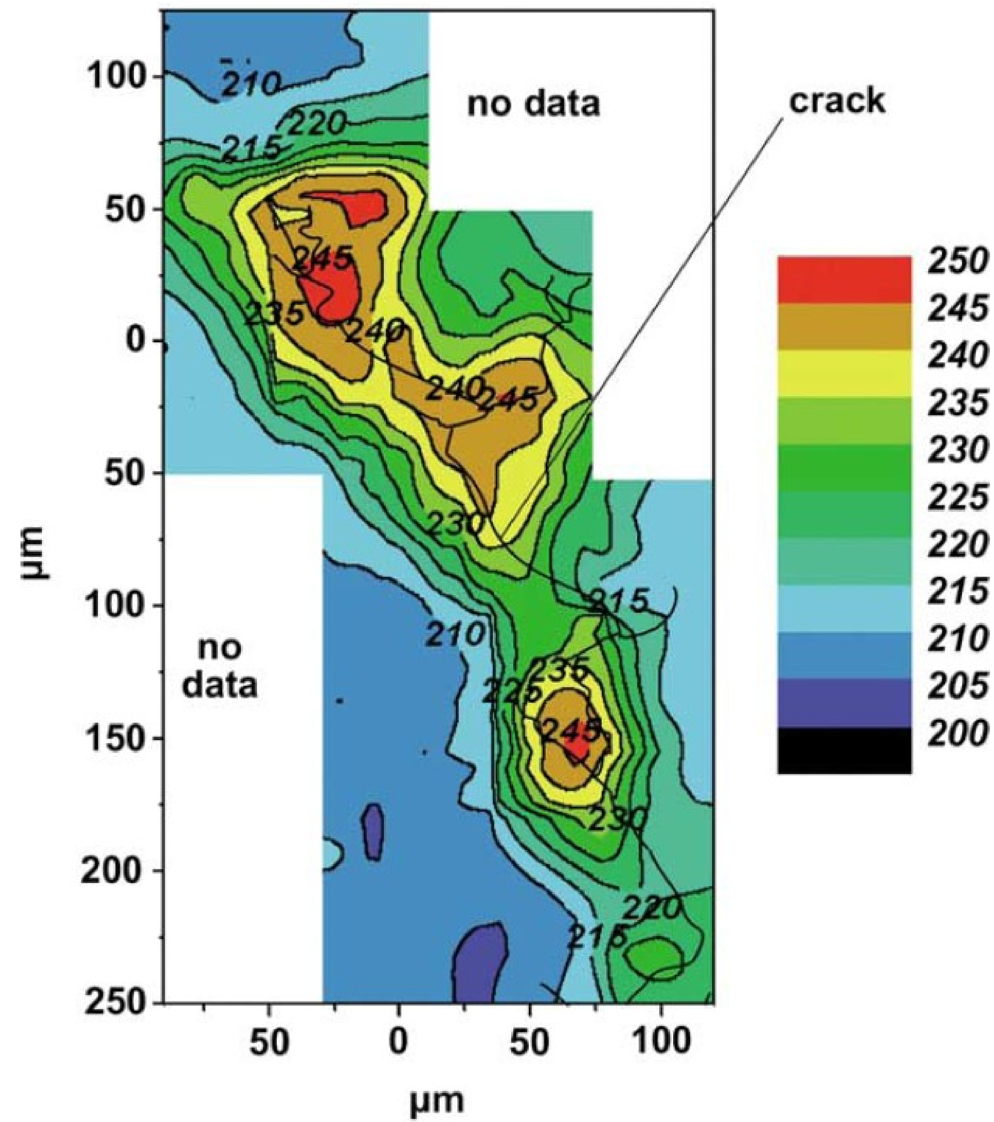
- **scanning positron microscope**
- TU Munich
- spatial resolution ≈ 2 μm
- Si substrate with etched pattern



David et al. Phys. Rev. Lett. 87, 067402 (2001)

Positron microscope

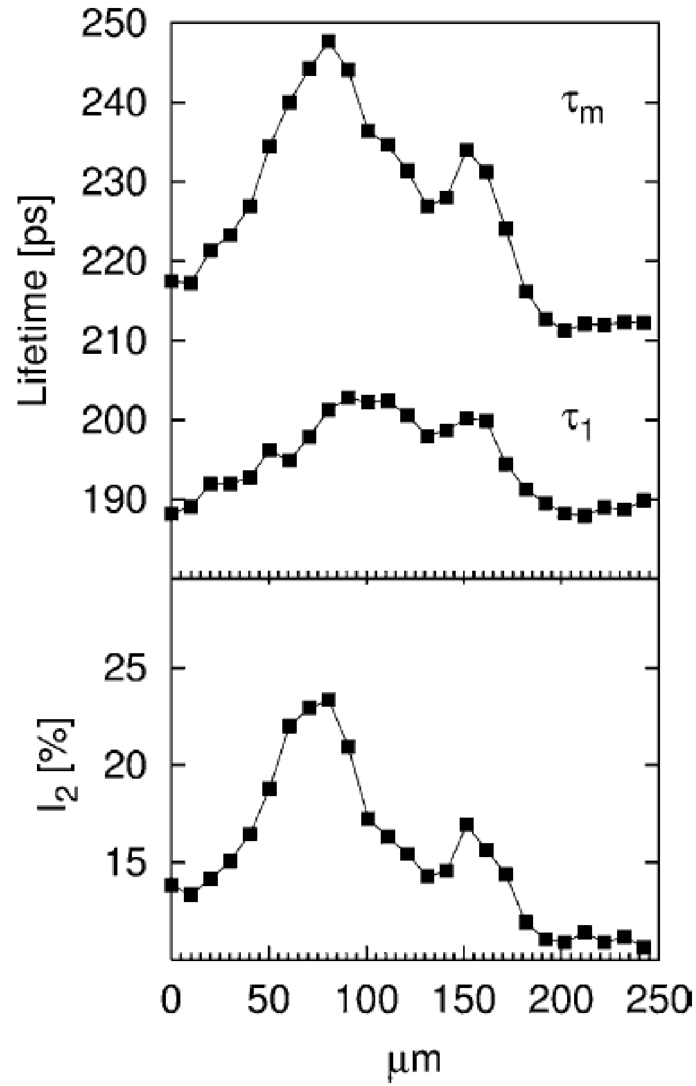
- **scanning positron microscope**
- TU Munich
- spatial resolution ≈ 2 μm
- Cu fatigue
- mapping using mean positron lifetime
- E = 16 keV



Egger et al. Appl. Surf. Sci. 194, 214 (2002)

Positron microscope

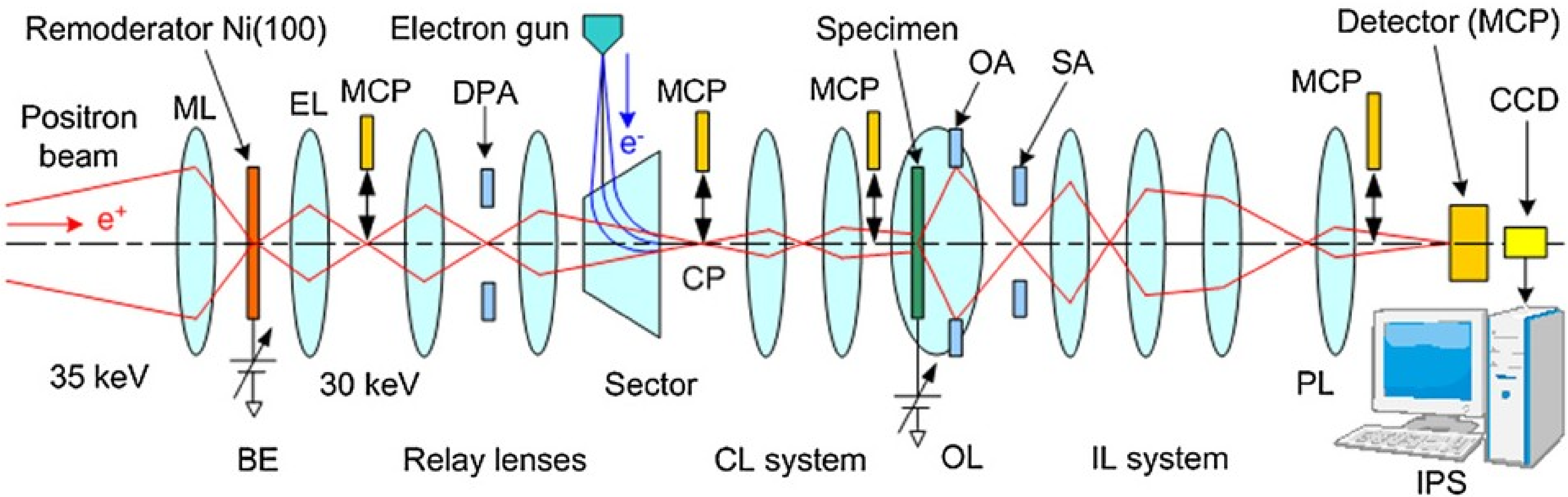
- **scanning positron microscope**
- TU Munich
- spatial resolution ≈ 2 μm
- Cu fatigue
- linear scan perpendicular to crack
- E = 16 keV
- two-component decomposition, τ_2 fixed at 400 ps



Egger et al. Appl. Surf. Sci. 194, 214 (2002)

Positron microscope

- **transmission positron microscope**
- KEK Tsukuba
- positron source: LINAC



Matsua et al. Nucl. Insr. Meth. A 645, 102 (2011)

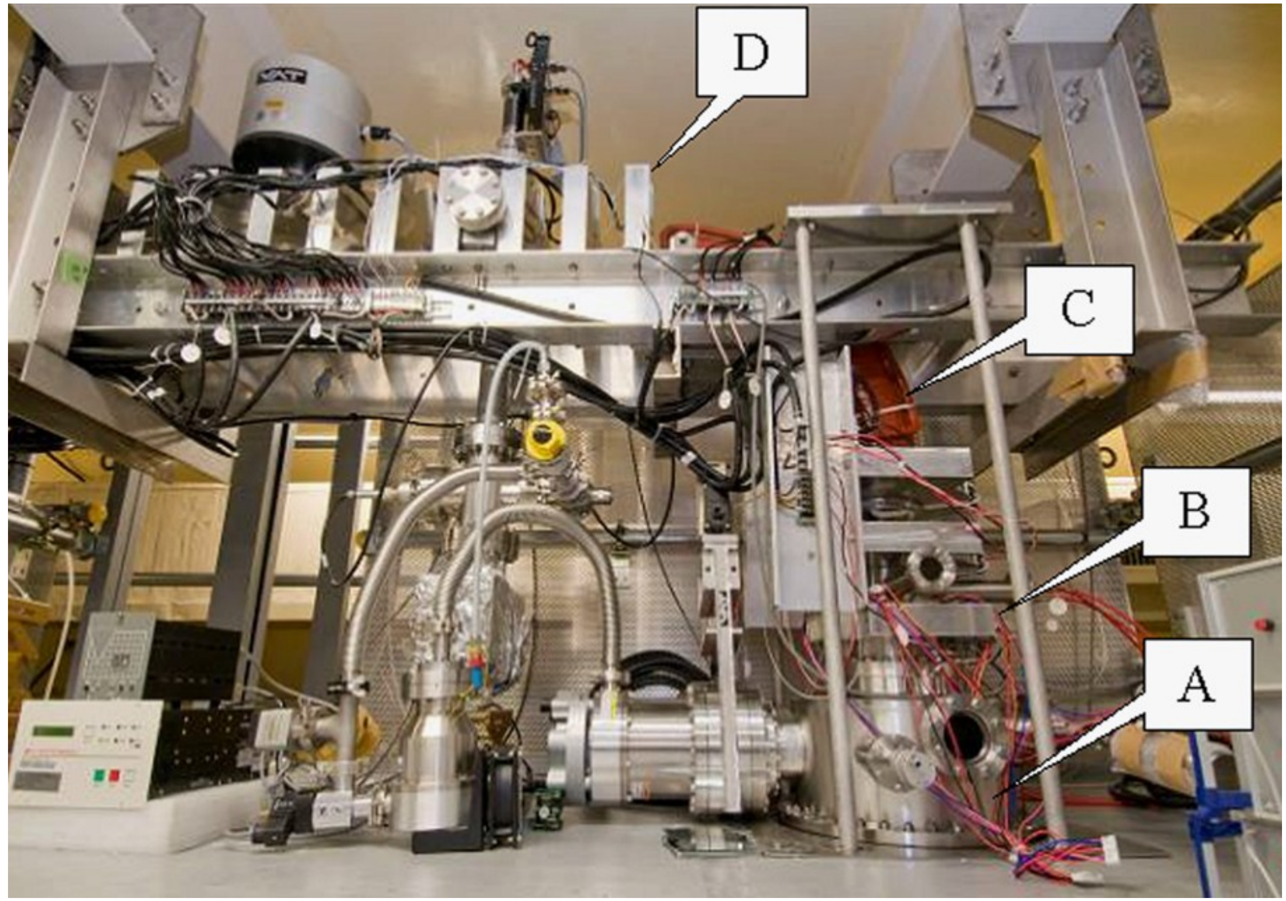
Positron microscope

- **transmission positron microscope**

remoderator (brightness enhancer)

- KEK Tsukuba

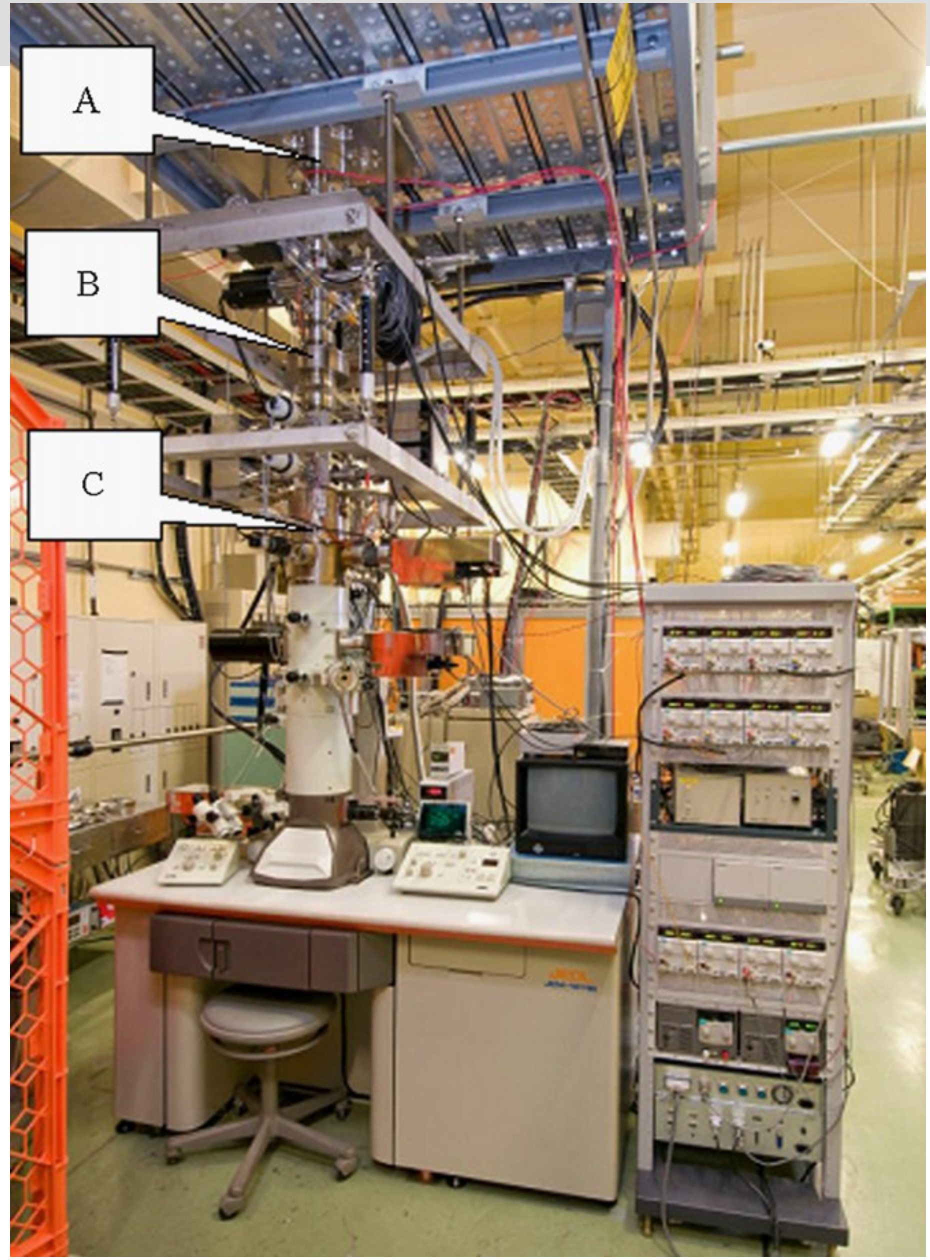
- positron source: LINAC



Matsua et al. Nucl. Insr. Meth. A 645, 102 (2011)

Positron microscope

- **transmission positron microscope**
- KEK Tsukuba
- positron source: LINAC



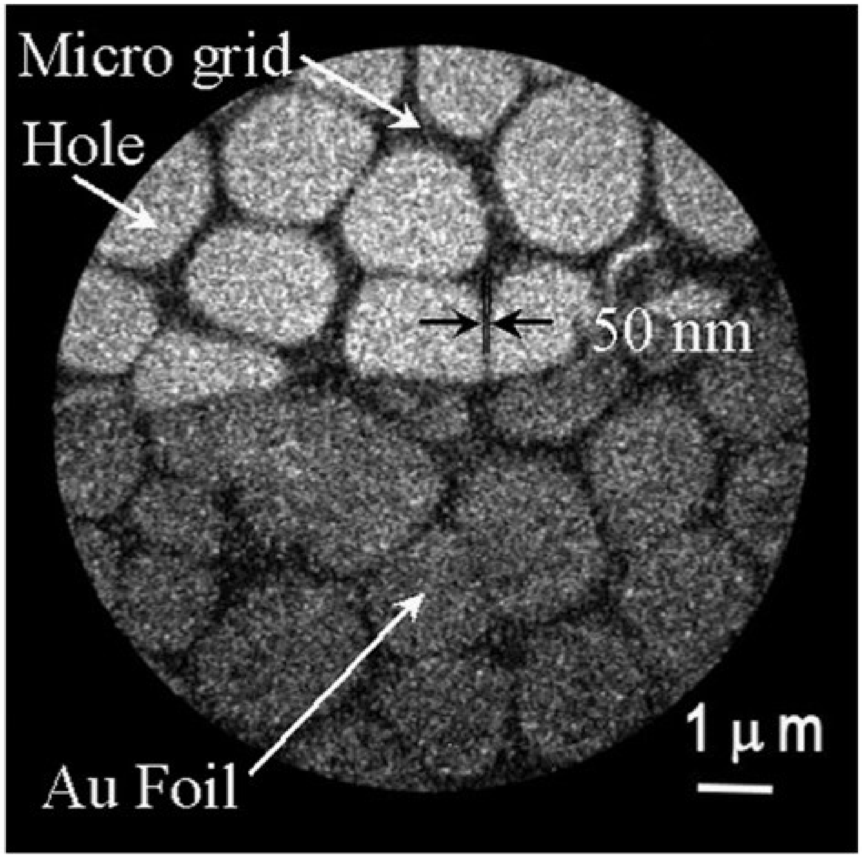
Matsua et al. Nucl. Insr. Meth. A 645, 102 (2011)

Positron microscope

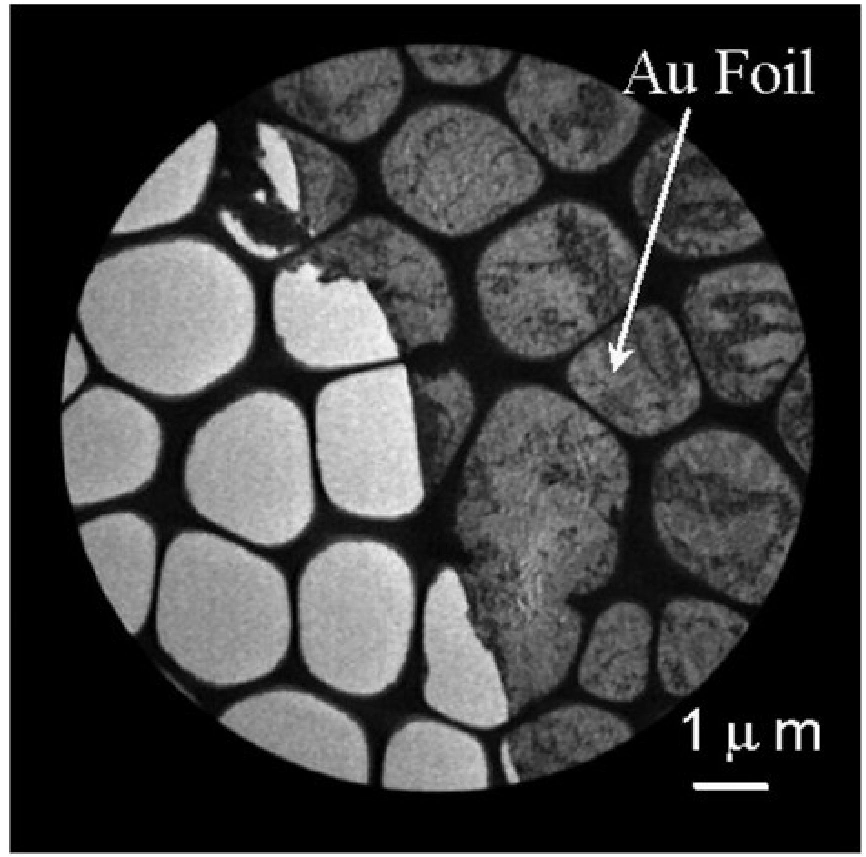
• **transmission positron microscope**

• 10 nm Au (100) foil on a supporting Cu mesh

positrons



electrons



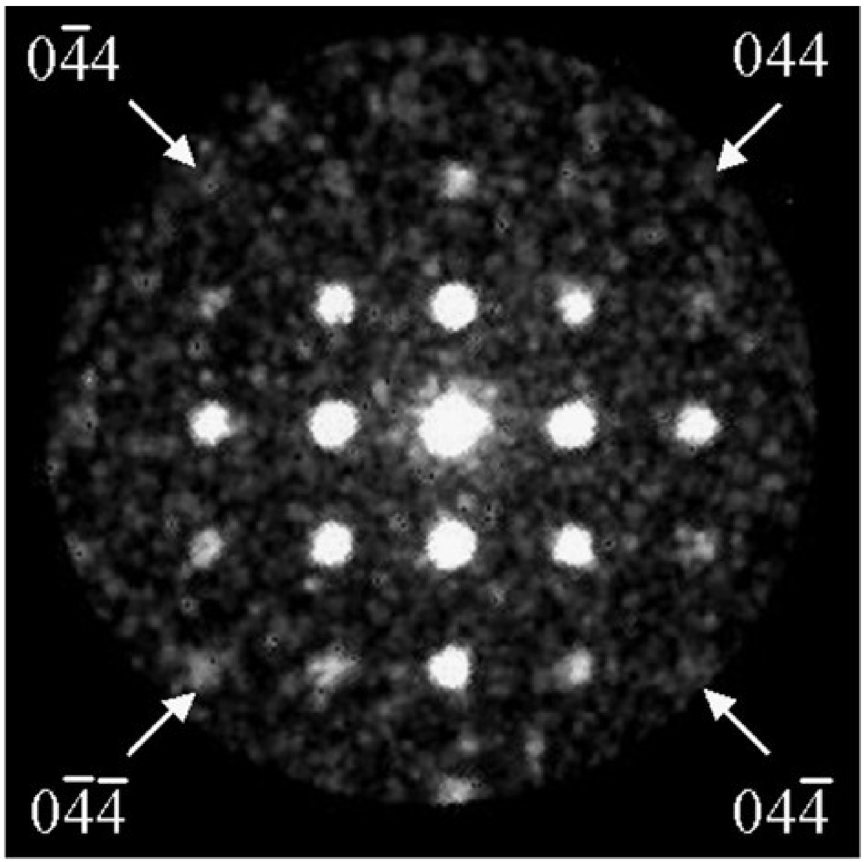
Matsua et al. Nucl. Insr. Meth. A 645, 102 (2011)

Positron microscope

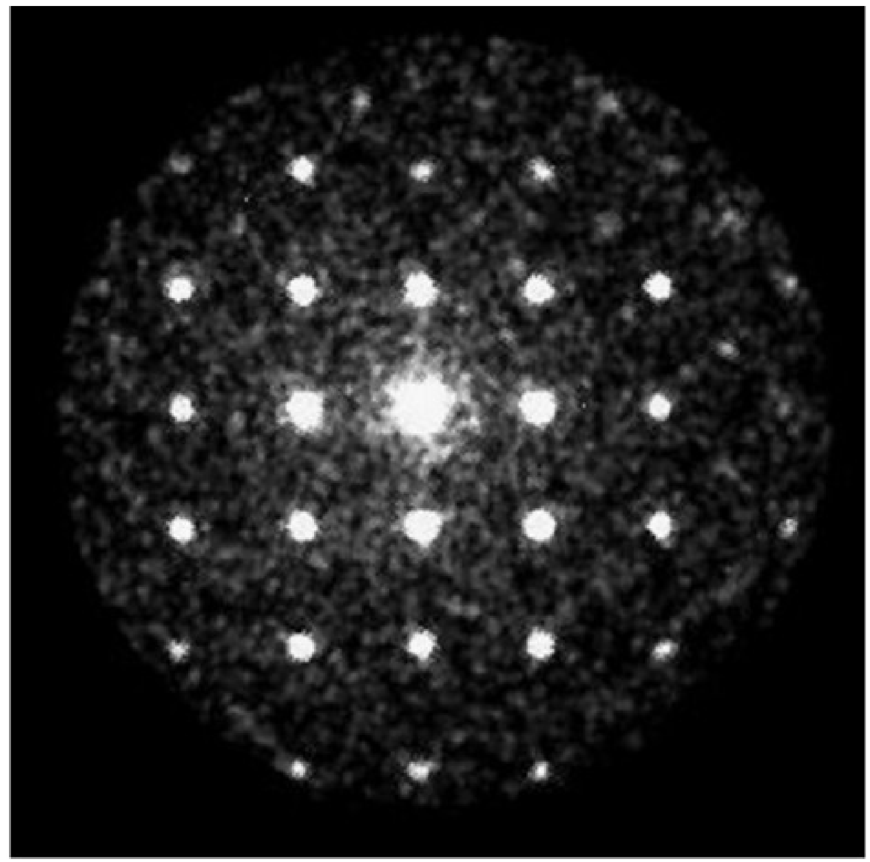
• **transmission positron microscope**

• 10 nm Au (100) foil on a supporting Cu mesh - diffraction

positrons



electrons

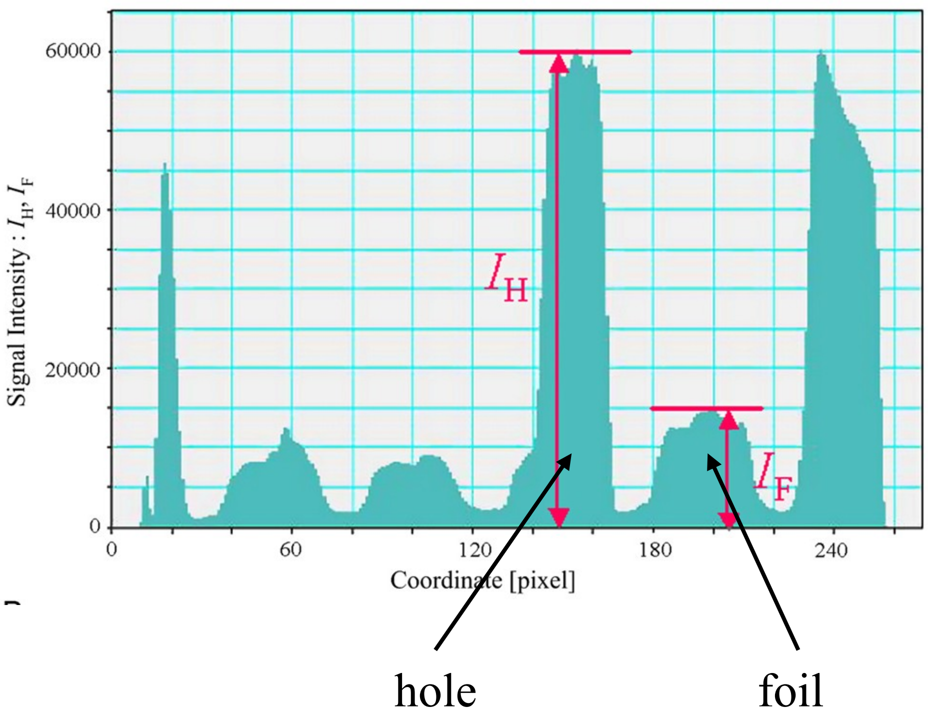


Matsua et al. Nucl. Insr. Meth. A 645, 102 (2011)

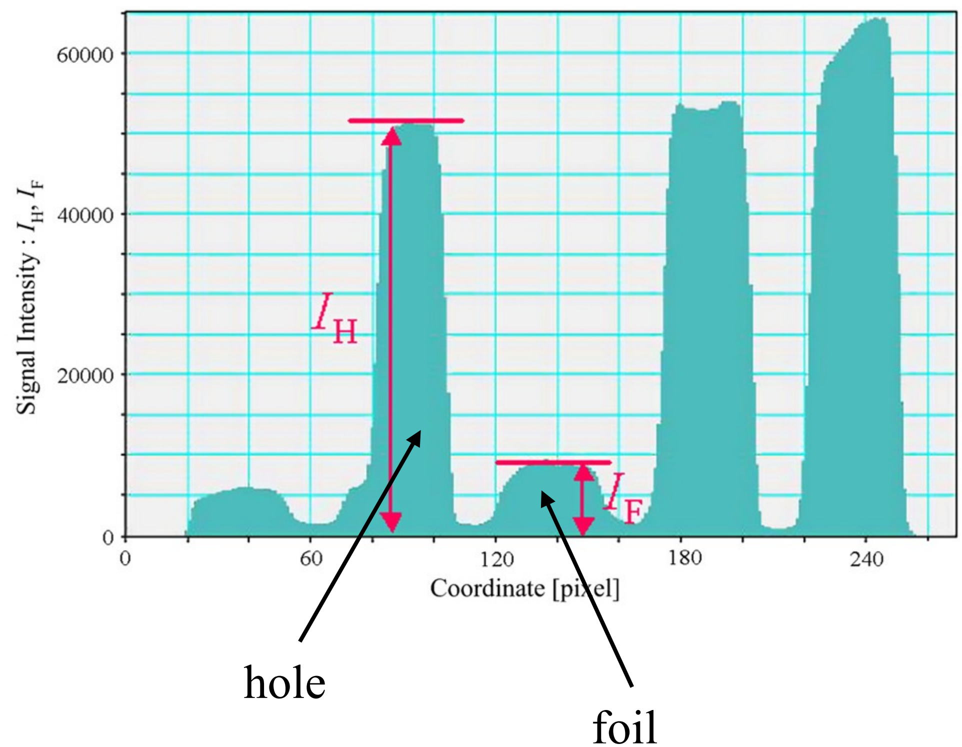
Positron microscope

- **transmission positron microscope**
- 35 nm Al foil on a supporting Cu mesh - transmittance

pozitrony



elektrony



Matsua et al. Nucl. Insr. Meth. A 645, 102 (2011)