

Modern Trends in Basic and Applied Laser Spectroscopy

Lund 6-7 April, 2010

Once upon a time

there was no laser ...

How Science changed the course of World History

How World History changed the course of Science

Ingvar Lindgren: After-dinner speech



Isaac Rabi (1898-1988)

Inventor of ABMR – first radio-frequency-resonance method 1937

Nobel Prize 1944

The Molecular Beam Resonance Method for Measuring Nuclear Magnetic Moments

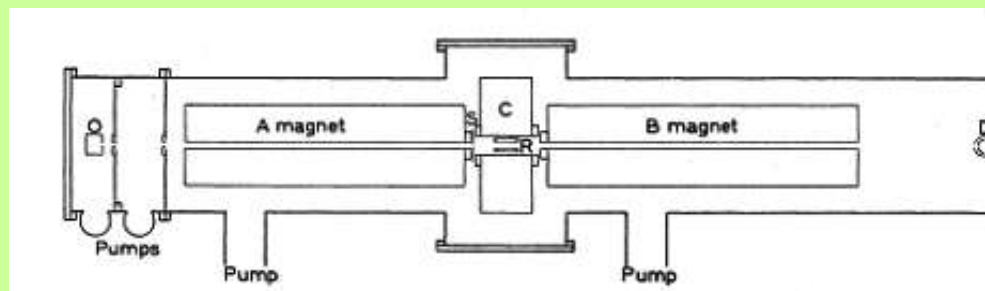
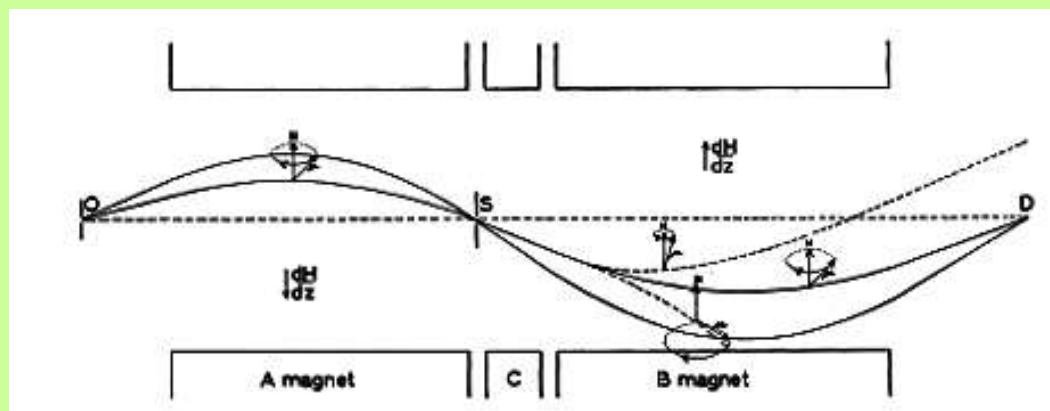
The Magnetic Moments of ${}^6\text{Li}$, ${}^7\text{Li}$ and ${}^{19}\text{F}$

I. I. RABI, S. MILLMAN, P. KUSCH, *Columbia University, New York, New York*

AND

J. R. ZACHARIAS, *Hunter College, New York, New York*

(Received January 20, 1939)



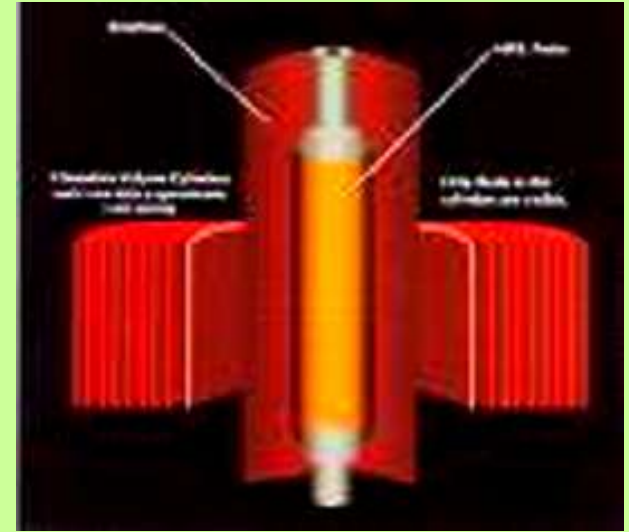
Radio-frequency induced transitions

**The demonstration of induced transitions by Rabi
represents **the start of a new epoch in physics****

New resonance methods followed rapidly

Nuclear Magnetic Resonance NMR

discovered 1945



Felix Bloch

1905-1983

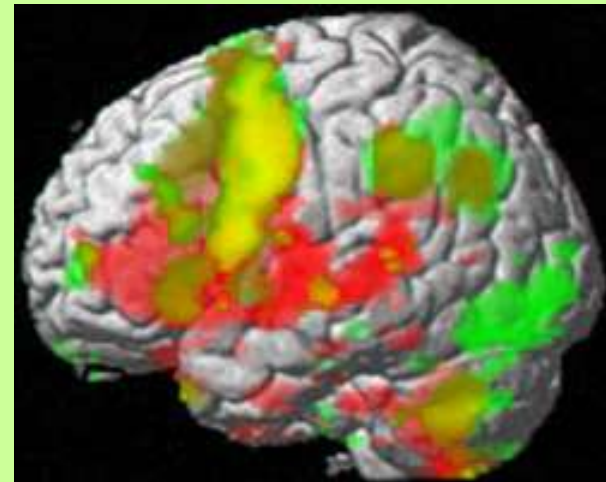
Edward Purcell

1912-1997

Nobel Prize 1952

"for their development of new methods for nuclear magnetic precision measurements and discoveries in connection therewith"

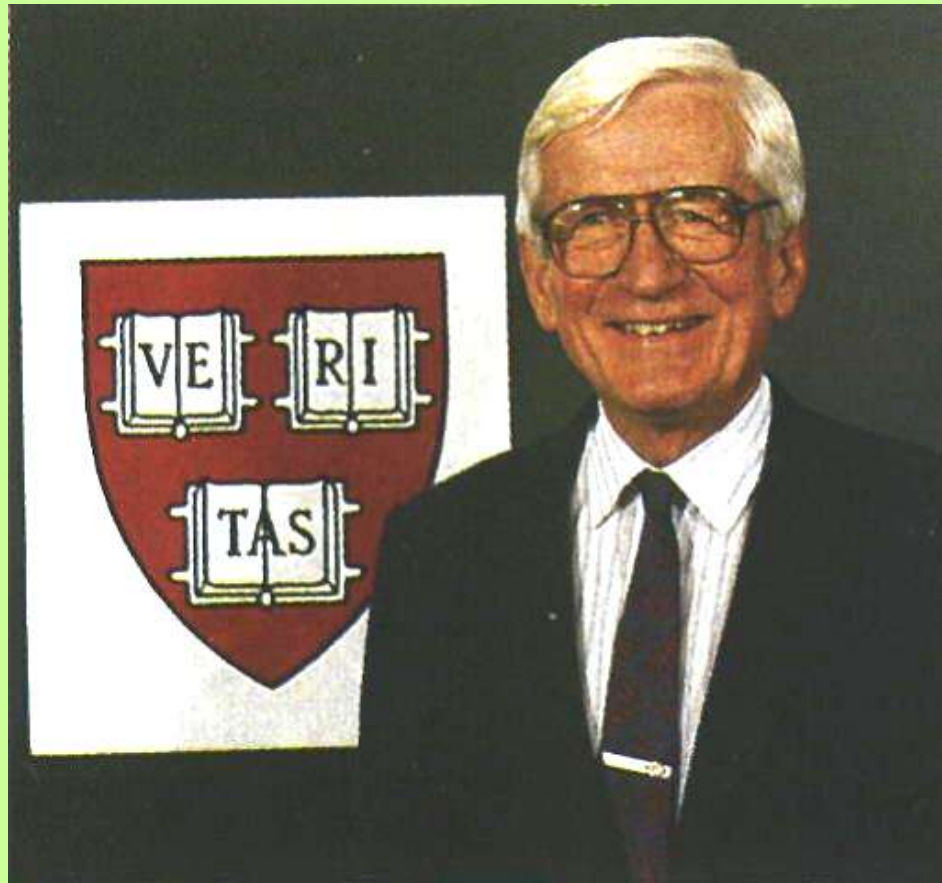
~~Nuclear~~ Magnetic Resonance Imaging MRI



Electron Spin (Paramagnetic) Resonance ESR/EPR

Discovered in 1944 by E.K. Zavoisky, USSR, and B. Bleaney, Oxford





Norman Ramsey 1915-

Nobel Prize 1989

Separate oscillatory fields 1949

A New Molecular Beam Resonance Method*

NORMAN F. RAMSEY

Harvard University, Cambridge, Massachusetts

August 22, 1949

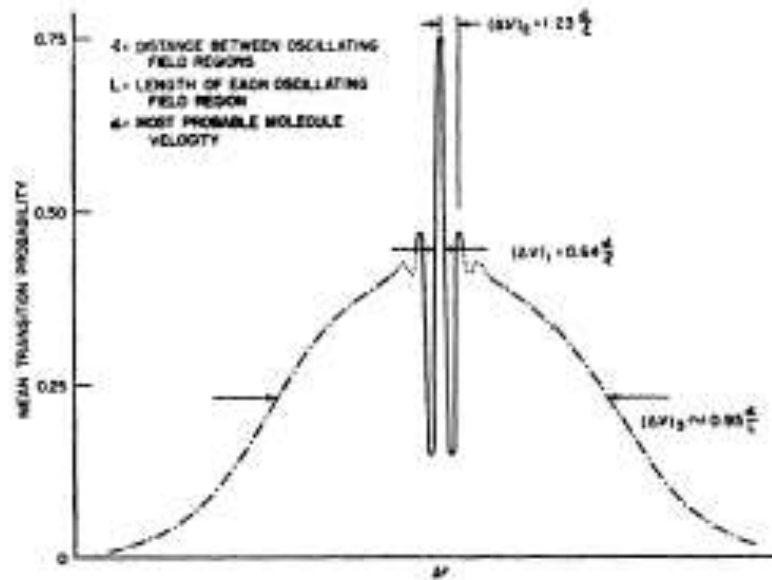
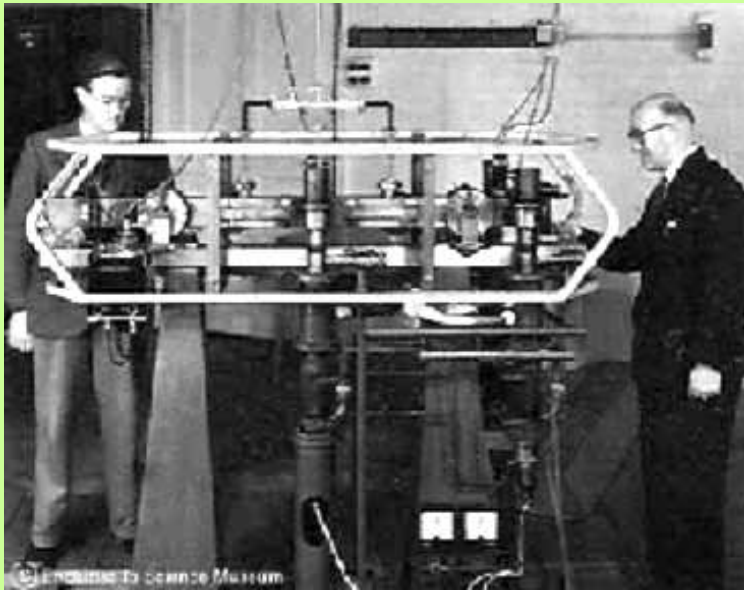
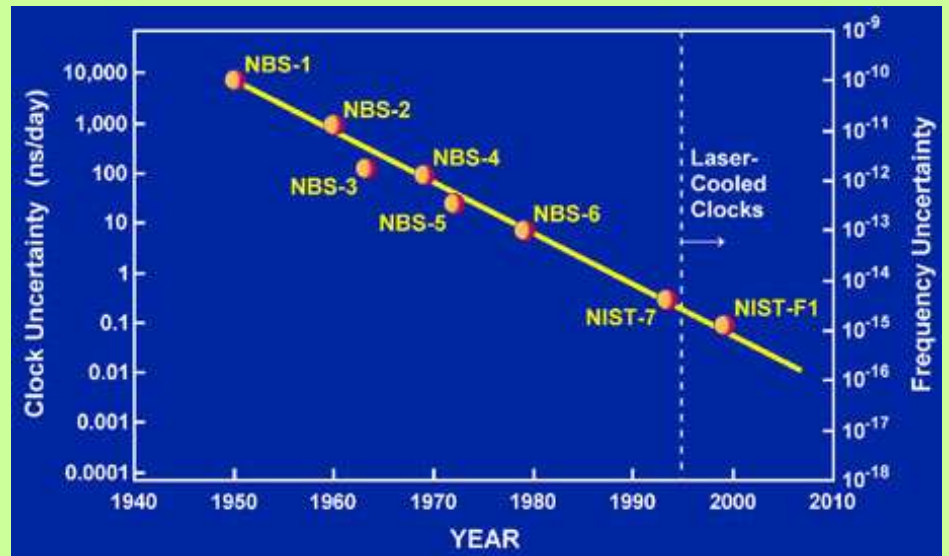
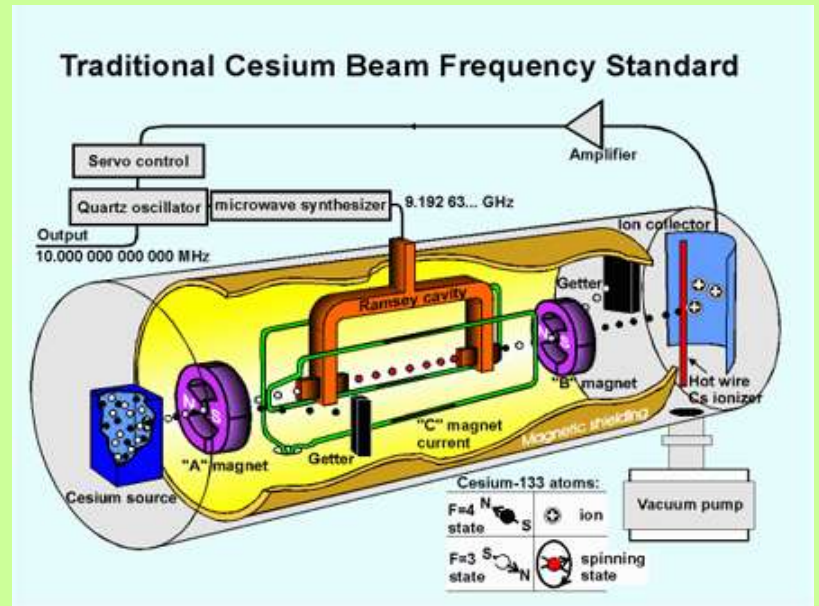


FIG. 2. Transition probability showing effect of finite length of oscillating field regions.

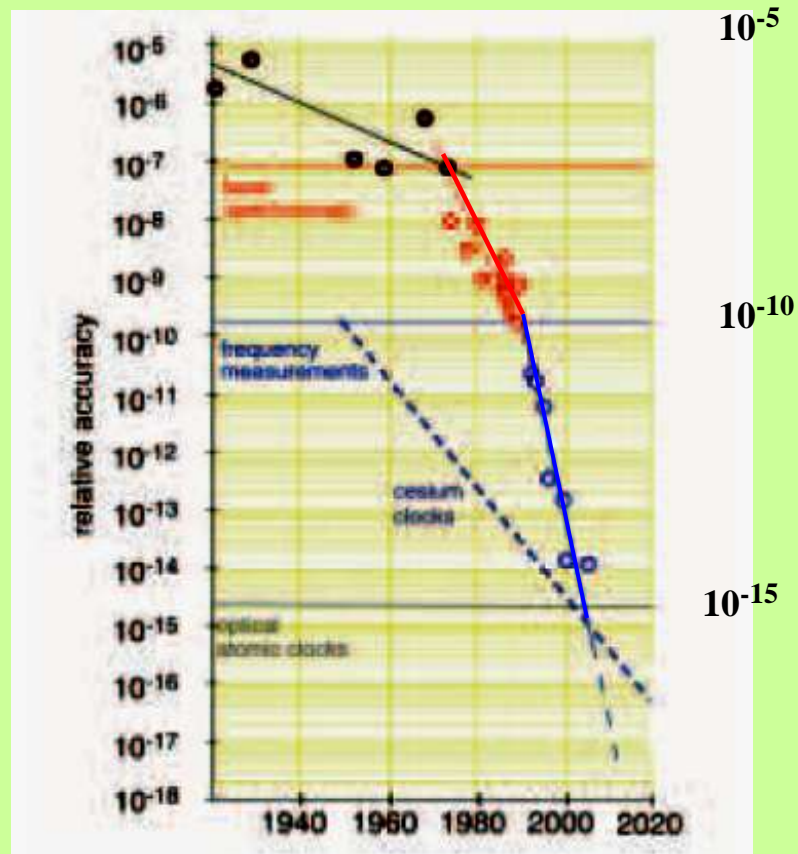
Led to the caesium clock and new def. of time 1967



NBS 1955:1sec/300y



METAS/Switzerland 2004:1sec/30 000 000y



Accuracy of the Rydberg constant
basis for next time standard?



Willis Lamb (1913-2008)

Nobel Prize 1955

"for his discoveries concerning the fine structure of the hydrogen spectrum"

Lamb shift 1947

PHYSICAL REVIEW

VOLUME 72, NUMBER 3

AUGUST 1, 1947

Fine Structure of the Hydrogen Atom by a Microwave Method* **

WILLIS E. LAMB, JR. AND ROBERT C. RETHERFORD

Columbia Radiation Laboratory, Department of Physics, Columbia University, New York, New York

(Received June 18, 1947)

$2s_{1/2}$ and $2p_{1/2}$ NOT degenerate

Bengt Edlén, Lund, observed in early 1930's significant deviation from Dirac theory in the fs for H-like ions.

Existence of the shift known for some time

The origin quite mysterious

Oppenheimer suggested it was of quantum-el. dyn. origin

Lamb thought it was of different origin

The Hyperfine Structure of Atomic Hydrogen and Deuterium†

J. E. NAFE, E. B. NELSON, AND I. I. RABI
Columbia University, New York, New York
May 19, 1947

**Hyperfine separations differ from theory by
0.26 and 0.31 %**

Well outside the limits of error

**Rabi suspected erroneous fine-structure
constant was used**

G. Breit, Phys. Rev. 72, 984 (1947)

Is the electron magn. mom. different from one Bohr magneton?

**Does the Electron Have an Intrinsic
Magnetic Moment?**

G. BREIT

Yale University, New Haven, Connecticut

September 29, 1947

THE hyperfine structure of the ground term of H^1 and H^2 is greater¹ than expected from nuclear magnetic moments by, respectively, 0.26 and 0.31 percent. The difference between these values is less certain than the approximate value 0.28 percent and will be assumed to be insignificant.² If the electron had a small, Pauli-type, intrinsic magnetic moment³ μ_e , the observed and calculated values would differ.



Gregory Breit (1899-1991)

Breit proposed deviation of order $\alpha \mu_B$

Expt'l verification of magn. mom. anomaly 1948

PHYSICAL REVIEW

VOLUME 74, NUMBER 3

AUGUST 1, 1948

The Magnetic Moment of the Electron†

P. KUSCH AND H. M. FOLEY

Department of Physics, Columbia University, New York, New York

(Received April 19, 1948)

A comparison of the g_J values of Ga in the $^2P_{3/2}$ and $^2P_{1/2}$ states, In in the $^2P_{1/2}$ state, and Na in the $^2S_{1/2}$ state has been made by a measurement of the frequencies of lines in the $h\nu$ spectra in a constant magnetic field. The ratios of the g_J values depart from the values obtained on the basis of the assumption that the electron spin gyromagnetic ratio is 2 and that the orbital electron gyromagnetic ratio is 1. Except for small residual effects, the results can be described by the statement that $g_L = 1$ and $g_S = 2(1.00119 \pm 0.00005)$. The possibility that the observed effects may be explained by perturbations is precluded by the consistency of the result as obtained by various comparisons and also on the basis of theoretical considerations.

$$\mu_S = 1.00119(5) \mu_B$$

These results are not in agreement with the recent suggestion by Breit⁶ as to the magnitude of the intrinsic moment of the electron.



Polykarp Kusch (1911-1993)

Nobel Prize 1955

"for his precision determination of the magnetic moment of the electron"

Influence of the war

MIT Radiation Laboratory

Established in Oct. 1940 by NDRC (National Defence Research Committee) for the purpose of **improving radar**

Lee DuBridge director, Rabi dep. director, dir. of research

”All research had to be useful”

RADAR (Radio Detection And Ranging)

**Developed in England around 1935,
10 m (30 MHz) 1939 1.5 m (600 MHz)**

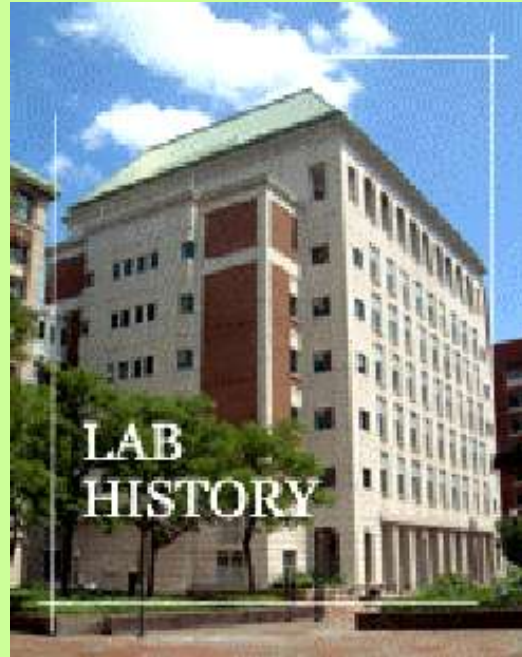
**Magnetron developed in England 1940
Could generate frequencies up to 3 GHz (10 cm)
Brought to USA in 1940**

Improved at Rad. Lab. to 10 GHz (3cm)

1940 \$0.5M 50 people

1945 \$40M 4000 people

Columbia Radiation Laboratory



Branch of MIT Rad. Lab.

**Established in 1942 under directorship of Isaac Rabi
Continued development of radar down to 1 cm**

Access to Radar had enormous impact on the war

Churchill: **"Battle of the Atlantic"**

Sinking of **"BISMARCK"** in May 1941 turning point



"Science changed the course of World History"

The work with radar during the war led to the development of **microwave spectroscopy, quantum-electrodynamics**

which led to the development of the MASER

which led to

” World History changed the course of Science ”

Shelter Island Conference 1947



Rebirth of Quantum-Electro-Dynamics (QED)



Lamb, Oppenheimer, Darrow, Weisskopf, Uhlenbeck, Kashak, Schwinger, Bohm

Pais, Feynman, Feshbach

Problems with QED

Basic theory Dirac, Pauli, Heisenberg late 1920's, Vacuum polarization

Serious divergencies Great despair

Heisenberg to Pauli 1935: "We know that everything is wrong"

Oppenheimer: Maybe **differences** are finite?

Charge renormalization Heisenberg, Weisskopf 1936

NOT ENOUGH

Electron self energy only log. divergent Weisskopf 1934

Mass renormalization Kramers, Weisskopf 1940 ...

Bethe showed 1947 that charge and mass renormalization works

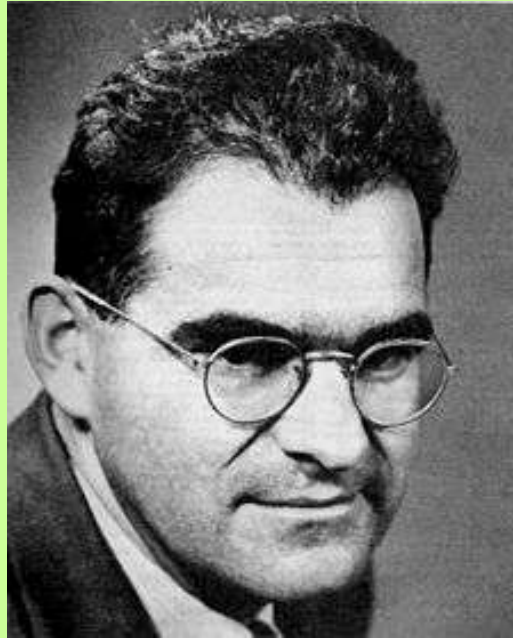
Non.rel. calc. of Lamb shift: 1040 MHz, Lamb: 1000 MHz (1057 MHz)



Hans Bethe (1906-2005)

99 years!

Nobel Prize 1967



Victor Weisskopf 1908-2002

Relativistic calc. of Lamb shift (w French) 1948



Julian Schwinger 1918-1994

Calculated 1948 the g-factor of the electron to be

$$g_s = 2(1 + \alpha/2\pi + \dots) = 2 \times 1.00116\dots$$

Kusch-Foley: $g_s = 2 \times 1.00119(5)$

Dyson showed 1949 that the formulations of Feynman and Schwinger were equivalent

Also showed that charge and mass renormalization removes the singularities **to all orders of perturbation theory**



Freeman Dyson 1923-

Nobel Prize 1965

"for their fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles"



Sin-Itiro Tomonaga
1906-1997



Julian Schwinger
1918-1994



Richard P. Feynman
1918-1988



Robert Oppenheimer (1904-1967)

Enrico-Fermi award 1963

”Father of the atomic bomb”

Born-Oppenheimer

QED

Two-meson theory (Marshak)

Black holes (Chandrasekhar NP 1983)

1947 Dir. Princeton Inst. Adv. Study

1946 Chairm. Advisor Comm. AEC

1954 removed (McCarthy, Teller)

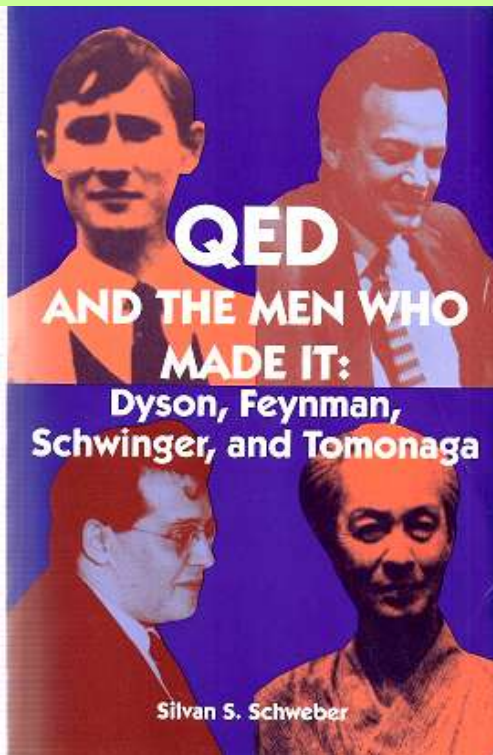
Argued against Hiroshima, Nagasaki

Strongly against H-bomb

**Bhagavad Gita: ”Now I am become
Death, the destroyer of the world”**



**J.Schweber: QED and the men who made it:
Dyson, Feynman, Schwinger, and Tomonaga
(Princeton Univ. Press 1994)**

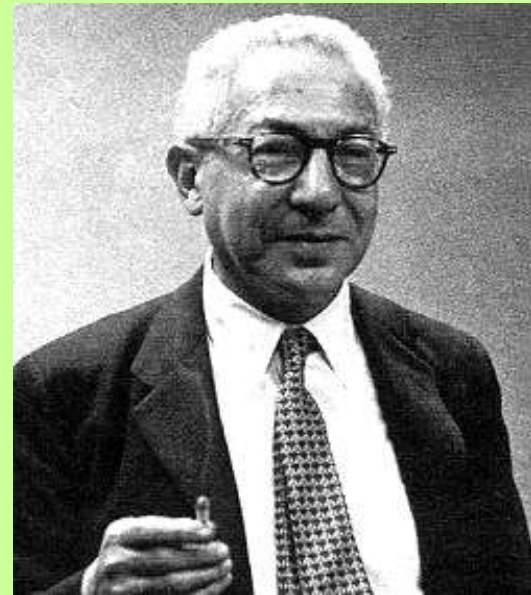


**Charles Thorpe:
Oppenheimer, The tragic
intellect (Univ. Chicago 2006)**



Since the mid 1930's nuclear and particle physics considered as the font lines of physics

The experiments of Rabi and his team shifted the focus to a large extent towards atomic physics and QED



New optical resonance methods invented 1949-50

Optical pumping, Optical double resonance



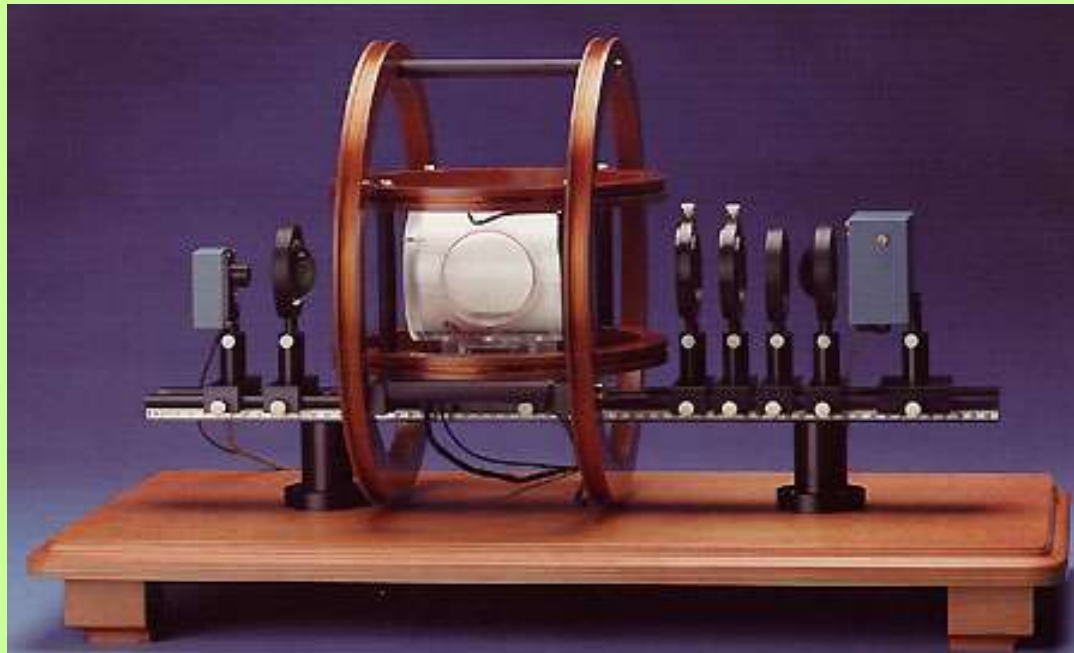
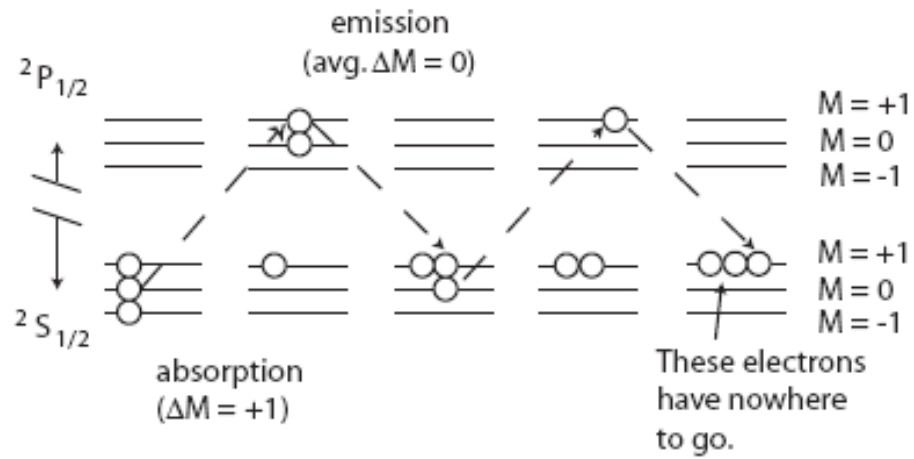
Alfred Kastler 1902-1984

Nobel Prize 1966



Jean Brossel 1918-2003

"for the discovery and development of optical methods for studying Hertzian resonances in atoms"



Rabi's A and B magnets replaced by optical light

Hans Kopfermann's optical laboratory

Philosophenweg, Heidelberg

**Andreas Steudel, Herbert Walther, Hans Bucka,
Sigfried Penselin, Gisbert zu Putlitz, Ernst Otten**

Leading optical institute at the time

Started early work with optical resonance methods



Brookhaven Conferences on Molecular Beams

arranged by Bill Cohen from 1955

every or every-second year

Atomic/molecular beams was the **HOT topic at the time**

Joe Hamilton's Atomic-Beam Laboratory, Princeton

THE REVIEW OF SCIENTIFIC INSTRUMENTS

VOLUME 26, NUMBER 12

DECEMBER, 1955

Focusing Atomic Beam Apparatus*

AARON LEMONICK,[†] FRANCIS M. PIPKIN,[‡] AND DONALD R. HAMILTON
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey

(Received August 16, 1955)

1955

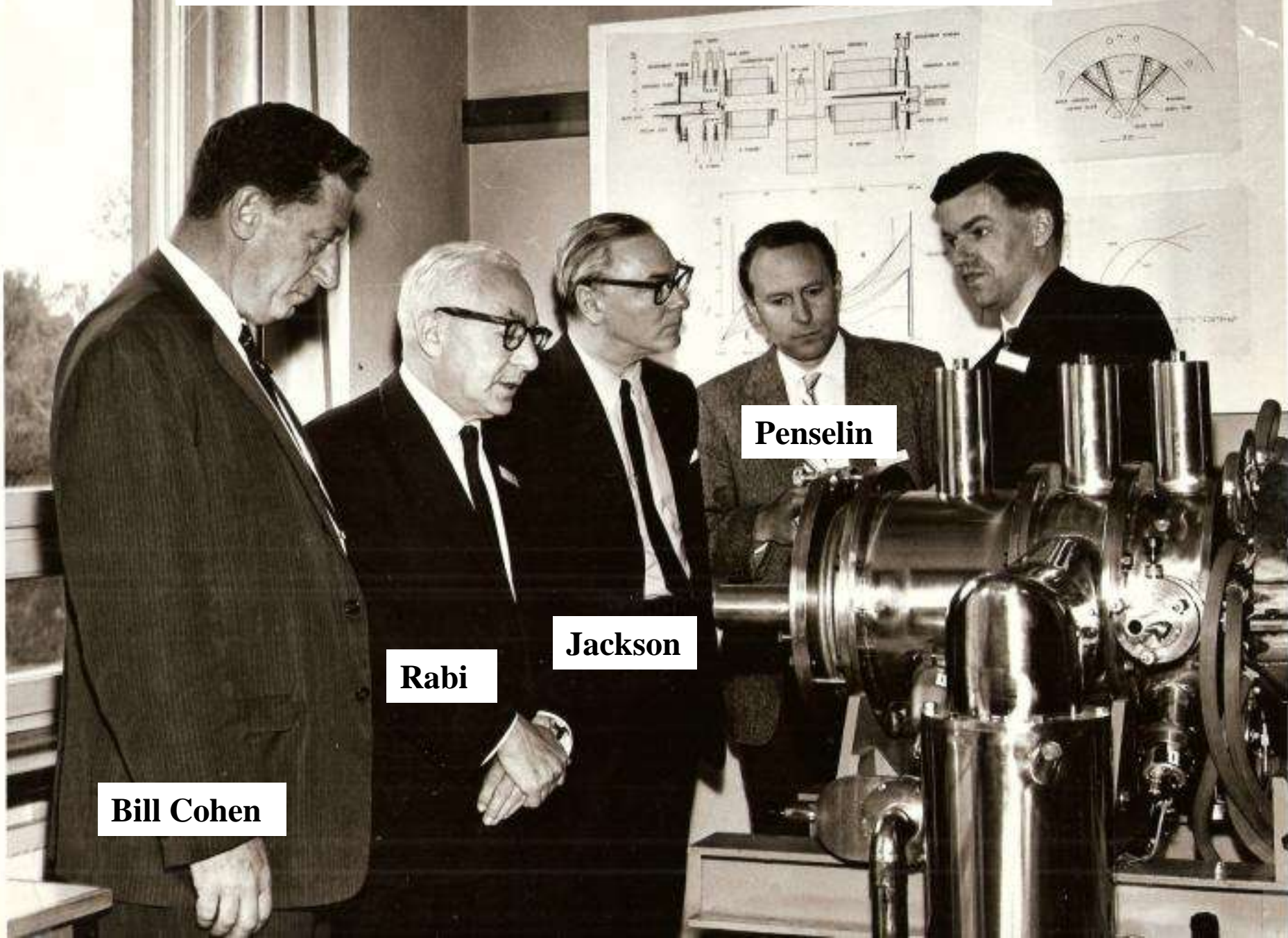
The construction and design principles of a focusing atomic beam apparatus are reported. This apparatus, which is of the radio-frequency magnetic resonance type and which has been used to measure the spins and hyperfine splittings of four radioactive nuclides as reported elsewhere, utilizes the six-pole focusing magnet of Friedburg and Paul and of Korsunskii and Fogel but in a way which avoids velocity aberrations. From an analysis of the optimization of intensities in the conventional and the focusing types of atomic beam apparatus it is concluded that the latter has an advantage of a factor of roughly twenty-five.

Francis Pipkin, Henry Stroke, Will Happer

1964 Brookhaven conference in Uppsala

Broadened scope to include optical resonance

"Brookhaven Conference" in Uppsala 1964



Bill Cohen

Rabi

Jackson

Penselin

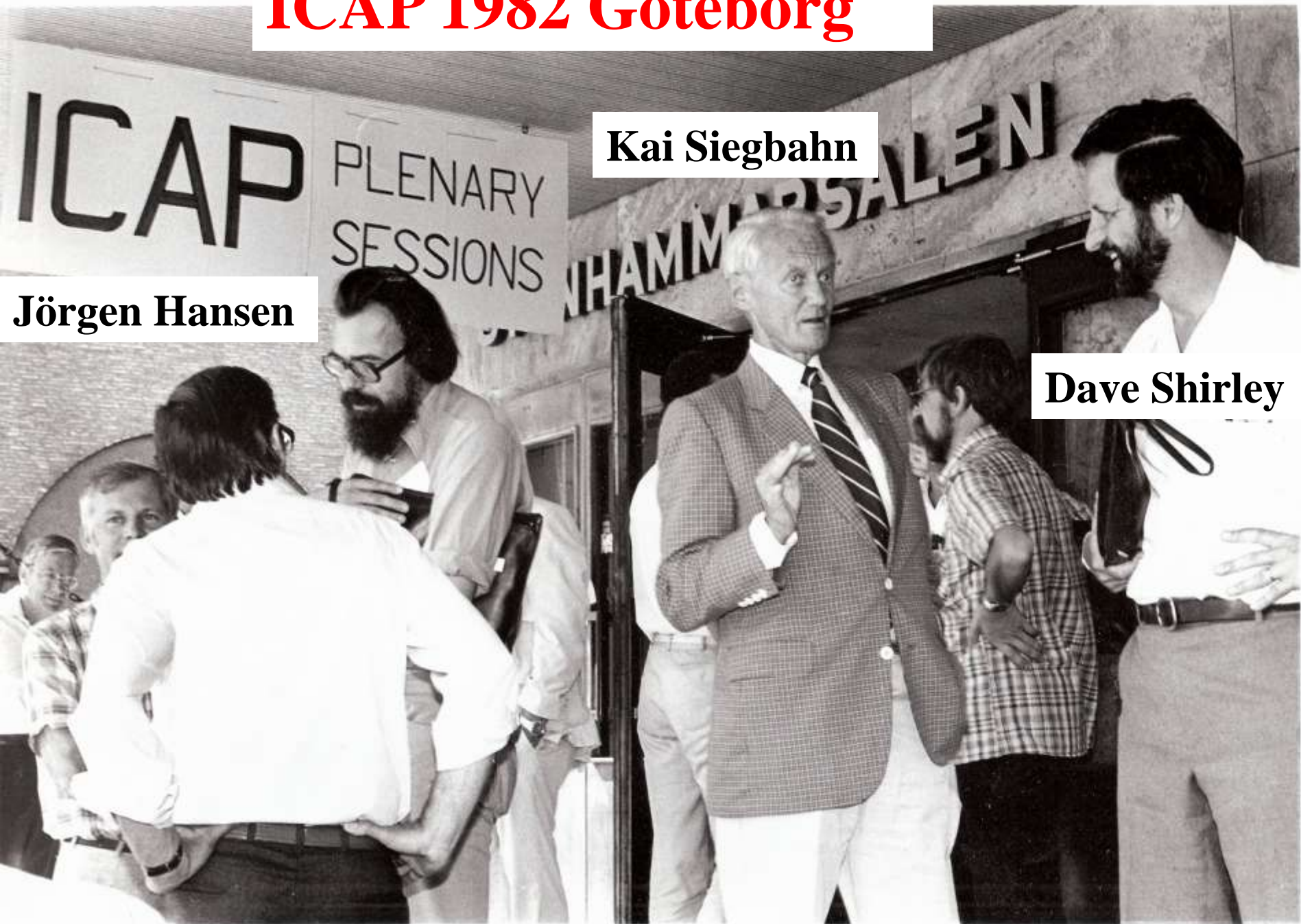
Brookhaven Atomic-Beam Conference was in 1968

converted to

International Conference on Atomic Physics

ICAP

ICAP 1982 Göteborg



Kai Siegbahn

Dave Shirley

Jörgen Hansen



Isaac Rabi Guest of honor







Five Nobel laureates at ICAP 8 in Göteborg 1982



Art Schawlow 1981

Kai Siegbahn 1981

**Aleksandr
Prokhorov 1964**

Isaac Rabi 1944

**Nicolas
Bloembergen 1981**

Three more laureates to be



von Klitzing 1985



Ramsey 1989



Ted Hänsch 2005

Local activity

**1966 Ingvar moves from Uppsala
with Arne Rosén to Gothenburg**

**Upon recom. by Ingvar Marklund
we recruited Sune, Curt Ekström,
Håkan Nykvist**

**Arne, Curt and Håkan work
with atomic beams**

**Sune start to study optical
resonance methods**

Went 1967 to Bucka in Berlin

**Then start to set up an optical
resonance group in Gothenburg**

Sune post.doc. with Will. Happer at Columbia 1972-73



First tunable dye laser comm. available 1972



Sune responsible for the first dye-laser equipment at Columbia

After returning home starts to set up a laser lab in Gothenburg

**In 1980 Sune moves to Lund
to start **Lund Laser Center****

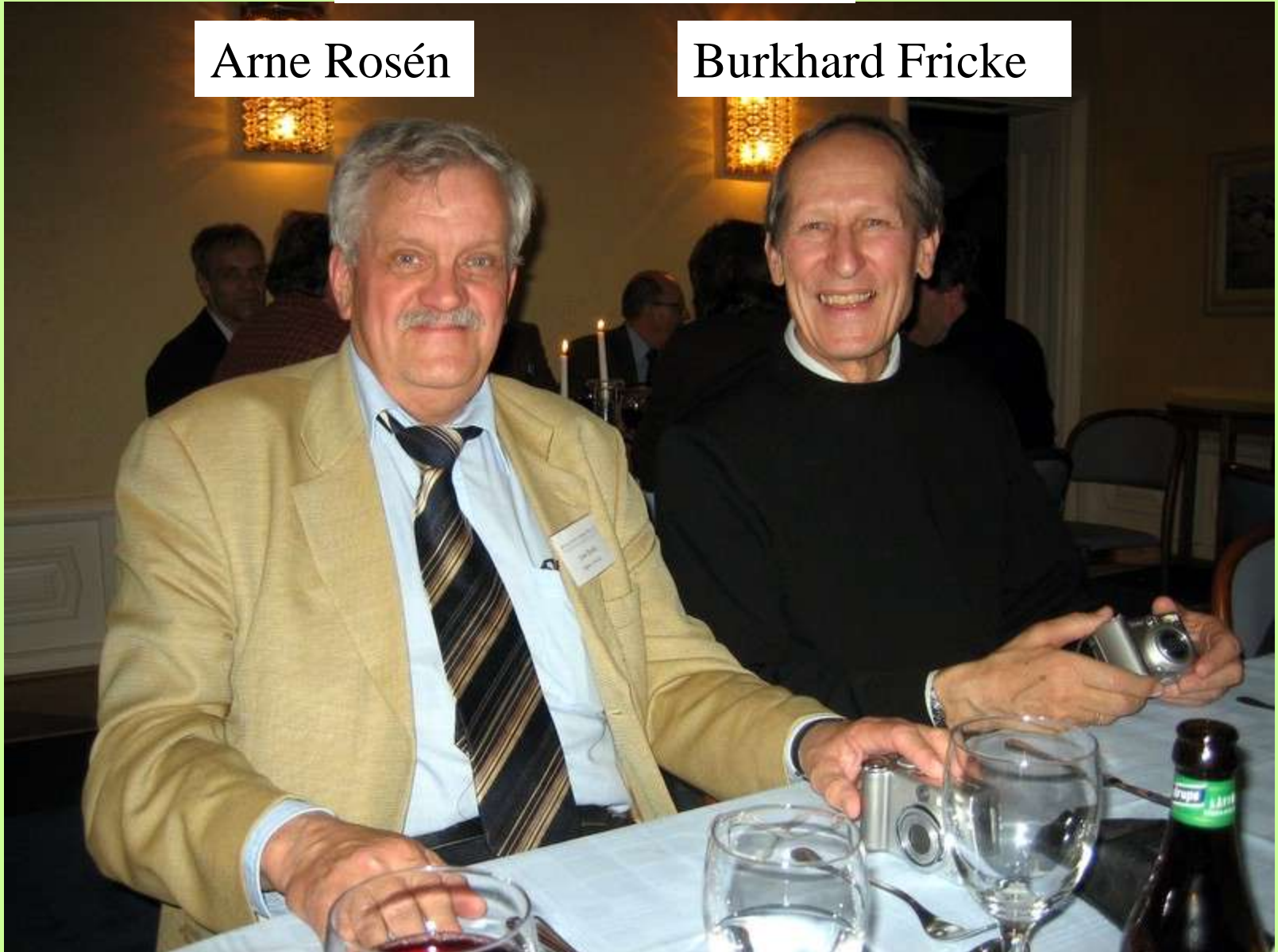


End of prehistory

Gothenburg 2006

Arne Rosén

Burkhard Fricke



Gothenburg 2006

Curt Ekström

Wim Hogervorst



Gothenburg 2006

Norman Ramsey

Dan Kleppner

Eleanor Campbell



Gothenburg 2006

Jan-Eric Sundgren
Chalmers' president



Thank you, Sune !

Happy retirement !