TRIUMF

50 anniversary anniversaire

Meson Hall 1974-1979

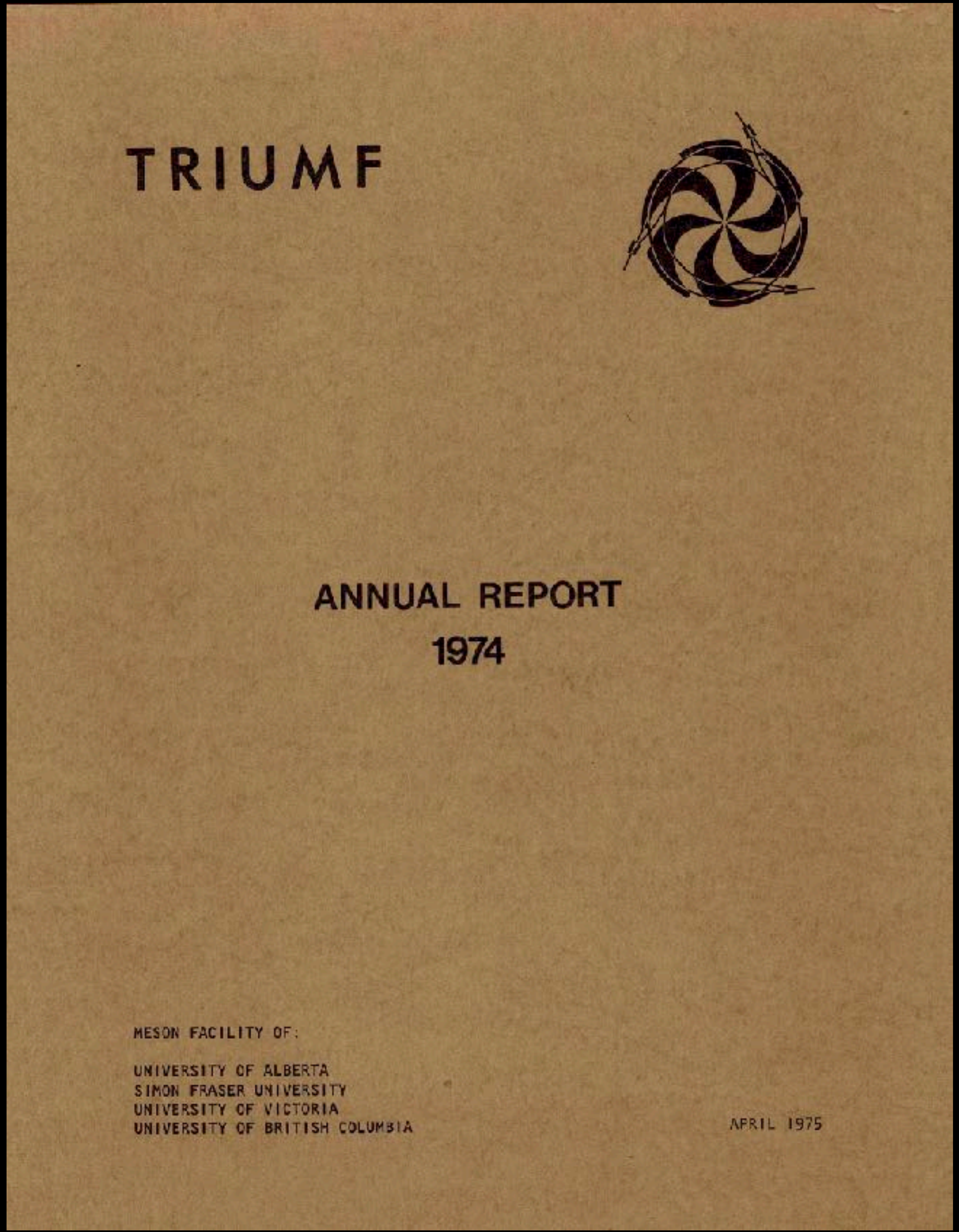
Ryugo Hayano

U Tokyo

東京大学 THE UNIVERSITY OF TOKYO

July 17, 2018

500 MeV
December 15, 1974


TRIUMF

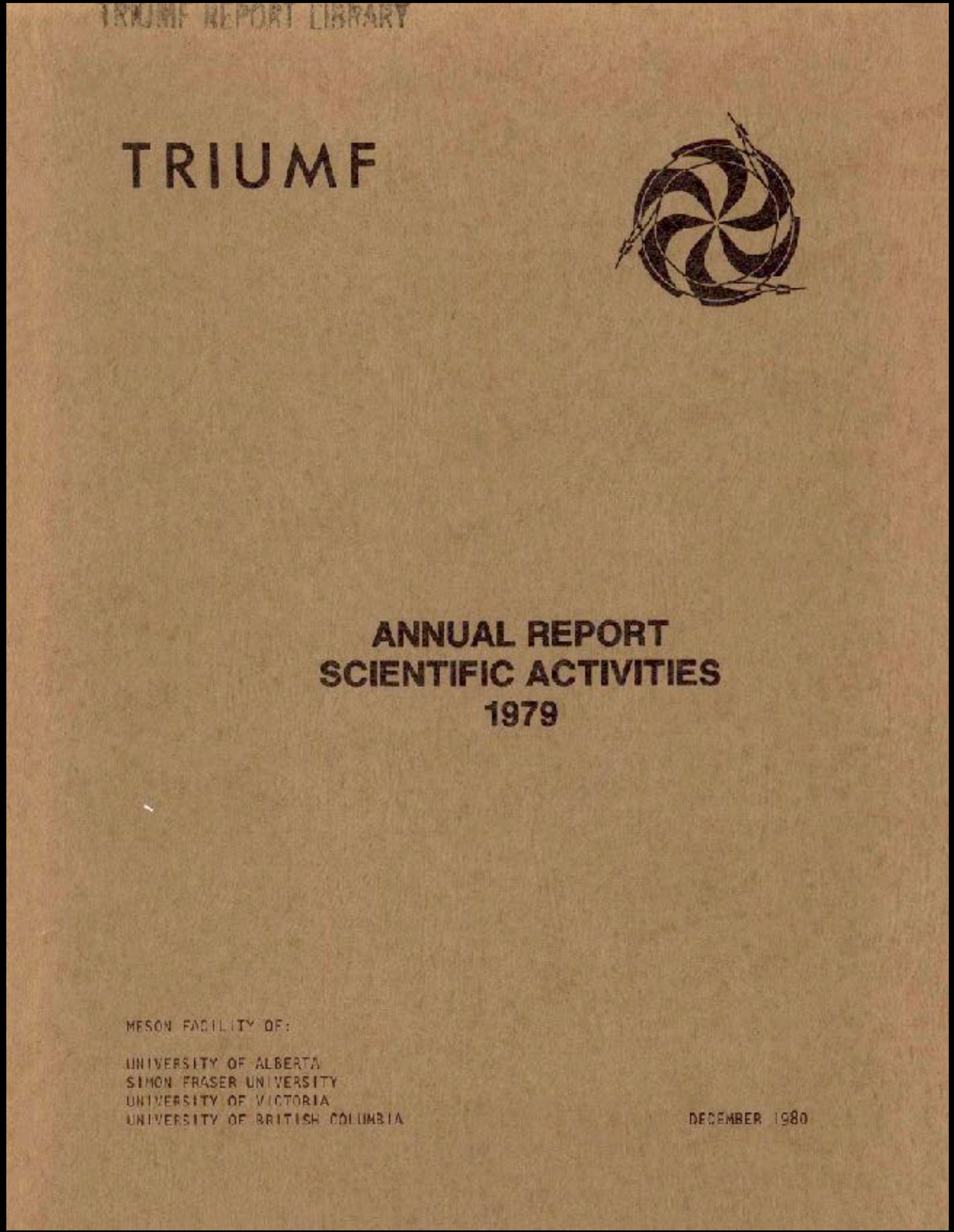
ANNUAL REPORT
1974

MESON FACILITY OF:

UNIVERSITY OF ALBERTA
SIMON FRASER UNIVERSITY
UNIVERSITY OF VICTORIA
UNIVERSITY OF BRITISH COLUMBIA

APRIL 1975

Hayano, PhD
March 29, 1979



TRIUMF

ANNUAL REPORT
SCIENTIFIC ACTIVITIES
1979

MESON FACILITY OF:

UNIVERSITY OF ALBERTA
SIMON FRASER UNIVERSITY
UNIVERSITY OF VICTORIA
UNIVERSITY OF BRITISH COLUMBIA

DECEMBER 1980


µA-Hour per year, 1975-1979
80,000
60,000
40,000
20,000
0
1975
1976
1977
1978
1979
Year

TRIUMF "Meson Factory"

$$500\ \text{MeV}\ p + A \rightarrow \pi^{\pm} + X$$

$$\downarrow$$

$$\pi \rightarrow \mu\ \nu$$

$$\uparrow$$

~~Meson~~ Lepton

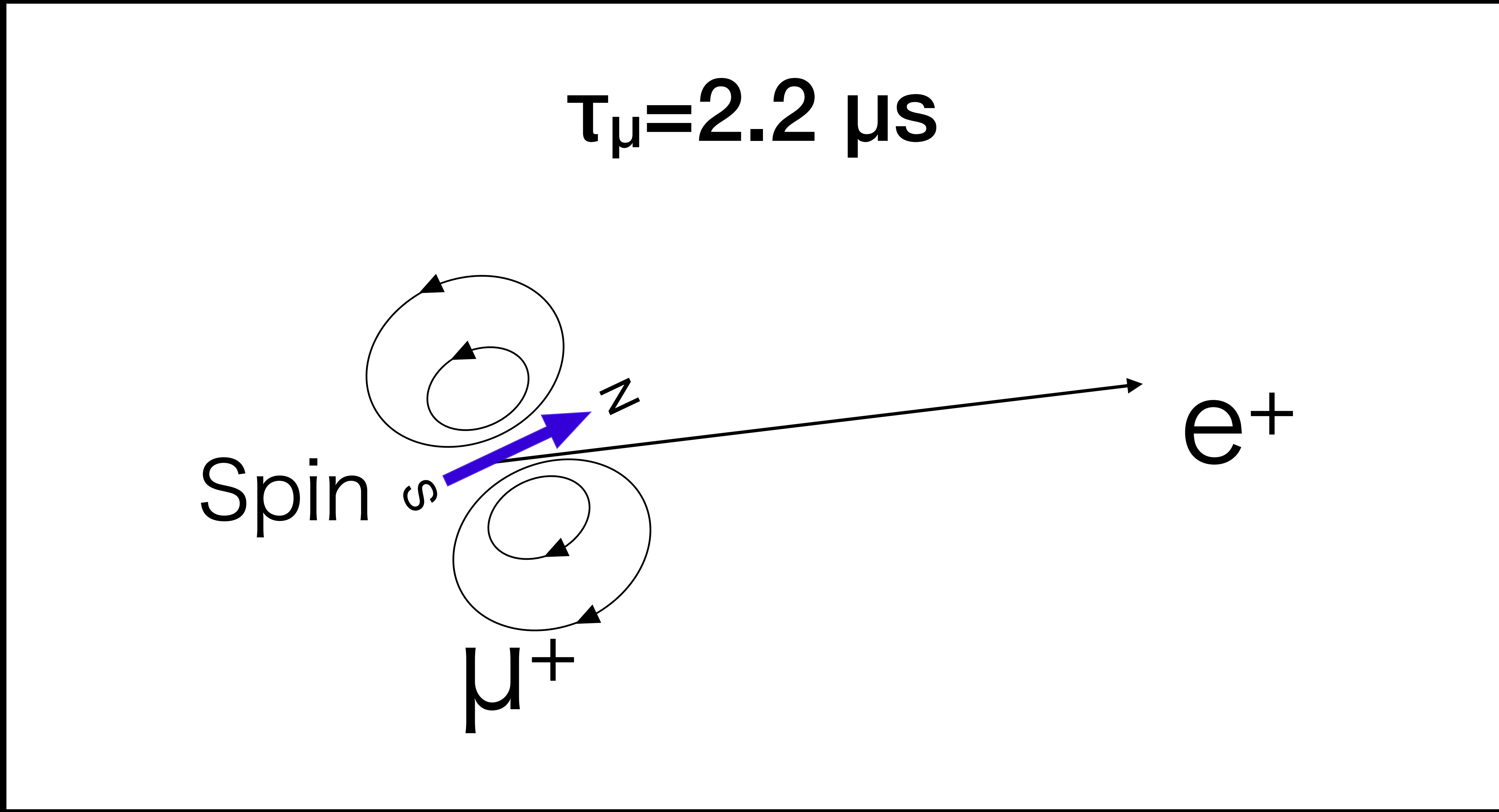
PhD, March 29, 1979 ← The FIRST TRIUMF PhD

“Spin fluctuations of itinerant electrons in MnSi studied by muon spin rotation and relaxation”

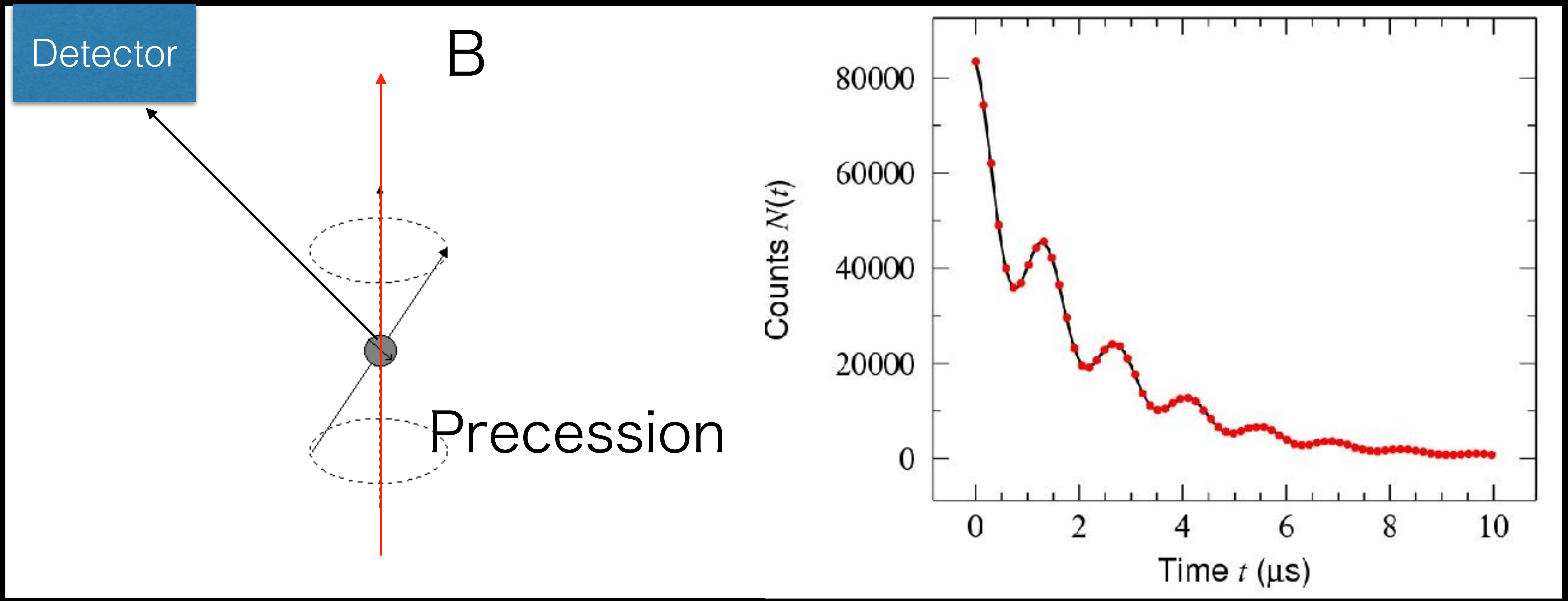
μSR

著者（漢字）	早野,龍五 ← Hayano, Ryugo
著者（英字）	
著者（カナ）	ハヤノ,リュウゴ
標題（和）	ミュオンスピン回転法及び緩和法によるMnSi中の遍歴電子のスピンのゆらぎの研究
標題（洋）	Spin Fluctuations of Itinerant Electrons in MnSi Studied by Muon Spin Rotation and Relexation
報告番号	104747
報告番号	甲04747
学位授与日	1979.03.29

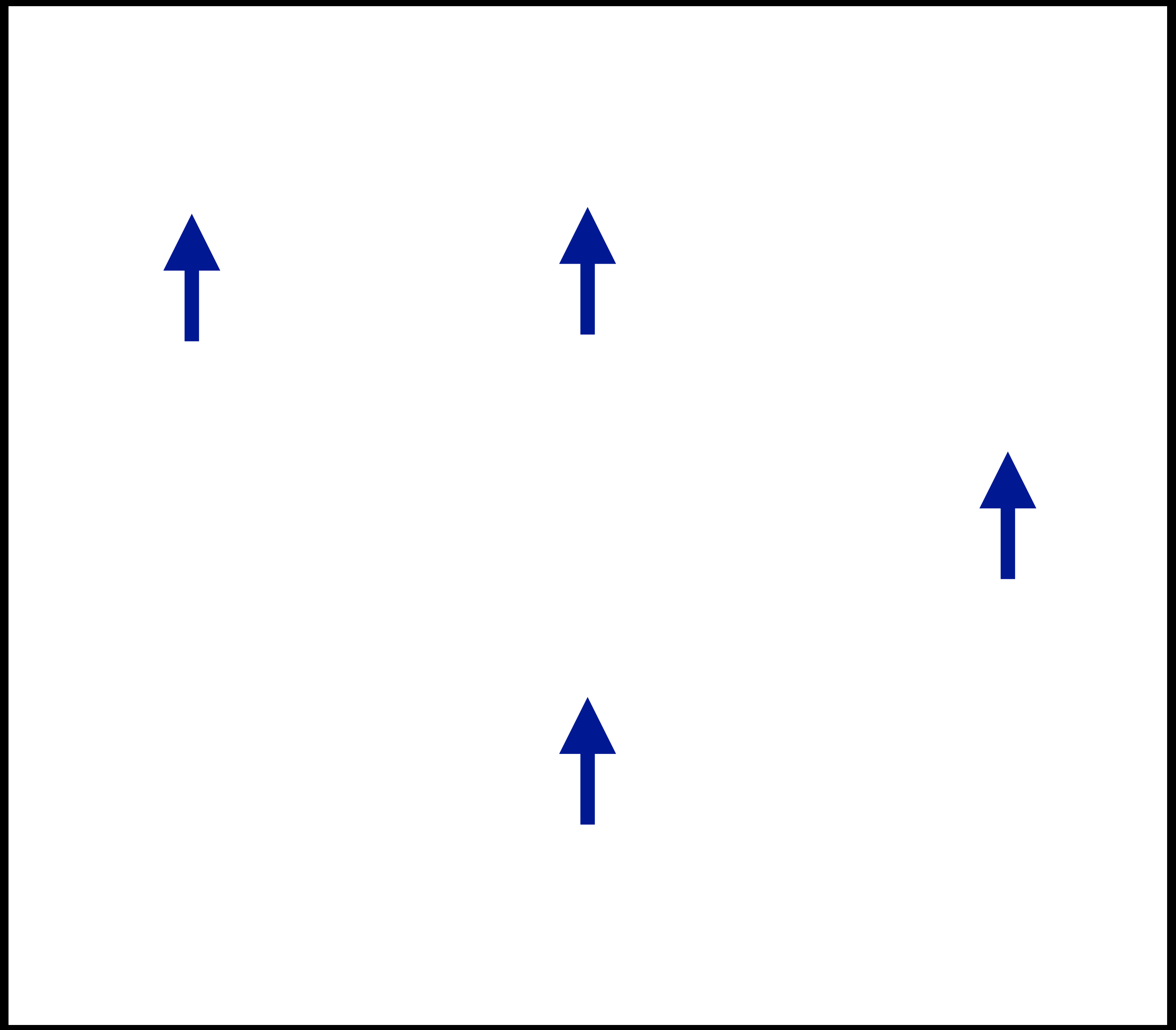
$\mu \rightarrow e$ decay asymmetry
(Parity violation)



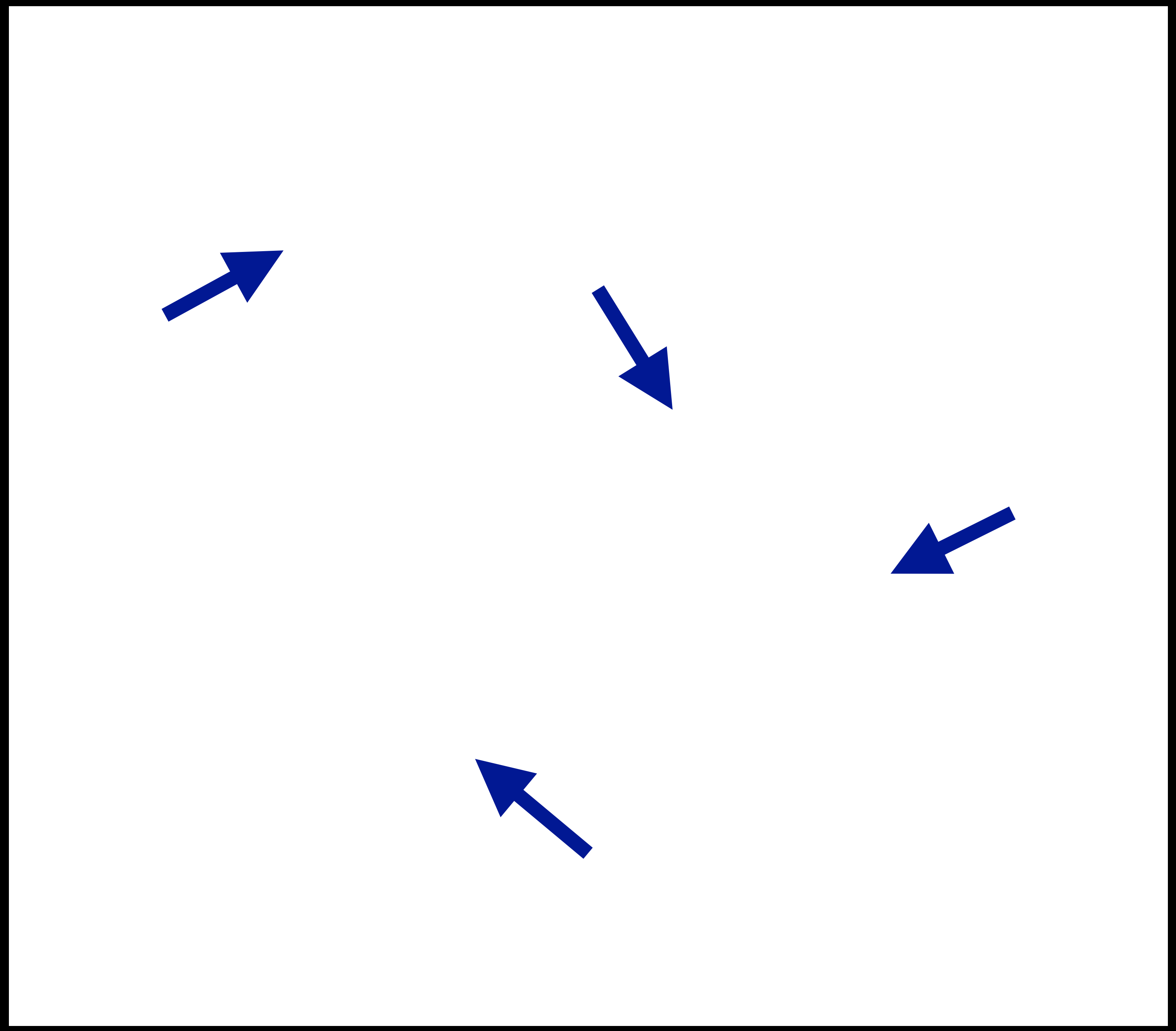
Transverse field μSR (spin rotation/precession)



μSR (Spin Relaxation)



→ Relaxation



μ spins
Initially polarized

μ spins
become unpolarized

A part of my thesis,

“muon spin RELAXATION”

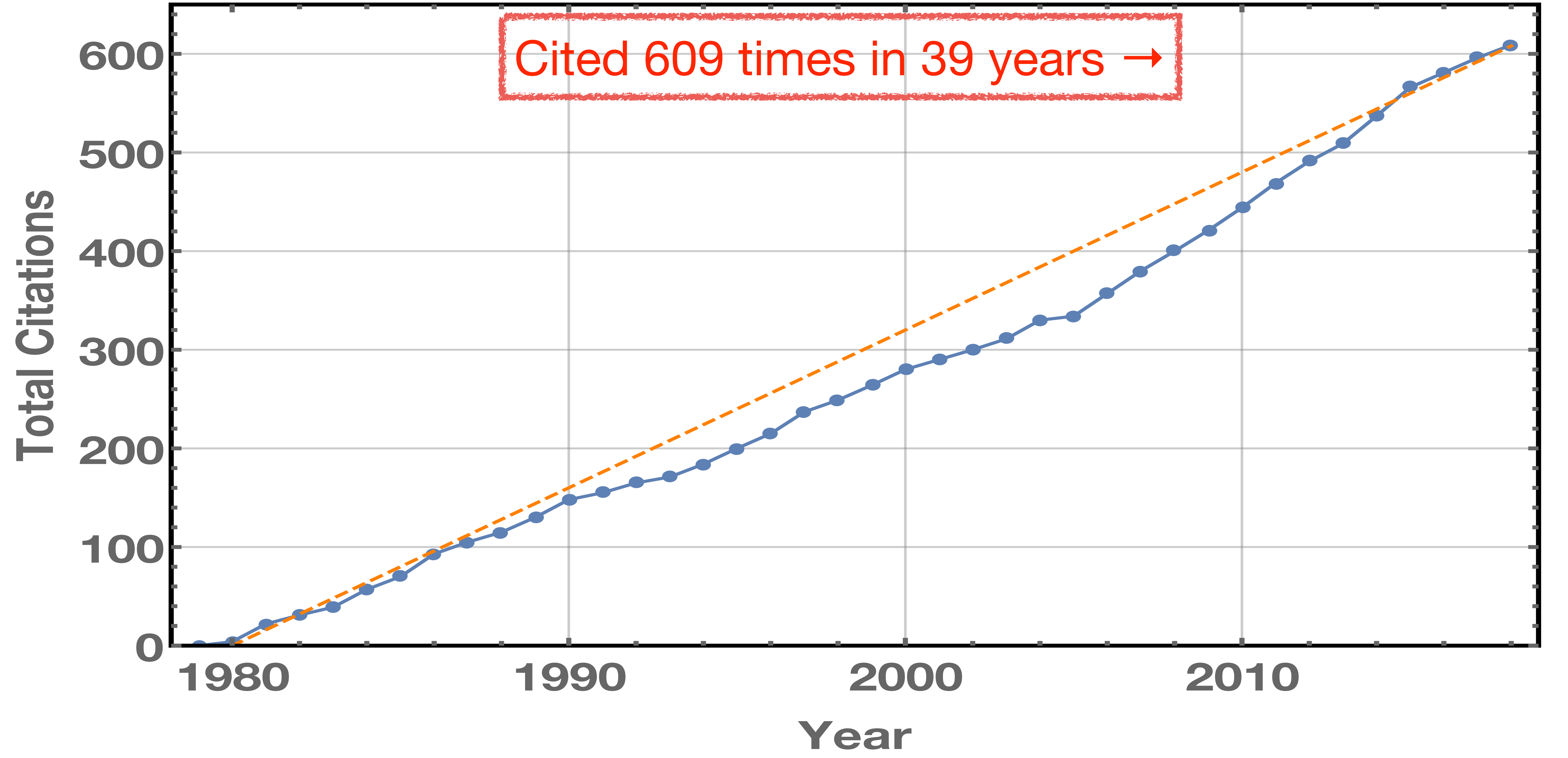
was published in Phys. Rev. B in 1979

PHYSICAL REVIEW B20 AUGUST 1979

Zero- and low-field spin relaxation studied by positive muons

R. S. Hayano, Y. J. Uemura, J. Imazato, N. Nishida, T. Yamazaki, and R. Kubo
Department of Physics, University of Tokyo, Bunkyo-ku, Tokyo, Japan
and TRIUMF, Vancouver, Canada

(Received 27 February 1979)



After 1979-

- KEK, BNL, …
- U-Tokyo Professor
- CERN “ASACUSA” (antimatter) leader
- Radiological protection in Fukushima
- U-Tokyo Emeritus
- Suzuki-method president

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- Suzuki-method president
- …

1974
Apr-Nov

LBL-2666 Preprint

RELATIVISTIC EFFECT ON MAGNETIC MOMENTS OF NEGATIVE MUONS BOUND TO HIGH-Z NUCLEI

T. Yamazaki, S. Nagamiya, O. Hashimoto,
K. Nagamine, K. Nakai, K. Sugimoto and K. M. Crowe

March 1974

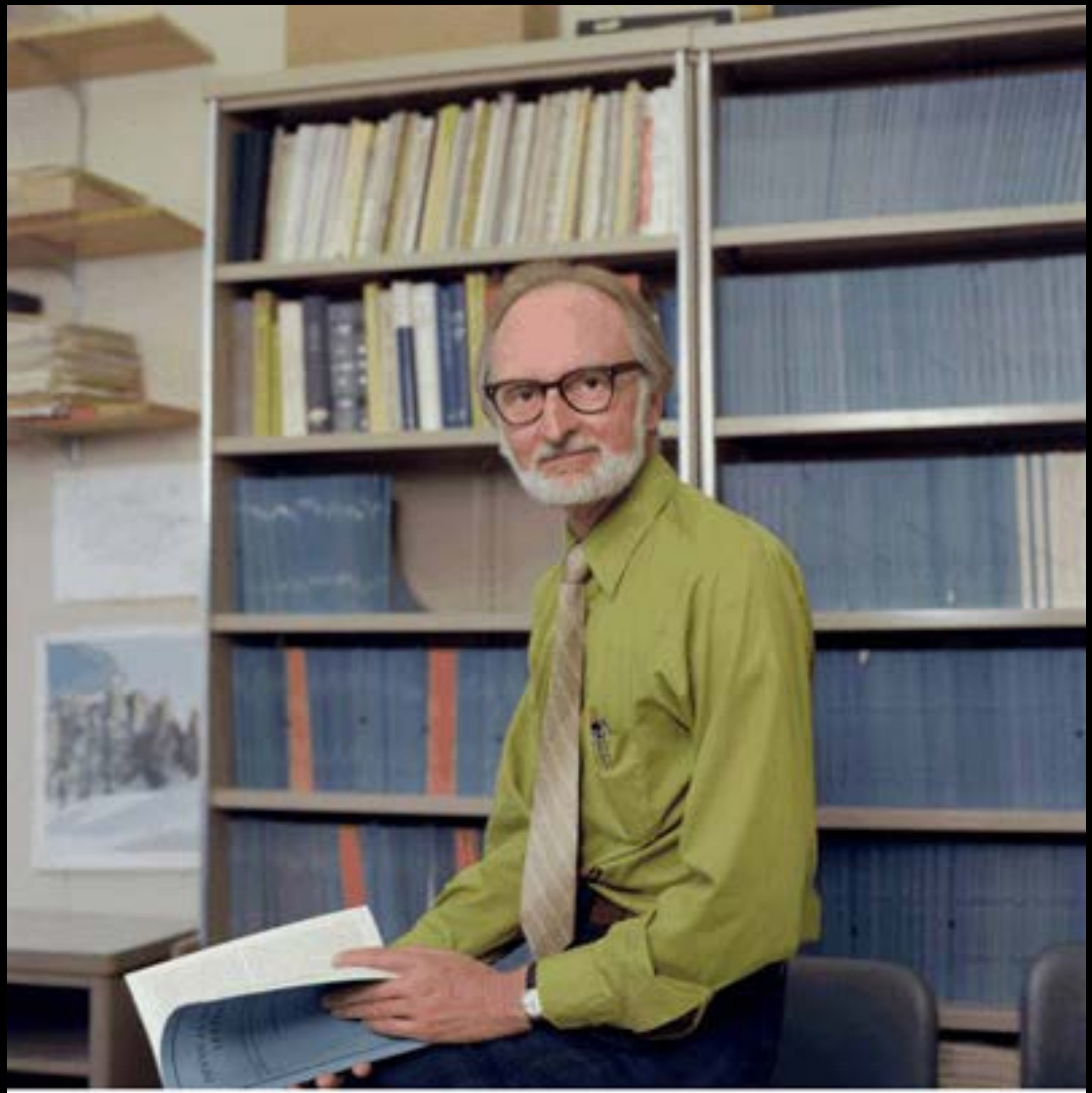
Prepared for the U. S. Atomic Energy Commission
under Contract W-7405-ENG-48

Toshi Yamazaki
1934-

Paul Kienle
1931-2013

U Tokyo Institute of Medical Science (Cyclotron bldg)

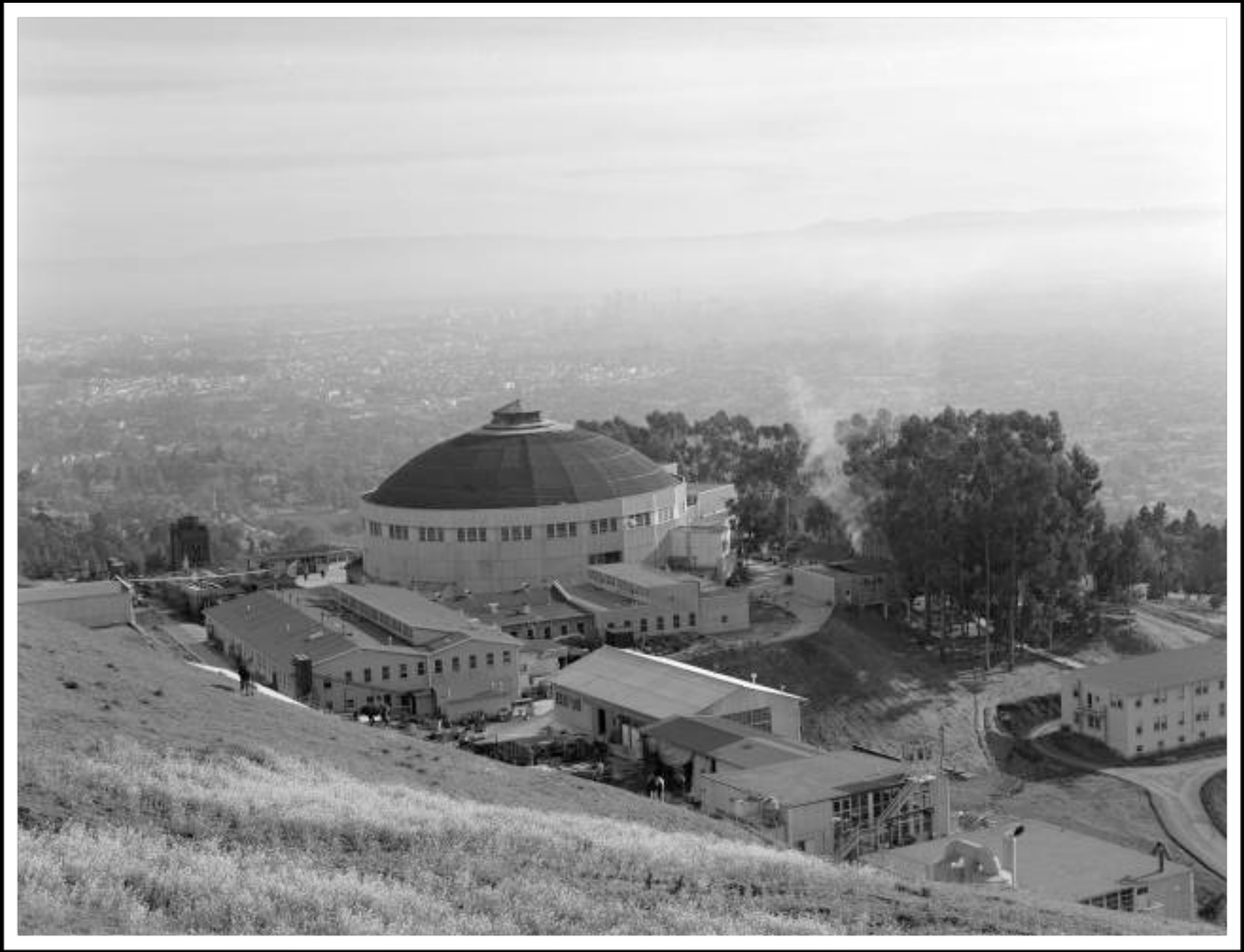
Fall 1974



Owen Chamberlain, 1920-2006

https://commons.lbl.gov/

184” cyclotron

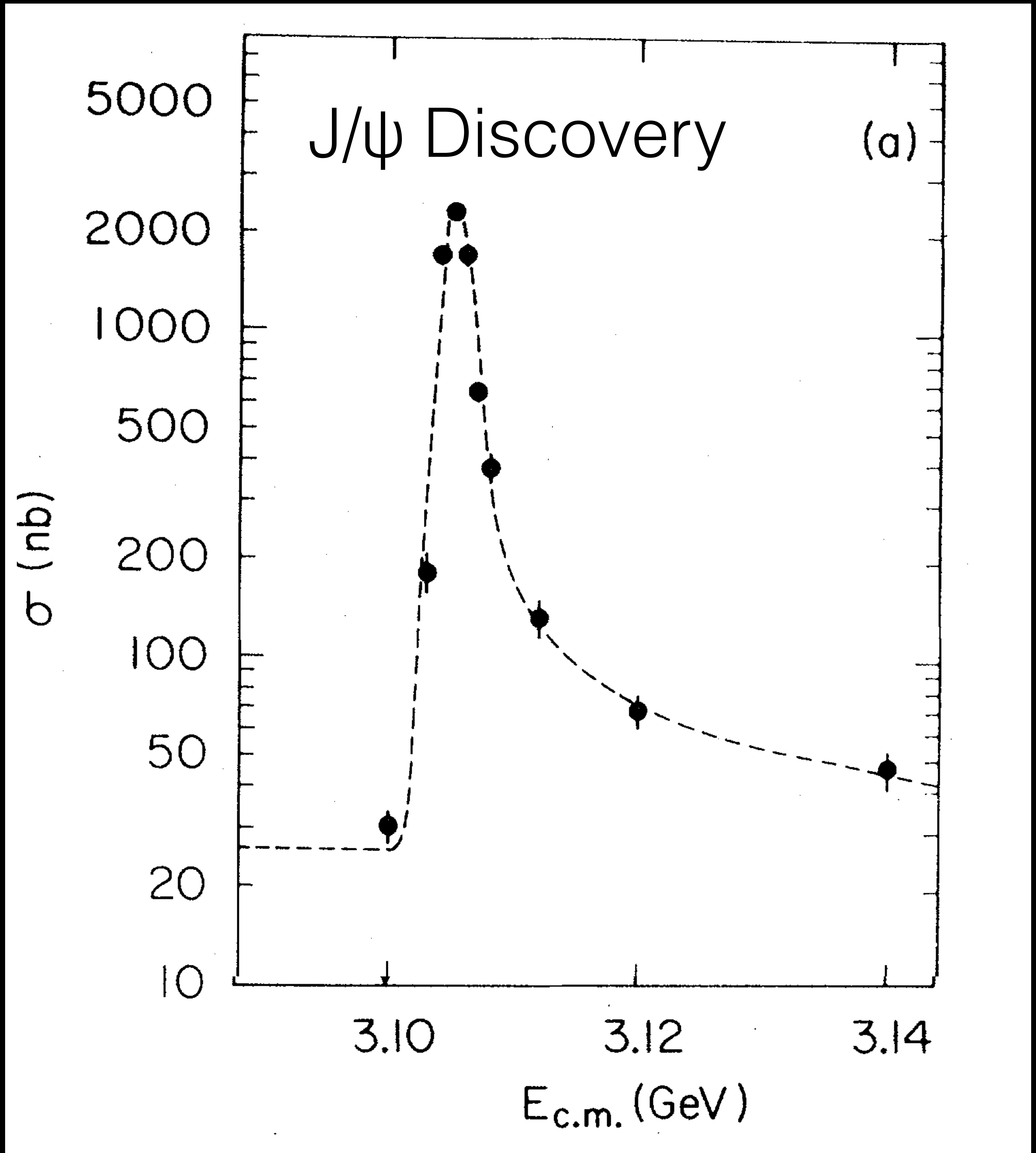


https://commons.lbl.gov/

Ken Crowe, 1926-2012

http://newscenter.lbl.gov/
2012/03/13/ken-crowe/

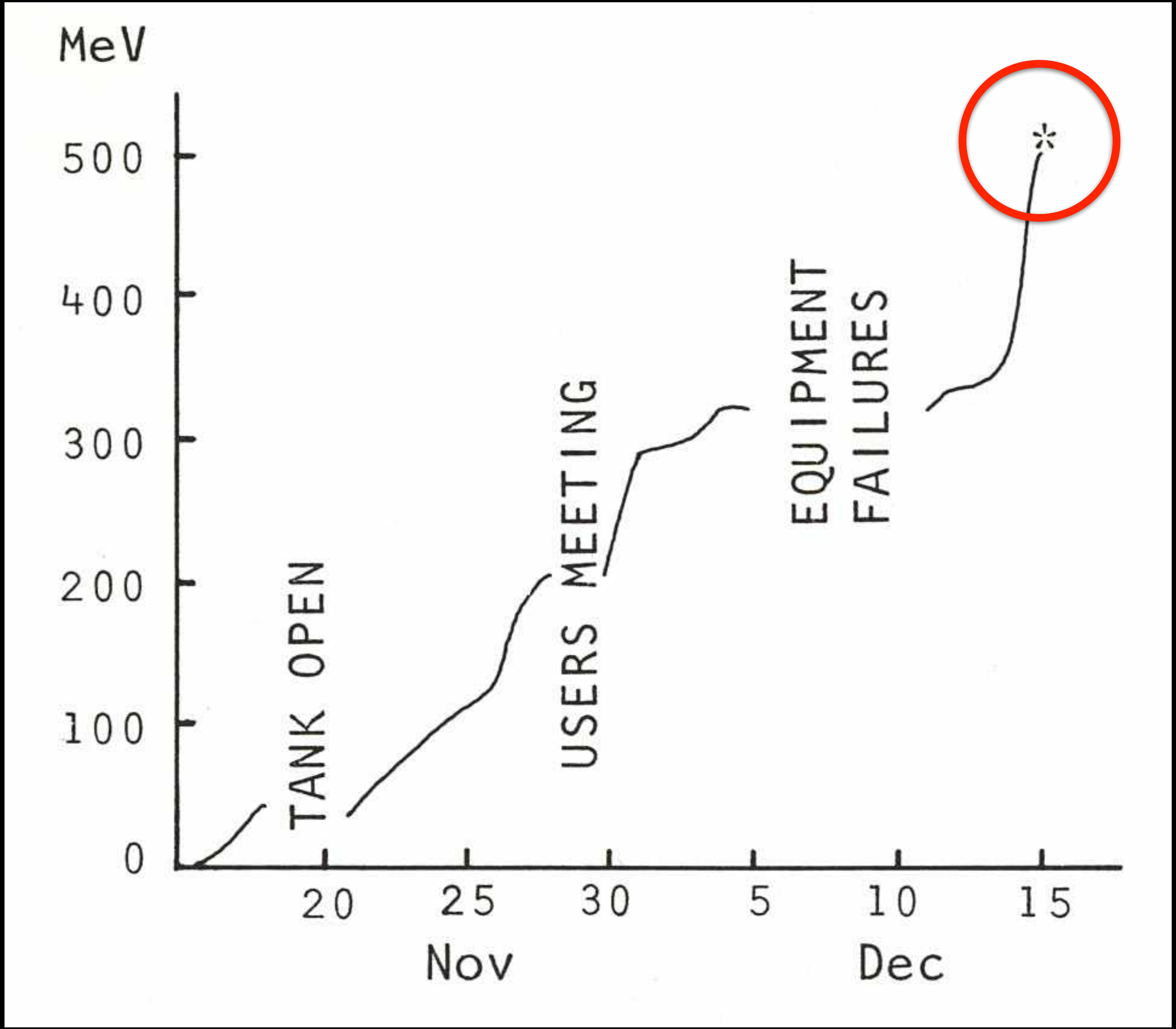
November 1974



December 1974

LBL→TRIUMF

Annual report 1974



Dec 15, 1974

↑

Toshi Yamazaki

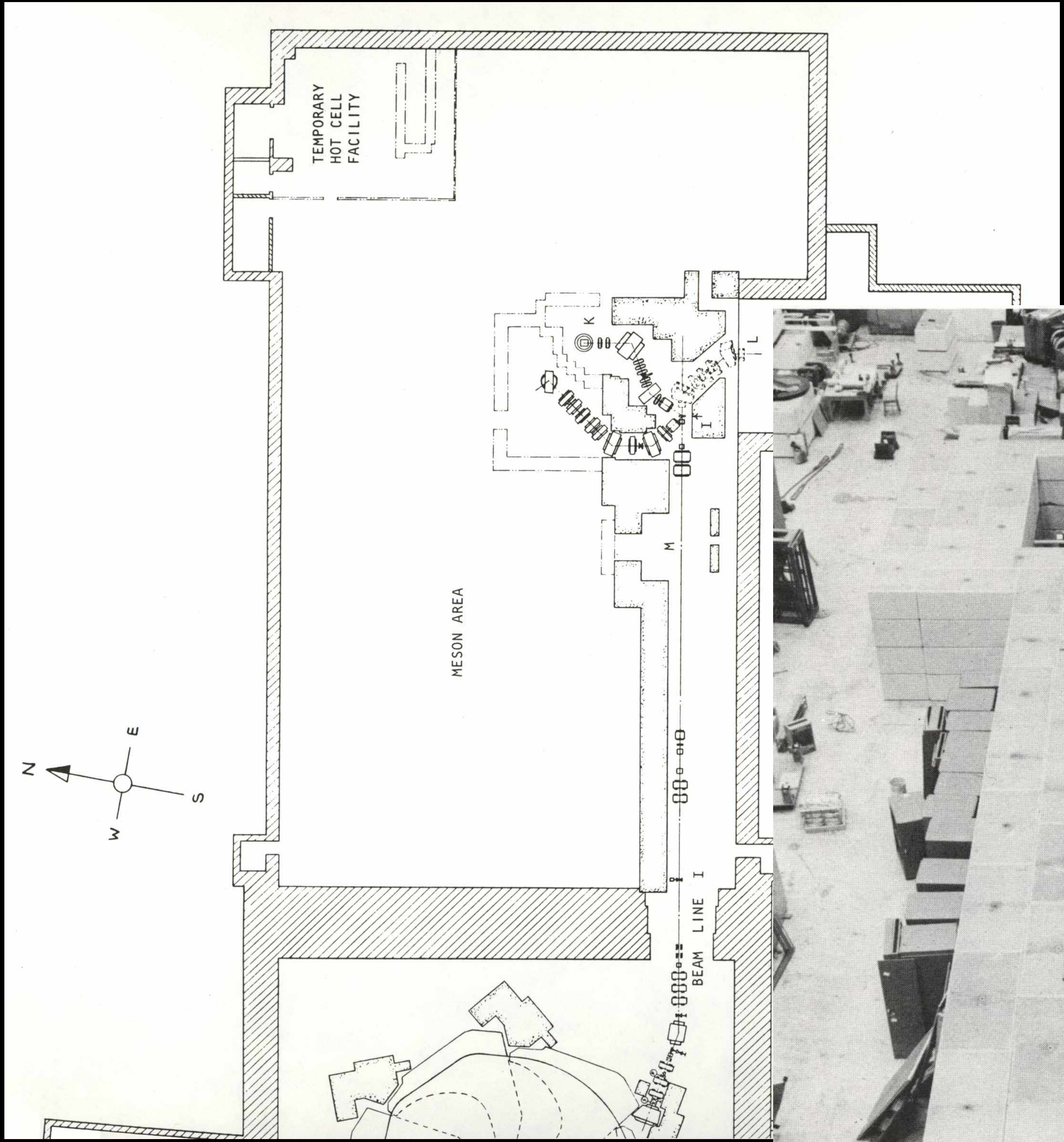
http://www.triumf.ca

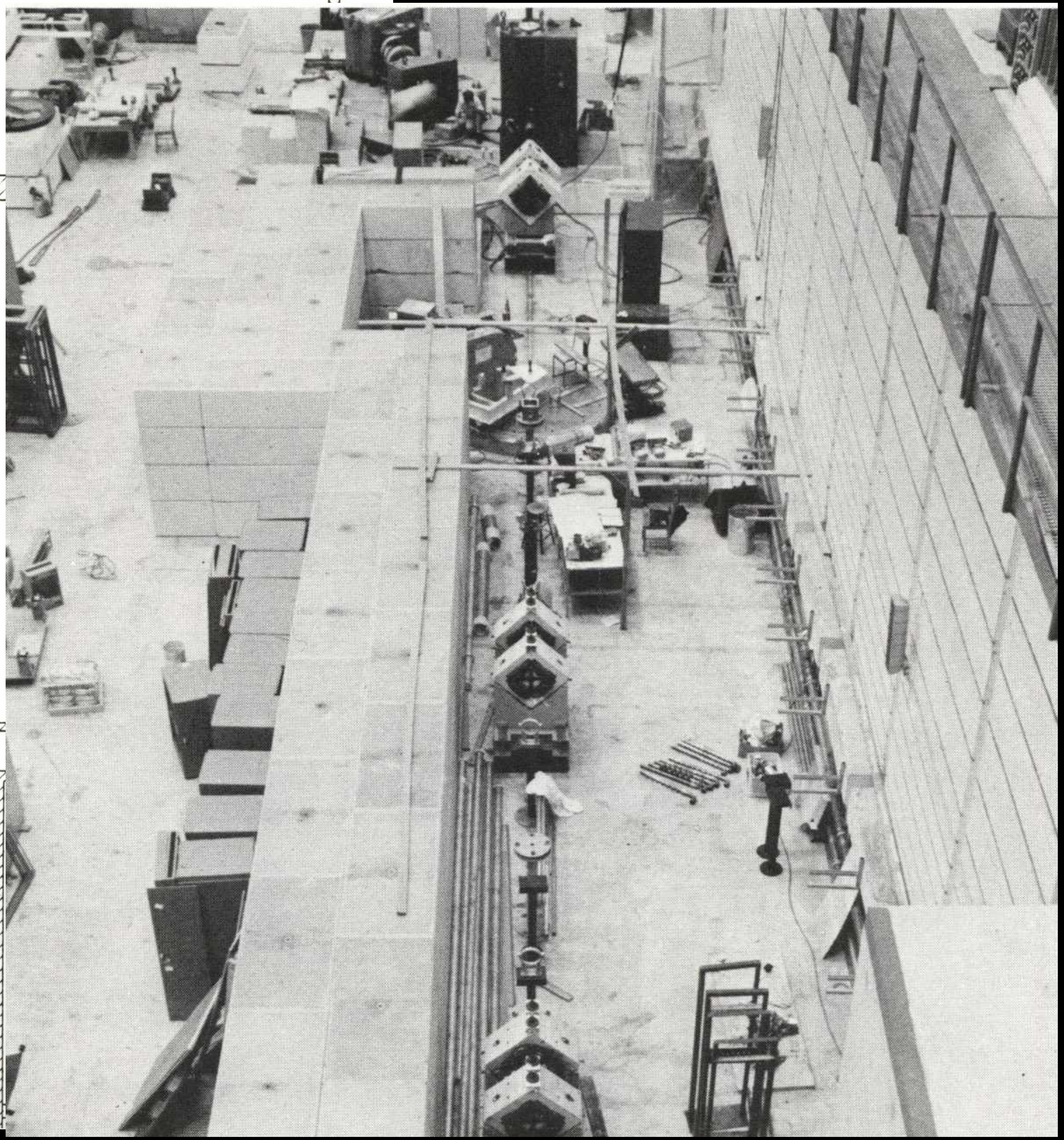
Jan 1975, I turned 23

@ Yamazaki's on West 2nd

From 1974 annual report

1974





Annual report 1974

Prof. T. Yamazaki and Dr. K. Nagamine, University of Tokyo, as well as two graduate students (R. Hayano and N. Nishida) are spending the 74/75 academic year at TRIUMF. They have contributed generously to the budding μSR programme here.

…

In addition, the Tokyo group has made a major financial contribution through the Toray Foundation, and TRIUMF is indeed grateful for their support.

Annual report 1974

…

The core of the μSR data acquisition system DAS is a PDP-11/40 based GT44 (Graphics) computer system, with 64k of memory, two large discs (1.2M words each), magnetic tape and a 17 in. CRT,

…

Jess Brewer


313 HEIGHT
1236 FUEL LEFT
-136 VER VEL
4 HOR VEL
10%
HEIGHT
ALTITUD
DISTANC
FUEL LE
WEIGHT
THRUST
ANGLE
VER VEL
HOR VEL
VER ACC
HOR ACC
SECONDS
TOO FAST. YOU'RE GOING TO CRASH

Annual report 1974

It is now installed in the MSR beam shack. Other than the computer itself, the major components of the DAS are a CAMAC crate and type-A controller, an EG&G time-digital converter (TDC 100) and an MBD-11, which is a microprogrammable branch driver made by Bi-Ra of Albuquerque.

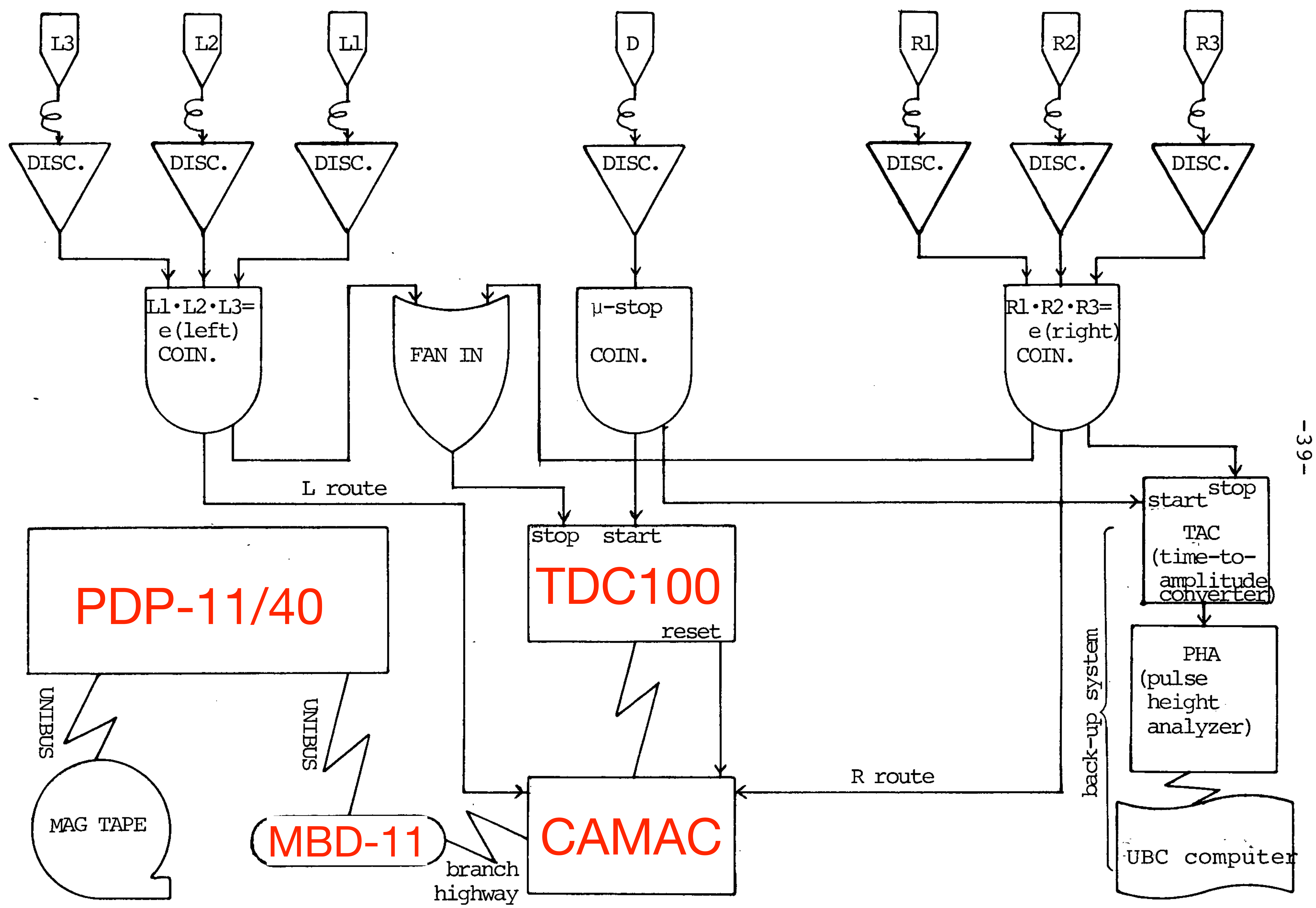
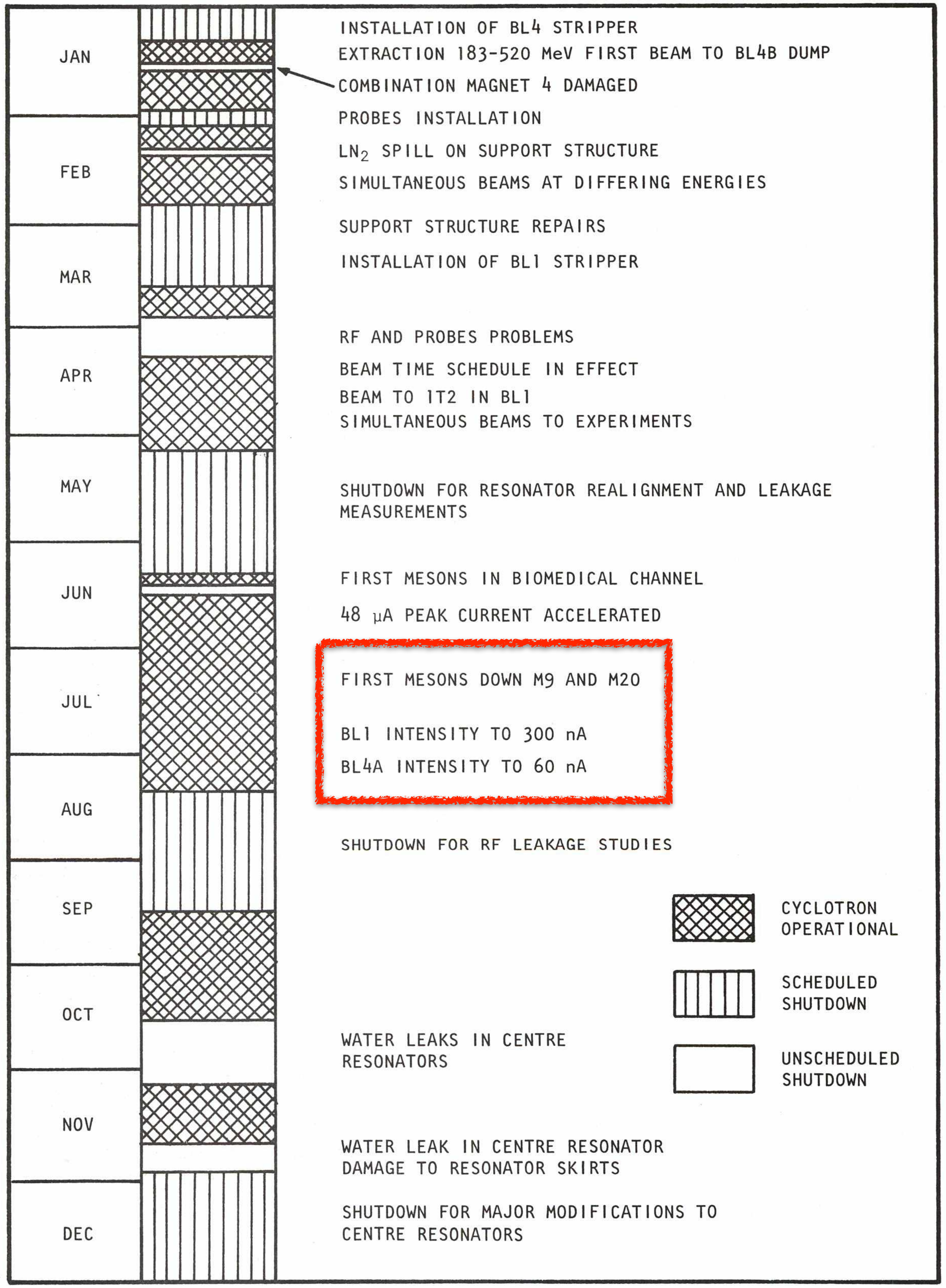


FIGURE 9: MSR data acquisition logic (simplified).

-39-

From Dave Garner's thesis, June 1979, UBC

1975



JUL →

←First mesons down M9 and M20 (300 nA)

Annual report 1975

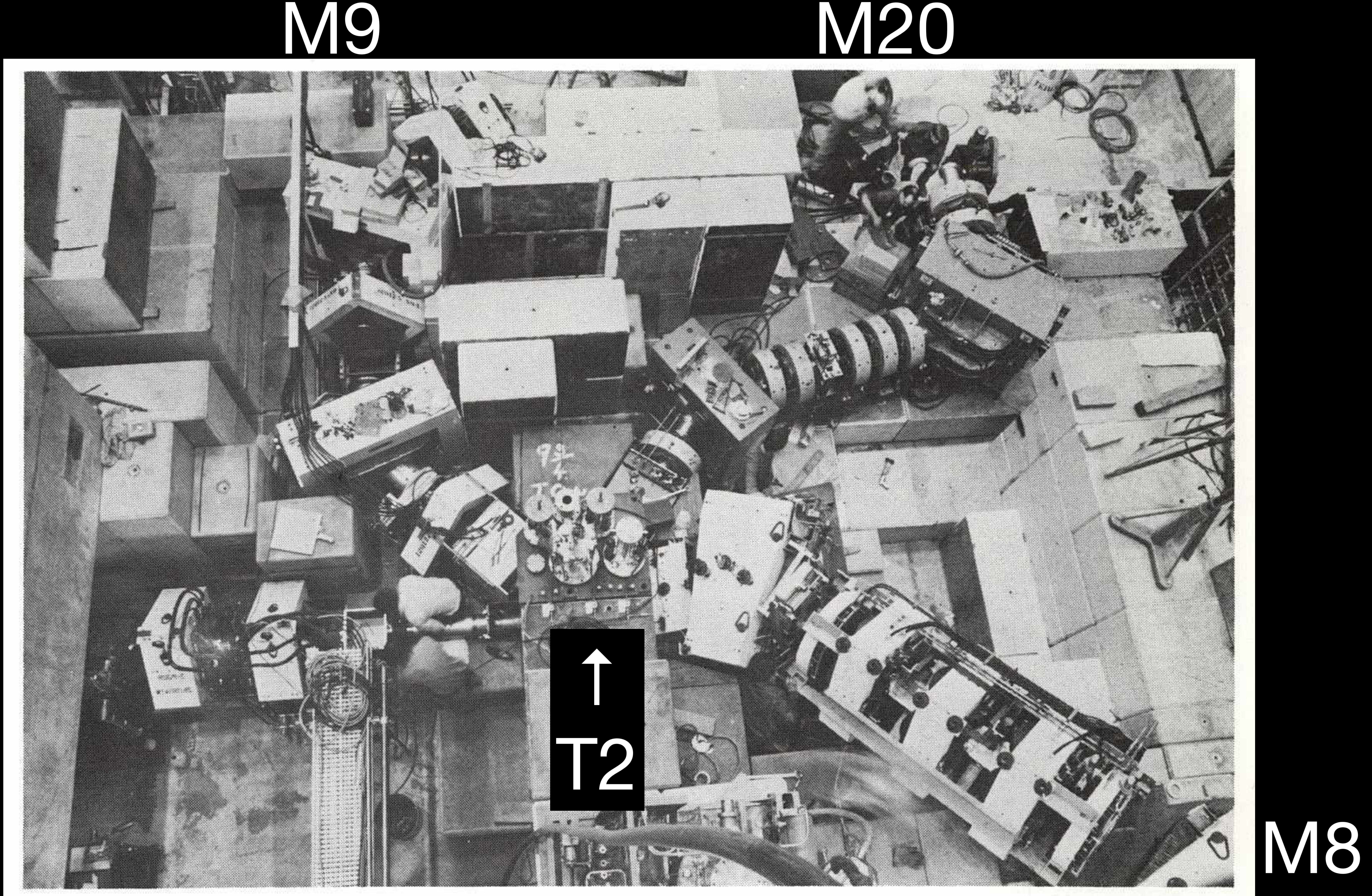
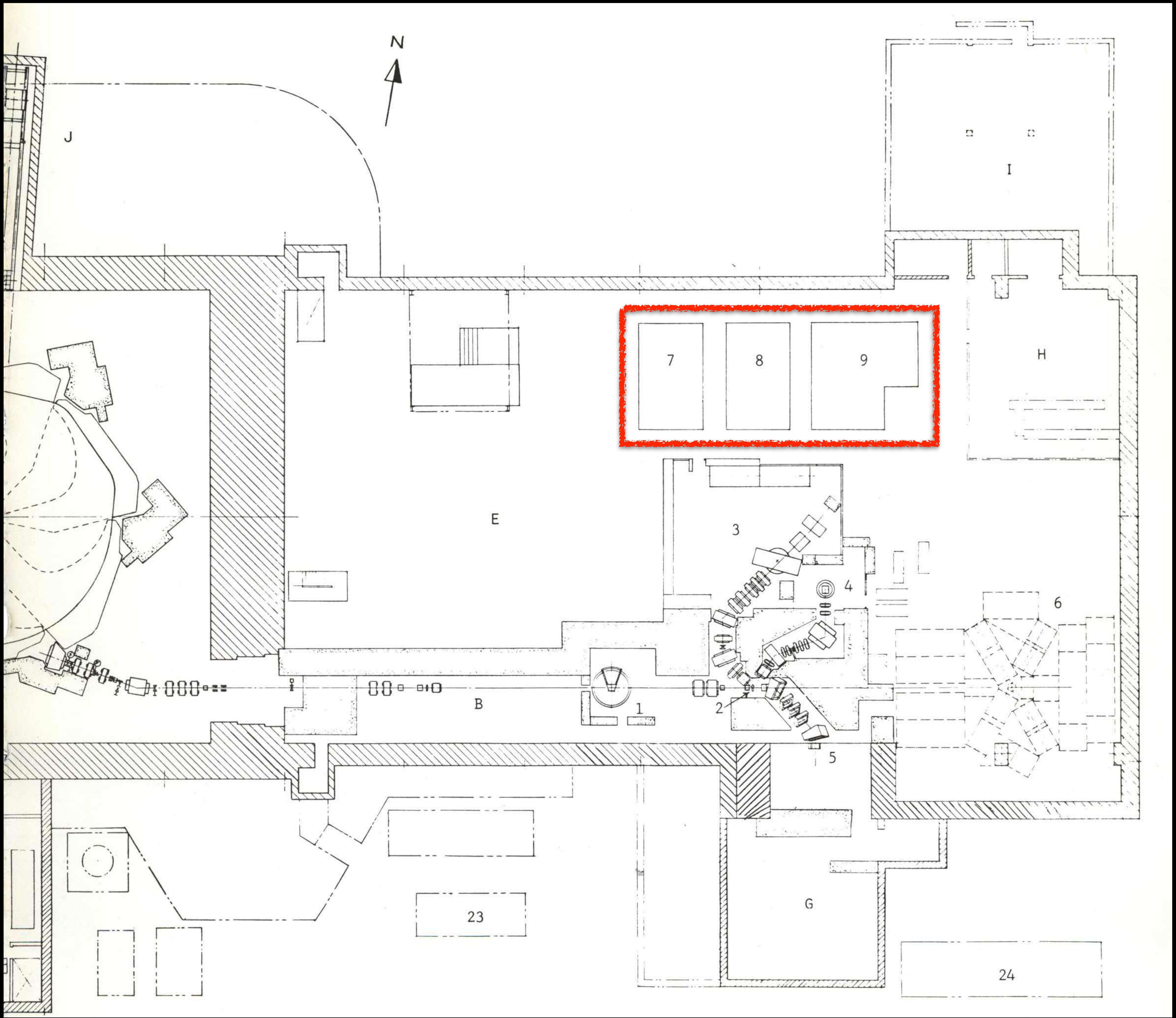


Fig. 19. View of 1T2 meson production target and the three meson channels, showing beam line 1 entering from the left and (clockwise) M9, M20 and M8.

Annual report 1975



←"Shack"s

From Jess Brewer’s Poster, TARA event

μSR IN CANADA — July 11, 1975

M20

Histogram shows μ^+ precession with ~ 15,000 events.

Event rate (~0.1 x μ stop rate) ≈ one per sec. per nanoamp of proton beam incident on 10 cm Be target.

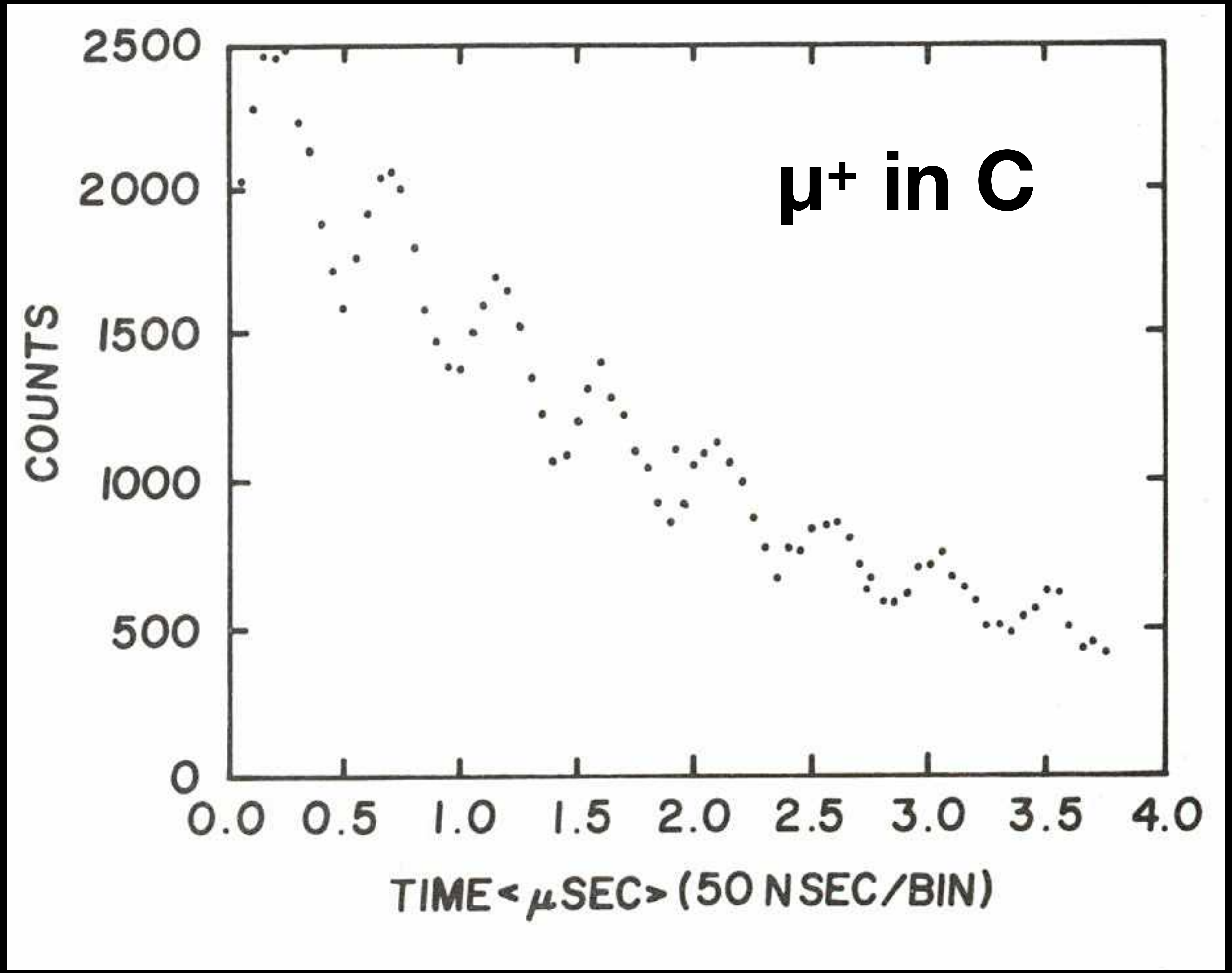
Tuned for "forward" muons from decay of 139 MeV/c pions.

Annual report 1975

A Varian magnet from the University of Tokyo, with associated counters, provides a very uniform field up to 10 kG; it was used to obtain the carbon μ^+SR spectrum →

…

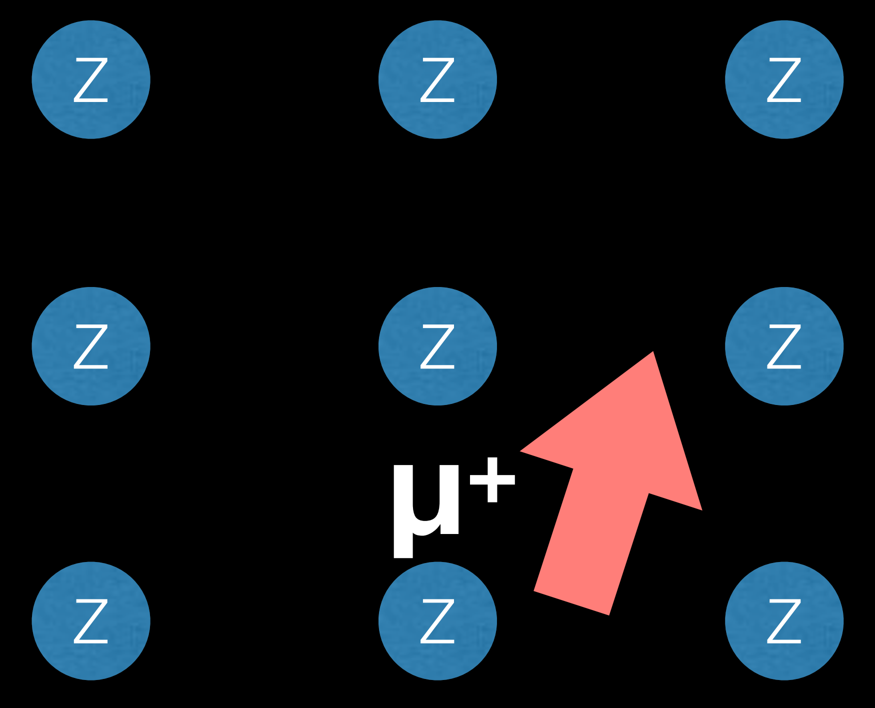
A large collection of experimental apparatus has been prepared for μSR research, and waits only for a consistent and substantial beam to begin producing results.

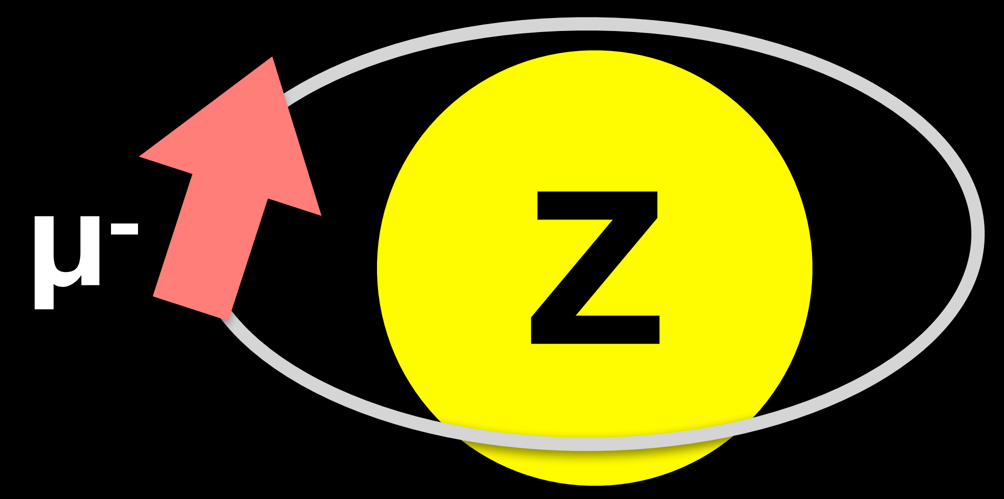


1976 : My priority → μ^-SR (nobody else was working on it)

μ^+SR in solid

- μ^+ probes B-fields at <u>interstitial</u> sites





μ^-SR

- μ^-Z atom probes B-fields at <u>lattice</u> sites (as in NMR)
- μ^-SR works even if there are no isotopes suitable for NMR

μ^-SR difficulties -

- μ^- spin depolarizes during capture/cascade
- μ^- “lifetime” short due to nuclear capture

↓

μ^-SR needs much MORE beam intensity

Annual report 1976

Table II. Beam Time to Experiments 1976

Experiment	Short title	Spokesman	Number of 12 h shifts scheduled	Hours of beam delivered	
				Jul-Dec	Mar-Jun
BEAM LINE 1					
1, 54	π scattering	R.R. Johnson	29	209.3	-
9	$\pi^- + p \rightarrow \gamma + n$	D.F. Measday	16	-	101.3
10	$pp \rightarrow \pi^+ + d$	G. Jones	94	597.5	272.8
23b	$\pi^+ \rightarrow e\nu_e\gamma$	P. Depommier	27	254.8	-
35, 71	μSR μ±SR	D.G. Fleming T. Yamazaki	23	145.8	50.3
41a,b	π capture	M. Salomon M. Hasinoff	28	79.8	98.0
42a, 80	π-mesic X-rays	G.R. Mason A. Olin	31	216.3	55.5
46	Polarized muonic ^{209}Bi	G.T. Ewan R.M. Pearce	2	16.0	-
52	$\pi \rightarrow e\nu$	D.A. Bryman	38	145.2	187.4
53	HEFPA	P.W. Martin	2	-	19.3
60	μ capture in MgO	J.B. Warren	10	56.7	8.0
61	Biomedical	L.D. Skarsgard	30	232.7	33.5

Annual report 1977

μ^-SR (Experiment 71)

- … μ^-SR is only practical at beam intensities of >10 μA.
- In 1977 the number of available shifts at 10 μA was limited by shutdowns … and the requirements of the $\mu \rightarrow e\gamma$ experiment.
  Thus μ^-SR has again been postponed in favour of μ^+SR, which can be applied more efficiently at low rates.

Annual report 1977

Table II. Beam Time to Experiments 1977

Area/ Beam Line	Experiment	Short Title	Spokesman	Number of 12-hour shifts scheduled
				(P) polarized beam
BEAM LINE 1				
M8	61	Biomedical	L.D. Skarsgard	106
	1,54	π scattering	R.R. Johnson	31
	53	Heavy fragments	D. Gill	14
M9	M9 development	-	-	6
	57	$\mu \to e\gamma$	P. Depommier J-M Poutissou	60
	52	$\pi \to e\nu$	D.A. Bryman	22 & 24 (parasitic with 57)
	13,51,80,89	Pionic X-rays	R.M. Pearce G.A. Beer S. Kaplan	27
	42a	π^3He	G.R. Mason	6
	41b	$\pi^-\pi^0$ charge exchange	M.D. Hasinoff M. Salomon	6 (parasitic with 42a)
	60	Muonium in insulators	J.B. Warren	9
	46,71,73	Muon studies	G.T. Ewan J. Brewer	18
M20	35,71,78	μSR	J. Brewer	151
Beam line 1	10	$pp \to \pi d$	G. Jones	64 (P)
	75	$pd \to \pi t$	W.C. Olsen	18 (P)

1977 TRIUMF μ→eγ

1977 SIN (PSI) μ→eγ

VOLUME 39, NUMBER 18 PHYSICAL REVIEW LETTERS 31 OCTOBER 1977

New Limit on the Decay $\mu^+ \to e^+\gamma$

P. Depommier, J.-P. Martin, J.-M. Poutissou, and R. Poutissou
Laboratoire de Physique Nucléaire, Université de Montréal, Montréal, Québec H3C 3J7, Canada

and

D. Berghofer, M. D. Hasinoff, D. F. Measday, and M. Salomon
Physics Department, University of British Columbia, Vancouver, British Columbia V6T 1W5, Canada

and

D. Bryman
TRIUMF, University of British Columbia, Vancouver, British Columbia V6T 1W5, Canada

and

M. Dixit and J. A. Macdonald
Physics Department–TRIUMF, University of Victoria, Victoria, British Columbia V8W 2Y2, Canada

and

G. I. Opat[a]
School of Physics, University of Melbourne, Parkville, Victoria 3052, Australia
(Received 16 August 1977)

Using two ... $\to e^+\gamma$ decay has been found t... fidence level.

Aug 1977
$R_{\mu e\gamma} < 3.6 \times 10^{-9}$

Evidence for the cons... topped during the experi-rests primarily on the ... $\mu^+ \to e^+\gamma$,[1] $\mu^+ \to e^+e^+e^-$,[2] ... (TINA, 45.7 cm diam present limits (90% co... .5 cm diam×35.5 cm) actions are

$$R_{\mu^+\to e^+\gamma} = \frac{\Gamma(\mu^+ \to e^+\gamma)}{\Gamma(\mu^+ \to e^+\nu_e\bar{\nu}_\mu)} < 2.2\times10^{-8}, \quad (1)$$

$$R \ldots = \frac{\Gamma(\mu^+ \to e^+e^+e^-)}{\ldots} < 1.9\times10^{-9} \quad (2)$$

$$\Gamma(\mu^- \to e^-\gamma)\,/\,\Gamma(\mathrm{total}) \quad \boxed{< 4.2 \times 10^{-13}} \quad \mathrm{CL}=90.0\%$$

... help distinguish among models.

We report here the results of a new search for the $\mu^+ \to e^+\gamma$ decay carried out at TRIUMF using two large NaI(Tl) crystals. The experiment was performed on the stopped π/μ channel ($M9$) with a 100-MeV/c beam composed of 61% π^+, 29% μ^+, and 10% e^+. The setup is shown in Fig. 1. Pions were stopped in a $15\times15\times0.6$ cm^3 scintillation-counter target (counter 3) oriented at 20° to the incident beam. The stopping rate was 2×10^5/sec; the decay $\pi^+ \to \mu^+\nu_\mu$ was the source of muons. The

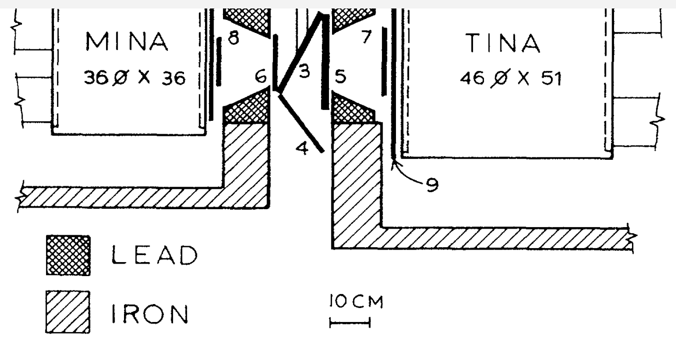


FIG. 1. Diagram of the setup used in the present experiment. The scintillation counters Nos. 1–10 (thickness not to scale) were used to identify charged particles.

Volume 72B, number 2 PHYSICS LETTERS 19 December 1977

A NEW UPPER LIMIT FOR THE DECAY $\mu^+ \to e^+\gamma$ ★

H.P. POVEL, W. DEY, H.K. WALTER, H.-J. PFEIFFER,
U. SENNHAUSER, J. EGGER, H.J. GERBER, M. SALZMANN
Institut für Hochenergiephysik, ETH-Zürich, Switzerland

A. van der SCHAAF, W. EICHENBERGER, R. ENGFER, E. HERMES, F. SCHLEPÜTZ, U. WEIDMANN
Physik-Institut, Universität Zürich, Switzerland

and

C. PETITJEAN and W. HESSELINK
SIN, CH-5234 Villigen, Switzerland

Received 21 October 1977

A search for the decay $\mu^+ \to e^+\gamma$, performed at SIN, yields a new upper limit $R_{\mu\to e\gamma} < 1.1 \times 10^{-9}$ (90% confidence). Electrons and photons from the decay of 7.5×10^{11} stopped μ^+ were measured with two NaI(Tl) detectors at 180° (1.2% efficiency for $\mu^+ \to e^+\gamma$). Their distribution in the region $E_e, E_\gamma > 26$ MeV shows agreement with the theory for $\mu^+ \to e^+\nu\bar{\nu}\gamma$.

Oct 1977
$R_{\mu e\gamma} < 1.1 \times 10^{-9}$

The present experimental ... tio $R_{\mu\to e\gamma} = \Gamma(\mu \to e\gamma)/\Gamma(\mu$ ... is one of the strongest const... nonconservation. The intere... has increased after it was rea... nonconservation can be incorporated in gauge theories in a natural way [2]. A new $\mu^+ \to e^+\gamma$ experiment was motivated by the high intensity and 100% duty cycle

... target T consists of two scintillator disks (Ø 40 mm, thickness 5 mm) each coupled to a photomultiplier by an air light guide. The electron detector consists of a NaI(Tl) crystal (Ø 277 mm, length 330 mm), a trigger counter S7, a counter S8 and two multiwire propor-

... d WC2 (64 wires per plane, ... s used for pile-up rejection of ... in the 400 ns integration time

... ron collimator is covered by scintillation counter S6 with a hole of Ø 80 mm; S6 suppresses neutral background produced by electrons in the collimator. The photon energy is measured in a

... gion below 43 MeV due to their energy loss of about 10 MeV in S1–S5. About 26% of the 53 MeV photons convert in the NaI(Tl) disk C (Ø 120 mm, thickness 20 mm) and give a signal in both planes of the hodoscope H consisting of 2 × 10 strips of plastic scintillator (width 14 mm, thickness 3 mm).

Cosmic-ray background is reduced to a negligible level by the anti-counters S9–S18 and by 1.5 m heavy concrete above the apparatus. Cadmium plates and borated paraffine blocks are used for shielding against

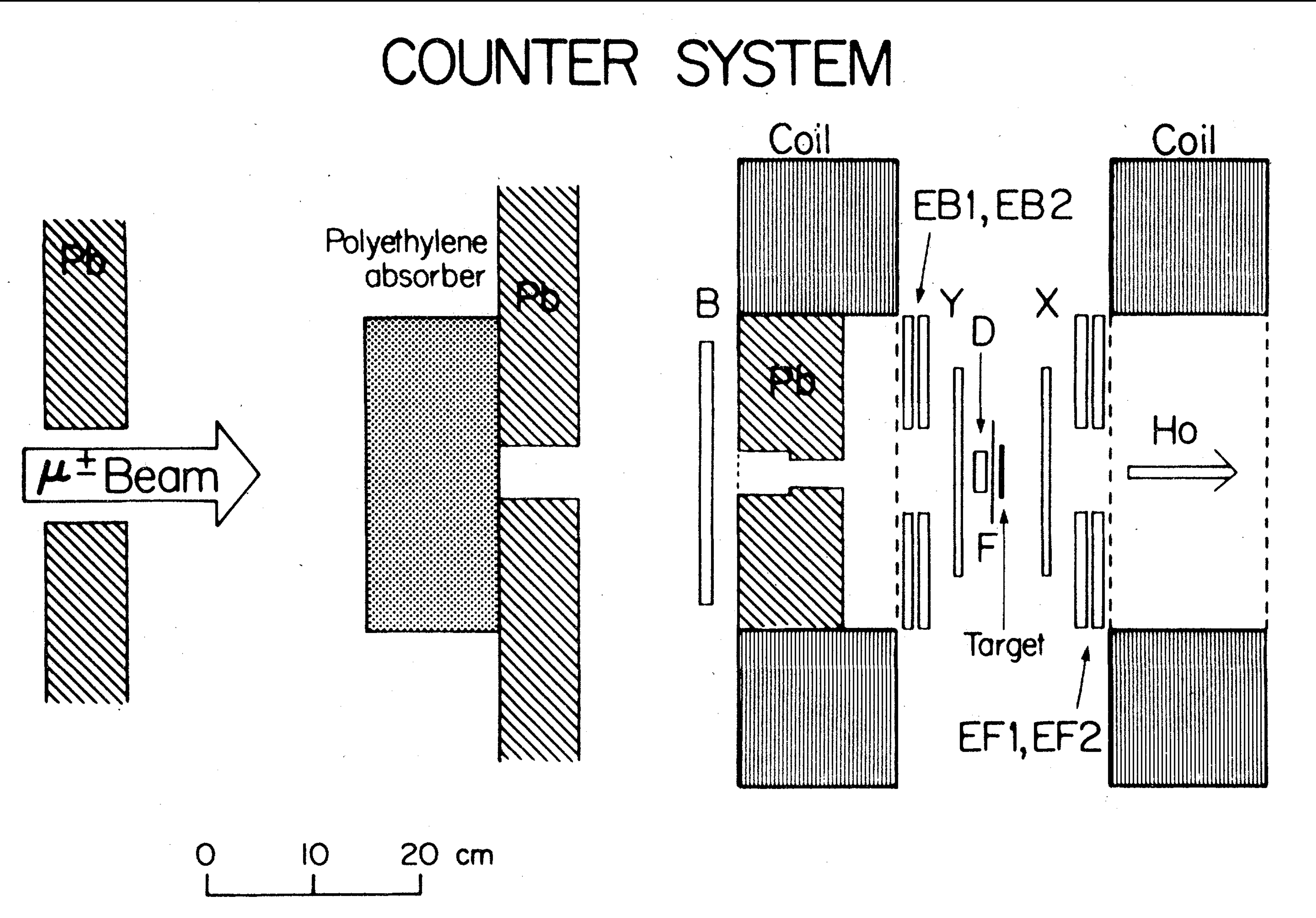
★ Work supported in part by the Swiss National Science Foundation, by the Schweizerisches Institut für Nuklearforschung and the Netherlands Organization for the Advancement of Pure Research (Z.W.O.).

1978 - my thesis was due in < 1 year

A new setup

- In Tokyo, I found an old pair of air-core coils previously used for beta spectrometer
- Instead of transverse B-field, why not longitudinal?
- $\mu^{\pm}$ depolarization may be suppressed by applying a longitudinal (holding) field

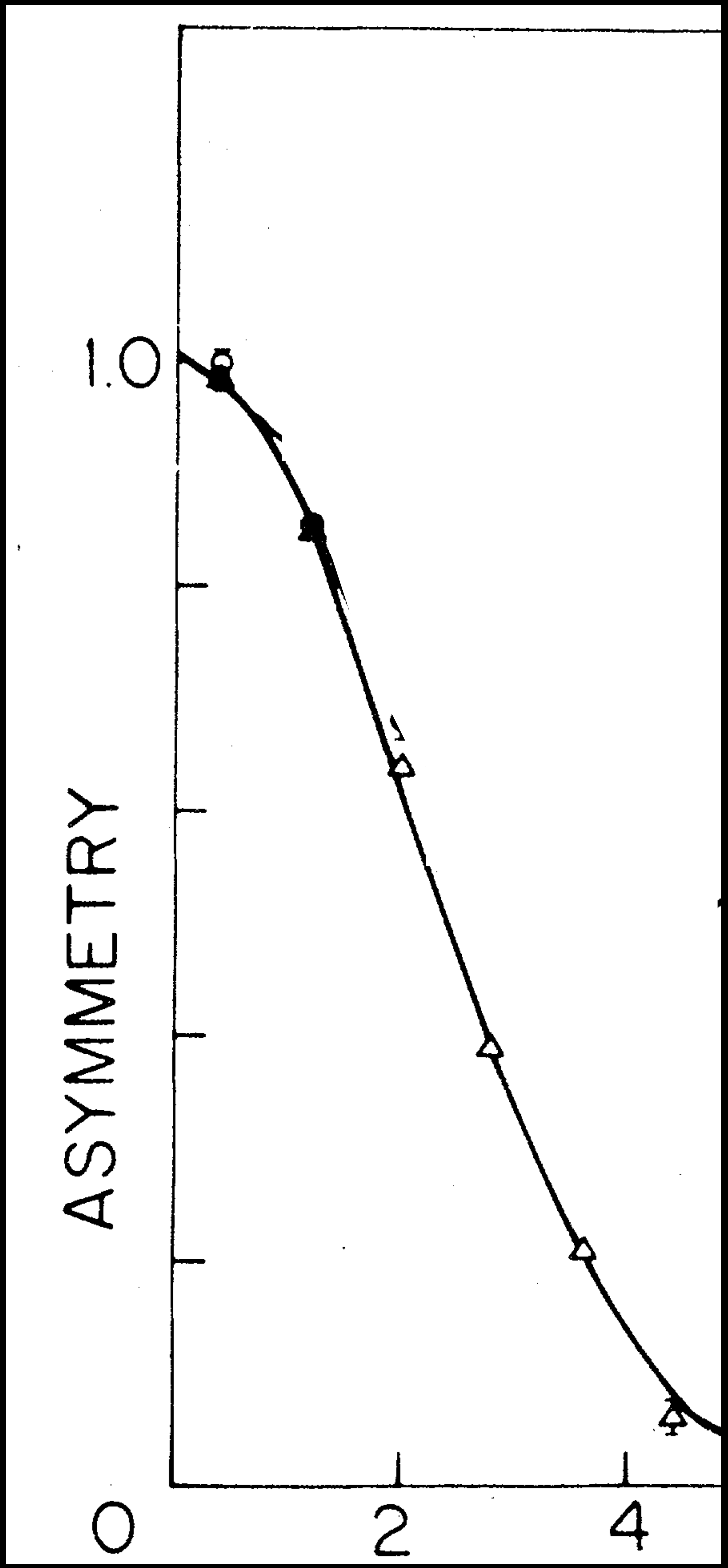
The new setup, Hayano et al. (1978)



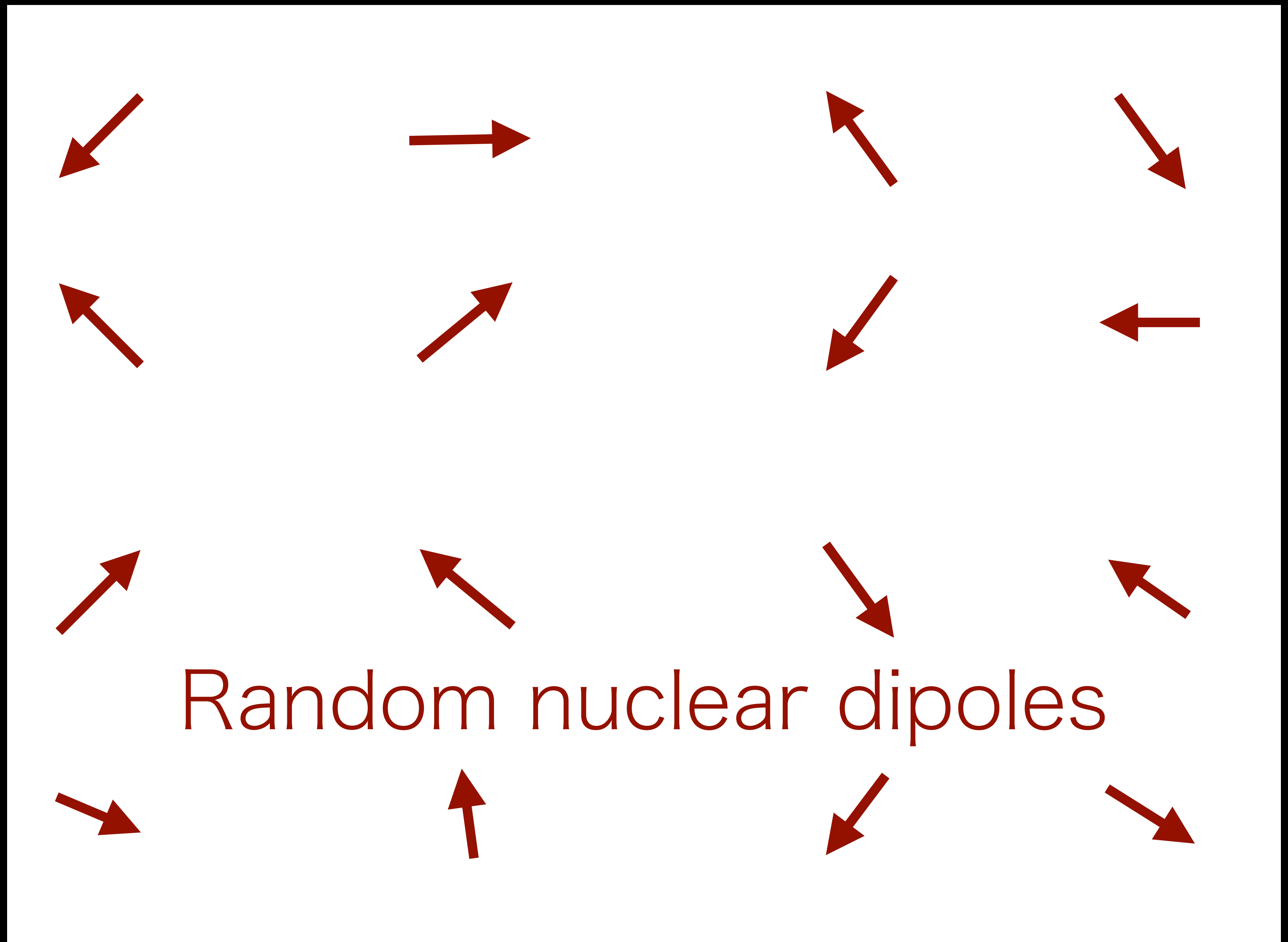
Spring 1978, @ M20

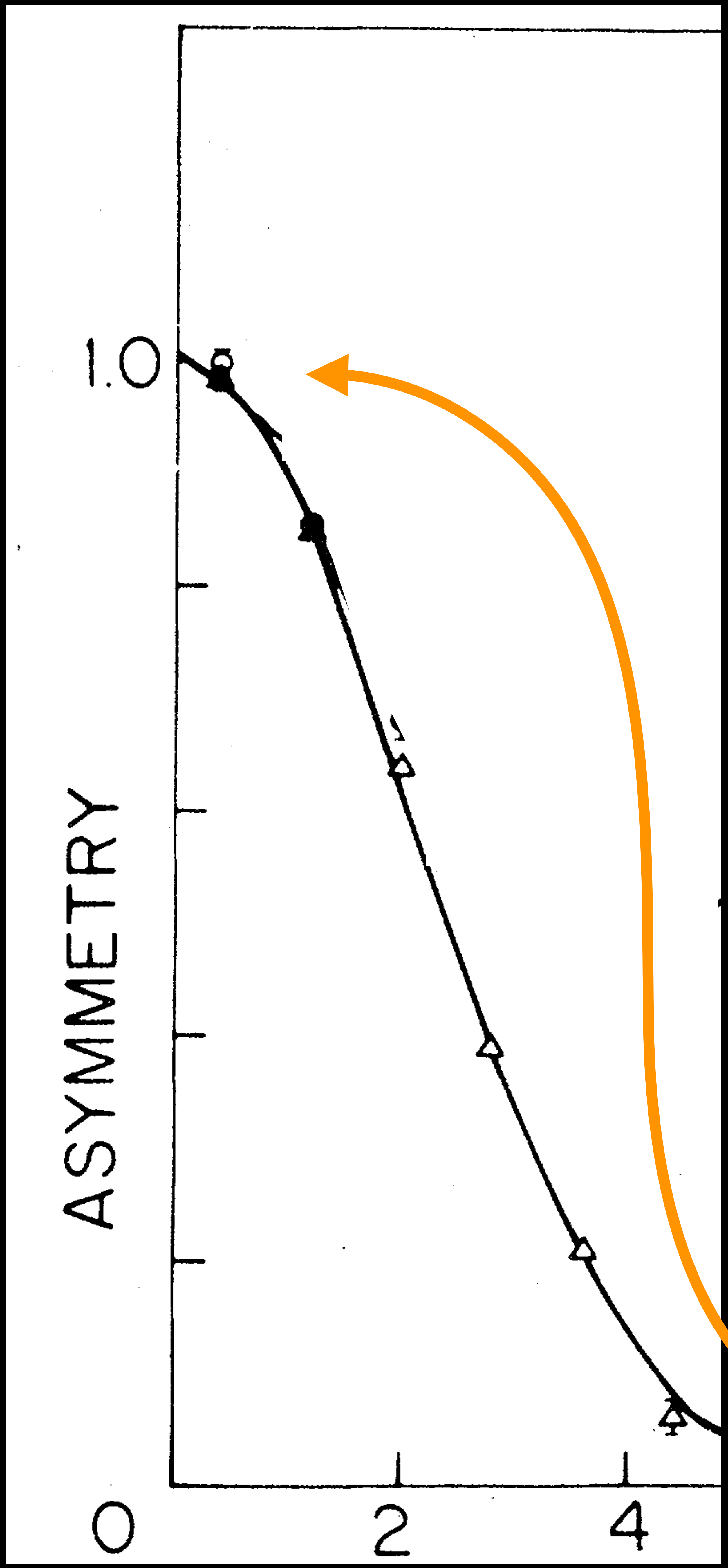
Nishida Imazato RH Uemura Yamazaki

1978
μ+ zero-field
forward/backward
asymmetry in MnSi

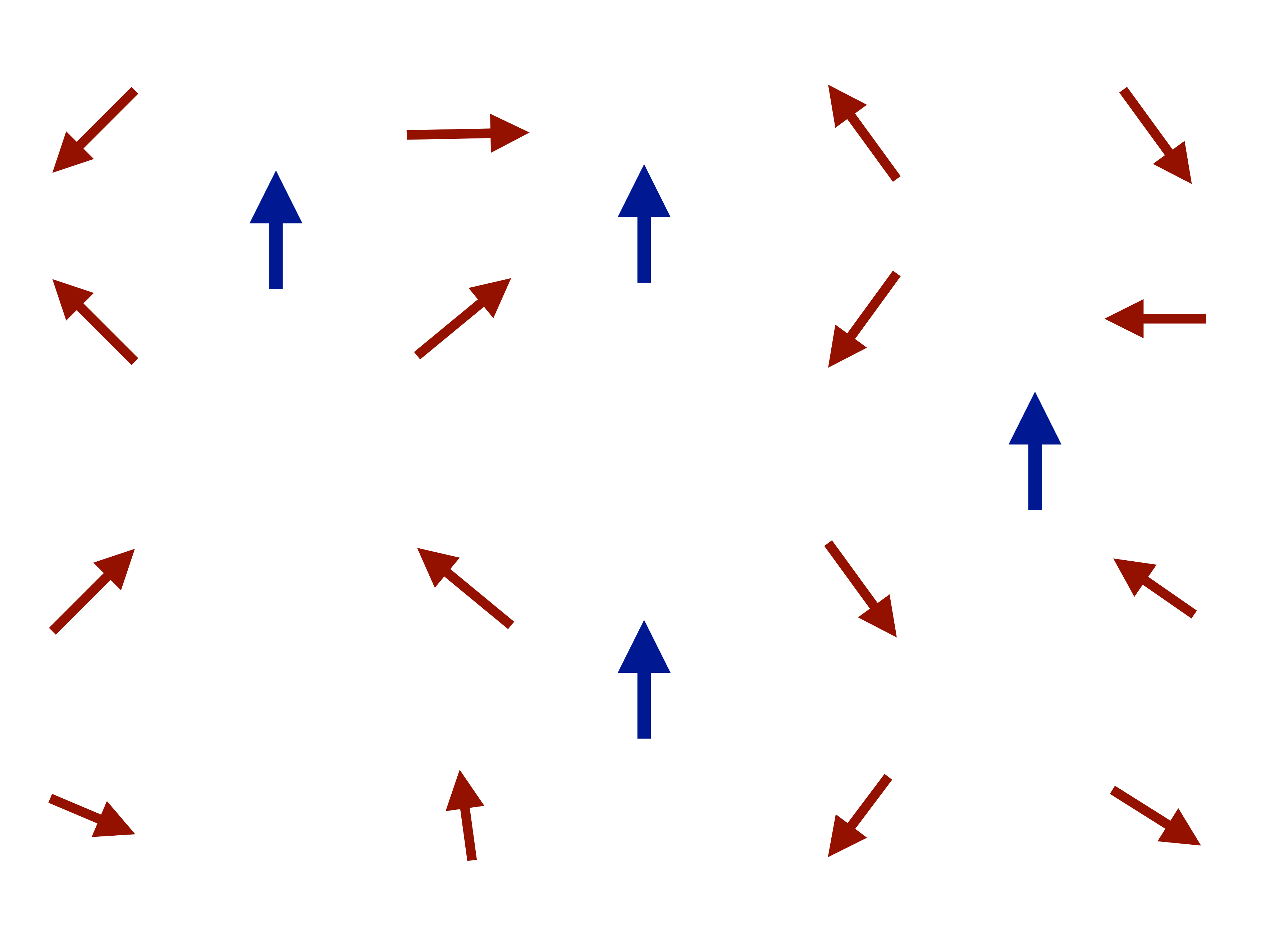


μS





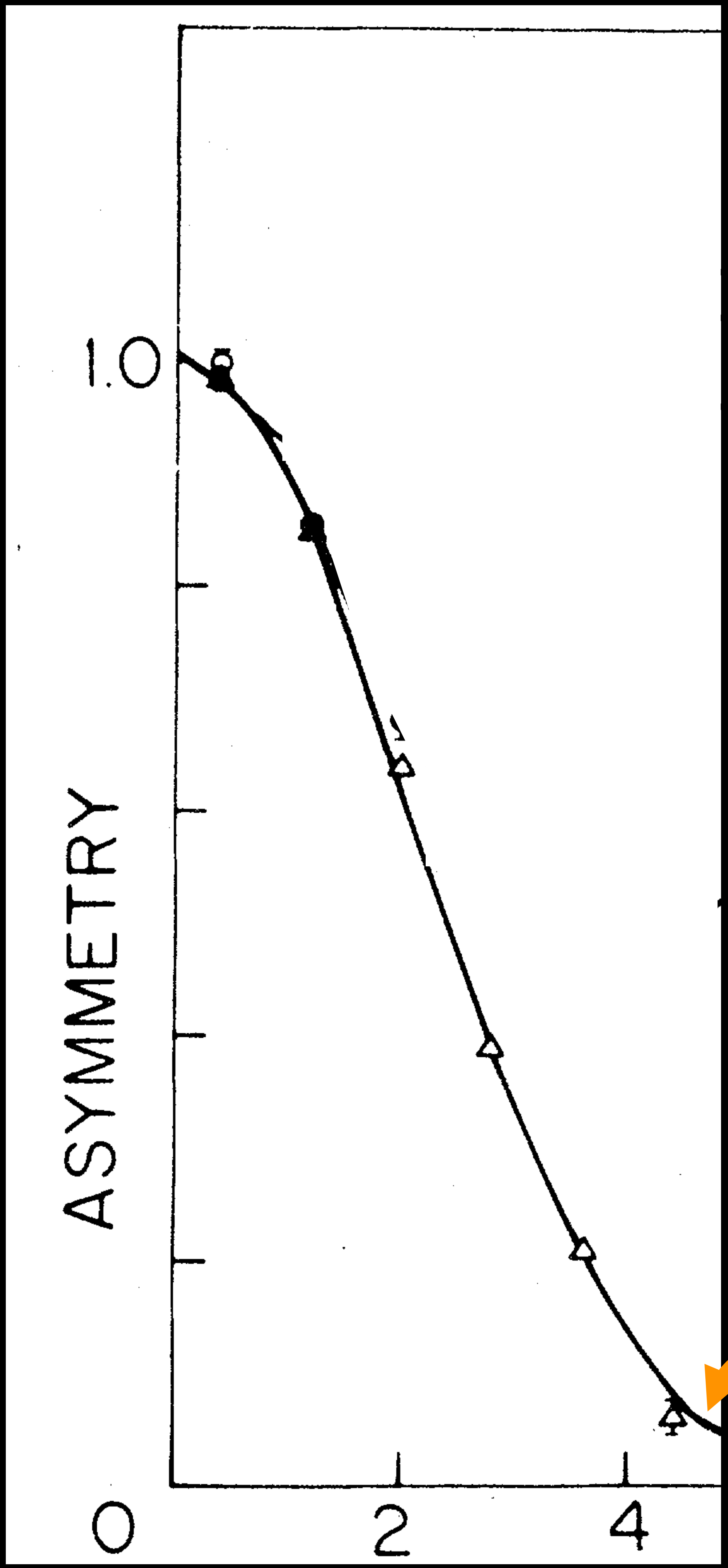
1978
μ^+ zero-field forward/backward asymmetry in MnSi

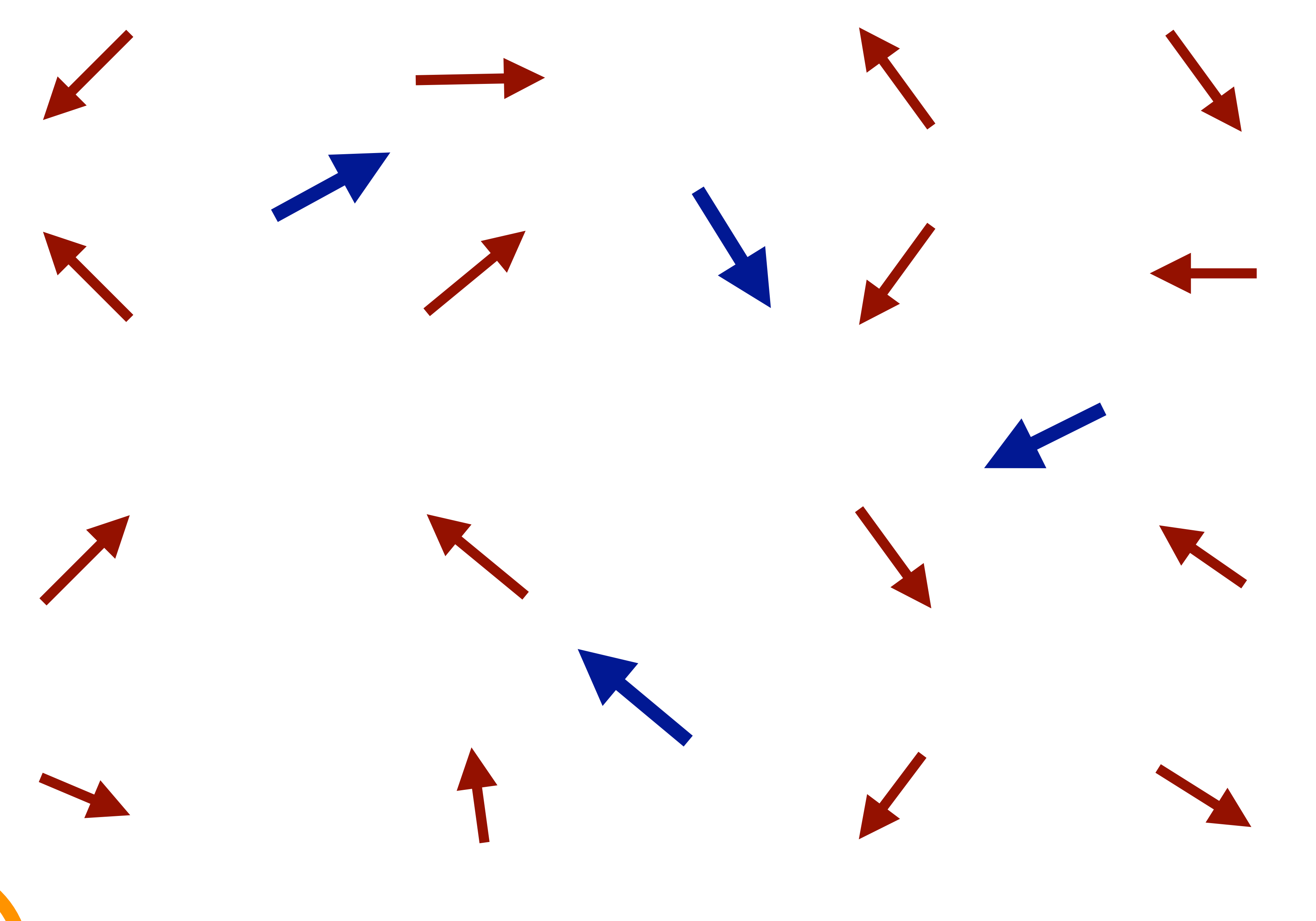


μ^+ spins were initially aligned

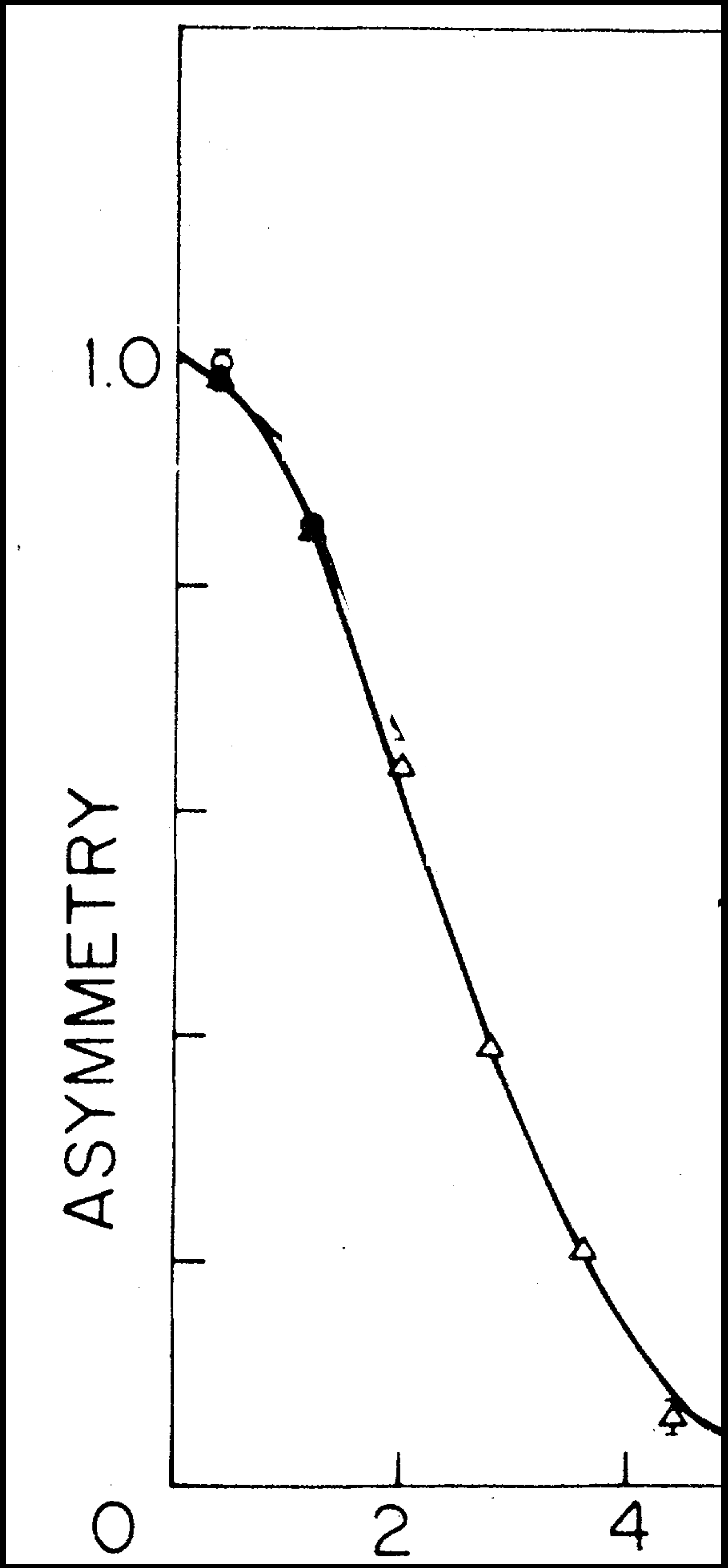
1978

μ^+ zero-field forward/backward asymmetry in MnSi



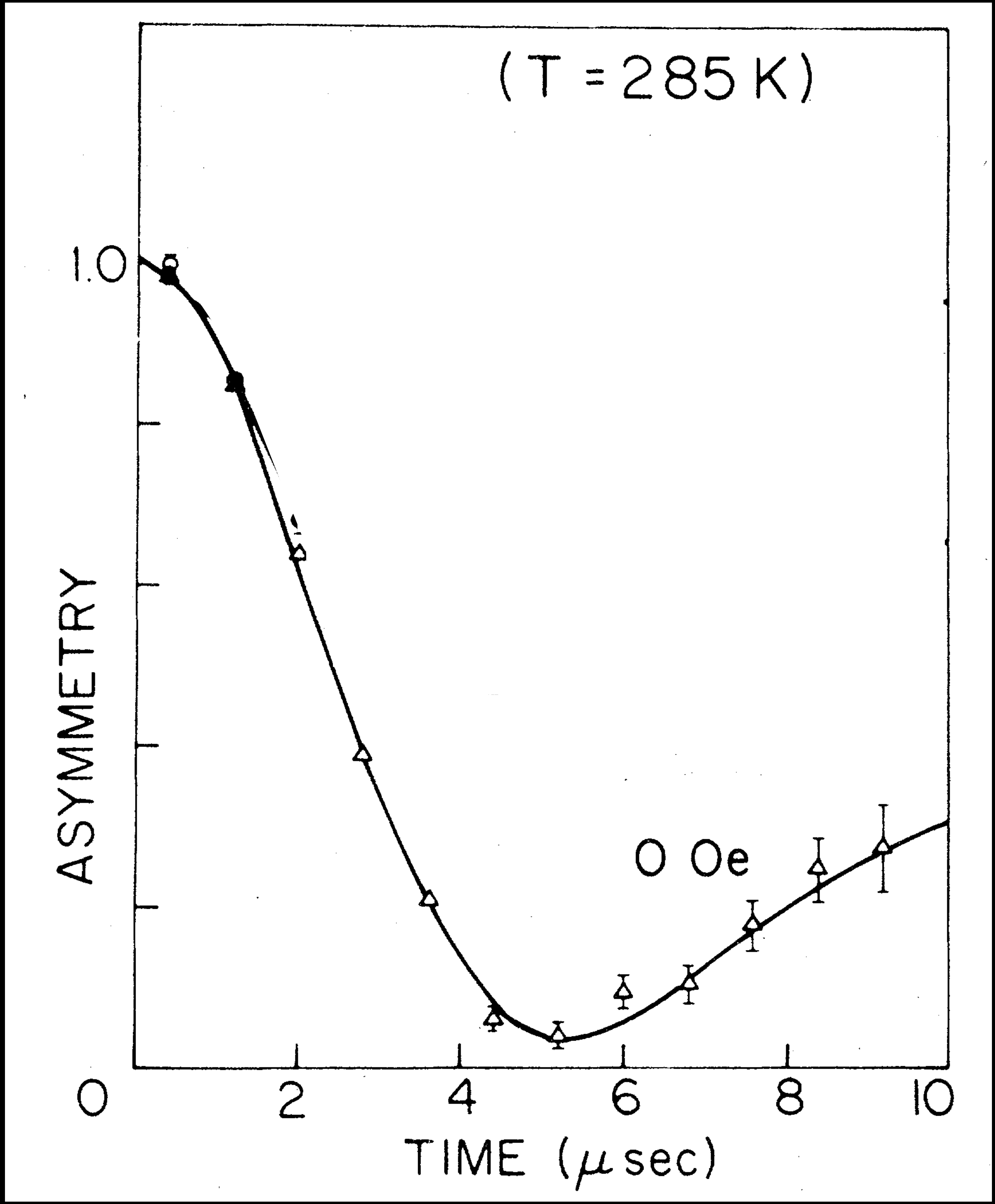


Initial “memory” lost
(relaxation)

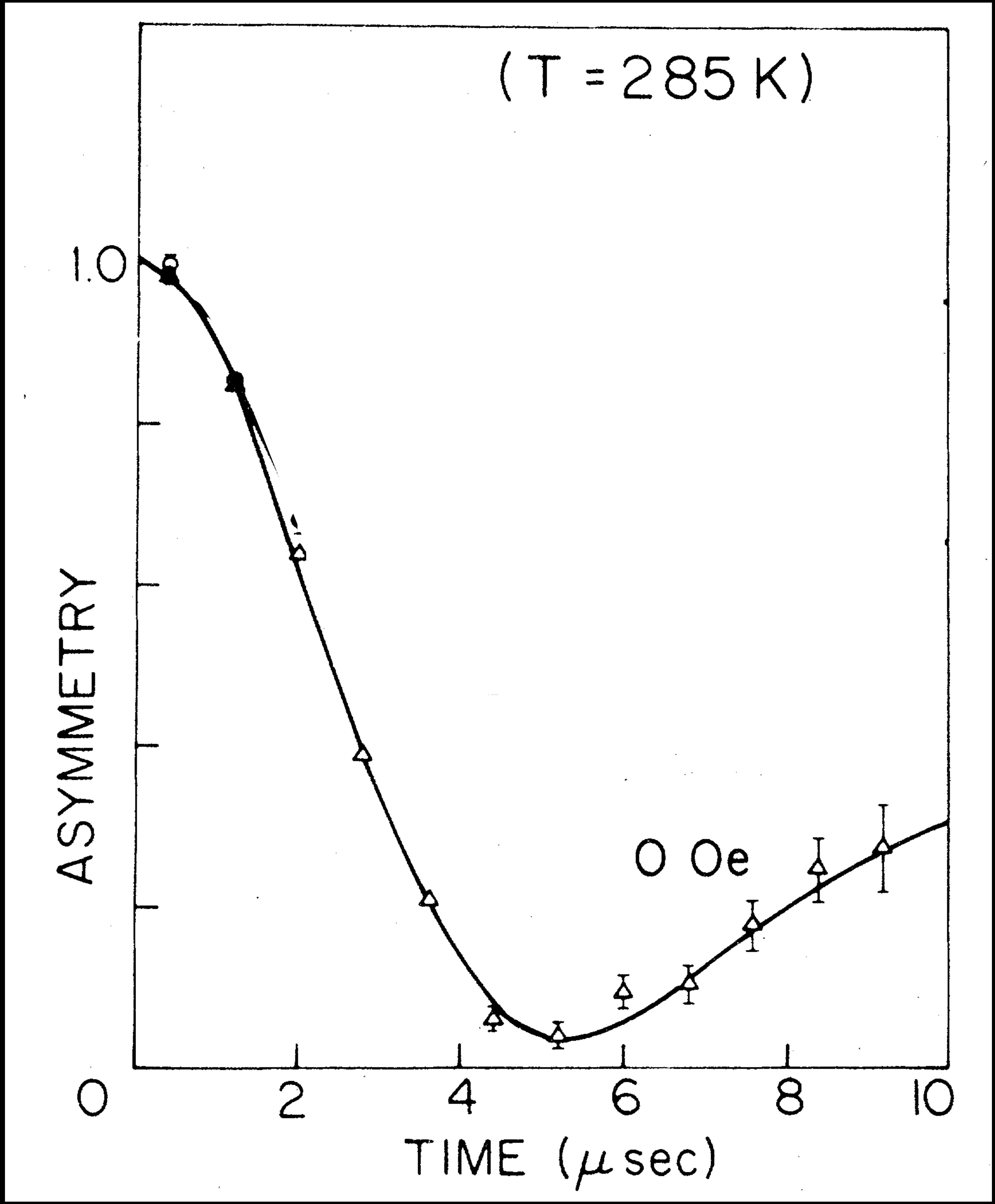


After some time
(remember, no e-mails in those days)
a FAX message arrived from Tokyo

“take data beyond 4 μs”

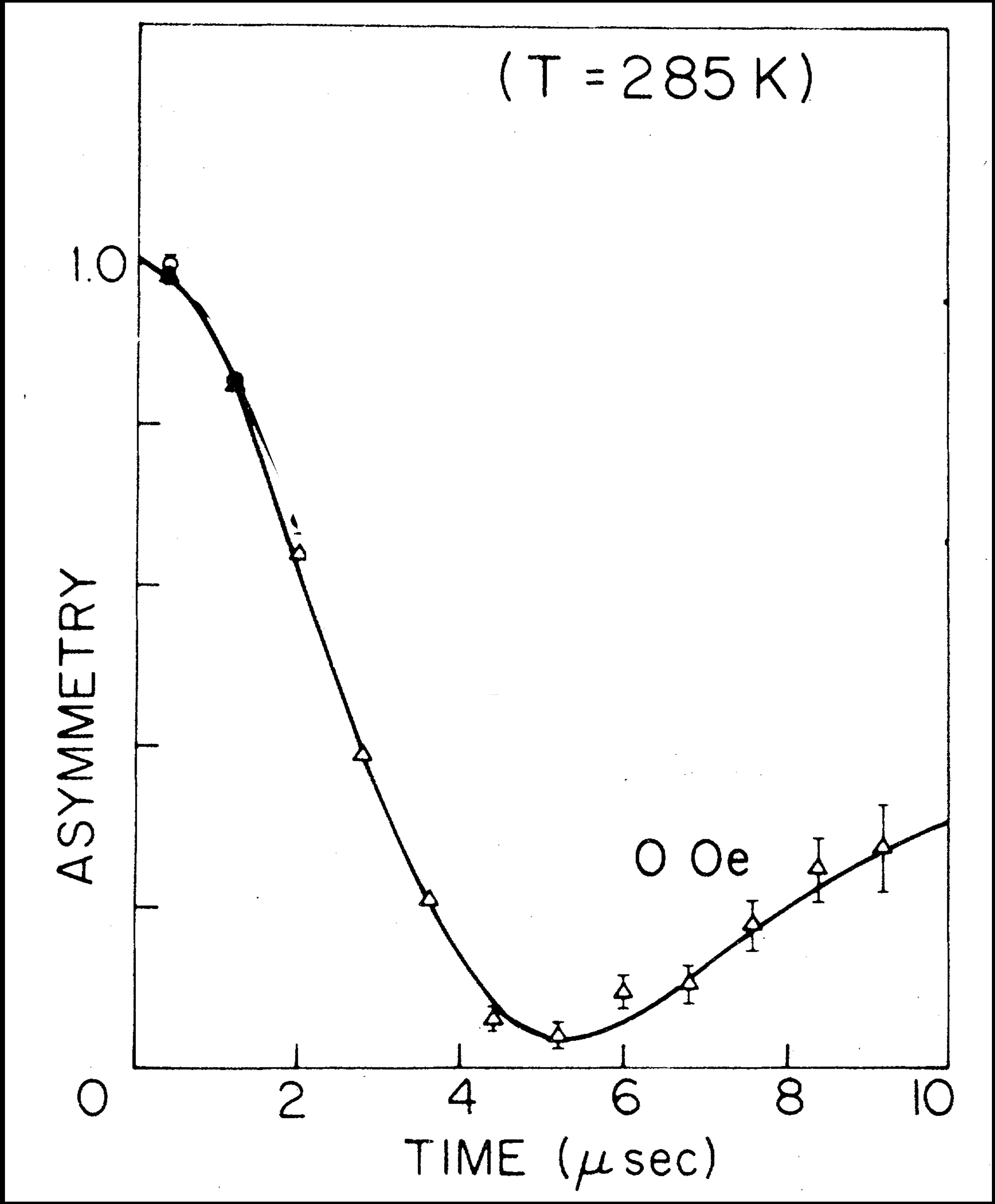


Wow !!



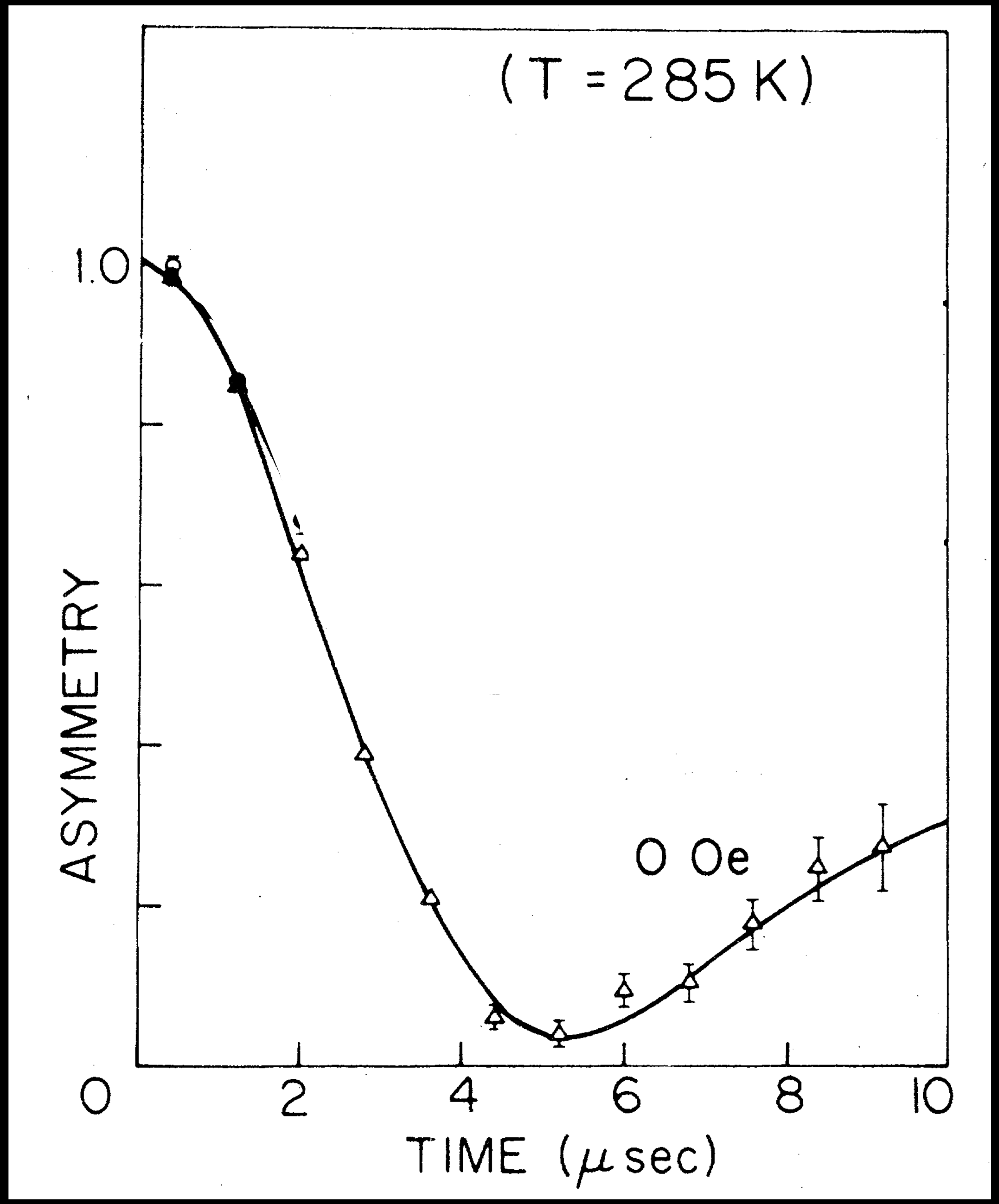
The first experimental observation of the “Kubo-Toyabe” function.

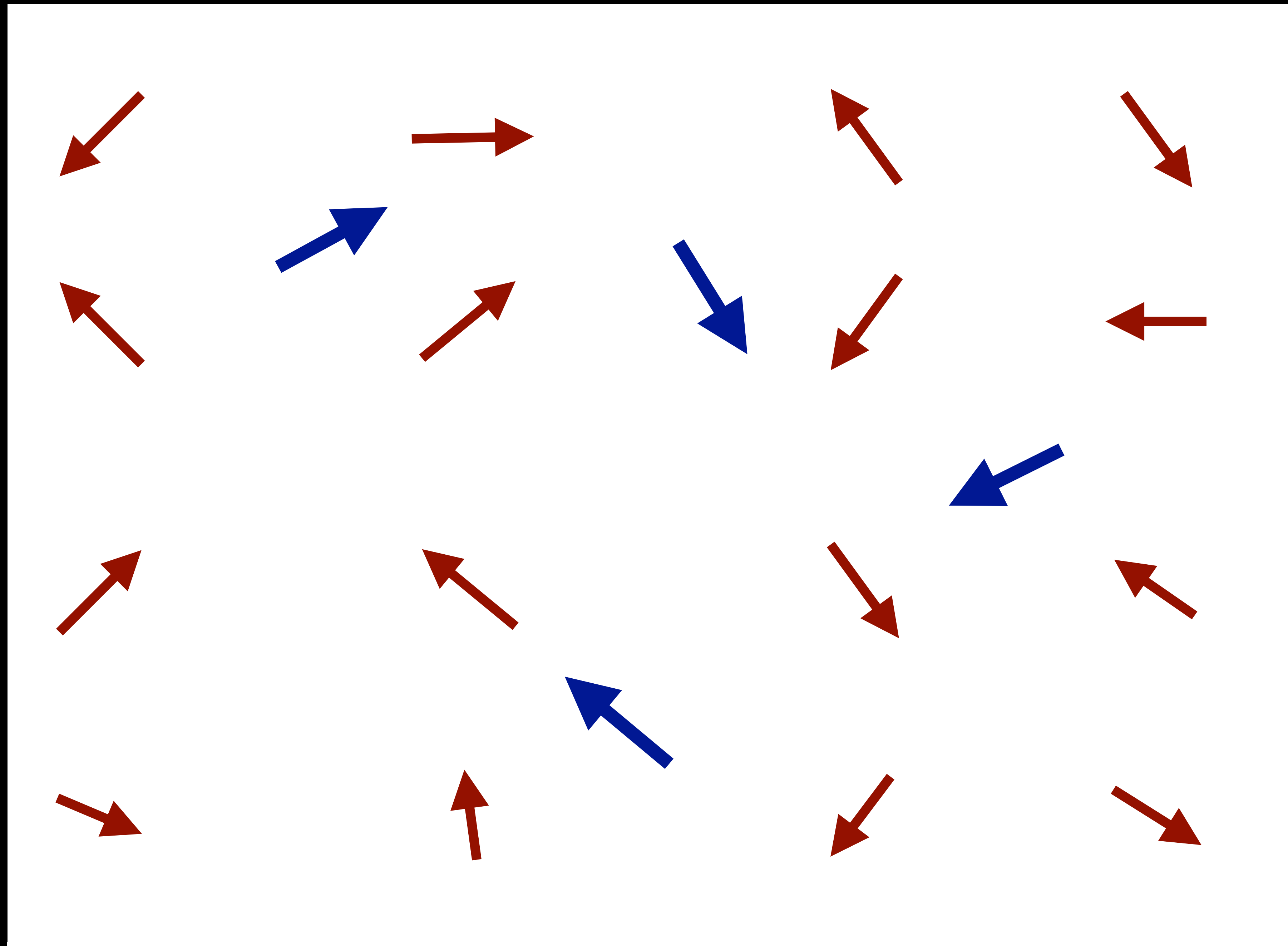
Ryogo Kubo, 1920-1995



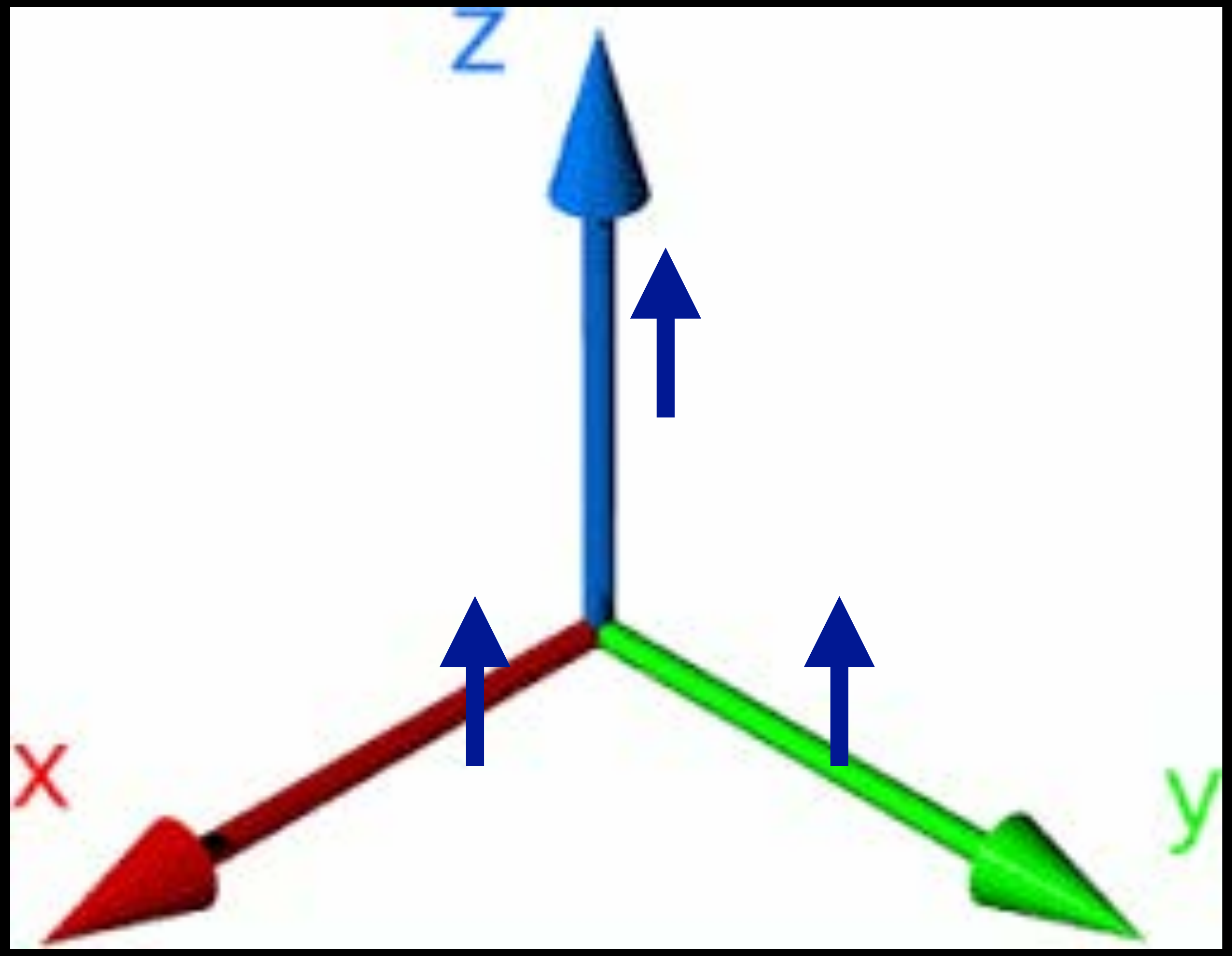
"I never expected that the zero-field spin relaxation experiment would ever become possible"
R. Kubo, 1978

Ryogo Kubo, 1920-1995





Initial “memory” is lost
(spin relaxation)



The x,y-components of random field relax the asymmetry.

The z-component “holds” the spin.

Asymmetry recovers to 1/3.

Annual report 1978

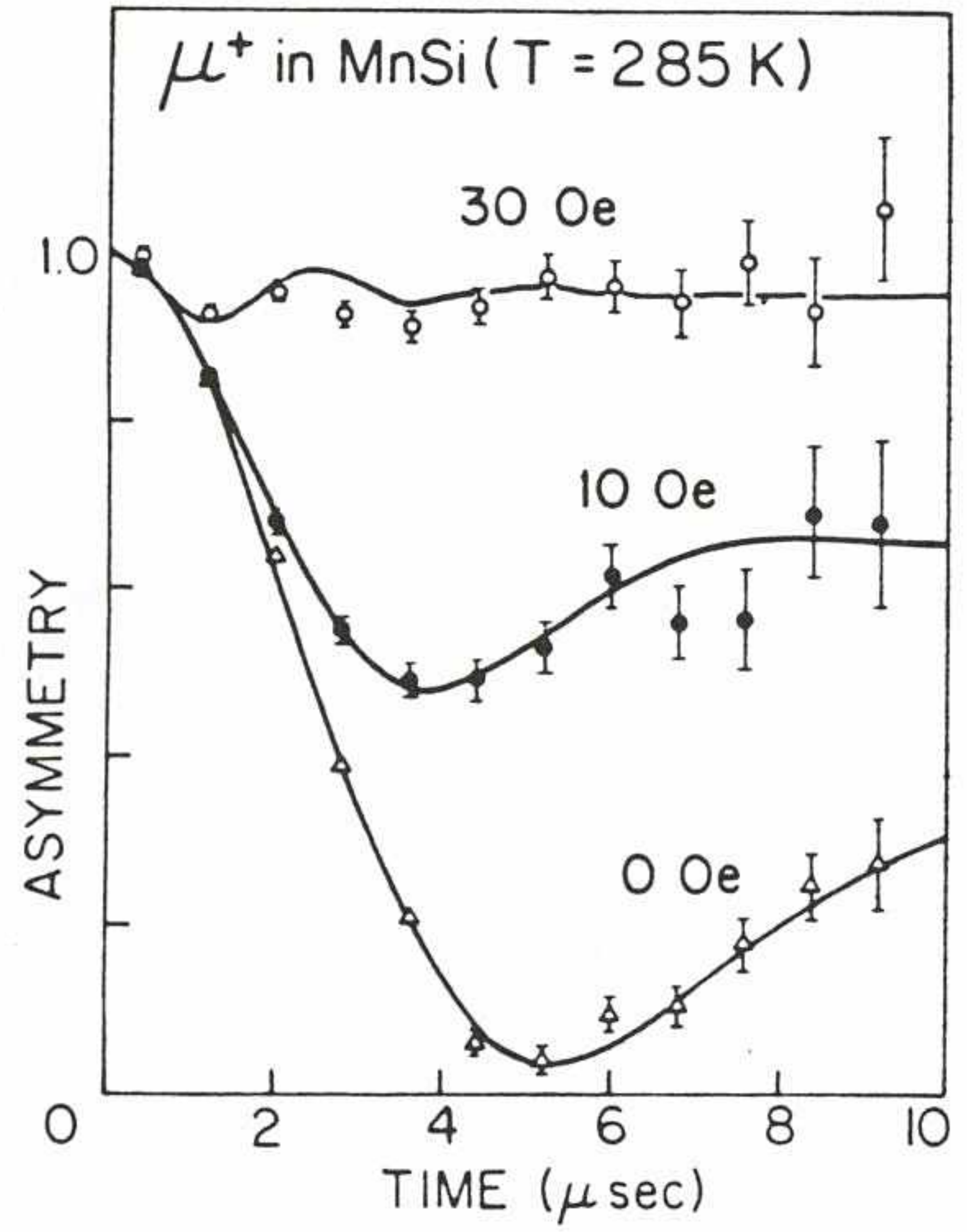
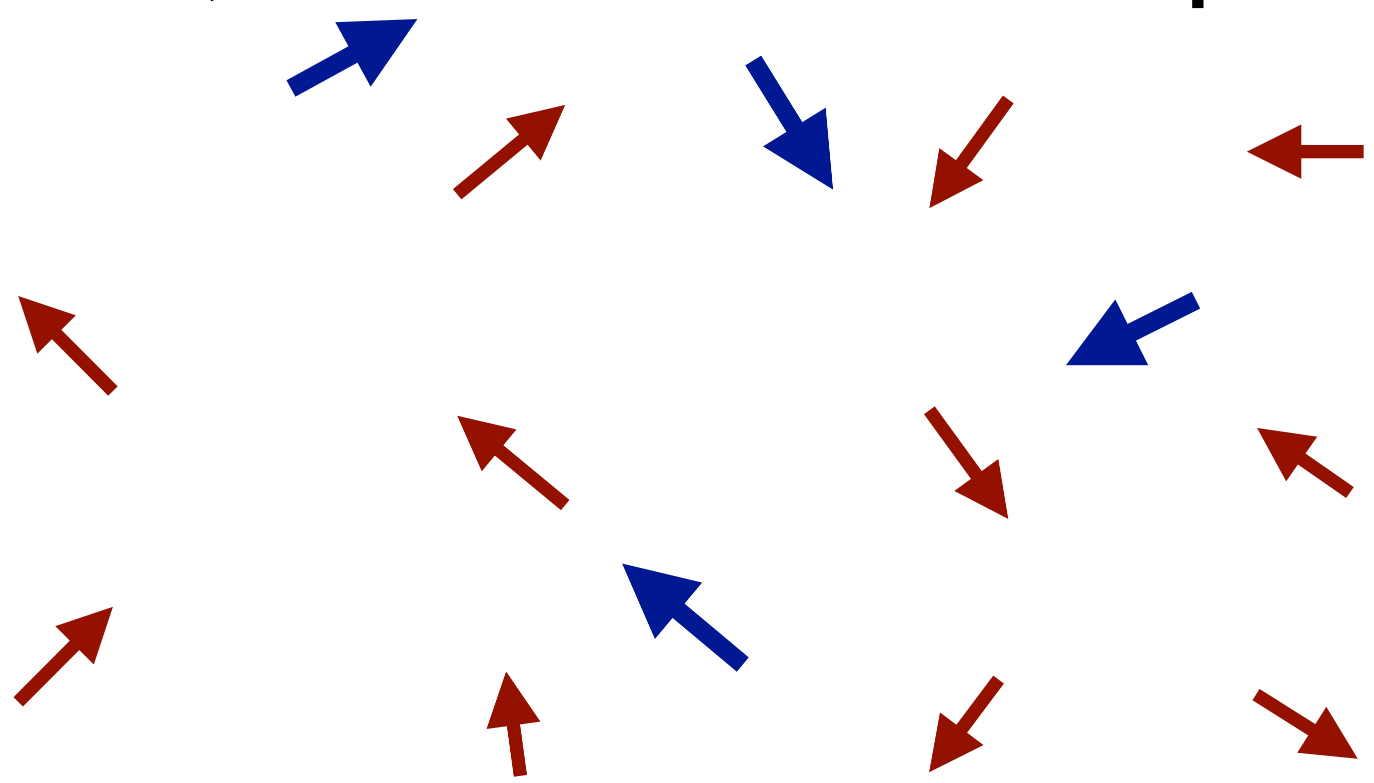


Fig. 66. Longitudinal relaxation of μ^+ decay asymmetry in MnSi in zero and weak longitudinal magnetic fields.

What if the fields are not static, or the muon hops?



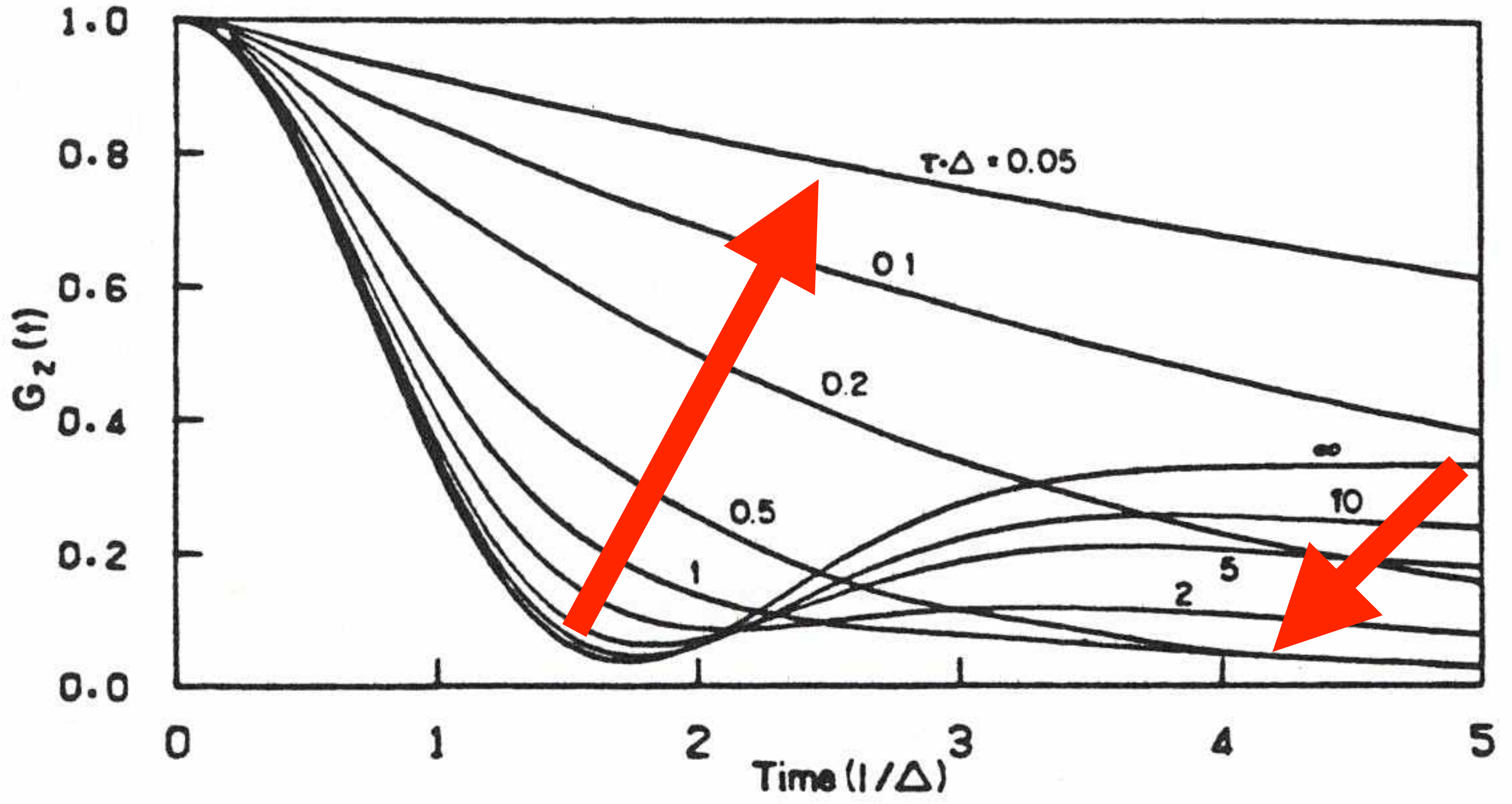


Fig. 75. Zero-field longitudinal relaxation function for muons affected by a Gaussian distribution of local dipolar magnetic fields. Effect of stochastic processes (e.g. muon 'hopping') in the strong collision limit: curves labelled by value of mean correlation time τ (τ = ∞ corresponds to static Kubo-Toyabe relaxation). Time (and τ) measured in units of 1/Δ, where Δ = width of static field distribution (≈ relaxation rate).

<u>Stochastic theory of zero-field μSR.</u> The zero-field spin relaxation function for the static nuclear dipole system was derived theoretically by Kubo and Toyabe [*Magnetic resonance & relaxation* (North-Holland, Amsterdam, 1967) p.810]:

$$G_z^{KT}(t) = \frac{1}{3} + \frac{2}{3}\left(1-\Delta^2 t^2\right)\exp\left(-\frac{1}{2}\Delta^2 t^2\right).$$

This function is characterized by the "recovery" of the polarization of the fraction (1/3) of spins whose orientation is initially parallel to the local field.

In 1979 a stochastic theory of spin relaxation has been formulated based on the strong-collision approximation to take into account the dynamical modulation of the random local field; the following iterative formula was obtained for the modulation rate $\nu = 1/\tau_c$:

$$G_z(t,\nu) = \exp(-\nu t)\Big\{G_z^{KT}(t) + \nu\int_0^t G_z^{KT}(t_1)G_z^{KT}(t-t_1)\,dt_1 + \nu^2\int_0^t\int_0^{t_2} G_z^{KT}(t_1)G_z^{KT}(t_2-t_1) \times G_z^{KT}(t-t_2)\,dt_1\,dt_2 + \ldots\ldots\Big\}.$$

As shown in Fig. 75, $G_z(t,\nu)$ is sensitive even to the very slow modulation ($\tau_c \cdot \Delta \gtrsim 2$)

AR 1979

TRIUMF - 6,281 publications (1974-2018)
Sum of Times Cited - 160,445

Web of Science

1.	**GEANT4-a simulation toolkit** By: Agostinelli, S; Allison, J; Amako, K; et al. NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT Volume: 506 Issue: 3 Pages: 250-303 Published: JUL 1 2003	884	1101	1096	1042	512	9468	591.75
2.	**Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC** By: Aad, G.; Abajyan, T.; Abbott, B.; et al. Group Author(s): ATLAS Collaboration PHYSICS LETTERS B Volume: 716 Issue: 1 Pages: 1-29 Published: SEP 17 2012	1050	931	831	597	253	4864	694.86
3.	**Geant4 developments and applications** By: Allison, J; Amako, K; Apostolakis, J; et al. IEEE TRANSACTIONS ON NUCLEAR SCIENCE Volume: 53 Issue: 1 Pages: 270-278 Part: 2 Published: FEB 2006	283	333	308	290	129	2490	191.54
4.	**THE BONN MESON-EXCHANGE MODEL FOR THE NUCLEON NUCLEON-INTERACTION** By: MACHLEIDT, R; HOLINDE, K; ELSTER, C PHYSICS REPORTS-REVIEW SECTION OF PHYSICS LETTERS Volume: 149 Issue: 1 Pages: 1-89 Published: MAY 1987	35	32	44	42	6	2115	66.09
5.	**Direct evidence for neutrino flavor transformation from neutral-current interactions in the Sudbury Neutrino Observatory** By: Ahmad, QR; Allen, RC; Andersen, TC; et al. Group Author(s): SNO Collaboration PHYSICAL REVIEW LETTERS Volume: 89 Issue: 1 Article Number: 011301 Published: JUL 1 2002	52	72	95	82	35	1827	107.47
6.	**Measurement of the rate of nu(e)+d -> p+p+e(-) interactions produced by B-8 solar neutrinos at the sudbury neutrino observatory** By: Ahmad, QR; Allen, RC; Andersen, TC; et al. Group Author(s): SNO Collaboration PHYSICAL REVIEW LETTERS Volume: 87 Issue: 7 Article Number: 071301 Published: AUG 13 2001	23	34	53	35	19	1412	78.44
7.	**The ATLAS Experiment at the CERN Large Hadron Collider** By: Aad, G.; Abat, E.; Abdallah, J.; et al. JOURNAL OF INSTRUMENTATION Volume: 3 Article Number: S08003 Published: AUG 2008	111	134	121	149	77	1324	120.36
8.	**The BABAR detector** By: Aubert, B; Bazan, A; Boucham, A; et al. Group Author(s): BABAR Collaboration NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT Volume: 479 Issue: 1 Pages: 1-116 Article Number: PII S0168-9002(01)02012-5 Published: FEB 21 2002	35	35	29	17	8	1123	66.06
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10.	**Measurement of day and night neutrino energy spectra at SNO and constraints on neutrino mixing parameters** By: Ahmad, QR; Allen, RC; Andersen, TC; et al. Group Author(s): SNO Collaboration PHYSICAL REVIEW LETTERS Volume: 89 Issue: 1 Article Number: 011302 Published: JUL 1 2002	14	17	16	7	6	862	50.71
11.	**Precision electroweak measurements on the Z resonance** By: Schael, S; Barate, R; Bruneliere, R; et al. Group Author(s): ALEPH Collaborat; DELPHI Collaborat; L3 Collaborat; et al. PHYSICS REPORTS-REVIEW SECTION OF PHYSICS LETTERS Volume: 427 Issue: 5-6 Pages: 257-454 Published: MAY 2006	88	93	99	88	29	793	61.00
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13.	**ZERO-FIELD AND LOW-FIELD SPIN RELAXATION STUDIED BY POSITIVE MUONS** By: HAYANO, RS; UEMURA, YJ; IMAZATO, J; et al. PHYSICAL REVIEW B Volume: 20 Issue: 3 Pages: 850-859 Published: 1979	28	29	15	15	13	609	15.23

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1	**9518**	**GEANT-a**	—
2	**4882**	**ATLAS**	—
3	**2501**	**GEANT4**	—
4	**2115**	**Bonn model (N-N Theory)**	—
5	**1827**	**SNO**	—
6	**1413**	**SNO**	—
7	**1350**	**ATLAS**	—
8	**1123**	**BABAR**	—
9	**929**	**T2K**	—
10	**862**	**SNO**	—
11	**795**	**ALEPH**	—
12	**713**	**ATLAS**	—
13	**609**	**Hayano et al**	✅

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