

Nuclear structure research at Notre Dame

How it all began

Lee Riedinger
Professor of Physics
University of Tennessee

April 7, 2018



Bredesen Center
for Interdisciplinary Research and Graduate Education



My two great years as a postdoc at Notre Dame 1969 to 1971

- Excellent people
- New accelerator
- Snow and football



**Campus views
in 1970 -
just a few
changes!**



Nuclear physics at Notre Dame has been built by its faculty leaders

- 1950s to 1970s faculty leaders
 - Walt Miller
 - Corny Browne
 - Bud Darden
 - John Mihelich and Emerson Funk
 - Paul Chagnon
 - Gene Marshalek
- 1970s -
 - Jim Kolata
 - Umesh Garg
 - Michael Wiescher
 - Ani Aprahamian
 - Stefan Frauendorf
 - Mark Caprio
 - Whole bunch of young faculty

I was a postdoc working with John and Emerson from 1969 to 1971



November 1991

John Mihelich

- Born 1/1922 in Colorado Springs
- BS in Physics at Colorado College in 6/1942
- Enlisted in Army in WWII, served in South Pacific; out in 12/1945
- Grad school at Illinois in nuclear physics PhD in 1950
- Met fellow grad student Jan, married for 70 years starting 12/1946
- Postdoc at BNL 1950 - 54
- Joined ND faculty in 1954
- Early-on spent summers at LBNL (1955) and ORNL (1956, 57, 58)
- Retired from faculty in 1987
- Three kids - Bill, Kathy, Peggy
- Moved to Ft. Collins in 2012, since daughters were there
- Jan died in May 2016
- John died in March 2017



Emerson Funk

- **Born 1/1931 in Michigan**
- **Married Irene in 1953**
- **BS in Physics from Wayne State in 1953**
- **PhD in Nuclear Physics from Michigan in 1958**
- **Joined ND faculty in 1958**
- **Retired in 1994**
- **Died June 2015**



May 1992

John's postdoc days at Brookhaven 1950 to 54

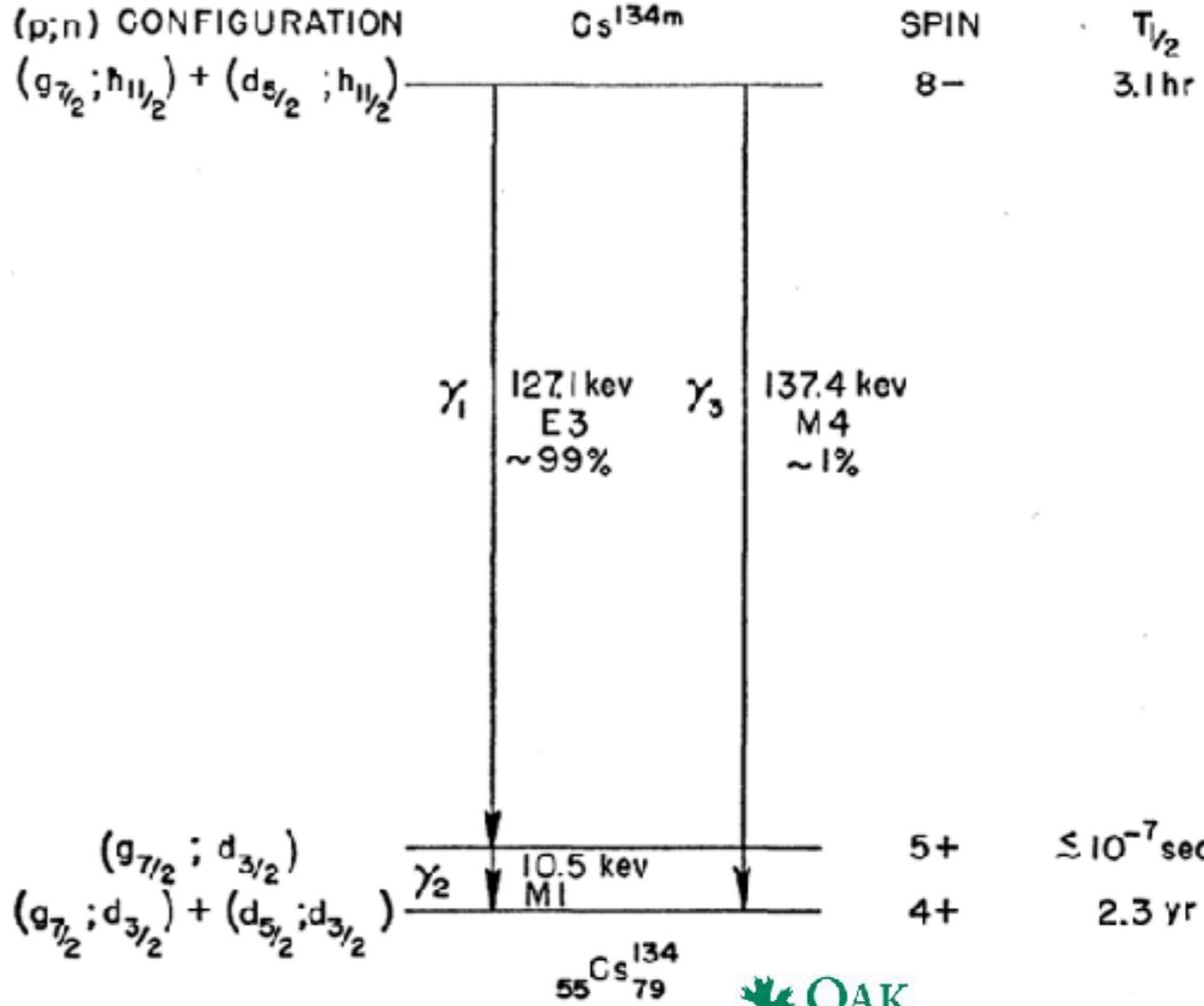
- Andy Sunyar and Maurice Goldhaber (BNL director from 1961 to 1973)
- Andy was a lifelong golfing buddy for John

Decay of Cs^{134m} (3.1 hr)

A. W. SUNYAR, J. W. MIHELICH, AND M. GOLDHABER
Brookhaven National Laboratory, Upton, New York*
 (Received June 2, 1954)



Andrew Sunyar in 1970.



John worked at ORNL for three summers with Tom Handley and Ben Harmatz after joining the ND faculty

- Proton irradiations of rare-earth oxide targets in ORNL 86" cyclotron, 12 to 22 MeV, up to 70 microamps
- Ion-exchange column and radiochemistry
- Conversion-electron spectrograph - electrons of energy between 10 and 380 keV were recorded
- Photographic detectors
- Found 10 new activities in isotopes of Tb, Dy, Ho, Er, Yb, and Lu ; 18 previously known activities were studied; multipolarities proposed

PHYSICAL REVIEW

VOLUME 108, NUMBER 4

NOVEMBER 15, 1957

Nuclear Spectroscopy of Neutron-Deficient Rare Earths (Tb through Hf)†

J. W. MIHELICH,* B. HARMATZ, AND T. H. HANDLEY
Oak Ridge National Laboratory, ‡ Oak Ridge, Tennessee
(Received June 21, 1957)

Classic papers - Harmatz, Handley, Mihelich

- Permanent-magnet conversion-electron spectrographs - electron lines up to 3 MeV- new data on $^{150,150m}\text{Eu}$, $^{152,154,154m,156}\text{Tb}$, $^{162,162m}\text{Ho}$, ^{166}Tm , ^{172}Lu , $^{182,182m,184}\text{Re}$, and ^{148m}Pm ; many odd-A isotopes also
- First systematic studies of β and γ vibrational bands

PHYSICAL REVIEW

VOLUME 123, NUMBER 5

SEPTEMBER 1, 1961

Nuclear Levels in a Number of Even-Even Rare Earths ($150 \leq A \leq 184$)

B. HARMATZ AND T. H. HANDLEY

Oak Ridge National Laboratory, Oak Ridge, Tennessee*

AND

J. W. MIHELICH†

University of Notre Dame, Notre Dame, Indiana‡

(Received April 17, 1961)

PHYSICAL REVIEW

VOLUME 128, NUMBER 3

NOVEMBER 1, 1962

Properties of Nuclear Levels in a Number of Odd-A Nuclei ($151 \leq A \leq 191$)

B. HARMATZ AND T. H. HANDLEY

Oak Ridge National Laboratory, Oak Ridge, Tennessee*

AND

J. W. MIHELICH†

University of Notre Dame, Notre Dame, Indiana

(Received June 29, 1962)

Two decades of radioactive decay work at ND - next steps after massive papers from Oak Ridge work

PHYSICAL REVIEW

VOLUME 129, NUMBER 2

15 JANUARY 1963

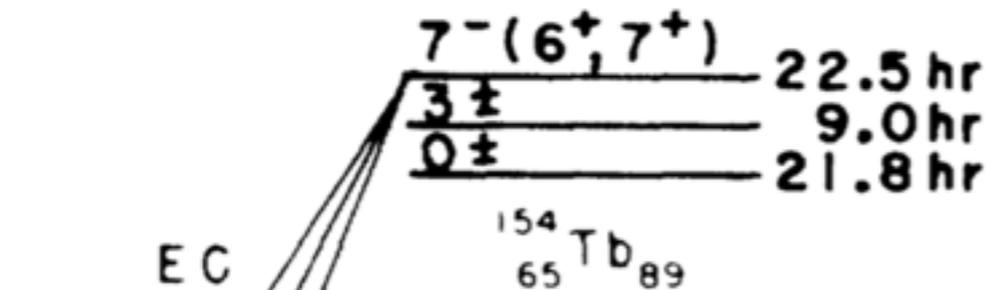
Lifetimes of the 246- and 46.7-keV Transitions in $\text{Po}^{210}\dagger$

E. G. FUNK, JR., H. J. PRASK,* F. SCHIMA, J. McNULTY, AND J. W. MIHELICH

University of Notre Dame, Notre Dame, Indiana

(Received 23 August 1962)

The half-lives of the 1431- and 1478-keV levels in Po^{210} have been measured, the experimental values being 1.8 ± 0.2 nsec and 29 ± 6 nsec, respectively. These levels are depopulated by $E2$ transitions of 246 and 46.7 keV whose transition probabilities are approximately three times greater than the single particle esti-



PHYSICAL REVIEW C

VOLUME 4, NUMBER 4

OCTOBER 1971

Decay of a New Isomer in ^{154}Tb to High-Spin Levels in ^{154}Gd

L. L. Riedinger, D. C. Sousa, E. G. Funk, and J. W. Mihelich

Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556

(Received 14 May 1971)

8.1
7.4
6.1
log ft
10

Equipment for directional correlation measurements on radioactive sources

Hot lab crucial for radiochemical preparations of sources for these 20 years of experiments at ND



PHYSICAL REVIEW

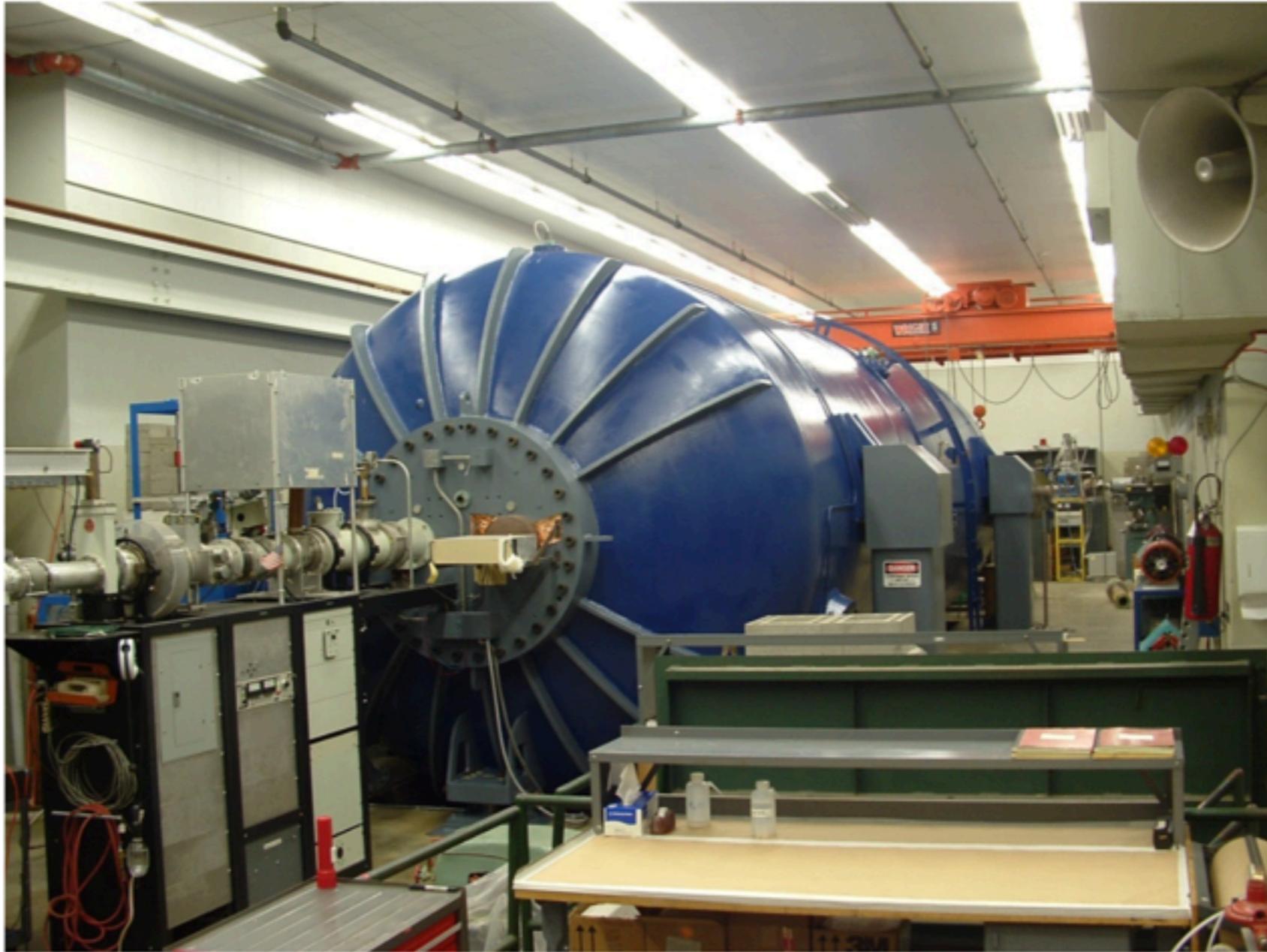
VOLUME 133, NUMBER 3B

10 FEBRUARY 1964

Study of the Decay of Tm^{168} to Levels in Er^{168} Using Coincidence and Directional Correlation Techniques*

J. J. REIDY,†† E. G. FUNK, AND J. W. MIHELICH
University of Notre Dame, Notre Dame, Indiana
(Received 9 September 1963)

New FN tandem accelerator in 1960s



Excellent technical staff led by Ed Berners and Jim Kaiser

Coulomb excitation work at ND

1.E.4:2.H

Nuclear Physics A219 (1974) 543—562; © North-Holland Publishing Co., Amsterdam

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COULOMB EXCITATION STUDIES OF ^{160}Dy , ^{162}Dy AND ^{164}Dy †

R. N. OEHLBERG ††, L. L. RIEDINGER ‡, A. E. RAINIS ‡‡, A. G. SCHMIDT,
E. G. FUNK and J. W. MIHELICH

University of Notre Dame, Notre Dame, Indiana 46556

Received 10 September 1973

PHYSICAL REVIEW C

VOLUME 20, NUMBER 6

DECEMBER 1979

Coulomb excitation of Yb nuclei

L. L. Riedinger

University of Tennessee, Knoxville, Tennessee 37916

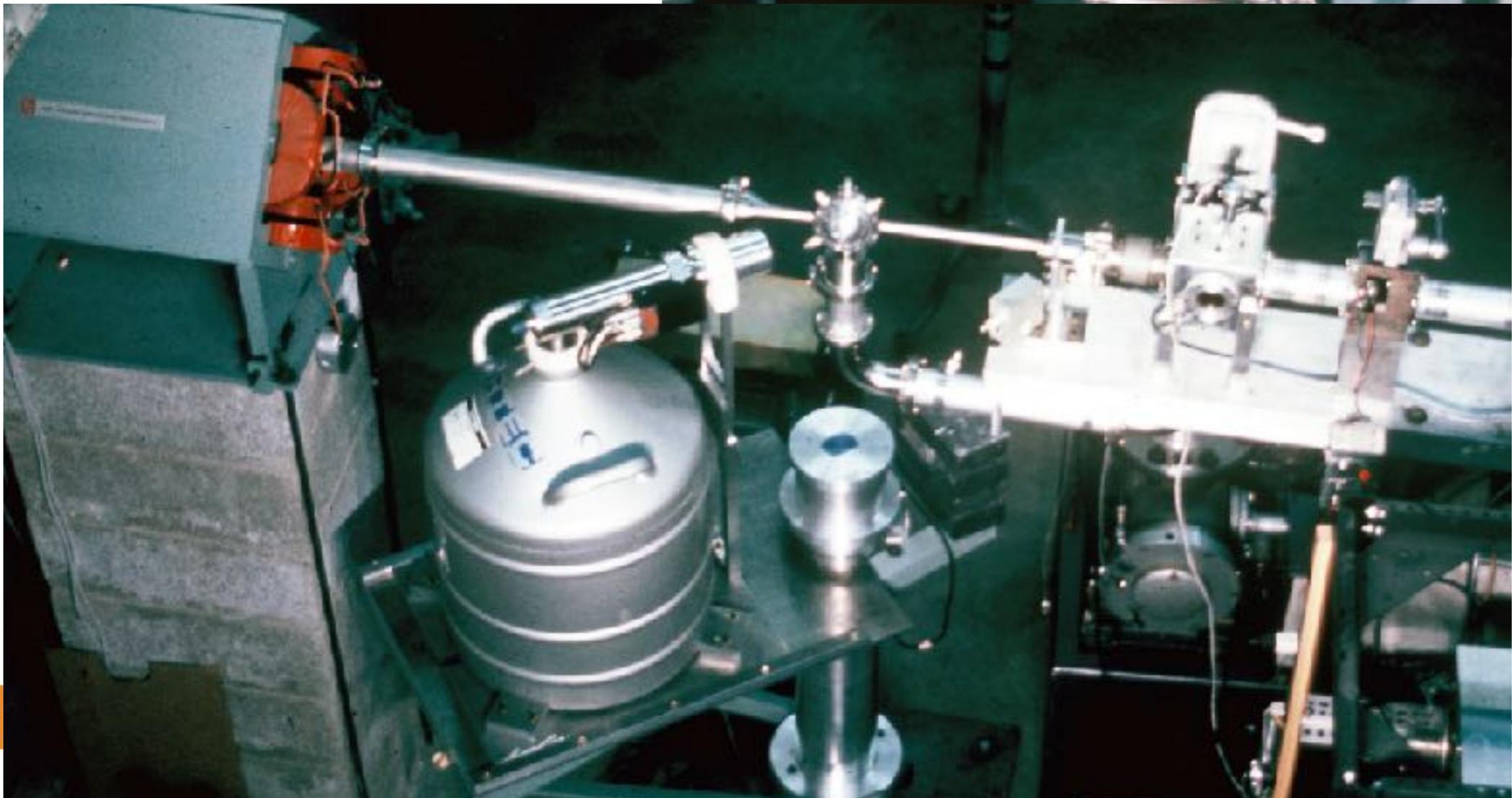
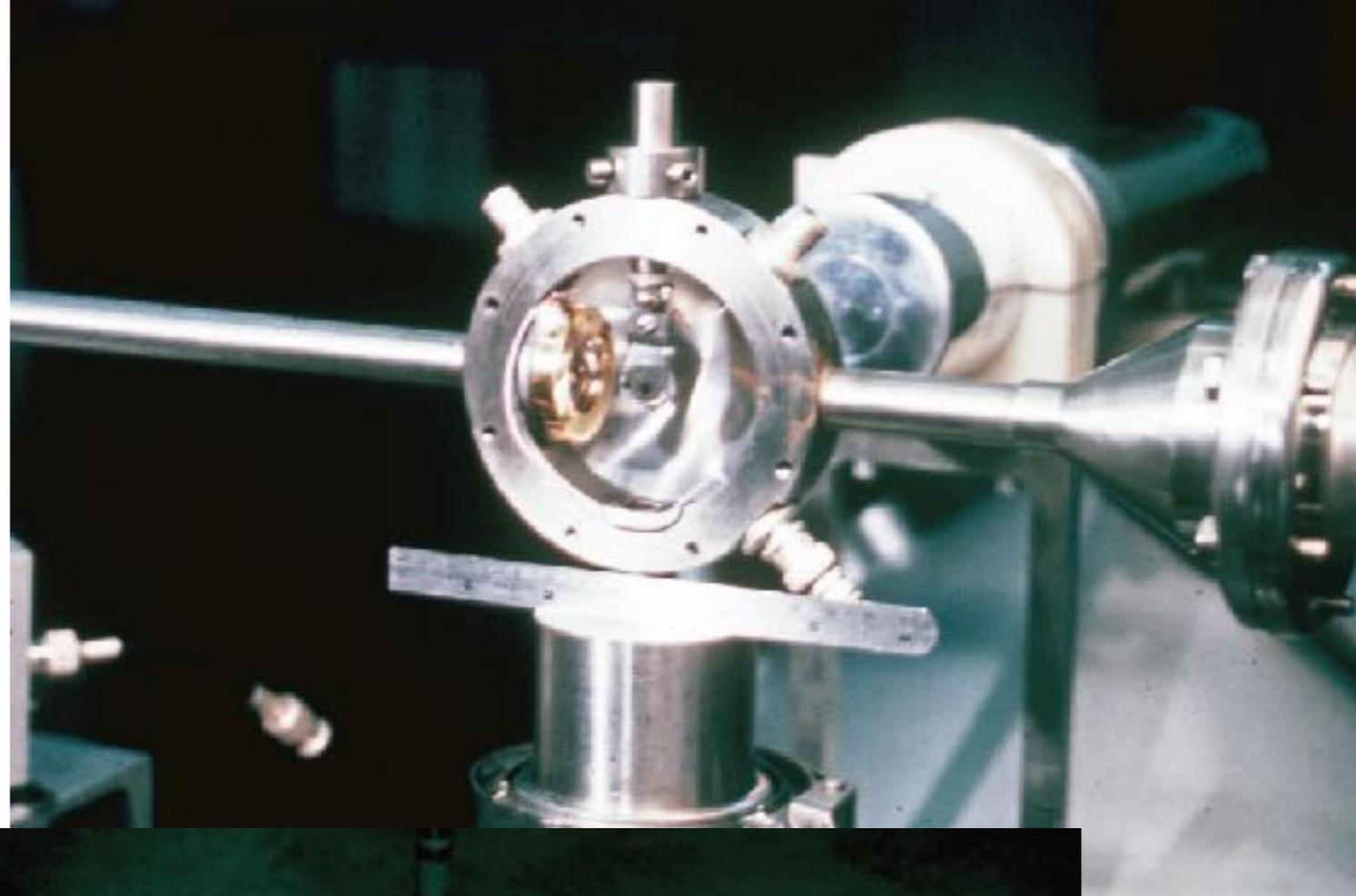
E. G. Funk, J. W. Mihelich, G. S. Schilling,* A. E. Rainis,† and R. N. Oehlberg†

University of Notre Dame, Notre Dame, Indiana 46556

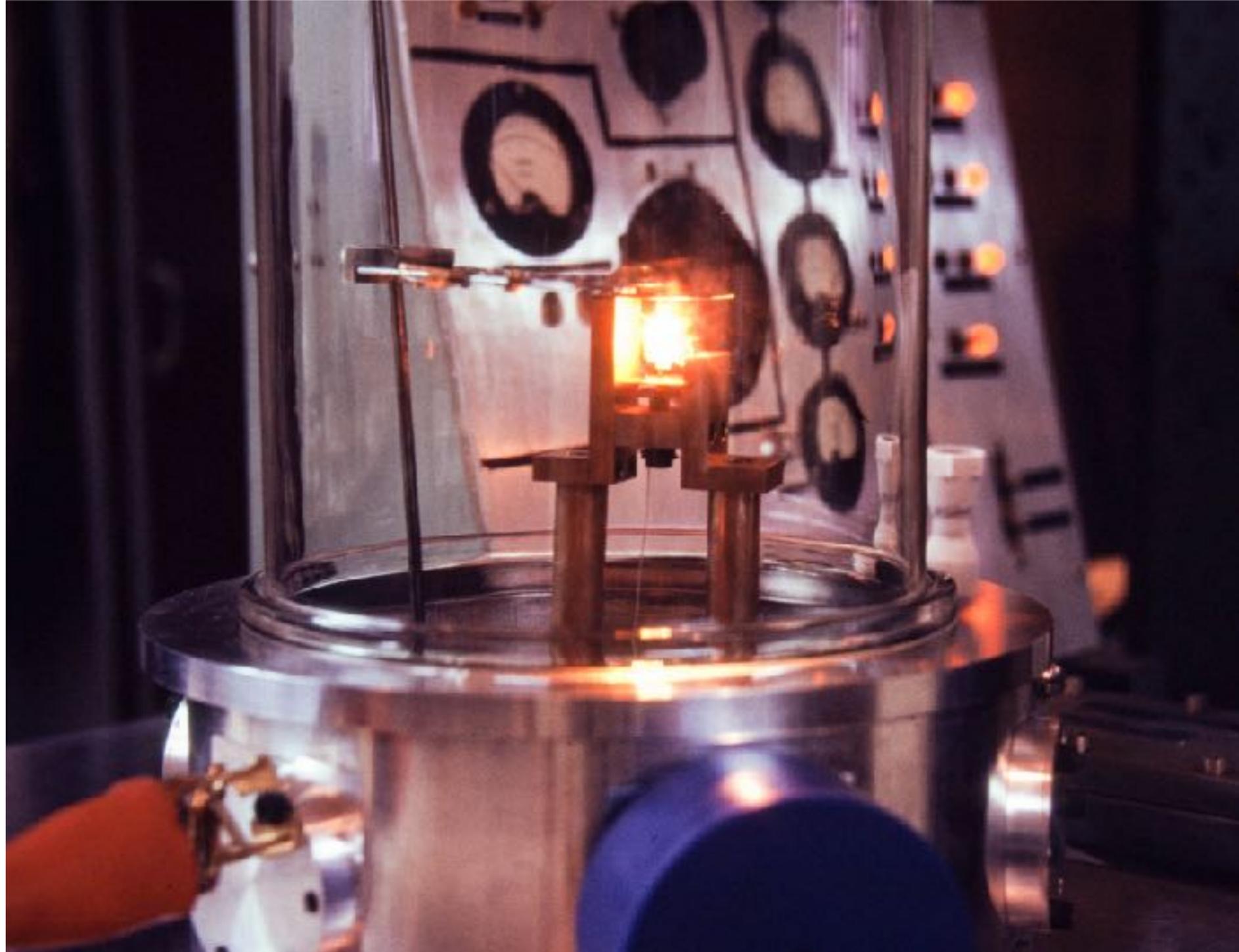
(Received 30 March 1979)

Coulexc gear at tandem

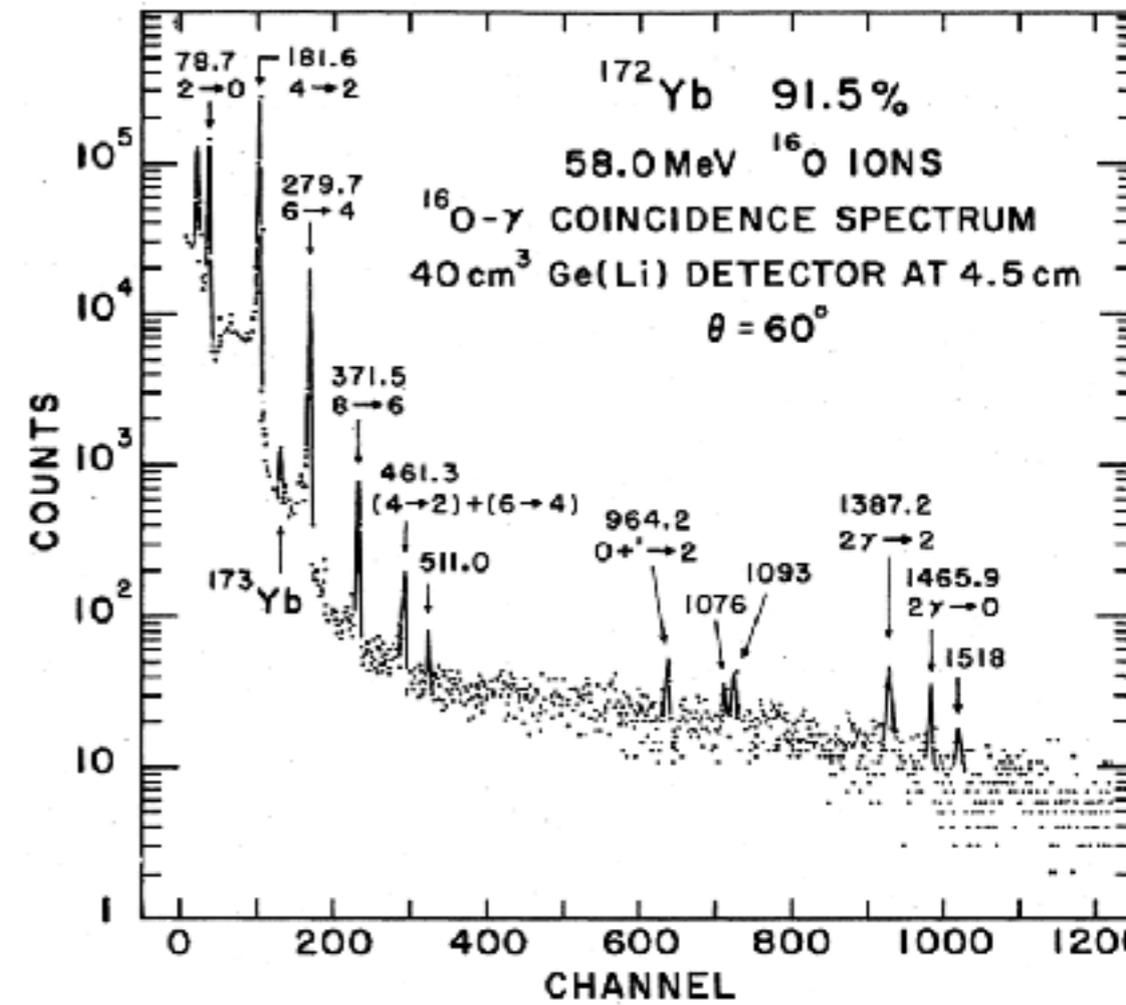
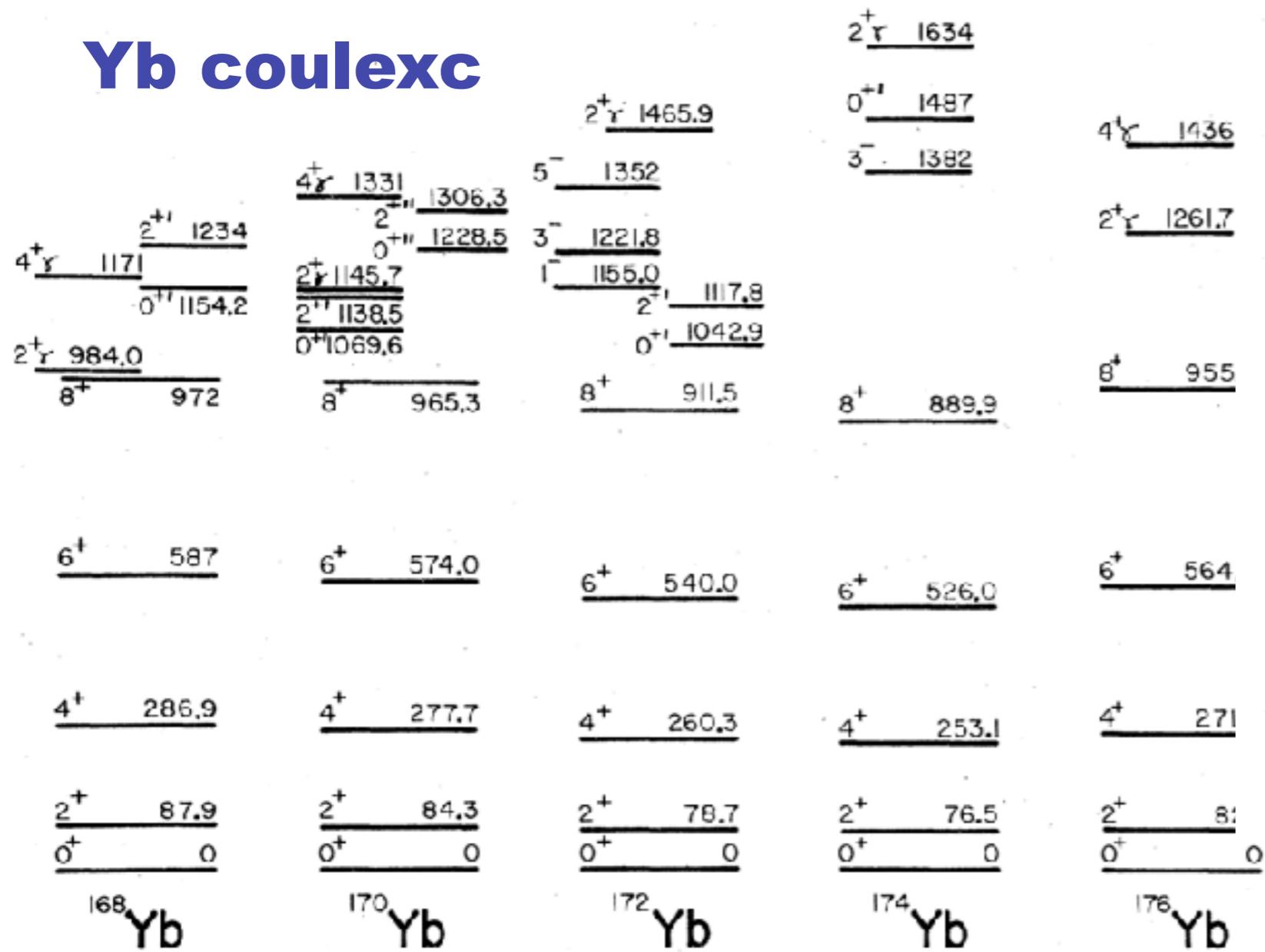
- 1 Ge(Li) γ -ray detector
- Annular Si detector for backscattered ^{16}O ions
- Coincidence between Ge and Si detectors
- Very simple compared to today!



My biggest challenge - learning how to make thin self-supporting rare-earth targets - Dy and Yb



Yb coulexc



First measurement of enhanced B(E2) values to 0+ states in three Yb isotopes

A	$B(E2; 0^+ \rightarrow 2^+)$ e^2b^2		$B(E4; 0 \rightarrow 4^+)$ e^2b^4		β_4 Nilsson <i>et al.</i> ^b	$B(E4)$ e^2b^4	$R(8/6)$ This exp ^c	β_4 Gotz <i>et al.</i> ^d	$B(E4)$ e^2b^4	$R(8/6)$ This exp ^e
	This calc	Recent exp ^a	Recent exp ^a							
168	5.68	5.81 ± 0.10	$0.036^{+0.073}_{-0.036}$		+0.02	0.077	1.16 ± 0.19	-0.01	0.027	1.21 ± 0.20
170	5.68				+0.01	0.058	0.93 ± 0.04	-0.02	0.015	0.97 ± 0.04
172	5.84	6.03 ± 0.06	$0.048^{+0.067}_{-0.046}$		-0.01	0.028	0.91 ± 0.05	-0.03	0.008	0.93 ± 0.05
174	5.74	5.95 ± 0.06	$0.044^{+0.078}_{-0.043}$		-0.02	0.015	0.85 ± 0.03	-0.04	0.002	0.87 ± 0.04
176	5.33	5.41 ± 0.08	$0.078^{+0.074}_{-0.072}$		-0.03	0.005	0.81 ± 0.06	-0.05	0	0.83 ± 0.06

In-beam γ -ray spectroscopy at ND

PHYSICAL REVIEW C

VOLUME 21, NUMBER 2

FEBRUARY 1980

High spin states in the $N = 82$ nucleus ^{145}Eu

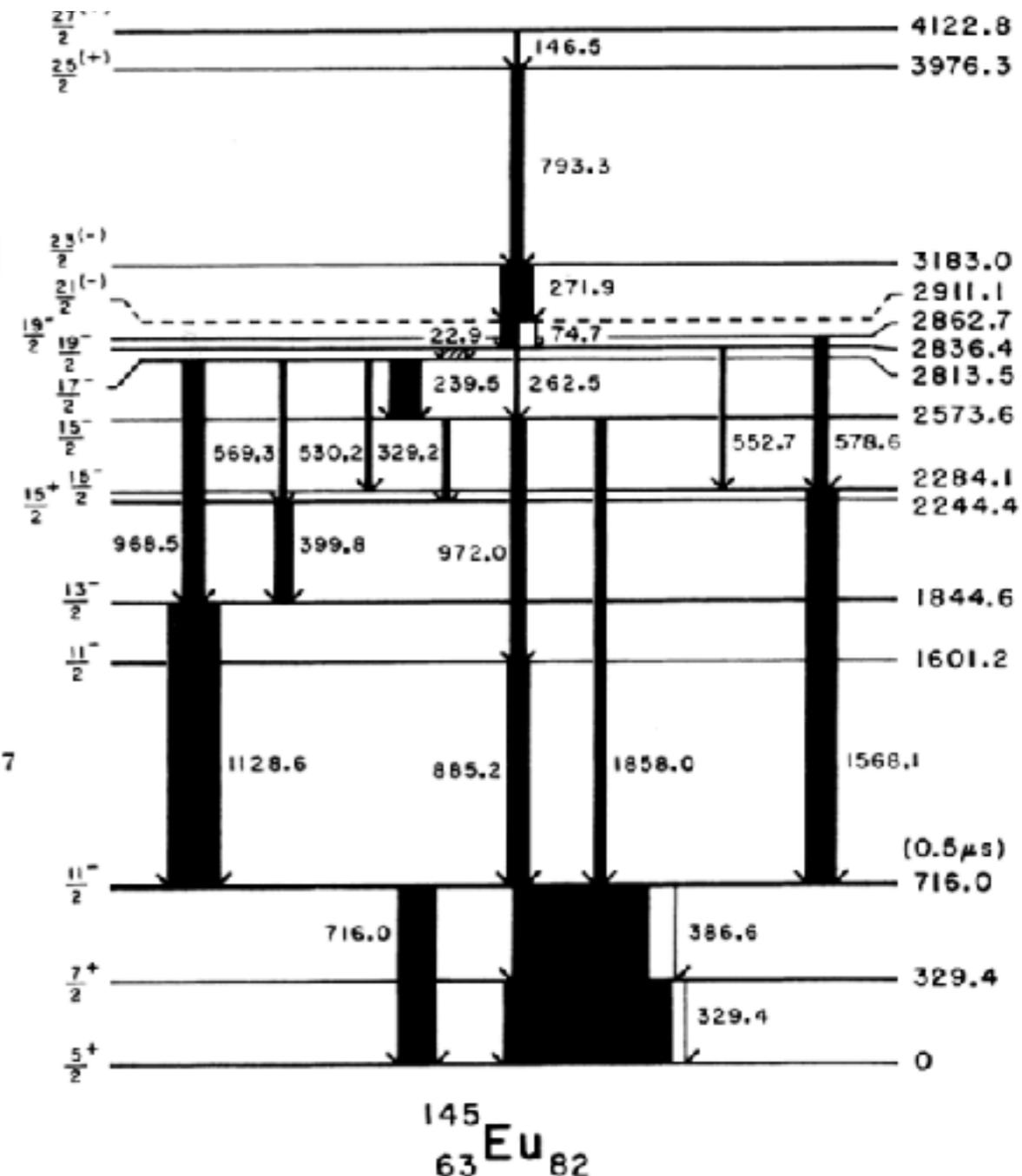
D. A. Rakel,* R. Kaczarowski,† E. G. Funk, and J. W. Mihelich

University of Notre Dame, Notre Dame, Indiana 46556

(Received 20 September 1979)

CH

- ($^6\text{Li},3n$) and ($^7\text{Li},4n$) reactions with tandem
- γ ray (2 Ge(Li) counters) and conversion-electron detection using Si(Li) detector and a filter made of permanent magnets
- States below 2.5 MeV explained as hole states coupled to even-even ^{146}Gd core-excited states and particle states coupled to the ^{144}Sm core-excited states



VIEW C

VOLUME 16, NUMBER 1

JULY 1977

Band structure in $^{147,149,151}\text{Eu}$ observed via (HI, xn) reactions

J. G. Fleissner, E. G. Funk, F. P. Venezia, and J. W. Mihelich

University of Notre Dame, Notre Dame, Indiana 46556*

(Received 7 March 1977)

May 1992 reunion of the large Mihelich group



May 1992 reunion of the large Mihelich group

Carl Paperiello - PhD around 1972

Bill Seremak - PhD around 1972



John was an important mentor for me (and for many)



Bill Seremak, Lee, John, Art Schmidt, Rich Oehlberg

Football - Tennessee at Notre Dame 11/9/1991



Big upset: Tennessee over ND 35-34



The next generation of nuclear structure faculty start to appear - Umesh and Ani



In-beam γ -ray spectroscopy at ND

PHYSICAL REVIEW C

VOLUME 45, NUMBER 1

JANUARY 1992

High spin states in ^{181}Ir and backbending phenomena in the Os-Pt region

R. Kaczarowski*

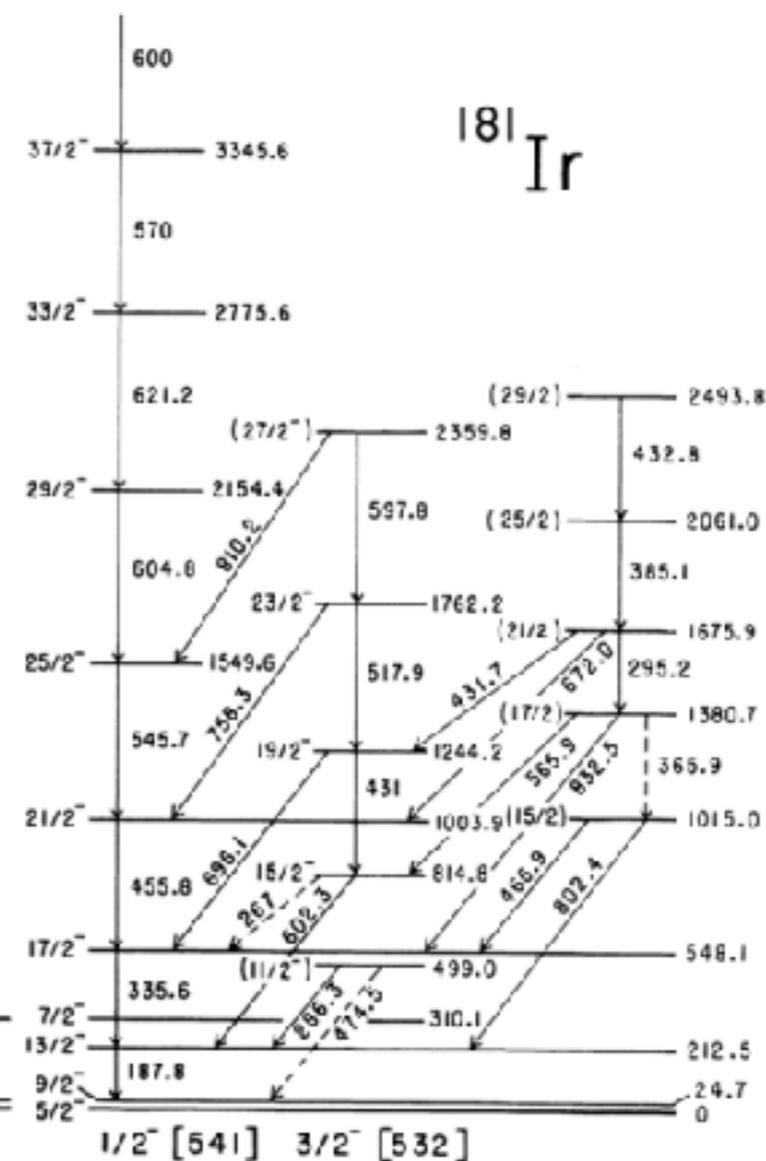
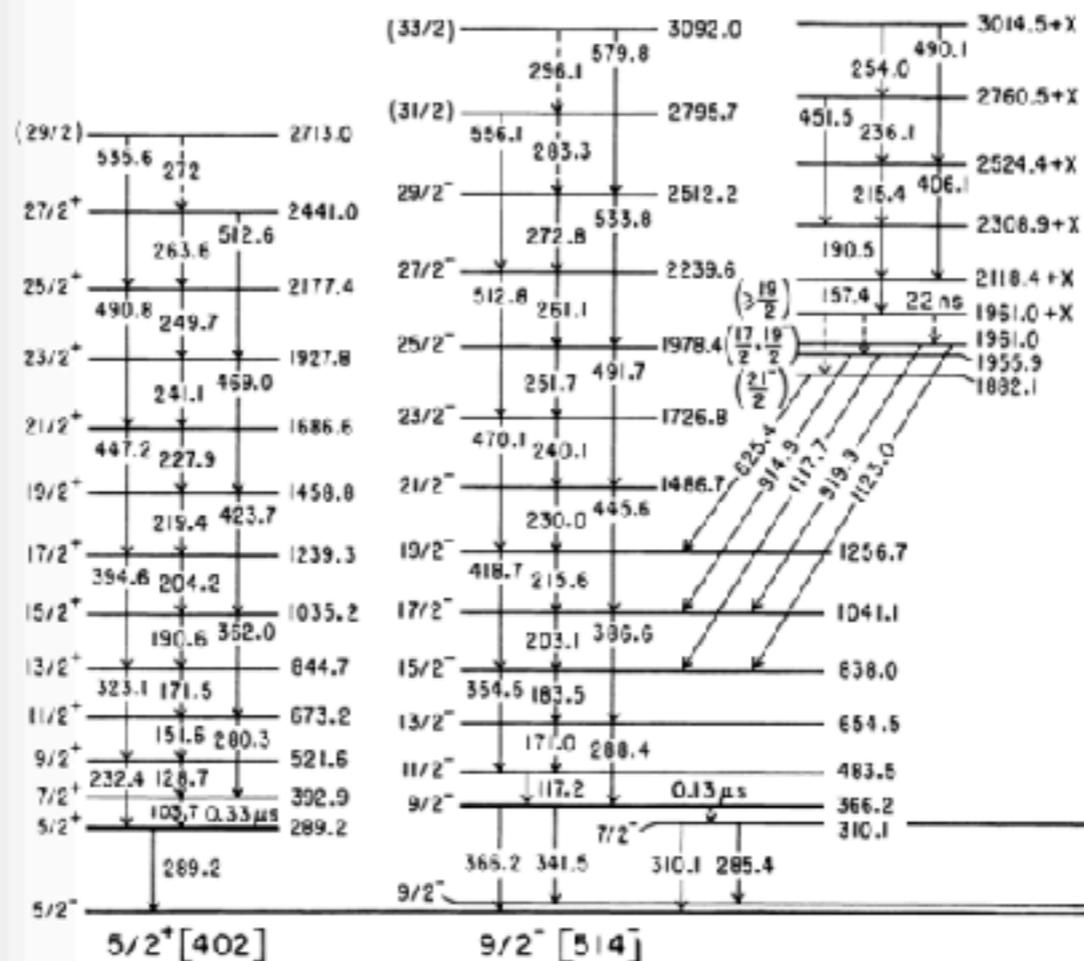
*Physics Department, University of Notre Dame, Notre Dame, Indiana 46556
and Soltan Institute for Nuclear Studies, 05-400 Swierk, Poland*

U. Garg, E. G. Funk, and J. W. Mihelich

Physics Department, University of Notre Dame, Notre Dame, Indiana 46556

(Received 12 July 1991)

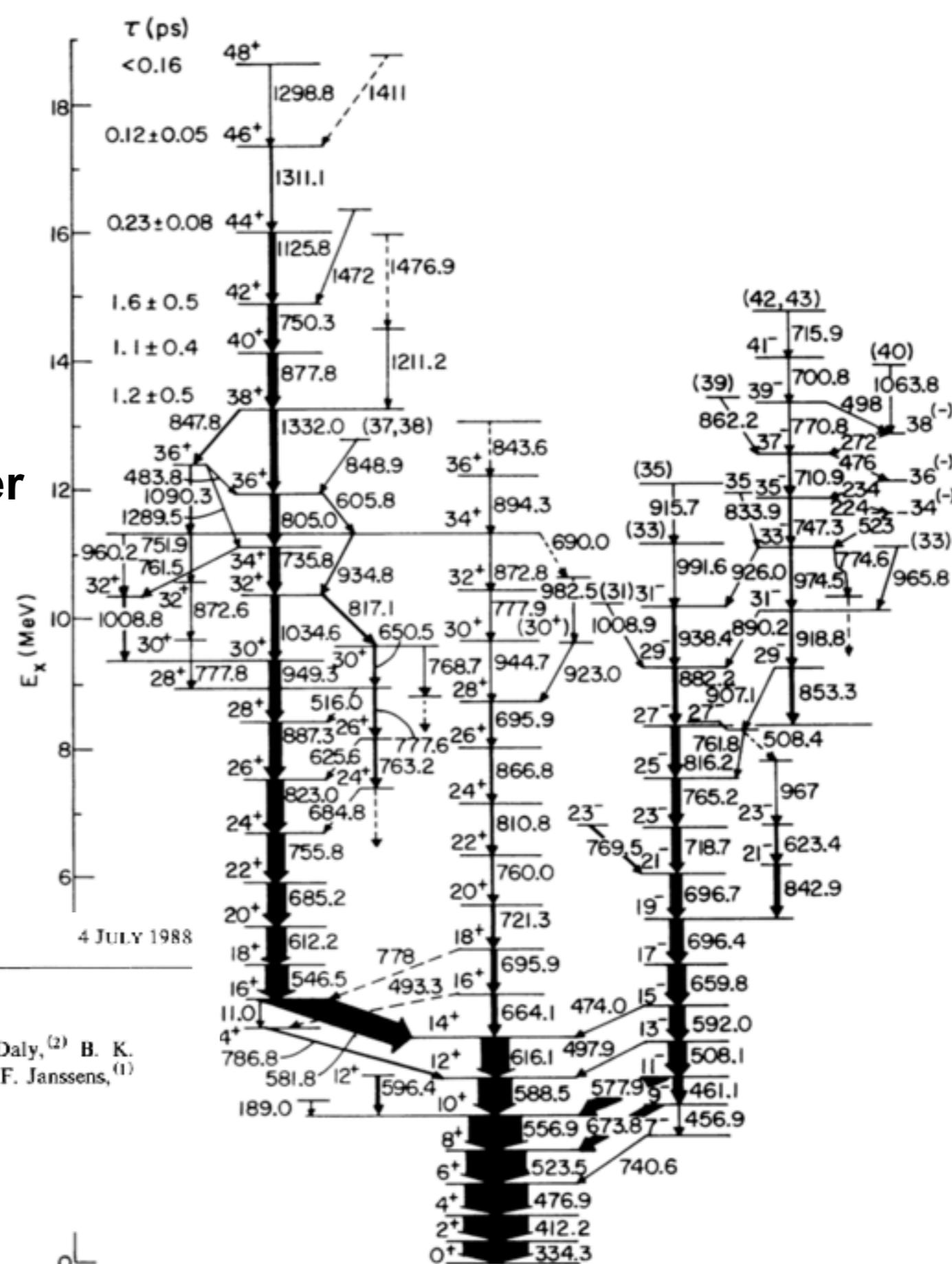
- ^{16}O -induced reactions with ND tandem
- γ ray detection with 2 Ge detectors
- Delayed backbend in the proton $h_{9/2}$ $1/2[541]$ band - due to larger deformation in this structure



ND array at ANL

Umesh Garg

- Argonne-Notre Dame γ -ray facility - 8 BGO Compton-suppressed Ge spectrometers and a central array of 14 BGO detectors as multiplicity filter
- States in ^{154}Dy up to $I = 48+$ with lifetimes measured
- Led to Gammasphere



VOLUME 61, NUMBER 1 PHYSICAL REVIEW LETTERS 4 JULY 1988

Structural Changes along and above the Yrast Line of ^{154}Dy

W. C. Ma,⁽¹⁾ M. A. Quader,⁽²⁾ H. Emling,^{(1),(a)} T. L. Khoo,⁽¹⁾ I. Ahmad,⁽¹⁾ P. J. Daly,⁽²⁾ B. K. Dichter,^{(1),(b)} M. Drigert,^{(3),(c)} U. Garg,⁽³⁾ Z. W. Grabowski,⁽²⁾ R. Holzmann,^{(1),(a)} R. V. F. Janssens,⁽¹⁾ M. Piiparinen,^{(2),(d)} W. H. Trzaska,⁽²⁾ and T.-F. Wang⁽¹⁾

⁽¹⁾Argonne National Laboratory, Argonne, Illinois 60439
⁽²⁾Purdue University, West Lafayette, Indiana 47907
⁽³⁾University of Notre Dame, Notre Dame, Indiana 46556
 (Received 29 December 1987)

Early Ani Aprahamian work at ND

- ^{154}Gd studied by γ -ray spectroscopy using $(\alpha, 2n)$ reaction at ND tandem
- Pittsburgh array of five Ge detectors with BGO anti-Compton shields
- Identified the double-phonon $K = 4^+$ $\gamma\gamma$ vibrational band
- Systematics of possible $K = 4^+$ double-phonon vibrational bands in the deformed rare-earth region

PHYSICAL REVIEW C

VOLUME 49, NUMBER 4

APRIL 1994

Multiphonon vibrational states in deformed nuclei

X. Wu, A. Aprahamian, S. M. Fischer, W. Reviol,* and G. Liu†
University of Notre Dame, Notre Dame, Indiana 46556

J. X. Saladin
University of Pittsburgh, Pittsburgh, Pennsylvania 15260
(Received 6 July 1993)

Ani became an expert on 0^+ states in deformed nuclei

- Many papers, many experiments at ND and at other places
- For example, they measured lifetimes of levels in three 0^+ bands in ^{178}Hf
- Used a double-flat crystal spectrometer (GAMS4) installed 15 m from the core of the high-flux reactor of the Institut Laue Langevin in Grenoble
- They observed a collective $K^\pi = 0^+$ band at 1772 keV that decays to the band at 1199 keV with collective transitions of 5–10 W.U.
- One explanation is that upper 0^+ band is a two-phonon $\beta\beta$ vibrational excitation - rarely seen in nuclei

J. Phys. G: Nucl. Part. Phys. **25** (1999) 685–689. Printed in the UK

PII: S0954-3899(99)99317-9

Collective $K^\pi = 0^+$ vibrational excitations in ^{178}Hf

A Aprahamian[†], R C de Haan[†], S R Leshner[†], J Döring[†], A M Bruce[‡],
H G Börner[§], M Jentschel[§] and H Lehmann[§]

[†] Department of Physics, University of Notre Dame, Notre Dame, IN 46556, USA

[‡] University of Brighton, Brighton BN2 4GJ, UK

[§] Institut Laue Langevin, 38042 Grenoble, Cedex 9, France

The long winning tradition in nuclear physics at Notre Dame

- **Hire the best faculty**
- **Build a home base of excellent equipment**
- **Attract top-flight students**
- **Foster a culture of excellence**
- **Collaborate and compete with the top groups in the world**
- **Leads to 80 years of first-class nuclear physics**

The long winning tradition in ~~nuclear physics~~ **football** at Notre Dame

- Hire the best ~~faculty~~ **coaches**
- Build a home base of excellent ~~equipment~~ **athletic facilities**
- Attract top-flight ~~students~~ **players**
- Foster a culture of excellence
- Collaborate and compete with the top ~~groups~~ **teams**
- Leads to 80 years of first-class ~~nuclear physics~~ **college football**

There are parallels between the Notre Dame long-term success in nuclear physics and in college football. Of course, one is much more important than the other!

Thanks to Notre Dame and to John and Emerson for shaping my career

