Positron Production
&
Positron Beam Experiments at NEPOMUC

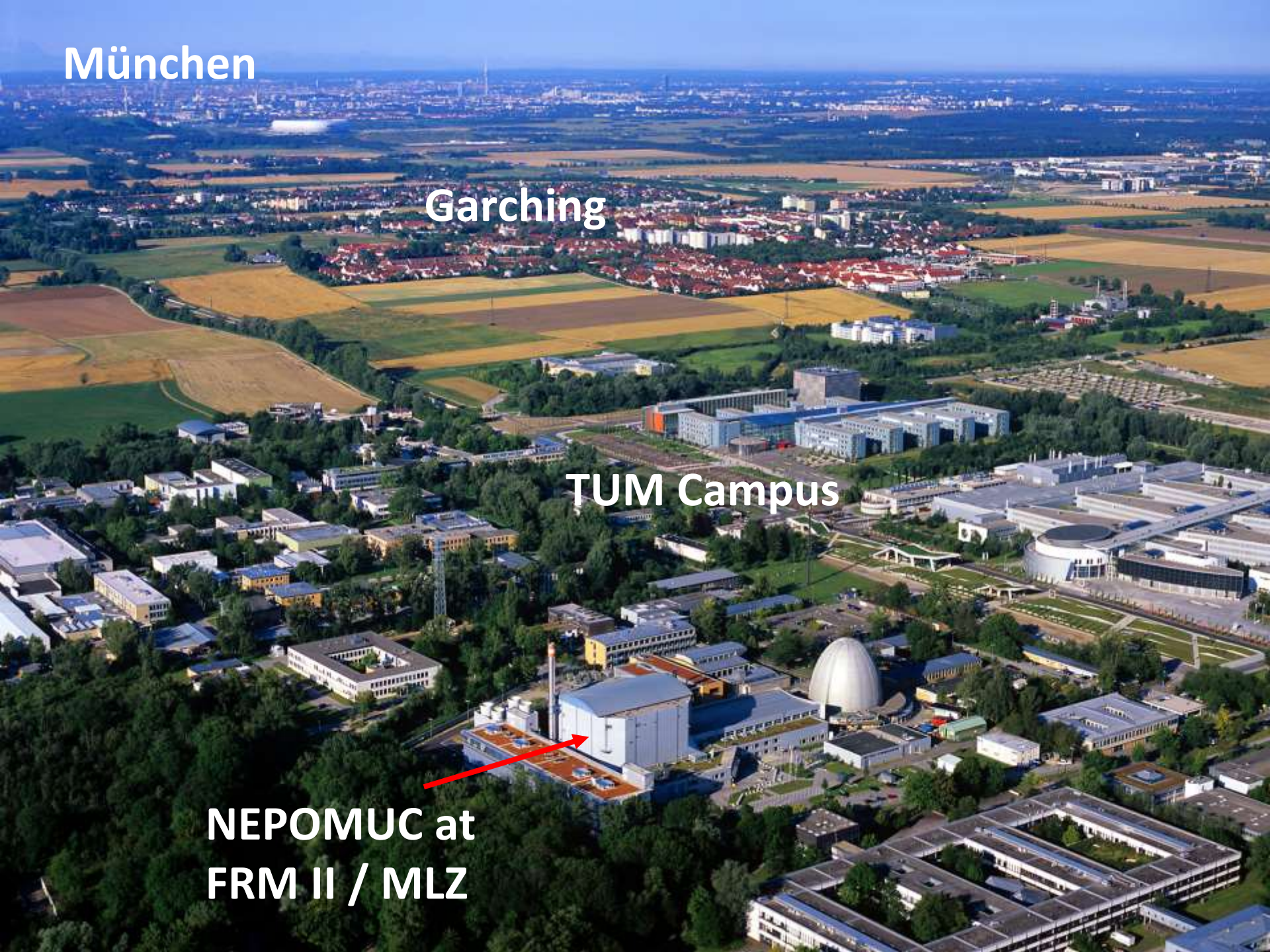
Christoph Hugenschmidt

Technische Universität München

MLZ Heinz Maier-Leibnitz Zentrum

Arbeitsgebiet Physik mit Positronen

NEPOMUC


München
Garching
TUM Campus
NEPOMUC at
FRM II / MLZ

Positron Beam Facility at NEPOMUC

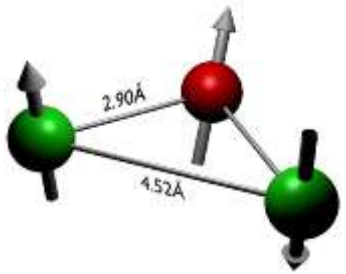
NEPOMUC

Positron Source
SR11

Coincident Doppler
Broadening Spectrometer

Surface Spectrometer

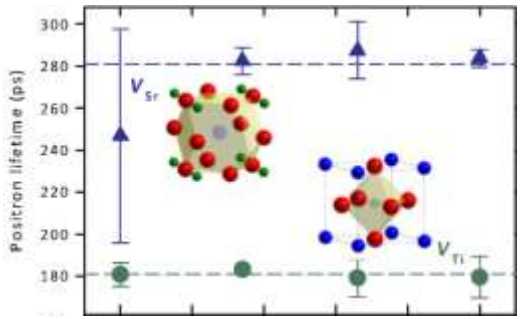
Fundamental Physics



H. Ceeh et al.
PRA 84 (2011) 062508

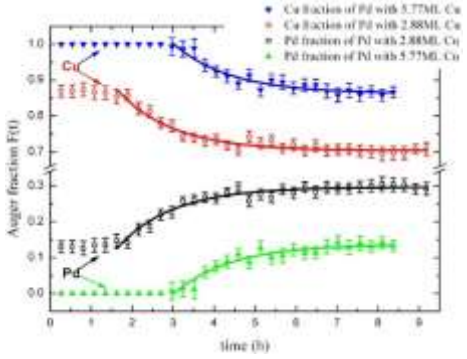
T. Sunn Pedersen et al.
New J. Phys. 14 (2012) 035010

Positron Lifetime Spectroscopy



D. Keeble et al. PRB 87 (2013) 195409

Positron Auger Electron Spectroscopy

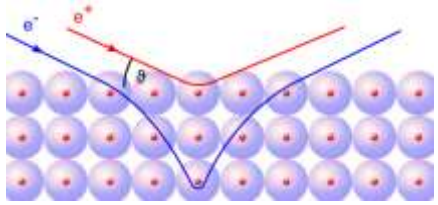


J. Mayer et al. PRL 05 (2010) 207401

Scanning Positron Beam

T. Gigl, et al. New J. Phys. 19 (2017) 123007

NEW: Positron Diffraction



C.H., Surf. Sci. Rep. 6 (2016) 547

Outline

Part I

Positron Microbeam

at

CDB Spectrometer

Part II

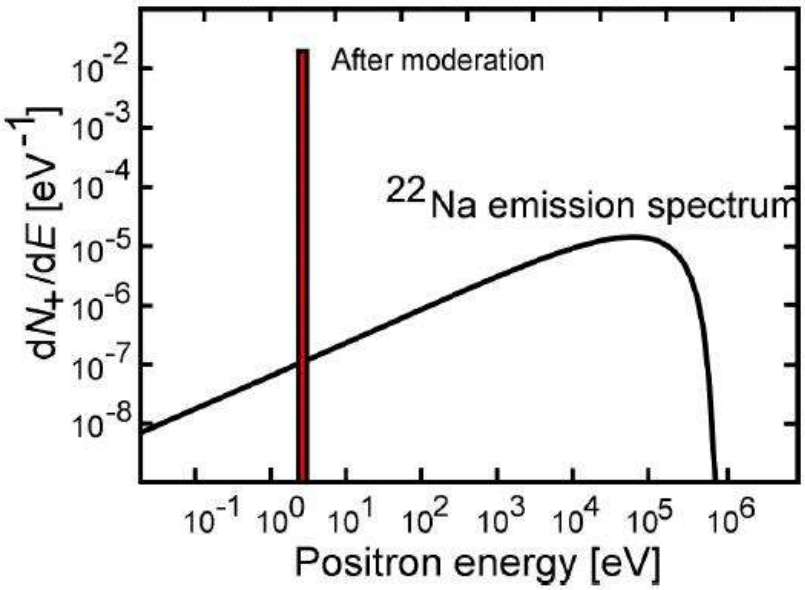
Al Welds

&

Defect Imaging

Positron Beams

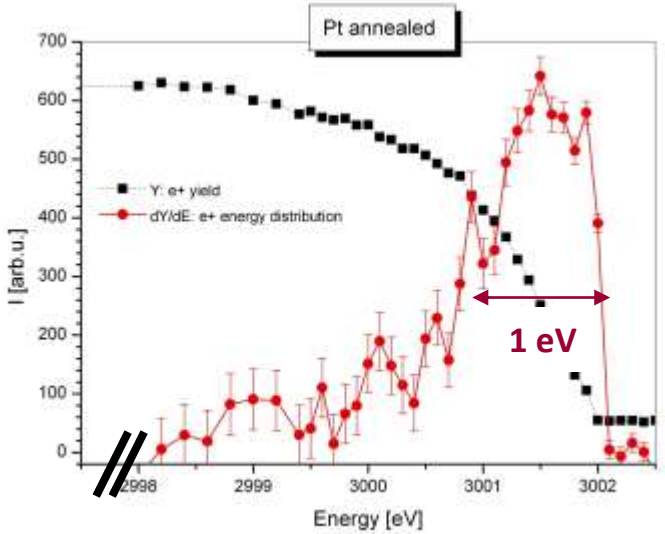
- **β^+ isotopes** $p \rightarrow n\, e^+ \upsilon_e$
  - → high e+ yield
  - → long τ
  - → lab beams
- **Pair production** $\gamma \rightarrow e^+ e^-$
  - → $E_\gamma > 2m_e c^2$
  - → high Z
  - → large scale facilities



- **E_{e+} ~ keV**
- **$\Delta E < 2$ eV**
- **NEPOMUC**:

Pt as converter **AND** moderator

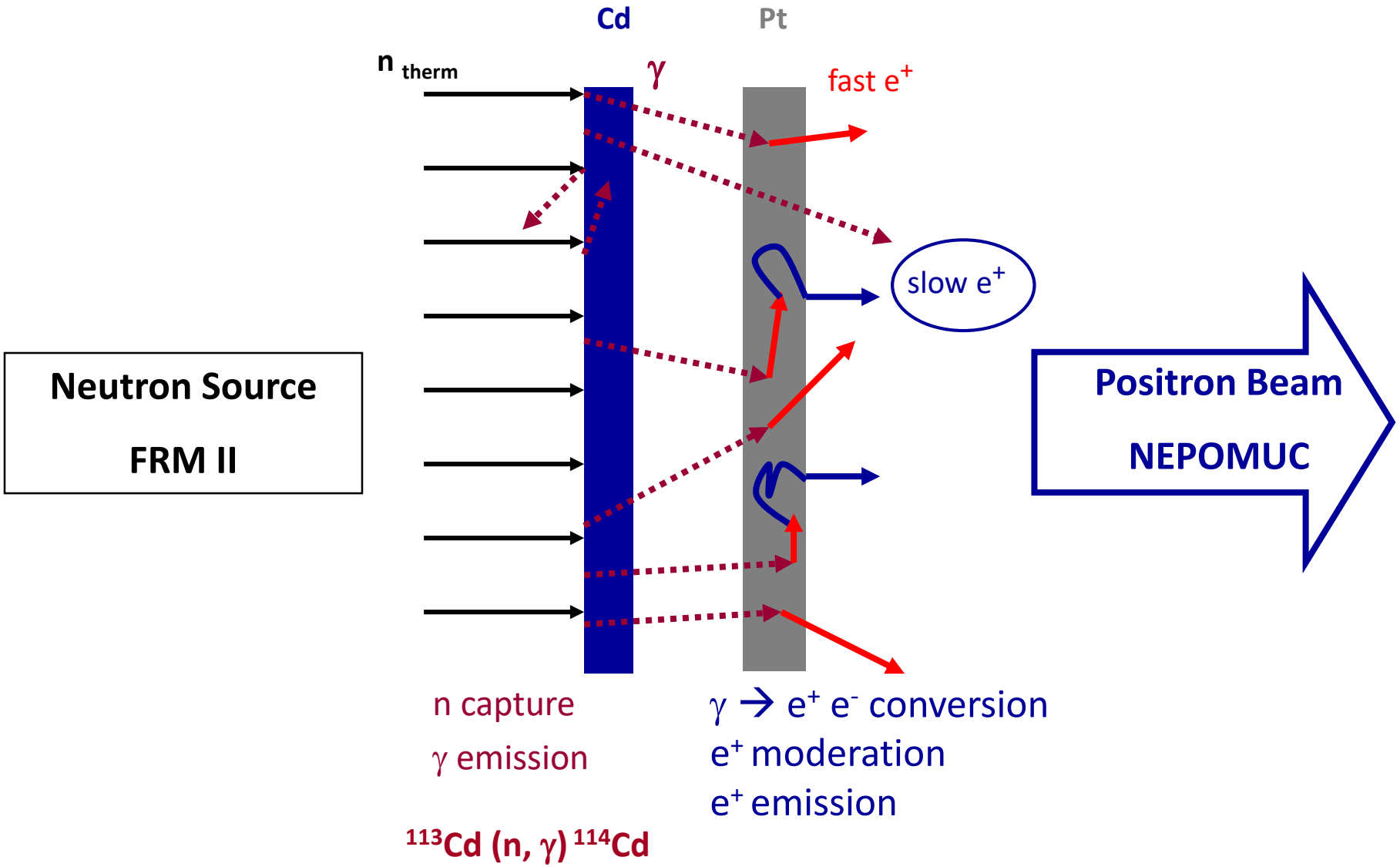
$\phi^+_{Pt} = -1.95(5)$ eV



C. H. et al. NIM B 198 (2002) 220

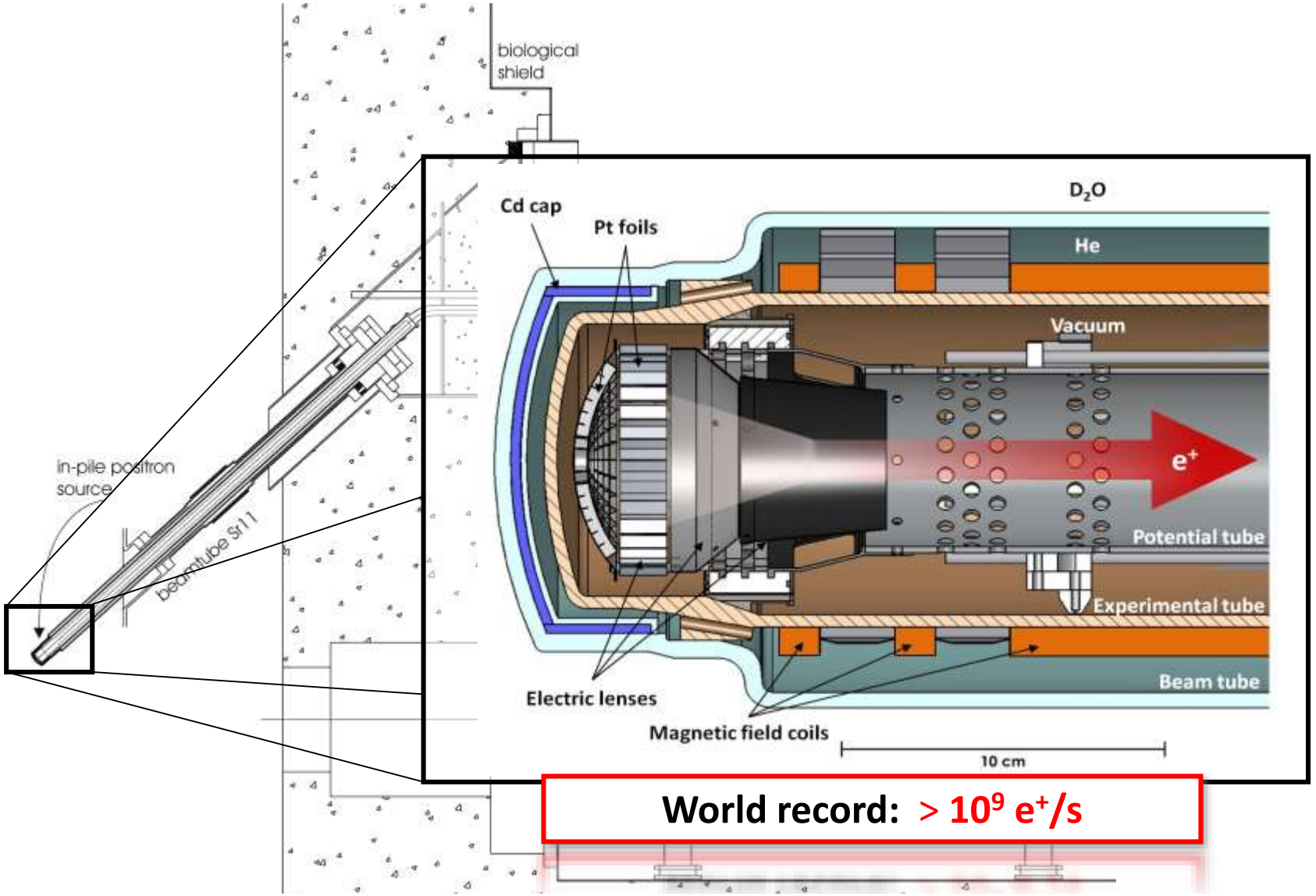
NEPOMUC

***NE**utron induced **PO**sitron Source **MU**ni**C**h*



NEPOMUC

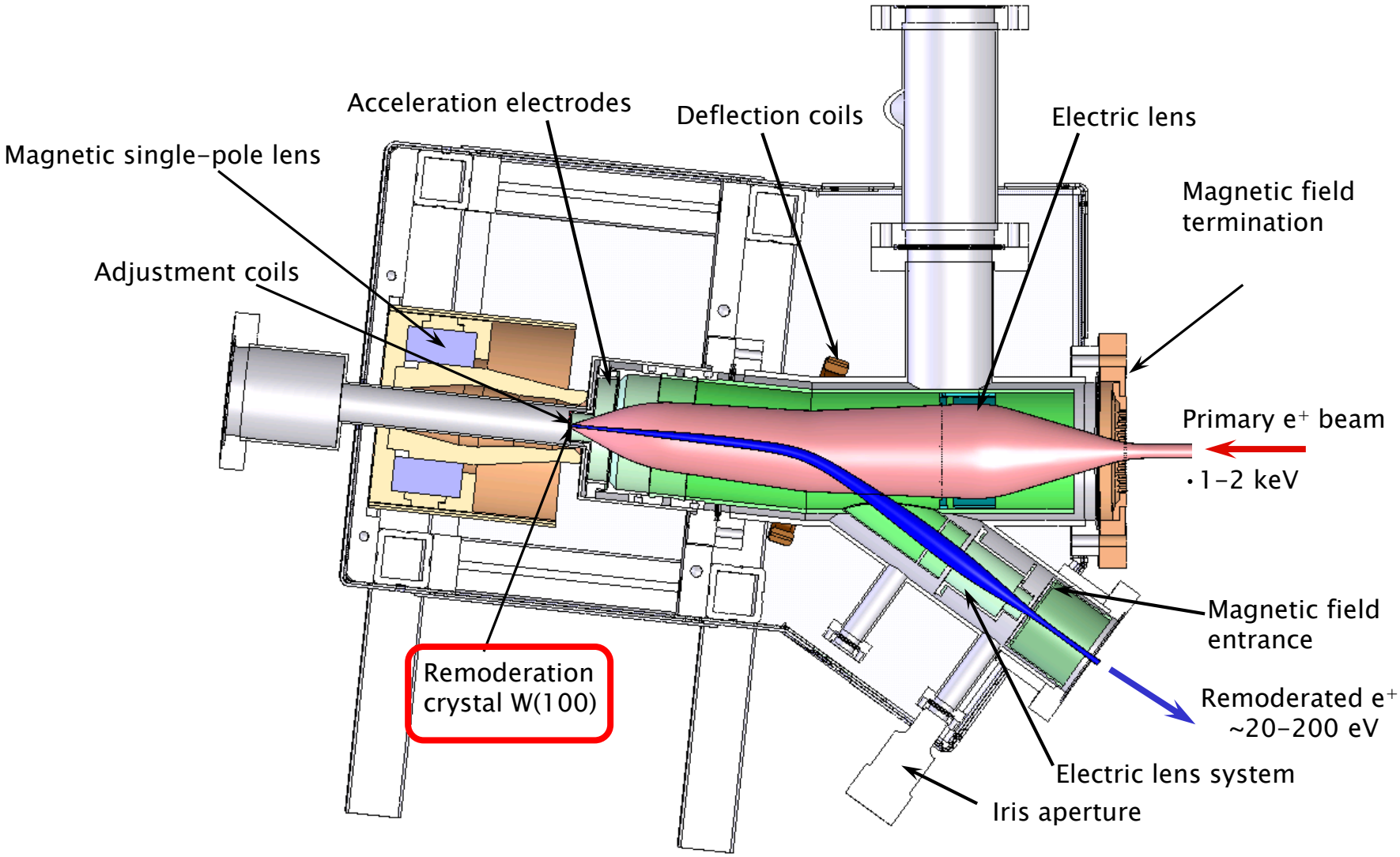
***NE**utron induced **PO**sitron Source **MU**ni**C**h*



World record: > 10^9 e^+/s

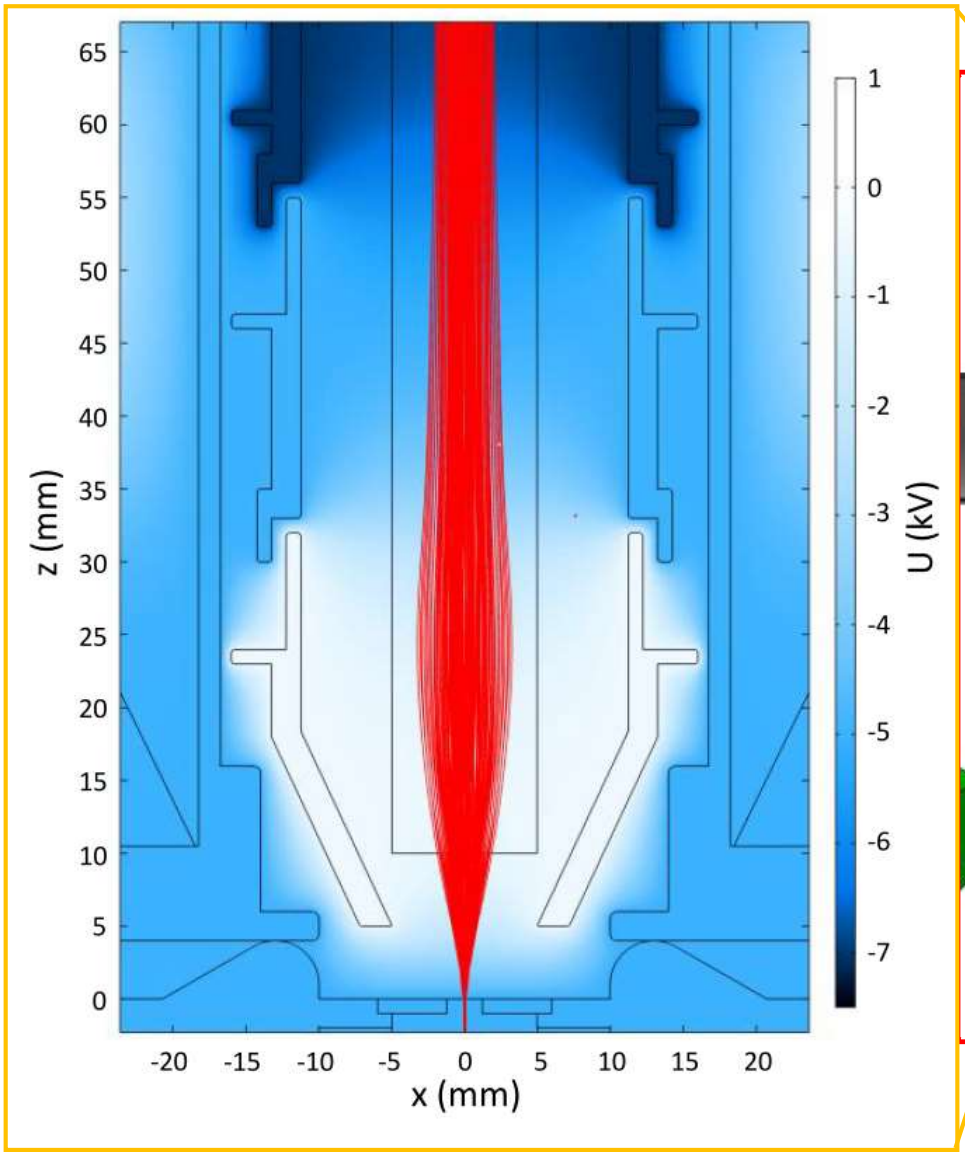
C. H. et al NIM A 593 (2008) 616; New J. Phys. 14 (2012) 055027; J. Phys. Conf. Ser. 443 (2013) 012079; Surf. Sci. Reports 71 (2016) 547

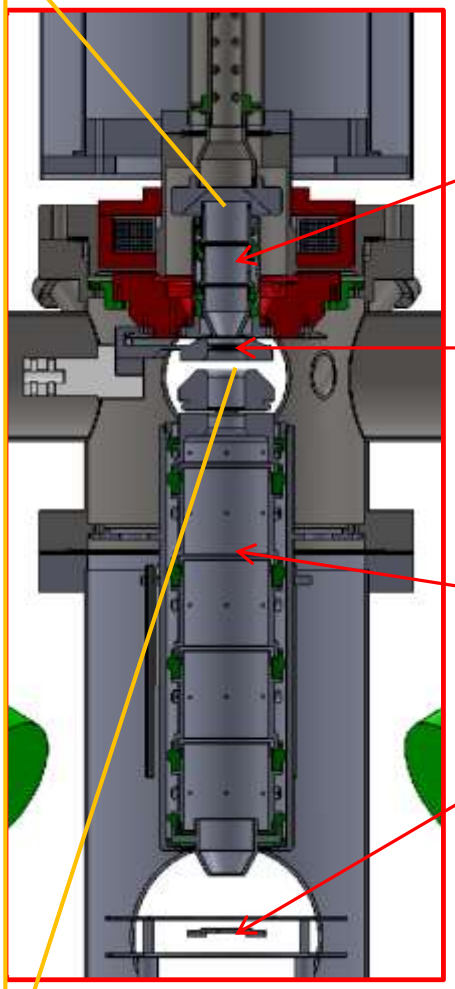
Brightness Enhancement by Remoderation



C. H. et al. New J. Phys. 14 (2012) 055027

Ni-Remoderator in CDB Spectrometer



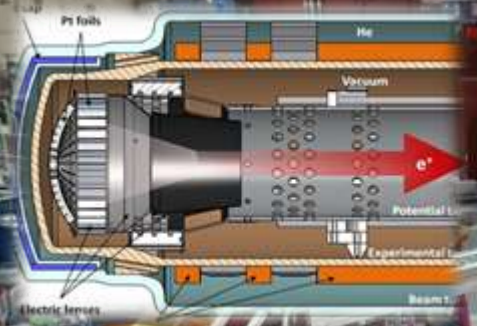


T. Gigl, L. Beddrich, M. Dickmann, B. Rienäcker, M.Thalmayr, S. Vohburger, and C. Hugenschmidt, New J. Phys. 19 (2017) 123007

Three-Fold Moderation for e^+ Microbeam

NEPOMUC

1. Pt Selfmoderation



2. W Reflexion Remoderation

Coincident Doppler Broadening Spectrometer

Scanning Positron Beam

T. Gigl, et al. New J. Phys. 19 (2017) 123007

3. Ni Transmission Remoderation

Outline

Part I

Microbeam

&

CDB Spectrometer

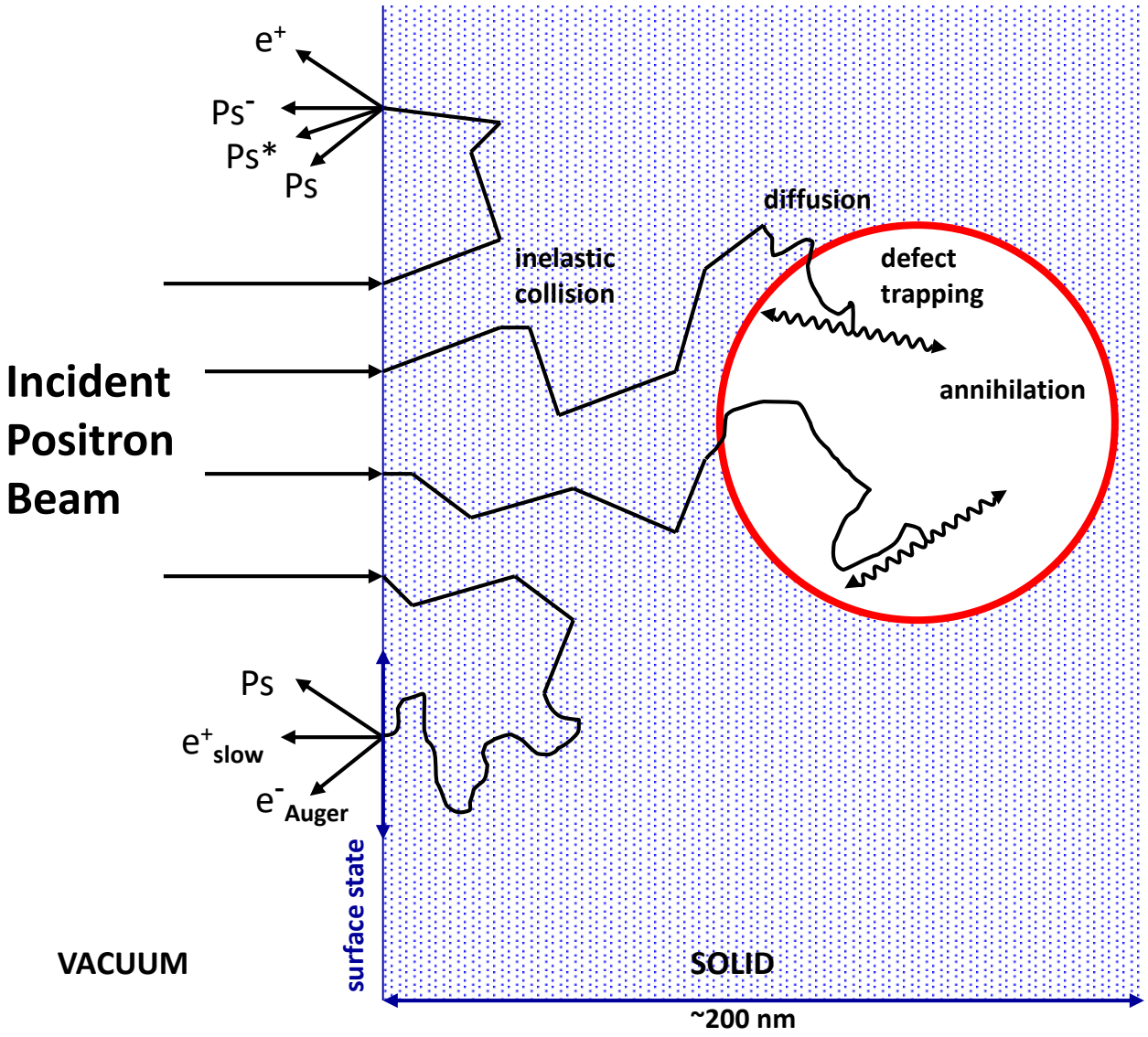
Part II

Al Welds

&

Defect Imaging

Positrons in Matter



Positrons fate:

- thermalization
  ~10^{-12} s
- diffusion
  ~10^{-10} s
  → ~100 nm
- defect trapping
- annihilation
  → 2 collinear γ-quanta

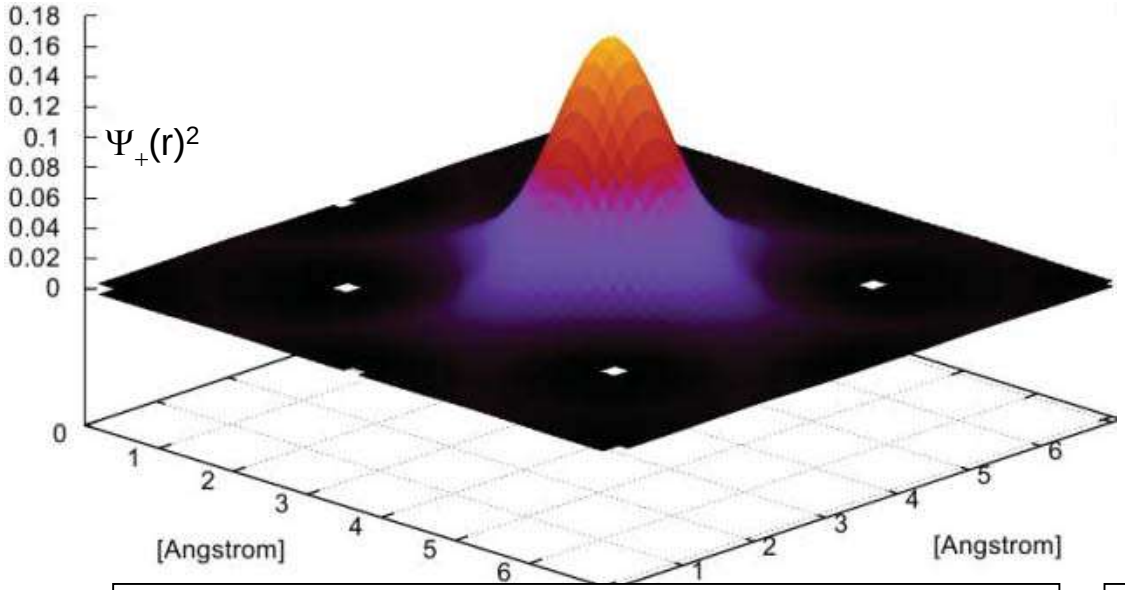
Experiment:

- positron lifetime τ
  → **ρ (e-)**
- Angular correlation **ΔΘ**
  Doppler-broadening **ΔE**
  → **p(e-)**
- Auger-electrons
  → **E_b(e-)**

REVIEW: Positrons in surface physics, C.H., Surf. Sci. Rep. 6 (2016) 547

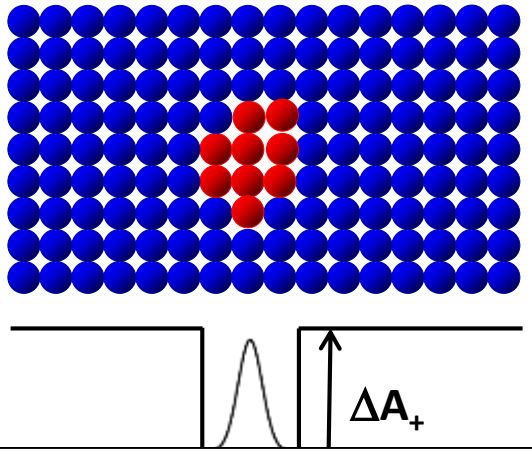
Positron Trapping

Monovacancy

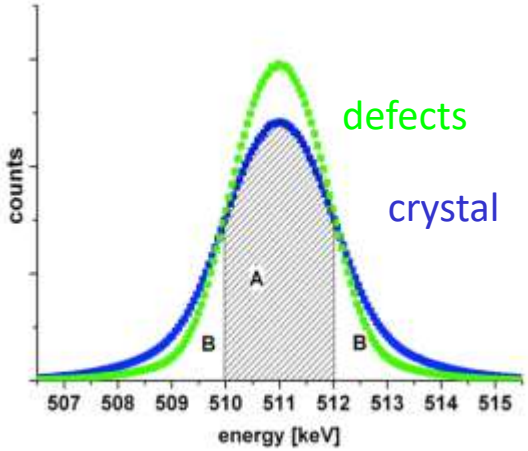


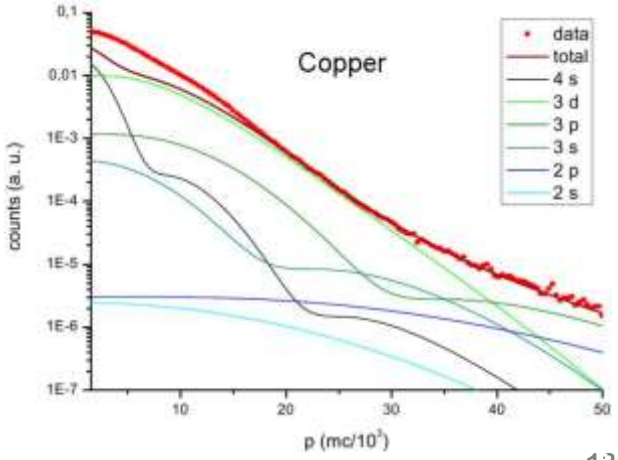
Doppler-Broadening Spectroscopy – DBS

Precipitates

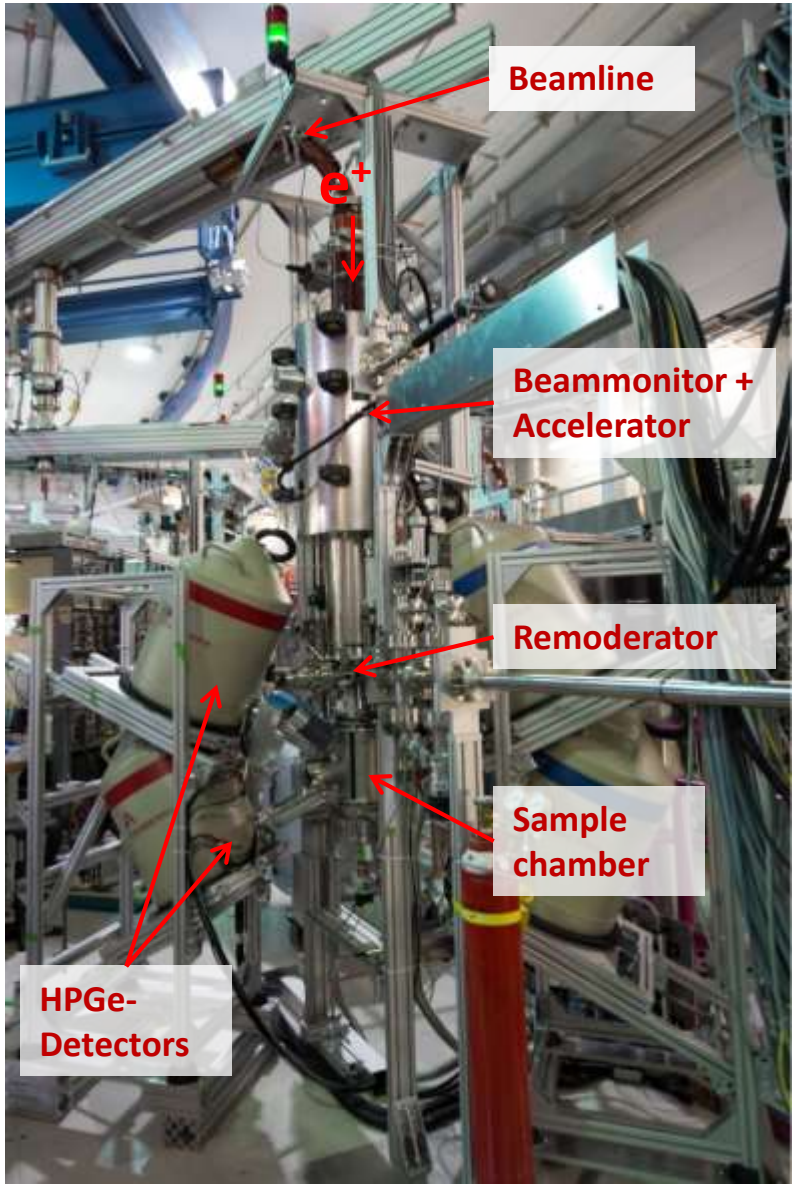


Coincident DBS – CDBS



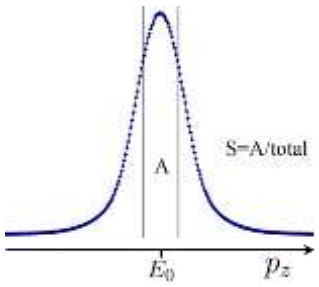


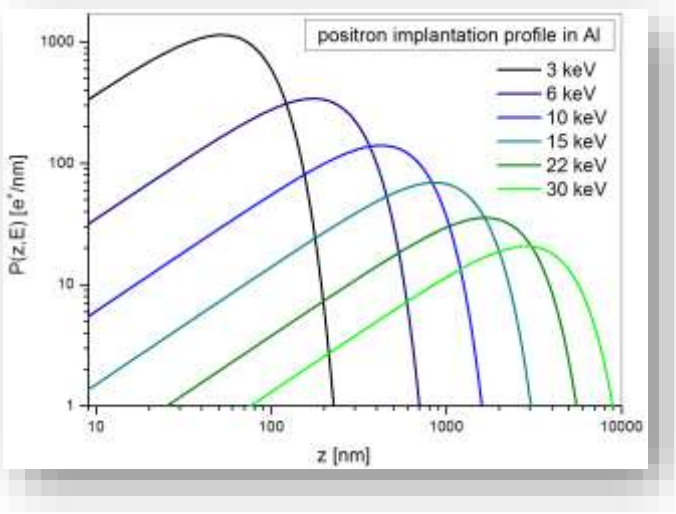
CDB Spectrometer at NEPOMUC



Doppler broadening spectroscopy

- S-parameter: S(E), S(x, y), S(T)

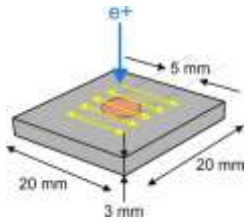


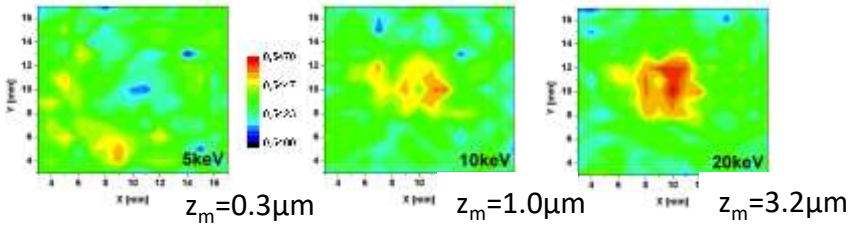


- Energy: **0.1 … 30 keV**
- Scan area: 19 x 19 mm^2
- Beam spot: **33 µm** … 250 µm
- Temperature: 60 … 1200 K
- 4 Ge Detectors, single + coincident mode

Defect Imaging with Positrons

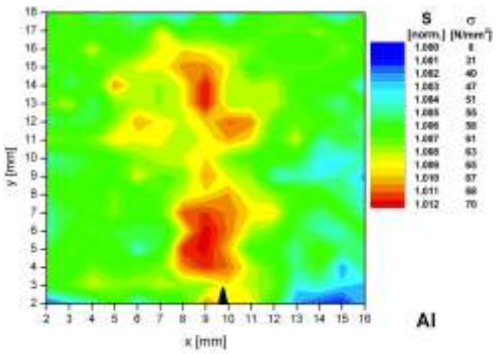
Mg^+ in Mg-Alloys



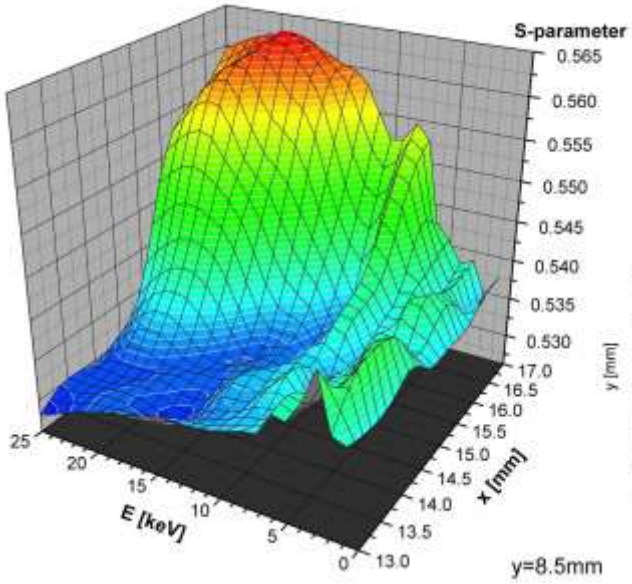


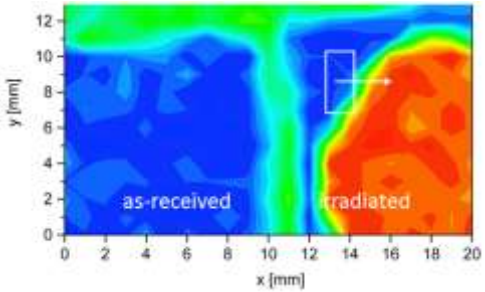
z_m=0.3µm z_m=1.0µm z_m=3.2µm

Plastic deformation

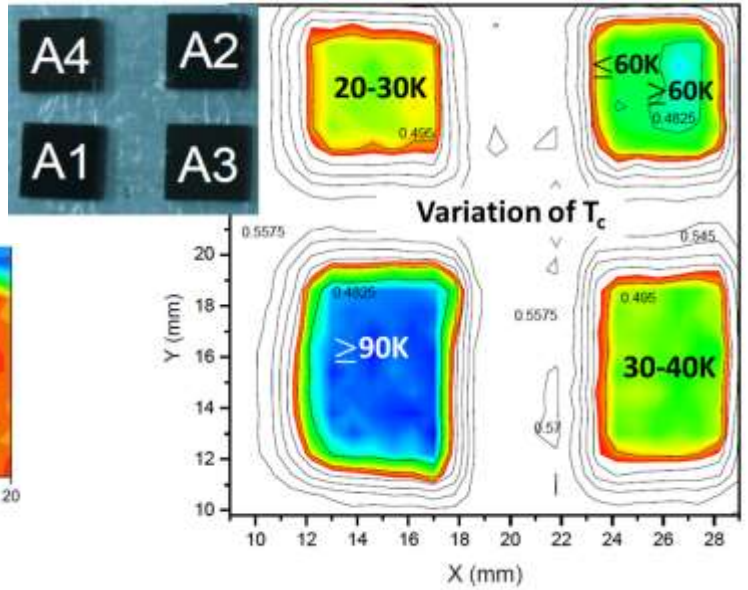


Zr^+ in Zircaloy





$YBa_2Cu_3O_{7-\delta}$



M. Stadlbauer, C. Hugenschmidt, K. Schreckenbach, P. Böni, PRB 76 (2007) 174104
C. Hugenschmidt, N. Qi, M. Stadlbauer, K. Schreckenbach, PRB 81 (2009) 064102
R. M. Hengstler-Eger, P. Baldo, L. Beck, J. Dorner, K. Ertl, P. B. Hoffmann, C. Hugenschmidt, M. A. Kirk, W. Petry, P. Pikart, A. Rempel, J. Nucl. Mat. 423 (2012) 170
M. Reiner, T. Gigl, R. Jany, G. Hammerl, C. Hugenschmidt, Appl. Phys. Lett. 106 (2015) 111910

Laser Beam Welded Al Alloy

AlCu6Mn

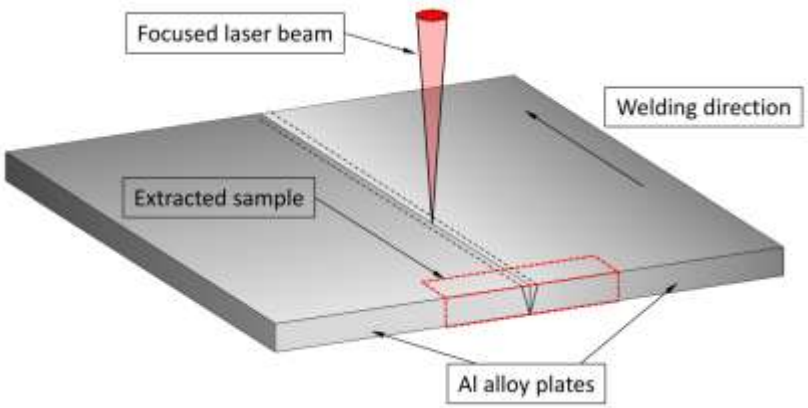
- Age hardenable Al alloy
- High strength & low weight

Laser beam welding (LBW)

- Beam spot & heat impact small
- Weld accuracy & reproducibility high

Weight reduction

- Replace steel and riveted joints



LBW Al Alloy

Sample preparation

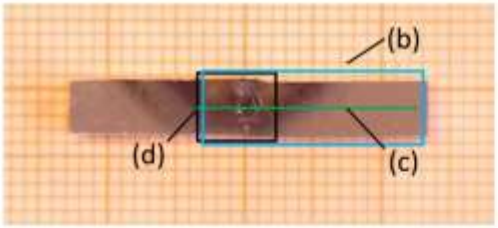
- Single-mode laser (IPG YLR-3000): 1070 nm
- Laser power: 2.6 kW
- Spot size: 50 µm
- Welding speed: 100 mm/s.

To be studied

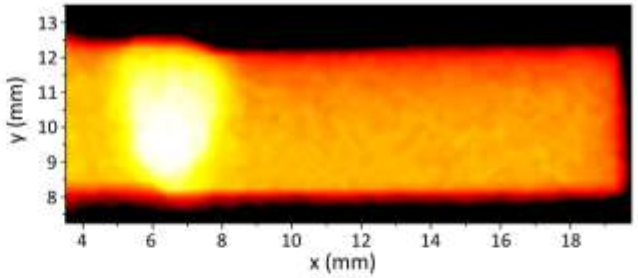
- Mechanical stability of joint?
- What about (point) defects?
- Spatial distribution of precipitates?

Defect Imaging on a LBW

DBS with scanning positron microbeam

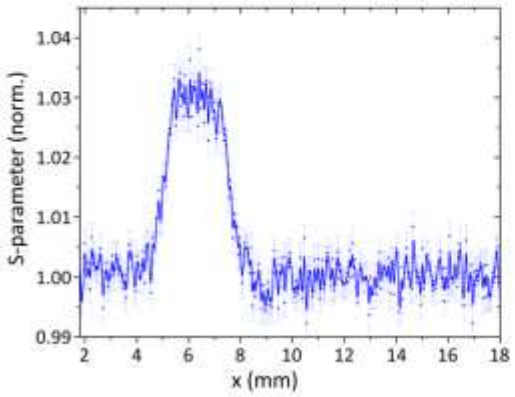


(a)



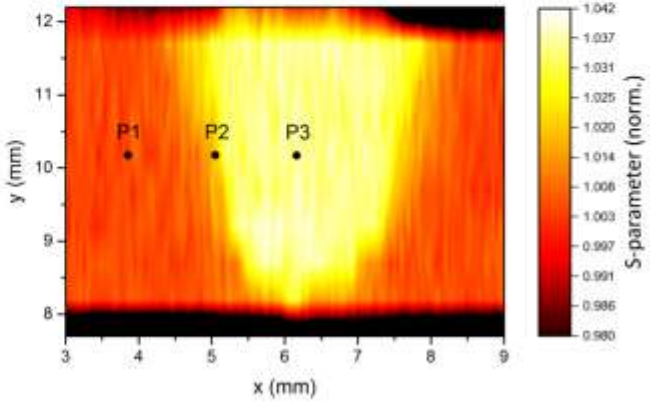
(b)

NEPOMUC rem. Beam
Overview **2D map**
Δx,y = 200 µm



(c)

Positron microbeam
High resolution **line scan**
y = 10 mm, Δx = 50 µm



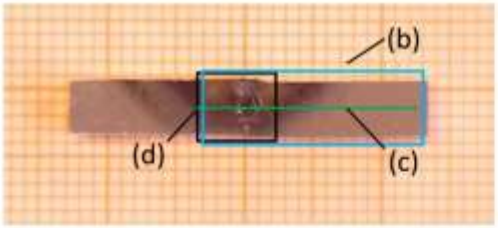
(d)

Positron microbeam
High resolution **2D map**
Δx = 50 µm, Δy =500 µm

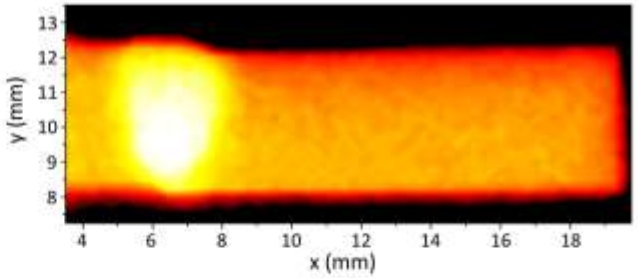
T. Gigl, L. Beddrich, M. Dickmann, B. Rienäcker, M.Thalmayr, S. Vohburger, and C. Hugenschmidt, New J. Phys. 19 (2017) 123007

Defect Imaging on a LBW

DBS results

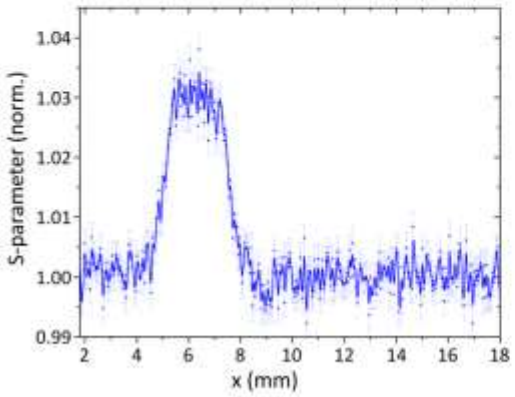


(a)

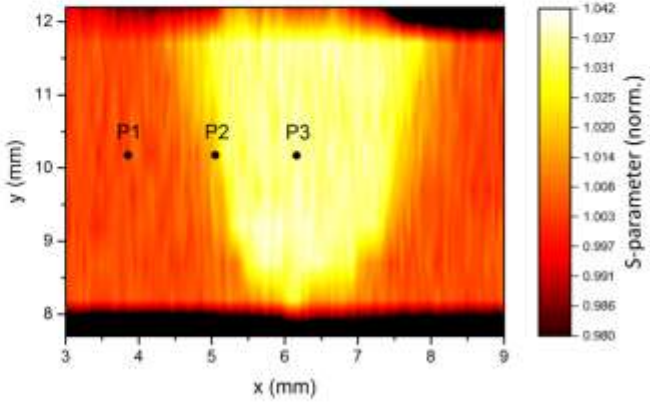


(b)

Gradient of S(y) outside LBW → defect gradient generated during **cold-rolling**



(c)



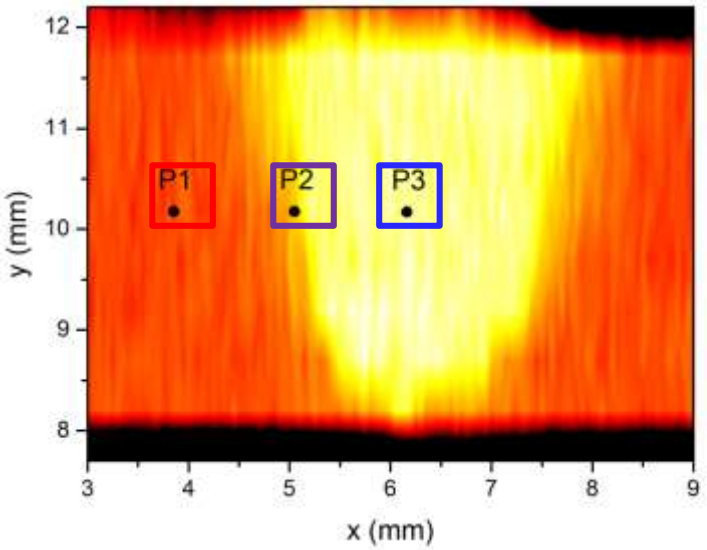
(d)

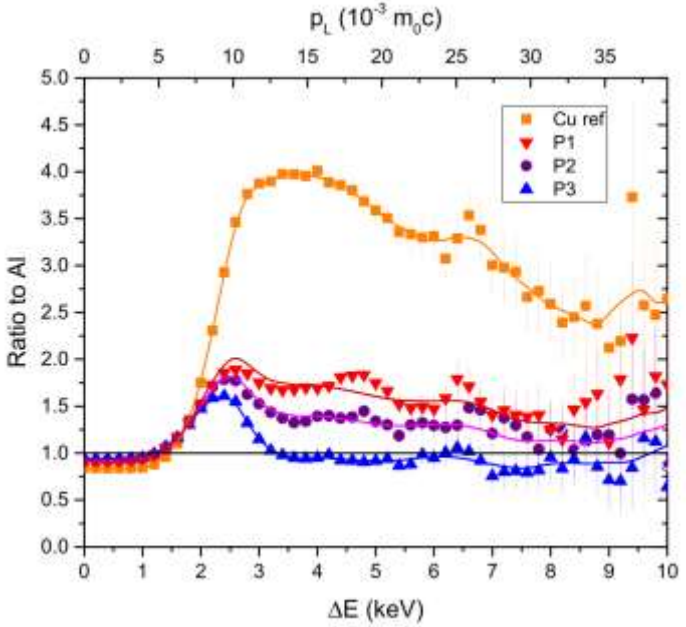
Sharp transition at LBW edges → well localized **small** heat affected zone (**HAZ**)

Drastic **increase of S in LBW** → creation and quenching of **vacancy-like defects**

T. Gigl, L. Beddrich, M. Dickmann, B. Rienäcker, M.Thalmayr, S. Vohburger, and C. Hugenschmidt, New J. Phys. 19 (2017) 123007

CDBS at LBW of AlCu6Mn





P1, P2

- Significant contribution of Cu signature
  → positron trapping at **Cu rich precipitates**;
  in agreement with artificially age-hardened precipitates (Θ phase, Al_2Cu phase)

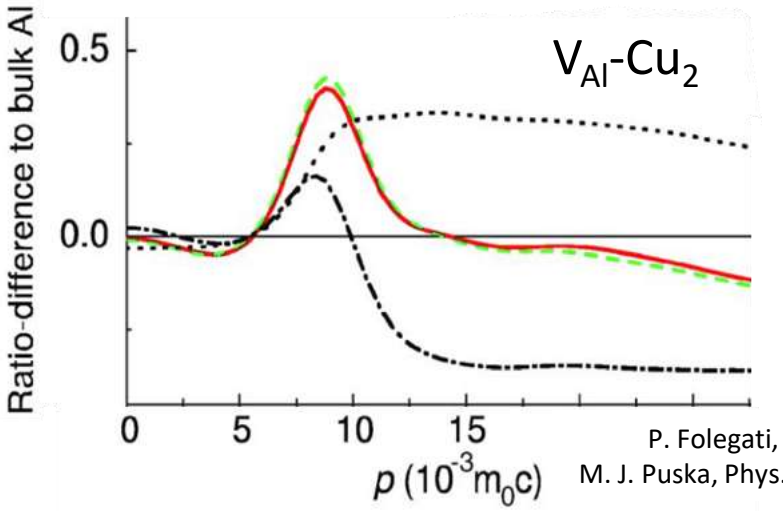
P3

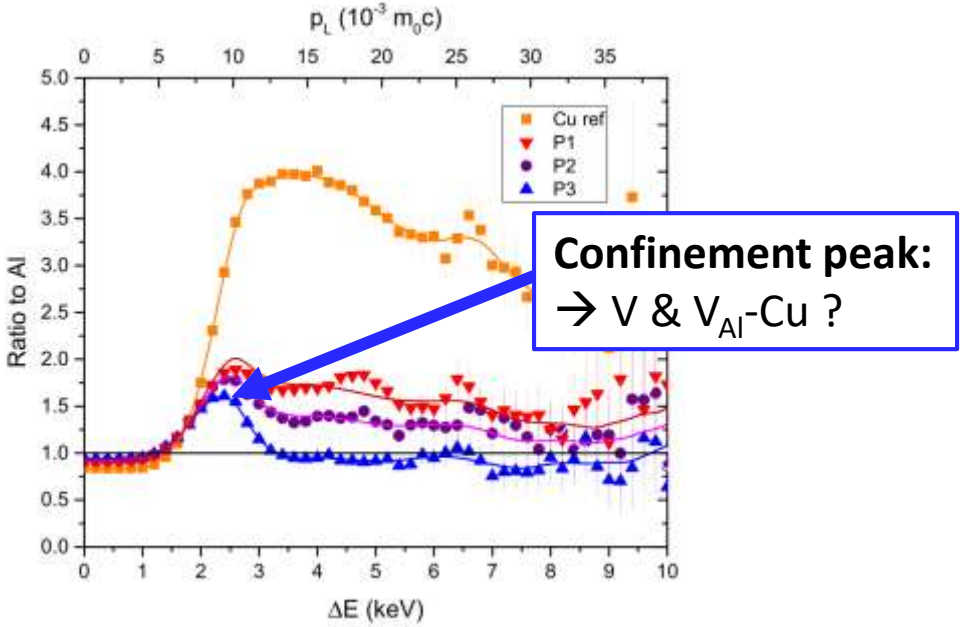
- Disappearance of Cu signature
  → melting of Cu rich phases + rapid cooling
  → formation of **supersaturated solid solution**

CDBS at LBW of AlCu6Mn

Theory

- ab-initio (red) agrees with linear combination of V_{Al} and Cu (green)





P. Folegati, I. Makkonen, R. Ferragut, M. J. Puska, Phys. Rev. B 75 (2007) 054201

Experiment

- Fraction of Cu seen by e+:

Base material → P1: 30% → **Cu rich precipitates**

HAZ → P2: 23% → **Cu rich precipitates + V_{Al}-Cu_x (?)**

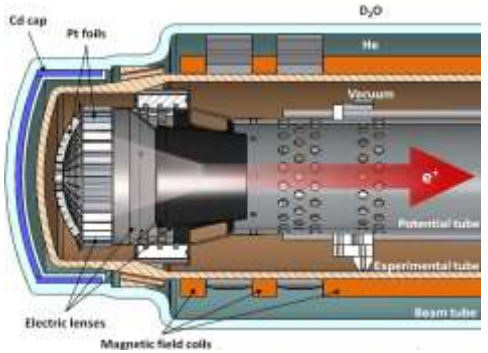
Weld nugget → P3: 12% → **V_{Al}-Cu_2 dominant**

C. Hugenschmidt et al., AIP Conf. Proc. 2182 (2019) 040001

Summary

Positron Beam Facility at NEPOMUC

- Highest beam intensity → 10^9 mod. e+/s !
- Forefront positron instrumentation available for users

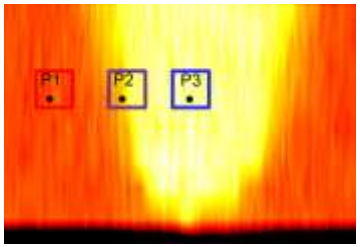


2D Imaging of Defects

- Positron microbeam <50µm by threefold moderation
- CDBS for elemental information

LBW of Al Alloys

- High concentration of vacancy-like defects
- Dissolution of Cu rich precipitates



Deutsche Forschungsgemeinschaft DFG

DAAD RISE

Japan Society for the Promotion of Science 日本学術振興会

Universität Bayern e.V.

BaCaTeC

Bundesministerium für Bildung und Forschung

THANK YOU !