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OVERVIEW OF THE LBL WORKSHOP

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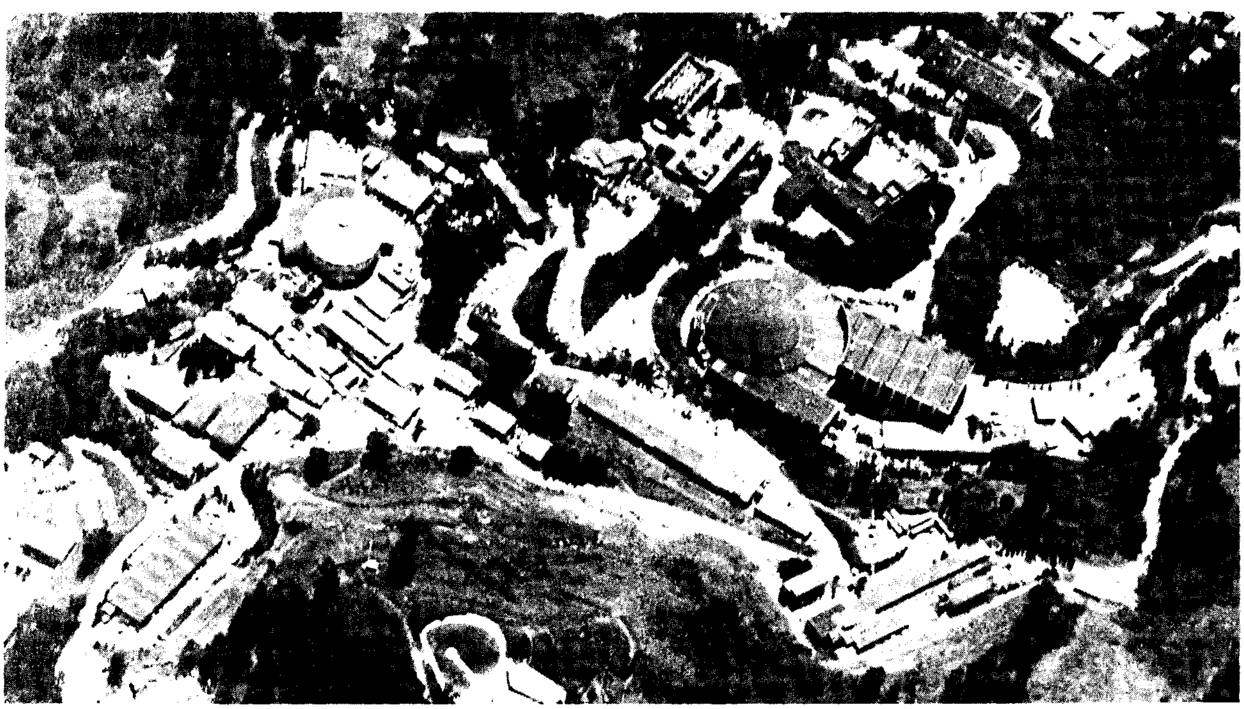

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OVERVIEW OF THE LBL WORKSHOP

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This overview of the LBL Workshop on Electro-Weak Symmetry Breaking at the SSC is provided as a brief guide to the more detailed papers which follow. It is based on a talk given at the opening of the Snowmass workshop and is intended mainly for a non-theoretical audience. The comments expressed in this overview are mine and do not necessarily represent the view of the majority of participants.

The LBL workshop had a loose organizational structure; theorists often work best in a freewheeling environment. Several subgroups were formed to attack some of the more important theoretical problems relevant to physics at the SSC.

These groups discussed

1. Non-Standard Higgs
2. Intermediate Mass Higgs
3. Non-Standard Higgs Bosons
4. Strongly Interacting W's and Z's
5. Supersymmetry
6. Interpretation of Unusual Events from CERN and DESY
7. Compositeness

The reports of the the subgroup chairmen can be found following this article.

In addition, a number of seminars were held with two purposes. Firstly, talks were given at the opening of the workshop to acquaint participants with the current state of affairs. Only two of these talks are included in the Proceedings. The one by M.K. Gaillard which acts as an introduction to the workshop and sets out its goals and the one by J. Ellis on the status of European Facilities. Other talks were given by Jay Marx (reporting on the SSC Reference Design, Ref. 1), Stu Loken (reporting on the activities of the PSSC, Ref. 2), Bob Cahn (reporting on the Chicago Workshop, Ref. 3), Dave Jackson (reporting on the ICFA meeting held in Japan in late May, Ref. 4), and Chris Quigg (reporting on some conclusions of EHLQ, Ref. 5). These talks all cover material which is readily available elsewhere and are not included in these proceedings.

Secondly, seminars were held on topical subjects relevant to the SSC. These seminars are written up in these proceedings and will not be discussed further in this summary.

The group looking at the new and unusual events from CERN and DESY attempted to draw together the information from these odd events, summarized in Table 1 of the report (L. Hall, et al., Ref. 6). They looked at and evaluated the various theoretical proposals for these events. In particular, they tried to look for common features of the events and to search for explanations which are capable of dealing with more than one type of event.

I will first comment on the events from the UA1 and UA2 collaborations with missing transverse energy (Ref. 7). The invariant mass of the system with the large transverse momentum in these events is quite large, the transverse mass of the jets, leptons, "photons" and missing transverse momentum provides a lower bound on the invariant mass of the parton-parton system which generates the final state. This transverse mass is given for the UA1 events in Table 3 of the report which shows that it is of order 100 GeV. The UA2 events with leptons and jets have a total invariant mass of order 150 GeV (roughly the same as the jet-jet mass peak also claimed by UA2) if they are interpreted as final states of W plus jet. The typical mass of the parton-parton system in either case is of order 150 GeV. In order to have a chance of explaining the rate of these events, the cross-section in the parton-parton system must be due to strong interactions, and the particles in the final state will be strongly interacting. This simple observation follows from the typical values of parton momenta which are required and the behavior of the parton distribution functions. The "old" physics background to these events is from W/Z + Jet final states which has a partonic cross-section of order $\alpha_s\alpha$ and is consequently much too small to explain the signal given that the W/Z has to decay leptonically in order to generate the missing transverse momentum.

The only candidate proposed by theorists before the events were found is supersymmetry which generates events with jets and missing transverse momentum. The immediate difficulty is that one naively expects events with several jets, two from events with squark pairs and four from events with gluino pairs. Some of these jets will either be soft or will coalese so that the physical final state could consist of fewer than the expected number of jets. Figure 6 of Hall et al. shows this effect. However, a problem remains with the supersymmetric interpretation of the events; the multiplicity of particles within, and the invariant mass of, the jets in the UA1 sample is lower than is expected. Also, although the number of events is small, the transverse momentum distribution is rather flat in the UA1 case, another problem which is not obviously explained by supersymmetry.

All other candidate explanations were invented after the events were found; they are summarized in Table 8 of the subgroup report. None of them is very compelling, and some fail to explain the quantitative features of the events.

The events interpreted as Z decay to $e^+e^-\gamma$ or $\mu^+\mu^-\gamma$ (Ref. 8) are summarized in Table 2 of the subgroup report. The most natural explanation is in terms of Bremsstrahlung, it gives a Dalitz distribution which agrees with the data but unfortunately has a rate which is a factor of fifty too small. None of the explanations discussed by the group are particularly compelling and most fail to explain the Dalitz distribution.

The other odd events found at PETRA (Ref. 9) are at a rather small rate and it is not completely clear that they are inconsistant with background. There is only one event from CELLO of the type $\mu^+\mu^- + 2$ jets. Again they were not anticipated by theorists although a number of explanations were discussed. The conclusion of this group was that one should wait and see. If the UA1 events are real the next run should settle the issue and provide more detail which would enable some of the explanations to be excluded.

If any of these strange events turns out to be real, their implications for the SSC are difficult to assess. In the case of supersymmetry, the working group looked at the consequences of supersymmetric particles in the 50 GeV mass range. In this case at 40 TeV the proton will have a sea of supersymmetric particles, which can initiate reactions at these energies. The report of J. Ellis (Ref. 18) can be consulted for more details.

Three groups were concerned with various aspects of the physics of the Higgs system. In the minimal Weinberg-Salam model there is one physical scalar whose mass is undetermined. If this mass is greater than 1 TeV or so, perturbation theory for the sector involving the Higgs and the W and Z becomes unreliable and a clear prediction of the behavior of the theory is lacking. If the Higgs is lighter than 1 TeV it is important that experiments are possible which can detect it over the whole mass range. If its mass is less than 70 GeV or so the various e^+e^- machines (LEPI, LEPII or SLC) should be able to find it. If its mass is greater than $2M_W$, it should be detectable at the SSC via its decay to either a W pair or a Z pair (see the report of Ken Lane, Ref. 10). In the case of the Z pair final state there should be enough events even if the Z can only be detected in its muonic and electronic decay modes. This leaves the mass region between the e^+e^- limit and $2M_W$. Here the Higgs will decay dominantly into t quark pairs (or b pairs, if its mass is below $2m_t$). The rate is large but the background for QCD production of t quark pairs is dominant so that even an experiment which could distinguish between t quark jets and other jets could not find the Higgs using this process (Ref. 5).

A suggestion by Gunion, Soldate, Kalnyiak and Galison that the associated prooduction of a W and the Higgs could provide a better signal to background ratio looks extremely promising. The report by Lane and the article contributed by Gunion, et al. (Ref. 11) to the Snowmass Proceedings discuss the issues in detail. The presence of the W, whose leptonic decay can be used as a tag, greatly improves the signal to background ratio. The usefulness of the process hinges on the ability to identify t quarks efficiently and in particular on the abilitly the reject other quarks (notably b) very strongly. The event rate is not large, the report of Lane suggests that at a luminosity of 10^{33} cm^{-2}sec^{-1} a t quark detection efficiency of atleast 25% is needed.

In the case that the Higgs mass exceeds the 1 TeV value the behavior of the theory and hence the experimental signals are not so clear. The report of the group headed by M. K. Gaillard (Ref. 12) can be consulted for details. There is an argument due to Einhorn (Ref. 13), based on an expansion in 1/N where the gauge theory is SU(N) so that $N = 2$ for the Weinberg Salam model, which suggests that there will always be a scalar bound state below 1 TeV. This particle would behave in much the same way as an elementary Higgs and should therefore not be too hard to find. A more pessimistic scenario is that the only manifestation of this large Higgs mass is a strongly coupled W and Z sector above 1 TeV. Models were looked at by the "Strongly interacting ..." group based on extrapolations from the behavior of the pion-pion system (which is due to another strongly interacting theory, QCD) and were used in order to predict event rates at the SSC. In particular, estimates were made of the multiplicity of W and Z final states. The main signals of this strongly interacting system are:

(a) A larger ratio of 3W and 4W final states to 2W final states than is predicted on the basis of quark anti-quark annihilation.

(b) A ratio of Z pair to W pair cross sections which is larger than that expected from quark anti-quark annihilation (Ref. 18). Furthermore this ratio should be larger at large pair masses.

(c) Variation of the W and Z pair cross-sections with the invariant mass of the pair which is different from that expected from production via quark anti-quark annihilation. The final states with 2 W's or 2 Z's should occur with rates large enough to defect even if we are severely limited in the number of W and Z decay modes which can be detected.

The event rates in some of the most pessimistic scenarios for the final states with three or more gauge bosons are not large and may be difficult to measure unless one can reconstruct W's and Z's from their hadronic modes with reasonable efficiency. This important question of the detection of W's and Z's was dicussed extensively at the Snowmass meeting and the report of Fernandez et al. (Ref. 14) should be consulted for more details.

The group on "Nonstandard Higgs" (P. Langacker, Ref. 15) considered the signals for Higgs production in models with Higgs sectors which are more complicated than the minimal Weinberg Salam model. The simplest extension is a model with two Higgs doublets. In such a model there are three neutral Higgs bosons and a charged pair. The couplings of these bosons to quarks and leptons is not fixed, but a generic feature is that the couplings of one neutral boson are enhanced relative to those in the minimal model while the couplings of another are supressed. The mechanisms for producing these neutral bosons are similar to those of the minimal model except that the rates may be enhanced. The signals are also similar. The production rates for charged Higgs bosons are rather small. (See also Eichten et al. Ref. 16). The only effective mechanism, unless there are quarks much heavier than the top, is the Drell-Yan one via an intermediate Z or γ where a pair of charged Higgs are produced. The charged Higgs will decay to a top and anti-bottom quark. In a model with Higgs in doublet representations only there is no WZH^+ vertex so that the Higgs cannot decay to ZW. The background in the top anti-bottom channel is small but good discrimination between jets of differant flavors is essential if charged Higgs are to be observed.

In models with both Higgs doublets and triplets there will appear doubly charged Higgs as well as singly charged ones with ZW couplings. In these cases WW or WZ fusion (Ref. 17) will be an effective mechanism for the single production of these Higgses. The rates are comparable to those of the neutral Higgs in the minimal model (Refs. 15 and 5).

The group looking at supersymmetry (J. Ellis Ref. 18) discussed alternatives to the "conventional" supersymmetric models in which the lightest superpartner is stable and is neutral and weakly interacting, usually a photino. This conventional scenario is favored by most theorists and is the one most often used in phenomenological discussions (Ref. 19). In this scenario the classic signature is of events with missing momentum, carried off by this lightest superpartner. This signature would be lost if the lightest sparticle were stable and were a gluino. In this case the gluino would deposit its energy in a hadronic calorimeter. Fortunately, it is rather unlikely that this scenario will be true, stable particle searches suggest that only a range of between 1 and 5 GeV is open for such a gluino's mass.

In certain models (Ref. 20, 21), the lightest sparticle may not be stable. Some such models (Ref. 20) are constrained by limits on neutrino masses and on the rate $\mu \to e\gamma$. Others are not constrained by existing data (Ref. 21). An important conclusion of the group was that in these models the missing momentum signature is diluted but not lost (Ref. 18). The missing momentum may also be accompanied by prompt hard photons.

In supersymmetric models there must be at least two Higgs doublets, so some of the discussions of the "Non-standard Higgs" group are relevant here. The minimal supersymmetric model with two doublets is more constrained than the two doublet non-supersymmetric model (Ref. 18). In particular there is almost always one neutral Higgs lighter than the Z^0 (Ref. 22). As in other two doublet models certain Higgs couplings can be enhanced.

One other area of theoretical speculation which was discussed by one of the groups concerns the issue of compositeness of quarks and leptons (Ref. 23). Motivated by the apparent arbitrariness of quark and lepton masses, some theorists have speculated that they may not be elementary but rather composed of some "preons". No semi-realistic model has yet emerged. Some signals for composite structure at the SSC are discussed in Ref. 5, but some work was begun on the question "What happens if the scale of compositness is 1 TeV and hence can be crossed at the SSC?" There was also some discussion of the use of polarization for disentangling the structure of any interactions caused by compositeness.

Finally, I would like to thank all those who helped to make this workshop so enjoyable and fruitful. My co-organizers Mary K. Gaillard and Tom Appelquist for their valuable work in planning and organization, the working group chairmen for summarizing clearly and concisely the work of their groups, Susan Fidelman for dealing with the day to day running of the workshop and for assisting in the preparation of these Proceedings, and finally to all the particpants for their enthusiasm and hard work.

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References

[1] Superconducting Supercollider Reference Designs Study for the U.S. Department of Energy, May 8, 1984.

[2] Summary Report of the PSSC Discussion Group Meeting, edited by P. Hale and B. Winstein, FNAL, 1984.

[3] $\bar{p}p$ Options for the Supercollider, edited by J.E. Pilcher and A.R. White, University of Chicago, 1984.

[4] Seminar on Future Prospectives in High Energy Physics, K.E.K., May 14-19, 1984.

[5] E. Eichten et al. Supercollider Physics, Rev. Mod. Phys. **56**, ???? (1984).

[6] L. J. Hall, R. L. Jaffe and J. L. Rosner, these proceedings.

[7] C. Arnison et al., Phys. Lett. **139B**, 115 (1984); C. Rubbia, Talk at the 4^{th} International Workshop on $p\bar{p}$ Collider Physics, Bern, 1984; P. Bagagnia et al., Phys. Lett. **139B**, 105 (1984).

[8] G. Arnison et al., Phys. Lett. **135B**, 250 (1984); P. Bagnaia et al., CERN EP/84-39.

[9] H. Berend et al., Phys. Lett. **141B**, 145 (1984); U. Becker and J. Branson cited in Ref. 6.

[10] K. Lane, these proceedings.

[11] J. Gunion et al. Finding an Intermediate Mass Higgs Boson, to appear in Proc. of the DPF Summer Study on the Design and Utilization of the SSC.

[12] M. K. Gaillard, these proceedings.

[13] M. B. Einhorn, University of Michigan preprint UM-HE-84-3 (1984).

[14] E. Fernandez et al. to appear in Proc. of the DPF Summer Study on the Design and Utilization of the SSC.

[15] P. Langacker, these proceedings.

[16] E. Eichten et al. to appear in Proc. of the DPF Summer Study on the Design and Utilization of the SSC.

[17] S. Dawson, LBL-17497 (1984).

[18] J. Ellis,"Supersymmetry", these proceedings.

[19] S. Dawson and A. Savoy-Navarro to appear in Proc. of the DPF Summer Study on the Design and Utilization of the SSC.

[20] L.J. Hall and M. Suzuki, Nucl. Phys. **B231**, 333 (1984).

[21] G.G. Ross and J.W.F. Valle, in preparation.

[22] Probir Roy, seminar presented at this workshop, these proceedings.

[23] I. Bars, Report of the compositeness working group, these proceedings.

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