Innovation Was Not Enough; The History of the Midwestern Universities Research Association

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This talk is a summary of material in a book (of the same title) by 5 of us MURA alumni, which is being published by World Scientific. My co-authors are:

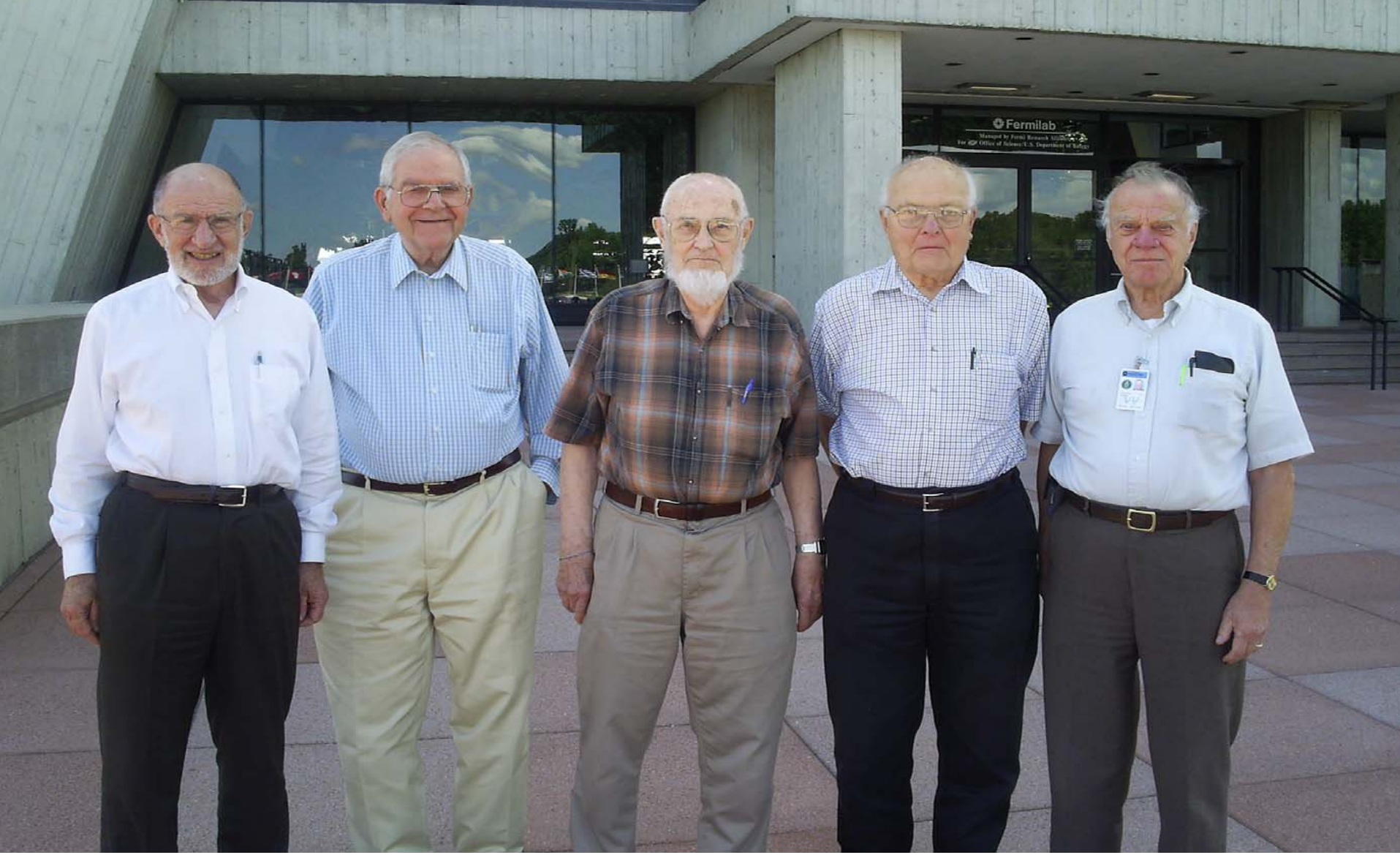
Fred Mills (Fermilab)

Andy Sessler (LBNL)

Keith Symon (Univ. of Wisconsin)

Don Young (Fermilab)

(We are all technically “retired”, of course.)



Andy Sessler

Fred Mills

Keith Symon

Don Young

Larry Jones

Some History

- In late 1952, the Brookhaven Cosmotron was completed, the Bevatron was under construction, and Strong Focusing (alternating-gradient) had just been invented.
- At a Cosmotron dedication event, Samuel Allison (Chicago) and P. Gerald Kruger (Illinois) suggested that Midwestern scientists should convene to consider ways of providing a high energy accelerator facility in the Midwest, and to educate the Midwestern physics community in the new alternating gradient concept, etc.

- A meeting was held in Chicago in April, 1953; a large group of Midwestern physicists were present, including E. Fermi (and me); speakers included Ernest Courant and John Blewett (BNL), and Bob Wilson (Cornell).
- The senior Midwestern physicists formed a formal organization, the Midwest Accelerator Conference (MAC) and decided to establish a study group, headed by Don Kerst. This study group of mostly younger physicists met in July at Brookhaven to continue their education; and indeed, the 10 of us had a very interesting 2 week visit to Brookhaven. The group, somewhat larger, and with occasional visitors, subsequently met for the month of August in Madison, where these studies continued.

(Standing, L-R) N. Francis, L.W. Jones, K. Terwilliger, C. Wright, R. Rollefson, F. Rohrlich, F. Cole, D. Kerst; (Seated L-R) L.J. Laslett, W.K.H. Panofsky, R. Hofstader, L. Johnston (in chair), E. Courant, J.

- During the 1953-’54 academic year, Kerst convened weekend meetings almost every month at different Midwestern universities, continuing the discussions of strong focusing, new accelerator ideas and possibilities, etc.
- A second, longer workshop was held at the University of Wisconsin in the summer of 1954; it was there that Keith Symon conceived of the FFAG (Fixed Field Alternating Gradient) concept.
- Kerst decided to continue a more intensive study program in the fall of 1954; a group convened in Ann Arbor every week for 2 – 3 days during this period. Kerst and Laslett came via overnight trains. It was during this period that Kerst originated the spiral sector FFAG focusing idea.

Michigan study group; L. Jackson Laslett, Dick Crane, Don Kerst, Kent Terwilliger, Keith Symon, &Larry

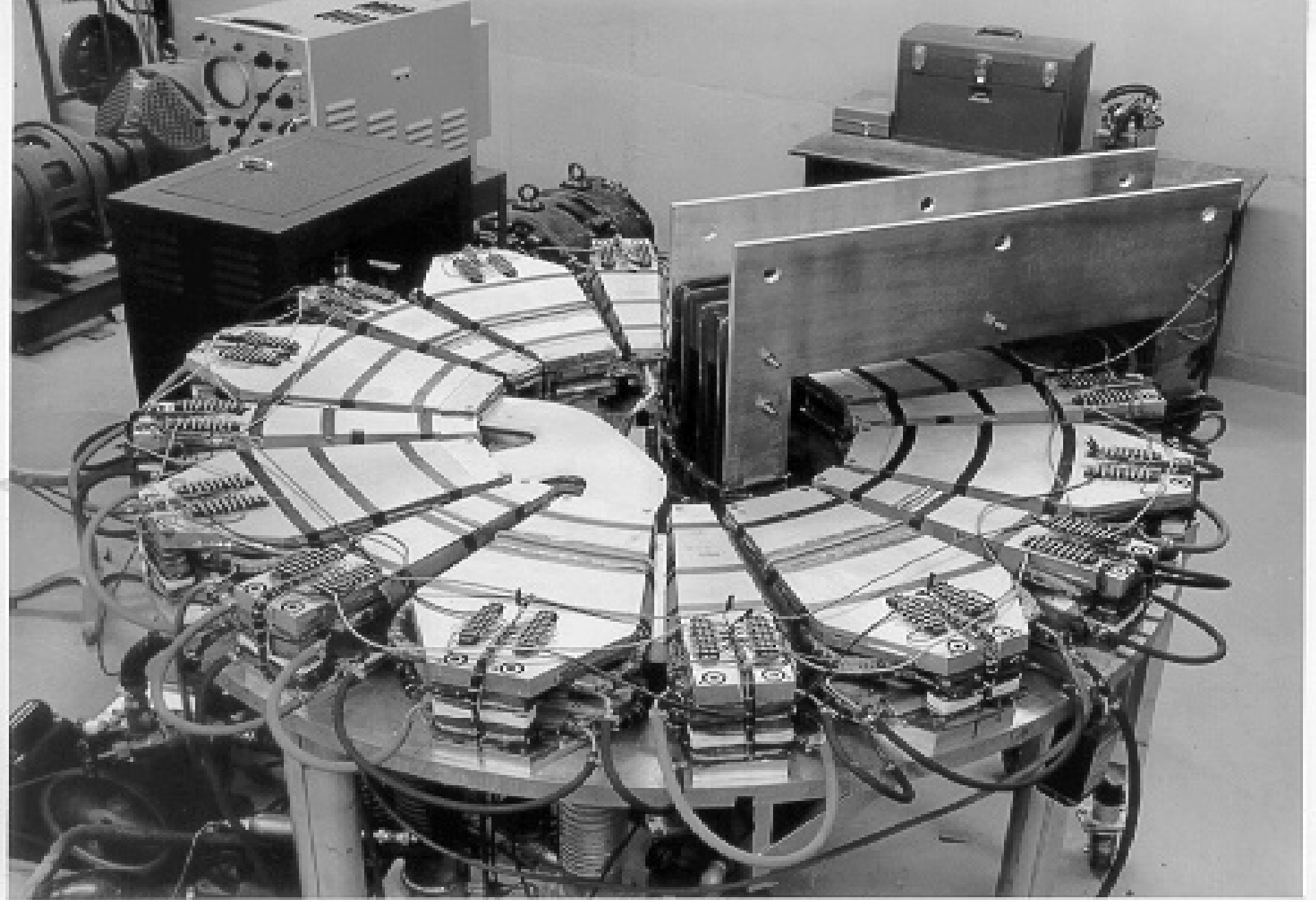
In the fall of 1954, the Organizing Committee of senior Midwestern Accelerator Conference (MAC) physicists formed the Midwestern Universities Research Association (MURA), a State of Illinois corporation.

- At the end of 1954, the design of a Radial Sector electron model accelerator was begun, the accelerator to be built at Michigan, and its magnets to be built at Purdue by Bob Haxby and Ed Rowe.
- Kerst established a full-time working group at Illinois, beginning in 1955. Frank Cole, Jim Snyder, and others formed an energetic group there, studying various aspects of the FFAG idea. Cole completed the design of the Radial Sector Model, while Jones and Terwilliger worked at Michigan on its construction. The larger group still held weekend meetings almost monthly.
- During the summer of 1955, the Working Group moved to the University of Michigan; Andy Sessler, Tihiro Ohkawa, Nils Vogt-Nilsen and others joined the group then, as well as summer visitors – including Ernest Courant, Dave Judd, Felix Adler, and Otto Frisch.

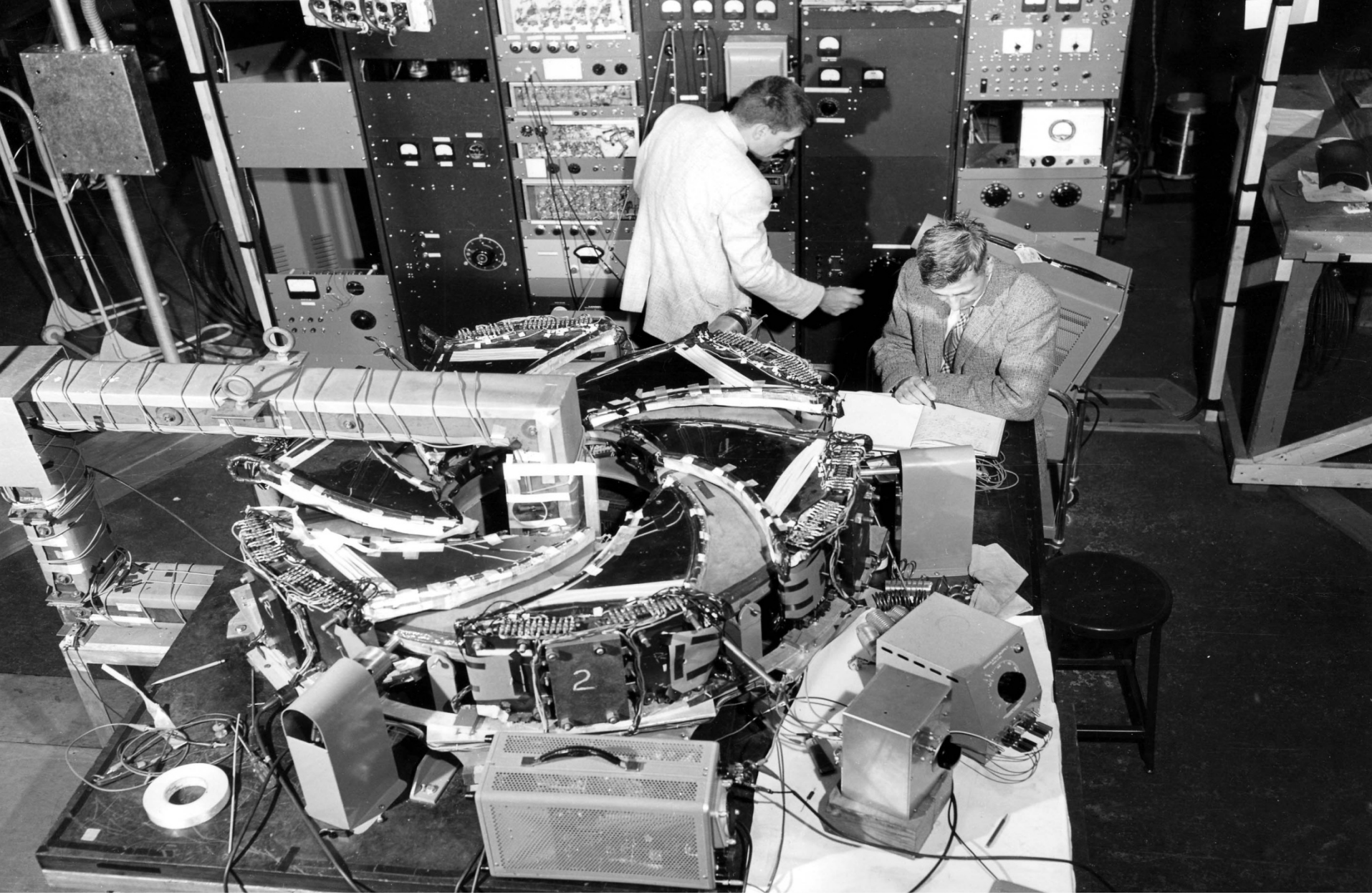
1955 Michigan MURA Summer Study; Ernest Courant, Tihiro Ohkawa,
Otto Frisch, and Dave Judd by the Radial Sector Model (under construction)

- During the time between the Michigan summer study and reconvening the working group in Urbana, Kerst conceived of the colliding beam idea, and much of the work at Illinois the following months was devoted to understanding the rf and other complexities of beam stacking and colliding beams.
- Work also began on the design and construction, at Illinois, of a Spiral Sector electron model, as work on the Radial Sector Model at Michigan and at Purdue continued.
- Monthly meetings continued at Illinois and on other Midwestern university campuses. At the meeting in Indiana in February 1956, Lichtenberg, Newton, and Ross (Indiana University physicists) proposed the storage ring idea for achieving colliding beams. This was proposed independently by Gerry O'Neill (Princeton) later that spring.

- In March, 1956 the first electron beam was successfully accelerated in the Radial Sector Model – using betatron acceleration.
- The MURA working group moved to Madison in the summer of 1956, including moving the completed Radial Sector Model there as well as the under-construction Spiral Sector Model. An rf acceleration system was added to the Radial Sector Model, and extensive studies of rf acceleration, phase displacement, and beam stacking were carried out, in addition to further studies of the betatron oscillation tune and stability.
- The operating Spiral Sector Model, completed in 1957 by Mills, Wallenmeyer, Peterson, and others, enabled more extensive studies of betatron oscillations and radio frequency acceleration, including space charge effects, etc.

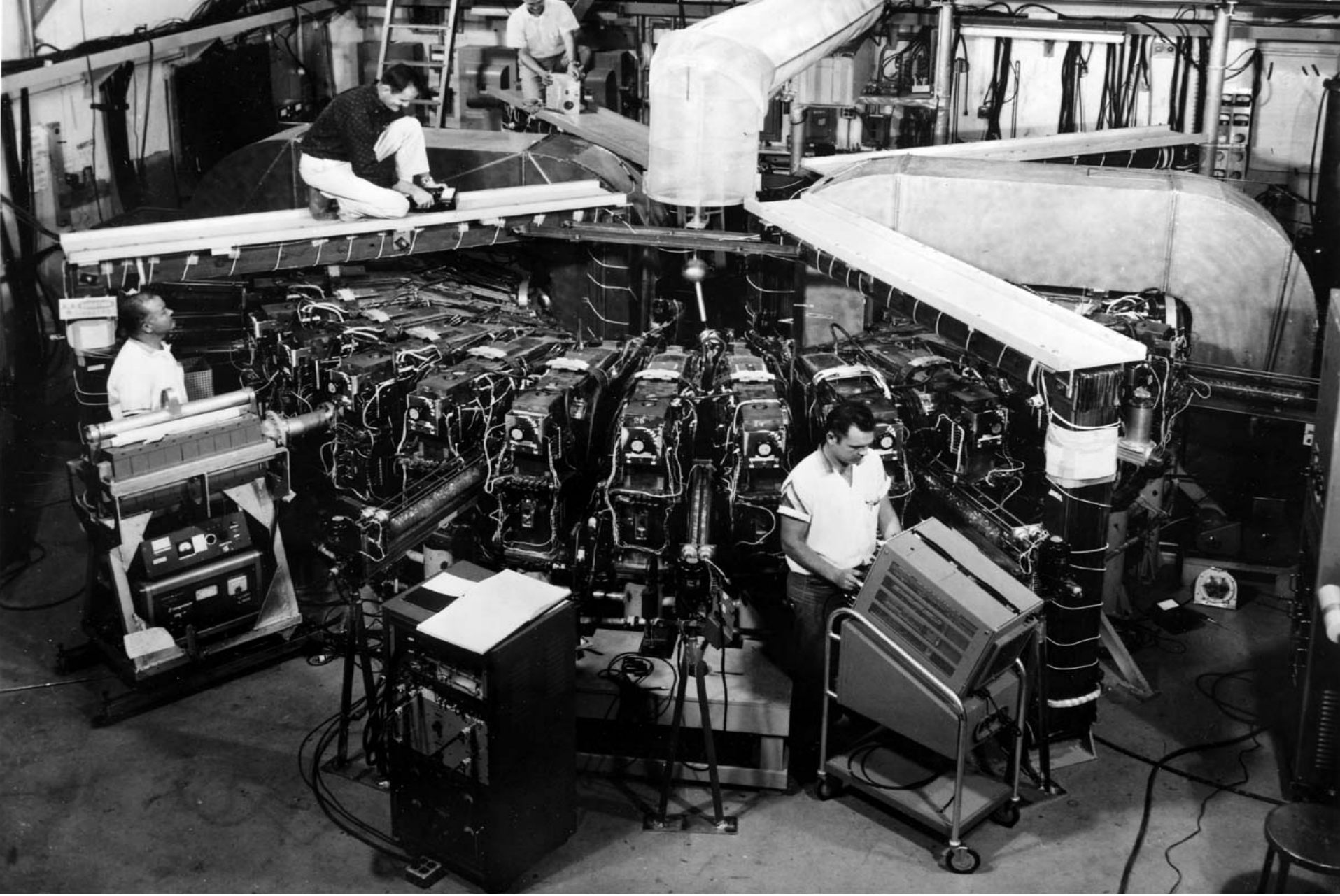


The Michigan Radial Sector FFAG Model; ~500 KeV electron accelerator



The Illinois, Spiral Sector FFAG Model, 180 keV electron accelerator at Madison; completed in 1957

- Kerst's original idea for a colliding beam machine was for two tangent FFAG machines sharing a common straight section, in which the beams would collide. In 1958, Ohkawa had the idea for a two-way FFAG accelerator-colliding beam machine; a Radial Sector FFAG accelerator with a ring of alternating polarity identical magnets with radial gradients which provided a.g. focusing and stable equilibrium orbits for protons orbiting both clockwise and counterclockwise.
- In Madison, the MURA group decided to build a 50 MeV FFAG electron accelerator based on this design; it was constructed and completed in the early 1960s, and again provided a facility for excellent studies and tests of many rf acceleration, space charge effects, and other accelerator questions, although in fact it was never operated in the 2-way mode.



The Ohkawa 2-way FFAG 50 MeV electron accelerator

Computing

At the University of Illinois, in 1954 – 1956, the Illiac was one of the most advanced computers. The MURA physicists were among the first accelerator physicists to make extensive use of digital computations. At the MURA lab in Madison, an IBM 704 was used extensively, both for orbit dynamics (betatron oscillations and rf studies) and later for magnet and rf cavity (for linacs) designs. Jim Snyder, Stan Snowdon, and Dick Christian were among the physicists who excelled in the relevant accelerator design calculations.

RF Theory

Symon and Sessler pioneered the development of the sophisticated Hamiltonian theory of rf acceleration, including the detailed physics of beam stacking and phase displacement – critical for colliding beams.

Non-linear Orbit Dynamics

FFAG machines have a magnetic field which varies as r^k, so the field gradient is not constant and hence the betatron oscillations are intrinsically non-linear. And for colliding beams, the stacked beam must be stable for a long period. Therefore it was important for the MURA group to make extensive studies of orbit dynamics.

Visitors

Of course, the group had occasional significant visitors to our laboratory in Madison.

1958 visit to MURA lab; L-R: Bob Haxby, Ragner Rollefson, Harrison Randall, Subramanyan Chandrasekhar, Niels Bohr, Charles Pruett, and Larry Jones

1959 Summer Study

In the summer of 1959, a very productive study was held at the Madison MURA laboratory. One of the most significant results of this study was the discussion by Matt Sands (Cal Tech) of sequential – stacked – synchrotrons. With modern technology, it had become practical to extract a beam from a synchrotron with preservation of the phase space density (beam quality), and inject it into another synchrotron, hence to achieve high energies by a sequence of accelerators of successively higher energies. This was also very relevant for the achievement of colliding beams with storage rings, with the necessary transfer of the beams from an accelerator to the storage rings.

International meetings

The FFAG ideas and results were presented at the 1956 and 1959 international conferences in Geneva (CERN), in 1963 and 1964 at the Dubna (USSR) international conferences, in 1965 at the Rome (Italy) International Accelerator Conference, and subsequently at meetings around the world. In 1963, Budker invited a few of us from MURA to visit Novosibirsk following the Dubna meeting; we were among the first Westerners to have this opportunity.

The MURA representatives were very well received by the international community; our ideas and achievements were welcomed, and we thoroughly enjoyed making international friends.

Proposals

Between 1955 and 1963, MURA submitted proposals to the AEC for the construction of FFAG proton accelerators:

- 1955 A 20 GeV spiral sector FFAG accelerator .
- 1956 2 tangent 15 GeV spiral sector accelerators/colliding beam facility.
- 1958 A 2-way (Ohkawa) 15 GeV colliding beams accelerator facility.
- 1962 A single 10 GeV spiral sector high intensity accelerator.
- 1962 (revised) A 12.5 GeV spiral sector high intensity accelerator.

Government Advisory Panels

During this period, the government frequently convened panels to advise the AEC, etc. on future accelerator programs, etc.

- 1954, Bacher Panel: Generally supportive.
- 1956 Haworth Panel: Recognized MURA and the need for a Midwest H.E. accelerator.
- 1958, Haworth Panel Supplement.
- 1958, Piore Panel: "No need for E>~30 GeV".
- 1959, Piore Panel, second report.
- 1963, Ramsey Panel: Supported the Berkeley 200 GeV proposal as 1st priority, and supported a high intensity MURA 12.5 GeV FFAG as second, later priority.

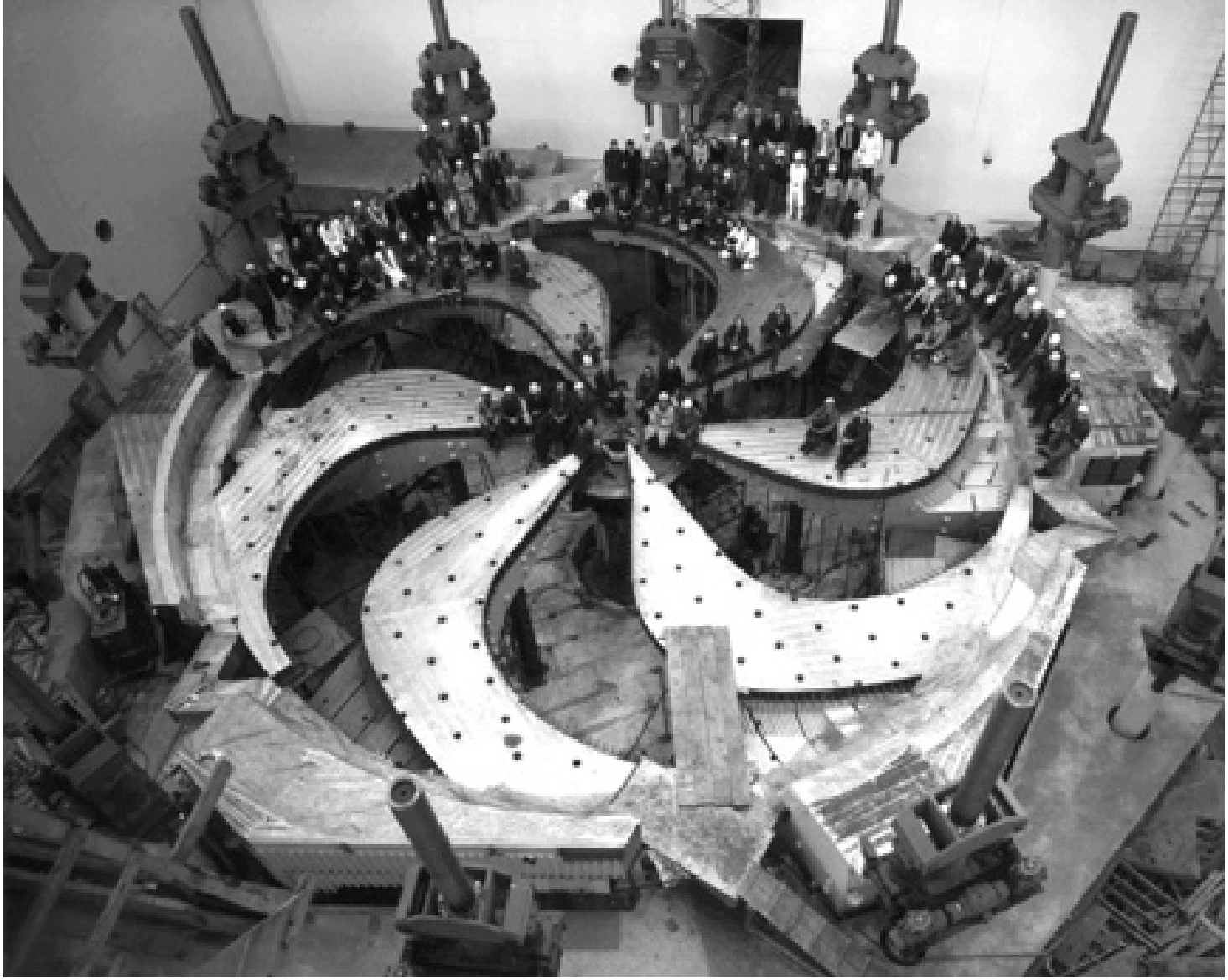
The End of MURA

In early 1964, a group of senior MURA physicists plus some Midwestern members of Congress arranged a meeting with President Lyndon Johnson. The President told them that the MURA proposal was being turned down; the first priority was the 200 GeV facility, and the constrained budget could not accommodate another major accelerator program.

Although the MURA organization continued for a couple more years, this was – in effect – the end of the MURA hope of building a major high-energy research accelerator in the Midwest. Following this 1964 decision, the group of MURA physicists began to disperse to other organizations and activities.

Some of MURA's accomplishments

- Invention of FFAG accelerators.
- Construction and successful operation of 3 electron FFAG accelerators and the detailed study of the betatron and synchrotron orbit dynamics with these models.
- Development of practical means of achieving colliding beams.
- Longitudinal manipulation of particles for beam stacking.
- Transverse stacking, for multiturn injection, etc.
- The understanding of non-linear forces and betatron oscillations.
- Many-body static and dynamic effects; space charge-induced tune shifts, wakefields, head-tail instabilities, "negative mass" instabilities, etc.
- Digital computer-aided 3-dimensional magnet design.
- Digital computer-aided design of proton linear accelerator rf systems.

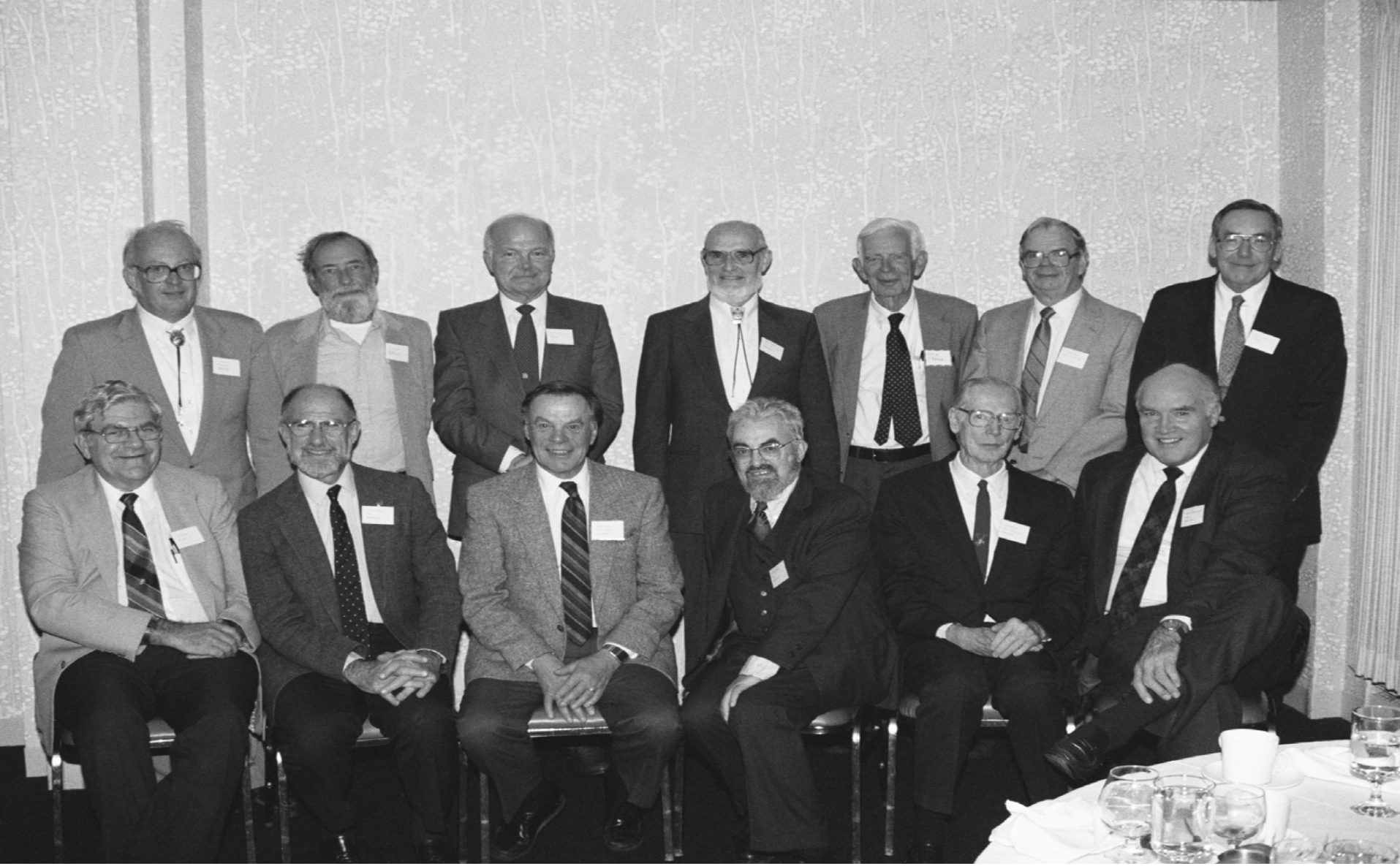


The TRIUMF FFAG spiral sector cyclotron [520 MeV H^- ions] at the University of British Columbia in Vancouver, Canada

POST-MURA, PHYSICAL SCIENCES LAB ACTIVITIES

The terminal MURA group, and the subsequent Physical Sciences Lab of the University of Wisconsin (which replaced it, and retained much of its staff) also produced much physics; e.g.:

- The first dedicated synchrotron light source facility, Aladdin, was built by Mills and Rowe, a 240 MeV electron storage ring with the 50 MeV Model as an injector.
- A productive cosmic ray program (in Colorado, on Mt. Evans and at Echo Lake) was undertaken by Mills and others from P.S.L., together with Larry Jones, Don Reeder, and Bruce Cork.
- Magnets and linear accelerators were designed, modeled, and engineered for Fermilab and other research facilities.
- A 30” hydrogen bubble chamber was built for the ZGS.
- Significant assistance to the Argonne staff in improving the operation of their 12.5 GeV ZGS.
- Very productive MURA staff later moved to LBNL (Sessler, Laslett), FNAL (Cole, Young, Mills), the AEC/DOE (Wallenmeyer, Laslett), etc.
- Kerst and Ohkawa moved into fusion energy research.



MURA alumni, 1989; rear, L-R: D. Swenson, E. Rowe, D. Young, K. Symon, H.R. Crane, C. Pruett, and F. Cole; front, L-R: F. Mills, A. Sessler, L. Jones, E. Courant, D. Kerst, and W. Wallenmeyer.

Reflections

The MURA group certainly made many contributions to accelerator physics, to the understanding of the particle dynamics in accelerators, the concepts of FFAG and colliding beams, the computer-aided designs of accelerator components, the experimental demonstrations with electron models, etc. etc.

MURA failed to achieve its goal of building a major accelerator. Perhaps MURA should have had a national advisory panel/review committee that might have made its proposals more compelling. However the members of the MURA group went on to very successful careers, and we all look back on our MURA experiences with great affection.

We remember Frank Cole's likening of MURA to Camelot; those of us involved indeed remember it as being exactly that way!