Positron Studies of Defects in irradiated and ion- implanted n-type SiC

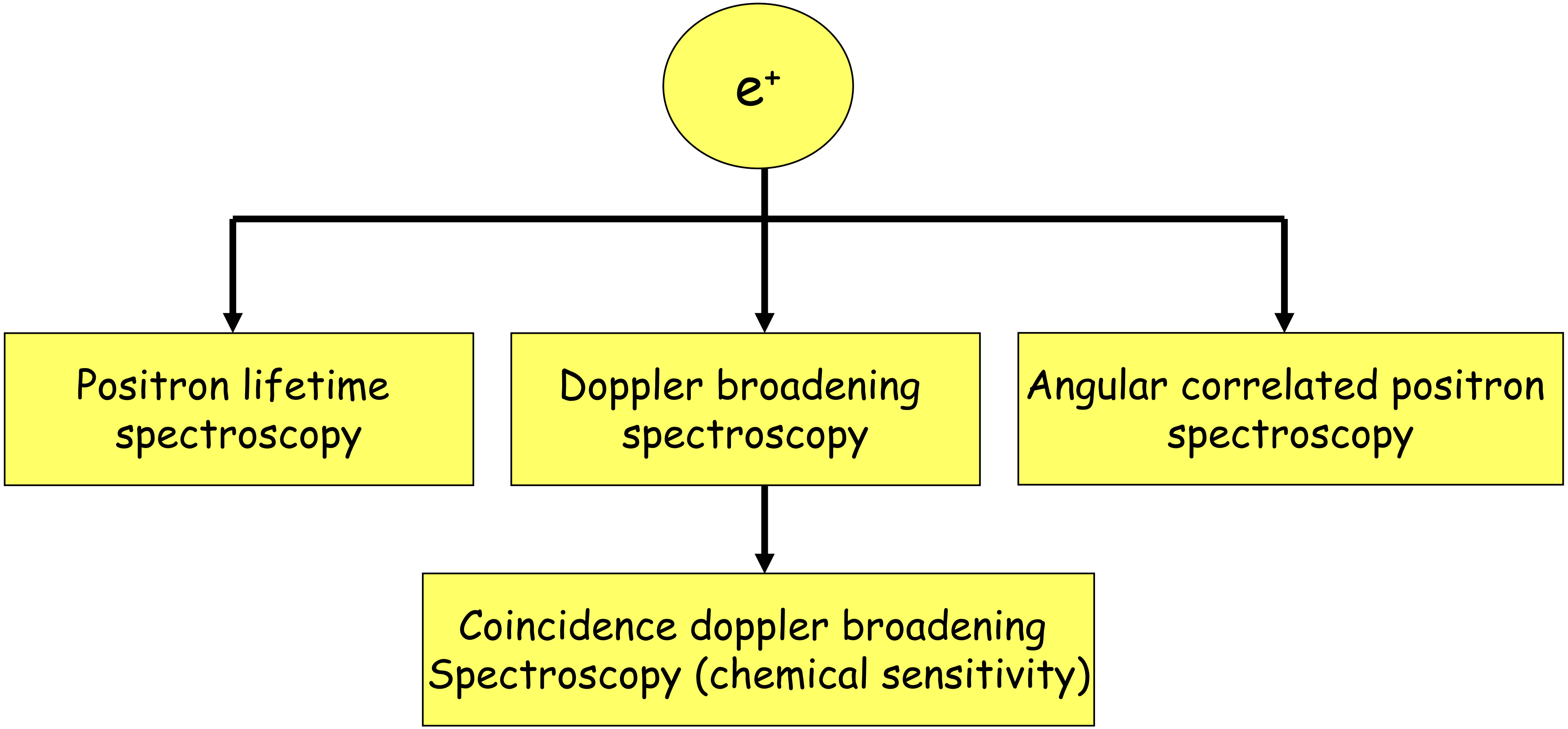
Martin-Luther-Universität Halle-Wittenberg

F. Redmann, A. Kawasuso, R. Krause-Rehberg

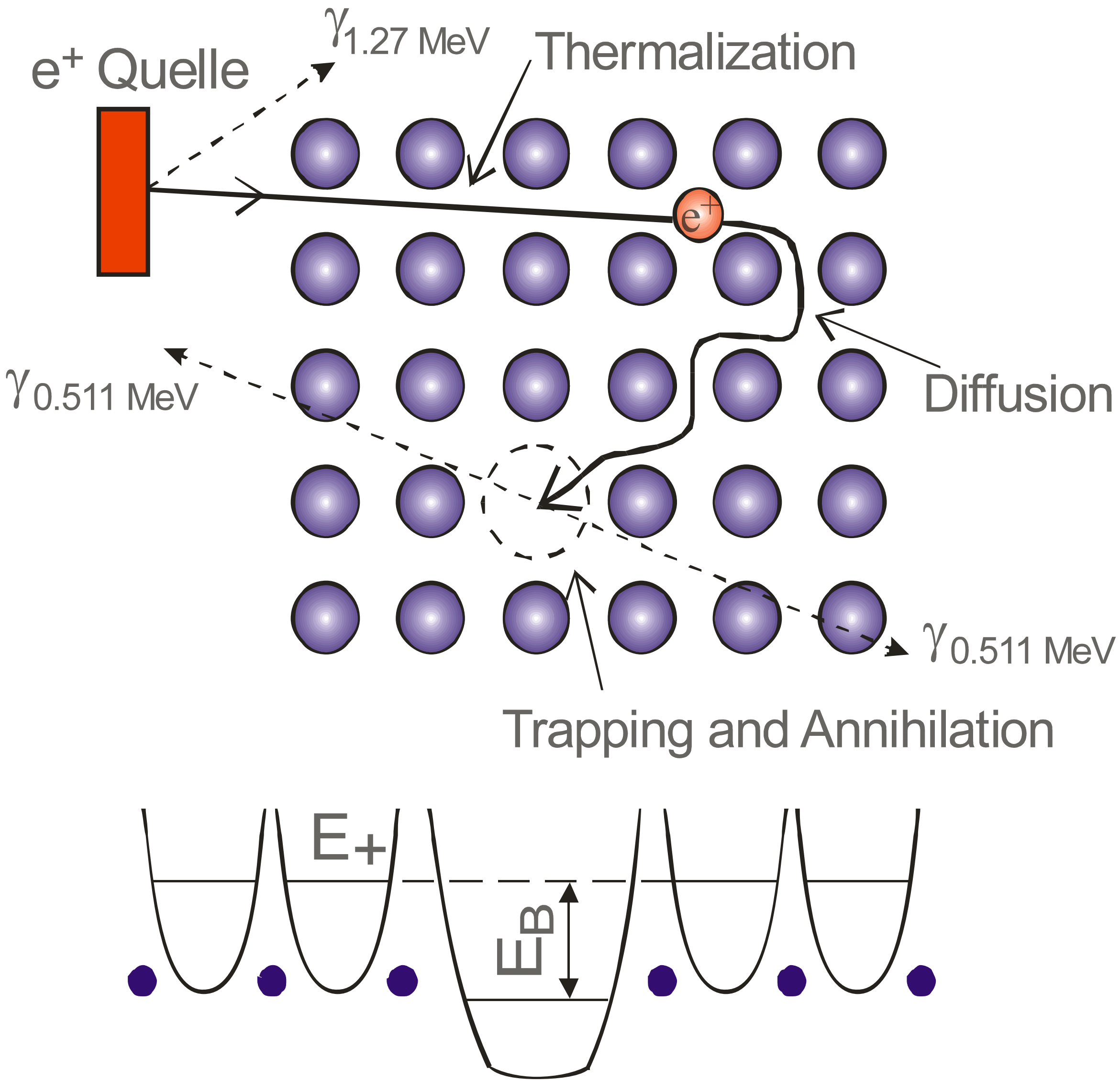
Universität Halle, FB Physik

- The method – some basics
- Combination of positron annihilation and DLTS
- Results about bulk and epilayer SiC measurements
- Future plan

The positron annihilation spectroscopy

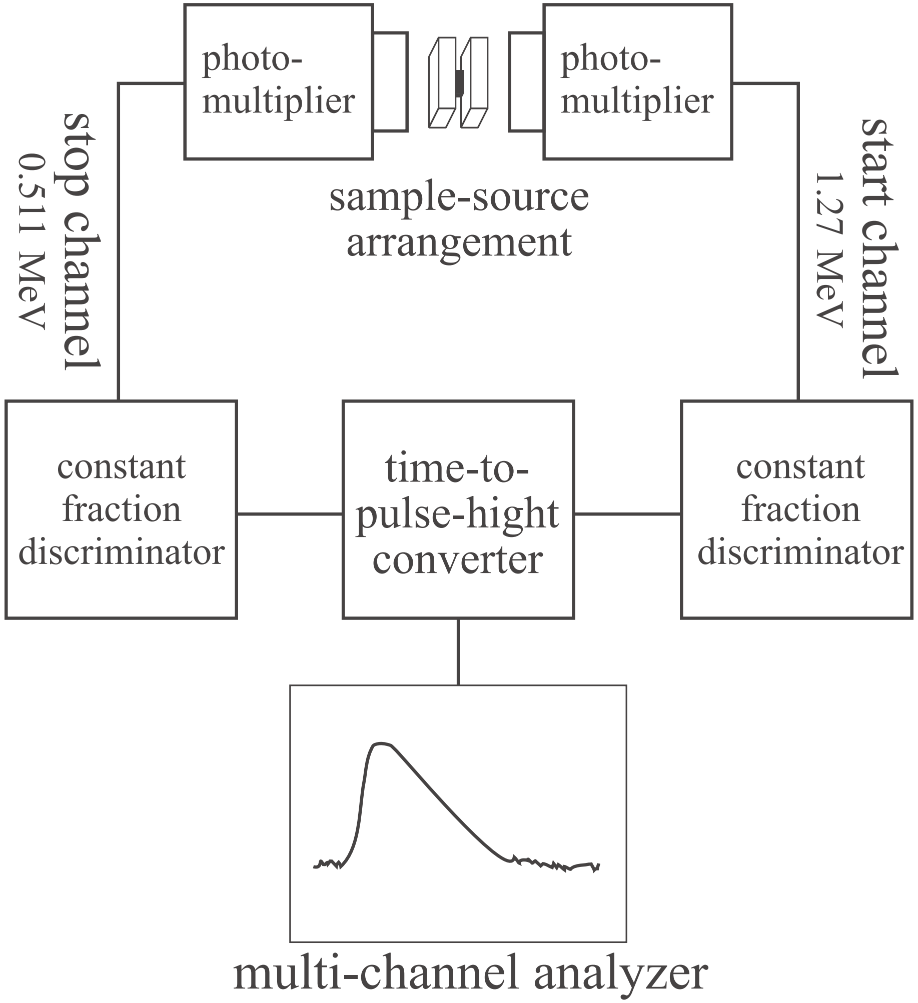


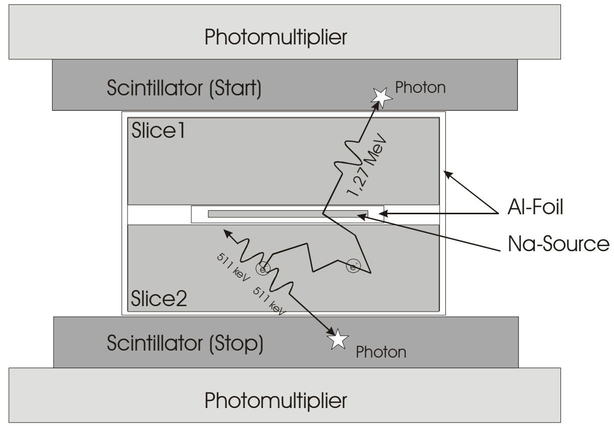
The positron lifetime spectroscopy

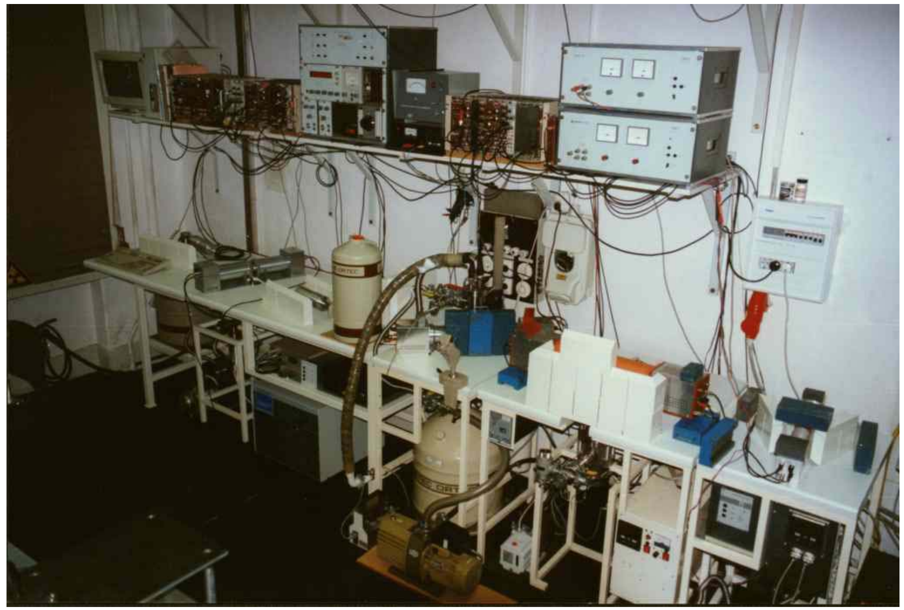


- positron wave-function can be localized in the attractive potential of a defect
- annihilation parameters change in the localized state
- e.g. positron lifetime increases in a vacancy
- lifetime is measured as time difference between 1.27 and 0.51 MeV quanta
- defect identification and quantification possible

Positron lifetime measurements

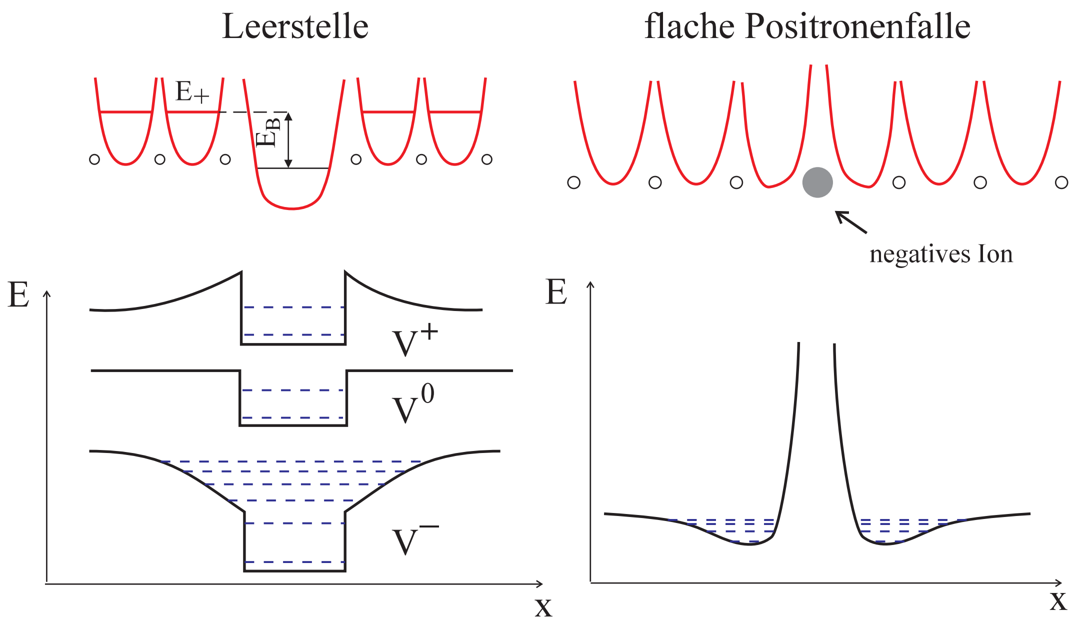


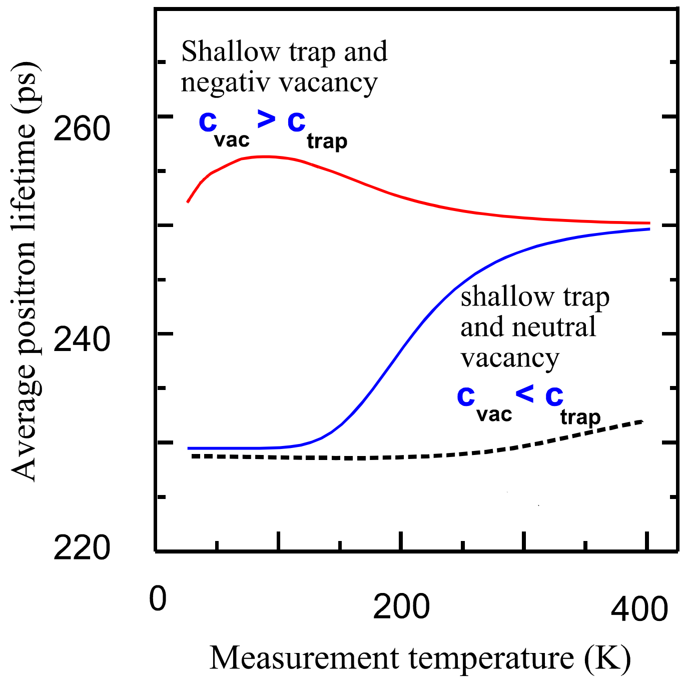




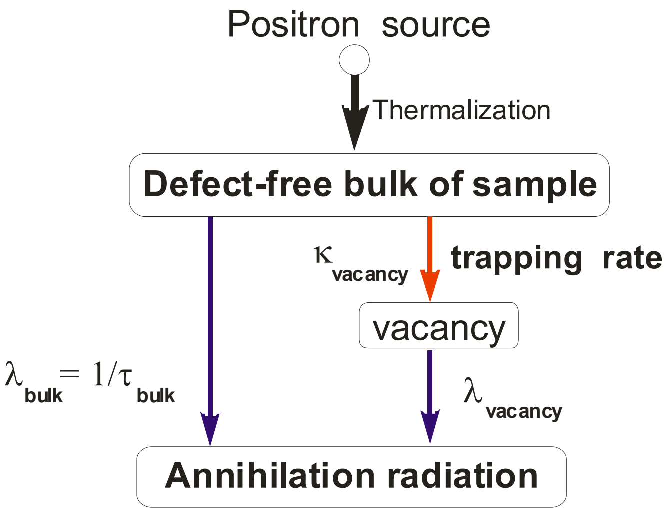
Trapping-centers

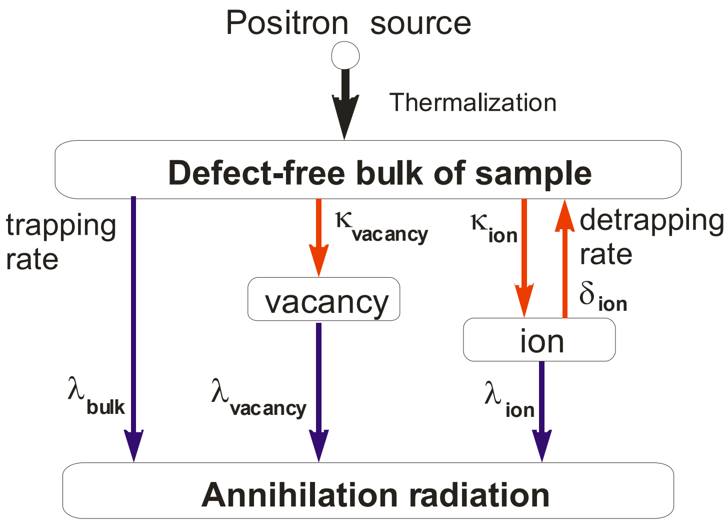
- Several trapping centers exist
- Shallow traps visible in combination with vacancies in low temperature region
- Charge state defines the trapping rate





Trapping model





$$\frac{dn_{bulk}(t)}{dt} = -\lambda_{bulk} \cdot n_{bulk} - \kappa_v \cdot n_{bulk}$$

$$\frac{dn_v(t)}{dt} = \kappa_v \cdot n_{bulk} - \lambda_v \cdot n_v$$

$$N(t) = \sum_i \frac{I_i}{\tau_i} \exp\left(-\frac{t}{\tau_i}\right)$$

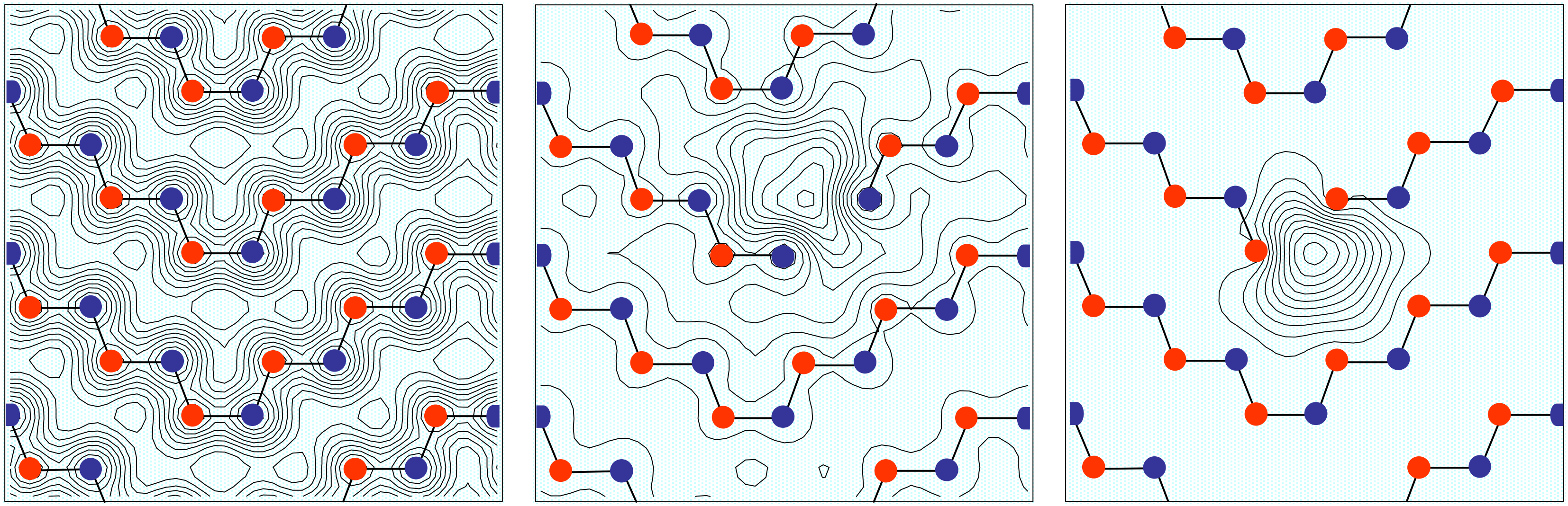
$$\tau_1 = \frac{1}{\lambda_{bulk} + \kappa_v} \qquad \tau_2 = \frac{1}{\lambda_v}$$

$$I_1 + I_2 = 1 \qquad I_2 = \frac{\kappa_v}{\lambda_{bulk} - \lambda_v + \kappa_v}$$

$$\kappa_v = \mu \cdot C = I_2 \left(\frac{1}{\tau_1} - \frac{1}{\tau_2}\right)$$

Electron density and annihilation probability

SiC 6H bulk	SiC 6H V_C	SiC 6H V_{Si}
143 ps	148 ps	187-215 ps

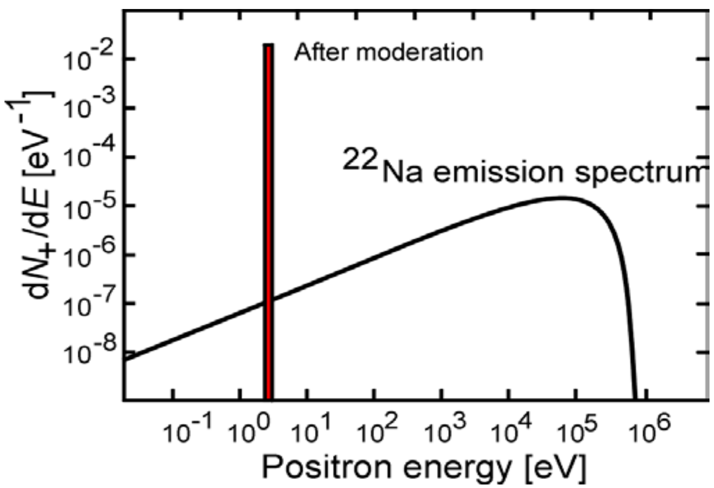


ATSUP calculation, after Puska

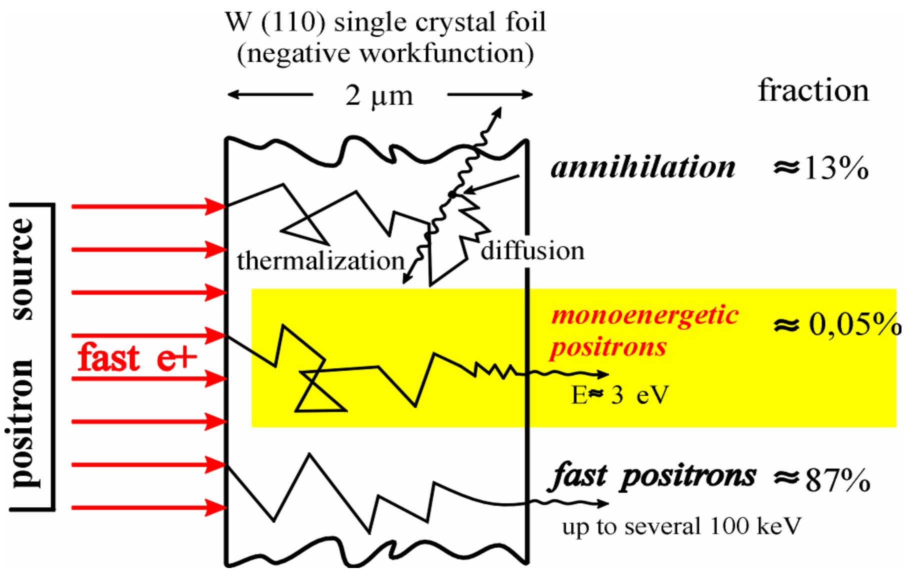
The slow positron beam

- semiconductor technology: thin layers (epitaxy, ion implantation)
- broad energy distribution due to β^+ decay
- some surfaces: negative workfunction $\Rightarrow$ moderation

Energy distribution after β^+ decay

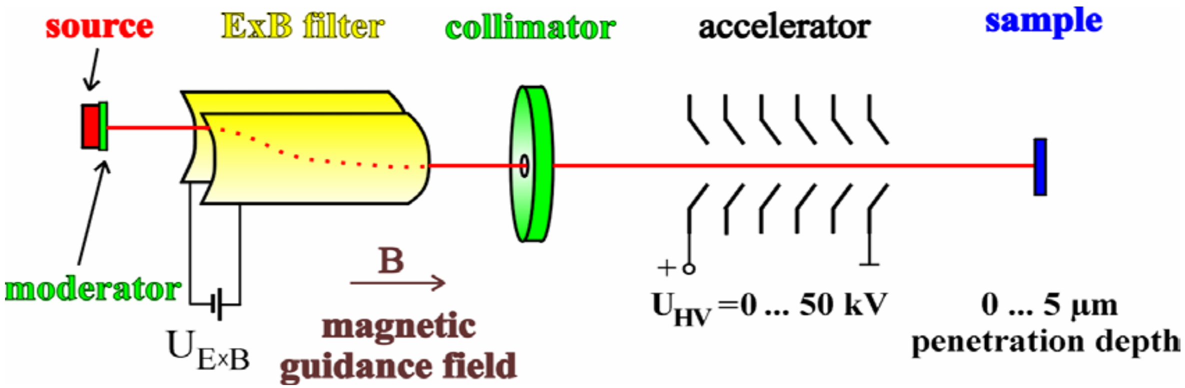


Effect of moderation



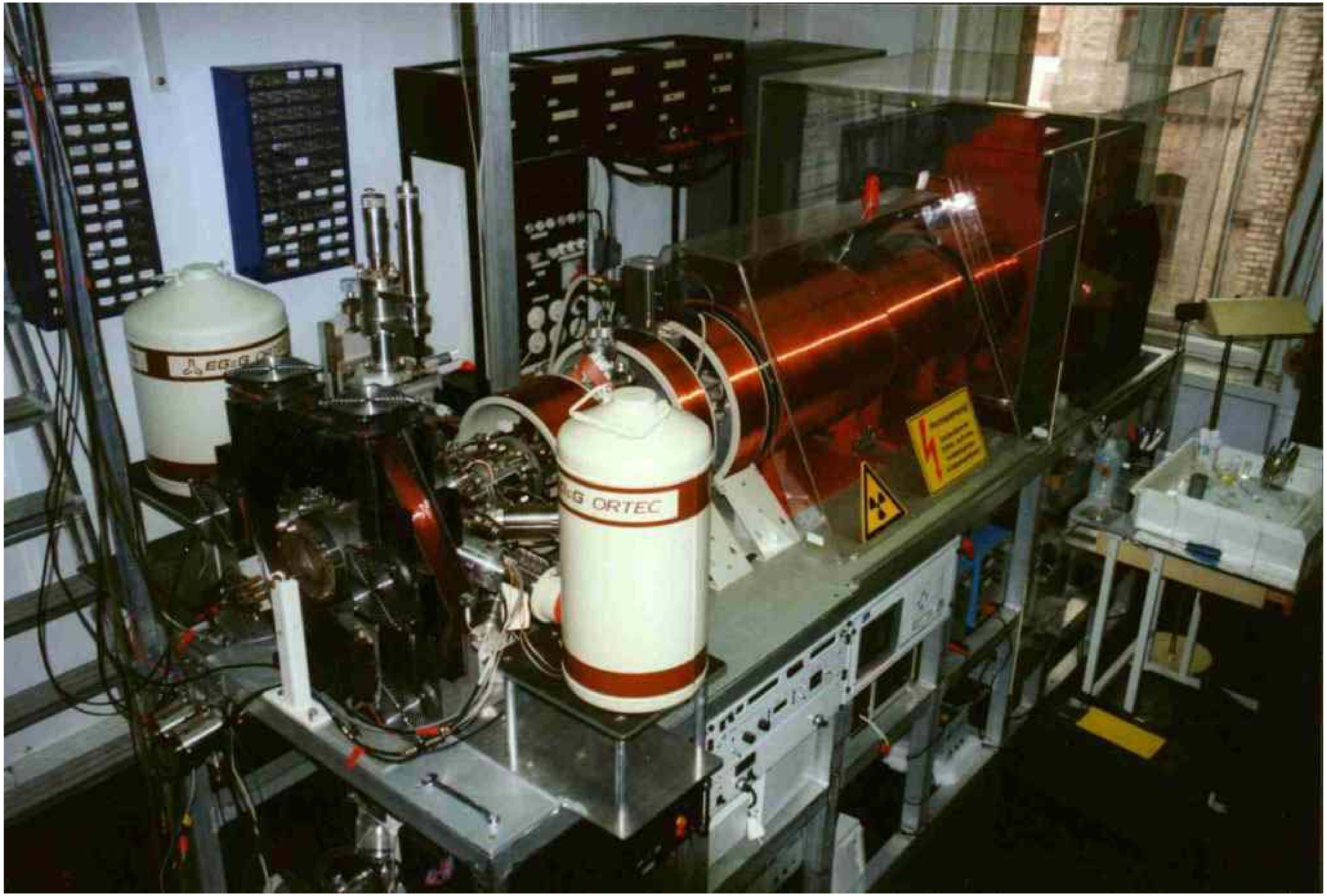
Conventional positron beam technique

- positron beam can be made from monoenergetic positrons
- often: magnetically guided for simplicity



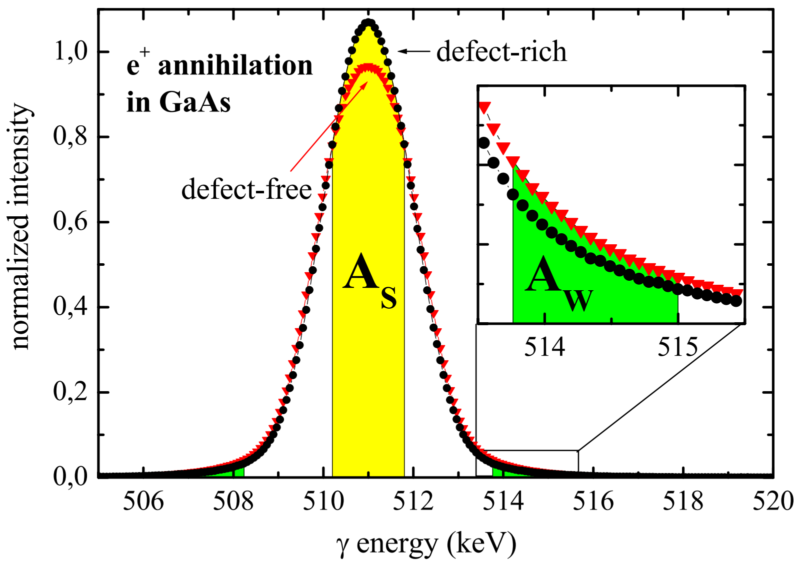
- disadvantage: no simple lifetime measurements
- defect studies by Doppler-broadening spectroscopy
- characterization of defects only by line-shape parameters or positron diffusion length

Positron-Beam in Halle

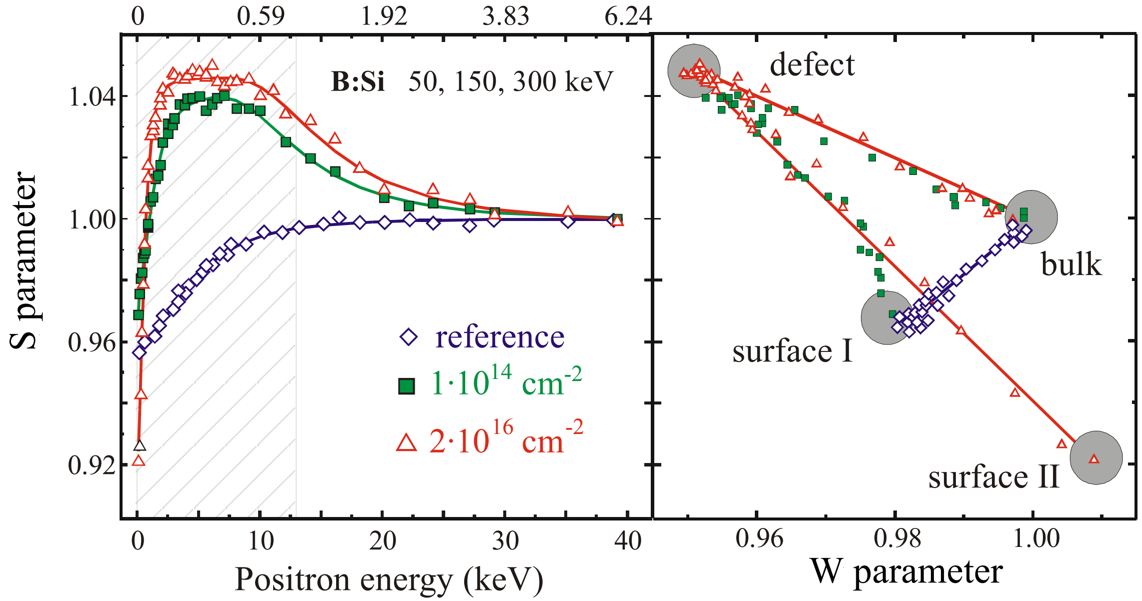


Information from Doppler-broadening spectroscopy

- S parameter does not contain all information
- W parameter determined by annihilation with core electrons ⇒ chemical sensitivity
- S-W-plot characterize different trapping centers
  L. Liszkay et al., Appl. Phys. Lett. **64** (1994) 1380



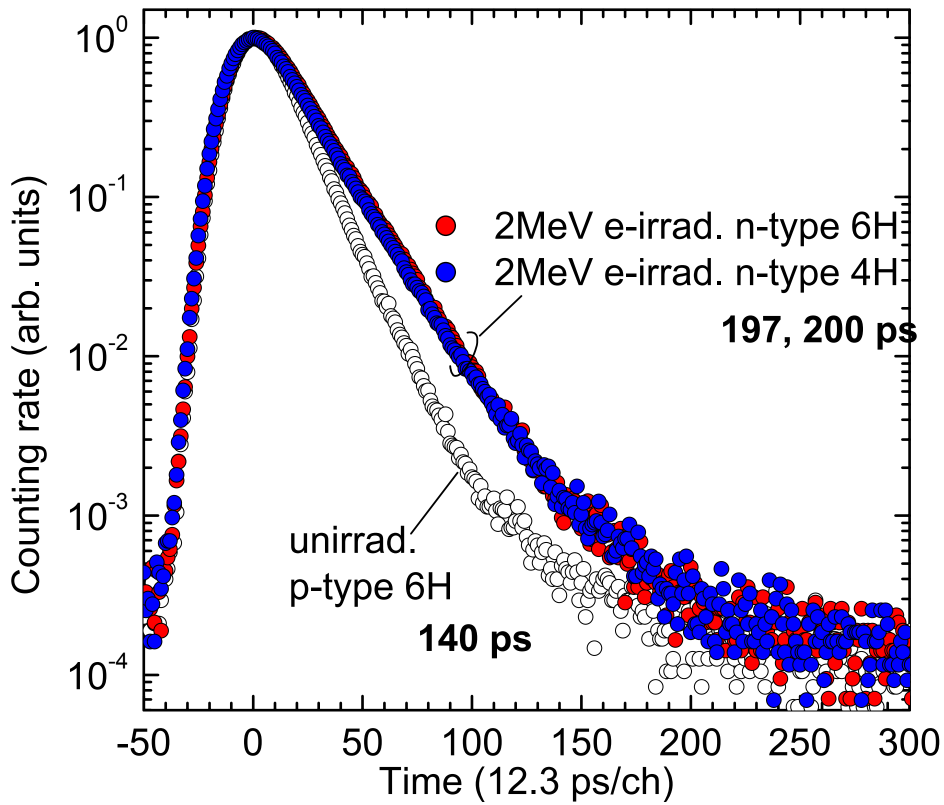
Ion implantation in Si



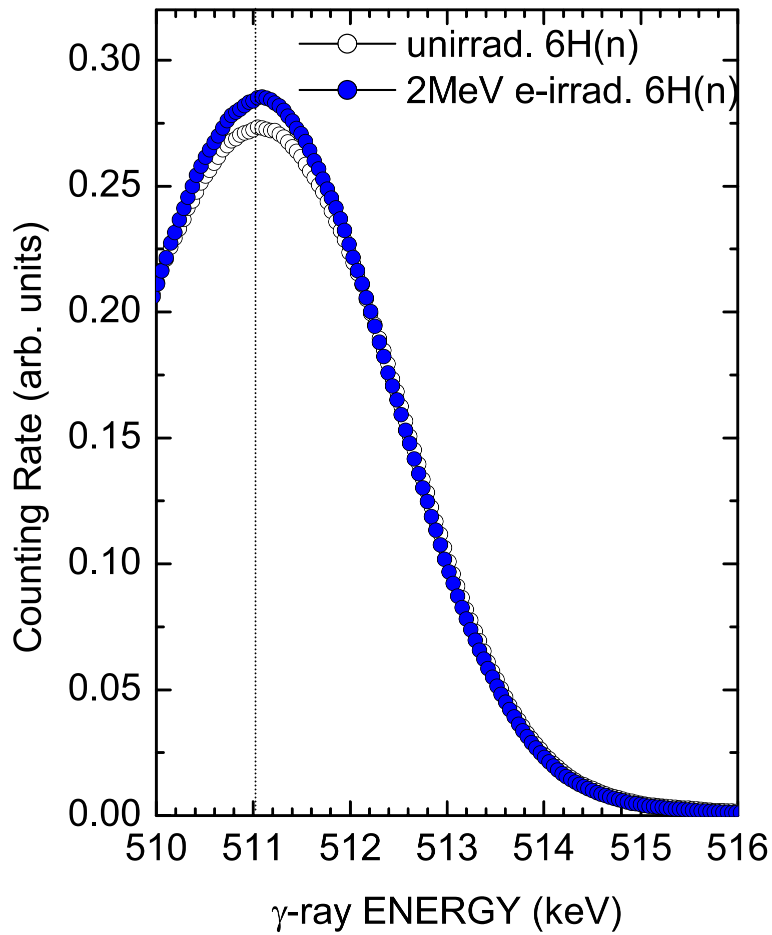
S. Eichler, PhD Thesis, 1997

Electron-irradiated 6H and 4H SiC

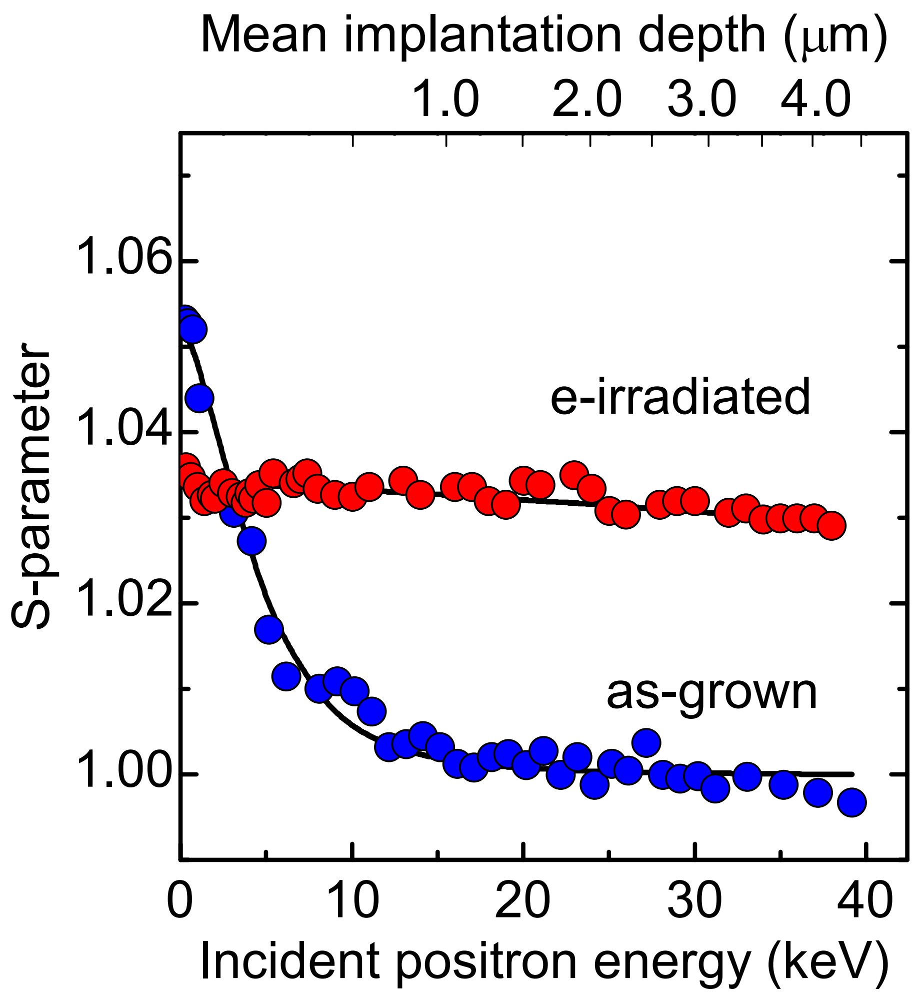
Positron lifetime spectrum



Doppler broadening Spectrum

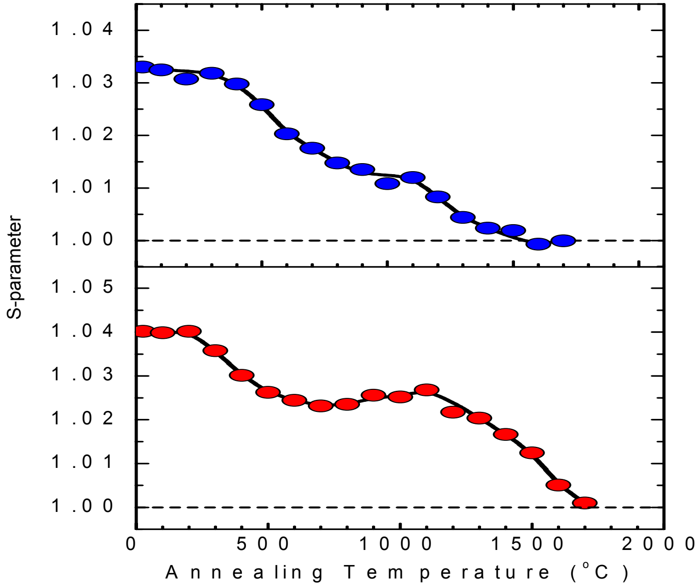


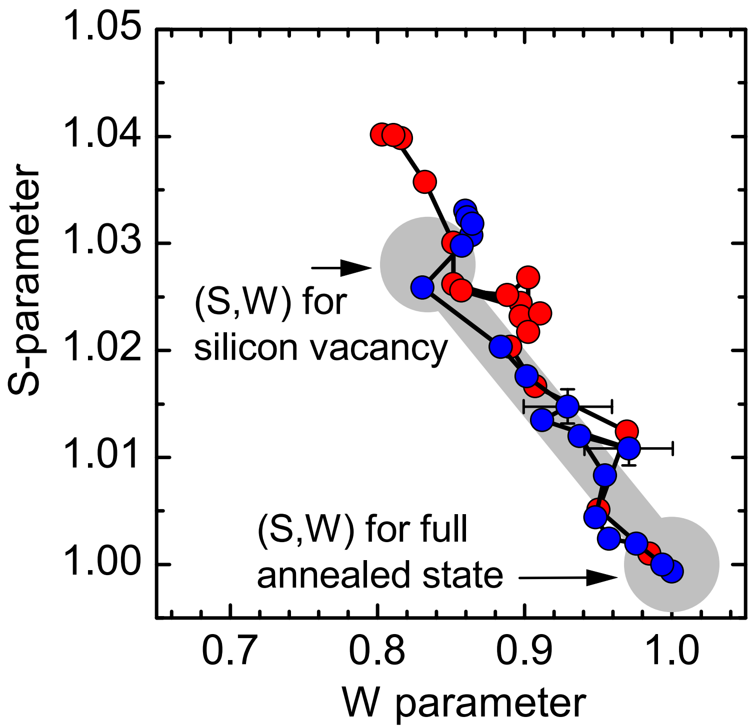
Vacancy depth profile- electron irradiation



- Nearly homogenious damage and increasing of the S-parameter in the complete layer

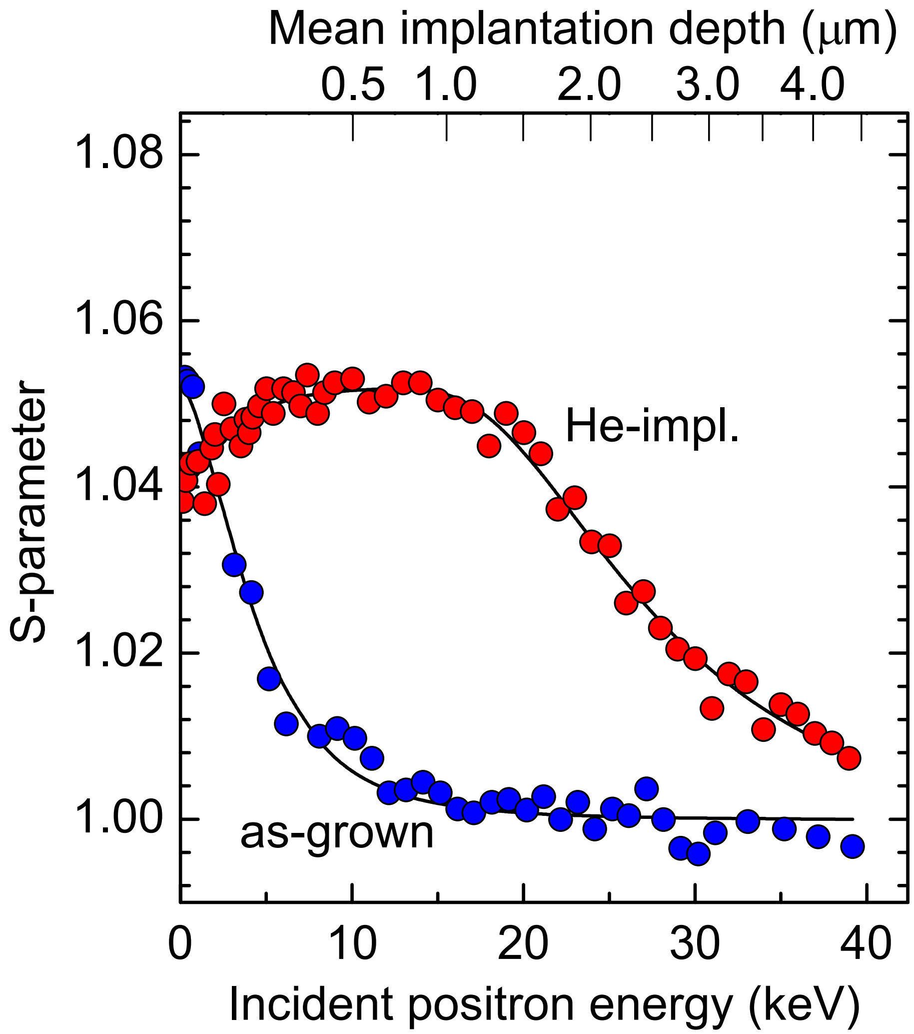
Annealing behavior of 4H/6H SiC

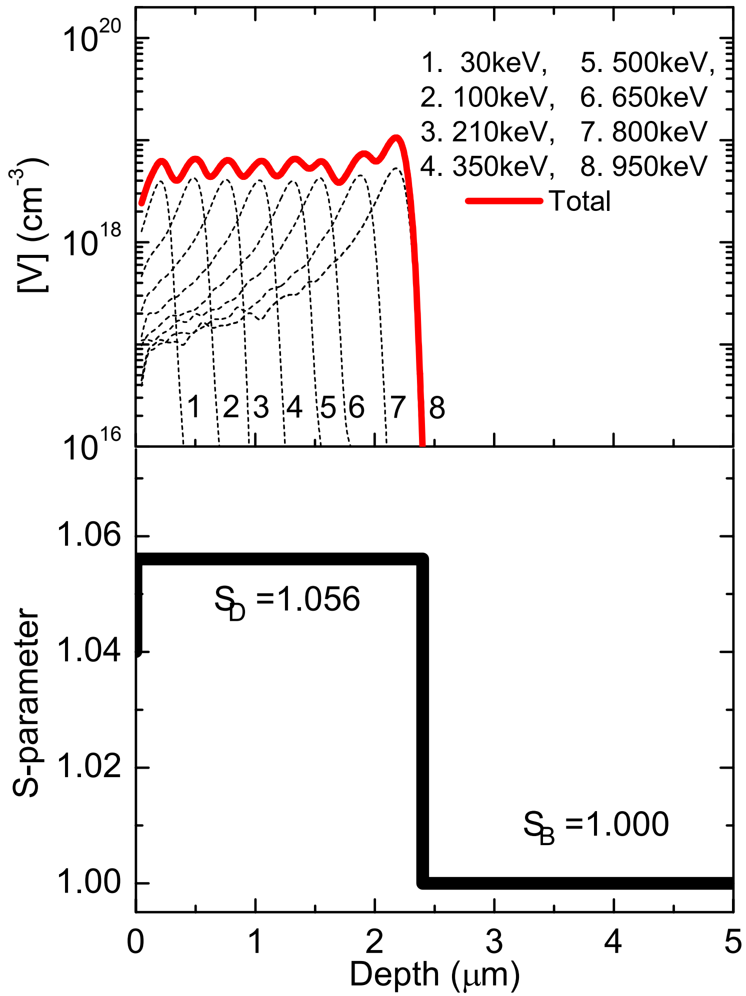




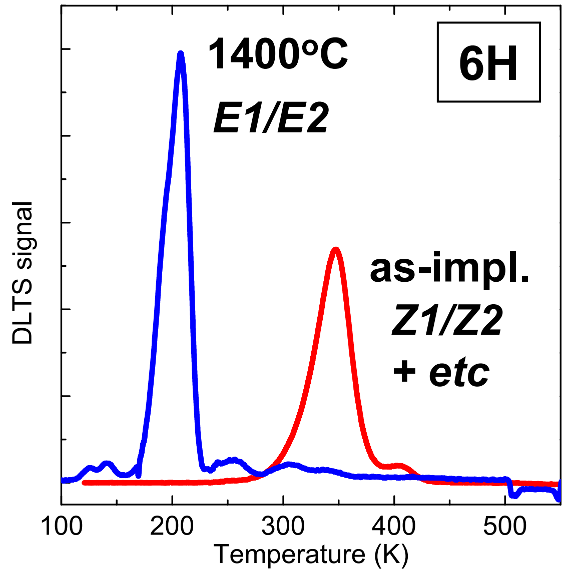
- Similar annealing behavior of the **Silicon Vacancy** IN 3C SiC electron spin resonance (ESR)
- Formation of vacancy-type complex in the temperature region of 1000°C involved with a Si-vacancy

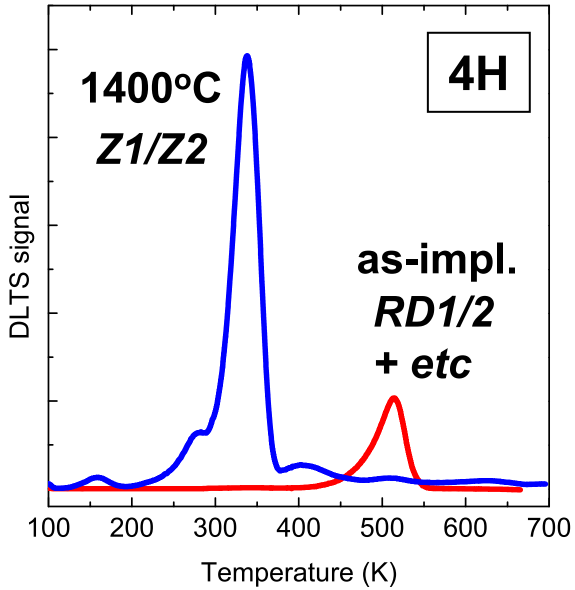
He-implantation

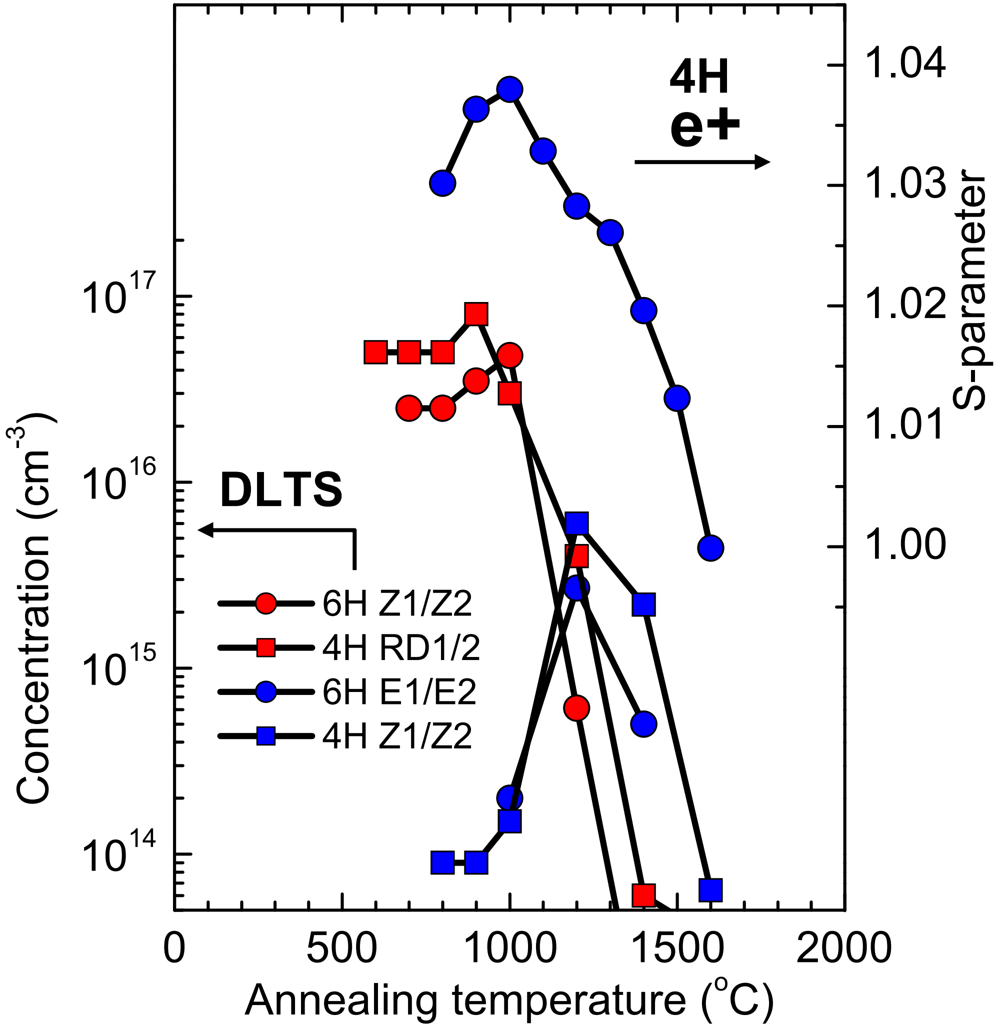




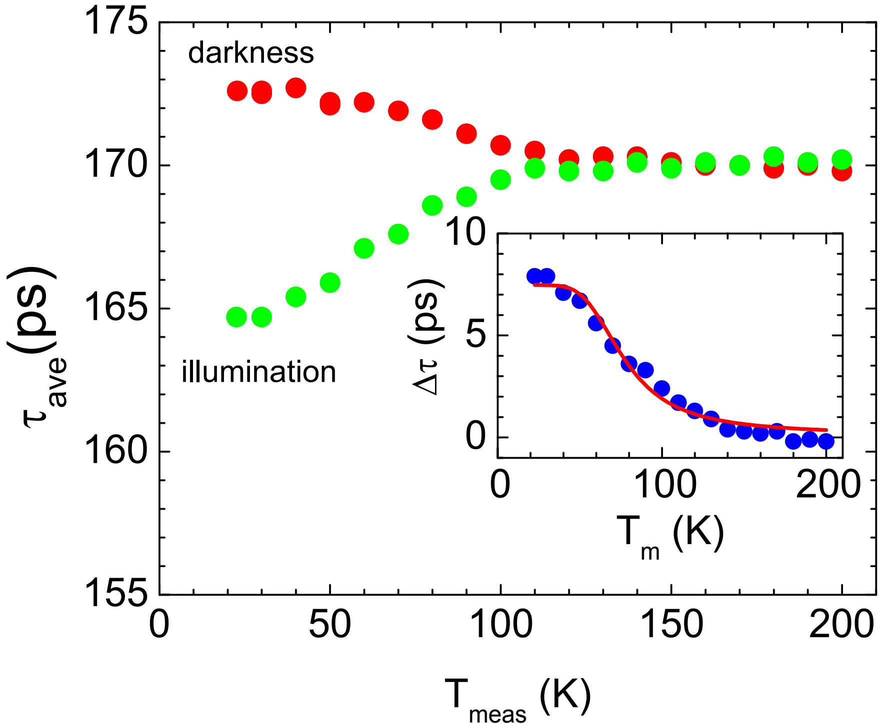
PAS and DLTS annealing behavior







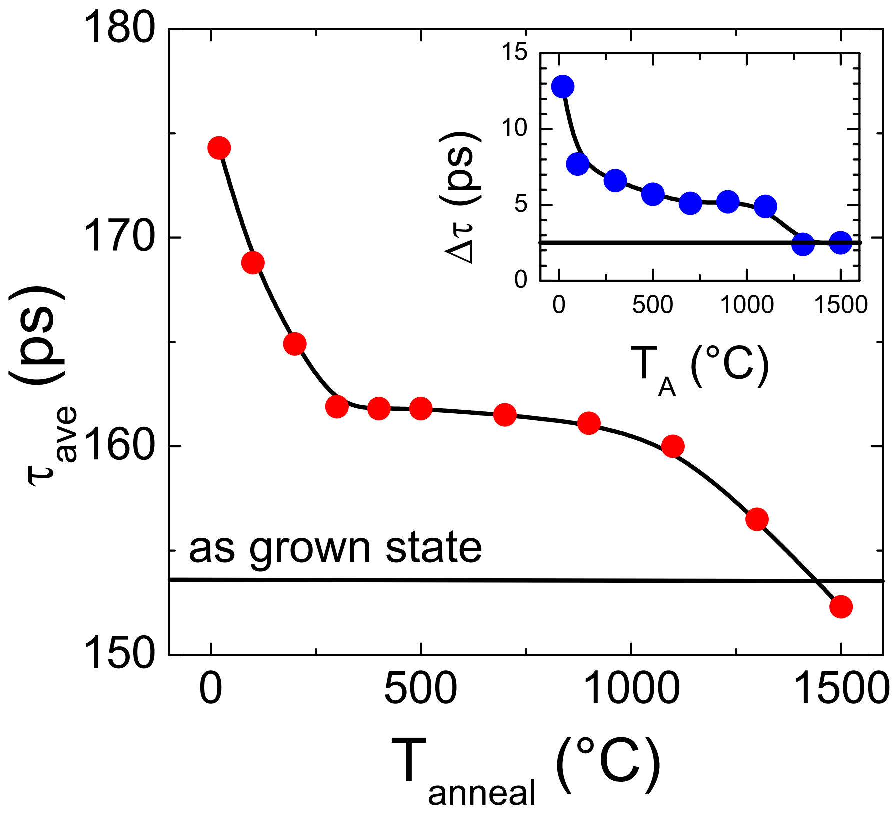
Electron irradiated 6H SiC bulk material



- After illumination with white light a decrease of the average positron lifetime appears below 110 K
- The spectra decomposition shows a defect-related lifetime of 185 ps (VSi) [Bra96] either in darkness or under illumination. The intensity decreases from 45% to 17% under illumination.
- The illumination effect appears also in as-grown material. The irradiation with 2 MeV was done to introduce additional Frenkel pairs.
- In the inset the difference of positron lifetime under illumination and darkness is presented. (the fitted Energy barrier: 32meV)

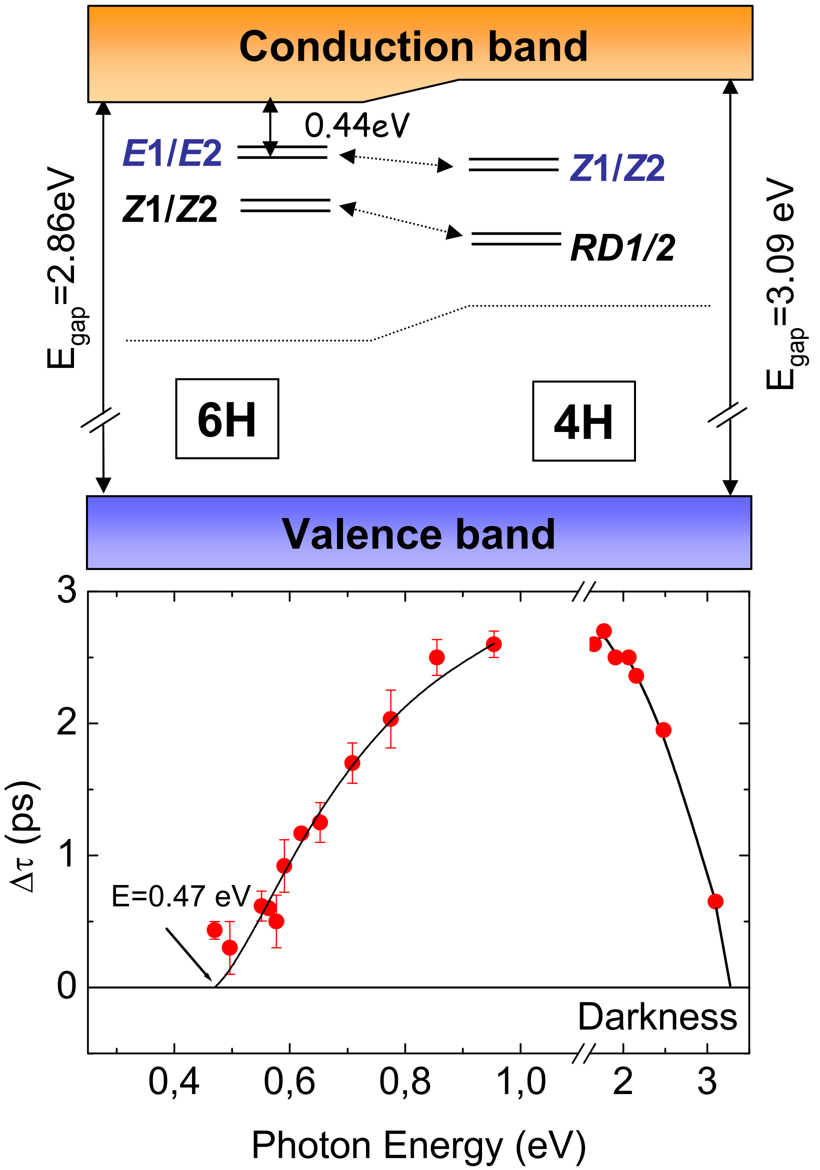
$\Delta\tau = \tau_{dark} - \tau_{illum}$

Electron irradiated 6H SiC bulk material



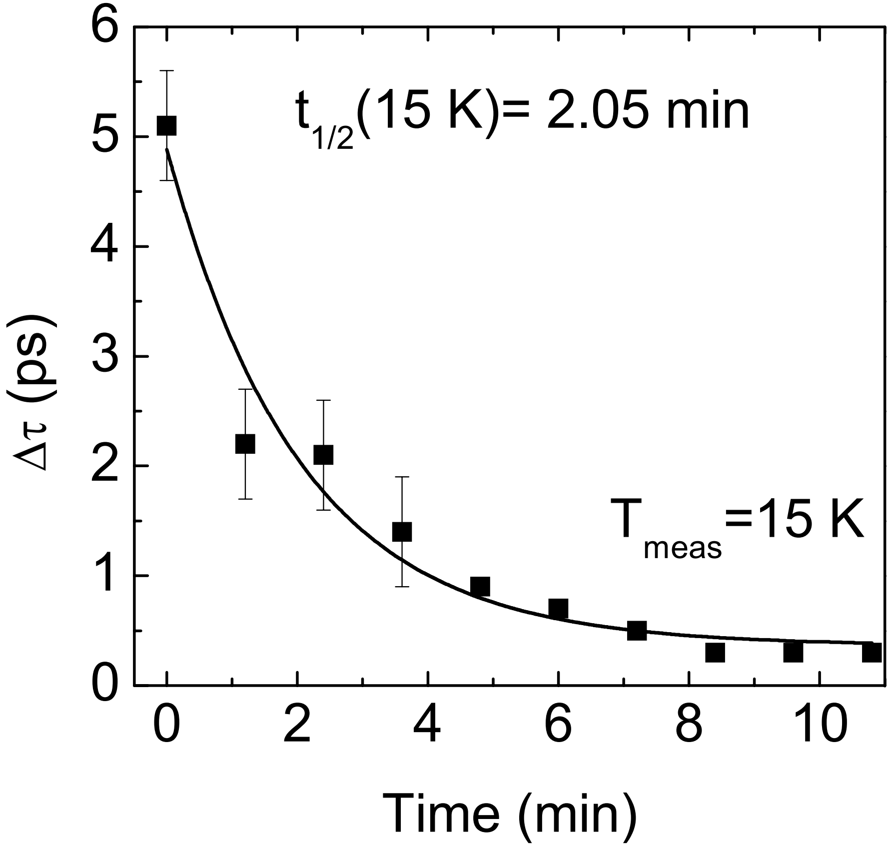
- Two annealing steps appear.
- The illumination effect and the vacancies disappear approximately at the same temperature.
- The E1/E2 defect also disappears at that temperature region [Zha89]

Electron irradiated 6H SiC bulk material



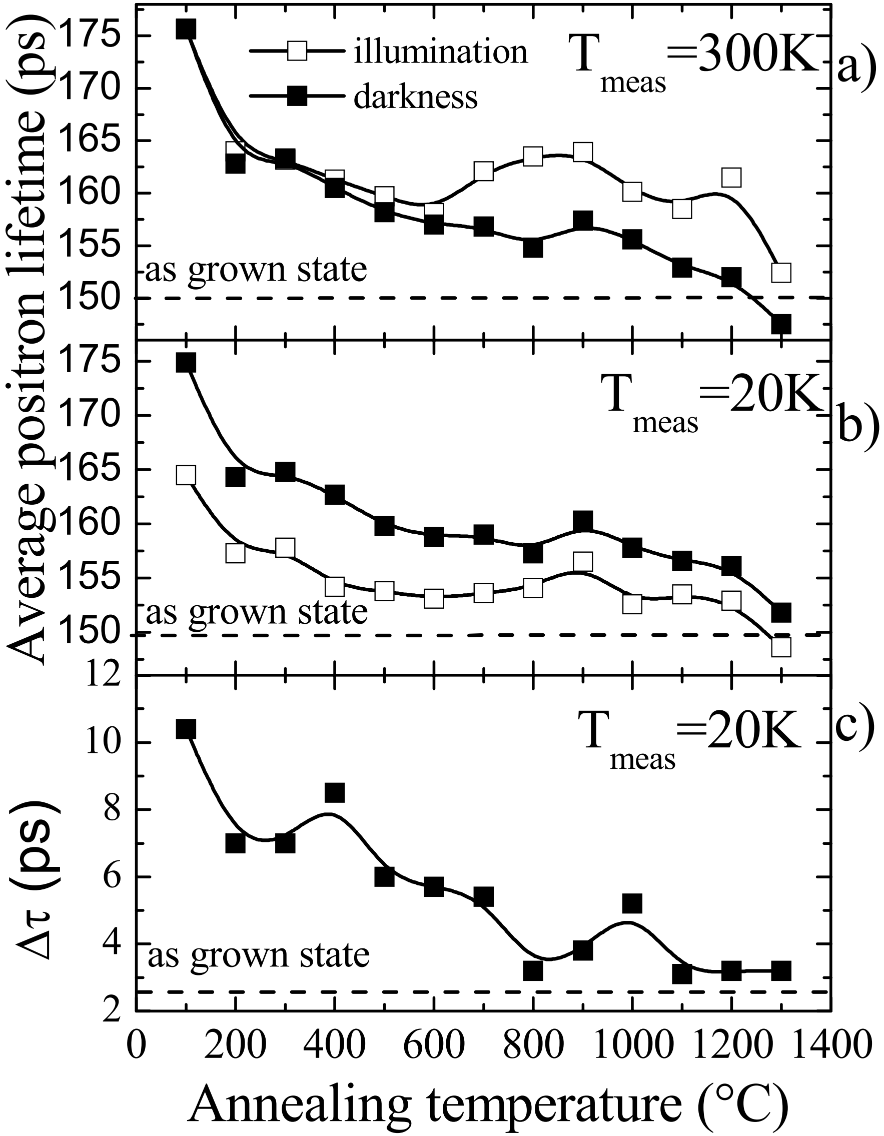
- The data were fitted to the Lucowsky model [Luc65] which gives the cross section for electron transition from a localized state to a parabolic and isotropic band. The threshold energy is determined to be E=0.47eV.
- Illumination effect disappears above 3eV due to direct transition of electrons from the valence band to the conduction band.
- Above 0.4 eV electrons are probably excited from localized levels to the conduction band. Thus, the charge state will change from negativ to neutral.

Persistency effect of illumination



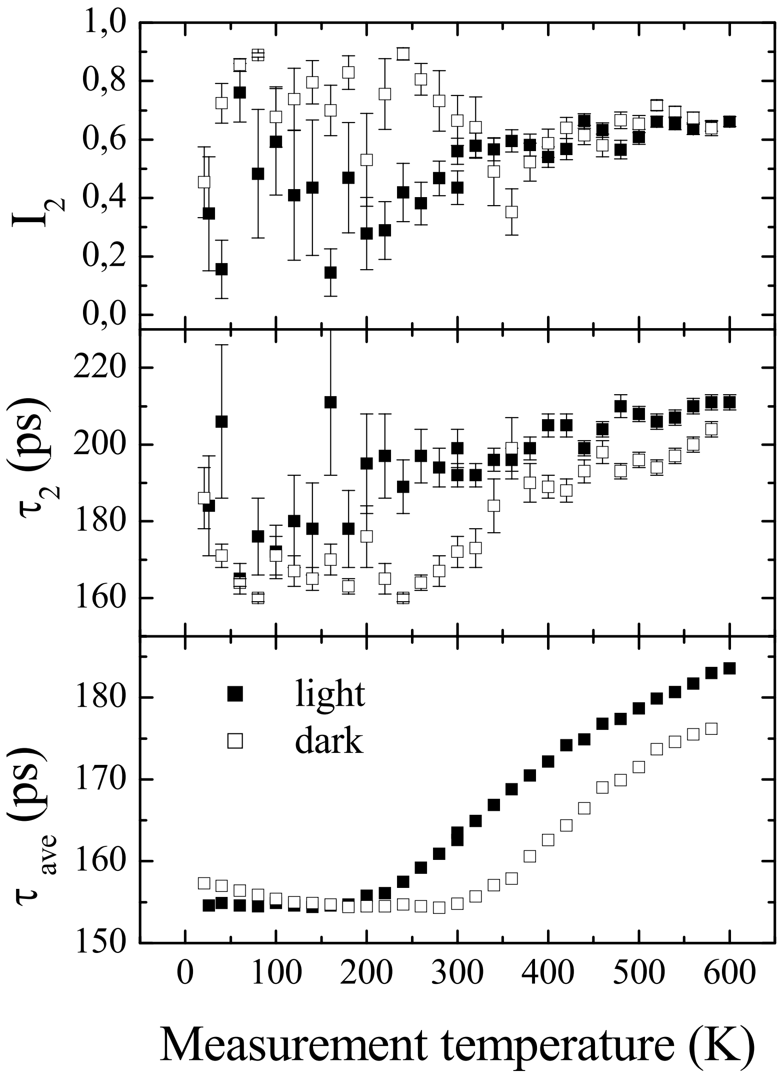
- Illumination effect disappears after 10 min
- Small energy barrier between the excited state and the ground state

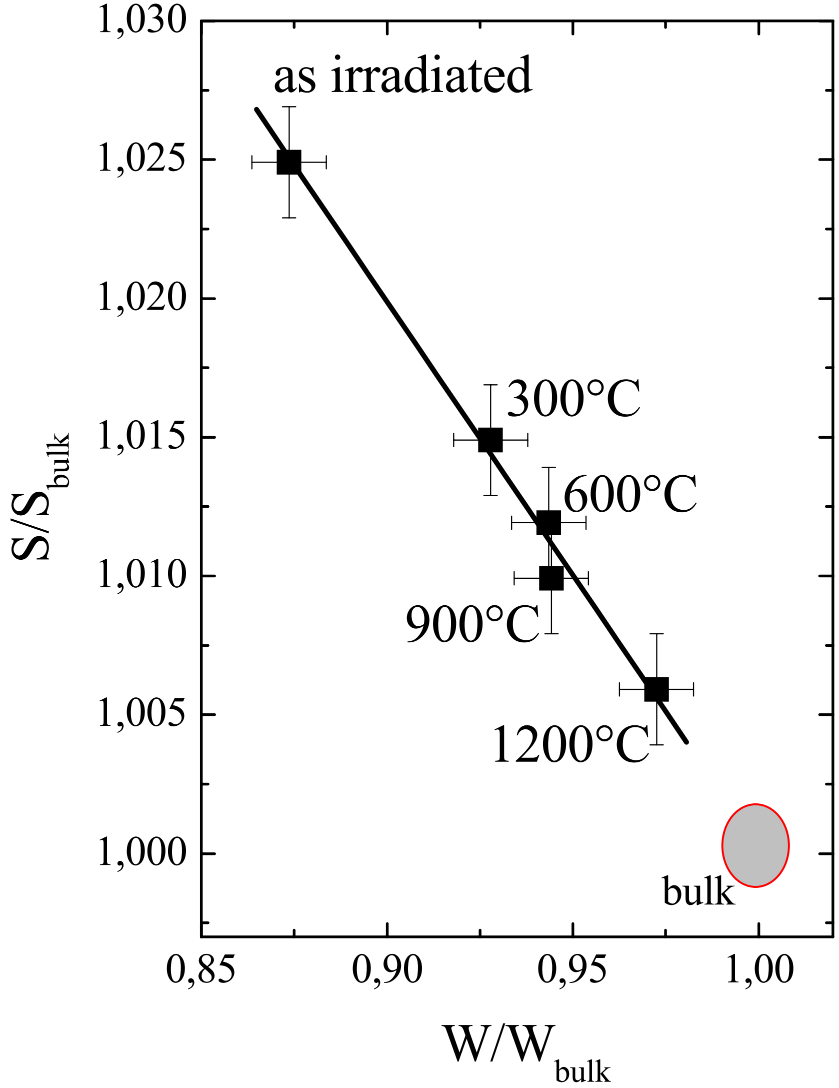
2MeV Electron irradiation (dose: 3E17 cm^{-2})



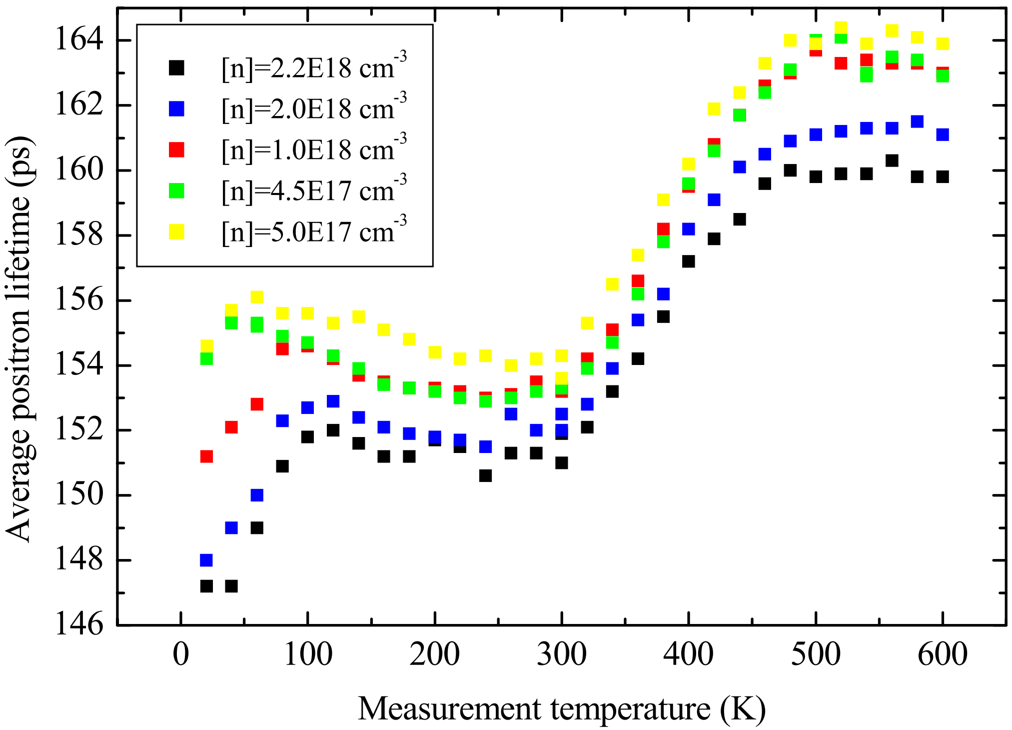
- Four step annealing was observed
- First step: annealing of Frenkel pairs
- Second step: carbon vacancies become mobile
- Third step: silicon vacancies become mobile and form complexes
- Fourth step: annealing of most defects introduced by electron irradiation

Decomposition of lifetime spectra T_{anneal}=800°C

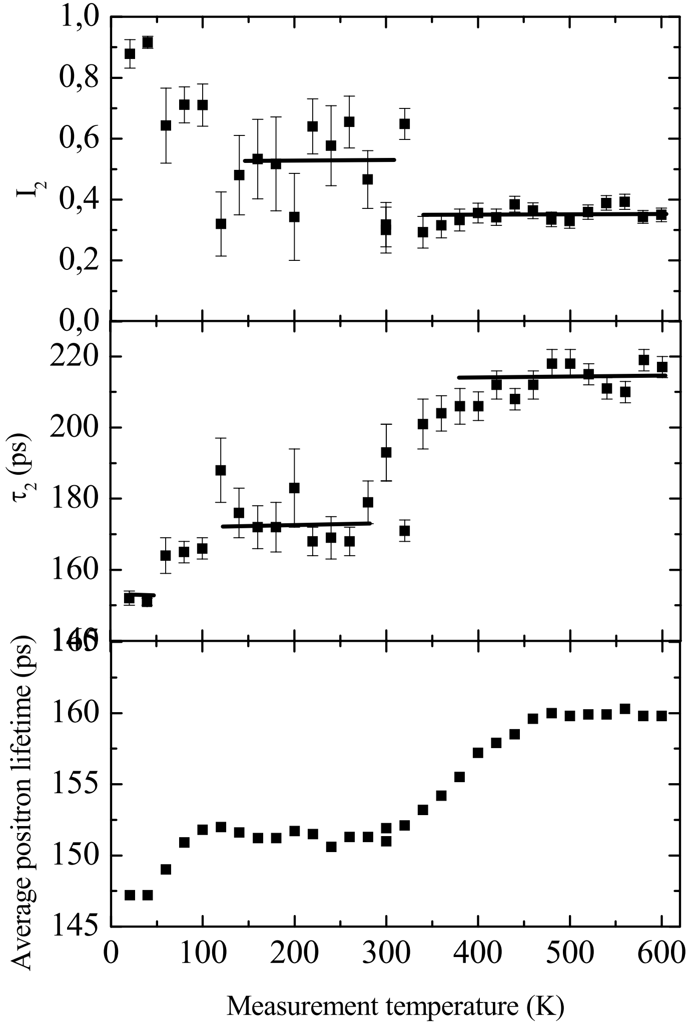




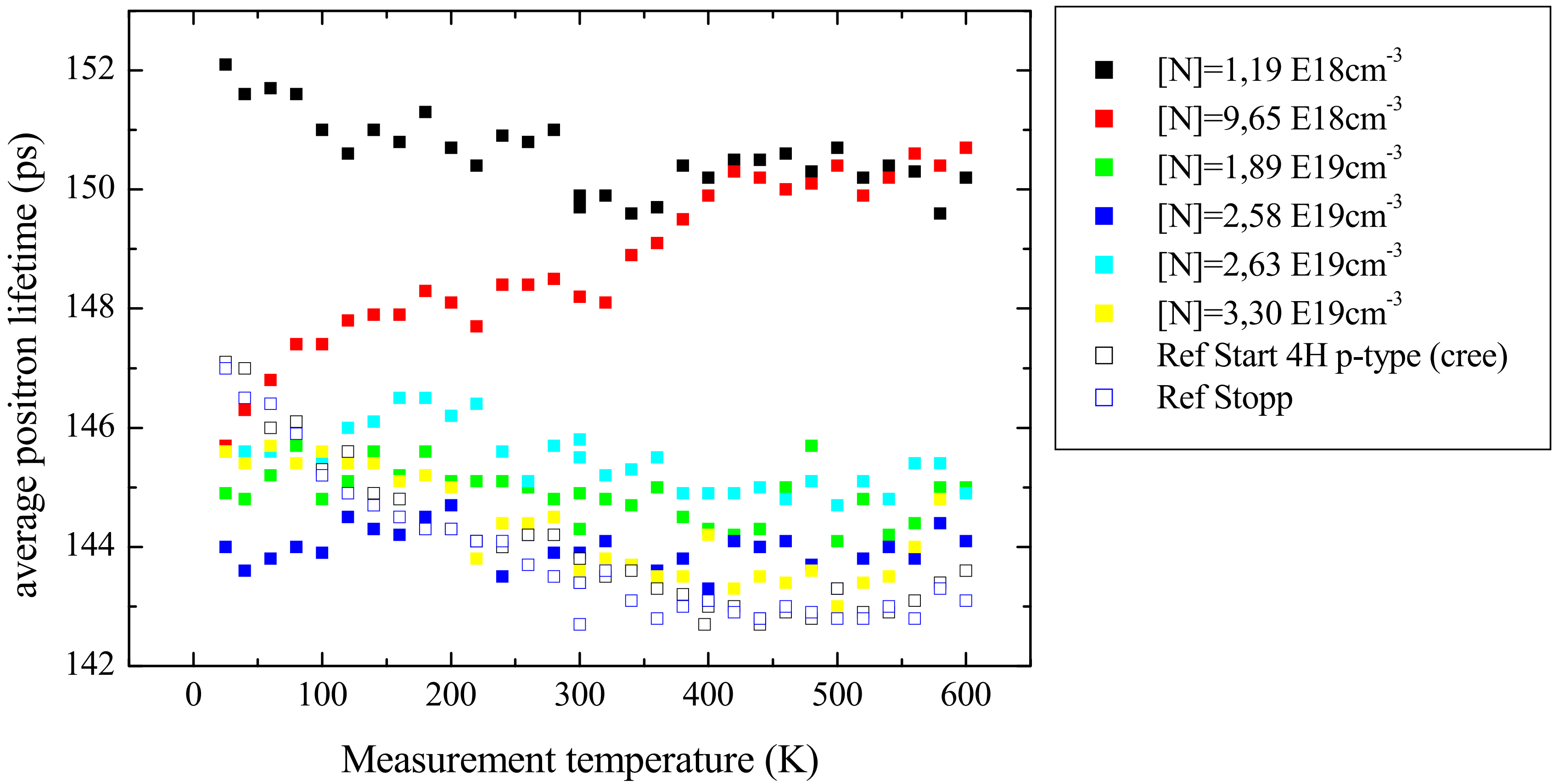
N-type 6H SiC different N-concentration



[n]=2.2E18cm-3

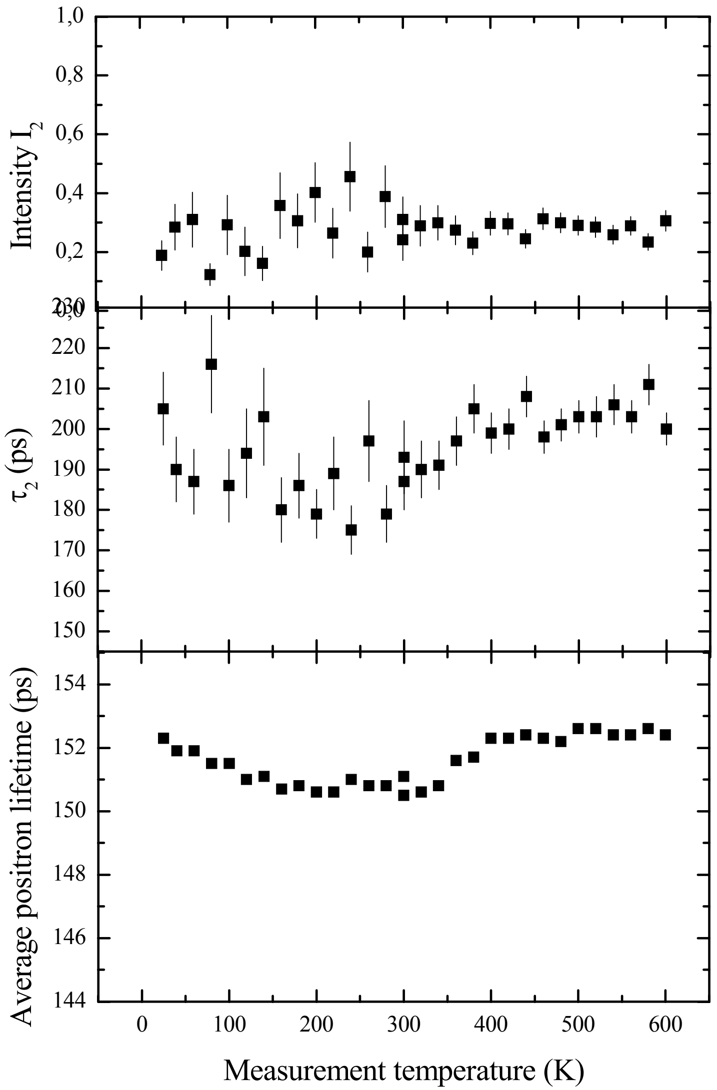


N-type 4H SiC different N-concentration

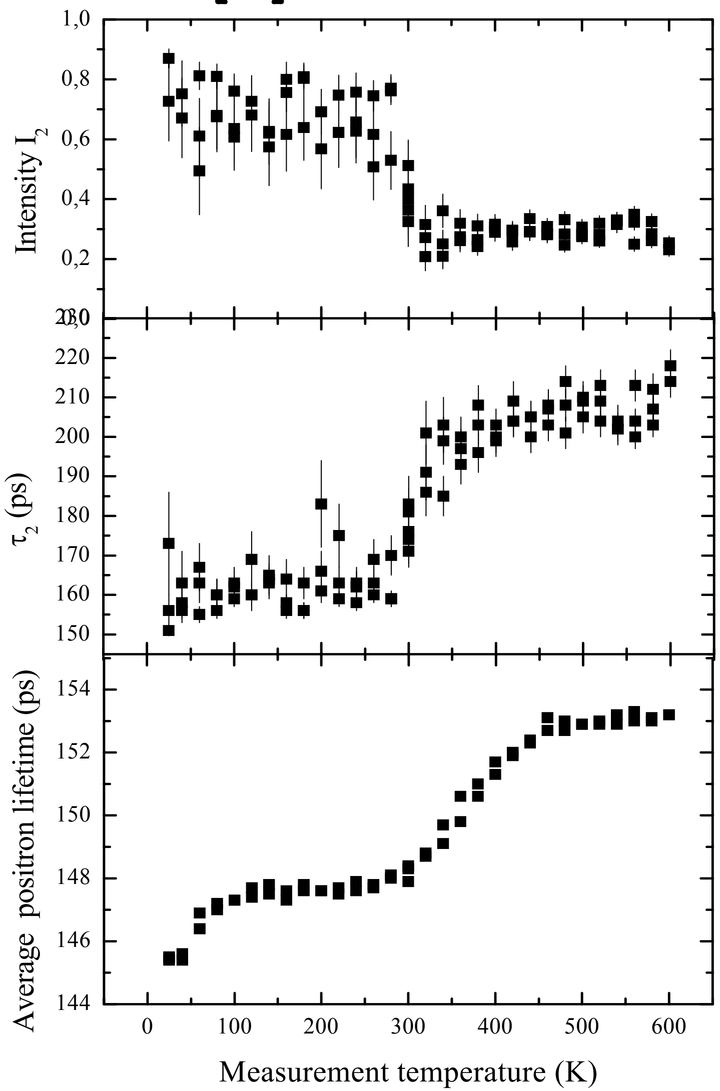


Low N-concentration comparison SiC 4H

[N]=1.19 E18cm^{-3}



[N]=9.65 E18cm^{-3}



Conclusions

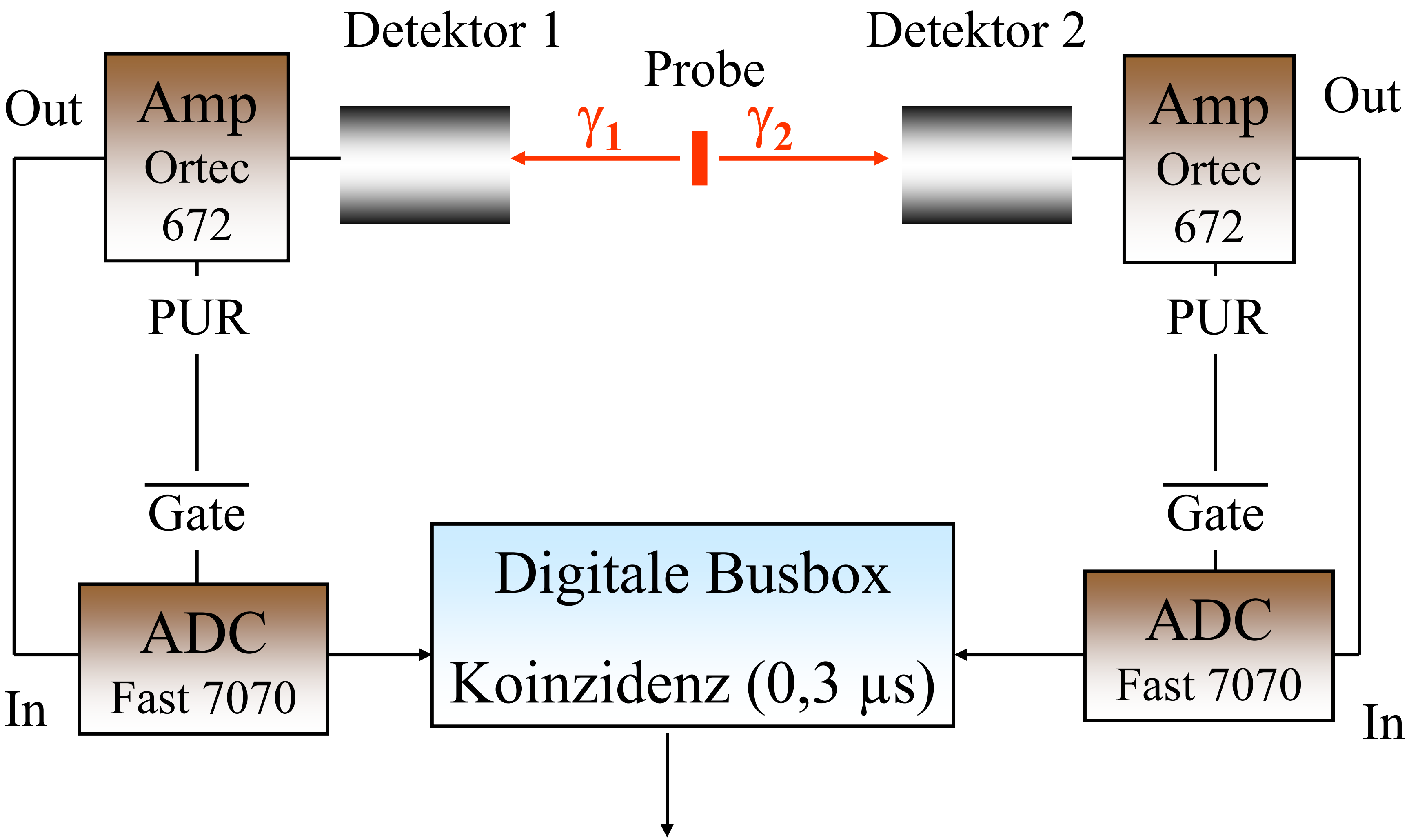
- Positron annihilation spectroscopy detect vacancy type defect in SiC after crystal growth, electron irradiation or He-implantation
- Main trapping center is the silicon vacancy or complexes with silicon vacancies
- The obtained defects E1/E2 (6H, DLTS) should be decorated with silicon vacancies
- Introduced defects can change their charge state through white light illumination-> vacancies are neutral or single negatively charged (change of trapping rate)
- The increasing N-concentration during the crystal growth reduces the vacancy concentration
- Origin of shallow traps in 6H and 4H is still unclear

Thanks

- A. Kawasuso, R. Krause-Rehberg, K. Petters for their fruitful discussion und lab-facility
- Michael Weidner and Thomas Frank for their sample treatment (Group: G. Pensl, Erlangen)
- DFG Deutsche Froschungs Gesellschaft
- IKZ :bulk crystals

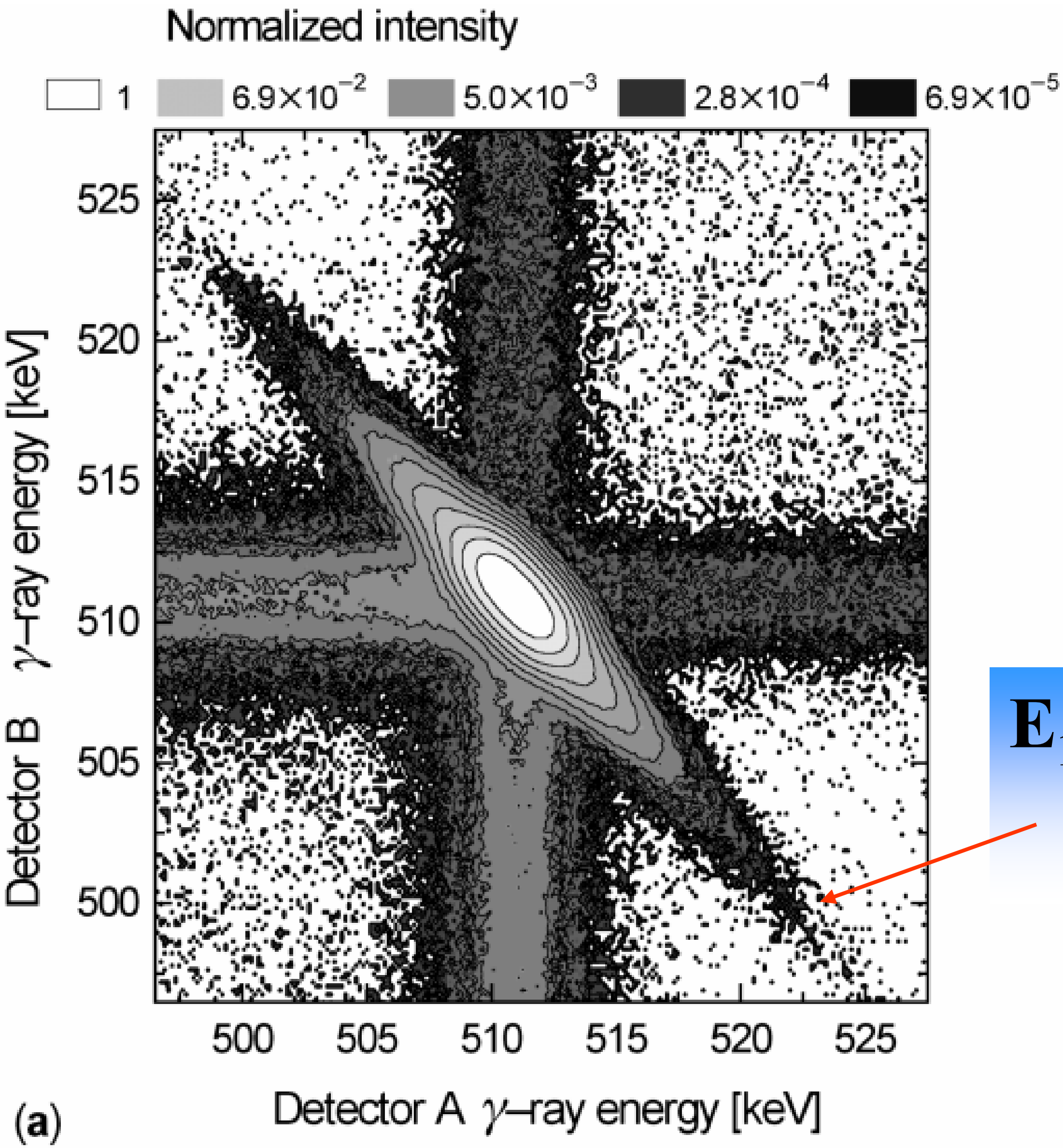
This talk can be downloaded from:
www.ep3.uni-halle.de/positrons

Coincidence system



PC mit MPA-WIN System

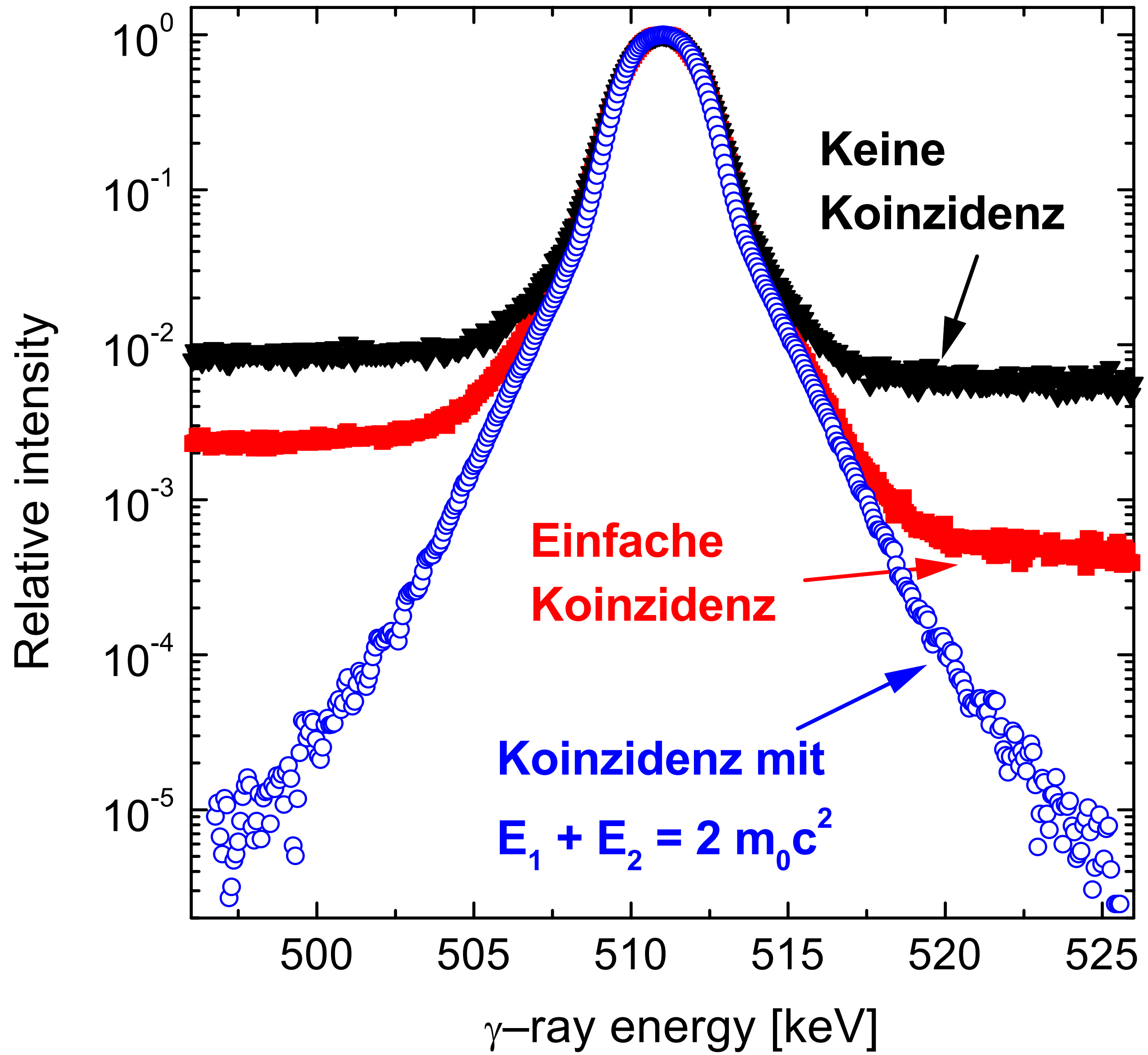
2dim coincidence sprctrum



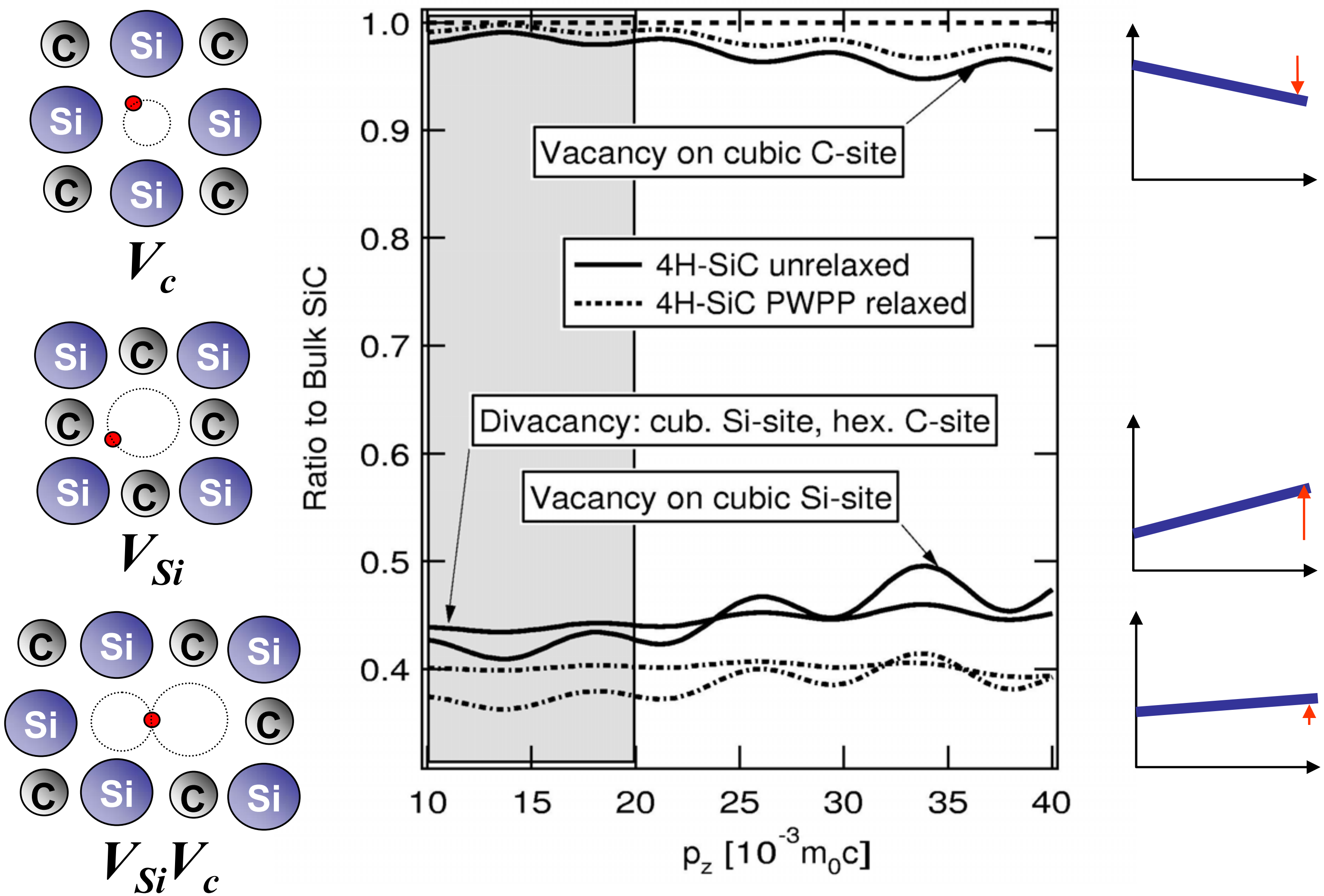
$E_1+E_2= 2\ m_0\ c^2$

$=1022$ keV

Background reduction



Theoretical high impuls contribution



T. Staab *et al*.
(to be published in Mater. Sci. Forum)

Coincidence spectrum