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Multiparticle Dynamics 1997: Concluding Talk *

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This contribution to the XXVII Symposium on Multiparticle Dynamics held in Frascati, Italy, September, 1997 consists of the following subject matter:

1. Introductory generalities.
2. Brief mention of some of the contributions to the meeting.
3. More extended discussion of a few specialized topics.
4. Discussion of the FELIX initiative for a QCD detector at the LHC.

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1. GENERALITIES

In this meeting there were a variety of important and interesting contributions, many if not most of which represent extrapolations of what has transpired in previous meetings in this series. I have discovered in fact that it is also true for this talk[1]. But anyway I felt a certain lack of focus in the course of the week, and it seems appropriate here to first review the most basic question to be asked: why do we do what we do in this field? In earlier times, when this series of meetings was initiated, it was to find out something about the nature of the strong force via multiparticle dynamics. But now at the fundamental level almost everyone agrees that this is a solved problem: the strong interactions are described by the Lagrangian and equations of motion of QCD. Only a few voices cry out from the most distant and obscure wildernesses on the planet, e.g. Milano, challenging the conventional wisdom.

This means for me that it is of less and less significance to “test QCD”, unless the test—usually a precise determination of α_s—is demonstrably superior to what has already been done. It becomes more and more important to “understand QCD”, which means to uncover all its consequences—especially those which lie beyond the methodology of perturbation theory—and provide appropriate descriptions of these phenomena. By “appropriate” means that they are at least in principle consistent with the general consequences of the underlying equations of motion, and at best derivable from them. It also is of course the case, almost by definition, that the best descriptions will account for the most data, will provide reliable predictions, and will be concise and comprehensive.

So the goal has not changed so much; in the first paragraph above, only the phrase “...the nature of the strong force...” has to be changed to “...the nature of QCD...”.

In this respect, we may compare QCD with its namesake QED, especially in the limit of HNET (heavy nucleon effective theory), i.e. atomic physics. Certainly the precision tests of QED are important, and remain so, just as for QCD. But beyond perturbative QED lies the physics of the ozone layer (atomic collisions and electromagnetic processes at very low energy), metallurgy, superconductivity, organic chemistry, and the life sciences themselves, just as examples. It is not necessary to approach these subfields direct from the QED Lagrangian, although it is a splendid thing to see how the derivations go. It is quite enough to savor them on their own terms.

It is hard to imagine that there ever will be the incredible richness of the HNET/QED world reflected in the world of QCD. But there are plenty of frontiers out there, with in my opinion the most

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interesting and exciting of them those which are the most nonperturbative, and least under direct theoretical control. To investigate them well demands, just as in HNET/QED, a very close interplay between theory and experiment.

Among the most basic frontiers of QCD is the question of what happens at much higher energy scales. The expectation is that there will be big changes in the phenomenology of generic hadron-hadron collisions, even at the qualitative level. This realization has been sharpened, at least for me, very recently. This is due to the emergence of a new initiative, FELIX, a detector proposed to comprehensively examine QCD phenomena at the LHC. I will return at some length to this in Section 4, because it is on my mind very much these days, and because it is an opportunity of great relevance to this field of multiparticle dynamics.

But there are many other QCD frontiers. There is an important large-distance frontier, something that can be called LQET (light-quark effective theory). Here the chiral effective action is the appropriate descriptive tool. There is a school of thought that it can be even derived, more or less, from the basic short-distance QCD action via integrating out the effects of instanton contributions. Instantons arguably are the driving mechanism of spontaneous breaking of the approximate chiral symmetry of QCD[2]. A more open question is how in detail confinement of color occurs; this is no doubt still the most important open frontier of QCD.

The large-distance theoretical frontier has an experimental counterpart. The extraordinary technological advances made in the large collider-detector community, both in high rate data acquisition and in precision tracking in complex background environments, has not been applied in full force to low energies. A fully modern detector for light-quark spectroscopy would play an important role; it is a pity that as far as I can see there is no such device even being proposed.

In between the short-distance and large-distance worlds of QCD lies the boundary region, and this is an area of crucial importance to the subject of multiparticle dynamics. Defining the energy and/or distance scale of this boundary is vital, as well as its "thickness": how much higher in energy scale or shorter in distance scale must one go before perturbative methods become reliable? There is an increasing tendency to push the boundary from the high energy perturbative side down to very low energy/momentum scales, especially in multiparticle dynamics, and I at least worry about how meaningful this is[1]. I will return to this question in Section 3.

Other important frontiers include the small-x, BFKL frontier in short-distance QCD, the problem of leading-particle behavior in hadron-hadron collisions, almost everything concerning inelastic diffraction, and even the parton structure of the nucleon. While there is a vast amount of information on the longitudinal distribution of partons in an infinite-momentum nucleon, there is almost nothing on how the different partons of a given configuration are correlated with each other. And there is very little information on how the partons are distributed transversely, even at the inclusive level. For example, we tell people that the proton is made of three (constituent) quarks. Then we also tell them (or should tell them) that there are an infinite number of quark-partons in the infinite-momentum proton. Where are they in the impact plane, relative to the location of the constituent quarks? Are they mostly inside them or outside? I think the honest answer is that we do not know the answer to such a simple question. I favor the latter option. But it remains the case that there is a frontier out there: what is the right answer and how do we find it out?

2. SOME INTERESTING NEWS

This is not a summary talk, and this section represents as close as it will get to being one, being a sequence of advertisements of some of the contributions that especially attracted my attention during the meeting. Only a few will be elaborated upon here, and in any case the best way to find out what any of them is really about, is to go directly to them and not to linger here expecting much more. It is also important to not trust this list and go straight to the rest of the proceedings.

NA50 (Giubellino[3]): The evidence for an unusual mechanism for ψ suppression in heavy ion collisions is to my eye quite impressive. What other properties of the collisions can be correlated with this abrupt change with increasing A? As always, I would like to understand the space-time geometry better; it seems that the ion-ion final-state system is already undergoing mainly spherical expansion at the ψ formation time for light-ion or noncentral collisions, while it may still be in a more dominantly longitudinal expansion stage for $Pb-Pb$ collisions. Can this change in the geometry have an effect on the change in the amount of suppression?

Screwy gluons: Bo Andersson's talk[3] featured, in addition to a fascinating, new (to me) argument for the value of the famous number $33/12\pi$ of QCD, a bold new idea on the color structure of the population of final-state soft gluons in the lego plot, namely that the color-lines connecting the emitted gluons wrap themselves tightly around the (cylindrical) lego phase space. It is so much fun that I cannot help but return to it in the next section, and attempt to describe it in my own language.

Gluon jets (Gary[3]): The DELPHI analysis of gluon jets tagged in $b-\bar{b}$ events continues to provide a supremely pure gluon-jet subset. They provide a superb standard of reference for basic gluon-fragmentation properties.

Rapidity gap events: Here there is steady progress from HERA and the Fermilab Tevatron, which I will not attempt to summarize. To me the most important news is that in the most recent D0 data on gaps between jets, the evidence seems to favor the color-evaporation mechanism described here by Halzen[3], and not the perturbative two-gluon-exchange mechanism (plus spectator effects) advocated by myself and others. If this holds up, there will be no known hard diffraction process where perturbative-QCD mechanisms are adequate for the description, however large the momentum transfer or virtuality of the projectiles. Again, I will return with an additional comment on this subject in the next section.

Observation of an exotic meson (Seth[3]; BNL E852): The evidence for a broad 1^{-+} state with mass about 1350 MeV, decaying into $\eta\pi$, looks quite good. Its quark-gluon structure should be either $q\bar{q}g$ or $q\bar{q}q\bar{q}$ and is the first of its kind to be established. It again is a strong reminder of how much remains to be done in the field of light-quark spectroscopy, and how much more might be accomplished with a new, totally modernized, dedicated effort.

Regge theory for heavy flavors (Srivastava[3]): The question of how Regge trajectories for mesons which are built from at least one heavy quark are to be extrapolated into the spacelike regime is a very nice problem, and is very nicely addressed in this contribution. It was all new to me.

FELIX (Eggert[3]): This initiative, to provide the LHC with a full-acceptance detector dedicated to investigating all aspects of QCD and multiparticle dynamics in hadron-hadron collisions, is of great potential importance to this field. I return to it at length in Section 4.

3. RANDOM ITEMS

This section consists of comments on the following topics: (1) the pushing of perturbative-QCD techniques to very low momentum scales, (2) Bo Andersson's screwy gluons, (3) the nature of inelastic diffraction, and (4) wee partons in onium-onium scattering.

1. *Perturbative QCD in the infrared*:

It has been a popular and rather successful activity for some time to use short-distance techniques for the study of multiparticle production. Parton cascades are carried to very low momentum scales, below 1 GeV, with the distributions of partons then identified with the distributions of produced hadrons. This is very close to what is done in the Monte Carlo simulations, for practical reasons, and now we see analytic calculations emulating the simulations. Yuri Dokshitzer provides in these proceedings[3] a review and something of a critique of this approach.

I am becoming more and more uncomfortable with all this[1]. It is not that this kind of thing should not be done, but that there needs to be a very cautious and critical attitude regarding what it means. It is not enough to fit the data; the significance of the agreement needs to be critically addressed.

Important tools in this approach are the notions of infrared safety, local parton-hadron duality, and preconfinement. Infrared safety means choosing variables which are perturbative-QCD user-friendly. Local parton-hadron duality means, in this context, that the partons produced in the QCD cascade are essentially in one-to-one correspondence with produced hadrons. Preconfinement means that the color pattern of produced partons is such that in the final stage, after gluons are (by hand) replaced by colored $q\bar{q}$ pairs, the quarks and antiquarks can be recombined into hadrons locally in phase-space almost all the time, thanks to the color structure of the QCD cascade.

Infrared-safe is not the same as infrared-accurate. An easy example is that exemplar of perturbative QCD, the infrared-safe e^+e^- cross-section ratio R. The perturbative R for a given flavor increases monotonically with energy while the data rides up and down over resonances. Locally there is little chance of getting an accurate value for R until s is above 2-4 GeV^2 for light flavors. Global averaging is needed over a GeV scale to retrieve safe predictions. And I think it especially important to recognize that the criterion for accuracy is *not* to be obtained from perturbation-theory estimates, but requires knowing something about the nonperturbative sector, i.e. the resonances.

In the case of R and its close relatives, one can do more, such as the QCD sum-rules. But these methods lean heavily upon the simple analyticity properties of the correlators, something not present for most applications in the multiparticle-production world.

Thanks in good part to the preconfinement feature of QCD cascading, pushing the effective hadronization scale to very low values does work on average rather well for gross features of multiparticle production. But again we may look at e^+e^- annihilation to question the significance. The average properties of the final multihadron final state can indeed be accounted for at low invariant masses economically using the perturbative-QCD cascade and local duality. But below s of 20–30 GeV^2 there are no discernible jets in to be seen in the final state. Isotropic phase space also does quite well in accounting for the data. In the 1970's, before the "right answer" was found, there were a plethora of competing interpretations of such data. If a QCD cascade is used just to generate a phase-space distribution, there is no reason to hail it as another triumph of QCD. However, if the same cascade is used in a Monte Carlo simulation, it may be hailed as a triumph of efficient use of computer time.

More interesting to me is the question of limitations of the method: they do exist. In particular the perturbative cascades *predict* occasional non-confinement. For example, even at the Z mass there is a small but nonvanishing probability that no gluons are emitted during the cascade and that one is left at the end of the line with only the original $q\bar{q}$ pair. (The probability for this, if local duality works, might be guessed to be of order the branching ratio for $Z \to \pi\pi$.) But at the hadronization time, when the QCD cascading is terminated, the q and $\bar{q}$ are very far apart, and there is nothing to be done about that issue using perturbative means alone. To me the message here is that the low-multiplicity tails of the sundry distributions are likely to be the most sensitive to deficiencies of the perturbative-cascade technique, and therefore may be the most important to study incisively. The bunch-parameter method described here by Chekanov[3] looks like a good way to approach the problem.

2. *Screwy gluons*:

Here is a paraphrase of Bo Andersson's talk[3]. It is what I would have him say, but probably not what he would have it be. The deficiencies here are my responsibility, of course.

At the end of a typical perturbative-QCD cascade, now in the higher multiplicity regime, the lego plot will be rather crowded with produced gluons, most all of which will have p_t of order the infrared cutoff. (Neglect quarks, other than leading quarks, and consider again for simplicity the e^+e^- process.) Consider also the large-N_c limit; then for a given event there is one color line which flows through the gluon population linking them together. The amplitude for the production process is largest when gluons connected by the color line have low subenergies, i.e. are close together in the lego plot. Just from massless kinematics, this (squared) subenergy contains a factor $(\cosh\Delta\eta - \cos\Delta\phi)$. For small separations, this is isotropic, just the square of the (lego) distance between the gluons. (I consider a single gluon to occupy a region of phase space which is a circle of radius 0.7; if the gluons are separated by much less than 1.4 lego units, they should be considered as merged into a single collinear gluon of approximately twice the p_t.) Now comes the main point: the aforementioned isotropy is only approximate, and for a fixed distance between gluons, the subenergy is minimized when the two gluons have the same η and different ϕ, rather having different η and the same ϕ. If this is demanded for all gluon pairs connected by a color line, then one sees that this must lead to the color line spiraling around the (cylindrical; ϕ is periodic!) lego plot.

I worry that the amplitude for producing this configuration, while arguably maximal in size, is a very special one, and that all the other somewhat similar amplitudes, where the color line wanders rather randomly amongst nearest-neighbor gluon pairs, will overwhelm this special one. In other words the color-line entropy in this Feynman-Wilson gluon fluid may be more important than its energy.

However, the bottom line, independent of the details, is that there has been identified a new *winding number* characterizing multiparton "final states". Whether it is maximal or has a broad distribution is less important than its existence. Of course it is essential to ask the question of what signatures in the final-state hadron distributions are implied. I am sure this question is being asked in Lund, and I very much look forward to the answer.

3. *Soft diffraction*:

Nowadays in the field of single diffraction, especially in the relatively new subfield of hard diffraction, there is used the formalism of the exchange of a Pomeron Regge pole. I am very uncomfortable with this situation, if only that the basic observational data are often presented in this very model-dependent fashion. Furthermore, as emphasized especially by Goulianos[3], the phenomenology of soft single diffraction does not support Regge-pole exchange, because the ratio of single diffraction dissociation to a given fixed mass interval to elastic scattering should be constant with increasing energy in the Regge-pole picture, while experimentally it clearly decreases.

While there is still room for debate on this point, it remains that there is at present great uncertainty in understanding what is going on in soft diffraction dissociation to high mass systems. There is every reason to be even more open-minded on what is happening in the many hard diffraction processes, which all seem so far to involve soft-Pomeron and/or soft QCD mechanisms in one way or another.

My own choice for meeting point between theory and experiment is the determination of the *gap fraction*, i.e. the probability per inelastic event, at the same cms energy and same gross event properties (such as Q^2 for electroproduction and jet locations and p_t's for hadron collisions), of finding a rapidity gap with gap edge in some prescribed location. (At HERA this is about 4–5% per unit rapidity, while at hadron colliders it is 0.5–1%.) I am still working on this proposition, and am sorry it is not yet ready in detail to present here.

Thinking in terms of gap fractions evokes a somewhat different picture of the diffraction process, more in line with the original picture of diffraction dissociation created by its inventors, Good and Walker[4]. When two hadrons pass through each other in a peripheral collision, the internal wave functions will be modified because there is more absorption on the overlapping parts of the disks than on the opposite, nonoverlapping parts. So just after the disks pass through each other, the internal wave functions will neither be the ground state hadron wave functions nor be orthogonal to them. At a later time, God throws the dice and either the ground states are chosen (elastic scattering), one ground state and one excited state is chosen (single diffraction), or only excited states are chosen (double dissociation or a fully inelastic interaction). The main point is that in this picture, the "decision" appears in the future–more precisely within the future light cone for the collision process. The diffraction process is not "prepared", before the collision occurs, by the nucleon "emitting a virtual Pomeron, which then collides with ...". This is a nontrivial distinction, since a photon- or gluon-exchange picture of the process does imply, a la the Weizsacker-Williams viewpoint, just such a "preparation". To be sure, even in the Good-Walker picture the probability that diffraction occurs will be influenced by initial-state quantities such as impact parameter, but this does not seem to me to be the same thing as the Weizsacker-Williams picture.

In any case the global space-time picture of single diffraction is to me a fascinating one. For example, in what we have described above, the decision in the future is that what starts out as a candidate "elastic" process ends up, thanks to God's roll of the dice, as high-mass diffraction. The "decision" is made on a large time scale, proportional to the energy of the softest particle produced in the diffracted system. On the other hand, view this same event in a boosted reference frame, in particular the center-of-mass frame of the produced massive diffractive state. In that frame the process starts out as an ordinary *inelastic* collision, but where at a certain time in the future (proportional to the fastest left-moving particle within the high-mass diffractive system), God's roll of the dice *stops* the left-moving particle production and leaves only a single unexcited projectile on the far side of the rapidity gap. So the physics of creation of a rapidity gap in the course of a collision must be essentially the same as that of the termination of one already present. And this is something which happens on very long time scales.

How this works in detail is clearly subtle, no matter what one's opinion of the nature of high-mass soft diffraction. I think there is still a great deal to understand about this process.

4. *Onium-onium scattering and the limitations of the BFKL picture*:

The relevance of the BFKL formalism of high-energy scattering of colored partons, in particular of small color dipoles, to actual scattering phenomenology is still controversial and uncertain. The critical view was expressed rather strongly in Bo Andersson's splendid and provocative summary of last year's conference[5]. I too feel uneasy about its relevance. I have also been for a very long time uneasy about the Fock-space picture of hadron wave functions used extensively for the description of exclusive and semi-exclusive high energy processes. There are many who argue that in an infinite-momentum proton there is a finite probability for finding a finite number of partons, because if the valence system forms a small-size configuration there seems to be no appreciable gluon field available to create the nonperturbative component. On the other hand the mean number of partons is measured to be infinite, unless the deep inelastic F_2 eventually goes to zero at very small x, something nobody expects to occur. In this Fock-space viewpoint, the multiplicity distribution of partons in a very energetic nucleon will not completely recede to large values as the energy tends to infinity, but will have a residual piece at finite multiplicity. What fraction of the distribution is in this piece? What is the probability of finding a finite number of partons in an infinite-momentum projectile?

To me there is a clear answer to the above questions, namely that there is always an infinite number of the wee partons. Nevertheless there is still a great deal that is right about the Fock-space way of thinking and therefore a problem to address. Recently I have come across a point of view which at least to me is helpful, and that is the reason for these paragraphs.

First of all, the origin of the usual primordial distribution of small-x, low-Q^2 partons is probably not to be found in perturbative mechanisms. There have been many such attempts, but to the best of my knowledge they just don't work. Small-x, low-Q^2 partons arguably belong to the physics of the soft Pomeron, i.e. the same physics responsible for the high energy behavior of the total pp cross section. This, in turn, is associated with large impact parameter collisions, i.e. the collisions of pion clouds with each other. So I assume that at least some part, if not all, of the primordial wee-parton distribution is to be associated with the internal structure of the pion clouds surrounding hadrons.

Now consider the BFKL process of the scattering of two small color dipoles, such as virtual photons. They are splendid candidates for a Fock-space configuration; I am not worrying here (yet) about the corrections to this configuration, calculable in principle from perturbative QCD, which might give a very dilute BFKL-like distribution at small x. Instead I concentrate on the presence of a very weak pion cloud around the color dipole. In an onium rest frame (or something like it for virtual photons), the small color dipole must introduce a small distortion in the structure of the neighboring vacuum, i.e. chiral condensate. This is another way of saying there must be a pion cloud around even these perturbative structures, whose strength is measured by the strength of the dipole. There will be an energy associated with this distortion. Even if it is minuscule in the onium rest frame, it becomes a large momentum density when the onium is boosted to high enough energies. And when this momentum density of the Lorentz-contracted disk exceeds, say 1 GeV/fm^2, the projectile will interact *strongly* with stationary hadrons or other onia moving in the opposite direction with momentum density also exceeding 1 GeV/fm^2. At this point, the perturbative description will not work. Onium-onium scattering will fail to be described by a BFKL picture at all.

The parton distributions for the small onia will therefore be of the Fock-space character at large x, while at sufficiently small x there will be a transition to the parton distributions of the boosted pion cloud. The critical x at which this occurs will be proportional to the square of the dipole moment of the onium or virtual photon. In particular, the critical x in deep-inelastic scattering below which this occurs will be inversely proportional to Q^2.

This is a rather strong conclusion, so strong that I find myself surprised, and therefore still cautious. If one accepts this point of view, it would seem that the Gribov bound in electroproduction[6] would be satisfied for a rather large domain in x and Q^2.

I was questioned by Bartels as to whether this picture is essentially just the same as the well-known phenomenon of the p_t diffusion of the rungs of the BFKL ladder in transverse-momentum space. This phenomenon also leads to the eventual breakdown of the BFKL picture, and the inevitable mixing of the perturbative Pomeron with the soft Pomeron. I think there is a distinction to be made, since the diffusion argument is made from the short-distance side of QCD, while the pion-cloud argument starts from the large-distance limit of QCD. The difference is similar to approaching intermediate-energy e^+e^- annihilation physics from the perturbative QCD or QCD sum-rule approach, rather than looking at it from the point of view of resonance spectroscopy and chiral perturbation theory. Both approaches may identify the same kinematic boundary, but they are certainly not to be regarded as identical.

4. FELIX: A QCD DETECTOR FOR THE LHC

Karsten Eggert[3] presented here a description of a new initiative, FELIX, for the study of QCD and multiparticle production at the LHC. The FELIX detector, with full acceptance, would be dedicated to the comprehensive study of both hard and soft QCD. At present there are the beginnings of an experimental collaboration, and a Letter of Intent (LOI) has been produced and submitted to the CERN LHC Committee[7]. This LOI is a rather long letter, consisting of about 200 pages of details, of which more than 70 have to do with the theoretical justification. A very large number of QCD theorists have in fact contributed to the document, and what emerges is a remarkable view of a quite different phenomenology emergent at the LHC energy scale, as well as a rich variety of fresh ideas on what novel QCD processes would be of interest to measure if only there were available a good enough instrument for doing so at hadron collider energies.

It seems to me that there is no better way to express an optimistic outlook for the future of this subfield than to directly pirate some of the material from this LOI. Without further ado, the question to be answered is why one should build FELIX to study QCD:

1. *QCD is universal*:

There is precious little in particle physics that does not depend upon QCD. Take away quarks, gluons and other conjectured colored particles and there is not much left. And while one may not be motivated by wanting to understand QCD better if one is intent on discovering the gluino, it nevertheless clearly helps to do so in making such a search.

2. *Dedicated study of QCD at the LHC is essential*:

This community of specialists in multiparticle dynamics is most aware of the deficiencies of the QCD database for hadron-hadron collider processes. It also is most aware of the limitations of theory and of simulation tools in adequately anticipating what will occur in even the most generic of collisions, not to mention the properties of the more unusual classes of events. This richness of the phenomenology, together with the importance of understanding it, if for no other reason than to optimize the analysis of new-physics processes, demands instrumentation, and the dedicated human effort behind the instrumentation, which will do an optimal job of understanding the QCD mechanisms underlying the properties of all final states to be observed at the LHC.

3. *Minijet production is strongly energy dependent*:

As discussed here by Giovannini[3] and by Treleani[3], parton densities at the LHC energy scale become so high that minijet production in generic central collisions becomes commonplace. Almost all such central events are expected to contain observable minijets in the 10 GeV range of p_t. These very high parton densities create at a short distance perturbative-QCD scale, "hot spots" of very large local energy densities. There is the real possibility that these evolve in nonperturbative ways, creating local thermalization and/or other phenomena not easy to anticipate in advance. Particle spectra may be enriched in heavy flavors and/or baryons and antibaryons. Especially in central proton-ion collisions–accessible at the LHC and observable with the FELIX detector–the gluon-gluon luminosity will be maximized. The evolution of the proton fragments can be followed, and one can anticipate that this class of phenomena may be especially rich in surprises.

4. *Parton densities can be measured to extremely low x, below* 10^{-6}:

FELIX can measure parton densities at very low x via the production of leading dilepton, dijet, and γ-jet systems with masses in the 5-20 GeV range, and laboratory momenta in the 1-5 TeV range. In this regime one expects, especially in proton-ion collisions, the breakdown of the usual BFKL/DGLAP evolution equations, and significant nonlinear effects to occur.

5. *Diffractive final states are endemic, many are important, and some are spectacular*:

The contributions to this meeting attest to the fact that the rather young field of hard diffraction is one of great interest and vitality, limited mostly by the present energy scale and by the absence of detector acceptance in the far forward and backward regions. The interest in hard diffraction in turn has focused more attention on soft diffraction as well, which as discussed above is not well understood either.

It is not acceptable scientifically that a set of processes which at the LHC will comprise almost half of all interactions, and which occurs even in rare multijet events at the one percent level, remain not understood. And given the expectation that for example, at an eminently measurable rate, there will exist events containing a central high-p_t dijet, two Roman-pot protons carrying the beam energies, and absolutely nothing else in the detector, there can be no excuse for not pursuing their observation and interpretation with the utmost of vigor.

The major detectors at the LHC can and should observe such final states, provided they sacrifice their hard-won luminosity by a factor 30 or so. However to really understand such events one will want to determine the t-dependence of Roman-pot protons, as well as to study the generalizations of the process to the large-t regime where one or both beam protons fragment. Only FELIX would have the capability for such studies.

There are a myriad of basic diffractive processes to study, as was exhibited in Eggert's talk, and FELIX will be a superb instrument for doing so. In addition, the A-dependence of diffraction is of great usefulness as a diagnostic of the underlying mechanisms, and that will be available as well.

In addition to the class of hard and soft diffraction into high-mass systems, there is another very interesting class of semihard processes associated with the conjectured fluctuation of the projectile into a transversely compact configuration, which therefore interacts with a small cross section. Electroproduction of vector mesons, especially ψ's, shows the rapid increase with energy expected. Coherent dissociation of a pion into a dijet pair from nuclei, apparently seen in the E791 experiment at Fermilab[8], is another example, one which can be reproduced at FELIX–even including the nuclear target. Another variant is coherent dissociation of a proton projectile into trijets.

6. *Particle production from deep inside the light cone may exist and deserves careful searches*:

Almost all generic particle production models, whether parton-cascade, string-fragmentation, or multiperipheral, put all the nontrivial activity in spacetime near the lightcone. However, some of us have speculated that the interior of the future lightcone might contain disoriented vacuum, or chiral condensate (DCC), the pionic decay products of which have large Centauro-like fluctuations of the neutral-to-charged ratio. So far searches for this, carried out by the MiniMax group at Fermilab and by the WA98 group at CERN, reported here by Peter Steinberg[3], have not turned up anything out of the ordinary. But this is a young subject and the techniques are still primitive, both theoretically and experimentally.

There is plenty of room for skepticism regarding whether the DCC picture is realistic. In particular one can question why the interior of the light cone should relax to vacuum rapidly at all. If it does not, then there must be new mechanisms of particle production associated with its decay at large proper times. And if it does promptly relax to vacuum, I see no strong argument why it chooses the chiral order parameter of the exterior vacuum, given the hot shell in between and the short time scale for sensing the small chiral symmetry breaking.

The bottom line is that the searches for novel phenomena along these lines are worth doing. The technique at the least has to include isolation and precise measurement of low p_t photons and charged secondaries, preferably with particle identification, in high associated-multiplicity environments (including minijet interiors). All but the particle-identification requirement is met by FELIX.

7. *Collisions with large impact parameter may probe the chiral structure of QCD*:

Large impact-parameter collisions by definition involve the passage of the pion clouds of the projectiles through each other, suggesting that a connection with LQET might eventually be established. Is the physics of this “supersoft Pomeron” linked somehow with the chiral sector of QCD? Study of this class of final states, especially nondiffractive, has not been done, especially given the lack of an experimental impact parameter tag. But as discussed below, FELIX offers the best opportunity in a long time for producing one. Emphasis on low mean multiplicity, low p_t, and leading-particle properties is a requisite in the exploration of this event class.

8. *New opportunities exist for tagging event classes*:

Determination of impact parameters event-by-event, as desired above, is routinely attained in heavy ion collisions, and is an essential analysis tool. It is determined by observation of the forward fragments, and by determination of the transverse energy at central rapidities. In hadron-hadron collisions at collider energies, such techniques are essentially nonexistent at present. There have been no forward detectors, and the fluctuations in transverse energy event-by-event due to other mechanisms have been too large. However with the prevalence of minijet production at the LHC energy scale, there is, as discussed here by Treleani[3], the opportunity of using the latter method, while FELIX would provide the former. The actual algorithms will have to be determined by a data driven approach, and of course success is not guaranteed.

There are many other categorizations of event classes in pp collisions. An especially interesting set is to convert the incident proton beam into a pion beam by isolation of the one-pion-exchange contribution via tagging or triggering on a leading neutron or Δ^{++}. Kaon beams can be made via a leading Λ tag, and of course "Pomeron" beams with Roman pot tags of leading protons. In addition an important portion of the FELIX program is to tag on Weizsacker-Williams photons (via the nonobservation of completely undissociated forward ions) in ion-ion running, creating a high-luminosity $\gamma - \gamma$ collider.

In addition there are pattern tags. The acceptance of FELIX is so large that the texture of the final state hadronic system is itself a signature. Beyond the very strong textures of jets, rapidity gaps, and mean particle densities, there may be observable the effects of color-flow ("antenna patterns") and/or fluctuation structures in the lego plot associated with intermittency, DCC production, etc. Working at this level will be challenging, requiring close interplay between the experiments and the phenomenology. But the extremely large lego acceptance of FELIX and the richer underlying physics at the LHC energy scale should make these opportunities much stronger.

9. *Benchmark processes*:

Because the FELIX program is so broad, it has been decided to focus on a few "benchmark" processes for detailed analysis. Candidates for these have been chosen, with an eye to exhibiting the variety of physics goals as well as to exercise the detector capability as broadly as possible. These include the following:

a) *Elastic scattering at large t*:

This has not been done since the ISR and clearly exercises the Roman pot capability.

b) *Spectra of leading particles*:

This is straightforward physics, of importance especially to the cosmic ray community, and exercises the FELIX forward spectrometer.

c) *Mueller-Navelet jets*:

Dijets of laboratory energy of, say, 3 TeV will be measured from the lowest p_t scale of 5-10 GeV out to large angles, along with the event structure (extra jets, rapidity gaps, etc.). At small angles the jet reconstruction will be an experimental challenge.

d) *Parton distributions at small x*:

This is the aforementioned measurement of low mass dileptons, dijets, and jet-photon systems at large laboratory energies.

e) *Hard double Pomeron exchange*:

This process is characterized by four jets and two or three rapidity gaps, and exercises the capability of pattern triggers.

f) *Tagged pion dissociation into dijets*:

We have already mentioned the physics interest. Experimentally this is very challenging, because it may require putting Roman-pot signals into the trigger, and because beam-gas backgrounds may be troublesome.

g) *Proton diffraction into three jets from nuclei*:

The physics is similar, but here the problems involve how the products of a dissociated ion are seen in the FELIX detector. It is probably even more difficult than the previous case.

h) *Vector meson production in gamma-gamma collisions*:

There is a serious problem of backgrounds from Pomeron-exchange processes.

It seems very clear to me that FELIX presents an extremely important opportunity for advancing the field of multiparticle dynamics. I hope that everyone will familiarize themselves with the enterprise, will spread the word, and if possible will contribute to the effort in one way or another. The best of course would be to join the collaboration. Short of that, there are many ways of helping the project along, both on the theoretical side and experimental. I urge you to contact the spokespersons, Karsten Eggert and Cyrus Taylor, and/or visit the FELIX web site (http://www.cern.ch/FELIX) and join the working group. It will be at best a very hard job to make FELIX a reality, and cohesive support from a broad sector of the community will be essential.

NOTE ADDED IN PROOF:

On November 5–6, the CERN LHCC acted in a nonpositive manner regarding the FELIX LOI[9]. I find especially noteworthy their statement that "while the physics topics addressed by the programme proposed in the LOI are of interest (particularly the complete reconstruction of diffractive events), the likely costs of constructing the proposed dedicated detector and of the modifications to the LHC collider are very high in comparison with the probable physics output." I strongly disagree with this assessment.

ACKNOWLEDGEMENT

On behalf of all the participants, I thank Giulia Pancheri and all the organizers for their hard work in creating a most pleasant and productive meeting.

REFERENCES

1. Very similar comments can be found in my summary talk from the 1994 conference: J. Bjorken, *XXIV International Symposium on Multiparticle Dynamics*, Vietri sul Mare, Italy, Sept. 1994, ed. A. Giovannini, S. Lupia, and R. Ugucciomi (World Scientific), p. 579.
2. T. Schaefer and E. Shuryak, hep-ph/9610451; *Rev. Mod. Phys.* (to be published).
3. Contribution to these Proceedings. If you are a contributor and are looking for your name, you are invited to peruse the full text of this talk to find it.
4. M. Good and W. Walker, *Phys. Rev.* **120**, 1857 (1960).
5. B. Andersson, *XXVI International Symposium on Multiparticle Dynamics*, Faro, Portugal, Sept. 1996, ed. J. Dias de Deus, P. Sa, M. Pimenta, S. Ramos, and J. Seixas (World Scientific), p. 471.
6. See for example, reference 1 for a discussion. Note that this point of view is more or less expressed by Fig. 4(a). In that talk I favored Fig. 4(b). At least something has changed in my summary talks.
7. FELIX : A full acceptance detector at the LHC (Letter of Intent); CERN/LHCC 97-45; LHCC/110; August, 1997.
8. R. Weiss-Babai; presented at the Hadron'97 Conference, Brookhaven National Laboratory.
9. The full text can be found in http://www.cern.ch/Committees/LHCC/LHCC31.html.