Slow positron defect profiling with enhanced depth resolution

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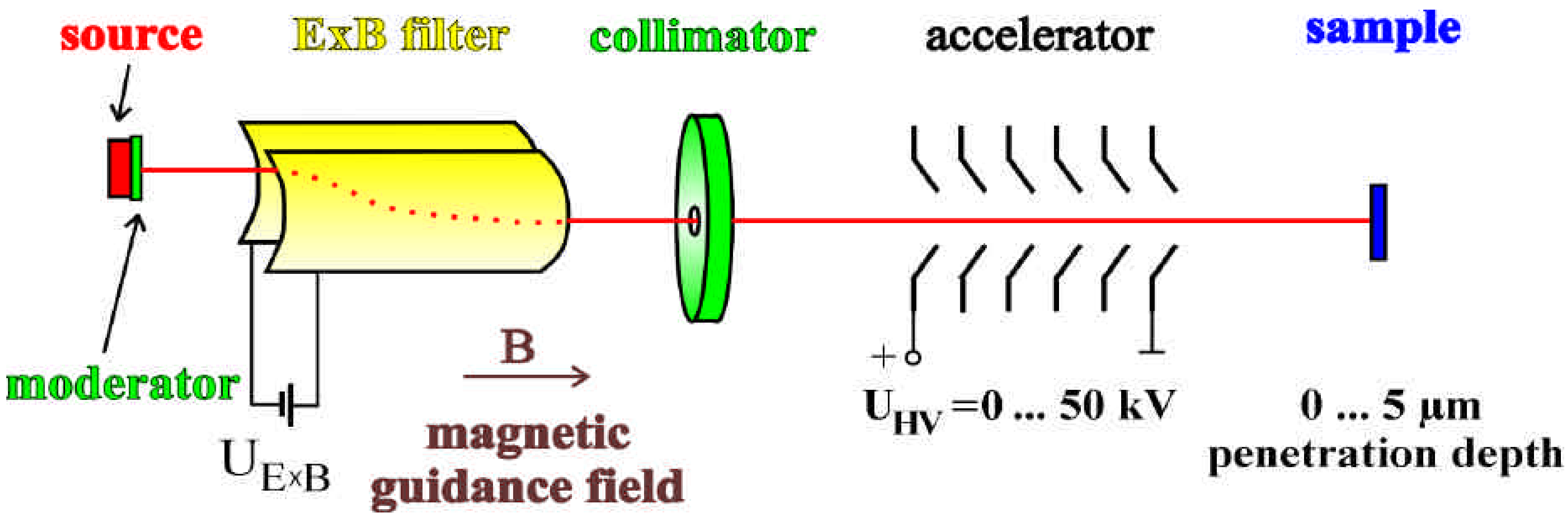
- Introduction
- Depth-resolution improvement by stepwise removal of sample surface
- Study of wedge-shaped samples by positron microbeam
- Conclusions

Depth-profiling by varying the positron energy

- conventional VEPAS positron implantation depth varied by accelerating voltage



magnetically guided positron beam system at Univ. Halle

Positron beam measurement with improved depth resolution

- mono-energetic positrons exhibit broad implantation profile
- the defect layers and interfaces deeper 1 µm are hardly visible
- no real depth profiling possible (often only step function)

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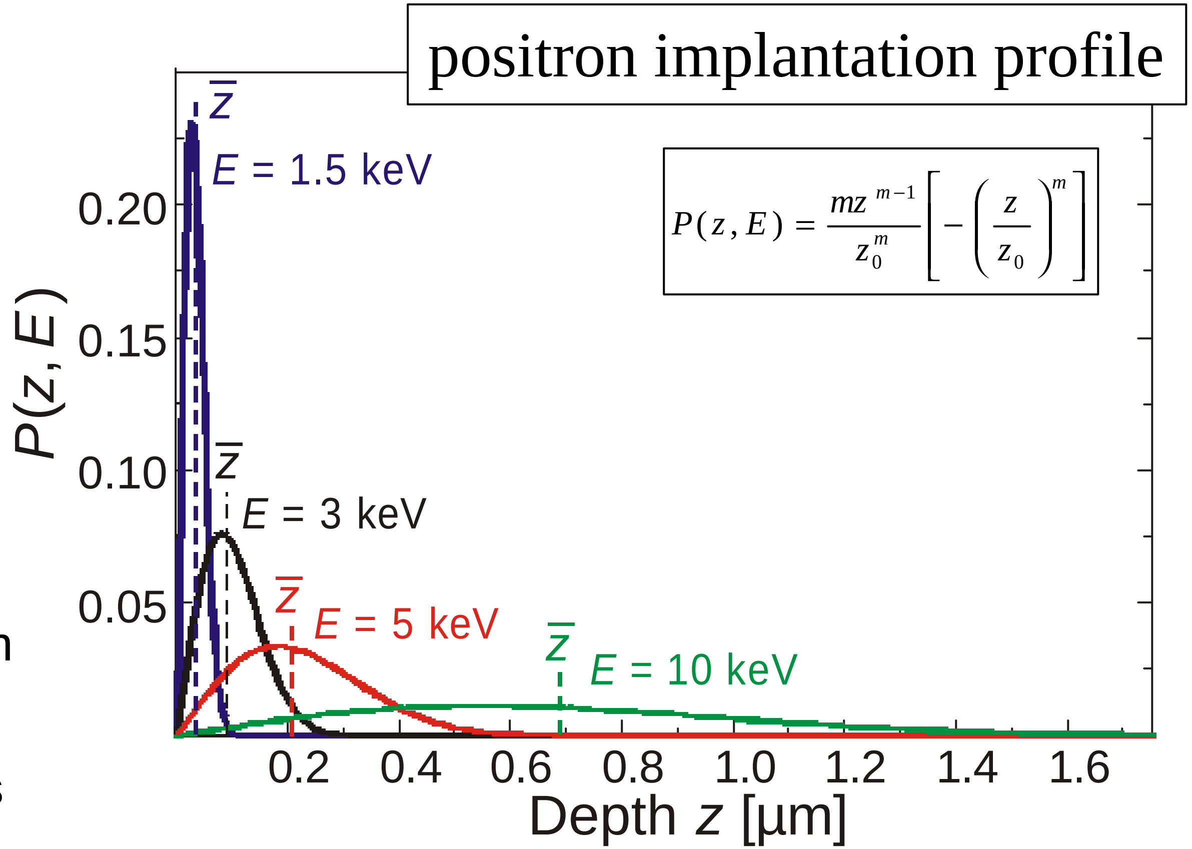
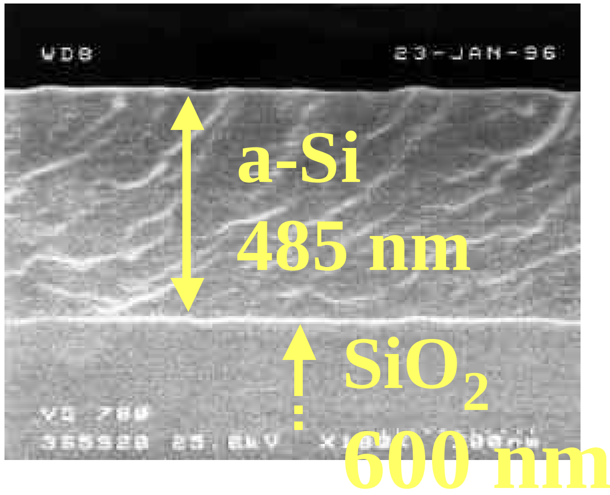
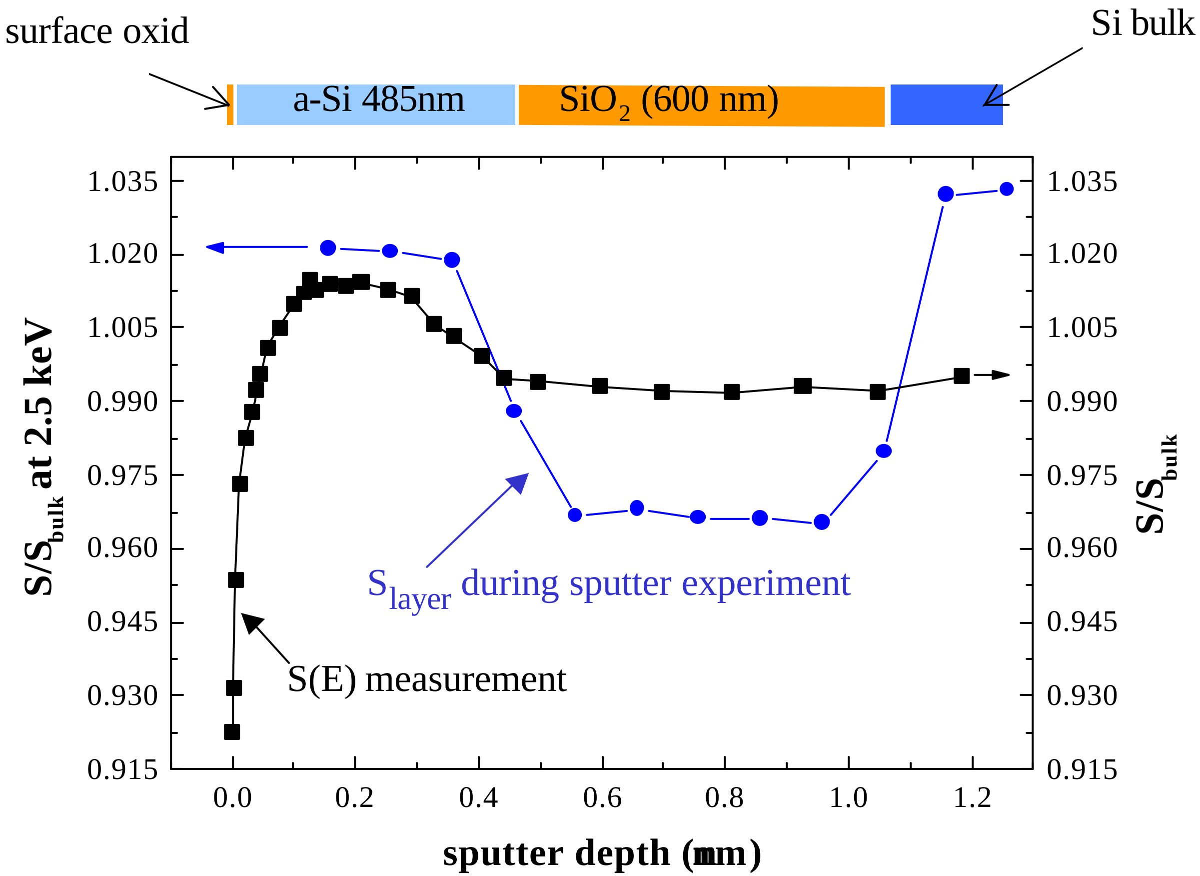
- step-by-step removal of sample surface by sputtering or etching
- measurement at low e^+ energy with high depth resolution
- optimum depth resolution depends on positron diffusion length L_+
- E_+ must be large enough to avoid influence of surface



First test: study of defined layer structure

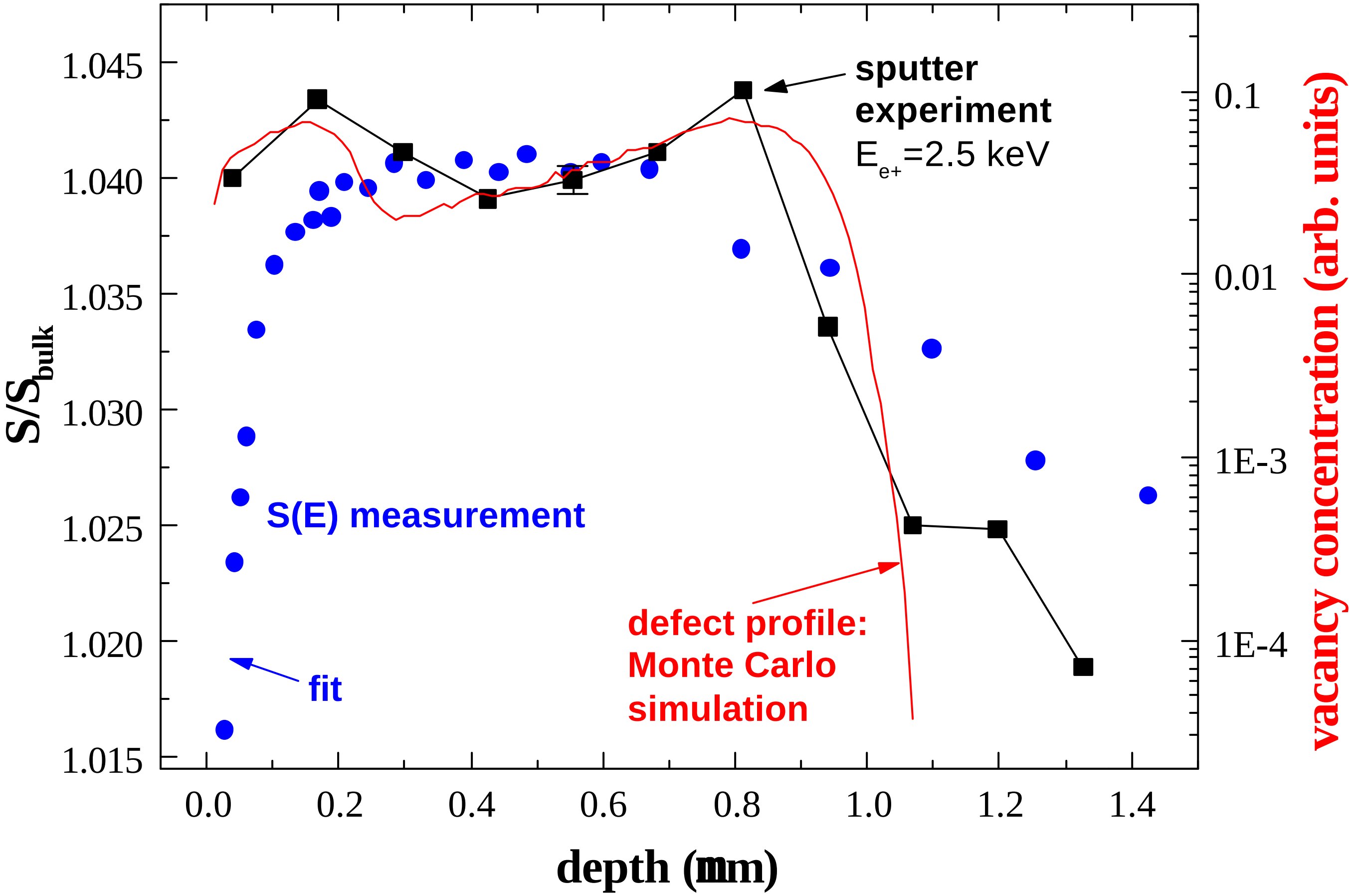
- test structure: a-Si/SiO_2/Si was stepwise removed by Ar^+ sputtering
- Ar pressure of 10^{-6} Torr for 30 min takes ≈ 100 nm away (I = 40 µA)
- full S(E) curves measured and S at 2.5 keV plotted as function of sputter depth





Second example: twofold B:Si implantation

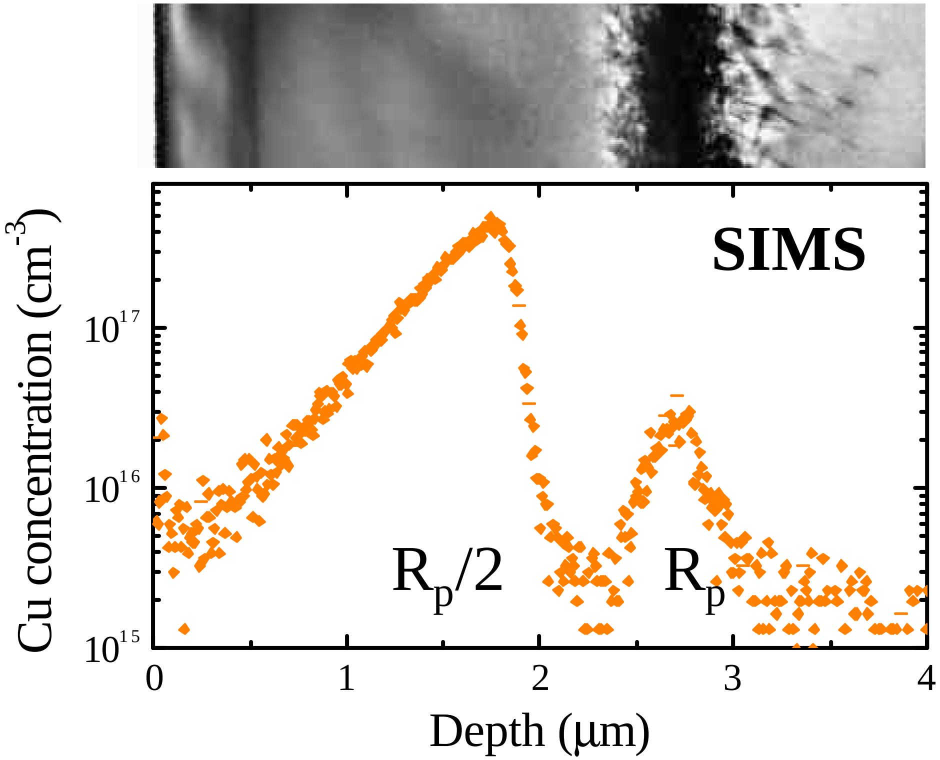
- **twofold implantation** B:Si (50 keV, 2.5×10^{15} cm^{-2} and 300 keV, 5×10^{15} cm^{-2}) creates double peak
- conventional $S(E_+)$ measurement cannot distinguish between peaks



Defects in high-energy self-implanted Si ¾ The $R_p/2$ effect

- after high-energy (3.5 MeV) self-implantation of Si (5×10^{15} cm^{-2}) and RTA annealing (900°C, 30s): two new gettering zones appear at R_p and $R_p/2$ (R_p = projected range of Si^+)
- visible by SIMS profiling after intentional Cu contamination

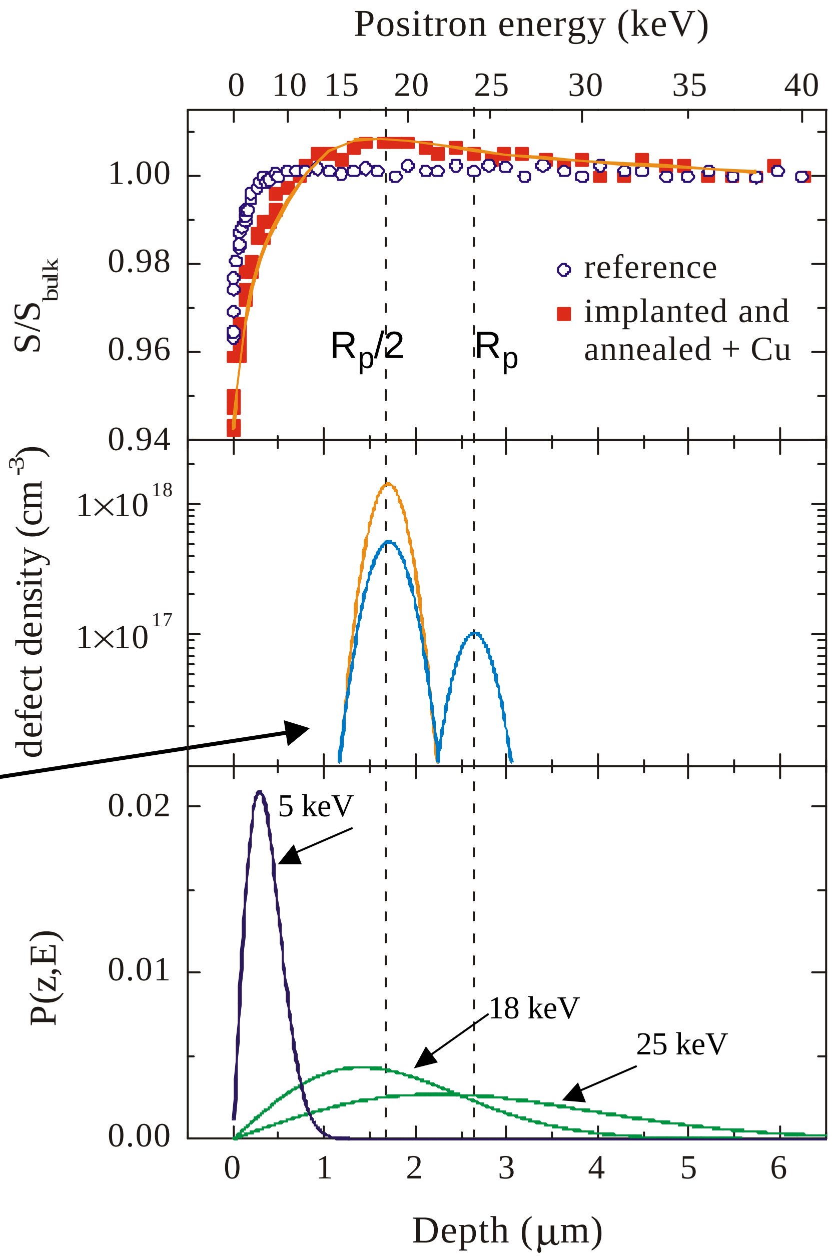
TEM image by P. Werner, MPI Halle



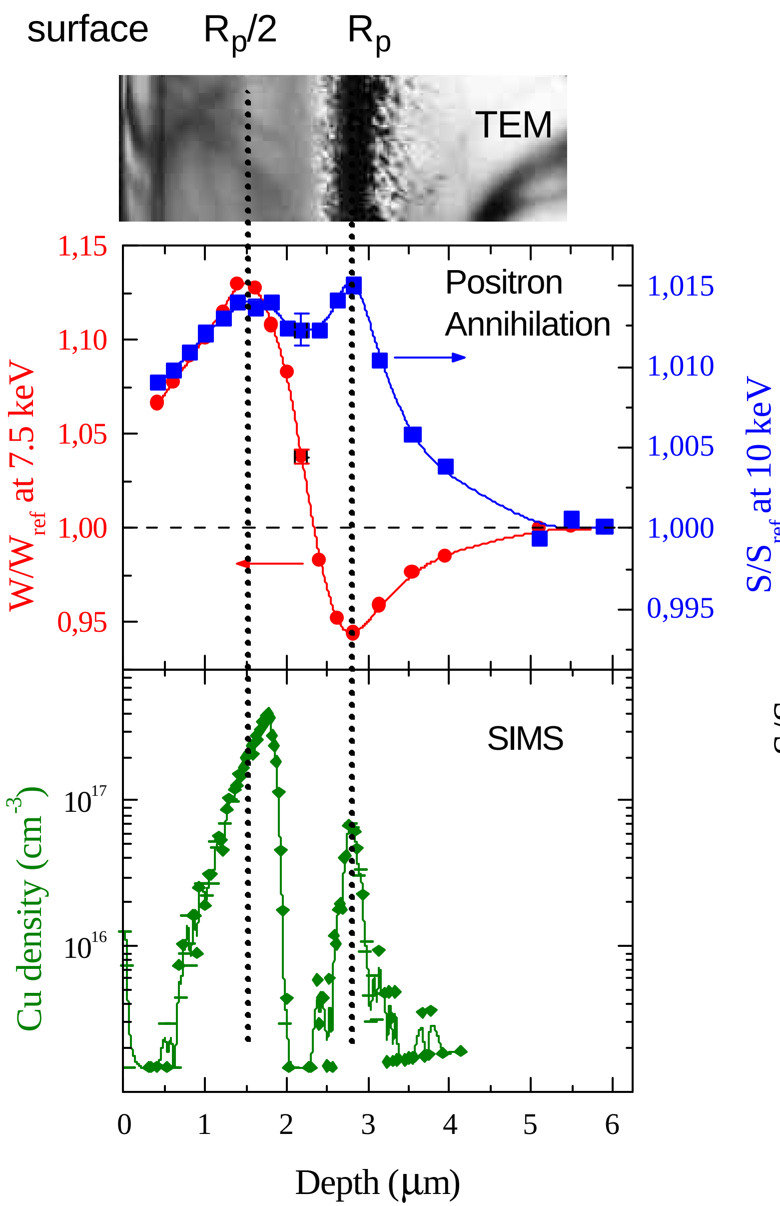
- at R_p: gettering by interstitial-type dislocation loops (formed by excess interstitials during RTA)
- no defects visible by TEM at $R_p/2$
- **What type are these defects?**

Investigation of the $R_p/2$ effect by conventional VEPAS

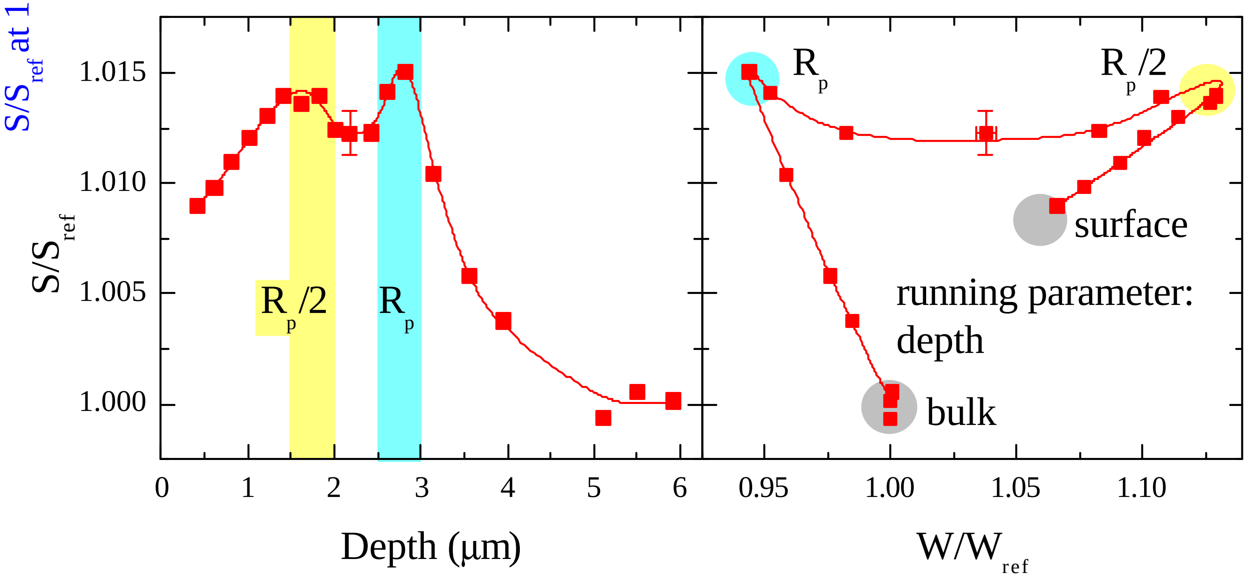
- the defect layers are expected in a depth of 1.7 µm and 2.8 µm corresponding to E_+= 18 and 25 keV
- implantation profile too broad to discriminate between the two zones
- simulation of S(E) curve gives the same result for assumed blue and yellow defect profile (solid line in upper panel)
- furthermore: small effect only
- no conclusions about origin of $R_p/2$ effect possible



Getter centers after high-energy self-implantation in Si

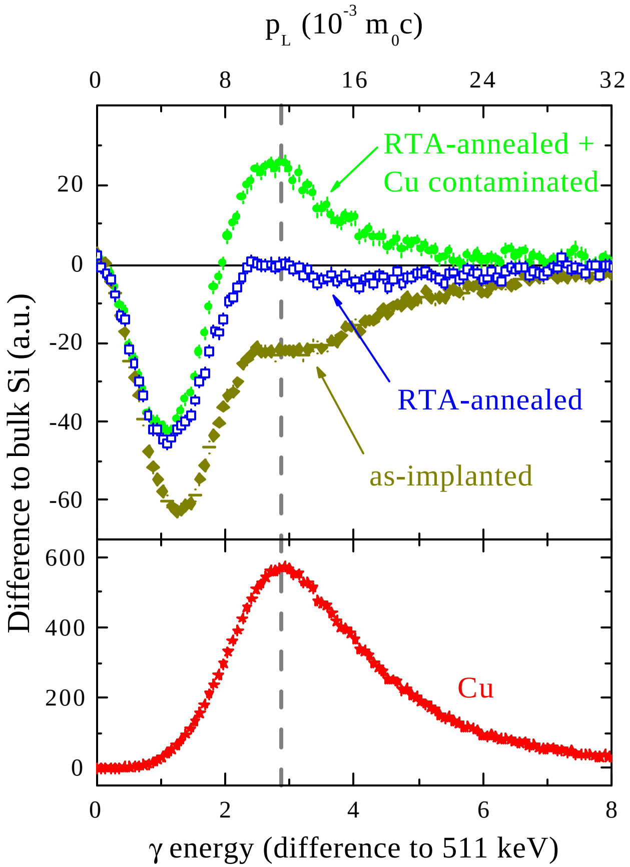


- VEPAS with improved depth resolution show clearly open-volume defects at $R_p/2$ and R_p
- they must be different (see S-W-plot)
- "normal" behavior of W parameter at R_p but high value at $R_p/2$: Cu decorates the vacancy-type defect

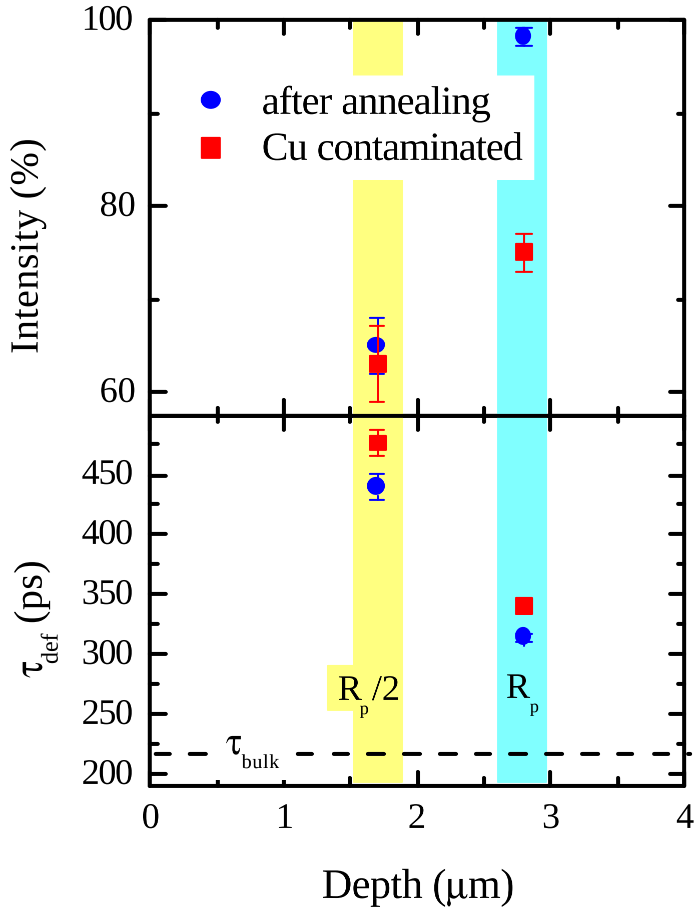


Doppler-coincidence and lifetime spectroscopy

- Doppler-coincidence spectroscopy shows the existence of Cu at the $R_p/2$ defect
- positron lifetime spectroscopy needed for determination of open volume size



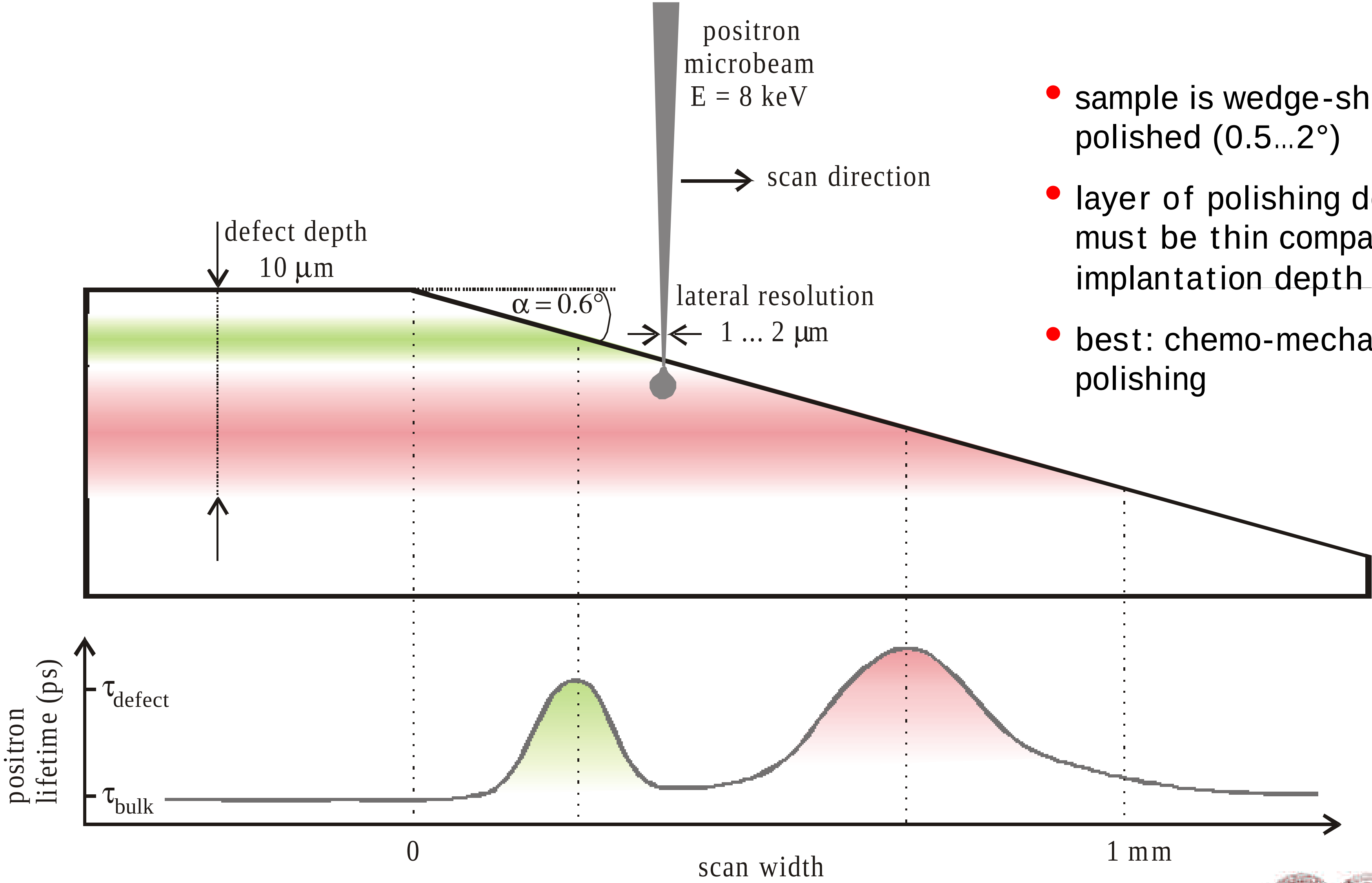
- samples were chemically etched and positron lifetime was measured at Munich Slow-Positron Lifetime Beam System
- at $R_p/2$: τ_d=450 ps (vacancy cluster, n > 10)
- at R_p: τ_d=320 ps (open volume = divacancy)



Conclusions

- **R_p/2:** small vacancy clusters are getter centers
- **R_p:** positrons are trapped by defects at dislocation loops

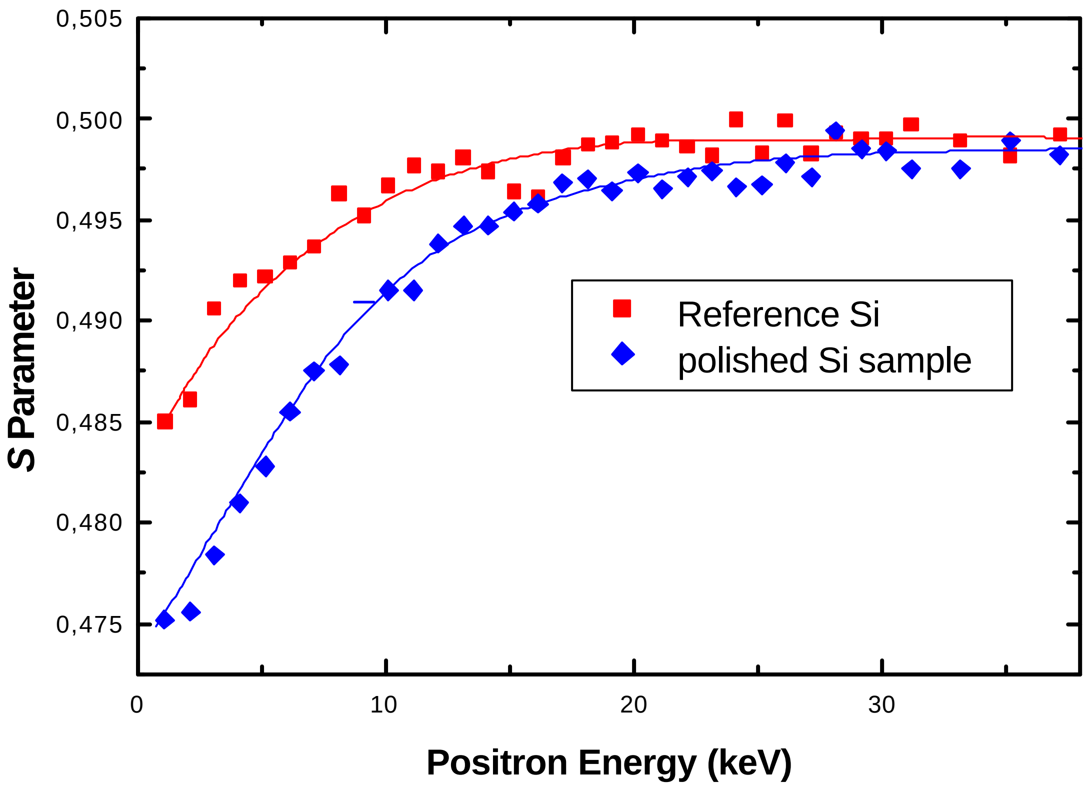
Enhanced depth resolution by using the Munich Scanning Positron Microscope



- sample is wedge-shaped polished (0.5…2°)
- layer of polishing defects must be thin compared to e^+ implantation depth
- best: chemo-mechanical polishing

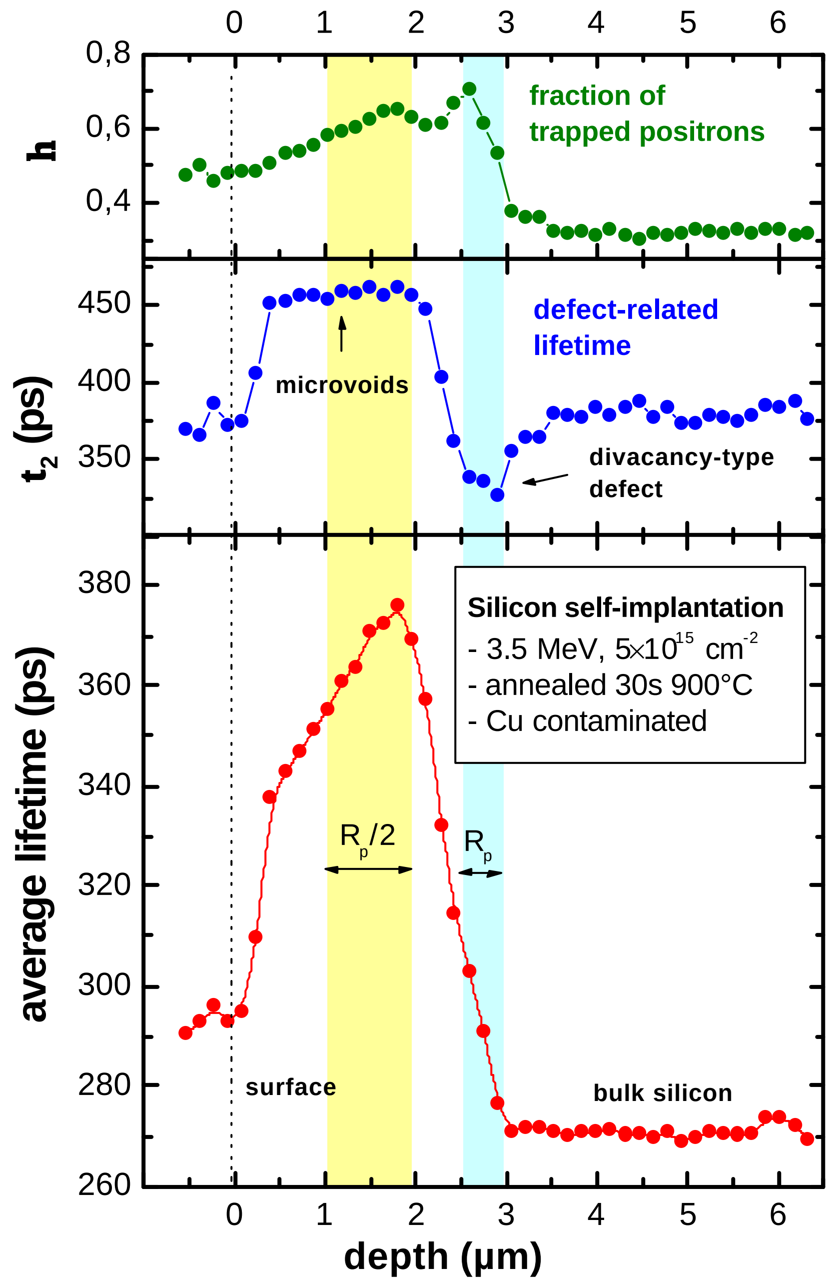
Does polishing create deep defect profile?

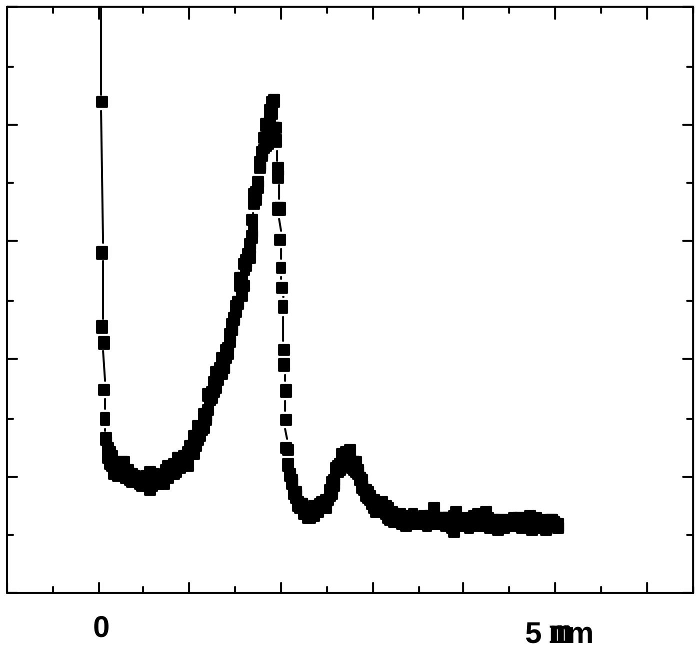
- Si reference sample was evenly polished using the same machine (no wedge)
- polishing changed surface S parameter, but diffusion length was similar $L_+ = 220 \pm 15$ nm
- no visible influence of layer of polishing defects



First defect depth profile using Positron Microscopy

- 45 lifetime spectra: scan along wedge
- separation of 11 µm between two measurements corresponds to depth difference of 155 nm (α = 0.81°)
- beam energy of 8 keV ⇒ mean penetration depth is about 400 nm; represents optimum depth resolution
- no further improvement possible due to positron diffusion: L_+(Si @ 300K) ≈ 230 nm
- both regions well visible:
  - vacancy clusters with increasing density down to 2 µm (R_p/2 region)
  - in R_p region: lifetime τ_2 = 330 ps; corresponds to open volume of a divacancy; must be stabilized or being part of interstitial-type dislocation loops





SIMS profile of Cu

Conclusions

- optimum depth resolution of VEPAS is determined by L_+ (defect density)
- can be obtained by stepwise removal of surface (sputtering or etching)
- problem of sputtering: surface gets rough for large depth & preferential sputtering in compounds
- excellent possibility: wedge-shaped sample studied by e^+ microbeam – ideal depth resolution in large depth possible

This presentation can be found as pdf-file on our Website:
http://www.ep3.uni-halle.de/positrons