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Using Science Centers to Expose the General Public to the Microworld

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ABSTRACT

Despite the remarkable progress in the past decades in understanding our Universe, we particle physicists have failed to communicate the wonder, excitement, and beauty of these discoveries to the general public. I am sure all agree there is a need, if our support from public funds is to continue at anywhere approximating the present level, for us collectively to educate and inform the general public of what we are doing and why. Informal science education and especially science and technology centers can play an important role in efforts to raise public awareness of particle physics in particular and of basic research in general. Science Centers are a natural avenue for particle physicists to use to communicate with and gain support from the general public.

1. Goals

Lets begin by restating goals of the Public Outreach and Education Task force (POET), the group that organized this plenary session:

- To encourage HEP physicists to support and participate in public outreach and education,

and by so doing to help

- rebuild the support that basic science has had not only from people in Washington but from the American public in general.

The rationale for these efforts can be stated as follows:

- We have an obligation to explain to them what we are doing and why.

- The general public, including your congressmen and your next door neighbor, finds science in general, and particle physics and astrophysics in particular tremendously exciting if they are exposed to them.

In this talk I will suggest a way, not exclusive of other suggestions, for members of DPF to aid in achieving these goals.

2. What Is A Science Center?

Most of you are familiar with science centers [1,2,3,4] but let me summarize briefly to set the stage for what follows.

"Informal science education," happens through channels that include television, newspapers, advocacy organizations, museums and science centers. Each of these channels reaches a different audience and presents a different kind of information. Informal science education plays a significant role in shaping public awareness of science and technology. Science centers have been recognized as important players in this arena.

In the past several decades, people all over the world have been starting science centers. There are now about 300 of these new-style museums, two-thirds of them in North America. Science centers have visitations of over 60 million people annually nationwide. Their emphasis is on presenting subject matter in a non-threatening, friendly, exploratory, fun manner.

Schools alone can't ensure that an increasing number of youngsters will be prepared to learn science, or even be motivated to try. Students' attitudes and choices are influenced by family, friends, media, and the possibilities revealed by their own experience. They need many varied and comprehensible encounters with science in order to want more of it. People today growing up in urban settings and absorbing information passively from screens, do not labor with ropes, levers, fire and liquids as farmers and artisans did in the last century, and so do not have well-formed intuitions about how the natural world behaves.

Science centers provide access to science, they improve our comfort level with technical ideas, artifacts and numbers and they enable us to obtain first-hand experience with phenomena. Operating in three dimensions, unlike print or electronic media, science centers provide opportunities for students, parents and teachers to play around first-hand with materials and experimental apparatus, and so to build intuitions about the natural world. Science centers provide experiential learning. As parents and children handle the displays, they act as both experimenters and experimental subjects. They watch demonstrations and ask questions about the dramatic and intriguing things they see. They enjoy the time spent in a safe, upbeat environment where their curiosity is both stimulated and rewarded.

Science centers are playing an increasingly important role in the nation's efforts to stimulate and motivate our youth to take an interest in science and mathematics, to learn high order thinking skills, so they can lead meaningful lives in the next century. As organizations science centers are not as concerned about the elite, the talented, the gifted, but more with the general population. We are populist organizations. We are deeply disturbed by the growing underclass in America.

Although there are many similarities between science centers, you find that each have their own particular character and philosophy. Some approach theme parks in their atmosphere; others are less glitzy. But they all share a similar mission. Each new science center has to define its own aims, methods, audience, and content within the context of local possibilities.

What is accomplished? In none of these interactions have adults or children mastered a body of theory, or rarely have they used mathematics to make a prediction. They have not followed an informed sequence of experiment -- What they have done is to share in some of the marvels of the natural world, made accessible to them. One of the problems in science centers is that we can't predict when learning will happen. A child may see something in an exhibit that enables him, months later, to grasp a concept the first time it is taught at school.

3. The Microworld-How to Go There and Whom to Bring?

The essence of the science center is interactive exploration of scientific phenomena. A typical science center offers exhibits on mechanics, electricity, optics, perception, health, and transportation that can appeal to children as well as their parents. On weekdays during the school year, hundreds of elementary school children visit the center with their teachers and chaperones. In addition, as individuals they participate in workshops, camp-ins and more structured programs using the rich resource of the center's exhibits.

> Visitors experiment with the laws of reflection.
> They appreciate the speed of sound by saying "woof" into a 100 meter long PVC pipe and listening to the echoes.
> Children work cooperatively to construct a Roman arch.
> And they are fascinated to watch the build-up of a normal distribution curve.

Most of contemporary science is microscopic--particle physics, DNA, and quantum mechanics--and difficult to present in the exhibit medium. How do we show something that is too small to see? How do we motivate visitors to care about something they can't experience directly? Does the apparatus hinder visitors' entry into the microworld? Can "quantum weirdness" spur interest, or only frustrate?

4. Past and ongoing efforts

4.1. A word about SciTech

SciTech is patterned on the philosophy of San Francisco's Exploratorium where I worked for a few months in 1982. SciTech has grown from an all volunteer effort in 1989 and a budget that year of $20,000, to a organization currently employing 20 FTE plus an additional half a dozen scientists, engineers and other professionals paid by other organizations, or "high-tech grass-roots" volunteers. The 1994 operating budget is about $600,000 We are currently serving 100,000 people per year and still growing.

4.2. Building Blocks of the Universe

The Building Blocks of the Universe Project[5] (Fig. 1) officially began with a grant from the National Science Foundation, in June 1990. The project was a collaboration between SciTech and COSI, Ohio's Center Of Science & Industry in Columbus. The partnership drew on the years of experience of the COSI staff. COSI is one of the leaders in interactive science exhibit development. It also took advantage of the wealth of talent amassed around our newly formed SciTech, drawn from nearby scientific institutions and industries, including Fermilab, Argonne, AT&T Bell Labs, and Amoco Research Center.

Who needs exhibits on the basic mechanisms of the Universe? Our experiences are naturally based on the macroscopic - that which we can see, feel and manipulate. These experiences generate but also limit our concepts, and this applies as much to the formalized concepts of a scientist as the intuitive concepts of others. In general, we are unfamiliar with the workings of the microscopic world. However, it is precisely this world which defines our own world, gives it its rules and exceptions, creates its possibilities and probabilities, and holds the secrets of the universe in which our existence is immersed. To break through to the microscopic world we - scientist and non-scientist alike - need new concepts, freed from the limits of our immediate experience. The Building Blocks of the Universe exhibition seeks to bring everyone at least to the gateway of a world which otherwise exists only in a guide book written in mathematics.
Present day physics, which seeks to explore the Big Bang, the top quark, the Higgs boson, and other building blocks seemed too complex to explain and describe in terms that an eleven year old could understand, not to mention the

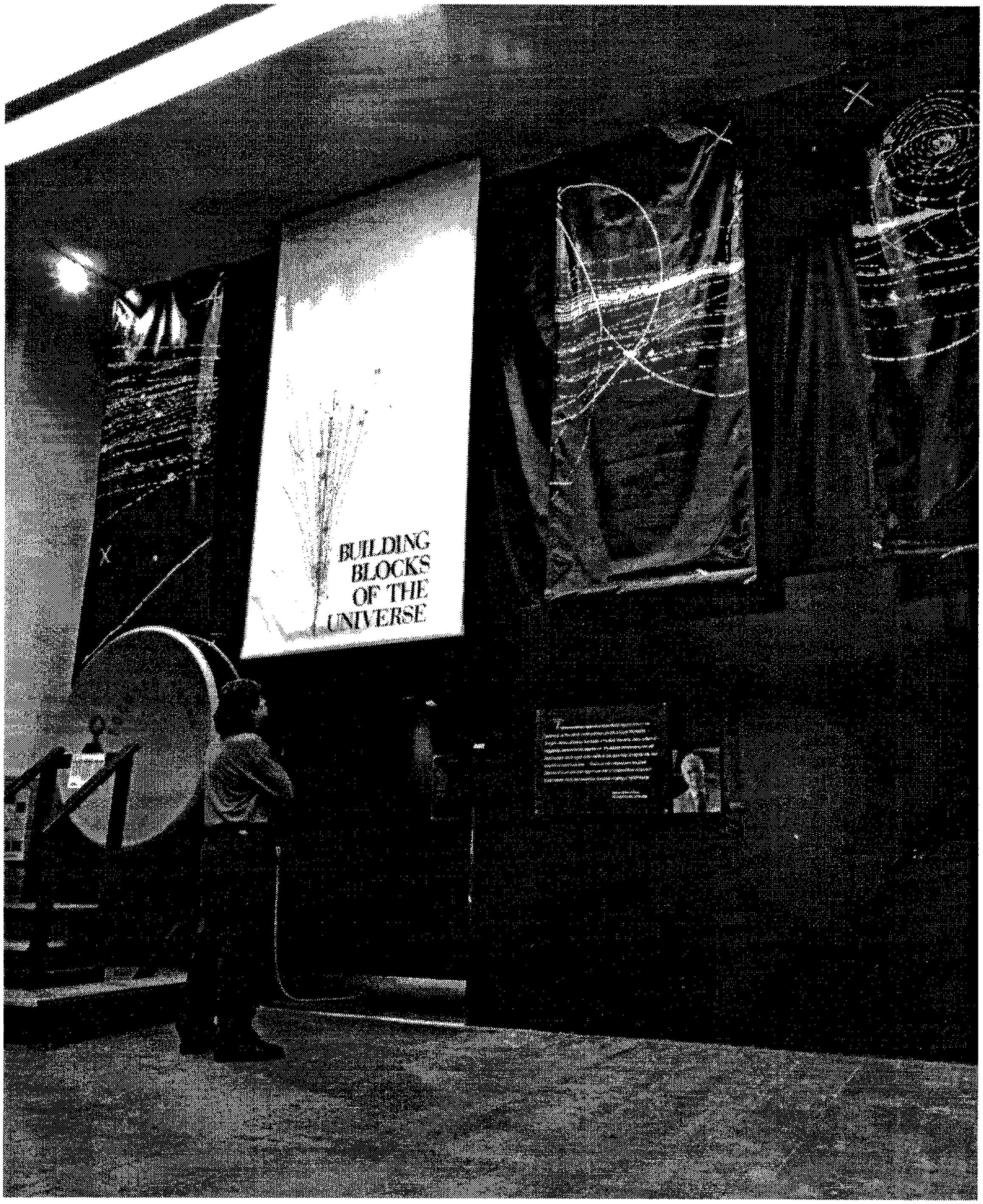

Fig. 1. Entrance to the 120 m^2 Building Blocks of the Universe Exhibition at SciTech in Aurora, Illinois. *Photo Credit: Fermilab Visual Media Services.*

non-physicist adult. However, through all the calculus, perturbation theory, and QCD, we must make every effort to find simple analogs and solutions.

We attempt with these interactive exhibits to convey to a wide audience some of the fascination of the world of the very small. In both centers, SciTech and COSI, existing exhibits already offer a rich variety of experiences of nature at the human scale. On entering this new group of exhibits, the visitor is led from the human scale to progressively smaller scales of size, discovering a sequence of new ways that matter is constituted.

We had to weigh the value and necessity of classical analogs of quantum behavior against their inevitable shortcomings. The challenge is to engender a sense of wonder and excitement, but not of mystery. The visitor must feel that the exhibits represent gateways that open up, not present barriers to surmount; that the new worlds discovered do not undermine common experience, but rather form an exciting extension of that experience.

Exhibit components incorporate the "hands-on" style which has proved so attractive and effective in science centers worldwide. The exhibits are linked and enhanced by an effective museum environment, using graphics, accurate non-technical text, and artistic displays to create an atmosphere in which visitors can learn about phenomena beyond the range of direct perception. Placing such exhibits in a general science environment is important. E.g. at SciTech 12 visitor experiences dealing with particle and nuclear physics are embedded in an environment of over 200 exhibits dealing with physics, astronomy, mathematics, and technology. Some of the elements of Building Blocks are described below.

4.3. An Investigation Into The Very Small

The notion of "small" generally conjures up pictures of paper clips, a strand of hair, a sliver of cake, or a grain of salt. To those of us who are fortunate to have used a microscope, those images might be extended down to mitochondria and proteins.

To prepare the visitor for "an investigation into the very small" we start with an activity suggested by Professor Ken Wilson. The participant is offered scissors and a piece of paper, and challenged to divide it in half as many times as possible. Most people think that dividing something in half is trivial, and can be done numerous times if desired. This part of the exhibit gives an appreciation of how fast factors of two multiply, as people realize that they can barely cut the paper ten times. A magnifying glass or a simple microscope might help, but then what? The participant, still able to hold the smallest piece of paper easily in his hands, surely realizes that there is still something smaller. Pictures of the paper down to the next few factors, are displayed, as are pictures of other common objects not normally viewed at that magnification. The participant is then led through a thought experiment, imagining what might be smaller. Is there some smallest unit that we can still call paper? Given the right tools, can that smallest unit be divided into yet smaller non-paper things? Can those be divided further? How far can we go? Is there some fundamental limit? How many cuts to reach the size of an atom?

The goal of this exhibit is to set the stage for the entire exhibition, and to slowly draw the visitor into the world of sub nuclear realities. It starts out with the things that he knows, and can touch, see and manipulate. It then provides an introduction, a gateway of sorts, into the microscopic universe, as the layers are peeled back, one after another.

Cutting the paper is followed by a projection microscope. If we have prepared the slide carefully the visitor can see Brownian motion. It would be more effective if we also had additional projection microscopes showing a variety of microscopic living and non-living objects, as at the New York Hall of Science.

4.4. *The Atom*

The Hydrogen atom is the simplest atom that is possible. It consists of a single proton in the central nucleus, and a single electron satellite, dancing around the center. Unlike the macroscopic world, the bound electron can only have one of a set number of possible energy levels. Inside an atom, there is no energy continuum. The electron is not allowed to have any energy it wants, take any position it wants. Instead, it is limited to be in one of a few possible energy levels.

Three concentric Plexiglas spheres, each covered with an array of red LED's, are used in our model, 10^9 the size of a real Hydrogen atom. Each sphere represents a single allowable energy level, and each light represents a possible position for an electron. Having but one electron, only one light can ever be illuminated at a time. But, since the electron is never stationary, this point of light flickers on and off randomly around a particular sphere. The flashing is done quickly so that the observer can never zero in on the electron position, and sees only a cloud of light where the electron might be found. Only the electron position is changing, not its energy.

While in one of the lower energy levels, the participant is asked to excite the atom into one of its higher energy configurations. There are three allowable excitations: inner to middle, middle to outer, and inner to outer. Each transition is made possible by the participant imparting energy of a characteristic frequency. The visitor is asked to whistle, or for those that can't whistle to use a toy Xylophone. If the note matches one of the three allowable frequencies, then the electron jumps to the indicated higher level. After some time, the electron is allowed to relax back down to a lower energy level. Again, there are three possible transitions, each with a characteristic frequency. A relaxation event is indicated by the automatic firing of one of three colored strobes, positioned inside the nucleus. The blast of light represents the single photon that would be released by the atom for such an event.

There are four major goals for this exhibit. First, it conveys the concept of quantized energy levels. Second, it shows that the bound electron is never stationary, and that its position at a particular energy is uncertain. Third, it demonstrates that it is the frequency which determines the nature of a transition. Finally, it shows that energy is radiated from the atom only when an electron drops into a lower level.

Nearby we have an exhibit with real atoms called "atomic fingerprints" The visitor views various gases in discharge tubes with a hand held diffraction grating.

4.5. Rubber Ball Nuclei

Hard rubber balls, 2 inches in diameter represent the individual nucleons. Those that are dyed red are protons. Those that are dyed blue are neutrons. The nucleons are held together by a piece of clear plastic tubing, extending from the center of one ball to the next. A plastic green bead rolls back and forth within each tube. It represents a meson, the messenger particle that is exchanged between the two objects, delivering the attraction of the strong nuclear force, keeping them bound together. It is important to note that the bonds are not rigid and fixed. Instead, they are rubbery and flexible, allowing angles and distances to change slightly, providing a more accurate representation of the atomic nucleus. This exhibit can be easily picked up, twisted and bounced. It appeals to the younger visitors.

4.6. Half Life Cluster

There are several stations which provide models for radioactive decay. In one of them the participant is handed a container of six-sided dice. One of the sides on each die is painted a distinctive color. In the first turn, the dice are spilled onto the playing surface. All dice with the colored side up are removed from the group, and stacked one upon the other on the board. The second turn is the same, with the remaining dice being spilled, and the few with the colored sides being stacked, next to those already present. This cycle continues until all dice have been stacked. The result is a graph, made by the individual stacks, that represents the "decay" of the dice. With each toss, 1/6 of all dice decay.

4.7. Valley Of The Isotopes (Fig. 2)

A map of the isotopes is usually three dimensional. Proton number is along the x-axis, with neutron number along the y-axis. The third dimension represents the binding energy of the isotope. Standard wall charts, unable to use 3 spatial dimensions, choose their third dimension to be mapped as a color, or a shade on the grid. However, on the museum floor, we have no such restriction, and we are free to build in x, y and z, as we please. Therefore, we have chosen to translate the binding energy into a depth along the z-axis. As binding energy increases, the depth in z increases. This is similar to digging a hole. The deeper the hole is, the higher the side walls are, the greater is the amount of energy needed to get out.

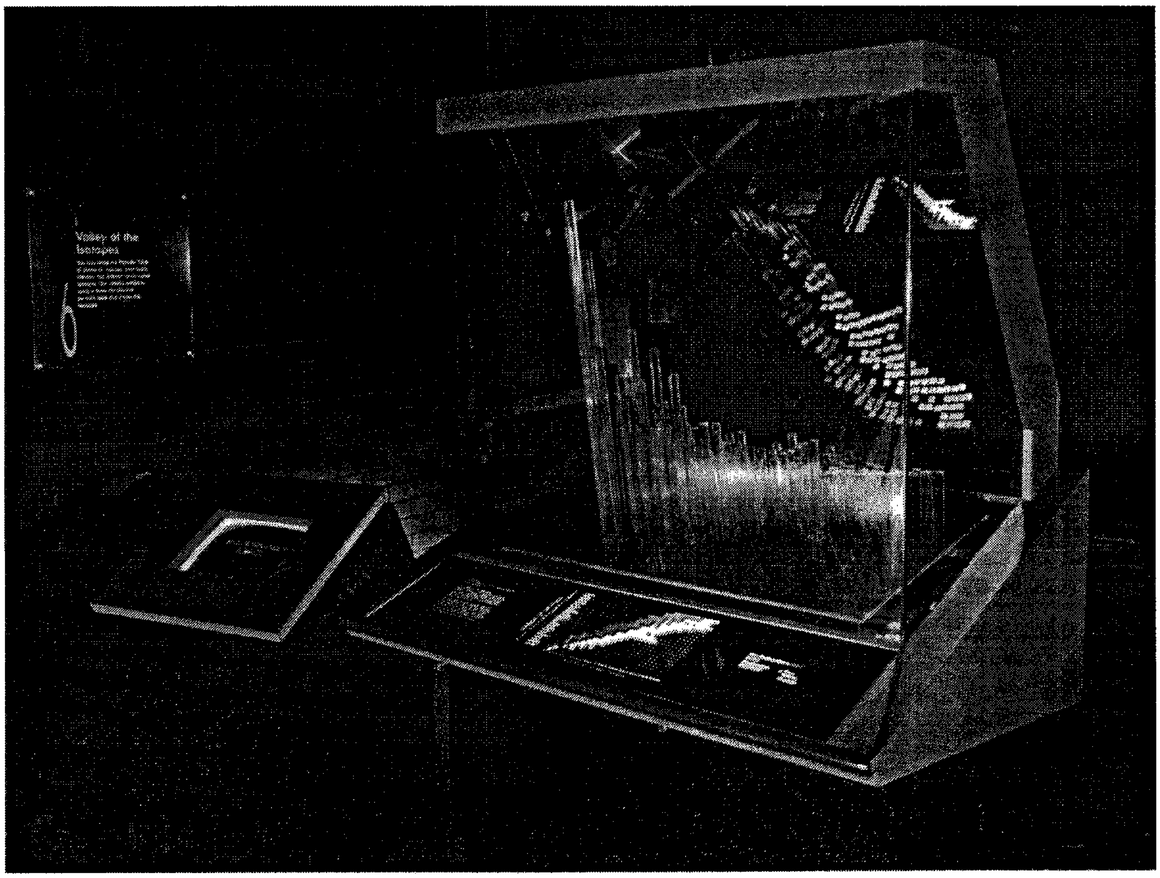

Fig. 2. The Valley of the Isotopes Light Sculpture and Interactive Exhibit. *Photo Credit: Fermilab Visual Media Services.*

As the table is mapped, a central depression is formed, with high walls on either side. This is called the Valley of the Isotopes. The entries within the valley have high binding energies and are therefore very stable. The entries that are on the high ridges, have smaller binding energies, making them much less stable and prone to decay. For instance, Iron-56 is the most stable of all isotopes, and is found at lowest point in the valley, while Sodium-22 is precipitously balanced on the ridge, a prime candidate for radioactive breakdown.

There are thousands of known isotopes, and to have a functional and easily maintainable exhibit for all of these would require a Herculean effort. Instead, we have chosen to reproduce a section of the valley. Our initial effort includes all isotopes through to Vanadium. The x-y grid is made with lights, mounted on circuit boards, and controlled by a computer. A light pipe is mounted over each light. The height of the pipe, and the color of the light represent the binding energy of the isotope. The result is a beautiful and dynamic light sculpture.

A voice in the computer invites the visitor to explore fusion processes, flashing the appropriate lights as a guide through the narrative, programmed to explain stellar evolution and how our sun burns Hydrogen to make Helium and energy. It details Carbon dating, and the behavior of some medical isotopes. It works better as a teaching tool than as an unstaffed exhibit.

4.8. Quark Machines And Particle Scoreboard (Fig. 3)

All matter of which we are commonly aware, including all elements in the periodic table, all nuclei, and all isotopes in the valley, can be made of three things: protons, neutrons, and electrons. We further know that protons and neutrons are composed of up and down quarks. The goal of this exhibit is to show that there are actually a total of six quarks, and that there are many other particles that can be created through their various combinations.

The basic component of these exhibits resembles a three-wheel slot machine. A color computer screen is used to simulate the wheels and the spinning motion and an arm mimics the look and feel of a true slot machine. Instead of lemons, cherries, and Lucky 7's popping up, quarks will appear, and baryons will be formed. In the case of the antiquark machine, antiquarks will appear, and antibaryons will be formed. The machines can be played, side by side, by two competitive would-be physicists, and the resulting baryons can be compared.

The probability of a particular quark appearing on a wheel is based on its existence in the real world. That means, it is most likely that an up or down quark will appear, and that a proton or neutron be formed. After that, there is a slim chance that either a strange or a charm quark will appear. Finally, there is a tiny remote chance that a bottom or top quark appears.

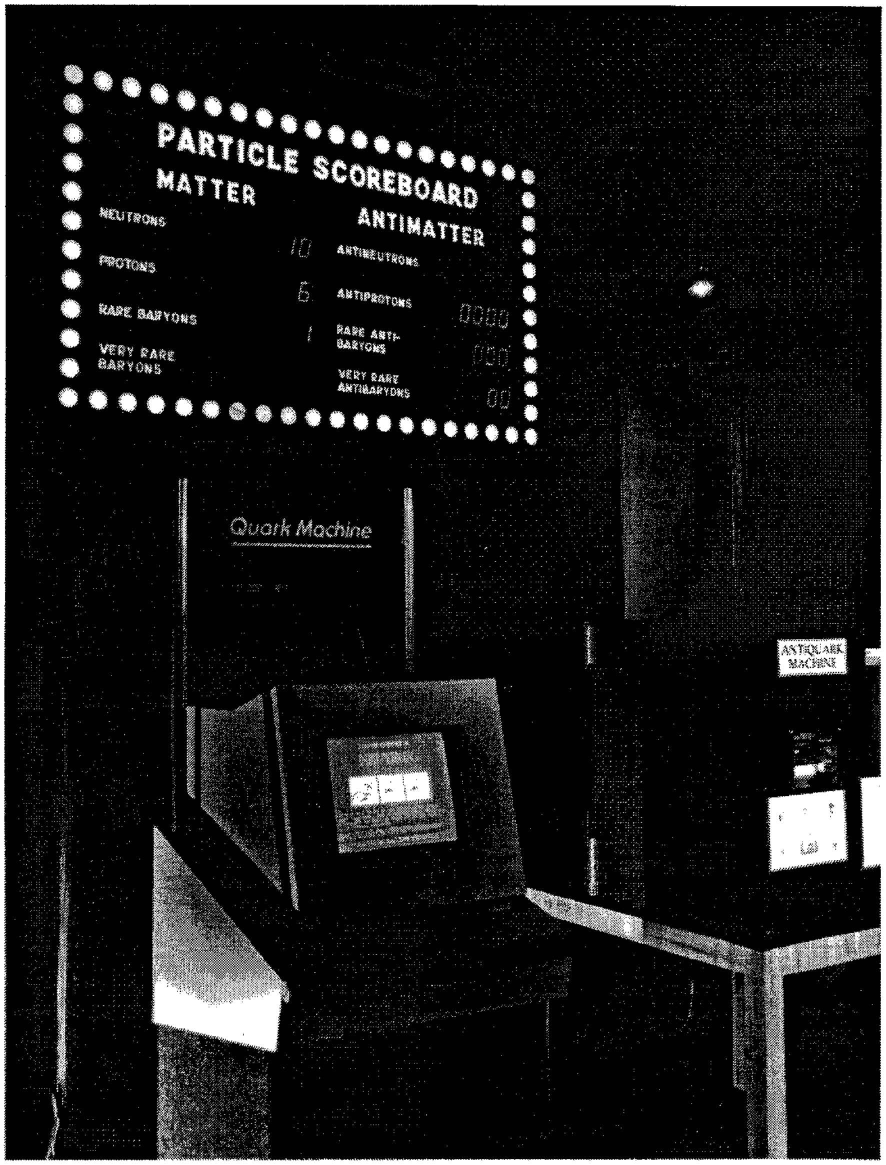

Fig. 3. The Quark Machine, The Antiquark Machine, and the Particle Scoreboard.
Photo Credit: Fermilab Visual Media Services.

5. Next steps

The goal of the effort is to assist in the quest to promote science literacy, and to produce a set of interactive experiential science exhibits, detailing the world of high energy physics. It focuses on the peculiar realities of atoms, subnuclear particles, quantum mechanics, and the fundamental principles that cooperate to tie our understanding of the cosmos, the quarks, and the coffee table all together into a single construct.

5.1. $E{=}mc^2$

We are continuing this program to bring 20th century physics into science centers with a current project funded by the U.S. Department of Energy called $E{=}mc^2$.

Everyone has heard of Einstein's famous formula "$E{=}mc^2$", but few people ever expect to know what it means. This exhibition will provide a wide audience with the opportunity to experience its meaning and understand it in simple terms. The subject of the exhibition is the equivalence and inter convertibility of energy and matter. The formula will come alive for museum visitors by providing them the experience of manipulating two real subatomic physics processes: positron-electron annihilation into two photons and photon conversion into electron-positron pairs.

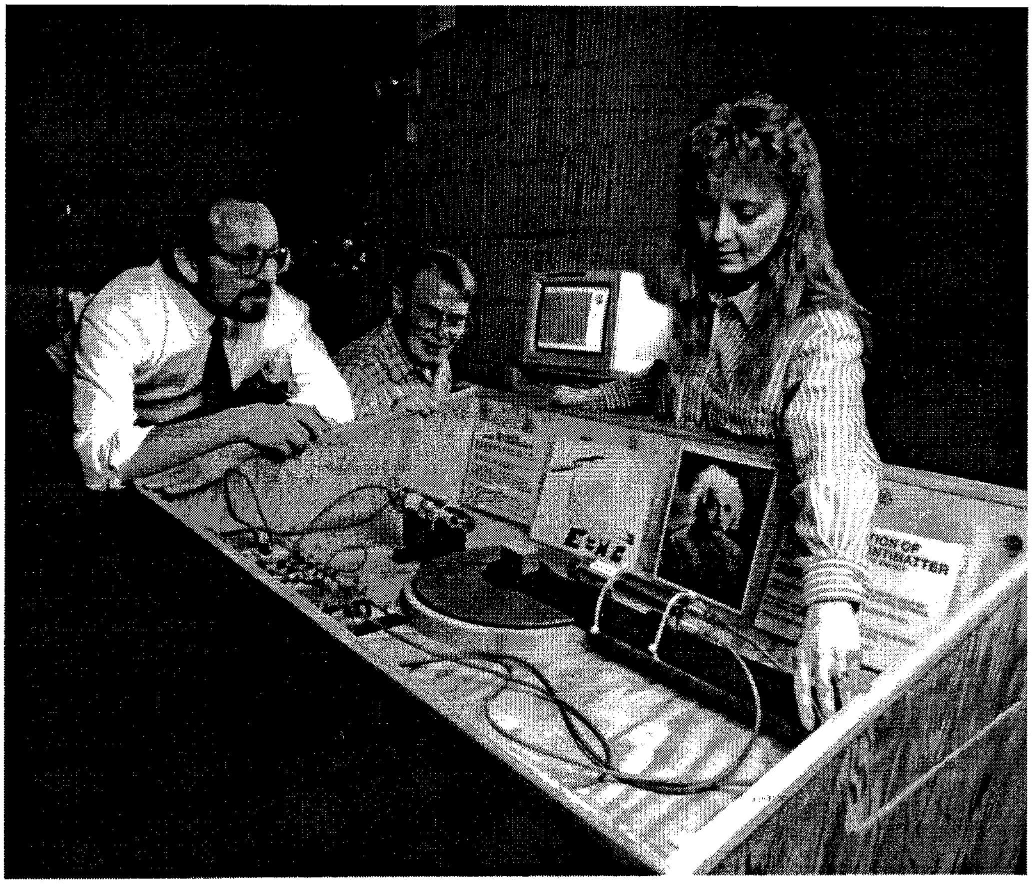

Fig. 4. An early prototype of Matter into Energy, part of the $E{=}mc^2$ Exhibition.
Photo Credit: Fermilab Visual Media Services.

Detectors used in basic physics research will be employed to "visualize" these transformation processes. Accompanying graphics panels, lecture and demonstration scripts, and computer animation will enhance the exhibits with explanations, historical notes about the development about our concepts of energy, and the relation of the exhibits to modern energy issues -- nuclear power, radiation, and medical applications.

In the matter-into-energy exhibit, (Figs. 4 and 5) positrons and electrons (the "matter") annihilate into photon pairs (the "energy"). We use a weak encapsulated Na22 positron emitter and detect the photons with two scintillation photo tube counters, both mounted on movable arms so the visitor can search for the antimatter annihilation process. A chirp signals a new event. The visitor can insert lead collimators to block the particles and stop the chirps.

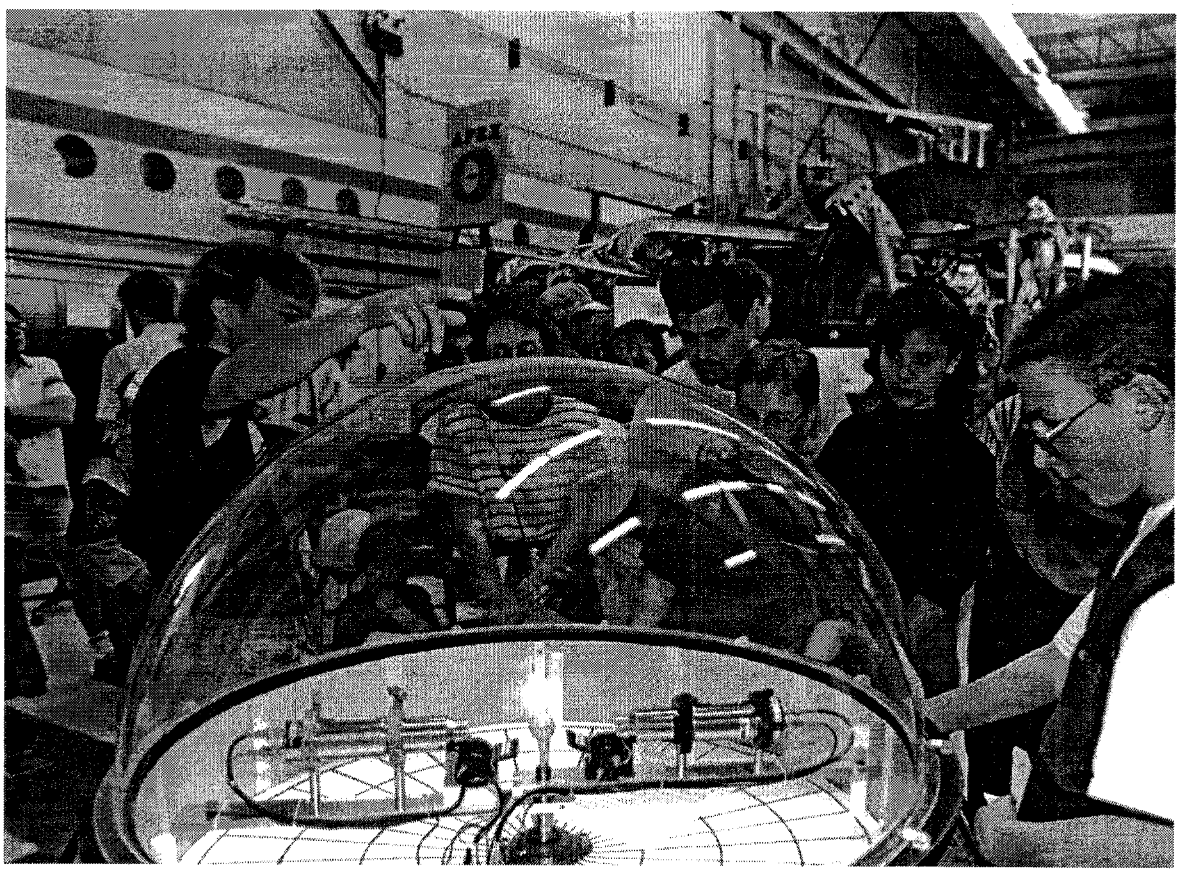

Fig. 5. The finished exhibit element, Matter into Energy for the $E=mc^2$ Exhibition. Photo taken at Argonne's May 21, 1994 Open House. More than 18,000 visitors attended.
Photo Credit: Argonne National Laboratory.

In Energy into Matter, photons from natural thorium having an energy of 2.6 MeV will enter a diffusion cloud chamber. The visitor can move a foil into the photon beam and so create electrons and positrons via pair production. These charged particles make visible tracks in the chamber. In this process the photon disappears and its energy reappears as a particle and an antiparticle. A small rare earth magnet will show that the two particles that make the tracks are of opposite electric charge.

The visitor will embark on a "treasure hunt" using a freeze frame video setup coupled to the cloud chamber to find, and be rewarded, for the rather infrequent pairs. Graphic aids will help the visitor recognize the various phenomena.

5.2. The Quantum World

On the drawing board is a new proposal, the Quantum World being developed by a partnership of current and retired Argonne physicists and some of the top high school physics teachers in our area.

6. Is There A Role For Scientists In A Science Center?

Despite the remarkable progress in the past decades in understanding our Universe, we particle physicists have failed to communicate the wonder, excitement, and beauty of these discoveries to the general public. I am sure all agree that there is a need, if our support from public funds is to continue at anywhere approximating the present level, for us collectively to educate and inform the general public of what we are doing and why.

Informal science education and especially science and technology centers can play an important role in efforts to raise public awareness of particle physics in particular and basic research in general. Science Centers are a natural milieu where particle physicists can communicate with and gain support from the general public.

Physicists can make a difference by volunteering at their local Science Center. Science centers do great 19th century physics, but they need help with the 20th century. And can probably help with 19th century physics too! This education effort is not just reserved for the retired or almost retired!

The most promising area of growth for science centers is in their relationship to teachers and schools. Because centers are outside the school bureaucracy, because they are entrepreneurial, and because they have accumulated resources for science teaching, they are well-positioned to deliver innovative programming. There is much recent emphasis on teacher training. And a great deal of effort in science centers is going into diversifying both the audience and the staff. This evolution of the role of science centers provides many opportunities for DPF members to get involved and help.

6.1. The Chasm between the Science Center and Research Communities

On the one hand there is the high-tech, ivory tower, high powered research establishment. On the other side is the science center community.

From the research community side we see oversimplification, lack of rigor, an environment sometimes approaching that of Disneyland.

The science center community sees Ph.D.'s, busy, important people rushing off to meetings, wheeling and dealing for grants, machine time or whatever.

The people who run science centers are by and large very bright, creative, dedicated, hard-working, humanistic, with a mission to accomplish.

Suppose your local science center has just completed an exhibit on radar tracking of tornadoes and needs help with a simple, clear explanation of the Doppler effect. But they are hesitant to call up their local physics department and ask for help.

6.2. How Do We Bridge This Chasm?

I urge DPF members to visit your local science center, wander around with a notebook, spot errors or obscurity in labels. I have discovered examples, some in large science centers, where some basic physics concept is explained incorrectly. Or suppose you see a set of wonderful exhibits on angular momentum, but then remember that last year in your freshman class you did this neat demonstration that might be turned into a robust, hands-on exhibit.

Meet with the science center director and offer to help. Commit to a half-day a week for a few months. Be helpful. Write signs. Build prototype exhibits in your University shop or in your basement. Become a part of the science center team as a regular volunteer. At first, the staff might not understand how you can help or that they need you. But they will soon see that you can help them present more accurate science to their visitors. You may even find they will ask you to become a member of their regular staff. (Attention graduate students: in this shrinking job market, science centers are a growth industry.) Gain their confidence. You will have a lot of fun and you will get a lot of very positive feedback. Then start discussing bringing modern physics into the center. Offer suggestions on a hands-on atom where the visitor can excite it to different levels, or some models of isotopes and signs that connect to real-life concerns.

Another area hungry for scientifically trained people are the teacher training programs at science centers. As a volunteer, or as a contract teacher, or as a member of the science center staff, you can participate in developing education programs and teaching classes or workshops. Not only can it be an opportunity for an avocation or vocation, but it can be a way to make a significant contribution to solving the deepening crisis of science illiteracy in our country.

I am more than happy to serve as a "marriage broker" and help form such partnerships. Please contact me at
MALAMUD@FNAL.GOV or MALAMUD@SCITECH.COM

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References

1. Frank Oppenheimer, "A Rationale for a Science Museum," reprinted from Curator, November 1968.

2. George W. Tressel, "A Museum is to Touch," 1984 Encyclopedia Britannica Yearbook of Science and the Future.

3. Sheila Grinell, "Science Centers Come of Age," in *Issues in Science and Technology* Spring 1988.

4. Sheila Grinell, "A New Place for Learning Science," published by the Association of Science-Technology Centers (1992.)

5. Miriam E. Bleadon et al, "Building Blocks of the Universe," presented at the Fourth IISSC, March 4-6, 1992 and published in the conference proceedings (Plenum, 1992.)