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A Basic Introduction to the White Pomeron

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Abstract

I give a brief and pedagogical introduction to the classical pomeron, state the basic ideas of the BFKL pomeron and the white pomeron, and indicate how Alan White's QCD_S theory predicts strong double pomeron production of IVB pairs through virtual loops of new color sextet Quarks. I briefly mention some other physics phenomena in high energy collisions in the laboratory and in cosmic rays that might be explained by QCD_S(six flavors of color triplet quarks augmented by two flavors of color sextet quarks). I comment briefly on Run II tests.

Contents

1 Introduction

The following naive attempt to introduce some of the ideas of Alan White's theory, QCD_S, is bound to be superficial and will miss much of its subtlety and power. Consider it as an "executive summary" for experimenters and an introduction and invitation for theorists to read the literature and write a better introduction.

1.1 The "classic" pomeron

In Leading Order QCD, LO-QCD, quark-quark scattering proceeds by single gluon exchange. Elastic and diffractive processes cannot proceed by one gluon exchange because the gluon carries (octet) color, which must be neutralized.The minimal additional exchange is another gluon of opposite color, to make a color singlet. In the Regge theory of elastic and diffractive scattering, 4-momentum transfer squared t (GeV^2) in the t-channel between scattering hadrons is predominantly, at high energy, carried by a "pomeron" $I\!P$. The pomeron is not a particle (not even a virtual particle) but a "Regge trajectory" which is something like the superposition of all possible exchanges with the quantum numbers of the vacuum but with a (complex) spin $\alpha(t) = \alpha_0 + \alpha' t$, where α_0 is the intercept and α' is the slope (trajectories appear to be at least approximately linear over a limited range of t). The intercept α_0 is related to the rise of total cross sections with energy and is approximately 1.08 at small scales Q^2 rising to ≈ 1.20 at larger Q^2 (smaller distances probed). The slope α' is ≈ 0.20 GeV^{-2} from systematic studies of data. The pomeron can be measured in different processes, e.g. by measuring the s-dependence of elastic (or inelastic diffractive) scattering at several fixed values of t (t and M^2).References [1, 2, 3] are recommended recent text books.

1.2 Some experimental issues

The pomeron is not well understood in QCD; it is non-perturbative and calculations of 1-, 2-, or n-gluon exchange diverge at low Q^2 as α_S (not to be confused with the α_{Regge}-parameters of the Regge trajectory) becomes large. In experiments at hadron and ep colliders one has tried to elucidate its nature experimentally, by (among other things) studying hard diffractive interactions. An example at the Tevatron [4] is single diffractive (SDE) dijet production, $pp \to p + JJX$, where one beam proton emerges "quasi-elastically" with a large fraction x_F (typically more than about 0.95) of its incoming momentum and a small t. The fractional momentum loss is $\xi = 1 - x_F$. Adjacent to it in rapidity, y, is a "rapidity gap" (+) (a region with no hadrons) Δy, typically more than 3 units. The large gap can occur because the exchanged pomeron is both colorless *and* has an effective spin $\alpha(t) > 1.0$. A $\pi-$ or ρ-trajectory can also be exchanged, it is also colorless but because $\alpha(t) < 1.0$ it does not normally give a large gap and its contribution dies with $\sqrt{s}$. These "rules-of-thumb" for pomeron exchange dominance: $x_F > 0.95$ and $\Delta y > 3$ are kinematically equivalent: $\Delta y = -ln\frac{1}{\xi}$. The dijet JJ measures the parton-parton scattering, and the X stands for "any other produced particles." This probes the (quark + $\frac{9}{4}$ gluon) structure of the exhanged pomeron at large $Q^2 \approx M_{JJ}^2$. If *both* protons are diffractively scattered to $x_F > 0.95$ adjacent to rapidity gaps $\Delta y > 3$ bracketing a central hadronic system of mass M the process is called Double Pomeron Exchange, DPE. The central mass is (remember this is a rule-of-thumb and not a sharp limit) $M < 0.05\sqrt{s}$ simply from the kinematic relation $M^2 = x_{F,1}x_{F,2}s$, giving a range up to about 100 GeV at the Tevatron and 700 GeV at the LHC. Thus at the Tevatron DPE reactions extend into the domain of dijets. CDF [5] discovered $pp \to p + JJX + p$ with M_{JJ} up to and somewhat beyond 100 GeV [6]. At the LHC, DPE extends well above the threshold for electroweak phenomena.

1.3 Reggeized gluons

I now return from experiment and phenomenology to theory. The LO-QCD diagram of single gluon exchange between scattering quarks (or gluons) is theoretically "sick" as it is not gauge invariant. The full theory must be gauge invariant, so the 1-g diagram must be extended by adding higher order diagrams. Two exchanged t-channel gluons, as naively supposed above, is not gauge invariant either. One has to add an infinite number of diagrams, involving also quark loops. There is a way of doing this summation that actually results in a gauge invariant (and therefore now healthy) exchange, called a *reggeized gluon* g_R. The resulting g_R has a t-dependent complex angular momentum, like the classical pomeron and other reggeons (meson and baryon families also lie on Regge trajectories, with different intercepts and slopes). However g_R is not (yet) a pomeron as it carries color(octet in SU(3)).

1.4 BFKL pomeron

We can construct a colorless exchange between quarks from two color compensating reggeized gluons, which will exchange gluons between them in the form of a ladder. Inevitably the ladder will contain quark loops. This is called the BFKL (Balitsky, Fadin, Kuraev and Lipatov) pomeron [7, 8] and it was a major and very lengthy feat to calculate it in QCD (the relation between α_{regge} and α_s) at NLO, and the NLO corrections are large which does not give confidence in rapid convergence. The BFKL theory makes predictions about parton distribution function evolution (related to the DGLAP evolution but in x rather than Q^2), very forward jets with large rapidity separation etc. As the BFKL pomeron is a color singlet exchange between quarks, it changes the $qq \to JJ$ scattering, also producing mini-jets between two well separated (in rapidity) jets.

1.5 White pomeron

In White's theory [9, 10, 11, 12], called QCD_S for reasons that will become apparent, the color of a reggeized gluon exchange is compensated not by another reggeized gluon but by a "cloud" or field of an infinite number of "wee" gluons. Wee can be approximately defined as having very small momentum even in the infinite momentum frame. The wee gluons are not only intimately related to the QCD vacuum, in a sense they *are* the QCD vacuum. **Color confinement and chiral symmetry breaking are realized in the theory.** The reggeized gluon together with its accompanying cloud of wee gluons becomes, when all pomeron self-interactions are included, the "critical pomeron" [13, 14] in QCD_S; I shall call it the "white pomeron" (pun intended). In standard QCD the coupling α_s runs (it is not a coupling *constant* so why is it still referred to as such?) down to $\alpha_s = 0$ as $s \to \infty$, the property known as asymptotic freedom. White showed that in his theory the number of flavors N_f of color triplet quarks is required to have the value $N_f = 16$. Asymptotic freedom requires it to be $\leq$ 16. We have six known quark flavors leaving 10 unaccounted for. However color sextet Quarks, Q_6, which transform as sextets under color SU(3), would each contribute 5 to the sum, so the requirement $N_f = 16$ can be satisfied with the 6 normal color triplet quarks and **a doublet (U,D) of new sextet Quarks!**. The new doublet must be heavy, not only because they have not yet been seen in experiments but theoretically they should be around the electroweak scale. In fact electroweak symmetry breaking, normally ascribed to a Higgs field with its associated Higgs boson, is here accomplished by different states required in the theory. No new interaction is required and the electroweak scale is a second QCD scale. **There is no Higgs boson** (or at least, no need for one). Instead there are meson-like composites $\Pi^-, \Pi^\circ, \Pi^+, \eta_6$ etc. analogous to $\pi^-, \pi^\circ, \pi^+, \eta$. The Π get "eaten" to give mass to W^-, Z°, W^+ as in the Higgs mechanism. The η_6 plays the role of the Higgs boson in generating the electroweak symmetry breaking, but it is not the Higgs. The η_6 also is a heavy Peccei-Quinn axion, the particle invented to solve the problem of CP-conservation in strong interactions (why do they conserve CP?) and normally expected to be *very* light. In QCD_S it can be heavy.

The white pomeron couples particularly strongly to sextet quarks and hence to W and Z through Q_6 intermediate states (loops).The DPE process, once above threshold, will therefore produce W-pairs, as recognized already in 1987 [15] inspiring me to say [16] considering DPE at the SSC, "Much more dramatic is a prediction of **direct and strong W^+W^- production by Pomerons** in Alan White's Critical Pomeron theory" see Fig.1. A more recent version of this diagram is given in Fig.2.

As $\sqrt{s}$ grows, the SDE and DPE $\to W^+W^-$ production cross sections will grow and become very strong and may even exceed normal non-diffractive dijet production at sufficiently high E_T and $\sqrt{s}$. The WW and ZZ purely leptonic DPE events will have atypically small n_{ass}, the number of associated charged particles in the event excluding the W, Z decay products, and very low forward activity, possibly with forward rapidity gaps on one or both sides. The leptonic-hadronic channels ($llJJ, l\not{E}_T JJ, \not{E}_T JJ$) will show Z, W, Z respectively peaks in M_{JJ} if one selects events with very little activity

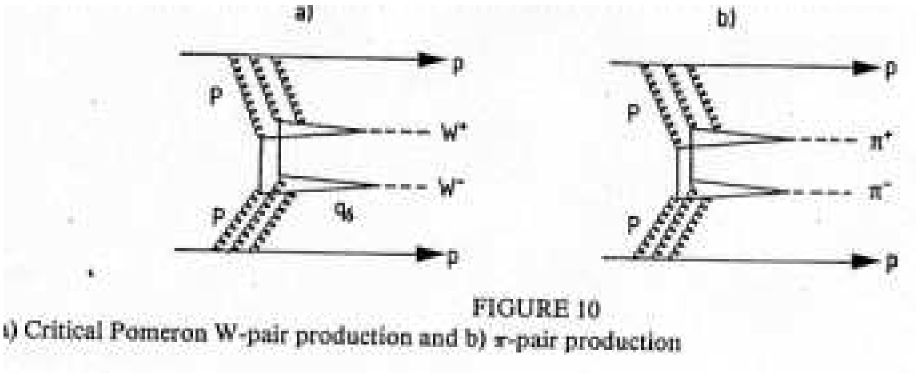

Figure 1: W-pair (a) and π-pair production by Double Pomeron Exchange [16]

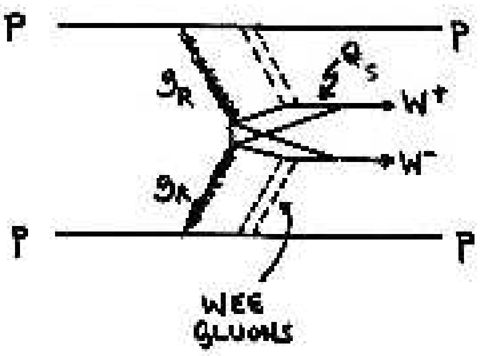

Figure 2: Diagram showing white pomeron emission from two protons, with creation of a W^+W^- through a sextet Quark loop.

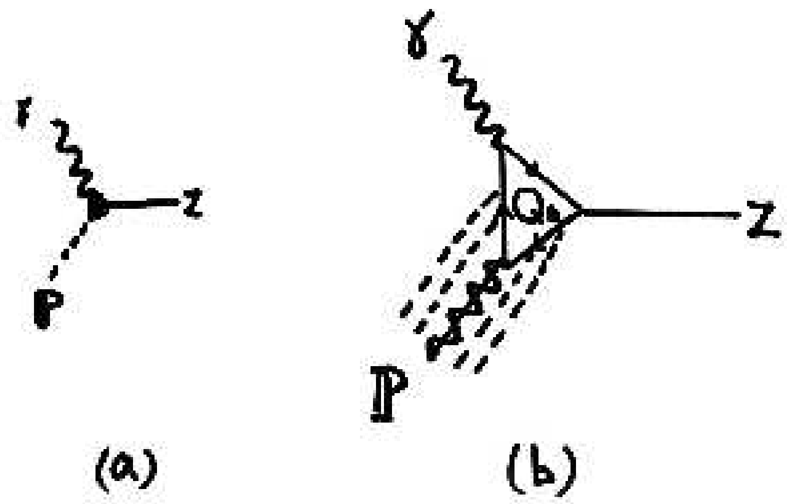

Figure 3: (a) The $\gamma I\!\!P Z$ vertex (b) zoom in to see Q_6 loop.

outside the jet cones and/or forward. Even the 4-jet channel may show evidence for WW and ZZ pair production by selecting very clean events and possibly by also requiring the dijets in the chosen combination to have high p_T. The η_6 probably manifests itself as a broad enhancement in M_{WW} without the peak one might have expected from a heavy Higgs boson. This is probably analogous to the broad peak in $M_{\pi\pi}$ seen in DPE at the CERN ISR [17] ($pp \to p + \pi^+\pi^- + p$) searching for glueballs.

1.5.1 The $\gamma I\!\!P Z$ vertex

QCD_S has a large $\gamma I\!\!P Z$ vertex at the electroweak scale through a virtual Q6 loop as shown in Fig.3. The electromagnetic, strong and weak vector bosons coming together! This must be a good way to study unification! Thus while at HERA, photon-vector meson mixing gives exclusive photoproduction of $\rho, \omega, \phi, J/\psi$ and (just) Υ, at higher energies (LC $\otimes$ Tevatron, TESLA $\otimes$ HERA or CLIC$\otimes$ LHC) one will have photoproduction of the Z, and can probe the white pomeron and sextet quark loops with the photon. This strongly suggests that linear e^+e^- colliders should be built where they can collide with high energy proton beams. Note that the physics of the pomeron sector at this energy scale is invisible to presently envisaged e^+e^- colliders.

1.5.2 Color sextet quarks, WIMPs and SIMPs

Color sextet quarks were first introduced by Georgi and Glashow [18] in 1979 as a possible explanation of the new Υ. "Will all fermions ever to be found simply fall into massive copies of the first family? Oh, what a boring possibility!" They were called "Quixes" and could give rise to large families of bound states. In 1980 Marciano [19] suggested that dynamical electroweak symmetry breaking might be generated if, in addition to the six color triplet quarks, there is a very heavy doublet (U, D) of color sextet Quarks, Q_6. The effective strength of the strong coupling of Q_6 is higher than that of q, depending on the scale Q^2 (sorry, different meaning for Q!) but you should not think of this a simply 3 Feynman lines at a vertex. For the pomeron the very strong coupling intimately involves *wee gluons.* There *could* be (but it is probably not required) a partner doublet of Heavy Leptons (L, ν_6). If so, the ν_6 would be a weakly interacting candidate component of dark matter (*WIMP).*The lighter of the two sextet Quarks is probably stable (which has enormous implications!) while the heavier will decay into it through W emission. The electric charges of D and U are opposite that of d and u, $+\frac{1}{3}$ and $-\frac{2}{3}$, and their *triality* is opposite, meaning that e.g.$[uu\bar{U}$ and $[\bar{u}\bar{s}D]$ are color singlets. This suggests the existence of superheavy stable baryons, in the hundreds of GeV range. The scale of this physics is the electroweak scale. Suppose that the lightest such *superbaryon* is the neutral N and so $P \rightarrow N + W$. This would give another dark matter candidate, in this case a strongly interacting *SIMP*. These are strongly interacting only at extremely short distances, i.e. large Q^2, when the Q begin to be resolved. At $\frac{1}{10}$ fermi they are still weakly interacting, just as $\pi\pi$ interactions are weak at 10 fermi. One might also have "superduperheavy" stable Hadrons such as $[DDU]$. One can even speculate about Supernuclei made of SuperHadrons!? Physics in the dark matter sector could be very rich!

2 Experimental Evidence

Prior to the start of Run II there were already several puzzling experimental anomalies that find a ready explanation in QCD_S.

2.1 Anomalous WJJ events in UA1

In 1987 UA1 published a paper [20] on large transverse momentum W balanced by two jets. While the p_T distribution and the rate of events was consistent with QCD predictions, the two highest $p_T(W)$ events stood out as having $p_T \approx$ 80-100 GeV/c and a jet pair mass M_{JJ} also around 80 - 100 GeV, consistent with M_W! The two event pictures shown in the paper only show tracks with $p_T > 1$ GeV/c, but they appear to be very clean. There is also an event that could be interpreted as $Z \rightarrow \nu\bar{\nu} + JJ$ but the dijet mass is high, $M_{JJ} = 148 \pm 17$ GeV. UA1 state that "Within the current theoretical framework of perturbative QCD we conclude that it is difficult to explain the three observed events. At this stage we cannot exclude unforeseen theoretical uncertainties, non-gaussian fluctuations in the response of the UA1 calorimetry or a statistical fluctuation of the data."

In 1989 Armin Boehrer [21] presented a paper to the Proton-Antiproton Conference with an update on this analysis. By then there were 4 anomalous events all with M_{JJ} compatible with M_W and high $p_T(W), > 50$ GeV/c, see Fig.4. These new events were not published after the conference talk.

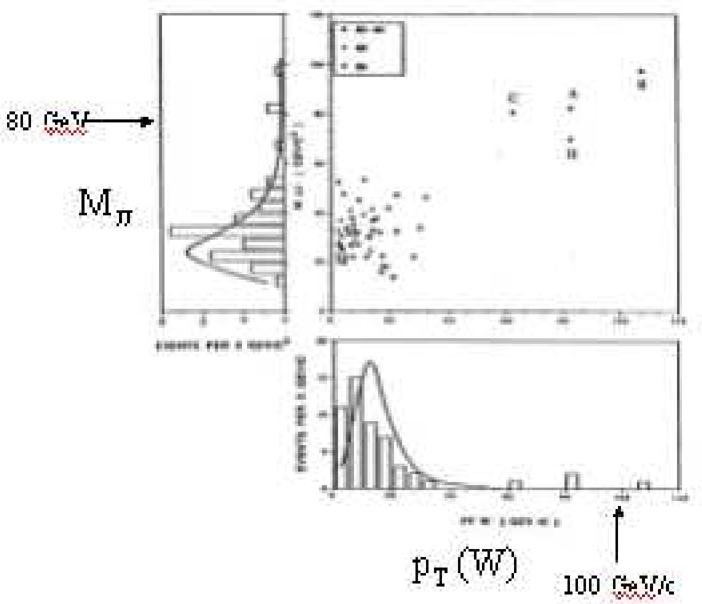

Figure 4: Events from UA1 with a leptonic W and two jets.

2.2 High E_T jet excess in CDF

At high E_T CDF [6] in Run I observed an excess of high E_T jets, Fig.5. It was found that one could reduce the significance of the discrepancy by increasing substantially the high-x content of the proton , a region where it is not well constrained. However in these fits (CTEQ4HJ) one gave extra weight to the jet data themselves; it keeps the data compatible with the standard model but "at a stretch". A possible interpretation in QCD_S is that these jet pairs are actually WW and ZZ pairs decaying hadronically. One should check to see if the events have anomalously low underlying event, and if the individual jet masses are compatible with M_W/M_Z. Also, it is natural in the theory for the *effective* α_S to flatten with Q^2 when the QCD_S scale is reached.

2.3 W^+W^- events in CDF Run I

In 1997 CDF published [23, 24] the observation of five W^+W^- leptonic events. The cross section, $\sigma(\bar{p}p \rightarrow W^+W^-) = 10.2^{+6.3}_{-5.1}(stat) \pm 1.6(syst)$ pb was in agreement with standard model predictions. In the CDFNOTE-3673 one event picture was shown (Run,Event = 63209,510174) with only 1 (3) track(s) (apart from the e, μ) with $p^T >$ 0.4 GeV/c and $|\eta| < 1.0$ (1.5), see Fig.6. The BBC counters on the E side were empty.

Liqun Zhang's thesis [25] shows event displays for all five events. Three of the others look normal and one (65298,549227) looked "quiet", but unfortunately quantitative track details were not available (and Liqun had left the field).

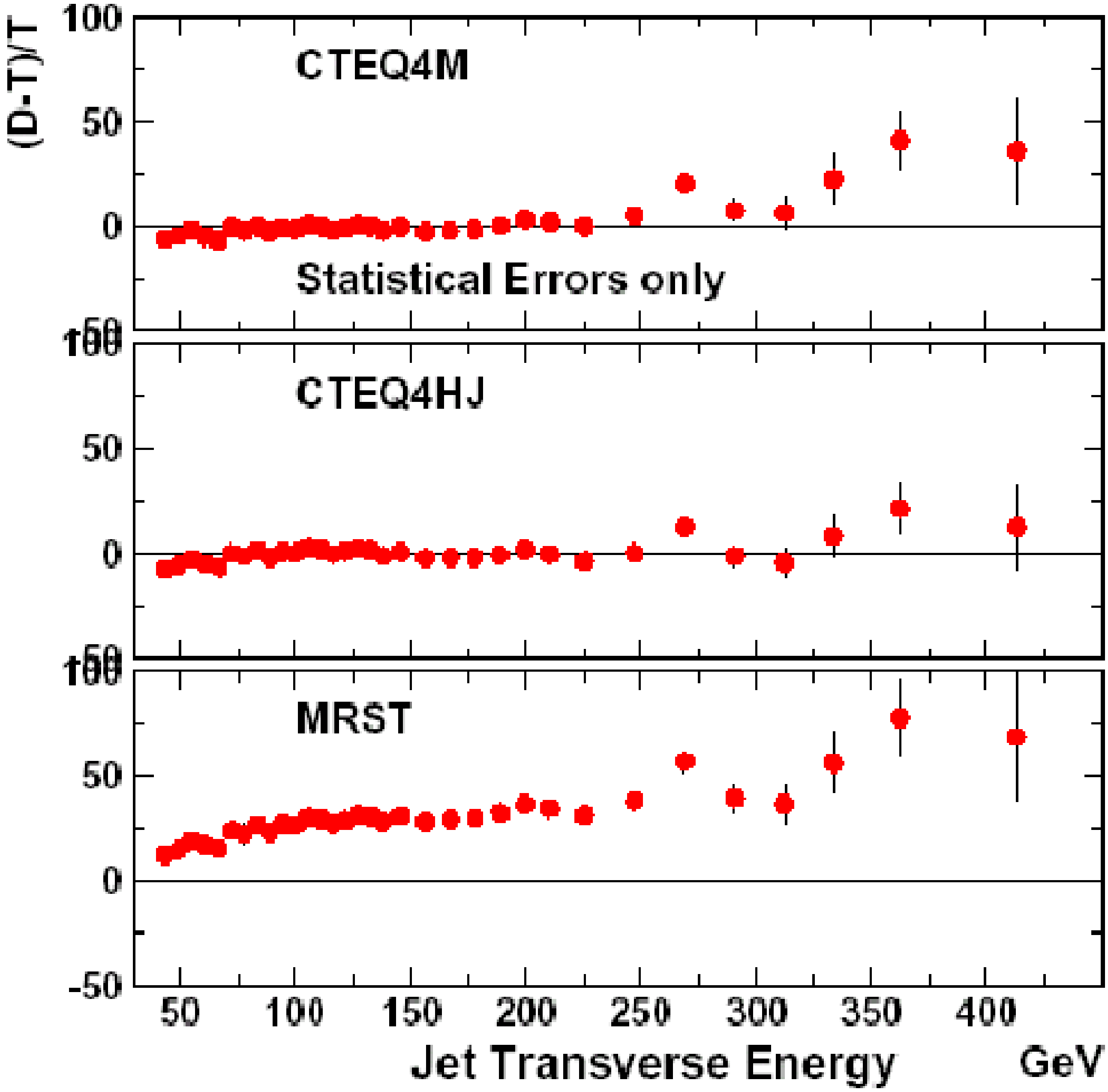

Figure 5: Ratio of CDF Run I high E_T jet spectrum to the Standard Model Monte Carlo PYTHIA, with different parton distribution functions.

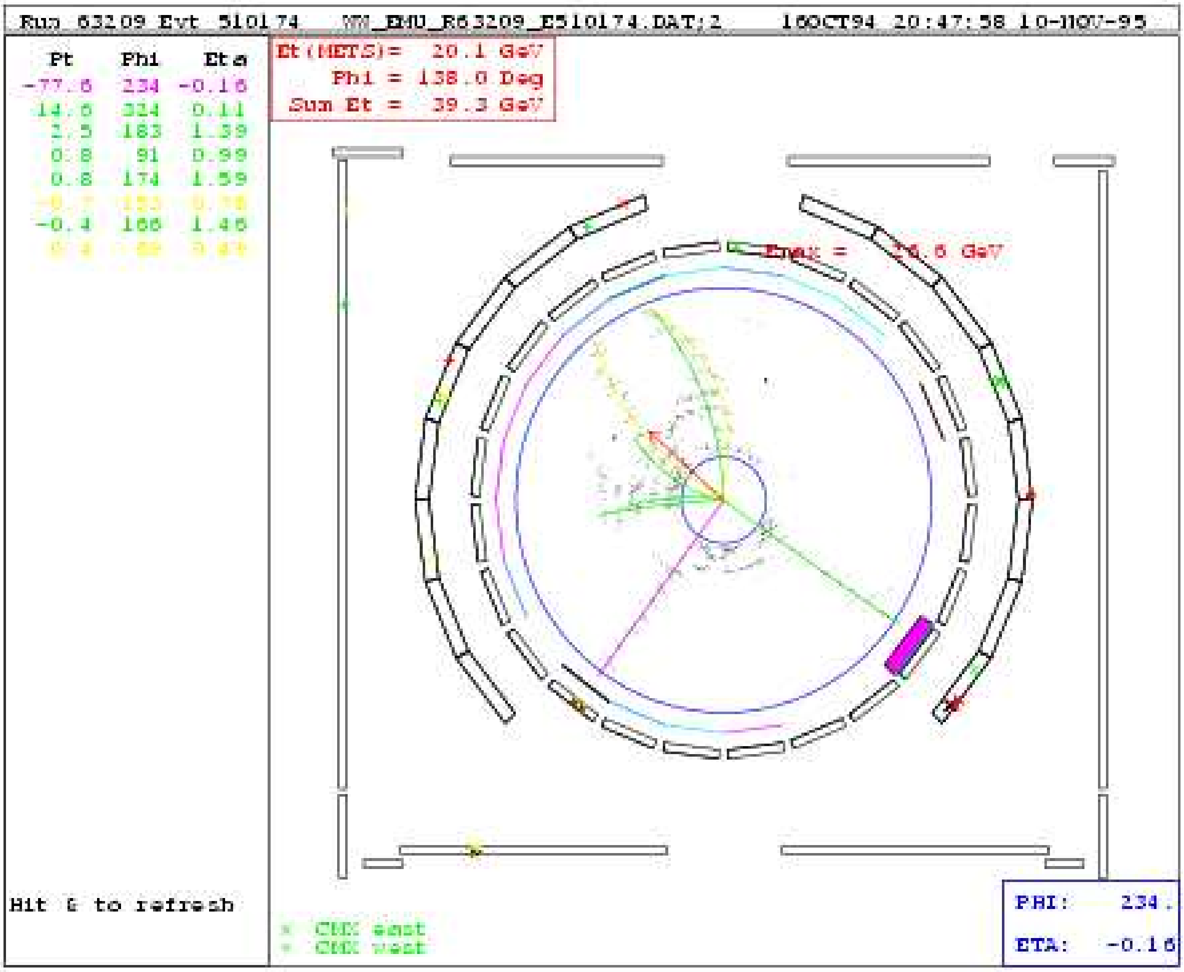

Figure 22: Event display for one of the $e\mu$ events: reconstructed CTC tracks and m hits in the $r-\phi$ plane. Note that the muon only leaves a minimum ionizing energy in calorimeters.

Figure 6: CDF Run I $WW(e, \mu, \not\!\!E_T)$ event.

2.4 Cosmic ray effects

If VV-pairs are prolifically produced above a threshold of $\sqrt{s} = 1$ TeV - 10 TeV, one might expect to see dramatic effects in cosmic ray interactions above the equivalent energy (for pp) of $\approx 5.10^{14} \to 5.10^{16}$ eV.

2.4.1 The knee

This energy threshold is just in the region of the famous "*knee*" in the spectrum, see Fig.7 which is not yet understood [26]. Perhaps it is a change in the *nature* of the interactions, with the average transverse momenta becoming large, rather than in the flux? Such a change, if dramatic (it cannot be a rare process) could lead one to underestimate the shower energy and steepen the spectrum. A possible contributor to the underestimation is the increased production of neutrinos through real W^+W^- and ZZ pairs.

2.4.2 High E_T jet excess ("cores")

A study [27] of events at or above this energy region shows a rate of events with two high E_T well separated jets which is up to two orders of magnitude higher than the rate expected from a standard QCD Monte Carlo which has been tuned to accelerator data (including $Sp\bar{p}S$ and Tevatron). This has been observed in both the Chacaltaya and the Kanbala large scale emulsion chamber experiments. These might be VV, or a "high E_T jet excess as suggested by the Tevatron data. Fig.8 shows the Chacaltaya data; the Kanbala data look identical.

3 Run II Tests

The masses of the sextet Quarks (U,D) are not determined in the theory, although they should be around the electroweak scale (a few hundred GeV), and it is not sure that there will be any observable effects at the Tevatron. On the other hand if no effects are seen in IVB pair production at the LHC the theory will probably be in trouble. With DPE extending nominally to $M_{DPE} \approx 100$ GeV at the Tevatron, with a tail extending significantly above that, and SDE extending to excited masses $M_{SDE} \approx \sqrt{0.05}\sqrt{s} = 440$ GeV, it is worth looking for evidence of predicted effects

3.1 Leptonic W-pairs and Z-pairs

Take W^+W^- and ZZ purely leptonic candidates, select events with low overall activity and forward rapidity gaps (little or no activity forward of 3°) on one or both sides. The central region may also show anomalously small activity. Is the rate of such events compatible with SM predictions? A complementary sample of WZ events should not show gaps, and given enough events this can be used as a control, as the SM will not expect a difference.

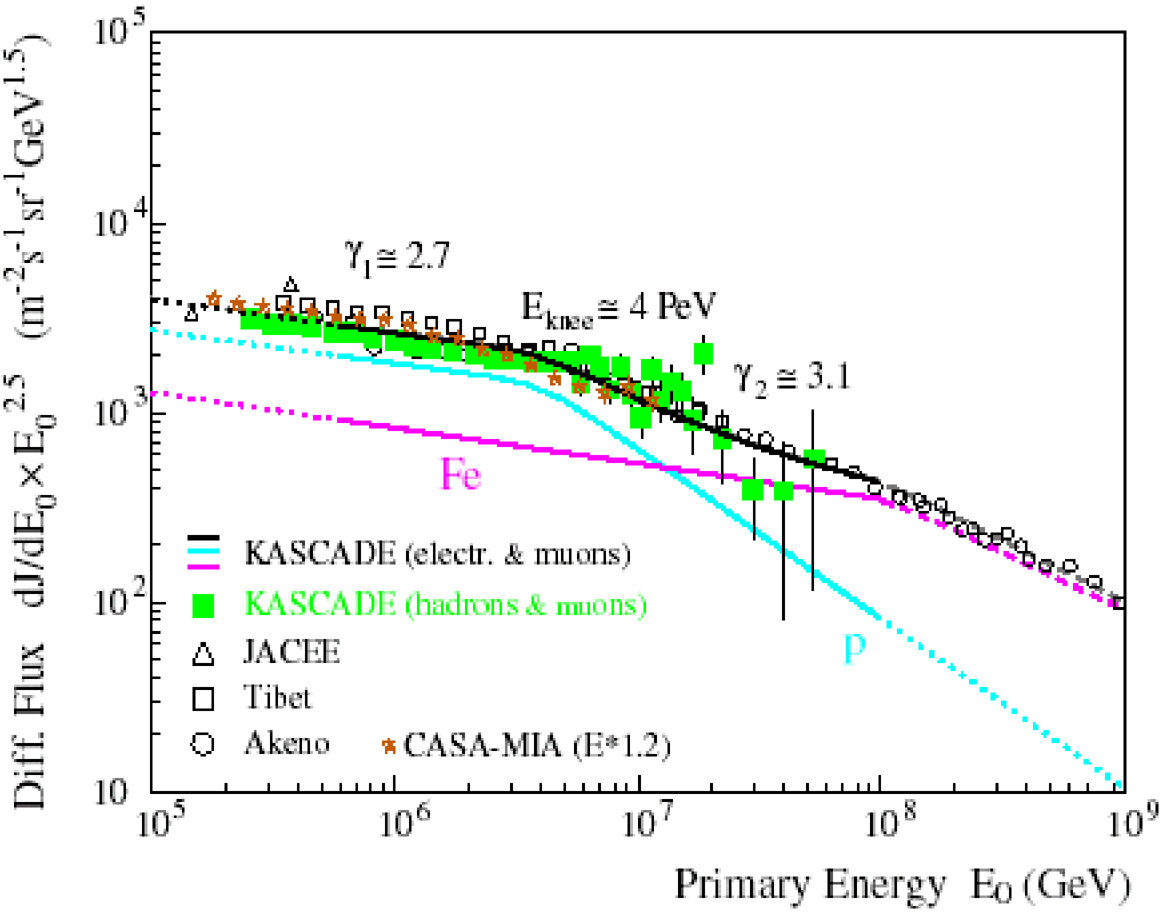

Figure 7: The cosmic ray spectrum $\times$ $E^{2.5}$ in the region of the knee, between the Tevatron and LHC energies.

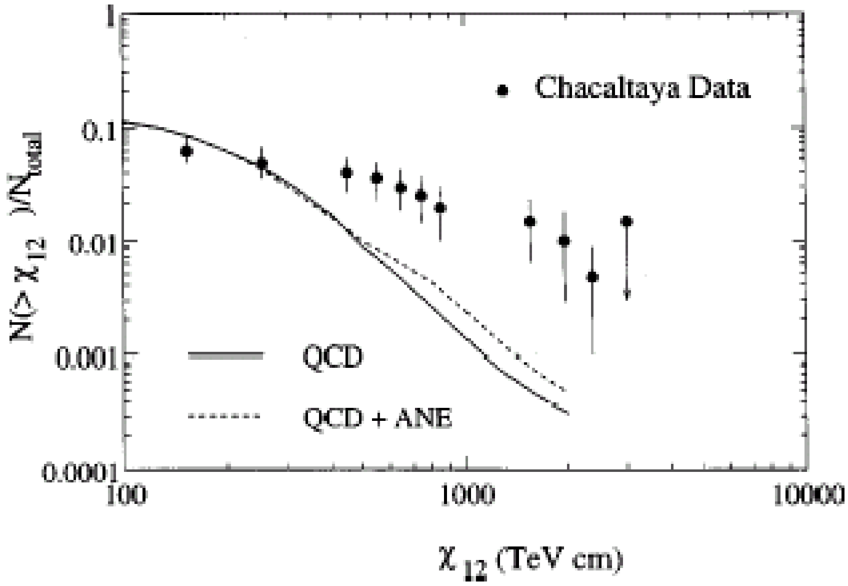

Figure 8: Distribution of the product of core energy $\times$ the spatial separation between the cores, compared with a QCD Monte Carlo tuned to lower energy (collider) data.The events are at a c.m. energy of several TeV.

3.2 WJJ and ZJJ events

Take events with an IVB decaying leptonically and exactly two jets (above 15 GeV e.g.). Excluding the tracks or towers in the jet cones, select events with very low associated activity central, forward and very forward on one or both sides. Make a scatter plot M_{JJ} vs $p_T(W)$ for these clean events to see if a hadronic $W \to JJ$ peak emerges.

3.3 JJJJ events

Seeing IVB pair production in the 4-jet channel would seem to be hopeless, and probably it is, although the ratio of branching fractions $\frac{WW \to 4J}{WW \to ll\nu\nu} \approx 12$ and similarly for ZZ. Of course the QCD background is much larger in the 4J case, but by selecting "superclean" events with very little activity forward and outside the jet cones, pairing the dijets such that the two pair M_{JJ} values are most equal, and plotting average M_{JJ} vs $p_T(JJ)$ one might see a signal. Retrospectively one can compare the underlying event and forward activity for events in the "signal" region and outside.

3.4 Two-photon events

Two photon events could be a useful control sample, as (like the IVB's) they are not strongly interacting, but the theory of the white pomeron does not predict any special enhancement (over the SM process DPE $\rightarrow \gamma\gamma$).

4 Conclusions

While the pomeron is an important part of the strong interaction, it has been an enigma in QCD for approximately 30 years. Theoretically it has been something of a fringe subject, while experimentally its fortunes revived in the last decade thanks to its prominence at HERA and high energy hadron colliders. White's theory of the critical pomeron and its implications, with a doublet of heavy color sextet quarks, electroweak symmetry breaking by strongly interacting composites rather than a Higgs boson, confinement and strong W^+W^- and ZZ production by double pomeron exchange remained somewhat obscure among both theorists and experimenters. However several puzzling observations find a ready explanation in QCD_S, notably some unlikely WW events in UA1, the CDF high-E_T jet excess, the excess of high E_T cores (jets) in cosmic ray emulsion chambers and the knee in the cosmic ray spectrum. It provides some candidates for dark matter, which might have a rich spectrum, without SUSY. The theory predicts dramatic WW and ZZ production at LHC, possibly glimpsed at the $Sp\bar{p}S$ collider and the Tevatron. This physics sector will not be in reach of a linear e^+e^- collider, but would be very well studied at an ep collider through the $\gamma I\!\!PZ$ vertex Fig.3.

5 Acknowledgements

I thank Alan White, who first stimulated my interest in the critical pomeron and its possible consequences in double pomeron exchange at the International Conference (third "Blois Workshop") on Elastic and Diffractive Scattering in 1989, a theory which has continued to intrigue me, for patiently explaining some of his ideas and commenting on this note.

References

[1] High Energy Particle Diffraction, V.Barone and E.Predazzi, Springer (2002).

[2] Quantum Chromodynamics and the Pomeron, J.R.Forshaw and D.A.Ross, Cambridge University Press (1997).

[3] Pomeron Physics and QCD, S.Donnachie, G.Dosch, P.Landshoff and O.Nachtmann, Cambridge University Press (2002).

[4] T.Affolder et al., CDF Collaboration, Phys.Rev.Lett: 881151802 (2002).

[5] T.Affolder et al., CDF Collaboration, Phys.Rev.Lett. **85**: 4215 (2000).

[6] M.Convery et al., Exclusive Dijet Production in Double Pomeron exchange. CDF-NOTE 6437 (May 1 2003).

[7] V.S.Fadin, E.A.Kuraev and L.N.Lipatov, Sov.Phys.JETP **44** 443 (1976).

[8] Y.Y.Balitsky and L.N.Lipatov, Sov.J.Nucl.Phys. **28** 822 (1978).

[9] Alan R.White, Electroweak-scale Excess Cross-Sections in the Sextet Quark "Standard Model", ANL-HEP-PR-97-09, hep-ph/9704248 (1997) and references therein.

[10] Alan R,White, Confinement and the supercritical Pomeron in QCD, Phys.Rev D **58** 074008 (1998) and references therein.

[11] Alan White: http://glodwick.hep.man.ac.uk/conference/talks/masthm.pdf ; Alan White http://conferences.fnal.gov/smallx/index.html

[12] Alan R.White, Phys.Rev **D29** (1984) p.1435 and references therein; ANL-HEP-CP-92-90, Color Sextet Quarks and New High Energy Interactions; and many other papers.

[13] A.A.Migdal,A.M.Polyakov and K.A.Ter-Martirosyan, Zh.Eksp.Teor.Fiz. **67** p.84 (1974).

[14] H.D.I.Abarbanel and J.B.Bronzan, Phys.Rev.D **9** p.2397 (1974).

[15] Alan R. White, Confinement and the Pomeron, Nucl.Phys.B (Proc.Supp.) **12** 190 (1990).

[16] M.G.Albrow, Nucl.Phys B (Proc.Suppl) **12** (1990) p.291.

[17] T.Akesson et al. (AFS Collaboration) Nucl.Phys. **B264** (1986) p.154.

[18] H.Georgi and S.Glashow, A Quixotic Interpretation of the Upsilon Particle, HUTP-79/A027 (1979)

[19] W.J.Marciano, Phys.Rev.**D21** (1980) p.2425

[20] C.Albajar et al., UA1 Collaboration, Phys.Lett **193** (1987) p.389.

[21] A.Böhrer, Status Report of the W and Z analysis in UA1, Proc. Proton-Antiproton Collider Workshop, Castiglione della Pescaia (1989).

[22] T.Affolder et al., Phys.Rev.D **64**, 032001 (2001).

[23] F.Abe et al. (CDF Collaboration) Evidence for W^+W^- Production in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV, Phys.Rev.Lett **78** (1997) 4536-4540.

[24] D.Carlsmith and L.Zhang,CDFNOTEs 2906(Dec 1994) and 3093 (Apr 1995). L.Zhang CDFNOTE 3673 (May 1996).

[25] Liqun Zhang, Thesis (Univ.Wisconsin-Madison) Observation of W^+W^- Production in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV.

[26] M.Boratav and A.Watson, Cosmic Rays above 10^{14} eV, astro-ph/0009469

[27] Z.Cao, L.K.Ding, Q.Q.Zhu and Y.D.He, Phys.Rev. **D56** (1997) 7361.