Glueballs and Exclusive Hadron Production at the Tevatron

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The study of *low mass* hadronic systems in double pomeron exchange processes is completely virgin territory at the Tevatron. These are events with the p and $\bar{p}$ at Feynman $x_F \geq 0.997$ or so, with central masses less than a few GeV and large rapidity gaps in both forward directions. Important physics topics are (a) to search for glueball states G by the exclusive process $p\bar{p} \to pG\bar{p}$ (b) to measure exclusive hyperon-antihyperon production up to $\Omega^-\bar{\Omega}^+$ (c) to search for exclusive χ_c and χ_b production (d) to search for events with an unusually large or small ratio of charged hadrons to π^o (DCC = disoriented chiral condensate?). These studies would all extend our understanding of QCD to the low-Q^2 domain. I discuss briefly how they could be carried out in CDF and DØ .

I. DOUBLE POMERON EXCHANGE

Double pomeron exchange, DPE, events [1] contain two large rapidity gaps, where by "large" is meant not exponentially damped on a scale of order one unit of rapidity. A region $\Delta\eta$ (or better Δy) as large as (say) 4 units with no hadrons is dominated by pomeron, P, exchange in the t-channel, with little background from other processes (non-diffractive or reggeon exchange). The "pomeron" is a colorless but strongly interacting entity with the quantum numbers of the vacuum: No charge, no isospin, positive parity, C-parity and G-parity. Probably at low $|t|$ and Q^2 it is predominantly two or more gluons in a colorless combination. Probing it with virtual photons at HERA [2], and observing diffractive W production at the Tevatron [3], demonstrate a $q\bar{q}$ component at large Q^2.

The total rapidity range of a $p\bar{p}$ collision is $\Delta y = ln\frac{s}{m_p^2}$, which was 8.4 at the CERN ISR ($\sqrt{s} = 63$ GeV), 13.0 at the $Sp\bar{p}S$ ($\sqrt{s} = 630$ GeV), and is 15.3 at the Tevatron ($\sqrt{s} = 2000$ GeV). $\Delta y = 6.9$ (7.4) at the fixed target experiments WA102 [4] (E690 [5]) with $p_{beam} = 450$ (800) GeV/c. At the colliders if we restrict ourselves to events with all central hadrons in $|\eta| \leq 1.5$ ($155^o \geq \theta \geq 25^o$) where they can be well measured, the forward rapidity gaps exceed 2.7 at the ISR and 6.1 at the Tevatron. The AFS experiment at the ISR [6] showed very little non-DPE background in central $\pi^+\pi^-$ production. Gaps exceeding 6 units at the Tevatron will have negligible background from non-pomeron exchange [1].

II. GLUEBALL PHYSICS

At this workshop Barnes [7], Kharzeev [10] and Pumplin [11] also discussed hadron spectroscopy in double pomeron exchange processes. There are different ways of thinking about the *exclusive* process $p\bar{p} \to pG\bar{p}$ with G a central gluonium or glueball state. (D.Robson [12] first suggested this channel.) One is to note that any hadrons or hadron pairs with the quantum numbers of the vacuum will be present as virtual states in the vacuum and they can be made real by the collision of two hadrons, whose role is essentially to allow 4-momentum to be conserved. (What is the spectrum of these states, for specific quantum numbers?) Another is to consider the fusion of a colorless pair (or triplet) of gluons from each beam particle, noting that the gluon density rises rapidly as $x_{Bjorken}$ becomes very small. Yet another is to note that glueball states, like all hadrons, must couple to the pomeron and if the quantum numbers are right the process will proceed by $PP \to G$. Allowed quantum numbers are $I = 0, C = +$ but any J^P [11]. The advantage of the *exclusive* process is clear: Glueballs are probably being produced with a high cross section in inelastic collisions but when the multiplicity is high the combinatorial background is overwhelming. In exclusive production there is **no** combinatorial background.

For this physics one would like to select events with 2, 4 or possibly 6 well measured charged particles in the central detectors. Particle identification (π, K, p) is important both for reconstructing the mass and checking that the overall charge, strangeness, and baryon number are zero. Additional neutral particles (γ, π^o, K_L^o, n) may be looked for and either used in the final state combination or used to reject non-exclusive events. The list of interesting final states is long and fairly obvious, including $\pi^+\pi^-$, K^+K^-, $K_S^oK_S^o$, $p\bar{p}$, $\Lambda\bar{\Lambda}$, $\phi\phi$, 4π, $\pi\pi KK$, $KKKK$, etc. The mass resolution

[1] I assume no *Odderon* exchange. That could be looked for by the exclusive production of a central ω or ϕ with $I^GJ^{PC} = 0^-1^{--}$.

when the charged tracks are all measured is very good, typically 10 MeV. It would be good to be able to use the electromagnetic calorimetry to measure neutral states like $\eta\eta \rightarrow 4\gamma$ but I suspect this is very difficult to trigger on, the backgrounds would be high and the mass resolution poor. However I have not done a study of this.

III. HYPERON AND OTHER PAIRS

At the Axial Field Spectrometer at the ISR exclusive central $p\bar{p}$ pairs were observed [6] with masses from 2 GeV to 2.8 GeV. With only 64 events there were no significant structures. (WA102 [4] also reported no significant structures with more events but more non-DPE background.) The total cross section for $pp \rightarrow ppp\bar{p}$ with the central p and $\bar{p}$ having $|\eta| \leq 1.5$ is 40$\pm$20 nb which, if s-independent[2], would correspond to a rate of 4 Hz at $L = 10^{32} cm^{-2} s^{-1}$. Actually with that luminosity and 36 bunches ($\Delta t = 396ns$) the fraction of inelastic collisions that occur in isolation (therefore useful for gap physics) is only about 13%. The optimum luminosity for gap physics is when $< n >= 1$, at $L \approx 5.10^{31} cm^{-2} s^{-1}$, and the fraction of events that occur singly is then 37%. So perhaps one could get thousands of events in an hour of special running, along with other channels that could come with the same trigger (say 2 or 4 central charged particles). This estimate is assuming full $|t|$ coverage and should be multiplied by the t-acceptance if it is limited.

If proton pairs are produced by DPE we must also have hyperon pairs $Y\bar{Y}$ produced. Just using charged particles, and allowing for displaced vertices, one can measure pairs of $\Lambda, \Xi^-, \Xi(1530), \Omega^-$ and maybe even Λ_c. Using γ and π^o other pairs like Σ^o, Σ^+ and Ξ^o become accessible. Why would one want to do this? The wealth of data possible can be used to measure the coupling of all these baryons to the pomeron, and relate them to elastic and total cross sections ... does the phenomenology hang together? How do the $Y\bar{Y}$ mass spectra depend on Y, and on t_1, t_2 if they are measured. If one measures also meson pair production ($\phi\phi$) how do the cross sections compare at the same mass (2-quarks vs 3-quarks)? With hyperon pairs one can measure polarizations and hence study spin-spin correlations which might reveal interesting things about the spin of the pomeron (are there correlations with t_1, t_2, $\Delta\phi(p\bar{p})$)? When $K^o\bar{K}^o$ pairs are produced are they $K^o_s K^o_s$ and $K^o_L K^o_L$ or sometimes $K^o_S K^o_L$, and is the answer dependent on $M_{K\bar{K}}$? If both kaons were to decay to $\pi^+\pi^-$ is there a correlation between their decay times as there is in ϕ decay?

IV. HYBRIDS, HEAVY MESONS, AND HIGGS

There can be a very interesting spectroscopy of, possibly narrow, hybrid states $b\bar{b}g$ [7] [13]. Those with the allowed quantum numbers (DPE is a *Quantum Number Filter*) will be produced exclusively; e.g. one gluon from each beam proton fuse $gg \rightarrow g$ and another make $gg \rightarrow b\bar{b}$.

Also we should search for the 0^+0^{++} χ_c and χ_b states; the latter decays to $\Upsilon\gamma$ to $\mu^+\mu^-\gamma$. One very interesting reason to study isolated central χ_b production is because it may instruct us about a possible *Higgs* production (discovery?) channel [8]. In the former case two gluons fuse to form the χ_b, and another soft gluon is exchanged between the two beam particles to leave them colorless and unexcited. (This is called non-factorisable double pomeron exchange, NFDP.) Measuring this cross section will enable us to better estimate the similar process where the two gluons (low p_T but $p_L \approx p_{beam} - \frac{M_H}{2}$) make a Higgs via a top-quark loop, and another soft gluon sorts out the color. The process is then $p\bar{p} \rightarrow pH\bar{p}$. Measuring the outgoing $x_F \approx 0.94$ beam particles in precision roman pot detectors (this requires dipole spectrometers on both sides to get to $|t| = t_{min}$) the missing mass resolution can be much better than the effective mass resolution of the $H \rightarrow b\bar{b}$ jet pair. . Neither CDF nor DØ have the apparatus for this but if the signal estimates and (DPE/QCD $b - \bar{b}$ dijet) backgrounds are encouraging then it could be done [9].

Studies of meson pairs may be extendable to the charm sector; the masses of D and D_s are little above the Ω mass, and there are exclusive decay modes e.g. $KK\pi$ with branching fractions around 9% and 5% respectively. Unfortunately exclusive $B\bar{B}$ pairs are probably unobtainable.

All these processes, systematically studied, will clearly tell us a lot about the nature of diffraction/pomerons, in addition to the hybrid or meson spectroscopy itself.

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[2] The cross section should be s-independent for $\alpha_P(0) = 1.0$, whereas it falls with s for reggeon exchange $\alpha_R(0) < 1.0$.

V. DISORIENTED CHIRAL CONDENSATES ETC.

High energy cosmic ray events have been observed with either an anomalously large ratio of charged hadrons:γ/e (Centauros; one striking event has a ratio 49:1) or a very small ratio (Anticentauro; one event has 1 charged track and 32 γ's in an η, ϕ circle of radius 0.7). Such events have been interpreted [14] as manifestations of a "Disoriented Chiral Condensate". No accelerator experiments have seen anomalous tails on the charged:neutral ratio [15]. No searches have yet been made in the central region of DPE events. It is worthwhile making a search, because as I have said for low-t, low Q^2 (no jets) events the pomeron might be dominated by just gluons. In that case this would be the first study of high mass ($\approx$ 50 GeV) "isotropic" events where the initial state is (to some degree) purely gluonic. One would trigger on gap-X-gap events, anti-select on jets, construct the ratio $\Sigma_{p_T}(\textit{charged tracks}) : \Sigma_{E_T}(\textit{electromagnetic cal})$ and study the tails (with a single vertex, rejecting cosmics, etc.).

High charged multiplicity events, DCC candidates or not, can be analysed for Bose-Einstein correlations, which can be used to measure the radius of the particle emission (separately for pions and kaons, if identified ... also for K_s^o if there are enough of them per event) in both the longitudinal and transverse directions. The K/π ratio is another interesting quantity to study either in a sample of DCC candidate events or in other special classes of events. Note that the AFS experiment [6] found, for 2-central tracks, R$[K^+K^-/\pi^+\pi^-]$ above 1.0 just above the $K\bar{K}$ threshold, but this is probably a manifestation of the prominent $f_o(970)$ resonance.

VI. EXPERIMENTAL CONSIDERATIONS

CDF and DØ have some complementary aspects for this physics and it would be best to have both experiments producing results, for cross checks where they overlap. DØ will have the apparent advantage of having roman pots (quadrupole spectrometers) on both the p and the $\bar{p}$ side, while CDF only has a dipole pot spectrometer on the $\bar{p}$ side. So DØ can tag both beam particles and measure their t and ϕ, which CDF cannot. Very interesting dependences of the central mass spectra ($\pi^+\pi^-$) on the relative azimuth $\Delta\phi$ have been observed [16] at $\sqrt{s} = 28$ GeV/c. Are these dependences due to regge exchanges which will die away with $\sqrt{s}$? DØ will pay a fairly severe rate penalty $\approx 10^{-4}$ for double tagging, because $|t_{min}| \approx 0.5 - 0.6$ GeV^2 on each side. Even when both p and $\bar{p}$ are detected, the *missing mass* resolution is O(GeV); the spectroscopy is done by reconstructing the effective mass of the central system. The CDF approach is to ignore the forward p and $\bar{p}$, allowing them to go down the beam pipe, which gives acceptance for all $|t|$. CDF can trigger on rapidity gaps on both sides, and to make this possible have installed *Beam Shower Counters (BSC)* where possible around the beam pipe (just in front of the low-β quadrupoles, before and after the electrostatic separators, and on the $\bar{p}$ side just before the Roman Pots at 56m). CDF hopes to install also *Miniplug Calorimeters* for $3.5 \leq |\eta| \leq 5.5$ ($\theta \leq 3^o$) and in this region there are also the *Cerenkov Luminosity Counters (CLC)* which count charged particles from the interaction region. All of these in veto will give rapidity gaps of 4 units on each side. It might be advantageous to require even larger gaps by (in CDF) vetoing on energy in the plug calorimeter (which has an $\eta\phi$ geometry) with $|\eta| \geq 2.0$ ... after all one cannot measure tracks well there. DØ could, I believe, make a similar trigger. These "2-gap" triggers will be *very* effective at vetoing multiple interactions. Of course some positive requirement (more than the beam crossing signal X_0) is also needed. This could be made in principal, in CDF or DØ , by requiring a minimal energy E in the complementary central region; above noise levels but as low as possible. CDF has the more attractive possibility of using its time-of-flight (*TOF*) barrel (216 ϕ-segments of fast scintillator) to trigger on a central charged particle multiplicity of 2,4 or 6 particles. (Actually the trigger would probably be only able to use ϕ segments of 15 deg for technical reasons.) The tracks which hit the *TOF* barrel are full length and very well measured. Most will also be identified: The *TOF* gives 2σ separation of π and K to 1.6 GeV/c, and the *Central Outer Tracker (COT)* will measure dE/dx to 10% which will provide further information on π, K, p identification.

The best way of implementing this physics program in CDF and DØ is probably to set up a trigger table based on two forward gaps and the various central requirements. One wants in addition the same central requirements with one or no forward gaps required, but with large prescaling factors to compensate for the much higher rates. These samples are used to measure cross sections and estimate the signal:background (multiplicity = 0 tails of non-diffractive events). Ideally one would like this trigger table to give a rate of about 50 Hz at $L = 5.10^{31}cm^{-2}s^{-1}$, and to take 3-4 hours of test data at such a luminosity (or at a lower luminosity if the trigger cross section is higher). These 0.5-1.0 million events should be analysed both for their own physics and to refine triggers. This should be enough to whet our appetite for the most promising and interesting channels, and either to take more dedicated running towards the end of stores or to include this as a fraction of the "QCD bandwidth".

VII. CONCLUSION

There is a great deal of new physics to study with low mass exclusive central states in DPE at the Tevatron. The hardware should exist (the CDF Miniplugs should be approved!) and the fraction of additional integrated dead-time needed is negligible.

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