Stanford Linear Accelerator Center
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Remarks
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Thank you for inviting me to speak on this happy occasion. In the fall semester of 1959, I took a course in electromagnetism at Princeton from G.K. O'Neill, who had proposed a storage ring for e- e- collisions. As O'Neill discussed his work, which fit well with the course material, I heard much about physics at Stanford, and eventually decided to study here as a graduate student. I arrived in the Fall of 1963, just a year after the founding of SLAC, and have followed the fortunes of this great facility ever since. I was at the University of Southern California working on applications of classical field theory in optics when the first signs of structure within the proton were reported – work that earned the 1990 Nobel Prize for Taylor, Kendall and Friedman. And I was chairman of a committee that nominated the "California Scientist of the Year" in 1977. The prize went to Gerson Goldhaber for his participation in a SLAC collaboration that observed "naked charm" in D mesons. The corresponding quark-antiquark meson, having modestly hidden its charm, merited only a Nobel Prize in 1976 for Richter and Ting. The particle they observed is the only one I know whose name changes as you fly over the continental divide (going West it changes from J/psi to psi/J.) The same runs at SPEAR in those days also disclosed evidence of the tauon, for which Martin Perl received half the 1995 Nobel Prize. These have been good years for SLAC, and I am delighted that this great laboratory is positioning itself today for decades more of outstanding work at the very foundations of physical science.

To begin the serious side of my remarks this evening, here are some words that seem appropriate to the state of fundamental physics as we enter the 21st century:

"We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.
Through the unknown, remembered gate
When the last of earth left to discover
Is that which was the beginning;
At the source of the longest river
The voice of the hidden waterfall
And the children in the apple-tree
Not known, because not looked for
But heard, half-heard, in the stillness
Between two waves of the sea.
Quick now, here, now, always –
A condition of complete simplicity
(Costing not less than everything)
And all shall be well and
All manner of thing shall be well
When the tongues of flame are in-folded
Into the crowned knot of fire
And the fire and the rose are one."

These closing lines of the fourth of T.S. Eliot's "Four Quartets" illustrate poetry's awesome evocative power. The language of poetry, especially T.S. Eliot's poetry, strikes resonances because its abstract manner of expression casts a broad net. The concrete words and subject matter are carefully chosen to awaken our perception of broad themes that reach far beyond the narrative of the poem.

I heard these particular lines years ago in a talk by Thomas Cottrell, a medical dean at Stony Brook, at an awards ceremony for young faculty members. They moved me so much that when it was my turn to speak, I put aside my notes and talked about the extraordinary convergence of particle physics and astronomy that was then emerging. The idea that somehow the end of the great reductionist adventure would be "to arrive where we started/ And know the place for the first time" seemed to capture a vision of the future course of fundamental science.

How convenient it has been for particle physics that Fred Hoyle's idea of cosmology turned out to be wrong! Hoyle's "continuous generation model" would offer little opportunity to probe the extremes of density and temperature that are typical at the origin of the rival "Big Bang model." The mechanism of the Big Bang (a phrase coined by Hoyle to ridicule the notion) turns the entire universe into a microscope. Distances out into space become times back into the past where scales shrink, and densities and temperatures soar. Our telescopes become detectors in the greatest high energy physics laboratory in nature, to observe the traces of the most awesome high energy event of all time.

We are very lucky to have this alternative means of studying microscopic phenomena, because the capacity of our technology to reach the necessary energies is lagging behind the phenomena we need to study. We know from galactic motions that there is more matter in the universe than we can see. And it seems likely that none of the stable objects in the current particle inventory of the Standard Model can account for it. But the exploration of the Standard Model itself, with its surprisingly wide spectrum of masses, has stretched our technology almost to the limit. We are at the ragged edge of society's ability to produce accelerators of the necessary size. We think we have the lightest Higgs excitation boxed in, and Fermilab's Tevatron may have a crack at glimpsing it. Surely CERN's Large Hadron Collider will excite a Higgs "something or other."

But the WIMPs, the Weakly Interacting Massive Particles that astronomers tell us must form clouds around all galaxies, may well have masses far beyond the scope of any accelerator yet conceived. The favored super-symmetry extension of the Standard Model exhibits a stable particle that might do the trick. Or perhaps the WIMPs are among the particles, such as axions, associated with mechanisms to explain "fine tuning" within the Standard Model, or all of the above.

It is important to understand these particles, because dark matter is important to the evolution of the cosmos. If we are going to use the cosmos as our laboratory, we need to know enough about the WIMPs to unravel their role in the cataclysmic early instants of the Big Bang. That means they have to be related to the Standard Model, and to the field theories whose details produce the properties of the vacuum.

Who ever would have guessed when SLAC began forty years ago that understanding the vacuum, basically empty space in our frozen epoch of cosmic evolution, would be the most challenging problem in physics today? The discovery in 1998, totally unexpected, that the expansion of the universe is *accelerating* , is both embarrassing and exciting. How could we have missed something that big? There is nothing in our current theories that even comes close to producing the right order of magnitude for the term in Einstein's equation, the cosmological constant, required for this effect. What the theory gives is a joke, more than a hundred orders of magnitude off the mark.

The vacuum plays an essential role in the inflation theories, to which Stanford scientists have contributed many of the most important ideas. And once again these theories are important because they lead to phenomena that must be understood to relate observable features of the universe to the structure and symmetries of microscopic models – models that may include strings, and that we hope will unify gravity with the gauge forces of the Standard Model. We are going to need all the help we can get to tie these future theories down to empirical reality.

The argument for building an accelerator beyond the LHC, it seems to me, must be strongly linked to these ideas. At some point we will simply have to stop building accelerators. I don't know when that point will be reached, but we must start thinking about what fundamental physics will be like when it happens. Theory, of course, will continue to run on. But experimental physics at the frontier will no longer be able to produce direct excitations of increasingly massive parts of nature's spectrum, so it will have to do something else. There are two alternatives. The first is to use the existing accelerators to measure parameters of the standard model with ever-increasing accuracy so as to capture the indirect effects of higher energy features of the theory, much as BaBar is doing today at this laboratory. The second is to turn to the laboratory of the cosmos, as physics did in the cosmic ray era before accelerators became available more than fifty years ago.

Are we ready for this? When the last accelerator is built, will there still be a gap in our knowledge that will prevent us from working productively in the "Laboratory of the Cosmos?" There is no question that our ability to interpret what we see in the sky depends on what we have learned about fundamental matter in our earthly laboratories. How strong is this dependence? How much more do we need from earth-bound accelerators before we can do without them? How can we best prepare for the end of the accelerator era in fundamental physics?

However, and whenever, this transition occurs, it is clear to me that the fates of deep space astronomy and particle physics are strongly entwined. In the long run, the future of particle physics lies in space-based experiments, and its productivity will depend on having a model of nature that is complete enough to exploit cosmic phenomena as a guide to theory. Now is the time to begin preparing for the long run.

I mentioned the "ragged edge" of society's ability to deliver big accelerators. "Society" likes science. It is willing to tax itself to provide funds for basic, discovery-oriented research. It reads popular science books, watches educational television shows on science, and encourages its young people to study such impractical science topics as dinosaurs and black holes. In Congress, science enjoys bipartisan support. All postwar administrations have supported basic research, including the administration of President George W. Bush. But there is a limit. Not, unfortunately, a well-defined or clearly articulated limit. We saw this in the saga of the Superconducting Super Collider. That project did not fail because of lack of love for particle physics, or even for lack of understanding of the importance of the Higgs mechanism. It failed, in my opinion, because the scale of the project exceeded a critical size – a size well within the ability of society to pay, but placed within a domain of society's parameter space that is unstable against chaotic behavior.

If the SSC was beyond a threshold of stability, and the LHC is beneath it, the Next Linear Collider is already in a gray area. I have expressed elsewhere my conviction, in agreement with the High Energy Physics Advisory Panel, that the NLC is a logical choice for a next big accelerator after LHC. I was always taken with the simplicity of lepton-antilepton collisions, which create "little big bangs" with simple spatial structure and simple quantum numbers. Moreover, I think a lepton collider is the right kind of machine to do precision experiments of the sort that are going to be necessary to probe mass regimes that are out of reach. Whether it will be the "last big accelerator," or whether a muon collider or something else will have that honor, I don't know. Perhaps we will find a way to keep building ever larger accelerators throughout the 21st century. But already with the NLC we are going to have to change the way such devices are financed. No single nation is likely to pick up as much of the cost of the NLC as host countries have in the past. To be successful, the project will need a new model of international support.

What can the science community do to increase the inclination of society to support these big machines? I think the best approach -- and this is after a year in Washington, D.C. -- is to tell the truth, the whole truth. But it must be told carefully, in language that society can understand.

The truth is that particle physics is as exciting as it ever was. It is not dead. The fact that we are having trouble seeing beyond the Standard Model is not bad news. It means that the next discoveries will have a disproportionate impact on our understanding of Nature. For the first time in a quarter-century experiment is driving theory at the frontier, and not the other way around.

The truth is that Nature functions in such a way as to bring together the science of the very large with the science of the very small, and that opportunities have emerged for discovery about the fundamental nature of the universe that we never expected. Technology places these discoveries within our reach, but we need to focus efforts across widely separated disciplines to realize the new opportunities.

The truth is that exploration of the new frontier will attract the best young minds who will produce new technology to overcome the barriers which define the limits of our perception. The excitement of discovery, and the human will to see farther are powerful sources of vitality in our society.

What we should not do is give the impression that the accelerators and other large scale apparatus are ends in themselves. Only the search for the ultimate shape of Nature can justify such large expenditures, and we must subordinate all other considerations to that grand end. Nor should we over-emphasize the practical impact of new technologies that will emerge from the search. Too few of us are truly aware of the actual histories of previous impacts. To those who know, the proposition that high energy physics was responsible for magnetic resonance imaging devices, for example, is naïve. And above all we should never assume that the lay public will not be able to appreciate what we are about. We need to support the science journalists who care, and those among us who have the knack of translating the fragmented and highly technical knowledge that is accumulating so rapidly into a coherent story as appealing to the lay public as it is to us.

I began with poetry, which can speak with such compelling effect that we imagine it to be the source of truth about ourselves and about the universe. This is an illusion. The truths that poetry evokes are within ourselves – within the experiences that lie in our memories and are drawn out by their resonances with the propositions of poetry's rhythmic lines. The truth lies in the experiences, the poetry comes later. In the final analysis the exploration of the universe is necessary to humanity because it provides the basis for its grandest art.

That sublime art, the comprehension in human terms, and the interpretation in human metaphors, of a decidedly unhuman universe, is the ultimate justification for institutions such as SLAC. It is fitting that we celebrate them on occasions such as this. Thank you for inviting me to help celebrate.

JHM
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