

# ACCELERATOR EXPERIMENTS FOR THE UNIFICATION

I. P. Neupane, Dept. of Physics, \*Tribhuvan Univ., Kathmandu; \*Seoul National University, Seoul

## Abstract

The spectrum of the elementary particles known today sets the scale of our future explorations. It is dominated in the boson sector by the W-Z triplet,  $m_w = 80.2 \pm 0.2$  GeV and  $m_z = 91.189 \pm 0.004$  GeV, and in the fermion sector by the top quark,  $m_t = 175.5 \pm 5.1$  GeV. Supersymmetric models imply the existence of many undiscovered particles that would be the partners of the particles, which we know today. Most models predict that several of them should populate the 100 – 1000 GeV mass ranges in which the Higgs mechanism is expected to operate. Our current knowledge of the particle world points to a mass range extending typically an order of magnitude above the W-Z mass for future exploration. In order to reach the large mass at which we target, the new accelerators must be operated in the collider mode rather than in the fixed target mode. In practice pp and  $e^+e^-$  colliders are only the tools able to reach such luminosity. Synchrotron radiation losses prevent the operation of  $e^+e^-$  colliders above the LEP-2 energy range (80 GeV). In pp case, synchrotron radiation losses remain small and a circular design can be maintained.

## 1 INTRODUCTION

The collider physics program includes the exciting prospect of confirming the first evidence for top quark production and studying its properties besides,

- precision of Electro-weak measurements of the W-width,

- the three boson couplings,
- a great variety of unique QCD tests,
- a rich program of b-quark physics,

and the search for new phenomena at the highest collision energies<sup>(1)</sup>. It is certain that the discovery of top quark opens a new direction for particle physicists to run their accelerators for the next century with new tools and developments of high gradient and high current accelerating structure. The mass spectrum of the elementary particles is dominated in the boson sector by the W-Z triplet<sup>(1)</sup>,  $m_w = 80.2 \pm 0.2$  GeV and  $m_z = 91.189 \pm 0.004$  GeV and in the fermion sector by the top quark<sup>(2)</sup>,  $m_t = 175.5 \pm 5.1$  GeV. A clear fact that the weak bosons have a non zero mass – in contrast with photons and gluons, calls for a mechanism preventing the divergence of the theory. The Higgs mechanism plays precisely this role. In the manner Higgs mechanism describes SU (2)  $\times$ U (1) symmetry breaking with the help of a single neutral scalar and in the form requiring the minimal number of additional particles, the vacuum expectation

value would be<sup>(1)</sup>,

$$v = (\sqrt{2}G_F)^{-1/2} = 2m_w / \left( \frac{e}{\sin \theta_w} \right) = 250 \text{ GeV}$$

and  $60 \text{ GeV} < m_H < 550 \text{ GeV}$ <sup>(3)</sup>. If the Higgs boson is not realized in nature, the W and Z bosons become strongly interacting particles at about 1 TeV energy. In such scenario the experimental upper bound of  $\sim 1$  TeV can be reinterpreted as the cut off scale to which the Standard Model of fermions and vector bosons may be expanded before new physical phenomena become apparent<sup>(4)</sup>.

## 2 PHYSICAL CONSTANTS AND UNIFICATION

When we combine the Planck relation,  $E = h c / \lambda$  with Einstein's mass energy relation, we find the Compton wavelength,  $\lambda = h / M c$ . In units with  $G = h = c = 1$ , all the physical quantities are essentially dimensionless. This is the final unification that mankind awaits, the unification of gravitational and quantum theories. Though no such theory of quantum gravity has been formulated yet, an indication of the scale of the unification can be had if one considers the gravitational energy of two equal masses separated by a distance equal to the Compton wavelength. The relation,

$$E = \frac{GM^2}{r} = \frac{GM^2}{\lambda} = \frac{hc}{\lambda}$$

gives the Planck mass. The Compton wavelength of the Schwarzschild radius of this mass is the Planck length,

$$l_p = \frac{h}{M_p c} = \frac{GM_p}{c^2} = \left( \frac{hG}{c^3} \right)^{1/2} \sim 10^{-33} \text{ cm}$$

and the time taken by light to travel a distance of  $l_p$  is the

$$t_p = \left( \frac{hG}{c^5} \right)^{1/2}$$

Planck time,

while our measurement now is good enough to the order of pico-second only. The Planck mass which is much larger than the mass of the elementary particles really represents the quantum of energy exchanged in interactions at Planck scale.

Since we cannot ever do experiments at  $10^{19}$  GeV or at  $10^{-33}$  cm, how could we ever test the primary theory

experimentally? These scales are many order of magnitudes higher and exclude direct exploration using accelerator experiments. So many believe that Superstring theory, because of its extraordinarily tiny length scale and gargantuan energy scale, cannot be tested. Either that belief is a myth<sup>(5)</sup> or it is the End of Science. One is the certain.

Some rare decay processes, such as

$$\mu \rightarrow e + \gamma, K \rightarrow \mu + e$$

are forbidden in the Standard Model, but not for general reason. So, it may be the case that these processes occur at some level in extension of the Standard Model and will give us information about small distance interactions. As evidence, the gauge couplings  $\alpha_1$ ,  $\alpha_2$  and  $\alpha_3$  seem to become equal above  $10^{16}$  GeV when calculated perturbatively in the Supersymmetric models<sup>(2)</sup>.

### 3 A NEW LAND TO BE EXPLORED

The theories including Supersymmetric predict the existence of several Higgs bosons. Also, required is a second doublet of complex Higgs fields with vacuum expectation values  $v_1$  and  $v_2$  coupling to down and up type fermions respectively, and related by,

$$1 = \frac{v_2}{v_1} \leq \frac{m_t}{m_b}$$

On one hand, the minimal Supersymmetric Standard Model (MSSM) predicts the existence of five physical Higgs bosons<sup>(4)</sup>.

- two CP-even neutrals mixing into  $h^0$  and  $H^0$  with mixing angle  $\alpha$
  - one CP-odd neutral  $A^0$
  - a pair of charged bosons:  $H^\pm$
- satisfying the inequalities

$$m_{h^0} < m_Z < m_{H^0}, m_{h^0} < m_A < m_{H^0}$$

$$m_W < m_{H^\pm}, m_{h^0} \approx 130 \text{ GeV}$$

On the other hand, the Supersymmetric models imply the existence of many undiscovered particles that would be the partners of the particles which we know today. The two families are related by R-parity that transforms bosons into fermions and fermions into bosons. SUSY predicts that every known lepton has a partner with spin zero. This theory does not require that the particle partners have the same masses; and no supersymmetric partners have been found. The lower limits on the masses once again are 45 to 80 GeV/  $c^2$ . Most models predict that several of them should populate the 100-1000 GeV mass range and the Higgs mechanism plays the role. So, we should continue searching for new phenomena at the lower end of this mass range. Unless we prepare new tools and get a clear hint about these phenomena through

two complementary approaches: a circular proton collider and a linear  $e^+e^-$  collider, we are no more sure about the existence of either the five Higgs bosons or the supersymmetric particles.

In order to reach the large masses at which we aim, the new accelerators must be operated in the collider mode rather than in the fixed target mode. The energy available for the production of new particles is  $(2E_{\text{beam}}/m_{\text{target}})^{1/2}$  times higher in the former case. However, the control of very dense nanometric beam and the development of high gradient and high current accelerating structures are among the most challenging. Can the accelerator labs be proved as right track for future exploration toward unification? This has become a clear and urgent goal of particle physicists. Shall we wait for the result of the decisive experiments at Fermilab's Tevatrons of proton-antiproton collider of  $\sqrt{s} = 1.8$  TeV by 2003 or we can expect a new general principle in particle physics from KEK? We enter the twenty-first century of leptone research again with mysteries and puzzles to solve.

### 4 CONCLUSIONS

The present knowledge of particle physics points to the mass range of 100-1000 GeV as the domain to concentrate the accelerator experiments for the twenty-first century. The  $e^+e^-$  linear colliders operating in TeV range are able to shed light on the details of WW scattering channels. Analogous processes can be studied at the CERN Large Hadron Collider (LHC) while the Tevatron and LEP-2 should continue searching for new phenomena at the lower end of the mass range. On the theoretical front, the large mass of the top quark encourages the particle physicists to think that the two mass problems- the fundamental fermion and boson masses- may be linked at the electroweak scale. Tevatron, KEK, LEP-2 and others can continually search for new phenomena at the lower end of the mass range 100-1000 GeV with new tools and developments of high gradient and high current accelerating structure.

### 5 REFERENCES

- [1] P.Darriulat: Lecture Notes, 5th Summer School on HEP, 97(1996)
- [2] Chris Quigg: Physics Today, 22, May 1997.
- [3] A.Blondel: ICHEP'96, Pro.of 28th International Conference on HEP, Poland (1997).
- [4] E.Boos et.al.: Phys.Rev. D-57, 1553 (1998)
- [5] G..Kane: Physics Today, 40, Feb.1997.