Material sciences with high-brightness, low energy positron beams

MARCEL DICKMANN

Bundesministerium
für Bildung
und Forschung

Universität der Bundeswehr München

Content

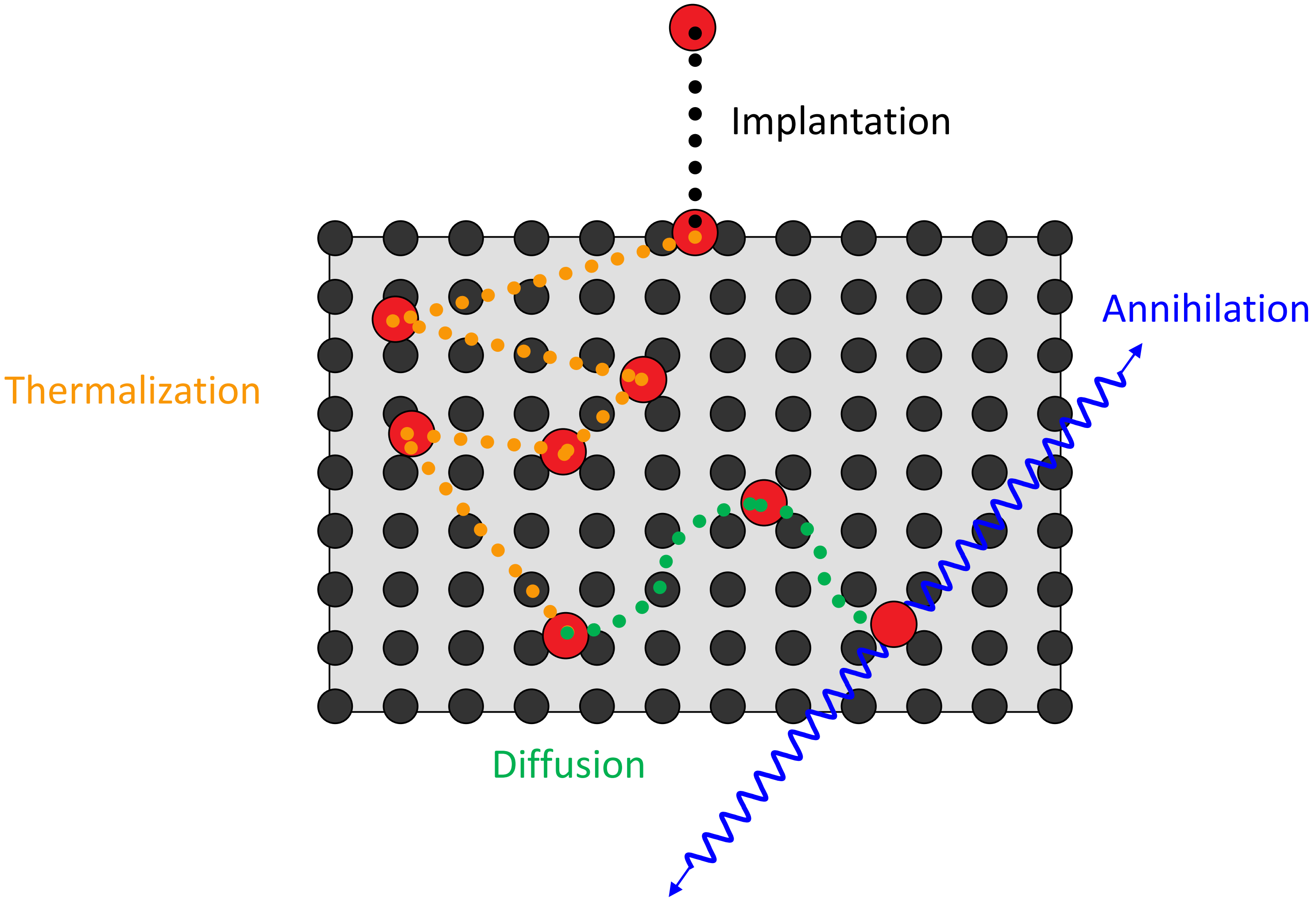
Principles of Positron (Lifetime) Spectroscopy

- Positrons in Matter
- Depth-resolved PALS
- Pulsed Positron Beams in Munich

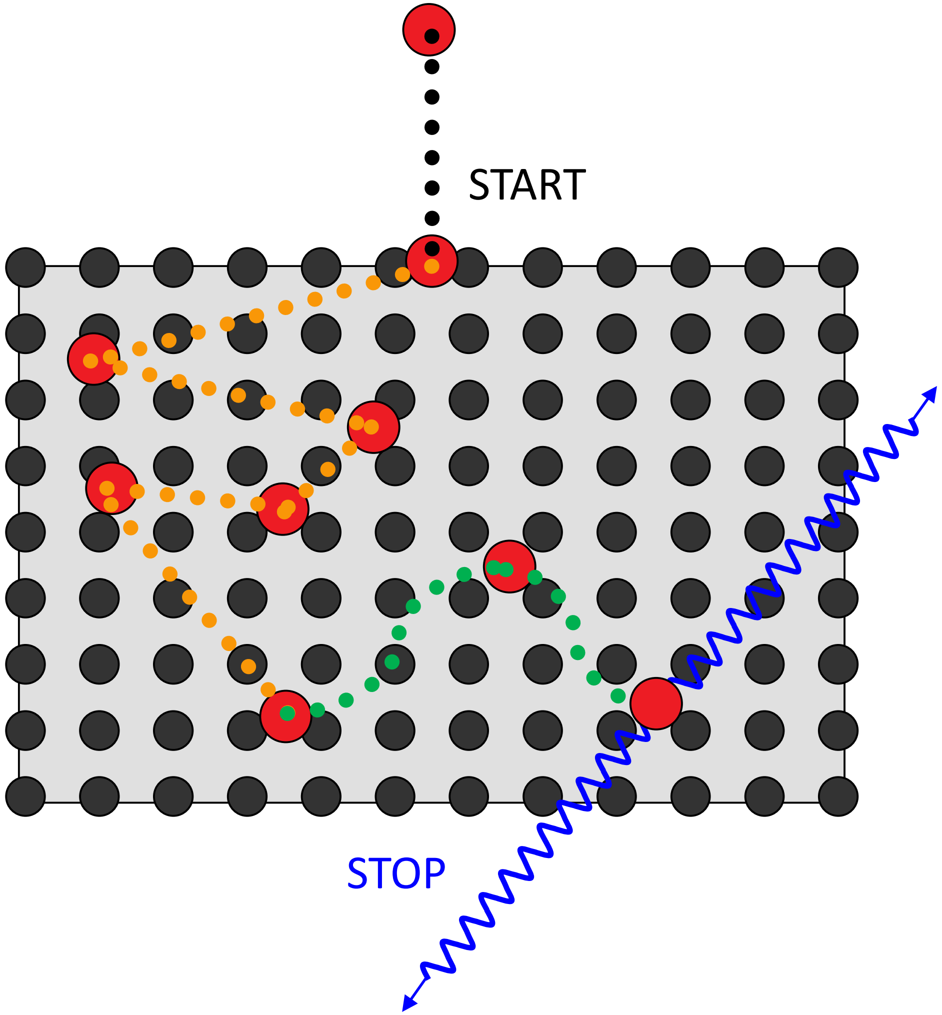
Selection of Investigated Materials using PALS

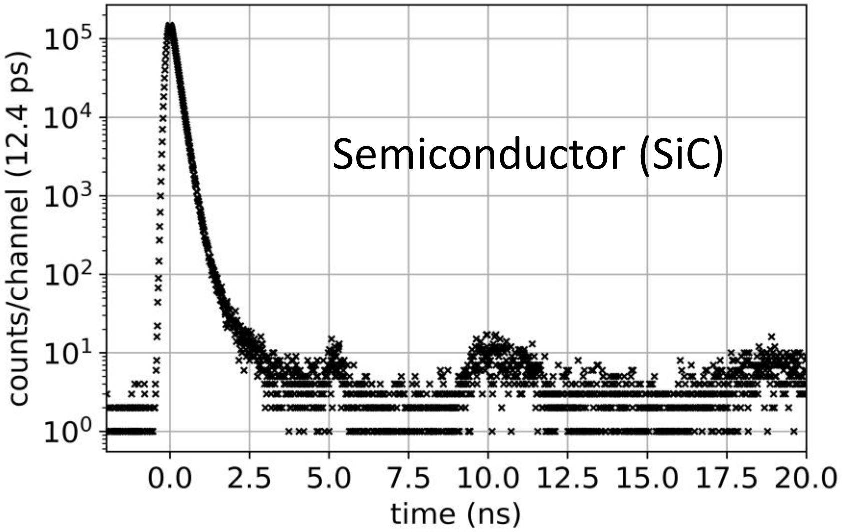
- NV Centers in Diamond
- Fusion Materials

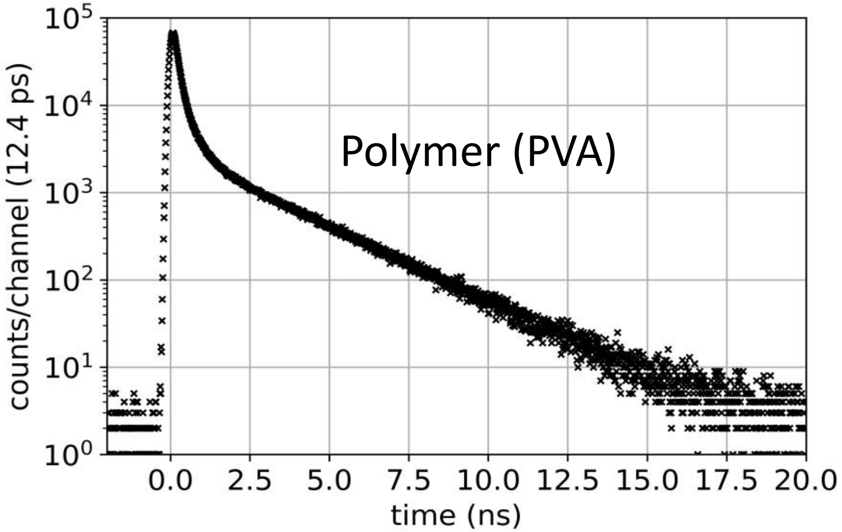
Implantation, Thermalization, Diffusion, Annihilation



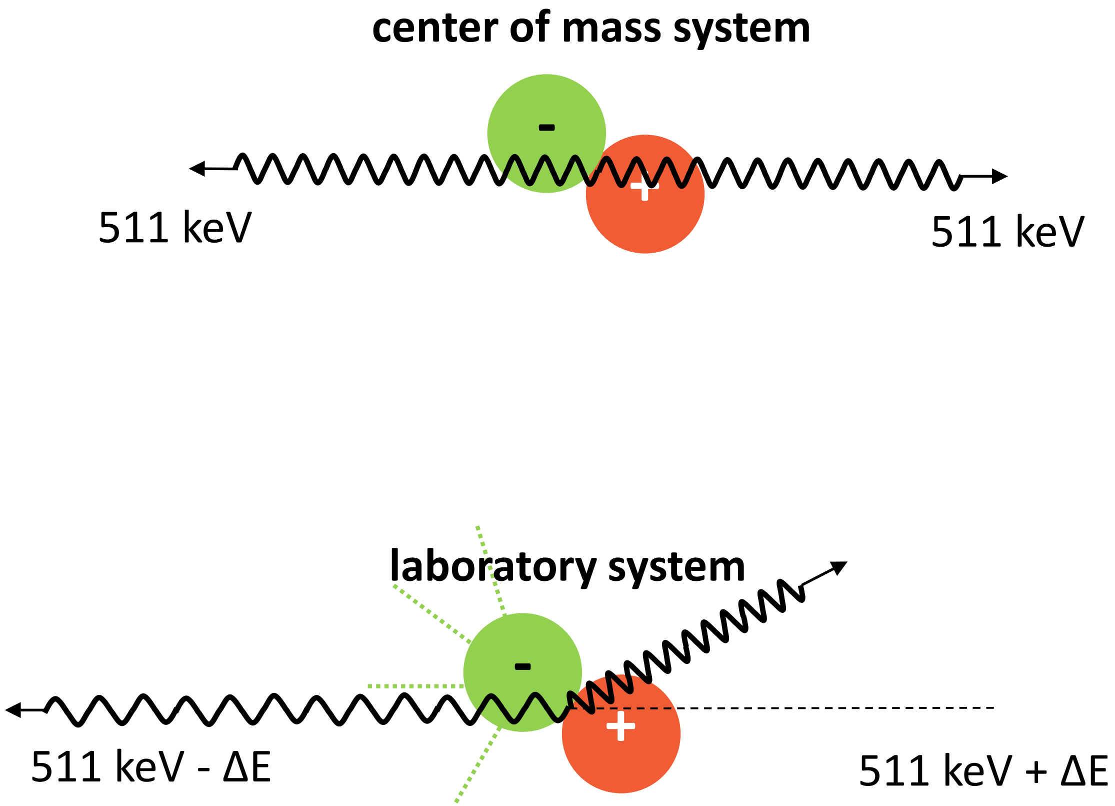
Positron Annihilation Lifetime Spectroscopy

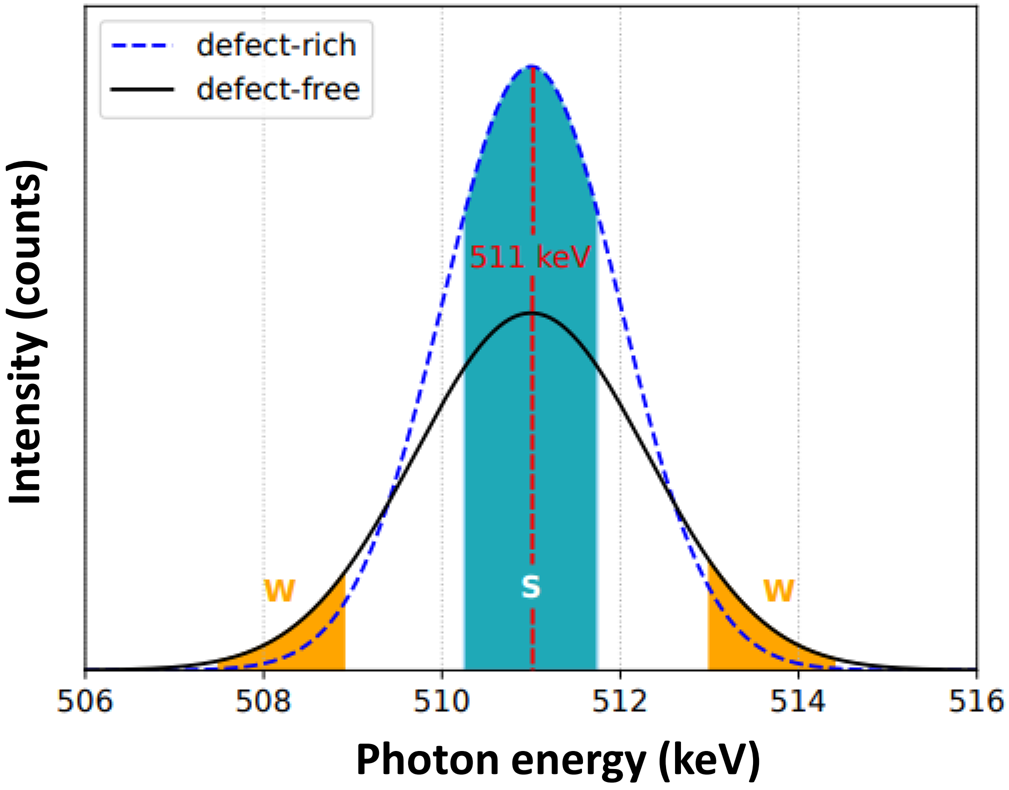






Doppler-Broadening Spectroscopy



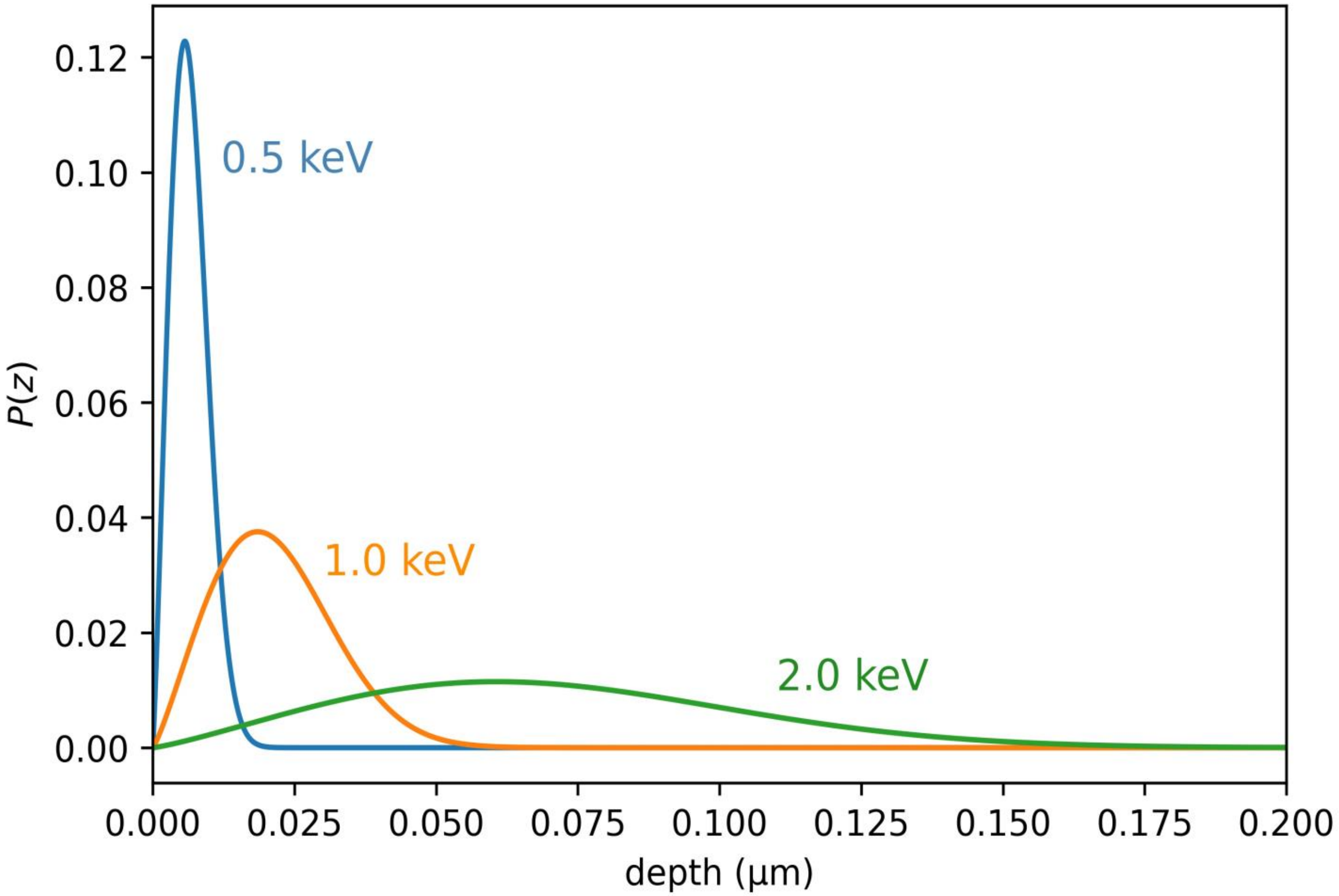


$S =$  / whole area

$W =$  / whole area

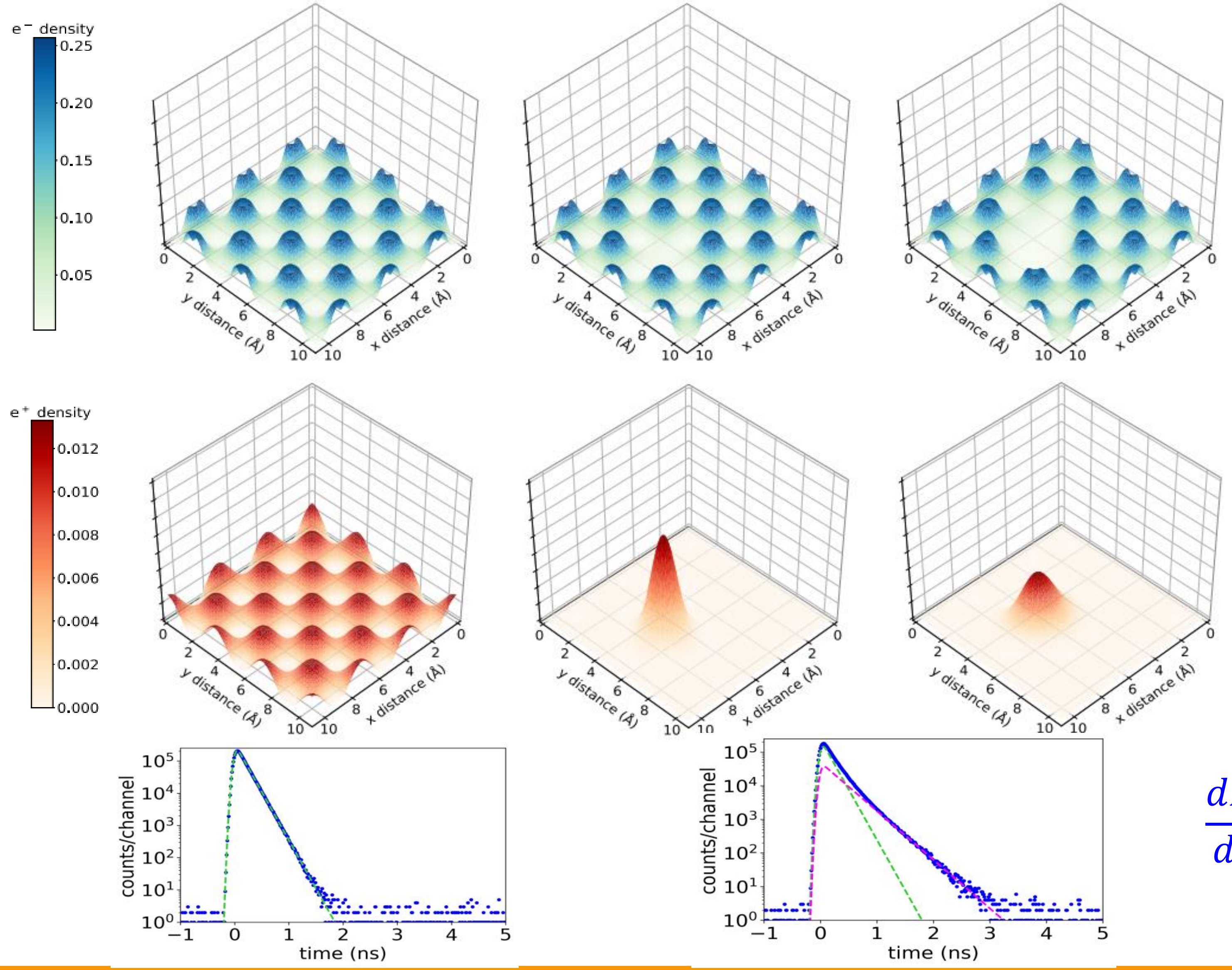
Positron Implantation

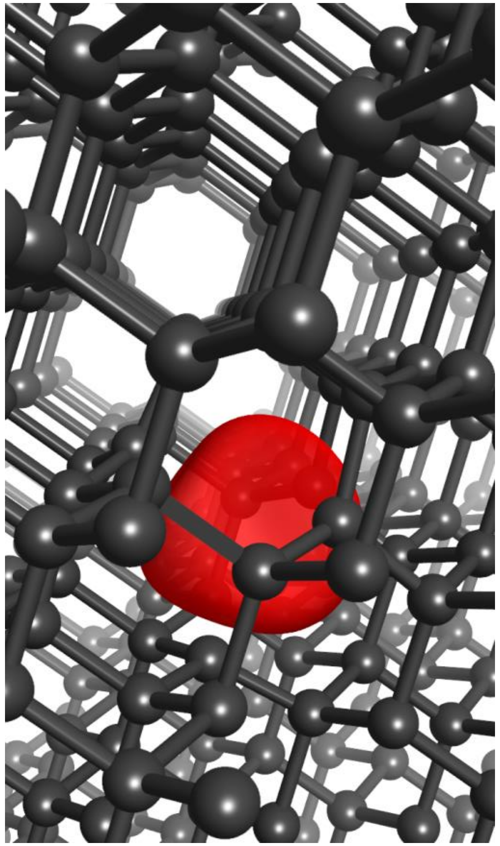
Positron implantation profiles using a mono-energetic beam



Material	density (g/cm³)	mean implantation depth (µm) @4keV	@20keV
PMMA	1.09	0.250	3.94
Quartz	2.65	0.102	1.78
Aluminum	2.70	0.106	1.76
Copper	8.96	0.032	0.468
Lead	11.3	0.045	0.407
Tungsten	19.3	0.021	0.230

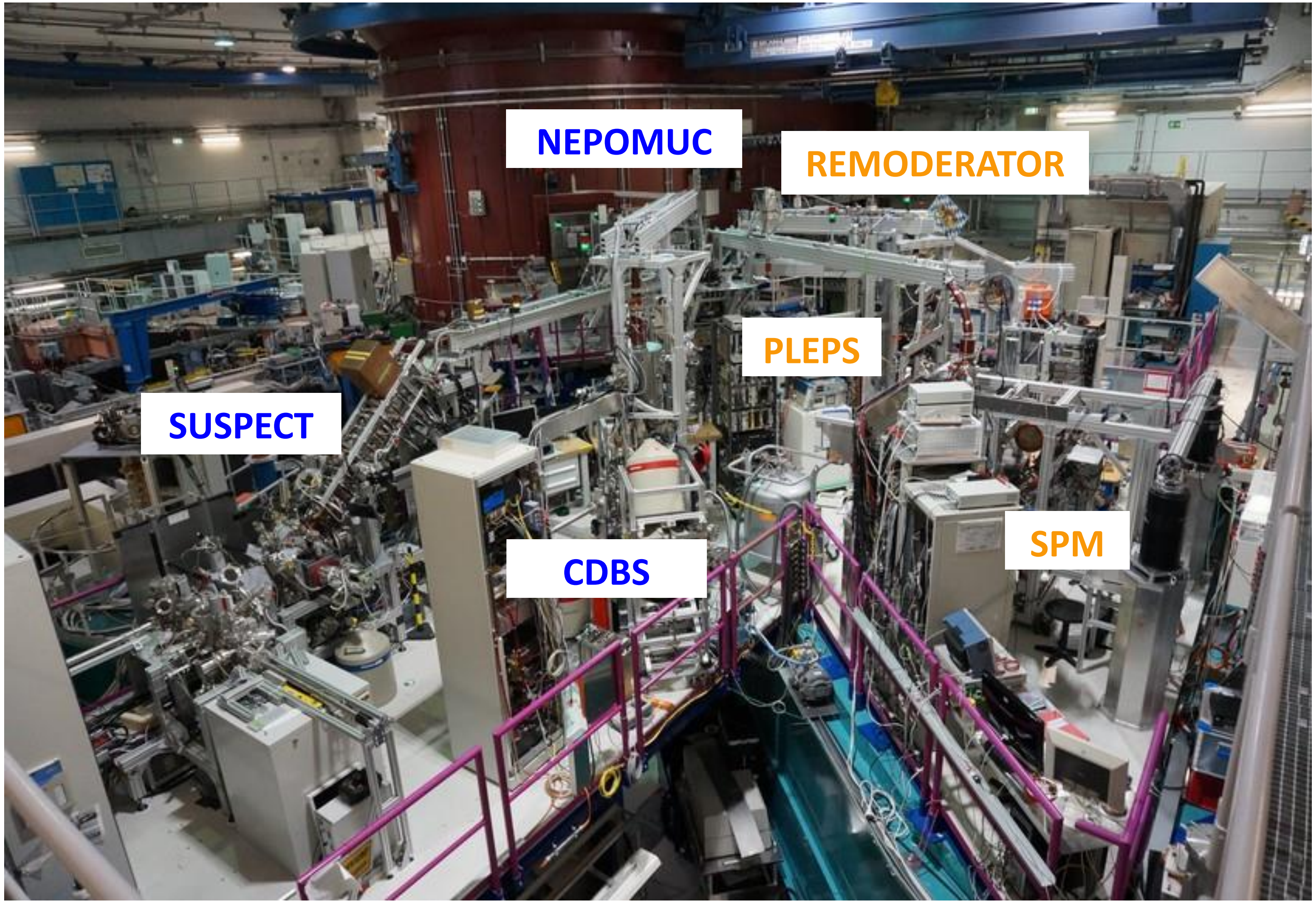
Positrons in Matter





$$\frac{dN}{dt}(t) = \sum_{i=1}^{n} \frac{I_i}{\tau_i} \cdot e^{-t/\tau_i}$$

Experimental Hall of the FRM II



NEPOMUC
NEutron-induced Positronsource MUniC

SUSPECT
SurfaceSPECTrometer

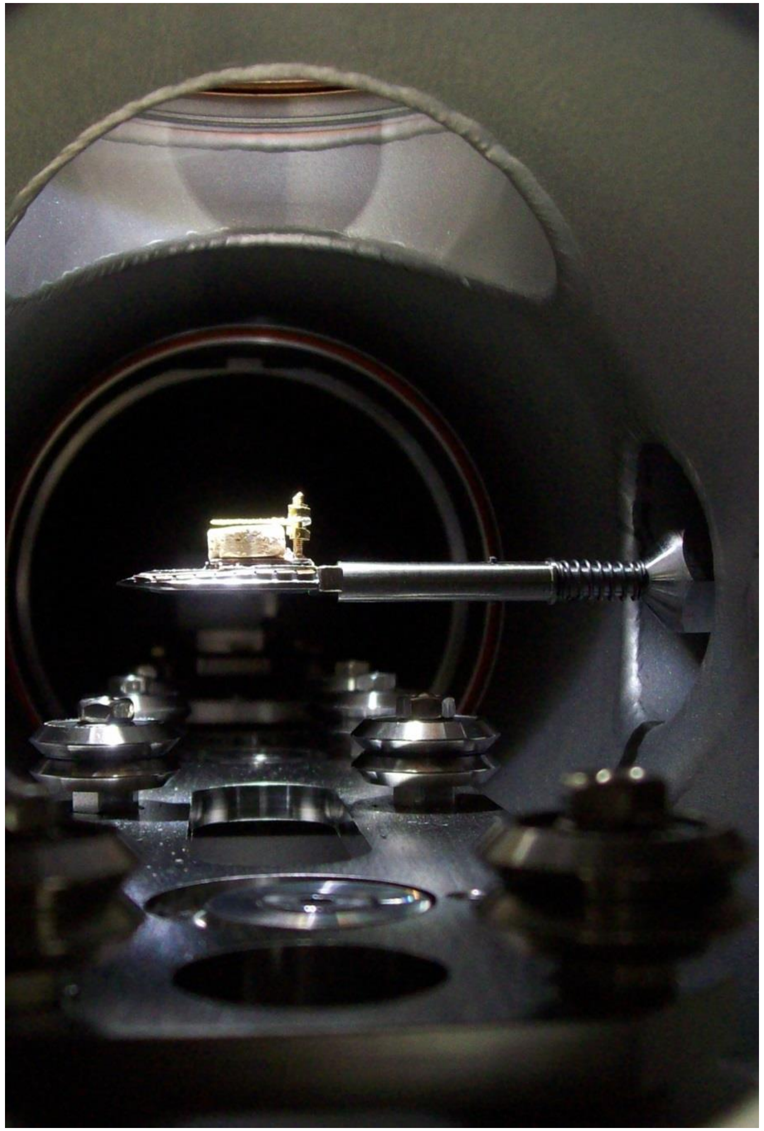
CDBS
Coincidence Doppler Broadening Spectrometer

PLEPS
Pulsed Low-energy Positron System

SPM
Scanning Positron Microscope

REMODERATOR

The Pulsed Beam System PLEPS



Implantation Energy
0.25 – 20 keV

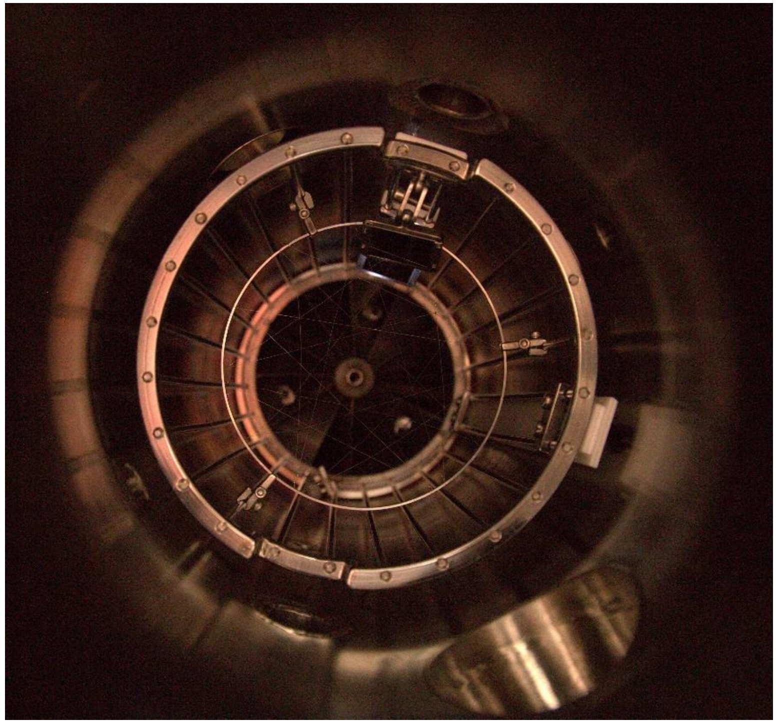
Beam Diameter
< 1mm

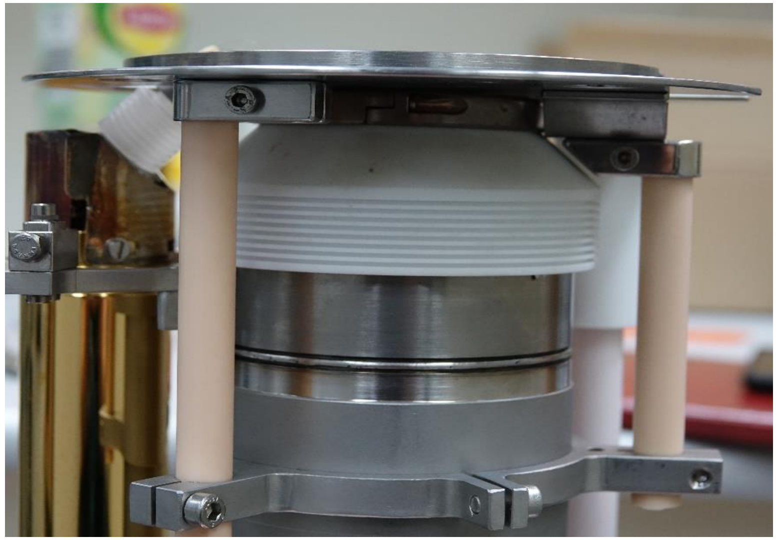
Total Time Resolution
180 ps (FWHM)

Measurement Time per Spectrum
10 min (4 Mio. Events)

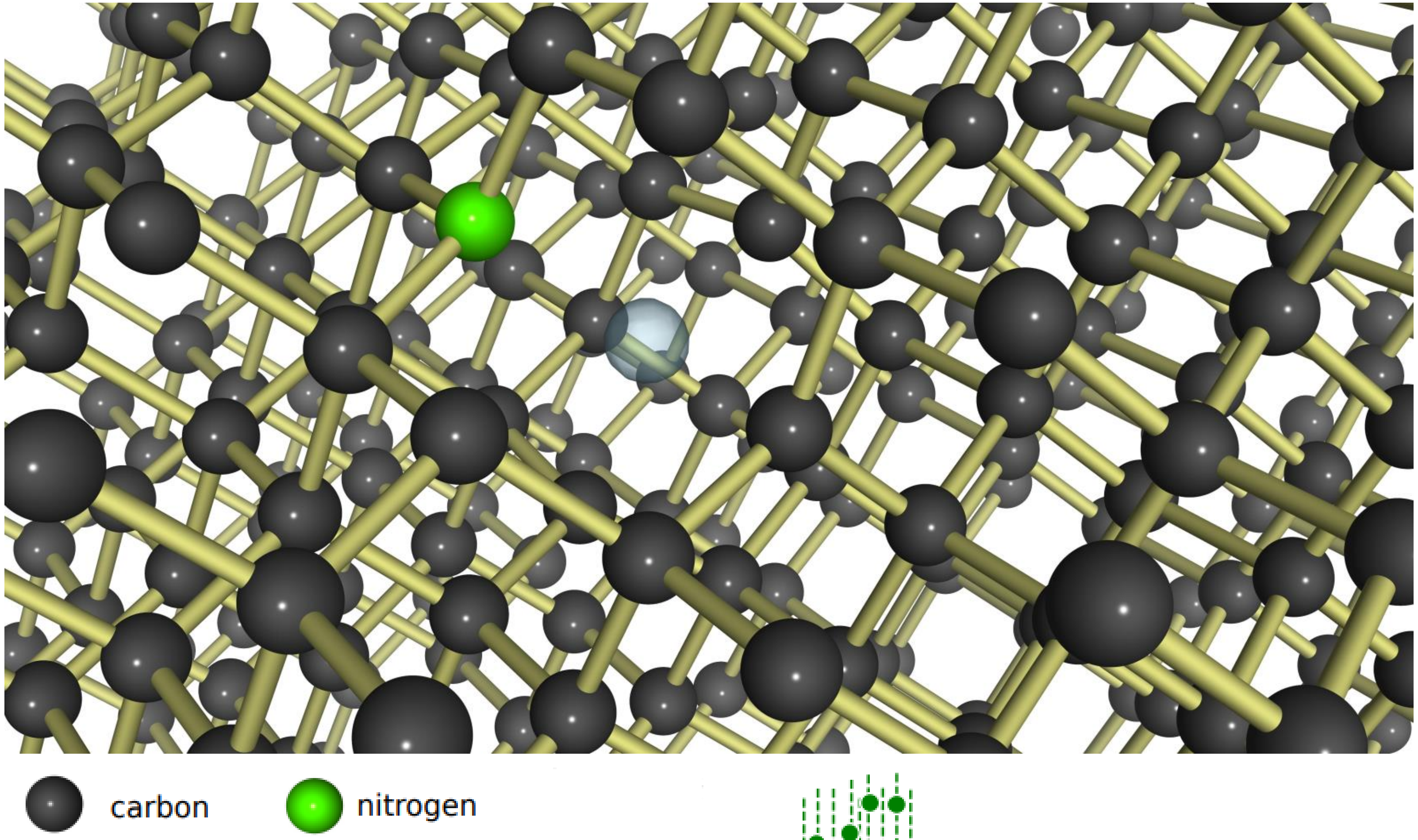
Sample Temperature
80 – 600 K

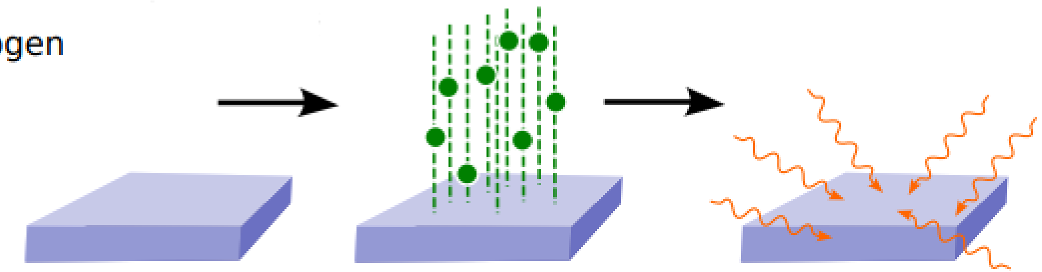
***In Situ* Light illumination**
200 – 2000 nm

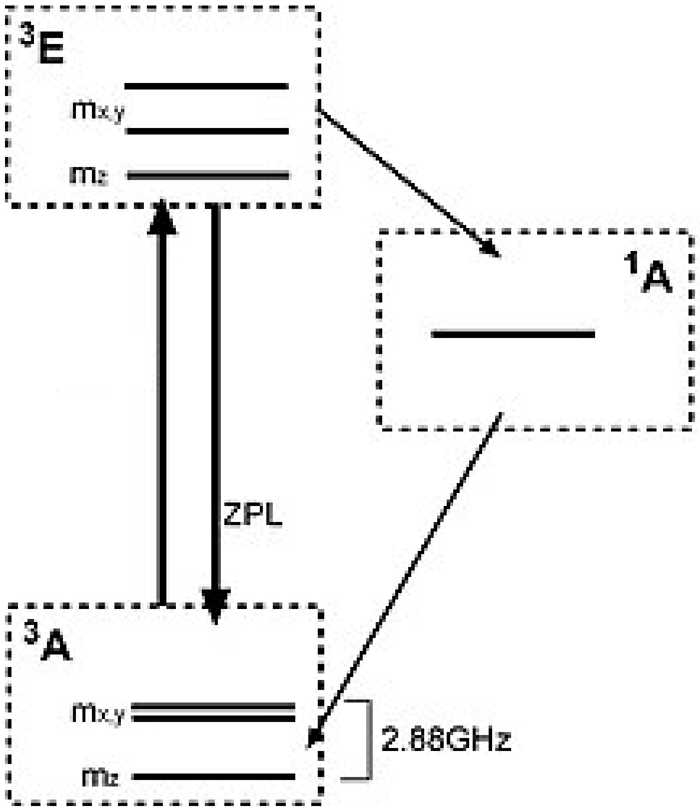




NV Centers in Diamond

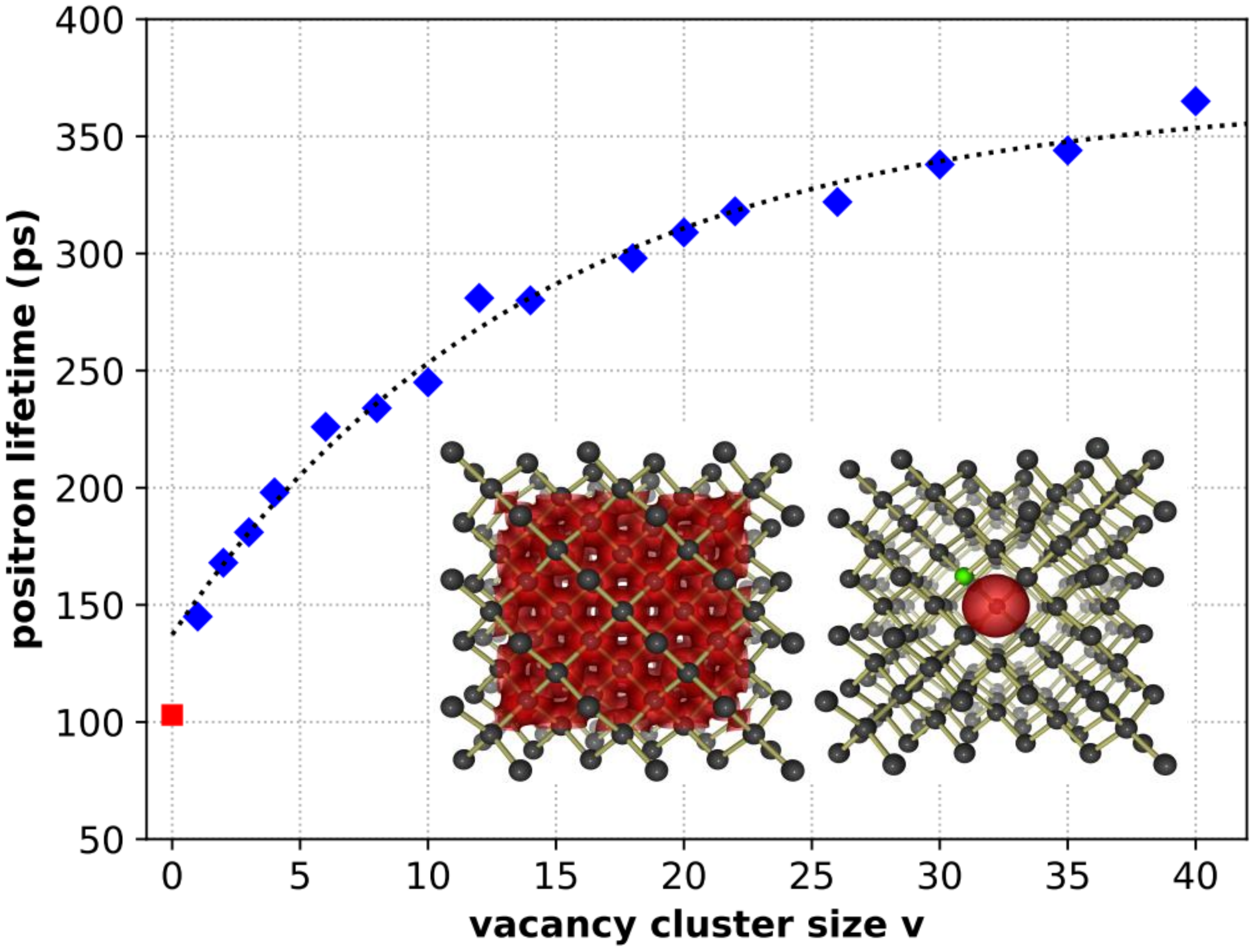


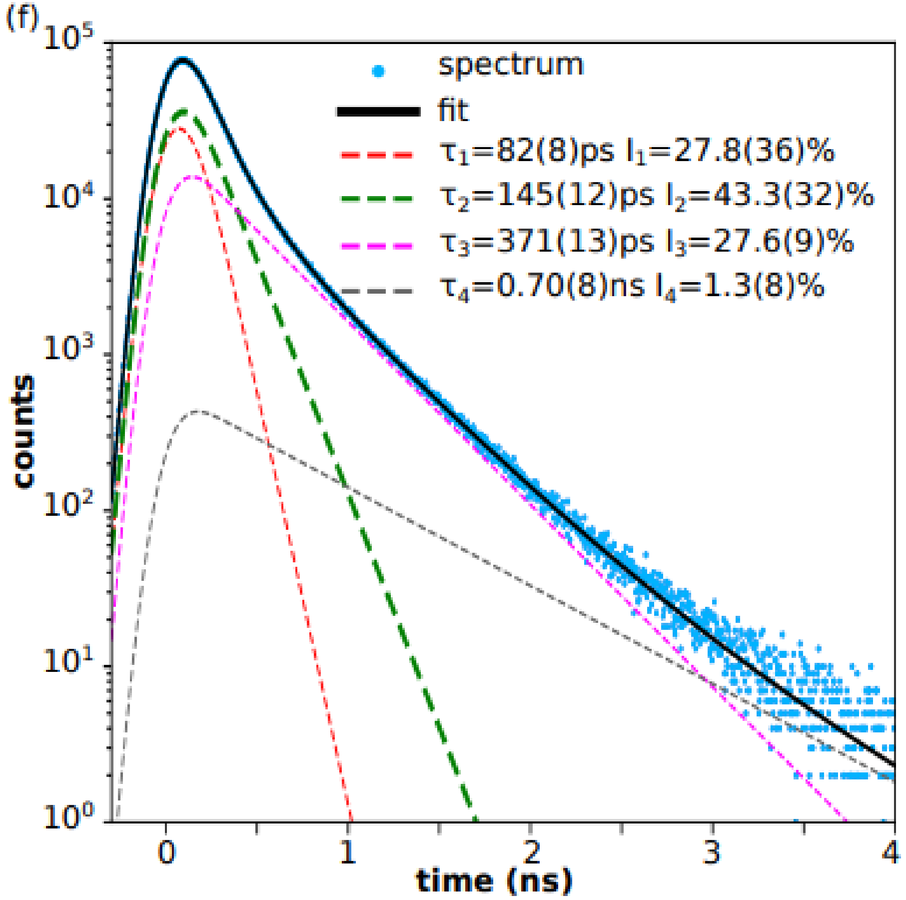




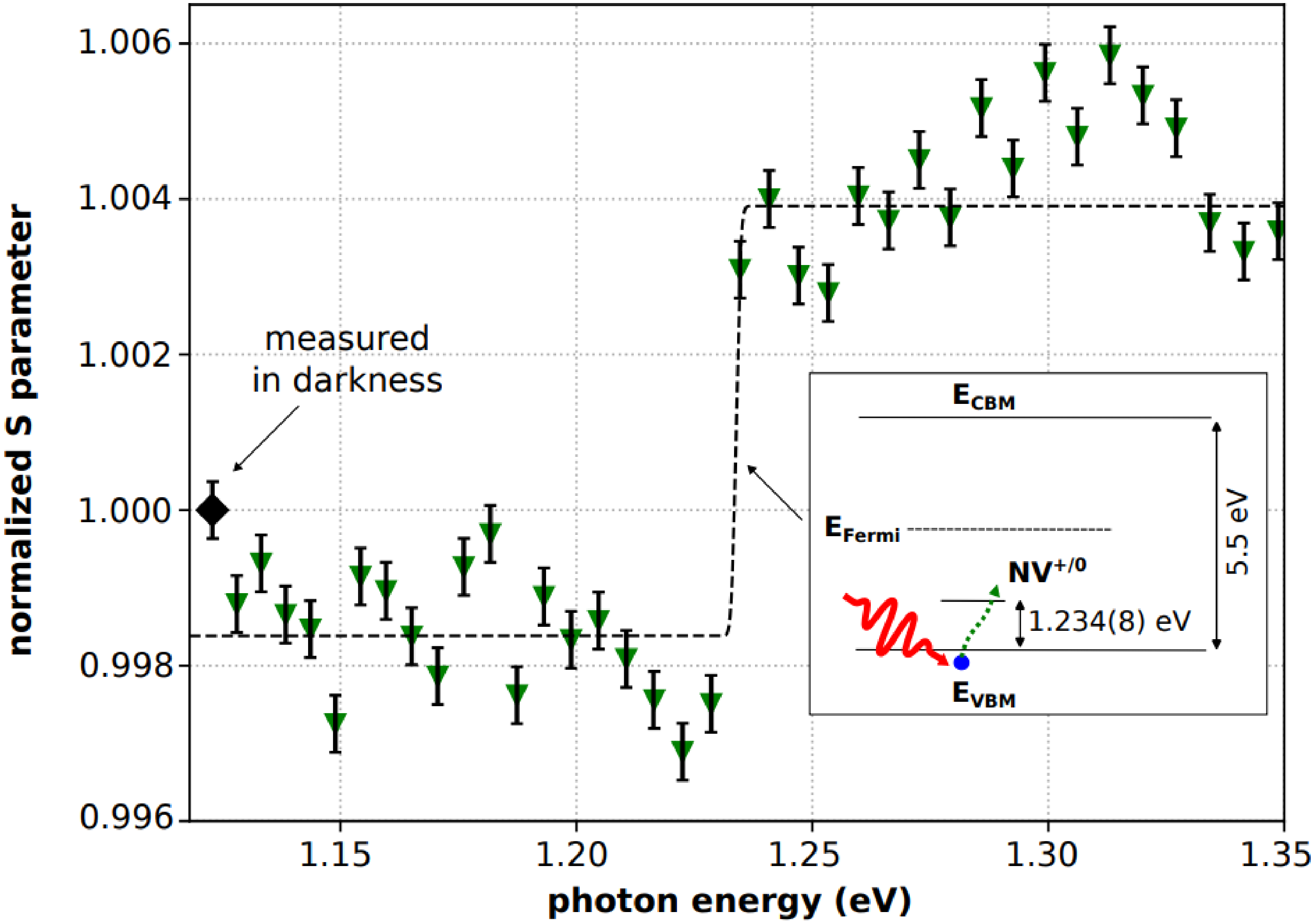
Possible charge states:
NV^0, NV^- and NV^+

Defects in Diamond revealed by PALS





S-parameter with *in situ* light illumination



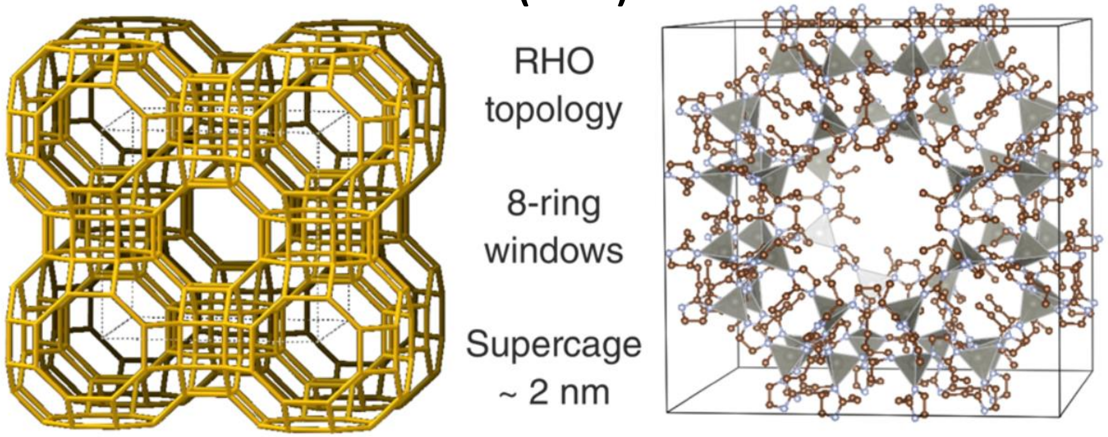
Measurement parameters

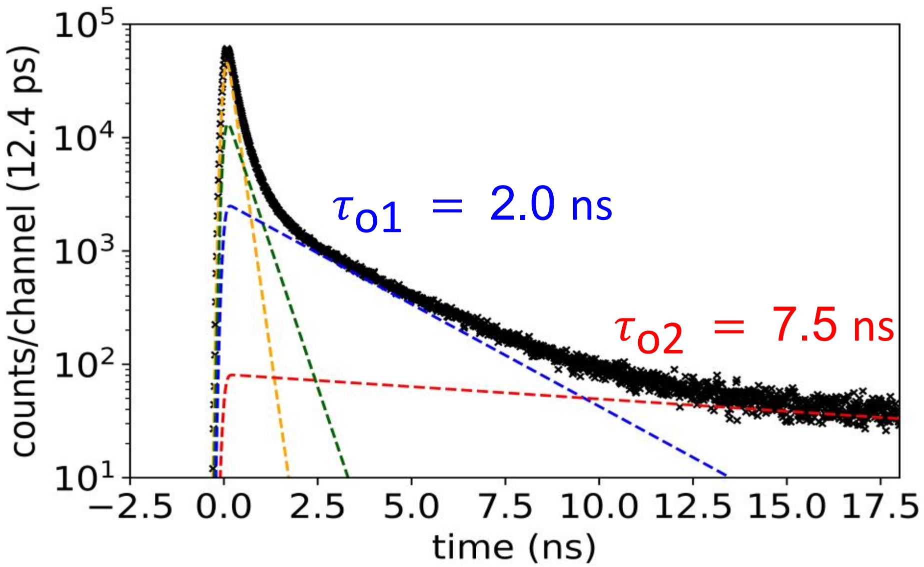
- Mono-chromatic light Δλ = 6 nm
- Room temperature
- Stored for > 10 h in complete darkness

- First proof of evidence for NV^+ centers next to NV^0 and NV^-
- Paper currently under review

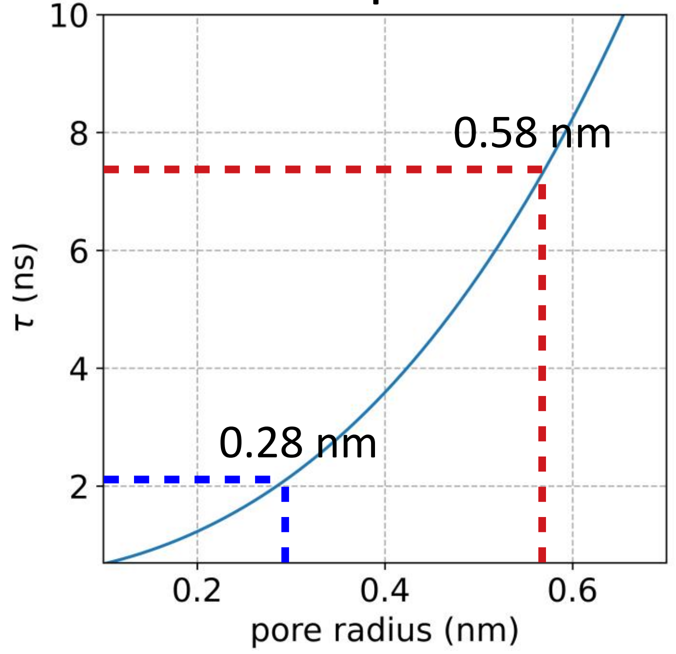
Porosimetry of Polymers

T. Stassin et al. *Advanced Materials* **2009662: (2021)**

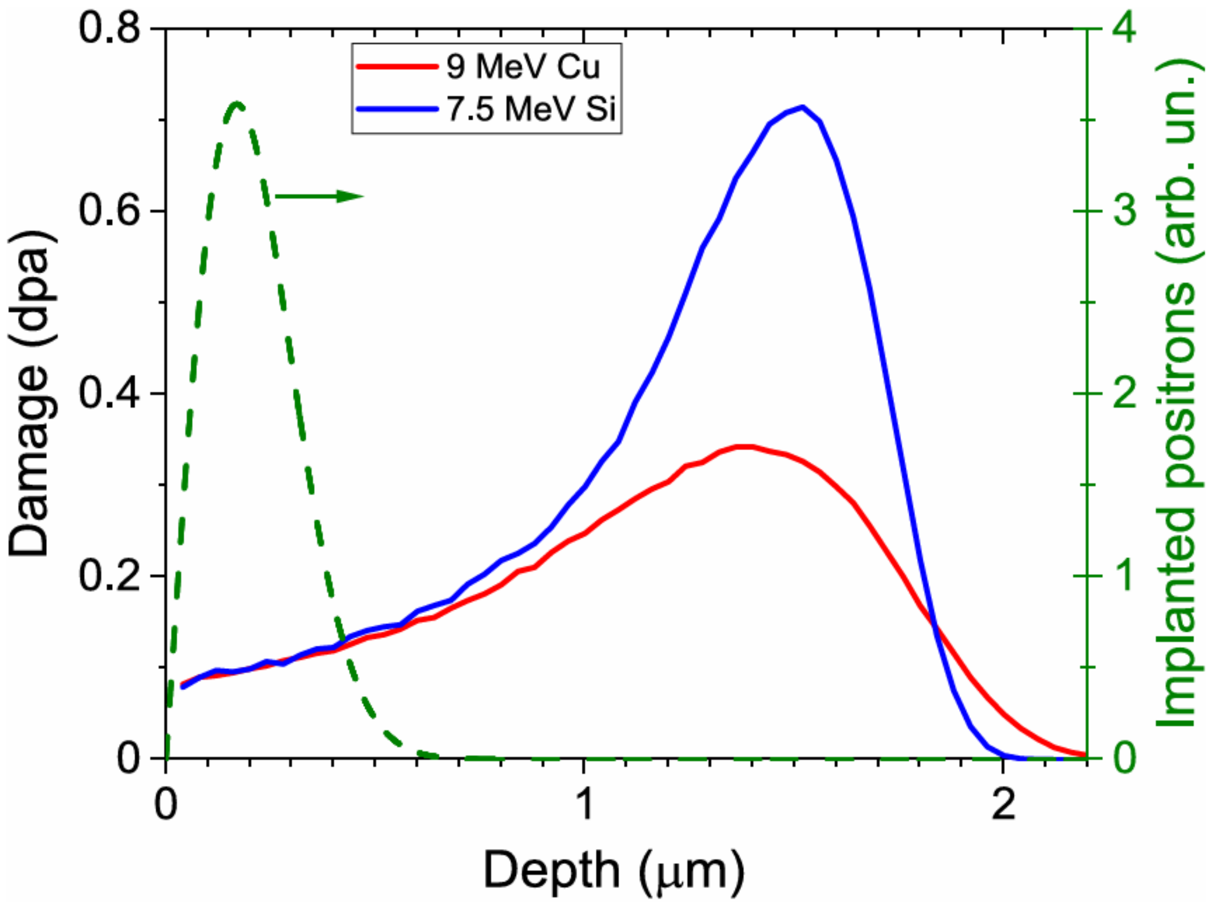




Tao-Eldrup Model:



Damage caused by heavy Ions

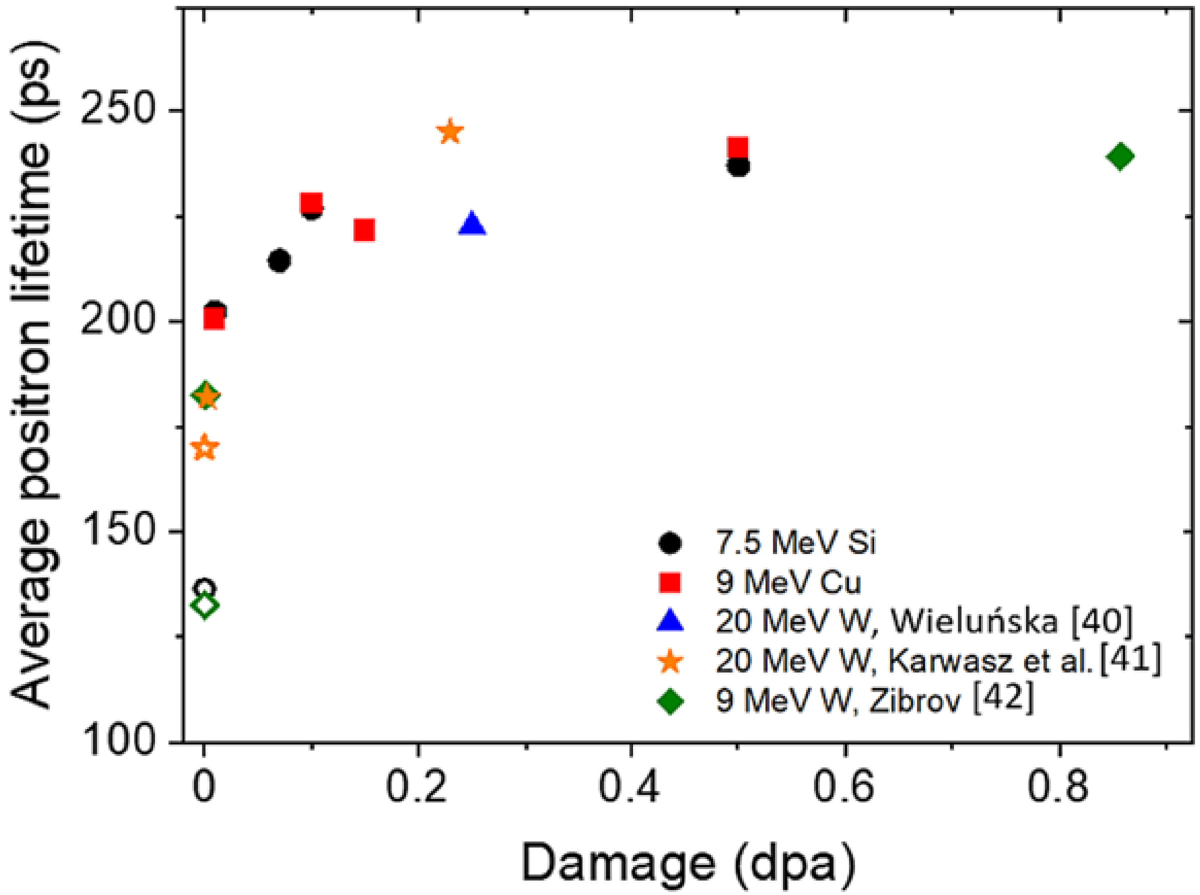


Experimental Goals:

- Irradiation-induced vacancy formation in tungsten
- Imitation of neutron-induced damage by heavy ions
- Comparison between Cu and Si ions
- Comparison between different damage levels (dpa)

B. Wieluńska-Kuś, M. Dickmann, W. Egger, M. Zibrov, L. Ciupinski, "Positron lifetime study of ion-irradiated tungsten: Ion type and dose effects." Nuclear Materials and Energy 38 (2024): 101610.

Comparison with previous results



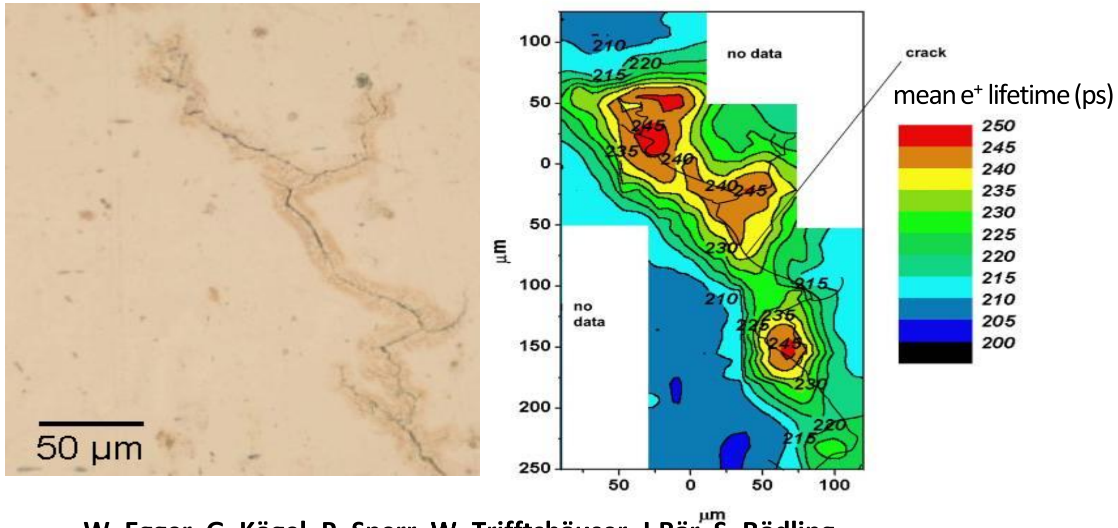
- The average positron lifetime increases non-linearly with damage level, showing a rapid increase at lower damage levels with saturation above 0.1 dpa.
- Both Si and Cu irradiation produced similar vacancy-type defect structures, with predominantly single vacancies at low damage levels and a growing presence of small vacancy clusters at higher levels.
- The results support previous studies and molecular dynamics simulations, suggesting that the defect concentration tends to stabilize at higher damage levels.

B. Wieluńska-Kuś, M. Dickmann, W. Egger, M. Zibrov, L. Ciupinski, "Positron lifetime study of ion-irradiated tungsten: Ion type and dose effects." Nuclear Materials and Energy 38 (2024): 101610.

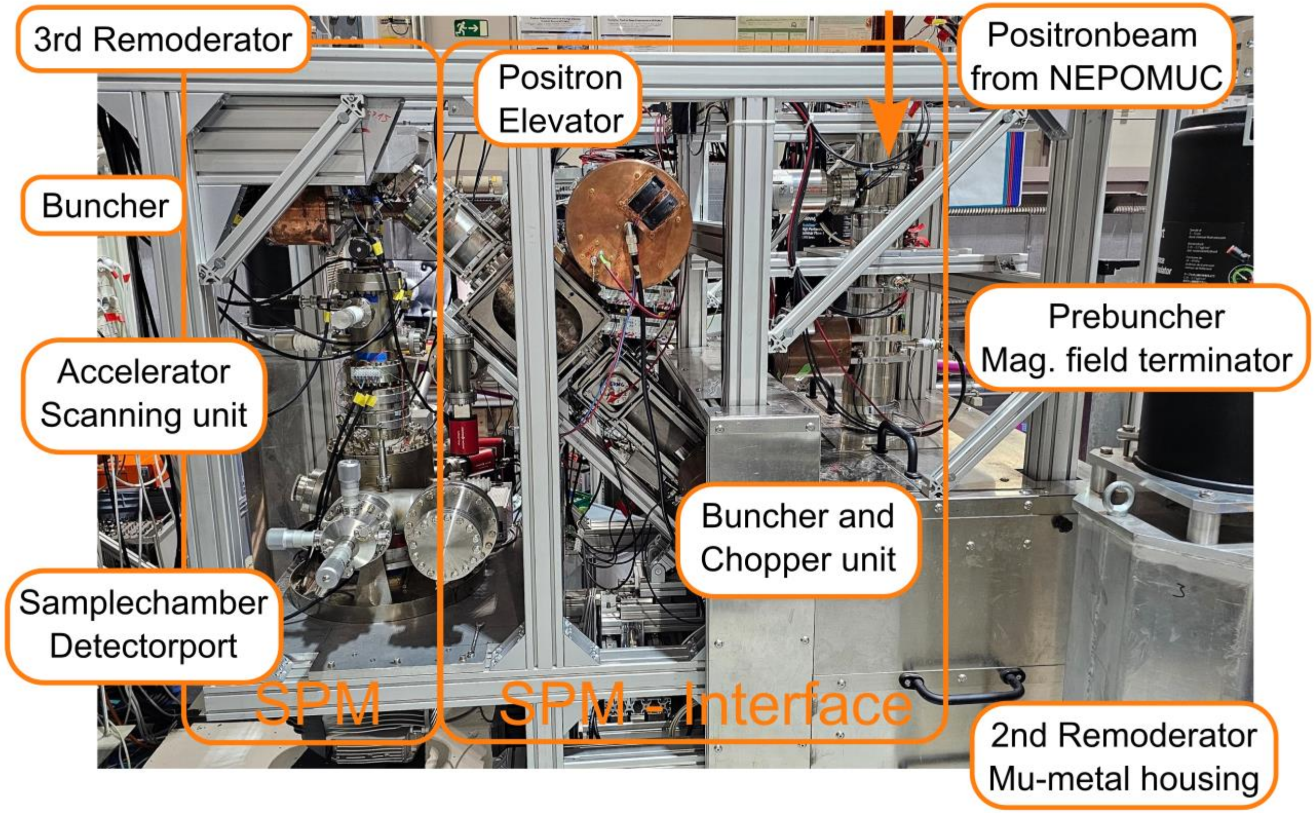
The Scanning Positron Microscope (SPM)

Beam Ø ≈ 1 mm

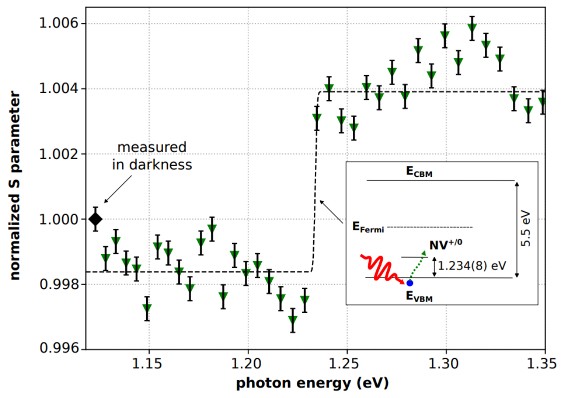
Beam Ø ≈ 1 µm

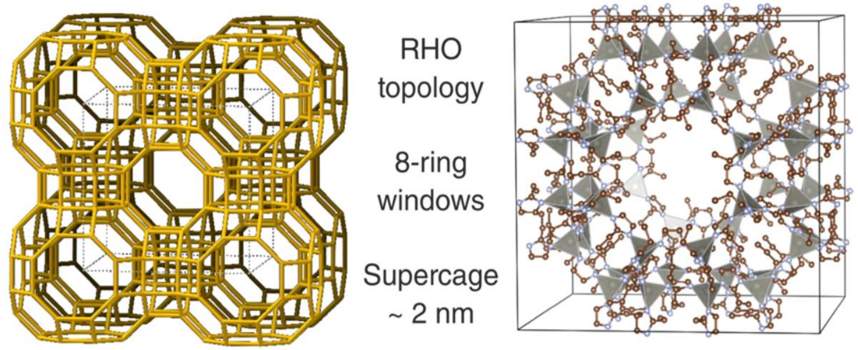


W. Egger, G. Kögel, P. Sperr, W. Trifftshäuser, J.Bär, S. Rödling, H.-J. Gudladt *Applied Surface Science* 194 (1): 214 - 217 (2002)



SUMMARY





- Positrons are ideal probes for open-volume defects
- Positron annihilation spectroscopy gives information on defect types and their concentration
- Wide range of applications in material sciences (e.g. semiconductors, metals, polymers, quantum materials, …)