Irradiation Induced Defects Examined by Positron Annihilation Spectroscopy

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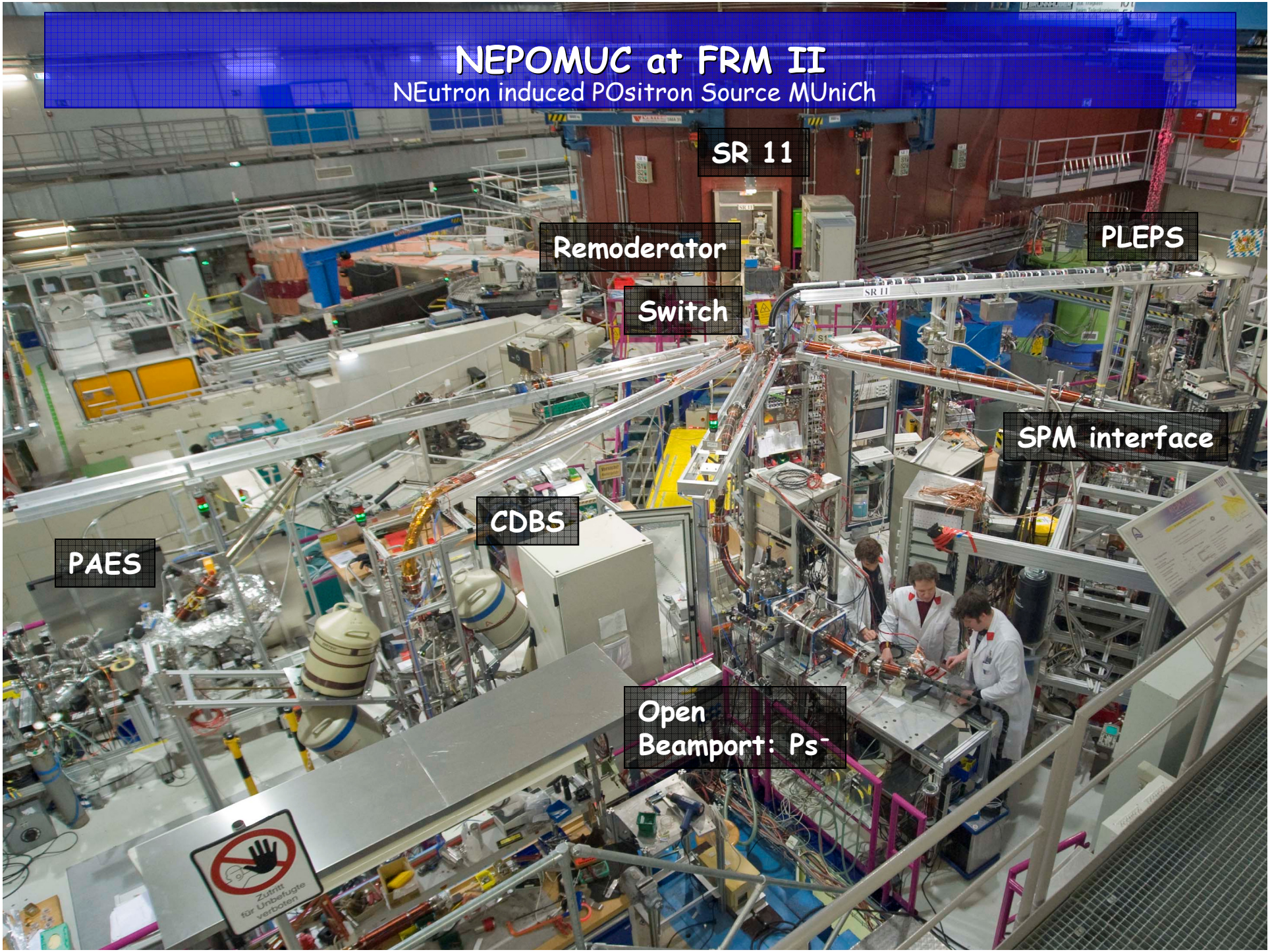

NEPOMUC at FRM II
NEutron induced POsitron Source MUniCh
SR 11
Remoderator
PLEPS
Switch
SPM interface
CDBS
PAES
Open
Beamport: Ps-
Zutritt
für Unbefugte
verboten

High Intensity Positron Beam

NEPOMUC: I_+ ~ 10^9 e^+/s mono-energetic ! → Lab-beam x 1000

→ reduced measurement time & improved signal/noise

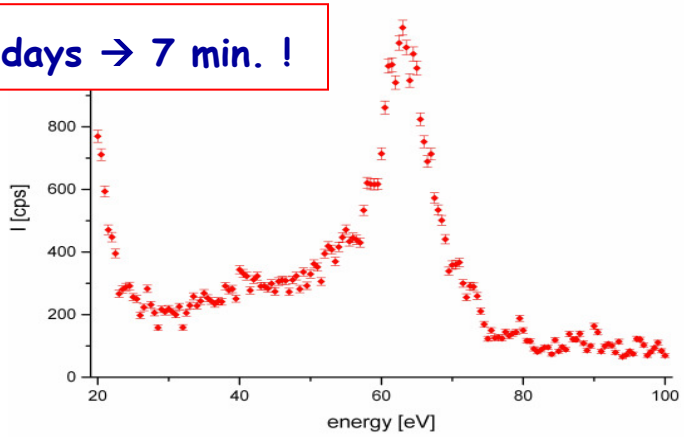
→ novel techniques !

C. H. et al. NIM A 593 (2008) 616

1) (t-dependent) PAES:

- „No" secondary electrons & non-destructive
- Top most atomic layer sensitivity
  → e.g. surface segregation

t_{meas}: 20 days → 7 min. !



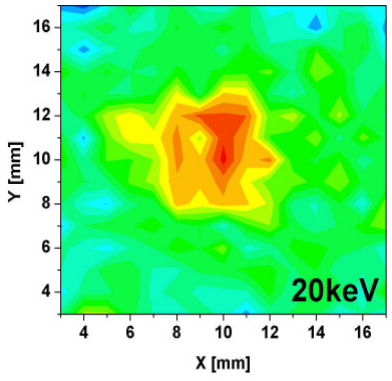
C. H. et al.; J. Phys. Conf. Ser. 225 (2010) 012015;
Surf. Sci. 604 (2010) 1772; PRL 05 (2010) 207401

2) Defect spectroscopy PL:

- defect type and concentration
- depth profiles

3) Spatial resolved (C)DBS:

- 3D-defect imaging
- Elements decorating defects
- T-dependent defect annealing



z_m=3.2µm

M. Stadlbauer, C. H. et al
PRB 76, 174104 (2007)
C.H et al. PRB 81, 064102 (2010)

Outline

- Motivation
- e+ as nano-probe in matter
- Examples:
  1) Defect mapping
  2) Defect annealing in thin layers
  3) Irradiated Zircaloy
  4) D_2 loaded defects in W
- Summary

Motivation

Characterization of inner wall materials after irradiation:

- Irradiation induces a zoo of defects
- Investigation of (open-volume) defects:
  - → type, profile and concentration
  - → loading
  - → annealing
- Positron beam
  - → non-destructive analysis of near-surface region

Positron Implantation

e^+ Mean implantation depth (Al):

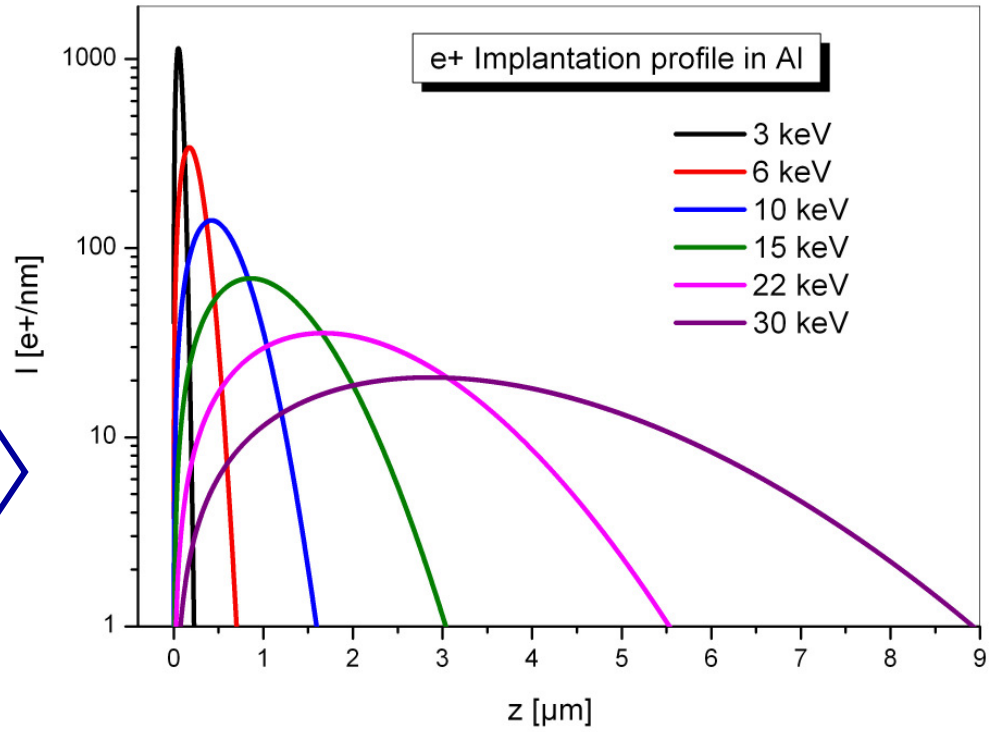
- ~10-50 eV → surface
- 10 keV → layers 600 nm
- 30 keV → bulk 4 μm

200 keV (^{22}Na) → bulk 150 μm

Makhovian implantation profile:

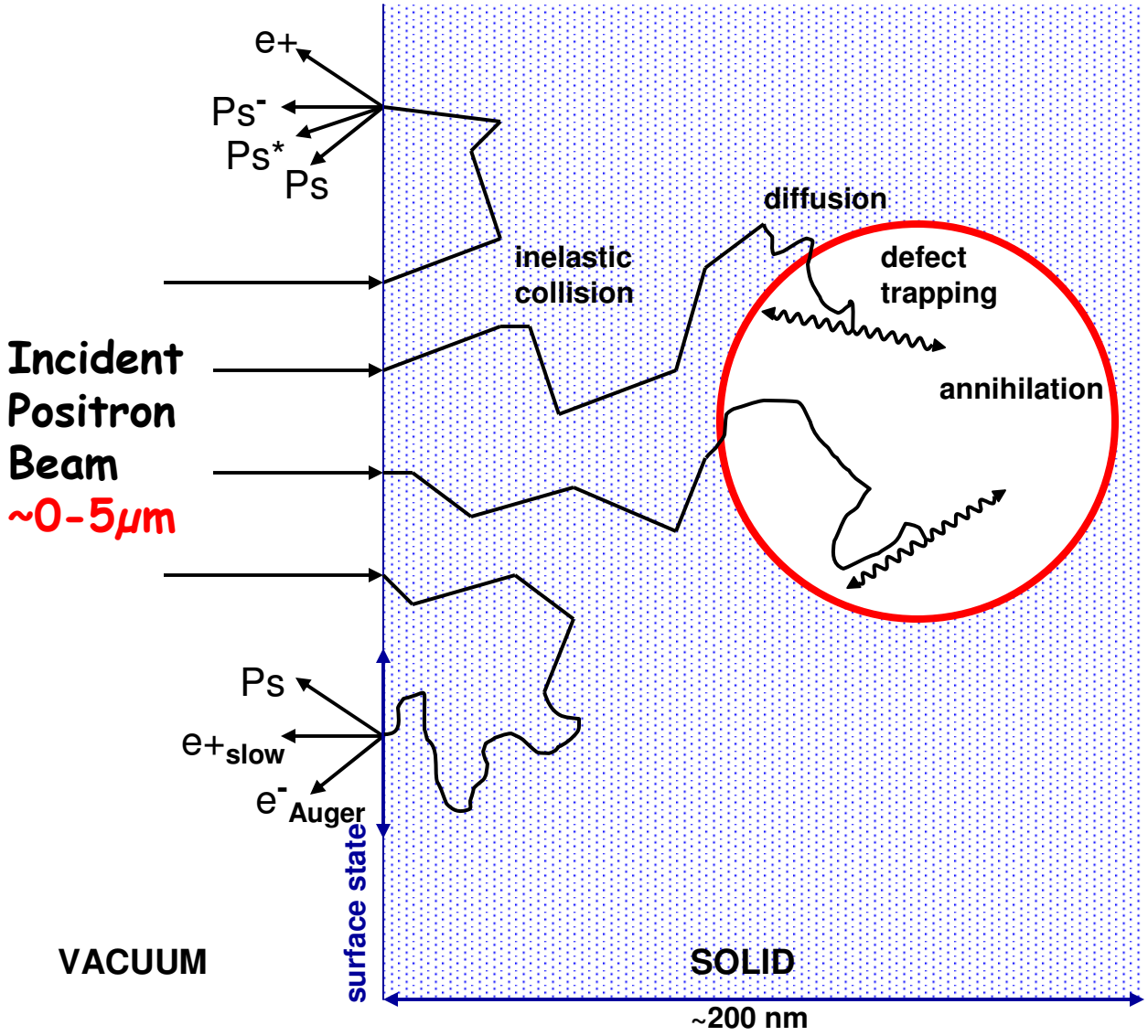
$$P(z,E) = \frac{m z^{m-1}}{z_0^m} \exp\left[-\left(\frac{z}{z_0}\right)^m\right]$$

z_0(n,m,A, E):
n,m,A material dependent parameters



Puska et al. Rev. Mod. Phys. 66 (1994) 841

Positron as Nanoprobe



Positrons fate:

- thermalization: ~few ps
- diffusion ~100ps
  → **~100 nm**
- defect trapping
- annihilation into 2 collinear γ–quanta

- positron lifetime τ

→ **ρ (e-)**

→ **defects**

- Doppler-broadening **ΔE**

  Angular correlation **ΔΘ**

→ **p(e-)**

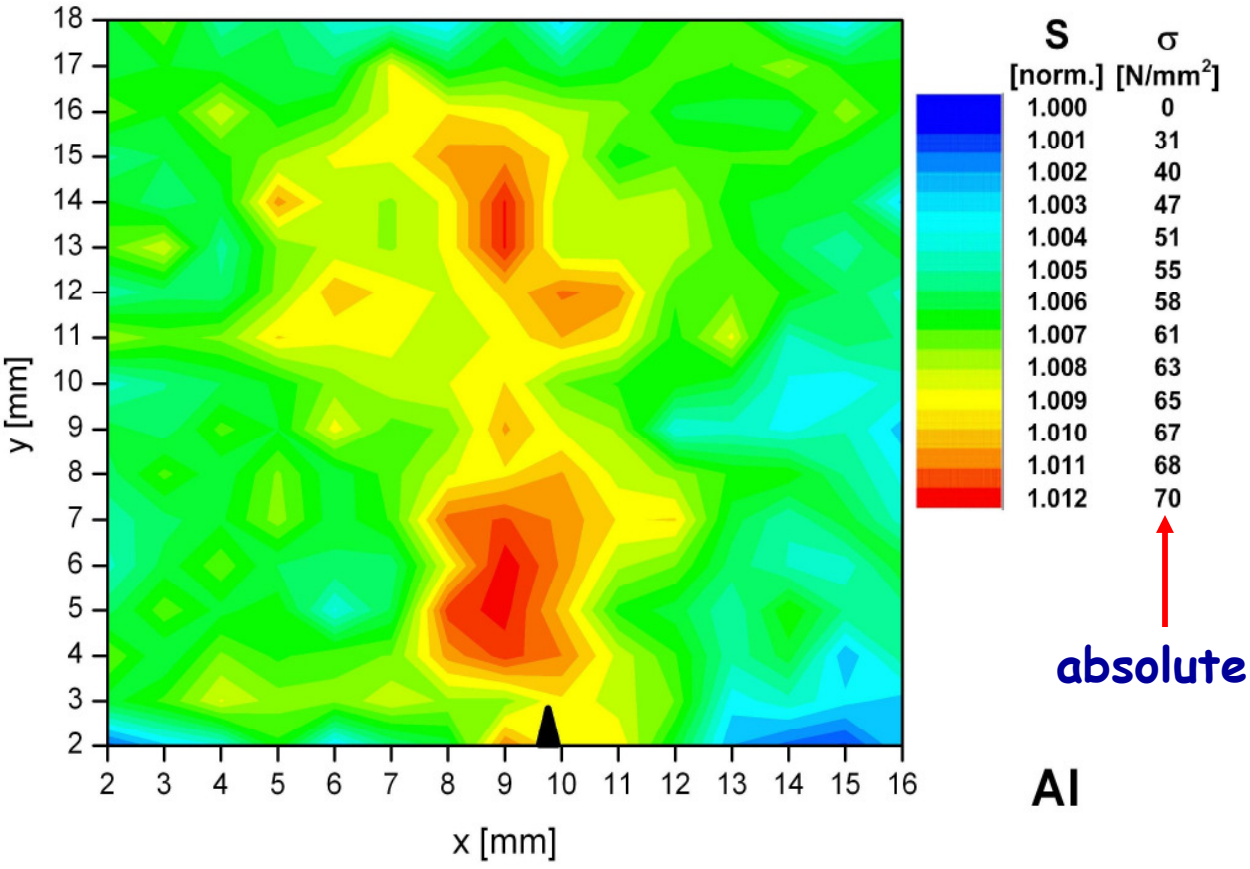
→ **defects & elements**

Defect mapping of deformed Al

Defect annealing in thin Au layers

Plastic Deformation in Al

Aim: 2D defect mapping + visualization of local σ in asymmetrically shaped samples

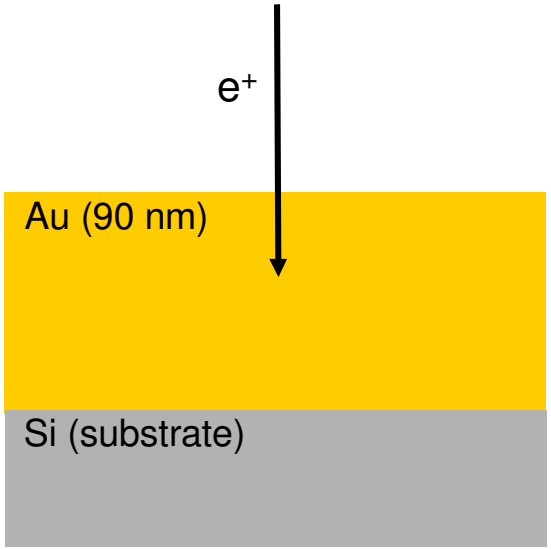


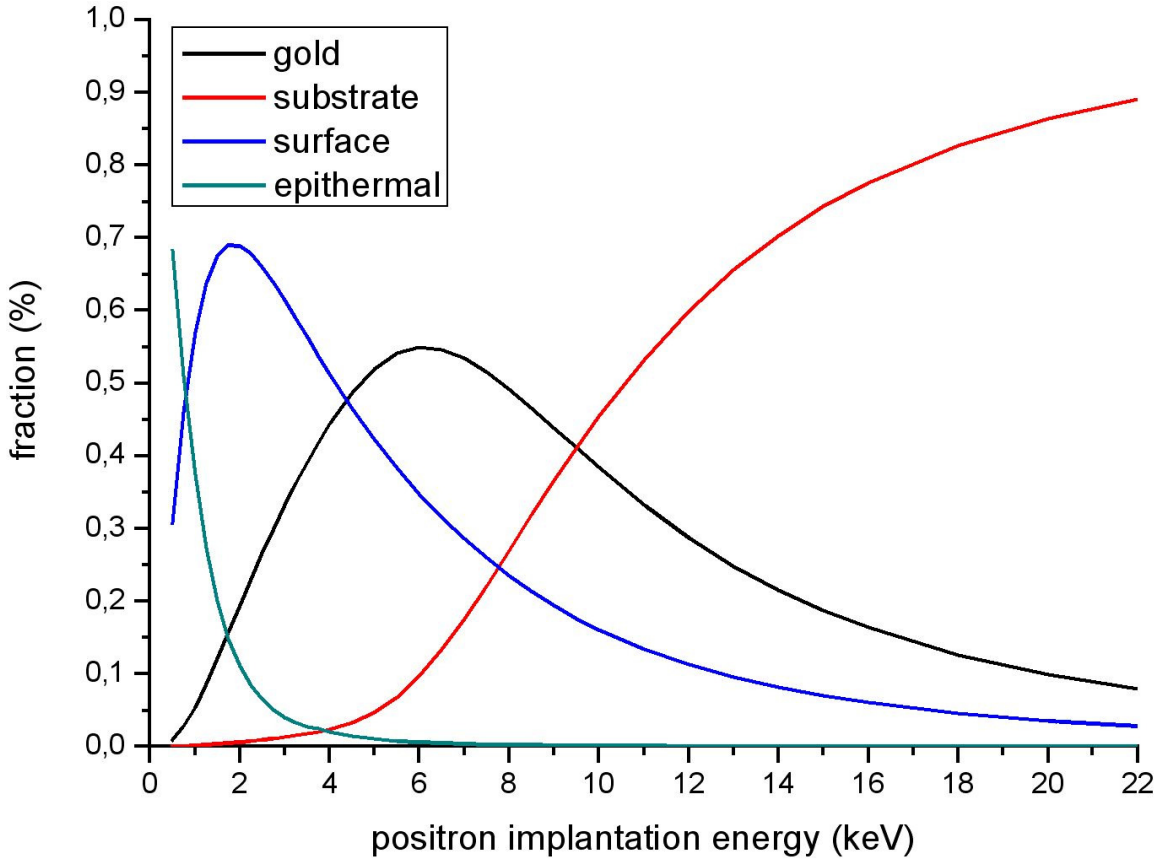
→ S(σ) correlation from references

C. H. et al. PRB 81 (2010) 064102

Thin Film Annealing

Thin Au layers on Si(100)





Thin Film Annealing

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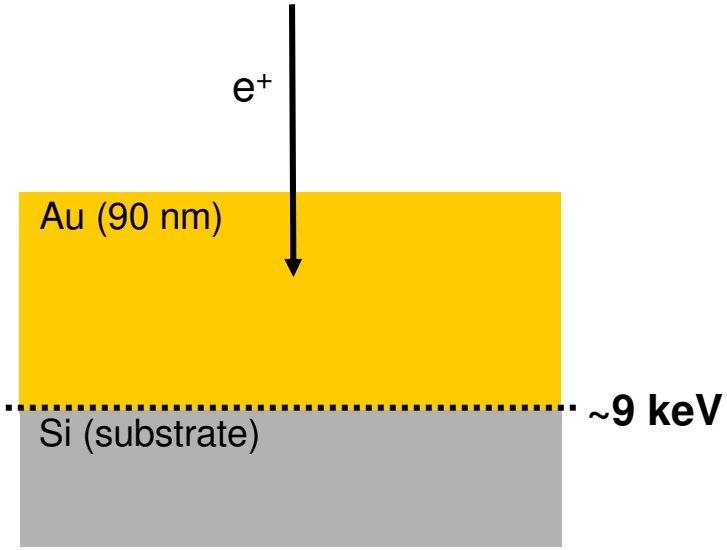
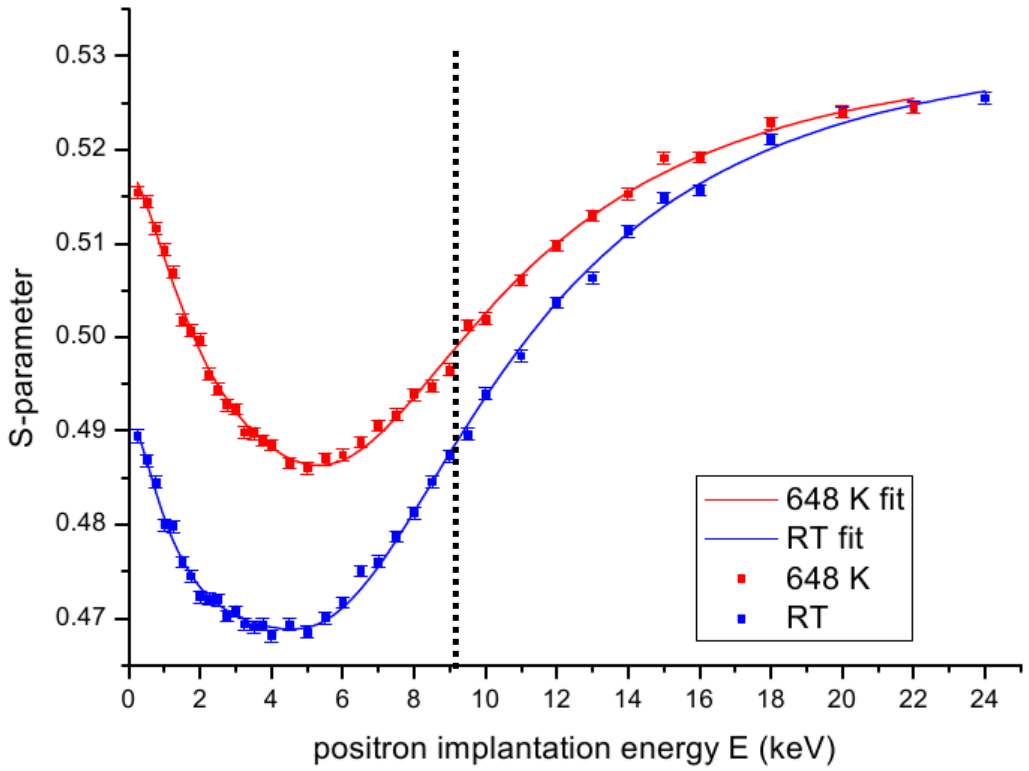




S(E) results:

→ **saturation trapping** at RT and at T = 648K
→ e^+ diffusion length: **1.2**(0.5)nm at RT → **41**(5)nm at 648 K
→ defect **annealing**

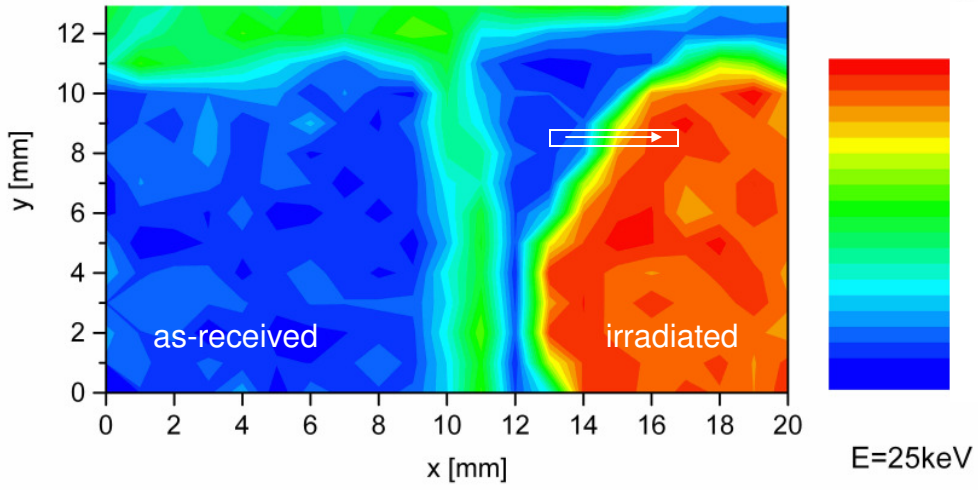
M. Reiner, C.H., unpublished results

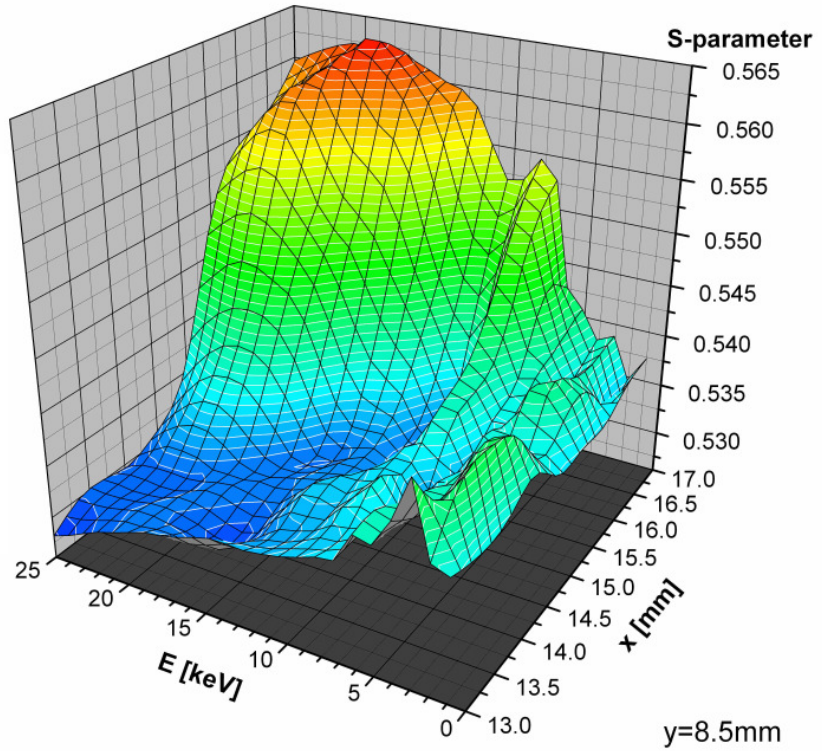
Irradiated Zircaloy

D_2 loaded defects in W

Zircaloy

Simulation of fission fragments induced defects:
Zr^+ irradiated Zircaloy: 3 MeV, 2.5 10^{13} Zr^+/cm^2
samples provided by R. Hengstler, AREVA NP GmbH





Results: (preliminary)

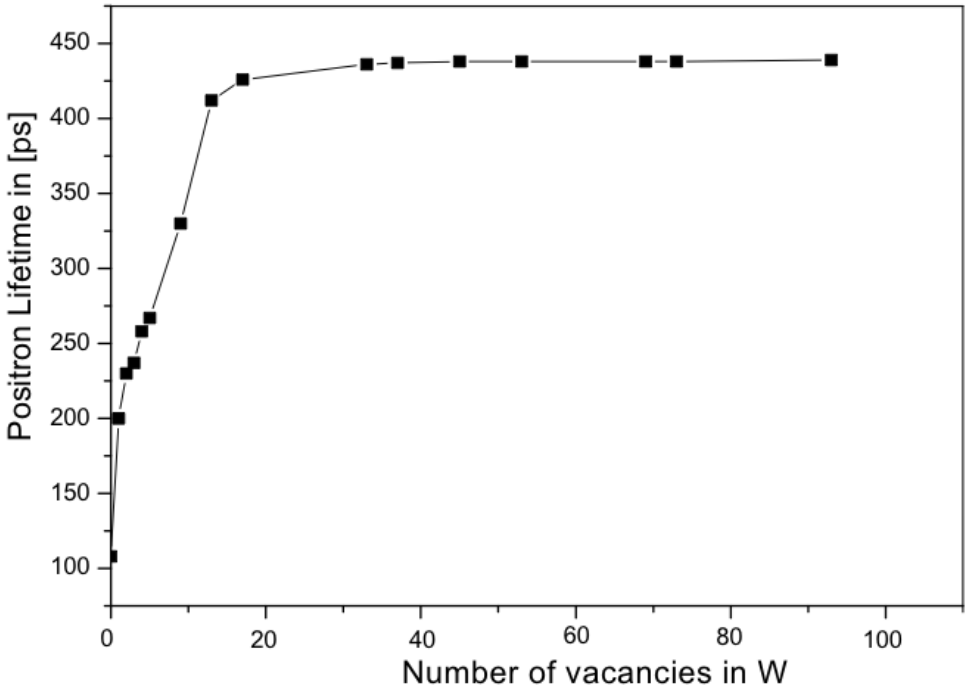
- Detection of ion irradiated spot
- Spatially resolved defect profile

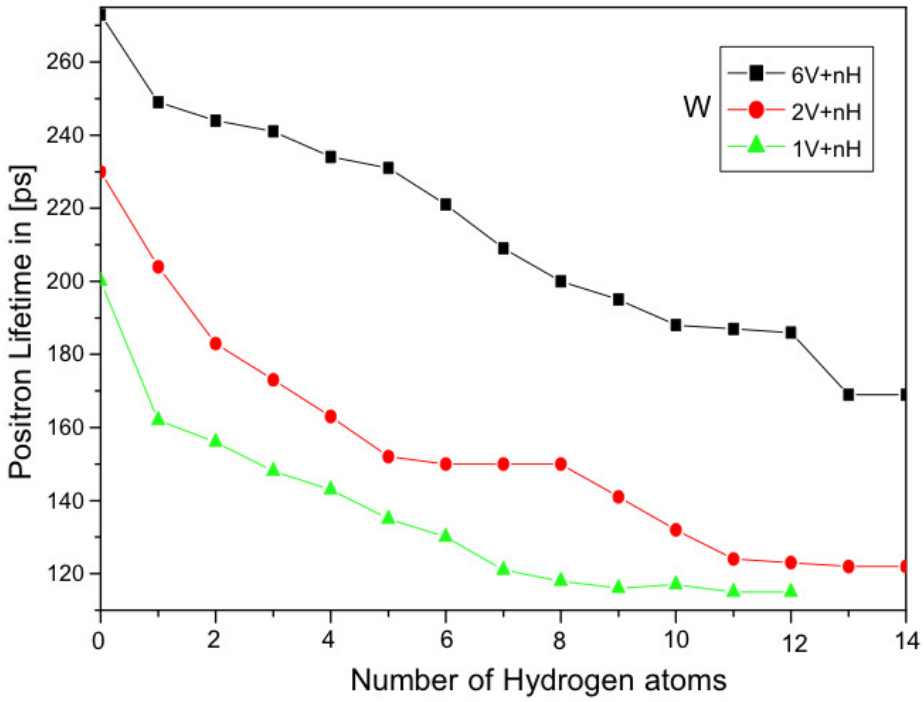
→ Future: Variation of dose, defect annealing ?

R. Hengstler, C.H., unpublished results

Vacancy Clusters in W

Calculated positron lifetime in unloaded and H loaded defects





Troev et al., Nucl. Instr. Meth. B 267 (2009) 535

Unloaded and D_2-Loaded Irradiated W

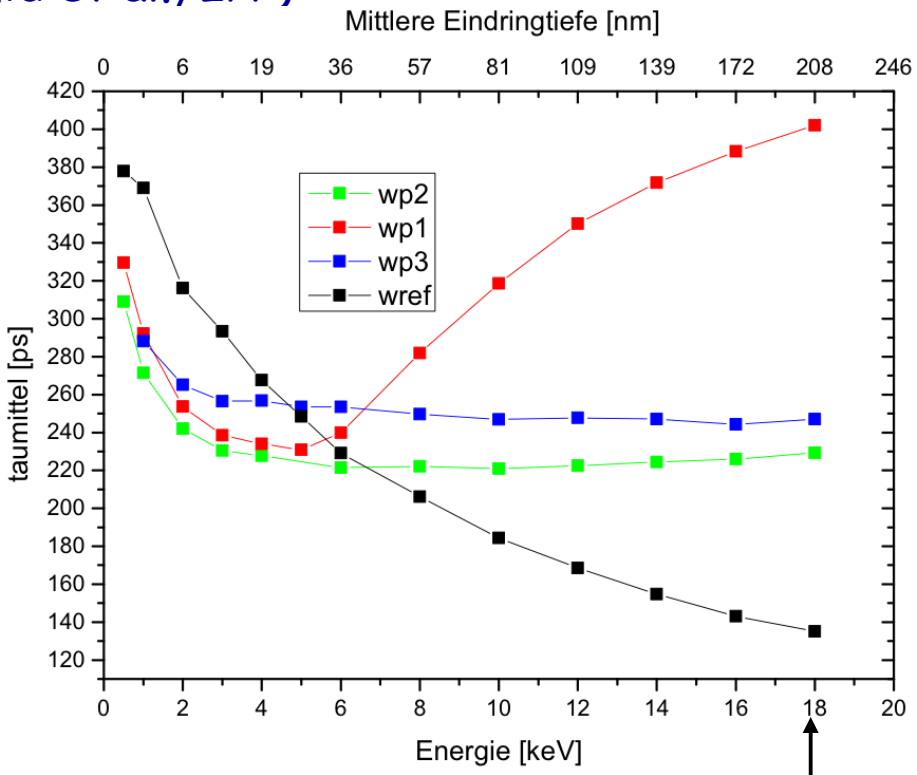
Preparation of W samples: (K. Schmid et al., IPP)

(1) 0.9dpa, 1-20MeV W "shallow profile" **+D_2,**

(2) 0.9dpa, 1-20MeV W "shallow profile"

(3) 9dpa, 20 MeV W

(4) W reference, ann. at 2470°C



e^+lifetime measurements:

(1,2,3): saturation trapping

(2→3): slightly larger voids in (3)

(2,3): ~80% in single vac. ~20% in vacancy clusters N=12-15

(1): ~35% ~65% N> 20

τ_2 extremely high → Ps formation in large voids due to D_2

... data analysis still in progress

Summary

Positron:

- **High sensitive nano-probe** for defects

Positron beam at NEPOMUC:

- 3D-defect mapping, defect annealing
- Positron lifetime → **void size, defect type/concentration**
- CDBS → chemical surrounding of defects

FEMaS – projects:

Thank You

- Near surface defects of **irradiated W and FeCr** (prel. results)
- Open-volume defects **loaded with H, D or He**

Contact:

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User-office FRM II:	http://www.frm2.tum.de/user-office/index.html
Next deadline:	**16 September 2011**