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THE NEED TO PLAN FOR A FULL-SCALE "ℓns-PHYSICS" PROGRAM AT THE SSC

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ABSTRACT

Arguments for a full "ℓns physics program" at the SSC are enumerated and elaborated on. They are: first—the inadequacy of data from a minimal program, second—the potential fundamental significance of a high-energy soft physics collective phenomenon and third—the possible diffractive production of much of the interesting "new physics" that will be searched for.

My task is to report on the theoretical discussion at this workshop of "inelastic" ℓns physics. If I begin by addressing the central questions for the workshop then the conclusions are immediate and simple and coincide with those of previous speakers.

1. Is there a distinction between the physics that can be studied at pp and $\bar{p}p$ colliders?

   All available knowledge on this question surely says no.

2. Is there anything to be learned by comparing pp and $\bar{p}p$ ℓns physics?

   The conventional wisdom is, of course, that pp and $\bar{p}p$ ℓns physics will be identical and certainly all experimental evidence points to this conclusion. However, it is worth remembering that there is no fundamental theoretical understanding of why this should be so. Personally I believe it tells us something very special if it is the case (that is if the underlying unbroken non-Abelian gauge group is bigger than SU(3), I expect[1] "ℓns" differences between pp and $\bar{p}p$ processes). I also believe that future generations will believe it vital to test this.

3. What luminosity is required?

   Again I follow other speakers in stating that low luminosity is fine, maybe even preferable!

Given my brief answers to the immediate overall purpose of this workshop I propose to report on our working group sessions by enlarging on why it is vital to plan for a full-scale program of ℓns physics both in the basic machine design and in the design of detectors. I propose to emphasize three distinct reasons which I shall first list and then enlarge on one after the other. I could, of course, simply appeal to the swings of fashion in theory, or to the empirical time dependence of the success of different accelerators and different kinds of detectors.

First reason - A minimal program of ℓns physics will simply produce data that is inadequate for even a phenomenological analysis of the self-consistency of the results--this was evident from our discussion of SPS collider data.

Second reason - High-energy soft-physics (perhaps another name for ℓns physics) may be a fundamental collective phenomenon which will ultimately fascinate particle physicists (both in its own right and because of its significance in QCD). KNO scaling is regarded by many theorists as a pointer in this direction (The scaling produced by both stochastic cell models and the Critical Pomeron were discussed by us).

Third reason - Much, if not all, of the conventional "new physics" that we have in mind in proposing the SSC may be most effectively produced diffractively. I shall even suggest that the electroweak Higgs system could be found diffractively.

THE INADEQUACY OF DATA

The decade of experiments at FNAL, the SPS, and the ISR, produced an enormous amount of data on low transverse momentum elastic and multiparticle processes. The community consensus is that very little fundamental was learned from such experiments. However, a lot of very thorough phenomenological analysis produced, for the most part, a good understanding of the inter-relation and self-consistency of data from all processes.

In contrast the minimal amount of data from the SPS $p\bar{p}$ collider on elastic, total and diffractive cross-sections has made it impossible to even determine whether or not there are distinctive phenomena in the higher energy range. This issue was discussed extensively in the workshop. For example UA4 results[2] imply that at large t and large M^2 (which is all they can measure) they see the same triple Pomeron cross-section (the same normalization) as at the ISR. Yet it is generally believed that the single diffractive cross-section has not risen from the ISR. This result is inconsistent with simple integration of the triple Pomeron formula (integrated over t)

$$\sigma_{SD} \sim \int_{M_0^2}^{\lambda s} dM^2 \frac{1}{M^2} \sim \ell n s$$

unless for some mysterious reason low mass diffraction is not produced as copiously at the collider as at the ISR.

The total single diffractive cross-section that UA5 infer[3] from their data is consistent in magnitude with that of UA4, and UA5 also see essentially no double-diffractive events (although the diffractive clusters they can detect may be inadequately separated in rapidity to be clearly detected[4]). Both features are surprising when compared with expectations from lower energy data, which were solid measurements of diffractive cross-sections. Since the higher energy data really is so limited compared to that at lower energies we really cannot make any firm conclusions.

The large fluctuations of multiplicity that UA5 see[3] in relatively small rapidity intervals look very interesting. Clearly what is needed is a good phenomenology of "normal" events which will distinguish the unusual events (whether they be "hot spots" of quark-gluon matter or anything else!) from the background. I would suggest that the Reggeon Calculus, which can actually be formulated[5] as a phenomenological theory of multiplicity fluctuations be used to this effect. The simplest example of relations between fluctuations that would be obtained is--

> events with twice the average multiplicity density on one half of the full rapidity interval and normal density on the other half, should contribute a cross-section twice that of the single diffractive cross-section. This is a simple application of the AGK cutting rules.[5]

With the enormous rapidity range available at the SSC it will be possible to study a vast range of rapidity-dependent fluctuation phenomena. Their consistent interpretation is bound to require a good measurement of all possible diffractive quantities. We will not get this if we simply plan for a repeat of the (up to the present) CERN $\bar{p}p$ collider ℓns physics program. If we are to learn anything from ℓns phenomena we must do more!

HIGH ENERGY SOFT HADRON-PHYSICS AS A COLLECTIVE PHENOMENA

The much discussed phenomenon of KNO scaling (which is strikingly present,[3] in at least the central rapidity region, in going from the ISR to the $\bar{p}p$ collider) has been seen by many theorists as strong evidence that a fundamental collective phenomenon is appearing in high-energy soft hadron physics. If this is the case it must surely be a uniquely exciting phenomenon. Condensed Matter and Statistical Mechanics physicists (and mathematicians) are currently working on a vast range of such phenomena in their own fields. If high-energy hadronic collisions producing several hundred particles in all kinds of configurations can really be regarded as such a phenomenon, then it can not be one of a standard array of possibilities. It must be unique in very many ways. Independent of its relation to QCD, it is not difficult to imagine a future generation of particle theorists deeply fascinated by such a phenomenon. In planning an accelerator of the magnitude of the SSC which will dominate experimental particle physics in two decades time it would therefore be very short-sighted not to build into the machine and detector designs the possibility to extensively study the relevant processes.

Carruthers[6] discussed the general possibility of a stochastic cell model for particle multiplicities. Particle emission is described by some small number (k) of cells containing stochastic fields distributed as Gaussian random variables. Predictions for multiplicity moments are then

$$\gamma_2 = \langle (n-\bar{n})^2 \rangle / \bar{n}^2 = \frac{1}{k} + \frac{1}{\bar{n}} \xrightarrow[\bar{n}\to\infty]{} \frac{1}{k}$$

$$\gamma_3 = \langle (n-\bar{n})^3 \rangle / \bar{n}^3 = \frac{2}{k^2} + \frac{3}{k\bar{n}} + \frac{1}{\bar{n}^2} \to \frac{2}{k^2} \; .$$

By relating galaxy clustering to hadron multiplicities Carruthers emphasized how similar turbulent or chaotic behavior can appear in vastly different systems simply sharing a common fractal dimension ("Fractal Dynamics").

The Critical Pomeron[7], formulated in terms of Reggeon Field Theory, also produces KNO scaling as well as many other high-energy scaling phenomena.[8] In the "ε-expansion" (the world has 6-ε space-time dimensions) Chiu and Wilson[9] have obtained

$$C_p = \frac{\langle n(n-1)\ldots(n-p+1)\rangle}{\langle n\rangle^p}$$

$$= 1 + \frac{\varepsilon}{12} \sum_{\ell=1}^{p} \left(\frac{4(2\ell-1)(p-\ell)}{\ell(\ell+1)} - \frac{(p+1)}{(p-\ell+1)} \right) + O(\varepsilon^2) \; .$$

The Critical Pomeron has the advantage that it connects up with the successful low energy Regge phenomenology of diffraction. I also think[1] it is likely to be the best language for deriving high-energy behavior from QCD.

I do not want to emphasize the success or failure of a particular "collective phenomenon" derivation of KNO scaling. There may actually be several ways that physicists will find of formulating the unique phenomenon that occurs in the real world. (From the history of physics it would be surprising if this were not the case.) I do wish to emphasize that the KNO scaling moments may be only a small sub-set of a whole range of "Fundamental Constants of Nature" which can be extracted from high-energy soft physics if there is a true collective phenomenon. The precise calculation of these numbers will be a deep theoretical challenge, whatever language is used. Personally I believe such numbers will certainly reflect the underlying strong-interaction gauge group and the very existence of the collective phenomenon may determine the fermion content. This brings me to my "third reason".

DIFFRACTIVE PRODUCTION OF "NEW PHYSICS"

My own attempt[1,10] to understand Critical Pomeron scaling in QCD suggests KNO scaling may be intimately related to an infra-red fixed-point produced by adding the maximal quark structure consistent with asymptotic freedom. The presence of such a fixed-point implies that the gauge coupling never evolves to the true strong-coupling regime. It maximizes the applicability of perturbation theory and could well be behind the striking success of QCD (as a parton model) in predicting jet cross-sections at the $\bar{p}p$ collider.

The most attractive quark structure to produce the infra-red fixed-point is

3 generations of color triplet quarks
\+ 1 generation of color sextet quarks.

Several people have suggested that a chiral condensate of color sextet quarks could produce the electroweak Higgs effect.[11] In this case there would be a profound relation between three effects observed at the CERN $\bar{p}p$ collider which are conventionally thought to be manifestations of distinct areas of physics, that is

(i) A soft-physics collective phenomenon
(ii) the parton-model (in QCD)
(iii) the electro-weak Higgs effect

The inter-relation between (i) and (ii) was essentially understood by Feynman[12] in his original formulation of the parton-model. To me it is very intriguing to consider that (i), (ii) and (iii) may actually be inter-related in a way that gives much more dynamical significance to the general idea of grand unification, at high-energy, of strong and electroweak interactions. Several points should be made if such a connection exists.

A. There has been much discussion at this workshop (particularly in the QCD section) as to whether heavy quarks have been and may be most effectively detected via diffractive production.[13] The production mechanism surely lies outside of conventional perturbative QCD but a general understanding of diffraction in QCD may well explain it--in itself this is a vital reason for studying the relation between (i) and (ii) above.

B. If the Higgs system is a chiral condensate of exotic QCD quarks not only will the self-interactions be strong, as several people are considering[14] to explain "unusual" SPS collider events, but Higgs "particles" and hence longitudinal W's and Z's will actually carry the full, familiar strong interactions.

C. If new "conventional" quarks are best looked for diffractively then so may be new "exotic" quarks. In fact the best "signature" of the Higgs system could be a diffractively produced new hadron spectrum composed of combinations of conventional and exotic quarks.

Since the most clearly delineated objective of the SSC is to understand the physics and scales behind the electro-weak Higgs system, I hope it is clear that this whole purpose could be greatly hindered, if not completely misdirected, if we do not adequately prepare to study diffractive processes. I emphasize therefore that we should prepare to study the physics of (i), (ii) and (iii) above with equal intensity at the SSC, not only because of their separate intrinsic interest, but also because they may be deeply related in a manner that we shall surely want to understand.

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