The Future of Science in the United States

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Mr. Chairman, Distinguished Members of the Committee, Ladies and Gentlemen:

It is a privilege to address this distinguished gathering on the important issue of the future of science in the United States. I am an experimental high energy physicist. I was born in Michigan and received my university degrees at the University of Michigan. Throughout my career, I have led large international collaborations conducting experiments in accelerator laboratories in the United States and Europe as well as on the space shuttle. Currently, I am leading a large international team of 500 physicists from 16 countries who are completing an experiment to be deployed on the International Space Station (ISS). My research has always been supported by the U.S. Department of Energy (DOE), by M.I.T. and I have always received strong worldwide support (Finland, France, Germany, India, Italy, Korea, the Netherlands, Pakistan, Portugal, P.R. of China, Russia, Spain, Switzerland, Taiwan…). My testimony is based on my own experience and observations in large-scale particle physics research and large international collaborations.

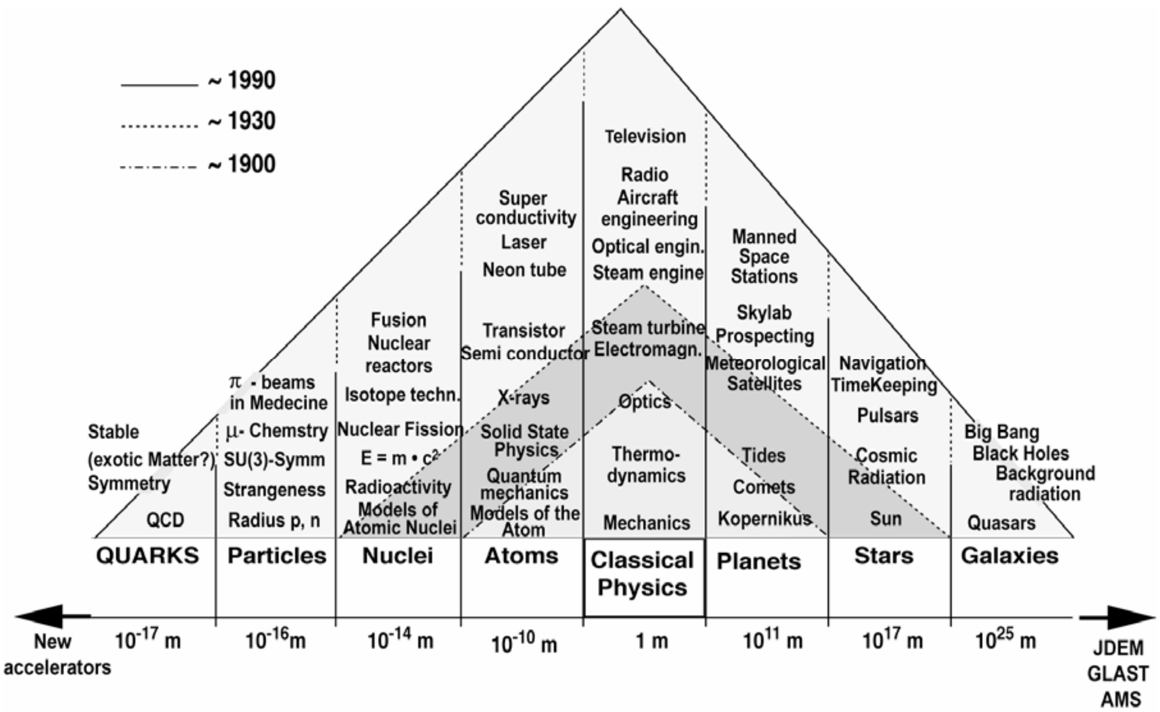
In the 21st century the United States is enjoying unprecedented levels of technological development such as in the fields of communication, computers, transportation, medicine, etc that have had dramatic effects on the quality of life. What is often forgotten is the fact that the foundation of these achievements was laid down some time ago by scientists who were driven by intellectual curiosity and not by economic concerns. History has taught us that support for basic research in science advances other areas of achievement in our society such as education and industry.

The German physicist and philosopher Christopher Lichtenberg wrote in his diary 200 years ago:

"To invent a remedy against toothache which would take it away in a moment might be more valuable than to discover another planet… But I do not know how to start the diary of this year with a more important topic than with the news of the new planet."

It was the planet Uranus, discovered in 1781 and which was recently investigated more closely by the Voyager spacecraft. Even at that time, one was confronted with a problem which is as important today as 200 years ago: should one build satellites to explore the universe, and accelerators to investigate the microcosm at a time when burning problems like energy production, disease and overpopulation, etc…trouble our society?

The following graph illustrates the relationship between basic physics research and its direct application to daily life. The inner triangle shows the area of basic research in the 1900's covering the scale from atoms to planets. The shaded triangle shows the areas of basic research in the 1930's which extended the scale from the nucleus to stars and its applications derived from earlier research. The outermost triangle shows the area of basic research today. It covers the scale from the size of quarks to galaxies. The outermost triangle also includes some of the key technology developed based on results of previous research.



The above graph demonstrates how fundamental research has provided the basis for technology in the past. Fundamental research started from human dimensions to explore on one side larger objects, i.e., the universe with its planets, stars, galaxies, etc. and on the other side, it has penetrated into the microcosm discovering ever smaller building blocks of matter, i.e., atoms, atomic nuclei, protons and neutrons, quarks, etc. Out of classical physics came the steam engine, photography, electrical engineering, radio, TV, airplanes, etc. The atomic world and quantum physics, which was necessary to understand it, delivered many new materials like semiconductors and superconductors with their many applications, i.e., the transistor, neon lamps, lasers, microprocessors, computers, etc. The world of atomic nucleus gave rise to applications like the isotope technique in medicine, material testing and fission energy in nuclear reactors. One notices that in the past, the pyramid has grown with new applications increasing its height while fundamental research continuously widens its base. The role of basic research finds itself always on the outermost corners of the pyramid and hence is sometimes blamed for being too remote from daily life. Only after some time when applications grow and the public becomes acquainted with the strange new phenomena they seem to become more "real". There is no reason that the pyramid should not continue to grow in the future and technological quantum jumps, fed by new discoveries, can be expected. Of course, the time it takes from the discovery of a new phenomenon to the introduction of its application into the market is still of the order of 20 to 40 years. Such a period is too long for many politicians and industrialists.

But research does not continue in a straight line. Errors are an integral part of the effort when penetrating into unknown territory and predictions are difficult. Hence, basic research needs sufficient freedom and a long perspective.

The prime motivation of basic research is human curiosity – the innate passion to learn something new, to ask questions and to obtain a deeper understanding of natural phenomena. Advancements in physics research are based on the close interaction between experiment and theory. Advancements in theory are based on the ability of theories to explain existing experimental results and to predict new phenomena to be confirmed by experiments. Revolutions in physics occur when an experimental result contradicts the theoretical prediction, which leads to the creation of a new theory or paradigm. There is no theory that can disprove an experimental result, whereas a theory, however logical and elegant, cannot be valid if it does not conform to experimental observations.

Careful experimentation in physics conducted in the second half of the 20th century, such as the observation of CP violation in K decay, the discovery of the J/psi particle, the discovery that neutrinos have mass and the discovery of high temperature superconductors, have opened up new fields of research in physics. These observations were carried out by experiments even though there was no apriori theoretical interest.

I began doing experiments measuring the size of the electron and studied the relationship between light rays and massive light rays. These experiments were carried out at the German National Accelerator (DESY). This was followed by an experiment at the Brookhaven National Laboratory leading to the discovery of a new form of matter. Subsequently, I returned to DESY to work on the highest energy electron positron collider, PETRA, leading to the discovery of gluons. In recent years I have led two international collaborations, one on the ground and one in space.

1. From 1982 to 2003, I led a 19 country, 600 physicist collaboration at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland. CERN's 16 mile circumference Large Electron Positron Collider created conditions close to those at the beginning of the universe. One of the purposes of our experiment was to search for the origin of mass. Even though the experiment was constructed at the height of the Cold War, it was the first large collaboration between the USSR, China, Europe and the United States and represented the largest contribution from the USSR to an international collaboration in physics research.

2. From 1994 to the present, I have been leading the AMS international collaboration building an experiment for deployment on the International Space Station. AMS will use the ISS as a unique orbiting laboratory to seek answers to the fundamental questions of modern physics and cosmology.

These two experiments are multi-billion dollar projects. Even though most of the financial and technical support came from outside the U.S., these experiments have been regarded by the world scientific community as U.S. DOE led experiments.

The completion of the International Space Station, with its unique capability to support complex modern accelerator type experiments, will be a truly outstanding laboratory facility of which the United States should be very proud and utilize to its full extent. The ISS will provide a base to do experiments without hindrance from the dense Earth atmosphere and gravity. On Earth we live under 100km of air, which is equivalent to 30 feet of water, and this absorbs all the primordial charged particles and high energy gamma rays. The highest energy particles are produced in cosmic rays and it is through understanding the nature of primary charged cosmic rays that clues on the foundation of modern physics will be revealed such as the existence of the universe made out of antimatter, the origin of dark matter, and the existence of strangelets, etc.

If the universe came from a "Big Bang", at the beginning there must have been equal amounts of matter and antimatter. The search for an explanation for the absence of antimatter is the main research topic of the current and next generation of particle accelerators world-wide. The existence of dark matter has been one of the mysteries of modern particle physics and cosmology – why so much of our universe is not observable. All matter on earth is made out of only two of the six known kinds of quarks. Strangelets are new types of matter composed of three types of quarks which should exist in the cosmos. These questions touch upon the foundations of modern physics and the AMS experiment will provide for the first time a most sensitive means to answer these questions.

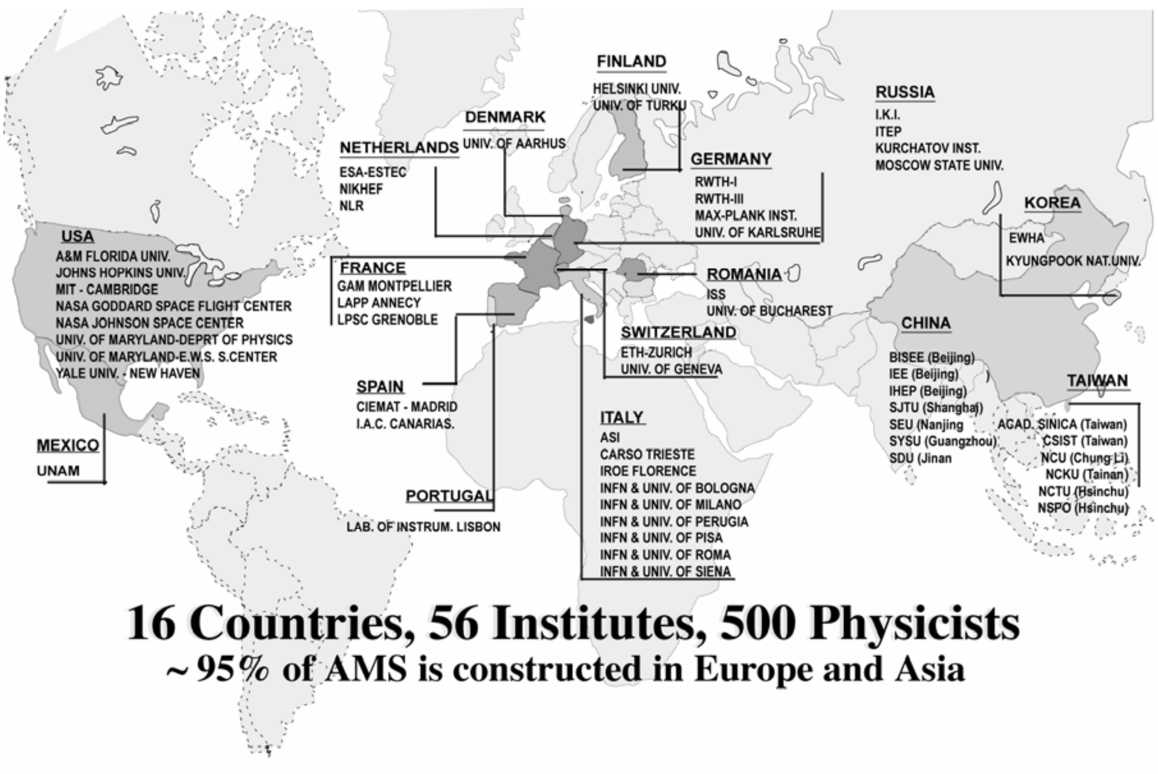
The AMS experiment is one of the largest international collaborations supporting fundamental science on the space station. Indeed, 95 % of the $1.2B cost to build AMS has been funded by sources outside the U.S. It uses the technology developed in particle physics modified for space application. AMS uses a large superconducting magnet for the first time in space research. The purpose of the magnet is to distinguish matter from antimatter by observing positive or negative charges tracked in the magnetic field.

As an important byproduct of the science to be produced by AMS, the experiment will also provide important applications for the U.S. space exploration program. These include precise mapping of cosmic ray radiation background as well as the use of superconducting magnet technology for propulsion, energy sources and to provide safe, light weight and complete radiation shielding for manned interplanetary space travel. Out of the 27,000 manned days spent in space, only 1% (303 manned days during the Apollo era) was spent outside the magnetosphere. This, together with the fact that our current knowledge of the nature of radiation from dangerous heavy ions is limited, makes the precision study of the nature of cosmic rays and their dependence on energy and time important input for future long distance human space travel or sustaining long periods on the moon.

Current estimates by NASA indicate that without protection, astronauts will receive lethal doses of radiation on a three-year trip to Mars. Superconducting magnet technology offers the only effective way to protect astronauts from this hazard because of its capacity to deflect radiation away with its strong magnetic field.

The following graph presents the AMS international collaboration.

Worldwide Participation in the AMS Experiment on the Space Station since 1994 – total spent $1.2 billion



At the beginning of my career, experimental particle physics research was dominated by the United States. Very few American physicists worked in Europe. Gradually, with improved economic conditions, other countries realized the importance of supporting fundamental research and the benefits to science, education and technological growth inherent in such investments. The European Organization for Nuclear Research (CERN) in Geneva, Switzerland was founded when many European countries made the decision to pool their resources to build larger and more powerful accelerators and to provide technical infrastructure for their physicists. Later Germany and Japan built their own unique accelerator and research facilities. The cancellation of the U.S. Superconducting Supercollider project (SSC) – mostly due to its own mismanagement - contributed significantly to the loss of U.S. dominance in the field forcing large numbers of U.S. physicists to go to Europe or Japan to conduct their research. Indeed, some of the most important discoveries in particle physics such as the discovery of the intermediate vector bosons, the discovery of gluon jets, the discovery of neutral currents, and the discovery that neutrinos have mass were all done at foreign facilities. All these major discoveries, though having had significant U.S. participation, are credited justifiably to European and Japanese laboratories and recognition given to the principal investigators. The only exception was the discovery of the gluon jet which was recognized as DOE/MIT discovery.

The nature of experimental particle physics research has changed dramatically because of the limited availability of research facilities and the increasing complexity of experimental detectors. These changes are illustrated in the following:

1. Teams have gone from a few physicists to presently thousands of physicists from many countries per team.
2. The cost of the experiments has increased from a few hundred thousand dollars to billions of dollars.
3. The time required to carry out the experiments has grown from a few months to decades.
4. More and more particle physicists are carrying out their research in space, on the ground and in subterranean laboratories. This is the result of the realization of the close connection between particle physics, astrophysics and cosmology. The brilliant LIGO project, the outstanding GLAST and JDEM experiments, the AMS and Super Kamiokande are examples of this trend.

Contrary to accelerator physics on the ground, science in space, either with balloons, satellites or with ground based telescopes, is still led by the United States through NASA. Both the GLAST experiment and the JDEM experiment will provide critical knowledge on the nature of our universe.

Despite the complexity of modern particle physics research, successful, large international collaborations are often proposed and lead by very few physicists whose vision, tenacity and understanding of physics make multinational collaborations possible. In addition, scientific recognition of major discoveries is commonly given to the laboratory at which the discovery was made. SLAC, Fermilab, Brookhaven, CERN and DESY are recognized as successful laboratories because so many major discoveries have been made in their facilities. In addition, even though modern groups may have thousands of physicists, a truly outstanding and dedicated young physicist will distinguish him or herself and be easily identified by the physics community. This is because the advancements in physics have always come from the efforts of a few people with unconventional ideas and not from public consensus. Indeed, one cannot vote on physics issues.

Having worked in laboratories in Europe, the United States and in space, I have the following observations on how the U.S. can maintain its world leadership in science in the future. These include:

1. The importance of U.S. participation in international collaborations.

The size and cost of modern physics experiments for accelerators and space make it mandatory to seek international collaboration. It is no longer possible or necessary for a single country to have the best technology in every field – an example is superconducting magnet technology. The world's best superconducting magnet technology is now in Europe and Japan and not in the U.S. In addition, the days of competing experiments with similar goals is a luxury we can no longer afford. Rather than competing, it is much more efficient to collaborate together towards a common goal.

2. The importance of the U.S. maintaining its international commitments.

In Europe when a research instrument, such as an accelerator or spacecraft, is approved by a government or governments, it is almost always carried out to a successful end. In the United States, the cancellation of ISABELLE and the SSC had a devastating effect on the world science community resulting in close to 500 U.S. physicists presently working at CERN on the Large Hadron Collider (LHC).

3. Providing strong support to important U.S. led international collaborations which connect particle physics, astrophysics and cosmology, such as JDEM, GLAST and AMS.

These large international collaborations are led scientifically and technically by U.S. These experiments have the potential of making groundbreaking discoveries in physics. This potential for major breakthroughs in science performed on the ISS must not be underestimated nor become the victim of expediency. The ISS is a visible symbol of American commitment to science and international collaboration and is a vital part of our national legacy of exploration and excellence. NASA should be strongly supported to carry out its world class experiments and to fulfill its commitments to our international partners.

4. The importance of ensuring that some of the future key international projects, such as the next generation of accelerators, be located in the U.S.

The advancement of physics is not determined by the amount of data taken and the number of papers published. The advancement of physics is driven by unpredicted and fundamental discoveries. The next generation accelerator will require enormous amounts of technical development in instrumentation, electronics, material, data storage and analysis as well as a large team of engineers and scientists. The laboratories at which discoveries are made traditionally are given the recognition and credit. For the U.S. to regain its leadership in particle physics it is important to ensure that the location of the next generation of accelerators be in the United States.

5. The importance of continuing strong support to basic research in universities to train students and to attract the world's best minds to work in the U.S.

Most of the major discoveries in experimental particle physics were not predicted at the time of the original justification to build the accelerator was formulated but came about unexpectedly and often in contradiction to prevailing theory or public opinion. A glance of the Nobel Prizes awarded to physicists will reveal that most of the prizes were given to university professors. This is because universities grant sufficient academic freedom to promote creativity and originality. Today fewer students in the United States are studying physics unlike our European and Asian counterparts. To strengthen science education in primary and secondary school as well as universities will enhance the numbers of students studying science and will ensure a better informed public on science issues.

I thank you for your attention.