Materials Characterization by Positron Annihilation Spectroscopy – A Canadian Perspective

Peter Mascher

Department of Engineering Physics
and
Centre for Emerging Device Technologies
McMaster University

Outline

- The Pioneers and Their Contributions
- The Next Generation
- The Future Outlook for Positrons in Canada

Positron Annihilation in Canada – The Pioneers

Alec T. Stewart †

DALHOUSIE UNIVERSITY

Queens UNIVERSITY

Innes K. MacKenzie †

DALHOUSIE UNIVERSITY

UNIVERSITY of GUELPH

Jules Carbotte †

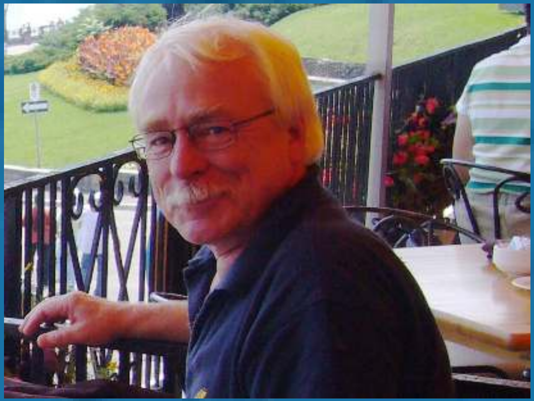
McGill UNIVERSITY

Don Kerr †

Ben Hogg †

University of Manitoba

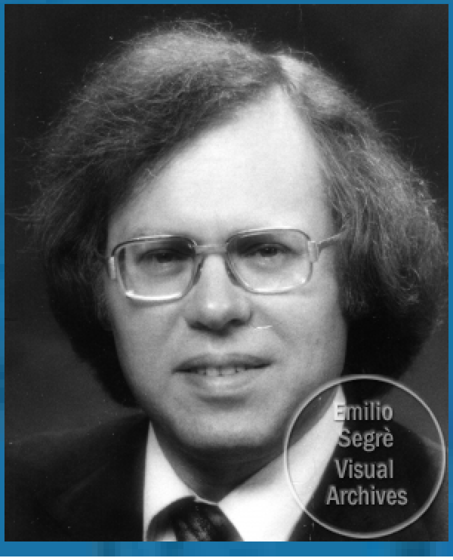
THE UNIVERSITY OF WINNIPEG

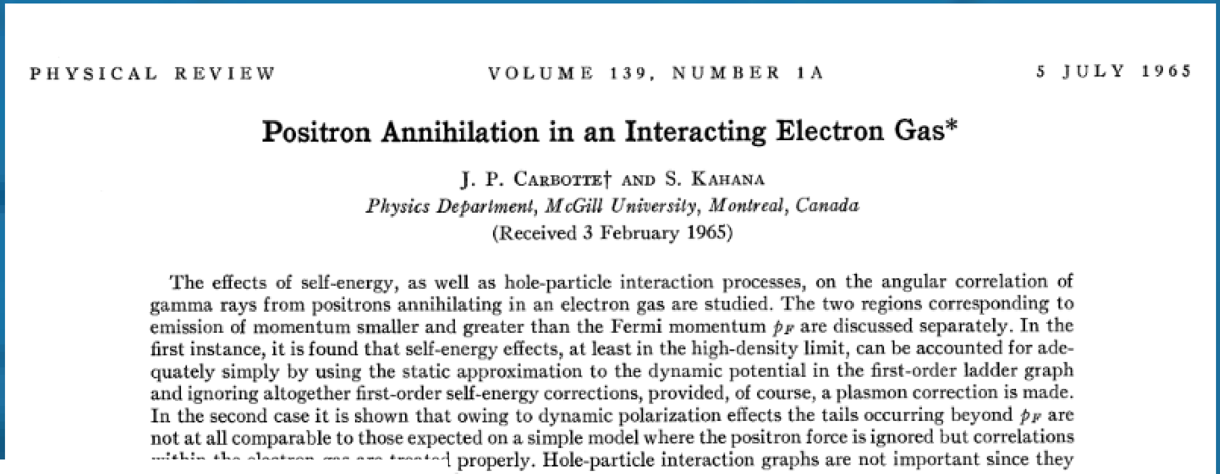


McMaster University

Steen Dannefaer

Fundamental Positron Theory



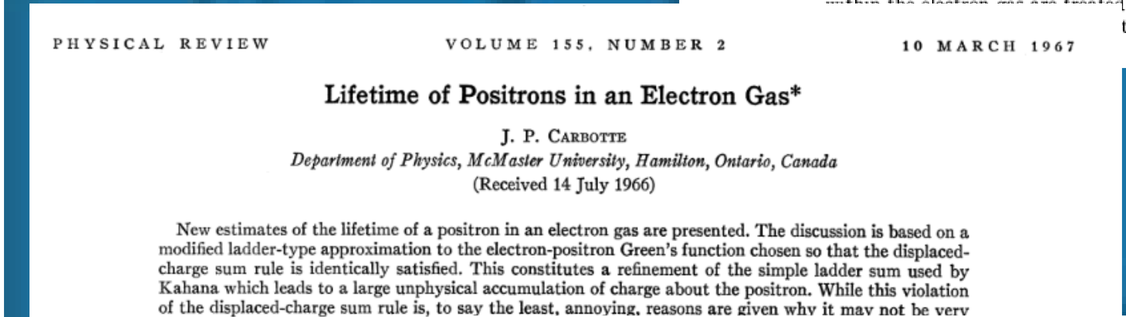

PHYSICAL REVIEW VOLUME 139, NUMBER 1A 5 JULY 1965

Positron Annihilation in an Interacting Electron Gas*

J. P. Carbotte† and S. Kahana
Physics Department, McGill University, Montreal, Canada
(Received 3 February 1965)

The effects of self-energy, as well as hole-particle interaction processes, on the angular correlation of gamma rays from positrons annihilating in an electron gas are studied. The two regions corresponding to emission of momentum smaller and greater than the Fermi momentum p_F are discussed separately. In the first instance, it is found that self-energy effects, at least in the high-density limit, can be accounted for adequately simply by using the static approximation to the dynamic potential in the first-order ladder graph and ignoring altogether first-order self-energy corrections, provided, of course, a plasmon correction is made. In the second case it is shown that owing to dynamic polarization effects the tails occurring beyond p_F are not at all comparable to those expected on a simple model where the positron force is ignored but correlations within the electron gas are treated properly. Hole-particle interaction graphs are not important since they

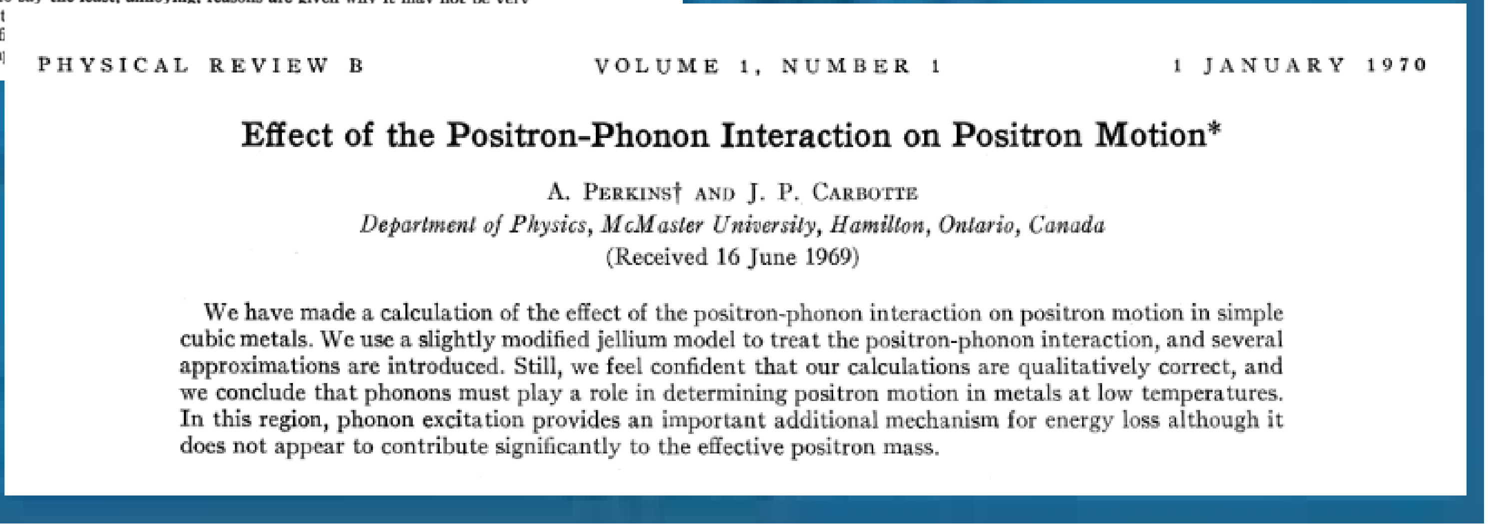
ther.


PHYSICAL REVIEW VOLUME 155, NUMBER 2 10 MARCH 1967

Lifetime of Positrons in an Electron Gas*

J. P. Carbotte
Department of Physics, McMaster University, Hamilton, Ontario, Canada
(Received 14 July 1966)

New estimates of the lifetime of a positron in an electron gas are presented. The discussion is based on a modified ladder-type approximation to the electron-positron Green's function chosen so that the displaced-charge sum rule is identically satisfied. This constitutes a refinement of the simple ladder sum used by Kahana which leads to a large unphysical accumulation of charge about the positron. While this violation of the displaced-charge sum rule is, to say the least, annoying, reasons are given why it may not be very serious if one is concerned only with t
obtained in the more consistent modifi
although they represent a distinct im

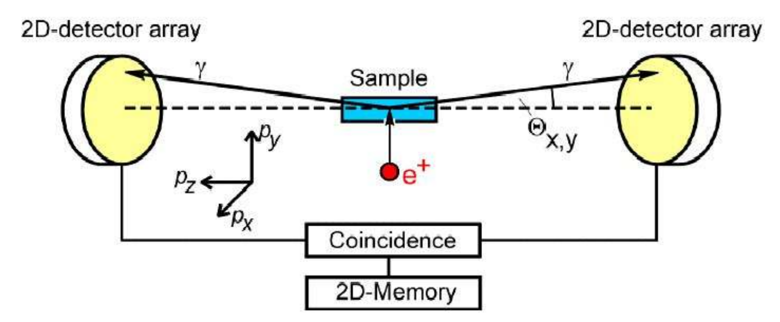

PHYSICAL REVIEW B VOLUME 1, NUMBER 1 1 JANUARY 1970

Effect of the Positron-Phonon Interaction on Positron Motion*

A. Perkins† and J. P. Carbotte
Department of Physics, McMaster University, Hamilton, Ontario, Canada
(Received 16 June 1969)

We have made a calculation of the effect of the positron-phonon interaction on positron motion in simple cubic metals. We use a slightly modified jellium model to treat the positron-phonon interaction, and several approximations are introduced. Still, we feel confident that our calculations are qualitatively correct, and we conclude that phonons must play a role in determining positron motion in metals at low temperatures. In this region, phonon excitation provides an important additional mechanism for energy loss although it does not appear to contribute significantly to the effective positron mass.

Momentum Distribution by Positron ACAR



2D-detector array

2D-detector array

γ

γ

Sample

$\Theta_{x,y}$

p_y

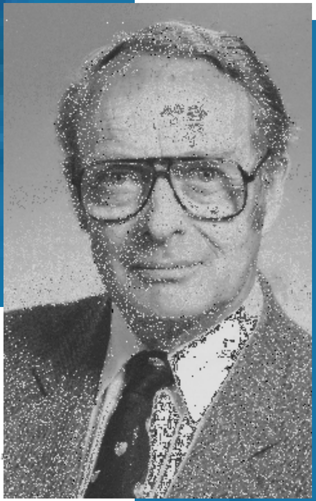
p_z

p_x

e^+

Coincidence

2D-Memory



CAN. J. PHYS. VOL. 68, 1990

Positron annihilation in simple condensed gases

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Department of Physics, Queen's University, Kingston, Ont., Canada K7L 3N6
and
University of North Carolina, Chapel Hill, NC 27514, U.S.A.

C. V. Briscoe
University of North Carolina, Chapel Hill, NC 27514, U.S.A.

AND

J. J. Steinbacher
Department of Physics, Queen's University, Kingston, Ont., Canada K7L 3N6

Received July 6, 1990

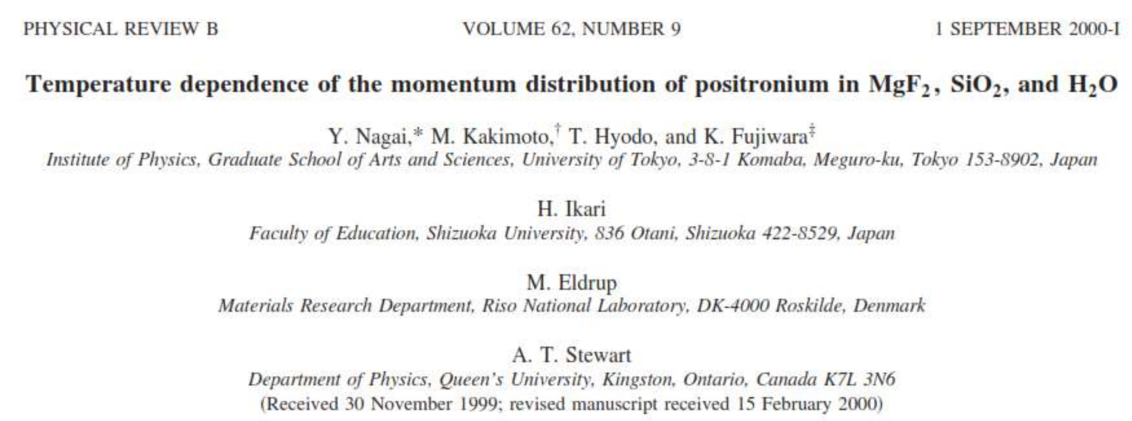
Thermalization of Positrons and Positronium

P. Kubica and A. T. Stewart
Department of Physics, Queen's University at Kingston, Kingston, Ontario

(Received 14 October 1974)

Positrons in metals and positronium in quartz have been observed to thermalize down to nearly liquid-helium temperatures before annihilation. The achievement of such low temperatures by both positrons and positronium in approximately 10^{-10} sec indicates that phonon scattering plays a major role in thermalization. These results have important implications for the ability to achieve high precision in Fermi-surface studies by the positron-annihilation technique.

VOLUME 34, NUMBER 14 PHYSICAL REVIEW LETTERS 7 APRIL 1975



PHYSICAL REVIEW B VOLUME 62, NUMBER 9 1 SEPTEMBER 2000-I

Temperature dependence of the momentum distribution of positronium in MgF_2, SiO_2, and H_2O

Y. Nagai,* M. Kakimoto,† T. Hyodo, and K. Fujiwara‡
Institute of Physics, Graduate School of Arts and Sciences, University of Tokyo, 3-8-1 Komaba, Meguro-ku, Tokyo 153-8902, Japan

H. Ikari
Faculty of Education, Shizuoka University, 836 Otani, Shizuoka 422-8529, Japan

M. Eldrup
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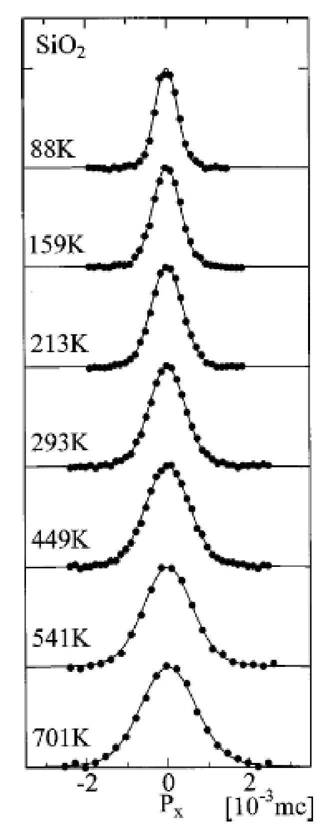
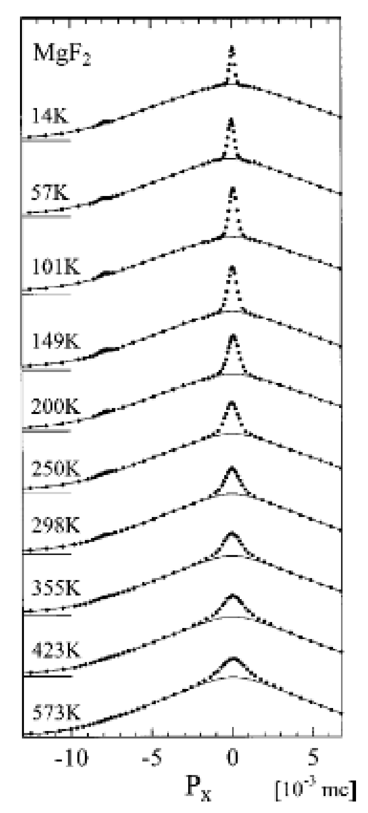
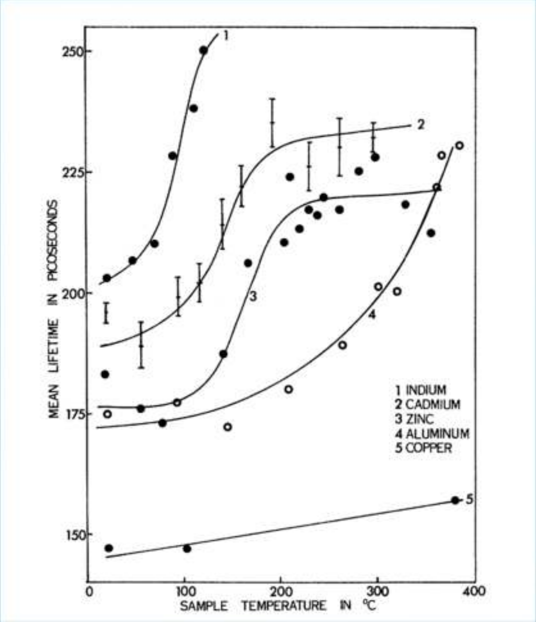
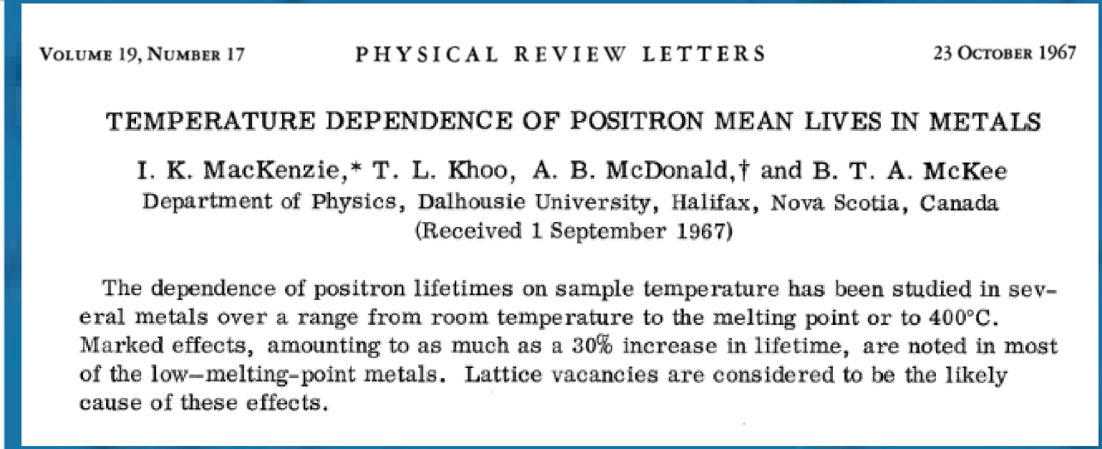
(Received 30 November 1999; revised manuscript received 15 February 2000)





Vacancies in Metals





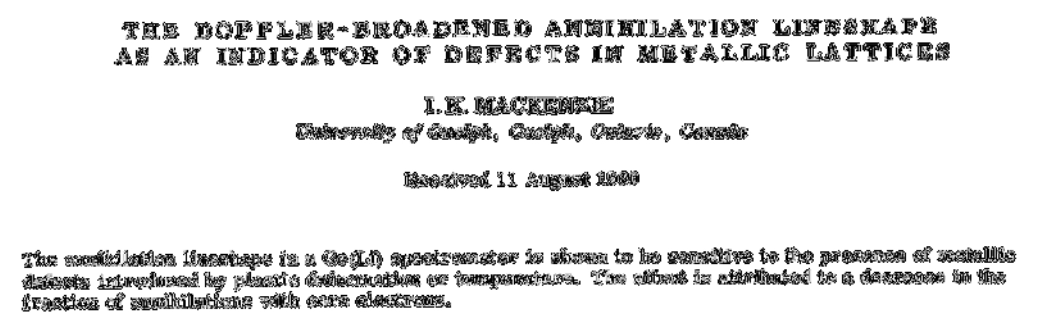
VOLUME 19, NUMBER 17 PHYSICAL REVIEW LETTERS 23 OCTOBER 1967

TEMPERATURE DEPENDENCE OF POSITRON MEAN LIVES IN METALS

I. K. MacKenzie,* T. L. Khoo, A. B. McDonald,† and B. T. A. McKee
Department of Physics, Dalhousie University, Halifax, Nova Scotia, Canada

(Received 1 September 1967)

The dependence of positron lifetimes on sample temperature has been studied in several metals over a range from room temperature to the melting point or to 400°C. Marked effects, amounting to as much as a 30% increase in lifetime, are noted in most of the low-melting-point metals. Lattice vacancies are considered to be the likely cause of these effects.

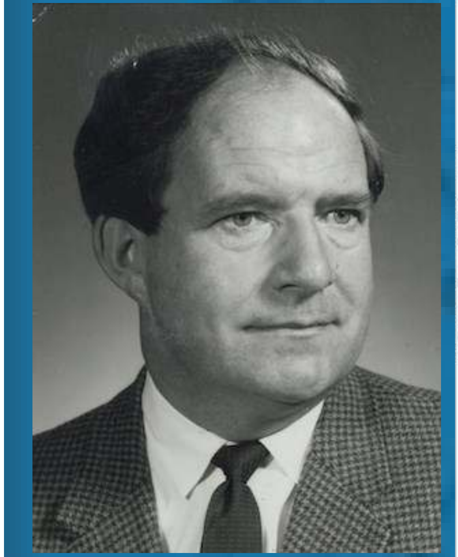


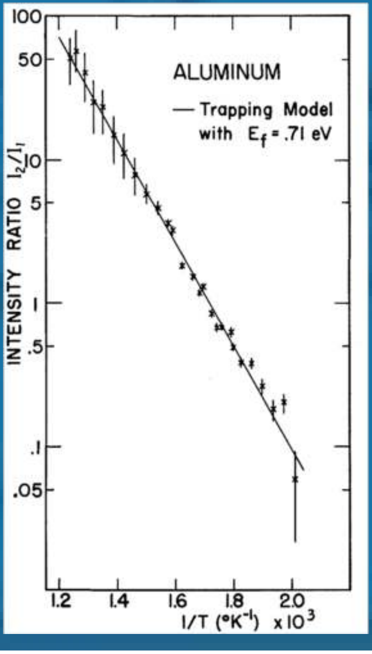
THE DOPPLER-BROADENED ANNIHILATION LINESHAPE AS AN INDICATOR OF DEFECTS IN METALLIC LATTICES

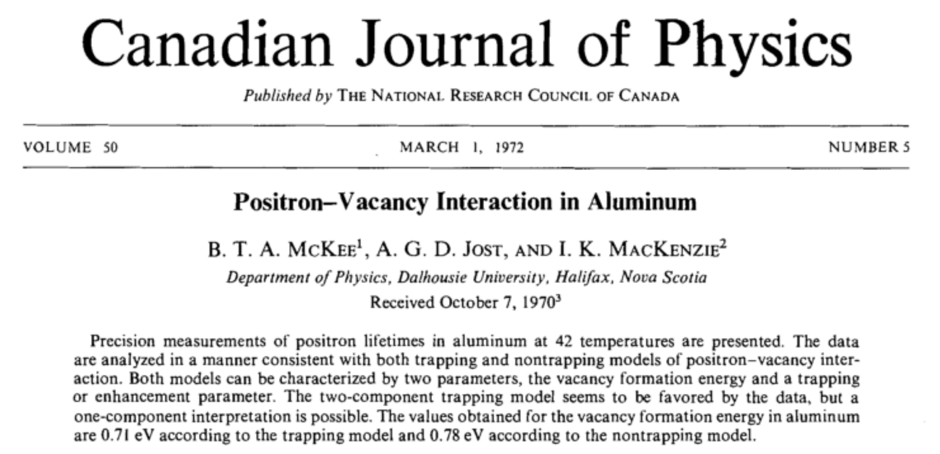
I. K. MACKENZIE
University of Guelph, Guelph, Ontario, Canada

Received 11 August 1969

The annihilation lineshape in a Ge(Li) spectrometer is shown to be sensitive to the presence of metallic defects introduced by plastic deformation or temperature. The effect is attributed to a decrease in the fraction of annihilations with core electrons.







Canadian Journal of Physics
Published by THE NATIONAL RESEARCH COUNCIL OF CANADA

VOLUME 50 MARCH 1, 1972 NUMBER 5

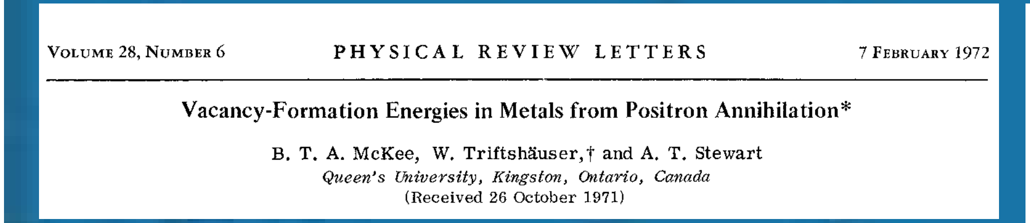
Positron–Vacancy Interaction in Aluminum

B. T. A. MCKEE[1], A. G. D. JOST, AND I. K. MACKENZIE[2]
Department of Physics, Dalhousie University, Halifax, Nova Scotia

Received October 7, 1970[3]

Precision measurements of positron lifetimes in aluminum at 42 temperatures are presented. The data are analyzed in a manner consistent with both trapping and nontrapping models of positron–vacancy interaction. Both models can be characterized by two parameters, the vacancy formation energy and a trapping or enhancement parameter. The two-component trapping model seems to be favored by the data, but a one-component interpretation is possible. The values obtained for the vacancy formation energy in aluminum are 0.71 eV according to the trapping model and 0.78 eV according to the nontrapping model.

Vacancy Formation Enthalpies - Metals



Volume 28, Number 6 PHYSICAL REVIEW LETTERS 7 February 1972

Vacancy-Formation Energies in Metals from Positron Annihilation*

B. T. A. McKee, W. Triftshäuser,† and A. T. Stewart
Queen's University, Kingston, Ontario, Canada

(Received 26 October 1971)

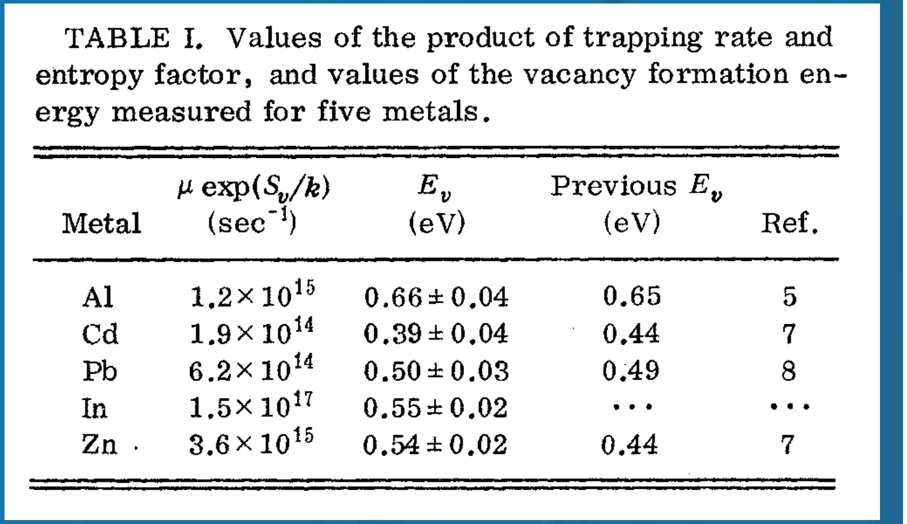
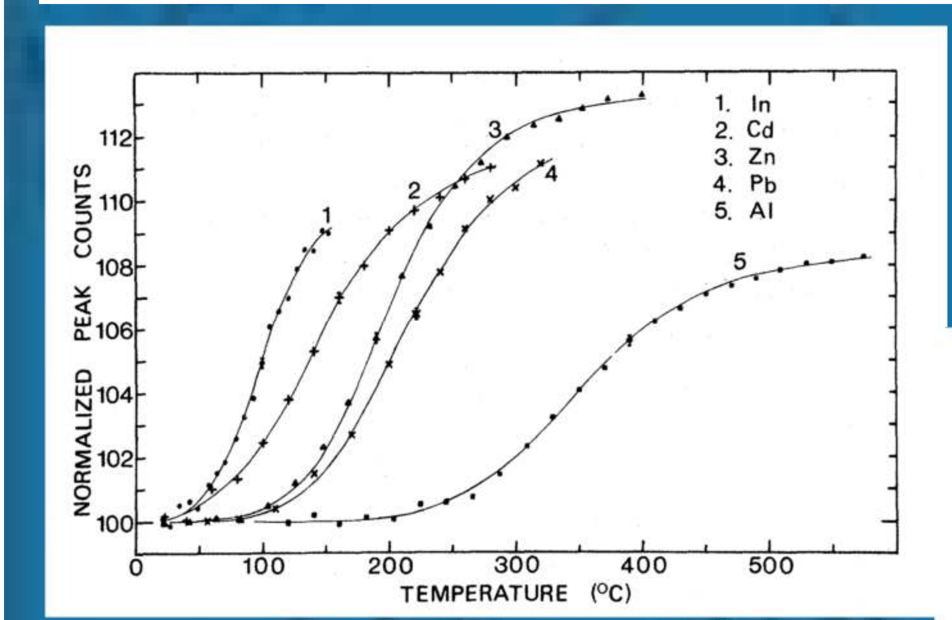
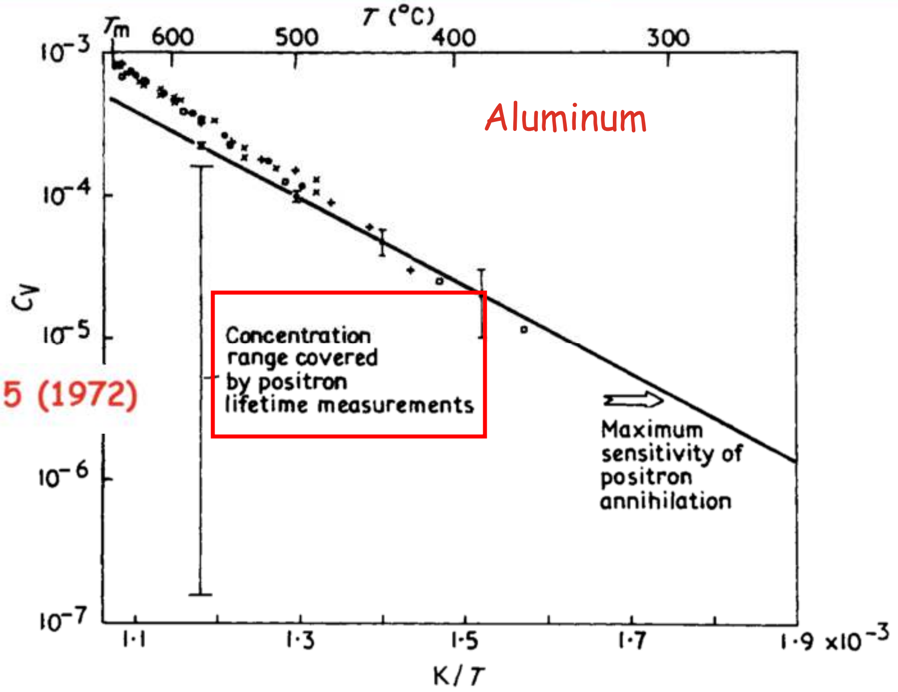


TABLE I. Values of the product of trapping rate and entropy factor, and values of the vacancy formation energy measured for five metals.

Metal	$\mu \exp(S_v/k)$ (sec^{-1})	E_v (eV)	Previous E_v (eV)	Ref.
Al	1.2×10^{15}	0.66 ± 0.04	0.65	5
Cd	1.9×10^{14}	0.39 ± 0.04	0.44	7
Pb	6.2×10^{14}	0.50 ± 0.03	0.49	8
In	1.5×10^{17}	0.55 ± 0.02	···	···
Zn	3.6×10^{15}	0.54 ± 0.02	0.44	7



B.T.A. McKee et al., Can. J. Phys. 50, 415 (1972)

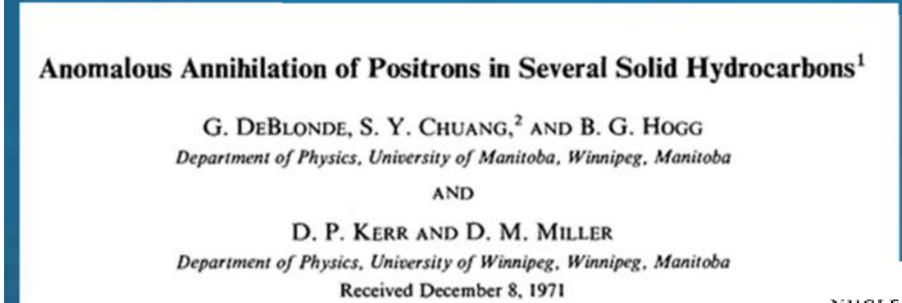


Aluminum

Concentration range covered by positron lifetime measurements

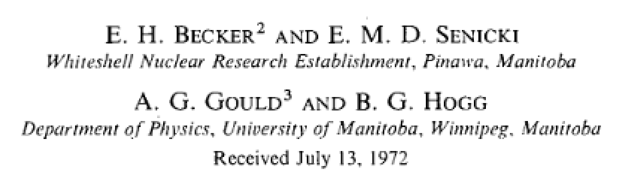
Maximum sensitivity of positron annihilation

Early Positron Studies at Winnipeg



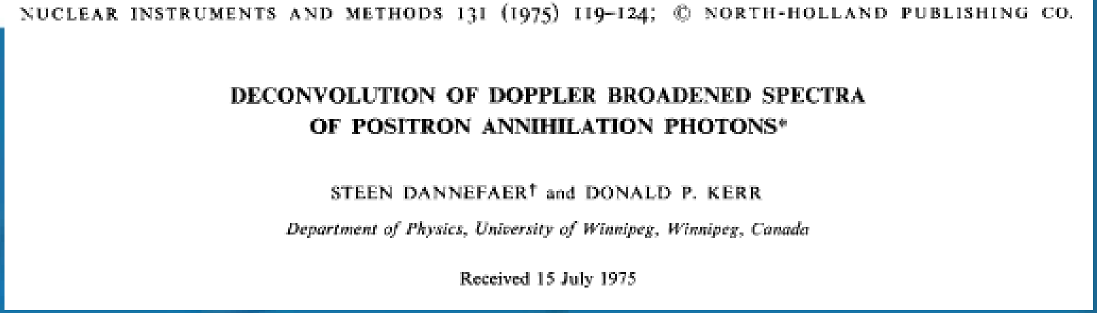
Anomalous Annihilation of Positrons in Several Solid Hydrocarbons[1]

G. DeBlonde, S. Y. Chuang,[2] and B. G. Hogg
Department of Physics, University of Manitoba, Winnipeg, Manitoba
AND
D. P. Kerr and D. M. Miller
Department of Physics, University of Winnipeg, Winnipeg, Manitoba
Received December 8, 1971



Study of Single Crystals of Magnesium and Zinc by Positron Annihilation[1]

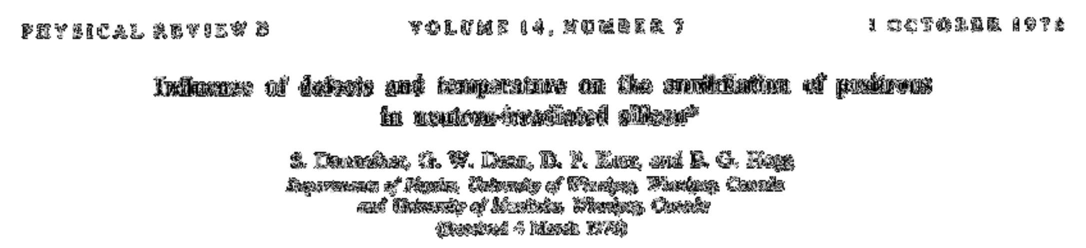
E. H. Becker[2] and E. M. D. Senicki
Whiteshell Nuclear Research Establishment, Pinawa, Manitoba
A. G. Gould[3] and B. G. Hogg
Department of Physics, University of Manitoba, Winnipeg, Manitoba
Received July 13, 1972



NUCLEAR INSTRUMENTS AND METHODS 131 (1975) 119–124; © NORTH-HOLLAND PUBLISHING CO.

DECONVOLUTION OF DOPPLER BROADENED SPECTRA OF POSITRON ANNIHILATION PHOTONS*

STEEN DANNEFAER† and DONALD P. KERR
Department of Physics, University of Winnipeg, Winnipeg, Canada
Received 15 July 1975



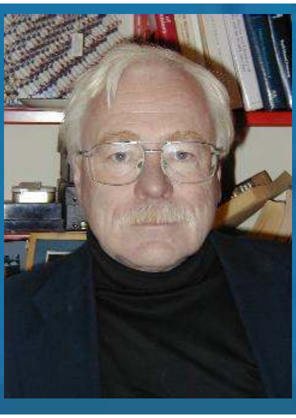
PHYSICAL REVIEW B VOLUME 14, NUMBER 7 1 OCTOBER 1976

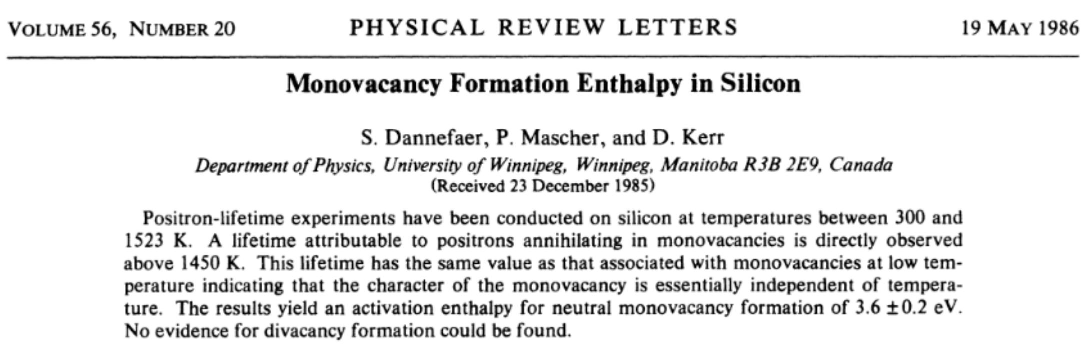
Influence of defects and temperature on the annihilation of positrons in neutron-irradiated silicon*

S. Dannefaer, G. W. Dean, D. P. Kerr, and B. G. Hogg
Department of Physics, University of Winnipeg, Winnipeg, Canada and University of Manitoba, Winnipeg, Canada
(Received 4 March 1976)

University of Manitoba

THE UNIVERSITY OF WINNIPEG





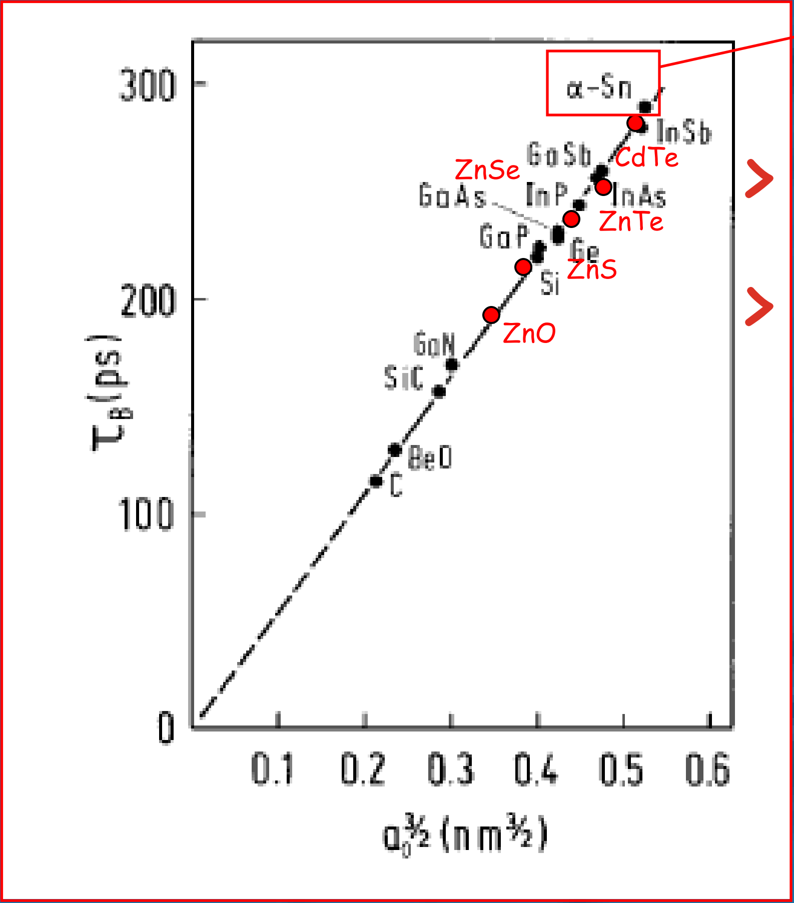
VOLUME 56, NUMBER 20 PHYSICAL REVIEW LETTERS 19 MAY 1986

Monovacancy Formation Enthalpy in Silicon

S. Dannefaer, P. Mascher, and D. Kerr
Department of Physics, University of Winnipeg, Winnipeg, Manitoba R3B 2E9, Canada
(Received 23 December 1985)

Positron-lifetime experiments have been conducted on silicon at temperatures between 300 and 1523 K. A lifetime attributable to positrons annihilating in monovacancies is directly observed above 1450 K. This lifetime has the same value as that associated with monovacancies at low temperature indicating that the character of the monovacancy is essentially independent of temperature. The results yield an activation enthalpy for neutral monovacancy formation of 3.6 ±0.2 eV. No evidence for divacancy formation could be found.

Positron Lifetimes in Semiconductors



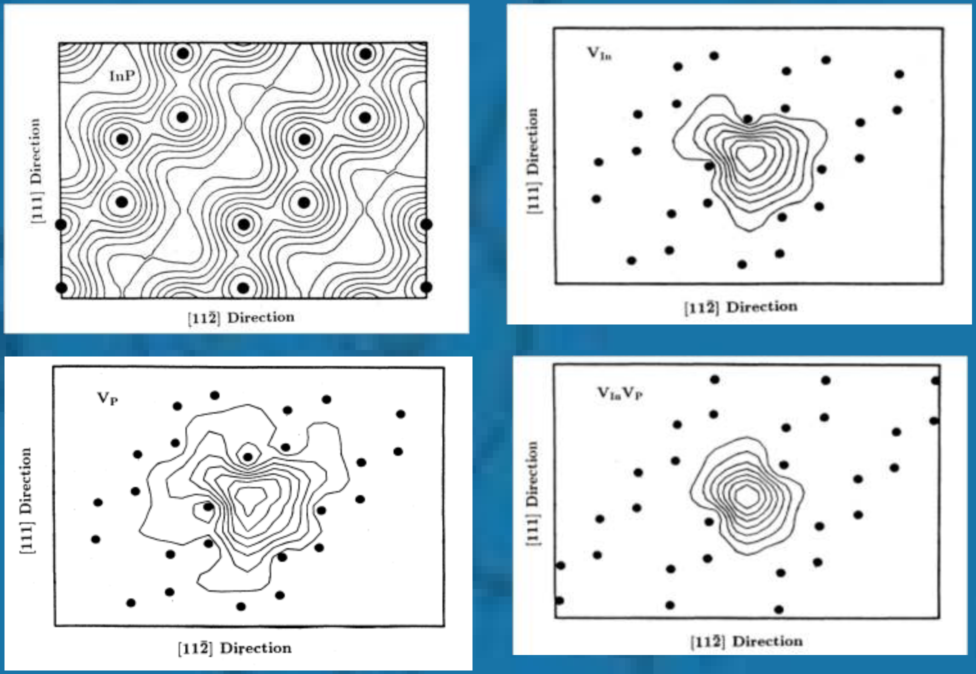
H. Siethoff, phys. stat. sol. (b) 205 R3 (1998)

W. Puff and P. Mascher, J. Phys. F 14, L231 (1984)

M. Martyniuk and P. Mascher, Physica B 308-310, 924 (2001)

G. Tessaro and P. Mascher, J. Cryst. Growth 197, 581 (1999)

McMaster University



M. Puska et al., PRB 39, 7666 (1989)

ICPA-14
McMaster University, July 2006

ICPA 14
Hamilton, Canada

http://icpa.mcmaster.ca

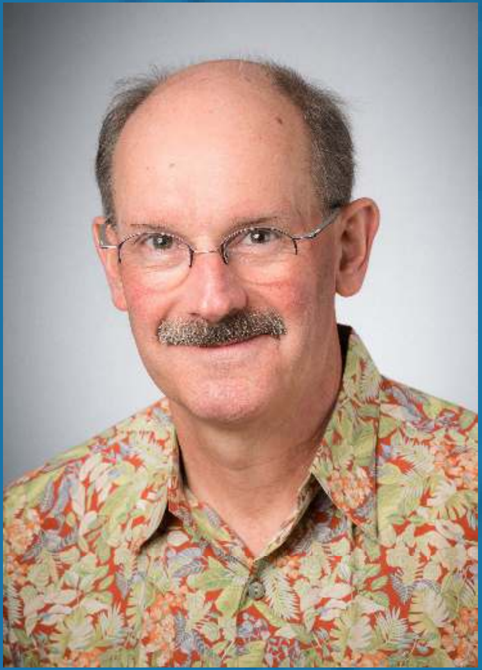
Positron Annihilation in Canada – The Next Generation


Peter J. Schultz

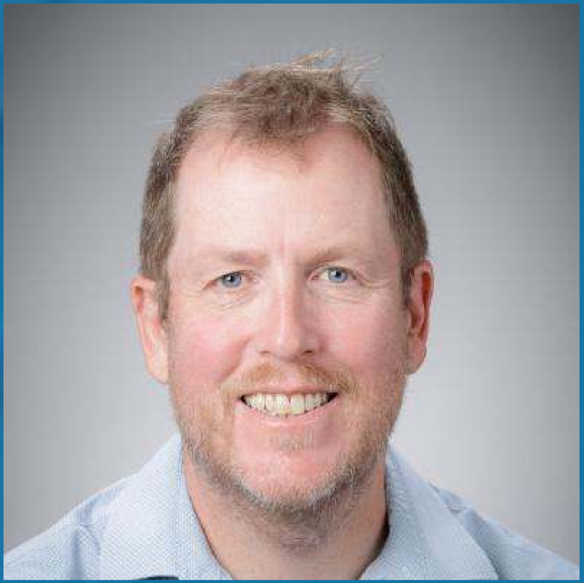
Western
Leading. Thinking.

UNIVERSITY of GUELPH

Peter J. Simpson

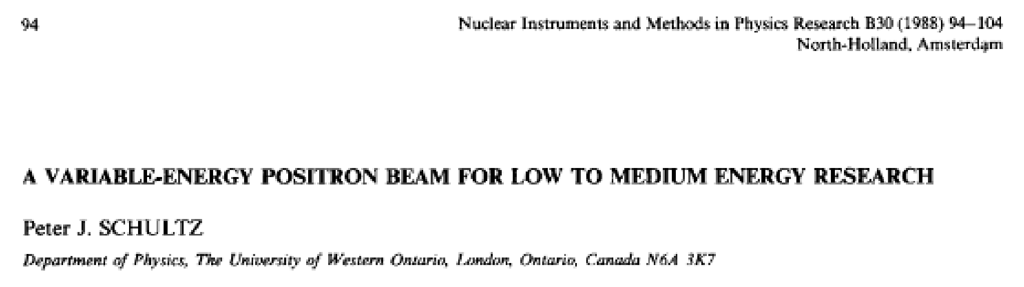

Peter Mascher

McMaster
University


Andy Knights

The First Canadian Positron Beam

Western
Leading. Thinking.



94 Nuclear Instruments and Methods in Physics Research B30 (1988) 94–104
North-Holland, Amsterdam

A VARIABLE-ENERGY POSITRON BEAM FOR LOW TO MEDIUM ENERGY RESEARCH

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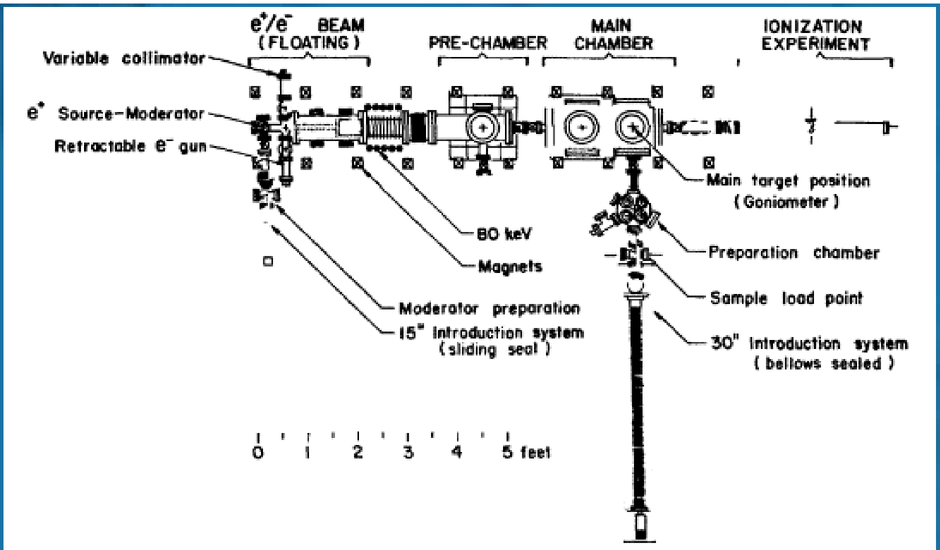
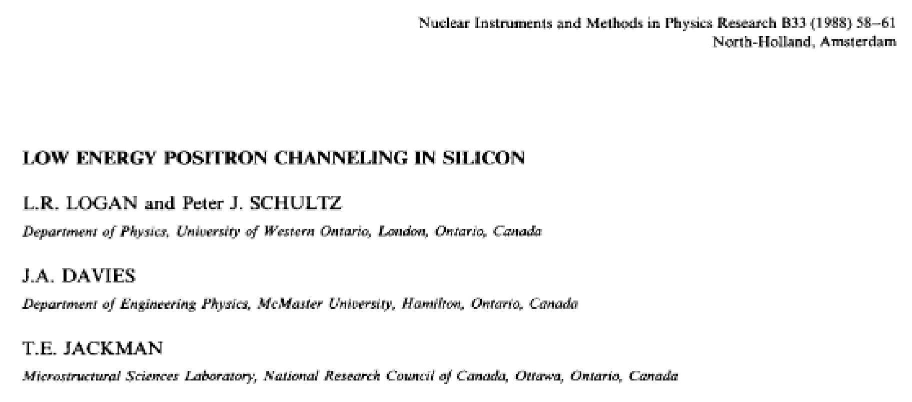
Department of Physics, The University of Western Ontario, London, Ontario, Canada N6A 3K7





Nuclear Instruments and Methods in Physics Research B33 (1988) 58–61
North-Holland, Amsterdam

LOW ENERGY POSITRON CHANNELING IN SILICON

L.R. LOGAN and Peter J. SCHULTZ

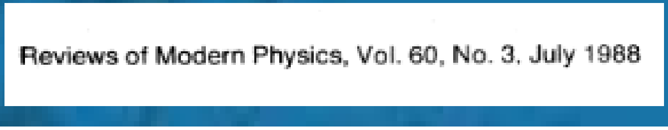
Department of Physics, University of Western Ontario, London, Ontario, Canada

J.A. DAVIES

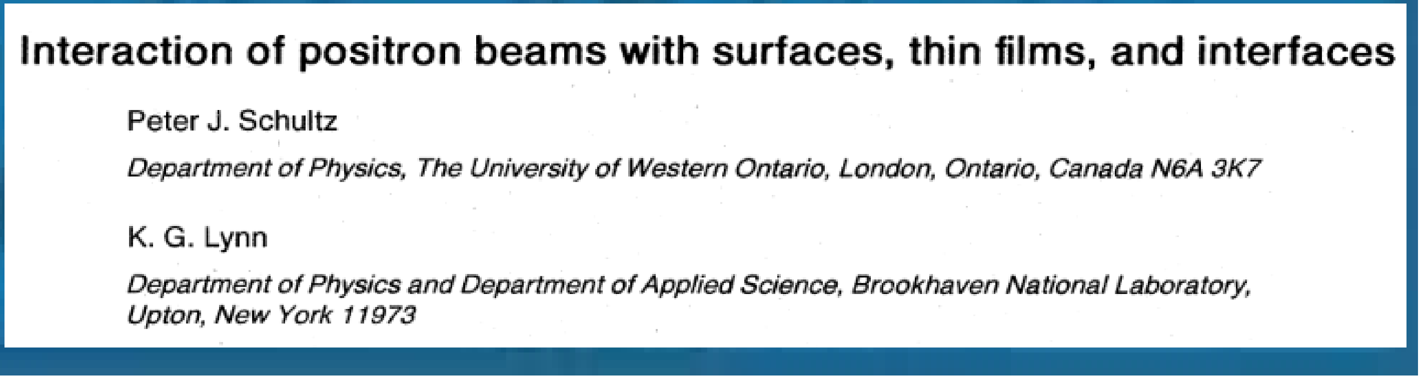
Department of Engineering Physics, McMaster University, Hamilton, Ontario, Canada

T.E. JACKMAN

Microstructural Sciences Laboratory, National Research Council of Canada, Ottawa, Ontario, Canada



Reviews of Modern Physics, Vol. 60, No. 3, July 1988



Interaction of positron beams with surfaces, thin films, and interfaces

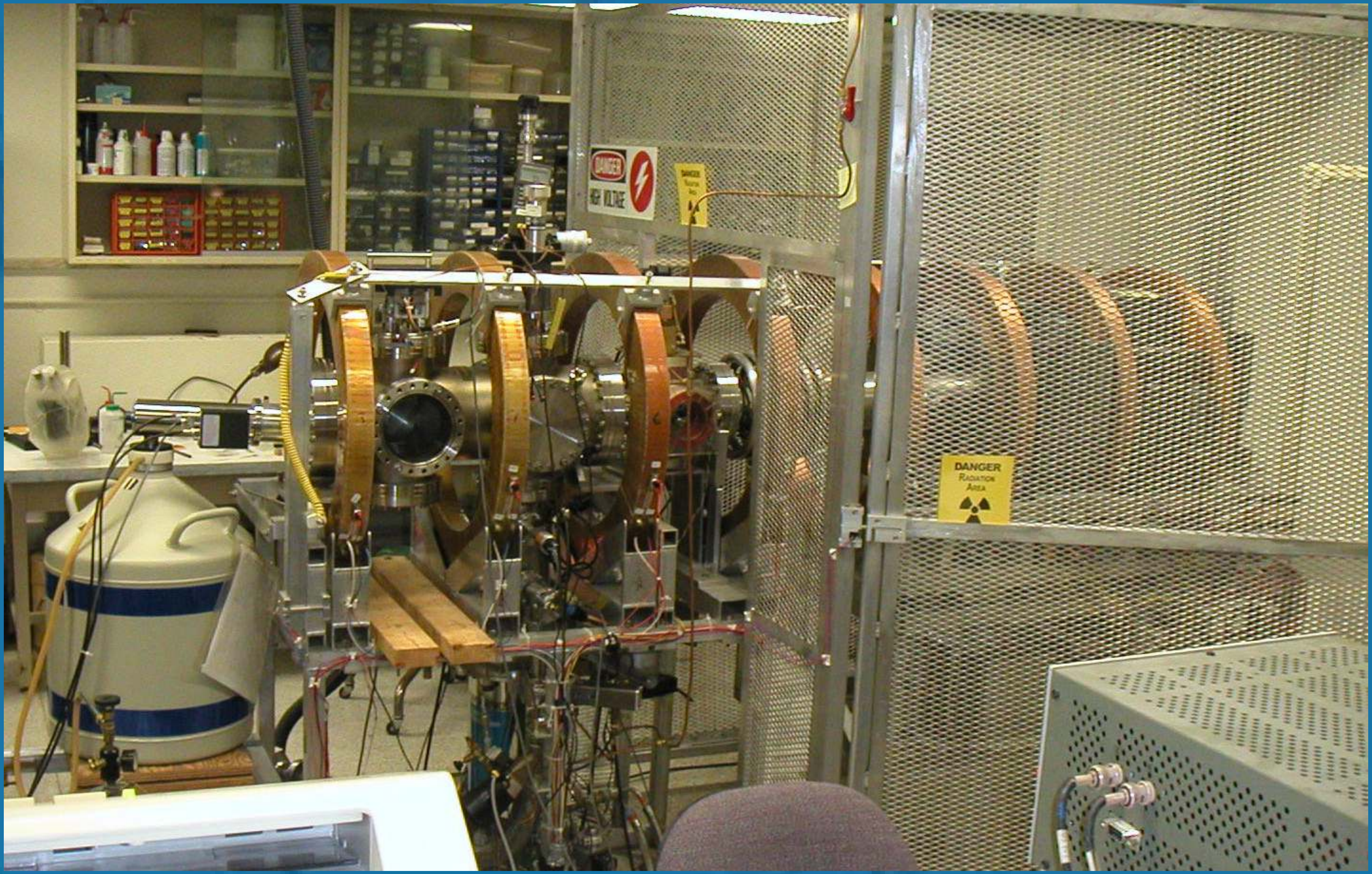
Peter J. Schultz

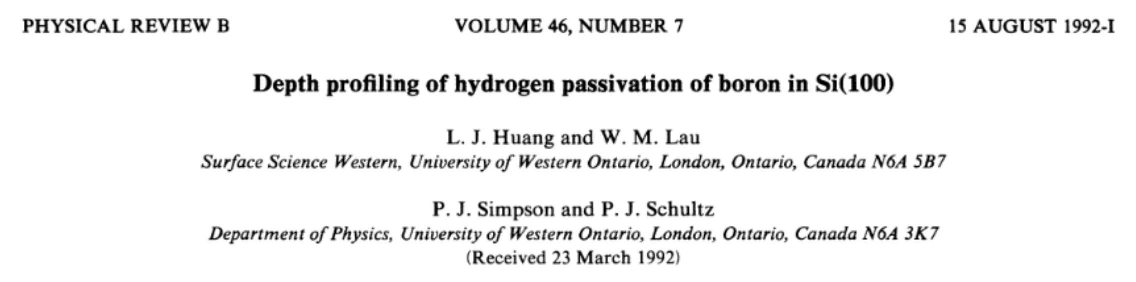
Department of Physics, The University of Western Ontario, London, Ontario, Canada N6A 3K7

K. G. Lynn

Department of Physics and Department of Applied Science, Brookhaven National Laboratory, Upton, New York 11973

The Positron Beam Facility at Western





PHYSICAL REVIEW B VOLUME 46, NUMBER 7 15 AUGUST 1992-I

Depth profiling of hydrogen passivation of boron in Si(100)

L. J. Huang and W. M. Lau
Surface Science Western, University of Western Ontario, London, Ontario, Canada N6A 5B7

P. J. Simpson and P. J. Schultz
Department of Physics, University of Western Ontario, London, Ontario, Canada N6A 3K7

(Received 23 March 1992)

Western
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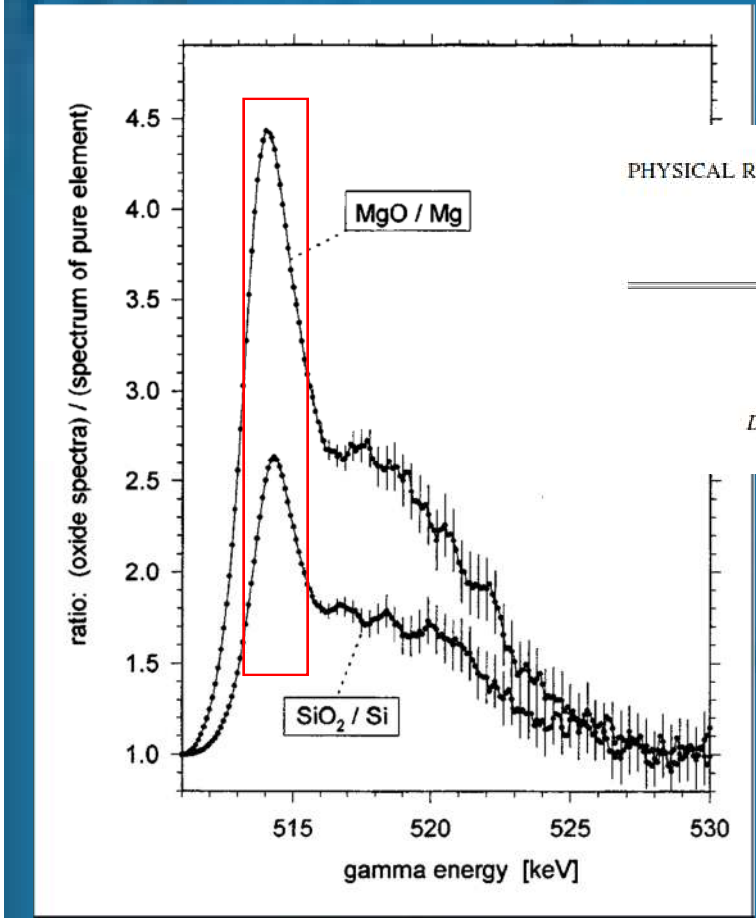
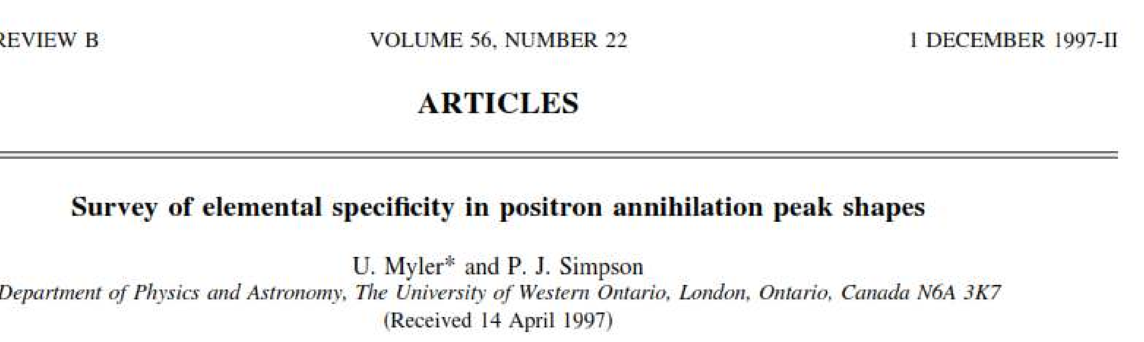




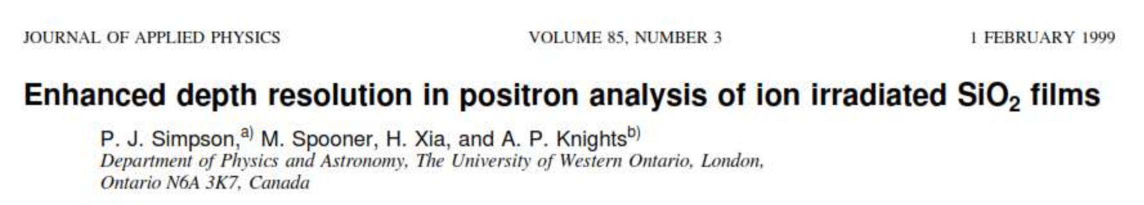
PHYSICAL REVIEW B VOLUME 56, NUMBER 22 1 DECEMBER 1997-II

ARTICLES

Survey of elemental specificity in positron annihilation peak shapes

U. Myler* and P. J. Simpson
Department of Physics and Astronomy, The University of Western Ontario, London, Ontario, Canada N6A 3K7

(Received 14 April 1997)



JOURNAL OF APPLIED PHYSICS VOLUME 85, NUMBER 3 1 FEBRUARY 1999

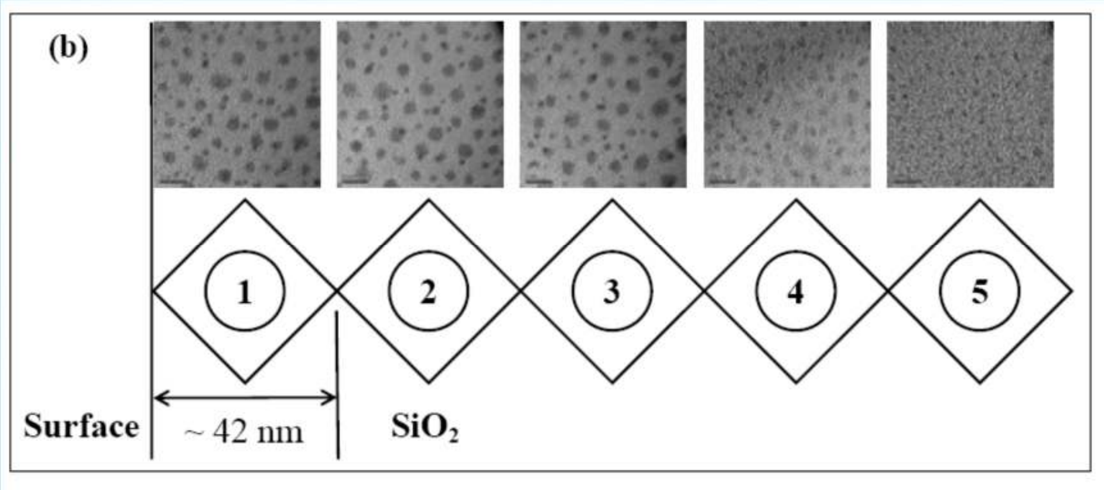
Enhanced depth resolution in positron analysis of ion irradiated SiO_2 films

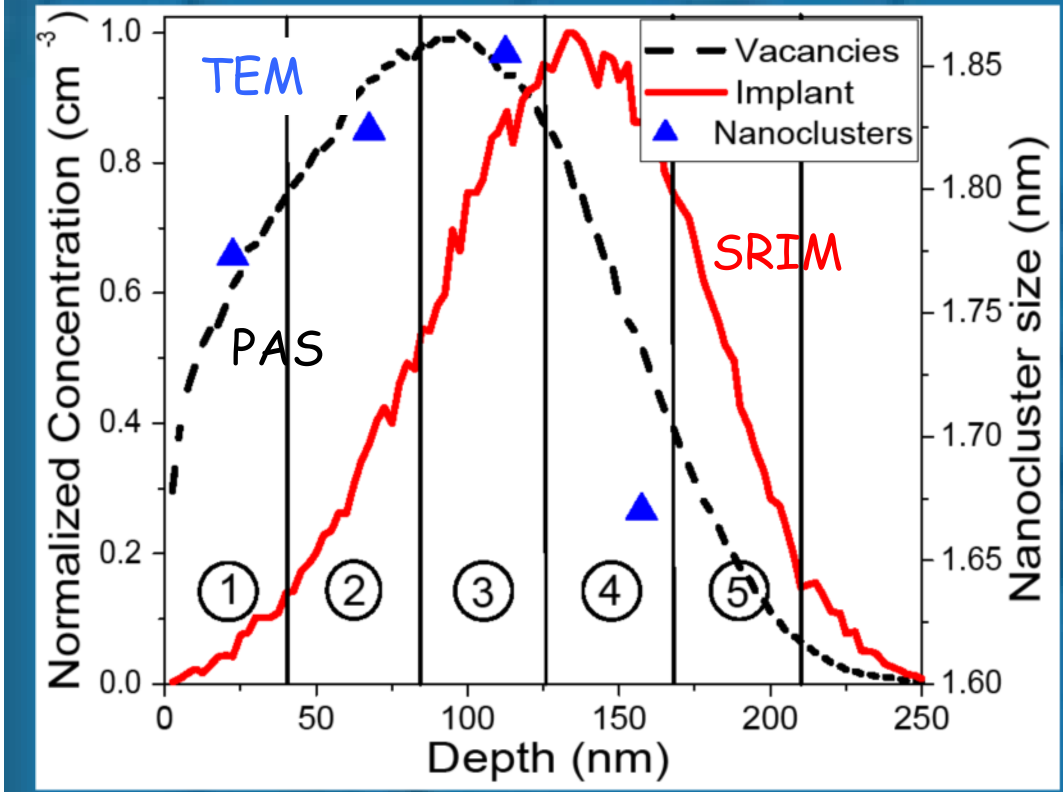
P. J. Simpson,[a)] M. Spooner, H. Xia, and A. P. Knights[b)]
Department of Physics and Astronomy, The University of Western Ontario, London, Ontario N6A 3K7, Canada

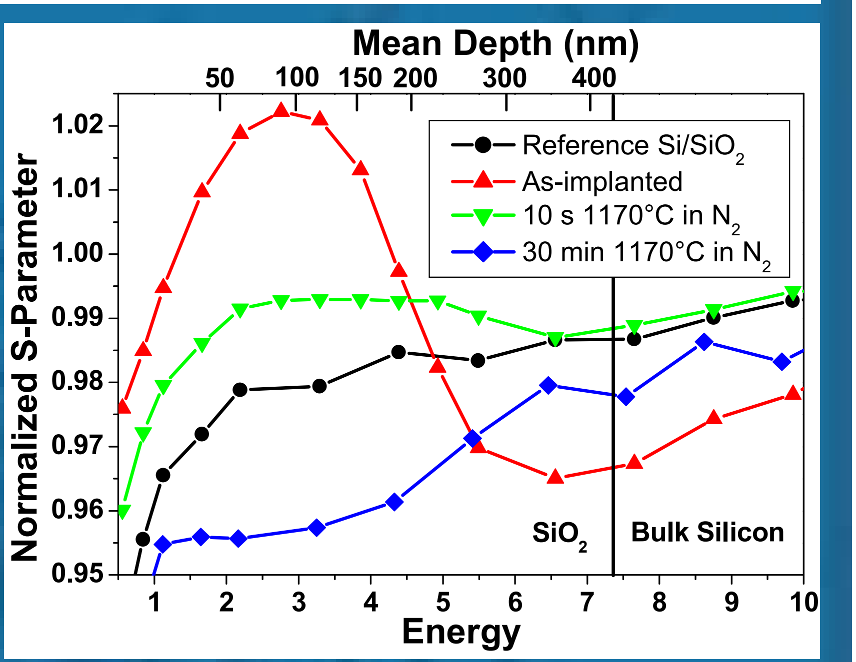
90 keV Si^- ions; $1.4x10^{17}$ cm^{-2}

430 nm SiO_x w/ 20% excess Si

Annealed at 1070C for 3 hrs







C.R. Mokry, P.J. Simpson, and A.P. Knights, JAP 105, 114301 (2009)

Positron Beams on the Move

Western
Leading. Thinking.

McMaster
University

The McMaster Intense Positron Beam Facility (MIPBF) Project Team

Peter Mascher	Project Leader	McMaster University
Chris Heysel	MNR	McMaster Nuclear Reactor 50 1959-2009
Scott McMaster	Beam Delivery System	McMaster Nuclear Reactor 50 1959-2009
Andrew P. Knights, Peter J. Simpson	Defect Probe	Western McMaster University
Cody Storry	Positron Storage and Interaction	YORK UNIVERSITÉ UNIVERSITY

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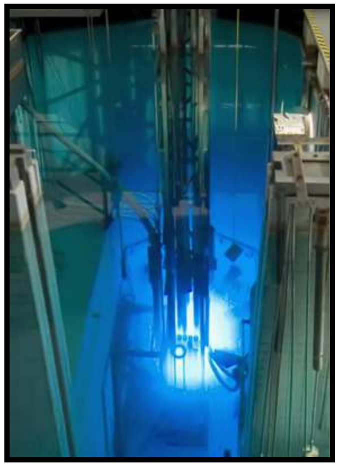
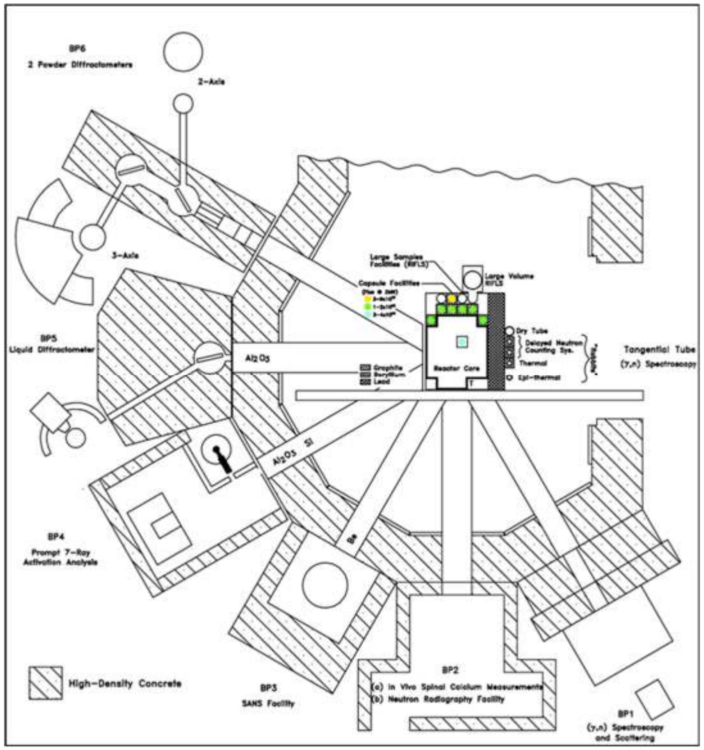
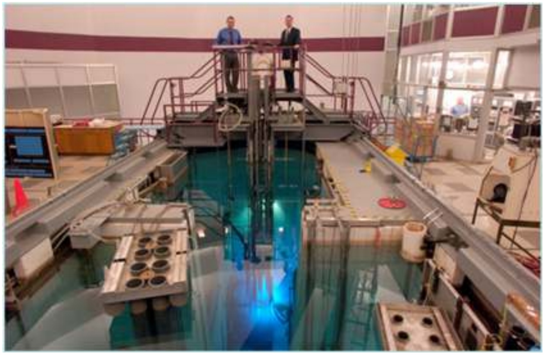
Ontario
MINISTRY OF RESEARCH & INNOVATION

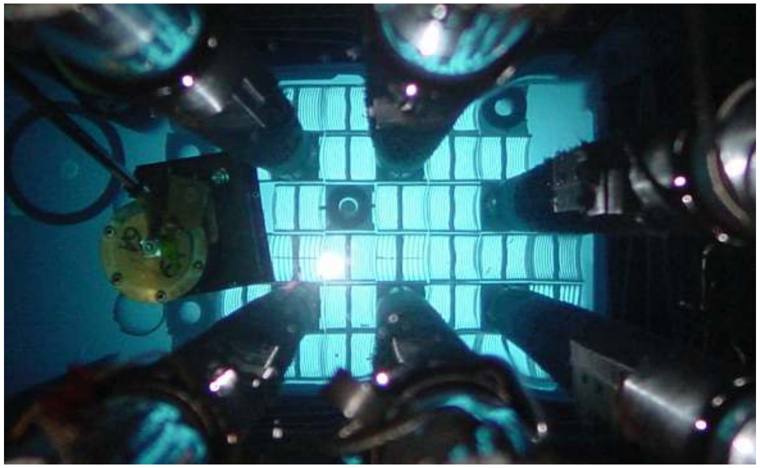


MNR Overview

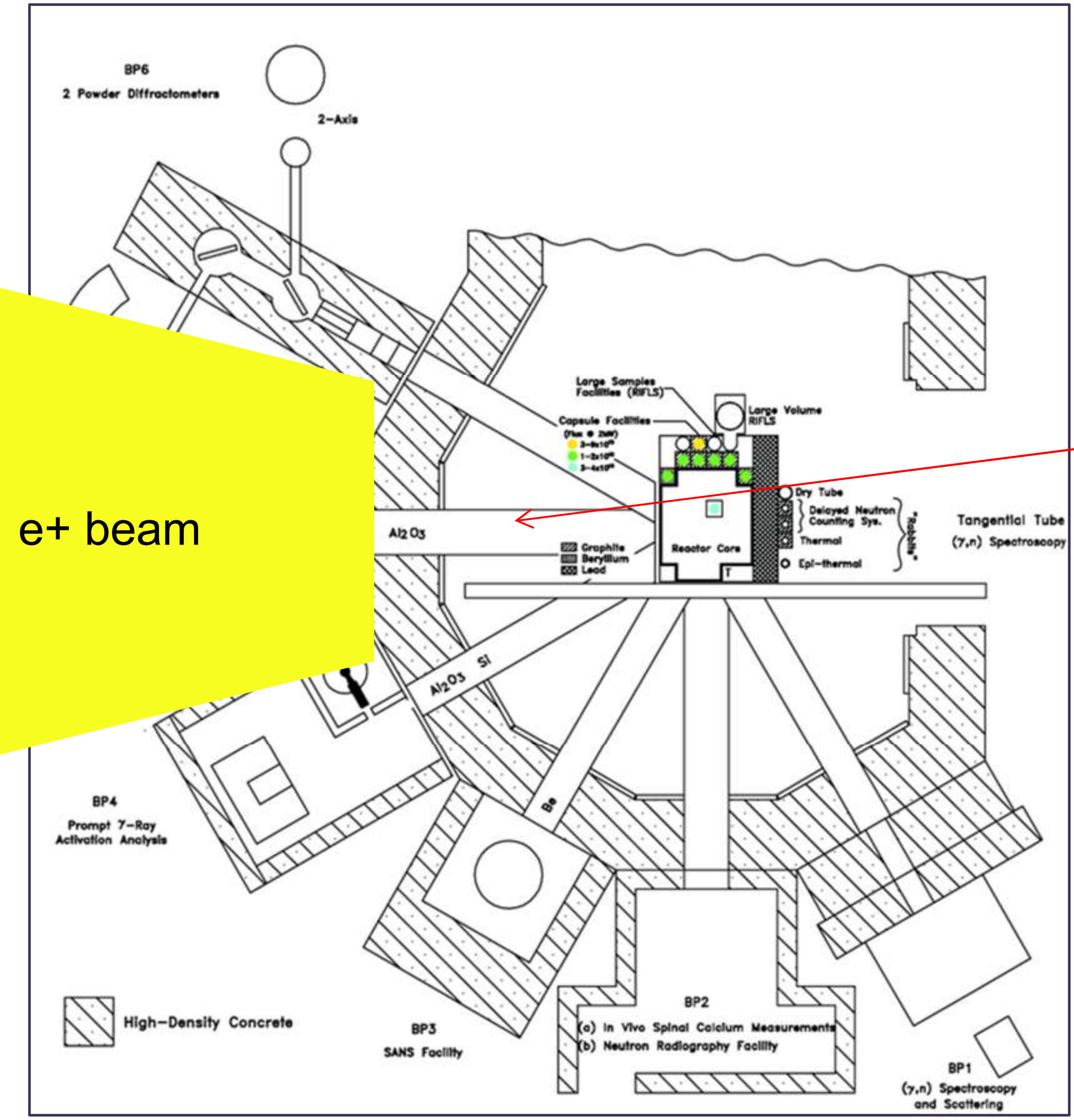


- Full containment
- Negative pressure
- MTR-type
- Swimming pool
- Forced downflow
- Licensed to 5 MW_{th}
- Normally operated at 3 MW_{th}
- 16 hours/day, 2 shifts, 5 or 6 days/week





In the core, gas chambers are inserted daily for medical isotope production and radial beam ports with direct access to the core (20cm diam ports)



Beam ports:

1 Radiography (industrial)

2 Radiography (industrial)

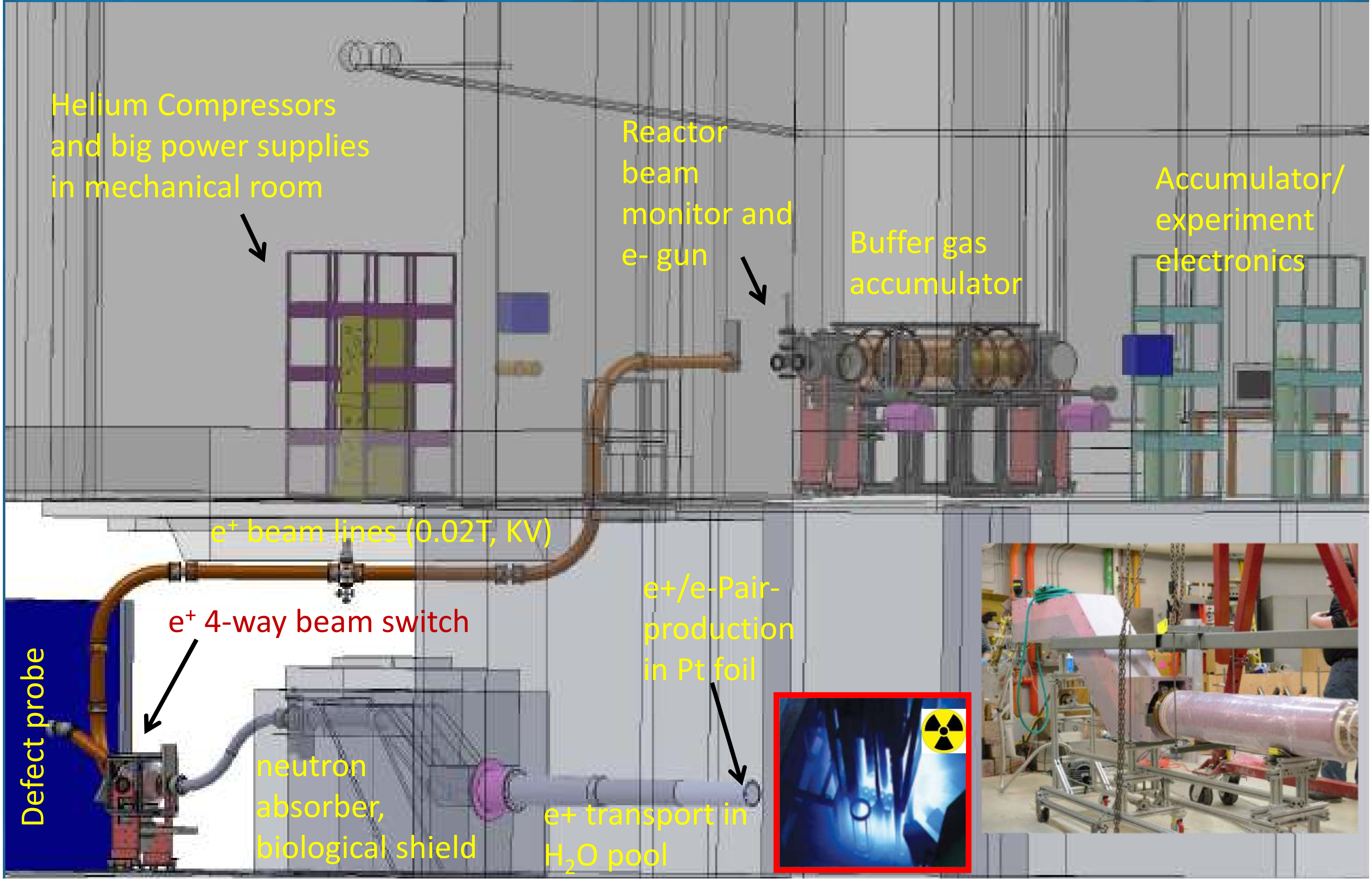
3 Radiography (research)

4 Prompt-gamma neutron activation analysis

5 **low energy e+ Beam**

6 Neutron Scattering

McMaster Intense Positron Beam Facility (MIPBF)



Helium Compressors and big power supplies in mechanical room

Reactor beam monitor and e- gun

Buffer gas accumulator

Accumulator/ experiment electronics

e^+ beam lines (0.02T, KV)

e^+ 4-way beam switch

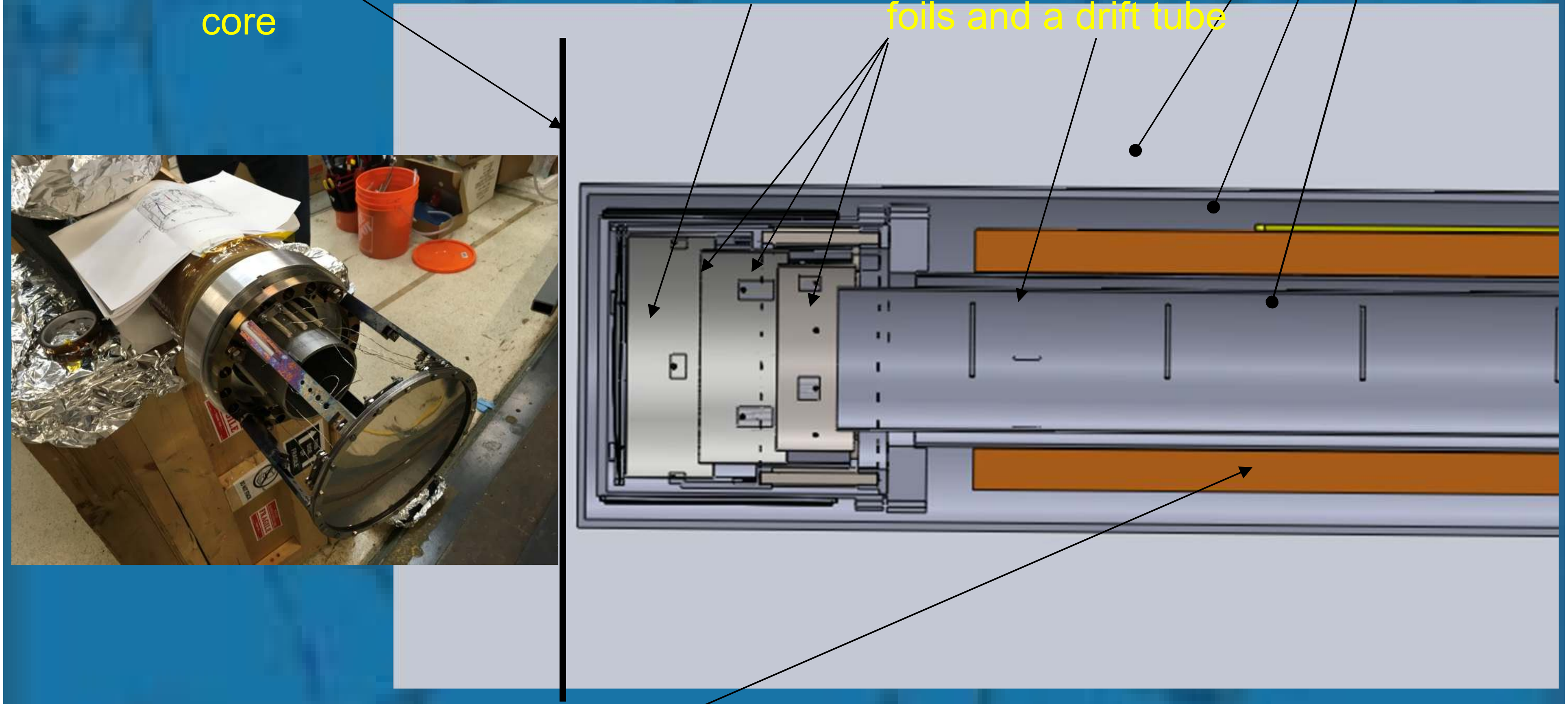
Defect probe

e+/e-Pair-production in Pt foil

neutron absorber, biological shield

e+ transport in H_2O pool

e^+ Production Foils Near Reactor Core



Edge of reactor core

Platinum foils: gammas in foil produce e^+/e^- pairs. ~15cm diameter.

Thermal e^+ accelerated by applied potentials on foils and a drift tube

Water (pool)

Air

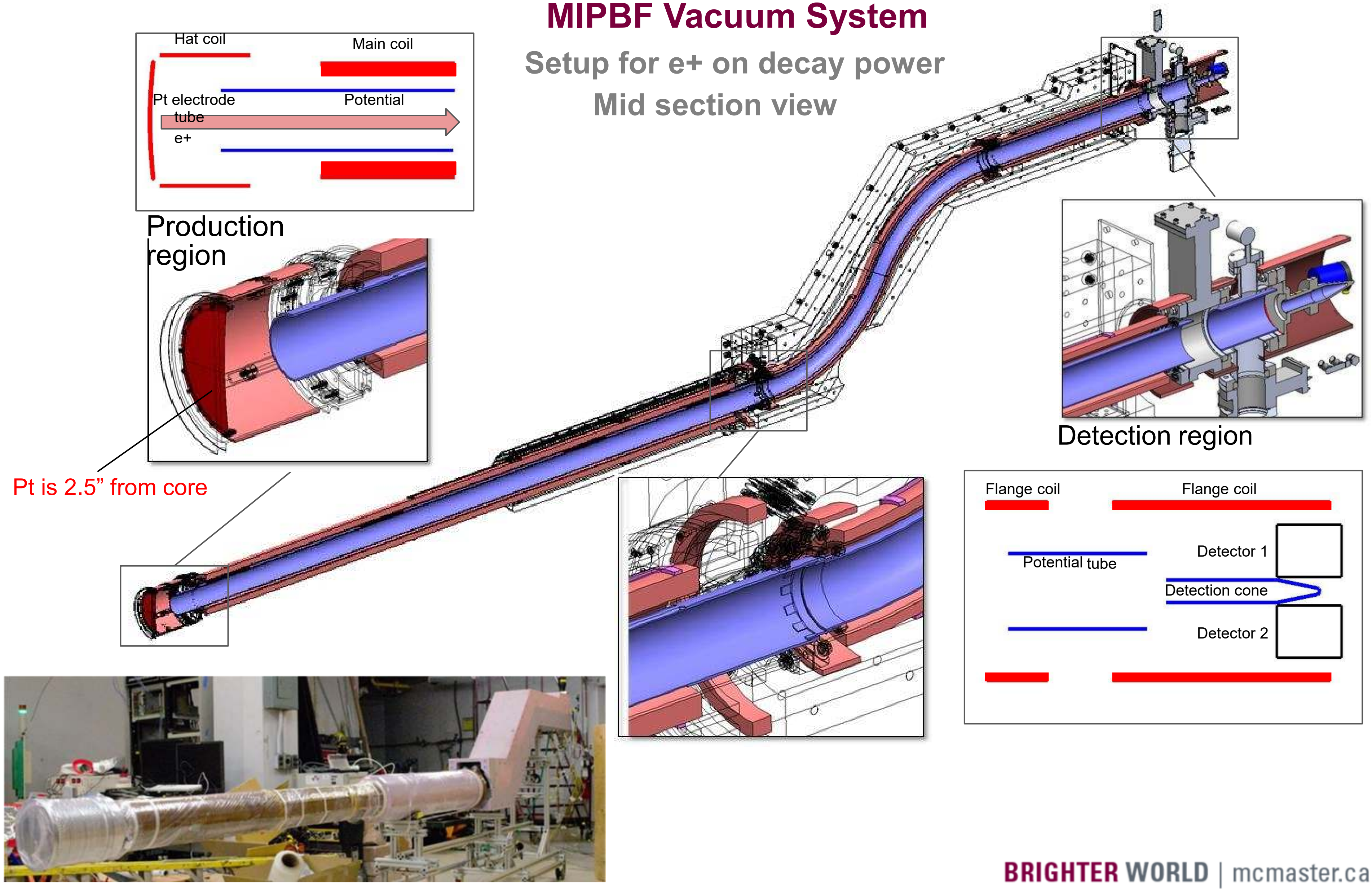
vacuum

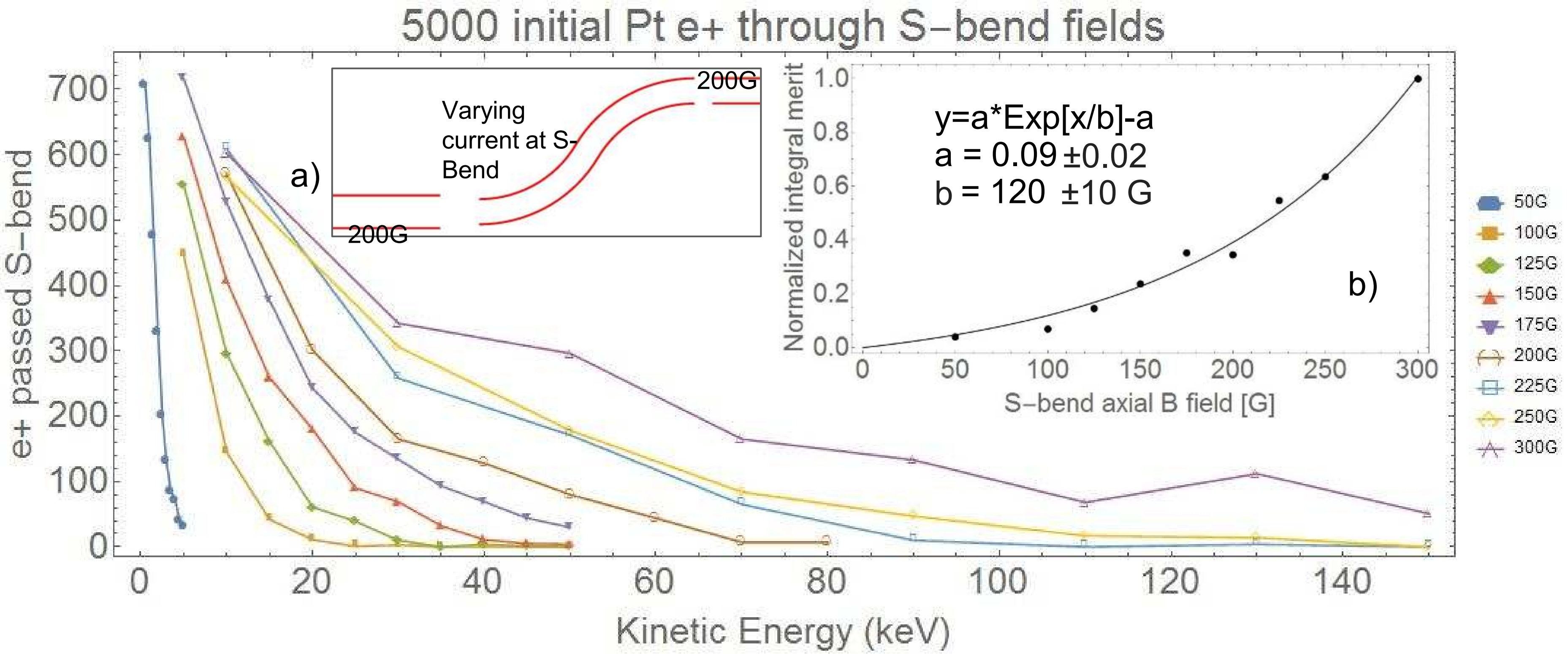
Solenoid (>0.01 Tesla) to guide low energy e^+ out of pool
Passively cooled by air (requirements at the reactor)

MIPBF Vacuum System

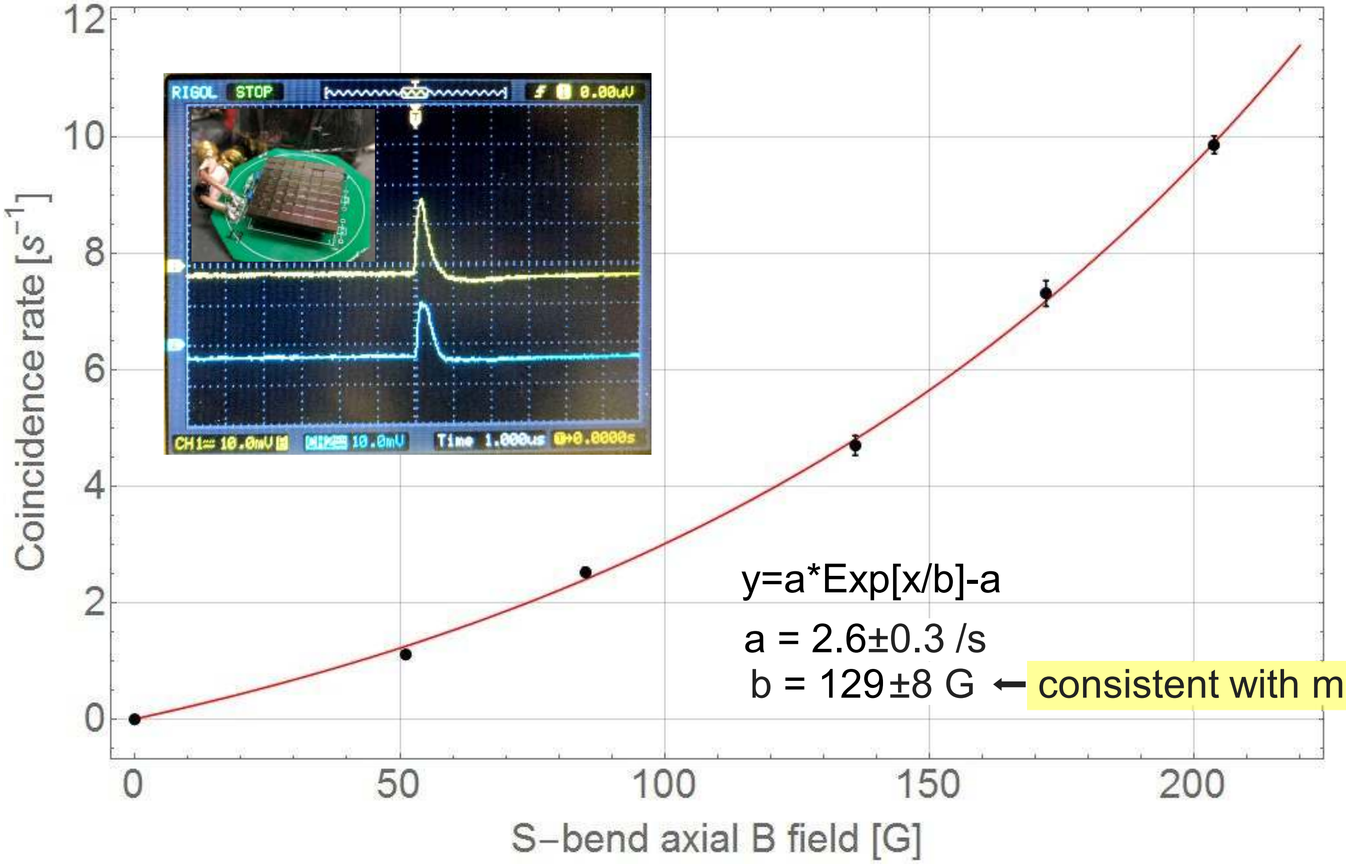
Setup for e+ on decay power

Mid section view





a) Simulation of 5000 e$^+$ starting from the platinum at varying energies and various S-bend axial magnetic fields. For <200G S-bend fields used, the detected e$^+$ have <100keV of kinetic energy. b) The area under each field curve as a merit to compare to experimental data.

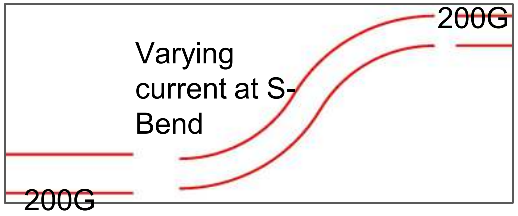


y=a*Exp[x/b]-a

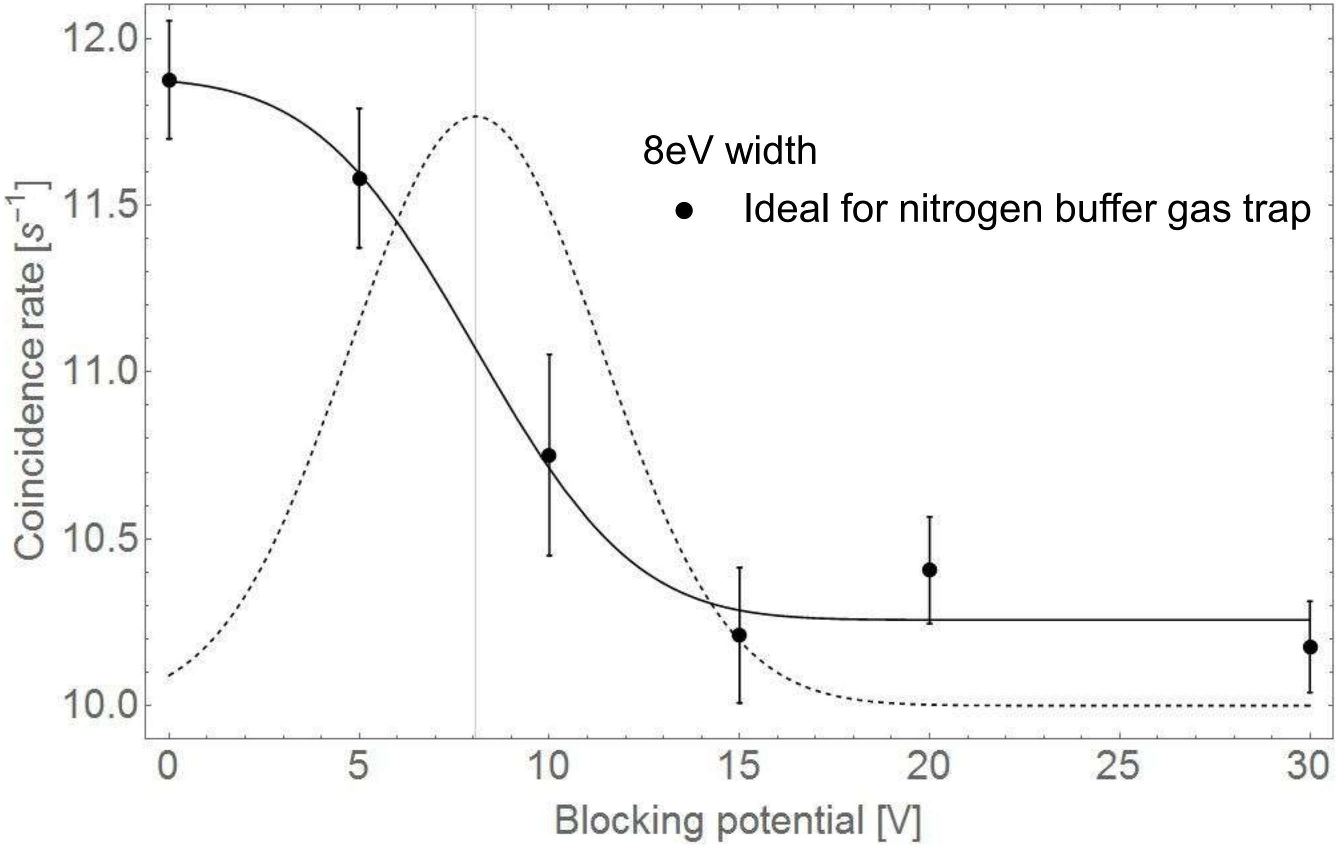
a = 2.6±0.3 /s

b = 129±8 G ⟵ consistent with model

Main solenoid = 200G
Short solenoid = 200G



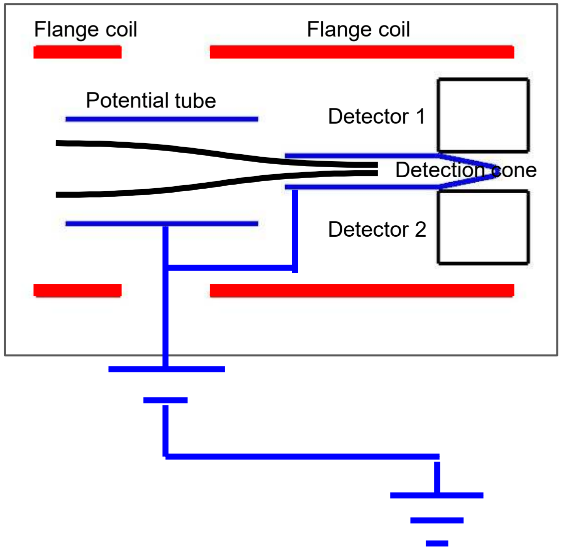
Measured e^{+} coincidence rate for varying S-bend axial magnetic fields



8eV width

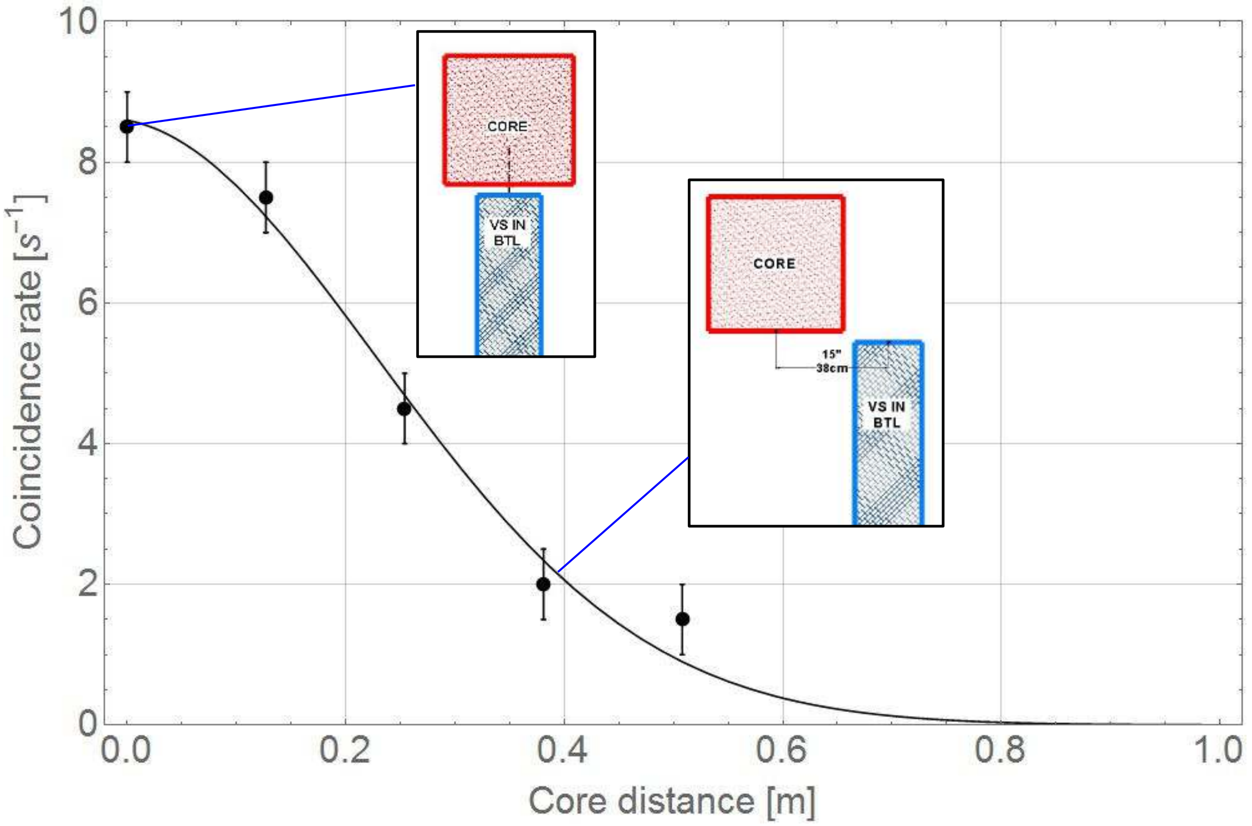
- Ideal for nitrogen buffer gas trap

Detection region



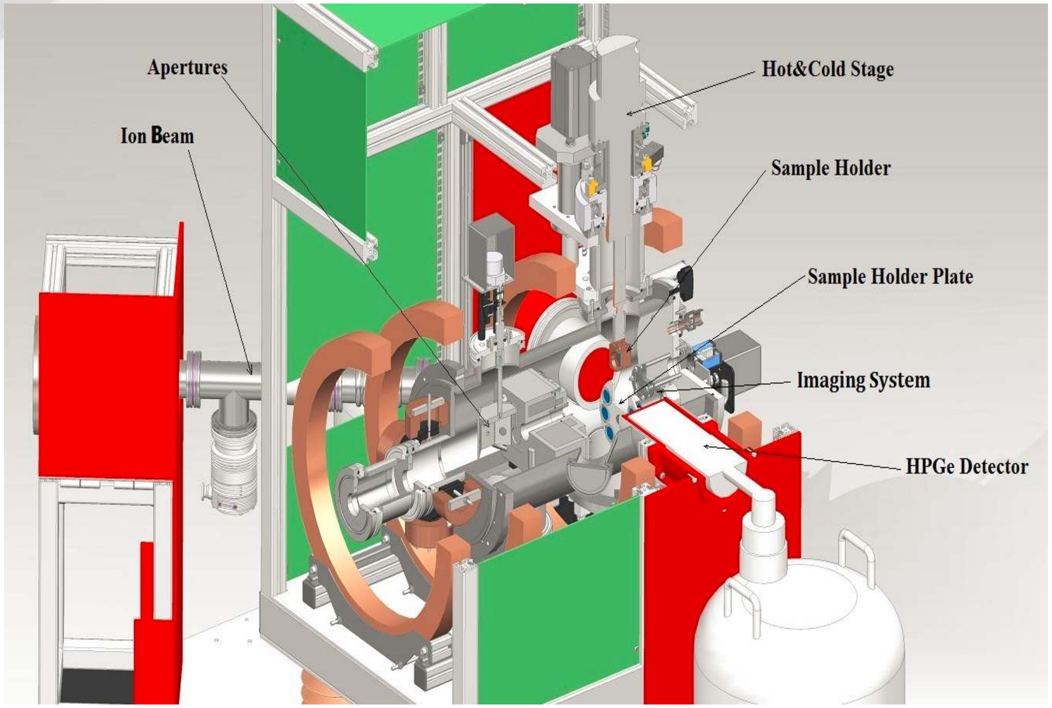
Positrons pair produced at the platinum foil are moderated by an applied 10V potential. A blocking potential before the detection region is scanned. The low energy e^+ are blocked and the remaining background counts are high energy e^+.

Measured Coincidence Rate vs. Core Distance



Positron Defect Probe at MIPBF

Courtesy Pierre CARIES, GAP Engineering Co.



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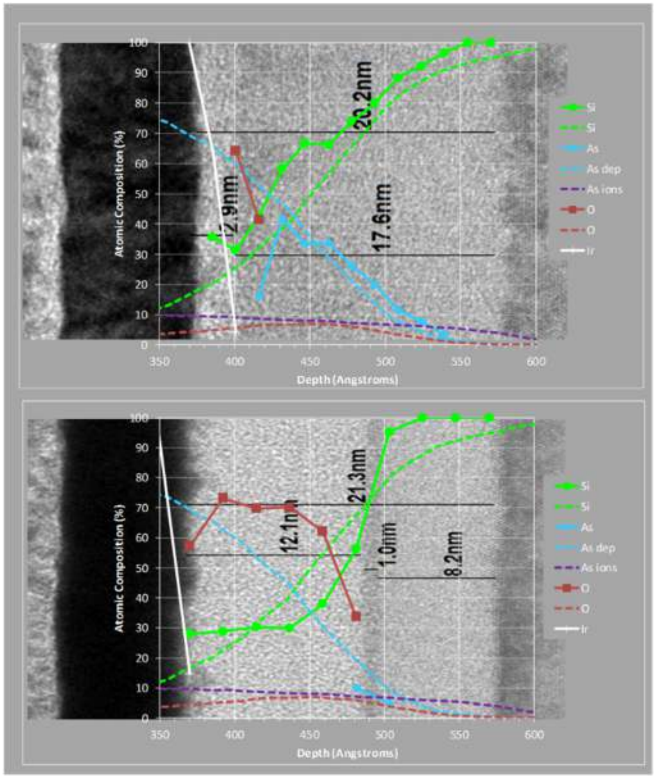
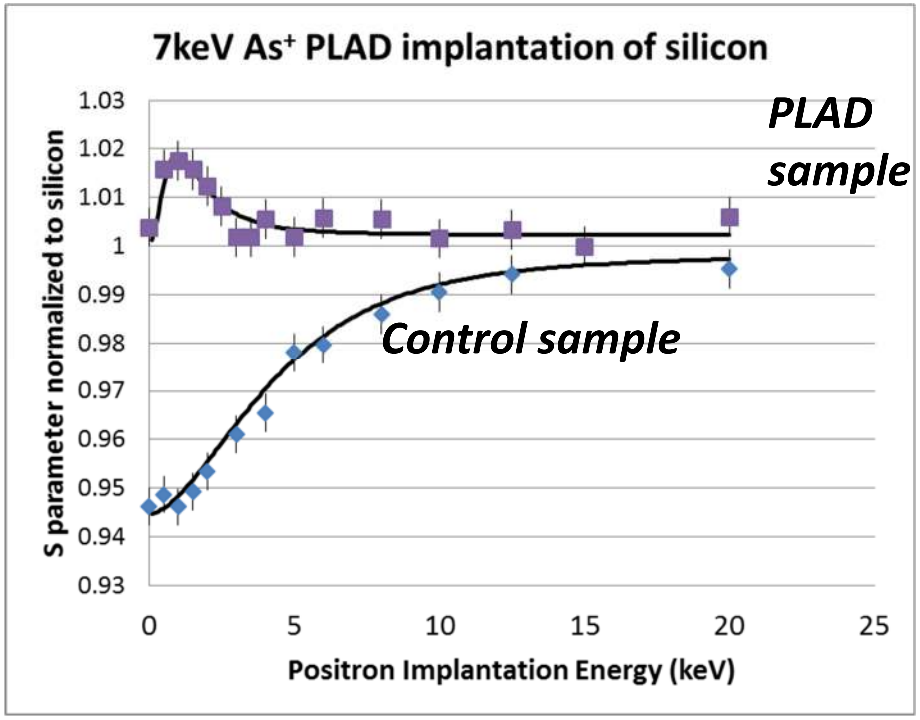
Peihai Li, M.A.Sc. Thesis, McMaster University 2015

Out of Core Test of Defect Characterization System

First Results using the Defect Characterization Chamber – Plasma Doping of Silicon (A.P. Knights et al., unpublished)





- Plasma Doping (PLAD) is a promising alternative to traditional beamline ion implantation
- Current collaboration with AMAT includes PAS in a round robin experiment to determine differences in the two doping technologies
- Preliminary data (first data taken on Defect Characterization chamber) shows defect formation at near-surface region of PLAD exposed wafer
- Fits to data indicate void formation in a thin layer (work on-going).

Progress Checklist and Next Steps

- ☐ Electrical and HVAC Installations – completed
- ☐ Defect Probe System – tested and operational
- ☐ Completion and Test of Positron Trap at York – Electronics and Positron Annihilation Detection System (completed)
- ☐ Finalization of Shielding and Source Design – completed
- ☐ Installation of Shielding and Source – completed
- ☐ Installation of Beam Tube and Positron Switch Yard – completed
- ☐ Installation of End-stations at McMaster – Summer 2021
- ☐ Thermal Load Issues Addressed and Solved – TBD
- ☐ NSERC Grant for New Na-22 Positron Source; Delivery Fall 2021