A symposium on 'High Energy Physics in the 21st Century' was held on 11 November 1995 at the Indira Gandhi Centre for Atomic Research, Kalpakkam as a part of the 61st Annual Meeting of the Indian Academy of Sciences, 10–12 November 1995 at Madras. The four themes of the symposium were: The Standard Model of High Energy Physics, Theoretical Scenarios for 10^3 GeV to 10^{19} GeV, Hints of New Physics from Cosmology, Astrophysics and Nonaccelerator Experiments, and New Ideas on Acceleration to Planckian Energies. Talks bearing on these themes were given by D. P. Roy, Romesh Kaul, Ramanath Cowsik and Abhijit Sen respectively. Three of these talks along with an introductory overview (by GR) and a final summary (by RR) which were also given in the Symposium are included in the following collection.

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High Energy Physics in the 21st century – An overview

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AT the beginning of the 20th century, the quest for the understanding of the atom topped the agenda of fundamental physics. This quest successively led to the unravelling of the atomic nucleus and then to the so-called 'elementary' particles – proton, neutron, pion, electron, etc. Particle Physics or High Energy Physics (HEP) made rapid strides in the latter part of this century, especially in the 60s and 70s. These developments culminated in the construction of the gauge theory of quarks and leptons. This theory which goes by the rather prosaic name of 'The Standard Model (SM) of High Energy Physics' was constructed almost in its final form by 1973 and since then it has passed with flying colours *all* the experimental tests performed in the next 20 years. So, at the end of the century, we now have a highly successful theory which is valid, down to a distance scale of about 10^{-16} cm (8 orders of magnitude smaller than the atomic scale). This theory can now be regarded as *the basis of all of physics except gravity*. This success story is described in the article on page 111 by D. P. Roy.

1900 A.D. ——————————→ 2000 A.D.
Atoms → Nuclei → Particles → Gauge theory of quarks and leptons
——*——————————————*——→
10^{-8}cm $\qquad\qquad$ 10^{-16}cm

The SM is a theory for all that is known in HEP, namely the weak, electromagnetic and strong interactions of the quarks and leptons. However, this is not the end of the story. There are too many loopholes and unsolved problems within SM: Higgs and symmetry breaking, QCD and confinement, neutrinos, CP and its violation, etc. The solution of these problems may already take us beyond SM.

However, the biggest loophole in SM is the omission of gravitation, the most important force of nature. Hence, it is now recognized that *Quantum Gravity (QG) is the next frontier of HEP*, and that *the true fundamental scale of physics is the Planck energy 10^{19} GeV*, which is the scale of QG.

In quantum mechanics, there is an inverse relationship between the length scale and the energy needed to probe that scale. A few characteristic length and energy scales are given below:

Landmark	Length	Energy
Nuclear physics	10^{-13} cm	200 MeV
Standard model	2×10^{-16} cm	100 GeV
↓	↓	↓
Quantum gravity	2×10^{-33} cm	10^{19} GeV

One can see the vastness of the domain one has to cover before QG is incorporated into physics. In their attempts to probe this domain of $10^2 - 10^{19}$ GeV, theoretical physicists have invented many ideas such as supersymmetry, supergravity, hidden dimensions, etc and based on these ideas, they have constructed many beautiful theories, the best among them being the superstring theory, which may turn out to be the correct theory of QG. These 'Theoretical scenarios for 10^3 GeV to 10^{19} GeV' is the topic of Romesh Kaul's article (page 116).

But, physics is not theory alone. Even beautiful theories have to be confronted with experiments and either confirmed or thrown out. Here we encounter a serious crisis facing HEP. In the next 10–15 years, new accelerator facilities with higher energies such as the Large Hadron Collider (~ 10^4 GeV) or the Linear Electron Collider will be built and so the prospects for HEP in the immediate future appear to be bright. Beyond that period, the accelerator route seems to be closed because known acceleration methods cannot take us beyond about 10^5 GeV. It is here that one turns to 'Hints of new physics from cosmology, astrophysics and nonaccelerator experiments'. This topic was covered by Ramanath Cowsik in the Symposium. (Unfortunately, his talk could not be included in the present collection.)

Very important hints about neutrinos, dark matter, etc. have come from Astrophysics and Cosmology. Nonaccelerator experiments on proton decay, neutrino masses, double beta decay and 5th force are important since they provide us with indirect windows on superhigh energy scales.

In spite of the importance of astroparticle physics and nonaccelerator experiments, these must be regarded as only our first and preliminary attack on the unknown frontier. *These are only hints!* Physicists cannot remain satisfied with hints and indirect attacks on the superhigh energy frontier. *So, what do we do?*

As already mentioned, the outlook is bleak, because known acceleration methods cannot take us far.

To sum up the situation, there are many interesting fundamental theories taking us to the Planck scale and even beyond, but unless the experimental barrier is crossed, these will remain only as metaphysical theories.

It follows that either, *new ideas of acceleration have to be discovered* or, *there will be an end to HEP by about 2010 A.D.*

It is obvious what route physicists must follow. Hence, we have the very important article – 'New ideas on acceleration to Planckian energies' by Abhijit Sen (page 121). Some of the ideas being pursued are laser beat-wave method, plasma wake field accelerator, laser-driven grating linac, inverse free electron laser, inverse Cerenkov acceleration, etc. What we need are a hundred crazy ideas. Maybe, one of them will work. Lawrence's discovery of the cyclotron principle is not the end of the road. Here lies an opportunity of discovery our country should not miss.

A task force for new methods of particle-acceleration

It is high time that we form a small group of people as the task force whose aim shall be to do research and discover new methods of acceleration. This should be a multidisciplinary team including laser, plasma and accelerator specialists. It must include particle-detector specialists also, since the success of this venture will ultimately depend on our mastery of not only new methods of particle-acceleration but also new methods of particle-detection. One or two theorists with bright ideas may play a useful role in this group.

What is contemplated is *not* a new Institute or a new Department in any existing institute, but rather a think-tank of young people in existing institutions who are prepared to commit a significant part of the next 25 years of their careers to this visionary dream of creating a Planckian accelerator in the laboratory. These must be people with their eyes and minds turned on the heavens but with their feet placed securely on the earth and their hands actively engaged in the laboratory. They must be visionaries prepared to gamble on crazy ideas, but at the same time, having the capacity to test the ideas in down-to-earth laboratories *in this country*.

One must guard against big expenditure of money; the emphasis must rather be on investing on ideas. Clearly, what is expressed above is only the sketch of a proposal. Much more thought is required, to carry it forward to the practical stage. Hopefully, if the seed is planted now, it may grow and fructify in the next 25 years.

Finally, we must face the question: why should we do High Energy Physics? The answer can be given in the form of the following questions.

Is quantum mechanics for ever? Is relativity for ever?

Classical physics failed to explain the stability of the atom and thus quantum mechanics was born. Quantum gravity suggests that quantum mechanics may fail to explain the stability of space–time and so a new form of mechanics may be necessary. Such new discoveries may come only through the study of deeper regions of space–time. From this point of view, the onward march to shorter distances (higher energies) assumes a great significance. *Ultimately, the real justification for pushing the frontier of HEP to higher energies is the expectation that we will reach the boundaries of validity of our present view of the physical universe – based on our present conceptual framework of space–time (relativity) and our present understanding of dynamics (quantum mechanics) and that the new discoveries will take us beyond those boundaries.*