Double pomeron physics in run II — Jon Pumplin

A "normal" event at the Tevatron produces ~ 0.3 hadron resonances per unit of $\Delta\eta \times \Delta\phi$. Hence in a region of length Δy, one expects $\sim 0.3 \times 2\pi \times \Delta y$ of them. Naively assuming no correlations, i.e., a Poisson distribution in the number, leads to the probability $\approx e^{-2.0\,\Delta y}$ of zero particles: a rapidity gap. A much more sophisticated argument from Regge theory also predicts the gap probability to be suppressed exponentially, albeit with a smaller coefficient: $\sigma_{\rm gap} \approx e^{2\,(\alpha_R - 1)\,\Delta y} \approx e^{-1.0\,\Delta y}$ based on the vector meson Regge intercepts α_ρ, α_ω near 0.5.

But rapidity gap cross sections are actually *not* suppressed exponentially in this way. Fitting the multiplicity distribution in a region $> 2-3$ units in rapidity, using a smooth distribution such as negative binomial or generalizations thereof, reveals an excess at zero multiplicity which is the rapidity gap cross section. The pomeron can be defined operationally as the thing that makes rapidity gaps. We must keep our minds open, however, to the possibility that there may be more than one kind of pomeron — e.g., the classical "soft" pomeron may be different from the pomeron that operates when there is a large momentum transfer t at one end of the gap; or when there is a large momentum transfer $p_\perp$ across the gap.

Roman pots that detect p or $\bar{p}$ very close to the beam directions can be used to study rapidity gaps according to the kinematic relation

$$\xi = 1 - x_p = \sum \sqrt{p_\perp^2 + m^2}\, e^y / \sqrt{s}\,.$$

For example if a $\bar{p}$ is observed with a momentum fraction $x_p = 0.98$, no pions with $p_\perp > 0.3\,\mathrm{GeV}$ can appear at $y > 4.7$, so there is a gap > 2.8 between any such pion and the leading proton which is at $y = 7.5$. The Roman pot method of observing gaps has several advantages: it allows us to study pure $\bar{p}$ going in the beam direction instead of an unknown mixture of $\bar{p}$ and $\bar{p}^*$; it allows measurement of the momentum transfer squared t; and if Roman pots can be placed both forward and backward, important azimuthal angular correlations between the forward and backward p and $\bar{p}$ can be observed. It will be important to see if final state properties change with t (or $t_{\rm forward}$ and $t_{\rm backward}$). It is also important to study how large the non-diffractive contamination is for, say, $x < 0.95$. Perhaps one could also get a handle on this by comparing forward protons with forward neutrons as HERA, using the Zeus forward neutron detector.

Double pomeron exchange (DPE) will be studied in Tevatron Run II in reactions of the form $p\bar{p} \to p\,X\,\bar{p}$. A variety of centrally produced systems X are worthy of study:

1. **X = soft, inclusive:** The fully differential cross section is $d\sigma/dt_1\,dt_2\,dy_1\,dy_2$, where t_1, t_2 are the 4-momentum transfers to the quasi-elastically scattered p and $\bar{p}$, and y_1, y_2 are the inside edges of the gaps. This cross section is integrated over t_1 and t_2 in the absence of Roman pots. The measurement can be compared with predictions based on measurements of single diffractive scattering by assuming Regge factorization.
2. **X = soft, exclusive:** Low multiplicity final states in DPE are a prime hunting ground for glueball states, since X automatically has isospin 0 and is made more-or-less from gluons [1]. In this case, azimuthal correlations with the quasi-elastic p and $\bar{p}$ can be particularly significant [2]. The absence of large $p_\perp$ presents a challenge for triggering on these final states, but low

multiplicity and the presence of the gaps and/or Roman pot triggers should make it possible.

3. **X = hard, inclusive:** Dijet production in DPE [4] has already been measured in Run I; but Run II offers, along with improved accuracy and the push to higher jet p_t, the possibility to study the dependence on momentum transfers to the p and $\bar{p}$. It should also be possible to measure the fraction of the jets that are $b\bar{b}$.
4. **X = hard, exclusive:** It is possible that some simple heavy quark systems can be produced exclusively in DPE [3]. A promising candidate to search for is the $b\bar{b}$ state $\chi_{b1}(1P)$, which has a mass of 9.892 GeV. It decays with a 35% branching ratio to $\gamma\,\Upsilon(1S)$, with subsequent decay $\Upsilon \to \ell^+\ell^-$ with 10% branching ratio ($\ell = e$ or μ). This would have a remarkable signature: nothing but $\ell^+\ell^-\gamma$ in the entire central detector. Although the rate will surely be small, the transverse momenta of several GeV along with the large quiet regions in the detector should be sufficient to make triggering possible. Meanwhile the large Q^2 scale offers the hope of attempting to calculate the cross section in pQCD. Depending on how the pomeron really works, exclusive processes may turn out to be very strongly suppressed by the condition that in spite of the large Q^2 scale, no extra soft gluons are radiated.

   The quantum number selection rules for the production of exclusive $b\bar{b}$ states are as follows. The pomeron is believed to have the same internal quantum numbers as the vacuum, so the state X produced by the "collision" of two pomerons must have $I = 0$ and $C = +$. The pomeron is an even-signature Regge trajectory, so it has spin and parity $J^P = 0^+,\ 2^+,\ 4^+,\ \ldots$; but when two of these are combined with the orbital angular momentum of the collision, all J^P values become allowed for X. For the purposes of a DPE experiment, $\chi_{b1}(1P)$ ($m = 9.892$, $J^{PC} = 1^{++}$) and $\chi_{b2}(1P)$ ($m = 9.913$, $J^{PC} = 2^{++}$) are the most promising because of their large (35%, 22%) branching ratios into $\gamma\,\Upsilon(1S)$. As a control experiment, the states $\Upsilon(1S)$ and $\Upsilon(2S)$ should not be produced in DPE, because they have odd charge conjugation.

   One could also look for $\Upsilon\Upsilon$ or $\psi\psi$ exclusive states, or even $\gamma\psi$ [5], in DPE.

Finally, an important experimental problem to be addressed is how to study gap physics in the presence of multiple $p\bar{p}$ collisions at the higher luminosity of Run II. Presumably the main tool will be to make use of scheduled or unscheduled running in which the luminosity is not in fact very high. For jet physics, the Roman pot method permits gap studies even when the gap cannot be observed directly because it is filled in by multiple interactions.

At the LHC, very high luminosity will make conventional rapidity gap physics impossible. With the help of Tevatron Run II, we should begin to think about whether similar physics can be done by a looser but more enforceable criterion of no *minijets* instead of no particles in a "gap" region. Since jet multiplicities are much less than particle multiplicities, this can only work if the required length Δy to define a gap is made larger.

As a final comment, backgrounds to DPE — along with some important questions regarding underlying events in jet physics — would benefit from an improved study of "minimum bias" physics, along the lines of what was done long ago and at a lower energy in the UA(5) experiment. Results from that experiment are still being used in the absence of measurements at $\sqrt{s} = 1.8\,\mathrm{TeV}$. This is another important topic to clean up before the LHC, where fluctuations from a large number of multiple interactions will be important.

References

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