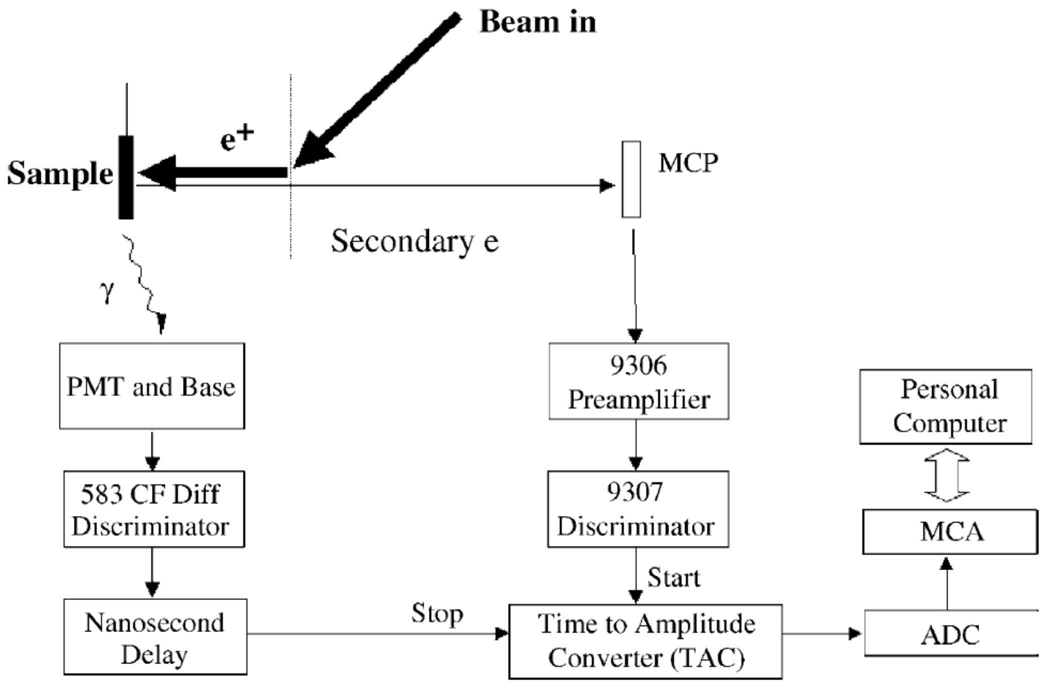
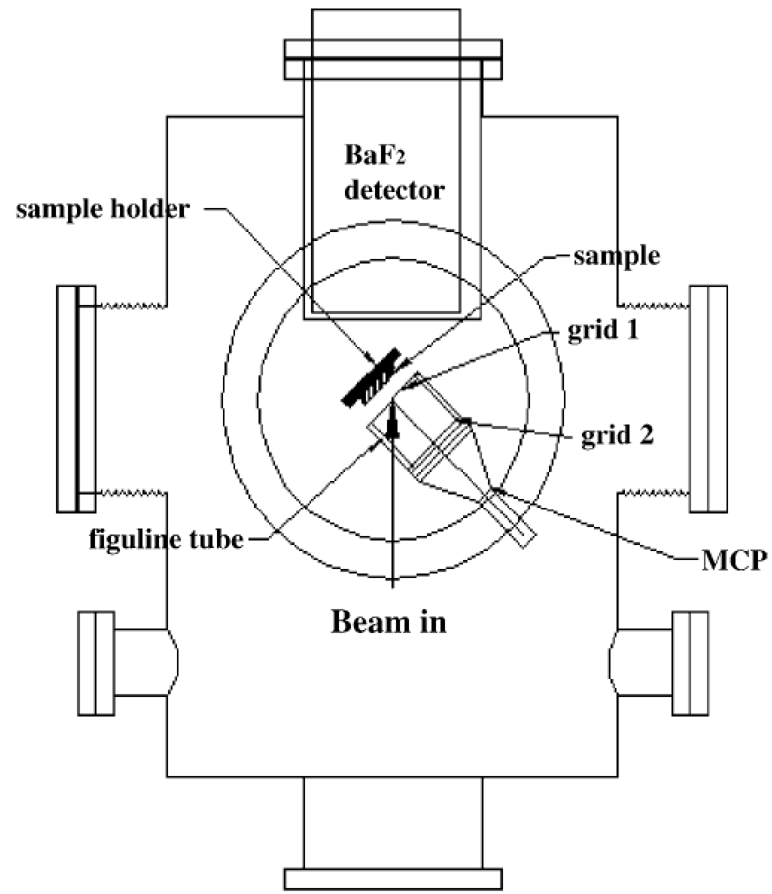
Positron lifetime spectroscopy using slow positrons

- **use of secondary electrons for timing**
- Wuhan University, China
- time resolution ≈ 500 ps, energy 0.5 – 30 keV





Wu et al. Appl. Surf. Sci. 252, 3121 (2006)

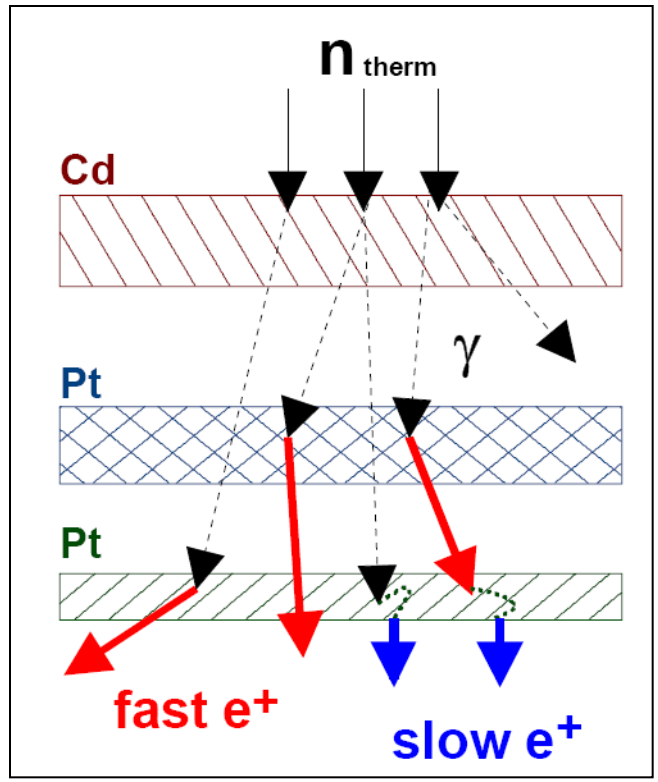
Positron lifetime spectroscopy using slow positrons

- NEPOMUC, FRM II, Munich
- reactor based slow e^+ source
- $\approx 1\ e^+$ / ns (= 1 GBq)
- $\approx$ E = 1 keV, ΔE = 50 eV

$$^{113}\mathrm{Cd}(\mathrm{n},\gamma)^{114}\mathrm{Cd}$$

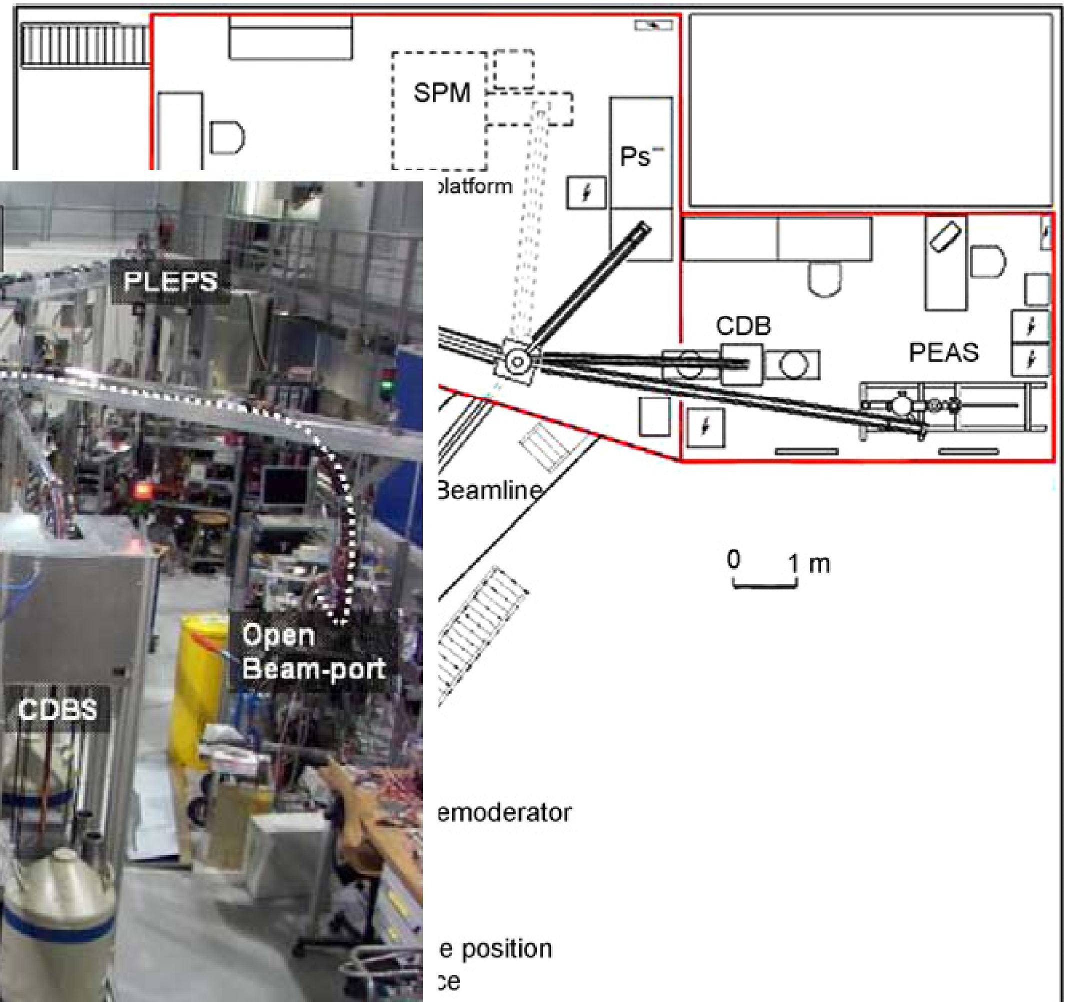
$$E_\gamma = 9.04\,\mathrm{MeV}$$

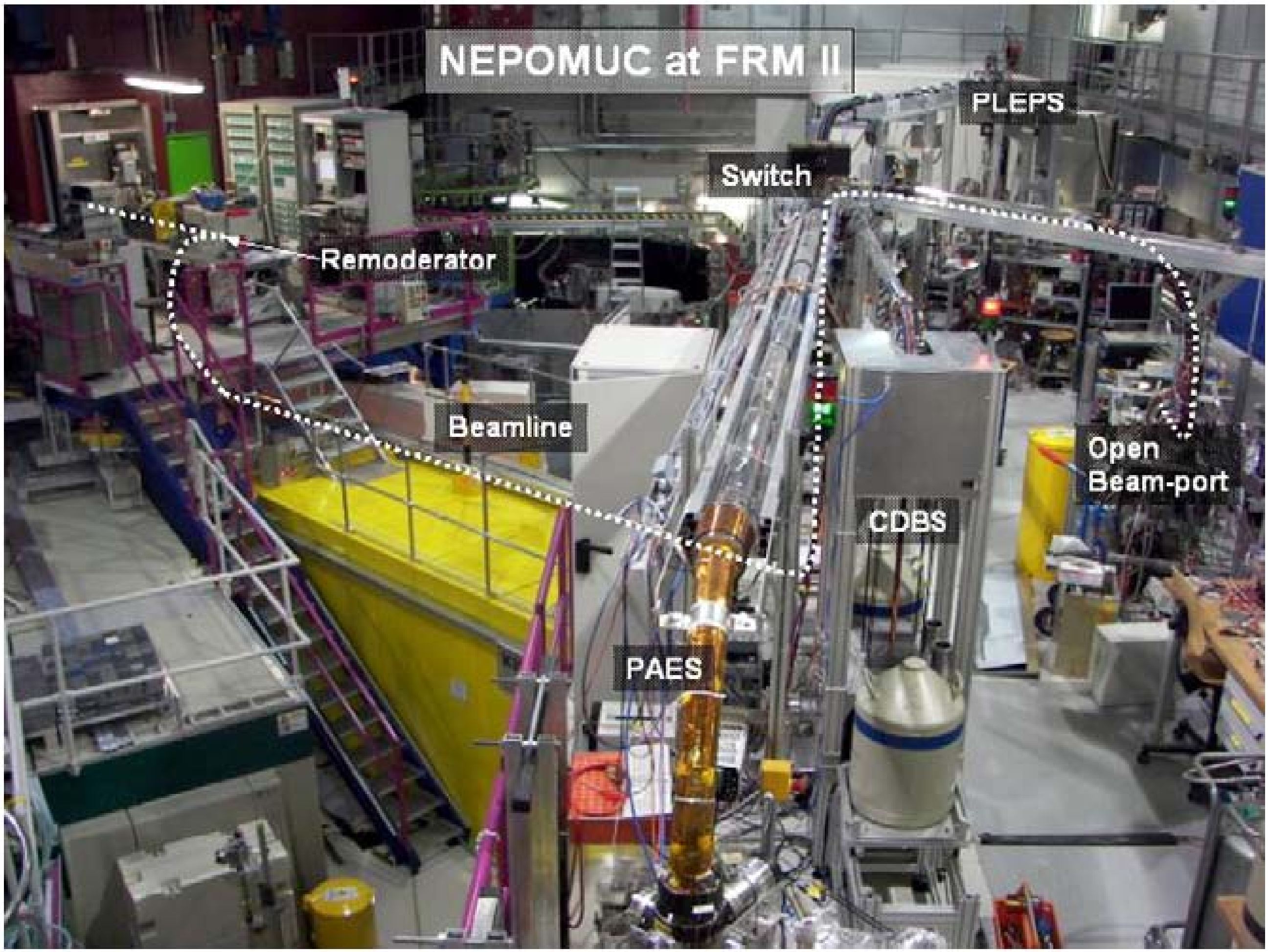
$$\gamma \rightarrow e^- + e^+$$



Positron lifetime spectroscopy using slow positrons

- **pulsed slow e^+ beam**
- NEPOMUC, FRM II Mnichov





Positron lifetime spectroscopy using slow positrons

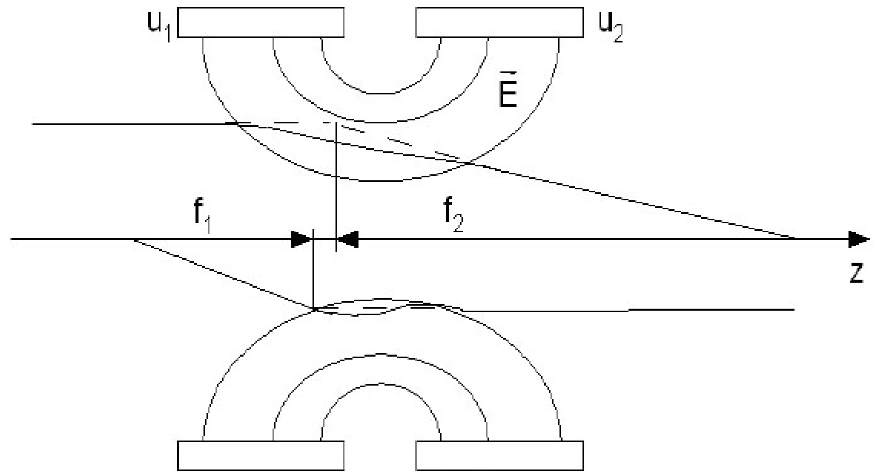
- **pulsed slow *e*⁺ beam**
- Liouville's theorem

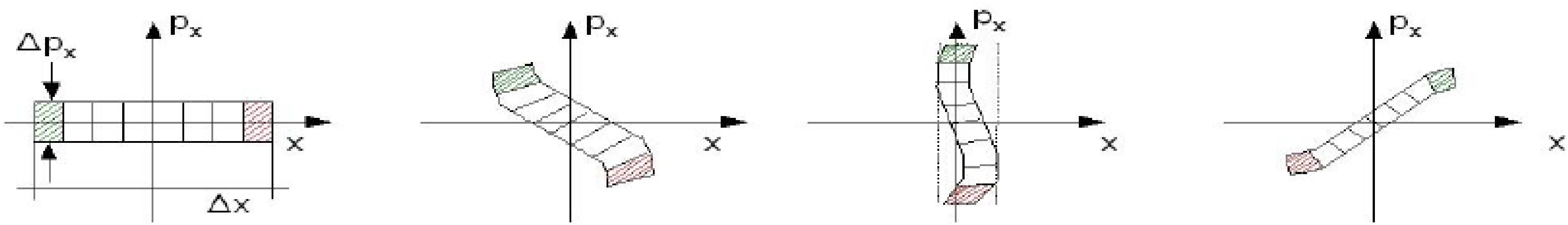
$$\Delta x\,\Delta p_x = \Omega_x = \text{konst}$$

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

$$\Delta E\,\Delta t = \Omega_E = \text{konst}$$

- electrostatic lens

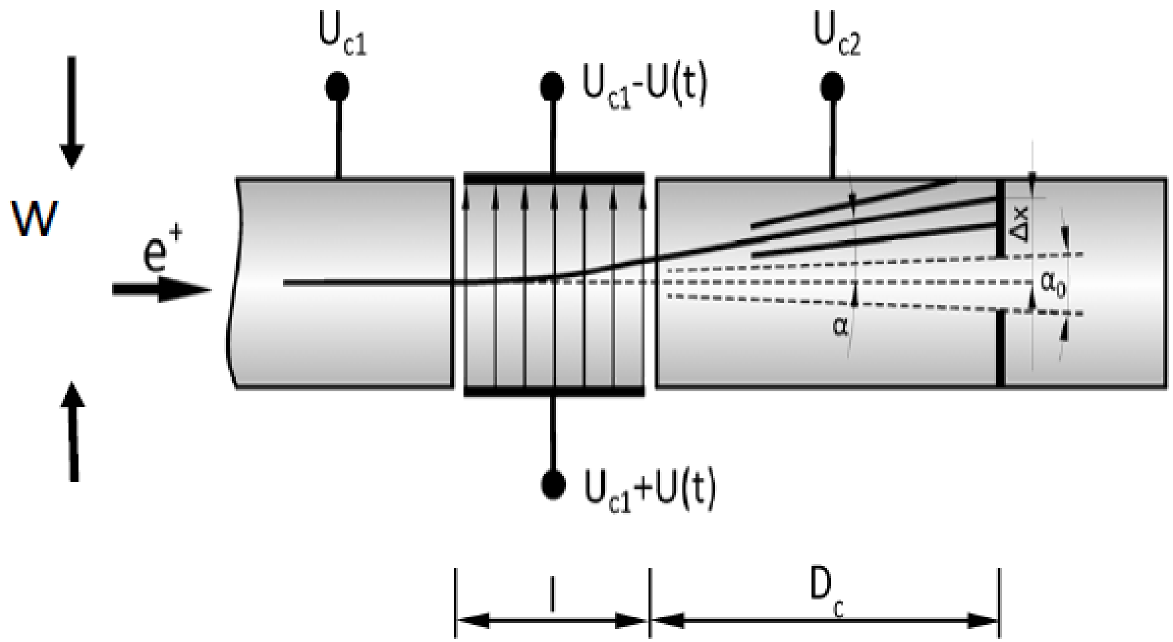


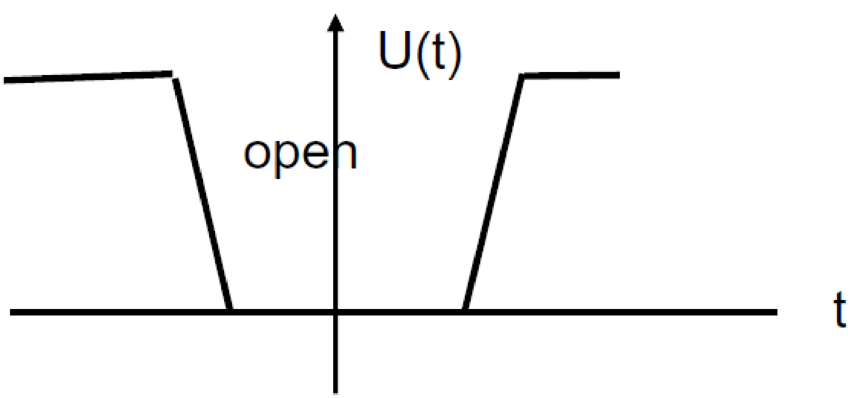


Kögel, EPOS meeting 2002

Positron lifetime spectroscopy using slow positrons

- **pulsed slow e^+ beam**
- chopper



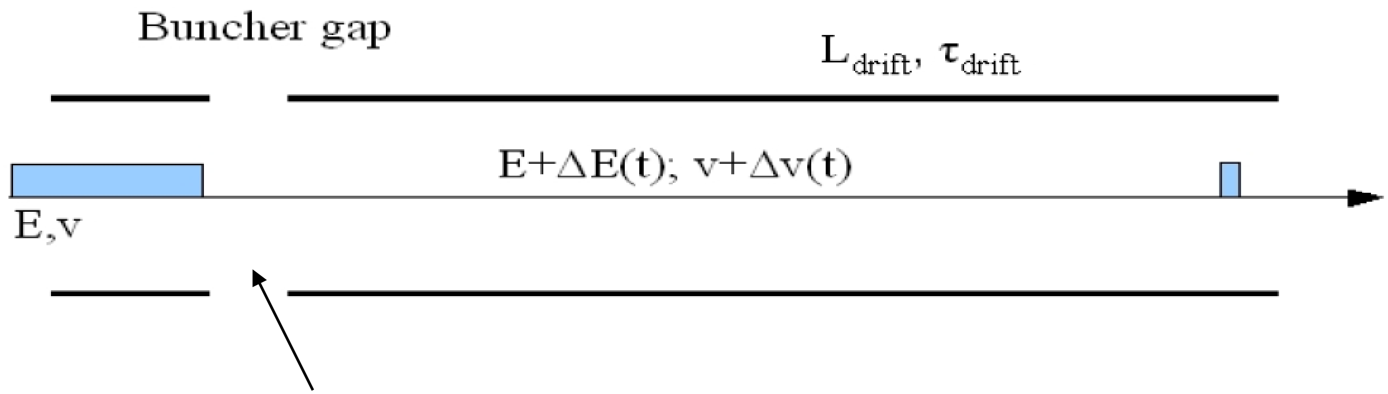


Kögel, EPOS meeting 2002

Positron lifetime spectroscopy using slow positrons

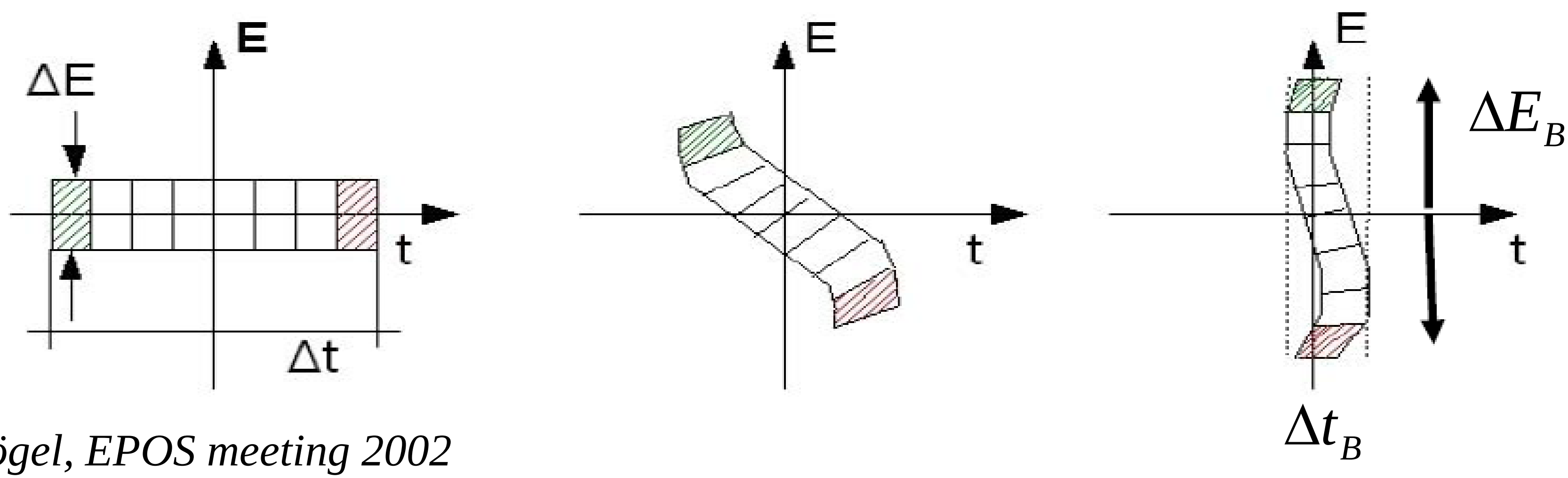
- **pulsed slow e^+ beam**
- buncher

$$\Delta E\,\Delta t = \Omega_E$$



$$dU/dt = \Delta E_B / \Delta t_B \quad (10\ ...\ 100\ \mathrm{V\ ns^{-1}})$$

$$\Delta E\,\Delta t = \Delta E_B\,\Delta t_B$$



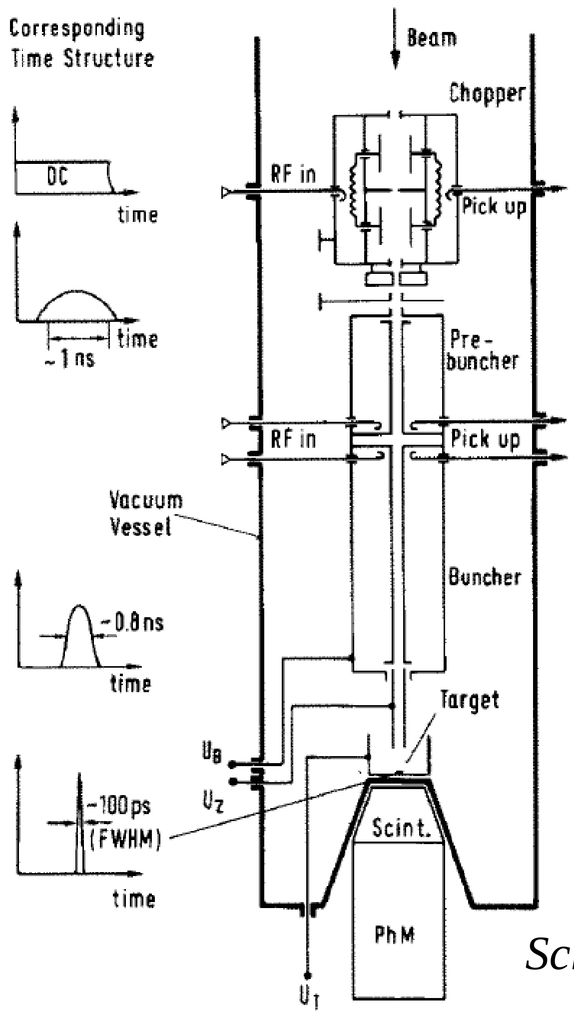
Kögel, EPOS meeting 2002

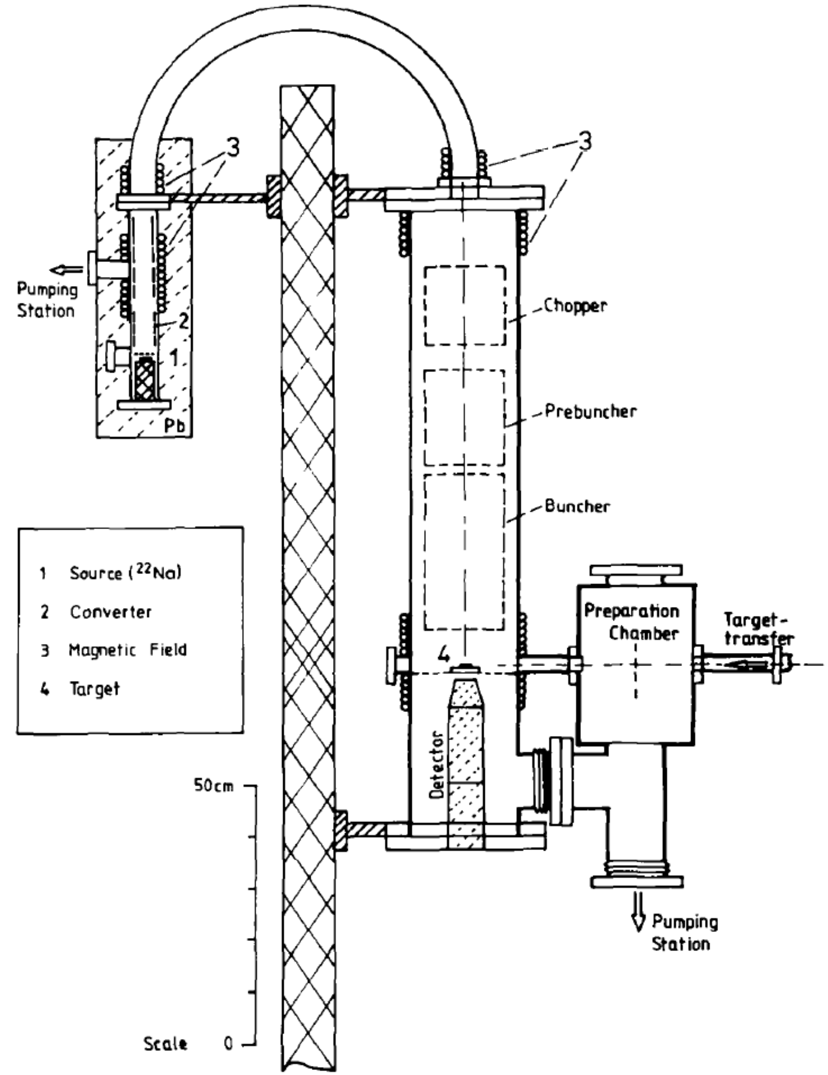
Positron lifetime spectroscopy using slow positrons

- **pulsed slow e^+ beam**
- buncher
- Lorentz force: $$eBv = m\frac{v^2}{r} \longrightarrow \frac{eB}{m} = \frac{v}{r} = \omega = 2\pi f$$
- frequency of e^+ rotation in beam $f = \frac{eB}{2\pi m}$
- $B \approx 10$ mT, $e = 1.6 \times 10^{-19}$ C, $m = 9.1 \times 10^{-31}$ kg $\rightarrow f \approx 280$ MHz
- PLEPS $B \approx 7$ mT $\rightarrow f \approx 200$ MHz

Positron lifetime spectroscopy using slow positrons

- **pulsed slow e^+ beam**
- NEPOMUC, FRM II Munich
- PLEPS

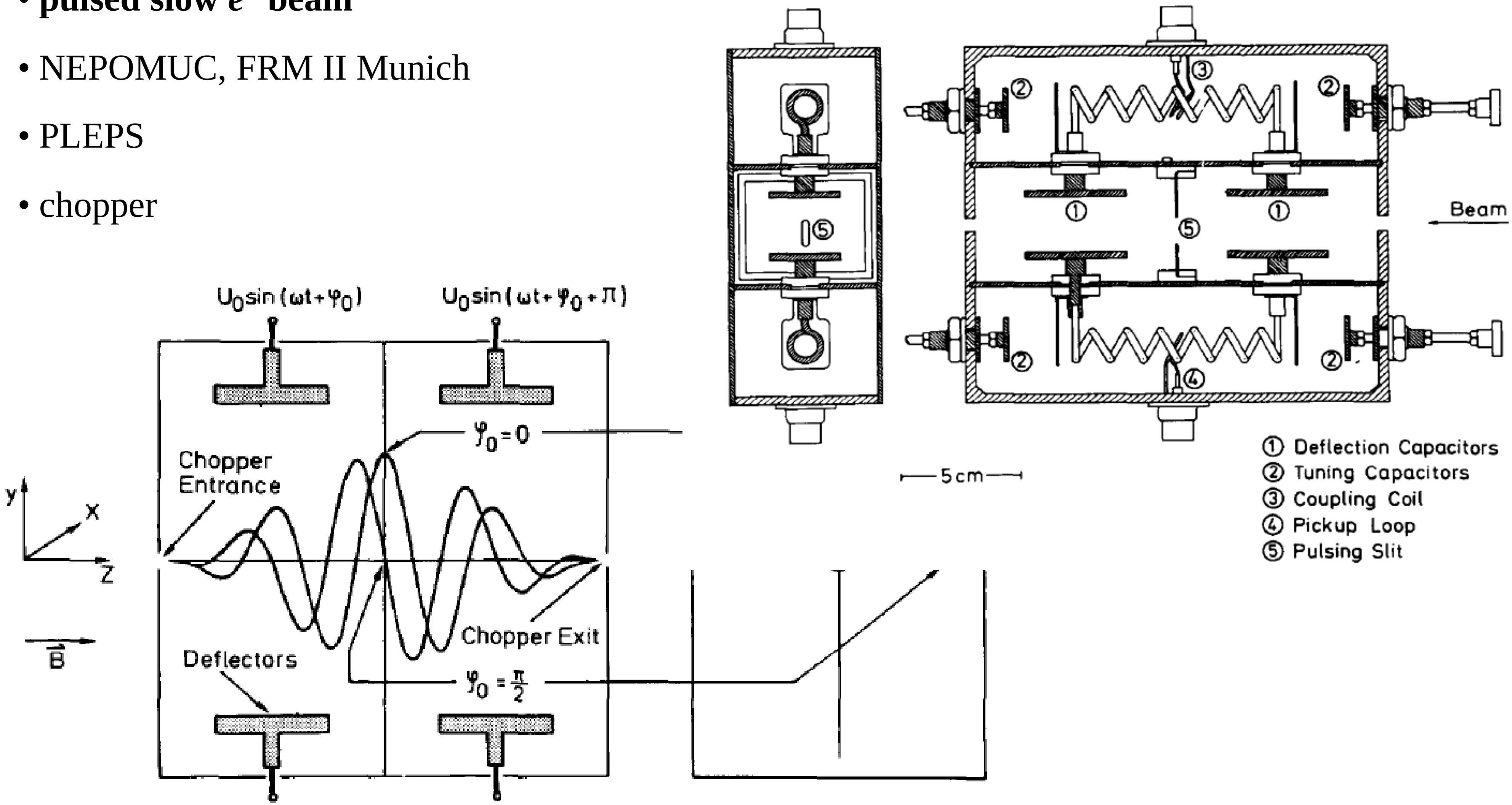




Schödlbauer et al. Nucl. Intr Meth. B 34, 258 (1988)

Positron lifetime spectroscopy using slow positrons

- **pulsed slow e^+ beam**
- NEPOMUC, FRM II Munich
- PLEPS
- chopper



Schödlbauer et al. Nucl. Intr Meth. B 34, 258 (1988)

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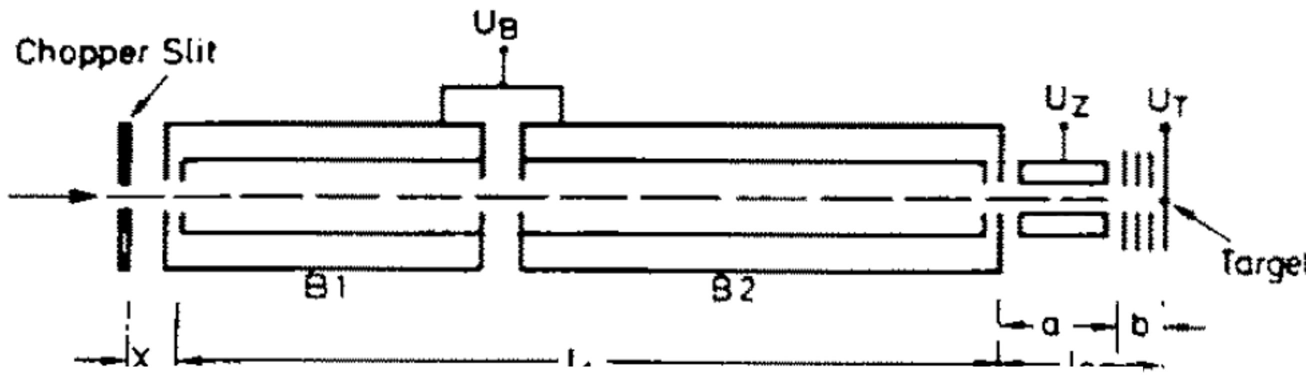
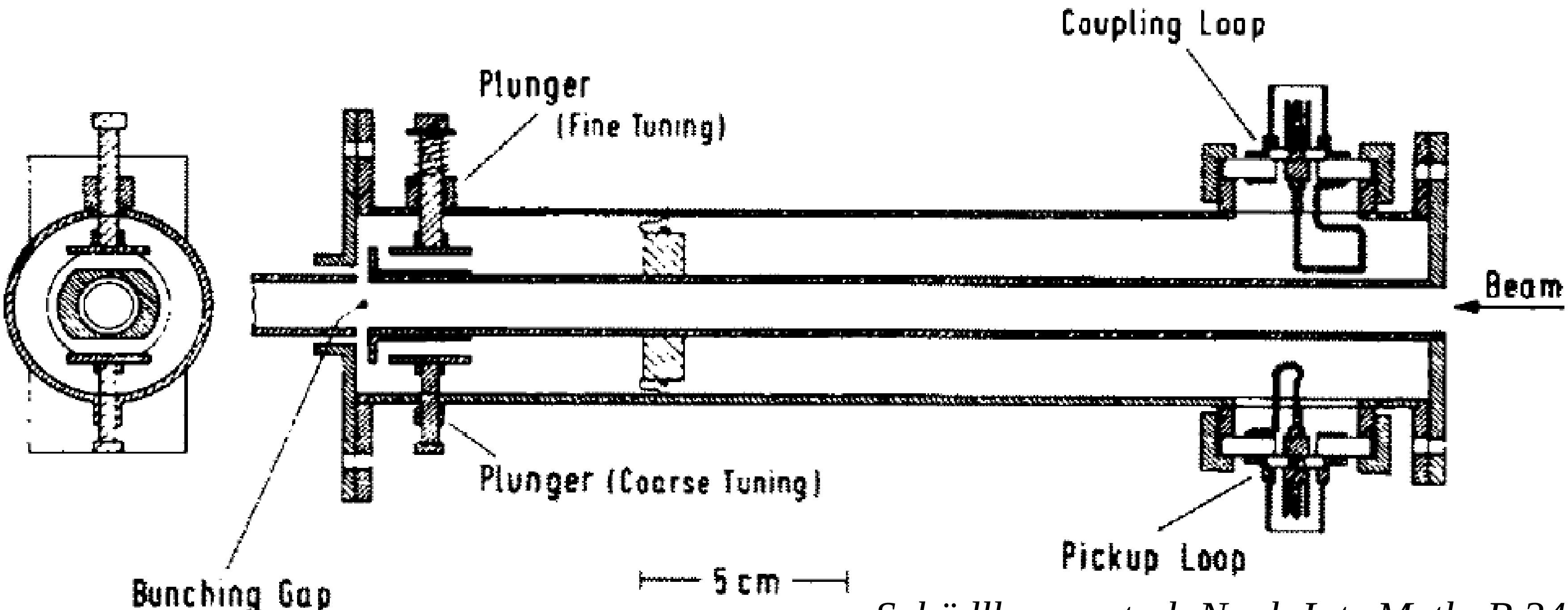
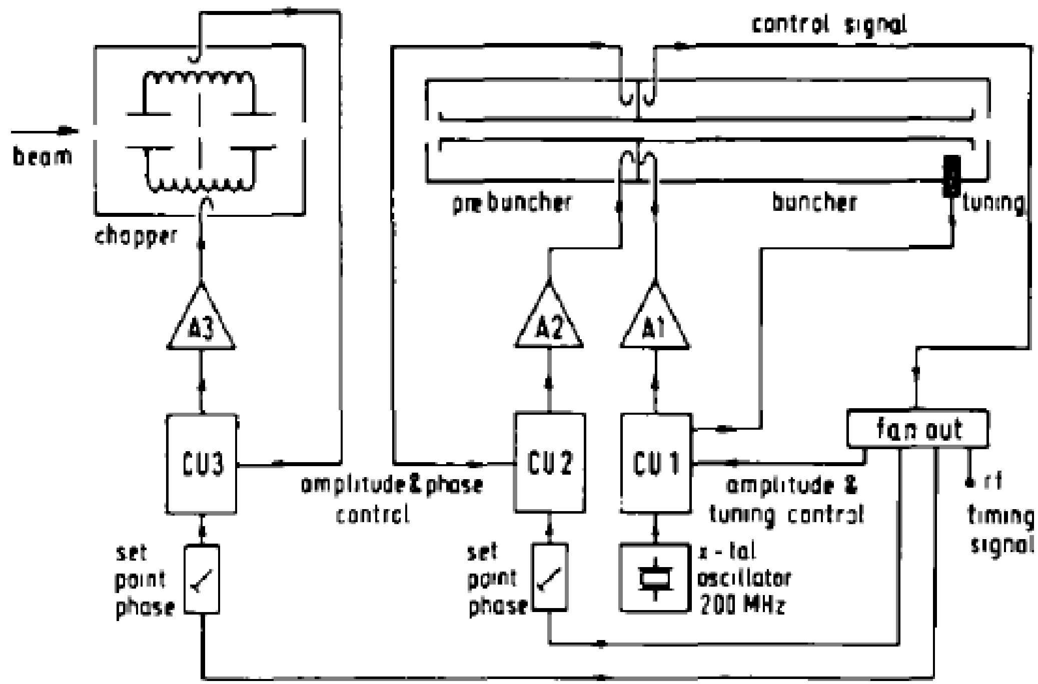




Schödlbauer et al. Nucl. Intr Meth. B 34, 258 (1988)

Positron lifetime spectroscopy using slow positrons

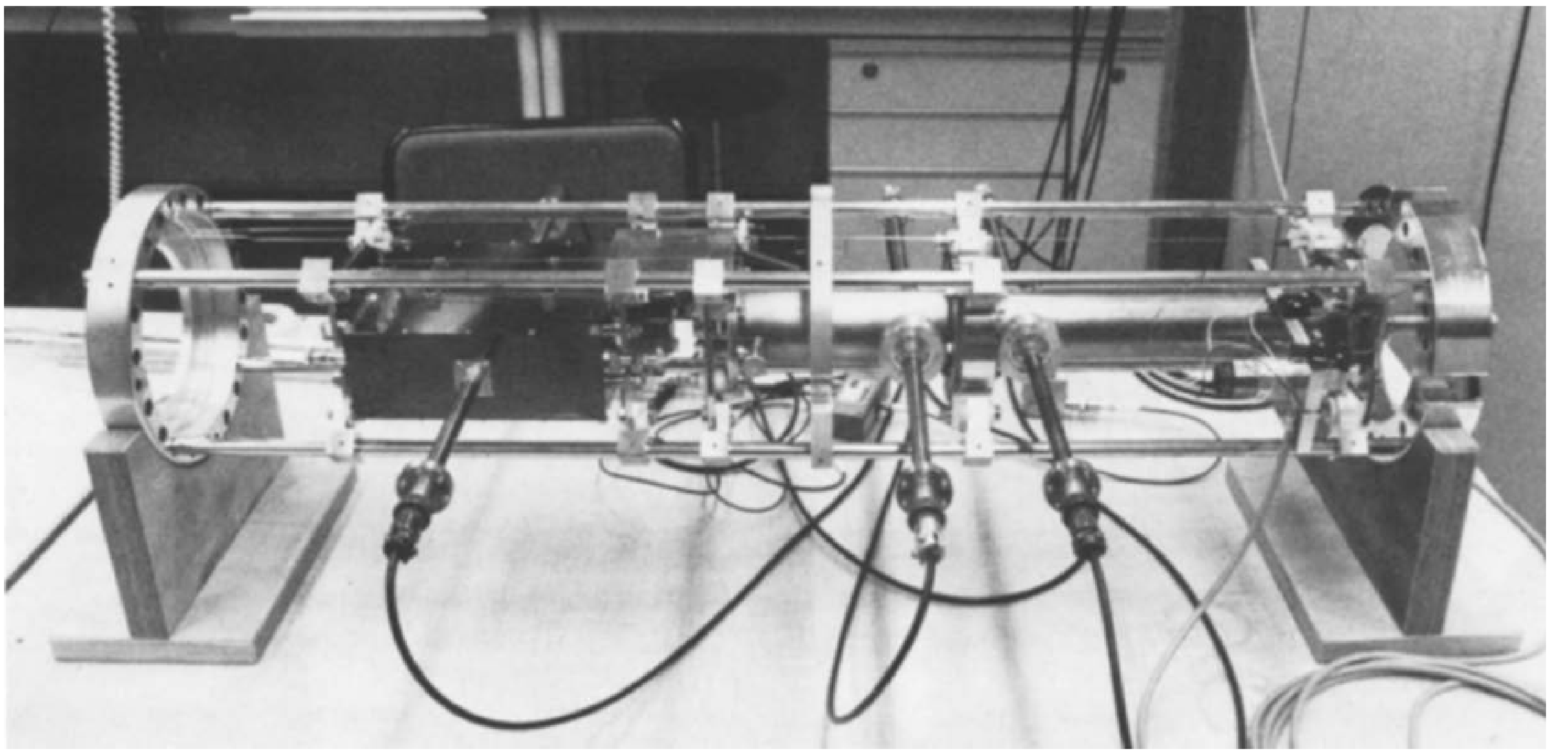
- **pulsed slow e^+ beam**
- NEPOMUC, FRM II Munich
- PLEPS
- chopper + buncher



Schödlbauer et al. Nucl. Intr Meth. B 34, 258 (1988)

Positron lifetime spectroscopy using slow positrons

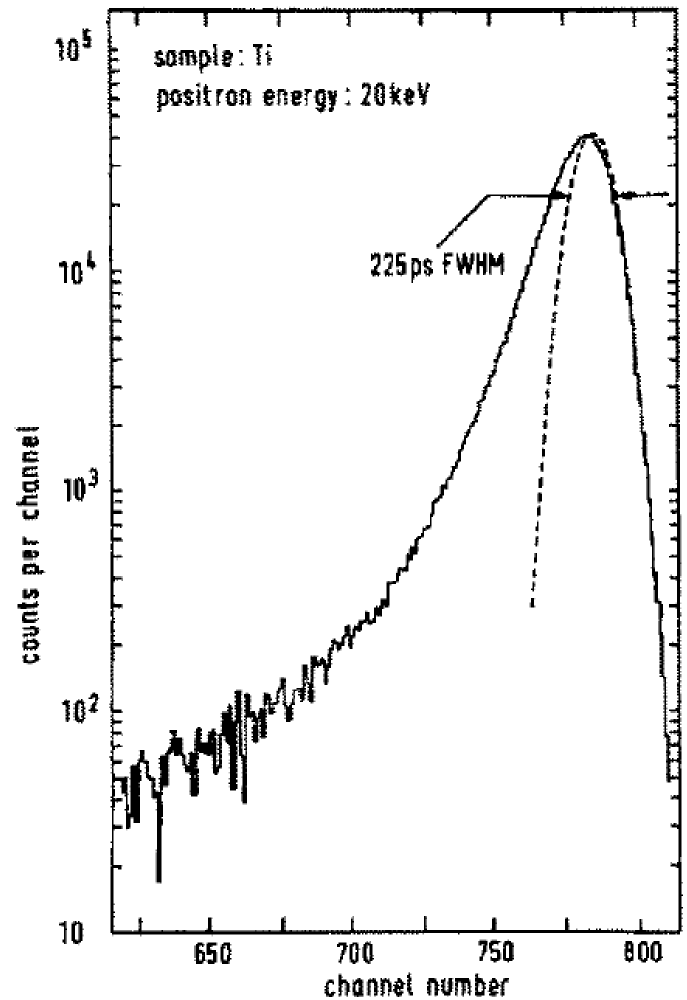
- **pulsed slow *e*⁺ beam**
- NEPOMUC, FRM II Munich
- PLEPS
- chopper + buncher



Schödlbauer et al. Nucl. Intr Meth. B 34, 258 (1988)

Positron lifetime spectroscopy using slow positrons

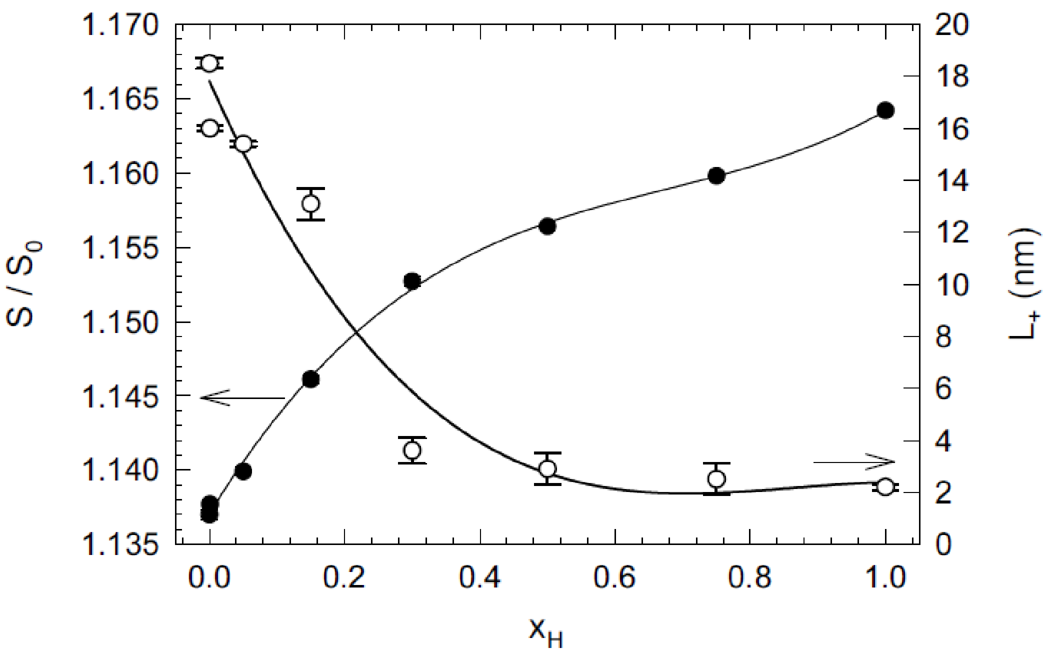
- **pulsed slow e^+ beam**
- NEPOMUC, FRM II Munich
- PLEPS
- time resolution 225 ps

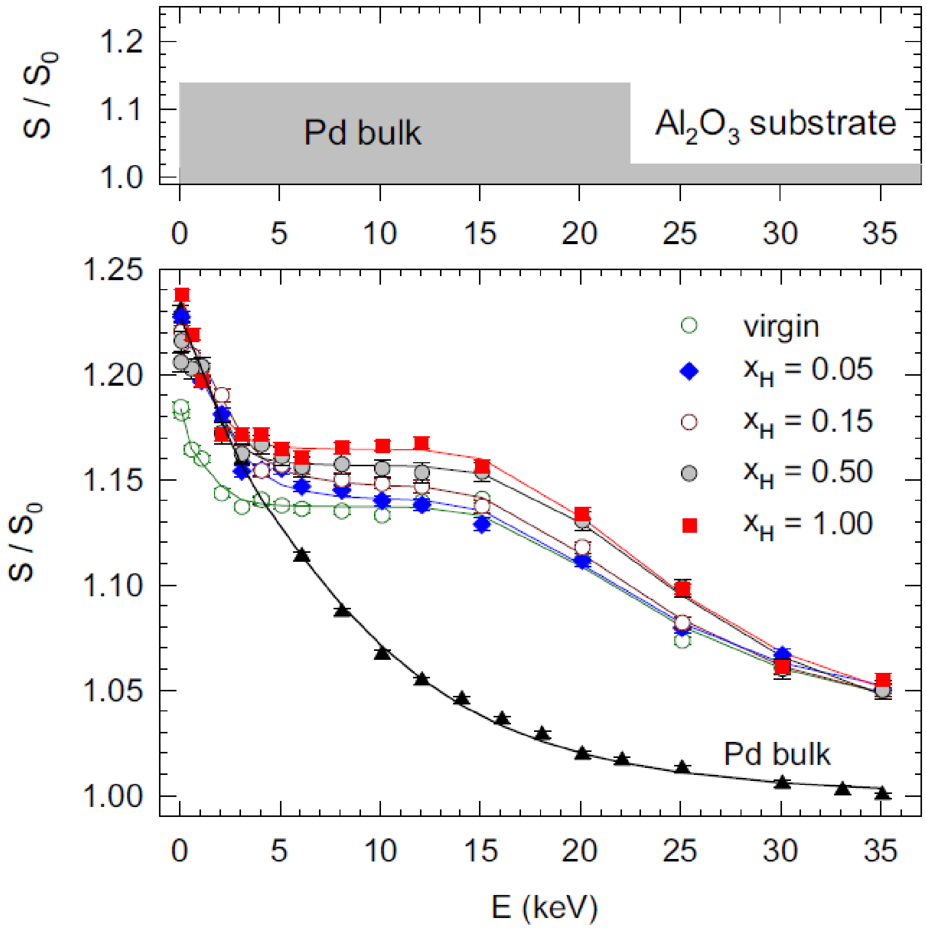


Schödlbauer et al. Nucl. Intr Meth. B 34, 258 (1988)

Positron lifetime spectroscopy using slow positrons

- **pulsed slow *e*$^+$ beam**
- PLEPS, NEPOMUC, FRM II Munich
- Pd films, 500 nm, 800°C
- Al_2O_3 (11-20) substrate
- electrochemically doped with hydrogen

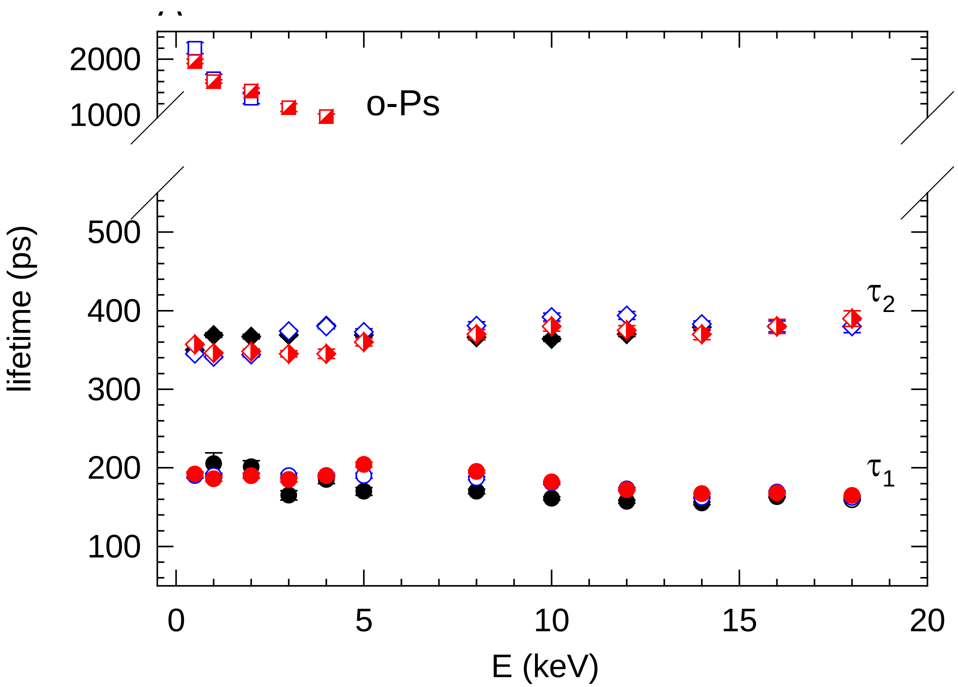


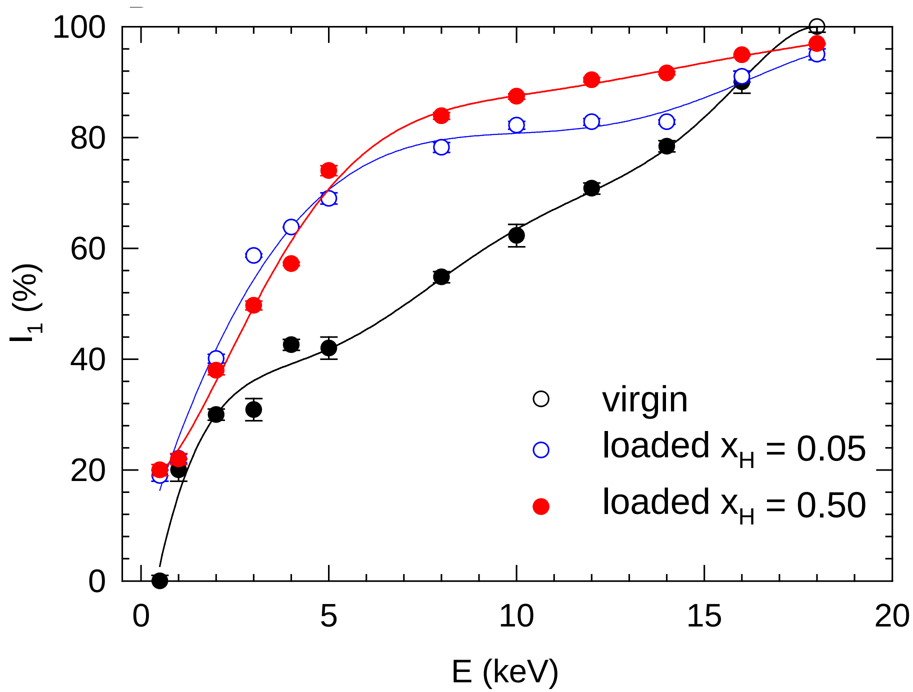


Positron lifetime spectroscopy using slow positrons

- **pulsed slow e^+ beam**
- PLEPS, NEPOMUC, FRM II Munich
- Pd films, 500 nm, 800°C
- Al_2O_3 (11-20) substrate
- electrochemically doped with hydrogen

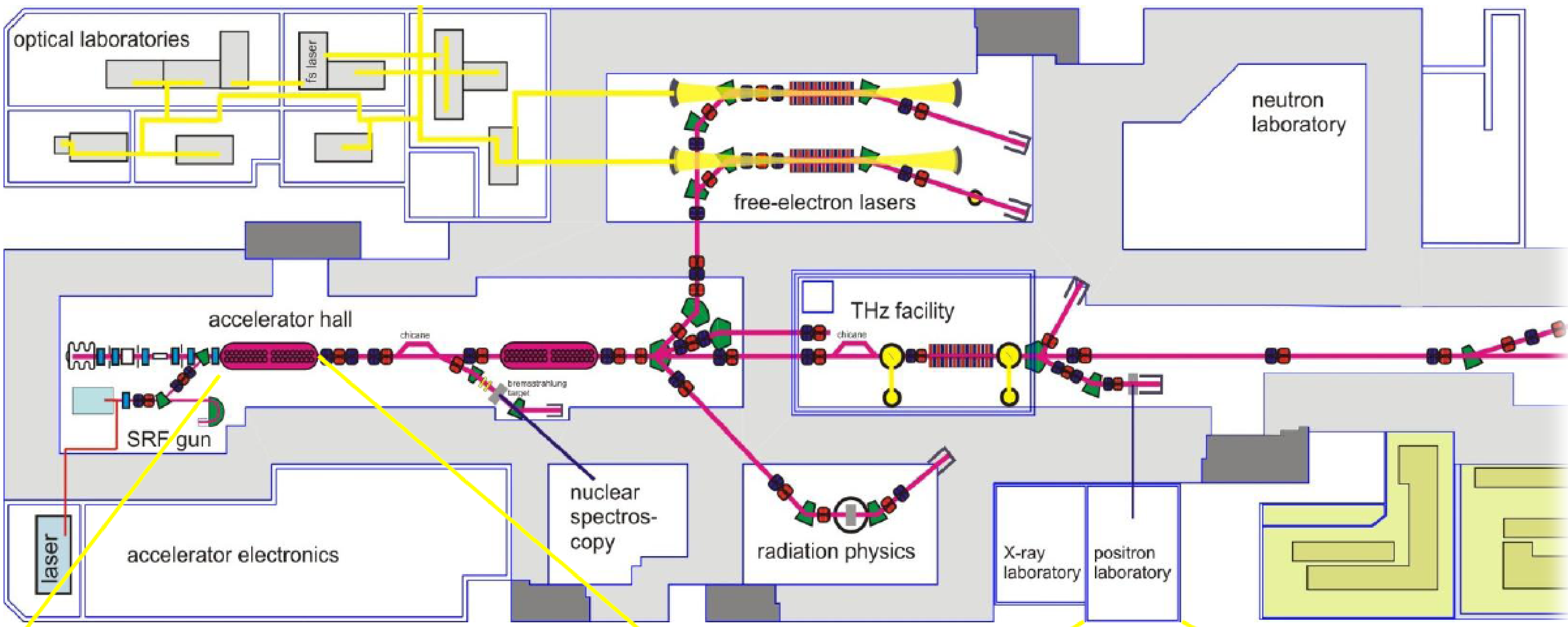
- $\tau_1 \approx$ 170 ps dislocations
- $\tau_2 \approx$ 350-400 ps vacancy clusters and surface state
- $\tau_3 \approx$ 1 – 2 ns o-Ps





Positron lifetime spectroscopy using slow positrons

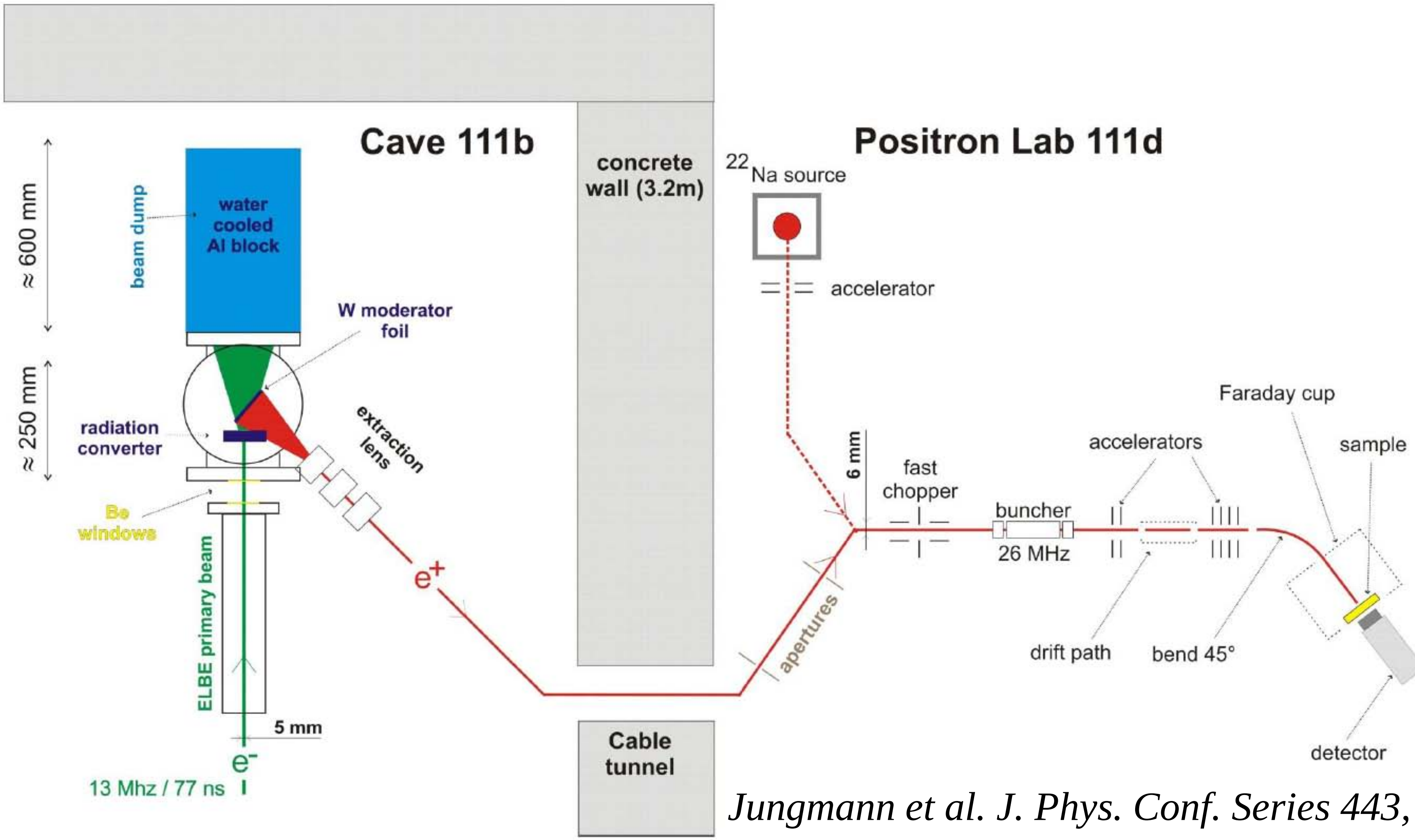
- **pulsed slow e^+ beam**
- EPOS, LINAC Elbe, Rossendorf
- ELBE: e^- T = 16 MeV, frequency f = 26 MHz (distance between pulses 38.5 ns), pulse width 5 ps



Jungmann et al. J. Phys. Conf. Series 443, 012088 (2013)

Positron lifetime spectroscopy using slow positrons

- **pulsed slow *e*$^+$ beam**
- EPOS, LINAC Elbe, Rossendorf



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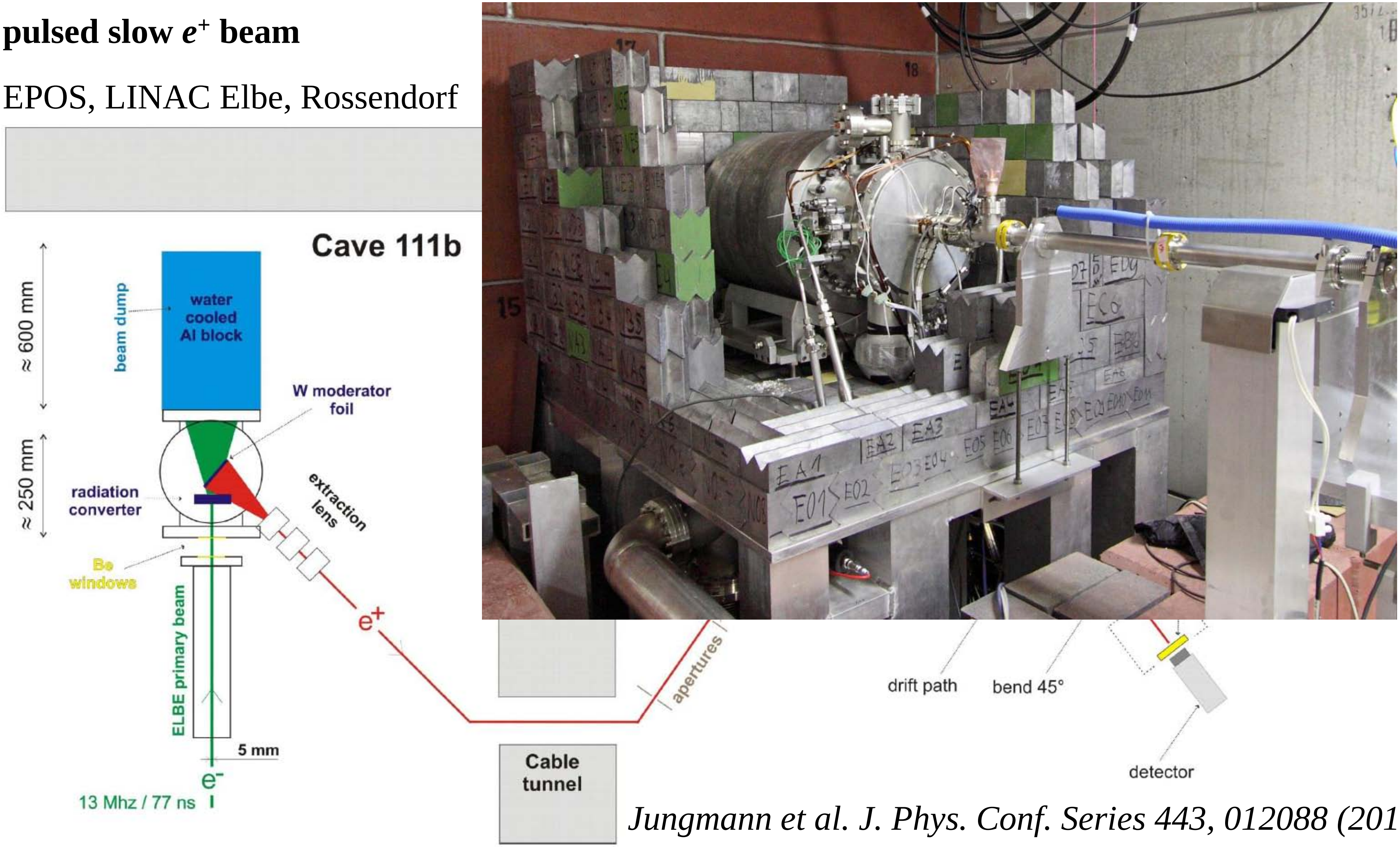

Jungmann et al. J. Phys. Conf. Series 443, 012088 (2013)

Positron lifetime spectroscopy using slow positrons

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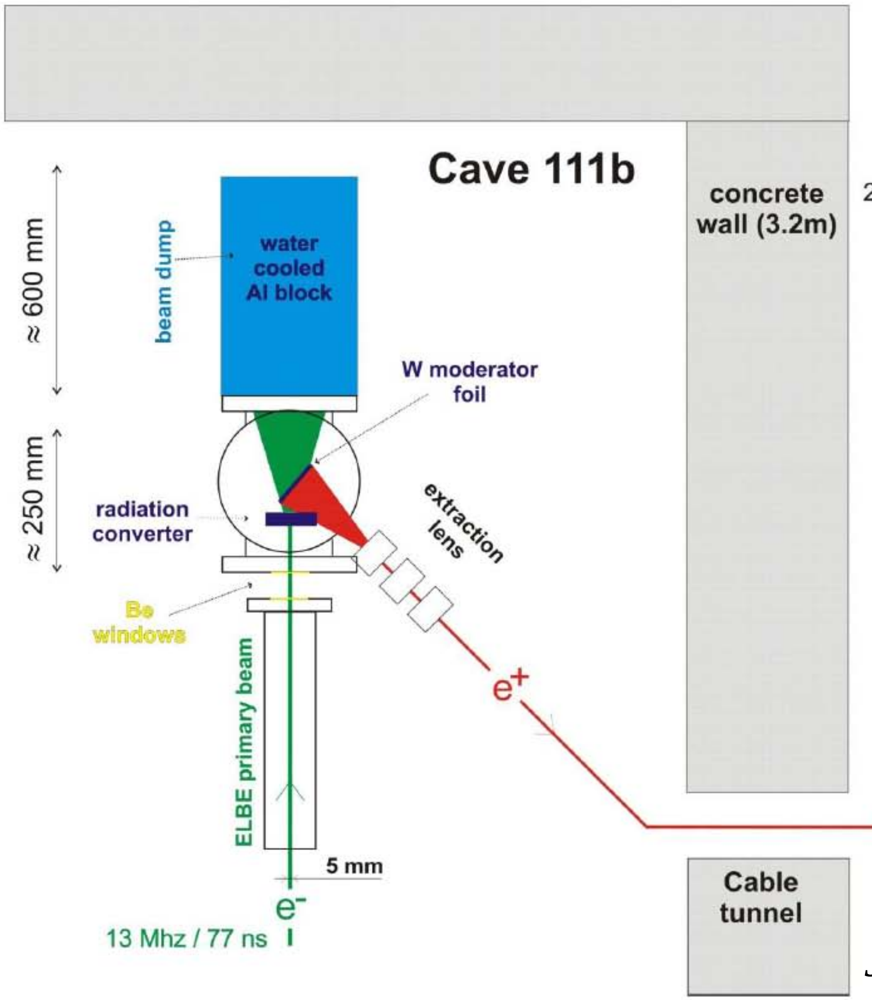

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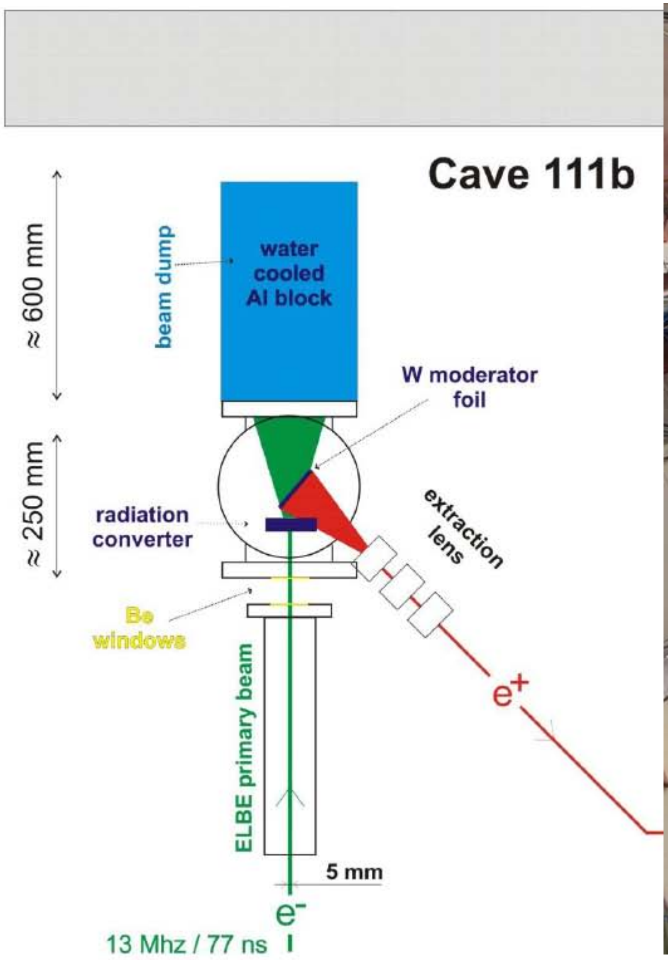

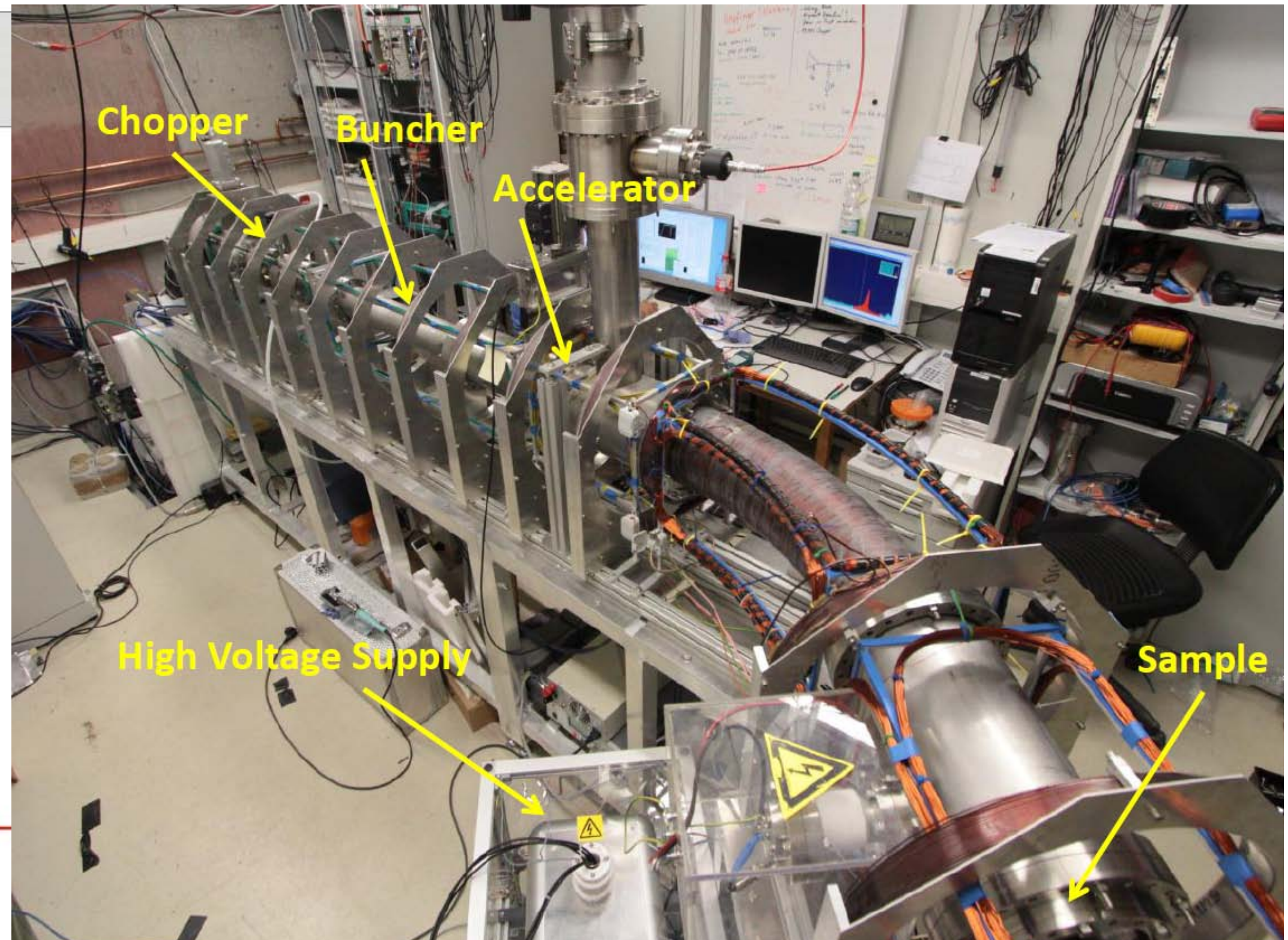

Jungmann et al. J. Phys. Conf. Series 443, 012088 (2013)

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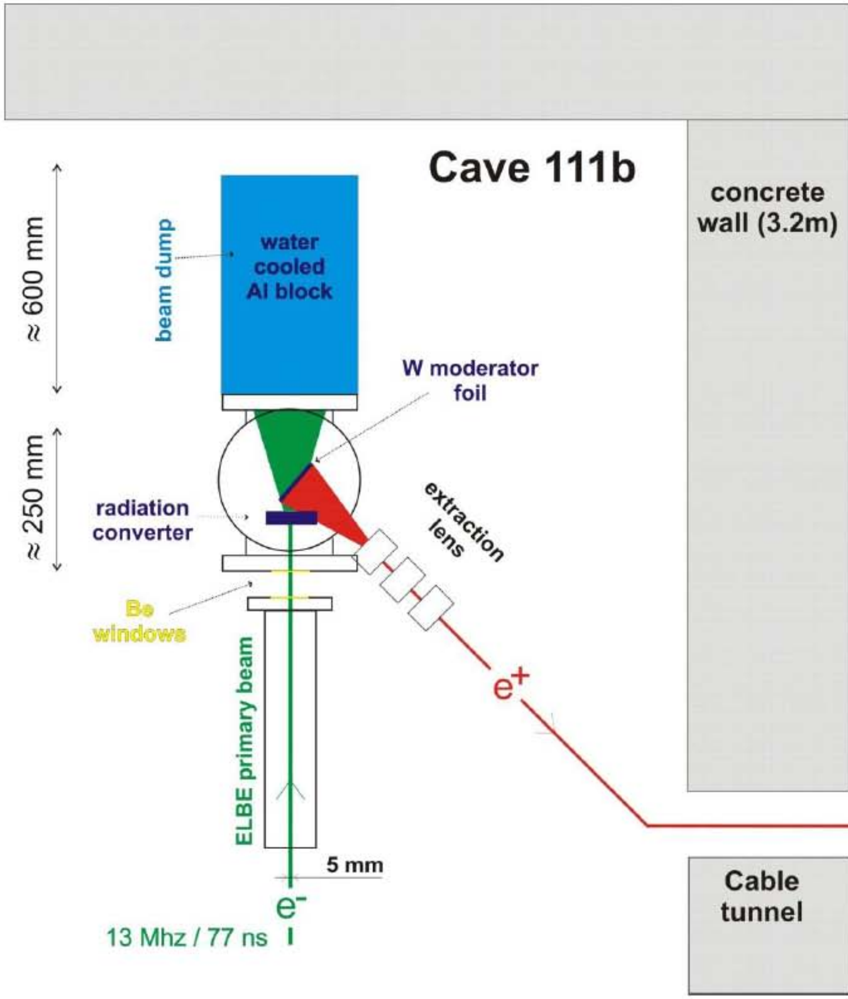
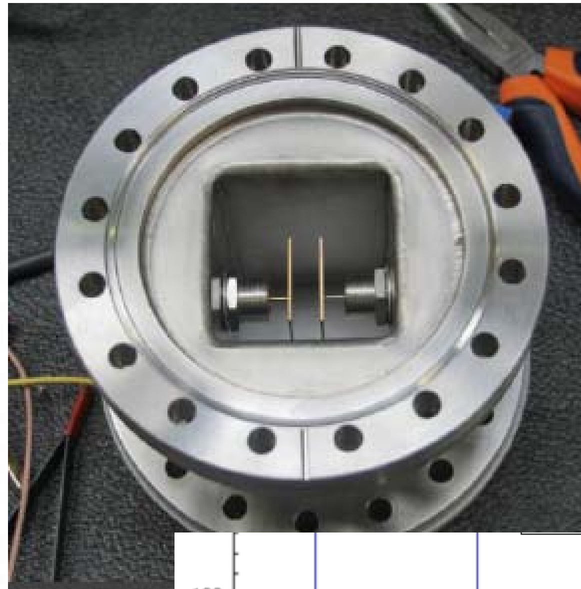
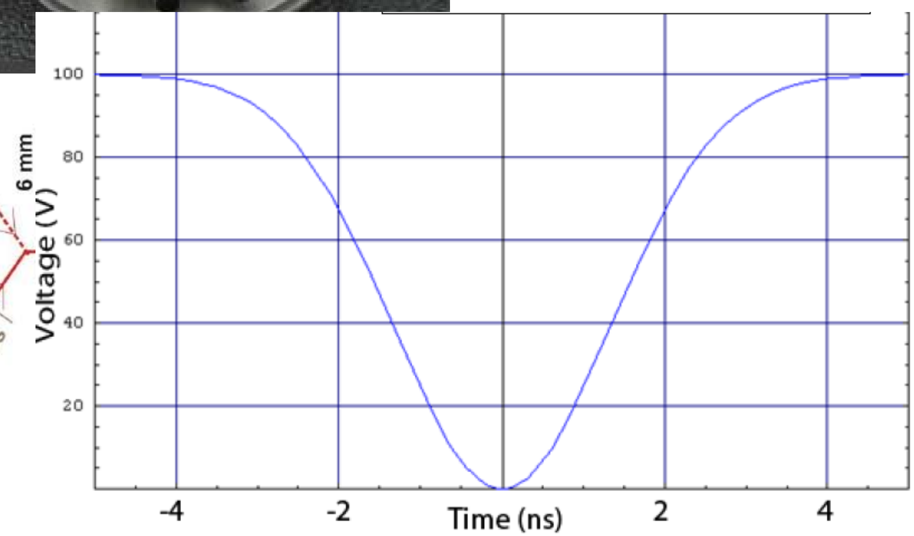


chopper



- 13 MHz, 100 V
- Gaussian pulse
- width 4 ns



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Positron lifetime spectroscopy using slow positrons

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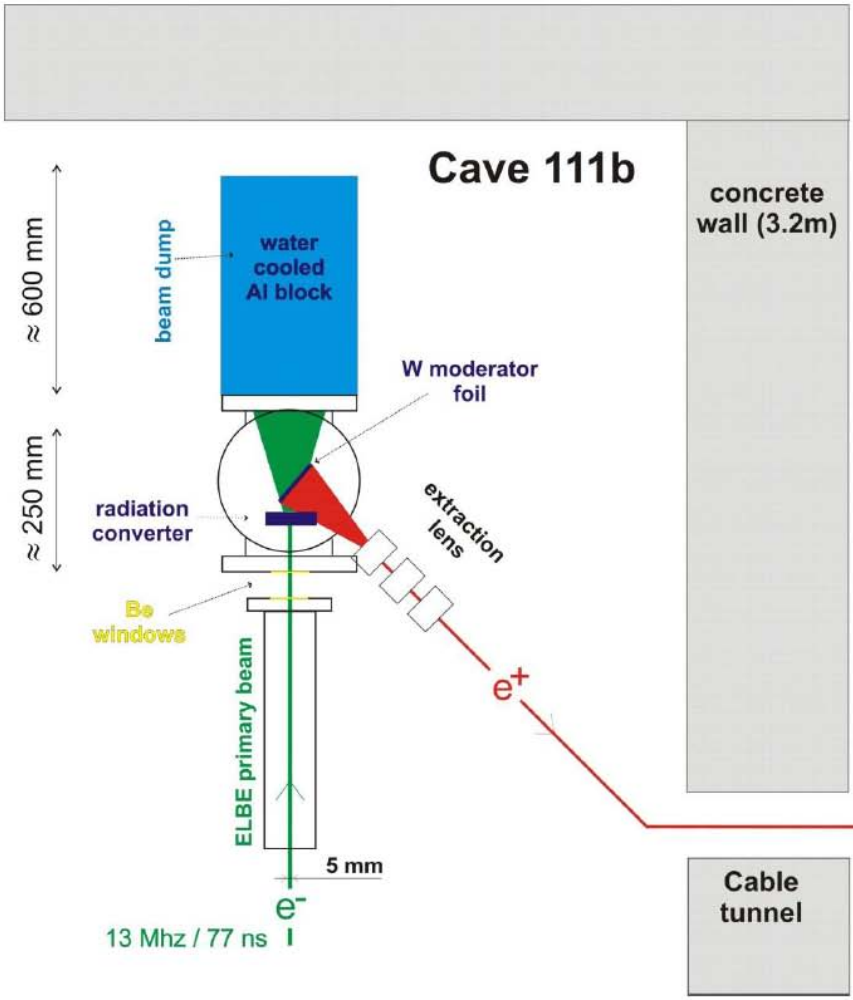
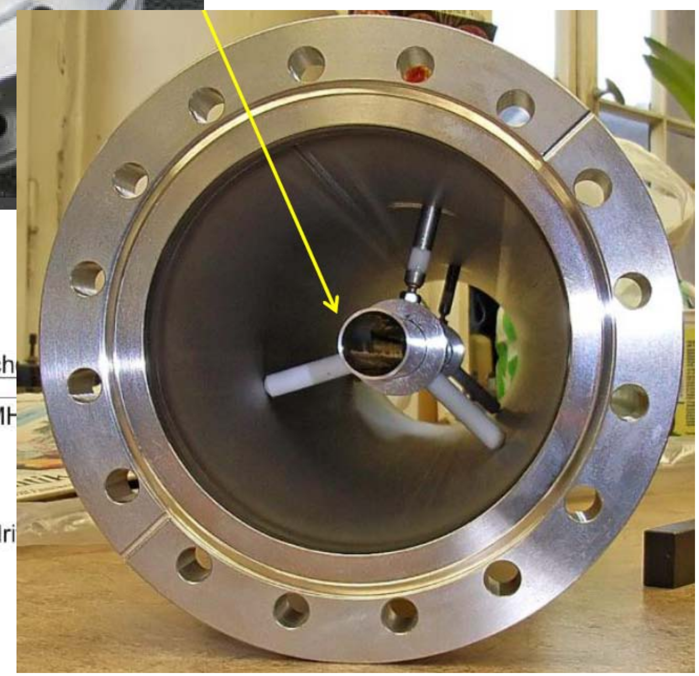


chopper

buncher



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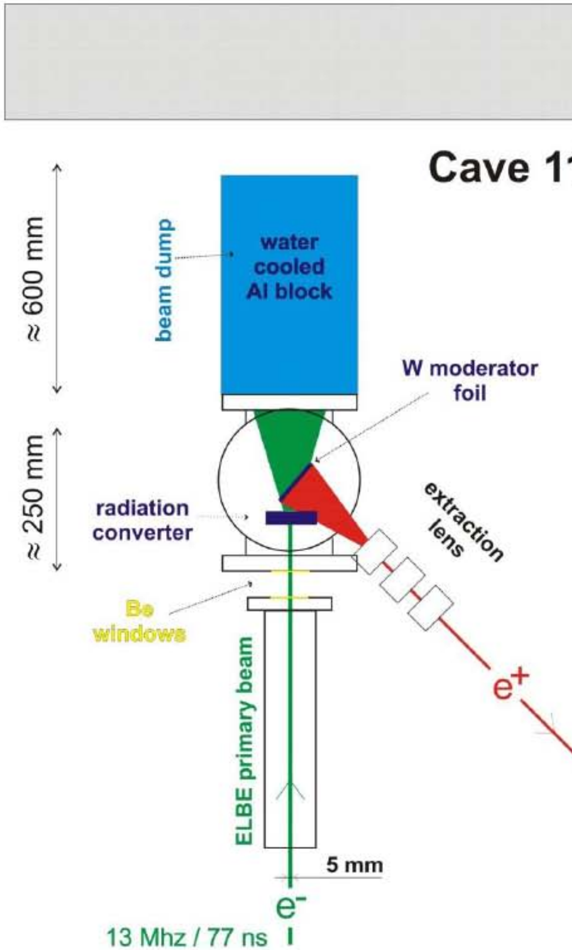

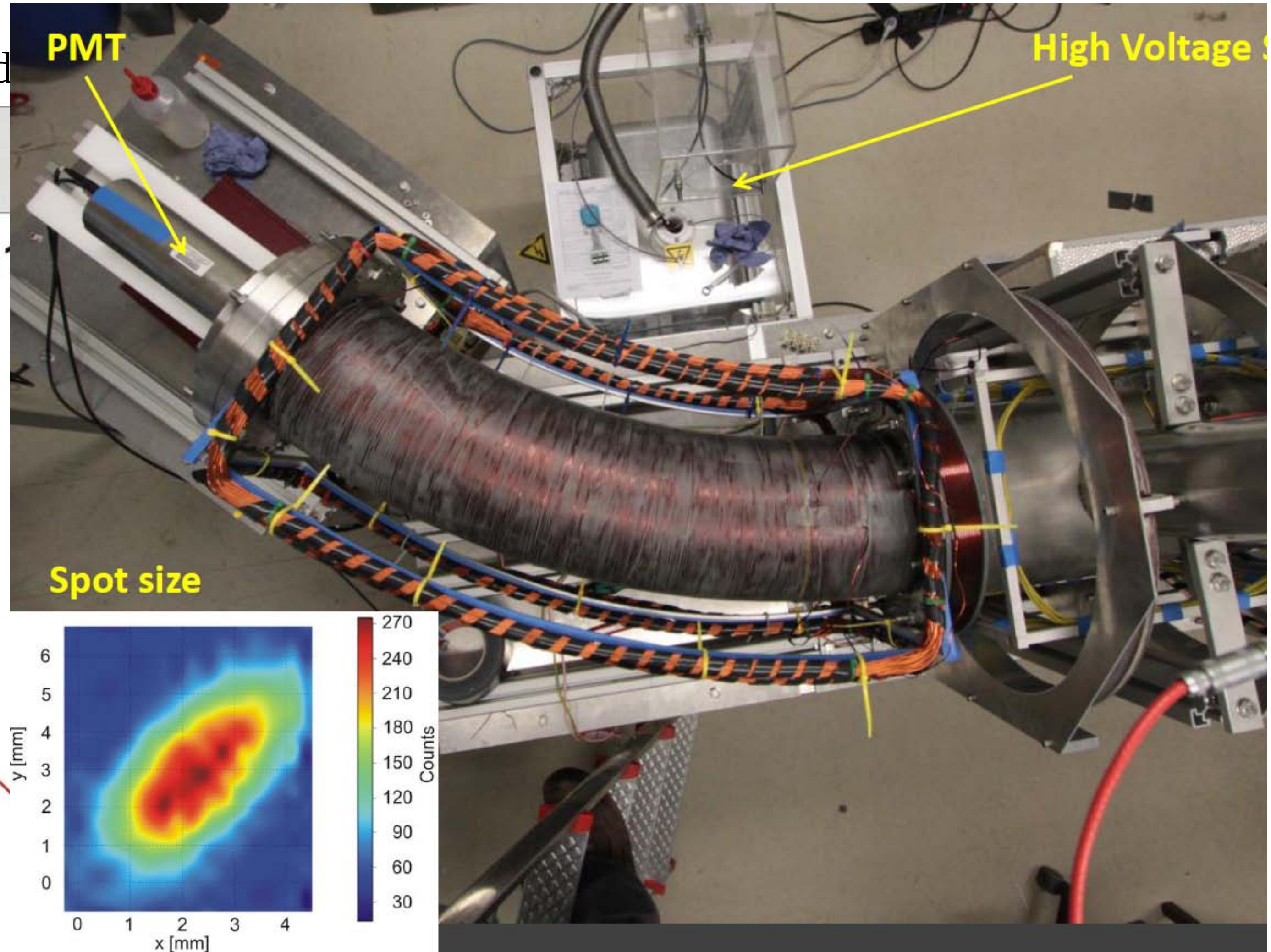

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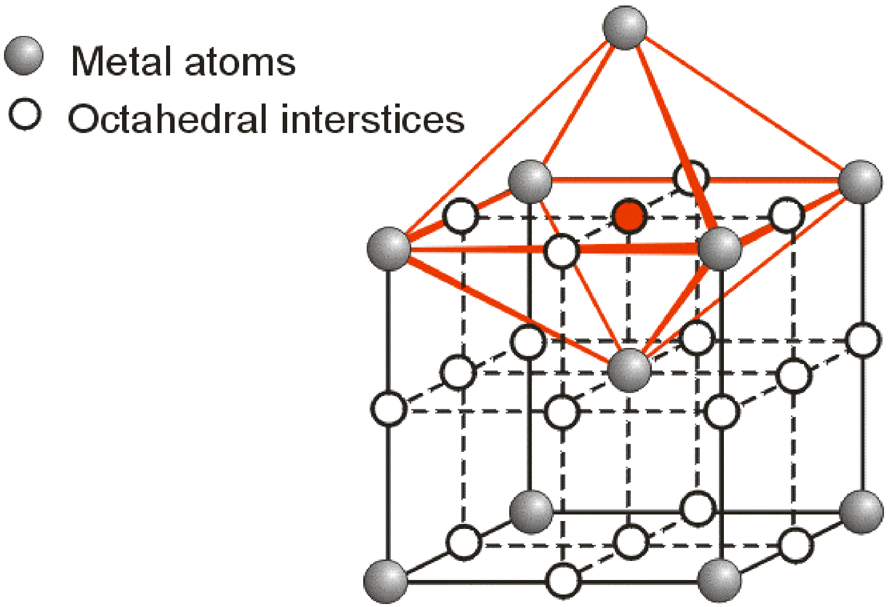
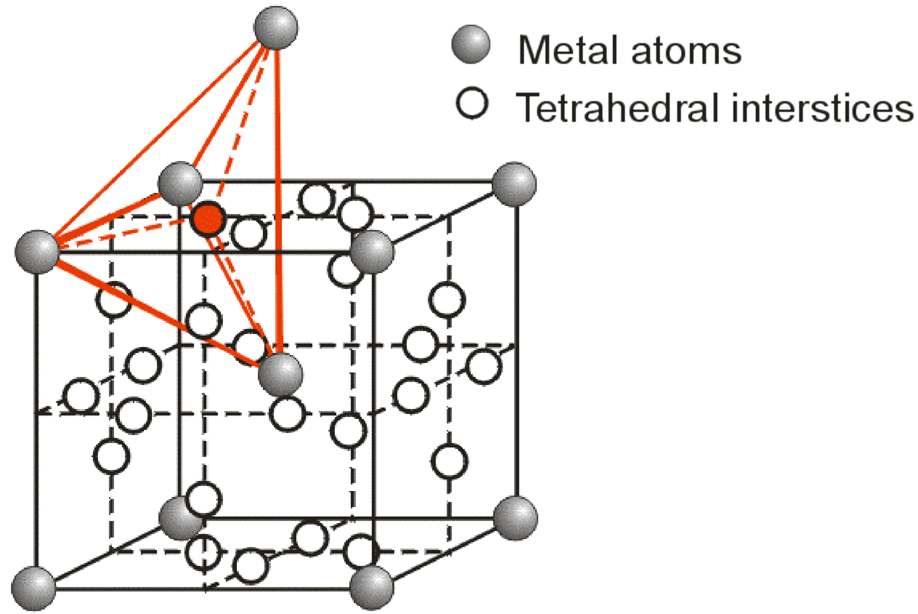
Vacancy - hydrogen interaction in Nb

- **Hydrogen absorption in Nb**
- interstitial sites in bcc Nb lattice

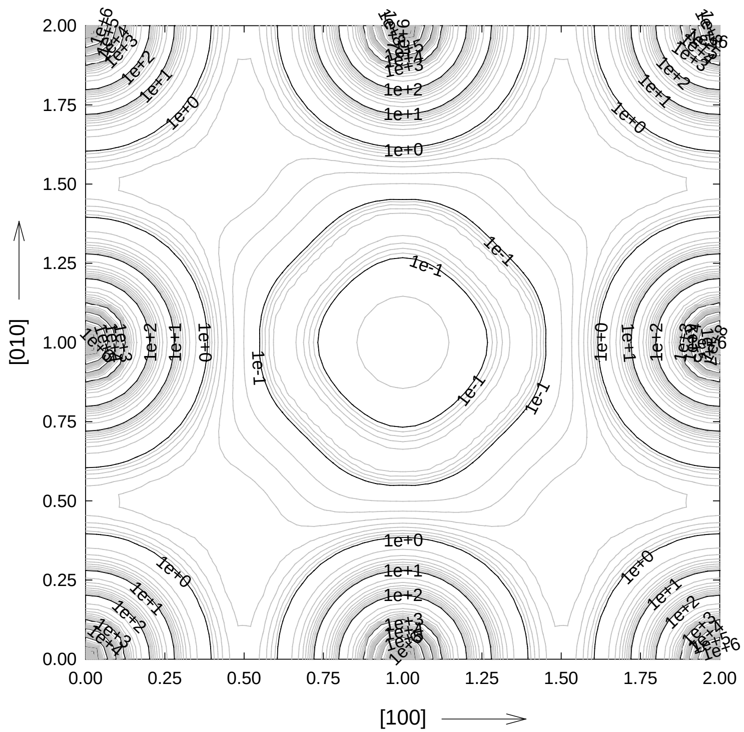


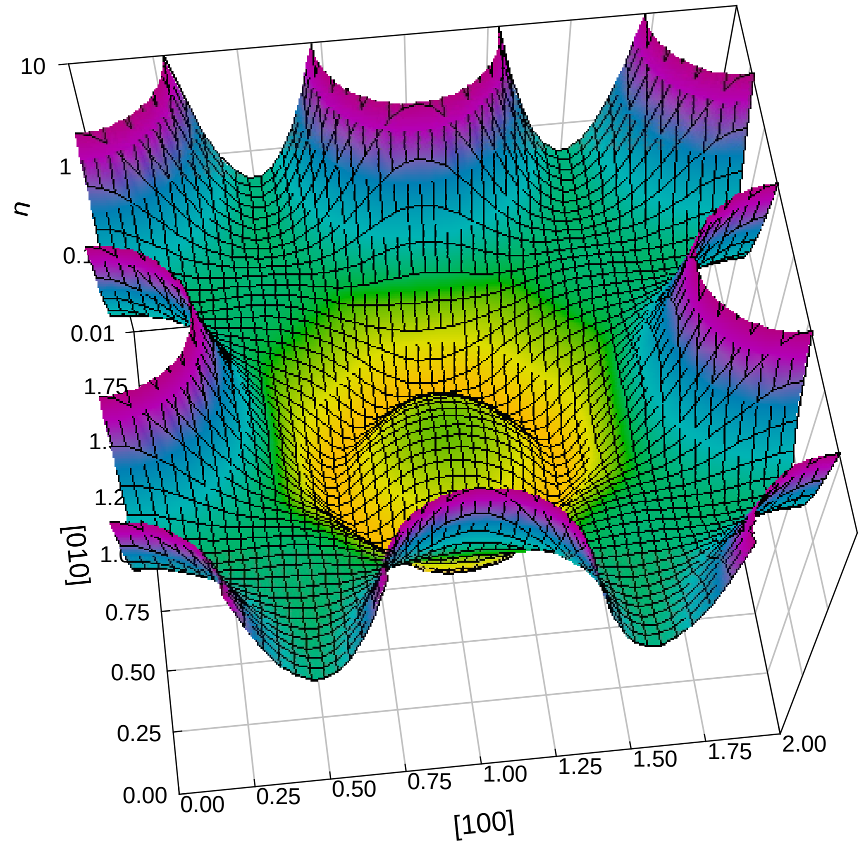


size (r_{Nb}):	0.155	0.291	**H ≈ 0.35**
N_i/cell	6	12	
N_i/M	3	6	

Vacancy - hydrogen interaction in Nb

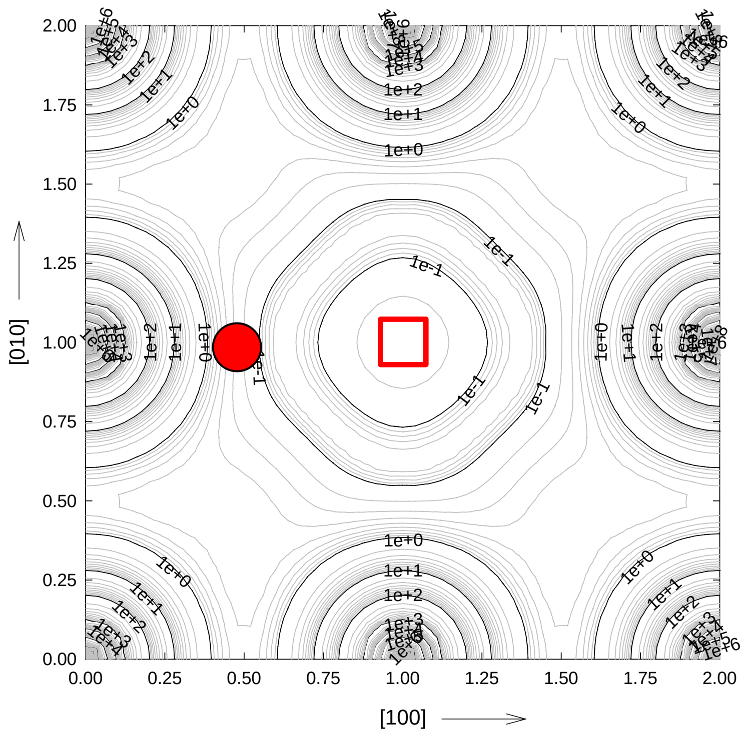
- **Nb with vacancy**

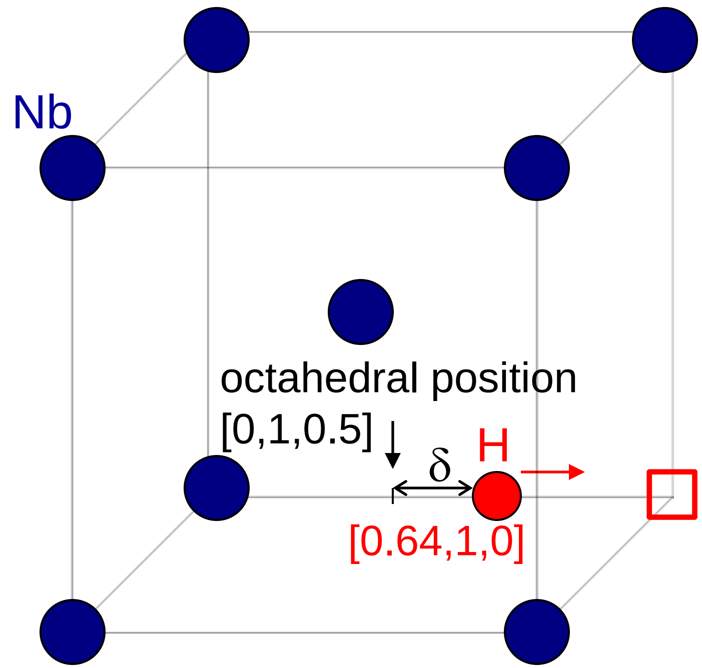




Vacancy - hydrogen interaction in Nb

• **Nb with vacancy**



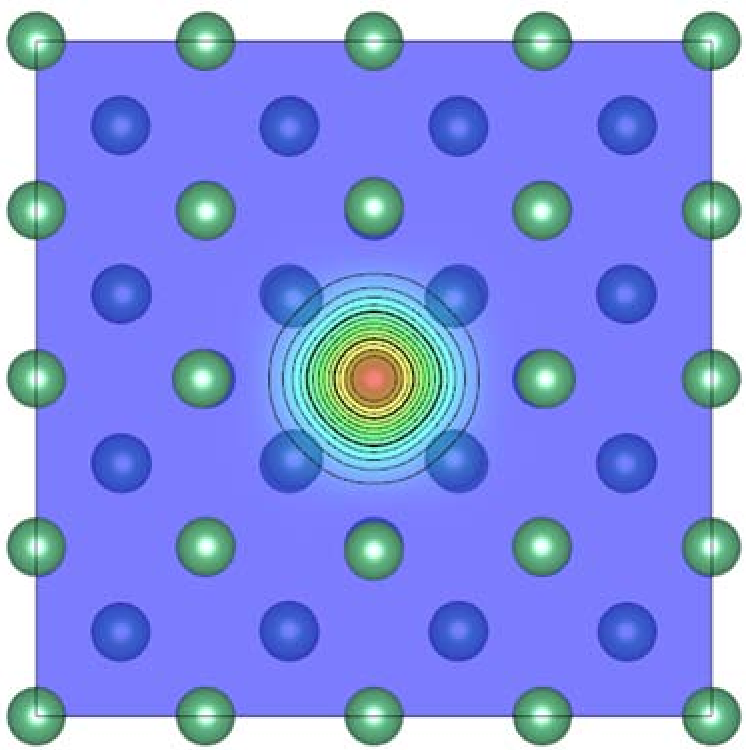


• displacement δ = 0.46(7) Å

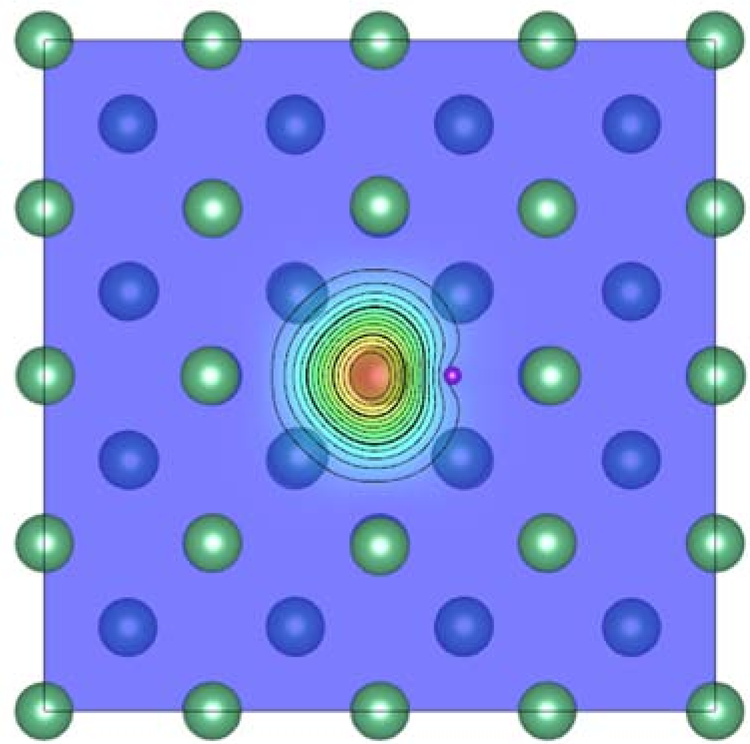
Vacancy - hydrogen interaction in Nb

- **Nb with vacancy**
- calculated positron density in (001) plane

V 202 ps



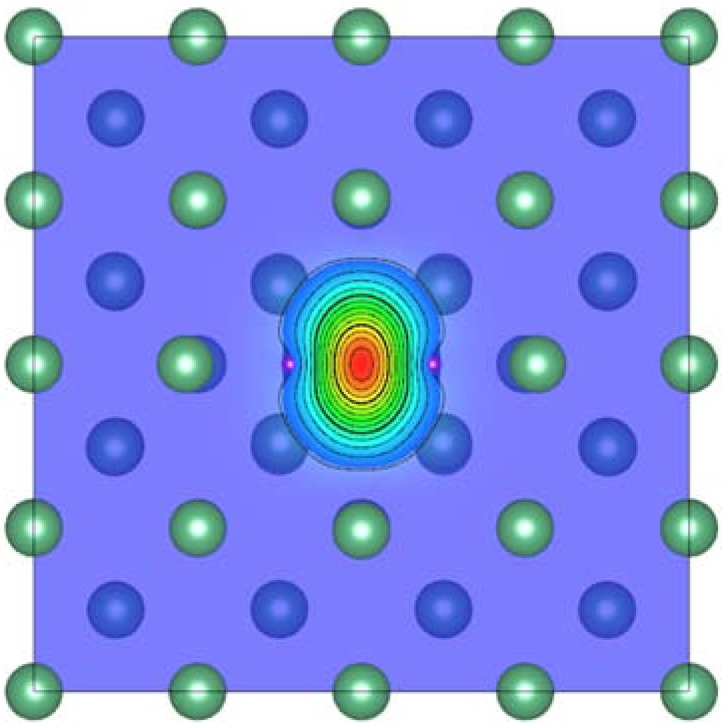
V – H 172 ps



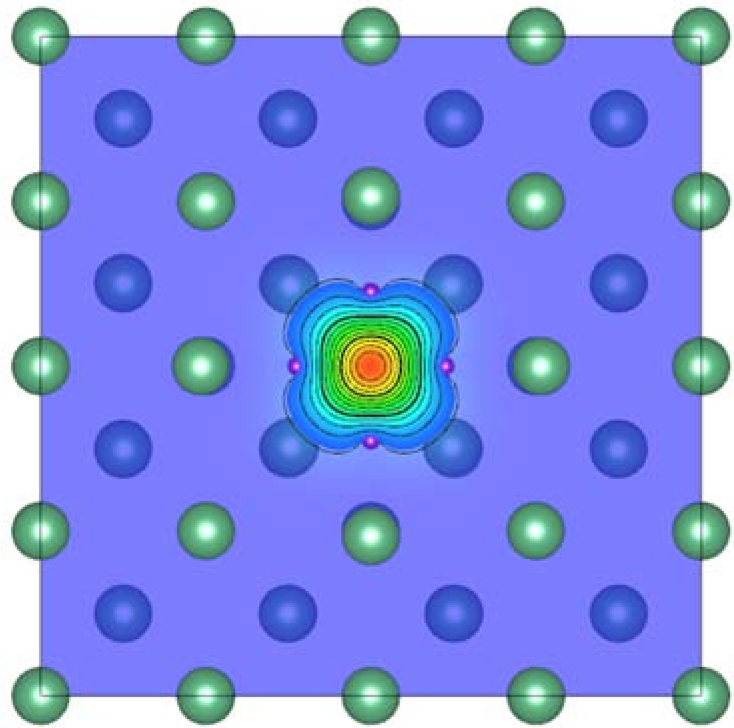
Vacancy - hydrogen interaction in Nb

- **Nb with vacancy**
- calculated positron density in (001) plane

V – 2H 167 ps

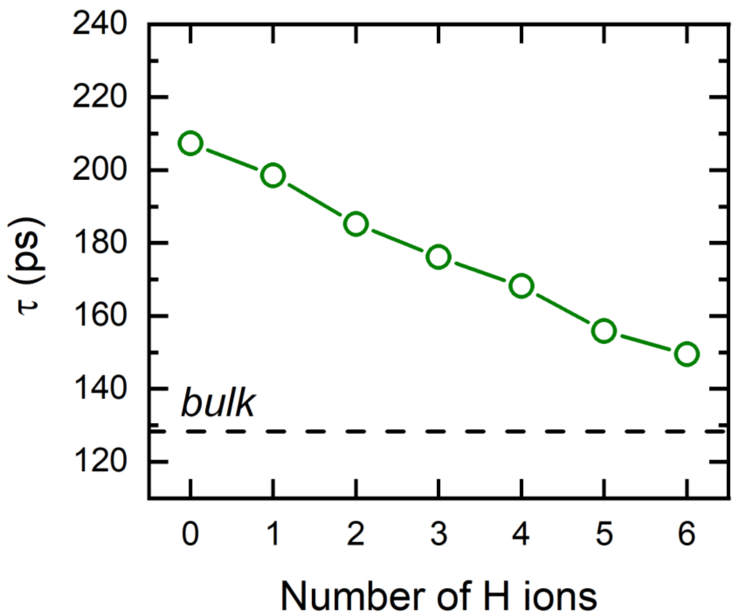


V - 4H 151 ps

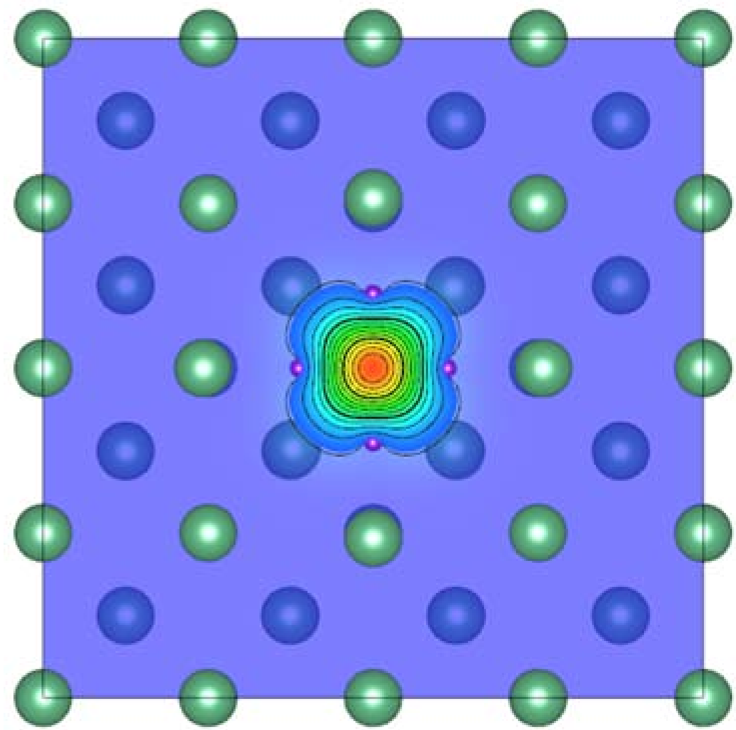


Vacancy - hydrogen interaction in Nb

- **Nb with vacancy**
- calculated positron density in (001) plane



V - 4H 151 ps



Vacancy - hydrogen interaction in Nb

• **pulsed slow *e*$^+$ beam**

• EPOS, LINAC Elbe, Rossendorf