VIIth BLOIS WORKSHOP SUMMARY : EXPERIMENTAL

M. G. ALBROW
Fermilab, P.O.Box 500, Wilson Rd., Batavia,
IL 60510, USA
email: albrow@fnal.gov

The Blois Workshop has become a conference not just restricted to diffractive scattering, but including topics such as searches for SUSY and Higgs, measurements of the top mass and b-decays. I will mention these briefly but will mostly discuss new results (and needed future measurements) in hard diffraction at HERA and the Tevatron.

1 Introduction

Diffraction (in a high energy physics context) can be defined [1] as any process involving pomeron, $I\!P$, exchange. Theorists and experimenters have two seemingly quite different definitions of the pomeron. To a theorist it is "the highest Regge trajectory, with the quantum numbers of the vacuum, responsible for the growth in hadronic total cross-sections at high energy". To an experimenter it is "the dominant strongly interacting entity exchanged over large rapidity gaps". "*It is a prime task of our research to investigate the relationship between (or equivalence of) these definitions*[1]".

Experimenters these days generally take the attitude that the pomeron can be considered as if it were a hadron that is emitted with a certain flux from one or both of the incoming hadrons in a collision. Being "like" a hadron it has quark and gluon structure functions which we want to measure. This can be done by studying hard (large Q^2, where Q is a large 4-momentum transfer) processes involving pomerons. Two examples are deep inelastic scattering DIS in ep collisions, and dijet production in $p\bar{p}$, both with a rapidity gap G. In the former case, interpreted as $\gamma I\!P$ collisions, $q(\beta, Q^2)$ is probed directly and the gluon distribution is inferred. Important variables are t, the square of the 4-momentum transfer carried by the pomeron (its "mass^2", always negative), and ξ, the fraction of the momentum of the parent hadron taken by the pomeron. ξ should be less than about 0.05 for pomeron exchange dominance; above that Regge exchanges (π, ρ) become increasingly important. However this statement is probably process-dependent and perhaps with dijets pomeron exchange stays important to larger ξ. Seeing high-E_T jets produced in $pI\!P$ collisions is independent evidence for partons in the pomeron, and by measuring them, and knowing the parton distribution functions (*pdf*s) in the proton, we can derive the *pdf*s in the pomeron as a function of the variable $\beta = p_{PARTON}/p_{POMERON}$, equivalent to Bjorken-$x$ for hadrons. However because both quarks and gluons scatter to give jets (but with different coupling strengths) jet measurements can only give some effective *pdf*, mixing q and g. What is needed (and we have started this program in CDF) is to measure other hard processes with different sensitivity to q and g, such as $W^{\pm}$, Drell-Yan and heavy Quark production. The signature of the diffractive event can be either a very high Feynman-x ($x_F = 1 - \xi$) beam particle or a large (typically > 3 units) rapidity gap or preferably both. The rapidity gap method does not tell you t and has less precision on ξ. On the other hand it does not require special high Feynman-x detectors (roman pots) with their usually restricted acceptance (and perhaps limited running time).

Our ultimate goal is to understand diffraction, presumably in the framework of QCD. We seem to be a long way from this, so we experimenters take a pragmatic approach. Can we find a set of *parton/pomeron pdf*s $q(\beta, Q^2)$ and $g(\beta, Q^2)$ with consistency between $\gamma I\!P$, $pI\!P$ and $I\!PI\!P$ interactions? Do the *pdf*s show any dependence on ξ (they should not for a pure pomeron sample but probably will if a ξ-dependent reggeon contamination is present) and t? If not, the quasiparticle paradigm may be at fault or it may just require modification, e.g. through flux issues. Whether or not we find a consistent picture for these three probes of the pomeron, we shall have made progress.

One can take a different viewpoint; perhaps it is wrong to think of the pomeron as an *entity*, hadron-like or otherwise. For example the optical theorem relates the total cross section: $AB \to X$ with the imaginary part of the forward scattering $AB \to AB$ amplitude. The symbol X stands for any possible final state and we sum over them all. By time reversal the process $AB \to X$ can also go backwards: $X \to AB$ so we can have $AB \to X \to AB$ and sum over all possible intermediate states X to get elastic scattering. This is an $s-$channel view of elastic scattering which one might call *recombination.* Partial recombination of the intermediate state X over just a few units of rapidity (resulting in a gap), rather than the full range, would give inelastic diffractive processes. The problem is that we do not know how to do calculations in this model, while the pomeron is something we can work with, inserting its structure function into Monte Carlo programs etc. The original prediction of inelastic diffraction by Good and Walker [2] was also an s-channel description: an incident proton wave on a target is a superposition of all allowed (same Quantum Numbers) states and these are differentially absorbed by the target. The change of the incident state vector generates $p \to p\pi^+\pi^-$ etc. Perhaps ultimately our understanding of diffractive processes will involve both $s-$channel and $t-$channel in some unified or *dual* picture.

Meanwhile we have made great progress in the last few years on the experimental front using the quasiparticle paradigm. The activity has been especially high at HERA where the observation of large rapidity gaps came as something of a surprise, despite having been predicted especially by Donnachie and Landshoff [3]. Before the $Sp\bar{p}S$ Collider was closed UA8 [4] saw diffractive dijets, albeit at very modest E_T by Tevatron standards. They concluded that $I\!P \supset q, g$ with a hard distribution and possibly a superhard component. At the Tevatron only elastic scattering and soft diffraction had been measured, until CDF and DØ both found a signal for an excess of events with rapidity gaps between two high E_T jets, a phenomenon predicted by Bjorken [5] as color singlet exchange. This can be two-gluon exchange, reminiscent of the early suggestion of Low and Nussinov [6,7] that the soft pomeron might be explained in QCD as two-gluon exchange, but the (4-momentum-transfer)^2, t, is of order 1000 GeV^2 rather than $\sim$ 1 GeV^2. We gained confidence in the gap signature method of studying diffraction and it is now commonly used at HERA and the Tevatron; I shall talk about the latter first.

2 Hadron Hadron Collisions

2.1 Jet-Gap-Jet (JGJ)

We may define the *Superhard Pomeron* to be a color singlet exchange giving a large rapidity gap carrying $|t|$ above about 100 GeV^2. Between jets, we may equate $|t| \approx E_T^2$. Note: this is not to be confused with a (soft) pomeron carrying a parton with $\beta = p_{parton}/p_{proton} \approx 1.0$, which should be called superhard-β [1]. The phenomenon was predicted by Bjorken but with an uncertainty due to not knowing how often the rapidity gap from the hard color-singlet would be killed by an independent soft gluon exchange between spectators. A Monte Carlo event simulation which attempts to describe complete events such as POMPYT [8], DTUJET/DPMJET or PHOJET [10] *should* be able to address this issue.

Is the exchanged object predominantly a single gluon, with the color "bleached" by soft color interactions in a manner still to be understood? Or do two semi-hard gluons dominate the exchange? Is the quark/gluon fraction the same in jet-gap-jet (JGJ in shorthand) events as in non-gap events? An optimized q/g-jet discrimination algorithm would be useful here; we know that we cannot separate q and g jets individually but with enough statistics we could measure the fractions. See the talks at this workshop from CDF [12] and DØ [14] for the latest results from these experiments. The general agreement is good: CDF finds that the fraction of opposite rapidity dijets with gaps is R(gap) $= 1.13 \pm 0.12(stat) \pm 0.11(syst)\%$ while DØ finds R(gap) $= 0.85 \pm 0.05(stat) \pm 0.07(syst)\%$ with somewhat different cuts. Especially as this ratio may be dependent on $E_T(jets)$ and/or $\Delta\eta$ the difference is not significant, but we do not have clear agreement on what those dependencies are. CDF concludes there is no E_T-dependence from 25 to 55 GeV while DØ find a rising fraction from 20 GeV to 75 GeV. However if one were to overlay the plots they would probably be consistent. The dependence on the rapidity separation between the jets, $|\eta_1 - \eta_2|$ also appears to be different between DØ and CDF, rising as the separation increases from 5 to 6 units in DØ and falling from 5.6 to 6.6 in CDF. In both cases we are talking about 50% effects but with similar errors. As these dependencies could give important clues about the process, and can be compared with Monte Carlo predictions, we will hopefully do much better in future. Optimizing triggers for two forward jets will help. The $\sqrt{s}$-dependence is another valuable indicator. One can study this either fixing the jet E_T's and η's, or one could require the gap region to expand logarithmically as $\sqrt{s}$ grows to keep the "forward" systems, each including a jet, the same but boosted. The latter case is like double diffractive dissociation (shorthand: X_1GX_2) which has hardly been studied. DØ presented [14] the s-dependence of JGJ keeping the rapidity interval $-1 < \eta < 1$ fixed, and finds the *fraction* of JGJ events higher at $\sqrt{s} = 630$ GeV than at 1800 GeV by a factor 2.6 ± 0.6 (stat) for $E_T > 12$ GeV, $\Delta\eta > 4$. This is interesting; different models predict different results, e.g. a simple 2-gluon model predicts a ratio ≈ 0.8. CDF are in the process of measuring this ratio but have not yet given a number.

Some unresolved experimental questions for the superhard pomeron are:

- Resolve the E_T and $\Delta\eta$ dependencies.
- What are the relative amounts of $qq : qg : gg$ in gap and non-gap events?
- How does the transition from JGJ to soft double diffraction (XGX) go?

• Can we make double superhard-$I\!P$ collisions: $JGXGJ$? This probably needs the rapidity range of LHC (but avoiding multiple interactions in a crossing!).

• This really belongs in the next section, but the superhard-$I\!P$ is also probed by photons in DIS $\gamma p \to JGJ$ collisions, but with t-values (E_T^2) probed about two orders of magnitude lower at present. How does this fit in with hadron collider observations?

2.2 Single Diffractive Excitation (GJJ, GW)

The success of using rapidity gaps in assocation with jets as signatures of color singlet exchange led to them being used also to study single diffractive excitation of dijets, W's and heavy flavors Q, even without Roman pots to tag the pomeron, using GJJ, GW and GQ events. If you select events with two forward (SS = same side i.e. same sign of η) jets and look at the multiplicity distributions on the opposite side a continuum is seen with a clear excess in bin-zero corresponding to gaps (see Fig 1 from CDF; DØ has similarly impressive plots). As mentioned in the introduction a pomeron tag allows β-reconstruction, but even in its absence we note that different pomeron structure functions predict different η-distributions for the jets, different ratios of W/dijet production and so on. DØ showed an interesting plot of η_{boost} which is the average η of the two leading jets, see Fig.2. A strong variation is observed; less than 0.2% of the very central dijets are diffractive while the number rises to 1% for forward dijets with $\eta_{boost} = 2.7$. Given the relationship between diffractive masses (including the dijet plus the forward fragments from the massive system) which increase as the dijet becomes more central, the allowed largest rapidity gap and the diffractive cross section decreasing with M_X and $\Delta\eta$, this behavior is qualitatively reasonable. CDF noted that the E_T distribution of the diffractive jets is very similar to that of non-diffractive jets. This might be considered as an approximate cancellation between the lower $\sqrt{\hat{s}}$ of the $I\!Pp$ collision and a harder (than p) $I\!P$ structure function $q/g(\beta)$ or as something more sinister! CDF also notes that the two jets are slightly more back-to-back in ϕ than in non-diffractive events and have fewer third jets (even allowing for the gap requirement). The latter two observations hint that the diffractive jets are relatively more quarkic than qluonic. DØ showed clear GJJ signals at $\sqrt{s} = 630$ GeV also. Unfortunately the amount of data taken at $\sqrt{s} = 630$ GeV will not allow a comparison of W/dijets at the two energies.

Diffractive W production has been observed by CDF[11] using the gap technique bolstered by expected correlations between the rapidity gap side and the charge and η of the W. There is also a "golden" diffractive W-candidate with a roman pot track and a rapidity gap of about 5 units! The fraction of all W that are diffractively produced is measured as 1.15 ± 0.55 %. Together the rates of diffractive W and dijet production point to a gluon content of the pomeron of order 0.7 ± 0.2[12]. Fig. 3 shows the combined costraints from CDF and from ZEUS in the plane "momentum fraction carried by hard partons in the pomeron" it vs gluon fraction of hard partons in the pomeron". However the momentum fraction is lower than the ZEUS results by a factor 4 - 5, which is not yet understood but raises issues of the pomeron "flux" in different processes. Goulianos[13] proposed that the pomeron flux $f_{I\!P}$ must be normalized above ISR energies so that we can not have more than one pomeron emitted. This damps the rise of the soft SDE cross section which would eventually have violated unitarity. Theorists talk of screening corrections.

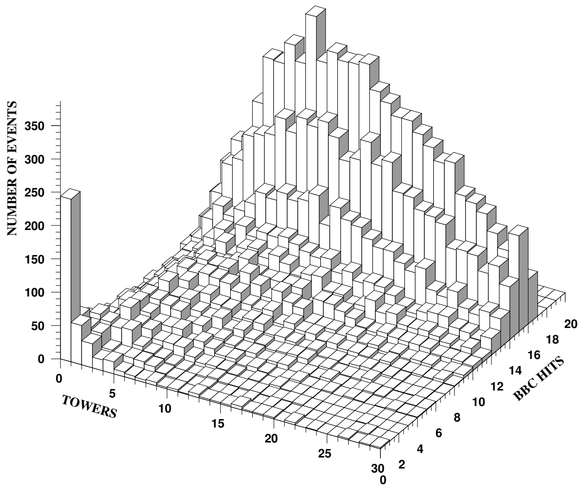

Figure 1: Calorimeter towers vs BBC counter hits in region opposite a forward dijet.

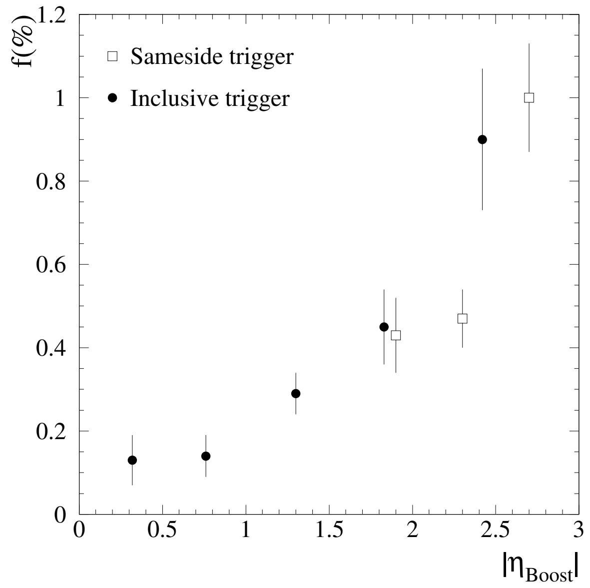

Figure 2: Fraction of dijets which have a rapidity gap as a function of dijet rapidity.

2.3 Double Pomeron Exchange (GJJG)

Both CDF and DØ have preliminary evidence for hard $DI\!\!PE$, or $I\!\!PI\!\!P \to JJX$ This is a very interesting process, which together with complementary studies of heavy flavor and Drell-Yan in "$I\!\!PI\!\!P$ collisions" will give us another handle on the pomeron paradigm. The central system should be independent of the type of incident hadrons. Perhaps we will never know this, except by one day comparing pp and $p\bar{p}$. Is there a difference in $I\!\!P$ "emitted" by mesons and baryons due to the 2(3) valence quark content? This could be studied in low-mass soft $DI\!\!PE$ with high enough $\sqrt{s}$ πp or Kp collisions. Note that for $DI\!\!PE$ dominance the central system should have $M_{cen} < 0.05\sqrt{s}$, approximately. So we would like π-beams of order 1 TeV to do this. As this is not likely soon, a better approach would be to use jets in SDE (GJJ) to compare the structure of pomerons emitted by mesons and baryons, as a function of t.

The mass limit of $DI\!\!PE$ being about 3 GeV at the ISR ($\sqrt{s} = 63$ GeV) it was a good reaction and place for glueball searches [15] especially as the quantum numbers for $I\!\!PI\!\!P \to$ "glueball" are constrained to be $I^G J^{PC} = 0^+\mathrm{even}^{++}$. The lightest glueballs probably have masses in the range 1.4 - 2.0 GeV and could perhaps be well studied using a variety of final states this way, also at the Tevatron.

More in line with the hard physics trend is to use the $DI\!\!PE$ mass range up to about 100 GeV to study high E_T jet and heavy flavor physics. Is there a superhard-β component giving events like $I\!\!PI\!\!P \to J + J$ with nothing else, like most LEP 1 (Z°) events? (The energies are similar too!) What would be the mix of $g/q/Q$ jets in such events? Because the whole of the central system is observed in CDF and DØ (unlike in SDE) full event studies can be made, either with respect to the beam axis or to a thrust axis e.g. The shopping list for these general properties would include $\frac{dN}{dy}, \frac{dN}{dp_T}, S, C, B$, Bose-Einstein, Double Parton Scattering, etc.

DØ and CDF both showed some preliminary evidence for $D\mathbb{P}E$ with central jets. DØ used a $GJJG$ method (no pots) and find about 10^{-6} of central dijets above 15 GeV have a gap excess on each side. CDF use a pot track on one side and look for excess gaps on the other ($GJJP$) together with jets above 7 GeV. There is work to do to establish these signals and the possible backgrounds but the results are similar and show at least an approximate factorization:

$$\sigma_{\mathbb{P}\mathbb{P}} = \sigma_{INCL} \times f_{DPE/SDE} \times f_{SDE/INCL}$$

It will be important, to get much more statistics in Run II, to make more efficient $D\mathbb{P}E$ triggers. A rapidity gap requirement (carefully controlled!) can have the added advantage of vetoing multiple interactions, which will be a problem in Run II for diffractive/gap physics. A study in UA1 at $\sqrt{s}$ = 630 GeV [16] required forward rapidity gaps and a low central E_T threshold. Jet production was observed which, *interpreted as from* $\mathbb{P}\mathbb{P}$ *collisions*, implied a hard β-distribution. However the lack of a "smoking gun" control (like Fig.1) means that the latter interpretation is, unfortunately, unproven.

How could we interpret events with two rapidity gaps from a non-pomeron or s-channel viewpoint? The recombination picture would say that from the intermediate multihadron (or multiparton) state X a bunch of right-movers recombine to form a gap and a bunch of left-movers do the same, leaving a central region looking very much like it would in a non-diffractive pp collision (similar jet E_T spectra, $\frac{dN}{dy}$, etc.). Another picture, closer to Good and Walker, is to say that (as we know) the vacuum is full of virtual states. These can be made real by the passage of two hadrons, required for energy-momentum conservation. The central system has the same quantum numbers as the vacuum (apart from angular momentum) provided that the coupling between it and the passing hadrons is through the pomeron. I think it possible that massive states made this way may be a window on really new phenomena (remember Centauro?). What you see when you "look at" the vacuum this way is a function of the "exposure time". For relatively large exposure times δt you see low energy/mass excitations such as a pion or kaon loop, made real in the processes $pp \to p\pi^+\pi^-p$ or pK^+K^-p. Resonances which have vacuum quantum numbers such as $f^0(975)$ and some glueballs can also be *realized* (to give a new meaning to an old word). For higher energy hadron collisions, shorter exposure times δt are possible and you can start to see higher Q^2 things like quark loops, either light q or heavy Q. These will sometimes be realized as high-E_T jet pairs: the q and $\bar{q}$ are realized on a short time scale and later hadronize on a long time scale (just like at LEP, only we are starting from the vacuum state rather than a massive virtual photon). The Higgs has the quantum numbers of the vacuum but will not be produced this way because it does not couple to the pomeron. The process can go through a heavy quark loop: $\mathbb{P}\mathbb{P} \to Q\bar{Q} \to H$, but unfortunately the cross section is very small and rapidity gaps will be hard to detect in the multiple interaction environment of LHC. Another (and more respectable, because calculable) process at LHC producing Higgs between rapidity gaps is WW-fusion.

DØ has presented a proposal to add roman pots on both beam pipes to study double pomeron exchange in Run II.

2.4 Elastic Scattering and Total Cross Section

A new but very preliminary result on $\sigma_T^{p\bar{p}}$ at $\sqrt{s} = 1800$ TeV was presented from Experiment E811 [17]. The intention is also to measure ρ but at present $\frac{d\sigma}{dt}$ is measured at some t-value and extrapolated to the optical point $t = 0$ using an (input) slope. The result ("$\sim$ 70 mb") is well below the last published CDF result of 80.0 ± 2.0 mb and close to that of E710. However I think we should wait for E811's finished result, preferably using their own slope and ρ value, before comparing. It would be good if a definitive Tevatron measurement is done. CDF could probably do a measurement of the *inelastic* cross section (including diffraction) as well as the machine parameters can tell us the luminosity. At present this is only known to about 30% - 50% but possibly the needed 5% (to make this method competitive) could be achieved.

For LHC there are two proposals to study elastic and diffractive scattering and total cross sections. TOTEM, presented by Velasco [18], aims to get into the Coulomb interference region with roman pots 1 mm from the beams with high-β operation. They aim for 1% uncertainty on σ_T. They will also study single diffraction, but not on the scale of another proposal, FELIX [19], which will be a very large experiment (combining ALEPH and UA1 magnets) covering *really* 4π with tracking and calorimeters. FELIX will run at lower luminosity than CMS and ATLAS so that single interactions can be cleanly studied, and it should be very exciting. Note that the rule of thumb that diffraction dominates for $x_F > 0.95$ gives a region for double pomeron masses up to 700 GeV.

3 Diffraction at HERA

The renaissance of interest in diffractive physics is largely due to the observation of rapidity gaps in deep inelastic scattering events and the realization that the pomeron could be probed with photons. This may not be quite as simple as it appears because the photon itself can behave like a hadron (VMD = vector meson dominance) or be "resolved" into a $q\bar{q}$ pair. However diffractive studies became a major enterprise at HERA (at least relative to CDF and DØ which have very small diffractive groups). Laforge showed [24] a "sheet of postage stamps", each stamp being the diffractive structure function $F_2^{D(3)}$ vs $x_{I\!P}$. Rows of stamps have the same β from 0.01 to 0.90 and columns have the same Q^2 from 2.5 GeV^2 to 65 GeV^2. This H1(1994) data has about 20,000 events. They then integrate over $x_{I\!P}$ and plot the Q^2-dependence at fixed values of β and vice-versa. Proton structure functions fall with Q^2 for $x_{Bj} > 0.2$ and rise below that. This is understood in terms of DGLAP evolution but depends on the low-Q^2 "starting function". The pomeron, for which β is the variable equivalent to x_{Bj}, seems to behave differently, rising with Q^2 even at $\beta \approx 0.65$. This is interpreted by H1 as meaning that at low-Q^2 there must be a high probability that the pomeron has a gluon with β above about 0.9, carrying effectively all the momentum. Reverse evolution down to $Q^2 = 5$ GeV^2 gives only a small contribution from u, d, s in a flavor singlet. Evolving these structure functions up to $Q^2 = 65$ GeV^2 the gluon distribution has become quite flat in

β, but gluons carry about 80% of the pomeron momentum. (Note that the CDF data are consistent with this, if $Q^2 \approx E_T^2 \approx M_W^2$.) The H1 $I\!P$ parton distributions are inserted into Monte Carlo event generators (RAPGAP, POMPYT) and used to predict more details of final states. Information about pomeron structure also comes, as it does in hadron-hadron, from dijet production in $\gamma I\!P$ collisions. H1 and ZEUS observe clear perturbative signals, dijet production with $E_T(jet) > 5$ GeV. Rapidity distributions of the jets are compared with expectations from different $q/g(\beta)$ distributions. ZEUS concludes, as did H1, that more than about 70% of the pomeron's momentum is carried by gluons. For details see the talk of Laforge [24]. ZEUS and H1 now have leading proton spectrometers (LPS) which use pots to tag the t, ξ of the pomeron and a clean $x_F = p/p_{beam} \approx 1$ peak is observed as expected. If we consider low mass diffraction ($M_X < 7.5$ GeV) the energy dependence allows us to extract an effective intercept $\alpha_{I\!P}(0)$ for the pomeron and study whether this is Q^2-dependent. The ZEUS and H1 data are consistent with each other but ZEUS notes a rising trend; both find $\alpha_{I\!P}(0)$ in the region 1.1 - 1.2 [24].

Related is diffractive excitation of the photon into vector mesons $\rho, \omega, \phi, J/\psi, \Upsilon$, all of which show beautiful signals. The total γp cross section falls with c.m. energy $W_{\gamma p}$ above the resonance region and then rises logarithmically, rather like $\sigma_T^{p\bar{p}}(s)$ but about a factor 1000 smaller. The VMD component into ρ and ω behave in much the same way, but for the higher mass J/ψ the rise is steeper, about $W^{0.9}$. This might be the beginning of a hard pomeron showing up ... unfortunately the statistics on Υ photoproduction are not yet there! A wonderful diffractive topic for a very high energy e^+e^- or $\mu^+\mu^-$ collider is $\Upsilon\Upsilon$ elastic scattering (and diffractive excitation etc.) from double VMD [25], well in the perturbative regime.

4 Non-Diffractive studies at HERA

This is a large field which was covered in talks by David [26], Oh [27], and Wolf [28]. Here I shall be brief, referring to the talks by these speakers in this volume.

Marc David reported on behalf of the H1 and ZEUS collaborations on the observation of events with very high Q^2 (order 15,000 GeV^2). Most of the high (but not so high!) Q^2 neutral current data are in excellent agreement with simulations and between the two experiments. However at the edge of the populated region (in x, y or y, M [26]) both experiments find a small excess of events. These numbers have since been updated, but at the meeting they were reported as ZEUS: observe 4 and expect 0.90 ± 0.08 and H1: observe 7 and expect 1.83 ± 0.33. Could this be a first glimpse at first generation leptoquarks? Or squarks with R-parity violation? Something else? Clearly more data is needed and is coming so we must wait and see, false alarms of this size having happened before.

Benedict Oh [27] presented many properties of hadronic final states. Global transverse energy profiles and thrust distributions are well fit at the hadron level by the LEPTO program of Dokshitzer and Webber. This calculates event shape variables to order $\alpha_S^2(Q^2)$ perturbatively with non-perturbative $\mathcal{O}\ (1/Q)$ corrections.

Gunter Wolf [28] discussed proton structure function measurements from HERA (non-diffractive). $F_2(x, Q^2)$ is measured below $x = 10^{-4}$ at Q^2 around 10 GeV^2. There is a continuous rise as x_{Bj} decreases, the rise steepening as Q^2 increases. This has to stop behaving this way, or unitarity will eventally be violated. Will HERA be energetic and luminous enough to see a change? The charm contribution has been measured by seeing D°, D^*. Wolf also discussed DGLAP-evolution and BFKL-evolution, but both give a good description of the data.

5 Heavy Flavors

5.1 Bottom

Studies on B-physics and the top quark in DØ were presented by Denisov [30] and Won [31] respectively. The Tevatron has proven its worth as a prolific source of B's and B-physics. Even in this relatively harsh environment high p_T muons can be triggered on and measured, in DØ out to $\eta = 3.3$, even in jets. A large fraction of these muons, at large p_T, come from semileptonic b-quark decays. Others come from J/ψ which in turn have come from B-meson decays. At 1800 GeV both CDF and DØ have measured cross sections about a factor 2 higher than theory out to about 40 GeV/c. New 630 GeV data show the same behavior, with CDF, DØ and UA1 being in good agreement and all stretching the theoretical prediction. The ratio of production 630/1800, a decreasing function of $p_T(min)$ but around 0.2 in the measured range, agrees well with predictions. $B\bar{B}$ correlations (or $\mu\mu$ correlations from b's) can help distinguish between production mechanisms. Gluon splitting $g \rightarrow b\bar{b}$ gives pairs with small to moderate $\Delta\phi$, while flavor creation $gg \rightarrow b\bar{b}$ produces them back-to-back. DØ find that the $\Delta\phi$ distribution can be reproduced by NLO but not LO QCD (HVQJET) calculations. DØ has used its forward muon detectors to extend the rapidity distributions of $\mu(b)$ to $\eta = 3$. NLO predictions have the same p_T distribution as the data but are a factor 4 lower. Forward J/ψ are an order of magnitude above earlier predictions as has been seen for central prompt production. This issue may be resolved by the "color octet model", in which a high-p_T gluon can split into a $c\bar{c}$ in a color octet state, which can then exchange gluons in a non-perturbative way to become a color-singlet J/ψ. I am reminded here of the Bjorken process producing JGJ events. This is a trend in QCD studies: a calculable hard process is modified by some softer color physics to make a very visible difference. We could probably learn about this onium production problem by studying the soft hadrons in a cone around the onium; this has not been done yet. CDF did not report on their B-physics at this meeting but, thanks especially to their silicon strip microvertex detector, are extremely active measuring lifetimes, production of exclusive states, searching for rare decays and preparing for CP-violation searches in Run II (which starts in 2000). DØ are adding silicon microvertex detectors, scintillating fiber trackers and a central magnetic field and have similar ambitions. Run II could be very exciting as CP-violation in the b-sector may well be discovered at the Tevatron. Meanwhile our understanding of the QCD aspects of b (and c) production leave a lot to be desired, but studies may shed light on the soft/hard interplay.

5.2 *Strange*

Strangeness fits in here because I just mentioned CP-violation and we heard a talk by Funk [29] on Experiment NA48, a precision measurement of ϵ'/ϵ at CERN using K°. It requires measuring the $\pi^\circ\pi^\circ$ and $\pi^+\pi^-$ decays of both K_L° and K_S° together. It includes a very impressive liquid Krypton calorimeter with 13,500 tower cells of 2 cm $\times$ 2 cm, giving a spatial resolution at high energy of 1 mm, a time resolution of 1 ns and and $\frac{\sigma}{E} \approx 3\%/\sqrt{E}$. The aim is to measure ϵ'/ϵ to better than $2{\times}10^{-4}$ which will hopefully give a quantum jump in our understanding of CP-violation. An experiment at Fermilab (KTeV) has similar ambitions.

5.3 *Top*

Moving on to the top quark, again we only heard from DØ (E.Won) [31] but CDF has measurements that are comparable (as a CDF member *and* summary speaker I am not allowed to put a sign on the comparison!). The top quark mass is known with a relative precision better than any other quark! Won [31] described DØś measurement combining lepton+jet and dilepton modes leading to 172.0 $\pm$ 7.5 GeV combining statistical and systematic errors. The CDF measurement is [32] 175.8 $\pm$ 6.9 GeV; if we combine them we get 173.9 with about 3% uncertainty. While we do not yet have a theory predicting this mass, the standard model and extensions of it do predict relations between masses, so that in the SM one can predict the Higgs mass if one knows the W and t masses very well. Fig.4 shows this relation showing the consistency between CDF, DØ and LEP regions (LEP do not of course see *real* tops but they are there in virtual loops and make their influence (and mass) felt).

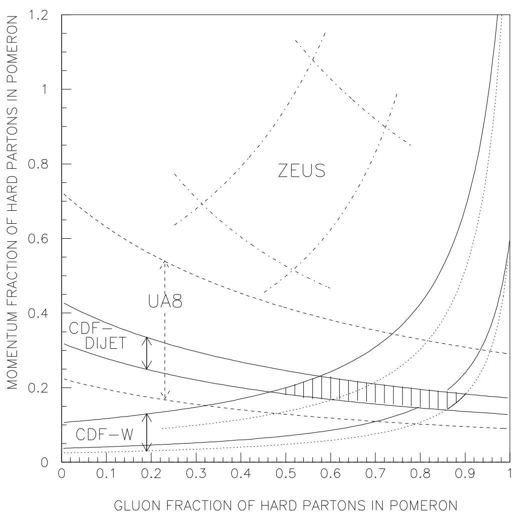

Figure 3: Diffractive dijet and W constraints on the fraction of gluons in the pomeron.

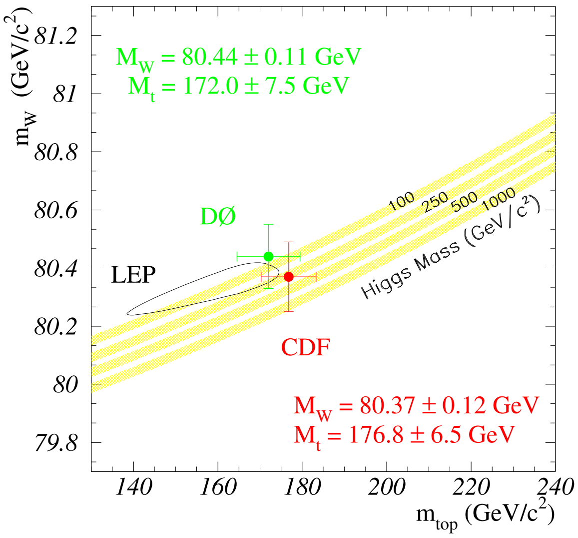

Figure 4: The relationship between M_W and M_t for different values of M_H and the data from CDF and DØ (real tops) and LEP (virtual tops).

The cross section for producing top quarks in hadron collision should be a good testing ground for QCD. As the mass is high non-perturbative corrections should be small; the theoretical uncertainties being in the region of $< 15\%$. Experimental uncertainties are still dominated by statistics: (DØ [31]):$\sigma = 5.74 \pm 1.88 pb$ (for $m_t = 170$ GeV); (CDF [33]):$\sigma = 7.6^{+1.8}_{-1.5} pb$ (for $m_t = 175$ GeV), but this will improve by a big factor in Run II and systematics such as the Tevatron luminosity uncertainty (4%? 8%?) may become important. New physics could show up in discrepancies between predicted and observed $t\bar{t}$ production cross sections.

6 Other Topics

One way in which this Workshop has evolved is in an increasing variety of topics, so there were inevitably some interesting talks which deserve a mention but which do not naturally fit in the preceding sections.

6.1 Polarized Protons

A. Krisch [34] showed a collection of fascinating and not-understood effects observed when the spins of colliding protons are under control. Take elastic pp scattering at $90°$ in the c.m. The asymmetry between scattering with spins parallel and antiparallel fluctuates with much structure as $\sqrt{s}$ increases, and does not appear to die away with collision energy (in fact at $p_{lab} = 14$ GeV/c it is about 60% !) Another interesting asymmetry is in inclusive pion production in the forward direction. Using a polarized 200 GeV proton beam there is a large (40%) up:down asymmetry in π^+ production at $x_F = 0.8$, it rises linearly from about $x_F = 0.2$. Negative pions π^- show the mirror image behavior. Such high-x_F pions are clearly sharing a valence quark with the incident proton and their production direction is influenced by the quark spin or orbital angular momentum.

Krisch also described methods of accelerating polarized protons at the AGS and RHIC, Fermilab and HERA, together with their fascinating "Siberian snakes", flippers and rotators etc.

6.2 LEP 2

Dongchul Son [20] reported on L3 results now that LEP runs above the W-pair threshold. The cross section, measured at two energies, is perfectly in line with Standard Model predictions. At 172.13 GeV it is 12.9 pb. He also presented mass and coupling results. He then described searches for new particles (heavy sequential and excited leptons, SM Higgs ($>$ 66.4 GeV) and MSSM Higgses, and SUSY). For these limits, see his talk. Hadronic multijet events were used to extract a value $\alpha_s(M_Z) = 0.111 \pm 0.006$ at 161 GeV or 0.114 ± 0.007 at 172 GeV; the running of $\alpha_s(Q^2)$ was also shown.

6.3 Tevatron Searches

J.Hauptman [21] presented searches by DØ for quark substructure, leptoquarks, and a "bosonic Higgs". The latter could not decay directly to $b\bar{b}$ or $t\bar{t}$ but decays through a virtual W-loop to $\gamma\gamma$. A mass limit of 81 GeV is set.

6.4 Hadronic final states at LEP

G. Giacomelli [22] presented many features of hadronic final states at both LEP-100 and LEP-200. These include multiplicity and rapidity distributions, thrust, Bose-Einstein correlations, the running of α_S, etc. This data is a mine of information, but I do not attempt to cover it here.

6.5 Diffractive Excitation of Nuclei

C.O.Kim [23] discussed diffractive dissociation of nuclei, seen as a two step process: excitation and decay. For example an ^{16}O nucleus can be excited to $^{16}O^*$ either by Coulomb or pomeron excitation, and then decay to four α particles. I know too little about this, but it seems to be an interesting probe especially of nuclear physics.

Acknowledgments

I would like to acknowledge valuable collaboration with my colleagues in the hard diffraction group in CDF, especially Dino Goulianos and Phil Melese for many discussions. I thank the organizers of this most enjoyable Workshop for their invitation. Funding from the US Department of Energy is gratefully acknowledged.

References

1. QCD Subgroup on Diffractive and Forward Physics, M.G.Albrow et al., Proc. Snowmass 96, New Directions for High-Energy Physics.
2. M.L.Good and R.G.Walker, *Phys. Rev.* **120** ,1855 (1960)
3. A.Donnachie and P.V.Landshoff, *Phys. Lett.* B **191**, 309 (1987)
4. R.Bonino et al.,*Phys. Lett.* B **211**, 214 (1988).
5. J.D.Bjorken, *Phys. Rev.* D **47**, 101 (1993)
6. F.E.Low, *Phys. Rev.* D **12**, 163 (1975)
7. S.Nussinov *Phys. Rev. Lett.* **34**, 1286 (1975)
8. P.Bruni,G.Ingelman, DESY 93-187; POMPYT, http://www3.tsl.uu.se/thep/pompyt/
9. DTUJET/DPMJET P.Aurenche et al.,*Phys. Rev.* D **45**, 92 (1992) Comp. Phys. Comm **83**, 107 (1994).
10. PHOJET, see R. Engel,J.Ranft and S.Roesler, *Phys. Rev.* D **52**, 1459 (1995).
11. F.Abe et al., *Phys. Rev. Lett.* **78**, 2698 (1997)
12. M.G.Albrow, Hard Diffraction in CDF, these proceedings.
13. K.Goulianos, *Phys. Lett.* B **338**, 379 (1995)
14. S.K.Kim, Diffractive Physics at DØ these proceedings.
15. M.G.Albrow et al., *Nucl. Phys.* B **264**, 154 (1986).
16. D.Joyce et al., *Phys. Rev.* D **48**, 1943 (1993).
17. J.Orear, Small Angle $p\bar{p}$ Elastic Scattering, these proceedings.

18. J.Velsco, The TOTEM Experiment at LHC, these proceedings.
19. FELIX, Letter of Intent, CERN/LHCC 97-45 (1997)
20. D.Son, Results of the L3 Experiment, these proceedings.
21. J.Hauptman, New Phenomena in DØ , these proceedings.
22. G.Giacomelli and R. Giacomelli, Multihadron Production at LEP, these proceedings.
23. C.O.Kim, Diffractive Excitation of Nuclei, these proceedings.
24. B.Laforge, Diffraction at HERA, these proceedings.
25. A.Mueller, *Nucl. Phys.* B **415**, 373 (1994), A. Mueller and G.Salam, *Nucl. Phys.* B **475**, 293 (1996).
26. M.David, High Q^2 Events at HERA, these proceedings.
27. B.Oh, Hadronic Final States at HERA, these proceedings.
28. G.Wolf, HERA: $F_2(Q^2, x)$, these proceedings.
29. W.Funk, CP violation in the K° system, these proceedings.
30. D.Denisov, B Physics in DØ these proceedings.
31. Eunil Won, Top Quark Mass in DØ these proceedings.
32. CDF, Measurement of the Top Quark Mass, Phys. Rev. Lett (subm. Sept 1997)
33. CDF, Measurement of the $t\bar{t}$ production cross-section... Phys. Rev. Lett (subm. Sept 1997)
34. A.Krisch, Siberian Snakes and Polarized Proton Beams, these proceedings.