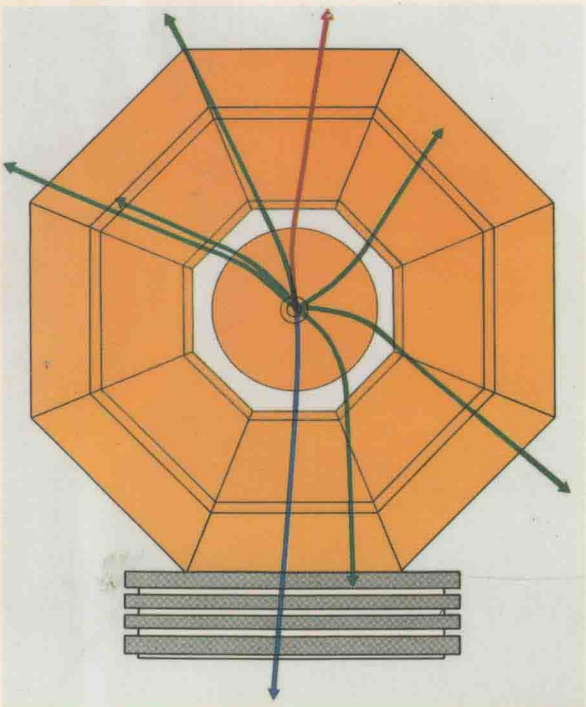
PHYSICS THROUGH THE 1990s



Elementary-Particle Physics

PHYSICS THROUGH THE 1990s

Elementary-Particle Physics

Elementary-Particle Physics Panel

Physics Survey Committee

Board on Physics and Astronomy

Commission on Physical Sciences, Mathematics, and Resources

National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1986

NATIONAL ACADEMY PRESS 2101 Constitution Avenue, NW Washington, DC 20418

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self- governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Board on Physics and Astronomy is pleased to acknowledge generous support for the Physics Survey from the Department of Energy, the National Science Foundation, the Department of Defense, the National Aeronautics and Space Administration, the Department of Commerce, the American Physical Society, Coherent (Laser Products Division), General Electric Company, General Motors Foundation, and International Business Machines Corporation.

Library of Congress Cataloging in Publication Data

National Research Council (U.S.). Elementary-
Particle Physics Panel.
Elementary-particle physics.

(Physics through the 1990s)
Bibliography: p.
Includes index.
1. Particles (Nuclear physics)—Congresses.
2. National Research Council (U.S.). Elementary-
Particle Physics Panel—Congresses. I. Title.
II. Series.
QC793.N36 1985 539.7'2 85-15210
ISBN 0-309-03576-7

Printed in the United States of America

First Printing, April 1986
Second Printing, October 1986

PANEL ON ELEMENTARY-PARTICLE PHYSICS

MARTIN L. PERL, Stanford Linear Accelerator Center, *Chairman*
CHARLES BALTAY, Columbia University
MARTIN BREIDENBACH, Stanford Linear Accelerator Center
GERALD FEINBERG, Columbia University
HOWARD A. GORDON, Brookhaven National Laboratory
LAWRENCE W. JONES, University of Michigan
BOYCE D. MCDANIEL, Cornell University
FRANK S. MERRITT, The University of Chicago
ROBERT B. PALMER, Brookhaven National Laboratory
JAMES M. PATERSON, Stanford Linear Accelerator Center
JOHN PEOPLES, JR., Fermi National Accelerator Laboratory
CHRIS QUIGG, Fermi National Accelerator Laboratory
DAVID M. RITSON, Stanford University
DAVID N. SCHRAMM, The University of Chicago
A. J. STEWART SMITH, Princeton University
MARK W. STROVINK, University of California, Berkeley

DONALD C. SHAPERO, National Research Council, *Executive Secretary*

Liaison Members

D. BERLEY, National Science Foundation, Liaison for National Science Foundation
L. S. BROWN, University of Washington, Liaison for Division of Particles and Fields, American Physical Society
W. A. WALLENMEYER, Department of Energy, Liaison for Department of Energy

Panel Editor

W. T. KIRK, Stanford Linear Accelerator Center

PHYSICS SURVEY COMMITTEE

BOARD ON PHYSICS AND ASTRONOMY

HANS FRAUENFELDER, University of Illinois, *Chairman*
FELIX H. BOEHM, California Institute of Technology
RICHARD G. BREWER, IBM San Jose Research Laboratory
DEAN E. EASTMAN, IBM T.J. Watson Research Center
JAMES E. GUNN, Princeton University
LEO P. KADANOFF, The University of Chicago
W. CARL LINEBERGER, University of Colorado
NORMAN F. RAMSEY, Harvard University
MORTON S. ROBERTS, National Radio Astronomy Observatory
MARSHALL N. ROSENBLUTH, University of Texas at Austin
WILLIAM P. SLICHTER, AT&T Bell Laboratories
SAM B. TREIMAN, Princeton University

DONALD C. SHAPERO, *Staff Director*
ROBERT L. RIEMER, *Staff Officer*
HELENE PATTERSON, *Staff Assistant*
SUSAN WYATT, *Staff Assistant*

Preface

This report on elementary-particle physics is part of an overall survey of physics carried out for the National Academy of Sciences by the National Research Council. The panel that wrote this report had three goals. The first goal was to explain the nature of elementary-particle physics and to describe how research is carried out in this field. The second goal was to summarize our present knowledge of the elementary particles and the fundamental forces. The third goal was to consider the future course of elementary-particle physics research and to propose a program for this research in the United States.

It is the hope and intention of the panel that this volume will be read and found useful outside the physics community. Therefore the text does not assume that the reader has any special knowledge of mathematics or of physics beyond an acquaintance with general notions such as mass and energy. Nor do we assume that the reader has any previous knowledge of the techniques of elementary-particle physics research, namely, accelerators and particle detectors. Indeed we have presented basic introductions to these techniques.

In the last two decades there has been a revolution in our knowledge of elementary-particle physics. We have identified three types of elementary particles—the quarks, the leptons, and the force-carrying particles; we have learned a great deal more about three of the fundamental forces; and the weak force and electromagnetic force have been unified in a beautiful and powerful theory. Major innovations have been made in the technologies of accelerators and of particle

detectors. In order to present all of this in a few chapters, we have had to limit ourselves to describing the main ideas and the major experimental and theoretical accomplishments. We apologize to our colleagues for leaving out descriptions or even mention of so much other important and beautiful work in elementary-particle physics.

Elementary-particle physics is an international science, and in describing its content and its methods we have used the work of all the world's elementary-particle physicists. In looking to the future needs and future opportunities of elementary-particle physics we have mostly limited our work and our presentation to the United States. We have done so because this was the charge to the Physics Survey Committee from the National Academy of Sciences of the United States and because we are constituted primarily as a panel of physicists from the United States who are not qualified to speak for physics abroad. Since one of the audiences for this report consists of members of the federal government of the United States who are concerned with science policy, in describing needs and opportunities we have naturally tended to use examples from the elementary-particle physics community in the United States. We hope that our colleagues abroad will understand that this was one of the purposes of the report and will not feel slighted by our inability in this limited space to present more examples from work of the elementary-particle physics community abroad.

The Elementary-Particle Physics Panel acknowledges the help it has had from many physicists who have graciously given their time for discussions on the contents of this volume, who have read and reviewed individual sections, and who have been kind enough to review and make suggestions for the entire volume. We are very grateful to John Ellis of CERN, who attended the early meetings of the Panel and wrote some of the first drafts of this report. We have tried to represent the views of the elementary-particle physics community as a whole, but of course it is only panel members who bear the responsibility for the material in this volume. We thank the Chairman of the Physics Survey Committee, William F. Brinkman, for his guidance, leadership, and wisdom. We express our gratitude to the Staff Director of the Board on Physics and Astronomy, Donald C. Shapero, who was so patient and generous in passing on to us his knowledge and experience of how to represent the views of a scientific community and of how to prepare a report of this nature. Finally, we thank the technical typists and illustrators who so patiently worked and reworked the many drafts of this report: Lydia Beers, Edythe Christianson, and the members of the Publications Office of the Stanford Linear Accelerator Center.

Contents

APPENDIXES

Executive Summary

Elementary-particle physics, the science of the ultimate constituents of matter and the interactions among them, has undergone a remarkable development during the past two decades. A host of new experimental results made accessible by a new generation of particle accelerators and the accompanying rapid convergence of theoretical ideas has brought to the subject a new coherence and has raised new possibilities and set new goals for understanding nature. The progress in particle physics has been more dramatic and more thoroughgoing than could have been imagined at the time of the 1972 survey of physics, *Physics in Perspective* (National Academy of Sciences, Washington, D.C., 1972). Many of the important issues identified in that report have been addressed, and many of the opportunities foreseen there have been realized. As a result, we are led to pose new and more fundamental questions and to conceive new instruments that will enable us to explore these questions.

Elementary-particle physics is the study of the basic nature of matter, energy, space, and time. Elementary-particle physicists seek the fundamental constituents of matter and the forces that govern their behavior. In common with all physicists, they seek the unifying principles and physical laws that determine the material world around us.

The atom, the atomic nucleus, and the elementary particles of which they are composed are too small to be seen or studied directly. Throughout this century, physicists have devised ever more sophisti-